BRITISH COLUMBIA

Ministry of Transportation and Infrastructure

Selkirk Passing Lane ML/ARD Assessment

Project No. A469-3
10 September 2018

LORAX ENVIRONMENTAL

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Ministry of Transportation and Infrastructure

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1. Introduction

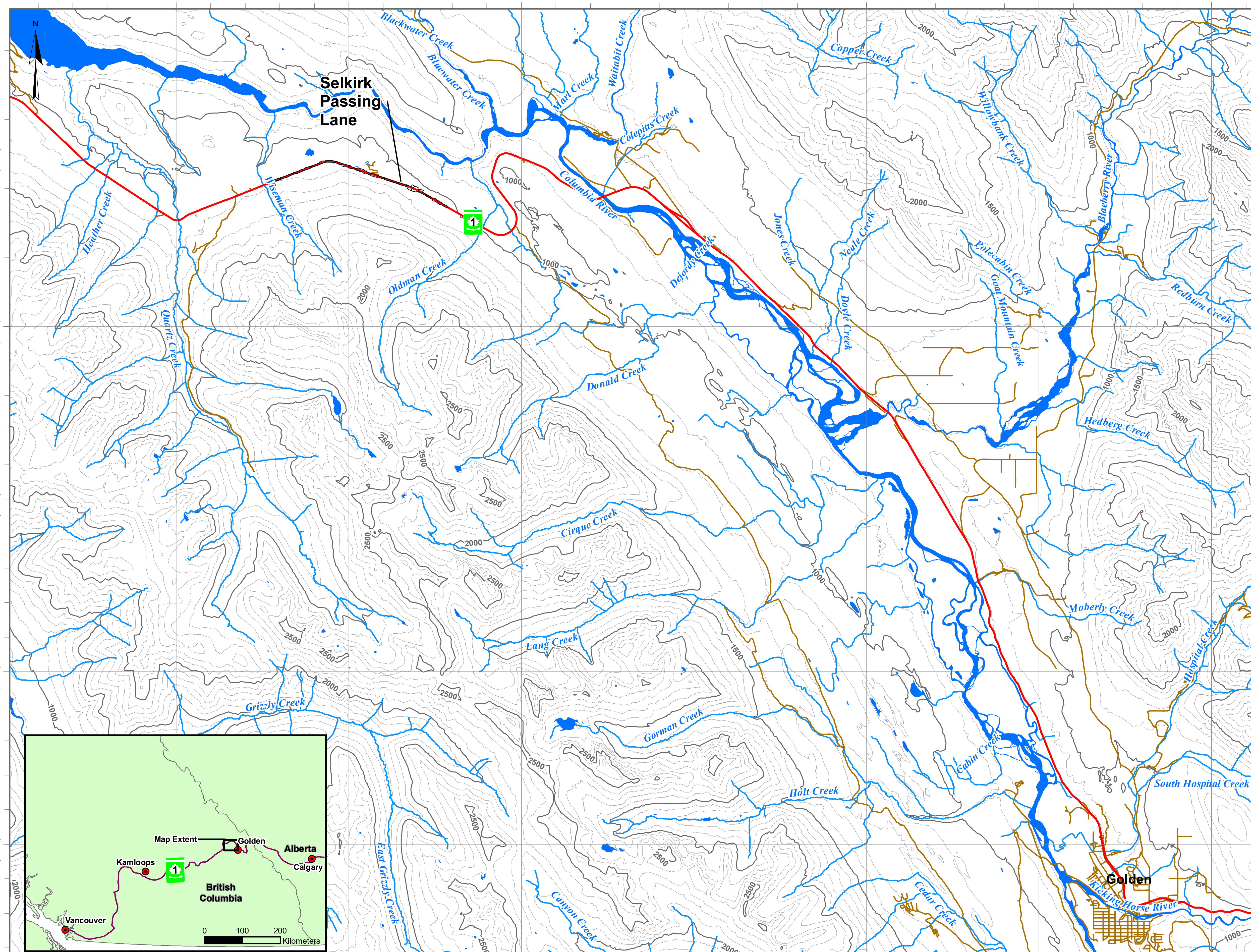
1. Introduction

The Selkirk Passing Lane section of Highway 1 is located approximately halfway between Rogers Pass and Golden in southeastern British Columbia (Figure 1-1). The highway expansion along this 5.4 km section of the highway is part of the BC Ministry of Transportation and Infrastructure (MoTI)'s larger ongoing Highway 1 Kamloops to Alberta Four-Laning Program. The Selkirk section is currently in the preliminary design stage. As part of the road design process, the MoTI requires a metal leaching/acid rock drainage (ML/ARD) assessment for materials excavated along the section of highway (MoTI, 2013). As detailed design drawings were not available at the time of the site visit, all outcrops encountered along the Selkirk section were sampled in the initial ML/ARD assessment.

The potential for the development of ML/ARD when rock is disturbed is dependent on the composition of the source rock. The oxidation of sulphide minerals (primarily pyrite, FeS_2) contributes to the acid generating potential of a material. Thus, materials with a higher amount of sulphide sulphur have a greater acid generating potential. The presence of carbonate minerals can neutralize the acid and minimize the effects of ML/ARD. Acidic drainage is generated as a result of the disturbance of sulphide-bearing rock in which the proportion of sulphide-bearing minerals exceeds the neutralization potential. Metal leaching is the dissolution and mobilization of metals from rock that can occur under circumneutral conditions and may be exacerbated in acidic conditions.

The Selkirk ML/ARD assessment involved an initial desktop review of the regional geology of the area, a site visit to collect bedrock and colluvium samples, and analysis of the laboratory results. Bedrock outcrops were encountered along the initial 2.2 km of the highway when travelling from west to east. A 300 m section of blasted bedrock was encountered approximately 3 km along the road. No bedrock outcrops were encountered along the eastern end of the road; however, it is anticipated that surficial material will be excavated in this area. In total 13 samples from the Selkirk section were submitted for acid-base accounting (ABA), elemental solid-phase analysis, and shake flask extractions (SFE), while a subset of 5 samples was selected for X-ray diffraction (XRD). Two of the five samples were sent for a second XRD analysis to assess the initial results. The results from these analyses are used to determine if there is potential for ML/ARD from the material planned to be excavated to widen the highway.

Following the introduction, a brief background of the project area is provided in Section 2, including the climate, hydrology and geology of the area. Section 3 provides a summary of the field investigation and Section 4 presents the analytical results. Conclusions and recommendations are provided in Section 5.



LEGEND

- Project Footprint
- Highway
- Local Road
- Waterbody
- Watercourse
- 200m Contour
- 50m Contour

Coordinate System: *NAD 1983 UTM Zone 11N*
Projection: *Transverse Mercator*
Datum: *North American 1983*
Units: *Meter*

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0 1 2 Km

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LORAX ENVIRONMENTAL

PROJECT:

Selkirk Passing Lane ML/ARD Assessment

TITLE: Selkirk Passing Lane Location

PROJECT #: A469-3 *FIGURE:* 1-1

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2. Background

2. Background

2.1 Climate

The average daily temperature at the weather station in Golden, BC ranges from a low of -7.9°C in January to a high of 17.3°C in July (Government of Canada, 2018). Typical winter lows are approximately -10°C and summer highs are in the 20 to 25°C range. The average annual precipitation is 466.8 mm, with 325.2 mm of rain and 158.7 mm of snow. The months with the highest rainfall are June to August (ranging from 45.3 to 50.6 mm per month), while months with the highest snowfall are December and January (42.5 and 45.3 mm per month, respectively). February to April is the driest time of the year with 24.1 to 24.4 mm of precipitation per month falling as a mixture of rain and snow. Snowfall in the area begins in the fall (October) and continues throughout the winter months until spring in May.

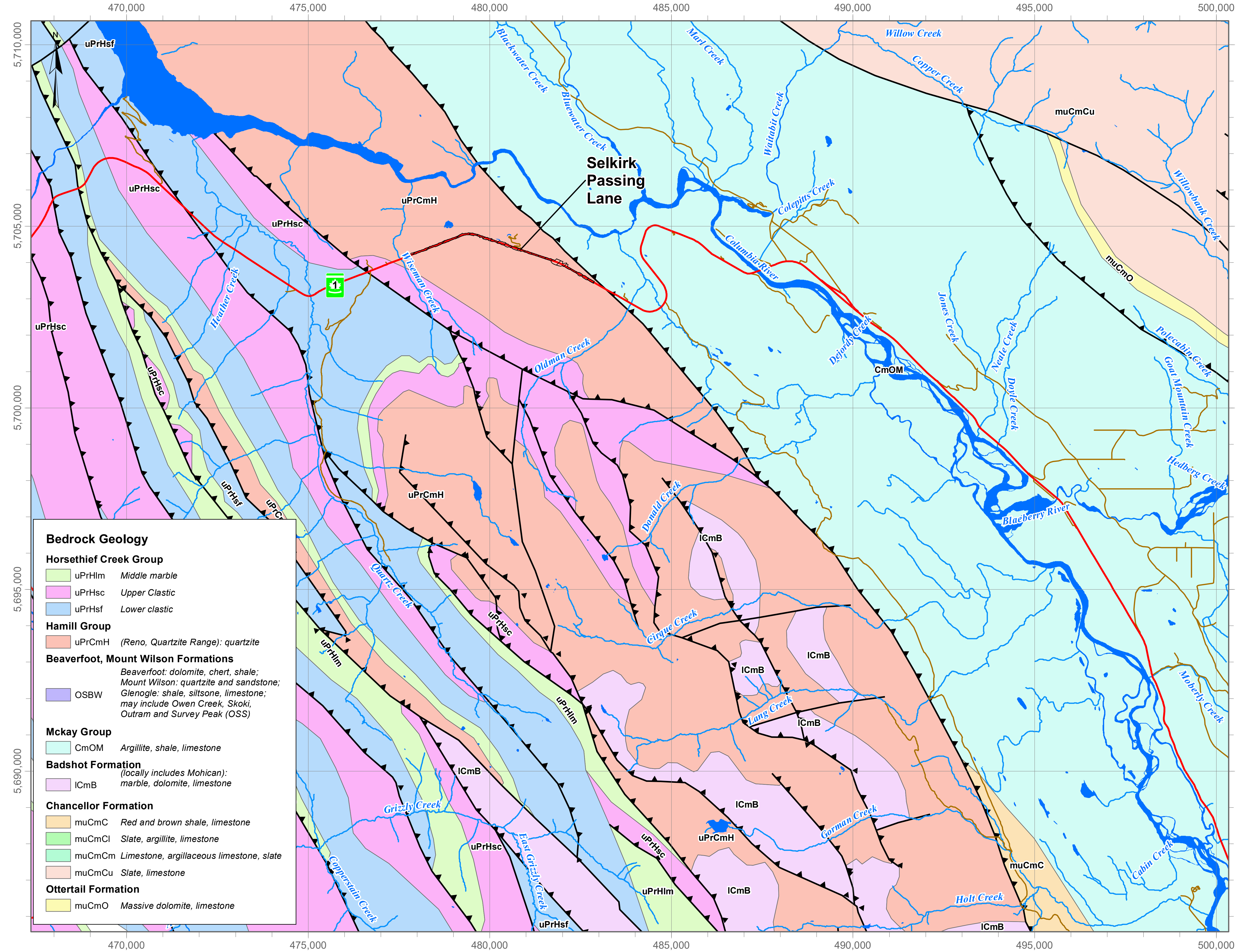
2.2 Hydrology

There are no major creeks that cross the Selkirk Passing Lane road section. However, Wiseman Creek is located approximately 200 m to the west of the section and Oldman Creek is located approximately 1 km east of the section. Both of these creeks drain to the north to the Columbia River. Seepage and artesian conditions have been noted by MoTI personnel conducting site reconnaissance along this section of road (Personal communication, 2018).

2.3 Geology

The project is located in the Dogtooth Mountains near the northern extent of the Purcell Mountain Range. This region is between the Rocky Mountain Trench to the east and the Selkirk Mountains to the west (Price, 2000). The majority of the bedrock in the region has a sedimentary origin but has been deformed by a series of faults and influenced by low-grade regional metamorphism within the lower greenschist facies (Poulton and Simony, 1980).

The northwest trending Purcell Thrust fault cuts across the region (Price, 2000). The main unit at surface to the east of the fault is the Upper Cambrian to Ordovician McKay Group (Figure 2-1). This unit is within the Rocky Mountain Trench (Price, 2000) and includes interbedded shale and limestone (Evans, 1932). Major units outcropping on the western side of the fault include the Middle to Upper Proterozoic Horsethief Creek Group of the Windermere Super Group and the Lower Cambrian Hamill Group (Poulton and Simony, 1980; Figure 2-1). The full length of the Selkirk Passing Lane project is within the Hamill Group unit.



LEGEND

- Project Footprint
- Highway
- Local Road
- Waterbody
- Watercourse
- Thrust fault
- Normal fault

Coordinate System: *NAD 1983 UTM Zone 11N*
Projection: *Transverse Mercator*
Datum: *North American 1983*
Units: *Meter*

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Lorax Environmental

PROJECT:

Selkirk Passing Lane ML/ARD Assessment

TITLE:

Regional Bedrock Geology

PROJECT #: A469-3 FIGURE: 2-1

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The Hamill Group unconformably overlies the Horsethief Creek Group (Devlin and Bond, 1988; Devlin, 1989). The Hamill Group in this region consists dominantly of a metamorphosed sandstone unit which has been described as quartzite (Kubli, 1990) and feldspathic and quartz arenite (Devlin and Bond, 1988). The variability in the description is likely due to the decrease in degree of metamorphism and deformation in the eastern exposures of this unit (Devlin and Bond, 1988). In general, the Hamill Group fines upwards with increasing sorting and quartz content. Hamill Group samples from the Dogtooth Mountains are dominantly quartz and feldspar with relatively minor lithic fragments (<10%) and up to 40% matrix material (Devlin and Bond, 1988). The matrix portion may include muscovite-sericite, opaque minerals, chlorite and metamorphic biotite.

2.3.1 Mineral Occurrences

The MINFILE and ARIS databases were accessed and mineral occurrences within 10 km of the Selkirk Passing Lane section highway were documented. The mineral claims in this immediate area are limited to the Goldie 2 (MINFILE 082N 096) and Quartz Creek Placer (MINFILE 082N 018) sites. The Goldie 2 site is a tufa deposit located north of the Selkirk road section and north of the Columbia River (Geoquest Consulting Ltd., 2001). The Quartz Creek Placer claim is a past producing gold placer claim located to the southwest of the road section. A sandstone sample from the area was noted to contain minor pyrite and quartz veins in the bedrock in the area are associated with minor pyrite, galena and chalcopyrite (Horne, 1984).

2.4 Stream Sediment Geochemistry

A total of 15 stream sediment samples from streams within 10 km of the Selkirk Road section were analyzed as part of a regional stream survey conducted in the area near Golden in 2005 (Naas, 2006). The most proximal creek sampled in this survey is Wiseman Creek, located approximately 200 m west of the section. Elements elevated relative to the regional median values include Sb, As, Ba, Au, and S. This creek is within the Hamill Group in the region where it was sampled. Elements that are at least two times the regional median value in one or more sediment samples from within 10 km of the study section include Sb, As, Ba, Cd, Ca, Cr, Cu, Au, Pb, Hg, Mo, Ni, Se, Ag, Sr, S, Ti, and U (Table 2-1). The Sb, As, Ba, and Ca values were five times the regional median value in one or more samples. The regional median value is calculated from all stations within the NTS 82N map sheet.

Table 2-1:
Summary of Elevated Elements in Stream Sediment Samples

Sample ID	Sb	As	Ba	Cd	Ca	Cr	Cu	Au	Pb	Hg	Mo	Ni	Se	Ag	Sr	S	Ti	U
	ppm	ppm	ppm	ppm	%	ppm	ppm	ppb	ppm	ppm	ppm	ppm	ppm	ppb	ppm	%	%	ppm
Regional Median[a]	0.18	3.7	33	0.06	2.28	20.5	19.8	0.6	11.2	12	0.41	26.7	0.3	28	64	0.04	0.003	0.8
Wiseman Creek - 082N052135[b]	***0.91***	***13.9***	***72.1***	0.04	0.8	21.5	23.2	***1.6***	16.4	14	0.4	36.1	<0.1	46	44.7	***0.09***	0.001	1.1
082N051429	***0.42***	***8.6***	13.9	***0.14***	0.86	***48.7***	37.2	0.6	***29.4***	23	***1.02***	***57.2***	***0.9***	***77***	35.1	***0.1***	0.003	***2.5***
082N051430	0.26	5.7	23.8	0.07	1.02	***42.7***	22.2	0.2	17.6	***27***	0.54	43.5	***0.8***	51	23.5	0.04	0.005	***2.4***
082N052039	0.11	3.6	23.8	0.04	1.22	13.9	13.9	0.6	7.6	9.0	0.32	23.7	0.5	28	19.5	0.01	0.006	1.1
082N052040	0.21	***7.9***	33	0.05	1.83	18.2	22.9	0.3	12.7	12	0.42	32.1	***0.7***	52	38.1	0.04	***0.007***	1.6
082N052042	0.36	***17.3***	23.2	0.07	0.7	21.2	31.9	0.8	18.0	***25***	0.45	39.5	0.5	50	22.9	<0.01	0.005	1.5
082N052044	***1.13***	***26.7***	29	0.04	1.29	25.9	32.4	1.1	***23.3***	19	0.4	37.9	0.2	***61***	46.1	0.04	0.003	0.7
082N052045	***0.44***	***13.6***	15.1	0.09	1.05	26.8	***41.0***	0.6	19.5	10	***0.92***	49.8	0.5	***77***	58.7	0.04	0.003	1.3
082N052046	***0.37***	***7.8***	30.2	0.04	1.66	28.5	30.3	0.4	15.1	12	0.44	39.6	0.1	51	55.6	<0.01	0.002	0.8
082N052047	0.35	***16.2***	27.6	0.07	1.03	25.1	33.7	0.5	17.7	18	0.51	43.6	***0.7***	***67***	54.6	0.01	0.006	1.6
082N052048	0.21	5.3	***117.9***	0.06	0.46	25.2	18.5	<0.2	13.0	23	0.33	31	0.4	***60***	29.9	<0.01	***0.012***	***2.2***
082N052094	0.16	1.9	***209.2***	0.04	0.18	7.7	7.3	***1.3***	6.5	18	0.28	10.8	0.6	29	28.3	0.02	0.005	***2.3***
082N052133	***0.51***	6.2	***154.4***	0.09	0.47	20.6	21.1	***1.6***	17.1	***36***	0.54	32.4	***1***	53	38.7	***0.09***	0.004	***2.4***
082N052136	0.27	5.2	***108.5***	0.1	***15.03***	9.4	9.0	1	6.0	11	0.42	13.1	0.6	26	***298***	0.04	***0.009***	0.7

Notes:
[a]The regional median value is calculated from all stream sediment samples collected within the NTS 82N map sheet.
[b]This sample was collected from Wiseman Creek, approximately 200 m west of the Selkirk road section.
Bold italic text indicates a value that is greater than 2 x the regional median concentration.
Grey shading indicates a value that is greater than 5 x the regional median concentration.

3. Field Investigation

3. Field Investigation

3.1 Site Visit Summary

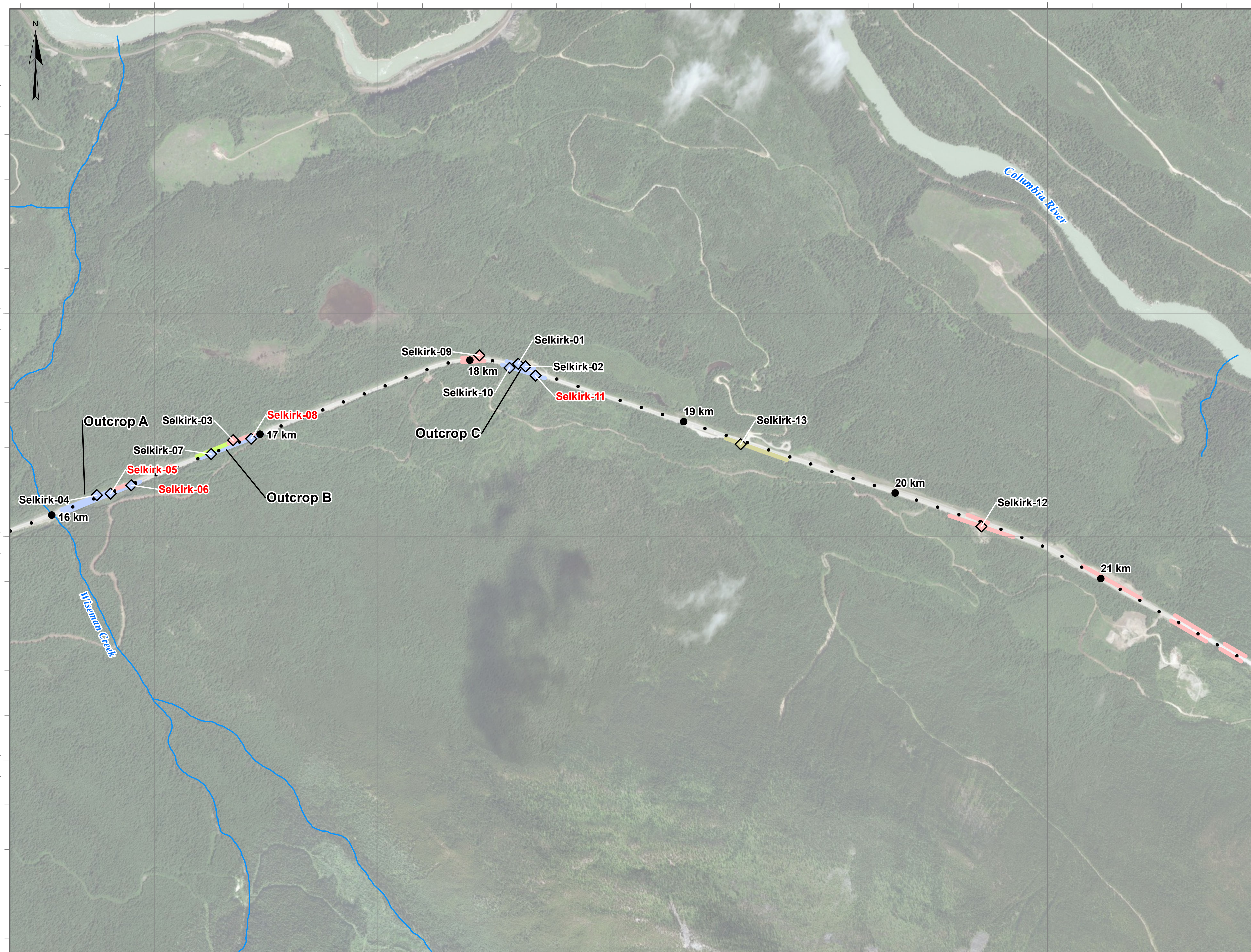
The field investigation of the Selkirk Passing Lane section of Highway 1 was undertaken on June 18, 2018. This involved walking the 5.4 km section of highway, making note of bedrock and unconsolidated surficial material outcrops, and collecting samples in support of the ML/ARD investigation. Bedrock outcrops were encountered in three areas along the highway (Figure 3-1). In addition to the bedrock outcrops, a section of the highway containing blasted bedrock and several areas where surficial material will likely be excavated were noted. Photos of the sampling locations are provided in Appendix A.1.

3.1.1 Bedrock Sampling Locations

All bedrock outcrops sampled along the Selkirk section were dominantly massive quartzite, occasionally cut by quartz veins, and highly fractured. The most westerly outcrop (Outcrop A on Figure 3-1) was massive quartzite, occasionally cross cut by veins (samples Selkirk -04 through -06). The colour of the quartzite at this outcrop varied from dark grey-green on the northern side of the road to light brown-grey on the southern side of the road. Moving eastward along the road, there is an outcrop located only on the southern side of the highway (Outcrop B; samples Selkirk -07 and -08). The bedrock encountered at this outcrop was consistent with the rock type at the previous outcrop. The third bedrock outcrop (Outcrop C), located at the curve in the road alignment, is also dominantly quartzite (Selkirk -02, -10 and -11), however, it is cross-cut by a dark grey-brown pelitic unit visible on the northern side of the road (Selkirk-01). Outcrop C had rusty staining on the surface, whereas outcrops A and B were light brown on the surface. In addition to the bedrock outcrops, one section along the road contained blasted rock (Selkirk-13). The blasted rock was of the same lithology as the bedrock outcrops encountered along the highway.

3.1.2 Surficial Material Sampling Locations

Several road cuts composed of colluvium and/or glacial material were encountered along the Selkirk road section (Figure 3-1). The material in these road cuts is poorly sorted, sandy with variable amounts of silt and minor gravel and cobbles. The cobbles are variable in lithology with some being derived from the quartzite. Samples Selkirk-03, -09, and -12 are surficial material samples.



LEGEND

Selkirk-xx PAG Sample
Selkirk-xx NPAG Sample
Km Marker (Glacier PK-Golden)
100m Marker (Glacier PK-Golden)

Potential Excavation Material Type
- Bedrock
- Blasted Rock
- Mixed
- Unconsolidated Surficial Material

Samples
- Blasted Rock
- Rock
- Unconsolidated Surficial Material

Notes:
- Kilometer Markers are from the BC Landmark Kilometer Inventory

***Coordinate System:** NAD 1983 UTM Zone 11N*
***Projection:** Transverse Mercator*
***Datum:** North American 1983*
***Units:** Meter*

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Lorax Environmental

PROJECT:

Selkirk Passing Lane ML/ARD Assessment

TITLE: Selkirk Passing Lane Sample Locations

PROJECT #: A469-3 *FIGURE:* 3-1

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4. Results

Ministry of
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and Infrastructure

4. Results

4.1 Acid-Base Accounting

The acid-base accounting (ABA) analyses consisted of paste pH, total S, sulphate S, sulphide S, inorganic C, acid potential, modified neutralization potential and fizz rating (Appendix B.1). Paste pH indicates if a sample has available neutralization potential (NP) or if it is currently acid generating at the time of sampling. The paste pH values for all the Selkirk samples are circum-neutral and range between pH 7.35 and pH 8.86, indicating that the material is not currently acid generating (Table 4-1).

The total S for the Selkirk quartzite samples is relatively low with values ranging from 0.011 to 0.31% (median: 0.040%). The single pelite sample and the surficial material samples have low total S (<0.015%). The median concentrations of sulphide S, sulphate S and insoluble S for the quartzite unit are 0.02%, <0.010% and 0.018%, respectively. These sulphur species are less than or equal to the detection limit for the pelite and the surficial material samples. The majority of the sulphur in all Selkirk samples is present as sulphide (Figure 4-1). In order to provide a conservative estimate of acid potential (AP), the AP is calculated based on the non-sulphate S in the sample (Table 4-1). The non-sulphate S includes both the sulphide S and the insoluble S. The insoluble S is included as this fraction may include sulphide minerals that were not completely digested during the analysis.

The total inorganic carbon (TIC) of the samples collected along the Selkirk road section is low (Table 4-1). The low carbonate content results in a low carbonate neutralization potential (CaNP; <10 kg $CaCO_3$/t) for the majority of the Selkirk samples, excluding one quartzite sample and two of the surficial material samples (Table 4-1). The CaNP is comparable to the modified NP for these samples (Figure 4-2). In addition to buffering capacity provided by any carbonate minerals present in the material, the modified NP also considered the buffering capacity of other minerals, including aluminosilicate minerals. Although NP associated with aluminosilicate minerals is not as readily available as the carbonate NP, dissolution rates of these minerals are typically sufficient to neutralize low-rates of acid production from low-sulphur materials.

The neutralization potential ratio (NPR) is calculated as the ratio of Modified NP to non-sulphate S AP. Due to the low NP of the rock, 4 of the 9 quartzite samples, inclusive of the blasted quartzite sample, are classified as PAG. Two of the PAG samples contained > 0.2% total S. The other two PAG samples contained <0.1% total S. The remaining five samples contain sufficient NP to neutralize the minor AP present in these samples. Selkirk-01 (pelite) is classified as non-PAG due to the low sulphide S content (<0.01%). The surficial materials are also classified as non-PAG due to a combination of low sulphide S content and high NP. Samples with sulphide S values below the detection limits contain no, or very low, sulphide and are not classified as PAG.

Table 4-1:
ABA Results Summary

Sample ID	Bedrock Outcrop	Side of Highway	Colour	Paste pH	CaNP	Modified NP	Total S	Sulphide S	SAP	AP[b]	NPR
				units	kg $CaCO_3$/t	kg $CaCO_3$/t	%	%	kg $CaCO_3$/t	kg $CaCO_3$/t	Mod NP / AP
Selkirk-02	C	North	Dark brown	7.61	<0.8	2.0	0.011	<0.01	<0.3[a]	0.3	5.83
Selkirk-04	A	North	Dark grey-green	8.86	28	29	0.069	0.05	1.6	2.1	13.3
Selkirk-05	A	South	Light brown-grey	7.35	1.7	2.8	0.095	0.04	1.3	1.7	1.63
Selkirk-06	A	South	Light brown-grey	8.49	1.7	2.5	0.22	0.20	6.3	6.8	0.37
Selkirk-07	B	South	Light brown-grey	8.53	2.5	3.3	0.022	<0.01	<0.3[a]	0.7	4.81
Selkirk-08	B	South	Light brown-grey	8.74	7.5	8.5	0.31	0.29	9.1	9.7	0.87
Selkirk-10	C	South	Light grey to pink	8.75	<0.8	1.9	0.013	<0.01	<0.3[a]	0.4	4.68
Selkirk-11	C	South	Light grey to pink	8.26	<0.8	1.4	0.040	0.02	0.6	1.2	1.12
Selkirk-13	Blasted rock	South	Grey-pink	8.49	0.8	2.5	0.017	<0.01	<0.3[a]	0.2	11.5
Selkirk-01	C	North	Dark grey-brown	8.49	<0.8	2.4	0.010	<0.01	<0.3[a]	0.3	7.69
Selkirk-03	Surficial	North	Light brown	8.05	132.5	140.1	0.014	<0.01	<0.3[a]	0.4	321
Selkirk-09	Surficial	North	Light brown	8.40	<0.8	2.2	0.0070	<0.01	<0.3[a]	0.2	10.1
Selkirk-12	Surficial	South	Light brown-grey	8.56	127.5	140.1	0.014	<0.01	<0.3[a]	0.4	321

Note:
Grey shading indicates PAG samples (NPR < 2.0)
[a]A value equal to the detection limit for sulphide S (0.01 %) is used to calculate the SAP.
[a]AP is calculated from the non-sulphate S content = $S_{Tot} - S_{Sul}$.

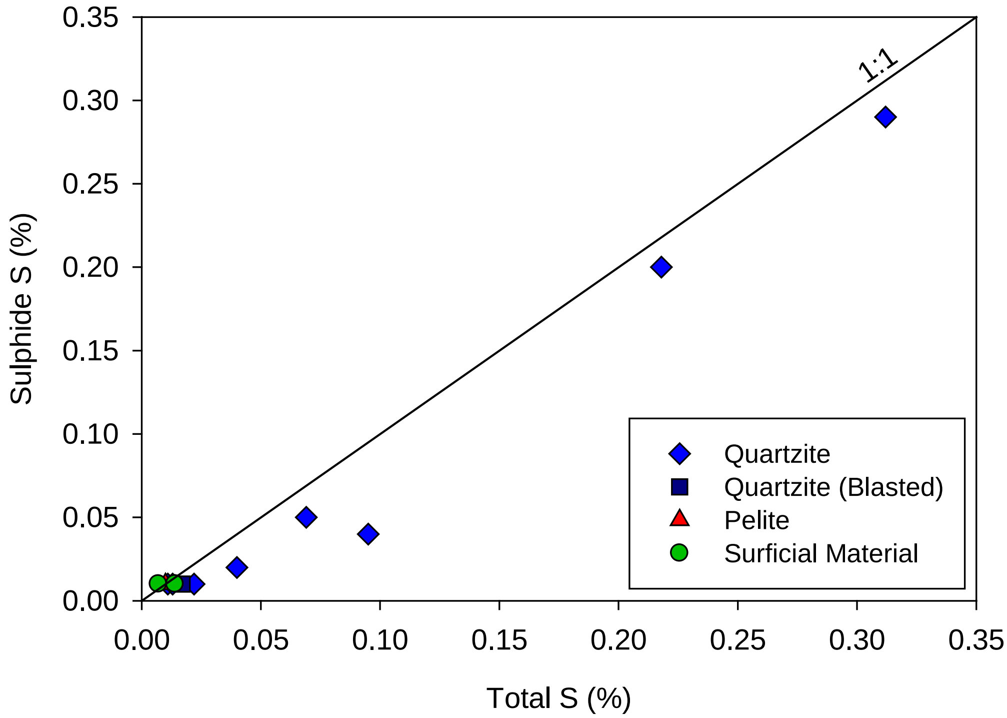

Figure 4-1: Sulphide S vs Total S

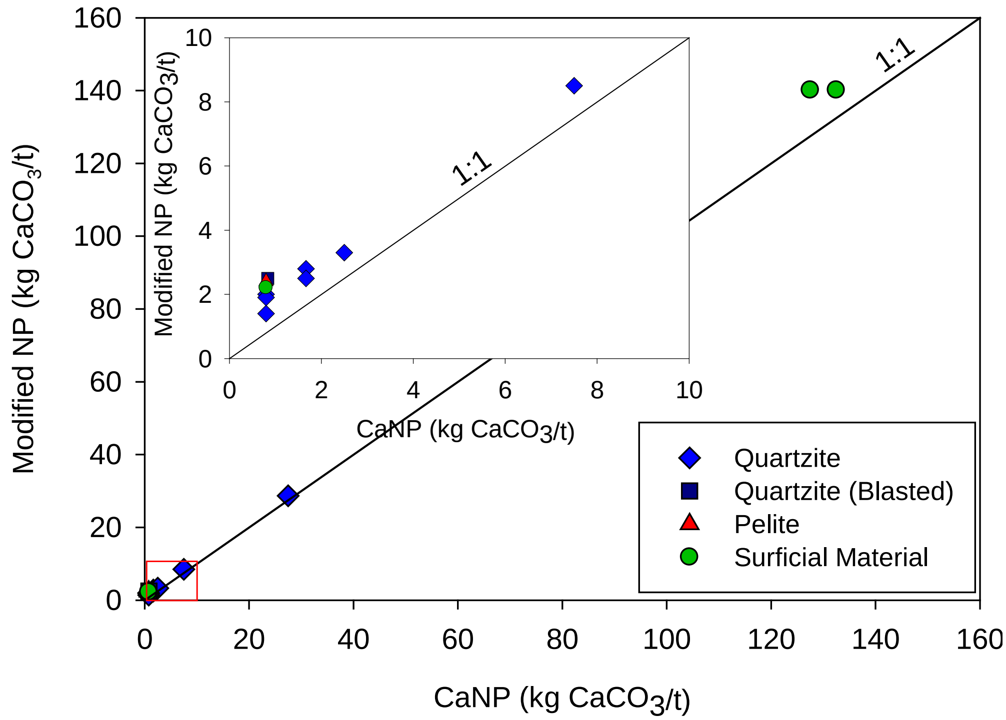

Figure 4-2: Modified NP vs CaNP

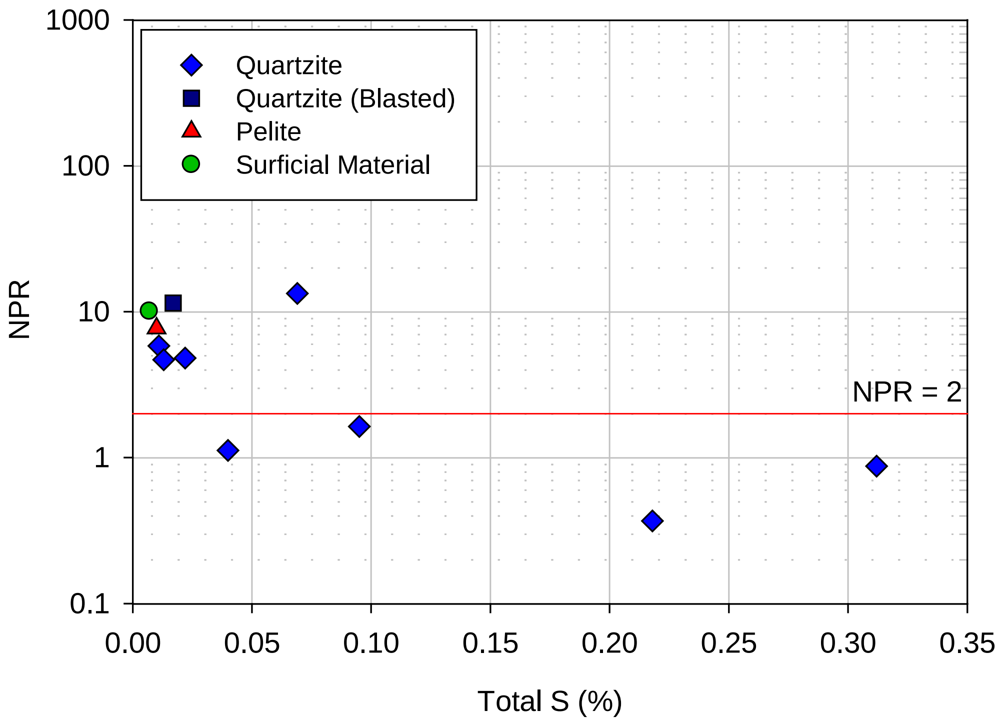

Figure 4-3: NPR *vs* Total S

4.2 Total Solid Phase Elemental Analysis Results

The total solid phase elemental analysis was conducted by aqua regia digestion with ICP-MS finish. Solid phase elemental concentrations provide an indication of metals and other elements that are elevated and that could potentially leach from the rock. The elemental concentrations are compared to the average upper continental crustal concentrations (AUCCC; Rudnick and Gao, 2014) to screen for elements significantly elevated above the average values (Appendix B.2). Elements that are greater than 3x their respective AUCCC values are included in Table 4-2 and include As, Mn, Mo and Sb. One of the quartzite samples contains elevated As and 7 of the samples contain elevated Mo, including the blasted rock sample. The only element elevated in the pelite sample is Sb. The surficial material samples have elevated Mn and Mo values in one sample each. However, an element present at an elevated concentration in the solid phase will not necessarily become a metal leaching issue. There are several factors that influence the leaching rates of elements, including the mineralogy, the stability of the minerals, and the chemistry of the water. Additional scrutiny is given to the SFE results associated with these elements and samples.

Table 4-2:
Summary of Selected Solid Phase Elements

Sample ID	As	Mn	Mo	Sb
	ppm	ppm	ppm	ppm
Quartzite				
Selkirk-02	1	49	2.49	0.37
Selkirk-04	<1	216	1.4	0.36
Selkirk-05	12	42	3.39	0.62
Selkirk-06	2	51	3.88	0.11
Selkirk-07	1	88	4.54	0.06
Selkirk-08	24	85	3.69	0.12
Selkirk-10	<1	36	4	<0.05
Selkirk-11	<1	31	3.64	0.14
Quartzite (Blasted)				
Selkirk-13	<1	38	3.93	0.16
Pelite				
Selkirk-01	<1	39	1.34	1.48
Surficial Material				
Selkirk-03	10	436	3.05	0.42
Selkirk-09	<1	78	3.97	0.18
Selkirk-12	2	179	2.71	0.1
AUCCC[a]	4.8	77.4	1.1	0.4

Notes:
[a]AUCCC = Average Upper Continental Crustal Concentrations (Rudnick and Gao, 2014)
Grey shading indicates values greater than 3x the AUCCC

4.3 Shake Flask Extraction Results

Shake flask extraction (SFE) tests are used to determine the solubility of metals in water. The concentrations are compared with the BC freshwater aquatic life water quality guidelines (WQG) in order to screen the results for parameters of potential concern (Appendix B.3). The only parameters that are above the BC WQG are Al (12 of 13 samples), As (1 sample), Cu (1 sample), and Hg (2 samples; Table 4-3). Both As and Cu concentrations exceed guidelines in the Selkirk-08 leachate (quartzite). This sample also had elevated As in the solid phase analysis (Table 4-2). The concentrations of the other elements that were elevated in the solid phase (Mn, Mo, and Sb) remain low in the leachate from all samples. Selkrik-11 (quartzite) and Selkirk-12 (surficial material) had elevated Hg.

Table 4-3:
Summary of Selected SFE Results

Sample ID	pH	Conductivity	Cl	F[a]	SO_4[a]	D-Al	D-Sb	D-As	D-Cr	D-Cu[a]	D-Mn[a]	D-Hg	D-Mo
	-	µS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	µg/L	mg/L
Short-term BC WQG	6.5-9.0	-	600	-	-	0.1	-	0.005	-	0.0076	1.2	-	2
Long-term BC WQG	-	-	150	1.13	218	0.05	0.009	-	0.001	0.0024	0.87	0.02	1
Quartzite													
Selkirk-02	7.82	211	39	0.27	3	0.088	0.0007	0.0008	0.00012	0.00077	0.00175	< 0.01	0.00053
Selkirk-04	9.44	219	8	0.23	<2	***1.06***	0.0010	0.0020	0.00043	0.00119	0.00202	< 0.01	0.00073
Selkirk-05	7.84	156	3	0.14	27	0.029	0.0002	0.0004	0.00004	0.00169	0.00074	< 0.01	0.00041
Selkirk-06	8.20	82	2	0.06	<2	***0.217***	0.0004	0.0008	0.00007	0.00082	0.00307	< 0.01	0.00043
Selkirk-07	8.61	94	2	0.10	<2	***0.214***	0.0002	0.0012	0.00009	0.00115	0.00277	< 0.01	0.00054
Selkirk-08	8.80	132	3	0.08	3	***0.461***	0.0004	***0.0054***	0.00026	0.00342	0.00237	< 0.01	0.00031
Selkirk-10	8.00	73	4	0.07	2	***0.148***	< 0.0002	0.0007	0.00008	0.00086	0.00176	< 0.01	0.00026
Selkirk-11	7.79	73	5	0.21	2	0.090	0.0007	0.0006	0.00015	0.00049	0.00233	0.04	0.00054
Quartzite (Blasted)													
Selkirk-13	7.66	46	1	0.08	3	0.055	0.0003	0.0004	0.00006	0.00041	0.00720	0.02	0.00016
Pelite													
Selkirk-01	8.36	93	3	0.24	3	***0.411***	0.0016	0.0034	0.00016	0.00230	0.00139	< 0.01	0.00088
Surficial Material													
Selkirk-03	8.15	117	1	0.21	2	***0.104***	< 0.0002	0.0007	0.00030	0.00237	0.00683	< 0.01	0.00036
Selkirk-09	7.94	85	2	0.11	<2	***0.129***	< 0.0002	0.0004	0.00003	0.00060	0.00399	< 0.01	0.00038
Selkirk-12	8.06	101	1	0.07	4	***0.145***	< 0.0002	0.0005	0.00009	0.00148	0.00330	0.03	0.00103

Notes:
[a]Hardness-dependent BC freshwater aquatic life WQG are based on a hardness of 60 mg/L
BC freshwater aquatic life WQG are for total metals
Grey shading indicates an exceedance of the long-term BC WQG
Bold red italics indicate an exceedance of the short-term BC WQG

4.4 XRD Results

The samples selected for X-ray Diffraction (XRD) represent the pelite unit (Selkirk-01) and quartzite samples covering the observed range of NP and AP values. All samples are dominantly quartz and muscovite (Table 4-4). No sulphide minerals were identified in the initial analysis of any of the samples; however, the detection limit for minerals is between 0.5% and 2%, depending on the crystallinity of the mineral. Minor quantities of carbonate minerals (≤2%) were identified in the quartzite samples and include calcite and ankerite. The quantity of calcite and ankerite do not correspond well with the amount of CaNP measured in the samples. However, the Selkirk-04 and Selkrik-08 samples have the highest calcite/ankerite content (1.6/2.0 % and 1.0/0.6 %, respectively) as well as higher CaNP (27.5 and 7.5 kg $CaCO_3$/t, respectively) relative to the other samples. The CaNP of sample Selkirk-04 is likely higher due to ankerite (2.0%). Minerals that may contribute to the slightly higher modified NP relative to the CaNP include chlorite and biotite.

Selkirk-04 and Selkirk-08 were submitted for reanalysis at the UBC laboratory to further investigate the discrepancy between the XRD and ABA results (Table 4-5). This analysis identified calcite (magnesian) and ankerite-dolomite as the two carbonates present. The percentage of carbonate in both samples was lower relative to the initial analysis and shows better agreement with the amount of CaNP measured. In addition, the reanalysis identified minor pyrite in the samples (0.1% and 0.6%, respectively) which corresponds to the sulphide S identified in the ABA analysis.

Table 4-4:
XRD Results

Mineral	Formula	Selkirk-01	Selkirk-04	Selkirk-06	Selkirk-08	Selkirk-10
		(wt %)	(wt %)	(wt %)	(wt %)	(wt %)
Quartz	SiO_2	23.9	28.4	68.2	67.1	81.9
Muscovite	$KAl_2(AlSi_3O_{10})(OH)_2$	56.2	55.0	25.9	10.1	5.2
Microcline	$KAlSi_3O_8$	10.9	3.3	2.0	12.5	9.2
Albite	$NaAlSi_3O_8$	4.7	2.6	0.3	6.9	1.8
Hematite	Fe_2O_3	1.8	0.1	0.2	0.1	0.1
Rutile	TiO_2	1.4	1.1	0.2	0.8	0.3
Biotite	$K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$	1.1	1.2	0.7	0.4	0.4
Calcite	$CaCO_3$	0.0	1.6	0.5	1.0	0.3
Chlorite	$(Fe,(Mg,Mn)_5,Al)(Si_3Al)O_{10}(OH)_8$	-	4.8	1.6	0.1	-
Ankerite	$CaFe(CO_3)_2$	-	2.0	0.3	0.6	0.8
Montmorillonite	$(Na,Ca)_{0.3}(Al,Mg)_2Si_2O_{10}(OH)_2 \cdot 10H_2O$	-	-	-	0.5	-
Total		100	100	100	100	100

Notes:
Zero values indicate that the mineral was included in the refinement, but the calculated concentration in below a measurable value.
Dashes indicate that the mineral was not identified by the analyst and not included in the refinement calculation for the sample.
The weight percent quantities indicated have been normalized to a sum of 100%. The quantity of amorphous material has not been determined.

Table 4-5: XRD Reanalysis Results for Selkirk-04 and Selkirk-08

Mineral	Ideal Formula	Selkirk-04	Selkirk-08
Quartz	SiO_2	36.9	67.5
Illite-Muscovite 2M1	$K_{0.65}Al_{2.0}Al_{0.65}Si_{3.35}O_{10}(OH)_2$- $KAl_2AlSi_3O_{10}(OH)_2$	48.6	7.0
Illite-Muscovite 1M	$K_{0.65}Al_{2.0}Al_{0.65}Si_{3.35}O_{10}(OH)_2$- $KAl_2AlSi_3O_{10}(OH)_2$	3.2	-
Kaolinite	$Al_2Si_2O_5(OH)_4$	3.2	1.4
K-feldspar (microcline intermediate)	$KAlSi_3O_8$	2.1	15.0
Plagioclase (albite)	$NaAlSi_3O_8$	2.3	7.5
Calcite, magnesian	$(Ca,Mg)CO_3$	1.3	0.3
Ankerite-Dolomite	$Ca(Fe^{2+},Mg,Mn)(CO_3)_2$ - $CaMg(CO_3)_2$	1.5	0.3
Rutile	TiO_2	0.8	0.5
Pyrite	FeS_2	0.1	0.6
Total		100	100

5. Conclusions and Recommendations

5. Conclusions and Recommendations

The main conclusions from the Selkirk Passing Lane field investigation and sample analyses are as follows:

- There are bedrock exposures of the Hamill Group stratigraphic unit along the Selkirk section of the highway. The majortiy of the exposure is a quartzite unit.
- Four of nine quartzite samples were classified as PAG. This is due in large part to the low NP of the quartzite, rather than a high AP. However, the sulphide S was greater than or equal to 0.20% in two of these samples.
- The pelite unit encountered in one bedrock outcrop is a minor unit in this area and is classified as non-PAG.
- The unconsolidated surficial materials collected along this road section are classified as non-PAG.
- The solid phase elemental analysis of the samples indicates that the majority of metals are not elevated relative to the AUCCC. The Mo concentrations are elevated above background in 7 of 9 quartzite samples and one surficial material sample. However, Mo remained well below BC WQGs in the SFE leachate.
- The SFE results indicate that Al, As, Cu, and Hg were leached at concentrations above BC WQGs and are potential parameters of concern in leachate.
- The XRD results from the reanalysis of Selkirk-04 and Selkirk-08 show good agreement with the ABA results for CaNP and sulphide content.

Since four of the samples collected were classified as PAG, further sampling is recommended once additional information is available on road alignment, locations of rock cuts, and estimated rock cut volumes. If possible, the additional sampling should take place when geotechnical drilling is occurring in order to sample unweathered bedrock. Recommendations on sampling locations and sample frequency will be dependent on the rock cut volumes along the road alignment. A further evaluation of the ML/ARD risk associated with the Selkirk Passing Lane highway expansion is proposed once this additional information is available.

6. Closure

6. Closure

This report has been prepared for the exclusive use of the BC Ministry of Transportation and Infrastructure for the assessment of the Selkirk Passing Lane Project. Please contact the undersigned should you require any additional information or clarification on the contents of this report.

Sincerely,

LORAX ENVIRONMENTAL SERVICES LTD.

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Appendices

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Appendix A.1: Site Visit Photos

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Appendix A.1: Site Visit Photos

Selkirk-01


Selkirk-02


Selkirk-03


Selkirk-04

Selkirk-05

Selkirk-06

Selkirk-07

Selkirk-08

Selkirk-09

Selkirk-10

Selkirk-11

Selkrik-12

Selkirk-13

Appendix B:
Selkirk Passing Lane Lab Results

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Appendix B.1: ABA Results

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Appendix B.1 ABA Results

Sample ID	Paste pH	TIC %	$CaCO_3$ NP	C(T) %	S(T) %	$S(SO_4)$ %	$S(S^{-2})$ %	Insoluble S %	AP	Modified NP	Net Modified NP	NPR (Mod NP/AP)	Fizz Test
Method Code	Sobek	CSB02V	Calc.	CSA06V	CSA06V	CSA07V	CSA08D	Calc.	Calc.	Modified	Calc.	Calc.	Sobek
LOD	0.2	0.01	n/a	0.005	0.005	0.01	0.01	n/a	n/a	0.5	n/a	n/a	n/a
Selkirk-01	8.49	<0.01	<0.8	0.02	0.01	<0.01	<0.01	0.01	<0.3	2.4	2.4	8.00	None
Selkirk-02	7.61	<0.01	<0.8	0.013	0.011	<0.01	<0.01	0.01	<0.3	2.0	2.0	6.67	None
Selkirk-03	8.05	1.59	132.5	1.75	0.014	<0.01	<0.01	0.01	<0.3	140.1	140.1	467	Moderate
Selkirk-04	8.86	0.33	27.5	0.359	0.069	<0.01	0.05	0.02	1.6	28.7	27.1	18.4	Slight
Selkirk-05	7.35	0.02	1.7	0.039	0.095	0.04	0.04	0.02	1.3	2.8	1.6	2.24	None
Selkirk-06	8.49	0.02	1.7	0.022	0.218	<0.01	0.2	0.02	6.3	2.5	-3.8	0.40	None
Selkirk-07	8.53	0.03	2.5	0.03	0.022	<0.01	<0.01	0.02	<0.3	3.3	3.3	11.0	None
Selkirk-08	8.74	0.09	7.5	0.094	0.312	<0.01	0.29	0.02	9.1	8.5	-0.6	0.94	None
Selkirk-09	8.40	<0.01	<0.8	0.025	0.007	<0.01	<0.01	<0.01	<0.3	2.2	2.2	7.33	None
Selkirk-10	8.75	<0.01	<0.8	0.019	0.013	<0.01	<0.01	0.01	<0.3	1.9	1.9	6.33	None
Selkirk-11	8.26	<0.01	<0.8	0.016	0.04	<0.01	0.02	0.02	0.6	1.4	0.8	2.24	None
Selkirk-12	8.56	1.53	127.5	1.64	0.014	<0.01	<0.01	0.01	<0.3	140.1	140.1	467	Moderate
Selkirk-13	8.49	0.01	0.8	0.036	0.017	0.01	<0.01	0.01	<0.3	2.5	2.5	8.33	None
Duplicates													
Selkirk-01	8.53									2.7			None
Selkirk-04				0.373	0.065								
Selkirk-10						<0.01							
Selkirk-13		0.01											
QC													
GTS-2A				2.04	0.33								
RTS-3A						1.05	2.54						
SY4		0.91											
NBM-1										40.6			Slight
Expected Values		0.91		2.01	0.341	0.98	2.46			40.4			Slight
Tolerance (+/-)		0.07		0.11	0.030	0.12	0.25			2.2			

Notes:

AP = Acid potential in tonnes $CaCO_3$ equivalent per 1000 tonnes of material. AP is determined from the measured sulphide-sulphur content.

NP = Neutralization potential in tonnes $CaCO_3$ equivalent per 1000 tonnes of material.

NET Modified NP = Modified NP - AP

Carbonate NP is calculated from TIC originating from carbonate minerals and is expressed in kg $CaCO_3$/tonne.

Sulphate Sulphur determined by 25% HCl Leach with S by ICP Finish

Sulphide Sulphur determined by Sobek 1:7 Nitric Acid Leach with S by ICP Finish

Insoluble S is acid insoluble S (Total S - (Sulphate S + Sulphide S)).

NPR = Neutralization Potential Ratio

Grey shading indicates a NPR < 2

Appendix B.2:
Solid Phase Metals Results

BRITISH COLUMBIA
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Appendix B.2 Solid Phase Metals Results

Sample ID	Ag ppm	Al %	As ppm	Ba ppm	Be ppm	Bi ppm	Ca %	Cd ppm	Ce ppm	Co ppm	Cr ppm	Cs ppm	Cu ppm
Method Code	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B
LOD	0.01	0.01	1	5	0.1	0.02	0.01	0.01	0.05	0.1	1	0.05	0.5
Selkirk-01	<0.01	0.39	<1	65	1	0.17	0.03	<0.01	14	4.5	75	2.57	6.3
Selkirk-02	<0.01	0.37	1	70	0.5	0.08	0.03	0.01	9.03	2.3	125	2.23	3.6
Selkirk-03	0.04	0.81	10	99	0.2	0.13	3.83	0.06	35.7	6.7	137	0.56	12.8
Selkirk-04	0.02	1.05	<1	95	0.5	0.12	0.85	0.04	88.3	17.1	65	0.91	1.6
Selkirk-05	0.03	0.49	12	33	0.5	0.08	0.07	0.02	27.6	8.9	156	0.37	64.6
Selkirk-06	<0.01	0.26	2	26	<0.1	0.02	0.07	0.04	20.9	2.8	182	0.29	3
Selkirk-07	0.02	0.2	1	26	<0.1	<0.02	0.1	<0.01	13.4	1.1	208	0.18	3.1
Selkirk-08	0.02	0.39	24	28	0.1	0.07	0.29	0.02	24.5	3.8	163	0.25	2.2
Selkirk-09	<0.01	0.22	<1	25	<0.1	<0.02	0.03	0.01	18.5	1.6	180	0.13	2.4
Selkirk-10	<0.01	0.12	<1	52	<0.1	<0.02	0.02	0.01	4.85	1.1	186	0.24	2.2
Selkirk-11	0.03	0.26	<1	45	0.2	<0.02	0.02	0.04	13.4	1.5	176	0.62	2.2
Selkirk-12	<0.01	0.44	2	31	0.1	0.08	4.4	0.02	33.8	4	117	0.53	5.5
Selkirk-13	<0.01	0.3	<1	663	0.2	<0.02	0.04	0.01	10.5	1.3	184	0.55	2
QC													
OREAS 901	0.26	1.09	65	93	4.3	4.52	0.08	0.05	84	68.8	20	1.08	1420
Certified Values	0.276	0.992	66	86	4.49	4.35	0.091	0.05	78	73	23.0	0.97	1440
Tolerance (%)	19.06	19.35	13.79	24.53	15.57	11.15	37.47	#N/A	15.77	16.85	20.87	40.21	10.09
AUCCC	0.053	8.15	4.8	628	2.1	0.16	2.57	0.09	63	17.3	92	4.9	28

Notes:
AUCCC: Average upper continental crustal concentrations (Rudnick and Gao, 2014)
Grey shading indicates values greater than 3x the AUCCC

Appendix B.2 Solid Phase Metals Results

Sample ID	Fe %	Ga ppm	Ge ppm	Hf ppm	Hg ppm	In ppm	K %	La ppm	Li ppm	Lu ppm	Mg %	Mn ppm	Mo ppm
Method Code	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B
LOD	0.01	0.1	0.1	0.05	0.01	0.02	0.01	0.1	1	0.01	0.01	2	0.05
Selkirk-01	2.86	1.2	<0.1	<0.05	0.03	<0.02	0.34	4.4	1	<0.01	0.03	39	1.34
Selkirk-02	1.04	1.1	<0.1	<0.05	0.02	<0.02	0.26	3	2	<0.01	0.04	49	2.49
Selkirk-03	2.1	2.2	<0.1	0.07	0.02	<0.02	0.15	16.1	13	0.04	1.09	436	3.05
Selkirk-04	2.73	1.9	<0.1	0.2	<0.01	<0.02	0.35	30.7	4	0.04	0.51	216	1.4
Selkirk-05	1.9	1.1	<0.1	0.08	0.02	<0.02	0.21	9.6	6	0.01	0.12	42	3.39
Selkirk-06	0.55	0.6	<0.1	0.06	0.02	<0.02	0.2	8.8	<1	<0.01	0.03	51	3.88
Selkirk-07	0.48	0.5	<0.1	<0.05	<0.01	<0.02	0.1	4.2	<1	<0.01	0.02	88	4.54
Selkirk-08	0.95	0.7	<0.1	<0.05	<0.01	<0.02	0.12	8.2	1	<0.01	0.11	85	3.69
Selkirk-09	0.89	0.7	<0.1	<0.05	0.01	<0.02	0.11	6.6	2	<0.01	0.06	78	3.97
Selkirk-10	0.39	0.3	<0.1	<0.05	<0.01	<0.02	0.1	1.6	<1	<0.01	<0.01	36	4
Selkirk-11	0.41	0.7	<0.1	<0.05	<0.01	<0.02	0.21	4.5	1	<0.01	0.03	31	3.64
Selkirk-12	1.1	1.4	<0.1	<0.05	<0.01	<0.02	0.12	14.2	9	0.04	0.56	179	2.71
Selkirk-13	0.57	0.6	<0.1	0.05	<0.01	<0.02	0.17	3.6	2	<0.01	0.05	38	3.93
QC													
OREAS 901	3.76	3	0.1	0.96	0.03	0.2	0.55	38.7	3	0.22	0.15	292	3.04
Certified Values	3.70	3.15	0.11	0.8	0.02	0.21	0.512	38.1	3.1	0.22	0.124	300	3.23
Tolerance (%)	10.68	31.43	237.27	#N/A	#N/A	33.81	14.88	10.66	98.78	40.91	30.16	11.67	13.87
AUCCC	3.92	17.5	1.4	5.3	0.05	0.056	2.32	31	24	0.31	1.5	77.4	1.1

Notes:
AUCCC: Average upper continental crustal concentrations (Rudnick and Gao, 2014)
Grey shading indicates values greater than 3x the AUCCC

Appendix B.2 Solid Phase Metals Results

Sample ID	Na %	Nb ppm	Ni ppm	P ppm	Pb ppm	Rb ppm	S %	Sb ppm	Sc ppm	Se ppm	Sn ppm	Sr ppm	Ta ppm
Method Code	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B
LOD	0.01	0.05	0.5	0.005	0.2	0.2	0.01	0.05	0.1	1	0.3	0.5	0.05
Selkirk-01	0.02	0.22	5.6	0.01	6.7	15.1	<0.01	1.48	1.8	<1	1.1	6	<0.05
Selkirk-02	0.03	0.11	4.7	<0.01	3.4	10.8	<0.01	0.37	0.9	<1	1.3	3.4	<0.05
Selkirk-03	0.02	0.16	17.9	0.03	9.3	7.4	<0.01	0.42	2	<1	0.6	78.9	<0.05
Selkirk-04	0.04	<0.05	12.2	0.03	6.5	11.1	0.06	0.36	1.7	<1	0.7	36.2	<0.05
Selkirk-05	0.02	<0.05	10.5	0.02	2.8	6.1	0.09	0.62	1.1	<1	0.7	7.9	<0.05
Selkirk-06	0.01	<0.05	7.6	<0.01	0.7	5.1	0.23	0.11	0.5	<1	0.8	3.1	<0.05
Selkirk-07	0.02	<0.05	4.2	<0.01	1.1	3.1	0.01	0.06	0.7	<1	0.5	3.6	<0.05
Selkirk-08	0.03	<0.05	5.4	<0.01	2.3	3.7	0.3	0.12	0.9	<1	0.6	30.5	<0.05
Selkirk-09	0.01	<0.05	10.4	<0.01	1.2	3.8	<0.01	0.18	0.5	<1	0.4	3.2	<0.05
Selkirk-10	0.02	<0.05	3.7	<0.01	1.2	3.1	<0.01	<0.05	0.4	<1	0.7	3.2	<0.05
Selkirk-11	0.01	<0.05	4.2	<0.01	1.3	6.5	0.04	0.14	0.5	<1	0.7	2.3	<0.05
Selkirk-12	0.02	0.3	14.4	0.03	5.5	7.9	<0.01	0.1	1.4	<1	0.5	106	<0.05
Selkirk-13	0.01	<0.05	4.2	<0.01	1.3	5.7	0.01	0.16	0.5	<1	0.5	16.5	<0.05
QC													
OREAS 901	0.02	0.12	36	0.07	14.2	24.6	0.03	1.41	5.1	3	1	21	<0.05
Certified Values	0.01	0.1	34.7	0.059	14.6	23.9	0.033	1.47	5.55	2.68	0.58	21.0	0.02
Tolerance (%)	#N/A	#N/A	13.60	31.19	13.42	18.95	85.76	46.94	14.50	103.28	139.31	15.95	#N/A
AUCCC	2.43	12	47	0.066	17	84	0.062	0.4	14	0.09	2.1	320	1

Notes:
AUCCC: Average upper continental crustal concentrations (Rudnick and Gao, 2014)
Grey shading indicates values greater than 3x the AUCCC

Appendix B.2 Solid Phase Metals Results

Sample ID	Tb ppm	Te ppm	Th ppm	Ti %	Tl ppm	U ppm	V ppm	W ppm	Y ppm	Yb ppm	Zn ppm	Zr ppm
Method Code	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B	ICM14B
LOD	0.02	0.05	0.1	0.01	0.02	0.05	1	0.1	0.05	0.1	1	0.5
Selkirk-01	0.17	0.06	8	0.01	0.09	0.85	7	0.1	0.99	<0.1	21	1.5
Selkirk-02	0.08	<0.05	5.1	<0.01	0.07	0.46	6	<0.1	0.76	<0.1	19	1.5
Selkirk-03	0.26	<0.05	7.2	0.01	0.06	0.5	9	0.1	3.68	0.3	29	2.9
Selkirk-04	0.44	<0.05	14.9	<0.01	0.07	2.02	4	<0.1	3.67	0.3	12	6.4
Selkirk-05	0.17	<0.05	7.3	<0.01	0.04	2.72	2	<0.1	1.3	0.1	6	3.2
Selkirk-06	0.07	<0.05	3.6	<0.01	0.03	0.32	1	<0.1	0.63	<0.1	6	1.9
Selkirk-07	0.07	<0.05	2	<0.01	<0.02	0.2	1	<0.1	0.69	<0.1	2	0.8
Selkirk-08	0.14	<0.05	8.5	<0.01	0.02	0.48	1	<0.1	1.06	<0.1	4	1.4
Selkirk-09	0.08	<0.05	3.5	<0.01	0.02	0.2	2	<0.1	0.64	<0.1	6	1.2
Selkirk-10	0.05	<0.05	1.3	<0.01	<0.02	0.11	<1	<0.1	0.41	<0.1	19	0.8
Selkirk-11	0.09	<0.05	3.9	<0.01	0.04	0.25	1	<0.1	0.79	<0.1	6	1.1
Selkirk-12	0.27	<0.05	4.9	0.02	0.06	0.43	6	<0.1	3.61	0.3	17	1.2
Selkirk-13	0.09	<0.05	4.2	<0.01	0.04	0.19	2	<0.1	0.76	<0.1	5	1.4
QC												
OREAS 901	0.8	0.1	9.4	<0.01	0.35	6.35	20	1.2	18.6	1.5	16	31.4
Certified Values	0.77	0.076	9.13	0.01	0.34	5.84	21	1.1	18.8	1.49	20.2	31.6
Tolerance (%)	16.49	174.47	12.74	#N/A	24.71	25.33	#N/A	#N/A	10.66	26.78	22.38	13.96
AUCCC	0.9	-	11	0.384	0.9	2.7	97	1.9	21	2	67	193

Notes:
AUCCC: Average upper continental crustal concentrations (Rudnick and Gao, 2014)
Grey shading indicates values greater than 3x the AUCCC

Appendix B.3: SFE Results

British Columbia
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Appendix B.3 SFE Results

Sample ID			Selkirk-01	Selkirk-02	Selkirk-03	Selkirk-04	Selkirk-05	Selkirk-06	Selkirk-07
Parameter	**Method**	**Units**							
Volume Nanopure Water		mL	750	750	750	750	750	750	750
Sample Weight		g	250	250	250	250	250	250	250
pH	meter		8.36	7.82	8.15	***9.44***	7.84	8.20	8.61
Redox	meter	mV	357	398	411	309	392	389	356
Conductivity	meter	µS/cm	93	211	117	219	156	82	94
Acidity (to pH 4.5)	titration	mg $CaCO_3$/L	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Total Acidity (to pH 8.3)	titration	mg $CaCO_3$/L	#N/A	2.3	1.9	#N/A	2.6	1.5	#N/A
Alkalinity	titration	mg $CaCO_3$/L	32.2	25.5	50.8	83.7	28.9	33.1	38.1
Chloride	Photometry	mg/L	3	39	1	8	3	2	2
Fluoride[a]	ISE	mg/L	0.24	0.27	0.21	0.23	0.14	0.06	0.10
Sulphate[a]	Turbidity	mg/L	3	3	2	<2	27	<2	<2
Ion Balance									
Major Anions	Calc	meq/L	0.80	1.68	1.10	1.92	1.23	0.72	0.82
Major Cations	Calc	meq/L	0.79	1.68	1.02	2.03	1.23	0.68	0.83
Difference	Calc	meq/L	0.01	0.00	0.08	-0.11	0.00	0.04	0.00
Balance (%)	Calc	%	0.7%	0.1%	3.6%	-2.8%	0.0%	2.7%	-0.2%
Dissolved Metals									
Hardness CaCO3		mg/L	8.7	4.9	42.1	2.8	46.0	22.0	7.4
Aluminum Al	ICP-MS	mg/L	***0.411***	0.088	***0.104***	***1.06***	0.029	***0.217***	***0.214***
Antimony Sb	ICP-MS	mg/L	0.0016	0.0007	< 0.0002	0.0010	0.0002	0.0004	0.0002
Arsenic As	ICP-MS	mg/L	0.0034	0.0008	0.0007	0.0020	0.0004	0.0008	0.0012
Barium Ba	ICP-MS	mg/L	0.0172	0.0157	0.0132	0.00325	0.00535	0.00538	0.00361
Beryllium Be	ICP-MS	mg/L	0.000025	0.000008	< 0.000007	0.000012	< 0.000007	< 0.000007	< 0.000007
Bismuth Bi	ICP-MS	mg/L	< 0.000007	0.000007	< 0.000007	< 0.000007	< 0.000007	< 0.000007	< 0.000007
Boron B	ICP-MS	mg/L	0.010	0.009	0.006	0.009	0.009	0.007	0.007
Cadmium Cd[a]	ICP-MS	mg/L	0.000012	0.000004	0.000019	0.000009	0.000014	0.000005	0.000005
Calcium Ca	ICP-MS	mg/L	3.03	1.63	14.6	0.94	15.7	7.81	2.59
Chromium Cr	ICP-MS	mg/L	0.00016	0.00012	0.00030	0.00043	0.00004	0.00007	0.00009
Cobalt Co	ICP-MS	mg/L	0.000093	0.000052	0.000102	0.000061	0.000033	0.000059	0.000046
Copper Cu[a]	ICP-MS	mg/L	0.00230	0.00077	0.00237	0.00119	0.00169	0.00082	0.00115
Iron Fe	ICP-MS	mg/L	0.024	0.032	0.106	0.152	0.014	0.024	0.038
Lead Pb[a]	ICP-MS	mg/L	0.00017	0.00006	0.00011	0.00019	0.00002	0.00006	0.00008
Lithium Li	ICP-MS	mg/L	0.0007	0.0004	0.0016	0.0006	0.0041	0.0008	0.0007
Magnesium Mg	ICP-MS	mg/L	0.273	0.212	1.34	0.107	1.66	0.616	0.235
Manganese Mn[a]	ICP-MS	mg/L	0.00139	0.00175	0.00683	0.00202	0.00074	0.00307	0.00277
Mercury Hg	ICP-MS	µg/L	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
Molybdenum Mo	ICP-MS	mg/L	0.00088	0.00053	0.00036	0.00073	0.00041	0.00043	0.00054
Nickel Ni[a]	ICP-MS	mg/L	0.0001	0.0002	0.0003	0.0002	0.0002	0.0003	0.0003
Phosphorus P	ICP-MS	mg/L	0.038	0.028	0.006	0.043	0.006	0.005	0.016
Potassium K	ICP-MS	mg/L	5.04	1.48	0.150	3.94	2.92	3.86	2.47
Selenium Se	ICP-MS	mg/L	0.00010	0.00006	0.00009	0.00006	0.00104	< 0.00004	0.00007
Silicon Si	ICP-MS	mg/L	2.42	1.79	3.23	2.99	2.61	2.65	2.62
Silver Ag[a]	ICP-MS	mg/L	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005
Sodium Na	ICP-MS	mg/L	10.2	35.3	3.68	40.1	5.44	2.70	13.6
Strontium Sr	ICP-MS	mg/L	0.0123	0.0071	0.0402	0.0029	0.0687	0.0208	0.0081
Sulphur (S)	ICP-MS	mg/L	1.0	1.7	0.4	0.4	11.9	0.6	0.3
Thallium Tl	ICP-MS	mg/L	0.000037	< 0.000005	0.000020	0.000009	0.000018	< 0.000005	< 0.000005
Tin Sn	ICP-MS	mg/L	0.00005	0.00014	0.00003	0.00014	0.00003	0.00005	0.00007
Titanium Ti	ICP-MS	mg/L	0.00100	0.00074	0.00096	0.00896	0.00023	0.00048	0.00020
Uranium U	ICP-MS	mg/L	0.000316	0.000060	0.000090	0.00827	0.000883	0.000355	0.000653
Vanadium V	ICP-MS	mg/L	0.00068	0.00033	0.00015	0.00195	0.00002	0.00025	0.00028
Zinc Zn[a]	ICP-MS	mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002
Zirconium Zr	ICP-MS	mg/L	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002

Notes:
[a]Hardness-dependent BC freshwater aquatic life WQG are based on a hardness of 60 mg/L
BC WQG are for total metals, except for D-Al, D-Cd and D-Fe
Grey shading indicates an exceedance of the long-term BC WQG
Bold italic text indicates an exceedance of the short-term BC WQG

Appendix B.3 SFE Results

Sample ID	**Selkirk-08**	**Selkirk-09**	**Selkirk-10**	**Selkirk-11**	**Selkirk-12**	**Selkirk-13**	**Blank**	**BC Freshwater Aquatic Life WQG**	
Parameter								**Short-term**	**Long-term**
Volume Nanopure Water	750	750	750	750	750	750	750	-	-
Sample Weight	250	250	250	250	250	250	-	-	-
pH	8.80	7.94	8.00	7.79	8.06	7.66	5.99	6.5-9.0	
Redox	346	432	421	428	433	421	-	-	-
Conductivity	132	85	73	73	101	46	2	-	-
Acidity (to pH 4.5)	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	-	-	-
Total Acidity (to pH 8.3)	#N/A	2.1	1.7	2.0	1.7	2.5	-	-	-
Alkalinity	52.3	32.6	26.8	21.9	34.7	13.6	-	-	-
Chloride	3	2	4	5	1	1	-	600	150
Fluoride[a]	0.08	0.11	0.07	0.21	0.07	0.08	-	-	1.13
Sulphate[a]	3	<2	2	2	4	3	-	-	218
Ion Balance									
Major Anions	1.20	0.72	0.69	0.63	0.81	0.37	#N/A	-	-
Major Cations	1.21	0.75	0.69	0.63	0.88	0.41	#N/A	-	-
Difference	-0.01	-0.04	0.00	0.00	-0.07	-0.04	#N/A	-	-
Balance (%)	-0.6%	-2.5%	0.3%	-0.2%	-4.2%	-5.1%	#N/A	-	-
Dissolved Metals									
Hardness CaCO3	6.3	30.0	15.0	7.5	38.7	12.1	-	-	-
Aluminum Al	***0.461***	***0.129***	***0.148***	0.090	***0.145***	0.055	-	0.1	0.05
Antimony Sb	0.0004	< 0.0002	< 0.0002	0.0007	< 0.0002	0.0003	-	-	0.009
Arsenic As	***0.0054***	0.0004	0.0007	0.0006	0.0005	0.0004	-	0.005	-
Barium Ba	0.00371	0.0131	0.0283	0.00899	0.00860	0.177	-	-	1
Beryllium Be	0.000007	< 0.000007	< 0.000007	< 0.000007	< 0.000007	< 0.000007	-	-	0.00013
Bismuth Bi	< 0.000007	< 0.000007	< 0.000007	< 0.000007	< 0.000007	< 0.000007	-	-	-
Boron B	0.007	0.014	0.012	0.010	0.006	0.010	-	-	1.2
Cadmium Cd[a]	0.000005	0.000016	0.000013	0.000007	0.000007	0.000011	-	0.00035	0.000145
Calcium Ca	2.13	11.6	5.69	2.75	13.8	4.18	-	-	-
Chromium Cr	0.00026	0.00003	0.00008	0.00015	0.00009	0.00006	-	-	0.001
Cobalt Co	0.000084	0.000071	0.000058	0.000043	0.000180	0.000022	-	0.11	0.004
Copper Cu[a]	0.00342	0.00060	0.00086	0.00049	0.00148	0.00041	-	0.0076	0.0024
Iron Fe	0.098	0.083	0.036	0.033	0.042	0.020	-	0.35	-
Lead Pb[a]	0.00009	0.00004	0.00006	0.00004	0.00007	0.00002	-	0.043	0.005
Lithium Li	0.0007	0.0001	0.0025	0.0006	0.0011	0.0010	-	-	-
Magnesium Mg	0.242	0.257	0.184	0.160	1.03	0.405	-	-	-
Manganese Mn[a]	0.00237	0.00399	0.00176	0.00233	0.00330	0.00720	-	1.2	0.87
Mercury Hg	< 0.01	< 0.01	< 0.01	0.04	0.03	0.02	-	-	0.02
Molybdenum Mo	0.00031	0.00038	0.00026	0.00054	0.00103	0.00016	-	2	1
Nickel Ni[a]	0.0005	0.0005	0.0006	0.0002	0.0008	0.0011	-	-	0.025
Phosphorus P	0.035	0.039	0.019	0.027	0.005	0.030	-	-	-
Potassium K	3.95	3.06	4.58	2.15	1.86	4.20	-	-	-
Selenium Se	0.00007	0.00020	0.00012	0.00014	0.00017	0.00005	-	-	0.002
Silicon Si	4.27	2.03	3.10	2.21	1.96	2.13	-	-	-
Silver Ag[a]	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	< 0.00005	-	0.0001	0.00005
Sodium Na	21.5	1.43	5.90	9.60	0.98	1.18	-	-	-
Strontium Sr	0.0078	0.0289	0.0259	0.00850	0.0349	0.0295	-	-	-
Sulphur (S)	1.6	< 0.1	< 0.1	0.1	1.9	1.3	-	-	-
Thallium Tl	< 0.000005	< 0.000005	0.000005	< 0.000005	< 0.000005	< 0.000005	-	-	0.0008
Tin Sn	0.00004	0.00005	0.00004	0.00005	0.00002	0.00003	-	-	-
Titanium Ti	0.00293	0.00034	0.00029	0.00024	0.00046	0.00046	-	-	-
Uranium U	0.000884	0.000068	0.000098	0.000025	0.000192	0.000020	-	-	0.0085
Vanadium V	0.00121	0.00016	0.00023	0.00031	0.00018	0.00024	-	-	-
Zinc Zn[a]	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	-	0.033	0.0075
Zirconium Zr	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	< 0.002	-	-	-

Notes:
[a]Hardness-dependent BC freshwater aquatic life WQG are based on a hardness of 60 mg/L
BC WQG are for total metals, except for D-Al, D-Cd and D-Fe
Grey shading indicates an exceedance of the long-term BC WQG
Bold italic text indicates an exceedance of the short-term BC WQG

Appendix B.4: XRD Results

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

Quantitative X-Ray Diffraction by Rietveld Refinement

Report Prepared for:	*SGS Canada Inc*
Project Number/ LIMS No.	*14094-101B/MI4517-JUL18*
Sample Receipt:	*July 23, 2018*
Sample Analysis:	*July 24, 2018*
Batch Number:	*1831 Selkirk and Doyle*
Reporting Date:	*July 27, 2018*

Instrument:	BRUKER AXS D8 Advance Diffractometer
Test Conditions:	Co radiation, 40 kV, 35 mA Regular Scanning: Step: 0.02°, Step time: 1s, 2θ range: 3-80°
Interpretations :	PDF2/PDF4 powder diffraction databases issued by the International Center for Diffraction Data (ICDD). DiffracPlus Eva and Topas software.
Detection Limit :	0.5-2%. Strongly dependent on crystallinity.

Contents:

Kim Gibbs, H.B.Sc., P.Geo.
Senior Mineralogist

Huyun Zhou, Ph.D., P.Geo.
Senior Mineralogist

ACCREDITATION: SGS Minerals Services Lakefield is accredited to the requirements of ISO/IEC 17025 for specific tests as listed on our scope of accreditation, including geochemical, mineralogical and trade mineral tests. To view a list of the accredited methods, please visit the following website and search SGS Canada - Minerals Services - Lakefield: http://palcan.scc.ca/SpecsSearch/GLSearchForm.do.

Method Summary

The Rietveld Method of Mineral Identification by XRD (ME-LR-MIN-MET-MN-D05) method used by SGS Minerals Services is accredited to the requirements of ISO/IEC 17025.

Mineral Identification and Interpretation:

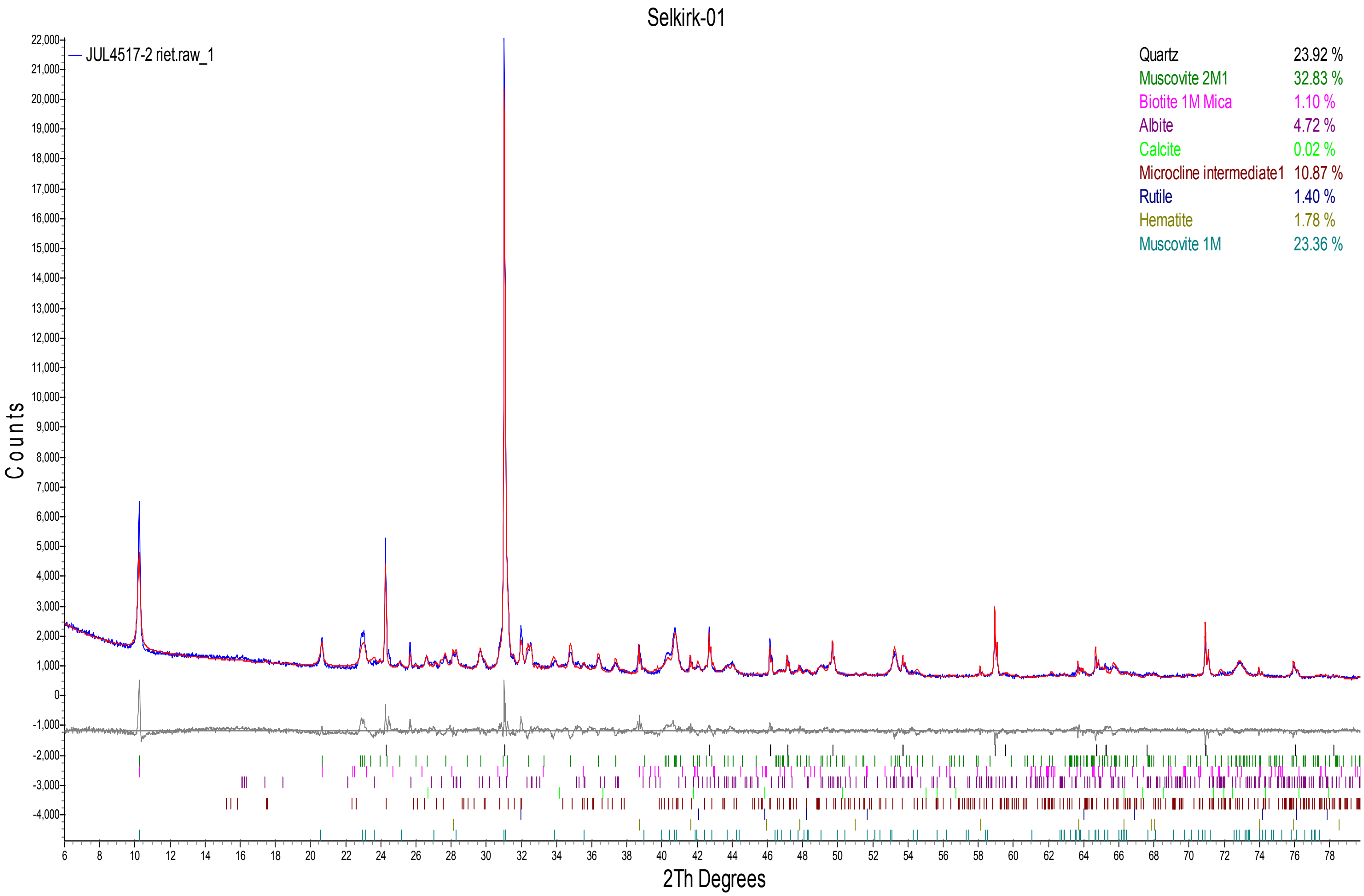
Mineral identification and interpretation involves matching the diffraction pattern of an unknown material to patterns of single-phase reference materials. The reference patterns are compiled by the Joint Committee on Powder Diffraction Standards - International Center for Diffraction Data (JCPDS-ICDD) database and released on software as Powder Diffraction Files (PDF).

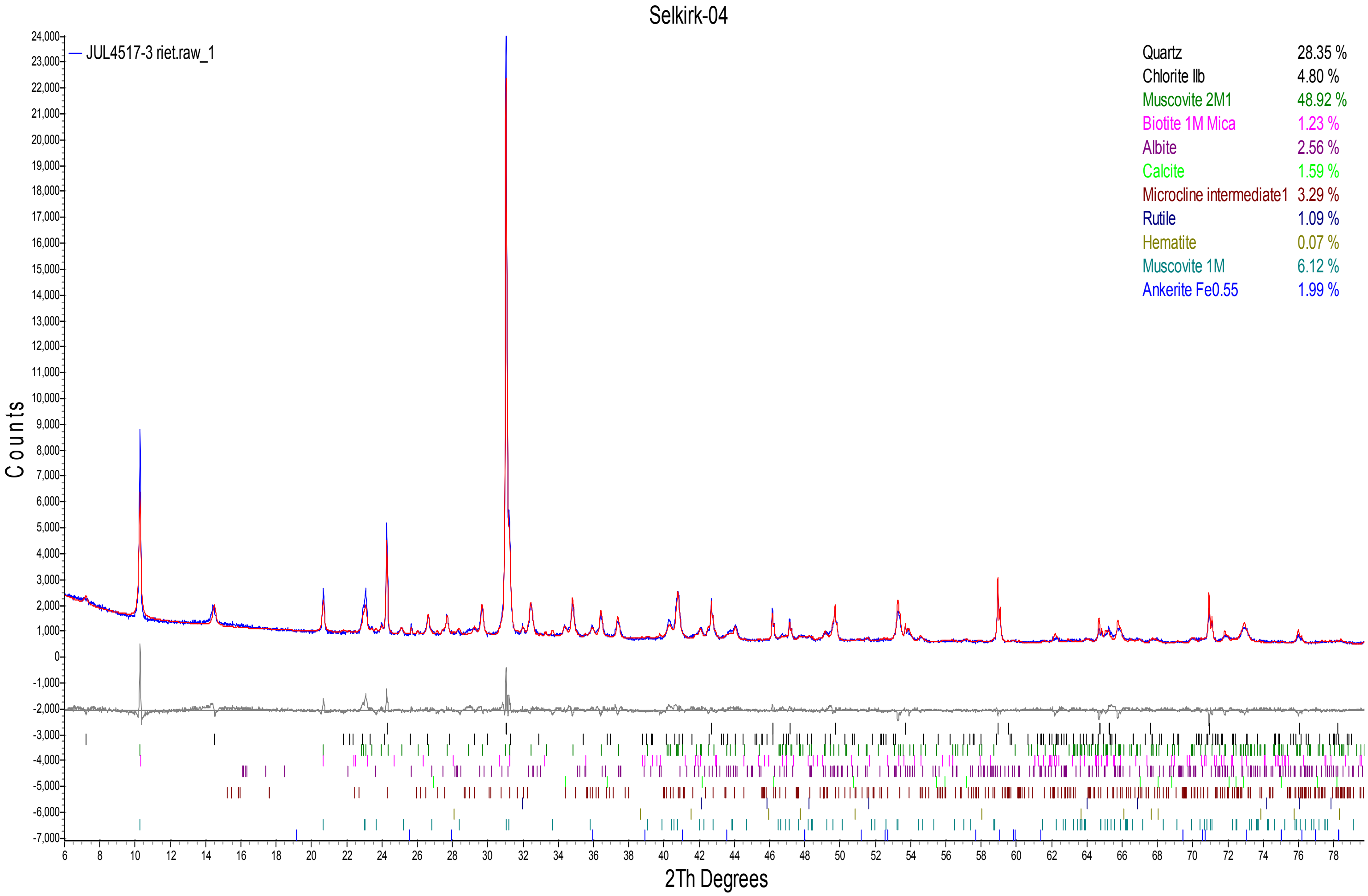
Interpretations do not reflect the presence of non-crystalline and/or amorphous compounds, except when internal standards have been added by request. Mineral proportions may be strongly influenced by crystallinity, crystal structure and preferred orientations. Mineral or compound identification and quantitative analysis results should be accompanied by supporting chemical assay data or other additional tests.

Quantitative Rietveld Analysis:

Quantitative Rietveld Analysis is performed by using Topas 4.2 (Bruker AXS), a graphics based profile analysis program built around a non-linear least squares fitting system, to determine the amount of different phases present in a multicomponent sample. Whole pattern analyses are predicated by the fact that the X-ray diffraction pattern is a total sum of both instrumental and specimen factors. Unlike other peak intensity-based methods, the Rietveld method uses a least squares approach to refine a theoretical line profile until it matches the obtained experimental patterns.

Rietveld refinement is completed with a set of minerals specifically identified for the sample. Zero values indicate that the mineral was included in the refinement calculations, but the calculated concentration was less than 0.05wt%. Minerals not identified by the analyst are not included in refinement calculations for specific samples and are indicated with a dash.


Selkirk-01
JUL4517-2 riet.raw_1
Quartz 23.92 %
Muscovite 2M1 32.83 %
Biotite 1M Mica 1.10 %
Albite 4.72 %
Calcite 0.02 %
Microcline intermediate1 10.87 %
Rutile 1.40 %
Hematite 1.78 %
Muscovite 1M 23.36 %
Counts
2Th Degrees


Selkirk-04
JUL4517-3 riet.raw_1
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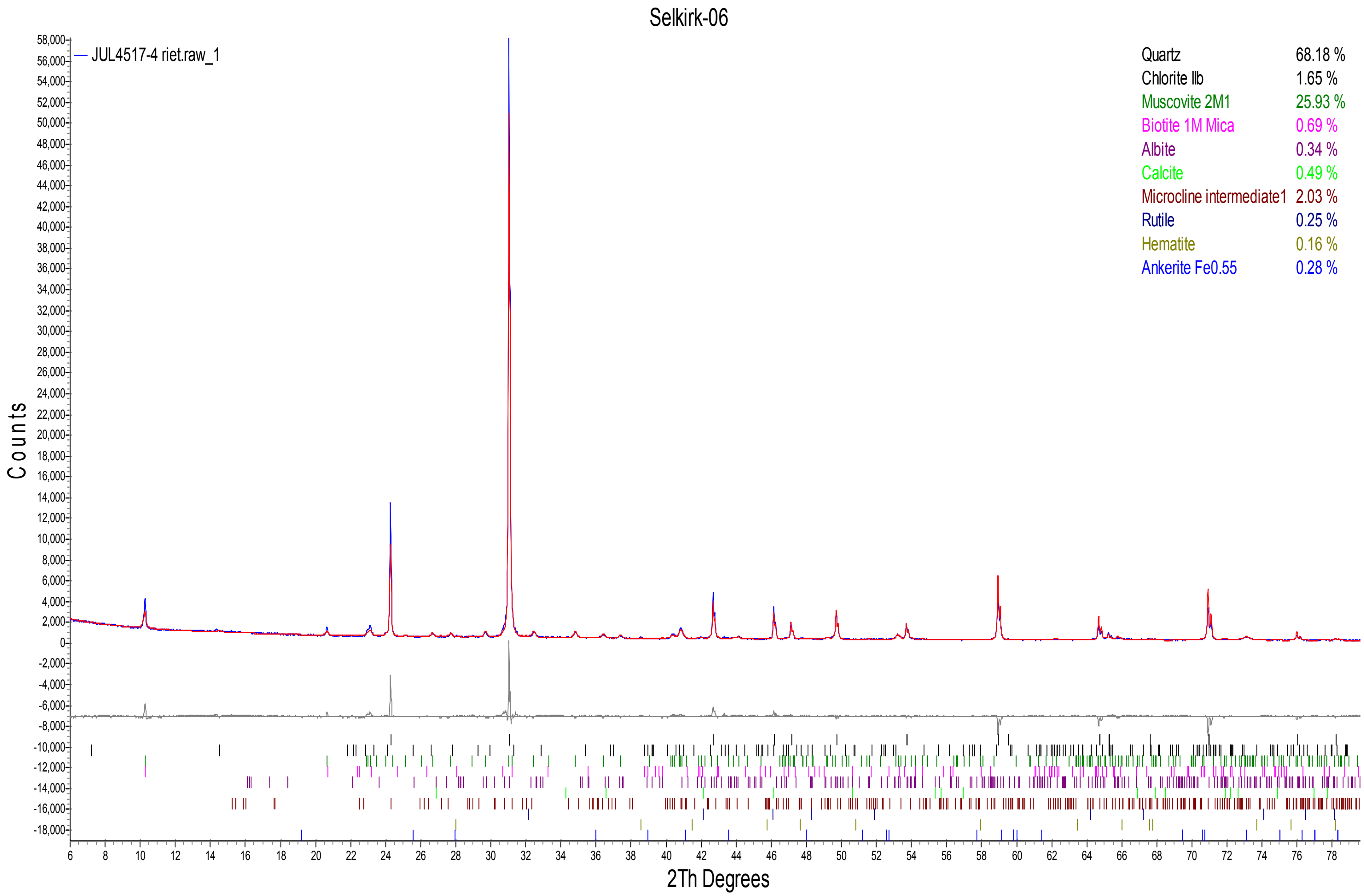
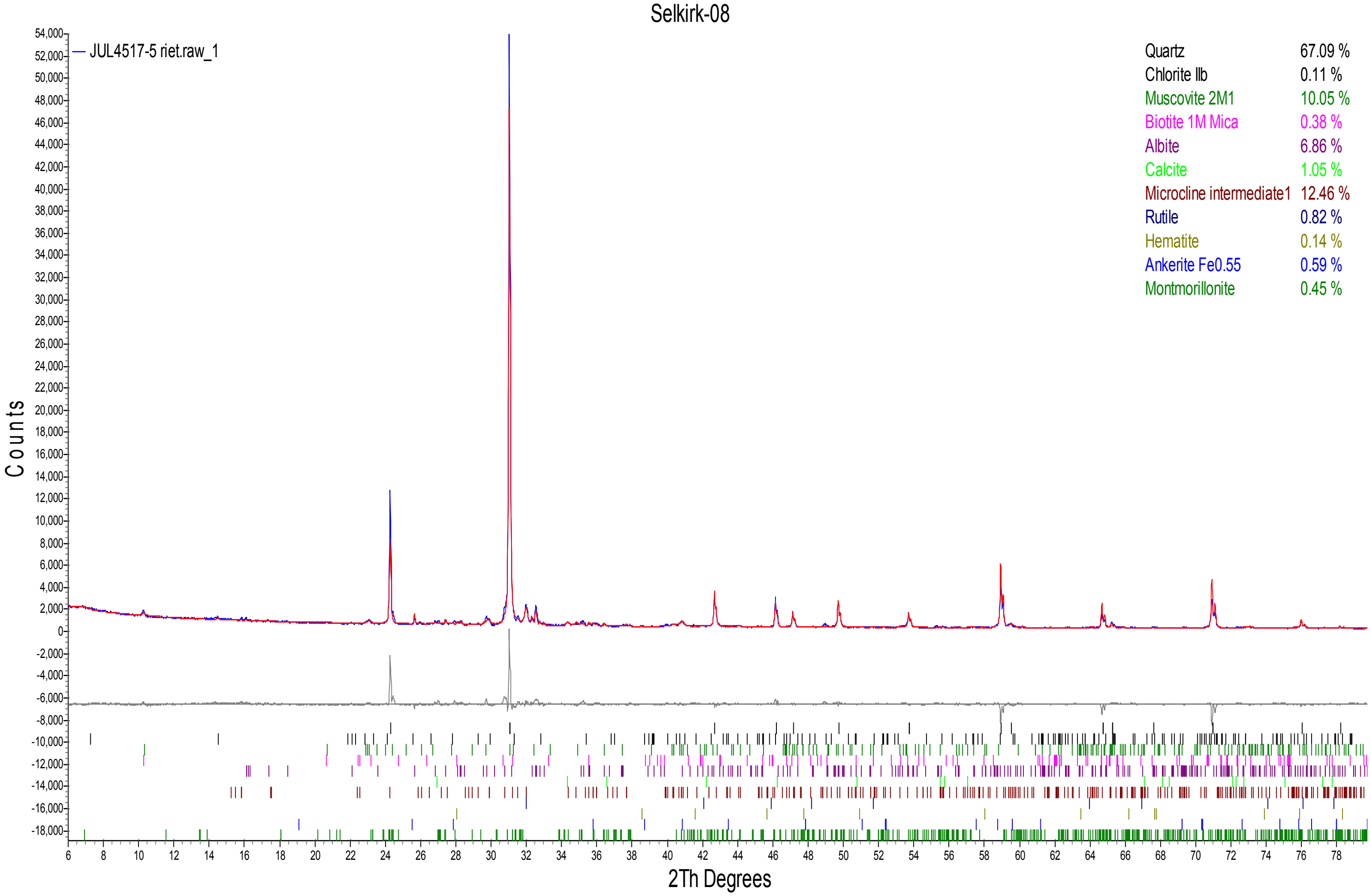
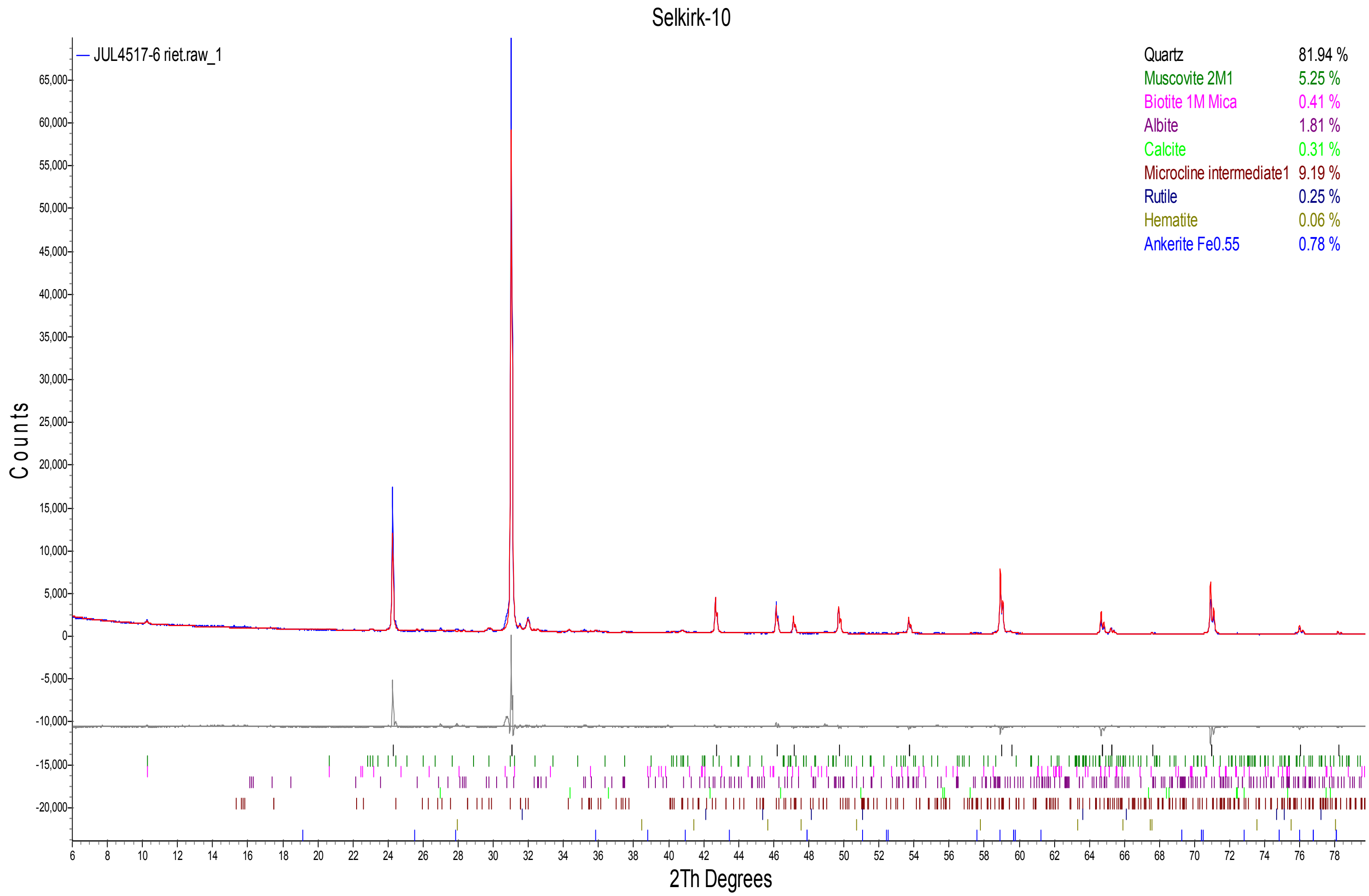
2Th Degrees
Quartz 28.35 %
Chlorite IIb 4.80 %
Muscovite 2M1 48.92 %
Biotite 1M Mica 1.23 %
Albite 2.56 %
Calcite 1.59 %
Microcline intermediate1 3.29 %
Rutile 1.09 %
Hematite 0.07 %
Muscovite 1M 6.12 %
Ankerite Fe0.55 1.99 %


Selkirk-06
JUL4517-4 riet.raw_1
Quartz 68.18 %
Chlorite IIb 1.65 %
Muscovite 2M1 25.93 %
Biotite 1M Mica 0.69 %
Albite 0.34 %
Calcite 0.49 %
Microcline intermediate1 2.03 %
Rutile 0.25 %
Hematite 0.16 %
Ankerite Fe0.55 0.28 %
Counts
2Th Degrees

SGS Canada Inc
14094-101B/MI4517-JUL18
27-Jul-18




Selkirk-10
JUL4517-6 riet.raw_1
Quartz 81.94 %
Muscovite 2M1 5.25 %
Biotite 1M Mica 0.41 %
Albite 1.81 %
Calcite 0.31 %
Microcline intermediate1 9.19 %
Rutile 0.25 %
Hematite 0.06 %
Ankerite Fe0.55 0.78 %
Counts
2Th Degrees

QUANTITATIVE PHASE ANALYSIS OF 2 POWDER SAMPLES USING THE RIETVELD METHOD AND X-RAY POWDER DIFFRACTION DATA.

Project: 1831 Selkirk and Doyle - PO# 43098

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EXPERIMENTAL METHOD

The two samples of **Project 1831 Selkirk and Doyle** were reduced to the optimum grain-size range for quantitative X-ray analysis (<10 μm) by grinding under ethanol in a vibratory McCrone Micronizing Mill for 10 minutes. Step-scan X-ray powder-diffraction data were collected over a range 3-80°2θ with CoKα radiation on a Bruker D8 Advance Bragg-Brentano diffractometer equipped with an Fe monochromator foil, 0.6 mm (0.3°) divergence slit, incident- and diffracted-beam Soller slits and a LynxEye-XE detector. The long fine-focus Co X-ray tube was operated at 35 kV and 40 mA, using a take-off angle of 6°.

RESULTS

The X-ray diffractograms were analyzed using the International Centre for Diffraction Database PDF-4 using Search-Match software by Bruker. X-ray powder-diffraction data of the samples were refined with Rietveld program Topas 4.2 (Bruker AXS). The results of quantitative phase analysis by Rietveld refinements are given in Table 1. These amounts represent the relative amounts of crystalline phases normalized to 100%. The Rietveld refinement plots are shown in Figures 1 – 2.

The X-ray patterns show the presence of a small amount of unknown clay minerals which could not be analyzed (see small humps fitted with calculated peaks on the corresponding Figures 1 and 2).

Table 1. Results of quantitative phase analysis (wt.%) XRD-Rietveld - Project 1831 Selkirk and Doyle

Mineral	**Ideal Formula**	**1 Selkirk-04**	**2 Selkirk-08**
Ankerite-Dolomite	$Ca(Fe^{2+},Mg,Mn)(CO_3)_2$ - $CaMg(CO_3)_2$	1.5	0.3
Calcite, magnesian	$(Ca,Mg)CO_3$	1.3	0.3
Illite-Muscovite 1M	$K_{0.65}Al_{2.0}Al_{0.65}Si_{3.35}O_{10}(OH)_2$- $KAl_2AlSi_3O_{10}(OH)_2$	3.2	
Illite-Muscovite 2M1	$K_{0.65}Al_{2.0}Al_{0.65}Si_{3.35}O_{10}(OH)_2$- $KAl_2AlSi_3O_{10}(OH)_2$	48.6	7.0
Kaolinite	$Al_2Si_2O_5(OH)_4$	3.2	1.4
K-feldspar (microcline intermediate)	$KAlSi_3O_8$	2.1	15.0
Plagioclase (albite)	$NaAlSi_3O_8$	2.3	7.5
Pyrite	FeS_2	0.1	0.6
Quartz	SiO_2	36.9	67.5
Rutile	TiO_2	0.8	0.5
Total		100.0	100.0

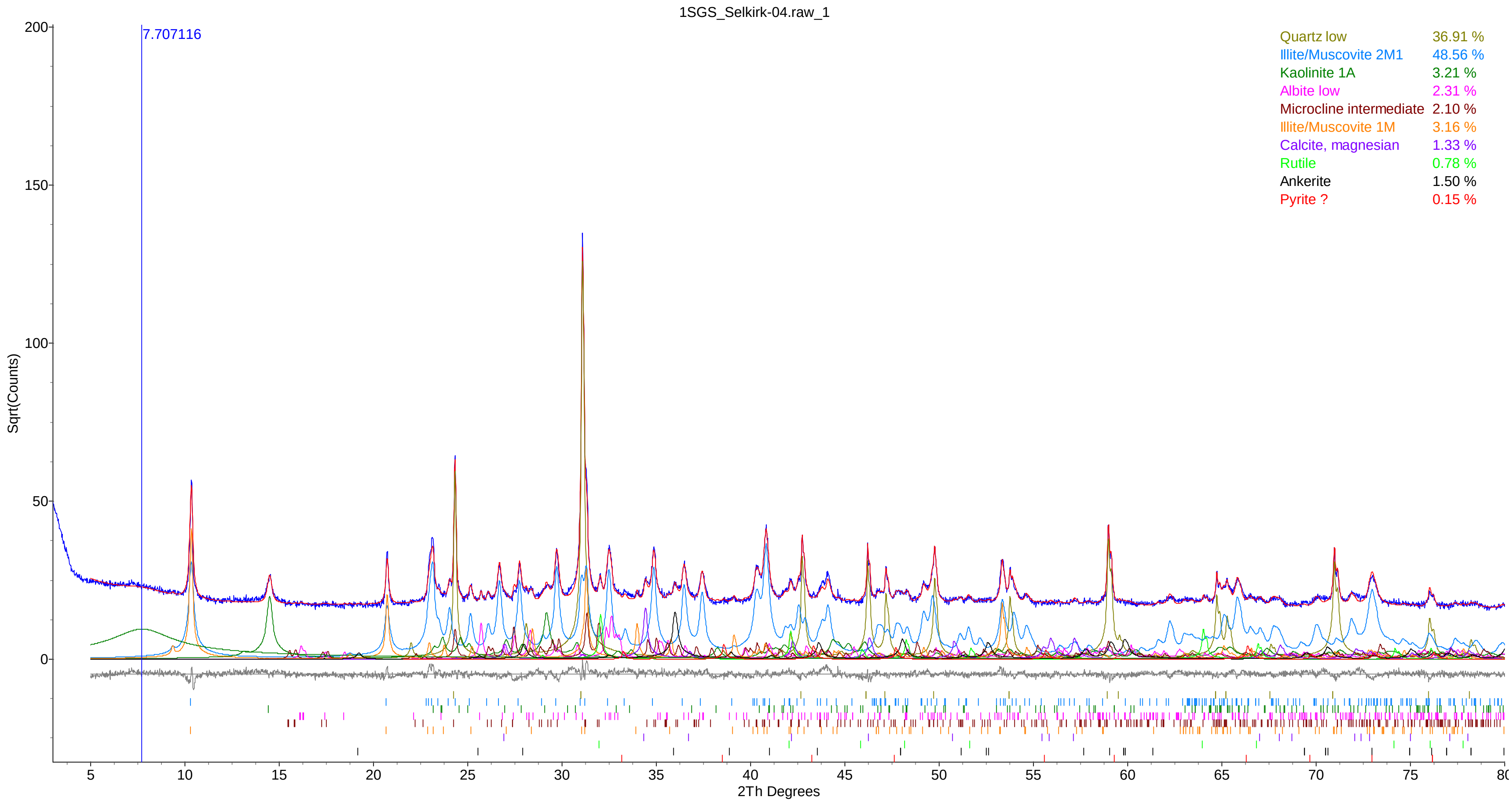

Figure 1. Rietveld refinement plot of sample **SGS Canada – Selkirk 04** (blue line - observed intensity at each step; red line - calculated pattern; solid grey line below - difference between observed and calculated intensities; vertical bars - positions of all Bragg reflections). Coloured lines are individual diffraction patterns of all phases.

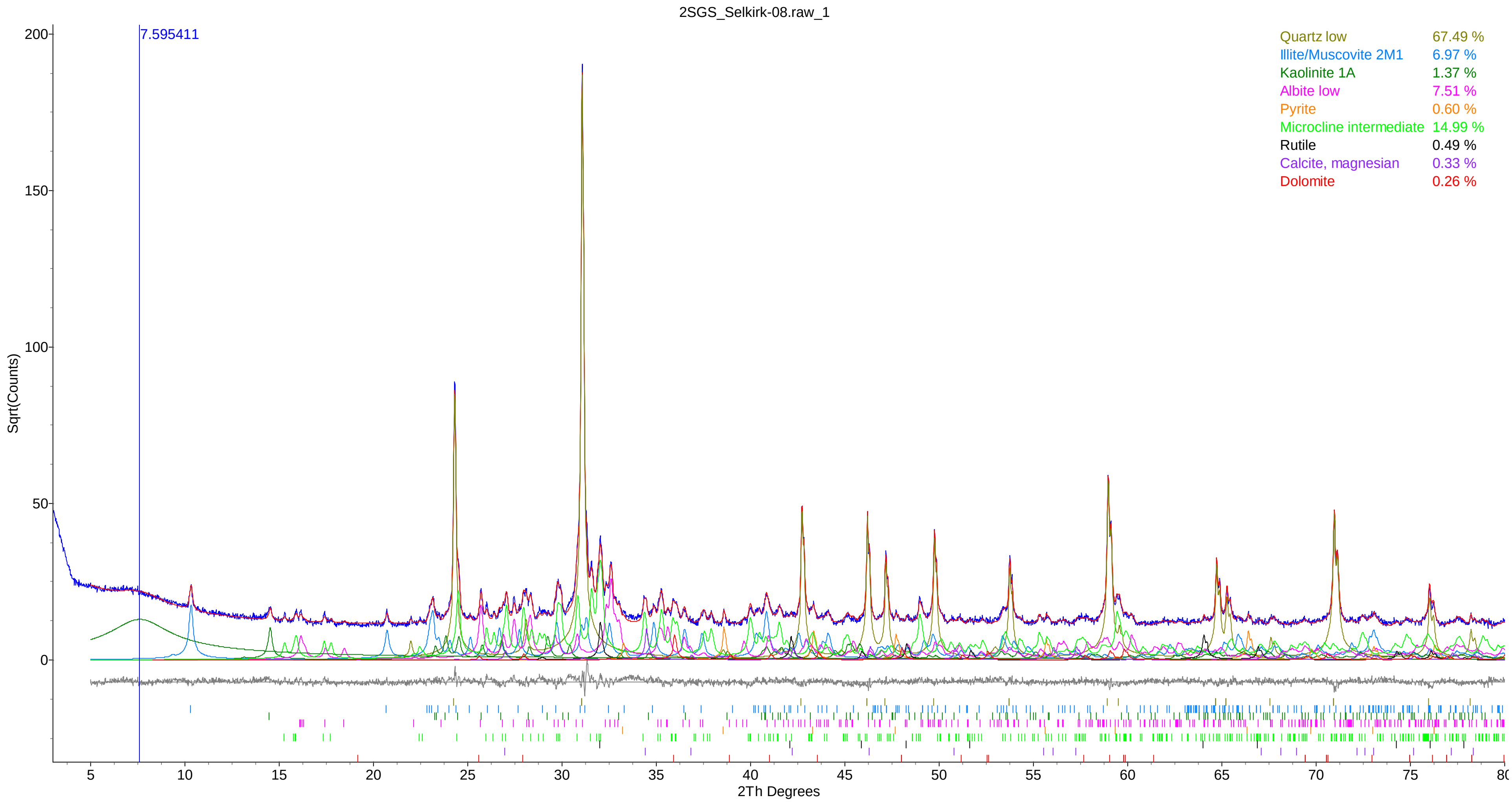

Figure 2. Rietveld refinement plot of sample **SGS Canada – Selkirk 08** (blue line - observed intensity at each step; red line - calculated pattern; solid grey line below - difference between observed and calculated intensities; vertical bars - positions of all Bragg reflections). Coloured lines are individual diffraction patterns of all phases.