WASTE ROCK MANAGEMENT PLAN
AT THE FARO MINE

003139

CURRAGH RESOURCES
FARO, YUKON

May/87
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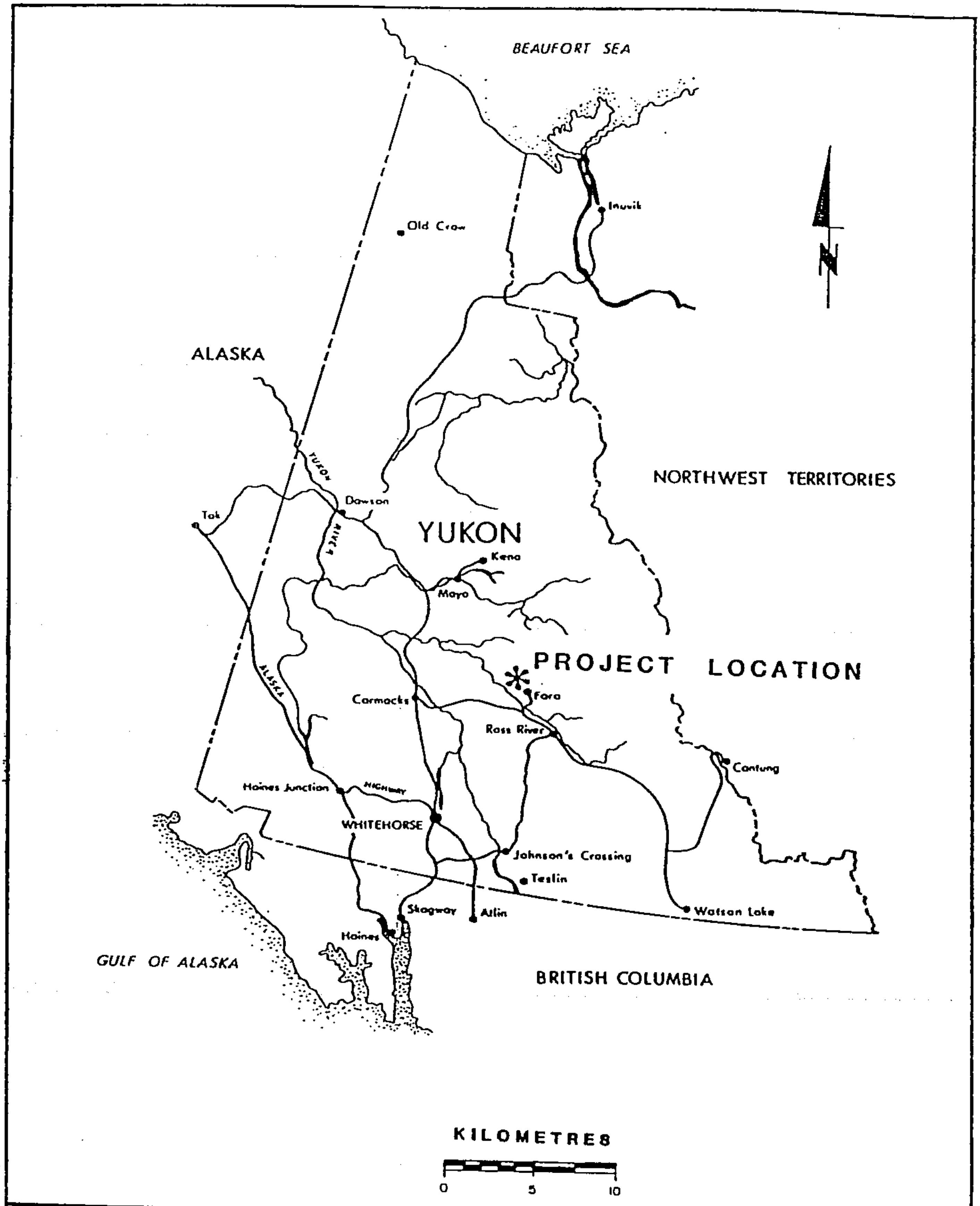


CURRAGH RESOURCES

LOCATION PLAN

INTRODUCTION

Curragh Resources operates the former Cyprus Anvil mine near Faro, Yukon (See Location Map). The saleable products of the Company are lead-silver and zinc concentrates.

To expose the lead-zinc-silver ore, significant quantities of waste rock must be mined. In large part (90 %), the waste is alkaline in nature, and will present no threat to receiving waters. The remaining 10 % of the waste contains significant values of sulphide minerals, primarily pyrite, galena, sphalerite and pyrrhotite, and is potentially acid producing.

This report describes the measures that will be implemented to minimize the potential for acid production from sulphide waste produced in the Faro Mine.

SUMMARY

Approximately 65 million tonnes of waste remain in the Faro Mine. Of this, approximately 59 million tonnes does not contain significant sulphide concentrations. Approximately 6 million tonnes contains significant (>2 %) sulphides and requires special consideration for permanent disposal. Approximately 3 million tonnes of sulphide waste will be encapsulated within non-sulphide rock, and the remaining 3 million tonnes from the final phase pit will be dumped back into previously mined out areas.

Encapsulation isolates sulphide rock from the environment within environmentally inert rock. Mechanical phenomena (observed in the construction of rock dumps by mine equipment) cause the surfaces of the dumps to form seals, preventing large ingresses of water to the sulphide material.

Dumping sulphides back into previously mined out areas reduces the potential that this material cannot leach to the environment. In all probability, the pit will flood, preventing oxidation of the waste dumped back into the pit.

DISCUSSION

The waste types at Faro are subdivided into four major types (>1% by volume). The appended report "Leachability of Anvil Ore, Waste Rock and Tailings" (Appendix A) identifies five types, however, the granodiorite and diorite can be discounted as they are less than 1 % of the remaining waste volume. The four types considered herein are:

1. Quartz Muscovite Schist: The major component of remaining waste. It is a variably calcareous or graphitic quartzo feldspathic schist with andalusite, and may or may not contain biotite or chlorite. Not an acid producer.

2. Calc Silicate Gneiss and Breccia: Variably calcereous, green banded metamorphized shale, comprising approximately 10 % of remaining waste. It is a net acid consumer.

3. Biotite Schist: Similar to Quartz Muscovite Schist, but contains significant biotite.

4. Sulphide Waste: Comprised of pyrite, pyrrhotite and material grading +0 % to -4 % combined lead and zinc, plus altered schists of varying thickness enveloping the entire sulphide body. Represents 10 % of remaining waste and is a potential acid producer.

There are other waste types at Faro, but in total would not amount to more than 2 to 3 % of the remaining waste.

Sulphide waste will not be dispersed within the dumps, but will be disposed of in specific locations. Such locations were selected on the following criteria:

1. Previously mined out areas that will not drain to receiving waters;
2. Sulphides not permitted to contact original ground surface;
3. The location allows non-sulphide waste to be dumped on top of the sulphides to form a protective cap.

The locations thus specified are shown on Figure 1, a 1" = 300' scale map of the pit and dump areas.

Realistically, the waste is considered to be either sulphide or non-sulphide. Sulphide waste consists of massive sulphides, plus the altered schists in the near vicinity of the sulphide body (See Fig. 2), known as the white mica envelope. For the remainder of the life of the Faro Mine, 65 million tonnes of waste will be mined, comprised of 6 million tonnes of sulphide waste and 59 million tonnes of non-sulphide waste.

Mining advances in a series of 4 phases, known as A, B, C and D. All waste from phases A, B and C will go to dumps. These phases contain 3 million tonnes of sulphide waste and 45 million tonnes of non-sulphide waste.

A large proportion of waste from the final phase D, will be disposed of in the area of the previously mined out A, B and C Phases. D Phase contains 3 million tonnes of sulphide waste and 15.7 million tonnes non-sulphide waste.

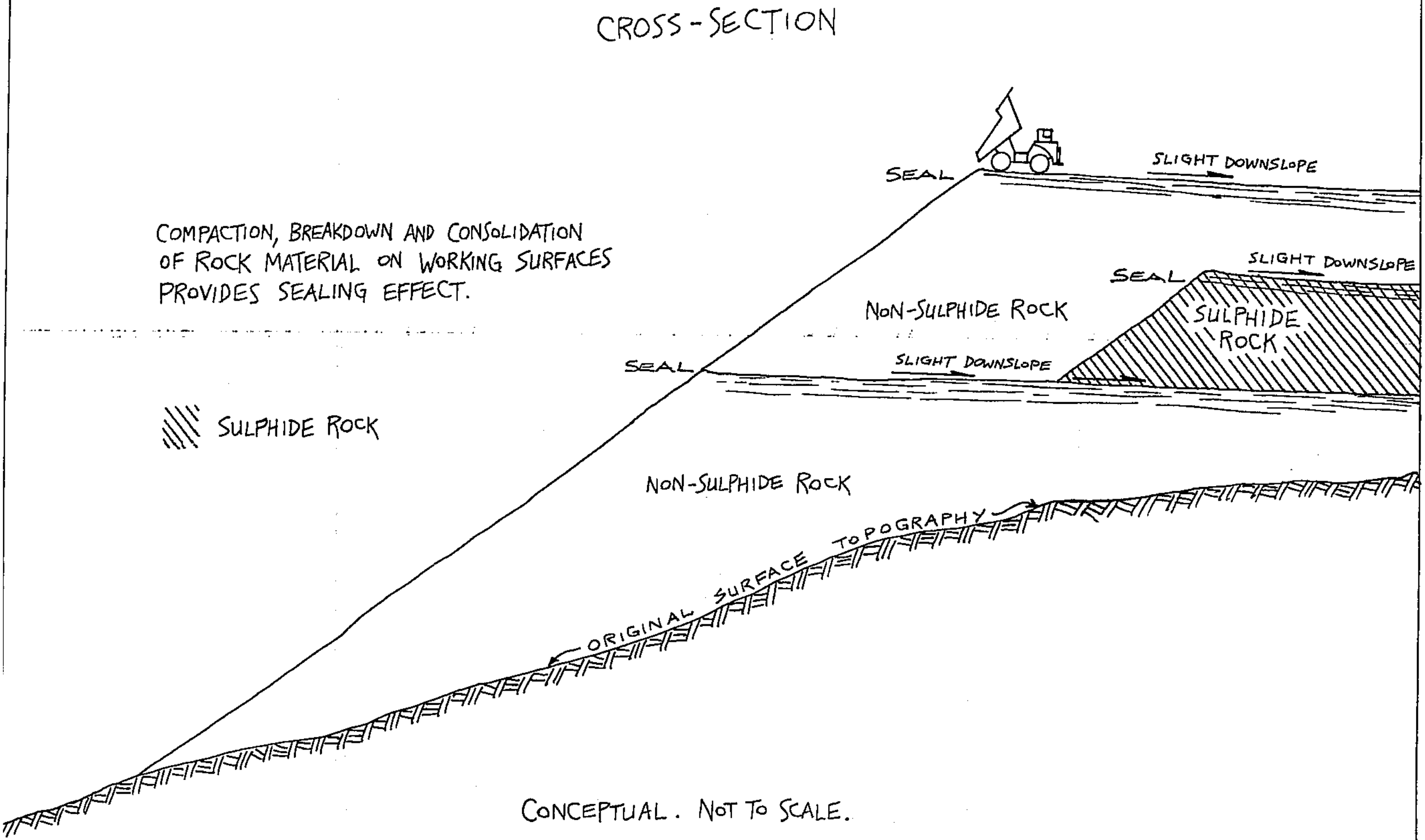
The sulphide waste from the first three phases will be encapsulated within non-sulphide rock (see Figure 3). Encapsulation satisfies criteria 2 and 3 above. As can be seen in the figure, sulphides do not contact original ground and are later capped by environmentally inert rock.

The concept of encapsulation is based on mechanical phenomena observed in the development of rock dumps by large haulage trucks. Firstly, end dumping from the top of a dump results in a natural segregation of particle sizes, grading from coarse at the bottom to fine at the top. Secondly, the severe dynamic loading generated by loaded trucks of 108 and 154 tonnes capacity (as in use at Faro) causes the fines on the dump surface to be further broken down and compacted.

The above phenomena create an effective seal on the surface of the dump. Further, dumps are generally constructed with the surface exhibiting a slight upgrade to the dump crest (dump point), resulting in drainage in the general direction of the pit or back into the dump.

Thus it can be seen that encapsulated sulphides will be within 3 seals - the surface of the capping dump, the surface of the sulphides and the surface of the dump underlaying the sulphides. Any seepage penetrating a seal will tend to flow away from the dump face on the next lower seal.

One further advantage of a specific sulphide dump is that if remedial measures are required, the area involved will not be extensive relative to total dump area. Such measures would probably entail merely effecting a competent seal above the sulphides to prevent contact with water. In order to minimize costs, such a seal will not be installed unless monitoring of the surface of the sulphide dump indicates it is necessary.



COMPACTION, BREAKDOWN AND CONSOLIDATION OF ROCK MATERIAL ON WORKING SURFACES PROVIDES SEALING EFFECT.

CONCEPTUAL. NOT TO SCALE.

FIGURE 3

DISPOSAL OF SULPHIDE WASTE BY ENCAPSULATION WITHIN NON-SULPHIDE ROCK	CURRAGH RESOURCES FARO MINE FARO, YUKON	07 MAY 1987 DR. BY: CGY

DISPOSITION OF WASTE

The vast bulk of waste at Faro is non-sulphide bearing. Sulphides are found only in close proximity to and within the ore body. Figures 4 & 5 are maps illustrating the distribution of sulphides (ore and waste) in Phases A and B. The massive sulphide waste is intermixed with the ore throughout the orebody and will be encountered until mining at Faro is complete. The white mica alteration envelope occurs above and below the orebody, thus the lower portion will not be mined as the ore occurs above it.

The final waste dump plans are subject to change as economics and regulations change. However, the sulphide dumps constructed prior to 1989 - 90 will not change.

Sulphide waste will be disposed of as follows:

1. 3 million tonnes to the area marked "Intermediate Dump" in Fugure 4;

2. 3 million tonnes from the Phase D pit to the area of the previously mined out A, B and C Phases.

Non-sulphide waste will go to the following destinations:

1. 16 million tonnes to the cross-valley fill on the Vangorda Road;

2. 13 million tonnes to the Zone 2 Dump;

3. 36 million tonnes to the Intermediate Dump.

It should be noted that, aside from the quantity destined for the Vangorda Road, the tonnages to the destinations above may quite possibly vary.

Variations in waste rock deposition planning and practice can be caused by several factors:

1. Improvements or changes to mine plans;
2. Changes in regulations;
3. Adoption of new technology and/or mining methods;
4. Poor foundation in proposed dumping areas;
5. Changes to the economic environment.

VANGORDA ROAD

A special case in the disposal of mine waste rock is the cross-valley fill which will form a causeway across the valley of the North Fork of Rose Creek. The surface of the causeway will be an integral portion of the Vangorda Road, which will provide access for ore haulage from the Vangorda Plateau deposits to the Faro concentrator.

The construction of the bulk of the causeway is by a simple method utilized the world over - end dumping blasted rock from the top of the causeway in a longitudinal direction. Approximately 16 million tonnes of waste rock will be incorporated within the causeway.

A unique feature of the Vangorda Road cross-valley fill is the incorporation of a rock drain to permit the passage of water through the fill. The purpose of the rock drain is to ensure that the flow of the North Fork of Rose Creek remains continuous, with minimal or no pooling of water upstream of the causeway. The formation of a large pool of water upstream of the causeway would create severe stability problems in the causeway and have an adverse impact on Rose Creek due to a major change in flow characteristics.

Materials Used In The Cross-Valley Fill

Approximately 16 million tonnes of waste rock will be required to construct the cross-valley fill. All material placed in the cross-valley fill will consist of non-sulphide rock. Sulphide waste will be disposed of in other specific locations as previously described.

The bulk of the material (approximately 14 million tonnes) in the cross-valley fill, with the exception of the rock drain, will be quartz muscovite and biotite schist, as these are the predominant waste types in the Faro Pit. Table 1 shows that these rock types have a much greater neutralization potential than acid generating potential. (The tabulated results are a summary of 10 samples sent to Chemex Labs Ltd., for analysis). The mean net neutralization potential is 50.9 tonnes of $CaCO_3$ equivalent per 1000 tonnes of material, with a mean paste pH of 8.3. Obviously such material will not pose an acid generating threat to the environment.

Construction Method of Cross-Valley Fill (Causeway)

The causeway forming the cross-valley fill across the North Fork of Rose Creek will proceed along the longitudinal axis of the roadway by end dumping waste from the roadway surface. This will in effect be a long narrow dumphead.

The initial phase of development was to construct a ramp along the crest of an existing dump to provide access to the cross-valley fill and rock drain (See Fig 6). Once the elevation of the road was attained, development continued at that elevation along the road alignment to the limit defining the origination of the rock drain. The commencement line of the rock drain was determined by design as approximately 60 m (200 ft) from the creek. This line was surveyed and flagged for the benefit of operations so that only the specified material for the rock drain would be dumped beyond this line.

Principle of the Rock Drain

The rock drain will consist of coarse, durable rock fragments contained within the mass of waste rock generated in the course of normal open pit mining. Several rock drains are employed in the Kootenay region coal operations.

When waste rock is dumped at the crest of a waste pile, significant segregation of particle sizes occurs as the material rolls down the dump face below the crest where dumping takes place. The largest fragments tend to separate from the mass of dumped waste and to roll down the dump face, and slightly beyond the toe of the dump. As a result, the large fragments (boulders) come to rest within a zone which extends a moderate distance beyond the line of intersection of the plane representing the face of the dump and the topographic surface on which the dump is constructed (see Fig. 7). Thus a zone of coarse segregated rock extends beyond the toe of the dump.

As the dump face is advanced, the zone of coarse rock at the toe becomes covered and constitutes a pervious drainage blanket (of coarse fragments) over the surface of contact between the base of the dump and its foundation.

As the causeway (dump) is advanced across the North Fork of Rose Creek, the coarse fragments will collect in the drainage channel, which will serve as a "French" drain to conduct surface flows from the upstream to downstream side of the causeway.

Inspection of material end dumped off the causeway to date shows that there is a gradual reduction in the size of the rock fragments proceeding (increasing) from the crest to the toe. This has been further substantiated by grain size analyses of dumps modelled in the laboratory. This reduction in particle sizes, from the crest to the toe serves as a well graded filter which prevents infiltration of fines from the upper regions of the causeway into the drainage blanket at the base of the causeway.

Materials Used In The Rock Drain

The rock drain will be constructed of large fragments of resistant rock. The most suitable material at Faro is the rock type known as calc-silicate breccia. This rock type is identifiable in diamond drill core, thus the calc silicate breccia tonnage and location are well defined. Curragh plans to mine approximately 2 million tonnes of calc-silicate breccia, of which 1.5 million tonnes will be placed in the rock drain.

Table 1 shows that the mean net neutralization potential of the calc-silicate breccia is 73.3 tonnes of $CaCO_3$ equivalent per 1000 tonnes of material, and a mean paste pH of 9.1. Such material is incapable of generating acid, thus is environmentally neutral.

Once sufficient material has been placed in the rock drain, which will bring the toe of the calc-silicate beyond the creek channel by approximately 60 m (200 ft), the remainder of the cross-valley fill will be run-of-mine non-sulphide waste. This waste will consist of primarily quartz muscovite and biotite schists, with minor amounts of calc-silicate breccia and calc-silicate gneiss.

APPENDIX A

LEACHABILITY OF ANVIL ORE, WASTE ROCK AND TAILINGS

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Division of Applied Biology
B.C. Research

ALUR 74-75-37

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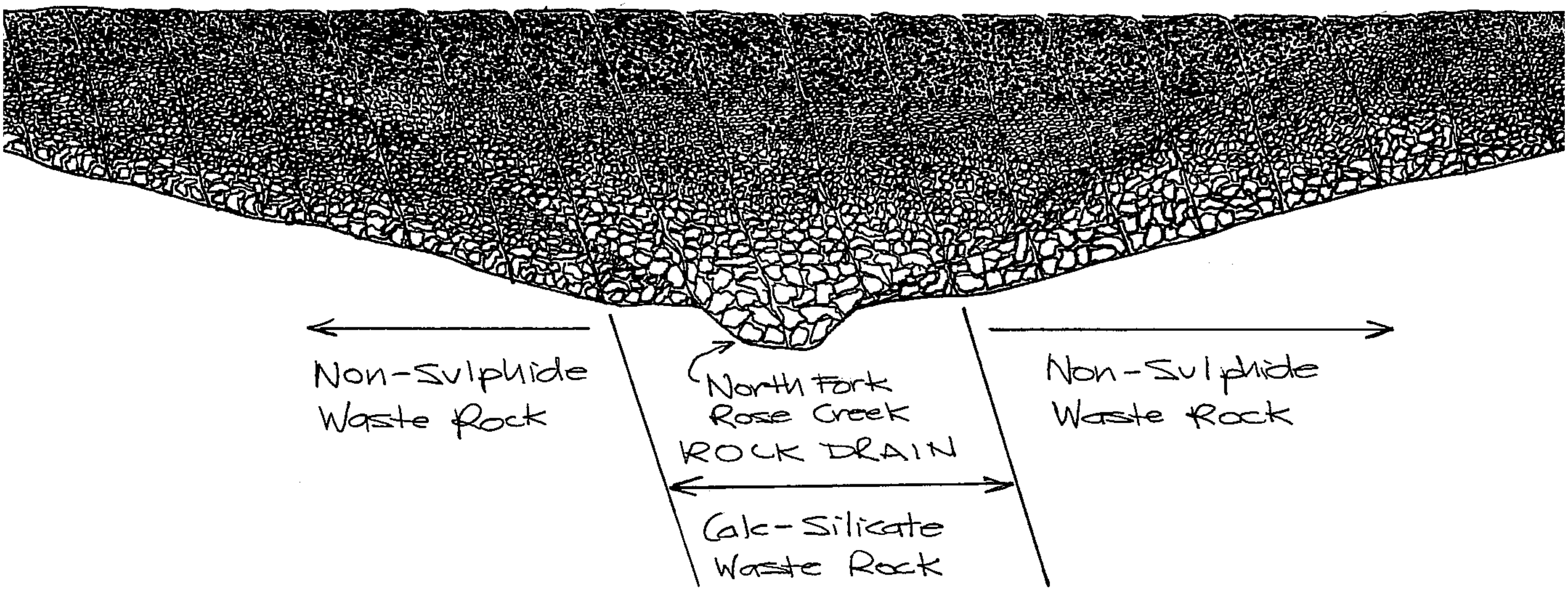
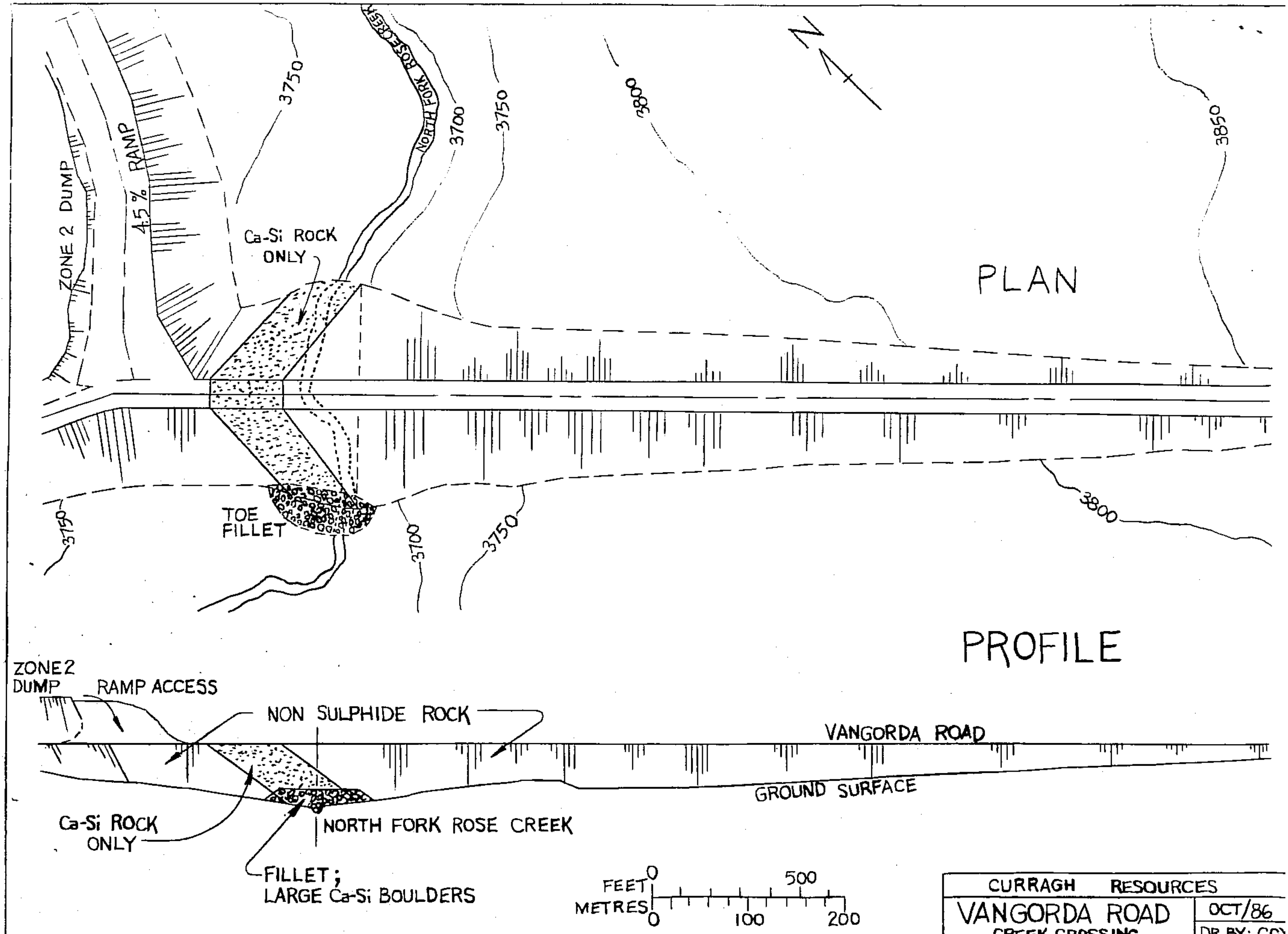
*Available on request to Manager, A.L.U.R. Program, Water, Lands, Forests and Environment Division, Department of Indian and Northern Affairs, Ottawa K1A 0H4

FIGURE 7

Development of Coarse Fragment Blanket at Toe of Causeway	CURRAGH RESOURCES FARO MINE FARO, YUKON 30.May/87



Conceptual.
Not to Scale



CURRAGH RESOURCES

VANGORDA ROAD
CREEK CROSSING

OCT/86
DR.BY: CG

SUMMARY

Dr. D.W. Duncan of B.C. Research visited the Anvil Mine, Faro, Yukon Territory, during January, 1974, and collected representative samples of the ore, tailings and waste rock. The sulfide components of all three sample types were amenable to microbiological oxidation and thus were a potential cause of acidic drainage water. However, in practice the ore and the tailings are not likely to be a problem, provided that 1) the ore stockpiles are processed and eliminated; 2) ore remaining in the open pit is isolated from oxygen, probably by flooding; and 3) the tailings are isolated from oxygen by minimizing the surface area of the tailings pond, preventing distribution of tailings outside the pond area and by decreasing the exposed surface area through reclamation.

About 95% of the waste rock going into the waste dumps cannot produce acidic drainage water. The remaining 5%, the sandy pyrite core, could produce acidic drainage water, and in fact could produce more acid than all the other waste could consume. The sandy pyrite should be isolated from the other waste rock and disposed of in such a manner that it will not be leached, i.e. dispose of it in a separate dump which could be covered.

The microbiological growth occurring in the seepage near the tailings dam is caused by members of the Sphaerotilus-Leptothrix group, and is not due to Thiobacillus ferrooxidans. The former organisms do not produce acidic drainage water. The drainage water leaving the tailings pond is alkaline due to the chemicals added in the mill. The local ground water is alkaline because of the alkaline nature of the host rock. No data are available concerning any drainage water from the ore stockpiles or the waste dumps.

INTRODUCTION

OBJECTIVE

To determine why the seepage waters at the Anvil Mine, Faro, Yukon Territory, are slightly alkaline despite the presence of large quantities of sulfide mineralization, and to assess the long term potential for formation of acidic drainage water.

BACKGROUND

During an open-pit mining operation, ore-grade material is mined and fed to the flotation mill for recovery of valuable metals. Occasionally the ore is stockpiled, because it is more economic to process other components of the orebody within a specified period of the life of the mine. The tailings, which are the waste product of the milling operation contain most of the pyrite and/or pyrrhotite originally present in the ore, plus a residual amount of the valuable metallic sulfides. The waste rock, which must be mined in order to reach the ore, is piled in waste dumps, and the type and quantity of sulfides it contains depends on the nature of the orebody. In many mining operations, the ore-grade material is surrounded by a halo of sulfide-bearing mineralization, frequently high in pyrite, but too low in valuable metals to be considered as ore. The sulfide in waste dumps made from such sulfide-rich material frequently leaches spontaneously once the mineralization has been disturbed and piled. In many mining operations the leaching of this waste rock is encouraged as a supplementary source of metal production. Thus, three types of material should be considered as potential leaching hazards: ore, tailings and waste rock.

The Anvil Mine of the Cyprus Anvil Mining Corporation is a massive sulfide orebody containing pyrite (FeS_2), pyrrhotite (Fe_7S_8), galena, (PbS) and sphalerite (ZnS) as its major components (1). Minor amounts of chalcopyrite ($CuFeS_2$) are also present. All of these sulfide minerals can be oxidized to their respective sulfate salts, either through chemical or biological action. In the case of the iron minerals, such actions can result in the production of free sulfuric acid. The tailings from this orebody are high in sulfide minerals, and thus are a potential leaching hazard, although the physical arrangement and initial alkalinity of most tailings ponds discourages active chemical or microbiological leaching. The ore is also a potential problem, if it is not immediately processed through the mill, and is kept in stockpiles for any length of time. Waste rock is the largest component of the material mined, and because of its sulfide content and method of disposal, it is probably the greatest potential source of acidic drainage water.

Water emanating from the Anvil property has been sampled under the direction of the Water Quality Engineer, Department of Indian Affairs and Northern Development, and has generally been found to be alkaline, in spite of the massive-sulfide nature of the orebody. A sample of waste rock examined previously under contract to the office of the Controller of Water Rights, Department of Indian Affairs and Northern Development, contained sufficient sulfur (as indicated by analysis with a Leco furnace) to produce more sulfuric acid than it could consume, but leaching could not be induced. This anomalous result, combined with the known sulfide content of the tailings, led to a request by the Controller of Water Rights, Department of Indian Affairs and Northern Development, Whitehorse, Y. T., that the long term potential for acid production from the waste products of the Anvil mining operation be investigated. Accordingly, B. C. Research entered into a contract with the Department of Supply and Services on behalf of the Arctic Land Use Research Program, to investigate this problem.

MATERIALS AND METHODS

FIELD VISIT

To gain a first-hand assessment of the Anvil mining operation and to hold discussions with personnel of both the Controller of Water Rights office of the Department of Indian Affairs and Northern Development, Whitehorse, and with members of the Cyprus Anvil Mining Corporation, Faro, Dr. D. W. Duncan of B. C. Research visited the Anvil mining operation on January 23 and 24, 1975. Discussions were held with Mr. Cliff Williams, Water Rights Engineer, Department of Indian Affairs and Northern Development; Mr. Jim Olk, Manager; Mr. Gerry Whitley, Environmental Engineer; and Mr. Daryl Hanson, Mine Geologist of the Cyprus Anvil Mining Corporation.

SAMPLES

Samples of the various geological types of waste rock and of the ore stockpiles were collected in co-operation with Mr. Hanson and samples of tailings were collected in co-operation with Mr. Whitley (Table 1). According to Mr. Hanson the various rock types were quite uniform in composition, so 30-lb composites made up of chip samples, were collected. These were crushed and split at the mine and 5-lb portions sent to Vancouver. One of the tailings samples was made up from the final rejects of the composites taken at the mill during the 8 - 4 and 4 - 12 shifts. The other was a grab sample.

Four additional samples were collected by Mr. Hanson from the face of the diorite dike and sent to Vancouver on February 28. Samples A and B were from an unaltered outcrop and samples C and D were from a heavily altered fault zone.

Two samples consisting of the water, debris and biological growth present in the seepage near the tailings dam were taken at the site monitored by the Department of Indian Affairs and Northern Development (Appendix II).

ACID PRODUCTION POTENTIAL

Acid production potential of the various samples was examined using procedures outlined in Appendix I. Waste rock and ore-grade samples were pulverized and ground prior to testing, whereas tailings samples and a portion of the sandy pyrite were examined as sampled.

STAFF

This study was carried out in the Division of Applied Biology of B. C.

Research, headed by Dr. C. C. Walden. Planning, field work, supervision, and analysis of the data were carried out by Dr. D. W. Duncan. Miss H. Kurtz was responsible for the acid production tests, assisted by Mr. D. Watt. Analytical support was provided by Miss M. Lewis, Miss D. Hartman, and Mr. G. Marsh. The manuscript was reviewed and edited by Mr. A. Bruynesteyn and Mr. A. Williamson.

DESCRIPTION OF THE ANVIL OPERATION

ORE GRADE MATERIAL

The mine property is located in the Anvil Range in the Central Yukon (Figure 1); geology of the area has been described by Tempelman-Kluit (1). The ore is basically a massive sulfide consisting primarily of pyrite (30 - 40%) with some pyrrhotite (up to 6%). The average assay is 30 - 35% iron. The ore contains about 10% combined lead and zinc, and the cutoff point for economic mining is considered to be 5% 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. In Company terminology, the ore is referred to as "black" rock.

In the early days of the operation, two low-grade stockpiles were set aside. The "yellow" stockpile consists of approximately 1,000,000 tons grading 5 - 8.5% combined lead and zinc, with the average grade being 7.2% combined lead and zinc. The "red" stockpile contains approximately 500,000 tons of ore containing greater than 8.5% combined lead and zinc, but less than 5.9% zinc. The average grade is about 9.2% combined lead and zinc. In theory, these two stockpiles could cause leaching problems, and there is some evidence that the sulfides they contain have oxidized. However, they are probably not long term problems, because the ore probably will be milled before the mine ceases operation.

In addition to the major sulfide minerals, the ore contains aluminum, barium, calcium, magnesium, manganese, and silica, probably as components of the host rock, and the following heavy metals: cadmium, chromium, cobalt, copper, gold, molybdenum, nickel, silver, strontium, titanium, and vanadium. With the exception of copper, normally present in the 0.1 - 0.2% range, the concentration of the other metals is less than 0.1%.

Water samples taken by the Department of Indian Affairs and Northern Development and identified as "Anvil Mine water at road crossing" had pH values ranging from 7.7 to 10.8 between July, 1973 and August, 1974 (Appendix II).

TAILINGS

The milling operation produces both a lead and a zinc concentrate. About 1½ lb of sodium carbonate and about 2 lb of lime are added per ton of ore during milling. Most of the lead and zinc, some of the copper and a small amount of the iron are removed from the ore. It is not known how much of the other heavy metals are removed in concentrates and how much remains with the tailings. A typical tailings assay is about 0.7% lead, 0.75% zinc, 36% iron and 0.15% copper. The size distribution in the tailings is 9 - 10% +100 mesh, and 45 - 50% -325 mesh.

The tailings are pumped to a tailings pond located in the valley below the mine, and the excess water flows into Rose Creek which is routinely sampled by the Controller of Water Rights. Between July and October, 1973, samples of the water of Rose Creek taken beside the tailings pond had a pH in the range 7.6 - 8.3 (Appendix II). During routine monitoring of the water seeping from the tailings pond, it was observed that in one area the water was acidic (pH 6.5) during February, 1973 (Appendix II). During the remainder of 1973 the pH of this seepage ranged from 7.5 - 8.1 and from 7.3 - 7.7 during 1974. In conjunction with this seepage into Rose Creek there was evidence of biological growth in the form of "moldy" looking white to grey streamers attached to the rocks and other debris present. Concern was expressed by both mine and Water Rights personnel that this growth represented leaching bacteria and indicated microbiological activity.

Examination of the material in the field suggested that it was not indicative of the growth of leaching bacteria, and subsequent laboratory examination of the two samples collected (pH 6.8 when measured 72 h later in Vancouver), showed that the growth was due to members of the Sphaerotilus-Leptothrix group. The Sphaerotilus-Leptothrix group are sheath-forming, fresh-water bacteria, some of which are typical inhabitants of polluted waters and drainage ditches (2). Members of this group may have ferric hydroxide and manganic oxide precipitated in, on or near their sheaths. Although the organisms growing in the seepage did not show evidence of the typical brown iron precipitate, Mr. Whitley indicated that up to 6 ppm of manganese was present.

The members of the Sphaerotilus-Leptothrix group are generally considered to be heterotrophs, (i.e. they oxidize organic matter for energy), as opposed to the leaching bacterium, Thiobacillus ferrooxidans, which is an autotroph. The latter organism obtains its energy requirements from the oxidation of ferrous iron to ferric iron, and from the oxidation of sulfides. The presence of streamers of Sphaerotilus-like organisms is normally considered to be a sign of polluted water, suggesting that the seepage has a high organic matter content. The total organic carbon content of the two water samples, measured after they had been stored at 2 C for two months, was 8 and 49 mg/l. The seepage did have an organic odor, but to the writer it did not appear to be the odor of xanthates or other flotation agents. Moreover, the seepage appeared to be coming out of the surrounding hillside, rather than the tailings dam itself. Members of the Sphaerotilus-Leptothrix group can tolerate a wide range of environmental conditions including acidic pH values, but they are not a primary source of free acid.

WASTE ROCK

In the terminology of the Anvil Mine, the waste rock is known as "white rock", and there is generally a very sharp line between the ore ("black rock") and the waste. The economic cutoff is 5% combined lead and zinc, but generally the lead and zinc content of the waste rock drops to a very low level. Overall, Mr. Hanson felt that the waste rock, other than the pyrite core, contained very little sulfide. There were some localized instances of pyrite, such as near the diorite dike at the north end of the pit, and at the ore/waste contact where a zone containing pyrite could be from 1 - 20 ft thick. He estimated that the waste rock contained less than 1% barite, expressed as BaO. The analytical data in Table 1 confirms these opinions.

According to Mr. Hanson there are five distinct types of waste rock in the pit:

Quartz Muscovite Schist - The major component of the host rock in the area is a quartz muscovite schist, which makes up the foot wall and the hanging wall of the pit. This material may or may not contain some biotite or chlorite.

Calc Silicate Gneiss - The next most important type of rock is referred to as the calc silicate. It is a green banded rock which is primarily found on the west side of the pit. It is considered to be a metamorphosed calcareous shale containing minor amounts of diopside.

Biotite Schist - The next most prevalent material is a biotite schist, containing quartz, graphite and sericite. Some samples did not contain graphite.

Granodiorite and Diorite - The granodiorite and diorite is present as a dike on the northwest side of the pit. It contains minor amounts of pyrite, feldspar and biotite.

Sandy Pyrite - A massive pyrite, containing from 0 - 5% combined lead and zinc (low concentrations are most common), acts like a core through the entire deposit. Almost no pyrrhotite is associated with this massive pyrite. It is characterized by being extremely granular, and thus is referred to as sandy pyrite. The maximum grain size observed was 1 mm, with much of the material being less than 0.2 mm.

WASTE DUMP

As of February, 1974, the waste dump at the Anvil Mine occupied approximately 300 acres, with an average height of 100 - 150 ft. Relative percentages of the waste rock making up the dump at the current time are presented in Table 2. The dump is horizontally and sub-vertically zoned with respect to rock type.

The Cyprus Anvil Mining Corporation estimates the ultimate waste dump will occupy approximately 800 acres with an average height of 200 - 250 ft, and will have the final composition shown in Table 2. Most of the granodiorite and diorite have already been placed on the dump, whereas most of the massive (sandy) pyrite will be dumped during the latter years of the life of the mine.

ACID PRODUCTION TESTS

ORE SAMPLES

The analytical results presented in Table 1 show that the ore samples taken from the "yellow" and "red" stockpiles were representative of the material placed in the stockpiles. Both samples were acidic and were theoretically capable of producing more acid than they consumed. During an actual leaching test they were able to produce excess acid. Thus, the mineralization represented by these stockpiles is able to produce excess sulfuric acid due to microbiological action.

TAILINGS SAMPLES

The two tailings samples examined were both acidic, with the grab sample being more acidic. They consumed less acid than the samples taken from the ore stockpiles. According to their sulfide content both tailings samples were theoretically able to produce more acid than they consumed and both were able to produce excess sulfuric acid in a laboratory shake-flask test when leached "as-discharged".

WASTE ROCK

As predicted by the mine geologist the waste rock samples, with the exception of the sandy pyrite, were low in sulfide, lead and zinc. The biotite schist, muscovite schist, and calc silicate all had an alkaline pH and consumed more acid than they were capable of producing. Thus they are not a potential source of acidic drainage water. The original sample obtained from the diorite dike had an alkaline pH and consumed 59 lb of acid per ton in order to stabilize the pH at 3.5, the same amount it was theoretically able to produce. However, during the actual acid production test, the sample was not able to produce excess sulfuric acid.

Four additional samples of the diorite dike were collected and examined. Samples A and B taken along the face of the unaltered outcrop were very similar to the original sample in both pH and acid consumption, but contained significantly less sulfur (Table 1). The unaltered diorite is not a potential source of acidic drainage water. Samples C and D were taken from the face of the dike in an area classified as a heavily altered fault zone. They were less alkaline than the other samples (pH 7.5 - 7.8) and consumed less acid (about 20 lb per ton). However, they were also lower in sulfur and are not a potential source of acidic drainage water.

In addition to the various waste samples collected in the Anvil open pit, cuttings were collected from a rotary drill hole at the ore-waste contact.

As shown in Table 1, this sample had a sulfide content of 3.6%, but was low in lead, zinc and barium. Ignoring the small contribution of the barite to the sulfide value, the sample was theoretically capable of producing 216 lb of sulfuric acid per ton, almost three times the 74 lb per ton it would consume. Thus, waste rock taken from near the ore waste contact could theoretically be an excess acid producer and in fact, was able to produce excess sulfuric acid in the laboratory. However, the amount of such waste is probably small compared to the total tonnage of waste rock.

The final sample of waste rock examined was the sandy pyrite, which makes up the core of the deposit. The sample examined was essentially pure pyrite and was theoretically capable of producing 3162 lb of sulfuric acid per ton, (see Table 1), about 55 times the amount it would consume. Because this sample was obviously the greatest potential source of sulfuric acid in the waste dumps,.it was examined for its leachability, both ground and as collected from the open pit, (a sandy, granular material). The leaching bacteria were capable of producing sulfuric acid from this material in either form.

DISCUSSION

ORE

The results of this investigation show that all three products of the Anvil Mine have some potential for producing more sulfuric acid than they can consume. The two stockpiles that currently exist are leachable, and could theoretically produce a water pollution problem if any significant amount of water percolated through them. However, in the long range they are not a potential problem because in normal practice they will be used as mill feed sometime during the life of the mine.

It is assumed that any ore remaining when the pit is mined out will be on the lower levels. The upper benches will probably all be in waste rock. In all probability the pit will fill with water preventing ready access of oxygen to the sulfides exposed near the bottom. The water entering the pit will probably be alkaline from contact with the host rock and will probably remain alkaline due to contact with the greater area of exposed waste rock on the upper benches. Thus the final pit is not considered to be a potential acidic water pollution problem.

TAILINGS

The tailings pond is the most significant potential source of acidic drainage water at the Anvil operation, since nearly all the sulfides remaining on the property will be concentrated within that structure. Although the potential tonnage of acid which could be produced with time is great and the mineralization within the tailings pond is leachable at the size range prevailing in the pond, the actual potential for acid production is quite small. The main reasons for this are the limited rate at which oxygen can diffuse into the tailings and the fact that only the pyrite on the surface of the tailing pond is actually in contact with oxygen, and thus susceptible to oxidation. Moreover, tailings ponds are well suited for reclamation, and once the active life of the pond has ceased, it can be covered with a layer of soil and planted, which will further reduce the access of oxygen to the reactive pyrite.

Another factor which will reduce the reactivity of the tailings is the temperature in the region in which the Anvil Mine is located. The tailings will be a compact mass located in the bottom of a valley, and in all probability, permafrost will rise with time through the tailings pond.

Because the sulfide tailings are leachable at the discharged particle size, care must be taken that contact with oxygen is minimal. Thus all tailings should be confined within the tailings pond, and not allowed to spread around the countryside or into Rose Creek. The dams built to retain the tailings must not have their exposed surfaces covered with tailings nor should they be built of sulfide-bearing material. The tailings dam or any other embankments surrounding the tailings pond have large surface areas exposed to the air, and tailings deposited on such a surface could begin to leach during the summer months. Thus, in order to prevent the tailings from becoming an acidic drainage water problem in the long term, good housekeeping practices must be carried out while the mine is in operation.

WASTE DUMPS

Waste dumps are the physical structures normally most amenable to leaching. About 95% of the material going on the Anvil waste dumps is low in sulfides and is a net acid consumer. The sandy pyrite, which makes up the remaining 5% is a net acid producer. This latter material can be oxidized microbiologically at its natural grain size (less than 1 mm). Moreover, at 5% of the total waste the sandy pyrite is capable of producing more acid than all the other waste can consume. Thus, if the waste dumps contain 5% sandy pyrite they are a potential source of acidic drainage water.

To disperse the sandy pyrite throughout the waste dumps is poor practice from an environmental point of view. The pyrite's extremely small particle size relative to the other waste rock will enhance its activity, whereas acid consumption by the other waste will be retarded by its larger particle size (boulders up to 6 ft in diameter). The pyrite will tend to collect in the voids between the alkaline waste rock where a microenvironment suitable for the bacteria can develop, since moisture and oxygen will be available in these "void spaces". These pockets of potential pyrite leaching could be well insulated from the external temperature and since pyrite oxidation is exothermic, the interior of the dump could well stay warm.

There is no danger of the other waste rock producing excess acid, but if the dumps built to date contain more than 2% sandy pyrite, they could theoretically be a problem. Hopefully the extension of the dumps with non-acid producing waste will isolate the existing pyrite from the available oxygen and prevent any long-term problem.

The climatic conditions at the Anvil Mine will definitely reduce the chances of microbiological activity becoming established. However, the writer has isolated *T. ferrooxidans* from mine water collected at Boliden, Sweden (approximately 65° north latitude) and Lyalikova (3) has isolated the same organism at mines on the Kola Peninsula which is even further north. Thus, it is possible for *T. ferrooxidans* to become established in northern climates. However the author has no information regarding the presence of these bacteria on the Anvil mine property.

Since T. ferrooxidans has been isolated at latitudes further north than the Anvil Mine, and since the sandy pyrite at the Anvil Mine is leachable and the amount present can theoretically produce more acid than the other waste can consume, it is mandatory that the method of disposal of the sandy pyrite ensure that it will not leach if it becomes inoculated. Distributing it through the waste dumps should be stopped. It should be disposed of in an isolated, low elevation area where it could be watched and eventually covered with a layer of soil to prevent access of oxygen.

CONCLUSIONS AND RECOMMENDATIONS

1. The ore-grade stockpiles are a potential source of acid. They should be sent to the mill before active operations close. Ore remaining in the final pit should not be a problem if the pit is allowed to flood.

2. The tailings are a potential source of acid. They should be confined behind competent tailings dams and their surface reclaimed when active operation ceases, to prevent their distribution by wind and water, and to deny oxygen access to the sulfide surfaces. During active operation, the deposition of tailings outside the ultimate tailings pond, or on to dam or embankment faces should be prevented.

3. About 95% of the waste rock generated in mining the Anvil ore body cannot generate more acid than it can consume. This waste rock can be disposed of in waste dumps without hazard.

4. The remaining 5% is the sandy pyrite core which is leachable and theoretically can produce more acid than all the other waste can consume. The sandy pyrite, which is discretly located in the pit, should be mined separately and should be disposed of in such a manner that it will not leach.

5. The alkaline pH of the tailings water is due to the sodium carbonate and lime added during the milling process. The fact that it remains alkaline implies that little if any sulfide oxidation is occurring in the tailings pond. The local streams all have an alkaline pH due to the alkaline nature of the host rock. No data was available on the pH of any water seeping from the waste dump, but it would be expected to be alkaline unless significant oxidation of the sandy pyrite was occurring.

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TABLE 1

ACID PRODUCTION POTENTIAL OF ANVIL SAMPLES

Sample Type	Sample	% Pb	% Zn	% Fe	% Cu	% Ba	% S	Natural pH	Acid Consumption (lb/ton)	Theoretical Acid Production (lb/ton)	Theoretical Acid Producer	Actual Acid Producer
Ore	yellow stockpile	3.49	4.26	29.7	0.12	-	37.5	5.7	87	2250	yes	yes
	red stockpile	3.23	5.93	28.1	0.16	-	35.8	5.6	102	2148	yes	yes
Tailings	16-h composite January 23	0.33	0.80	28.8	0.10	-	37.5	6.8	41	2250	yes	yes
	8:00 a.m. grab January 24	0.22	0.54	31.2	0.08	-	37.9	5.2	17	2274	yes	yes
Waste Rock	diorite dike	0.04	0.06	3.9	<0.01	0.09	0.98	9.1	59	59	?	no
	diorite dike A (unaltered)	-	0.01	3.7	<0.01	-	0.26	9.2	73	16	no	
	diorite dike B (unaltered)	-	<0.01	3.0	<0.01	-	0.29	8.9	58	17	no	
	diorite dike C (altered)	-	0.04	4.9	0.02	-	0.24	7.5	19	14	no	
	diorite dike D (altered)	-	0.02	3.8	<0.01	-	0.16	7.8	21	10	no	
	biotite schist	<0.01	0.01	4.9	<0.01	-	0.09	9.2	30	5	no	
	muscovite schist	<0.01	0.02	4.9	<0.01	-	0.09	7.9	40	5	no	
	calc silicate	0.06	0.08	4.6	<0.01	-	0.46	9.4	145	28	no	
	sandy pyrite	0.30	0.45	48.5	0.03	-	52.7	6.0	54	3162	yes	yes
	drill cuttings in muscovite schist at ore contact	0.28	0.51	7.3	0.04	0.28	3.6	6.4	74	216	yes	yes

TABLE 2

COMPOSITION OF ANVIL WASTE DUMPS

	February, 1975	Ultimate
Area (acres)	300	800
Height (ft)	100 - 150	200 - 250
Granodiorite and diorite (%)	15 - 20	5 - 10
Biotite schist and graphitic schist (%)	15 - 25	25 - 35
Muscovite schist (%)	15 - 25	20 - 25
Calc silicate gneiss (%)	25 - 50	25 - 45
Sandy pyrite (%)	<5	5

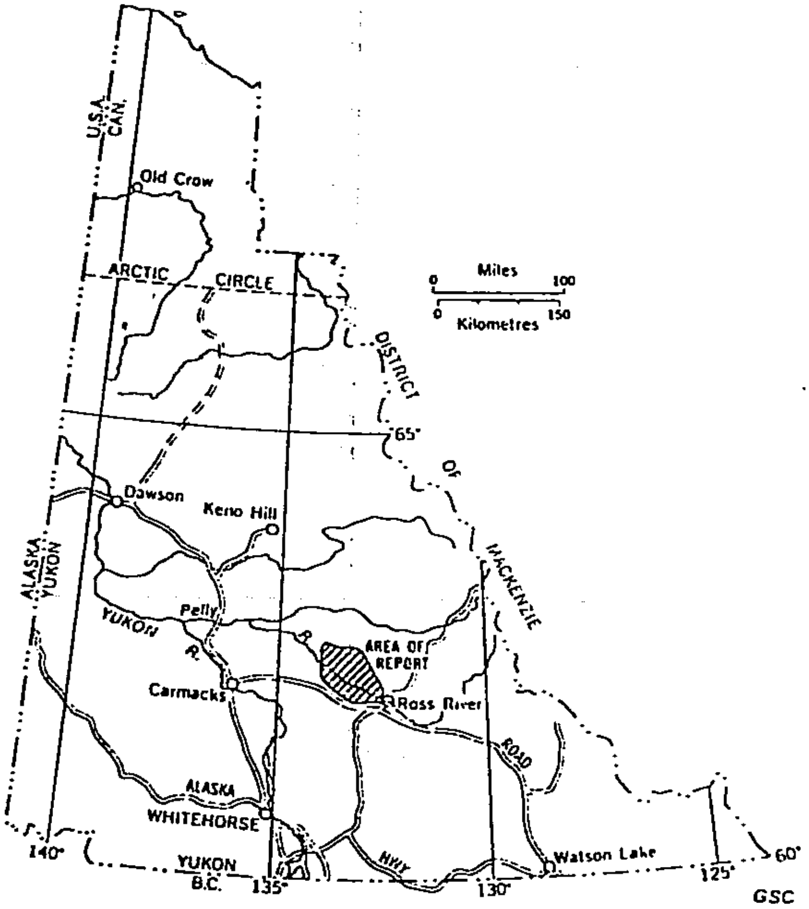

FIGURE 1

LOCATION MAP OF ANVIL PROPERTY (SEE REFERENCE 1)