Proceedings of the 11th Annual British Columbia Mine Reclamation Symposium in Campbell River, BC, 1987.
The Technical and Research Committee on Reclamation

ENVIRONMENTAL & RECLAMATION MEASURES EQUITY SILVER MINES LTD.

ROBERT J. PATTERSON
Environmental Co-Ordinator
Equity Silver Mines Limited
Houston, British Columbia

January, 1987

ABSTRACT

Acid Mine Drainage (A.M.D.) formed from oxidation of disposed pyritic wastes presents a potential pollution hazard for Equity Silver Mines Limited and the mining industry in general. Failure to collect and treat these acidic effluents can eventually affect the quality of receiving streams and endanger aquatic life forms. Treatment and discharge of A.M.D. to the receiving environment must comply with stringent anti-pollution laws.

Wastes mined at Equity Silver Mines Ltd. are predominantly acid generating and must be handled according to a materials management plan to minimize impact on the environment. Effluent collection and treatment facilities have been constructed to address the short term environmental concerns with reclamation and research programs being developed to address and monitor abatement measures for control over the long term.

The purpose of this paper will be to offer a brief overview of these measures. Key topics for discussion will be: kinetics of Acid Mine Drainage, acid generating potential, water treatment and sludge handling, special wastes, waste dump construction, waste rock amendments, bacteriocide research, simulations, and reclamation measures. Programs designed to evaluate impact on the receiving environment, although they form an extensive part of the program, will not be discussed in this paper.

INTRODUCTION

Equity Silver Nines Limited is located in the Central Interior of British Columbia, within the Omineca Mining Division, 35 kilometers southeast of Houston and approximately 575 kilometers by air north-northeast of Vancouver (Figure 1).

FIGURE 1: LOCATION OF EQUITY SILVER MINES LTD

The deposit consists of three economic mineralized zones: The Southern Tail, Main and Waterline Zones. Mining of the Southern Tail commenced in April, 1980 and was completed in the first quarter of 1984. Main Zone production was initiated during the last quarter of 1983 and the Waterline Zone remains undeveloped to-date. Remaining reserves are in the order of five to six years contingent on favourable metal prices.

The three deposits (Figure 2) occur within a window of interbedded volcanic and minor sedimentary rocks. The older volcanic sequence is bounded on the west by a small granite-like stock and on the east by a gabbro-monzonite complex. All are overlain by a series of younger lava flows.

Economic mineralization (Cu-Ag-Au) occurs as tetrahedrite and chalcopyrite. Pyrite is the predominant sulphide mineral throughout the waste and mineralized zones and occurs in disseminated, massive and crystalline forms. Oxidation of these sulphides results in the formation of Acid Mine Drainage (A.M.D.). Although reaction mechanisms are complex, the key parameters have been identified as moisture, oxygen, a source of sulphide minerals and the presence of certain strains of iron and sulphur oxidizing bacteria. (Kleinman & Erickson, 1983). Elimination of any one of these parameters will suppress the acid producing reactions.

Equity Silver Mines Ltd. has and is continuing to encapsulate wastes with glacial till in an effort to eliminate control factors governing the rate of oxidation and subsequent production of A.M.D. These measures along with the water treatment processes and research programs will be outlined in the paper.

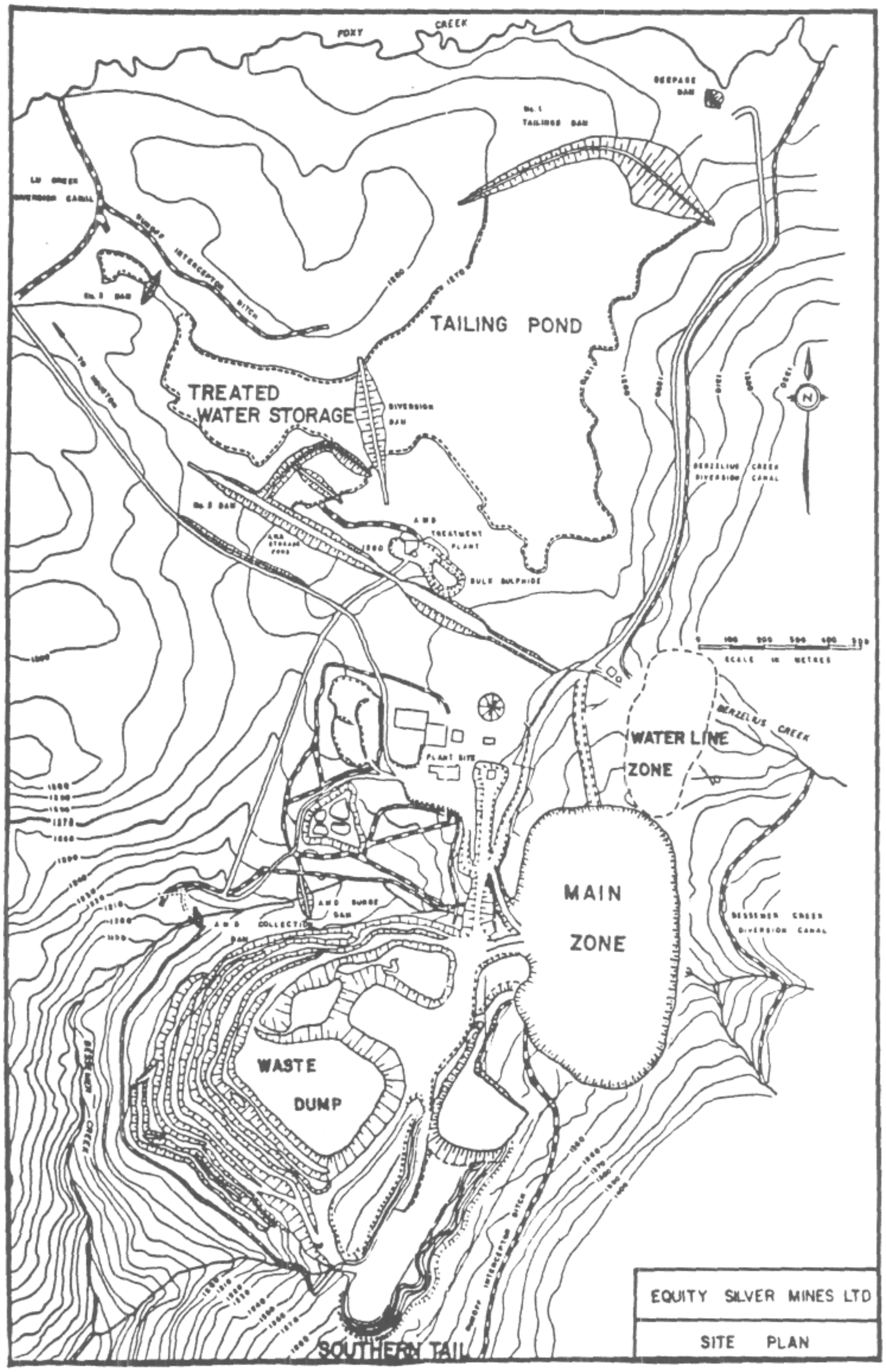

FIGURE 2: EQUITY SILVER MINES LTD. SITE PLAN ILLUSTRATING KEY GEOGRAPHIC FEATURES

KINETICS OF ACID GENERATION

The degree to which acid generation occurs varies with the nature and concentration of available sulphide (pyrite) material. Pyrite mineralization at Equity Silver ranges from disseminations to the massive form. Where these massive forms occur along fracture planes, liberation and exposure due to blasting is thought to be maximized, likewise acid generation processes.

KINETICS OF ACID GENERATION

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

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

$$Fe^{++} + \frac{1}{4} O_2 + H^{+} \rightarrow Fe^{+++} + \frac{1}{2} H_2O \qquad (3)$$

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

FIGURE 3: TYPICAL OXIDATION REACTION FOR SULPHIDE (PYRITE) MINERALS

Metal and acid forming ions liberated during the initial stages of oxidation, combine with alkaline materials inherent in the host rock and settle out of solution as soluble metal precipitates (Reactions 1 and 2 - Figure 3). With continued oxidation (Reaction 3) and the lowering of solution ph, metallic precipitates are taken back into solution. This step occurs when available alkalinity in the waste is depleted. Liberated metal ions, particulariIy iron in the ferric state (Fe+3), act as an oxidizer which further react with sulphide materials. As the process accelerates and the ph of the solution drops below 2.5, the rate of activity of the ferric iron (Fe+3) is governed by the combined effect of bacterial oxidation of ferrous iron (Fe+2), the reduction of ferric iron (Fe+3) by pyrite, (Reaction 4) and the associated formation of ferric sulphate and hydroxal complexes. If the reactions are allowed to proceed uncontrolled the cycle will continue until the sulphide supply is depleted.

ACID GENERATING POTENTIAL

In assessing the reactivity of an ore body, waste materials are tested for acid producing potential and buffering (alkalinity) capacity. Results of testing at Equity are quoted as a ratio, Acid Generating Potential : Acid Consumption Capability. For instance, an index ratio of 4.5, merely means testing has indicated that the waste material has the potential to produce 4.5 times more acid than it is capable of neutralizing. Where these ratios are low, kinetic tests in columns should be used to substantiate static acid-base accounting. Release of neutralizing capacity is greatly affected by factors such as particle size and hydroxide coating. Erroneous conclusions based on static test results alone are not uncommon.

The acid producing potential of pyritic waste material within the Nain Zone Pit varies between a low of 0.15 to a high of 65, with the majority of values falling within the 10 to 20 range (Sperling, 1984). Zones of acid generating potential are illustrated in Figure 4.

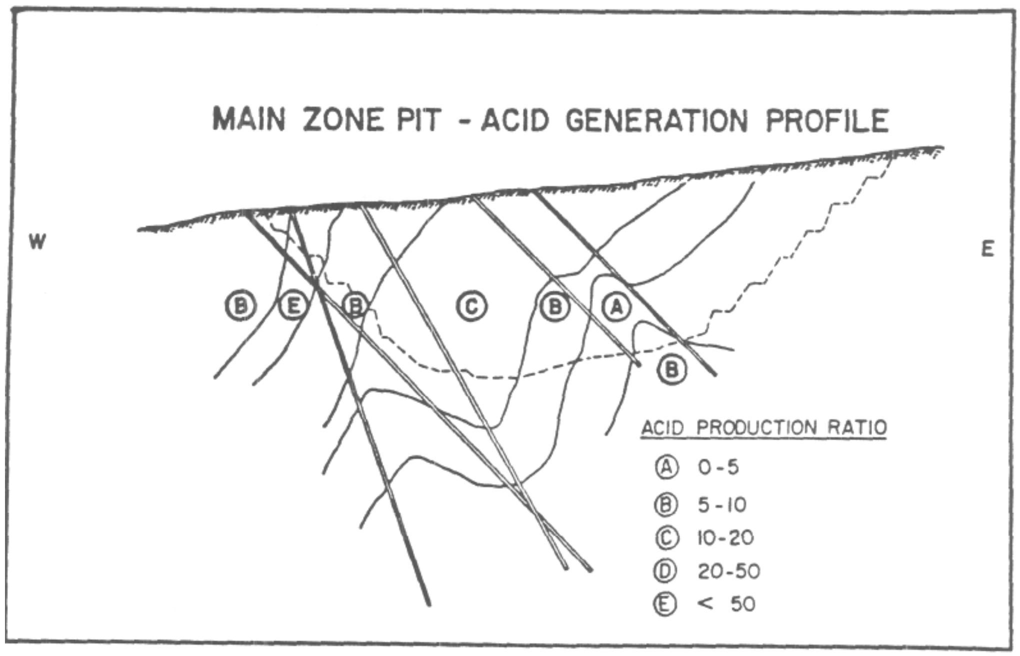

FIGURE 4: COMPOSITE CROSS SECTION OF MAIN ZONE ORE BODY WITH ACID PRODUCING POTENTIAL ZONING

Non-acid producing wastes occuring on the east wall of the Main Zone Pit are selectively mined for construction purposes and used at sites where A.M.D. must be eliminated, i.e. tailing dams. Use of non-acid producing materials for these projects precludes the possibility of reducing acid producing potential through acid-base accounting by strategic placement of wastes. All wastes classified as acid producers must be stockpiled on a common dump and reclaimed to reduce oxidation rates.

WATER TREATMENT AND SLUDGE HANDLING

Approximately 800,000 cubic metres of A.M.D. must be collected annually and processed through a lime neutralization treatment plant. Treated water from the plant complies with stringent quality objectives and is discharged to the receiving environment at dilution ratios governed by metal content and stream flow rates.

A.M.D. TREATMENT STATISTICS

VALUES IN mg/L

	ph	ACIDITY	SO_4	Cu(d)	Zn(d)	Fe(d)
RAW A.M.D.	2.35	10,000	8,500	120	80	800
TREATED	7.80	NIL	1,600	0.01	0.04	0.03

PUMPING COST	0.15 dollars / M^3
TREATMENT COST	0.70 dollars / M^3
ANNUAL VOLUME TREATED	800,000 M^3

Table 1 - A.M.D. Treatment. Statistics

Estimated costs for pumping and treating A.M.D. at present acidity levels is in the order of $0.85 per cubic metre. Typical A.M.D. treatment statistics are illustrated in Table 1. The sediment (sludge) produced from the treatment process consists mainly of metal hydroxides. Yearly accumulation of this sludge represents not only a short term storage problem but a long term reclamation concern.

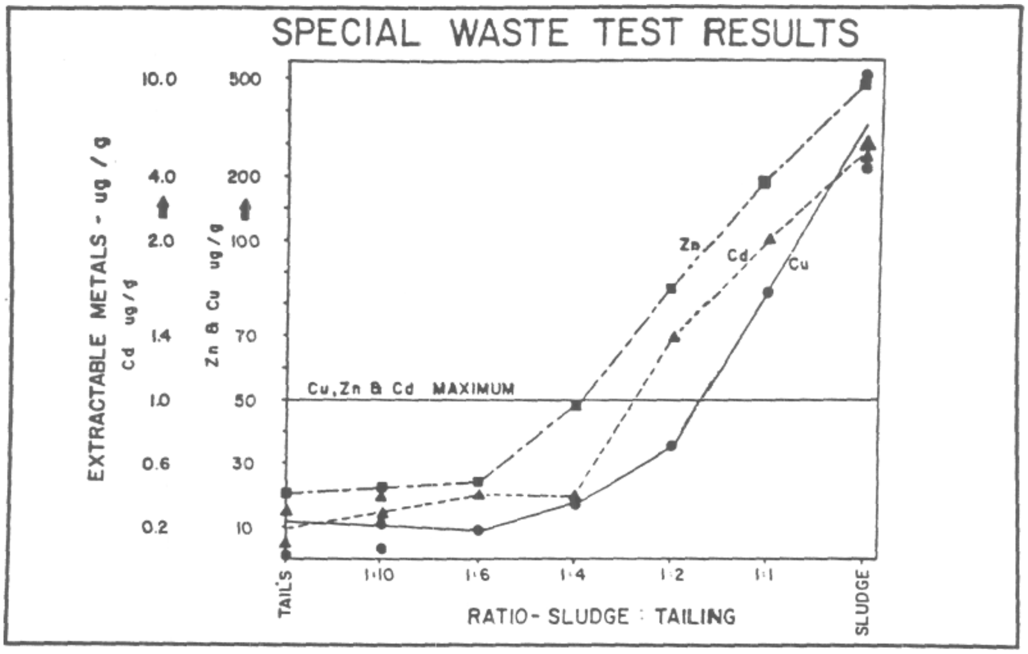

FIGURE 5 - RESULTS OF SPECIAL WASTE TESTING USING VARIOUS RATIOS OF A.M.D. SLUDGE AND TAILING

A.M.D. sludge, through testing, has been classified a Special Waste according to the proposed Special Waste Act. By mixing A.M.D. sludge with mill tailing discharge at ratios as low as 1:4, extracted metals from the composite meet guidelines laid out in the act. Figure 5 illustrates that tailing complies with Special Waste guidelines, whereas A.M.D. sludge far exceeds the limits set forth. Mixtures of A.M.D. sludge to tailing between the ratios of 1:10 and 1:6 show little change from baseline extractions within the tailing. Deviation from this trend becomes evident at ratios of 1:4 or less. Permitting has been completed to accommodate mixing the two products at a 1 : 10 ratio. Disposal of the material will be handled in this fashion during the period when the mine is in operation. Alternate options for sludge handling after abandonment include disposal in large ponds or beneath water within the Main zone pit.

The mechanics of pumping sludge has met with several operating difficulties. Pumping was initially carried out in a pond containing a surface layer of water. This resulted in a vortex around the pump with sludge being supported by water thus preventing lateral movement of the material. A waste rock divider dyke within the two cell arrangement was subsequently sealed with glacial till to prevent short-circuiting of water between the active pond and pond being excavated. Elimination of the water sources improved sludge pumping and at 5 percent solids sludge migrated over the full length of the pond supplying feed to the pump.

WASTE DUMP CONSTRUCTION

Disposal of all acid generating waste material is restricted to a common dump site (Figure 2). Prior to identifying A.M.D. occurrences, pyritic wastes were liberally used for fills throughout much of the property. Sites difficult to access for purpose of A.M.D. collection have required, where possible, excavation of acid generating material. Similar clean-up will be scheduled throughout the mine life to consolidate areas of contamination.

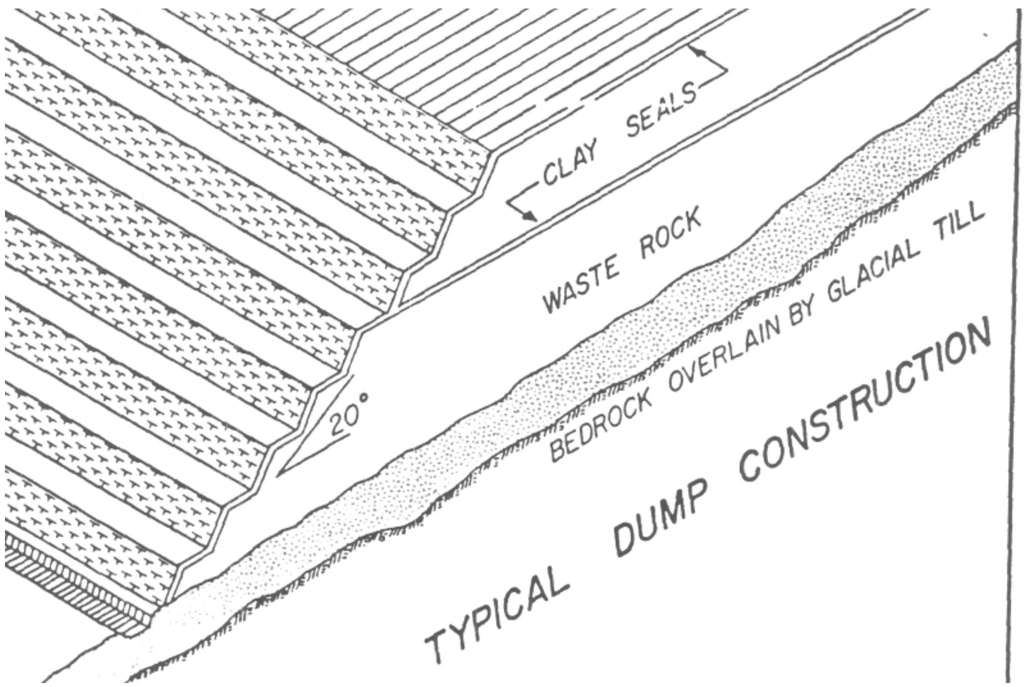

FIGURE 6: TYPICAL DUMP PROFILE AMD IMPERVIOUS CLAY SEALS

Initially the waste dump was constructed by disposal along a common horizon. This construction technique produced high dump faces with static loads in excess of shear strengths of the underlying glacial till, consequently resulted in several minor localized failures. Geotechnical investigation (Klohn Leonoff, 1984) indicated that dump faces would have to be reduced from the natural angle of repose (37 degrees) to an overall slope of 20 degrees to achieve a safe weight distribution. Dump faces were reconstructed from the lower limits upwards, eventually merging with the existing dump head. In achieving the design slope angle, the dump had to be reconstructed in individual lifts of 10 meter thickness, each stepped in to conform to the 20 degree overall slope (Figure 6).

Reconstruction of the dump coincided with the period when A.M. D. occurrences became most prevalent. The new design accommodated a continuous reclamation program whereby completed berms and side slopes could be top-dressed with a one meter layer of glacial till and seeded to establish a protective vegetative cover.

Air exchange within dump structures accelerates during the winter months as gases produced from the oxidation process set up convection currents during periods of maximum atmospheric pressure variation, much the same process as in a fireplace chimney. To further reduce this air exchange, an intermediate layer of till was placed within the dump during the course of construction (Figure 6).

Glacial till is removed from active mining areas and from stockpiles inventoried during the pre-production stage. Disposal of till for reclamation purposes during the mining cycle precludes the need to stockpile material and in turn decreases final abandonment costs. Glacial till hauled to the dump represents a small incremental cost over and above normal operating expenditure.

To accommodate waste disposal demands, the dump will be extended easterly (Figure 2) to backfill the Southern Tail pit. By placing a portion of the waste below water within the pit, oxidation processes will be eliminated.

Wastes (especially the fine fraction) placed below the water table provide a supply of available alkalinity. Provided the acid generating processes within the area are minimized, residual alkalinity should maintain water quality within permit specification. A one meter layer of inert material (Gabbro) was placed at the appropriate horizon to accommodate fluctuation in the water table. This will safeguard alternate wetting and drying of pyritic wastes that would otherwise contribute to A.M.D. generation. A spillway has been constructed at the south end of the pit to ensure that a constant water level is maintained. Those materials placed above the water table will be encapsulated with a clay layer to decrease oxygen diffusion.

Results of existing reclamation efforts have yet to be fully assessed, although where these measures have been instituted at localized sites there has been a downward trend in acidity and dissolved metal concentrations. Monitoring programs are presently being developed or modified as assessment tools.

Temperature probes installed in the southern flank of the dump, have been used over the past 3 years to monitor internal dump temperatures. Observations to date reveal that the reaction produced through oxidation has elevated internal temperatures to 55 degrees celsius. A recent decline of several degrees has been observed and is thought to be a product of reclamation measures. A program of thermal imaging of pits and dumps has been recently completed by Environmental Protection Service based in Vancouver, B.C. The practice of photo heat tracing (Thermography) is presently under investigation as a tool to assess the effect of till covers on pyritic wastes and a detection method for pin-pointing problematic zones yet to be reclaimed.

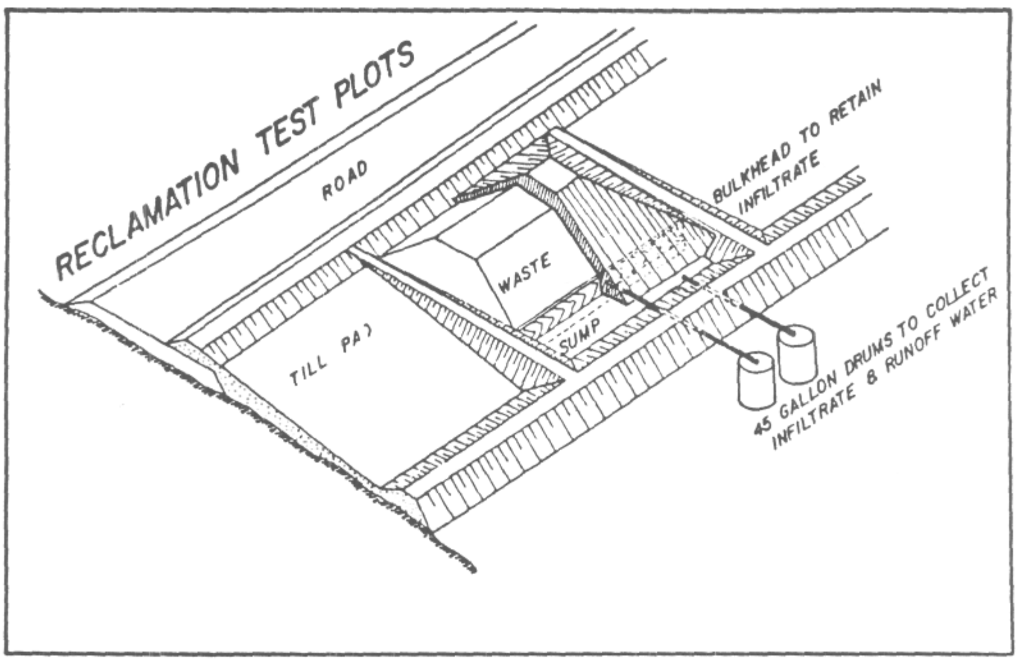

FIGURE 7: SCHEMATIC OF RECLAMATION TEST PLOTS

Test plots (Figure 7) representing scaled down versions of the waste dump have been developed to evaluate present reclamation measures. Glacial till covers have been added to wastes at thicknesses comparable to present use on the waste dump. Uncovered control units will be used to assess the effect of present till thicknesses.

A qualitative water monitoring program has been in place since 1983 to evaluate the impact of reclamation efforts. This program has recently been expanded to provide hydraulic balances of runoff within domains. Hydraulic balances, along with metal analyses, will be used to calculate contaminant flows out of the waste dump and delineate problematic zones.

WASTE ROCK AMENDMENTS

The anionic surfactant (Sodium Lauryl Sulphate) has been tested to evaluate bacterial suppression methods within waste fills. Although the initial lab testwork looked encouraging, results of in-field testing proved to be less than favourable. Nevertheless, use of this product should not be overlooked pending favourable conditions. To be effective, a sufficient dosage of the soap product must be available to completely infiltrate the spoil. Application rates at Equity Silver were based on treating the top meter of waste as outlined by past experience at coal operations. Recent findings at Equity Silver indicate that this oxidation zone, in coarse rock, can be in excess of 10 meters. Because of this oxidation depth, spoil piles could not be effectively saturated with treatment solutions. Recent tests carried out by the U.S. Bureau of Mines on Equity waste material support this assessment (Watzlaf, 1986). As a further complication the surfactant used biodegraded rapidly under the acidic conditions thus would require reapplication more frequently than the two to three months period experienced in the coalfields.

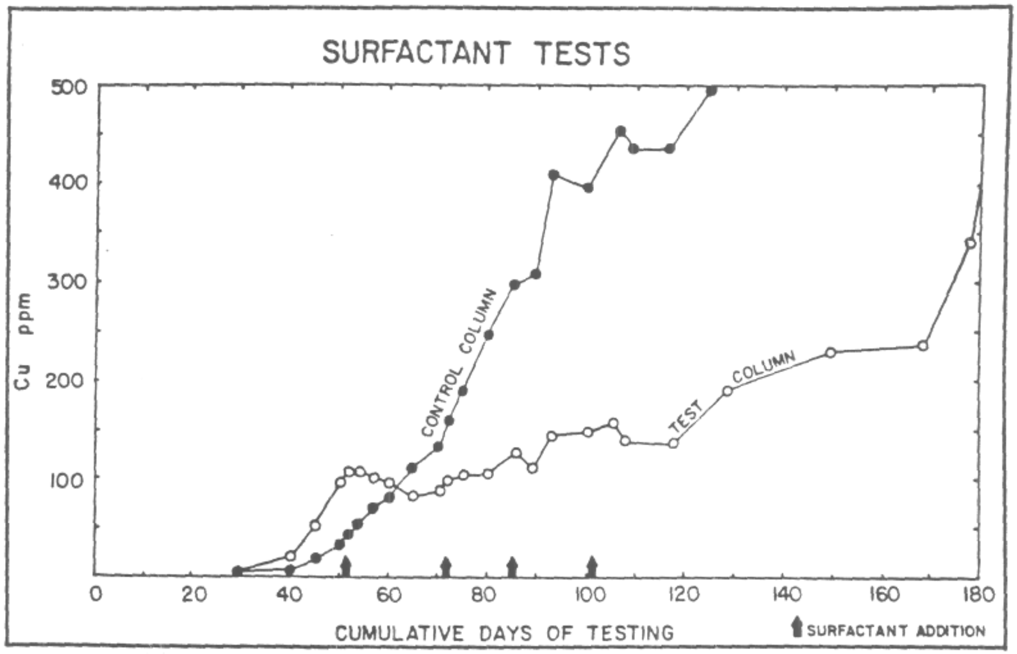

FIGURE 8: EFFECT OF S.L.S. ON OXIDATION RATES

Results of lab simulations using sodium lauryl sulphate (S.L.S.) are illustrated in Figure 8. Where S.L.S. was used in a test column containing pyritic waste, oxidation rates and dissolved metal content were suppressed in relationship to an uncontrolled test. Copper was used as a trend indicator, although other metals, sulphates or acidity values could have been similarity used. After surfactant addition was discontinued, copper values in the test column approached the trend set in the control column, thus indicating re-population of bacterial colonies and acceleration of oxidation processes.

Precipitates formed from the treatment of A.M.D. consist of met hydroxides and residual lime. Injection of these precipitates into waste rock voids was initially considered an option for sealing and adding alkalinity to pyritic wastes. Tests were carried out to evaluate the impact of this amendment on oxidized pyritic waste rock.

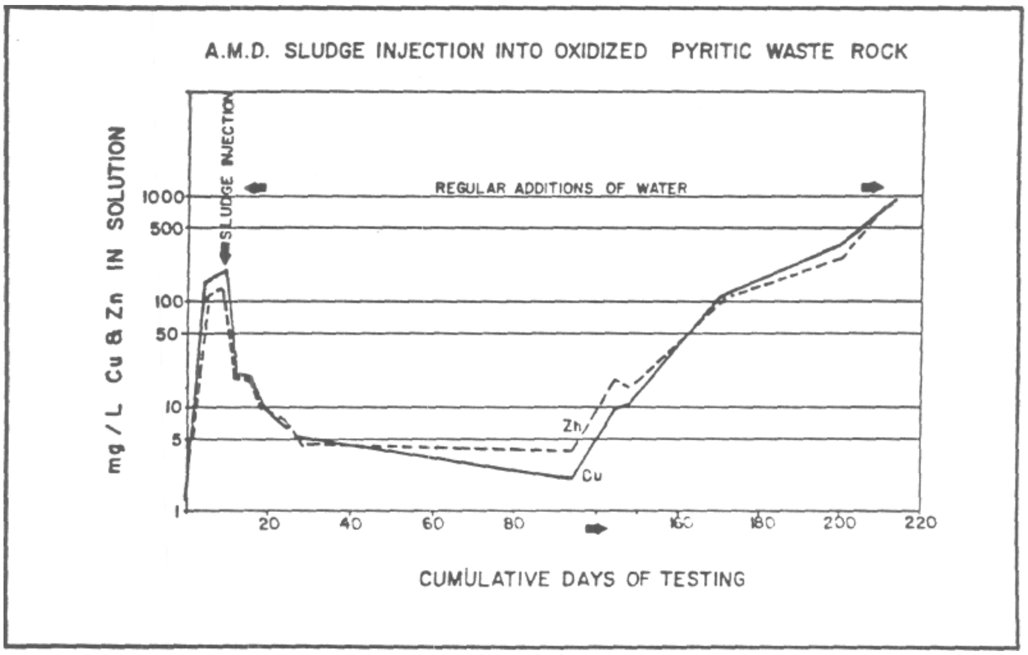

FIGURE 9: A.M.D. SLUDGE INJECTION INTO OXIDIZED PYRITIC WASTE

Injection of the product revealed a significant improvement on water quality. However, over an elapsed period acid generation processes within the waste exceeded the buffering capacity of the sludge resulting in a deterioration of effluent quality. Sludge injected into the waste was redissolved, further adding to the metal loading in the effluent (Figure 9). Under less severe conditions alkaline sludges may be a suitable amendment for control of A.M.D. Operational aspects of a scaled up program were not investigated nor the geotechnical effect on dump structures.

SIMULATIONS

Disposal and abatement concepts are tested in columns containing the rock types in question. These test vessels, constructed from five foot lengths of P.V.C. pipe, are equipped with either porous or impervious bases depending on the water course regime being evaluated. Solutions are circulated through each column by purging air through plastic tubing connected to the effluent receptacle and top of column .

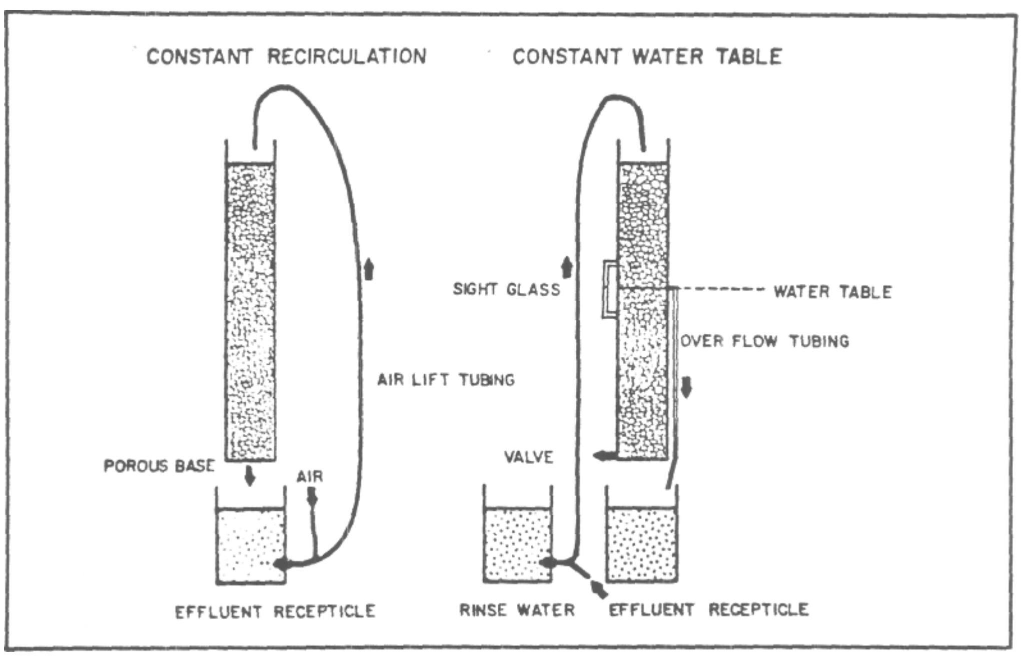

FIGURE 10: COLUMN TESTS

Acid generation processes can be accelerated by subjecting wastes to a constant circulating load of effluent (Figure 10). Essentially this technique enhances leaching by cumulating acidity and bacterial concentrations and works well for testing products such as surfactants as an abatement measure.

Similar columns, with sealed bases, have been used to evaluate oxidation processes below a fixed water table. Water is held within the lower section of the column by sealing off the base and providing a drain midway to decant off water introduced through the top section (Figure 10). The decant serves as a sample point for monitoring water quality in the upper horizon above the water table with substrate water quality being monitored from a valved under drain. Results from these tests indicate minimal oxidation of pyritic waste while in the submerged state.

RECLAMATION

Reclaimed areas are revegetated to stabilize glacial till covers and reduce precipitation infiltration through evapotranspiration losses. Various grass and legume species are evaluated using test plots for selection of suitable mixtures. Assessment of these plots is carried out annually and documented for future reference. Seeding programs employing hand and aerial methods have been reasonably effective in establishing vegetation on well graded and unconsolidated soil types and to a lesser degree on the dense consolidated glacial till, especially on side slopes. Hydroseedling methods were subsequently tested and found to provide better results. As results of the test work were encouraging, Equity Silver has since purchased a hydroseeder to supplement traditional seeding techniques.

Although reclamation efforts are primarily geared towards reducing oxidation within wastes dumps, the aesthetic and habitat benefits are also deemed important. An increase in deer population has been observed over the past few years and is thought to be a product of reclamation efforts.

CONCLUSION

Control measures at Equity Silver Nines Limited have been effective in minimizing the environmental impact of A.M.D. Reclamation practices appear to have reduced oxidation rates at confined sites, although considerably more monitoring will be required to fully evaluate control measures on the larger disposal site. Alternate methods tested for suppressing acid generation processes initially appeared encouraging however have since been curtailed due to questionable long term benefit, both operationally and that of environmental security. With existing reserves in the neighbourhood of 5 years, plans are now being developed to prepare for mine abandonment. This will require a host of studies associated with sludge disposal, tailing pond abandonment and further research into A.M.D. mitigation methods for the waste dump.

ACKNOULEDGEMENT

As spokesperson for Equity Silver Mines Limited, the author would like to thank the executive of the Reclamation Symposium for the invitation to present this paper, and to the management and operating crews at Equity Silver for their undivided support in dealing with environmental concerns.

References

Kleinmann, Robert L.P. & Erickson, Patricia M. (1983) Control of acid drainage from coal refuse using anionic surfactants, U.S. Bureau of Mines Report of Investigations RI 8847.

Klohn Leonoff Consulting Engineers, 1984. Waste dump stability review. Parameters & Report to Equity Silver Mines Ltd.

Sperling, T. (1984) A study of acid generating rock distribution in the main zone (unpublished) Equity Silver in-house report.

Watzlaf, G.R. (1986) Control of acid mine drainage from mine wastes using bacterial inhibitors. National meeting of the American Society for Surface Mining & Reclamation March 17-20, 1986.