Because the original rock compositions were complexly interfingered, the subsequent alteration also has a complex pattern of alteration. The more mafic hanging wall rocks, such as the metadacite, have been most extensively altered. Throughout the rock, secondary clay minerals, quartz, and earthy iron oxides characteristically fill in foliation planes and cross-cutting fractures.

The upper one to 30 feet of the deposit has been intensely weathered to produce an iron-oxide-rich gossan. The deposit has been enriched in copper below the gossan to a maximum depth of 225 feet. Chalcocite and bornite in a matrix of pyrite and chert (quartz) make up the deposit.

3.5.6 Waste Characterization

3.5.6.1 Introduction

The mining operation will include the removal and temporary stockpiling of topsoil, overburden, and waste rock. These materials will be stored in designated stockpiles during the operation of the mine and then returned to the open pit as backfill during site reclamation.

The objectives of the waste characterization study included the establishment of baseline concentrations and distributions of selected components within the topsoil, overburden, and waste rock. In addition, these materials were characterized with regard to their leachability in order to determine the method necessary to temporarily store these materials during the proposed short-term operation of the mine. Finally, the chemical behavior of the materials was used to determine the best environmental approach to backfilling and reclamation.

The characteristics of the topsoil are such that this material can be safety stored in an unlined site. It will be stored separately from all of the other waste materials so that it can be used as the final cover on the reclaimed site. Using this native topsoil as the final cover will enhance the site reclamation by accelerating the revegetation.

The overburden consists of glacial till, sandstone, and saprolite. Each of these materials was characterized separately since each has significantly different physical and chemical properties and mineralogy. It has been concluded that the till and sandstone can be stored in an unlined site known as the Type I stockpile. Stormwater runoff from this site will be collected in a series of settling ponds for clarification before discharge to surface waters of the state. The overburden will be returned to the open pit in the approximate stratigraphic position that they currently occupy in order to promote the reestablishment of the natural groundwater flow patterns.

Saprolite is a gritty material rich in silt and clay, which has been formed in the upper part of the Precambrian bedrock. Characterization of this material revealed that one-half of it could also be stored in the unlined Type I site. Approximately one-half of the total saprolite has an acid production potential and/or chemical leachability such that it will have to be stockpiled in a lined storage site. This lined site, known as the Type II stockpile, will contain a system for the collection and treatment of the water which comes in contact with this waste material.

Waste rock is defined as the Precambrian bedrock. It will be necessary to separate the waste rock in the field for placement in lined and unlined stockpiles based on observation and/or sulfur analysis. Approximately 30 percent of the waste rock can be stored in an unlined site, with the remaining 70 percent being stored in a lined site.

Saprolite and waste rock that will be stored in an unlined stockpile is referred to as Type I material. Saprolite and waste rock that will be stored in a lined stockpile is referred to as Type II material. Type I material contains less than one percent total sulfur. Type II material contains greater than one percent total sulfur. Experimental data shows that the actual level for dividing the saprolite and waste rock into Type I and Type II materials is close to two percent total sulfur based on leachability tests. The one percent level was chosen to provide an additional margin of safety.

The Type II material, which contains greater than one percent total sulfur, will be backfilled into the mine pit prior to the Type I waste rock. As the Type II material is returned to the pit, lime will be added to the material in order to retard the lowering of the pH and potential release of chemicals from the waste as it reacts with the inflowing groundwater. The accumulating rock will be sloped in order to enhance internal drainage. Sumps will collect the contact water and pumps will deliver to the wastewater treatment facility for as long as is required for safe operations in the pit.

Following the return of the Type I waste rock to the open pit, the Type I saprolite will then be added to the pit. The saprolite will be placed within the pit at approximately the same stratigraphic position it now occupies. This reworked saprolite will have a relatively low permeability and will retard the exchange of groundwater within the lower waste rock with that within the overlying sediments.

3.5.6.2 Materials and Sample Preparations

Samples of topsoil, overburden (till, sandstone, and saprolite), and waste rock were collected for testing and evaluation. Each of these materials was collected and handled in different manners.

Collected samples were transported to Foth & Van Dyke facilities using chain-of-custody procedures as outlined below. From the point of collection the name of the person who collected the samples, the date, time, and place of collection was recorded. The date, time, and name of persons assuming custody of the samples on behalf of Foth & Van Dyke was also recorded. Also, the name of the person who relinquished custody of the samples to Foth & Van Dyke was recorded with the date and time the transfer occurred. In addition to the above, WDNR personnel observed both the selection of the core materials and verified that the selected cores matched the Kennecott core logs, and observed waste rock sample treatment and compositing at Foth & Van Dyke's offices.

Two sets of topsoil samples were collected. The locations of both sets, KWC and KWR, are shown in Figure No. 3.5-18. The KWC series were collected from six backhoe pits dug within the perimeter of the open pit. These samples were double-bagged and refrigerated during collection.

These soils (KWC) were composited in the laboratory by cone and quartering for use in the chemical leaching studies. Part of the sample collection in the field and preparation in the laboratory was observed by WDNR personnel. Detailed soil pit descriptions are included in Appendix 3.5-M. The samples were composited such that there were three final samples representing the eastern, central, and western soils in the open pit area. Sample compositing data are included in Table No. 1 of Appendix 3.5-N.

The KWR soils were collected with a hand auger at the ten sites shown in the above-mentioned figure. The sites are located beneath the Type I stockpile area. The samples were collected from the upper ten to twenty inches of soil at each site. The samples were double-bagged and refrigerated during collection, shipment, and storage in the laboratory until they were composited to form one sample. Sample compositing data are included in Table No. 1 of Appendix 3.5-N. Subsamples of the composited soil were used in the soil sorption study.

The till, sandstone, and saprolite samples were obtained from soil borings conducted as part of the geotechnical and exploration coring program previously described. The location of the sampling sites are shown in Figure No. 3.5-19 and the logs and sample descriptions are presented in Appendices 3.5-F and 3.5-G. The samples were bagged and refrigerated upon collection and during transportation to, and storage in, the laboratory.

The till and sandstone samples were composited to form three major composites representing material in the east, central, and west portions of the open pit. A single composite was formed from Type I and II of the saprolite samples. Sample compositing data are included in Table No. 1 of Appendix 3.5-N. Subsamples of the composites were used in the chemical leaching and soil sorption studies. Subsamples of till and saprolite were also used to generate artificial stormwater runoff for the polymer testing portion of the wastewater treatment program. Sample compositing was observed by WDNR personnel.

Five waste rock composites were prepared based upon the percent sulfur assay values, which had been previously determined by Kennecott. The five samples, WR-1 through 5, represent the range of sulfide mineralization, from least to most, that will be expected in the waste rock. The range of sulfide mineralization is shown in Table No. 3.5-10 (Section 3.5.6.3.1). An additional composite, WW-1, was prepared from semi-massive sulfides. Each composite contains samples from a wide spatial distribution within the open pit and represents the major waste rock lithologies expected to be excavated in the pit.

The waste rock samples were selected from cores which had been stored in a secure facility in the vicinity of Ladysmith since they were collected in the late 1960s and early 1970s. WDNR personnel observed the selection of the core materials and verified that the selected core samples matched the Kennecott core logs. The locations of the samples used in the composites are shown in Figure No. 3.5-20.

The core samples were transported to the laboratory where they were broken into chips with a mean median diameter of one to two inches. Each chip was brushed in order to remove any attached fine material. This was done to distinguish and separate the chips from the fines. The major orthogonal axes of each chip were measured to the nearest millimeter. The mean axial lengths for each sample were calculated from the chip data. Volumes and surface areas were calculated using a density correction factor. The measurements, calculations, and data are included in Table Nos. 2 and 3 of Appendix 3.5-N.

A representative subsample of each waste rock sample was ground in a ball mill grinder in order to produce rock powder of less than 400 mesh mean diameter. The samples were ground in order of increasing total sulfur content and calculations were made of the carryover of iron and sulfur from sample to sample. The data and calculations included in Table No. 4 and the preceding five pages in Appendix 3.5-N show that the carryover is not considered to be a significant problem.

The samples were carefully composited in a fashion to assure comparability between coarse and ground rock composites. The sample treatment and compositing were also observed by WDNR personnel. Sample compositing data are included in Table No. 5 of Appendix 3.5-N. The waste rock composites were used for the acid production/neutralization potential, chemical leaching, and EP toxicity tests; and bench test studies.

Based on an evaluation of cross sections of waste rock distribution, it is estimated that approximately 98 percent of the waste rock materials that will be stored in the unlined Type I storage site are typified by sample WR-1. These materials contain less than 0.2 percent; total sulfur. Since it is possible that some degradation of the primary sulfide minerals may have occurred in the core samples stored for 15 to 20 years, an additional composite core sample was made from very low sulfur-bearing rock, which was collected in 1987. This "fresh" composite, WR-1A, was tested for its acid production potential and was found to be similar in behavior to the "old" low sulfur composite, WR-1. Sample compositing data from WR-1A are also included in Table No. 5 of Appendix 3.5-N. It was determined that aging of samples WR-2 through WR-5, would not affect the reliability of the results of the waste characterization study.

Other material, such as wastewater treatment plant precipitate and settling pond solids, are characterized in Section 3.5.6.3.7.

3.5.6.3 Laboratory Analyses

3.5.6.3.1 Bulk Chemical Analyses

Bulk chemical analyses were performed on all of the waste materials. The parameters analyzed, as listed in Appendix 3.5-O, include the major and minor elements approved by WDNR. As seen in the appendix, there was some variation in parameters analyzed depending upon the type of material. The results of the analyses are included in Appendix 3.5-O.

A summary table listing the major element concentrations of the topsoil, till, sandstone, and saprolite is presented in Table No. 3.5-9. As seen therein, the major component of these materials is silicon, followed by lesser amounts of aluminum and iron. Minor concentrations of titanium were found in all of the samples. Also, minor amounts of tin were found in the till, sandstone, and saprolite samples. Calcium and magnesium are minor constituents in the topsoil, till, and saprolite.

The compositions of the topsoil and till are quite similar with the exception that the till contains more tin and copper than the topsoil. This general similarity was expected since the soils have formed within the glacial till.

The west topsoil and till composites have more iron than the other topsoil and till composites. The west till composite also contains more copper and titanium than the central and east composites. The west sandstone composite has elevated copper values, and the east sandstone composite has elevated manganese values as compared to the other sandstone composites.

TABLE NO. 3.5-9

Major Element Concentrations from the Bulk Chemical Analyses of the
Topsoil, Till, Sandstone, and Saprolite Samples

Parameters	Units	Topsoil			Till			Sandstone			Saprolite
		West	Central	East	West	Central	East	West	Central	East	
Al	ug/g	30,600	28,000	32,600	52,600	38,900	41,200	6,140	7,530	5,440	34,800
Si	ug/g	259,000	260,000	295,000	344,000	336,000	318,000	437,000	395,000	376,000	347,000
Ca	ug/g	1,200	1,100	800	2,600	1,800	1,700	110	140	560	2,100
K	ug/g	260	180	110	310	240	170	69	16	27	130
Mg	ug/g	840	620	780	2,000	3,000	1,400	190	46	77	1,000
Na	ug/g	22	19	16	9	6	14	6	7	6	6
Cr	ug/g	9.5	6.0	7.5	9.1	9.6	11	2.3	1.7	1.6	9.2
Cu	ug/g	4.0	2.7	2.8	83	13	15	34	3	13	160
Fe	ug/g	10,000	4,400	6,000	10,000	5,700	7,000	680	430	1,100	12,000
Mn	ug/g	610	280	470	460	160	190	10	67	200	310
Pb	ug/g	9.0	5.0	10	2.3	3.5	2.3	0.4	0.6	1.3	29
Sn	ug/g	<200	<233	<200	1,600	620	1,900	710	960	570	560
Ti	ug/g	3,100	3,190	3,110	4,100	1,800	2,400	630	430	180	1,300
Zn	ug/g	18	19	17	21	18	22	3	3	10	110
MOISTURE	%	23	23	14	8.3	9.7	8.4	13	13	13	13
C	ug/g	-	-	-	590	630	510	1,700	200	190	280
S	%	0.21	0.21	0.20	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10

The major element concentrations found in the waste rock samples are summarized in Table No. 3.5-10. Similar to the topsoil and overburden samples, the waste rock composites are made up primarily of silicon with lesser amounts of aluminum and iron. Also, titanium is a minor constituent in these samples. Its occurrence is further discussed below.

Several progressive compositional changes can be observed in the data. The sulfur and copper concentrations increase from sample WR-1 to WR-5, while the opposite trend is noted for calcium and manganese. There is also some noteworthy variability in the elemental compositions. High tin and zinc concentrations were found in sample WR-1. The high lead and zinc content of WR-3 is probably due to small amounts of galena (PbS) and sphalerite (ZnS). The small amounts of cobalt and nickel also found in WR-3 are common minor constituents of sphalerite and pyrite (FeS).

The results of the bulk chemical analyses of the waste materials are to be used as a basis of comparison of the leachability of the different wastes. They are also used to establish the baseline concentration of the measured parameter within the waste materials and of the topsoil and till beneath the Type I stockpile.

The measured parameters of the topsoil, till and saprolite are within the normal ranges of these parameters determined through other soil studies in the United States (Kabata-Pendias and Pendias, 1984). The metal concentrations measured within the sandstone are less than or equal to those measured in other sandstones (Krauskopf, 1972). The range of metal and sulfur values measured within the waste rock samples generally falls within a broad range of values normally expected in areas of disseminated sulfide mineralization associated with massive sulfide deposits (BCMC, 1974).

3.5.6.3.2 Acid Production and Neutralization Studies

The acid production studies were conducted on samples of powdered waste rock in order to determine method of waste rock storage when waste rock is temporarily stockpiled during the mining operation. The neutralization studies were conducted to determine whether neutralization of the waste rock would be required during backfilling.

The estimation of acid production potential using powdered rock suspension provides a worst case approximation for the Flambeau waste rocks. The reasons for this are:

1. Powdered rock will be the material size for only two to three percent of the stockpiled waste and will represent a maximum of ten percent of the backfilled waste.

TABLE NO. 3.5-10

Major Element Concentrations from the Bulk Chemical Analyses
of the Waste Rock Samples

Parameters	Units	WR - 1	WR - 2	WR - 3	WR - 4	WR - 5
Al	ug/g	109,000	122,000	124,000	108,000	109,000
Si	ug/g	357,000	330,000	336,000	349,000	269,000
Ca	ug/g	5,200	1,500	2,300	1,800	252
K	ug/g	700	590	360	870	118
Mg	ug/g	9,400	6,400	7,100	8,900	345
Na	ug/g	45	62	43	38	22
Co	ug/g	18	28	60	35	23
Cr	ug/g	24	29	25	17	2.3
Cu	ug/g	540	2,700	3,900	5,000	6,400
Fe	ug/g	33,000	38,000	42,000	45,000	38,000
Pb	ug/g	9	16	60	24	7
Mn	ug/g	310	160	130	180	19
Ni	ug/g	7.1	14	31	11	6.1
Sn	ug/g	2,600	<300	680	<300	460
Ti	ug/g	2,600	3,000	2,900	2,600	2,000
Zn	ug/g	1,200	98	7,900	830	41
S	%	<0.10	0.49	0.70	2.0	4.8

2. Chemical reactivity is related to exposed surface area. The surface area of the powder is about one million times greater per unit mass than that of the anticipated waste rock grain sizes. The powdered material will, therefore, be considerably more reactive than the actual waste.

3. The exposure of the sulfide grains was greatly enhanced by crushing these rocks. The sulfide minerals in most of the Flambeau rocks are concentrated within layers within the rocks rather than randomly distributed throughout the rocks. Therefore, the larger the size of the rock fragments the fewer sulfide grains, on average, that will be exposed for chemical reactions.

4. The powdered grain sizes are optimal for attack by microorganisms such as *Thiobacillus ferrooxidans*. This aerobic bacteria produces sulfuric acid as a result of its oxidation of very fine-grained sulfide minerals, especially pyrite.

The initial acid production potential tests followed the methods of B.C. Research (1982). This included calculating the theoretical potential acid production which, in kilograms per tonne, is equivalent to the percent sulfur of the sample multiplied by 30.62 (factor from B.C. Research, 1982). After suspending waste rock powder in deionized (DI) water for 30 minutes, the "natural" pH could be determined. If the "natural" pH was greater than 3.50, the suspension was titrated with sulfuric acid to a pH of 3.50. The volume of acid used in the titration times 4.9 (for suspensions with liquid to solid ratios of 10 to 1) equals potential acid consumption, in kilograms per tonne, of the sample. If the potential acid production of a sample exceeded the potential consumption of acid, then theoretically it might release acid upon exposure to the surficial environment. Data from two duplicated acid consumption tests are included in Table No. 1 of Appendix 3.5-P.

In addition to the rapid titration employed in the above consumption tests, stepwise titration was performed on other sets of powdered waste rock samples. During these titrations, the suspension pH was recorded after each standard volume of acid was added to the suspension. The acid required to titrate the suspension to a pH of 3.50 was then determined graphically. The data from this test is included in Table No. 2 of Appendix 3.5-P. All of the "natural" pHs and quantities of acid consumption were different for each of these three tests.

Based upon the above experiments, it was concluded that the lowest sulfur-bearing waste rock samples, WR-1 through 2, would not be acid producers and that the higher sulfur-bearing samples, WR-3 through 5, may be acid producers. A sample of semi-massive sulfide ore, designated WW-1, was tested with the waste rock samples as a check on the method. Sample WW-1, with a sulfur content of 34 percent, is a strong acid producer, as expected.

In order to determine if samples WR-3 through 5 would be acid producers, additional samples were suspended in a nutrient medium and inoculated with cultures of *Thiobacillus ferrooxidans*. This microbial confirmation test demonstrated that WR-3 and 4 would definitely not be acid producers and that WR-5 might. Data and procedures for this test are included in Table No. 3 of Appendix 3.5-P.

During the course of this study, it became apparent that two variables were causing the variables in the "natural" pH measurements and the determined acid production potentials. They were the time-dependent pH buffering capacity of the powdered waste rock, and the length of time that had lapsed between the time the rocks had been ground and when the tests had been conducted.

The time-dependent buffering capacity of the waste rock samples was evaluated by starting with the acid consumption test. Instead of terminating the experiment when the titration endpoint had been reached, the samples were allowed to rest for certain time periods as shown in Table No. 4 of Appendix 3.5-P. At the end of the time interval, the pH was measured and since this pH had always risen above 3.50, more acid was added to return the suspension pH to 3.50. These re-equilibrations were conducted for a total lapsed time of 130 to 140 hours. The results of the test, included in Appendix 3.5-P, indicate that although the buffering capacity of these wastes is low, it is persistent.

Numerous "natural" pH measurements were determined during this study. The data were tabulated and organized with respect to the time between addition of water to the sample, and the time that had elapsed between the grinding of the samples and determinations of sample pH. Certain trends in the data became apparent. The tabulated data, included in Table No. 5 of Appendix 3.5-P, shows that for a time lapse or "age", there was a slight increase in pH with increasing time of suspension in the low sulfur samples WR-1 through 3. There was a slight decrease in pH with increasing suspension time in the high sulfur samples WR-4 and 5 and WW-1. For a given time of suspension, the pH initially decreased with increasing "age" and then increased.

Calculated acid consumption values determined for different ages of waste rock powder are presented in Table No. 3.5-11. The data indicate that for each material tested the acid consumption decreased and then increased with increasing age of the powders. The highest acid consumption values were recorded in samples 180 to 300 days after they were ground.

TABLE NO. 3.5-11

Theoretical Potential Acid Production (kg/tonne), Natural pH and Calculated Acid Consumption for the Waste Rock Composites Aged for Various Times Before Testing

Sample	Percent Sulfur	Potential Acid Production	16 DAY		30 DAY		180 DAY		300 DAY	
			Natural pH	Acid Consumption	Natural pH	Acid Consumption	Natural pH	Acid Consumption	Natural pH	Acid Consumption
WR-1	<0.10	<3.06	6.88	2.55	6.48	1.08	6.95	13.92	7.93	13.72
WR-1A	<0.17	<5.21	8.06	2.45	--	--	--	--	7.64	3.82
WR-2	0.49	15.0	5.32	1.18	4.90	0.83	5.40	3.58	5.68	2.35
WR-3	0.70	21.4	5.15	1.67	4.75	1.23	5.15	2.70	5.45	4.95
WR-4	2.0	61.2	4.82	1.37	4.42	1.03	4.96	4.26	4.96	3.28
WR-5	4.8	147.0	4.30	0.39	4.30	0.48	4.40	1.37	4.28	1.03
WW-1	34	1,040.0	3.72	0.15	3.90	0.27	--	--	3.35	0.25

All of the powdered waste rock samples and WW-1 were progressively titrated with dilute calcium hydroxide solutions from their natural pHs to a pH greater than 9.0. Based upon the data included in Appendix 3.5-P, the quantity of calcium hydroxide, or lime, that would have to be added to the wastes to increase the suspension pH to 6.0 and 7.0 was calculated. An illustration of a typical base and acid titration of a waste rock suspension (WR-3) is shown in Figure 3.5-21. The calculated quantities of dry powdered lime were added to 20 grams of rock powder to which 200 mL of DI water were added. After stirring for one hour, the suspension pH was recorded and the samples were centrifuged and analyzed for sulfate, copper, iron, and manganese.

The results, included in Table No. 6 of Appendix 3.5-P, are summarized in Table No. 3.5-12 for samples WR-4, WR-5, and WW-1. The results indicate that no reduction in sulfate occurred with lime treatment and that only slight reductions in manganese occurred as a result of the lime addition. Other factors operate to mitigate these concentrations as discussed in Section 3.5.6.3.3.2. Significant reductions to copper and iron concentrations were recorded for different concentrations of added lime. The most significant reduction of copper in the suspensions occurred between the pH 6 and pH 7 treatments. The most significant reduction of iron occurred as a result of liming the suspension to pH 6.

The measured pHs of the "pH 6" suspensions ranged from 5.4 to 5.7 and those of the "pH 7" suspensions from 6.4 to 6.9. The fact that the actual pH values were lower than the calculated pH values is considered to be a function of incomplete dissolution of the calcium hydroxide, which is a sparingly soluble material.

3.5.6.3.3 Leaching Studies

Two different column leaching tests were performed on the materials that will be stored in stockpiles during the operation of the mine. One test, referred to as the wet/dry leaching test, simulated the reactions of the material stored above grade to alternating wet and dry cycles caused by rainwater infiltration. The other test, referred to as the saturated leaching test, simulated the reaction between those materials that will be returned to the pit which will ultimately be in continuous contact with groundwater. The column leaching tests were performed under the following conditions:

1. All materials were leached with a synthetic solution made up with DI water approximately the pH of rainwater (i.e., pH of 5.3). The columns were saturated for one day and allowed to drain for four days. This cycle was repeated 16 times. Leachate samples were collected during the first day of drainage during cycles 1, 2, 4, 8, and 16. Parameters for which there are no holding times, or for which there are very short holding times, were analyzed immediately.

TABLE NO. 3.5-12

A Comparison Between Selected Parameters of Three High Sulfur Wastes Leached with DI Water and with Lime Added to Increase the Suspension pH

Parameter	Units	Untreated			pH 6			pH 7		
		WR-4	WR-5	WW-1	WR-4	WR-5	WW-1	WR-4	WR-5	WW-1
SO4	mg/l	180	180	180	200	190	730	190	380	750
Cu	ug/l	24,000	59,000	180,000	7,100	28,000	190,000	1,200	4,800	1,400
Fe	ug/l	450	11,000	130,000	120	530	1,500	400	570	1,200
Mn	ug/l	420	510	570	370	470	360	330	390	300
Ca(OH)2 ADDED	g/Kg	--	--	--	0.31	0.67	4.25	0.63	1.07	5.07
	(#/tonne)	--	--	--	0.68	1.48	9.36	1.39	2.36	11.20

These included pH, specific conductivity, temperature,mercury, and sulfate. A subsample from each column was preserved for metals analysis. Samples collected during cycles 4 and 8 were analyzed for key parameters. These key parameters were determined from the cycle 1, 2, and 16 sets of analyses. The selection of the key parameters was approved by the WDNR staff. The list of all parameters analyzed in the wet/dry leaching tests is presented in Table No. 3.5-13, and the complete chemical analyses are included in Appendix 3.5-Q. Those materials subjected to wet/dry leaching include the three topsoil, till and sandstone composites, the saprolite composite, and the powdered and chip-sized (one- to two-inch diameter) subsample of the five waste rock composites.

2. Some wet/dry leaching was performed on semi-massive ore composite WW-1. Most of the leachate derived from this material was used in the bench testing portion of the wastewater treatment facility design.

3. Those materials which will be in continuous contact with groundwater by being returned to the pit were further leached within their respective columns. These columns were further leached by a process of saturation with synthetic groundwater, cycled every two to three days, and maintained under anoxic conditions by sparging the columns with argon gas. The composition of the synthetic groundwater was based on the first seven consecutive months of analyses of groundwater samples collected from upgradient well nest MW-1005. The method of determination of the composition of the synthetic groundwater is included in Appendix 3.5-Q.

   Based upon the results of the analyses of the wet/dry leaching samples, a reduced list of parameters for the saturated leaching samples was approved by WDNR staff. Following the completion of the analyses of the cycle one and two leachate samples, additional reductions in the parameter list for the cycle 4 and 8 samples were approved by the WDNR staff. The complete list of saturated leaching parameters is presented in Table No. 3.5-14, and the complete chemical analyses are included in Appendix 3.5-Q. Following sample collection, removed leachate was immediately replaced by new synthetic groundwater.

4. Several sizes and types of columns were used in the leaching experiments depending upon the volume and nature of the material to be leached.

   The waste rock composite powders that have high liquid to solid ratios in these tests were leached in 250-mL polycarbonate centrifuge bottles. By centrifuging the samples each time a sample was to be collected (i.e. leachate drained), the retention of the powders could be maximized. However, this produced relatively small leachate

TABLE NO. 3.5-13

Parameters Analyzed During the Sampling Cycles for the Wet/Dry Leaching of the Waste Materials

Parameter	Topsoil					Till				
	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum		X	X	X	X	X	X	X	X	X
Arsenic	X	X			X	X	X			X
Barium	X	X			X	X	X			X
Beryllium	X	X			X	X	X			X
Cadmium	X	X			X	X	X			X
Chromium	X	X	X	X	X	X	X	X	X	X
Cobalt	X	X			X	X	X			X
Copper	X	X			X	X	X	X	X	X
Iron	X	X	X	X	X	X	X	X	X	X
Lead	X	X			X	X	X	X		X
Manganese	X	X	X	X	X	X	X	X	X	X
Mercury	X	X	X	X	X	X	X	X	X	X
Molybdenum	X	X			X	X	X			X
Nickel	X	X			X	X	X			X
Selenium	X	X			X	X	X			X
Silver	X	X			X	X	X			X
Sodium	X	X			X	X	X			X
Thallium	X	X			X	X	X			X
Tin	X	X			X	X	X			X
Titanium	X	X	X	X	X	X	X	X	X	X
Uranium	X	X			X	X	X			X
Fluoride	X	X	X	X	X	X	X			X
Sulfate	X	X	X	X	X	X	X	X	X	X
TDS	X	X	X	X	X		X	X		
Spec. Cond.	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X
Temp.	X	X	X	X	X	X	X	X	X	X

TABLE NO. 3.5-13 (Cont.)

Parameter	Sandstone Cycle 1	Sandstone Cycle 2	Sandstone Cycle 4	Sandstone Cycle 8	Sandstone Cycle 16	Saprolite Cycle 1	Saprolite Cycle 2	Saprolite Cycle 4	Saprolite Cycle 8	Saprolite Cycle 16
Aluminum	X	X	X	X	X	X	X	X	X	X
Arsenic	X	X	X	X	X	X	X			X
Barium	X	X			X	X	X			X
Beryllium	X	X			X	X	X			X
Cadmium	X	X			X	X	X			X
Chromium	X	X	X	X	X	X	X	X	X	X
Cobalt	X	X			X	X	X			X
Copper	X	X	X	X	X	X	X	X	X	X
Iron	X	X	X	X	X	X	X	X	X	X
Lead	X	X	X	X	X	X	X	X	X	X
Manganese	X	X	X	X	X	X	X	X	X	X
Mercury	X	X	X	X	X	X	X	X	X	X
Molybdenum	X	X			X	X	X			X
Nickel	X	X			X	X	X			X
Selenium	X	X	X	X	X	X	X			X
Silver	X	X			X	X	X			X
Sodium	X	X	X	X	X	X	X			X
Thallium	X	X			X	X	X			X
Tin	X	X			X	X	X			X
Titanium	X	X	X	X	X	X	X	X	X	X
Uranium	X					X	X			
Zinc	X	X	X	X	X	X	X	X	X	X
Fluoride	X					X				
Sulfate	X	X	X	X	X	X	X	X	X	X
TDS	X	X				X	X			
Spec. Cond.	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X
Temp.	X	X	X	X	X	X	X	X	X	X

TABLE NO. 3.5-13 (Cont.)

Parameter	Rock Chips					Rock Powder				
	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum	X	X	X	X	X	X	X	X	X	X
Arsenic	X	X			X	X	X			X
Barium	X	X			X	X	X			X
Beryllium	X	X			X	X	X			X
Cadmium	X	X			X	X	X			X
Chromium	X	X			X	X	X			X
Cobalt	X	X	X	X	X	X	X			X
Copper	X	X	X	X	X	X	X	X	X	X
Iron	X	X	X	X	X	X	X	X	X	X
Lead	X	X	X		X	X	X	X	X	X
Manganese	X	X	X	X	X	X	X	X	X	X
Mercury	X	X	X	X	X	X	X	X	X	X
Molybdenum	X	X			X	X	X			X
Nickel	X	X	X	X	X	X	X			X
Selenium	X	X			X	X	X			X
Silver	X	X			X	X	X			X
Sodium	X	X	X	X	X	X	X			X
Thallium	X	X			X	X	X			X
Tin	X	X			X	X	X			X
Titanium	X	X			X	X	X			X
Uranium	X	X			X	X	X			X
Zinc	X	X	X	X	X	X	X	X	X	X
Fluoride	X					X				
Sulfate	X	X	X	X	X	X	X	X	X	X
TDS	X	X				X				
Spec. Cond.	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X
Temp	X	X	X	X	X	X	X	X	X	X

TABLE NO. 3.5-14

Parameters Analyzed During the Sampling Cycles for the Saturated Leaching of the Waste Materials

	Till					Sandstone				
Parameter	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum	X	X	X	X	X	X	X	X	X	X
Chromium	X	X			X	X	X	W	W	X
Copper	X	X	X	X	X	X	X	X	X	X
Iron	X	X	C	C	X	X	X	X	X	X
Lead	X	X			X	X	X			X
Manganese	X	X			X	X	X	X	X	X
Mercury	X	X	X	X	X	X	X	X	X	X
Sodium	X	X			X	X	X			X
Titanium	X	X	C	C	X	X	X	X	X	X
Zinc	X	X			X	X	X			X
Fluoride	X	X	X	X	X	X	X	X	X	X
Sulfate	X	X	X	X	X	X	X	X	X	X
Chloride	X	X	X	X	X	X	X	X	X	X
TDS	X	X	X	X	X	X	X	X	X	X
Alkalinity	X	X	X	X	X	X	X	X	X	X
Spec. Cond.	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X
Temp.	X	X	X	X	X	X	X	X	X	X

TABLE NO. 3.5-14 (Cont.)

	Saprolite				
Parameter	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum	X	X	X	X	X
Copper	X	X	X	X	X
Iron	X	X	X	X	X
Lead	X	X	X	X	X
Manganese	X	X	X	X	X
Mercury	X	X			X
Sodium	X	X			X
Titanium	X	X	X	X	X
Zinc	X	X			X
Fluoride	X	X	X	X	X
Sulfate	X	X	X	X	X
Chloride	X	X	X	X	X
TDS	X	X	X	X	
Alkalinity	X	X	X	X	X
Spec. Cond.	X	X	X	X	X
pH	X	X	X	X	X
Temp.	X	X	X	X	X

	Rock Chips					Rock Powder				
Parameter	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Aluminum	X	X	X	X	X	X	X	X	X	X
Copper	X	X	X	X	X	X	X	2-5	2-5	X
Iron	X	X	4,5	4,5	X	X	X	X	X	X
Lead	X	X			X	X	X	2,3	2,3	X
Manganese	X	X	2-5	2-5	X	X	X	5	5	X
Mercury	X	X	X	X	X	X	X	X	X	X
Zinc	X	X	2,4,5	2,4,5	X	X	X	X	X	X
Fluoride	X	X			X					
Sulfate	X	X	X	X	X	X	X	X	X	X
Chloride	X	X	X	X	X					
TDS	X	X	X	X	X					
Alkalinity	X	X	X	X	X					
Spec. Cond.	X	X	X	X	X	X	X	X	X	X
pH	X	X	X	X	X	X	X	X	X	X
Temp.	X	X	X	X	X	X	X	X	X	X

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1. Where an "X" appears all of the composite samples (e.g., till) and all of the waste rock samples for that cycle and parameter were analyzed.
2. A "W", "C", or "E" means only the west, central, or east composite sample was analyzed.
3. In the waste rock analyses, a "2-5" means samples WR-2 through 5 were analyzed. A "2, 3" means samples WR-2 and 3 were analyzed.

sample volumes. These samples required disturbance to perform the test. They were the only samples that were disturbed during a given leaching experiment.

The waste rock chip composites and the saprolite composite were leached in 7-1/2-gallon cylindrical high-density polyethylene tanks. Since the saprolite composite contained both less than and greater than one percent sulfur bearing materials, these tests provided worst case analysis of the saprolite to be stored in the unlined area. The samples were supported above the base of the tanks by a circular plate made from sheet acrylic, in which drain holes had been drilled, and mounted on legs made of cast acrylic rod. In order to limit the loss of any fine grained material which might result from the leaching process, the top of the acrylic plate was covered with a mat of heavy metal-free borosilicate glass wool. During the saturated leaching, the argon gas was bubbled through the tank from beneath the support plate.

The till and topsoil composites were similarly leached but in five-gallon tanks. A drawing of a typical tank is shown in Figure No. 3.5-22.

Due to the difficulties experienced in obtaining sandstone samples, these materials were leached in columns made from two-inch-diameter by 24-inch-long sections of cast acrylic tubing. The set-up within the column was similar to that in the tanks with the exception of the differences in column materials and dimensions. These columns drained poorly and when the saturated leaching experiment was begun, these samples were quantitatively transferred to 3.8-liter polyethylene tanks. In spite of the difficulty in testing, the results are considered to be representative of field conditions.

Prior to initiating the leaching tests, all of the columns were leached with 1N nitric acid and thoroughly rinsed with DI water. This leaching was conducted to remove possible trace metal contaminants from the surfaces of the tanks and support materials. The charging of the columns with the waste materials and synthetic rainwater was observed by WDNR personnel. Sample weights, liquid volumes, and calculated liquid to solid ratios are included in Appendix 3.5-Q.

5. Specific conductivity, temperature, and pH were always measured during each cycle, whether samples were collected or not.

3.5.6.3.3.1 <u>Wet/Dry Leaching Study</u>

The specific conductivity and pH measurements made for all of the wet/dry cycles of the topsoil and the till, sandstone, and saprolite composites are presented in Table No. 3.5-15. The pH

TABLE NO. 3.5-15

pH and Specific Conductivity Values for the Wet/Dry Leaching of the Topsoil Samples

Cycle	Date	Parameters	West	Central	Topsoil East
1	08/02/88	pH	6.35	6.70	6.67
		Spec. Con.	39	76	49
2	08/07/88	pH	5.70	5.75	5.75
		Spec. Con.	31	27	36
3	08/12/88	pH	5.38	5.62	5.58
		Spec. Con.	25	37	33
4	08/17/88	pH	5.46	5.67	5.57
		Spec. Con.	35	28	28
5	08/22/88	pH	5.73	5.94	5.77
		Spec. Con.	27	37	24
6	08/27/88	pH	5.53	5.84	5.60
		Spec. Con.	27	55	25
7	09/01/88	pH	5.60	5.96	5.68
		Spec. Con.	32	60	25
8	09/07/88	pH	5.68	6.02	5.68
		Spec. Con.	43	64	36
9	09/11/88	pH	5.60	5.90	5.62
		Spec. Con.	35	58	29
10	09/16/88	pH	5.82	6.39*	5.84
		Spec. Con.	42	306*	32
11	09/21/88	pH	5.85	6.12	5.89
		Spec. Con.	47	121	34
12	09/26/88	pH	5.84	6.17	5.91
		Spec. Con.	46	108	37
13	10/01/88	pH	6.11	6.28	6.21
		Spec. Con.	57	77	49
14	10/06/88	pH	5.90	6.25	6.07
		Spec. Con.	47	90	43

TABLE NO. 3.5-15 (Cont.)

Cycle	Date	Parameters	West	Central	Topsoil East
15	10/11/88	pH	6.00	6.26	6.04
		Spec. Con.	85	100	53
16	10/15/88	pH	5.83	6.09	5.93
		Spec. Con.	61	79	55

Units: pH - Standard units
Spec. Con. - umhos/cm
* = Slow-draining turbid sample

TABLE NO. 3.5-15 (Cont.)

pH and Specific Conductivity Values for the Wet-Dry
Leachings of the Till, Sandstone, and Saprolite Samples

			Till			Sandstone			
Cycle	Date	Parameter	West	Central	East	West	Central	East	Saprolite
1	03/17/88	pH	6.95	7.15	7.20	7.90	7.75	7.55	7.65
		Spec. Con.	16	10	39	75	273	321	52
2	03/22/88	pH	5.30	5.85	6.30	7.50	--	6.70	7.15
		Spec. Con.	20	22	29	214	852	271	26
3	03/27/88	pH	7.06	7.08	7.20	8.88	8.21	8.99	8.46
		Spec. Con.	21	23	24	156	245	176	38
4	04/01/88	pH	7.24	6.89	7.25	8.03	8.12	7.71	8.56
		Spec. Con.	39	32	66	--	180	73	98
5	04/06/88	pH	7.03	6.89	7.45	8.30	8.12	7.73	8.67
		Spec. Con.	17	17	30	273	146	94	33
6	04/11/88	pH	7.05	6.99	7.05	8.66	8.21	8.51	8.57
		Spec. Con.	13	13	22	--	105	235	30
7	04/16/88	pH	7.47	7.08	7.59	8.63	7.80	8.52	8.66
		Spec. Con.	11	12	22	--	89	--	29
8	04/21/88	pH	8.07	7.52	7.93	8.56	7.88	8.64	8.88
		Spec. Con.	31	15	19	--	79	--	29
9	04/26/88	pH	7.92	7.40	8.22	8.35	7.44	8.35	8.51
		Spec. Con.	14	13	20	--	82	--	26
10	05/01/88	pH	8.20	7.58	7.82	8.69	7.48	8.27	8.62
		Spec. Con.	32	20	23	--	75	--	32
11	05/06/88	pH	7.85	7.16	8.02	8.63	7.49	8.43	8.62
		Spec. Con.	14	13	24	--	64	--	35

TABLE NO. 3.5-15 (Cont.)

			Till			Sandstone			
Cycle	Date	Parameter	West	Central	East	West	Central	East	Saprolite
12	05/10/88	pH	8.38	8.50	7.95	8.79	7.59	8.53	8.85
		Spec. Con.	26	41	22	--	46	--	30
13	05/16/88	pH	8.18	8.18	8.22	8.07	7.30	8.30	8.80
		Spec. Con.	13	22	22	283	43	--	29
14	05/21/88	pH	8.45	8.47	8.22	8.06	7.40	8.35	8.80
		Spec. Con.	29	54	30	26	41	--	32
15	05/26/88	pH	8.34	8.07	7.95	8.00	7.30	8.20	8.76
		Spec. Con.	12	20	22	151	35	--	27
16	05/31/88	pH	8.04	8.04	7.63	7.90	7.30	8.16	8.76
		Spec. Con.	10	13	16	125	33	--	33

UNITS: pH - standard units
Spec. Con. - umhos/cm

values for the topsoil composites declined approximately one standard unit from Cycle 1 to Cycles 3 and 4. The values increased gradually through the remaining cycles, where they appear to have stabilized in the 5.7 to 6.2 range. The Cycle 16 values were about one-half standard unit below the Cycle 1 values.

The pH values measured in the till leachates declined by one and one-half units between Cycles 1 and 2. Thereafter the pH values rose, and by Cycle 16 were in the range of 7.8 to 8.3, approximately one standard unit above the initial readings. The sandstone leachate pH values declined about one-half to one unit between Cycles 1 and 2. However, they then increased more than two units between Cycles 2 and 3. Thereafter they decline, especially those of the central sandstone composite, to the Cycle 16 values which are in the range of 7.5 to 8.5 and essentially the same as the Cycle 1 values. The pH measurements in the saprolite composite indicate that a slight decline in pH occurs between Cycles 1 and 2. Following the second Cycle, they increase and appear to stabilize in the range of 8.5 to 9.0, which is about one standard unit greater than the Cycle 1 values.

Unlike the pH values, where trends were observable, the conductivity values fluctuated considerably. There were no particular trends in conductivity values evident.

Concentration of selected parameters measured in the leachate from the topsoil, till, sandstone, and saprolite composites are presented in Table No. 3.5-16. The quantities of these parameters leached from the composites were calculated by multiplying the concentrations by the volume of rainwater used to saturate the sample, divided by the amount of sample. These quantities are presented in Table No. 3.5-17. The quantities of metals leached, and the time when they were leached the most, varied considerably between types of composite materials.

The maximum quantities of aluminum, chromium, iron, and titanium leached from the topsoil occurred in Cycle 1. The quantities of these elements declined rapidly as the cycles proceeded. The quantities of copper leached varied with cycle number, but they were within a narrow range through the course of 16 cycles. Manganese leached increased as the cycles progressed. The maximum quantities of aluminum, chromium, iron, and titanium were found in the leachate from the central topsoil composite. The maximum manganese quantities were found in the west topsoil composite leachate.

The maximum quantities of aluminum, chromium, iron, manganese, and titanium were leached from the till composites during cycles 4 and 8. Copper quantities were greatest in the Cycle 1 leachate. The peak elemental quantities for most of the

TABLE NO. 3.5-16

Concentrations of Selected Parameters in Wet-Dry Topsoil, Till, Sandstone, and Saprolite Leachate

Topsoil Wet-Dry Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	3,380	36,800	18,600
Cr	ug/L	6	80	32
Cu	ug/L	10	23	14
Fe	ug/L	3,100	33,000	15,000
Mn	ug/L	110	860	260
Ti	ug/L	272	2,880	1,530

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	498	653	7,770
Cr	ug/L	<2	2	13
Cu	ug/L	11	<10	7
Fe	ug/L	820	1,100	8,700
Mn	ug/L	60	54	210
Ti	ug/L	24	57	686

TABLE NO. 3.5-16 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	321	121	528
Cr	ug/L	2	3	3
Cu	ug/L	--	--	--
Fe	ug/L	460	150	640
Mn	ug/L	330	53	440
Ti	ug/L	81	66	98

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	149	137	260
Cr	ug/L	<2	<2	<2
Cu	ug/L	--	--	--
Fe	ug/L	1,300	1,300	820
Mn	ug/L	1,200	1,300	1,500
Ti	ug/L	<4	<4	5

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	117	30	80
Cr	ug/L	<2	<2	<2
Cu	ug/L	11	13	<10
Fe	ug/L	6,600	1,800	3,000
Mn	ug/L	1,900	1,900	3,100
Ti	ug/L	<4	<4	<4

TABLE NO. 3.5-16 (Cont.)

Till Wet-Dry Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	2,360	2,060	2,770
Cr	ug/L	<2	2	2
Cu	ug/L	1,000	530	110
Fe	ug/L	1,100	990	1,800
Mn	ug/L	110	23	110
Ti	ug/L	75	85	93

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	3,640	9,250	8,010
Cr	ug/L	3	8	10
Cu	ug/L	46	25	38
Fe	ug/L	3,200	7,200	10,000
Mn	ug/L	92	92	130
Ti	ug/L	190	591	445

TABLE NO. 3.5-16 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	20,700	29,700	21,800
Cr	ug/L	18	43	31
Cu	ug/L	130	45	39
Fe	ug/L	13,000	19,000	35,000
Mn	ug/L	320	200	150
Ti	ug/L	1,100	1,910	1,300

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	40,800	12,000	10,900
Cr	ug/L	38	<3	<3
Cu	ug/L	270	31	20
Fe	ug/L	28,000	7,000	7,400
Mn	ug/L	550	76	71
Ti	ug/L	2,200	775	667

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	13,600	4,680	12,500
Cr	ug/L	19	7	12
Cu	ug/L	26	12	89
Fe	ug/L	5,500	3,400	7,700
Mn	ug/L	79	19	180
Ti	ug/L	903	242	606

TABLE NO. 3.5-16 (Cont.)

Sandstone Wet-Dry Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	13,400	10,200	3,050
Cr	ug/L	350	36	12
Cu	ug/L	3,800	110	54
Fe	ug/L	80,000	13,000	4,200
Pb	ug/L	75	23	5
Mn	ug/L	940	720	131
Ti	ug/L	649	245	58

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	5,960	10,400	2,280
Cr	ug/L	120	66	13
Cu	ug/L	860	160	60
Fe	ug/L	22,000	26,000	3,500
Pb	ug/L	17	26	6
Mn	ug/L	180	340	48
Ti	ug/L	280	345	35

TABLE NO. 3.5-16 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	683	3,610	3,780
Cr	ug/L	7	28	13
Cu	ug/L	390	48	27
Fe	ug/L	890	8,770	2,200
Pb	ug/L	<30	8	2
Mn	ug/L	<150	220	40
Ti	ug/L	39	137	108

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	127	786	100
Cr	ug/L	<6	<3	--
Cu	ug/L	22	24	--
Fe	ug/L	<110	310	--
Pb	ug/L	<2	<2	<2
Mn	ug/L	<22	13	--
Ti	ug/L	<4	15	<4

TABLE NO. 3.5-16 (Cont.)

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	488	710	1,100
Cr	ug/L	2	<2	<40
Cu	ug/L	41	<10	<200
Fe	ug/L	330	120	<1,100
Pb	ug/L	<2	<2	<40
Mn	ug/L	<11	<11	<220
Ti	ug/L	<8	<8	<80

Saprolite Wet-Dry Leachate Concentrations

Parameter	Units	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	7,220	4,280	13,200	2,480	441
Cr	ug/L	4	5	16	<3	<2
Cu	ug/L	660	76	190	27	<10
Fe	ug/L	3,000	1,300	6,000	930	130
Pb	ug/L	68	11	18	9	<2
Mn	ug/L	570	38	100	19	<11
Ti	ug/L	181	91	320	52	<4
Zn	ug/L	240	59	99	19	<11

TABLE NO. 3.5-17

Calculated[a] Quantities of Selected Parameters Leached from Wet-Dry Topsoil, Till, Sandstone, and Saprolite

Topsoil Wet-Dry Quantities Leached

Parameter	Units	Cycle 1			Cycle 2			Cycle 4		
		West	Central	East	West	Central	East	West	Central	East
Al	ug/g	1.53	11.02	6.18	0.23	0.20	2.58	0.15	0.036	0.18
Cr	ug/g	2.7×10^{-3}	0.024	0.011	$<9.1\times10^{-4}$	6.0×10^{-4}	4.3×10^{-3}	$<9.1\times10^{-4}$	9.0×10^{-4}	9.9×10^{-4}
Cu	ug/g	4.5×10^{-3}	6.9×10^{-3}	4.6×10^{-3}	5.0×10^{-3}	$<3.0\times10^{-3}$	5.6×10^{-3}	--	--	--
Fe	ug/g	1.40	9.88	4.98	0.37	0.33	2.89	0.21	0.045	0.21
Mn	ug/g	0.050	0.26	0.086	0.027	0.016	0.070	0.15	0.016	0.15
Ti	ug/g	0.12	0.86	0.51	0.011	0.017	0.23	0.037	0.020	0.032

Parameter	Units	Cycle 8			Cycle 16		
		West	Central	East	West	Central	East
Al	ug/g	0.068	0.041	0.086	0.053	9.0×10^{-3}	0.027
Cr	ug/g	$<9.1\times10^{-4}$	$<6.0\times10^{-4}$	$<6.6\times10^{-4}$	$<9.1\times10^{-4}$	$<6.0\times10^{-4}$	$<6.6\times10^{-4}$
Cu	ug/g	----	----	----	5.0×10^{-3}	3.9×10^{-3}	$<3.3\times10^{-3}$
Fe	ug/g	0.59	0.39	0.27	2.99	0.54	1.00
Mn	ug/g	0.54	0.39	0.50	0.86	0.57	1.03
Ti	ug/g	$<1.8\times10^{-4}$	$<1.2\times10^{-3}$	1.7×10^{-3}	$<1.8\times10^{-3}$	$<1.2\times10^{-3}$	$<1.3\times10^{-3}$

Till Wet-Dry Quantities Leached

Parameter	Units	Cycle 1			Cycle 2			Cycle 4		
		West	Central	East	West	Central	East	West	Central	East
Al	ug/g	1.08	1.11	1.27	1.67	5.01	3.68	9.51	16.07	10.02
Cr	ug/g	$<9.2\times10^{-4}$	1.1×10^{-3}	9.2×10^{-4}	1.4×10^{-3}	4.3×10^{-3}	4.6×10^{-3}	8.3×10^{-3}	0.023	0.014
Cu	ug/g	0.46	0.29	0.051	0.021	0.014	0.018	0.060	0.024	0.018
Fe	ug/g	0.51	0.54	0.83	1.47	3.90	4.60	5.97	10.28	16.09

TABLE NO. 3.5-17 (Cont.)

Topsoil Wet-Dry Quantities Leached

Parameter	Units	Cycle 1			Cycle 2			Cycle 4		
		West	Central	East	West	Central	East	West	Central	East
Mn	ug/g	0.050	0.012	0.051	0.042	0.050	0.060	0.15	0.11	0.069
Ti	ug/g	0.034	0.046	0.043	0.087	0.32	0.20	0.51	1.03	0.60
		Cycle 8			Cycle 16					
		West	Central	East	West	Central	East			
Al	ug/g	18.75	6.49	5.01	6.25	2.53	5.75			
Cr	ug/g	0.018	$<1.6\times10^{-3}$	$<1.4\times10^{-3}$	8.7×10^{-3}	3.8×10^{-3}	5.5×10^{-3}			
Cu	ug/g	0.12	0.017	9.2×10^{-3}	0.012	6.5×10^{-3}	0.041			
Fe	ug/g	12.87	3.79	3.40	2.53	1.84	3.54			
Mn	ug/g	0.25	0.041	0.033	0.036	0.043	0.083			
Ti	ug/g	1.01	0.42	0.31	0.41	0.13	0.28			

Sandstone Wet-Dry Quantities Leached

Parameter	Units	Cycle 1			Cycle 2			Cycle 4		
		West	Central	East	West	Central	East	West	Central	East
Al	ug/g	2.52	0.64	0.11	1.12	0.65	0.082	0.13	0.23	0.14
Cr	ug/g	0.066	2.3×10^{-3}	4.3×10^{-4}	0.023	4.1×10^{-3}	4.7×10^{-4}	1.3×10^{-3}	1.8×10^{-3}	4.7×10^{-4}
Cu	ug/g	0.71	6.9×10^{-3}	1.9×10^{-3}	0.16	0.01	2.2×10^{-3}	0.073	3.0×10^{-3}	9.7×10^{-4}
Fe	ug/g	15.05	0.82	0.15	4.14	1.63	0.13	0.17	0.55	0.079
Pb	ug/g	0.014	1.4×10^{-3}	1.8×10^{-4}	3.2×10^{-3}	1.6×10^{-3}	2.2×10^{-4}	<0.01	5.0×10^{-4}	7.2×10^{-5}
Mn	ug/g	0.18	0.045	4.7×10^{-3}	0.034	0.021	1.7×10^{-3}	<0.03	0.014	1.4×10^{-3}
Ti	ug/g	0.12	0.015	2.1×10^{-3}	0.053	0.022	1.3×10^{-3}	7.3×10^{-3}	8.6×10^{-3}	3.9×10^{-3}

TABLE NO. 3.5-17 (Cont.)

Sandstone Wet-Dry Quantities Leached

		Cycle 1			Cycle 2			Cycle 4		
Parameter	Units	West	Central	East	West	Central	East	West	Central	East
	West	Cycle 8 Central	Cycle 8 East	West	Cycle 16 Central	Cycle 16 East				
Al	ug/g	0.024	0.049	3.6×10^{-3}	0.092	0.045	0.040			
Cr	ug/g	$<1.1 \times 10^{-3}$	1.9×10^{-4}	----	3.8×10^{-4}	$<1.2 \times 10^{-4}$	$<1.4 \times 10^{-3}$			
Cu	ug/g	4.1×10^{-3}	1.5×10^{-3}	----	7.7×10^{-3}	$<6.3 \times 10^{-4}$	<0.01			
Fe	ug/g	<0.02	0.020	----	0.062	7.5×10^{-3}	<0.04			
Pb	ug/g	$<3.8 \times 10^{-4}$	$<1.2 \times 10^{-4}$	$<7.2 \times 10^{-5}$	$<3.8 \times 10^{-4}$	$<1.2 \times 10^{-4}$	$<1.4 \times 10^{-3}$			
Mn	ug/g	$<4.1 \times 10^{-3}$	8.2×10^{-4}	----	$<2.1 \times 10^{-3}$	$<6.9 \times 10^{-4}$	<0.01			
Ti	ug/g	$<7.5 \times 10^{-4}$	9.4×10^{-4}	$<1.4 \times 10^{-4}$	$<1.5 \times 10^{-3}$	$<5.0 \times 10^{-4}$	$<2.9 \times 10^{-3}$			

Saprolite Wet-Dry Quantities Leached

Parameters	Units	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/g	2.94	1.74	5.38	1.01	0.18
Cr	ug/g	1.6×10^{-3}	2.0×10^{-3}	6.5×10^{-3}	$<1.2 \times 10^{-3}$	$<8.1 \times 10^{-4}$
Cu	ug/g	0.27	0.031	0.077	0.011	$<4.1 \times 10^{-4}$
Fe	ug/g	1.22	0.53	2.44	0.38	<0.05
Pb	ug/g	0.027	4.5×10^{-3}	7.3×10^{-3}	3.7×10^{-3}	$<8.1 \times 10^{-4}$
Mn	ug/g	0.23	0.016	0.041	7.7×10^{-3}	$<4.5 \times 10^{-3}$
Ti	ug/g	0.074	0.037	0.13	0.021	$<1.6 \times 10^{-3}$
Zn	ug/g	0.10	0.24	0.040	7.7×10^{-3}	$<4.5 \times 10^{-3}$

selected metals from the central and eastern till leachates occurred in the Cycle 4 leachates. The peaks for the western till leachate tended to be found in the Cycle 8 leachate.

The west sandstone composite was clearly the most leachable of the sandstone composites. All of the selected parameters were measurably leached from all of the sandstone composites during the first two leaching cycles.

The saprolite composite released the most copper, lead, manganese, and zinc during Cycle 1. The maximum quantities of aluminum, chromium, iron, and titanium were leached during Cycle 4.

The sandstone composites are the most leachable material of the topsoil, till, sandstone, and saprolite group. The maximum values of iron and copper leached from these materials came from the sandstone. In terms of bulk chemistry, the sandstone samples have the lowest iron concentration and the second lowest copper concentration. Zinc and lead were common to all of these unconsolidated materials but are most abundant in saprolite, which leached the maximum quantity of each. Considering the other selected metals, the saprolite composite was the least leachable of the composites.

The pH measured in the waste rock chip leachate decreased from 5.4 for the lowest percent sulfur waste (WR-1) to approximately three for the highest percent sulfur waste during Cycle 1. In the later cycles, however, the pH of the WR-3 leachate is generally greater than that of WR-2. The pHs of all of the composites increased during the cycles. The Cycle 16 pHs are about two units greater than the Cycle 1 pHs. It is therefore expected that, when stockpiled, the leachate derived from the waste rock chips will become progressively more basic as time of storage increases, rather than more acidic. This relationshipis summarized in Table No. 3.5-18.

Cycle 1 pH measurements of the waste rock powder leachate also showed a general decrease from WR-1 (pH = 7.3) to WR-5 (pH = 4.4). However, the pH of the WR-3 leachate was always greater than that of WR-2, and with the exception of Cycle 1, the pH of WR-4 was always greater than that of WR-2. The pH of all of the powdered waste rock leachates increased about one unit during the 16 loading cycles. It is therefore expected that the leachate derived from stockpiled waste rock powder or chips, will become progressively more basic as storage time increases as shown on Table No. 3.5-18. The variability in relative pH between waste rock samples is a function of both the total sulfur content of the rocks and the specific sulfide minerals contained within the rocks.

Significant decreases in conductivity were observed in all of the leachates as the leaching progressed. The measured conductivities of the waste rock chip leachate were much greater

TABLE NO. 3.5-18

pH and Specific Conductivity for the Wet-Dry
Leaching of the Waste Rock Samples

Cycle	Date	Parameter	Rock Chips					Rock Powder				
			WR - 1	WR - 2	WR - 3	WR - 4	WR - 5	WR - 1	WR - 2	WR - 3	WR - 4	WR - 5
1	03/17/88	pH	5.40	4.45	4.20	3.60	2.95	7.30	5.65	5.75	5.15	4.35
		Spec. Con.	751	481	1,548	1,674	2,751	179	187	308	353	365
2	03/22/88	pH	5.80	4.10	4.25	3.55	3.15	7.40	5.45	6.15	5.75	4.70
		Spec. Con.	339	541	1,256	1,518	2,129	36	32	68	101	51
3	03/27/88	pH	6.48	4.31	4.62	3.74	3.27	7.99	6.48	7.18	6.68	5.26
		Spec. Con.	221	453	964	1,057	1,463	32	20	32	68	36
4	04/01/88	pH	6.95	4.44	4.67	3.60	3.17	7.97	6.42	7.31	6.67	5.37
		Spec. Con.	254	328	688	1,070	1,092	36	19	28	42	25
5	04/06/88	pH	6.62	4.44	4.95	3.94	3.61	8.38	6.50	7.38	6.82	5.50
		Spec. Con.	101	220	418	447	460	25	14	23	30	22
6	04/11/88	pH	6.90	4.70	5.15	4.07	3.72	7.73	6.02	7.24	6.70	5.18
		Spec. Con.	68	140	333	337	335	36	15	25	37	51
7	04/16/88	pH	7.08	5.25	5.27	4.10	3.77	8.26	6.26	7.46	6.77	5.16
		Spec. Con.	74	82	238	249	228	31	14	24	31	23
8	04/21/88	pH	7.20	5.40	5.45	4.33	3.93	7.96	6.17	7.40	6.78	5.19
		Spec. Con.	48	54	192	170	178	28	16	23	31	23
9	04/26/88	pH	7.18	5.70	5.61	4.38	3.73	8.04	6.30	7.35	6.83	5.22
		Spec. Con.	43	42	143	128	148	26	14	21	26	21
10	05/01/88	pH	7.27	5.39	5.78	4.31	3.91	7.96	6.08	7.30	6.61	5.00
		Spec. Con.	60	43	166	127	145	34	15	26	28	23
11	05/06/88	pH	7.10	5.50	5.70	4.58	3.85	7.69	5.84	7.25	6.59	4.94
		Spec. Con.	44	31	90	85	95	40	13	19	21	21
12	05/11/88	pH	7.85	6.00	5.90	4.71	4.13	7.78	6.07	7.02	6.72	5.16
		Spec. Con.	40	38	84	85	78	32	15	24	23	22
13	05/16/88	pH	7.34	5.93	5.85	4.69	4.18	8.12	6.30	7.27	6.78	5.23
		Spec. Con.	36	26	87	77	56	26	11	20	17	14
14	05/21/88	pH	7.61	6.06	6.00	4.66	4.13	7.85	6.16	7.24	6.64	5.12
		Spec. Con.	33	34	76	89	69	27	11	30	16	17
15	05/26/88	pH	7.40	6.05	5.90	4.95	4.12	7.99	6.11	7.37	6.93	5.18
		Spec. Con.	33	25	50	40	47	32	11	22	22	22
16	05/31/88	pH	7.46	5.94	5.87	5.15	4.10	8.00	6.11	7.11	6.73	5.13
		Spec. Con.	54	23	73	19	65	19	10	14	12	16

UNITS: pH - standard units
Spec. Con. - umhos/cm

than that of the waste rock powders. These apparent differences in conductivity and pH values are probably a result of the significant differences in liquid to solid ratios between the chip and powder columns. The liquid to solid ratio of the powder columns is 20 times greater than the ratio of the chip columns with respect to liquid. The pH and specific conductivity data for the waste rock leachates are presented in Table No. 3.5-18.

Concentrations of selected parameters in the wet/dry waste rock leachate are presented in Table No. 3.5-19. Calculated quantities of these parameters are presented in Table No. 3.5-20. The maximum leached quantities of all of the selected parameters occur in the Cycle 1 WR-1 chip leachate. These values, which are expected to be typical for Type I waste rock, are of low intensity. The quantities of these materials decrease sharply as the leaching proceeds through the cycles. In general, these trends are observed in the chip leachates from the WR-2 through 5 composites. The other composites differ from WR-1 in that the maximum quantity leached may occur during Cycle 2 and that the rate of decline of leaching is not as great. This is especially true for the waste rock composites with the higher sulfur contents. Lead was detected only in the rock chip-derived leachate from WR-3.

The results of the wet/dry waste rock chip leachings indicate that the greatest release of material will occur during the first few times the rocks are subjected to major precipitative events. The quantities of material decrease considerably after that time. The presence of lead in the WR-3 leachate is a function of the presence of galena in the WR-3 rock composite. No significant impact on the soils and water beneath the Type I stockpile is expected as a result of this release of lead. Not only is the quantity of lead leached very small, but the estimated amount of WR-3 in the Type I stockpile is less than one percent of the waste rock in that storage area.

The maximum quantities of the material leached from the powdered waste rock tend to occur during Cycles 4 and/or 8 for sample WR-1. As the sulfur content of the rocks increases, the cycle of maximum leaching shifts toward the earliest cycles. Most of the maximum for sample WR-5 occur during the first leaching cycle. Similar to the time-based quantities of material leached from the waste rock chips, the maximum quantities leached from the waste rock powder are expected to occur during the first few major precipitative events. In addition, the quantities leached will decrease thereafter with time.

The quantities of material leached from the rock powders are generally two to ten times greater than those leached from the rock chips. Since the bulk chemistry and mineralogy of the chip and powder form of each waste rock are identical, the difference in leachability can be assumed to be a function of the greater surface area per unit of mass of the powder. Since weathering

TABLE NO. 3.5-19

Concentrations of Selected Parameters in Wet-Dry Waste Rock Leachate

WR-1 Wet-Dry Leachate Concentrations

		Rock Chips					Rock Powder				
Parameter	Units	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	1,740	89	181	41	52	166	646	10,200	14,000	2,110
Co	ug/L	390	100	<40	<40	<40	<40	<40	--	--	<40
Cu	ug/L	660	200	22	<10	<10	64	250	84	140	41
Fe	ug/L	1,800	95	65	<55	<55	280	2,600	14,000	14,000	2,100
Pb	ug/L	<2	<2	<2	--	<2	<2	2	20	20	8
Mn	ug/L	340	110	54	<11	<11	19	<11	23	<55	<11
Ni	ug/L	91	<30	--	--	<30	<30	<30	--	--	<30
Zn	ug/L	730	220	42	13	<11	27	130	270	380	120
SO4	mg/L	400	150	100	11	5	50	<25	<20	<50	<10

TABLE NO. 3.5-19 (Cont.)

WR-2 Wet-Dry Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	1,400	2,360	693	31	31	136	122	3,280	9,400	280
Co	ug/L	148	230	99	<40	<40	<40	<40	--	--	<40
Cu	ug/L	29,000	34,000	9,100	670	150	1,100	92	120	270	97
Fe	ug/L	950	2,600	880	<55	<55	290	160	3,200	5,600	610
Pb	ug/L	<2	<2	<2	--	<2	<2	<2	12	12	9
Mn	ug/L	620	840	460	61	15	370	54	29	40	12
Ni	ug/L	85	110	<30	<30	<30	<30	<30	--	--	<30
Zn	ug/L	2,500	4,300	1,900	200	44	850	140	150	380	140
SO4	mg/L	240	270	150	20	7	70	<25	<50	<20	<10

TABLE NO. 3.5-19 (Cont.)

WR-3 Wet-Dry Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	2,080	1,530	321	44	18	209	189	2,760	9,000	700
Co	ug/L	1,100	1,200	610	110	40	230	<40	--	--	<40
Cu	ug/L	240,000	180,000	56,000	7,300	1,700	3,300	82	150	500	110
Fe	ug/L	5,600	7,600	1,400	120	<55	210	220	2,600	5,600	520
Pb	ug/L	5	4	2	--	<2	2	<2	55	750	4
Mn	ug/L	2,200	2,100	1,000	300	83	512	84	19	<28	<11
Ni	ug/L	650	680	340	67	<30	130	<30	--	--	<30
Zn	ug/L	53,000	56,000	28,000	7,700	2,000	5,600	200	310	1,000	110
SO4	mg/L	930	790	380	74	26	150	<25	12	<20	<10

TABLE NO. 3.5-19 (Cont.)

WR-4 Wet-Dry Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	12,800	16,400	8,430	473	46	181	81	1,830	1,000	570
Co	ug/L	1,100	1,200	720	80	<40	140	<40	--	--	<40
Cu	ug/L	280,000	210,000	100,000	10,000	610	21,000	380	160	290	81
Fe	ug/L	78,000	71,000	4,000	3,700	60	980	<55	820	1,300	240
Pb	ug/L	<2	2	<2	--	<2	<2	<2	37	<20	3
Mn	ug/L	1,600	1,900	1,400	180	<11	470	190	64	<110	19
Ni	ug/L	660	480	270	110	<30	51	<30	--	--	<30
Zn	ug/L	11,000	13,000	10,000	1,300	120	1,900	250	60	290	34
SO4	mg/L	1,100	940	670	60	22	180	<50	16	<20	<10

TABLE NO. 3.5-19 (Cont.)

WR-5 Wet-Dry Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	30,500	22,900	8,550	353	41	1,260	83	361	546	100
Co	ug/L	1,700	1,400	580	55	<40	180	<40	--	--	<40
Cu	ug/L	620,000	470,000	200,000	24,000	5,200	65,000	7,500	3,600	3,800	1,800
Fe	ug/L	230,000	150,000	57,000	4,200	910	9,600	62	210	380	140
Pb	ug/L	<2	<2	<2	--	<2	2	<2	4	4	9
Mn	ug/L	6,100	4,500	1,800	210	77	540	57	15	<22	<11
Ni	ug/L	660	560	260	48	<30	79	<30	--	--	<30
Zn	ug/L	2,100	2,000	850	130	38	330	49	23	150	89
SO4	mg/L	2,100	1,500	700	60	22	170	<25	<10	<20	<10

TABLE NO. 3.5-20

Calculated Quantities of Selected Parameters Leached from Wet-Dry Waste Rock

WR-1 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	0.91	0.047	0.095	0.022	0.027	1.66	6.46	102.00	140.00	21.10
Co	ug/g	0.20	0.052	<0.02	<0.02	<0.02	<0.40	<0.40	<0.40	<0.40	<0.40
Cu	ug/g	0.35	0.10	0.012	<0.01	<0.01	0.64	2.50	0.84	1.40	0.41
Fe	ug/g	0.94	0.050	0.034	<0.03	<0.03	2.80	26.00	140.00	140.00	21.00
Pb	ug/g	<0.002	<0.002	<0.002	<0.002	<0.002	<0.02	0.02	0.20	0.20	0.08
Mn	ug/g	0.18	0.058	0.028	<0.01	<0.01	0.19	<0.11	0.23	<0.35	<0.11
Ni	ug/g	0.048	<0.02	--	--	<0.02	<0.30	<0.30	<0.30	<0.30	<0.30
Zn	ug/g	0.38	0.12	0.022	6.8x10(-3)	<0.01	0.27	1.30	2.70	3.80	1.20
SO4	mg/g	0.21	0.079	0.052	5.8x10(-3)	0.003	0.50	<0.25	<0.20	<0.50	<0.10

TABLE NO. 3.5-20 (Cont.)

WR-2 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	0.74	1.24	0.37	0.016	0.016	1.36	1.22	32.80	94.00	2.80
Co	ug/g	0.078	0.12	0.052	<0.02	<0.02	<0.40	<0.40	--	--	<0.40
Cu	ug/g	15.29	17.92	4.80	0.35	0.079	11.00	0.92	1.20	2.70	0.97
Fe	ug/g	0.50	1.37	0.46	<0.03	<0.03	2.90	1.60	32.00	56.00	6.10
Pb	ug/g	<0.001	<0.001	<0.001	<0.001	<0.001	<0.02	<0.02	0.12	0.12	0.09
Mn	ug/g	0.33	0.44	0.24	0.032	7.9x10(-3)	3.70	0.54	0.29	0.40	0.12
Ni	ug/g	0.045	0.058	<0.02	<0.02	<0.02	<0.30	<0.30	--	--	<0.30
Zn	ug/g	1.32	2.27	1.00	0.11	0.021	8.50	1.40	1.50	3.80	1.40
SO4	ug/g	0.13	0.14	0.079	0.10	<4x10(-3)	0.70	<0.25	<0.50	<0.20	<0.10

TABLE NO. 3.5-20 (Cont.)

WR-3 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	1.18	0.87	0.18	0.025	0.010	2.09	1.89	27.60	90.00	7.00
Co	ug/g	0.62	0.68	0.35	0.062	0.022	2.30	<0.40	--	--	<0.40
Cu	ug/g	135.80	101.80	31.68	4.13	0.96	33.00	0.82	1.50	5.00	1.10
Fe	ug/g	3.17	4.30	0.79	0.068	<0.03	2.10	2.20	26.00	56.00	5.20
Pb	ug/g	2.8x10(-3)	2.3x10(-3)	1.1x10(-3)	--	<0.002	0.02	<0.02	0.55	7.50	0.04
Mn	ug/g	1.24	1.19	0.57	0.17	0.047	5.12	0.84	0.19	<0.28	<0.11
Ni	ug/g	0.37	0.38	0.19	0.038	<0.02	1.30	<0.30	--	--	<0.30
Zn	ug/g	29.98	31.68	15.84	4.36	1.13	56.00	2.00	3.10	10.00	1.10
SO4	mg/g	0.53	0.45	0.21	0.042	0.015	1.50	<0.25	0.12	<0.20	<0.10

TABLE NO. 3.5-20 (Cont.)

WR-4 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	6.26	8.02	4.12	0.23	0.022	1.81	0.81	18.30	10.00	5.70
Co	ug/g	0.54	0.59	0.35	0.039	<0.02	1.40	<0.40	--	--	<0.40
Cu	ug/g	137.00	102.70	48.92	4.89	0.30	210.00	3.80	1.60	2.90	0.81
Fe	ug/g	38.16	34.73	1.96	1.81	0.029	9.80	<0.55	8.20	13.00	2.40
Pb	ug/g	<0.001	0.001	<0.001	--	<0.001	<0.02	<0.02	0.37	<0.62	0.03
Mn	ug/g	0.78	0.93	0.68	0.008	<0.01	4.70	1.90	0.64	<1.1	0.19
Ni	ug/g	0.32	0.23	0.13	0.054	<0.01	0.51	<0.30	--	--	<0.30
Zn	ug/g	5.38	6.36	4.89	0.64	0.059	19.00	2.50	0.60	2.90	0.34
SO4	mg/g	0.54	0.46	0.33	0.029	0.011	1.80	<0.50	0.16	<0.20	<0.10

TABLE NO. 3.5-20 (Cont.)

WR-5 Wet-Dry Leached Quantities

Parameter	Units	Rock Chips					Rock Powder				
		CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	11.58	8.70	3.25	0.13	0.016	12.60	0.83	3.61	5.46	1.00
Co	ug/g	0.65	0.53	0.22	0.021	<0.02	1.80	<0.40	--	--	<0.40
Cu	ug/g	235.50	178.50	75.96	9.12	1.97	650.00	75.00	36.00	38.00	18.00
Fe	ug/g	87.35	56.97	21.65	1.60	0.35	96.00	0.62	2.10	3.80	1.40
Pb	ug/g	<0.001	<0.001	<0.001	--	<0.001	0.02	<0.02	0.04	0.04	0.09
Mn	ug/g	2.32	1.71	0.68	0.080	0.029	5.40	0.57	0.15	<0.22	<0.11
Ni	ug/g	0.25	0.21	0.10	0.018	<0.01	0.79	<0.30	--	--	<0.30
Zn	ug/g	0.80	0.76	0.32	0.049	0.014	3.30	0.49	0.23	1.50	0.89
SO4	mg/g	0.80	0.57	0.27	0.023	8.4x10(-3)	1.70	<0.25	<0.10	<0.20	<0.10

1. All quantities represent material leached or desorbed.

and leaching are processes that involve surface physical and chemical reactions, those materials with the greater surface areas like the rock powders will react to a greater extent and produce leachates with greater metal concentrations than those with lesser surface areas.

Some of the leaching trends exhibited by the waste rock samples reflect variation in bulk chemistry between the samples. For instance, the sulfur and copper concentrations decrease from WR-5 to WR-1. The leached quantities of sulfur and copper for both the chips and powders are greatest for WR-5 materials, and lowest for WR-1 materials. The bulk iron concentration is greatest in WR-1 and decreases with increasing sulfur content to WR-5. The greatest quantity of iron is leached from the WR-5 chip columns, and the least from the WR-1 chip columns. This reversal is probably due to the dual release of iron and sulfur due to the hydrolysis of the pyrite grain. The WR-5 material has considerably more pyrite than the other samples, and would therefore be expected to release more of both sulfur and iron than the other samples. In fact, the release of sulfur due to the weathering of pyrite must be accompanied by a release of iron. This coupled release is the part of the main acid-generating reaction (Nordstrom, 1982).

The bulk chemical concentration of aluminum is essentially the same for all of the waste rock composites. It is interesting to note that the maximum quantity of aluminum leached from the waste rock chips is from sample WR-5, and the minimum is from sample WR-1. This trend is reversed from the rock powders.

A comparison of the leachability of the waste rock samples with that of the topsoil and overburden reveals several observations. Although all of the materials contain quantities of tin and titanium, both of these elements occur in compounds of extremely low solubility. In addition, these two elements are usually not chemically reactive. Tin was not detected in any of the leachates. Titanium was found in the topsoil and overburden leachates.

Cobalt, nickel, and sulfate are not found in the leachate from the topsoil and overburden materials. Chromium and titanium are not found in the leachate from the waste rock composites. The waste rock powders release more aluminum, copper, iron, zinc, and sulfate to their leachates than the topsoil and overburden samples do to theirs. In addition, the powder release more lead and manganese than the topsoil and overburden composites release.

The quantities of metals leached from those materials that will be stockpiled in unlined sites decreased after the first leachings to levels typical (Kabata-Pendias and Pendias, 1984) of that formed in soil solution with the exception of iron and aluminum in the topsoil and till. The ability of the soils beneath these stockpiles to sorb and retain these metals is a consideration for determining the acceptability of using unlined sites for the temporary stockpiling of waste materials.

As seen in the next section, soil and till beneath the stockpiles have significant capacities to retain copper and iron from solutes equilibrated with these materials. It is shown in the *Preliminary Engineering Report for Wastewaster Treatment Facilities* that most of the iron is in colloidal rather than the dissolved state. In soils, iron and aluminum both tend to be in the colloidal state and to exhibit similar behavior at/near neutral pHs. It is expected that the aluminum colloids released during the leaching of the topsoil and till will be retained as iron will be.

The released manganese is similar to that found in soil solutions elsewhere (op. cit.). Leached sulfate quantities are low enough such that it would be expected that dilution by the soil solution would prevent detectable concentrations of sulfate from appearing in the groundwater beneath the unlined sites.

3.5.6.3.3.2 Saturated Leaching Study

When the 16 wet/dry leaching cycles had been completed, synthetic groundwater was added to the columns and the argon gas was fed into the basal parts of the columns. Every five days of saturation completed a saturated cycle. Sixteen saturated cycles were completed. At the end of each cycle, pH, specific conductivity and temperature were measured. Also, leachate samples were collected at the end of Cycles 1, 2, 4, 8, and 16.

The pH and specific conductivity values measured at the end of all of the cycles for the saturated leaching of the till, sandstone and saprolite composites are presented in Table No. 3.5-21. The data show that there was very little change in pH between Cycle 16 wet/dry values and Cycle 1 saturated values. During the course of the saturated leaching test there was virtually no change in the pH of the leachate of these materials. Specific conductivity values, however, gradually increased such that the Cycle 16 conductivities were about one and one-half times those of the Cycle 1 conductivities.

Concentrations of selected parameters measured in the saturated leachates from the till, sandstone and saprolite composites are presented in Table No. 3.5-22. The calculated quantities of leachate matter are presented in Table No. 3.5-23.

Of considerable importance is the fact that most of the overburden composite samples sorbed, or retained, iron and manganese during most of the cycles. The till and sandstone samples also sorbed sulfate during most of the cycles. In addition, till also sorbed the bicarbonate alkalinity most of the time. The saprolite composite sorbed neither the sulfate nor the bicarbonate. The sandstone composites sorbed

TABLE NO. 3.5-21

pH and Specific Conductivity Values for the Saturated Leaching of the Till, Sandstone, and Saprolite Samples

			Till			Sandstone			Saprolite
Cycle	Date	Parameter	West	Central	East	West	Central	East	
1	08/06/88	pH	7.81	7.76	8.00	8.25	7.74	8.07	8.65
		Spec. Con.	275	279	325	355	354	347	383
2	08/11/88	pH	7.38	7.37	7.63	8.56	7.90	8.44	8.40
		Spec. Con.	285	313	356	416	415	414	410
3	08/16/88	pH	7.31	7.24	7.78	8.86	8.26	8.79	8.52
		Spec. Con.	308	325	379	423	425	425	425
4	08/21/88	pH	7.31	7.20	7.78	8.92	8.61	8.87	8.42
		Spec. Con.	302	317	399	426	428	428	434
5	08/26/88	pH	7.40	7.34	8.04	9.08	8.94	8.52	8.67
		Spec. Con.	337	351	424	435	435	439	445
6	08/31/88	pH	7.27	7.30	8.25	8.94	8.79	8.77	8.65
		Spec. Con.	330	351	440	435	432	435	457
7	09/06/88	pH	7.44	7.45	8.16	7.69	7.82	7.80	8.73
		Spec. Con.	320	355	406	461	458	455	574
8	09/10/88	pH	7.35	7.42	8.20	8.90	8.65	8.69	8.59
		Spec. Con.	327	346	453	444	441	441	474

TABLE NO. 3.5-21 (Cont.)

			Till			Sandstone			Saprolite
Cycle	Date	Parameter	West	Central	East	West	Central	East	
9	09/15/88	pH	7.23	7.32	8.04	9.18	9.00	8.93	8.65
		Spec. Con.	339	360	439	412	410	410	473
10	09/20/88	pH	7.20	7.31	7.98	9.16	8.89	8.94	8.65
		Spec. Con.	344	360	452	415	410	404	489
11	09/25/88	pH	7.36	7.36	8.06	9.14	8.92	8.94	8.73
		Spec. Con.	337	362	463	412	406	401	492
12	09/30/88	pH	7.44	7.50	8.08	9.11	8.86	8.92	8.70
		Spec. Con.	343	870	468	424	413	409	505
13	10/05/88	pH	7.29	7.57	8.11	9.17	8.95	8.95	8.66
		Spec. Con.	339	376	478	425	410	402	501
14	10/10/88	pH	7.47	7.70	8.13	9.13	9.00	8.78	8.68
		Spec. Con.	339	360	478	426	410	408	502
15	10/15/88	pH	7.40	7.93	8.04	9.03	8.87	8.84	8.70
		Spec. Con.	347	363	492	436	415	415	529
16	10/20/88	pH	7.60	8.05	8.07	9.15	8.87	8.93	8.69
		Spec. Con.	344	358	489	442	413	413	535

UNITS: pH - standard units
Spec. Con. - umhos/cm

TABLE NO. 3.5-22

Concentrations of Selected Parameters in Saturated Till, Sandstone, and Saprolite Leachate

Sandstone Saturated Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	4,540	617	1,370
Cr	ug/L	42	5	7
Cu	ug/L	210	<10	22
Fe	ug/L	5,300	400	2,533
Mn	ug/L	92	41	180
Ti	ug/L	344	5	63
SO4	mg/L	<5	10	17
Alk	mg/L	14	18	16

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	7,290	1,220	3,833
Cr	ug/L	59	<3	<3
Cu	ug/L	290	13	48
Fe	ug/L	7,500	550	5,100
Mn	ug/L	92	39	460
Ti	ug/L	756	44	177
SO4	mg/L	9	15	9
Alk	mg/L	18	23	23

TABLE NO. 3.5-22 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	811	240	338
Cr	ug/L	4	--	--
Cu	ug/L	35	<10	<10
Fe	ug/L	720	130	550
Mn	ug/L	22	<11	43
Ti	ug/L	61	<4	13
SO4	mg/L	11	7	17
Alk	mg/L	28	37	29

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	1,190	165	324
Cr	ug/L	6	--	--
Cu	ug/L	45	<10	<10
Fe	ug/L	1,200	200	600
Mn	ug/L	23	<11	46
Ti	ug/L	102	<4	<4
SO4	mg/L	13	13	13
Alk	mg/L	36	36	57

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	430	420	510
Cr	ug/L	<3	<3	<3
Cu	ug/L	40	21	9
Fe	ug/L	530	300	1,100

TABLE NO. 3.5-22 (Cont.)

Parameter	Units	West	Central	East
Mn	ug/L	<11	23	89
Ti	ug/L	9	5	27
SO4	mg/L	11	10	11
Alk	mg/L	27	29	29

Till Saturated Leachate Concentrations

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/L	963	5,040	845
Cr	ug/L	4	9	5
Cu	ug/L	27	27	<10
Fe	ug/L	710	3,300	650
Mn	ug/L	23	47	<11
Ti	ug/L	38	326	34
SO4	mg/L	10	<5	9
Alk	mg/L	32	37	50

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/L	472	1,030	459
Cr	ug/L	<3	<3	<3
Cu	ug/L	17	13	10
Fe	ug/L	400	860	420
Mn	ug/L	22	19	<11
Ti	ug/L	16	51	6
SO4	mg/L	98	12	9
Alk	mg/L	18	37	50

TABLE NO. 3.5-22 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/L	379	299	203
Cr	ug/L	--	--	--
Cu	ug/L	20	<10	<10
Fe	ug/L	--	240	--
Mn	ug/L	--	--	--
Ti	ug/L	--	<4	--
SO4	mg/L	9	6	7
Alk	mg/L	18	28	57

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/L	211	108	1,360
Cr	ug/L	--	--	--
Cu	ug/L	21	<10	13
Fe	ug/L	--	110	--
Mn	ug/L	--	--	--
Ti	ug/L	--	<4	--
SO4	mg/L	9	6	8
Alk	mg/L	21	33	90

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/L	340	580	190
Cr	ug/L	<3	<3	<3
Cu	ug/L	50	22	17
Fe	ug/L	170	410	110
Mn	ug/L	35	<11	<11

TABLE NO. 3.5-22 (Cont.)

Parameter	Units	West	Central	East
Ti	ug/L	<4	32	4
SO4	mg/L	13	10	10
Alk	mg/L	36	29	87

TABLE NO. 3.5-22 (Cont.)

Saprolite Saturated Leachate Concentrations

Parameter	Units	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/L	321	756	68	83	93
Cu	ug/L	35	31	14	24	31
Fe	ug/L	180	300	<55	75	<55
Mn	ug/L	55	39	42	37	<11
Ti	ug/L	357	--	<4	<4	--
SO4	mg/L	30	36	39	42	42
Alk	mg/L	80	85	89	140	170

TABLE NO. 3.5-23

Calculated Quantities of Selected Parameters Leached From the Saturated Till, Sandstone, and Saprolite Samples

Saturated Till Quantities Leached

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/g	0.44	2.73	0.39
Cr	ug/g	1.8x10(-3)	4.9x10(-3)	2.3x10(-3)
Cu	ug/g	0.012	0.015	<4.6x10(-3)
Fe	ug/g	+0.82	0.44	+0.85
Mn	ug/g	+0.11	+0.12	>+0.11
Ti	ug/g	0.018	0.18	<1.6x10(-3)
SO_4	mg/g	+1.4x10(-3)	>+3.3x10(-3)	+1.9x10(-3)
Alk	mg/g	5.1x10(-3)	9.0x10(-3)	0.013

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/g	0.22	0.56	0.21
Cr	ug/g	<1.4x10(-3)	<1.6x10(-3)	<1.4x10(-3)
Cu	ug/g	7.8x10(-3)	7.0x10(-3)	4.6x10(-3)
Fe	ug/g	+1.15	+1.09	+1.19
Mn	ug/g	+0.13	+0.16	>+0.14
Ti	ug/g	7.4x10(-3)	0.028	2.8x10(-3)
SO_4	mg/g	0.038	+4.1x10(-4)	+3.1x10(-3)
Alk	mg/g	+2.7x10(-3)	7.0x10(-3)	0.011

TABLE NO. 3.5-23 (Cont.)

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/g	0.17	0.16	0.093
Cr	ug/g	--	--	--
Cu	ug/g	9.2x10(-3)	<5.4x10(-3)	4.6x10(-3)
Fe	ug/g	--	+1.64	--
Mn	ug/g	--	--	--
Ti	ug/g	--	<2.2x10(-3)	--
SO_4	mg/g	+3.7x10(-3)	+4.6x10(-3)	+5.2x10(-3)
Alk	mg/g	+4.7x10(-3)	1.5x10(-4)	0.012

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/g	0.097	0.058	0.62
Cr	ug/g	--	--	--
Cu	ug/g	9.6x10(-3)	<5.4x10(-3)	6.0x10(-3)
Fe	ug/g	--	+1.92	--
Mn	ug/g	--	--	--
Ti	ug/g	--	<2.2x10(-3)	--
SO_4	mg/g	+4.6x10(-3)	+5.4x10(-3)	+5.9x10(-3)
Alk	mg/g	+4.4x10(-3)	+4.6x10(-3)	0.026

TABLE NO. 3.5-23 (Cont.)

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/g	0.16	0.31	0.087
Cr	ug/g	<1.4x10(-3)	<1.4x10(-3)	<1.4x10(-3)
Cu	ug/g	0.023	0.012	7.8x10(-3)
Fe	ug/g	+1.78	+1.97	+2.0
Mn	ug/g	+0.18	>+0.23	>+0.21
Ti	ug/g	<1.8x10(-3)	0.017	1.8x10(-3)
SO_4	mg/g	+3.6x10(-3)	+4.2x10(-3)	+6.4x10(-3)
Alk	mg/g	5.4x10(-3)	+2.3x10(-3)	0.023

1. Those quantities marked with a plus sign (+) denote quanities sorbed or retained by the samples.
2. All other quantities are leached or desorbed.

TABLE NO. 3.5-23 (Cont.)

Saturated Sandstone Quantities Leached

CYCLE 1

Parameter	Units	West	Central	East
Al	ug/g	2.85	0.19	0.33
Cr	ug/g	0.026	1.6x10(-3)	1.7x10(-3)
Cu	ug/g	0.13	<3.1x10(-3)	5.3x10(-3)
Fe	ug/g	1.75	+0.66	8.2x10(-3)
Mn	ug/g	+0.11	+0.72	+0.022
Ti	ug/g	0.22	1.6x10(-3)	0.015
SO_4	mg/g	>+5.1x10(-3)	+9.6x10(-4)	1.0x10(-3)
Alk	mg/g	+4.2x10(-3)	+9.4x10(-4)	+1.2x10(-3)

CYCLE 2

Parameter	Units	West	Central	East
Al	ug/g	4.57	0.38	0.92
Cr	ug/g	0.037	<9.4x10(-4)	<7.2x10(-4)
Cu	ug/g	0.18	4.1x10(-3)	0.011
Fe	ug/g	3.13	+0.62	0.62
Mn	ug/g	+0.11	+0.073	0.045
Ti	ug/g	0.47	0.014	0.042
SO_4	mg/g	+2.6x10(-3)	6.1x10(-4)	+9.4x10(-4)
Alk	mg/g	+1.7x10(-3)	6.3x10(-4)	5.2x10(-4)

TABLE NO. 3.5-23 (Cont.)

Parameter	Units	West	Central	East

CYCLE 4

Parameter	Units	West	Central	East
Al	ug/g	1.000	0.075	0.081
Cr	ug/g	2.5x10(-3)	--	--
Cu	ug/g	0.022	<3.1x10(-3)	<2.4x10(-3)
Fe	ug/g	+1.12	+0.79	+0.47
Mn	ug/g	+0.16	>+0.08	+0.055
Ti	ug/g	0.038	<1.2x10(-3)	3.1x10(-3)
SO_4	mg/g	+1.3x10(-3)	+1.9x10(-3)	9.8x10(-4)
Alk	mg/g	4.6x10(-3)	5.0x10(-3)	2.0x10(-3)

CYCLE 8

Parameter	Units	West	Central	East
Al	ug/g	0.75	0.052	0.078
Cr	ug/g	3.8x10(-3)	--	--
Cu	ug/g	0.028	<3.1x10(-3)	<2.4x10(-3)
Fe	ug/g	+0.82	+0.73	+0.46
Mn	ug/g	+0.16	>+0.08	+0.054
Ti	ug/g	0.064	<1.2x10(-3)	<9.6x10(-4)
SO_4	mg/g	+4.9x10(-5)	+1.5x10(-5)	2.1x10(-5)
Alk	mg/g	9.6x10(-3)	4.7x10(-3)	8.7x10(-3)

TABLE NO. 3.5-23 (Cont.)

CYCLE 16

Parameter	Units	West	Central	East
Al	ug/g	0.27	0.13	0.12
Cr	ug/g	<1.9x10(-3)	<9.4x10(-4)	<7.2x10(-4)
Cu	ug/g	0.025	6.6x10(-3)	2.2x10(-3)
Fe	ug/g	+1.24	+0.70	+0.34
Mn	ug/g	>+0.16	+0.078	+0.044
Ti	ug/g	5.6x10(-3)	1.5x10(-3)	6.5x10(-4)
SO_4	mg/g	+1.3x10(-4)	+9.6x10(-4)	+4.6x10(-4)
Alk	mg/g	3.9x10(-3)	2.5x10(-3)	2.0x10(-3)

1. Those quantities marked with a plus sign (+) denote quantities sorbed or retained by the samples.
2. All other quantities are leached or desorbed.

TABLE NO. 3.5-23 (Cont.)

Calculated Quantities of Selected Parameters Leached from the Saturated Till, Sandstone, and Saprolite Samples
Saturated Saprolite Quantities Leached

PARAMETER	UNITS	CYCLE 1	CYCLE 2	CYCLE 4	CYCLE 8	CYCLE 16
Al	ug/g	0.13	0.31	0.028	0.034	0.038
Cu	ug/g	0.014	0.013	5.7x10(-3)	9.8x10(-3)	0.013
Fe	ug/g	+0.95	+1.03	>+1.25	+1.37	>+1.51
Mn	ug/g	+0.088	+0.10	+0.12	+0.13	>+0.17
Ti	ug/g	0.15	--	<1.6x10(-3)	<1.6x10(-3)	--
SO_4	mg/g	6.9x10(-3)	8.7x10(-3)	9.3x10(-3)	9.8x10(-3)	9.2x10(-3)
Alk	mg/g	0.024	0.025	0.025	0.045	0.056

1. Those quantities marked with a plus sign (+) denote quantities sorbed or retained by the samples.
2. All other quantities are leached or desorbed.

bicarbonate during some of the cycles. The importance of these sorptions or retentions is that the concentrations of iron and manganese released to groundwater in contact with the backfilled waste rock will be reduced to background levels as the groundwater saturates the backfilled pit. In addition, the retention of the anions, sulfate and bicarbonate, will enhance the long-term retention of iron, manganese and other metals by the formation of stable secondary minerals.

During the transition from the wet/dry leaching to the saturated leaching, the amounts of leachable aluminum, chromium and titanium in the till composite leachates decreased. As the saturated leaching progressed, the quantities leached of each of these metals decreased further. The quantity of leached copper remained essentially the same during the transition, and, although the amounts of copper leached varied during the saturated cycles, there was little overall change in the quantity leached during the saturated cycles.

The quantities of aluminum, chromium, copper, and titanium leached from the sandstone composites increased during the transition from the wet/dry to the saturated leaching. The leached quantities of these metals then decreased during the saturated leachings.

The quantities of copper, titanium and sulfate leached from the saprolite increased during the transition between the wet/dry and saturated leachings and the quantity of aluminum remained about the same. During the saturated leachings, the quantities of aluminum, copper, and titanium leached from the saprolite decreased. The leached amounts of sulfate, however, increased as the saturated leachings progressed.

The pH and specific conductivity values measured during each of the saturated waste rock leachings are presented in Table No. 3.5-24. The data show that during the transition between the wet/dry and saturated leachings of the waste rock chips the pH of the WR-3 through WR-5 leachate remained the same while the pH of the WR-1 and WR-2 leachate increased by approximately one-half a standard unit. During the course of the saturated leaching, the pH of the WR-1 through WR-3 remained unchanged and the pH of WR-4 and WR-5 decreased approximately one, and one-half, units, respectively.

During the transition between the two leaching tests, the leachate pH of all of the powered waste rock composites increased between one-half and one standard units. As the saturated leaching progressed, the leachate pH of WR-1 remained the same. The leachate pHs of the other waste rock samples increased between one and three units.

Concentration of selected parameters in saturated waste rock leachate are presented in Table No. 3.5-25 and calculated quantities of the parameters are also presented in Table

TABLE NO. 3.5-24

pH and Specific Conductivity Values for the Saturated Leaching of the Waste Rock Samples

Cycle	Date	Parameter	Rock Chips					Rock Powder				
			WR - 1	WR - 2	WR - 3	WR - 4	WR - 5	WR - 1	WR - 2	WR - 3	WR - 4	WR - 5
1	08/06/88	pH	8.00	6.71	5.95	5.41	3.80	8.67	7.00	7.65	7.48	5.58
		Spec. Con.	469	373	511	569	604	293	291	310	313	307
2	08/11/88	pH	7.65	6.41	5.80	4.63	3.58	7.78	7.27	7.75	7.31	7.15
		Spec. Con.	497	384	540	598	655	445	432	425	448	435
3	08/16/88	pH	8.00	6.65	5.83	4.50	3.70	8.25	8.00	8.10	8.20	8.30
		Spec. Con.	506	400	543	609	655	424	446	421	427	445
4	08/21/88	pH	7.85	6.46	5.65	4.28	3.56	8.07	7.98	8.25	8.15	8.40
		Spec. Con.	531	414	571	651	680	439	459	420	441	488
5	08/26/88	pH	8.08	6.70	6.07	4.38	3.70	8.80	8.50	8.58	8.69	8.93
		Spec. Con.	546	430	572	662	697	431	430	430	432	433
6	08/31/88	pH	7.83	6.50	5.94	4.38	3.63	8.82	8.43	8.15	8.42	8.85
		Spec. Con.	558	435	580	671	683	446	438	432	435	453
7	09/06/88	pH	7.99	6.82	5.56	4.38	3.43	8.22	7.87	7.90	8.10	8.47
		Spec. Con.	550	442	693	789	710	460	443	437	445	471
8	09/10/88	pH	7.80	6.34	5.84	4.28	3.36	8.60	8.30	8.35	8.40	8.63
		Spec. Con.	592	450	604	708	755	483	460	443	454	483
9	09/15/88	pH	8.07	6.55	5.88	4.29	3.41	8.82	8.48	8.50	8.66	8.98
		Spec. Con.	575	451	586	687	777	413	395	395	400	433
10	09/20/88	pH	7.95	6.44	5.89	4.30	3.38	8.62	8.31	8.40	8.51	8.60
		Spec. Con.	580	461	603	706	808	441	397	392	401	468

TABLE NO. 3.5-24 (Cont.)

Cycle	Date	Parameter	Rock Chips					Rock Powder				
			WR - 1	WR - 2	WR - 3	WR - 4	WR - 5	WR - 1	WR - 2	WR - 3	WR - 4	WR - 5
11	09/25/88	pH	8.03	6.51	5.96	4.36	3.40	8.70	8.38	8.47	8.54	8.52
		Spec. Con.	598	469	610	727	844	464	406	395	404	488
12	09/30/88	pH	7.94	6.42	6.04	4.51	3.54	8.56	8.37	8.48	8.52	8.53
		Spec. Con.	591	479	636	781	892	475	413	397	408	535
13	10/05/88	pH	8.14	6.75	6.08	4.48	3.47	8.68	8.40	8.58	8.54	8.54
		Spec. Con.	609	484	660	785	910	535	427	406	411	569
14	10/10/88	pH	8.20	6.75	6.12	4.44	3.42	8.89	8.48	8.60	8.50	8.82
		Spec. Con.	622	494	666	786	972	497	435	407	424	546
15	10/15/88	pH	8.11	6.36	5.97	4.31	3.28	8.73	8.40	8.46	8.44	8.62
		Spec. Con.	628	494	701	816	1,025	535	442	415	426	568
16	10/20/88	pH	8.11	6.36	6.04	4.35	3.29	8.65	8.55	8.63	8.62	8.93
		Spec. Con.	655	513	688	841	1,070	580	439	415	424	580

UNITS: pH - standard units
Spec. Con. - umhos/cm

TABLE NO. 3.5-25

Concentrations of Selected Parameters in Saturated Waste Rock Leachate

WR-1 Saturated Quantities Leached

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	73	35	73	74	130	742	904	85	46	80
Cu	ug/L	17	18	<10	24	38	22	<20	--	--	15
Fe	ug/L	81	<55	--	--	<55	1,200	1,200	840	160	<110
Mn	ug/L	32	34	--	--	34	34	<4	--	--	<22
Zn	ug/L	35	<11	--	--	<11	62	74	22	<22	<22
SO4	mg/L	48	55	60	75	92	15	20	14	16	140
Alk	mg/L	78	82	87	130	130	--	--	--	--	--

WR - 2 Saturated Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	48	31	40	31	92	392	476	192	87	110
Cu	ug/L	230	250	230	340	460	270	40	<20	<20	31
Fe	ug/L	<55	<55	--	--	<55	500	840	340	160	<110
Mn	ug/L	270	250	290	340	440	320	6	--	--	<22
Zn	ug/L	180	<11	190	210	220	750	60	26	<22	<22
SO_4	mg/L	49	65	70	76	110	50	24	38	21	<100
Alk	mg/L	<10	<10	<10	<10	<10	--	--	--	--	--

TABLE NO. 3.5-25 (Cont.)

Concentrations of Selected Parameters in Saturated Waste Rock Leachate

WR - 3 Saturated Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	41	46	18	24	69	627	262	78	62	69
Cu	ug/L	7,200	6,800	7,200	6,900	5,000	41	60	<20	<20	34
Fe	ug/L	69	64	--	--	<55	750	680	140	150	<110
Mn	ug/L	650	690	780	900	1,100	28	16	--	--	<22
Zn	ug/L	12,000	12,000	--	--	11,000	110	136	32	30	26
SO_4	mg/L	120	190	150	190	210	39	50	15	17	<50
Alk	mg/L	<10	<10	<10	<10	<10	--	--	--	--	--

WR - 4 Saturated Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	272	335	831	290	330	443	146	71	124	120
CU	ug/L	16,000	14,000	22,000	25,000	30,000	50	42	36	38	82
Fe	ug/L	1,200	1,100	490	500	<55	310	210	170	240	<110
Mn	ug/L	450	460	570	630	880	130	<4	--	--	< 22
Zn	ug/L	2,300	1,900	3,000	3,300	4,200	27	<11	30	<22	54
SO_4	mg/L	170	190	180	220	280	48	17	35	21	< 60
Alk	mg/L	<10	<10	<10	<10	<10	--	--	--	--	--

TABLE NO. 3.5-25

Concentrations of Selected Parameters in Saturated Waste Rock Leachate

WR - 5 Saturated Leachate Concentrations

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/L	1,000	954	751	820	2,000	489	--	106	38	59
Cu	ug/L	53,000	63,000	76,000	93,000	165,000	5,500	--	36	20	31
Fe	ug/L	3,100	14,000	11,000	310	440	100	--	<110	<110	<110
Mn	ug/L	1,100	1,100	1,400	1,700	3,000	110	--	<22	<22	<22
Zn	ug/L	370	400	450	530	830	120	--	<22	<22	<22
SO4	mg/L	190	200	210	220	400	66	21	23	24	43
Alk	mg/L	<10	<10	<10	<10	<10	--	--	--	--	--

No. 3.5-26. The calculations of the quantity of iron in the leachate samples of all of the waste rock composite (for all but a few cycles of the WR-5 rock chips column) revealed that iron is retained by the waste material, probably by the precipitation of one or more iron-bearing minerals. This is also the case for manganese but only when the pH of the leachate is greater than approximately 6.5. Bicarbonate was retained by all of the rock chips columns. Bicarbonate may also have been retained by the rock powder, but alkalinity was not quantitated in the rock powder leachate, so this was not determined.

A blank sample of synthetic groundwater was equilibrated and tested under the same conditions as all of the saturated waste samples. During the saturated leaching cycles, it was observed that a dark reddish-brown precipitate formed and collected within the centrifuge bottle containing the blank solution. The changes in the composition of the blank solution suggest that, in addition to the probable precipitation of the dark reddish-brown ferrihydrite (hydrous ferric oxide), calcium and magnesium carbonate also precipitate from solution.

When the saturated leaching tests were completed, the waste rock columns were carefully unpacked in order to check the chip surfaces for precipitates. Most of the chips within the WR-1 through WR-4 columns were covered with a thin dark reddish-brown precipitates which are probably ferrihydrite. The surfaces of the chips in the WR-5 column were covered with a light yellowish-brown precipitate, which is probably jarosite, a hydrous potassium ferric sulfate. The formation of jarosite is favored by low pH and high sulfate concentration, conditions which are met in the WR-5 chip column. Where individual pyrite grains are visible in the rock chips in all of the columns, they are partially or completely covered with ferrihydrite. When the columns were first charged, the pyrite grains were a bright brassy color.

Some of the rock chips in all of the waste rock columns contain the hydrous copper carbonate minerals azurite and malachite, which is the more common of the two. Some of the malachite grains in the WR-3 through WR-5 columns have epitaxial overgrowths of malachite on them. The copper concentrations in the leachate solutions in these columns are great enough to support the precipitation of this mineral (Kern and Weisbrod, 1967).

The precipitation of mineral phases within the waste rock columns suggests that the increased release of metals observed during the course of the saturated leaching tests will be initially limited by the solubility product of those minerals. Eventually the rate of diffusion of metals through these phases will govern the rate of metal release.

TABLE NO. 3.5-26

Calculated Quantities of Selected Parameters Leached from Saturated Waste Rock

WR-1 Saturated Quantities Leached

Parameter	Units	Rock Chips					Rock Powder				
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/g	0.038	0.018	0.038	0.039	0.018	7.42	9.04	0.85	0.46	0.80
Cu	ug/g	8.9x10^{-3}	9.4x10^{-3}	<0.5x10^{-3}	1.3x10^{-3}	0.020	0.22	<0.22	----	----	0.15
Fe	ug/g	+1.27	>+1.38	----	----	>+1.67	+13.0	+13.0	+16.6	+23.4	>+23.9
Mn	ug/g	+0.13	+0.13	----	----	+0.17	+ 2.4	+ 2.7	----	----	>+ 2.5
Zn	ug/g	0.018	<5.8x10^{-3}	----	----	<5.8x10^{-3}	0.62	0.74	0.22	<0.22	<0.22
SO_4	mg/g	0.018	0.022	0.024	0.031	0.039	0.020	0.070	0.010	0.030	1.27
Alk.	mg/g	0.030	0.031	0.033	0.055	0.054	----	----	----	----	----
WR-2 Saturated Quantities Leached											
Al	ug/g	0.025	0.016	0.021	0.016	0.049	3.92	4.76	1.92	0.87	1.10
Cu	ug/g	0.12	0.13	0.12	0.18	0.24	2.70	0.40	<0.20	<0.20	0.31
Fe	ug/g	>+1.29	>+1.39	----	----	>+1.71	+20	+17	+22	+23	>+24
Mn	ug/g	2.3x10^{-3}	+0.018	+0.007	+7.5x10^{-4}	0.042	0.50	+2.6	----	----	>+2.5
Zn	ug/g	0.095	0.10	0.10	0.11	0.12	7.50	0.60	0.26	<0.22	<0.22
SO_4	mg/g	0.019	0.027	0.029	0.032	0.049	0.37	0.11	0.25	0.08	<0.87
Alk.	mg/g	>+0.01	>+0.01	>+0.01	>+0.01	<+0.01	----	----	----	----	----
WR-3 Saturated Quantities Leached											
Al	ug/g	0.023	0.026	0.067	0.14	0.049	6.27	2.62	0.78	0.62	0.69
Cu	ug/g	4.07	3.85	4.07	3.90	2.83	0.41	0.60	<0.20	<0.20	0.34
Fe	ug/g	+1.37	+1.49	----	----	>+1.49	+17.5	+18.2	+24.6	+23.5	>+23.9
Mn	ug/g	0.21	0.23	0.26	0.32	0.42	+ 2.4	+ 2.5	----	----	>+2.5
Zn	ug/g	6.79	6.79	----	----	6.22	1.10	1.36	0.32	0.30	0.26
SO_4	mg/g	0.060	0.10	0.076	0.10	0.11	0.26	0.37	0.02	0.04	<0.37
Alk.	mg/g	>+0.01	>+0.01	>+0.01	>+0.01	>+0.01	----	----	----	----	----

TABLE NO. 3.5-26 (Cont.)

WR-4 Saturated Quantities Leached

		Rock Chips					Rock Powder				
Parameter	Units	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16	Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 16
Al	ug/g	0.13	0.16	0.41	0.14	0.16	4.43	1.46	0.71	1.24	1.20
Cu	ug/g	7.83	6.85	10.76	12.23	14.68	0.50	0.42	0.36	0.38	0.82
Fe	ug/g	+0.63	+0.76	+1.13	+1.21	>+1.49	+21.9	+22.9	+23.3	+22.6	>+22.9
Mn	ug/g	0.088	0.085	0.13	0.15	0.27	+1.4	>+2.6	----	----	>+2.5
Zn	ug/g	1.13	0.93	1.47	1.61	2.05	0.27	<0.11	<0.30	<0.20	0.54
SO_4	mg/g	0.077	0.086	0.081	0.10	0.13	0.35	0.040	0.22	0.080	<0.47
Alk.	mg/g	>+0.01	>+0.01	>+0.01	>+0.01	>+0.01	----	----	----	----	----
WR-5 Saturated Quantities Leached											
Al	ug/g	0.38	0.36	0.28	0.31	0.76	4.89	----	1.06	0.38	0.59
Cu	ug/g	20.1	23.9	28.9	35.3	62.7	55.0	----	0.36	0.20	0.31
Fe	ug/g	0.23	4.3	3.10	+1.03	+1.04	+24.0	----	>+24	>+24	>+24
Mn	ug/g	0.32	0.31	0.41	0.52	1.01	+1.6	----	>+2.5	>+2.5	>+2.5
Zn	ug/g	0.14	0.15	0.17	0.20	0.32	1.20	----	<0.22	<0.22	<0.22
SO_4	mg/g	0.067	0.071	0.074	0.078	0.14	0.53	0.080	0.10	0.11	0.30
Alk.	mg/g	>+4.2x10^{-3}	>+4.7x10^{-3}	>+5.3x10-3	>+5.8x10^{-3}	>+6.2x10^{-3}	----	----	----	----	----

The quantities of metals leached from the rock chip columns tended to increase during the transition from wet/dry to saturated leaching. During the saturated cycles, the quantities leached continued to increase. Similar observations can be made in a general sense, with regard to the waste rock powder column tests. These saturated leaching studies demonstrated what could occur within the pit when the backfilled material comes in contact with groundwater. If no lime is added to the backfilled Type II material, then release of some metals will occur. The actual quantity of metals released will be a partial function of the solubility products of several secondary minerals. It has been shown previously that the addition of lime to the waste rock when it is returned to the pit will substantially decrease the concentration of iron and copper in the water in contact with the waste rock. Although the lime treatment had little effect on the manganese and sulfate concentration, the saturated leaching studies show that these substances will be retained by the waste rock without any treatment. Therefore, based on the test results no significant quantities of copper, iron, manganese, or sulfate will be released from the backfilled pit.

3.5.6.3.4 Soil Sorption

The objective of this study was to evaluate the capacity of the soils beneath the Type I waste storage site (KWR soils) and the underlying till to sorb, or retain, leachate released by the Type I materials. In addition, samples of sandstone and saprolite were also reacted with the leachate in order to determine how they, in addition to the till, might react to site-generated leachate within the stockpile.

Leachate formed from a till composite was generated following the method included in Appendix 3.5-R. The method of sample equilibration is also included in Appendix 3.5-R, along with the laboratory analyses of the final equilibrated solutions. A summary of the results of the equilibration of iron and copper is presented in Table No. 3.5-27.

The reactions between the soils and iron and copper differed for each type of material. When high concentrations of iron and copper were reacted with till samples, the till sorbed or retained some of the iron and copper from the equilibrating solutions. At lower concentrations the till desorbed or released iron and copper. It appears that the topsoil reacted in similar fashion, but the quantities sorbed were less and desorbed greater than those by the till.

The sandstone samples desorbed iron, copper, and chromium for all leachate compositions. The behavior of the sandstone was predictable based on the leaching studies. The saprolite material desorbed iron under all tested conditions. However, the saprolite sorbed copper at high copper concentration and desorbed it at lower concentrations of applied copper.

TABLE NO. 3.5-27

Calculated Gains (+) and/or Losses (-) of Iron and Copper by Equilibrated Topsoil and Overburden Samples

	Topsoil		Till		Sandstone		Saprolite	
Equilibrating Solution (ug Fe/L)	Final Solution (ug/L)	Soil Gain/Loss (ug/g)	Final Solution (ug/L)	Soil Gain/Loss (ug/g)	Final Solution (ug/L)	Soil Gain/Loss (ug/g)	Final Solution (ug/L)	Soil Gain/Loss (ug/g)
9,400	9,500	-	3,900	+48.3	18,000	-56.1	12,000	-19.2
4,700	8,600	-36.3	2,400	+19.7	11,000	-44.4	9,600	-37.1
2,350	3,800	-13.9	2,300	-	7,100	-34.1	9,100	-49.8
940	3,700	-27.3	1,700	-7.0	9,600	-63.7	6,700	-41.0
0	2,700	-27.0	1,400	-12.7	9,900	-72.6	9,100	-67.1
(ug Cu/L)								
50	31	+0.19	23	+0.24	430	-2.81	35	+0.11
25	20	+0.047	19	+0.051	250	-1.59	25	-
12.5	<10	+ ?	18	-0.050	190	-1.27	17	-0.033
5	<10	?	12	-0.064	250	-1.80	24	-0.14
0	<10	?	10	-0.091	250	-1.83	47	-0.35

Several of the project groundwater monitoring wells are screened in the till. One of these wells, MW-1005, had variable but unusually high (several thousand ug/l) concentrations of iron in the well water when compared to other parts of the state, but is typical for the local area. Several wells near the site, also screened in the till, have been reported to contain high concentrations of iron in the water (Hindall, 1979). The results of the sorption study indicate that the till will naturally support elevated concentrations of iron in groundwater (see final solution concentrations in Table No. 3.5-27). Apparently this behavior is duplicated in the field in at least some of the surrounding area. The result of the retention of iron and copper by the topsoil and till samples is that the water leaving the till and entering the groundwater is expected to contain concentrations of iron and copper equivalent to those found in the on-site monitoring wells.

3.5.6.3.5 Extraction Procedure Toxicity

Extraction procedure toxicity for eight metals have been determined for the powdered waste rock samples WR-1 through WR-5. The standard U.S. EPA procedure was used and the extracts were analyzed for arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver. The results of the analyses, included in Appendix 3.5-R, indicate that none of the waste rock would be classified as hazardous.

3.5.6.3.6 Radiochemistry

In 1978, Kennecott staff conducted a thorough study of ore and waste rock core samples in order to determine if any of them were radiation emitters. All Flambeau drill cores were examined for general radiation using a Model 111B scintillation counter. All resulting readings were within the normal background count range of 0.005 to 0.015 MR/HR.

Five composite samples made from 14 mill bench test samples were prepared in 1980. These composite samples were analyzed for Gross Alpha, Gross Beta, and Radium-226 by Eberline Laboratories (Albuquerque, NM). The results of these analyses, included in Appendix 3.5-R, indicate that the radioactivity in the ore from the Flambeau deposit is within normal background ranges for PreCambrian bedrock.

The results of the bulk chemical analyses of the waste rock samples indicate that the uranium content of these materials is less than microgram per gram (see Appendix 3.5-O). At these uranium concentrations, it would be expected that only very low level or background radiation would be emitted. Also, the concentration of radium-226, a daughter product of uranium decay, would be expected to be very low.

3.5.6.3.7 Characterization of Wastewater Treatment Plant Lime Sludge and Settling Pond Polymer Solids

The wastewater treatment plant for the proposed project will treat contact water for acid neutralization and to remove metals. The treatment process will produce a treated effluent that will be discharged to the Flambeau River, and a lime sludge that will be placed on the Type II stockpile.

Runoff from the Type I stockpile will be directed to a series of settling ponds for sediment removal prior to discharge to the Flambeau River. At times it may be necessary to add polymer and possibly lime to the runoff to assist in removing colloids. These colloids may contain trace amounts of metals.

Bench test studies were completed to demonstrate the adequacy and efficiency of the wastewater treatment plant process design, and the efficiency of polymer addition to the Type I runoff. During the studies, samples of lime sludge from the wastewater treatment bench test and samples of settled colloids from the settling pond bench test were chemically characterized. These samples were analyzed for arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, zinc, and iron. The results of these analyses, along with those of the test supernatants and raw wastewaters, are included in Appendix B of the Kennecott Flambeau Project *Preliminary Engineering Report for the Wastewater Treatment Facilities* (March 1989).

One result of the bench test studies was that the solids content of both the wastewater treatment plant sludge and polymer solids was less than one percent. This occurrence is not uncommon in bench scale testing. While the solids content in the bench test study was less than what would be expected during full-scale operation, the bench test sludge analyses are considered to be reasonable approximations of the composition of the sludge and solids that will result from actual operations. In the wastewater treatment plant, thickeners have been included in the process to bring the solids content of sludge to 25 percent.

Table No. 3.5-28 compares the test results of the raw wastewater to those for the wastewater treatment plant lime sludge on a weight-per-weight basis. The derivation of the values is shown in the table included in Appendix 3.5-R. As expected, the quantities of metals in the sludge exceed those in the raw wastewater due to concentration in the treatment process.

Lime sludge at 25 percent solids will be trucked from the wastewater treatment plant and spread on the material within the Type II stockpile. The hydroxides, oxyhydroxides, and sulfates which make up the sludge are soluble under acidic conditions. Since the Type II stockpile is expected to be acidic, the applied sludge will probably dissolve. The concentrations of the metals released by the dissolution of the lime sludge will

TABLE NO. 3.5-28

Quantities of Metals Leached From the Semi-Massive Waste Rock Sample (WW-1) Compared with Those in the Wastewater Lime Sludge Produced From the Leachate

Parameter	Quantity of Metals Leachated (ug/g)	Quantity of Metals in Sludge (ug/g)
As	0.036	159
Cu	34.2	163,000
Hg	2.7×10^{-4}	1.5
Se	2.2×10^{-3}	<5
Ag	6.2×10^{-3}	37
Cd	0.034	165
Pb	0.10	37
Ni	0.030	130
Zn	8.74	45,000
Cr	5.1×10^{-3}	7.3

exceed the solubility products for several minerals that will be stable under the conditions that will be encountered within and on the stockpile. Since the sludge will be spread mainly on the central portion of the stockpile, the formation of insoluble and sparingly soluble oxyhydroxides and sulfates within the pile will be enhanced. These minerals will form as solubility products are exceeded due to the slow evaporation of water within the stockpile. A portion of the metals released from the dissolution of the lime sludge will be transported through the stockpile. These will be collected along the base of the stockpile and will be recycled back to the wastewater treatment facility.

When the Type II waste rock is backfilled into the pit, some of the secondary minerals that formed within the stockpile, especially the oxides and oxyhydroxides, will be stable. Others, such as the sparingly soluble sulfates, will slowly be transformed into stable oxides, oxyhydroxides and carbonates. The soluble hydrous sulfates, which will make up only a minor proportion of the secondary minerals, will dissolve. The dissolved minerals, along with the materials released as a result of the short-term leaching during backfilling of the waste rock, will slowly form new secondary minerals that will be in equilibrium with the groundwater within the crystalline bedrock. Therefore, materials in the sludge will form stable secondary minerals in both the stockpile and the backfilled open pit and will not be released to the groundwater.

Table No. 3.5-29 compares the results of the raw Type I runoff to those for the polymer solids on a weight-per-weight basis. The derivation of these values is also included in Appendix 3.5-R. Also as expected, the quantities of metals in the polymer solids exceeds those in the raw runoff.

Only a small amount of polymer solids is expected to be produced during the mining operation. They will be removed from the settling ponds along with accumulated sediments on an as-needed basis, and transported to the Type I stockpile where they will be spread on the till stored there. Past experience has shown that the polymers will physically break down to colloid-sized material when they are stored in an aerated environment. Since the solids will be stored on the stockpile till, and since the till contains numerous fine pores, the colloids will be trapped within these pores, thereby preventing their migration through the Type I stockpile. The application of the solids to the till will not measurably alter the bulk composition of the original till material. When the till is backfilled to the mine pit the colloids will be stable and will not release dissolved metals.

3.5.6.3.8 Quantitation and Distribution of Total Sulfur in the Waste Rock

The Flambeau deposit is a stratabound sulfide deposit (May 1977). In this type of deposit the zones of mineralization are

TABLE NO. 3.5-29

Quantities of Metals Leached (in Runoff) from the Till and Till/Saprolite Composites Compared with Those in the Polymer Sludge Produced from the Runoff

Parameter	Till Runoff - Series 1		Till Runoff-Series 2		Till/Saprolite Runoff	
	Runoff[1] (Raw)	Polymer[1] Sludge	Runoff[1] (Raw)	Polymer[1] Sludge	Runoff[1] (Raw)	Polymer[1] Sludge
As	5.9×10^{-3}	12	3.7×10^{-3}	16	5.6×10^{-3}	16
Cd	$<1.6 \times 10^{-3}$	<2.0	$<5.4 \times 10^{-3}$	<1.9	$<5.6 \times 10^{-3}$	<1.8
Cr	0.022	36	0.013	36	0.018	33
Cu	0.064	170	0.047	190	0.22	530
Pb	5.4×10^{-3}	19	3.2×10^{-3}	19	0.056	86
Hg	$<2.7 \times 10^{-4}$	<0.17	$<2.7 \times 10^{-4}$	<0.35	$<2.8 \times 10^{-4}$	<0.17
Ni	<0.016	22	<0.016	23	<0.017	21
Se	$<1.6 \times 10^{-3}$	0.62	$<1.6 \times 10^{-3}$	0.58	$<1.7 \times 10^{-3}$	0.54
Ag	$<2.1 \times 10^{-4}$	<10	$<2.1 \times 10$	<10	6.1×10^{-4}	<10
Zn	0.036	58	0.024	72	0.083	170
Fe	0.011[2]	22[2]	7.0×10^{-3} [2]	23[2]	8.4×10^{-3} [2]	22[2]

1. ug/g unless otherwise noted.
2. mg/g

confined to specific strata or lithologic units. The Flambeau deposit was altered by a supergene process which enriched the copper content of the upper part of the mineralized zone and also depleted this altered part of much of the sulfur.

The quantity of pyritic sulfur in mining wastes is considered to be the determining factor in the acid production potential and leachability of these wastes (Nordstrom, 1982). In sulfide deposits, such as the Flambeau deposit, pyritic sulfur is essentially equivalent to total sulfur. A considerable data base has been compiled by Kennecott Mining Corporation. This data was collected as part of the rock assay program. Additional total sulfur analyses have been conducted on some previously unassayed core and a compilation of all of the total sulfur analyses is included in Appendix 3.5-S.

The release of sulfate and the subsequent production of acid normally occurs in exposed surficial (i.e. oxidizing) environments. It may occur via inorganic or biochemical reactions, or both. If the pH of the water is in the range of 2.0 to 3.5, the production of acid is greatly enhanced by microbial activity, especially by the bacteria *Thiobacillus thiooxidans* and *T. ferrooxidans* (Stevenson, 1986). It is, therefore, necessary to store wastes which have reaction pH near 3.5 in storage sites where the acid produced, plus consequent leached metals, can be collected and treated. The pH of WR-5 approached 3.5 during the wet/dry leaching study, while leachate from WR-1 tends to have near-neutral pH.

The total sulfur analyses of the waste rocks indicate that a wide range of sulfur concentrations exist within these rocks, ranging from less than 0.10 to more than 30 percent. There is, however, a strong bimodal distribution of sulfur within the waste rocks. Most of the rocks contain either less than 0.2 percent or more than 2 percent total sulfur.

Based upon the results of the acid production and leaching analyses of the waste rock, it was concluded that waste rock with a total sulfur content of less than one percent total sulfur could be stockpiled in the unlined Type I storage site. Waste rock containing more than one percent total sulfur will be stockpiled in the lined Type II storage site.

The combined distribution of stratabound sulfur and the supergene alteration zones were plotted on geologic cross sections in order to delineate the area of Type I and Type II waste rock. Three such sections are shown in Figure Nos. 3.5-23 through 3.5-25. Only a small amount, approximately two to three percent, of the waste rock contains sulfur concentrations in the range of one-half to two percent. The delineation of the division between Type I and Type II waste rock will be quite evident in the field. Based upon the plotted sulfur distributions, it is evident that nearly all (approximately 98 percent) of the Type I waste rock will be similar to the WR-1 waste rock composite. In addition, it is considered that most of the Type II waste rock will be similar to the WR-5 waste rock composite.

3.5.6.4 Conclusions

The results of the waste characterization studies have led to the development of five conclusions. They are as follows:

1. The temporary stockpiling of the topsoil, overburden, and waste rock can be accomplished using a combination of lined and unlined storage facilities.
2. These materials can be returned to the mine site as part of the reclamation activities. This can be accomplished in a manner such that the groundwater and surrounding environment will not be significantly impacted.
3. It has been determined that none of the waste rock material is hazardous in terms of the EP Toxicity Test for the eight target metals.
4. Neither the ore nor the waste rock are emitters of radiation. Neither the ore nor the waste rock contain more than trace concentrations of uranium.
5. The baseline concentration of metals and sulfate has been established for all of the materials, including those that occur beneath the unlined stockpiles.

The above-grade storage of waste materials will be in three sites. One will be an unlined site which will store the topsoil. Another will be designated the Type I storage site; it will contain the till, sandstone, saprolite, and waste rock which contain less than one percent total sulfur. The third site will be lined and will contain the saprolite and waste rock which contain more than one percent total sulfur.

Precipitation which contacts the Type II waste rock will be collected and treated in order to remove metals and sulfate from this water prior to its discharge to the Flambeau River.

The tests of the waste rock acid production and leachability were performed on materials of two different grain sizes. These sizes were chosen to represent truly "worst case" scenarios. The very reactive powdered waste rock will represent approximately two to three percent of the fresh waste rock when it is first added to the stockpiles. As weathering proceeds and trucks compress the rock, more fine-grained material will be formed (Whiting, 1985). It is estimated that not more than ten percent, by volume, of the waste will eventually be fine-grained.

Both weathering and leaching are surface phenomena. Smaller particles have a greater surface area per unit weight than larger particles. The greater the surface area of rock particles, the greater will be the leachability of the materials within the particles (Krauskopf, 1972). The sizes of the chips used in the previously described waste rock evaluation are considered to represent the smallest-sized particles that preserve the prominent lithologic layering observed in the samples. The average-sized rock fragment stockpiled in the storage site is expected to be about one cubic foot. The proportion of exposed sulfide grains will be considerably less for the larger fragments than for those used in the tests.

The wet/dry leaching experiments also overestimated the leachate generation since the leaching columns were constructed to promote free drainage. In typical waste rock stockpiles, the quantity and speed of drainage is considerably less (Whiting, 1985). It is conservatively estimated that the actual quantities of metals and sulfate leached from the stockpiled waste rock will be less than one-tenth of those measured in the laboratory.

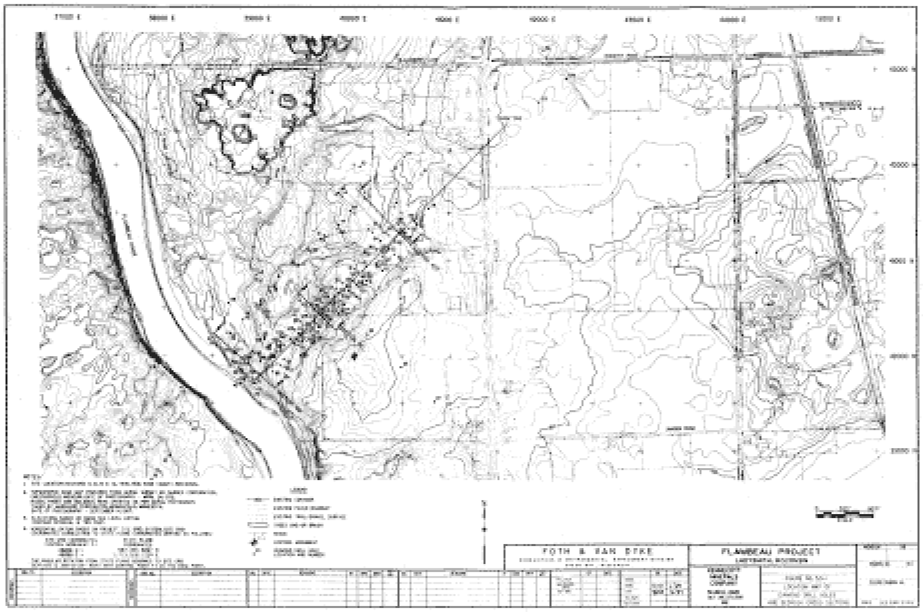
It is expected that the concentration of metals that exfiltrate from the base of the unlined storage sites will be considerably reduced before the water bearing those metals reaches the groundwater. Most metals that form ionized cationic species, such as copper, iron, and manganese, are retained by soils through sorption or precipitation reactions (Ellis, *et al*, 1983). The previously discussed soil sorption study demonstrated that the topsoil and till that is located beneath the Type I storage site has the capacity to sorb, or retain, significant quantities of copper and iron. This was especially true when concentrations of these metals were greater than those found within the groundwater monitored at the site. It is not expected that sulfate concentrations would be reduced based upon these studies and upon reported studies conducted elsewhere (Mehlich, 1981).

Overburden materials will be placed in the Type I storage area before waste rock is added to the area. *In situ* sorption, or retention, of metals can be enhanced by stockpiling the till material first. The sandstone material should be added on top of the till so that the till can retain the metals released by this leachable sandstone. The sandstone at the Flambeau site is especially leachable, probably due to the occurrences of the widely distributed patches of black, amorphous, metal-bearing material within it (for data, refer to Appendix 3.5-R).

The backfilling of the open pit should begin with the emplacement of the Type II material in a manner such that contact water can be collected and treated during the backfilling. Lime should be added to the rock in order to maintain a pH of 6.5 to 7.0 in this contact water while the pit is being filled. The Type I waste rock should be backfilled next, followed by the Type I saprolitic material. Even though the saprolite is chloritic (Appendix 3.5-R), it does have the ability to sorb iron and manganese (see Section 3.5.6.3.3.2). In addition, the saprolite will retard the transfer of water between the crystalline bedrock and the overlying till due to its low permeability. The permeability will become even lower as the saprolite is spread and consequently compressed.

The upper part of the pit should be filled with the sandstone, followed by the till, and lastly with the topsoil. Careful replacement of overburden has resulted in the creation of reclaimed sites with favorable soil environments, especially where lime and fertilizer have been added to the topsoil (Singh *et al*, 1982).

Figures for Section 3.5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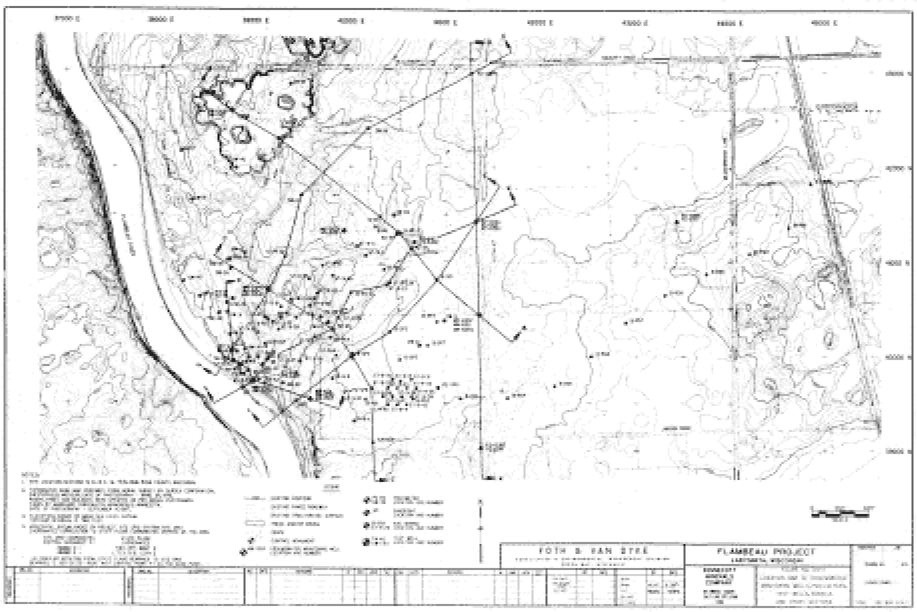
FLAMBEAU PROJECT
KENNECOTT MINERALS COMPANY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NOTES:
LEGEND
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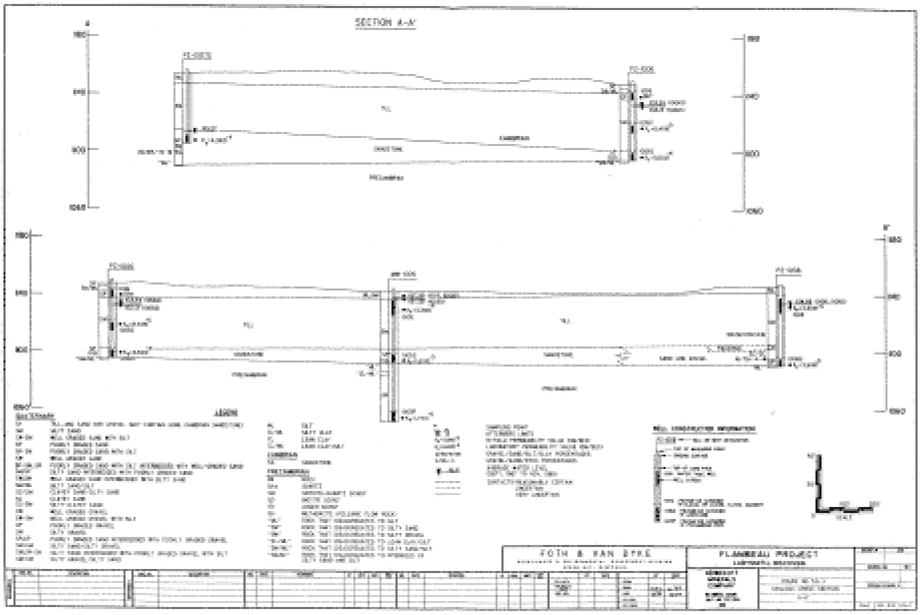
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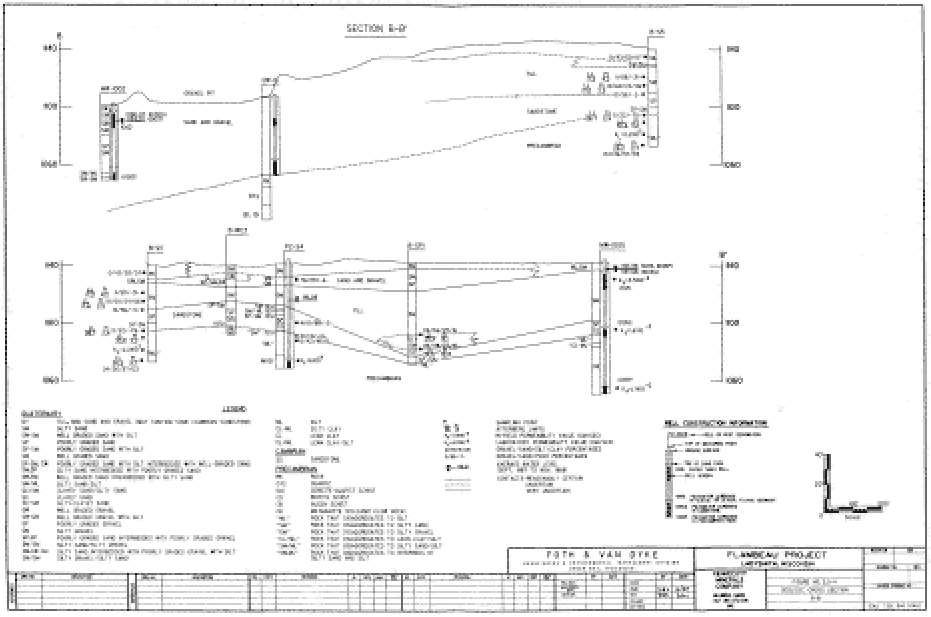
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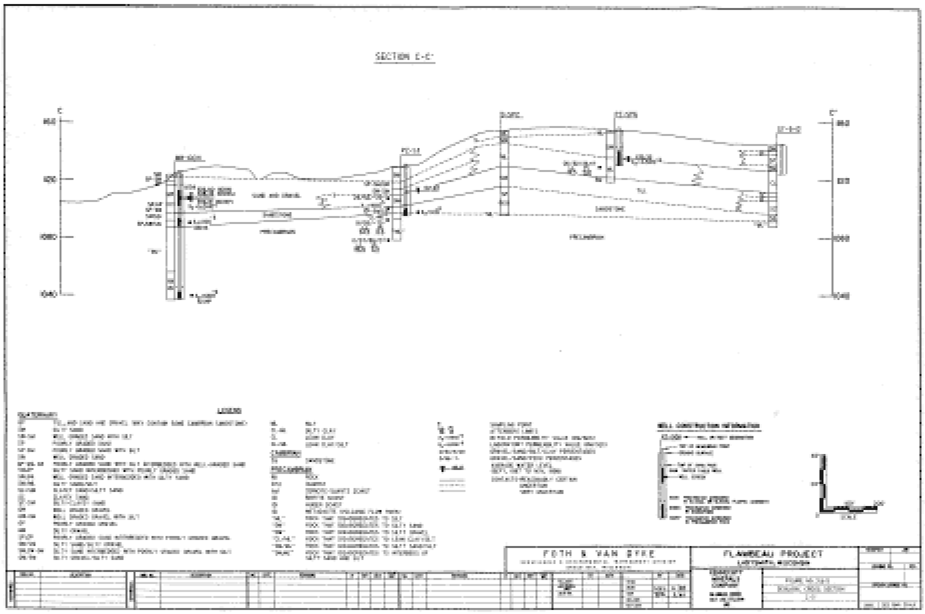
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FOTH & VAN DYKE
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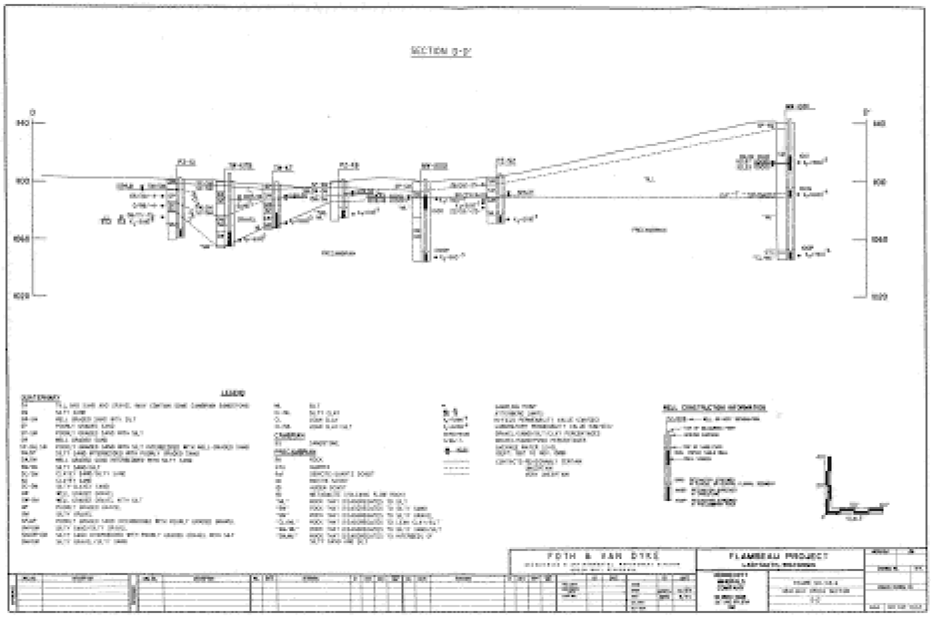
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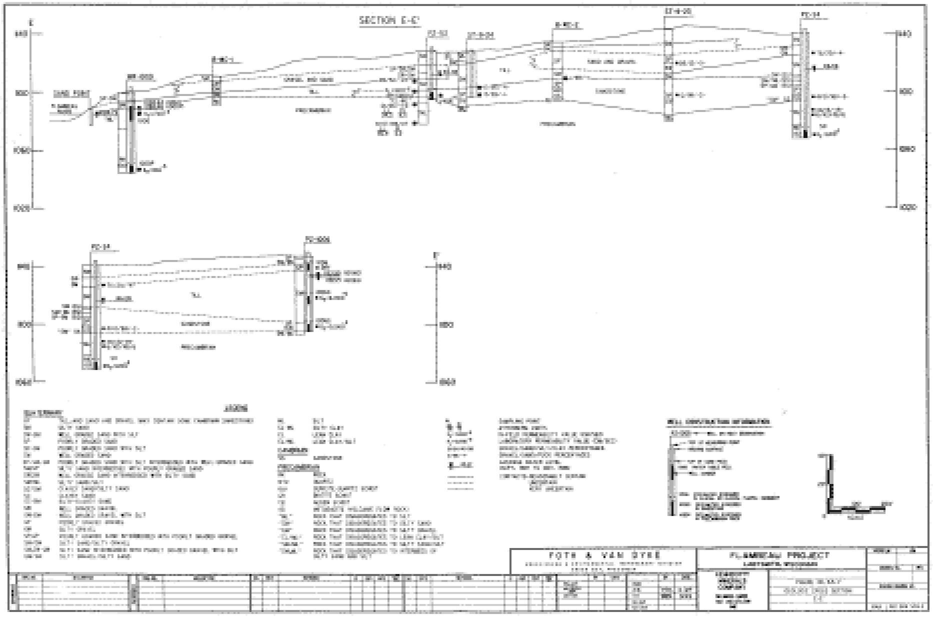
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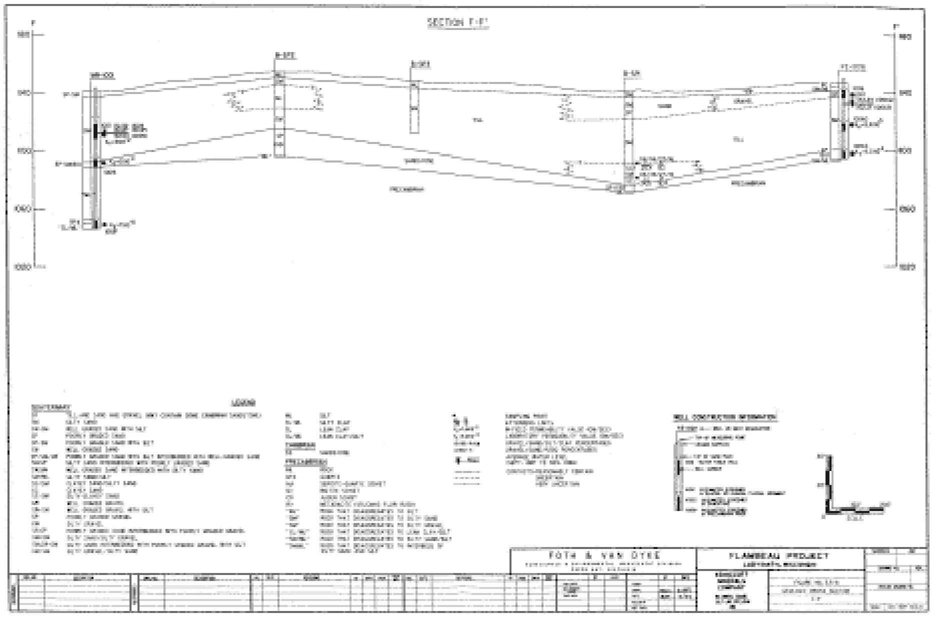
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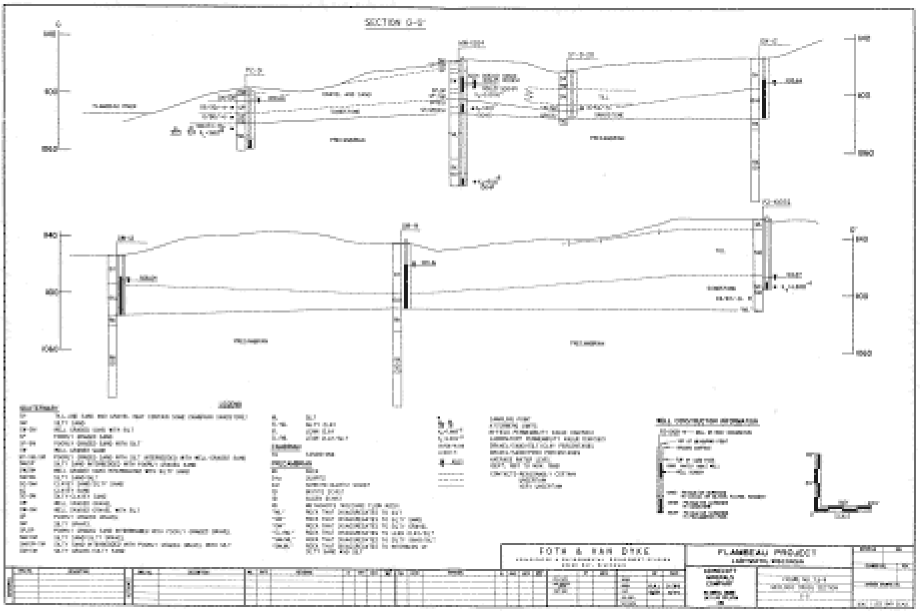
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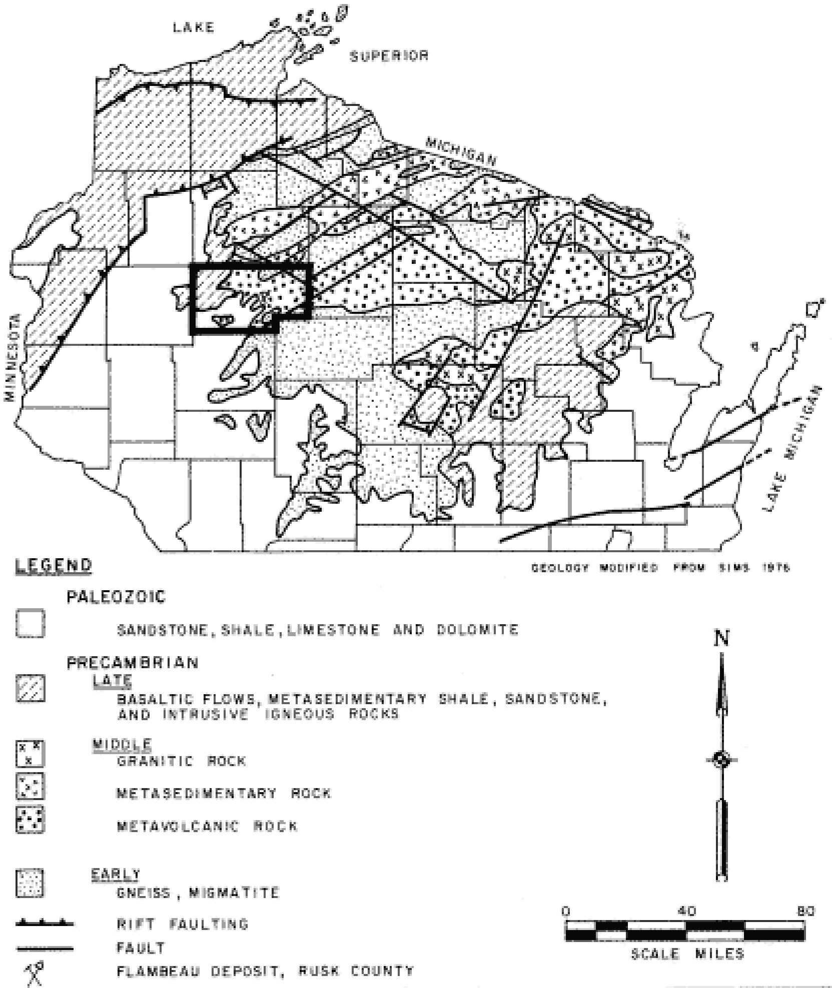

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	CAD No.	SCALE	

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FIGURE NO. 3.5-10
GENERALIZED GEOLOGIC MAP OF PRECAMBRIAN ROCKS IN NORTHERN WISCONSIN

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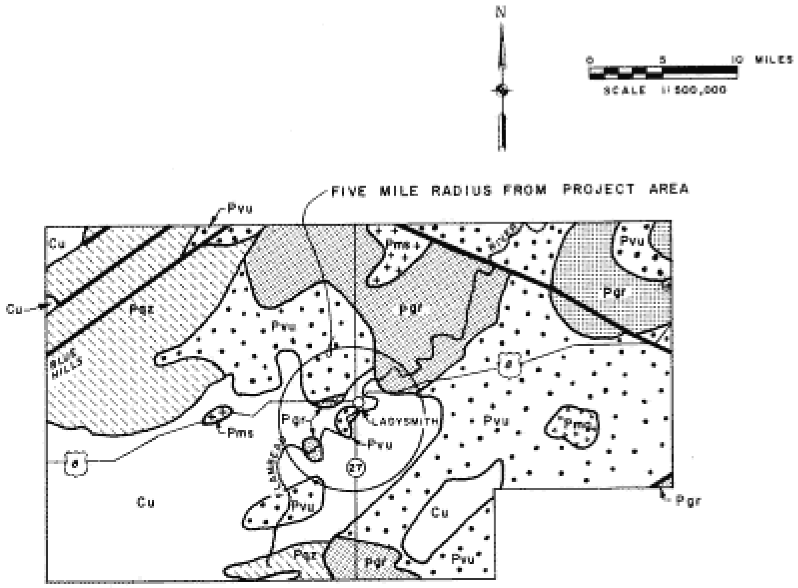

LEGEND

CAMBRIAN

Cu	SANDSTONE

PRECAMBRIAN

Pqz	QUARTZITE
Pgr	INTERMEDIATE TO GRANITIC INTRUSIVE ROCKS
Pmg	METAMORPHOSED ULTRAMAFIC TO MAFIC INTRUSIVE ROCKS
Pms	METAVOLCANIC AND METASEDIMENTARY ROCKS
Pvu	MAFIC, INTERMEDIATE AND FELSIC METAVOLCANIC ROCKS WITH SUBORDINATE METASEDIMENTARY ROCKS; DOMINANTLY OF GREENSCHIST METAMORPHIC FACIES
▬	FAULT

MAP SOURCE: BEDROCK GEOLOGY MAP OF WISCONSIN
BY MUDREY, BROWN, AND GREENBERG, 1982,
UNIVERSITY OF WISCONSIN - EXTENSION
GEOLOGIC AND NATURAL HISTORY SURVEY

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	CHECKED BY	BJS	3/89
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	CAD No.	SCALE	

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FIGURE NO. 3.5-11
BEDROCK GEOLOGY OF
RUSK COUNTY, WISCONSIN

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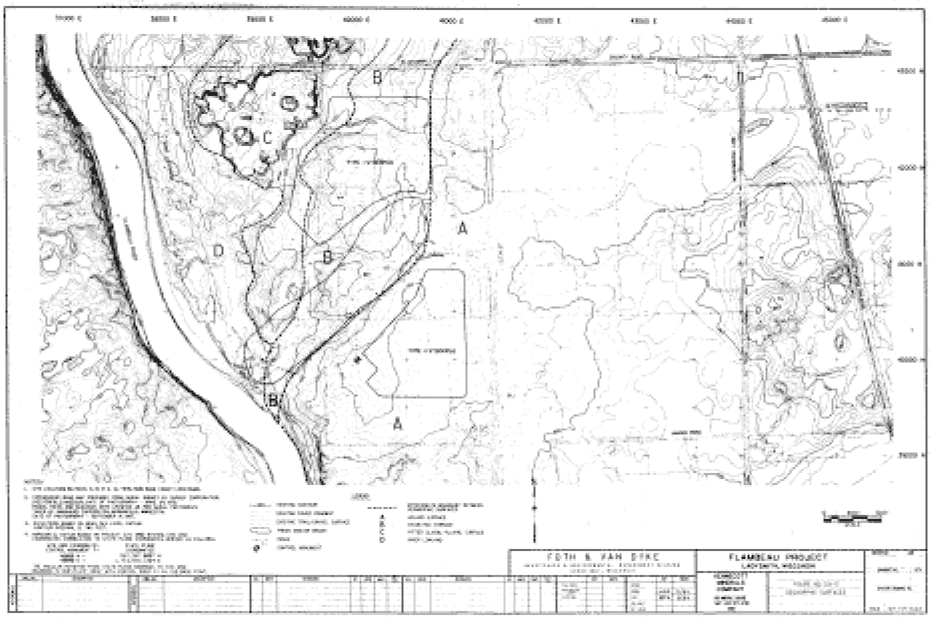
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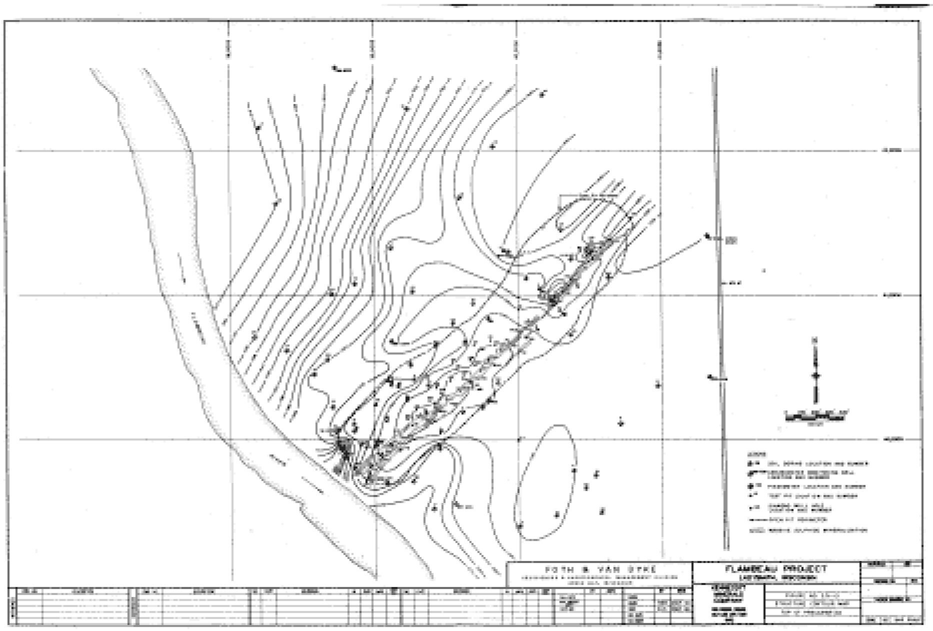
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STRUCTURE CONTOUR MAP
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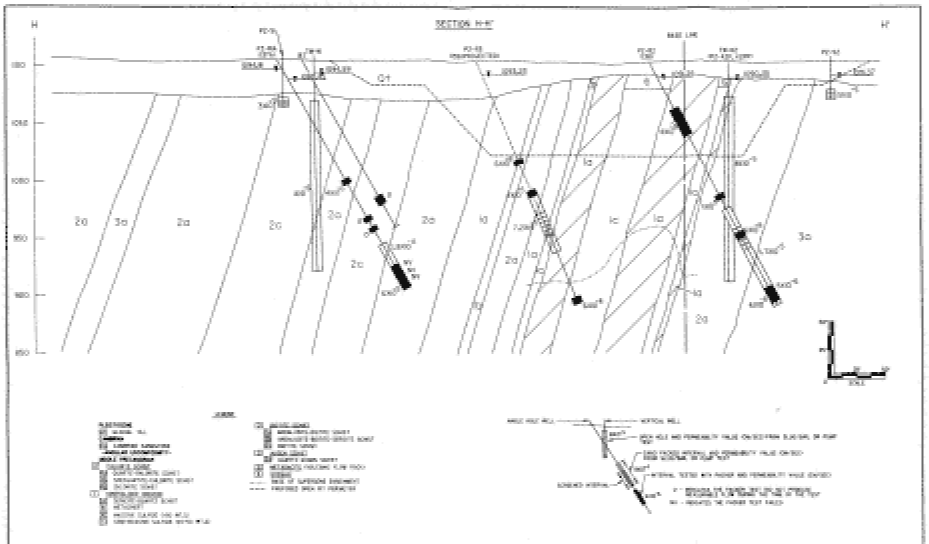

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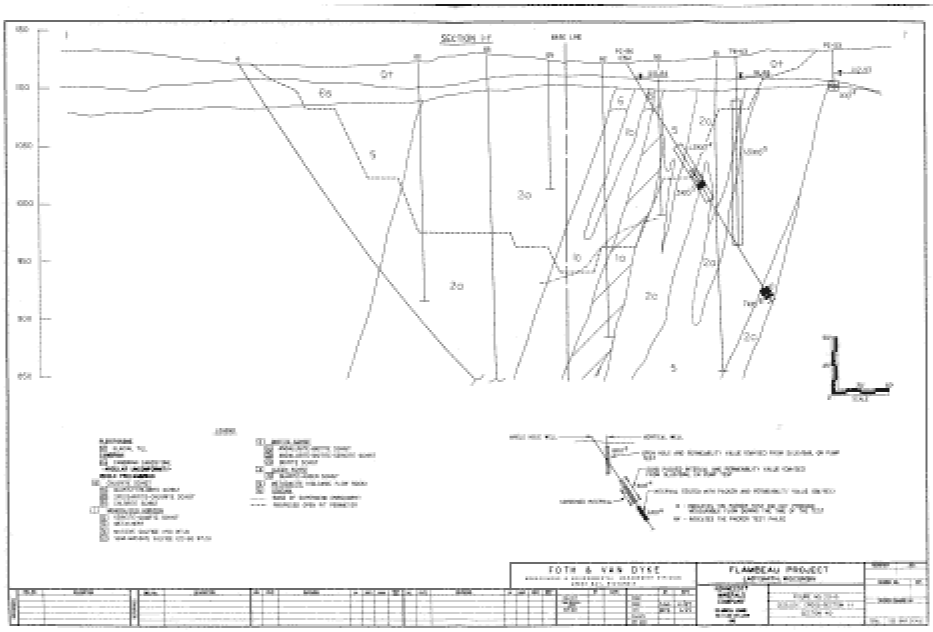
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VERTICAL WELL
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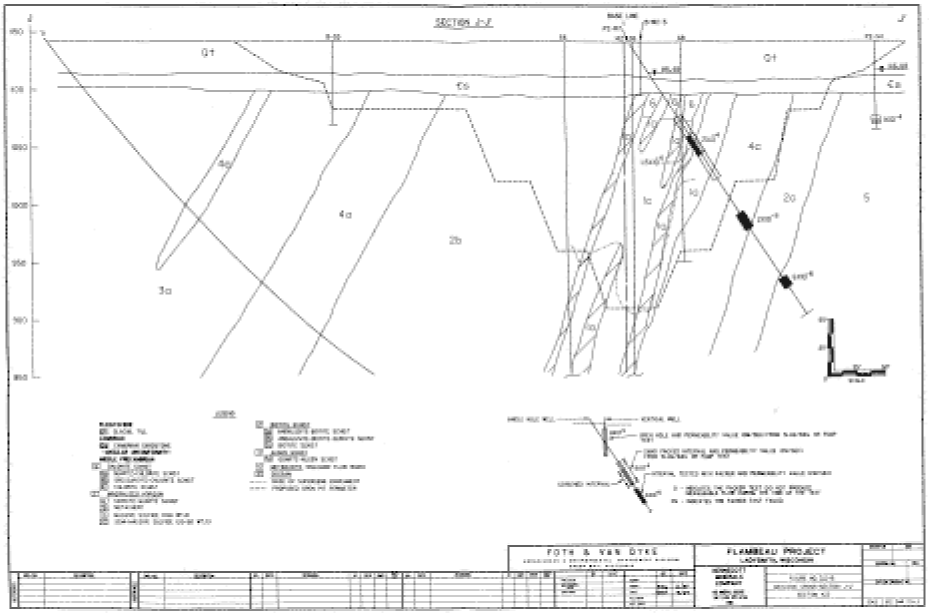
FLAMBEAU PROJECT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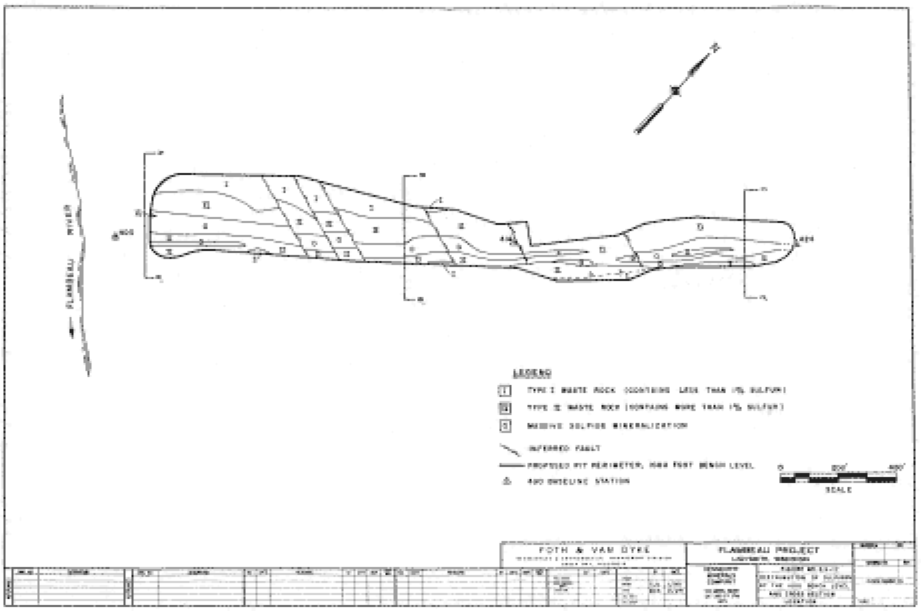
FLAMBEAU RIVER
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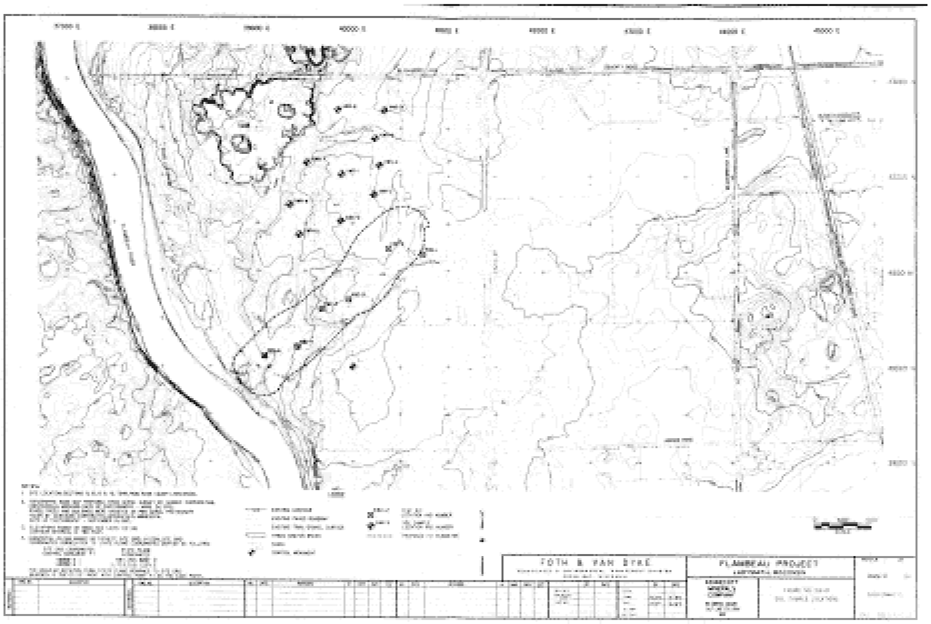
TYPE I WASTE ROCK (CONTAINS LESS THAN 1% SULFUR)
TYPE II WASTE ROCK (CONTAINS MORE THAN 1% SULFUR)
MASSIVE SULFIDE MINERALIZATION
INFERRED FAULT
PROPOSED PIT PERIMETER, FOOT BENCH LEVEL
BASELINE STATION
0
200'
400'
SCALE
FOTH & VAN DYKE
FLAMBEAU PROJECT
LADYSMITH, WISCONSIN
KENNECOTT MINERALS COMPANY
DISTRIBUTION OF SULFIDES
AND CROSS SECTION
LOCATION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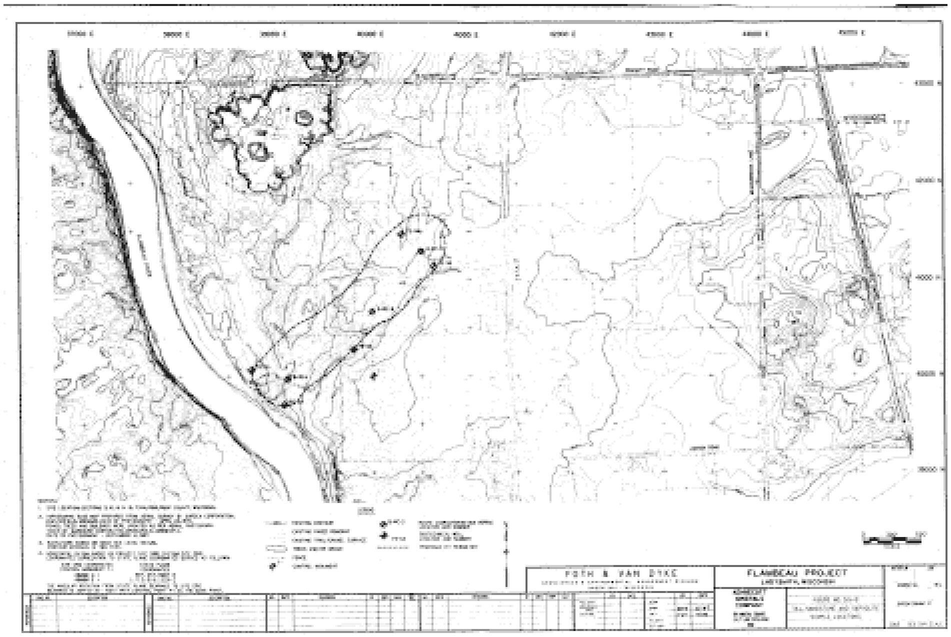

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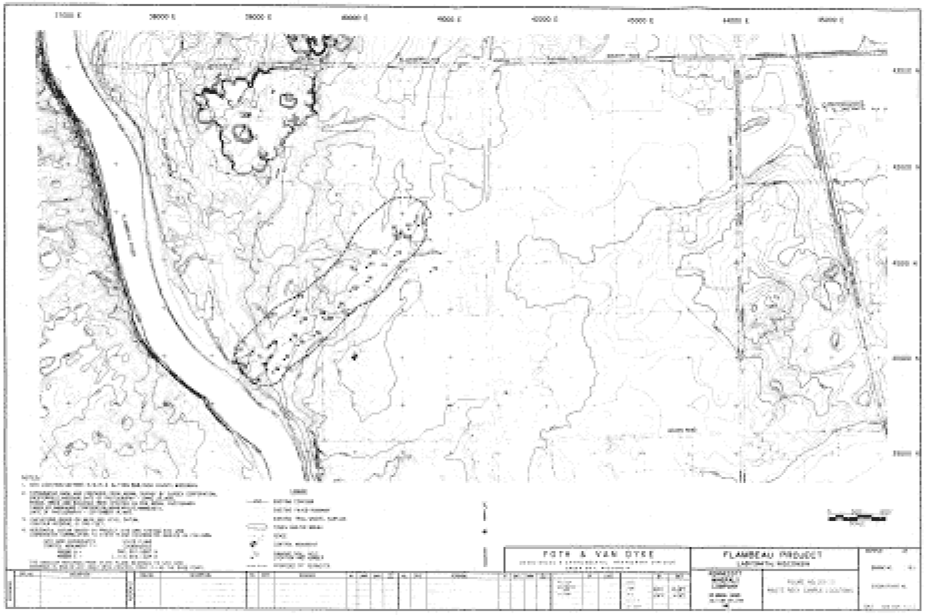
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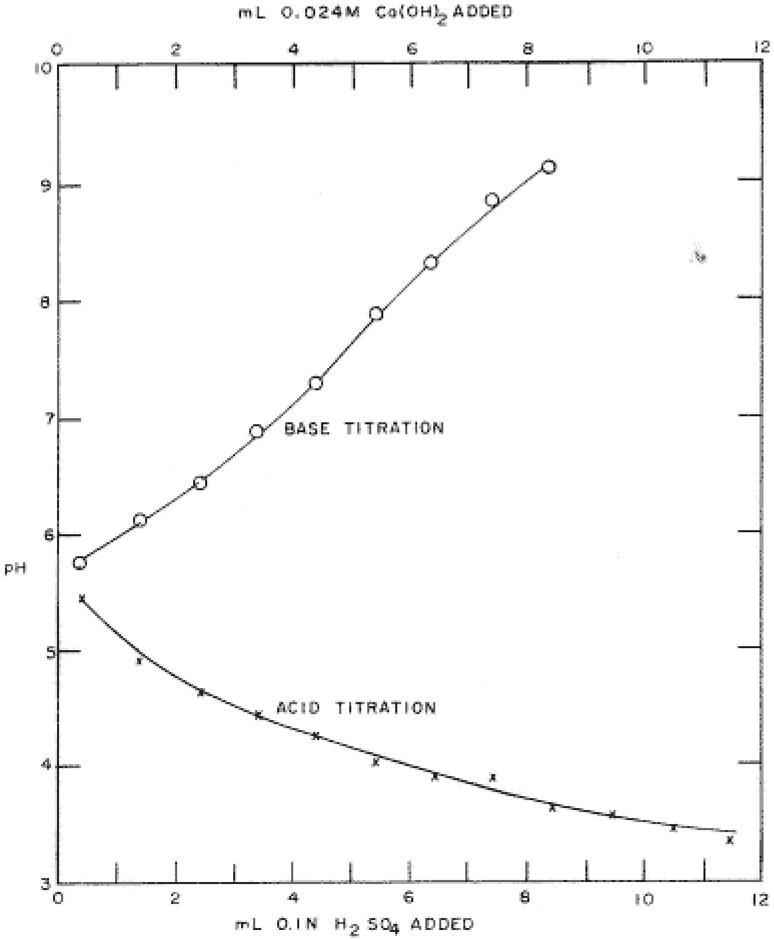

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	CHECKED BY	J.F.T.	3/89
	APPROVED BY		
	CAD No.	SCALE NONE	

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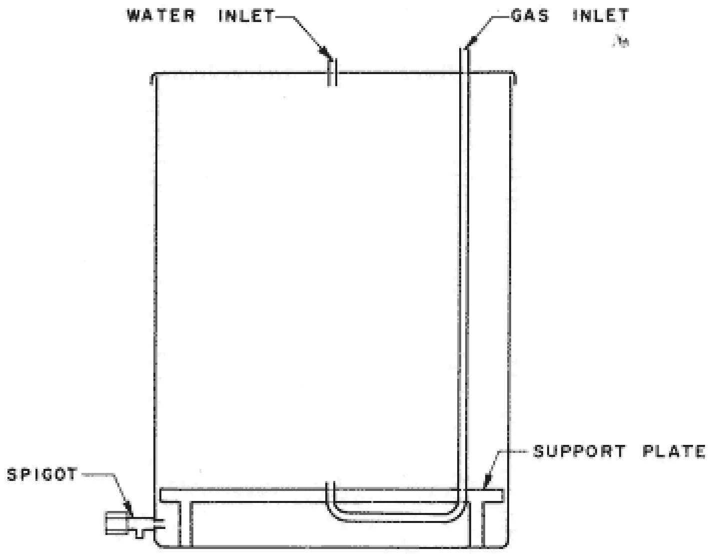
FIGURE NO. 3.5-21
ACID AND BASE TITRATION
OF WR-3 SUSPENSION

Job No
Dwg No
REV



FOTH & VAN DYKE
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION
GREEN BAY, WISCONSIN

NOTES	APPROVAL		DATE
	DESIGNED BY		
	DRAWN BY	SJL	1/89
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	APPROVED BY		
	CAD No.	SCALE NO SCALE	

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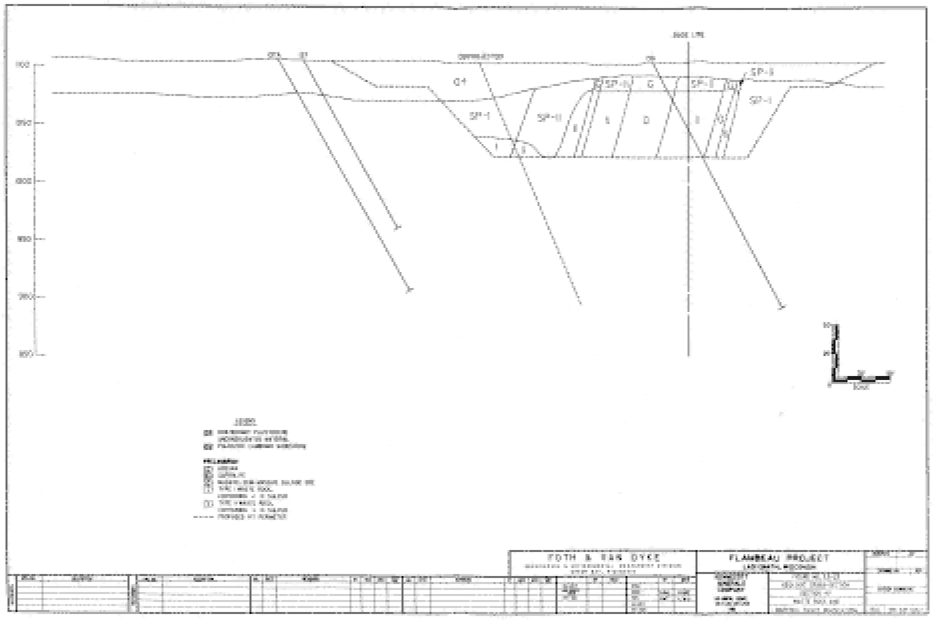
FIGURE NO. 3.5-22
DETAIL OF LEACHING EXPERIMENT TANK

Job No
Dwg No
REV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SP-III
SP-I
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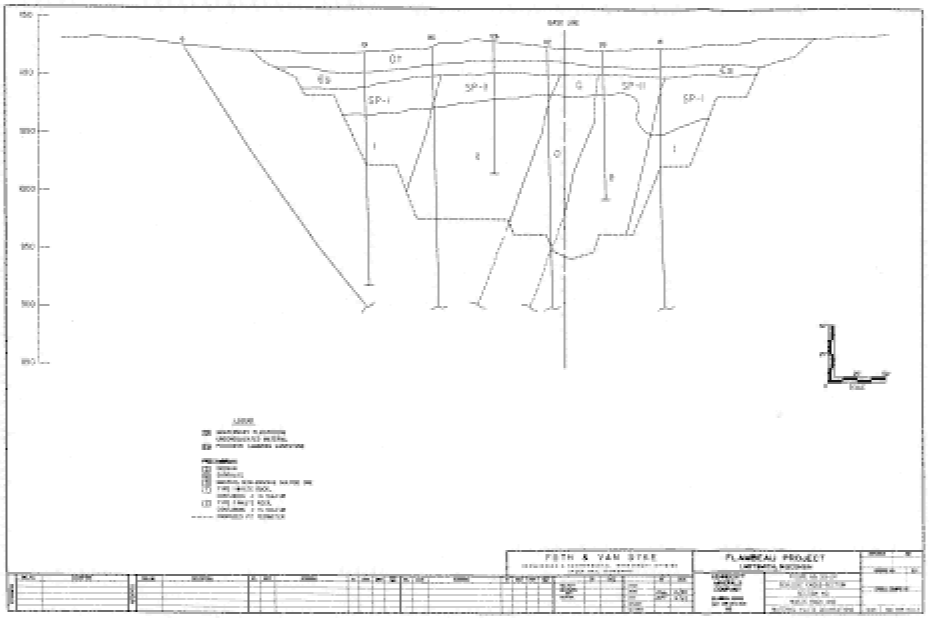

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FOTH & VAN DYKE
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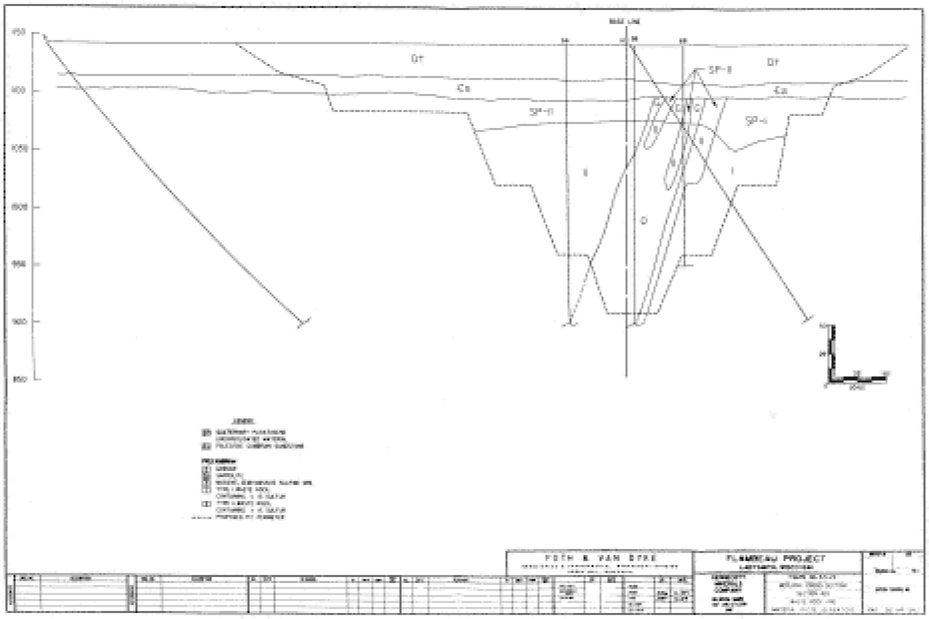
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3.6 Groundwater

Existing hydrogeologic and groundwater quality conditions in the vicinity of the proposed mine are discussed in this section. A discussion of these conditions is presented in the following four sub-sections:

3.6.1 Field and Laboratory Methods - discusses the procedures followed during data acquisition from the project site's 92 monitoring wells.

3.6.2 Regional Hydrogeology - discusses hydrogeologic conditions within a five-mile radius of the project area as set forth in NR182.08(2)(c)4.

3.6.3 Project Site Hydrogeology - discusses hydrogeologic conditions within the project area (generally, south of Blackberry Lane, east of the Flambeau River, north of Meadowbrook Creek, and west of Meadowbrook Road.

3.6.4 Groundwater Quality - discusses groundwater quality within the project area.

3.6.1 Field and Laboratory Methods

Extensive hydrogeologic information was collected as part of the 1976 EIS and Mining Permit Application preparations. These data, derived from the installation and testing of 42 monitoring wells, were used in part to determine the groundwater flow and chemistry characteristics within the glacial fluvial and till deposits (i.e., glacial overburden) and the sandstone of the project area. The 1976 effort did not characterize groundwater flow within the Precambrian bedrock because of its low permeability and small impact on the overall hydrologic regime. King (1983) presented, as a Ph.D. dissertation, a hydrogeologic and groundwater modeling study of the project site. This effort summarized site hydrogeology and estimated the hydrologic impacts of the proposed project assuming the 1976 mining plan.

To expand upon and verify this previous work, hydrogeological field and laboratory investigations, involving the installation and testing of 50 additional monitoring wells, were conducted from 1987 to 1989 to further define:

1. The nature and orientation of the groundwater flow in the glacial overburden, sandstone, and Precambrian units.

2. Background groundwater quality from samples collected from monitoring wells at the project site and from private water supply wells near the project site.

Data acquisition methods are first presented for the previous hydrogeologic investigations, including the King dissertation,