

THE EFFECTIVENESS OF VEGETATION
IN CONTROLLING ACID GENERATION IN
BASE METAL TAILINGS

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ABSTRACT

Noranda Inc., which currently owns 18 mines in Canada and the United States, maintains a high degree of commitment to environmental protection. Reclamation research in the early 1970's at Noranda Waite Amulet site led to a successful vegetation program. However, the expected benefits of vegetation in reducing acid generation at Waite Amulet have not been realized.

Further research efforts have been undertaken at Heath Steele Mines Ltd., Newcastle, N.B., Waite Amulet, Rouyn-Noranda, P.Q., and a high carbonates tailings site in Ontario. The program involves a characterization of the geochemistry and hydrogeology and an evaluation of the parameters which control oxidation. Modelling tools will be evaluated for predicting the geochemical behaviour of these tailings with time and under varying reclamation scenarios.

Direct vegetation of reactive tailings has not restricted oxygen diffusion nor has it limited water infiltration. Consequently, oxidation of sulphide tailings is occurring, acid water containing heavy metals is being generated and complex geochemical processes of neutralization, precipitation, co-precipitation and adsorption are taking place to ameliorate pore water quality. The upper 1 to 2 m zone of oxidation is influenced by such factors as the water table and the sulphide content and particle sizing of the tailings. Infiltrating water due to precipitation and snowmelt transports pore water containing dissolved metals through the tailings and into the groundwater and surface seepage systems.

1.0 Introduction

Environmental protection is an important element of Noranda Inc's operations. In 1986, the Board of Directors approved an environmental policy which states the following:

Noranda Inc. operations will strive to be exemplary leaders in environmental management by minimizing the environmental impact on the public, employees, customers and property, limited only by technological and economic viability. The following principles are basic to achieving this environmental objective:

1. The potential risks of new projects to employees, the public and the environment must be assessed so that effective control measures can be foreseen and taken, and all parties made aware of these facts.
2. Noranda group operations will implement site specific environmental, health, hygiene, safety and emergency response policies in the spirit of guidelines issued by Noranda Inc. as well as in conformation to applicable laws and regulations.

3. Noranda group operations will constantly evaluate and manage risks to human health, the environment and physical property.
4. Noranda group operations will be subject to periodic environmental, health, hygiene, safety and emergency preparedness audits.
5. A report on environment, health and hygiene, safety and emergency preparedness will be presented annually to the Board.

Though the policy is recent, the corporation has maintained a high degree of commitment to environmental protection over the years.

Noranda Minerals Inc., one of four Divisions within the corporation, currently operates, maintains or is decommissioning 18 mines in Canada and the United States. Of these, 10 are operating, 3 are being maintained in a closure mode awaiting improved metal prices or sale, and 5 are closed and are either being decommissioned or being prepared for sale. Among operating mines, 6 may enter the reclamation phase within 2-5 years unless additional reserves are identified through continuing exploration. Noranda Inc. tailings areas total approximately 3500 ha, of which 50% is classified as reactive due to the presence of sulphides.

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Mining activities which may have a significant impact on the design of a reclamation plan - vegetation and acid generation being two of the parameters here-include:

- o open pit operations in which case rock dumps may be formed - the rock representing the capping/stripping and boundary material surrounding the mineralized zone which must be removed to expose the ore, and
- o development of a tailings pond which confines the remaining gangue material after the minerals are extracted from the ore.

Tailings and mine rock may be reactive, acid generating sources - the balance determined by the acid generating and consuming capacity of the host material. Today, techniques exist which can determine a positive or negative potential for acid generation. These technologies were not available when some of the early reclamation work was undertaken.

2.0 The Early Waite Amulet Vegetation Experience

It was not many years ago when a vegetative cover over a tailings area or a rock dump was considered to be the panacea. Noranda's history in this approach began in the

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1960's when the current Home Division initiated work on the Waite Amulet tailings pond near Rouyn-Noranda, Quebec. The objectives of these early efforts were to:

- o control fugitive dust due to wind erosion of the surface;
- o control surface water erosion;
- o improve site aesthetics;
- o improve the water balance by an active vegetative cover which would intercept, evaporate and evapotranspire moisture thereby preventing its entry into and flow through the tailings mass;
- o control acid generation.

The 41 ha Waite Amulet dam contains approximately 5.9 Mt of tailings with a 60-90% sulphide composition, pyrite being the main mineral. Tailings were deposited from 1933 to 1962 with the exception of one shutdown period.

In the late 1960¹s, surface water quality monitoring revealed evidence of acid generation due to the oxidation of iron sulphides. Neutralization of acidic water was

initiated at that time. By 1969, the Home Division had decided upon the need for a vegetative cover to control tailings dusting and acid generation as well as to improve site aesthetics.

Surface pH of the tailings ranged between 2.2-3.0. Starting in 1969, an experienced contractor undertook the reclamation work. Lime at 11.2 t/ha, fertilizer and seed were added based upon experience at other sites and although a green tinge developed, the vegetation died back within a month. A second attempt was made the next year with a higher limestone addition rate (15.7 t/ha) with an unfortunate similar result - total failure. Noranda then decided it was time for a new approach.

Limestone neutralization tests were conducted in the laboratory and a tailings acid demand of 56 t/ha of lime was indicated. In 1972, 10 100 m² plots were established and 112-168 t/ha of limestone and varying fertilizer and seed mixtures were applied. Although results were promising, costs were quite high. Variability in test plot performance introduced some technical uncertainty and consequently the Home Division was reticent about proceeding with another full scale reclamation attempt.

3.0 Noranda/University of Guelph Program - Vegetation

Noranda Inc. initiated a five year research program with the University of Guelph, beginning in 1974, to evaluate the variability of sulphide tailings and how this could affect plant growth and to improve the technique for assessing growth potential of these sulphide materials. Although copious data were generated, correlations between growth potential and chemical and physical characteristics of tailings were not evident! Conventional metallurgical and agricultural analyses did not elucidate the problem. What did develop from the research program, however, was a rapid growth room assessment technique whereby a relatively large number of tailings samples with varying applications of lime, fertilizer and seed could be evaluated. This technique has subsequently been applied within Noranda Inc. companies and some reclamation projects based on these laboratory scale assessments have been successfully carried out.

Waite Amulet was vegetated in stages from 1978 to 1981 using agricultural limestone at a rate of 45 t/ha and lush, self-sustaining and maintenance free vegetation exists to date.

4.0 The Effectiveness of Waite Amulet Vegetation

Stream water quality monitoring on and adjacent to the Waite Amulet site continued and in 1982 an expanded sampling program was undertaken. The news was not good. Acidity, iron, zinc and copper concentrations averaged as high as 8000, 2400, 115 and 14 mg/L respectively at some individual sampling stations located on four streams draining the site and pH generally ranged between 2.5-3.0. An improvement in water quality has not been evident.

Qualitatively, the vegetative cover has been effective in controlling fugitive dust and surface water erosion, as well as in improving site aesthetics. Indeed, these objectives have been fully achieved. A reduction in the rate of acid generation which can be ascribed to vegetation is believed to be minimal, if any took place at all. An active, water consuming surface cover will tend to depress the water table and consequently the potential for oxygen penetration is enhanced. However, it must be stressed that baseline data collection was inadequate for a proper, quantitative evaluation of acid generation and water balance after reclamation was completed.

By 1984, an acid storage pond and a modern waste water treatment plant were constructed at a cost of 1.8 M\$. The lime neutralization facility has been operating efficiently on a seasonal basis at a cost of 0.2 M\$ annually.

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5.0 The Current Noranda Inc. Research Effort

With such a significant inventory of reactive tailings requiring decommissioning, practical and economical technology to control acid generation needs to be developed. The number of properties approaching the decommissioning phase within the next five years adds a sense of urgency to the quest for a better understanding of processes involved in acid generation and for environmentally efficient and reasonably cost effective technology.

Consequently, Noranda Inc. initiated discussions with the federal Department of Energy, Mines and Resources (CANMET) and other mining companies to formulate a national research program. The Reactive Tailings (RATS) program, now funded equally between the sponsoring industry and CANMET, began to evolve in 1984.

Currently, Noranda Inc. is sponsoring research on two fronts - first, a RATS study at the Waite Amulet tailings site being conducted by Centre de Recherche Noranda and CANMET and second, a University of Waterloo, Institute for Groundwater Research program. In general, the broad objectives of these efforts are to:

- o characterize the geochemistry within reactive tailings;

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- o identify the processes which control the geochemistry;
- o determine, evaluate and demonstrate the mechanisms which control the geochemical reactions ; and
- o predict the geochemical behaviour of reactive tailings under various reclamation scenarios.

Several technical papers focussed on these broad objectives have already been published on the Waite Amulet study program by Siwik and Dave, 1987, and Dave et al. 1986, and others will follow. A series of papers will also be generated by D.W.Blowes on the University of Waterloo program.

The technical discussion which follows includes information from the Waterloo investigations as they pertain to the vegetation/acid generation relationship.

The sites included here are:

- o Heath Steele Mines Limited, Newcastle, New Brunswick (managed by Brunswick Mining & Smelting Corporation Limited)

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- o Waits Amulet Tailings Site, Rouyn-Noranda, Quebec (managed by the Home Division)

- o a high carbonate tailings site in Ontario, formerly owned by a Noranda Inc. company; and

- o Nordic Mine Tailings, Elliot Lake, Ontario, not a Noranda Inc. site but one researched by the University of Waterloo.

The field methods utilized by the University of Waterloo are outlined in Appendix A. A description of geochemical processes is provided in Appendix B.

5.1 Heath Steele Mines Limited, Newcastle, New Brunswick

The 4 ha tailings pond at Heath Steele Mines Limited was examined by Boorman and Watson, 1976 of the New Brunswick Research and Productivity Council. Although no reclamation work has been initiated on these tailings, the location was included in the University of Waterloo program to examine the geochemistry ten years after the earlier research effort. Deposition of tailings containing 85% sulphide minerals, mostly pyrite and pyrrhotite, was discontinued in 1964. Pore water chemistry in the vadose and groundwater zones was determined as well as gas concentrations in the unsaturated tailings layer.

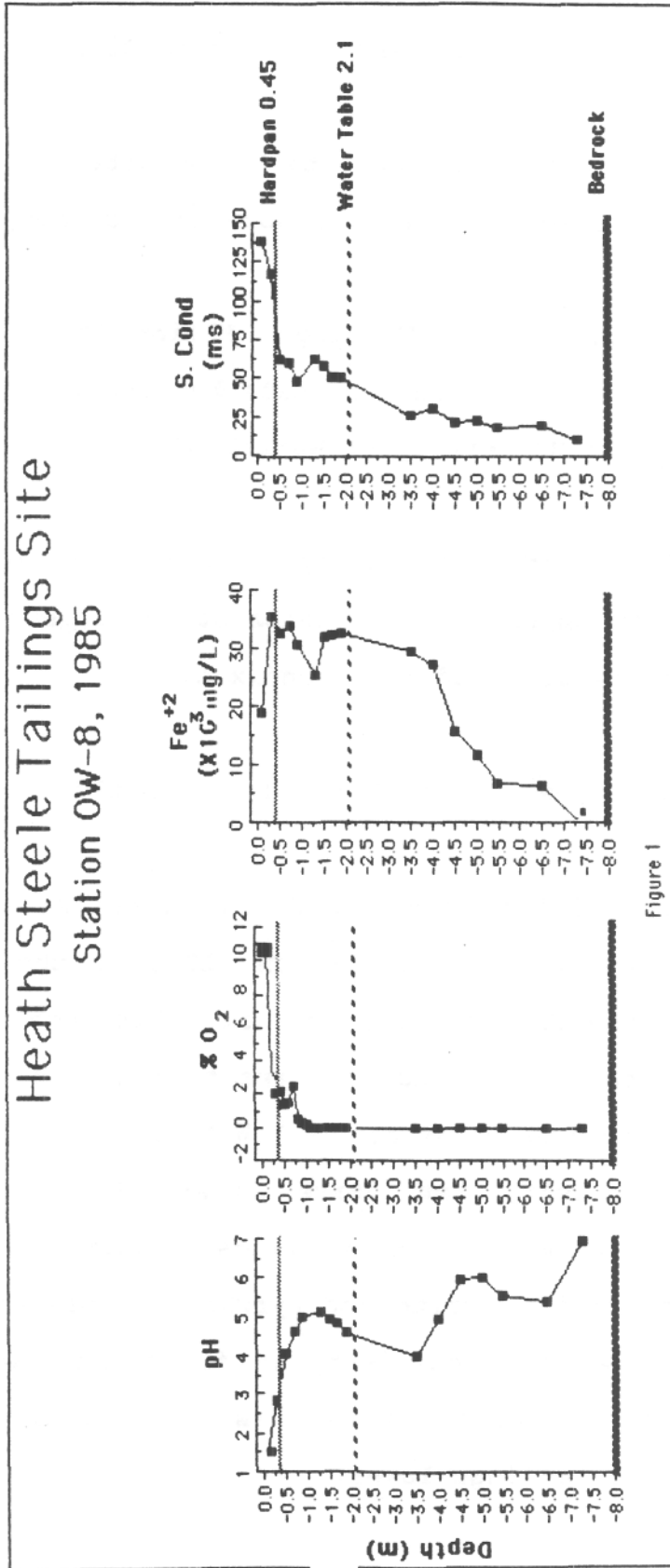


Figure 1

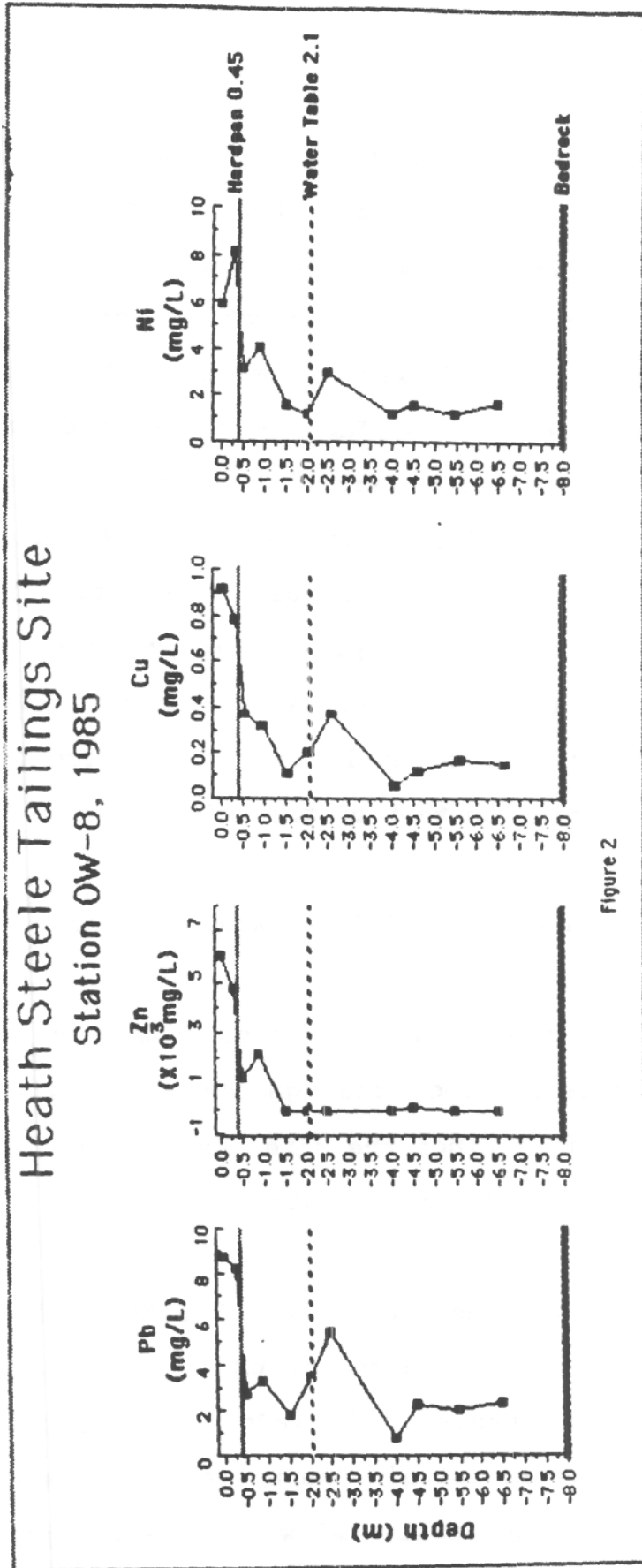


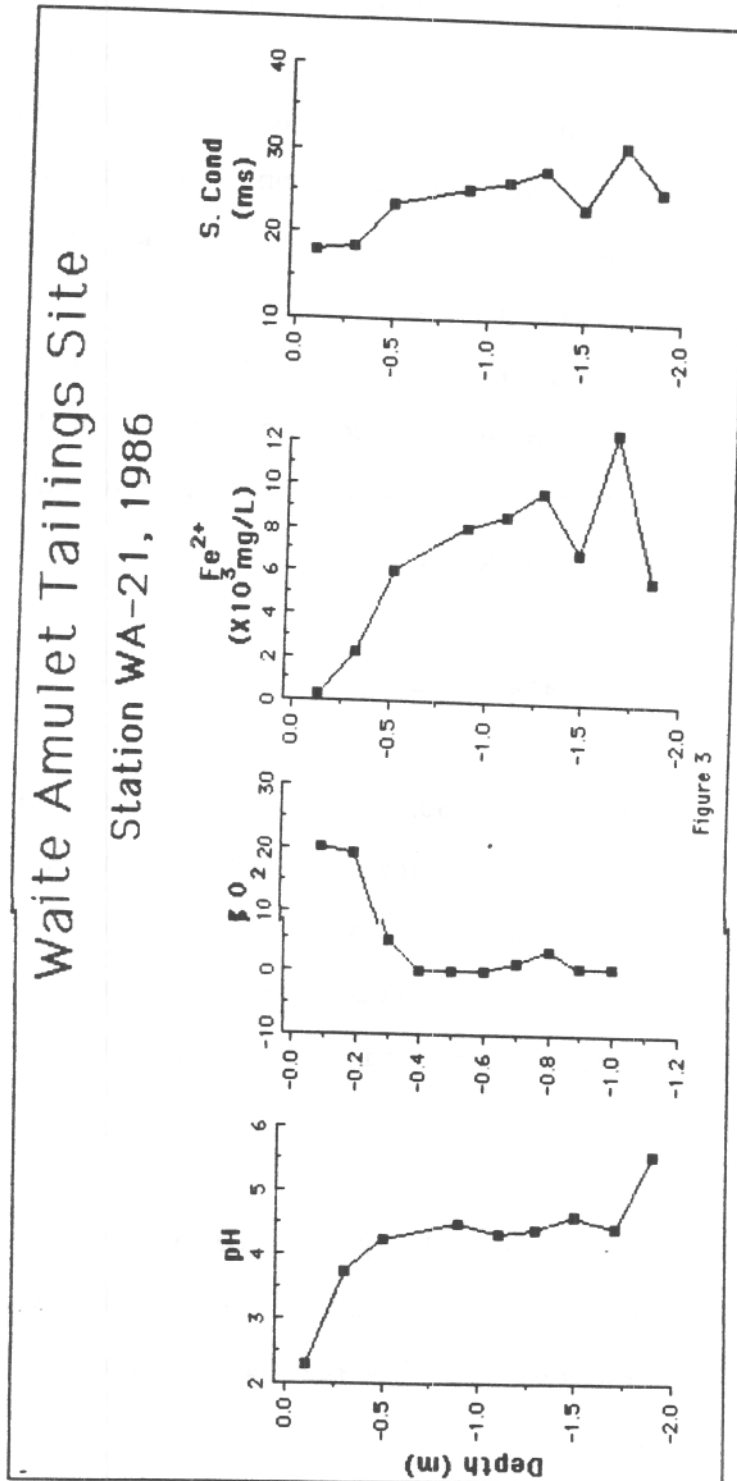
Figure 2

Low pH and extremely high levels of Fe^{2+} and specific conductance were recorded at this site (Figure 1). The low pH, high Fe^{2+} conditions were observed to be directly related to oxygen penetration depths. Very high concentrations of several metals (Cu, Pb, Zn, Ni) were observed near the surface in the vadose zone (Figure 2). These metals were probably released to solution by the oxidation of sulphide minerals. This tailings impoundment has not had the benefit of a vegetation program, but the processes controlling pore water evolution appear to be the same as at the other sites investigated. Very high concentrations of metals in solution are attributed to the high sulphide content of the tailings.

5.2 Waite Amulet Tailings, Rouyn-Noranda, Quebec

The Waite Amulet tailings impoundment is an ideal location for investigating the geochemistry within a reactive tailings mass since the site has barren, directly vegetated and clay capped and vegetated regions.

Results from the Quebec field site indicate that pyrite oxidation has generated low pH, high Fe^{2+} and high specific conductance levels in the vadose zone of the tailings. Near the surface and within the unsaturated zone, the pore water pH level is generally below 2.5. Redox potential is quite



high, demonstrating an abundance of oxidized species in solution at shallow depths. Concentrations of Fe^{2+} increase in the vadose zone as illustrated in Figure 3 as O_2 is consumed in the pyrite oxidation reactions. The solution pH increases with depth as the O_2 concentration declines. Similar changes in tailings pore water geochemistry were observed at each sampling location. The depth of the low pH, high redox potential zone was observed to increase with O_2 penetration which in turn was a function of the distance to the water table. Pore waters with high Fe^{2+} concentrations and specific conductance have been displaced downwards past the water table by the gradual infiltration of rainwater and snowmelt.

5.3 A High Carbonate Tailings Site, Ontario

Tailings containing approximately 4% sulphide and 20% carbonate minerals were deposited from the early 1940's to the early 1960's. The mill at this site extracted gold from the sulphide-bearing, carbonate-rich ore. A successful vegetation program was initiated in 1971 on the 30 ha tailings surface.

Investigations included pore water sampling in the unsaturated and saturated zones and gas sampling in the vadose zone at several locations on and adjacent to the tailings pond.

High Carbonate Tailings Site

Location D-5, 1985

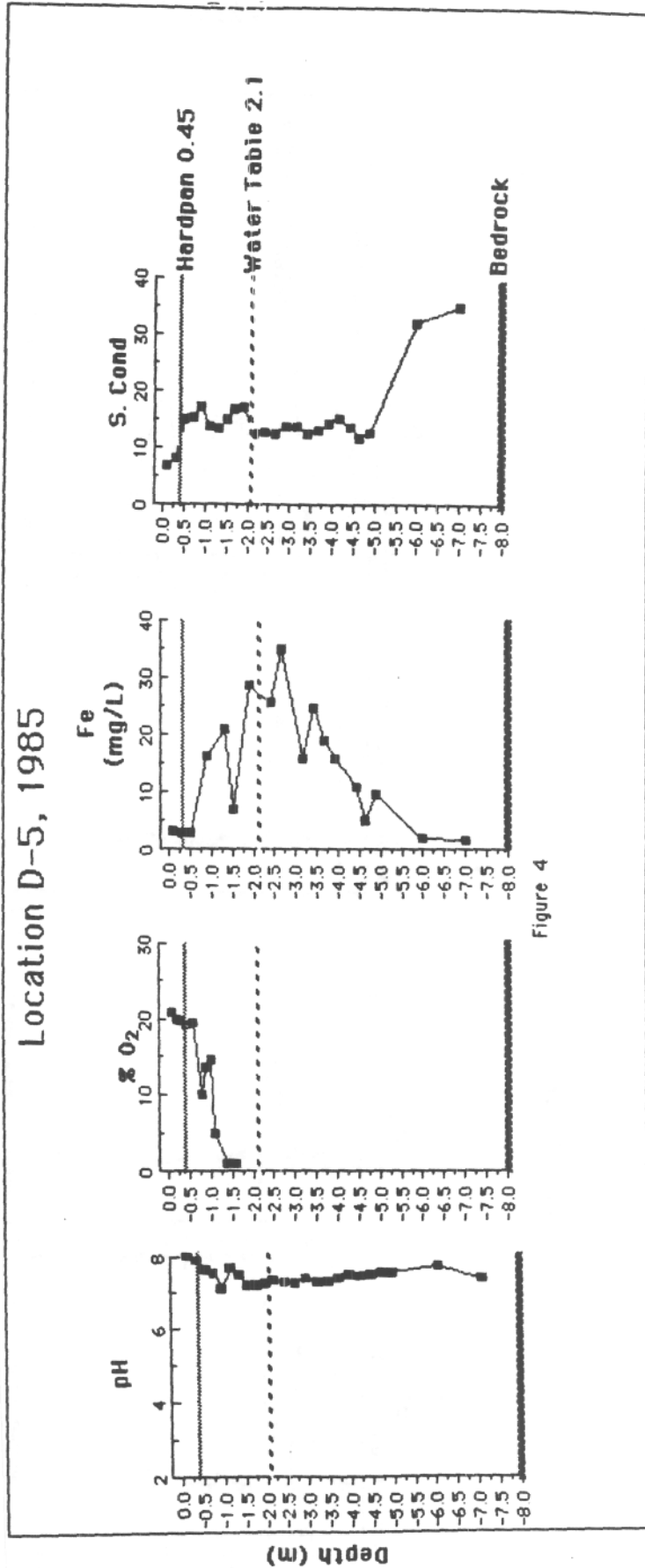
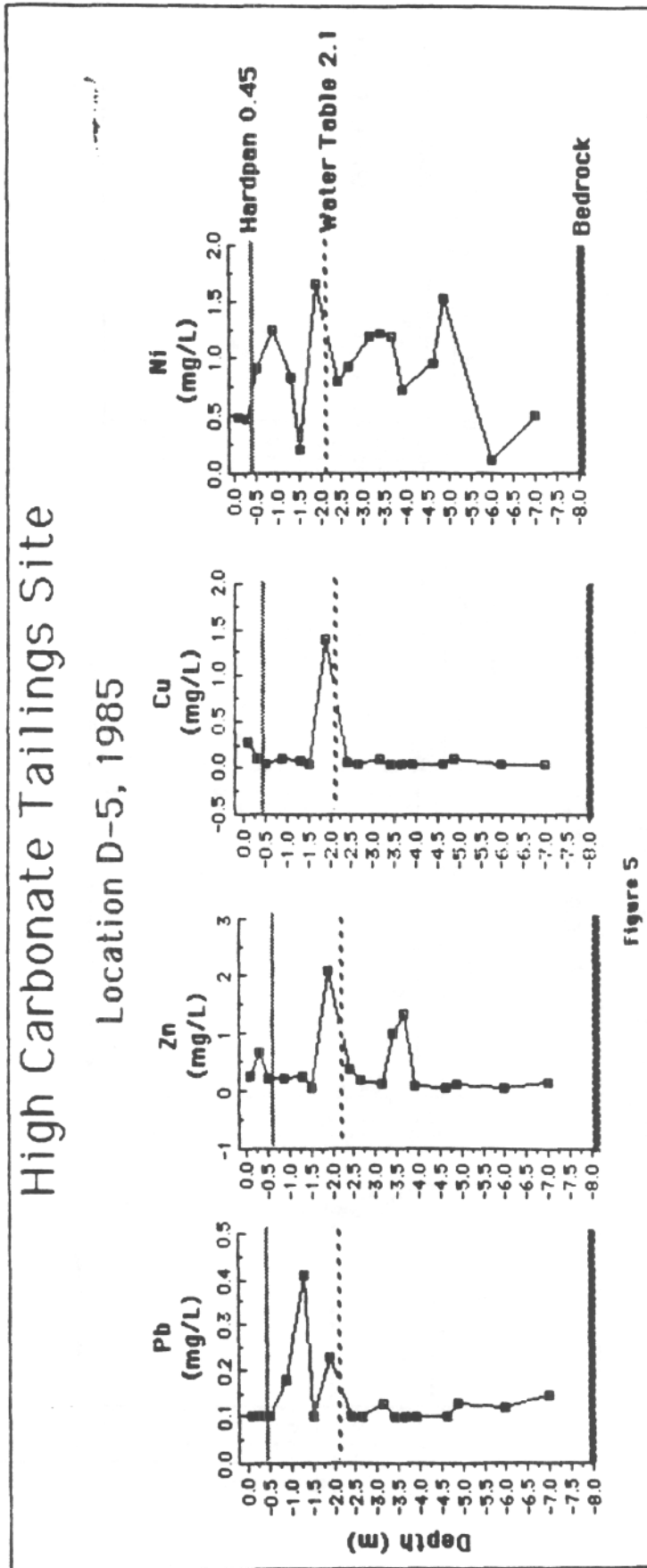


Figure 4



No acidic pore waters were detected. High concentrations of Fe^{2+} and specific conductance observed in the vadose zone indicate pyrite oxidation is occurring (Figure 4). The high pH levels suggest that the buffering capacity of the carbonate minerals and the rate of carbonate dissolution are sufficient to consume the H^+ generated by pyrite oxidation. Concentrations of other metals (Cu, Pb, Zn, Ni) exist at shallow depths in the unsaturated zone (Figure 5). It is likely that these elements were released to solution as a result of sulphide mineral oxidation.

5.4 Nordic Mine Tailings, Elliot Lake, Ontario

The Nordic Mine tailings, composed mainly of silicate minerals - approximately 5% pyrite and 0.06% calcite - were deposited from 1957 to 1968. A successful vegetation cover was established between 1973 and 1978. Blair et al., 1980, Dubrovsky et al., 1981, Smyth, 1982, Morin et al., 1982 have investigated the vadose and groundwater zones at several locations on and adjacent to these tailings.

The results of the investigations are summarized by Dubrovsky et al. (1985). These authors observed that low pH, high Fe^{2+} and SO_4^{2-} waters are present at shallow depths at each of the sampling locations. Dubrovsky (1986) suggests that the high Fe^{2+} , SO_4^{2-} pore waters are being

displaced downwards through and out of these tailings by infiltrating rainfall and snowmelt at 0.24 to 2.0 m/a (average of 1.0 m/a), and that the low pH pore waters are being neutralized by carbonate consuming reactions.

Smyth (1982) concluded that the effects of pyrite oxidation were greatest at locations where the water table was deep and the tailings were coarse and, therefore, where O₂ diffusion would be greatest.

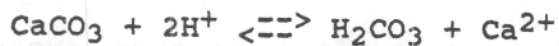
6.0 Discussion

Oxidation of sulphide minerals was evident in the upper 1 to 2 m of the vadose zone in the four tailings impoundments which were investigated. The extent of oxygen diffusion into the tailings is dependent on the depth of the water table and the sulphide content and particle sizing of the tailings. It appears to be independent of the presence of vegetation. Tailings with high pyrite content consume O₂ rapidly, and, therefore, the O₂ penetration depth is limited by this factor.

The oxidation of sulphide minerals generates low pH conditions and releases various constituents, principally Fe²⁺ and SO₄²⁻, as well as concentrations of Cu, Pb, Zn, Ni and As. High concentrations of Fe²⁺ represent a large

potential source of acidity; each mole of Fe^{2+} will generate two moles of H^+ as a result of oxidation and precipitation of ferric hydroxides.

The H^+ generated by pyrite oxidation is neutralized by H^+ consuming reactions - the dominant process being the dissolution of carbonate minerals as described by the reaction



under low pH conditions. This process can raise the pH to neutral or basic levels at which many metal concentrations will be controlled by hydroxide solubility constraints. Metal levels not influenced by precipitation-dissolution reactions may be controlled by adsorption-desorption processes on the surfaces of tailings solids and by co-precipitation. The mechanisms will depend on the bulk solution chemistry and on pH conditions. The overall effect of carbonate consuming reactions is to retard the movement of low pH fluid and, in many cases, high metal concentrations relative to the movement of infiltrating water through and out of the tailings impoundment.

At the high carbonate tailings location, the neutralization capacity was large enough to maintain neutral to alkaline pH conditions throughout the mass, including the vadose zone.

The elevated pH at this site limited metal concentrations to much lower levels than were observed at any of the other higher sulphide tailings ponds.

Pore water is being displaced downwards through the vadose and into the groundwater zone at each location due to infiltrating rainfall and snowmelt. Pore waters containing Fe^{2+} and SO_4^{2-} will eventually be displaced out of the tailings impoundment, either into the underlying groundwater flowsystem or into the surface seepage system. In the Nordic Mine tailings, the high Fe^{2+} and SO_4^{2-} pore waters have entered the underlying aquifer (Dubrovsky et al., 1985) while at Waite Amulet the discharge is via seepage along the flanks of the pond.

7.0 Conclusions

A self-sustaining vegetative cover can be established directly on reactive tailings. Rapid techniques for assessing the application rate of fertilizer, seed and alkali and for designing a vegetation program have been developed. Vegetation effectiveness in controlling acid generation, however, is limited, if not negligible. Based on preliminary information evolving from the RATS and the University of Waterloo research, the following conclusions have been formulated:

- 7.1 Pyrite oxidation is occurring within tailings containing 4-90% sulphide minerals independent of a vegetative cover. Metals such as Fe^{2+} , Zn, Pb, Cu, Ni, and As, and SO_4^{2-} are being released to the pore water in this oxidative zone.
- 7.2 Processes of neutralization, precipitation, co-precipitation and adsorption also occur within tailings below the reactive zone. The data from the four tailings sites illustrate a decrease in some metal concentrations and an increase in pH as the pore water is displaced downwards. With time, this flow will report either to groundwater or to surface seepage.
- 7.3 The zone of active sulphide oxidation is a direct function of the depth of oxygen penetration. This may be controlled by the depth of the water table and by the sulphide content and particle sizing of the tailings. Significant quantities of reactive tailings remain above the water table at each of the sites and as these sulphides are consumed, the downward flow of reaction products will continue.

- 7.4 Direct vegetation of reactive tailings does not restrict pyrite oxidation nor does it limit water infiltration sufficiently to significantly reduce water flow from the impoundment. Direct vegetation may cause the average water table to recede during the growing season and, therefore, the total mass of sulphides available for oxidation may increase.
- 7.5 The rate of acidity and heavy metal discharge from a reactive tailings mass cannot be predicted or modeled based upon the existing level of understanding of the geochemistry. Ongoing research efforts within RATS and the University of Waterloo program will address these unknowns.

Appendix A

Field Methods

Pore water from the tailings vadose zone was sampled using the modification of the Patterson et al. (1978) technique described by Smyth (1982). Samples were obtained at approximately 20 cm intervals throughout the unsaturated layer.

Vadose zone pore gas samples were collected using the method described by Reardon and Poescente (1984), and analyses were determined using a portable meter (Nova model 305LBD). Pore gas samples were also returned to the laboratory and analyzed by gas chromatography.

Water samples from the groundwater zone were collected using modified Cassagrande drive point piezometers of the type described by Dubrovsky et al. (1981). Samples were collected using the syringe sampling technique of Gillham (1982) .

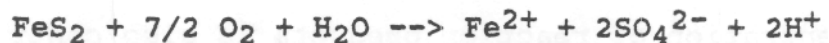
Pore water samples retained for analyses by atomic absorption were acidified immediately with concentrated HCl and refrigerated. Ferrous iron was determined in the field using the potassium dichromate method (Waser, 1966). The pH and redox potential of the pore waters were measured using a liquid filled combination pH electrode (Orion Ross) and a

combination platinum electrode (Orion 96-78). Electrodes were calibrated using pH 1.7, 4.0 and 7.0 buffers which were maintained at groundwater temperatures. Measurements of pH and redox potential in the saturated zone were made in closed flow-through cells also maintained at groundwater temperatures.

Appendix B

Geochemical Processes

Geochemical reactions which control pore water chemistry are oxidation-reduction, dissolution-precipitation, coprecipitation and adsorption. The dominant reaction in the geochemical evolution of tailings pore water is the oxidation of pyrite to produce low pH conditions and high concentrations of Fe^{2+} and SO_4^{2-} . The oxidation of pyrite may be described by the reaction



Nicholson (1984) suggested that in tailings environments the rate of pyrite oxidation is limited by the rate of oxygen diffusion into the tailings impoundment.

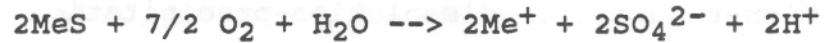
Ferrous iron in solution may be further oxidized to ferric iron through the reaction



Ferric iron can then precipitate as ferric hydroxide to release an additional three moles of hydrogen ion through the reaction



Ferric iron can also oxidize additional pyrite or other sulphide minerals through reactions of the form



where Me represents a metallic ion. Oxidation of pyrite and other sulphide minerals releases additional metals, particularly Cu, Ni, Pb, Zn and As into solution. These oxidation products are transported by the physical processes of advection, dispersion and molecular diffusion. Concentration of reaction products is also controlled by the geochemical processes of precipitation and dissolution, adsorption and desorption, and co-precipitation.

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