rock composite was nearly identical to the mean NP from the waste rock database, although individual samples displayed lower NP values. The NPR for the waste rock composite was 0.8, slightly lower than the database mean of 1.3. Thus the results from the humidity cell tests on the selected waste rock sample are likely to represent reasonable worst case results, rather than average or expected results. However, the range in NPR results of 0.1 to 137 for the 37 waste rock samples indicates the waste rock characteristics are highly variable.

Table 6: Summary of Ore and Waste Rock Static Test Database and Kinetic Test Samples

Sample	% Total S	AP kg/t	NP kg/t	NNP kg/t	NP/AP (NPR)
ORE or MINERALIZED ZONE					
1996 Database					
Min / max	0.15 to 2.24	5 to 70	16 to 33	-40 to 25	0.1 to 137
Mean	0.94	29	26	-3	0.8
Humidity Cell Ore pre-test	1.14	35	32	-3	0.9
Humidity Cell Tailings pre-test	1.63	51	49	-2	1.0
WASTE ROCK					
1996 Database					
Min / max	0.01 to 3.91	0.3 to 122	10.4 to 85	-109 to 78	0.1 to 137
Mean	0.68	21	27	6	1.3
Humidity Cell Waste Rock pre-test	1.17	36	28	-8	0.8

As no metals data were available for the sample suite presented in Klohn 1996, metal content, in particular arsenic content, could not be compared. Therefore it is not clear whether the low arsenic content of the waste rock composite of 556 ppm (Table 1) is consistent throughout the waste rock materials.

Greater clarity of the potential quantity of waste rock that might contain elevated metal levels may be determined by review of the 7305 ICP's mentioned in the BHP geology report (1993).

3.3.2 Humidity Cell Reaction Rates

Comparison to results from other kinetic humidity cells from the International Kinetic Database (Morin, 1999) are shown in Figure 1, and indicate that both the NP and sulphate depletion rates for the ore, waste rock, and fine grained ore are comparatively low.

3.3.3 Threshold NPR Values

MEMI attempted to determine the source of Klohn's selected NPR thresholds for eventual acidic drainage of 3 at 22°C and 7 under colder conditions. Table 7 provides ratios of Klohn's reported NP depletion rates and S depletion rates for the various humidity cell tests, which can typically be used to calculate the threshold NPR values for material that will not lead to net acid generation with prolonged weathering under the specific test conditions (Morin and Hutt, 1997).

Table 7: Comparison of NP and S Depletion Rate Ratios

	Ore	Waste Rock	Tailings
Cell @ 4°C	5.0	7.9	
Cell @ 22°C	2.2	2.0	2.6

As Table 7 indicates, Klohn's threshold NPR values of 3 and 7 for site materials under the two temperature conditions could not be exactly duplicated. However the above values appear to be reasonably close. Given the calculated values in Table 7, it appears that Klohn's selected threshold NPR value of 3 for materials at 22°C may be slightly conservative.

Klohn's selected threshold values based on humidity cell results are also considered by MEMI to be conservative relative to actual field conditions. This is because NP depletion can depend on the rate of flushing, i.e. the amount water moving through the humidity cell or field column. Since buffering minerals tend to be soluble in water, more so than sulphides, greater flows can mean greater dissolution of buffering minerals, beyond that need to neutralize acidity produced by sulphide oxidation, particularly where sulphide oxidation rates are low, as at Ulu. The relatively large volumes of water used in a humidity cell test (as compared to field conditions) can result in an overestimation of field NP depletion rates and an overestimation of the NPR threshold for eventual generation of acidic drainage in the field. Thus Klohn's selected threshold values of 3 and 7 for materials at 4°C and 22°C are likely conservative for field conditions, where flushing rates are lower through most of the year.

3.3.4 ARD Potential by Rock Type

MEMI also reviewed the existing database to assess the influence of rock type on ARD potential as defined by Klohn's selected NPR threshold value of 3 for 22 ^{O}C. MEMI tabulated the 15 samples from the 1990 testwork performed as part of the environmental overview by Rescan and reported in "Ulu Project, Northwest Territories, Environmental Overview" dated December 1991 numbered ARD-1 to ARD-15 and the 32 samples from the 1996 testwork performed by Klohn and reported in "Echo Bay Mines Ltd. – Lupin Operation, Ulu Project, Preliminary Assessment of Acid Rock Drainage Potential" dated October 1996 numbered Ulu KC-1 to Ulu KC-32, by rock type if a description was provided. The generalized rock types or units were: 1) Intrusive – gabbro and diabase, 2) volcanics, 3) greywacke and biotite schist, 4) basalt/porphyry/band tuff, 5) mineralized zone, and 6) other – unspecified. The ABA data by rock type is provided in Table 8, located at the end of the text of this report.

As only % total sulphur was available for the 1990 samples and since sulphate-sulphur was negligible in the 1996 samples, MEMI calculated acid potential (AP) in kg $CaCO_3$/tonne by multiplying total sulphur % by 31.25. The neutralization potential (NP) for the 15 1990 samples was originally presented in kg H_2SO_4/tonne, therefore MEMI converted the NP to kg $CaCO_3$/tonne by dividing the NP presented by 30.625 and multiplying by 31.25. Upon making these changes to the 1990 samples, discrepancies were noted in some of the reported AP's, which would affect both calculated NNP and NPR values. MEMI makes no claims as to accuracy of the numbers presented in Table 8, as MEMI has used the % total sulphur and NP's presented in the Klohn 1996 report. If the % total sulphur or the NP's presented in Klohn (1996) are incorrect, then Table 8 in this report is also incorrect. It was assumed that all ABA analyses were conducted in a similar manner, although the actual method used to develop the 1990 data was not identified.

The database indicated the following trends by rock type, as compared to Klohn's NPR threshold criteria of 3:

- Seven samples were classified as gabbro/diabase. The total sulphur content for this group ranged from 0.02% to 0.29%. Only two samples had an NPR of less than 3 (2.5 and 2.9), with a mean NP/mean AP ratio for the seven samples of 5.7. Therefore, gabbro and diabase waste rock can be classified as likely not potentially acid generating (NPAG).
- The two mafic volcanic samples with a total sulphur content of 0.74% and 0.93% and NPR's of 1.5 and 0.6, respectively, would be classified as potentially acid generating (PAG).
- Of the two greywacke samples, one had a total sulphur content of 0.25% and an NPR of 2. The other sample had a total sulphur content of 0.17% and an NPR of 3.8. While 50% of greywacke samples would be classified as PAG and 50%

would be classified as NPAG, the differences between the samples are small, such that one might conservatively assume all greywacke to be PAG.

- The two biotite schist samples with NPR's of 6.4 and 9.6 would be classified as NPAG.
- The total sulphur content of the seventeen samples of basalt/porphyry/band tuff ranged from 0.01% to 1.49%, and the NPR of these samples ranged from 0.5 to 137, indicating a high variability in sample mineralogy. Due to the high variability, and a mean NP/ mean AP ratio of 2.7, all basalt samples might conservatively be classified as PAG. It should be noted that 6 of the 17 samples were collected from the camp pads and the NPR's of these 6 samples ranged from 0.5 to 2.4 which would indicate that at least some of the material used for camp pads construction would be classified as PAG on the basis of Klohn's revised threshold NPR criteria of 3.
- Ten samples from the mineralized zone produced total sulphur contents ranging from 0.15% to 2.24%, with a mean NP/mean AP ratio of 0.9. Therefore all mineralized or altered rock should be considered as PAG.
- The other unspecified samples were mainly from the portal area. Total sulphur ranged from 0.2% to 3.91% with a mean of 2.2%. The mean NP/mean AP ratio was 0.3. These materials would be considered as PAG.

In summary, based on the ABA database compiled to date, and a threshold NPR of 3 for separating PAG and NPAG material, gabbro and diabase material for the most part are likely to be NPAG, greywacke may be PAG or NPAG depending on the sulphur content, mafic volcanics are likely to be PAG, basalt material is highly variable but generally PAG and all ore and altered material are PAG. Note that the database is dominated by surface samples, and deeper materials may not maintain the indicated trends. Also note that the samples may have been biased to those containing visible sulphides.

3.3.5 Identification of PAG material

Based on preliminary work, Klohn (1996) indicated that % total sulphur was the critical parameter in determining acid generating potential, and proposed a cutoff of 0.9% total sulphur to identify potentially PAG material assuming a threshold NPR criteria of 1. Klohn noted that the selection of such a lower than typical threshold NPR criteria would require confirmation using kinetic tests. Subsequent kinetic testwork conducted by Klohn (1998) did not support the use of an NPR threshold criteria of 1. Klohn (1998) concluded that "... only materials with a neutralization potential ratio (NPR) of greater than 3 will not lead to net acid generation with prolonged weathering at 22°C. Under colder conditions, the NPR required to eliminate the possibility of ARD can be as high as 7. However, in the latter case, the amount of acid released on an annual basis is so low that it should not cause any significant impact."

The increase in Klohn's threshold NPR values for PAG material was carried forward by MEMI in a similar manner conducted by Klohn in 1996. Total Sulphur was graphed versus NPR from the ABA database (Table 8) to show the % total sulphur "cut-off" consistent with threshold NPR values of 3 and 7 (Figure 20).

As Figure 20 indicates, all but one sample with an NPR of less than 3 had a total sulphur greater than 0.2%. The one exception (ARD-10) was described (Table 8) as a fresh gabbro from 171 m to 172.06 m along the drillhole 90VD66. This sample contained 0.13% total sulphur content and reported an NPR of 2.5.

Thus a total sulphur cutoff of 0.2% appears to be consistent with the threshold NPR criteria of 3 identified by Klohn (1998) for material that will not lead to prolonged weathering at 22°C. Even materials below this threshold may not generate acidic drainage for decades, as indicated by the field column tests on coarse ore samples with an NPR of approximately 1.

4.0 EXTENDED FIELD COLUMN TEST

As recommended by Klohn (1998), the field column testing program was continued beyond 1998. Leachate collection was undertaken by Echo Bay staff, and results were provided to MEMI for inclusion in this report.

4.1 Field Column Setup

As described by Klohn (1998), the field setup consisted of two field columns each containing a 15-kg subsample of the coarse ore composite. The field columns were installed in an open area near the termination of the winter road at Lupin. Each field column consisted of two staggered 18-L plastic pails. The upper pail with a perforated bottom contained the 15-kg test sample and the lower pail served as a leachate collector. The system was held upright in a slot in a broad-base wood frame made up of two pallets tied together with iron wire.

4.2 Column Maintenance and Leachate Collection

As described by Klohn (1998), the physical integrity of the field columns was to be inspected monthly during the dry season and during each sampling event in the wet season. Either pail could be replaced if serious disintegration was observed, and replacement pail(s) were to be thoroughly cleaned prior to being used. Each inspection was also to ensure that the field columns were well supported in the wood-frame base such that they would not topple over in a strong wind.

Leachate collection was to be conducted weekly in each column, as soon as spring freshet began, although collection was dependent on precipitation – a minimum of 200 ml filtrate was required for chemical analysis. The collection method was to follow the steps given below (Klohn, 1998):

1. Pull out the waste rock (upper) container in the column assembly and sit it on a clean plastic sheet.
2. Decant the leachate in the collector (lower) pail into a clean, plastic sampling container; measure its volume, pH, conductivity and temperature; filter it through a 0.45 µm cellulose acetate filter, ship a subsample (minimum 200 ml, preferably 500 ml) together with a data record sheet to Klohn (Calgary).
3. With a rubber policeman or spatula and using a minimum amount of water (<20 ml), return all the fine solids collected in the lower pail and filter paper to the upper pail.
4. Re-assemble the column system and put it back in the wood-frame support.

4.3 1998 – 2002 Monitoring and Sampling

Echo Bay field staff monitored and sampled the field columns at least three times over each summer season (June to September) from 1998 to 2002. The following parameters were measured in the field at time of sample collection: volume of water, pH, conductivity, and air temperature. The samples were not filtered in the field, however on June 6, 1998 "sharkskin" filter paper was placed in the bottom of the sample columns to hold in the solids. The leachate samples collected were sent to Norwest Labs of Edmonton, Alberta, for analysis of total metals and dissolved sulphate. Of note, the samples collected from 1998 to 2000 were not analyzed until November 2000. This resulted in the 1998 and 1999 samples being analysed well past the recommended holding time of 6 months for metals and the 1998, 1999 and 2000 samples being analysed past the recommended holding time of 28 days for sulphates.

4.4 Field Column Results

The analytical data for the two field columns containing the coarse ore composite sample are provided on Tables 9 and 10 (located at the end of the text). These tables include the three data points from 1997 reported in Klohn 1998, as well as the Echo Bay data provided through to the end of 2002. Volumes of sample leachate collected in 2002 were not provided, such that calculated leach rates and the cumulative leach rates are presented only to the end of 2001. Figures 2 through 7 show the concentrations, release rates and cumulative released load trends over time for various parameters for both Field Columns 1 and 2, in a manner similar to Klohn (1996). Graphs of individual parameters (concentrations and loadings) versus time are shown on Figures 2 though 15.

Field columns differ from humidity cells in that flushing rates are low, such that all oxidation products may not be removed in the leachate. Oxidation products, such as sulphate and soluble metal salts, may remain in the field column, building up an increasing store of salts over time that become available for dissolution in subsequent flushing events. Thus, while the concentrations in the field column tests may more closely reflect actual dump leachate quality than humidity cell test concentrations, field column leaching rates may not reflect internal oxidation or reaction rates, and estimates or extrapolations using these values should be viewed with caution. As noted by Klohn (1998), the actual concentrations and released loading rates from the field columns are influenced by temperatures, and the frequency and volume of flushing.

As indicated on Table 9 and 10, and Figures 2, 5 and 8, pH was neutral to slightly alkaline in the leachate collected from both columns. Values ranged from 6.9 to 7.9 for leachate collected from Field Column #1 and from 6.7 to 8.0 for Field Column #2. Although erratic, the pH showed a slightly downward trend over the period 1997 to 2001 in both columns.

Dissolved sulphate concentrations generally increased over the period and ranged from 74 mg/l to 665 mg/l in leachate collected from Field Column #1 and 74 mg/l to 480 mg/l in leachate collected from Field Column #2 (Figure 2, 5 and 9). No particular trend was seen for timing of seasonally high sulphate concentrations, although concentration highs may be occurring more frequently during the early spring/summer sampling events. Arsenic concentrations ranged from 0.17 mg/l to 1.74 mg/l in leachate collected from Column #1 and 0.11 mg/l to 0.97 mg/l in leachate collected from Column #2, both with slightly increasing trends, Column #1 more obviously so (Figures 2, 5 and 10). Zinc concentrations (Figures 2, 5 and 11) were erratic, especially in Column #1. Values ranged from 0.013 mg/L to 0.332 mg/l in Column #1, and 0.009 mg/l to 0.044 in Column #2. No specific trends were apparent, although Column #2 zinc concentrations may be slowly decreasing.

Similar to the sulphate concentrations, the calculated sulphate release rates (i.e. loads) generally showed an increasing trend for both field columns. The graphs (Figures 3, 6 and 12) indicate reduced release rates for the first sampling event of each year, suggesting a decrease in the sulphide oxidation rate during the winter season, consistent with lower winter temperatures. Over the entire period the sulphate release rates varied from 0.004 mM/kg/wk to 0.129 mM/kg/wk in Field Column #1 and 0.003 mM/kg/wk to 0.176 mM/kg/wk in Field Column #2.

The NP release rates from the field columns were estimated from released moles of Ca + Mg + .5Na + .5K, the protocol used by Klohn (1998). Klohn (1998) found that the 1997 NP release rates appeared to be influenced by absorbed salt in the columns due to the use of salt water as a drilling fluid, such that no actual values were presented in their report. Results from the sampling event in June 1998 (Column #1) also appeared to be influenced by absorbed salt (i.e. contained elevated Ca and Na concentrations). However results from the sampling event in July 1998 in both columns showed a significant drop in Ca and Na concentrations, and the start of an overall generally increasing trend in the NP release rates, suggesting that the salt influence became minor at that point.

The arsenic release rates, although fairly low and erratic, showed an increasing trend (Figures 3 and 14). Values ranged from 0.0004 mg/kg/wk to 0.016 mg/kg/wk for Column #1 and 0.0002 mg/kg/wk to 0.026 mg/kg/wk for Column #2. Arsenic release rates appeared to increase at the later part of each season's sampling events. Zinc release rates were very low and also showed an increasing trend, particularly in Column #1 (Figures 3 and 15). Values ranged from 0.00005 mg/kg/wk to 0.0025 mg/kg/wk for Column #1 and 0.00003 mg/kg/wk to 0.0008 mg/kg/wk for Column #2. Zinc release rates were more erratic and did not appear to show significant seasonal trends.

Following the protocols in Klohn (1998), the S and NP depletion rates were calculated to estimate the time required for total S and NP depletion. The S depletion rates were calculated for the period from January 1997 to September 2001 (i.e. from the total cumulative leach rates over the entire test period) and the NP depletion rates were calculated from cumulated leach rates for the period from August 1998 (when all the remnant salts appeared to have been released) to September 2001. These rates, along with the arsenic and zinc loading rates, are shown on Table 11 along with the values provided by Klohn from the 1997 data.

The estimated years to depletion are not necessarily valid for field columns, where sulphate and ions considered representative of neutralizing reactions may not be completely flushed from the columns because of the limited precipitation. Although leachate from the field column tests is considered unlikely to represent internal reaction rates, the sulphur depletion and NP depletion rates can be manipulated in a manner similar to humidity cell results to suggest neutralization potential ratios (NPR) for materials that would likely not lead to net acid generation with prolonged weathering. Manipulation of the field column data suggests such threshold NPR values may be in the order of 1.3 for Column #1 and 2.0 for Column #2.

As shown in Table 11, the expanded collection of data from the field columns shows some differing results compared to those found on the basis of the first three sampling events by Klohn (1998). Most significantly, the longer-term sulphate release rates for Column #1 and Column #2 are 5.5 and 3.75 times higher, respectively, than those rates calculated from the 1997 data. This may be due to more rapid oxidation of sulphides, but may also be due increasing quantities of sulphate salts being stored in the field columns and becoming available for flushing as the test proceeded. Assuming the influence of salt contamination is minor, and that sulphur and NP depletion rates continue in a similar manner and reflect actual reaction rates, the estimated times for depletion suggest that these columns would eventually produce acidic drainage, but only after more than 200 years.

It is considered possible that sulphur release rates would continue to accelerate as increasing quantities of sulphate salts are stored in the field columns and become available for flushing. This means that the predicted lag times to onset of acidic drainage may continue to decrease as the field column matures. However, comparisons with humidity cell results (section 4.5) suggests that the sulphate release rates may be predominantly controlled by site temperatures and that the longer-term rates from the field columns are appropriate for expected site temperatures.

Table 11: Comparison of Field Column Rates

	1997 (Klohn, 1998)		1997 - 2001	
	Field Column #1	Field Column #2	Field Column #1	Field Column #2
S depletion rate (mM/kg/week)	0.004	0.004	0.022	0.015
NP depletion rate (mM $CaCO_3$/kg/week)	Not calculated due to remnant salt		0.029	0.03
Threshold NPR	N/A	N/A	1.3	2.0
Time for S depletion (years)	1707	1726	310	450
Time for total NP depletion (years)	Not calculated		211	207
As loading rate (mg/kg/week)	0.001 – 0.004	0.001 – 0.003	0.0004 – 0.016 increasing	0.0002 – 0.026 slightly increasing
Zn loading rate (mg/kg/wk)	0.0002 – 0.0009	0.0002 – 0.0004	0.00005 – 0.0025 increasing	0.02 - 0.0008 slightly increasing
SO4 conc. (mg/l) mean	84 – 240 172	88 – 209 149	74 – 665 270	74 – 480 269
As conc. (mg/l) mean	0.25 - 0.40 0.32	0.20 – 0.45 0.30	0.17 – 1.74 0.47	0.11 – 0.97 0.33
Zn conc. (mg/l) mean	0.05 – 0.16 0.09	0.01 – 0.04 0.03	0.0132 – 0.332 0.069	0.009 – 0.0439 0.023

The longer-term results also show wider ranges in arsenic and zinc release rates, and substantially increased maximum rates. The release rates for both metals appear to be increasing over time, possibly reflecting increases in actual reaction rates, but more likely as a result of greater quantities of retained salts in the field columns being available for flushing as the test proceeds. It is expected that these metals leaching rates may continue to increase as the field column matures.

The wider ranges and generally increasing release rates are reflected in the wider range and generally increasing sulphate, arsenic and zinc concentrations, also shown in Table

11. Actual arsenic concentrations exiting the field columns occasionally exceed the federal *Metal Mining Effluent Regulations* maximum allowable values (i.e. a maximum of 1 mg/l total arsenic, monthly average of 0.5 mg/l total arsenic). These field columns contain only the coarse fraction (> 1.5 mm) of the composite ore sample. Inclusion of the fine 'tailings' fraction would be expected to further increase these concentrations.

4.5 Comparison with Humidity Cells

The results from the extended field column tests on the coarse ore composite are compared to results from humidity cells tests on the same coarse ore composite sample at 4 ^{O}C and 22 ^{O}C on Table 12. Results from the humidity cells conducted on the fine fraction of the ore ('tailings') at 22 ^{O}C, and on waste rock at 4 ^{O}C and 22 ^{O}C are also shown.

The results indicate that the sulphur release rate for the field columns calculated for the full field test program fell within the range in the humidity cell rates generated on the same material at 4 ^{O}C, and 22 ^{O}C. The average sulphur release rate for the field columns was 0.0185 mM/kg/wk, which was approximately 1.5 times higher than the coarse ore cell at 4 ^{O}C and 0.36 times the rate at 22 ^{O}C. This is consistent with the site climate, described as "experiencing very cool summers, with January temperatures often below –30^{O}C "(Rescan, 1991). Site temperatures are therefore likely to be closer to 4 ^{O}C than 22^{O}C for most of the year. The sulphur release rate for the field columns also fell between rates estimated for waste rock with similar sulphide content tested in humidity cells at 4 ^{O}C and 22 ^{O}C. These results suggest that the sulphide oxidation rates for the Ulu materials are primarily influenced by temperature and grain size, rather than other test variables such as flushing rate or volume.

This conclusion differs from those made by Klohn (1998) based on the early field column results. Early results indicated "...much lower sulphide oxidation rate compared to controlled weathering in the laboratory..." attributed to the dual effects of an overall lower mean temperature and less frequent flushing in the field.

The NP depletion rates for the field columns were lower than NP depletion rates for the same material tested in humidity cells at 4 ^{O}C and 22 ^{O}C. The field column rate of 0.03 mM $CaCO_3$/kg/week was about half the NP depletion rate of the ore humidity cell at 4 ^{O}C, and about 25% of the NP depletion rate of the ore humidity cell at 22 ^{O}C. This suggests that the reduced volume and frequency of flushing in the field columns had a significant effect in reducing NP depletion rates as compared to humidity cell results, while having essentially no effect on sulphur depletion rates.

Table 12: Comparison of the Results of Weathering of Ulu Ore and Waste Rock under Different Conditions

	Ore					Waste Rock	
	Field Column #1	**Field Column #2**	**Cell @ 4°C**	**Cell @ 22°C**	**Tailings Cell 22°C**	**Cell @ 4°C**	**Cell @ 22°C**
S depletion rate (mM/kg/week)	0.022	0.015	0.012	0.052	0.119	0.010	0.044
NP depletion rate (mM $CaCO_3$/kg/week)	0.029	0.03	0.060	0.116	0.305	0.079	0.087
Threshold NPR	1.3	2.0	5.0	2.2	2.6	7.9	2.0
Time for S depletion (years)	310	450	563	132	82	698	159
Time for total NP depletion (years)	211	207	102	53	31	68	62
As loading rate (mg/kg/week)	0.0004 to 0.016 increasing	0.0002 to 0.026 slightly increasing	0.02to 0.063 decreases with time	0.02 to 0.153 decreases with time	0.28 to 0.61 decreases slightly		
Zn loading rate (mg/kg/week)	0.00005 to 0.0025 increasing	0.0008 to 0.04 increasing	0.03 to 0.0961 erratic	0.0006 to 0.1061 erratic	0.001 to 0.209 erratic		
SO4 conc. (mg/l) range/mean	74 to 665 270	74 to 480 269	3.3 to 26 7	10 to145 25	28 to- 857 78	0.7 to 18 7	13 to 69 25
As conc. (mg/l) range/mean	0.17 to 1.74 0.47	0.11 to 0.97 0.33	0.05 to 0.25 0.10	0.05 to 0.6 0.22	0.35 to 2.5 1.7	0.05 to.05 0.05	0.05 to.05 0.05
Zn conc. (mg/l) 1 range/mean	0.0132 to 0.332 0.069	0.009 to 0.0439 0.023	0.01 to 0.38 0.046	0.01 to 0.43 0.07	0.01 to 0.84 0.12	0.01 to 23 0.88	0.01 to 0.67 0.06

Note 1: The maximum Zn concentration for waste rock at 4° C of 23 mg/l occurred only on cycle 17 and may be a lab error. The next highest value was 0.13 mg/l.

As noted previously, S and NP release rates from the column are not necessarily representative of the internal reaction rates, as all oxidation and neutralization products may not be flushed from the field column between each sampling event. Thus threshold NPR values estimated from field column results should be viewed with caution. The calculated values of 1.3 and 2.0 are similar to the threshold NPR value of 2.2 estimated from the humidity cell on the same material at 22 $^{\circ}$C, and much lower than the threshold NPR value of 5.0 calculated from the humidity cell on the same material at 4 $^{\circ}$C. This suggests that threshold NPR values to avoid the onset of acid generation proposed by Klohn (1998) may be conservative, due to the substantially lower NP depletion rates resulting from less frequent flushing under field conditions as compared to humidity cell test conditions. Specifically, Klohn's suggested threshold values of 3 based on humidity cell tests at 22 °C on waste rock, coarse and fine ore; and 7 based on humidity cell test at 4 °C appear to be conservative given temperature and flushing conditions at the site, but longer term testing under site field conditions and/or dismantling and flushing of the field columns would be required to confirm this.

The NP production rates to sulphate production rates for all sampling events on all tests conducted on the coarse ore composite sample are shown on Figure 16. NP to sulphate production ratios of 1 and 3 are indicated on the graph. The figure indicates that the ratios between NP and sulphur production rates for the field columns lay between 1 and 3, and were generally closer to 1 than to 3. This may indicate that NP depletion in the field is controlled more by acid neutralization than by NP solubility, which appears to influence humidity cell results. Coarse ore tested in the humidity cell at 22 °C generally showed a slightly higher ratio, and at 4 °C generally had a NP to sulphate production ratio of greater than 3. The graph also shows that the field tests typically provided lower NP production rates compared to the humidity cell tests, but not lower sulphate production rates.

Figure 17 is similar to Figure 16 except that the results for the fine ore (tailings) cell and waste rock cells are also included within the limited axes. The field test columns produced the lowest NP to sulphate production rate ratios. Ratios were typically highest for coarse ore and waste rock cells at 4 °C, closely followed by the fine-grained ore (tailings) at 22 °C. The tailings cell produced the highest NP and sulphate production rate values. Ratios for the ore and waste rock cells at 22 °C were higher than the field column test, but not as high as the other tests.

The field columns were consistent with the humidity cell tests in that all tests on the coarse ore sample indicated that NP would be depleted prior to sulphide, such that the material would eventually produce acidic drainage. The projected time for acid generation from the field columns was substantially longer, primarily due to the apparent slower loss of NP from reduced flushing under field conditions.

As shown on Table 12, arsenic and zinc release or loading rates were substantially lower (1 to 3 orders of magnitude) from the field columns as compared to the humidity cells conducted on the coarse ore composite sample. The field release rates appear to be increasing over time, whereas release rates from the humidity cells appeared to be decreasing over time. The increasing rates in the field cells may indicate that the field cells are immature, i.e. the leach rates will continue to increase as oxidation products store up in the column, and become available for later flush events.

Comparative arsenic production rates are also shown on Figure 18. Figure 19 includes arsenic production rates for the waste rock and fine ore tailings tests, and indicates that substantially higher arsenic rates produced by the fine ore fraction.

Despite the lower arsenic and zinc loading rates demonstrated by the field columns, concentrations are elevated compared to humidity cell concentrations. Table 12 indicates that average arsenic concentrations from the field columns of 0.33 and 0.47 mg/l were 2 to 4 times higher than average concentrations produced from the humidity cell tests on the same coarse ore material. This may be a result of the reduced flushing rate in the field. Maximum concentrations released from the field columns (1.74 and 0.97 mg/l respectively) approached the average concentrations produced from the fine ore test cell at 22 ^{O}C. These concentrations may be of concern as they occasionally exceed the federal *Metal Mining Effluent Regulations* maximum allowable values (i.e. a maximum of 1 mg/l total arsenic, monthly average of 0.5 mg/l total arsenic).

As indicated on Table 12, average zinc concentrations released from the field columns were similar to, or slightly lower than, those released from the humidity cell tests on the same coarse ore sample.

4.6 Conclusions from Review of Field Column Data

Review of the extended field column test results on duplicate coarse ore samples indicated the following:

- pH generally showed a downward trend over the period for both columns.
- Sulphate release rates tended to increase in the later sampling events each year, suggesting lower oxidation rates occurred during the winter months.
- The sulphate release rates generally showed an increasing trend for both field columns, which was opposite to the trend for both ore and waste rock humidity cells. It is considered possible that sulphur release rates would continue to accelerate as increasing quantities of sulphate salts are stored in the field columns and become available for flushing. This means that the predicted lag times to onset of acidic drainage may continue to decrease as the field column mature.
- Whereas the early field column results reported by Klohn (1998) gave rise to a much lower sulphide oxidation rate compared to controlled weathering in the laboratory, the longer-term field rates were comparable with rates from the humidity cell tests on both coarse ore and waste rock, and were appropriate for expected site temperatures. This suggests that the sulphate release rates for Ulu materials may be predominantly influenced by site temperatures and grain size, rather than other test variables such as flushing rates or volumes.
- The NP release rate for field columns are less than half that of the coarse ore humidity cell at 4^{O}C. This suggests that the reduced volume and frequency of flushing under the field columns had a significant effect in reducing NP

dissolution and depletion rates as compared to humidity cell results, while having essentially no effect on sulphur depletion rates.

- Klohn's NPR threshold values to avoid acidic drainage, calculated from humidity cell results, were 3 and 7 for 22°C and 4°C respectively. These values are likely conservative due to the relatively large volumes of water used in a humidity cell test as compared to field conditions.
- The field column threshold NPRs to avoid acidic drainage, at 1.3 and 2.0, were lower than those predicted from humidity cells. This is due to the reduced NP depletion rate, as a result of lower flushing volumes and frequency under field conditions. Field column values should be reviewed with caution as all oxidation products may not be released as they are produced, and the sulphate release rates may continue to increase as products build up and become available for release on subsequent flush events. Confirmation of lower threshold NPR values would require continued test work (allowing for stabilization of oxidation rates), or dismantling and analysis of field column to confirm).
- Arsenic and zinc release or loading rates under field conditions were less than those in the humidity cell tests on similar coarse ore material, but showed an increasing trend which may indicate that the release rates were limited in the field columns by incomplete flushing. It is expected that these metals leaching rates may continue to increase as the field column matures.
- Arsenic loading rates showed seasonal trends, with higher release rates measured later in each year, suggesting lower oxidation rates occurred during the winter months. Zinc release rates were more erratic and did not appear to show significant seasonal trends.
- The field columns displayed higher arsenic concentrations than the humidity cells, with average arsenic concentrations (0.33 and 0.47 mg/l) that were 2 to 4 times higher than average concentrations produced from the humidity cell tests on the same coarse ore material. The higher concentrations are likely due to the reduced volume and frequency of flushing under field conditions.
- Zinc concentrations released from the field columns were similar to those released from humidity cell tests on similar coarse ore material, but demonstrated greater variability and range.
- Materials tested in the humidity cells and field columns tended to contain relatively high sulphide content relative to the general sample populations. Thus the results may be considered to a represent reasonable worst case for the grainsize tested. All tested samples had NPR values of 1.0 or less, and were projected to eventually produce acidic drainage, albeit after a lag time of decades or more.
- Both the NP and sulphate depletion rates for the ore, waste rock, and fine grained ore are low relative to kinetic test results from the International Kinetic Database (Morin, 1999).