POTENTIAL FOR ACID FORMATION FROM TAILINGS FROM THE COEUR D'ALENE MINING AREA, IDAHO

A Thesis

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LAWRENCE JAMES MARTIN

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A preliminary draft of the thesis entitled "Potential for Acid Formation in Tailings from the Coeur d'Alene Mining Area, Idaho" by Lawrence James Martin for the Master of Science degree with a major in Geology has been reviewed and found adequate. The committee hereby grants permission for the preparation of the final copy incorporating suggestions made by the committee. Permission is also given for the scheduling of the final examination to be held with authorized by the graduate dean after submission of two final copies of the thesis to the Graduate School.

Major Professor __________ Date 4/13/81

Committee Members C. M. Wai Date 4/17/81

Terry R Howard Date 4/17/81

Review of Final Draft

This thesis entitled "Potential for Acid Formation from Tailings from the Coeur d'Alene Mining Area" by Lawrence James Martin has been reviewed and approved by the University of Idaho officials whose signatures appear below.

Major Professor (for candidate's committee) 8/19/81 Date

George Williams
Departmental Administrator 8/21/81 Date

Maynard M. Miller
College Dean 8/26/81 Date

Arthur R. Gittins
Graduate Dean (for Graduate Council) September 9, 1981 Date

ABSTRACT

Tailings disposal in the steep narrow canyons of the South Fork of the Coeur d'Alene River has long been a problem for the mining companies of the Coeur d'Alene mining area.

Pyrite (FeS_2) in the tailings can be oxidized to form sulfuric acid and ferric hydroxide. The rate determining set in this process is the oxidation of ferrous iron to ferric iron. Carbonates in the tailings can neutralize the acid formed by pyrite oxidation.

Tailings from six active mines were collected for analysis of mineralogy and potential for acid formation. Samples from one of the active mines were found to be acid producing.

Tailings that do not produce acid could be disposed by backfilling selected areas of the valley. Additional reclamation would have to take place to reduce the potential for erosion by the river. Acid-producing tailings could be disposed in a similar manner if safeguards to reduce or prevent acid formation are used.

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CHAPTER I

INTRODUCTION

Statement of the Problem

The disposal of mill tailings has been both a historic problem and an ongoing problem in the Coeur d'Alene mining area (Figure 1). Past mining activities have resulted in the abandonment of a number of controlled tailings sites (sites where identifiable embankments may be found) and a number of uncontrolled tailings deposits where waste material has been deposited along flood plains or stream in the area. The present disposal of tailings occurs at a number of recently constructed tailings ponds along the valley of the South Fork and its tributaries. Recent studies have inventoried the abandoned controlled tailings sites (Gross, 1981) and uncontrolled tailings deposits (Ioannou, 1979). Suggestions for reclaiming the abandoned tailings sites and uncontrolled tailings deposits have been presented as a result of these studies (IDHW and UI, 1980).

Surface impoundment areas for the disposal of tailings were first constructed in the area in the 1920's and 1930's. Federal legislation in 1968 required that the impoundment areas be used for surface disposal of tailings. The mountainous nature of the area generally limits tailings impoundments to sites in the stream valleys near the mills. Tailings impoundment structures now occupy many of the readily available, economically and environmentally suitable sites in the area.

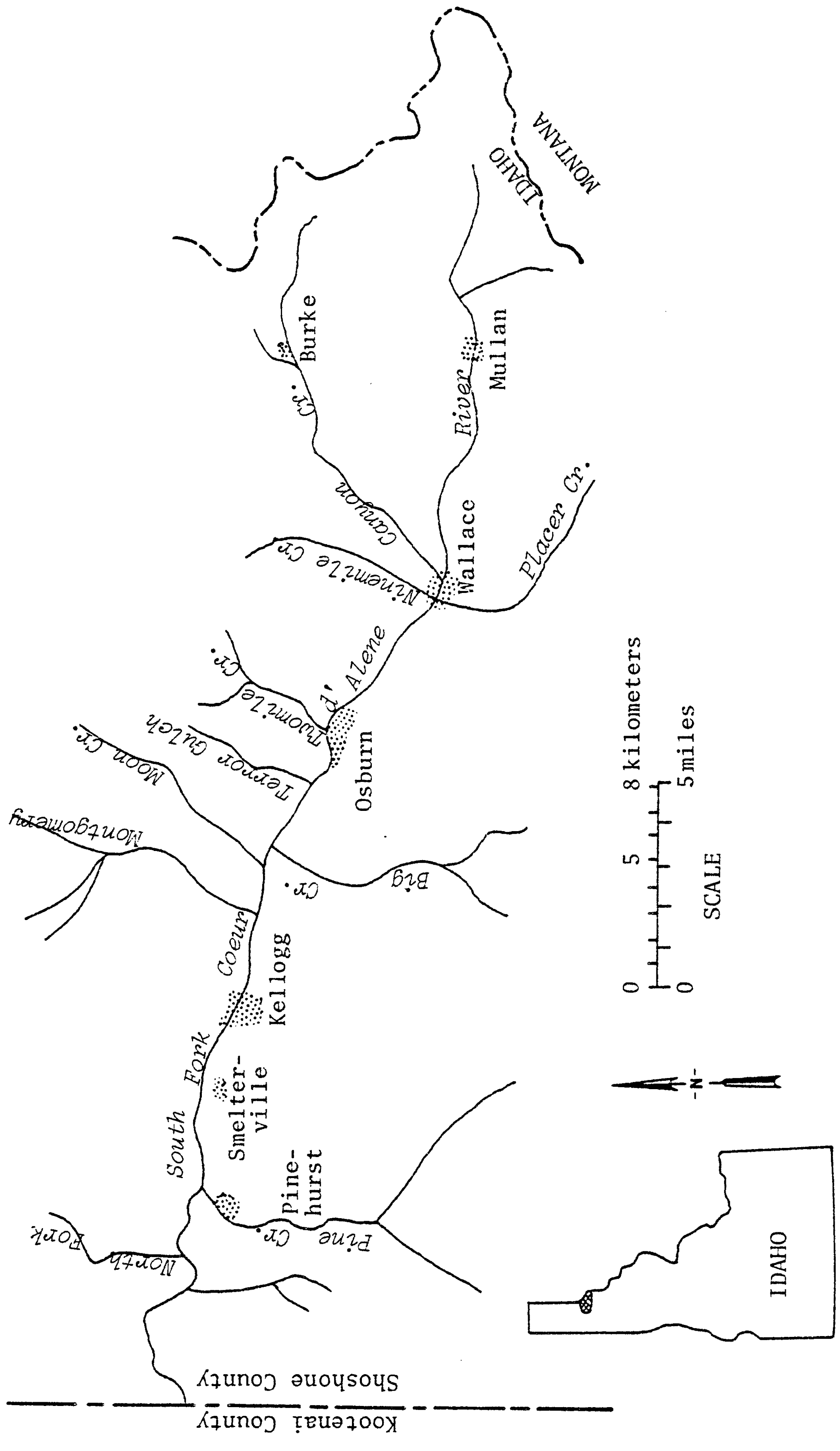


Figure 1. Map of the Coeur d'Alene Mining Area, Idaho

It is generally believed that mining in the Coeur d'Alene District will continue for at least 50 more years. Additional areas for tailings disposal will be required during this period if mining is to continue.

Economically viable alternative methods of disposal are needed that would not preclude other uses of the disposal area at a later time. Several methods of disposal are available. Briefly, these methods are:

1. Construction of additional tailings ponds for disposal of tailings in the same manner as is now done. New ponds would have to be built in the valley of the South Fork Coeur d'Alene River to replace present ponds as they are filled.
2. Underground disposal of tailings in mined areas. This method is already being used to the extent possible without interfering with potential future mining. Excess tailings must be disposed on the surface.
3. Disposal of tailings in uninhabited areas upstream from the minds. Lack of flat land and costs involved with transporting tailings upstream inhibit disposal of tailings in this manner.
4. Deposition of tailings as a backfill material in a controlled environment on the floodplain of the South Fork by backfilling. Tailings would be deposited in an area only until the thickness was sufficient to raise the land surface from its present flood-prone level to a higher level that might stimulate development for residential, industrial or recreational uses.

Disposal of mill tailings by backfilling in a controlled environment on the floodplain of the South Fork of the Coeur d'Alene River would be advantageous for several reasons.

1. Additional areas for disposal of tailings from future mining will be available.
2. Uncontrolled tailings now occupying the floodplain of the South Fork could be stabilized. Disposal of tailings by backfilling a controlled environment on the floodplain would require construction of a sturdy dike to contain the tailings and reduce the potential for tailings erosion during floods. Construction of a dike would result in a channelized river, unable to rework uncontrolled tailings under the backfilled areas. Visual improvement of the South Fork following revegetation of the backfilled areas will be an added benefit.
3. Usable flat land on the valley floor above the flood stage of the South Fork will be created. Reclaimed areas could conceivably be used for industrial, residential, and/or recreational purposes.

Mill tailings in the Coeur d'Alene Mining District have the demonstrated potential for acid production and associated degradation of the groundwater and surface water in the vicinity of the disposal areas. Deposition of acid producing tailings on the valley floor in controlled environments by a backfilling technique could create environmental problems as the acid moved through the alluvial material and into the surface water-groundwater systems adjacent to the disposal site. The environmental suitability of the tailings as a backfill material can be determined from the potential for acid production of the tailings. Tailings with a low potential for acid production would be the most suitable for use as a backfill material. This thesis is directed toward delineating the potential for acid production from tailings of each of the active mills in the area.

Purpose and Objectives

The purpose of this thesis is to delineate the potential for acid production from tailings from each of the mills in the area and recommend design criteria for disposal of these tailings.

General objectives of this thesis are:

1. Determine the potential for acid production from tailings from active mills in the Coeur d'Alene mining area.
2. Recommend design criteria for disposal of mill tailings by land backfilling.

Specific objectives of this thesis are:

1. Review the principles of acid production from mill tailings; delineate the controlling factors in the formation of acid from mill wastes typical of the Coeur d'Alene district.
2. Sample and analyze tailings from mills in the district.
3. Describe the potential for acid production from tailings based upon mineralogical content and results of beaker experiments.

4. Recommend methods for disposal of tailings by land backfilling such that potential water pollution problems will be minimized.

Methods of Study

Tailings samples were collected from the six active mills in the Coeur d'Alene mining area. Tailings from the active mines were examined under a microscope to determine the mineralogical composition of the samples. Percentages of carbonates in the tailings from all of the sample sites were determined by heating tailings in concentrated hydrochloric acid. Percentages of sulfides were determined by heating tailings in concentrated nitric acid.

Beaker experiments were performed using tailings from the active mills. A small amount of tailings were placed in a beaker with distilled water. The pH of the solution was measured periodically over a three-week period. At the end of three weeks, water from the beakers was tested for acidity, alkalinity, and sulfate concentration. Acid production was indicated by high levels of sulfate and acidity and low levels of alkalinity. Possible designs for tailings disposal sites were evaluated based upon the consideration of the acid producing potential of the tailings and the typical controlling factors of the disposal areas.

Geologic Setting

Regional Geology

The Coeur d'Alene mining district is an east-west belt, approximately 50 kilometers long by 15 kilometers wide, in the Coeur d'Alene Mountains of northern Idaho (Figure 2). The district lies on the western edge of a 500 square-kilometer block of ancient siliceous sedimentary rocks known as the Belt Series. The rocks of the Belt Series are metamorphosed quartzites and argillites formed from sands and muds that were deposited in a sinking shallow sea in the Algonkian part of the Precambrian Era. No fossils are found in the Belt Series. Mud cracks and ripple marks are abundant. The rocks of the Belt Series are believed to be about 1,500 million years old (Cook, 1963). A generalized section of the Belt Series in the Coeur d'Alene mining district is given in Table 1.

The generally accepted theory of the origin of the Coeur d'Alene ores is as follows. In Cretaceous times, approximately 100 million years ago, several small granitic stocks invaded the Belt Rocks in this area. These stocks were probably outliers of the Idaho Batholith of the south. Previous to this, faulting along the Lewis and Clark Line, between Coeur d'Alene, Idaho, and Missoula, Montana, had taken place. This movement is locally represented by the Osburn fault and branching faults. The metalliferous ores were deposited by thermal solutions flowing from the intruded stocks. The ore deposits occur as tabular veins along or adjacent to steeply dipping fault shear zones (Hobbs et al., 1965).

Two types of ore are found in the district: 1) lead and zinc sulfides with subordinate tetrahedrite, in which the lead and zinc are the

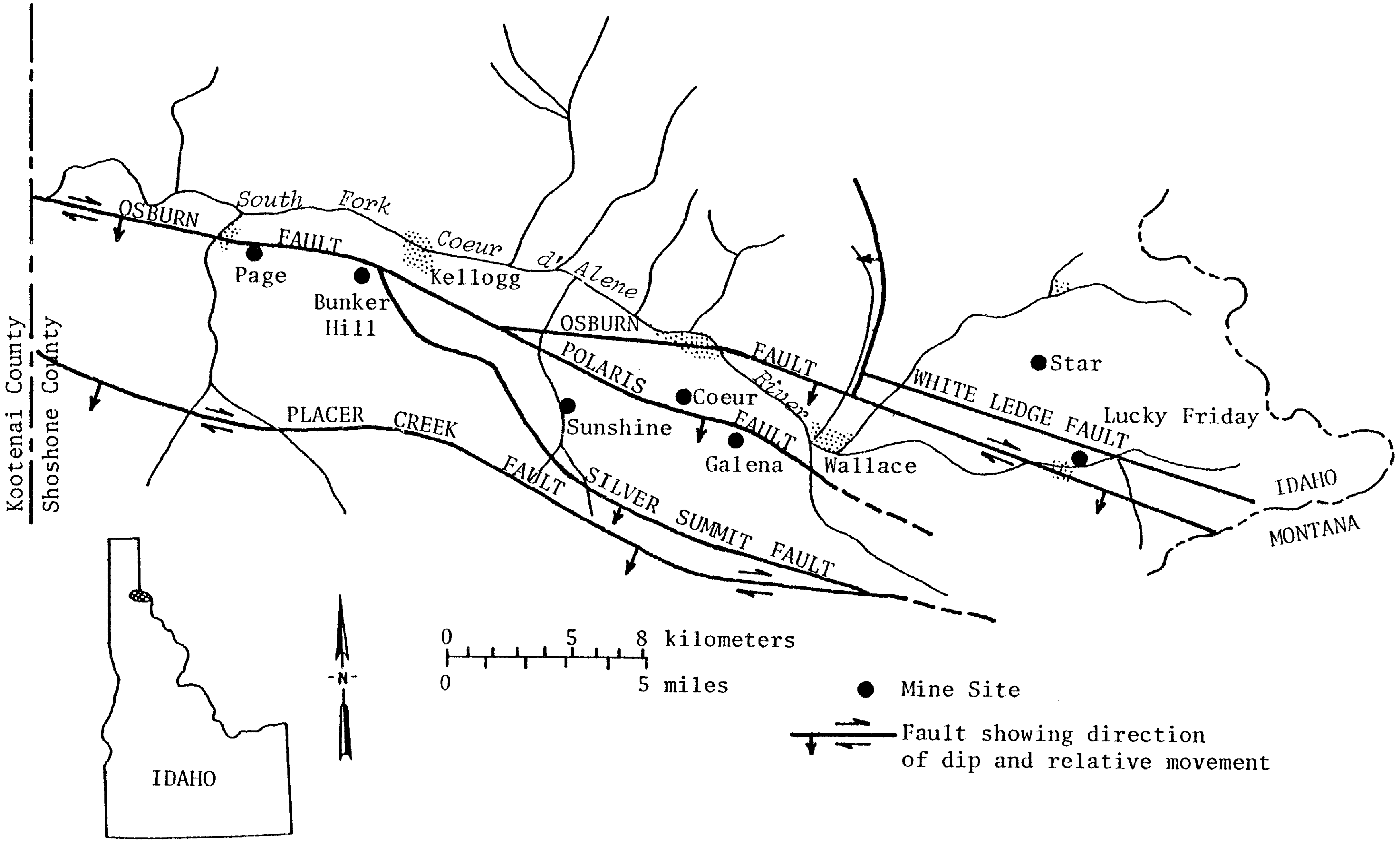


Figure 2. Location of Major Faults and Mine Sites in the Coeur d'Alene Mining Area

Table 1
Characteristics of the Belt Series, Coeur d'Alene Mining Area

Group	Formation		Lithology	Thickness (ft)	Thickness (m)	Ore-bearing
Missoula	Striped Peak Formation		Interbedded quartzite and argillite with some arenaceous dolomitic beds. Purplish gray and pink to greenish gray. Ripple marks, mud cracks common, top eroded.	1,500+	457+	No
Ravalli	Wallace Formation	Upper Part	Mostly medium- to greenish dray finely laminated argillite. Some arenaceous dolomite and impure quartzite, and minor gray dolomite and limestone in the middle part.	4,500-6,500	1,372-1,981	Yes, but limited.
		Lower Part	Light-gray more or less dolomitic quartzite interbedded with greenish-gray argillite. Ripple marks, mud cracks abundant.			
	St. Regis Formation	Upper Part	Light greenish-yellow to light green-gray argillite; thinly laminated. Some carbonate-bearing beds.	1,400-2,000	427-610	Yes
		Lower Part	Gradational from interbedded argillite and impure quartzite at top to thick-bedded pure quartzite at base. Red-purple color characteristic; some green-gray argillite. Some carbonate-bearing beds. Ripple marks, mud cracks, and mud-chip breccia common.			
	Revett Formation		Thick-bedded vitreous light yellowish-gray to nearly white pure quartzite. Grades into nearly pure and impure quartzite at top and bottom. Cross-stratification common.	1,200-3,400	366-1,036	Yes
	Burke Formation		~~Light~~ greenish-gray impure quartzite. Some pale red and light yellowish-gray pure to nearly pure quartzite. Ripple marks, swash marks and pseudoconglomerage.	2,200-3,000	571-914	Yes
	Prichard Formation	Upper Part	Interbedded medium-gray argillite and quartrose argillite and light-gram impure to pure quartzite. Some mud cracks and ripple marks.	12,000+	3,658+	Yes
		Lower Part	Thin to thick-bedded, medium gray argillite and quartrose argillite, laminated in part. Pyrite abundant. Some discontinuous quartzite zones. Base buried.			

*From Hobbs et al., 1965, p. 14.

most important economically, and 2) silver-bearing tetrahedrite sometimes with associated galena, in which silver is commercially more important. The principal gangue minerals are quartz, siderite, ankerite, and pyrite. The lead-zinc ores are found north of the Osburn fault in the Wallace-Burke-Mullan area, and south of the Osburn fault in the Wardner-Kellogg-Pink Creek area. The silver ores are found in the Silver Belt, a structural and mineralogical subdivision of the Coeur d'Alene district. The Silver Belt lies between Wallace and Kellogg, and is founded on the north by the Osburn fault and on the south by the Placer Creek fault (Reid, 1961).

Geology of Active Mines

Material for this section was abstracted primarily from Reid (1961), Cook (1963), and E&MJ (1980a, 1980b).

Sunshine. The Sunshine Mine is located on Big Creek, south of the Osburn fault, at the west end of the Silver Belt. The Sunshine Mine is the largest primary silver mine in the United States.

Veins in the mine occur in three formations of the Belt Series: the Wallace, St. Regis, and Revett formations. Production from the Wallace formation is minor because ore shoots are generally too short and narrow to be mined economically. Most of the mine's production has come from the St. Regis and the top 250 meters of the Revett. A 90 to 120-meter wide zone near the contact of the St. Regis and Revett is especially productive.

Ore deposits occur in long narrow veins containing sulphides of silver, copper, and lead in a carbonate and quartz gangue. The principal ore mineral is argentiferous tetrahedrite occurring as fracture fillings and narrow veinlets in a gangue of massive siderite and quartz. Except where truncated by faults, the extent of mining along the ore shoots is dictated by economics. Widths of the veins varies but is generally from 1/2-2 meters.

Galena. The Galena Mine is located 4 kilometers west of Wallace and 2-1/2 kilometers south of the Osburn fault. The Galena intercepts ore bodies within the Revett and St. Regis formations. Ore is developed at the same rate as extraction to maintain 6 years of reserves.

Veins in the Galena Mine contain siderite and minor amounts ot tetrahedrite, chalcopyrite, galena, pyrite, quartz, and arsenopyrite. The siderite has replaced the county rock along joints and fractures. Other mineralization took place at a later date by replacement of the siderite.

The targets for development are the siderite veins containing economic deposits of tetrahedrite. These veins generally contain lesser amounts of chalcopyrite and galena. The veins are almost vertical and range in width from 1/2-3 meters.

Coeur. The Coeur Mine is located on the Osburn fault, between the Galena and Sunshine Mines, southeast of Osburn. Like the Galena, the Coeur develops ore at the same rate that mining takes place. An ore reserve of approximately 7 years is maintained.

The production veins in the Coeur are south of the shaft in a quartzite rock zone in the footwall north of the Polaris fault. The veins consist of siderite, quartz, tetrahedrite, chalcopyrite, and pyrite. The most important ore minerals are tetrahedrite and chalcopyrite.

Bunker Hill. The Bunker Hill mine is located southwest of Kellogg. The mine consists of 620 claims totaling 2,500 hectares. More than 20 major ore bodies have been or are being mined. Annual production is approximately 113,000 metric tons of lead, 20,000 metric tons of zinc, 275-350 metric tons of silver, more than 450 metric tons of cadmium, and many byproducts.

Most of the ore comes from the lower St. Regis formation. The important vein minerals are galena, sphalerite and tetrahedrite. Common gangue minerals are siderite, quartz and ankerite. Ore composition varies greatly between ore bodies.

Lucky Friday and Star. The Hecla Mining Company operates both of these mines. The Lucky Friday is located about 1.5 kilometers east of Mullan. The Star is about 3 kilometers northwest of Mullan. Both mines are north of the Osburn fault. The company maintains 4-5 years of ore reserves by developing as much or more minable ore than is extracted each year.

The Lucky Friday mine is sited on an ore shoot regularly averaging 10-12% lead and more than 450 grams of silver per metric ton. Galena is the dominant vein mineral. Tetrahedrite occurs as the main silver bearing mineral.

In the Star mine, ore has been extracted from ore bodies in more than 20 veins. Vein minerals are sphalerite and galena which average 4-6% each of lead and zinc along with 50-100 grams of silver per metric ton. Workings at the Star mine are the deepest in the Coeur d'Alene with active mining at the 2,400-meter level and development at 2,470 meters.

Gangue minerals at both the Lucky Friday and Star mines are: quartz, siderite, pyrite, and occasionally magnetite. The vein(s) at both mines are contained in the St. Regis-Revett contact zone. Ore bodies at both mines are quite persistent. There appears to be no end in sight for mineralization other than economic and technical limitations of mining at great depths.

CHAPTER II

REVIEW OF PREVIOUS STUDIES

Introduction

Acid formation related to mining activities has been extensively studied in coal mining areas in the eastern United States. The same types of chemical reactions that have been documented in the coal mining areas occur at hard rock mines in the western United States. Many studies of acid formation have been conducted in the Coeur d'Alene mining area. Recent studies of the occurrences and treatment of acid were made by Reece (1974), Trexler (1975), and Marcy (1979). Some of the studies of tailings ponds that have taken place in the last decade are: Mink (1972), Rouse (1977), Williams et al. (1979), and Norton (1980). Extensive bibliographies of acid mine drainage can be found in: Appalachian Regional Commission (1969), Skelly and Loy (1973), Williams (1975), Water Resources Scientific Information Center (1975), and Martin and Mills (1976).

Occurrence and Treatment of Acid in Mine Drainage Waters

Many minerals that are mined occur near or in association with pyrite. Pyrite oxidizes in the presence of oxygen and water to form soluble acid salts which can be transported to ground or surface water systems. The receiving water will become acidic if there is an abundance of these salts and little alkalinity available in the water.

Formation of Acid

Pyrite oxidation takes place at very slow rates in a naturally reducing environment. During mining, pyrite becomes exposed to air in underground workings, or above ground in open pits, overburden piles, and tailings piles. Acid can be formed at any of these locations if the pyrite comes in contact with oxygen and water.

The basic reactions of pyrite exidation are well known. The reactions as given by Martin and Mills (1976) are presented below.

$$FeS_{2(s)} + 7/2\ O_2 + H_2O \rightarrow Fe^{+2} + 2SO_4^{-2} + 2H^+ \qquad (1)$$

pyrite → ferrous iron

$$Fe^{+2} + 1/2\ O_2 + H^+ \rightarrow Fe^{+3} + 1/2H_2O \qquad (2)$$

ferrous iron → ferric iron

$$Fe^{+3} + 3H_2O \rightarrow Fe(OH)_3 + 3H^+ \qquad (3)$$

ferric iron → ferric hydroxide

$$FeS_{2(s)} + 14\ Fe^{+3} + 8H_2O \rightarrow 14Fe^{+2} + 2SO_4^{-2} + 16H^+ \qquad (4)$$

pyrite + ferric iron → ferrous iron

These equations represent the gross stoichiometry of the reactions that occur in a mine or waste pile where pyrite is exposed in oxygen and water. The equations do not indicate intermediate products, mechanisms, rates of reaction sites. When pyrite is exposed to oxygen and water, the sulfide is oxidized to sulfate releasing acid, sulfate, and ferrous iron (equation 1). The ferrous iron is oxidized to ferric iron (equation 2). At normal pH ranges (6-8) ferric iron hydroloyzes forming acid and insoluble ferric hydroxide, also known as "yellow boy."

An alternate pathway for pyrite oxidation is shown by equation 4. Ferric iron, dissolved due to the low pH of the solution from the initial formation of acid, oxidizes the sulfide to sulfate and is reduced to the ferrous form.

Summing equations 1 through 3 (shown in equation 5) shows that the oxidation of one mole of pyrite produces four equivalents of acidity.

$$FeS_2 + 12/4\ O_2 + 7/2H_2O \rightarrow Fe(OH)_3 + 2H_2SO_4 \qquad (5)$$

The rate determining step in the process is the oxidation of ferrous iron to ferric iron, as shown in equation 6.

$$Fe^{+2} + O_{2(aq)} \rightarrow Fe^{+3} \qquad (6)$$

The kinetics of this equation are important in controlling acid formation. The rate of transport of oxygen to the pyrite crystal, surface area of the crystal, rate of oxidation of pyrite by oxygen, and presence of catalyst will determine the rate of the reaction.

Oxygen is transported to the pyrite crystal by two methods: convective transport includes the renewal of oxygen at the surface of a refuse pile by air currents, and the breathing of a semi-confined gas volume due to changes in atmospheric pressure. Molecular diffusion through a gas mixture occurs as a result of the gradient in the oxygen concentration formed following reaction 1. If the surface of the pyrite crystal is covered with water, oxygen will also have to diffuse through the water layer. A water barrier is about 300,000 times more effective than an air barrier to oxygen diffusion. This indicates that when a pyrite surface is submerged under water, than an effective barrier to pyrite oxidation is established (Marcy, 1979).

March (1979) reports that reaction rates are greater for smaller grain sizes. This indicates a relation between surface area and the number of reaction sites. The size factor is important when dealing with tailings that have been crushed to very small sizes.

The rate of ferrous iron (Fe^{+2}) oxidation is a function of pH in abiotic systems and is slow. The reaction is catalyzed by *Thiobocillus ferrooxidans*, *Thiobacillus thiooxidons*, and/or *Ferrobacillus ferrooxidons*. The reaction rate may be accelerated by a factor of more than 10^6 (Singer and Stum, 1970).

Transport of Oxidation Products

The major problem of acid formation is the migration of acid from the reaction site to the surrounding environment. Two steps have been recognized in the removal of oxidation products from reaction sites. The products are initially removed from the surface of the pyrite crystals by movement of absorbed water in the unsaturated zone. The products are then flushed from the reaction sites by water infiltrating down from precipitation or by fluctuations of groundwater levels.

Flushing of a system may cause temporary flooding of the oxidation sites, decreasing the rate of oxidation. As the reaction sites become flooded, the reaction shown in equation 3 occurs.

Neutralization of Acid by Natural Buffering

Alkalinity is the ability of water to neutralize acid. The principal sources of alkalinity in most surface waters are carbonate and bicarbonate.

Alkalinity is released into surface waters by the dissolution of minerals, particularly limestone.

Carbon dioxide, from the atmosphere, combines with water to form carbonic acid as shown in equation 7. Carbonic acid partially dissociates to hydrogen ion and bicarbonate as shown in equation 8. These reactions continue until equilibrium is attained.

$$H_2O + CO_2 \rightleftarrows H_2CO_3 \qquad (7)$$

$$H_2CO_3 \rightleftarrows H^+ + HCO_3^- \qquad (8)$$

As a result of these reactions, natural water becomes slightly acidic. If this water comes in contact with calcereous materials, such as limestone, the following reaction takes place:

$$CaCO_{3(s)} + H^+ + HCO_3^- \rightarrow Ca^{+2} + 2HCO_3^- \qquad (9)$$

The degree of carbonation, along with the potential for reaction with calcereous materials, forms the buffer system of most natural waters. When acid from pyrite oxidation is added to the natural system, the system reacts as shown below:

$$H^+ + SO_4^{-2} + Ca^{+2} + HCO_3^- \rightarrow Ca^{+2} + SO_4^{-2} + H_2O + CO_2 \qquad (10)$$

The natural buffering system can be destroyed if the amount of acid added is greater than the buffering capacity of the system. If this occurs, the pH will drop to a low value until the buffering system is restored by dissolution of carbon dioxide in the water.

Methods of Preventing and Treating Acid Formation

Treatment and abatement techniques for acid drainage fall into five categories: 1) preventing or reducing the formation of acid at the source, 2) controlling the flow of water through the tailings, 3) containing polluted waters, 4) dilution of the acid to achieve effluent quality, and 5) treating the waste water using techniques which will neutralize the acid and remove dissolved and suspended solids (Williams, 1975).

Controlling Acid Formation. There are two categories of control for the oxidation of ferrous iron: thermydynamic control and kinetic control. Thermodynamic control involves the elimination of oxygen and maintenance of reducing conditions at the reaction sites. Kinetic control involves the suppression of catalytic agents, in this case, the sulfide metabolizing bacteria. Zawadzki (1968), Hartford (1970), and Aleem (1972) discuss methods of eliminating the catalysis provided by the sulfide metabolizing bacteria.

Infiltration Control. The quality of water flowing through tailings may be reduced by lowering of the pH and an increase in the concentration of heavy metals. The magnitude of the problem may be reduced by controlling flow through the tailings pile. Methods of controlling flow include: surface blankets for tailings, surface water diversion, and groundwater diversion.

Surface blankets and impermeable barriers placed on tailings will reduce or prevent percolation of rainfall and snowmelt into the tailings. The availablity of air to the pyrite is also reduced. Impermeable barriers are generally a synthetic membrane such as HYPALON or PVC.

Surface blankets have low permeabilities. Chemical soil sealants and clay layers are examples of low permeability surface blankets (Alpin and Argall, 1973).

Diversion of surface water around tailings piles will reduce erosion of and recharge to the tailings. Diversion of surface water can be accomplished by several methods. A stream may be relocated in a newly excavated channel. It may be routed through artificial structures, such as culverts or concrete channels. Water flowing into tailings from higher ground may be rerouted around the tailings by ditches, preventing recharge to the tailings.

Reduction of hydraulic head in groundwater flow systems can be employed to reduce the volume of water seeping into a tailings pile. A thorough understanding of local and regional flow systems is needed before this technique can be implemented. More information on dewatering can be found in Martin and Mills (1976), Skelly and Loy (1973), and U.S. Environmental Protection Agency (1975a).

Fluctuations in groundwater levels may create conditions where tailings are alternately flooded and dewatered. The rise and fall of groundwater levels flush oxidation products from the tailings and remove heavy metals that have been leached from the tailings. Pumping of groundwater around the tailings will lower the phreatic surface in the tailings. The cost of pumping may be prohibitive. Installation of collector drains prior to tailings disposal may be a method of maintaining the phreatic surface below the tailings. Alternatively, groundwater levels may be raised to continually maintain the site in a flooded condition.

Methods of Containing Polluted Waters. In areas where the annual evaporation exceeds annual precipitation, containment of mine drainage in evaporation ponds may be an effective means of treatment. A constructed pond with an impermeable bottom would allow the poor quality water to evaporate and prevent its transfer into the surrounding water resource systems. The dissolved constituents would precipitate out of solution and eventually be removed for disposal or recovery.

Lakes constructed in abandoned surface mines can become sites for propagation of aquatic life and water-related recreation. The objective of the design is to cover all acid-forming minerals by water in the lake occupying the mined area. The method is analogous to sealing and flooding an underground mine.

Dilution of Polluted Waters. Dilution of acid drainage to improve the quality of the water was once a common method of treatment. The acid water was allowed to enter streams and become naturally diluted. Streamflow was sometimes regulated to combine high streamflows with the release of acidic waters. Legislation to control the quality of point sources of waste water has effectively halted this practice. Dilution of waste water must now take place prior to releasing it into a stream. Since premixing is not feasible in most instances, this method is no longer used.

Neutralization of Acidic Water. Neutralization is the adjustment of pH using lime or limestone. Soda ash, caustic soda, and anhydrous ammonia can be used in place of limestone or lime in the neutralization process but are much more expensive. A simple representation of the process is given by equation 11.

$$H_2SO_{4(L)} + CaCO_{3(s)} \rightarrow CaSO_{4(s)} + H_2O_{(L)} + CO_{2(g)} \qquad (11)$$

Neutralization reduces the acidity and decreases the concentration of sulfates in treated water. There still remains a problem of disposal of the calcium sulfate sludge. Williams (1975) presents a treatment operation for waste water composed primarily of acid mine drainage.

Coeur d'Alene River Water Quality Studies

In July, 1932, Ellis found no live fish in the Coeur d'Alene River from the mouth to the confluence of the North and South Forks or in the South Fork below Wallace. The river channel at Cataldo Mission was only 3.5-4.5 meters deep. During 1912 to 1917, the channel was reported to be 12-15 meters deep (Ellis, 1940). Apparently, the depth of tailings deposited as sediments was more than 8 meters at the site.

Chupp (1956) conducted a survey to find the extent and cause of waterfowl mortality along the main stem of the Coeur d'Alene River. His study revealed appreciable amounts of lead and zinc in the soil, plants, and water of the lower Coeur d'Alene Valley. Tissue analysis from a number of dead waterfowl collected in the area showed abnormally high amounts of lead.

A study of water quality in the South Fork initiated by the University of Idaho in December, 1968, showed toxic limits for fish were exceeded by Zn and Cd. Concentrations of most other elements were slightly higher or comparable to concentrations in the North Fork of the Coeur d'Alene

River above the confluence. Data indicated two main sources of metals: Canyon Creek near Wallace and the South Fork east of Smelterville. A third source, during high flows in the South Fork, is tailings deposited on the valley floor of the South Fork and its tributaries (Mink, 1971).

Heavy metals accumulate in plants that draw groundwater from the tailings and natural alluvium mixture that covers much of the valley floor. Redtop (Agrostis alba), a grass that grows abundantly in the waste-alluvium mixture, was found to accumulate Zn, Pb, Mn, Fe, Cu, Ag, and Mg. Animals eating Redtop showed symptoms of metal poisoning. Metal poisoning was verified when bone marrow from a horse, diagnosed as having lead poisoning, showed high lead concentrations (Galbraith, 1971).

Sceva and Schmidt (1971) conducted a water quality study of the South Fork for the EPA. They found that Bunker Hill operations at Kellogg and Smelterville were by far the largest source of metals being discharged into the South Fork. Operations at the Lucky Friday, Dayrock, Consolidated Silver, Cresent, and Sunshine mines and the Hecla mill had relatively minor effects on the South Fork. Groundwater percolating through old tailings in Canyon Creek, Ninemile Creek, and the South Fork valleys was found to contribute substantially to the zinc quantities in the Coeur d'Alene River.

The construction of tailings ponds improved the quality of water in the South Fork by eliminating the dumping of mine wastes on the floodplain or in the river. Studies (Mink, 1972) have shown that correctly managed tailings ponds are effective in improving the general quality of water in the South Fork, especially suspended solids.

The EPA conducted a survey of water quality of the Coeur d'Alene River in 1975. The conclusions of that study were (EPA, 1975b, pp. 48-49):

1. The number one problem in the Coeur d'Alene basin is heavy metal loading. High concentrations of Pb, Cd, As, Hg, Sb, and Zn can be directly attributed to the mining activities along the South Fork of the Coeur d'Alene River.
2. The Bunker Hill Company was determined to be the largest contributor of heavy metals loading in the river. The levels of Zn, Cd, Pb, Fe, F, and P increase immediately downstream of the Bunker Hill Company operations.
3. The majority of heavy metals loading for Zn and Cd originated from uncontrolled inflows attributable to the Bunker Hill Company. These include seepages from tailings ponds, unpermitted discharges, and violations of permitted discharges.
4. The highest levels of As and Sb were found downstream of Big Creek, where the Sunshine Mining operation is located.
5. Zinc concentrations exceed the concentration generally toxic for a salmonoid fishery (300 μg/l) and the algacidal level (800 μg/l) throughout most of the South Fork waters. Cd and Pb also exceed EPA's hazard levels for their respective parameters for an aquatic environment.
6. Phosphorous levels exceed the level for potential algal blooms below the Bunker Hill operations. The zinc levels in this same reach are much greater than the algacidal level.
7. The waters of the South Fork below Wallace and the main stem of the Coeur d'Alene River below the confluence of the

North Fork and South Fork are acutely toxic to Rainbow Trout. The toxicity is believed to be due to the high concentration of heavy metals throughout the area which are in excess of values known to be toxic to Rainbow Trout.

Tailings Pile and Mine Site Studies

Morilla (1975) studied the hydrogeologic factors controlling the movement of groundwater through the abandoned Page tailings pile. He determined the flow system of the tailings pile to be dynamic, responding rapidly to precipitation and periods of no recharge. Construction of a sewage treatment facility on the Page tailings site was begun in 1973. The facility treats sewage from most of the South Fork Valley. Filling of the unlined lagoons in July, 1974, resulted in a rise in local groundwater levels in the immediate area. Seeps and springs formed along the edges of the dikes (Hitt, 1974). High concentrations of Zn and other heavy metals were found in the seeps, showing that leaching and transport by groundwater takes place. Gross (1981) reported that heavy metals, especially zinc, are present in the tailings pile and the surrounding alluvium. Galbraith (1971) found concentrations of 105 ppm Zn and 1.0 ppm Pb in the Page tailings. The mean concentration of elements in mounded water from 11 samples around the Page pile was 40 ppm Zn and 0.5 ppm Pb. Morilla (1975) found similar concentrations in zinc. Norbeck (1974) found a mean zinc concentration of 33 ppm in three wells in alluvium up gradient from the pile. Infiltration from the unlined sewage treatment ponds, by raising the groundwater levels, may be reducing the rate of oxidation of sulfide ores in the lower portion of the pile.

Mink and Williams (1975) found that settling ponds receiving water only from the ore concentrating process were effective in reducing suspended solids. Outflows from these ponds do not contain toxic elements in dangerous concentrations. Settling ponds receiving other industrial wastes, in addition to wastes from the concentrating process, were not adequately reducing discharge of heavy metals of neutralizing pH. They also found that in some cases the rate of leaching the jig tails under settling ponds was increased due to recharge from ponds with poorly sealed dikes. A peripheral discharge system of tailings to the pond was found to minimize leakage and therefore reduce groundwater contamination.

Williams et al. (1979) conducted a comprehensive study of geohydrologic conditions in the vicinity of the Central Impoundment Area of the Bunker Hill Company. They found high concentrations of dissolved solids and metals in all of the seeps in the bank of the South Fork adjacent to the Central Impoundment Area. They also found a decrease in the water quality of the South Fork as it flowed past the Central Impoundment Area.

Gross (1981) investigated water quality at Lucky Friday impoundment No. 1 and the Galena tailings pond along Lake Creek. At the Galena pond, low concentrations of metals were found inside the pile. No significant changes in the water quality of Lake Creek were found between sampling stations above and below the tailings pile. At the Lucky Friday impoundment, water quality in the stream and impoundment indicated that the water quality of the South Fork was not adversely affected by the pond. No significant increase in metals was found in the South Fork as it passed the impoundment.

Norton (1980) dug pits to study the soil profiles and obtain samples at various depths in tailings at the Smelterville Flats. Norton concluded that: 1) the concentration of metals is independent of the grain size fraction of the alluvium, 2) the South Fork continues to rework and mix the mine waste through erosion and deposition processes, and 3) the quantity of metals leached and moved by groundwater in the Smelterville Flats is small compared to the metal content moved by the South Fork of the Coeur d'Alene River.

Leaching of Heavy Metals from Tailings and Soil

Leaching of metals by groundwater passing through mine tailings is initiated by the oxidation of sulfides. Groundwater entering the tailings system is usually neutral or slightly alkaline. Upon leaving the system (discharging into the Coeur d'Alene River) the pH is generally less than 7, demonstrating that the lowering of the pH of the groundwater was accomplished in the tailings deposit. Leaching of heavy metals from the sediments of the South Fork of the Coeur d'Alene River contributes to the poor quality of water in the river (Reece et al., 1978).

Heavy metals have been deposited on the soil in the area as fallout from smelter fumes. Water percolating down through the soil may carry some of the ions that were contained in the fumes into the groundwater system (Keely, 1979).

CHAPTER III

ACID PRODUCING POTENTIAL OF TAILINGS FROM THE COEUR D'ALENE MINING AREA

Introduction

Acid production from tailings from past mining operations has seriously affected 1) water quality and fisheries in the South Fork, 2) metal concentrations in soil and plants, and 3) groundwater quality in the Coeur d'Alene mining area. Containment of tailings in surface impoundments has alleviated some of these problems. Future mining is likely to continue in the same mines, from the same geologic strata, and from ore bodies having similar mineralogies. Therefore it seems reasonable to expect tailings from future mining operations to be similar to tailings from past mining operations.

Tailings were sampled from milling sources in the South Fork valley in 1979. At that time mills were active at the Bunker Hill, Sunshine, Coeur, Galena, Star, and Lucky Friday mines.

The potential for acid production from these tailings was determined by analysis of the tailings mineralogy and beaker experiments. The percentage of sulfide and carbonate minerals in each tailings sample was determined. Beaker experiments were performed to obtain water samples that had been in contact with tailings. Standard chemical analyses of the water samples were used to detect acid formation from pyrite oxidation in the tailings.

Beaker Experiments

Approximately 50 grams of each tailings sample from the active mines were placed in a beaker with 500 ml of deionized water. The samples were stirred with magnetic stirrers. The pH of the solutions was taken periodically over a four-week period. The pH values of the samples over time are presented in Table 2 and Figure 3. The pH of water changes rapidly during the first days in contact with tailings as the chemical equilibrium of the system is established. After a few days the pH of the solution approaches a constant value. A plot of pH versus time will produce a curve that becomes asymptotic to the equilibrium pH value (Reece, 1974).

Figure 3 shows that the pH of water in contact with tailings from five of the active mills (Sunshine, Galena, Lucky Friday, Star, and Coeur) approach neutral values after three to four weeks. Water in contact with tailings from one of the active mills (Bunker Hill) remained acidic throughout the entire period of the test.

Based on the results of monitoring the pH of water in contact with tailings, it appears that tailings from the Bunker Hill mill will cause water to become acidic. Water in contact with tailings from the other active mills will tend to have a neutral pH.

Water samples were taken from the beakers after three and four weeks. Acidity and alkalinity of these samples were determined by titration with sodium hydroxide and nitric acid to phenolphthalein and methyl orange endpoints, respectively. Sulfate was determined gravimetrically following precipitation with hot barium chloride. Analysis was done following standard methods (APHA, 1975). Acidity was determined as a measure of

Table 2

pH of Water in Contact with Tailings During Beaker Experiments

Elapsed Time (hours)	Bunker Hill	Sunshine	Star	Lucky Friday	Coeur	Galena
0.25	4.6	5.9	5.6	5.5	4.5	5.0
50	4.5	6.1	5.8	6.0	5.7	5.7
67	4.8	6.0	6.0	6.4	6.2	5.8
89	4.6	6.6	6.3	6.7	6.0	6.3
120	4.8	7.0	6.4	6.4	6.2	6.4
143	4.7	6.8	6.5	6.4	6.2	6.2
169	4.8	7.1	6.5	6.6	6.2	6.2
216	4.8	6.3	6.3	6.5	6.3	6.6
237	4.8	6.9	6.5	6.7	6.3	6.7
257	4.8	6.8	6.5	6.6	6.4	6.5
302	4.7	6.9	6.6	6.8	6.5	6.8
334	4.6	6.6	6.7	6.7	6.7	6.9
382	4.6	7.1	6.8	6.8	6.8	6.9
405	4.4	7.3	6.7	6.8	6.7	7.0
448	4.3	7.3	6.8	6.8	6.7	7.0
476	4.4	7.4	6.8	6.8	6.7	6.9
497	4.4	7.4	6.9	7.1	6.6	7.2
669	4.3	7.4	6.9	7.1	6.8	7.1

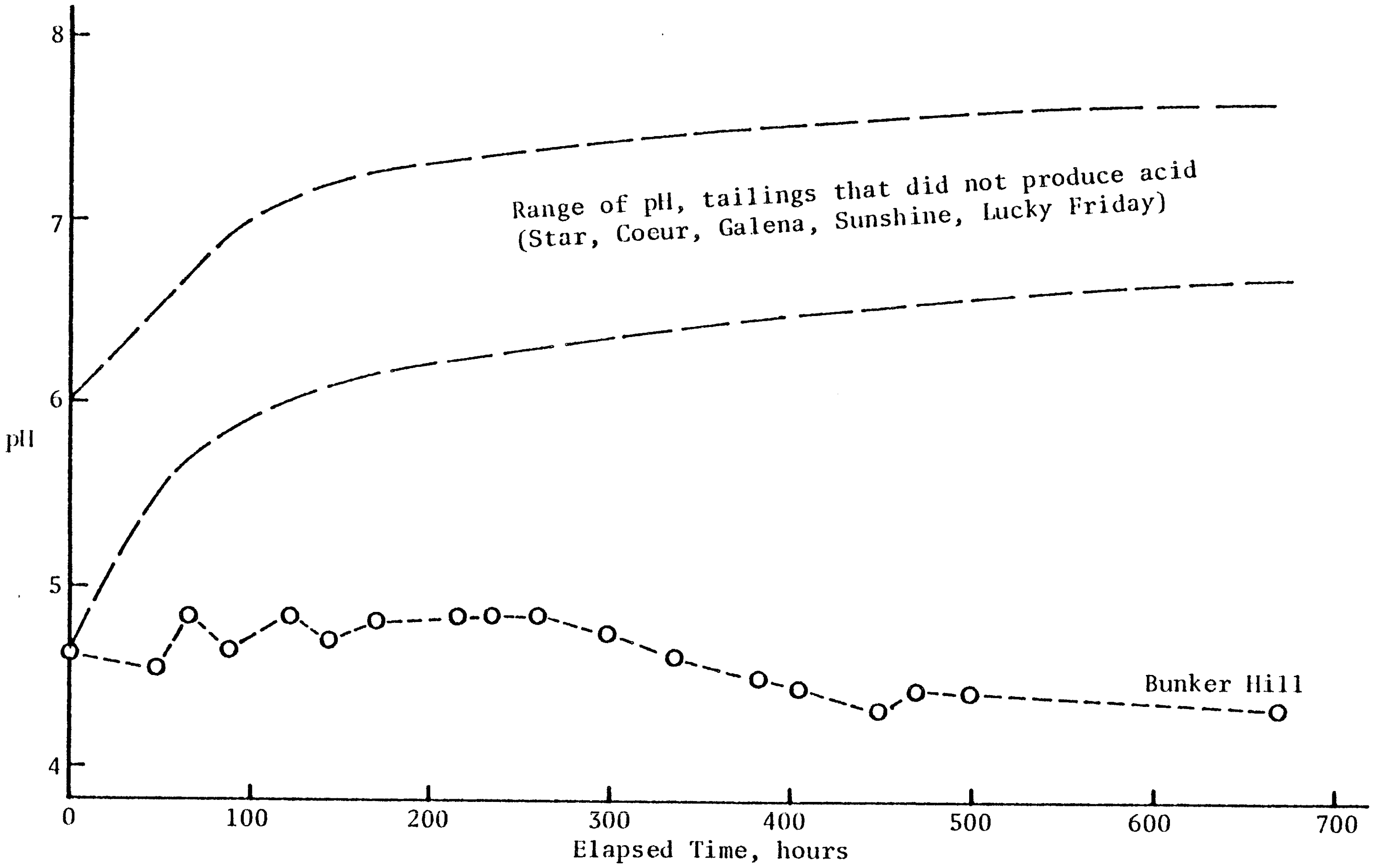


Figure 3. pH of Water Versus Time of Contact with Tailings from Mills in the Coeur d'Alene Mining Area

the amount of acid that was produced and not neutralized. Alkalinity was determined to give an indication of the amount of acid that could still be neutralized in the water. Sulfate ion is produced in the process of pyrite oxidation (equations 4 and 5); therefore, sulfate determination is an indirect measure of pyrite oxidation and acid formation. Tables 3 and 4 show the results of analyses of water samples for sulfate, acidity, and alkalinity.

The results of sulfate determination show that sulfate was present in all of the samples. This indicates that tailings from every active mill contained some pyrite which was oxidized to form sulfates. Because only a small amount of precipitate was formed during the sulfate analyses, the percentage of error may be high. Therefore, comparison of sulfate concentrations between samples may not be valid. Since precipitate was observed to form in every sample, the presence of sulfate can be verified. The concentration, as presented, may be in error.

The sulfate concentrations do not vary in proportion to the concentration of sulfide minerals in the tailings (Table 5). Several factors may affect sulfate concentrations. Other sulfide minerals may be present, primarily galena and sphalerite. These minerals oxidize more slowly than pyrite and may not have reacted within the time period of testing. This would result in a lower than anticipated sulfate concentration. Another problem in the sulfate determination may be the formation of gypsum during the beaker experiments by precipitation of $CaSO_4$. In this case, the concentration of sulfate ion in the water samples would be more of a reflection of the solubility product of $CaSO_4$ than the amount of pyrite that has been oxidized.

Analyses for acidity show that was in contact with tailings from the Bunker Hill mill had a significant level of acidity. Water samples that

Table 3

Results of Analyses of Water Samples
From Beaker Experiments After 497 Hours (3 Weeks)

Sample	pH	Sulfate mg/l $SO_4^=$	Acidity mg/l $CaCO_3$	Alkalinity mg/l $CaCO_3$
Bunker Hill	4.4	30	56	0
Sunshine	7.4	10	0	31
Star	6.9	80	0	9
Lucky Friday	7.1	50	0	27
Coeur	6.6	30	4	20
Galena	7.2	40	0	29

Table 4

Results of Analyses of Water Samples
From Beaker Experiments After 669 Hours (4 Weeks)

Sample	pH	Sulfate mg/l $SO_4^=$	Acidity mg/l $CaCO_3$	Alkalinity mg/l $CaCO_3$
Bunker Hill	4.3	120	52	0
Sunshine	7.4	60	0	40
Star	6.9	150	0	32
Lucky Friday	7.1	110	1	29
Coeur	6.8	80	2	22
Galena	7.1	136	0	29

were in contact with tailings from other sources had either low levels of acidity or no acidity. Acid produced by pyrite oxidation in all of the samples, except the Bunker Hill tailings, was neutralized by carbonates in the tailings. Bunker Hill tailings apparently produced more acid than could be neutralized by carbonates in the tailings, resulting in acidic water.

Tests for alkalinity show that water samples that had been in contact with the tailings from the Sunshine, Star, Lucky Friday, Coeur, or Galena mills would be able to neutralize acid. Water samples that had been in contact with Bunker Hill tailings had neutralized as much acid as possible and become acidic. As acid is formed, by pyrite oxidation, it is neutralized by carbonate in the water. The carbonate-bicarbonate buffering system in the water is maintained by dissolution of carbonate minerals in the tailings. A condition of zero alkalinity is reached when all of the carbonate minerals have dissolved and all of the carbonate in solution has reacted with acid in the water. Bunker Hill tailings were the only ones tested that produced sufficient acid to consume all of the carbonate in the tailings.

Acid formation at the Bunker Hill mine has been documented by several researchers (Reece, 1974; Rouse, 1977; Trexler, 1975; Williams et al., 1979). The other active mines have not had serious problems because of acid production. Some of these mines had had problems with poor quality water draining from tailings ponds, but generally low pH was not the cause for poor water quality.

Tailings Mineralogy

Samples of tailings from each of the six major active mills were mounted on slides and examined under a microscope. The tailings were found to consist of quartz, carbonates, and sulfides. Visual examination of the tailings showed that the carbonates were primarily siderite, and the sulfides were primarily pyrite (Schiebel, 1980). Minor amounts of sphalerite and galena may be present as a portion of the sulfide content. Other carbonate minerals present were ankerite and calcite.

Siderite dissolves in water to ferrous ion and carbonate ions. The ferrous ion can be oxidized to ferric ion (equations 2 and 3) resulting in the formation of acid. The carbonate ion from the siderite neutralized this acid. If all reactions go to completion the net effect of siderite on the pH is neutral.

Ankerite has an effect similar to siderite. In this case, metal ions which do not undergo hydrolysis are substituted for iron, the pH effect should be slightly basic. Ankerite should neutralize some acid water that it contacts.

Calcite has a very definite basic effect on water. It dissolves rapidly, releasing carbonate ions which undergo hydrolysis, consuming hydrogen ions, and calcium ions which remain unhydrolyzed (Reece, 1974). Calcite has a major ability to neutralize acid.

Pyrite has been shown to oxidize to sulfuric acid in the presence of oxygen and water (equation 5). The other sulfide minerals, galena and sphalerite, are present only in minor amounts and oxidize slowly (Reece, 1974). These minerals contribute only slightly to acidity.

The other major minerals in the tailings, quartz, is only slightly soluble and dissolves slowly. The pH of water is only slightly affected by contact with quartz for a long period of time.

The two minerals having the greatest pH effect are pyrite and calcite. Pyrite has a large acidic effect while calcite has a large basic effect. The other minerals should have only minor effects on the pH.

The percentage of each mineral constituent in the tailings was determined by treatment with hydrochloric and nitric acids. Samples of tailings, approximately 10 grams, were placed in a beaker. Concentrated hydrochloric acid was added. The samples were then heated to boiling. The carbonates, being soluble in HCl, were separated by filtering. The sample was then dried and weighed to determine the weight of carbonates in the original sample. The samples were then treated with hot nitric acid. The sulfide minerals, being soluble in HNO_3, were separated by filtering. After drying and weighing of the residue, the weight of sulfide in the original sample was determined. The residue at this point consisted of relatively pure quartz. A flow diagram of this procedure is given in Figure 4. The results of this analysis are given in Table 5.

Table 5
Percentage of Mineral Constituents
by Weight, Active Mines

Mine	Sulfide	Carbonate	Quartz
Bunker Hill	8	14	78
Sunshine	1	58	41
Star	1	19	80
Lucky Friday	<1	23	77
Coeur	3	47	50
Galena	3	50	47

The mineralogy of the tailings appears reasonable based on the geology of the area. Since the host rocks in the mines are primarily quartzites, a significant amount of quartz would be expected in the tailings. Carbonate is a gangue mineral at all of the mines, accounting for

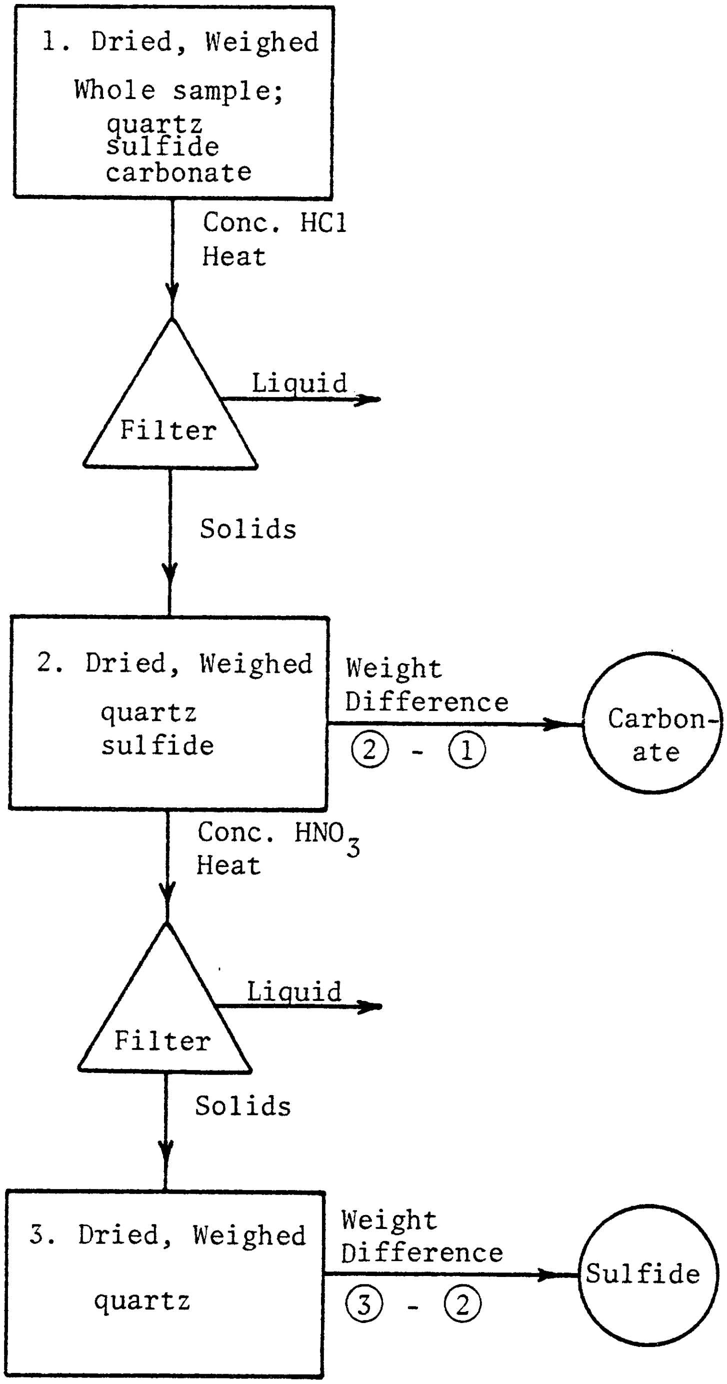


Figure 4. Flow Diagram for the Determination of Weight Percent of Mineral Constituents in Tailings Samples

its presence in tailings. Sulfide minerals are the target of mining operations. Some of the sulfides are broken down and removed in the concentrating process, leaving only the unwanted sulfides in the tailings.

Reece (1974) showed that tailings with a pyrite:calcite greater than 0.6 will produce acid. Tailings with a pyrite:calcite less than 0.6 will not produce acid. The mineralogy analysis as performed will not separate calcite from total carbonates or pyrite from total sulfides. Therefore pyrite:calcite ratios could not be computed for the tailings samples. Pyrite:calcite ratios would indicate the theoretical potential for acid production from tailings.

Tests for sulfate in water that had been in contact with tailings showed that tailings from all of the active mills produce acid. This is to be expected since all of the tailings contained pyrite. Analyses for acidity and alkalinity indicate that tailings from five of the active mills (Sunshine, Star, Lucky Friday, Coeur, and Galena) are capable of neutralizing the acid produced due to the presence of carbonates in the tailings. Tailings from the Bunker Hill mill, which have a large amount of sulfide relative to the amount of carbonate present, produce acid in excess of the amount that could be neutralized by carbinate minerals in the tailings. Sulfide:carbonate ratios in tailings from the other mines that do not produce acidic water are much smaller. Although sulfide:carbonate ratios cannot be used directly to predict potential acid production from tailings, they may be indicative of the pyrite:calcite ratios which can be used as an indicator of the potential for acid production.

CHAPTER IV

DESIGN OF SITES FOR DISPOSAL OF TAILINGS BY LAND BACKFILL

Introduction

Presently the method of tailings disposal is uniform throughout the Coeur d'Alene mining district. The coarse fraction of the tailings are separated by cycloning and used as backfill in the mine as much as possible. The fine tailings and the remainder of the coarse fraction, along with other mine and mill wastes, are discharged to a tailings impoundment. Typically the discharge takes place from a pipeline on the periphery of the dam. The coarser fraction settles out first, near the dam, and is available as a construction material to raise the height of the dam as the impoundment fills. The fine fraction, or slimes, settle out of the solution away from the dam and tailings discharge areas. This arrangement helps to keep the phreatic surface in the dam low, reducing the amount of seepage through the dam and minimizing the possibility of a dam failure. Water is allowed to decant from the impoundment after the tailings have settled (Kealy, 1970).

The impoundments presently used in the area will eventually be filled. New sites for similar types of impoundments will be needed or tailings will have to be disposed of in another manner. Impoundments now being used are located on the sites most desirable to the mining companies. The sites available for future construction of large impoundments are both less desirable to the mining companies and more desirable for other uses.

The areas proposed for use in the backfilling procedure are the large flat areas on the floodplain of the South Fork downstream from Wallace. These areas are generally undeveloped due to the danger of flooding by the South Fork. Channelizing the river and deposition of tailings as backfill on the flats in these areas would have the effect of: 1) reducing demand for already scarce, flat, usable land for residential/commercial building sites; 2) providing new areas for tailings disposal; 3) increasing the potential for recreational development of the area; 4) increasing the aesthetic value of the land; and 5) reducing the erosion of tailings that now occupy the valley floor.

Designs for Non-acid Producing Tailings

Laboratory tests indicate that tailings from the Sunshine, Star, Lucky Friday, Coeur, and Galena mines will not be acid producing. These tailings could be used as backfill material on the floodplain of the South Fork without creating a potential chemical hazard to the groundwater system or the river.

The main problem in using these tailings as backfill, from a pollution standpoint, would be the physical erosion of the tailings by wind and water. The erosion problems could be overcome. A dike of native material could be built completely around the area to be filled, to the elevation of the top of the tailings. This would leave only a flat surface at the top of the tailings exposed for erosion. Revegetation of this surface would greatly reduce the potential for erosion. Construction of buildings, parking lots, streets, recreational facilities, or any other covering over the tailings would prevent erosion from occurring.

Revegetation and/or building on the disposal site after backfilling has been completed would also make the area more visually aesthetic. The combination of increased protection from flooding and aesthetics should make the land much more desirable for development as industrial, residential, or recreational sites.

Revegetation of the tailings after deposition may be difficult. Since the tailings lack topsoil or nutrients necessary for plant growth, it will probably be necessary to adjust the pH, fertilize, and irrigate the tailings (University of Idaho, 1980; U.S. Environmental Protection Agency, 1976; and Farmer et al., 1976).

Another problem associated with the disposal of tailings on the floodplain of the valley is the construction of dikes around the tailings to protect them from flood events. Since every dike would have a probability for failure during a given flood event, the tailings are being placed on a site where a large flood could potentially destroy parts of the dikes and erode massive quantities of tailings. While disposal by this technique could not be made fail safe, the potential for failure could be made quite small.

An example of disposal of tailings by the backfilling technique is illustrated in Figures 5 and 6 which show a hypothetical plan and cross section for a backfill area bounded on one side by the valley wall and on the other side by the South Fork and freeway. The end boundaries are dependent on the extent of the undeveloped land. The thickness of the tailings must be sufficient to create a land surface higher than the floodplain. These figures are an example of a hypothetical means of tailings disposal. They do not represent a given site, but are indicative

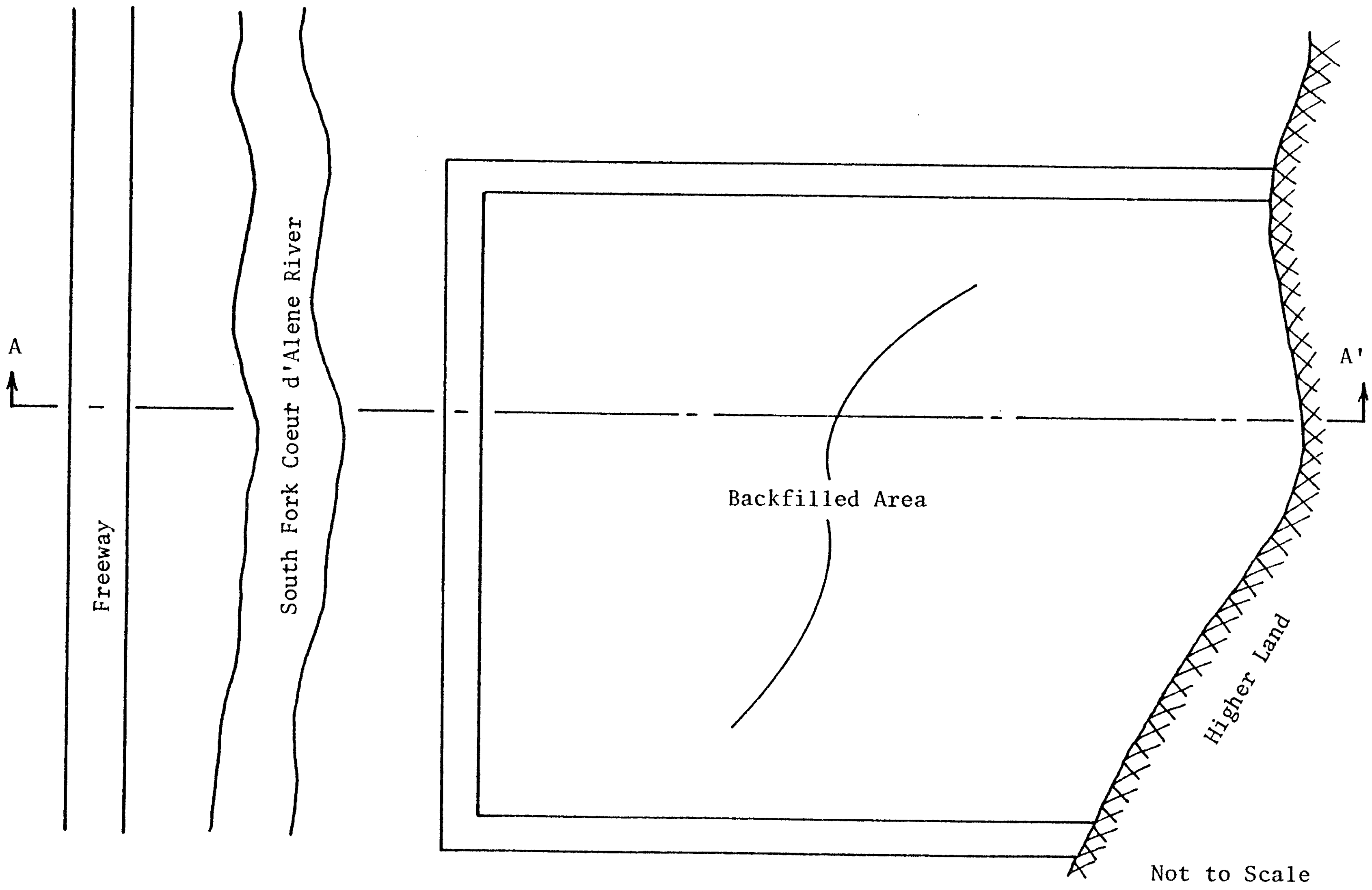


Figure 5. Hypothetical Plan View of a Backfilled Area on the Floodplain of the South Fork Coeur d'Alene River

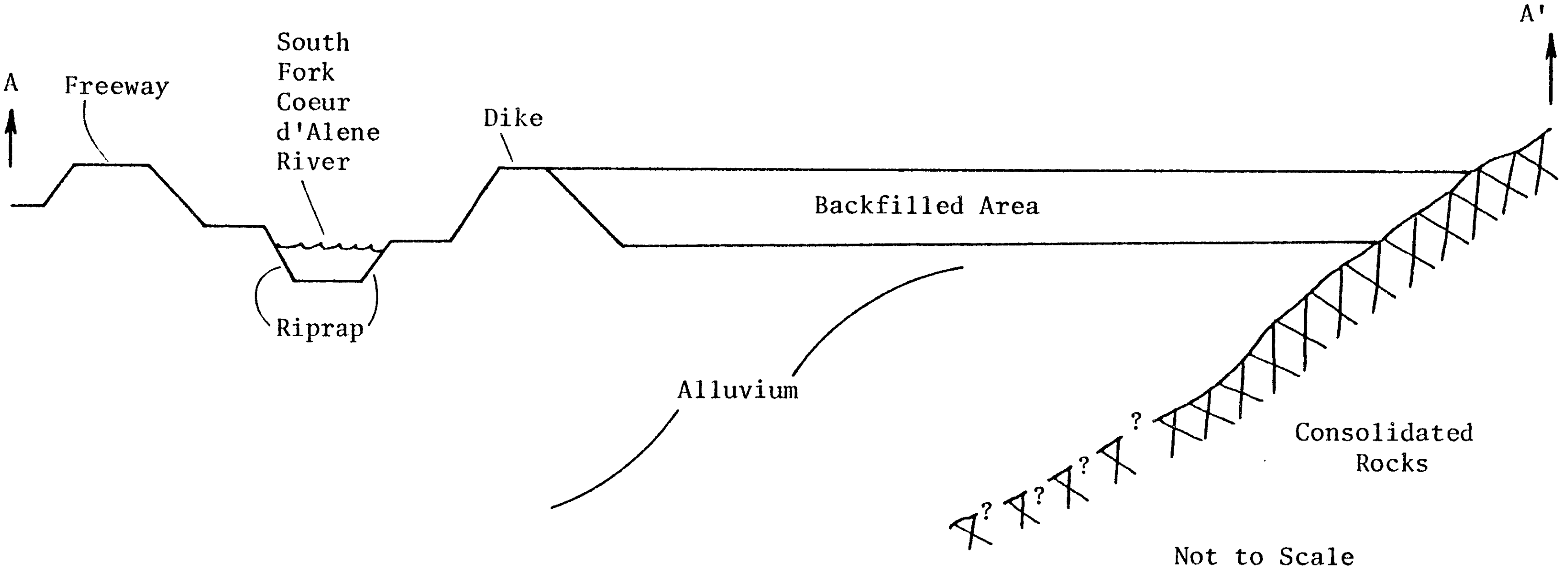


Figure 6. Hypothetical Cross-Section A-A' of a Backfilled Area on the Floodplain of the South Fork Coeur d'Alene River (see Figure 5 for location of cross section)

of the types of structure that would be necessary for disposal of tailings by backfilling in many areas of the South Fork valley.

The dikes would be constructed of native alluvial material from the barren floodplain of the South Fork. The dikes would have to be high enough and sufficiently sturdy to protect the backfilled tailings from erosion by the river. The size of the backfill area would depend on the distance from the river to the valley wall and the length of the undeveloped area available for construction of dikes and backfilling. After the area is completely filled it can be reclaimed by building industrial, residential, or recreational facilities on the surface, or by a program of revegetation.

Tailings That Will Generate Acid

Tailings from one of the active mills was determined to be acid producing by laboratory testing. These tailings must be isolated from the environment or treated to prevent the leaching of metals, or other undesirable chemical constituents, into the natural water systems of the area.

Isolation of the tailings could be effectively accomplished by eliminating the flow of water through the tailings. Controlling the flow of water through the tailings could reduce or eliminate removal of oxidation products from the reaction sites. Placement of a low permeability layer below the tailings would reduce the flow of water through the tailings to the groundwater system. A low permeability layer could be placed over the tailings to keep the amount of water entering the tailings at a minimum. While it would probably be impossible to totally prevent water from flowing through the tailings, it should be feasible to keep the volume of flow at a minimum.

In some areas, a synthetic impermeable liner could be placed under the tailings to prevent movement of water through the tailings. This is probably not a practical method to use in the Coeur d'Alene area. Cool, wet winters would require a design to hold water for evaporation in the summer months.

Another method of reducing the effect of acid producing tailings on the environment is to inhibit the formation of acid in the tailings. This can be done by reducing the availability of oxygen to the tailings. Several methods are available for reducing the availability of oxygen to the tailings (Skelly and Loy, 1973): 1) the tailings could be saturated with water; 2) a physical barrier could be placed to prevent the free flow of oxygen through unsaturated tailings; or 3) a barrier of organic matter could be placed over the tailings to consume the oxygen in biochemical reactions before the oxygen could reach the tailings. The latter two methods could only be used as preventive measures after the final abandonment of a site for disposal. The first method could be employed continuously as a site was being filled. These methods are diagrammed in Figures 7 and 8 and are described in the following paragraphs.

Saturation of the tailings could be achieved naturally. The tailings could be disposed in such a way that they would always remain below the natural level of the groundwater in the area. Since the rate of diffusion of oxygen through water is much less than for oxygen through air, disposal of tailings in this manner will greatly reduce the rate of acid formation.

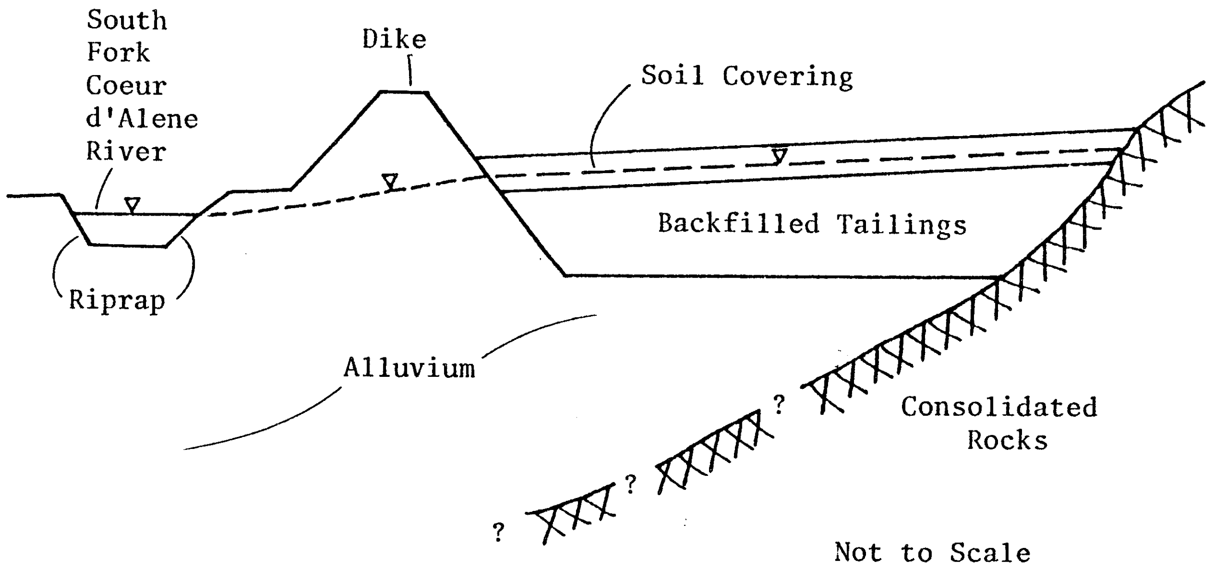
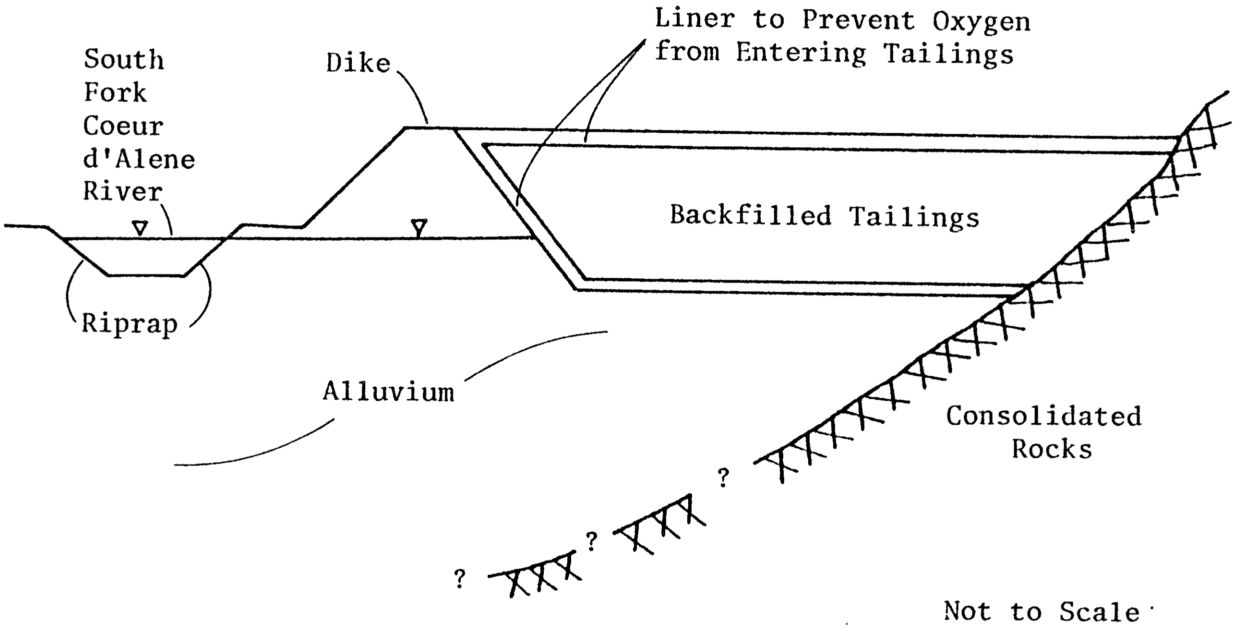


Figure 7. Disposal of Tailings Below the Groundwater Table



Not to Scale

Figure 8. Disposal of Acid-Producing Tailings Surrounded by a Barrier to the Free-Flow of Oxygen

A layer of organic material could be placed over the tailings as the final step in abandoning a disposal site. Oxygen, instead of entering the tailings, might be consumer in biochemical reactions with the organic matter. Eventually the organic material might be consumer and a new layer would have to be emplaced to prevent pyrite oxidation from occurring.

A physical barrier, such as asphalt, concrete, or plastic, could be placed around the tailings to prevent the free flow of oxygen through the tailings. This type of protection would be extensive and subject to possible failure of the physical barrier.

An alternate method of treating the acid forming problem of tailings would be to collect and treat the acid water as it flows out of the tailings. This method would require a closed system at the disposal site and treatment of the effluent for a long time into the future. While such a system is technologically feasible, the economics of maintaining and operating the treatment plant would probably prevent implementation of such a plan.

Discussion of Potential for Tailings Disposal by Backfilling

Tailings that do not produce acid may be disposed by backfilling areas on the floodplain of the South Fork in the future. Disposal by backfilling is similar to the present method of disposal in tailings ponds. In both cases, tailings are contained in a specific area by dikes. Water is allowed to move naturally through tailings into the surrounding groundwater system. Dikes around backfill areas would not be as high as dikes around tailings ponds, nor would they be raised as the enclosed area was filled.

Tailings deposited as a slurry tend to retain water, instead of draining freely, resulting in a thixotropic deposit unsuitable for supporting buildings. Therefore, consideration should be given to dry placement of tailings in backfill areas.

A prototype backfill area was constructed north of Osburn, near Terror Gulch, in 1979. Dry tailings were trucked in the placed over an impermeable liner. The shear strength of the tailings varied from place to place, probably relative to the amount of compaction received during placement (Bliss, 1981). A second backfill area adjacent to the first is planned for construction in 1981 by Dames and Moore (Engineering Consultants, Vancouver, B.C.).

Disposal of acid-producing tailings by the backfill method will require a design to limit the production of acid or to prevent the acid from entering the surrounding environment. Dikes may have to be built to withstand a larger magnitude flood to protect acid-producing tailings from erosion during floods, since this type of tailings is potentially more harmful to the environment than tailings that do not produce tailings.

Present disposal methods do not treat acid-producing tailings differently than tailings that do not produce acid. While it may be legal to use tailings as backfill material with regard to their potential for acid production, it is not a good idea to proceed in that manner.

The main benefit derived from use of tailings as a backfill material is the reclamation of barren land along the South Fork. Additional storage areas for disposal of tailings will also result.

A reconnaissance of the valley in 1973 identified 14 potential sites for disposal of tailings by backfilling. The total volume of tailings that could be disposed at these sites was estimated to be 2.25 million cubic meters. Since that time, a tailings pond has been constructed on the largest of the sites, removing one million cubic meters from the total available storage. The volume of tailings disposed in tailings ponds in the valley in 1973 was approximately 750,000 cubic meters. At that rate backfilling the 13 available sites would add about two years to the volume tailings storage in the valley (Ralston, 1981).

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Previous studies have documented the effects on the environment of tailings disposal prior to the use of tailings impoundments. Tailings impoundments have been shown to be effective in improving water quality in the South Fork.
2. Tailings from the Bunker Hill mill were found to be acid-producing. Tailings from the Lucky Friday, Sunshine, Coeur, Galena, and Star mills did not produce acidic water.
3. Disposal of tailings by backfilling unlined areas on the floodplain of the South Fork will affect the environment in proportion to the amount of acid produced by the tailings. Most of the tailings tested did not produce acid and are therefore acceptable for disposal by this method.
4. Disposal of acid-producing tailings by land backfilling should not be attempted unless some method of preventing acid formation or acid treatment is incorporated into the design of the site.
5. Disposal of tailings by backfilling unused areas on the floodplain of the South Fork has major potential because: a) there is a significant amount of land available for tailings disposal in this manner, b) tailings from five of the six active mills were found to be non-acid-producting and therefore suitable for disposal by backfilling unlined areas.

6. There may be factors other than the potential for acid production that will determine the suitability of using tailings as a backfill material. Tailings from some of the mills will produce basic water. This could cause as much of a problem to the environment as acidic water.

Recommendations

1. Tailings from each ore body within the mines in the Coeur d'Alene mining area should be tested for potential acid production to determine the suitability of tailings from each ore body for disposal by land backfilling on the floodplain of the South Fork.
2. The location of potential sites for disposal of tailings by land backfilling, the volume of tailings that could be placed at each site, present land use at each site, and ownership of each site should be determined.
3. The height of dikes that would provide flood protection to tailings in backfilled areas should be determined. Also, cost estimates for dike construction and preparation of each site for backfilling should be made.
4. Research should be conducted to determine the advantages and disadvantages of using a layer of organic material as a barrier to the free flow of oxygen into a tailings pile.

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