THE EFFECTS OF PERMAFROST ON THE GEOCHEMISTRY AND HYDROLOGY OF A METAL-SULFIDE TAILING IMPOUNDMENT 20 YEARS LATER[1]

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Abstract: Tailing waste from a molybdenum disulfide ore body was impounded at the Urad Mine, in Colorado, from 1967 though 1974. The tailing was deposited during conditions favorable for the development of massive permafrost layers in one of the impoundments. An evaluation of the groundwater hydrology and geochemistry of the upper impoundment was performed in 1991. Sampling techniques facilitated recovery of tailing sand core samples for textural and permeability analyses; and allowed a comprehensive characterization of the groundwater chemistry by field and laboratory analyses of pore water and soil chemistry.

Four regimes of groundwater flow were identified, including confined and unconfined flow through the tailing along the axis of the valley, lateral recharge from several snow-avalanche chutes, a perched water table, and unsaturated flow through the vadose zone near the dam crest. The perched water table is confined by fine-grained tailing and an underlying layer of frozen tailing. The perched water table still exhibits some characteristics of the tailing slurry water as it was deposited twenty years ago. An acidified vadose zone is well developed adjacent to, and below the dam crest in areas where the frozen tailing was either absent or has been depleted by heat flux from groundwater recharge. A vertical section through the impoundment has been developed from exploratory drilling data that depicts the geochemistry and groundwater hydrology. As much as 75 percent of the total mass contribution of heavy metal contamination may originate in the vadose zone, while a significant portion of the tailing is locked in a deep freeze of permafrost.

Construction of barriers may decrease the production of acid and metals from the vadose zone. Other measures that decrease the thermal energy input into the tailing may facilitate and maintain the "permafrost" layers that appear to be suppressing or preventing the acidification of the entire impoundment.

Additional Key Words: Sulfide Tailing; Sub-Alpine Climate; Permafrost; Vadose Zone Chemistry.

Introduction

The Urad mine and associated concentrator and tailing facilities were constructed in the mid-1960's for mining a low-grade orebody of molybdenum disulfide (MoS_2) using block-caving techniques. The location of the site is shown on Figure 1. Approximately 14 million tons of ore containing an average 6.6 pound of MoS_2 per ton of ore and less than five percent pyrite were mined from the granite porphyry inside Red Mountain. MoS_2 was concentrated and extracted from the crushed ore using flotation techniques. The tailing waste was deposited as a slurry onto one of two impoundments (Fig. 2). The orebody was exhausted by 1976 and reclamation of the tailing impoundments ensued. Both tailing impoundments were covered by a 3- to 10-foot thick layer of rock, amendments were added, and the areas were seeded with a

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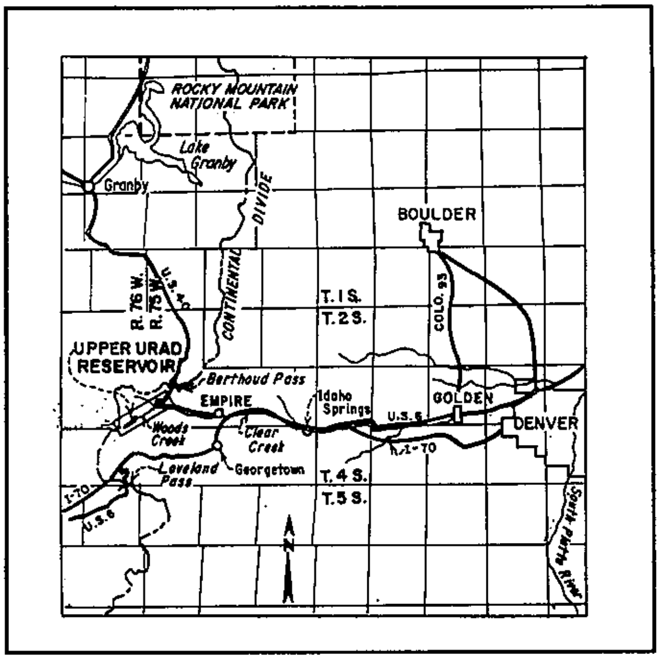


Figure 1. Location of the Urad Mine and Woods Creek

special high-altitude mixture of grasses (Brown and Jackson, 1984). The reclamation effort is considered successful since moderate to thick stands of perennial grasses, shrubs, and trees cover both areas.

An hydrogeologic evaluation of the upper tailing impoundment was performed in 1990 and 1991. The study revealed that layers of ice, or frozen tailing, had been encased within the tailing sands as they were deposited. The layers of frozen tailing have a pronounced affect on the hydrology and geochemistry of the impoundment twenty years after mining was terminated. The acidification of the pyritic tailing within the impoundment has been substantially retarded by the influence of the barrier effect of the ice. Maintenance of the ice barriers by management of sources of heat flux that could lead to their deterioration is a possible "passive" treatment application for the impoundment. Such management, augmented by other controls, could control the pH of the drainage and seepage that emanates from the tailing to decrease the scope of active treatment and other passive treatment requirements.

In this paper we will summarize the findings of the evaluation and provide some alternatives that are being considered for long-term management of the tailing impoundment.

Site Description

The mine and tailing facilities were constructed in the Woods Creek basin, which is a tributary of Clear Creek. Two water storage impoundments and two on-stream tailing impoundments were constructed in 1964-66 to support the mining. The general arrangement of the tailing and water structures, including major flood and bypass pipelines are shown on Figure 2. The climate of the minesite and facilities is typical for subalpine forests and alpine tundras that straddle the Continental Divide through central Colorado. The mean annual precipitation through the valley varies from 25 to 40 inches per year, and occurs mostly as snowfall during the long cold winters. The elevation of the Urad facilities varies from 10,000 to 10,800 feet MSL. The upper tailing impoundment was the focus of the 1990 evaluation. The upper impoundment contains approximately 2/3rds (9.3 million tons) of the total tailing. Its surface area is about 35 acres, and the elevation of the tailing dam crest is 10,490 ft. MSL.

An understanding of the tailing deposition method that was used during mine operation is important

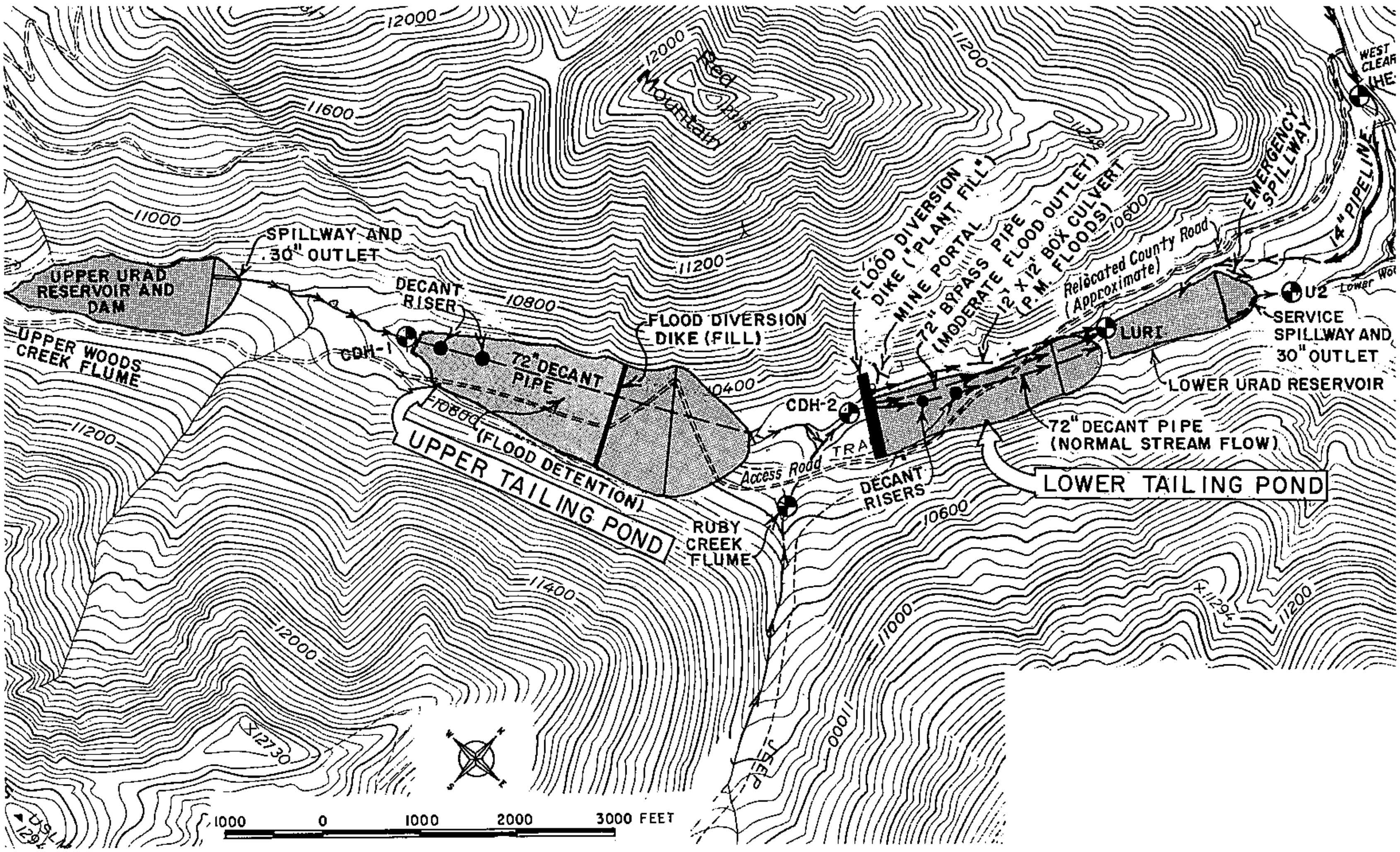


Figure 2. General Location and Water Diversion/Flood Facilities

for also understanding the hydrology and geochemistry of the impoundment and the origin of the frozen tailing layers. Figure 3 illustrates the general tailing deposition method that was used. The tailing was deposited by the upstream method. A starter dam composed of compacted earth fill was first constructed. The dam embankment was subsequently enlarged by depositing tailing such that the axis of the dam crest moved in the upstream direction of the valley as vertical lifts of tailing were placed. Subdrains were installed beneath the starter dam and the downstream portion of tailing fill to allow the pore-water from the tailing sands to drain, thereby ensuring structural stability.

After the initial fill of tailing behind the starter dam, an alternating sequence of dam building (during summertime) followed by impoundment filling (during wintertime) was generally followed. During dam building, tailing was discharged through pipes at the crest of the dam and the tailing slurry flowed across the beach to a pool where decanter pipes collected the supernatant water for reuse. The coarse fractions of tailing settled out near the crest and were used to construct the dam, while the finer fractions (or slime tailing) flowed to the pool near the decanter pipes and deposited in the pool as the velocity slowed. During wintertime, the area impounded by the newly created coarse-sand dam was filled with unsegregated (or whole) tailing which was conveyed across the beach in pipes and discharged near the water pool. The above description is an ideal case. Dam building may have occurred in wintertime, but this was generally discouraged because of the likelihood of forming ice lenses in the tailing.

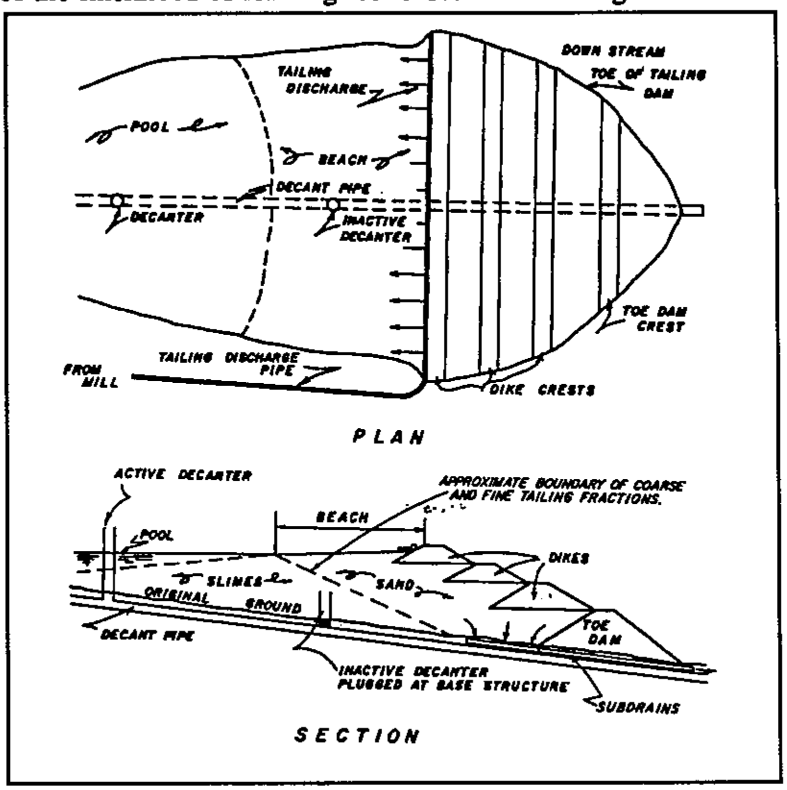


Figure 3. Typical Tailing Pond Operation During Deposition

Scope and Format of Characterization Study

A team of consultants (see Acknowledgements) was formed in 1990 by Climax Molybdenum and Wheeler and Associates to characterize the hydrology, geology, and geochemistry of the upper tailing impoundment. The purpose of the study was to determine the existing groundwater hydrology and the geochemistry of the impoundment; and to evaluate passive treatment alternatives that would either minimize the scope of, or replace the need for, an active treatment facility. The upper impoundment was specifically chosen because of the known presence of frozen tailing and ice layers that had been discovered during exploratory borings in 1977. The influence of the frozen tailing on the hydrology was believed to be

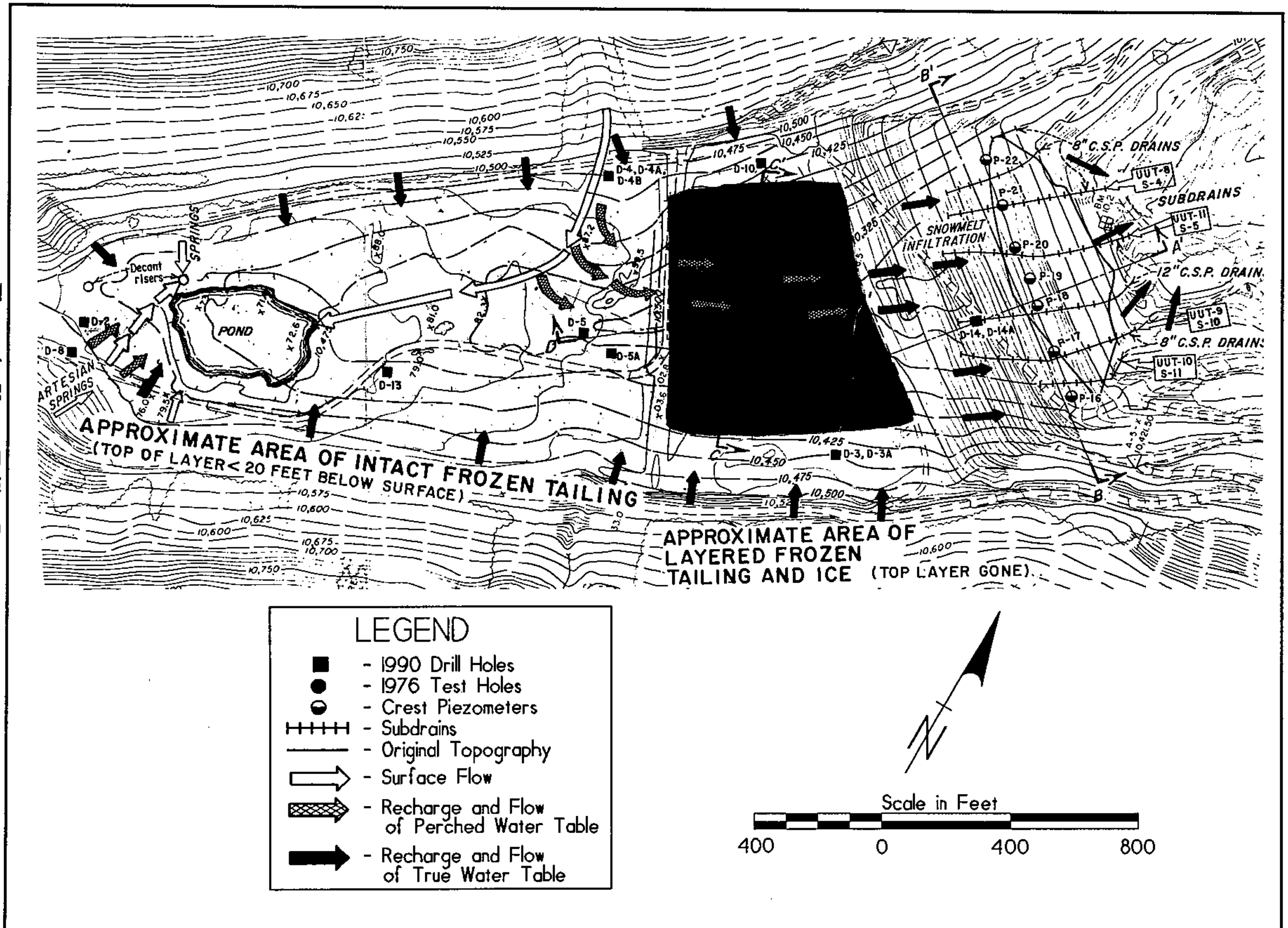


Figure 4. Upper Tailing Impoundment
General Flow Patterns and Zones of Permafrost/Frozen Tailing

significant. Figure 4 shows the topography of the upper impoundment as well as the location of exploratory holes and pits.

One objective for the field investigation was generally to confirm the findings of Cherry (Cherry et al., 1980a) in their characterization studies of tailing in Canada. Specifically, they found that in areas of horizontal and upward flow through tailing, the oxygen supply as well as the resulting acidification of the tailing would be limited. Other studies had shown that the unsaturated (vadose) zone is a major contributor of metals to the pore-water discharge. The extent of the vadose zone of the upper impoundment was to be determined. Finally, an evaluation of methods for treating the pore-water using "passive" techniques was a primary purpose of the study. Passive treatment methods might include hydrologic barriers or seals, in-situ treatment, wetland treatment, and others.

Exploratory borings and surface pits were drilled and excavated at select locations across the expanse of the upper impoundment. These are shown as filled squares in plan view on Figure 4. The data from these borings were augmented by bailed samples from piezometer wells (half-filled circles) and geotechnical logs from exploratory borings (filled circles) that had been drilled during the mid-1970's. Analysis of samples from these well and surface pit sites, as well as sampling from the subdrains and tributary streams, provided the data for geochemical characterization of the tailing impoundment.

The exploratory wells were drilled using hollow-stem augers and a continuous sampling technique which collected tailing samples in 2-inch diameter, 5 ft. long plexiglass tubes. The plexiglass cores were cut into 6-inch replicate lengths. One core was used for field analyses, a second core was reserved for permeability testing, and a third was sent to a laboratory for more detailed analysis. The remainder of the core was stored for later use as required.

The pore water from the pyritic tailing was expected to be very reactive when exposed to atmospheric oxygen. The pore water was extracted from the field core sample using a "squeezer" apparatus similar to those developed by Patterson, Dykes, and McLeod (1978). After extraction, the pore water was immediately analyzed for dissolved oxygen, ferrous and total iron, temperature, and pH; and then analyzed for less time-sensitive parameters such as specific conductance, manganese and zinc.

The laboratory replicates of the cores were analyzed for major cations and anions, pH, total inorganic carbon, and specific heavy metals of concern. Selected cores were also analyzed using sequential extraction techniques to determine the chemical character of surface coatings. Textural analyses, moisture analyses, and falling head permeameter tests were administered to the third replicate core from selected sample tubes.

Results

Tailing Characteristics

The textural classification of the tailing ranges from silty clay (97% passing a 200 mesh sieve) in the former slime tailing pool near drill hole D-2 (Fig. 4), to sandy silt (44% minus 200 mesh) near the midpoint of the impoundment, to silty sand (20% minus 200 mesh) at drill hole D-14 in the dam section. Generally all of the tailing is less than 1.2 mm (#16 Sieve). The hydraulic conductivity of the tailing based on laboratory permeameter analyses varies from 2 x 10^{-7} cm/sec to 1 x 10^{-4} cm/sec for slime tailing and coarse (dam) tailing, respectively. The hydraulic conductivity of the underlying alluvium ranges from 10^{-6} to 10^{-3} cm/sec. A comparison of well recovery tests with laboratory permeameter tests indicate that the ratio of horizontal to vertical hydraulic conductivity (K_h/K_v) is approximately 10:1 and possibly higher.

Hydrologic Zones

Four major flow patterns, or hydrologic zones, were characterized and identified by comparing the chemical analyses, the tailing core log, and the field test results. Most of these zones are controlled or affected by a fifth zone, the frozen tailing layers.

1. Ice Layer Formation and Fate

A review of the tailing deposition method, previously described, reveals the source of the frozen tailing layers in the tailing. As shown on Figure 3, a reverse slope (sloping in the upstream direction of the valley) of about one percent or less developed during tailing deposition to carry the slurry to the "slime pool" for decanting and return of excess water. During winter conditions the flow of dilute slurry across the wind-blown beach at sub-zero temperatures provided ideal conditions for forming thick sheets of ice.

Studies by Greenstein (1983) and Harris (1981) have characterized three types of permafrost that could form in the alpine regions of the Rocky Mountains. The type of permafrost depends on the annual freeze and thaw indices, which are the sum of degree days for days when the temperature is below and above freezing, respectively. These relationships are shown on Figure 5.

In areas where the thaw index exceeds the freeze index (near a mean annual temperature of 0°C), only sporadic occurrences of permafrost would be expected. Where the freeze index exceeds the thaw index by up to 50%, permafrost may be expected. However, the permafrost occurrence may be discontinuous and sensitive to snowpack conditions on top of the ground. Where the freeze index exceeds the thaw index by more than 50%, continuous layers of permafrost can be expected. As shown on Figure 5, the upper impoundment is in the region of expected, but discontinuous permafrost during most years and for the mean of the ten year period. The lower tailing impoundment, only 315 feet lower in elevation, is marginally in the zone of sporadic permafrost, where permafrost would not be expected except under ideal surface conditions.

Additional studies performed by Smith and Riseborough (1983) have correlated the sensitivity of permafrost layers to six site factors:

1. Surface layer composition (peat or silt)
2. Surface roughness
3. Albedo
4. Moisture content
5. Slope aspect, and
6. Snow cover

Of these six factors, wetness or moisture content of the surface soil and the amount of snow cover were found to have the greatest effect on the permafrost layer. As the percent saturation varies from 60% to 100% during wintertime conditions, Smith and Riseborough found that the effective mean annual surface temperature of the soil could drop by as much as 3°C. Smith and Riseborough also state that if the snow cover is reduced by half, the mean annual surface temperature of the soil could decrease by over 2°C.

During tailing deposition the surface soils were maintained in a saturated state. Because of severe winds that course down the Woods Creek valley during winter, exposed vegetation and bare soils dominate the top of the impoundment while the snow pack in adjoining protected areas is significant. No wind velocity data is available in the valley. However, wind gusts on top of a nearby peak are often reported to be 90 mph or more, and it is estimated that gusts in the valley might reach 70 to 80 mph. Both of these conditions (saturated soils and wind) would tend to strengthen the propensity for permafrost formation in the discontinuous zone. It is no surprise, then, that the frozen tailing layers developed during tailing deposition. In addition, many of the six factors are still at near optimum conditions over most of the upper impoundment. Figure 4 shows the areal extent of the continuous and discontinuous frozen tailing layers as they were mapped in 1990 from the drill data.

The geometry of the ice layers has been influenced by considerable consolidation of the tailing sands since 1976. There has been up to 15 feet or more of consolidation near the center of the valley and near the tailing dam crest. The effect of this is that, where the tailing strata was originally planar and sloped

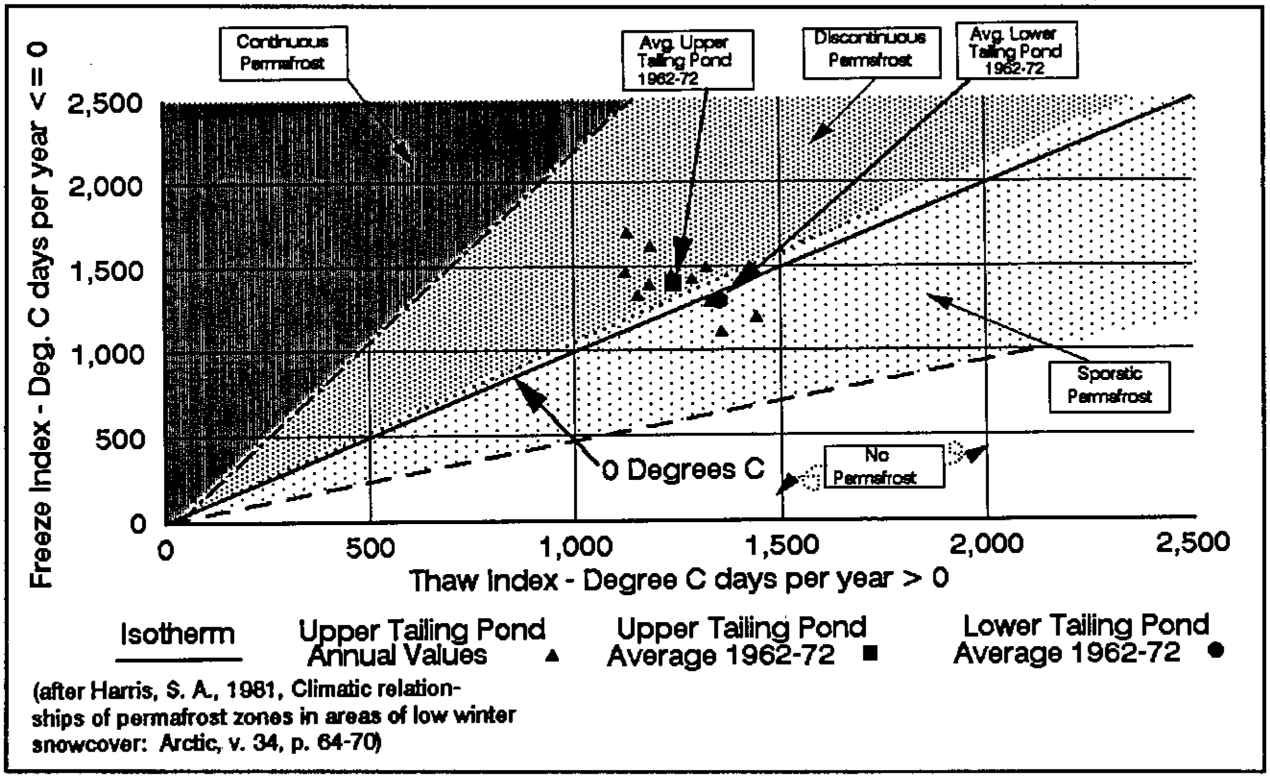


Figure 5. Freeze-Thaw Indices for Upper and Lower Tailing Impoundments

toward the water pool, there is now a three dimensional trough caused by the consolidation, but that still marginally slopes in the upstream direction of the valley. This trough forms the confining layer for perched water on top of the frozen tailing layers and has a significant influence on lateral inflows from the hillsides alongside the tailing impoundment.

The chemistry of the frozen pore-water within the permafrost zone was quite different than in other zones. Table I shows typical concentrations of several constituents from various zones that were sampled. The pore-water in the ice zones generally had a pH greater than neutral, low iron, moderately low manganese, and high concentrations of chloride. It is likely that the chloride concentration represents process water from the ferric chloride leach circuit of the concentrator. Chloride is widely used as a tracer because it is conserved in dissolved form with little propensity for sorption or precipitation. The hypothesis that chloride in the tailing had its origin in the concentrator (i.e. as a tracer of original tailing water) was helpful in determining the origin and flow within other hydrologic zones of the tailing.

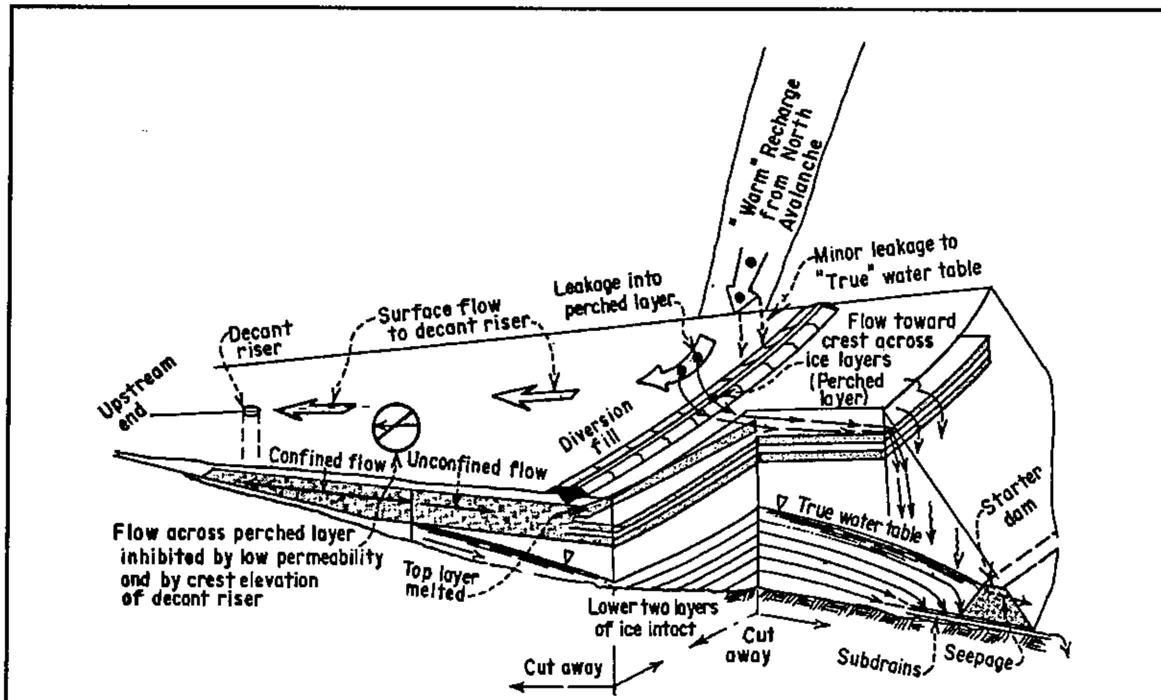
2. Hydrologic Zones and their Geochemistry

Four distinct hydrologic zones characterized by flow patterns (or regimes) were identified, mapped, and correlated beside the frozen tailing layers. Three of these are related in some manner to the frozen tailing layers, and the fourth is the vadose zone which is independent from the permafrost. The four zones are represented on the isometric view of Figure 6. Typical chemical compositions of waters from the four zones are shown on Table I.

Table I
TYPICAL CHARACTERISTICS OF TAILING PORE-WATER IN HYDROLOGIC ZONES
(values in mg/l)

Parameter	Ice	Perched Layer	Beneath Ice	Lateral Recharge[1]	Vadose Zone
pH	7.7	7.6	7.0	4.3	3.5
Iron	<0.02	0.02-0.08	3.9	.6	30-400
Manganese	10	35	12	170	440-490
Spec. Cond.	2,200	1,800	1,600	2,350	3,300
Chloride	92	50-85	50	5	2-30
Sulfate	900	800	700	1,400	2,400

1. May include some effects of overlying vadose zone.



ISOMETRIC VIEW OF GROUND WATER FLOW FROM NORTH AVALANCHE CHUTE

Figure 6. Isometric View of Groundwater Flow Regimes

<u>Perched Water Table on Top of Frozen Tailing Layers</u>

The trough-shaped geometry of the frozen tailing layers in combination with the low hydraulic conductivity of the tailing in the "slime tailing" provides groundwater boundaries for a perched layer of water that lies on top of the ice. This layer exhibits some characteristics, though more dilute, of the original tailing water and is generally low in metals concentration and neutral or slightly alkaline (the concentrator circuit was controlled at a pH of about 8.5). The primary source of water for this perched layer is surface runoff from avalanche chutes along the sides of the tailing and from artesian springs that emanate from the tailing/alluvial contact at the southwest (upstream) end of the tailing as shown on Figure 4. There are two outlets from this zone, including:

1) two decant riser pipes that skim the water from the top of the pond, and

2) an underground "spillway effect" at the downstream lip of the ice troughs, where perched water can flow downward towards the regional water table.

Water from the artesian springs to the south is not believed to adversely affect the frozen tailing layers. The flow from the springs maintains a constant state of saturation over the southern end of the tailing, hence favoring permafrost. The water emanating from the springs, originating from the shaded southern slope, is fairly cold (less than 4°C) and would not be a substantial heat source that would deteriorate the ice. In fact, remnants of the ice zones are thin, but still evident along the edges of the slime tailing near the springs.

Exploratory borings in 1976 revealed three frozen tailing layers near the crest of the impoundment, each 10 to 15 feet thick and separated by about 10 feet of non-frozen tailing. Only the two bottom layers remained in 1990. Finding and managing the source of heat that has caused the loss of the upper ice layer and may be deteriorating the lower layers will be a key factor if the permafrost layers are to be preserved. Radiant heat conducted through the tailing and conductive heat flux conveyed by water were considered to be the most likely sources.

An oxidized vadose zone has developed to a depth of 18 feet in the area around drill hole D-6. The studies of permafrost (cited previously) show that this zone of low moisture content will provide a measure of insulation. Modeling of the surface hydrology has shown that most of the annual precipitation is consumed by evaporation, and that only minimal deep percolation has occurred. Therefore, conduction of heat through the tailing is not believed to be the primary cause of ice deterioration.

The major source of the heat flux is likely intermittent stream flows that course down an avalanche chute near the northwest abutment of the dam (Fig. 4). The avalanche chute has a sunny, southern exposure with snow-fields that melt early in the season and have (relatively) warm flow temperatures. An active surface stream flows down the chute for about four weeks each spring and then dries up as the snowpack is depleted. As shown by the white arrows on Figure 4, the flow path is through the rock cover on top of the tailing, eventually reporting to the water pond and the decant riser.

There is evidence that a portion of this stream flow is percolating into the perched water table and flowing over the lip of the ice layers (previously described as the underground spillway). Relatively high chloride concentrations in drill hole D-6 (90 mg/l) and D-11 (92 mg/l) and a gradient of chloride in the subdrains decreasing from 30 mg/l at the northwest abutment (subdrain S-4) to less than 6 mg/l at subdrain S-10 near the center of the dam indicate that a flow of "original tailing water" is occurring over the lip of the ice layer trough near D-6. Therefore, the avalanche chute is the most likely source of the heat flux.

Longitudinal Confined and Unconfined Flow (Regional Water Table) Beneath Frozen tailing layers

Beneath the frozen tailing layers is a second flow regime, which is characterized by low metal concentrations, moderate to alkaline pH and generally low dissolved oxygen. This flow appears to be fed by abutment flows through the colluvium and by alluvial flows from the stream channel at the upstream limit of the tailing. The existence of artesian springs in the area of the pond are an indication that abutment flows are pressurizing the tailing beneath the frozen tailing layers. This would be consistent with a confined aquifer condition where the strata is saturated over the entire vertical profile. Further downstream, near the dam crest, the phreatic surface is below the bottom of the frozen tailing layers. Therefore, somewhere beneath the frozen tailing there must be a point of separation where the water flowing beneath the frozen tailing layers changes from a confined state to unconfined flow.

Deep Percolation from Abutments to the Regional Water Table

The third hydrologic zone is characterized by recharge from the hillsides, via the colluvium and deeply bedded tailing sands, to the regional water table described in the previous section. The surficial portion of this flow is generally confined to the avalanche chutes. The effect of the surface flows in the northwest chute was discussed in the previous section and appears to be responsible for deterioration of the discontinuous ice zones. A three to five foot thick saturated zone, the groundwater component of abutment recharge, occurs within the colluvial deposits along the sidehills. This groundwater flows beneath the ice layers directly to the regional water table. Consideration of this flow as a separate flow regime is based on the fact that the frozen tailing layers are generally nonexistent within a narrow (50-70 foot wide) zone on the side perimeters of the impoundment. Chloride concentrations are also very low (generally less than 2 mg/l), which would indicate a continuous flushing source of tributary water.

Although this flow probably is initially low in metals, contact with the tailing would result in increased concentrations. The flow from the abutments tends to seasonally push up the water table near the dam crest into the vadose zone, flooding a thin layer of the unsaturated zone and mobilizing metals that would otherwise be trapped in the unsaturated sands as high concentration solutes and possibly as sulfate salts. This expectation is based on the analysis of manganese from core samples at the water table, described in the following section.

Vadose Zone

A zone of partially saturated tailing (vadose zone) overlays the zone of discontinuous frozen tailing and ice in the area near the dam crest as shown on Figure 4. The depth of the vadose zone varies from 3 to 30 feet in this region. The vadose zone also continues across the entire expanse of the sloped front face of the embankment to depths of 72 feet. In the upper part of the vadose zone, approximately 15 feet of tailings are highly oxidized. Tailings below this oxidized zone are light gray in color and exhibit very little evidence of oxidation.

The difficulty of extracting water from the unsaturated tailing makes evaluation of the characteristics of the pore-water more difficult as well. Attempts to collect this water using suction lysimeters and squeezing the sand cores using immiscible replacement media were unsuccessful. A method of saturating the cores, squeezing the samples to recover the diluted pore water, and multiplying the analytical results by the saturation ratio (saturated moisture content divided by natural moisture content) was successful. Although some effects to chemistry by dilution are expected, the relative values provide information about metals mobilization and acidification within the vadose zone.

As mentioned previously, the top of the tailing impoundment blows clean of snow during winter months. Computer modeling used to simulate the water balance for these conditions indicated that summertime precipitation would marginally support ground cover and allowing only a minimal excess for infiltration. Therefore, deep percolation into the vadose zone is expected to be minimal in the flat area of tailing.

The prevailing winds are from the upstream direction. Therefore, most of the snow removed from the flat area is deposited on the front face of the dam. Snow course measurements have shown that up to 50-inches of snowpack water can accumulate in the drifts in this area (over 15 feet of snowpack). Most of the melt-water percolates through the vadose zone overlying the front of the dam face. Water characteristics from seepage flows at the toe of the dam and bailed water samples from piezometers drilled on the front face of the dam show a substantial mass flow of metals and low pH water from these areas.

Table I indicates the difference between the pore-water chemistry of the vadose zone compared to the other flow regimes. The results of sequential extraction analyses of surface coatings of the tailing particles in the vadose zone and resaturated pore-water analyses (as described above) were modeled using MINTEQA2 (Version 3) to speciate the components of the pore-water of the vadose zone. High levels of manganese and trace metals in the oxidized zone (to a depth of 10-15 feet) were found to be inconsistent (higher) with the model predictions. The conclusion was that because of the extremely low water content in the coarse sands, soluble metal salts probably exist as coatings on the sand and would be highly mobile when percolation from snow-melt water occurs.

The lower vadose zone of gray tailing has low oxygen content and is characterized by higher pH and generally lower concentrations of metals. The analyses and speciation modeling indicated that more of the metals exist as adsorbed, as opposed to dissolved species in this zone because of the more favorable pH values.

A mass balance of the entire tailing impoundment was performed using manganese as the tracer component because it is conserved through much of the pH range within the tailing. The results of this calculation indicated that as much as 75 percent of the total manganese that discharges from the impoundment originates in the vadose zone, and particularly from the front face of the dam where snow-melt water seasonally flushes and oxidizes the tailing sands.

CONCLUSIONS OF THE EVALUATION

1. The ice and frozen tailing layers that underlie the tailing impoundment are a hydraulic barrier that controls the groundwater hydrology and tends to minimize the oxidation of pyritic tailing sands that have been deposited.

2. The preservation of these frozen tailing layers is important if oxidation of the sands is to be minimized. Two methods have been proposed to facilitate this. First, the seasonal flow of snow-melt water from the avalanche chutes should be redirected (since it can't be stopped) to minimize deep percolation and to ensure that the flow reports to the stream as efficiently as possible to minimize the heat flux into the tailing sands. Second, the maintenance of favorable perma-frost conditions should be continued. Conductive and convective heat flux controls should be considered to maximize the removal of heat during wintertime (by saturation and low insulation) and maximize the insulation during summer (by desaturation of the shallow cover material).

3. The flat top of the tailing impoundment surface overlying developed vadose zones should be maintained in relatively "smooth" condition to ensure that wind removal of snow continues. By not allowing a snow-pack to build, the summer precipitation balances the evapotranspiration of the vegetation and deep percolation and drainage through the vadose zone is minimized. Permitting the development of a significant snowpack would not only upset the hydrological balance by providing a source of water to the vadose zone, but also would prevent the wintertime heat sink because of its insulating value. Allowing trees to grow on the tailing is certainly a desirable goal of reclamation, but may be counter-productive to water treatment efforts.

4. Methods for sealing the surface of the front dam face should be evaluated in an effort to minimize the drainage of high volumes of snow-melt water through the underlying vadose zone.

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HIGH ALTITUDE TAILING RECLAMATION[1]

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Abstract: Tailing, if present, is the most difficult aspect of mine reclamation. Physical characteristics of tailing often provide good soil-plant water relations, but that characteristic is frequently overshadowed by its high erodability. Chemical characteristics such as high acidity, alkalinity, salinity, and heavy metal concentrations are common in metal mine tailing and can prohibit direct revegetation of the tailing. When detrimental physical and chemical characteristics exist, an accepted tailing reclamation technique is to place a cover material over the tailing and revegetate that material. The cover material should: 1) be relatively inert; 2) be deep enough for an adequate root zone for vegetation; 3) possess good soil-plant water and nutrient relations; 4) be resistant to erosion; and, 5) minimize capillary movement of water and contaminanats from the tailing into the cover material. In some instances, the cover material must also act as a barrier to movement of oxygen and water to and from the tailing.

Specific case studies of high elevation tailing reclamation are discussed; including relative difficulties, successes, and costs, along with data for 18 years of vegetation monitoring at the reclaimed Urad Mine tailing ponds. The data indicate that production and diversity on the Urad tailing ponds has always exceeded that of the control and that vegetation cover on the ponds initially exceeded that of the control, but is now below that of the control.

Additional Key Words: Revegetation; cover; production; diversity; heavy metals; reclamation costs

Introduction

Some general distinctions will be helpful before describing various tailing reclamation projects.

High Elevation or High Latitude

Not many examples of truly high elevation tailing ponds exist, and only a few of those have been reclaimed. For purposes of this paper, high elevation will be defined as above approximately 2,450 meters (8,000 feet). Distinctions vary with latitude because high latitude sites exhibit somewhat similar climatic conditions at lower elevations. An equivalent north latitude to a 2,750 meter (9,000 foot) elevation in Colorado would be a low elevation site north of the 60th parallel, i.e., the Yukon or Northwest Territories in Canada, and most of Alaska.

High elevation or high latitude sites are not necessarily more difficult to reclaim than other sites that have severe climates. Harsh winters and shorter, colder growing seasons at high altitude or latitude sites are not necessarily more limiting than conditions of a desert environment, they are simply different. Different species are required, planting times are different, mulches may be more important in the desert, and erosion control measures may differ. The major problems in revegetating tailing are chemical and physical limitations, and these problems are universal irrespective of climate.

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