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Yukon Branch

OXIDATION OF YUKON MINE TAILINGS

Regional Program Report 84-15

by

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ABSTRACT

During 1982 the Environmental Protection Service conducted a lab experiment to; 1) determine the oxidation potential of mine tailings from several abandoned mines in the Yukon, and 2) to determine if the iron-oxidizing bacteria, Thiobacillus ferrooxidans, was present and if it was contributing to the oxidation process. A fresh sample of tailings from Cyprus Anvil Mining Corporation was used as a reference because of its well known oxidation potential.

Although all four abandoned mines tested were theoretical acid produces only two mines showed oxidation potential. The results, overall, suggest that T. ferrooxidans is present at each mine location but is not necessarily active. Tailings at two mines showing no oxidation potential possess acid consuming ability which is probably the prime factor inhibiting bacterial activity.

The study showed this small scale experiment is useful in determining oxidation potential of mine tailings and also indicated the need for further assessment of the oxidation potential of the Wellgreen nickel mine and the Arctic mine.

RESUME

Le Service de Protection de l'environnement a conduit en 1982 des experiences de laboratoire pour 1°) determiner le potentiel d'oxydation des bassins de decantation de plusieurs mines abandonneer au Yukon et 2°) determiner si la bacterie oxidante du fer, Thiobacillus ferrooxidans, fut presente et si elle contribue au processus d'oxidation. Un echantillon frais due bassin de decantation de la corporation miniere Cyprus Anvil fut utilise comme reference du a son potentiel d'oxidation bien connu.

Bien que les quatre mines abandonnees testees furent theoriquement producteurs acides, seulement deux mines demontrent un potentiel d'oxidation.

Globalement, les resultats suggerent que T. ferrooxidans est present a chaque location mais n'est pas necessairement active. Les bassins de decantation aux deux mines, demontrant aucum potentiel d'oxidation, possedent la capacite de consommer les acides, lquelle est probablement le principal facteur inhibitant l'activite bacterienne.

L'etude montre que l'experience a petite echelle est utile dans la determination de potentiel d'oxidation de bassin de decantation et indique aussi la necessite pour des evaluations futures due potentiel d'oxidation de la mine de nickel Wellgreen et la mine Arctic.

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF FIGURES

1 INTRODUCTION

The objective of this study was to determine the rate of oxidation of tailings from four abandoned Yukon mines suspected of being acid-generating and secondly, to determine the presence of *Thiobacillus ferrooxidans*, an iron-oxidizing bacteria.

The four abandoned mines, Wellgreen Mine (north of Burwash Landing), Arctic Gold and Silver Mine (near Carcross), Venus Mine (on Windy Arm, Tagish Lake) and Mount Nansen Mine (west of Carmacks) were chosen for their known iron sulphide content in the ore.

Fresh mine tailings from the Cyprus Anvil Mine were used as a control because of their well known oxidizing potential (Duncan 1975, Sharer 1981).

Refer to Figure 1 for mine locations.

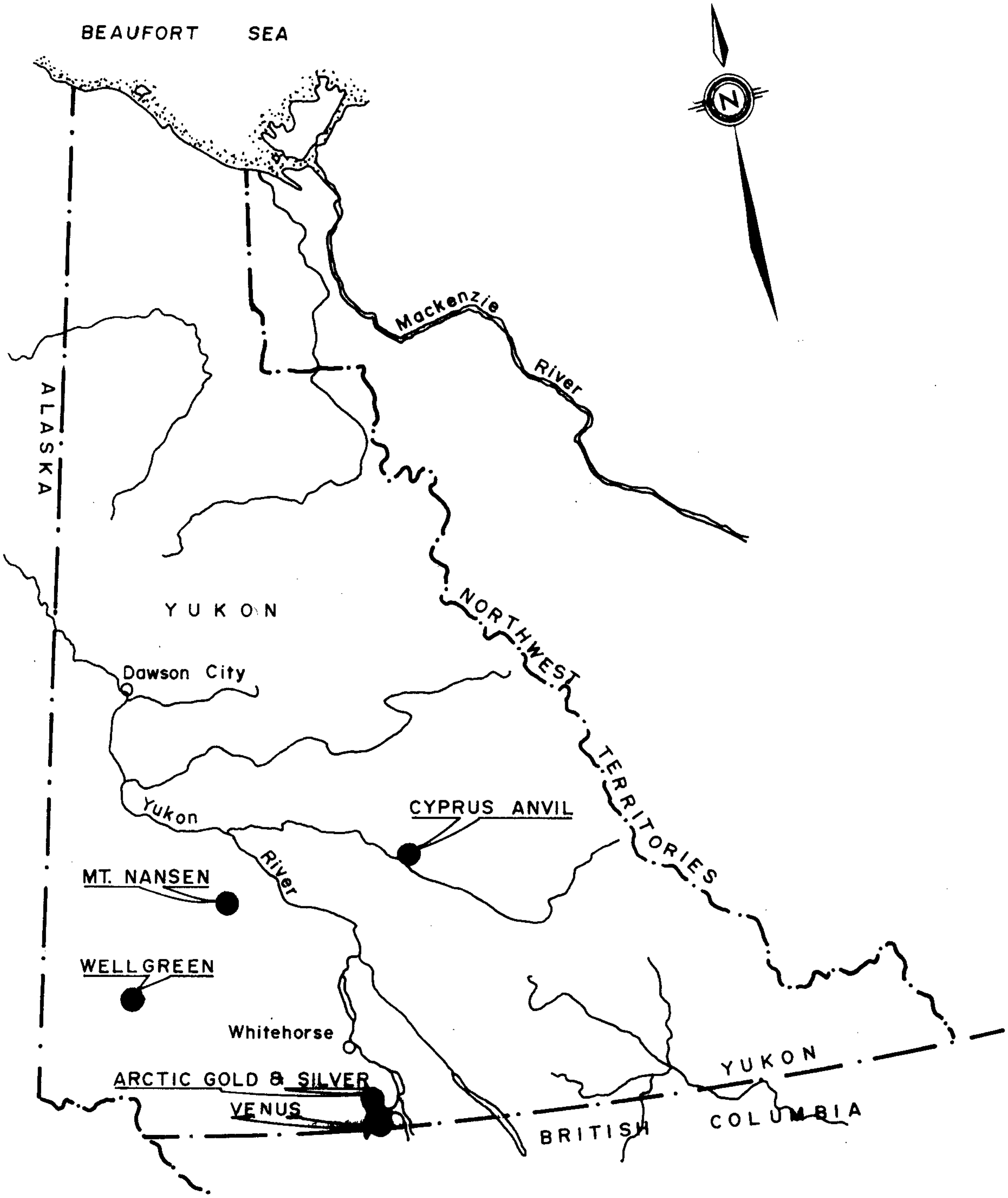


FIGURE 1: MINE LOCATION

2 MINE DESCRIPTION

2.1 Wellgreen Mine (61°28'N, 139°32'W)

The Wellgreen Property is located at kilometre 1788 of the Alaska Highway, 46 kilometres north of the community of Destruction Bay. Initial development occurred during the early 1950's, ending in 1956. In June of 1970 Hudson's Bay Mining and Smelting Company resumed underground development and a 550 tons per day mill was constructed and in production by May 1972. Due to the lack of continuity in the ore body mining and milling operations ceased in June of 1973. The operation has not reopened since that time.

The property in underlain by Lower Permian volcanics and sediments. The ultramafic body with which the ore is associated consists mainly of serpentinized and feldspathic peridotite with a footwall zone of massive pyrrhotite, chalcopyrite and pentlandite lenses.

The ore consists mainly of pyrrohite (Fe_7S_8) 80%, with pentlandite (Fe, Ni_9S_8) 6-8%, chalcopyrite ($CuFeS_2$) 6%, and silicates, 3-4%. The ore includes traces of antimony, cobalt and platinoid metals.

The existing tailings pond covers an area of approximately 70,000 m^2 and contains about 172,000 tonnes of mill tailings. The tailings surface is rusty brown and firmly cemented to a depth from 0 to 10 cm. During spring break-up the tailings pond fills with several metres of meltwater, but by mid-summer water levels drop to expose a large portion of the tailings surface. Insitu pH of tailings pond water recorded in June of 1982 by EPS staff ranged from 6.1 to 6.7. An isolated pond on tailings material was found to have a pH of 2.2 on the same day. Insitu pH of the tailings pond water was 3.7 in July of 1983. The water level on that date was considerably lower than that seen in June 1982.

2.2 Arctic Gold and Silver Mine (60°05'N, 134°42'W)

The mill site and tailings pond of Arctic Gold and Silver Mines Ltd. are located approximately 4 kilometres south of Carcross and

1,000 metres above sea level on Montana Mountain. The original ore deposit was discovered in 1905 and was worked extensively until the mid 1920's. No further activity took place until 1964 when the ore body was re-assessed. By May, 1968, a mill had been constructed and was in operation. Production was short lived and by December, 1969, the operation was closed down.

Host rock in the area is largely granodiorite intruding volcanic rocks, with ore minerals in quartz-carbonate veins. Minerals reported are pyrite, arsenopyrite, sphalerite, galena and chalcopyrite.

The milling process produced approximately 45,300 tonnes of tailings. The tailings, light brown to gray in color, are contained in one tailings structure that has a maximum depth of about 3 metres. During July of 1982 the pH of surface water on the tailings was 7.9 while the pH of water discharging from the decant was 3.7. The flow at the decant was estimated to be no more than 0.023 m^3/min or 5.0 IGPM.

2.3 Venus Mine (60°01'N, 134°38.2'W)

The mill and tailings are located on the west shore of Tagish Lake along Windy Arm. It is 16 kilometres south of the community of Carcross at kilometre 85 of the Klondike Highway. This area was first explored for gold and silver deposits at the turn of the century and several deposits were worked during World War I. A 100 ton per day stamp mill was built at that time to treat the ore from several properties. Modern exploration and development began in 1966 which resulted in the construction of a 300 ton per day mill in September 1970.

Due to operational problems the mill ceased operating after 9 months. A third development phase in 1979-1980 saw the construction of a new mill, which has not been put into production at time of writing.

Host rocks at Venus are similar to those at nearby Arctic Gold & Silver Mine with granodiorite intruding volcanics. Veins are quartz and carbonate with ore minerals pyrite, galena, arsenopyrite, sphalerite, chalcopyrite and chalcocite.

The mill produced approximately 59,000 tonnes of tailings, light brown to gray in color, similar to Arctic Gold and Silver. The tailings are contained within one structure and are approximately 1-2 metres in depth. Spring runoff pools on the surface and covers a third of the tailings area during the summer months. PH measurements from surveys done in 1975 (Robson, Weagle) and 1981 (Jack) ranged from 8.0 to 8.6 during the summer season. The pH recorded from a more recent visit by EPS staff in July of 1982 measured 8.5.

2.4 Mount Hansen (62°03'N, 137°07'W)

The Mount Hansen property is located approximately 77 kilometres west of the community of Carmacks and is accessible by road. Original exploration in the area took place in 1946 at the nearby Brown-McDade property. More recent exploration was carried out in 1964, 1965 and 1966. A 70 ton per day mill started production in September of 1968 and operated until April 1969. Mill production again resumed in 1976 from April to November. The mill has been inactive since November, 1976, although exploration and development of the property continues.

The geology of the deposit is composed of vein structures cutting much older metamorphic rocks in three principal vein systems. Ore minerals are arsenopyrite, pyrite, galena, sphalerite, and minor silver sulphides.

Mill tailings total approximately 18,500 tonnes and are contained within three separate tailings structures in sequence below the mill discharge. The tailings are greyish brown in appearance. All three ponds fill with water during summer months. Tailings pond water pH reported in the Environmental Protection Report (Anonymous 1979) was 7.8 and pH measured at all three tailings ponds in July 1982 by EPS staff ranged from 8.0 to 8.5.

2.5 Cyprus Anvil (62°08'N, 136°16'W)

The Cyprus Anvil lead-zinc mine is situated approximately 21 kilometres east of the town of Faro, in the Anvil Range of central

Yukon. The mine, which began operation in 1969, has a 10,000 tons per day capacity mill fed by an open pit mine. The company suspended production in June, 1982, and has not resumed production at time of publication.

Ores are massive sulfides consisting primarily of pyrite (FeS_2) 30-40%, with some pyrrhotite (Fe_7S_8) up to 6%, and massive galena and sphalerite. The average assay for iron (Fe) is 30-35%. The ore contains about 10% combined lead and zinc. Barite is a major non-sulfide component; the ore containing from 0-15% as BaO, with 5% being the usual assay. The tailings from this ore body are high in sulfide minerals and their potential leaching has been studied by others (Duncan, 1975; Sharer, 1981).

3 SAMPLE COLLECTION AND PREPARATION

Representative grab samples of mine tailings from the four abandoned sites were collected during May and June of 1982. In addition to collecting surface, oxidized tailings a sample was collected at depths between 10 and 30 centimeters below the surface to try and obtain unoxidized tailings.

In preparation for the leaching experiment, each sample was screened to less than 100 mesh. A portion of each was then submitted to a commercial assayer for metals analysis. (Refer to Appendix I, Table 1).

A fresh sample of mill tailings, collected May 27, 1982, was kindly provided by Mr. Cornish, Environmental Control Superintendent at the Cyprus Anvil Mine. Iron content of the ore at the time of collection was approximately 24% which is close to the average reported for ore reserves and comparible to samples used by Dr. J. Sharer in his bench tests referred to below. The portion of tailings used in the experiment was washed three times with distilled water to remove residual alkalinity added during the milling process.

4 LEACHING EXPERIMENTS

4.1 Apparatus

The procedure used a variable speed, temperature controlled New Brunswick Scientific Shaker/Incubator modified to hold sixteen 250 millilitre Erlenmeyer Flasks. Glass marbles were placed in each flask to promote mixing and turbulence. PH measurements were performed at the EPS Lab in Whitehorse using a Fisher Scientific Acumet 402 Digital pH/Ion Meter.

Assay analysis was performed by Bondar Clegg and Company Ltd. of Whitehorse and extractable metals and sulfate analyses were performed by the Environmental Protection Service Chemistry Laboratory in Vancouver. See Appendix II for description of analytical procedures.

4.2 Test Procedure

In preparation for the leaching experiment, cultures of the bacteria Thiobacillus ferrooxidans were maintained for a period of 2 months beforehand at the EPS Lab in Whitehorse. The bacteria were kindly provided by E.J. Brown of the Institute of Water Resources, University of Alaska, who isolated them from two placer creeks - Eva and Ester Creeks - near Fairbanks, Alaska. The culture medium used to maintain the bacteria was that used by Brown, Luong and Forshaug (1982): $FeSO_4.7H_2O$(30 g/L), $MgSO_4.7H_2O$(0.4 g/L), $(NH_4)_2SO_4$ (0.4 g/L), KH_2PO_4 (0.1 g/L) and 10N H_2SO_4 to bring the medium to pH 1.8-2.0.

Duplicate 50 gram portions of each tailings sample (less than 100 mesh) were placed in 250 ml flasks. One of each pair was then inoculated with 10 mls of cultured T. ferrooxidans. The flasks were then filled to 150 mls with distilled water. An initial pH was measured after the samples were well mixed.

Each flask was covered with a perforated foil lid and placed in the incubator/shaker apparatus. The agitation was set at 100 cycles per minute and the temperature was maintained between 22 and 24° C throughout the 70 day experiment period.

The pH of each sample was measured and recorded on the 4th and 7th day and every 7 days thereafter. On day 14 and every 14 days thereafter a 1.5 ml sample of supernatant was removed from each flask for sulfate and extractable metals determination. The sulfate sample was diluted to a ratio of 60:1 (.5 mls supernatant plus 29.5 ml distilled water). The metals sample was diluted to a ratio of 10:1 (1 ml supernatant plus 9 mls distilled water).

Water losses due to evaporation made it necessary to add between 25 and 35 mls of distilled water to each flask on Day 49. This addition was made after withdrawing aliquots for sulfate and metals determination.

The experiment was terminated after 70 days and a second assay was made of the metals in each dried sample.

4.3 General Chemistry of Bacterial Leaching

Thiobacillus ferrooxidans is a chemolithotrophic (rock eating) organism that obtains energy from the oxidation of inorganic substances. The rod shaped bacterium was originally discovered in acidic waters draining from coal mines and was later related to the dissolution of metals in copper leaching operations. *T. ferrooxidans* is acidophilic (acid-loving) and tends to live in environments with high sulfuric acid concentrations such as hot springs, volcanic fissures or sulfide ore deposits. Some species of the bacterium are also thermophilic, meaning they thrive best in temperatures between 20° and 35°C. *T. ferrooxidans* receives its growth energy from the oxidation of either iron or sulphur and potentially other reduced metals such as uranium, copper or arsenic (after Brown and Forshaug, 1983).

$$Fe^{+2} + 1/4O_2 + H^+ \text{ -----> } Fe^{+3} + 1/2H_2O \qquad (1)$$

$$AsO_2^- + 1/2O_2 + H_2O \text{ -----> } AsO_4^{-3} + 2H^+ \qquad (2)$$

The ore minerals found in this study responsive to bacterial oxidation are pyrite FeS_2, pyrrhotite Fe_7S_8 and arsenopyrite $FeAsS_2$. The minerals oxidize by the conversion of sulphide in sulfate and the release of divalent iron (Sharer, 1981):

$$2FeS_2 + 7O_2 + 2H_2O \text{ -----> } 2Fe^2 + 4SO_4^{2-} + 4H^+ \qquad (3)$$

$$FeS + O_2 + 2H_2O \text{ -----> } Fe^{2+} + SO_4^{2-} + 4H^+ \qquad (4)$$

$$FeAsS_2 + 4O_2 + 2H_2O \text{ -----> } Fe^{2+} + AsO_2^- + 2SO_4^{2-} + 4H^+ \quad (5)$$

Normally these reactions proceed very slowly, however the presence of T. ferrooxidans and sufficient acidity will cause the Fe^{2+} released by the above equations to be oxidized into Fe^{3+}. The trivalent iron can in turn increase the rate of dissolution of the iron sulphides:

$$Fe^{3+} + FeS_2 + 8H_2O \text{ -----> } 2Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad (6)$$

Thus the Fe^{3+} takes over the role of oxygen in equation 3 and 4 and perhaps in 5 as well. It is clear that once a threshold of acidity is reached which will enable the bacteria to multiply rapidly, the rate of oxidation will increase the rate of acid production and mobilization of heavy metals. The acidity of waters over mine tailings provides a rapid indication of the leaching potential of iron sulphide tailings (Forstner and Wittman, 1981, p.259).

4.4 Acid Consuming Potential Determination

To determine the acid consuming potential of the abandoned mine tailings used in the experiment a titration test similar to that used by Duncan and Walden (1975) was conducted.

Ten (10) gram portions of pulverized tailings were suspended in 100 ml of distilled water within a 250 ml erlenneyer flask. Each sample was stirred continuously for the duration of the test using a magnetic stirrer apparatus. After 15 minutes of stirring the natural pH of each sample was recorded and then the samples were titrated to pH 3.5 using 1.0 normal sulfuric acid.

The addition of acid was repeated every half hour until the change was less than 0.1 pH over a four hour period. The total volume of acid was recorded and converted to lbs per ton of sample using the following equation:

$$\text{Acid Consuming ability (lb/ton)} = \frac{\text{ml of 1.0 N } H_2SO_4 \times 0.049 \times 2000}{\text{grams of sample}}$$

Acid producing potential was calculated using the expressions:

$$\text{percentage } H_2SO_4 = \frac{\text{percentage total sulphur}}{\text{percentage sulphur in } H_2SO_4}$$

and

acid producing potential (lbs/ton) = percentage H_2SO_4 x 2000

The results of the titration tests and calculations are given in Sections 5-6 - Acid Consuming Potential.

5 RESULTS AND DISCUSSION

All mine tailings assay and water chemistry results are presented in Appendix I, Tables 1 through 10. Refer to List of Appendices for table description. Figures 2, 3 and 4 are presented for discussion purposes. In Figure 2 pH, copper, iron, zinc and sulfate levels are shown comparing uninoculated and inoculated Cyprus Anvil tailings. Similarly, Figure 3 compares results obtained by Dr. Sharer in his 1981 Cyprus Anvil tailing oxidation experiments. Figure 4 compares the inoculated and uninoculated pH, cobalt, iron, nickel and sulfate results for the Wellgreen unoxidized samples.

5.1 Cyprus Anvil Mine

The results presented in Figure 2 show an increase in copper, iron, zinc and sulfate associated with a decrease in pH. This indicates the mill tailings will oxidize readily under test conditions, a result that is supported by Dr. Sharer's findings in his 1981 tailings oxidation experiments (shown in Figure 3).

Similar oxidation rates in both the uninoculated and inoculated samples as shown by the decrease in pH levels confirms the presence of the iron-oxidizing bacteria, T. ferrooxidans. Note the slight increased concentration of the metals and sulfate found in the inoculated sample could either be a result of higher T. ferrooxidans concentrations or the low pH of bacteria medium added to the sample initially. Sulfate concentration between Day 42 and Day 56 show a slight decrease due to the 25 mls of distilled water added on Day 49 to make up for the water lost through evaporation.

5.2 Wellgreen Mine

Results as shown in Appendix I, Tables 3 and 10, indicate the surface tailings are acid generating and also suggest the presence of T. ferrooxidans. The pH levels remained acidic and relatively unchanged throughout the experiment period. The initial pH of the inoculated sample was slightly lower than the uninoculated sample because of the addition of bacteria culture medium.

In comparison, the unoxidized tailings remained alkaline except when T. ferrooxidans was added. In reference to the graphs in Figure 4, the pH of the inoculated sample began to decline after 42 days. In association with this decrease, the cobalt, iron and nickel concentrations increased dramatically after day 42. Sulfate showed a more moderate increase.

The uninoculated sample showed no change in pH, metals or sulfate. This clearly shows that T. ferrooxidans is not present in the unoxidized, subsurface tailings.

5.3 Venus Mine

Results presented in Appendix I, Tables 5, 6 and 10 show that both the oxidized (surface) and unoxidized (subsurface) tailings remained alkaline throughout the test period. Sulfates increased only slightly but the metals analysed showed little or no change. There was very little difference in pH, metals and sulfate concentrations between the inoculated and uninoculated samples. This indicates that T. ferrooxidan could be present but because of the tailings acid consuming ability, it remained dormant (See Section 5-6).

5.4 Arctic Gold and Silver Mine

Results for pH, metals and sulfate are presented in Appendix I, Tables 7, 8 and 10. Natural oxidation occurred in both tailing samples (oxidized and unoxidized) with the inoculated samples showing a more enhanced oxidation rate. These similarities confirm the presence of T. ferrooxidans in the ore. Reduced arsenic and iron levels in the supernatant suggest they are being consumed by the bacteria.

5.5 Mount Nansen Mine

Results for pH, metals and sulfate are shown in Appendix I, Tables 9 and 10. The tailings samples remained alkaline and did not oxidize appreciably. Inoculation with T. ferrooxidans did not enhance the oxidation rate which may indicate the bacteria is present but the tailings acid consuming ability prevented the bacteria from becoming established (See Section 5-6).

5.6 Acid Consuming Potential

Results of the acid consuming potential tests are presented in Table II. They show that only Mount Nansen and Venus mine tailings had the ability to consume acid. This appears to explain why these tailings did not oxidize in the leaching experiment. In contrast, Wellgreen and Cyprus Anvil had no acid consuming potential, and these tailings were seen to oxidize in the presence of acidophilic bacteria.

Arctic mine tailings seem to be a special case. The ores and tailings appeared to be strongly oxidized. This oxidation could have removed most of the sulphide minerals, explaining the low sulphur assays in Table II, but it was incomplete and left sufficient residual sulphur to show a slight potential for acid generation. These tailings had no acid consuming potential, which confirms the oxidation noted in the field. In the laboratory tests, acid generation appeared to be rapid during oxidation of the remaining sulphide, but the reaction seems to have been completed before day 14.

FIGURE 2: CYPRUS ANVIL (E.P.S. 82)
pH, Cu, Fe, Zn and SO_4 (extractable)
(results for the sample inoculated with T. ferrooxidans are shown in black)

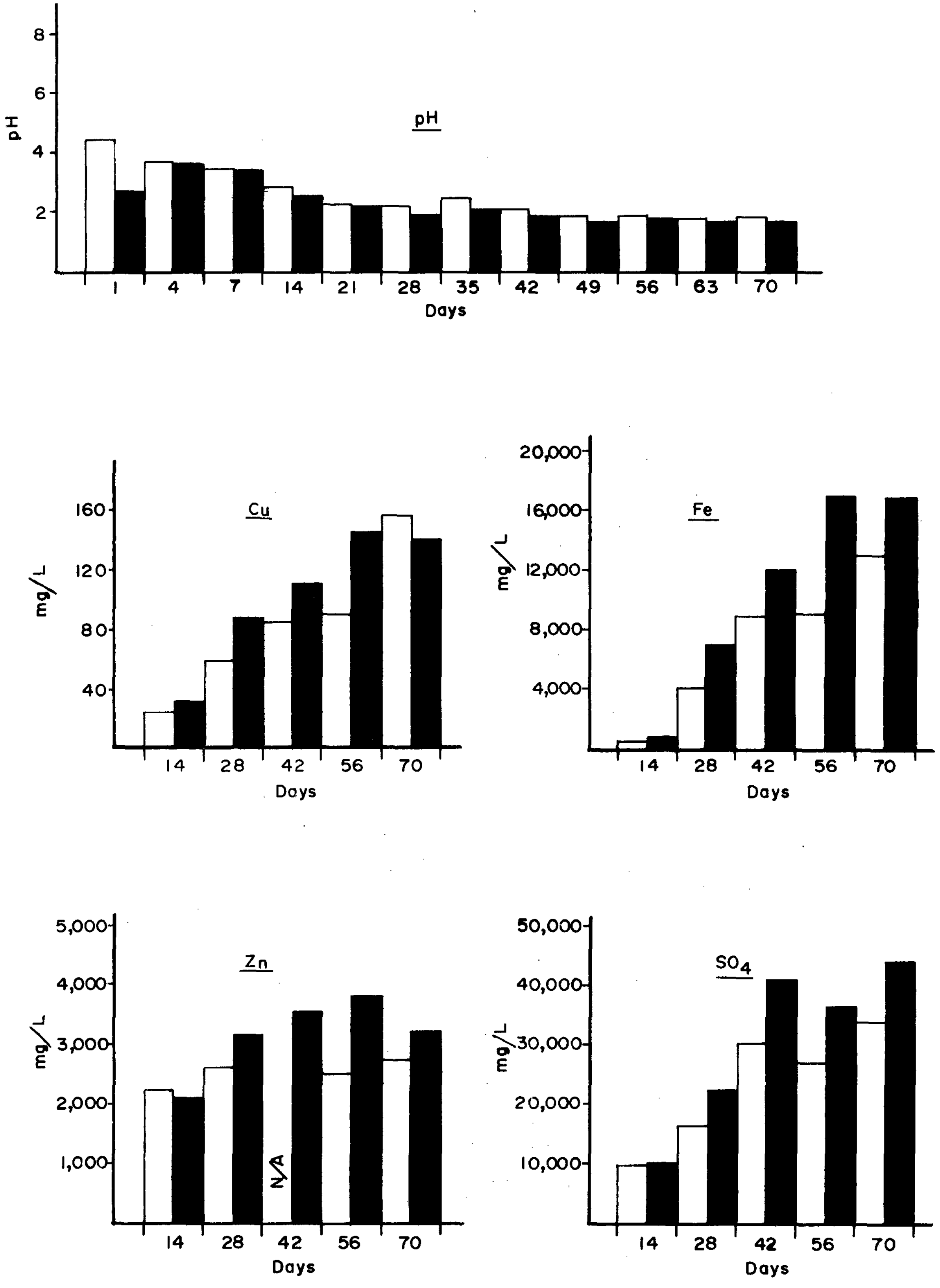
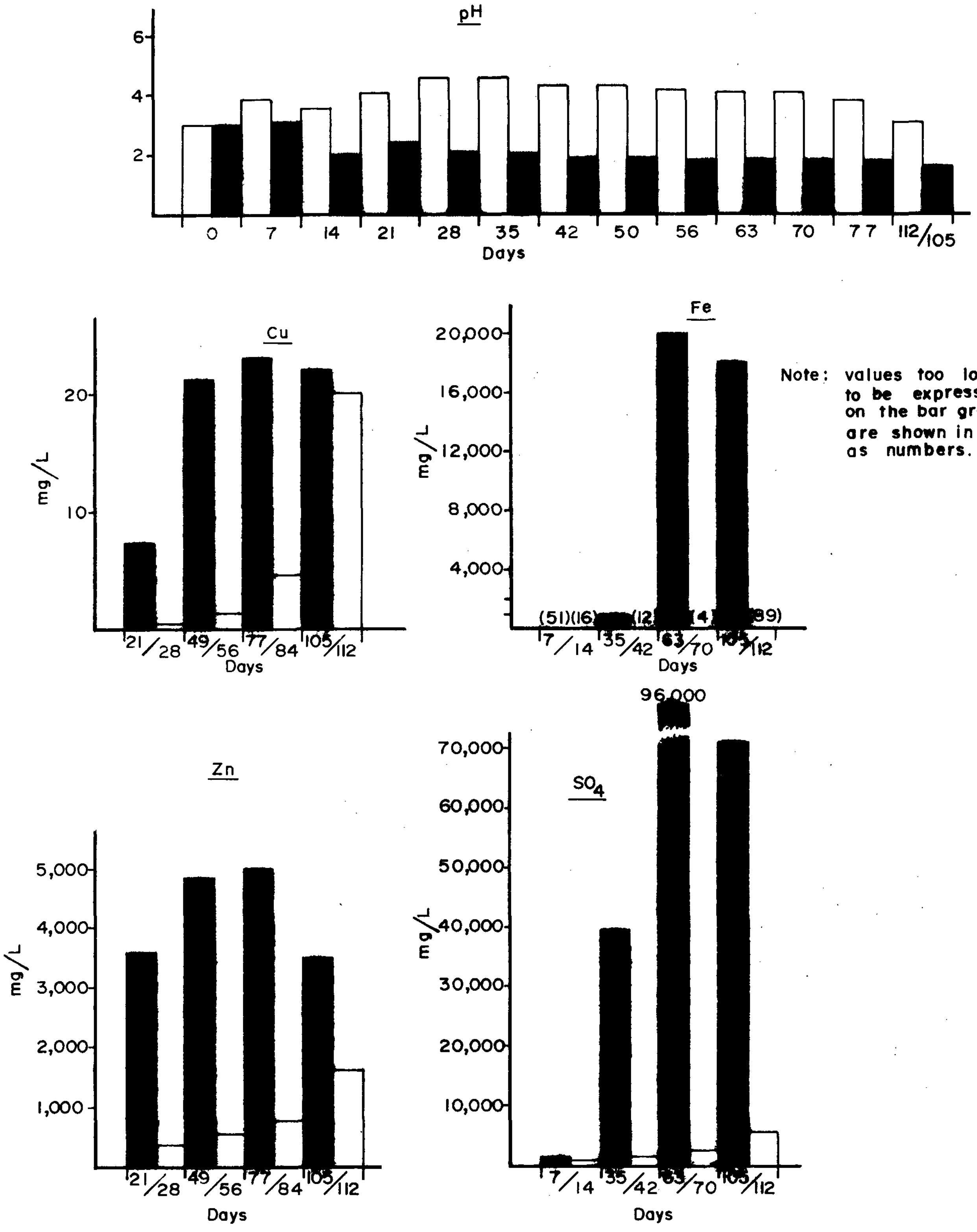
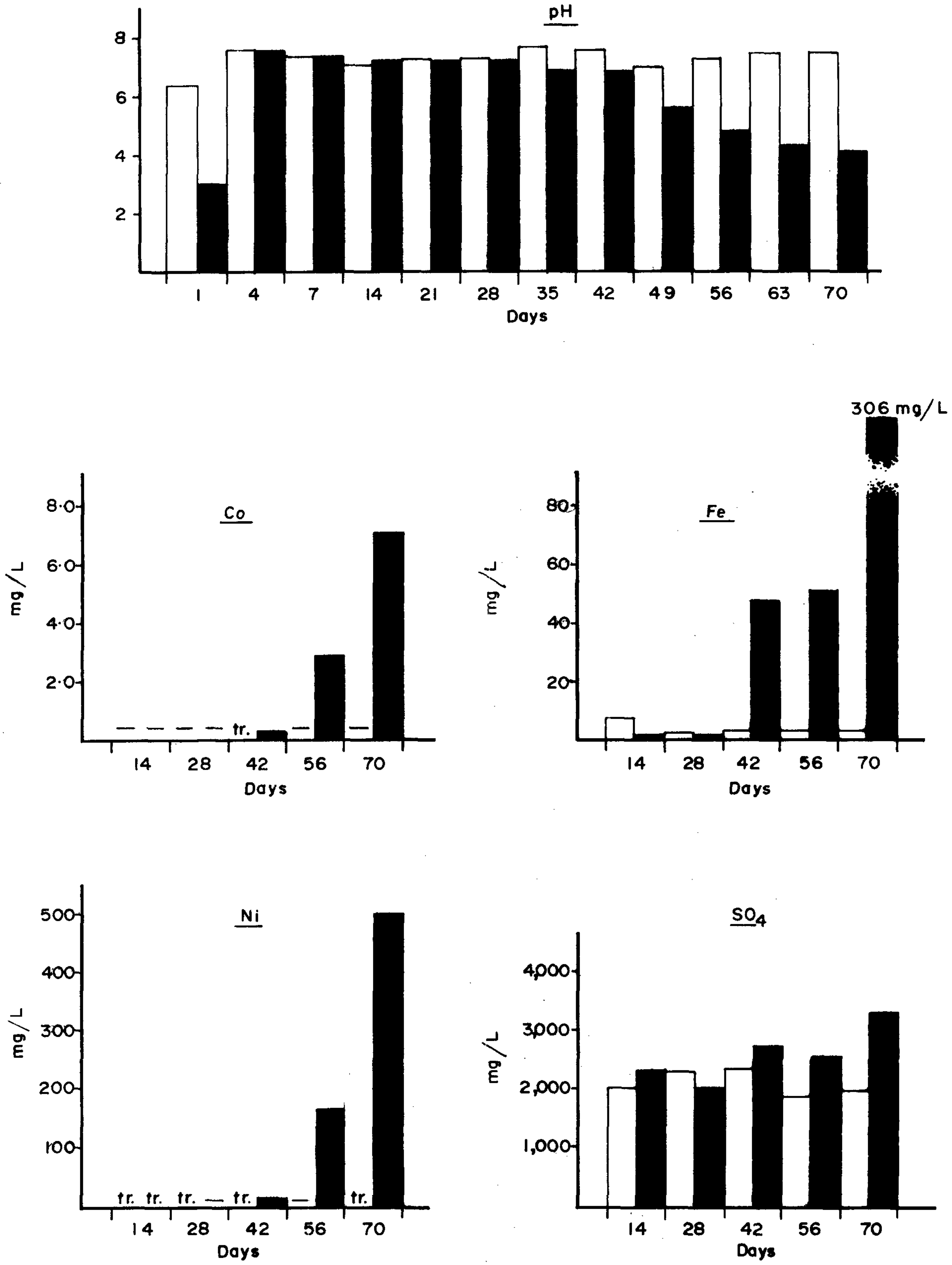


FIGURE 3: CYPRUS ANVIL (SHARER, 1981)
pH, Cu, Fe, Zn and SO (**dissolved**)
(Results for the sample inoculated with *T. ferrooxidans* are shown in black)



Note: values too low to be expressed on the bar graph are shown in ( ) as numbers.

FIGURE 4: WELLGREEN (UNOXIDIZED)
pH, Co, Fe, Ni and SO_4 (extractable)
(results for the sample inoculated with <u>T. ferrooxidans</u> are shown in black)
—: below detection limit
tr.: trace of element detected



6 CONCLUSION

Results reported by Duncan (1975) and Sharer (1981) on Cyprus Anvil tailings support the findings of this report:

1. the existing tailings possess acid generating potential;
2. similar oxidation characteristics between samples with and without inoculation by T. ferrooxidans suggest strongly that the bacterium is present in the Anvil ore deposit.

The results obtained for Wellgreen, Arctic Gold & Silver, Venus and Mount Nansen tailings indicate that T. ferrooxidans is present at all four locations, but only Wellgreen and Arctic Gold and Silver samples showed strong oxidation.

Both Wellgreen surface tailings samples oxidized readily showing that T. ferrooxidans is probably present in the weathered surface material. The subsuface tailing did not oxidize, suggesting that T. ferrooxidans is not present in the mined or subsurface ores and is found only at the surface. This is supported by the results from the inoculated sample. The bacterium became established only after 42 days of incubation and showed a well-defined decline in pH associated with an increase in cobalt, iron, nickel and sulfates. The reaction was similar to results for Cyprus Anvil ores.

Arctic Gold and Silver surface and subsurface tailings oxidized readily. They showed little enhancement from the inoculation by T. ferrooxidans indicating the bacterium is already present in the ore body. However, since the leaching reaction was completed before day 14, all the remaining iron sulphides must have been oxidized by that time. This suggests that the continued oxidations of the tailings in place is unlikely to produce increasing quantities of acid.

Both Venus and Mount Nansen tailings displayed little or no oxidation potential. Venus Mines' proximity to Arctic Gold and Silver and the similar geology suggest that T. ferrooxidans is present but the acid consuming ability of the ore prevents the bacteria from becoming established. This may also be the case at Mt. Nansen. Unlike the other properties, these mines show no acidity in adjacent surface waters. Even though their acid producing potential is greater than their acid consuming potential, the difference suggests some threshold range for the tailings which inhibits their oxidation both in place and in the lab.

The apparatus used in this experiment has provided results comparable to those reported by Sharer (1981) and Duncan (1975) for Cyprus Anvil tailings. This shows that the small scale method tested here is adequate to assess the leaching potential of mine tailings and to determine the presence of *T. ferrooxidans*.

7 RECOMMENDATIONS

The findings of this report show a need for further investigation at the Wellgreen and Arctic Gold and Silver sites. Additional tests are needed to:

1. confirm the results presented in this report;
2. determine the extent of microbiological activity due to <u>T. ferrooxidans</u> within the tailings; and
3. assess the long-term environmental impact associated with any leachate released from the tailings.

The methods used in this experiment should be changed to allow for an increased dosage of dilution water initially to 200 mls so that dilution water would not have to be added during the test period.

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APPENDICES

APPENDIX I

WATER QUALITY RESULTS - SO_4 AND EXTRACTABLE METALS (mg/l)

APPENDIX I Table 1 MINE TAILINGS ASSAY RESULTS (ppm)

	CYPRUS ANVIL			WELLGREEN (oxidized)			WELLGREEN (Unoxidized)			VENUS (Oxidized)		
	Init.	Final 107	Final *108	Init.	Final 109	Final *110	Init.	Final 111	Final *112	Init.	Final 113	Final *114
As	250	270	100	65	115	57	135	103	195	44300	41400	41600
Co	N/A	155	165	110	118	120	75	195	160	16	10	10
Cu	750	490	595	4000	3900	3400	3800	3800	3450	44	40	38
Fe†	23.6	23.2	22.4	24.0	24.6	23.4	12.4	21.3	18.3	7.75	6.80	7.65
Ni	N/A	20	20	4000	2050	2400	2300	5300	3600	16	28	22
Pb	2600	3450	3350	N/A	25	25	N/A	20	45	3500	3050	3250
Zn	410	700	575	39	33	33	46	53	60	2650	2300	2300
S	24.5						10.38					

	VENUS (Unoxidized)			ARCTIC GOLD & SILVER (Oxidized)			ARCTIC GOLD & SILVER (Unoxidized)			MOUNT NANSEN (Oxidized)		
	Init.	Final 115	Final *116	Init.	Final 117	Final *118	Init.	Final 119	Final *120	Init.	Final 121	Final 122
As	57900	51900	54400	38900	42700	39800	14100	13900	13700	36400	36600	36500
Co	14	14	12	16	6	2	4	1	1	150	11	10
Cu	82	80	80	325	123	120	56	28	27	450	340	350
Fe†	8.5	8.95	9.05	7.5	7.75	6.75	2.25	2.15	2.15	7,80	7.80	7.90
Ni	22	29	30	6	7	7	10	10	9	3300	17	18
Pb	6300	6950	7050	5200	6650	6650	940	1350	1260	6800	7300	7300
Zn	4600	4650	4950	310	120	98	135	58	70	6700	7200	6300
S	4.83						0.74			3.39		

* inoculated with _T. ferrooxidans_

† results shown as percentages

APPENDIX I Table 2 WATER QUALITY RESULTS - SO_4 and Extractable Metals (mg/l) - CYPRUS ANVIL MINE

NOTE: number 108 inoculated with *T. Ferrooxidans*

DAY	SO_4		As		Co		Cu		Fe		Mn		Ni		Pb		Zn	
	107	108	107	108	107	108	107	108	107	108	107	108	107	108	107	108	107	108
14	9990	10200	<5.0	<5.0	4.9	5.5	26.7	33.0	338	667	199	187	3.0	3.0	2.0	15.0	2230	2090
28	16500	22500	<5.0	<5.0	15.9	23.1	58.2	86.1	4180	7010	211	253	2.0	5.0	<2.0	2.0	2600	3160
42	30900	41100	<5.0	<5.0	8.9	8.0	83.9	110	8810	12000	137	239	2.3	<2.0	<0.2	<2.0	177	3030
56	27000	36600	<5.0	<5.0	4.0	5.0	91	147	9120	17900	184	275	4.0	<4.0	<4.0	<4.0	2500	3810
70	33900	44100	<5.0	<5.0	5.8	13.4	156	141	13000	17100	215	240	2.0	<2.0	<2.0	<2.0	2790	3180

APPENDIX I Table 3 WATER QUALITY RESULTS - SO_4 and Extractable Metals (mg/l) - WELLGREEN MINE (oxidized)
NOTE: number 110 inoculated with *T. Ferrooxidans*

DAY	SO_4		As		Co		Cu		Fe		Mn		Ni		Pb		Zn	
	109	110	109	110	109	110	109	110	109	110	109	110	109	110	109	110	109	110
14	6300	6750	<5.0	<5.0	27.2	20.3	330	317	1220	911	17.9	13.7	770	613	<2.0	<2.0	17.7	6.8
28	5790	6480	<5.0	<5.0	22.1	28.6	315	487	246	656	15.7	20.6	692	875	<2.0	<2.0	13.6	10.3
42	6720	6990	<0.5	<0.5	33.1	31.3	147	122	189	306	21.9	21.7	539	515	<0.2	<0.2	16.8	14.3
56	5460	5880	<5.0	<3.0	13.0	21.3	213	445	127	164	9.09	13.6	<4.0	<4.0	<1.0	<1.0	13.0	7.6
70	6660	6480	<5.0	<5.0	48.1	38.3	795	767	660	228	30.7	23.7	1330	1070	<2.0	<2.0	58.3	15.2

APPENDIX I   Table 4   WATER QUALITY RESULTS - SO_4 and Extractable Metals (mg/l) - WELLGREEN MINE (unoxidized)

NOTE: number 112 inoculated with *T. Ferrooxidans*

DAY	SO_4		As		Co		Cu		Fe		Mn		Ni		Pb		Zn	
	111	112	111	112	111	112	111	112	111	112	111	112	111	112	111	112	111	112
14	2010	2280	<3.0	<5.0	<0.3	<0.05	0.7	0.13	7.3	1.65	0.17	0.19	2.0	0.8	<1.0	0.7	0.1	0.03
28	2280	2220	<0.5	0.5	<0.05	<0.05	0.21	<0.05	1.9	0.35	0.18	0.34	0.9	<0.2	<0.2	<0.2	0.1	0.26
42	2310	2700	<0.5	<0.5	0.05	0.23	0.89	0.29	2.51	47.6	0.06	4.08	1.8	14.5	<0.5	<0.2	0.1	0.08
56	1860	2520	<0.5	<3.0	<0.05	2.9	<0.05	15.3*	2.61	51.2	<0.01	13.6	<0.2	165	<0.2	<1.0	<0.02	<0.1
70	1980	3270	<0.5	<5.0	<0.05	7.1	<0.05	1.1	2.68	306	0.11	25.5	0.3	501	<0.2	<2.0	<0.02	<0.2

APPENDIX I Table 5 WATER QUALITY RESULTS - SO_4 and Extractable Metals (mg/l) - VENUS MINE (oxidized)
NOTE: number 114 inoculated with *T. Ferrooxidans*

DAY	SO_4		As		Co		Cu		Fe		Mn		Ni		Pb		Zn	
	113	114	113	114	113	114	113	114	113	114	113	114	113	114	113	114	113	114
14	2490	2550	2.1	10.0*	<0.05	<0.3	0.08	<0.3	2.28	16.8*	0.63	1.44	0.2	<1.0	2.4	*10.0	0.64	2.0
28	2670	2940	0.5	0.6	<0.05	<0.05	<0.05	<0.05	0.35	0.52	0.34	0.67	<0.2	<0.2	<0.2	<0.2	0.26	0.31
42	2790	2880	0.6	1.2	<0.05	<0.05	<0.05	<0.05	0.47	1.94	0.33	0.59	<0.2	<0.2	<0.2	<0.2	0.26	0.43
56	2610	2610	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.73	0.44	0.63	<0.2	<0.2	<0.2	0.3	0.19	0.29
70	2880	2910	1.5	1.4	<0.05	<0.05	<0.05	<0.05	1.2	1.28	0.39	0.76	<0.2	<0.2	<0.2	0.2	0.24	0.34

* suspect or unreliable results.

APPENDIX I Table 6 WATER QUALITY RESULTS - SO_4 and Extractable Metals (mg/l) - VENUS MINE (unoxidized)
NOTE: number 116 inoculated with <u>T. Ferrooxidans</u>

DAY	SO_4		As		Co		Cu		Fe		Mn		Ni		Pb		Zn	
	115	116	115	116	115	116	115	116	115	116	115	116	115	116	115	116	115	116
14	2220	2730	0.9	2.0	<0.05	<0.05	<0.05	<0.05	1.28	3.06	0.9	1.93	0.3	0.2	1.0	2.6	0.64	0.97
28	2580	2880	0.5	0.6	<0.05	0.06	<0.05	0.07	0.59	1.93	0.52	1.19	<0.2	<0.2	0.4	<0.2	0.54	0.67
42	3240	3120	1.8	0.9	<0.05	<0.05	<0.05	<0.05	3.02	1.16	0.77	0.99	<0.2	<0.2	0.6	<0.2	1.03	0.6
56	2580	2670	0.6	1.0	<0.05	<0.05	<0.05	<0.05	0.33	1.05	0.59	1.04	<0.2	<0.2	<0.2	0.4	0.44	0.65
70	3090	2820	5.8	1.6	<0.05	<0.05	<0.05	<0.05	7.91	1.59	0.82	1.13	<0.2	<0.2	1.5	0.4	1.36	0.63

APPENDIX I Table 7 WATER QUALITY RESULTS - SO_4 and Extractable Metals (mg/l) - ARCTIC GOLD & SILVER MINE (oxidized)

NOTE: number 118 inoculated with <u>T. Ferrooxidans</u>

DAY	SO_4		As		Co		Cu		Fe		Mn		Ni		Pb		Zn	
	117	118	117	118	117	118	117	118	117	118	117	118	117	118	117	118	117	118
14	21800	19200	2210	3560	22.4	22.5	188	138	6510	7760	77.0	56.7	2.0	2.0	486	622	197	145
28	12900	16380	769	2290	11.6	17	112	110	3380	5780	49.1	46.8	<2.0	<4.0	58	117	117	114
42	16300	19000	836	1740	4.27	4.04	110	99.9	3680	6380	51.4	47.7	1.7	0.4	61.1	112	130	126
56	15200	17000	620	1850	2.0	<1.0	108	85	3360	5130	49.6	39.2	<4.0	<4.0	45.0	86.0	128	104
70	15500	17900	500	1990	1.0	<1.0	92	92	2750	5440	40.7	40.8	<4.0	<4.0	36.0	86.0	102	109

APPENDIX I Table 8 WATER QUALITY RESULTS - SO_4 and Extractable Metals (mg/l) - ARCTIC GOLD & SILVER MINE (unoxidized)

NOTE: number 120 inoculated with T. Ferrooxidans

DAY	SO_4		As		Co		Cu		Fe		Mn		Ni		Pb		Zn	
	119	120	119	120	119	120	119	120	119	120	119	120	119	120	119	120	119	120
14	4620	6810	42	291	2.4	4.0	16.7	16.5	671	1230	25.2	23.6	4.0	5.0	5.0	29.0	37.9	42.7
28	3480	5940	37	188	1.2	3.5	14.7	18.7	212	1130	22.6	26.8	3.0	3.0	<1.0	7.0	31.2	47.3
42	*8040	*7200	37.5	192	1.04	0.99	16.9	20.1	179	1090	26.7	29.3	2.1	2.6	<0.2	4.8	41.7	57.2
56	3360	5250	11.1	185	0.67	<0.5	14.0	27.6	55.1	1290	19.5	38.8	2.8	6.0	<0.2	6.0	32.7	76.4
70	3990	6660	8.2	110	0.89	<0.5	19.5	16.5	57.7	779	24.9	25.8	4.0	<2.0	<0.2	3.0	46.2	51.5

APPENDIX I Table 9 WATER QUALITY RESULTS - SO_4 and Extractable Metals (mg/l) - MOUNT NANSEN MINE (oxidized)
NOTE: number 122 inoculated with <u>T. Ferrooxidans</u>

DAY	SO_4		As		Co		Cu		Fe		Mn		Ni		Pb		Zn	
	121	122	121	122	121	122	121	122	121	122	121	122	121	122	121	122	121	122
14	2160	2370	20.0	5.5	<0.05	<0.05	1.30	0.24	67.0	17.5	3.9	7.81	<0.2	<0.2	124	39.5	9.5	4.08
28	2220	2348	<0.5	<0.5	<0.05	<0.05	0.06	<0.05	1.0	0.93	1.48	2.11	<0.2	<0.2	0.7	0.4	0.82	1.64
42	3030	2480	0.6	<0.5	<0.05	<0.05	0.12	<0.05	3.51	0.61	1.78	2.07	<0.2	<0.2	0.6	0.3	1.14	1.81
56	2142	2142	0.7	<0.5	<0.05	<0.05	0.07	<0.05	2.24	1.19	1.29	2.42	<0.2	<0.2	1.0	0.8	2.07	2.07
70	2400	2430	0.7	<0.5	<0.05	<0.05	<0.05	<0.05	2.35	<0.05	1.77	2.98	<0.2	<0.2	1.0	<0.2	1.21	1.92

APPENDIX I Table 10 pH RESULTS

DAY	CYPRUS ANVIL		WELLGREEN[1]		WELLGREEN[2]		VENUS[1]		VENUS[2]		ARCTIC GOLD & SILVER[1]		ARCTIC GOLD & SILVER[2]		MOUNT NANSEN MINE[1]	
	107	*108	109	*110	111	*112	113	*114	115	*116	117	*118	119	*120	121	*122
1	4.38	2.75	3.07	2.59	3.37	3.03	7.66	5.47	7.42	5.18	2.21	2.17	2.79	2.58	7.93	4.38
4	3.70	3.65	2.90	2.79	7.62	7.59	8.20	7.89	8.05	7.82	1.72	1.69	2.40	1.97	7.85	7.45
7	3.47	3.46	3.01	2.88	7.35	7.35	7.76	7.76	7.74	7.57	1.90	1.74	2.62	1.94	7.13	7.20
14	2.87	2.68	3.05	2.90	7.04	7.19	7.61	7.73	7.70	7.59	1.91	1.73	2.70	1.94	7.62	7.44
21	2.27	2.21	3.05	2.89	7.30	7.24	7.75	7.76	7.72	7.56	1.97	1.80	2.59	2.01	7.11	7.17
28	2.22	1.87	3.21	3.01	7.29	7.26	7.79	7.75	7.74	7.67	2.06	1.87	2.44	2.04	7.23	7.31
35	2.50	2.10	3.45	3.27	7.65	6.91	8.00	8.00	8.00	8.00	2.50	2.30	2.95	2.50	7.90	7.80
42	2.09	1.93	3.24	3.06	7.60	6.73	7.94	7.89	7.81	7.83	1.99	1.78	2.52	2.01	7.69	7.54
49	1.95	1.72	3.31	3.12	6.99	5.66	7.74	7.81	7.81	7.78	1.92	1.73	2.54	2.01	7.60	7.45
56	1.95	1.76	3.31	3.17	7.33	4.82	7.89	7.84	7.84	7.77	1.97	1.76	2.58	2.07	7.29	7.27
63	1.88	1.68	3.33	3.22	7.58	4.33	7.93	7.86	7.80	7.73	2.02	1.77	2.59	2.05	7.63	7.47
70	1.91	1.76	3.32	3.21	7.54	4.14	7.88	7.74	7.73	7.70	2.04	1.80	2.66	2.14	7.50	7.30

1 Oxidized sample
2 Unoxidized sample (taken at depth of 0.1-0.3 m)
* Inoculated with _T. ferrooxidans_

APPENDIX I TABLE 11 ACID PRODUCING AND CONSUMING POTENTIALS

SAMPLE	TOTAL S.(%)	ACID PRODUCING POTENTIAL (lbs/ton)	ACID CONSUMING POTENTIAL (lbs/ton)	THEORETICAL ACID PRODUCER	ACID PRODUCER
Mount Nansen	3.39	207	35	Yes	No
Venus	4.83	295	75	Yes	No
Arctic Gold and Silver	0.74	45	nil	Yes	Yes
Wellgreen	10.38	636	nil	Yes	Yes
Cyprus Anvil	24.55	1503	*27	Yes	Yes

* Acid Consuming Potential determined by Duncan, 1975, Leachability of Anvil Ore, Waste Rock and Tailings.

APPENDIX II

WATER SAMPLE PRESERVATION AND ANALYSIS METHODS

APPENDIX II MINE TAILINGS OXIDATION STUDY - WATER SAMPLE PRESERVATION AND ANALYSIS METHODS

PARAMETER	DETECTION LIMIT	ANALYTICAL PROCEDURE
* Sulfate SO_4	1.0 mg/l	Barium Chloranilate-UV Spectrophotometric
**Extractable Metals	mg/l	Inductively Coupled Argon Plasma (ICAP) combined with Optical Emission Spectrometer (OES)
As	0.05	
Co	0.005	
Cu	0.005	
Fe	0.005	
Mn	0.001	
Ni	0.02	
Pb	0.04	
Zn	0.005	

* Sample was diluted 60:1 (.5 ml sample per 29.5 ml distilled water) No preservatives added.

**Sample was dilute 10:1 (1 ml sample per 9 ml distilled water) Each sample was preserved to pH <1.5 using 0.2 ml of HNO_3.

APPENDIX II   MINE TAILINGS OXIDATION STUDY - TAILINGS SAMPLED ASSAY

METHOD: (Bondar Clegg Assayers)

Analysis By Atomic Absorption (Co, Cu, Pb, Mn, Ni, Zn & Fe)
Each minus 100 mesh sample is weighed at 0.5 gm and placed into a test tube then 1.5 ml of HNO_3 is added and the sample is heated in a hot water bath for 1/2 hour. The 0.5 ml of HCl are added and the sample is heated for 1 1/2 hours further. The sample is then removed from the bath and the mixture is diluted to 10 ml with water (a solution containing 1000 ppm $AlCl_3$ is used when analyzing for Mn and Fe). The sample is then mixed and allowed to settle before analyzing. The samples are analyzed by atomic absorption using standards with a similar matrix.

Analysis for Arsenic
A minus 100 mesh sample weighing 0.1 gm is treated in a test tube with an acid mixture of HNO_3-$HClO_4$ on a sand bath for 4 hours or until all the HNO_3 is driven off.

After cooling, the sample is diluted and potassium iodide solution added, followed by stannous chloride, Arsine is then produced by the addition of 20 mesh zinc. The gas is generated into an absorbing solution of silver diethyldithiocarbamate in pyridine. The resulting color is compared with standards carried through this color procedure in order to determine the arsenic content in ppm.