

ASSESSMENT OF HYDRAULIC BACKFILLING
IN METAL MINES
WITHIN THE STATE OF IDAHO

by
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ASSESSMENT OF HYDRAULIC BACKFILLING IN METAL MINES WITHIN THE STATE OF IDAHO

INTRODUCTION

In July of 1985, the state of Idaho acquired primacy over the Underground Injection Control (UIC) program from the U.S. Environmental Protection Agency (EPA), to be administered by the Idaho Department of Water Resources (IDWR). Under the current regulations, only Class V injection wells may be operated within the state. This class of injection wells essentially encompasses all non-hazardous injection practices that do not satisfy the established criteria for Classes I through IV.

In accordance with federal UIC regulations, the state (IDWR) is to conduct initial inventories and assess the potential environmental impact for each subclass of Class V wells. Of these various subclasses, mining, sand or other backfill wells (VX13) have been specifically addressed in this report. This subclass, as defined by EPA, are wells "used to inject a mixture of water and sand, mill tailings and other solids into mined out portions of subsurface mines. . . ." As implied, each backfilled stope is considered to be a well.

Many terms that have been used in the mining industry better describe this injection practice than the EPA assigned title of "mining, sand or other backfill wells." Some of these terms include "hydraulic backfilling," "sand backfilling" and "hydraulic stowing." Hydraulic backfilling has been used universally throughout this report because it most accurately and clearly reflects the actual injection practice.

DESCRIPTION OF HYDRAULIC BACKFILLING

Basic Mining Operations

The horizontal cut and fill method, either timbered or untimbered, depending on ground conditions, is typically used in mining areas where ore deposits occur in narrow, nearly vertical veins. When a ready supply of mill tailings is available, this

mining method is frequently used in conjunction with the hydraulic backfill practice. The generalized sequence of development utilizing this mining method are as follows:

- 1) Tunnel-like passages are driven from each level station to the ore vein. They are either termed laterals, drifts, or crosscuts depending on their orientation to the vein.
- 2) At predetermined intervals, a raise is advanced in a vertical direction along the ore body.
- 3) Using the initial raise development as a platform, the ore is drilled, blasted, and scraped to the ore chute in a series of 6 to 8 foot high horizontal cuts.
- 4) After each horizontal cut is cleaned of all ore, classified mill tailings are hydraulically transported from the surface to the open portion of the stope.

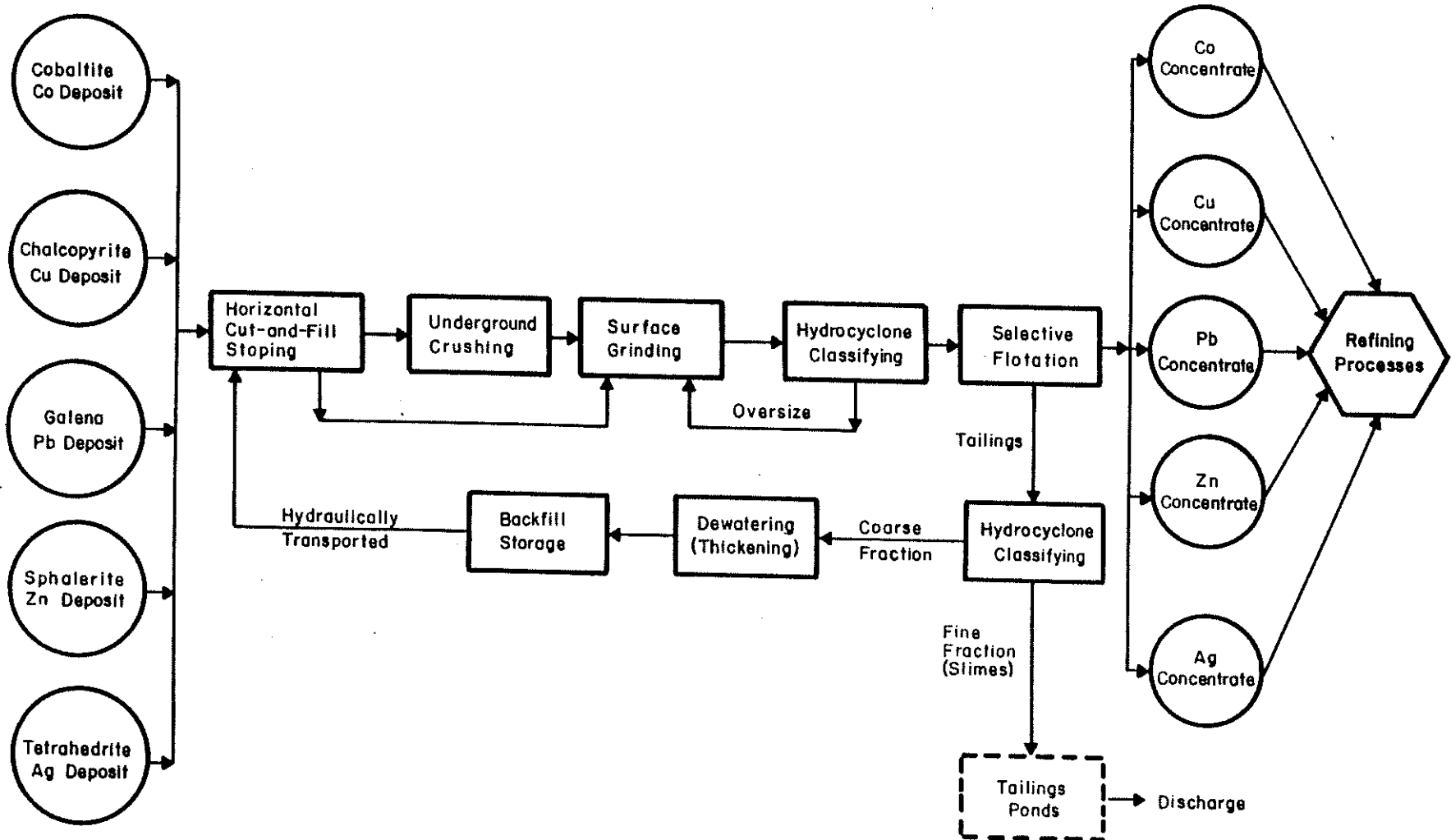
Figure 1 illustrates the general mining progression from the initial subsurface ore recovery through to the final ore extraction process.

General Procedure Used

Following the ore extraction or milling process, the tailings are classified according to particle size in devices known as hydrocyclones. The coarser fraction is dewatered or thickened and then stored for future use as backfill material. Generally, it consists of around 90 percent by weight of particles greater than 325 mesh (McNay, et al., 1975). About 50 to 60 percent by weight of the rock brought to the surface is returned to the stopes (Wahler, 1976). The remaining fine fraction of the tailings or "slimes" is discharged to the tailings pond.

When a stope is ready to be backfilled, the classified tailings are mixed with water to form a slurry. The backfill slurry is then hydraulically transported to the stope, usually by means of gravity, although pumps are occasionally used when the stopes occur at higher elevations than the backfill storage area. Upon emplacement in a stope, the final slurry density consists of

Figure 1- Flow Chart of Principal Mining Operations (Adapted from Gerber, et al., 1979)



about 60 to 70 percent solids by weight. The dimensions of a completely filled stope are the width of the ore vein, by half the length between raises, by the vertical distance between levels. Figure 2 displays the typically geometry of both completely backfilled and partially backfilled stopes.

A backfill drains principally by decantation that occurs concurrently with emplacement, although percolation that follows, serves as an additional dewatering mechanism. The rate of percolation through the backfill is a function of the hydraulic conductivity of the medium (Bates, et al., 1967). Certain methods of backfill placement promote particle segregation which inhibits percolation. This occurs when the coarser particles settle first, leaving the fines with lower permeability near the top of the backfill. Various types of drains are sometimes installed prior to backfilling to help alleviate this problem (McNay, et al. 1975). Usually a backfill has sufficiently drained and compacted within 2 to 4 days after emplacement to allow heavy equipment to operate on it (Given, 1973). At this point about 10 percent moisture is inherently retained within the backfill due to capillary forces (Farmin, et al., 1951).

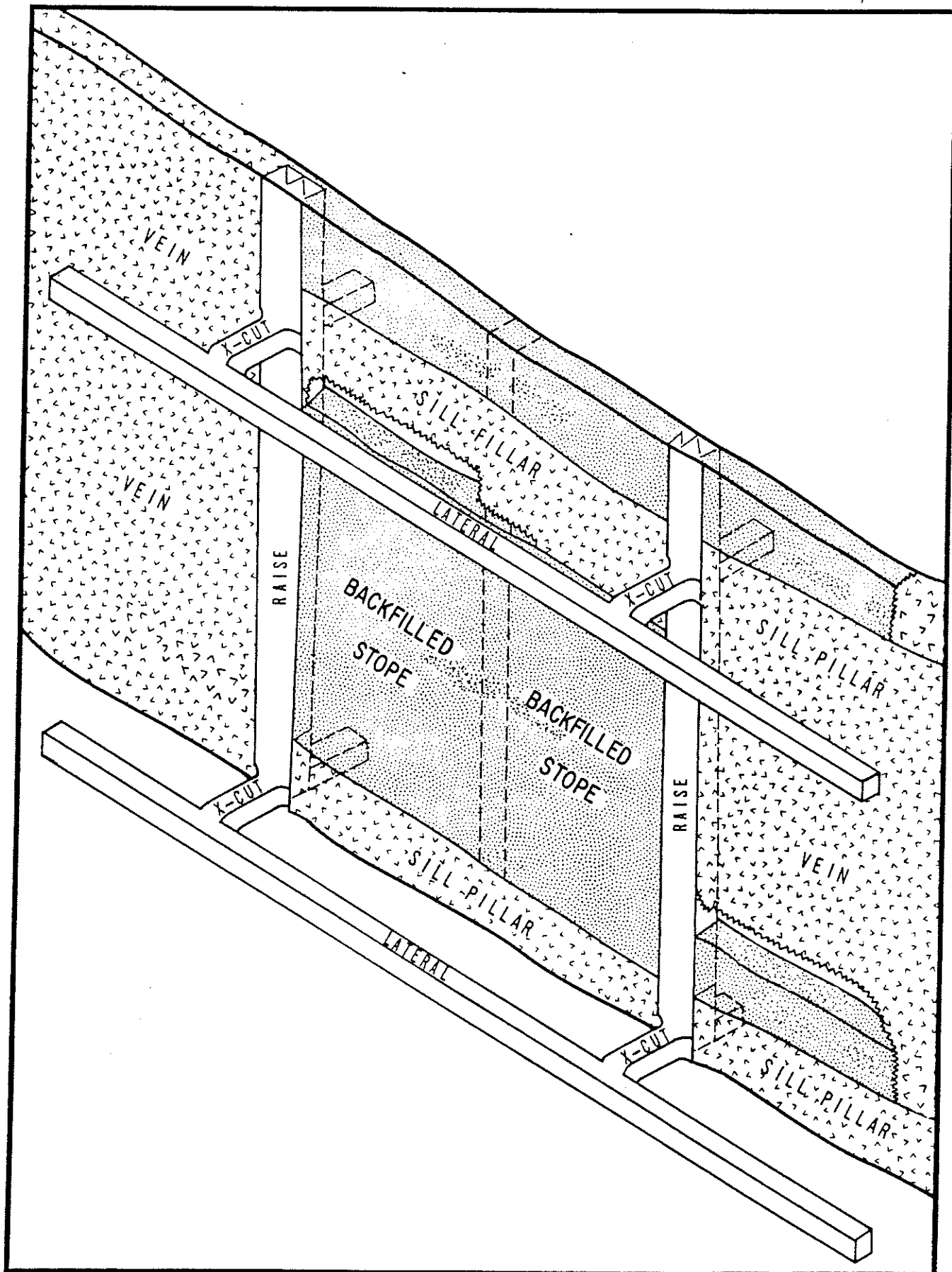
Approximately 10 percent cement is commonly added to the slurry for capping of the backfill. This practice increases the strength of its upper surface and promotes faster development of a stope. Occasionally, lesser quantities of cement are added to the entire backfill to help in the consolidation process.

INVENTORY

Methodology

A preliminary list of the mining companies that had used the hydraulic backfill practice was obtained from the Idaho Mining Association. The U.S. Bureau of Mines and the U.S. Mine Safety and Health Administration were contacted to further substantiate the completeness of the acquired list. Upon verification, inventory forms were sent to each of the mining companies for initial documentation of the individual mines where hydraulic backfilling was used, along with the present status of the mine.

Figure 2- Generalized Diagram of Hydraulic Backfill Practices (Adapted from Wahler, 1976)



Following this initial inquiry, a questionnaire was developed to address specific items that directly or indirectly affect the hydraulic backfill practice (Appendix). Most of this information requested of the mining companies was furnished in the completed questionnaires. However, a few questions pertaining to water quality issues and proposed plans for mine abandonment were left blank, because the data was either unavailable or presently unknown.

The total number of backfilled stopes within a mine that was submitted by the mining companies was generally only a rough estimate. For a more reliable figure to be established, a mining company would have to sift through old development records and plats for the individual levels, along with adequate field verification of accessible backfilled stopes. Frequently, this required data is not available because a mine's ownership has changed significantly throughout its history and the pertinent information has been misplaced or lost.

Results

Ten subsurface mines currently practice, or in the past have used, hydraulic backfilling (Table 1). All of the mines except one are located within the Coeur d'Alene District of northern Idaho. The remaining mine is in the Blackbird District of east-central Idaho (Figure 3).

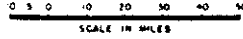
Table 2 lists the first year that hydraulic backfilling was practiced at the individual mines, along with the overall dimensions of the backfilled stopes. These areas range in size from 3 to 30 feet (ft) for the stope widths, 10 to 400 ft for half the distances between raises, and 75 to 240 ft for the level heights. The approximate number of backfilled stopes and the highest elevation where they occur are also included in the table. As will be demonstrated later, the highest level where backfilling practices were utilized was of prime importance when assessing a mine's pollution potential from the hydraulic backfill process.

Table 1. Mines That Have Used Hydraulic Backfill Practices

Present Operator	Mine	General Surface Location	Principal Ore	Status
<u>Coeur d'Alene District</u>				
ASARCO	Coeur	SW1/4, NE1/4, Sec. 30, T48N, R4E	Silver and Copper	Active
	Galena	NE1/4, SE1/4, Sec. 29, T48N, R4E	Silver and Copper	Active
	Page	NW1/4, NW1/4, Sec. 10, T48N, R2E	Lead and Zinc	Inactive
Bunker Ltd.	Bunker Hill	NW1/4, NE1/4, Sec. 13, T48N, R2E	Lead, Zinc, Copper and Silver	Standby
Hecla	Consolidated			
	Silver	NE1/4, SW1/4, Sec. 13, T48N, R3E	Silver	Standby
	Dayrock	SW1/4, NE1/4, Sec. 14, T48N, R4E	Lead and Silver	Inactive
	Lucky Friday	NW1/4, NE1/4, Sec. 35, T48N, R5E	Lead, Zinc and Silver	Standby
	Star-Morning	SE1/4, Sec. 21, T48N, R5E	Lead and Zinc	Inactive
Sunshine	Sunshine	SW1/4, SW1/4, Sec. 15, T48N, R3E	Silver	Standby
<u>Blackbird District</u>				
Noranda	Blackbird	SW1/4, Sec. 27, T21N, R18E	Cobalt and Copper	Inactive

C A N A D A

STATE OF IDAHO



W A S H I N G T O N

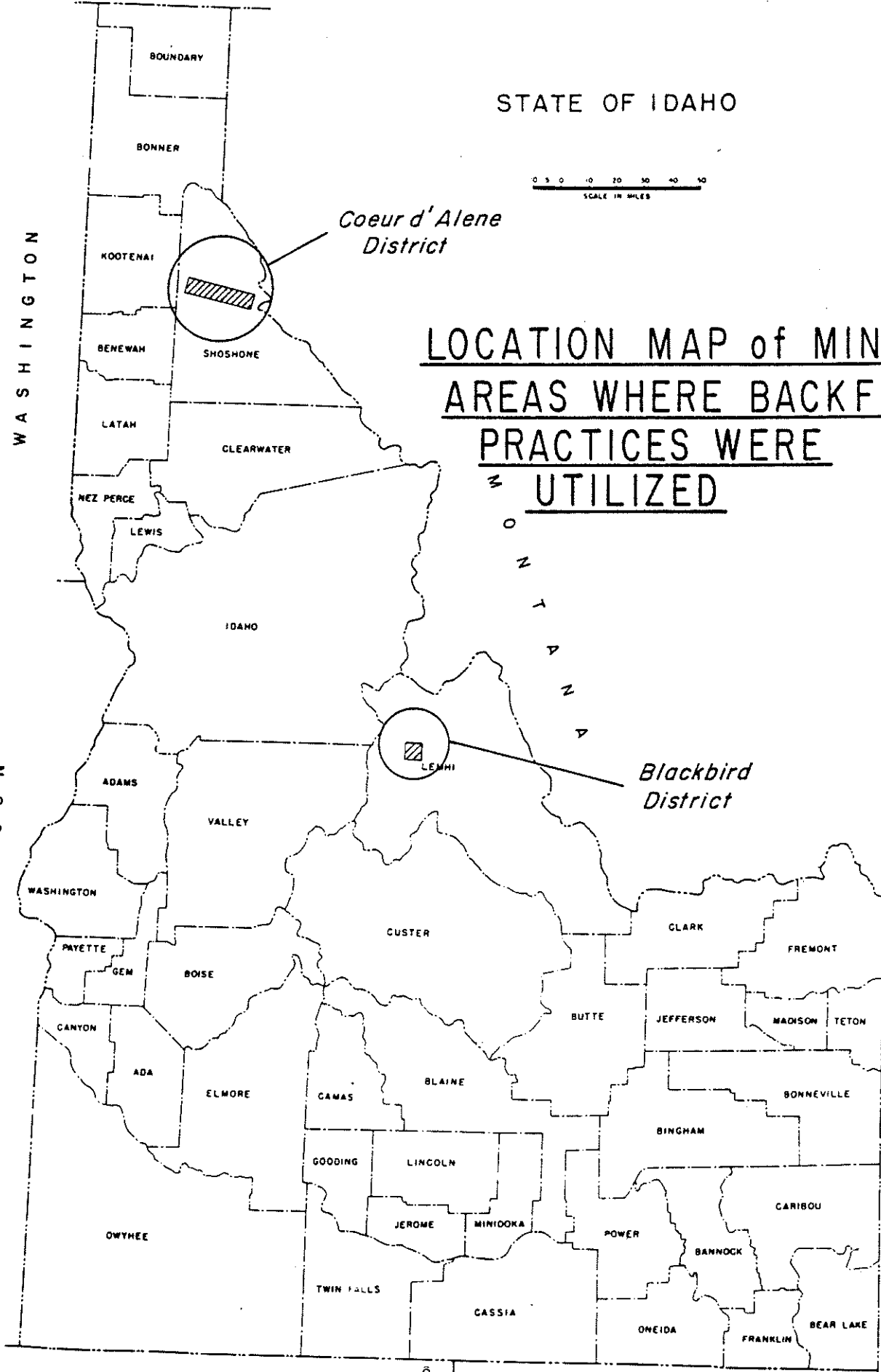
Coeur d'Alene District

LOCATION MAP of MINING
AREAS WHERE BACKFILL
PRACTICES WERE
UTILIZED

O
R
I
G
I
N
A
L

Blackbird District

O R E G O N



N E V A D A

U T A H

W Y O M I N G

Figure 3

Table 2. General Characteristics of Backfilled Stopes

Mine	Date of Initial Use	Average Dimensions (in feet)			Estimated Amount	Highest Elevation*	Lowest Land Surface*
		Stope Width	Half Length Between Raises	Level Height			
Coeur	1973	-	-	-	1	+1750	+3000
Galena	1954	-	-	-	1	+640	+3000
Page	1956	6.5	130	varies	1	+1380	+2500
Bunker Hill	1960	5 30	100 400	240 240	150	+2200	+2400
Consolidated Silver	1965	5.5	120	200	1	-600	+2500
Dayrock	1949	3	50	100-150	1	+3100	+3200
Lucky Friday	1960	5-15	60-150	200	30	+1000	+3400
Star-Morning	1958	5 10	10 200	75 200	40	+4370	+3300
Sunshine	1961	7	150	220	230	-300	+2500
Blackbird	1951	6-20	100	100	120	+7200	+6700

* = in feet, above (+), or below (-) Mean Sea Level

ASSESSMENT

Geography

The Coeur d'Alene District is considered to have one of the world's greatest concentrations of base metals and silver. Discovery and subsequent development of the district began in the mid-1880's. Figure 4 shows the geographic locations of the inventoried mines within the district. Topographically, the area is characterized by high relief and generally rugged terrain with consistently steep slopes that merge with narrow and elongated valleys. The area is drained by the westward-flowing South Fork of the Coeur d'Alene River, which bisects the district.

The Blackbird District contains the largest ore reserves of cobalt within the United States. Initial discovery in the district was in 1893, although, the main period of development occurred from 1949 to 1967. Flat topped mountains and intervening steep V-shaped canyons typify the topography of the area. The north-flowing Panther Creek drains the area and serves as a major tributary to the Salmon River.

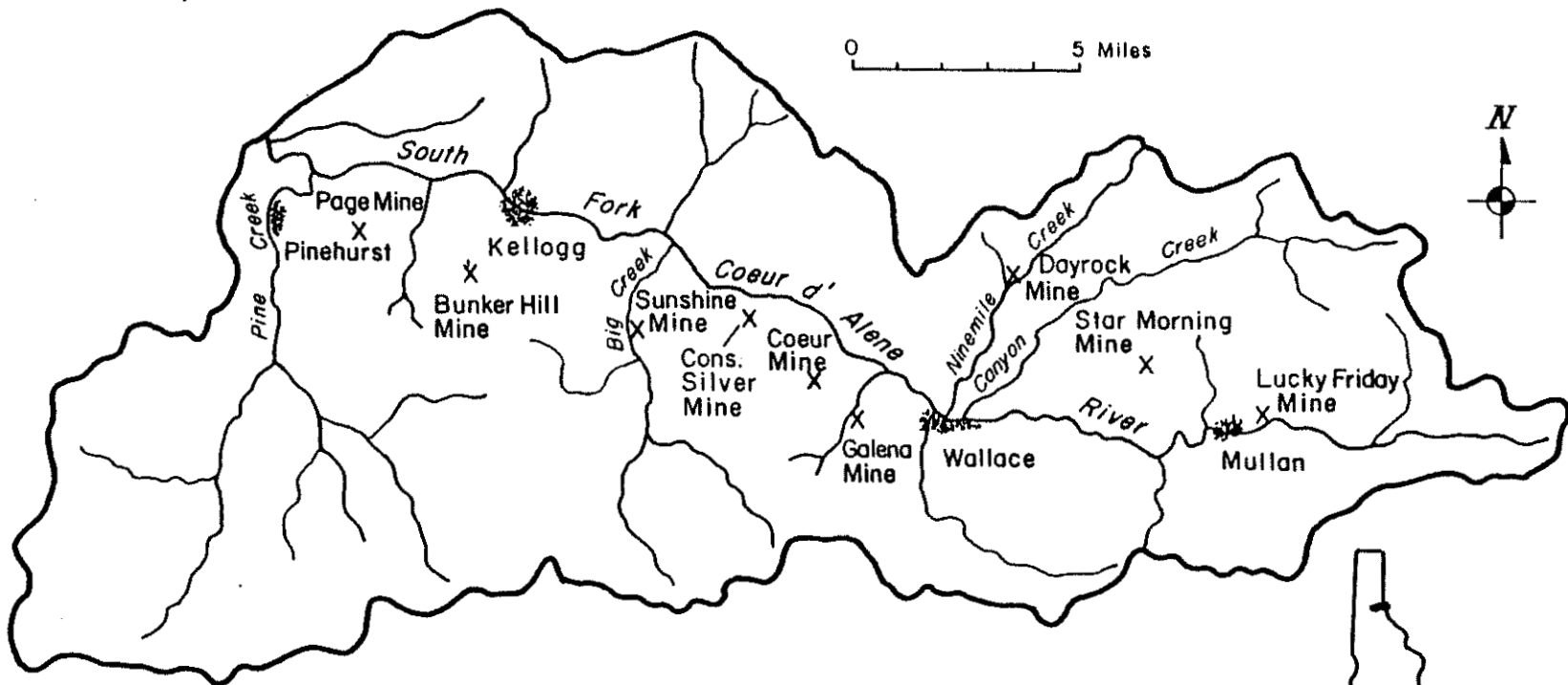
Regional Geology

Belt Supergroup

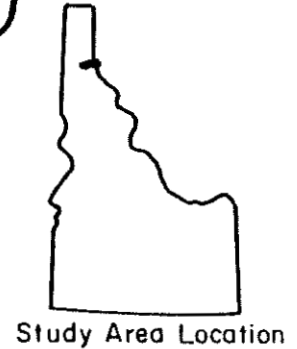
Bedrock present in both the districts, including the formations encountered within the mines, belong to the Belt Supergroup. In the Coeur d'Alene District the formations include, from bottom to top, the Prichard, Burke, Revett, St. Regis, Wallace and Striped Peak. However, ore deposits are predominantly restricted to the transition zone between the Revett and St. Regis and as a result, most of the mines within the District are developed in these host rock formations. The general lithology of this zone is gradational from a basal pure quartzite to an interbedded argillite and impure quartzite (Hobbs, et al., 1965). In the Blackbird District, intensely metamorphosed units of the basal Yellowjacket Formation constitutes the only formation of the Belt Supergroup present (Bennett, 1978). Ruppel (1975) proposed a very tentative correlation between the Prichard Formation of northern Idaho and

Figure 4 - Index Map to Mines in Coeur d'Alene District

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— Drainage Boundary for South Fork Coeur d'Alene River Basin.



Study Area Location

the Yellowjacket Formation of east-central Idaho. Table 3 offers a general description of these formations of the Belt Supergroup.

The structural evolution of both districts have played a significant role in governing the occurrence of the ore deposits, such that, the mineralized veins occur along fracture systems or shear zones that have developed in the Belt rocks (Dahl, 1981 and Lopez, 1981). Principal orientation of the structural features within the Coeur d'Alene District are abruptly terminated bisected by the west to northwest trending Osburn Fault system, which is an extension of the Lewis and Clark Lineament of western Montana. South of this major fault, structural trends tend to parallel it, although some secondary features are oriented north-easterly. However, north of the Osburn Fault, major structures trend northerly, with only minor development of features parallel to it (Hobbs, et al, 1965). Within the Blackbird District, north to northwest trending faults and associated shear zones are the primary features which delineate the zones of mineralization. Bennett (1977) determined from Landsat imagery that additional lineations oriented east to northeast occur throughout the area.

Quaternary Alluvium

Varying amounts of detrital material of fluvial and in part glacial origin occur throughout both districts. Generally, these deposits consist of sand and gravel within the individual drainage systems which progressively thicken down-gradient. Colluvial talus and soil layers are present along the steep mountain slopes.

The Coeur d'Alene District has by far, a greater accumulation of alluvium, especially within the main stem of the South Fork of the Coeur d'Alene River. However, above the confluence of Canyon Creek, the South Fork valley is essentially absent of alluvium or it is extremely thin (Ioannou, 1979). Below the town of Kellogg, a discontinuous layer of clayey silt occurs within the sand and gravel and extends a indefinite distance to the west (Norbeck, 1974).

Table 3. Generalized Section of the Belt Supergroup

Group	Formation	Lithology	Thickness (feet)	
Coeur d'Alene District (Hobbs, et al., 1965)				
Mis-soula	Striped Peak Formation	Interbedded quartzite and argillite with some arenaceous dolomitic beds. Purplish gray and pink to greenish gray.	1,500+	
	Wallace Formation	Upper part	Mostly medium- to greenish-gray finely laminated argillite. Some arenaceous dolomite and impure quartzite in the middle part.	4,500-6,500
Lower part		Light-gray dolomitic quartzite interbedded with greenish-gray argillite.		
Ravalli	St. Regis Formation	Upper part	Light greenish-yellow to light green-gray argillite; thinly laminated. Some carbonate-bearing beds.	1,400-2,000
		Lower part	Gradational from thick-bedded red-purple pure quartzite at base to interbedded green-gray argillite and impure quartzite at top. Some carbonate-bearing beds.	
	Revett Quartzite	Thick-bedded vitreous light yellowish-gray to nearly white pure quartzite. Grades into nearly pure and impure quartzite at bottom and top.	1,200-3,400	
	Burke Formation	Light greenish-gray impure quartzite. Some pale red and light yellowish-gray pure to nearly pure quartzite.	2,200-3,000	
	Prichard	Upper part	Interbedded medium-gray argillite and quartzose argillite and light-gray impure to pure quartzite.	12,000+
Lower part		Thin to thick bedded, medium-gray argillite and quartzose argillite; laminated in part. Pyrite abundant.		
Blackbird District (Bennett, 1977)				
	Yellowjacket Formation	Dark-gray, feldspathic, micaceous quartzite. Intensely deformed in region of Blackbird Mine.	9,000+	

Hydrogeology

Belt Supergroup

Numerous hydrogeologic studies conducted at Bunker Hill Mine have gathered significant information regarding the local ground-water flow regime within the Belt Supergroup. From this detailed mine-specific work, certain basic concepts of mine hydrology have been developed and are thought to apply to the other mines in the Coeur d'Alene District (and to a lesser extent the Blackbird Mine).

Pre-Mining Flow Regime

Prior to mine development, the movement of ground water through the Belt Supergroup was considered to be in approximate equilibrium; that is to say, recharge equaled discharge. The mountain ridges were the principal areas of recharge and valley bottoms were the primary areas of ground-water discharge.

Deformation of the Belt Supergroup have produced the primary avenues or fractures through which ground-water flow occurs. Induced stresses prevalent during the structural history of the group have manifested themselves in accordance with the lithologic makeup present. The brittle nature of the quartzite-rich units has produced extensive fracture systems, whereas slippage along the less competent argillite-rich layers have produced imbricated shear zones. Even though the fracture systems and associated shear zones are numerous in the Belt Supergroup, the interconnected portion of these openings is thought to be small. This is evident by the low yields produced by wells completed in the group, along with the relatively instantaneous response that occurs from a recharge event to the flow system.

Impact of Mine Openings

The extensive workings within an actively dewatered mine have created new areas of ground-water discharge that are at significantly lower elevations than the original sites of outflow. These openings constitute zones of essentially infinite hydraulic conductivity and act as huge drains on the ground-water

system producing predominantly vertical flow components adjacent to the mine.

Inflow to a mine occurs from either natural or imported sources. In the upper levels of a mine, direct surface water infiltration may occur where drifts, raises or stopes encounter the surface drainage systems. If these openings are extensive, local subsidence or caving of the land surface can occur. The movement of ground water into a mine is governed by the extent of the fracture systems encountered in the individual mine openings. The frequency of fractures that intersect the various raises, stopes or unsealed exploration drill holes, determine the degree of ground-water inflow, although the size of the fracture openings generally decreases with depth. The individual flows range from a drip to several gallons per minute, depending on the size of the opening. Besides these widely distributed natural sources of inflow, water is brought into the mine for cooling and drilling purposes as well as the slurry water used in the hydraulic backfill process.

When a mine is actively being dewatered, either by pumping or gravity means, all of the sources of inflow are removed from the mine and either recycled or discharged to the tailings pond. However, when a mine has been abandoned and is allowed to fill with water, depending on the new equilibrium established within the flow regime, discharge may occur through adits or where the saturated fracture systems intersect land surface.

Quaternary Alluvium

A simplified conceptual model for the movement of ground water within the alluvial material is presented as follows. During a recharge event such as spring snow melt, water is transmitted through the saturated talus and soil present along the ridge slopes as interflow. Where this interflow encounters a fracture system in the Belt Supergroup, hydrologic communication exists. If the fracture system is unsaturated, downward flow will occur. However, if the fracture system is fully saturated and constitutes a greater pressure head than in the saturated

soil and talus layer, discharge will occur and serve as an additional source of interflow. As the recharge pulse progressively moves down-gradient, flow lines from adjacent drainages will continually converge until reaching the main valley bottom.

Because of the lag time required to convey a recharge event through a ground-water system versus the instantaneous response of surface water, a dynamic relationship exists between them. During and immediately after a recharge event, high flows within surface water drainages serve to recharge the aquifer system; whereas, after the event has passed, local gradients change allowing ground water to discharge to the surface water serving as its base flow.

Geochemistry

Backfill Composition

Bates, et al. (1967) stated that the composition of the backfill material is representative of the host rock and ore type extracted at each particular mine. Table 4 delineates the minerals of primary and secondary abundance within the backfill material of the individual mines. The host rock or Belt Supergroup predominantly consists of relatively chemically inert aluminum silicates, which include quartz, sericite/muscovite, biotite and feldspars. Table 5 indicates that 85 percent of the oxides present within the Belt Supergroup are silica (SiO_2) and alumina (Al_2O_3). Gangue, where present in the ore veins, consists of mainly carbonates (siderite) with lesser amounts of potential acid-producing sulfides (pyrite).

Potential for Acid Production

The oxidation of pyritic-rich zones can generate acidic conditions within a mine which allows leaching of the more soluble metals from the ore. Figure 5 shows the relationship between the various regulating factors in acid production. The primary impact of hydraulic backfilling on acid production is that the drainage it produces serves as an additional flushing agent for the heavy metal load. The backfill itself may also

Table 4. Mineralogy of Backfill Material
(Fryklund, 1964 and Bennett, 1977)

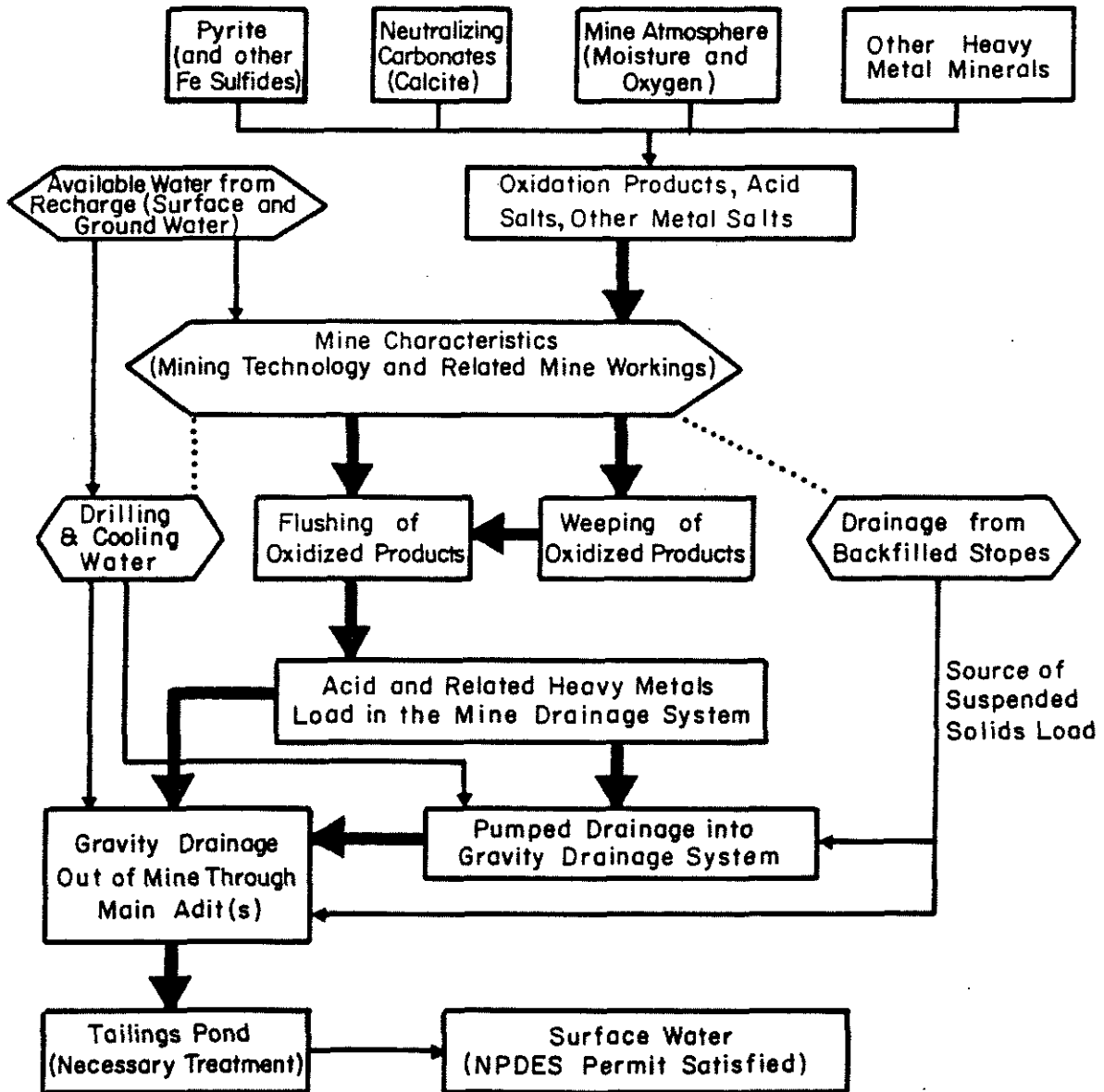
Mine	Quartz SiO ₂	Siderite* FeCO ₃	Mica Group K(?)AlSi ₃ O ₁₀ (OH,F) ₂
Coeur	Secondary	Primary	
Galena	Secondary	Primary	
Page	Primary	Secondary	
Bunker Hill	Primary	Secondary	
Cons. Silver	Secondary	Primary	
Dayrock	Primary	Minor	Secondary Sericite(Al) ₂
Lucky Friday	Primary		
Star-Morning	Primary		
Sunshine	Secondary	Primary	
Blackbird	Primary		Secondary Biotite(Mg,Fe) ₃

* = Includes varying amounts of Ankerite Ca(Mg,Fe)(CO₃)₂

Table 5. Chemical Analysis of Belt Supergroup:
 Ravalli/Pre-Ravalli Groups, in percent
 of unaltered rocks in Coeur'D Alene
 District (Hobbs et al., 1965, p. 28).

<u>Oxides</u>	<u>Percent</u>	<u>Oxides</u>	<u>Percent</u>
SiO ₂	70.8	K ₂ O	3.6
Al ₂ O ₃	14.3	TiO ₂	0.51
Fe ₂ O ₃	2.6	P ₂ O ₅	0.13
FeO	1.13	MnO	0.04
MgO	1.78	CO ₂	0.64
CaO	0.91	H ₂ O	1.85
Na ₂ O	1.97		<u>100.26</u>

Figure 5-Schematic of Water Flow and the Variables Controlling Acid Production within a Mine
(Adapted from Williams, et al., 1976)



LEGEND

- Good Quality Water
- Acidic Water (With Heavy Metal Load)
- Additional Flushing Mechanism

supplement acid generation if significant concentrations of pyrite are present within it.

The results of beaker experiments performed on selected mine tailings by Martin (1981) are presented in Table 6. According to the tailings that he analyzed, it was concluded that only Bunker Hill indicated conditions favorable for acid production. However, the Bunker Hill tailings that were analyzed are most likely from the mine's upper levels which are considerably richer in pyrite than the lower levels where a majority of the backfilling was practiced. The initial acid generated in the other mine tailings was sufficiently neutralized by the presence of carbonates. Significant concentrations of acid-neutralizing calcite are present in the Dayrock Mine and to a lesser extent in the Sunshine Mine (Fryklund, 1964).

According to Toepfer (1952), even in mines where high pyrite concentrations are present, precautions are generally taken to utilize only backfill material with low-pyrite content because of the potential fire hazard it produces during oxidation. Stewart (1958) stated that a maximum of about 8 percent pyrite can be tolerated, and can be beneficial in the process of cementation of the backfill. Cement commonly used during the emplacement of the backfill probably helps to neutralize any potential acid production because of its high percentage of lime.

Flooding of mines during abandonment has in many cases reduced the production of acid because of the oxygen-depleted environment that results. However, some mines are nearly impossible to completely flood because of local topography and patterns of mine development. If flooded, numerous acid seeps or non-point pollution sources along the hillside would result. Both the Bunker Hill and Blackbird mines generate acid drainage and are impracticable to fully flood, although, according to Table 2, only Blackbird Mine has backfilled stopes present in the potentially unsubmerged portion of the mine.

Table 6. Percentage of Mineral Groups by Weight from Selected Mine Tailings (Martin, 1981, p. 36)

Mine Tailings	Sulfides ¹	Carbonates ²	Silicates ³
Coeur	3	47	50
Galena	3	50	47
Bunker Hill	8	14	78
Lucky Friday	<1	23	77
Star-Morning	1	19	80
Sunshine	1	58	41

1 = Predominantly pyrite with subordinate sphalerite, galena, tetrahedrite, and chalcopyrite.

2 = Principally siderite with some ankerite and calcite.

3 = Primarily quartz with minor sericite.

Potential Residue from Ore Extraction Process

During the early years of the mining industry, gravity separation was the primary method used to concentrate the ore. This technique utilized the physical differences in density or specific gravity between the various ore and gangue minerals. Because of the mechanical inefficiency of this method, large volumes of coarse ore waste or "jig" tailings were produced.

With the advent of the selective froth flotation process for ore concentration, the less efficient gravity separation method was eventually phased out by the 1930's. This process involved a more effective technique for recovery of the economically important minerals, and as a result reduced the metal load present in the waste tailings. The flotation process technique further promoted the advance of the hydraulic backfill practice because it generated a ready supply of classified mill tailings.

The steps involved in this selective froth flotation process include the following (Gerber, et al., 1979):

- 1) The ore is finely ground and mixed with water to form a slurry or pulp.
- 2) The pulp is then treated with flotation reagents and sent to a series of flotation cells with agitators.
- 3) As the mixture is continuously agitated, bubbles begin to rise and form a mineralized froth. The gangue and depressed portion of the ore settle.
- 4) The desired metal(s) is then skimmed off from the froth and sent to further concentration steps.
- 5) The remaining pulp is then sequentially treated with slightly different reagents that will allow other desired metals to form individual froths.
- 6) The flotation tailings are dewatered, the water is partially recycled for continued use in the flotation cells and the thickened tailings are discharged.
- 7) The tailings are then classified according to particle size; the coarser fraction is used for backfill material and the remaining finer fraction is sent to the tailings pond.

Table 7 lists the various chemical reagents that are, or have been used at the individual flotation mills. Each of the reagents are categorized according to the primary function they perform. They include (Given, 1973):

- 1) pH Regulators - any substance used to regulate or modify the pH of an ore pulp or flotation process stream.
- 2) Depressants - a substance used to prevent or suppress flotation of one mineral without impairing flotation of another.
- 3) Activators - a substance used to promote flotation in the presence of a collecting agent.
- 4) Frothers - an organic substance used to stabilize air bubbles, principally by reducing surface tension.
- 5) Collectors - a substance used to selectively coat the particles to be floated with a water repellent surface that will adhere to air bubbles.

EPA (1982) addressed effluent limitations and guidelines for the mining industry. Certain reagents used in the flotation process were considered to be potentially toxic and in some cases evidence of the residue was found to be present in the backfill drainage. Sodium cyanide, known to have been used at six of the ten inventoried mines, was the main reagent of environmental concern. Because the primary function of cyanide is to depress pyrite and sphalerite, much of it associates with these depressed minerals in the tailings and may be ultimately leached into the mine drainage following hydraulic backfilling. As the cyanide-laden waters are removed from an active mine, they are discharged to the tailings pond where they are required to be effectively treated to non-detectable levels in fulfillment of their National Pollutant Discharge Elimination System (NPDES) permit. Some cyanide residue may remain within the backfill after initial draining. Its degree of chemical stability and associated persistence in a mine is unknown.

Other mill reagents determined to be of potential environmental harm are the collectors which contain the cresyl group. Of the collectors listed in Table 7, the Aerofloat

Table 7. Reagents Used In Selective Flotation Process

Mine	pH Regulator	Depressant	Activator	Frother	Collector
Coeur	CaO	NaCN	-	MIBC	Minerec 1661 Aero 404
Galena	CaO	NaCN	-	MIBC	Minerec 1661 Aero 404
Page	Na ₂ CO ₃	NaCN ZnSO ₄	CuSO ₄	MIBC Pine Oil	Z-11
Bunker Hill	CaO Na ₂ CO ₃	NaCN ZnSO ₄	CuSO ₄	MIBC	Z-11
Cons. Silver	-	-	-	MIBC	Z-11
Dayrock	CaO Na ₂ CO ₃	NaCN	CuSO ₄	MIBC	Z-6 Z-11
Lucky Friday	Na ₂ CO ₃	ZnSO ₄	CuSO ₄ NaSH	MIBC Barrett Oil	Aerofloat 25 Aerofloat 242 Z-4 Z-6
Star-Morning	CaO Na ₂ CO ₃	CaCN ZnSO ₄	CuSO ₄	MIBC Barrett Oil Dow 250	Aerofloat 31 Z-4 Z-11
Sunshine	-	NaSO ₃ ZnSO ₄	-	MIBC	Aerofloat 31 Aerofloat 242 Aero S-3477
Blackbird	CaO H ₂ SO ₄	-	Na ₂ S	MIBC Pine Oil	Aerofloat 31 Z-4 Z-6

Chemical Composition

MIBC = Methyl Isobutyl Carbinol

Dow 250 = Polypropylene Glycol Methyl Ether

Aerofloat 25 = D cresyl Dithiophosphoric Acid

Aerofloat 31 = D cresyl Dithiophosphoric Acid

Aerofloat 242 = Cresol and Ammonium Salt of Aryl Dithiophosphoric Acid

Aero 404 = Dithiophosphate and Mercaptobenzothiazole Salt

Aero S-3477 = Dithiophosphate Salt

Minerec 1661 = Isoethyl Thionouretate

Z-4 = Sodium Ethyl Xanthate

Z-6 = Potassium Amyl Xanthate

Z-11 = Sodium Isobutyl Xanthate

products (25, 31 and 242) are the only reagents that contain this substance. Since there is no evidence of these collectors (or any chemically altered forms) present within the backfill drainage, it is assumed that they have a conservative affinity towards the ore concentrate as opposed to the tailings.

Water Quality

Direct sampling of backfill drainage from the inventoried mines was not possible because of time and fund restraints of this study. With the present depressed state of the mining industry, limited backfilling is being performed. As a result, water quality data that was indirectly related to backfill drainage was used to help determine if any possible degradation could result from this practice.

Table 8 lists the maximum acceptable levels for the various toxic substances of importance, along with their potential health effects caused by over-exposure.

Backfill Slurry

Water that is mixed with the mill tailings to form the backfill slurry comes from either a separate freshwater source or recycled flotation mill effluent or both. Generally, an external water supply is obtained from a nearby stream, although ground water from shallow alluvium is occasionally used. Water from these sources are essentially absent of metals and has low concentrations of dissolved solids. This is especially true of the the surface water supplies. Quality of recycled mill water can be more mineralized than freshwater sources because of the tendency for various ions to concentrate after repetitive use.

Composite Drainage from Mines

Each individual source of inflow, whether natural or imported, influences the overall quality of the effluent removed from a mine. Drainage from backfilled stopes contributes only about 5 to 10 percent of the total volume drained from a mine

Table B. Contaminant General Characteristics, Regulation, and Toxicity

Substance	Solubility	Mobility	Drinking Water*		Health Effects from Chronic Exposure	Miscellaneous Comments	
			Freshwater Aquatic Life [#]	24 hr. Avg. Max. Allowable			
Antimony	Low	Moderate	146	<1600	<9000	Pulmonary, cardiovascular and skin damage; adversely affects reproduction and fetal development; and reduces life span.	
Arsenic (tri-valent)	Moderate	Extreme	50	40	440	Fatigue, gastrointestinal disturbances, kidney degeneration, tendency to edema, polyneuritis, liver cirrhosis, bone marrow injury, exfoliate dermatitis, and increased incidence of lung and skin cancer.	
Cadmium	Low, except at low pH	Moderate	10	0.014	1.8	Decalcification of bones, hypertension, abnormal liver function, moderate anemia, and nonspecific nervous system disorders.	
Cobalt	Increases w/ lower pH	Influenced by the presence of organic compounds	-	100	500	Polycythemia, vomiting, diarrhea, goiter, and congestive heart failure.	
Copper	Increases w/ lower pH	Extreme	-	1000	13.7	In children: behavioral changes, diarrhea, and progressive marasmus.	
Cyanide	-	Varies, depending on complex formed	-	200	3.5	52.0	Low doses cause loss of appetite, headaches, weakness, nausea, dizziness, and symptoms of irritation of the upper respiratory tract and eyes; increasing exposure may result in death.
Lead	Low, except at low pH	Influenced by the presence of organic compounds	50	1.15	92.5	Gastrointestinal disturbances, loss of appetite, fatigue, motor nerve paralysis, amenia, impaired kidney functions, and reproductive abnormalities.	
Mercury	Low, except in organic forms	Fairly low	2	0.00057	0.0017	Neurological damage, kidney degeneration, digestive disturbances, vision problems, chromosome breakage, and birth defects.	
Silver	Low	Fairly low	50	.12	1.7	Gastrointestinal damage, respiratory tract irritation, ocular damage, and general argyria (discoloration of skin, mucous membranes, and eyes).	
Zinc	Moderate	Extreme	-	5000	47	210	Induced irritability, muscular stiffness and pain, loss of appetite, and nausea.

* = Values are in micrograms per liter (ug/l)

References used in compilation include Woodard-Clyde Consultants et al. (1985), Environmental Research & Technology, Inc. (1982), Environmental Protection Agency (1976), and Hem (1983).

(Wahler, 1976). The drainage quality data for various mines is displayed in Table 9.

The mines that have low pH or acidic conditions present in their drainage have a significantly higher metal load than the mines that have slightly alkaline waters. These include the Page Mine with elevated levels of cadmium, iron and lead; the Bunker Hill Mine with substantially high concentrations of iron, manganese, lead and zinc, and the Blackbird Mine which shows large amounts of all the metals analyzed (cobalt, copper, iron and manganese). Each of these mines are known or thought to have high percentages of pyrite within some of their ore bodies.

Three of the mines with above neutral pH levels indicate elevated concentrations of certain metals. Discharge from the Morning Portal of the Star-Morning Mine shows manganese and zinc present at relatively high levels. Raw effluents from the Sunshine and Galena mines indicated slightly elevated levels of lead. The reasons for the elevated occurrence of these metals under alkaline conditions is not immediately apparent, but it is probably related to their relative abundance in the ore veins of the respective mines.

Of the mine drainages that were analyzed for antimony, all of them show high concentrations of varying proportions. The source for the wide-spread persistence of this element is most likely from antimony-rich tetrahedrite, the primary silver mineral present in the Coeur d'Alene District.

In accordance with the Federal Clean Water Act of 1972, EPA established the National Pollutant Discharge Elimination System (NPDES) program. This program, as it directly affected the mining industry, required that the quality of the raw effluent from a mine satisfy its specific NPDES standards prior to being released to surface water. Table 10 states the present status of the permits for the inventoried mines, along with any relevant descriptive data. Four of the mines have previously been abandoned and allowed to flood. The Dayrock Mine had an active permit prior to its abandonment, but it has since expired. It, along with the Page Mine, have been flooded many years, but

Table 9. Chemical Analyses¹ of Raw Mine Drainage
(in micrograms per liter)

Mine	Discharge Rate (gpm)	pH	Cd	Co	Cu	Fe	Mn	Pb	Sb	Zn
Coeur ²	80	-	2	-	25	-	-	57	-	35
Galena	160	7.8	90	-	10	720	90	700	2,000	190
Page (A/F)	0	3.3	133,600	-	410	60,300	2,900	51,100	3,900	600
Bunker Hill ³	1,600-2,500	3.3	300	-	300	59,000	69,000	2,300	-	120,000
Cons. Silver ²	140-690	8.7	1	-	7	-	-	13	-	30
Dayrock (A/F)	0	7.9	80	-	10	450	100	150	9,700	70
Lucky Friday	750	8.9	90	-	10	200	150	160	2,000	60
Star-Morning (A/F)	10-870 ⁶	7.9 ⁴	10 ⁴	-	10 ⁴	40 ⁵	16,400 ⁵	80 ⁴	-	1,540 ⁴
Sunshine	980	8.8	90	-	10	903	100	1,090	9,000	70
Blackbird (A/F) ⁷	<5-200	2.6	-	21,100	45,000	150,000	7,800	-	-	-

A/F = Abandoned and Flooded (drainage analysis of mines which show no discharge were sampled prior to their abandonment)

1 = Acquired from Ellsworth (1972), except where annotated

2 = Composite effluent after retention in tailings pond, furnished by mine operator

3 = Mean values at Kellogg Portal from Ralston, et al. (1973)

4 = Mean values at Morning Portal from 12-85 to 5-86 furnished by mine operator

5 = Collected at Morning Portal by IDWR on 6-2-86

6 = Morning Portal discharge measured 12-85 to 5-86 furnished by mine operator

7 = Mean values at 6850 Portal from Baldwin, et al. (1978)

Table 10. National Pollutant Discharge Elimination System (NPDES) Permits

Applicant	Mine	Permit #	Expiration Date	Permit Status	Facility Status	Description of Outfall (#)	Receiving Water
ASARCO	Coeur	000002-7	8-88	Active	Active	(002) Effluent from operating mine and mill	S. Fork Coeur d'Alene River
	Galena					(001) Effluent from operating mine and mill	Lake Creek
	Page	-	-	-	A/F*	-	-
Bunker Ltd.	Bunker Hill	000007-8	?	Review for Renewal	Standby	(006) Central Treatment Plant: includes mine drainage from Kellogg Adit	Bunker Creek
Day Mines, Inc.	Dayrock	000011-6	8-81	Expired	A/F*	(001) and (002) Effluent from previously active mine and mill	Nine Mile Creek
Hecla	Cons. Silver	000015-9	9-88	Active	Standby	(001) Effluent from operating mine and mill	S. Fork Coeur d'Alene River
	Lucky Friday	000017-5	?	Review for Renewal	Standby	(001) and (002) Effluent from operating mine and mill	S. Fork Coeur d'Alene River
	Star-Morning	000016-7	5-89	Request for Variance	A/F	(001) Mine drainage from Star Adit (002) Mine drainage from Morning Adit	Canyon Creek S. Fork Coeur d'Alene River
Sunshine	Sunshine	000006-0	6-81	Operating Under Expired Permit	Standby	(001) Effluent from operating mine and mill	S. Fork Coeur d'Alene River
Noranda	Blackbird	002525-9	10-89	Request for Variance	A/F	(001) Mine drainage from 6850 Adit	Blackbird Creek

A/F = Abandoned and Flooded

* = No apparent discharge from adits

neither apparently discharge to the land surface through any of their adits or other openings. As a result, no NPDES permits are necessary under their present status. Both the Star-Morning and Blackbird mines are also inactive and have been allowed to flood. However discharge, varying seasonally, occurs through their main adits. Permits of shut-down mode status are implemented at each of these mines. The rest of the mines that are either active or on standby have active NPDES permits or are in the process of being renewed.

Current industry practice for the treatment of mine drainage involves the following (EPA, 1982):

- 1) The effluent is discharged to a tailings pond.
- 2) Lime is added for pH adjustment to allow precipitation of the metals.
- 3) A flocculant is added to promote the settling of the suspended solids.
- 4) Passive aeration helps to reduce the levels of the cresyl containing compounds.
- 5) The destruction of cyanide is thought to occur from photo-decomposition by ultraviolet light and biochemical oxidation.

Underground Sources of Drinking Water (USDW)

Data acquired from the IDWR water right files along with information on the public water supplies furnished by the Idaho Department of Health and Welfare (IDHW) were used in compiling this inventory of public ground-water supplies. Most of the supplies are obtained from the Quarternay Alluvium, the principal Underground Source of Drinking Water (USDW) in both districts, although the Belt Supergroup locally serves as a developed source of ground water. Table 11 is a listing of the major public ground-water supplies that are used in the Coeur d'Alene and Blackbird Districts. Their respective geographic locations in each district are shown in Figures 6 and 7.

Because of the larger population within the Coeur d'Alene District and the greater degree of development of ground water in

Table 11. Listing of Major Public Ground-Water Supplies

No.	Location	Owner	Pop. ¹	Aquifer ²	TD ³	Max. ⁴ Rate	Chemical Analysis	Well Log
Coeur d'Alene District								
1	T48N R2E S03ab	The Boat Restaurant	?	BS	200	E10	Y	Y
2	S05ab	Pinehurst Laundromat	?	Qal	95	18	N	Y
3	T48N R3E S02bb	Loper's Trailer Park	45	Qal(?)	53	*70	Y	N
4	S03db	Byington Trailer Park	15	?	?	?	N	N
5	S05da	Silver Valley Estates	180	Qal	41	45	Y	Y
6	S06ad	Pik Kwik Grocery	?	Both	152	9	Y	Y
7	S13ac	Sunnyslope Subdivision	130	BS	?	270	Y	N
8	S513bd	Gene Day Park	S25	Qal	40	?	Y	N
9	T48N R4E S18cb	Blue Anchor Trailer Park	100	Qal	50	*120	Y	Y
10	S20bc	ASARCO, Inc.	~150	Qal	38	18	N	N
11	S21cc	M & H Trailer Court	60	Qal(?)	55	?	Y	N
12	T48N R5E S18db	Gem Hill Water Group	~30	Qal(?)	17	*65	N	N
13	T49N R2E S35dc	Valley Center Flick	25	BS	230	18	Y	Y
14	T49N R3E S31cc	McCreary's Trailer Park	<u>65</u>	BS(?)	60	*90	Y	N
			825					

Blackbird District

1-B	T20N R18E S25bc	McDonald Flat Campgrnd.	S20	Both	38	E15	N	Y
2-B	S35ac	Salmon National Forest	?	Qal(?)	45	E25	N	Y
3-B	T20N R19E S07cd	Cobalt Ranger Station	?	?	Spr.	?	N	N
4-B	T20N R20E S12ac	Williams Cr. Picnic Area	?	Both	115'	E2	N	Y

1 = Population served estimated by Department of Health & Welfare, except where annotated
 ~ = estimated from water right file
 S = seasonal use

2 = Aquifer abbreviations
 Qal = Quaternary Alluvium
 BS = Belt Supergroup

3 = Total depth of well (in feet)

4 = Total discharge (in gallons per minute) determined from water right file, except where annotated

• = Determined from graph of total allowed rate versus number of connections
 E = Estimate from well log

COEUR D'ALENE DISTRICT

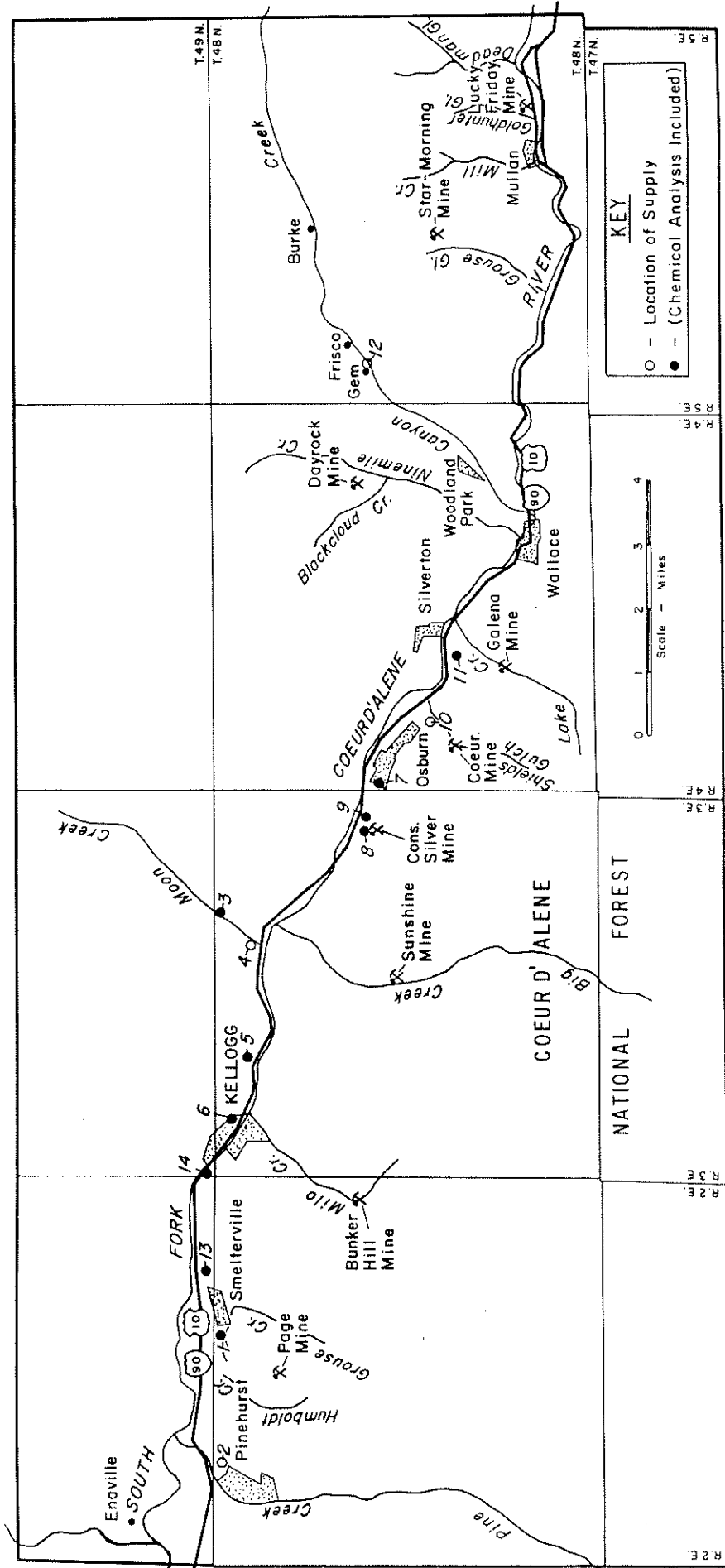


Figure 6 - Public Ground - Water Supplies

BLACKBIRD DISTRICT

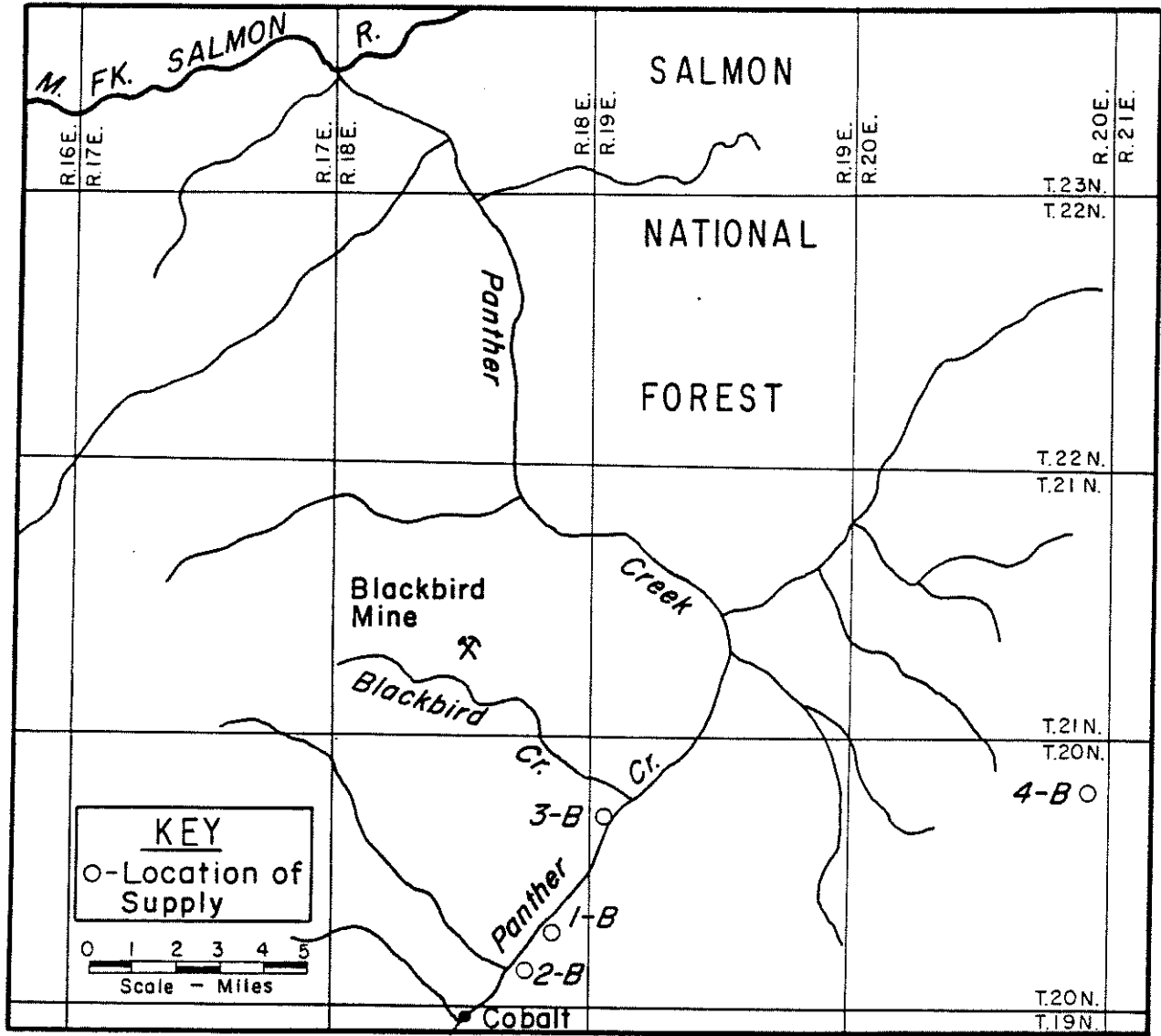


Figure 7 - Public Ground - Water Supplies

the area, certain comments can be made regarding this exploited resource. Only ground-water sources that are used as a common supply for multiple households or are for general public use were included in the inventory. Many shallow large diameter wells are known to occur throughout the area and were not included in the inventory. However, a majority of their source of water is thought to be indirectly derived from surface water because of their proximity to them. Originally, most households obtained water for domestic purposes from wells and springs, but with the advance of community surface water supply systems, many were abandoned. According to a present population estimate of the South Fork valley of 16,500, only slightly over 5 percent of the total population are thought to be using ground water for their primary drinking water source. This estimate includes an additional 10 percent adjustment to the calculated population total of 825 indicated in the table.

The results of ground-water sampling performed by the Panhandle Health District and the Division of Environment, IDHW, of selected public drinking water supplies in the Coeur d'Alene District are presented in Table 12. Four of the ten ground-water supplies indicate elevated levels of certain heavy metals. Sample numbers 7 and 9, or the Sunnyslope Subdivision and Blue Anchor Trailer Park, both of which are located on the western edge of the town of Osburn, showed high concentrations of cadmium in mid-1981. Also, sample number 11 or the M & H Trailer Court, located near the town of Silverton, had concentrations of mercury approaching the maximum contaminant level in April, 1980. And finally sample number 13, or the Valley Center Flick, located just east of the town of Smelterville, had zinc levels that greatly exceeded the recommended standards in 1978.

Pollution sources that have caused the poor quality water experienced at these sites are most likely of external origin than from within the mine or backfilled stopes. This would certainly be true at the sites near presently active mines. Because of the draining effect they produce on the local flow regime, all ground-water movement is towards the mine and not

Table 12. Chemical Analyses of Public Ground-Water Supplies
(in micrograms per liter)

No.	Date Sampled	EC ¹	Ag	As	Cd	Cr	Cu	Fe	Hg	Mn	Pb	Se	Zn
1	02-28-78	171	-	0	2	<10	77	30	<.5	<10 ²	5	<5	210
3	02-08-83	227 ²	<1	<10	<1	<10	-	-	<.5	-	<10	<5	-
5	04-30-82	119 ²	<1	<10	<1	<10	-	-	<.5	-	<10	<5	-
6	02-28-78	274	-	8	4	<10	8	130	<.5	-	7	<5	1200
7	06-29-81	99 ²	<1	<10	8.5 ²	<10	-	40	<.5	<10	<10	<5	-
8	09-26-79	-	-	-	<1	-	-	-	-	-	-	<5	-
9	04-21-81	-	<1	<10	13	<10	-	-	<.5	-	<10	<5	-
11	04-17-80	-	<1	<10	<1	<10	25 ²	20 ²	1.8	<10 ²	<10	<5	92 ²
13	10-06-78	197 ²	<1	<10	<1	<10	-	-	<.5	-	<10	<5	9500 ²
14	02-23-82	-	<1	<10	<1	<10	-	140 ²	<.5	30 ²	<10	<5	357 ²

1 = Electrical Conductance, in micromhos per centimeter at 25°C

2 = Most recent or only analysis

Note: The respective locations of the USDW's are shown in Figure 6A.

away. Therefore, the potential for pollutants within a mine to impact a USDW are restricted to the mines composite drainage after it is discharged to the tailings pond. The primary contaminant sources that are completely separate of a mine's interior include seepage from poorly sealed tailings ponds, leaching of emplaced or reworked (jig) tailings, and in certain areas leaching of smelter waste.

Ground-water quality data of the four seasonally used water supplies present in the Blackbird District was not available. However, because of their distance from the Blackbird Mine along with their probable up-gradient locations, potential contamination caused by any of its backfilling activities is unlikely.

CONCLUSIONS

Undoubtedly some hydrologic communication exists between the Belt Supergroup and the Quaternary Alluvium. At the presently flooded mines, depending upon the new equilibrium established within the surrounding flow regime, ground water may move through the backfilled stopes and progress down-gradient to an underground source of drinking water. However, in the actively dewatered mines, all movement of ground water is towards the mine because of the draining effect they produce on the local flow regime.

The now inactive Blackbird Mine may have unsubmerged backfilled stopes that could supplement acid production within the mine. Drainage from Blackbird is diverted to the main 6850 adit, where it is sent for subsequent treatment. The other mines that have been allowed to flood, which include the Page, Dayrock, and Star-Morning, have used sodium cyanide in their flotation mills and as a result some cyanide residue may occur within the backfill material.

RECOMMENDATIONS

Since no site-specific data concerning the presence of cyanide in backfill drainage is available, a short-term sampling program is recommended at the mines where sodium cyanide has been

used in the flotation mills. Sampling at the mines that currently backfill should take into account any potential effect of residence time after backfill emplacement. Such a discriminative approach is not possible at the flooded mines, although sampling of their composite water will yield meaningful results as to the overall presence of cyanide.

Because of the lack of data regarding the cresyl group collectors, sampling is also suggested at the mines that have used these reagents.

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APPENDIX

Hydraulic Backfill Assessment Questionnaire

Company Name:

Address:

Telephone Number:

Personnel - Mine Supervisor:

Environmental Officer:

Hydraulic Backfill Engineer:

Name of Mine:

Location (1/4, 1/4, Sec., Twp., Rge.):

Status of Operation:

General Characteristics of Mine

Type of ore mined:

Host rock formation:

General lithology:

Approximate surface elevation (ft.):

Total depth of mine (ft.):

Approximate total volume of mine (cu. ft.):
(including filled stopes)

Hydraulic Backfill Practices

Date of initial use of backfill practice:

Shallowest elevation of backfilled stopes:

Number of backfilled stopes present:

Average dimensions of backfilled stopes:

Source of water used in sand slurry:

Volume of water used daily (gpd):
(include max. and min.)

*Chemical quality of source water:

Mineralogy of backfill material:

*Chemical quality of water drained from backfilled stopes:

Description of reagents used in ore extraction process:

Mine Dewatering Practices

Volume of water removed from mine daily (gpd):
(include max. and min.)

*Chemical quality of composite water:

Fate of water removed from mine

Recycled (yes/no):

Disposal/treatment method:

Vertical distribution of natural inflow into mine:
(elevation and approximate flow)

*Chemical quality of natural water:

Proposed Mine Abandonment Procedure

Will mine be flooded?

Estimated top elevation of submerged portion of mine:

Will all backfilled stopes be submerged?

Method other than flooding to be use:

Additional Notes

Does the mine have any localized acidic conditions formed
from the oxidation of pyritic-rich gangue?

*Please attach any copies of water quality analyses.

(pH, specific conductance, trace element conc., etc.)