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ANALYTICAL RESULTS AND COMPARATIVE OVERVIEW OF GEOCHEMICAL STUDIES CONDUCTED AT THE HOLDEN MINE, SPRING 1996

By

J.E. Kilburn* and S.J. Sutley*

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*U.S.G.S., MS 973, Denver Federal Center, Denver, CO, 80225

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INTRODUCTION

Inactive or abandoned mine sites associated with volcanogenic massive sulfide (VMS) deposits have yielded some of the most acidic, metalliferous mine drainage on record, and are of particular environmental concern. The U. S. Geological Survey (USGS), in cooperation with the U. S. Forest Service (USFS), is currently conducting geochemical and mineralogical studies at the Holden mine, a relatively low-grade, Kuroko-type VMS deposit, in order to assess the character, origin, and scope of contaminated waters derived from this former producer of base-and precious-metal ore. Because of their pyrite- and sulfide-rich nature, massive sulfide deposits such as Holden have an unusually high acid-generating capacity. Under oxidizing conditions, water draining these deposits can react with the sulfides to form acidic, metal-rich waters that represent potentially significant sources of acid and metal-loading in the environment, jeopardizing not only local water quality but neighboring aqueous and terrestrial ecosystems as well. Moreover, Holden, like many sulfide-rich bodies, is characterized by an abundance of soluble metal salts, and their dissolution during episodes of wet weather or heavy runoff (e.g. snowmelt) is considered a major seasonal influence on the area's mine water chemistry.

In May 1996, detailed geochemical studies were carried out at Holden in order to complement previous USGS investigations (Kilburn and others, 1994; Kilburn and others 1995 a, b; Kilburn and Sutley, 1996) and evaluate the magnitude and flushing effects of heavy seasonal runoff on the chemistry of mine related effluents and nearby Railroad Creek. This report presents the analytical results, sample localities and an overview of the May 1996 investigation.

Site Description and Mining History

The Holden deposit is sheltered in a glacially modified valley located immediately east of the divide that forms the serrated crest of the northern Cascade Range of north-central Washington state. The mine and related workings border Railroad Creek, one of the larger watercourses that feeds Lake Chelan, a large landlocked fjord some 20 km east of the orebody (figure 1). Topographic relief is great in the Holden area (approximately 2,500 m) with the mine surrounded by towering peaks and hanging valleys. In some of the higher basins and cirques, small glaciers persist and mark the headwaters of Railroad Creek's major tributaries, including Copper Creek, Big Creek, and Holden Creek. The valley floor is covered by a deep overburden (mostly glacial debris and talus) that is largely hidden by thick underbrush and scattered stands of timber consisting of fir, cedar, spruce, and balsam. The climate is temperate and typified by warm dry summers and cold wet winters. Mean annual precipitation at Holden is 35 in; mostly in the form of snow. Because of its remote locale, access to the Holden site is limited to regularly scheduled boat service out of Chelan or by chartered floatplane to the Forest Service ranger station at Lucerne, a former resort community on Lake Chelan. From Lucerne, a graded dirt road negotiates the steep Railroad Creek valley to the mine.

Initial claims were staked at the Holden site in 1892. Over the next 36 years a number of individuals and syndicates held options on the deposit, although efforts to develop the claims proved ineffectual. In 1928 the Britannia Mining and Smelting Co., a subsidiary of the Howe Sound Co., acquired the property. Administration of the claims and authority to conduct further exploration was soon passed to another subsidiary, the Chelan Copper Mining Co. This was a time of rapid development , including the erection of the mill facility to process and concentrate the ore and construction of the community of Holden to accommodate the miners and their families (Youngberg and Wilson, 1952; McWilliams, 1958). In 1937 the subsidiary relationship was dissolved and the Howe Sound Co. took possession of the property and began active production in 1938. The mine discontinued operations in 1957 because of escalating production costs and a decline in the copper market. Although the ore was of a relatively low tenor (averaging roughly 1.1 percent Cu, 0.2 percent Zn, 0.2 oz/short ton Ag, and 0.06 oz/short ton Au) (Nold, 1983) over 212 million pounds of Cu, 40 million pounds of Zn, 2 million ounces of Ag, and 600 thousand ounces of Au were extracted from 10 million tons of ore. At present, the mine site consists largely of mill tailings, waste dumps, portals and shafts, a partially dismantled mill and other surface structures. However, the town of Holden, located on the north side of Railroad Creek opposite the mine complex, remains quite active and serves as a mountain retreat sponsored by the Lutheran church.

Geologic Setting

The Holden mine lies within the crystalline core of the northern Cascade Range, a region characterized by massive Mesozoic plutons and late Paleozoic or older metasedimentary and metavolcanic rocks.

Published geologic maps of the Holden (Cater and Crowder, 1967) and Lucerne (Cater and Wright, 1967) quadrangles serve as comprehensive guides to the areas geology, while studies by Cater (1982) provide a closer and more in depth look at regional plutonic compositions and relations.

The Holden orebody is interpreted as a metamorphosed, Kuroko-type, VMS deposit exhaled in a late Triassic island-arc setting (Dragovitch and Derkey, 1994). The deposit is stratabound within a series of steeply dipping, high-grade metamorphic rocks, largely consisting of calc-silicate gneisses and amphibolites. These rocks are more or less andesitic in chemical makeup, suggesting andesitic volcanics and related volcaniclastic sedimentary rocks as likely protoliths. The immediate host of the orebody is a pyritic, sericite-quartz schist sequence within the high-grade metamorphic rocks. Exposures of the ore-bearing schist, which range from 90 to 180 m in thickness, can be traced for about 5 km at the surface. The deposit is stratiform within the schist unit and displays the well developed zoning typical of VMS deposits, with a lower or original copper-rich footwall and a zinc-rich upper or original hanging wall. This primary zoning has survived the ravages of high-grade metamorphism as well as intense deformation, which has overturned the deposit, resulting in a copper-rich zone structurally above the zinc-rich zone (Nold, 1983). Principal ore and ore-related minerals found at Holden include pyrite, pyrrhotite, chalcopyrite, sphalerite, and native gold. Galena, magnetite, and molybdenite are also present but merely considered accessories. Gold is mostly linked to chalcopyrite in the structural hanging wall, whereas silver is associated with sphalerite in the structural footwall (McWilliams, 1958). Mineralization is for the most part disseminated, although massive ores are found locally in the zinc-rich zone (Nold, 1983).

Summary of Previous USGS Geochemical Investigations

The main focus of recent USGS studies at the Holden mine was to (1) characterize the behavior of a massive sulfide deposit as it experienced weathering in a temperate climate and (2) provide the Forest Service with information regarding the nature and extent of the mine's acid drainage and its aftereffects on local creeks and streams. With this emphasis, the USGS completed a reconnaissance geochemical study in and around the Holden complex in July 1994 to rapidly identify, at a relatively low cost, the probable sources and general character of waters draining the abandoned mine site (Kilburn and others, 1994; Kilburn and others, 1995 a, b). Detailed follow-up studies were undertaken the following summer

(July 1995) in order to assess the extent and further characterize the contamination earmarked by the earlier investigation (Kilburn and Sutley, 1996). In brief, these studies collectively revealed a dynamic and complex hydrogeologic regime, typified by a wide-range in mine effluent compositions. Three sources of contaminated water discharging directly into Railroad Creek were identified, including: (1) intermittent, acidic to highly acidic, Fe-dominant seeps emerging from the base of the mill tailings; (2) acidic, Cu and Zn-rich, Fe-poor seepage that surfaced immediately west of the tailings and below the abandoned mill; and (3) weakly acidic, flocculent-rich effluent that flowed from the main portal of the mine. Upon entering Railroad Creek, it appeared that the contaminated discharge was quickly assimilated by the greater volume of creek water a short distance from their point of introduction by various physical and chemical processes. In addition, limited exploration and sampling in the old mill facility revealed a point source of intense sulfide weathering and metal sulfate dissolution; a circumstance, when interpreted with other data, suggestive of a probable source of migrating acid drainage from the mill area.

A complete listing of the analytical results, sample locality maps, and descriptions of field and chemical methods employed for the 1994 and 1995 studies are given in Kilburn and others (1994) and Kilburn and Sutley (1996), respectively.

Field and Laboratory Methods

Sample media for the May 1996 investigation included mine and mine-related effluents, creek water (collected both adjacent to solid mine waste and above the Holden mine complex where exposure to mine and milling activity was considered minimal), secondary sulfate minerals, oxidized mill refuse, and hydrous metal oxide precipitates.

Water samples were collected from within, above, and below the mine workings in polypropylene bottles previously rinsed with 10% HNO_3. At each site a 60-mL sample, filtered through a 0.45 μm acetate membrane filter and acidified with concentrated HNO_3 as well as an untreated 250-mL sample were collected. On-site measurements of pH, specific conductance, and water temperature were also taken. The untreated water samples were analyzed for selected anions (SO_4^{2-}, F^-, Cl^-, and NO_3^-) by the method of Fishman and Pyen (1979) using ion chromatography. Filtered and acidified water samples were analyzed for major, minor and trace elements by an unpublished inductively coupled plasma-mass spectrometry (ICP-MS) method (A.L. Meier, written commun. 1996) and by inductively coupled plasma-atomic emission spectrometry (ICP-AES) using the procedure of Briggs (1990). The ICP-MS technique is regarded as a trace method, and is generally preferred when interpreting extremely low levels of dissolved metals and other elements in the low and sub-ppb range (e.g. rare earth elements) that may be dissolved in mine-related effluents, and is exceptional in defining the character of primitive or largely uncontaminated waters such as creeks or streams. Conversely, the ICP-AES method is considered more reliable at determining the high to extreme concentrations of Fe, Al, the base-metals and other elements that often accompany degraded effluents such as acid-mine drainage.

Two dissimilar types of precipitates were collected at the Holden site. One is comprised of metal hydroxides (mostly Al) that appear as clot-like flocculent masses in water draining the main portal (1500 level) of the mine and other areas. The second type consists of soluble secondary sulfate minerals that develop as heterogeneous efflorescences within the mill facility and around the base of the mill tailings. The flocculent material was collected from 3 sites along the portal drainage by simply transferring the substance via a plastic spoon into a 250 mL polypropylene bottle that was rinsed on site with portal discharge prior to sampling. Utilizing plastic gloves, 5 bulk sulfate samples were gathered by hand from various localities within the mill and stored in individual plastic zip-lock bags to reduce contact with ambient air and curb potential hygroscopic reactions (dehydration and/or hydration). In addition to the sulfates, intensely oxide-cemented material was collected from debris or muck piles within the mill facility. The mineralogical compositions of the precipitates and oxidized debris were determined using standard X-ray diffraction (XRD) techniques (Klug and Alexander, 1974). Packed powder samples were prepared for analysis by back loading a conventional cavity-type diffraction mount and analyzed on a Philips APD-3720 diffractometer using Cu K_α radiation, a step size of $0.03° 2\theta$, and a count time of 4 seconds.

Tables 1-3 record the analytical results for each of the hydrogeochemical samples collected during the spring 1996 field season. The mineralogy of secondary sulfate minerals identified at the Holden site in 1994, 1995, and 1996 is found in tables 4, 5, and 6, respectively. In the data tables (tables 1-3), if a specific element was analyzed for but not detected, a "less than" symbol (<) was entered in front of the lower limit of determination. On the other hand, if an element was measured above the highest reporting value, a "greater than" symbol (>) was entered in the tables in front of the upper limit of determination. Analytical interference is indicated by "int" in the data column.

RESULTS AND OVERVIEW

In order to provide a systematic reference for seep and drainage water sampled, this report occasionally relies on the pH-metal classification scheme of Ficklin and others (1992), whereby mine and natural drainage water can be quickly categorized and compared according to pH and the sum of base metals (Cu+Zn+Cd+Co+Ni+Zn) in solution (figures 3-4). In addition, water samples collected in May 1996 were analyzed by both ICP-AES and ICP-MS methods as opposed to previous USGS Holden studies, where analysis was limited to the ICP-MS procedure. In the interpretation of Holden's degraded effluents, however, ICP-AES data is preferred because of the method's ability to report higher Cu and Zn values and the intrinsic risk of isotopic interferences that often accompany ICP-MS analysis (particularly Fe and Al analysis). Nevertheless, both methods are reasonably compatible and are used in this report in a nonrigorous, comparative manner to illustrate seasonal variations in mine water chemistry (with the exception of portal water Zn/Cu ratios, where ICP-MS data is exclusively applied).

Portal Water

Effluent, comparable in volume to a small creek, emerges from the main portal (1500 level) of the mine and rapidly flows downhill nearly a quarter of a mile before issuing directly into Railroad Creek (figure 5). As anticipated, the magnitude or quantity of portal discharge was clearly greater during the 1996 spring runoff than noted in the prior USGS summer investigations. Suspended in this outflow or adhering to rocks and debris the length of the drainage is a thick, tan-white, flocculent substance (floc) previously identified chemically as amorphous Al hydroxides intermixed with lesser amounts of Fe hydroxide precipitates (Kilburn and others, 1995a,b; Kilburn and Sutley, 1996). These ubiquitous clotlike masses, which probably precipitated as a result of pH-dependent solubility reactions (Smith and others, 1989), play an active role in substantially tempering the dissolved metal content of the portal effluent by not only controlling aqueous Al and Fe concentrations, but also serving as an effective sink for many dissolved ionic species through coprecipitation and adsorption reactions (Kilburn and Sutley, 1996).

Data obtained from the analysis of the 1996 portal effluent (sites 601, 605, and 606, figure 2) is generally consistent with past USGS studies and depicts a weakly acidic (pH 4.31-4.72), rather conservative (nonreacting) system, with major chemical properties such as pH, conductivity, and dissolved metal content remaining remarkably stable as the portal water descends the hillside above Railroad Creek. This is somewhat surprising, however, since numerous rills, rivulets, and sheets of surface runoff not normally present in midsummer and fall were observed entering the portal water drainage at numerous localities between the mine entrance and Railroad Creek. In addition, the attenuating effects of heavy discharge from the mine and hillside fail to effectively mask a substantial increase in the dissolved metal composition of the portal effluent, with base-metal levels measured (in µg/L) at up to 58 Cd, 4,000 Cu, and 9,600 Zn. This marks a significant rise in dissolved metals when compared to midsummer levels noted in 1994 and 1995, when aqueous Cd, Cu, and Zn were measured (in µg/L) at only up to 29, 940, and 6,200, respectively (Kilburn and others 1994; Kilburn and Sutley, 1996); a circumstance attributed to the seasonal, snowmelt-triggered flushing of metals from soluble sulfate minerals. Also of interest is the relative increase in the dissolved Cu content of the portal water in relation to Zn, with a Zn/Cu concentration ratio of 2.4 associated with the late-spring runoff (May 1996). Contrasting midsummer ratios varied from 6.7 (July 1994) to 8.4 (July 1995) (Kilburn and others, 1994; Kilburn and Sutley, 1996). Because of the onset of high seasonal discharge, the lower ratio may in part be related to an excess of dissolving Cu-sulfate minerals coupled with the dissolution of Cu-bearing ferrous sulfate salts. The latter phenomenon, which initially entails the incorporation of Cu in preference to Zn as a solid solution replacement for Fe^{II} within the crystal structure of Fe^{II} sulfates, was documented in experimental solubilty studies involving melanterite [$(Fe^{II},Zn,Cu)SO_4 \cdot 7H_2O$]-saturated solutions collected at Iron Mountain, California (Alpers and others;1994; Alpers and Nordstrom, 1996) and is considered a major factor in that areas (Iron Mountain) seasonal variation in mine water chemistry.

Fe-dominant Tailings Seepage

With the exception of relatively high-volume seeps and flows near the confluence of Railroad Creek and Copper Creek, the magnitude of basal tailings discharge was largely unaffected by the heavy late spring runoff and appeared close to midsummer levels (although additional seepage was undoubtably concealed beneath stabilizing rip-rap or as suspected upwellings in Railroad Creek where volumes could not be estimated). This condition may in part be linked to surface water diversion channels installed by or for the Forest Service to deflect surface waters out and away from the tailings. It is also conceivable that surface and groundwater flows that successfully penetrate the tailings may encounter hydrologic conditions that necessitate high residence or retention times.

Seepages sampled at the base of the tailings impoundment in May 1996, as in previous years, were found to be acidic to highly acidic, high metal solutions (Ficklin and others, 1992) (figure 3), marked by a wide range in elemental compositions and related chemical properties such as pH and specific conductance (Kilburn and others, 1994; Kilburn and Sutley, 1996). Tailings effluent collected in 1996 just above the confluence of Railroad Creek and Copper Creek (sites 626-627, 629, figure2) and from a ferricrete terrace or ledge some 250 m upstream from Copper Creek (sites 632-633, 654-656, figure 2) proved the most polluted. Collectively, these seeps were acidic (pH 2.73-3.44), high ionic strength solutions (with a conductivity range of 2,870-4050 µS/cm), containing dissolved metal concentrations (in µg/L) of up to120,000 Al, 56 Cd, 1,100 Cu, 1,200,000 Fe, and 11,000 Zn. Sulfate levels, (ranging from 2,700 to 6,300 mg/L) were consistent with the high Fe and conductivity values, and jointly suggest a high degree of local pyrite weathering and Fe-sulfate dissolution. The foregoing metal levels compare favorably with effluents sampled from these same localities in July 1995 (Kilburn and Sutley, 1996), and outwardly indicate little seasonal variation in metal concentrations. This may be somewhat misleading, however, since hydrogeochemical sampling in July 1995 followed in the wake of heavy rainfall which could have enhanced the dissolved metal content of effluent seepage through dissolution and flushing mechanisms. In any case, the total mass of dissolved solids entering Railroad Creek just above its confluence with Copper Creek is undoubtably greater (spring 1996) than in 1995 because of much higher seepage volumes.

Small, ephemeral, seep-fed ponds were sampled in conjunction with the seepage along the eastern base of the tailings (sites 607 and 611, figure 2) and near the confluence of Railroad Creek and Copper Creek (site 625, figure 2). These ponds displayed similar pH and dissolved metal compositions as their propagating tailings effluents, suggesting short residence times, since modifying processes such as dilution, oxidation, and evaporation appear to have had little or no impact on their immediate chemical makeup.

The pivotal controls for high acid, extreme metal drainage discussed by Plumlee and others (1992;1993) are clearly in place at the Holden deposit where mining of massive sulfide ore has afforded oxygenated water easy access to tremendous volumes of highly permeable, fine-grained, sulfide-rich tailings with little inherent buffering capacity. Under these circumstances, the highly acidic, Fe-dominant tailings seepage identified in this and previous investigations was quite predictable and certainly compatible with a pyrite-dominated system. However, the concentrations of accompanying base-metals, although relatively high, is a departure from the extreme levels frequently encountered in waters derived from weathering VMS mines and deposits and may reflect a lack of significant chalcopyrite and sphalerite in the tailings.

Mill Site, Holding Ponds, and Waste Dumps

Nowhere at the Holden site is visual evidence of spring runoff more conspicuous than the area above and west of the tailings impoundment, where heavy surface discharge from the mill is promptly channeled into holding ponds some 15-20 m below the abandoned facility. This excessive outflow is in sharp contrast to midsummer levels noted by the USGS in 1994 and 1995, when mill effluents were limited to minor seeps and trickles. Likewise, the holding ponds are largely dissipated by midsummer and completely dry by early autumn. The onset of high seasonal runoff is also marked by relatively heavy discharge directly or indirectly associated with waste rock piles located to the east and west of the mill facility. By midsummer, however, surface runoff identified with the waste pile east of the mill is totally absent, while seepage linked with the western waste pile is greatly diminished (and virtually nonexistent by early autumn).

Effluent samples collected from the mill facility in May 1996 were characterized by a broad range in water chemistry that appeared inversely proportional to the amount or volume of their discharge; with dissolved metal levels ranging from high to extreme according to the classification of Ficklin and others (1992) (figure 3). This is best illustrated when the metal content of heavy runoff sampled from the western portion of the facility is compared to drip water collected from within the recesses of the mill . The heavy runoff (site 651, figure 2) was a weakly acidic (pH 5.80), Al (32 μg/L) and Fe (<50 μg/L) depleted solution containing dissolved base-metal concentrations (in µg/L) of 22 Cd, 450 Cu, and 2,900 Zn. In contrast, moderately acidic drip water (pH 4.06) obtained from what appeared to be ore (crushed) storage bins (site 647, figure 2), revealed exceptionally high metal concentrations including (in µg/L) 760,000 Al, 4,800 Cd, 650,000 Cu, 290,000 Fe, and 610,000 Zn.

Although intense sulfide weathering associated with residual ore material in the mill is ultimately responsible for the mill facilities acidic-metalliferous drainage, the dissolution and flushing of soluble secondary sulfate salts is considered the immediate or primary control during the spring runoff and other cycles of wet weather (e.g. summer thunderstorms). These salts, which are by-products of sulfide oxidation, are abundant and widespread in the old mill workings (including Fe, Cu, and Zn phases) (see tables 5 and 6) and represent transient storage of acid and metals in the solid phase. During the course of hydrologic events, such as the heavy spring runoff witnessed at Holden, the soluble salts readily dissolve, releasing their toxic constituents to the environment. It is the author's contention that the gravitational migration of acidic, metalliferous ground and surface water introduced at or in the vicinity of the mill may have major environmental ramifications. There is some evidence that as this effluent moves downward and laterally away from the mill area, it may eventually surface as Fe-poor, Cu-Zn-rich seepage along the banks of Railroad Creek (sites 634 and 637, figure 2), or pass beneath the western periphery of the tailings impoundment, mixing with and enhancing the base-metal content of Fe-rich tailings solutions; an enrichment previously hypothesized by Kilburn and Sutley (1996).

The two holding ponds below the mill and adjacent to Railroad Creek are fed by at least two discrete sources of weakly acidic, Fe-poor effluents including, (1) channeled surface runoff from the mill and (2) seepage springs that surface at a break in slope about 15 m below the large waste rock pile west of the mill area. These tributary effluents are enriched in dissolved base-metals, with the seepage springs (site 650, figure 2) exhibiting the slightly higher concentrations including (in µg/L) 83 Cd, 5,900 Cu, and 12,000 Zn. The holding ponds (sites 638-639, figure 2), which are characterized by a profusion of white-tan, metal-hydroxide precipitates (probably Al), accommodate similar metal concentrations of up to (in µg/L) 71 Cd, 5,300 Cu, and 10,000 Zn. Although midsummer base-metals levels from these localities are high (up to (in µg/L) 62 Cd, 3,000 Cu, and 6,500 Zn at the seepage springs) (Kilburn and Sutley, 1996), the elevated late May concentrations signify a prominent seasonal fluctuation, particularly when the attenuating effects of heavy spring runoff are taken into account. It is believed that the holding ponds may also serve as short-term reservoir for Fe-poor, Cu-Zn-rich effluents (site 637, figure 2) known to discharge into Railroad Creek some 40-50 m north of the contaminated ponds.

The second waste rock pile is located some 100 m east of the mill facility, above the western portion of the tailings . In late May 1996, weakly acidic, Fe-poor, base-metal-rich effluent emerging from the base of the waste pile was artificially channeled across the western margins of tailings before discharging into Railroad Creek via the Copper Creek diversion. As the effluent, which appeared milky-white owing to the precipitation of amorphous solids (probably Al-hydroxides), flowed downward toward Railroad Creek, base-metal concentrations were substantially tempered by natural physical and chemical processes (e.g. dilution and sorption), and ranged from (in µg/L) 110 Cd, 8,400 Cu, and 14,000 Zn below the waste pile (site 622, figure 2) to (in µg/L) 21 Cd, 1,500 Cu, and 2,700 Cu (site 623, figure 2) near the juncture with the Copper Creek diversion. It is important to reiterate that by midsummer the only manifestation of this runoff is a dry, furrow-like, trench, marked by white coated (Al hydroxides ?) rocks and debris.

Railroad Creek

In May 1996, water outflow was rapidly increasing in neighboring Railroad Creek (which lies adjacent to the mine and milling complex), as stable or base flow level that characterizes late fall and winter discharge was replenished by typically heavy spring runoff. An obvious chemical manifestation of this recharging event was the prominent increase in the overall acidity of Railroad Creek (ranging from pH 5.52 to 6.34) in contrast to the near-neutral (pH 7), midsummer levels recorded in previous USGS investigations (Kilburn and others, 1994; Kilburn and Sutley, 1996). This is not surprising, and is probably related to the flushing of accumulated soluble minerals, brines, and acids (resulting from organic decay) from the thin mountain soil.

To what extent the metalliferous mine related effluents impact Railroad Creek or endanger the stability of local ecosystems remains open to question. Detailed hydrogeochemical studies conducted in July 1995 (Kilburn and Sutley, 1996) suggest a rapid neutralization of the acidic, midsummer mine drainage and dilution and/or downstream precipitation of accompanying dissolved solids upon entering and mixing with waters of

Railroad Creek. The influence of this seasonal discharge (summer) on the water chemistry of Railroad Creek was naturally most pronounced in shallow, relatively unagitated mixing zones and eddys opposite seepage and portal water inflow , where the influx of dissolved metals formed spatially transient hydrogeochemical anomalies. Conversely, turbulent and surging creek water appeared to have been only slightly impacted by mine related effluents. However, subsequent data obtained from the May 1996 study revealed increased metal loadings in Railroad Creek (as opposed to midsummer levels) and targeted areas where acid drainage may have been overlooked, but is now suspected. Of the major mixing zones sampled in May 1996, the Railroad Creek-portal water junction (site 603, figure 2) demonstrated the greatest seasonal variance in water chemistry and was characterized by exceptionally high levels of dissolved Cd (45 μg/L), Zn (8,500 μg/L), and surprisingly Al (5,600 μg/L) and Cu (3,100 μg/L); a marked increase in heavy metals when compared to summer 1995 concentrations of (in μg/L) 5 Cd, 1,200 Zn, 61 Al and 160 Cu (Kilburn and Sutley, 1996). This hydrogeochemical anomaly, which can be easily traced for at least 12 to 15 m downdrainage (site 604, figure 2), is no doubt enhanced by incomplete mixing of creek and portal waters as evidenced by the lack of Al hydrolysis, which in turn indicates that metal hydroxides are not actively sorbing and controlling dissolved metals at this juncture. The influence of mine engendered discharge on turbulent, free-flowing creek water was also more distinct in May of 1996 than found in previous USGS summer investigations, with dissolved base-metal and Fe levels adjacent to and below the mine complex (sites 613,618, 635-636, figure 2) ranging from (in μg/L), 0.7-2 Cd, 26-81 Cu, 55-1700 Fe, and 110-230 Zn. In comparison, metal concentrations from these same localities were measured in the summer of 1995 at only up to (in μg/L) <1 Cd, 7.4 Cu, 1,200 Fe, and 31 Zn, despite sampling in the aftermath of heavy rainfall and resultant flushing events. The most intriguing sample (site 602, figure 2) collected from Railroad Creek was gathered upstream from the mine complex, where the impact of mining and milling activity was considered remote. The sample contained in (μg/L) 1000 Al, 15 Cd, 890 Cu, and 2,500 Zn. This site, which displayed background metal concentrations in the summer of 1995, may be a seasonal indication of prospects up the valley from Holden or represent possible breaches in the underground workings of the mine itself.

SUMMARY

Although sulfide weathering (mostly pyrite) is ultimately responsible for the acid mine drainage encountered at the Holden mine and milling complex, it is believed the dissolution and flushing of soluble metal salts is the primary control during the snowmelt-triggered spring runoff and other cycles of wet weather (e.g. summer thunderstorms); a situation that may have important remedial implications. Manifestations of this largely seasonal phenomenon were recognized at the mine site in late May 1996, when hydrogeochemical studies revealed a substantial increase in the magnitude (volume) and dissolved metal content of mine related effluents; a circumstance leading to increased metal loadings in nearby Railroad Creek.

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Table 1. Analytical data for untreated water samples collected at the Holden mine, May 1996 (anion analysis by ion chromatography).

Sample #	Source	Temp C	pH	Cond	SO_4	F	Cl	NO_3
				µS/cm	mg/L	mg/L	mg/L	mg/L
600	Railroad Creek	4	5.52	43	4	<0.1	0.8	<0.1
601	Portal Effluent	7	4.72	385	240	0.4	1.3	0.1
602	Railroad Creek	4.5	5.63	120	48	0.2	0.8	0.7
603	Railroad Creek	7	4.85	373	240	0.4	1.3	0.1
604	Railroad Creek	6	5.64	70	19	0.1	0.6	0.7
605	Portal Effluent	8	4.31	472	290	0.6	1.7	0.1
606	Portal Effluent	9	4.47	412	250	0.4	1.4	0.1
607	Tailing Pond	18	3.01	947	710	0.9	0.6	<0.1
608	Tailing Seep	7	3.30	837	620	0.9	0.6	0.4
609	Tailing Seep	9.5	2.90	841	470	0.8	0.5	<0.1
610	Tailing Seep	9.5	3.23	1298	1100	1.2	0.5	0.1
611	Tailing Pond	10	2.92	1559	1200	1.0	0.3	0.1
612	Mtn Runoff	10.5	5.00	62	19	0.1	0.3	0.2
613	Railroad Creek	4	5.65	45	10	<0.1	0.4	0.6
614	Swale Water	16	4.74	36	11	<0.1	0.3	0.1
615	Tailing Seep	5	3.28	2480	2000	<0.1	0.9	<0.1
616	Tailing Seep	8	3.45	2070	1500	0.4	0.4	<0.1
617	Tailing Seep	7	4.24	1207	840	0.7	0.5	0.1
618	Railroad Creek	4	6.10	56	14	0.1	0.8	0.7
619	Copper Creek	3	5.67	35	5	<0.1	0.2	0.5
620	Copper Creek	3	5.93	35	5	<0.1	0.3	0.7
621	Mtn Runoff	8	6.82	32	5	<0.1	0.3	<0.1
622	Waste Pile Pond	8	4.41	576	380	0.9	0.3	0.1
623	Waste Runoff	13	5.29	151	60	0.2	0.4	0.2
624	Waste Runoff	11	5.20	147	59	0.2	0.5	0.2
625	Tailing Pond	11	3.11	3300	4100	<0.1	<0.1	0.1
626	Tailing Seep	8	3.16	4050	6300	<0.1	<0.1	<0.1
627	Tailing Seep	8	3.12	3240	3900	<0.1	<0.1	0.2
628	Railroad Creek	6	4.56	669	250	0.3	0.6	0.3
629	Tailing Seep	8	3.18	2870	2700	1.0	<0.1	0.8
630	Unknown	3	3.95	313	240	0.4	0.4	<0.1
631	Tailing Seep	5	3.49	3350	4000	<0.1	<0.1	<0.1
632	Tailing Seep	5	3.44	3970	5500	<0.1	<0.1	<0.1
633	Tailing Seep	5	2.84	3520	3900	<0.1	<0.1	<0.1
634	Creek Bank Seep	2	4.24	343	200	0.3	0.5	<0.1
635	Railroad Creek	4	6.21	45	8	<0.1	0.4	0.7
636	Railroad Creek	4	6.34	45	8	<0.1	0.4	0.6

Table 1. Analytical data for untreated water samples collected at the Holden mine, May 1996 (cont.).

Sample #	Source	Temp C	pH	Cond µS/cm	SO_4 mg/L	F mg/L	Cl mg/L	NO_3 mg/L
637	Creek Bank Seep	4	5.73	203	83	0.2	1.0	<0.1
638	Holding Pond	5	5.05	430	250	0.4	0.5	0.2
639	Holding Pond	5	5.08	441	250	0.5	0.5	0.2
640	Mill Runoff	4	5.15	390	200	0.9	0.6	0.1
643	Mill Drip Water	3	3.25	4350	4500	6.6	<0.1	<0.1
646	Mill Drip Water	3	3.42	4040	3800	6.6	<0.1	<0.1
647	Mill Drip Water	3	4.06	6850	8500	<0.1	<0.1	<0.1
649	Mill Runoff	4	4.71	342	180	2.6	0.8	0.3
650	Seep Below Mill	3	4.75	662	int	1.0	0.5	0.9
651	Mill Runoff	7	5.80	91	35	2.2	0.7	0.2
652	Mill Drip Water	2	3.41	6380	7700	int	int	int
653	Mill Drip Water	3	4.24	5620	6000	int	int	int
654	Tailing Seep	7	2.86	3520	3100	2.7	int	0.3
655	Tailing Seep	7	2.73	3860	3700	2.9	int	<0.1
656	Tailing Seep	7	3.05	3560	2700	3.1	int	int
657	Reservoir In Tails	7	3.32	593	230	1.0	0.5	0.1
658	Creek Bank Seep	6	2.89	740	200	0.7	0.8	<0.1
659	Sauna Pond	10	6.18	33	6	1.9	0.4	0.2

Table 2. ICP-AES analysis of filtered and acidified water samples collected at the Holden mine, May 1996

Sample #	600	601	602	603	604
Al ppm	<0.02	6.3	1.0	5.6	0.082
B ppb	<50	<50	<50	<50	<50
Ba ppb	<10	14	<10	13	<10
Be ppb	<10	<10	<10	<10	<10
Ca ppm	5.9	36	13	32	7.4
Cd ppb	<10	54	15	45	<10
Co ppb	<20	<20	<20	<20	<20
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	<20	3400	890	3100	320
Fe ppm	0.091	0.18	0.051	0.15	<0.05
K ppm	<0.5	2.3	1.0	2.2	0.61
Li ppb	<20	23	<20	20	<20
Mg ppm	<1	6.3	2.1	5.7	1.0
Mn ppb	<20	290	83	260	32
Mo ppb	<80	<80	<80	<80	<80
Na ppm	1.0	5.5	2.2	5.1	1.3
Ni ppb	<20	<20	<20	<20	<20
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	3.5	8.9	5.1	8.3	3.8
Sr ppb	21	120	46	110	28
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	<20	9600	2500	8500	970

Sample #	605	606	607	608	609
Al ppm	7.7	6.6	27	27	15
B ppb	50	<50	<50	<50	<50
Ba ppb	11	12	50	<10	25
Be ppb	<10	<10	<10	<10	<10
Ca ppm	42	37	79	83	49
Cd ppb	65	55	11	15	<10
Co ppb	<20	<20	<20	21	<20
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	3700	3200	750	960	79
Fe ppm	0.23	0.19	2.8	3.1	16
K ppm	2.7	2.4	6.6	3.5	4.2
Li ppb	27	24	40	37	24
Mg ppm	7.9	6.8	23	12	11
Mn ppb	360	310	1200	1600	1300
Mo ppb	<80	<80	<80	<80	<80
Na ppm	6.3	5.8	7.7	5.6	4.8
Ni ppb	<20	<20	<20	39	<20
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	9.9	9.1	28	21	21
Sr ppb	140	120	230	140	140
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	11000	10000	500	900	360

Table 2. ICP-AES analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	610	611	612	613	614
Al ppm	23	18	0.066	0.045	0.098
B ppb	<50	<50	<50	<50	<50
Ba ppb	11	14	15	<10	180
Be ppb	<10	<10	<10	<10	<10
Ca ppm	98	95	6.8	5.3	2.7
Cd ppb	16	10	<10	<10	<10
Co ppb	24	<20	<20	<20	<20
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	690	260	20	26	30
Fe ppm	42	81	0.13	0.94	0.049
K ppm	4.7	7.2	0.83	0.54	1.1
Li ppb	41	37	<20	<20	<20
Mg ppm	16	19	1.2	<1	<1
Mn ppb	1900	1900	72	<20	85
Mo ppb	<80	<80	<80	<80	<80
Na ppm	6.2	6.3	1.1	1.0	<1
Ni ppb	36	<20	<20	<20	<20
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	24	19	4.8	3.5	6.1
Sr ppb	180	200	21	20	25
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	930	470	74	110	76

Sample #	615	616	617	618	619
Al ppm	25	18	7.7	0.070	<0.02
B ppb	<50	<50	<50	<50	<50
Ba ppb	<10	11	20	<10	<10
Be ppb	<10	<10	<10	<10	<10
Ca ppm	130	120	90	5.9	4.4
Cd ppb	18	21	<10	<10	<10
Co ppb	23	25	<20	<20	<20
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	990	650	<20	28	<20
Fe ppm	170	140	59	1.7	<0.05
K ppm	14	12	5.0	0.66	0.70
Li ppb	55	49	22	<20	<20
Mg ppm	44	28	18	<1	<1
Mn ppb	2100	1700	940	23	<20
Mo ppb	<80	<80	<80	<80	<80
Na ppm	7.7	6.5	7.9	1.1	<1
Ni ppb	<20	<20	<20	<20	<20
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	17	20	17	3.4	3.3
Sr ppb	400	300	270	21	16
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	1300	3000	400	120	<20

Table 2. ICP-AES analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	620	621	622	623	624
Al ppm	<0.02	<0.02	9.8	0.55	0.62
B ppb	<50	<50	<50	<50	<50
Ba ppb	<10	<10	13	13	12
Be ppb	<10	<10	<10	<10	<10
Ca ppm	4.2	3.5	67	15	15
Cd ppb	<10	<10	110	21	21
Co ppb	<20	<20	36	<20	<20
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	<20	<20	8400	1500	1500
Fe ppm	<0.05	<0.05	0.051	0.060	<0.05
K ppm	0.70	0.63	4.7	1.6	1.5
Li ppb	<20	<20	66	<20	<20
Mg ppm	<1	<1	7.2	1.7	1.6
Mn ppb	<20	<20	650	110	110
Mo ppb	<80	<80	<80	<80	<80
Na ppm	<1	1.3	4.8	1.5	1.5
Ni ppb	<20	<20	55	<20	<20
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	3.1	5.5	15	6.6	6.5
Sr ppb	15	17	140	44	44
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	<20	<20	14000	2700	2700

Sample #	625	626	627	628	629
Al ppm	95	120	57	3.6	61
B ppb	<50	<50	<50	<50	<50
Ba ppb	<10	<10	<10	<10	<10
Be ppb	<10	<10	<10	<10	<10
Ca ppm	140	190	110	14	90
Cd ppb	35	56	45	<10	28
Co ppb	99	160	46	<20	64
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	260	280	1000	55	480
Fe ppm	760	990	530	43	390
K ppm	5.5	8.0	4.1	0.97	3.5
Li ppb	74	88	94	<20	58
Mg ppm	120	150	64	6.1	69
Mn ppb	6300	7600	3600	350	3600
Mo ppb	<80	<80	<80	<80	<80
Na ppm	15	19	9.4	1.7	12
Ni ppb	140	210	<20	<20	86
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	32	36	29	4.6	26
Sr ppb	280	330	260	37	190
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	9500	11000	3100	590	7300

Table 2. ICP-AES analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	630	631	632	633	634
Al ppm	12	24	34	65	4.0
B ppb	<50	<50	<50	<50	<50
Ba ppb	22	<10	<10	<10	14
Be ppb	<10	<10	<10	<10	<10
Ca ppm	14	110	140	130	31
Cd ppb	17	31	52	28	30
Co ppb	<20	64	91	56	<20
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	480	100	37	470	1800
Fe ppm	0.30	800	1200	600	0.16
K ppm	1.1	10	12	1.3	2.1
Li ppb	<20	57	50	77	<20
Mg ppm	5.2	74	130	78	4.6
Mn ppb	250	5100	8800	5000	200
Mo ppb	<80	<80	<80	<80	<80
Na ppm	2.0	12	16	14	3.4
Ni ppb	<20	<20	<20	<20	<20
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	11	16	17	30	11
Sr ppb	49	290	430	350	110
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	2600	2000	4900	4200	4500

Sample #	635	636	637	638	639
Al ppm	0.067	0.062	0.16	3.1	3.4
B ppb	<50	<50	<50	<50	<50
Ba ppb	<10	<10	24	16	15
Be ppb	<10	<10	<10	<10	<10
Ca ppm	5.1	5.5	23	49	52
Cd ppb	<10	<10	<10	64	71
Co ppb	<20	<20	<20	<20	21
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	81	63	380	4700	5300
Fe ppm	0.070	0.055	<0.05	0.11	0.11
K ppm	0.50	<0.5	1.9	4.0	4.3
Li ppb	<20	<20	<20	31	34
Mg ppm	<1	<1	2.8	7.7	8.2
Mn ppb	<20	<20	21	330	350
Mo ppb	<80	<80	<80	<80	<80
Na ppm	1.0	<1	4.6	5.1	4.3
Ni ppb	<20	<20	<20	42	42
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	3.4	3.4	6.4	8.4	8.5
Sr ppb	21	22	110	150	160
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	230	200	1500	9200	10000

Table 2. ICP-AES analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	640	643	646	647	649
Al ppm	2.8	280	260	760	2.8
B ppb	<50	<50	<50	<50	<50
Ba ppb	15	<10	<10	<10	13
Be ppb	<10	<10	<10	15	<10
Ca ppm	36	270	300	400	22
Cd ppb	64	2900	1200	4800	67
Co ppb	<20	380	270	1400	<20
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	4800	270000	240000	650000	9200
Fe ppm	0.18	25	77	290	0.77
K ppm	3.3	0.49	0.70	<0.5	1.3
Li ppb	30	560	480	1500	<20
Mg ppm	7.3	140	150	510	7.9
Mn ppb	280	8300	13000	33000	250
Mo ppb	<80	<80	<80	<80	<80
Na ppm	3.5	12	7.8	16	3.0
Ni ppb	<20	280	230	1100	<20
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	7.2	43	32	57	6.4
Sr ppb	110	200	190	260	80
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	9000	350000	190000	610000	8700

Sample #	650	651	652	653	654
Al ppm	5.0	0.032	620	560	49
B ppb	57	<50	<50	<50	<50
Ba ppb	14	11	11	<10	<10
Be ppb	<10	<10	<10	10	<10
Ca ppm	77	6.9	300	320	120
Cd ppb	83	22	1700	1500	49
Co ppb	36	<20	930	840	76
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	5900	450	560000	540000	830
Fe ppm	<0.05	<0.05	340	260	800
K ppm	6.4	0.66	0.77	0.69	3.1
Li ppb	39	<20	960	920	65
Mg ppm	12	2.3	370	340	110
Mn ppb	590	55	14000	13000	6600
Mo ppb	<80	<80	<80	<80	<80
Na ppm	5.9	1.4	16	15	17
Ni ppb	140	<20	260	240	<20
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	11	5.4	60	44	28
Sr ppb	280	28	270	250	400
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	12000	2900	290000	230000	5100

Table 2. ICP-AES analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	655	656	657	658	659
Al ppm	53	39	15	10	<0.02
B ppb	<50	<50	<50	<50	<50
Ba ppb	<10	<10	110	17	<10
Be ppb	<10	<10	<10	<10	<10
Ca ppm	95	120	15	9.5	3.4
Cd ppb	40	42	12	23	<10
Co ppb	62	72	<20	<20	<20
Cr ppb	<20	<20	<20	<20	<20
Cu ppb	1100	310	570	700	<20
Fe ppm	950	1100	22	15	0.057
K ppm	1.6	7.6	6.9	4.3	0.62
Li ppb	76	53	27	<20	<20
Mg ppm	97	120	10	2.1	<1
Mn ppb	6000	7200	730	120	<20
Mo ppb	<80	<80	<80	<80	<80
Na ppm	14	17	2.7	1.9	<1
Ni ppb	<20	<20	<20	<20	<20
P ppb	<100	<100	<100	<100	<100
Pb ppb	<80	<80	<80	<80	<80
Si ppm	26	18	21	25	2.8
Sr ppb	300	370	120	37	14
Ti ppb	<100	<100	<100	<100	<100
V ppb	<10	<10	<10	<10	<10
Zn ppb	3300	4100	1100	1500	38

Table 3. ICP-MS analysis of filtered and acidified water samples collected at the Holden mine, May 1996

Sample #	600	601	602	603	604	605	606	607	608
Ag ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
As ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Au ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ba ppb	6.5	14	8.1	13	6.5	11	12	54	<0.6
Be ppb	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4
Bi ppb	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cd ppb	<0.7	50	13	46	5.8	58	53	3.5	<0.7
Ce ppb	<0.2	1.9	0.3	1.6	<0.2	2.2	1.9	15	<0.2
Co ppb	<0.6	7.4	2.0	7.0	1	8.7	7.9	8.3	<0.6
Cr ppb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	<0.5
Cs ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cu ppb	6.5	3700	970	3200	360	4000	3500	780	<2
Dy ppb	<0.4	0.8	<0.4	0.8	<0.4	0.9	0.9	2.4	<0.4
Er ppb	<0.5	0.5	<0.5	<0.5	<0.5	0.7	0.6	2	<0.5
Eu ppb	<0.2	0.2	<0.2	<0.2	<0.2	0.2	0.2	0.7	<0.2
Ga ppb	<1	<1	<1	<1	<1	<1	<1	<1	<1
Gd ppb	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	<0.9	2	<0.9
Ge ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Hf ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ho ppb	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	0.7	<0.3
In ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
La ppb	<0.4	0.7	<0.4	0.7	<0.4	0.8	0.6	7.7	<0.4
Li ppb	<2	23	6	21	3	28	25	43	<2
Mn ppb	<3	290	73	260	30	340	310	1200	<3
Mo ppb	0.6	<0.4	0.5	<0.4	0.5	<0.4	<0.4	<0.4	<0.4
Nb ppb	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nd ppb	<0.7	2.4	<0.7	1	<0.7	2.0	2.2	8.3	<0.7
Ni ppb	<1	7.5	2	5.8	<1	5.8	5.9	16	<1
Pb ppb	0.2	28	6.5	25	2.3	35	31	3.0	0.4
Pr ppb	<0.1	0.3	<0.1	0.3	<0.1	0.4	0.3	1.9	<0.1
Rb ppb	0.8	5.1	2	4.6	1	6.0	5.6	10	<0.8
Re ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sb ppb	0.1	0.3	0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Sm ppb	<0.3	0.3	<0.3	0.5	<0.3	0.4	0.3	2.4	<0.3
Sn ppb	0.3	0.1	0.1	0.2	0.2	0.1	0.2	<0.1	0.1
Sr ppb	22	130	46	120	29	160	140	250	<0.6
Ta ppb	0.6	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tb ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	<0.1
Te ppb	<6	<6	<6	<6	<6	<6	<6	<6	<6
Th ppb	2	<2	<2	<2	<2	<2	<2	<2	3
Tl ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Tm ppb	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
U ppb	<0.4	2.6	0.4	2.4	<0.4	3.7	3.0	1.6	<0.4
V ppb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
W ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Y ppb	5.7	10	7.0	10	6.0	12	12	30	5.8
Yb ppb	<1	<1	<1	<1	<1	<1	<1	<1	<1
Zn ppb	3.4	8000	2400	7400	1000	9600	8600	360	<0.8
Zr ppb	0.5	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2

Table 3. ICP-MS analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	609	610	611	612	613	614	615	616	617
Ag ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
As ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Au ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ba ppb	10	12	16	16	6.1	200	9.9	12	23
Be ppb	0.9	0.6	0.8	<0.4	<0.4	<0.4	0.6	0.4	<0.4
Bi ppb	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cd ppb	11	9.8	4.6	0.9	0.7	0.8	8.9	16	1
Ce ppb	17	16	12	0.5	<0.2	<0.2	14	10	4.7
Co ppb	27	22	15	1	<0.6	0.9	16	13	5.6
Cr ppb	0.6	<0.5	0.6	<0.5	<0.5	<0.5	2.6	0.8	<0.5
Cs ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cu ppb	1100	730	300	24	30	34	1100	740	20
Dy ppb	3.9	3.4	2.4	<0.4	<0.4	<0.4	2.5	1.9	1.1
Er ppb	2.2	2.0	1	<0.5	<0.5	<0.5	2	1	0.7
Eu ppb	0.81	0.71	0.4	<0.2	<0.2	<0.2	0.6	0.4	0.3
Ga ppb	<1	<1	<1	<1	<1	<1	<1	<1	<1
Gd ppb	4.1	3.3	2	<0.9	<0.9	<0.9	3	2	<0.9
Ge ppb	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1
Hf ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ho ppb	0.8	0.7	0.4	<0.3	<0.3	<0.3	0.5	0.4	<0.3
In ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
La ppb	10	8.4	6.2	0.6	<0.4	<0.4	6.3	4.4	2.2
Li ppb	39	42	40	<2	<2	2	63	51	22
Mn ppb	1700	1900	2000	68	15	80	2500	2000	940
Mo ppb	<0.4	<0.4	<0.4	0.6	0.4	<0.4	<0.4	<0.4	<0.4
Nb ppb	<1	<1	<1	<1	<1	<1	1	<1	<1
Nd ppb	11	11	7.2	<0.7	<0.7	<0.7	7.2	6.8	2.5
Ni ppb	48	34	21	3	<1	2	12	9.8	4.8
Pb ppb	0.60	0.68	1.1	<0.2	0.3	0.2	0.65	1.2	0.5
Pr ppb	3.2	2.4	1.4	0.1	<0.1	<0.1	1.9	1.6	0.6
Rb ppb	9.5	11	12	1	0.8	2	14	16	8.2
Re ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sb ppb	<0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.3	0.2	0.2
Sm ppb	3.7	1.9	1.3	<0.3	<0.3	<0.3	2.1	1.4	0.3
Sn ppb	0.2	0.3	0.2	0.2	0.1	0.2	0.2	0.2	<0.1
Sr ppb	160	200	230	22	21	25	510	320	300
Ta ppb	<0.1	<0.1	<0.1	0.7	<0.1	<0.1	<0.1	<0.1	<0.1
Tb ppb	0.63	0.5	0.3	<0.1	<0.1	<0.1	0.3	0.3	0.1
Te ppb	<6	<6	<6	<6	<6	<6	<6	<6	<6
Th ppb	<2	2	2	<2	2	2	3	3	2
Tl ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Tm ppb	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3
U ppb	2.8	1.6	1.4	<0.4	<0.4	<0.4	2.6	3.6	0.5
V ppb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	1	<0.5	<0.5
W ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Y ppb	38	34	27	6.8	5.6	5.4	27	20	13
Yb ppb	2	<1	1	<1	<1	<1	<1	<1	<1
Zn ppb	750	660	330	70	110	77	920	2000	300
Zr ppb	0.3	0.3	0.3	<0.2	<0.2	<0.2	0.2	0.83	<0.2

Table 3. ICP-MS analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	618	619	620	621	622	623	624	625	626
Ag ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
As ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Au ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ba ppb	5.8	5.7	5.6	7.0	15	13	12	3.6	2
Be ppb	<0.4	<0.4	<0.4	<0.4	0.6	<0.4	<0.4	1.9	2.2
Bi ppb	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cd ppb	0.8	<0.7	<0.7	<0.7	110	21	22	6.8	6.6
Ce ppb	<0.2	<0.2	<0.2	<0.2	7.3	1.3	1.4	100	110
Co ppb	<0.6	<0.6	<0.6	<0.6	36	7.0	6.6	52	59
Cr ppb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	7.7	8.4
Cs ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cu ppb	38	<2	<2	<2	8500	1700	1700	490	480
Dy ppb	<0.4	<0.4	<0.4	<0.4	2.8	0.6	0.4	11	12
Er ppb	<0.5	<0.5	<0.5	<0.5	1	<0.5	<0.5	5.6	6.4
Eu ppb	<0.2	<0.2	<0.2	<0.2	0.5	<0.2	<0.2	3.6	4.2
Ga ppb	<1	<1	<1	<1	<1	<1	<1	<1	<1
Gd ppb	<0.9	<0.9	<0.9	<0.9	2	<0.9	<0.9	11	13
Ge ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	0.4
Hf ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	0.1
Ho ppb	<0.3	<0.3	<0.3	<0.3	0.5	<0.3	<0.3	2.3	2.4
In ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.5	0.61
La ppb	<0.4	<0.4	<0.4	<0.4	4.8	1.0	0.8	32	34
Li ppb	<2	<2	<2	<2	69	13	13	79	85
Mn ppb	24	<3	<3	<3	570	110	110	>4000	>4000
Mo ppb	0.5	0.6	0.5	0.7	<0.4	<0.4	<0.4	<0.4	<0.4
Nb ppb	<1	<1	<1	<1	<1	<1	<1	<1	<1
Nd ppb	<0.7	<0.7	<0.7	<0.7	6.2	1	1	49	51
Ni ppb	<1	<1	<1	<1	48	11	11	150	170
Pb ppb	0.4	0.3	0.2	0.2	12	2.1	2.1	0.6	0.5
Pr ppb	<0.1	<0.1	<0.1	<0.1	1.7	0.2	0.2	12	13
Rb ppb	0.8	<0.8	<0.8	<0.8	18	3.8	3.6	21	22
Re ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sb ppb	0.2	<0.1	<0.1	0.1	<0.1	0.1	<0.1	<0.1	0.1
Sm ppb	<0.3	<0.3	<0.3	<0.3	1.3	<0.3	<0.3	11	12
Sn ppb	0.2	0.2	<0.1	0.2	0.1	0.3	0.2	0.2	<0.1
Sr ppb	22	16	16	18	150	48	47	360	410
Ta ppb	0.2	0.4	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tb ppb	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	<0.1	1.9	2.0
Te ppb	<6	<6	<6	<6	<6	<6	<6	<6	<6
Th ppb	2	2	2	2	2	<2	2	6	5
Tl ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Tm ppb	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	<0.3	0.9	0.8
U ppb	<0.4	<0.4	<0.4	<0.4	5.1	0.7	0.6	16	18
V ppb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	4.2	4.8
W ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Y ppb	5.9	5.5	6.0	5.7	26	8.8	9.1	87	96
Yb ppb	<1	<1	<1	<1	<1	<1	<1	4.1	5.0
Zn ppb	120	2	<0.8	2	12000	2800	2800	5200	5600
Zr ppb	<0.2	<0.2	<0.2	<0.2	0.99	<0.2	<0.2	2.1	2.3

Table 3. ICP-MS analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	627	628	629	630	631	632	633	634	635
Ag ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
As ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Au ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ba ppb	8.9	5.7	9.8	22	4.8	4.9	2	15	6.2
Be ppb	0.8	<0.4	1.0	<0.4	0.8	0.8	1.4	<0.4	<0.4
Bi ppb	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cd ppb	24	2	11	14	5.6	12	5.5	33	2
Ce ppb	51	3.3	52	4.7	29	57	60	1.5	<0.2
Co ppb	15	3.2	32	9.3	7.5	12	14	10	<0.6
Cr ppb	5.7	<0.5	3.8	<0.5	3.7	3.7	6.8	<0.5	<0.5
Cs ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cu ppb	1200	73	550	500	320	310	570	1900	89
Dy ppb	8.4	0.5	6.0	1.0	4.9	7.3	8.5	0.4	<0.4
Er ppb	4.3	0.5	3.6	0.6	2.6	4.0	4.9	<0.5	<0.5
Eu ppb	2.6	<0.2	2.1	<0.2	1.7	2.5	2.7	<0.2	<0.2
Ga ppb	<1	<1	<1	<1	<1	<1	<1	<1	<1
Gd ppb	8.1	<0.9	6.0	<0.9	4.9	8.2	9.6	<0.9	<0.9
Ge ppb	0.3	0.1	0.2	<0.1	0.3	0.4	0.4	<0.1	<0.1
Hf ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ho ppb	1.6	<0.3	1.4	<0.3	1.0	1.5	1.8	<0.3	<0.3
In ppb	0.4	<0.2	0.2	<0.2	0.4	<0.2	0.2	<0.2	<0.2
La ppb	19	1.3	17	2.2	12	21	22	1.4	<0.4
Li ppb	110	6	58	15	62	50	73	14	<2
Mn ppb	>4000	380	3900	260	>4000	>4000	>4000	220	8
Mo ppb	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	0.5
Nb ppb	<1	<1	1	<1	<1	<1	<1	<1	<1
Nd ppb	35	2	25	2.9	18	29	36	0.8	<0.7
Ni ppb	14	7.8	87	12	8.4	15	16	12	1
Pb ppb	1.5	0.4	0.4	0.5	0.79	0.4	0.6	0.3	0.4
Pr ppb	7.5	0.4	6.2	0.6	3.9	7.6	8.4	0.2	<0.1
Rb ppb	23	2	12	3.2	43	28	17	5.3	<0.8
Re ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Sb ppb	<0.1	0.3	0.1	<0.1	<0.1	0.1	<0.1	<0.1	0.2
Sm ppb	8.1	0.4	5.7	0.5	4.1	6.0	8.9	<0.3	<0.3
Sn ppb	0.2	0.2	0.4	0.2	0.2	0.3	0.2	0.3	0.1
Sr ppb	370	41	220	53	400	530	410	130	23
Ta ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tb ppb	1.4	<0.1	1.1	<0.1	0.62	1.3	1.3	<0.1	<0.1
Te ppb	<6	<6	<6	<6	<6	<6	<6	<6	<6
Th ppb	6	3	4	3	4	3	4	3	3
Tl ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Tm ppb	0.6	<0.3	0.5	<0.3	0.3	0.5	0.6	<0.3	<0.3
U ppb	7.4	0.5	7.2	0.8	3.2	2.6	4.3	<0.4	<0.4
V ppb	12	<0.5	2.2	<0.5	22	10	2.2	<0.5	<0.5
W ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Y ppb	63	10	55	13	46	74	68	9.3	5.6
Yb ppb	3	<1	2	<1	1	2	4	<1	<1
Zn ppb	2200	560	4400	2700	1200	2400	2400	4300	260
Zr ppb	0.4	<0.2	1.2	<0.2	0.6	0.4	0.2	<0.2	<0.2

Table 3. ICP-MS analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	636	637	638	639	640	643	646	647	649
Ag ppb	<0.2	<0.2	<0.2	<0.2	<0.2	2.8	0.74	2.7	<0.2
As ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Au ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ba ppb	6.6	25	17	16	16	4.8	5.6	6.9	12
Be ppb	<0.4	<0.4	<0.4	<0.4	<0.4	5.1	4.2	7.2	<0.4
Bi ppb	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cd ppb	1	9.2	66	68	71	2300	980	3000	79
Ce ppb	<0.2	<0.2	3.5	3.6	3.5	30	50	84	1.9
Co ppb	<0.6	0.8	17	18	15	350	260	930	12
Cr ppb	<0.5	<0.5	<0.5	<0.5	<0.5	34	21	100	<0.5
Cs ppb	<2	<2	<2	<2	<2	2	<2	2	<2
Cu ppb	68	410	4600	4900	5000	>20000	>20000	>20000	11000
Dy ppb	<0.4	<0.4	1.0	0.7	0.9	12	15	29	0.7
Er ppb	<0.5	<0.5	0.6	0.7	0.6	5.8	8.3	16	<0.5
Eu ppb	<0.2	<0.2	0.2	0.2	<0.2	4.1	5.3	8.7	<0.2
Ga ppb	<1	<1	<1	<1	<1	1	1	2	<1
Gd ppb	<0.9	<0.9	<0.9	<0.9	<0.9	11	16	27	<0.9
Ge ppb	<0.1	<0.1	<0.1	<0.1	<0.1	0.4	0.3	0.7	<0.1
Hf ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	0.1	<0.1
Ho ppb	<0.3	<0.3	<0.3	<0.3	<0.3	2.3	3.0	6.2	<0.3
In ppb	<0.2	<0.2	<0.2	<0.2	<0.2	28	16	31	0.4
La ppb	<0.4	<0.4	4.1	4.1	3.5	9.6	15	22	1.2
Li ppb	<2	4	32	33	31	590	520	1300	17
Mn ppb	5	19	320	330	280	>4000	>4000	>4000	290
Mo ppb	0.5	<0.4	<0.4	<0.4	<0.4	<0.4	<0.4	0.4	<0.4
Nb ppb	<1	<1	<1	<1	<1	2	<1	<1	<1
Nd ppb	<0.7	<0.7	3.6	3.3	3.3	30	44	67	2
Ni ppb	<1	3	41	44	17	260	220	720	11
Pb ppb	0.4	<0.2	5.8	7.2	7.8	5.3	5.1	7.4	6.5
Pr ppb	<0.1	<0.1	0.9	1.0	0.9	5.6	8.3	14	0.3
Rb ppb	<0.8	2.7	6.2	5.9	5.1	13	7.3	2.6	2
Re ppb	<0.2	<0.2	<0.2	<0.2	<0.2	0.3	0.50	1.2	<0.2
Sb ppb	<0.1	0.1	0.1	<0.1	<0.1	0.44	<0.1	0.79	0.2
Sm ppb	<0.3	<0.3	0.4	0.5	0.3	10	14	26	<0.3
Sn ppb	0.2	0.2	0.2	0.2	<0.1	0.50	<0.1	1.6	0.3
Sr ppb	23	120	160	160	120	260	240	260	97
Ta ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tb ppb	<0.1	<0.1	<0.1	<0.1	<0.1	1.9	2.8	5.3	<0.1
Te ppb	<6	<6	<6	<6	<6	<6	<6	<6	<6
Th ppb	3	3	3	3	3	8.6	5	8.8	3
Tl ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Tm ppb	<0.3	<0.3	<0.3	<0.3	<0.3	0.7	1.1	2.1	<0.3
U ppb	<0.4	<0.4	<0.4	0.4	0.4	110	70	250	0.8
V ppb	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	0.7	<0.5
W ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Y ppb	6.0	6.2	16	15	14	68	96	160	9.7
Yb ppb	<1	<1	<1	<1	<1	4.8	6.3	12	<1
Zn ppb	210	1500	7500	7800	7800	160000	92000	>200000	9200
Zr ppb	<0.2	<0.2	0.2	1.2	0.2	<0.2	<0.2	0.2	<0.2

Table 3. ICP-MS analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	650	651	652	658	654	655	656	657	658
Ag ppb	<0.2	<0.2	2.4	2.4	<0.2	<0.2	<0.2	<0.2	<0.2
As ppb	<4	<4	<4	5	<4	<4	<4	<4	<4
Au ppb	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Ba ppb	14	10	14	10	3.2	1	3.4	130	20
Be ppb	<0.4	<0.4	5.9	4.6	1.0	0.8	0.5	0.5	<0.4
Bi ppb	<5	<5	<5	<5	<5	<5	<5	<5	<5
Cd ppb	78	22	1100	1000	16	11	12	6.7	22
Ce ppb	5.5	<0.2	56	68	52	65	60	28	3.2
Co ppb	34	2.8	670	630	15	16	15	11	12
Cr ppb	<0.5	<0.5	130	61	8.6	10	5.4	2.0	2.5
Cs ppb	<2	<2	3	3	<2	<2	<2	<2	<2
Cu ppb	6000	540	>20000	>20000	1100	1300	560	630	800
Dy ppb	1.5	<0.4	24	20	7.0	7.6	7.6	4.2	1.2
Er ppb	1	<0.5	13	11	3.8	4.7	4.0	2.1	0.7
Eu ppb	0.3	<0.2	6.8	7.0	2.1	2.8	2.1	0.6	0.2
Ga ppb	<1	<1	7.2	2	<1	2	<1	<1	<1
Gd ppb	1	<0.9	22	20	8.1	8.8	7.2	3.6	1
Ge ppb	<0.1	<0.1	0.9	1.0	0.3	0.2	0.2	<0.1	<0.1
Hf ppb	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Ho ppb	0.4	<0.3	4.5	4.1	1.4	1.6	1.7	0.8	0.4
In ppb	<0.2	<0.2	38	23	0.68	1.3	0.3	0.2	0.4
La ppb	7.3	<0.4	13	19	21	24	24	16	1.1
Li ppb	44	6	910	870	61	88	57	29	18
Mn ppb	580	56	>4000	>4000	>4000	>4000	>4000	800	130
Mo ppb	<0.4	<0.4	0.4	0.6	<0.4	<0.4	<0.4	<0.4	<0.4
Nb ppb	<1	<1	<1	1	<1	<1	<1	<1	<1
Nd ppb	6.7	<0.7	48	59	31	37	31	15	2.3
Ni ppb	140	2	190	190	18	11	14	5.8	5.6
Pb ppb	0.60	1.0	54	19	0.82	1.9	0.5	0.84	36
Pr ppb	1.7	<0.1	9.8	11	7.0	9.0	7.5	3.8	0.5
Rb ppb	9.4	1	6.3	14	14	18	22	20	26
Re ppb	<0.2	<0.2	0.73	0.81	<0.2	<0.2	<0.2	<0.2	<0.2
Sb ppb	<0.1	0.1	0.66	1.3	0.1	0.1	<0.1	<0.1	<0.1
Sm ppb	0.7	<0.3	22	20	6.5	8.6	5.9	3.7	0.4
Sn ppb	0.2	0.2	1.1	0.89	0.3	0.2	0.3	0.2	0.2
Sr ppb	310	31	270	300	450	430	490	150	44
Ta ppb	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Tb ppb	0.1	<0.1	4.0	3.6	1.0	1.4	1.3	0.68	0.2
Te ppb	<6	<6	<6	<6	<6	<6	<6	<6	<6
Th ppb	3	3	11	7	4	5	3	3	2
Tl ppb	<4	<4	<4	<4	<4	<4	<4	<4	<4
Tm ppb	<0.3	<0.3	1.5	1.4	0.5	0.5	0.4	<0.3	<0.3
U ppb	0.9	<0.4	110	96	4.2	5.7	3.1	2.6	4.8
V ppb	<0.5	<0.5	3.9	<0.5	7.3	4.8	8.4	<0.5	<0.5
W ppb	<2	<2	<2	<2	<2	<2	<2	<2	<2
Y ppb	24	6.3	130	120	66	72	78	40	14
Yb ppb	<1	<1	11	9.4	1	4.0	3	2	<1
Zn ppb	8900	3200	110000	86000	2600	1900	2200	1000	1400
Zr ppb	0.4	<0.2	<0.2	<0.2	0.67	0.3	0.5	0.3	0.2

Table 3. ICP-MS analysis of filtered and acidified water samples collected at the Holden mine, May 1996 (cont.)

Sample #	659
Ag ppb	<0.2
As ppb	<4
Au ppb	<0.2
Ba ppb	5.7
Be ppb	<0.4
Bi ppb	<5
Cd ppb	<0.7
Ce ppb	<0.2
Co ppb	<0.6
Cr ppb	<0.5
Cs ppb	<2
Cu ppb	5.6
Dy ppb	<0.4
Er ppb	<0.5
Eu ppb	<0.2
Ga ppb	<1
Gd ppb	<0.9
Ge ppb	<0.1
Hf ppb	<0.1
Ho ppb	<0.3
In ppb	<0.2
La ppb	<0.4
Li ppb	<2
Mn ppb	<3
Mo ppb	0.5
Nb ppb	<1
Nd ppb	<0.7
Ni ppb	<1
Pb ppb	0.3
Pr ppb	<0.1
Rb ppb	<0.8
Re ppb	<0.2
Sb ppb	0.2
Sm ppb	<0.3
Sn ppb	0.2
Sr ppb	16
Ta ppb	<0.1
Tb ppb	<0.1
Te ppb	<6
Th ppb	<2
Tl ppb	<4
Tm ppb	<0.3
U ppb	<0.4
V ppb	<0.5
W ppb	<2
Y ppb	5.9
Yb ppb	<1
Zn ppb	18
Zr ppb	<0.2

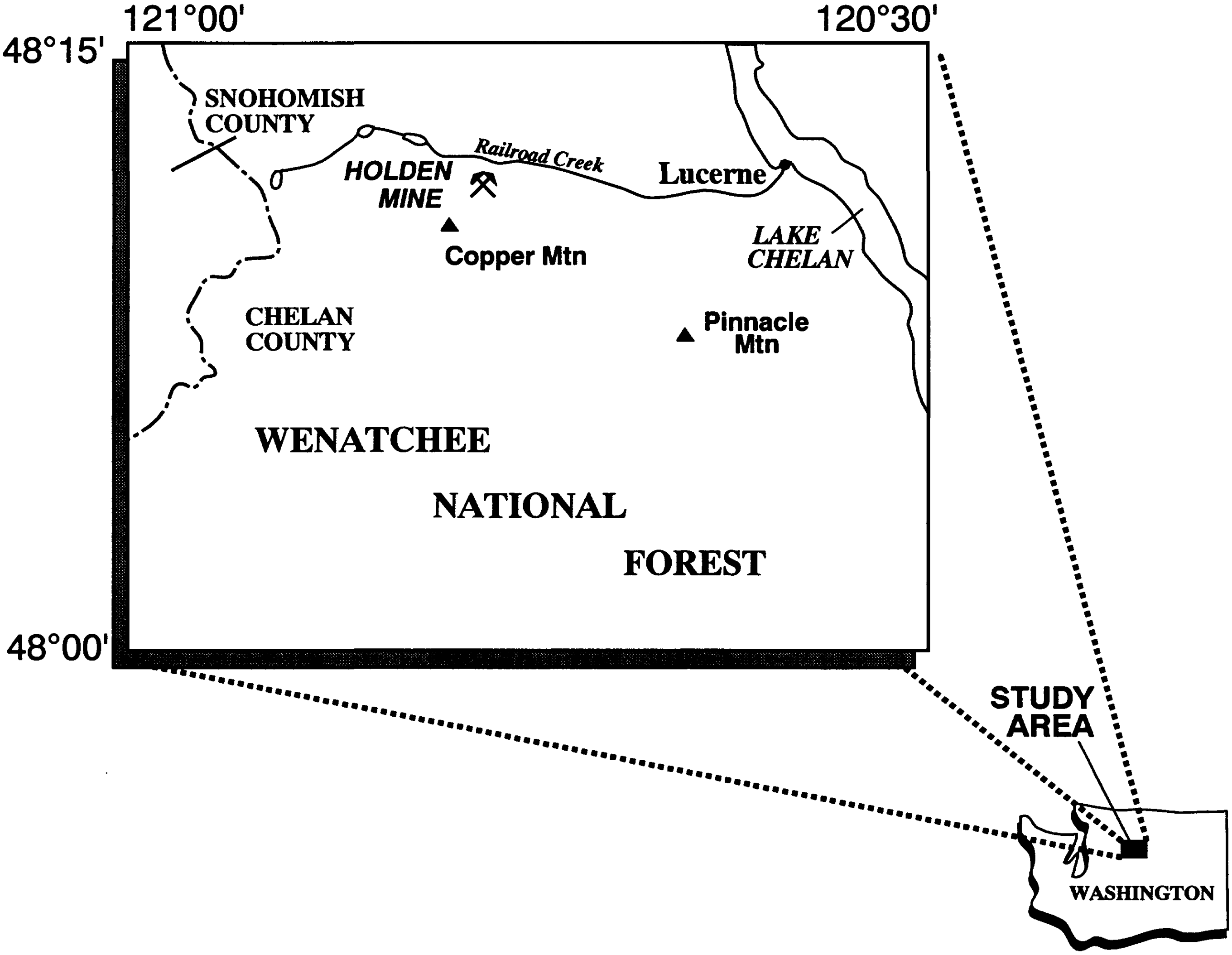

Figure 1. Location of the Holden Mine, Chelan County, Washington.

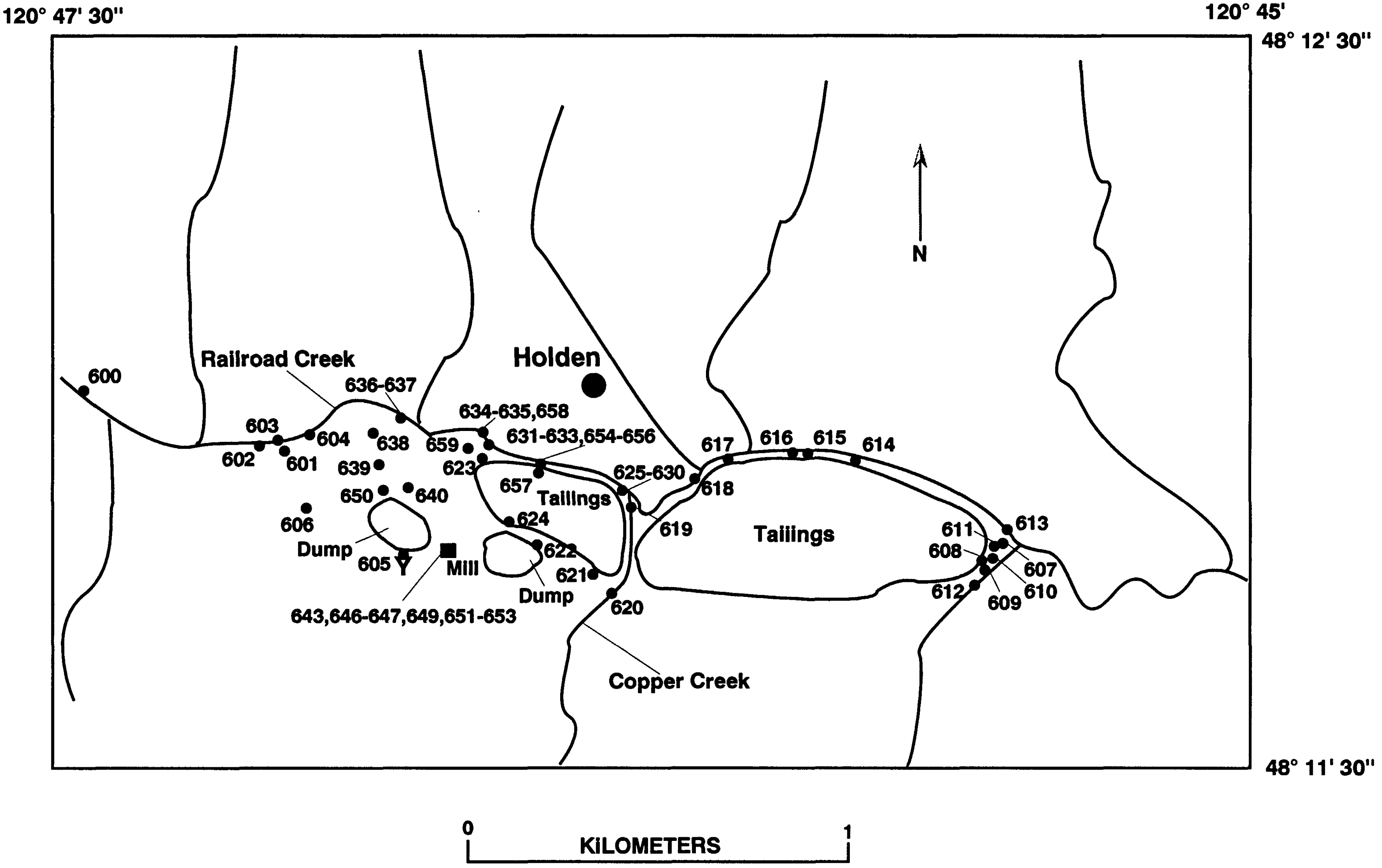

Figure 2. Map showing the location of water samples collected at the Holden mine and milling complex, Chelan County, Washington, May 1996.

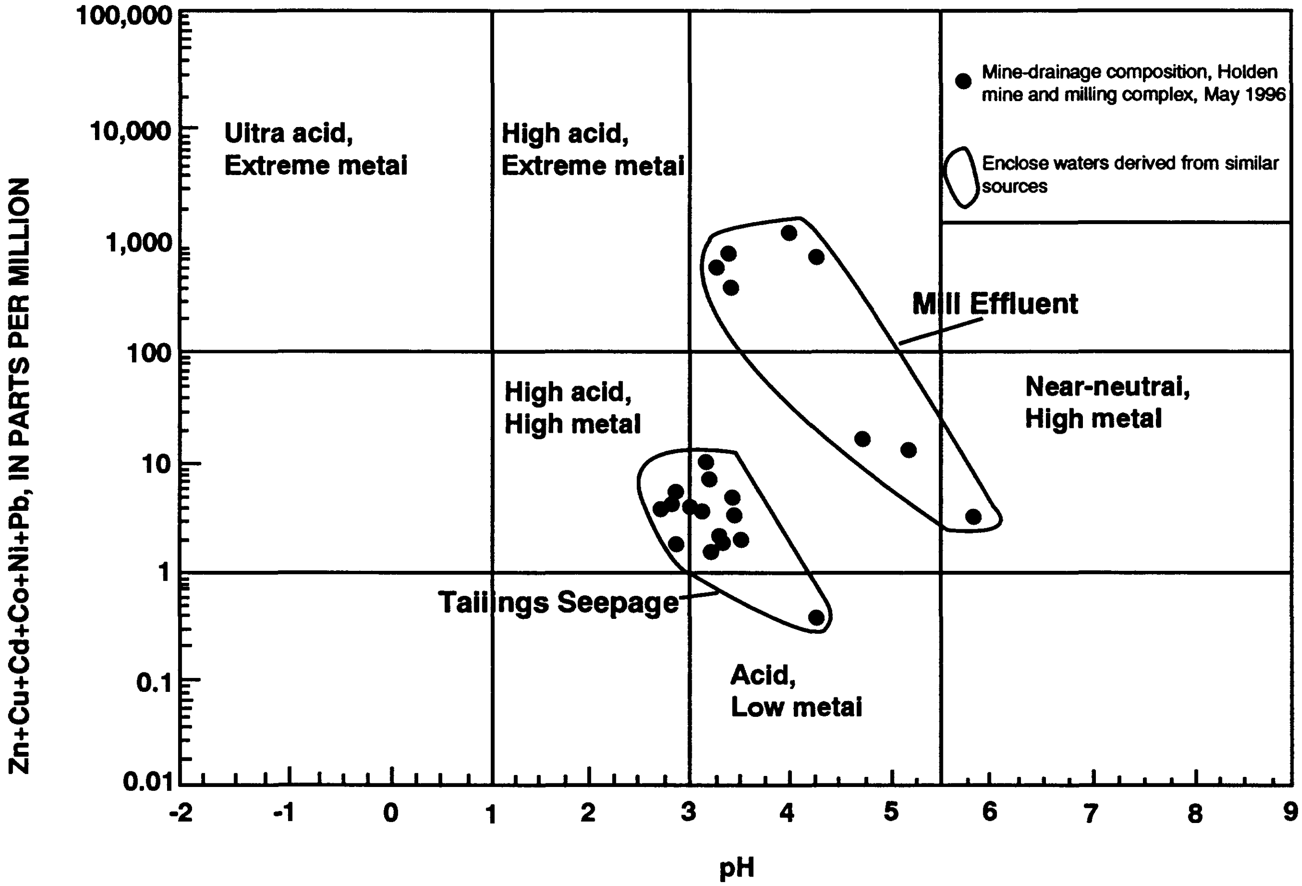

Figure 3. Ficklin diagram plotting pH verses dissolved base-metal content of tailings seepage and mill effluent collected at the Holden mine, May 1996.

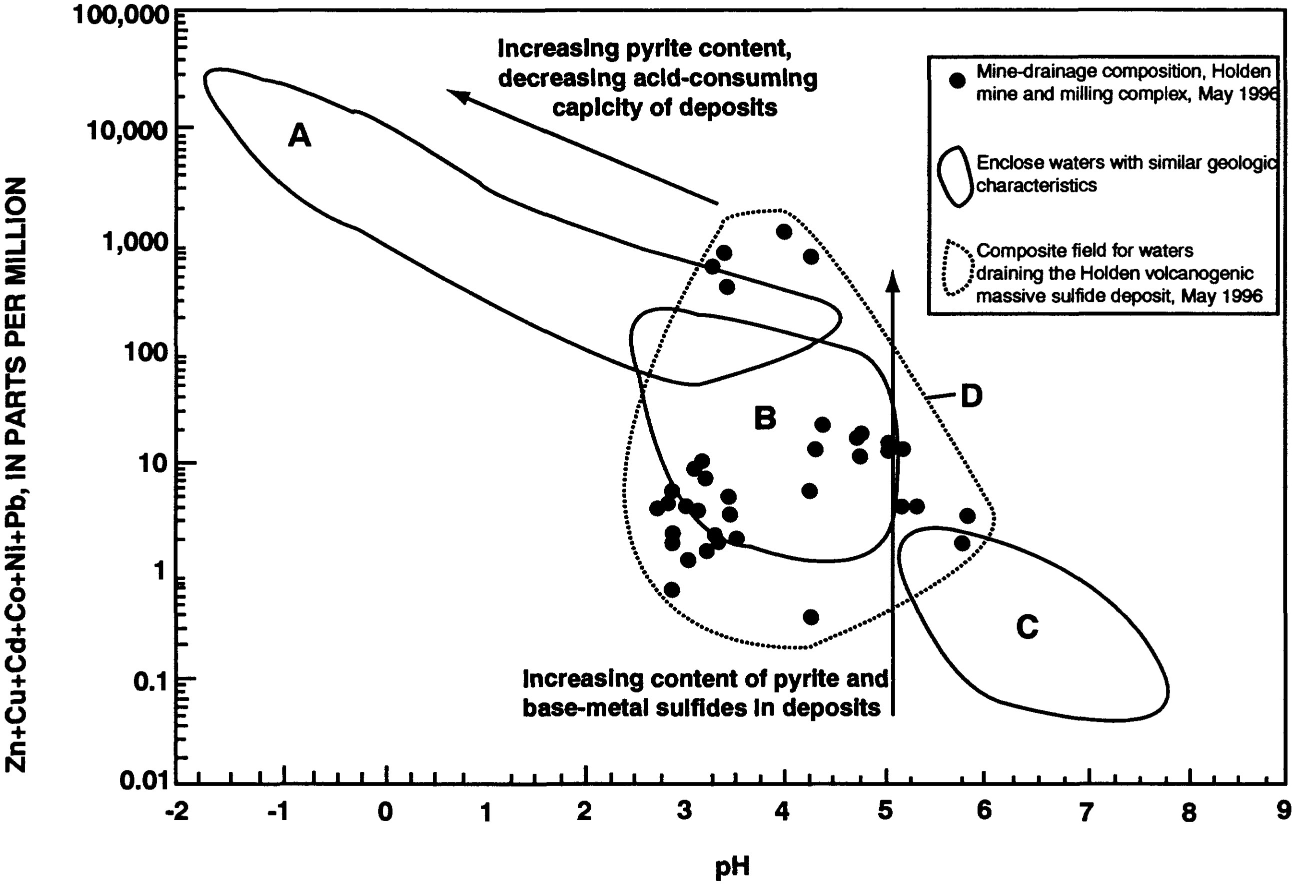

Figure 4. Ficklin diagram plotting pH verses dissolved base-metal content of mine drainage waters. Fields A, B, and C, from Plumlee and others (1994), define fields for the West Shasta district VMS deposits, sulfide-rich vein deposits in rocks with low-buffering capacity, and sulfide-rich veindeposits in carbonate host rocks, respectively. Field D defines the range of effluents collected at the Holden mine and milling comlex, May 1996.

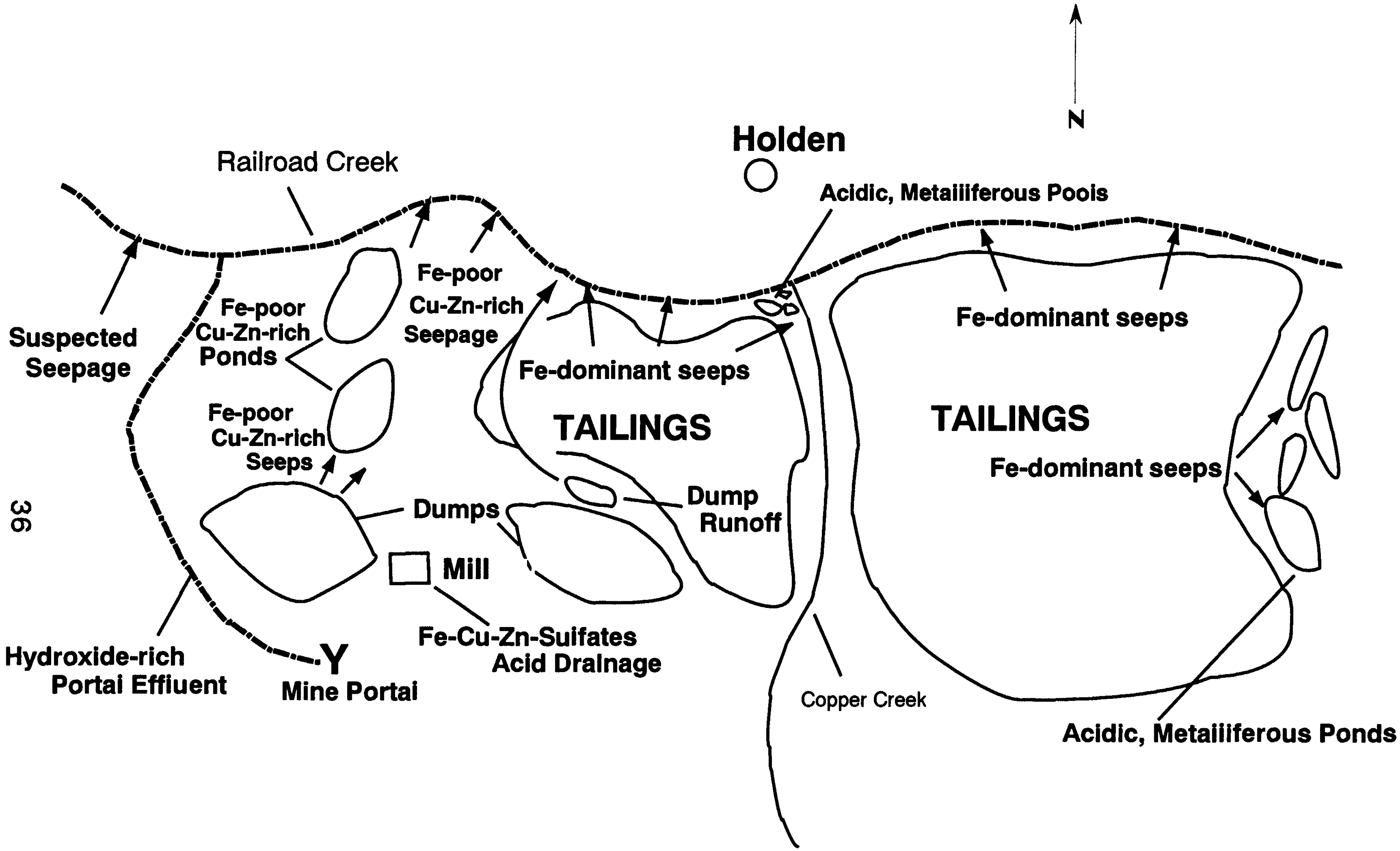

Figure 5. Schematic map showing the relative locations of contaminated effluents and soluble metal salts at the Holden mine, May 1996. NOT TO SCALE

Table 4. Secondary sulfate minerals identified at the western base of the tailings, July1994.

MINERAL	FORMULA
Pickeringite	$MgAl_2(SO_4)_4 \cdot 22H_2O$
Hexahydrite	$MgSO_4 \cdot 6H_2O$
Alunogen	$Al_2(SO_4)_3 \cdot 17H_2O$
Halotrichite	$Fe^{II}Al_2(SO_4)_4 \cdot 22H_2O$
Siderotil	$Fe^{II}SO_4 \cdot 5H_2O$
Melanterite	$Fe^{II}SO_4 \cdot 7H_2O$
Rozenite	$Fe^{II}SO_4 \cdot 4H_2O$
Romerite	$Fe^{II}Fe_2{}^{III}(SO_4)_4 \cdot 14H_2O$
Jarosite	$KFe_3{}^{III}(SO_4)_2(OH)_6$
Antlerite	$Cu_3(SO_4)(OH)_4$
Chalcanthite	$CuSO_4 \cdot 5H_2O$
Bonattite	$CuSO_4 \cdot 3H_2O$
Dietrichite	$ZnAl_2(SO_4)_4 \cdot 22H_2O$
Gunningite	$ZnSO_4 \cdot H_2O$
Gypsum	$CaSO_4 \cdot 2H_2O$

Table 5. Secondary sulfate minerals identified in the abandoned Holden mill, July 1995

MINERAL	FORMULA
Starkeyite	$MgSO_4 \cdot 4H_2O$
Alunogen	$Al_2(SO_4)_3 \cdot 17H_2O$
Siderotil	$Fe^{II}SO_4 \cdot 5H_2O$
Rozenite	$Fe^{II}SO_4 \cdot 4H_2O$
Bilinite	$Fe^{II}Fe_2{}^{III}(SO_4)_4 \cdot 22H_2O$
Hydronium Jarosite	$(H_3O)Fe_3{}^{III}(SO_4)_2(OH)_6$
Natrojarosite	$NaFe_3{}^{III}(SO_4)_2(OH)_6$
Ammoniojarosite	$(NH_4)Fe^{III}(SO_4)_2(OH)_6$
Butlerite	$Fe^{III}(SO_4)(OH) \cdot 2H_2O$
Xitieshanite	$Fe^{III}(SO_4)(OH) \cdot 7H_2O$
Antlerite	$Cu_3(SO_4)(OH)_4$
Chalcanthite	$CuSO_4 \cdot 5H_2O$
Bonattite	$CuSO_4 \cdot 3H_2O$
Gunningite	$ZnSO_4 \cdot H_2O$

Table 6. Secondary sulfate minerals identified in the abandoned Holden mill, May 1996

MINERAL	**FORMULA**
Pickeringite	$MgAl_2(SO_4)\cdot 22H_2O$
Epsomite	$MgSO_4\cdot 7H_2O$
Hexahydrite	$MgSO_4\cdot 6H_2O$
Halotrichite	$Fe^{II}Al_2(SO_4)_4\cdot 22H_2O$
Siderotil	$Fe^{II}SO_4\cdot 5H_2O$
Melanterite	$Fe^{II}SO_4\cdot 7H_2O$
Rozenite	$Fe^{II}SO_4\cdot 4H_2O$
Romerite	$Fe^{II}Fe^{III}(SO_4)\cdot 14H_2O$
Chalcanthite	$CuSO_4\cdot 5H_2O$
Antlerite	$Cu_3(SO_4)(OH)_4$
Goslarite	$ZnSO_4\cdot 7H_2O$
Bianchite	$(Zn,Fe^{II})SO_4\cdot 6H_2O$
Gypsum	$CaSO_4\cdot 2H_2O$