THE GIBRALTAR NORTH PROJECT ASSESSING ACID ROCK DRAINAGE[1]

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Abstract: The Gibraltar Mine is a large open pit copper operation located north of Williams Lake , British Columbia. Acid rock drainage (ARD) was first discovered on the property in 1982. Since this period all drainage has been collected and pumped to the concentrator for neutralization in the lime circuit. Copper is also recovered from some of the waste rock dumps using sulfuric acid leaching followed by solvent extraction and electrowinning. The Gibraltar North project is a new ore body being considered for development. An extensive program of testing and analysis was conducted to determine the potential of the waste from the project to produce ARD and to develop mitigative measures. The quantity of potentially acid generating material was estimated in two ways. First, statistics for acid base accounting (ABA) data were used to estimate the percentage of waste rock and ore that would likely be acid generating. Second, the location of a pyrite "halo" was mapped using visual pyrite estimates and assay results; a sulfur criterion was developed to separate blocks that were potentially acid-generating. Estimates of the quantity of potentially acid generating material from the two methods were different because the ABA data base under represented the quantity of waste rock in the upper benches and over represented the quantity of waste rock in the lower benches. Results highlighted the need for careful selection of samples in ARD testing programs. The potentially acid-generating zones on the pit walls were mapped using the location of the pyrite halo. In this way the quantity and location of potentially acid and non-acid-generating walls were identified. The Gibraltar North tailing exhibited a significantly higher potential to generate ARD compared to the current tailing.

Additional Key Words: acid rock drainage (ARD), acid base accounting (ABA), acid-generation estimations, neutralizing potential, pyrite halo, sulfur plots, tailing acid generation, and pit wall acid generation.

Introduction

Location and Description of Operations

The Gibraltar Mine, which has been in operation since 1977, is located approximately 160 km south of Prince George, British Columbia, near McLeese Lake (fig.1). Access is by way of a 18 km paved highway that joins Highway 97 near the north end of McLeese Lake. The ore bodies occur as large low-grade copper-molybdenum porphyry deposits.

Ore is mined by the open pit method and is concentrated using conventional crushing, grinding, and flotation processes. Tailing is discharged to a impoundment area with 80% of the water recycled as process water. Additional copper is extracted from the waste dumps using sulfuric acid as a leach solution followed by solvent extraction and electrowinning to remove copper.

Ore reserves occur in five mineralized zones. These are the Gib West, Gib East, Polyanna, Granite Lake, and recently discovered Gib North zone. Mining has occurred in all zones except the Gib North, which is not being developed due to economic restraints.

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Gibraltar North Pit Project - Description

The recently discovered Gib North Zone lies to the northwest of the Gib East pit and is intersected by the access road into the minesite. If developed, the projected pit dimensions will be 1,000 by 550 m by 230 m deep. Stripping will entail 7.2 million mt of overburden and 109 million mt of waste to produce 34.7 million mt of ore. As the zone contains a thick mantle of waste, stripping would take up to 4 yr to expose ore, followed by 3 yr of ore production.

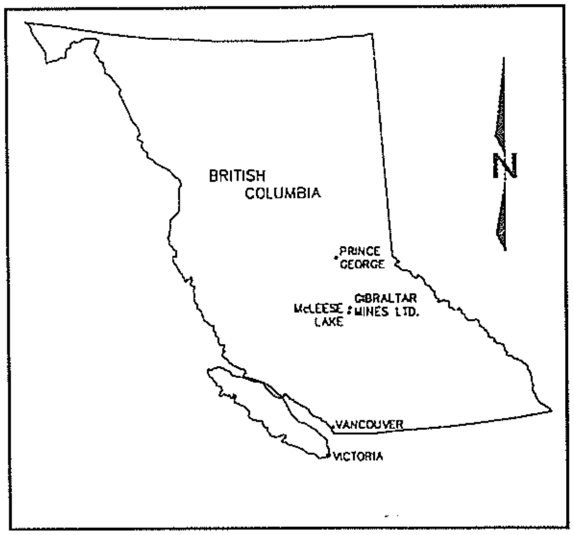

Figure 1. Location map.

Current Status of ARD

ARD was not detected at the minesite until several years after startup of mining. As early as 1975 copper-contaminated flows were detected coming out of rock fills on the property. It was not until 1982, an extremely wet year, that ARD manifested its presence throughout most waste fills on the property. The presence of this seepage prompted the construction of a property-wide collection and pumping system during the 1982 - 83 construction periods. All surface drainage was then treated and discharged to the tailing pond.

The present practice in regard to handling of wastes is disposal on a dump structure adjacent to the pit being mined. Each dump is surrounded by a ditch system for leach solution return where leaching is being practiced, as well as by a secondary ditch system to collect seepage out of the leach circuit. Reclamation steps have been execised on several dumps. Reclamation is geared more to aesthetic improvement than to ARD prevention, although the practice no doubt has had some mitigative benefits.

Acid-Base Accounting For The Gib North Zone

Sample Selection

A total of 27 vertical drill holes were chosen to obtain samples for acid-base accounting on the Gib North zone and were also used for metal analysis. These holes were all within the proposed open pit as currently planned and were distributed over as wide an area of the surface of the pit as possible. However, as limited drilling was conducted away from the ore body, fewer samples of waste rock were available from the upper benches distant from the ore zone.

Samples were composited over 13.7 m of core, which represents the proposed bench interval. The composites were made up from 3 m pulp samples. Each composite was comprised of five pulps with the fifth only half the mass of the other four. Four of the pulps were 50 g and the fifth was 25 g. A total of 395 samples were tested for ABA, including 151 ore and 244 waste rock samples.

Analytical Methods

Samples were tested for ABA according to the methods described in Sobek et al. (1978). The standard analyses for paste pH, total sulfur, sulfate sulfur, and neutralization potential (NP) were performed. In addition, a total carbon assay was obtained from the Leco furnace used for the total sulfur determination. The "fizz" rating and color of precipitate in the NP titration were also recorded. The acid potential (AP), net neutralization potential (NNP), equivalent NP from the carbon assay (assuming all the carbon was present as carbonate), and neutralization potential-acid potential ratio (NP/AP) were determined by calculation from the assayed ABA parameters.

An inductively coupled plasma metal scan was also performed on 326 samples (143 ore and 183 waste rock). Copper grade information, obtained from previous assays of the samples, was used to separate the samples into ore and waste, using a 0.18% copper cutoff.

ABA Results

ABA results for the waste rock and ore are summarized in tables 1 and 2.

Table 1. ABA results for waste rock

Statistic	Paste pH	Total S, %	Potential, mt/kmt $CaCO_3$			NP/AP
			AP	NP	NNP	
Number	183	244	244	244	244	244
Mean	9.01	.66	20	24	3	5
Variance	.31	1.05	1023	284	1344	169
Std. Dev.	.55	1.02	32	17	37	13
Maximum	11.07	6.82	213	80	75	170
Upper quartile	9.43	.74	23	32	21	4.6
Median	9.07	.31	10	21	7	1.8
Lower Quartile	8.63	.14	4	10	-7	.7
Minimum	7.45	.01	0.3	3	-209	.02

In general the paste pH was neutral to alkaline. All of the sulfate sulfur assays were less than detection (not shown in table). These data suggest the samples had not oxidized significantly prior to testing and no acidic salts are present. The total sulfur was relatively low for waste rock with a mean of only 0.66%. The NP was very low with a mean of only 24 mt/kmt $CaCO_3$.

The paste pH was lower in the ore samples compared to the waste rock, with some relatively acidic paste pH recorded. Sulfate sulfur results were all below detection. Despite the low pH in some samples, very few oxidation products (acidic salts) had apparently accumulated. It is not clear if these oxidation products are present in situ in the ore or were formed after drill core recovery. The total sulfur and AP were substantially higher, and the NP slightly lower in the ore compared to the waste rock. In general the sulfur content (and AP) increased with copper grade (fig. 2) and is additional support for the existence of a pyrite halo around the ore body.

Table 2. ABA results for ore samples.

Statistic	Paste pH	Total S, %	Potential, mt/kmt $CaCO_3$			NP/AP
			AP	NP	NNP	
Number	143	151	151	151	151	151
Mean	8.03	2.98	93	17	-76	0.33
Variance	0.58	4.40	4296	146	4964	0.18
Std. Dev.	0.76	2.10	65	12	70	0.43
Maximum	9.31	11.5	359	62	39	2.7
Upper Quartile	8.62	3.54	111	26	-27	0.41
Median	8.15	2.47	77	14	-56	0.18
Lower Quartile	7.52	1.43	45	7	-106	0.08
Minimum	4.98	0.41	13	3	-355	0.01

The carbon assay results were converted to an equivalent NP, assuming all the carbon was present as carbonates. The actual NP and equivalent NP from the carbon assay agreed for most samples (fig. 3). About 10 to 15 samples had a higher carbon equivalent, suggesting that a portion of the carbon may not have been present as carbonate or that the NP was underestimated by the assay titration for a few samples.

An NP/AP of 1 (equivalent to NNP = 0) is sometimes used to separate potentially acid and non-acid generating samples. Plots of NP and AP relative to this criterion are shown in figures 4 and 5. About 35% of the waste rock and about 95% of the ore samples were potentially acid-generating. There was a slight trend to lower NP with a higher AP. Cumulative frequency plots for ABA parameters are shown in figure 6. The significantly lower acid production potential of the waste rock relative to the ore is apparent. Only about 5% of the waste rock was strongly potentially acid generating (NNP < -50 mt/kmt $CaCO_3$ or NP/AP < 0.2).

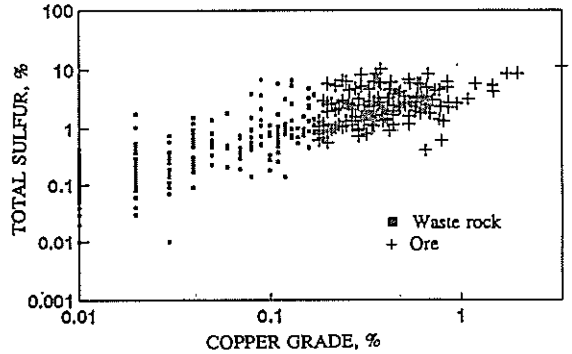

Figure 2. Sulfur versus copper grade

In general, the ABA characteristics of Gib North project waste rock are consistent with a low sulfur-very low NP system. A significant proportion of the waste rock according to ABA is potentially acid generating; however, the extent of acid production may not be large given the low sulfur content. The acid production potential correlates with the copper, and therefore the ore is much more strongly potentially acid producing than the waste rock.

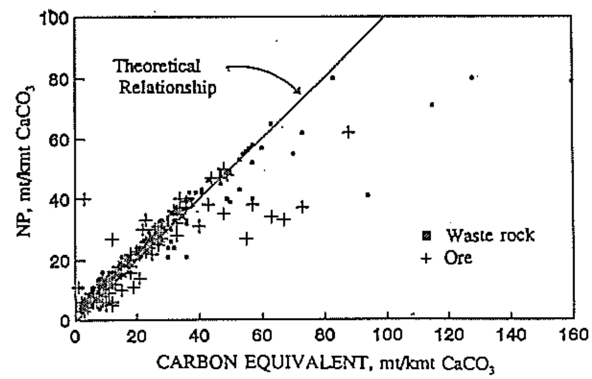

Figure 3. NP versus carbon equivalent.

Pyrite-Copper-Geology Database

An independent assessment of the quantity of material with a potential to produce ARD was made using visual pyrite estimates, copper assays, and the geological model of the Gib North deposit. The data indicate that there is a pyrite halo around the Gib North ore body, which should provide a reasonable estimate of the quantity of potentially acid-generating material. This halo can be identified by visual estimates of pyrite made by the geologists during core logging. Beyond the halo, the waste material is practically devoid of sulfide minerals.

The limit of the pyrite halo was chosen to be equivalent to a 0.6% total sulfur based on the following reasons:

1. Only 17% of the samples with less than 0.6% sulfur had a NP/AP less than 1, whereas 75% of the samples greater than 0.6% sulfur had a NP/AP less than 1 from the ABA database for waste rock.
2. At a 1:1 NP-AP ratio, 0.6% sulfur is equivalent to an NP of about 19 mt/kmt CaCO3, close to the median NP of 21 mt/kmt CaCO3 for the ABA database for waste rock.
3. Lappako (1991) found that rocks with less than 0.6% S did not produce ARD owing to neutralization by silicate minerals in long-term

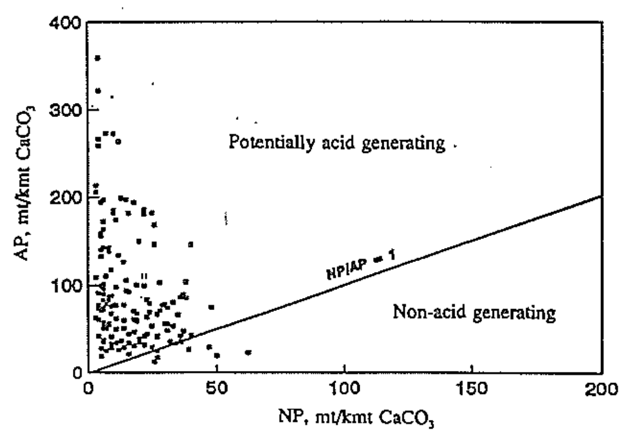

Figure 4. Ore AP:NP

field tests of low sulfur-containing rocks in Minnesota. This finding may not be universally applied to all minesites because of differences in sulfide mineral reactivity and climatic conditions at a particular site, however, it does serve as a useful guide.

4. From observation of drill core and sulfur data, a low sulfur value such as 0.6% S is a reasonable boundary to identify the extremity of the higher sulfur containing material.

Sections were prepared approximately every 18 m across the ore body. Traces for all the currently available holes were plotted with actual copper and sulphur assays and visual pyrite estimates. The sulphur dataset was limited (ABA database only), whereas visual pyrite estimates and copper assays were available for all the holes.

Samples greater than 0.6% sulfur or 1% visual pyrite were automatically considered to be within the pyrite halo. For values between 0.5% and 1.0%, the sulfur associated with the copper was added to the visual pyrite estimate assuming all the copper was present as chalcopyrite. Waste blocks were separated from the ore blocks using krigged copper estimates (0.18% Cu cutoff).

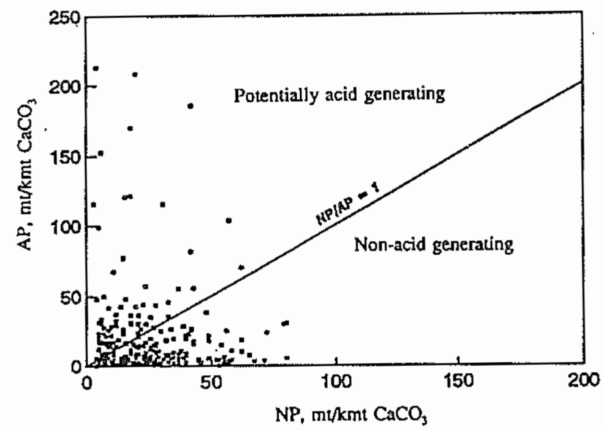

Figure 5. Waste AP:NP

The location of the pyrite halo on the drill hole traces was identified by the actual or calculated sulfur values. The geological model of the ore body was then used to identify the location of the pyrite halo between drill hole traces. The halo was assumed to follow the general outline of the ore body then contoured onto the section.

Finally the contoured sulfur halos on the sections were transferred to bench plans through the pit. The intersection of the bench level with the pyrite halo on each section was marked, and the resulting points were connected to identify the location of the halo on plan.

In general, there were very few discrepancies in the overall shape of the pyrite halo generated by the visual pyrite and by sulfur assay values; only small isolated pods of halo material in the upper part of the pit identified by the visual pyrite method were not included in the estimates based on the actual sulfur assay information. The visual pyrite method, therefore, may be conservative. The use of pyrite estimates to determine the location of the pyrite halo is believed accurate to about ±20%.

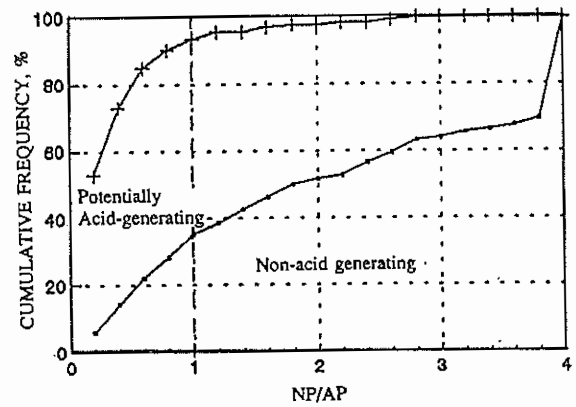

Figure 6. Cumulative frequency plots for NP:AP

Estimates of Acid-Generating Material

Criteria Used To Estimate Acid Generating Material

Three factors control whether acid rock drainage (ARD) is likely to be produced at a minesite:

1. The magnitude and variability in the maximum capacity of the rocks to produce and to consume acid.
2. The availability of potentially acid-producing and neutralizing minerals on particle surfaces.
3. The relative rates of acid production and neutralization.

Static methods such as acid-base accounting (ABA) directly assess the magnitude and variability of the maximum capacity of the rocks to produce and to consume acid. To make predictions, the results from ABA are compared with empirical criteria because mechanistic models of the acid production process are not available. The other two factors that control ARD production are included indirectly in these criteria. Separate criteria have been developed to classify homogeneous individual rock samples and heterogeneous rock dumps composed of several rock types with different acid production potentials.

<u>Criteria for Individual Waste Rock Samples.</u> Ferguson and Morin (1991) and Cravotta et al. (1990) both presented theoretical arguments suggesting that the NP/AP criterion could be about 2:1. However, in the database presented by the former authors, 166 laboratory leaching tests indicated no sample with a positive NNP produced acidic leachate. Moreover, there is no clear documented evidence of rock with a positive NNP producing ARD under field conditions.

A safety factor is required for mines in wet climates where carbonate minerals may be preferentially removed in the mine wastes relative to sulfide minerals. The precipitation at Gibraltar is only 500 mm/yr, therefore, the potential for preferential removal of carbonates should be low. A NNP = 0 (NP/AP = 1) should provide an adequate measure of safety for an initial evaluation of the ABA data.

<u>Criteria for Tailings.</u> Ferguson and Morin (1991) combined studies by Environment Canada of tailings deposits at 20 mines in British Columbia and by Lindahl (1990) at 15 mines in Sweden. Some of the Canadian mines were operating, whereas all the Swedish mines were abandoned. The authors found that the NP/AP = 1 criterion could be used to separate acid and non-acid-producing mines. This criterion was used for the Gib North project.

<u>Acid Generating Waste Rock by ABA Dataset</u>

The percentage of ABA samples from each bench generally follows the percentage of waste rock production (fig. 7), although the upper benches are somewhat under represented and the lower benches over represented. Since the sulfur content generally appears to increase with depth, the ABA dataset may overestimate the actual acid production potential of the waste rock. ABA statistics by bench were weighted according to waste rock production by bench. The weighted mean sulfur content was found to be 42% less than the mean sulfur of the ABA database. The two mean NP values are about the same. The weighted mean NNP and NP/AP indicate a lower potential to generate ARD, compared with the original database.

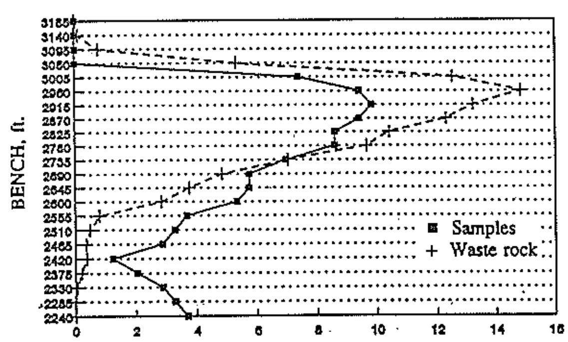

Figure 7. Percent samples and waste rock production by bench.

The weighted quantity of potentially acid-generating material was calculated by multiplying the percentage waste rock production per bench by the percentage of potentially acid-producing samples per bench according to the ABA dataset. The NP/AP < 1 criterion was used to identify the potentially acid producing samples. In general, about 28 million mt or 26% of the total waste rock production, is predicted to be potentially acid generating. This is 11% lower than the percentage of samples predicted to be potentially acid generating from the ABA database. The ABA database therefore was skewed because of too few samples in the upper benches and too many in the lower benches.

Most of the holes used for the ABA database were relatively close to the ore body and possibly were within the pyrite halo. Therefore, the weighted values calculated above may be conservative. This weighted value was compared to the quantity of material within the pyrite halos.

Acid-Generating Waste Rock Within the Pyrite Halo

The quantity of material within the pyrite halo (assumed to be potentially acid generating) was estimated by a block-counting method. A grid representing 15.2 x 15.2 m blocks was placed on top of each bench plan. The waste blocks within the pyrite halo and the pit boundary were counted, and the total for each bench was multiplied by 8,530 mt per block. This method is believed accurate, with the possible exception of errors introduced in counting partial blocks.

For some benches, the quantity of waste rock within the pyrite halo was apparently greater than the total quantity of waste from that bench; the error may arise from counting too many partial blocks. The percentage of potentially acid-generating material for these benches was simply adjusted to 100% and the tonnage recalculated. About 14.5 million mt of waste rock, or 14% of the total production, is predicted to be potentially acid generating using the pyrite halos method. This is about 13.5 million mt or 12% less than that calculated by weighting the ABA database. The pyrite halo method is believed more accurate because it accounts for smaller scale variations close to the ore body and is consistent with the geological model of the deposit.

Figure 8 shows the production of potentially acid-generating waste rock by bench using both the pyrite halo and the weighted ABA database. Both methods show most of the potentially acid-producing waste rock to be from benches 2960 to 2600. The weighted ABA database, however, indicated more potentially acid generating material would be produced from these benches.

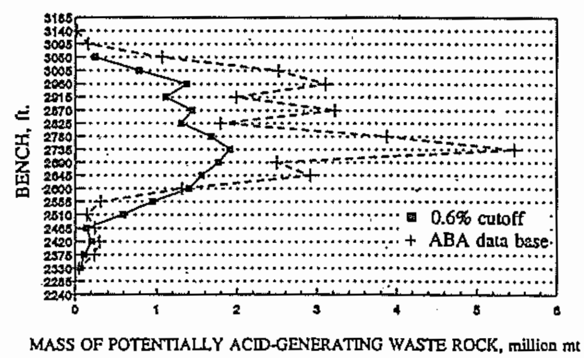

Figure 8. Production of potentially acid-generating rock by bench.

Both methods of calculation indicated the percentage of potentially acid generating material would increase with depth, consistent with the increasing sulfur content. As the pit narrows with depth, more waste rock would be taken from within the pyrite halo, confirming that these percentages are consistent with the geological model. The percentage of potentially acid-generating waste according to the ABA dataset was higher than the pyrite halo for all but a few benches.

Pit Walls

The location of potentially acid-generating rock exposed on the ultimate pit walls was identified by projecting the pyrite halos onto the trace of the ultimate pit walls for each bench. As expected, pit walls remaining in the lower benches may be potentially acid generating, primarily below the 2600 level. Some potentially acid-generating material may also be left exposed at higher elevations on the south and east walls.

The exposed surface areas of potentially acid-generating and non-acid-generating pit walls were calculated for each bench by multiplying the running footage of the bench classified according to ARD potential by the cross-sectional length of the bench. The berm was assumed to be 14.6 m and the bench 15.2 m (overall angle 26.5°) for a total of 29.8 m. Overall, about 59% of the walls will be non-acid generating and 41% potentially acid generating. Less than 20% of the ultimate pitwall above the 2600 bench would be potentially acid generating. Below the 2600 level, more than 50% is potentially acid generating.

The pitwater originating from the upper portion of the pit should be alkaline with low metal concentrations. Runoff from the upper alkaline benches would flow over the potentially acid-generating walls. At least some neutralization of acidic drainage and coating of sulfide minerals should occur on these lower walls. Moreover, since most of the potentially acid-generating walls will be exposed during the last stages of mining, they will have limited time to generate ARD prior to closure. Therefore, the pitwater should not be highly contaminated during mining.

At other minesites, pitwater is generally not as contaminated as seepage from waste rock dumps and abandoned tailings ponds because the surface area of exposed sulfide minerals is much less. The location of potentially acid-generating walls at lower levels in the Gibraltar North pit should further limit the potential for acid production.

Tailing

Ore Classification. Three types of ore were chosen for the metallurgical tests. These are:

Chlorite (GN-1) comprises only 1% of ore body. It is mainly a high level ore with distinctive dark green chlorite alteration; pyrite concentration are estimated at 2% to 4%; often elevated zinc.

Sericite-Chlorite (GN-2) comprises 80% to 90% of the orebody. It is hosted by a mixture of quartz-sericite, quartz-sericite-chlorite and chlorite; pyrite ranges from moderate to high; zinc is usually low.

Quartz-Sericite (GN-3) comprises 1% to 10% of the orebody. It is not always a good copper-silver host, particularly away from the ore zone.

Six head samples of ore were tested for ABA. These samples were chosen to represent specific types and characteristics of the ore and are not necessarily representative of the ore body as a whole. The ABA results are shown in table 3. The sulfur content of the metallurgical samples was high, corresponding to the 40th to over 80th percentile of the ore ABA database. The average was above the 80th percentile. The NP of these samples was low, corresponding to only the 15th to the 40th percentile, and therefore may represent a worst case ARD potential.

Weighted average ABA characteristics were calculated using the percentage of each ore type. The weighted average sulfur was relatively high (4.81%) and the NP very low (7 mt/kmt $CaCO_3$). The weighted average indicated the heads were strongly potentially acid generating.

Table 3. ABA data for ore head samples

Sample	Paste pH	Total Sulfur, %	SO_4, %	Potential, mt/kmt $CaCO_3$			NP/AP
				AP	NP	NNP	
GN-1	8.03	2.01	<.05	63	7	-56	.11
#1GN-2	7.44	3.52	<.05	110	5	-105	.05
#2GN-2	7.46	6.83	<.05	213	10	-203	.05
#3GN-2	7.36	3.44	<.05	108	6	-102	.06
#4GN-2	7.64	4.05	<.05	127	9	-116	.07
GN-3	7.51	8.23	<.05	257	4	-253	.02
Avg.	7.57	4.68	<.05	146	7	-139	.06
Std. Dev.	.22	2.15	0	67	2	67	.03
Max	8.03	8.23	NA	257	10	-56	.11
Min	7.36	2.01	NA	63	4	-253	.02

NA - Not applicable

Tailing. Eight separate scavenger and two cleaner tailings samples were analyzed for ABA. The cleaner tailings were from GN-2 ore, the largest ore type by mass. Three of the scavenger samples of the GN-3 ore type exhibited an acidic pH. These contained high sulfur (7% or greater) and very low NP. The low paste pH confirmed that scavenger tailings with high sulfur content would be acid generating. The sulfur content of the GN-1 ore type was much lower than that of the other two. NP levels of all samples were very low. All samples were potentially acid generating, although two were very marginal. In general, scavenger tailings from the GN-3 and some GN-2 ore types were strongly potentially acid generating.

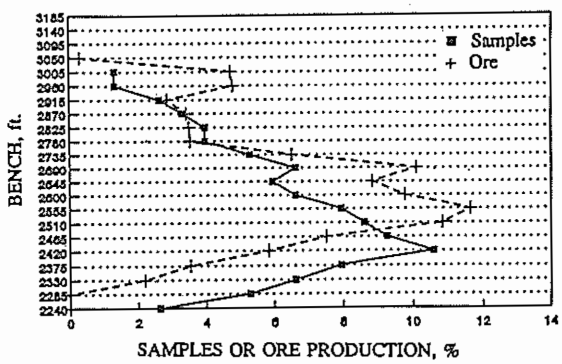

Figure 9. Percent samples and production by bench.

The ABA dataset for the Gib North ore samples was weighted according to ore production by bench in the same manner as for waste rock. In general, the percentage of samples and percent ore production by bench were in better agreement than for waste rock (fig. 9). The weighted mean values for the ABA characteristics were similar to the mean values from the raw data (table 4).

Table 4. Summary of weighted statistics for ore.

Statistics	Statistics for Gib North Ore			
	Sulfur, %	Potential, mt/kmt $CaCO_3$		
		AP	NNP	NP/AP
Absolute Mean	2.98	17	-76	.33
Weighted Mean	2.88	17	-73	.34

From results it is obvious that the Gib North ore is potentially acid generating. The finding of an acidic paste pH in some samples indicates acidic leachate would be expected from samples with elevated sulfur and very low NP. The metallurgical testing indicated the acid production potential of the ore would be reduced by about 27% due to milling. However, the scavenger, cleaner, and combined tailings are still expected to be potentially acid generating. Only the GN-1 ore type gave marginally acid-producing tailings, but that ore type comprises an insignificant proportion of the total ore feed. The Gibraltar North scavenger tailings have a significantly higher sulfur content and net acid production potential compared with the Gib East pit tailings currently being produced (table 5).

Table 5. Comparison of tailing from two ore zones

ABA statistic	Gib East[1]	Gib North[2]
Total sulfur	.81	3.46
NP	9	6
NNP	-16	-102

[1]Mean of 4 samples
[2]Weighted mean

The coarse fraction of the Gib North tailings is expected to have a higher acid production potential than the fines. Cycloned tailings, probably largely comprised of the coarse fraction, are currently used for am construction. The existing tailings dams could become potentially acid generating if the Gib North tailings were used for construction. The existing tailings pond slimes may also become potentially acid generating if Gib North tailings were deposited within the current basin. The tailings from the Gib North project need to be disposed of in a secure location to ensure ARD will not become a problem.

Conclusion

On the basis of the test work the following conclusions can be drawn.

♦ This study illustrates the importance of conducting a thorough assessment of the potential to produce ARD prior to mining. Placing tailing from the Gib North project onto the beach or dam at the end of mining could have a significant impact on acid production.

♦ The goal of any program should be to establish consistency between geochemical test results, geological knowledge of the deposit, and water quality information. If consistency can be established, the conclusions developed from the program will have greater confidence.

♦ Collecting representative samples is not a simple task. Samples should be sorted by grade, occur within the pit boundary, cover the range of rock types, provide good spatial coverage, and be proportional to the waste quantities by bench and by rock type. A significant number of samples are often required to provide a reasonable dataset. Even in this study, weighting of ABA statistics by bench showed the raw dataset was somewhat skewed.

♦ Visible pyrite estimates are not always accurate, but when combined with metal assays and a geological model they can provide a check of geochemical test results and identify smaller scale versions in acid generation potential.

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