Carbonate-Hosted Lead-Zinc Mineralization on the Cariboo Zinc Property, Quesnel Lake Area, East-Central British Columbia (NTS 093A/14E, 15W)

by S. Paradis[1,3], G.J. Simandl[2,3], J. Bradford[4], C. Leslie[5] and C. Brett[6]

KEYWORDS: Cariboo terrane, carbonate-hosted, nonsulphide, oxide, vein, breccia, sphalerite, galena, cerussite, smithsonite, hemimorphite

INTRODUCTION

The carbonate-hosted sulphide and nonsulphide deposits on the Cariboo Zinc property are located north of Quesnel Lake in east-central British Columbia (NTS 93A/14E, 15W), at a latitude of approximately 52°49'N and longitude 120°55'W (Figure 1). They are hosted by rocks of the Cariboo terrane, which represents a displaced segment of the ancestral North American margin (Struik, 1988). The Cariboo terrane is known to host a wide variety of metallic deposits, including polymetallic Ag-Pb-Zn (±Au) veins, carbonate- and sediment-hosted massive sulphides (i.e., Zn-Pb Mississippi Valley type, sedimentary exhalative Zn-Pb-Ag Besshi type), Au placers and nonsulphide deposits (Struik, 1988; Höy and Ferri, 1998).

Individual carbonate-hosted Pb-Zn occurrences on the Cariboo Zinc property crop out along a northwest-trending belt about 8 km long. They comprise pervasive fine-grained sulphide and nonsulphide disseminations and aggregates forming pods, sulphide- and nonsulphide-bearing quartz veins, and crackle breccias similar to those found in Mississippi Valley–type deposits. This paper, based on our 2009 field observations and previous work by Teck Corporation and Pembrook Mining Corporation, provides a basis for ongoing laboratory investigations of sulphide and nonsulphide minerals from the Cariboo Zinc deposits. It also contributes to a better understanding of geological constraints on nonsulphide deposits of southern BC.

BACKGROUND INFORMATION ON NONSULPHIDE DEPOSITS

Nonsulphide deposits were the main source of Zn prior to the 1930s. However, the mining industry turned its attention to sulphide ore following the development of differential flotation and breakthroughs in smelting technology. Today, most Zn derives from sulphide ore (Hitzman et al., 2003; Simandl and Paradis, 2009). Nevertheless, the successful operation of a dedicated processing plant to extract Zn metal at the Skorpion mine in Namibia demonstrates that deposits containing nonsulphide and mixed Zn-Pb ores represent valid exploration targets.

Carbonate-hosted, nonsulphide base-metal deposits form in supergene environments from sulphide deposits (such as Mississippi Valley–type [MVT], sedimentary exhalative [SEDEX], Irish-type and vein-type deposits and, to a lesser extent, skarns). Several carbonate-hosted sulphide deposits in the Kootenay terrane and elsewhere in BC have near-surface Zn- and Pb-bearing iron-oxide gossans (Simandl and Paradis, 2009; Paradis and Simandl, work in progress, 2010). Such gossans form when carbonate-hosted, base-metal sulphide mineralization is subject to intense weathering and metals are liberated by the oxidation of sulphide minerals. Liberated metals can be trapped locally, forming direct-replacement, nonsulphide ore deposits, or they can be transported by percolating waters down and away from the sulphide protore, forming wallrock-replacement carbonate-hosted nonsulphide base-metal deposits (Heyl and Bozion, 1962; Hitzman et al., 2003; Simandl and Paradis, 2009). The direct-replacement nonsulphide deposits, also known as 'red ores', consist commonly of Fe-oxyhydroxides (red in colour), goethite and hematite, with lesser concentrations of hemimorphite, smithsonite, hydrozincite and cerussite; they typically contain >20% Zn, >7% Fe and Pb±As. Wallrock-replacement deposits can be located in proximity to protore or several hundreds of metres away (Heyl and Bozion, 1962; Hitzman et al., 2003; Reichert and Borg, 2008). The wallrock-replacement deposits, also known as 'white ores', consist of smithsonite, hydrozincite and minor Fe-hydroxides, and contain <40% Zn, <7% Fe and very low concentrations of Pb. Wallrock-replacement deposits are commonly rich in Zn and poor in Pb relative to the direct-replacement carbonate-hosted nonsulphide base-metal deposits (Simandl and Paradis, 2009). From the metallurgical and environmental perspectives, the 'white ores' are simpler and preferable.

REGIONAL GEOLOGY

The Cariboo Zinc sulphide and nonsulphide occurrences occur within the Cariboo terrane of central BC (Figure 2). To the east, the Cariboo terrane is in fault contact with the western margin of the North American miogeocline along the Rocky Mountain Trench (Figure 1). To the west, it is in fault contact (along the westerly-verging Pleasant Valley thrust) with rocks of the Barkerville subterrane (Figure 2), which corresponds to a northern extension of the Kootenay terrane. Rocks of the Barkerville

[1] *Geological Survey of Canada–Pacific, Sidney, BC*
[2] *British Columbia Ministry of Energy, Mines and Petroleum Resources, Victoria, BC*
[3] *School of Earth and Ocean Sciences, University of Victoria, Victoria, BC*
[4] *Pembrook Mining Corporation, Vancouver, BC*
[5] *Richfield Ventures Corporation, Quesnel, BC*
[6] *RebelEX Resources Corporation, Vancouver, BC*

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subterrane are interpreted as an outboard facies of the North American continental margin (Struik, 1988; Colpron and Price, 1995), whereas rocks of the Cariboo terrane contain facies that suggest a more proximal continental-shelf setting (Struik, 1988; Ferri and O'Brien, 2002; Schiarizza and Ferri, 2003). Rocks of the Cariboo and Barkerville terranes are structurally overlain, across the gently dipping Pundata thrust fault, by Lower Mississippian to Lower Permian basalts and chert of the Antler Formation of the Slide Mountain terrane (Struik, 1988).

The Cariboo terrane comprises thick sequences of Precambrian to Early Mesozoic siliciclastic and carbonate rocks that show similarities with rocks of the North American miogeocline. In the Quesnel Lake area, the Cariboo terrane is represented by the Late Proterozoic Kaza Group, the Late Proterozoic to Late Cambrian Cariboo Group and the Ordovician to Mississippian Black Stuart Group (Figure 2).

The Cariboo Group includes argillite, slate and phyllite of the Isaac Formation; carbonate of the Cunningham Formation; argillite and phyllite of the Yankee Belle Formation; white quartzite of the Yanks Peak Formation; shale, phyllite and micaceous quartzite of the Midas Formation; carbonate of the Mural Formation; and slate, phyllite and minor limestone of the Dome Creek Formation (Struik, 1988). Sedimentary rocks of the Isaac, Cunningham and Yankee Belle formations correlate with those of the Windermere Supergroup, and the quartzite of the Yanks Peak Formation correlates with that of the Hamill Group in southern BC (Struik, 1988). The archaeocyathid-bearing carbonate of the Mural Formation is biostratigraphically correlative with the Badshot Formation of the

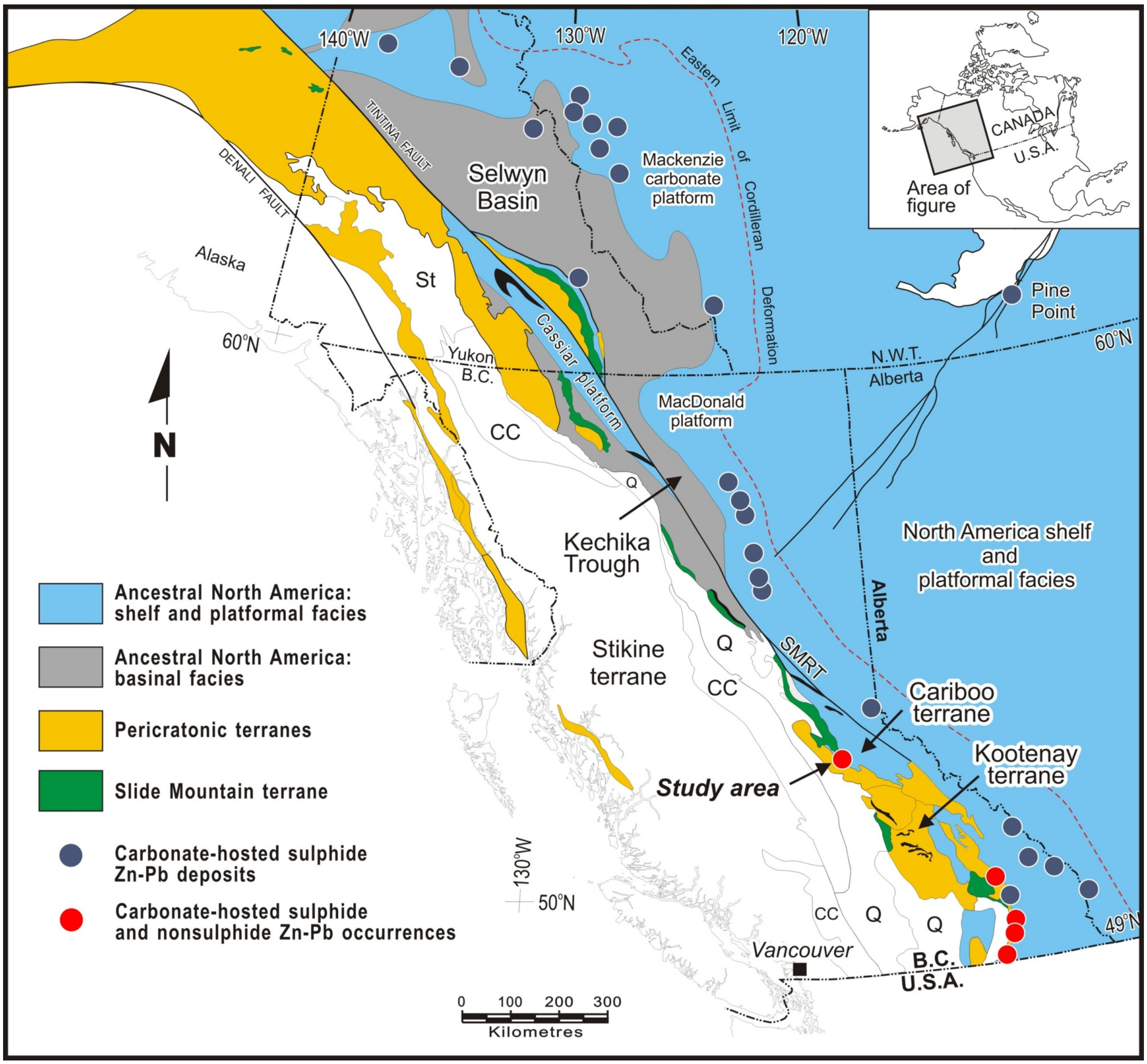


Figure 1. Location of the Cariboo Zinc property study area with respect to other significant carbonate-hosted sulphide and nonsulphide occurrences in the northern cordillera (modified from Nelson et al., 2002, 2006). Abbreviations: St, Stikine terrane; CC, Cache Creek terrane; Q, Quesnel terrane; SMRT, southern Rocky Mountain Trench.

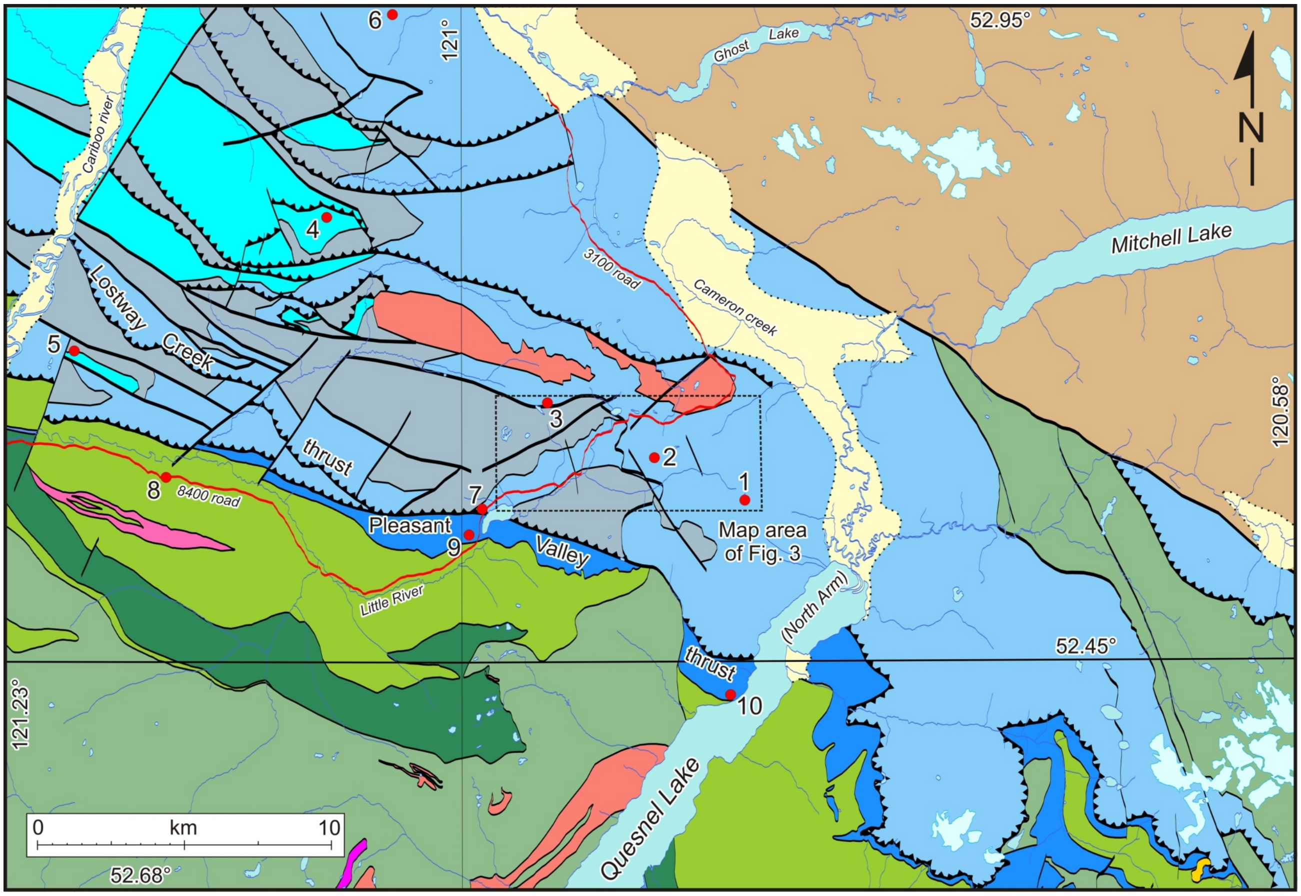
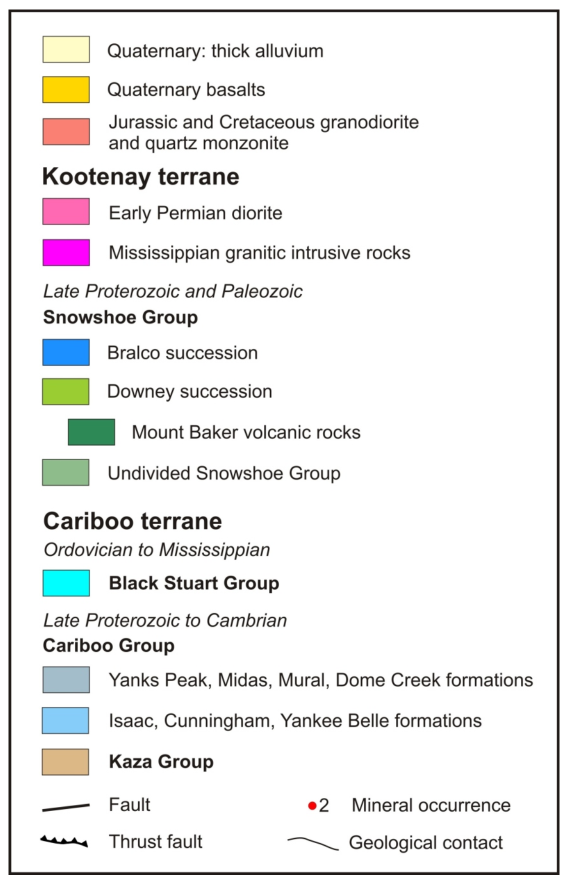


Figure 2. General bedrock geology between the Cariboo River and Mitchell Lake (after Campbell, 1978; Struik, 1983a, b, 1988; Ferri and O'Brien, 2003), east-central British Columbia. The dotted rectangle is the area covered by Figure 3. Mineral occurrences, according to BC MINFILE (BC Geological Survey, 2009): 1, Sil; 2, Grizzly Lake; 3, Lam; 4, Comin Throu Bear; 5, Maybe; 6, Mt. Kimball; 7, Maeford Lake; 8, Ace; 9, Mae; 10, Cariboo Scheelite. Occurrences 1, 2, and 3 form the Cariboo Zinc property.



Kootenay Arc, which hosts numerous stratabound carbonate-hosted Zn-Pb sulphide and nonsulphide deposits and polymetallic Pb-Zn (±Ag) veins (Struik, 1988; Paradis, 2007).

The carbonate-hosted sulphide and nonsulphide occurrences (Flipper Creek, Dolomite Flats, Main, Gunn and Que) of the Cariboo Zinc property (Figure 3) belong to a number of stratabound Zn-Pb occurrences in Late Proterozoic to Early Paleozoic platform carbonates and carbonaceous shale of the Cariboo terrane. These include the Maybe (MINFILE 093A 110; BC Geological Survey, 2009), Vic (MINFILE 093A 070), Cunning (MINFILE 093A 222), and Comin Throu Bear (MINFILE 093A 158) stratabound massive sulphide deposits (Höy and Ferri, 1998). Numerous polymetallic Zn-Pb (±Ag±Au) veins crosscut sedimentary rocks of the Cariboo and Black Stuart groups; some examples include the Joy (MINFILE 093A 049), MB (MINFILE 093A 68), and VIP (MINFILE 093 162) showings.

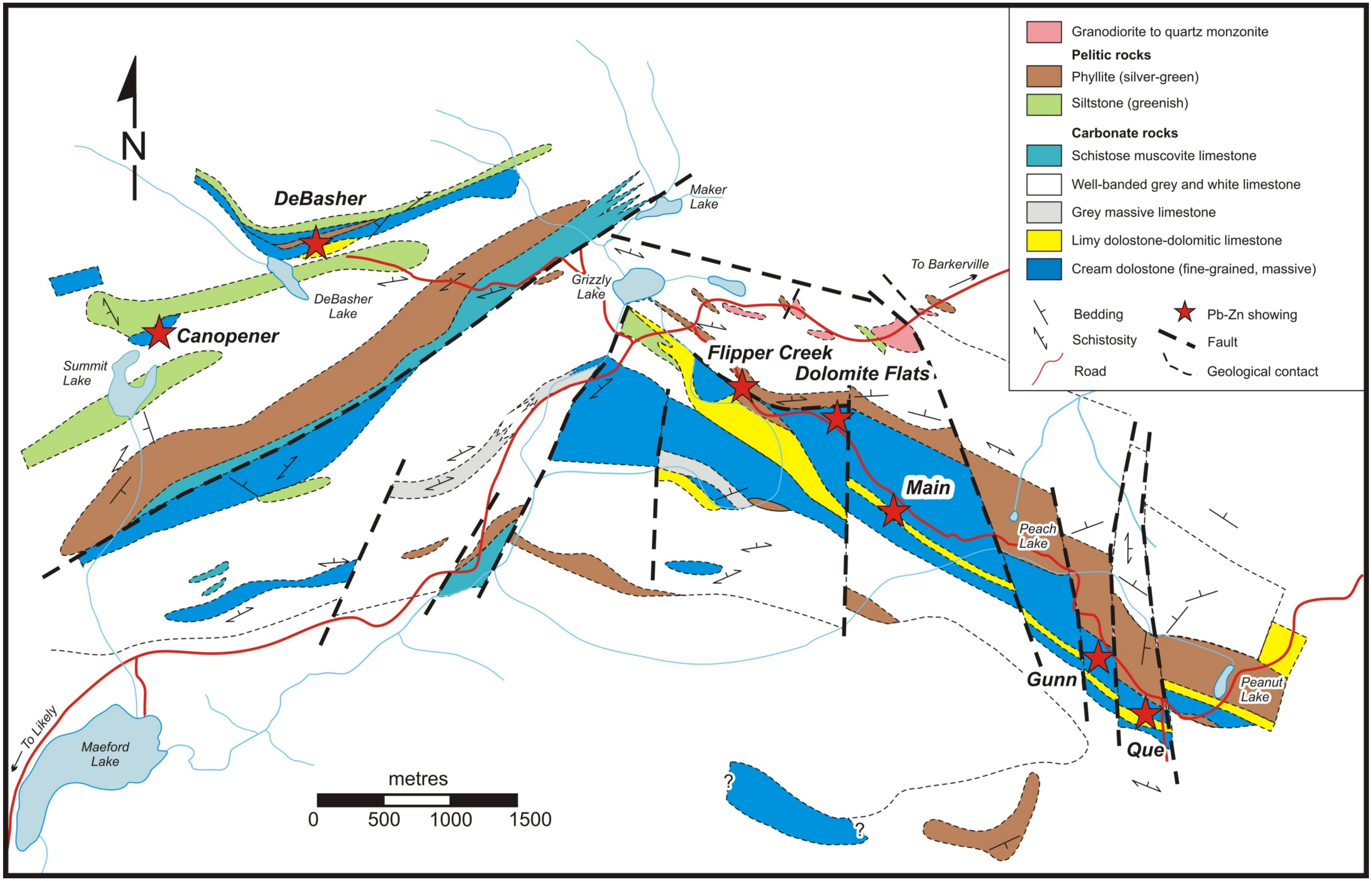


Figure 3. Regional geology of the Cariboo Zinc property area, east-central British Columbia (from Lormand and Alford, 1990).

GEOLOGY OF THE CARIBOO ZINC PROPERTY

Based on the regional mapping of Struik (1983b, 1988), the property is underlain by Late Proterozoic carbonate and pelitic metasedimentary rocks of the Cunningham and Isaac formations of the Cariboo Group (Figure 2).

The carbonate hosting the Zn-Pb sulphide and nonsulphide mineralization was designated by Murrell (1991) as the Isaac Formation; however, Höy and Ferri (1998) referred to it as the Cunningham Formation. Bradford and Hocking (2008) favoured the interpretation of Höy and Ferri (1998), based on the extrapolation of geological mapping done west of the Cariboo Zinc deposit area by Struik (1988).

A geological map of the study area (Figure 3), produced by Lormand and Alford (1990), outlines folded sequences consisting of interlayered carbonate and metapelitic sediments. The metasedimentary rocks strike 240º and dip to the northwest in the northern part of the property, and strike 310º and dip to the northeast in the southern part (Murrell, 1991; McLeod, 1995). This suggests the presence of a major open fold, with a hinge located near the Grizzly Lake area. A strong southwest- to northwest-striking foliation is present in metapelitic units on the eastern limb of the fold. The western limb is characterized by a southwest-striking foliation that generally dips northwest. Several north- to northeast-trending faults are interpreted to crosscut the metasedimentary rocks (Figure 3).

Three main varieties of carbonate rocks encountered during our visit are

> light to medium grey, mottled dolomitic limestone or limy dolostone, commonly with rounded, distinct to diffuse ‘fragments’ of white dolomite and locally appearing brecciated (e.g., Main prospect);
>
> creamy white, fine-grained dolostone that is locally silicified; and
>
> thinly bedded/layered grey limestone.

The interlayered metapelite consists of fine-grained medium to dark silver-grey and green phyllite, siltstone and garnet-muscovite schist, the latter representing a more highly metamorphosed equivalent of the phyllite (Murrell, 1991).

Most of the Pb-Zn mineralization seems to be associated with the dolostone–dolomitic limestone interval adjacent to the ‘phyllite’ unit (Figure 3). We do not have detailed information to determine if this generalization is correct for the Canopener occurrence. At the Main prospect, the separation between the dolostone–dolomitic limestone interval and the phyllite appears wider (Figure 3) because the contact between the dolostone and the phyllite (largely eroded) is interpreted to be subhorizontal.

Intrusive rocks, mainly granodiorite and quartz monzonite, crop out north and southeast of the mineralized belt but have not been observed on the Cariboo Zinc property. The presence of similar intrusive rocks at depth is suggested by geophysical data (Figure 4).

CARBONATE-HOSTED SULPHIDE AND NONSULPHIDE MINERALIZATION

The Cariboo Zinc property encompasses several Zn-Pb sulphide and nonsulphide occurrences in a southeast-trending belt about 8 km long. The main occurrences, from west to east, are Canopener, DeBasher, Flipper Creek, Dolomite Flats, Main, Gunn and Que (Figure 3). In the BC MINFILE database, DeBasher corresponds to the LAM showing (MINFILE 093A 050), Flipper Creek, Dolomite Flats, and Main are encompassed by the Grizzly Lake prospect (MINFILE 093A 065), and Gunn and Que correspond to the Sil showing (MINFILE 093A 062).

Descriptions of the occurrences visited (i.e., Flipper Creek, Dolomite Flats, Main, and Gunn) are based on our field observation and the reports of Murrell (1991) and Bradford and Hocking (2008). The description of the DeBasher showing is summarized from Murrell (1991) and Bradford and Hocking (2008). No description of the Canopener (also known as Summit Lake) occurrence is given in BC MINFILE or in assessment reports.

DeBasher

The DeBasher showing is located on the west side of road 8400 and northeast of DeBasher Lake (Figure 3). Sulphide mineralization consists of quartz veins and mosaic breccias containing erratically distributed galena and sphalerite. Patches of orange oxide boxwork (after sphalerite) were the only nonsulphides observed by Bradford and Hocking (2008). The hostrocks are siliceous limy dolostone overlain by cream dolostone. These rocks are overlain by phyllite along a faulted contact (Murrell, 1991). Mineralization seems to be preferentially located at the faulted dolostone-phyllite contact.

Flipper Creek

The Flipper Creek prospect was discovered during road building in 1989 (Murrell, 1991). It is located 650 m southeast of the 8400 road and extends for 240 m in a northwesterly direction along the south bank of Flipper Creek. This mineralization coincides with a 100 m by 350 m Pb-Zn soil anomaly outlined by Teck Corporation during follow-up work (Bradford and Hocking, 2008).

Mineralization, hosted by medium-grained white dolostone, consists of sphalerite clots and pods, veins and distinctive breccia zones approximately 0.5 m thick containing barite, galena and sphalerite. The breccia is crosscut by a white, fine- to coarse-grained barite vein trending 185º. The seams and pods of galena and sphalerite occur within and along the margin of the vein (Figure 5). Barite-associated mineralization may postdate some earlier sphalerite- and galena-bearing veinlets.

According to Murrell (1991), mineralization is preferentially located at the contact between phyllite to the north and underlying cream dolostone to the south. This contact may correspond to a northwest-trending fault along Flipper creek[1] (Figure 3).

Murrell (1991) reported patchy green sphalerite hosted within the cream dolostone and associated with

[1] *unofficial place name*

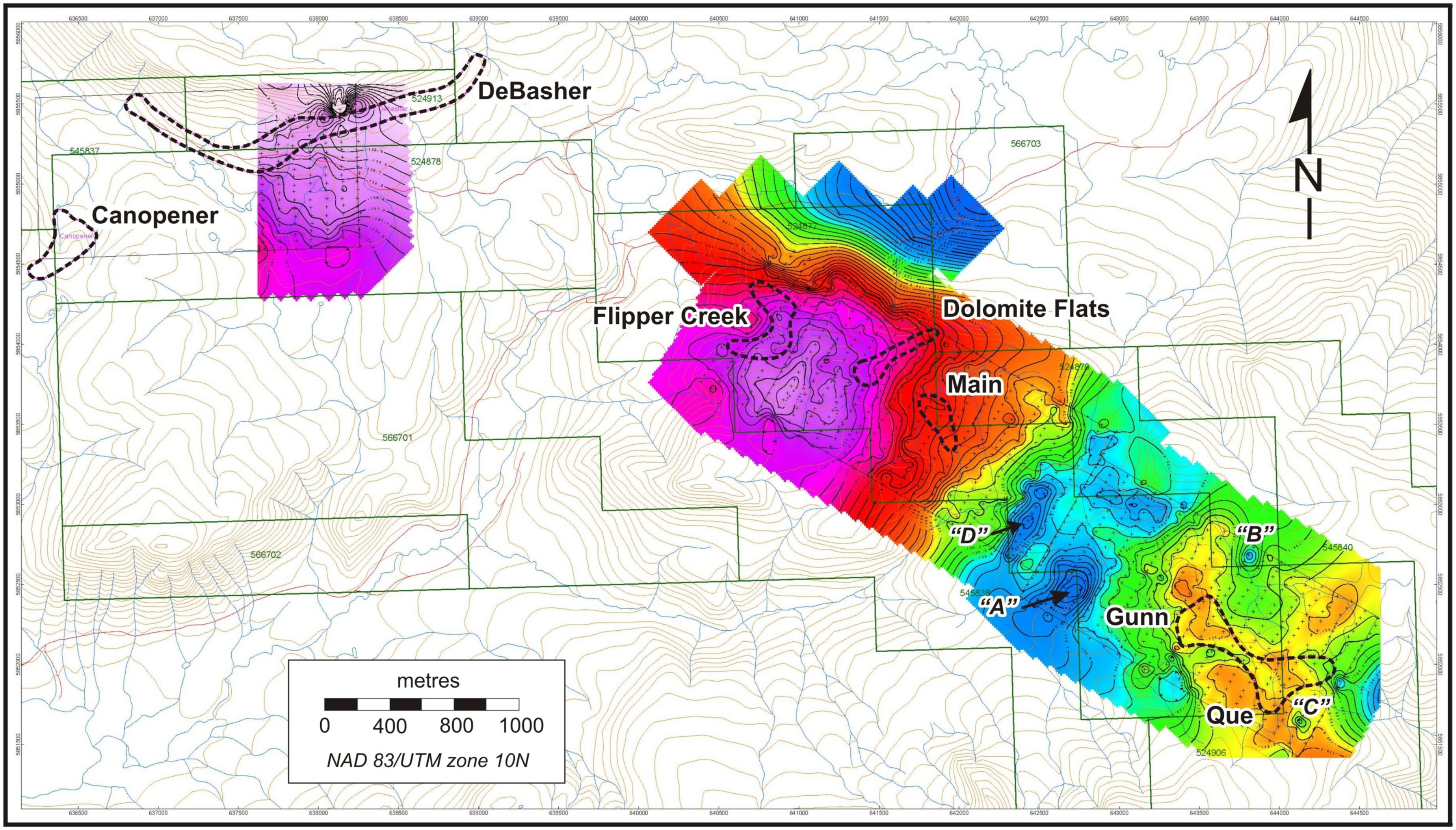


Figure 4. Cariboo Zinc property, east-central British Columbia, showing ground gravity contours of calculated Bouguer gravity anomalies (Luckman, 2008). Anomalies A, B, C, and D are discussed in the text.

white barite in proximity to the fault. Irregular disseminated blebs, wisps and veinlets of galena were uncovered during our visit, and orange-red sphalerite was observed within a dark grey brecciated dolostone (Murrell, 1991).

Dolomite Flats

The Dolomite Flats prospect is located approximately 800 m east-southeast of the Flipper Creek occurrence and 600 m northwest of the Main prospect (Figure 3). The mineralization is present in several low-relief dome-shaped outcrops, up to 40 m by 20 m in size, along the main access road (Figure 6A). The two main rock types present in this area are limestone and dolostone.

The limestone crops out on the side of the road between the Main and Dolomite Flats occurrences. It is beige to medium grey and pitted on weathered surfaces, and pale grey on fresh surfaces. Subtle layering that is locally discernible may represent relicts of original bedding or metamorphic layering. This rock reacts well with HCl and does not appear to be mineralized.

White- to cream-coloured, fine- to medium-grained crystalline dolostone is the dominant lithology at the Dolo-

Figure 5. Barite vein with seams of galena at the border and in the middle of the vein, Flipper Creek prospect, Cariboo Zinc property, east-central British Columbia.

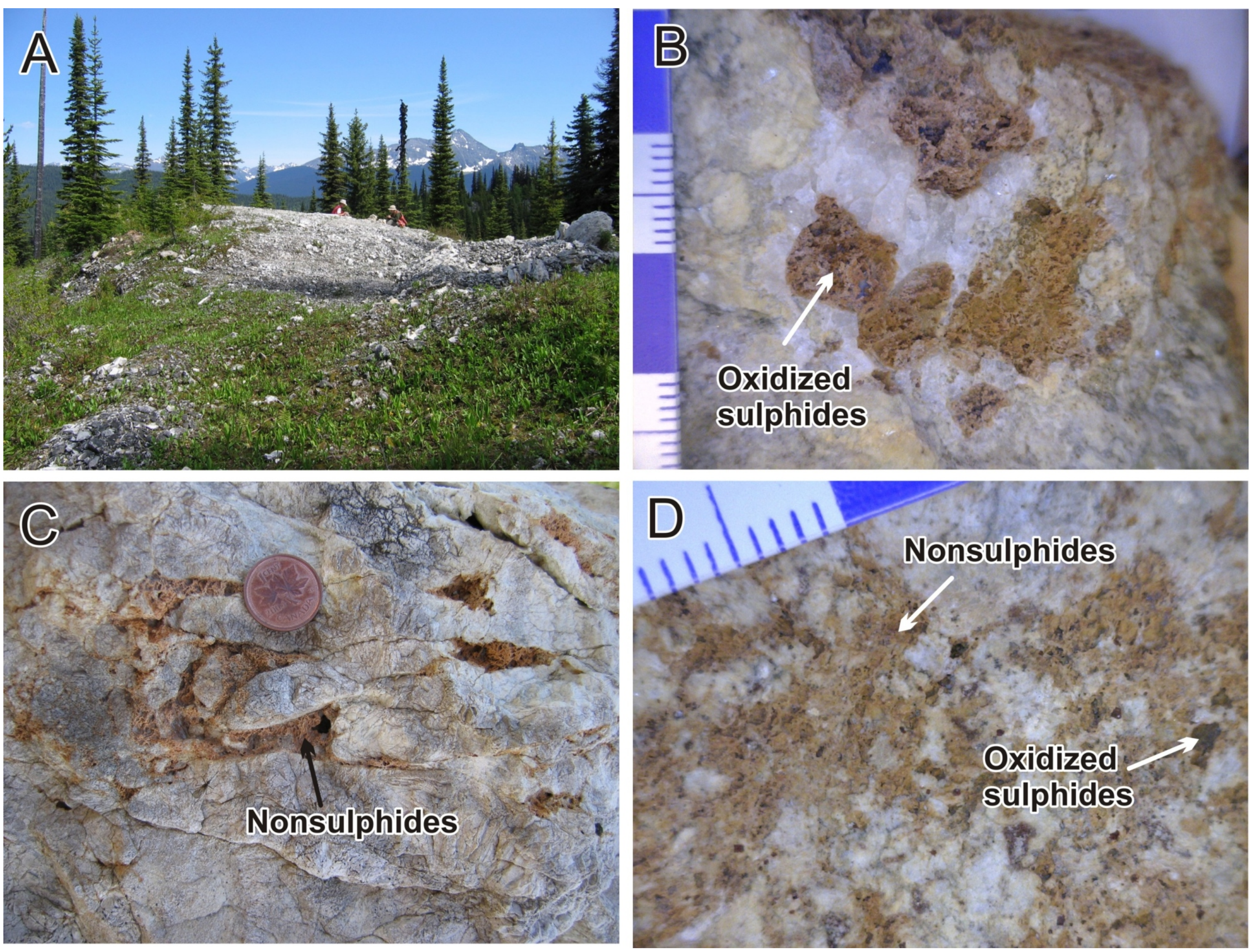


Figure 6. Dolomite Flats prospect, Cariboo Zinc property, east-central British Columbia: **A)** typical outcrop exposure in the Dolomite Flats prospect area; **B)** orange-brown patches corresponding to oxidized sulphides disseminated in the dolostone; **C)** fracture-filling oxidized sulphides occasionally forming boxwork texture in the dolostone; **D)** close-up of fine grains and aggregates of nonsulphides and oxidized sulphides in the dolostone.

mite Flats prospect. The dolostone is characterized by low response to 'Zinc Zap' (Zn indicator solution) and weak acid reaction (largely limited to calcite microfracture coatings). It commonly contains less than 1% millimetre-size grains of a soft grey to black mineral, and locally contains white mica and possibly clinopyroxene, preferentially concentrated along hairline fractures (microscope study is needed to confirm the mineralogy).

Base-metal (Zn-Pb) sulphide and nonsulphide mineralization appears to be confined to the dolostone. In proximity to mineralization, the dolostone hostrock is generally medium- to coarse-grained, with crystals up to 1 cm in size. The main sulphide minerals are orange-brown to dark grey sphalerite and pyrite that are commonly (at least partially) oxidized and accompanied by some quartz and talc grains. These are disseminated within the dolostone or occur as fracture fillings (Figure 6B, C). No obvious structural control for the disseminated sphalerite mineralization is visible on the scale of the outcrop; however, at hand-specimen scale, sphalerite appears to be partially controlled by hairline fractures.

Nonsulphide minerals are typically soft reddish brown to orange, probably dominated by smithsonite or hemimorphite; however, the mineralogy has yet to be confirmed. These minerals are widespread throughout the fine-grained cream-coloured dolostone (characterized by a weak response to Zinc Zap) in low concentrations as fine aggregates or minute specks (Figure 6D). Where present in above-average concentrations, they form dull fracture coatings and/or sugary textured and porous pods with strong Zinc Zap response. Locally, the nonsulphides are associated with quartz grains, and visible relicts of sphalerite and pyrite crystals. The most spectacular occurrences of nonsulphides at this locality consist of radiating nonsulphide needles lining cavities.

An exploration hole, drilled with a hand-held Packsack drill in 1998, reached a depth of 34 m in dolostone breccia and ended in mineralization (hole 98-2; McLeod, 1999). The anomalous samples from this hole (Table 1) are considered to be generally representative of the known mineralization.

Diamond-drill hole 94-1 (length 92.4 m), collared 380 m southeast of hole 98-2 (halfway between the Main and Dolomite Flats zones), returned anomalous Pb and Zn in interlayered limestone, phyllite and dolostone between 63.7 m and the end of the hole. Several samples returned up to 2.21% Zn over 0.6 m intervals (e.g., sample G12 [79.86–80.47 m] returned 0.01% Pb and 2.21% Zn; McLeod, 1995). This hole also ended in galena-sphalerite mineralization. Additional drilling took place in 1999 within the general area of the Dolomite Flats prospect; however, it targeted a gravity anomaly rather than geochemical anomalies. Pembrook Mining now believes that the 1999 drillholes were collared below the most favourable contact, which is located within the dolostone near the phyllite contact.

Lead is present in the form of galena as isolated short (<5 cm) and narrow (<2 mm) fracture fillings and small pods (<3 cm). These galena fillings are not common in the outcrops and are rather irregularly distributed.

Results of chemical analyses of samples collected during the 2009 visit were not available at the time of writing.

Table 1. Zn and Pb content of samples from drillhole 98-2 (McLeod, 1999; Bradford and Hocking, 2008), Dolomite Flats prospect, Cariboo Zinc property, east-central British Columbia.

Sample no.	Zn (wt.%)	Pb (wt.%)	Width (m)	Recovery (%)
GL2 #1	1.34	0.01	0–2.5	40
GL2#2	5.95	0.03	2.5–3.5	60
GL2#7	1.00	0.42	16.6–27.4	90
GL2#8	1.06	0.35	27.4–28.2	90
GL2#9	0.90	0.31	28.2–31.4	75
GL2#10	3.75	0.50	31.4–34	60

Main

The Main prospect, discovered in 1989, is exposed in a trench approximately 48 m long and 28 m wide (Figure 7A). Another smaller trench is located 230 m northwest of the main trench.

Mineralization consists of numerous intersecting 2–3 cm wide quartz veins containing galena and lesser sphalerite (Figure 7B, C). Mineralization is largely fracture controlled. The main quartz-galena (±sphalerite) vein system strikes 300–360º and dips east at 60–90º. It crosscuts barren quartz veins (2–3 cm wide) with orientations of 150º/80ºW, 135º/50ºS and 120º/45ºS.

Areas (up to 1 m by 0.5 m) consisting largely of massive galena (±euhedral sphalerite) are present along exposed faces of major fractures within the principal trench of the Main prospect (Figure 7D); in most cases, however, these fractures are less than 5 cm thick and, as the galena content decreases, quartz content increases.

Mapping has shown that phyllite is present in the area; however, unlike elsewhere on the property, it is flat lying or dips gently to the south (Murrell, 1991).

Teck Corporation drilled two Winkie holes, GL90-1 and GL90-2 oriented at 307º and 288º, respectively, and plunging 45º, directly beneath the main trench to test for possible vertical extensions of the surface mineralization (Murrell, 1991). Both drillholes were anomalous in Zn throughout, with values up to 3.9% Zn and 1.1% Pb over 0.5 m. Lead values were lower than expected, based on the spectacular nature of the galena-rich surface exposures.

Gunn

The Gunn showing is associated with an extensive Zn-Pb soil anomaly (Cannon, 1970; Bradford, 2006). One large outcrop of dolostone with numerous small trenches occurs adjacent to the dirt road. Several outcrops and numerous larger trenches occur over a 250 m by 125 m area south of the dirt road, approximately 150 m southeast of the Main prospect (Figure 3).

Mineralization consists of quartz-galena (±sphalerite) veins and fracture fillings, barite-galena-sphalerite veins, pods of oxidized sulphides, and disseminated fresh and oxidized sphalerite. The carbonate host is a fine- to medium-grained recrystallized white dolostone (Figure 8A). The dolostone weathers pale to medium grey with an occasional pinkish tint, appears beige adjacent to the veins and is white on fresh surfaces. Adjacent to the mineralized veins, the dolostone occasionally contains fine-grained disseminated dark grey– and honey-coloured, partially oxidized sphalerite (Figure 8B–D).

A white to pale grey–weathering silicified knob located immediately south of the road contains galena-bearing veins with variably weathered sphalerite, and barite-galena-sphalerite veins (Figure 8E). Trenching in the vicinity of the knob has revealed several additional showings over an area measuring 250 m by 125 m (Murrell, 1991; Bradford and Hocking, 2008).

The principal Gunn excavation (Figure 8F), located 250 m west of the road, shows a complex network of quartz-galena (±sphalerite±nonsulphides) veins enclosed in siliceous cream-coloured dolostone that also locally hosts fine-grained, disseminated, dark grey sphalerite and encloses irregular zones of nonsulphide Zn-Pb mineralization. The veins generally trend northwest or north (280°/67°S, 300°/80–90°N to 110–130°/46°S and 000°/45°E). One set of mineralized veins trends 040° and dips 60°SE. Most of the veins are less than 5 cm thick and vary in mineralogy and mineral proportions along strike. They consist of quartz and galena with subordinate amounts of calcite, sphalerite and nonsulphide minerals. The nonsulphides include white to pale grey, translucent to transparent radiating crystals, 2–3 mm in length (probably cerussite; Figure 9A), and stubby white transparent crystals, 1.5 mm in length and 0.5 mm in diameter (Figure 9B) that are tentatively identified as anglesite. Other nonsulphides observed are hydrozincite and hemimorphite. At two locations within the main excavation, Pembrook Mining Corporation and Zincore Metals Inc. geologists reported 16–30% Zn with much lower Pb values across widths of 3–6 m. These zones most likely sampled a combination of vein-type and nonsulphide replacement-type mineralization.

Que

The Que showing comprises a large number of shallow exploratory trenches and stripped outcrops and subcrops (Figure 10A) located at the extreme southeast corner of the Cariboo Zinc property, approximately 750 m south of the Gunn zone (Figure 3). The showing consists of irregularly distributed dolostone-hosted sphalerite, galena and nonsulphide mineralization. The area of known mineralization outlined between 1981 and 2008 by various operators continues to expand, as Pembrook Mining Corporation located several new mineralized outcrops during our 2009 field visit.

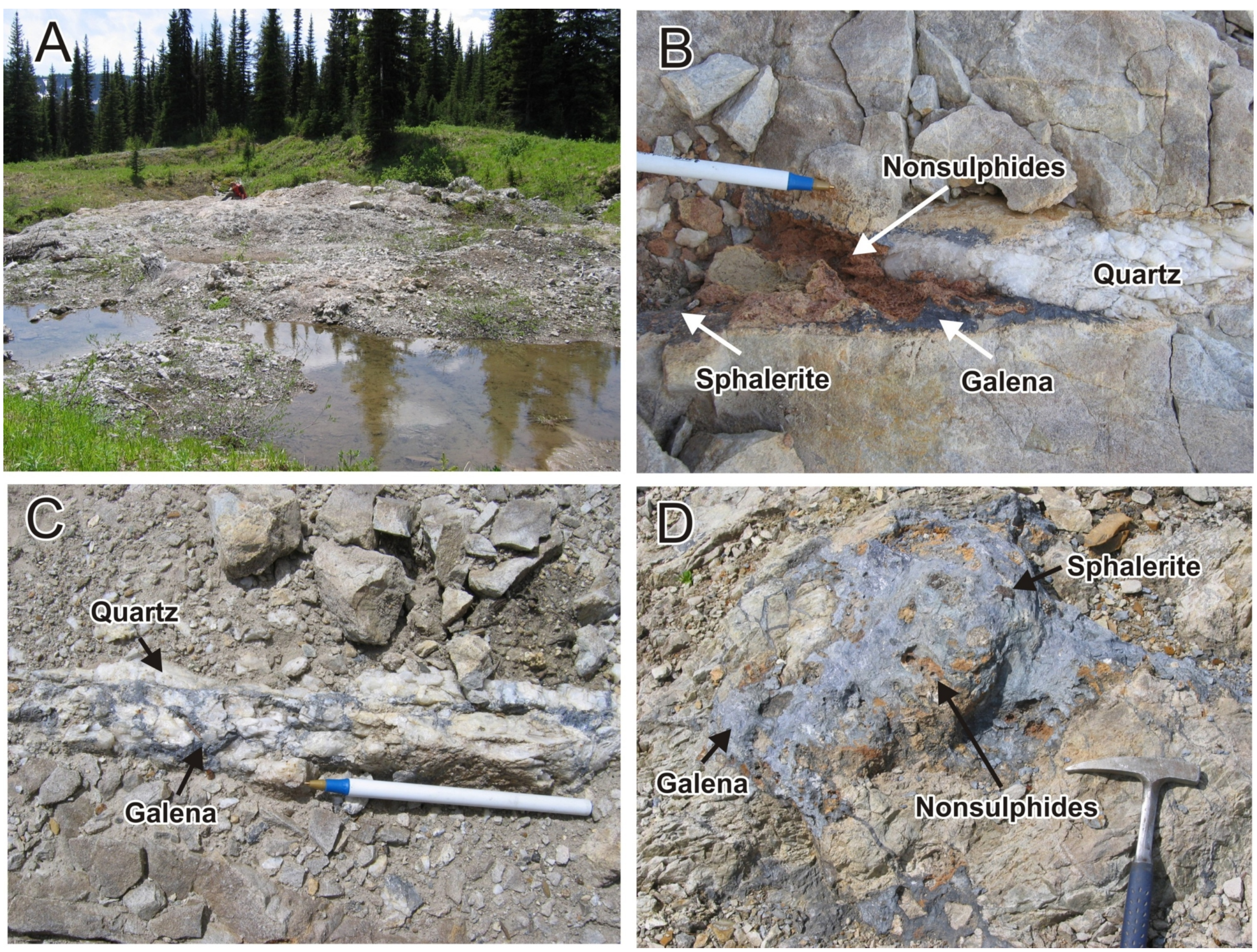


Figure 7. Main prospect, Cariboo Zinc property, east-central British Columbia: **A)** main trench; **B)** quartz-sphalerite-galena-nonsulphide (after sphalerite) vein; **C)** quartz-galena vein; **D)** pod of galena, nonsulphides (cerussite) and sphalerite that form part of a vein-breccia system.

Boulders of nonsulphide mineralization are scattered throughout the area. At least at one locality, the presence of several large angular and friable nonsulphide-bearing blocks (>1 m in diameter), which strongly react to 'Zinc Zap', suggests a local origin (Figure 10B, 10C). One of the main base-metal nonsulphide minerals is probably cerussite (Figure 10D), but detailed mineralogical investigation is required.

During our 2009 property visit, white-coated galena (sphalerite-free) nodules up to 4–5 cm across (Figure 11)

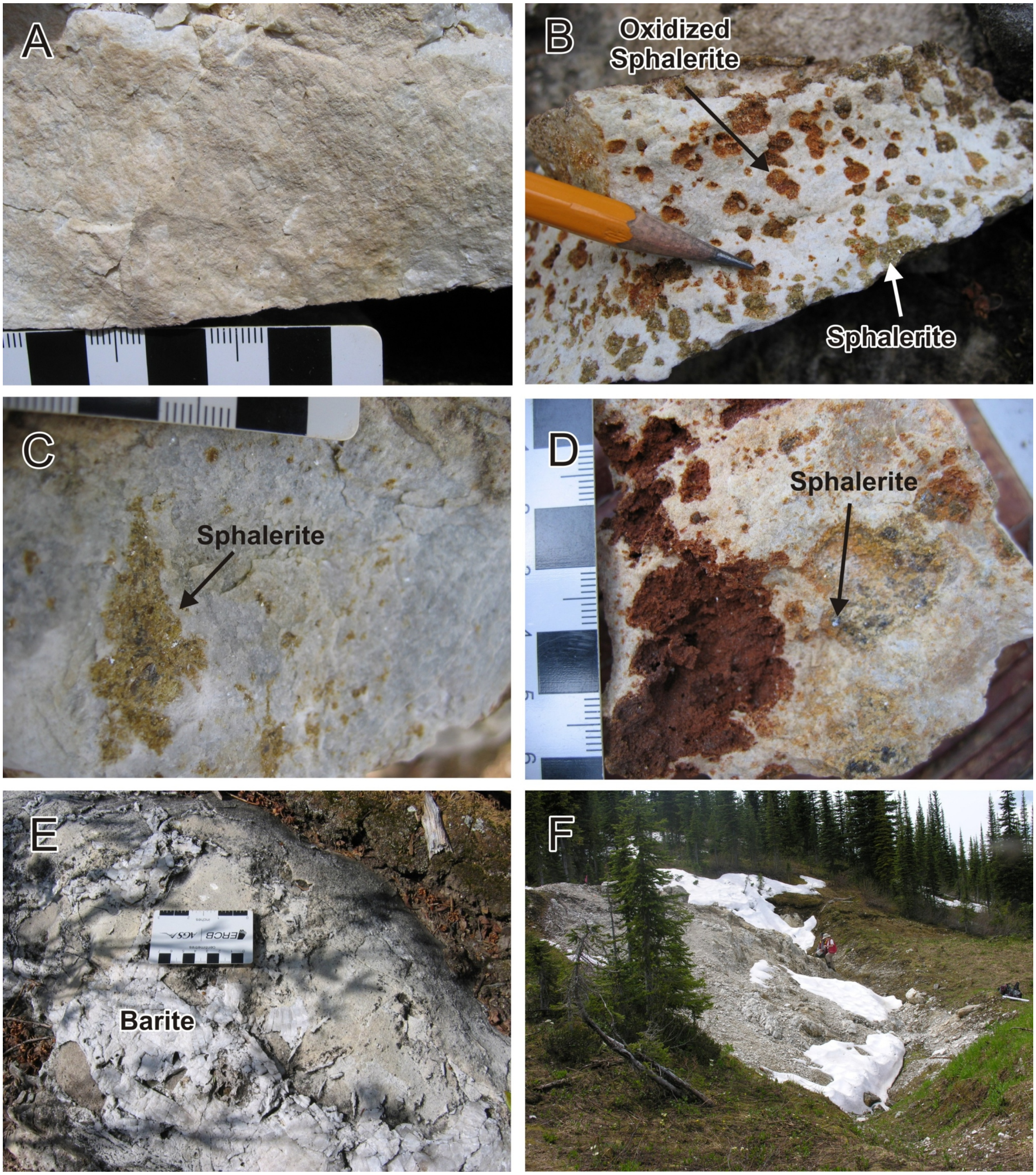


Figure 8. Gunn showing, Cariboo Zinc property, east-central British Columbia: **A)** fine-grained recrystallized white dolostone; **B)** disseminated oxidized (orange) and fresh (yellowish) sphalerite in the fine-grained white dolostone; **C)** aggregates of fresh yellow sphalerite in the fine-grained white dolostone; **D)** oxidized reddish brown sulphides (presumably sphalerite) in the white dolostone; **E)** barite-galena-sphalerite vein crosscutting the dolostone (only barite is clearly visible in the photograph); **F)** main Gunn excavation.

were uncovered in a north-flowing stream less than 50 m upstream from an occurrence of high-grade nonsulphide-rich boulders. These rounded nodules may be important because the creek bed consists exclusively of flat, coarse, angular dolostone fragments, indicating a proximal origin. No rounded exotic pebbles, commonly observed in the nearby overburden, were seen in the stream. These galena nodules may have formed by dissolution of the surrounding hostrocks and partial conversion of galena to anglesite. This would be consistent with the process described by Heyl and Bozion (1962), Reichert and Borg (2008) and Simandl and Paradis (2009). Cavities within the rounded nodules still contain remnants of the host dolostone and orange-coloured nonsulphide minerals. These cavities formed by partial dissolution of the host dolostone and sphalerite crystals. Sharp and angular quartz grains protruding from the galena would have broken off or separated from the galena if the nodules had been transported downstream for any significant distance. The presence of quartz suggests a type of mineralization (or protore) similar to that observed in the Main and Gunn occurrences. One of the nodules contains 'striated' relicts of amphibole crystals or stacked sericite sheets. Both amphibole and sericite were observed locally, adjacent to galena-rich veins at or near the Main prospect.

DISCUSSION

This discussion is based on the 2009 field observations and previous investigations by the industry. No results of chemical analyses, thin section petrography or powder x-ray diffraction on samples collected during 2009 were available at the time of writing.

Field Observations

All the mineralization observed during our field visit is stratabound, hosted by Mg-bearing carbonates (i.e., limy dolostone–dolomitic limestone and fine-grained creamy dolostone). It seems to be located close to the contact between the cream dolostone and the limy dolostone (Figure 3) and, according to company reports, near the contact between the dolomitic carbonate rocks and the overlying phyllite. Although overall the mineralization is stratabound, it is in part structurally controlled on the outcrop scale. It occurs as disseminations of fine specks and centimetre-size aggregates, irregular replacement zones, veins and fracture fillings locally forming narrow breccia zones. Sphalerite occurs mostly as pervasive fine- to medium-grained, low-grade disseminations in dolostone; aggregates forming centimetre-size clots; and, less frequently, fracture and breccia fillings. Galena occurs mainly as fracture and vein fillings in association with quartz and/or calcite, sphalerite and barite. Galena-rich crackle and mosaic dolostone breccias (±sphalerite) are less common. In all of the occurrences, galena and sphalerite are at least partially transformed into Zn-Pb nonsulphides. Smithsonite, hemimorphite, cerussite, hydrozincite and possibly anglesite are probably the main nonsulphide Zn and Pb minerals. They form millimetre-scale orange patches, oxide boxworks (after sphalerite), open-space fillings and irregular replacement pods and masses with or without remnants of sphalerite and galena. The best Zn-Pb nonsulphide mineralization was observed as blocks or subcrops within the Que zone (Figure 10c). The friable nature of the nonsulphide blocks indicates a proximal source.

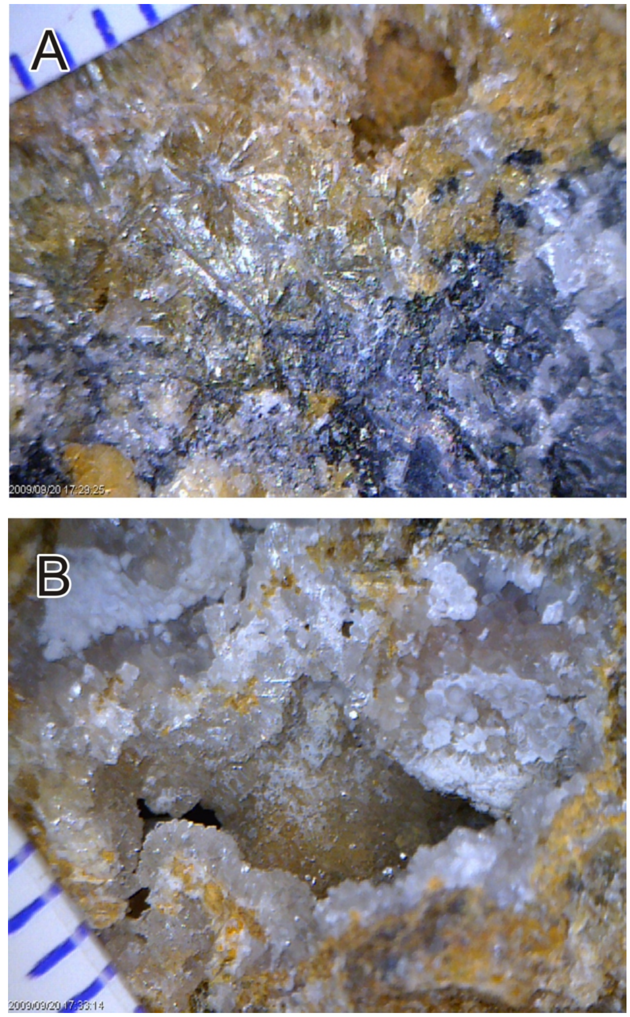


Figure 9. Gunn showing, Cariboo Zinc property, east-central British Columbia: **A)** white to pale grey, translucent to transparent radiating crystals, 2–3 mm in length (probably cerussite); **B)** stubby white transparent crystals (probably anglesite) lining cavities.

The presence of galena nodules covered by a white coating (Figure 11), within the same area, is consistent with near-surface oxidation of sulphide ores (Simandl and Paradis, 2009).

Surprisingly, Fe-sulphides (pyrite and/or marcasite) are absent (or present in low concentrations) throughout the area, with the exceptions of the DeBasher and Dolomite Flats occurrences, where pyrite is found associated with aggregates of sphalerite. This is significant because pyrite is more reactive in surface environments than sphalerite or galena. The destabilization of pyrite is expected to result in the formation of acidic solutions that are then able to attack sphalerite and, to some extent, galena. This means that either pyrite already reacted or it was never present in the system. If pyrite was originally present but later destroyed, then its oxidation may have resulted in the formation of solutions with a capacity to transport Zn. Such solutions favour the formation of 'white' Zn-rich nonsulphide deposits in the area. This aspect must be followed up by detailed petrographic studies.

Several minerals tentatively identified during this study, or reported in previous studies, are known to gener-

Figure 10. Que showing, Cariboo Zinc property, east-central British Columbia: **A)** shallow exploratory trenches (arrow) and stripped outcrops and subcrops; **B)** close-up of aggregates of nonsulphide minerals (orange and white); **C)** large, angular nonsulphide-bearing blocks; **D)** radiating, tabular translucent crystals of cerussite in cavity.

ate distinct infrared spectral responses that, under favourable conditions, may be detectable by remote sensing, a relatively new and probably underutilized exploration tool in British Columbia. The vegetation cover, however, may reduce the effectiveness of such an approach.

The significance of galena nodules remains to be confirmed. They may be relicts of primary sulphide mineralization, partially rounded by interaction with supergene fluids (as described by Reichert and Borg, 2008) and subject to additional rounding during short downstream transport.

Review of Existing Data with Focus on Pb-Zn Nonsulphides

Exploration in the area has consisted of traditional prospecting, geological mapping, geophysical and geochemical surveys, trenching and limited drilling. Both geochemical and geophysical methods are effective exploration tools in selecting Pb-Zn sulphide targets on the Cariboo Zinc property (Cannon, 1970; Murrell, 1991; Bradford, 2006). Additional information may be extracted from existing surveys, if the nonsulphide Pb-Zn mineralization is also targeted. For example, the ground gravity contours of the calculated Bouguer anomaly (Figure 4) represents results of the most recent gravity survey. It shows a general trend of increasing gravity to the northwest and de-

Figure 11. Galena nodules, Que showing, Cariboo Zinc property, east-central British Columbia.

creasing gravity to the southeast (Luckman, 2008). The gravity highs superimposed on this trend may reflect the presence of Pb-Zn mineralization or localities where minor igneous intrusions approach the surface. General spatial association of relatively discrete gravity highs with known Zn-Pb sulphide mineralization is observed at the Gunn and Que showings (Figure 4). The main exploration target was the Pb-Zn sulphide mineralization (either Irish-type or MVT); therefore, the interpretation was geared towards the selection and testing of gravity highs. Numerous drill targets were previously identified by Paget Resources Corporation or the predecessor companies, based on gravity highs (Luckman, 2008). As a byproduct of the search for gravity highs, the surveys also commonly identified gravity lows. Figure 4 provides few examples of gravity lows that were not previously discussed. Some of them are located at the edge of the surveyed area and may be an artifice of the data processing. Others, including anomalies A, B, C and D, may require closer attention. They may possibly correspond to karst features or the presence of porous (vuggy) nonsulphide mineralization.

The large, nearly circular negative anomaly (Figure 4, anomaly A) is not associated with a strong geochemical signature, but it coincides with the projected location of the strata hosting the main occurrence. It may also be an expression of a karst structure. Anomalies B and C have a much smaller footprint. The lowest value of these anomalies corresponds to one or two gravity readings. They could 1) represent operational glitches during the survey; 2) reflect the difficulty of obtaining the proper inner terrain corrections using the clinometers at those particular locations; or 3) be mineralization related. Anomaly B is located near the historical borehole 98-01, which tested a gravity anomaly detected during the 1996 survey. This short vertical borehole intersected a 4 m section of 3.26% Zn and 97 ppm Pb near the surface (McLeod, 1999). Low core recovery, no mention of sulphides in the company's core log and very low Pb values strongly suggest that this may be direct-replacement–type nonsulphide Zn mineralization. Two critical gravity readings on the survey line adjacent to anomaly B are missing, complicating the assessment of this anomaly. Anomaly C corresponds to a single anomalous reading. It is located within the Que showing area. Historical chemical analyses of at least three samples collected within 100 m of this anomaly returned between 400 and 5000 ppm Pb. Anomaly D is a multistation type. The lowest Bouguer values are concentrated along a single traverse, cutting across the projection of the favourable carbonate horizon that hosts the Main prospect. This gravity low may coincide with the trace of a north-northeast-trending fault (with or without associated karst), with probable graben- or half-graben–style down-drop east of the fault.

Karst features, such as sinkholes, caverns and solution-collapse breccias and other structures, are recognized to be important controls on MVT mineralization in several Pb-Zn districts (e.g., Pine Point, Tri-State, east and central Tennessee, upper Mississippi Valley). In the Cariboo Zinc area, the karst structures may also provide the channels for downward migration of supergene Zn-bearing fluids and/or result in depressions of the water table. Both of these possibilities are important for the genesis of nonsulphide wallrock-replacement Zn-Pb deposits (Simandl and Paradis, 2009). Furthermore, the karst structures and related topographic depressions are also known to control the distribution of 'residual- and karst-fill-' types of nonsulphide deposits, as defined by Heyl and Bozion, (1962) and Hitzman et al. (2003). We had no strong reasons to consider this category of nonsulphide Pb-Zn deposits in the Salmo area of southern BC (Simandl and Paradis, 2009); however, this category of mineralization could be encountered in the Cariboo district. Knowledge of physical properties of nonsulphide mineralization in the Cariboo Zinc district would greatly improve the quality of the interpretation, but such data are not presently available.

CONCLUSION

The area is characterized by a large number of stratabound Pb-Zn occurrences hosted by dolomitic carbonates along a northwest-trending belt about 8 km long. Both Pb-Zn sulphide and nonsulphide types of mineralization are present at the Flipper Creek, Dolomite Flats, Main, Gunn and Que occurrences. The continuity of sulphide and nonsulphide mineralization exposed within the Cariboo Zinc property is not well constrained.

Modern exploration programs are typically integrated (i.e., combining traditional prospecting and mapping with geophysical and geochemical methods). The area was investigated to some extent in terms of its Zn-Pb massive sulphide potential but remains nearly virgin in terms of exploration aimed at nonsulphide base-metal deposits. Existing surveys could be reinterpreted to identify areas favourable for nonsulphide mineralization. For example, the possible significance of the positive Bouguer anomalies was previously addressed. Negative Bouguer anomalies were not discussed. They should be carefully assessed to determine if they reflect karst structures, which could be potential controls on nonsulphide Pb-Zn ores. Estimates of physical properties of nonsulphide and sulphide mineralization (based on samples collected in 2009) will facilitate future interpretation of the geophysical surveys done on the Cariboo Zinc property.

Detailed laboratory work, including microscopy, scanning electron microscopy, powder x-ray diffraction, and geochemical and isotopic analyses will help develop customized genetic and exploration models for sulphide and nonsulphide Pb-Zn mineralization within the Cariboo terrane. It may also open the door for use of cutting-edge exploration technologies. For example, depending on vegetation cover, the short-wave infrared spectral response of some nonsulphide base-metal ore minerals (e.g., hydrozincite and smithsonite) may make remote sensing a potentially cost-effective exploration method that has yet to be tested in British Columbia.

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