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Plains CO_2 Reduction (PCOR) Partnership
Energy & Environmental Research Center (EERC)

FORT NELSON TEST SITE – PRELIMINARY GEOCHEMICAL OBSERVATIONS

Plains CO_2 Reduction (PCOR) Partnership Phase III
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FORT NELSON TEST SITE – PRELIMINARY GEOCHEMICAL OBSERVATIONS

EXECUTIVE SUMMARY

The Energy & Environmental Research Center conducted a screening-level geochemical laboratory test program (2009 through 2011) to investigate the potential effects of the injection of carbon dioxide (CO_2) and sour CO_2 (i.e., a mixture of CO_2 and H_2S ranging from 86.5% CO_2 and 13.5% H_2S to 95% CO_2 and 5% H_2S) on the cap rock, transition-zone rock, and reservoir rock from Spectra Energy Transmission's Fort Nelson Carbon Capture and Storage (CCS) Feasibility Project in northeastern British Columbia, Canada. Drill cutting samples from six different formations representing potential cap rock and storage reservoir rocks were used for characterization and laboratory testing. The primary goals of this program were as follows: 1) identify the predominant mineral phases of the potential sink and seal formations; 2) determine possible interactions and mineralogical changes within the cap rock, transition-zone rock, and reservoir rock when exposed to CO_2 and sour CO_2 at near- and far-from-wellbore reservoir conditions; 3) determine the mineral dissolution and precipitation potential resulting from the exposure of the cap rock, transition-zone rock, and reservoir rock to CO_2 and sour CO_2; and 4) determine potential changes in reservoir fluid properties as a result of CO_2 and sour CO_2 injection into the geologic storage reservoir(s).

Baseline and postexposure mineralogical and petrophysical characterization data were obtained using x-ray diffraction, x-ray fluorescence, scanning electron microscopy, and inductively coupled plasma–mass spectrometry techniques. Exposure tests using CO_2, sour CO_2, and brine were conducted under three sets of pressure and temperature conditions to represent the conditions of the reservoir from the near wellbore to the edge of the CO_2 plume.

Interpretation of the results may be limited by the uncertainty of provenance associated with drill cuttings, the potential for cuttings to be contaminated with drill-related impurities and cuttings from above formations, and the difficulty in applying results from static batch experiments to dynamic reservoir systems. With these caveats in mind, the following data trends and observations can be made:

- No significant changes in minerology were observed in the cap rock, transition-zone rock, or reservoir rock during exposure to either pure CO_2 or sour CO_2 at any of the reservoir conditions that were investigated. However, minor shifts in chemical composition were observed that suggest dolomite dissolution and calcite and sulfur precipitation may occur at both the near-wellbore and far-from-wellbore conditions.

- Although counterintuitive, in the Fort Simpson shale, the sour CO_2 mixture is likely less reactive geochemically than pure CO_2, as the dissolution of pyrite is enhanced by the presence of CO_2, and the presence of H_2S possibly inhibits the dissolution of pyrite.

- Exposure of carbonate formation rock to pure CO_2, as compared to sour CO_2, may result in a higher probability of dissolving natural cementing material (e.g., calcite, gypsum, and pyrite) and mobilizing iron from the clay and carbonate mineral matrix.

- Based on the samples available for this study, potential for calcite and calcium chloride precipitation appears to be minimal and on the order of less than 1 wt%. The significance of these precipitation reactions on reservoir injectivity for other formations should be investigated further.

- The chemistry of the reservoir fluid is important. Analysis of the synthesized brine showed little-to-no effect when exposed to high-pressure CO_2, whereas the synthetic brine showed increased calcium and magnesium concentrations.

Overall, the results of this screening geochemical study suggest that adequately understanding dissolution and precipitation reactions will require further investigation through a series of more detailed, targeted geochemical and geomechanical investigations.

Plains CO_2 Reduction (PCOR) Partnership

Energy & Environmental Research Center (EERC)

FORT NELSON TEST SITE – PRELIMINARY GEOCHEMICAL OBSERVATIONS

INTRODUCTION

The Energy & Environmental Research Center (EERC), through the Plains CO_2 Reduction (PCOR) Partnership, is working with Spectra Energy Transmission (SET) to investigate the feasibility of a carbon capture and storage (CCS) project to mitigate carbon dioxide (CO_2) emissions produced by SET's Fort Nelson Gas Plant (FNGP). The FNGP is located in northeastern British Columbia, Canada. In addition to completing the capture, transportation, and storage of the CO_2 emissions, the CO_2 will also contain contaminants of as much as 5% by volume of hydrogen sulfide (H_2S) and a small amount of methane (CH_4) and is referred to as "sour" CO_2. The plans are to inject the sour CO_2 into a deep saline-filled carbonate formation. The purpose of the project is to develop a better understanding of how CO_2 and sour CO_2 may interact and/or react with stratigraphic geology and minerology throughout the injection zone and the cap rock and possibly affect injectivity and storage capacity within the target formation.

Over the past 50 years, exploration activities for mineral and energy resources in the region have yielded a significant amount of information about the geology of northeastern British Columbia and northwestern Alberta. The sedimentary succession in the Fort Nelson area consists, in descending order from the surface to the Precambrian crystalline basement (Figures 1 and 2), of:

- Quaternary glacial drift and unconsolidated sediments.
- Lower Cretaceous shale.
- Mississippian (carboniferous) carbonates.
- Middle and Upper Devonian shale and carbonates.

The shale of the Middle Devonian Fort Simpson Group (Fort Simpson Aquitard) will provide the primary seal for preventing leakage of the injected sour CO_2 to the surface.

The Muskwa and Otter Park Formations have been described as being shaly carbonates or carbonate-rich shales, and because of their inconsistent lithologic characteristics, they are considered in this study to be "transition" rocks. As transitional formations, they can serve as neither reservoir nor sealing rocks.

The porous and permeable zones within the Sulphur Point and Keg River Formations are considered to be the most likely injection targets for the large-scale CO_2 storage. The Slave Point Formation in the Fort Nelson area has adequate porosity and permeability as well, but for CCS

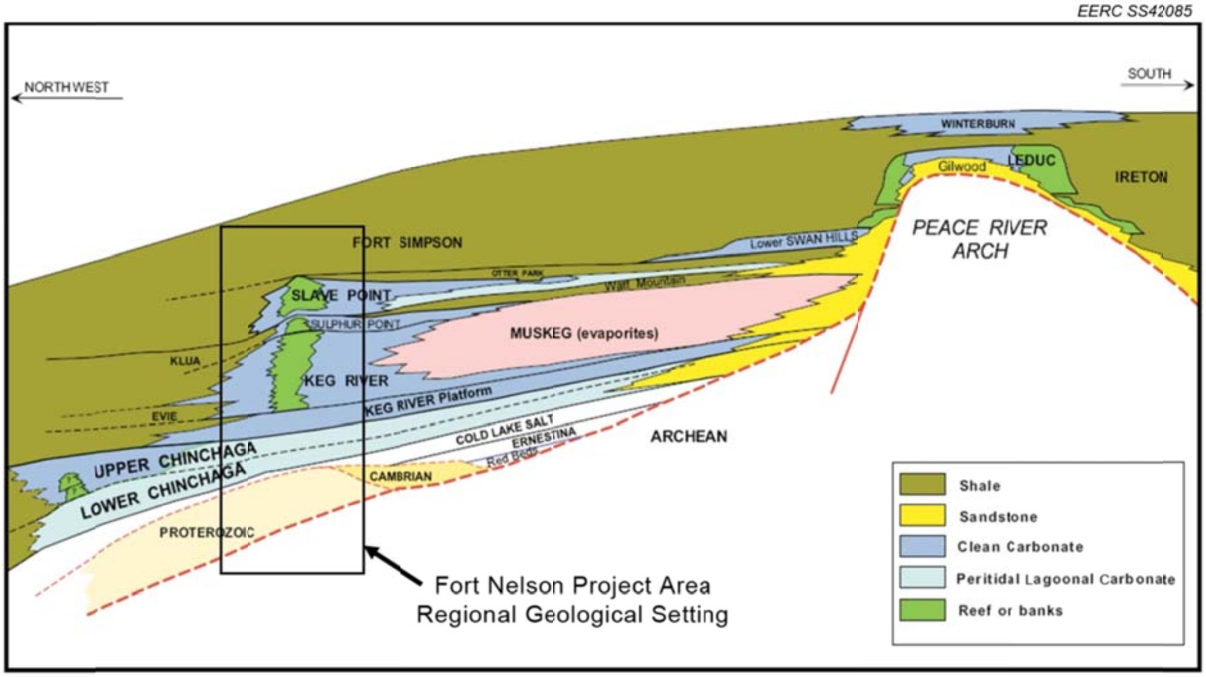

Figure 1. Stratigraphic architecture of the Middle Devonian Formations in the Fort Nelson area, northeastern British Columbia (British Columbia Ministry of Energy, Mines, and Petroleum Resources, 2007).

operations, it is preferred to inject deeper in the reef complex, which will increase trapping (more reef matrix and vugs to trap CO_2 when injecting deeper) and increase opportunity for mixing of CO_2 with formation brine (solution trapping) as the CO_2 migrates upwards, and it reduces the risk of buoyant CO_2 moving too quickly structurally updip along the Slave Point/Muskwa interface to nearby gas pools. The CO_2 will migrate upward into the Slave Point over time and therefore be part of the overall storage capacity

To gain a more thorough understanding of the sealing and storage capabilities of the reservoir with regard to geochemical reactions, 26 drill cutting samples from Exploratory Well c-61-E were collected from the formations shown in Table 1, with a lithology shown in Figure 3.

From 2009 through 2011, geochemical laboratory tests were conducted to describe the mineral and petrophysical characteristics of the formations discussed in Table 1 and to determine possible interaction with these formations when exposed to injections of CO_2 and sour CO_2. Mineralogical and petrophysical analyses and geochemical batch reactor tests were conducted on these samples. The remainder of this report presents the results of these analyses and tests.

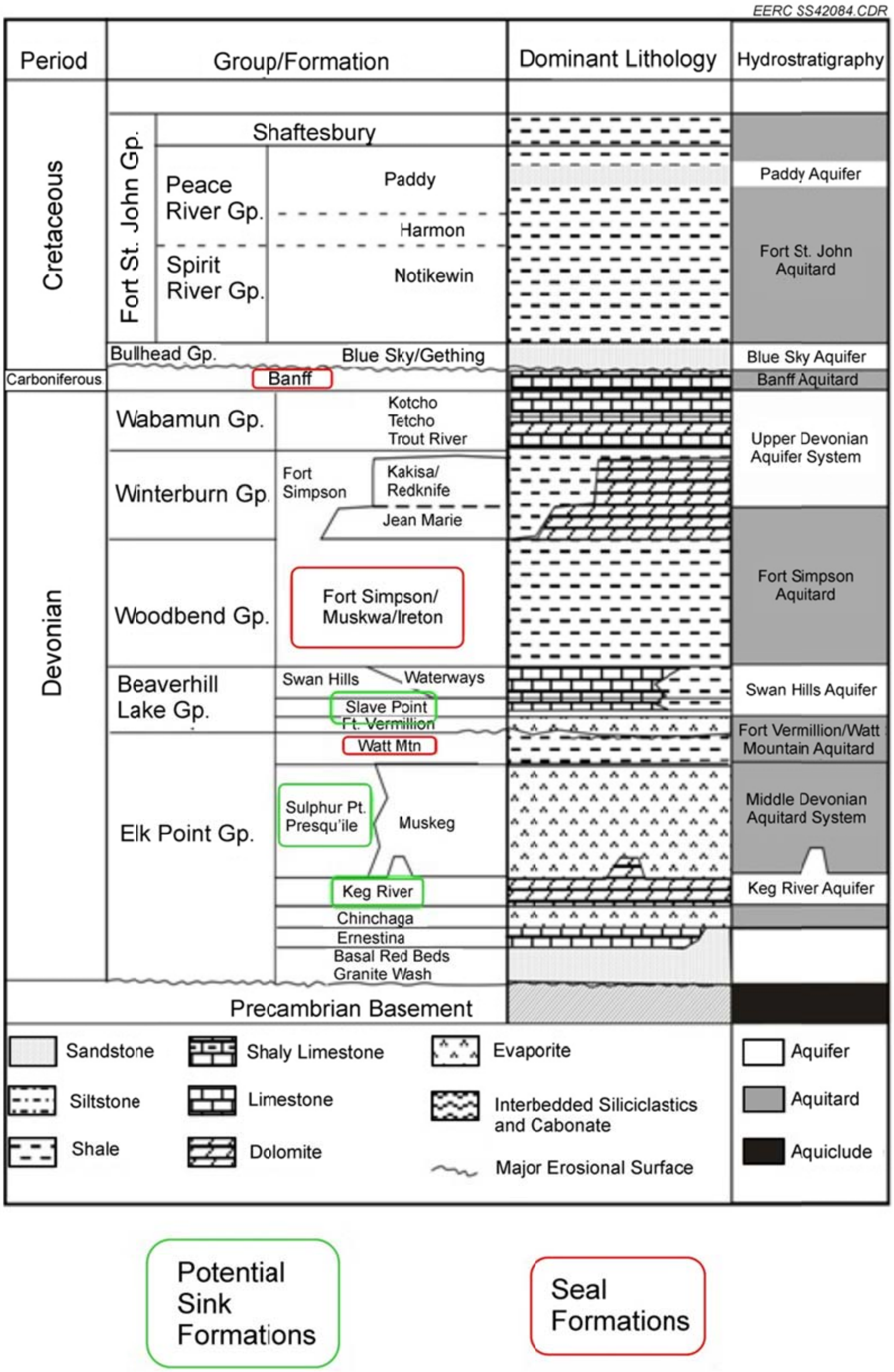

Figure 2. Stratigraphic and hydrostratigraphic delineation and nomenclature as well as general lithology for the northern part of the Alberta Basin, including northeastern British Columbia (Gorecki and others, 2010).

Table 1. Cap Rock, Transition, and Reservoir Samples*

Sample Classification	Formation (no. of samples)	Starting Depth, meters	Approximate Thickness, meters
Cap Rock	Fort Simpson (11)	1840	200
Transitional Rock	Otter Park (5) Upper/Lower Slave Point (5)	2050	150
Reservoir	Sulphur Point (4) Keg River (1)	2200	50

* Drill cutting samples from Exploratory Well c-61-E.

PROJECT OVERVIEW AND OBJECTIVES

A series of geochemical laboratory tests were conducted from 2009 through 2011 to develop basic information on 1) the mineral and petrophysical characteristics of key cap rock, transition-zone rock, and reservoir rock of the Fort Nelson CCS project and 2) the geochemical reactions of these rocks with CO_2 and sour CO_2 at reservoir conditions. The primary goals of these activities were as follows:

- Identify the predominant mineral phases of the potential sink and seal formations.
- Determine possible interactions of the cap rock, transition-zone rock, and reservoir rock with CO_2 and sour CO_2 at near- and far-from-wellbore reservoir conditions.
- Determine the mineral dissolution and precipitation potential resulting from the exposure of the cap rock, transition-zone rock, and reservoir rock to CO_2 and sour CO_2.
- Determine potential changes in reservoir fluid properties as a result of CO_2 and sour CO_2 injection into the geologic storage reservoir(s).

These geochemical data will provide insights regarding the potential impact of sour CO_2 injection on the planned CCS operations at the Fort Nelson site, with an emphasis on addressing the following critical operational questions:

- How might sour CO_2 injectivity and storage capacity be affected?
- Are there any potential impacts of sour CO_2 injection on geochemical processes within the storage and sealing formations?

The geochemical laboratory tests that were conducted to provide insight into these questions included mineralogical/petrophysical characterization of "as-received" drill cutting samples and batch reactor tests at reservoir conditions to investigate the nature of the potential reactions of these samples with CO_2 and sour CO_2. The remainder of this report summarizes the

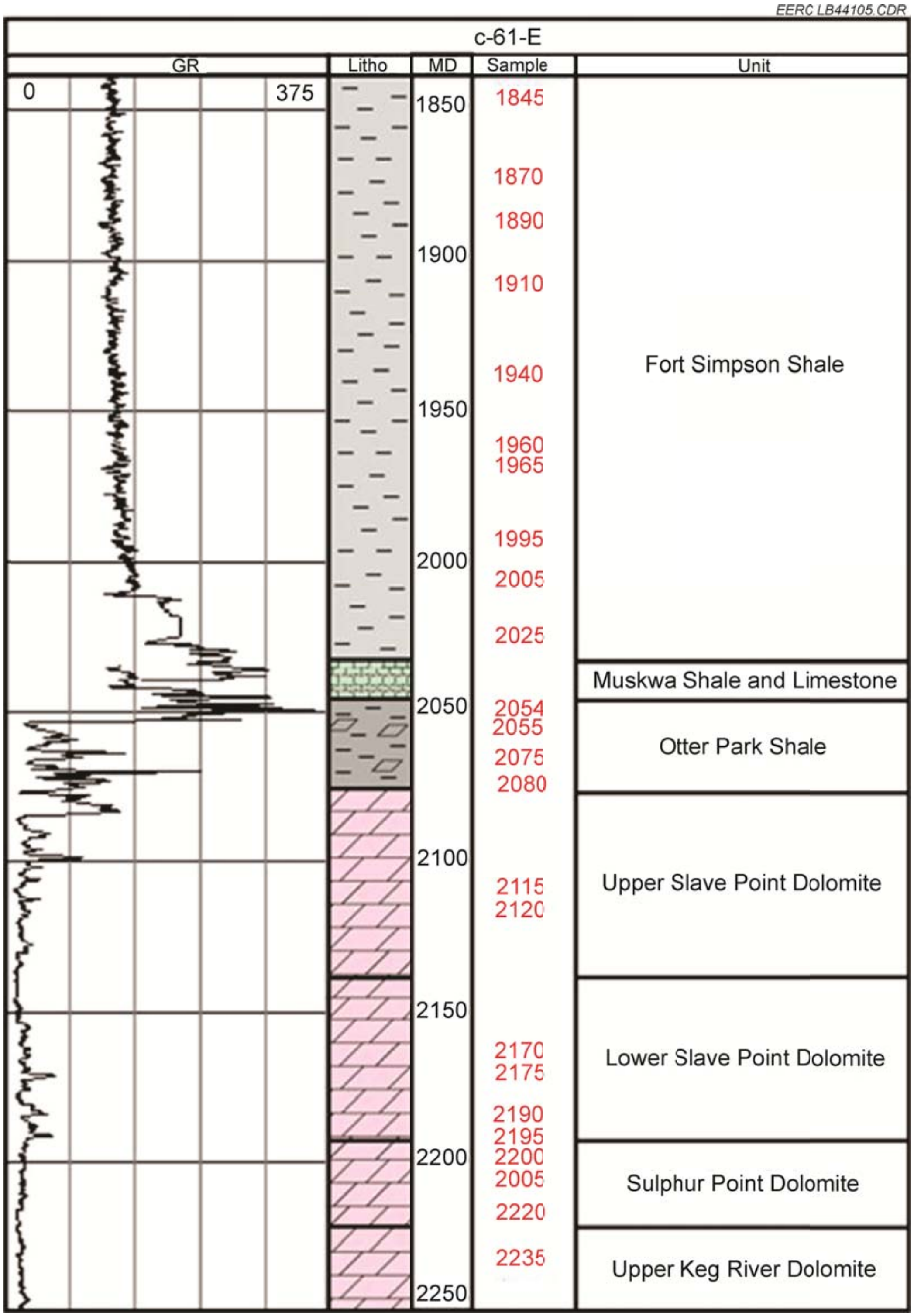

Figure 3. Gamma ray and lithology logs from Well c-61-E and sample locations from the Fort Simpson, Otter Park, Upper and Lower Slave Point, Sulphur Point, and Keg River Formations.

sample collection and analysis, baseline mineralogical/petrophysical characterization of "as-received" drill cuttings, and comparisons of preexposure (baseline) results to postexposure results.

LIMITATIONS OF SCREENING STUDIES

Interpretation of the results of the geochemical screening studies conducted on the Fort Nelson materials may be limited in a variety of ways:

- There is a high degree of uncertainty with respect to the provenance of any specific rock chip in a sample of cuttings. While most chips in a sample of cuttings may come from a relatively narrow interval of rock, the presence of just one or two chips that are from an "out of zone" portion of the wellbore can have a significant influence on the geochemical reactions that occur in a laboratory-scale experiment.

- The results generated by static batch reactor experiments have only limited applicability to a real-world reservoir that has a dynamic flow component. For the Fort Nelson project the dynamic pressure and temperature regimes that will occur in the reservoir as a result of an injection operation will greatly complicate the nature and speed with which any geochemical reactions may occur, and in fact may preclude some of the reactions observed in a static experiment from occurring at all.

- While efforts were made to remove any pieces of metal from the drill bit that may have been in the cuttings sample, the possibility that some of the iron-related reactions that were observed could be related to such metal contamination may not be entirely ruled out.

EXPERIMENTAL APPROACH

Drill Cutting Samples

Drill cuttings are small chips of rock (typically not greater than 1 cm in length) that are brought to the surface as part of the circulation of drilling fluid during the process of drilling a well. Cuttings are removed from the drilling fluid at the surface using a mechanism on the drilling rig referred to as the "shaker." While a vast majority of these drill cuttings are removed for disposal, on-site geologists will periodically collect cuttings from the shaker and examine them as a means of estimating the stratigraphic location of the drill bit. Using the known rates of drill bit penetration and drilling fluid circulation, the geologist on-site can estimate the depth from which the cuttings originated. During collection, cuttings are typically washed with water and a mild detergent to remove drilling fluids. The cuttings for detailed analyses are placed into vials and labeled according to the estimated depth from which they came. The depths are then compared to other stratigraphic interpretive data (e.g., geophysical well logs) as a basis for associating the cuttings with a specific formation.

During the drilling of Exploratory Well c-61-E in April 2009, samples of drill cuttings were collected from within the 1840- to 2240-m depth interval. This depth interval is representative of the cap rock, transition-zone rock, and reservoir rock within the following geologic formations: Fort Simpson shale, Otter Park shale, Upper and Lower Slave Point dolomite, Sulphur Point dolomite, and Upper Keg River dolomite (Table 1 and Figure 3). Note: samples of the cuttings from the Muskwa and Watt Mountain Formations, which are also located in this depth interval, were not obtained as part of this effort. A total of 160 vials of cuttings were collected, each containing approximately 7–9 g of material (Figure 4). A visual examination of some of these cutting samples, in their as-received state, indicated the presence of an unusual purple coloring. Analyses and discussions with the on-site geologist indicated that this discoloration was likely attributable to stains that were caused by an additive in the drilling fluid.

Sample Collection

Of the 160 vials of drill cuttings, a total of 26 samples were collected for further evaluation by this study, as shown in Table 2. These samples were taken across depth intervals ranging from approximately 5 to 15 m in length and included:

- Cap rock formation:
  - Fort Simpson shale (eleven samples)

- Transition rock formations:
  - Otter Park shale (five samples)
  - Upper and Lower Slave Point dolomite (five samples)

- Reservoir rock formations:
  - Sulphur Point dolomite (four samples)
  - Upper Keg River dolomite (one sample)

The collection of drill cuttings is less expensive and more rapid than the collection of samples from discrete cores; however, it does introduce two limitations: 1) the depth of the sample is not precisely known, i.e., within 5 to 15 m, and 2) there is the potential for cross contamination of the sample with drilling debris. Neither of these limitations affected the ability of this study to achieve its primary goals. Since this study was designed as a geochemical screening study of the cap rocks, transition-zone rocks, and reservoir rocks within relatively large formations, there was no need to have precise locations (i.e., within 1 m) of the sample depths. Similarly, the examination of the geochemical reactions of the rock samples emphasized the broad identification of mineral reactivity based on mineralogical assessments of the rocks, before and after exposure to near- and far-from-wellbore reservoir conditions, and elemental analysis of the accompanying brines. At this level of analysis, the presence of drilling debris could readily be detected and removed from the analysis.

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Figure 4. Example of as-received drill cuttings from Exploratory Well c-61-E.

Table 2. Description of the 26 Samples That Were Collected, Analyzed, and Tested Throughout the Project

	Depth, m
Fort Simpson Shale	1960
	1965
	1840–1845
	1860–1875
	1880–1895
	1905–1920
	1925–1940
	1950–1975
	1985–2000
	2005–2015
	2020–2027
Otter Park Shale	2054
	2055
	2075
	2080
	2060–2085
Upper Slave Point Dolomite	2115
	2120
Lower Slave Point Dolomite	2170
	2175
	2185–2190
Sulphur Point Dolomite	2195
	2200
Upper Keg River Dolomite	2205–2215
	2220–2230
	2235–2240

Characterization Methods

A suite of analytical tools and techniques were used to determine the mineralogical, chemical, and petrophysical characteristics of the cutting samples, both as-received cuttings as well as after exposure to CO_2 and sour CO_2 under varying CO_2 and H_2S concentrations, temperatures and pressures (see Batch Exposure Tests: CO_2 and Sour CO_2). The goal of this testing was to apply an array of analytical tests that would allow for the mineralogical characterization of the cap rock, transition-zone rock, and reservoir rock and the detection of mineralogical changes in these rocks that might occur following exposure to CO_2 and sour CO_2 at reservoir conditions.

The specific analytical tools and techniques that were applied to all, or a portion, of the cutting samples as part of this geochemistry program included x-ray diffraction (XRD), x-ray fluorescence (XRF), and scanning electron microscopy–energy-dispersive spectroscopy (SEM–EDS). When used together, these devices provide a highly developed characterization of sample mineralogy that includes bulk percentages of crystalline mineral phases as well as trace minerals and chemical composition. Indirect information regarding the sample mineralogy was also generated by analyzing the brines that were in contact with the drill cuttings during their exposure to the CO_2 and sour CO_2 using inductively coupled plasma–mass spectroscopy (ICP–MS). A brief description of each of these analytical tools that were used as part of this study is provided as follows.

X-Ray Diffraction

XRD detects and identifies crystalline phases in powdered samples and is capable of characterizing the atomic structure of various materials. For quantitative phase analysis (QPA), the Rietveld method is used to reduce the difference between a calculated diffraction pattern and the experimental data (Winburn and others, 2000; Young, 1993). Effects that normally detract from the quality of information from semiquantitative XRD, such as preferred orientation, instrument aberrations, and peak overlap, can be accounted for using the Rietveld method. QPA was performed using the TOPAS version 4.2 software system (Bruker AXS, Inc.).

XRD analyses of a bulk sample are usually considered to be semiquantitative. XRD is unable to quantify mineralogical phases below 0.5 wt%, and if solid solutions are present or amorphous phases exist, then it is difficult to interpret the mineral assemblage. Moreover, simple mineral structures, e.g., pyrite (FeS_2), can be identified with relatively high precision (±5 wt% error) whereas more complex phases, for example, clays such as illite ($(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$) and others, are more difficult to quantify. The error of quantitative identification of major mineral phases for XRD analysis varies from 5% to 30% (Moore and Reynolds, 1997).

X-Ray Fluorescence

XRF provides the bulk chemical composition of powdered rock samples. The method generates semiquantitative determinations of elements with atomic numbers ranging from 6 through 92. Although XRF, by itself, cannot distinguish elemental arrangements, it excels at detecting trace minerals, elemental replacement, and small concentrations (Rousseau, 2001; Beckhoff and others, 2006).

Because of the preparation process and the method and standards used, all detected phases are reported as oxides of the element, which can later be recalculated as elements, if applicable, such as when the element exists in a reduced, rather than oxidized, form. XRF is more accurate in the identification of the elemental assemblages present in a bulk sample. Mineralogical identification requires interpretation, which limits its application to the identification of less complex phases.

Scanning Electron Microscopy–Energy-Dispersive Spectroscopy

SEM is used to capture detailed images at high magnification. Rather than using transmitted or reflected light, as in typical optical microscopy, SEM is an analytical technique that derives information about a sample's surface by bombarding it with high-energy electrons.

The signal of electrons that bounce back from the surface (called backscattered electrons) are acquired and processed to create high-resolution images of the textural and morphological features within the sample.

The impact of electrons on the sample's surface generates x-ray signals that are processed using EDS to produce a quantitative chemical composition for selected points on the surface of the sample. By combining both the quantitative surface chemistry and surface textural characteristics, mineral phase information can be inferred and compared with that from other methods (Goldstein and others, 2003).

Inductively Coupled Plasma–Mass Spectrometry

ICP–MS is highly sensitive mass spectrometry that is capable of detecting metals and several nonmetals in fluids at concentrations below one part per trillion, or one part in 10^{12}. ICP–MS is based on the coupling of ICP, which produces ions (ionization), with an MS, which separates and detects the ions in the solution. The extremely low detection limits for a wide variety of elements is one of its advantages; however, the detection limits and error of the analysis depend on many factors, such as solution background (e.g., high salinity) and the element itself (Thomas, 2001).

Batch Reactor Tests: Samples Exposed to CO_2 and Sour CO_2

The injection of CO_2 and sour CO_2 into a reservoir has the potential to alter the geochemistry of fluids and formation rock minerals. CO_2 will dissolve into water and form a weak solution of carbonic acid which will lower the local pH and potentially dissolve acid-soluble materials such as carbonate minerals or metal oxides. Similarly, H_2S dissociates following dissolution in water, also lowering the pH and providing a source of sulfur. Injection activities may also cause a local temperature and/or pressure flux, or localized "drying," which may alter specific aspects of reservoir geochemistry. Although these processes do not ordinarily pose a problem for reservoir activities, the investigation of potentially detrimental site-specific geochemical reactions such as excess mineral dissolution or precipitation was investigated through laboratory batch reactor experiments.

This laboratory geochemical test program investigated mineralogical reactions resulting from the contact of CO_2 and sour CO_2 with cap rock, transition-zone rock, and reservoir rock at conditions representative of different locations within the injection reservoir. The reservoir conditions were created by varying pressure, temperature, fluid composition, and sour CO_2 composition. The examination of changes in the mineralogy of unexposed and exposed cuttings provides semiquantitative data about the potential for mineral dissolution and precipitation. The comparison of baseline brine concentrations to exposed brine concentrations also provides data about potential dissolution of mineral phases caused by exposure to CO_2 and sour CO_2.

Experimental Design

The batch reactor tests were conducted in small, standard scintillation vials (Figure 5) on as-received or powdered cuttings that were saturated with a synthetic brine (i.e., solutions of 1% to 3% NaCl) or a synthesized brine, which was formulated to emulate the chemical characteristics of the natural reservoir fluids. Open vials containing these samples were inserted into a high-pressure chamber (Figure 6), which was regulated for temperature and pressurized to reservoir pressure with CO_2 or sour CO_2. A set of control experiments was also conducted where the synthetic and synthesized brines were pressurized with CO_2 or sour CO_2 in the absence of drill cuttings.

Time of Exposure

The batch reactors were incubated in the high-pressure chamber for a period of 28 days (4 weeks). This 4-week exposure time (or residence time) was conservatively selected for the batch reaction tests after an initial evaluation of control samples. The initial evaluation consisted of magnesium silicate (in the form of foresterite), calcite, dolomite, and other minerals and indicated that complete carbonation of the foresterite was achieved after approximately 2 weeks and that fluid saturation, as a result of carbonate dissolution, was achieved after 25–26 days.

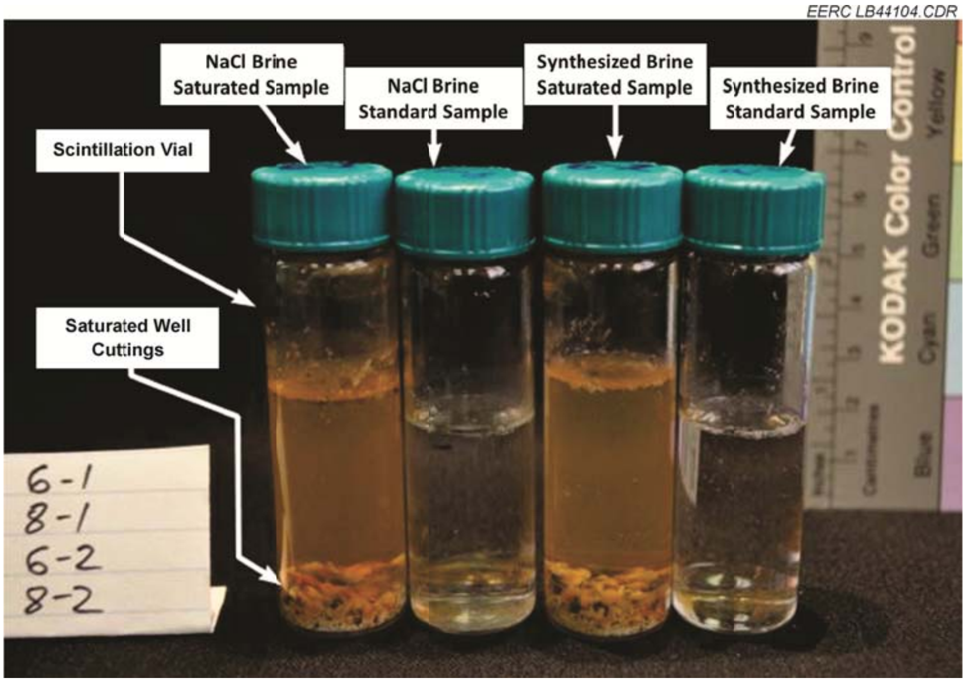


Figure 5. Typical batch reactor test sample suite: standard scintillation vials with 1) cuttings saturated in synthetic brine (1% to 3% NaCl) and synthesized brine and 2) control samples of synthetic and synthesized brines following exposure to pure CO_2 or sour CO_2 at reservoir pressure and temperature conditions without cuttings.

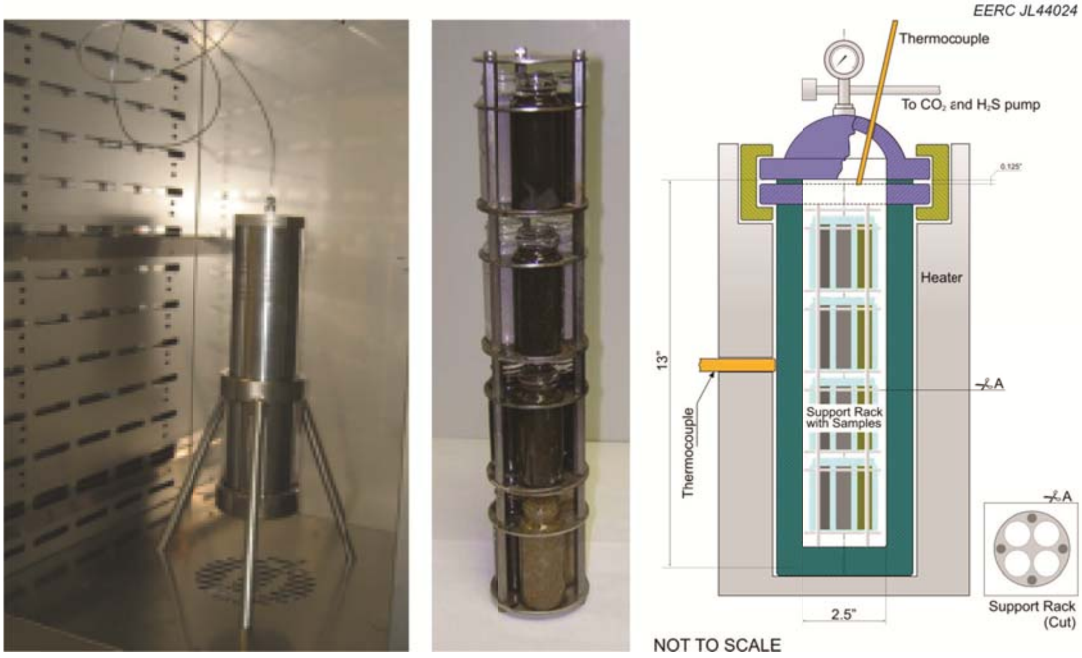


Figure 6. High-pressure CO_2 chamber inside a temperature incubator (left) and adjustable sample support rack of CO_2 batch reactors with scintillation vials inserted (center [photograph] and right [schematic representation]) for placement inside the high-pressure chamber.

Reactor Pressure and Temperature

Reservoir pressure and temperature will vary as a function of time, as the injected gas moves from the wellbore into the formation. At the time of the gas injection, the pressure near the wellbore will increase above preinjection levels, resulting in the initiation of the flow of gas into the storage reservoir. The rate of exchange of gas between the wellbore and reservoir is directly related to the difference in pressure, which dissipates as a function of distance from the wellbore.

The temperature of the injected gas (CO_2) will also vary because of several factors, including 1) the temperature of the gas delivered to the wellhead, which will be dictated by the latent heat from compression and friction that is generated during transport; 2) the heating or cooling of the gas that occurs as it travels downhole and is subjected to the natural in situ thermal gradient, with the extent of heating or cooling being a function of the injection rate and the heat capacity of the gas; and 3) the cooling of the injection gas as it decompresses upon exiting the wellbore due to the Joule–Thomson effect, which is dependent upon the pressure drop and gas composition.

Figure 7 presents the pressures, temperatures, and CO_2 phase that are expected in the reservoir for near-wellbore and far-from-wellbore locations based on preliminary dynamic modeling simulations of the Fort Nelson CCS project site. To mimic these anticipated reservoir

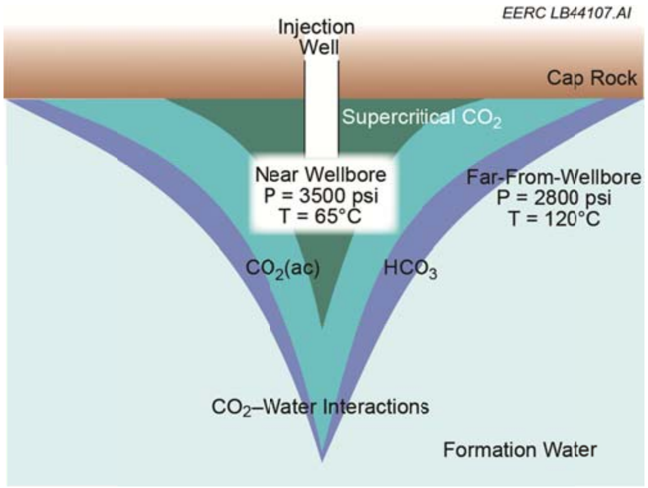


Figure 7. Simplified temperature, pressure, and CO_2 gas–water contact profiles during CO_2 injection.

conditions, the following two sets of pressure and temperature conditions were examined as part of the geochemical laboratory test program:

- P = 3500 psi and T = 65°C near-wellbore conditions
- P = 2800 psi and T = 120°C far-from-wellbore conditions

During the initial tests of the geochemical laboratory test program (Batch Reactor Test 1), the results of these preliminary reservoir modeling studies were not available, and initial screening experiments were conducted at a generic pressure and temperature of 3000 psi and 100°C. These screening studies were conducted on both the cuttings as well as samples of the as-received cuttings that were ground to produce a fine powder (approximately 200 µm). However, based on the results of these screening studies, all of the subsequent laboratory experiments (i.e., Batch Reactor Tests 2 through 5 – see “Batch Reactor Test Matrix” below), which were conducted at the modeled pressure and temperature reservoir conditions, only tested samples of the as-received drill cuttings.

Reactor Gas Composition

The gas compositions for Batch Reactor Test 1 were estimated prior to the preliminary reservoir modeling studies. The initial test conditions examined as part of Batch Reactor Test 1 were 1) 100% CO_2 and 2) 95 mol% CO_2 and 5 mol% H_2S.

The sour CO_2 that is produced at the FNGP will have a variable H_2S concentration, with the maximum concentration expected to approach 14% (13.6 mol%). Recognizing the potential for wide variations in H_2S concentration at the site, the two reaction gas compositions defined for Batch Reactor 2–5 tests were 1) 100% CO_2 and 2) 86.5 mol% CO_2 and 13.5 mol% H_2S.

Reactor Brine Composition

Reproducing the in situ reservoir brine composition for the batch reactor tests was an important consideration since this fluid composition, which is in equilibrium with the reservoir rock and subsurface gaseous atmosphere, will influence the type and rate of potential mineral dissolution and/or precipitation reactions that take place.

In the absence of site-specific data, a simple synthetic brine consisting of 2.5% NaCl ("simple brine") solution was selected as the baseline brine for Batch Reactor Test 1. However, for the subsequent batch reactor experiments (i.e., Batch Reactor Tests 2 through 5), a more complex brine was synthesized to emulate a site-specific brine composition that was provided by SET and Dr. Ernie Perkins of Alberta Innovates – Technology Futures (synthesized brine) (Table 3). However, for control and comparison purposes, the simple synthetic brine consisting of 2.5% NaCl was also included as part of the experimental matrix for Batch Reactor Tests 2 through 5.

Batch Reactor Test Matrix

The batch reactor experiments were conducted as five separate studies designated as Batch Reactor Test 1 (November 2009), Batch Reactor Test 2 (November 2010), Batch Reactor Test 3 December 2010), Batch Reactor Test 4 (January 2011), and Batch Reactor Test 5 (February 2011). As mentioned in the previous section, the Batch Reactor Test 1 experiments were focused on finalizing the experimental design and were based on several assumptions about average pressure and temperature conditions, as well as brine and gas composition. The test conditions of the subsequent batch reactor experiments (i.e., Batch Reactor Tests 2 through 5) were modified

Table 3. Chemical Composition of Site-Specific Brine from Fort Nelson

Formation:	Slave Point
Date Sampled	9-Feb-10
Total Dissolved Solids (TDS), mg/L	26,102
pH	7
Relative Density	1.015
Resistivity, Ω-m	0.247
Barium, mg/L	4
Calcium, mg/L	1722
Carbon, mg/L	60
Chloride, mg/L	15200
Magnesium, mg/L	152
Manganese, mg/L	1.6
Potassium, mg/L	977
Sodium, mg/L	7726
Strontium, mg/L	102
Sulfur, mg/L	138

based on preliminary reservoir modeling of the Fort Nelson site that was performed in-house at the EERC and site-specific data that were provided by SET. Batch Reactor Tests 2 and 4 were conducted under near-wellbore conditions (3500 psi and 65°C), and Batch Reactor Tests 3 and 5 were conducted under far-from-wellbore conditions (2800 psi and 120°C). Table 4 provides a summary of the test conditions for Batch Reactor Test 1, and Table 5 provides a summary for the test conditions for Batch Reactor Tests 2 to 5. A more detailed discussion of each of these studies is presented in the remainder of this section.

Description of Batch Reactor Test 1 (November 2009)

Batch Reactor Test 1 was conducted on Well c-61-E cuttings which were collected over a large portion of the stratigraphic column (i.e., a depth interval of 1960–2200 m) and which included samples from the Fort Simpson shale, Otter Park shale, Upper and Lower Slave Point dolomite, and Sulphur Point Formation dolomite. As previously noted, Batch Reactor Test 1 was designed to expose selected as-received cuttings and powdered cuttings to CO_2 and sour CO_2 under generic reservoir conditions, i.e., average reservoir pressure of 3000 psi and temperature of 100°C (Table 4). Initially, it was important to establish baseline data for future tests by comparing changes in the ground sample to the unmodified cuttings. Synthetic brine consisting of 2.5 wt% NaCl was used in these experiments to simultaneously reduce the complexity and uncertainty of the test and to provide a brine matrix which generally resembled reservoir conditions. XRD analyses were performed on the as-received cuttings prior to the exposure experiments to provide baseline mineralogy. After exposures to either CO_2 or sour CO_2, all of the samples of cuttings were analyzed using XRD.

Two batch reactors were operated simultaneously during this test. Twelve samples consisting of six pairs of samples from adjacent depths were chosen for this experiment. These twelve samples were split into three aliquots:

- Cuttings for analysis of as-received material, prior to exposure in the batch reactor.
- Unmodified cuttings subjected to batch exposure studies (one sample of each pair was exposed to CO_2 while the other sample was exposed to sour CO_2).

Table 4. Batch Reactor Test Conditions for Test 1[1]

	Batch Reactor Test 1 (November 2009)	
Test Material	Cap Rock, Transition-Zone Rock, and Reservoir Rock (1960 to 2200 m) (drill cuttings and powdered rocks)	
	CO_2 Reactor	CO_2/H_2S Reactor
Pressure	20.7 MPa (3000 psi)	20.7 MPa (3000 psi)
CO_2 Partial Pressure, mol%	100	95
H_2S Partial Pressure, mol%	0	5
Temperature	100°C (212°F)	100°C (212°F)
Saturation Conditions	Synthetic brine[2]	Synthetic brine

[1] All tests were conducted for a duration of 28 days using a sample mass of 2–3 grams.

[2] Synthetic brine – 2.5 wt% NaCl.

Table 5. Batch Reactor Test Conditions for Tests 2 Through 5[1]

	Batch Reactor Test 2 (November 2010)		Batch Reactor Test 4 (January 2011)	
Test Material	Cap Rock, Transition-Zone Rock, and Reservoir Rock (2005 to 2240 m) (drill cuttings only)		Cap Rock (1845 to 2000 m) (drill cuttings only)	
	CO_2 Reactor	CO_2/H_2S Reactor	CO_2 Reactor	CO_2/H_2S Reactor
Pressure	24.1 MPa (3500 psi)	24.1 MPa (3500 psi)	24.1 MPa (3500 psi)	24.1 MPa (3500 psi)
CO_2 Partial Pressure, mol%	100	86.5	100	86.5
H_2S Partial Pressure, mol%	0	13.5	0	13.5
Temperature	65°C (149°F)	65°C (149°F)	65°C (149°F)	65°C (149°F)
Saturation Conditions	Synthesized brine[2] Synthetic brine[3]	Synthesized brine Synthetic brine	Synthesized brine Synthetic brine	Synthesized brine Synthetic brine
	Batch Reactor Test 3 (December 2010)		Batch Reactor Test 5 (February 2011)	
Test Material	Cap Rock, Transition-Zone Rock, and Reservoir Rock (2005 to 2240 m) (drill cuttings only)		Cap Rock (1845 to 2000 m) (drill cuttings only)	
	CO_2 Reactor	CO_2/H_2S Reactor	CO_2 Reactor	CO_2/H_2S Reactor
Pressure	19.3 MPa (2800 psi)	19.3 MPa (2800 psi)	19.3 MPa (2800 psi)	19.3 MPa (2800 psi)
CO_2 Partial Pressure, mol%	100	86.5	100	86.5
H_2S Partial Pressure, mol%	0	13.5	0	13.5
Temperature	120°C (248°F)	120°C (248°F)	120°C (248°F)	120°C (248°F)
Saturation Conditions	Synthesized brine Synthetic brine	Synthesized brine Synthetic brine	Synthesized brine Synthetic brine	Synthesized brine Synthetic brine

[1] All tests were conducted for a duration of 28 days using a sample mass of 2–3 grams.

[2] Synthesized brine – site-specific composition shown in Table 3.

[3] Synthetic brine – 2.5 wt% NaCl.

- Cuttings, after wet grinding in a micronizing mill to approximately 200 µm, subjected to batch exposure studies (one sample of each pair was exposed to CO_2 while the other sample was exposed to sour CO_2).

From these tests, it was determined that 1) the investigation of mineralogical changes on the surface of rocks provides a better understanding of reaction products and 2) brine analyses suggested that the differences in concentration of dissolved solids were not significant between exposed powdered samples and exposed as-received cuttings. Based on these results, it was decided that further tests with powdered samples were not necessary.

The two sets of reactor conditions of Batch Reactor Test 1 differed only in the gas composition, i.e., 100% CO_2 versus sour CO_2 comprising 95 mol% CO_2 and 5 mol% H_2S. To minimize the potential effects of rock heterogeneity within any given formation and to allow for more unbiased comparisons among the exposures, samples subjected to the sour CO_2 exposure reactor originated from depths adjacent to the samples submitted to the CO_2-only exposure reactor.

The preliminary results from Batch Reactor Test 1 provided insights regarding the design of future experimental tests. Although XRD mineralogical analysis is an important and widely used technique, it has limited applications for detecting small mineralogical changes which may occur in the rock. Therefore, subsequent batch reactor experiments incorporated XRF and SEM–EDS into the analytical program for a subset of the samples.

Description of Batch Reactor Tests 2–5 (2010–2011)

Batch Reactor Tests 2 and 3 were conducted on Well c-61-E cuttings which were collected from the 2005- to 2240-m depth interval at locations throughout the Fort Simpson shale, Otter Park shale, Upper and Lower Slave Point dolomite, Sulphur Point dolomite, and Upper Keg River Formation dolomite (Figure 3). These drill cuttings provided an array of samples that included reservoir rock, transition-zone rock, and cap rock. Batch Reactor Tests 4 and 5 were limited to cap rock (Fort Simpson shale) samples only and included the depth interval from 1840 to 2000 m. More specifically and further defined in Table 5:

- Exposure of cuttings to near-wellbore pressure and temperature conditions was examined over the entire stratagraphic column in Batch Reactor Test 4 (1840 to 2000 m) and Batch Reactor Test 2 (2005 to 2240 m), with varying gas composition and brine composition.

- Exposure of cuttings to far-from-wellbore pressure and temperature conditions was examined over the entire stratagraphic column in Batch Reactor Test 5 (1840 to 2000 m) and Batch Reactor Test 3 (2005 to 2240 m), with varying gas composition and brine composition.

As previously mentioned, the test conditions for Batch Reactor Tests 2–5 were modified in comparison to those of the Batch Reactor Test 1 in accordance with additional SET input, new information about the planned CO_2 injection procedure at the site, and an increased understanding of the reservoir conditions. The primary changes in the experiments included the following (Table 5):

- The number of samples per run was increased from six to seven depth intervals per each test condition, and only drill cuttings were tested (i.e., powdered cuttings were not prepared or tested). The amount of material available per each 5-meter interval was often limited; therefore, the cuttings from some intervals were combined based on similar stratigraphy and geochemical characteristics. This allowed for the development of a more consistent data set for each of the batch reactor tests.

- Pressure and temperature in the Batch Reactor Tests 2 and 4 were set to the near-wellbore reservoir conditions according to the results from numerical simulation and modeling predictions: 24.1 MPa (3500 psi) and 65°C (149°F).

- Pressure and temperature in the Batch Reactor Tests 3 and 5 were set to the far-from-wellbore reservoir conditions according to the results of numerical simulation and modeling predictions: 19.3 MPa (2800 psi) and 120°C (248°F).

- Partial pressures of CO_2 and H_2S were changed to 86.5 and 13.5 mol%, respectively, for the sour CO_2 exposure studies.

- Brine composition was adjusted to also include a synthesized brine to better match the chemical characteristics of the in situ reservoir brine.

In addition to the modified test conditions, postexposure sample analyses were modified as follows:

- ICP–MS analyses of the postexposure brines were performed for all of the samples for Batch Reactor Tests 2 through 5.

- XRF mineralogical analysis techniques were utilized in Batch Reactor Test 4 (seven of seven samples) and Batch Reactor Test 5 (seven of seven samples).

- SEM–EDS mineralogical analyses were used to a limited extent in Batch Reactor Test 2 (one of seven samples) and Batch Reactor Test 3 (one of seven samples).

Summary of Batch Reactor Test Characterization Analysis

The complete analytical characterization matrix that was performed for the cuttings in each batch reactor experiment is provided in Appendix A. Samples are identified by batch reactor experiment, sample collection depth, and the analyses that were performed on the pre- and postexposure samples. The following provides a summary of the analytical characterization matrix and highlights the pre- and postexposure comparison data that are available for assessment in the results and discussion section (see Results and Discussion).

Batch Reactor Test 1

The following characterization analyses were performed on samples from Batch Reactor Test 1:

- XRD data are available on the as-received (preexposure baseline) and postexposure sample mineralogy of the six pairs of samples exposed to the generic reservoir conditions. The samples represent the following formations and depths:

    - Fort Simpson shale (1960 m/1965 m)
    - Otter Park shale (2054 m/2055 m and 2075 m/2080 m)
    - Upper Slave Point dolomite (2115 m/2120 m)
    - Lower Slave Point dolomite (2170 m/2175 m)
    - Sulphur Point dolomite (2195 m/2200 m)

- ICP–MS data for pre- and postexposure brine are available for two sample groups, which include exposures to the following formations and depths:

    - Otter Park shale (2054 m)

  - Lower Slave Point dolomite (2170 m)

Batch Reactor Tests 2 Through 5

The following characterization analyses were performed on samples from Batch Reactor Tests 2 through 5:

- XRD data are available for 14 pre- and postexposure sample groups exposed to near-wellbore and far-from-wellbore reservoir conditions as defined in Table 5. The samples represent the following formations and depths:

  - Fort Simpson shale (1845, 1870, 1890, 1910, 1940, 1960, 1995, 2005, and 2025 m)
  - Otter Park shale (2075 m)
  - Lower Slave Point dolomite (2190 m)
  - Sulphur Point dolomite (2205 and 2220 m)
  - Upper Keg River Formations (2235 m)

- XRF data are available for seven pre- and postexposure sample groups exposed to near-wellbore and far-from-wellbore reservoir conditions. All seven sample groups were collected from the Fort Simpson Formation shale at the following depths:

  - Fort Simpson shale (1845, 1870, 1890, 1910, 1940, 1960, and 1995 m).

- SEM–EDS data are available for one pre- and postexposure sample group, representing the Sulphur Point Formation dolomite (2220 m).

- ICP–MS data are available for 14 pre- and postexposure sample subsets exposed to varying combinations of reservoir and brine conditions. These include the following:

  - Simple synthetic brine (NaCl solution):
    - Near-wellbore CO_2 exposure for the following formations and depths:
      - Fort Simpson shale (2005 and 2025 m)
      - Otter Park shale (2075 m)
      - Lower Slave point dolomite (2170 and 2190 m)
      - Sulphur Point dolomite (2205 and 2220 m)
      - Upper Keg River Formations dolomite (2235 m)
    - Far-from-wellbore CO_2 and sour CO_2 exposure for the following formation and depths:
      - Fort Simpson shale (1845, 1870, 1890, 1910, 1940, 1960, and 1995 m)

  - Complex synthesized brine:
    - Near-wellbore CO_2 exposure for the following formation and depths:
      - Fort Simpson shale (1845, 1870, 1890, 1910, 1940, 1960, and 1995 m)
    - Near-wellbore sour CO_2 exposure for the following formations and depths:
      - Fort Simpson shale (1845, 1870, 1890, 1910, 1940, 1960, 1995, 2005, and 2025 m)

- Otter Park shale (2075 m)
- Lower Slave Point dolomite (2190 m)
- Sulphur Point dolomite (2205 and 2220 m)
- Upper Keg River Formation dolomite (2235 m)

RESULTS AND DISCUSSION

Baseline Characterization As-Received Cuttings

Baseline characterization of the predominant mineral phases was generated for the 26 as-received cutting samples using a combination of four analytical techniques (Appendix A: Tables A-1 and A-2):

- XRD
- XRF
- SEM–EDS

Detailed baseline characterization data for the 26 samples of cuttings are presented in Appendix B.

XRD analysis was performed on all of the samples (Appendix B: Tables B-1 and B-2; Figures B-1 and B-2). For a subset of the samples, the XRD analyses were supplemented with:

- XRF (samples of the Fort Simpson Formation shale only: Table B-3).

- SEM–EDS (samples of the Sulphur Point Formation dolomite only: Tables B-4 to B-7; Figure B-4).

Because of the predominance of the XRD data, these data provide the primary mineralogical data set for this study. The selected data from the other analyses are used to supplement the XRD data and provide corroborative data for the XRD interpretations.

XRD Results

The baseline characterization XRD data for the 26 samples of cuttings indicate the following (Appendix B: Tables B-1 and B-2; Figures B-1 and B-2):

- Cap rock formation:

    - Fort Simpson shale is predominantly quartz (30 ± 10%), clay (sum of kaolinite, illite, and chlorite) (37 ± 7%), and silicates (sum of albite, microcline, orthoclase, and sanidine) (18 ± 7%).

- Transition rock formations:
  - Otter Park shale is predominantly dolomite (68%), quartz (18%), and clay (7.2%).
  - Upper and Lower Slave Point dolomite is predominantly dolomite (94%) and quartz (2.6%).

- Reservoir rock formations:
  - Sulphur Point dolomite is predominantly dolomite (92% ± 1%) and quartz (4.2% ± 0.8%).

  - Upper Keg River dolomite is predominantly dolomite (95%) and quartz (1.4%).

Minor pyrite (0.2% to 3.1%) and gypsum (0.1% to 4%) were also observed throughout the entire depth interval that was tested.

A summary figure of the predominant minerals as determined by XRD on the as-received samples is shown in Figure 8 (reproduced from Appendix B: Figure B-2).

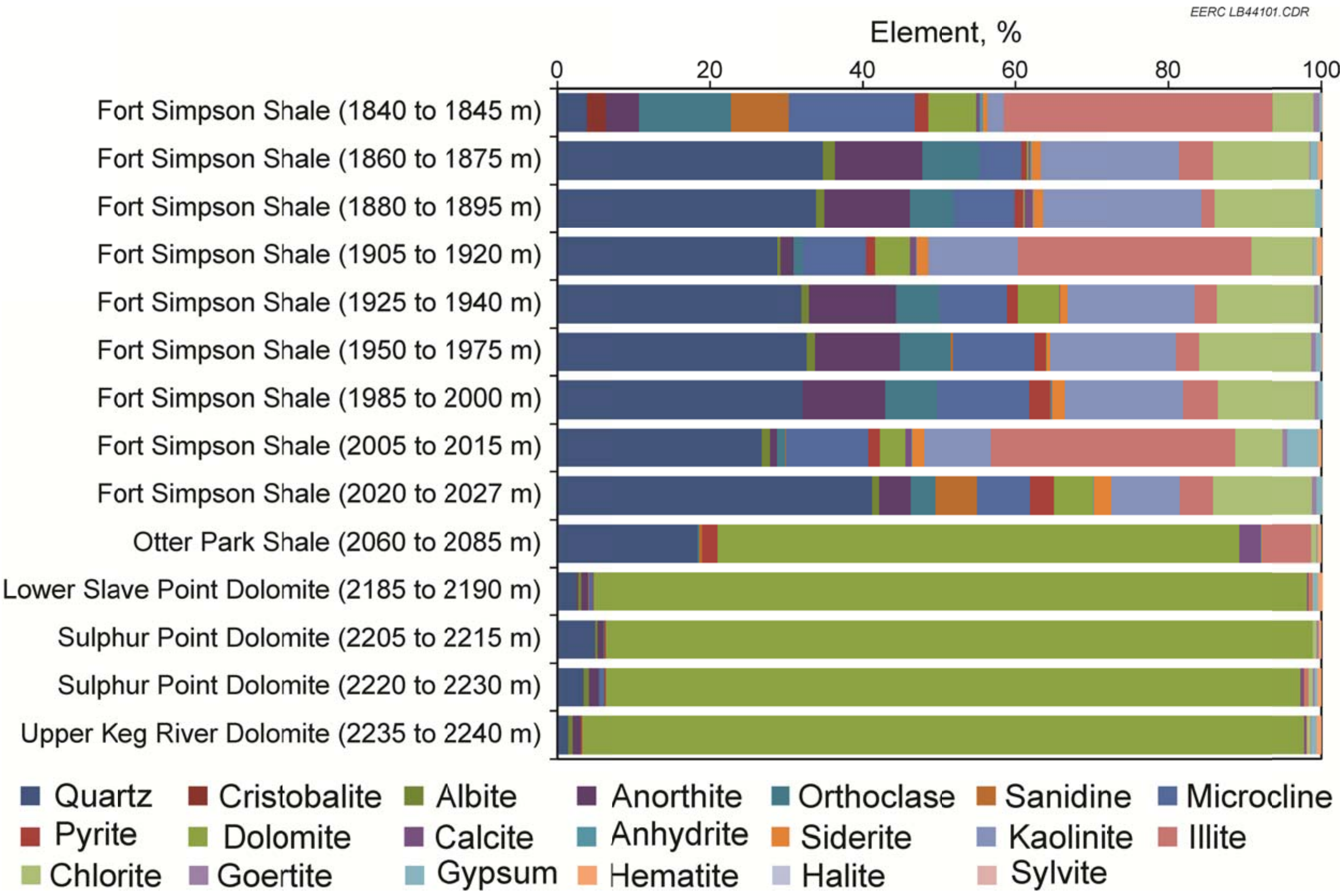


Figure 8. Baseline analysis at predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (values are reported in percent). Cristobalite is used as an internal standard and is likely not present in the sample.

XRF Results

XRF analyses were limited to drill cutting samples from the cap rock (Fort Simpson Formation shale). The mineralogical composition of the cap rock described by the XRD analysis was generally supported by the XRF analysis. For example, high aluminum (19% to 21%), silica (53% to 55%), and potassium (5.5% to 6.6%) indicate an abundance of clay minerals.

Calcium (1.4% to 5.3%) and magnesium (2.4% to 2.6%) concentrations generally correlated with the XRD readings. However, the XRF analysis for samples collected from the depth intervals 1860 to 1875 m and 1880 to 1895 m indicated the presence of increased amounts of calcium (4.3% and 5.3%) and magnesium (2.5% and 2.4%). In contrast, XRD did not identify commensurate concentrations of either dolomite (0.2%) or calcite (0.2% to 1%) for these depth intervals. It is possible that these carbonates were highly disordered or amorphous in nature and were therefore undetectable by XRD. It is not uncommon for biogenically formed carbonates to be amorphous in nature (Radha and others, 2012).

Lastly, the presence of sulfur (0.2% to 0.5%) confirms the existence of pyrite and gypsum in the mineral mix (Appendix B: Table B-3).

A summary figure showing the baseline analysis of the predominant elements as determined by XRF on the as-received samples prior to Batch Reactor Tests 2 to 5 is shown in Figure 9 (reproduced from Appendix B: Figure B-3).

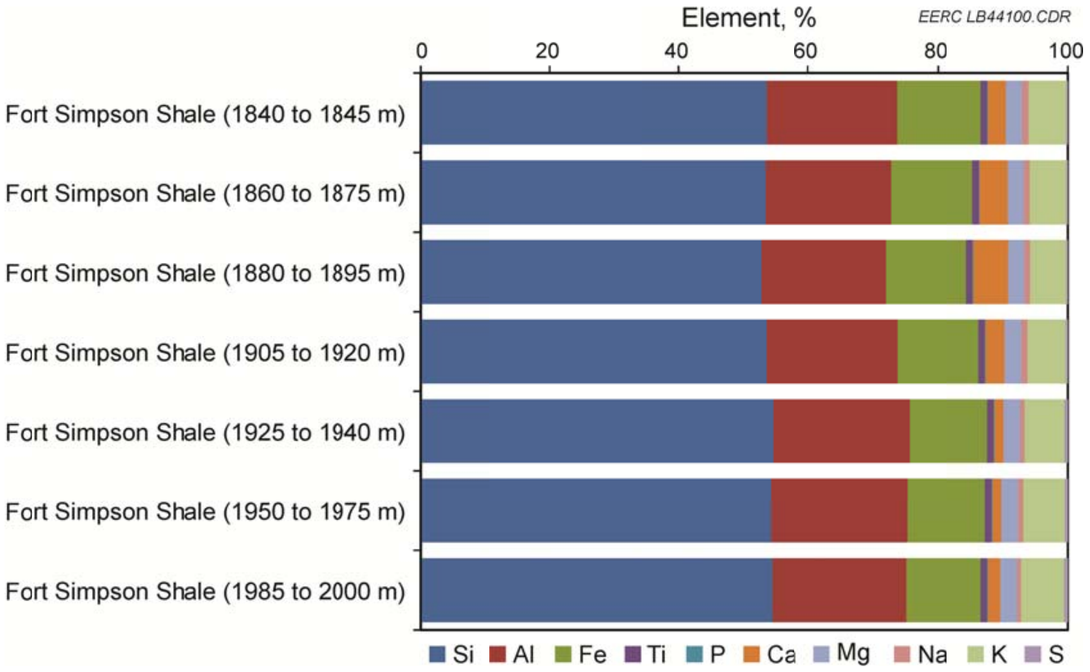


Figure 9. Baseline analysis of predominant elements in c-61-E drill cuttings as determined by XRF on as-received cuttings (values are reported in percent).

SEM–EDS Results

The SEM–EDS analysis of the surface chemical composition was performed on cuttings from only the Sulphur Point Formation dolomite (2220 m) (Appendix B: Tables B-4 through B-7). The sample is composed primarily of microporous and argillaceous dolomite with small accumulations of pyrite. Some dolomite zones appear to contain iron, possibly indicative of ankerite alteration. Pyrite exists as both subhedral to anhedral fine-grained inclusions to large recrystallized zones, showing both cubic and radial forms. Potassium, magnesium, aluminum, and iron-rich clay zones were also found in the mix. An SEM–EDS image of the Sulphur Point Formation dolomite (2220 m) sample is shown in Figure 10 (reproduced from Appendix B: Figure B-4.

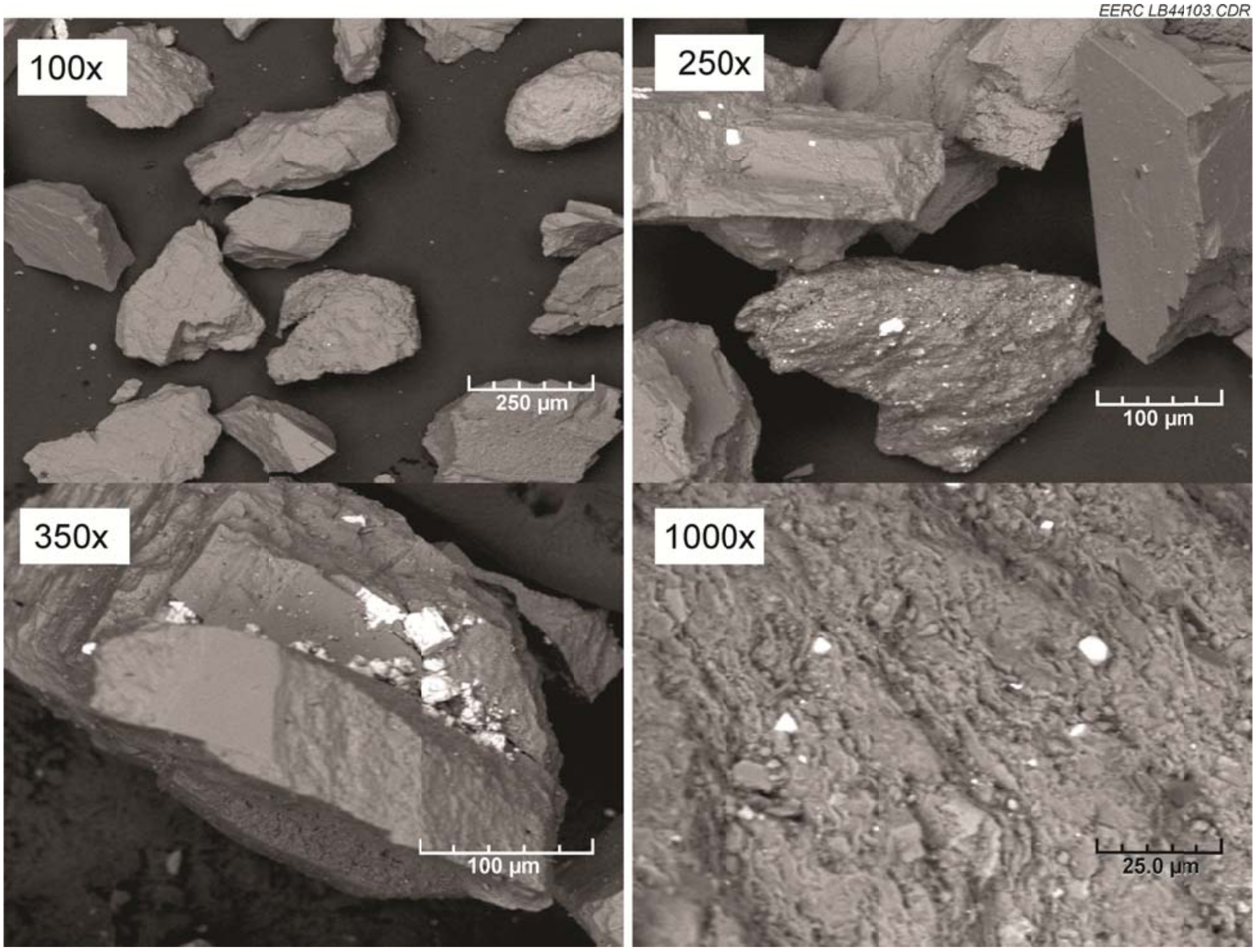


Figure 10. Baseline SEM–EDS images of the Sulphur Point Formation dolomite as-received cutting sample collected at 2220 m. The images represent preexposure baseline at 100× resolution (upper left-hand corner), 250× resolution (upper right-hand corner), 350× resolution (lower left-hand corner), and 1000× resolution (lower right-hand corner). The pyrite appears white in these images.

Baseline Mineralogy Summary

This baseline characterization effort has shown that quartz and other silicates were measured in higher quantities by XRD than were found through other methods (XRF and SEM–EDS). This result is believed to be a product of oriented-aggregate sample preparation. Another explanation of this result could be attributed to the loss of additional clay in the amorphous background.

At the same time, in general, the analytical results for this project are consistent with published descriptions of the Fort Simpson Formation (Douglas and Norris, 1961). Paleoenvironmental interpretation based on this rock mineralogy and fabric suggests that Keg River, Sulphur Point, and Slave Point reef complexes were deposited along a shallow shelf extending onto the flooded continental shelf. Brief marine regressions caused the back-reef environment to fill with siliclastic carbonate debris and evaporite deposits (Meijer, 2008). Continental influx persistently provided clastic sediments to the system, which accelerated following a large-scale marine transgression that covered the area, resulting in the deposition of organic-rich marine shales, including the Fort Simpson shale.

Illite group clay-rich cap rock samples contain inclusions of secondary dolomite and pyrite which are likely the result of enriched water moving through the system during lithification and/or hydrocarbon maturation. In some cases, these inclusions now outnumber the volume of autochthonous rock. Small portions of calcite, silt-sized quartz, and lithic fragments were also detected through analysis. Sample porosity is not possible to visualize or quantify with the drill cutting material.

Mineral Characterization at Reservoir Conditions

Determinations of the mineral dissolution and precipitation potential resulting from the exposure of the cap rock, transition-zone rock, and reservoir rock to CO_2 and sour CO_2 was assessed by comparing pre- and postexposure analyses of the cutting samples. Changes in mineral form inferred from pre- and postexposure analyses of brine major ion chemistry is discussed in the following section (see Potential Changes in Reservoir Fluid Properties).

Comparisons were made on a relative basis, comparing the preexposure baseline percentages against the postexposure percentages of different minerals or elements. To minimize these effects, it should be recognized and caution applied not to draw firm conclusions but rather identify trends as each method has inherent inaccuracies and each sample has material variations. Assessments were limited to those sample group combinations of similar type which contained both preexposure (baseline) and postexposure measurements for the same analytical method. For the Fort Simpson Formation shale, a large number of samples were collected to allow for statistical analysis. However, for all other formations, a limited number of analyses for sample cuttings precluded the use of statistical tests, and the results are simply described for observed differences between measurements of pre- and postexposure results.

Fort Simpson Shale (cap rock)

Two separate analyses provided mineralogy assessments before and after exposure: XRD and XRF. The complete assessments of all combinations of pre- and postexposure measurements are provided in Appendix C. These comparisons are summarized below and are organized by the type of analytical measurement.

XRD Pre- and Postexposure Comparisons

Pre- and postexposure XRD analysis was performed on cuttings samples from:

- 1845 m (Batch Reactor Tests 2 [near-wellbore] and Batch Reactor Test 3 [far-from-wellbore]).
- 1870 m (Batch Reactor Tests 2 and 3).
- 1890 m (Batch Reactor Tests 2 and 3).
- 1910 m (Batch Reactor Tests 2 and 3).
- 1940 m (Batch Reactor Tests 2 and 3).
- 1960 m (Batch Reactor Test 1).
- 1960 m (Batch Reactor Tests 2 and 3).
- 1995 m (Batch Reactor Tests 2 and 3).
- 2005 m (Batch Reactor Tests 2 and 3).
- 2025 m (Batch Reactor Test 2 and 3).

On a sample-by-sample basis, changes were observed between pre- and postexposure percentages of several minerals (Appendix C: Figure C-1a and Figures C-2a to C-2e). However, these changes were not consistent in either direction or magnitude from one sample to the next, likely due to material variability from one sample to another. For example, sometimes postexposure mineral percentages of quartz were significantly greater (more than 10%) than preexposure values, and sometimes they were no different or less than preexposure. Similar trends were observed for clays and silicates, the other predominant minerals found in the Fort Simpson Formation shale.

The mean and standard deviation pre- and postexposure mineralogy results for XRD on the nine samples collected from the Fort Simpson Shale Formation (1840 to 2027 m) are presented in Figure 11 (reproduced from Appendix C: Figure C-2h). On average, the XRD analysis did not detect significant changes in the mineralogy between the pre- and postexposure samples.

Wilcoxon Rank Sum (WRS) tests were conducted on the nine samples collected from the Fort Simpson Formation shale (1840 to 2027 m) to test whether or not there were statistically significant differences in the mineral percentages between pre- and postexposure XRD measurements. The WRS tests showed that most mineral percentages were not statistically different between pre- and postexposure at the 95% confidence level. Only microcline in the CO_2 exposure at near-wellbore conditions and chlorite in the CO_2/H_2S exposure at near-wellbore conditions were somewhat lower than the preexposure baseline. No other mineral percentages were significantly different form the preexposure baseline. These results are consistent with observations drawn from Figure 11.

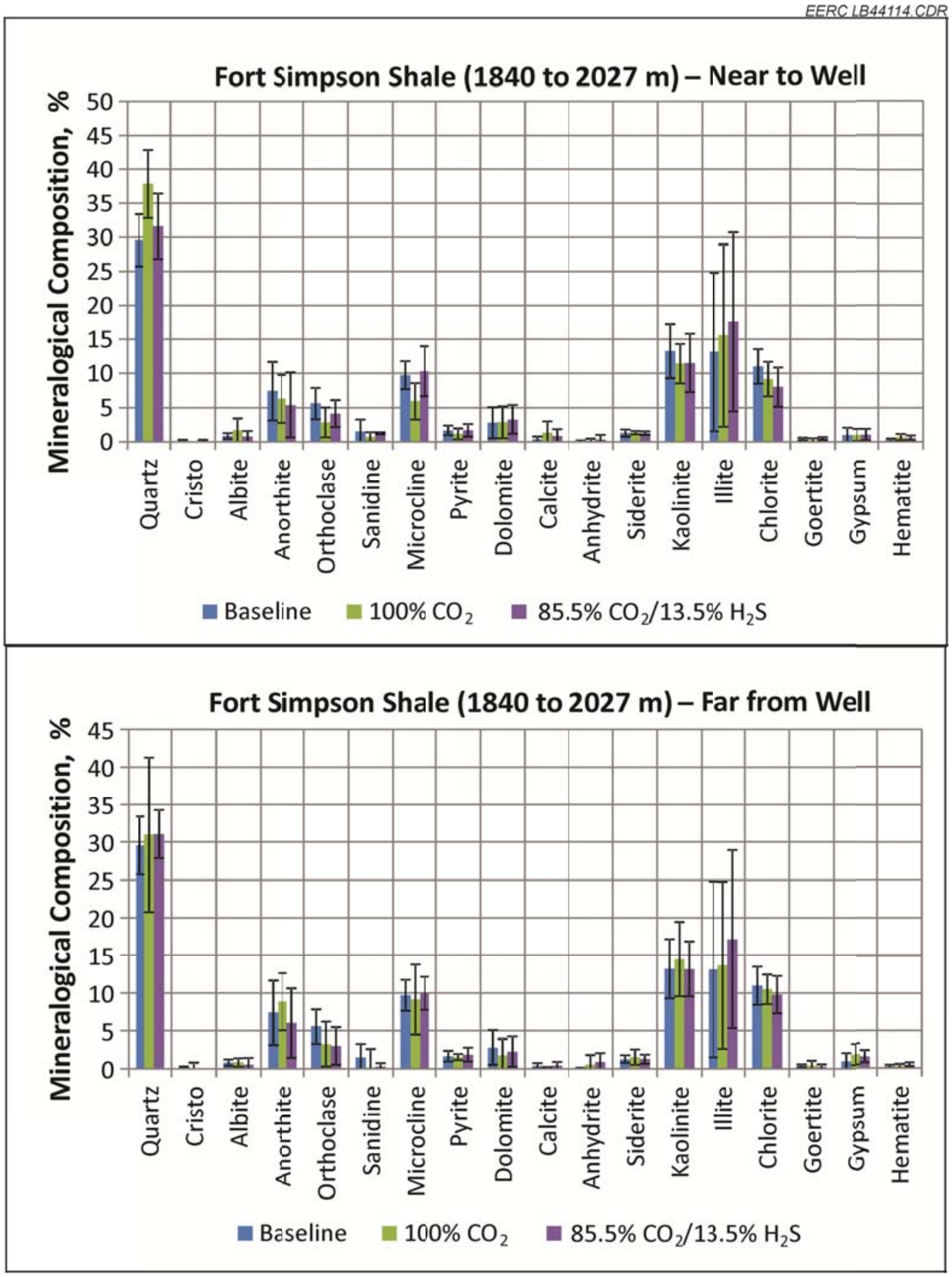


Figure 11. Fort Simpson Formation shale (1840 to 2027 m) mean and standard deviation predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Tests 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are on top, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are on bottom. Only cuttings saturated with synthesized brine are shown.

XRF Pre- and Postexposure

Pre- and postexposure XRF analysis was performed on seven of the ten samples that were analyzed by XRD, which included cutting samples from:

- 1845 m (Batch Reactor Tests 2 [near-wellbore] and Batch Reactor Test 3 [far-from-wellbore]).
- 1870 m (Batch Reactor Tests 2 and 3).
- 1890 m (Batch Reactor Tests 2 and 3).
- 1910 m (Batch Reactor Tests 2 and 3).
- 1940 m (Batch Reactor Tests 2 and 3).
- 1960 m (Batch Reactor Tests 2 and 3).
- 1995 m (Batch Reactor Tests 2 and 3).

Almost no changes were observed between pre- and postexposure XRF results on a sample-by-sample basis (Appendix C: Figures C-3a to C-3d).

The mean and standard deviation for pre- and postexposure XRF results on the seven samples collected from the Fort Simpson Formation shale (1840 m to 2000 m) are presented in Figure 12 (reproduced from Appendix C: Figure C-3e). On average, XRF analysis did not detect significant changes in the elemental composition between the pre- and postexposure samples.

WRS tests were conducted on the seven samples to test whether or not there were statistically significant differences in the elemental composition percentages between pre- and postexposure XRF measurements. The WRS tests showed that none of the element percentages was significantly different between pre- and postexposure at the 95% confidence level. These results are consistent with Figure 12.

Although not statistically significant across all seven Fort Simpson Formation shale samples, there appeared to be a slight increase in sulfur deposition for some of the CO_2-exposed samples. For example, higher precipitation of sulfur was observed in samples exposed to sour CO_2 at far-from-wellbore conditions; however, the increases over baseline were small and on the order of 0.1% to 0.5%.

Otter Park Shale (transitional rock)

XRD was used to assess the sample mineralogy before and after exposure. The complete assessments of all combinations of pre- and postexposure measurements are provided in Appendix C. These comparisons are summarized below.

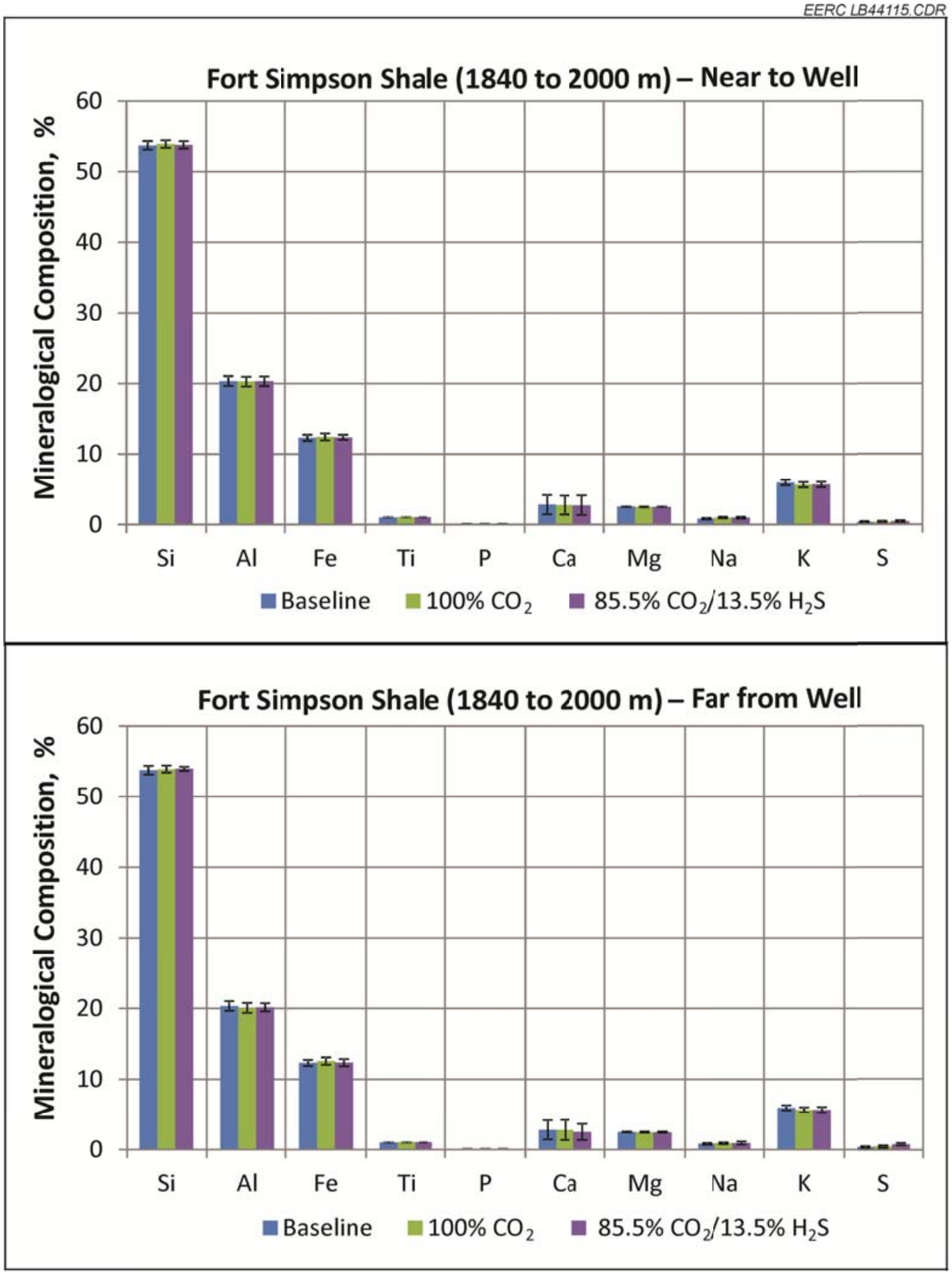


Figure 12. Fort Simpson Formation shale (1840 to 2000 m) mean and standard deviation predominant elemental composition in c-61-E drill cuttings as determined by XRF on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are on top, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are on bottom. Only cuttings saturated with synthesized brine are shown.

XRD Pre- and Postexposure Comparisons

Pre- and postexposure XRD analysis was performed on cutting samples from:

- Otter Park shale, 2054 m (Batch Reactor Test 1).
- Otter Park shale, 2075 m (Batch Reactor Test 1, Batch Reactor Test 2 [near-wellbore] and Batch Reactor Test 3 [far-from-wellbore]).

XRD data did not show any significant changes in pre- and postexposure mineralogy (Appendix C: Figure C-1a to C-1b and Figure C-2e). Changes were not consistent in either direction or magnitude from one sample to the next. While the data appeared to show a decrease in quartz and a slight increase in dolomite for the CO_2-exposed samples, the values presented are within method uncertainty and cannot be used to draw conclusions or postulate mechanistic changes. Pre- and postexposure mineralogy results for XRD on the Otter Park Formation shale (2075 m) are presented in Figure 13 (reproduced from Appendix C: Figure C-2e).

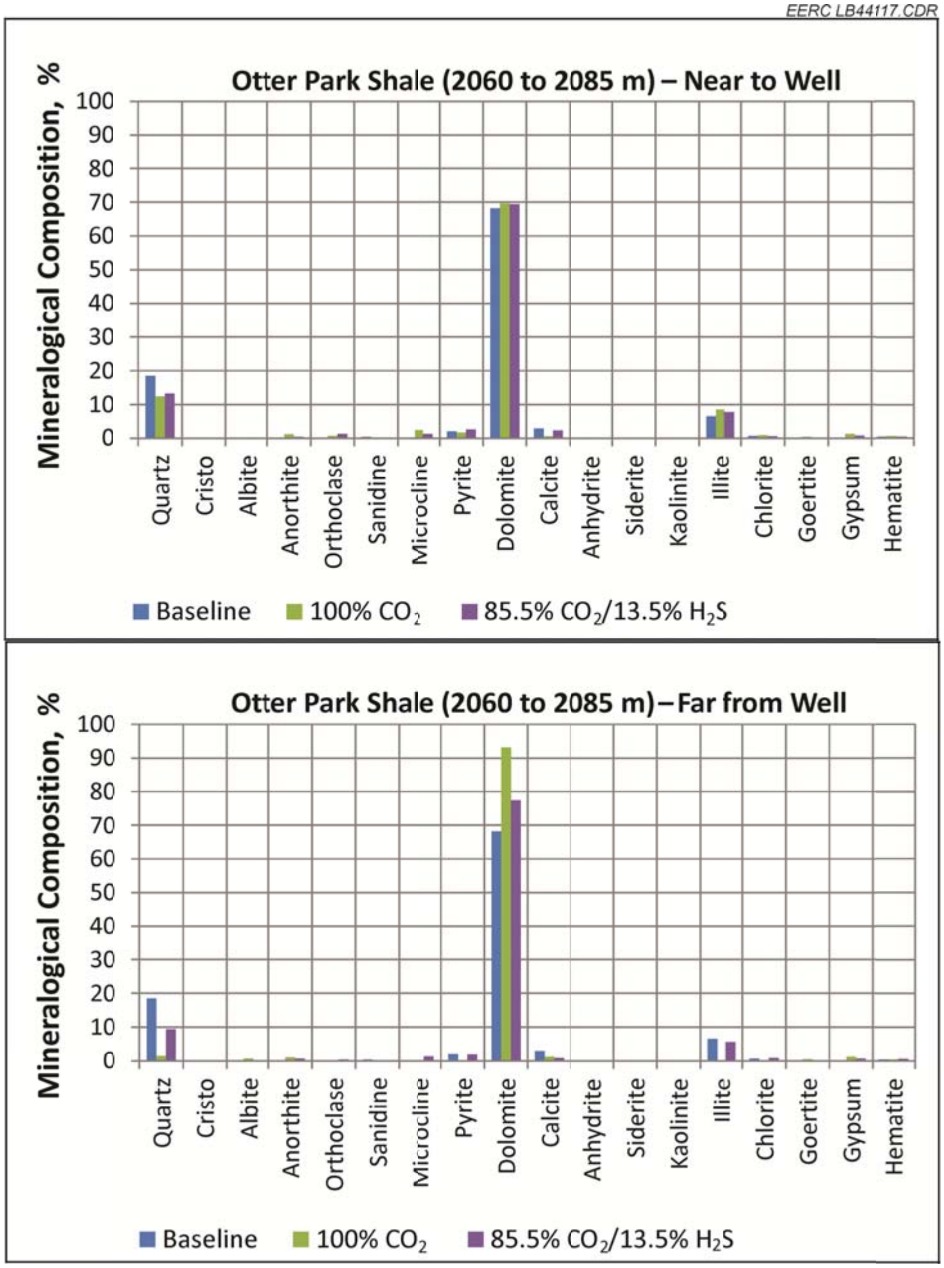


Figure 13. Predominant mineral phases in c-61-E drill cuttings collected from the Otter Park Formation shale (2075 m) as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are on top, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are on bottom. Only cuttings saturated with synthesized brine are shown.

Upper and Lower Slave Point Dolomite (transitional rock)

XRD was used to provide mineralogy assessment of the samples before and after exposure. The complete assessments of all combinations of pre- and postexposure measurements are provided in Appendix C. These comparisons are summarized below.

XRD Pre- and Postexposure Comparisons

Pre- and postexposure XRD analysis was performed on cutting samples from:

- Upper Slave Point dolomite, 2115/2120 m (Batch Reactor Test 1).
- Lower Slave Point dolomite, 2170/2175 m (Batch Reactor Test 1).
- Lower Slave Point dolomite, 2190 m (Batch Reactor Test 2 [near-wellbore] and Batch Reactor Test 3 [far-from-wellbore]).

XRD data did not show any significant changes in pre- and postexposure mineralogy (Appendix C: Figure C-2a and Figure C-3f) except for possible dissolution of dolomite in the Lower Slave Point sample exposed to far-from-wellbore conditions and pure CO_2. Other apparent mineralogical changes were not consistent in either direction or magnitude from one sample to the next of clays and silicates. This result is thought to be a product of oriented-aggregate sample preparation. Additional clay may also have been lost in the amorphous background. Pre- and postexposure mineralogy results for XRD on the Lower Slave Point Formation dolomite (2190 m) are presented in Figure 14 (reproduced from Appendix C: Figure C-3f).

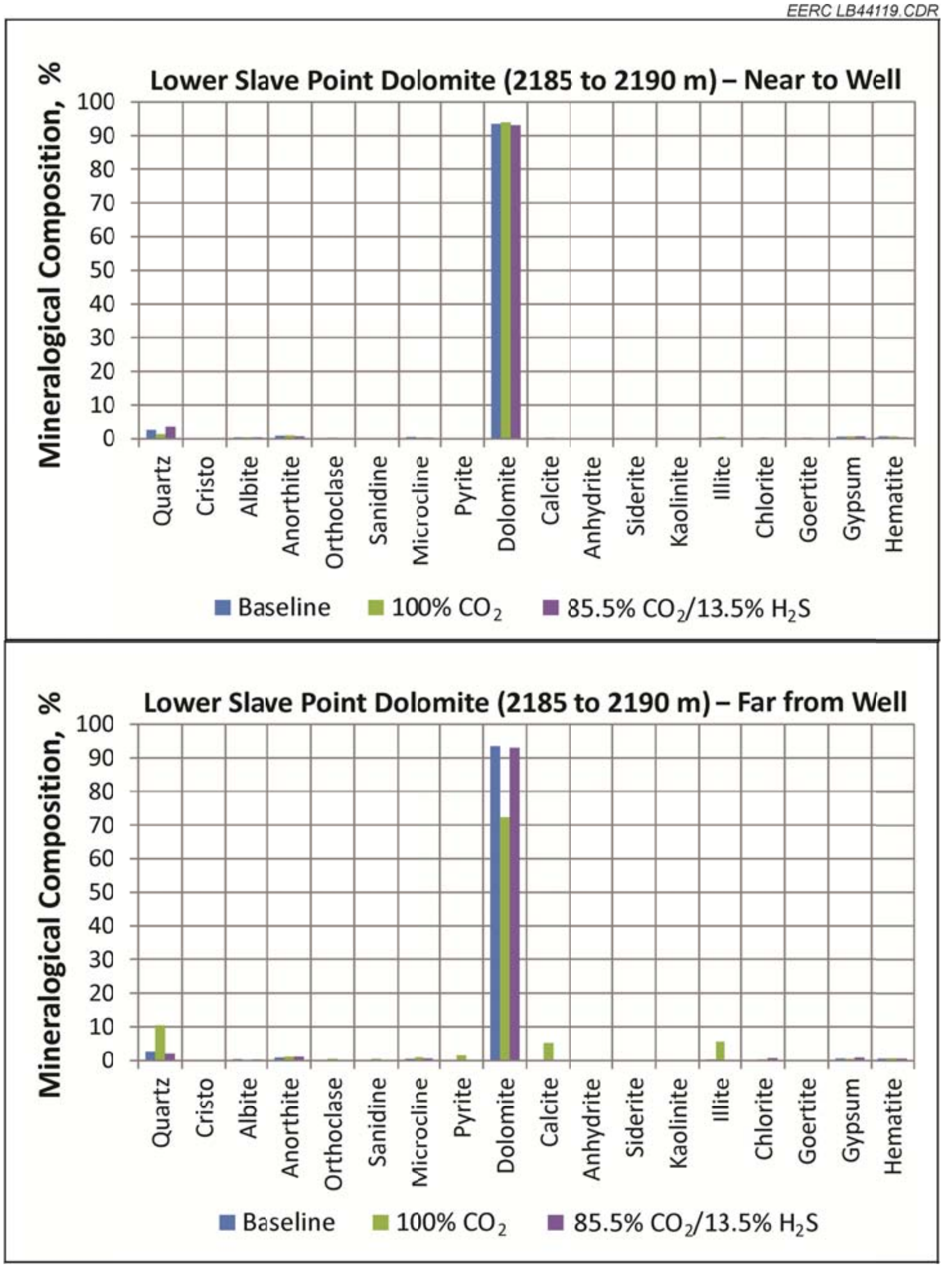


Figure 14. Predominant mineral phases in c-61-E drill cuttings collected from the Lower Slave Point Formation dolomite (2190 m) as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are on top, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are on bottom. Only cuttings saturated with synthesized brine are shown.

Sulphur Point Dolomite (reservoir rock)

Two separate analyses provided mineralogy assessments before and after exposure: XRD and SEM–EDS. The complete assessments of all combinations of pre- and postexposure measurements are provided in Appendix C. These comparisons are summarized below and are organized by the type of analytical measurement.

XRD Pre- and Postexposure Comparisons

Pre- and postexposure XRD analysis was performed on cutting samples from:

- Sulphur Point dolomite, 2195/2200 m (Batch Reactor Test 1).
- Sulphur Point dolomite, 2205 m (Batch Reactor Test 2 [near-wellbore] and Batch Reactor Test 3 [far-from-wellbore]).
- Sulphur Point dolomite, 2220 m (Batch Reactor Tests 2 and 3).

XRD data did not show any appreciable changes in pre- and postexposure mineralogy (Appendix C: Figure C-1c and Figures C-2f to C-2g). Changes were not consistent in either direction or magnitude from one sample to the next—with respect to clays and silicates. This result is thought to be a product of oriented-aggregate sample preparation. Additional clay may also have been lost in the amorphous background. Pre- and postexposure mineralogy results for XRD on the Sulphur Point Formation dolomite (2220 m) are presented in Figure 15 (reproduced from Appendix C: Figure C-2g).

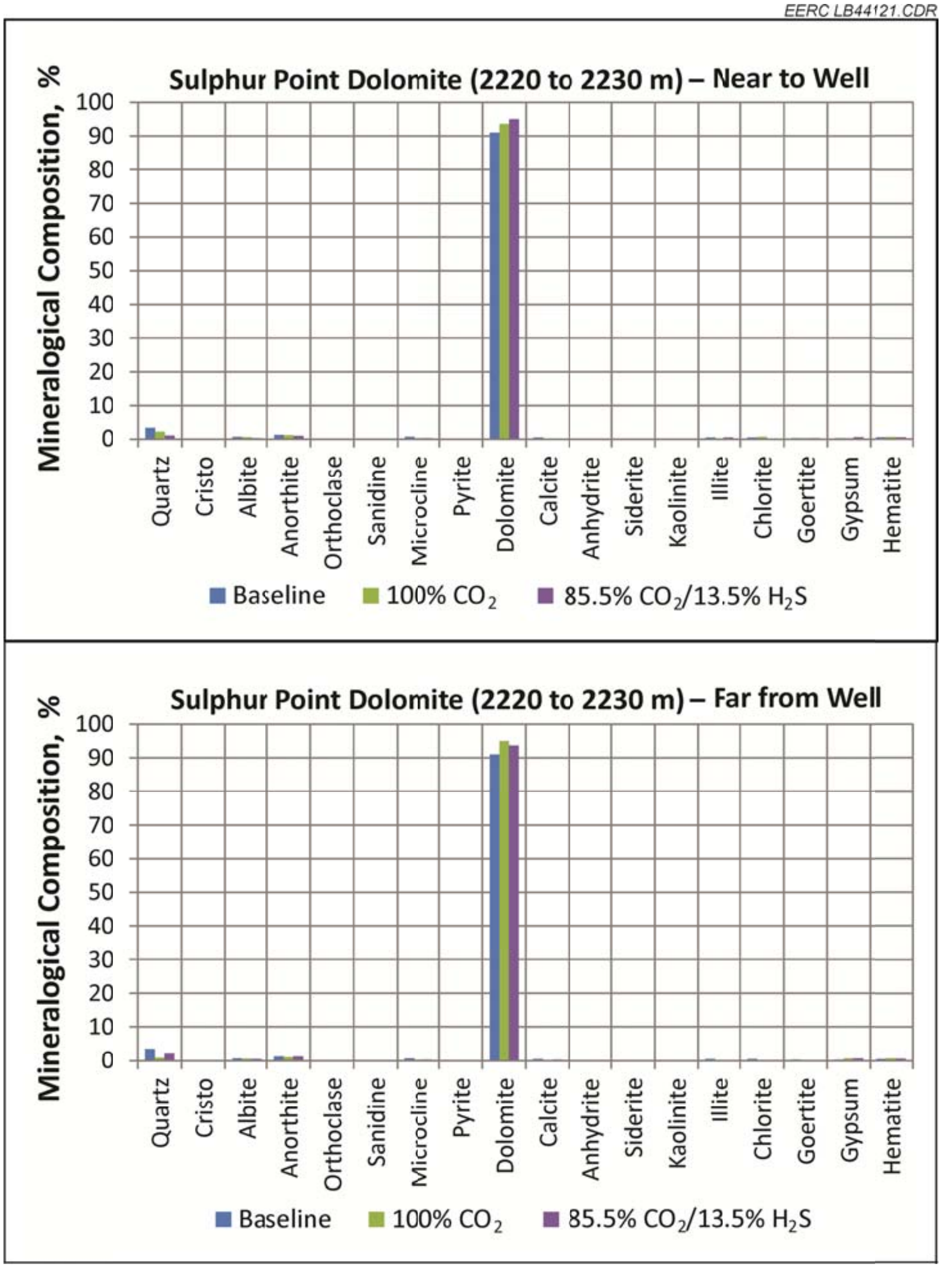


Figure 15. Predominant mineral phases in c-61-E drill cuttings collected from the Sulphur Point Formation dolomite (2220 m) as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are on top, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are on bottom. Only cuttings saturated with synthesized brine are shown.

SEM-EDS Pre- and Postexposure

Pre- and postexposure SEM–EDS analysis was performed on cutting samples from:

- Sulphur Point dolomite, 2220 m (Batch Reactor Test 2 [near-wellbore] and Batch Reactor Test 3 [far-from-wellbore]).

The comparison of the SEM–EDS images and mineral quantifications for the single set of as-received and exposed samples suggests the following:

- Possible dissolution of dolomite in cuttings exposed to sour CO_2.
- Possible pyrite dissolution and reprecipitation of iron-bearing minerals (presumably goethite).
- Minor precipitation of calcite and calcium chloride for sour CO_2 exposure cases.
- Minor precipitations of elemental sulfur and NaCl.

An example SEM–EDS electron backscatter micrograph for pre- and postexposure to sour CO_2 at near-wellbore conditions (65°C and 3500 psi) (Batch Reactor Test 2) is provided in Figure 16 (reproduced from Appendix C: Figures C-4a and C-4c).

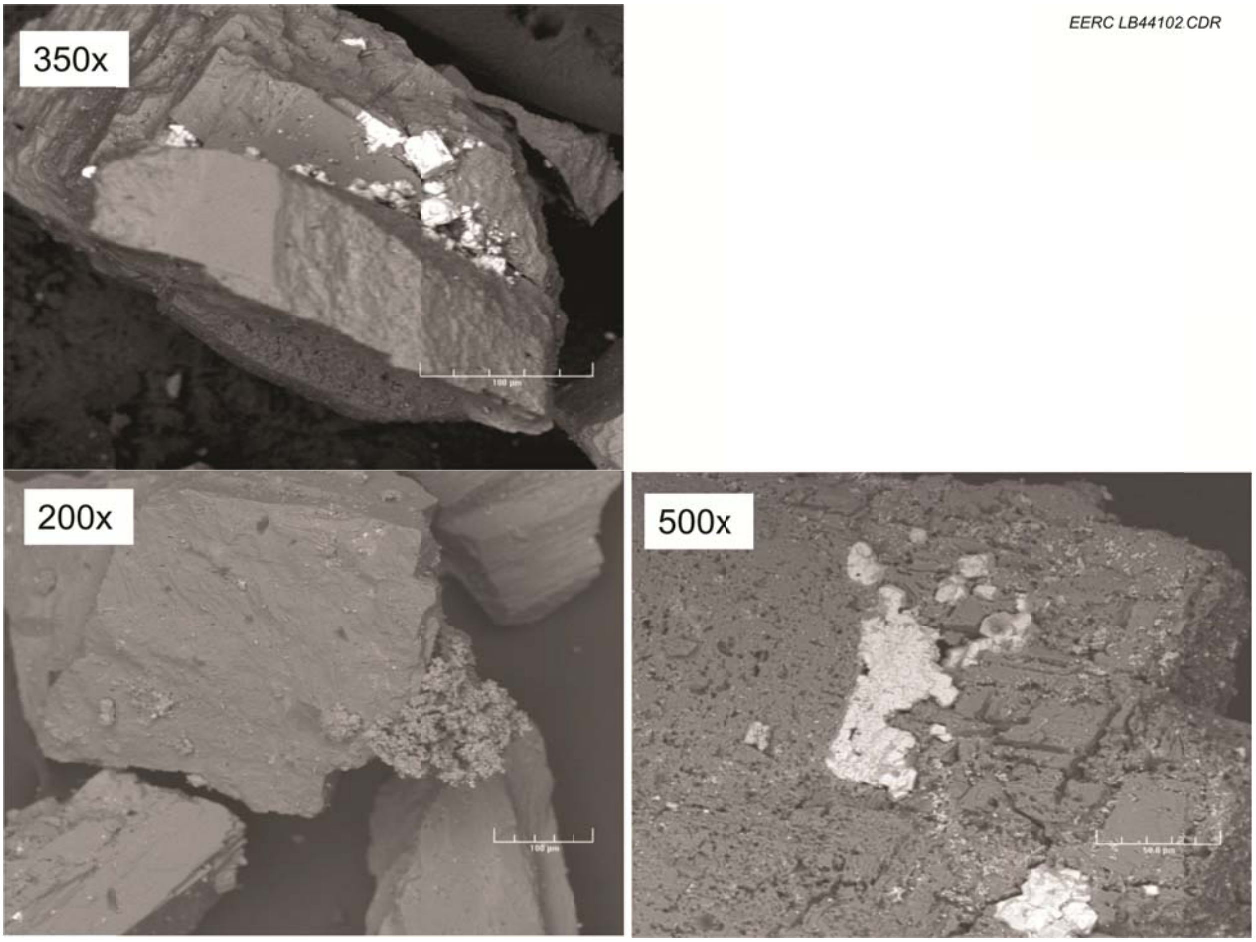


Figure 16. Comparison of SEM–EDS electron backscatter micrographs of Sulphur Point Formation (2220 m) preexposure (350×, top) and after sour CO_2 exposure and saturation with synthetic brine (NaCl solution) at near-wellbore conditions (65°C and 3500 psi) (200× and 500×, bottom). Note the pyrite dissolution and iron-bearing mineral (presumably goethite) reprecipitation on the postexposure 200× sample. Also note the smooth, unaltered surface of the unreacted dolomite (preexposure, 350× sample) and straight stripes and corroded surface of the dolomite after the exposure (postexposure, 500×).

Upper Keg River Dolomite (reservoir rock)

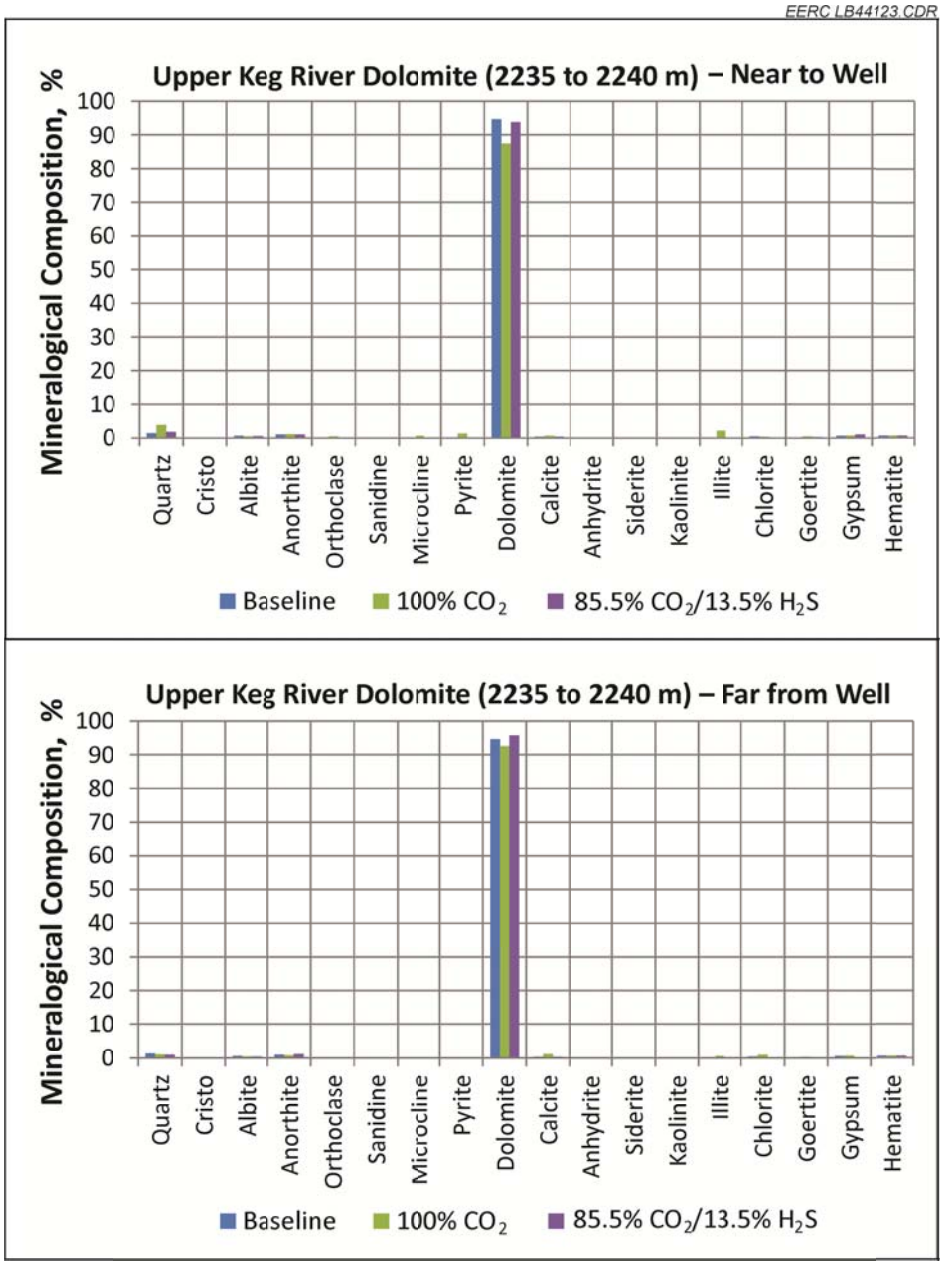
The Upper Keg River dolomite sample (2235 m) was analyzed using XRD. The complete assessments of all combinations of pre- and postexposure measurements are provided in Appendix C. These comparisons are summarized below and are organized by the type of analytical measurement.

XRD Pre- and Postexposure Comparisons

Pre- and postexposure XRD analysis was performed on cuttings samples from:

- Upper Keg River dolomite, 2235 m (Batch Reactor Test 2 [near-wellbore] and Batch Reactor Test 3 [far-from-wellbore]).

XRD data did not show any significant changes in pre- and postexposure mineralogy (Appendix C: Figure C-2g). Changes were not consistent in either direction or magnitude from one sample to the next for clays and silicates. This result is thought to be a product of oriented-aggregate sample preparation. Additional clay may also have been lost in the amorphous background. Pre- and postexposure mineralogy results for XRD on the Upper Keg River Formation dolomite (2235 m) are presented in Figure 17 (reproduced from Appendix C: Figure C-2g).



Upper Keg River Dolomite (2235 to 2240 m) – Near to Well

Upper Keg River Dolomite (2235 to 2240 m) – Far from Well

Figure 17. Predominant mineral phases in c-61-E drill cuttings collected from the Upper Keg River Formation dolomite (2235 m) as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are on top, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are on bottom. Only cuttings saturated with synthesized brine are shown.

Potential Changes in Reservoir Fluid Properties

In addition to the baseline and CO_2-exposed sample characterization and comparison of mineral and element composition discussed earlier, possible changes to mineral and chemical composition were also evaluated from pre- and postexposure analyses of brine major ion chemistry. The synthetic brine (NaCl solution) and the synthesized brines were analyzed for major ions by ICP–MS following exposure to CO_2 or sour CO_2 with and without sample cuttings. The brines exposed without cuttings provide a baseline control, and the brines exposed with cuttings provide data to evaluate the possible effects of mineral dissolution under different simulated reservoir conditions.

Comparisons were made on a relative basis, evaluating nonexposed baseline brine ion concentrations against the CO_2-exposed sample ion concentrations. Assessments were limited to those sample group combinations which contained measurements for both nonexposed (baseline) and exposed samples of the same brine type (i.e., synthetic [NaCl solution] or synthesized) and reservoir conditions (i.e., near-wellbore [65°C and 3500 psi] or far-from-wellbore [120°C and 2800 psi]). The complete assessments of all combinations of pre- and postexposure measurements are provided in Appendix D. These comparisons are summarized below and are organized by formation(s) and brine type.

Fort Simpson Shale (cap rock)

Synthetic Brines

Synthetic brines (NaCl solution) were mixed with Fort Simpson Formation shale cuttings and exposed to the following:

- Near-wellbore conditions (65°C and 3500 psi) and 100% CO_2.
- Far-from-wellbore conditions (120°C and 2800 psi) and both 100% CO_2 and 86.5% CO_2/13.5% H_2S.

The synthetic brines (NaCl solution) containing Fort Simpson shale all showed increased concentrations of calcium, magnesium, potassium, and strontium cations between baseline and postexposure (Appendix D: Figures D-3a and D-3b) especially in those samples exposed to far-from-wellbore conditions. An example of the Fort Simpson shale exposed to synthetic brine at far-from-wellbore conditions (1950 to 1975 m) is shown in Figure 18 (see page D-10 for figure). The increased sulfur concentrations may support the presence of pyrite and/or gypsum. However, the increases in sulfur were most pronounced for the CO_2/H_2S exposures, which also increased the sulfur concentrations of the baseline (i.e., brine exposed to CO_2/H_2S with no cuttings), indicating addition of sulfur to the system via H_2S.

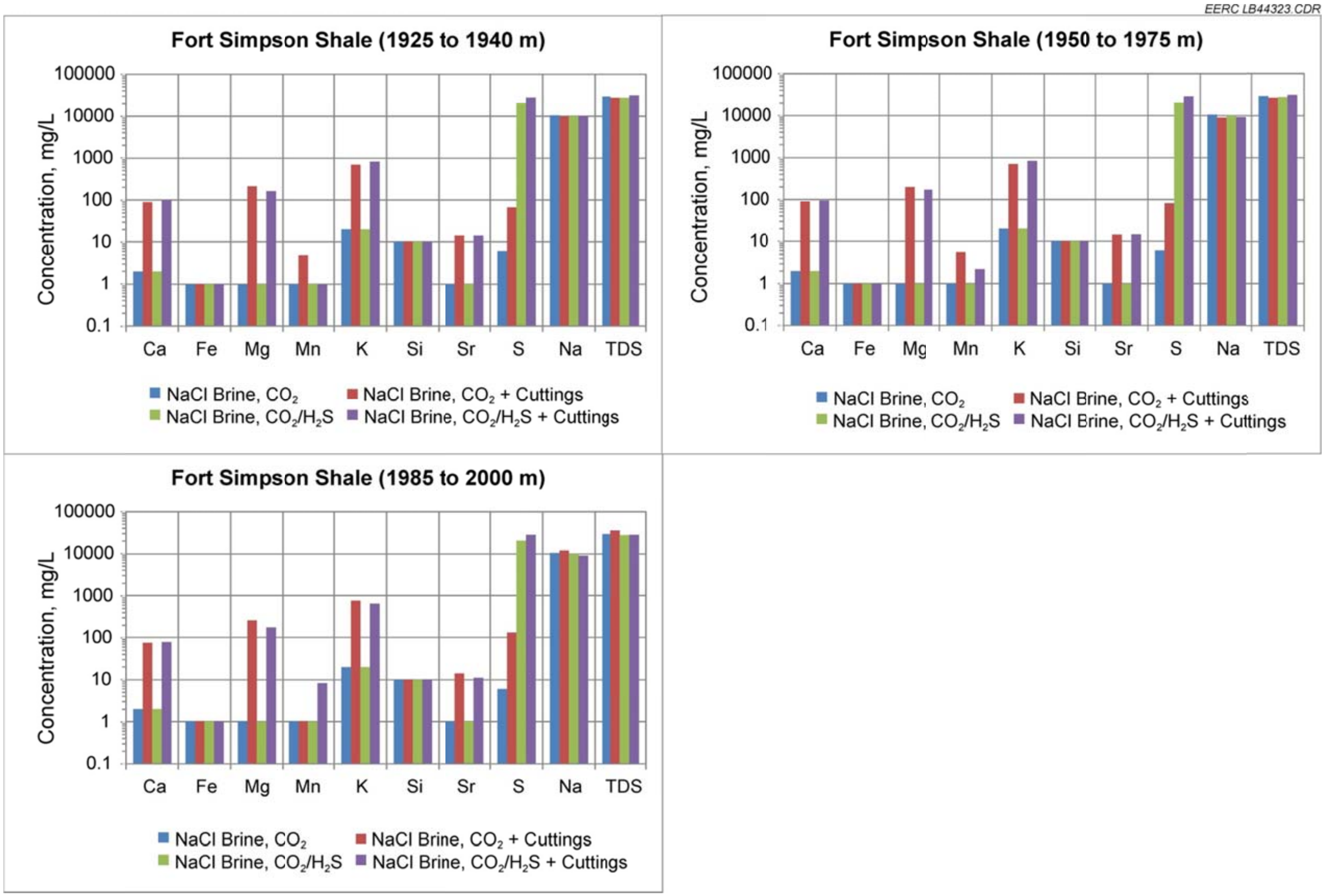


Figure 18. Baseline and postexposure ICP–MS analyses of synthetic brine (NaCl solution) for Batch Reactor Test 2–5 experiments. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. Samples were exposed to far-from-wellbore conditions (120°C and 2800 psi).

Synthesized Brines

Synthesized brines were mixed with Fort Simpson Formation shale cuttings and exposed to the following:

- Near-wellbore conditions and both 100% CO_2 and 86.5% CO_2/13.5% H_2S.

The synthesized brines showed increased concentrations of Mg, Mn, K, and S concentrations between baseline and postexposure. The mean and standard deviation of the postexposure synthesized brine results for ICP–MS on the seven samples collected from the Fort Simpson Formation shale (1840 to 2000 m) is compared against baseline in Figure 19 (reproduced from Appendix D: Figure D-5). Increased sulfur concentrations were associated with the CO_2/H_2S exposures and likely reflect sulfur entering the system via H_2S. WRS tests showed that only manganese concentrations increased significantly (95% confidence) as compared to baseline.

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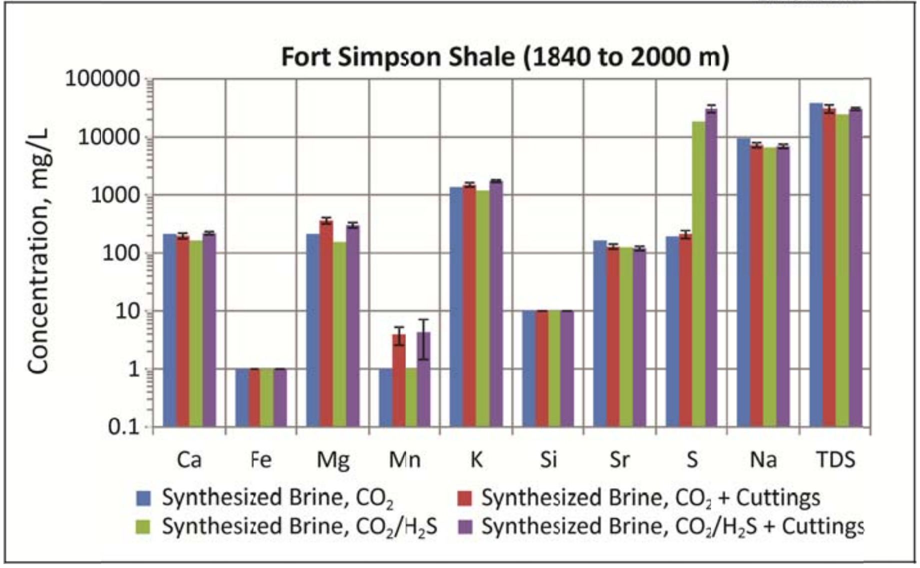

Figure 19. Baseline and mean ± standard deviation postexposure ICP–MS analyses of synthesized brines exposed to Fort Simpson Formation shale cuttings at near-wellbore conditions. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Otter Park Shale (transitional rock)

Synthetic Brines

Synthetic brines (NaCl solution) were mixed with Otter Park Formation shale cuttings and exposed to the following:

- Near-wellbore conditions (65°C and 3500 psi) and 100% CO_2.

The synthetic brines (NaCl solution) showed increased concentrations of calcium and magnesium between baseline and postexposure (Appendix D: Figure D-2a).

Synthesized Brines

Synthesized brines were mixed with Otter Park Formation shale cuttings and exposed to the following:

- Near-wellbore conditions and 86.5% CO_2/13.5% H_2S.

The synthesized brines did not show increased concentrations between baseline and postexposure, as shown in Figure 20 (adapted from Appendix D: Figure D-4c).

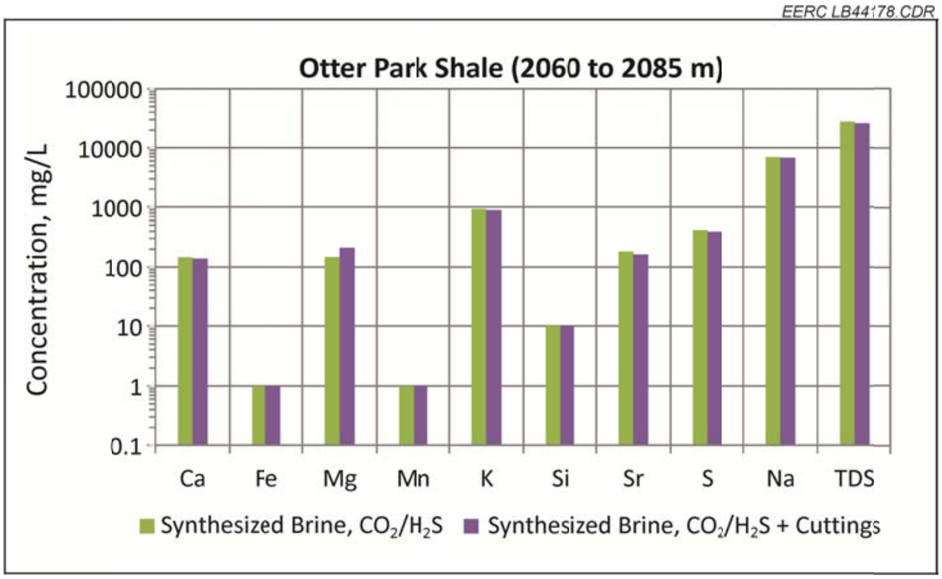

Figure 20. Baseline and postexposure ICP–MS analyses of synthesized brine for the Otter Park Formation shale (2075 m) at near-wellbore conditions. CO_2 conditions were not conducted on this sample. CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Upper and Lower Slave Point Dolomite (transitional rock)

Synthetic Brines

Synthetic brines (NaCl solution) were mixed with Lower Slave Point Formation dolomite cuttings and exposed to the following:

- Near-wellbore conditions (65°C and 3500 psi) and 100% CO_2.

The synthetic brines (NaCl solution) showed increased concentrations of calcium and magnesium between baseline and postexposure (Appendix D: Figure D-2a).

Synthesized Brines

Synthesized brines were mixed with Lower Slave Point dolomite cuttings and exposed to the following:

- Near-wellbore conditions and 86.5% CO_2/13.5% H_2S.

The synthesized brines did not show increased concentrations between baseline and postexposure, as shown in Figure 21 (adapted from Appendix D: Figure D-4c).

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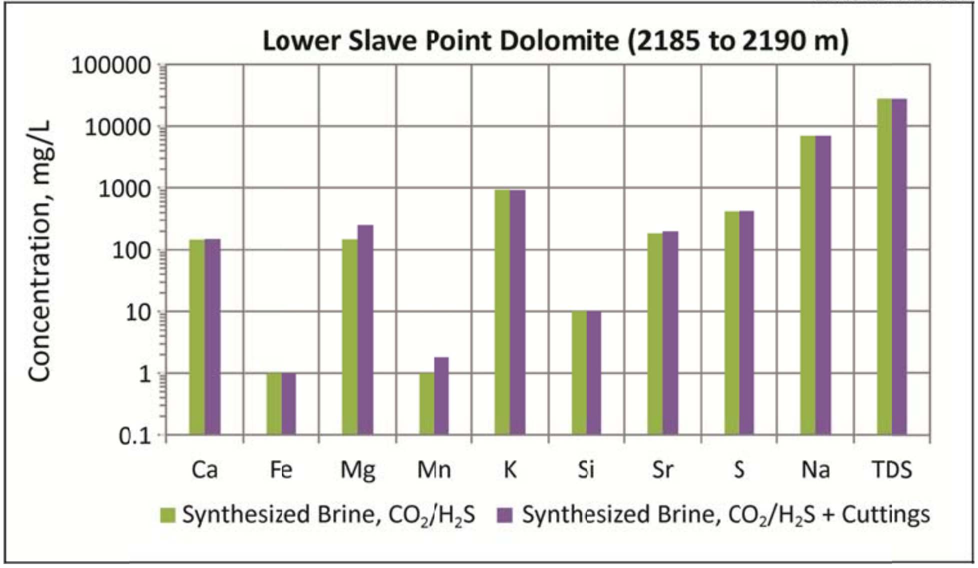

Figure 21. Baseline and postexposure ICP–MS analyses of synthesized brine for the Lower Slave Point Formation dolomite (2190 m) at near-wellbore conditions. CO_2 conditions were not conducted on this sample. CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Sulphur Point Dolomite (reservoir rock)

Synthetic Brines

Synthetic brines (NaCl solution) were mixed with Sulphur Point Formation dolomite cuttings and exposed to the following:

- Near-wellbore conditions (65°C and 3500 psi) and 100% CO_2.

The synthetic brines (NaCl solution) showed increased concentrations of calcium and magnesium between baseline and postexposure (Appendix D: Figure D-2b).

Synthesized Brines

Synthesized brines were mixed with Sulphur Point Formation dolomite cuttings and exposed to the following:

- Near-wellbore conditions and 86.5% CO_2/13.5% H_2S.

The synthesized brines did not show increased concentrations between baseline and postexposure, as shown in Figure 22 (adapted from Appendix D: Figures D-4c and D-4d).

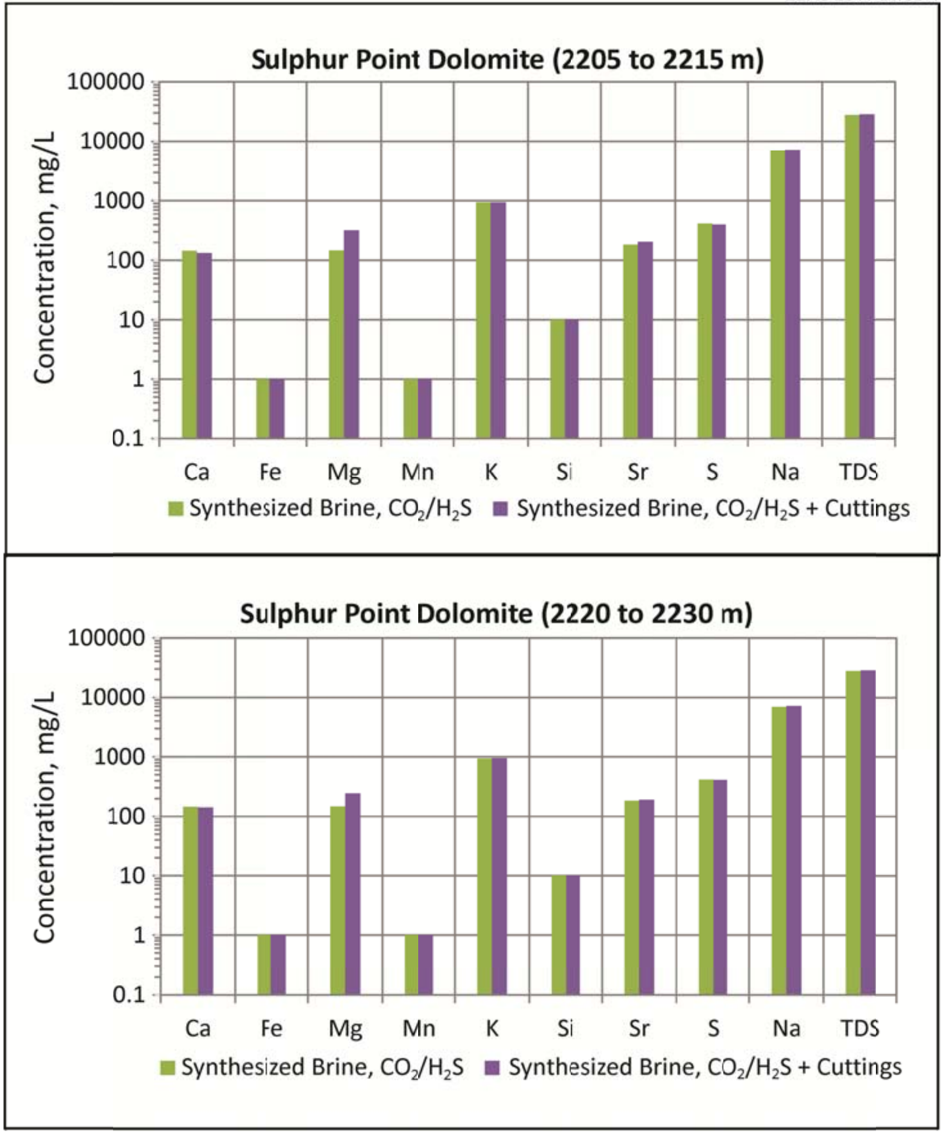

Figure 22. Baseline and postexposure ICP–MS analyses of synthesized brine for the Sulphur Point Formation dolomite (2205 m and 2220 m) at near-wellbore conditions. CO_2 conditions were not conducted on this sample. CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Upper Keg River Dolomite (reservoir rock)

Synthetic Brines

Synthetic brines (NaCl solution) were mixed with Sulphur Point Formation cuttings and exposed to the following:

- Near-wellbore conditions (65°C and 3500 psi) and 100% CO_2.

The synthetic brines (NaCl solution) showed increased concentrations of calcium and magnesium between baseline and postexposure (Appendix D: Figure D-2b).

Synthesized Brines

Synthesized brines were mixed with Sulphur Point Formation dolomite cuttings and exposed to the following:

- Near-wellbore conditions and 86.5% CO_2/13.5% H_2S.

The synthesized brines showed an increase in magnesium concentration between baseline and postexposure, as shown in Figure 23 (adapted from Appendix D: Figure D-4d).

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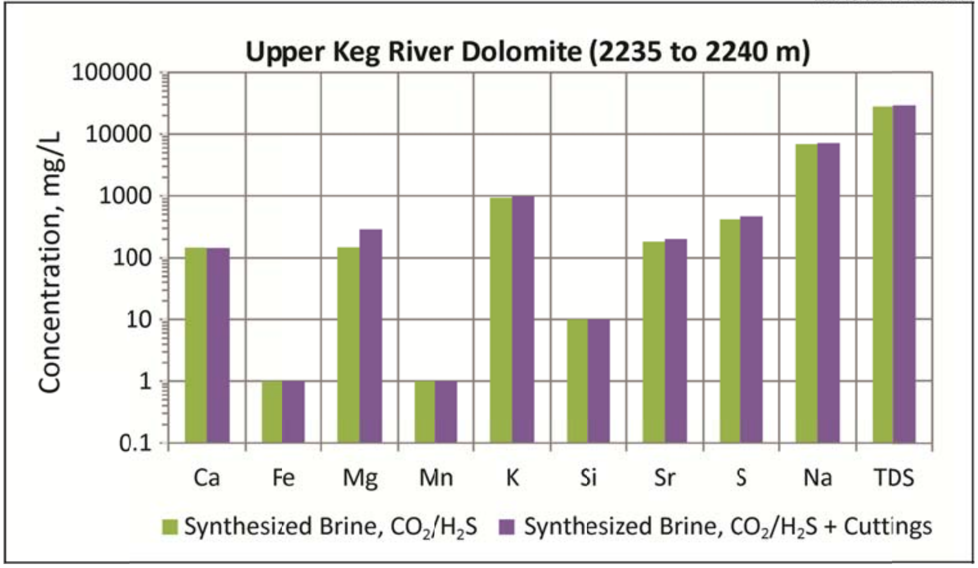

Figure 23. Baseline and postexposure ICP–MS analyses of synthesized brine for the Upper Keg River Formation dolomite (2235 m) at near-wellbore conditions. CO_2 conditions were not conducted on this sample. CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Brine Summary

The synthetic brine (NaCl solution) mixed with reservoir formation rock/cuttings generally resulted in higher calcium and magnesium concentrations in the postexposure ICP–MS results than in the baseline, suggesting dissolution of calcite and/or dolomite minerals. In contrast, the synthesized brine mixed with formation rock/additive generally did not show significant differences in calcium and magnesium concentrations between the baseline and postexposure ICP–MS results. Consequently, the brine chemistry and composition appear to affect mineral dissolution. In most samples, whether exposed to synthetic or synthesized brine, an increase in Mn was observed. However, it is worth noting that the simulated brine composition that was closest to the actual formation brine composition appeared to exert the little-to-no effect.

SUMMARY AND CONCLUSIONS

The injection of CO_2 and sour CO_2 into a reservoir may have the potential to alter the geochemical stability of fluids and minerals. In its most basic form, CO_2 will dissolve into water and form a weak solution of carbonic acid, which will lower the local pH and potentially dissolve acid-soluble materials such as carbonate minerals or metal oxides. The H_2S also forms a weak acid in solution, lowering the pH and providing an additional source of sulfur. To a much lesser extent, injection activities may cause a local temperature and/or pressure flux, or localized "drying," which may alter specific aspects of the reservoir geochemistry. Although these processes do not ordinarily pose a problem for reservoir activities, the potential for detrimental geochemical reactions, such as excess dissolution or precipitation, needs to be assessed.

This project investigated the effects of four factors which have the potential to cause mineralogical reactions at different locations within the reservoir: 1) pressure, 2) temperature, 3) brine composition, and 4) sour CO_2 composition.

General conclusions can be made with respect to expected (or theorized) reactions and the results of the geochemical laboratory studies. These possible reactions include carbonate mineral dissolution, calcite precipitation, iron mobilization and precipitation, elemental sulfur deposition, and ion exchange in clays and carbonates. Brief summaries for each of these reactions are provided as follows with specific conclusions for each of the primary formations at the Fort Nelson CCS project site immediately following.

Primary Reactions

Carbonate Mineral Dissolution

Many of the carbonate containing drill cuttings containing carbonates showed an apparent and varying degree of dissolution of dolomite and calcite (up to approximately 7 wt% reduction) following exposure to CO_2 and sour CO_2 at reservoir conditions. This observation was based on analyses of the samples by XRF and SEM–EDS, but generally not supported by XRD analyses. Simultaneously, the concentration of calcium and magnesium increased in the synthetic brine (as analyzed by ICP–MS) analyzed by the ICP–MS analysis, supporting the dolomite dissolution hypothesis. However, ICP–MS analysis of the synthesized brine (believed to be closer in composition to the actual brine than a simple aqueous solution of NaCl) did not show significant increases in calcium or magnesium, suggesting that, as one might expect, brine chemistry is important. In addition, the samples that were exposed to synthetic brine in far-from-wellbore conditions showed considerably higher increases in Ca and Mg than those exposed to near-wellbore conditions suggesting that the geochemical reactions are very sensitive to exposure temperatures and pressures, at least for the sample evaluated. It is important to keep in mind that the estimated formation brine may already be in equilibrium with magnesium and calcium, and therefore, no further dissolution could occur. Also, the straight NaCl solution, which is not truly representative of the actual formation water, was likely not in equilibrium with these minerals and thus dissolution was able to occur.

Calcite dissolution in the reservoir is theorized to be the primary geochemical reaction that may take place under pure CO_2 exposure conditions. Dolomite is generally more resistant to acidic treatment; however, in these series of experiments, some degree of dolomite dissolution was observed in many of the carbonate rocks, with more significant effects observed when exposed to sour CO_2 in the presence of NaCl brine, high temperature, and low pressure (i.e., far-from-wellbore conditions). A lower degree of dolomite dissolution was observed in batch reactor experiments using synthesized brine at low-pressure and high-temperature conditions and following exposure to sour CO_2. Under the conditions of these experiments, it appears that the dolomite and a small amount of cementing calcite present in the reservoir will “buffer” the fluid pH, preventing pronounced dissolution reactions. Should dissolution of dolomite and calcite occur, a small degree of mechanical weakening of the reservoir and cap rock formations and a slight increase in rock porosity and permeability of reservoir and cap rock formations could be expected. At the same time, it is also possible that dissolved calcium may precipitate as calcite elsewhere in the formation in the short term, which could cause clogging of reservoir porosity and permeability if chemical controls are not emplaced (specifically regarding calcium oversaturation or basic fluid influx). However, it should be noted that this hypothesis is based on batch reactor tests which do not have any flow. The movement of fluids that would occur in a reservoir undergoing active, large-scale injection may prevent clogging and loss of permeability. On limited samples, calcite deposition was observed by data from the SEM–EDS analysis.

Iron Mobilization and Potential Precipitation of Iron-Bearing Minerals

Following exposure of iron-rich Slave Point Formation cutting samples to CO_2, a reaction product (goethite) was observed on the walls of the vial and cutting samples, which had noticeable rust-red or yellow coloration. The XRD analyses of the precipitate material confirmed that goethite and hematite minerals had precipitated, while overall iron concentrations in the cutting samples decreased. The same reaction was not observed in the cuttings exposed to sour CO_2. Iron in various states was originally present in the samples and originated from the carbonate or shale matrix, where it can substitute with other cations within the crystal structure of the mineral. It is likely that iron (Fe^{2+} or Fe^{3+}) displacement by protons (H^+) is responsible for iron hydroxide precipitation ($Fe[OH]_3$), where protons are supplied as a result of introduction of CO_2. Also, precipitation of iron hydroxide could be supported by carbonate dissolution and consequent buffering of the pH in the solution. It is possible that these observations are a result of contamination of the Slave Point cutting samples being contaminated with cuttings from overlying shale formations.

Elemental Sulfur, Unknown Sulfur Material, and Halite Deposition

Halite and elemental sulfur deposition was observed by the SEM analyses after sample exposure to the pure CO_2 and sour CO_2. The halite precipitation was more prevalent for the pure CO_2 exposure conditions, and the sulfur deposition was observed after the sour CO_2 exposure. It is possible that the halite precipitation was caused by the temperature drop that occurs at the end of the batch reactor experiment, causing the salt to drop out of solution. However, both halite and sulfur precipitation were observed in other exposure regimes, where sulfur deposition could be explained by pyrite dissolution and cation exchange.

Ion Exchange in Clays and Carbonates

Insignificant losses of potassium and aluminum were observed in all samples from the 1845–2005-m-depth interval (Fort Simpson Formation shale). The loss of potassium and aluminum in clays could be explained by cation exchange mechanism where K^+ and Al^{3+} ions in clay structure were exchanged by some different ion, for example, H^+. Loss of aluminum and potassium could also be attributed to dissolution of K-feldspars or other silicates.

Cap Rock (Fort Simpson shale)

The batch reactor tests performed with the Fort Simpson shale samples showed that:

- The mineralogical assemblage of the primary rock is stable and resistant to mineralogical changes. Only minor dissolution of dolomite, pyrite, and ion exchange in clays is predicted to occur. While the brine analyses suggested potentially significant dissolution of dolomite (based on increases in Ca and Mg), the percentage of dolomite in these rocks is small.

- Although counterintuitive, the sour CO_2 mixture is likely less reactive geochemically than pure CO_2, as the dissolution of pyrite is enhanced by the presence of CO_2 and the presence of H_2S possibly inhibits the dissolution of pyrite mineral.

- The precipitation of elemental sulfur may occur in case of sour CO_2 injection at the far-from-wellbore pressure and temperature conditions; however, any decrease in porosity would probably be beneficial for cap rock integrity.

Transitional Rock (Otter Park shale)

The batch reactor tests performed with the Otter Park shale samples showed that:

- The dissolution of dolomite and cementing calcite was suggested by the ICP–MS data from the synthetic brine analyses.

- Similar to the samples for the Fort Simpson Formation, the dissolution of pyrite was more prominent for the samples exposed to pure CO_2.

- The precipitation of elemental sulfur may occur in the case of sour CO_2 injection.

- The precipitation of halite was observed; however, the timing of the appearance of halite is unclear, and it is possible that halite precipitated during the drying process after sample removal from the batch reactors.

Upper and Lower Slave Point Dolomite

The batch reactor tests performed on the Upper and Lower Slave Point dolomite samples showed that:

- Dolomite and cementing calcite may dissolve during the initial stages of CO_2 injection, as suggested by the ICP–MS data for the synthetic brine.

- Elemental sulfur precipitation may occur in the case of sour CO_2 injection.

- The precipitation of halite was observed, although it is not clear when this occurred. It is possible that halite precipitated during the drying process, following sample removal from the batch reactors.

- Minor calcium chloride and calcite precipitated, which was likely due to oversaturation of the fluid with other ions, e.g., HS^-.

Reservoir Rock (Sulphur Point dolomite)

The batch reactor tests performed on the Sulphur Point dolomite samples showed that:

- Dolomite could possibly dissolve during the initial stages of the CO_2 injection, as suggested by the ICP–MS data for the synthetic brine.

- Elemental sulfur precipitation may occur during sour CO_2 injection.

- The precipitation of halite was observed, although when the appearance of halite occurred is unclear. It is possible that halite precipitated during the drying process, following sample removal from the batch reactors.
- Minor precipitation of calcium chloride and calcite was observed and is likely due to oversaturation of the fluid with other ions, e.g., HS^-.

- The dissolution of iron-bearing phases, such as pyrite, was observed, and re-precipitation of goethite is possible.

Upper Keg River Dolomite

The batch reactor tests performed on the Upper Keg River dolomite samples showed that:

- The dolomite could possibly dissolve during the initial stages of the CO_2 injection, as indicated by the ICP–MS data under synthetic brine conditions.

- Elemental sulfur precipitation may occur during sour CO_2 injection.

- The precipitation of halite was observed, although when the appearance of halite occurred is unclear. It is possible that halite precipitated during the drying process, following sample removal from the batch reactors.

- Minor precipitation of calcium chloride and calcite was observed and is likely due to oversaturation of the fluid with other ions, e.g., HS^-.

- The dissolution of iron-bearing phases, such as pyrite, was observed, and reprecipitation of goethite is possible.

The determination of CO_2 and sour CO_2 exposure effects to the formation rocks at reservoir conditions is limited by the size of the data sets that were generated during this screening study. Because of the natural mineralogical variability within each formation, numerous samples are required before statistical conclusions can be drawn. In recognition that this program was a screening study, the following data trends and observations can be made:

- No significant changes in minerology were observed in the cap rock, transition-zone rock, or reservoir rock during exposure to either pure CO_2 or sour CO_2 at any of the reservoir conditions that were investigated. However, minor shifts in chemical composition were observed that suggest dolomite dissolution and calcite, halite, and sulfur precipitation may occur at both the simulated near-wellbore and far-from-wellbore conditions.

- Exposure of formation rock to pure CO_2, as compared to sour CO_2, may result in a higher probability of cementing material dissolution, such as calcite, gypsum, and pyrite, and the mobilization of iron from the clay and carbonate minerals matrix.

- Limited data suggest that dissolution of carbonates from cement, both within the cap rock and reservoir rock, may occur during exposure to CO_2 or sour CO_2. Confirmation of this dissolution and an assessment of its potential effect on the mechanical strength of the rock should be investigated further with geomechanical laboratory testing using a larger data set and numerical modeling.

- Based on the samples available for this study, potential for calcite and calcium chloride precipitation appears to be minimal and on the order of less than 1 wt%. The significance of these precipitation reactions on reservoir injectivity for other formations should be investigated further. The deposition of minor amounts of sulfur and sodium chloride was also observed, although the effects of these reactions are likely to be less significant because of the instability of these compounds under reservoir conditions.

- The potential for iron deposition was also observed as a limited set of samples from deposition could affect injectivity into the reservoir as a result of the precipitation of iron hydroxide. Iron displacement by hydrogen also has the potential to reduce the mechanical strength of the cap rock and the reservoir rocks. However, because of the sampling technique employed in this study, it is likely that the iron that was observed was present in the cuttings because of contamination by drilling debris and was not representative of the reservoir formations. Further investigation of this hypothesis is warranted.

- The chemistry of the reservoir fluid is important. Analysis of the synthesized brine showed little-to-no effect when exposed to high-pressure CO_2, whereas the NaCl brine showed increased calcium and magnesium concentrations. It should be kept in mind that this is likely an effect of the NaCl not being in equilibrium with these minerals, whereas the synthesized brine is closer in composition to actual formation brine and is therefore closer in equilibrium with the formation minerals and thus less prone to reaction.

Overall, the results of this screening geochemical study suggest that adequately understanding dissolution and precipitation reactions will require further investigation through a series of more detailed, targeted geochemical and geomechanical investigations. That being said, the initial conclusions of this effort suggest that no geochemical changes would occur in the reservoir that would preclude CO_2 injection.

Because of the limited scope and data set afforded by this screening approach, only observations and data trends can be presented. A much larger, focused data set is needed before statistical conclusions can be drawn. Analytical method uncertainty and natural variability of formation minerology and chemical composition need to be more fully accounted for and statistically quantified.

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APPENDIX A

SAMPLE COLLECTION AND ANALYSIS SUMMARY

SAMPLE COLLECTION AND ANALYSIS SUMMARY

INTRODUCTION

Appendix A summarizes the sample collection and analysis for the Fort Nelson well c-61-E cuttings. The information is organized into two sections:

- Batch Reactor Test 1 Program
- Batch Reactor Tests 2–5 Program

BATCH REACTOR TEST 1 PROGRAM

Sample cuttings analyzed in the Batch Reactor Test 1 experiments were selected from six depth intervals that included the Fort Simpson shale, Otter Park shale, Upper Slave Point dolomite, Lower Slave Point dolomite, and Sulphur Point Formation dolomite (Figure A-1).

The "as-received" cuttings were analyzed using x-ray diffraction (XRD).

Laboratory batch reactor experiments were used to investigate the effects of changes in the reservoir conditions caused by the injection of CO_2 or sour CO_2 on the nature and extent of the mineralogical reactions of the drill cutting samples. A preliminary screening analysis was conducted in Batch Reactor Test 1 on cuttings and powdered cutting (~200 µm) samples that were saturated with synthetic brine (i.e., solutions of 1% to 3% NaCl). The temperature and pressure conditions were 100°C and 3000 psi. Samples were exposed to either 100 mol% CO_2 or a sour CO_2 mixture of 95 mol% CO_2 and 5 mol% H_2S. The postexposure sample analysis summary for Batch Reactor Test 1 is provided in Table A-1.

BATCH REACTOR TESTS 2–5 PROGRAM

Sample cuttings analyzed in the Batch Reactor Tests 2–5 experiments were selected from 14 depth intervals that included the Fort Simpson shale, Otter Park shale, Lower Slave Point dolomite, Sulphur Point dolomite, and Upper Keg River Formation (Figure A-2).

The as-received cuttings were analyzed using XRD. A subset of the as-received cuttings was analyzed using x-ray fluorescence (XRF) and/or scanning electron microscopy–energy-dispersive spectroscopy (SEM–EDS) (Table A-2).

Batch Reactor Tests 2–5 were selected to evaluate potential geochemical interactions of CO_2 or sour CO2 with these cuttings samples at both "near-wellbore" (65°C and 3500 psi) and "far-from-wellbore" (120°C and 2800 psi) conditions. The cuttings were saturated with synthesized brine, which was formulated to emulate the chemical characteristics of the natural reservoir fluids. In addition, a separate set of cutting samples were saturated with synthetic brine (i.e., solutions of 1% to 3% NaCl) for comparison to the Batch Reactor Test 1 experiments.

Samples were exposed to either 100 mol% CO_2 or a sour CO_2 mixture of 86.5 mol% CO_2 and 13.5 mol% H_2S. The postexposure sample analysis summary for Batch Reactor Tests 2–5 is provided in Table A-2.

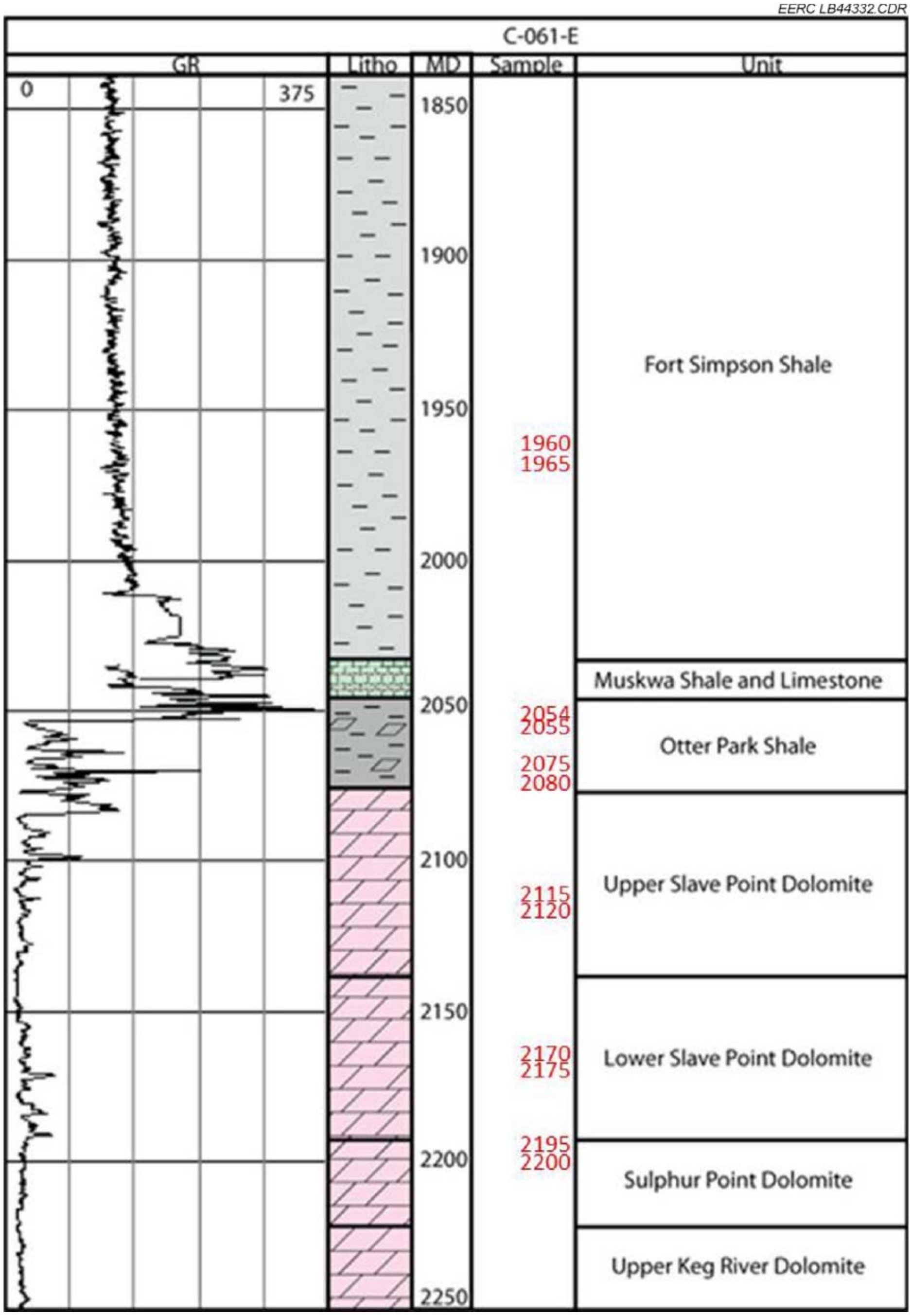


Figure A-1. Gamma ray and lithology logs from Well c-061-E and drill cutting samples analyzed in the Batch Reactor Test 1 experiments.

Table A-1. Sample Collection and Analysis Summary for Drill Cuttings Used in the Batch Reactor Test 1 Experiments*

		Baseline	Batch Reactor Test 1 Cuttings (100°C, 3000 psi)				Batch Reactor Test 1 Powder (100°C, 3000 psi)			
Depth, m	Formation	XRD	Brine	Gas	XRD	ICP–MS	Brine	Gas	XRD	ICP–MS
1960	Fort Simpson shale	x	N	C	x	–	N	C	x	–
1965	Fort Simpson shale	x	N	CH	x	–	N	CH	x	–
2054	Otter Park shale	x	N	C	x	x	N	C	x	x
2055	Otter Park shale	x	N	CH	x	x	N	CH	x	x
2075	Otter Park shale	x	N	C	x	–	N	C	x	–
2080	Otter Park shale	x	N	CH	x	–	N	CH	x	–
2115	Upper Slave Point dolomite	x	N	C	x	–	N	C	x	–
2120	Upper Slave Point dolomite	x	N	CH	x	–	N	CH	x	–
2170	Lower Slave Point dolomite	x	N	C	x	x	N	C	x	x
2175	Lower Slave Point dolomite	x	N	CH	x	x	N	CH	x	x
2195	Sulphur Point dolomite	x	N	C	x	–	N	C	x	–
2200	Sulphur Point dolomite	x	N	CH	x	–	N	CH	x	–

*Baseline: analysis conducted on the as-received drill cuttings.
Brine: S = synthesized brine, N = NaCl synthetic brine.
Gas: C = CO_2 only (100 mol%), CH = CO_2/H_2S (95 mol% CO_2/5 mol% H_2S).
Powder: powdered cuttings of approximately 200 µm.
ICP–MS: inductively coupled plasma–mass spectrometry.

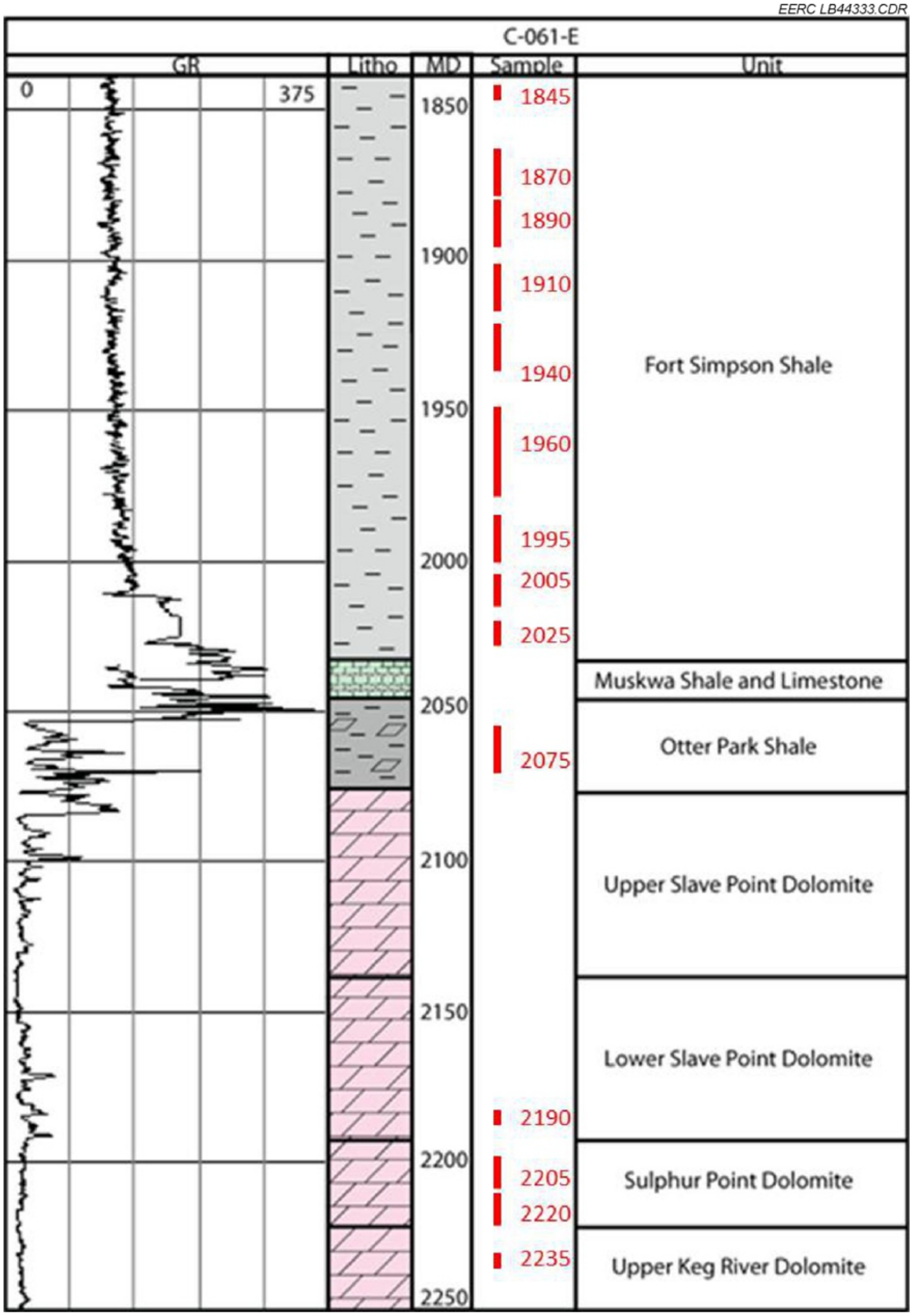


Figure A-2. Gamma ray and lithology logs from Well c-061-E and drill cutting samples analyzed in the Batch Reactor Tests 2–5 experiments.

Table A-2. Sample Collection and Analysis Summary for Drill Cuttings Used in the Batch Reactor Test 2–5 Experiments*

Depth Range, m	Depth 2, m	Formation	Baseline			Batch Reactor Test 2/4 (65°C, 3500 psi) (2005–2240 m/1845–2005 m)						Batch Reactor Test 3/5 (120°C, 2800 psi) (2005–2240 m/1845–2005 m)					
			XRD	XRF	SEM-EDS	Brine	Gas	XRD	XRF	SEM-EDS	ICP-MS	Brine	Gas	XRD	XRF	SEM-EDS	ICP-MS
1840 to 1845	1845	Fort Simpson Shale	–	–	–	S	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	x	–	x
			x	x	–	–	–	–	–	–	–	–	–	–	–	–	–
1860 to 1875	1870	Fort Simpson Shale	–	–	–	S	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	x	–	x
			x	x	–	–	–	–	–	–	–	–	–	–	–	–	–

*Baseline: analysis conducted on the as-received drill cuttings.
Brine: S = synthesized brine, N = NaCl synthetic brine.
Gas: C = CO_2 only (100 mol%), CH = CO_2/H_2S (86.5 mol% CO_2/13.5 mol% H_2S).
ICP–MS: inductively coupled plasma mass spectrometry.
Profiler:

Continued . . .

Table A-2. Sample Collection and Analysis Summary for Drill Cuttings Used in the Batch Reactor Test 2–5 Experiments (continued)*

Depth Range, m	Depth 2, m	Formation	Baseline			Batch Reactor Test 2/4 (65°C, 3500 psi) (2005–2240 m/1845–2005 m)						Batch Reactor Test 3/5 (120°C, 2800 psi) (2005–2240 m/1845–2005 m)					
			XRD	XRF	SEM–EDS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS
1880 to 1895	1890	Fort Simpson shale	–	–	–	S	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	x	–	x
			x	x	–	–	–	–	–	–	–	–	–	–	–	–	–
1905 to 1920	1910	Fort Simpson shale	–	–	–	S	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	x	–	x
			x	x	–	–	–	–	–	–	–	–	–	–	–	–	–

*Baseline: analysis conducted on the as-received drill cuttings.
Brine: S = synthesized brine, N = NaCl synthetic brine.
Gas: C = CO_2 only (100 mol%), CH = CO_2/H_2S (86.5 mol% CO_2/13.5 mol% H_2S).
ICP–MS: inductively coupled plasma mass spectrometry.
Profiler:

Continued . . .

Table A-2. Sample Collection and Analysis Summary for Drill Cuttings Used in the Batch Reactor Test 2–5 Experiments (continued)*

Depth Range, m	Depth 2, m	Formation	Baseline			Batch Reactor Test 2/4 (65°C, 3500 psi) (2005–2240 m/1845–2005 m)						Batch Reactor Test 3/5 (120°C, 2800 psi) (2005–2240 m/1845–2005 m)					
			XRD	XRF	SEM–EDS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS
1925 to 1940	1940	Fort Simpson shale	–	–	–	S	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	x	–	x
			x	x	–	–	–	–	–	–	–	–	–	–	–	–	–
1950 to 1975	1960	Fort Simpson shale	–	–	–	S	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	x	–	x
			x	x	–	–	–	–	–	–	–	–	–	–	–	–	–

*Baseline: analysis conducted on the as-received drill cuttings.
Brine: S = synthesized brine, N = NaCl synthetic brine.
Gas: C = CO_2 only (100 mol%), CH = CO_2/H_2S (86.5 mol% CO_2/13.5 mol% H_2S).
ICP–MS: inductively coupled plasma mass spectrometry.
Profiler:

Continued . . .

Table A-2. Sample Collection and Analysis Summary for Drill Cuttings Used in the Batch Reactor Test 2–5 Experiments (continued)*

Depth Range, m	Depth 2, m	Formation	Baseline			Batch Reactor Test 2/4 (65°C, 3500 psi) (2005–2240 m/1845–2005 m)						Batch Reactor Test 3/5 (120°C, 2800 psi) (2005–2240 m/1845–2005 m)					
			XRD	XRF	SEM–EDS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS
1985 to 2000	1995	Fort Simpson shale	–	–	–	S	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	x	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	x	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	x	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	x	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	x	–	x
			x	x	–	–	–	–	–	–	–	–	–	–	–	–	–
2005 to 2015	2005	Fort Simpson shale	–	–	–	S	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	–	–	–
			–	–	–	–	–	–	–	–	–	N	C	x	–	–	–
			–	–	–	–	–	–	–	–	–	S	CH	x	–	–	–
			–	–	–	–	–	–	–	–	–	N	CH	x	–	–	–
			x	–	–	–	–	–	–	–	–	–	–	–	–	–	–

*Baseline: analysis conducted on the as-received drill cuttings.
Brine: S = synthesized brine, N = NaCl synthetic brine.
Gas: C = CO_2 only (100 mol%), CH = CO_2/H_2S (86.5 mol% CO_2/13.5 mol% H_2S).
ICP–MS: inductively coupled plasma mass spectrometry.
Profiler:

Continued . . .

Table A-2. Sample Collection and Analysis Summary for Drill Cuttings Used in the Batch Reactor Test 2–5 Experiments (continued)*

			Baseline			Batch Reactor Test 2/4 (65°C, 3500 psi) (2005–2240 m/1845–2005 m)						Batch Reactor Test 3/5 (120°C, 2800 psi) (2005–2240 m/1845–2005 m)					
Depth Range, m	Depth 2, m	Formation	XRD	XRF	SEM–EDS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS
2020 to 2027	2025	Fort Simpson shale	–	–	–	S	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	–	–	x
			x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2060 to 2085	2075	Otter Park shale	–	–	–	S	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	–	–	x
			x	–	–	–	–	–	–	–	–	–	–	–	–	–	–

*Baseline: analysis conducted on the as-received drill cuttings.
Brine: S = synthesized brine, N = NaCl synthetic brine.
Gas: C = CO_2 only (100 mol%), CH = CO_2/H_2S (86.5 mol% CO_2/13.5 mol% H_2S).
ICP–MS: inductively coupled plasma mass spectrometry.
Profiler:

Continued . . .

Table A-2. Sample Collection and Analysis Summary for Drill Cuttings Used in the Batch Reactor Tests 2–5 Experiments (continued)*

Depth Range, m	Depth 2, m	Formation	Baseline			Batch Reactor Test 2/4 (65°C, 3500 psi) (2005–2240 m/1845–2005 m)						Batch Reactor Test 3/5 (120°C, 2800 psi) (2005–2240 m 1845–2005 m)					
			XRD	XRF	SEM–EDS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS
2185 to 2190	2190	Lower Slave Point dolomite	–	–	–	S	C	x	–	–	x	–	–	–	–	–	–
						N	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	–	–	x
			x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2205 to 2215	2205	Sulphur Point dolomite	–	–	–	S	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	–	–	x
			x	–	–	–	–	–	–	–	–	–	–	–	–	–	–

*Baseline: analysis conducted on the as-received drill cuttings.
Brine: S = synthesized brine, N = NaCl synthetic brine.
Gas: C = CO_2 only (100 mol%), CH = CO_2/H_2S (86.5 mol% CO_2/13.5 mol% H_2S).
ICP–MS: inductively coupled plasma mass spectrometry.
Profiler:

Continued . . .

Table A-2. Sample Collection and Analysis Summary for Drill Cuttings Used in the Batch Reactor Test 2–5 Experiments (continued)*

Depth Range, m	Depth 2, m	Formation	Baseline			Batch Reactor Test 2/4 (65°C, 3500 psi) (2005–2240 m/1845–2005 m)						Batch Reactor Test 3/5 (120°C, 2800 psi) (2005–2240 m/1845–2005 m)					
			XRD	XRF	SEM–EDS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS	Brine	Gas	XRD	XRF	SEM–EDS	ICP–MS
2220 to 2230	2220	Sulphur Point dolomite	–	–	–	S	C	x	–	–	–	–	–	–	–	–	–
			–	–	–	N	C	x	–	x	x	–	–	–	–	–	–
			–	–	–	S	CH	x	–	–	–	–	–	–	–	–	–
			–	–	–	N	CH	x	–	x	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	C	x	–	–	x
			–	–	–	–	–	–	–	–	–	S	CH	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	–	–	x
			x	–	–	–	–	–	–	–	–	–	–	–	–	–	–
2235 to 2240	2235	Upper Keg River dolomite	–	–	–	S	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	C	x	–	–	x	–	–	–	–	–	–
			–	–	–	S	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	N	CH	x	–	–	x	–	–	–	–	–	–
			–	–	–	–	–	–	–	–	–	S	C	x	–	x	x
			–	–	–	–	–	–	–	–	–	N	C	x	–	x	x
			–	–	–	–	–	–	–	–	–	S	CH	x	–	–	x
			–	–	–	–	–	–	–	–	–	N	CH	x	–	–	x
			x	–	–	–	–	–	–	–	–	–	–	–	–	–	–

*Baseline: analysis conducted on the as-received drill cuttings.
Brine: S = synthesized brine, N = NaCl synthetic brine.
Gas: C = CO_2 only (100 mol%), CH = CO_2/H_2S (86.5 mol% CO_2/13.5 mol% H_2S).
ICP–MS: inductively coupled plasma mass spectrometry.
Profiler:

APPENDIX B

BASELINE MINERALOGY ON “AS-RECEIVED” CUTTING SAMPLES

BASELINE MINERALOGY ON “AS-RECEIVED” CUTTING SAMPLES

INTRODUCTION

Appendix B summarizes the results of the mineralogical analyses that were conducted on the “as-received” cuttings samples (subsequently referred to as “baseline”).

The as-received cuttings were analyzed using x-ray diffraction (XRD) to provide a baseline mineralogical analysis. Subsets of these samples were also analyzed using x-ray fluorescence (XRF) and/or scanning electron microscopy–energy-dispersive spectroscopy (SEM–EDS). The complete sample collection and analysis summary is provided in Appendix A.

Appendix B is organized by laboratory batch reactor experiment and analysis method. Laboratory batch reactor experiments were used to investigate the effects of changes in the reservoir conditions caused by the injection of CO_2 or sour CO_2 on the nature and extent of the mineralogical reactions of the drill cutting samples. A preliminary screening analysis was conducted in Batch Reactor Test 1 (100°C and 3000 psi). Subsequent experiments (Batch Reactor Tests 2 through 5) were selected to evaluate potential geochemical interactions of CO_2 or sour CO_2 with these cuttings samples at both near-wellbore (65°C and 3500 psi) and “far-from-wellbore” (120°C and 2800 psi) pressure and temperature conditions. The analytical protocols used to evaluate the as-received cuttings prior to the Batch Reactor Test 1 and Batch Reactor Tests 2–5 experiments were different; therefore, Appendix B is organized into two main sections each with subsections for a specific baseline analysis type:

- Section Batch Reactor Test 1 Program
  - XRD results

- Section Batch Reactor Tests 2–5 Program
  - XRD results
  - XRF results (as applicable)
  - SEM–EDS results (as applicable)

BATCH REACTOR TEST 1 PROGRAM

Sample cuttings analyzed in the Batch Reactor Test 1 experiments were selected from six depth intervals that included the Fort Simpson shale, Otter Park shale, Upper Slave Point dolomite, Lower Slave Point dolomite, and Sulphur Point Formation dolomite.

Baseline XRD Results

The tabulated baseline mineralogy results for XRD are summarized in Table B-1, and a graphical summary is presented in Figure B-1.

BATCH REACTOR TEST 2–5 PROGRAM

Sample cuttings analyzed in the Batch Reactor Tests 2–5 experiments were selected from 14 depth intervals that included the Fort Simpson shale, Otter Park shale, Lower Slave Point dolomite, Sulphur Point dolomite, and Upper Keg River Formation.

Baseline XRD Results

The tabulated baseline mineralogy results for XRD are summarized in Table B-3, and a graphical summary is presented in Figure B-3.

Baseline XRF Results

Seven of the samples that were analyzed using XRD were also analyzed using XRF (1845, 1870, 1890, 1910, 1940, 1960, and 1995 m). All seven samples were collected from the Fort Simpson Formation shale. The tabulated baseline mineralogy results for XRF are summarized in Table B-4, and a graphical summary is presented in Figure B-4.

Baseline SEM–EDS Results

Baseline mineralogical analysis using SEM–EDS was conducted on the 2220-m Sulphur Point Formation dolomite sample. The SEM–EDS results include images of the cutting sample at four different resolutions: 100×, 250×, 350× and 1000× (Figure B-6). In addition, the SEM–

Table B-1. Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings Prior to Batch Reactor Test 1 Experiments. Values are reported in percent. The baseline mineralogy XRD results that were analyzed prior to the batch reactor Test 1 experiments did not include the minerals cristo, albite, anorthite, orthoclase, sanidine, and microcline.

Formation (Depth [m])	Quartz	Cristobalite	Albite	Anorthite	Orthoclase	Sanidine	Microcline	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite	Halite	Sylvite
Fort Simpson Shale (1960)	37.8	–	–	–	–	–	–	0.6	3.2	1.9	0.0	0.6	4.0	36.3	10.2	0.2	2.0	0.5	2.5	0.3
Fort Simpson Shale (1965)	34.7	–	–	–	–	–	–	0.8	3.0	1.7	0.0	0.9	4.9	44.4	5.1	0.5	2.3	0.3	1.3	0.2
Otter Park Shale (2054)	5.7	–	–	–	–	–	–	0.6	64.6	15.0	0.0	0.8	0.2	5.4	3.7	0.2	2.8	0.8	0.1	0.2
Otter Park Shale (2055)	6.3	–	–	–	–	–	–	0.4	67.2	12.4	0.0	0.4	0.1	3.7	4.9	0.0	3.1	0.7	0.8	0.0
Otter Park Shale (2075)	9.8	–	–	–	–	–	–	1.6	71.2	1.4	0.0	0.6	0.3	8.3	2.1	0.1	3.5	0.6	0.5	0.1
Otter Park Shale (2080)	9.5	–	–	–	–	–	–	1.1	70.7	1.7	0.0	0.6	0.0	7.8	3.2	0.2	3.5	0.6	1.0	0.2
Upper Slave Point Dolomite (2115)	1.9	–	–	–	–	–	–	0.5	93.4	0.7	0.2	0.4	0.0	0.1	0.7	0.0	1.6	0.2	0.3	0.1
Upper Slave Point Dolomite (2120)	2.1	–	–	–	–	–	–	0.3	92.4	1.1	0.0	0.3	0.1	1.1	0.7	0.0	1.4	0.3	0.2	0.0
Lower Slave Point Dolomite (2170)	1.7	–	–	–	–	–	–	0.2	92.6	0.8	0.0	0.2	0.2	1.2	1.0	0.1	1.4	0.4	0.3	0.0
Lower Slave Point Dolomite (2175)	1.9	–	–	–	–	–	–	0.3	91.6	1.0	0.7	0.4	0.1	1.3	0.3	0.0	1.6	0.5	0.5	0.0
Sulphur Point Dolomite (2195)	3.1	–	–	–	–	–	–	0.2	90.8	1.3	0.0	0.5	0.0	0.1	0.9	0.0	1.8	0.5	0.7	0.1
Sulphur Point Dolomite (2200)	1.9	–	–	–	–	–	–	0.2	92.3	0.7	0.6	0.3	0.0	1.1	0.8	0.1	1.4	0.4	0.2	0.0

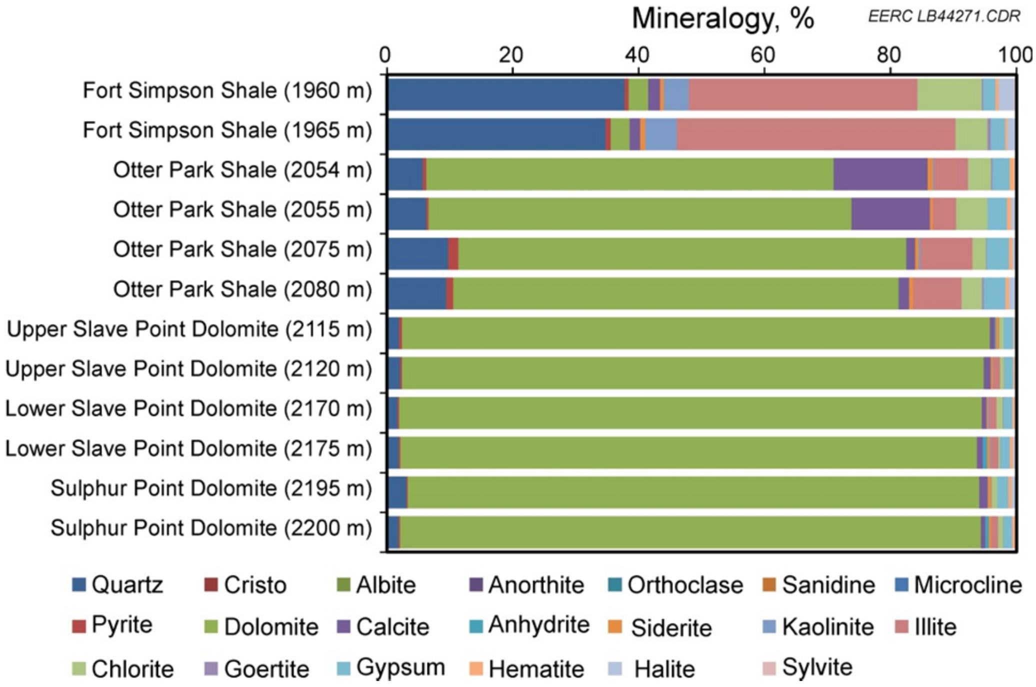


Figure B-1. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings prior to Batch Reactor Test 1 experiments. Values are reported in percent. The baseline mineralogy XRD results that were analyzed prior to the Batch Reactor Test 1 experiments did not include the minerals cristo, albite, anorthite, orthoclase, sanidine, and microcline.

EDS results include “spotlight” summaries of element weight percentages at eight different “tag” locations on the sample. The spotlight locations and tabulated weight percentages are shown in Tables B-6a to B-6d.

Table B-2. Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD On As-Received Cuttings Prior to Batch Reactor Test 2–5 Experiments. Values are reported in percent. the baseline mineralogy xrd results that were analyzed prior to the batch reactor tests 2-5 experiments did not include the minerals halite or sylvite.

Formation (Depth [m])	Quartz	Cristobalite	Albite	Anorthite	Orthoclase	Sanidine	Microcline	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite	Halite	Sylvite
Fort Simpson Shale (1840 to 1845)	3.8	2.5	0.0	4.5	11.9	7.7	16.3	1.8	6.4	0.5	0.4	0.6	2.1	35.2	5.3	0.8	0.3	0.1	–	–
Fort Simpson Shale (1860 to 1875)	34.8	0.0	1.6	11.3	7.6	0.0	5.5	0.7	0.2	0.2	0.2	1.2	18.1	4.4	12.7	0.1	1.0	0.5	–	–
Fort Simpson Shale (1880 to 1895)	33.9	0.0	1.1	11.1	5.9	0.0	7.9	1.1	0.2	1.0	0.1	1.3	20.7	1.7	13.2	0.0	0.9	0.2	–	–
Fort Simpson Shale (1905 to 1920)	28.8	0.0	0.5	1.7	1.2	0.0	8.2	1.2	4.5	0.8	0.1	1.5	11.8	30.5	8.1	0.1	0.4	0.7	–	–
Fort Simpson Shale (1925 to 1940)	32.0	0.0	1.0	11.3	5.6	0.0	9.0	1.4	5.4	0.1	0.0	1.0	16.6	2.9	12.8	0.5	0.3	0.1	–	–
Fort Simpson Shale (1950 to 1975)	32.7	0.0	1.1	11.0	6.8	0.3	10.6	1.5	0.1	0.0	0.0	0.4	16.5	3.0	14.7	0.6	0.7	0.1	–	–
Fort Simpson Shale (1985 to 2000)	32.2	0.0	0.0	10.7	6.7	0.0	12.2	2.7	0.1	0.1	0.1	1.6	15.5	4.5	12.8	0.4	0.7	0.0	–	–
Fort Simpson Shale (2005 to 2015)	26.7	0.0	1.1	0.9	1.2	0.1	10.7	1.5	3.3	0.8	0.1	1.6	8.8	31.9	6.3	0.6	4.0	0.4	–	–
Fort Simpson Shale (2020 to 2027)	41.2	0.0	0.9	4.1	3.2	5.6	6.9	3.1	5.1	0.0	0.1	2.4	8.9	4.3	13.0	0.6	0.8	0.1	–	–
Otter Park Shale (2060 to 2085)	18.4	0.0	0.0	0.0	0.2	0.4	0.0	2.0	68.2	2.8	0.1	0.1	0.0	6.5	0.7	0.1	0.1	0.4	–	–
Lower Slave Point Dolomite (2185 to 2190)	2.6	0.1	0.4	0.9	0.0	0.1	0.5	0.1	93.5	0.2	0.0	0.1	0.0	0.4	0.1	0.0	0.6	0.6	–	–
Sulphur Point Dolomite (2205 to 2215)	4.9	0.0	0.3	0.8	0.1	0.0	0.0	0.2	92.6	0.0	0.0	0.0	0.0	0.0	0.5	0.3	0.0	0.3	–	–
Sulphur Point Dolomite (2220 to 2230)	3.4	0.0	0.7	1.3	0.0	0.0	0.7	0.2	91.0	0.5	0.0	0.1	0.0	0.5	0.5	0.3	0.3	0.5	–	–
Upper Keg River Dolomite (2235 to 2240)	1.4	0.0	0.6	1.0	0.0	0.0	0.0	0.2	94.6	0.3	0.0	0.1	0.0	0.0	0.4	0.1	0.7	0.6	–	–

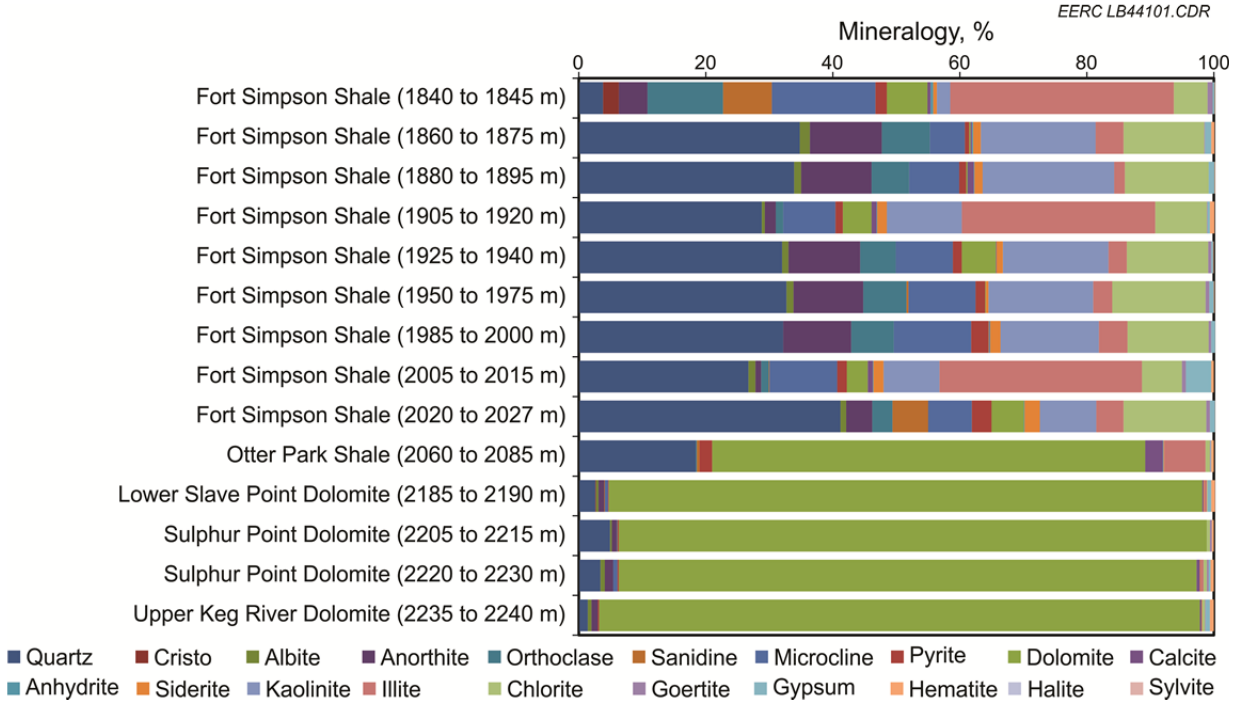


Figure B-2. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings prior to Batch Reactor Test 2–5 experiments. Values are reported in percent. The baseline mineralogy XRD results that were analyzed prior to the Batch Reactor Tess 2–5 experiments did not include the minerals halite or sylvite.

Table B-3. Predominant Elements in c-61-E Drill Cuttings as Determined by XRF on As-Received Cuttings Prior to Batch Reactor Test 2–5 Experiments. Values are reported in percent.

Formation (Depth [m])	Si	Al	Fe	Ti	P	Ca	Mg	Na	K	S
Fort Simpson Shale (1840 to 1845)	53.5	20.2	12.9	1.1	0.1	2.7	2.5	0.9	5.8	0.2
Fort Simpson Shale (1860 to 1875)	53.4	19.5	12.6	1.0	0.1	4.3	2.5	0.9	5.5	0.2
Fort Simpson Shale (1880 to 1895)	52.7	19.3	12.4	1.0	0.1	5.3	2.4	0.9	5.5	0.2
Fort Simpson Shale (1905 to 1920)	53.5	20.3	12.5	1.0	0.1	2.9	2.5	0.9	5.8	0.3
Fort Simpson Shale (1925 to 1940)	54.6	21.1	12.0	1.0	0.1	1.4	2.6	0.7	6.1	0.5
Fort Simpson Shale (1950 to 1975)	54.2	21.1	12.0	1.0	0.1	1.4	2.6	0.8	6.3	0.4
Fort Simpson Shale (1985 to 2000)	54.4	20.7	11.6	1.0	0.1	1.9	2.5	0.6	6.6	0.5

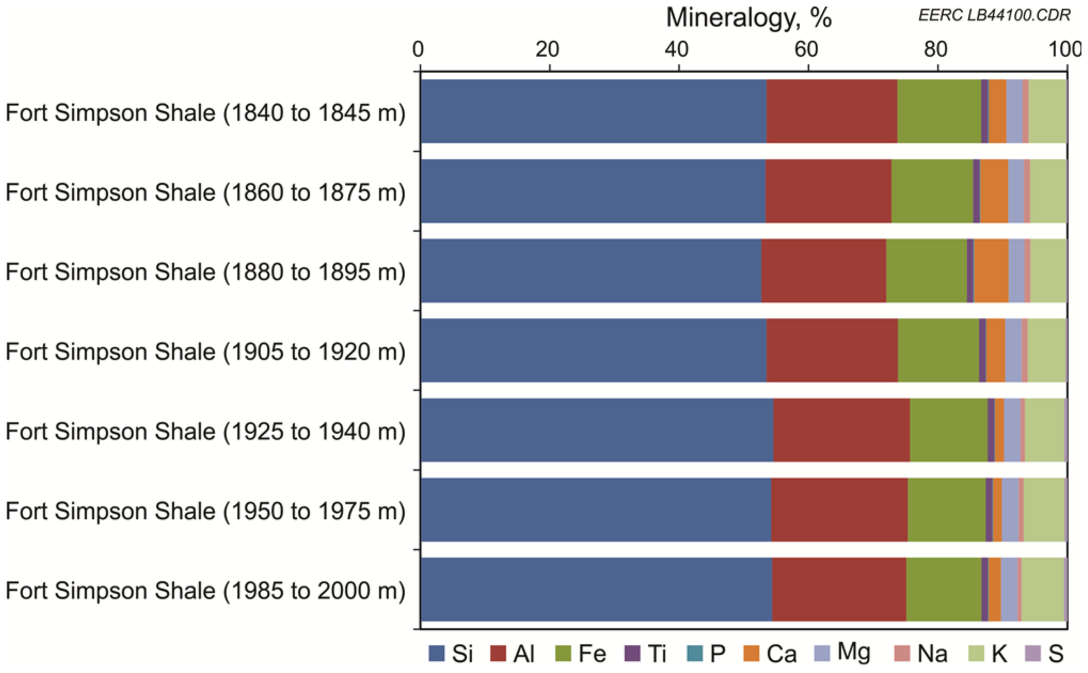


Figure B-3. Predominant elements in c-61-E drill cuttings as determined by XRF on as-received cuttings prior to Batch Reactor Test 2–5 experiments. Values are reported in percent.

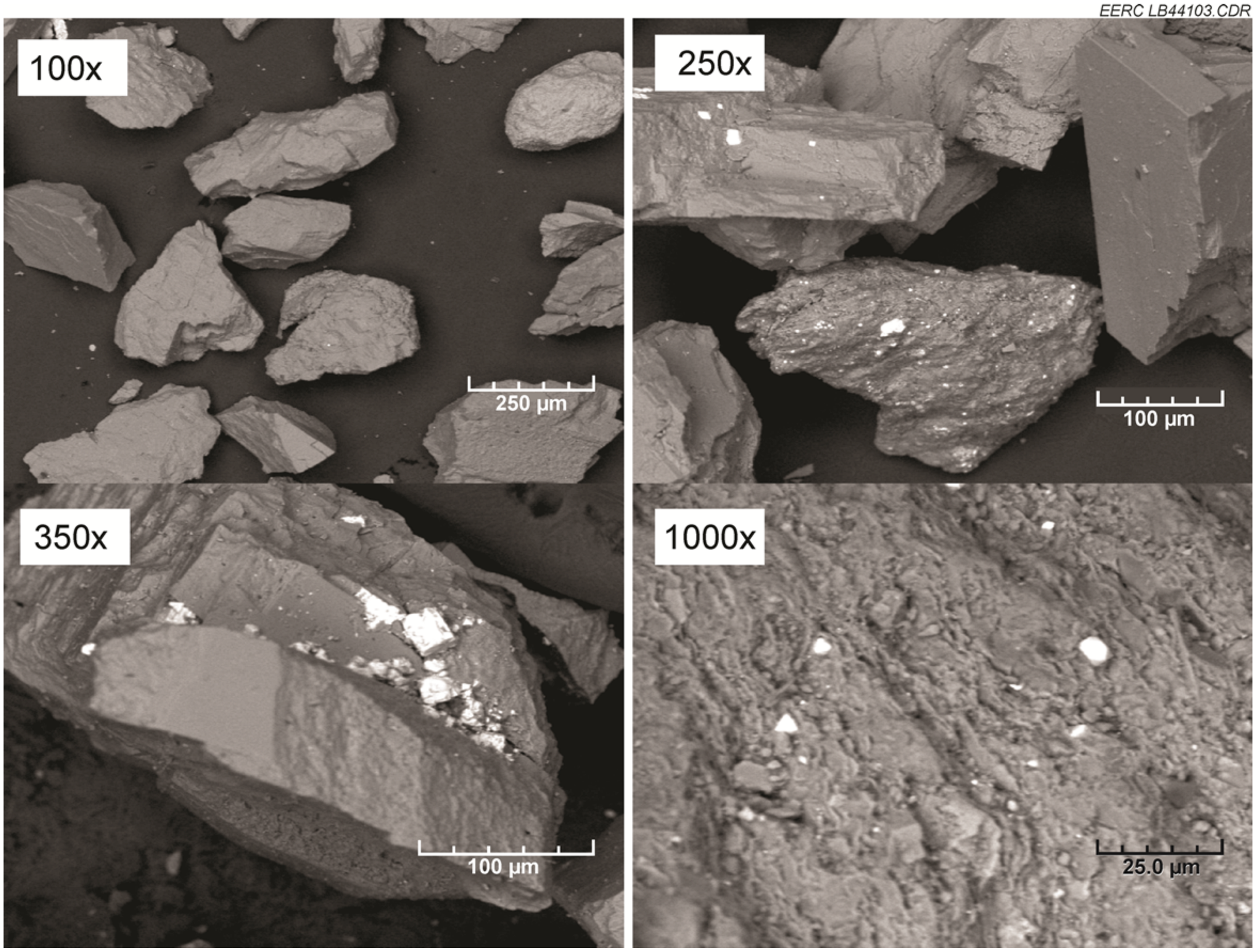
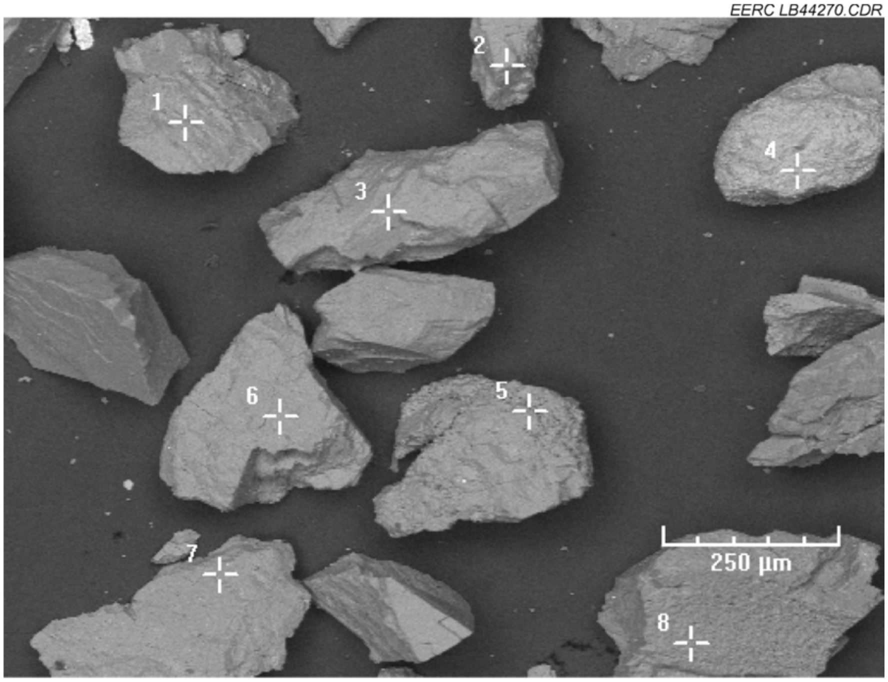


Figure B-4. SEM–EDS images of the Sulphur Point Formation dolomite cuttings sample collected at 2220 m. The images were taken at 100× (upper left-hand corner), 250× (upper right-hand corner), 350× (lower left-hand corner), and 1000× (lower right-hand corner) resolutions.

Table B-4a. Spotlight Summary of SEM–EDS Results for the Sulphur Point Formation Dolomite Cuttings Sample Collected at 2220 m. Values are reported in percent. The image resolution was 100×, and the eight tag locations used to develop the spotlight summary are shown in the image.



Tag	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Ba
1	0.1	34.8	0.3	0.3	0.2	0.0	0.0	0.0	61.5	0.0	2.8	0.0
2	0.6	42.3	0.4	0.3	0.3	0.0	0.0	0.0	56.1	0.0	0.2	0.0
3	0.2	38.5	0.0	0.1	0.2	0.2	0.0	0.0	60.6	0.0	0.2	0.0
4	0.5	2.0	0.5	0.4	0.4	0.2	0.0	0.0	95.5	0.0	0.5	0.0
5	0.1	41.1	0.2	0.4	0.2	0.0	0.0	0.0	57.1	0.0	0.9	0.0
6	0.3	42.7	0.3	0.1	0.1	0.1	0.0	0.0	56.1	0.0	0.3	0.0
7	0.2	44.1	0.3	0.2	0.2	0.1	0.1	0.0	54.9	0.0	0.0	0.0
8	0.2	27.1	0.0	0.4	0.7	0.0	0.1	0.0	71.2	0.0	0.2	0.0

Table B-5. Spotlight Summary of SEM–EDS Results for the Sulphur Point Formation Dolomite Cutting Sample Collected at 2220 m. Values are reported in percent. The image resolution was 250×, and the eight tag locations used to develop the spotlight summary are shown in the image.

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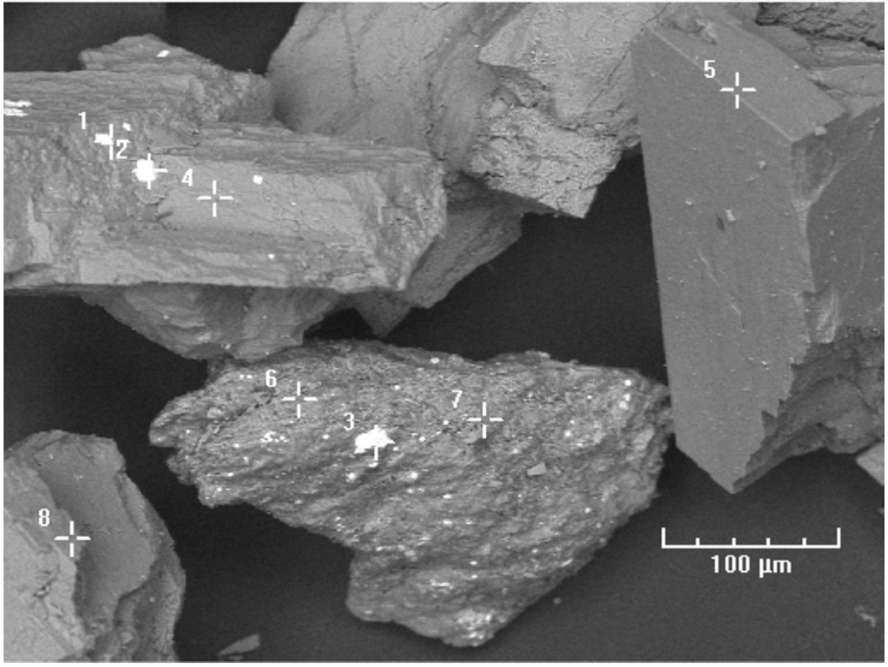
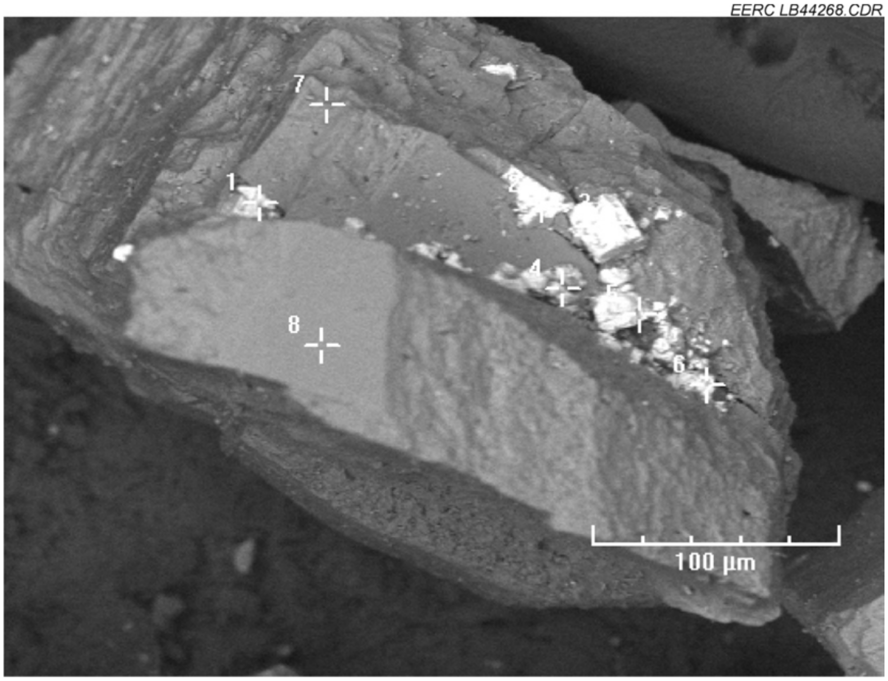


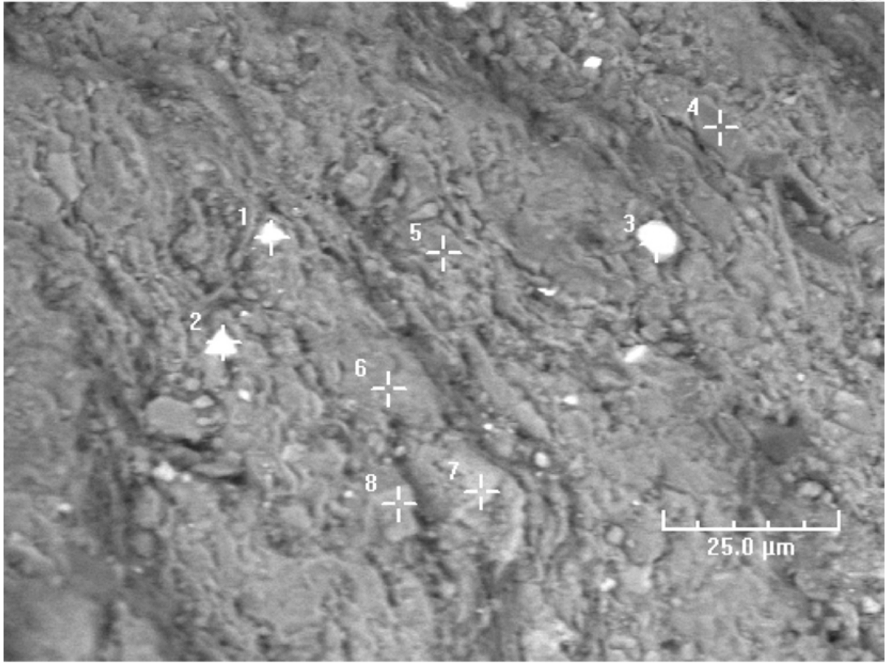
Tag	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Ba
1	0.0	18.2	0.0	1.0	0.0	1.5	0.0	0.0	74.2	0.0	5.0	0.0
2	0.2	4.2	0.0	1.0	0.1	49.0	0.0	0.0	4.6	0.4	40.5	0.0
3	0.0	1.8	0.0	0.0	0.0	39.4	0.0	0.0	2.0	0.4	56.5	0.0
4	0.4	39.3	0.4	1.0	0.1	0.0	0.0	0.0	50.1	0.0	8.6	0.0
5	0.1	40.1	0.1	0.1	0.0	0.0	0.0	0.0	58.4	0.0	1.1	0.0
6	0.0	2.5	4.7	22.1	0.0	2.2	0.0	41.7	17.0	0.0	9.8	0.0
7	0.0	28.8	0.1	0.1	0.3	0.0	0.0	18.7	41.2	0.0	11.0	0.0
8	0.2	35.7	0.4	0.6	0.3	0.2	0.0	0.0	62.1	0.0	0.5	0.0

Table B-6. Spotlight Summary of SEM–EDS Results for the Sulphur Point Formation Dolomite Cutting Sample Collected at 2220 m. Values are reported in percent. The image resolution was 350×, and the eight tag locations used to develop the spotlight summary are shown in the image.



Tag	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Ba
1	0.6	1.6	0.0	0.0	0.0	57.6	0.0	0.0	1.8	1.2	37.2	0.0
2	0.3	0.6	0.1	0.1	0.1	58.4	0.1	0.0	0.6	1.4	38.3	0.0
3	0.1	0.8	0.1	0.0	0.1	57.3	0.1	0.0	1.3	1.2	39.1	0.0
4	0.2	4.0	0.0	0.1	0.0	39.1	0.0	0.0	11.4	1.5	38.8	4.9
5	0.0	4.6	0.0	0.0	0.0	20.4	0.0	0.0	4.6	0.0	70.5	0.0
6	0.0	15.4	0.0	0.0	0.0	22.7	0.0	0.0	21.3	0.0	40.6	0.0
7	0.6	44.8	0.6	0.1	0.2	0.0	0.0	0.0	53.6	0.0	0.2	0.0
8	0.4	38.3	0.4	0.2	0.4	0.2	0.0	0.0	60.2	0.0	0.0	0.0

Table B-7. Spotlight Summary of SEM–EDS Results for the Sulphur Point Formation Dolomite Cutting Sample Collected at 2220 m. Values are reported in percent. The image resolution was 1000×, and the eight tag locations used to develop the spotlight summary are shown in the image.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Tag	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Ba
1	0.0	0.8	0.7	1.1	0.2	57.5	0.1	0.0	0.5	1.1	38.0	0.0
2	0.0	1.1	4.2	9.2	0.0	49.0	0.0	1.3	1.2	0.7	33.3	0.0
3	0.0	0.6	0.8	1.2	0.1	56.9	0.1	0.0	0.4	1.1	38.7	0.0
4	0.0	2.2	22.4	63.3	0.0	0.0	0.0	6.0	0.1	0.0	6.0	0.0
5	0.0	0.5	6.3	88.3	0.0	0.0	0.0	3.1	0.4	0.0	1.4	0.0
6	0.0	1.5	18.6	67.5	0.0	0.0	0.0	7.5	0.2	0.2	4.0	0.5
7	0.0	6.6	27.1	28.4	0.0	0.0	0.0	0.2	1.7	0.0	36.0	0.0
8	0.1	12.3	0.6	3.7	1.4	0.0	0.0	0.1	53.8	0.1	27.9	0.0

APPENDIX C

MINERALOGY PRE- AND POST-CO_2 AND SOUR CO_2 EXPOSURE RESULTS

MINERALOGY PRE- AND POST-CO_2 AND SOUR CO2 EXPOSURE RESULTS

INTRODUCTION

Appendix C summarizes the analytical results for cutting samples before and after exposure to CO_2 or sour CO_2 in batch reactor experiments. Laboratory batch reactor experiments were used to investigate the effects of changes in the reservoir conditions caused by the injection of CO_2 or sour CO_2 on the nature and extent of the mineralogical reactions of the drill cutting samples. A preliminary screening analysis was conducted in Batch Reactor Test 1 (100°C and 3000 psi) on cuttings and powder that were saturated with synthetic brine (i.e., solutions of 1% to 3% NaCl). Subsequent batch reactor experiments (Batch Reactor Tests 2–5) were conducted to evaluate potential geochemical interactions of CO_2 or sour CO_2 with these cutting samples at both "near-wellbore" (65°C and 3500 psi) and "far-from-wellbore" (120°C and 2800 psi) pressure and temperature conditions. The Batch Reactor Test 2–5 experiments were conducted on cuttings that were saturated with either synthetic brine (NaCl solution) or synthesized brine, which was formulated to emulate the chemical characteristics of the natural reservoir fluids.

The "as-received" cuttings were analyzed using x-ray diffraction (XRD) to provide a baseline mineralogical analysis (i.e., preexposure analysis). Subsets of these samples were also analyzed using x-ray fluorescence (XRF) and/or scanning electron microscopy–energy-dispersive spectroscopy (SEM–EDS). The complete baseline mineralogy summary is provided in Appendix B.

Following exposure to CO_2 or sour CO_2 in the batch reactor experiments, cuttings were analyzed using XRD to provide a postexposure mineralogical analysis (i.e., postexposure analysis). Subsets of these samples were also analyzed using XRF and/or SEM–EDS. Therefore, cutting samples have pre- and postexposure measurements of mineralogy using XRD, and some cuttings samples have pre- and postexposure measurements of mineralogy using XRD and/or SEM–EDS. Appendix C summarizes the pre- and postexposure results.

Appendix C is organized into two main sections, each with subsections for a specific analysis type:

- Batch Reactor Test 1 Program
  - XRD results

- Batch Reactor Test 2–5 Program
  - XRD results
  - XRF results (as applicable)
  - SEM–EDS results (as applicable)

BATCH REACTOR TEST 1 PROGRAM

Sample cuttings analyzed in the Batch Reactor Test 1 experiments were selected from six depth intervals that included the Fort Simpson shale, Otter Park shale, Upper Slave Point dolomite, Lower Slave Point dolomite, and Sulphur Point Formation dolomite.

Pre- and Postexposure XRD Results

The tabulated pre- and postexposure mineralogy results for XRD are summarized in Tables C-1a and C-1b. Graphical summaries are presented in Figures C-1a to C-1c.

BATCH REACTOR TEST 2–5 PROGRAM

Sample cuttings analyzed in the Batch Reactor Test 2–5 experiments were selected from 14 depth intervals that included the Fort Simpson shale, Otter Park shale, Lower Slave Point dolomite, Sulphur Point dolomite, and Upper Keg River Formation.

Pre- and Postexposure XRD Results

The tabulated pre- and postexposure mineralogy results for XRD are summarized in Tables C-3a to C-3g. Graphical summaries are presented in Figures C-3a to C-3g.

The mean and standard deviation pre- and postexposure mineralogy results for XRD on the nine samples collected from the Fort Simpson Formation shale (1840 m to 2027 m) are presented in Figure C-3h.

Wilcoxon Rank Sum (WRS) tests were conducted on the nine samples collected from the Fort Simpson Formation shale (1840 to 2027 m) to test whether or not there were statistically significant differences in the mineral percentages between pre- and postexposure XRD measurements. The null hypothesis for all tests was:

Probability [prexposure > postexposure] ≠ 0.5

(i.e., the preexposure baseline XRD results have either higher or lower mineral percentages than the postexposure XRD results).

The WRS tests showed that most mineral percentages were not significantly different between pre- and postexposure at the 95% confidence level. The results which were significantly different included:

- Microcline in the CO_2 exposure at near-wellbore conditions was significantly lower than the baseline.

- Chlorite in the CO_2/H_2S exposure at near-wellbore conditions was significantly lower than the baseline.

No other mineral percentages were significantly different from baseline. These results are consistent with the mean and standard deviation plots in Figure C-3h.

Pre- and Postexposure XRF Results

Seven of the samples that were analyzed using XRD were also analyzed using XRF (1845, 1870, 1890, 1910, 1940, 1960, and 1995 m). All seven samples were collected from the Fort Simpson Formation shale. The tabulated pre- and postexposure mineralogy results for XRF are summarized in Tables C-4a to C-4d. Graphical summaries are presented in Figures C-4a to C-4d.

The mean and standard deviation pre- and postexposure mineralogy results for XRF on the seven samples collected from the Fort Simpson Formation shale (1840 to 2000 m) are presented in Figure C-4e.

WRS tests were conducted on the seven samples collected from the Fort Simpson Formation shale (1840 to 2000 m) to test whether or not there were statistically significant differences in the element percentages between pre- and postexposure XRF measurements. The null hypothesis for all tests was:

> Probability [preexposure > postexposure] $\neq 0.5$
> (i.e., the preexposure baseline XRF results have either higher or lower element percentages than the postexposure XRF results).

None of the postexposure element percentages was significantly different from baseline at the 95% level. These results are consistent with the mean and standard deviation plots in Figure C-4e.

Pre- and Postexposure SEM–EDS Results

Pre- and postexposure mineralogical analyses using SEM–EDS were conducted on the cuttings sample collected from 2220 m (Sulphur Point Formation dolomite). The postexposure conditions only included cuttings saturated with synthetic brine (NaCl solution) and exposed to 100% CO_2 and 86.5 mol% CO_2/13.5 mol% H_2S under near-wellbore conditions (65°C and 3500 psi). The SEM–EDS pre- and postexposure images at different resolutions are shown in Figures C-6a to C-6c. In addition, the SEM–EDS results include spotlight summaries of element weight percentages at eight different tag locations on the sample. The pre- and postexposure spotlight tabulated weight percentages for Sample 2220 m are shown in Tables C-6a to C-6c.

Postexposure SEM–EDS analyses were conducted on the 2235-m Upper Keg River Formation dolomite for cuttings saturated with synthetic brine (NaCl solution) and synthesized brine and exposed to 100% CO_2 under far-from-wellbore conditions (120°C and 2800 psi). Preexposure (baseline) SEM–EDS analysis of Sample 2235 m was not conducted; therefore, pre- and postexposure comparisons could not be made. Neither exposures to CO_2/H_2S at far-from-wellbore conditions nor exposures to either CO_2 or CO_2/H_2S at near-wellbore conditions were conducted. The postexposure SEM–EDS images at different resolutions for the synthetic (NaCl solution) and synthesized brine are shown in Figures C-6d and C-6e, respectively. In addition, the postexposure spotlight tabulated weight percentages for Sample 2235 m are shown in Tables C-6d and C-6e.

Table C-1a. Fort Simpson Formation Shale and Otter Park Formation Shale Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 1 Experiments (postexposure). Values are reported in percent. All experiments were conducted at 100°C and 3000 psi. All cuttings or powder were saturated with synthetic brine (NaCl solution). "Powder" were powdered cuttings of approximately 200 µm. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 95 mol% CO_2 and 5 mol% H_2S.

Formation (Depth [m])	Type	Conditions	Quartz	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite	Halite	Sylvite
Fort Simpson Shale (1960)	Baseline	NA	37.8	0.6	3.2	1.9	0.0	0.6	4.0	36.3	10.2	0.2	2.0	0.5	2.48	0.31
Fort Simpson Shale (1960)	Cuttings	CO_2	42.5	1.1	0.7	0.4	0.0	0.4	4.5	40.4	6.6	1.0	0.2	0.2	1.78	0.15
Fort Simpson Shale (1960)	Powder	CO_2	37.6	0.1	3.1	1.1	0.0	0.3	1.3	32.2	4.9	0.7	0.6	0.6	17.4	0.11
Fort Simpson Shale (1965)	Baseline	NA	34.7	0.8	3.0	1.7	0.0	0.9	4.9	44.4	5.1	0.5	2.3	0.3	1.27	0.18
Fort Simpson Shale (1965)	Cuttings	CO_2/H_2S	36.4	1.3	2.5	0.9	0.0	0.2	1.7	29.6	8.4	0.5	0.1	0.1	18.13	0.24
Fort Simpson Shale (1965)	Powder	CO_2/H_2S	41.7	1.8	1.2	0.9	0.0	0.0	4.0	43.1	4.6	0.5	0.0	0.3	1.76	0.12
Otter Park Shale (2054)	Baseline	NA	5.7	0.6	64.6	15.0	0.0	0.8	0.2	5.4	3.7	0.2	2.8	0.8	0.09	0.18
Otter Park Shale (2054)	Cuttings	CO_2	4.5	0.7	73.3	12.0	0.0	0.4	0.3	3.7	2.4	0.2	1.2	0.5	0.72	0.11
Otter Park Shale (2054)	Powder	CO_2	5.4	0.0	73.0	13.7	0.0	0.0	0.3	2.9	2.2	0.2	1.1	0.3	0.67	0.18
Otter Park Shale (2055)	Baseline	NA	6.3	0.4	67.2	12.4	0.0	0.4	0.1	3.7	4.9	0.0	3.1	0.7	0.77	0.03
Otter Park Shale (2055)	Cuttings	CO_2/H_2S	5.3	0.5	70.3	14.7	0.0	0.3	0.3	2.3	2.0	0.1	1.1	0.2	2.81	0.11
Otter Park Shale (2055)	Powder	CO_2/H_2S	2.7	0.3	72.0	13.6	0.1	0.3	0.8	2.9	4.0	0.1	1.9	0.3	1.05	0.05
Otter Park Shale (2075)	Baseline	NA	9.8	1.6	71.2	1.4	0.0	0.6	0.3	8.3	2.1	0.1	3.5	0.6	0.48	0.11
Otter Park Shale (2075)	Cuttings	CO_2	10.3	0.9	74.5	0.3	0.0	0.7	0.9	6.1	2.2	0.2	1.8	0.5	1.65	0.1
Otter Park Shale (2075)	Powder	CO_2	8.0	1.4	71.7	1.2	0.0	0.6	0.3	4.8	1.5	0.1	1.4	0.5	8.34	0.13
Otter Park Shale (2080)	Baseline	NA	9.5	1.1	70.7	1.7	0.0	0.6	0.0	7.8	3.2	0.2	3.5	0.6	1	0.16
Otter Park Shale (2080)	Cuttings	CO_2/H_2S	8.9	1.5	79.7	0.2	0.0	0.2	0.4	5.6	1.4	0.0	1.4	0.3	0.22	0.14
Otter Park Shale (2080)	Powder	CO_2/H_2S	9.0	1.5	74.3	1.1	0.0	0.5	0.6	6.3	2.6	0.1	2.0	0.4	1.51	0.05

Table C-1b. Upper Slave Point Formation Dolomite, Lower Slave Point Formation Dolomite, and Sulphur Point Dolomite Formation Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings (Baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 1 Experiments (postexposure). Values are reported in percent. All experiments were conducted at 100°C and 3000 psi. All cuttings or powder were saturated with synthetic brine (NaCl solution). "Powder" were powdered cuttings of approximately 200 µm. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 95 mol% CO_2 and 5 mol% H_2S.

Formation (Depth [m])	Type	Conditions	Quartz	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite	Halite	Sylvite
Upper Slave Point Dolomite (2115)	Baseline	NA	1.9	0.5	93.4	0.7	0.2	0.4	0.0	0.1	0.7	0.0	1.6	0.2	0.28	0.05
Upper Slave Point Dolomite (2115)	Cuttings	CO_2	1.7	0.1	94.0	0.1	0.0	0.2	0.5	1.0	0.9	0.1	1.0	0.4	0	0.11
Upper Slave Point Dolomite (2115)	Powder	CO_2	2.0	0.1	93.9	0.1	0.0	0.1	0.5	1.0	0.7	0.1	0.8	0.3	0.3	0.08
Upper Slave Point Dolomite (2120)	Baseline	NA	2.1	0.3	92.4	1.1	0.0	0.3	0.1	1.1	0.7	0.0	1.4	0.3	0.21	0.03
Upper Slave Point Dolomite (2120)	Cuttings	CO_2/H_2S	2.0	0.1	90.6	0.5	0.0	0.4	0.3	2.5	1.3	0.1	1.1	0.6	0.38	0.11
Upper Slave Point Dolomite (2120)	Powder	CO_2/H_2S	3.7	0.2	92.2	0.2	0.0	0.2	0.5	0.8	0.9	0.1	0.9	0.5	0	0.07
Lower Slave Point Dolomite (2170)	Baseline	NA	1.7	0.2	92.6	0.8	0.0	0.2	0.2	1.2	1.0	0.1	1.4	0.4	0.29	0.02
Lower Slave Point Dolomite (2170)	Cuttings	CO_2	1.6	0.1	94.5	0.5	0.0	0.1	0.5	0.8	0.4	0.0	0.4	0.2	0.88	0.07
Lower Slave Point Dolomite (2170)	Powder	CO_2	1.4	0.0	95.6	0.0	0.0	0.1	0.3	0.0	0.7	0.2	1.1	0.3	0.14	0.06
Lower Slave Point Dolomite (2175)	Baseline	NA	1.9	0.3	91.6	1.0	0.7	0.4	0.1	1.3	0.3	0.0	1.6	0.5	0.52	0.03
Lower Slave Point Dolomite (2175)	Cuttings	CO_2/H_2S	1.4	0.1	93.3	0.8	0.0	0.2	0.4	0.9	0.7	0.1	0.9	0.5	0.82	0.08
Lower Slave Point Dolomite (2175)	Powder	CO_2/H_2S	0.5	0.1	96.3	0.1	0.0	0.1	0.3	0.8	0.7	0.2	0.6	0.3	0	0.09
Sulphur Point Dolomite (2195)	Baseline	NA	3.1	0.2	90.8	1.3	0.0	0.5	0.0	0.1	0.9	0.0	1.8	0.5	0.67	0.07
Sulphur Point Dolomite (2195)	Cuttings	CO_2	2.1	0.1	91.6	1.2	0.0	0.3	0.2	0.6	0.6	0.1	0.6	0.4	2.2	0.08
Sulphur Point Dolomite (2195)	Powder	CO_2	1.21	0.15	94.78	0.22	0	0.09	0.46	0.89	0.57	0.08	0.66	0.45	0.36	0.08
Sulphur Point Dolomite (2200)	Baseline	NA	1.9	0.2	92.3	0.7	0.6	0.3	0.0	1.1	0.8	0.1	1.4	0.4	0.17	0.04
Sulphur Point Dolomite (2200)	Cuttings	CO_2/H_2S	2.3	0.1	96.0	0.0	0.1	0.0	0.3	0.0	0.1	0.1	0.5	0.4	0	0.08
Sulphur Point Dolomite (2200)	Powder	CO_2/H_2S	1.8	0.1	94.6	0.1	0.0	0.2	0.4	0.0	1.3	0.0	1.0	0.3	0.01	0.08

Table C-2a. Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Quartz	Cristo	Albite	Anorthite	Orthoclase	Sanidine	Microcline	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite
Fort Simpson Shale (1840 to 1845)	Near	Synthesized	CO_2	36.9	0.0	0.8	10.7	3.8	1.6	3.1	0.8	5.6	1.0	0.1	1.2	17.4	5.3	10.5	0.2	0.4	0.6
Fort Simpson Shale (1840 to 1845)	Near	NaCl	CO_2	38.1	0.0	3.2	0.3	2.0	0.0	2.3	0.5	5.0	1.3	2.1	1.3	6.2	32.1	4.2	0.0	0.3	1.2
Fort Simpson Shale (1840 to 1845)	Near	Synthesized	CO_2/H_2S	5.5	2.5	0.0	10.0	14.1	10.3	29.0	2.8	6.8	1.2	0.6	1.5	4.8	1.6	6.1	1.7	0.6	1.0
Fort Simpson Shale (1840 to 1845)	Near	NaCl	CO_2/H_2S	3.4	2.5	0.0	3.9	10.9	7.5	21.5	1.7	4.7	0.4	2.4	0.5	4.2	25.3	8.6	2.2	0.1	0.2
Fort Simpson Shale (1840 to 1845)	Far	Synthesized	CO_2	34.1	0.0	1.1	9.8	3.7	0.0	2.0	0.9	0.5	0.0	0.1	1.2	18.8	19.1	7.6	0.0	0.9	0.3
Fort Simpson Shale (1840 to 1845)	Far	NaCl	CO_2	35.9	0.0	3.2	8.4	6.6	0.0	5.6	0.5	0.3	0.3	0.1	1.2	19.0	3.1	14.4	0.0	0.8	0.7
Fort Simpson Shale (1840 to 1845)	Far	Synthesized	CO_2/H_2S	32.2	0.0	0.4	1.5	1.3	0.0	9.5	2.1	0.4	0.1	0.1	1.5	13.2	26.1	10.0	0.0	0.8	0.8
Fort Simpson Shale (1840 to 1845)	Far	NaCl	CO_2/H_2S	34.5	0.0	1.0	11.3	5.0	0.0	6.8	1.6	4.5	0.1	0.0	1.3	17.7	2.6	12.5	0.3	0.6	0.2
Fort Simpson Shale (1840 to 1845)	Baseline	NA	NA	3.8	2.5	0.0	4.5	11.9	7.7	16.3	1.8	6.4	0.5	0.4	0.6	2.1	35.2	5.3	0.8	0.3	0.1
Fort Simpson Shale (1860 to 1875)	Near	Synthesized	CO_2	36.1	0.0	0.3	2.8	1.5	2.2	2.1	0.0	0.4	3.1	0.0	1.2	13.1	29.3	7.0	0.0	0.6	0.3
Fort Simpson Shale (1860 to 1875)	Near	NaCl	CO_2	50.0	0.0	4.3	5.4	4.6	0.0	1.1	0.2	0.8	4.6	0.4	0.5	16.2	0.9	10.0	0.2	0.9	0.0
Fort Simpson Shale (1860 to 1875)	Near	Synthesized	CO_2/H_2S	34.4	0.0	0.5	1.8	1.8	0.0	5.3	0.7	3.4	2.3	0.0	0.9	14.2	27.3	6.3	0.0	0.3	0.8
Fort Simpson Shale (1860 to 1875)	Near	NaCl	CO_2/H_2S	47.5	0.0	0.0	0.0	0.0	0.0	0.0	0.1	7.8	2.4	0.3	0.3	12.1	26.3	2.7	0.0	0.5	0.0
Fort Simpson Shale (1860 to 1875)	Far	Synthesized	CO_2	34.5	0.0	1.3	11.8	5.9	0.0	5.4	0.9	0.1	0.1	0.1	1.2	18.6	2.9	13.0	0.9	3.2	0.2
Fort Simpson Shale (1860 to 1875)	Far	NaCl	CO_2	35.2	0.0	0.9	12.2	5.4	0.0	7.8	1.5	0.2	0.6	0.1	0.8	18.1	3.5	12.5	0.4	0.5	0.1
Fort Simpson Shale (1860 to 1875)	Far	Synthesized	CO_2/H_2S	28.9	0.0	0.2	1.6	1.2	0.0	10.2	1.9	2.9	1.1	0.0	1.1	13.9	26.5	8.0	0.0	2.3	0.2
Fort Simpson Shale (1860 to 1875)	Far	NaCl	CO_2/H_2S	32.8	0.0	0.9	3.3	1.8	0.0	5.5	1.8	0.1	0.9	0.1	1.5	14.6	27.0	8.7	0.0	0.1	0.7
Fort Simpson Shale (1860 to 1875)	Baseline	NA	NA	34.8	0.0	1.6	11.3	7.6	0.0	5.5	0.7	0.2	0.2	0.2	1.2	18.1	4.4	12.7	0.1	1.0	0.5

Table C-2b. Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Quartz	Cristo	Albite	Anorthite	Orthoclase	Sanidine	Microcline	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite
Fort Simpson Shale (1880 to 1895)	Near	Synthesized	CO_2	38.3	0.0	1.9	9.1	5.9	0.3	5.9	0.8	0.5	4.6	0.0	1.6	12.3	5.1	9.9	0.5	3.2	0.1
Fort Simpson Shale (1880 to 1895)	Near	NaCl	CO_2	42.7	0.0	0.0	16.1	6.4	0.0	5.3	0.6	0.4	2.6	0.5	2.1	8.9	3.4	7.6	0.6	1.6	1.3
Fort Simpson Shale (1880 to 1895)	Near	Synthesized	CO_2/H_2S	47.5	0.0	0.8	11.3	5.7	0.0	1.1	0.1	3.9	2.9	0.0	1.5	13.4	2.4	6.9	0.5	1.2	0.7
Fort Simpson Shale (1880 to 1895)	Near	NaCl	CO_2/H_2S	35.3	0.0	0.5	6.0	1.9	0.0	5.7	0.8	3.7	2.7	0.2	0.9	9.8	25.8	5.3	0.0	0.9	0.7
Fort Simpson Shale (1880 to 1895)	Far	Synthesized	CO_2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1880 to 1895)	Far	NaCl	CO2	37.9	0.0	4.0	8.7	8.1	0.4	0.8	0.9	0.3	0.2	0.0	1.7	17.5	2.7	12.1	0.0	4.7	0.1
Fort Simpson Shale (1880 to 1895)	Far	Synthesized	CO_2/H_2S	35.3	0.0	0.9	11.5	6.2	0.0	6.5	0.0	0.3	0.4	0.1	1.0	18.4	4.0	12.7	0.0	1.8	0.9
Fort Simpson Shale (1880 to 1895)	Far	NaCl	CO_2/H_2S	30.9	0.0	0.8	12.3	2.3	0.4	8.1	2.0	4.4	3.8	0.0	1.1	17.3	1.5	12.5	0.2	2.1	0.3
Fort Simpson Shale (1880 to 1895)	Baseline	NA	NA	33.9	0.0	1.1	11.1	5.9	0.0	7.9	1.1	0.2	1.0	0.1	1.3	20.7	1.7	13.2	0.0	0.9	0.2
Fort Simpson Shale (1905 to 1920)	Near	Synthesized	CO_2	44.5	0.0	4.5	9.9	4.0	0.6	5.0	1.6	0.1	2.0	0.0	0.9	11.3	1.3	11.4	0.0	1.4	1.4
Fort Simpson Shale (1905 to 1920)	Near	NaCl	CO_2	33.8	0.0	0.8	13.2	3.2	0.1	12.0	1.9	0.4	0.2	0.1	1.1	17.5	2.7	10.9	0.3	2.0	0.0
Fort Simpson Shale (1905 to 1920)	Near	Synthesized	CO_2/H_2S	32.0	0.0	0.4	1.2	2.6	0.4	6.7	0.4	5.1	0.1	0.1	0.9	13.8	28.8	5.8	0.3	1.0	0.6
Fort Simpson Shale (1905 to 1920)	Near	NaCl	CO_2/H_2S	31.0	0.0	0.9	0.0	3.1	0.0	8.0	0.3	5.3	0.1	0.1	1.1	14.6	27.0	7.5	0.0	0.4	0.8
Fort Simpson Shale (1905 to 1920)	Far	Synthesized	CO_2	29.4	0.0	0.0	8.9	2.2	0.0	5.8	1.6	4.0	0.3	0.1	0.8	15.5	19.7	10.6	0.0	1.1	0.0
Fort Simpson Shale (1905 to 1920)	Far	NaCl	CO_2	33.2	0.0	1.0	12.2	2.6	0.3	9.8	1.8	4.7	0.2	0.2	0.9	17.0	4.3	10.9	0.2	0.7	0.0
Fort Simpson Shale (1905 to 1920)	Far	Synthesized	CO_2/H_2S	33.0	0.0	1.2	11.7	3.5	0.0	10.8	2.4	0.3	0.1	0.1	0.6	16.7	6.3	11.3	0.5	1.6	0.0
Fort Simpson Shale (1905 to 1920)	Far	NaCl	CO_2/H_2S	34.7	0.0	0.8	11.3	2.9	0.5	9.6	2.1	0.4	0.1	0.0	0.8	17.0	5.9	12.8	0.5	0.5	0.0
Fort Simpson Shale (1905 to 1920)	Baseline	NA	NA	28.8	0.0	0.5	1.7	1.2	0.0	8.2	1.2	4.5	0.8	0.1	1.5	11.8	30.5	8.1	0.1	0.4	0.7

Table C-2c. Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Quartz	Cristo	Albite	Anorthite	Orthoclase	Sanidine	Microcline	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite
Fort Simpson Shale (1925 to 1940)	Near	Synthesized	CO_2	32.5	0.0	0.2	1.9	0.4	0.8	6.8	0.4	6.1	0.0	0.1	1.2	11.0	31.7	5.5	0.0	0.4	1.0
Fort Simpson Shale (1925 to 1940)	Near	NaCl	CO_2	33.0	0.0	0.3	2.5	0.7	0.0	9.4	1.6	0.5	0.9	0.1	1.2	10.6	30.2	8.5	0.1	0.2	0.2
Fort Simpson Shale (1925 to 1940)	Near	Synthesized	CO_2/H_2S	32.7	0.0	0.5	11.5	3.8	0.3	12.0	1.9	0.3	0.2	0.4	0.9	17.7	2.2	12.7	0.7	2.2	0.0
Fort Simpson Shale (1925 to 1940)	Near	NaCl	CO_2/H_2S	34.0	0.0	0.6	11.7	2.8	0.1	10.9	1.0	4.5	0.1	0.3	0.6	17.6	4.6	10.2	0.2	0.7	0.4
Fort Simpson Shale (1925 to 1940)	Far	Synthesized	CO_2	32.0	0.0	1.4	9.9	3.1	0.0	10.7	1.6	5.2	0.1	0.0	0.9	16.3	6.7	10.5	0.6	1.2	0.0
Fort Simpson Shale (1925 to 1940)	Far	NaCl	CO_2	31.3	0.0	1.7	0.1	1.1	0.2	9.0	0.2	5.9	0.1	0.1	1.2	11.8	27.0	8.3	0.2	1.0	0.8
Fort Simpson Shale (1925 to 1940)	Far	Synthesized	CO_2/H_2S	27.9	0.0	0.0	0.0	0.5	1.3	10.6	1.1	5.5	0.0	0.3	2.8	11.9	27.1	7.9	0.2	2.1	0.8
Fort Simpson Shale (1925 to 1940)	Far	NaCl	CO_2/H_2S	27.5	0.0	0.6	7.7	1.3	0.0	7.9	2.5	5.0	0.7	0.1	0.8	15.2	17.1	10.0	0.0	3.6	0.1
Fort Simpson Shale (1925 to 1940)	Baseline	na	Na	32.0	0.0	1.0	11.3	5.6	0.0	9.0	1.4	5.4	0.1	0.0	1.0	16.6	2.9	12.8	0.5	0.3	0.1
Fort Simpson Shale (1950 to 1975)	Near	Synthesized	CO_2	42.8	0.0	2.5	8.7	2.7	0.0	4.9	1.1	4.1	0.1	0.0	1.2	13.7	4.6	11.4	0.8	0.7	0.6
Fort Simpson Shale (1950 to 1975)	Near	NaCl	CO_2	31.5	0.0	0.9	1.4	1.2	0.0	9.0	2.1	0.1	0.3	0.1	1.4	11.5	28.0	10.2	0.2	1.8	0.2
Fort Simpson Shale (1950 to 1975)	Near	Synthesized	CO_2/H_2S	35.9	0.0	1.2	9.9	6.2	0.0	9.5	2.2	0.1	0.6	0.1	1.3	16.3	2.9	12.7	0.5	0.6	0.0
Fort Simpson Shale (1950 to 1975)	Near	NaCl	CO_2/H_2S	37.2	0.0	2.1	9.4	3.6	0.8	11.0	0.9	0.3	0.0	0.2	1.1	15.7	4.5	12.1	0.3	0.4	0.5
Fort Simpson Shale (1950 to 1975)	Far	Synthesized	CO_2	35.1	0.0	1.4	11.2	3.0	0.0	11.1	1.9	0.4	0.0	0.0	0.8	16.1	2.8	12.8	0.5	2.8	0.0
Fort Simpson Shale (1950 to 1975)	Far	NaCl	CO_2	35.0	0.0	3.1	8.1	5.6	0.0	11.1	1.5	0.3	0.7	0.1	0.7	15.3	3.4	13.5	0.5	0.9	0.2
Fort Simpson Shale (1950 to 1975)	Far	Synthesized	CO_2/H_2S	28.1	0.0	0.6	2.3	1.3	0.0	11.9	2.3	1.5	0.7	0.1	1.2	11.8	25.0	10.5	0.0	2.7	0.2
Fort Simpson Shale (1950 to 1975)	Far	NaCl	CO_2/H_2S	32.7	0.0	0.2	1.1	1.9	0.4	9.7	2.4	0.1	0.0	0.1	1.2	12.2	27.1	8.7	0.0	1.9	0.4
Fort Simpson Shale (1950 to 1975)	Baseline	NA	NA	32.7	0.0	1.1	11.0	6.8	0.3	10.6	1.5	0.1	0.0	0.0	0.4	16.5	3.0	14.7	0.6	0.7	0.1

Table C-2d. Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth)	P, T Conditions	Brine	Gas Conditions	Quartz	Cristo	Albite	Anorthite	Orthoclase	Sanidine	Microcline	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite
Fort Simpson Shale (1985 to 2000)	Near	Synthesized	CO_2	44.3	0.0	4.3	5.4	6.0	1.0	5.7	1.0	0.2	0.1	0.0	1.4	11.8	3.3	12.8	0.0	1.4	1.4
Fort Simpson Shale (1985 to 2000)	Near	NaCl	CO_2	33.0	0.0	0.8	0.0	0.9	0.0	9.9	1.8	0.5	0.0	0.1	1.5	9.4	31.4	7.3	0.3	2.8	0.5
Fort Simpson Shale (1985 to 2000)	Near	Synthesized	CO_2/H_2S	31.2	0.0	1.3	0.1	1.1	0.0	12.2	2.5	0.3	0.0	0.1	1.7	10.7	29.6	8.9	0.2	0.1	0.2
Fort Simpson Shale (1985 to 2000)	Near	NaCl	CO_2/H_2S	32.4	0.0	0.4	0.0	2.0	0.3	9.4	1.8	0.6	0.0	0.1	0.9	9.9	32.4	7.2	0.0	2.3	0.5
Fort Simpson Shale (1985 to 2000)	Far	Synthesized	CO_2	33.6	0.0	0.9	10.7	4.7	0.8	12.2	2.2	0.3	0.0	3.5	1.2	14.5	3.4	9.9	0.6	1.5	0.1
Fort Simpson Shale (1985 to 2000)	Far	NaCl	CO_2	34.8	0.0	0.0	11.2	6.5	0.4	10.0	2.0	0.3	0.0	3.9	1.3	13.7	2.0	13.3	0.3	0.3	0.0
Fort Simpson Shale (1985 to 2000)	Far	Synthesized	CO_2/H_2S	35.4	0.0	0.6	9.7	5.9	0.8	8.3	1.5	4.3	0.1	3.2	1.4	13.9	3.2	10.6	0.3	0.4	0.5
Fort Simpson Shale (1985 to 2000)	Far	NaCl	CO_2/H_2S	33.8	0.0	1.3	9.4	6.3	0.4	9.3	0.6	0.2	0.1	0.0	4.1	12.5	7.3	12.6	0.4	0.9	0.9
Fort Simpson Shale (1985 to 2000)	Baseline	NA	NA	32.2	0.0	0.0	10.7	6.7	0.0	12.2	2.7	0.1	0.1	0.1	1.6	15.5	4.5	12.8	0.4	0.7	0.0
Fort Simpson Shale (2005 to 2015)	Near	Synthesized	CO_2	31.0	0.0	0.5	0.0	0.2	0.0	12.0	1.8	5.4	0.1	0.0	1.7	7.7	32.2	6.7	0.2	0.3	0.5
Fort Simpson Shale (2005 to 2015)	Near	NaCl	CO_2	26.8	0.0	0.3	1.0	2.4	0.1	10.2	1.9	4.2	0.9	0.0	2.9	7.5	32.1	5.7	0.4	3.3	0.5
Fort Simpson Shale (2005 to 2015)	Near	Synthesized	CO_2/H_2S	32.8	0.0	1.3	1.7	0.8	0.0	7.7	2.1	5.2	0.1	0.1	1.4	7.2	31.4	6.7	0.3	0.6	0.7
Fort Simpson Shale (2005 to 2015)	Near	NaCl	CO_2/H_2S	26.8	0.0	0.8	2.4	1.0	0.0	11.3	1.8	4.1	1.0	0.2	1.5	8.3	30.3	6.1	0.4	3.4	0.7
Fort Simpson Shale (2005 to 2015)	Far	Synthesized	CO_2	18.5	0.1	0.1	8.3	2.5	0.0	13.7	2.1	0.1	0.0	0.2	2.6	10.5	23.3	12.3	0.6	4.3	0.8
Fort Simpson Shale (2005 to 2015)	Far	NaCl	CO_2	31.0	0.0	0.2	0.3	1.0	0.0	9.0	1.5	5.4	0.9	0.1	2.5	8.0	28.6	7.9	0.0	2.8	0.7
Fort Simpson Shale (2005 to 2015)	Far	Synthesized	CO_2/H_2S	30.0	0.0	0.4	12.2	6.1	0.0	9.4	2.6	4.5	1.4	2.6	1.3	12.4	4.2	11.4	0.9	0.4	0.2
Fort Simpson Shale (2005 to 2015)	Far	NaCl	CO_2/H_2S	31.5	0.0	0.6	0.0	1.9	0.0	11.1	3.3	0.1	0.0	0.8	1.3	6.6	32.8	8.8	0.1	0.2	0.9
Fort Simpson Shale (2005 to 2015)	Baseline	NA	NA	26.7	0.0	1.1	0.9	1.2	0.1	10.7	1.5	3.3	0.8	0.1	1.6	8.8	31.9	6.3	0.6	4.0	0.4

Table C-2e. Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Tests 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Quartz	Cristo	Albite	Anorthite	Orthoclase	Sanidine	Microcline	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite
Fort Simpson Shale (2020 to 2027)	Near	Synthesized	CO_2	34.4	0.0	0.0	7.7	1.0	0.0	7.5	2.7	3.2	1.1	1.0	1.5	4.4	27.3	7.0	0.4	0.7	0.4
Fort Simpson Shale (2020 to 2027)	Near	NaCl	CO_2	28.6	0.0	0.7	1.3	0.9	0.9	13.6	2.4	3.8	0.1	1.2	1.5	6.2	31.2	6.4	0.4	0.1	1.0
Fort Simpson Shale (2020 to 2027)	Near	Synthesized	CO_2/H_2S	32.4	0.0	0.9	0.7	0.7	0.1	9.0	2.4	4.5	0.1	1.3	1.4	5.1	32.2	5.7	0.2	2.6	0.7
Fort Simpson Shale (2020 to 2027)	Near	NaCl	CO_2/H_2S	29.8	0.0	1.4	0.1	0.7	0.1	11.9	2.3	4.7	1.3	0.1	1.6	5.5	31.3	5.9	0.5	2.3	0.6
Fort Simpson Shale (2020 to 2027)	Far	Synthesized	CO_2	30.9	0.0	0.7	0.2	0.7	0.8	12.1	1.3	3.9	0.1	0.2	3.7	5.7	31.7	7.1	0.2	0.1	0.7
Fort Simpson Shale (2020 to 2027)	Far	NaCl	CO_2	27.4	0.0	0.6	12.0	6.4	0.8	11.5	2.2	3.6	0.0	3.7	2.3	11.0	1.6	14.6	0.9	0.4	0.9
Fort Simpson Shale (2020 to 2027)	Far	Synthesized	CO_2/H_2S	28.7	0.0	0.8	3.7	1.0	0.5	12.4	2.9	0.5	0.1	1.5	0.7	6.5	31.9	5.8	0.5	1.9	0.7
Fort Simpson Shale (2020 to 2027)	Far	NaCl	CO_2/H_2S	30.2	0.0	0.5	1.8	1.5	0.3	10.7	3.1	4.1	0.1	1.2	1.3	6.5	30.0	6.1	0.4	1.5	0.8
Fort Simpson Shale (2020 to 2027)	Baseline	NA	NA	41.2	0.0	0.9	4.1	3.2	5.6	6.9	3.1	5.1	0.0	0.1	2.4	8.9	4.3	13.0	0.6	0.8	0.1
Otter Park Shale (2060 to 2085)	Near	Synthesized	CO_2	12.4	0.0	0.1	1.1	0.7	0.0	2.4	1.6	69.6	0.6	0.0	0.1	0.0	8.5	0.8	0.4	1.2	0.6
Otter Park Shale (2060 to 2085)	Near	NaCl	CO_2	12.5	0.0	0.2	0.2	0.3	0.3	0.4	2.5	74.8	1.6	0.0	0.0	0.0	5.1	1.3	0.2	0.1	0.5
Otter Park Shale (2060 to 2085)	Near	Synthesized	CO_2/H_2S	13.2	0.0	0.0	0.3	1.2	0.0	1.3	2.6	69.4	2.3	0.0	0.1	0.0	7.7	0.6	0.2	0.7	0.4
Otter Park Shale (2060 to 2085)	Near	NaCl	CO_2/H_2S	13.0	0.1	0.0	1.0	0.6	0.3	1.6	2.5	71.5	0.8	0.0	0.0	0.0	7.1	0.0	0.3	0.7	0.6
Otter Park Shale (2060 to 2085)	Far	Synthesized	CO_2	1.4	0.0	0.7	1.0	0.0	0.0	0.0	0.2	93.1	1.2	0.0	0.2	0.0	0.1	0.1	0.5	1.2	0.4
Otter Park Shale (2060 to 2085)	Far	NaCl	CO_2	2.4	0.0	0.3	1.2	0.0	0.0	0.3	0.2	94.4	0.1	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.4
Otter Park Shale (2060 to 2085)	Far	Synthesized	CO_2/H_2S	9.3	0.0	0.1	0.6	0.4	0.2	1.4	1.9	77.4	0.9	0.0	0.0	0.0	5.5	0.9	0.2	0.6	0.6
Otter Park Shale (2060 to 2085)	Far	NaCl	CO_2/H_2S	14.6	0.0	0.0	0.8	1.0	0.3	3.2	2.7	67.8	0.2	0.1	0.1	0.0	7.3	0.8	0.2	0.3	0.6
Otter Park Shale (2060 to 2085)	Baseline	NA	NA	18.4	0.0	0.0	0.0	0.2	0.4	0.0	2.0	68.2	2.8	0.1	0.1	0.0	6.5	0.7	0.1	0.1	0.4

Table C-2f. Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Quartz	Cristo	Albite	Anorthite	Orthoclase	Sanidine	Microcline	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite
Lower Slave Point Dolomite (2185 to 2190)	Near	Synthesized	CO_2	1.4	0.0	0.5	1.0	0.3	0.0	0.3	0.1	93.9	0.3	0.0	0.1	0.0	0.5	0.2	0.3	0.7	0.6
Lower Slave Point Dolomite (2185 to 2190)	Near	NaCl	CO_2	2.2	0.0	0.2	0.8	0.3	0.0	0.6	0.2	94.5	0.2	0.0	0.1	0.0	0.0	0.0	0.2	0.2	0.5
Lower Slave Point Dolomite (2185 to 2190)	Near	Synthesized	CO_2/H_2S	3.6	0.0	0.4	0.8	0.2	0.0	0.3	0.2	93.1	0.1	0.0	0.1	0.0	0.0	0.0	0.2	0.7	0.4
Lower Slave Point Dolomite (2185 to 2190)	Near	NaCl	CO_2/H_2S	0.9	0.0	0.5	1.3	0.1	0.0	0.1	0.2	95.2	0.0	0.0	0.1	0.0	0.0	0.2	0.3	0.5	0.7
Lower Slave Point Dolomite (2185 to 2190)	Far	Synthesized	CO_2	10.4	0.0	0.1	1.1	0.5	0.5	1.0	1.6	72.3	5.2	0.0	0.1	0.0	5.6	0.3	0.2	0.5	0.7
Lower Slave Point Dolomite (2185 to 2190)	Far	NaCl	CO_2	17.5	0.0	0.0	0.6	0.4	0.0	4.5	3.6	61.7	0.5	0.1	0.2	0.2	7.6	1.3	0.5	1.1	0.2
Lower Slave Point Dolomite (2185 to 2190)	Far	Synthesized	CO_2/H_2S	2.0	0.0	0.3	1.2	0.0	0.0	0.6	0.2	93.0	0.0	0.0	0.1	0.0	0.0	0.7	0.2	0.9	0.6
Lower Slave Point Dolomite (2185 to 2190)	Far	NaCl	CO_2/H_2S	2.0	0.0	0.4	1.0	0.0	0.0	0.3	0.2	94.5	0.2	0.0	0.0	0.0	0.0	0.0	0.2	0.6	0.5
Lower Slave Point Dolomite (2185 to 2190)	Baseline	NA	NA	2.6	0.1	0.4	0.9	0.0	0.1	0.5	0.1	93.5	0.2	0.0	0.1	0.0	0.4	0.1	0.0	0.6	0.6
Sulphur Point Dolomite (2205 to 2215)	Near	Synthesized	CO_2	2.3	0.0	0.5	1.8	0.2	0.0	0.4	0.2	92.9	0.0	0.0	0.1	0.0	0.2	0.0	0.3	0.5	0.7
Sulphur Point Dolomite (2205 to 2215)	Near	NaCl	CO_2	1.2	0.0	0.5	1.0	0.1	0.0	0.0	0.1	95.5	0.0	0.0	0.0	0.0	0.3	0.1	0.2	0.3	0.6
Sulphur Point Dolomite (2205 to 2215)	Near	Synthesized	CO_2/H_2S	1.5	0.0	0.5	0.7	0.0	0.0	0.7	0.1	94.2	0.0	0.0	0.2	0.0	0.0	0.9	0.2	0.5	0.5
Sulphur Point Dolomite (2205 to 2215)	Near	NaCl	CO_2/H_2S	1.5	0.0	0.6	1.1	0.0	0.0	0.5	0.2	94.4	0.0	0.0	0.0	0.0	0.3	0.4	0.3	0.5	0.4
Sulphur Point Dolomite (2205 to 2215)	Far	Synthesized	CO_2	1.7	0.0	0.3	1.1	0.0	0.0	0.4	0.2	94.5	0.3	0.0	0.0	0.0	0.5	0.2	0.2	0.2	0.5
Sulphur Point Dolomite (2205 to 2215)	Far	NaCl	CO_2	1.8	0.0	0.4	1.1	0.2	0.1	0.1	0.6	93.9	0.1	0.0	0.0	0.0	0.3	0.1	0.1	0.7	0.6
Sulphur Point Dolomite (2205 to 2215)	Far	Synthesized	CO_2/H_2S	1.3	0.0	0.3	1.1	0.0	0.0	0.1	0.2	94.8	0.0	0.0	0.1	0.0	0.4	0.2	0.1	1.0	0.5
Sulphur Point Dolomite (2205 to 2215)	Far	NaCl	CO_2/H_2S	0.9	0.0	0.4	1.4	0.0	0.0	0.0	0.1	95.0	0.3	0.1	0.2	0.0	0.0	0.1	0.2	0.9	0.6
Sulphur Point Dolomite (2205 to 2215)	Baseline	NA	NA	4.9	0.0	0.3	0.8	0.1	0.0	0.0	0.2	92.6	0.0	0.0	0.0	0.0	0.0	0.5	0.3	0.0	0.3

Table C-2g. Predominant Mineral Phases in c-61-E Drill Cuttings as Determined by XRD on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Quartz	Cristo	Albite	Anorthite	Orthoclase	Sanidine	Microcline	Pyrite	Dolomite	Calcite	Anhydrite	Siderite	Kaolinite	Illite	Chlorite	Goertite	Gypsum	Hematite
Sulphur Point Dolomite (2220 to 2230)	Near	Synthesized	CO_2	2.2	0.0	0.6	1.2	0.0	0.0	0.3	0.2	93.6	0.0	0.0	0.0	0.0	0.0	0.6	0.3	0.3	0.6
Sulphur Point Dolomite (2220 to 2230)	Near	NaCl	CO_2	1.3	0.0	0.4	1.2	0.0	0.1	0.3	0.1	95.2	0.2	0.0	0.0	0.0	0.1	0.1	0.3	0.3	0.5
Sulphur Point Dolomite (2220 to 2230)	Near	Synthesized	CO2/H_2S	1.1	0.0	0.4	1.0	0.0	0.1	0.3	0.1	95.0	0.1	0.0	0.0	0.0	0.5	0.0	0.3	0.6	0.5
Sulphur Point Dolomite (2220 to 2230)	Near	NaCl	CO_2/H_2S	2.9	0.0	0.5	1.0	0.0	0.0	0.2	0.1	93.6	0.0	0.0	0.0	0.0	0.4	0.5	0.3	0.0	0.5
Sulphur Point Dolomite (2220 to 2230)	Far	Synthesized	CO_2	0.9	0.0	0.6	1.2	0.0	0.0	0.3	0.2	95.0	0.2	0.0	0.0	0.0	0.0	0.2	0.2	0.7	0.7
Sulphur Point Dolomite (2220 to 2230)	Far	NaCl	CO_2	2.8	0.0	0.4	0.8	0.1	0.0	0.8	0.1	93.4	0.3	0.0	0.1	0.0	0.0	0.7	0.2	0.0	0.5
Sulphur Point Dolomite (2220 to 2230)	Far	Synthesized	CO_2/H_2S	2.1	0.0	0.5	1.3	0.0	0.0	0.3	0.2	93.7	0.3	0.0	0.0	0.0	0.0	0.2	0.2	0.7	0.6
Sulphur Point Dolomite (2220 to 2230)	Far	NaCl	CO_2/H_2S	4.7	0.0	0.6	1.3	0.0	0.0	0.3	0.1	91.4	0.0	0.0	0.1	0.0	0.0	0.1	0.2	0.6	0.5
Sulphur Point Dolomite (2220 to 2230)	Baseline	NA	NA	3.4	0.0	0.7	1.3	0.0	0.0	0.7	0.2	91.0	0.5	0.0	0.1	0.0	0.5	0.5	0.3	0.3	0.5
Upper Keg River Dolomite (2235 to 2240)	Near	Synthesized	CO_2	3.9	0.0	0.4	1.1	0.5	0.0	0.6	1.2	87.5	0.6	0.0	0.1	0.0	2.1	0.3	0.4	0.7	0.6
Upper Keg River Dolomite (2235 to 2240)	Near	NaCl	CO_2	4.6	0.0	0.7	1.4	0.0	0.0	0.0	0.2	90.5	0.6	0.0	0.1	0.0	0.0	0.4	0.3	0.4	0.8
Upper Keg River Dolomite (2235 to 2240)	Near	Synthesized	CO_2/H_2S	1.8	0.0	0.5	1.1	0.0	0.0	0.2	0.2	93.8	0.3	0.0	0.0	0.0	0.2	0.0	0.3	1.0	0.6
Upper Keg River Dolomite (2235 to 2240)	Near	NaCl	CO_2/H_2S	4.2	0.1	0.5	1.4	0.0	0.0	0.0	0.3	91.0	0.1	0.0	0.1	0.0	0.0	0.7	0.2	0.8	0.7
Upper Keg River Dolomite (2235 to 2240)	Far	Synthesized	CO_2	1.1	0.0	0.4	0.8	0.2	0.0	0.2	0.2	92.5	1.2	0.0	0.1	0.0	0.6	1.0	0.3	0.8	0.6
Upper Keg River Dolomite (2235 to 2240)	Far	NaCl	CO_2	2.8	0.0	0.4	1.0	0.2	0.0	0.9	0.2	91.5	0.3	0.0	0.0	0.0	1.0	0.3	0.3	0.4	0.8
Upper Keg River Dolomite (2235 to 2240)	Far	Synthesized	CO_2/H_2S	0.9	0.0	0.4	1.2	0.0	0.0	0.0	0.3	95.8	0.4	0.0	0.0	0.0	0.0	0.2	0.2	0.1	0.6
Upper Keg River Dolomite (2235 to 2240)	Far	NaCl	CO_2/H_2S	4.1	0.0	0.4	2.6	0.5	0.0	1.9	0.5	85.9	0.1	0.0	0.3	0.0	0.7	1.0	0.1	1.1	1.0
Upper Keg River Dolomite (2235 to 2240)	Baseline	NA	NA	1.4	0.0	0.6	1.0	0.0	0.0	0.0	0.2	94.6	0.3	0.0	0.1	0.0	0.0	0.4	0.1	0.7	0.6

Table C-3a. Predominant Elements in c-61-E Drill Cuttings as Determined by XRF on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Si	Al	Fe	Ti	P	Ca	Mg	Na	K	S
Fort Simpson Shale (1840 to 1845)	Near	Synthesized	CO_2	53.3	20.2	13.4	1.1	0.1	2.6	2.5	1.1	5.4	0.2
Fort Simpson Shale (1840 to 1845)	Near	NaCl	CO_2	53.7	20.1	13.0	1.1	0.1	2.9	2.5	0.8	5.6	0.2
Fort Simpson Shale (1840 to 1845)	Near	Synthesized	CO_2/H_2S	53.7	20.4	13.0	1.1	0.1	2.3	2.5	1.1	5.5	0.3
Fort Simpson Shale (1840 to 1845)	Near	NaCl	CO_2/H_2S	53.5	20.3	13.1	1.1	0.1	2.6	2.5	0.8	5.6	0.4
Fort Simpson Shale (1840 to 1845)	Far	Synthesized	CO_2	53.6	20.3	13.4	1.1	0.1	2.4	2.5	0.9	5.4	0.3
Fort Simpson Shale (1840 to 1845)	Far	NaCl	CO_2	53.8	20.1	13.5	1.1	0.1	2.3	2.5	0.9	5.4	0.3
Fort Simpson Shale (1840 to 1845)	Far	Synthesized	CO_2/H_2S	53.8	20.3	13.3	1.1	0.1	1.8	2.5	0.9	5.4	0.7
Fort Simpson Shale (1840 to 1845)	Far	NaCl	CO_2/H_2S	53.8	20.0	13.1	1.1	0.1	2.4	2.5	0.9	5.4	0.8
Fort Simpson Shale (1840 to 1845)	Baseline	NA	NA	53.5	20.2	12.9	1.1	0.1	2.7	2.5	0.9	5.8	0.2
Fort Simpson Shale (1860 to 1875)	Near	Synthesized	CO_2	53.8	19.2	12.4	1.0	0.1	4.5	2.4	1.1	5.2	0.2
Fort Simpson Shale (1860 to 1875)	Near	NaCl	CO_2	53.6	19.3	12.3	1.0	0.1	4.7	2.4	0.8	5.4	0.2
Fort Simpson Shale (1860 to 1875)	Near	Synthesized	CO_2/H_2S	53.2	19.4	12.4	1.0	0.1	4.8	2.4	1.1	5.3	0.4
Fort Simpson Shale (1860 to 1875)	Near	NaCl	CO_2/H_2S	53.3	19.3	12.6	1.0	0.1	4.6	2.5	0.8	5.4	0.4
Fort Simpson Shale (1860 to 1875)	Far	Synthesized	CO_2	53.7	19.5	13.1	1.1	0.1	3.7	2.4	0.8	5.3	0.3
Fort Simpson Shale (1860 to 1875)	Far	NaCl	CO_2	53.6	19.2	12.8	1.0	0.1	4.4	2.4	0.8	5.2	0.3
Fort Simpson Shale (1860 to 1875)	Far	Synthesized	CO_2/H_2S	53.7	19.4	12.7	1.0	0.1	3.8	2.4	0.9	5.3	0.7
Fort Simpson Shale (1860 to 1875)	Far	NaCl	CO_2/H_2S	53.7	19.5	12.6	1.0	0.1	3.7	2.4	0.9	5.3	0.7
Fort Simpson Shale (1860 to 1875)	Baseline	NA	NA	53.4	19.5	12.6	1.0	0.1	4.3	2.5	0.9	5.5	0.2

Table C-3b. Predominant Elements in c-61-E Drill Cuttings as Determined by XRF on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Si	Al	Fe	Ti	P	Ca	Mg	Na	K	S
Fort Simpson Shale (1880 to 1895)	Near	Synthesized	CO_2	53.4	19.3	12.4	1.0	0.1	4.9	2.4	1.1	5.2	0.2
Fort Simpson Shale (1880 to 1895)	Near	NaCl	CO_2	53.3	19.1	12.3	1.0	0.1	5.4	2.4	0.8	5.3	0.2
Fort Simpson Shale (1880 to 1895)	Near	Synthesized	CO_2/H_2S	53.2	19.2	12.6	1.0	0.1	4.8	2.4	1.1	5.2	0.4
Fort Simpson Shale (1880 to 1895)	Near	NaCl	CO_2/H_2S	53.1	19.1	12.2	1.0	0.1	5.6	2.4	0.8	5.3	0.4
Fort Simpson Shale (1880 to 1895)	Far	Synthesized	CO_2	53.0	18.7	12.4	1.0	0.1	5.9	2.4	1.1	5.2	0.3
Fort Simpson Shale (1880 to 1895)	Far	NaCl	CO_2	52.9	19.0	12.3	1.0	0.1	5.5	2.4	0.9	5.5	0.3
Fort Simpson Shale (1880 to 1895)	Far	Synthesized	CO_2/H_2S	53.7	19.2	12.3	1.0	0.1	4.7	2.4	0.8	5.1	0.7
Fort Simpson Shale (1880 to 1895)	Far	NaCl	CO_2/H_2S	53.1	19.1	12.1	1.0	0.1	5.2	2.4	0.8	5.4	0.8
Fort Simpson Shale (1880 to 1895)	Baseline	NA	NA	52.7	19.3	12.4	1.0	0.1	5.3	2.4	0.9	5.5	0.2
Fort Simpson Shale (1905 to 1920)	Near	Synthesized	CO_2	53.7	20.6	12.4	1.0	0.1	2.6	2.5	1.1	5.6	0.3
Fort Simpson Shale (1905 to 1920)	Near	NaCl	CO_2	53.6	20.5	12.4	1.0	0.1	3.1	2.5	0.8	5.7	0.3
Fort Simpson Shale (1905 to 1920)	Near	Synthesized	CO_2/H_2S	53.5	20.4	12.5	1.0	0.1	2.8	2.5	1.0	5.6	0.5
Fort Simpson Shale (1905 to 1920)	Near	NaCl	CO_2/H_2S	53.6	20.5	12.5	1.0	0.1	2.6	2.5	0.9	5.8	0.4
Fort Simpson Shale (1905 to 1920)	Far	Synthesized	CO_2	53.7	20.1	12.6	1.0	0.1	2.8	2.5	1.1	5.6	0.4
Fort Simpson Shale (1905 to 1920)	Far	NaCl	CO_2	53.3	20.1	12.3	1.0	0.1	3.3	2.5	1.1	5.9	0.4
Fort Simpson Shale (1905 to 1920)	Far	Synthesized	CO_2/H_2S	53.9	20.3	12.6	1.0	0.1	2.3	2.5	0.9	5.5	0.8
Fort Simpson Shale (1905 to 1920)	Far	NaCl	CO_2/H_2S	54.1	20.7	12.6	1.1	0.1	2.0	2.5	0.7	5.5	0.8
Fort Simpson Shale (1905 to 1920)	Baseline	NA	NA	53.5	20.3	12.5	1.0	0.1	2.9	2.5	0.9	5.8	0.3

Table C-3c. Predominant Elements in c-61-E Drill Cuttings as Determined by XRF on As-Received Cuttings (baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Si	Al	Fe	Ti	P	Ca	Mg	Na	K	S
Fort Simpson Shale (1925 to 1940)	Near	Synthesized	CO_2	54.1	20.7	12.4	1.0	0.1	1.9	2.5	1.0	5.8	0.4
Fort Simpson Shale (1925 to 1940)	Near	NaCl	CO_2	53.9	20.7	12.5	1.0	0.1	2.2	2.6	0.7	5.9	0.4
Fort Simpson Shale (1925 to 1940)	Near	Synthesized	CO_2/H_2S	54.0	20.9	12.2	1.0	0.1	1.9	2.6	1.0	5.8	0.5
Fort Simpson Shale (1925 to 1940)	Near	NaCl	CO_2/H_2S	53.8	20.8	12.2	1.0	0.1	2.2	2.6	0.8	5.9	0.5
Fort Simpson Shale (1925 to 1940)	Far	Synthesized	CO_2	54.4	20.8	12.5	1.1	0.1	1.7	2.6	0.7	5.7	0.5
Fort Simpson Shale (1925 to 1940)	Far	NaCl	CO_2	53.7	20.6	12.2	1.0	0.1	2.4	2.6	0.8	6.1	0.5
Fort Simpson Shale (1925 to 1940)	Far	Synthesized	CO_2/H_2S	53.9	20.8	12.1	1.0	0.1	2.1	2.6	0.9	6.1	0.4
Fort Simpson Shale (1925 to 1940)	Far	NaCl	CO_2/H_2S	54.1	20.8	12.4	1.0	0.1	1.5	2.6	0.9	5.9	0.5
Fort Simpson Shale (1925 to 1940)	Baseline	NA	NA	54.6	21.1	12.0	1.0	0.1	1.4	2.6	0.7	6.1	0.5
Fort Simpson Shale (1950 to 1975)	Near	Synthesized	CO_2	54.5	20.9	12.1	1.0	0.1	1.2	2.6	0.9	6.0	0.6
Fort Simpson Shale (1950 to 1975)	Near	NaCl	CO_2	54.5	21.0	12.0	1.0	0.1	1.4	2.6	0.7	6.1	0.6
Fort Simpson Shale (1950 to 1975)	Near	Synthesized	CO_2/H_2S	54.4	20.8	12.1	1.0	0.1	1.4	2.6	1.0	6.1	0.5
Fort Simpson Shale (1950 to 1975)	Near	NaCl	CO_2/H_2S	54.5	21.0	12.0	1.0	0.1	1.4	2.6	0.7	6.1	0.6
Fort Simpson Shale (1950 to 1975)	Far	Synthesized	CO_2	54.4	20.8	12.1	1.0	0.1	1.4	2.6	1.0	6.1	0.5
Fort Simpson Shale (1950 to 1975)	Far	NaCl	CO_2	54.3	20.8	12.0	1.0	0.1	1.6	2.6	0.7	6.3	0.5
Fort Simpson Shale (1950 to 1975)	Far	Synthesized	CO_2/H_2S	54.4	20.7	12.0	1.0	0.1	1.4	2.6	1.0	6.0	0.8
Fort Simpson Shale (1950 to 1975)	Far	NaCl	CO_2/H_2S	54.3	20.7	11.8	1.0	0.1	1.7	2.5	0.7	6.2	0.9
Fort Simpson Shale (1950 to 1975)	Baseline	NA	NA	54.2	21.1	12.0	1.0	0.1	1.4	2.6	0.8	6.3	0.4

Table C-3d. Predominant Elements in c-61-E Drill Cuttings as Determined by XRF on As-Received Cuttings (Baseline) and Following Exposure to CO_2 or Sour CO_2 in Batch Reactor Test 2–5 Experiments (postexposure). Values are reported in percent. Near-wellbore conditions were conducted at 65°C and 3500 psi, and far-from-wellbore conditions were conducted at 120°C and 2800 psi. Cuttings were saturated with either synthetic brine (NaCl solution) or synthesized brine. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S.

Formation (Depth [m])	P, T Conditions	Brine	Gas Conditions	Si	Al	Fe	Ti	P	Ca	Mg	Na	K	S
Fort Simpson Shale (1985 to 2000)	Near	Synthesized	CO_2	54.8	20.8	11.7	1.0	0.1	1.5	2.5	0.8	6.2	0.5
Fort Simpson Shale (1985 to 2000)	Near	NaCl	CO_2	54.8	20.7	11.8	1.0	0.1	1.5	2.5	0.5	6.3	0.6
Fort Simpson Shale (1985 to 2000)	Near	Synthesized	CO_2/H_2S	54.7	20.9	11.8	1.0	0.1	1.1	2.5	0.7	6.3	0.7
Fort Simpson Shale (1985 to 2000)	Near	NaCl	CO_2/H_2S	54.6	20.8	11.6	1.0	0.1	1.7	2.5	0.6	6.4	0.7
Fort Simpson Shale (1985 to 2000)	Far	Synthesized	CO_2	54.5	20.3	11.8	1.0	0.1	2.0	2.5	0.9	6.2	0.6
Fort Simpson Shale (1985 to 2000)	Far	NaCl	CO_2	54.1	20.4	11.4	1.0	0.1	1.7	2.5	1.6	6.5	0.7
Fort Simpson Shale (1985 to 2000)	Far	Synthesized	CO_2/H_2S	54.4	20.3	11.6	1.0	0.1	1.5	2.5	1.5	6.2	0.9
Fort Simpson Shale (1985 to 2000)	Far	NaCl	CO_2/H_2S	53.8	20.3	11.0	1.0	0.1	1.6	2.4	2.4	6.5	0.9
Fort Simpson Shale (1985 to 2000)	Baseline	NA	NA	54.4	20.7	11.6	1.0	0.1	1.9	2.5	0.6	6.6	0.5

Table C-4a. Spotlight Summary of Preexposure SEM–EDS Results for the Sulphur Point Formation Dolomite Cutting Sample Collected at 2220 m

Resolution	Tag	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Ba
100×	1	0.1	34.8	0.3	0.3	0.2	0.0	0.0	0.0	61.5	0.0	2.8	0.0
100×	2	0.6	42.3	0.4	0.3	0.3	0.0	0.0	0.0	56.1	0.0	0.2	0.0
100×	3	0.2	38.5	0.0	0.1	0.2	0.2	0.0	0.0	60.6	0.0	0.2	0.0
100×	4	0.5	2.0	0.5	0.4	0.4	0.2	0.0	0.0	95.5	0.0	0.5	0.0
100×	5	0.1	41.1	0.2	0.4	0.2	0.0	0.0	0.0	57.1	0.0	0.9	0.0
100×	6	0.3	42.7	0.3	0.1	0.1	0.1	0.0	0.0	56.1	0.0	0.3	0.0
100×	7	0.2	44.1	0.3	0.2	0.2	0.1	0.1	0.0	54.9	0.0	0.0	0.0
100×	8	0.2	27.1	0.0	0.4	0.7	0.0	0.1	0.0	71.2	0.0	0.2	0.0
250×	1	0.0	18.2	0.0	1.0	0.0	1.5	0.0	0.0	74.2	0.0	5.0	0.0
250×	2	0.2	4.2	0.0	1.0	0.1	49.0	0.0	0.0	4.6	0.4	40.5	0.0
250×	3	0.0	1.8	0.0	0.0	0.0	39.4	0.0	0.0	2.0	0.4	56.5	0.0
250×	4	0.4	39.3	0.4	1.0	0.1	0.0	0.0	0.0	50.1	0.0	8.6	0.0
250×	5	0.1	40.1	0.1	0.1	0.0	0.0	0.0	0.0	58.4	0.0	1.1	0.0
250×	6	0.0	2.5	4.7	22.1	0.0	2.2	0.0	41.7	17.0	0.0	9.8	0.0
250×	7	0.0	28.8	0.1	0.1	0.3	0.0	0.0	18.7	41.2	0.0	11.0	0.0
250×	8	0.2	35.7	0.4	0.6	0.3	0.2	0.0	0.0	62.1	0.0	0.5	0.0
350×	1	0.6	1.6	0.0	0.0	0.0	57.6	0.0	0.0	1.8	1.2	37.2	0.0
350×	2	0.3	0.6	0.1	0.1	0.1	58.4	0.1	0.0	0.6	1.4	38.3	0.0
350×	3	0.1	0.8	0.1	0.0	0.1	57.3	0.1	0.0	1.3	1.2	39.1	0.0
350×	4	0.2	4.0	0.0	0.1	0.0	39.1	0.0	0.0	11.4	1.5	38.8	4.9
350×	5	0.0	4.6	0.0	0.0	0.0	20.4	0.0	0.0	4.6	0.0	70.5	0.0
350×	6	0.0	15.4	0.0	0.0	0.0	22.7	0.0	0.0	21.3	0.0	40.6	0.0
350×	7	0.6	44.8	0.6	0.1	0.2	0.0	0.0	0.0	53.6	0.0	0.2	0.0
350×	8	0.4	38.3	0.4	0.2	0.4	0.2	0.0	0.0	60.2	0.0	0.0	0.0
1000×	1	0.0	0.8	0.7	1.1	0.2	57.5	0.1	0.0	0.5	1.1	38.0	0.0
1000×	2	0.0	1.1	4.2	9.2	0.0	49.0	0.0	1.3	1.2	0.7	33.3	0.0
1000×	3	0.0	0.6	0.8	1.2	0.1	56.9	0.1	0.0	0.4	1.1	38.7	0.0
1000×	4	0.0	2.2	22.4	63.3	0.0	0.0	0.0	6.0	0.1	0.0	6.0	0.0
1000×	5	0.0	0.5	6.3	88.3	0.0	0.0	0.0	3.1	0.4	0.0	1.4	0.0
1000×	6	0.0	1.5	18.6	67.5	0.0	0.0	0.0	7.5	0.2	0.2	4.0	0.5
1000×	7	0.0	6.6	27.1	28.4	0.0	0.0	0.0	0.2	1.7	0.0	36.0	0.0
1000×	8	0.1	12.3	0.6	3.7	1.4	0.0	0.0	0.1	53.8	0.1	27.9	0.0

Table C-4b. Spotlight Summary of Postexposure SEM–EDS Results for the Sulphur Point Formation Dolomite Cutting Sample Collected at 2220 m. Cuttings were saturated with synthetic brine (NaCl solution) and exposed to CO_2 at near-wellbore conditions (65°C and 3500 psi).

Resolution	Tag	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Ba	V	Ni
100×	1	33.4	6.5	0.0	0.0	0.0	0.0	48.5	0.0	10.8	0.0	0.7	0.0	0.1	0.0
100×	2	31.0	10.0	0.1	0.0	0.0	0.0	45.4	0.0	13.0	0.0	0.6	0.0	0.0	0.0
100×	3	29.7	2.2	0.1	0.3	0.0	0.0	49.5	0.0	8.2	0.0	9.9	0.0	0.0	0.0
100×	4	0.2	39.8	0.2	0.2	0.2	0.0	0.0	0.1	58.3	0.0	0.4	0.0	0.7	0.0
100×	5	0.9	33.4	0.3	0.3	0.3	0.0	1.1	0.0	61.9	0.0	1.4	0.0	0.5	0.0
250×	1	31.4	4.3	0.0	0.2	0.0	0.0	54.1	0.0	9.7	0.0	0.2	0.0	0.0	0.0
250×	2	31.7	3.0	0.0	0.0	0.0	0.0	54.9	0.0	9.8	0.0	0.4	0.0	0.2	0.0
250×	3	32.7	4.9	0.0	0.1	0.0	0.0	50.1	0.1	11.8	0.0	0.3	0.0	0.0	0.0
250×	4	31.5	6.7	0.1	0.4	0.1	0.1	47.4	0.1	12.7	0.0	0.9	0.0	0.0	0.0
250×	5	30.1	6.2	0.0	0.1	0.0	0.0	47.8	0.0	13.8	0.0	2.0	0.0	0.0	0.0
250×	6	0.4	30.2	0.1	0.1	0.7	0.2	0.4	0.0	67.3	0.0	0.3	0.0	0.0	0.2
250×	7	0.3	31.0	0.1	0.2	0.3	0.1	0.1	0.0	67.4	0.0	0.3	0.0	0.3	0.0
250×	8	0.2	30.8	0.0	0.1	0.2	0.2	0.4	0.0	67.6	0.0	0.2	0.0	0.3	0.0
500×	1	30.8	8.0	0.0	0.1	0.0	0.0	42.1	0.0	13.6	0.0	5.4	0.0	–	–
500×	2	29.6	5.1	0.0	0.1	0.0	0.0	47.3	0.0	14.4	0.0	3.5	0.0	–	–
500×	3	29.7	7.4	0.0	0.2	0.0	0.0	45.5	0.0	14.4	0.0	2.9	0.0	–	–
500×	4	14.3	27.6	0.0	0.0	0.0	0.0	15.3	0.0	32.1	0.0	10.7	0.0	–	–
500×	5	1.0	22.2	0.0	0.2	0.3	0.1	0.6	0.0	58.6	0.0	16.8	0.0	–	–
500×	6	15.6	24.6	0.0	0.2	0.0	0.0	18.9	0.0	38.5	0.0	2.2	0.0	–	–
500×	7	0.2	36.6	0.3	0.3	0.4	0.0	0.0	0.0	61.3	0.0	0.7	0.0	–	–
500×	8	0.2	41.3	0.0	0.1	0.1	0.1	0.4	0.0	57.6	0.0	0.1	0.0	–	–
750×	1	35.3	0.0	0.0	0.1	0.1	0.0	62.6	0.2	1.6	0.0	0.0	0.0	0.2	0.0
750×	2	35.8	0.0	0.0	0.0	0.0	0.0	62.4	0.2	1.1	0.0	0.0	0.0	0.5	0.0
750×	3	31.8	0.4	0.0	0.0	0.0	0.1	61.7	0.0	5.6	0.0	0.2	0.0	0.2	0.0
750×	4	37.0	0.1	0.1	0.1	0.2	0.0	59.6	0.5	1.4	0.0	0.0	0.4	0.6	0.0
750×	5	1.6	0.8	0.7	0.5	0.3	0.2	0.9	0.0	94.7	0.0	0.0	0.0	0.0	0.1
750×	6	5.4	2.0	8.3	67.1	0.0	0.0	11.1	2.3	1.9	0.0	2.0	0.0	0.0	0.0
1000×	1	37.2	0.3	0.1	0.4	0.0	0.0	60.3	0.2	1.3	0.0	0.0	0.0	0.2	0.0
1000×	2	39.1	0.1	0.0	0.1	0.1	0.0	58.8	0.2	1.2	0.0	0.0	0.1	0.2	0.2
1000×	3	0.8	39.6	0.0	0.0	0.0	0.0	1.9	0.0	57.2	0.0	0.0	0.0	0.2	0.2
1000×	4	38.4	1.8	0.0	0.1	0.1	0.0	56.8	0.4	2.4	0.0	0.0	0.0	0.1	0.0
1000×	5	36.3	0.0	0.0	0.1	0.1	0.0	61.5	0.1	0.9	0.0	0.6	0.0	0.4	0.0
1000×	6	8.6	0.0	0.0	0.0	0.0	0.1	88.6	0.0	0.4	0.0	0.4	1.5	0.3	0.1

Table C-4c. Spotlight Summary of Postexposure SEM–EDS Results for the Sulphur Point Formation Dolomite Cuttings Sample Collected at 2220 m. Cuttings were saturated with synthetic brine (NaCl solution) and exposed to 85.5 mol% CO_2/13.5 mol% H_2S at near-wellbore conditions (65°C and 3500 psi).

Resolution	Tag	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Fe	Ba
200×	1	1.5	1.0	0.1	0.4	0.1	54.8	0.5	0.0	1.1	1.0	39.6	0.0
200×	2	3.0	0.3	0.0	0.2	0.0	56.5	0.1	0.0	0.3	0.9	38.6	0.0
200×	3	0.1	1.1	0.0	0.2	0.0	54.1	0.2	0.0	2.8	0.6	40.9	0.0
200×	4	1.0	0.9	0.2	0.4	0.0	55.0	0.6	0.0	1.1	0.9	39.9	0.0
200×	5	0.3	41.9	0.3	0.2	0.1	0.0	0.0	0.0	57.1	0.0	0.2	0.0
200×	6	0.4	37.6	0.2	0.2	0.2	0.2	0.1	0.0	60.9	0.0	0.2	0.0
200×	7	0.6	5.6	0.3	0.5	0.6	0.5	0.2	0.0	91.1	0.0	0.5	0.0
200×	8	0.2	42.3	0.0	0.3	0.3	0.1	0.0	0.0	56.5	0.0	0.3	0.0
500×	1	3.1	2.4	0.0	0.4	0.6	0.3	2.4	0.0	90.9	0.0	0.0	0.0
500×	2	0.0	0.0	0.0	0.0	0.4	0.2	0.2	0.2	98.8	0.0	0.2	0.0
500×	3	0.8	2.8	0.4	0.3	0.3	0.0	0.0	0.0	95.4	0.0	0.0	0.0
500×	4	0.2	38.3	0.1	0.3	0.3	0.1	0.0	0.0	60.5	0.0	0.0	0.0
500×	5	3.7	20.9	0.1	0.0	0.0	25.6	2.9	0.0	27.2	0.0	19.7	0.0
750×	1	0.4	41.3	0.2	0.3	0.3	0.1	0.0	0.0	56.5	0.0	0.8	0.0
750×	2	0.6	41.2	0.3	0.5	0.2	0.1	0.0	0.1	55.4	0.0	1.5	0.0
750×	3	8.4	17.7	14.5	16.3	0.0	8.0	3.2	0.0	29.4	0.0	2.3	0.0
750×	4	1.6	38.4	0.4	0.4	0.1	1.3	0.1	0.0	55.9	0.0	1.9	0.0
750×	5	0.0	44.0	0.6	0.2	0.1	0.1	0.0	0.0	53.6	0.0	1.4	0.0
750×	6	0.7	42.9	0.0	0.0	0.1	0.0	0.4	0.0	54.9	0.0	1.0	0.0
750×	7	0.8	42.0	0.4	0.1	0.0	0.9	0.0	0.0	51.9	0.0	3.9	0.0
750×	8	0.7	42.9	0.8	0.3	0.2	0.1	0.1	0.0	53.1	0.0	1.7	0.0
1000×	1	29.3	10.8	0.0	0.1	0.0	0.8	41.9	0.0	15.6	0.0	1.4	0.0
1000×	2	25.4	1.3	0.0	0.1	0.0	0.1	61.8	0.0	11.3	0.0	0.0	0.0
1000×	3	24.1	1.3	0.0	0.6	0.0	15.3	36.1	0.1	3.0	0.0	19.5	0.0
1000×	4	1.1	2.4	0.3	0.4	0.2	1.1	0.7	0.0	92.7	0.0	1.1	0.0
1000×	5	28.5	3.7	0.0	0.0	0.0	0.6	56.6	0.0	10.0	0.0	0.6	0.0
1000×	6	37.9	0.9	0.0	0.0	0.0	0.0	58.1	0.4	2.5	0.0	0.0	0.1
1000×	7	0.3	26.3	0.0	0.1	0.4	0.0	1.0	0.0	71.7	0.0	0.1	0.0
1000×	8	0.3	33.1	0.0	0.2	0.4	0.0	0.2	0.0	65.7	0.0	0.0	0.0

Table C-4d. Spotlight Summary of Postexposure SEM–EDS Results for the Upper Keg River Formation Dolomite Cutting Sample Collected at 2235 m. Cuttings were saturated with synthetic brine (NaCl solution) and exposed to 100% CO_2 at far-from-wellbore conditions (120°C and 2800 psi).

Resolution	Tag	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Cr	Fe	Ba	Sr
100×	1	39.5	0.0	0.0	0.0	0.0	0.0	60.0	0.0	0.4	0.0	0.0	0.1	0.0	–
100×	2	38.4	0.0	0.0	0.0	0.0	0.0	60.9	0.0	0.4	0.0	0.0	0.0	0.2	–
100×	3	0.0	0.3	0.0	5.8	0.0	0.0	33.2	2.9	27.5	0.0	0.0	30.3	0.0	–
100×	4	0.0	4.1	0.0	4.2	0.0	1.0	46.1	6.9	30.5	0.0	0.0	7.2	0.0	–
100×	5	0.0	0.1	0.3	5.8	0.0	0.0	42.9	32.7	3.9	0.0	0.1	14.3	0.0	–
100×	6	0.4	0.2	0.3	0.2	0.0	0.0	47.4	49.7	1.3	0.0	0.2	0.0	0.3	–
150×	1	35.0	0.0	0.0	1.3	0.0	0.0	58.1	0.1	1.6	0.0	0.0	2.7	0.0	1.1
150×	2	1.2	1.5	0.0	1.7	0.0	0.0	57.5	1.5	31.8	0.0	0.0	2.8	0.0	2.1
150×	3	0.9	8.9	0.0	4.5	0.0	0.1	22.6	3.2	45.1	0.0	0.0	10.3	0.0	4.4
150×	4	0.1	0.2	0.0	1.2	0.5	19.2	2.9	0.0	3.1	0.4	0.0	0.6	2.3	69.5
150×	5	0.5	0.1	0.2	0.4	0.0	0.0	47.5	49.1	1.5	0.0	0.1	0.2	0.0	0.4
150×	6	0.0	2.1	0.0	1.6	0.0	0.0	37.9	1.2	12.8	0.0	0.0	42.7	0.0	1.7
500×	1	0.1	2.4	0.1	4.0	0.0	0.0	53.2	11.6	22.2	0.0	0.0	6.4	0.0	–
500×	2	0.0	0.3	0.2	5.7	0.0	0.0	48.9	3.4	25.4	0.0	0.0	16.2	0.0	–
500×	3	0.0	13.5	0.3	3.6	0.0	0.0	53.6	19.5	5.9	0.0	0.0	3.6	0.0	–
500×	4	0.4	0.2	0.0	30.2	4.0	54.0	1.8	0.4	5.9	0.8	0.0	1.1	1.3	–
500×	5	0.5	0.3	0.3	0.3	0.0	0.1	47.3	49.3	1.8	0.0	0.1	0.0	0.0	–
500×	6	0.6	0.4	0.4	0.2	0.0	0.0	47.2	48.8	2.3	0.0	0.1	0.0	0.0	–
500×	1	26.7	0.0	0.0	0.0	0.0	0.0	72.1	0.0	0.7	0.0	0.0	0.2	0.1	–
500×	2	0.8	0.3	0.3	0.2	0.0	0.1	48.1	48.4	1.4	0.0	0.2	0.0	0.1	–
500×	3	0.0	0.4	0.2	21.5	2.2	25.5	24.3	1.0	14.6	0.9	0.0	8.7	0.6	–
500×	4	0.0	1.1	0.0	5.0	0.0	0.0	50.3	0.4	28.3	0.0	0.1	14.8	0.0	–
500×	5	0.1	19.7	0.0	0.9	0.0	0.0	29.9	0.5	46.7	0.0	0.0	2.3	0.0	–
750×	1	33.2	0.0	0.0	1.4	0.0	0.0	59.6	0.2	2.6	0.0	0.0	1.6	0.2	1.2
750×	2	0.0	30.0	0.0	2.2	0.0	0.0	5.7	0.0	44.2	0.0	0.0	15.8	0.0	2.1
750×	3	0.8	0.0	0.0	0.5	0.0	23.0	11.1	3.4	35.2	5.5	0.0	6.1	0.0	14.3
750×	4	0.0	0.2	0.0	0.6	0.6	20.6	1.0	0.0	2.4	0.4	0.0	0.2	1.9	72.2
750×	5	0.1	7.7	0.3	11.7	0.0	0.0	33.4	4.2	29.0	0.0	0.0	5.3	0.0	8.4
750×	6	0.1	0.7	0.2	1.5	0.0	0.0	59.1	0.7	33.8	0.0	0.0	2.5	0.0	1.4

Table C-4e. Spotlight Summary of Postexposure SEM–EDS Results for the Upper Keg River Formation Dolomite Cutting Sample Collected at 2235 m. Cuttings were saturated with synthesized brine and exposed to 100% CO_2 at far-from-wellbore conditions (120°C and 2800 psi).

Resolution	Tag	Na	Mg	Al	Si	P	S	Cl	K	Ca	Ti	Cr	Fe	Ba
100×	1	36.9	0.0	0.0	0.0	0.0	0.0	62.1	0.0	0.5	0.0	0.1	0.0	0.3
100×	2	26.3	0.0	0.0	0.0	0.0	0.1	73.3	0.0	0.1	0.2	0.0	0.0	0.0
100×	3	37.2	0.0	0.0	0.0	0.0	0.0	62.2	0.0	0.3	0.0	0.0	0.0	0.1
100×	4	38.3	0.0	0.0	0.1	0.0	0.0	61.1	0.0	0.5	0.0	0.0	0.0	0.0
100×	5	39.1	0.1	0.0	0.0	0.0	0.0	60.2	0.1	0.5	0.0	0.0	0.0	0.0
250×	1	37.8	0.0	0.0	0.0	0.0	0.0	61.3	0.0	0.5	0.0	0.1	0.0	0.2
250×	2	39.8	0.0	0.1	0.1	0.0	0.0	59.2	0.0	0.5	0.0	0.0	0.0	0.4
250×	3	40.6	0.1	0.0	0.0	0.0	0.0	59.0	0.0	0.3	0.0	0.1	0.0	0.0
250×	4	39.3	0.0	0.0	0.0	0.1	0.0	60.0	0.0	0.4	0.0	0.0	0.0	0.1
250×	5	39.0	0.0	0.0	0.1	0.0	0.0	60.0	0.0	0.5	0.0	0.1	0.0	0.2
500×	1	30.0	0.0	0.0	0.0	0.0	0.1	69.0	0.0	0.3	0.0	0.2	0.0	0.3
500×	2	39.3	0.0	0.0	0.0	0.0	0.0	60.3	0.0	0.4	0.0	0.0	0.0	0.0
500×	3	22.3	0.0	0.0	0.0	0.0	0.0	76.7	0.0	0.1	0.0	0.0	0.2	0.7
500×	4	40.2	0.0	0.0	0.0	0.0	0.0	58.8	0.0	0.6	0.0	0.0	0.0	0.4
500×	5	34.8	0.0	0.0	0.1	0.0	0.0	64.5	0.1	0.5	0.0	0.0	0.0	0.0
500×	6	36.6	0.0	0.0	0.0	0.0	0.0	62.8	0.0	0.5	0.0	0.0	0.0	0.1
500×	1	38.8	0.0	0.0	0.0	0.0	0.0	60.8	0.0	0.4	0.0	0.0	0.0	0.0
500×	2	36.4	0.0	0.0	0.0	0.0	0.0	63.3	0.0	0.3	0.0	0.0	0.1	0.0
500×	3	37.4	0.0	0.1	0.1	0.0	0.0	61.4	0.2	0.6	0.0	0.0	0.0	0.2
500×	4	38.3	0.0	0.0	0.0	0.0	0.0	61.3	0.0	0.3	0.0	0.0	0.0	0.0
500×	5	39.2	0.0	0.0	0.0	0.1	0.0	60.2	0.0	0.5	0.0	0.0	0.0	0.0

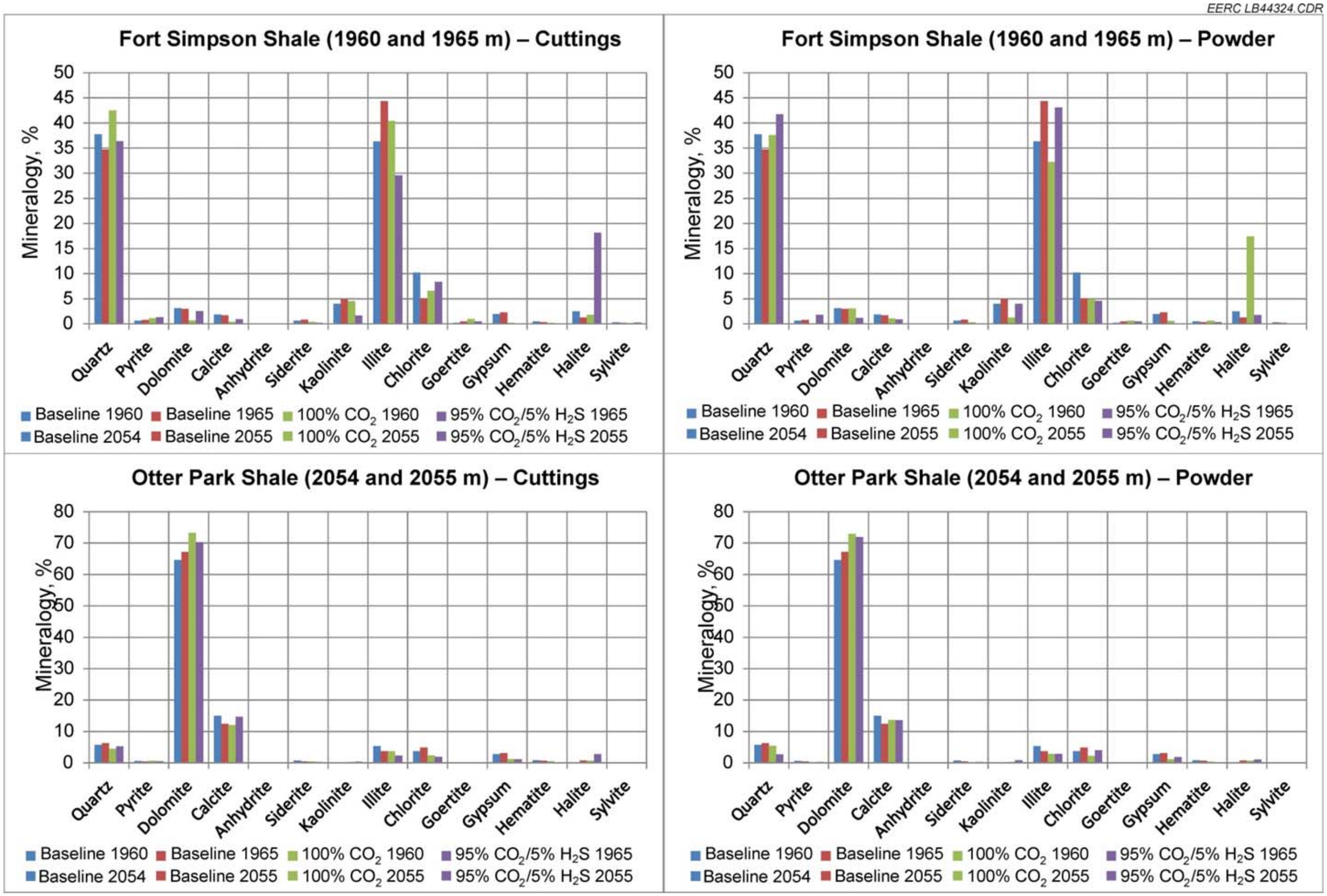


Figure C-1a. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 1 experiments (postexposure). Samples exposed as cuttings are in the left column, and samples exposed as powders (~200 µm) are in the right column. All cuttings or powder were saturated with synthetic brine (NaCl solution). CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 95 mol% CO_2 and 5 mol% H_2S.

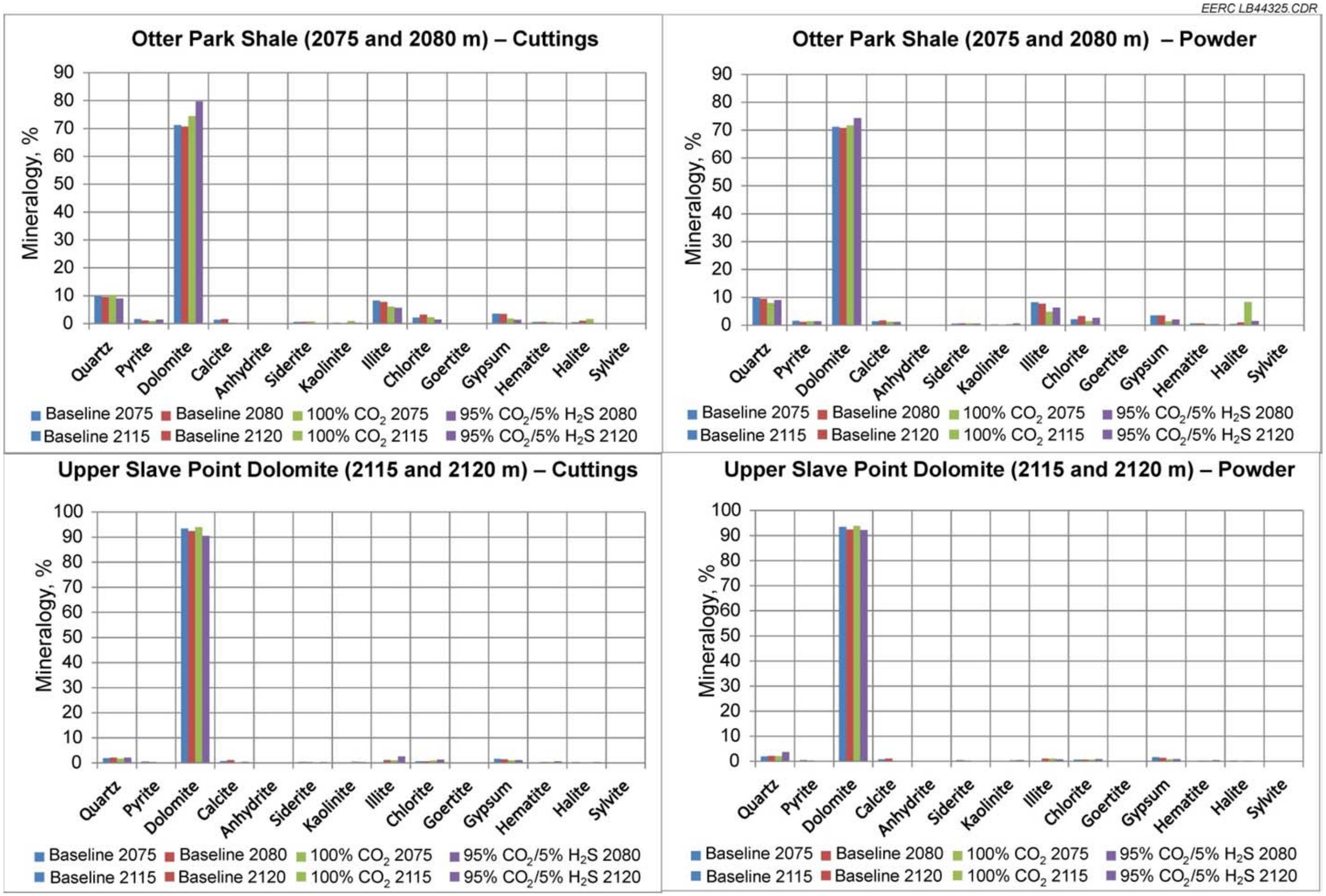


Figure C-1b. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 1 experiments (postexposure). Samples exposed as cuttings are in the left column, and samples exposed as powders (~200 µm) are in the right column. All cuttings or powder were saturated with synthetic brine (NaCl solution). CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 95 mol% CO_2 and 5 mol% H_2S.

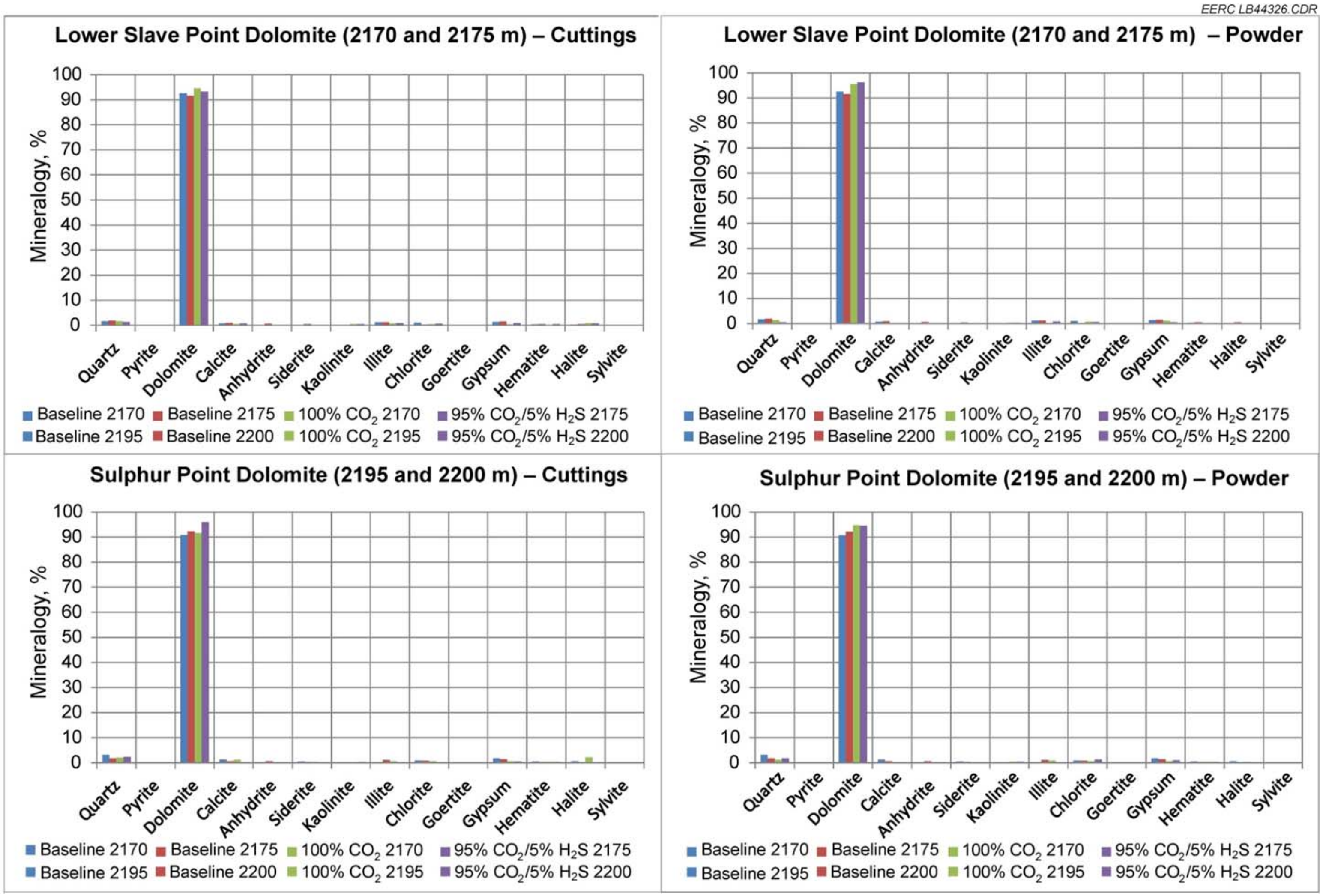


Figure C-1c. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 1 experiments (postexposure). Samples exposed as cuttings are in the left column, and samples exposed as powders (~200 µm) are in the right column. All cuttings or powder were saturated with synthetic brine (NaCl solution). CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 95 mol% CO_2 and 5 mol% H_2S.

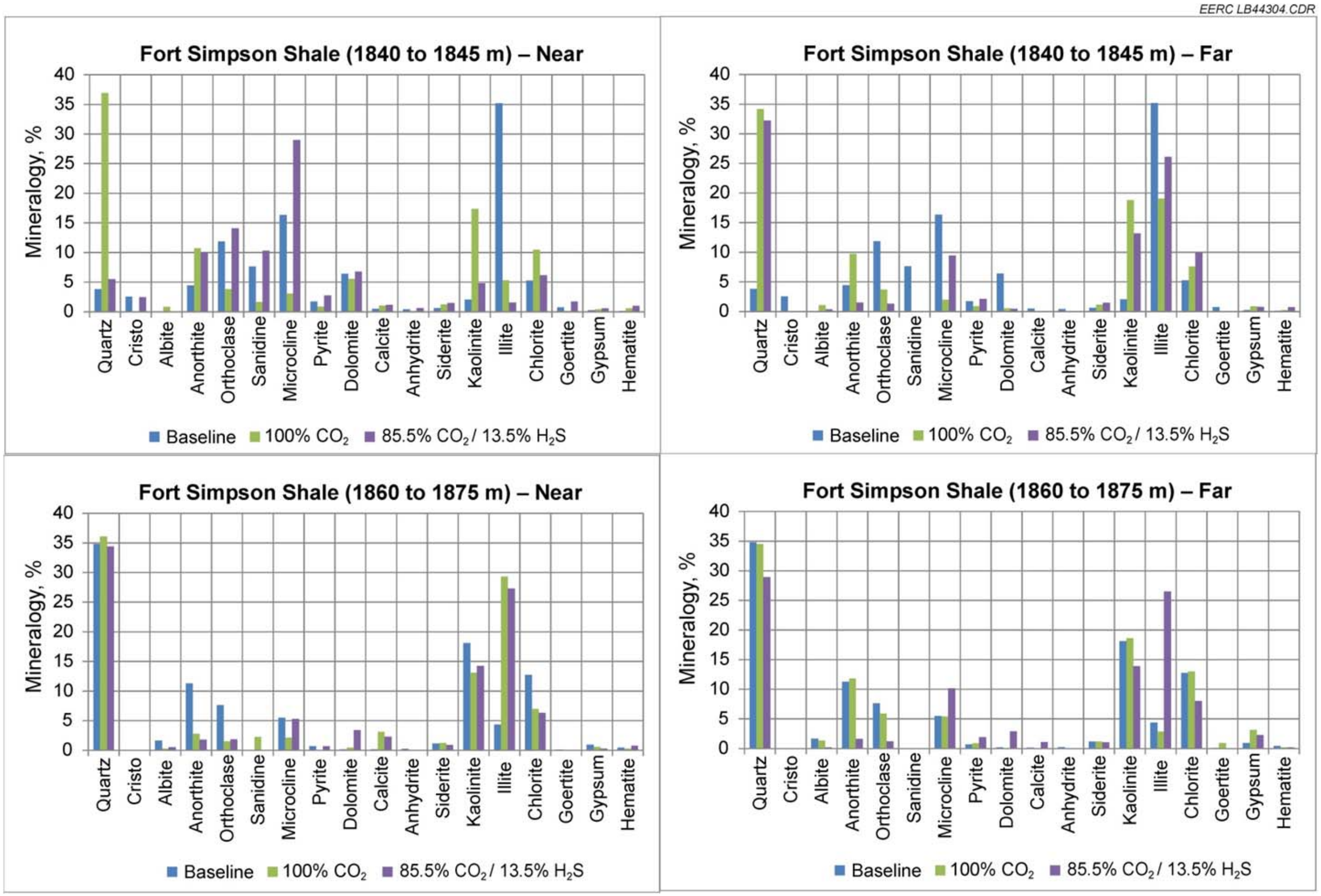


Figure C-2a. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

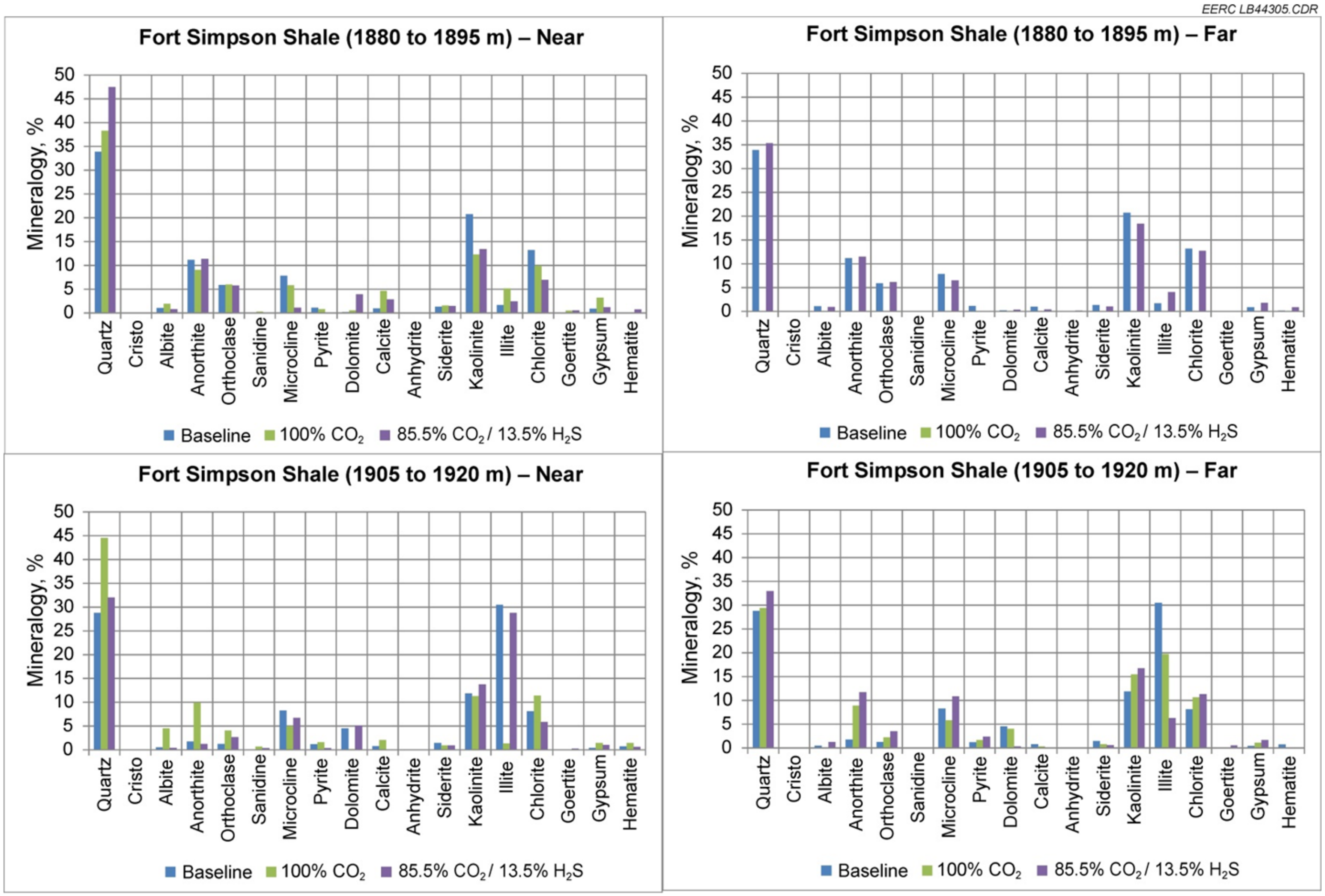


Figure C-2b. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

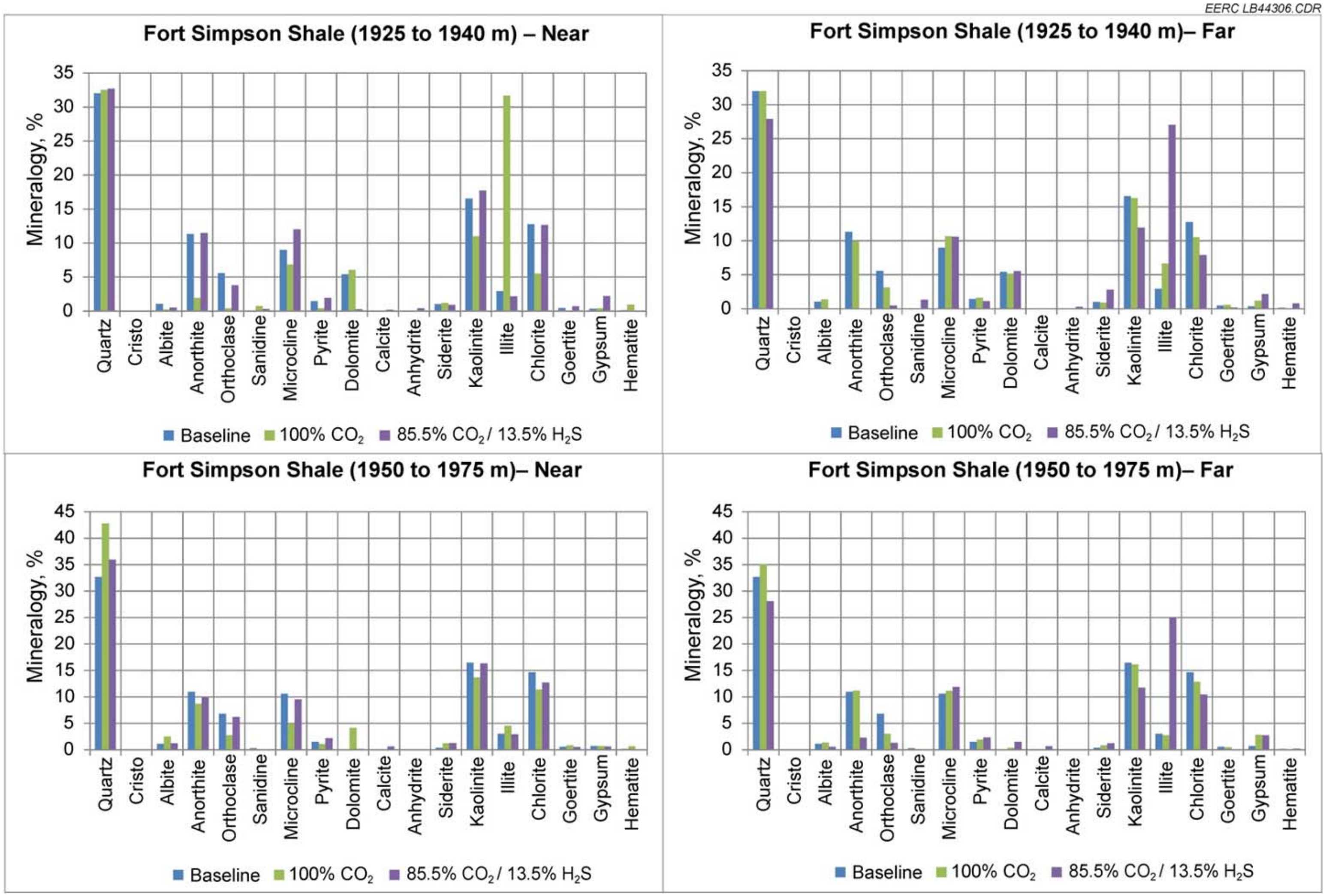


Figure C-2c. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

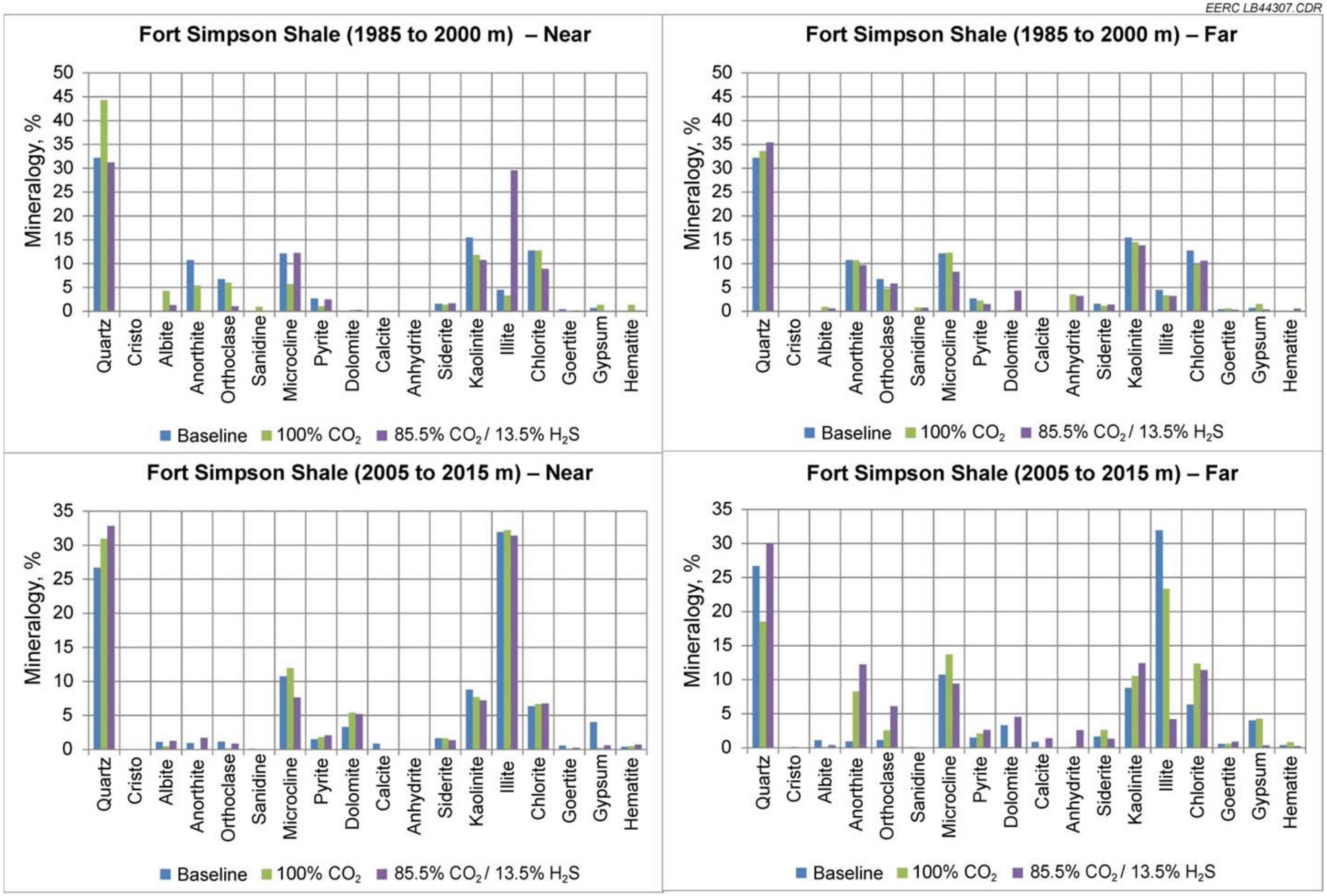


Figure C-2d. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

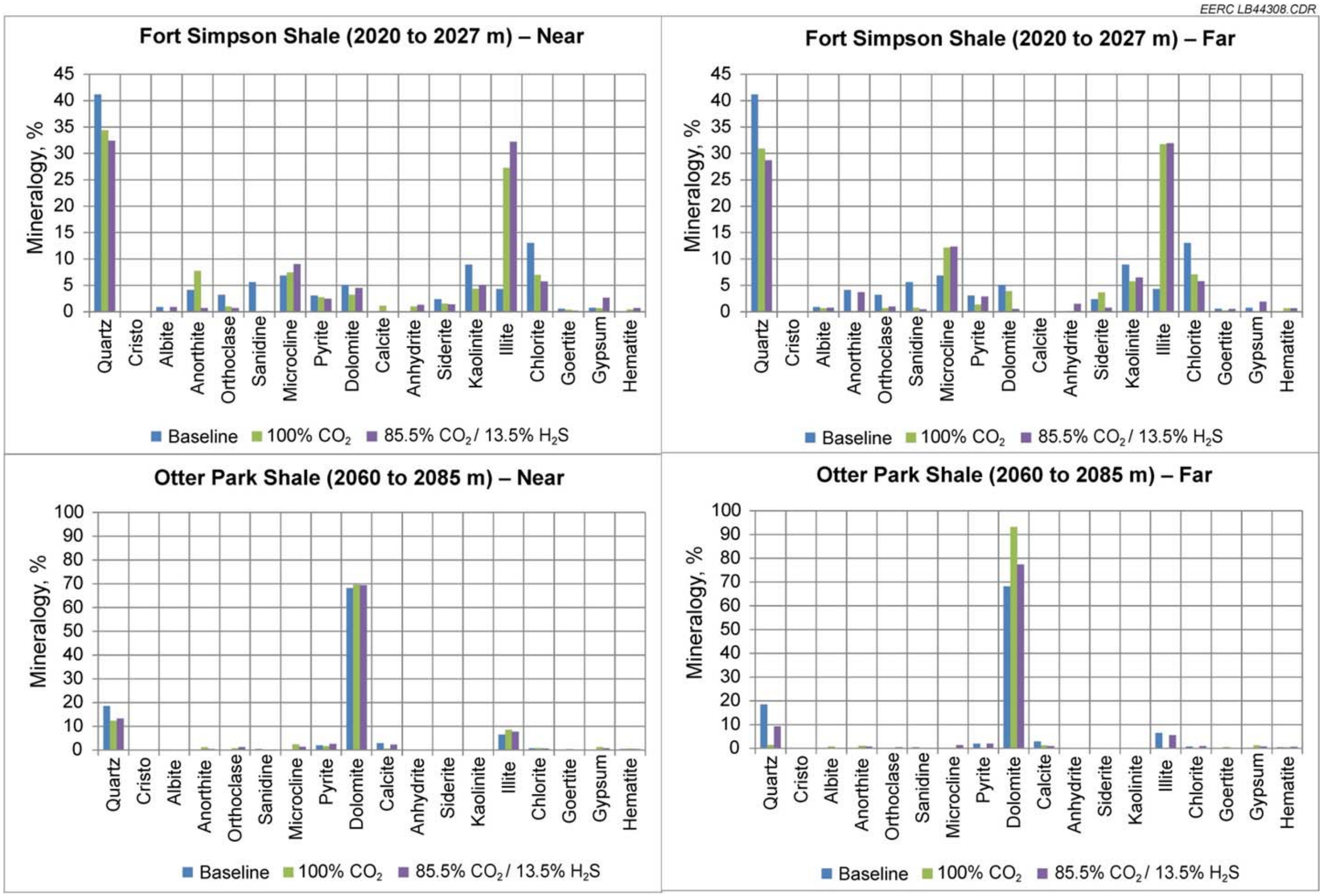


Figure C-2e. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

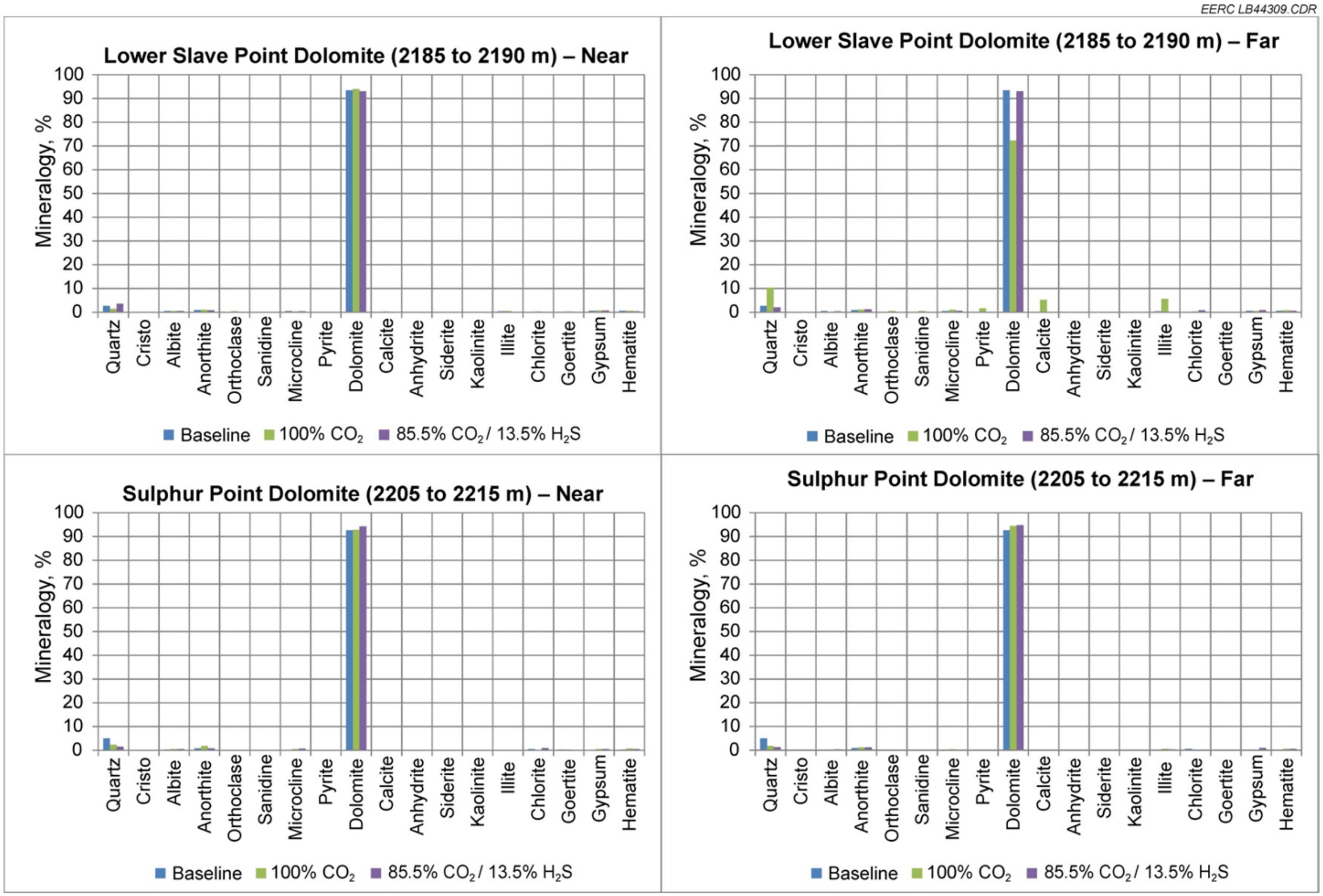


Figure C-2f. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

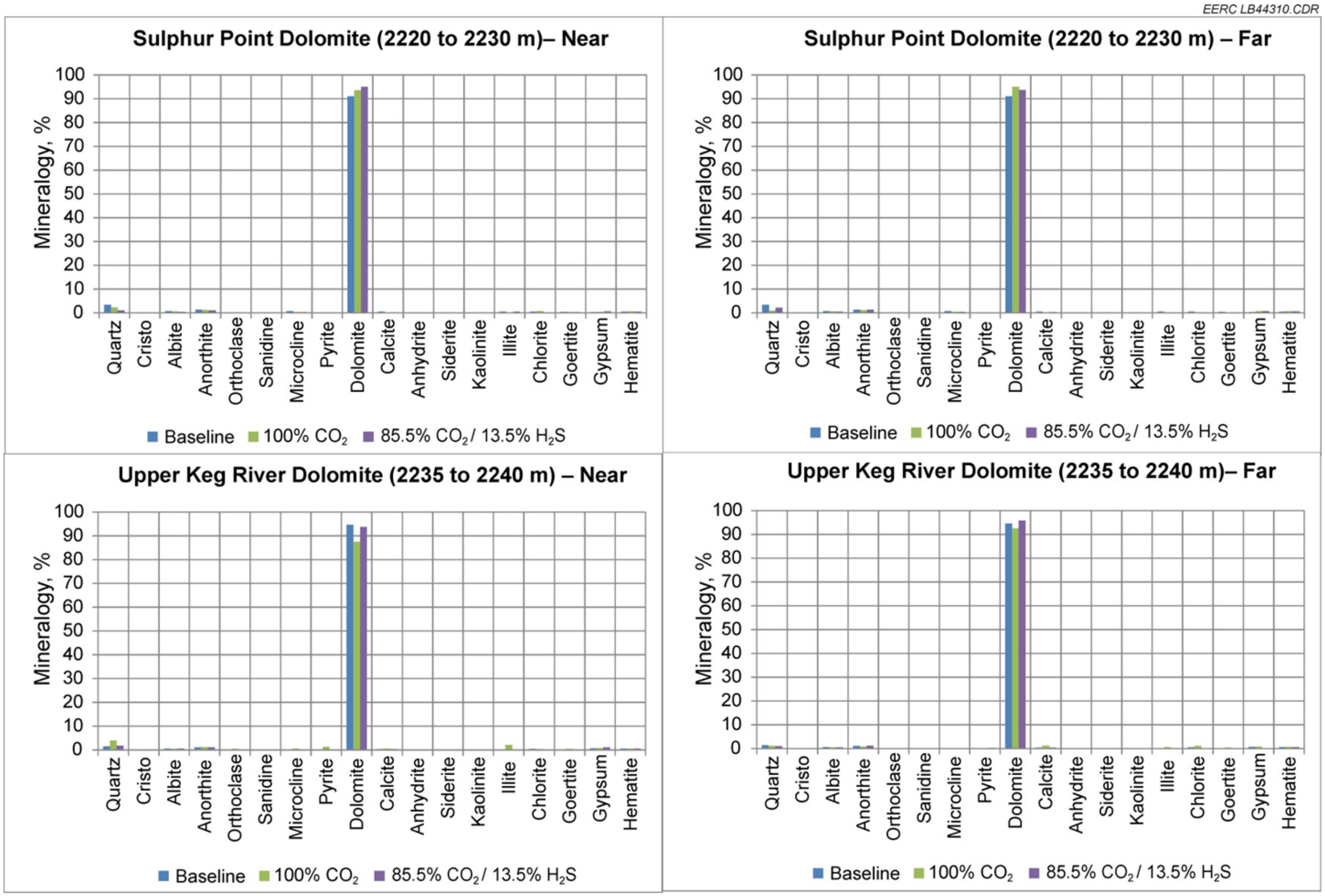


Figure C-2g. Predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

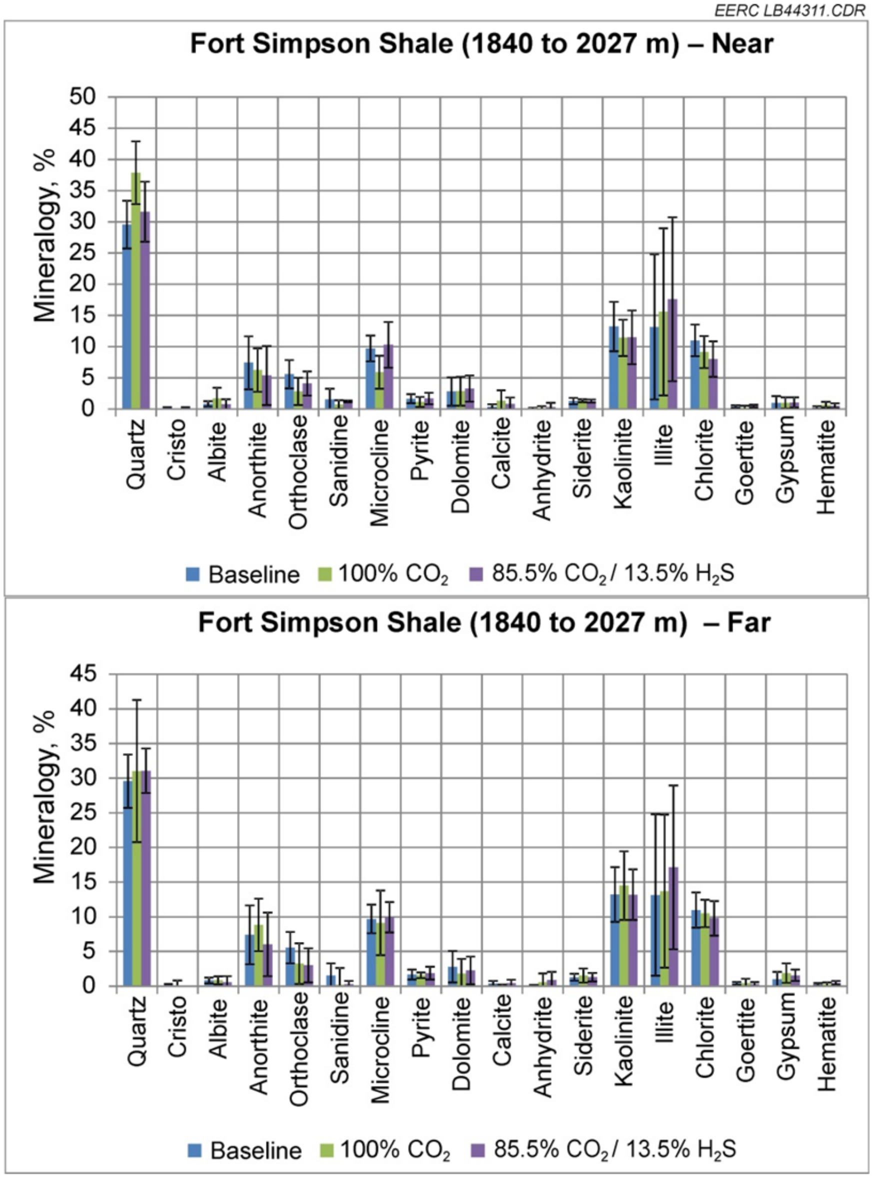
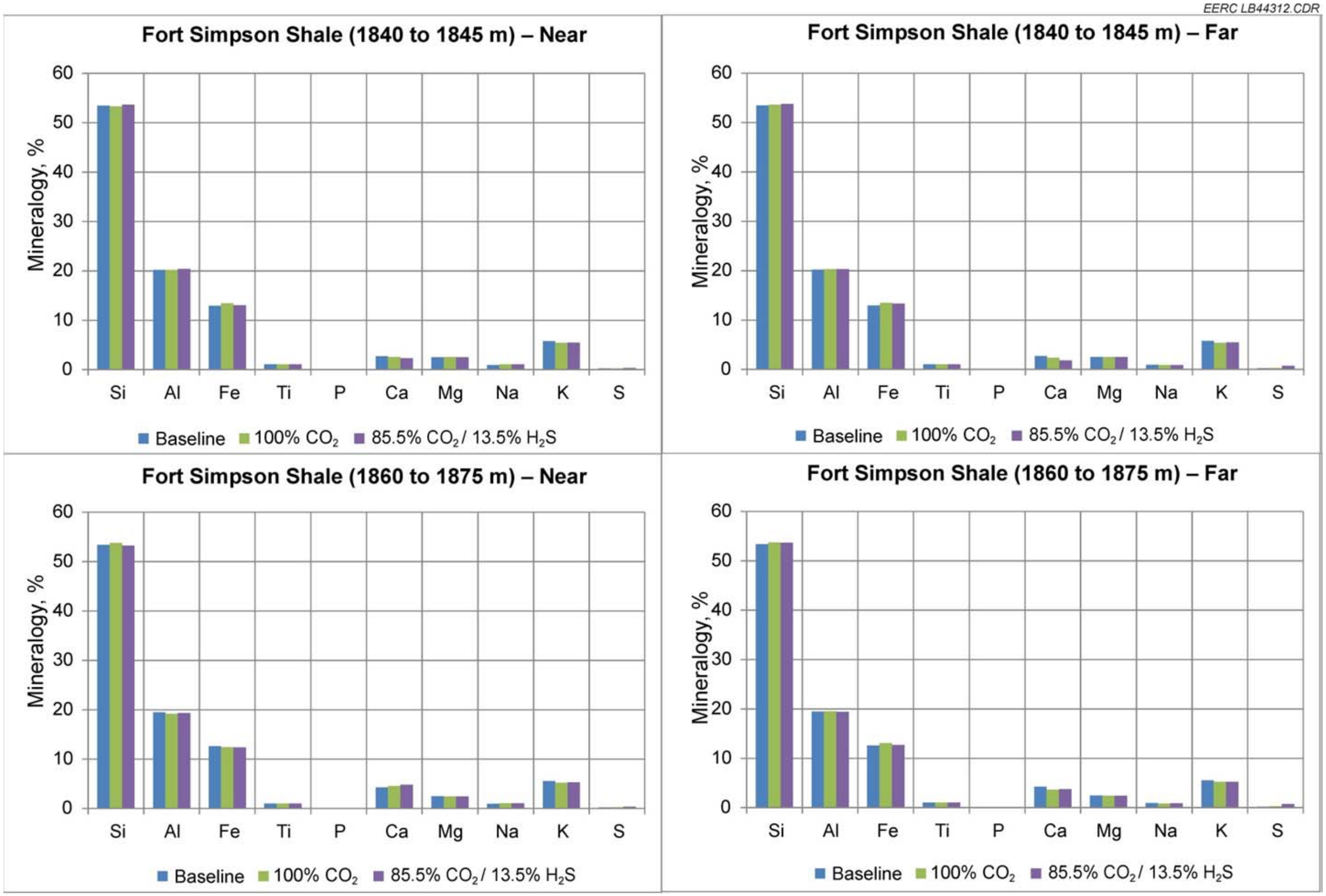


Figure C-2h. Fort Simpson Formation shale (1840 m to 2027 m) mean and standard deviation predominant mineral phases in c-61-E drill cuttings as determined by XRD on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are on top, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are on bottom. Only cuttings saturated with synthesized brine are shown.



Fort Simpson Shale (1840 to 1845 m) – Near

Fort Simpson Shale (1840 to 1845 m) – Far

Fort Simpson Shale (1860 to 1875 m) – Near

Fort Simpson Shale (1860 to 1875 m) – Far

Figure C-3a. Predominant mineral phases in c-61-E drill cuttings as determined by XRF on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

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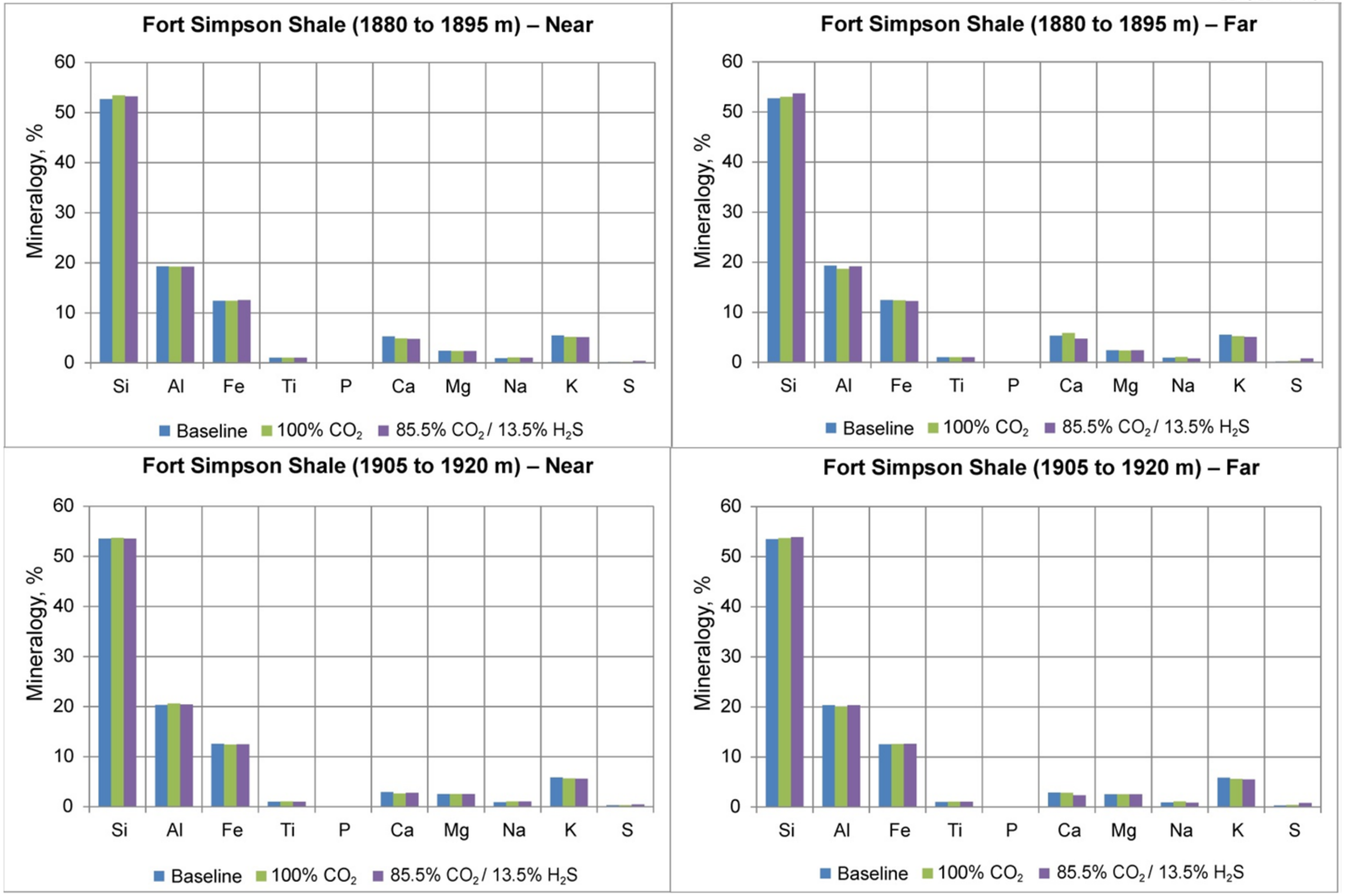

Figure C-3b. Predominant mineral phases in c-61-E drill cuttings as determined by XRF on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

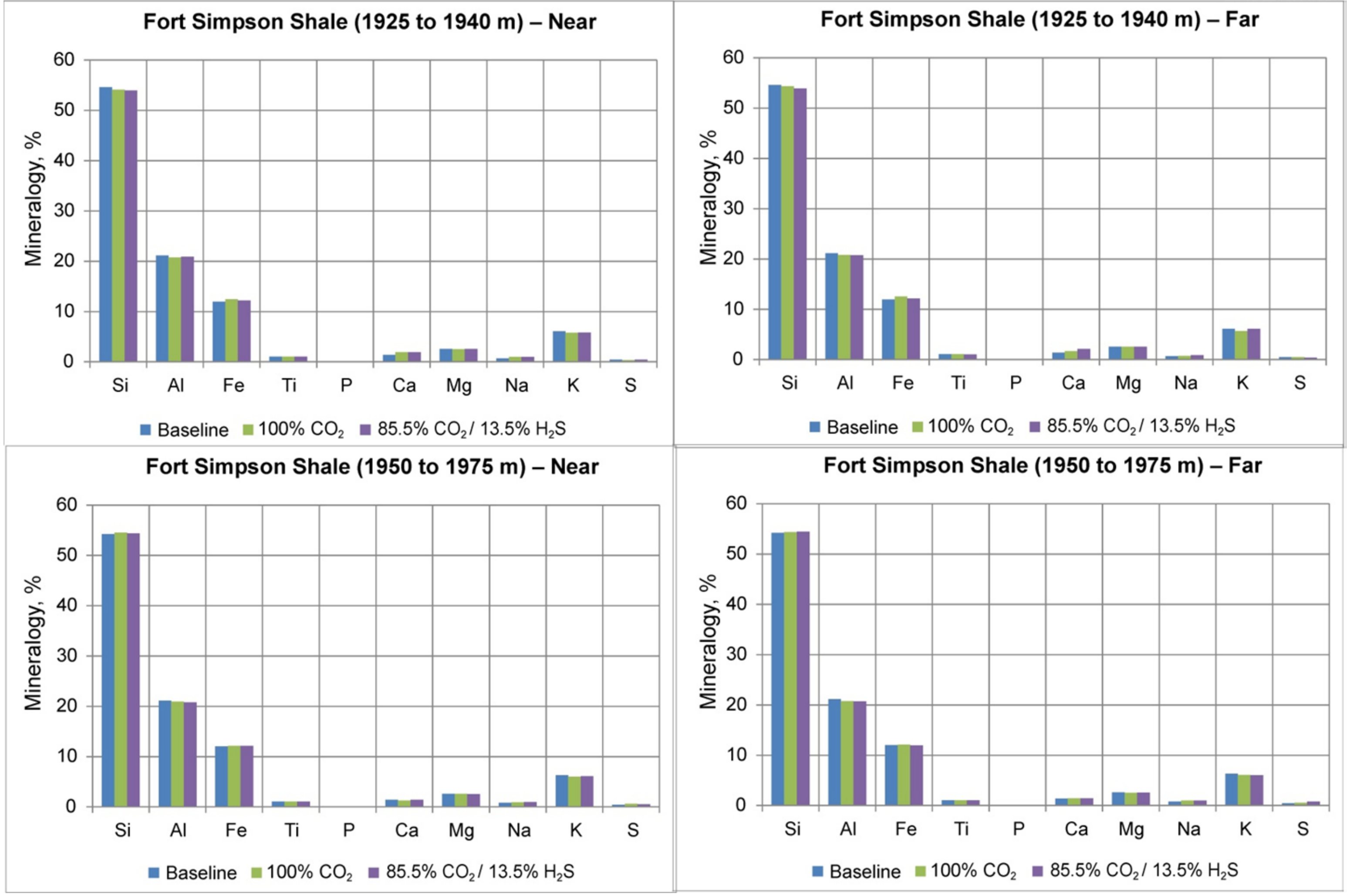

Figure C-3c. Predominant mineral phases in c-61-E drill cuttings as determined by XRF on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

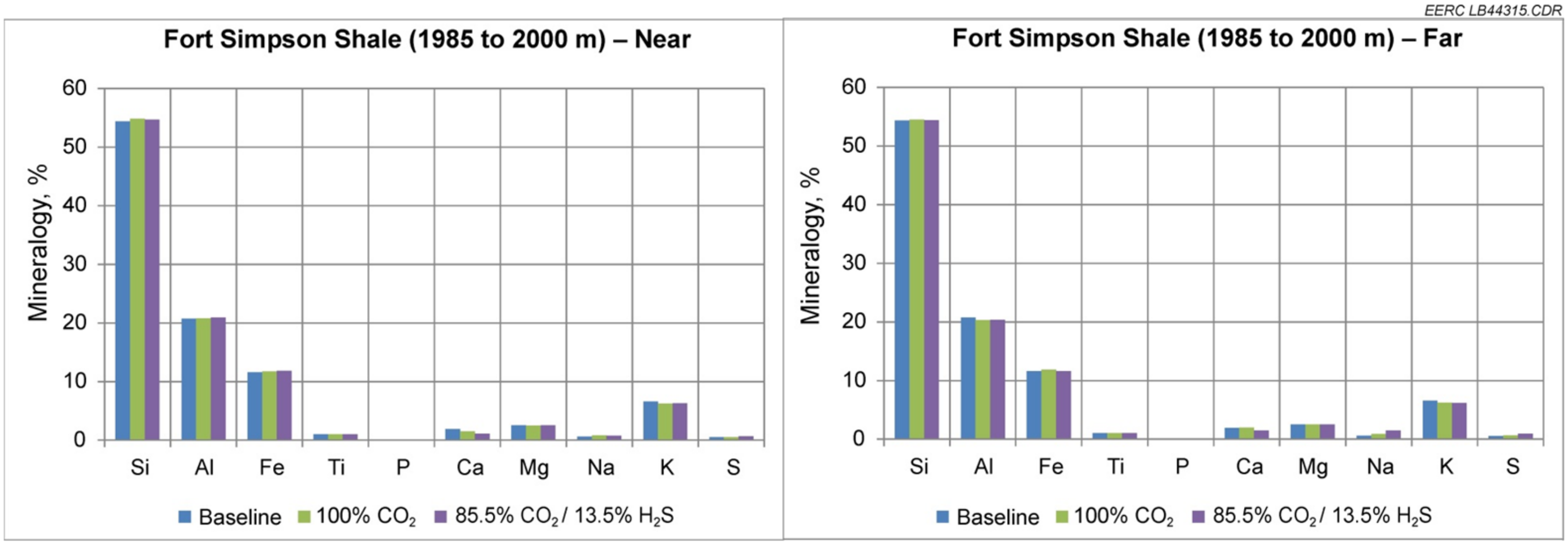

Figure C-3d. Predominant mineral phases in c-61-E drill cuttings as determined by XRF on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are in the left column, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are in the right column. Only cuttings saturated with synthesized brine are shown.

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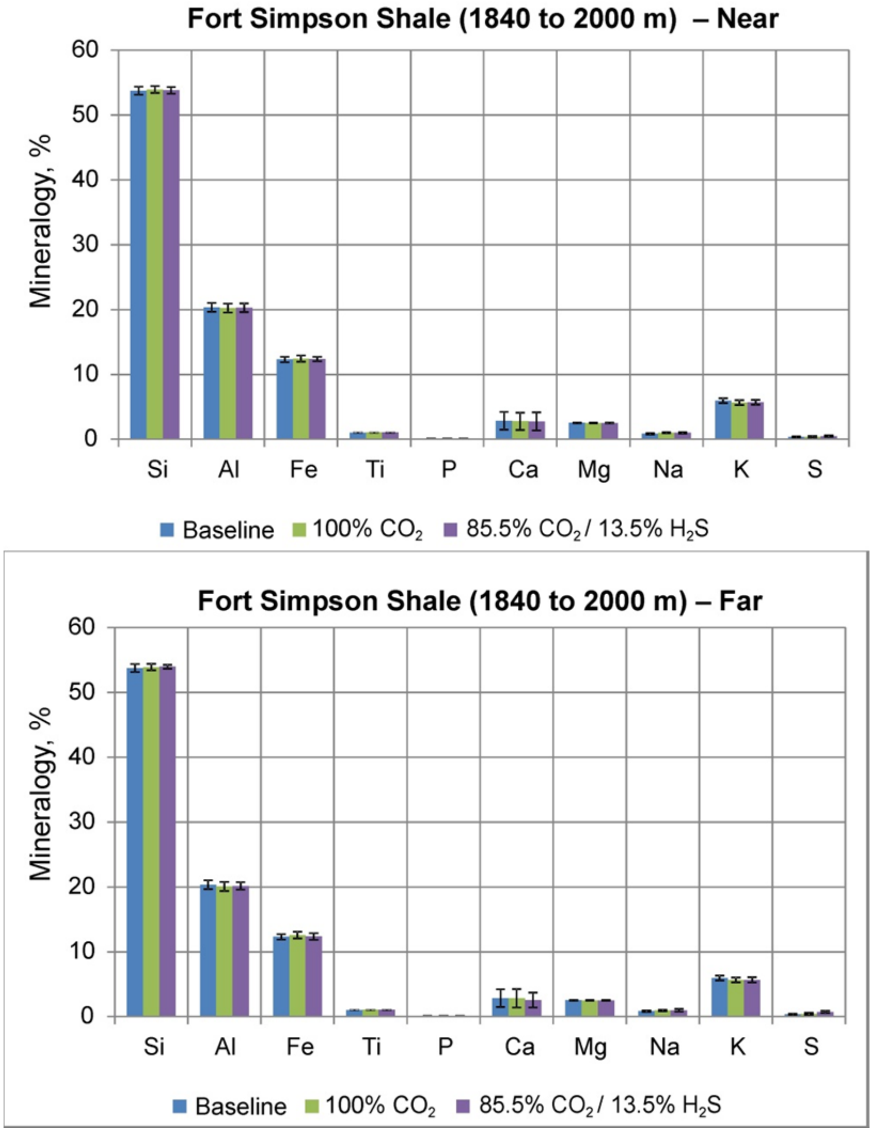

Figure C-3e. Fort Simpson Formation shale (1840 to 2000 m) mean and standard deviation predominant mineral phases in c-61-E drill cuttings as determined by XRF on as-received cuttings (baseline) and following exposure to CO_2 or sour CO_2 in Batch Reactor Test 2–5 experiments (postexposure). Samples exposed to near-wellbore conditions (65°C and 3500 psi) are on top, and samples exposed to far-from-wellbore conditions (120°C and 2800 psi) are on bottom. Only cuttings saturated with synthesized brine are shown.

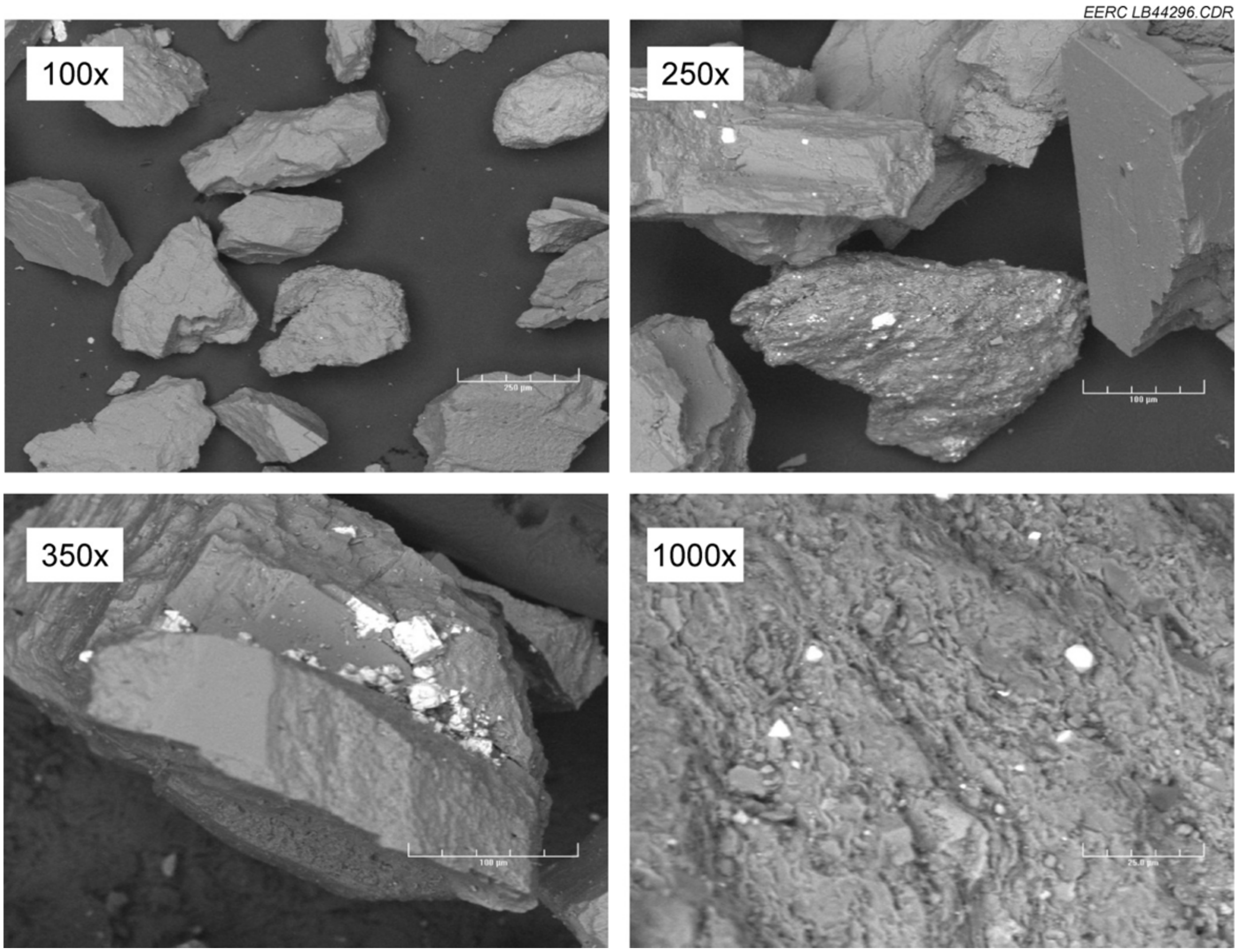

Figure C-4a. SEM–EDS images of the Sulphur Point Formation dolomite cutting sample collected at 2220 m. The images represent preexposure baseline at 100× resolution (upper left-hand corner), 250× resolution (upper right-hand corner), 350× resolution (lower left-hand corner), and 1000× resolution (lower right-hand corner).

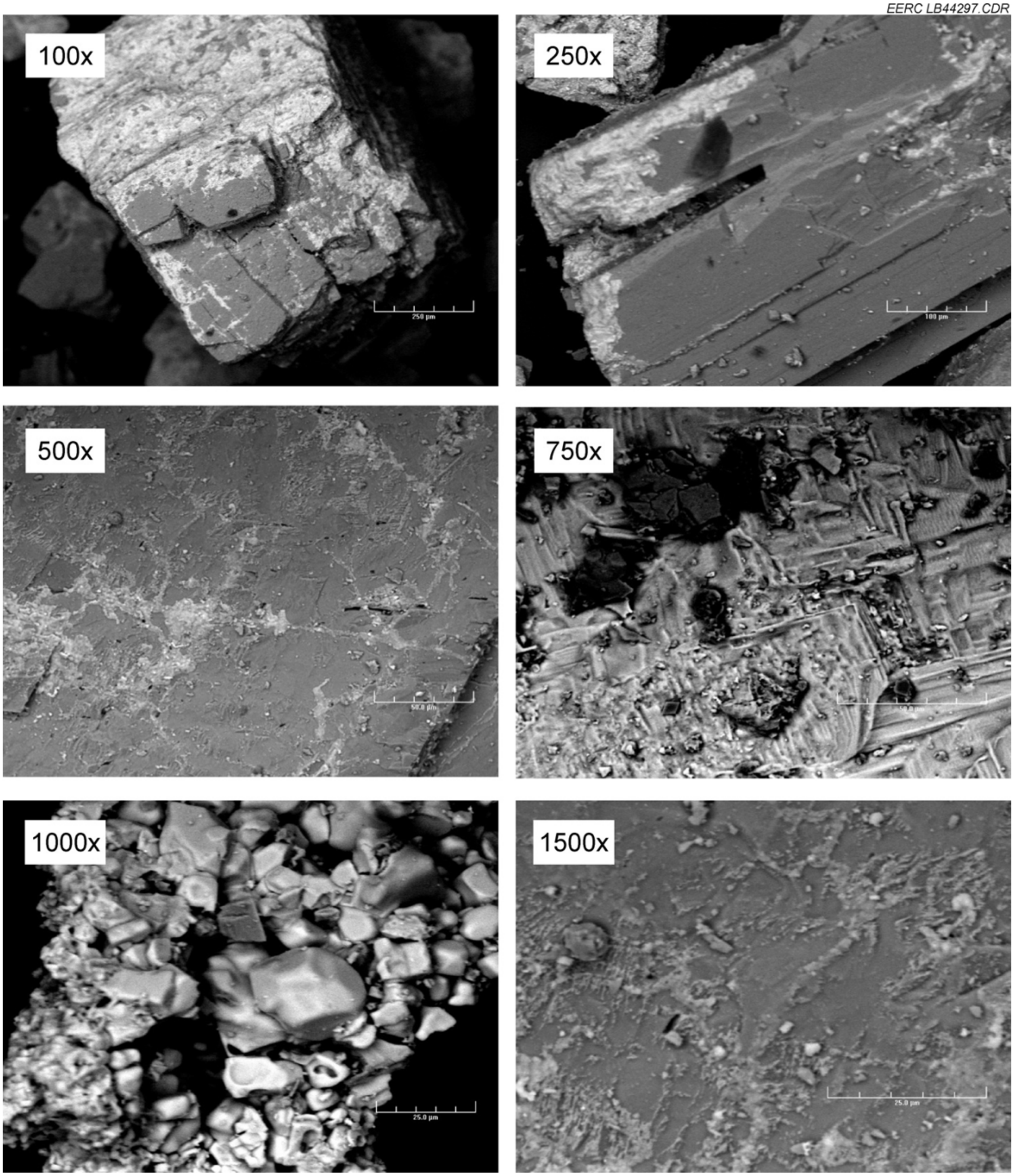

Figure C-4b. SEM–EDS images of the Sulphur Point Formation dolomite cutting sample collected at 2220 m. The images were collected following 100% CO_2 exposure under near-wellbore conditions (65°C and 3500 psi) with synthetic brine (NaCl solution) at 100× resolution (upper left-hand corner), 250× resolution (upper right-hand corner), 500× resolution (middle left), 750× resolution (middle right), 1000× resolution (lower left-hand corner), and 1500× resolution (lower right-hand corner).

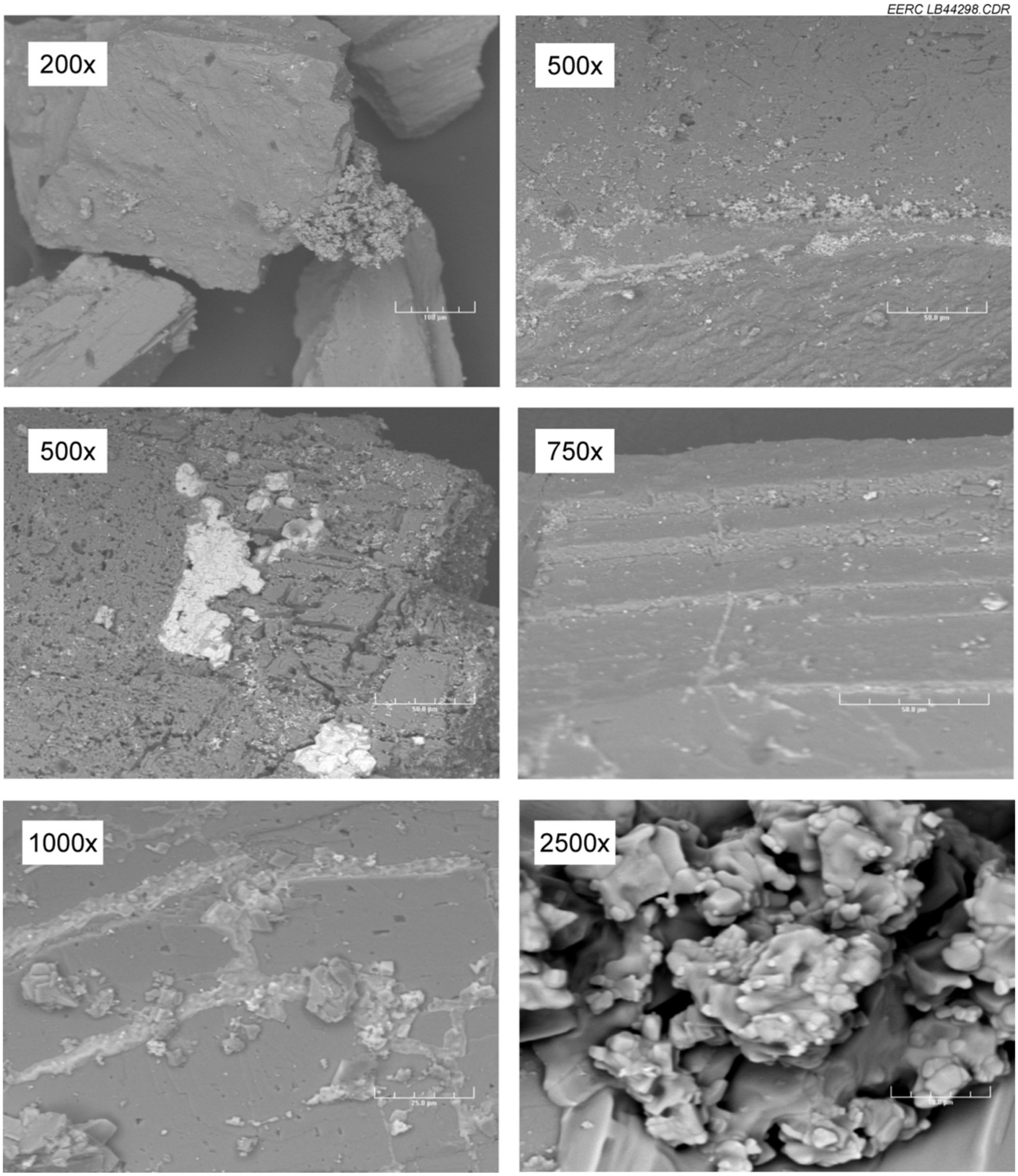

Figure C-4c. SEM–EDS images of the Sulphur Point Formation dolomite cutting sample collected at 2220 m. The images were collected following 86.5 mol% CO_2/13.5 mol% H_2S exposure under near-wellbore conditions (65°C and 3500 psi) with synthetic brine (NaCl solution) at 200× resolution (upper left-hand corner), 500× resolution (upper right-hand corner), 500× resolution (middle left), 750× resolution (middle right), 1000× resolution (lower left-hand corner), and 2500× resolution (lower right-hand corner).

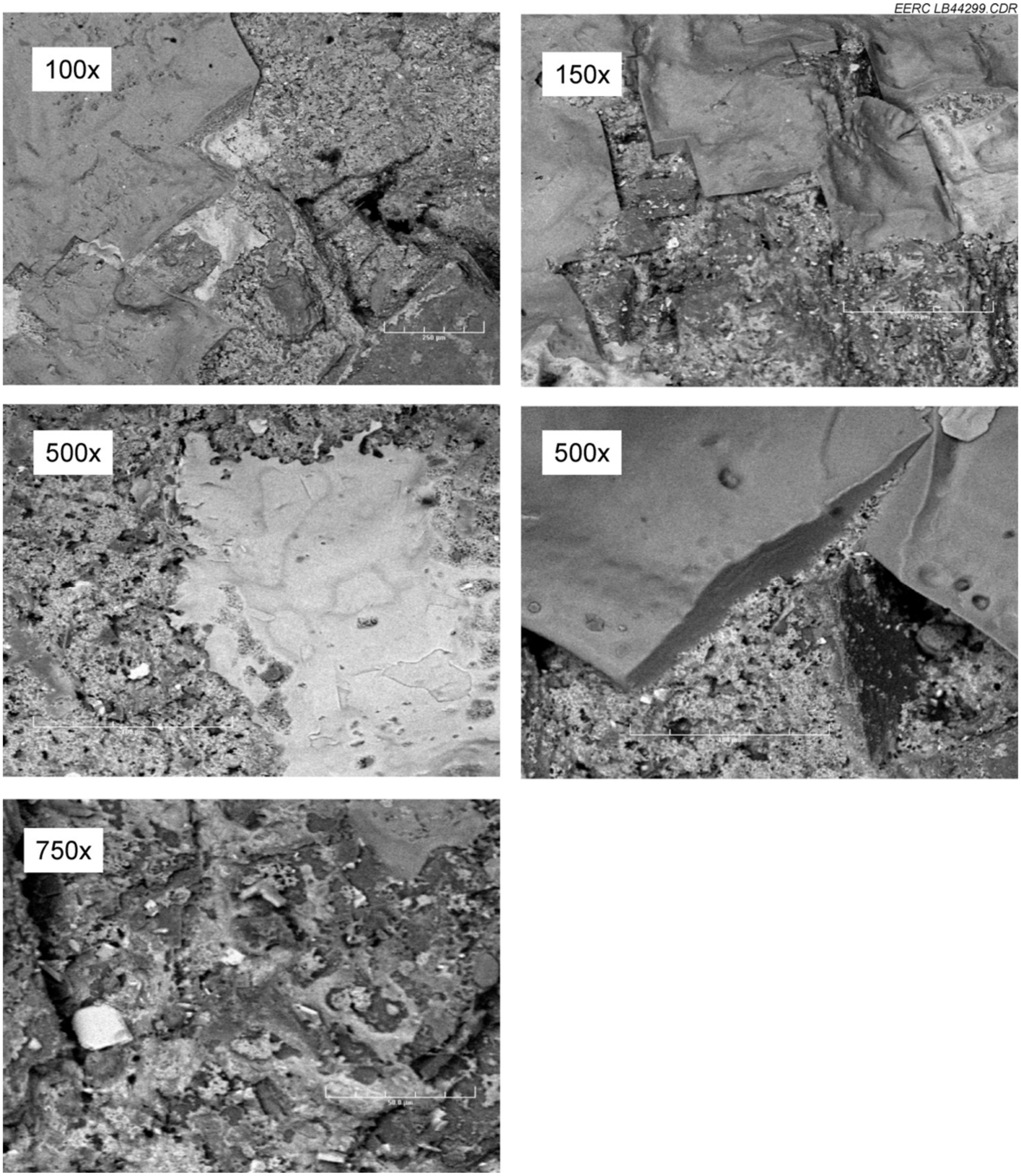

Figure C-4d. SEM–EDS images of the Upper Keg River Formation dolomite cutting sample collected at 2235 m. The images were collected following 100% CO_2 exposure under far-from-wellbore conditions (120°C and 2800 psi) with synthetic brine (NaCl solution) at 100× resolution (upper left-hand corner), 150× resolution (upper right-hand corner), 500× resolution (middle left), 500× resolution (middle right), and 750× resolution (lower left-hand corner).

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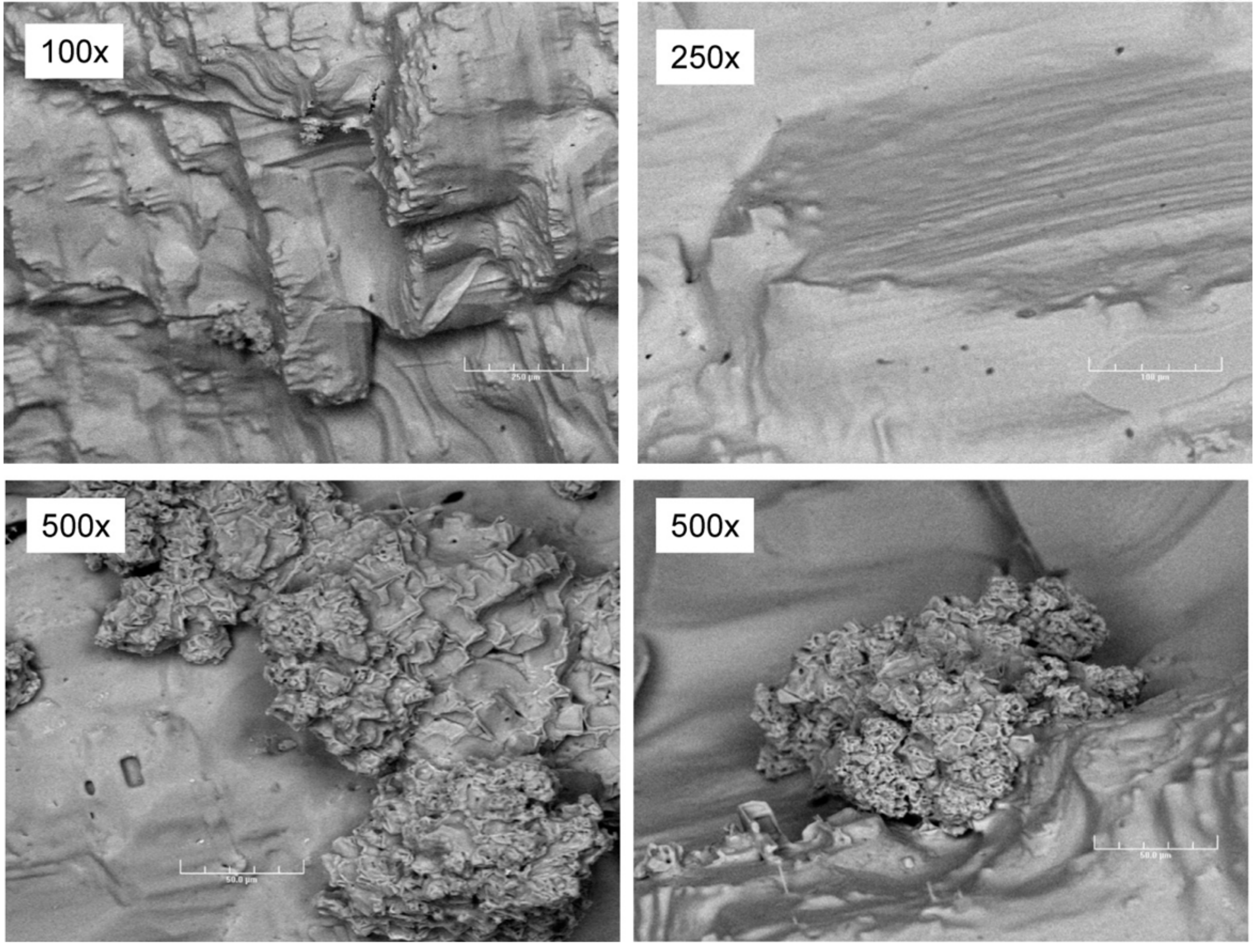


Figure C-4e. SEM–EDS images of the Upper Keg River Formation dolomite cutting sample collected at 2235 m. The images were collected following 100% CO_2 exposure under far-from-wellbore conditions (120°C and 2800 psi) with synthesized brine at 100× resolution (upper left-hand corner), 250× resolution (upper right-hand corner), 500× resolution (middle left), and 500× resolution (middle right).

APPENDIX D

FORMATION FLUID (BRINE) BASELINE AND POST-CO_2 AND SOUR CO_2 EXPOSURE RESULTS

FORMATION FLUID (BRINE) BASELINE AND POST-CO_2 AND SOUR CO_2 EXPOSURE RESULTS

INTRODUCTION

Appendix D summarizes the analytical results for brines that were exposed to CO_2 or sour CO_2 in batch reactor experiments. Laboratory batch reactor experiments were used to investigate the effects of changes in the reservoir conditions caused by the injection of CO_2 or sour CO_2 on the nature and extent of the mineralogical reactions of the drill cutting samples. A preliminary screening analysis was conducted in Batch Reactor Test 1 (100°C and 3000 psi) on cuttings and powder that were saturated with synthetic brine (i.e., solutions of 1% to 3% NaCl). Subsequent batch reactor experiments (Batch Reactor Tests 2–5) were conducted to evaluate potential geochemical interactions of CO_2 or sour CO_2 with these cutting samples at both "near-wellbore" (65°C and 3500 psi) and "far-from-wellbore" (120°C and 2800 psi) pressure and temperature conditions. The Batch Reactor Tests 2–5 experiments were conducted on cuttings that were saturated with either synthetic brine (NaCl solution) or synthesized brine, which was formulated to emulate the chemical characteristics of the natural reservoir fluids.

The synthetic brine (NaCl solution) and the synthesized brine were analyzed for major ions by inductively coupled plasma–mass spectrometry (ICP–MS) following exposure to CO_2 or sour CO_2 with and without cuttings. The exposures without cuttings provide a baseline control and the exposures with cuttings provide data to evaluate the effects of mineral dissolution under different reservoir conditions on brine major ion chemistry. Appendix D is organized into two sections:

- Batch Reactor Test 1 program
  - ICP–MS results

- Batch Reactor Tests 2–5 program
  - ICP–MS results

BATCH REACTOR TEST 1 PROGRAM

ICP–MS analysis of the synthetic brine (NaCl solution) for Batch Reactor Test 1 was conducted for exposures to Samples 2054 m (Otter Park Formation shale) and 2170 m (Lower Slave Point Formation dolomite). The tabulated postexposure (CO_2 or sour CO_2 with cuttings) results for ICP–MS analyses of the synthetic brine (NaCl solution) are summarized in Table D-1, and a graphical summary is presented in Figure D-1.

BATCH REACTOR TEST 2–5 PROGRAM

ICP–MS analyses of the synthetic brine (NaCl solution) and synthesized brine for Batch Reactor Tests 2–5 were conducted for exposures to samples collected from the Fort Simpson

Table D-1. Postexposure ICP–MS Analyses of Synthetic Brine (NaCl solution) for Batch Reactor Test 1 Experiments. All experiments were conducted at 100°C and 3000 psi. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 95 mol% CO_2 and 5 mol% H_2S. “Powder” were powdered cuttings of approximately 200 µm. Results are reported in mg/L.

Formation (Depth [m])	Type	Brine	Conditions	Temperature	Pressure	Al	Ca	Mg	K	Si
Otter Park Shale (2054)	Baseline	NA	NA	NA	NA	–	−	−	−	−
Otter Park Shale (2054)	Cuttings	NaCl	CO_2	100°C	3000 psi	10	347	45	12	90
Otter Park Shale (2054)	Powder	NaCl	CO_2	100°C	3000 psi	9	355	95	11	56
Otter Park Shale (2054)	Cuttings	NaCl	CO_2/H_2S	100°C	3000 psi	11	327	120	17	58
Otter Park Shale (2054)	Powder	NaCl	CO_2/H_2S	100°C	3000 psi	11	345	113	17	61
Lower Slave Point Dolomite (2170)	Baseline	NA	NA	NA	NA	–	−	−	−	−
Lower Slave Point Dolomite (2170)	Cuttings	NaCl	CO_2	100°C	3000 psi	10	97	76	5	54
Lower Slave Point Dolomite (2170)	Powder	NaCl	CO_2	100°C	3000 psi	10	103	81	5	58
Lower Slave Point Dolomite (2170)	Cuttings	NaCl	CO_2/H_2S	100°C	3000 psi	11	143	127	7	58
Lower Slave Point Dolomite (2170)	Powder	NaCl	CO_2/H_2S	100°C	3000 psi	11	129	132	4	57

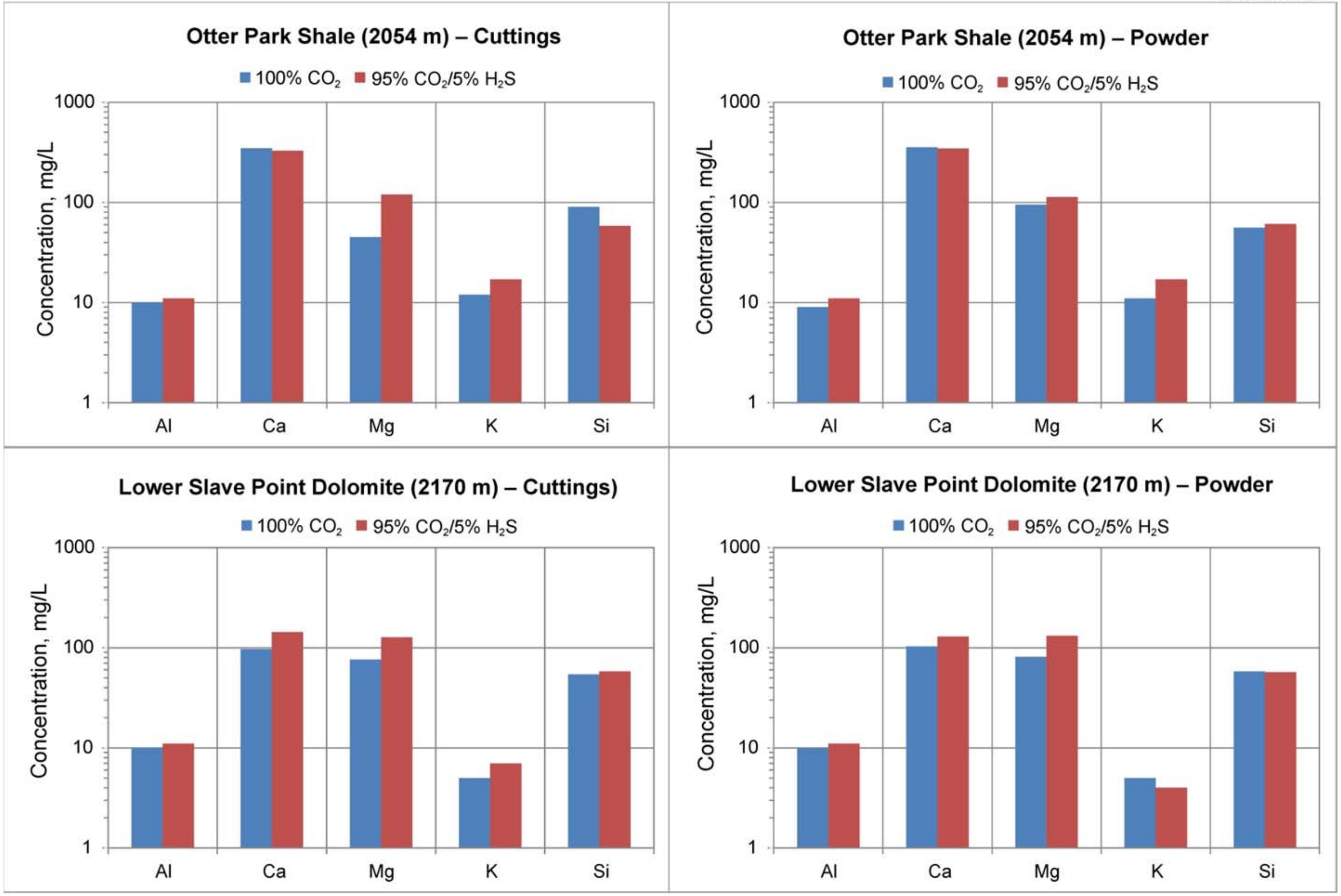


Figure D-1. Postexposure ICP–MS analyses of synthetic brine (NaCl solution) for Batch Reactor Test 1 experiments (100°C and 3000 psi). CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 95 mol% CO_2 and 5 mol% H_2S. Samples exposed as cuttings are presented in the left-hand column, and samples exposed as powder (powdered cuttings of approximately 200 µm) are presented in the right-hand column. Results are reported in mg/L.

shale, Otter Park shale, Lower Slave Point dolomite, Sulphur Point dolomite, and Upper Keg River Formation dolomite. The samples were organized into two groups of seven samples, as summarized below.

- Group 1 depth intervals:
    - 1840 to 1845 m (Fort Simpson shale)
    - 1860 to 1875 m (Fort Simpson shale)
    - 1880 to 1895 m (Fort Simpson shale)
    - 1905 to 1920 m (Fort Simpson shale)
    - 1925 to 1940 m (Fort Simpson shale)
    - 1950 to 1975 m (Fort Simpson shale)
    - 1985 to 2000 m (Fort Simpson shale)

- Group 2 depth intervals:
    - 2005 to 2015 m (Fort Simpson shale)
    - 2020 to 2027 m (Fort Simpson shale)
    - 2060 to 2085 m (Otter Park shale)
    - 2185 to 2190 m (Lower Slave Point dolomite)
    - 2205 to 2215 m (Sulphur Point dolomite)
    - 2220 to 2230 m (Sulphur Point dolomite)
    - 2235 to 2240 m (Upper Keg River dolomite)

The tabulated baseline (CO_2 or sour CO2 without cuttings) and postexposure (CO_2 or sour CO_2 with cuttings) results for ICP–MS analyses of the synthetic brine (NaCl solution) and synthesized brine are summarized in Tables D-2a and D-2b.

Graphical summaries for ICP–MS results associated with baseline and postexposure synthetic brine (NaCl solution) conducted at near-wellbore conditions are presented in Figures D-2a and D-3b.

Graphical summaries for ICP–MS results associated with baseline and postexposure synthetic brine (NaCl solution) conducted at far-from-wellbore conditions are presented in Figures D-3a and D-3b.

Lastly, graphical summaries for ICP–MS results associated with baseline and postexposure synthesized brine conducted at near-wellbore conditions are presented in Figure D-4a to D-4d. Far-from-wellbore synthesized brine ICP–MS results were not available, as described below.

Because of rapid pressure release when the batch reactor scintillation vials were opened, the majority of the fluid in the vials associated with two of the batch reactor experiments was lost, and the analyses of these brines cannot be considered valid. These fields are denoted as with an asterisk (*) in Tables D-2a and D-2b. Therefore, no data are reported for:

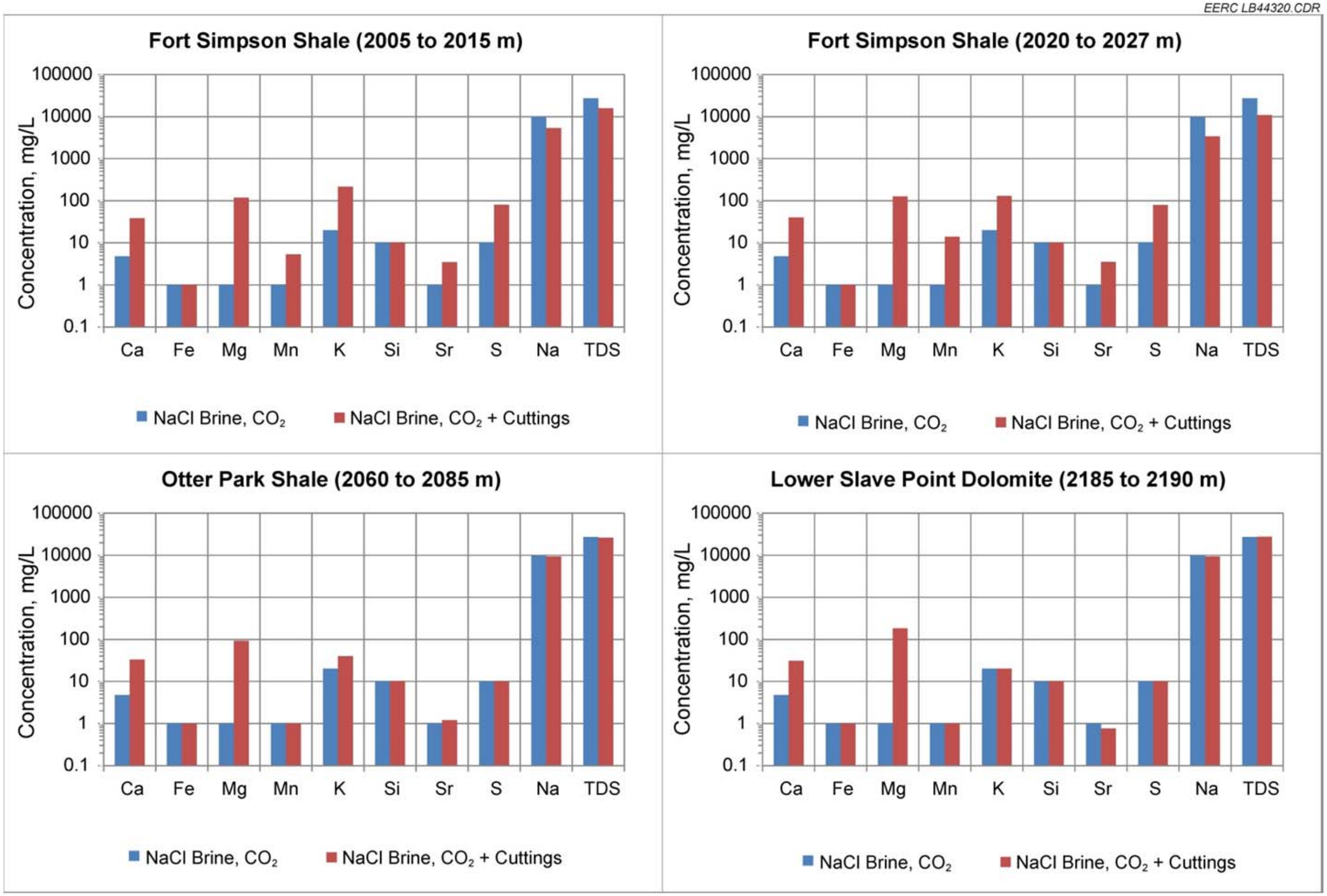
- Group 1, synthesized brine, CO_2/H_2S exposure under far-from-wellbore conditions.

Table D-2a. Baseline and Postexposure ICP–MS Analyses of Synthetic Brine (NaCl solution) and Synthesized Brine for Batch Reactor Test 2–5 Experiments. Near-wellbore conditions were conducted at 65°C and 3500 psi. CO_2 gas conditions were 100 mol% CO_2, and CO_2/H_2S gas conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. "Standard" was the stock synthetic or synthesized brine solution exposed to either CO_2 or CO_2/H_2S conditions with no cuttings. Results are reported in mg/L. Fields are denoted as with an asterisk (*) were lost because of depressurization of the test vials. Fields denoted with an "—" were not analyzed.

			Synthesized Brine										Synthetic Brine (NaCl solution)									
Formation (depth [m])	P, T Conditions	Gas Conditions	Ca	Fe	Mg	Mn	K	Si	Sr	S	Na	TDS	Ca	Fe	Mg	Mn	K	Si	Sr	S	Na	TDS
Fort Simpson Shale (1840 to 1845)	Near	CO_2	192	1	346	3.1	1600	10	136	195	7880	30,000	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1860 to 1875)	Near	CO_2	212	1	402	2.5	1550	10	139	216	7840	29,800	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1880 to 1895)	Near	CO_2	208	1	398	2.4	1520	10	133	212	7420	30,800	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1905 to 1920)	Near	CO_2	202	1	356	3.7	1550	10	131	240	7360	40,100	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1925 to 1940)	Near	CO_2	224	1	394	5.7	1600	10	138	242	7760	31,000	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1950 to 1975)	Near	CO_2	161	1	278	5.4	1220	10	102	148	5760	23,500	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1985 to 2000)	Near	CO_2	179	1	364	4.8	1490	10	124	230	7040	30,600	–	–	–	–	–	–	–	–	–	–
Standard	Near	CO_2	214	1	214	1	1370	10	165	191	9380	38,400	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (2005 to 2015)	Near	CO_2	–	–	–	–	–	–	–	–	–	–	38.4	1	119	5.3	216	10	3.48	80	5360	15,800
Fort Simpson Shale (2020 to 2027)	Near	CO_2	–	–	–	–	–	–	–	–	–	–	40.2	1	127	14	130	10	3.52	79	3360	10,800
Otter Park Shale (2060 to 2085)	Near	CO_2	–	–	–	–	–	–	–	–	–	–	33.2	1	91.8	1	40	10	1.2	10	9360	26,200
Lower Slave Point Dolomite (2185 to 2190)	Near	CO_2	–	–	–	–	–	–	–	–	–	–	30.8	1	183	1	20	10	0.76	10	9400	27,400
Sulphur Point Dolomite (2205 to 2215)	Near	CO_2	–	–	–	–	–	–	–	–	–	–	28.6	1	308	1	20	10	0.86	10	9880	27,000
Sulphur Point Dolomite (2220 to 2230)	Near	CO_2	–	–	–	–	–	–	–	–	–	–	26.4	1	198	1	20	10	1.32	10	1130	34,600
Upper Keg River Dolomite (2235 to 2240)	Near	CO_2	–	–	–	–	–	–	–	–	–	–	31.4	1	159	1	20	10	1.16	10	9960	29,200
Standard	Near	CO_2	–	–	–	–	–	–	–	–	–	–	4.8	1	1	1	20	10	1	10	9840	27,200
Fort Simpson Shale (1840 to 1845)	Near	CO_2/H_2S	195	1	268	10.4	1590	10	102	38,800	6140	27,200	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1860 to 1875)	Near	CO_2/H_2S	232	1	322	3.7	1760	10	112	34,400	6800	30,500	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1880 to 1895)	Near	CO_2/H_2S	228	1	326	3.3	1720	10	116	29,600	6940	31,400	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1905 to 1920)	Near	CO_2/H_2S	218	1	290	4	1700	10	122	30,400	6680	30,700	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1925 to 1940)	Near	CO_2/H_2S	220	1	278	1.7	1820	10	124	27,200	7440	30,600	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1950 to 1975)	Near	CO_2/H_2S	206	1	284	2.5	1780	10	131	29,800	7020	30,300	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (1985 to 2000)	Near	CO_2/H_2S	234	1	348	4.5	1870	10	133	25,000	7760	32,200	–	–	–	–	–	–	–	–	–	–
Standard	Near	CO_2/H_2S	165	1	153	1	1190	10	125	18,400	6620	24,700	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (2005 to 2015)	Near	CO_2/H_2S	89.4	1	139	8.8	534	10	65.6	268	3310	14,000	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (2020 to 2027)	Near	CO_2/H_2S	86.8	1	171	10.2	484	10	61.4	282	3050	14,800	–	–	–	–	–	–	–	–	–	–
Otter Park Shale (2060 to 2085)	Near	CO_2/H_2S	138	1	210	1	880	10	161	391	6720	26,200	–	–	–	–	–	–	–	–	–	–
Lower Slave Point Dolomite (2185 to 2190)	Near	CO_2/H_2S	147	1	252	1.8	916	10	198	419	6880	27,400	–	–	–	–	–	–	–	–	–	–
Sulphur Point Dolomite (2205 to 2215)	Near	CO_2/H_2S	132	1	320	1	942	10	204	400	7080	28,300	–	–	–	–	–	–	–	–	–	–
Sulphur Point Dolomite (2220 to 2230)	Near	CO_2/H_2S	141	1	244	1	954	10	189	409	7160	28,200	–	–	–	–	–	–	–	–	–	–
Upper Keg River Dolomite (2235 to 2240)	Near	CO_2/H_2S	143	1	286	1	972	10	200	468	7120	29,000	–	–	–	–	–	–	–	–	–	–
Standard	Near	CO_2/H_2S	145	1	146	1	932	10	183	413	6880	27,800	–	–	–	–	–	–	–	–	–	–

Table D-2b. Baseline and Postexposure ICP–MS Analyses of Synthetic Brine (NaCl solution) and Synthesized Brine for Batch Reactor Test 2–5 Experiments. Far-from-wellbore conditions were conducted at 120°C and 2800 psi. CO_2 gas conditions were 100 mol% CO_2, and CO_2/H_2S gas conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. "Standard" was the stock synthetic or synthesized brine solution exposed to either CO_2 or CO_2/H_2S conditions with no cuttings. Results are reported in mg/L. Fields denoted ith an asterisk (*) were lost because of depressurization of the test vials. Fields denoted with an "—" were not analyzed.

			Synthesized Brine										Synthetic Brine (NaCl solution)									
Formation (Depth [m[)	P, T Conditions	Gas Conditions	Ca	Fe	Mg	Mn	K	Si	Sr	S	Na	TDS	Ca	Fe	Mg	Mn	K	Si	Sr	S	Na	TDS
Fort Simpson Shale (1840 to 1845)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	60.2	1	119	10.8	440	10	9.58	36	6600	17,900
Fort Simpson Shale (1860 to 1875)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	74.4	1	168	6.8	544	10	10.8	47	8240	22,300
Fort Simpson Shale (1880 to 1895)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	99.6	1	236	1.9	698	10	14	59	10,100	30,300
Fort Simpson Shale (1905 to 1920)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	78.6	1	204	3.3	700	10	13.4	46	9680	30,900
Fort Simpson Shale (1925 to 1940)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	88.4	1	212	4.9	700	10	14.1	67	9780	27,500
Fort Simpson Shale (1950 to 1975)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	89.4	1	199	5.5	708	10	14.4	81	9020	26,700
Fort Simpson Shale (1985 to 2000)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	74.8	1	256	1	748	10	14.1	131	11,900	35,600
Standard	Far	CO_2	–	–	–	–	–	–	–	–	–	–	2	1	1	1	20	10	1	6	10,500	29,100
Fort Simpson Shale (2005 to 2015)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*	*	*
Fort Simpson Shale (2020 to 2027)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*	*	*
Otter Park Shale (2060 to 2085)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*	*	*
Lower Slave Point Dolomite (2185 to 2190)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*	*	*
Sulphur Point Dolomite (2205 to 2215)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*	*	*
Sulphur Point Dolomite (2220 to 2230)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*	*	*
Upper Keg River Dolomite (2235 to 2240)	Far	CO_2	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*	*	*
Standard	Far	CO_2	–	–	–	–	–	–	–	–	–	–	*	*	*	*	*	*	*	*	*	*
Fort Simpson Shale (1840 to 1845)	Far	CO_2/H_2S	–	–	–	–	–	–	–	–	–	–	67.6	1	151	1	776	10	10.9	32,400	10,200	30,600
Fort Simpson Shale (1860 to 1875)	Far	CO_2/H_2S	–	–	–	–	–	–	–	–	–	–	112	1	178	2.4	730	10	10.5	34,000	9120	30,400
Fort Simpson Shale (1880 to 1895)	Far	CO_2/H_2S	–	–	–	–	–	–	–	–	–	–	96	1	180	1	806	10	12.5	30,800	10,200	34,000
Fort Simpson Shale (1905 to 1920)	Far	CO_2/H_2S	–	–	–	–	–	–	–	–	–	–	53.2	1	185	1	762	10	9.14	32,600	9740	33,000
Fort Simpson Shale (1925 to 1940)	Far	CO_2/H_2S	–	–	–	–	–	–	–	–	–	–	99.6	1	164	1	830	10	14.2	27,800	9840	31,400
Fort Simpson Shale (1950 to 1975)	Far	CO_2/H_2S	–	–	–	–	–	–	–	–	–	–	94.2	1	172	2.2	834	10	14.5	28,600	9240	31,200
Fort Simpson Shale (1985 to 2000)	Far	CO_2/H_2S	–	–	–	–	–	–	–	–	–	–	77.6	1	174	8.3	640	10	11.1	28,000	9000	27,600
Standard	Far	CO_2/H_2S	–	–	–	–	–	–	–	–	–	–	2	1	1	1	20	10	1	20,400	10,000	27,400
Fort Simpson Shale (2005 to 2015)	Far	CO_2/H_2S	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–	–	–
Fort Simpson Shale (2020 to 2027)	Far	CO_2/H_2S	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–	–	–
Otter Park Shale (2060 to 2085)	Far	CO_2/H_2S	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–	–	–
Lower Slave Point Dolomite (2185 to 2190)	Far	CO_2/H_2S	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–	–	–
Sulphur Point Dolomite (2205 to 2215)	Far	CO_2/H_2S	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–	–	–
Sulphur Point Dolomite (2220 to 2230)	Far	CO_2/H_2S	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–	–	–
Upper Keg River Dolomite (2235 to 2240)	Far	CO_2/H_2S	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–	–	–
Standard	Far	CO_2/H_2S	*	*	*	*	*	*	*	*	*	*	–	–	–	–	–	–	–	–	–	–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Fort Simpson Shale (2005 to 2015 m)

Fort Simpson Shale (2020 to 2027 m)

Otter Park Shale (2060 to 2085 m)

Lower Slave Point Dolomite (2185 to 2190 m)

Figure D-2a. Baseline and postexposure ICP–MS analyses of synthetic brine (NaCl solution) for Batch Reactor Test 2–5 experiments. CO_2 conditions were 100 mol% CO_2. CO_2/H_2S conditions were not conducted on these sample batches. Samples were exposed to near-wellbore conditions (65°C and 3500 psi).

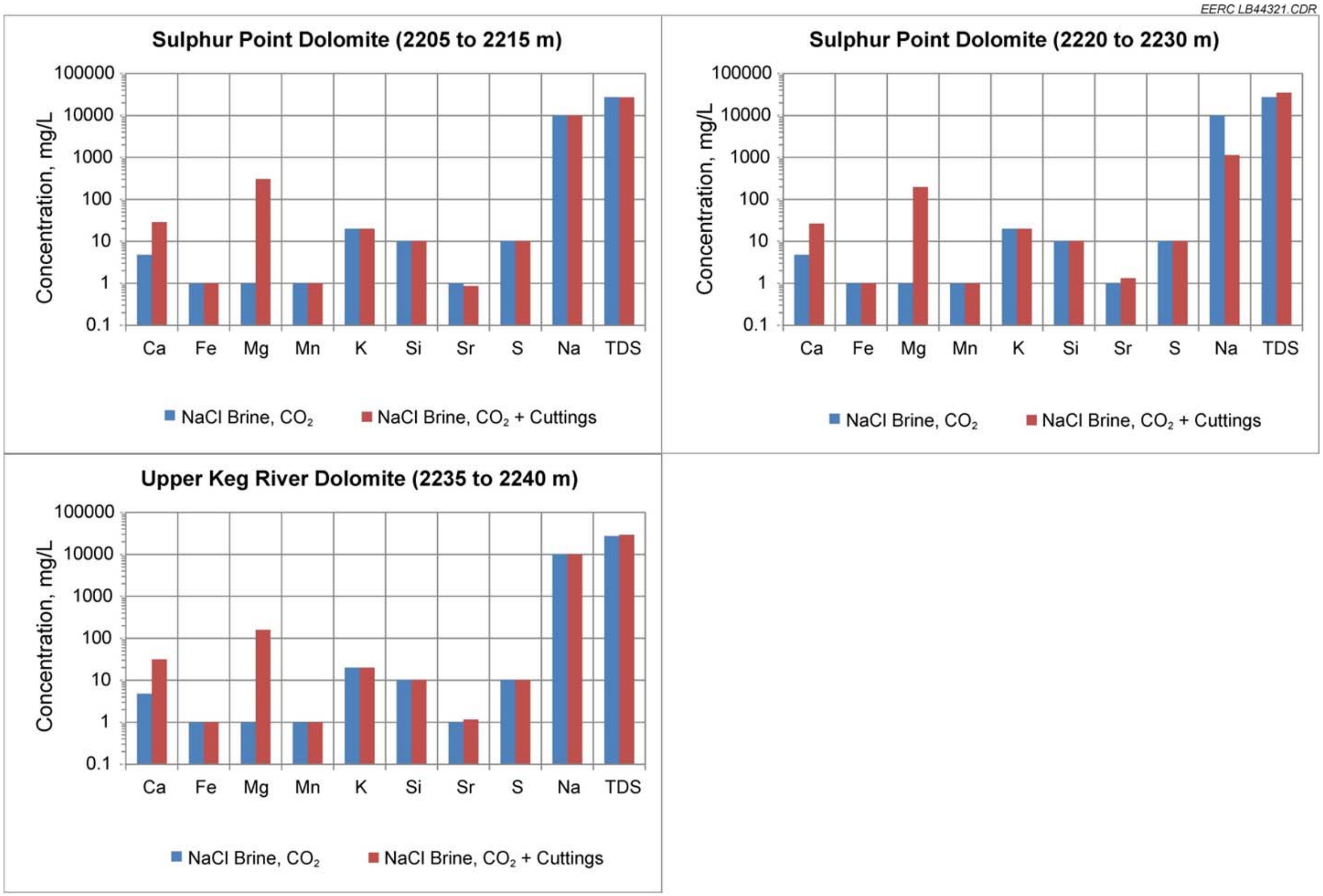


Figure D-2b. Baseline and postexposure ICP–MS analyses of synthetic brine (NaCl solution) for Batch Reactor Test 2–5 experiments. CO_2 conditions were 100 mol% CO_2. CO_2/H_2S conditions were not conducted on these sample batches. Samples were exposed to near-wellbore conditions (65°C and 3500 psi).

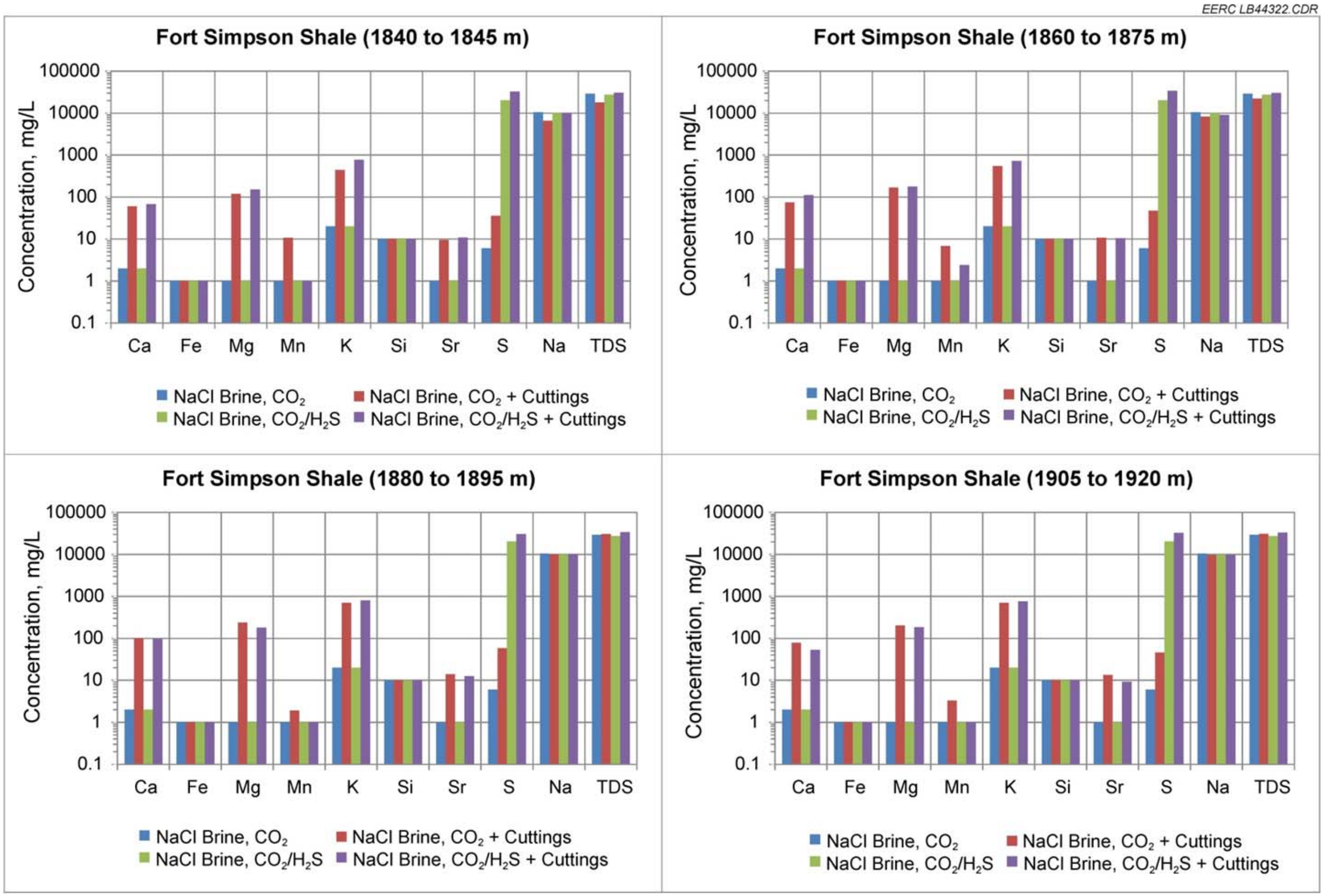


Figure D-3a. Baseline and postexposure ICP–MS analyses of synthetic brine (NaCl solution) for Batch Reactor Test 2–5 experiments. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. Samples were exposed to far-from-wellbore conditions (120°C and 2800 psi).

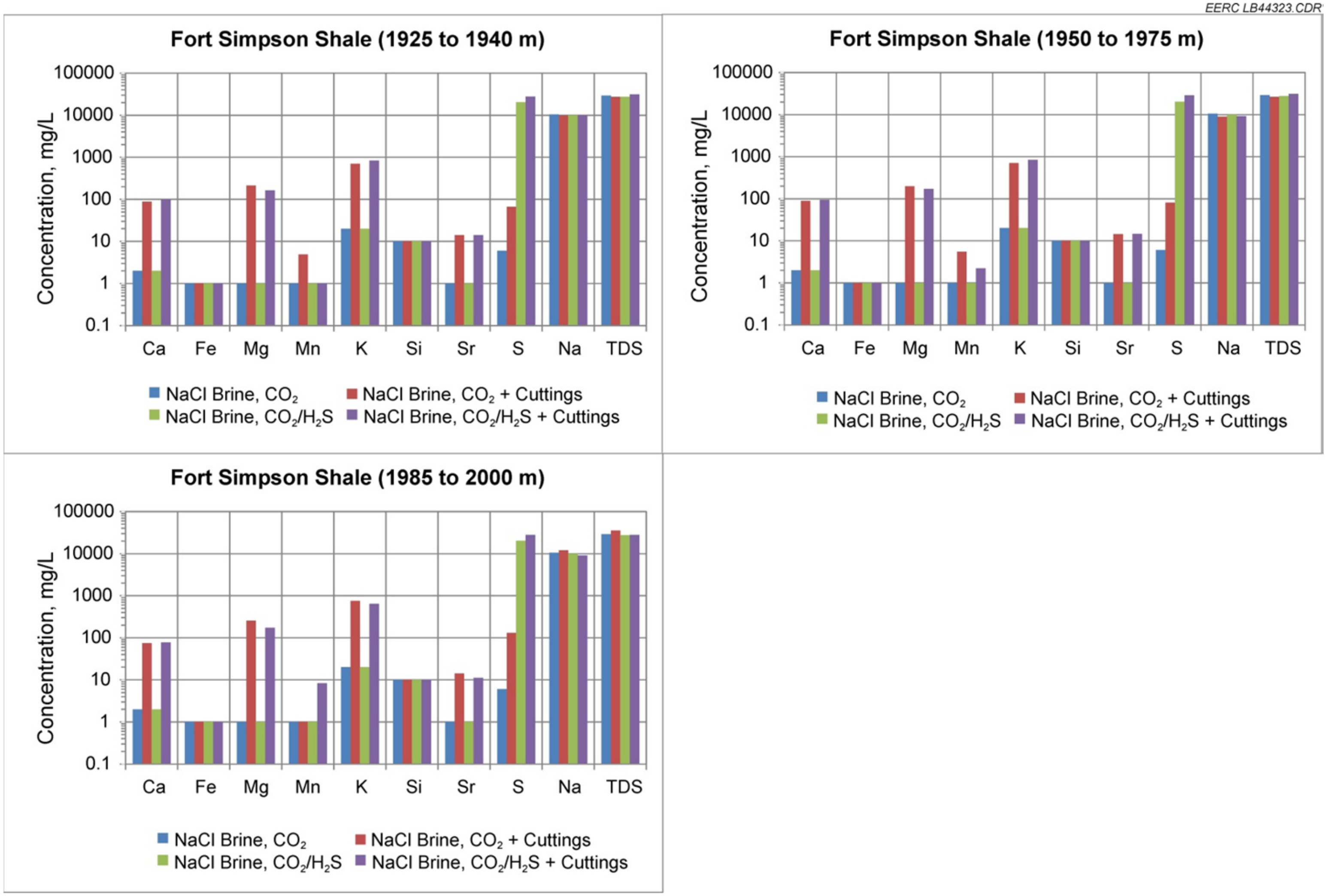


Figure D-3b. Baseline and postexposure ICP–MS analyses of synthetic brine (NaCl solution) for Batch Reactor Test 2–5 experiments. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. Samples were exposed to far-from-wellbore conditions (120°C and 2800 psi).

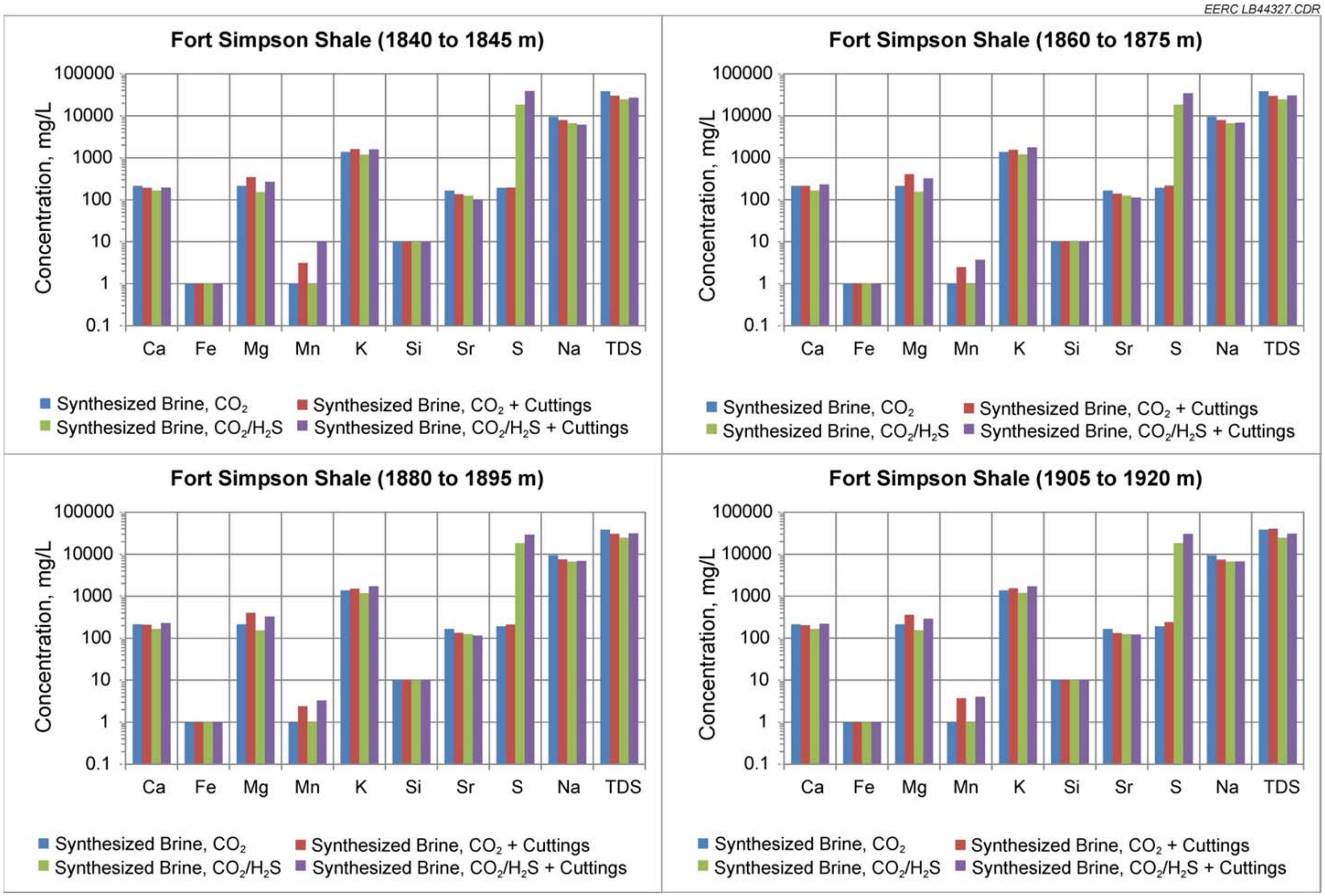


Figure D-4a. Baseline and postexposure ICP–MS analyses of synthesized brine for Batch Reactor Test 2–5 experiments. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. Samples were exposed to near-wellbore conditions (65°C and 3500 psi).

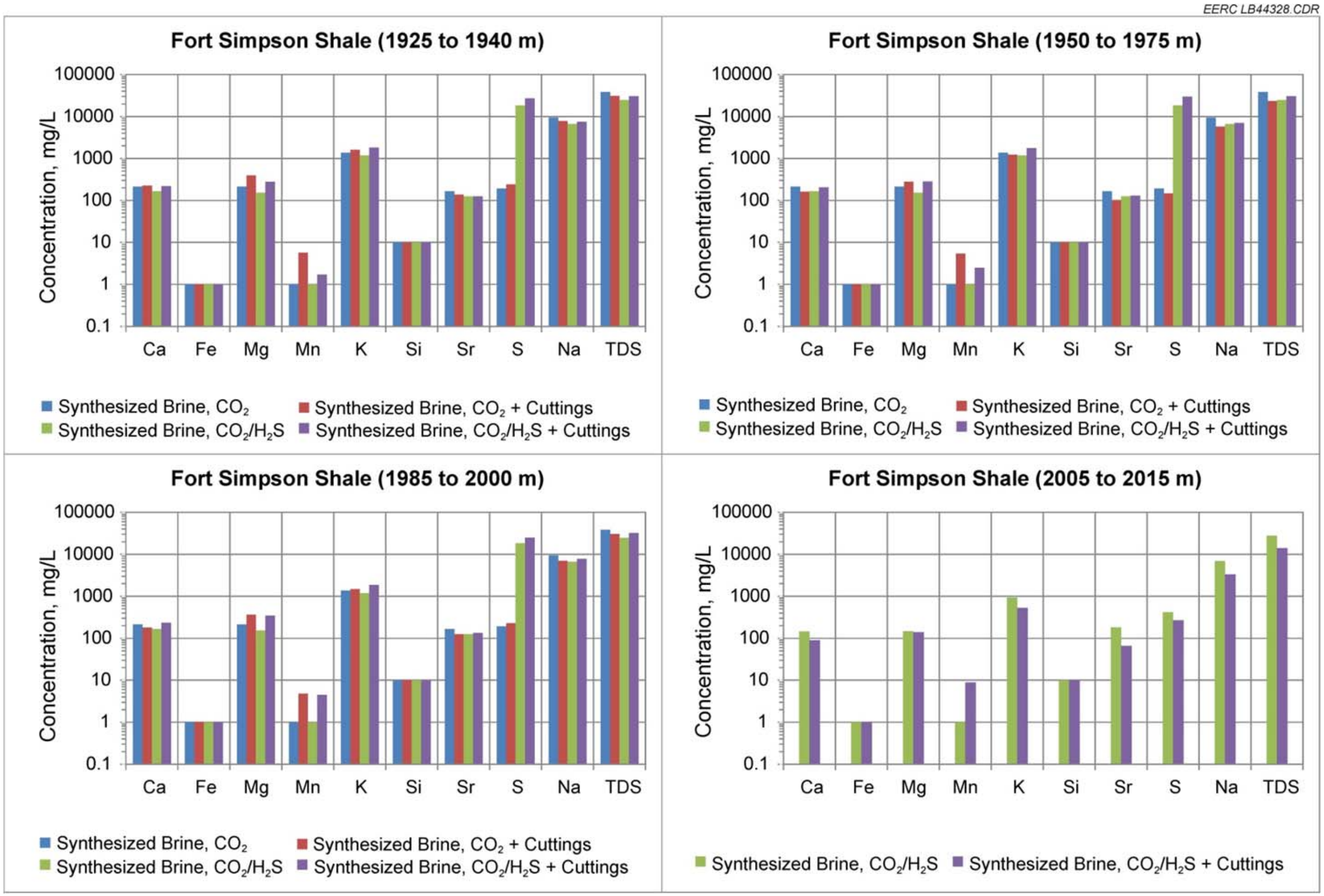
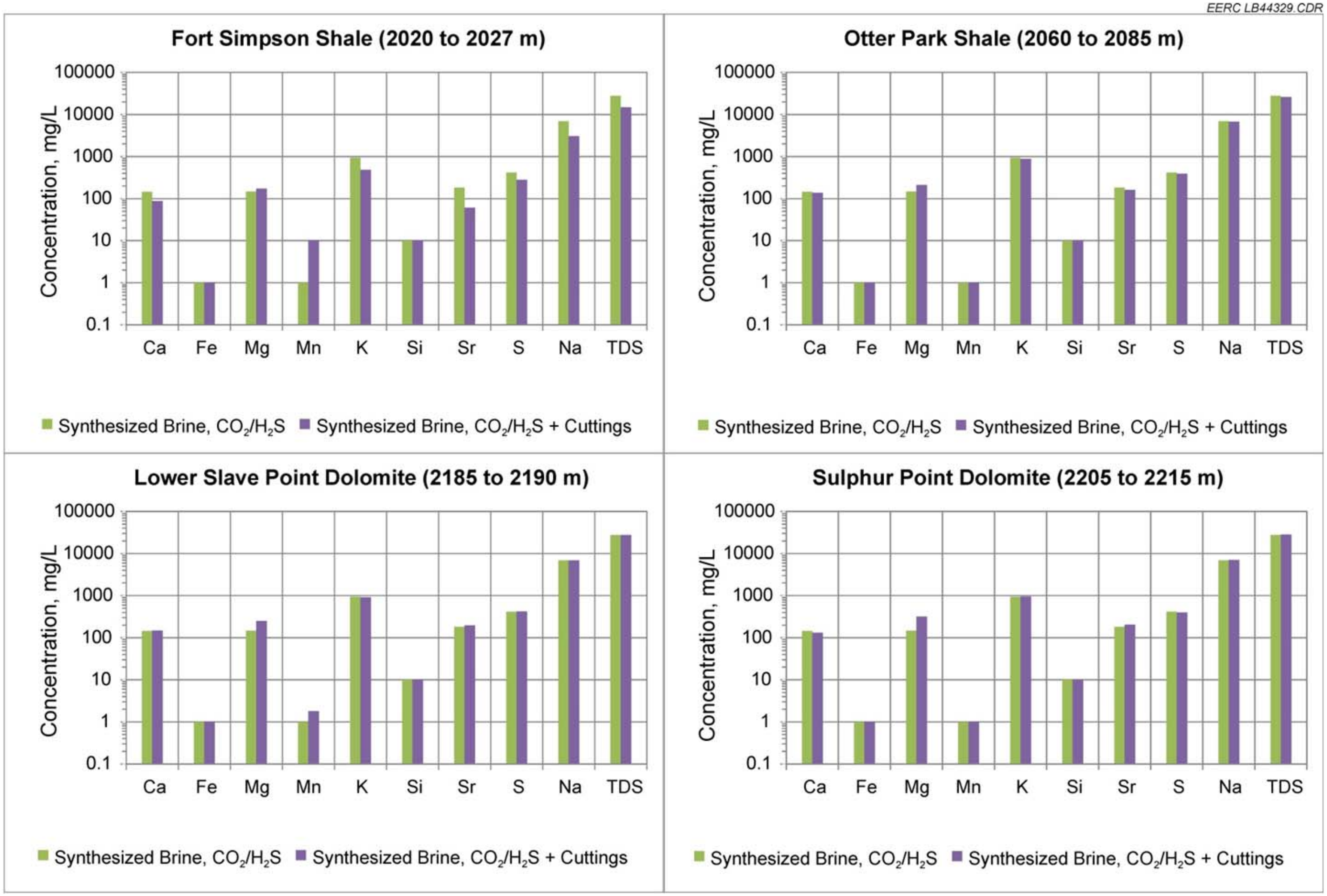


Figure D-4b. Baseline and postexposure ICP–MS analyses of synthesized brine for Batch Reactor Test 2–5 experiments. CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. Samples were exposed to near-wellbore conditions (65°C and 3500 psi). CO_2 conditions were not available for sample Fort Simpson shale (2005 to 2015 m).



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Fort Simpson Shale (2020 to 2027 m)

Otter Park Shale (2060 to 2085 m)

Lower Slave Point Dolomite (2185 to 2190 m)

Sulphur Point Dolomite (2205 to 2215 m)

Figure D-4c. Baseline and postexposure ICP–MS analyses of synthesized brine for Batch Reactor Test 2–5 experiments. CO_2 conditions were not conducted on these sample batches. CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. Samples were exposed to near-wellbore conditions (65°C and 3500 psi).

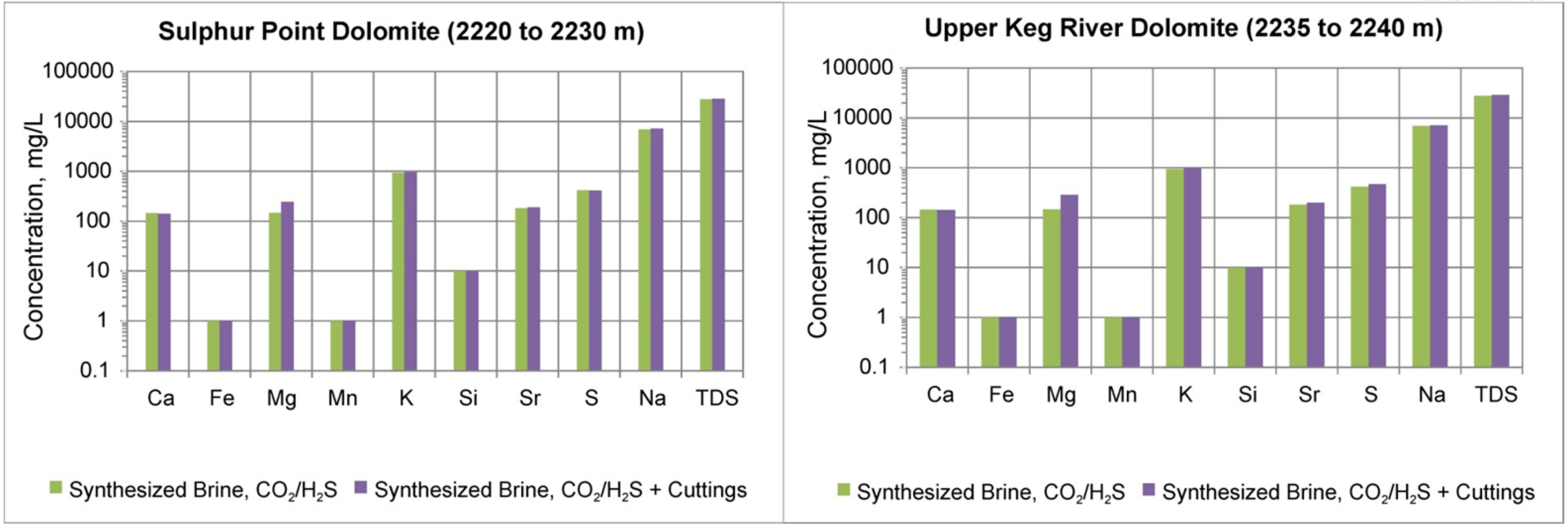

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Figure D-4d. Baseline and postexposure ICP–MS analyses of synthesized brine for Batch Reactor Test 2–5 experiments. CO_2 conditions were not conducted on these sample batches. CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. Samples were exposed to near-wellbore conditions (65°C and 3500 psi).

- Group 2, synthetic (NaCl solution) brine, CO_2 exposure under far-from-wellbore conditions.

In addition, ICP–MS analyses were not conducted on the following group and exposure combinations. These fields are denoted with an "—" in Tables D-2a and D-2b and represent omissions in the experimental program.

- Synthesized brine:
  - Group 2, CO_2 exposure under near-wellbore conditions
  - Group 1, CO_2 exposure under far-from-wellbore conditions
  - Group 2, CO_2 exposure under far-from-wellbore conditions
  - Group 2, CO_2/H_2S exposure under far-from-wellbore conditions

- Synthetic brine (NaCl solution):
  - Group 1, CO_2 exposure under near-wellbore conditions
  - Group 1, CO_2/H_2S exposure under near-wellbore conditions
  - Group 2, CO_2/H_2S exposure under near-wellbore conditions
  - Group 2, CO_2/H_2S exposure under far-from-wellbore conditions

A graphical summary of the mean and standard deviation for ICP–MS results associated with the Fort Simpson Formation shale (1840 to 2000 m) baseline and postexposure synthesized brine conducted at near-wellbore conditions is presented in Figure D-5.

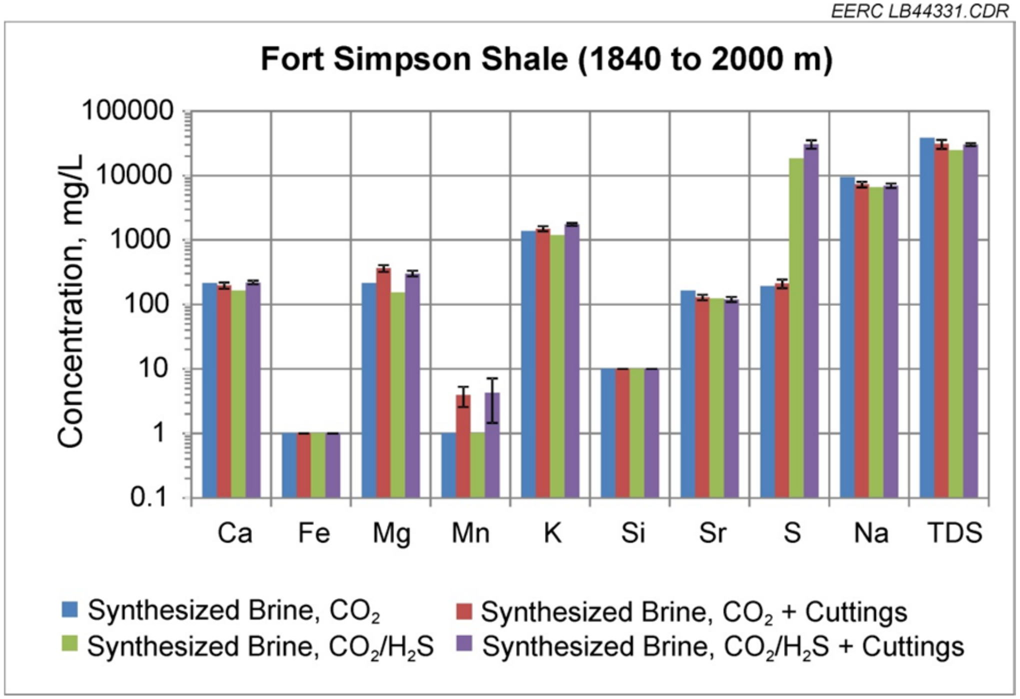
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Figure D-5. Baseline and mean ± standard deviation for postexposure ICP–MS analyses of synthesized brines for samples exposed to near-wellbore conditions (65°C and 3500 psi). CO_2 conditions were 100 mol% CO_2, and CO_2/H_2S conditions were 86.5 mol% CO_2 and 13.5 mol% H_2S. Results are reported in mg/L.