2.4   Rock Characterization

2.4.1   Introduction and Background

Geochemical characterization of the Wolverine deposit began in 1996 with Westmin Resources Limited, and included static and kinetic testing of mine rock samples. Yukon Zinc initiated an acid rock drainage/ metal leaching (ARD/ML) characterization program of the deposit in 2005, consisting of static and kinetic testwork. As the underground test mining program advances, the present ARD/ML characterization program is ongoing and additional sampling and analyses will continue during the fall/winter of 2005/06. Currently available results are presented in this section. A comprehensive ARD/ML report will be prepared in early 2006 when additional data, including humidity cell test and paste backfill study results, are available.

Methodologies described in this section are based on accepted methods described in the *Draft Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia* (Price, 1997).

2.4.2   Characterization Program

Key Issues

Under the proposed mine plan, all waste rock extracted from the mine will be disposed of in the tailings facility under a permanent water cover. Some of the waste rock will also temporarily be stored in a surface containment facility, prior to its use as backfill in the mine. Active water treatment will be utilized to mitigate any water quality issues with the tailings pond water. The only mine components with potential ARD/ML issues are the underground workings and the small volume of development rock located at the mouth of the main portal. Within the underground workings, the formation of acidic mine water with elevated metals concentrations could potentially occur, both during the operational phase of mining and during the flooding of the mine following closure. This could result in the discharge of poor quality water from the underground workings to the receiving environment through groundwater flow.

Six major lithologies have been identified in the deposit that will be excavated during mining. Table 2.4-1 summarizes the geologic characteristics of the six lithologies, and provides the estimated tonnage of each rock type that will be excavated during the mine operation.

Program Details

Based on the proposed mine plan, the rock characterization program includes the following components:

Overburden and Roadcuts

Overburden samples of soils and glacial materials potentially used as construction materials were collected and analyzed for acid base accounting (ABA) parameters as part of the tailings impoundment studies. These data and findings are reported in Section 2.8.

Samples of bedrock and overburden from the proposed mine access road were not collected, pending the finalization of the route. Collection and analysis of these samples is planned for Summer 2006, once the mine road route has been surveyed and conditions permit sample collection. At present, no mineral occurrences are known to exist along the corridor of the proposed mine road alignment.

Waste Rock and Mine Workings

Waste rock will be temporarily stored on surface, and then deposited in the tailings pond. Wall rock in the mine workings will be exposed for approximately 14 years prior to closure and flooding. Therefore, the characterization program was designed to assess the potential for short term acid generation from the temporary waste rock storage facility, the potential for ARD/ML from the mine workings during operation, and the post closure water quality of the mine after closure.

Table 2.4-1   Major Lithologies of the Wolverine Deposit

Lithology	Description	Estimated Tonnage	Percent of Total
Non-carbonaceous Argillite	Aphanitic, hard, siliceous (cherty) black argillite. Commonly with a minor tuffaceous component	611,799	32%
Argillite	Aphanitic, massive, carbonaceous to strongly graphitic black argillite. May or may not contain significant amounts of carbonate.	317,587	16%
Calcite-Pyrite Exhalite	Distinctive unit containing up to 30% fine grained pyrite within a matrix of white calcite, both occurring as swirly cm scale bands. Generally occurs in the proximal hanging wall to the sulphide zone in the Wolverine stratigraphy, and is also common in the Fisher Zone.	106,632	5%
Iron Formation and Silica-Pyrite Exhalite	Magnetite iron formation commonly ranges from 10 to 80 percent disseminated to banded magnetite within a fine grained siliceous matrix. Silica dominated exhalite or chert with or without pyrite and/or calcite. Often chloritic and usually well banded. Addition of small amounts of fine carbonaceous sedimentary rocks that forms a dark grey to black variety of this unit.	188,722	10%
Interbedded Rhyolite/Argillite	Intimately interbedded black argillite (carbonaceous, siliceous, tuffaceous) and massive to tuffaceous rhyolite. Ranges from cm scale interbeds to mm scale argillite bands within massive rhyolite.	350,742	18%
Rhyolite and Rhyolite Fragmental	Grey rhyolite with distinctive fragmental texture defined by wispy sub mm dark green to black anastasmosing sericitc bands separating cm size felsic "fragments". Fragments are typically sub angular and irregularly shaped with jagged boundaries.	343,445	18%

Notes: The remaining 1% of the deposit volume consists primarily of andesite

The 2005 program consisted of two components; compilation of the 1996 ARD/ML database, and the collection and analysis of samples for ABA, metals analysis, and kinetic testing.

The 1996 database consisted of ABA and metals data on 49 discrete samples from the deposit. Humidity cell testing was carried out for a period of 26 weeks on four composite samples representing the hangingwall (two cells) and footwall (two cells) of the deposit.

In 2005, thirty-seven samples representing the six major lithologies of the deposit were collected from drill core and analyzed for ABA and metals. Six humidity cells representing each of these major lithologies will be initiated in the fall of 2005. No data from these cells is yet available for this report. Analysis of additional rock samples is planned to augment the ABA database, once appropriate samples are available.

Monitoring of runoff from the temporary waste rock pad was also initiated to assess the weathering characteristics of the waste rock and mine surfaces.

Tailings

Results and findings of the tailings geochemistry are reported in Section 2.8.

2.4.3   Sample Selection and Analysis

Samples collected during the 1996 program were selected from five drillholes that covered the lithologies in the hangingwall, footwall and the massive sulphide mineralization. Samples collected during the 2005 program include discrete samples selected by the six major lithologies present in the deposit, and several composite samples of rock and massive sulphide. Composite samples have been excluded from the current database. The samples were selected from eighteen drillholes advanced in 2005.

Static test analyses carried out on the samples collected in 1996 included acid-base accounting (EPA 600/2-78-054) and 30 element ICP metal scans on the sample solids. Neutralization potential was determined using the Sobek method. ABA analyses were conducted by Process Research Associates Ltd. (PRA) in Vancouver, and ICP metal scans by International Plasma Laboratory Ltd. (IPL) also of Vancouver.

Static test analyses completed in 2005 included acid-base accounting and 35 element ICP-MS analysis for metals. Neutralization potential was determined using the Modified Sobek method. Both the ABA and ICP analyses were carried out by ALS Chemex, Ltd. of North Vancouver.

Humidity cell tests were conducted on the four composite samples in 1996-97 by PRA. The tests were conducted using the standard humidity cell test procedure and were operated for a period of 26 weeks.

2.4.4   Mineralogy

The geology of the deposit is described in detail in Section 2.3. Six major rock types are found in the deposit, consisting of varieties of argillites, exhalites and rhyolites. Carbonate alteration is widespread through the deposit. Carbonate minerals consist of calcite, dolomite, siderite and ankerite. The massive sulphide mineralization may contain up to 75% sulphide minerals with quartz and carbonate gangue; although sulphide minerals generally compose about 50% of the massive sulphides.

Sulphides (and native metals) observed in order of decreasing abundance were: pyrite, sphalerite, chalcopyrite, pyrrhotite, galena, tetrahedrite, arsenopyrite, marcasite, stannite, meneghinite (and possibly other lead sulphosalts), and native gold.

Pyrite and sphalerite are abundant in all samples of massive and replacement style sulphides. Many of the sphalerite grains are completely encapsulated by pyrite. Galena and tetrahedrite are common, though much less abundant than pyrite and sphalerite, in most samples of massive sulphide but are rarely observed in replacement style sulphide. Galena within some portions of the Wolverine deposit (near the base of the Lynx sulphide lens) is high in selenium. Since galena is the only mineral within the massive sulphides where selenium is present in concentrations detectable by EDS analysis, it was concluded that most of the selenium in the Wolverine massive sulphide mineralization is substituting for sulphur in the galena structure (galena – clausthalite solid solution series).

Chalcopyrite and pyrrhotite are abundant in samples of massive sulphide from the base of the stratiform lenses, but are less abundant elsewhere. Arsenopyrite is a minor phase in a small number of massive sulphide samples, but is absent in others. The distribution of arsenopyrite in the deposit is poorly understood, but it is known to occur in both sphalerite-rich and chalcopyrite-rich parts of the deposit. The other sulphides (and native elements) listed above were only rarely observed.

2.4.5 Static Test Results

Six major lithologies in the deposit underwent static testing during the 1996 and 2005 sampling programs. Table 2.4-2 below summarizes the number of samples that underwent static testing for various analytical methods.

Table 2.4-2   Static Test Sampling and Analysis Summary (Number of Samples)

Lithology	Paste pH	Total Sulphur	Sulphate Sulphur	Sobek NP (1996)	Modified Sobek NP (2005)	Carbonate NP (2005)	Trace Elements
Non-carbonaceous Argillites	17	17	17	10	6	6	17
Argillites	7	7	7	2	5	5	7
Calcite-Pyrite Exhalite	7	7	7	2	5	5	7
Iron Formation and Silica-Pyrite Exhalite	6	6	6	-	6	6	6
Interbedded Rhyolite/Argillite	8	8	8	3	5	5	8
Rhyolite and Rhyolite Fragmentals	15	15	15	8	7	7	15

2.4.5.1   Sulphur Speciation

Total sulphur concentrations in the sampled lithologies ranged from 0.11-8.03% (Table 2.4-3). The Calcite-Pyrite Exhalite (EXCP) unit reported the highest overall sulphur concentrations, with the rhyolite and rhyolite fragments unit reporting the lowest overall concentrations.

Table 2.4-3   Statistical Summary of Total Sulphur Data (in percent)

Lithology	Number of Samples	Mini- mum	Maxi- mum	Mean	Median	10th Percen tile	90th Percen tile
Non-carbonaceous Argillite	17	0.25	7.60	2.26	1.72	0.78	3.92
Argillite	7	0.33	3.12	1.51	1.32	0.46	3.04
Calcite-Pyrite Exhalite	5	0.40	8.03	3.71	2.13	1.06	7.20
Iron Formation and Silica-Pyrite Exhalite	6	0.73	3.04	1.64	1.82	0.74	2.41
Interbedded Rhyolite/Argillite	8	0.57	2.16	1.03	0.91	0.72	1.43
Rhyolite and Rhyolite Fragmental	15	0.11	2.15	0.90	0.74	0.22	1.88

Concentrations of sulphate sulphur were generally very low, ranging from less than detection limit (0.01%) to values of 0.47% (Table 2.4-4). Generally the calcite-pyrite exhalite rocks had the greatest sulphate concentrations; all other rock types reported sulphate concentrations at or below the detection limit.

Table 2.4-4   Statistical Summary of Sulphate Sulphur Data (in percent)

Lithology	Number of Samples	Minim- um	Maxi- mum	Mean	Median	10th Percen tile	90th Percen tile
Non-carbonaceous Argillites	17	<0.01	0.05	0.03	0.03	0.01	0.05
Argillites	7	<0.01	0.03	0.0	0.02	0.01	0.03
Calcite-Pyrite Exhalite	5	<0.01	0.47	0.2	0.17	0.04	0.41
Iron Formation and Silica-Pyrite Exhalite	8	<0.01	0.38	0.2	0.27	0.09	0.37
Interbedded Rhyolite/Argillite	8	<0.01	0.31	0.1	0.04	0.01	0.20
Rhyolite and Rhyolite Fragmentals	15	<0.01	0.05	0.03	0.03	0.02	0.05

Sulphide concentrations of the lithologies were highly similar to the total sulphur concentrations (Table 2.4-5). Highest overall concentrations were observed in the calcite-pyrite exhalite unit, whereas the lowest concentrations were observed in the rhyolite and rhyolite fragmentals unit.

The primary sulphur forms in the deposit are sulphides. Sulphate minerals appear to represent a small proportion of the sulphur present.

Table 2.4-5   Statistical Summary of Sulphide Sulphur Data (in percent)

Lithology	Number of Samples	Mini- mum	Maxi- mum	Mean	Median	10th Percen tile	90th Percen tile
Non-carbonaceous Argillites	17	0.24	7.60	2.3	1.72	0.78	3.90
Argillites	7	0.33	3.1	1.5	1.32	0.44	3.03
Calcite-Pyrite Exhalite	5	0.32	8.03	3.5	1.87	0.82	7.19
Iron Formation and Silica-Pyrite Exhalite	8	0.57	2.84	1.5	1.48	0.69	2.35
Interbedded Rhyolite/Argillite	8	0.56	1.85	1.0	0.89	0.71	1.33
Rhyolite and Rhyolite Fragmentals	15	0.11	2.15	0.9	0.71	0.21	1.88

2.4.5.2   Carbonate Speciation

Carbonate alteration is widespread through the deposit, with calcite ($CaCO_3$) appearing to be the primary carbonate mineral. Comparison of neutralization potential data (modified Sobek versus carbonate neutralization potentials) suggests that most of the neutralization capacity of the deposit rocks is due to carbonates such as calcite (Figure 2.4-1). However, the variability shown in the data also indicates that, in some samples, a portion of the neutralization capacity is provided by non-carbonate minerals, whereas other samples appear to contain carbonate minerals such as siderite which provide no neutralization capacity.

2.4.5.3   Trace Element Composition

Figure 2.4-2 highlights the relative abundance of several key environmental elements (Ni, Cu, Zn, As, Cd, Sb, Se, Hg, Pb), as compared to average crustal values. Results are presented for each of the six major rock types in the deposit. Nickel and mercury are at or below the average crustal concentration, whereas the remaining elements show varying degrees of enrichment. Selenium shows the highest average enrichment, followed in a general decreasing order by antimony, cadmium, arsenic, zinc lead and copper.
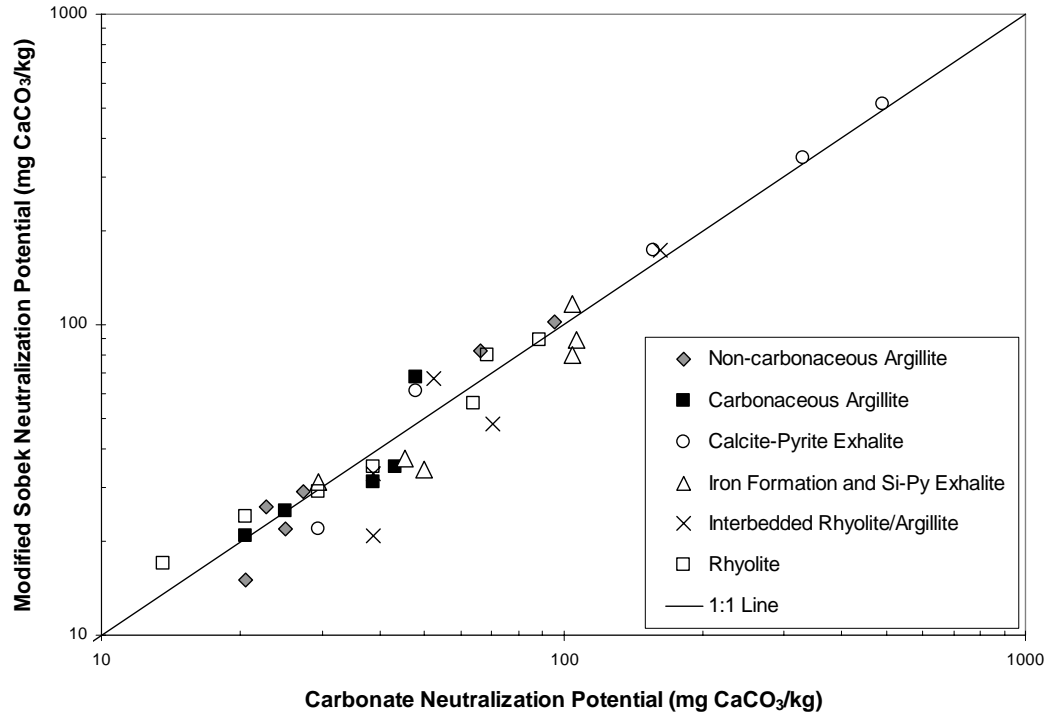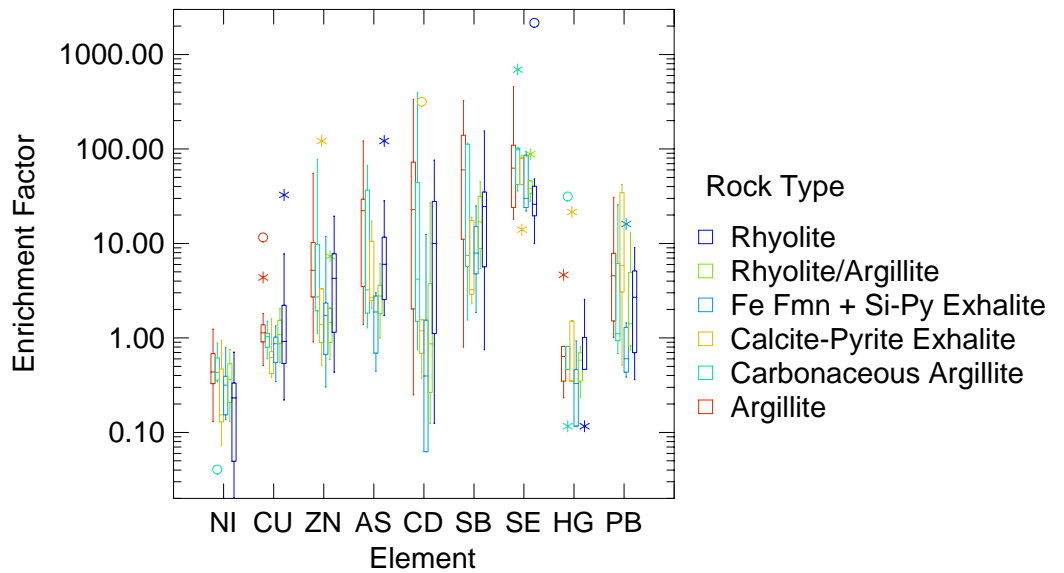
Figure 2.4-1   Comparison of Modified Sobek to Carbonate Neutralization Potentials, 2005 ABA Data

Notes: Enrichment factors based on abundance of elements in the earths crust
Data reproduced from Price (1997)

Figure 2.4-2   Crustal Enrichment Factors for Key Elements

Neutralization potential (NP) of the rock types was compared to their calcium and magnesium concentrations and is shown in Figure 2.4-3. The results indicates that there is a strong correlation between the NP value of the rocks and their calcium and magnesium concentration, which suggests that the primary source of neutralization potential in the deposit rocks are calcium and magnesium carbonates. Ongoing ARD/ML studies of the deposit will include the collection and analysis of additional ABA samples to further confirm this relationship.
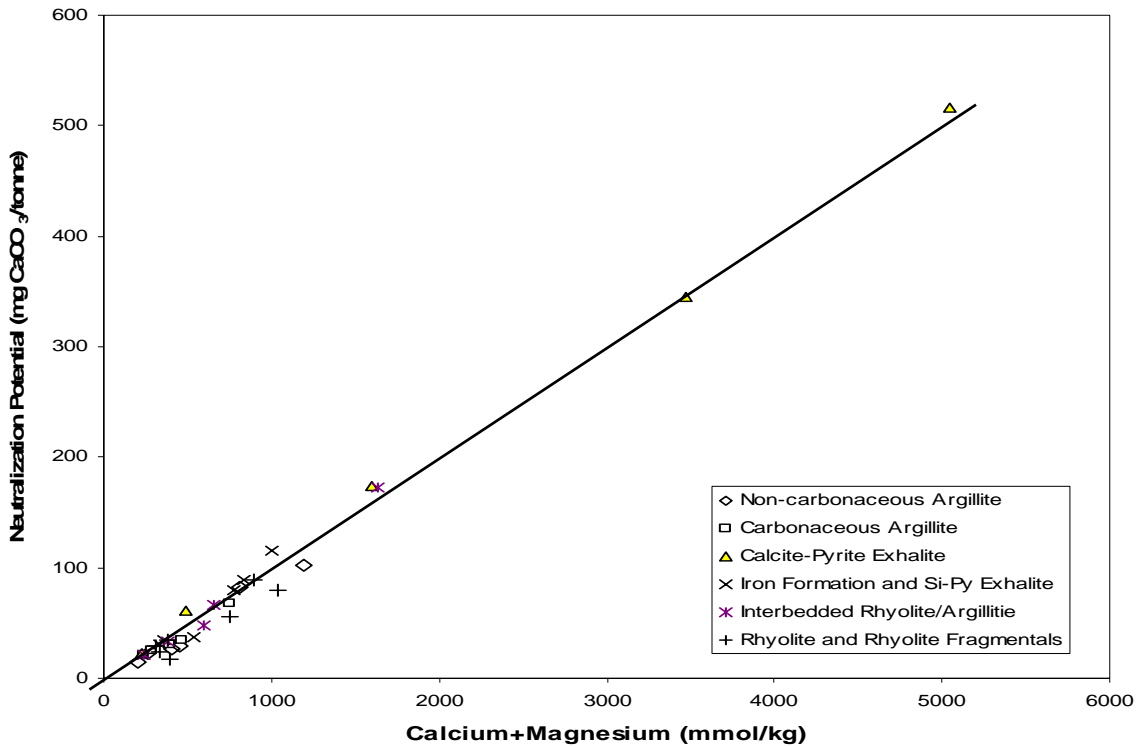

Figure 2.4-3   Neutralization Potential versus Calcium + Magnesium in Waste Rock Samples

2.4.5.4   Acid-base Accounting

Figures 2.4-4 and 2.4-5 illustrate the distribution of neutralization potential (NP) and acid potential (AP) values for samples from the 1996 and 2005 characterization programs. Data plots are shown for each of the programs as different methods to measure neutralization potential were used in the two programs. The Sobek NP method used in 1996 is the historic industry standard; however, in comparison to the Modified Sobek test, it tends to overestimate the amount of available NP by including minerals that may not provide neutralization capacity in the field.
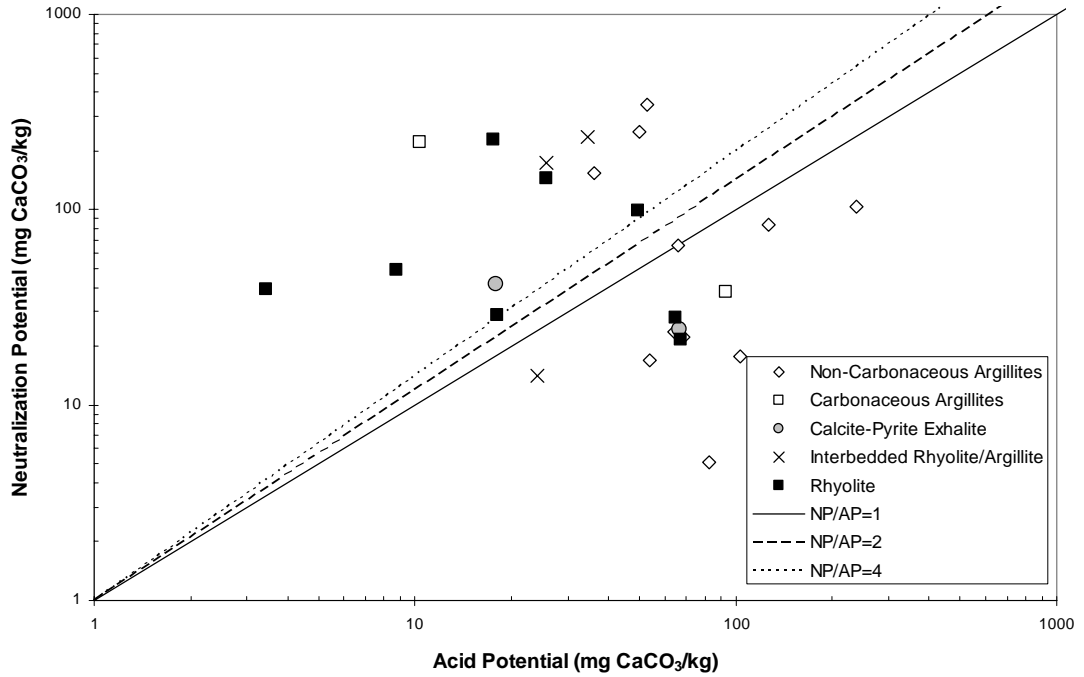
Figure 2.4-4   Neutralization Potential vs. Acid Potential by Rock Type, 1996 ABA Data
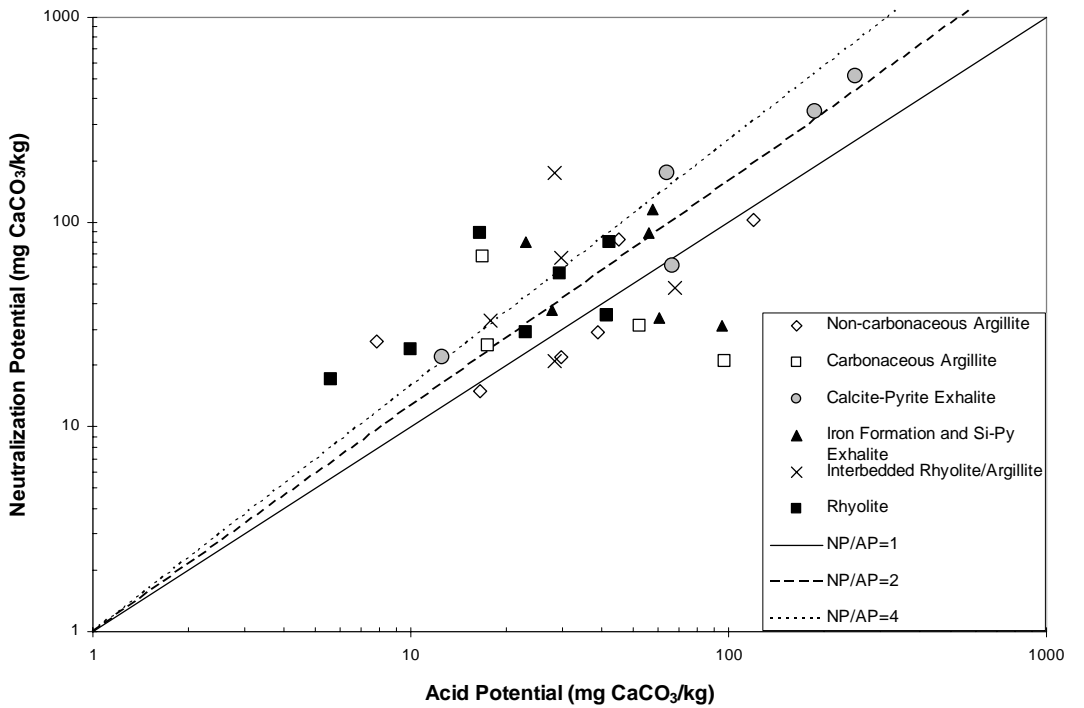

Figure 2.4-5   Neutralization Potential vs. Acid Potential by Rock Type, 2005 ABA Data

Data shown on both figures show a range of neutralization potentials and acid potentials for each rock type. Acid potential values varied from 3-238 mg CaCO3/ kg (1996 data) and 5-251 mg CaCO3/ kg (2005 data). Neutralization potential values ranged from 5-345 mg CaCO3/ kg (1996 data) and 16-516 mg CaCO3/ kg (2005 data). In general the overall ranges of NP and AP values were fairly similar between the two datasets.

Both datasets showed a wide range of NP/AP values. The 1996 dataset is almost evenly divided between NP/AP values <1, and NP/AP values >4. No correlation with rock type is evident, as samples from all lithologies are classified as either non-acid generating (NAG), or potentially acid generating (PAG). Samples from the 2005 dataset showed a similar distribution pattern of NP/AP values. No correlation was observed based on lithology; samples of each rock type were classified as both NAG and PAG. Variations in NP/AP values for all rock types appear to be controlled by the presence or absence of mineralization and carbonate alteration, rather than inherent qualities of each particular rock type.

2.4.6   Kinetic Testing Program

2.4.6.1   Humidity Cells

As part of the 1996/97 program, four humidity cells were operated for a period of 26 weeks using composite samples to represent the footwall and hangingwall of the deposit. Data for these cells were presented in the Wolverine Project Description Report (2004).

Three of the cells produced leachates with near-neutral pH (6.0-7.0) during their operation. However, one cell produced weakly acidic (pH 4.5-6.0) leachates for the length of its operation. Sulphate loadings, estimated from the last 9 weeks of data were relatively low and ranged from 13.6-20 mg/kg/wk. Carbonate molar ratios calculated for the data suggest that excess carbonate was still present in the cells throughout their operation, neutralizing any potential acid generation (Figure 2.4-6).

Metal leaching from the cells was generally at levels below detection limit. A notable exception was zinc, which reported leachate concentrations on the order of 0.1-1.0 mg/L, with an average of 0.3 mg/L. Zinc loadings ranged from 0.03-0.27 mg/kg/wk.

New cells have recently been initiated, using samples collected during 2005. Leachate analyses will use significantly lower detection limits and include the analysis of selenium.
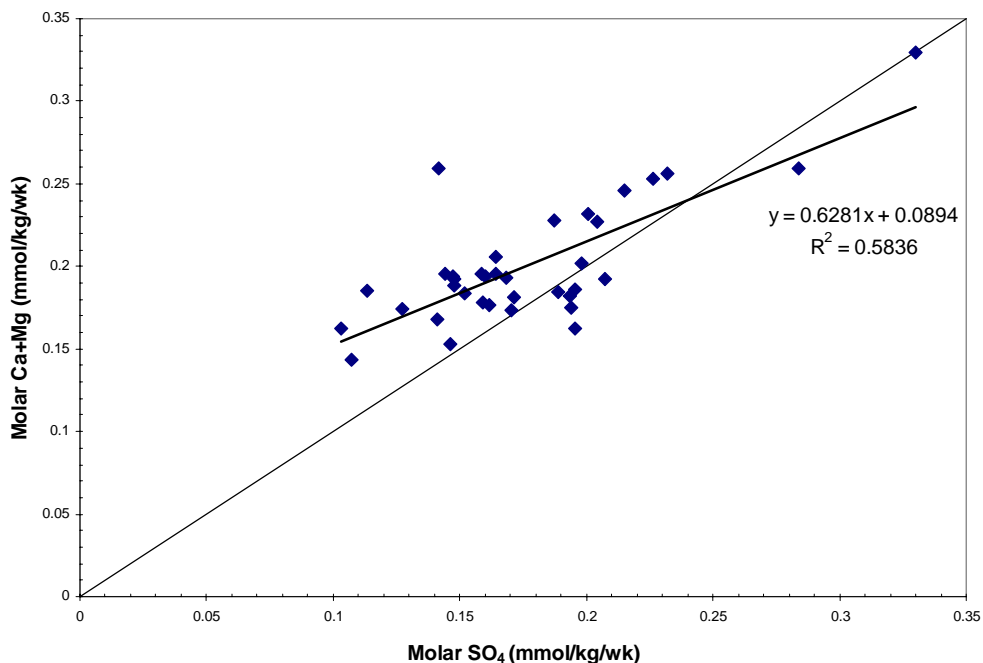
Figure 2.4-6   Molar Ca+Mg versus molar sulphate, 1996 humidity cell data

2.4.6.2   Post-Closure Mine Water Quality Estimate

A preliminary assessment of the post-closure water quality of the mine was made using information from the proposed mine plan and the 1996/97 humidity cell data. An estimate was made for zinc, as other metals of concern (i.e. As, Sb, Cd, Se) reported below detection limit concentrations. However, the detection limits are 10 to 100 times the *CCME Guidelines for the Protection of Aquatic Life.*

The zinc concentration of the mine water was estimated using the following assumptions:

- Loading is sourced from the mine rock surfaces only. It is assumed that the mine rock surfaces begin weathering once they are exposed, and that the oxidation products accumulate on the rock surfaces until the mine is flooded.

- For the purposes of this estimate, backfill materials were not considered, due to the present lack of information on their characteristics. The backfill may add additional load to the mine water, resulting in higher zinc concentrations, or it may mitigate mine water quality through the release of alkalinity from cement in the paste backfill, resulting in reduced concentrations. However, based on experience at other sites, the high pH of the backfill and its low hydraulic conductivity is expected to result in low metal release rates. A paste backfill study will be conducted in conjunction with the Feasibility Study and these results will be incorporated into the detailed water quality estimate in the subsequent ARD/ML report.

- An estimated 1.9 million m^3 of rock will be excavated from the mine; the resulting void space at closure is estimated to be 0.5 million m^3.

- The volume of mine rock that acts as a loading source is assumed to be equivalent to 10% of the mine void space.

- Loads calculated from the humidity cells were averaged over the last 9 weeks of cell operation (weeks 18-26). These loads were applied to all the rock types exposed in the mine workings.

- The anticipated weathering rates and loadings from the wall rock surfaces were assumed to be one-tenth of the weathering rates and loadings measured from the humidity cells, due to the lower temperatures and lower surface area of the mine rock surfaces.

- No allowances were made for the geochemical controls on zinc solubility in the mine water, such as pH, saturation or complexation with other metals or compounds.

Figure 2.4-7   Estimated Dissolved Zinc Concentrations for the Post-Closure Flooded Mine Water.

	Mean	Minimum	Maximum
Zinc (mg/L)	0.35	0.07	0.64

The estimate should be regarded as highly preliminary as it was developed using a limited amount of geochemical data and gross estimates of the mine geometry and volumes. However, it does indicate that the post-closure mine water may be adversely effected, as the mine floods due to the release of soluble metal complexes on mine surfaces. This process is expected to occur during mine flooding and effectively cease once the mine is flooded. Mine water quality is expected to stabilize once the mine is flooded, as available soluble metals are released into the mine water, and sulphide oxidation ceases due to the lack of oxygen.

2.4.7   Conclusions

Rocks from the Wolverine deposit show a range of acid generation potential. Overall, the bulk of the rock is likely to be potentially acid generating. Metal leaching from the rock, notably zinc, may occur, possibly prior to the onset of acidic conditions. Carbonate alteration within the deposit is also widespread and may mitigate any potential acid generation within the workings. The ultimate ARD/ML conditions within the mine will be controlled by the type and nature of rock exposed during excavation. Further, the addition of cemented backfill to the mine may result in excess neutralization capacity within the mine; conversely, it could serve as a source for additional metals loading to the mine.

A preliminary water quality estimate for the mine suggests that zinc levels may reach 0.6 mg/L in the mine water following flooding. Other metals may be similarly elevated, but insufficient data presently exists to fully assess the possibility. Significant increases to metal concentrations once the mine has flooded are not expected.

The ongoing ARD/ML program, including the operation of humidity cells for the six major lithologies, will be used to predict the onset of acidic conditions and to estimate the water quality of the mine following closure. Water quality analyses will use detection limits appropriate to CCME Guidelines.