

EIS-57/report/v. 1

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Foth & Van Dyke

REPORT

**Environmental Impact Report  
for the  
Kennecott Flambeau Project**

Scope I.D.: 87K10

Volume I - Report Narrative

*Kennecott Minerals Company  
Ladysmith, Wisconsin*

April 1989

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FLAMBEAU  
EXHIBIT 8

VOLUME 1  
ENVIRONMENTAL IMPACT REPORT  
FOR THE  
KENNECOTT FLAMBEAU PROJECT



*Gerald W. Sevick*  
4/1/89

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APRIL 1989

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April 3, 1989

**Kennecott**

Kathy Curtner, Acting Director  
Wisconsin Department of Natural Resources  
Bureau of Environmental Analysis and Review  
P. O. Box 7921  
Madison, WI 53707

87K10-61

Dear Ms. Curtner:

RE: Kennecott Flambeau Project  
Environmental Impact Report

Kennecott Minerals Company (Kennecott) is pleased to provide the Wisconsin Department of Natural Resources (WDNR) with 40 complete copies of the report and appendices titled *Environmental Impact Report for the Kennecott Flambeau Project* prepared by Foth & Van Dyke.

As per a previous understanding developed with Mr. Robert Ramharter of your staff, it is our understanding that the WDNR will be responsible for the distribution of the final EIR to appropriate state and federal agencies. Kennecott will distribute the document to appropriate local officials.

This Environmental Impact Report has been prepared and is submitted to support the Mining Permit Application for the Kennecott Flambeau Project which has been simultaneously submitted to Mr. Gordon Reinke, Bureau of Solid Waste Management, WDNR.

Kennecott requests that the Wisconsin Department of Natural Resources initiate the following action on the documents being filed:

1. Prepare and finalize a draft and final Environmental Impact Statement (EIS) for the proposed Project described in the EIR and Mining Permit Application.
2. Coordinate with federal agencies to assure that the Department's EIS will be responsive to the needs of federal agencies that have permitting jurisdiction over the proposed Project.
3. Review and approve all permit applications, license applications, and similar documents regarding the proposed Project that are filed with and require approval of the Department.

If you or your staff have any questions regarding the final  
EIR please contact me at your convenience.

Sincerely,

KENNECOTT

*Lawrence E. Mercado*

Lawrence E. Mercado  
Director, Process Development

Enclosure

### 3.5 Geology

The geologic information presented in this report is the result of several field investigations and laboratory testing programs conducted since 1968. Part of the geologic information was collected prior to the approval of the 1976 EIS. The rest of the geologic information was collected in 1987 through 1989 prior to this submittal.

#### 3.5.1 Field and Laboratory Methods

Sections 3.5.1.2 through 3.5.1.6 describe the diamond core, hydrogeologic, waste characterization borings, and geotechnical drilling programs conducted on or around the project area from 1968 to 1988. Table No. 3.5-1 summarizes the project drilling.

##### 3.5.1.1 Site Grid System

In 1969, five on-site triangulation control points were established by a professional engineer using standard surveying techniques. The control points were established for surveying drill hole locations and are based on a U.S. Cadastral Survey benchmark located adjacent to State Highway 27 near Meadowbrook Creek.

A north-south mine coordinate grid system was established based on control point F1, which was designated 40,000 North and 40,000 East as shown on Figure No. 3.5-1. A baseline oriented in a N45°E direction, parallel to the strike of the ore body, was also established. The baseline was designated 20,000 North for computer evaluation of mineral reserves and mine design studies. Points every 200 feet along the baseline from the Flambeau River to Highway 27 were surveyed and section lines were established at these points perpendicular to the baseline. These points were used to locate drill holes. The following equations can be used to convert the coordinates from the mine grid to the oblique (baseline) grid.

$$\begin{aligned}\text{Oblique N} &= (\text{Mine N} - \text{Mine E}) (0.707107) + 19,421.40 \\ \text{Oblique E} &= (\text{Mine E} + \text{Mine N}) (0.707107) - 15,617.16\end{aligned}$$

##### 3.5.1.2 Initial Investigations

Discovery of the Flambeau Deposit occurred on November 6, 1968, when the first diamond drill hole intersected copper sulfide mineralization. From 1968 to 1974, a total of 135 diamond drill holes were completed to provide core samples for assaying and this data used to delineate the deposit. Table No. 3.5-1 lists all diamond drill holes, borings, and wells drilled on and around the project area from 1968 to 1988.

During the period 1968 to 1971, diamond drill holes numbered DDH 22-1 through DDH 22-117 were drilled. In 1974, 18 additional

TABLE NO. 3.5-1  
List of Core, Borehole and Well Drilling

Drilling Program	Identification of Holes		
1968 - 1975			
Delineation Core Drilling	(135) 22-1 to 22-135		
Soil Test Holes	(65) ST-9-1 to ST-9-13 ST-9-17 to ST-9-29 ST-9-30 to ST-9-56 and ST-9-68 ST-9-57 to ST-9-67		
Water Wells	(29) OW-1 to OW-20 OTW-29 and OTW-34 OW-39 to OW-45		
1987 - 1988			
Infill Core Drilling	(26) 22-136 to 22-162		
Baseline Groundwater Monitoring	MW-1000	MW-1002	MW-1004S
	MW-1000P	MW-1002G	MW-1004P
	MW-1001	MW-1003	MW-1005
	MW-1001G	MW-1003P	MW-1005G
	MW-1001P	MW-1004	MW-1005P
Wetlands	PZ-1006	PZ-1006S	PZ-1A
	PZ-1006G		PZ-1B
Geotechnical - Soils	PZ-S1	PZ-S3	B-S5
	PZ-S2	PZ-S4	B-S5A
	B-S2A	B-S4A	
Rock	PZ-R1	B-R4	B-R6
	(22-137A)	(22-140)	(22-141)
	(22-137)		
	PZ-R2	PZ-R5	PZ-R7
	(22-138)	(22-136)	(22-142)
	PZ-R3		
	(22-139)		

TABLE NO. 3.5-1 (Cont.)

Drilling Program	Identification of Holes		
Waste Characterization	B-WC-1	B-WC-2	B-WC-3
	B-WC-1A	B-WC-2A	B-WC-3A
	B-WC-1B		
Permeability Test Wells	TW-K1	TW-K4	TW-K6R
	TW-K2	TW-K5	TW-K7
	TW-K3	TW-K5R	TW-K17B
	TW-K3R	TW-K6	PZ-K8
Groundwater Modeling	PZ-1007S	PZ-1009G	PZ-K2PP
	PZ-1008	PZ-SP6	PZ-K4P
	PZ-1008G	PZ-SP8	PZ-K4PP
	PZ-1009	PZ-K2P	
Type II Waste Rock Storage Area	B-SP1	B-SP4	B-SP7
	B-SP2	B-SP5	PZ-SP8
	B-SP3	PZ-SP6	
Railroad Spur	B-RS1	B-RS5	B-RS9
	B-RS2	B-RS6	B-RS10
	B-RS3	B-RS7	B-RS11
	B-RS4	B-RS8	B-RS12

holes (DDH 22-118 through DDH 22-135) were drilled on the west half of the deposit. All drilling was conducted by Longyear Company using standard wire-line rock coring techniques. HQ, NQ, and BQ cores were obtained.

Mud rotary drilling methods with a tricone bit were used in the overburden. These methods were also sometimes used in the Cambrian sandstone and the top of the extremely clay-altered Precambrian rock. Cuttings were examined to identify the Precambrian surface.

The locations of the diamond drill holes are shown on Figure No. 3.5-1. Logs of drill holes used to construct geologic sections H-H' through J-J' (Figure Nos. 3.5-14 through 3.5-16 located in Section 3.5.3.4.2) are included in Appendix 3.5-A.

Thirteen soil test holes (borings ST-9-1 through ST-9-13) were drilled in and south of the proposed pit area in 1972. In 1973, 13 additional soil test holes (borings ST-9-17 through ST-9-29) were drilled. The drilling was conducted by STS Consultants Limited, using auger or mud rotary drilling methods and standard split-barrel sampling techniques. Piezometers constructed of PVC pipe were installed in several of these borings.

In 1975, 28 additional soil test holes (ST-9-30 through ST-9-56 and ST-9-68) were drilled south of the proposed open pit and 11 borings (ST-9-57 through ST-9-67) were drilled within the proposed pit. Borings that penetrated to the Precambrian bedrock surface were used in this report. Geologic logs and soil test data of these borings are included in Appendix 3.5-B and locations are shown on Figure No. 3.5-2.

The purpose of the soil boring program was to provide hydrogeologic and geotechnical information, including *in-situ* and recompacted soil permeabilities, densities, grain size analyses, and Atterberg Limits.

From 1987 to 1989, those STS borings which had been completed as piezometers were used for groundwater elevation measurements. The locations of the STS borings that were used for the 1987-1989 investigations are shown on Figure No. 3.5-2. The geologic logs and laboratory analytical data from the 1972, 1973, and 1975 investigations were also used in the geologic and hydrogeologic site characterization provided in this report.

In 1970 and 1971, 20 water wells (OW-1 through OW-20) were drilled by Longyear Company north and south of the proposed mine site. Also drilled in 1971 were two large diameter pump-test wells (OTW-29 and OTW-34). In 1972, seven additional wells (OW-39 through OW-45) were drilled. The wells were drilled using mud rotary drilling methods in the overburden and coring methods in the Precambrian bedrock. Cuttings were examined to determine approximate thicknesses of overburden strata. Logs of

these wells are included as Appendix 3.5-C. Several of these wells were used in the 1987-1989 investigation for groundwater elevations. Wells that were used during 1987-1989 are shown on Figure No. 3.5-2, and are designated as "OW" wells.

#### 3.5.1.3 1987-1988 Coring Program

The 1987-1988 coring program was conducted to increase the confidence of the supergene enriched reserve estimate on the east one-half of the deposit, to verify the presence, grade, and continuity of gossan mineralization, and to provide samples for rock mechanics testing.

A total of eight inclined holes (DDH 22-136 through DDH 22-142 and 22-137A) were drilled for rock mechanics investigations. In addition, seven inclined and thirteen vertical holes (DDH 22-143 through DDH 22-162) were drilled on generally 100-foot horizontal spacings. Total footage amounted to 4,542 feet. HQ core (2.4-inch diameter) was drilled using split tubes to improve core recovery.

Core was logged to a scale of one inch equals ten feet. Core recoveries averaged 84.5 percent. This relatively low recovery figure includes poor core recoveries in the intensely weathered and clay-altered bedrock. Core recoveries in the sulfide mineralization were greater than 95 percent. Twenty-four holes were surveyed using a down-hole camera. Readings were taken at appropriate intervals and were interpreted to indicate a slight trend of borehole alignment to the east.

Core from sulfide-rich areas was analyzed for base and precious metals, and sulfur, on intervals ranging from a fraction of a foot to ten feet. Core outside of the mineralized horizon was sampled by taking a representative six-inch piece of unsplit core from each two feet over ten-foot intervals and analyzed for sulfur. Core collected within the mineralized horizon was generally split in half, with one-half sent for analysis, and the other half stored. Samples of mineralization and waste rock were also collected for density measurements.

All diamond drill holes were backfilled with a neat cement grout upon completion of drilling. Drill sites were straw-mulched and seeded using a grass mixture recommended by the Wisconsin Department of Natural Resources (WDNR) district office. The WDNR conducted several site inspections during the 1987-1988 drilling program to inspect the effectiveness of site reclamation.

#### 3.5.1.4 Hydrogeologic Drilling Programs

Hydrogeologic drilling investigations completed during 1987-1988 included baseline groundwater monitoring, wetland investigations, rock permeability, and well installation for groundwater evaluation. Another investigation tested the

permeability of the soil strata in the river pillar, which is the area between the Flambeau River and the west end of the proposed open pit.

Additional geologic and hydrogeologic information was obtained from the soil and rock geotechnical testing program for the pit design, and from the waste rock characterization borings. Boring programs were also used to supply geologic data for the Type II waste rock storage area and the railroad spur corridor. A list of borings and wells completed for each program is presented on Table No. 3.5-1. Geologic logs, well construction diagrams, and well development forms are presented in Appendices 3.5-D through 3.5-K of this report. This data was used to prepare geologic Cross Sections A-A' through G-G' as shown on Figure Nos. 3.5-3 through 3.5-9.

In addition to the geologic information obtained from drilling programs, geophysical data was obtained for selected wells and piezometers. In January 1989, 16 wells were gamma-logged by Foth & Van Dyke using a Johnson-Keck Model GR-81 gamma-logger. The gamma logs found in Appendices 3.5-A through 3.5-K were used primarily to help determine geologic contacts in the OW-wells. Geologic logs, well construction diagrams, and well development forms for the hydrogeologic program are also found in these appendices.

#### 3.5.1.4.1 Baseline Groundwater Monitoring

Fifteen groundwater monitoring wells, MW-1000 through MW-1005P, were installed during the period of September 16, 1987, to October 5, 1987, as shown in Figure No. 3.5-2.

Nine monitoring wells (four piezometers and five water table wells, Table No. 3.5-1) were drilled and installed by Wisconsin Test Drilling, Inc., Schofield, Wisconsin, using a CME-55 truck-mounted drill rig. Hollow-stem augers (4.25-inch inner diameter) or mud rotary methods using a tricone bit (6-inch diameter) were used to complete the borings. Each boring was sampled at five-foot intervals using standard split-barrel sampling methods.

Six monitoring wells (five piezometers and one water table well) were drilled and installed by Luisier Drilling, Inc., Lena, Wisconsin, using a Schramm T66-HB air/rotary drill rig. The borings were completed using mud rotary methods with a tricone bit (6.5-inch diameter) from the ground surface to the top of the Precambrian surface. A split-barrel sampler (three-inch outer diameter) was pushed or driven with an air hammer to obtain samples. In each boring completed for the purpose of installing a piezometer, about 30 feet of altered bedrock schist was cored, using a 4.875-inch diameter carbide bit to obtain 3.25-inch diameter core.

#### 3.5.1.4.2 Wetlands

Three piezometers, PZ-1006, PZ-1006G, and PZ-1006S, were installed on September 23 and 24, 1987. As shown on Figure No. 3.5-2, this well nest is located about 100 feet west of State Highway 27. The well nest was installed to investigate hydrologic conditions between the proposed open pit and wetlands located on the east side of the highway. The boring for PZ-1006S was sampled at five-foot intervals using standard split-barrel sampling methods. Piezometers PZ-1006 and PZ-1006G were installed in adjacent, unsampled borings.

Two piezometers, PZ-1A and PZ-1B, were installed on October 30, 1987, in the wetland adjacent to the Flambeau River and northwest of the proposed pit. These piezometers were installed by Wisconsin Test Drilling, Inc., using either a track-mounted CME-45 or a truck-mounted CME-55 drill rig, and hollow-stem augers (4.25-inch inner diameter) or mud rotary drilling methods. The boring for piezometer PZ-1A was continuously sampled using standard split-barrel sampling procedures (ASTM D-1586); piezometer PZ-1B was installed in an unsampled boring located about five feet south.

#### 3.5.1.4.3 Permeability Test Wells

Six test wells, TW-K1 through TW-K6, were installed by Luisier Drilling, Inc., between March 6 and 9, 1988 (Table No. 3.5-1). All of these wells are located on the pit perimeter and were installed to investigate the general permeability of the Precambrian bedrock along the proposed pit perimeter.

The wells were drilled with an air-rotary drill rig. A nine-inch-diameter tricone bit and bentonite drilling fluid were used in the segment of the hole drilled through Quaternary sediments and Cambrian sandstone. A six-inch-diameter down-hole air hammer was used for the segment of the hole drilled into the Precambrian bedrock. Rock cuttings were collected at ten-foot intervals. The nine-inch borings were drilled into the Precambrian bedrock for a distance of two to 15 feet. The drilling fluid was then replaced with a thick bentonite slurry. Steel casing with a six-inch inner diameter was placed through the slurry and driven with an air hammer into bedrock for a distance of 0.5 to 17 feet, depending on the hardness of the rock. The wells were then completed using the down-hole air hammer and air, or air and water as drilling mediums.

Three of the wells, TW-K3, TW-K5, and TW-K6, caved shortly after completion and before adequate permeability testing could be done. The three wells were redrilled on March 24 to 27, 1988. Four-inch-diameter PVC was set in these three wells. These wells were developed by surging and bailing with a cable tool rock bailer (13 feet long by 4.5-inch diameter) and/or surged and bailed with compressed air using the drill rig.



In addition to the rock test wells, three shallow wells, TW-K7, PZ-K8, TW-K17B, were installed during the period of September 19 to 21, 1988, to determine the thickness, extent, and permeability of overburden sediments in the area of the river pillar.

Each boring was sampled at five-foot intervals using a three-inch outer diameter, split-barrel sampler and mud rotary and/or air drilling methods. The sampler was pushed or driven with an air hammer. The depth to the Precambrian surface ranged from 14 to 45 feet at the three locations along the river pillar.

Two four-inch-diameter PVC wells, TW-K7 and TW-K17B, were installed in the Pleistocene gravel and one two-inch-diameter PVC well, PZ-K8, was installed in the uppermost part of the clay-altered Precambrian bedrock. The four-inch-diameter wells were developed by surging with air and jetting with a jetting tool. The two-inch-diameter well was developed by surging and bailing with a PVC hand bailer.

Pump tests were conducted on wells TW-K2, TW-K3R, TW-K4, TW-5R, and TW-K17B. Methods and results are discussed in Section 3.6.1.2.5.

#### 3.5.1.4.4 Groundwater Evaluation

Five water table piezometers and six deeper piezometers (Table No. 3.5-1) were installed at seven locations to obtain water elevations for groundwater evaluation. The piezometers PZ-1007S, PZ-1008, PZ-1008G, PZ-1009, and PZ-1009G were installed by Wisconsin Test Drilling, Inc., on November 8 to 15, 1988, using mud rotary and auger drilling methods. The borings were sampled at five-foot intervals using standard split-barrel sampling methods and standard procedures as described in Section 3.5.1.8.2.

Piezometers PZ-SP6 and PZ-SP8 were installed on November 15, 1988, by Twin City Testing Corporation, St. Paul, Minnesota. These piezometers were installed in borings completed for the geotechnical investigation of the proposed Type II waste rock storage area. The drilling was done using mud rotary drilling methods and standard procedures as outlined in Section 3.5.1.8.2.

The piezometers PZ-K2P and PZ-K2PP, PZ-K4P and PZ-K4PP were installed in existing six-inch-diameter test wells TW-K2 and TW-K4, respectively. The piezometers were constructed by Luisier Drilling, Inc. The deep piezometers, PZ-K2PP and PZ-K4PP, were installed on November 14, 1988. A five-foot screen and seven-foot sand pack were placed at the bottom of TW-K2 and TW-K4. Bentonite grout was then placed up to the level of the bottom of the shallower piezometers PZ-K2P and PZ-K4P. The shallower piezometers were installed on November 15, 1988. A few feet of

sand was placed above the grout seal of the deeper piezometers. The shallower piezometers were then constructed with five-foot screens using standard well construction procedures.

#### 3.5.1.5 Waste Characterization Boring Program

From December 2 through December 6, 1987, Luisier Drilling, Inc., completed three borings, B-WC-1, B-WC-2, and B-WC-3, to obtain soil samples for waste characterization studies. The three borings were sampled continuously using a three-inch diameter, split-barrel sampler, and coring methods (3.25-inch-diameter core). Depth to hard rock was less than anticipated, so borings B-WC-1A and B-WC-1B, B-WC-2A, and B-WC-3A were drilled adjacent to B-WC-1, B-WC-2, and B-WC-3, respectively, in order to obtain a sufficient volume of sample for testing.

#### 3.5.1.6 Geotechnical Drilling Programs

The geotechnical drilling programs conducted during 1987 and 1988 included geotechnical testing of soil and rock samples for material characterization and strength testing for open pit design. Soil borings and laboratory testing of soils were also completed for the Type II waste rock storage area and railroad spur.

##### 3.5.1.6.1 Geotechnical Logging Testing for Open Pit Design - Soils

Eight borings, as listed on Table No. 3.5-1, were completed at five locations along the projected ultimate pit perimeter. These borings were completed to provide soil information, and also to obtain samples for material characterization investigations and rock mechanics strength testing for pit slope design. The locations are shown on Figure No. 3.5-2. A soil test rig was used to obtain blow counts using standard split-barrel sampling methods. Due to the presence of boulders and extremely dense soils, it was necessary to use a large rotary rig and air hammer to drive the split barrel and obtain undisturbed soil samples. Borings PZ-S1, PZ-S2, PZ-S4, and B-S5 were drilled to obtain soil samples; borings B-S2A, B-S4A, and B-S5A were drilled adjacent to PZ-S2, PZ-S4, and B-S5, respectively, to obtain blow counts.

Boring PZ-S3 was drilled by Wisconsin Test Drilling, Inc., using mud rotary drilling methods and a CME-45 track-mounted drill rig on October 28 to 29, 1987. A piezometer was installed in the boring at a depth of 32 feet and screened in sandstone. The boring was sampled at five-foot intervals using standard split-barrel sampling procedures (ASTM D-1586). Additional samples were obtained using thin-wall tubes and plastic liners in a split-barrel sampler with a three-inch diameter.

Borings B-S2A, B-S4A, and B-S5A were completed on November 30 through December 1, 1987, using standard split-barrel sampling procedures and hollow-stem augers or mud rotary methods. Blow counts, soil samples, and water levels were obtained from these borings. No attempt was made to drill and obtain blow counts at location PZ-S1 due to the known occurrence of large boulders.

Luisier Drilling, Inc., completed four geotechnical borings, PZ-S1, PZ-S2, PZ-S4, and B-S5, from November 30 through December 9, 1987. Soil and rock samples for material properties and strength testing were obtained from these borings. Piezometers were installed in three of the borings to obtain water level measurements and permeability information from the top of the Precambrian bedrock.

The geotechnical borings were sampled at five-foot intervals using a three-inch outer diameter, split-barrel sampler and mud rotary and/or air drilling methods. Attempts were made to obtain additional, undisturbed samples of the till, sandstone, and clay-altered bedrock using (Shelby) thin-wall tubes, or plastic liners in the three-inch-diameter split-barrel sampler. A few samples were obtained using these sampling methods. However, the dense and variable nature of the soil and bedrock resulted in collapse or crumpling of most of the thin-wall tubes and plastic liners.

An alternative sampling method using two-foot lengths of galvanized pipe with 0.25-inch-thick walls was used to obtain undisturbed samples. The pipe was driven using an air hammer. Samples of till and clay-altered bedrock were obtained using the galvanized pipe. An attempt to sample the sandstone was also made. The pipe could be driven into the sandstone, but was not strong enough to be withdrawn without ripping. Samples of clay-altered bedrock were also obtained by coring, using a 4.875-inch carbide bit to obtain a 3.25-inch-diameter sample.

Undisturbed samples of till, clay-altered bedrock, and sandstone were also obtained using the three-inch-diameter split-barrel sampler. Split-barrel samples were retained in plastic bags. Undisturbed split-barrel samples were wrapped in plastic wrap and foil to preserve the moisture; tube samples were sealed with paraffin wax and/or plastic wrap and tape.

#### 3.5.1.6.2 Geotechnical Logging and Testing for Open Pit Design - Rock

Geotechnical rock logging for open pit slope design included the measurement of the frequency and orientation of fractures in oriented and unoriented rock core, packer testing of selected intervals of rock, and installation of piezometers in selected angled core holes. Piezometer numbers and the corresponding angled core holes are listed on Table No. 3.5-1.

From October 1987 to January 1988, eight inclined, oriented core holes were drilled at angles ranging from 55° to 60° from the horizontal. The vertical depths of the holes ranged from 198 to 340 feet. The core holes were drilled employing triple-tube core barrels to provide subsurface structural, lithologic, and geomechanical information as well as core samples for strength testing. The core holes were located to thoroughly characterize the river pillar geotechniques and to provide maximum information for pit slope design. (Figure Nos. 3.5-14, 3.5-15, and 3.5-16 located in Section 3.5.3.4.2, show the locations of these geotechnical rock core holes.)

Core orienting was done employing the Call clay imprint technique (Call, 1988). Measurements included fracture attitude, spacing, and type. Geotechnical field measurements were conducted in eight oriented core holes and 19 exploration holes drilled in 1988. Measurements were taken to evaluate material strength, fracture spacing, fracture dip, broken zone intervals, rock-quality designation (RQD), and point load tests.

Packer tests were conducted in the oriented core holes to estimate bedrock permeability. The packer tests were done during and after drilling by Longyear Company under the direction of Kennecott personnel. Packer tests were conducted on intervals of the core hole from which core with the greatest amount of fracturing was obtained. The most fractured and presumably most permeable intervals were tested. The driller was instructed to clean the holes of excess mud and cuttings prior to inserting the packers. Single and double packers were used to isolate intervals of the borehole ranging from five to 27 feet. The target interval was five feet. Where caved intervals of the borehole were encountered, the interval was increased until a seal could be obtained.

The packers were inflated with helium to pressures ranging from 320 to 530 pounds per square inch (psi). Three tests were then conducted at each depth interval. Water pressure was applied to the test interval and a flow meter reading was recorded at the beginning and end of each test. The water pressure was set at approximately one-half the design pressure for the first and third tests; and at the design pressure for the second test. Water pressures ranged from 60 to 340 psi. Results of the packer tests are summarized in Section 3.6.

Upon completion of drilling and packer testing, five of the borings (R1, R2, R3, R5, and R7) were converted to piezometers. The piezometers consist of 1.25-inch-diameter PVC pipe and screen installed in the 3.875-inch-diameter drill holes. Each piezometer was constructed with 20 feet of screen and a sand pack of variable length located in the most permeable section of the borehole. Permeable sections were identified by the presence of fractures in the core and by results of the packer tests. A bentonite grout seal was installed in each piezometer above the sand pack to the ground surface. Prior to

construction, the borings were flushed with clear water. Development consisted of cleaning out the well with air and of bailing and surging with a hand bailer.

#### 3.5.1.6.3 Type II Waste Rock Storage Area

Eight borings were drilled during the period from November 7 to 11, 1988, in the proposed Type II waste rock storage area as shown in Table No. 3.5-1. The borings were completed by Twin City Testing Corporation using mud rotary and/or auger drilling methods. Six borings (B-SP3 through B-SP8) were completed to a depth of 36 feet; two borings (B-SP1 and B-SP2) were completed at the Precambrian bedrock surface. Two of the borings, B-SP6 and B-SP8, were completed as piezometers PZ-SP6 and PZ-SP8. Standard field methods as described in Section 3.5.1.8.2 were used.

Additional geologic information for the proposed Type II waste rock storage area was obtained from borings ST-9-12, ST-9-13, ST-9-33, and ST-9-42. These borings were drilled in 1972 and 1975 by STS Consultants Limited, and were terminated at the Precambrian bedrock surface.

#### 3.5.1.6.4 Railroad Spur Corridor

Twelve borings, B-RS1 through B-RS12 as listed on Table No. 3.5-1 and shown on Figure No. 3.5-2, were completed by Twin City Testing Corporation in the proposed railroad spur corridor. The drilling was done during the period from November 14 to 17, 1988. The borings were completed to a depth of 21 feet using hollow-stem augers. The borings were sampled at 2.5-foot intervals using standard split-barrel sampling methods and standard field procedures as described in Section 3.5.1.8.2.

#### 3.5.1.7 Soil and Rock Testing

Soil and rock samples were tested as part of several programs. Consolidated, undrained triaxial compression and direct shear tests were performed on samples of silty sand till, sandstone, and clay-altered bedrock. The testing was done as part of the geotechnical testing program for pit design. The testing was done in 1988 by STS Consultants Ltd., using the triaxial compression test procedures outlined in the Corps of Engineers Testing Manual EM110-21906, Appendix X, and the direct shear test procedures (ASTM D-3080) outlined by the American Society for Testing and Materials, (ASTM, 1988). Results of these analyses are included in Appendix 3.5-L.

Additional soils testing performed for the geotechnical and other testing programs included grain-size analysis, determination of Atterberg Limits, and determination of moisture/density relations. These analyses were done by Foth & Van Dyke's Soil Testing Laboratory using standard procedures ASTM D-422, ASTM D-4318, and ASTM D-1557-Method "A",

respectively. Densities of soil and rock samples were determined using ASTM D-2937, and moisture contents were determined using ASTM D-2216 (ASTM, 1988).

The permeability of granular soils was determined using the constant head method as outlined by the standard method ASTM D-2434. The permeability of fine-grained soil samples (thin-wall and rigid-wall) was determined using EPA Method 9100 (EPA, 1986). These analyses were also done by Foth & Van Dyke. Results are included in the appropriate appendices for each testing program.

Comprehensive laboratory testing was performed on rock samples as another portion of the slope design program. This program was designed to determine strength, density, and elastic properties. Rock testing was conducted at the University of Utah and the University of Arizona in late 1987 and early 1988. Rock samples were selected to provide a representative areal distribution for all major rock types in the study area. Soil testing was conducted by Foth & Van Dyke and STS Consultants, Ltd. in early 1988. Additional soil test data are also available from the 1975-1976 and 1972 laboratory work by Soil Testing Services of Wisconsin. Most of this data is included in a report written by Call as a part of the evaluation of pit slope design (Call, 1988).

Rock testing of 2.1 to 2.4-inch-diameter core included 26 uniaxial compression tests with ten elastic property determinations, 18 triaxial tests, 16 Brazilian disk tension tests, seven direct shear tests on foliation and joint planes, and 63 density determinations. In addition, routine point load tests (diametral and irregular lump) were conducted at approximately five-foot core intervals during the field logging program. A total of 686 point load tests were completed.

Average uniaxial compressive strengths ranged from 5,534 psi (metadacite) to 47,831 psi (metachert). Young's modulus values ranged from  $1.2 \times 10^6$  psi to  $11.0 \times 10^6$  psi and Poisson's ratios ranged from 0.15 to 0.31. Triaxial compression tests revealed mean intact rock cohesions from 120 to 1065 psi with mean angles of internal friction of  $24^\circ$  to  $64^\circ$ . Average Brazilian tension strengths ranged from 112 psi (biotite schist) to 697 psi (footwall chlorite schist). Direct shear tests along foliation planes revealed a mean cohesion of 7.78 psi with a mean angle of internal friction of  $18.3^\circ$ . The joint direct shear strength was determined to have a 0.81 psi cohesion and angle of internal friction of  $32.4^\circ$ . Mean rock density values ranged from 130 lbs/ft<sup>3</sup> (metadacite) to 302 lbs/ft<sup>3</sup> (massive sulfide). Median (IS 50) point-load test results ranged from 65 psi (biotite schist) to 1,301 psi (semi-massive sulfide). The geologic terms in parenthesis are further described in Section 3.5.3.4.2.

### Flambeau River Pillar

A river pillar slope stability analysis was conducted as part of the Flambeau slope design program. Geotechnical and geologic findings revealed that rock conditions within the river pillar are suitable for safe and stable slope conditions. No adverse structures or rock strengths have been identified to preclude overall wall stability. The river pillar stability analysis included site-specific strength estimates of intact rock and joint shear strengths previously described. It was determined, using rotational shear analysis, that only six percent intact rock is required along the potential failure path to assure river pillar stability. This condition is easily exceeded because the rotational shear surface cuts across the joint and foliation orientation.

A structurally controlled failure analysis was also conducted for the river pillar. Conservative assumptions for failure analysis were employed. The assumption of a wedge, bounded by continuous foliation and cross-joint structures, resulted in a safety factor of 1.75 under dry conditions and 1.15 when saturated. Fracture shear strengths as described above were employed in this analysis, together with the fracture orientation data derived from core holes drilled in the river pillar. Cross-jointing is not expected to be continuous; fracture spacing from the oriented-core drilling program was found to be 2.1 feet for the prominent Flambeau foliation and 9.0 feet for cross-jointing.

#### 3.5.1.8 Quality Assurance/Quality Control Procedures

The general procedures that were followed to provide valid field and laboratory data are summarized below. Specific variations to the general procedures are included as part of the description of individual drilling programs. The individual drilling programs were described above in Section 3.5.1.2 through 3.5.1.6.

##### 3.5.1.8.1 Core Drilling, Assaying, and Data Analysis

#### Core Drilling

In the 1968-1971, 1974, and 1987-1988 diamond core drilling programs, rotary tricone drilling was used to penetrate the overburden and most of the Cambrian sandstone. Core drilling commenced upon the observation of Precambrian or Cambrian lithologies in the rotary cuttings. In a few instances, ore mineralization was lost in the cuttings prior to switching to core drilling. A Kennecott geologist or consultant was on-site at all times to monitor the drilling and to determine hole locations, orientations, depths, and type of drilling (rotary or core) to be employed.

Core was removed from the core barrel and placed in appropriate core boxes located on-site. The top and bottom footage of each drill run was labeled, and each core box identified as to project, hole number, box number, and footage. The core boxes were then transferred to a nearby facility for core logging and storage.

Upon completion of each hole drilled during the 1960s and 1970s, down-hole deviations in the inclination of the hole were generally determined at 200-foot intervals using then standard down-hole acid bottle surveying methods. Most holes drilled during the 1987-1988 program were surveyed at appropriate intervals using a Sperry-Sun single-shot camera to obtain down-hole deviations for both the inclination and azimuth of the hole. Down-hole deviations for the azimuth were obtained for six inclined holes prior to the 1987-1988 program and little to no deviation was observed in the vertical holes.

Upon completion of the down-hole surveys, the holes were marked on the surface, and the collar elevations and mine coordinates were determined and recorded using standard surveying techniques.

#### Core Logging and Splitting

All core was logged by a Kennecott geologist or consulting geologist at a nearby core storage facility using standard logging procedures. Core recovery measurements were made and recorded. Lithologies, alteration, mineralization, and structures (including angle of core to bedding) were noted. Geotechnical data, including fracture frequency and orientation, were obtained from core drilled during 1987-1988.

Intervals for assaying were designated for all mineralized core. Drill runs and lithologic/mineralization contacts were used to pick assay intervals. An attempt was made to use five-foot assay intervals in similar lithologies; however, in some instances, shorter intervals were used to provide more detail in ore zones. Ten-foot assay intervals were occasionally used in areas of little to no sulfide mineralization.

After each hole was logged and the assay intervals designated, the core was prepared for assaying using the following procedure.

1. Core for each assay interval was split in half using a hydraulic core splitter or rock saw.
2. One core half was returned to the core box and is presently stored, unless used for metallurgical or waste rock characterization testing.

3. The other core half was crushed to minus 0.25-inch, and the crushed sample was split in half using a 0.5-inch riffle splitter. Each half was placed in a separate bag, labeled with the same sample number based on preprinted sample tags. The sample number and assay interval were entered onto an assay log for each hole. One half was sent to a commercial laboratory for assaying. The other half is in storage, unless it was used in metallurgical or waste rock characterization testing. During the 1987-1988 program, the core half for assaying was not crushed on-site but was sent directly to a laboratory for preparation and analysis.

#### Assaying

All prepared samples for assaying were sent to independent commercial laboratories for analysis as follows:

DDHs 22-1 through 22-58 (1968-1970)	Union Assay Office, Inc. Salt Lake City, UT
DDHs 22-59 through 22-117 (1970-1971)	Lerch Brothers, Inc. Hibbing, MN
DDHs 22-118 through 22-135 (1974)	Union Assay Office, Inc. Salt Lake City, UT
DDHs 22-136 through 22-162 (1987-1988)	Bondar-Clegg, Inc. Lakewood, CO

All three laboratories are well established and recognized in the industry for providing accurate and precise assays.

In general, 0.25-inch samples received by the laboratory were crushed to minus 10-mesh. A split taken from the minus 10-mesh material was then ground to a minus 100-mesh pulp for assaying.

Samples were routinely assayed for copper, gold, silver, zinc, and sulfur. Samples were occasionally assayed for copper oxide and lead.

Gold and silver were assayed using standard fire assay methods. Copper, zinc, and sulfur were analyzed using standard wet chemical gravimetric, titration and/or atomic absorption techniques.

All unused minus 10-mesh coarse rejects and pulps were returned to Kennecott, and are currently stored in a facility located near the project area.

#### Assay Quality Control

No check assaying was conducted on a systematic basis. A small number of samples (19) from previous years were reassayed by

Hawley and Hawley in Tucson, Arizona, in 1970. This small number of check assays did not indicate any significant problems with work done by Union Assay Office and Lerch Brothers. Both laboratories have been used by Kennecott for large mining or development projects, where extensive internal quality control procedures were used.

Minus 10-mesh coarse rejects (39) for assay intervals from most ore zones encountered during the 1987-1988 drilling were reassayed by Rocky Mountain Geochemical Corporation (RMGC) in Salt Lake City in 1988, and the pulps generated by RMGC were reassayed by CMS in Salt Lake City.

Check assays, in general, confirmed initial assays. Check assays on the pulp of the same sample show good reproducibility, and were within acceptable levels established for the industry. Check assays on separate coarse rejects of the same sample showed some variation which could be improved by grinding a larger portion of the sample to minus 100-mesh before assaying.

#### Data Analysis

All drill hole data, including collar elevations and coordinates, down-hole surveys, sample intervals, assay results, and geologic codes were computerized for ore reserve calculations. The computer printouts with these data were checked against original survey notes, assay certificates, and drill hole logs in 1988.

#### 3.5.1.8.2 Surficial Geology, Geotechnical, and Hydrogeologic Drilling Programs

##### 1987-1988 Drilling Programs

A Foth & Van Dyke geologist/hydrogeologist or geological engineer supervised the drilling and sampling of all boreholes and the installation of all monitoring wells and piezometers. Appropriate ASTM Standards and guidelines set by the WDNR were followed for all field investigations.

Some borehole and well locations were located in the field by pacing off distances and were later surveyed by the civil engineering company of Morgan and Parmley, Ltd., Ladysmith, Wisconsin. Other locations were initially surveyed by Morgan and Parmley and, after completion of drilling and well installation, measuring-point elevations and locations were surveyed. The mine site coordinate system with 40,000 N and 40,000 E designated at ground control monument F1 was used to locate all core hole, well, and boring locations and all hole locations were also tied into the state plane coordinate system.

Soil samples were collected according to ASTM Standard D-1586, *Penetration Test and Split-Barrel Sampling of Soils* (ASTM, 1988).

An exception to the standard procedure was made when extremely dense soils were encountered. In these cases, additional blow counts were used to obtain an amount of soil sample sufficient to conduct laboratory analyses. Split-barrel samples were collected at five-foot intervals, unless otherwise specified for a particular drilling program, or if additional samples were necessary to adequately describe changes in stratigraphy.

Each boring was logged in the field by Foth & Van Dyke's geologists/hydrogeologists or geological engineers. The soil and rock samples were described and classified using the Unified Soil Classification System (USCS) according to ASTM Standard D-2488, *Description and Identification of Soils* (ASTM, 1988). Munsell Color notation was used to describe the color of soil and rock samples (Munsell Color, 1975). Color photographs were taken of split-barrel samples and rock core and are on file at Foth & Van Dyke's Green Bay office.

After completion of sampling and geologic logging, each boring was backfilled with bentonite or cement grout according to WDNR regulations. The grout was tremied in from the bottom of the boring to within about one foot below the ground surface. The upper foot of the boring was backfilled with soil cuttings.

Soil samples were transported from the site to the testing laboratory according to ASTM Standard D-4220, *Preserving and Transporting Soil Samples* (ASTM, 1988).

Soil samples were analyzed for grain-size distribution according to ASTM Standard D-422 and Atterberg Limits were determined according to ASTM D-4318 (ASTM, 1988) by Foth & Van Dyke's Soil Testing Laboratory. The geologists' field logs, drillers' logs, and laboratory soil test data were used to prepare the geologic logs presented in Appendices 3.5-D through 3.5-K and used to construct the geologic cross sections shown in Figure Nos. 3.5-3 through 3.5-9.

#### Initial Investigations

Geologic data collected for the 1974 EIR were reviewed and evaluated by Foth & Van Dyke's geologists in terms of field methods employed, documentation of field activities, qualifications of personnel involved in the acquisition of data, and laboratory procedures. The data was checked for general correspondence with data collected in the 1987-1988 investigations. In most cases, the old data corresponded closely with the 1987 to 1988 findings. Any revisions or reinterpretations of the old data were noted on the original

data sheets included as Appendix 3.5-B or are discussed in the text. After the data was evaluated and determined to be reliable, it was used in conjunction with the new data.

#### 3.5.2 Regional Geology

The Flambeau deposit is located in the Chippewa River drainage basin within rocks of Precambrian age. In central and southwestern Rusk County, the Precambrian rocks are unconformably overlain by sandstone of Cambrian age. The Cambrian sandstone thickens to the west and south to a maximum thickness of about 800 feet at the southwest edge of the Chippewa River basin at the Wisconsin/Minnesota state border (Young and Hindall, 1972). Glacial and fluvial deposits of Quaternary age overlie the Precambrian and Cambrian bedrock and cover most of the county. The geologic time scale for the region is shown on Table No. 3.5-2.

##### 3.5.2.1 Regional Geomorphology and Topography

Most of the landforms in central and eastern Rusk County are of glacial or fluvial origin. The landforms in northwestern Rusk County are predominantly low dissected bedrock hills. This is an area of Precambrian quartzite and includes the Blue Hills which extend west into Barron County (Figure No. 3.5-11, Section 3.5.2.3.2). The bedrock hills are covered by glacial deposits known as the Chippewa Moraine.

The Chippewa Moraine is a broad end moraine that trends approximately north-south in western Rusk County. The moraine was formed by the Chippewa Sublobe of the Lake Superior Lobe of the Laurentide Ice Sheet in Late Wisconsinan time. Ice advanced out of the Lake Superior Basin and flowed predominantly from the northeast toward the southwest over Rusk County. The elevation of the moraine ranges from about 1,700 feet at the northern end of the county, where it overlies the Precambrian rock, to about 1,100 feet at the southern end, where it overlies Cambrian sandstone.

East of the Chippewa Moraine is a broad area of collapsed glacial-fluvial sediment and other ice-contact sediments. These sediments are located primarily adjacent and roughly parallel to the Chippewa and Flambeau Rivers. The surface of the collapsed glacial-fluvial sediment is at an elevation of about 1,250 feet at the northern edge of the county and slopes to an elevation of 1,150 feet at the southern end. Eastern Rusk County is covered by low-relief ground moraine on the upland areas and uncollapsed glacial-fluvial sediment in most of the stream and river valleys (Hadley and Pelham, 1976). The most prominent landform features in eastern Rusk County are low drumlins that trend northeast/southwest. Eskers occur in the shallow drainageways which parallel the drumlins.

TABLE NO. 3.5-2

Regional Geologic Time Scale

ERA	Period	Epoch	Age	Approximate Number of Million Years Ago
Cenozoic	Quaternary	Recent Pleistocene	Wisconsinan	0.007-0.075
-----Disconformity-----				
Paleozoic	Cambrian			505-600
-----Angular Unconformity-----				
Precambrian		Late Middle Early		600-1600 1600-2500 >2500

3.5.2.2 Regional Surficial Geology

The Quaternary glacial and glacial-fluvial deposits generally range from 50 to 100 feet thick over most of the county. The thickest deposits occur in the Chippewa Moraine and in the river valleys (Young and Hindall, 1972).

Most of these glacial and glacial-fluvial deposits were deposited by ice and melt-water of the Chippewa Sublobe. The oldest deposits of the Chippewa Sublobe belong to the Marathon Formation and may be Illinoian and Early Wisconsinan in age. The Marathon Formation is overlain by deposits of the Lincoln Formation which are greater than 40,800 years old (Mickelson et al., 1983). The uppermost stratigraphic unit is the Copper Falls Formation which is less than 25,000 years old (Johnson, 1986).

The following descriptions of the glacial stratigraphic units is summarized from Mickelson et al (1984). The units are described using the United States Department of Agriculture (USDA) classification system. Average ratio of percentages by weight of sand:silt:clay are given for the matrix material of the tills. Clay is the grain-size fraction less than 0.002 mm in diameter. Silt is the grain-size fraction 0.002 to 0.05 mm in diameter. Sand is the grain size fraction 0.05 to 2 mm in diameter.

The Marathon Formation has two till members. The lower Wausau Member contains brown, noncalcareous, loam till. Percent sand:silt:clay ratios are 43:34:23, respectively. The till was deposited by the southeastward-flowing ice of the Chippewa Sublobe. Overlying the Wausau Member is the siltier, calcareous Edgar Member. The Edgar Member is brown loam till. Percent sand:silt:clay ratios are 33:43:24, respectively. The till was deposited by the southward flowing ice of the Chippewa Sublobe. The Wausau Formation is a surface unit in Wood, Marathon, and Clark Counties. The formation thickens to the north and extends beneath the Lincoln Formation; its northward extent beneath the Copper Falls Formation (further north) is not known.

The till of the Lincoln Formation is darker red brown than the underlying Marathon Formation and overlying Copper Falls Formation. The Lincoln Formation includes two till members. The lower Bakerville Member is red brown, sandy loam till. Percent sand:silt:clay ratios are 62:25:13, respectively. The till was deposited by the southward-flowing Chippewa Sublobe. The upper Merrill Member is dark red brown, sandy loam till. Percent sand:silt:clay ratios are 62:28:10, respectively. The till was deposited by the south-southeastward-flowing St. Croix Sublobe. The Lincoln Formation is the surface unit in much of Marathon, Clark, Langlade, Lincoln, and Marathon County. The formation thickens to the north and extends beneath the Copper Falls Formation; however, its northward extent beneath the

Copper Falls Formation is not known. The Copper Falls Formation is the surface glacial stratigraphic unit over Rusk County and most of northwestern Wisconsin.

The Copper Falls Formation consists of roughly one-half fluvial sediment and one-half till. The fluvial sediment was deposited from melt-water in front of the ice sheet, on top of stagnant ice, or under the ice as eskers. The till consists of 35 to 80 percent sand, 15 to 50 percent silt, and 2 to 15 percent clay with some pebbles, cobbles, and boulders. The till of the main Superior Lobe in Douglas County averages about 70 percent sand, 25 percent silt, and 5 percent clay; the till of the Chippewa Sublobe in Bayfield, Ashland, and Iron Counties averages about 60 percent sand, 35 percent silt, and 5 percent clay. At the type section of the Copper Falls Formation in Ashland County, the till varies from silt loam to loam and sandy loam. The percentage of sand generally increases to the south and the tills are redder to the north. The till is slightly calcareous. Most of the Copper Falls Formation was deposited in Late Wisconsin time but may include some Early Wisconsin material.

Detailed studies have been conducted in Barron County and four till members have been defined (Johnson, 1986). The southern limit of the Copper Falls Formation is the St. Croix and Chippewa Moraines. Two till members of the Copper Falls Formation deposited by ice of the Chippewa Sublobe have been described in Barron County. The lower Pokegama Creek Member is yellow red to strong brown sandy loam till that was deposited between 25,000 and 15,000 years ago. Percent sand:silt:clay ratios are 69:20:11, respectively. The Mikana Member is red brown sandy loam till that was deposited about 15,000 years ago. Percent sand:silt:clay ratios are 71:24:08, respectively.

### 3.5.2.3 Regional Bedrock Geology

#### 3.5.2.3.1 Cambrian

Cambrian-age sandstone of the Mt. Simon Formation occurs in southwestern Rusk County and throughout west-central Wisconsin. The contact between the Cambrian sandstone and the underlying Precambrian rock is an angular unconformity. During the Late Precambrian, and possibly the early Cambrian, weathering produced a saprolite at the top of the Precambrian rock (Cummings and Scrivner, 1980). Weathered material from the saprolite was incorporated into the basal unit of the upper Cambrian Mt. Simon Formation. The Precambrian/Cambrian contact is exposed at several localities in west-central Wisconsin, including south of Ladysmith.

The Mt. Simon Formation was deposited during the late Cambrian (Dresbachian). The formation ranges from a few feet thick in

central Rusk County to about 100 feet thick at Chippewa Falls. It reaches a maximum thickness of about 800 feet in southern Wisconsin (Asthana, 1969).

The Mt. Simon Formation contains three units. The lowermost is a conglomeratic or pebbly sandstone. The middle unit is a coarse to medium-grained sandstone. The uppermost unit is a coarse to very fine-grained sandstone.

Fossil fragments and trace fossils in the sandstone indicate marine deposition. The Mt. Simon Formation has been interpreted as sediment deposited during marine transgression onto the Precambrian Shield.

#### 3.5.2.3.2 Precambrian

The Southern Province of the Canadian Precambrian Shield is a large block of ancient rock that stretches from southwestern Ontario south into upper Minnesota, Wisconsin, and Michigan. In northern and central Wisconsin, the Province consists of three ages of rock which are, in order of decreasing age, Early, Middle, and Late Precambrian (Sims, 1976). The distribution of rock types of these three ages is shown on Figure No. 3.5-10.

Early Precambrian rocks are those dated older than 2,500 million years. These rocks consist of highly altered sediments and granite. They occur throughout central Wisconsin and as narrow belts north of Rusk County. Middle Precambrian rocks have been age-dated between 1,600 and 2,500 million years. They consist of interbedded and altered volcanic, sedimentary, and granitic rocks (Sims, 1976). The Flambeau deposit occurs within a Middle Precambrian-age volcanic belt that is approximately 30 miles wide by 180 miles long as shown on Figure No. 3.5-10.

Late Precambrian rocks range in age from 600 to 1,600 million years. These rocks contain thick lava flows, flat-lying weakly altered sandstone, and shale. Late Precambrian rocks are located north of Rusk County and are best exposed in the Apostle Islands State Park, Bayfield, Wisconsin.

Early and Middle Precambrian rocks occur as steeply dipping belts that trend east-northeast. These rock belts were folded and faulted about 1,800 million years ago.

The distribution of Precambrian and Cambrian rocks in Rusk County are shown on Figure No. 3.5-11. The Precambrian-age rocks consist of east-northeast trending, steeply dipping schistose belts of volcanic and sedimentary rock. The volcanics and sediments have been regionally altered and are referred to as "greenstones". The term greenstone is frequently used for rocks rich in the mineral chlorite that have been so extensively altered that accurate rock names are sometimes difficult to apply. Surrounding the greenstone belts are large intrusive bodies of various rock compositions. Unconformably overlying



the middle Precambrian rocks are outcrops of gently dipping Barron quartzite found throughout much of northwestern Rusk County.

### 3.5.3 Geology of the Project Area

The Flambeau deposit occurs within a complex suite of Middle Precambrian-age volcanic rocks that dip about 70° to the northwest and trend northeast-southwest across the project area. In the northwestern and central part of the project area, Cambrian sandstone overlies the Precambrian rocks. Silty sand till or glacial-fluvial sediments overlie the bedrock. A generally thin layer of windblown silt and fine sand is the surface sediment over most of the area.

#### 3.5.3.1 Geomorphology and Topography of the Project Area

Four geomorphic surfaces are present in the project area. These surfaces (A, B, C, and D), the proposed pit, and the Type I and Type II waste rock storage areas are delineated on Figure No. 3.5-12.

It is proposed that the Type II stockpile be located in an upland area (Area A), the surface of which is generally at an elevation of about 1,150 feet. This surface continues to the east and includes the area of the proposed railroad spur. The upland area is primarily a glacial depositional feature. As shown on Cross Sections A-A' and F-F' (Figure Nos. 3.5-3 and 3.5-8), the upland area is underlain by a thick layer of silty sand till.

The Type I stockpile and most of the proposed pit is located on a dissected terrace surface (Area B), the elevation of which is generally about 1,140 feet. The dissected terrace surface is probably an erosional feature cut into the silty sand till, with some deposition of glacial-fluvial sediment at the surface. The surface may have been formed by glacial melt-water which eroded a broad channel into the till surface. Later, glacial-fluvial sediment was deposited as melt-water flow subsided. As shown on Cross Sections B-B', C-C', and E-E' (Figure Nos. 3.5-4, 3.5-5, and 3.5-7), a variable thickness of glacial-fluvial sediment occurs over the silty sand till in some parts of the dissected terrace surface.

Northwest and west of the proposed Type I stockpile is an area of pitted glacial-fluvial sediment. This is Area C as shown on Figure No. 3.5-12. The pitted surface is generally at an elevation of 1,120 to 1,130 feet and as shown on Cross Section B-B' (Figure No. 3.5-4), the surface is underlain by coarse-grained glacial-fluvial sediment. The glacial-fluvial sediment is irregularly bedded and stratified, very poorly sorted, and typically contains cobbles and some large boulders. The coarse texture and poor sorting probably indicate the sediment was

deposited by melt-water near the margin of the ice sheet. After recession of the ice margin, the Flambeau River cut into the glacial-fluvial sediment.

In the area of the southwest end of the proposed pit, the Precambrian surface is at a higher elevation, and the Flambeau River flows on bedrock as shown on Cross Section E-E', Figure No. 3.5-7.

Area D as shown on Figure No. 3.5-12 is a low, relatively flat area at a general elevation of 1,100 to 1,110 feet. The area is located east of and adjacent to the Flambeau River and includes a small elongate wetland. The area is underlain by poorly sorted glacial-fluvial sediment with probably some Recent, fine-grained, alluvial sediment at the surface. The surface was probably formed by the meandering Flambeau River in Recent time.

#### 3.5.3.2 Soils in the Project Area

The soils in the vicinity of the proposed mine were mapped by Soil Conservation Service personnel in 1964 to 1966. The mapping was updated by Soil Conservation Service personnel in June and August 1988 at the request of Foth & Van Dyke to verify soil boundaries. These activities have resulted in the production of the map shown in Figure No. 2 in Appendix 3.8-C, the Wetlands Inventory and Assessment. The soil mapping was conducted using Soil Conservation Service guidelines and soil classification. Brief descriptions of the soil units encountered during the mapping and verification are presented in Table No. 3.5-3.

Soils of the Rosholt-Bevent-Chetek and Magnor-Auburndale Associations, and Seelyville Muck, were identified and mapped in the site area. Approximately two-thirds of the mapped soils are part of the Rosholt-Bevent-Chetek Association. These soils are well-drained to excessively well-drained and have formed in loamy deposits which overlie sand and gravel outwash plains. Slopes of these soils range from gently sloping to moderately steep. Soils of this association are most common in the northwestern part of the site.

The Rosholt Sandy Loam is the most common soil series mapped on the site. The surface layer of this soil consists of dark brown sandy loam, six inches thick, overlying eight inches of yellowish brown and dark brown sandy loam. The subsoil is dark brown sandy loam in the upper eight inches and yellowish red, gravelly loamy sand in the lower seven inches. The substratum is pale brown stratified sand and gravel. The Rosholt Series ranges in slope from two to 12 percent on the site.

The Magnor-Auburndale soils are silt loams which have formed in loess overlying loamy glacial till. These upland soils are nearly level to gently sloping and are somewhat poorly to poorly

TABLE NO. 3.5-3

Brief Descriptions of the Soil Mapping Units  
in the Vicinity of the Proposed Mine

Soil No.	Soil Type	Description	Slope
33	Chetek Sandy Loam	Somewhat excessively drained, sloping loamy soils developed in sand and gravel stream terraces	2-20%
38	Rosholt Sandy Loam	Well-drained, nearly level to moderately sloping loamy soils developed in stratified sand and gravel stream terraces	2-12%
43	Antigo Silt Loam	Well-drained, gently rolling silty soils developed in sand and gravel stream terraces	2-6%
44	Terrace excarpment	Well-drained, steeply sloping sandy to loamy soils developed in sand and gravel stream terraces	>30%
48	Brill Silt Loam	Moderately well-drained, gently sloping silty soils developed in sand and gravel stream terraces	2-6%
77	Auburndale Silt Loam	Poorly drained, nearly level silty soils developed in loamy glacial till on uplands	0-2%
156	Magnor Silt Loam	Somewhat poorly drained, nearly level to gently sloping silty soils developed in glacial till on uplands	0-6%
157	Freeon Silt Loam	Moderately well-drained, moderately steep sloping silty soils developed in ground moraine	6-12%

Table No. 3.5-3 (Cont.)

Soil No.	Soil Type	Description	Slope
324	Poskin Variet Silt Loam	Somewhat poorly drained, nearly level silty soils developed in sand and gravel outwash plains	0-2%
326	Cable Silt Loam	Very poorly drained, nearly level silty soils developed in loess deposits which overlie glacial till	0-2%
334	Plover Sandy Loam	Somewhat poorly drained, nearly level loamy soils developed in stratified lacustrine deposits which overlie sand and gravel stream terraces	0-2%
339	Bevent Loamy Fine Sand	Well-drained, gently rolling sandy soils which developed in stratified loamy and sandy deposits, stream terraces, and glacial lake basins	2-6%
400	Seelyville Muck	Very poorly drained, nearly level organic soils developed in depressions under marsh and swamp vegetation	0-2%

drained. The imperfect internal drainage of the soils has resulted in the development of the mottles commonly observed in the subsurface horizons.

The Seelyville Muck commonly adjoins the soils of the Magnor-Auburndale Association. This very poorly drained muck has formed in topographic depressions under marsh vegetation. These soils contain high concentrations of sapric material in their surface horizons.

### 3.5.3.3 Surficial Geology of the Project Area

The surficial deposits in the project area include a thin layer of windblown silt and fine silty sand, siltysand till, glacial-fluvial sand and gravel, and glacial-fluvial gravel and sand. The combined thickness of the surficial deposits varies from about ten feet (MW-1000) at the river pillar at the southwest end of the proposed pit, to 65 feet (B-SP1) at the northwest corner of the proposed Type II waste rock storage area. Northwest of the project area, glacial-fluvial sand and gravel adjacent to the Flambeau River is more than 90 feet thick.

#### 3.5.3.3.1 Surface Silt and Sand

The sediment at the ground surface varies from brown or red-brown silt to silty fine sand. The sediment is typically less than five feet thick, but has a variable distribution over the project area. It probably was deposited by aeolian processes and may include some fine-grained, well-sorted fluvial sediment.

#### 3.5.3.3.2 Till

The most widespread surficial deposit is silty-sand till. The till is thickest in the upland area. It averages about 40 feet thick in the area of the Type II stockpile as shown on Cross Section F-F', Figure No. 3.5-8. In the area of the pit, the till is thinner and is overlain or interbedded with glacial-fluvial sediment as shown on Cross Section E-E', Figure No. 3.5-7.

Approximately 10 to 20 feet of till is present in the proposed area of the pit; the till is generally thinner over the ore body and is slightly thicker to either side. At the southwest end of the proposed pit, at the location of MW-1000 shown on Figure No. 3.5-2 and Cross Section D-D', Figure No. 3.5-6, only about five feet of till occurs above the rock surface. To the southeast of MW-1000, the till thickens to about 45 feet at the location of MW-1001. To the northwest of MW-1000, the till is absent at the river pillar.

The till is typically red-brown (5Y 4/4) or dark red brown (5Y 3/4), well-graded, silty, fine sand, with fine and coarse gravel. The percentage of gravel ranges from one to 26 percent; the percentage of sand ranges from 48 to 78 percent; and the

percentage of silt and clay varies from 21 to 43 percent. The average percent gravel:sand:P200 (silt and clay) ratios are 10:66:28, respectively (13 samples analyzed). The pebble-size fraction consists mostly of igneous and metamorphic rock types. The till is slightly calcareous as determined by waste characterization studies. Laboratory analytical data are summarized on Table No. 3.5-4.

The till is predominantly silty sand, but ranges from clayey sand to sandy-silt. The finer-grained till occurs below the silty-sand till in the area southeast of the proposed pit, and the area of the Type II storage pile. The range of grain size distributions probably indicates that more than one stratigraphic till member is present in the project area. Most of the till, however, is likely to belong to the Copper Falls Formation. The lower, more clayey till, may correlate with the Lincoln or Marathon Formations (Johnson, 1986).

#### 3.5.3.3.3 Glacial-Fluvial Sediment

The glacial-fluvial sediment is thickest in the area to the west of the proposed Type I stockpile. It has a variable thickness on the dissected terrace surface in the area of the Type I stockpile and pit. The sediment ranges from a few feet thick in the area of the pit to a maximum of about 42 feet at TW-K17B as shown on Cross Section D-D', Figure No. 3.5-6.

The glacial-fluvial sediment varies from well-graded, silty sand with gravel, to poorly graded gravel. The glacial-fluvial sediment is typically thin-bedded, and is extremely variable in texture, both horizontally and vertically. Although generalized, Cross Section D-D' shown on Figure No. 3.5-6 illustrates the textural variability of the glacial-fluvial sediment. Grain-size analysis data are summarized on Table Nos. 3.5-5 and 3.5-6.

The gravelly, glacial-fluvial sediment contains 53 to 83 percent gravel, 12 to 35 percent sand, and four to 12 percent silt and clay. Average percentages of gravel:sand:P200 (silt and clay) were 70:24:6, respectively (five samples analyzed). The sandy glacial-fluvial sediment contains 10 to 30 percent gravel, 54 to 87 percent sand, and three to 18 percent silt and clay. The average gravel:sand:P200 (silt and clay) percentages are 22:70:9, respectively (eight samples analyzed).

#### 3.5.3.4 Bedrock Geology of the Project Area

Cambrian-age sandstone of the Mt. Simon Formation occurs in the project area. The sandstone is underlain by metamorphosed volcanic rocks of Precambrian age.

TABLE NO. 3.5-4  
Summary of Soil Test Data  
Silty Sand Till (SM)

Boring No.	Sample No.	Depth (ft)	USCS Class	LL	PI	% g-s-P200*	Permeability (cm/sec)	Max. Dry Density (PCF)	Opt. Moisture (%)	Date of Test
ST-9-25	3	15-16	SM			05-72--23-				1973
ST-9-26	6	30-31.5	SM			07-64--29-				1973
ST-9-26	7	35-36.5	SM			15-64--21-				1973
ST-9-27B	1	10-11.5	SM			12-63--25-				1973
ST-9-28B	2	10-11.2	SM			05-78--17-				1973
ST-9-29	2	10-10.5	SM			13-59--28-				1973
PZ-S3	7	21-22	SM			26-52--22-				1987
B-S5	3	15-16	SM	17.2	4.2			137.7	6.5	1987
B-S5	3-7	15-25	SM							1987
B-S5	4	18-20	SM			11-58--31-				1987
B-S5	7	25-27	SM			10-60-24-06				1987
PZ-1008S	6	30-31.5	SM			08-62-20-10				1988
PZ-1009G	5	25-26.5	SM			17-55-19-09				1988
PZ-1009G	9	45-46.5	SM			01-70-22-07				1988
B-SP1	11	49.5-51	SM/SC	20.4	8.1	06-56-22-16				1988
B-SP1	13	59.5-61	SC	34.0	16.4	06-48-27-19				1988
			Min.	17.2	4.2	01-48--21-				
			Max.	34.0	16.4	26-78--43-				
			Ave.	23.9	9.6	10-62--28-				
			n =	3	14					

\*P200 = Clay (<0.005 mm fraction) plus silt (<0.075 to 0.005 mm fraction).

TABLE NO. 3.5-5  
Summary of Soil Test Data  
Glacial-Fluvial Gravel and Sand

Boring No.	Sample No.	Depth (ft)	USCS Class	% g-s-P200*	Date of Test
ST-9-19A	1	21-22.2	GW	72-22-06	1973
ST-9-23A	2	25-26.5	GP	83-12-05	1973
PZ-S1	2	10-11.5	GP	66-30-04	1987
PZ-S3	3	10-12	GP-GM	53-35-12	1987
PZ-S4	4	11-12	GP	76-20-04	1987
			Min.	53-12-04	
			Max.	83-35-12	
			Ave.	70-24-06	
			n =	5	

\*P200 = Clay (<0.005 mm fraction) plus silt (<0.075 to 0.005 mm fraction).

TABLE NO. 3.5-6  
 Summary of Soil Test Data  
 Glacial-Fluvial Sand and Gravel

Boring No.	Sample No.	Depth (ft)	USCS Class	% g-s-P200*	Date of Test
ST-9-17A	4	35-36.5	SW	15-77-08	1973
ST-9-17A	5	40-41.5	SW	30-60-10	1973
ST-9-18	3	15-16.5	SW-SM	30-55-15	1973
ST-9-20	5	25-26.2	SW-SM	41-54-05	1973
ST-9-22A	1	15-16.5	SW	14-87-03	1973
ST-9-23A	2A	25-26.5	SW	15-74-11	1973
PZ-1008S	10	50-51.5	SP	18-78-04	1988
B-SP4	8	34.5-36	SM	10-72-18	1988
			Min.	10-54-03	
			Max.	30-87-18	
			Ave.	22-70-09	
			n =	8	

\*P200 = Clay (<0.005 mm fraction) plus silt (<0.075 to 0.005 mm fraction).

### 3.5.3.4.1 Cambrian Sandstone

Fine and medium-grained sandstone of the Mt. Simon Formation is the uppermost bedrock unit in the project area. Sandstone was not encountered in borings at the southwest end of the pit as shown on Cross Sections D-D' and E-E', Figure Nos. 3.5-6 and 3.5-7, respectively. In the area of the northwest one-third of the pit, 20 to 30 feet of sandstone is present. The thickness of sandstone increases to the northwest, as shown on Cross Sections A-A' and E-E', Figure Nos. 3.5-3 and 3.5-7, respectively.

The sandstone is about five to 15 feet thick in the northern part of the Type II waste rock stockpile area but does not occur under the southern part.

The sandstone has variable color, grain-size distribution, and degree of cementation. Mineralogically, the sandstone is predominantly quartz. Near the base of the unit, clays such as kaolinite and sericite have been eroded from saprolitic Precambrian rock and incorporated into the sandstone as small aggregates of grains, dispersed matrix material, or thin laminations. The sandstone is typically pale brown (10YR 6/3) or pale yellow (2.5Y 7/4). It varies to light green-gray (5GY 7/1) or light olive gray (5Y 6/2) where it contains silty matrix material eroded from the Precambrian, or yellow red (5YR 5/6) at the contact with the overlying till.

The sandstone is typically poorly cemented, but varies from loose to well-cemented. The sandstone typically contains coarse quartz grains and silty material at the base of the sequence and grades upward to loose, fine and medium-grained sandstone at the top of the sequence. As indicated by blow counts, the sandstone is very dense.

Using the USCS system, the sandstone is classified as poorly graded sand (SP) or poorly graded sand with silt (SP-SM) as found on Table No. 3.5-7. The sandstone is composed of zero to eight percent gravel-size fragments, 87 to 99 percent sand, and one to ten percent silt and clay from 15 samples analyzed. The average gravel:sand:P200 (silt and clay) ratios are 1:95:4, respectively.

### 3.5.3.4.2 Precambrian

Rocks containing the Flambeau deposit were originally a complex suite of interfingering volcanic flows, ash, and ejecta material which were deposited in an oceanic volcanic basin. The deposit was later overturned during a period of mountain building that included intense folding, faulting, and alteration of the rock. After overturning, the volcanic rocks were eroded, clay-altered, and the top of the deposit was supergene-enriched. The topography at the top of the buried Precambrian bedrock is shown on Figure No. 3.5-13.

TABLE NO. 3.5-7

Summary of Soil Test Data  
Sandstone (SP, SP-SM)

Boring No.	Sample No.	Depth (ft)	USCS Class	LL	PI	% g-s-P200*	Permeability cm/sec at % compaction	Max. Dry Density (PCF)	Opt. Moisture (%)	Date of Test
ST-9-19	68	28-28.5	SP-SM			0-93-07				1973
ST-9-22	8	40-41	SP-SM			0-90-10				1973
ST-9-22	9	45-46.5	SP-SM			0-96-04				1973
ST-9-24	5	25-26	SP			0-96-04				1973
ST-9-24	6	30-30.2	SP			0-99-01				1973
PZ-S1	4	17-18	SP			0-97-03				1987
PZ-S1	6	20-21	SP			1-98-01				1987
PZ-S3	9	27.5-28	SP				$K_L=8.8 \times 10^{-5}$			1988
PZ-S4	14	34-35.5	SP			8-90-02				1987
PZ-S4	15	35.5-37	SP			2-96-02	$3.6 \times 10^{-3}$ (90%)			1987
PZ-S4	18	41-43	SP			0-98-02				1987
PZ-S5	8	29.8-31.5	SP			1-96-03	$3.5 \times 10^{-3}$ (91.5%)			1987
B-WC-2A	12	25-26	SP			1-98-01				1987
B-WC-3	8	31-34	SP			0-96-04	$2.8 \times 10^{-3}$ (90%)			1988
PZ-1007S	11	55-56.5	SP-SM			4-87-09				1988
Composite**			SP					113.9	10.9	1988
					Min.	0-87-01				
					Max.	8-99-10				
					Ave.	1-95-04				
					n =	14				

\*P200 = Clay (&lt;0.005 mm fraction) plus silt (&lt;0.075 to 0.005 mm fraction).

\*\*Sample composited from PZ-S1, S3, S4, S5 and B-WC2A, WC3.

For a detailed description of the Flambeau deposit, the reader is referred to May (1977).

#### Volcanic Rock and Alteration

Volcanic rock hosting the ore deposit is generally made up of thick sequences of flow rock, ejecta debris, ash, and volcanic sediments. Rock layers immediately beneath the deposit are usually thinner and more complexly interfingered.

Two types of alteration, regional metamorphic and supergene, have significantly changed the composition, fabric and texture of the Precambrian rock. Regional alteration of the volcanic rock probably occurred during folding and mountain building processes. Metamorphic mineral assemblages of chlorite, biotite, and andalusite are common within these rocks, and indicate that when the rocks were uplifted, they were subjected to intense pressure at low and medium temperature.

Supergene alteration is a process in which fluctuating acidic groundwater reacts with the rock to form a different suite of minerals. This process, which may represent ancient weathering, has intensely altered the bedrock to depths of 50 to 400 feet below the surface. The upper ten to twenty feet of volcanic rock has been intensely altered by the supergene process to form saprolite. The saprolite grades into altered volcanic rock. Dark-colored minerals such as chlorite, which are rich in iron and magnesium, have had iron and magnesium leached, resulting in a bleached appearance. Chlorite and other such minerals have been highly altered to clay and micaceous-type minerals.

The combined effects of regional metamorphism and subsequent superimposed intense supergene alteration have obliterated much of the original rock texture and structure. Rock identification is impossible in the saprolite and difficult in the deeper, less decomposed and altered rock. Relict textural evidence and extrapolation of rock types encountered at depth were used to classify and interpret much of the rock in the supergene-altered portion of the Flambeau deposit. Waste rock fractures within the zone of supergene alteration generally contain an abundance of clay and platy silicate minerals.

Rocks that occur within the proposed pit have been subdivided into hanging wall, mineralized horizon, and footwall. Hanging wall volcanic rocks lie above or "hang over" the northwest-dipping deposit and, therefore, occur along the north wall of the pit. The mineralized horizon contains variable amounts of iron pyrite mineralization with lesser amounts of associated copper and gold. Lying beneath the mineralized horizon or at the "foot" of the horizon are the footwall volcanic rocks. These rocks occur along the south side of the proposed pit wall.

The Precambrian rocks on the project site strike approximately N45°E and dip about 70°NW. The bedrock geology is shown on geologic Cross Sections H-H', I-I', and J-J' as shown on Figure Nos. 3.5-14 through 3.5-16. These geologic sections are constructed along mine sections 401, 410, and 422, respectively. Geologic logs of core holes used to construct the cross sections are presented in Appendix 3.5-A. The locations of the sections are shown on Figure No. 3.5-1.

The rock classification used for the Flambeau deposit is based on characteristic metamorphic mineral assemblages. Whole-rock chemical analysis and thin sections studies have aided in interpretation of parent rock types.

#### Hanging Wall Rocks

Hanging wall rocks consist of four series of volcanic-derived material. Closest to the mineralized horizon is a series of rocks termed andalusite-biotite schist which are Units 2a, 2b, and 2c as shown on Figure Nos. 3.5-14 through 3.5-16. The combined thickness of these units ranges from 140 to 280 feet. Originally, the rock was probably volcanic ash, sediments, and pebble-size ejecta. Intense pressure and temperature created during regional alteration have flattened the pebble ejecta into thin lensoids and have altered the rock to a schist which contain crystals that are aligned parallel to the schist strike direction (N45°W).

Figure No. 3.5-15 shows a metadacite flow rock (Unit 5) which ranges in thickness from 120 feet to 380 feet. This rock is distinguished from other volcanic rock in that it has poorly developed schistosity. The rock is more massive in texture and contains crystals that are more randomly oriented than the schists.

Thin beds of volcanic-derived sediments (Unit 4a and Unit 4b) occur scattered throughout the major rock units in the hanging wall, but do not occur adjacent to the mineralized horizon. These beds generally have well-developed schistosity and contain distinctive chlorite and garnet minerals.

Quartz-augen schist (Unit 3a) occurs in the hanging wall rock but at a greater distance from the mineralized zone than the other rock units. The quartz augen were formed from fragments ejected from a volcanic pipe in a super-heated cloud of ash and steam. The thickness of this rock unit is unknown but has been cored over distances of 260 feet.

#### Mineralized Horizon

The Flambeau deposit occurs within a distinctive volcanic-sedimentary package of rock termed the mineralized horizon. The horizon trends the length of the proposed pit and ranges in thickness from 20 to 200 feet. Dominant rock types within the

mineralized horizon are a quartz-rich sediment and volcanic ash (Unit 1a), massive sulfide (Unit 1c), semi-massive sulfide (hatched) and chert (Unit 1b). Only the quartz-rich sediment (Unit 1a) has well-developed schistosity.

The hanging wall contact of the mineralized horizon is usually sharp, whereas the footwall contact is interbedded with volcanic layers. The mineralized horizon forms a bedrock ridge which has resisted erosion due to a higher quartz content than the surrounding volcanic rock. This ridge is illustrated on Figure No. 3.5-14.

The Flambeau deposit is generally tabular in shape and occurs along the hanging wall of the mineralized horizon. Figure No. 3.5-17 shows in plan view the distribution of the massive and semi-massive sulfide mineralization that makes up the deposit. Significant sulfide mineralization has not been intersected by core holes drilled west of the Flambeau River or east of State Highway 27.

The top 50 to 180 feet of the deposit has been altered by supergene weathering processes which have produced a higher grade of copper in the upper part of the horizon. Below the supergene-enriched copper zone are primary sulfides that contain lower grade copper mineralization. The mined ore will be recovered primarily from the enriched part of the deposit.

Asbestiform mineralization will not pose a problem since bedrock formations that could include small amounts of these minerals have been intensely clay-altered. This alteration has destroyed most of these asbestiform minerals. The above bedrock formations nearly all fall outside of the proposed pit limits. No asbestiform minerals occur within the massive sulfide enriched portion of the deposit.

#### Footwall Rocks

The footwall rocks (Unit 2c, Unit 4a, and Unit 4c) that lie close to the mineralized zone are thin-layered. These footwall rocks contain more chlorite and carbonate minerals such as dolomite and calcite and are possibly flow rocks or sediments. Andalusite-biotite schist (Unit 2a) envelopes the west one-third of the deposit. Quartz-augen schists (Unit 3a) of unknown thickness occur further out into the footwall.

#### Saprolite

The upper ten to twenty feet of volcanic rock has been intensely altered by the supergene process to form saprolite. The saprolite is generally thicker and more clayey where it is developed from the more mafic rock types such as the metadacite. Using the USCS, the saprolite generally is silt (ML), but ranges from silty gravel (GM) to fat clay (CH) as shown on Table No. 3.5-8. The average percentages of gravel:sand:P200 (silt

TABLE NO. 3.5-8  
Summary of Soil Test Data  
Saprolite (ML)

Boring No.	Sample No.	Depth (ft)	USCS Class	LL	PI	% s-s-P200**	Permeability cm/sec at % compaction)	Max. Dry Density (PCF)	Opt. Moisture (%)	Date of Test
ST-9-1	9, 10, 11	52-59	ML	28.4	NP	-	1.1x10 <sup>-6</sup> (95%)	111.4	16.0	1972
ST-9-2	14-18	65-77	ML	-	-	-	5.0x10 <sup>-6</sup> (96%)	134.6	8.0	1972
ST-9-3	14-16, 18	65-75	ML	-	-	-	6.4x10 <sup>-6</sup> (88%)	125.0	11.5	1972
ST-9-4	7-9, 10, 11	32-43	ML	25.1	4.3	-	1.1x10 <sup>-6</sup> (95%)	121.2	10.5	1972
ST-9-5	12, 13, 12, 15, 18, 19	31-41	ML	34.1	9.4	-	6.1x10 <sup>-5</sup> (94%)	110.0	16.8	1972
ST-9-7	12, 13, 18, 19	45-53	CH*	56.0	25.6	-	2.5x10 <sup>-8</sup> (98%)	97.8	23.1	1972
PZ-S1	8	25-27	ML	33.2	6.4	08-17-75	K <sub>v</sub> =3.3x10 <sup>-8</sup> **	-	-	1988
PZ-S2	7-10	23-31	ML	-	-	-	-	119.5	11.7	1988
B-S2	4	15.5-17.5	GM*	-	NP	60-23-17-1	K <sub>v</sub> =3.3x10 <sup>-7</sup>	-	-	1987
PZ-S2	5	17-18.5	ML	-	-	-	-	-	-	1987
PZ-S2	6	20-21.5	SM*	-	-	22-55-23	-	-	-	1987
PZ-S3	14-16	36-39	ML	34.3	8.5	01-26-73	-	-	-	1987
PZ-S3	20	49.5-50.5	ML	35.9	4.2	00-07-93	-	-	-	1987
PZ-S4	22	50-51.5	SM*	-	-	32-41-27	-	-	-	1987
PZ-S4	23	51.5-53	ML/CL-	24.7	3.8	06-42-52	-	-	-	1987
B-S5	11	45-46	ML	28.7	2.9	00-22-78	-	-	-	1987
B-S5	12	47-51.5	ML	30.6	3.2	-	-	115.5	11.9	1987
B-S5	15	55-57	ML	-	-	-	K <sub>v</sub> =2.2x10 <sup>-7</sup>	-	-	1988
B-S5	18	62-67	ML	26.2	2.7	04-36-60	-	-	-	1987
			Min.	24.7	2.7	00-07-52				
			Max.	35.9	9.4	08-42-93				
			Ave.	30	5	03-25-72				
			n =	10	6					

\*Data not used in averages or ranges.  
\*\*P200 = Clay (<0.005 mm fraction) plus silt (<0.75 to 0.005 mm fraction).  
\*\*\*Thin-wall or flex-wall permeability.

and clay) in the silty saprolite are 3:25:72, respectively (ten samples analyzed).

### Structure

Schistosity is the dominant rock fabric and imparts a distinctive platy texture to the rock enclosing the deposit. Several faults have been intersected by core drilling; these offset the deposit from one to 30 feet. Rock fragments, interpreted to be fault breccia, have been observed in the more brittle massive sulfide rock. However, faults within the volcanic rock are generally thin and filled with clay and micaceous minerals. The orientations of the faults are uncertain, but an east-southeast direction is inferred. Schistosity planes are interpreted to be continuous along strike particularly at or near the footwall contact. Cross-cutting fractures are expected to be discontinuous.

### 3.5.4 Seismology/Earthquakes

No earthquakes have been recorded in the Ladysmith area in historic times (Mudrey, 1984). The closest earthquake epicenters have been located in southeastern Wisconsin and the Upper Peninsula of Michigan (Docekal, 1970).

### 3.5.5 Summary of Geological Information

Investigations conducted since 1968 have provided detailed information for geologic, hydrogeologic, and geotechnical site characterization.

The Quaternary sediments consist predominantly of silty sand till and generally poorly sorted, glacial-fluvial sediment. These sediments are probably mostly Late Wisconsinan in age and belong to the Copper Falls Formation. However, finer-grained till was encountered in a few boreholes and probably occurs as patchy remnants in depressions in the bedrock surface.

The Quaternary sediments are underlain by Cambrian-age sandstone of the Mt. Simon Formation. The sandstone is composed of fine to coarse-grained quartz sand with variable amounts of fines and cementation. The lower part of the sandstone contains saprolitic material eroded from the underlying Precambrian rocks.

The underlying Precambrian rock is a metamorphosed suite of interfingering volcanic flows, ash, and ejecta material that was deposited in an oceanic volcanic basin. The rocks have undergone regional metamorphism and intense supergene alteration. These processes have resulted in extensive alteration of the rock to clay minerals. The upper part of the rock has been intensively altered to saprolite. The thickness of the saprolite and degree of alteration of the underlying rock is variable, depending largely on original rock composition.



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 safely 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 3.5-0, 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 3.5-0.

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	--	--	3.55	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
SO <sub>4</sub>	mg/l	180	180	180	200	190	750	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) <sub>2</sub> ADDED	g/Kg (#/tonne)	..	..	..	0.31	0.67	4.25	0.63	1.07	5.07
		..	..	..	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.

- 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.
- 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.

- 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
Arsenic						X	X	X	X	X
Barium						X	X	X	X	X
Beryllium						X	X	X	X	X
Cadmium						X	X	X	X	X
Chromium						X	X	X	X	X
Cobalt						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	X	X
Molybdenum						X	X	X	X	X
Nickel						X	X	X	X	X
Selenium						X	X	X	X	X
Silver						X	X	X	X	X
Sodium						X	X	X	X	X
Thallium						X	X	X	X	X
Tin						X	X	X	X	X
Titanium						X	X	X	X	X
Uranium						X	X	X	X	X
Fluoride						X	X	X	X	X
Sulfate						X	X	X	X	X
TDS						X	X	X	X	X
Spec. Cond.						X	X	X	X	X
pH						X	X	X	X	X
Temp.						X	X	X	X	X

TABLE NO. 3.5-13 (Cont.)

Parameter	Sandstone				Saprolite					
	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
Arsenic						X	X	X	X	X
Barium						X	X	X	X	X
Beryllium						X	X	X	X	X
Cadmium						X	X	X	X	X
Chromium						X	X	X	X	X
Cobalt						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	X	X
Molybdenum						X	X	X	X	X
Nickel						X	X	X	X	X
Selenium						X	X	X	X	X
Silver						X	X	X	X	X
Sodium						X	X	X	X	X
Thallium						X	X	X	X	X
Tin						X	X	X	X	X
Titanium						X	X	X	X	X
Uranium						X	X	X	X	X
Zinc						X	X	X	X	X
Fluoride						X	X	X	X	X
Sulfate						X	X	X	X	X
TDS						X	X	X	X	X
Spec. Cond.						X	X	X	X	X
pH						X	X	X	X	X
Temp.						X	X	X	X	X



TABLE NO. 3.5-13 (Cont.)

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

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

TABLE NO. 3.5-14 (Cont.)

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

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 "4", "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 Wet/Dry Leaching Study**

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

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

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TABLE NO. 3.5-15 (Cont.)

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

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

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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

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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

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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 (Cont.)

Sandstone Wet-Dry Quantities Leached

Parameter	Units	Cycle 1		Cycle 2		Cycle 4	
		West	East	West	East	West	East
		Central	East	Central	East	Central	East
Al	ug/g	0.024	0.049	0.092	0.045	0.040	
Cr	ug/g	<1.1x10 <sup>-3</sup>	1.9x10 <sup>-4</sup>	3.8x10 <sup>-4</sup>	<1.2x10 <sup>-4</sup>	<1.4x10 <sup>-3</sup>	
Cu	ug/g	4.1x10 <sup>-3</sup>	1.5x10 <sup>-3</sup>	7.7x10 <sup>-3</sup>	<6.3x10 <sup>-4</sup>	<0.01	
Fe	ug/g	<0.02	0.020	0.062	7.5x10 <sup>-3</sup>	<0.04	
Pb	ug/g	<3.8x10 <sup>-4</sup>	<1.2x10 <sup>-4</sup>	<3.8x10 <sup>-4</sup>	<1.2x10 <sup>-4</sup>	<1.4x10 <sup>-3</sup>	
Mn	ug/g	<4.1x10 <sup>-3</sup>	8.2x10 <sup>-4</sup>	<2.1x10 <sup>-3</sup>	<6.9x10 <sup>-4</sup>	<0.01	
Ti	ug/g	<7.5x10 <sup>-4</sup>	9.4x10 <sup>-4</sup>	<1.5x10 <sup>-3</sup>	<5.0x10 <sup>-4</sup>	<2.9x10 <sup>-3</sup>	

Saprolite Wet-Dry Quantities Leached

Parameters	Units	Cycle 1		Cycle 2		Cycle 4		Cycle 8		Cycle 16	
		West	East	West	East	West	East	West	East	West	East
		Central	East	Central	East	Central	East	Central	East	Central	East
Al	ug/g	2.94	1.74	5.38	1.01	1.01	0.18	0.18	<8.1x10 <sup>-4</sup>	<8.1x10 <sup>-4</sup>	<4.1x10 <sup>-4</sup>
Cr	ug/g	1.6x10 <sup>-3</sup>	2.0x10 <sup>-3</sup>	6.5x10 <sup>-3</sup>	<1.2x10 <sup>-3</sup>	<1.2x10 <sup>-3</sup>	<6.1x10 <sup>-4</sup>	<6.1x10 <sup>-4</sup>	<0.05	<0.05	<4.5x10 <sup>-3</sup>
Cu	ug/g	0.27	0.031	0.077	0.011	0.011	0.38	0.38	<8.1x10 <sup>-4</sup>	<8.1x10 <sup>-4</sup>	<1.6x10 <sup>-3</sup>
Fe	ug/g	1.22	0.53	2.44	0.38	0.38	3.7x10 <sup>-3</sup>	3.7x10 <sup>-3</sup>	<4.5x10 <sup>-3</sup>	<4.5x10 <sup>-3</sup>	<4.5x10 <sup>-3</sup>
Pb	ug/g	0.027	4.5x10 <sup>-3</sup>	7.3x10 <sup>-3</sup>	7.7x10 <sup>-3</sup>	7.7x10 <sup>-3</sup>	0.021	0.021	<1.6x10 <sup>-3</sup>	<1.6x10 <sup>-3</sup>	<4.5x10 <sup>-3</sup>
Mn	ug/g	0.23	0.016	0.041	0.13	0.13	0.021	0.021	<1.6x10 <sup>-3</sup>	<1.6x10 <sup>-3</sup>	<4.5x10 <sup>-3</sup>
Ti	ug/g	0.074	0.037	0.13	0.021	0.021	0.021	0.021	<1.6x10 <sup>-3</sup>	<1.6x10 <sup>-3</sup>	<4.5x10 <sup>-3</sup>
Zn	ug/g	0.10	0.24	0.040	0.040	0.040	7.7x10 <sup>-3</sup>	7.7x10 <sup>-3</sup>	<4.5x10 <sup>-3</sup>	<4.5x10 <sup>-3</sup>	<4.5x10 <sup>-3</sup>

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 relationship is 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

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	553	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	36	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

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	1,740	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.)

## MR-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	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					

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TABLE NO. 3.5-19 (Cont.)

## MR-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	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						

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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	<0.55	<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	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	--	--	<0.40
Cu	ug/g	15.29	17.92	4.80	0.35	0.079	11.00	0.92	1.20	2.70	56.00	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	0.09
Pb	ug/g	<0.001	<0.001	<0.001	<0.001	<0.001	<0.02	<0.02	0.12	0.12	0.40	0.12
Mn	ug/g	0.33	0.44	0.24	0.032	7.9x10(-3)	3.70	0.54	0.29	0.40	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	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	<0.10

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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	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	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	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	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	<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	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	<0.10

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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	0.088	<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

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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.

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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 Wastewater 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

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

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TABLE NO. 3.5-21 (Cont.)

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

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

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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

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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

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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 <sub>4</sub>	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 <sub>4</sub>	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 <sub>4</sub>	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 <sub>4</sub>	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 <sup>(-3)</sup>	<1.4x10 <sup>(-3)</sup>	<1.4x10 <sup>(-3)</sup>
Cu	ug/g	0.023	0.012	7.8x10 <sup>(-3)</sup>
Fe	ug/g	+1.78	+1.97	+2.0
Mn	ug/g	+0.18	>+0.23	>+0.21
Ti	ug/g	<1.8x10 <sup>(-3)</sup>	0.017	1.8x10 <sup>(-3)</sup>
SO <sub>4</sub>	mg/g	+3.6x10 <sup>(-3)</sup>	+4.2x10 <sup>(-3)</sup>	+6.4x10 <sup>(-3)</sup>
Alk	mg/g	5.4x10 <sup>(-3)</sup>	+2.3x10 <sup>(-3)</sup>	0.023

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.)

## 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 <sup>(-3)</sup>	1.7x10 <sup>(-3)</sup>
Cu	ug/g	0.13	<3.1x10 <sup>(-3)</sup>	5.3x10 <sup>(-3)</sup>
Fe	ug/g	1.75	+0.66	8.2x10 <sup>(-3)</sup>
Mn	ug/g	+0.11	+0.72	+0.022
Ti	ug/g	0.22	1.6x10 <sup>(-3)</sup>	0.015
SO <sub>4</sub>	mg/g	>+5.1x10 <sup>(-3)</sup>	+9.6x10 <sup>(-4)</sup>	1.0x10 <sup>(-3)</sup>
Alk	mg/g	+4.2x10 <sup>(-3)</sup>	+9.4x10 <sup>(-4)</sup>	+1.2x10 <sup>(-3)</sup>

## CYCLE 2

Parameter	Units	West	Central	East
Al	ug/g	4.57	0.38	0.92
Cr	ug/g	0.037	<9.4x10 <sup>(-4)</sup>	<7.2x10 <sup>(-4)</sup>
Cu	ug/g	0.18	4.1x10 <sup>(-3)</sup>	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 <sub>4</sub>	mg/g	+2.6x10 <sup>(-3)</sup>	6.1x10 <sup>(-4)</sup>	+9.4x10 <sup>(-4)</sup>
Alk	mg/g	+1.7x10 <sup>(-3)</sup>	6.3x10 <sup>(-4)</sup>	5.2x10 <sup>(-4)</sup>

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 <sup>(-3)</sup>	--	--
Cu	ug/g	0.022	<3.1x10 <sup>(-3)</sup>	<2.4x10 <sup>(-3)</sup>
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 <sup>(-3)</sup>	3.1x10 <sup>(-3)</sup>
SO <sub>4</sub>	mg/g	+1.3x10 <sup>(-3)</sup>	+1.9x10 <sup>(-3)</sup>	9.8x10 <sup>(-4)</sup>
Alk	mg/g	4.6x10 <sup>(-3)</sup>	5.0x10 <sup>(-3)</sup>	2.0x10 <sup>(-3)</sup>
CYCLE 8				
Parameter	Units	West	Central	East
Al	ug/g	0.75	0.052	0.078
Cr	ug/g	3.8x10 <sup>(-3)</sup>	--	--
Cu	ug/g	0.028	<3.1x10 <sup>(-3)</sup>	<2.4x10 <sup>(-3)</sup>
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 <sup>(-3)</sup>	<9.6x10 <sup>(-4)</sup>
SO <sub>4</sub>	mg/g	+4.9x10 <sup>(-5)</sup>	+1.5x10 <sup>(-5)</sup>	2.1x10 <sup>(-5)</sup>
Alk	mg/g	9.6x10 <sup>(-3)</sup>	4.7x10 <sup>(-3)</sup>	8.7x10 <sup>(-3)</sup>

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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 <sup>(-3)</sup>	<9.4x10 <sup>(-4)</sup>	<7.2x10 <sup>(-4)</sup>
Cu	ug/g	0.025	6.6x10 <sup>(-3)</sup>	2.2x10 <sup>(-3)</sup>
Fe	ug/g	+1.24	+0.70	+0.34
Mn	ug/g	>+0.16	+0.078	+0.044
Ti	ug/g	5.6x10 <sup>(-3)</sup>	1.5x10 <sup>(-3)</sup>	6.5x10 <sup>(-4)</sup>
SO <sub>4</sub>	mg/g	+1.3x10 <sup>(-4)</sup>	+9.6x10 <sup>(-4)</sup>	+4.6x10 <sup>(-4)</sup>
Alk	mg/g	3.9x10 <sup>(-3)</sup>	2.5x10 <sup>(-3)</sup>	2.0x10 <sup>(-3)</sup>

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

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

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

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

3.5-107

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TABLE NO. 3.5-25

Concentrations of Selected Parameters in Saturated Waste Rock Leachate  
 MR-1 Saturated Quantities Leached

Parameter	Units	Rock Chips				Rock Powder			
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 1	Cycle 2	Cycle 4	Cycle 8
Al	ug/L	73	35	73	74	742	904	85	46
Cu	ug/L	17	18	<10	24	22	<20	..	..
Fe	ug/L	81	<55	..	..	1,200	1,200	840	160
Mn	ug/L	32	34	..	..	34	<4	..	..
Zn	ug/L	35	<11	..	..	62	74	22	<22
SO <sub>4</sub>	mg/L	4.8	55	60	75	15	20	14	16
Alk	mg/L	78	82	87	130	..	..	..	..

MR - 2 Saturated Leachate Concentrations

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

TABLE NO. 3.5-25 (Cont.)

Concentrations of Selected Parameters in Saturated Waste Rock Leachate  
 MR - 3 Saturated Leachate Concentrations

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

MR - 4 Saturated Leachate Concentrations

Parameter	Units	Rock Chips				Rock Powder			
		Cycle 1	Cycle 2	Cycle 4	Cycle 8	Cycle 1	Cycle 2	Cycle 4	Cycle 8
Al	ug/L	272	335	831	290	443	146	71	124
Cu	ug/L	16,000	14,000	22,000	25,000	50	42	36	38
Fe	ug/L	1,200	1,100	490	500	310	210	170	240
Mn	ug/L	450	460	570	630	130	<4	..	..
Zn	ug/L	2,300	1,900	3,000	3,300	27	<11	30	<22
SO <sub>4</sub>	mg/L	170	190	180	220	48	17	35	21
Alk	mg/L	<10	<10	<10	<10	..	..	..	..

## 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 (hydrus 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

MR-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 <sup>-3</sup>	9.4x10 <sup>-3</sup>	<0.5x10 <sup>-3</sup>	1.3x10 <sup>-3</sup>	0.020	0.22	<0.22	....	....	0.15
Fe	ug/g	+1.27	>+1.38	....	....	>+1.67	+13.0	+13.0	....	+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 <sup>-3</sup>	....	....	<5.8x10 <sup>-3</sup>	0.62	0.74	0.22	<0.22	<0.22
SO <sub>4</sub>	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	0.050	0.031	0.033	0.055	0.054	....	....	....	....	....
MR-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 <sup>-3</sup>	+0.018	+0.007	+7.5x10 <sup>-4</sup>	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 <sub>4</sub>	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	....	....	....	....	....
MR-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 <sub>4</sub>	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.)

MR-4 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	0.13	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 <sub>4</sub>	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	....	....	....	....	....
MR-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 <sub>4</sub>	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 <sup>-3</sup>	>+4.7x10 <sup>-3</sup>	>+5.3x10 <sup>-3</sup>	>+5.8x10 <sup>-3</sup>	>+6.2x10 <sup>-3</sup>	....	....	....	....	....

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

Equilibrating Solution (ug Fe/L)	Topsoil		Till		Sandstone		Saprolite	
	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 3.5-0). 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 Leached (ug/g)	Quantity of Metals in Sludge (ug/g)
As	0.036	159
Cu	34.2	163,000
Hg	$2.7 \times 10^{-4}$	1.5
Se	$2.2 \times 10^{-3}$	<5
Ag	$6.2 \times 10^{-3}$	37
Cd	0.034	165
Pb	0.10	37
Ni	0.030	130
Zn	8.74	45,000
Cr	$5.1 \times 10^{-3}$	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 <sup>1</sup> (Raw)	Polymer <sup>1</sup> Sludge	Runoff <sup>1</sup> (Raw)	Polymer <sup>1</sup> Sludge	Runoff <sup>1</sup> (Raw)	Polymer <sup>1</sup> Sludge
As	5.9 x 10 <sup>-3</sup>	12	3.7 x 10 <sup>-3</sup>	16	5.6 x 10 <sup>-3</sup>	16
Cd	<1.6 x 10 <sup>-3</sup>	<2.0	<5.4 x 10 <sup>-3</sup>	<1.9	<5.6 x 10 <sup>-3</sup>	<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 x 10 <sup>-3</sup>	19	3.2 x 10 <sup>-3</sup>	19	0.056	86
Hg	<2.7 x 10 <sup>-4</sup>	<0.17	<2.7 x 10 <sup>-4</sup>	<0.35	<2.8 x 10 <sup>-4</sup>	<0.17
Ni	<0.016	22	<0.016	23	<0.017	21
Se	<1.6 x 10 <sup>-3</sup>	0.62	<1.6 x 10 <sup>-3</sup>	0.58	<1.7 x 10 <sup>-3</sup>	0.54
Ag	<2.1 x 10 <sup>-4</sup>	<10	<2.1 x 10 <sup>-4</sup>	<10	6.1 x 10 <sup>-4</sup>	<10
Zn	0.036	58	0.024	72	0.083	170
Fe	0.0112	222	7.0 x 10 <sup>-3</sup>	232	8.4 x 10 <sup>-3</sup>	222

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

37000 E

38000 E

39000 E

40000 E

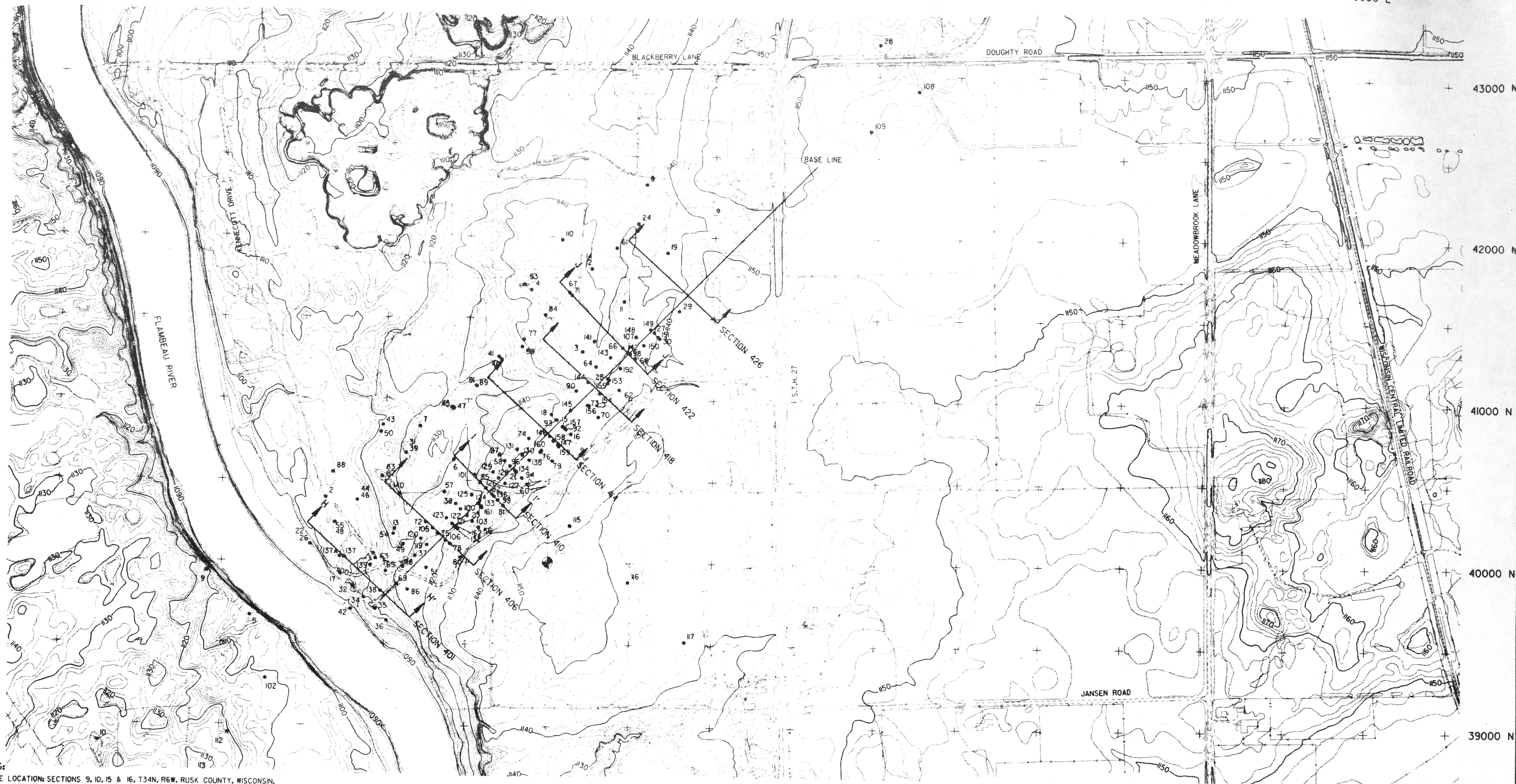
41000 E

42000 E

43000 E

44000 E

45000 E



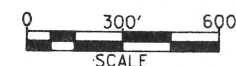
NOTES:

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI, DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATION, MINNEAPOLIS, MINNESOTA, DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:
 

SITE GRID COORDINATES		STATE PLANE COORDINATES	
CONTROL MONUMENT F-1		CONTROL MONUMENT F-1	
40000 N =	587,357.8087 N	40000 E =	1,713,516.1229 E

LEGEND

- 100- EXISTING CONTOUR
- EXISTING PAVED ROADWAY
- - - EXISTING TRAIL/GRAVEL SURFACE
- TREES AND/OR BRUSH
- - - FENCE
- F-1 CONTROL MONUMENT
- 110 DIAMOND DRILL HOLE LOCATION AND NUMBER



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MINERALS  
COMPANY  
1545 MINERAL SQUARE  
SALT LAKE CITY, UTAH  
84142

FIGURE NO. 3.5-1  
LOCATION MAP OF  
DIAMOND DRILL HOLES  
AND BEDROCK CROSS SECTIONS

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE

DWG. NO.	DESCRIPTION	DWG. NO.	DESCRIPTION	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR	

BY	CHK'D	ENGR	ENGR	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR	
M.J.C.	J.W.S.	J.W.S.	J.W.S.		4/26/89	ADD SECTIONS 406, 404, 408 & 406					

BY	CHK'D	ENGR	ENGR

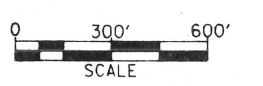
37000 E 38000 E 39000 E 40000 E 41000 E 42000 E 43000 E 44000 E 45000 E

43000 N  
42000 N  
41000 N  
40000 N  
39000 N



**NOTES:**  
 1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.  
 2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI, DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATION, MINNEAPOLIS, MINNESOTA, DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.  
 3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.  
 4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:  
 SITE GRID COORDINATES STATE PLANE COORDINATES  
 CONTROL MONUMENT F-1 40000 N = 587, 357, 8887 N  
 40000 E = 1, 713, 516, 1229 E  
 THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

- LEGEND**
- 1100— EXISTING CONTOUR
  - — — — — EXISTING PAVED ROADWAY
  - - - - - EXISTING TRAIL/GRAVEL SURFACE
  - ⊕ TRESSES AND/OR BRUSH
  - - - - - FENCE
  - ⊕ F-1 CONTROL MONUMENT
  - ⊕ MW-1004 GROUNDWATER MONITORING WELL LOCATION AND NUMBER
  - ⊕ PZ-R5 PIEZOMETER LOCATION AND NUMBER
  - ⊕ OW-39 SANDPOINT LOCATION AND NUMBER
  - ⊕ SP SANDPOINT LOCATION AND NUMBER
  - ⊕ B-SP2 SOIL BORING LOCATION AND NUMBER
  - ⊕ ST-9-29 TEST WELL LOCATION AND NUMBER
  - ⊕ TW-K6 TEST WELL LOCATION AND NUMBER
  - ⊕ OW-34



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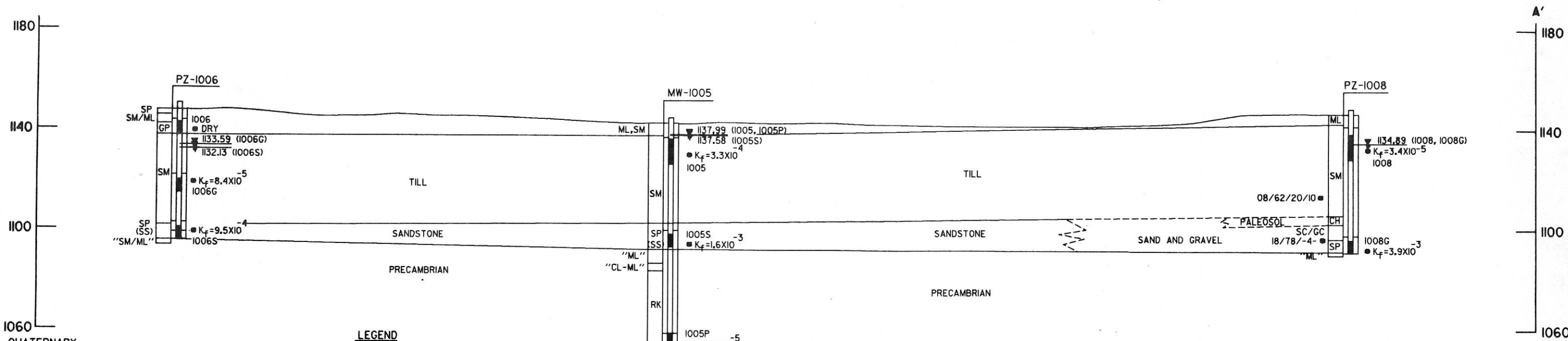
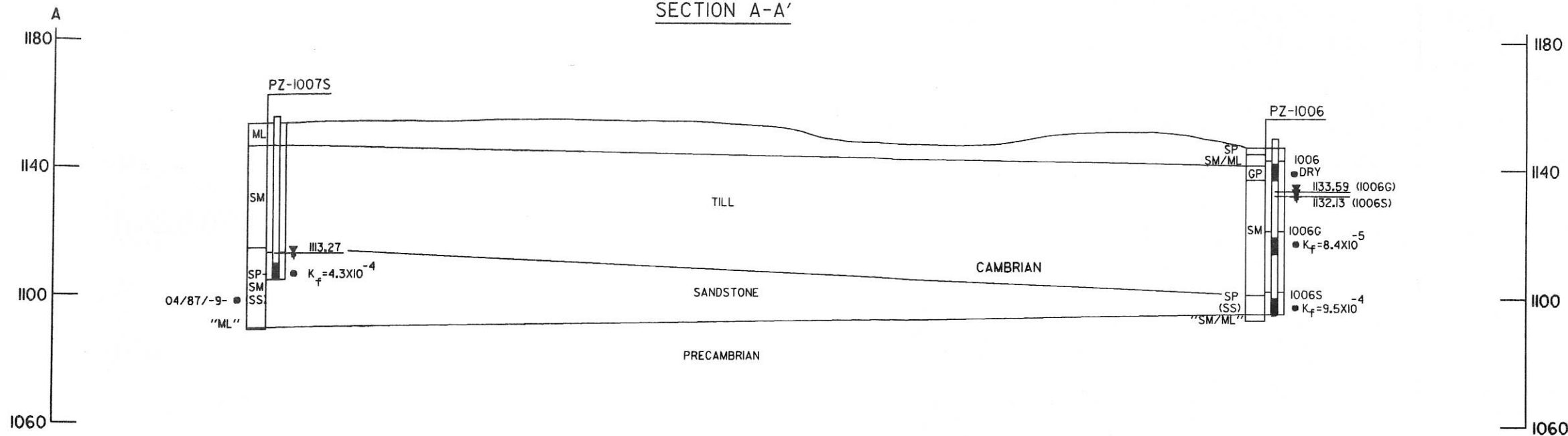
REF.	DWG. NO.	DESCRIPTION	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR NO.	NO.	DATE	REVISIONS	BY	DATE	BY	DATE	PROJ. ENGR	MGR. PROCESS ENGR	ENR. MGR.	DESIGN	DRAWN	CHK'D	DES. ENGR	SECT. ENGR	MICROFILM	JOB

**KENNECOTT MINERALS COMPANY**  
 155 MINERAL SQUARE  
 SALT LAKE CITY, UTAH  
 84142

FIGURE NO. 3.5-2  
 LOCATION MAP OF GROUNDWATER MONITORING WELLS, PIEZOMETERS, TEST WELLS, BORINGS AND CROSS SECTIONS

SCALE SEE BAR SCALE

SECTION A-A'



**QUATERNARY**

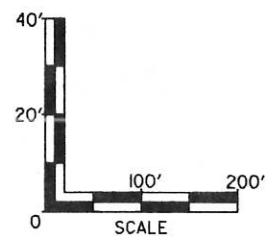
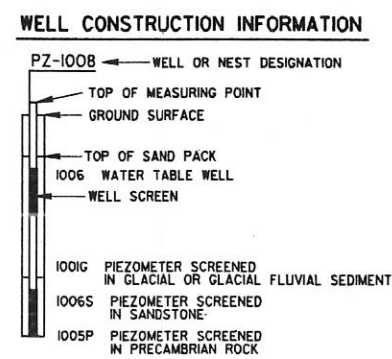
Q+	TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
SM	SILTY SAND
SW-SM	WELL GRADED SAND WITH SILT
SP	POORLY GRADED SAND
SP-SM	POORLY GRADED SAND WITH SILT
SW	WELL GRADED SAND
SP-SM, SW	POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
SM, SP	SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
SW, SM	WELL GRADED SAND INTERBEDDED WITH SILTY SAND
SM/ML	SILTY SAND/SILT
SC/SM	CLAYEY SAND/SILTY SAND
SC	CLAYEY SAND
SC-SM	SILTY-CLAYEY SAND
GW	WELL GRADED GRAVEL
GW-GM	WELL GRADED GRAVEL WITH SILT
GP	POORLY GRADED GRAVEL
GM	SILTY GRAVEL
SP, GP	POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
SM/GM	SILTY SAND/SILTY GRAVEL
SM, GW-GM	SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
GM/SM	SILTY GRAVEL/SILTY SAND

**LEGEND**

ML	SILT
CL-ML	SILTY CLAY
CL	LEAN CLAY
CL/ML	LEAN CLAY/SILT
<b>CAMBRIAN</b>	
SS	SANDSTONE
<b>PRECAMBRIAN</b>	
RK	ROCK
Qtz	QUARTZ
(1a)	SERICITE-QUARTZ SCHIST
(2)	BIOTITE SCHIST
(3)	AUGEN SCHIST
(5)	METADACITE (VOLCANIC FLOW ROCK)
"ML"	ROCK THAT DISAGGREGATES TO SILT
"SM"	ROCK THAT DISAGGREGATES TO SILTY SAND
"GM"	ROCK THAT DISAGGREGATES TO SILTY GRAVEL
"CL/ML"	ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
"SM/ML"	ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
"SM, ML"	ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

**SAMPLING POINT**  
 ATTERBERG LIMITS  
 IN-FIELD PERMEABILITY VALUE (CM/SEC)  
 LABORATORY PERMEABILITY VALUE (CM/SEC)  
 GRAVEL/SAND/SILT/CLAY PERCENTAGES  
 GRAVEL/SAND/P200 PERCENTAGES  
 AVERAGE WATER LEVEL  
 (SEPT. 1987 TO NOV. 1988)

**CONTACTS**-REASONABLY CERTAIN  
 UNCERTAIN  
 VERY UNCERTAIN

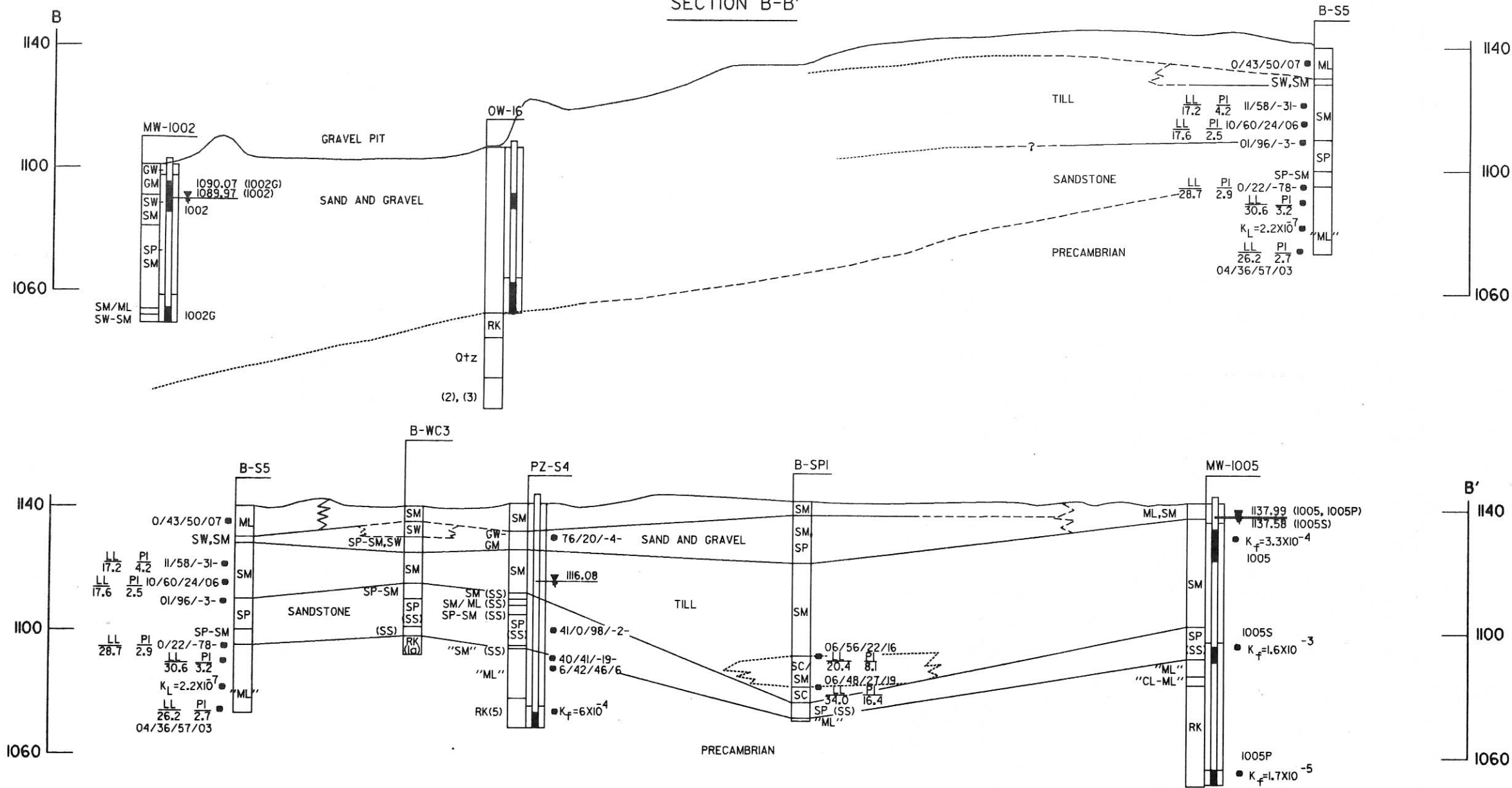


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REFERENCES	DWG. NO.	DESCRIPTION	DWG. NO.	DESCRIPTION	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR	NO.	DATE	REVISIONS	BY	DATE	BY	DATE	KenneCott Minerals Company 655 Mineral Square Salt Lake City, Utah 0482	FIGURE NO. 3.5-3 GEOLOGIC CROSS SECTION A-A'	MICROFILM	JOB
	DWG. NO.	DESCRIPTION	DWG. NO.	DESCRIPTION	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR	NO.	DATE	REVISIONS	BY	DATE	DRAWING NO.	REV.			DIVISION DRAWING NO.	SCALE

SECTION B-B'



QUATERNARY

- Qt Till, and sand and gravel (may contain some Cambrian sandstone)
- SM Silty sand
- SW-SM Well graded sand with silt
- SP Poorly graded sand
- SP-SM Poorly graded sand with silt
- SW Well graded sand
- SP-SM, SW Poorly graded sand with silt interbedded with well-graded sand
- SM, SP Silty sand interbedded with poorly graded sand
- SW, SM Well graded sand interbedded with silty sand
- SM/ML Silty sand/silt
- SC/SM Clayey sand/silty sand
- SC Clayey sand
- SC-SM Silty-clayey sand
- GW Well graded gravel
- GW-GM Well graded gravel with silt
- GP Poorly graded gravel
- GM Silty gravel
- SP, GP Poorly graded sand interbedded with poorly graded gravel
- SM/GM Silty sand/silty gravel
- SM, GW-GM Silty sand interbedded with poorly graded gravel with silt
- GM/SM Silty gravel/silty sand

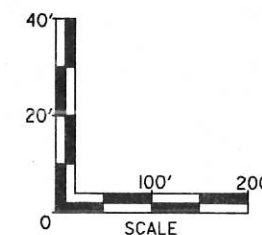
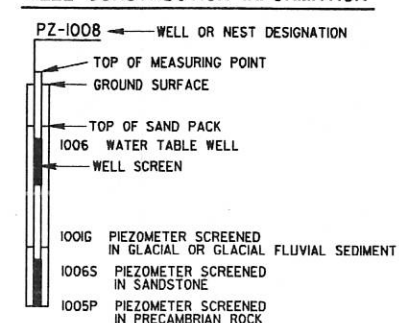
LEGEND

- ML Silt
- CL-ML Silty clay
- CL Lean clay
- CL/ML Lean clay/silt
- CAMBRIAN**
- SS Sandstone
- PRECAMBRIAN**
- RK Rock
- Qtz Quartz
- (10) Sericite-quartz schist
- (2) Biotite schist
- (3) Augen schist
- (5) Metadacite (volcanic flow rock)
- "ML" Rock that disaggregates to silt
- "SM" Rock that disaggregates to silty sand
- "GM" Rock that disaggregates to silty gravel
- "CL/ML" Rock that disaggregates to lean clay/silt
- "SM/ML" Rock that disaggregates to silty sand/silt
- "SM, ML" Rock that disaggregates to interbeds of silty sand and silt

- LL PI
- 26 13
- $K_f = 7.9 \times 10^{-5}$
- $K_f = 4.0 \times 10^{-9}$
- 01/50/41/08
- 0/93/-7-
- ▼ 113.27

- SAMPLING POINT
- ATTERBERG LIMITS
- IN-FIELD PERMEABILITY VALUE (CM/SEC)
- LABORATORY PERMEABILITY VALUE (CM/SEC)
- GRAVEL/SAND/SILT/CLAY PERCENTAGES
- GRAVEL/SAND/P200 PERCENTAGES
- AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
- CONTACTS-REASONABLY CERTAIN
- UNCERTAIN
- VERY UNCERTAIN

WELL CONSTRUCTION INFORMATION



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 SALT LAKE CITY, UTAH  
 84142

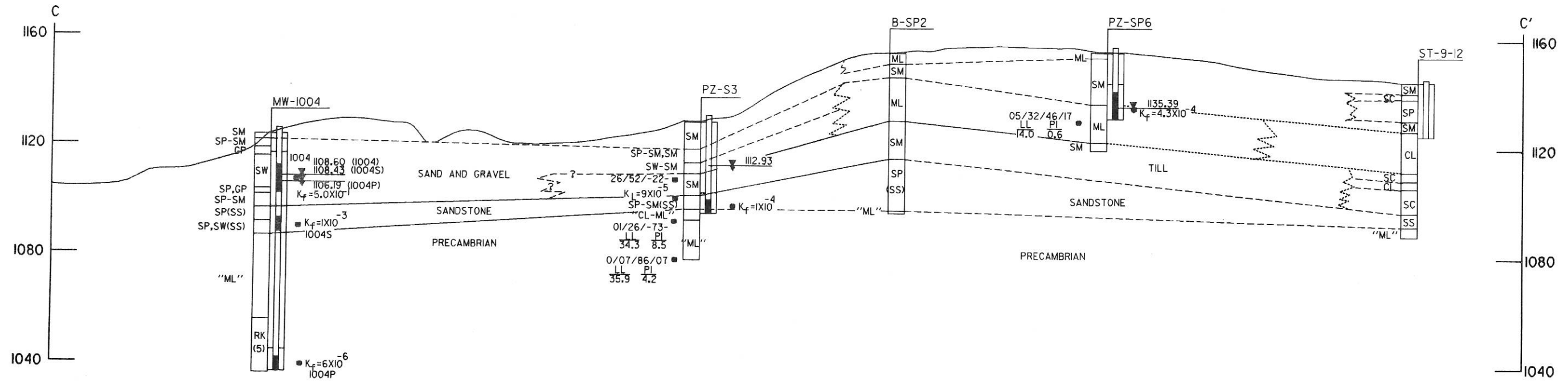
FIGURE NO. 3.5-4  
 GEOLOGIC CROSS SECTION  
 B-B'

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE

DWG. NO.	DESCRIPTION	DWG. NO.	DESCRIPTION	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR NO.	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR NO.

PROJ. ENGR	BY	DATE	DESIGN	BY	DATE

SECTION C-C'



QUATERNARY

- Qt TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
- SM SILTY SAND
- SW-SM WELL GRADED SAND WITH SILT
- SP POORLY GRADED SAND
- SP-SM POORLY GRADED SAND WITH SILT
- SW WELL GRADED SAND
- SP-SM, SW POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
- SM, SP SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
- SW, SM WELL GRADED SAND INTERBEDDED WITH SILTY SAND
- SM/ML SILTY SAND/SILT
- SC/SM CLAYEY SAND/SILTY SAND
- SC CLAYEY SAND
- SC-SM SILTY-CLAYEY SAND
- GW WELL GRADED GRAVEL
- GW-GM WELL GRADED GRAVEL WITH SILT
- GP POORLY GRADED GRAVEL
- GM SILTY GRAVEL
- SP, GP POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
- SM/GM SILTY SAND/SILTY GRAVEL
- SM, GW-GM SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
- GM/SM SILTY GRAVEL/SILTY SAND

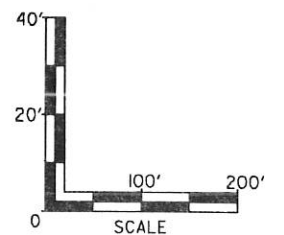
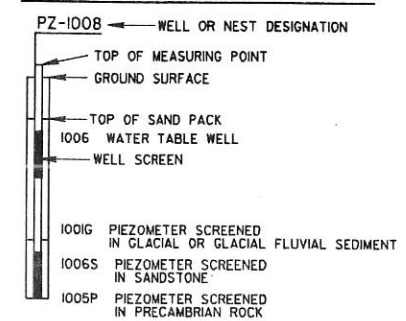
LEGEND

- ML SILT
  - CL-ML SILTY CLAY
  - CL LEAN CLAY
  - CL/ML LEAN CLAY/SILT
- CAMBRIAN**
- SS SANDSTONE
- PRECAMBRIAN**
- RK ROCK
  - Qtz QUARTZ
  - (1a) SERICITE-QUARTZ SCHIST
  - (2) BIOTITE SCHIST
  - (3) AUGEN SCHIST
  - (5) METADACITE (VOLCANIC FLOW ROCK)
  - "ML" ROCK THAT DISAGGREGATES TO SILT
  - "SM" ROCK THAT DISAGGREGATES TO SILTY SAND
  - "GM" ROCK THAT DISAGGREGATES TO SILTY GRAVEL
  - "CL/ML" ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
  - "SM/ML" ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
  - "SM, ML" ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

- LL PI
- 26 13
- $K_f = 7.9 \times 10^{-5}$
- $K_f = 4.0 \times 10^{-9}$
- 01/50/41/08
- 0/93/-7-
- ▽ 113.27

- SAMPLING POINT
- ATTERBERG LIMITS
- IN-FIELD PERMEABILITY VALUE (CM/SEC)
- LABORATORY PERMEABILITY VALUE (CM/SEC)
- GRAVEL/SAND/SILT/CLAY PERCENTAGES
- GRAVEL/SAND/P200 PERCENTAGES
- AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
- CONTACTS-REASONABLY CERTAIN
- UNCERTAIN
- VERY UNCERTAIN

WELL CONSTRUCTION INFORMATION



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LADYSMITH, WISCONSIN

KENNECOTT  
MINERALS  
COMPANY  
615 MINERAL SQUARE  
SALT LAKE CITY, UTAH  
8412

FIGURE NO. 3.5-5  
GEOLOGIC CROSS SECTION  
C-C'

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE

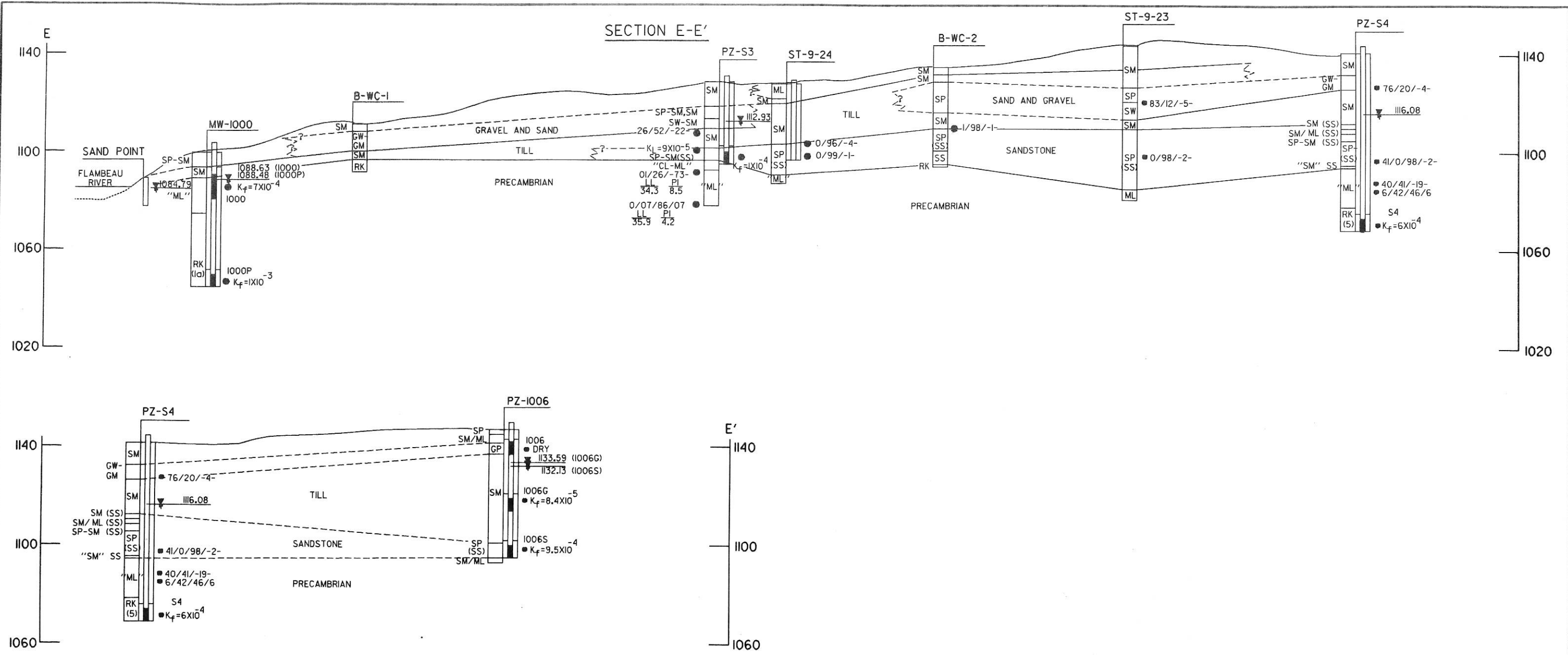
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BY	DATE	DESIGN	BY	DATE

PROJ. ENGR	DESIGN	BY	DATE



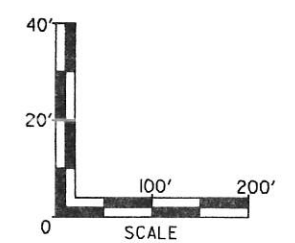
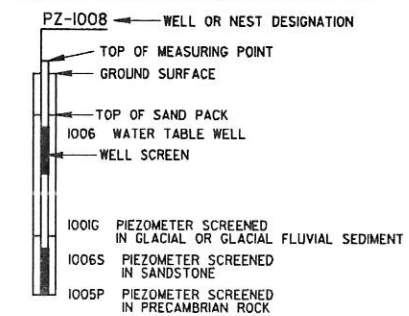




- QUATERNARY**
- QT TILL, AND SAND AND GRAVEL (MAY CONTAIN SOME CAMBRIAN SANDSTONE)
  - SM SILTY SAND
  - SW-SM WELL GRADED SAND WITH SILT
  - SP POORLY GRADED SAND
  - SP-SM POORLY GRADED SAND WITH SILT
  - SW WELL GRADED SAND
  - SP-SM, SW POORLY GRADED SAND WITH SILT INTERBEDDED WITH WELL-GRADED SAND
  - SM, SP SILTY SAND INTERBEDDED WITH POORLY GRADED SAND
  - SW, SM WELL GRADED SAND INTERBEDDED WITH SILTY SAND
  - SM/ML SILTY SAND/SILT
  - SC/SM CLAYEY SAND/SILTY SAND
  - SC CLAYEY SAND
  - SC-SM SILTY-CLAYEY SAND
  - GW WELL GRADED GRAVEL
  - GW-GM WELL GRADED GRAVEL WITH SILT
  - GP POORLY GRADED GRAVEL
  - GM SILTY GRAVEL
  - SP, GP POORLY GRADED SAND INTERBEDDED WITH POORLY GRADED GRAVEL
  - SM/GM SILTY SAND/SILTY GRAVEL
  - SM, GW-GM SILTY SAND INTERBEDDED WITH POORLY GRADED GRAVEL WITH SILT
  - GM/SM SILTY GRAVEL/SILTY SAND
- LEGEND**
- ML SILT
  - CL-ML SILTY CLAY
  - CL LEAN CLAY
  - CL/ML LEAN CLAY/SILT
- CAMBRIAN**
- SS SANDSTONE
- PRECAMBRIAN**
- RK ROCK
  - Qtz QUARTZ
  - (1a) SERICITE-QUARTZ SCHIST
  - (2) BIOTITE SCHIST
  - (3) AUGEN SCHIST
  - (5) METADACITE (VOLCANIC FLOW ROCK)
  - "ML" ROCK THAT DISAGGREGATES TO SILT
  - "SM" ROCK THAT DISAGGREGATES TO SILTY SAND
  - "GM" ROCK THAT DISAGGREGATES TO SILTY GRAVEL
  - "CL/ML" ROCK THAT DISAGGREGATES TO LEAN CLAY/SILT
  - "SM/ML" ROCK THAT DISAGGREGATES TO SILTY SAND/SILT
  - "SM, ML" ROCK THAT DISAGGREGATES TO INTERBEDS OF SILTY SAND AND SILT

- SAMPLING POINT**
- ATTERBERG LIMITS
  - IN-FIELD PERMEABILITY VALUE (CM/SEC)
  - LABORATORY PERMEABILITY VALUE (CM/SEC)
  - GRAVEL/SAND/SILT/CLAY PERCENTAGES
  - GRAVEL/SAND/P200 PERCENTAGES
  - AVERAGE WATER LEVEL (SEPT. 1987 TO NOV. 1988)
- CONTACTS-REASONABLY CERTAIN**  
 ----- UNCERTAIN  
 - - - - - VERY UNCERTAIN
- PERMEABILITY VALUES**
- LL PI
  - 26 13
  - $K_f = 7.9 \times 10^{-5}$
  - $K_f = 4.0 \times 10^{-9}$
  - 01/50/41/08
  - 0/93/-7-
  - 113.27

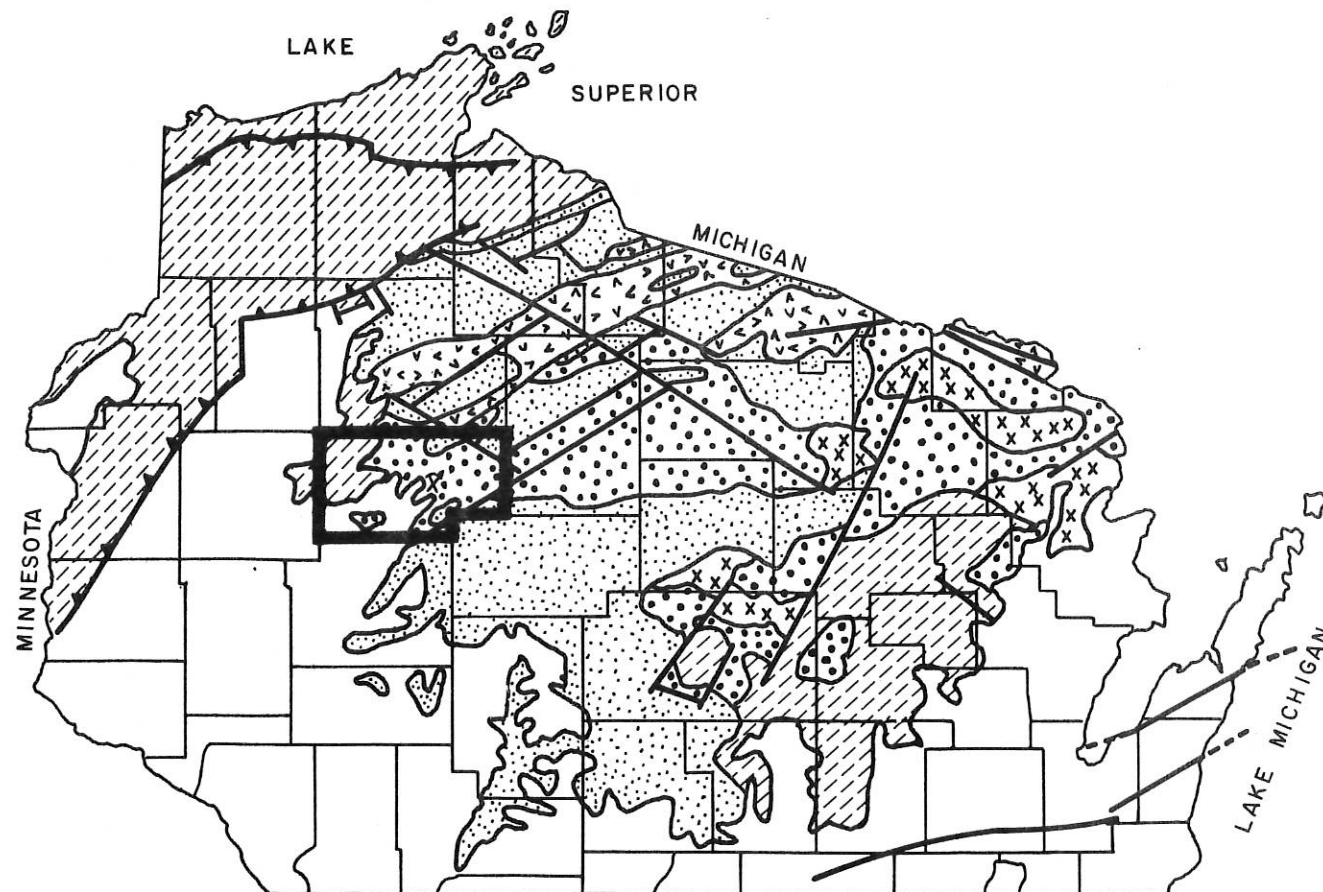
**WELL CONSTRUCTION INFORMATION**



<b>FOTH &amp; VAN DYKE</b>										<b>FLAMBEAU PROJECT</b>									
GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION										LADYSMITH, WISCONSIN									
GREEN BAY, WISCONSIN										KENNECOTT MINERALS COMPANY									
655 MINERAL SQUARE										SALT LAKE CITY, UTAH									
0402										FIGURE NO. 3.5-7									
DESIGN										GEOLGIC CROSS SECTION									
DRAWN										E-E'									
MRS 2/89										SCALE SEE BAR SCALE									
CHK'D										DIVISION DRAWING NO.									
3/89										DRAWING NO. REV.									
DES. ENGR										MICROFILM JOB									
SECT ENGR										SCALE SEE BAR SCALE									



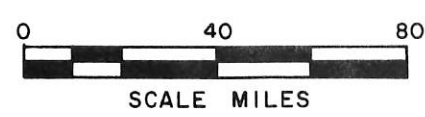




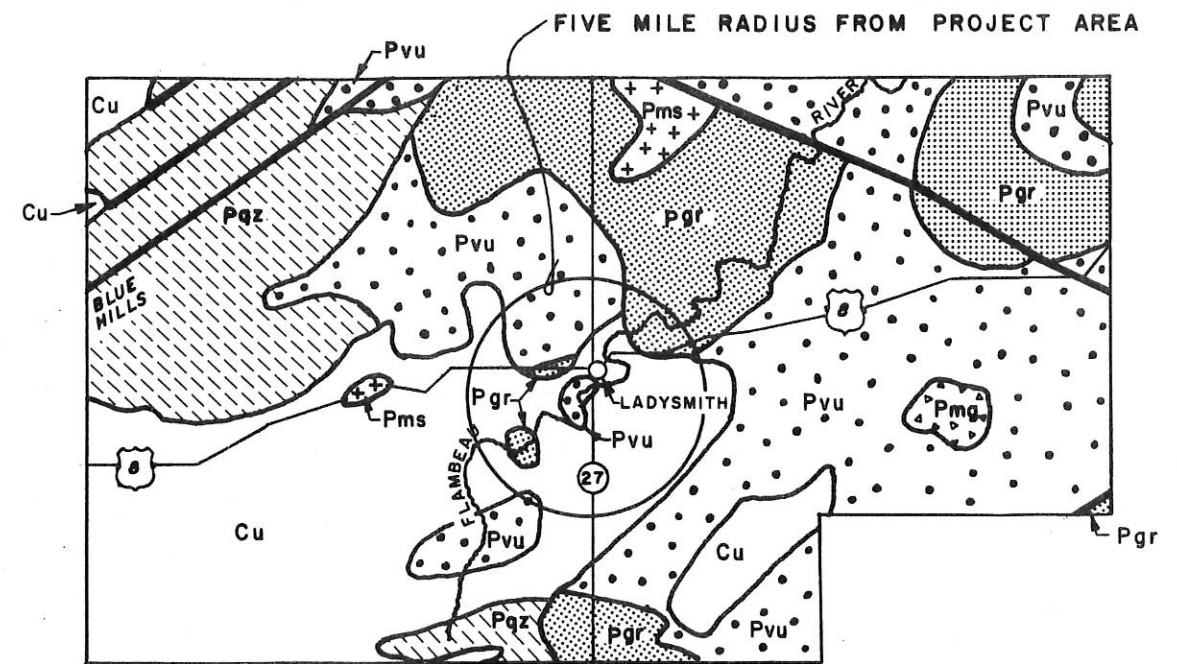
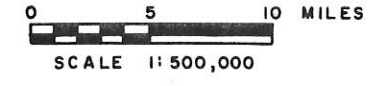
**LEGEND**

GEOLOGY MODIFIED FROM SIMS 1976

- PALEOZOIC**
- SANDSTONE, SHALE, LIMESTONE AND DOLOMITE
- PRECAMBRIAN**
- LATE**
- ▨ BASALTIC FLOWS, METASEDIMENTARY SHALE, SANDSTONE, AND INTRUSIVE IGNEOUS ROCKS
- MIDDLE**
- ⊗ GRANITIC ROCK
- ⊕ METASEDIMENTARY ROCK
- ⊙ METAVOLCANIC ROCK
- EARLY**
- ⊘ GNEISS, MIGMATITE
- RIFT FAULTING
- FAULT
- ⚒ FLAMBEAU DEPOSIT, RUSK COUNTY



<b>FOTH &amp; VAN DYKE</b> GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION GREEN BAY, WISCONSIN			<b>KENNECOTT MINERALS COMPANY</b>		
			<b>FLAMBEAU PROJECT</b> <b>LADYSMITH, WISCONSIN</b>		
NOTES		APPROVAL	DATE	<b>FIGURE NO. 3.5-10</b> GENERALIZED GEOLOGIC MAP OF PRECAMBRIAN ROCKS IN NORTHERN WISCONSIN	
		DESIGNED BY			
		DRAWN BY	SJL 12/88		
		CHECKED BY	BJS 12/88		
		APPROVED BY		Job No	Dwg No
		CAD No.	SCALE		REV



**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

<b>FOTH &amp; VAN DYKE</b> GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION GREEN BAY, WISCONSIN			<b>KENNECOTT MINERALS COMPANY</b> <b>FLAMBEAU PROJECT</b> <b>LADYSMITH, WISCONSIN</b>		
NOTES	APPROVAL	DATE	<b>FIGURE NO. 3.5-II</b> BEDROCK GEOLOGY OF RUSK COUNTY, WISCONSIN		
	DESIGNED BY				
	DRAWN BY S J L	1/89			
	CHECKED BY BJS	3/89			
	APPROVED BY				
	CAD No.	SCALE	Job No	Dwg No	REV





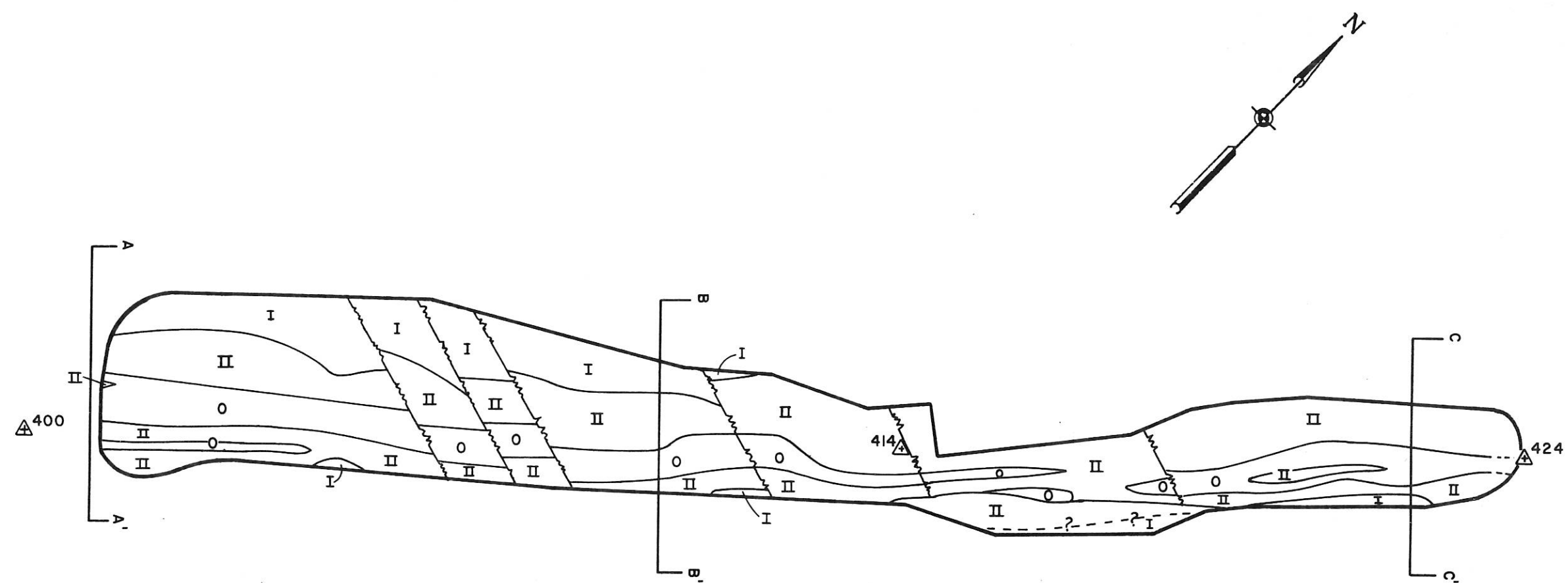






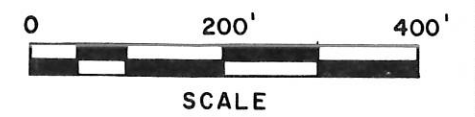


FLAMBEAU RIVER



**LEGEND**

- I TYPE I WASTE ROCK (CONTAINS LESS THAN 1% SULFUR)
- II TYPE II WASTE ROCK (CONTAINS MORE THAN 1% SULFUR)
- O MASSIVE SULFIDE MINERALIZATION
- INFERRED FAULT
- PROPOSED PIT PERIMETER, 1000 FOOT BENCH LEVEL
- △ 400 BASELINE STATION



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

**FLAMBEAU PROJECT**  
 LADYSMITH, WISCONSIN

**FIGURE NO. 3.5-17**  
 DISTRIBUTION OF SULFIDES  
 AT THE 1000 BENCH LEVEL  
 AND CROSS SECTION  
 LOCATION

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	

DWG. NO.	DESCRIPTION	NO.	DATE	REVISIONS	BY	CHKD	ENGR	ENGR	NO.	DATE	REVISIONS	BY	CHKD	ENGR	ENGR	BY	DATE	DESIGN	BY	DATE
																			S.J.L.	1/89
																			BJS	3/89

KENNECOTT  
 MINERALS  
 COMPANY  
 1515 MINERAL SQUARE  
 SALT LAKE CITY, UTAH  
 84112

37000 E      38000 E      39000 E      40000 E      41000 E      42000 E      43000 E      44000 E      45000 E



NOTES:  
 1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.  
 2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI, DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATION, MINNEAPOLIS, MINNESOTA, DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.  
 3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.  
 4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:  
 SITE GRID COORDINATES      STATE PLANE COORDINATES  
 CONTROL MONUMENT F-1      587,357.8887 N  
 40000 N =      1,713,516.1229 E  
 40000 E =  
 THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°-13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

- LEGEND
- 1100— EXISTING CONTOUR
  - — — — — EXISTING PAVED ROADWAY
  - - - - - EXISTING TRAIL/GRAVEL SURFACE
  - ▭ TREES AND/OR BRUSH
  - + F-1 FENCE
  - ⊙ CONTROL MONUMENT
  - ⊗ KWC-2 TEST PIT LOCATION AND NUMBER
  - ⊕ KWR-9 SOIL SAMPLE LOCATION AND NUMBER
  - - - - - PROPOSED PIT PERIMETER



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

**FLAMBEAU PROJECT**  
 LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY  
 155 MINERAL SQUARE  
 SALT LAKE CITY, UTAH 8412

MICROFILM JOB  
 DRAWING NO. REV.  
 DIVISION DRAWING NO.  
 SCALE SEE BAR SCALE

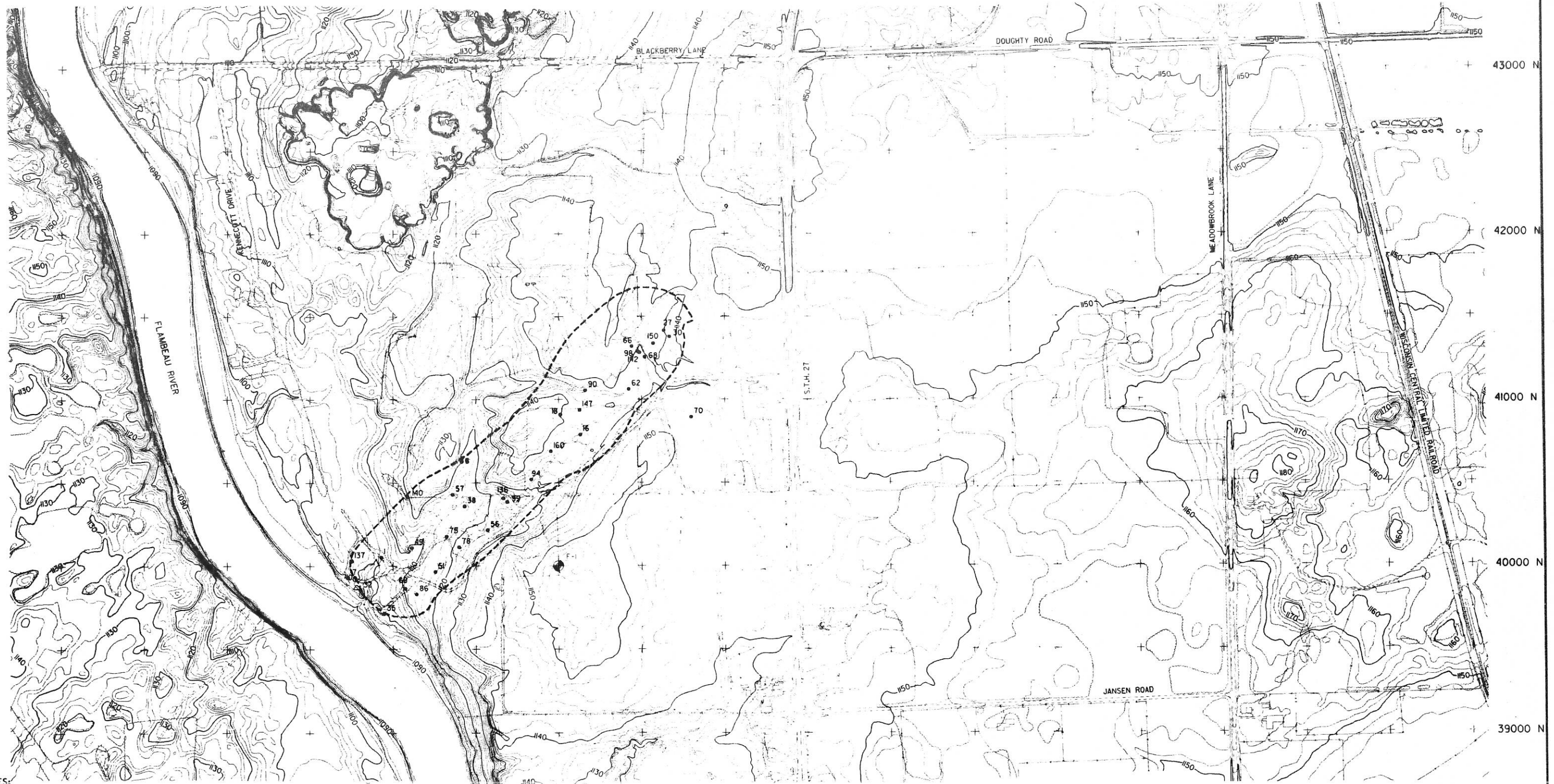
REFERENCES	DWG. NO.				DESCRIPTION				NO. DATE REVISIONS				BY CHD ENR EGR				NO. DATE REVISIONS				BY CHD ENR EGR			
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DESIGN      MJD      3/87  
 DRAWN      JAW      3/87  
 CHD  
 DES. ENGR  
 SECT ENGR

FIGURE NO. 3.5-18  
 SOIL SAMPLE LOCATIONS



37000 E      38000 E      39000 E      40000 E      41000 E      42000 E      43000 E      44000 E      45000 E



**NOTES:**

1. SITE LOCATION: SECTIONS 9, 10, 15 & 16, T34N, R6W, RUSK COUNTY, WISCONSIN.
2. TOPOGRAPHIC BASE MAP PREPARED FROM AERIAL SURVEY BY SURDEX CORPORATION, CHESTERFIELD, MISSOURI. DATE OF PHOTOGRAPHY - APRIL 24, 1970. ROADS, TREES AND BUILDINGS WERE UPDATED AS PER AERIAL PHOTOGRAPH TAKEN BY MARKHURD CORPORATION, MINNEAPOLIS, MINNESOTA. DATE OF PHOTOGRAPHY - SEPTEMBER 14, 1987.
3. ELEVATIONS BASED ON MEAN SEA LEVEL DATUM. CONTOUR INTERVAL IS TWO FEET.
4. HORIZONTAL DATUM BASED ON PROJECT SITE GRID SYSTEM. SITE GRID COORDINATES CORRELATION TO STATE PLANE COORDINATES DERIVED AS FOLLOWS:  

SITE GRID COORDINATES	STATE PLANE COORDINATES
CONTROL MONUMENT F-1	
40000 N =	587,357.0087 N
40000 E =	1,713,516.1229 E

THE ANGULAR ROTATION FROM STATE PLANE BEARINGS TO SITE GRID BEARINGS IS 359°13'-23" RIGHT WITH CONTROL POINT F-1 AS THE BASE POINT.

- LEGEND**
- 1100 — EXISTING CONTOUR
  - — — EXISTING PAVED ROADWAY
  - — — EXISTING TRAIL/GRAVEL SURFACE
  - ▭ TREES AND/OR BRUSH
  - F-1 — FENCE
  - ⊙ CONTROL MONUMENT
  - 70 DIAMOND DRILL HOLE LOCATION AND NUMBER
  - - - - - PROPOSED PIT PERIMETER

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

**FLAMBEAU PROJECT**  
 LADYSMITH, WISCONSIN

MICROFILM      JOB

DRAWING NO.      REV.

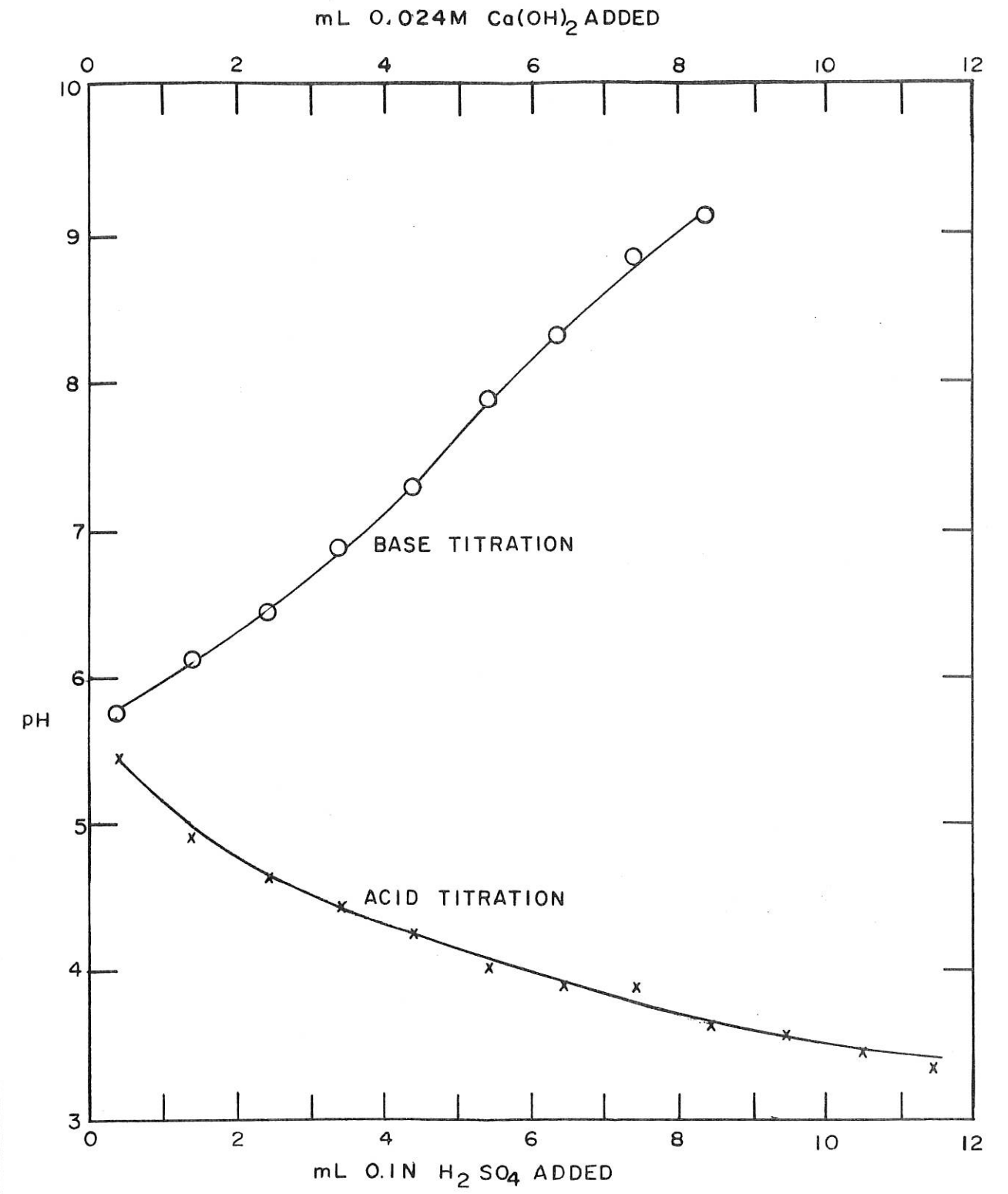
DIVISION DRAWING NO.

SCALE      SEE BAR SCALE

REFERENCES	DWG. NO.		DESCRIPTION		NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR	NO.	DATE	DESIGN	BY	DATE
	NO.	DATE	NO.	DATE																			

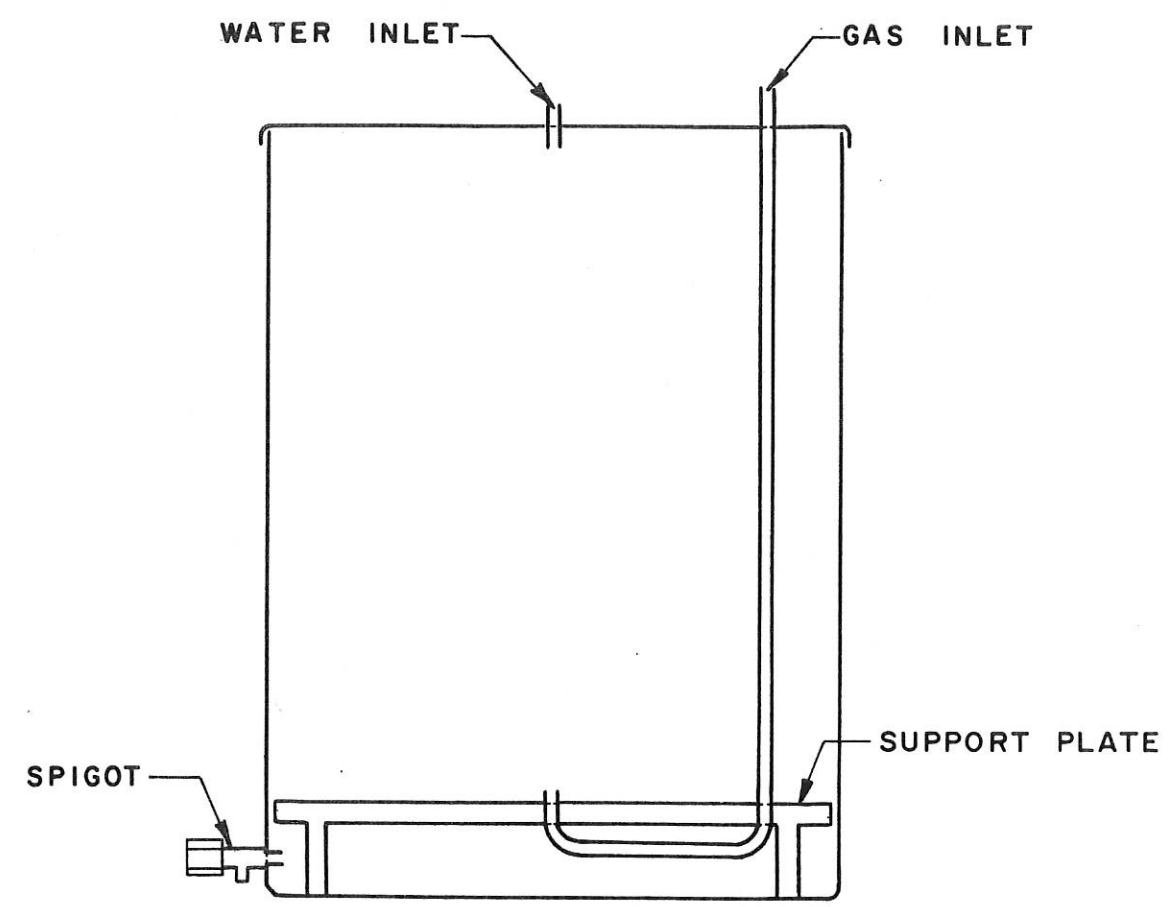
**KENNECOTT MINERALS COMPANY**  
 615 MINERAL SQUARE  
 SALT LAKE CITY, UTAH  
 84142

FIGURE NO. 3.5-20  
 WASTE ROCK SAMPLE LOCATIONS

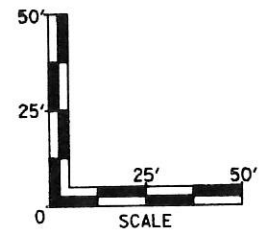
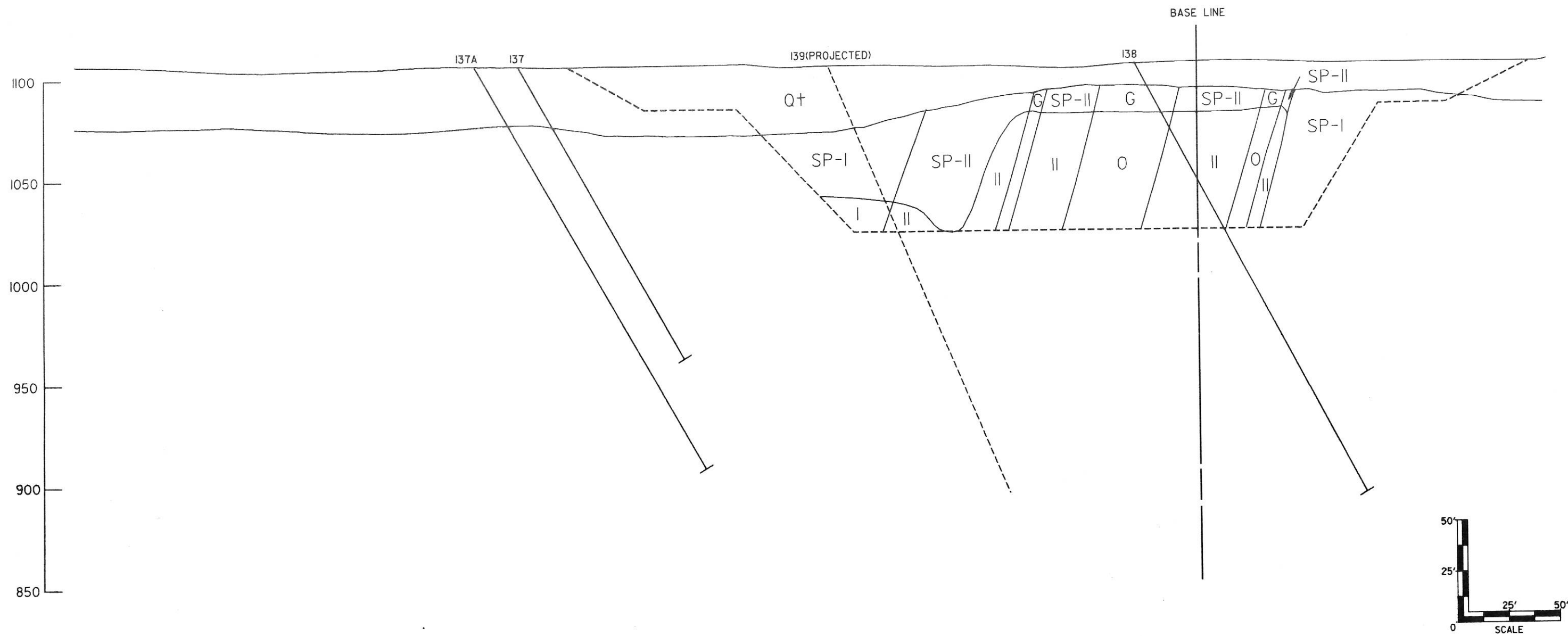


<b>FOTH &amp; VAN DYKE</b> GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION GREEN BAY, WISCONSIN			KENNECOTT MINERALS COMPANY <b>FLAMBEAU PROJECT</b> LADYSMITH, WISCONSIN		
NOTES	APPROVAL	DATE	<b>FIGURE NO. 3.5-21</b> ACID AND BASE TITRATION OF WR-3 SUSPENSION		
	DESIGNED BY				
	DRAWN BY	R.D.M. 2/89			
	CHECKED BY	J.E.T. 3/89			
	APPROVED BY				
	CAD No.	SCALE NONE	Job No	Dwg No	REV





<b>FOTH &amp; VAN DYKE</b> GEOSCIENCES & ENVIRONMENTAL MANAGEMENT DIVISION GREEN BAY, WISCONSIN			KENNECOTT MINERALS COMPANY <b>FLAMBEAU PROJECT</b> LADYSMITH, WISCONSIN		
NOTES	APPROVAL	DATE	FIGURE NO. 3.5-22 DETAIL OF LEACHING EXPERIMENT TANK		
	DESIGNED BY				
	DRAWN BY	SJL 1/89			
	CHECKED BY	JET 3/89			
	APPROVED BY				
	CAD No.	SCALE NO SCALE	Job No	Dwg No	REV



**LEGEND**

- Qt** QUATERNARY PLEISTOCENE UNCONSOLIDATED MATERIAL
- Cs** PALEOZOIC CAMBRIAN SANDSTONE
- PRECAMBRIAN**
- G** GOSSAN
- Sp** SAPROLITE
- O** MASSIVE, SEMI-MASSIVE SULFIDE ORE
- I** TYPE I WASTE ROCK, CONTAINING < 1% SULFUR
- II** TYPE II WASTE ROCK, CONTAINING > 1% SULFUR
- PROPOSED PIT PERIMETER

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

**FLAMBEAU PROJECT**  
 LADYSMITH, WISCONSIN

KENNECOTT MINERALS COMPANY  
 1915 MINERAL SQUARE  
 SALT LAKE CITY, UTAH 8412

MICROFILM	JOB
DRAWING NO.	REV.
DIVISION DRAWING NO.	
SCALE	SEE BAR SCALE

DWG. NO.	DESCRIPTION	DWG. NO.	DESCRIPTION	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR NO.	NO.	DATE	REVISIONS	BY	CHK'D	ENGR	ENGR NO.	PROJ. ENGR	BY	DATE	DESIGN	BY	DATE	
																								PROJ. ENGR

FIGURE NO. 3.5-23  
 GEOLOGIC CROSS-SECTION  
 SECTION 401  
 WASTE ROCK AND  
 MATERIAL WASTE DELINEATIONS



