ENVIRONMENTAL AND RECLAMATION PRACTICES AT EQUITY SILVER MINES LIMITED

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INTRODUCTION

Equity Silver Mines Limited is a large silver producer, located 38 kilometers south of Houston, B.C. Materials are mined by conventional open pit methods, with ore being shipped to a concentrating plant and waste to a common disposal site.

Pyrite being the predominant mineralization in the waste material, oxidizes rapidly producing acid mine drainage (A.M.D.). Short term environmental safeguards are in place in the form of effluent collection and treatment facilities. Research and monitoring programmes are being developed to evaluate reclamation as a method for mitigation of acid mine drainage.

The purpose of this paper will be to offer a brief overview of research and reclamation programmes at Equity Silver Mines Limited. Key topics to be reviewed will be: chemistry of A.M.D., acid generation potential, water treatment and sludge handling, special wastes, surfactant research (bacteriocides), column tests, waste rock admixtures, waste dump construction, and reclamation of waste dumps.

DISCUSSION

Chemistry of Acid Generation

The kinetics of acid formation are dependent on: (1) oxygen availability; (2) surface areas of pyrite; (3) activity of iron-oxidizing bacteria; and (4) chemical characteristics of inflowing waters.

Oxidation rates can be controlled by limiting factors 1, 2 and 4 through reclamation.

Acid generation proceeds stepwise from a slow abiotic (naturally occurring) reaction to an accelerated cyclic *Thiobacillus ferrooxidans* catalytic reaction.

Step 1

Initially the pyritic waste materials are oxidized abiotically (and to a lesser degree assisted by *Thiobacillus ferrooxidans* action).

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{2+} + SO_4{=} + 2H^+ \qquad (1)$$

In a low acidity environment the ferrous iron is further oxidized abiotically, to the ferric iron state.

$$Fe^{2+} + 5H_2O + 1/4\ O_2 \rightarrow Fe\ (OH)_3 + 2H^+ \qquad (2)$$

During this stage of the reaction, if alkalinity exceeds acidity, the ferric iron precipitates as ferric hydroxide.

Chemical properties of this reaction are typically exhibited by pH values slightly above 4.5, high sulphates, low iron values and no acidity counts.

Step 2

A further decline in pH will result in a decrease in the rate of ferric hydroxide formation. At the lower pH Fe(OH)3 is more soluble and an increase in $Fe^{+\wedge}$ activity is evident. During this step Thiobacillus ferrooxidans takes on an increased role of oxidizing ferrous iron to ferric iron.

Typical chemical properties at this stage are pH ranges between 2.5 and 4.5, high sulphates, high acidity counts and an increase in total iron levels.

Step 3

As the pH falls below 3, oxidation of ferrous iron to ferric iron proceeds at a rate totally determined bv the activity of T. ferrooxidans.

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

Ferric iron produced in reaction (3) exerts primary control on the cycle by limiting the availability of Fe^{+3}, the major oxidant of pyrite.

$$FeS_2 + 14\ Fe^{3+} + 8\ H_2O \rightarrow 15\ Fe^{2+} + 2\ SO_4^{2-} + 16\ H^+ \qquad (4)$$

The steady rate activity of Fe^{3+} is determined by the combined effects of bacterial oxidation of Fe^{2+} , reduction of Fe^{+3} by pyrite, and the associated formation of ferric sulphate and hydroxy complexes.

Reaction (3) establishes the cyclic pattern at which accelerated acid production takes place.

Step 3 is chemically characterized by pH 2.5, high sulphate levels, high acidity, total iron and a rapid increase in the Fe^{3+}/Fe^{2+} ratio as determined by biological activity.

Step 4

Reactions (3) and (4) accelerated by T.ferrooxidans action will produce a host of reaction intermediates. Surplus supplies of these intermediates can promote acid formation devoid of bacterial action. As in Step 3 the cycle can be interrupted by limiting oxygen or by eliminating T. ferrooxidans activity using bactericidal agents, otherwise the cycle will continue until the sulphide supply is exhausted.

Acid Generation Tests

In assessing acid generation potential of an orebody, it is necessary to evaluate theoretical production and consumption (buffering) properties.

Results of testing are often quoted in ratios, acid generation potential: acid consumption or buffering capacity. For instance an index ratio of 4.5, merely means testing has indicated the waste material can theoretically produce 4.5 times more acid than it is capable of neutralizing.

Preliminary investigation into acid producing potential of Main Zone waste materials indicates ratios vary from a low of 0.15 to a high of 65, with the majority falling within the 10 to 20 range. Figure 1 illustrates stratification of acid generating zones.

Non-producing wastes have been inventoried on the east wall of the Main Zone pit and are presently being used for bulk fill on the downstream faces of tailings impoundment structures.

Those wastes classified as acid producers must be stockpiled on a common dump and reclaimed to reduce potential for oxidation.

Water Treatment and Sludge Handling

Approximately one million cubic metres of A.M.D. must be collected annually and processed through a lime neutralization treatment plant. Effluent produced is of suitable quality for discharge to local streams.

Byproducts produced from the treatment process consist of metal hydroxides. Yearly accumulations of this sludge represent short term storage problems and long term reclamation concerns. At best this material thickens to 5 percent solids within the settling ponds. Air drying does assist densification, however, would require filter beds with surface areas in excess of those presently available.

Several storage concepts have been investigated and include mixing with mill tailing or surface treatment of oxidized waste.

The latter option has been ruled out by laboratory testing.

Injection of alkaline sludge into reactive waste rock voids initially revealed significant improvement in effluent quality. However, over an elapsed period acid generation processes exceeded buffering capacity of the sludges and a deterioration in effluent quality was observed. Redissolution of metal hydroxides intensify concentrations of metals in solution. Refer to Figure 2.

Under less adverse conditions injection of alkaline sludges in waste rock voids may be an ideal method for controlling oxidation and production of A.M.D.

A.M.D. sludge, through testing, has been classified a Special Waste according to the terms laid out in the proposed Special Waste Act. As we are dealing with large volumes produced annually, storage or disposal of these sludges represent long term reclamation concerns.

FIGURE 1

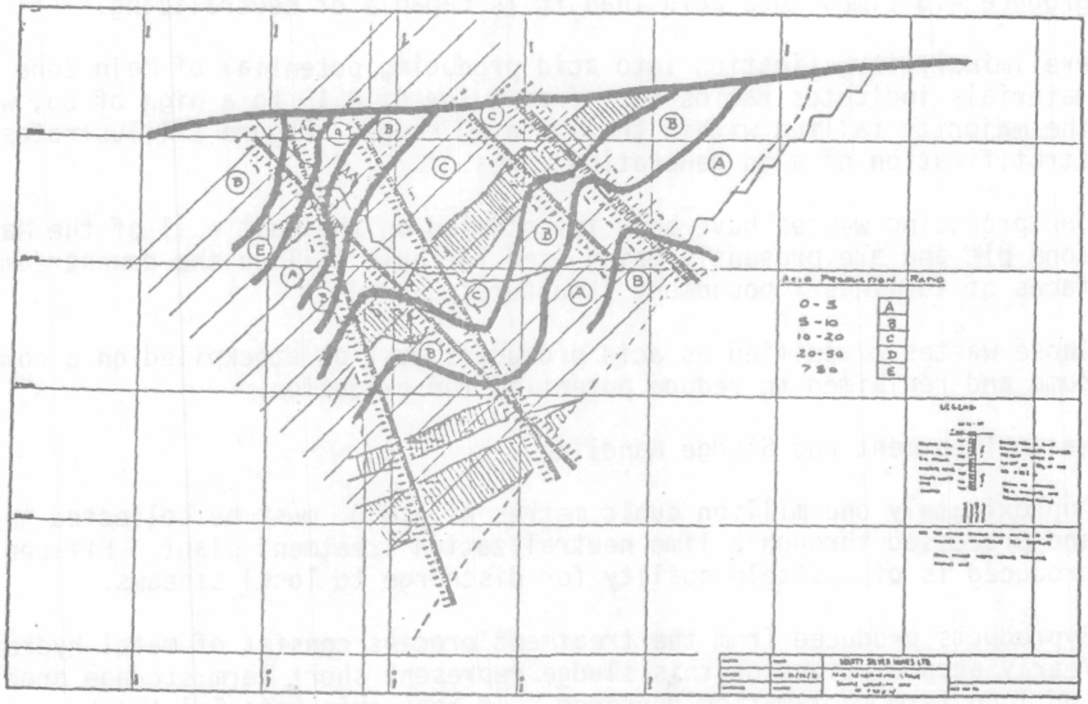
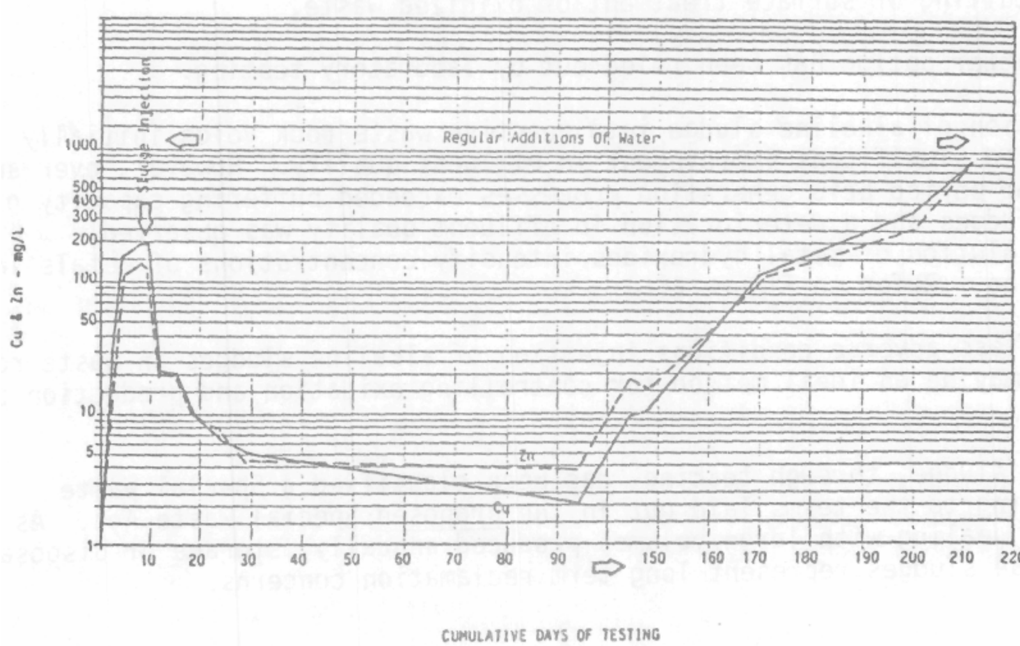


FIGURE 2

A.M.D. SLUDGE INJECTION INTO OXIDIZED PYRITIC WASTE



By mixing A.M.D. sludge with mill tailing at ratios as low as 1:4, extracted metals from the composite do not exceed guidelines laid out in the Act. Figure 3 and Table 1 illustrates that tailing alone fall within Special Waste guidelines, whereas A.M.D. sludge far exceed the limits set forth. A mixture of A.M.D. sludge to tailings between ratios 1:10 and 1:6 show little deviation from baseline extractions within the tailings. Deviation from the norm becomes evident at ratios of 1:4 or less.

This concept of storing A.M.D. sludge is presently being channelled through regulatory groups in anticipation of finalizing permitting early this year.

Sodium Lauryl Sulphate (S.L.S.) Testwork

The bacterium, Thiobacillus ferrooxidan, plays an integral role in promoting A.M.D. Sodium Lauryl Sulphate, a common anionic detergent is known to be an effective agent for reducing bacterial colonization with subsequent reductions in A.M.D. often observed.

Prior to initiating a field test, many test parameters had to be evaluated in the lab. Adsorption rates were assessed to insure sufficient product remained in situ rather than being flushed out of the spoil pile. Degradation rates were tested under both acidic and receiving water conditions. We did observe increased breakdown of S.L.S. under the acidic conditions, and have since attributed this to hydrolization rather than biodégradation alone. Biodégradation and hydrolysis rates are illustrated in Figures 4 and 5.

S.L.S. was tested in columns of waste material to evaluate the effectiveness of the product as a bacteriocide and its ultimate impact on oxidation rates. Low level concentrations (50 ppm) were added to the test column at intervals designated in Figure 6. During the period of testing we observed a marked reduction in A.M.D. production as indicated by levels of dissolved copper in the effluent. The control column, untreated, illustrates rapid oxidation when bacterial action is uninhibited.

Field tests with S.L.S. showed no reduction of oxidation rates within spoil piles. Degradation of S.L.S. prior to infiltration through the reactive zone is speculated to be the prime cause of failure. Also, reactive zones appear to be deeper seated than initially speculated and difficult to saturate with treatment solutions.

Column Tests

Columns containing specific waste types are used to evaluate various disposal sceneries.

These test vessels, constructed from five foot lengths of PVC piping, have either porous or impervious bases, depending on the water course regime being evaluated. Water is fed to the top of each column by purging air into feed lines. Figures 6 and 7 typlify the two modes in which these columns are operated.

FIGURE 3

Zn, Cu AND Cd EXTRACTIONS IN µg/g

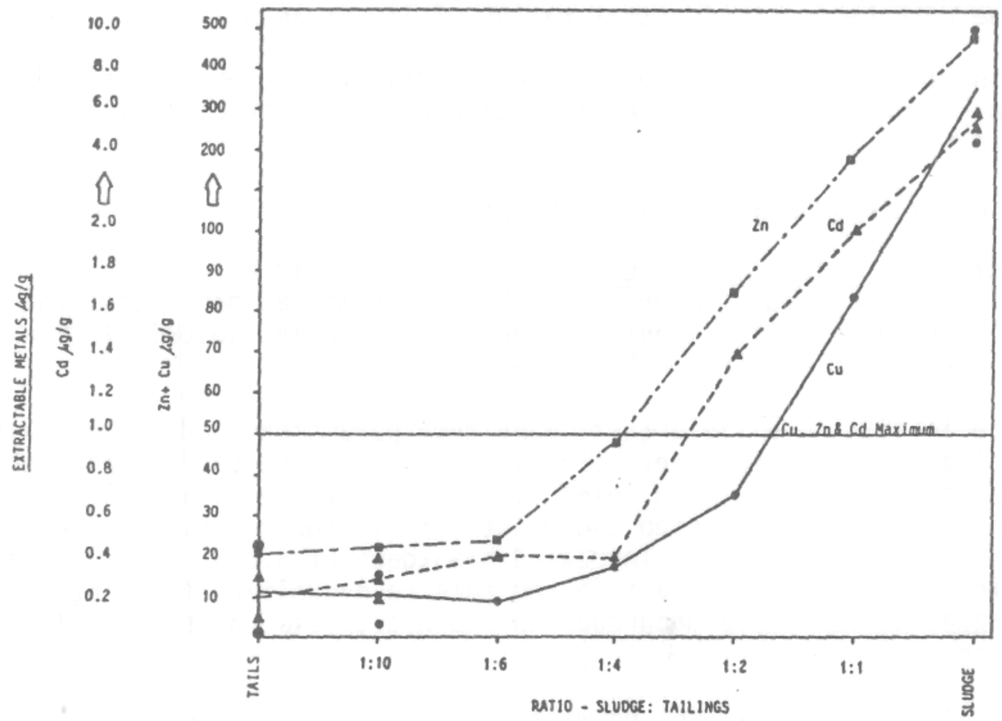


TABLE 1

SPECIAL WASTE EXTRACTION TESTS
EXTRACTABLE METALS IN SAMPLE - µg/g

RATIO SLUDGE:TAILINGS	Sb	As	Cd	Co	Cu	Cr	Pb	Hg	Ni	Zn	LAB PERFORMING TEST	
LIMITS	10.0	10.0	1.0	-	50.0	10.0	10.0	1.0	50.0	50.0	EXTRACTION BY:	FILTRATE ANALYSIS BY:
TAILINGS	L1.0	5.0	0.3	0.2	0.3	L0.04	L1.0	L0.02	1.0	29.5	A.S.L.	A.S.L.
TAILINGS	0.34	0.27	0.1	0.2	22.6	0.10	0.2	0.001	0.8	12.2	Equity	A.S.L.
1:1	0.07	0.95	2.0	10.4	83.2	0.04	1.4	0.001	25.8	161.0	Equity	A.S.L.
1:2	0.15	1.82	1.4	5.8	35.8	0.02	0.3	0.001	15.0	85.6	Equity	A.S.L.
1:4	0.33	2.42	0.4	3.2	18.6	0.01	1.8	0.001	9.0	49.6	Equity	A.S.L.
1:6	0.21	0.54	0.4	2.0	9.2	0.01	1.1	0.001	4.4	24.2	Equity	A.S.L.
1:10	0.21	0.72	0.2	1.0	10.9	0.01	0.9	0.001	4.0	24.4	Equity	A.S.L.
1:10	0.27	1.9	0.4	1.8	15.8	L0.10	0.4	0.001	4.2	28.6	Equity	A.S.L.
1:10	L4.0	L4.0	0.3	1.0	3.8	0.04	0.2	0.001	3.4	16.6	A.S.L.	A.S.L.
SLUDGE	0.02	0.14	5.8	32.2	500.0	0.10	0.1	0.001	75.0	564.0	Equity	A.S.L.
SLUDGE	L1.0	6.40	5.0	26.0	218.0	0.52	1.4	L0.02	67.2	404.0	A.S.L.	A.S.L.

FIGURE 4

S.L.S. BIODEGRATION TEST
(125 ppm S.L.S. SOLUTION IN FRESH STREAM WATER)

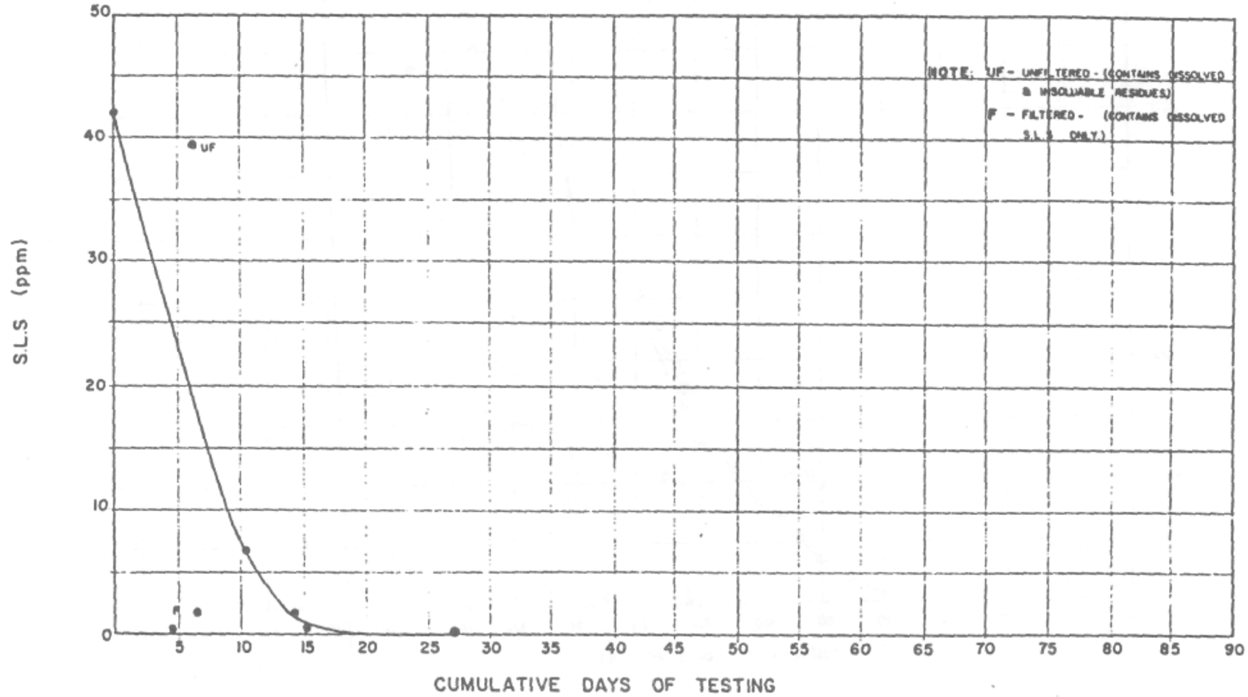


FIGURE 5

S.L.S. BIODEGRATION RATES
(TEST UNDER ACIDIC CONDITIONS)

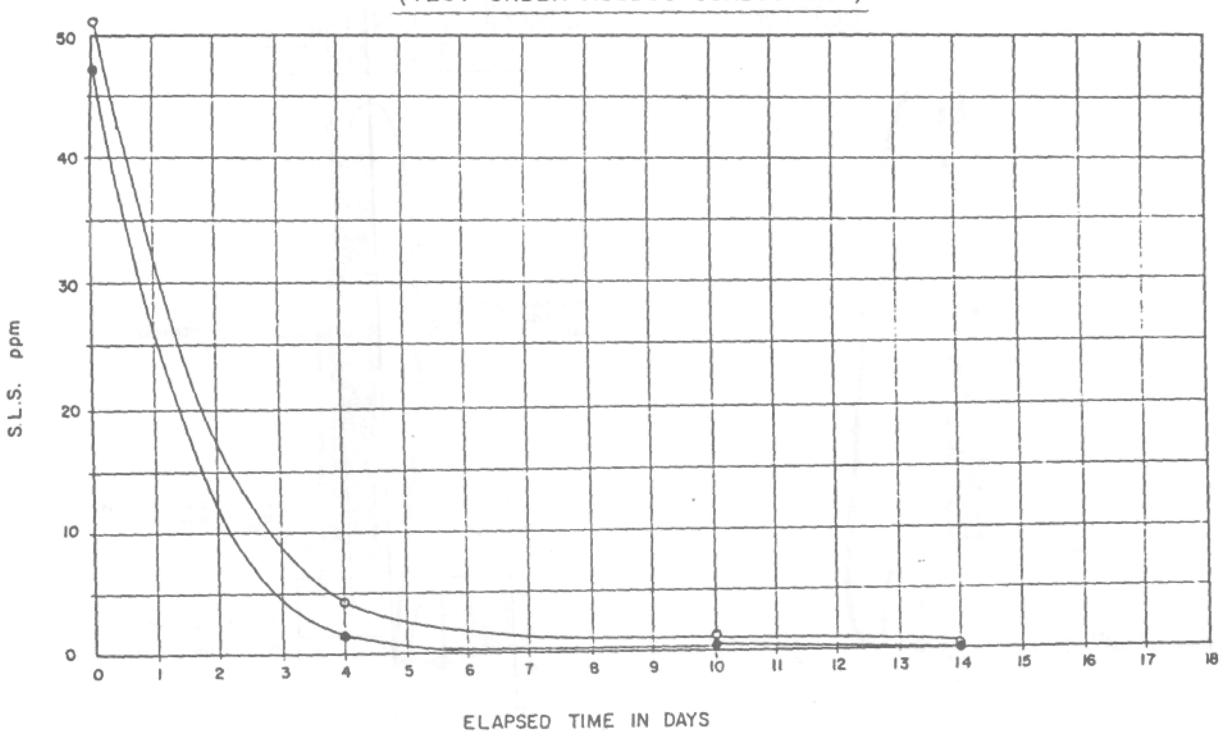


FIGURE 6

SURFACTANT TESTS

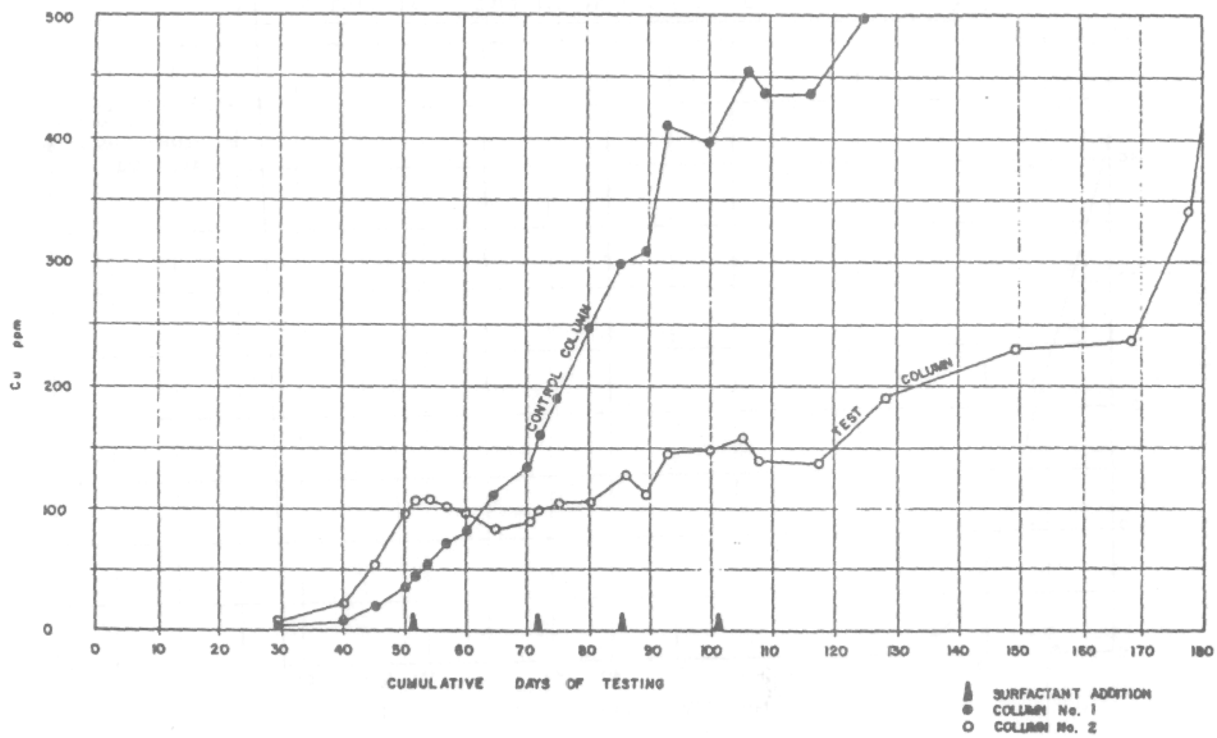


FIGURE 7

CONSTANT RECIRCULATION

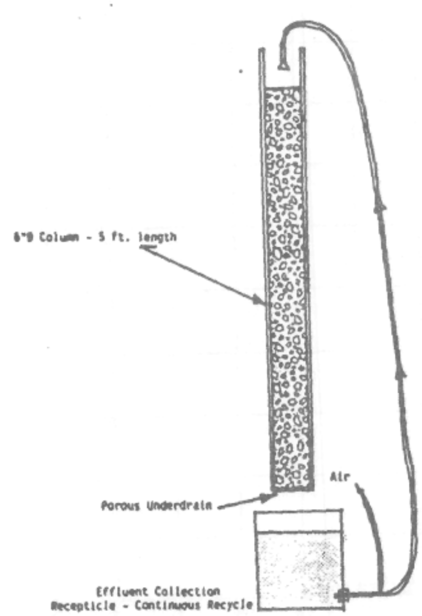
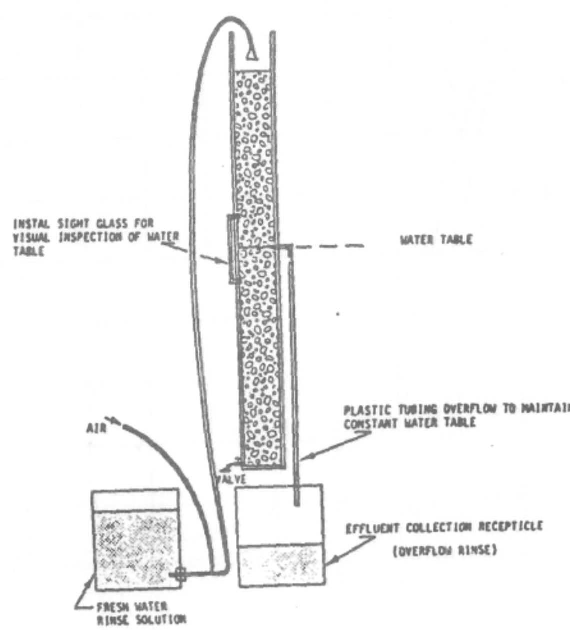


FIGURE 8

SIMULATED CONSTANT WATER TABLE
TEST APPARATUS



When immediate observation of waste rock reactivity is required, the continuous recycle system provides the quickest results. By recycling effluents, we essentially simulate heap leaching by cumulating acidity and bacterial concentrations. This type of simulation worked well for evaluating the bacteriocidal properties of S.L.S. (anionic surfactant). Samples that are suspect acid producers may also be subjected to these test conditions and evaluated over accelerated time frames.

The concept of burying reactive waste materials below a fixed water table is under investigation. By modifying the standard column we are able to simulate a fixed water table.

Water is held within the lower half section of column by sealing off the bottom and providing a drain midwaiy to decant off water introduced through the top section. This decant pipe serves as a sample point for monitoring water quality in the upper horizon. Quality resultant of substrate materials is monitored from a valved under drain. Finding from this research indicate no detectable oxidation of pyritic waste while in the submerged state.

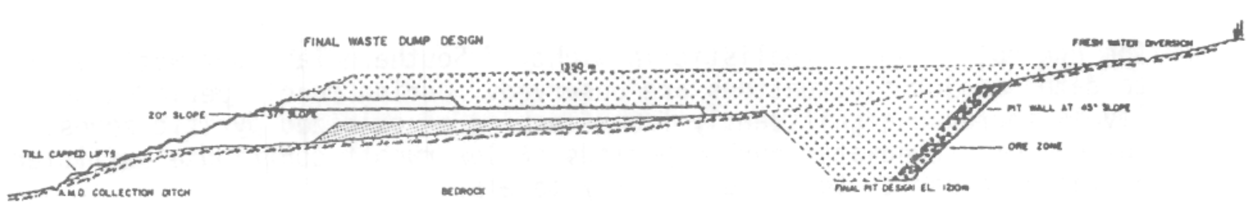
Waste Dump Construction

Major changes in waste dump design criteria have been prompted by stability and reclamation needs.

The standard construction techniques using high dump heads and natural angle of repose were terminated in the early stage of development. Deep lenses of glacial till (south side of waste dump) could not sustain loading, resulting in significant settlement during the 1981 period. Geotechnical investigations indicated dump faces would have to be flattened to a 20° overall slope for proper weight distribution and commenced during the latter part of 1981. Reconstruction was initiated from the lower limits upwards, and eventually merged with the existing dump head. In achieving the desired slope angle, the dump was constructed in individual lifts of 10 m thickness, each stepped in to conform to the 20° slope. Refer to Cross Section Figure 9.

FIGURE 9

TYPICAL WASTE DUMP CROSS SECTION



Besides addressing stability concerns, the reconstructed dump provides finished areas which may be progressively reclaimed. By placing a 1 m thick cap over the finished berms, we lessen the opportunity for water and oxygen transfer through spoiled wastes. An intermediate bed of glacial till has recently been placed within the dump to decrease air and water movement through the central core. Placement of the seal will reduce air exchange, particularly during colder periods, when venting of warm gases from internal oxidation set up a chimney effect within the dump.

Within *a* year, waste disposal on existing dumps will encroach on the Southern Tail pit limits. To accommodate future disposal of Main Zone wastes, the waste dump will have to be extended easterly to include the
dump.

Figures 10 and 11 illustrate present dump configuration and final design respectively.

Several conceptual plans have been addressed for backfilling the pit. These include disposal of waste below a water table and tailing sand injection of waste voids as a measure to reduce acid mine drainage.

Research has indicated pyritic waste may be stored beneath water with no significant impact on water quality.

Wastes overlying the water table would have to be separated by an impervious blanket to prevent migration of runoff through upper layers of waste into the water table. Impervious seals might include materials such as glacial till or tailings sands.

Consultants suggest a scheme of injecting tails into the voids of waste rock as a measure to reduce acid mine drainage. Void occupancy by tailings would decrease or eliminate air and water diffusion. The proposal is in the conceptual stage only.

A similar option might entail alternate placement of waste and tailings to decrease air and water transfer through the vertical component yet maintain horizontal drainage for groundwater.

Southern Tail pit water exhibits alkaline properties, often in the range of 150-200 mg/L equivalent CaCOs. If the potential for acid generation is decreased then alkaline groundwaters would add sufficient buffering capacity to hold water quality in line.

The concept is not unrealistic in light of Southern Tail pit water analysis to date. Major fluctuations are observed. During runoff periods, acidity levels increase significantly from flushing of oxidized pyritic zones. Inflows of groundwater during periods of low runoff contribute sufficient buffering capacity to offset acidity levels.

Reclamation - Trials and In-Field Practices

Test plots were established on the waste dump (summer 1983) to evaluate

FIGURE 10

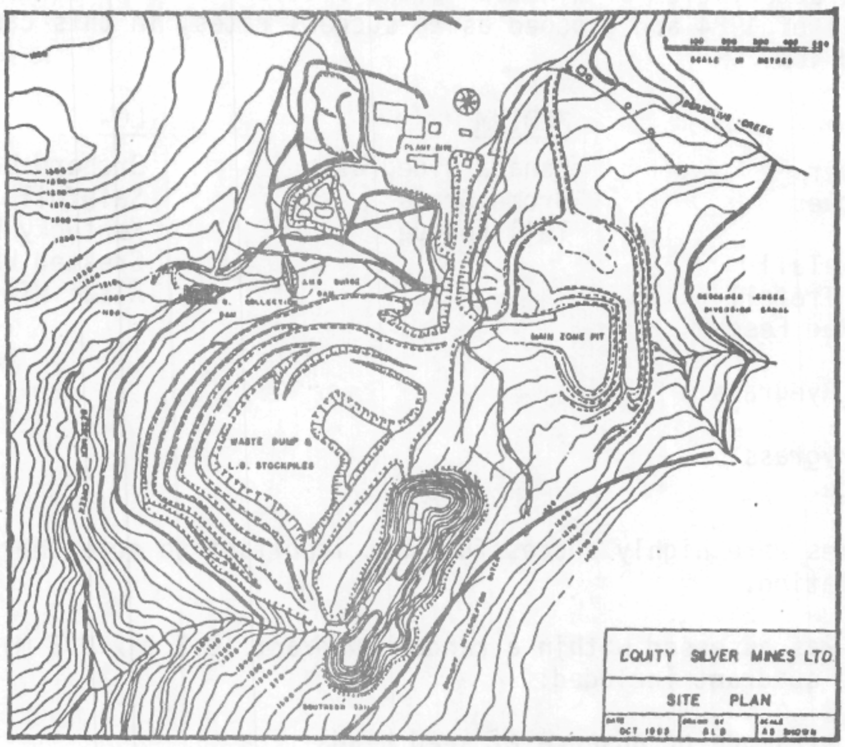
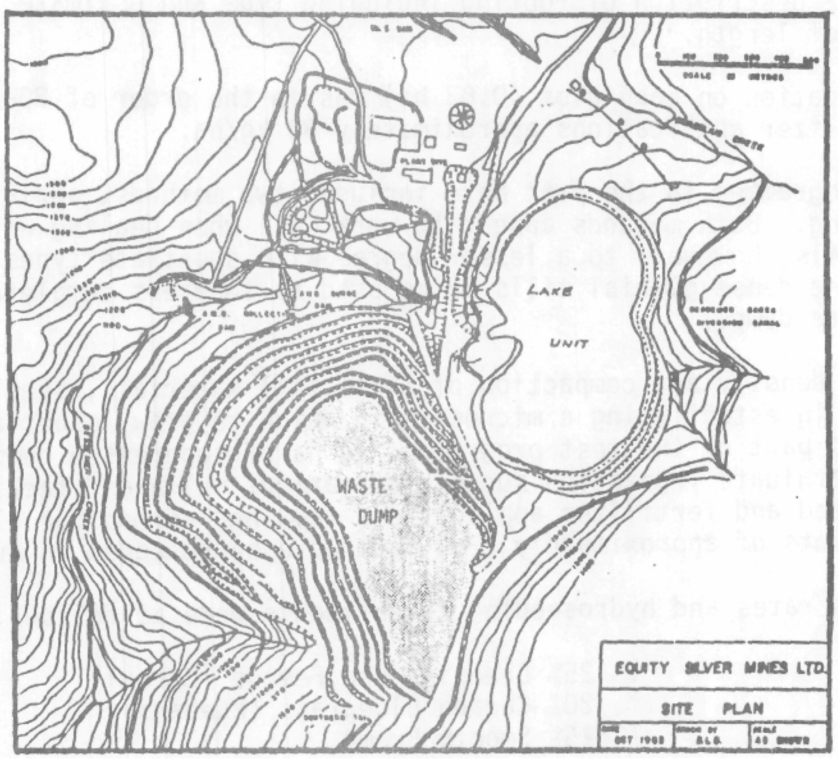


FIGURE 11



growth characteristics of nineteen plant species. The plots were evaluated in the fall of 1984 and grouped as to success rates, in this case, high, medium and low.

HIGH	MEDIUM	LOW
White Clover	Canada Bluegrass	Orchard Grass
Alsike Clover	Brome Grass	Sainfoil
Redtop	Tall Fescue	Kentucky Bluegrass
Meadow Fox-Tail		Crested Wheatgrass
Birdsfoot Trefoil		Altai Wild Rye
Creeping Red Fescue		
Timothy		
Perennial Ryegrass		
Alfalfa		
Reed Canarygrass		
Hard Fescue		

Most legumes were highly successful, but important to note there was poor root nodulation.

Each plot was assessed within a random quadrant (0.5 m x 0.5 m). Observations within the quadrant included:

(1) presence or absence of seed heads
(2) the average height and diameter of each species
(3) an estimate of percent groundcover by the Braun-Blanquet scale
(4) a description of rooting including type and estimate of length.

Seed application on each plot (0.03 ha) was in the order of 80-100 kg/ha, with fertilizer applications approximately 90 kg/ha.

Seeding programmes in the past have included two methods, aerial and hand broadcasting. Both methods appear to work well when dealing with "A" horizon soils, however, to a lesser degree with substrate types. Substrates refer to the dense glacial tills being used to topdress completed sections of the waste dumps.

Because of density and compaction of these till materials, seedlings have difficulty in establishing a microsite in which to grow, especially on side slopes. As part of the test programme, 14 ha of topdressed dump were hydroseeded to evaluate vegetation success of various mulch arid tackifier combinations. Seed and fertilizer applications remained common for all sites. Six test plots of approximately 2 ha each were hydroseeded in August 1984.

Application rates and hydroseeding constituents were as follows:

Seed Mix : 25% Creeping Red Fescue (Boreal)
20% Canada Bluegrass (Ruebans)
15% Smooth Brome

15% Climax Timothy
5% Tall Fescue
10% Mite Clover - Double Innoculated
10% Alsike Clover - Double Innoculated

Seed Application : 80 kg/ha

Fertilizer Mix : 21-7-14

Fertilizer Rate : 125 kg/ha

Test Plots :
(1) 80 kg/ha seed
125 kg/ha fertilizer

(2) 80 kg/ha seed
125 kg/ha fertilizer
200 kg/ha mulch

(3) 80 kg/ha seed
125 kg/ha fertilizer
350 kg/ha mulch

(4) 80 kg/ha seed
125 kg/ha fertilizer
500 kg/ha mulch

(5) 80 kg/ha seed
125 kg/ha fertilizer
80 kg/ha tackifier

(6) 80 kg/ha seed
125 kg/ha fertilizer
900 kg/ha mulch
80 kg/ha tackifier

Mulch - Spra mulch x 80 - natural wood fibre and cellulose
Tackifier - Ecology Controls M-Binder
Contractor - Terrasol Revegetation Erosion Control Limited
Equipment - Truck-mounted 3000 gallon hydraulic seeder.

Initial observation of areas tested revealed good grass germination however with less evidence of legumes. This is a common phenomenon and has been observed at other test sites. The legumes appear to become the dominant species two or three years after seeding.

All test plots will be assessed during the 1985 period.

SUMMARY

Most of this paper has been devoted to problems associated with A.M.D. and a lesser degree to the reclamation details. It was however, intended to place emphasis on the importance of evaluating acid generation potential and to stress the problems associated with reclamation measures when dealing with an acid generating orebody.