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Abstract: Carbonate-hosted Zn-Pb deposits of the Kootenay Arc are hosted by deformed Lower Cambrian, platformal carbonate rocks of the Badshot Formation or its equivalent, the Reeves member of the Laib Formation. The deposits range in size from 6 to 10 Mt and contain 3 to 4% Zn, 1 to 2% Pb, 0.4% Cd, and traces of Ag. They are essentially stratabound and stratiform lenticular concentrations of sulphide minerals (sphalerite, galena, pyrite, local pyrrhotite, and rare arsenopyrite) in isoclinally folded dolomitized or silicified carbonate rocks. The origin of these deposits is enigmatic. Some are analogous in their geological setting and features to the Irish-type carbonate-hosted Zn-Pb deposits.

Résumé : Les gisements zinco-plombifères de l'arc de Kootenay sont encaissés dans des roches carbonatées déformées de plate-forme. Ces roches du Cambrien inférieur font partie de la Formation de Badshot ou de son équivalent, le membre de Reeves de la Formation de Laib. La taille des gisements varie de 6 à 10 millions de tonnes et ils contiennent de 3 à 4 % de zinc, de 1 à 2 % de plomb, 0,4 % de cadmium et des traces d'argent. Il s'agit essentiellement de concentrations lenticulaires stratoïdes et stratiformes de sulfures (sphalérite, galène, pyrite, localement pyrrhotite et rarement arsénopyrite) dans des roches carbonatées dolomitisées ou silicifiées qui sont déformées en plis isoclinaux. Leur origine est énigmatique. Certains des gisements ont un contexte géologique et des caractéristiques analogues à ceux des gisements zinco-plombifères encaissés dans des roches carbonatées de type irlandais.

INTRODUCTION

Carbonate-hosted Zn-Pb deposits of the Kootenay Arc in British Columbia, Canada (Fig. 1) are commonly referred to as "Kootenay Arc–type deposits" (Höy, 1982; Nelson, 1991). They are hosted in miogeoclinal carbonate rocks of the Lower Cambrian Badshot Formation and Reeves member of the Laib Formation. The major carbonate-hosted deposits of the Kootenay Arc are listed in Table 1.

Several deposits are past-producers (e.g., Reeves MacDonald, Jersey, HB, Bluebell) and others have seen intensive exploration work (e.g., Duncan, Wigwam). None are presently in production. The largest deposits range in size from 6 to 10 million tonnes (Mt) and contained 3 to 4% Zn, 1 to 2% Pb, 0.4% Cd, and traces Ag (Höy, 1982; Höy and Brown 2000).

The origins of these deposits are enigmatic because of the intense deformation that has modified most of their original features. However, several of the less-deformed deposits share a number of syngenetic-diagenetic characteristics with Irish-type carbonate-hosted Zn-Pb deposits. The objectives of this paper are to report on preliminary field observations and review the extensive literature descriptions by Fyles and Hewlett (1959), Muraro (1962), Fyles (1964, 1970), (Höy 1982), and Legun (2000) of the deposits.

REGIONAL GEOLOGIC SETTING

The Kootenay Arc in the southeastern Canadian Cordillera refers to an arcuate geomorphic feature defined by a curving belt of complexly deformed rocks extending at least 400 km from near Revelstoke in the northern part of the Arc to the southwest across the Canadian-U.S.A boundary (Fyles, 1964). The Kootenay Arc lies between the Purcell Anticlinorium in the Purcell Mountains on the east, and the Monashee metamorphic complex on the west (Fig. 1). The Arc consists of a thick succession of thrust-imbricated Proterozoic to lower Mesozoic miogeoclinal to basinal strata of sedimentary and volcanic protoliths (Brown et al., 1981). Colpron and Price, (1995) outlined a regionally consistent stratigraphic succession along the Kootenay Arc that is summarized below (Fig. 2).

The lower part of the stratigraphic section along the Kootenay Arc is composed of Eocambrian siliciclastic and carbonate rocks of the Hamill Group and Mohican Formation. The rocks are overlain by the Lower Cambrian Archaeocyathid-bearing carbonate rocks of the Badshot Formation and its equivalent, the Reeves member of the Laib Formation (Fyles and Eastwood, 1962; Fyles, 1964; Read and Wheeler, 1976), which host many Zn-Pb sulphide deposits. The Badshot Formation is characterized by cliff-forming, white to medium grey, commonly laminated marble or dolomitic marble. Locally, grey calcareous schist is interlayered with the carbonate rocks. In the southern part of the Kootenay Arc, the carbonate rocks are overlain with apparent conformity by the lower Paleozoic siliciclastic, basinal shale and mafic volcanic rocks of the Lardeau Group (Colpron and Price, 1995).

Three phases of folding are recognized within the Kootenay Arc. Large amplitude (10 km-scale) west-verging recumbent folds were deformed by two phases of upright, tight to isoclinal folds, under conditions of lower-greenschist- to amphibolite-facies metamorphism (Fyles, 1964; Warren and Price, 1993). This polyphase deformation has produced a pervasive transposition of bedding that locally obscures the stratigraphic relationships (Colpron and Price, 1995).

SULPHIDE DEPOSITS

The carbonate-hosted Zn-Pb deposits are distributed along the entirety of the Kootenay Arc, and define the Salmo and Duncan camps. The Bluebell deposit, a fracture-controlled replacement deposit (Ransom, 1977; Höy, 1980, 1982), is located between the Salmo and Duncan camps, and smaller deposits occur in the northern part of the Kootenay Arc (Fig. 1). Dolomitized, brecciated, and silicified carbonate rocks host all the Zn-Pb deposits. The dolomite is medium to dark grey, fine grained, poorly layered and texturally different from the barren, generally well layered limestone. Dolomite forms an envelope that completely or partially surrounds the sulphide mineralization.

The deposits are stratiform and stratabound. They consist of disseminated to massive sulphide aggregates which form lenses, irregular and planar layers, and laminae in dolomite or silicified carbonate rocks. The deposits are irregular in outline with the sulphide minerals following bedding or foliation planes within the host carbonate rocks. The sulphide laminae and the host carbonate rocks are deformed into mesoscopic folds that mimic the large-scale regional structures, and are commonly elongated parallel to the regional structural grain.

The main sulphide minerals are sphalerite, galena, and pyrite. Pyrrhotite and traces of arsenopyrite are observed in some deposits. The dominant gangue is dolomite, calcite, and rarely quartz. Sulphide mineralization appears to have formed primarily by replacement of the host carbonate rocks, with minor open-space filling of breccia zones, fractures, and vugs. Common sulphide textures are fine- to medium-grained disseminations, layered encrustations, crystalline galena and sphalerite, and colloform sphalerite.

A brief description of the Salmo and Duncan camps is given below. It is based on recent field investigations by the author and descriptions of Fyles and Hewlett (1959), Fyles (1964, 1970), Höy (1982), and Legun (2000).

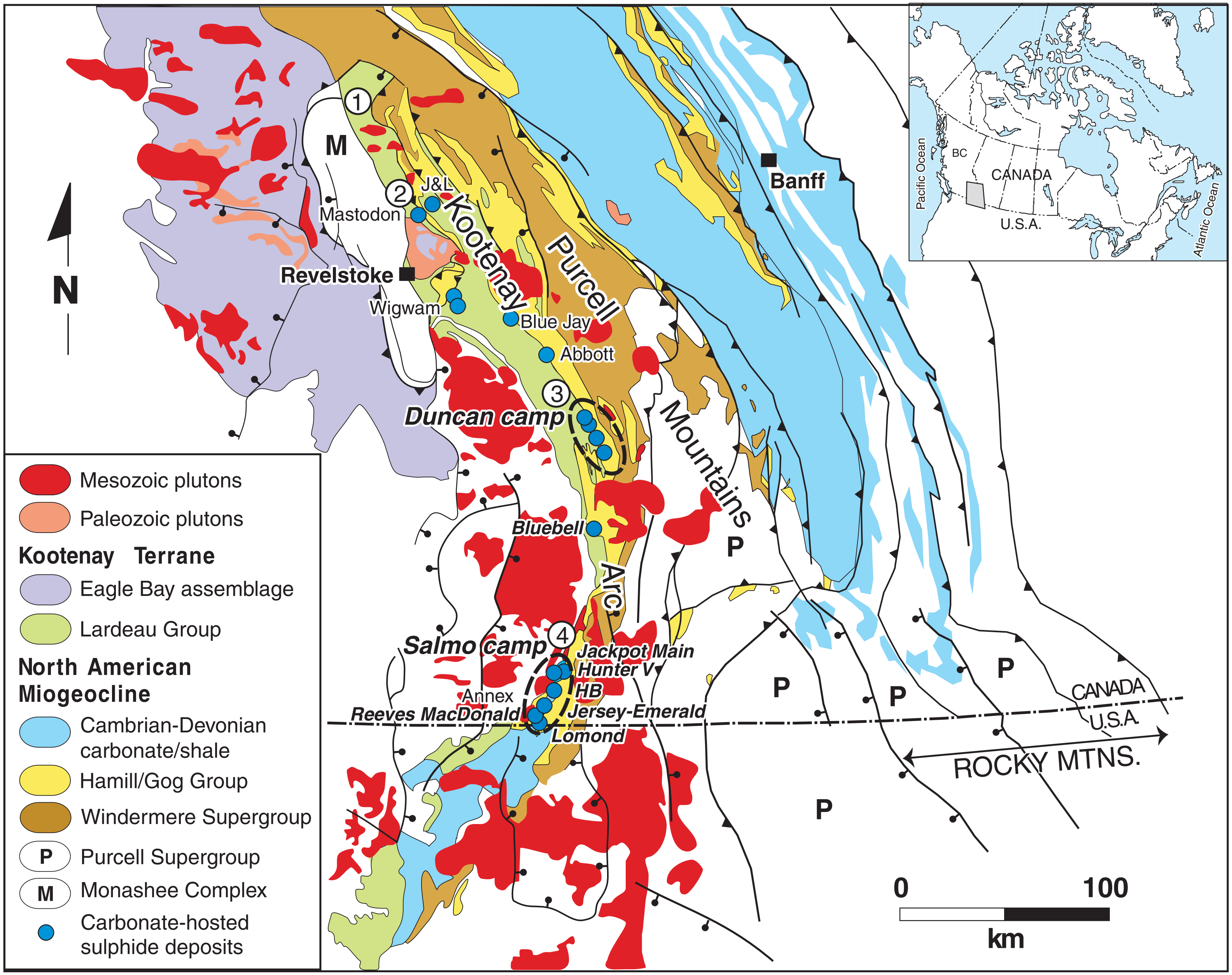

Figure 1. Simplified geological map of southeastern British Columbia showing the location of the carbonate-hosted Zn-Pb deposits. Numbers 1 to 4 refer to the general location of the stratigraphic sections of Figure 2. Modified from Wheeler and McFeely (1991) and Logan and Colpron (2006)

Table 1. Production and reserve of the main carbonate-hosted Zn-Pb deposits of the Kootenay Arc.

Deposit	BC minfile #	UTM northing / easting (NAD 83)	Deposit classification class / type	Status	Formation / unit	Lithology	Mineralization	Tonnage / grades	Notes
Lomond	082FSW018	5427881 / 475438	SHMS / oxides	Past-producer	Nelway Fm	Dolomite	Conformable oxidized sulphide zones	Production (1948-49): 18 t of 1182 g of Ag, 4401 kg of Pb, 436 kg of Zn.	Podiform oxidized Pb-Zn sulphide minerals exposed for a strike length of 300 m. One pod is 6 by 15 m in size and 5 m thick.
Reeves Macdonald	082FSW026	5430233 / 474250	SHMS / Irish, MVT	Past-producer	Laib Fm – Reeves member	Dolomitized limestone	Laminated bands, lenses, and disseminations of Py-Sph-Ga	Production (1949-71): 5,848,021 t at 1% Pb, 3-6% Zn	O'Donnell, Reeves, B.L., and No. 4 orebodies make up the Reeves MacDonald mine and they are all faulted segments of a single ore zone. The orebodies are in a steeply plunging secondary syncline on the south limb of the Salmo River anticline.
Annex	082FSW219	5429069 / 472295	SHMS / Irish, MVT	Past-producer	Laib Fm – Reeves member	Dolomitized limestone	Laminated bands, lenses, and disseminations of Py-Sph-Ga (minor Cpy)	Production (1970-75): 763,314 t	The orebody is possibly a downfaulted section of the Reeves MacDonald ore zone but it contains higher metal grades.
Jersey-Emerald	082FSW009 082FSW010	5438442 / 483859	SHMS / Irish, MVT	Past-producer	Laib Fm – Reeves member	Dolomitized limestone	Tabular or lenticular bands of disseminated Sph-Ga-Py-Po (minor Asp); W-skarn (minor Mo)	Production: 8.4 Mt at 1.95% Pb, 3.83% Zn.	Jersey = 10 orebodies (A to J) that follow secondary folds and locally bedding faults on the right-side-up limb of the Jersey andicline. Emerald = superimposed W-skarn mineralization.
HB	082FSW004	5444397 / 485436	SHMS / Irish, MVT	Past-producer	Laib Fm – Reeves member	Dolomitized limestone	Layer-parallel lenses of Py-Sph-Ga (minor Po)	Production (1912-1978): 6.66 Mt. Measured and indicated reserves (1978): 36,287 t at 0.1% Pb, 4.1% Zn.	Three steeply dipping, parallel zones extending as pencil-like shoots for 900 m along the south plunge of the controlling structures.
Hunter V	082FSW014	5453872 / 487827	SHMS / Irish, MVT	Past-producer	Laib Fm – Reeves member	Dolomitized limestone	Disseminated Sph-Py (minor Ga, Te, native Ag) follow banding in the dolomite	Production (1902-1929): 56,820 t of 4.35 g/t Ag, 0.016 g/t Au	Fg sulphide minerals within siliceous limestone matrix. Jackpot Main adjoins to the east.
Jackpot Main	082FSW012	5454271 / 488556	SHMS / Irish, MVT	Developed prospect	Laib Fm – Reeves member	Dolomitized limestone	Disseminated Sph-Py-Po (minor Ga) follow banding in the dolomite	Reserves: 3 Mt of 5% Pb+Zn	Four mineralized zones: East, Lerwick, West, and Main.
BlueBell	082FNE043	5512234 / 510023	SHMS / Veins and replacement	Past-producer	Badshot and Mohican fms	Marble / limestone	Fracture-controlled replacement bodies of Ga-Sph-Po-Py-Asp-Cpy	Production: 4.82 Mt at 5.2% Pb, 6.3% Zn, 45 g/t Ag	3 zones (~500 m apart along strike) = Confort, Bluebell, and Kootenay Chief.
Duncan (no.5 to 8)	082KSE023	5579092 / 503457	SHMS / Irish, MVT	Developed prospect	Badshot Fm	Marble/dolostone, siliceous dolostone	Disseminated, lenticular clusters and massive layers of Py-Sph-Ga (minor Po)	Indicated reserves: 9 Mt at 2.7% Pb, 2.9% Zn	The orientation of the zones is essentially parallel to that of the enclosing formations with steep dips.
Abbott	082KNW056	5608724 / 488723	SHMS / Irish and veins	Past-producer	Badshot Fm / Index Fm	Marble/limestone, calcareous and carbonaceous phyllite	Clusters and disseminations of Ga-Sph-Py in a Qz-Cal gangue	Measured reserves: 39,030 t at 286.3 g/t Ag, 1.2 g/t Au, 10.26% Pb, 16.12% Zn	Sulphide lens strikes at 155° and dips at 75° to the SW. It is approximately 20 m along strike and 11 m in width.
Blue Jay	082KNW079	5627360 / 470322	SHMS / MVT, replac+ement	Past-producer	Badshot Fm	Marble / limestone	Ga-Sph streaks, pods, and disseminations in limestone	Production (1979-81): 3 t of 13,477 g of Ag, 1468 kg of Pb, 1158 kg of Zn	Replacement sulphide minerals in limestone has been traced for at least 213 m.
Wigwam	082KNW068	5636927 / 431917	SHMS / MVT	Developed prospect	Badshot Fm	Marble/limestone, quartzite	Conformable lenses and disseminations of Po-Py-Sph-Ga (minor Cpy)	Indicated resources: 632,814 t at 2.14% Pb and 3.54% Zn	Sulphide-bearing horizons in siliceous limestone are lensoid, varying from 1 mm to 6 m in thickness, the longest being 700 m in length.
Mastodon	082M 005	5677296 / 421781	SHMS / Irish, MVT	Past-producer	Badshot Fm	Marble / limestone	Tabular or lenticular pods and veins of Ga-Sph-Cpy	Production: 28, 975 t at 0.5% Pb, 9.5% Zn, 6.22 g/t Ag	Tabular or lenticular pods and veins associated with faults/shears and as replacement of limestone.
J & L	082M 003	5682240 / 421760	SHMS / Irish, SEDEX, Veins	Developed prospect	Hamill Gr	Limestone and quartz-sericite schist	Stratiform and conformable lenses and laminae of Py-Asp-Sph-Ga (minor Cpy, Po, Te, Su)	Inferred and indicated reserves: 4.77 Mt at 7.2 g/t Au, 72 g/t Ag, 4.3% Zn, 2.7% Pb	On surface, the Main zone is 1.85 km and over 800 m underground, and has an average true width of 1.6 m. The North zone which forms 4 parallel subzones, has been traced for 1.54 km and is possibly an extension of the Main zone.

Abbreviations: Asp = Arsenopyrite, Cal = calcite, Cpy = chalcopyrite, Fg = fine grained, Fm = formation, Ga = galena, Mag = magnetite, MVT = Mississippi Valley–type, Po = pyrrhotite, Py = pyrite, Qz = quartz, SHMS = sediment-hosted massive sulphides, Sph = sphalerite, Su = sulphosalts, Te = tetrahedrite.

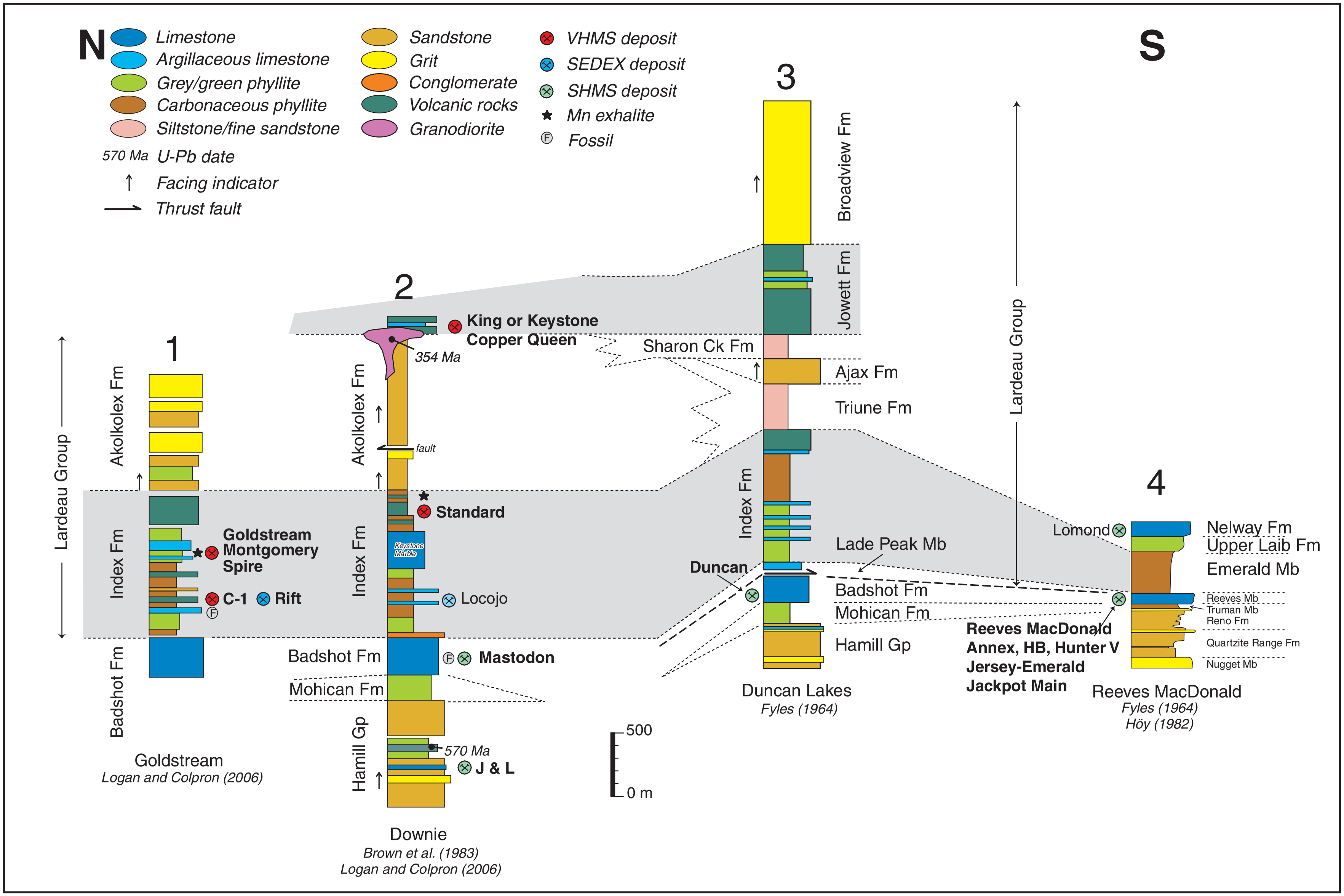

Figure 2. Stratigraphic sections of the Lower Paleozoic rocks in the Kootenay Arc from the Goldstream deposit area in the northern part of the Arc to the Reeves MacDonald deposit area in the southern part of the Arc. The shaded grey intervals correspond to the units correlated with the greatest confidence. General location of the sections is shown in Figure 1. Abbreviations: Fm = formation, Gp = group, Mb = member, SEDEX = Sedimentary exhalitive, SHMS = Sediment-hosted massive sulphide, VHMS = volcanic-hosted massive sulphide. Modified from Logan and Colpron (2006).

Salmo camp

The Salmo camp, or the Mine Belt of Fyles and Hewlett (1959), comprises the Reeves MacDonald, Jersey, and HB mines. Production from these deposits is listed in Table 1. They are hosted in fine-grained, poorly layered or massive dolomite of the Reeves member, which is texturally different from the barren, generally medium-grained, well banded grey-and-white or black-and-white limestone of the Reeves member. The mineralized dolomite is dark grey, poorly layered, and mottled with black flecks, wisps, and bands outlined by concentration of carbon (Fyles, 1970). This dolomite generally hosts the sulphide deposits.

The deposits, their enveloping dolomite and the limestone host rock are folded. They lie within secondary isoclinal folds along the limbs of anticlinal structures. They are stratiform, tabular, and lenticular disseminations of pyrite, sphalerite, and galena in dolomitized zones. Brecciated zones are common within the more massive sulphide mineralization. They consist of limestone and dolomite fragments cemented by sulphide minerals (Fyles and Hewlett, 1959; Legun, 2000).

The dolomitization was controlled by the Reeves syncline and that sulphide mineralization followed the same structure in the dolomite (Höy and Brown, 2000). The upper portions of several deposits are deeply oxidized and consist of extensive zinc-enriched iron oxide gossans, which overlie the sulphide deposits.

Duncan camp

The Duncan camp consists of several complexly deformed and faulted sulphide bodies, which occur in a thick section of dolomite or silicified carbonate rocks of the Badshot Formation. Höy (1982) interpreted the Badshot carbonate rocks in this area as an "extensively brecciated and locally dolomitized, bank margin facies developed on a shoal complex". The dolomite is either massive or it displays the same textures as dolomitic envelopes enclosing the sulphide deposits in the Salmo camp.

About 20 mineralized zones occur on the hinge of a phase-two fold, which is on the east limb of the phase-one Duncan anticline (Höy, 1982). None of the deposits has been mined; however, one of the mineralized zones has reserves of 9 Mt grading 2.7% Pb and 2.9% Zn (Muraro, 1962).

Mineralization consists mainly of fine-grained pyrite and subordinate sphalerite, galena, and pyrrhotite concentrated in layers of the dolomite and silicified carbonate rocks. The sulphide bodies are vertical lenses and sheets of sulphide minerals with generally well-defined, but locally gradational, margins. The structural orientation of the sulphide bodies is essentially parallel to that of the enclosing formations, i.e., the largest dimension is parallel to the strike and the intermediate dimension is parallel to the dip (Fyles, 1964).

ORIGIN OF THE KOOTENAY DEPOSITS AND POTENTIAL FOR IRISH-TYPE DEPOSITS

The origin of the deposits is enigmatic. Fyles and Hewlett (1959) interpreted the deposits as replacement zones controlled by phase-two folds and locally by faults and breccia zones associated with them. Sangster (1970) and Addie (1970) believed these deposits are syngenetic, formed by sulphide accumulation in small basins within a deep-water carbonate platform. Muraro (1962) suggested that these deposits formed by pre-metamorphic, pre-tectonic hydrothermal replacement of the host rock controlled by stratigraphy. Höy (1982) suggested a syngenetic-diagenetic origin, with sulphide minerals accumulating simultaneously with shallow-water carbonate rocks, and local accumulation of sulphide minerals in cavities or breccia zones of the lithified Reeves or Badshot carbonate rocks.

All of the authors agree that the genesis of these deposits is difficult to ascertain because of the intense deformation that has modified most of the original features. Preliminary investigation of the Salmo and Duncan deposits by the author of this report suggests that these deposits share many geological characteristics with the classic Irish-type carbonate-hosted massive-sulphide deposits. Some of these characteristics are 1) stratabound nature, i.e., sulphide minerals in dolomitized or silicified carbonate rocks; 2) simple mineralogy, i.e., sphalerite, galena, and iron oxides; 3) occurrence along or immediately adjacent to faults that may have formed conduits for upward-migrating hydrothermal fluids; 4) layered appearance of the sulphide minerals; and 5) a range of complex textures ranging from replacement of host carbonate rocks by sulphide minerals to local open-space fillings.

FUTURE WORK

The objectives of the 2007 and 2008 fieldwork seasons will be to 1) visit and sample the main carbonate-hosted Zn-Pb deposits of the Kootenay Arc; 2) map selected mineral occurrences; 3) compare the observed mineralization and host rocks to those reported in the published British Columbia Geological Survey's reports, maps, and assessment files and the Geological Survey of Canada's maps and geological reports; 4) select non-mineralized and mineralized carbonate and sulphide samples for geochemical and isotopic analyses (i.e., O, C, Sr, S, Pb, Sm, Nd); and 5) select sulphide samples for geochronological analyses by Re-Os method, which may provide timing on the mineralizing event(s).

The results will lead to the development of vectors and key exploration criteria that identify and refine favourable lithologies and/or stratigraphic units for base-metal carbonate-hosted sulphide deposits in the Kootenay Arc, and to improve the deposit models for these deposits.

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