

MINERALOGICAL AND GEOCHEMICAL CHARACTERIZATION OF SUPERGENE
CARBONATE-HOSTED NONSULPHIDE Zn-Pb MINERALIZATION IN SOUTHERN
AND CENTRAL BRITISH COLUMBIA

by

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ABSTRACT

Carbonate-hosted nonsulphide base metal deposits form in supergene environments as base metal sulphides are oxidized and chemical weathering causes the metals to be leached out and deposited as metal-bearing gossans. The metals can be deposited by *direct-replacement* as nonsulphide minerals directly above the sulphide ore, or can travel away from the underlying sulphides with percolating water and be deposited as *wall-rock-replacement* deposits. *Direct-replacement* deposits, known as “red ores”, are usually rich in iron oxides, occur in association with primary sulphide minerals, and may contain economic concentrations of zinc and lead. *Wall-rock-replacement* deposits, known as “white ores”, are typically less oxidized, are not associated with primary sulphide minerals, and contain higher concentrations of zinc but lesser amounts of lead and iron. Both forms of mineralization have been recognized as valid exploration targets in British Columbia, but detailed mineralogy and chemistry of representative deposits is needed to better establish exploration models. Petrography, X-ray diffraction, and scanning electron microscopy analyses were completed on select nonsulphide deposits, i.e., Red Bird, Lomond, and Oxide in the Salmo district of the Kootenay terrane, and Cariboo Zinc in the Quesnel Lake district of the Cariboo terrane. Sulphide protore to the nonsulphide deposits of the Salmo district was also studied by analyzing samples from the Reeves MacDonald, HB, and Jersey-Emerald properties. At the Lomond deposit, there is extensive oxidation and cerussite occurs as a lead nonsulphide phase within vugs. At the Red Bird prospect, hemimorphite is the predominant nonsulphide mineral, with remnants of hydrozincite on the crust of oxidized samples. At the Cariboo Zinc property, smithsonite is the most abundant zinc nonsulphide phase, though hemimorphite is also present. Lead nonsulphides on the property consist of anglesite and cerussite. The Oxide prospect is not associated with sulphide ore and the main nonsulphide phases are hemimorphite and hopeite. All of the nonsulphide deposits studied fit the *direct-replacement* style of nonsulphide mineralization, with the exception of the Oxide prospect, which shows traits of *wall-rock-replacement* style mineralization. Though the nonsulphide deposits differ to some extent in mineralization styles, all fit the general supergene model of nonsulphide mineralization and further characterization can assist in creating an exploration model for similar deposits in BC and the rest of the Cordillera.

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1.0 INTRODUCTION

Carbonate-hosted nonsulphide base metal (CHNSBM) deposits are commonly overlooked by the mineral exploration industry, but they are becoming more attractive targets due to recent technological advances in processing nonsulphide zinc ore (Simandl and Paradis, 2009). Prior to the 1930s most zinc ore came from nonsulphide deposits, but with advanced smelting technology to process sulphides, nonsulphide ore was soon forgotten. Recently, the Skorpion Mine in Namibia opened a processing plant on their property that can effectively and economically extract zinc metal from nonsulphide deposits (Simandl and Paradis, 2009). Much research has been done on similar deposits around the world, although carbonate-hosted Zn-Pb deposits in British Columbia (BC) have not been studied in detail and there is a possibility that many remain undiscovered. Analytical work must be done on the mineralogy and paragenesis of the nonsulphide minerals contained in these deposits in order to define an exploration model for carbonate-hosted Zn-Pb mineralization in the western Cordillera. In this thesis, I present petrographic and geochemical data to assist in this process.

CHNSBM deposits form in supergene environments as primary sulphide ore is oxidized and base metals pass into solution, subsequently precipitating out as metal-bearing gossans (Simandl and Paradis, 2009). The common sulphide deposits associated with CHNSBM deposits are Mississippi Valley-type (MVT) and other types of carbonate-replacement deposits, and less commonly sedimentary exhalative (SEDEX) deposits, volcanogenic massive sulphide (VMS) deposits, and skarns. Hypogene nonsulphide deposits do exist but have not been recognized in BC and will not be considered in this study. During the supergene weathering process, zinc concentrations typically increase, whereas lead and by-product silver concentrations decrease. Hitzman et al. (2003) described two specific forms of nonsulphide ore from various nonsulphide deposits around the world: “red ore” and “white ore”. “Red ore” is gossanous, usually found immediately above the sulphide protore, and typically contains >20% Zn, 7% Fe and Pb, and minor silver (Simandl and Paradis, 2009). Typical “red ore” nonsulphide minerals include iron-oxyhydroxides, goethite, hematite, hemimorphite, smithsonite, and/or hydrozincite and cerussite (Reichert and Borg, 2008).

“White ore” contains up to 40% Zn but less than 7% Fe and Pb. Smithsonite and hydrozincite are common minerals in white ore, with only small amounts of Fe-oxyhydroxides and cerussite (Reichert and Borg, 2008).

Due to the high concentrations of zinc and occasionally lead, combined with the ease of extracting nonsulphide zinc ore with modern hydrometallurgical techniques, carbonate-hosted nonsulphide Zn-Pb deposits are valid exploration targets (Paradis et al., 2009). Known nonsulphide ore occurrences in the study area were mined and/or explored for sulphide ore in the past, yet the origin of the nonsulphide ore is not well known because of the lack of attention paid to this deposit type. Paradis (2007) and Paradis et al. (2011) suggest that carbonate-hosted sulphide deposits in the Kootenay and Cariboo terranes of the western Cordillera share characteristics with both Irish-type and MVT mineralization, but this remains to be conclusively determined.

The purpose of this thesis is to characterize the mineralogy and geochemistry of rocks from four nonsulphide deposits — Red Bird, Lomond, and Oxide in the Salmo district of the Kootenay terrane, and Cariboo Zinc in the Quesnel Lake district of the adjacent Cariboo terrane — and to compare and contrast their composition and paragenesis, subsequently determining if they fit the aforementioned classification schemes proposed for other CHNSBM deposits around the world. Sulphide ore will be examined from the HB, Jersey-Emerald, and Reeves MacDonald deposits of the Kootenay terrane to characterize the likely sulphide protore to the nonsulphide deposits. Field work and a preliminary mineralogical investigation done by Simandl and Paradis (2009) suggests that the Red Bird prospect formed via *direct-replacement*, whereas the Oxide prospect formed by *wall-rock-replacement*. The Cariboo Zinc deposit is also thought to have a *direct-replacement* origin (Paradis et al., 2010). X-ray diffraction (XRD) analyses and scanning electron microscopy (SEM) will be used to resolve the nonsulphide mineralogy and geochemistry of these deposits. Characterizing the mineralogy and geochemistry of these deposits and comparing them with models others have proposed for similar deposits around the world will ultimately assist in creating an exploration model for CHNSBM mineralization in BC and the rest of the Cordillera.

2.0 PREVIOUS WORK

Different models have been proposed for supergene carbonate-hosted nonsulphide Zn-Pb deposits in an attempt to classify them based on ore-forming processes. Reichert and Borg (2008) suggest that there are two stages to the formation of nonsulphide ore: the “oxidation stage” (early oxidation of sulphides) and the “post-oxidation stage” (non-acidic stage). During the oxidation stage, oxygen reaches the sulphide ore and reacts with pyrite or other sulphides, producing an acidic environment in which stable nonsulphide minerals begin to precipitate. According to Reichert and Borg (2008), the “post-oxidation stage” begins when the sulphide ore is completely oxidized and the neutralization process is complete. Lead is more immobile and most of it stays in the oxidized zone, but zinc remains sufficiently soluble to percolate down the groundwater flow gradient and precipitate as nonsulphide carbonates, oxides, and silicates, whereas nonsulphide lead minerals only precipitate in low quantities (Reichert and Borg, 2008).

Hitzman et al. (2003) modified an original supergene classification scheme by Heyl and Bozion (1962) and subdivided CHNSBM deposits into *direct-replacement*, *wall-rock-replacement*, and *residual or karst-fill* type. *Direct-replacement* deposits occur immediately above the sulphide ore and the nonsulphide minerals precipitate as zinc-rich gossans due to oxidizing chemical reactions (Figure 1a). *Wall-rock-replacement* deposits form as zinc that is liberated from sulphide ore travels within fluid percolating away from the protore and migrates out into the carbonate host rock, where it precipitates as nonsulphide zinc minerals (Figure 1b) (Hitzman et al., 2003). *Wall-rock-replacement* deposits are economically favourable because the high reactivity of the adjacent calcareous wall-rock may concentrate zinc to much higher grades than previously existed in the sulphide protore. These deposits often have simpler mineralogy as well, due to the mobility of metals; zinc is much more mobile than lead, silver, and iron, and therefore the less mobile minerals stay behind and precipitate in the *direct-replacement* type of mineralization (Hitzman et al., 2003). *Residual or karst-fill* deposits occur in carbonate terrains due to mechanical erosion of rocks, causing zinc carbonates and silicates to concentrate in the cave systems (Hitzman et al., 2003). It is

unlikely that karst systems are abundant in the areas of study because they are usually formed in wet, tropical climates whereas the other two deposit types are typically formed in arid to semiarid environments. However, karsts are known to exist in other places in BC, and Luckman (2008) has suggested the possible presence of karst systems in the Cariboo Zinc region due to anomalous circular gravity lows, so this deposit type, although not as likely in the region of study, is still a possibility.

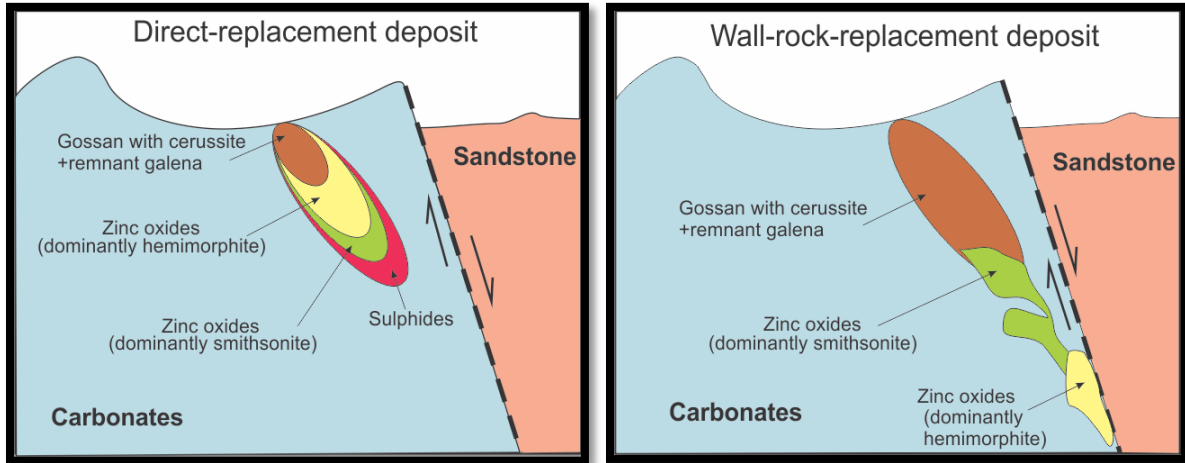


Figure 1. (a) Conceptual model of a *direct-replacement* type deposit, where zinc-rich gossans replace original sulphide ore in a supergene environment above the original deposit. (b) Conceptual model of a *wall-rock-replacement* type deposit, where mobile zinc is transported laterally down the groundwater flow gradient and precipitated in the host carbonate. (Simandl and Paradis, 2009; modified from Heyl and Bozion, 1962, and Hitzman et al., 2003.)

3.0 REGIONAL GEOLOGY

The western Cordillera of Canada contains terranes that were primarily formed during collisional tectonics and accretion of allochthonous terranes onto the western margin of North America (Reid et al., 2002). The Kootenay terrane in southern BC and the Cariboo terrane in central BC are host to the deposits of interest in this study (Figure 2).

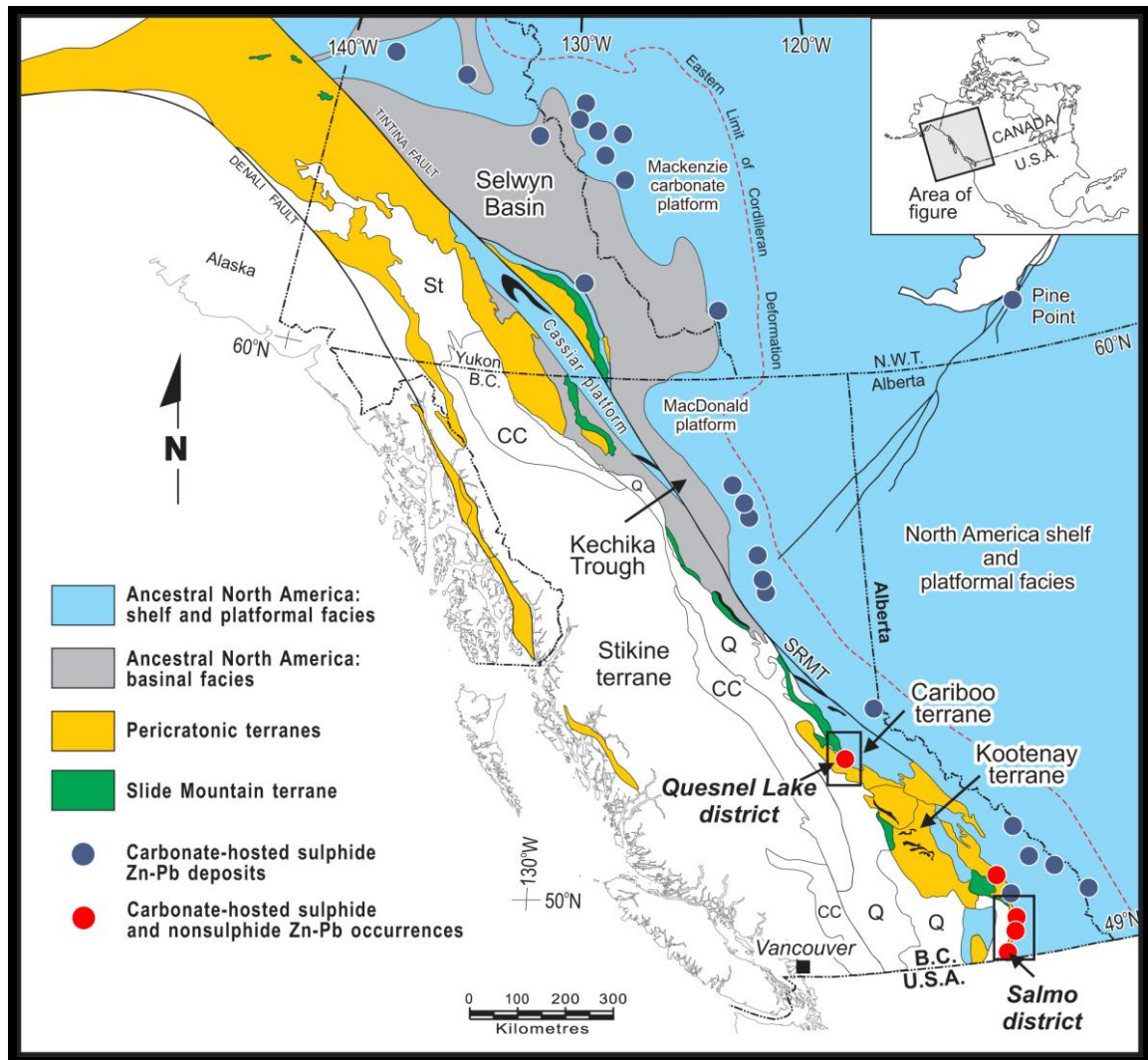


Figure 2. Simplified geologic map of the western Cordillera with the location of the Kootenay and Cariboo terranes as well as the districts of study, showing locations of significant carbonate-hosted sulphide and nonsulphide occurrences. CC = Cache Creek terrane, St = Stikine terrane, Q = Quesnel terrane, and SRMT = southern Rocky Mountain Trench. Modified from Paradis et al. (2009).

3.1 Geology of the Kootenay terrane

The Kootenay terrane consists of a pericratonic assemblage of mid-Paleozoic rocks that lies along a suture between the ancestral North American margin to the east and the Intermontane superterrane to the west (Colpron and Price, 1995). It is metamorphosed from greenschist to amphibolite facies and polydeformed so the original stratigraphy is obscured, although throughout the terrane geologic units are consistent and a regional stratigraphic

sequence can be traced (Colpron and Price, 1995). Rock units in the Kootenay terrane include quartzites overlain by shales, with various limestone and dolostone intervals throughout (Gorzynski, 2001). Figure 3 shows the simplified geology of the Kootenay terrane and surrounding region in southeastern BC.

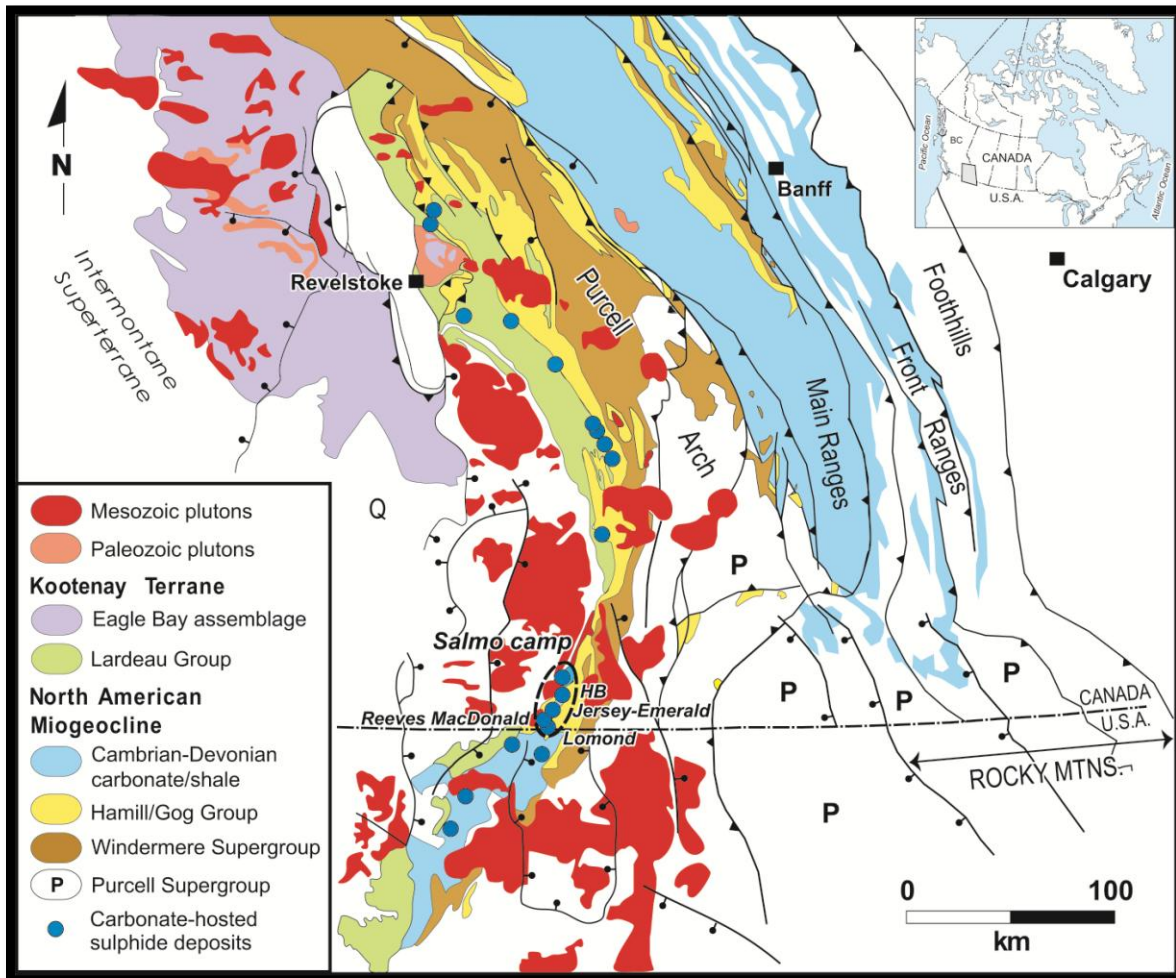


Figure 3. Major geologic features of southeastern BC, showing the location and geology of the Kootenay terrane, as well as the location of significant carbonate-hosted sulphide deposits. Properties of study are labelled, and select cities are shown. Q = Quesnel terrane. Modified from Paradis (2007).

Within the Kootenay terrane, the Kootenay Arc is a curvilinear belt of complexly deformed Lower Paleozoic rocks that extends south for 400km from Revelstoke in BC to northern Washington, USA (Paradis, 2007). The arc consists of a thick succession of thrust-imbricated Proterozoic to Lower Mesozoic miogeoclinal to basinal strata of sedimentary and volcanic origin (Simandl and Paradis, 2009). Folding is extensive in the Kootenay Arc, as

shown by three main phases: the earliest consists of west-verging, recumbent folds, and the next two phases are upright, tight, isoclinal folds that deform the earlier phases (Paradis, 2007). Deformation is coeval with lower greenschist to amphibolites facies metamorphism that occurs throughout the entire region (Paradis, 2007).

The entire Kootenay Arc features carbonate-hosted Zn-Pb sulphide deposits (Figure 3), but the largest and highest concentration of deposits is near the Salmo district in southern BC (Gorzynski, 2001; Paradis, 2007). In the lower stratigraphic succession of the Kootenay Arc near Salmo, rock units include Eocambrian siliciclastic and carbonate rocks, overlain by Lower Cambrian carbonates that host a number of Zn-Pb sulphide and nonsulphide deposits (Simandl and Paradis, 2009). Two of the major limestone/dolostone units, the Lower Cambrian Reeves Member of the Laib Formation and the Cambrian-Ordovician Nelway Formation, contain the most significant zinc and lead mineralization in the region (Fyles and Hewlett, 1959; Gorzynski, 2001).

3.1.1 Laib and Nelway formations

Strata of the Lower Cambrian Laib Formation host the Red Bird nonsulphide showing as well as the HB, Jersey-Emerald, and Reeves MacDonald sulphide deposits (Simandl and Paradis, 2009). The Oxide prospect is underlain by both the Laib Formation and the overlying Ordovician argillites and slates of the Active Formation (Simandl and Paradis, 2009). The Laib Formation consists of the Upper Laib Formation (composed of phyllites and quartzites), which does not contain significant carbonate-hosted Zn-Pb mineralization, and the Lower Laib Formation that contains extensive mineralization (Gorzynski, 2001). The Lower Laib Formation consists of three members (Figure 4). The Truman Member is the oldest, consisting of a thin sequence of phyllites and limestones (Gorzynski, 2001). The Reeves Member, which hosts most of the mineralization in the district, lies above the Truman Member and consists of fine- to medium-grained limestone that has locally altered to dolostone. The Reeves Member is in turn overlain by the Emerald Member, which consists of black phyllites and schists.

The Cambrian-Ordovician Nelway Formation is host to the iron oxide-rich Lomond deposit as well as other minor Zn-Pb showings (Paradis, 2007). The Nelway Formation directly overlies the Laib Formation and is overlain by the Ordovician Active Formation (Figure 4). It consists of Zn-Pb hosting limestone and dolostone with minor siltstone, as well as various quartz-calcite veins and calcareous breccia zones (Gorzynski, 2001).

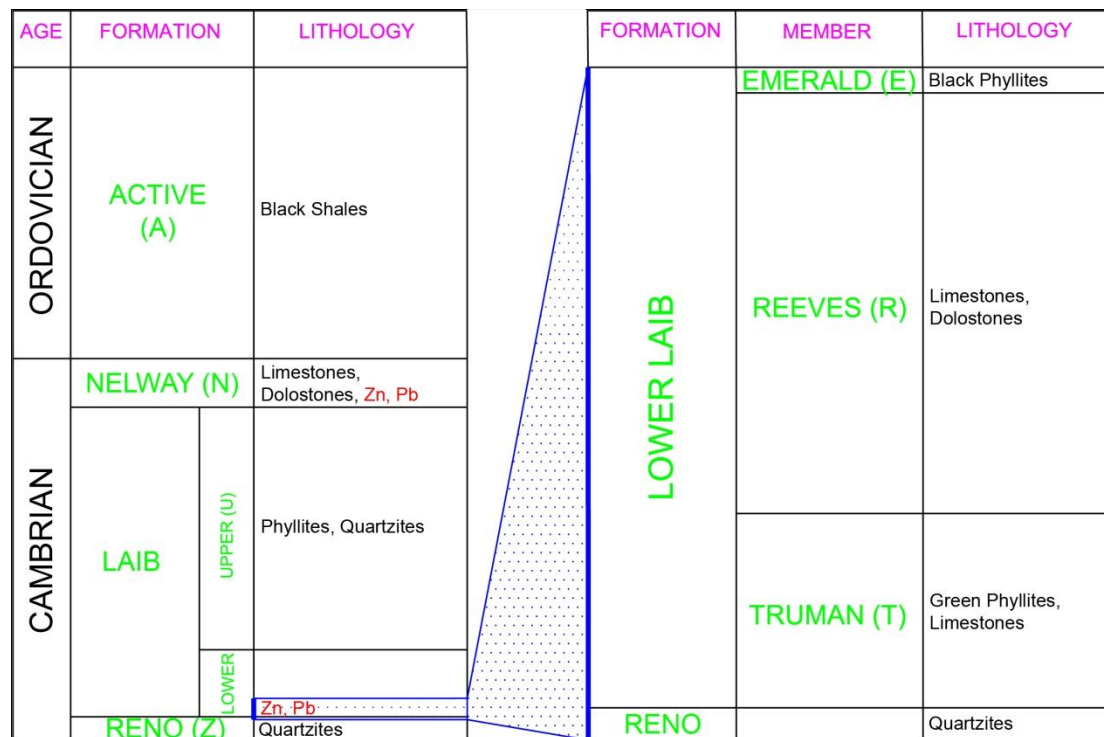


Figure 4. Stratigraphic section showing Cambrian to Ordovician geology of the Salmo Zn-Pb district in the south Kootenay Arc. Modified from Gorzynski (2001).

3.2 Geology of the Cariboo terrane

The Cariboo terrane (Figure 5) hosts the nonsulphide Cariboo Zinc property of the Quesnel Lake district and consists of Precambrian to Early Mesozoic miogeoclinal clastic and carbonate rocks (Höy and Ferri, 1998b). The Cariboo terrane is interpreted as a displaced segment of the ancestral North American margin, bounded by the ancestral western margin of North America on the east and by the Pleasant Valley Thrust on the west (Paradis et al., 2009). The Pleasant Valley Thrust separates the Cariboo terrane from the Barkerville terrane, which is interpreted to be a northern extension of the Kootenay terrane (Höy and Ferri,

1998a). Though considered to be a fault-offset northern extension of the Kootenay terrane, the rocks of the Cariboo terrane in the study area are less metamorphosed and deformed than the rocks of the Salmo district in the Kootenay terrane.

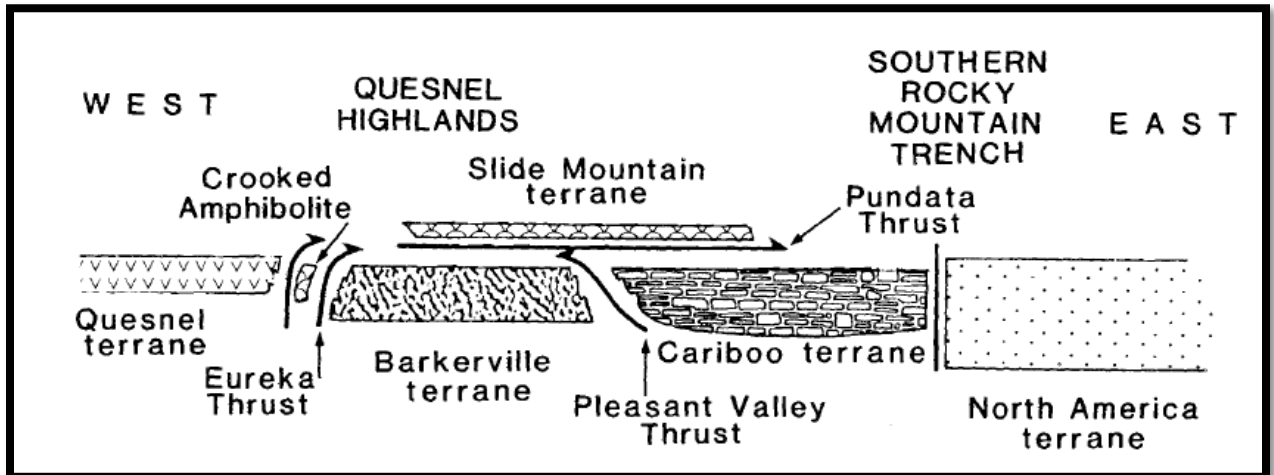


Figure 5. Cross-section of the Cariboo terrane and adjacent terranes, showing bounding faults and the overlap assemblage of the Slide Mountain terrane (Struik, 1986).

The study area is dominated by rocks of the Late Proterozoic Kaza Group, the Late Proterozoic to Cambrian Cariboo Group, and the Ordovician to Mississippian Black Stuart Group (Paradis et al., 2009). The Cariboo Group hosts the nonsulphide mineralization in the Quesnel Lake district. According to Struik (1988), the Cariboo Group is part of the Windermere Supergroup and consists of various formations, two of which — the Isaac and Cunningham formations — contain nonsulphide Zn-Pb mineralization. Within these formations, the Cariboo Zinc property hosts several Zn-Pb sulphide and nonsulphide occurrences in a southeast-trending belt about 8km long (Paradis et al., 2011). The main occurrences of the Cariboo Zinc property, from west to east, are Canopener, DeBasher, Flipper Creek, Dolomite Flats, Main, Gunn, and Que. The zones of study include the eastern showings: Dolomite Flats, Main, Gunn, and Que (Figure 6). In the BC MINFILE database, the Dolomite Flats and Main zones encompass the Grizzly Lake prospect and the Gunn and Que zones correspond to the Que showing (Paradis et al., 2011).

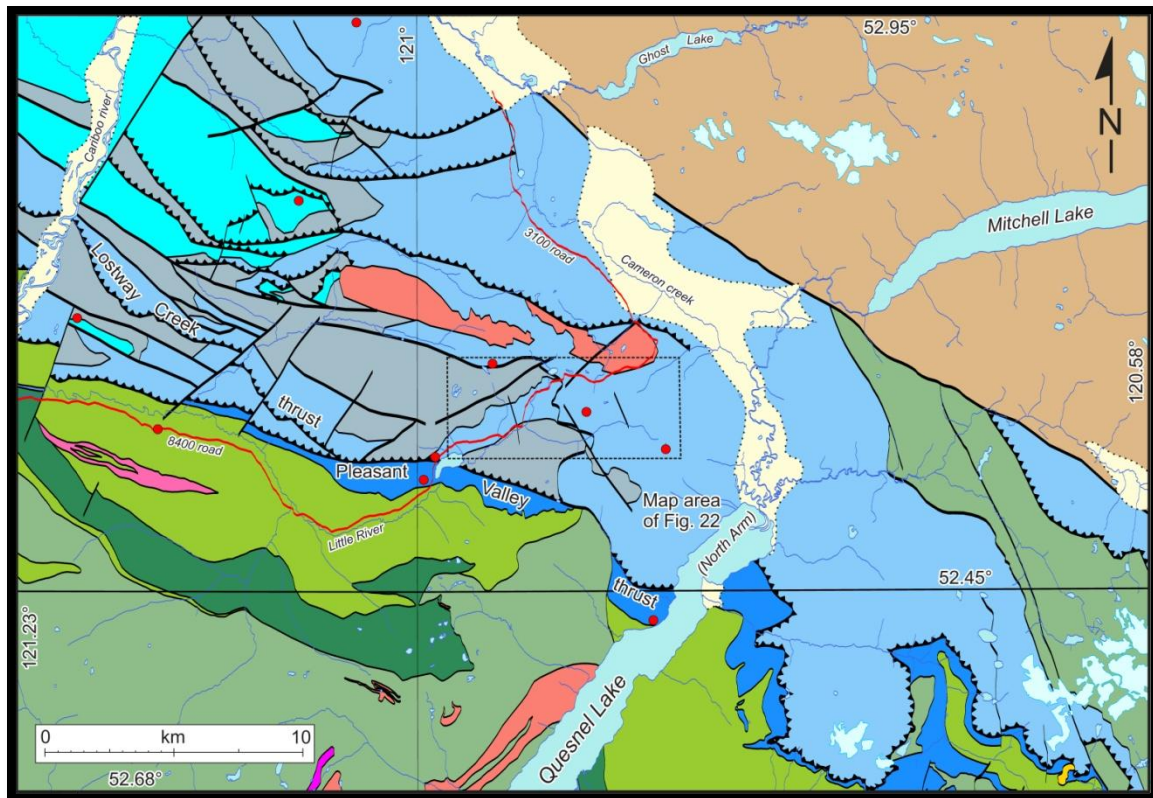
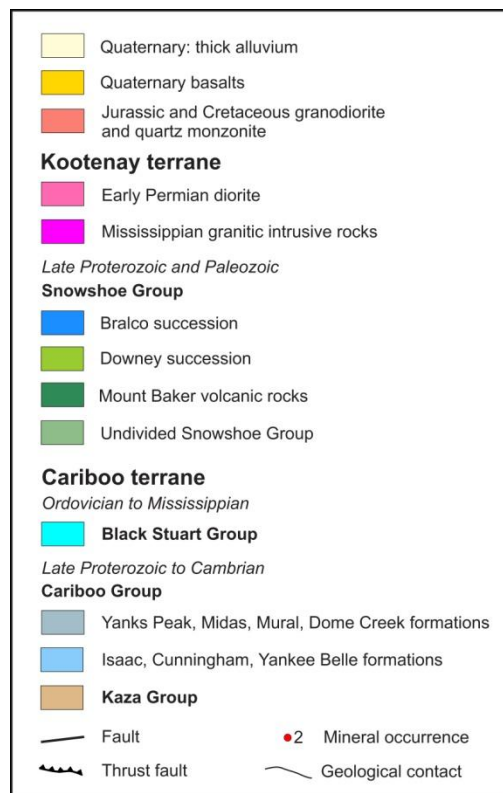


Figure 6. General geology of the Cariboo terrane around the Cariboo Zinc property, showing locations of mineral occurrences. Zones of study are within the dashed black line. Legend to the right. Modified from Paradis et al. (2009).



3.2.1 Cunningham and Isaac formations

The Late Proterozoic Cunningham and Isaac formations both host significant Zn-Pb mineralization in the Cariboo terrane, and the Cariboo Zinc property overlies rocks of both formations (Figure 7) (Struik, 1988). These rocks are generally northwest-striking, northeast-dipping bedded carbonates and clastic rocks (Paradis et al., 2009). The 2.5km-thick Isaac Formation, the oldest unit in the Cariboo Group (Reid et al., 2002), is mostly composed of fine-grained calcareous siltstones along with pyrite-rich shales, with discontinuous mineralized carbonate intervals throughout. It is structurally incompetent and accommodates deformation by hosting tight and isoclinal folds. The Cunningham Formation, which conformably overlies the Isaac Formation, is an 800m-thick unit of massive limestone with minor siltstone, shale, and dolostone (Reid et al., 2002). This formation is much more competent and has fewer folds – instead it has been deformed by brittle faulting or broad, open buckle folds (Reid et al., 2002). On the scale of the Cariboo Zinc property, intense folding is not obvious; however, strike and dip measurements suggest a major open fold associated with the deposit (Paradis et al., 2009).

AGE	FORMATION	MEMBER	LITHOLOGY
NEOPROTEROZOIC	YANKS PEAK		Sandstone (Quartzite)
	YANKEE BELLE	AMOS BOWMAN	Mixed Meta- Carbonate / Siliciclastic (Shale, Sandstone, Limestone)
		BETTY WENDLE	
	CUNNINGHAM		Meta-Limestone with Minor (<10%) Shale, Zn, Pb
	ISAAC	UPPER	
		LOWER	Primarily Shale (Phyllites/Schist) with intervening Carbonate units and minor Sandstone and Conglomerate units, Zn, Pb

Figure 7. Stratigraphic section showing the Neoproterozoic geology of the Windermere Supergroup in the Cariboo terrane in central BC. The Isaac and Cunningham formations host the deposits of study in the Cariboo terrane. Modified from Reid et al. (2002).

4.0 METHODS

Twenty-four hand samples and twenty-three thin sections were analyzed for nonsulphide mineralogy and paragenetic relationships (Table 1). All of the properties are located in the Salmo district of southern BC, with the exception of the Cariboo Zinc property, which is located in the Quesnel Lake district of central BC.

Table 1. Deposits and districts of study, with number of hand samples and thin sections analyzed as well as the nature of mineralization.

Deposit and District	Number of Hand Samples	Number of Thin Sections	Nature of Mineralization
Red Bird – Salmo	9	9	Nonsulphide with remnant sulphides
Lomond – Salmo	1	-	Nonsulphide
Oxide – Salmo	2	2	Nonsulphide
Reeves MacDonald – Salmo	-	1	Sulphide
Jersey-Emerald – Salmo	-	1	Sulphide with minor nonsulphides
HB – Salmo	-	1	Sulphide
Cariboo Zinc – Quesnel Lake	12	9	Nonsulphide with remnant sulphides

Petrography and scanning electron microscopy (SEM) were completed on the polished thin sections to determine nonsulphide mineralogy and paragenetic relationships. X-ray diffraction (XRD) and textural and mineralogical analyses were completed on all of the hand samples. Select rocks from this study were also sent out for whole rock geochemistry.

Petrography on polished thin sections was done using a Nikon Eclipse E600 POL petrographic microscope at the Department of Earth and Ocean Sciences at the University of British Columbia. Photo micrographs were taken using the software DSLR Remote Pro, connected to a Canon EOS Rebel T2i with a COOLPIX MDC lens. A crude naming scheme was developed for the hand samples and thin sections and is shown in Table 2. The word “mineralized” was avoided in order to differentiate between sulphide mineralization and nonsulphide mineralization. Since quartz is ubiquitous in most of the samples, and since quartz was not a fundamental part of the study, the samples were simply called dolostone or limestone rather than “siliceous” dolostone or limestone.

Table 2. Naming scheme for sulphide-containing and nonsulphide-containing rock samples.

Minerals Contained	Rock Name
Only sulphides, no nonsulphides, OR >10% sulphides and <2% nonsulphides	Sulphide-rich dolostone (or dolomitized limestone)
>10% nonsulphide minerals	Nonsulphide-rich dolostone (or dolomitized limestone)
5 –10% nonsulphide minerals	Nonsulphide-containing dolostone (or dolomitized limestone)
<5% nonsulphide minerals (and <10% sulphides)	Nonsulphide-poor dolostone (or dolomitized limestone)

XRD was used to analyze nonsulphide minerals in the hand samples. The sample to be analyzed was ground into a fine powder with a corundum mortar and smeared onto a glass slide with ethanol. Step-scan X-ray powder-diffraction data were collected over a range of 3-80°2 θ with CoKa radiation on a Bruker D8 Focus Bragg-Brentano diffractometer, equipped with a monochromator foil, 0.6mm (0.3°) divergence slit, incident- and diffracted-beam Soller slits and a LynxEye detector. The long line-focus Co X-ray tube was operated at 35kV and 40mA, using a take-off angle of 6°. The program run on the hand samples had a scan step of 0.04°2 θ and a time of 0.5 seconds per step, running from 3-80°2 θ and giving a total run time of 18 minutes per sample. The spin used was 50rpm. Mineral identification was completed using the International Centre for Diffraction Database PDF-4 and Search-Match software by Siemens (Bruker). Mineral spectra were analyzed with the software DiffracPLUS EVA by Bruker AXS.

SEM was completed on the polished thin sections using a PHILIPS XL30 scanning electron microscope, equipped with the Bruker Quantax 200 Microanalysis system and light element XFLASH 4010 detector (Silicon Drift Detector), based on an energy-dispersive X-ray spectrometer (EDX). Data acquisition and spectra evaluation was completed with the software ESPRIT for EDS, by Bruker AXS.

Select whole rock samples were sent to ACME Analytical Laboratories in Vancouver, BC: the one sample from the Lomond deposit, the two samples from the Oxide prospect of the Salmo district, four samples from the Red Bird prospect, and four samples from the Cariboo Zinc property. Major oxides and some minor elements were analyzed using 0.2g samples by inductively coupled plasma emission spectrometry (ICP-ES) following a lithium

metaborate/tetraborate fusion and dilute nitric digestion. Loss on ignition (LOI) was also determined by weight difference after ignition at 1000°C.

5.0 PROPERTY MINERALIZATION

Combining all properties of study in the Salmo and Quesnel Lake districts, the sulphide minerals found were sphalerite, galena, and pyrite. The nonsulphide zinc minerals observed throughout the two districts were hemimorphite, smithsonite, hydrozincite, hopeite and willemite, and the nonsulphide lead minerals found were anglesite and cerussite. Table 3 shows general properties of the aforementioned nonsulphide minerals, and a mineralogy table of all rock samples analyzed is shown in Table 4.

Table 3. Properties of the main zinc and lead nonsulphide minerals found in the Salmo and Quesnel Lake districts of BC. Modified from Paradis (personal communication, 2010).

Main Zinc Minerals		Formula	Colour	Luster	Density (g/cm ³)	Hardness
	Smithsonite	ZnCO ₃	White	Earthy, dull	4.5	4.4
	Hemimorphite	Zn ₄ Si ₂ O ₇ (OH) ₂ ·H ₂ O	White, brown, blue, greenish grey	Vitreous	3.6	5
	Hydrozincite	Zn ₅ (CO ₃) ₂ (OH) ₆	White, pale yellow, pale grey	Pearly	3.6–3.8	2–2.5
	Willemite	Zn ₂ SiO ₄	White, green, red, brown, black, pink, blue	Vitreous/resinous	3.9–4.2	5.5
	Hopeite	Zn ₃ (PO ₄) ₂ ·4H ₂ O	Yellow, white	Vitreous/pearly	3–3.1	3.5
Main Lead Minerals						
	Cerussite	PbCO ₃	Colourless, white, tan, grey	Adamantine	6	3
	Anglesite	PbSO ₄	White, colourless, grey, blue, yellow	Vitreous to adamantine	6.3	3

Table 4. Mineralogy table of the samples of study from the Salmo and Quesnel Lake districts. * = trace (<2%), ** = minor (2 – 10%), *** = major (>10%).

Salmo district																	Amount of Oxidation (Qualitative)
	Silica	Carbonates				Hydrated zinc carbonates	Zinc Silicates	Hydrated Zinc Silicates	Oxides	Phosphates	Lead Sulphates	Sulphides					
Name	Quartz	Calcite	Dolomite	Smithsonite	Cerussite	Zn(CO ₃)(OH) ₆	Zn ₂ SiO ₄	Hemimorphite	Goethite	Hematite	Zn ₃ (PO ₄) ₂ ·4H ₂ O	Anglesite	Galena	Sphalerite	Pyrite		
Formula	SiO ₂	CaCO ₃	CaMg(CO ₃) ₂	ZnCO ₃	PbCO ₃				Fe(OH)	Fe ₂ O ₃		PbSO ₄	PbS	ZnS	FeS		
Red Bird																	
C-473745A	**	***	***					**						**	***		
C-473745C		**	**						***						***		
09-SP-174	**	***						*							***		
09-SP-191	*		***					**							***		
09-SP-192			***					**							***		
09-SP-193	**		***					**	**					*	***		
09-SP-196	**	***	***					**	**				**	**	***		
09-SP-201	**	***	***					**					**	**	***		
09-SP-203	**	***	***					**					**	**	***		
09-SP-204	**	***	***					***					*	*	***		
09-SP-207		*	*						***						***		
Lemond																	
2008-GS-22C					**				***	***					***		
Oxide																	
2008-SP-85		**						***			***				***		
2008-SP-88								***							***		
Reeves MacDonald																	
2007-SP-022-11	***	***	***									**	**	**	***		
Jersey-Emerald																	
08-SP-75-2			***					**						**	*		
HB																	
2007-SP-033-2	**	***	***											***	*		
Cariboo Zinc																	
09-SP-221B	*		***	***										*	***		
09-SP-222B	**		***	***				**					*	*	***		
09-SP-224B			***	***	**			**				**	**	*	***		
09-SP-225B	**		***	***	**			**				***	**	**	***		
09-SP-225D	**		***	***	**			**				***	***	**	***		
09-SP-228	***		***	***	***			***				*	*	**	***		
09-SP-230	**		***	***	***			***				**	**	*	***		
09-SP-231D	**		***	***	*			***				*	*	*	***		
09-SP-231E	**		***	***	**			***				***	***	*	***		
09-SP-237A	**		***	***	**	**		***				***	***	*	***		
09-SP-242	***		***	***	**	**		***				***	***	*	***		
#495	***		***	***	**	**		***				***	***	*	***		

5.1 Sulphide protore in the Salmo district

In order to briefly characterize the sulphide protore of the nonsulphide mineralization in the region, one sample was taken from each of three known sulphide deposits in the Salmo district. The locations of the deposits within the Salmo district (sulphide and nonsulphide mineralization) are shown in Figure 8.

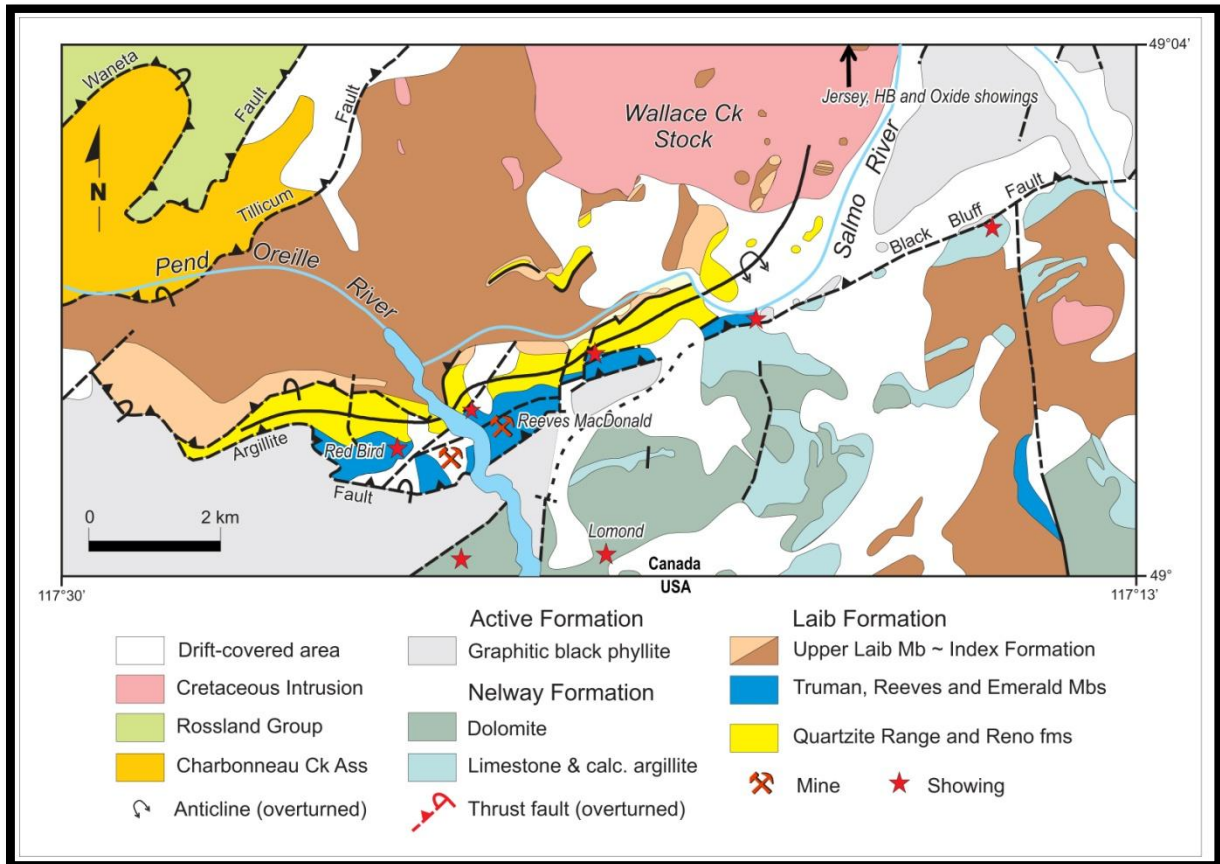


Figure 8. Simplified geologic map of the Salmo district, showing the locations of the Red Bird and Reeves MacDonald properties. The Jersey-Emerald, HB, and Oxide showings occur 3.5km, 8.5km, and 22.5km to the north of the map area respectively. Modified from Fyles and Hewlett (1959).

The sulphides of the Reeves MacDonald, HB, and Jersey-Emerald properties are all hosted within the Reeves Member dolomitized limestone of the Lower Laib Formation (Paradis et al., 2011). Rocks of the Kootenay Arc, and therefore of the Salmo district, have undergone at least three phases of deformation during Jurassic to Cretaceous orogenic events in the Cordillera that created the predominant north-east trending folds of the region (Paradis,

personal communication, 2011). The sulphide bodies at Salmo are conformable and stratabound, although they are now tightly folded with the sulphide mineralization transposed along bedding (Figure 9) (Paradis et al., 2011). They form bands, lenses, and massive to disseminated layers within the host dolostone, and occasionally form the matrix of brecciated dolomite. The sulphides previously described in the Salmo district are pyrite, sphalerite, minor galena, and traces of chalcopyrite (Paradis et al., 2011). All were seen in the samples analyzed with the exception of chalcopyrite.



Figure 9. Typical sulphide mineralization of the Salmo district from the Reeves MacDonald deposit: interlayered and folded sulphides (mostly pyrite and sphalerite with lesser galena) hosted in dolomitic limestone of the Reeves Member of the Lower Laib Formation. Photo courtesy of Suzanne Paradis.

5.1.1 Reeves MacDonald

The Reeves MacDonald deposit is located 30km south-southwest of Salmo, BC, and mineralization on the property is hosted by a dolomitic envelope of the Reeves Member limestone of the Lower Laib Formation (Paradis et al., 2011). Past production from 1949 to 1971 totalled 5,848,021 tonnes of sulphide ore with average grades of 3.50% Zn and 1.39% Pb (Paradis et al., 2011). The nonsulphide ore has not been mined. The limestone and dolomitized limestone on the property have been folded and metamorphosed to greenschist

facies, and two normal faults extend the length of the property from east to west, offset by thrust faults that also offset the once-stratabound mineralization (Paradis et al., 2011). The property has been affected by the three main phases of regional deformation in the Kootenay terrane, and mineralization on the property is associated with a regional anticline known as the Salmo River Anticline (Giroux and Grunenberg, 2010).

The polished thin section analyzed from the Reeves MacDonald deposit is a sulphide-rich dolomitized limestone in which the groundmass consists mostly of dolomite with windows of calcite. Remnants of parallel layering are present. Sphalerite occurs in masses and lenses with galena subsequently infilling through the fractures (Figure 10). Disseminated pyrite overprints the rest of the mineralogy. Quartz grains occur in disseminations throughout the groundmass and overprint the sulphide phases. No oxidation is seen in this sample.

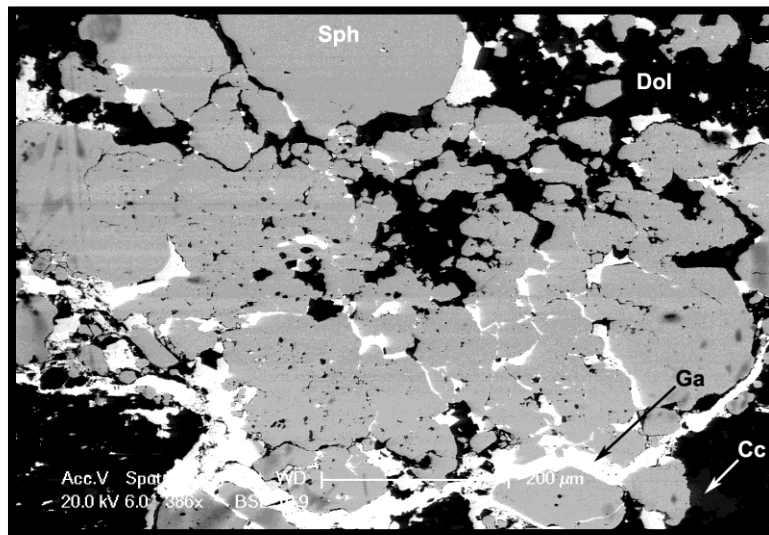


Figure 10. SEM/BSE (Scanning electron microscopy/backscattered electron mode) image of sample 2007-SP-022-11: typical sulphide ore at the Reeves MacDonald deposit, with galena infilling fractures in the massive sphalerite. The calcite “windows” within the dolomite are also shown. Sph = sphalerite, Dol = dolomite, Ga = galena, Cc = calcite.

5.1.2 Jersey-Emerald

The Jersey-Emerald property is located 10km southeast of the village of Salmo, BC, and the property hosts the former Jersey and Emerald Zn-Pb-silver mines (Giroux and Grunenberg, 2010). Past production from 1919 to 1973 totalled 7,968,080 tonnes of ore, with

average grades of 3.83% Zn and 1.95% Pb (Giroux and Grunenberg, 2010). Like most of the mineralization in the Salmo district (with the exception of the Lomond and possibly the Oxide showings), the host rock for the Jersey-Emerald sulphide ore is the Reeves Member of the Lower Laib Formation. Sulphide mineralization is contained within the east limb of the Salmo River Anticline, known locally as the Jersey-Emerald Anticline (Giroux and Grunenberg, 2010).

One polished thin section was examined by petrography and SEM and found to contain medium-grained, slightly weathered dolomite with at least two phases of dolomitization evident and no observable calcite. Sphalerite overprints the dolomitic groundmass in subparallel lenses throughout the sample, and pyrite is present in small cubic disseminations overprinting sphalerite, as well through veinlets within the sphalerite mineralization (Figure 11). In less than 2% of the sample, secondary oxidation is observed, with small anhedral hemimorphite laths beginning to form in the vicinity of oxidized, red sphalerite.

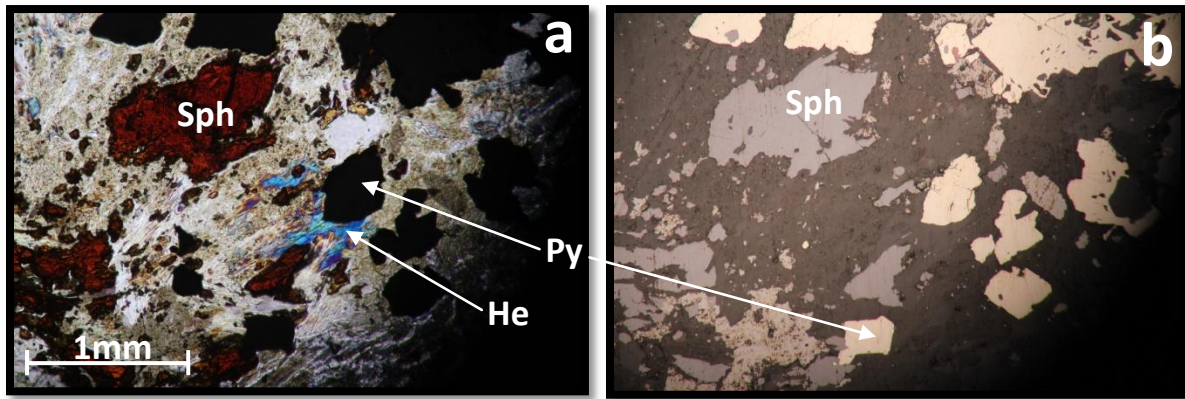


Figure 11. (a) Crossed-polarized light (XPL), transmitted light photo micrograph of sample 08-SP-75-2 from the Jersey-Emerald property. (b) Same image but in reflected light. Sph = sphalerite, Py = pyrite, He = hemimorphite. The weathered white-to-beige mass in the background of 11(a) is a serpentized metamorphic silicate, possibly chlorite.

5.1.3 HB

The HB property is located 8km southeast of Salmo, BC, and is hosted by the Reeves Member of the Lower Laib Formation (Paradis et al., 2011). Past production from 1912 to

1978 totalled 36,287 tonnes of ore, with average grades of 4.1% Zn and 0.1% Pb (Paradis et al., 2011). Like the Reeves MacDonald and Jersey-Emerald properties, mineralization is associated with the regional Salmo River Anticline. However, on the property the ore-hosting sedimentary rocks are folded into a broad syncline with mineralization contained in the west limb (Paradis et al., 2011). A thrust fault known as the Argillite Fault occurs less than 100m east of the ore body, and the property has been intruded by Late Jurassic batholiths (Giroux and Grunenberg, 2010).

The polished thin section analyzed from the HB property is a sulphide-rich dolomitized limestone. The groundmass consists of calcite and dolomite but the textural relationships between the two are not observable due to abundant secondary oxidation. Sphalerite is present as fractured masses and lenses in 15% of the sample, and fine-grained cubic disseminations of pyrite overprint the sphalerite. No galena is evident. This sample is unique in that sulphide mineralization occurs within calcite as well as dolomite, with about 50% dolomite and 30% calcite in the sample (Figure 12). Quartz is present as angular disseminated grains, and secondary oxidation is observable in 30% of the sample but no nonsulphide zinc minerals are present.

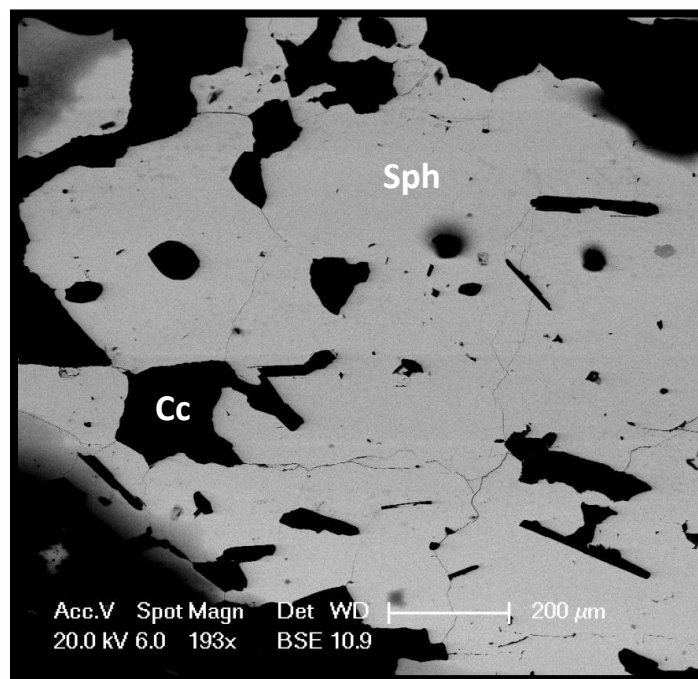


Figure 12. SEM/BSE image of fractured sphalerite forming in the calcite section of the groundmass of sample 2007-SP-033-2 from the HB property. Sph = sphalerite, Cc = calcite.

5.2 Sulphide protore in the Quesnel Lake district

No sulphide-only deposits were observed in the Quesnel Lake district, but sulphide mineralogy is abundant in association with the nonsulphides at the Cariboo Zinc property. According to Paradis et al. (2009), the sulphide mineralization on the Cariboo Zinc property primarily consists of fine-grained disseminations and aggregates forming pods, sulphide-bearing quartz veins, and crackle breccias similar to those found in MVT deposits. Unlike the sulphide mineralization in the Salmo district, stratabound yet cross-cutting quartz-galena veins occur at the Cariboo Zinc property and galena is much more abundant. Other sulphides on the property include sphalerite and pyrite. Barite veins also exist on the east side of the property in the Gunn Zone, none of which were seen in the Salmo district.

The rocks of the Quesnel Lake district are significantly less deformed than the rocks of the Salmo district, though it is possible that the same deformation events occurred in this district as in the Salmo district, albeit to a lesser extent (Paradis et al., 2011). On the Cariboo Zinc property, a detailed structural analysis has not been done, but it has been suggested by McLeod (1999) and Murrell (1991) that a major open fold exists on the property with the hinge near the Grizzly Lake area. This was suggested based on northwest-dipping strata in the northern part of the property and northeast-dipping strata in the southern part of the property. Even so, the folding is not obvious and the area is not polydeformed (as in the Salmo district). A typical outcrop at the Cariboo Zinc property is shown in Figure 13.

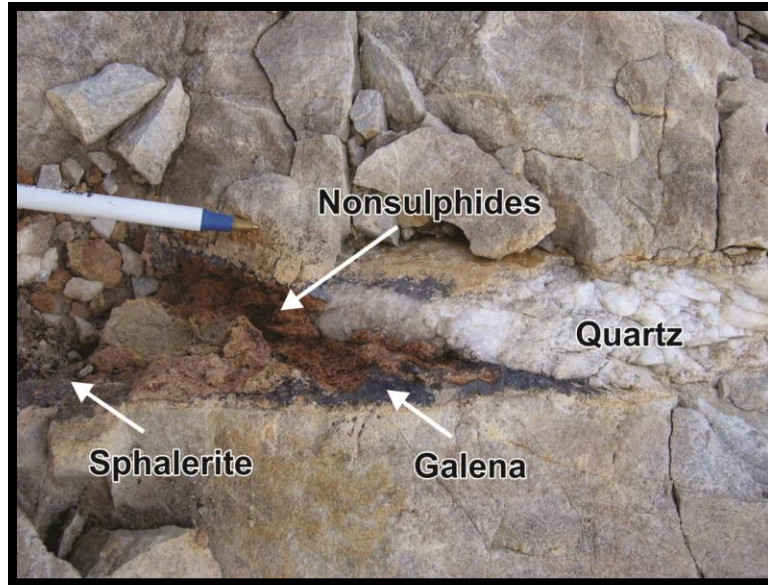


Figure 13. Photograph of typical mineralization at the Cariboo Zinc property. Quartz-sphalerite-galena-smithsonite (after sphalerite) vein at the Main Zone. (Paradis et al., 2009.)

5.3 Nonsulphide mineralization in the Salmo district

5.3.1 Red Bird

The Red Bird prospect is located on the same property as the Reeves MacDonald deposit and may represent an extension of this sulphide mineralization, offset by one of the faults on the property (Gorzynski, 2001; Simandl and Paradis, 2009). The property lies along Red Bird Creek, about 3km west of the Reeves MacDonald showing. The Red Bird prospect contains nonsulphide zinc minerals but no nonsulphide lead minerals, and oxidation is known to extend down to at least 450m below the surface, as seen from underground workings and drillholes (Gorzynski, 2001). The Reeves limestone that hosts the nonsulphide mineralization is locally altered to dolostone (Gorzynski, 2001). Samples 09-SP-174, C-473745A, and C-473745C were taken from The Beer Bottle Oxide Zone (Zone B) in Trench B 2000-1 (Figure 14a). The rest of the samples (with the exception of 09-SP-207, which was taken from Trench C 2000-02) were taken from Trench C 2000-1 in Zone C, which is to the east of Zone B and separated from it by a normal fault (Figure 14b).

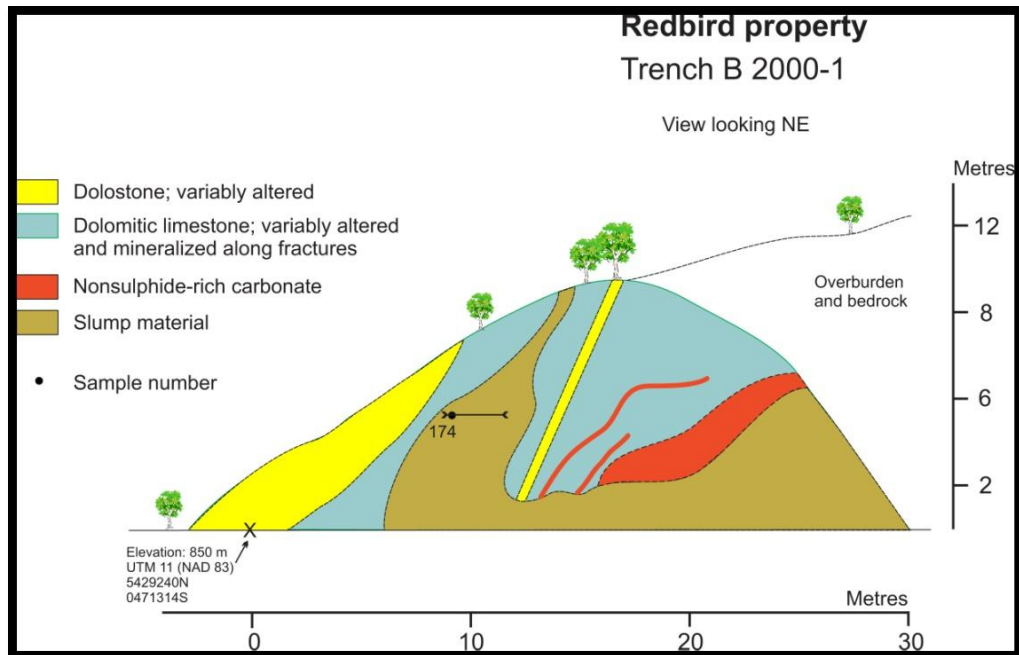


Figure 14. (a) Schematic diagram of Trench B 2000-1 on the west side of the Red Bird prospect, where samples 09-SP-174, C-473745A, and C-473745C were taken. Note that the exact locations for C-473745A and C-473745C are unknown, and the “09-SP” was taken off of the sample number for clarity. Modified from Paradis et al. (2011).

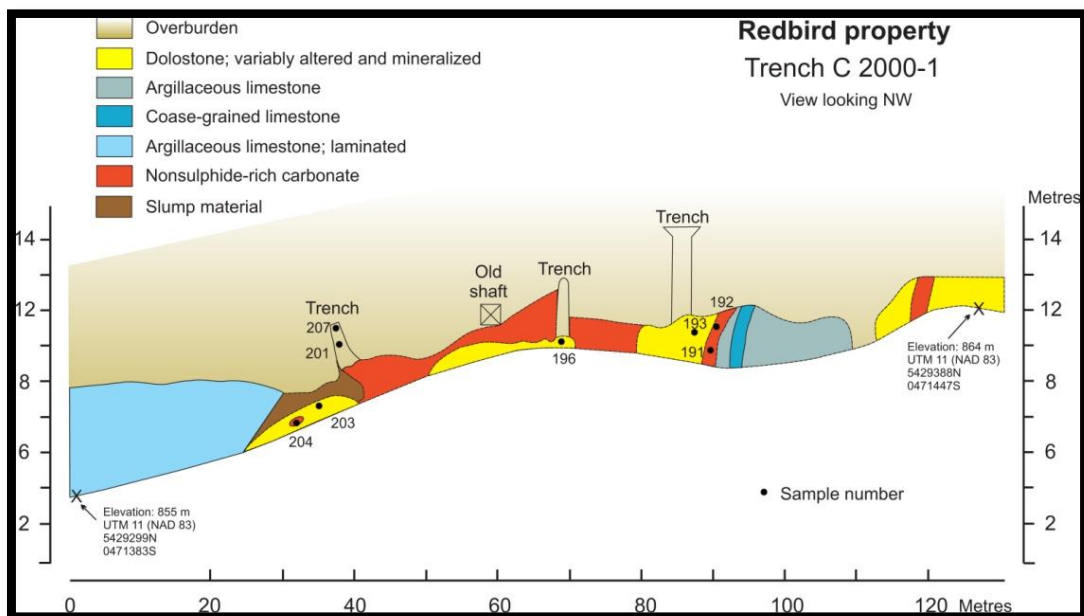


Figure 14. (b) Schematic diagram of Trench C 2000-1 on the east side of the Red Bird prospect, showing the locations of the samples of study. The “09-SP” was taken off of the sample numbers for clarity. Modified from Paradis et al. (2011).

At the Red Bird prospect, hemimorphite ($\text{Zn}_4(\text{Si}_2\text{O}_7)(\text{OH})_2 \cdot \text{H}_2\text{O}$) is the primary nonsulphide mineral, seen in every sample from traces up to concentrations of 70%. Hydrozincite ($\text{Zn}_5(\text{CO}_3)_2 (\text{OH})_6$) is only present in one hand sample and is seen as a white, friable outer crust. Willemite (Zn_2SiO_4) is seen in traces in one thin section (Table 4). Goethite and limonite are the main iron oxides present throughout the property. No galena is identified in any of the Red Bird samples, hence the lack of nonsulphide lead minerals. Sphalerite and pyrite are the only sulphide phases observed.

Of the eleven samples from the Red Bird prospect (grouping hand samples and their thin section offcuts into one sample number), six of the samples contain both calcite and dolomite in the groundmass (Table 4). Two of them are from the surface of Trench B 2000-1, while the remaining samples are from Trench C 2000-1 and range in depth from 7m to surface level. All of these samples have the same relationship between calcite and dolomite, with calcite flooding through discontinuous grains of dolomite. The dolomite is present as angular, possibly brecciated grains infilled by massive calcite, and the hemimorphite mineralization is primarily between dolomite grains (Figure 15). Oxidation is extensive, occurring around pyrite grains and in stringer veinlets that often contain weathered, oxidized sphalerite. Hemimorphite is commonly associated with these oxide veinlets, growing into them from the carbonate groundmass, and is rarely present as large euhedral crystals except in sample C-473745C, where there are many vugs available for continued crystal growth (Figures 16a and b).

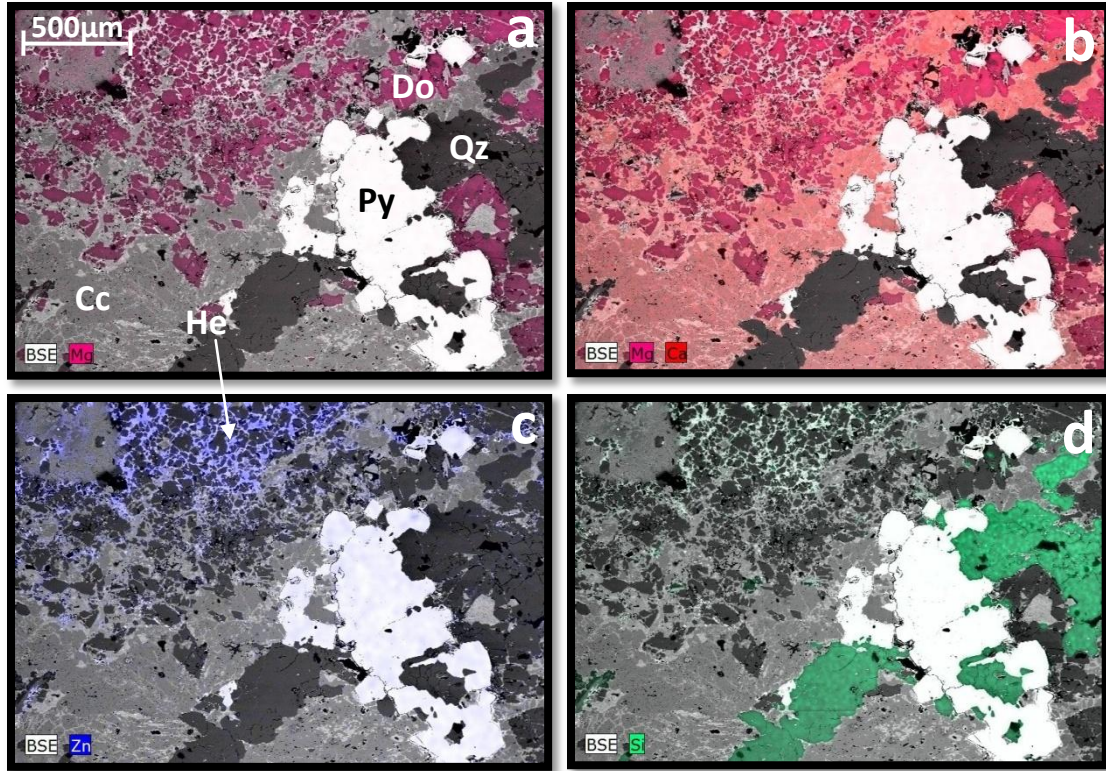


Figure 15. SEM/BSE images from sample 09-SP-201, showing the typical relationship between dolomite and calcite at the Red Bird prospect, as well as hemimorphite replacement between dolomite grains. Coloured elements are shown for clarity. (a) Magnesium is coloured to decipher the dolomite grains. (b) Magnesium and calcium are coloured to show the textural relationship between dolomite and calcite. (c) Zinc is coloured to show the presence of hemimorphite between dolomite grains. (d) Silica is coloured to show the hemimorphite between dolomite grains as well as the presence of quartz beneath the pyrite mineralization. Do = dolomite, Qz = quartz, Py = pyrite, Cc = calcite, He = hemimorphite.

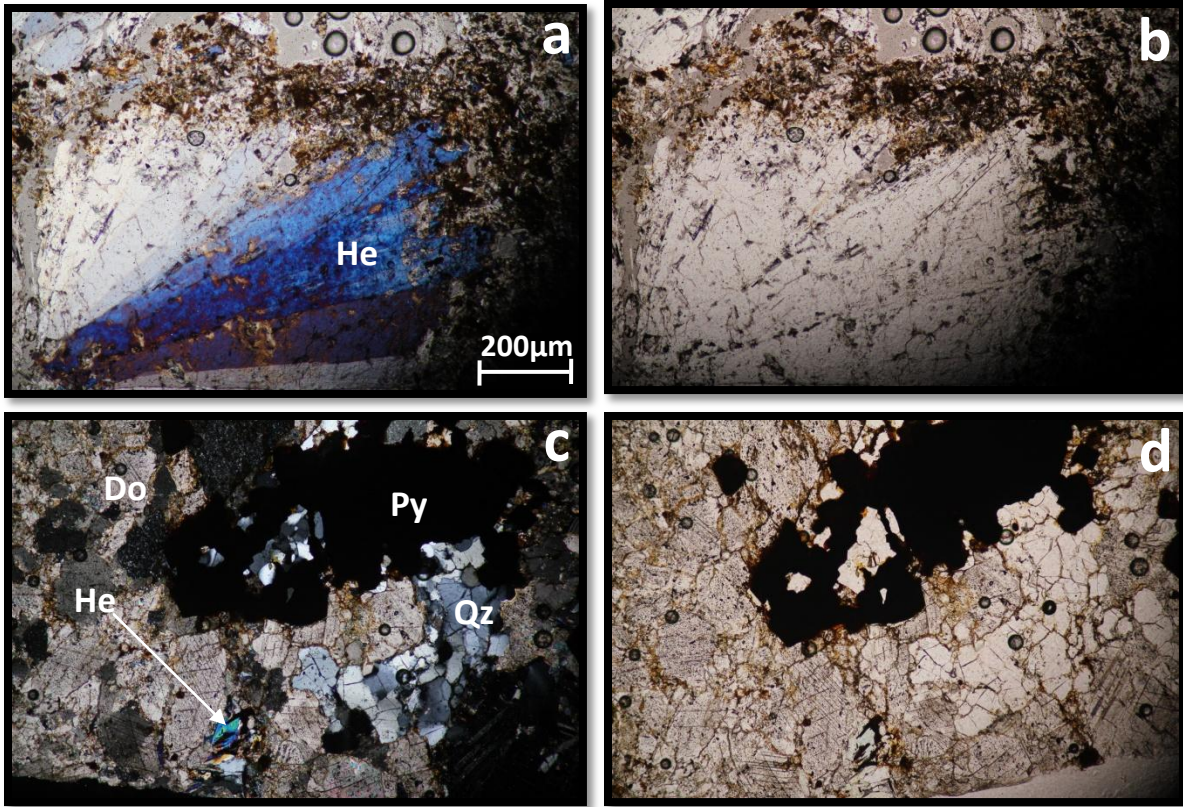


Figure 16. (a) XPL and (b) PPL (plane polarized light) photo micrographs of a large hemimorphite grain in sample C-473745C. Hemimorphite is growing as a radiating rosette into a vug, with extensive oxidation and minor brecciation occurring around the rim. He = hemimorphite. (c) XPL and (d) PPL photo micrographs of the most typical form of hemimorphite nucleation at Red Bird: anhedral small masses within iron oxide veinlets in the vicinity of weathered pyrite, all contained within a dolomitic groundmass. Do = dolomite, Py = pyrite, He = hemimorphite, Qz = quartz. The scale bar is the same for all four images.

Three of eleven samples at the Red Bird prospect have a groundmass of only dolomite and no calcite (Table 4). All three samples are from Trench B and were taken from less than 0.5m below the surface. They are extensively oxidized and two of them contain goethite that masks the rest of the groundmass (Figure 17). The dolomitic groundmass contains many fractures infilled with iron oxides, where hemimorphite is nucleating. Hemimorphite also precipitates as a replacement texture within the groundmass of dolomite, in the vicinity of oxidized, disseminated pyrite, and inside vugs. No other nonsulphide zinc minerals are found at Red Bird, with the exception of sample 09-SP-196, in which traces of

willemite are seen in SEM (Figure 18). In this sample, at least two generations of dolomite exist, as seen by dolomite overprinting a brecciated grain of willemite.

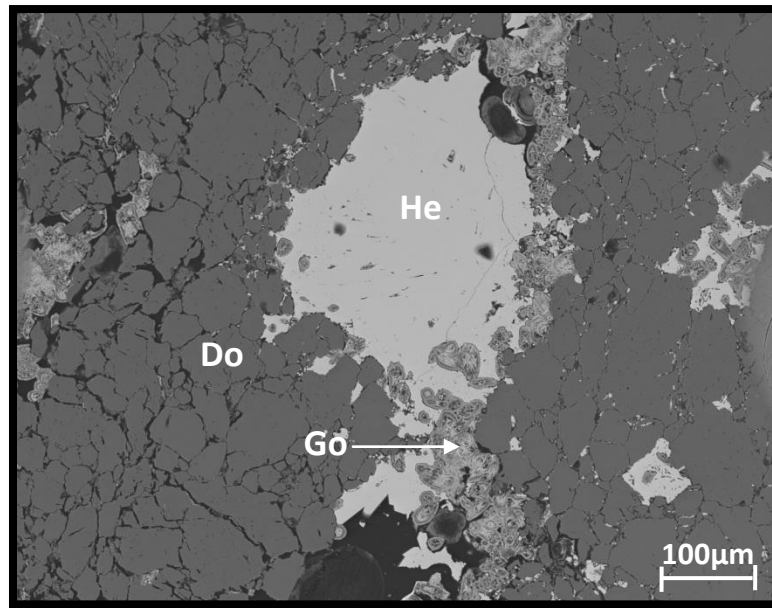


Figure 17. SEM/BSE image of sample 09-SP-193, showing a vug infilled with hemimorphite. Goethite is forming around the edges of the vug and in fractures within the dolomite grains. He = hemimorphite, Do = dolomite, Go = goethite.

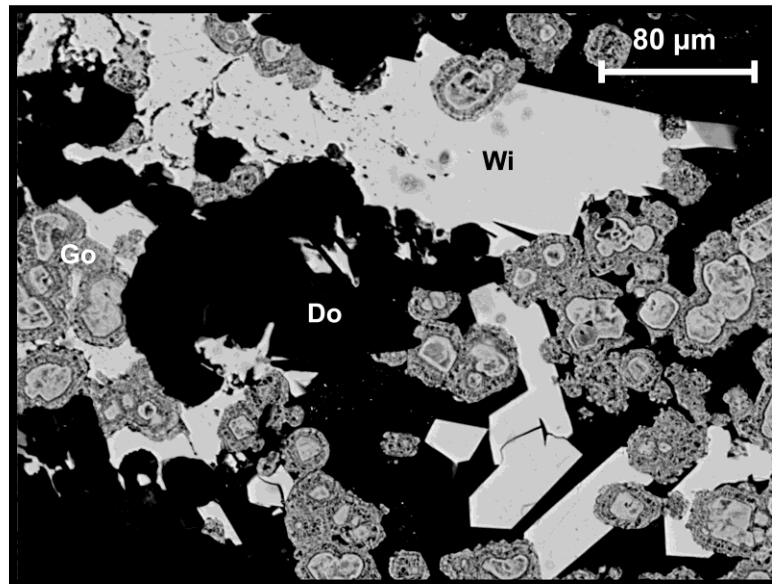


Figure 18. SEM/BSE image of willemite with overprinting dolomite that has subsequently been overprinted by goethite. Sample 09-SP-196. Wi = willemite, Go = goethite, Do = dolomite.

Sample 09-SP-174, from Trench B 2000-1 at 4.8m depth, is the one sample that contains no dolomite. The groundmass is purely calcite with no nonsulphide mineralization present. Two distinct phases of disseminated quartz occur throughout the calcite groundmass, and no other minerals are seen.

Four samples from the Red Bird prospect were sent for whole rock geochemistry (Appendix IV) and returned average grades of 17.9% Zn, 1.82% Pb, and 14.98% Fe. The highest zinc grade was 43.7% in sample 09-SP-191, and the highest lead grade was 5.09% in sample 09-SP-207. Iron contents are also significant due to abundant secondary oxidation.

The general paragenesis for the Red Bird samples is as follows:

- 1) Massive layered carbonate groundmass that underwent at least one phase of dolomitization (more in some cases).
- 2) Stratiform masses and lenses of sphalerite.
- 3) Pyrite disseminations or fracture-fill.
- 4) Quartz and talc overprint the sulphide mineralogy in some of the samples.
- 5) Formation of hemimorphite/secondary oxidation.

Hydrozincite is only seen on the crust of one hand sample and likely occurs after all other phases. The relationship between willemite and the other minerals is unknown.

5.3.2 Lomond

The Lomond deposit is located 27km south of Salmo, BC, and contains extensively oxidized Zn-Pb sulphides (Paradis et al., 2011). The host rock at Lomond is dolomite from the Middle Cambrian to Early Ordovician Nelway Formation. The nonsulphide mineralization occurs within cream-to-grey banded dolomite containing gossanous zones that conform to the dolomitic banding (Paradis et al., 2011). The hand sample studied at this property was an iron oxide gossan.

The sample contains orange, friable limonite crust with harder areas of goethite and botryoidal hematite within vugs. No fresh sulphides were observed in this sample. Prismatic cerussite crystals with an average length of 1-2mm were seen in one of the vugs, likely associated with previous galena (Figure 19). Whole rock geochemistry of the sample returned grades of 1.77% Zn, 2.4% Pb, and 55.45% Fe.

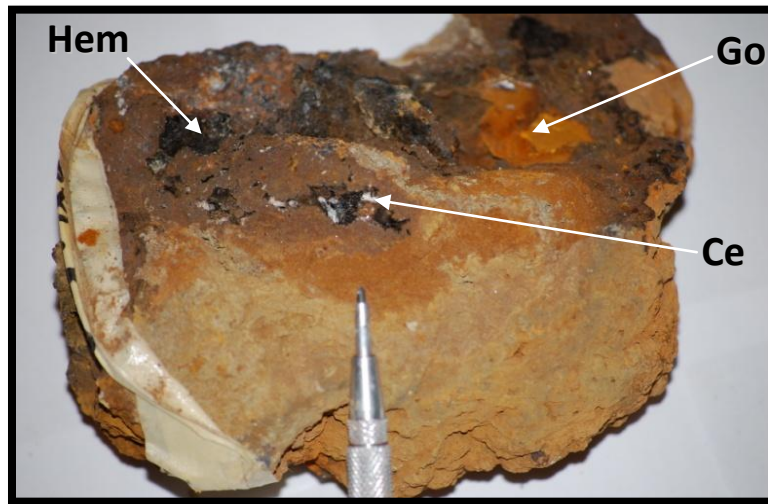


Figure 19. Photograph of sample 2008-GS-22C: an iron oxide gossan from the Lomond deposit. Hem = hematite, Go = goethite, Ce = cerussite. The rest of the orange, friable oxidation consists of limonite.

5.3.3 Oxide

The Oxide prospect is located further north than the previously mentioned showings, 6km southeast of Ymir, BC (O'Brien and Reid, 1998). The exact host rock of the mineralization is unknown due to lack of exposure and the fact that no drilling has been done on the property (Paradis, personal communication, 2010). However, it is known that the property is underlain by black argillite and slate of the Lower to Middle Ordovician Active Formation, grey limestone of the Reeves Member of the Laib Formation, and micaceous and white quartzite of the Quartzite Range Formation (Fyles and Hewlett, 1959). It is likely that the mineralization is hosted in the Reeves Member of the Laib Formation for two reasons. First, the mineralization on the property is associated with the Oxide Fault, a regionally extensive fault that occupies the same structural position as the Argillite Fault with which all

of the Reeves Member sulphide and nonsulphide deposits of the Salmo district are spatially associated (O'Brien and Reid, 1998). It is interpreted by O'Brien and Reid (1998) to represent a post-metamorphic reactivation of a northern segment of the Argillite Fault. Second, a north-plunging anticline in the vicinity of the property includes a zone of Reeves limestone that has been thickened along the fold hinge. Based on geological mapping and prospecting by Cominco (O'Brien and Reid, 1998), it has been determined that there is no evidence for preserved, unweathered sulphide ore at depth.

Both samples from the Oxide prospect, 2008-SP-85 and 2008-SP-88, were sent for whole rock geochemical analyses (Table 9) and returned values of 38.8% and 31.5% Zn, 0.13% and 0.14% Pb, and 0.72% and 1.53% Fe, respectively. Sample 2008-SP-88 contains 100% hemimorphite, with no remnants of any carbonate groundmass. The hand sample consists entirely of botryoidal spheres of hemimorphite that vary in colour from white to yellow to brown. In thin section, the hemimorphite forms euhedral to subhedral radiating rosettes that grow into large vugs, where they are brecciated and have undergone minor secondary oxidation.

Sample 2008-SP-85 is almost predominantly composed of hemimorphite and hopeite, with the carbonate groundmass completely replaced by hemimorphite and secondary oxidation. XRD analyses showed calcite to be present and no evidence of dolomite, though dolomite could still exist as part of the original groundmass. In thin section, slightly oxidized radiating rosettes of hemimorphite are occasionally fractured, and hopeite infills all of the groundmass (Figure 20). The only evidence of the previous carbonate groundmass is in small needles of calcite on the outer edges of hopeite where the latter meets hemimorphite (Figure 21).

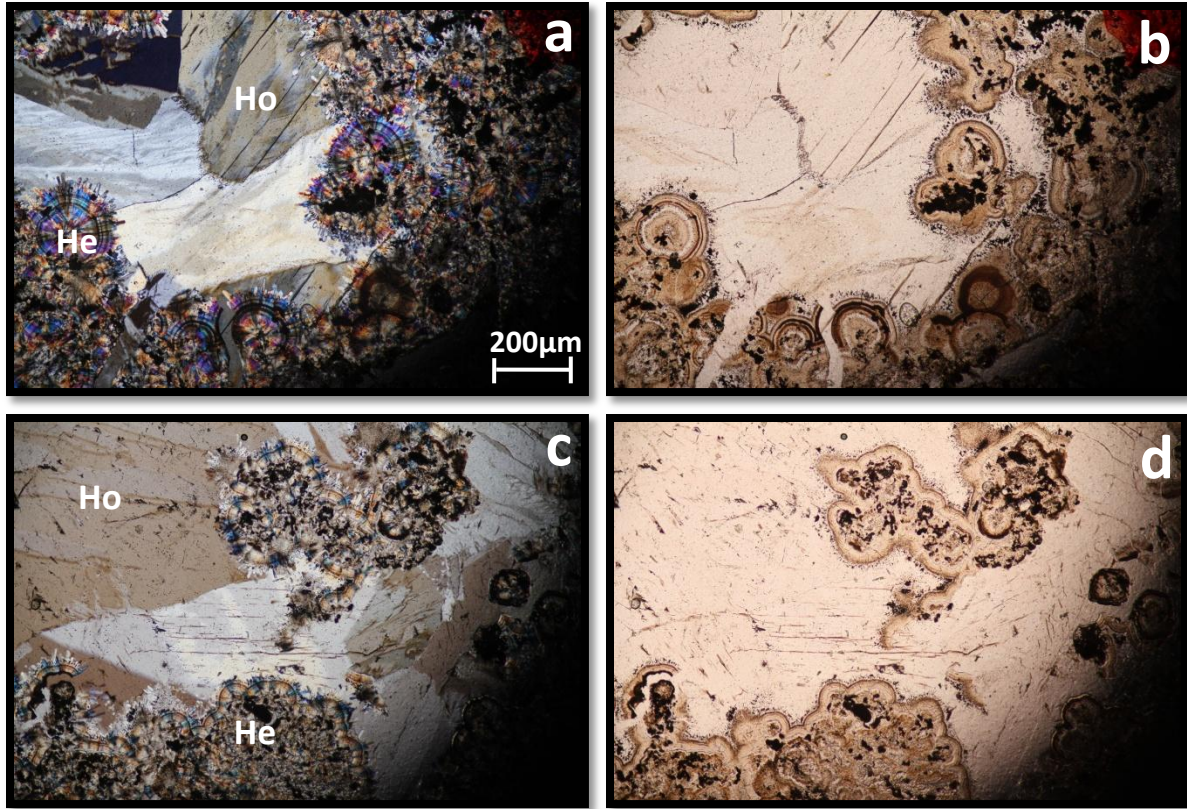


Figure 20. (a) XPL and (b) PPL photo micrographs of sample 208-SP-85, showing hopeite infilling fractures in hemimorphite. (c) XPL and (d) PPL photo micrographs of the same sample, again showing hopeite infilling hemimorphite. Ho = hopeite, He = hemimorphite. The scale bar is the same for all four images.

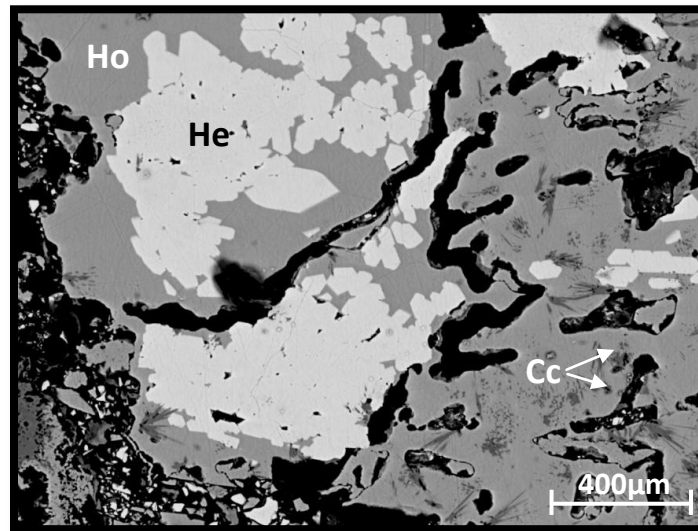


Figure 21. SEM/BSE image showing the relationship between hemimorphite, hopeite, and remnant calcite in sample 208-SP-85. Ho = hopeite, He = hemimorphite, Cc = calcite.

5.4 Nonsulphide mineralization in the Quesnel Lake district

5.4.1 Cariboo Zinc

The Cariboo Zinc property is located in the Quesnel Lake district north of Quesnel Lake in east-central BC (Paradis et al., 2009). The property is underlain by locally folded and interlayered Late Proterozoic carbonate and pelitic metasedimentary rocks of the Cunningham and Isaac formations of the Cariboo Group, which host both sulphide and nonsulphide mineralization (Paradis et al., 2011). The mineralization on the Cariboo Zinc property consists of pervasive fine-grained sulphide and nonsulphide disseminations and aggregates forming pods, masses, veins, and breccias in a dolostone-dolomitic limestone unit. The host to the nonsulphide mineralization is a dolostone unit adjacent to phyllite of the Cunningham Formation (Paradis et al., 2011). The showings studied in this thesis are presented in Figure 22.

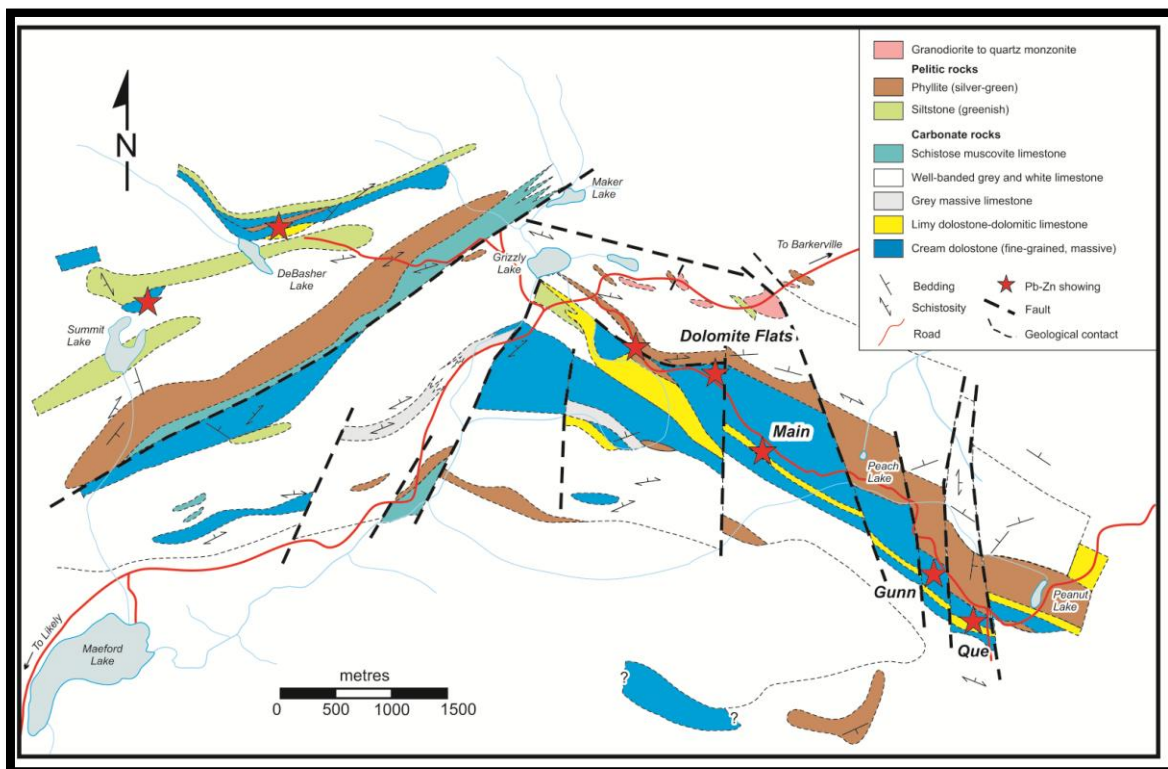


Figure 22. General geology of the Cariboo Zinc property, with names of the showings selected for study: Dolomite Flats, Main, Gunn and Que. Modified from Paradis et al. (2009).

The host rock for all of the Cariboo Zinc samples is purely dolomite. Smithsonite (ZnCO_3) is the most common nonsulphide mineral on the property and occurs in seven of the samples, with hemimorphite present in small quantities in nine of the samples. Two lead nonsulphide minerals, cerussite (PbCO_3) and anglesite (PbSO_4), are also present at Cariboo Zinc and partially replace galena. Hydrozincite is present as a crust on two oxidized surface samples from the Que Zone. As in the Salmo district, some recrystallized quartz is present, but most of the quartz on the property is contained within primary quartz-galena veins.

Smithsonite has two forms. One form is predominant and consists of fine-grained masses that form oxidation halos around sphalerite grains and infill fractures within the dolomitic matrix, occasionally forming networks inside of vugs (Figure 23). The other form of smithsonite appears as discontinuous grains within the groundmass (Figure 25).

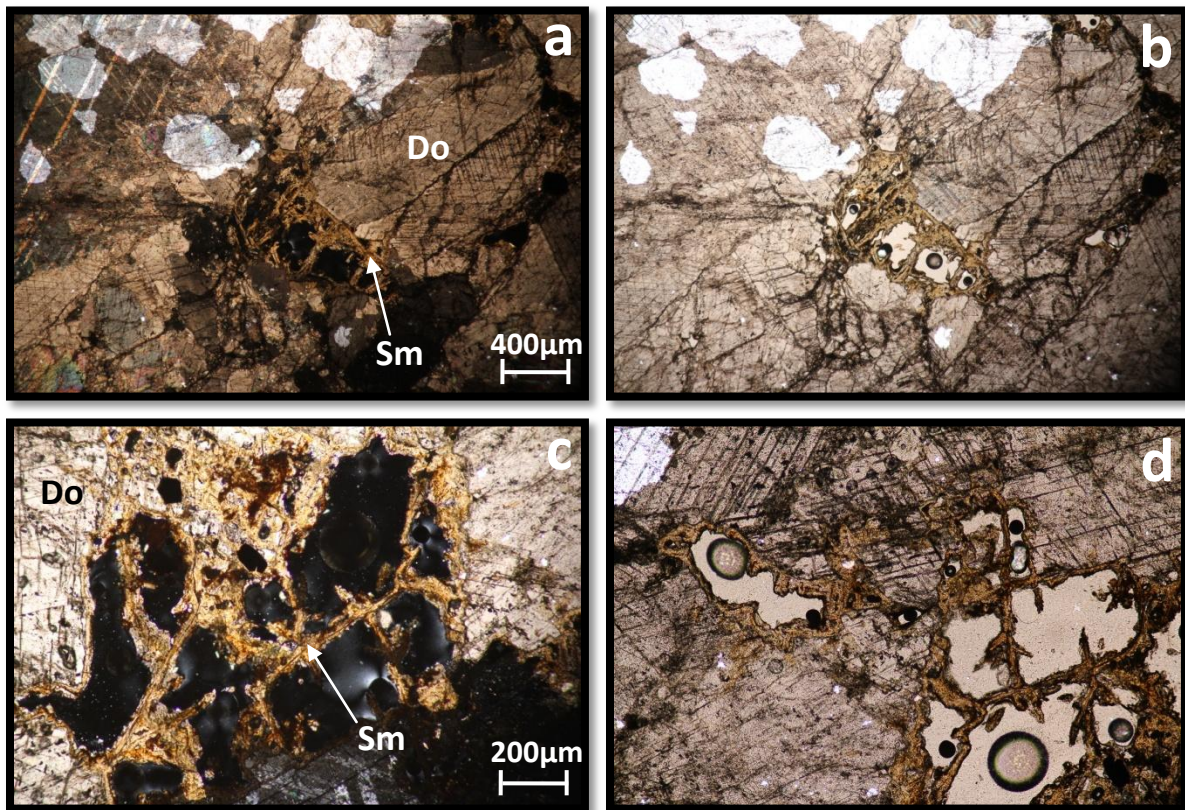


Figure 23. (a) XPL and (b) PPL photo micrographs of sample 09-SP-221B, showing smithsonite infilling fractures in the dolomitic groundmass and forming networks inside of a vug. (c) XPL and (d) PPL photo micrographs of the same sample in a different spot and at a higher magnification. Do = dolomite, Sm = smithsonite.

Hemimorphite is found alone with no smithsonite in two samples: 09-SP-231D from the Gunn Zone and 09-SP-237A from the Que Zone. In sample 09-SP-231D, hemimorphite is present inside a galena vein, likely replacing previous sphalerite. It is generally present as small anhedral radiating masses within oxidized stringer veinlets or within fractures in the dolomitic groundmass, and rarely forms euhedral crystals. Smithsonite and hemimorphite are associated in five samples (Table 4). In one hand sample, hemimorphite can be seen cross-cutting yellow fine-grained friable smithsonite, but this is not conclusive evidence of hemimorphite being a late mineral (Figure 24). Despite smithsonite and hemimorphite being present within the same sample, direct relationships between smithsonite and hemimorphite are only seen in polished thin section #495, a breccia, where hemimorphite infills the space between smithsonite grains (Figure 25).

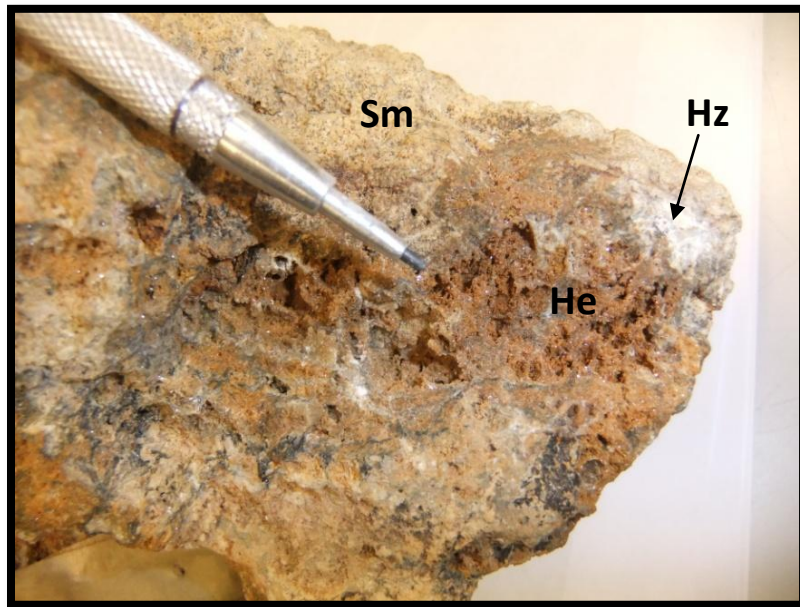


Figure 24. Smithsonite, hemimorphite, and white, friable hydrozincite from sample 09-SP-224B, Cariboo Zinc property. Blue, weathered veinlets of hemimorphite cross-cut the yellow smithsonite on the surface of the sample. Hydrozincite is present as a white, friable crust. Sm = smithsonite, He = hemimorphite, Hz = hydrozincite.

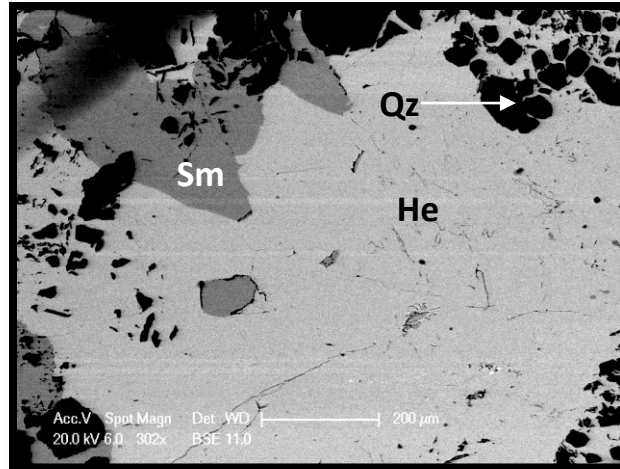


Figure 25. SEM/BSE image from sample #495, a brecciated nonsulphide-rich dolostone. Optically continuous smithsonite is shown with infilling hemimorphite and overprinting quartz grains. Sm = smithsonite, Qz = quartz, He = hemimorphite.

Of the lead nonsulphides, cerussite is observed at the Main Zone, Gunn Zone, and Que Zone, whereas anglesite is observed in one sample at the Main Zone (Table 4). Though anglesite is only present in one sample, it is much more obvious than cerussite: it forms as euhedral prismatic laths with second-order interference colours in XPL, whereas cerussite has no distinct form. Neither mineral is visually identifiable in hand sample at Cariboo Zinc, and cerussite is only identified in hand sample with XRD. Both are seen together in sample 09-SP-225B as intergrown laths inside a vug within a quartz-galena vein (Figure 26).

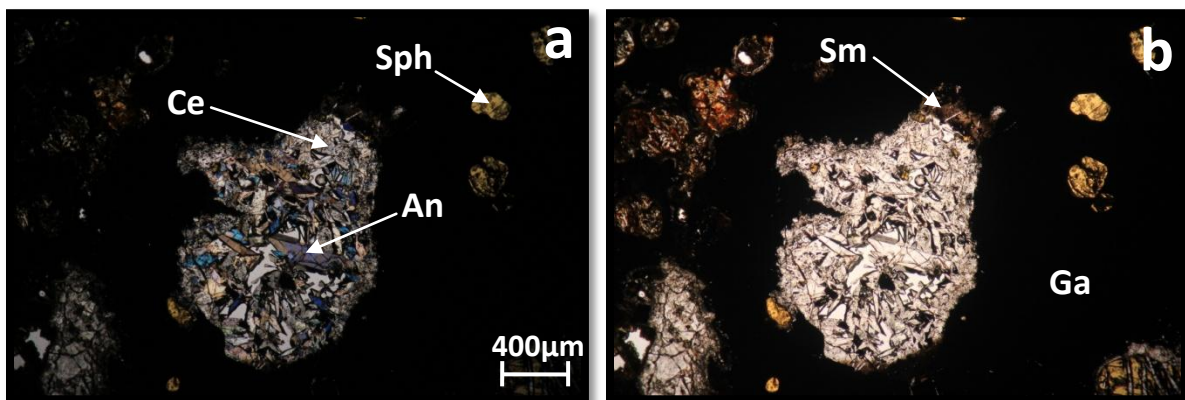


Figure 26. (a) XPL and (b) PPL photo micrographs of sample 09-SP-225B. Sphalerite grains within the fresh galena vein are weathered, and smithsonite has nucleated around them and grown into the vug. Ce = cerussite, An = anglesite, Sph = sphalerite, Sm = smithsonite, Ga = galena.

The sulphide phases at Cariboo Zinc consist of galena (mostly in veins with quartz), sphalerite (as masses, lenses or subhedral disseminated grains), and very minor disseminated pyrite. Sphalerite within the galena veins tends to weather and fracture, and smithsonite precipitates from it while the galena remains fresh (Figure 27).

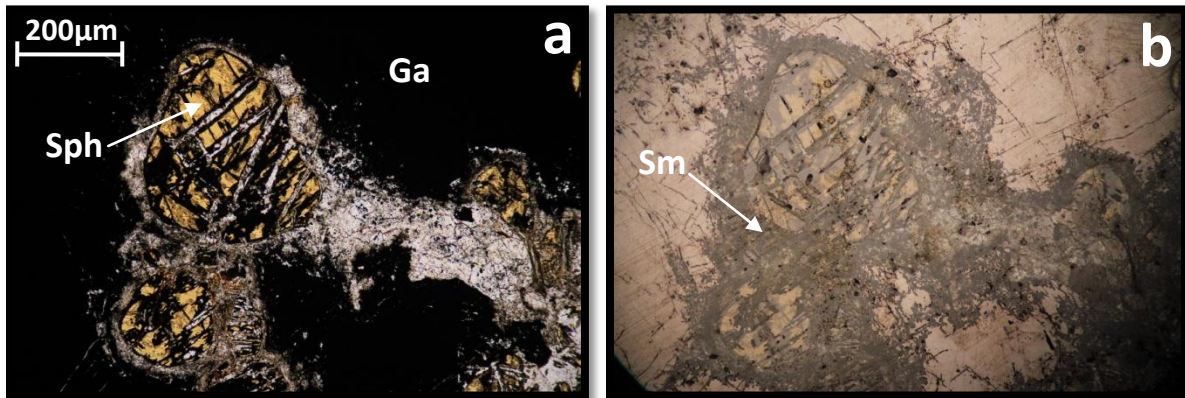


Figure 27. (a) PPL and (b) reflected light photo micrographs of weathered, fractured grains of sphalerite with smithsonite infilling fractures and flowing through a galena vein in sample 09-SP-225B, Cariboo Zinc Property. Sph = sphalerite, Ga = galena, Sm = smithsonite.

Four samples were sent for whole rock geochemistry (Table 9) and returned average grades of 25.19% Zn and 0.35% Pb. The highest zinc grade was 51.03% in sample 09-SP-237A, and the highest lead grade was 0.94% in sample 09-SP-242.

The general paragenetic sequence for the Cariboo Zinc property, when the minerals are present, is as follows:

- 1) Massive dolomitic groundmass.
- 2) Quartz-galena veining (synchronous in most cases, except in some samples where galena can be seen cross-cutting quartz).
- 3) Formation of disseminated quartz within the groundmass.
- 4) Sphalerite/pyrite mineralization (timing relationships not observed).
- 5) Smithsonite formation.
- 6) Hemimorphite formation.
- 7) Anglesite and cerussite growth in vugs (synchronous).

6.0 DISCUSSION

6.1 Sulphide mineralization: protore to nonsulphide mineralization

6.1.1 *Salmo district*

The sulphide deposits of the Salmo district have been referred to as “Kootenay Arc-type deposits” (Höy, 1982; Nelson, 1991; Paradis et al., 2011). Previously, researchers have interpreted the sulphide protore to be metamorphosed MVT, SEDEX or Irish-type deposits, but recent Re-Os age dating by Paradis (personal communication, 2010) on stratabound carbonate-hosted sulphides of the Kootenay Arc give broad Ordovician to Devonian ages for the Zn-Pb mineralization. This suggests they may be classified as MVT deposits that were emplaced during rifting along a continental margin (Giroux and Grunenberg, 2010). The age constraints are minimal, but the sulphides must be older than Early Ordovician (the age of the Nelway Formation that hosts the Lomond deposit) and younger than the Middle Jurassic (the first of the orogenic events that post-date the sulphide mineralization).

According to Paradis (2007), the main sulphide minerals in the Salmo district are sphalerite, pyrite, and galena, with pyrrhotite and traces of arsenopyrite observed in some deposits. Of the sulphide-rich samples observed in this study from the Salmo district, all contained sphalerite and pyrite as the primary sulphide ore with the exception of Reeves MacDonald, which also contained minor galena. The Reeves MacDonald and HB mineralization are both hosted in a dolomite-calcite matrix, whereas the Jersey-Emerald mineralization is hosted in a dolomitic matrix. All of the samples analyzed contain irregular masses of sphalerite with disseminations of pyrite. The Reeves MacDonald sample is the only one with observable galena (though the other properties have also been known to host galena), which came after the sphalerite and infilled through fractures.

Sulphide mineralization within the Reeves MacDonald, HB, and Jersey-Emerald deposits are all hosted within the Reeves Member of the Lower Laib Formation. The styles of deformation between the three deposits are similar: the stratabound sulphide mineralization at all three properties is contained within secondary isoclinal folds along the same regional

anticline (Paradis et al., 2011), and all of the properties also have major faults running through them. Despite subtle differences in the mineralogy of these deposits (Table 4), their paragenetic relationships and deposit-scale characteristics are similar enough to suggest that they all formed at the same time and by the same mineralizing event.

6.1.2 Quesnel Lake district

Age constraints on the Cariboo Zinc sulphide mineralization are much broader than at Salmo because of the complete lack of age dating done in this region of the Quesnel Lake district. However, regionally speaking the Cariboo terrane has areas of polyphase deformation so it is possible that the same Middle Jurassic orogenic event that deformed the Salmo district also occurred in the Quesnel Lake district but is not visible on the scale of the Cariboo Zinc property (Paradis, personal communication, 2010). The sulphide mineralization had to have occurred in between the Neoproterozoic (the age of the Cunningham and Isaac formations that host the mineralization) and the Middle Jurassic. Field evidence shows vein- and MVT-style characteristics rather than SEDEX-style mineralization, so the sulphide mineralization is likely much younger than the Neoproterozoic and could have occurred at the same time as the sulphides in the Salmo district.

The deposits of the Salmo district and the deposits of the Quesnel Lake district are both spatially associated with fault zones that may have acted as fluid conduits in mineralization (Paradis et al., 2011), but the style of mineralization is slightly different. Though no sulphide-only samples were analyzed at Cariboo Zinc, paragenetic relationships between the sulphide and nonsulphide minerals and the timing of metamorphism and deformation with respect to the mineralogy both indicate a similar sequence of events to those that occurred at Salmo.

6.2 Nonsulphide mineralization

According to Takahashi (1960), important processes in determining the mode of formation of common supergene nonsulphide minerals include pH, partial pressure of carbon dioxide (P_{CO_2}), temperature, and concentrations of Zn, Pb, and silica in solution. In supergene environments, the temperature and pressure are likely to remain stable at 25°C and 1atm, so the effects of temperature can likely be discounted when referring to supergene nonsulphide mineralization.

Some of the defining factors for determining if nonsulphide mineralization is “red ore” and *direct-replacement* in origin vs. “white ore” and *wall-rock-replacement* in origin are metal content, presence or absence of primary sulphides, and amount of gossanous material. “Red ore” and therefore *direct-replacement* deposits will generally have lower zinc concentrations, primary sulphide minerals nearby, and extensive iron oxide gossans (Paradis et al., 2011). “White ore” and therefore *wall-rock-replacement* deposits will have higher zinc concentrations, absence of primary sulphides, and less extensive oxidation. Of the four nonsulphide deposits studied, three exhibited properties of “red ore” and *direct-replacement* origin: the Red Bird, Lomond, and Cariboo Zinc deposits, while one, the Oxide prospect, exhibited properties of “white ore” and *wall-rock-replacement* origin. Samples from the Red Bird prospect are oxidized and gossanous as well as spatially associated with sulphide ore. The Lomond sample is also very clearly “red ore” due to the extensive iron oxide gossans, and though not enough samples were observed to identify sulphide protore in the vicinity of the nonsulphide minerals, it is also likely *direct-replacement* in origin. The rocks of the Cariboo Zinc property show traits of both “red ore” and “white ore” with respect to the amount of gossanous mineralogy present, although the close proximity to the sulphide protore and the variable extent of oxidation suggests that it is a *direct-replacement* type deposit as well. The Oxide prospect contains rocks with very minor amounts of oxidation, and no sulphide ore has been identified anywhere on the property. It has therefore been classified as “white ore” and as a *wall-rock-replacement* type deposit. For detailed mineralogy of the samples from each deposit, see Appendix III.

6.2.1 “Red Ore”

The Red Bird prospect and the Lomond property share many similarities, although only one sample was analyzed from the Lomond deposit. The Cariboo Zinc mineralization, though clearly *direct-replacement* in origin, is not as extensively oxidized as the rocks in the Salmo district. The Dolomite Flats and Main zones of the Cariboo Zinc property show minor oxidation, whereas the Gunn and Que zones show locally extensive oxidation. As such, Cariboo Zinc will still be considered to be “red ore”, but it should be noted that the distinction between “red ore” and *direct-replacement* mineralization vs. “white ore” and *wall-rock replacement* mineralization does not hold as well for the Cariboo Zinc property as it does for the deposits of the Salmo district.

The Red Bird, Lomond, and Cariboo Zinc properties fit the general criteria for “red ore”, with the exception of zinc content: compared to the Oxide prospect, which is interpreted to be “white ore” and *wall-rock-replacement* in origin, some samples at the Red Bird and Cariboo Zinc properties have higher concentrations of zinc, which is not expected for *direct-replacement* mineralization (Table 9). Though the zinc content is not necessarily representative of typical “red ore”, sulphide ore is present on all three properties, and all are associated with some degree of oxidation.

There are four fundamental differences between the Red Bird prospect of the Salmo district and the Cariboo Zinc property of the Quesnel Lake district: the amount of oxidation, the style of mineralization, the presence of smithsonite at Cariboo Zinc but absence at Red Bird, and the presence of lead nonsulphides at Cariboo Zinc but not at Red Bird. Both districts have zones of dolomitization that completely or partially surround the sulphide and nonsulphide mineralization. In the Salmo district the dolomite forms large envelopes around the stratabound massive sulphide lenses and calcite is present locally, and in the Quesnel Lake district the whole property is hosted in dolomite, although limestone is present regionally. Both properties also have hydrozincite present on the crust of select hand samples, and both have disseminated quartz in the groundmass.

Samples from the Red Bird and Lomond occurrences are gossanous (Figure 28), which is interpreted to be due to the presence of abundant pyrite in the Salmo district. The

Cariboo Zinc rocks are somewhat less oxidized than the rocks of the Salmo district, which correlates well with the lack of pyrite found in the samples from this property (Figure 29).



Figure 28. Photo of a typical zone at the Red Bird prospect of the Salmo district, showing the amount of oxidation that is typical of the area. Photo courtesy of Suzanne Paradis.



Figure 29. Photo of typical replacement-style nonsulphides at the Cariboo Zinc property of the Quesnel Lake district, showing lesser oxidation than the Salmo district showings. Photo courtesy of Suzanne Paradis.

The main difference in nonsulphide zinc mineralogy between the Red Bird and Cariboo Zinc properties is the formation of hemimorphite (and trace willemite, also a zinc silicate, in one sample) as the main nonsulphide phase at Red Bird whereas smithsonite is the main phase at Cariboo Zinc. Hemimorphite is also present at Cariboo Zinc, but it formed after smithsonite and to a lesser extent. Takahashi (1960) found that between pH values of 6.2 and 8.1, smithsonite is the least soluble mineral and will form first. Most natural waters are between pH values of 6 and 8, so its formation as the first nonsulphide mineral in the paragenetic sequence at Cariboo Zinc is consistent with Takahashi's study. Also, according to Takahashi (1960) and Reichert and Borg (2008), smithsonite is also favoured by high P_{CO_2} values from the carbonate host rock. According to the geochemical model proposed by Reichert and Borg (2008), smithsonite forms during the first "oxidation stage" of nonsulphide zinc mineralization as the sulphuric acid produced will start to react with the carbonate host rock and neutralize the pH. Because of this, CO_2 is produced and the P_{CO_2} increases, favouring smithsonite precipitation. During the "post-oxidation stage", P_{CO_2} will decrease to levels similar to atmospheric CO_2 values and favour formation of zinc silicates, presuming there is enough silica in the system.

Secondary hemimorphite formation is observed at the Cariboo Zinc property and usually forms after smithsonite. At this property, the carbonate host rock is cross-cut by quartz-sulphide (\pm nonsulphide) veins, but it is possible that there was not enough silica to favour the precipitation of hemimorphite over smithsonite. The P_{CO_2} values were likely too high to allow hemimorphite to precipitate initially, and therefore smithsonite formed as the first nonsulphide mineral in the paragenetic sequence. In one sample, hemimorphite is the only nonsulphide present. In this particular sample the hemimorphite has completely replaced the original sphalerite, which could occur if the oxidation stage had completed, sphalerite had completely weathered to smithsonite, and hemimorphite formed as the next stage in the paragenetic sequence.

The lack of smithsonite and the abundance of hemimorphite at the Red Bird prospect is interpreted to be primarily based on pH and abundance of silica in the system. The Reeves Member dolomitized limestone that hosts most of the deposits of the Salmo district is underlain by a thick succession of quartzite, providing a potential source of silica. According

to McPhail et al. (2003), low pH, high silica content, and lower P_{CO_2} favour hemimorphite saturation despite the usual occurrence of smithsonite as the first nonsulphide zinc mineral to precipitate in CHNSBM deposits. Reichert and Borg (2008) agree that the amount of hemimorphite seems to correlate with the amount of SiO_2 available in the system and Takahashi (1960) states that hemimorphite is only the least soluble phase under pH values of 6.2. The nonsulphide mineralization at Red Bird is in agreement with these findings. The abundant silica likely came from the underlying quartzite of the Reno Formation, and the acidic environment could be due to the abundance of pyrite on the property that would have oxidized and produced numerous Fe-oxides, reducing both the pH and P_{CO_2} of the system. The gossanous supergene rocks at Red Bird therefore provided an acidic environment from the formation of sulphuric acid that allowed hemimorphite to precipitate. Smithsonite was not the first nonsulphide zinc mineral to form at Red Bird, as predicted by Takahashi (1960), because the pH values were too low. A stability diagram for smithsonite, hemimorphite and hydrozincite is shown in Figure 30.

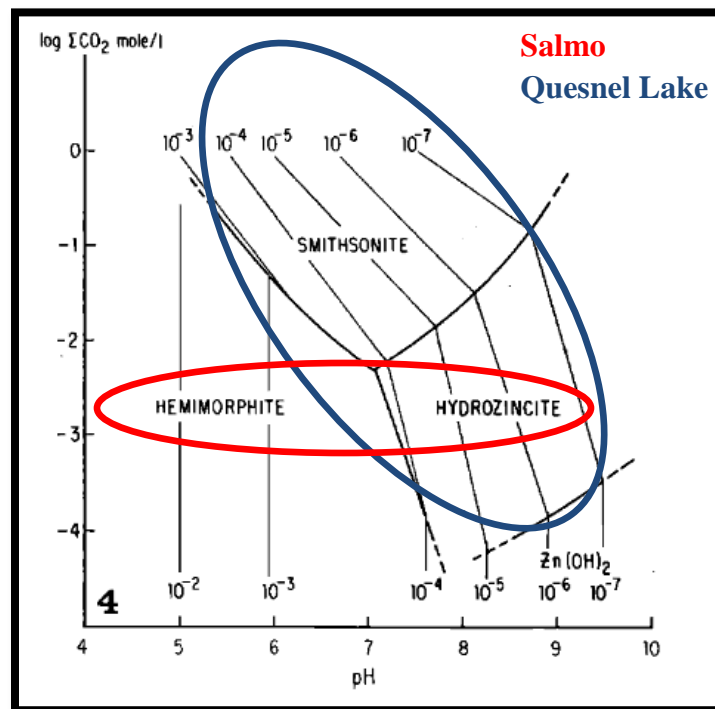


Figure 30. Stability fields of hemimorphite, smithsonite, hydrozincite, and zinc hydroxide, as determined from solubilities at 25°C and 1atm. Numbers are Zn concentrations in mol/L. The red circle shows the likely stability field in the Salmo district, while the blue circle shows the likely stability field in the Quesnel Lake district. Modified from Takahashi (1960).

The lack of lead nonsulphide minerals at Red Bird is explained by the lack (or low content) of galena in the protore. No galena was observed in any of the Red Bird samples, although galena exists in the Reeves MacDonald deposit just to the east of the Red Bird prospect. Perhaps the Salmo district had lower concentrations of lead to begin with; therefore the lack of lead nonsulphide minerals at the Red Bird prospect reflects a difference in the protore composition. At Cariboo Zinc, both cerussite and anglesite are observed, though anglesite is only seen in one sample. According to Reichert and Borg (2008), cerussite is stable at high P_{CO_2} values, which is consistent with the high P_{CO_2} values predicted for the precipitation of smithsonite, also seen on the property.

A commonality between the Red Bird and Cariboo Zinc properties is the presence of small amounts of white, friable hydrozincite on the oxidized crust of some of the hand samples. According to Takahashi (1960), CO_2 gas can escape less easily at depth because of the slow rate of diffusion and its entrapment in the interstices between minerals. At the surface, however, CO_2 can escape more readily, resulting in the lower P_{CO_2} values required for precipitation of hydrozincite. From the observations made in this study, hydrozincite is not observed at depth in either deposit. General paragenetic relationships for the mineralization in the Salmo and Quesnel Lake districts are shown in Figures 31 and 32.

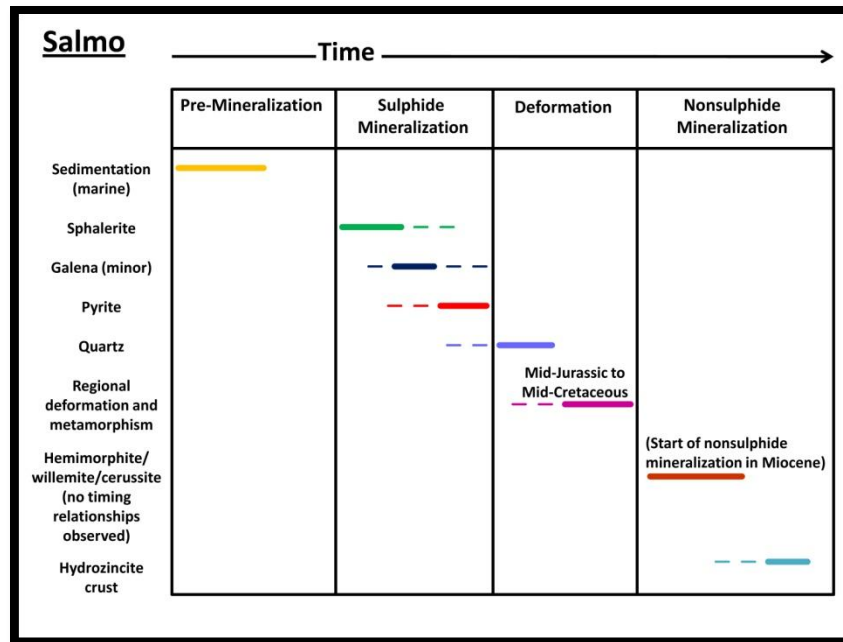


Figure 31. Diagram showing the general paragenesis of the mineralized rocks of the Salmo district, from sedimentation to nonsulphide mineralization (based on samples from the Red Bird prospect). Ages are indicated when known.

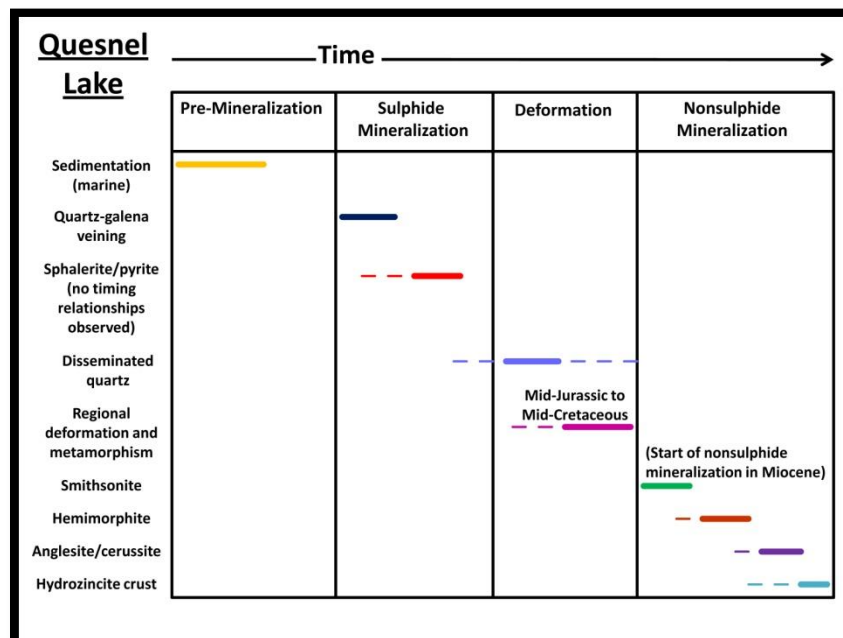


Figure 32. Diagram showing the general paragenesis of the mineralized rocks of the Quesnel Lake district, from sedimentation to nonsulphide mineralization (based on samples from the Cariboo Zinc property). Ages are indicated when known.

Although the Red Bird and Cariboo Zinc nonsulphide mineralization have distinct mineralogical differences, the general sequence of events is similar. Both are interpreted to be direct-replacement deposits of somewhat different sulphide protore in similar environments and in similar host rocks.

The mineralization at the Lomond deposit is hosted in the Nelway Formation, although the mineralogy, texture (carbonate-replacement), and hydrothermal alteration are similar to the nonsulphide mineralization hosted within the Reeves Member of the Laib Formation. The styles of deformation are also similar: the mineralization is contained within secondary isoclinal folds along the same regional anticline as the other nonsulphide showings of the Salmo district (Paradis et al., 2011), and the property is associated with fault zones as well. This suggests the same mode of mineralization at the Lomond deposit and at the other Salmo showings. However, only one sample was examined from the Lomond deposit, and no thin section was obtained. As a result, analysis of the Lomond deposit needs further work. The presence of cerussite within a vug in this gossanous sample suggests the presence of lead in the form of galena that has been subsequently weathered away. It is also probable that the extensive oxidation is due to widespread presence of pyrite in the sulphide protore, similar to the Red Bird prospect.

6.2.2 “White Ore”

Based on the current classification system, the Oxide prospect of the Salmo district clearly contains “white ore” and is of *wall-rock-replacement* origin. The rocks of this property do not contain many iron oxides and therefore are less gossanous than rocks of the other properties observed in the Salmo district. The prospect is also different from the Red Bird and Cariboo Zinc properties in that no sulphide ore is found on the property, and the original carbonate groundmass has been completely replaced by nonsulphide minerals. The geochemistry, though comparable to some samples from the Red Bird and Cariboo Zinc properties, also shows values of 30–40% Zn, typical of wall-rock-replacement deposits (Table 9).

The nonsulphide mineralogy of the Oxide prospect is also unique. Hemimorphite replaces the entire carbonate groundmass, whereas hopeite, a zinc phosphate not seen in any of the other properties studied, infills fractures in the hemimorphite and also cross-cuts it. Very little information exists in the scientific literature on the mineral hopeite, but the presence of it at the Oxide prospect is likely due to different environmental conditions in the fluid system. The pH must have been lower than 6.2 for the abundant hemimorphite found on the property to form, but no thermodynamic data is known for hopeite.

The Oxide prospect bears the most similarity to the Red Bird prospect, as it is hosted in the same formation and contains abundant hemimorphite, but it is interpreted to be the one nonsulphide property studied that fits the classification of *wall-rock-replacement* type deposits, the metal-bearing fluid having traveled sufficiently far from the sulphide protore to precipitate nonsulphide minerals in a different environment.

7.0 CONCLUSIONS

In the Salmo district, both the Red Bird prospect and Lomond deposits are characteristic of being “red ore” and *direct-replacement* in origin, whereas the Oxide prospect shows traits of “white ore” and is interpreted to be *wall-rock-replacement* in origin. In the Quesnel Lake district, the Cariboo Zinc property bears similarities to the *direct-replacement* deposits of the Salmo district, with slightly different variables controlling the nonsulphide mineralization. The *direct-replacement* rocks of the Salmo district are extensively gossanous “red ores”, likely due to the original presence of significant pyrite in the protore, which created the acidity needed to precipitate hemimorphite. The *wall-rock replacement* Oxide prospect of the Salmo district contains hopeite as well as hemimorphite, and no remnant sulphides were found. The nonsulphide mineralogy of the Cariboo Zinc property is more variable than the Salmo district, consisting of hemimorphite, smithsonite, hydrozincite, cerussite, and anglesite. Remnants of galena are common and lack of pyrite is notable. The Cariboo Zinc property is a *direct-replacement* deposit that formed in slightly different environmental and geological conditions than the mineralization in the Salmo

district. It is possible that the only fundamental difference in pH and P_{CO_2} conditions between the Salmo and Quesnel Lake districts resulted from the presence of extensive pyrite in the protore in the Salmo district and its low abundance in the Quesnel Lake district, a factor which ultimately controlled the precipitation of smithsonite as opposed to hemimorphite at the Cariboo Zinc property.

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APPENDIX I: List of Hand Samples and Thin Sections

Table 5. List of hand sample and thin section sample numbers.*

	Sample Number	Hand Sample	Thin Section
Salmo district	Red Bird prospect		
	C-473745A	-	✓
	C-473745C	-	✓
	09-SP-174	✓	✓
	09-SP-191	✓	-
	09-SP-192	✓	✓
	09-SP-193	✓	✓
	09-SP-196	-	✓
	09-SP-201	✓	✓
	09-SP-203	✓	✓
	09-SP-204	✓✓	✓
	09-SP-207	✓	--
	Lomond		
	2008-GS-22C	✓	--
	Oxide		
	2008-SP-85	✓	✓
	2008-SP-88	✓	✓
	Reeves MacDonald		
	2007-SP-022-11	--	✓
	Jersey-Emerald		
	08-SP-75-2	--	✓
	HB		
	2007-SP-033-2	--	✓
Quesnel Lake district	Cariboo Zinc		
	09-SP-221B	✓	✓
	09-SP-222B	✓	✓
	09-SP-224B	✓	✓
	09-SP-225B	✓	✓
	09-SP-225D	✓	-
	09-SP-228	--	✓
	09-SP-230	✓	--
	09-SP-231D	✓	✓
	09-SP-231E	✓	✓
	09-SP-237A	✓✓	✓
	09-SP-242	✓	--
	495	✓	✓

* ✓ = one sample, ✓✓ = two samples from same location, -- = no sample provided.

APPENDIX II: Sample Locations.

A. Salmo district sulphide protore:

Table 6. Sample location and host rock information for the sulphide deposits of the Salmo district.

Deposit	Sample Number	UTM Location	Elevation	Depth	Host Formation	Zone/Showing
Reeves MacDonald	2007-SP-022-11	5430153.8N 4741108.9E	832.8m	Surface	Reeves Mb, Laib Fm	Reeves MacDonald Glory Hole
Jersey-Emerald	08-SP-75-2	5440008N 483970E	Unknown	60m	Reeves Mb, Laib Fm	60m underground in old mine
HB	2007-SP-033-2	5443721N 485203E	1078.8	N/A	Reeves Mb, Laib Fm	Bottom of main glory pit

B. Salmo district nonsulphides:

Table 7. Sample location and host rock information for the nonsulphide deposits of the Salmo district.

Deposit	Sample Number	UTM Location	Elevation	Depth	Host Formation	Zone/Showing
Red Bird	C-473745A	5429233N 471306E	Unknown	Surface	Reeves Mb, Laib Fm	Zone B*. Trench B-2000-01
Red Bird	C-473745C	5429233 471306E	Unknown	Surface	Reeves Mb, Laib Fm	Zone B. Trench B-2000-01
Red Bird	09-SP-174	5429240N 471314E	855m	4.8m	Reeves Mb, Laib Fm	Zone B. Trench B-2000-01
Red Bird	09-SP-191	5429388N 471447E	863m	1m	Reeves Mb, Laib Fm	Zone C. Trench C 2000-01
Red Bird	09-SP-192	5429388N 471447E	864m	0.5m	Reeves Mb, Laib Fm	Zone C. Trench C 2000-01
Red Bird	09-SP-193	5429388N 471447E	864m	0.5m	Reeves Mb, Laib Fm	Zone C. Trench C 2000-01
Red Bird	09-SP-196	5429388N 471447E	863m	1m	Reeves Mb, Laib Fm	Zone C. Trench C 2000-01
Red Bird	09-SP-201	5429388N 471447E	863m	1m	Reeves Mb, Laib Fm	Zone C. Trench C 2000-01
Red Bird	09-SP-203	5429388N 471447E	857m	6.5m	Reeves Mb, Laib Fm	Zone C. Trench C 2000-01
Red Bird	09-SP-204	5429388N 471447E	856m	7m	Reeves Mb, Laib Fm	Zone C. Trench C 2000-01
Red Bird	09-SP-207	5429335N 471450E	874m	Surface	Reeves Mb, Laib Fm	Zone C. Trench C 2000-02
Lomond	2008-GS-22C	5427787N 475355E	777m	Surface	Nelway Fm	Oxide Zone
Oxide	2008-SP-85	5457482N 489475E	1484m	Surface	Laib Fm	Oxide prospect
Oxide	2008-SP-88	5457365N 489966E	1467m	Surface	Laib Fm	Oxide prospect

*Zone B = Beer Bottle Oxide Zone

C. Quesnel Lake district nonsulphides:

Table 8. Sample location and host rock information for the nonsulphide deposits of the Quesnel Lake district.

Deposit	Sample Number	UTM Location	Elevation	Depth	Host Formation	Zone/Showing
Cariboo Zinc	09-SP-221B	5853951N 641596E	1545m	Surface	Cunningham and Isaac Formations of Cariboo Group	Dolomite Flats
Cariboo Zinc	09-SP-222B	5854015N 641702E	1533m	Surface	Cunningham and Isaac Formations of Cariboo Group	Dolomite Flats
Cariboo Zinc	09-SP-224B	5853582N 641791E	1541m	Surface	Cunningham and Isaac Formations of Cariboo Group	Main Zone
Cariboo Zinc	09-SP-225B	5853400N 641939E	1532m	Surface	Cunningham and Isaac Formations of Cariboo Group	Main Zone
Cariboo Zinc	09-SP-225D	5853400N 641939E	1532m	Surface	Cunningham and Isaac Formations of Cariboo Group	Main Zone
Cariboo Zinc	09-SP-228	5852385N 643548E	1689m	Surface	Cunningham and Isaac Formations of Cariboo Group	Gunn Zone
Cariboo Zinc	09-SP-230	5852259N 643479E	1697m	Surface	Cunningham and Isaac Formations of Cariboo Group	Gunn Zone
Cariboo Zinc	09-SP-231D	5852188N 643413E	1699m	Surface	Cunningham and Isaac Formations of Cariboo Group	Gunn Zone
Cariboo Zinc	09-SP-231E	5852188N 643413E	1699m	Surface	Cunningham and Isaac Formations of Cariboo Group	Gunn Zone
Cariboo Zinc	09-SP-237A	5851520N 644120E	1735m	Surface	Cunningham and Isaac Formations of Cariboo Group	Que Zone
Cariboo Zinc	09-SP-242	5851843N 643242E	Unknown	Surface	Cunningham and Isaac Formations of Cariboo Group	Que Zone
Cariboo Zinc	495	5852256N 643481E	1695m	Surface	Cunningham and Isaac Formations of Cariboo Group	Gunn Zone

APPENDIX III: Thin Section Descriptions

A. Sulphide protore:

Deposit: Reeves MacDonald

Sample Number: 2007-SP-022-11

Rock Name: Sulphide-rich dolomitized limestone

Mineralogy:

- 80% Calcite and dolomite – massive and weathered with remnants of parallel layering. Calcite and dolomite are present together throughout the sample, with calcite forming discontinuous windows within the dolomite.
- 11% Quartz – overprinting, subhedral grains present throughout the carbonate groundmass.
- 4% Sphalerite – anhedral grains up to 1mm across, some brecciated with small fragments overprinting galena. Present in clusters with galena in small parts of the sample.
- 3% Galena – massive fresh galena infills fractures within the sphalerite and overprints it in ~1% of the sample.
- 2% Pyrite – subhedral, disseminated cubic crystals overprint the other sulphide phases.

Paragenesis:

1. Massive layered carbonate (calcite and dolomite) groundmass
2. Sphalerite overprints the groundmass
3. Galena infills fractures in sphalerite
4. Pyrite appears in disseminations that overprint the previous sulphides

Deposit: Jersey-Emerald

Sample Number: 08-SP-75-2

Rock Name: Sulphide-rich dolostone

Mineralogy:

- 70% Dolomite – massive, equigranular (average width 100µm), subhedral crystals form the groundmass of the sample. At least two phases of dolomite exist and bleed into one another throughout the sample in roughly equal concentrations.
- 13% Chlorite – yellow to green, slightly pleochroic in PPL with second-order interference colours in XPL. Crystals are massive and weathered with roughly parallel extinction, occurring in large stringy masses in association with sphalerite and pyrite and infilling fractures between the two. Also appears in sub-parallel veinlets within the dolomitic groundmass.
- 10% Sphalerite – irregular anhedral masses throughout the sample, forming clusters within the dolomitic groundmass that are overprinted and infilled by pyrite. Isotropic – deep red in PPL, opaque in XPL. Distinguished from pyrite in reflected light by low reflectivity, anhedral form, and abundance of polishing scratches. Appears to be layered with subparallel bands throughout the groundmass.
- 5% Pyrite – opaque/isotropic disseminations throughout the sample, usually in sub-parallel bands of mineralization associated with pyrite. Occurs as both subhedral, cubic crystals (~170µm across on average) overprinting sphalerite and as randomly oriented veinlets through fractures in the sphalerite.
- 2% Hemimorphite – small anhedral masses about 140µm lengthwise on average. Weathered crystals overprint dolomite in the vicinity of sphalerite. These masses form incomplete radiating rosettes, but are very sparse and brecciated. Radiating extinction exists and second-order interference colours are present.

Paragenesis:

1. Dolomitic groundmass with two phases of dolomite present – seem to be intergrown
2. Sphalerite mineralization in anhedral masses throughout sample
3. Pyrite mineralization overprints and infills fractures in sphalerite
4. Minor (<2%) secondary hemimorphite forms in the vicinity of sphalerite

Deposit: HB

Sample Number: 2007-SP-033-2

Rock Name: Sulphide-rich dolomitized limestone

Mineralogy:

- 50% Dolomite – massive groundmass with subhedral grains (800µm across on average). Equigranular, weathered, and oxidized. Appears to meet and overprint finer-grained calcite on one side of the sample.
- 30% Calcite – fine-grained (50µm across on average), subhedral, equigranular grains meet dolomite on one side of the sample. Birefringence is higher than for the dolomite and the calcite grains are also more equigranular than the dolomite grains.
- 15% Sphalerite – extremely weathered, possibly in the process of being altered to a nonsulphide zinc mineral. Yellow in both PPL and XPL with no pleochroism. The sphalerite mineralization is present in sub-parallel bands within the dolomitic part of the groundmass, and is massive with no internal structure.
- 3% Pyrite – traces of cubic disseminations overprint all other phases with the exception of the secondary oxidation.
- 2% Quartz – minor clusters of subhedral quartz grains within the carbonate groundmass. Only present in two corners of the sample in very small amounts.

Paragenesis:

1. Carbonate groundmass (calcite and dolomite)
2. Quartz formation
3. Sphalerite mineralization
4. Minor amounts of disseminated pyrite
5. Abundant secondary oxidation (covering 30% of the sample but not obscuring the groundmass enough that the minerals are indistinguishable)

B. Nonsulphide Mineralization:

1. Red Bird prospect

Sample Number: C-473745A

Rock Name: Nonsulphide-rich brecciated dolomitic limestone

Mineralogy:

- 30% Calcite – weathered, continuous, and massive throughout the sample. Sub-parallel laminations occur in parts of the sample but are obscured by major secondary oxidation.
- 25% Dolomite – associated with calcite within the groundmass. Recrystallized, angular, inequigranular grains range from 10µm to 80µm in diameter. Grains are interspersed throughout the calcite groundmass and the relationship between the two carbonates is difficult to determine due to abundant secondary oxidation, but calcite appears to infill between the subhedral dolomite grains.
- 10% Hemimorphite – coarse-grained (up to 1mm long and 0.5mm wide), anhedral, brecciated grains that are overprinted by extensive bright red oxidation. Second-order orange to blue interference colours, radiating extinction, and moderate relief. Forms a replacement texture with carbonate in the vicinity of weathered, oxidized sphalerite grains.
- 5% Sphalerite – disseminated grains with an average diameter of 150µm. Opaque and weathered with extensive overprinting oxidation around the edges. Appears in close association with hemimorphite grains throughout the sample.
- 5% Quartz – subhedral clusters present in two areas of the sample, forming masses of up to 400µm in length. Grains are subrounded but extensively fractured and partially brecciated.
- 1% Talc – minor quantities of single grains appear throughout.
- 24% Secondary iron oxide staining that makes the rest of the groundmass indistinguishable.

Paragenesis:

1. Carbonate groundmass (calcite and dolomite)
2. Sphalerite mineralization
3. Quartz and talc appear to form after sphalerite
4. Hemimorphite replaces the carbonate groundmass
5. Extensive secondary oxidation that obscures the original mineralogy

Sample Number: C-473745C

Rock Name: Nonsulphide-rich brecciated dolomitic limestone

Mineralogy:

- 70% Hemimorphite – coarse-grained, euhedral to subhedral radiating rosettes of hemimorphite up to 4mm in diameter. Found replacing the carbonate groundmass in association with minute specks of oxidized disseminated sphalerite. Higher relief than the carbonate groundmass, though both are the same colour white in PPL. Bright second-order blue and pink interference colours in XPL. Overprinted by oxidation around the edges, often breaking up into vugs with small brecciated pieces inside the vug.
- 5% Calcite – subhedral, weathered, oxidized, and fractured grains form the groundmass along with dolomite.
- 5% Dolomite – forms the groundmass for the zinc mineralization along with calcite. Difficult to definitively tell between calcite and dolomite, but from SEM analyses the dolomite appears as isolated grains within a continuous calcite groundmass.
- 20% Secondary bright red iron oxide staining throughout the many fractures in the sample, overprinting the primary mineralogy.

Paragenesis:

1. Carbonate groundmass (calcite + dolomite)
2. Disseminations of sphalerite that were subsequently weathered and oxidized
3. Hemimorphite replacement of carbonate groundmass
4. Extensive secondary oxidation that obscures the original mineralogy

Sample Number: 09-SP-174

Rock Name: Oxidized limestone

Mineralogy:

- 75% Calcite – two distinct forms are present and meet at a front. One form is medium-grained (about 200µm in diameter on average), equigranular, and massive with many fractures and sections of the grains plucked out. The grains are subhedral and generally subrounded. The second form of calcite is much coarser-grained, with crystals of 1.5mm or more in diameter. These form radiating rosettes similar to the form of hemimorphite, and meet the massive calcite at a front where some angular fragments of the massive calcite are broken off. Both forms of calcite are brecciated in parts of the sample.
- 20% Goethite – grungy, fine-grained oxidation that overprints all of the minerals in the

sample. More concentrated within fractures but also disseminated across entire sample.

5% Quartz – anhedral and brecciated grains in clusters throughout the groundmass.

Paragenesis:

1. Calcite (at least two generations)
2. Quartz formation
3. Minor brecciation
4. Secondary oxidation with goethite

Sample Number: 09-SP-192

Rock Name: Nonsulphide-containing dolostone

Mineralogy:

- 90% Dolomite – fine- to medium-grained, massive, and weathered with grains ranging from 20µm to 50µm in diameter. Anhedral grains with subparallel layering are visible throughout the sample but generally massive. Contains many fractures and small vugs.
- 5% Hemimorphite – brecciated and fractured radiating rosettes replace the dolomitic groundmass and grow into vugs. Second-order yellow to blue interference colours and high relief compared to the dolomite. Also appears in fractures and veins within the dolomite. Most of the oxidation occurs near the contact between hemimorphite and dolomite, and the grains would have an average diameter of 400µm if not fractured and brecciated.
- 1% Quartz – minor fragments of anhedral quartz grains overprint the dolomitic groundmass.
- 4% Oxidation infills fractures within the dolomite and appears at the contact between dolomite and hemimorphite, but does not obscure the original mineralogy.

Paragenesis:

1. Dolomite formation
2. Quartz formation
3. Hemimorphite formation
4. Secondary oxidation

Sample Number: 09-SP-193

Rock Name: Oxidized, nonsulphide-poor dolostone

Mineralogy:

- 80% Dolomite – two generations present. One generation contains angular grains from 100µm to 200µm in diameter that are overprinted by fractured quartz grains. This generation meets the extremely fine-grained, dynamically recrystallized dolomite of the other generation at a front.
- 10% Quartz – angular, brecciated grains appear in clusters of 5-20 grains with an average length and width of 500µm and 400µm respectively.
- 7% Goethite – grungy, extensively oxidized, fine-grained regions infill fractures and overprint the original groundmass. This mineral forms most of the extensive oxidation throughout the sample. Two veinlets of goethite cross-cut one another at 60/120° angles and are associated with the growth of hemimorphite.
- 3% Hemimorphite – mostly appears as small fragments 20-30µm across and in association with iron oxide veinlets. One complete euhedral grain of 100µm in diameter is directly adjacent to (and slightly overprinted by) a goethite vein. The rest of the hemimorphite appears only in small fragments replacing the dolomite groundmass.

Paragenesis:

1. Dolomite formation
2. Quartz formation
3. Hemimorphite formation (and subsequent brecciation)
4. Goethite formation

Sample Number: 09-SP-196

Rock Name: Nonsulphide-containing dolostone

Mineralogy:

- 80% Dolomite – massive, anhedral crystals form the very fine-grained, dynamically recrystallized groundmass. Thin parallel fractures are present throughout and are infilled with nonsulphides and iron oxides. In PPL it appears there could be two

generations of dolomite due to different coloured carbonates bleeding into one another, but in XPL both have the same properties so this has not been conclusively determined. Grains are angular and oxidation occurs around the grain boundaries. Possible minor in situ brecciation.

- 7% Pyrite – inequigranular, anhedral crystals with an average diameter of 150µm overprint the dolomitic groundmass in massive clusters. A replacement texture exists around the edges of the pyrite grains, as well as extensive oxidation.
- 5% Hemimorphite – elongate clusters of anhedral grains occur within fractures in the dolomitic groundmass. The grains are not spherical and appear to be stretched and mildly brecciated. Primarily fracture-controlled within vugs/fractures in the dolomite as well as adjacent to weathered pyrite masses. Second-order blue to purple interference colours.
- 7% Goethite – small botryoidal masses with an average diameter of 150µm primarily overprint the hemimorphite and willemite, though the goethite also infills fractures through dolomite and overprints the dolomite to some extent. Goethite post-dates the in situ brecciation of the sample.
- 1% Willemite – slender prismatic laths, approximately 25µm wide by 100µm long, that have undergone in situ brecciation. Only appears in one corner of the sample as a few brecciated grains. Overprints dolomite but overprinted by goethite, a strange timing relationship that has not been conclusively determined due to the lack of willemite in all other samples from the Red Bird prospect.
- <1% Sphalerite – traces of oxidized disseminations.

Paragenesis:

1. Dolomite groundmass – possibly two generations but not conclusive
2. Sphalerite/pyrite mineralization – cannot tell which came first due to the minute disseminations of sphalerite, but it is most likely that sphalerite pre-dates pyrite
3. Hemimorphite/willemite formation – the relationship between the two is not determined as they do not appear to be associated with each other in the sample. However, both came after the dolomite and the sulphides, with the exception of one brecciated dolomite grain that appears to overprint willemite. This may be due to in situ brecciation.
4. Goethite formation and secondary oxidation

Sample Number: 09-SP-201

Rock Name: Nonsulphide-poor dolomitized limestone

Mineralogy:

- 45% Calcite – massive and extensively weathered, with oxidation within fractures between the grains. Difficult to determine grain size as a result of the weathering. Small stringer veinlets occur throughout the calcite, originating in halos around overprinting brecciated dolomite grains.
- 35% Dolomite – small (5-40µm in diameter), angular, weathered, brecciated grains overprint the massive calcite. A replacement texture appears around these angular anhedral grains and bleeds out into the calcite, creating small stringers.
- 5% Quartz – subhedral clusters of fractured grains overprint the calcite and dolomite groundmass.
- 5% Pyrite – disseminated clusters of anhedral grains overprint the quartz and carbonate groundmass. Occurs irregularly throughout the sample.
- 2% Sphalerite – thin, irregular stringer veinlets occur throughout the sample and are extensively oxidized, often associated with minor amounts of hemimorphite.
- 2% Hemimorphite – small, irregular masses infill fractures through brecciated dolomite grains and appear in association with oxidized sphalerite veinlets. Hemimorphite is not seen replacing calcite in any part of the sample.
- 1% Talc – small laths (average of 20µm wide by 100µm long) occur in disseminations throughout the sample.
- 5% Secondary iron oxide staining that obscures other phases.

Paragenesis:

1. Calcite/dolomite groundmass – difficult to differentiate timing relationships due to multiple possible generations and the brecciation of dolomite overprinting the calcite
2. Sphalerite mineralization
3. Pyrite mineralization
4. Quartz formation
5. Talc formation
6. Hemimorphite formation
7. Secondary iron oxidation that obscures original mineralogy

Sample Number: 09-SP-203

Rock Name: Nonsulphide-poor dolomitized limestone

Mineralogy:

- 40% Dolomite – small, anhedral, brecciated grains overprint the calcite groundmass. Grains are about 20µm in diameter on average and are associated with infilling hemimorphite and extensive iron oxidation.
- 40% Calcite – fine-grained, massive, weathered groundmass with some infilling oxidation (but not as much as the oxidation associated with the dolomite). Also, no hemimorphite exists within the calcite, only within fractures between dolomite grains.
- 5% Quartz – small clusters of dynamically recrystallized grains. Average diameter of individual clusters is about 500µm to 1mm. Overprints the carbonate groundmass and contains fractures. Partially brecciated.
- 4% Pyrite – large clusters of extensively weathered, oxidized, anhedral pyrite grains. No crystal shape remains and the grains are only identified as pyrite in SEM. Weathered extensively around the edges and hemimorphite is starting to form in the vicinity.
- 3% Hemimorphite – disseminated, anhedral, incomplete grains appear in the vicinity of weathered pyrite and in between brecciated dolomite grains. No euhedral hemimorphite exists – it is only present as disseminated, grungy grains around pyrite/dolomite.
- 2% Sphalerite – remnants of weathered, oxidized sphalerite are apparent in microfractures and stringer veinlets throughout the carbonate groundmass.
- 1% Talc – small, highly birefringent laths overprint most other minerals within the sample.
- 5% Secondary iron oxide staining that obscures original mineralogy.

Paragenesis:

1. Calcite/dolomite – dolomite likely formed after calcite
2. Sphalerite/pyrite mineralization: no relationship is seen between sphalerite and pyrite, however pyrite occurs after sphalerite in most other samples from the Red Bird prospect
3. Quartz formation
4. Talc formation
5. Hemimorphite begins to form
6. Secondary oxidation that obscures original mineralogy

Sample Number: 09-SP-204

Rock Name: Nonsulphide-rich dolomitic limestone

Mineralogy:

- 40% Dolomite – extensively oxidized, brecciated, angular grains throughout a calcite-rich matrix. Inequigranular, anhedral grains with extensive fractures and weathering.
- 25% Calcite – fine-grained matrix throughout much of sample, with one spot containing coarser-grained crystals inside a vug. Weathered and partially obscured by oxidation.
- 20% Hemimorphite – anhedral masses obscured by iron oxide staining within veinlets. Grains form small fragments in fractures between dolomite grains. Also associated with iron oxides and vugs.
- 3% Quartz – subhedral masses that are moderately brecciated and fractured.
- 1% Sphalerite – remnants within veinlets, but abundant secondary oxidation overprints it.
- 1% Pyrite – minor oxidized disseminations throughout.
- 10% Secondary oxidation that overprints other minerals within the sample.

Paragenesis:

1. Calcite/dolomite matrix
2. Dolomite brecciation
3. Sphalerite/pyrite formation – no timing relationships seen within this sample
4. Hemimorphite infills throughout fractures
5. Secondary oxidation that obscures original mineralogy

2. *Oxide prospect*

Sample Number: 2008-SP-85

Rock Name: Nonsulphide-rich limestone

Mineralogy:

- 60% Hemimorphite – euhedral to subhedral radiating rosettes of various sizes. Weathered, brecciated, and moderately oxidized. Brown in PPL with second-order orange to blue interference colours in XPL. Botryoidal with radiating extinction.

Grains are intergrown with one another, except when they are in the vicinity of vugs and are coarser-grained and more prismatic with brecciated fragments inside the vug.

- 35% Hopeite – appears as a massive flooding of the space between hemimorphite grains. Clear in PPL, first-order grey to second-order blue in XPL. Radiating extinction. The entire groundmass looks to be hopeite, except for remnant calcite present on the edges of some grains.
- 5% Calcite – primarily present on the boundaries of hopeite as small needle masses. Also present in very minor quantities within the groundmass (when visible).

Paragenesis:

1. Calcite formation
2. Hemimorphite formation and subsequent brecciation
3. Hopeite floods through hemimorphite grains
4. Minor secondary oxidation

Sample Number: 2008-SP-88

Rock Name: Hemimorphite

Mineralogy:

- 100% Hemimorphite – subhedral to anhedral radiating rosettes that have completely replaced the previous groundmass (likely dolomite/calcite). Botryoidal crystals are overprinted by minor weathering and secondary oxidation. Grains are intergrown except in the presence of vugs, where they are present in more prismatic forms and grow into open spaces within the vug. Extensively oxidized around the edges.

Paragenesis:

1. Previous groundmass formation (likely dolomite/calcite)
2. Hemimorphite replacement
3. Minor secondary oxidation

3. Cariboo Zinc Property

Sample Number: 09-SP-221B

Rock Name: Nonsulphide-rich dolostone

Mineralogy:

- 80% Dolomite – coarse-grained (up to 5mm in diameter), weathered, fractured, oxidized matrix material. Irregular fractures and vugs occur throughout.
- 13% Smithsonite – fracture-controlled, grungy, friable, fine-grained masses that follow fractures and vugs. Primarily infills fractures between dolomite grains but also branches out into vugs and forms irregular web-like networks.
- 3% Pyrite – subhedral disseminated grains that have been extensively oxidized.
- 1% Sphalerite – disseminated remnants within fractures (indicated by SEM).
- 1% Quartz – small subhedral grains occur irregularly throughout the sample.
- 2% Secondary oxidation that partially obscures original minerals.

Paragenesis:

1. Dolomite groundmass formation
2. Sphalerite/pyrite mineralization
3. Quartz formation
4. Smithsonite formation
5. Secondary oxidation that obscures original mineralogy

Sample Number: 09-SP-222B

Rock Name: Unmineralized dolostone

Mineralogy:

- 95% Dolomite – bright white, massive, crystalline dolomite. Two phases of dolomite exist: one is coarser-grained (average of 150µm in diameter) with anhedral grains and is slightly more weathered. The other is fine-grained, equigranular, and seems to be dynamically recrystallized. The fine-grained dolomite takes up ~80% of the

- sample whereas the coarser-grained dolomite takes up ~15% of the sample.
- 5% Quartz – clusters of fine-grained anhedral grains throughout the sample.

Paragenesis:

1. Dolomitic groundmass formation
2. Quartz formation
3. Very minor secondary oxidation

Sample Number: 09-SP-224B

Rock Name: Nonsulphide-containing dolostone

Mineralogy:

- 80% Dolomite – coarse-grained, equigranular, massive grains throughout the entire groundmass. Weathered and oxidized, especially in the presence of fractures and vugs.
- 5% Smithsonite – fine-grained (almost clay-sized) friable masses appear between grains of dolomite through stringer veins and grow as irregular networks into vugs.
- 3% Hemimorphite – mostly oxidized, small, anhedral grains associated with stringer veinlets. Likely replaces sphalerite and is overprinted by secondary oxidation.
- 1% Galena – Small, disseminated, oxidized grains throughout.
- 0.5% Sphalerite – Minor amounts of oxidized disseminations that are only identified definitively with SEM.
- 0.5% Pyrite – Minor amounts of very oxidized subhedral disseminations that are only identified with SEM.
- 10% Secondary oxidation that overprints all other mineralogy.

Paragenesis:

1. Dolomitic groundmass formation
2. Galena/sphalerite/pyrite mineralization: no timing relationships are observed in this sample due to the lack of association of these minerals
3. Hemimorphite/smithsonite formation: no timing relationships are observed, as they do not appear together and both are extensively oxidized
4. Secondary oxidation that obscures original mineralogy

Sample Number: 09-SP-225B

Rock Name: Nonsulphide-rich dolostone

Mineralogy:

- 30% Galena – massive and fresh with minimal weathering. One large galena-quartz vein forms much of the groundmass, though the galena is the main part of the vein exposed in this thin section, with minimal quartz. Contains vugs infilled by cerussite and smithsonite.
- 30% Smithsonite – two forms exist within the sample. One form is a fine-grained, orange-brown, claylike material that infills fractures in the galena groundmass in the vicinity of weathered sphalerite grains and also forms replacement halos around sphalerite. Another form grows into vugs as angular prismatic grains about 50µm in diameter on average.
- 10% Dolomite – fine- to medium-grained, weathered, fractured, oxidized, and massive grains. Many microfractures and veinlets of smithsonite infill between the grains. Appears as the groundmass where the galena vein is not present. Much of the dolomite is overprinted by nonsulphide minerals and secondary oxidation.
- 10% Sphalerite – extensively weathered subhedral grains with an average diameter of 100µm. Contains numerous fractures that are infilled by smithsonite and some fragments of hemimorphite grains. Yellow in PPL and XPL with no pleochroism.
- 5% Hemimorphite – fragments of weathered, anhedral masses occur in proximity to weathered sphalerite grains.
- 5% Quartz – forms the outermost part of the galena vein. Unweathered and massive.
- 5% Anglesite – forms prismatic/tabular laths that grow into vugs within the large galena vein. Clear in PPL, second-order pink to blue interference colours in XPL. Occurs in association with cerussite within the same vug.
- 3% Cerussite – occurs as tabular laths growing into vugs within the large galena vein. Associated with anglesite but to a lesser extent, and with lower relief and lower (first-order) interference colours.
- 2% Pyrite – weathered, subhedral, cubic disseminations that have been oxidized and are no longer isotropic. Yellow-brown in PPL and XPL.

Paragenesis:

1. Dolomitic groundmass formation
2. Quartz-galena veining
3. Sphalerite/pyrite mineralization (timing relationships not observed)

4. Smithsonite/hemimorphite replacement of carbonate (timing relationships not observed)
5. Anglesite and cerussite growth into vugs

Sample Number: 09-SP-228

Rock Name: Sulphide-rich dolostone

Mineralogy:

- 60% Quartz – forms the groundmass of the sample. Fine-grained, massive, dynamically recrystallized, subhedral grains throughout the sample. Forms in vugs 500µm to 1mm in diameter.
- 20% Weathered metamorphic silicates – extensively weathered, radiating Mg-Al silicates that have not been conclusively identified with petrography or SEM analyses. Grains appear as radiating rosettes that look very similar to hemimorphite (albeit with no zinc) and grow into vugs with second order interference colours.
- 10% Sphalerite – extensively weathered, oxidized, subhedral, angular grains. Brecciated in parts of the sample and always speckled and fractured. Brown-grey in PPL, opaque in XPL.
- 5% Dolomite – the only sample at the Cariboo Zinc Property in which dolomite overprints quartz. Fine-grained, weathered, and fractured anhedral dolomite grains appear to be brecciated and overprint the dynamically recrystallized quartz groundmass. These grains contain zinc (as seen in SEM) and are likely starting to be replaced by hemimorphite or smithsonite.
- 4% Pyrite – angular, brecciated, weathered pyrite grains with extensive oxidation around the edges. Disseminated in small clusters throughout.
- 1% Galena – traces of disseminations seen in SEM within the quartz groundmass.

Paragenesis:

1. Quartz groundmass (likely a large vein within a dolomitic groundmass)
2. Sphalerite/galena/pyrite mineralization
3. Metamorphic silicate nucleation into vugs
4. Dolomite brecciation
5. Minor secondary oxidation that does not obscure original mineralogy

Sample Number: 09-SP-231D

Rock Name: Nonsulphide-poor dolostone

Mineralogy:

- 80% Dolomite – inequigranular, subhedral, massive groundmass. Weathered and fractured with irregular veining throughout.
- 10% Quartz – present primarily within veins in association with galena – present on either side of galena and dynamically recrystallized.
- 5% Galena – massive and fresh in association with a quartz vein, with large hemimorphite grains nucleating where sphalerite was likely present previously.
- 3% Hemimorphite – coarse-grained, subhedral, radiating rosettes form within and immediately adjacent to the galena veining. An oxidized halo exists around the hemimorphite grains.
- 2% Secondary oxidation and extensively weathered nonsulphides.

Paragenesis:

1. Dolomitic groundmass formation
2. Quartz-galena veining (presumably with the presence of sphalerite initially as well)
3. Hemimorphite formation within and adjacent to galena veins
4. Secondary oxidation that partially obscures original mineralogy

Sample Number: 09-SP-231E

Rock Name: Nonsulphide-poor dolostone

Mineralogy:

- 75% Dolomite – massive, equigranular grains throughout the sample, with the exception of in the vicinity of the quartz vein, where the grains are angular and overprint the quartz with many fractures between the grains.
- 15% Quartz – present within veining (one primary vein <1cm in width) and as small, inequigranular, dynamically recrystallized masses that overprint the groundmass.
- 5% Smithsonite – anhedral, fine-grained masses infill fractures between dolomite grains that are overprinted by disseminated remnants of what was previously sphalerite. Also forms a thin (30µm) halo around the quartz vein.

- 4% Galena – present as fresh masses in association with quartz veining.
1% Cerussite – traces identified in SEM.

Paragenesis:

1. Dolomitic groundmass formation
2. Quartz/galena veining (+ initial sphalerite?)
3. Smithsonite/cerussite formation (no timing relationships observed, but if similar to other samples then cerussite would have crystallized after smithsonite)
4. Very minor secondary oxidation

Sample Number: 09-SP-237A

Rock Name: Nonsulphide-rich dolostone

Mineralogy:

- 80% Hemimorphite – coarse-grained (up to 5mm in diameter), perfectly radiating rosettes with oxidation around the edges. Clear to oxidized red in PPL, first-order orange to second-order blue in XPL.
- 5% Quartz – angular, fractured, disseminated grains overprint the dolomitic groundmass throughout (likely due to in situ brecciation).
- 5% Dolomite – weathered, oxidized, subhedral, massive crystals form the groundmass when seen.
- 10% Abundant secondary oxidation that obscures the original mineralogy.

Paragenesis:

1. Dolomitic groundmass formation
2. Quartz formation
3. Hemimorphite replacement of dolomite
4. Secondary oxidation that obscures the original mineralogy

Sample Number: 495

Rock Name: Brecciated nonsulphide-rich dolostone

Mineralogy:

- 45% Dolomite – medium-grained (600µm-800µm in diameter on average) and extensively weathered and fractured. Partially brecciated with thin fractures through every grain that are infilled with smithsonite.
- 30% Hemimorphite – grains range from small anhedral masses infilling fractures within dolomite to large (2mm in diameter on average), euhedral radiating rosettes that are overprinted by brecciated quartz.
- 15% Quartz – fine-grained brecciated grains are disseminated throughout the entire groundmass and overprint all other minerals.
- 10% Smithsonite – two forms of smithsonite exist. One form appears as discontinuous grains of about 200µm-400µm in diameter within the dolomitic groundmass. This form appears to be a brecciated replacement of former sphalerite, and hemimorphite overprints these smithsonite grains. The grains are angular, weathered, and brown in both PPL and XPL. The other form of smithsonite is a fine-grained, brown-grey grunge that infills fractures in the dolomitic groundmass throughout the entire sample.

Paragenesis:

1. Dolomitic groundmass formation
2. Possible quartz vein formation (though not conclusively determined)
3. Smithsonite replacement of former sphalerite
4. Hemimorphite formation
5. Brecciation emplacing quartz over the rest of the groundmass
6. Minor (~1%) secondary oxidation that does not obscure the original mineralogy

APPENDIX IV: Whole Rock Geochemistry.

Table 9. Select major element geochemistry on samples from the Oxide, Lomond, Red Bird and Cariboo Zinc properties.

				Element	Zn	Pb	Fe	Mn	Mg	Al	Cd	Ag	Au
				Units	%	%	%	%	%	%	%	GM/T	PPB
				Detection limit	0.01	0.02	0.01	0.01	0.01	0.01	0.001	2	0.5
				Method	ICP-ES	ICP-ES	ICP-ES	ICP-ES	ICP-ES	ICP-ES	ICP-ES	ICP-ES	ARMS
Sample #	Deposit	UTM-Location	Lithology										
08-GS-22	Lomond	5427787 N 475355 E	Iron oxide gossan	1.77	2.47	55.45	<0.01	0.03	0.05	<0.001	<2	5.1	
08-SP-85	Oxide	5457482 N 489475 E	Nonsulphide-rich carbonate	38.77	0.13	0.72	0.06	0.09	0.42	0.23	32	1.2	
08-SP-88	Oxide	5457365 N 489966 E	Nonsulphide-rich carbonate	31.52	0.14	1.53	0.06	0.19	1.47	0.008	4	21.2	
09-SP-174	Red Bird, Trench B 2000-01	5429240 N 471314 E	Oxidized limestone	1.03	0.76	13.55	0.06	0.32	0.25	0.185	<2	0.7	
09-SP-191	Red Bird, Trench C 2000-01	5429388 N 471447 E	Nonsulphide-rich dolostone	43.7	0.68	4.75	0.01	1.12	0.16	0.019	89	13.8	
09-SP-204	Red Bird, Trench C 2000-01	5429388 N 471447 E	Nonsulphide-rich dolomitic limestone	15.03	0.69	2	0.02	2.26	0.09	0.108	22	6.9	
09-SP-207	Red Bird, Trench C 2000-02	5429335 N 471450 E	Iron oxide gossan	11.9	5.09	39.6	0.01	0.19	0.1	0.017	24	8.5	
09-SP-221	Cariboo Zinc, Dolomite Flats	5853951 N 641596 E	Nonsulphide-rich dolostone	5.6	<0.02	0.34	0.11	10.78	0.02	0.018	<2	<0.5	
09-SP-231	Cariboo Zinc, Gunn Zone	5852188 N 643413 E	Nonsulphide-poor dolostone	0.8	0.29	0.11	0.03	10.26	<0.01	0.002	<2	<0.5	
09-SP-237A	Cariboo Zinc, Que Zone	5851520 N 644120 E	Nonsulphide-rich dolostone	51.03	0.14	0.43	0.03	0.06	0.04	0.023	3	13.3	
09-SP-242	Cariboo Zinc, Que Zone	5851843 N 643242 E	Nonsulphide-rich dolostone	43.32	0.94	0.67	0.03	1.3	0.19	0.111	2	3.2	