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APPLICATION OF MODELLING AND SUBAQUEOUS TAILINGS DISPOSAL TO THE MT. MILLIGAN MINE

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ABSTRACT

As a part of a comprehensive acid drainage assessment program, extensive ABA testwork was performed which allowed subsequent geostatistical analyses and modelling of the spatial distribution of the mine rock NNP character. The objective was to identify spatial anomalies of acid generation characteristics for application to mine planning.

Mine plans were then prepared which would allow waste and low grade to be sorted by their NNP values and placed in dumps which were situated to allow material with ARD potential to be managed by an optimized control strategy.

The ABA data for ore was incorporated with the metallurgical testwork data to calculate NNP values for the tailings. This information allowed a design to be developed which would maintain separate cleaner and rougher tailings discharge streams to the tailings disposal facility. Subaqueous tailings disposal methods were planned to isolate the potentially reactive cleaner tailings materials in a permanently flooded pond within the main tailings basin. A conventional spigotting method could then be used for the nonreactive majority of the tailings materials.

INTRODUCTION

The Mt. Milligan project which is located in north central British Columbia comprises of an orebody of approximately 300 million tonnes of ore grading 0.23% copper and 0.56 g/t gold. The proposed mine would include two open pits identified as the Southern Star and the Main zones. Although presently uneconomic, the potential continues for a sizable open pit mine with an approximate milling rate of 60,000 tonnes/day.

In 1991, a comprehensive environmental report was prepared for the project as a requirement of the B.C. Mine Development Review Process (MDRP). This included a thorough assessment of the potential for acid rock drainage (ARD) generation from the waste rock and tailings.

With initial test results available, it was apparent that the deposit could be characterized generally as having a low but undeniable potential to generate acid. With this background, a fundamental objective became the development of a database which would allow potential problem areas to be spatially located within the ore body and then management schemes for waste rock and tailings to be designed specifically to accommodate these materials. The database and design features were intended to enable operating personnel to plan and implement preventative procedures for ARD management.

INTRODUCTORY TEST WORK

The ARD assessment program included static and kinetic test work which was sequenced to allow design modifications to be made on the basis of preceding results.

Initially, test work focused on the Main Zone which had originally been identified for feasibility evaluation and a static acid-base accounting (ABA) scoping study was conducted on 66 composite samples assembled from 2937 samples collected from 47 drillholes. This determined the neutralization and acid generation potential of the ore, waste rock, pit wall and pit floor rock. Results showed that 62% of the samples contained excess alkalinity which could theoretically neutralize any acid generated assuming a 1:1 neutralization/generation criteria. The remaining 38% were capable of generating more acid than they could theoretically neutralize.

Next, kinetic column leach tests were performed at B.C. Research for a 26 week period on seven composite samples which spanned the entire spectrum of acid generation potential values identified in the initial scoping study. With very low levels of sulphates and metals detected in the leachate and pH which remained greater than 7, a subsequent series of accelerated tests were conducted by first increasing the exposure to air and water using a continuous trickle leach, and later by artificially stripping the available neutralizing material using sulphuric acid washes followed by inoculation with acid generating bacteria. Finally, the two columns which had the highest alkalinity removal rates were subjected to additional acidification and bacterial inoculation. This program was completed with the conclusion that acid generation would not proceed as a self-sustained natural reaction.

Four composite samples which simulated the layered waste dumps as they would likely be developed in the mining sequence were assembled. Static tests were then conducted to evaluate their acid generation potential. The results showed that only one of the four composites did not contain adequate neutralizing materials to consume the contained acid. Column leach tests followed to evaluate the leachability of these composite samples. This program verified the results of the original 7 column test program. Consequently, the waste rock and low-grade material from the Main Zone were predicted to have a low probability of developing acid generation.[1]

A comprehensive program of static and kinetic testwork had indicated that the Mt. Milligan Main Zone had marginal potential to generate ARD which was not likely to occur until a significant period of time had lapsed. Testwork, however, had been structured to examine composite samples which could not provide information regarding the uniformity or variability of ARD parameters within the zone. This scoping work provided a macroscopic view of the issue but no specific database for the operators' use in preventing or controlling ARD if it developed. Specific information was needed to determine whether potential problem areas or "hot spots" existed.[2]

ACID-BASE ACCOUNTING AND SPATIAL MODELLING

Upon Placer Dome's acquisition of the project, the engineering feasibility study and environmental assessment was expanded to include the Southern Star Zone. As for the Main Zone, a comprehensive ABA assessment was designed to define the scope of subsequent testing. However, key to our objective and to improve upon the initial results from composite samples, tests were structured using discrete core samples to develop a spatial model of the ore body ARD characteristics by assembling a three dimensional matrix of data.

Samples for this purpose were selected by taking a discrete two meter reject sample at every 15 m bench elevation, in diamond drill holes spaced approximately 100 m apart and on section lines spaced 100 m

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[1]Additional kinetic tests have been run at the Placer Dome Research Centre for a 2'/4 year period from late 1991 to the present time. These longer-term tests have verified the nonreactive nature of the rock and indicate that if ARD occurs it will be after a very long lag time.

[2]Additional ABA tests were performed on overburden samples and rock outcrops from the Main and Southern Star Zones. Results indicated that the overburden material contains neutralizing materials which could be used to assist in neutralizing waste material where appropriate. Outcrop test results indicated that the sulphide minerals in the Mt. Milligan deposits were not reactive and had very slow reaction rates when compared to the oxidation rates experienced at sites which have acid drainage problems.

[3]Petrographie examinations on Mt. Milligan samples provided a qualitative indication that the slow reaction rate resulted from a simple sulphide mineralogy; the absence of rapidly oxidizing sulphide species (eg., pyrrhotite); the relatively large surface areas of sulphide grains, the widespread occurrence of acid consuming carbonates such as calcite and ankerite; and a massive rock texture which slows the rate of exposure to fluids associated with the weathering processes.

apart. A total of 873 samples were collected, representing all rock types, grades and locations within and surrounding the Southern Star Zone.

This spatially oriented database was used to map zones of potentially higher acid generating or acid consuming capability within the Southern Star Zone. ABA results were plotted on vertical cross sections which showed the final pit limits and the sampled diamond drill holes.

Contouring of net neutralization potential (NNP) values on sections showed that samples with elevated values of acid generation or neutralization potential could generally be grouped together, however there was no strong continuity of such zones between section lines. This indicated that small pockets of rock exist within the orebody with elevated levels of acid generation potential, but no large, continuous blocks exist. Materials from the isolated, small pockets of higher potential reactivity could require special attention in the development of the waste dumps.

The results of the ABA scoping and spatial modelling studies of the Southern Star Zone indicated that similar to the ABA results for the Main Zone, approximately 60% of the rock samples had an indicated capacity to neutralize any generated acid while 40% had a potential to generate more acid than could be neutralized.

The zone was not a homogeneous rock mass with respect to acid generation and neutralization potential. However with sufficient data points these differences could be illustrated by a three dimensional matrix and two dimensional cross sections of NNP as shown in Figure 1. The comprehensive, computer database and cross sections could be used by the operating personnel, to assist them in assessing *in situ* rock prior to mining and to plan the construction sequence of waste dumps and low-grade stockpiles.

Although significant quantities of waste rock and low-grade material would contain adequate neutralizing materials to neutralize any ARD generated, other zones of the mineralized body include rock which would require special attention. Waste rock could be isolated in a conservative dump location and possibly blended with rock which contains excess neutralizing material. Ore material would be processed in the mill and potentially reactive tailings could be conservatively stored.

OREBODY GEOSTATISTICS

The use of a large number of samples in this study allowed a statistical examination to be conducted to test for correlations between the acid-base characteristics of the rock and mineralogical/geological information. Scatter plots and bar graphs were developed to illustrate the acid-base correlations relative to each of the three main rock types: andesite, latite and monzonite. Similar attempts to correlate the acid-base characteristics with gold equivalent grade (g/t) were unsuccessful. Additional comparisons illustrated that there were no significant relationships between the variables of acid generation potential and neutralization potential and an anecdotal database of the estimated contents of pyrite, chalcopyrite and carbonate.

The geostatistical model was not completed due to the time constraints for filing the MDRP Stage I Report. Nevertheless, the results of this six month program were encouraging in that they demonstrated the potential of applying standard industry methods to evaluate and illustrate correlations of geological and ARD characteristics of an orebody. This study also provided a basis for the development of a more complete and refined operating strategy by the mine planners and operators which is described in the following sections.

WASTE ROCK DISPOSAL PLAN

Waste rock and overburden generated by the development of the orebody would be hauled from the open pit for disposal in the two waste dumps identified as the North Dump and the South Dump. These are located north and east of the open pit as shown in Figure 2.

The North Dump would include an overburden stockpile and a waste rock dump that would contain material characterized by a significant, positive NNP. All waste rock with a marginal (or negative) neutralization potential would be stored in the South Dump.

A component of the operational planning process for the disposal of waste and low-grade rock would be the continual assessment of acid generation potential by means of a routine sampling program of run-of-mine rock. Using the AEA data base and spatial models discussed above as a predictive tool, additional field sampling and static testing would be conducted frequently to characterize the rock by its neutralization and acid generation potentials. Rock that did not have sufficient neutralization potential to adequately buffer its acid generating potential *would* be hauled to a specific storage location established for this purpose within the South Dump. Operating personnel would thus have procedures and methods in place that would allow day-by-day detection and handling of all rock in a manner that would facilitate any further mitigative action to prevent acid generation and drainage.

The South Dump location was selected for consolidating suspect material because its foundation of low permeability till over bedrock would significantly reduce the potential for seepage to groundwater. Also, the ground surface slopes towards an adjacent mine sediment control pond which would intercept all drainage from the dump.

A totally contained system would thus be available to intercept the drainage from the South Dump location. In addition, the implementation of other preventative and mitigative measures were possible such as constructing a neutralizing overburden bed during the pre-production phase; blending neutralizing waste rock or intermediate layers of local limestone rock during operations; and finally if necessary, placing an impermeable cap of overburden or locally-available glacial till to restrict the infiltration of surface water through the dump after closure.

Adopting large scale waste rock blending as a general acid drainage control strategy was ruled out because the potential for acid generating "hot spots" to occur throughout the waste dumps would remain. On the other hand by consolidating marginal material, ongoing assessment and research programs including test sites of blended materials would be facilitated.

Despite all the measures that would be taken to prevent the occurrence of acid generation, should it occur to some degree then the mine sediment control pond would provide storage capacity to allow time to construct an effluent treatment plant if needed to produce acceptable final effluent.

TAILINGS MODELLING

The available pilot plant sample sets for ABA test work had not been large and ARD predictability was correspondingly uncertain. To provide an alternative basis for ARD prediction, a computer model was developed that could use the exploration database of 636 ore and low-grade sample assays to predict the ARD potential of the Southern Star tailings. With a concentrate chalcopyrite and pyrite specification, and recovery rate established by the metallurgical pilot test program, the concentrate sulphur content could be calculated using the copper, total sulphur and sulphate assay data from the exploration database. The difference between total (non-sulphate) sulphur reported in the assays and the calculated concentrate sulphur yielded the sulphur content of the tailings from which its acid generation potential could then be calculated.

The model was used to predict the tailings NNP for both combined, and separated rougher and cleaner tailings streams. For the separated streams, sulphur distribution in the cleaner and rougher streams was varied to reflect pilot plant results and historic operating experience. Neutralizing carbonaceous minerals were presumed to report to the rougher tailings.

Figure 3 provides schematic illustration of the relative NNP distributions for the combined tailings, and the separated cleaner and rougher tailings streams. Separation of the cleaner and rougher tailings, and removal of the majority of the reactive material (pyrite) to the cleaner tailings would result in a significant shift of the NNP of the cleaner tailings to the acidic range (less than zero kg $CaCO_3$/t). The NNP of the rougher tailings shifts correspondingly to the alkaline range (greater than zero kg $CaCO_3$/t).

Model results for a combined Southern Star rougher-cleaner tailings indicated that the combined stream would have marginal capacity to buffer that materials' acid generating potential. About 60% of the samples had NNP values that were greater than zero kg/t and hence had excess buffering capacity. However, the remaining 40% had excess potential to generate acid. This distribution was consistent with the static test assessments of all other Main Zone and Southern Star Zone materials.

Results for separated Southern Star rougher tailings indicated that about 95% of the data set had a positive NNP which would have sufficient capacity to buffer acid generating potential. About 85% of the separated cleaner tailings' data set had a negative NNP and an indicated potential to generate acid.

From the model results, it could be concluded that if the cleaner tailings were discharged to the tailings storage facility as a separate stream, a much smaller volume would require ARD preventative handling and isolation. Recent MEND research in subaqueous tailings disposal of reactive sulphide materials, has demonstrated that submergence is an effective prevention and control method. Consequently, this was the method proposed for the cleaner tailings.

TAILINGS DISPOSAL PLAN

Rougher and cleaner tailings would be transported via separate piping systems to the Tailings Storage Facility to be located adjacent and north-east of the Millsite in the Limestone Creek valley as shown in Figure 2. As an operating strategy, a separate containment area for cleaner (sulphide) tailings would be provided that ensured that these tailings solids would remain permanently submerged during the operating period and after mine closure. Located immediately west of the Fresh Water Storage Dam, the sulphide tailings area would be secured within the north and south Limestone Creek valley walls, and by the construction of a watertight Sulphide Tailings Dam to the west.

Adequate capacity would be available within the sulphide tailings containment area to accommodate the cleaner tailings material from both the Main Zone and the Southern Star Zone. This volume would be provided as a conservative planning measure to ensure that all potentially reactive material could be securely stored. The specific storage requirements for the tailings components would be determined using ongoing sampling and ABA techniques to ensure the safe deposition of all potentially reactive material. Routine testing through ABA analysis would be performed on the tailings materials used for dam construction to ensure that no material that could become acid generating was used for that purpose. It was recognized that such use could result in unacceptable surface exposure and subsequent acid generation.

After closure, the final reclamation of the tailings area would be comprised of a dry area to be created from the containment dams and the highly buffered, rougher tailings solids, and a lake which would remain over the potentially reactive, sulphide tailings solids. The seepage control dams that would be in place downstream of the containment dams would remain to collect seepage. Monitoring would continue for as long as necessary to ensure that criteria requirements continued to be met.

CONCLUSION

Through a comprehensive program of assessment and predictive testing, it was determined that the Mt. Milligan waste rock and tailings would have a marginal potential to generate ARD when viewed from a macroscopic perspective. Through a program of detailed investigation, it was determined that the orebody was not homogeneous with respect to its acid generation and neutralization properties. This information was presented in a database which allowed both the mine designers and future operators to plan for the conservative handling and storage of potential problem materials. The development of waste dump and tailings impoundment designs to facilitate ARD management by preventative strategies can be achieved by modest investment and timely application. The potential benefit in reduced ARD control measures and closure costs could be in the tens of millions of dollars.

This case history has illustrated how the application of ARD predictive methods can be integrated from exploration through to mine planning to yield a conservative design and an environmentally sound project.

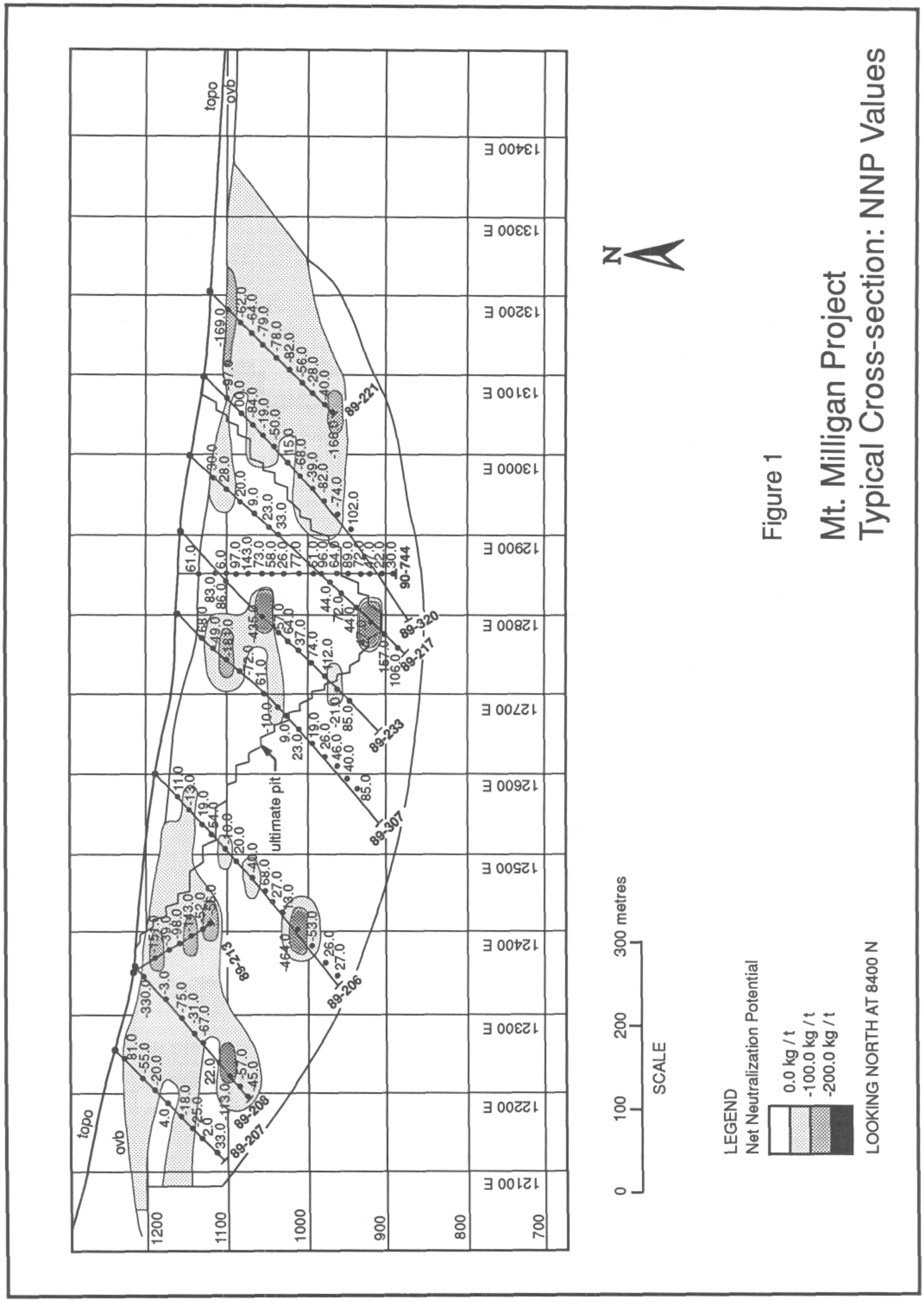


Figure 1

Mt. Milligan Project
Typical Cross-section: NNP Values

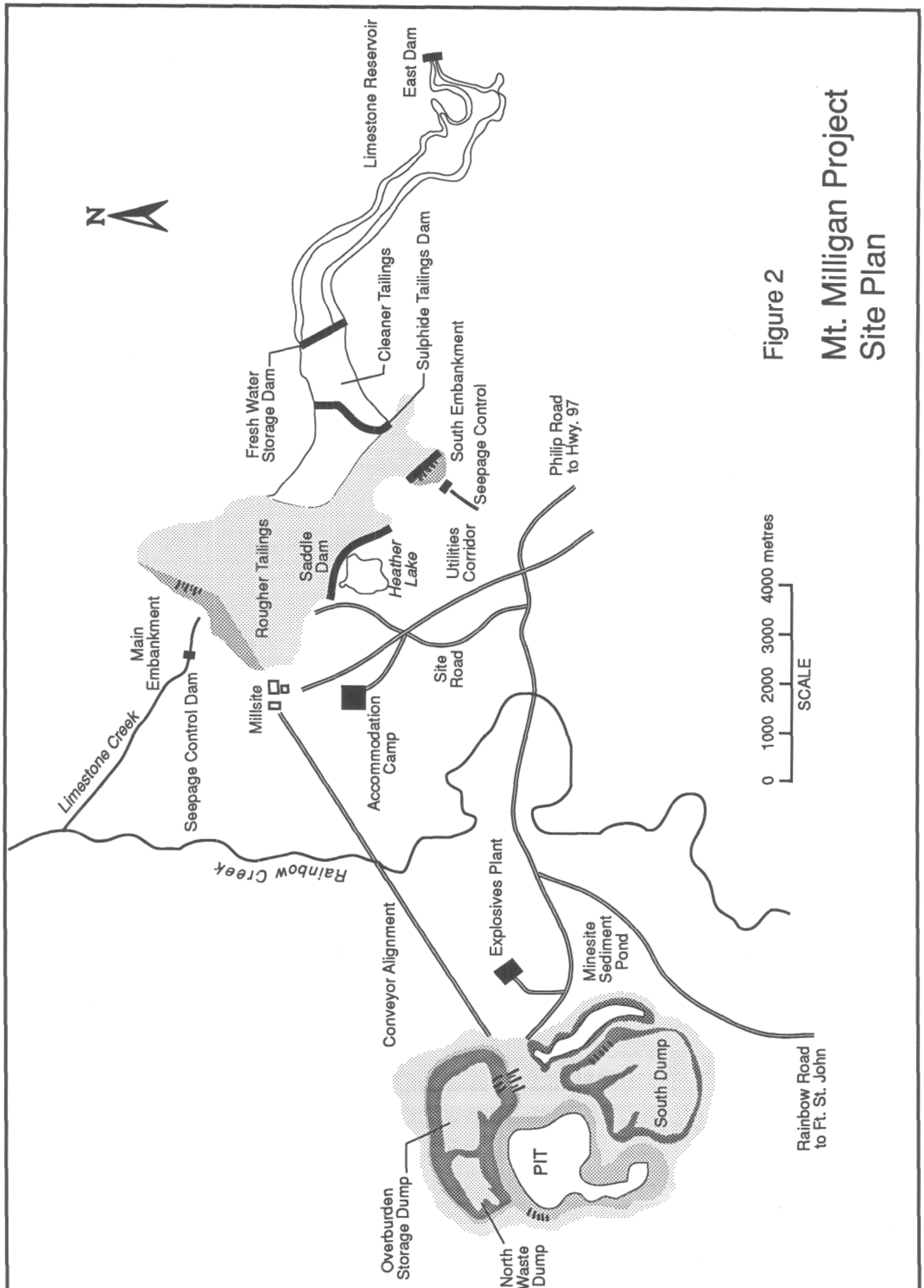
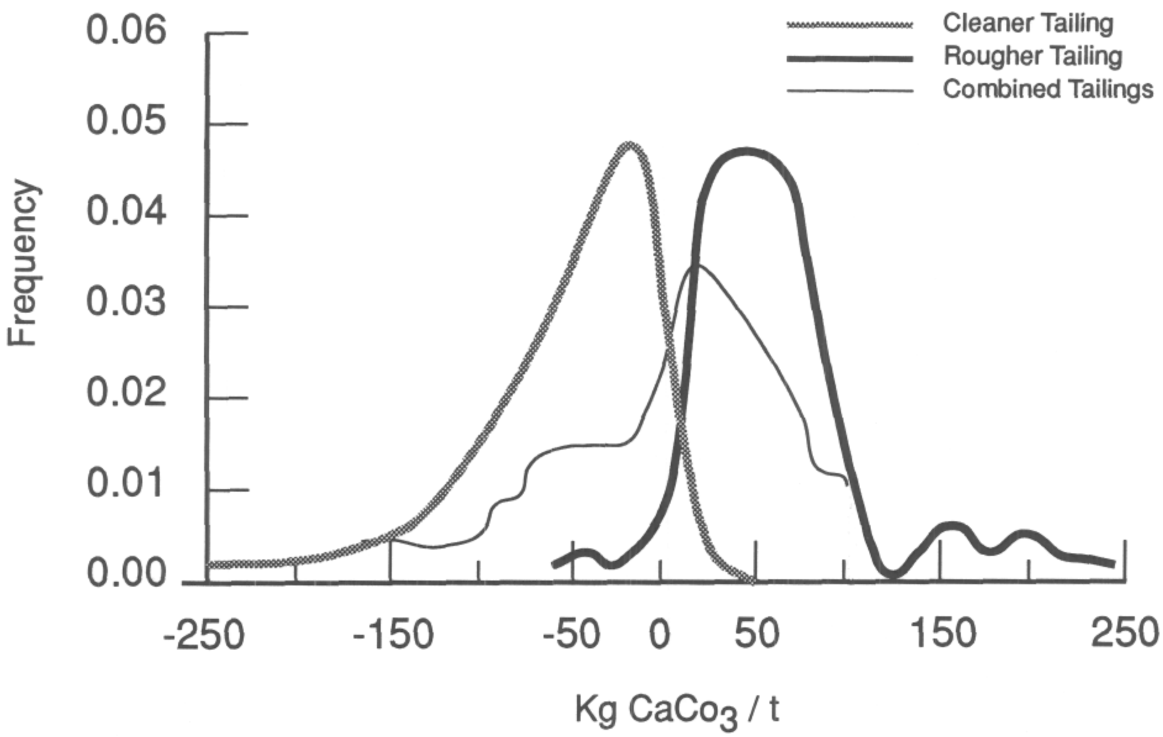


Figure 2
Mt. Milligan Project
Site Plan



Relative NNP Distribution for Combined and Separated Rougher / Cleaner Tailings Streams

Figure 3

Mt. Milligan Project
Relative NNP Distribution