THE IDAHO COBALT BELT

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The Idaho cobalt belt (ICB) is a northwest-trending belt of cobalt (Co) ± copper (Cu)-bearing mineral deposits and prospects in the eastern Salmon River Mountains of east-central Idaho, U.S.A. (Fig. 1).The Blackbird Co-Cu deposit is near the center of the ICB, where it is over 10 km wide. From the Blackbird area, the ICB extends at least 25 km to the southeast and northwest.

Ore zones and prospects of the ICB are hosted in Mesoproterozoic metasedimentary strata of the Lemhi sub-basin of the Belt-Purcell intracratonic basin. Most are within or near the banded siltite unit of the Apple Creek Formation, which consists of about 2 km of interlayered gray siltite and argillite within a 14-km-thick section of predominantly gray fine-grained siliciclastic strata (Evans and Green, 2003). Metamorphic grades increase northwestward along the ICB, from greenschist facies at its southeast end, to amphibolite facies ± garnet ± chloritoid in its central part, to upper amphibolite-facies± sillimanite at its northwest end (Nold, 1990).

Iron Creek Prospects

The Iron Creek prospects are at the southeast end of the ICB (Fig. 1), where the upper part of the coarse siltite unit of the Apple Creek Formation hosts several semi-concordant zones of mineralized rocks. Host strata and ore zones generally strike west-northwest and dip steeply north-northeast. The coarse siltite unit consists here of biotitic siltite (after muddy siltstone) with thin laminae of biotite phyllite (after mudstone). In mineralized rocks, biotite generally is altered to chlorite. Only two mineralized zones have been tested by drilling—the lower Jackass magnetite-pyrite zone, and the upper No-Name chalcopyrite zone.

The Jackass magnetite-pyrite zone is south of and down section from the No-Name zone. It contains abundant magnetite and chlorite + pyrite ± minor chalcopyrite. Magnetite veinlets with unmatching walls coalesce to form semi-massive to massive magnetite in chloritized host rocks. Some massive magnetite is brecciated and re-cemented by finer-grained magnetite. Fine to coarsely crystalline pyrite is disseminated in magnetite and in chloritized host rocks. The fine-grained pyrite is disseminated to semi-massive. It is concentrated in bands that parallel foliation in breccia containing aligned lenticular clasts of siltite in a chlorite-rich matrix. This probably indicates that brecciation and shearing of breccia preceded alteration to chlorite and deposition of magnetite and fine-grained pyrite. Coarsely crystalline pyrite is disseminated in a matrix of fine-grained pyrite, which it appears to have replaced. The coarse pyrite contains Co as a trace element.

Minor arsenopyrite and skutterudite were identified in fragments of vein quartz, found in colluvium between the No-Name and Jackass zones (Greg Hahn, unpublished report, 1984).

The No-Name chalcopyrite zone is north of and up-section from the Jackass zone. It has a strike length of about 1.2 km, and is about 15 m thick. It has average grades of about 1.8 wt. percent Cu and 0.03 wt. percent Co.

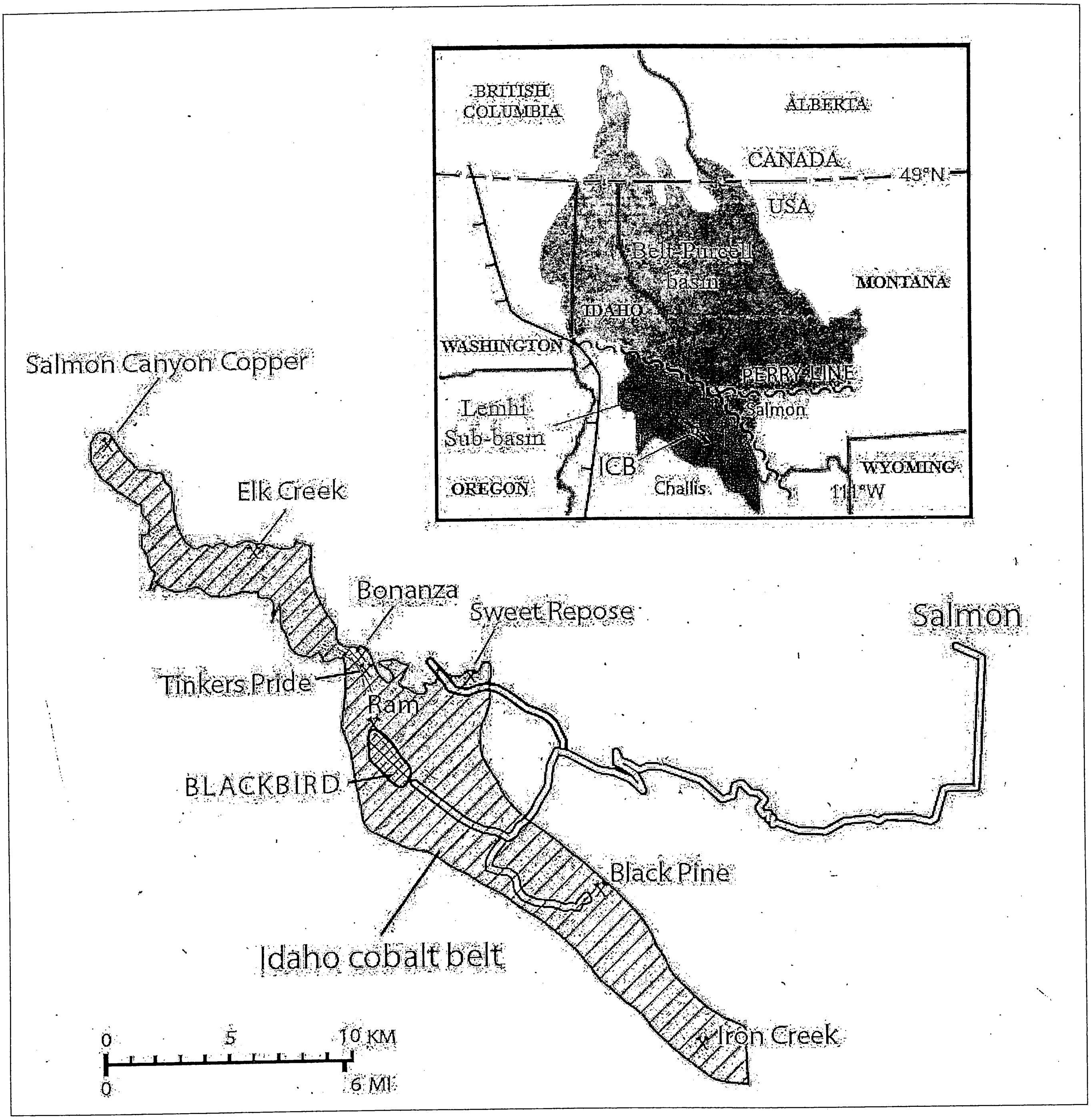

Figure 1. Small-scale regional map (inset) shows the location of the Idaho cobalt belt in relation to the Belt-Purcell basin and the Lemhi sub-basin. Larger-scale map shows the Idaho cobalt belt and locations of selected Cu-Co deposits and prospects. For more geologic context, see figs. 1, 2, and 3 of the field trip to the Idaho cobalt belt and the Beartrack gold mine (Bookstrom et al., this volume).

It has been tested by drilling to a maximum depth of 365 m. (Greg Hahn, unpublished data, 1984).

A polished slab of folded, sheared, chloritized, and mineralized ore from the No-Name zone contains anastomosing replacement veinlets of late chalcopyrite (with sharp un-matching, flame-like boundaries) ± remnants of earlier coarse-grained cobaltian pyrite. The host rock of these veinlets is interlaminated siltite and chlorite phyllite, in which phyllitic layers are folded into tight, intrastratal folds. Thicker siltite layers are bent and broken, rather than tightly folded, which indicates that they were lithified before they were bent and broken. Chalcopyrite-pyrite veinlets also cut earlier quartz veinlets that are folded and stretched into boudins. The vergence of folds is consistent in phyllite laminae, siltite layers, and quartz veinlets. Therefore, lithification, shear folding, breakage of siltite beds, and quartz veining must have preceded introduction of pyrite and chalcopyrite.

According to Nash (1989) ore minerals in the Iron Creek prospects are concentrated in zones of intrastratal folds and disrupted bedding. This only shows, however, that mineralization followed soft-sediment folding after an unknown span of time. Although intrastratal folds and disrupted bedding are common in the coarse siltite and banded siltite units, such features are only mineralized locally, and where they are mineralized, other beds and later fractures also are mineralized. Furthermore, chalcopyrite veins and veinlets are preferentially oriented parallel to foliation in chloritic phyllite. Inasmuch as biotite phyllite is characteristic of unaltered country rocks, the chlorite in ore zones probably replaced biotite. Thus, biotite-grade metamorphism probably preceded chloritization and mineralization of the Iron Creek ore zones.

Black Pine Deposit

The Black Pine deposit is about halfway between the Iron Creek prospects and the Blackbird area (Fig. 1). It is hosted in interlayered siltite and chloritized biotite phyllite of the banded siltite unit of the Apple Creek Formation. According to George King (written commun., 2013), the Black Pine area contains at least 12 stacked, semi-concordant zones of mineralized strata. Two ore zones are estimated to contain a total of about 225 kt, grading about 4.2 wt. percent Cu, 0.013wt. percent Co, and about 1 ppm Au. Although these ore zones are semi-concordant with host strata, a myriad of minor post-ore faults render the Black Pine ore zones somewhat discontinuous (See Fig. 4 of the ICB Field Guide by Bookstrom et al., this volume).

In the Black Pine copper zone, chalcopyrite, pyrite, and minor glaucodot [(Co,Fe)AsS] occur with quartz and siderite in semi-concordant lodes of disseminated to semi-massive ore and gangue minerals. According to Nisbet et al. (1994) such lodes range from 7 cm to 1.7 m thick. Discordant veins cut rocks that were lithified before they were fractured and mineralized. Mineral assemblages of discordant veins in the Black Pine area are similar to those in lodes and concordant veins. Nold (1990) described microscopic blebs of pyrrhotite, sphalerite, and magnetite in Black Pine pyrite.

Glaucodot is the dominant ore mineral in the cobalt zone, which is upsection from the copper zone. One trench exposes fine-grained glaucodot, disseminated in a breccia with a chlorite-rich matrix. This indicates that epigenetic introduction of glaucodot followed lithification, *and accompanied* or followed brecciation and chloritization. A small flotation mill on the north bank of Copper Creek recovered copper from pilot-scale mining of the copper zone. The mill has been removed, and a small accumulation of tailings in Copper Creek has been remediated.

Blackbird Deposit

The Blackbird mine area is mostly in the valley of Meadow Creek, which is a tributary to Blackbird Creek. However, the mine area also extends into the drainage basins of Bucktail, Little Deer, and Big Deer creeks. These drainage basins are tributary to Panther Creek and the Salmon River. The Blackbird deposit includes at least 12 ore zones and many prospects of several different types and combinations of types. Early types of ore are stratabound, deformed, metamorphosed, and recrystallized. By contrast, later types of ore are relatively undeformed and unmetamorphosed.

Blackbird-type cobaltite-biotite ± tourmaline ore is hosted in biotite-rich layers of the banded siltite unit. Sunshine-type cobaltite-quartz-chlorite ± tourmaline ore is hosted in quartz-rich layers of the banded siltite unit. Such biotite- and quartz-rich ore zones contain disseminated to semi-massive cobaltite lodes. These ore zones are semi-stratabound, and they appear to have been folded, sheared, and metamorphosed along with their host strata. Late iron- and copper-bearing sulfides commonly cut, rim, and partially replace early cobaltite in cobaltite-biotite and cobaltite-quartz-chlorite ore zones.

Some mafic dikes cut early cobaltite-biotite ore, but are cut by some polymetallic quartz veins containing abundant chalcopyrite. Such dikes have not yielded zircon for U-Pb dating, but they have geochemical characteristics typical of within-plate alkaline basalts. They show no depletion of Nb and Ta relative to La (characteristic of arc magmatism), and they resemble mafic rocks of a bimodal suite of gabbroic and granitic intrusions in the Salmon River Mountains. Such intrusions have been dated as Mesoproterozoic in age (1370 ± 10 Ma) by Evans and Zartman (1990), Doughty and Chamberlain (1996), and Aleinikoff et al. (2012).

Tourmaline-matrix breccias, polymetallic quartz veins, and late Dandy sulfide-matrix breccias generally are discordant. Most tourmaline-matrix breccias are south of the Blackbird mine area, where they cut host rocks of the banded siltite unit and the lower part of the Gunsight Formation. A dike-like body of tourmaline-matrix breccia also appears to cut cobaltite-biotite ore in the south Idaho ore zone.

Polymetallic quartz-siderite veins, containing abundant chalcopyrite ± pyrrhotite, pyrite, and minor fine-grained glaucodot cut cobaltite-biotite ore. A swarm of such veins is localized along axial-plane cleavage in the hinge zone of the Idaho syncline. Some polymetallic quartz veins cut some mafic dikes, as indicated on geologic maps of the Uncle Sam mine workings by Vhay (1948).

Dike-like bodies of sulfide-matrix breccia are concentrated in the Dandy zone, which is northwest of the Uncle Sam zone. Dandy breccia dikes strike north and dip steeply, sub-parallel to pervasive axial-plane cleavage of the Idaho syncline and related minor folds. Late Dandy breccia dikes cut early cobaltite-biotite ore zones, which dip 55 ± 10° northeast (along the northwest-striking limb of the Idaho syncline). Dandy breccia contains clasts of host rocks, vein quartz, and cobaltite-biotite ore in an undeformed matrix of pyrrhotite, pyrite, marcasite, and chalcopyrite ± traces of very fine grained, disseminated glaucodot.

Composite ores, in which early cobaltite is cut, rimmed, and partly replaced by iron- and copper-bearing sulfides, are common in the central part of the Blackbird mine area. Abundances of late, iron- and copper-bearing sulfides decrease with increasing distance from the Dandy zone of sulfide-matrix breccias. Undeformed pods and tabular veins of quartz ± siderite (or tourmaline or biotite) ± chalcopyrite (± minor glaucodot ± minor magnetite) are widely scattered in and around the Blackbird mine area.

Total past production from the Blackbird mine area was about 2.4 Mt of ore, containing 19 kt of Co, 51 kt of Cu and 5.4 kt of Au. Known resources are estimated to be 14 Mt of ore with tonnage-weighted average grades of 0.48 wt. percent of Co and 0.61 wt. percent of Cu (Douglas Causey, written commun., 2011). This is a minimum estimate, because most of the ore zones are open down-dip below about the 6500-ft elevation (about 350 ft below the 6850 Level).

Although Blackbird production and resources of copper are larger than those of cobalt, the unit value of cobalt generally is about 4 to 10 times that of copper. Therefore, cobalt is the most valuable co-commodity in the composite Blackbird deposit. Gold was recovered from polymetallic veins, cut by gold-bearing veinlets in the Uncle Sam zone. However, gold was not recovered from ore mined by Calera Mining Company. Remedial actions to remove or stabilize mine and mill wastes have been underway since 1995, and, except for continuing operation of the water-treatment system, are nearing completion.

The Ram ore zone was discovered in 1995, and was explored by drilling to provide the basis for estimation of tonnage and grade by and preparation of a feasibility report (Formation Metals, Inc., 2007). In 2008, the U.S. Forest Service issued a permit to Formation Metals, Inc. to allow development and production, and in 2009, that company was awarded access to haulage roads across patented claims of the Blackbird mine area. Preliminary development work, done in 2010-2012, has now been put on hold, pending suitable metal prices and financing (Formation Metals, Inc., 2007 and 2009; Associated Press, 2013).

Tinkers Pride and Bonanza Copper Prospects

The Tinkers Pride and Bonanza Copper prospects are between 4 and 5 km north-northwest of Blackbird (Fig. 1), on the north side of Big Deer Creek. They are on the western, upthrown side of a west-dipping reverse-to-thrust fault that bounds the west side of the Blackbird structural block. These prospects are hosted in interlayered garnet-bearing biotite schist and quartzite, interpreted as metamorphosed banded siltite. Concordant mineralized zones contain disseminated chalcopyrite and glaucodot. Discordant quartz veins and pods ± tourmaline ± malachite (after chalcopyrite) ± erythrite (after glaucodot) also are sparsely distributed in this area. Maps and reports by Shenon and Full on the geology and prospects of the Big-Deer-Creek area are available in Frank (2010, DMEA docket 3739).

Elk Creek Prospect and Salmon Canyon Copper Mine

The Salmon Canyon Copper mine is hosted in banded gneiss at the northwest end of the ICB (Fig. 1). The Elk Creek prospect is a Cu-Co geochemical anomaly in biotitic schist. It is about halfway between the Salmon Canyon Copper mine and the Bonanza prospect.

At the Salmon Canyon copper mine, banded gneiss (containing garnet ± sillimanite porphyroblasts in alternating biotite-rich and quartz-rich layers), hosts disseminated ore minerals. The banded gneiss looks like highly metamorphosed banded siltite. Mineralized banded gneiss contains disseminated glaucodot, arsenopyrite, pyrite, pyrrhotite, and chalcopyrite. Some euhedral arsenopyrite porphyroblasts appear to have glaucodot cores. Nold (1990) photographed and described ball texture with rounded garnet, rolled in a matrix of relatively ductile pyrite and chalcopyrite. He interpreted this texture to indicate that relatively ductile ore minerals became wrapped around less ductile garnets during deformation that continued after mineralization and garnet growth.

We have no production records from the Salmon Canyon Copper mine, but portals of two adits, their mine-waste dumps, and the foundation of a small mill remain. A small stockpile of ore is near the Salmon River road, but we know of no mill tailings, so the mill may not have operated.

Isotopic Geochronology

Aleinikoff et al. (2012) reported an age determination of 1370 ± 4 Ma on xenotime that is rimmed and replaced by cobaltite in a sample of cobaltite-biotite ore from the Merle zone. This indicates that cobaltite in early cobaltite-biotite ore was deposited after about1370 Ma, and is therefore not syngenetic with respect to sediments of the banded siltite. Aleinikoff et al. (2012) reported a maximum age of 1409 ± 10 Ma for banded siltite, based on U-Pb zircon ages of the youngest set of detrital zircon grains recovered from a sample of siltite, representing the upper part of the banded siltite unit in the Blackbird area.

Zirakparvar (2007, and written commun., 2011) reported age determinations of 151 ± 32 Ma, 113 ± 8 Ma and 94 ± 8 Ma on garnets in samples from the Blacktail pit, the Salmon Canyon Copper mine, and Tinkers Pride area. Garnets commonly contain inclusions of cobaltite in early cobaltite-biotite and cobaltite-quartzite-chlorite ore zones. This indicates that such ores must have formed before about 113 Ma. Nevertheless, Aleinikoff et al. (2012) also described cobaltite rims on grains of monazite, dated at 110 to 93 Ma. In addition, Panneerselvam et al. (2012) found extremely radiogenic lead in minerals of polymetallic samples from Blackbird. They interpreted this as evidence that Blackbird polymetallic vein and replacement deposits formed after about 100 Ma. Similarly, the Sr-isotopic ratio of siderite from a late quartz-siderite-chalcopyrite vein indicates it is no older than Mesozoic (Robert Fleck, written commun., 2007). However, cobaltite in early cobaltite-biotite ore has not been analyzed for Pb isotopes, so all we know is that it is younger than xenotime, dated at 1370 ± 4 by Aleinikoff et al. (2012).

Sulfur isotopes

Johnson et al. (2012) reported that sulfur isotopic $\delta^{34}S$ values are nearly uniform at 8.0 ± 0.4 per mil in 19 samples of representative sulfide minerals from the ICB. This is very different from wide ranges of S isotopic ratios that typify volcanic-related massive-sulfide (VMS) deposits and sediment-hosted massive-sulfide (SEDEX) deposits (Johnson and others, 2012). Wide ranges of S-isotopic values also occur in sediment-hosted Cu deposits of western Montana (Aleinikoff et al., 2012). According to Johnson et al. (2012, p. 1207), sulfur isotopic values of ICB ore minerals "show characteristics of deposit types that form in deeper environments and could be related to metamorphic or magmatic processes, although the isotopic evidence for magmatic components is relatively weak."

Fluid inclusions

Landis and Hofstra (2012; p. 1189) reported at least two populations of fluid inclusions in gangue quartz from Blackbird ore zones—one hypersaline, and the other dilute, and probably secondary. Based on Na, Cl, and Br ratios of hypersaline brine trapped in fluid inclusions in gangue quartz from ore zones, they concluded that the brine is a mixture of evaporated seawater and magmatic fluid, trapped at about 279° to 347°C. They also reported that trapped volatiles have ^3He derived from a mantle source, and that "two extracts from gangue quartz have estimated $^{40}K/^{40}Ar$ that permit a Precambrian age."

History of Classification and Metallogenic Interpretation

Umpleby (1913) suggested that the Blackbird Co-Cu deposits are epigenetic hydrothermal deposits, related to mafic dikes of probable Tertiary age. Anderson (1947; Vhay, 1948) interpreted the Blackbird deposits as epigenetic deposits, formed by hydrothermal replacement along shear zones in metasedimentary biotite schist and quartzite. Vhay (1948) also suggested that the Blackbird deposit is genetically related to a nearby granitoid pluton, which he regarded as part of the Cretaceous Idaho batholith. Evans and Zartman (1990), however, reported a Mesoproterozoic U-Pb zircon age of 1370 ± 10 Ma for megacrystic monzogranite of that pluton.

Hughes (1983, 1990), Hahn and Hughes (1984), and Nash and Hahn (1989) suggested that stratabound Cu-Co deposits and prospects of the ICB are volcanic-related submarine-exhalative massive-sulfide (VMS) deposits, associated with mafic dikes and aquagene mafic tuffs. Earhart (1986) suggested that the Blackbird Co-Cu deposit is similar to mafic-volcanic-related Besshi-type VMS deposits. Lydon (2007) also classified Blackbird as a Besshi-type VMS deposit.

Nold (1990) suggested that deposits of the ICB are metamorphosed sediment-hosted Cu-Co deposits, similar to Co-bearing Cu deposits of the Zambian copper belt. Copper in such deposits is thought to be mobilized by oxidation of Cu-bearing minerals in redbeds, and transported in oxidized hydrothermal fluids to sites of reductive deposition by reaction with carbonaceous host rocks, or sour gas (CH_4 + H_2S, as in Revett-hosted Cu-Ag deposits, according to Aleinikoff et al., 2012).

Kissin (1993) suggested that deposits of the Idaho cobalt belt resemble five-element vein (Ag-Ni-Co-As-Bi) deposits. Examples of five-element deposits include veins of the Cobalt-Gowganda district in Ontario, and metamorphosed replacement deposits along sulfidic *fahlband* layers in the Modum district of southern Norway (Gammon, 1966). In contrast, Bending and Scales (2001) suggested similarities between deposits of the ICB and sedimentary-exhalative massive sulfide (SEDEX) deposits, such as the Sullivan Zn-Pb-Cu deposit, and Mount Isa Zn-Pb deposits (with a stratabound metamorphic Cu zone?). According to MacIntyre (1991, p. 56), SEDEX deposits form by "precipitation of sulfide and sulfate minerals from metalliferous brines that were exhaled along active submarine faults. Metals and fluids are most likely derived from the sedimentary pile either by normal dewatering during basinal subsidence or by hydrothermal leaching during periods of elevated heat flow and convective circulation of seawater through the sedimentary pile."

The stratabound Sheep Creek Cu-Co deposit, in lower-Belt strata of the Helena embayment of the Belt-Purcell basin, also has been informally regarded as a possible analogue for Cu-Co deposits of the ICB. Lydon (2007) classified the Sheep Creek deposit as a SEDEX-type deposit. According to Graham et al. (2012), the Sheep Creek Cu-Co-Ag deposit is a synsedimentary to early diagenetic pyrite ± barite deposit, in which pyrite, barite and carbonate were replaced by chalcopyrite and quartz. Cobalt occurs as a trace element in pyrite at Sheep Creek (as it does in the Iron Creek prospects at the southeast end of the ICB).

Based largely on structural and textural observations, and on kinematic interpretations, Lund et al. (2011) suggested that the Blackbird deposits are of epigenetic origin and Cretaceous age. They also suggested that Cu and Co could have been leached from pale pinkish quartzite of the Swauger Formation, and redeposited to form Cu- and Co-bearing deposits and prospects of the ICB. This would make the Blackbird deposits an inverted analogue of sediment-hosted Cu ± Ag ± Co deposits, with oxidized pinkish quartzites of the Swauger Formation as source rocks, upsection from grayish host rocks of the banded siltite unit. However, the buoyancy of hydrothermal fluids and the tight range of positive S isotopic values for ore minerals of the ICB do not support such an analogy with sediment-hosted Cu deposits.

John Slack (2012) suggested that Fe-Co-Cu-Au-Bi-Y-REE deposits of the Idaho cobalt belt represent a sulfide-facies variant of iron-oxide copper-gold (IOCG) systems. On the basis of local abundances of Y, REEs, and Be in some Blackbird ores, he suggested a predominantly felsic magmatic source (represented by a nearby granite pluton, dated at 1.37 Ga) for these elements and associated metals. However, he suggested a sedimentary source of boron in hydrothermal fluid, based on boron-isotope data for ore-related tourmaline (as reported by Trumbull and others, 2011).

Evaluation of Alternative Classifications and Metallogenic Hypotheses

Like VMS and SEDEX deposits, the ICB contains stratabound and semi-concordant zones of ore and mineralized strata. This has served as a reliable guide to exploration for extensions of mineralized zones along the strikes and dips of the mineralized zones and their host strata. However, VMS and SEDEX deposits are syngenetic, and they have wide-ranging S-isotopic values. By contrast, deposits of the ICB yield structural, textural, and isotopic evidence that they formed well after lithification and fracturing of their host rocks, and are therefore epigenetic rather than syngenetic in origin. Cobaltite in early cobaltite-biotite ore at Blackbird is younger than xenotime (dated at 1370 Ma), which it rims and replaces. Host rocks of the banded siltite unit, dated at 1409 ± 10 Ma by Aleinikoff et al. (2012), were lithified, folded, and metamorphosed to biotite grade before they were intruded by megacrystic monzogranite at about 1370 Ma (Evans, 1981, 1986). Thus, xenotime in stratabound cobaltite-biotite ore is about 40 million years younger than its host rocks, and cobaltite is younger than that. Therefore, the Blackbird deposit is not a syngenetic VMS or SEDEX deposit. Furthermore S isotopic values of ICB ore minerals are very dissimilar from those of VMS and SEDEX deposits.

Like sediment-hosted Cu deposits, the ICB contains ore zones that are stratabound but epigenetic. However, the generally accepted genetic model for sediment-hosted Cu deposits involves leaching of Cu from oxidized red beds, followed by reductive deposition by interaction with black shale or sour gas. Ore minerals of the ICB are at least 4 km downsection from pale pink quartzite of the Swauger Formation, and it is unlikely that buoyant hydrothermal fluid would transport metals downsection to sites of deposition in the banded siltite and coarse siltite units of the Apple Creek Formation, which are underlain by a very thick section of predominantly gray strata. Furthermore, S isotopic values of ICB ore minerals are very dissimilar from those of sediment-hosted Cu-Ag deposits in the Revett Formation of the Belt Supergroup in western Montana.

Like IOCG deposits, which are enriched in Fe and Cu ± Co ± Au ± REE, the deposits and prospects of the ICB are epigenetic, and they are enriched in Fe and Cu + Co + Au + REE. However, the Blackbird deposit also is enriched in As and Bi and lacks abundant iron-oxide minerals and sodic-calcic alteration minerals that are characteristic of most IOCG systems. Instead, biotite is the characteristic alteration mineral at Blackbird, where iron occurs mostly in biotite and iron-bearing sulfide minerals. As suggested by Landis and Hofstra (2012, p. 1189), the hypersaline basinal brine involved in transport and deposition of ore minerals in the ICB was more reduced than those involved in formation of IOCG deposits, so that "iron was fixed in biotite and tourmaline instead of iron oxides."

Like 5-element (Ag-Ni-Co-As-Bi) vein and replacement deposits, ICB deposits and prospects are epigenetic, and they are enriched in Co, As, and Bi. However, the Blackbird deposit contained only minor Ag and Ni. Anderson (1947, p. 24) reported native silver in association with quartz and copper minerals, but he noted that "the silver content of the ore is low, not over 0.5 ounce per ton." He also reported that Ni occurs with Co, "but the proportion of nickel is so low (0.03 per cent) as to discourage…recovery." Slack (2012, table 1) listed sparse gersdorffite(?) and millerite as Ni-bearing minerals found at Blackbird.

ICB ores are enriched in Cu and Au, rather than Ag and Ni. That is more typical of IOCG-type deposits than 5-element deposits. Nevertheless, Co deposits of the Modum district in southern Norway were classified as 5-element replacement deposits by Kissin (1993), and those deposits seem very similar to the Blackbird Co-Cu deposit. In the Modum district, cobaltite and skutterudite are hosted in sulfide-bearing metasedimentary *fahlband* layers, which Gammon (1966) interpreted as metamorphosed organic-rich and sulfidic beds. Biotite-rich layers of the Blackbird zone are not sulfidic *fahlbands*, but they may have served a similar function as chemically favorable sites for deposition of cobaltite (and other ore minerals).

Pre-cobaltite xenotime (1370 ± 4 Ma at Blackbird) and marialite in metasedimentary host rocks and peripheral to a nearby pluton of A-type megacrystic monzogranite (dated at 1370 ± 10 Ma) probably resulted from contact metamorphism related to emplacement, crystallization and cooling of that pluton. However, whether cobaltite was first deposited at Blackbird shortly after deposition of Mesoproterozoic xenotime, dated at 1370 ± 4 Ma, or shortly before garnet formation began in Early Cretaceous time, is not known. The paragenetic sequence of Blackbird ore minerals may have resulted from juxtaposition of ore minerals deposited during separate episodes of Mesoproterozoic and Cretaceous mineralization, as suggested by Slack (2012). However, all but early xenotime could have resulted from a single episode with multiple stages of mineralization during Cretaceous time, as suggested by Lund et al. (2012).

The close spatial juxtaposition of multiple sequential ore-mineral assemblages in the fairly equally spaced Iron Creek, Black Pine, Blackbird, Tinkers Pride, and Bonanza Copper areas seems most likely within a system of convective hydrothermal cells that were active during a single long episode with multiple stages. It seems less likely that products of separate episodes of Mesoproterozoic and Cretaceous mineralization would be so closely juxtaposed. It also seems unlikely that ore-minerals deposited in Mesoproterozoic time would have sulfur-isotopic characteristics identical to those produced in Cretaceous time. Nevertheless, some mafic dikes appear to cut early cobaltite-biotite ore, as shown on geologic maps of bedrock and mine workings by Vhay (1948). No Blackbird mafic dike has yielded zircon for isotopic dating, but samples from such dikes are geochemically similar to mafic rocks of a nearby bimodal suite of mafic and felsic intrusions dated 1370 ± 10 Ma by Evans and Zartman (1990) and Doughty and Chamberlain (1996). Furthermore, the Blackbird dikes have geochemical characteristics of within-plate alkaline basalt. This would not be expected in subduction-related igneous rocks of Cretaceous age. If the Blackbird mafic dikes are the same age as mafic intrusions of the bimodal intrusive suite, dated at 1370 ± 10 Ma, and early cobaltite was deposited before being cut by such dikes, then early cobaltite must have been deposited soon after xenotime, dated at 1370 ± 4 Ma by Aleinikoff et al. (2012).

Stratabound and more-or-less conformable cobaltite-biotite and cobalt-quartz-chlorite ore zones and their host rocks share structural and textural fabrics, which indicate that both underwent Cretaceous dynamothermal metamorphism. Porphyroblasts of garnet and chloritoid commonly contain cobaltite inclusions, indicating that early cobaltite was deposited before Cretaceous garnet growth, which probably peaked at about 113 ± 8 Ma. Crenulation of cleavage probably developed during late stages of garnet growth, as indicated by a crenulated inclusion in a rolled garnet from the Tinkers Pride area, dated at 94 ± 8 Ma. The base of the garnet zone generally follows the shape of the Idaho syncline. This seems to indicate that the garnet zone was folded along with its host strata. Such folding must have occurred before the garnet zone was cut by the reverse and thrust faults that bound the Blackbird structural block. Discordant polymetallic quartz veins and Dandy sulfide-matrix breccia dikes occupy fractures parallel to axial-plane cleavage and appear much less deformed and metamorphosed than early stratabound ore zones.

Clues from successive ore and gangue minerals, fluid inclusions, and sulfur isotopes indicate that ore and gangue minerals of the ICB were derived from temporally changing combinations of hypersaline basinal brine + metasedimentary sources of boron and arsenic (and possibly copper and cobalt) + gaseous emanations from sources in the mantle or deep Precambrian basement + deep metamorphic ± igneous sources of sulfide ± metals.

In the central part of the Blackbird area, metamorphic brown biotite of the Blackbird zone was sheared and altered to greenish hydrothermal biotite ± tourmaline, some of which was preferentially replaced by cobaltite. Peripheral to that, early cobaltite also was deposited in quartz-rich layers containing biotitic interlayers and streaks. Cobaltite preferentially replaced biotite in such quartz-rich layers, but chlorite later replaced most biotite and some garnets during retrograde metamorphism.

Quartz-tourmaline veins of the Bonanza Copper area (north of Blackbird) resemble tourmaline breccias of the Haynes-Stellite and West-Fork areas (south of Blackbird). Late polymetallic veins and breccias of the Blackbird area are relatively undeformed and unmetamorphosed. They probably formed during retrograde metamorphism and hydrothermal activity that followed peak metamorphism.

Mineral assemblages in the Black Pine area resemble those of late polymetallic veins in the Blackbird area, but they are in stratabound zones as well as in discordant veins. The assemblage of disseminated glaucodot, arsenopyrite, and chalcopyrite in the Salmon Canyon Copper area is similar to mineral assemblages of the Black Pine area, but the Salmon Canyon ore is much more highly deformed and metamorphosed. Magnetite and chalcopyrite in mineralized zones of the Iron Creek area resemble mineral assemblages of late quartz veins ± magnetite ± pyrite ± chalcopyrite in outer to peripheral parts of the Blackbird area.

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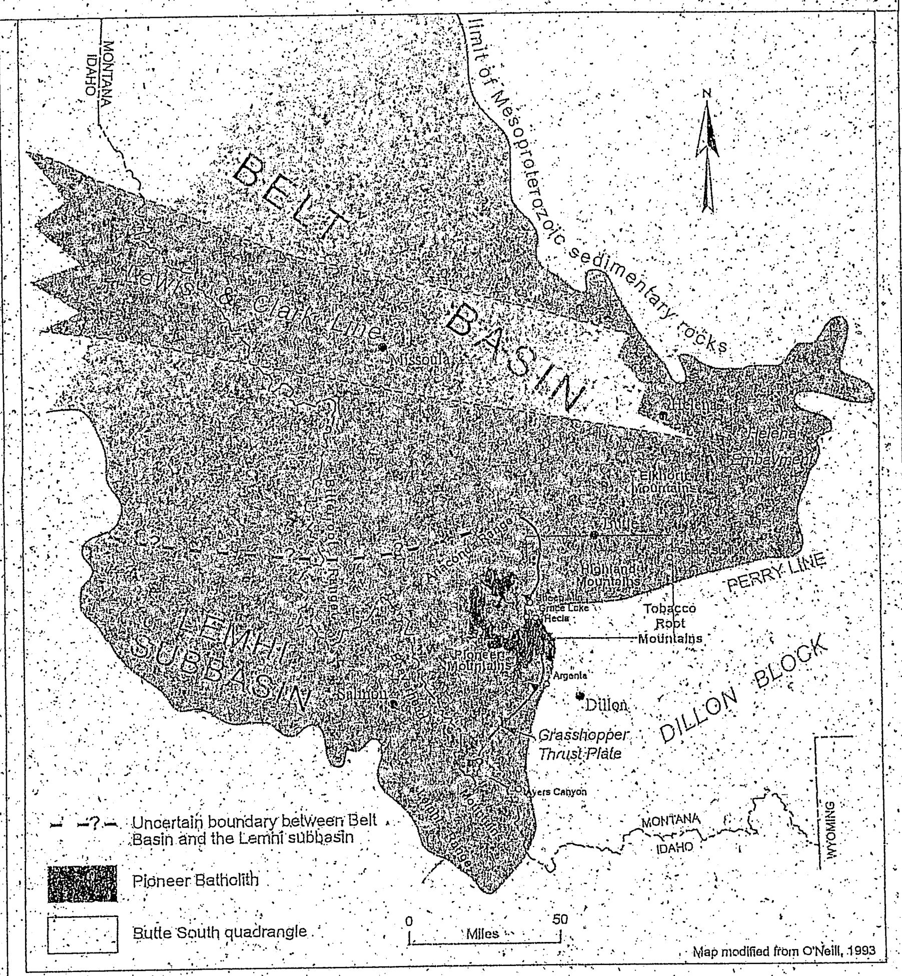

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