Geotechnical review: Crandon Project waste disposal system: project report 2: volume 1, Analyses and interpretation. v. 2, pt. 1

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GEOTECHNICAL REVIEW
CRANDON PROJECT
WASTE DISPOSAL SYSTEM
PROJECT REPORT 2
VOLUME 1

COPY NO. 10

Golder Associates
CONSULTING GEOTECHNICAL AND MINING ENGINEERS

GEOTECHNICAL REVIEW
CRANDON PROJECT
WASTE DISPOSAL SYSTEM
PROJECT REPORT 2
VOLUME 1

ANALYSES AND INTERPRETATION

Submitted to:

Exxon Minerals Company
655 Washington Street
Post Office Box 813
Rhinelander, Wisconsin 54501

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Golder Associates

CONSULTING GEOTECHNICAL AND MINING ENGINEERS

October 23, 1981

786085/MA/324
F/N 173.1

Exxon Minerals Company
P. O. Box 813
Rhinelander, Wisconsin 54501

Attention: Mr. C. E. Fowler

Re: Waste Disposal System
Crandon Project
Crandon, Wisconsin

Gentlemen:

We are pleased to present the final draft of Project Report 2, Geotechnical Review, Crandon Project Waste Disposal System. This report presents the results of field and laboratory investigations and the interpretation of this data to provide an understanding of the existing geologic and hydrogeologic conditions and to determine the physical properties of the glacial materials. The report includes three volumes as follows:

Volume 1, Analyses and Interpretation
Volume 2, Laboratory Test Data, Test Pit Logs, and G40 Series Boring Logs
Volume 3, G41 Series Boring Logs

We appreciate the continuing opportunity to provide services to Exxon Minerals Company for the Crandon Project and extend our thanks to you and the Exxon staff for their excellent cooperation.

Very truly yours,

GOLDER ASSOCIATES

Gary H. Collison

Gary H. Collison, P.E.
Associate

GHC:dap

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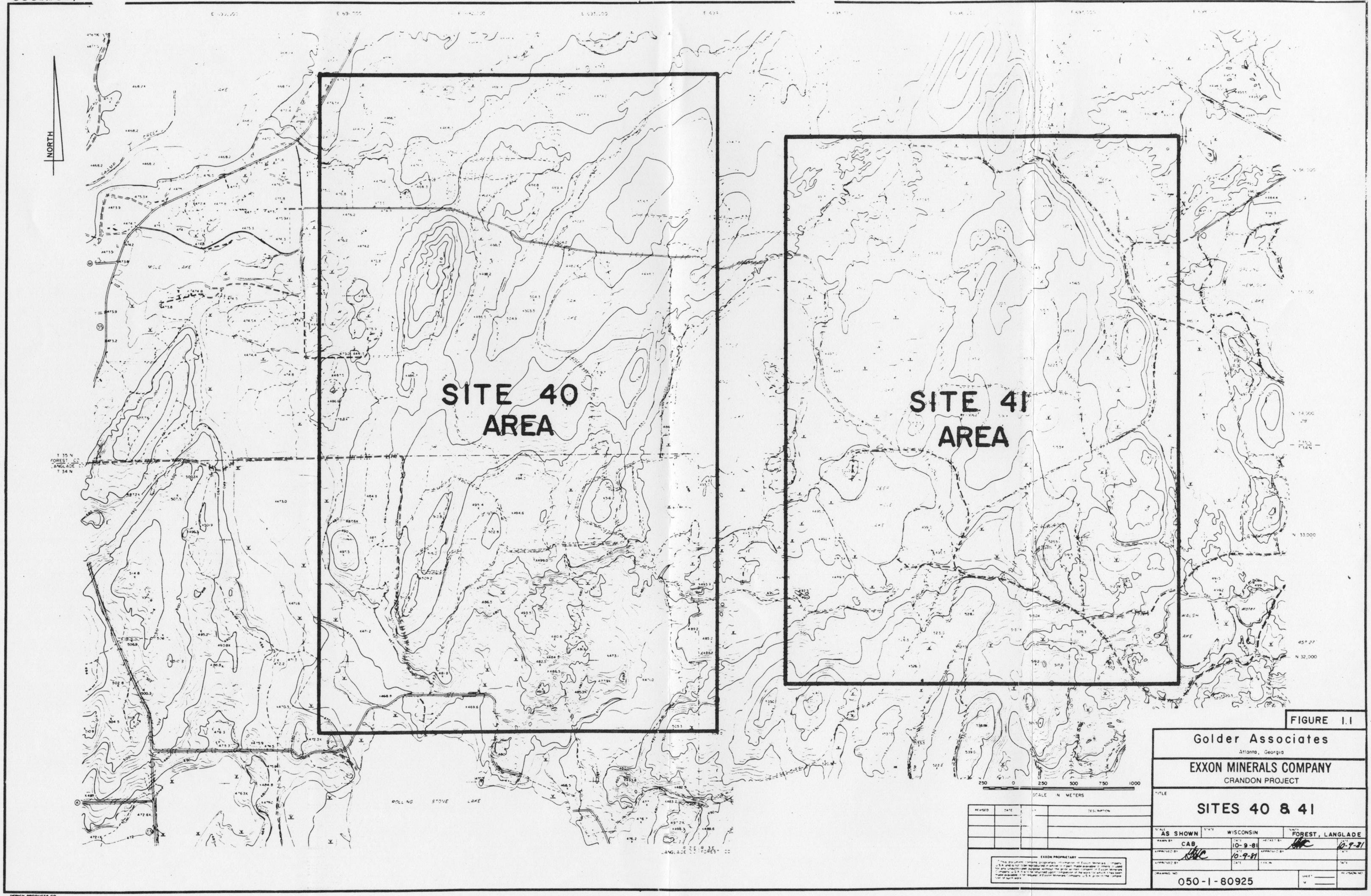
1.0 INTRODUCTION

Exxon Minerals Company has retained Golder Associates to provide preliminary engineering design for use in permitting the waste disposal system for their Crandon Mining Project in Forest County, Wisconsin. The purpose of this report is to present the results of field and laboratory investigations and the interpretation of this data to provide an understanding of the existing geologic and hydrologic conditions and to determine the physical properties of the glacial materials.

This report is presented in three volumes. Volume 1 presents Golder Associates' interpretation of the data to determine the physical properties and stratigraphy of the geologic materials and to describe the characteristics of the groundwater system. Volume 2 presents the logs of the G40 series test borings and test pit excavations supervised by Golder Associates and the results of laboratory tests performed on samples from the borings and test pits. Volume 3 presents the logs of the G41 series test borings.

The investigations cover two potential disposal sites which have been selected from various alternative siting areas (Ref. 1). The location of these two sites, Sites 40 and 41, are shown on Figure 1.1. The location boundaries shown on Figure 1 are approximate. They are intended to show the general location of each site for discussion reference purposes. They are not precise limits of a recommended waste system. As the geotechnical investigations and other related waste disposal system studies progressed, it became evident that of these two sites, Site 41 appeared to be better suited for developing a waste disposal system than Site 40. Therefore, more exploratory work and detailed evaluation have been performed for this site.


NORTH
SITE 40
AREA
SITE 41
AREA
MOLE LAKE
ROLLING STONE LAKE
DEEP HOLE LAKE
HEMLOCK LAKE
WELSH LAKE
SCALE IN METERS
250 0 250 500 750 1000
FIGURE 1.1
Golder Associates
Atlanta, Georgia
EXXON MINERALS COMPANY
CRANDON PROJECT
SITES 40 & 41
AS SHOWN
WISCONSIN
FOREST, LANGLADE
CAB
10-9-81
10-9-81
10-9-81
050-1-80925
EXXON PROPRIETARY
DESIGN PRODUCTS CO

The specific subsurface conditions at proposed waste disposal Sites 40 and 41 have been investigated by test borings, test pits, borehole permeability tests, and laboratory tests on samples obtained from the borings and test pits. In addition, a major pump test was conducted at Site 41. These data along with surface geologic mapping, geophysical investigation in the area surrounding the proposed waste disposal sites, and published and unpublished geological and soil information have been used to assess the specific site conditions and material properties. Data which is not included in the three volumes of this report but which has been used in this study are referenced.

Test borings for investigation of the subsurface conditions (not specifically related to exploration of the orebody) at the proposed waste disposal sites and surrounding areas were a result of programs designed and supervised by Golder Associates and Dames & Moore. These programs were implemented over a period of several years to investigate different areas around the Project site, for different specific purposes (such as groundwater monitoring versus definition of the glacial stratigraphy from the ground surface to the top of rock), and for increased level of stratigraphic detail in some areas, particularly in Site 41. A detailed discussion of the test boring programs designed by Golder Associates is presented in Appendix A and the logs of the test borings are presented in Volumes 2 and 3. Detailed logs and discussion of the test borings by Dames & Moore are presented in Reference 6.

Test pits were dug under the direct supervision of Golder Associates to provide bulk samples of the near surface soils for laboratory testing. The test pits were dug with a backhoe and were limited to depths from 1.5 to 5.2 m

(5 to 17 ft.). A more detailed discussion of the test pit program is included in Appendix A and the test pit logs are in Volume 2.

Laboratory tests were performed on samples obtained from the borings and test pits supervised by Golder Associates. These tests were primarily standard soils tests consisting of index properties (grain size analyses, Atterberg limits, and specific gravity), compaction, triaxial shear, and laboratory permeability. Index properties were determined for samples from boreholes and test pits. Other soils tests were performed on samples from the test pits. In addition to the physical soil tests, carbonate content tests were performed on a limited number of samples from borings G41-G15 and G41-G15A and the results are presented in Section 4.7 of this report. A complete description of the laboratory soil test program and test methods is presented in Appendix B. The laboratory soil test results are contained in Volume 2.

A great deal of emphasis has been placed on determining the characteristics of the glacial aquifer and hydraulic characteristics of the glacial soils which will be used in construction of the waste disposal facilities. Aquifer characteristics were directly investigated by a pump test at Site 41. A brief summary of the results of this test are included in Appendix E of this report. A complete description of the test and analysis is provided in a separate report (Ref. 7). Determination of the groundwater potentiometric contours at the proposed disposal sites and surrounding area is summarized in Section 2.4 of this report. Details of the methods used in determining the potentiometric contour levels are also presented in a separate report (Ref. 5). Permeability test data from borehole tests, direct laboratory measurements on compacted samples from test pits, and estimates from grain size data using Hazen's approximation are discussed and evaluated in Appendix C.

The level of the bedrock and weathered rock below the glacial soils has been defined at many points around the orebody, proposed waste disposal sites, and in surrounding areas. From these data a contour map of the bedrock and weathered rock surface has been prepared and is presented in Section 2.3 of this report along with a brief description of the bedrock geology. The locations of data used in preparing this map along with a discussion of the data interpretation is provided in Appendix D.

2.0 AREA GEOLOGY

2.1 Glacial History

Large areas of North America were once covered by thick ice sheets during a period of time termed the Pleistocene Epoch. Four major advances of the ice sheets occurred during this time period and lasted from approximately 2 million to 7,000 years ago. The last major advance of the Pleistocene ice sheets, called the Wisconsin stage, began about 75,000 years ago. The glacial events which deposited and shaped the surficial materials within the Crandon Project area and the surrounding region occurred primarily during this glacial stage.

Several ice sheet advances during the Wisconsin stage have been documented. The bulk of the surficial material in the region is the result of glaciation during two substages of the Wisconsin stage. The Altonian advance occurred approximately 75,000 to 28,000 years ago and was followed by the Woodfordian advance which lasted from about 22,000 to 12,500 years ago (Ref. 2). These glacial advances were separated by interim periods of glacial retreat.

During the Altonian and Woodfordian advances, several glacial ice lobes crossed the north-central region of Wisconsin. These glacial ice lobes were tongue-like projections from the main mass of the ice sheet. Each lobe was formed by several cycles of advancing and retreating ice which make the glacial history of the region very complex.

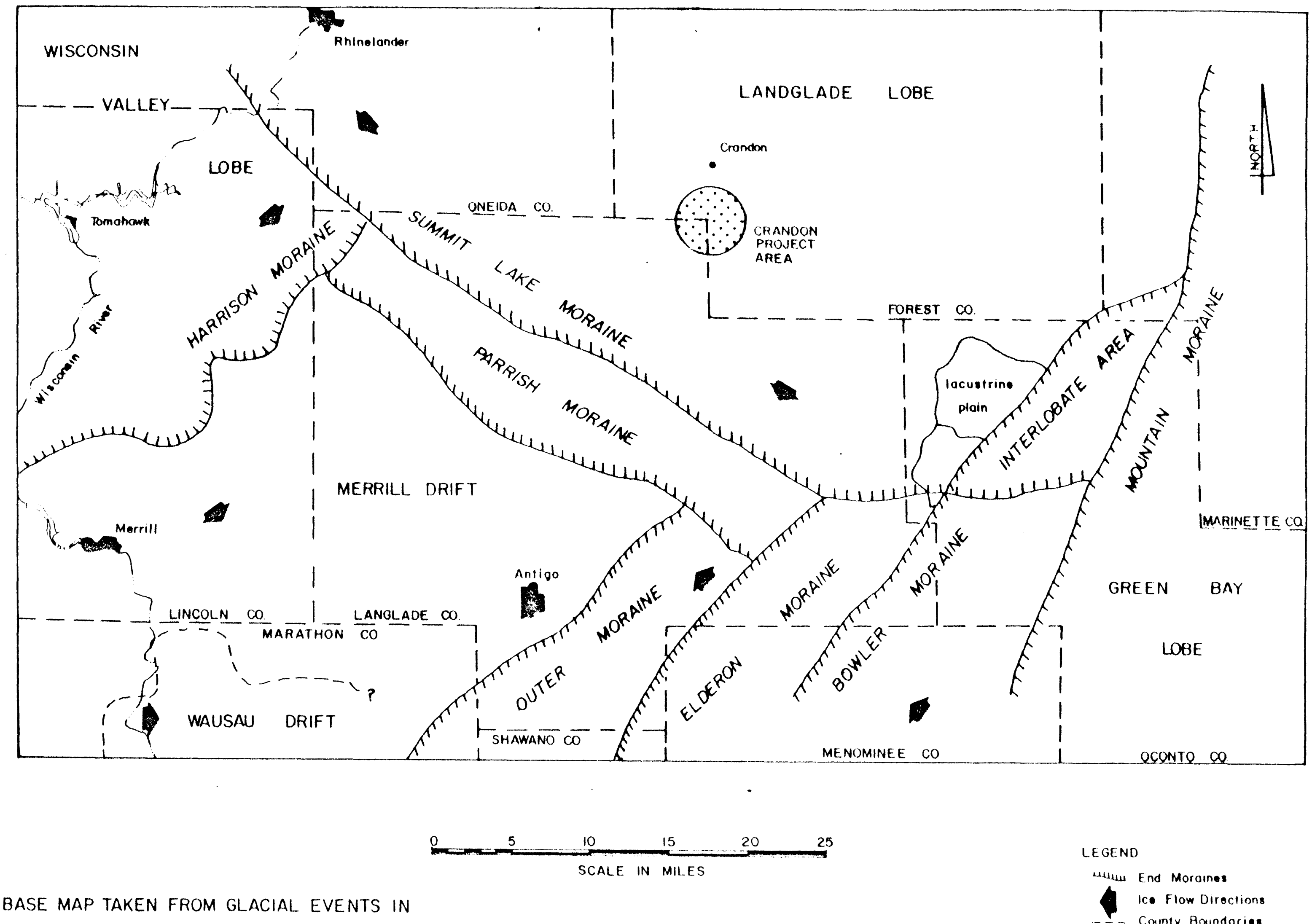
The advance and retreat of an ice sheet significantly affects the landscape of a glaciated area by depositing glacial drift and creating new landforms. Glacial drift is the material transported and deposited by the glacier. Glacial drift can be broadly categorized into deposits of till and stratified drift. Till is material deposited directly by the ice and stratified drift is material deposited by, or in, water derived from the melting of the ice.

Two of the older glacial drifts in the region are present at the existing ground surface to the south of the Crandon Project area and are termed the Wausau and Merrill glacial drifts (Ref. 3). The Wausau drift was deposited by an ice lobe advancing from the west, possibly in early Altonian or pre-Wisconsin time, and is east and west of the city of Wausau (Figure 2.1). The Merrill drift, which is north of the Wausau drift, was deposited in late Altonian time by ice flowing from the north-northwest. Material from these glacial drift deposits may exist below the present ground surface in the Crandon Project area but it is also possible this material has been mixed with material from more recent glacial activity.

The bulk of the drift in the Crandon Project area is most likely the result of Woodfordian glaciation by the Green Bay and Langlade Lobes. The Green Bay Lobe advanced from the southeast while the ice of the Langlade Lobe flowed from the northeast. The complex interfingering and overlapping nature of the contact between the glacial drifts of the two ice lobes is exhibited at the present ground surface south of the Crandon Project site (Figure 2.1). This interlayered relationship of the two drifts may also be present in the subsurface materials of the project area.

MAJOR GLACIAL LOBES and DRIFT BOUNDARIES

FIGURE 2.1



BASE MAP TAKEN FROM GLACIAL EVENTS IN NORTH-CENTRAL WISCONSIN IN LATER QUATERNARY ENVIRONMENTS OF WISCONSIN, MICKELSON, ET AL., WISCONSIN GEOLOGICAL AND NATURAL HISTORY SURVEY, 1974

Golder Associates

Scale AS SHOWN
Date OCT. 1981
Job No. 786085

Drawn CAB
Checked FCB
Approved GHC

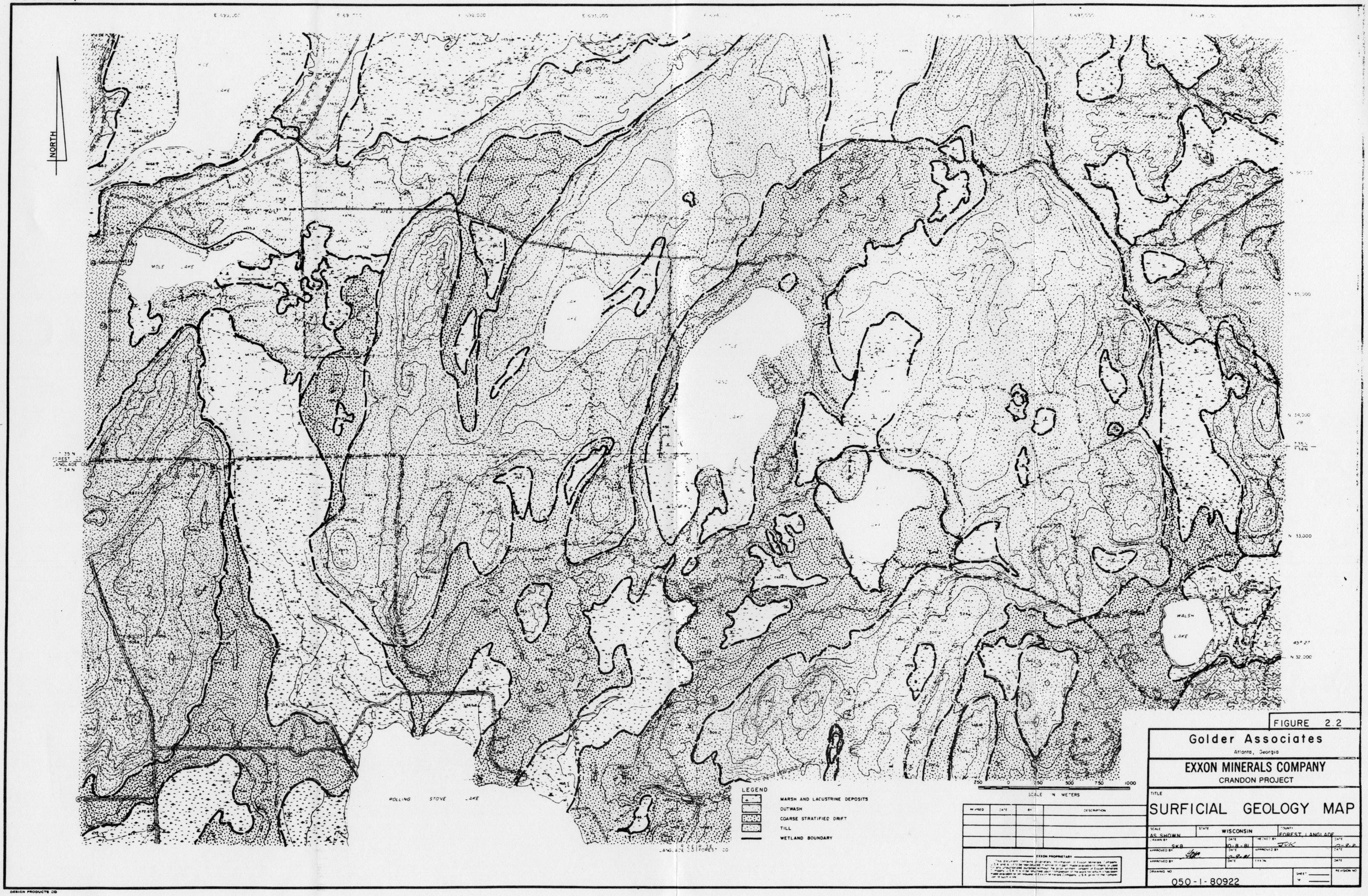
The advance of the Wisconsin Valley Lobe down the Wisconsin River Valley, west of the project area, also occurred during Woodfordian time. However, there is little evidence of deposition of glacial drift by this ice lobe in Forest County or the Crandon Project area.

2.2 Surface Mapping

Mapping of the surficial materials and glacial landforms within the Crandon Project area has been completed by Dames & Moore, the U.S. Department of Agriculture Soil Conservation Service, and the Wisconsin Geological and Natural History Survey. Each group approached the work with a different purpose and accomplished it with different mapping techniques. These different approaches in combination with the interpretive nature of the mapping resulted in three slightly different surface material maps.

The surficial geologic mapping done by Dames & Moore was the result of site specific test boring data and reconnaisance work within the Crandon Project area. This map has been slightly modified by Golder Associates to reflect the additional data obtained by Golder Associates' test boring program. This modified map is shown as Figure 2.2. Revisions to Dames & Moore's surficial geology map were restricted to the northeast corner of Langlade County where a more extensive surface deposit of glacial till was further defined by the additional investigation.

The surficial materials and glacial landforms in the project area are primarily the result of the advance and retreat of the Langlade Lobe. These glacial landforms are the product of specific geologic processes.


NORTH
MOLE LAKE
WALSH LAKE
ROLLING STONE LAKE
LEGEND
MARSH AND LACUSTRINE DEPOSITS
OUTWASH
COARSE STRATIFIED DRIFT
TILL
WETLAND BOUNDARY
250 0 250 500 750 1000
SCALE IN METERS
FIGURE 2.2
Golder Associates
Atlanta, Georgia
EXXON MINERALS COMPANY
CRANDON PROJECT
TITLE
SURFICIAL GEOLOGY MAP
SCALE AS SHOWN
STATE WISCONSIN
COUNTY FOREST, LANGLADE
DRAWN BY SKB
DATE 10-8-81
EXXON PROPRIETARY
DRAWING NO 050-1-80922

The upland areas are largely composed of glacial till deposited by the ice of the Langlade and Green Bay Lobes. The upland areas are typically shaped by the movement of the glacier and they trend to the southwest.

During the retreat of the Langlade Lobe, melting of the glacier ice exposed the uplands and released large quantities of meltwater which deposited stratified drift on or adjacent to the ice. These ice-contact stratified drift deposits exhibit a hummocky surface topography. Meltwater streams moving away from the glacial ice margin laid down outwash deposits. These outwash plains tend to have a relatively flat topographic surface and often occur as valley fills.

Lacustrine or lake deposits are present in the project area adjacent to some existing lakes. These deposits may represent the bottom sediments of more extensive ancestral lakes and have a flat topographic surface.

Swamp and marsh deposits associated with wetlands are present throughout the project area. Large wetlands occur in the lowlands while small, perched wetlands exist in upland depressions.

The U.S. Department of Agriculture Soil Conservation Service (SCS) has mapped the soils in the project area by their physical and chemical properties and have estimated their expected behavior in certain engineering, recreation and woodland uses (Ref. 9). Their brief soil description also includes an interpretation of the underlying glacial drift. Only selected parts of Forest and Langlade Counties immediately surrounding the proposed mine waste disposal areas were mapped. The SCS work indicates there are more extensive surface deposits of glacial till present in the immediate project area than shown on Figure 2.2.

The SCS investigates only the soil within about 1.5 m (5 ft.) of the ground surface. This near surface soil sampling limits the applicability of the interpreted underlying glacial material and the soil's estimated performance in certain uses.

The Wisconsin Geological and Natural History Survey (Ref. 3) has examined the glacial geology of Forest County. The origin and development of the glacial landforms and their associated surficial materials were discussed and mapped. The section of Langlade County which lies within the project area was not mapped.

The glacial landforms in the proposed Site 41 waste disposal area, as mapped by the Wisconsin Survey, are ground moraine and drumlins. Minor areas of outwash and ice-contact stratified drift were also indicated to be present. The interpreted landforms in the proposed Site 40 area were ground moraine, drumlins, outwash terraces and kame terraces. Outwash and kame terraces are glacial landforms of stratified drift. The mapping done by the Wisconsin Survey in the proposed Site 41 area is similar to that shown in Figure 2.2. However, only the northern portion of proposed Site 40 which lies in Forest County has been examined by the Wisconsin Survey. Their interpretive work suggests more surface deposits of stratified drift to be present than are shown on Figure 2.2.

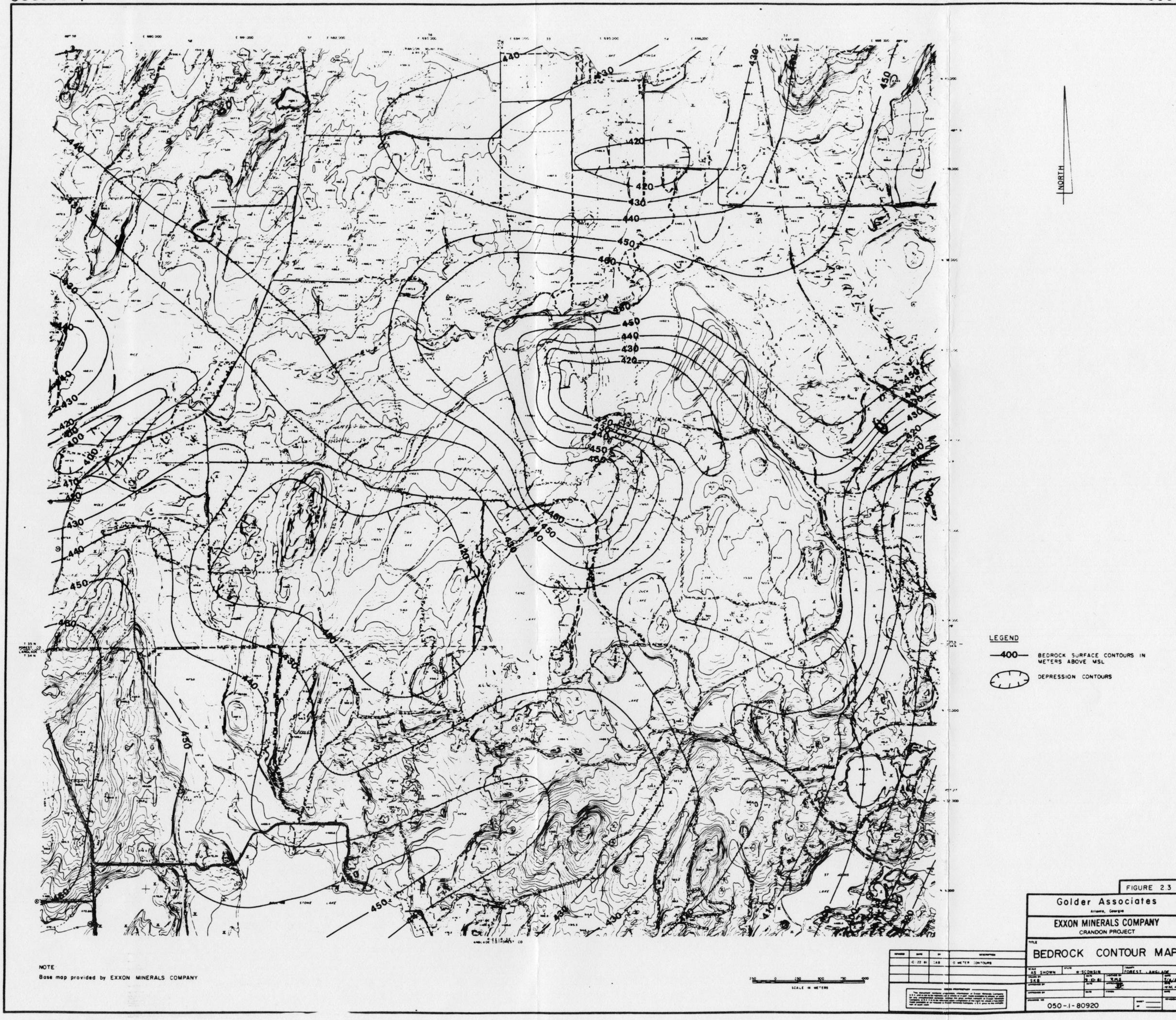
Although the various mapping techniques and personnel involved have produced somewhat different interpretations of the geologic origin of the surficial materials, these differences are relatively minor. These differences are not anticipated to affect the overall design of the proposed waste disposal system.

2.3 Bedrock

The bedrock of northern Wisconsin is an extension of the Canadian Shield. The Canadian Shield is a continental block of the earth's crust which has been relatively stable over a long period of time. The rock types present in the region are Precambrian igneous and metamorphic rocks which were formed approximately 1.9 billion to 1.5 billion years ago. Igneous rocks are formed by the cooling and crystallization of molten rock material, while metamorphic rocks represent sedimentary or igneous rocks modified by changes in temperature and pressure. Within the Crandon Project Area, the bedrock is primarily a metamorphosed volcanic tuff.

The regional trend of the bedrock surface in north-central Wisconsin is downward to the east and southeast at approximately 7-10 ft. per mile (Ref. 3). Within Forest County the bedrock surface is irregular (Ref. 3). Detailed work in the Crandon Project area has also defined an irregular bedrock surface. The interpreted bedrock surface for the Crandon Project and surrounding area is shown on Figure 2.3, Bedrock Contour Map.

The Bedrock Contour Map is the result of the synthesis and interpretation of data from various sources. The area shown on Figure 2.3 is a portion of a larger geographical area for which bedrock contours have been interpreted. The map of the larger area with the data locations shown is included in Appendix D along with a discussion of the map construction.


NORTH
LEGEND
400 BEDROCK SURFACE CONTOURS IN METERS ABOVE MSL
DEPRESSION CONTOURS
NOTE
Base map provided by EXXON MINERALS COMPANY
SCALE IN METERS
FIGURE 2.3
Golder Associates
Atlanta, Georgia
EXXON MINERALS COMPANY
CRANDON PROJECT
BEDROCK CONTOUR MAP
AS SHOWN
WISCONSIN
FOREST, LANGLADE
050-1-80920

2.4 Groundwater

Groundwater occurs within the glacial overburden and in the bedrock. The principal aquifers are within the glacial overburden, occurring under unconfined (water table) and semi-confined (leaky) conditions. Locally perched groundwater conditions occur within the surficial glacial deposits above the main aquifers. These zones of perched water appear to be of limited areal extent (Ref. 4).

Groundwater recharge occurs most readily in the upland areas of the site and flows essentially vertically in an unsaturated mode to the groundwater table. After water percolates to the aquifer, it flows essentially horizontally toward the areas of lower groundwater levels; directions normal to the groundwater contour lines.

Groundwater levels over the Crandon Project site have been primarily determined by measurements in observation wells installed in test borings. Groundwater observation wells have been installed at various times over the past 3 years under the supervision of Golder Associates and Dames & Moore. The observation wells have been installed at various depths and locations to evaluate the groundwater conditions at the site. Many of the observation wells have been monitored over long periods to measure fluctuations in groundwater levels and groundwater chemistry. The results of these activities have been assembled by Dames & Moore and are reported in Ref. 4. A detailed evaluation of the potentiometric conditions in the glacial material has been made in order to define the groundwater conditions. The resulting potentiometric contour map is shown on Figure 2.4. This groundwater contour map was constructed through joint efforts by Golder Associates and Dames &

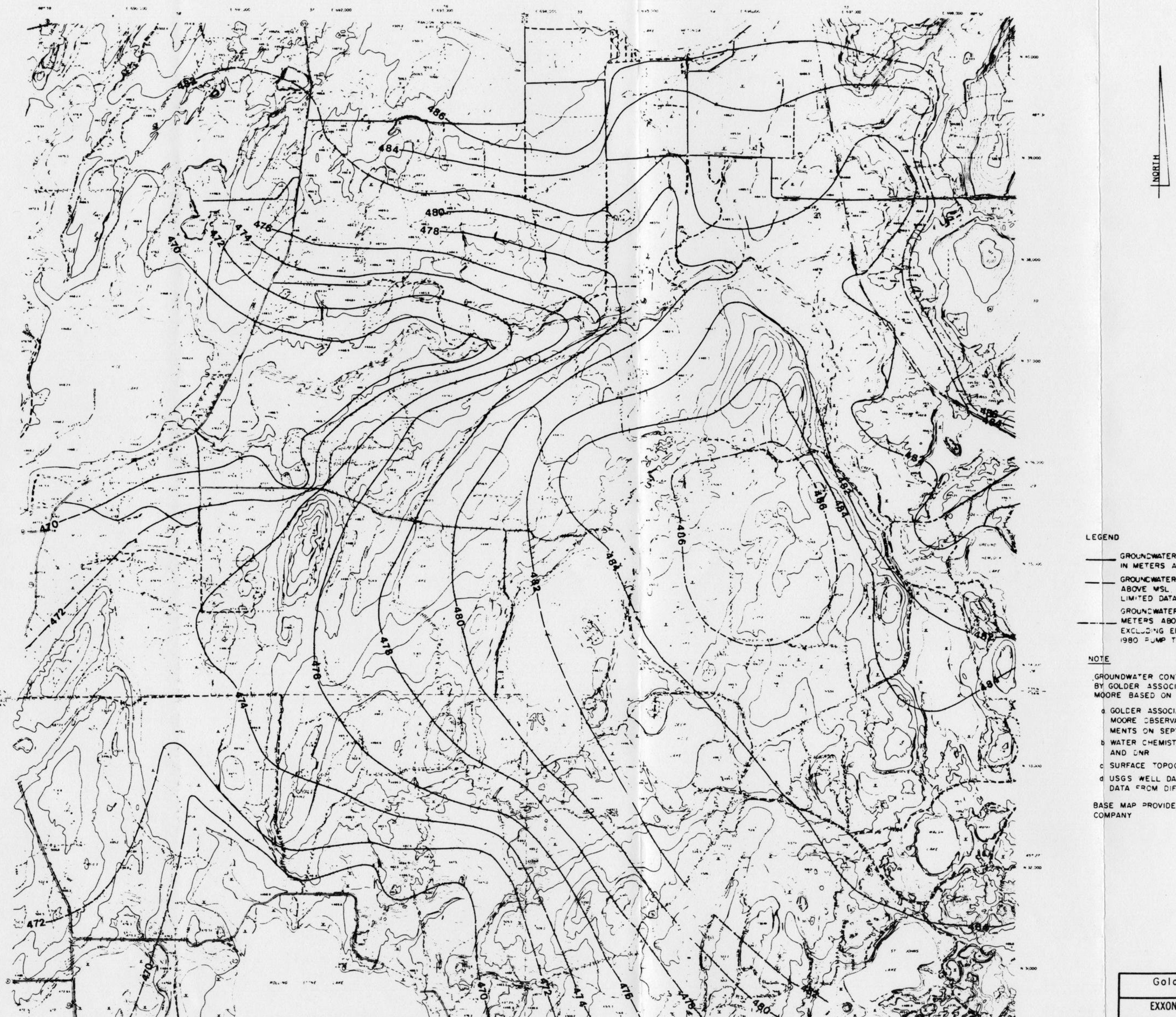


FIGURE 2.4

Golder Associates

Atlanta, Georgia

EXXON MINERALS COMPANY

CRANDON PROJECT

GROUNDWATER POTENTIOMETRIC CONTOURS

AS SHOWN | WISCONSIN | FOREST, LANGLADE

SKB | 9-2-81 | RMS

050-1-81111

Moore for the purpose of providing a single, acceptable representation of the potentiometric groundwater elevations for the area. This contour map is based on water level measurements in the accessable observation wells obtained on September 10 and 11, 1980, plus well data provided by the United States Geological Survey. A complete description of the methods used to derive the Groundwater Potentiometric Contours map (Figure 2.4) and the data used in the map's construction are presented in Ref. 5.

Principal areas of groundwater discharge surrounding the Project site are along the major drainages: Swamp Creek, Ground Hemlock Creek, Upper Pickerel Creek; Rice Lake, Rolling Stone Lake, Ground Hemlock Lake, and the wetlands associated and contiguous with these features. All of these bodies of water and wetlands are below approximately elevation 488 m (1600 ft.). Around the Crandon orebody and proposed waste disposal areas are numerous lakes and wetlands which are perched above the main water table aquifer. These lakes and wetlands receive little to no groundwater recharge. They are fed by surface water runoff and probably inhibit percolation of the surface water to the main groundwater aquifer. Around the orebody, Skunk, Oak, Little Sand, Duck and Deep Hole Lakes are perched partially or completely above the main groundwater aquifer. A more thorough discussion of the groundwater discharge/recharge regime is presented in Ref. 4. Additional discussion and data regarding the perched lakes and wetlands is provided in Ref. 4 and 5.

3.0 GLACIAL STRATIGRAPHY

3.1 General Description of Glacial Materials

The methods of glacial deposition and the various time periods of deposition in the Crandon Project area have created a variable distribution of soil materials at the ground surface and with depth. The surface glacial deposits were previously discussed in Section 2.2 and shown in Figure 2.2. The specific types of glacial deposition of the materials mapped at the surface are not necessarily indicative of the method of deposition of the materials at depth at the same location.

Based on the test boring and laboratory data and the understanding of general glacial deposition processes, the primary materials found throughout the depth of the glacial deposits at the proposed waste Sites 40 and 41 are till and coarse grained stratified drift. Lesser amounts of fine grained stratified drift and lacustrine deposits were also identified. Outwash materials were found surrounding the sites (as were shown on the Surface Geology Map, Figure 2.2) but not directly identified beneath the two proposed waste disposal sites. Weathered rock was penetrated beneath the glacial materials in some of the boreholes. At some locations this material was sufficiently weathered to be termed a residual soil. A brief description of each of the glacial materials follows:

Till - A well graded (poorly sorted) heterogeneous mixture of silt, sand, gravel, some cobbles and boulders, and traces of clay. This material was directly deposited by a glacier.

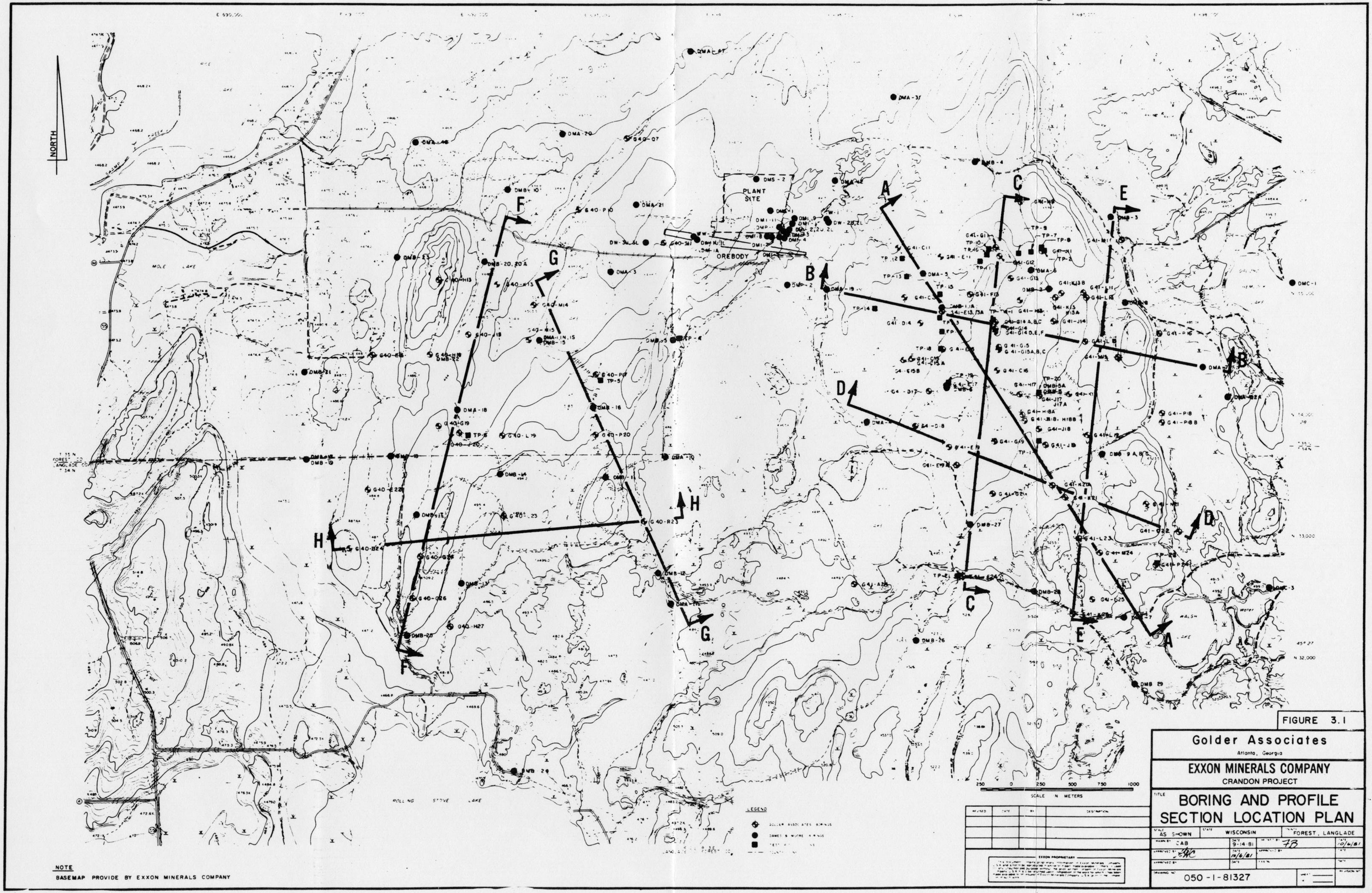
Coarse Grained Stratified Drift - Moderately uniformly graded (well sorted) sand and fine gravel with traces of silt. This is a water deposited, glaciofluvial material.

Fine Grained Stratified Drift - Moderately uniformly graded (well sorted) silt and/or fine sand, often layered and including clay and/or coarse sand. This material appears to be a glaciolacustrine sediment deposited in a glacial lake or other body of still water in front of a glacier.

Lacustrine Deposits - Deposits of fine grained soils, mostly silts and clays. Predominantly found surrounding and beneath present day lakes and major wetlands. These materials are sedimented from still bodies of water. They are similar to the silt and clay layers found in the fine grained stratified drift. These deposits do not constitute a single mappable unit.

Outwash - Uniformly graded (well sorted) sand and gravel usually containing very little to no silt. This material has been mapped at the surface but not encountered at depths beneath the proposed waste disposal areas.

The subsurface glacial stratigraphy has been interpreted for proposed waste disposal Sites 40 and 41 based on the data from the numerous test borings at these two sites and from the laboratory grain size analyses of the samples tested. The plan location of the test borings at the waste disposal sites and surrounding area are shown on Figure 3.1. A detailed discussion of the differences in grain size distribution of the various glacial deposits and assessments of their physical properties (such as permeability, friction angle, etc.) is presented in Section 4 which follows. No attempt has been made to correlate particular

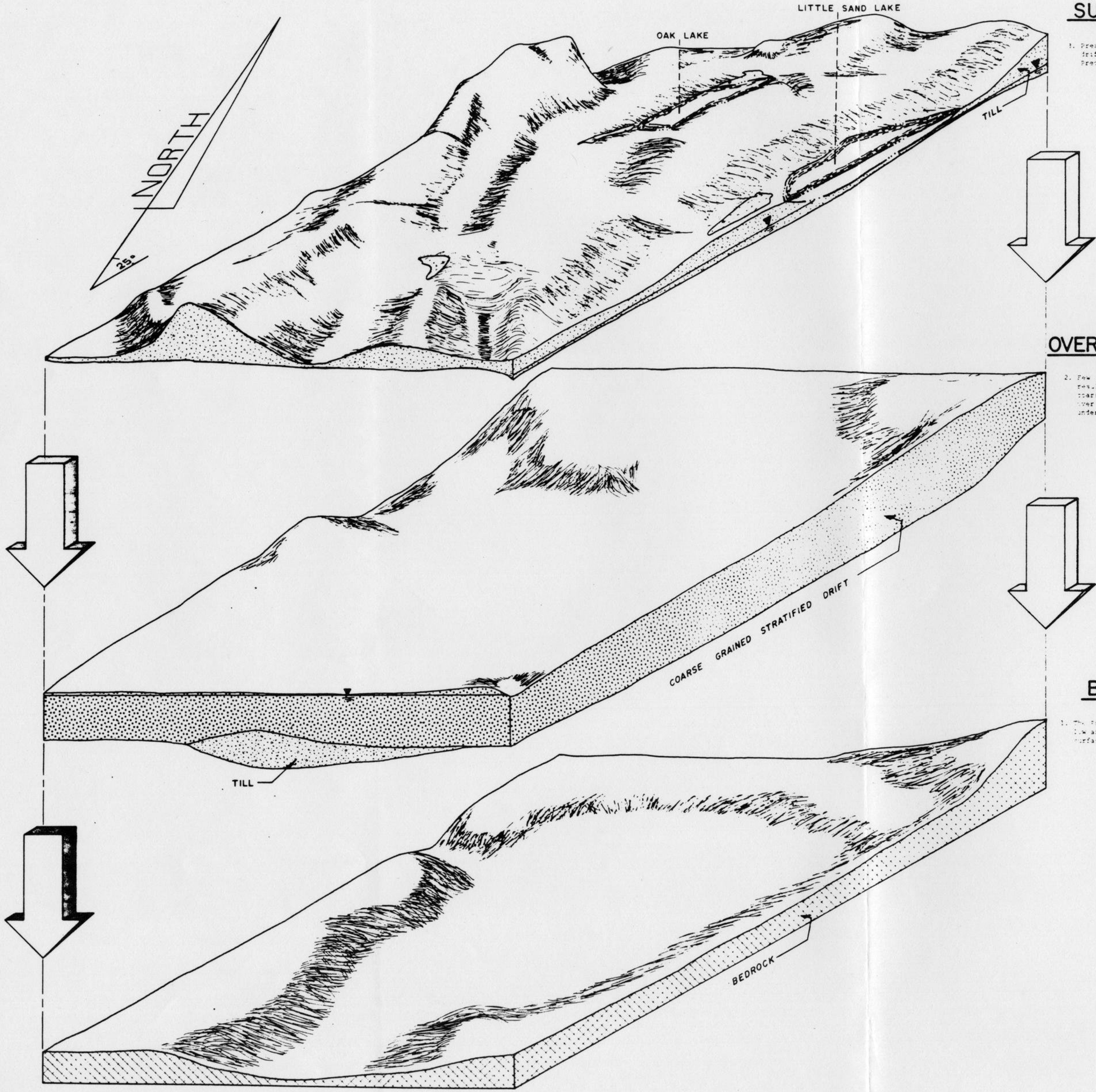

NORTH
PLANT SITE
OREBODY
MOLE LAKE
ROLLING STONE LAKE
LEGEND
SCALE IN METERS
250 0 250 500 750 1000
FIGURE 3.1
Golder Associates
Atlanta, Georgia
EXXON MINERALS COMPANY
CRANDON PROJECT
BORING AND PROFILE
SECTION LOCATION PLAN
AS SHOWN
WISCONSIN
FOREST, LANGLADE
CAB
9-14-81
10/6/81
050-1-81327
NOTE
BASEMAP PROVIDE BY EXXON MINERALS COMPANY

glacial strata to the specific glacial history stages which were discussed in Section 2.1. This approach provides a good understanding of the main glacial stratagraphic units, their relationship to the groundwater hydrology of the area, and a basis for describing materials of varying physical properties.

3.2 Stratigraphy Block Diagrams

As a visual aid in perceiving the distribution of the various glacial materials at Sites 40 and 41, the block diagrams shown on Figures 3.2 and 3.3 were prepared. The diagrams give an overall three dimensional view of the proposed disposal sites. They are intended to provide a overall understanding of the terrain, bedrock, and major glacial formations. They are not a precise duplication of the borehole data but employed this data in their construction.

Each diagram was constructed by outlining the area to be drawn on a topographic map of the area. A block of this rectangular area was then drawn in what is known as 'cabinet' projection. In this particular block diagram, the sides of the block are projected at an angle of 30^{o} from the front side of the block. With this projection, measurements in direction parallel to all the edges are on the same scale. This allows borehole locations and other data points to be easily transposed from the base map to the block. Both block diagrams were oriented approximately north-south. To obtain the various geologic formation's surface features, such as the bedrock surface and the coarse grained stratified drift surface, boreholes were located on the block and then depths to the various strata plotted. The surface for a given deposit was then constructed by drawing a network of lines between the various



SURFACE TOPOGRAPHY

1. Present day topography [illegible] composed of till uplands and drift lowlands. A [illegible] over a Precambrian valley at the [illegible] boundary.

OVERBURDEN STRATIGRAPHY

2. Few deep boreholes were drilled at Site 40 and as a result the deep stratigraphy is not well defined. The coarse grained stratified drift appears to be continuous over the entire site area with a possible extensive underlying till layer.

BEDROCK SURFACE

1. The Precambrian relief is generally subdued with a broad low area lying in the center of the site. The bedrock surface rises steeply to the north-east.

VERTICAL SCALE IN METERS
0 25 50 100
0 250 500 1000
HORIZONTAL SCALE IN METERS

NOTE:

This expanded block diagram is intended to show the relationship between the bedrock topography and the various overlying glacial deposits. It allows for better understanding of the terrain and geological conditions at the site. It does not represent the exact geological strata at a given point and should be viewed in conjunction with the geologic sections.

REVISED	DATE	BY	DESCRIPTION

EXXON PROPRIETARY

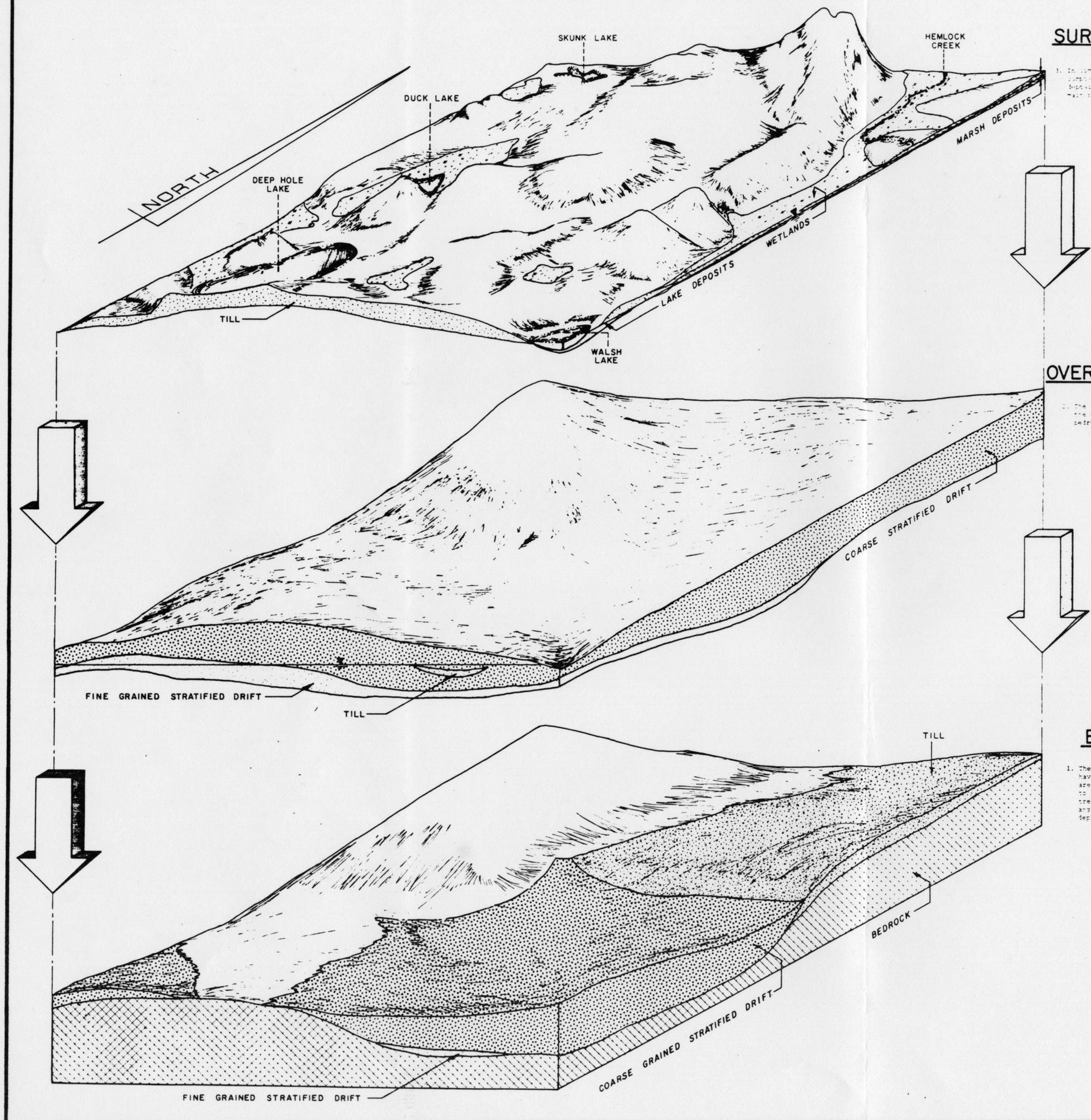
FIGURE 3.2

Golder Associates
Atlanta, Georgia

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: SITE 40 GLACIAL STRATIGRAPHY BLOCK DIAGRAM

SCALE	STATE		COUNTY	
AS SHOWN	WISCONSIN		FOREST, LANGLADE	
DRAWN BY SKB	DATE 10-9-81	CHECKED BY JK		DATE 10/21
APPROVED BY	DATE 10-22-81	APPROVED BY		DATE
APPROVED BY	DATE	EXXON		DATE
DRAWING NO. 050-1-80923		SHEET ___ OF ___		REVISION NO.



SURFACE TOPOGRAPHY

1. In common with Site [illegible], the drumlin topography is comprised of the youngest till deposits. The thickest deposits of till appear to have accumulated along the main bedrock valley.

OVERBURDEN STRATIGRAPHY

1. The coarse grained stratified drift is shown to cover the entire site area, still reflecting the underlying bedrock relief.

BEDROCK SURFACE

1. The earliest glacial materials deposited appear to have been confined mainly to the low-lying bedrock areas. This sketch shows the bedrock under Site 41 to have a valley running from the south-east then trending northwards across the Site. At right angles to this valley is a broader east-west bedrock depression.

NOTE:

This expanded block diagram is intended to show the relationship between the bedrock topography and the various overlying glacial deposits. It allows for better understanding of the terrain and geological conditions at the site. It does not represent the exact geological strata at a given point and should be viewed in conjunction with the geologic sections.

VERTICAL SCALE IN METERS: 0 25 50 100

HORIZONTAL SCALE IN METERS: 0 250 500 1000

REVISED	DATE	BY	DESCRIPTION

FIGURE 3.3

Golder Associates
Atlanta, Georgia

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE: SITE 41 GLACIAL STRATIGRAPHY BLOCK DIAGRAM

SCALE: AS SHOWN	STATE: WISCONSIN	COUNTY: FOREST, LANGLADE	
DRAWN BY: SKB	DATE: 10-9-81	CHECKED BY: JK	DATE: 2/21
APPROVED BY: Yac	DATE: 10-22-81	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO: 050-1-80924	SHEET OF		REVISION NO.

borings that intersect that given surface. The trend of the surface shape is interpreted and shading is used to illustrate that trend. The diagrams were constructed using horizontal scales of 1:1250 and a ten times exaggeration along the vertical axis. The front and side faces of the block are essentially geological sections along those faces.

These diagrams show how the bedrock surface has influenced the subsequent deposition of glacial materials. The coarse grained stratified drift is noted to be continuous over both sites as is the overlying till deposit. Site 41 has a till and/or fine grained stratified drift underlying the coarse drift. These deposits may be similarly present at Site 40 but there is insufficient deep borehole information to confirm the continuous presence of the lower till/fine grained stratified drift.

3.3 Geologic and Boring Profiles

Eight Boring Profiles and eight Geologic Sections (Figures 3.4 to 3.19) have been prepared to illustrate the subsurface conditions in the proposed waste disposal Sites 40 and 41. The plan locations of these profiles are shown on the Boring and Profile Section Location Plan, Figure 3.1. The profiles are presented at the end of this Section of the report. The profile section locations were chosen to intersect a large number of borings (particularly the deeper ones), to cover those portions of the disposal sites where waste facilities are more likely to be developed, and to present the subsurface conditions in a variety of compass directions.

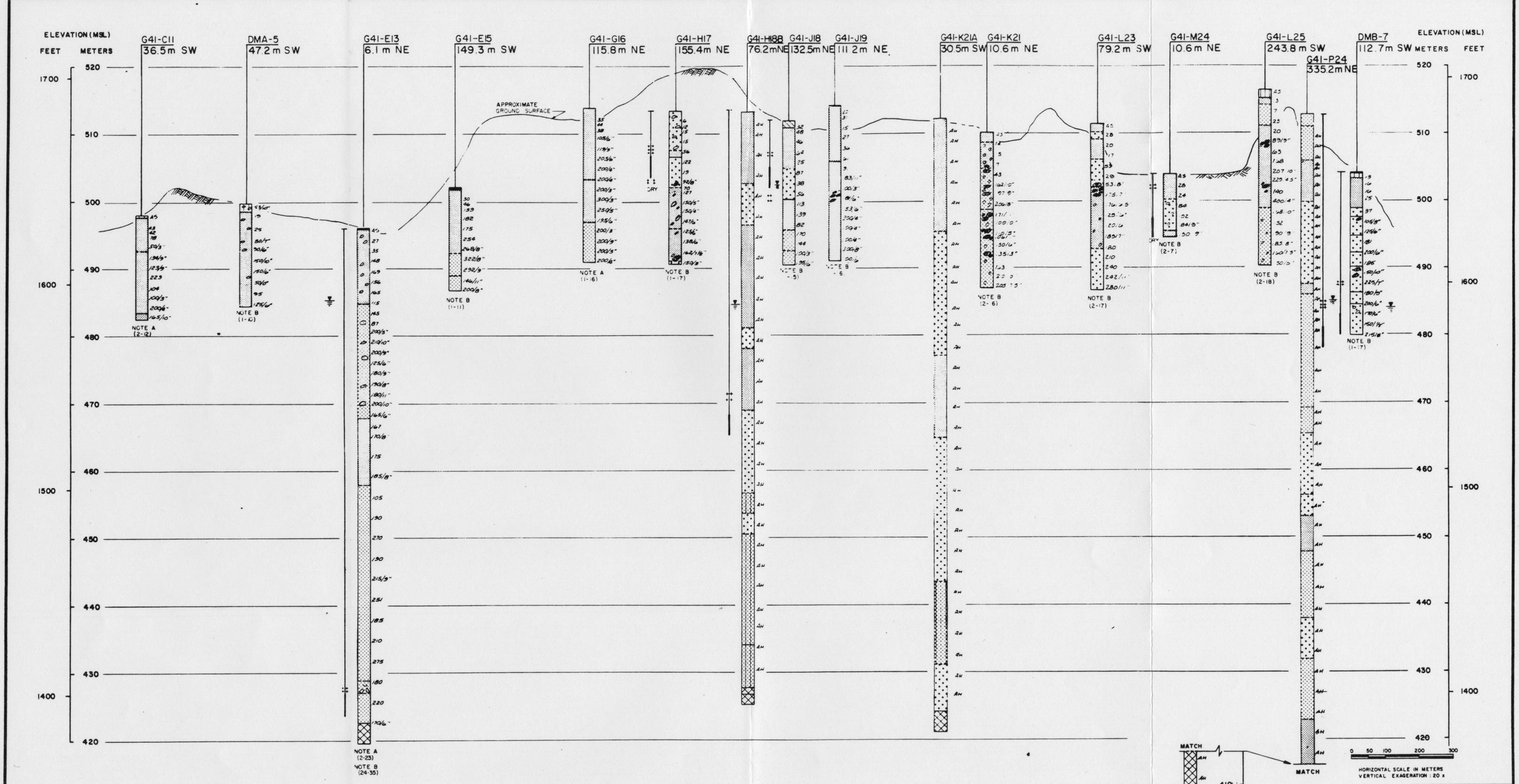
The Boring Profiles show the stratigraphy at each boring based on the Unified Soil Classification System designations for each strata. These same classification system designations are included on each boring log in Volumes 2 and 3. The Boring Profiles include borings from the Golder Associates and Dames & Moore soil exploration programs. The Dames & Moore logs also provide the Unified Soil Classification System designation for each strata. For reference purposes, the complete Unified Soil Classification System designation definitions are provided in Appendix A. The groundwater levels shown on the boring profiles are those measured just after each boring was drilled. For those borings which are not exactly on the profile section line in plan view (such as boring G41-E13 on Boring Profile A-A) the profile is located at the projection of the boring location normal to the profile section line. Also, the profile of these borings is shown with the top elevation equal to that of the field location of the boring and therefore may not coincide with the ground line drawn on the Boring Profile. The G41-G14 series and G41-G15 series borings were not all sampled throughout their full depth. The borings in these two groups were drilled at different times and because they were closely spaced sampling was not performed over the same interval in each boring. However, when the sampled intervals of the borings in each group are combined a complete profile of the materials from the ground surface to rock can be shown. This combination is used to depict the stratigraphy at the locations of these two groups of borings on the Boring Profiles.

The Geologic Profiles (Figures 3.12 to 3.19) depict the interpreted stratigraphy of the materials based on Golder Associates' interpretation of the method of glacial deposition such as till, coarse grained stratified drift, etc. The various glacial materials, and hence strata, do not correlate on a direct one-to-one basis with the classification of the materials by the Unified System. (This is discussed in detail in Section 4 of this report.) The Geologic Profiles are slightly different from the Boring Profiles in the treatment of those borings which do not fall precisely on the profile section lines. In these cases the Geologic Profiles show an interpretation of the glacial stratigraphy at the section line rather than showing the stratigraphy projected directly from the boring as was done on the Boring Profiles. For borings located on the section lines, the glacial stratigraphy is a direct presentation of the interpretated glacial deposition for the various materials. The groundwater levels shown on the Geologic Profiles have been taken from the potentiometric contour map shown on Figure 2.4.

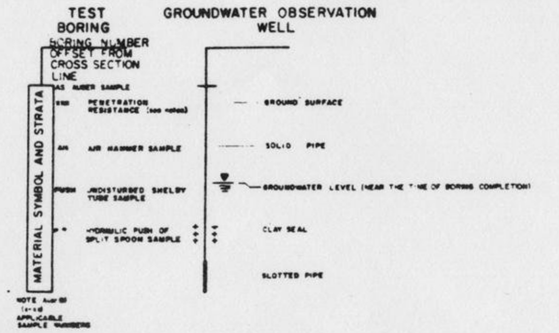
The Boring Profiles are a precise representation of the data obtained from the individual test borings. The Geologic Profiles are for illustrative purposes to show trends implied from the glacial history and boring data. The distribution of the glacial stratigraphy at locations other than those at the borings directly at the profile section line has been inferred from the borings in the area and the actual distribution of materials may vary from that shown. The Geologic Profiles aid in the understanding of the subsurface materials and provide a guide to the general stratigraphy of the major glacial deposits.

From the Geologic Profiles, it can be seen that the thickness of the till which outcrops at the ground surface is much more extensive at Site 41 than at Site 40. This is significant from the standpoint of developing a waste disposal system since the till is less pervious than the underlying coarse grained stratified drift materials and the facilities will be constructed in and from the upper level materials. The Geologic Profiles also point out that the coarse grained stratified drift material is quite extensive and is continuous throughout both disposal sites. The coarse grained stratified drift beneath the two disposal sites is also shown to be continuous with the stratified drift materials exposed at the surface or directly beneath the major wetlands which are groundwater discharge areas. Although the glacial stratigraphy is generally shown to be rather complex (in that it's not a simple clear cut layered system) these two trends are evident.

As an over simplification, the subsurface conditions may be thought of as a layer of till overlying a layer of coarse grained stratified drift which overlays a deeper layer of till (or fine grained stratified drift). Beneath the lower till/fine grained stratified drift layer is bed-rock with a cap of residual soil and/or weathered rock in most places. This more simplified system is useful to keep in mind for an overall understanding of the groundwater hydrologic system. Precipitation enters the system through the upper materials, which is till over much of the project area, and moves downward to the groundwater level. Ground-water then moves laterally through the coarse grained stra-tified drift (because of its high horizontal hydraulic conductivity compared to the till) to the groundwater dis-charge areas which are continuous with the coarse grained stratified drift. A more complete discussion of the groundwater discharge/recharge system is provided in Ref. 4 and a more detailed discussion of the hydraulic properties of the glacial strata are provided in Appendix E of this report and in Ref. 7.



BORING PROFILE LEGEND



NOTE A - STANDARD PENETRATION TEST - DRIVING 2" OD SAMPLER WITH 140lb HAMMER FREELY FALLING 30"

NOTE B - PENETRATION TEST - DRIVING 2" TO 3.25" OD SAMPLER WITH 300lb TO 380lb HAMMER FREELY FALLING 20" TO 25"

(2 - 12) NOTE A OR B APPLIES TO SAMPLE 2 THROUGH SAMPLE 12

SEE BORING LOGS FOR DETAILS

SYMBOL / RANGE OF MATERIAL DESCRIPTIONS	UNIFIED CLASSIFICATION RANGE
- Topsoil and/or Rootmat	-
- Peat, fiberous organic material	PT
- Silty CLAY, trace fine sand to SILT, trace to some clay, trace fine sand	ML- CL, CL, OL
- Sandy SILT, some clay to clayey SILT, trace fine sand	ML
- Silty fine to coarse SAND to SILT, some fine to coarse sand, trace clay	SM to ML
- Fine to coarse SAND (or GRAVEL), trace silt to clayey SILT, trace fine sand (often layered)	SP to ML
- Fine to coarse SAND, some silt to silty, trace to some fine to coarse gravel to coarse sandy GRAVEL, some silt	SM to GM
- Fine to coarse SAND, trace to some gravel, trace to some silt to gravelly fine to coarse SAND, trace silt	SW, SP, SM, or GW, GP, GM combinations
- Fine to coarse SAND, trace silt to fine to coarse GRAVEL, trace silt	SP, GP, SW, GW
- Cobbles and/or boulders occasionally encountered	-
- Cobbles and/or boulders locations noted	-
- Metavolcanic Tuff, sound and weathered including residual soil	-

NOTE
1. SEE BORING AND PROFILE SECTION LOCATION PLAN NO. 050-1-81312 FOR LOCATION OF SECTION LINE

REVISED	DATE	BY	DESCRIPTION

FIGURE 3.4

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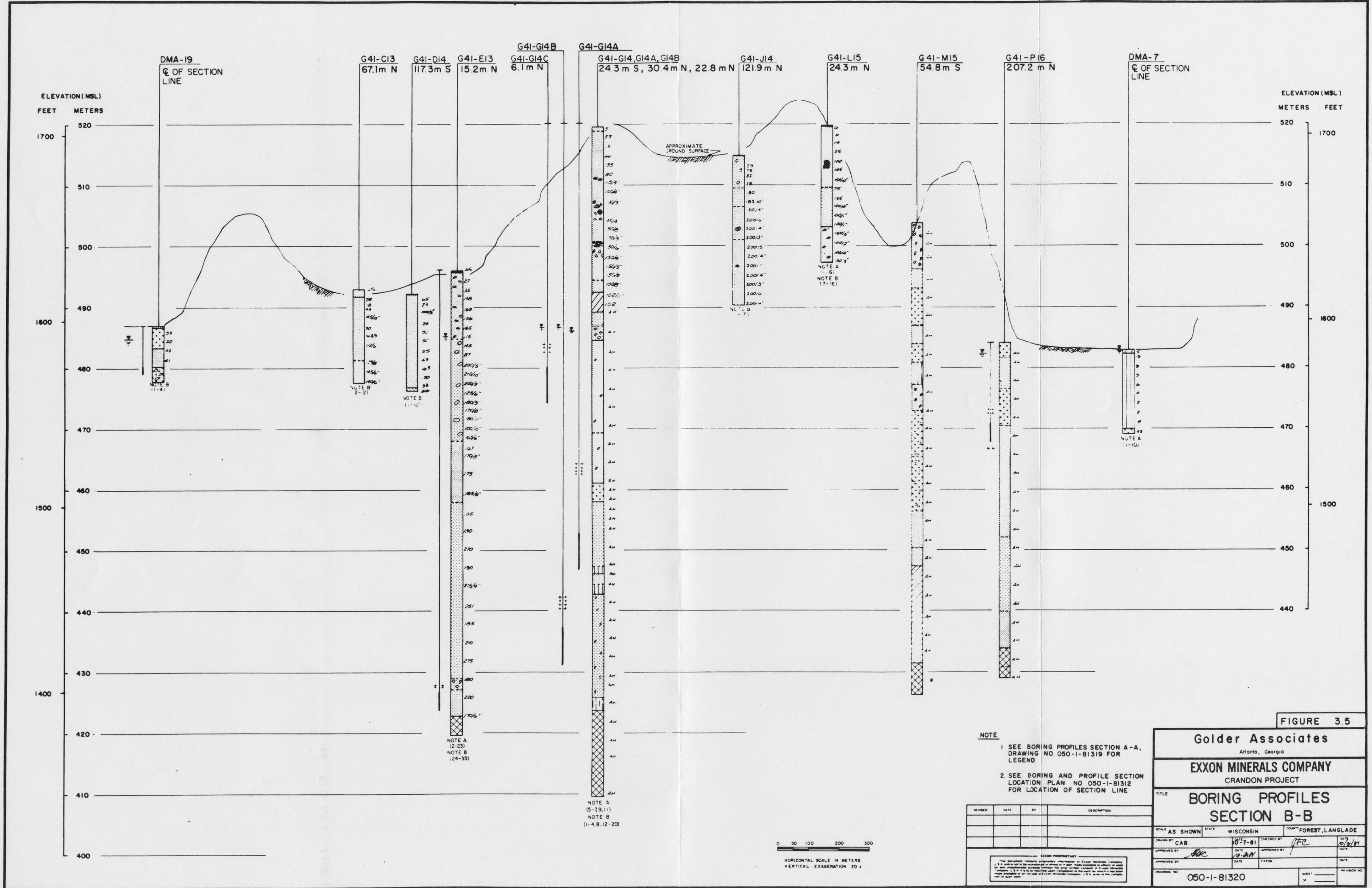
Atlanta, Georgia

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE **BORING PROFILES SECTION A-A**

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST, LANGLADE	
DRAWN BY CAB	DATE 10-7-81	CHECKED BY JFC	DATE 10-7-81
APPROVED BY JDC	DATE 10-8-81	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO 050-1-81319		SHEET OF	REVISION NO


ELEVATION (MSL)
FEET METERS
DMA-19
℄ OF SECTION LINE
G41-C13
67.1m N
G41-D14
117.3m S
G41-E13
15.2m N
G41-G14B
G41-G14C
6.1m N
G41-G14A
G41-G14, G14A, G14B
24.3m S, 30.4m N, 22.8m N
G41-J14
121.9m N
G41-L15
24.3m N
G41-M15
54.8m S
G41-P16
207.2 m N
DMA-7
℄ OF SECTION LINE
APPROXIMATE GROUND SURFACE
NOTE A
NOTE B
NOTE
1. SEE BORING PROFILES SECTION A-A, DRAWING NO 050-1-81319 FOR LEGEND
2. SEE BORING AND PROFILE SECTION LOCATION PLAN NO 050-1-81312 FOR LOCATION OF SECTION LINE
HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION 20x
FIGURE 3.5
Golder Associates
Atlanta, Georgia
EXXON MINERALS COMPANY
CRANDON PROJECT
BORING PROFILES
SECTION B-B
AS SHOWN
WISCONSIN
FOREST, LANGLADE
CAB
10-7-81
050-1-81320

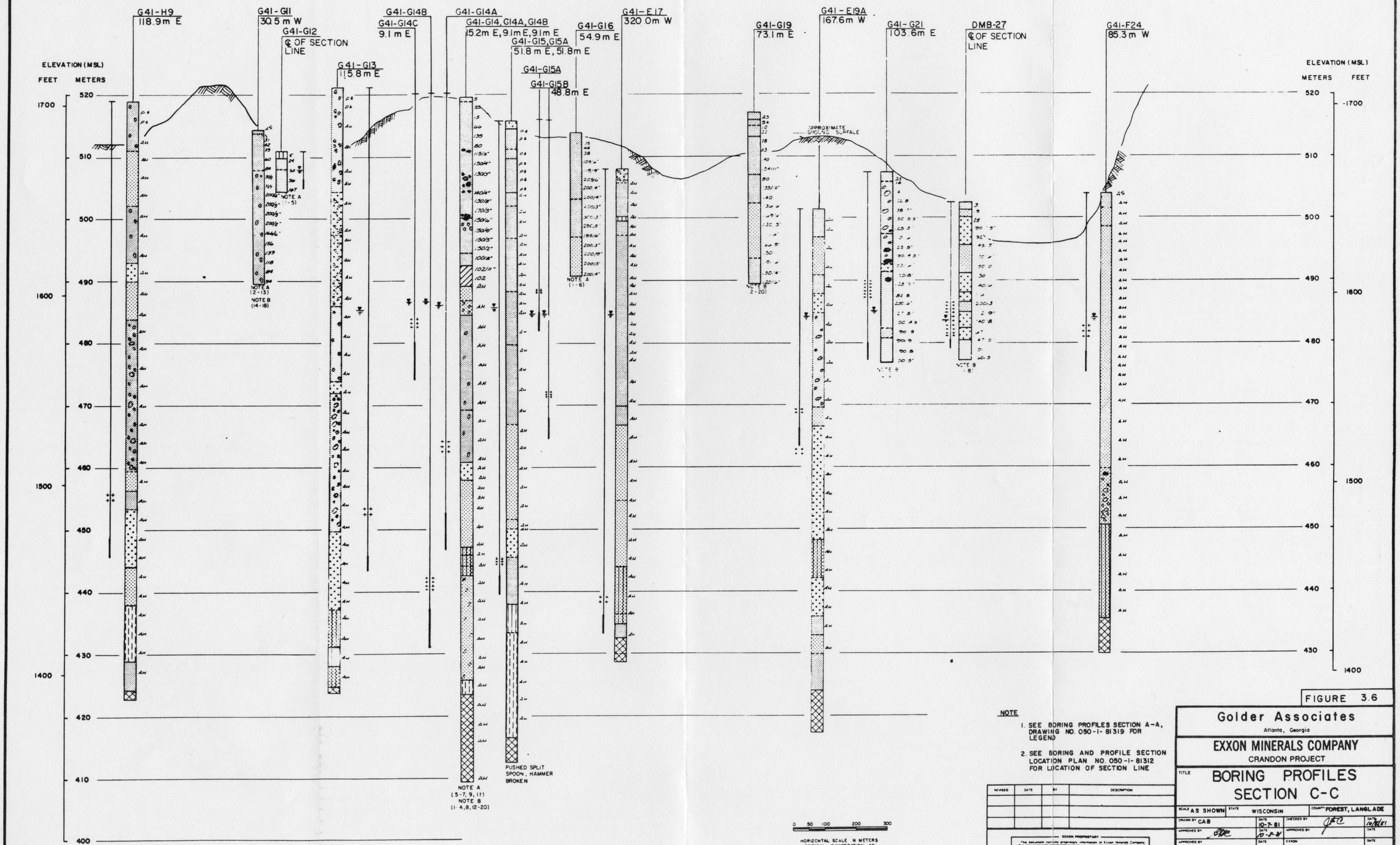


FIGURE 3.6

NOTE

1. SEE BORING PROFILES SECTION A-A, DRAWING NO. 050-1-81319 FOR LEGEND

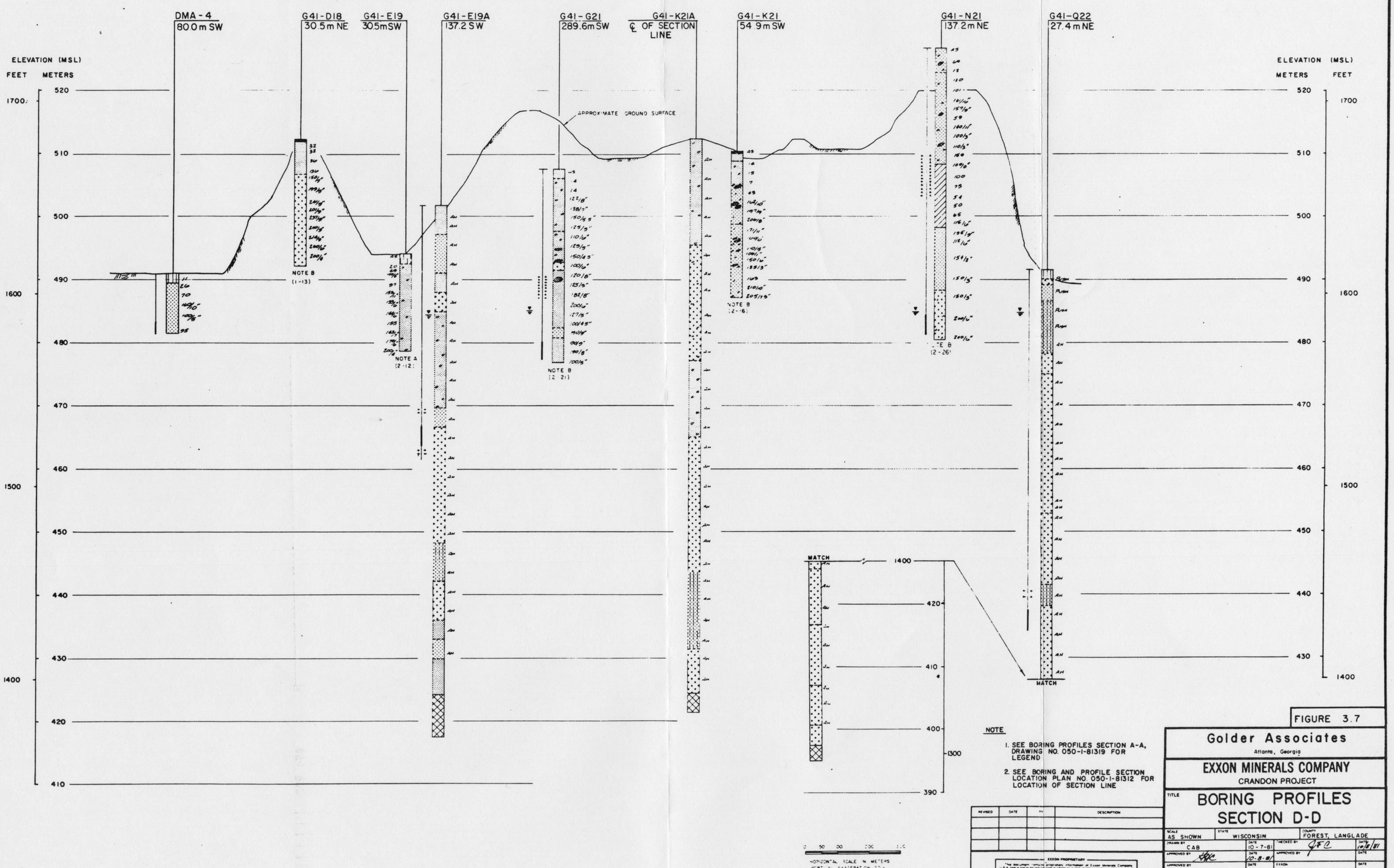
2. SEE BORING AND PROFILE SECTION LOCATION PLAN NO. 050-1-81312 FOR LOCATION OF SECTION LINE

Golder Associates
Atlanta, Georgia

EXXON MINERALS COMPANY
CRANDON PROJECT

TITLE BORING PROFILES SECTION C-C

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST, LANGLADE	
DRAWN BY CAB	DATE 10-7-81	CHECKED BY	DATE
APPROVED BY	DATE	APPROVED BY	DATE
DRAWING NO 050-1-81321		SHEET OF	REVISION NO



NOTE

1. SEE BORING PROFILES SECTION A-A, DRAWING NO. 050-1-81319 FOR LEGEND
2. SEE BORING AND PROFILE SECTION LOCATION PLAN NO. 050-1-81312 FOR LOCATION OF SECTION LINE

FIGURE 3.7

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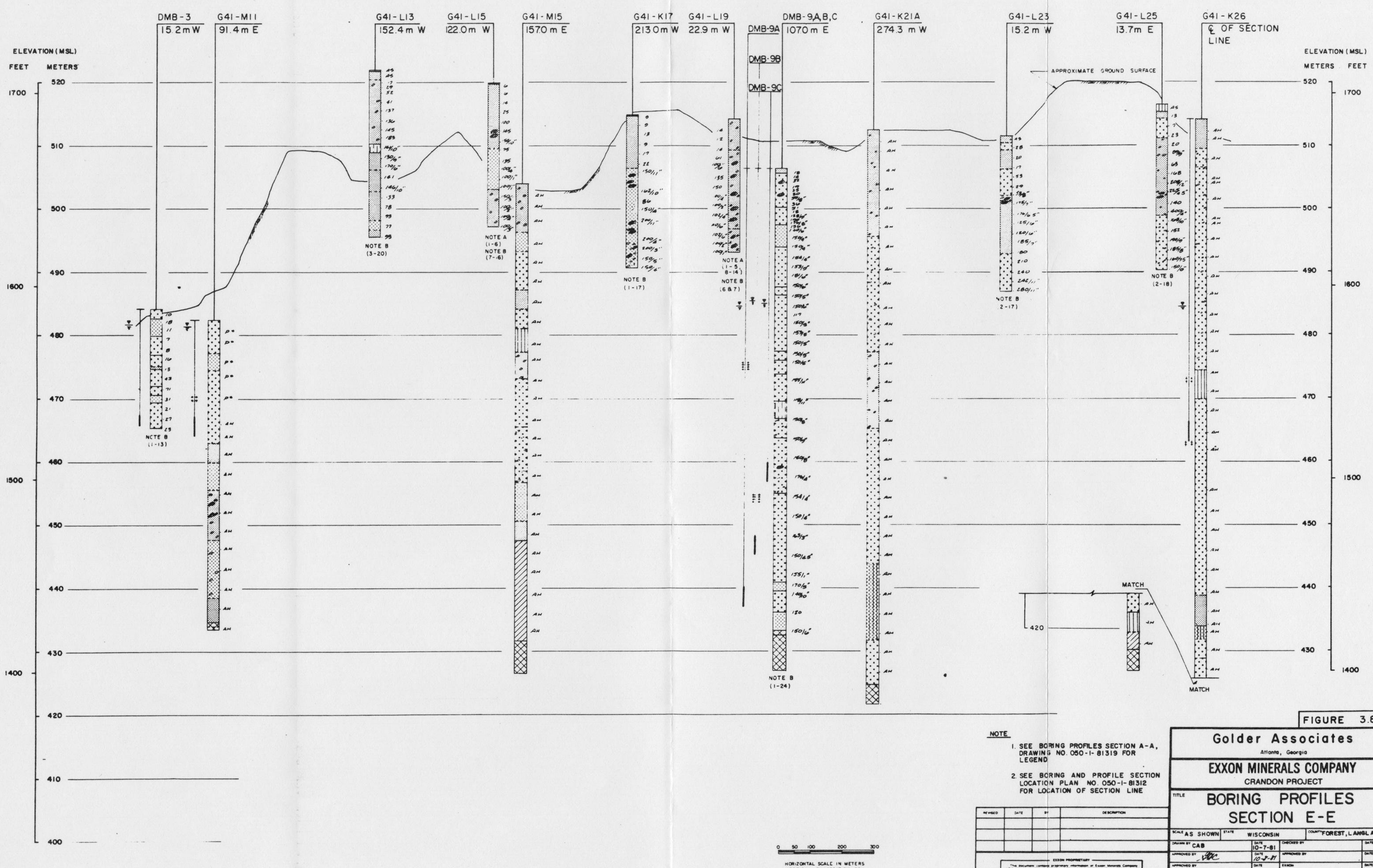
CRANDON PROJECT

TITLE BORING PROFILES SECTION D-D

SCALE AS SHOWN | STATE WISCONSIN | COUNTY FOREST, LANGLADE
DRAWN BY CAB | DATE 10-7-81 | CHECKED BY JFC | DATE 10/8/81
DATE 10-8-81
DRAWING NO 050-1-81322



NOTE

1. SEE BORING PROFILES SECTION A-A, DRAWING NO. 050-1-81319 FOR LEGEND
2. SEE BORING AND PROFILE SECTION LOCATION PLAN NO. 050-1-81312 FOR LOCATION OF SECTION LINE

FIGURE 3.8

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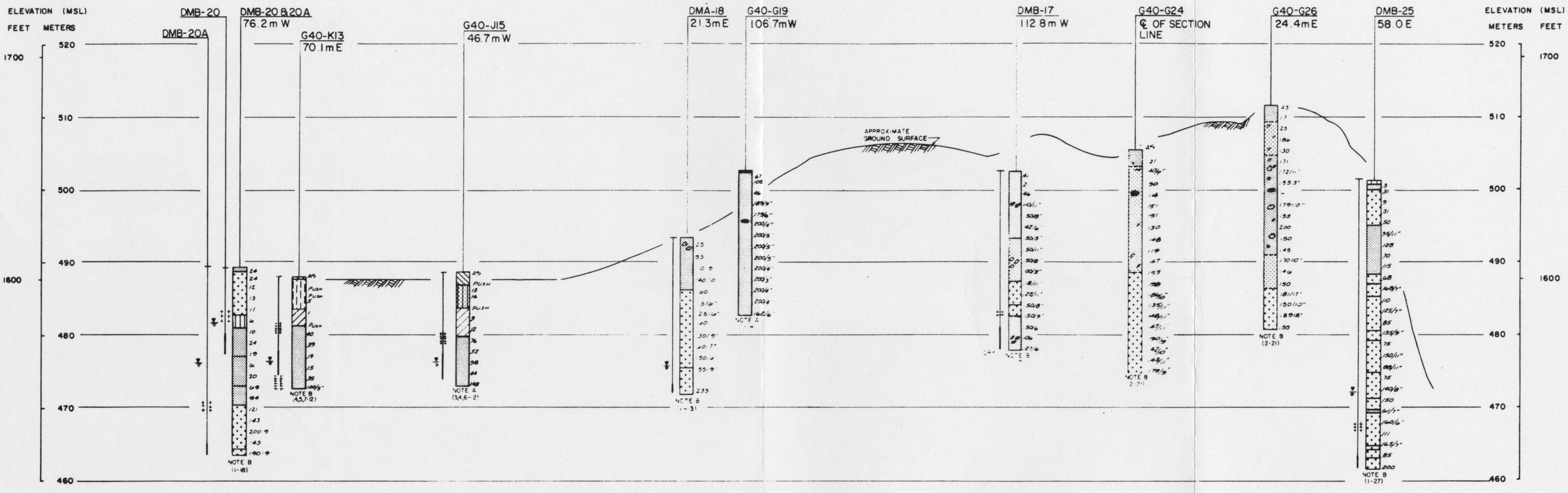
TITLE BORING PROFILES SECTION E-E

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST, LANGLADE	
DRAWN BY CAB	DATE 10-7-81	CHECKED BY	DATE
APPROVED BY	DATE 10-8-81	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO. 050-1-81323		SHEET OF	REVISION NO.



NOTE

1. SEE BORING PROFILES SECTION A-A, DRAWING NO. 050-1-81319 FOR LEGEND
2. SEE BORING AND PROFILE SECTION LOCATION PLAN NO. 050-1-81312 FOR LOCATION OF SECTION LINE

0 50 100 200 300

HORIZONTAL SCALE IN METERS
VERTICLE EXAGERATION 20x

FIGURE 3.9

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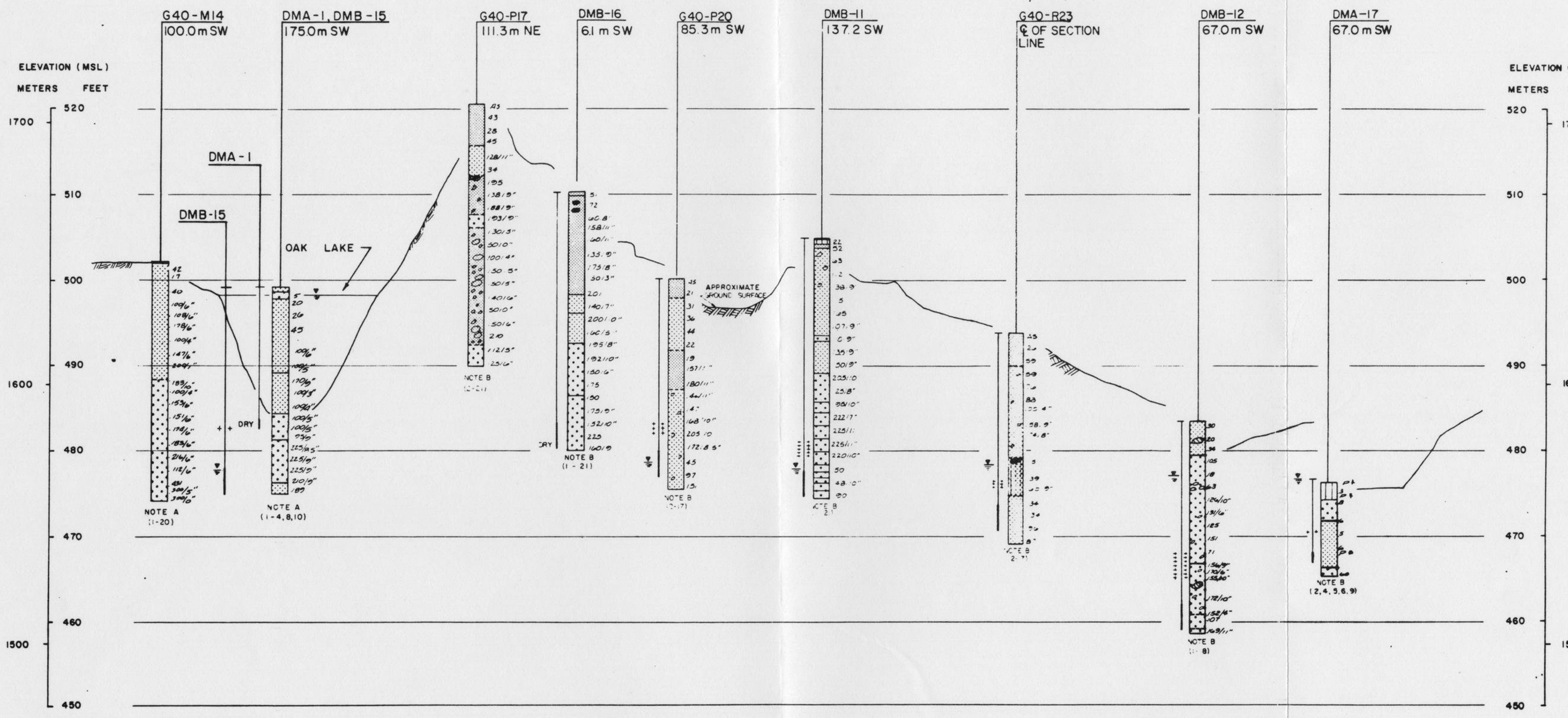
CRANDON PROJECT

TITLE BORING PROFILES SECTION F-F

REVISED	DATE	BY	DESCRIPTION

SCALE AS SHOWN; STATE WISCONSIN; COUNTY FOREST, LANGLADE
DRAWN BY CAB; DATE 10-7-81
DRAWING NO. 050-1-81324



NOTE

1. SEE BORING PROFILES SECTION A-A, DRAWING NO. 050-1-81319 FOR LEGEND
2. SEE BORING AND PROFILE SECTION LOCATION PLAN NO. 050-1-81312 FOR LOCATION OF SECTION LINE

HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION 20x

FIGURE 3.10

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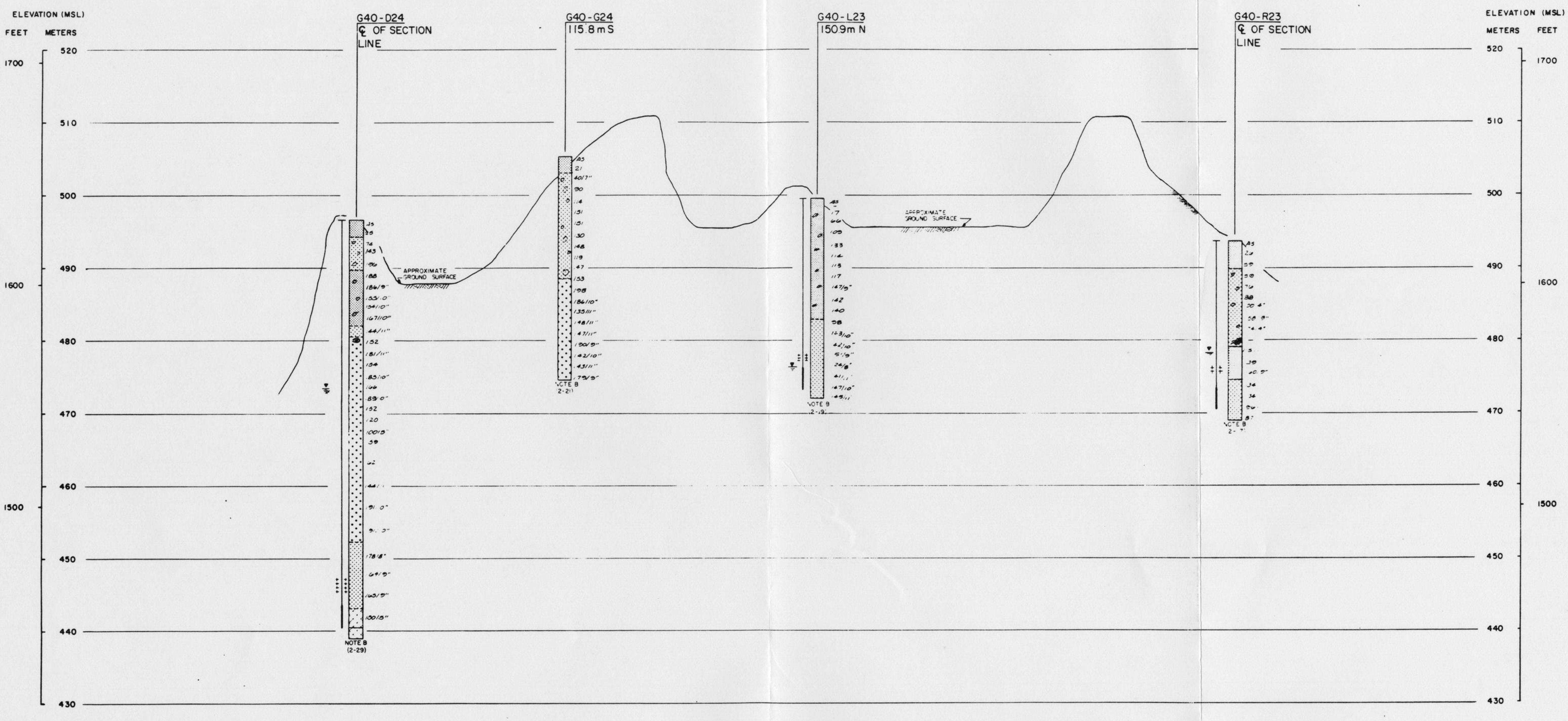
CRANDON PROJECT

TITLE BORING PROFILES SECTION G-G

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST, LANGLADE	
DRAWN BY CAB	DATE 10-7-81	CHECKED BY	DATE
APPROVED BY	DATE 10-8-81	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO 050-1-81325		SHEET OF	REVISION NO

REVISED	DATE	BY	DESCRIPTION



NOTE

1. SEE BORING PROFILES SECTION A-A, DRAWING NO. 050-1-81319 FOR LEGEND
2. SEE BORING AND PROFILE SECTION LOCATION PLAN NO. 050-1-81312 FOR LOCATION OF SECTION LINE

HORIZONTAL SCALE IN METERS
VERTICAL EXAGGERATION 20x

FIGURE 3.11

Golder Associates
Atlanta, Georgia

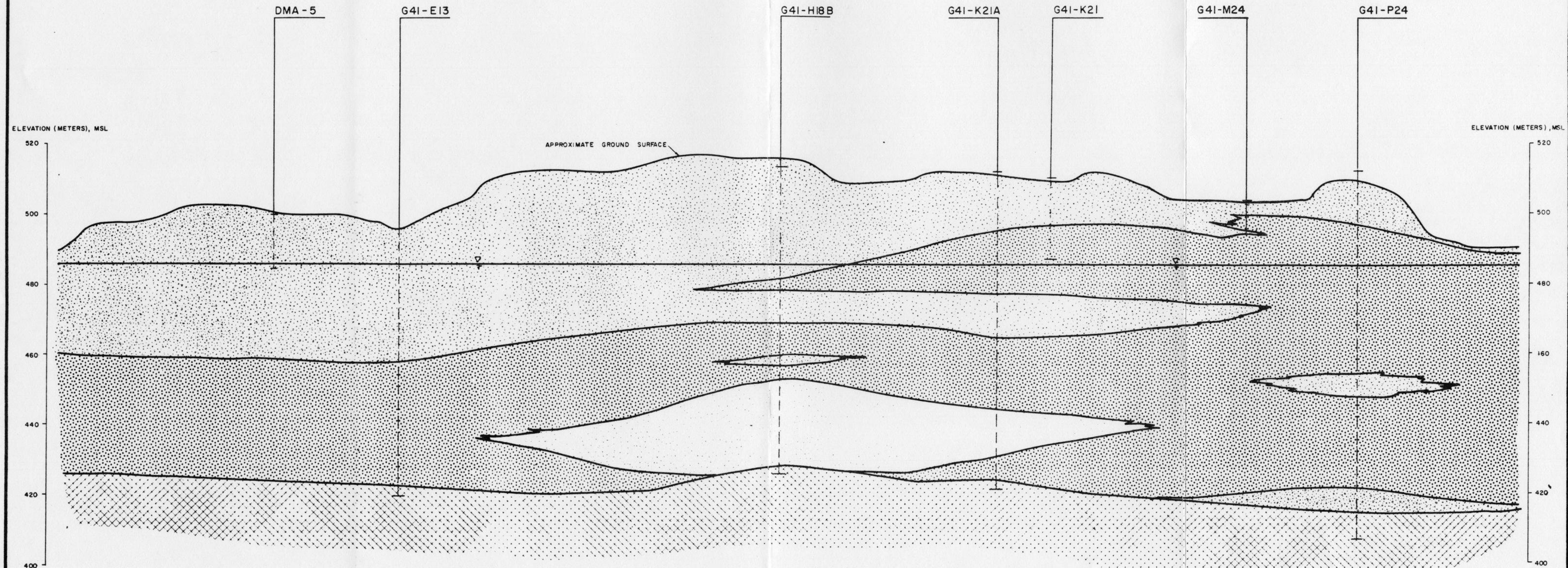
EXXON MINERALS COMPANY
CRANDON PROJECT

BORING PROFILES
SECTION H-H

SCALE	STATE	COUNTY
AS SHOWN	WISCONSIN	FOREST, LANGLADE

DRAWN BY SKB DATE 10-7-81

DRAWING NO 050-1-81326



NOTES

1. PROFILE SECTION LOCATIONS SHOWN ON BORING AND PROFILE SECTION LOCATION PLAN, DRAWING NO. 050-1-81312.
2. GROUNDWATER LEVEL PROFILE FROM GROUNDWATER POTENTIOMETRIC CONTOURS, DRAWING NO. 050-1-81111.
3. BEDROCK PROFILE FROM BEDROCK CONTOURS, DRAWING NO. 050-1-80920.
4. THIS PROFILE IS FOR ILLUSTRATIVE PURPOSES ONLY. THE DISTRIBUTION OF THE GLACIAL MATERIALS HAS BEEN INFERRED FROM THE DATA FROM THE TEST BORINGS SHOWN ON THIS SECTION, TEST BORINGS FROM THE GENERAL SITE AREA, AND TRENDS IMPLIED FROM THE GLACIAL HISTORY AND BORING DATA. THIS ACTUAL DISTRIBUTION OF MATERIALS MAY VARY FROM THAT SHOWN.

LEGEND

GEOLOGICAL DEPOSIT SYMBOLS

- WETLAND AND MARSH
- LACUSTRINE SEDIMENTS AND FINE GRAINED STRATIFIED DRIFT
- COARSE GRAINED STRATIFIED DRIFT
- TILL
- BEDROCK
- INTERPRETED STRATA BOUNDARIES
- STRATA BOUNDARIES UNKNOWN

G41-H18B
- GROUND SURFACE AT BORING LOCATION
- BOREHOLE ON LINE OF SECTION
- BOTTOM OF BOREHOLE

DMA-5
- GROUND SURFACE AT BORING LOCATION
- BOREHOLE OFF LINE OF SECTION
- BOTTOM OF BOREHOLE

GROUNDWATER LEVEL

0 50 100 200 300

HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION : 10 x

REVISED	DATE	BY	DESCRIPTION

FIGURE 3.12

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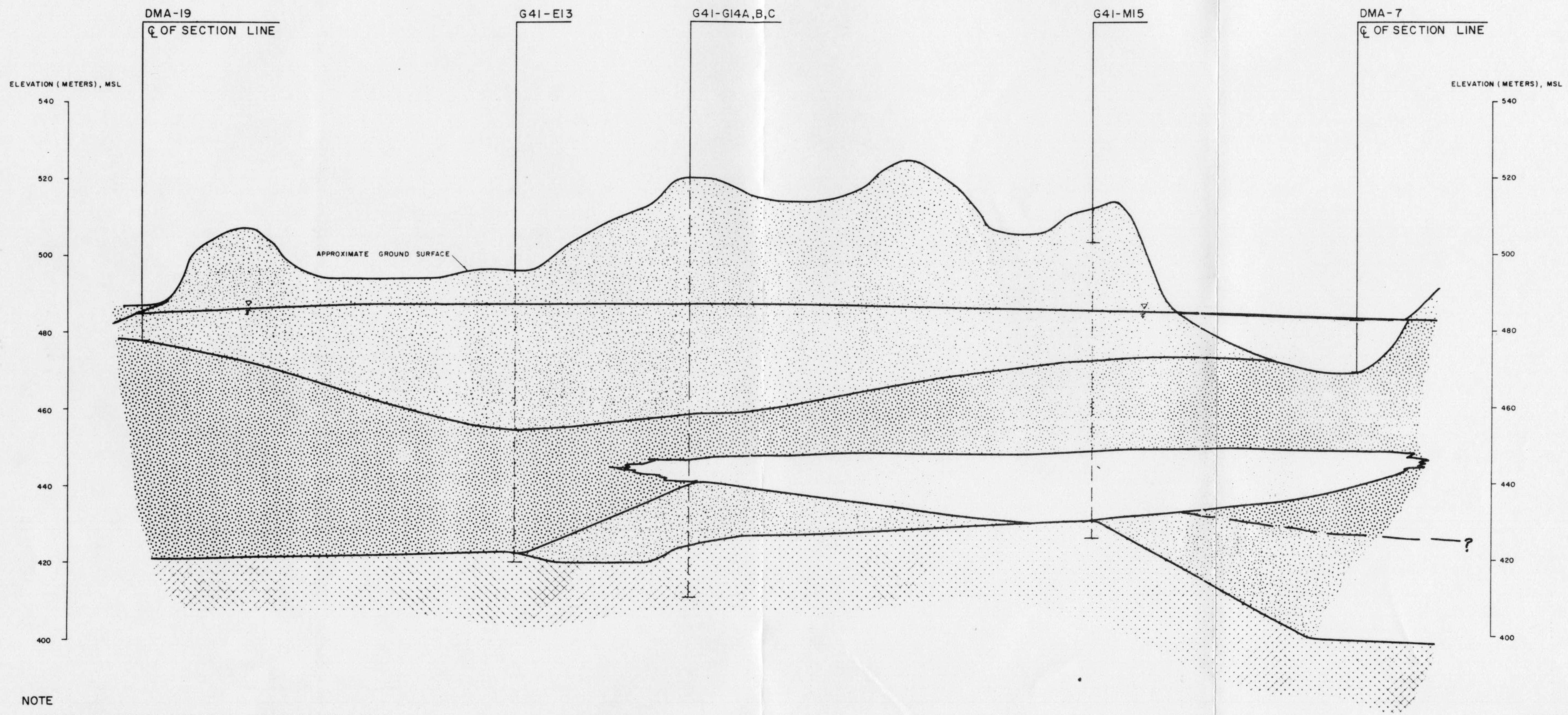
TITLE
GEOLOGIC PROFILES
SECTION A-A

SCALE AS SHOWN	STATE WISCONSIN		COUNTY FOREST, LANGLADE	
DRAWN BY CAB	DATE 9-16-81	CHECKED BY CVK.		DATE 10-9-81
APPROVED BY EHC	DATE 10-9-81	APPROVED BY		DATE
APPROVED BY	DATE	EXXON		DATE
DRAWING NO. 050-1-80911		SHEET OF		REVISION NO

DESIGN PRODUCTS CO.



NOTE

SEE GEOLOGIC PROFILES SECTION A-A DRAWING NO. 050-1-80911, FOR LEGEND AND GENERAL NOTES.

0 50 100 200 300

HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION 10x

FIGURE 3.13

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CRANDON PROJECT

TITLE
GEOLOGIC PROFILES
SECTION B-B

SCALE AS SHOWN	STATE WISCONSIN		COUNTY FOREST, LANGLADE		
DRAWN BY CAB	DATE 9-16-81	CHECKED BY JVK	DATE 10-9-81		
APPROVED BY	DATE 10-9-81	APPROVED BY	DATE		
APPROVED BY	DATE	EXXON	DATE		
DRAWING NO 050-1-80912		SHEET OF		REVISION NO	

REVISED	DATE	BY	DESCRIPTION

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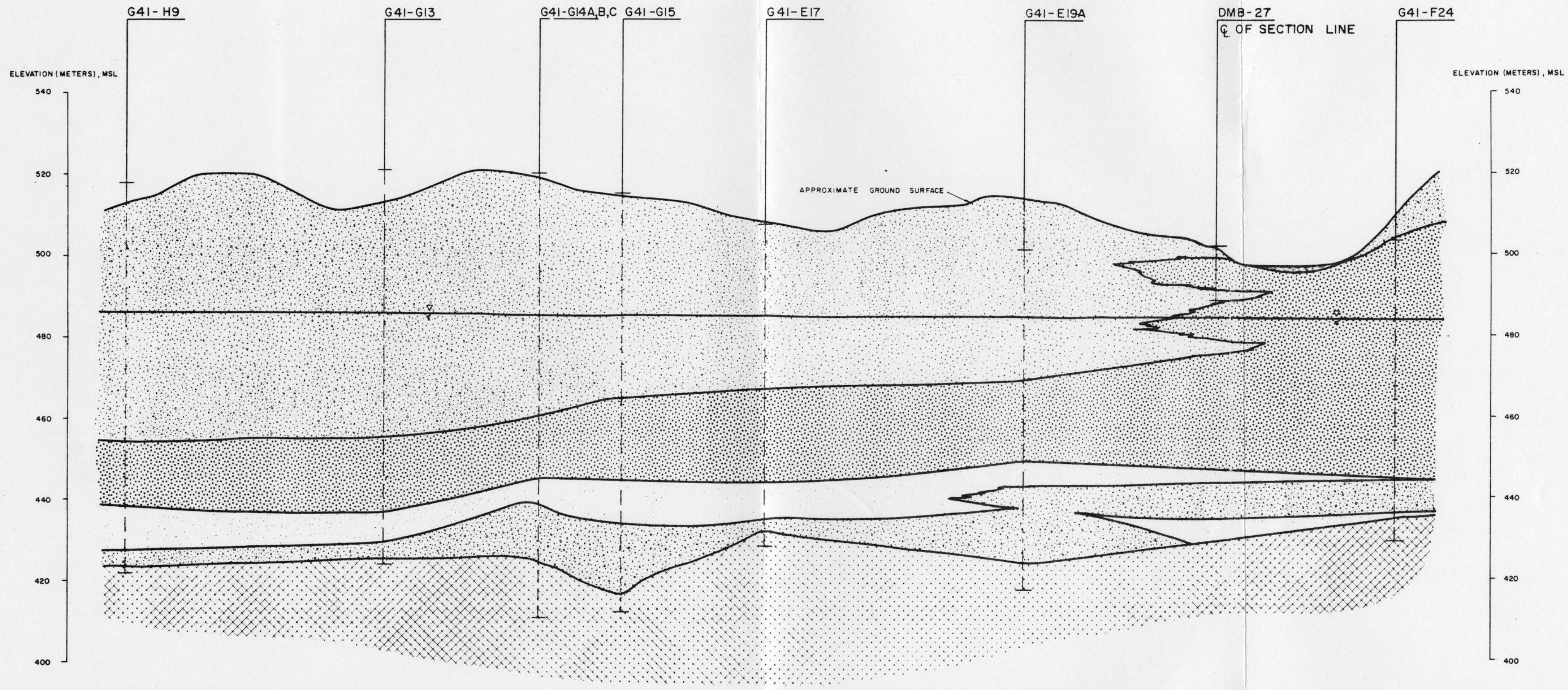

NOTE

SEE GEOLOGIC PROFILES SECTION A-A DRAWING NO. 050-1-80911, FOR LEGEND AND GENERAL NOTES.

0 50 100 200 300

HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION 10 x

REVISED	DATE	BY	DESCRIPTION

EXXON PROPRIETARY

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FIGURE 3.14

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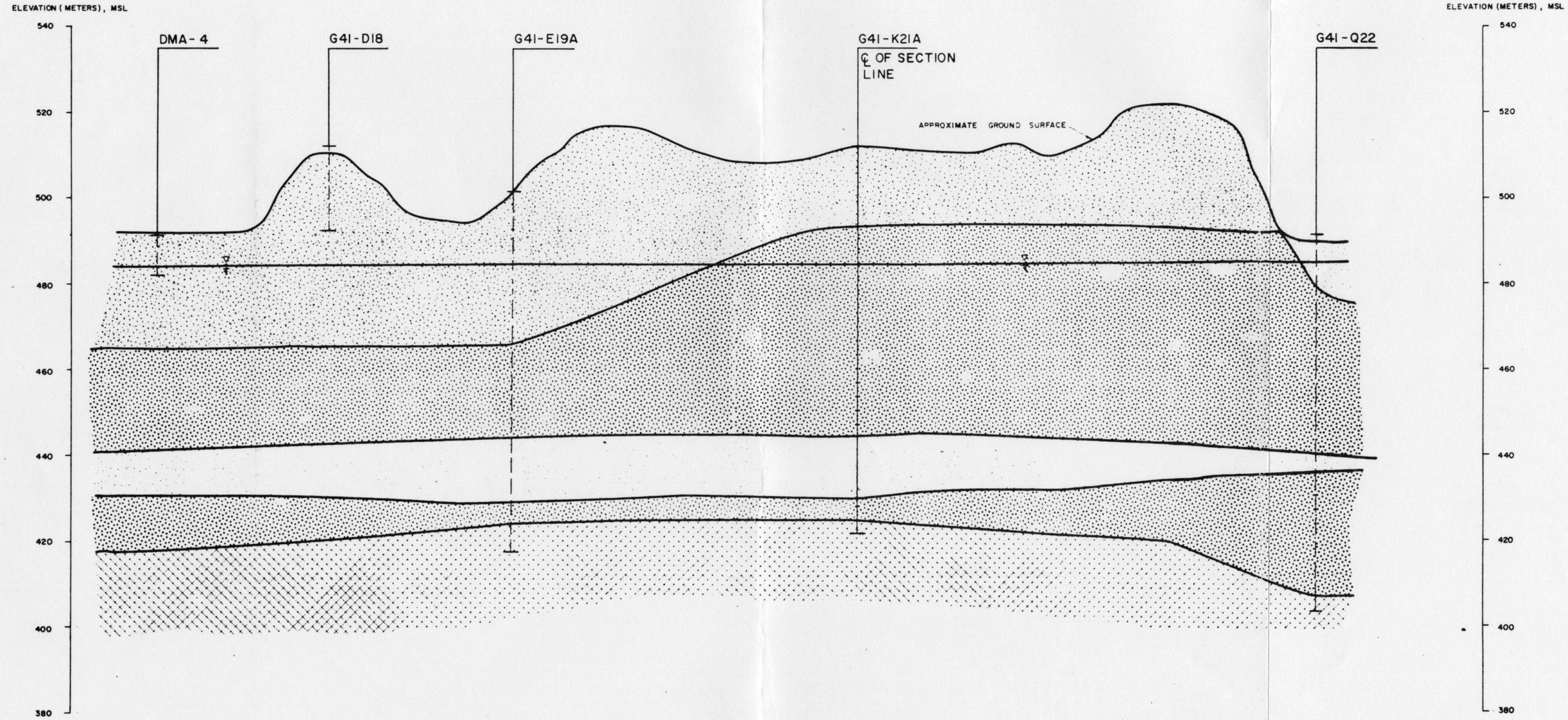
EXXON MINERALS COMPANY, U.S.A.
CRANDON PROJECT

TITLE
GEOLOGIC PROFILES
SECTION C-C

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST, LANGLADE
DRAWN BY CAB	DATE 9-16-81	CHECKED BY JVK — DATE 10-9-81
APPROVED BY [signature]	DATE 10-9-81	APPROVED BY — DATE
APPROVED BY	DATE	EXXON — DATE
DRAWING NO. 050-1-80913	SHEET ___ OF ___	REVISION NO.

DESIGN PRODUCTS CO.



NOTE

SEE GEOLOGIC PROFILES SECTION A-A DRAWING NO. 050-1-80911, FOR LEGEND AND GENERAL NOTES.

0 50 100 200 300

HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION : 10 x

REVISED	DATE	BY	DESCRIPTION

FIGURE 3.15

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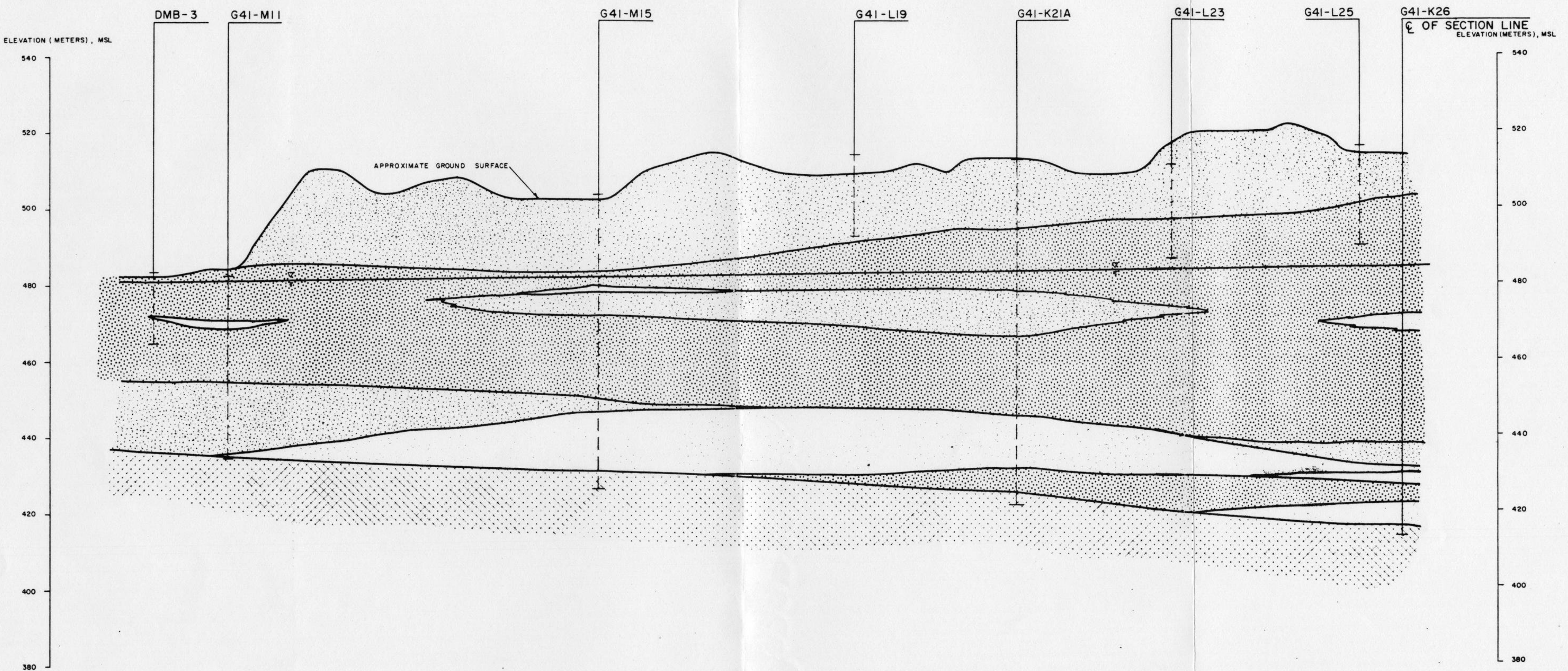
TITLE
GEOLOGIC PROFILES SECTION D-D

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST, LANGLADE	
DRAWN BY CAB	DATE 9-16-81	CHECKED BY JVK	DATE 10-9-81
APPROVED BY [signature]	DATE 10-9-81	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO 050-1-80915		SHEET ___ OF ___	REVISION NO



NOTE

SEE GEOLOGIC PROFILES SECTION A-A DRAWING NO. 050-1-80911, FOR LEGEND AND GENERAL NOTES.

0 50 100 200 300

HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION : 10 x

FIGURE 3.16

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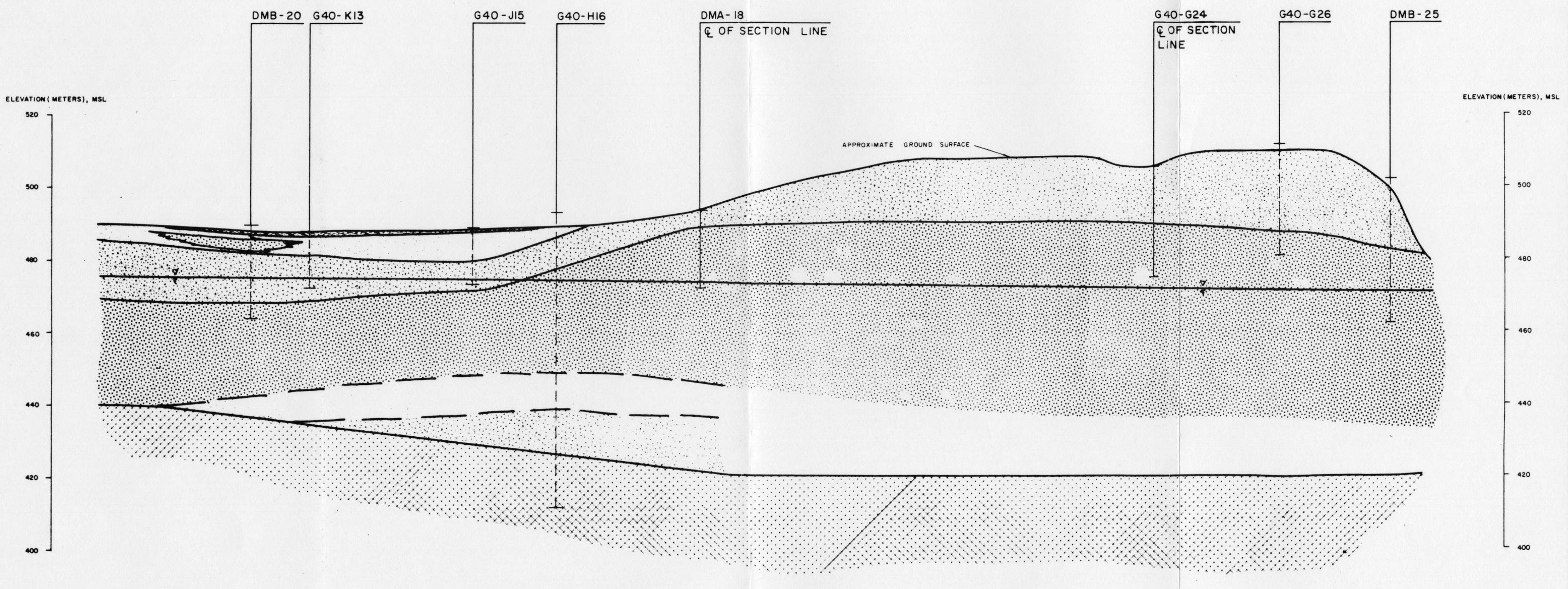
EXXON MINERALS COMPANY, U.S.A.
CRANDON PROJECT

TITLE GEOLOGIC PROFILES SECTION E-E

REVISED	DATE	BY	DESCRIPTION

SCALE AS SHOWN	STATE WISCONSIN		COUNTY FOREST, LANGLADE		
DRAWN BY CAB	DATE 9-16-81	CHECKED BY JVK		DATE 10-9-81	
APPROVED BY [signature]	DATE 10-9-81	APPROVED BY		DATE	
APPROVED BY	DATE	EXXON		DATE	
DRAWING NO. 050-1-80916		SHEET OF		REVISION NO.	



NOTE

SEE GEOLOGIC PROFILES SECTION A-A DRAWING NO. 050-1-80911, FOR LEGEND AND GENERAL NOTES.

0 50 100 200 300

HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION : 10 x

FIGURE 3.17

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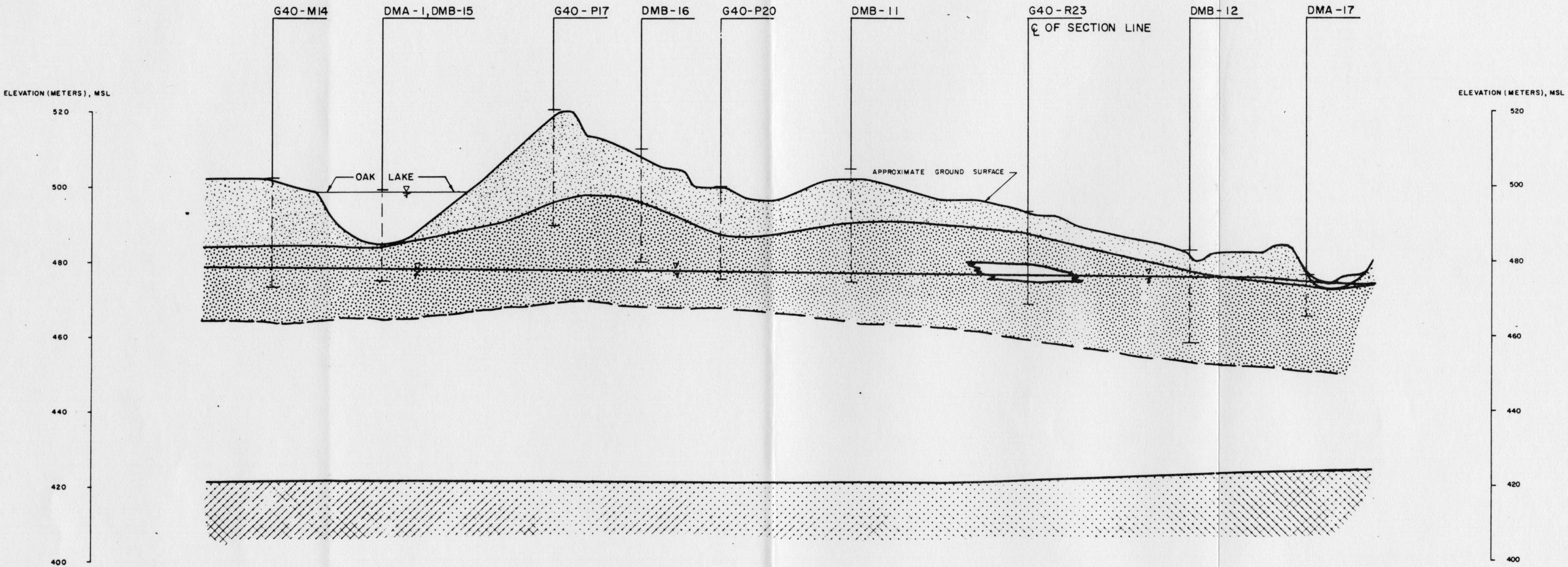
CRANDON PROJECT

GEOLOGIC PROFILES
SECTION F-F

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST, LANGLADE
DRAWN BY CAB	DATE 9-16-81	CHECKED BY JVK DATE 10-9-81
APPROVED BY	DATE 10-9-81	

DRAWING NO. 050-1-80917



NOTE

SEE GEOLOGIC PROFILES SECTION A-A DRAWING NO. 050-1-80911, FOR LEGEND AND GENERAL NOTES.

0 50 100 200 300

HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION : 10 x

FIGURE 3.18

Golder Associates
Atlanta, Georgia

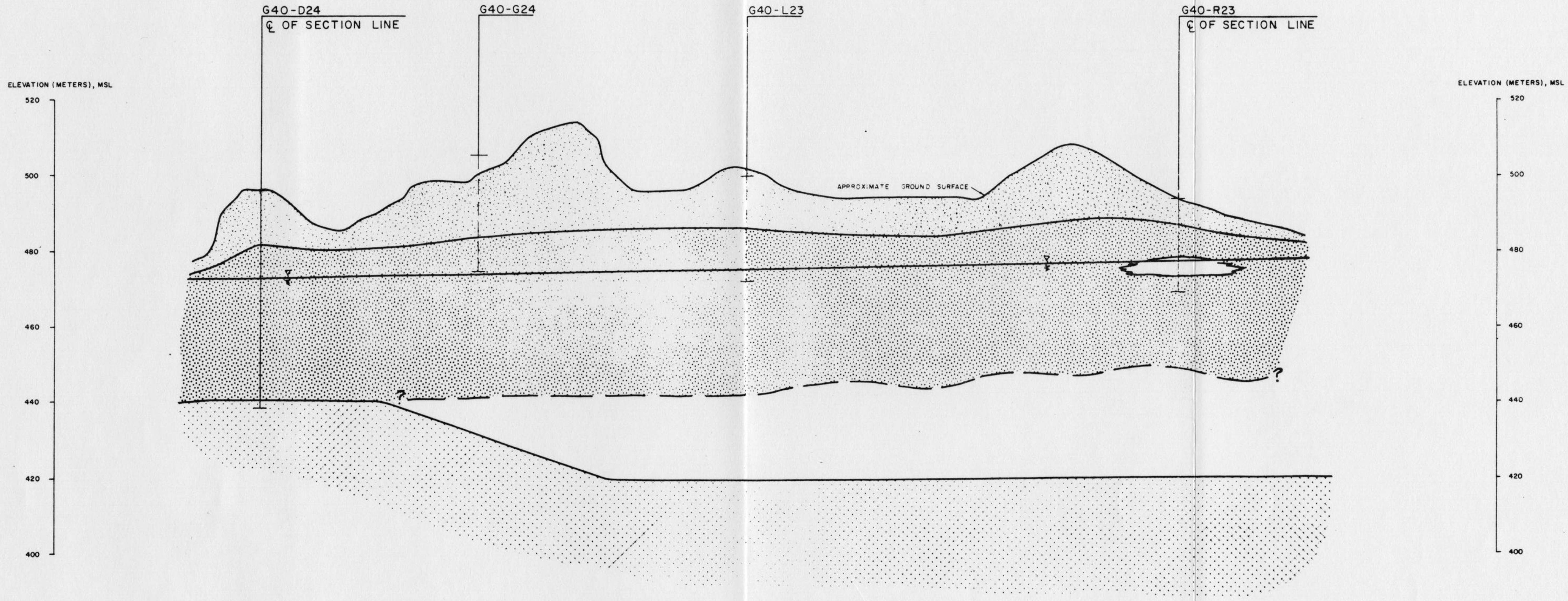
EXXON MINERALS COMPANY, U.S.A.
CRANDON PROJECT

TITLE
GEOLOGIC PROFILES
SECTION G-G

SCALE	STATE	COUNTY
AS SHOWN	WISCONSIN	FOREST, LANGLADE

DRAWN BY CAB, DATE 9-16-81; DATE 10-9-81

DRAWING NO. 050-1-80918



NOTE

SEE GEOLOGIC PROFILES SECTION A-A DRAWING NO. 050-1-80911, FOR LEGEND AND GENERAL NOTES.

0 50 100 200 300

HORIZONTAL SCALE IN METERS
VERTICAL EXAGERATION . 10 x

REVISED	DATE	BY	DESCRIPTION

FIGURE 3.19

Golder Associates
Atlanta, Georgia

EXXON MINERALS COMPANY, U.S.A.
CRANDON PROJECT

TITLE
GEOLOGIC PROFILES
SECTION H-H

SCALE AS SHOWN	STATE WISCONSIN	COUNTY FOREST, LANGLADE	
DRAWN BY CAB	DATE 9-16-81	CHECKED BY JK	DATE 9-10-81
APPROVED BY [signature]	DATE 10-9-81	APPROVED BY	DATE
APPROVED BY	DATE	EXXON	DATE
DRAWING NO. 050-1-80919		SHEET ___ OF ___	REVISION NO.

4.0 MATERIAL PROPERTIES

4.1 General Characteristics

The majority of the glacial materials encountered in the project area are till and stratified drift which are granular soils; combinations of sand and gravel with varying amounts of silt and often containing cobbles and boulders. Traces of clay were encountered but represent only a very small fraction of the till and stratified drift materials. The predominantly fine grained soils, silt and clay, were most associated with lacustrine deposits around the present day wetlands, as layers within the fine grained stratified drift, or residual soil. These fine grained soils represent only a small fraction of the glacial overburden.

From the glacial history and results of the penetration tests taken during the boring program, it is evident that the till and stratified drift materials are compact to dense (Standard Penetration results between 10 and 50 blows per foot) in the upper 4.5 to 6.1 m (15 to 20 ft.) and very dense (Standard Penetration tests above 50 blows per foot) below this level. The individual grains of the granular materials are rounded to sub-angular. The high density of these materials, their grain angularity and their grain size ranges make them excellent materials for embankment construction and foundation support. These materials will not undergo long term settlement due to consolidation to an amount which will be preceptively significant to waste disposal facilities. Although these granular soils may range from sand, gravel, and cobbles with little fines (silt and clay size particles) to sand or sand and gravel with up to 40 percent fines (predominantly silt), their overall engineering strength characteristics will be similar, having high friction angles and little to no cohesion.

The predominantly fine grained soils, silts and clay combinations, were most always associated with the larger existing wetlands. The proposed mine waste disposal facilities are anticipated to be constructed in, and with, the granular glacial soils. There is presently no intention to utilize the fine grained wetland deposits for construction purposes. Therefore, the engineering properties of these fine grained materials as applicable to construction considerations are not addressed in detail. Similarly, the outwash soils, fine grained stratified drift, residual materials, and rock are not proposed as materials for construction so their engineering properties are not addressed in detail.

Samples of each of the glacial materials have been subjected to index properties tests (grain size distribution and Atterberg limits) and each has been classified in accordance with the lettered designations of the Unified Soil Classification System. These data were used in the interpretation of the glacial deposition origin of the materials. A discussion of the differences of the index properties of the glacial materials is presented in the following Sections of this report. References to specific data are provided therein.

Strength parameters are of importance for those materials anticipated to be used in, or providing foundations for, construction of waste disposal facilities. These materials are the till and, possibly, the coarse grained stratified drift. Of these two materials, only the till has been subjected to laboratory triaxial shear testing.

The till soil was easily sampled in bulk by test pits and the triaxial tests performed on laboratory compacted samples. Undisturbed samples of dense granular soils (till or coarse grained stratified drift) could not be obtained from the test borings. Estimates of the friction angle for the coarse grained stratified drift are provided on the basis of grain size distribution of the samples tested and estimated density of these materials from the borehole penetration tests. The strength parameters and densities are discussed further in the following Sections of this report.

A great deal of emphasis has been placed on determining the hydraulic characteristics of the glacial soils. Aquifer characteristics were directly investigated by a pump test at Site 41 (Appendix E and Ref. 7). Permeability testing was performed in some of the test borings and laboratory measurements were made on compacted samples from the test pits. Also, soil permeability was estimated from the grain size data using Hazen's approximation. The permeability test data is evaluated in detail in Appendix C.

From the test boring data and results of laboratory tests, pertinent physical properties for the various glacial strata are summarized on Table 4.1. Each glacial material is discussed separately in the following Sections of this report with comments on their physical properties and specific data references.

4.2 Till Deposits

Glacial till is material deposited directly by a glacier. In the project area it consists of a heterogeneous mixture of predominantly silt, sand, gravel, cobbles, boul-

TABLE 4.1

SUMMARY OF GLACIAL MATERIAL PROPERTIES

Material Type	Unified Soil Classification Symbol	Gradation	Atterberg Limits			Shear Strength Parameters		Permeability	Density - Moisture			Remarks
									In situ	Compacted		
			L.L. %	P.L. %	P.I. %	c' N/m^2	ø' deg	k m/s (ft./sec.)	Dry Unit Wt. kg/m^3 (pcf)	Max. Dry Density kg/m^3 (pcf)	Optimum Moisture Content %	
Glacial Till	Predominantly SM and SP-SM	See Fig. 4.2 and 4.3	Predominantly non-plastic			0	34 to 40	1×10^{-6} to 1×10^{-8} (3×10^{-6} to 3×10^{-8})	1762 to 2211 (110 to 138)	1986 to 2195 (124 to 137)	7.2 to 12.5	Primary construction material
Coarse Grained Stratified Drift	Predominantly SP and SP-SM	See Fig. 4.4 and 4.5	Non-plastic			0	35	1×10^{-3} to 1×10^{-5} (3×10^{-3} to 3×10^{-5})	(100-130)	-	-	May be used as construction material
Fine Grained Stratified Drift	Ranges from ML to SP	See Fig. 4.6	Varies			-	-	1×10^{-4} to 1×10^{-8} (3×10^{-4} to 3×10^{-8})	-	-	-	Not anticipated for use in construction
Outwash	SP Only one sample tested	See Fig. 4.7	Non-plastic			-	-	1×10^{-3} to 1×10^{-5} (3×10^{-3} to 3×10^{-5})	-	-	-	Not anticipated for use in construction
Lacustrine	Ranges from OL to SM	See Fig. 4.8	Varies			-	-	1×10^{-5} to 1×10^{-8} (3×10^{-5} to 3×10^{-8})	-	-	-	Not anticipated for use in construction

NOTES:

1. Each glacial material is discussed separately in Sections 4.2 through 4.6 of this report.
2. Unified Soil Classification System designations are representative of the majority of the materials of the deposit.
3. Permeability ranges are representative of the majority of the materials of the deposit. See Appendix C, for evaluation of permeability tests and estimates from Hazen's approximation. See Appendix E for summary of pump test and Reference 7 for details of pump test and analysis.
4. See Table 4.2 in Section 4.2 for summary of test results on till samples from test pits.
5. Cohesion measured in triaxial tests believed to be a result of test procedure (see Table 4.2). Cohesion considered to be zero for effective stress analyses. Zero cohesion inconsequential to facility design analyses.
6. See Volume 2 for individual laboratory test results.

ders, and traces of clay. The till is typically fairly well graded (poorly sorted) as evidenced by grain size curves of the tested samples. The till exposed at the ground surface forms the characteristic drumlin topography of the area. The till uplands have a general northeast-southwest orientation reflecting the main direction of ice flow. The physical characteristics of the till materials found at various depths are identical.

Till is differentiated from stratified deposits by the shape of the grain size curves. The till is not water sorted material and therefore tends to have grain sizes throughout the range of silt, sand and gravel sizes. Till does not have a large percentage of single sized particles. This grain size distribution is presented graphically on Figures 4.2 and 4.3 where each grain size curve of till samples tested is plotted on one graph for Site 40 and one for Site 41. The till samples tested have uniformity coefficients ranging from 6 to 290, with all but 9 samples being above 10. The uniformity coefficient (C_u) is defined as the ratio of the grain size at which 60 percent of the particles are finer by weight to the grain size at which 10 percent of the particles are finer by weight (D_{60}/D_{10}). In the Unified Classification System, poorly graded granular materials are those with uniformity coefficient less than 8.

As can be seen from Figures 4.2 and 4.3, the till soils encompass a wide range of grain sizes, with all but three samples having more than 5 percent fines (silt and clay sizes) and most having more than 10 percent fines. Only a few samples could be classified as primarily gravel (more than 50 percent of the material larger than the No. 4 U.S. Standard sieve size) and only a few were primarily

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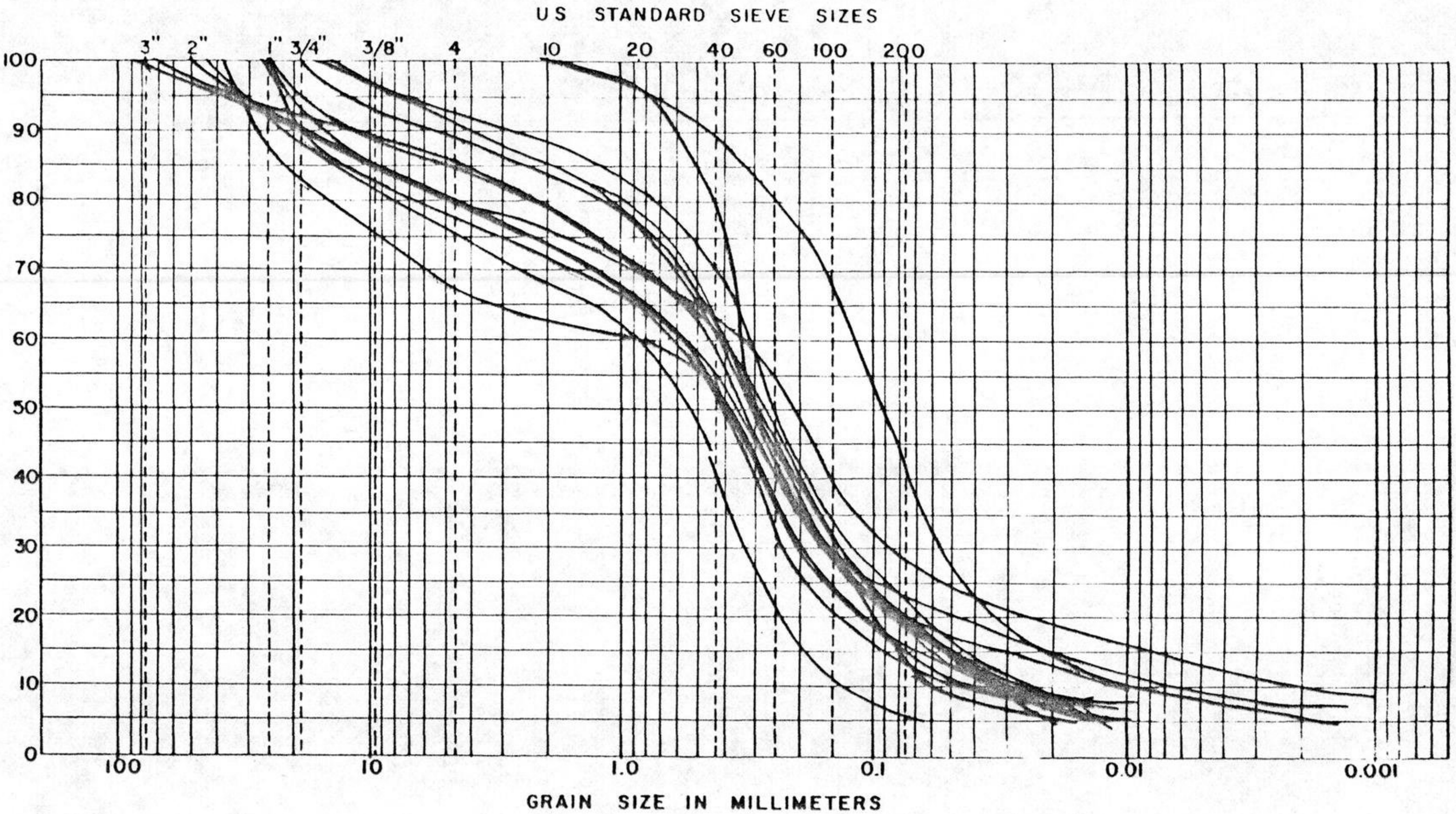

COBBLES	GRAVEL		SAND			FINES	
	COARSE	FINE	COARSE	MEDIUM	FINE	SILT SIZES	CLAY SIZES

BORING NO.	ELEV. OR DEPTH	W_n	W_L	W_p	I_p	DESCRIPTION OR CLASSIFICATION
-	--	-	-	-	-	Samples of Till from Site 40 (See Table C-2 in Appendix C for listing of samples)

FIGURE 4.2

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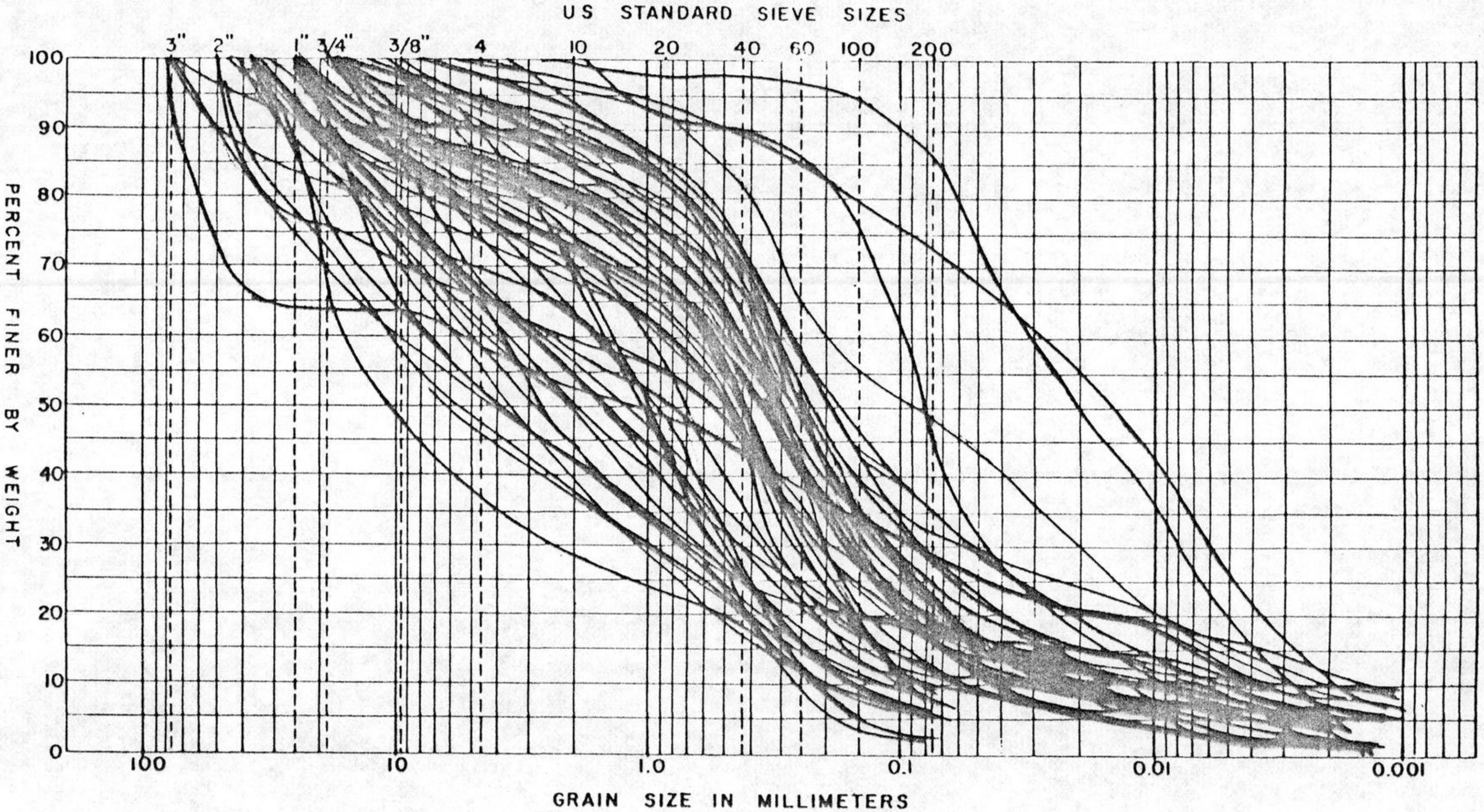

COBBLES	GRAVEL		SAND			FINES	
	COARSE	FINE	COARSE	MEDIUM	FINE	SILT SIZES	CLAY SIZES

BORING NO.	ELEV. OR DEPTH	W_n	W_L	W_p	I_p	DESCRIPTION OR CLASSIFICATION
-	-	-	-	-	-	Samples of Till from Site 41 (See Table C-2 in Appendix C for listing of samples)

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FIGURE 4.3

fine grained soils (more than 50 percent of the material smaller than the No. 200 U.S. Standard sieve size). The majority of the till samples fall into the Unified Soil Classification System designation of SM soils. These materials have more than 50 percent sand size particles and more than 12 percent fines (material finer than the No. 200 sieve). The second largest category of till samples fell into the SP-SM Unified classification. These materials are also more than 50 percent sand but have between 5 and 12 percent fines. A few samples were in the SW-SM category. The difference between the SP and SW designations are determined by the uniformity coefficient. Those three samples exhibiting less than 5 percent fines are classified as SP and GP. A completed list of the till samples and their uniformity coefficients is provided in Section C-4.0 of Appendix C.

Permeability of the till soils will vary widely because of the variation in the percentage of fines. The range of permeability estimated and tested for the till soils is between $1x10^{-4}$ and $1x10^{-10}$ m/s ($3x10^{-4}$ and $3x10^{-10}$ ft./sec.) with most values in the $1x10^{-6}$ and $1x10^{-8}$ m/s ($3x10^{-6}$ and $3x10^{-8}$ ft./sec.) range. The ranges of permeability from the various test and estimate methods are as follows:

Hazen Approximation:	$7x10^{-4}$ to $2x10^{-8}$ m/s ($2x10^{-3}$ to $6x10^{-8}$ ft./sec.)
Laboratory tests:	$2x10^{-6}$ to $3x10^{-10}$ m/s ($6x10^{-6}$ to $9x10^{-10}$ ft./sec.)
Borehole tests:	$4x10^{-4}$ to $6x10^{-8}$ m/s ($1x10^{-3}$ to $2x10^{-7}$ ft./sec.)
Pump test (horizontal):	$3x10^{-6}$ m/s ($9x10^{-6}$ ft./sec.)
(vertical):	$9x10^{-7}$ m/s ($3x10^{-6}$ ft./sec.)

The pump test value is one of the highest in the above group. The vertical hydraulic conductivity was directly measured by the pump test and the horizontal hydraulic conductivity was estimated from the vertical. In Golder Associates' experience pump test values are typically higher than laboratory test values because the pump test affects a large mass of the material and the measured hydraulic conductivity is usually a response from the more permeable portions of the mass. A complete discussion of the laboratory, borehole, and Hazen approximations of permeability determination are presented in Section C-4.0 of Appendix C. A review of the pump test is presented in Appendix E with complete details of the test and analysis in Ref. 7.

All of the test pits were excavated in till soils. Measurements of in-place density were made in five of the test pits with values ranging from 1769 to 2216 kg/m^3 (110.4 to 138.3 pcf). Bulk samples from these test pits were subjected to laboratory compaction, permeability and strength tests. The test results are summarized in Table 4.2. As expected, triaxial test results show the friction angle of this material to be fairly high, ranging from 34 to 40 degrees.

4.3 Coarse Grained Stratified Drift Deposits

Coarse grained stratified drift is a glaciofluvial material deposited by glacial meltwater. In the proposed waste disposal site areas it consists of a mixture of predominantly sand with some gravel and low percentage of fines. This soil is moderately uniformly graded (well sorted) as evidenced by the grain size curves of the samples tested. This material has been found at depth below

TABLE 4.2

SUMMARY OF BULK SAMPLE TEST RESULTS

SAMPLE IDENTIFICATION	CLASSIFICATION PROPERTIES					IN SITU PROPERTIES			STANDARD PROCTOR ①		TRIAXIAL SHEAR STRENGTH ②			PERMEABILITY VALUES ⑨ HAZEN		PERMEABILITY VALUES ⑨ COE METHOD ④②			PERMEABILITY VALUES ⑨ CONSTANT HEAD ②⑤			PERMEABILITY VALUES ⑨ CONSTANT HEAD ①⑥		
Test Pit No. Depth m (ft.)	Liquid Limit (W_L) %	Plastic Limit (W_p) %	Plasticity Index (I_p) %	Specific Gravity	Unified Classification	Natural Moisture %	Dry Density kg/m^3 (PCF)	Dry Density 19.05 mm (-3/4") mat. kg/m^3 (PCF)	Maximum Dry Density kg/m^3 (PCF)	Optimum Moisture Content %	Dry Density kg/m^3 (PCF)	Cohesion ③ kPa (PSF)	Angle of Int. Friction ø°	D10 Size mm	Estimated Permeability m/s	Dry Density kg/m^3 (PCF)	Final Moisture Content %	Permeability m/s	Compacted Dry Density kg/m^3 (PCF)	Molding Moisture Content %	Permeability m/s	Compacted Dry Density	Molding Moisture Content %	Permeability
TP-1	-	-	NP	-	SM	7.2	2216 (138.3)	2169 (135.4)	2163 (135.0)	7.2	1650 (103.0)	12.45 (260)	34.0	.005	2.5×10^{-7}	1841 (114.9) (See	15.9 Note 7)	3.9×10^{-5}	2092 (130.6)	4.5	1.9×10^{-6}	2054 (128.2)	7.7	3.5×10^{-8}
1.52 - 2.13 (5.0 - 7.0)											1815 (113.3)	15.08 (315)	39.0			2049 (127.9) (See	10.4 Note 7)	1.4×10^{-7}	2115 (132.0)	8.4	1.1×10^{-7}			
											1921 (119.9)	13.17 (275)	40.0											
TP-2 2.59 - 2.90 (8.5 - 9.5)	-	-	NP	-	SM	14.6	1961 (122.4)	1854 (115.7)	2083 (130.0)	9.2	1769 (110.4)	12.45 (260)	39.5	.06	3.6×10^{-5}	1759 (109.8)	18.0	2.3×10^{-5}	1902 (118.7)	8.5	1.7×10^{-7}	2033 (126.9)	9.4	2.3×10^{-8}
TP-4	25	16	9	2.65	CL	14.1	1836 (114.6)	1820 (113.6)	1994 (124.5)	12.5	1708 (106.6)	17.24 (360)	35.5	.0021	4.4×10^{-8}	1581 (98.7)	17.6	2.9×10^{-6}	1870 (116.7)	13.5	2.5×10^{-10}			
1.67 - 1.98 (5.5 - 6.5)																			1836 (114.6)	14.3	2.9×10^{-10}			
TP-5 1.83 - 2.13 (6.0 - 7.0)	-	-	NP	-	SM	4.8	1769 (110.4)	1721 (107.4)	2187 (136.5)	8.1	1799 (112.3)	12.45 (260)	35.0	.018	3.2×10^{-6}	1962 (122.5)	12.2	2.5×10^{-6}	1998 (124.7)	8.0	1.2×10^{-7}	2102 (131.2)	8.3	1.9×10^{-6}
TP-6 1.22 (4.0)			NP	-	SM	7.9	1894 (118.2)	1852 (115.6)																
TP-TW-41	-	-	NP		SM				2110 (131.7)	8.7				.030	9.0×10^{-6}							2079 (129.8)	9.0	6.0×10^{-9}
0.61 - 1.83 (2.0 - 6.0)																			2091 (130.5)	7.4 (See	Note 10) 2.9×10^{-8}	2091 (130.5)	7.4	3.5×10^{-8}

NOTES:

1. Performed using materials passing 19.05 mm (3/4") sieve.
2. Performed using materials passing 12.70 mm (1/2") sieve.
3. The triaxial tests were performed using oven-dried, air-cooled samples and employing vacuum as the confining pressure. Because of this, cohesion component from the shear stress normal stress plot (including the CL materials from TP-4) is judged to be due to the testing procedures and does not represent true cohesion. Cohesion of zero to be used for effective stress analyses.
4. COE abbreviation for the U.S. Army Corps of Engineers.
5. Tests performed in triaxial cell employing pressure differential of 2 to 10 psi (13.79 to 68.95 kPa).
6. Tests performed in a Proctor mold using pressure differential of 5 to 15 psi (34.48 to 103.43 kPa).
7. Results are suspected to be influenced by piping along side of the mold. Results not considered valid.
8. See Appendix B for description of laboratory test procedures.
9. See Appendix C for evaluation of permeability test data.
10. For comparison, after performing the permeability test in a Proctor Mold, the specimen was extruded and tested in the triaxial cell under pressure differential of 5 to 15 psi (34.48 to 103.43 kPa). Notes #2 and 5 are not applicable for these test results.

TABLE 4.2

both proposed disposal sites and is believed to be continuous over a larger area. This material represents the major aquifer layer through which most of the lateral groundwater movement occurs.

Coarse grained stratified drift is differentiated from till by the shape of the grain size distribution curves. Because of the water sorting, this material tends to have a large percentage of single sized, or closely sized, particles. The grain size distribution curves for those samples tested from Site 40 are shown on Figure 4.4 and those from Site 41 on Figure 4.5. The samples tested have uniformity coefficients ranging from 2 to 15 with all but four being below 8.

As can be seen from Figures 4.4 and 4.5, the coarse grained stratified drift soils are predominantly sand sized with less than 10 percent fines. Many of the samples exhibit less than 5 percent fines. The majority of these soils fall into the Unified Soil Classification System designations SP and SP-SM. A complete list of the samples, their Unified classification, and their uniformity coefficients are presented in Section C-4.0 of Appendix C.

With such low fines content, uniformity of grading, and water sorted, layered deposition, these soils exhibit high permeability values. The range of permeability values based on Hazen's approximation is between 1×10^{-3} and 1×10^{-5} m/s (3×10^{-3} and 3×10^{-5} ft./sec.). A list of the estimated permeability for each sample is presented in Appendix C. The hydraulic conductivity of this material was directly tested in the pump test at Site 41. The horizontal hydraulic conductivity was measured at 1.3×10^{-4} m/s (4.3×10^{-4} ft./sec.) and the vertical hydraulic conductivity

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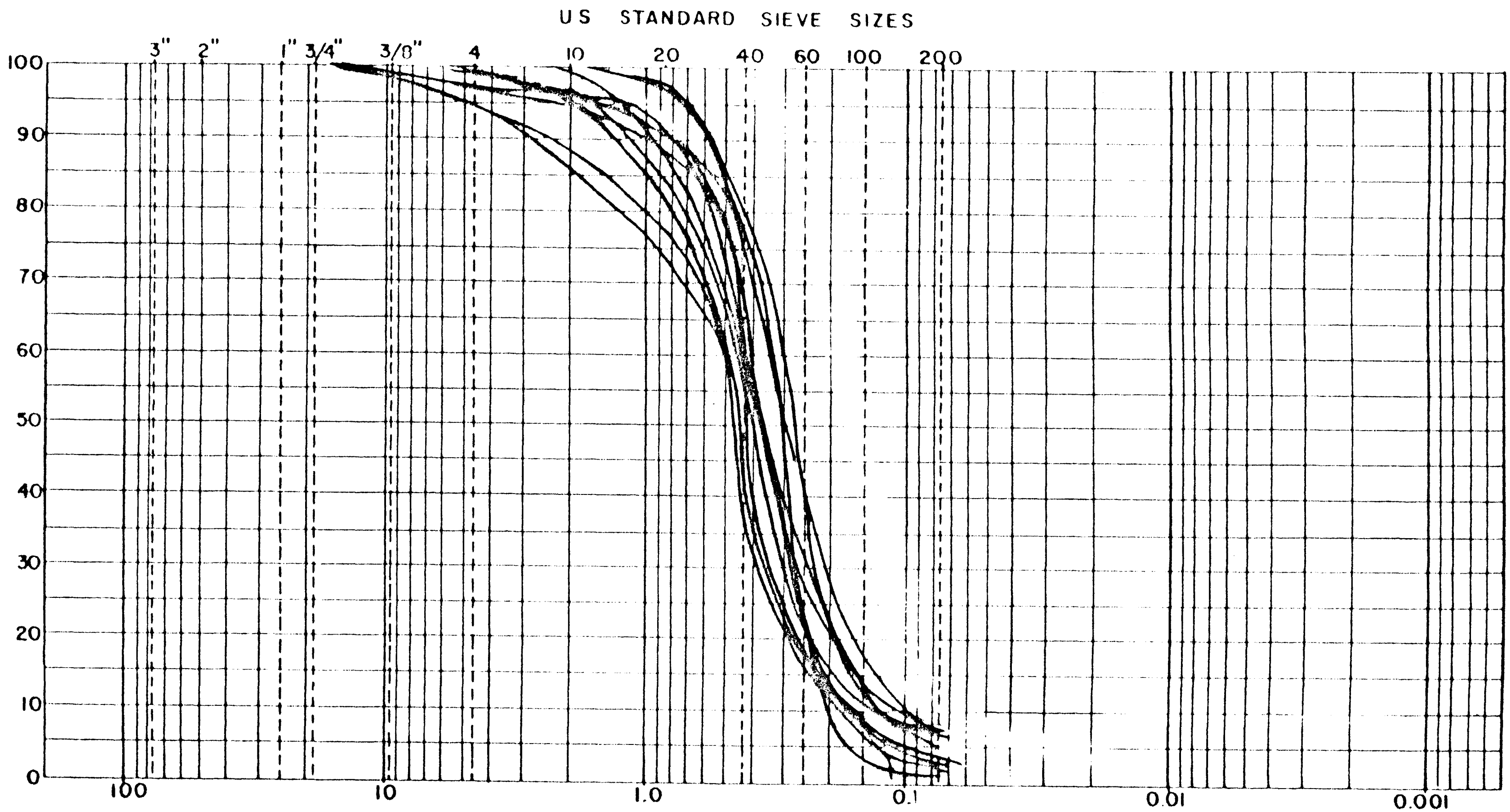

COBBLES	GRAVEL		SAND			FINES	
	COARSE	FINE	COARSE	MEDIUM	FINE	SILT SIZES	CLAY SIZES

BORING NO.	ELEV. OR DEPTH	W_n	W_L	W_p	I_p	DESCRIPTION OR CLASSIFICATION
-	-	-	-	-	-	Coarse Grained Stratified Drift from Site 40 (See Table C-2 in Appendix C for a listing of samples)

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FIGURE 4.4

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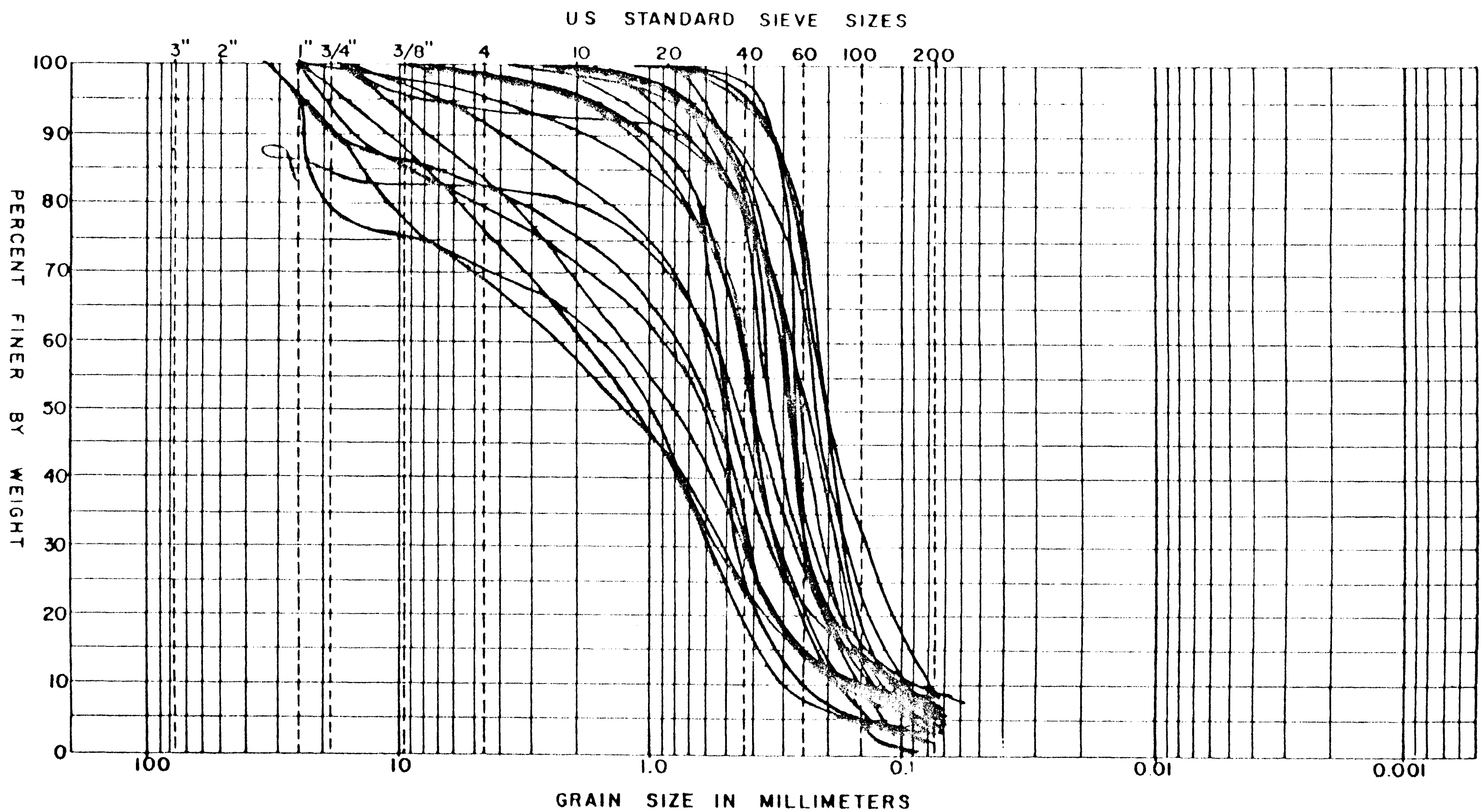

COBBLES	GRAVEL		SAND			FINES	
	COARSE	FINE	COARSE	MEDIUM	FINE	SILT SIZES	CLAY SIZES

BORING NO.	ELEV. OR DEPTH	W_n	W_L	W_p	I_p	DESCRIPTION OR CLASSIFICATION
-	-	-	-	-	-	Coarse Grained Stratified Drift from Site 41 (See Table C-2 in Appendix C for a listing of samples)

FIGURE 4.5

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was estimated at 1.3×10^{-5} m/s (4.3×10^{-5} ft./sec.). A summary of the pump test and analyses is provided in Appendix E of this report and the details in Ref. 7.

Bulk samples of the coarse grained stratified drift were not obtained from the boring or test pit exploration programs. No laboratory permeability, triaxial shear, or compaction tests were performed on this material. However, based on the grain size distribution and density exhibited by the high penetration resistance, the friction angle of this material is estimated to be 35 degrees and in-place density is estimated to range from 1602 to 2083 kg/m^3 (100 to 130 pcf).

4.4 Fine Grained Stratified Drift Deposits

Fine grained stratified drift is a lacustrine material deposited in a body of still water. This material is termed fine grained stratified drift to differentiate it from the coarse grained stratified drift previously described. Several borehole samples of this material revealed alternating bands of sand and fines (silt and clay). In a glacial environment this is commonly recognized as a varve deposit which reflects seasonal or yearly changes in the depositional environment.

The fine grained stratified drift grain size curves have a shape similar to that of the coarse grained stratified drift, but are finer in overall grain size. As with the coarse grained stratified drift, the water deposition process yields a large percentage of single sized, or closely sized, particles. The grain size distribution curves for all of the samples tested from both Sites 40 and 41 are shown on Figure 4.6. The samples tested have uniformity coefficients ranging from 2 to 13 with only one being greater than 8.

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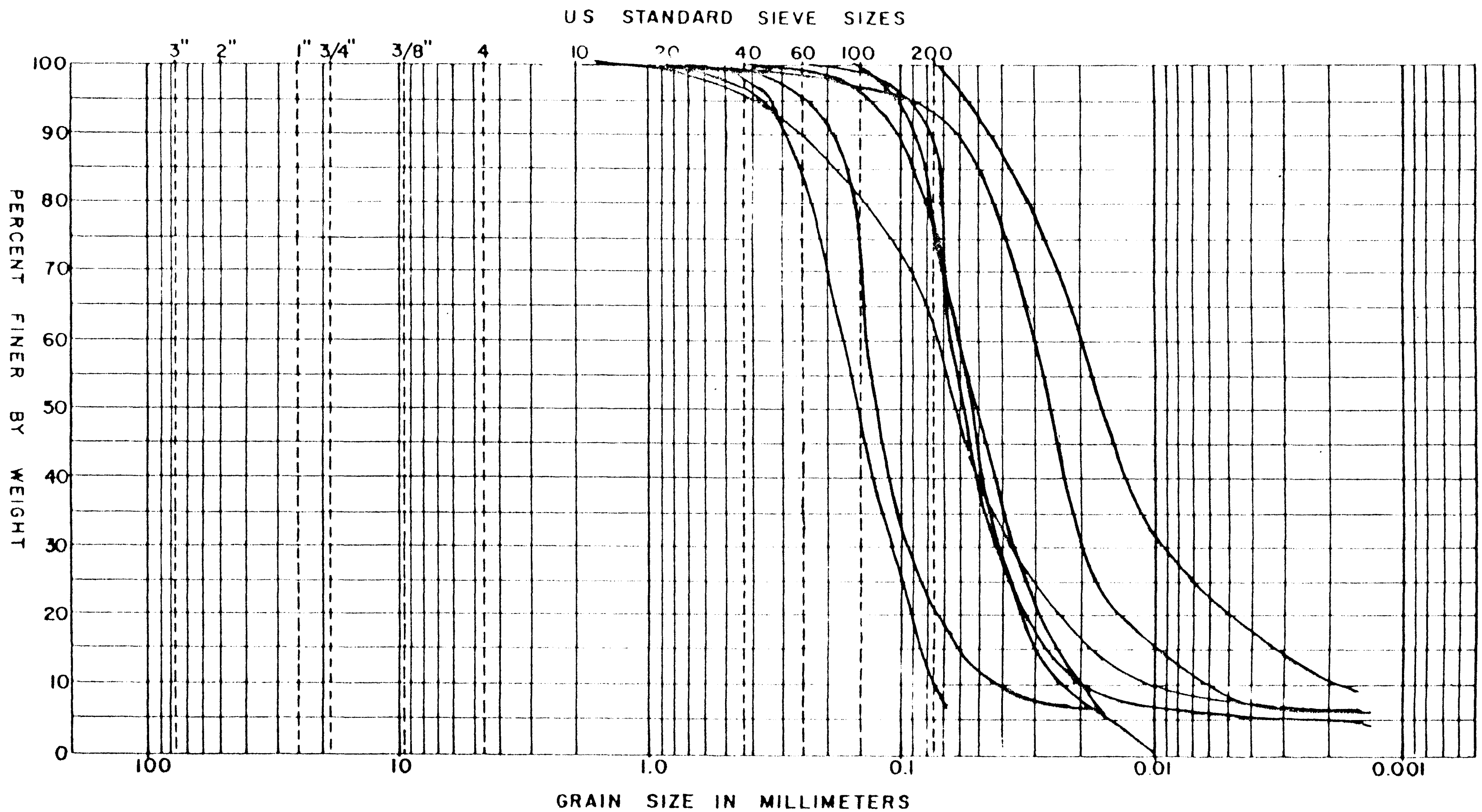

COBBLES	GRAVEL		SAND			FINES	
	COARSE	FINE	COARSE	MEDIUM	FINE	SILT SIZES	CLAY SIZES

BORING NO.	ELEV. OR DEPTH	W_n	W_L	W_p	I_p	DESCRIPTION OR CLASSIFICATION
-	-	-	-	-	-	Fine Grained Stratified Drift from Sites 40 and 41 (See Table C-2 in Appendix C for a listing of the samples)

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FIGURE 4.6

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The fine grained stratified drift soils all exhibit fairly high percentages of fines. The majority of the samples tested fall into the Unified Soil Classification System designation ML, being predominantly silt. However, SP-SM and SM designations were also found in the tested samples. Because of the depositional process and confirmed from the field classifications, this material may range from uniformly graded sand to silt, SP to ML. A complete list of the samples with their Unified classifications and uniformity coefficients is provided in Section C-4.0 of Appendix C.

Because of the range of the fines content of these soils, permeabilities based on the Hazen's approximation are variable, ranging between 1×10^{-4} to 1×10^{-8} m/s (3×10^{-4} to 3×10^{-8} ft./sec.). A list of the estimated permeabilities for each sample is presented in Appendix C. Permeability measurements and triaxial strength tests for these materials have not been made. These materials constitute a very small fraction of the overall volume of glacial soils and have not been found in areas where they will be of concern in construction of a waste disposal facility.

4.5 Outwash Deposits

Outwash materials are uniformly graded (well sorted) sand and gravel materials deposited by meltwater streams moving away from the glacial margin. Outwash tends to be deposited in plains with a relatively flat topographic surface and often occur as valley fills. Outwash soils have been mapped at the surface (see Figure 2.2) but have not been noted as a separate formation below Site 40 or Site 41.

One sample of outwash material, from boring G41-P18B at a depth of 0.37m (4.50 ft.) has been noted. This particular sample was classified as outwash from the surface mapping in the wetland near Ground Hemlock Lake where the boring is located. The grain size distribution of this sample is very uniform (uniformly coefficient of 2) and the permeability estimated from this sample by Hazen's approximation is 1.4 X 10^{-4} m/s (4.6 X 10^{-4} ft./sec.). The grain size curve for this sample is shown on Figure 4.7. Its Unified classification is SP.

The grain size distribution of this sample is similar to the coarse grained stratified drift materials. In general, there is little difference between the stratified drift and outwash from the standpoint of their grain size characteristics, and hence their hydraulic conductivity characteristics. Outwash deposited soils may exist at depth beneath the proposed disposal sites but they could not be differentiated from the coarse grained stratified drift. Their importance as a separate formation at depth is not significant since they are similar to, or part of, the coarse grained stratified drift formation. The outwash does not occur within those areas of Site 40 or Site 41 which would ultimately be developed as a waste disposal area. Therefore, their specific strength properties are of no consequence to the project. All physical properties of the outwash are assumed to be similar to those of the coarse grained stratified drift.

4.6 Lacustrine Deposits

Lacustrine deposits are materials sedimented from still bodies of water. They are predominantly fine grained soils, silt and clay, but may range to sand with a high

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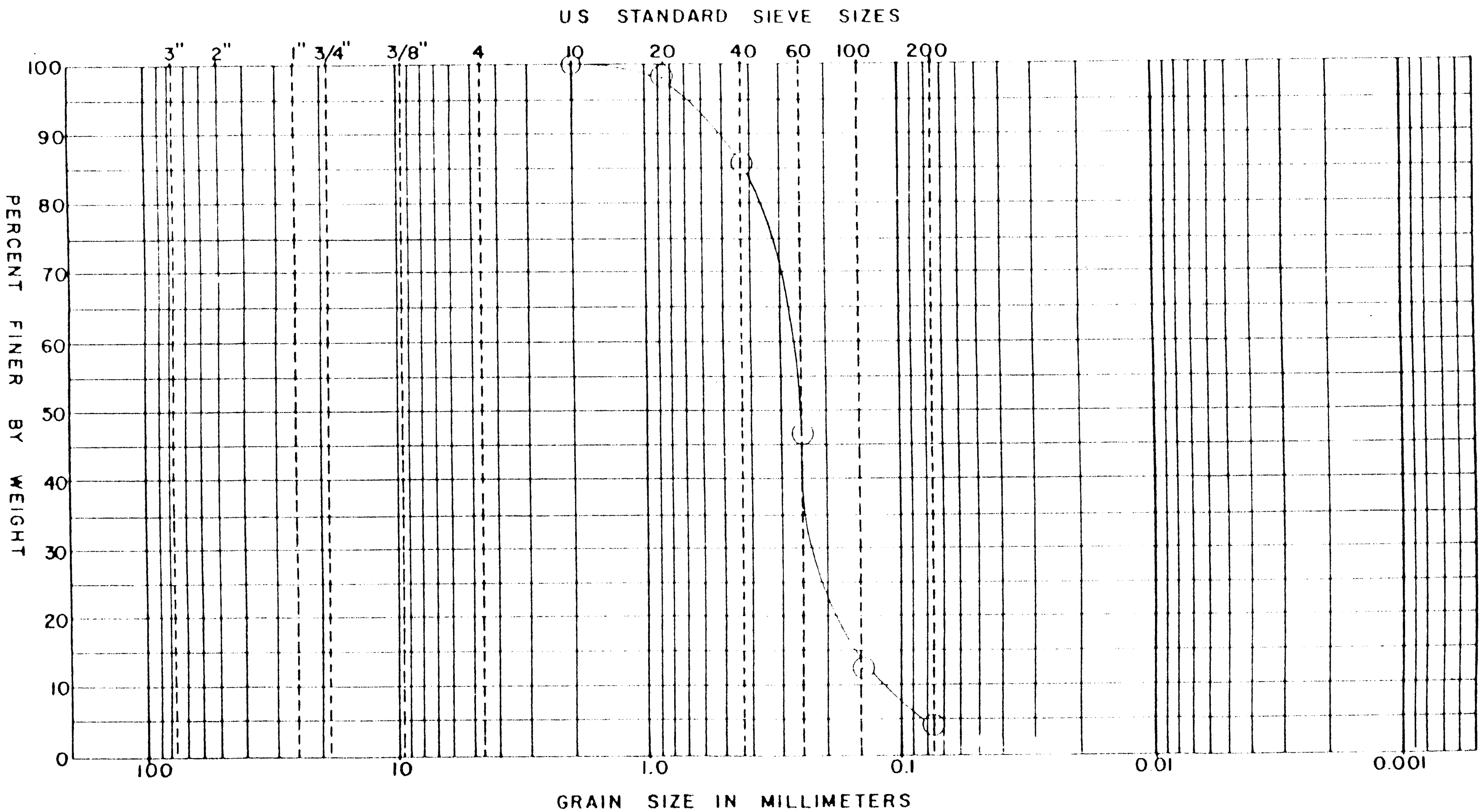

COBBLES	GRAVEL		SAND			FINES	
	COARSE	FINE	COARSE	MEDIUM	FINE	SILT SIZES	CLAY SIZES

BORING NO.	ELEV. OR DEPTH	W_n	W_L	W_p	I_p	DESCRIPTION OR CLASSIFICATION
G41-P18B SA-2 -O-	1.37m-1.83m (4.5'-6.0')	-	-	-	-	Outwash red-brown, fine to medium SAND, trace silt (SP)

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FIGURE 4.7

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percentage of fines. These soils are somewhat similar to the silt and clay materials found in the fine grained stratified drift. The lacustrine deposits are generally found surrounding and/or beneath present day wetlands and lakes.

The samples of lacustrine sediments tested exhibit a fairly wide range of grain size distribution shape. The uniformity coefficients of the samples tested ranged from 3 to 45. The grain size distribution curves for the tested samples from Sites 40 and 41 are shown on Figure 4.8. Because of the very high fines content of these soils, permeabilities estimated using Hazen's approximation range between $1X10^{-5}$ and $1X10^{-8}$ m/s ($3X10^{-5}$ and $3X10^{-8}$ ft./sec.). A list of the Unified classifications, uniformity coefficients, and estimated permeabilities is presented in Section C-4.0 of Appendix C.

Direct permeability measurements and strength parameters for these materials have not been made. These materials constitute a very small portion of the overall glacial deposits and, since they are primarily found in association with wetlands or lakes, are not intended for use in construction of waste disposal facilities. Where waste facilities may encroach on a small upland wetland which has lacustrine sediments, it is anticipated that this material will be stripped and possibly salvaged as topsoil. There are insufficient available volumes of this material for consideration of using them in construction.

4.7 Carbonate

The Green Bay Lobe glacial soils are reported to be a calcareous drift containing approximately 2 to 56 percent carbonate fragments in the gravels (Ref. 11). Dames and Moore (Ref. 6) performed percent carbonate tests on the

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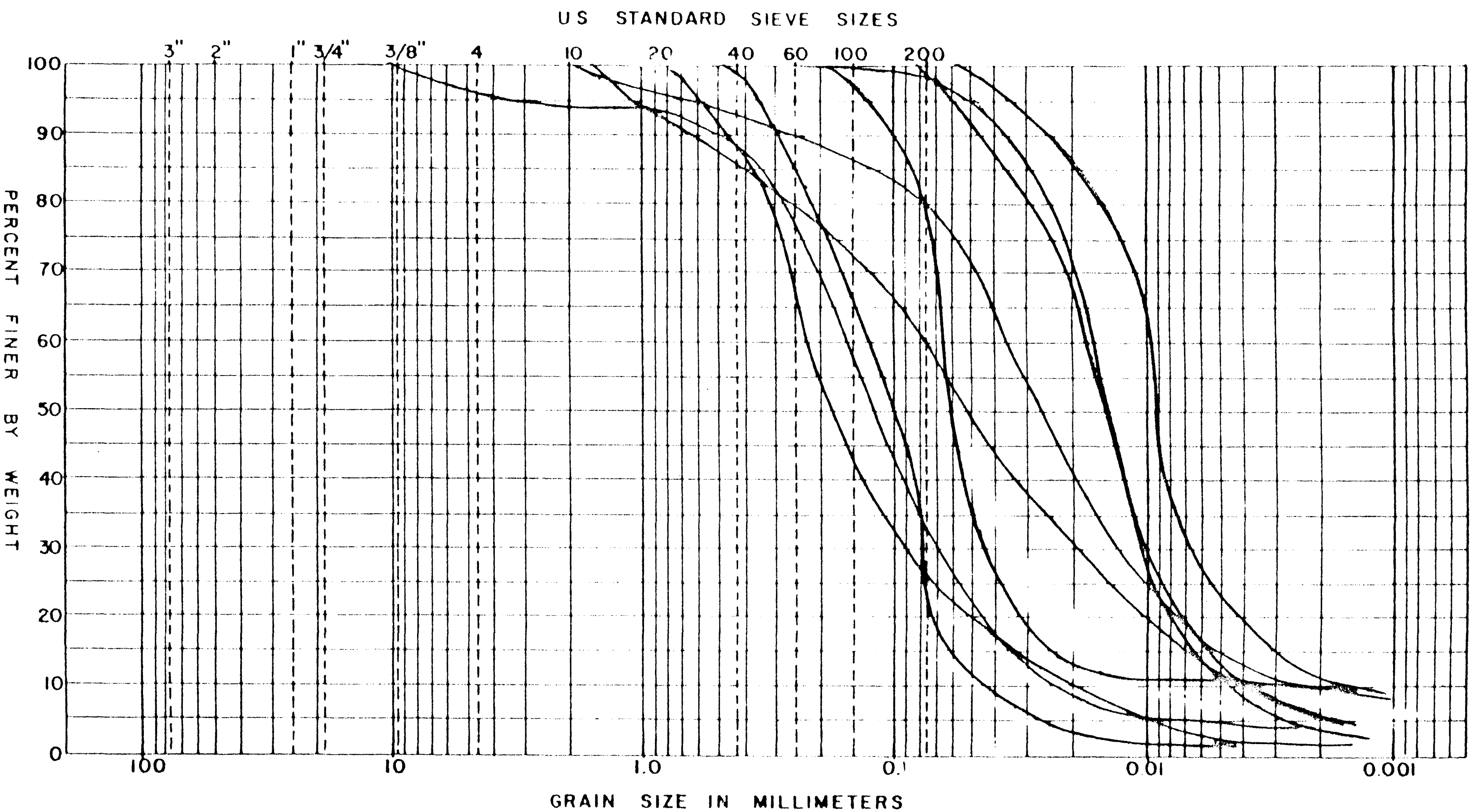
GRAIN SIZE DISTRIBUTION



COBBLES	GRAVEL		SAND			FINES	
	COARSE	FINE	COARSE	MEDIUM	FINE	SILT SIZES	CLAY SIZES

BORING NO.	ELEV. OR DEPTH	W_n	W_L	W_p	I_p	DESCRIPTION OR CLASSIFICATION
-	-	-	-	-	-	Lacustrine Deposits from Sites 40 and 41 (See Table C-2 in Appendix C for a listing of the samples)

Drawn L.K.
Checked [illegible]
Reviewed [illegible]

FIGURE 4.3

786085

material larger than the No. 4 U.S. sieve, and soil pH tests on selected samples as an aid in determining the glacial history of the materials. Golder Associates had carbonate content tests performed on 13 samples from the G41-G15 series borings. These results are included in Table 4.3. The soil pH of the 21 samples tested by Dames and Moore ranged from 6.95 to 9.35 with only 4 of the samples having a pH below 8.0. Dames and Moore found 24 of the 62 samples checked to contain carbonate pebbles and the carbonate percentage ranged from 0.8 to 35.7 (Ref. 6). The carbonate tests by Golder Associates included the entire grain size range of each sample tested and carbonate contents between 1.0 and 6.2 percent were measured. The pH tests by Dames and Moore and the carbonate content tests by Golder Associates were performed on samples ranging from 2.6 to 93.5m (8.5 to 306.7 ft.) below the ground surface.

The U.S.D.A. Soil Conservation Service performed soil survey mapping in the Crandon Project area for Exxon in 1978 (Ref. 9). The area mapped by the SCS includes most of the land presently proposed for the alternate disposal locations, Sites 40 and 41. The surface soils mapped by the SCS at the disposal sites fall into the following categories:

1. Histosols (ponded wetlands)
2. Monico stony loam
3. Iron River Variant stony loam

Of these 3 categories, the Monico and the Iron River Variant stony loams are of most interest in this study since they comprise the vast majority of the surface soils at the disposal sites. The SCS information on these soils indicates the Monico stony loam to have a pH ranging from

Table 4.3

CARBONATE CONTENT TEST RESULTS

Sample Identification				Carbonates (CO_3)
Boring No.	Sample No.	Depth m	Depth ft.	Percentage
G41-G15	S#2	14.63-14.78	48.0-48.5	2.0
G41-G15	S#5B	19.96-20.27	65.5-66.5	2.7
G41-G15	S#6	21.49-21.79	70.5-71.5	1.4
G41-G15	S#11	29.26-29.57	96.0-97.0	1.6
G41-G15	S#14	37.19-37.49	122.0-123.0	1.2
G41-G15	S#18	49.68-49.83	163.0-163.5	1.5
G41-G15	S#21	58.98-59.13	193.5-194.0	1.8
G41-G15	S#25	68.28-68.43	224.0-224.5	1.0
G41-G15	S#29	80.77-81.02	265.0-265.8	6.2
G41-G15	S#33	93.42-93.48	306.5-306.7	4.3
G41-G15A	S#2	3.05- 3.35	10.0-11.0	3.3
G41-G15A	S#5	8.53- 8.69	28.0-28.5	3.0
G41-G15A	S#6	10.06-10.15	33.0-33.3	2.7

Test Performed in accordance with ASTM procedure D 3042-72.

4.5 to 5.5. The Iron River Variant stony loam is noted as having pH ranging from 4.5 to 6.5. The SCS studies include only the upper 1.5 m (5 ft.) of soil. For both of these soils, the pH is noted to increase with increasing depth.

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GHC:dap

REFERENCES

1. Golder Associates, Siting Report for Disposal of Tailings, Crandon Project, April, 1979.

2. Willman, H.B. and J.C. Frye, Pleistocene Stratigraphy of Illinois, Illinois Geological Survey Bulletin 94, 1970.

3. Simpkins, W. W., McCartney, M.C., and D. M. Mickelson, Glacial Geology of Forest County, Wisconsin, Wisconsin Geological and Natural History Survey, unpublished.

4. Dames & Moore, Exxon Minerals Company Crandon Project Environmental Baseline Study, Section 2.3, Groundwater, draft of August, 1981.

5. Golder Associates, Groundwater Potentiometric Contours, Crandon Project, Waste Disposal System, Project Report 7, September, 1981.

6. Dames & Moore, Exxon Minerals Company Crandon Project Environmental Baseline Study, Section 2.2, Geology Study and Study Methods, April, 1981.

7. Golder Associates, Pump Test and Analyses, Crandon Project, Waste Disposal System, Project Report 4, September, 1981.

8. Geoterrex Ltd., Logistic Report on a Refraction Seismic Survey in Crandon, Wisconsin, April, 1980.

9. Correspondence from Mr. William L. Ludwig, District Conservationist, United States Department of Agriculture Soil Conservation Service, (P.O. Box 37, Rhinelander, Wisconsin, 54501) to Mr. Lewis N. Blair, Chief Environmental Affairs, Exxon Minerals Company (P.O. Box 326, Crandon, Wisconsin 54520), November 13, 1978.

10. Horslev, M.J., "Time Lag and Soil Permeability in Groundwater Observation", Bulletin No. 36, Waterways Experiment Station, Corps of Engineers, Vicksburg, Mississippi, 1951.

11. Mickelson, D.M., Nelson, A.R., and Stewart, M.T., Glacial events in north-central Wisconsin, in Late quaternary environments of Wisconsin: Knox, J.R., and Mickelson, D.M., editors, American Quaternary Association, 1974.

APPENDIX A

GEOTECHNICAL FIELD EXPLORATION

A-1.0 INTRODUCTION

The geotechnical exploration programs for the Crandon Project waste disposal facilities consisted of test borings, test pits and geophysical surveys. These programs were designed to provide data over a wide geographical area encompassing the proposed waste disposal Sites 40 and 41. They were performed during different time periods concurrent with the waste disposal siting studies. The various programs were used to develop different types of information for preliminary design of the waste disposal facilities for permitting.

The test boring and test pit programs provide site specific subsurface information on the types and thickness of the glacial soils, type and depth of the underlying rock and location of the groundwater level. The geophysical program provided the depth to rock at numerous locations over a much larger area than the proposed waste disposal sites, primarily for input to the groundwater hydrologic modeling studies. The test borings and test pits were located over a small area including proposed waste disposal Sites 40 and 41 and their immediate vicinity.

A-2.0 TEST BORING PROGRAM

A-2.1 General

The test boring program developed by Golder Associates was directed toward providing subsurface information for the specific areas of the proposed alternate waste disposal sites. This exploration was accomplished in three phases: Phase 1 from February, 1979 to April, 1979, Phase 2 from November, 1979 to January, 1980, and Phase 3 from April, 1981 to June, 1981. The Phase 2 program was developed to primarily cover a larger area than the Phase 1 program as dictated by siting study requirements. The Phase 3 program was developed to provide data at deeper levels over the Site 41 area and to cover a slightly larger area than the Phase 2 program. The borings drilled during each Phase are listed in Table A-1.

The boring program included penetration testing and split spoon sampling, undisturbed sampling of soft materials with thin-wall tube samplers, rock core sampling, in situ permeability tests, and the installation of groundwater observation wells. Qualified engineers, geologists and technicians from Golder Associates' staff inspected the boring programs, logged all holes, described all samples and adapted the work to conditions encountered.

A grid system for borehole identification was developed for each prospective tailings site with lettered north-south orientated grid lines and numbered east-west grid lines. The distance between the grid lines was 200 meters. Boreholes were located to provide areal coverage of the potential tailings facilities sites and to explore the overall range of subsurface conditions expected to occur. The boreholes at each site were numbered from their position on the respective grid system.

TABLE A-1
LIST OF TEST BORINGS BY PHASE

Boring No.	Depth (m)	To Rock	Obs. Well
Phase 1-G40 Series			
E16	15.70	--	--
G19	19.96	--	--
H13	59.53	--	--
H16	81.69	X	X
J15	15.70	--	X
K13	15.32	--	X
L19	36.73	--	--
M14	28.96	--	--
M15	94.49	X	X
Phase 1-G41 Series			
C11	15.51	--	--
C13	15.39	--	--
C15	66.23	X*	X
C15A	44.20	--	--
C15B	8.08	--	X
D14	16.15	--	--
D17	15.48	--	--
D18	19.87	--	--
E11	15.09	--	--
E13	76.35	X*	X
E13A	57.30	--	--
E15	15.24	--	--
E17	79.25	X*	X
E19	15.33	--	--
F13	17.01	--	--
G11	24.84	--	--
G12	6.40	--	X
G14	29.41	--	--
G15	103.02	X	X
G15A	34.44	--	X
G15B	51.82	--	X
G15C	44.50	--	--
G16	22.98	--	--
G19	27.58	--	--
H13	31.94	--	--
H17	22.65	--	X
H18	22.95	--	X
H18A	6.55	--	X
J11	30.39	--	--
J14	24.45	--	--
J17	12.19	--	--
J17A	9.14	--	--
J18	21.49	--	X
J19	23.03	--	--
K13	86.87	X	X
K13A	37.24	--	X
K13B	6.10	--	X
Phase 1-G41 Series (Continued)			
K17	24.17	--	--
L11	27.58	--	--
L13	26.37	--	--
L15	22.65	--	--
L19	21.06	--	--
P18	39.62	--	X
P18B	13.56	--	X
Phase 2-G40 Series			
D24	57.45	X*	X
E22	15.70	--	--
G24	30.72	--	--
G26	30.78	--	--
H27	76.20	X	X
J20	23.16	--	--
L23	27.68	--	X
P10	21.58	--	--
P17	30.63	--	--
P20	24.69	--	X
Q7	21.49	--	--
R23	24.69	--	X
S11	24.63	--	--
Phase 2-G41Series			
F24	74.06	X*	X
G14A	73.46	--	X
G14B	109.76	X	X
G14C	48.77	--	X
G14D	78.33	--	X
G14E	50.29	--	X
G14F	101.19	--	X
G21	30.63	--	X
K21	23.10	--	--
L23	24.66	--	--
L25	26.06	--	--
M24	9.39	--	X
N21	45.87	--	X
P24	105.16	X*	X
Phase 3-G41 Series			
A24	54.86	X	X
E19A	84.12	X*	X
G13	97.23	X	X
H9	96.01	X	X
H18B	87.78	X*	X
K21A	90.83	X*	--
K26	100.58	X*	X
M11	48.92	X	X
M15	77.42	X*	--
P16	55.17	X	X
Q22	96.47	X*	X

*Rock Cored

The borehole logs are presented in Volume 2. The location plan of the boreholes, as drilled, was shown on Figure 3.1 and is also included in Volume 2. The coordinate locations and elevations of the boreholes were provided by Exxon and are included with the logs.

The drilling and sampling work was contracted directly by Exxon with technical specifications provided by Golder Associates. Phases 1 and 2 of the work were awarded to Soil Testing Services (STS) of Wisconsin, Green Bay, Wisconsin. Three well drilling firms were subcontracted by STS to drill the deeper holes because of the power of the well drilling equipment and air compressor capabilities for driving samples. The Phase 3 program was carried out with well drills by Dennys Drilling Inc., Duluth, Minnesota.

A total of 91 holes were drilled, with a total footage of 3,799.07 m (12,464.1 ft.). The holes ranged in depth from 6 m to 110 m (20 ft. to 360 ft.) with the average depth being about 41.7 m (137 ft.). The shallowest holes were drilled to investigate the conditions of the bottoms of the wetland areas while the deeper holes penetrated to bedrock.

A-2.2 Boring and Sampling Procedures

The boreholes were primarily drilled by the mud-rotary method. A biodegradable viscosity increasing agent, Revert, was used to form the drilling fluid. Tri-cone bits were normally used to drill the holes with drilling rods of 60 mm (2-3/8 in.) diameter ("N" rods) and larger diameters. Nominal hole diameters ranged between 102 mm and 152 mm (4 in. and 6 in.). A minimum of 1.5 m (5 ft.) of casing was used to start each hole. The holes were held open with mud below the bottom of the casing. Occasionally, a special problem or an in situ permeability test required the use of additional casing. Upon completion, all holes not including installation of an observation well were filled with cement grout to the ground surface.

Disturbed and undisturbed samples were obtained from the boreholes. Samples were generally taken every 1.5 m (5 ft.) to a depth of 30.5 m (100 ft.) and every 3.1 m (10 ft.) below a depth of 30.5 m (100 ft.). The disturbed samples were obtained by driving a split spoon sampler with a drop hammer. At the start of the program, 51 mm (2 in.) O.D. split spoons were driven with a 63.5 kg (140 lb.) hammer freely falling 762 mm (30 in.). The number of blows it takes to drive the sampler the last 305 mm (12 in.) of an 457 mm (18 in.) penetration provides a rough indication of in situ density and is called the Standard Penetration Resistance ("N"). The very high density of the soil, however, made driving resistance of the split spoons very high resulting in small sample recoveries. In order to increase the sample recovery, 76 mm (3 in.) O.D. split spoons were substituted and driven with 136.1 kg to 163.3 kg (300 lb. to 360 lb.) drop hammers. The number of blows it took to drive this larger sampler was also recorded on the boring logs. On the well drilling rigs with air compressors, the sampler was driven with the air hammer. The air hammer combines a fast vibratory motion with down-pressure to advance the sampler. This method resulted in very good sample recovery in the very dense soil. All samples were placed in glass jars which were packed in corrugated cardboard boxes for shipment and storage. All samples have been retained by Exxon.

Several undisturbed samples were taken in some of the wetlands where soft material was encountered. Thin-walled sampling tubes, 76 mm (3 in.) O.D., were pushed into the soil by hydraulic pressure. The tubes were capped and sealed in wax for transport and storage.

Twenty-three of the boreholes were drilled to bedrock with bedrock samples being obtained by coring in twelve of them. The rock was cored with a diamond bit on a double tube core barrel, yielding a minimum core diameter of 54 mm (2-1/8 in.) ("NWM" core barrel).

A-2.3 Observation Well Installation

Wells for the observation of groundwater levels were installed in 46 boreholes. These wells were placed at various depths over the prospective sites. Shallow wells were installed in a few wetlands to observe the relationship between the seasonally ponded water in the wetlands and the groundwater levels below. These wells were sealed from the surface waters and often located above anticipated groundwater levels. Most of the deep wells were installed at various levels below the anticipated groundwater levels. The installation depths were varied to provide water quality samples from different levels and to observe the relationship between the hydrostatic levels at these depths.

The observation wells consisted of 1.5 m to 6.1 m (5 ft. to 20 ft.) of machine slotted, 51 mm (2 in.) O.D. PVC pipe set at the desired depth with a gravel backfill. Solid 51 mm (2 in.) O.D. PVC pipe was then continued to the surface. Water was flushed through the assembly until the drilling mud and filter cake was washed from the hole. Gravel was then placed around the slotted and solid PVC pipe to the desired depth. A bentonite clay seal, a minimum of three feet thick, was placed over the gravel. The annulus around the solid pipe was then backfilled with cement grout to the surface. The PVC pipe was cut off 0.6 m to 0.9 m (2 ft. to 3 ft.) above the ground surface and capped with a steel protection pipe with hinged top and lock. Specific well installation details are presented with their respective boring logs.

A-2.4 Borehole Permeability Tests

During the Phase 1 exploration program, numerous in situ permeability tests were planned in the boreholes and a total of 19 were performed. Many problems were encountered during the testing requiring on site test modifications and resulting in variations in test methods.

The planned method required 102 mm (4 in.) I.D. casing to be driven into the soil at least 0.6 m (2 ft.) beyond a larger starter hole. The casing was then cleaned by washing with a 102 mm (4 in.) diameter bit, using water and/or air, to a point about one foot below the bottom of the casing. The casing was then filled with clean water. The drop in water level with respect to time was then measured from the top of the casing. In order for the results of this test to be directly interpreted as permeability, the bottom of the casing must be in saturated soils.

Due to field problems, the tests could not always be performed in the described manner. In many instances the granular soils would run up into the casing after it was cleaned, a condition often termed "running sand." This condition voids the test since it is not possible to estimate the amount of sand in the casing during any period of measurement and the soil conditions at the bottom of the casing are highly disrupted. Repeated washing and cleaning of the casing usually resulted in more running sand. Due to this condition, many of the tests below the groundwater level were deleted. In lieu of these tests, falling head tests were performed in the materials above the groundwater level. Although the results of the tests done above the groundwater may not be interpreted strictly to permeability values, they provide a relative comparison of the permeability of the materials.

An alternate method was attempted for tests below the groundwater where the running sand could not be stopped. A drive well point, 660 mm (26 in.) long, 51 mm (2 in.) I.D. with a stainless steel screen, was driven three feet into the natural material below the bottom of the casing. Water was then poured into the attached standpipe and the fall of the water level with respect to time was measured. However, the materials were very dense and hard driving of the well point eventually eliminated this procedure.

At the onset of the program, it was planned to perform the permeability tests at various levels within the same borehole. However, once casings were driven into the soil below the starter hole they could sometimes not be pulled out. Also, driving the casing past each test would require a separate hole and even then running sand and abandoned casing was a problem. These problems combined to make the costs of the permeability tests very high and the results questionable, thereby resulting in abandonment of some scheduled tests and performing others above the groundwater levels.

The test results are summarized in Table C-1, RESULTS OF BOREHOLE PERMEABILITY TESTS, and the evaluation of test results is presented in Appendix C. The test results, because of the problems in performing the tests, are not considered valid as direct measurements of the permeability of the materials tested. These test results have not been used as specific values for analyses relating to the design of the proposed waste disposal system.

A-3.0 TEST PIT PROGRAM

A program of test pit exploration was performed to provide site specific information and samples not readily obtainable from other methods of exploration. The program consisted of 23 test pits excavated with a backhoe to depths of 1.52 m to 5.18 m (5 ft. to 17 ft.). The test pits were located in readily accessible areas and at locations to provide samples of till soil materials for testing. The program was not intended to be an exhaustive exploration program, but to obtain data to be used in conjunction with the test boring program to characterize the site soils.

All of the test pits were logged by an engineer or engineering geologist. Bulk samples of selected materials were retained for laboratory testing. In situ densities of the materials were tested in six of the pits by the sand cone density test method (ASTM D-1556).

Details of the test pits and in situ densities are shown on the test pit logs included in Volume 2. The test pit locations are included on Figure 3.1, Boring and Profile Section Location Plan, and on Figure V2, Boring Location Plan in Volume 2.

Test pit TP-TW41 was excavated for use as a mud pit during the drilling of the test well for the pump test. This pit was logged and a 227 kg (500 lb.) sample obtained for future laboratory testing of till plus a bentonite clay admixture.

Test pits TP-7 through TP-22 were excavated to provide a large bulk sample of till material for future testing. These test pits were logged and materials inspected until a sample of till material was found with approximately 12 to 15 percent fines. This sample represents till with a fines content less than the average fines content of all till samples tested. A sufficient amount of this material was found in test pit TP-22 to provide approximately 900 kg (2,000 lb.) of till sample. This sample was retained for future testing of the till with a bentonite clay admixture.

A-4.0 SOIL CLASSIFICATION

The description of the soils provided on the boring logs and test pit logs in Volumes 2 and 3 of this report were made by the Golder Associates field personnel. These descriptions are based on the knowledge and experience of those personnel. The soil descriptions include a written portion and the Unified Soil Classification System letter designation symbols.

The written portion of the soil descriptions are separated into two primary groups, those for granular soils and those for cohesive soils. Granular soils consist of boulders, cobbles, gravel, sand, and silt. Cohesive soils are those which possess the characteristics of cohesiveness and plasticity. They may be granular soils with the addition of clay or organic silt which causes cohesion and plasticity, or they may be clay or organic silt with no coarse components. The constituent parts (gravel, sand, etc.) are defined by their grain size as indicated on the grain size distribution curves found in Volume 2 or Section 4 of this report.

The following terminology is used to denote the percentage by weight of each component:

Description Term	Range of Proportion
Trace	1-10%
Some	10-20%
Adjective (e.g. sandy)	20-35%
And	35-50%

The terminology used for soils of various degrees of plasticity is given below:

Designation	Degree of Plasticity
Silt	None
Clayey Silt	Slight
Silty Clay	Medium
Clay	High

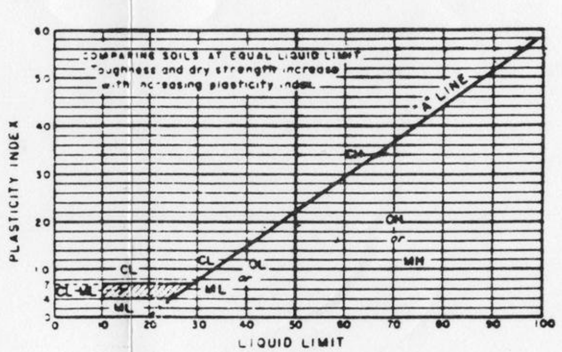
The Unified Soil Classification System chart providing a definition of the letter designation symbols is shown on Figure A-1.

UNIFIED SOIL CLASSIFICATION
INCLUDING IDENTIFICATION AND DESCRIPTION

FIELD IDENTIFICATION PROCEDURES (Excluding particles larger than 3 inches and basing fractions on estimated weights)				GROUP SYMBOLS [1]	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS	LABORATORY CLASSIFICATION CRITERIA
COARSE GRAINED SOILS — More than half of material is larger than No 200 sieve size [2] (The No 200 sieve size is about the smallest particle visible to the naked eye)	GRAVELS — More than half of coarse fraction is larger than No 4 sieve size (For visual classifications, the ¼" size may be used as equivalent to the No 4 sieve size)	CLEAN GRAVELS (Little or no fines)	Wide range in grain size and substantial amounts of all intermediate particle sizes	GW	Well graded gravels, gravel-sand mixtures, little or no fines	Give typical name, indicate approximate percentages of sand and gravel, max size, angularity, surface condition, and hardness of the coarse grains, local or geologic name and other pertinent descriptive information, and symbol in parentheses.	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing	GP	Poorly graded gravels, gravel-sand mixtures, little or no fines		Not meeting all gradation requirements for GW
		GRAVELS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	GM	Silty gravels, poorly graded gravel-sand-silt mixtures	For undisturbed soils add information on stratification, degree of compactness, cementation, moisture conditions and drainage characteristics.	Atterberg limits below "A" line, or PI less than 4 (Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.)
			Plastic fines (for identification procedures see CL below)	GC	Clayey gravels, poorly graded gravel-sand-clay mixtures		Atterberg limits above "A" line with PI greater than 7 (Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.)
	SANDS — More than half of coarse fraction is smaller than No 4 sieve size	CLEAN SANDS (Little or no fines)	Wide range in grain sizes and substantial amounts of all intermediate particle sizes	SW	Well graded sands, gravelly sands, little or no fines.	EXAMPLE:- Silty sand, gravelly, about 20% hard, angular gravel particles ½-in maximum size; rounded and subangular sand grains coarse to fine, about 15% non-plastic fines with low dry strength; well compacted and moist in place, alluvial sand; (SM)	$C_u = \frac{D_{60}}{D_{10}}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between one and 3
			Predominantly one size or a range of sizes with some intermediate sizes missing	SP	Poorly graded sands, gravelly sands, little or no fines.		Not meeting all gradation requirements for SW
		SANDS WITH FINES (Appreciable amount of fines)	Non-plastic fines (for identification procedures see ML below)	SM	Silty sands, poorly graded sand-silt mixtures		Atterberg limits below "A" line or PI less than 4 (Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.)
			Plastic fines (for identification procedures see CL below)	SC	Clayey sands, poorly graded sand-clay mixtures		Atterberg limits above "A" line with PI greater than 7 (Above "A" line with PI between 4 and 7 are borderline cases requiring use of dual symbols.)

Laboratory classification criteria for coarse grained soils: Use grain size curve in identifying the fractions as given under field identification. Determine percentages of gravel and sand from grain size curve. Depending on percentage of fines (fraction smaller than No 200 sieve size) coarse grained soils are classified as follows: Less than 5% GW, GP, SW, SP. More than 12% GM, GC, SM, SC. 5% to 12% Borderline cases requiring use of dual symbols.

FINE GRAINED SOILS — More than half of material is smaller than No 200 sieve size (The No 200 sieve size is about the smallest particle visible to the naked eye)	IDENTIFICATION PROCEDURES ON FRACTION SMALLER THAN No. 40 SIEVE SIZE			GROUP SYMBOLS	TYPICAL NAMES	INFORMATION REQUIRED FOR DESCRIBING SOILS
	DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)			
SILTS AND CLAYS — Liquid limit less than 50	None to slight	Quick to slow	None	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands with slight plasticity.	Give typical name, indicate degree and character of plasticity, amount and maximum size of coarse grains, color in wet condition, odor if any, local or geologic name, and other pertinent descriptive information, and symbol in parentheses.
	Medium to high	None to very slow	Medium	CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
	Slight to medium	Slow	Slight	OL	Organic silts and organic silt-clays of low plasticity	For undisturbed soils add information on structure, stratification, consistency in undisturbed and remolded states, moisture and drainage conditions.
SILTS AND CLAYS — Liquid limit greater than 50	Slight to medium	Slow to none	Slight to medium	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts	EXAMPLE:- Clayey silt, brown; slightly plastic; small percentage of fine sand, numerous vertical root holes; firm and dry in place; loess; (ML)
	High to very high	None	High	CH	Inorganic clays of high plasticity, fat clays.	
	Medium to high	None to very slow	Slight to medium	OH	Organic clays of medium to high plasticity.	
HIGHLY ORGANIC SOILS	Readily identified by color, odor, spongy feel and frequently by fibrous texture.			Pt	Peat and other highly organic soils	



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

[1] Boundary classifications - Soils possessing characteristics of two groups are designated by combinations of group symbols. For example GW-GC, well graded gravel-sand mixture with clay binder.
[2] All sieve sizes on this chart are U.S. standard.

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Figure 7.—Unified soil classification chart. From drawing 103–D–347.

Chart from: Earth Manual, U.S. Department of the Interior, Bureau of Reclamation, Second Edition, 1974.

JOB NO. 786085	SCALE None	UNIFIED SOIL CLASSIFICATION CHART
DRAWN LJW	DATE 10-7-81	
CHECKED	DWG. NO.	
Golder Associates		FIGURE A-1

APPENDIX B

LABORATORY TESTING

B-1.0 INTRODUCTION

The laboratory testing program was designed to permit identification, classification and assessment of the engineering properties of the materials encountered. This testing program consisted of grain size analyses, specific gravity determinations, Atterberg Limit tests, Standard Proctor compaction tests, triaxial shear tests and various permeability measurement tests. In addition, carbonate content tests were performed on a limited number of samples (see Section 4.7). The classification tests, including grain size analyses and Atterberg Limit determinations, were performed on samples from the borings and bulk samples from the test pits. Retrieval of undisturbed samples from the borings which were representative of the predominant glacial soils was not feasible due to the granular nature of the materials and their high in situ densities. Therefore, the triaxial shear strength, permeability and compaction tests were performed on bulk samples from the test pits. The pertinent details for the laboratory test procedures are described in the following section.

Results of the individual laboratory tests for grain size distribution, Atterberg Limits, Standard Proctor compaction, triaxial shear, and laboratory permeability are presented in Volume 2. The carbonate content test results were presented in Section 4.7 of this report. Results of classification, triaxial, in situ density, in situ moisture content, Standard Proctor compaction, laboratory permeability, and permeability estimates from grain size for the test pit samples tested were presented on Table 4.2.

B-2.0 LABORATORY TESTING PROCEDURES

B-2.1 Index and Classification Tests

Atterberg Limit tests, specific gravity determination and particle size analyses were performed by the following ASTM Standards:

ASTM D 422-63 (1972):	Particle Size Analysis of Soils
ASTM D 423-66 (1972):	Liquid Limit of Soils
ASTM D 424-59 (1971):	Plastic Limit and Plasticity Index of Soils
ASTM D 854-58 (1979):	Specific Gravity of Soils

Minor variations in the particle size determination procedures were employed to better suit the soils being tested. In some cases, material passing the No. 20 U.S. Standard sieve screen was used in the hydrometer portion of the analyses.

B-2.2 Compaction Tests

Standard Proctor tests, following ASTM test procedure D-698: Method D and Method D were used in testing the bulk samples from the test pits. With both methods, materials passing through a 19 mm (3/4 in.) sieve were used to determine the moisture-density relationship of the soils tested.

B-2.3 Triaxial Shear Tests

These tests were performed employing vacuum instead of conventional confining pressure application through fluid surrounding the sample. This special technique of vacuum confining presure was employed to facilitate sample preparation and testing of the predominantly granular materials. The soil sample was air dried to approximately one percent moisture content, and the portion passing a 13 mm (1/2 in.) sieve was used to prepare the test specimen. The test specimen was formed by pouring the prepared soil sample through a funnel into a 102 mm (4 in.) diameter mold. A rubber membrane was attached to the mold to cover its interior surface. At approximately each 25 mm (1 in.) lift, the soil sample was compressed manually with a plunger of the same diameter as that of the inside of the mold. The prepared specimen was placed on the pedestal of the triaxial chamber and sealed at both the top and bottom. A small vacuum was then applied at the bottom of the sample and the mold removed. The remainder of the cell assembly was completed in the usual manner for triaxial testing.

A multiple stage triaxial test was conducted on the same specimen using internal vacuum confining pressures of approximately 17 kPa, 51 kPa, and 85 kPa (5 in., 15 in., and 25 inches of mercury) respective in successive stages. Throughout the test the specimen was loaded vertically at the rate of 46 mm per second (0.03 in. per minute). During the first two stages, when the stress-strain curve began to flatten out (an increase in strain with little increase in stress), the confining vacuum pressure was increased to the next higher increment. The third stage was continued to failure of the specimen. As an example of the effects of the degree of compaction on shear strength, the soil sample from test pit TP-1 was tested at three different molding densities. Other soil samples from test pits TP-2, TP-4 and TP-5 were tested at only one density value.

B-2.4 Permeability Tests

Four of the test pit samples were tested in the laboratory for their permeability characteristics. To evaluate a possible range of influencing factors due to test procedures, several test methods, as described in the following, were employed:

1. The U.S. Army Corps of Engineers' Method: The test samples were prepared by sprinkling oven-dried soil passing a 13 mm (1/2 in.) sieve into a mold with a maximum 13 mm (1/2 in.) of free water maintained above the top of the sample. The details of this method are given in the Corps of Engineers publication EM 1110-2-1906: Laboratory Soil Testing, page VII-8. A standard falling head permeability test was then performed on the prepared sample.

2. Constant Head Test in Triaxial Chamber: In this method, the test specimen was prepared by compaction in a Proctor mold employing the Standard Proctor test procedure. Since the use of the sample diameter larger than 102 mm (4 in.) was not feasible, materials passing a 13 mm (1/2 in.) sieve were used to prepare the specimens. The specimen was then extracted from the mold and placed in a triaxial chamber with a flexible membrane lining along the sides of the specimen. The specimen was saturated using the back pressure technique. A constant pressure head was applied at the bottom of sample with flow being measured at the top of specimen. To evaluate the effect of density on permeability characteristics, separate specimens were prepared by varying molding moisture and the number of compaction blows for two of the four test pit samples.

3. Constant Head Test using Proctor Mold: Specimens for this test were also prepared using the Standard Proctor mold and test procedures. Before compacting a sample in the mold, the side of the mold was wiped with a moist towel and dry bentonite powder was sprinkled on the moist surface. A very thin

bentonite film (approximately 0.8 mm or 1/32 in.) was thus prepared on the inside surface of the mold to prevent piping along side of the mold during the permeability test. The test specimen, with material passing the 19 mm (3/4 in.) sieve, was then compacted in the mold. The specimen remained in the mold during testing and the mold was fitted with a sealed top and bottom cover plate. Before permeability measurements were made, the specimens were subjected to various pressure gradients between 34 kPa to 103 kPa (5 psi to 15 psi) and this pressure maintained until the liquid inflow was equal to the outflow. Permeability measurements were then made at the same pressure gradient for which the inflow and outflow were equal.

APPENDIX C

PERMEABILITY DATA EVALUATION

C-1.0 INTRODUCTION

Data for overburden permeability estimates were developed by Golder Associates from the field borehole permeability tests and laboratory tests. In addition, laboratory grain size analyses results were also interpreted to obtain approximate permeability values using Hazen's formula. In the following sections, these data and their results are discussed and evaluated. Data developed by Dames & Moore has been reviewed by Golder Associates but is not included in this evaluation. In addition to the data presented herein, a field pump test has been performed to investigate overall aquifer characteristics. A summary of this pump test is presented in Appendix E and a complete discussion of the test and analysis is provided in Reference 7.

C-2.0 BOREHOLE PERMEABILITY TESTS

C-2.1 General

Various methods adopted to perform the borehole permeability tests, their limitations and the difficulties encountered during the testing were described in detail in Appendix A, Section A-2.4. The pertinent details and field measurements for each test are described in their respective boring logs. Table C-1, Results of Borehole Permeability Tests, summarizes the computed permeability values based on the available field data as interpreted by Golder Associates. The formulas and time durations used for calculating the permeability values for each test are also included in Table C-1.

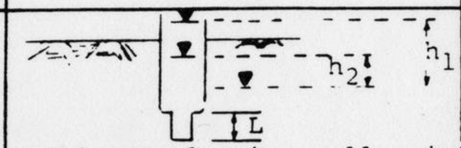
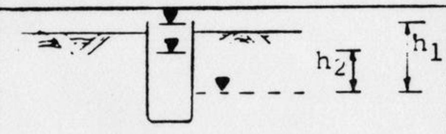
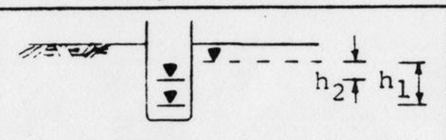
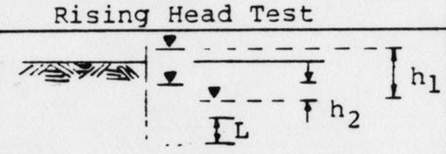
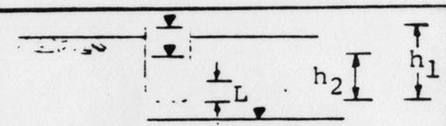
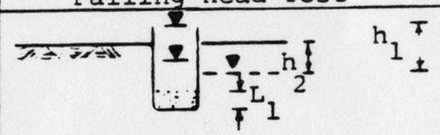
C-2.2 Calculation Procedures

Borehole permeability tests were performed at levels both above and below the groundwater table. In the former tests, since the soils above the water table are partially saturated, calculated permeability values should be regarded more as percolation rates or, at best, approximate estimates of the permeability characteristics. To differentiate various time segments of a test, a semi-logarithmic plot of time (natural scale) vs. hydrostatic head (log scale) was drawn for each test. The straight line portion of this plot indicating steady flow was then used to calculate the reported permeability values.

In tests above the groundwater table, it is typically noted that the initial percolation rates are higher which probably accounts for saturation of the soil as the wetting front moves downward and outward. After the initial saturation period, the percolation rate normally reaches a constant value. It was noted in one case, where

TABLE C-1

RESULTS OF BOREHOLE PERMEABILITY TESTS

CASE	TEST CONDITION	FORMULA USED TO CALCULATE PERMEABILITY, k
(a)	 Falling Head using well-point	$k = \frac{d^2 \ln(\frac{2mL}{D})}{8L(t_2-t_1)} \ln\frac{h_1}{h_2}$ Use m = 1, assuming horizontal & vertical permeability to be equal
(b)	 Falling Head Test	$k = \frac{2\pi R}{11(t_2-t_1)} \ln(\frac{h_1}{h_2})$
(c)	 Rising Head Test	$k = \frac{2\pi R}{11(t_2-t_1)} \ln(\frac{h_1}{h_2})$
(d)	 Falling Head Test	$k = \frac{R^2}{2L(t_2-t_1)} \ln(\frac{L}{R}) \ln(\frac{h_1}{h_2})$
(e)	 Falling Head Test	$k = \frac{R^2}{2L(t_2-t_1)} \ln(\frac{L}{R}) \ln(\frac{h_1}{h_2})$
(f)	 Falling Head Test	$k = \frac{2\pi R + 11L_1}{11(t_2-t_1)} \ln(\frac{h_1}{h_2})$
(g)	 Falling Head Test	$k = \frac{2\pi R + 11L_1}{11\ (t_2-t_1)} \ln(\frac{h_1}{h_2})$

NOTATION:

h_1 = piezometric head at time = t_1
h_2 = piezometric head at time = t_2
d = diameter, well point
D = diameter, casing
R = radius, casing
m = transformation ratio
L = intake length
L_1 = length, sand run-up or soil plug inside casing bottom
ln = natural logarithm
Formulas from Reference 10

BORING NO.	TEST NO.	TEST ELEVATION m (ft.) (1)	CLASSIFICATION (2)	CALCULATIONS BASED ON: TEST CONDITION	TIME PERIOD (min.)	CALCULATED PERMEABILITY, k, m/s	REMARKS (3)
G41-C15A	1	451.90 (1482.6)	Till (SP-SM)	Case (a)	5-20	2.3×10^{-6}	Large run-up prior to testing See Note #4
G41-E13A	1	492.47 (1615.7)	Till (SM)	Case (e)	2-15	1.9×10^{-6}	Test at level above the ground-water table
	2	489.11 (1604.7)	Till (SM)	Case (e)	5-15	3.5×10^{-6}	Test at level above the ground-water table
	3	482.71 (1583.7)	Till (SM)	Case (d)	5-30	5.5×10^{-6}	Test at level ablve the ground-
	4	476.31 (1562.7)	Till (SM)	Case (d)	0.5-15	7.8×10^{-6}	
	5	464.42 (1523.7)	Till (SM)	Case (b)	0.75-5	3.7×10^{-4}	Run-up prior to testing, See Note #4
	6	453.15 (1486.7)	CGSD (SP)	Case (a)	11-16	7.7×10^{-7}	Slight silting during test
	7	437.60 (1435.7)	CGSD (SP-SM)	Case (a)	0.5-31	2.9×10^{-7}	Very high silting during test, See Note #4
G41-G15A	1	481.98 (1581.3)	Till (SM)	Case (c)	0-40	2.6×10^{-5}	Rising head test, limited value due to only one observation
	1	481.98 (1581.3)	Till (SM)	Case (a)	0-15	8.9×10^{-7}	Hole apparently clogged after sampling. See Note #4
G41-15C	1	509.32 (1671.0)	Till (SM)	Case (e)	10-25	1.5×10^{-6}	Test at level above the ground-water table
	2	502.92 (1650.0)	Till (GM)	Case (e)	5-15	3.6×10^{-7}	Test at level above the ground-water table
	3	496.67 (1629.5)	Till (SM)	Case (e)	20-45	6.5×10^{-6}	Test at level above the ground-water table
	4	490.42 (1609.0)	Till (SM)	Case (e)	1-15	6.1×10^{-8}	Test at level above the ground-water table
	5	471.22 (1546.0)	Till (SM)	Case (d)	5-15	1.1×10^{-7}	Silting of hole during test, See Note #4
G41-J17A	1	508.99 (1669.9)	Till (SM)	Case (e)	5-30	1.0×10^{-7}	Test at level above the ground-water table
G41-K13A	1	480.88 (1577.7)	Till (SP-SM)	Case (d)	5-20	1.7×10^{-7}	Test through boulder, see the text
G41-K13B	1	511.09 (1676.8)	Till (SM)	Case (f)	20-30	1.0×10^{-6}	Test at level above the ground-water table
G41-P18B	1	470.86 (1544.8)	Till (SM)	Case (g)	See Note #5	2.7×10^{-5}	Sand run-up during test, See Note #4

NOTES:

1. Elevation indicates the lowest level of the test section.
2. Classification includes estimated glacial soil type (and Unified Soil Classification letter designation) with CGSD being coarse grained stratified drift.
3. Detailed review of each field permeability test is included in the text.
4. Not considered representative of in situ conditions due to reason noted.
5. Average of 0 to 2 and 25 to 35.

TABLE C-1

the test level was approximately 6.1 m (20 ft.) above the groundwater table, that the percolation rate increased with time. It is suspected that this increase is due to leakage around the casing.

The tests below the groundwater table were affected either by run-up conditions or silting. Since run-up markedly disturbs the in situ conditions, results are not considered representative of in situ characteristics. Even though permeability values are calculated for such cases, these data are not considered valid and are so noted in Table C-1 as well as in Section C-2.3, Test Review. Some of the borehole permeability tests were apparently subjected to silting of the hole by fines which remained in suspension. To some extent, this silting was identified from the semi-logarithmic plot of time vs. hydrostatic head, by a gradual change of the slope of the curve. Several such slope changes would indicate heavy silting and relative times of occurrence. The effects of silting on the calculated permeability values would be variable. However, in view of predominantly granular materials being tested, silting would tend to indicate lower rather than higher permeability values. It is judged that the calculated permeability values may be lower by approximately one order of magnitude than their true values. The tabulated permeability values are calculated from stabilized readings after 10 to 30 minutes of testing and are not adjusted for silting.

C-2.3 Test Review

To illustrate the limitations of the tabulated permeability values, each borehole permeability test is reviewed separately in the following:

Boring G41-C15A: Running sand was encountered while driving the casing prior to this test. Various methods to control the running sand were not successful and a well point had to be driven to the test elevation through the run-up materials. Because of these conditions, the test is not considered representative of in situ conditions.

Boring G41-E13A: Seven tests were performed at this location at depths varying from 3.4 m (11 ft.) to 58.2 m (191 ft.) below the ground surface from elevation 492.5 m (1615.7 ft.) to 437.6 m (1435.7 ft.). Test numbers 1 and 2, performed at elevations 492.5 m (1615.7 ft.) and 489.1 m (1604.7 ft.), were above the groundwater table. Although full saturation of the surrounding soil may not have been achieved, the calculated permeability values from these two tests are in reasonable agreement with each other as well as with tests 3 and 4 which were conducted below the groundwater table. Tests 3 and 4, at elevations 492.7 m (1583.7 ft.) and 476.3 m (1562.7 ft.), appear to be satisfactory and representative of in situ conditions. Test 5, at elevation 464.6 m (1523.7 ft.), was performed in a new hole 1.5 m (5 ft.) south of the original boring location. This test was affected by approximately 4.6 m (15 ft.) run-up, and therefore, is not indicative of in situ conditions. The last two tests at this location, tests 6 and 7, were at elevations 453.1 m (1486.7 ft.) and 437.6 m (1435.7 ft.). The borehole was advanced using revert drilling mud and well points were driven to the test levels to avoid running conditions. The water level vs. time data suggests slight clogging during test 6 and more severe clogging during test 7 as evidenced by a decrease in the amount of water intake with time. This decrease in test 7 was particularly noticeable and reflects a computed permeability change from $3x10^{-6}$ to $3x10^{-7}$ m/s ($9x10^{-6}$ to $9x10^{-7}$ ft./sec.) after the first three minutes of the test. There is no readily apparent reason for this decrease in permeability so it is not possible to determine which permeability value is more accurate.

Boring G41-G15A: A rising head permeability test was performed in this boring at elevation 481.9 m (1581.3 ft.) and yielded a permeability value of 2.6×10^{-5} m/s (7.8×10^{-5} ft./sec.). After this test was completed, a split spoon sample was driven at the bottom of the hole. The hole was then filled with water and a falling head permeability test performed. The falling head test yielded a significantly lower permeability value of 8.9×10^{-7} m/s (2.7×10^{-6} ft./sec.). Apparently, the sampling and silting of the borehole clogged the bottom of the hole for the falling head test.

Boring G41-G15C: Five falling head tests were performed in this boring; four above the groundwater level and one below. Tests 1 and 2, at elevations 509.3 m (1671.0 ft.) and 502.9 m (1650.0 ft.), suggest steady flow conditions to have been established quickly and the reported permeability values are based on these steady conditions.

Test 3, at elevation 496.7 m (1629.5 ft.), had a rapid drop in water level not noted in the other tests. However, the flow rate appeared steady after about 20 minutes and the reported value is based on these measurements.

Test 4, at elevation 490.4 m (1609.0 ft.), indicated an increase in water take with time. The reported value is for the first 15 minutes of the test. It is possible that the increase in flow with time was due to leakage around the casing.

The one test below the groundwater level, test 5, was performed at elevation 471.2 m (1546.0 ft.). The measurements suggest a possible silting of the hole with time. The reported permeability value is based on the measurements for the first 15 minutes of testing where the silting may have had somewhat less effect although the low results do suggest some effect.

Boring G41-J17A: The falling head test at elevation 508.9 m (1669.9 ft.) was located above the watertable. The reported permeability value is based on the flow rates for the 5 to 30 minutes time duration interval.

Boring G41-K13A: A falling head test was conducted at elevation 480.9 m (1577.7 ft.), after drilling through a 0.5 m (1.5 ft.) thick boulder below elevation 481.6 m (1579.9 ft.). Thus, the test section was 0.2 m (0.7 ft.) below the bottom of the boulder with the casing driven to the top of the boulder. The data were reduced assuming that the boulder was not broken and acted as part of the casing. However, it is very likely that leakage occurred between the casing and the boulder. Also, the boulder might have been fractured or broken during drilling. Because of these variables, the test results are considered questionable. The calculated permeability values depict decreasing permeability with time indicating a sealing of the hole. The permeability value noted in the table is the average value between 5 and 20 minutes time duration.

Boring G41-K13B: The falling head test at elevation 511.1 m (1676.8 ft.) was conducted at a level above the water table. The reported permeability value in the table is based on stabilized flow rates after 20 minutes time duration.

Boring G41-P18B: Sand run-up of approximately 1.52 m (5 ft.) was noted during the test and is therefore not considered indicative of in situ conditions.

C-3.0 LABORATORY PERMEABILITY TESTS

Several procedures of sample preparation and testing were employed to evaluate the permeability characteristics of the test pit samples. The various test procedures adopted were described in Appendix B, Section B-2.4 and the results were summarized in Table 4.2.

The specimens prepared by sedimentation using the Corps of Engineers methods, had fairly low densities since there is no mechanical compaction of the sample. Also, sedimenting of the sample can cause a moderate layering effect which would not be representative of in situ or embankment construction conditions. Two samples tested by this method developed piping along the side of the mold which was visually obvious and the other samples were also suspected of having developed piping. Because of these conditions, the results from this test procedure are not considered indicative of the permeability of the materials in their in situ condition nor their anticipated compacted condition. The permeability values determined by this procedure are believed to be much higher, possibly up to two orders of magnitude higher, than those of the in situ or compacted materials. These values have not been used in analyses for design of the waste disposal facilities.

The Constant Head tests were performed by two different methods. The first method involved the use of a triaxial apparatus with back pressure saturation and a flexible membrane along the sides of the sample. This method permits the measurement of degree of saturation by determining the "B" parameter before taking the permeability readings. Also, there did not appear to be any smearing of soil on the upper and lower porous stones and the method of preparation of the sample should not have produced an appreciable layering of the fines in the material to affect the permeability measurement. However, it is suspected that there was some increased flow at the soil-membrane interface which yielded a higher permeability value than if this flow had not occurred. It is judged that the permeability value for predominantly granular (SM) material will be slightly lower than the average indicated permeability range of $1x10^{-7}$ to $2x10^{-7}$ m/s ($3x10^{-7}$ to $6x10^{-7}$ ft./sec.) by this test method.

In the second method of Constant Head permeability test, a Proctor mold with bentonite coating on the inside surface of the mold was used. Due to the bentonite coating any piping along the side of the mold was essentially eliminated under the pressure gradients of 34 kPa to 103 kPa (5 psi to 15 psi). However, this method does not assure full saturation, which is believed to be the reason for the permeability values on the order of $2x10^{-8}$ m/s ($6x10^{-8}$ ft./sec.) which are lower than those obtained by the first test method.

C-4.0 HAZEN'S APPROXIMATION

The flow of groundwater through sands and silts depends upon the size and shape of the voids in the soil. Hazen found from numerous tests with loose filter sands that the permeability of these sands depends upon the effective particle size and the uniformity coefficients; thereby relating permeability to grain size distribution. For loose sands having a uniformity coefficient between 2 and 5, the Hazen empirical equation is:

$$k = C(D_{10})^2$$

where k is the coefficient of permeability in centimeters per second and D_{10} is the effective size (10 percent of the sample, by weight, being smaller than this size) in centimeters. C is a constant whose value ranges from 90 to 120, and a value of 100 is usually used. For soils other than loose uniform sands, permeability values computed from the Hazen equation should be considered only approximate.

Estimated coefficients of permeability for the glacial materials have been made using Hazen's approximation and the D_{10} particle sizes from the grain size curves. These estimates have been made using a value of 100 for the constant term 'C' in Hazen's equation. The grain size distribution curves give the particle diameters in millimeters. Therefore, with C=100, and grain sizes in millimeters (not centimeters), Hazen's equation may be rewritten as:

$$k = \frac{(D_{10})^2}{100}$$

with the result in meters per second.

Table C-2 presents results of permeability estimates using the above formula. The table also given the D_{10} size in millimeters and the uniformity coefficient (D_{60}/D_{10}). Table C-2 is arranged with the data categorized by glacial material type, disposal site (Site 40 and 41), boring number, and sample number.

These results are not precise determinations of soil permeability but do provide an indication of the variability of permeability which may be expected for the various materials. Where permeability measurements have been made by laboratory test or from the pump test, their data fall within the range estimated by the Hazen approximations.

TABLE C-2

PERMEABILITY ESTIMATES BY HAZEN'S APPROXIMATION

GLACIAL TILL DEPOSITS

Boring No.	Sample No.	Unified Classification	D_{60} (mm)	D_{10} (mm)	Uniformity Coefficient (D_{60}/D_{10})	Permeability (10^{-5} m/s)
TP-1	1	SM	0.60	0.040	15	1.6
TP-2	1	SM	0.78	0.060	13	3.6
TP-4	1	CL	0.20	0.0020	100	0.0040
TP-5	1	SM	0.46	0.015	31	0.23
TP-22	1	GP-GM	10	0.075	130	5.6
TP-TW-41	1	SM	0.46	0.030	15	0.90
G40-D24	6	SM	0.31	0.014	22	0.20
G40-G24	4	SW-SM	0.55	0.060	9	3.6
G40-G26	8	SM	0.40	0.024	17	0.58
G40-H27	7	SM	0.12	0.0094	13	0.088
G40-J20	7	SM	0.40	0.030	13	0.90
G40-L23	6	SM	0.38	0.030	13	0.90
G40-M15	2	SM	0.33	0.0065	51	0.081
	38	SM	0.34	0.0016	210	0.0026
	39	SM	0.46	0.0090	51	0.081
G40-P10	6	SM	0.61	0.032	19	1.0
G40-P17	6	SP-SM	0.76	0.13	6	17
	16	SP-SM	0.40	0.021	19	0.44
G41-C15	32	SP-SM	1.2	0.076	16	5.8
G41-D18	5	SP-SM	0.55	0.087	6	7.6
G41-E13	3	SM	0.42	0.041	10	1.7
	5	SM	0.31	0.041	8	1.7
	9	SM	3.6	0.060	60	3.6
	13 & 14	SM	0.54	0.019	28	0.36
G41-E15	8	SP-SM	2.8	0.16	18	26
G41-E17	7	SM	0.45	0.0080	56	0.064
	24	SP-SM	4.0	0.11	36	12
G41-G11	1	SM	0.33	0.0014	240	0.0020
	14	SP-SM	1.4	0.076	18	5.8
	15	SM	0.42	0.010	42	0.10
G41-G14A	1	SP-SM	1.7	0.20	9	40
	2	GP-GM	11	0.22	50	48
	3	SM	0.30	0.0090	33	0.081
	4	SM	0.37	0.013	28	0.17
	5	SM	0.35	0.023	15	0.53
	7	SM	0.38	0.030	13	0.90
	9	SM	0.42	0.032	13	1.0
	10	SM	0.40	0.044	9	1.9

TABLE C-2

PERMEABILITY ESTIMATES BY HAZEN'S APPROXIMATION (Continued)

GLACIAL TILL DEPOSITS (Continued)

Boring No.	Sample No.	Unified Classification	D_{60} (mm)	D_{10} (mm)	Uniformity Coefficient (D_{60}/D_{10})	Permeability (10^{-5} m/s)
G41-G14B	3	SM	0.32	0.023	14	0.53
	4	SM	0.32	0.021	15	0.44
	5	SM	0.47	0.024	20	0.58
	6	SP-SM	7.5	0.11	68	12
	7	SM	0.56	0.050	11	2.5
	9	SM	0.097	0.0078	12	0.061
	10	ML	0.027	0.0017	16	0.0029
	11	SM	3.8	0.013	290	0.17
G41-G15	1	SM	2.3	0.010	230	0.10
	5A & 5B	SM	0.28	0.0030	93	0.0090
	8	SM	0.33	0.030	11	0.90
	17	SM	0.37	0.020	19	0.40
	27	SM	0.30	0.0054	56	0.029
G41-G15A	3	SM	0.54	0.040	14	1.6
	4	SM	0.45	0.020	23	0.40
	7	GM	5.4	0.0015	3600	0.0023
	10B	SM	0.32	0.0094	34	0.088
G41-G15B	2A	GP-GM	7.3	0.13	56	17
G41-G21	12	SM	0.45	0.015	30	0.23
	20	SM	0.36	0.030	12	0.90
G41-H13	1	SM	0.27	0.0054	50	0.029
G41-H17	3	SP	1.5	0.21	7	44
	6	GP	15	0.21	71	44
G41-H18A	3	SM	0.24	0.0050	48	0.025
G41-J17	3	SM	0.70	0.023	30	0.53
	6	SM	0.51	0.0050	100	0.025
G41-J18	7	SP	4.6	0.26	18	68
	11	SM	0.36	0.019	19	0.36
	15	SP-SM	5.0	0.15	33	23
G41-K13	1	SM	0.37	0.0020	190	0.0040
	9A & 9B	SW-SM	1.5	0.12	13	14
	14	SM	0.97	0.012	81	12
G41-K13A	16	SP-SM	2.5	0.098	26	9.6
	23A	SP-SM	0.44	0.077	6	5.9
G41-K13B	1	ML	0.064	0.0030	21	0.0090
	3	CL-ML	0.031	0.0023	13	0.0053
	5	SM	0.53	0.030	18	0.90
G41-K21	8	SM	0.60	0.015	40	0.23
G41-M11	14	SP-SM	0.63	0.060	11	3.6

TABLE C-2

PERMEABILITY ESTIMATES BY HAZEN'S APPROXIMATION (Continued)

GLACIAL TILL DEPOSITS (Continued)

Boring No.	Sample No.	Unified Classification	D_{60} (mm)	D_{10} (mm)	Uniformity Coefficient (D_{60}/D_{10})	Permeability (10^{-5} m/s)
G41-P16	3	SW-SM	1.0	0.090	11	8.1
	12	SP-SM	1.7	0.076	22	5.8
G41-L11	4	SM	0.40	0.010	40	0.10
G41-L15	2	SM	0.44	0.012	37	0.14
	9	SP-SM	0.43	0.076	6	5.8
G41-L19	2	SM	0.62	0.016	39	0.26
G41-L23	8	SM	0.33	0.0040	83	0.016
G41-L25	5	SM	0.80	0.015	53	0.23
	14	SW	5.8	0.20	29	40
G41-P18	10	SM	0.42	0.0036	120	0.013
	12	SP-SM	3.6	0.15	24	23
G41-P24	7	SM	0.60	0.027	22	0.73
	26B	SW-SM	3.0	0.076	39	5.8
G41-M24	1	SM	0.43	0.013	33	0.17
G41-N21	3	SP-SM	2.0	0.070	29	4.9

COARSE GRAINED STRATIFIED DRIFT

Boring No.	Sample No.	Unified Classification	D_{60} (mm)	D_{10} (mm)	Uniformity Coefficient (D_{60}/D_{10})	Permeability (10^{-5} m/s)
G40-D24	22	SP	0.31	0.16	2	26
G40-G24	14	SP	0.46	0.12	4	14
G40-G26	19	SP	0.50	0.17	3	29
G40-H13	5	SP	0.43	0.20	2	40
G40-H16	18	SP-SM	0.44	0.14	3	20
	24	SP-SM	0.31	0.030	10	0.90
G40-K13	4	SP-SM	0.30	0.13	2	17
	6B	SP-SM	0.43	0.16	3	26
G40-L23	17	SP	0.43	0.18	2	32
G40-M15	22	SP-SM	0.40	0.094	4	8.8
G40-P10	11	SP-SM	0.50	0.14	4	20
G40-P20	15	SP-SM	0.41	0.13	3	20
G40-R23	15	SP-SM	0.34	0.090	4	8.1
G40-S11	12	SP-SM	0.95	0.18	5	32
G41-C15	3	SP	0.27	0.16	2	26
	25	SP-SM	0.43	0.10	4	10
G41-E13	25	SP	0.31	0.14	2	20
	30	SP-SM	0.22	0.11	2	12
	34	SP-SM	0.38	0.12	3	14

TABLE C-2

PERMEABILITY ESTIMATES BY HAZEN'S APPROXIMATION (Continued)

COARSE GRAINED STRATIFIED DRIFT (Continued)

Boring No.	Sample No.	Unified Classification	D_{60} (mm)	D_{10} (mm)	Uniformity Coefficient (D_{60}/D_{10})	Permeability (10^{-5} m/s)
G41-E19A	13A	SP	0.27	0.11	2	12
G41-F24	15	SW-SM	1.3	0.15	9	23
G41-G14A	13	SP-SM	0.52	0.098	5	9.6
	14	SP	0.43	0.18	2	32
	15	SP-SM	0.35	0.10	4	10
	16	SP-SM	0.24	0.092	3	8.5
	17	SP-SM	0.23	0.080	3	6.4
G41-G19	16	SP-SM	1.5	0.10	15	10
G41-G21	18	SP-SM	0.44	0.15	3	23
G41-H18	9	SP	0.54	0.16	3	26
G41-H18A	4	SP	2.4	0.25	10	63
G41-K13	11	SP-SM	0.30	0.076	4	5.8
G41-K21	14	SP	0.60	0.26	4	68
G41-K26	18	SP	0.25	0.15	2	23
G41-M11	5	SP	0.26	0.15	2	23
G41-L23	15	SP	1.8	0.30	6	90
G41-N21	26	SP	0.79	0.20	4	40
G41-P24	4	SP-SM	0.80	0.16	5	26
	23	SP-SM	0.43	0.076	3	5.8

FINE GRAINED STRATIFIED DRIFT

G40-H16	27	ML	0.072	0.010	7	0.10
G40-M15	32	SP-SM	0.18	0.076	2	5.8
G41-C15	31	ML	0.029	0.0054	5	0.029
G41-E17	30	ML	0.065	0.020	3	0.40
	31	ML	0.020	0.0016	13	0.0026
G41-G14A	18	ML	0.060	0.020	3	0.40
G41-G14B	1	SM	0.14	0.038	4	1.4
	2	ML	0.061	0.023	3	0.53

OUTWASH DEPOSITS

G41-P18B	2	SP	0.25	0.12	2	14.4

TABLE C-2

PERMEABILITY ESTIMATES BY HAZEN'S APPROXIMATION (Continued)

LACUSTRINE SEDIMENTS

Boring No.	Sample No.	Unified Classification	D_{60} (mm)	D_{10} (mm)	Uniformity Coefficient (D_{60}/D_{10})	Permeability (10^{-5} m/s)
G40-H16	2	SM	0.16	0.024	7	0.58
G41-C15	8	SM	0.13	0.050	3	2.5
	11	ML	0.068	0.0015	45	0.0023
G41-C15B	2A	PT	0.23	0.020	12	0.40
G41-G12	1	ML	0.034	0.0021	16	0.0044
G41-H18A	2	SM	0.074	0.0038	19	0.014
G41-P18	5	ML	0.016	0.0037	4	0.014
G41-P18B	Tube	ML	0.0095	0.0014	7	0.0020
	8	ML	0.017	0.0045	4	0.020

APPENDIX D

BEDROCK CONTOURS

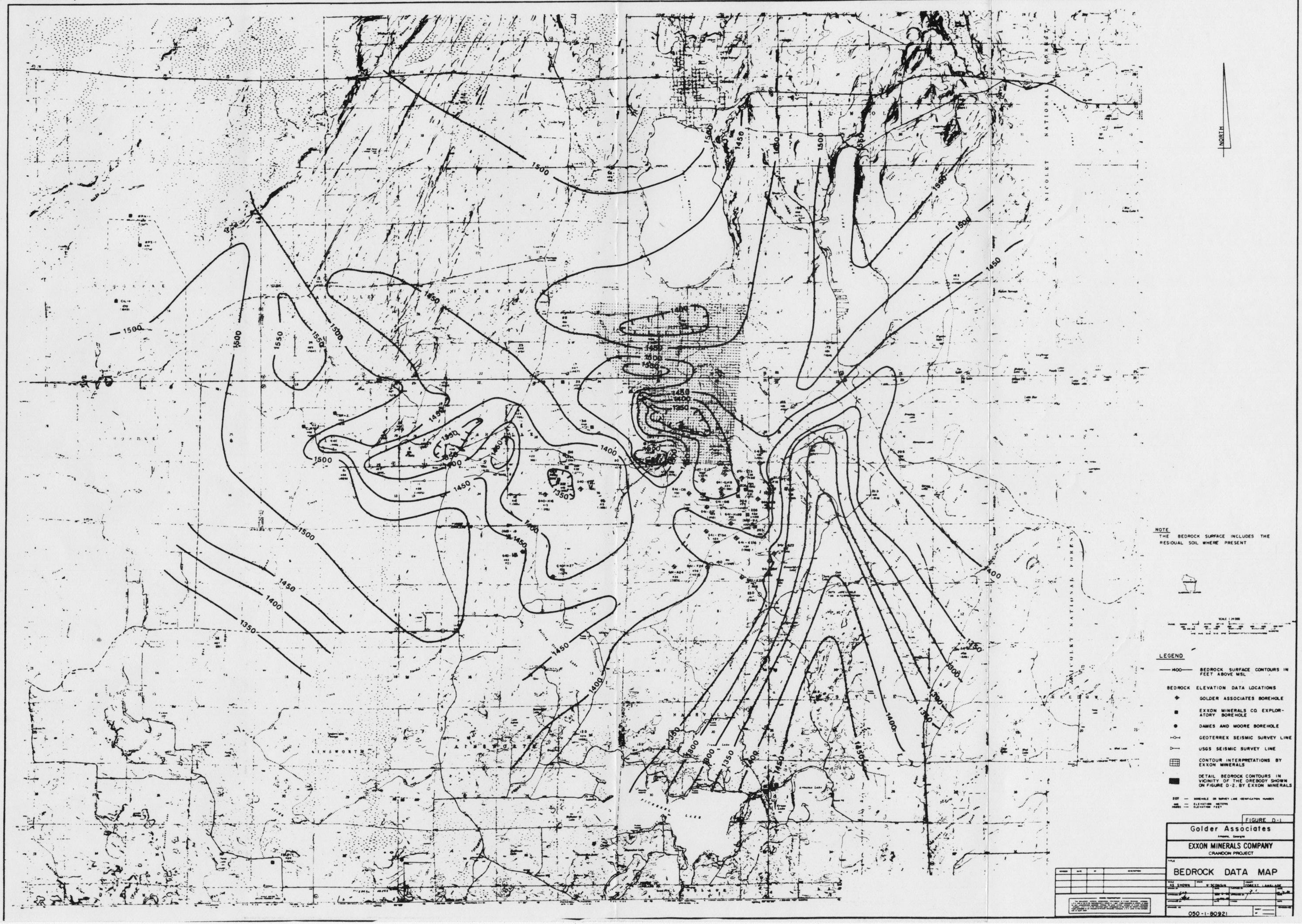
A contour map of the bedrock and weathered rock was prepared for the Crandon Project area. The boundaries for the map approximately correspond to the surface watershed divides and represent an area which will encompass future groundwater modeling efforts. Data for this map was obtained over an area of about 260,000 km^2 (100 sq. mi.).

The rock surface map is the result of the synthesis and interpretation of various data. The data used to develop the bedrock contour map were from:

1. Test borings supervised by Golder Associates;
2. Refraction seismic survey program developed by Golder Associates, performed by Geoterrex Limited;
3. Test borings supervised by Dames & Moore;
4. Mineral exploration borings supervised by Exxon Minerals Company; and
5. Refraction seismic survey program conducted by United States Geological Survey (USGS).

The locations of these data are shown on a composite USGS quadrangle basemap, Figure D-1, Bedrock Data Map. Figure 2.3, Bedrock Contour Map, shows contours as a metric basemap which covers a smaller area than shown on Figure D-1.

The primary purpose for determining the bedrock contours was to define the trends of the base of the glacial overburden which would thus set the base of the glacial aquifer. For this purpose, weathered rock and/or sound rock were considered to define the basement surface.


NORTH
NATIONAL
NICOLET
NICOLET NATIONAL FOREST
1500
1450
1400
1350
1550
NOTE
THE BEDROCK SURFACE INCLUDES THE RESIDUAL SOIL WHERE PRESENT
LEGEND
1400 BEDROCK SURFACE CONTOURS IN FEET ABOVE MSL
BEDROCK ELEVATION DATA LOCATIONS
GOLDER ASSOCIATES BOREHOLE
EXXON MINERALS CO. EXPLORATORY BOREHOLE
DAMES AND MOORE BOREHOLE
GEOTERREX SEISMIC SURVEY LINE
USGS SEISMIC SURVEY LINE
CONTOUR INTERPRETATIONS BY EXXON MINERALS
DETAIL BEDROCK CONTOURS IN VICINITY OF THE OREBODY SHOWN ON FIGURE D-2. BY EXXON MINERALS
FIGURE D-1
Golder Associates
EXXON MINERALS COMPANY
CRANDON PROJECT
BEDROCK DATA MAP
AS SHOWN
WISCONSIN
FOREST, LANGLADE
050-1-80921

The detailed test boring data for those borings supervised by Golder Associates are provided in Volumes 2 and 3 of this report. Detailed logs of those borings supervised by Dames & Moore are in Reference 6. Exploration borings supervised by Exxon included those at the orebody and those in surrounding areas. The plan location density of drill holes and rock contouring done by Exxon around the orebody was in much greater detail than shown on the Bedrock Contour Map in Figure 2.3. This detailed information is shown on Figure D-2 as provided by Exxon. A list of the locations and bedrock elevations of other Exxon exploration holes was provided in correspondence of February 26, 1979, a copy of which is included at the end of the text of this Appendix.

Geophysical data was obtained near the Mole Lake area by the USGS. The data from this seismic program was provided in correspondence of May 8, 1980. A copy of this data is included after the copy of the Exxon exploration drilling correspondence at the end of the text of this Appendix. Depth to rock at each end of the survey line was given as data. These depths were converted to elevations and then averaged to provide a single data point for the bedrock surface interpretation.

Seismic exploration was also undertaken by Exxon in an area north of the orebody around Swamp Creek. This area is highlighted on Figure D-1. Bedrock contours shown on Figures D-1 and 2.3 in this area were provided by Exxon. This survey was performed by Geoterrex Ltd., of Lakewood, Colorado during July - October, 1981.

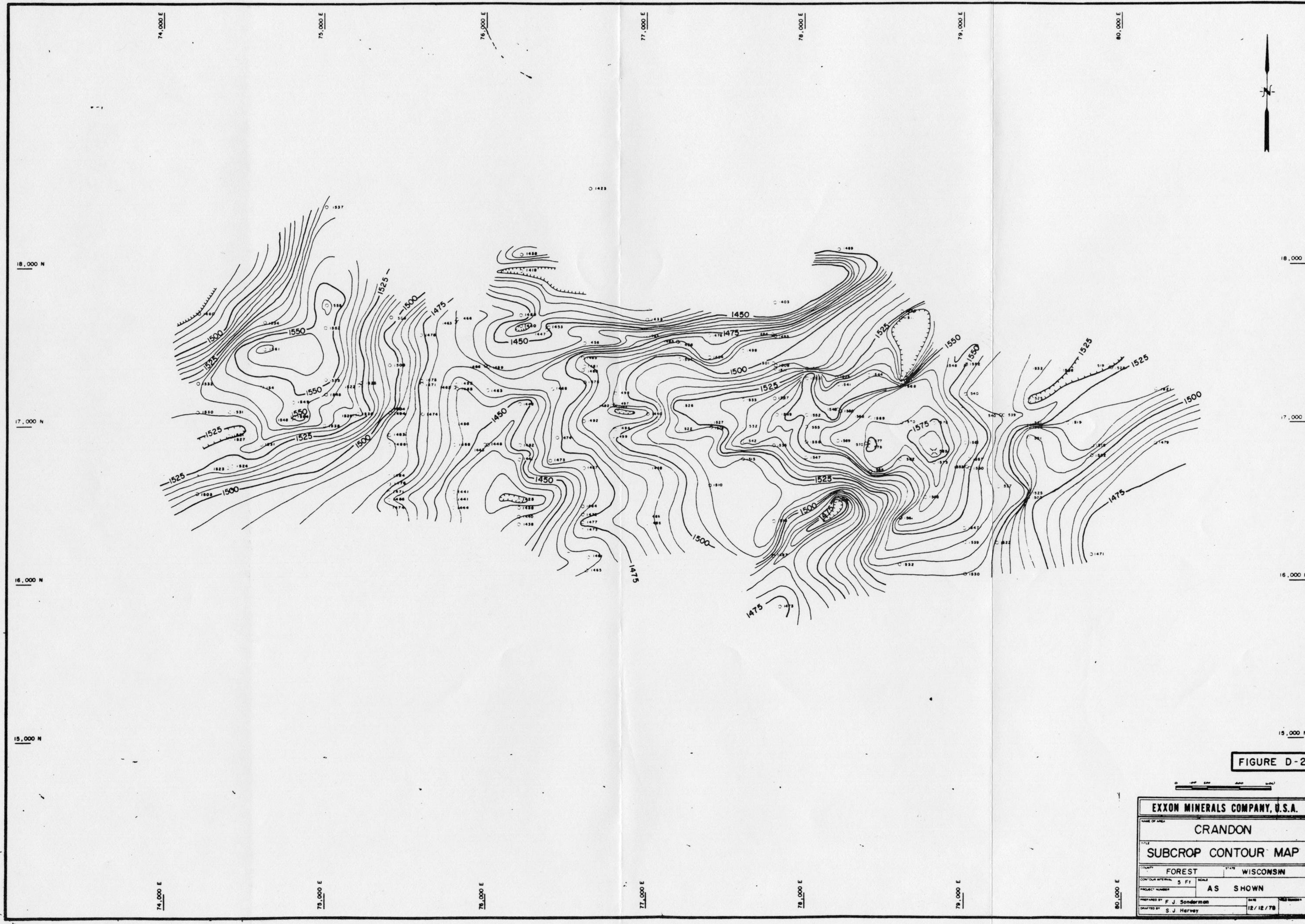

74,000 E
75,000 E
76,000 E
77,000 E
78,000 E
79,000 E
80,000 E
18,000 N
17,000 N
16,000 N
15,000 N
N
1450
1475
1500
1525
1550
1575
EXXON MINERALS COMPANY, U.S.A.
NAME OF AREA
CRANDON
TITLE
SUBCROP CONTOUR MAP
COUNTY FOREST
STATE WISCONSIN
CONTOUR INTERVAL 5 Ft
SCALE AS SHOWN
PROJECT NUMBER
PREPARED BY F. J. Sonderman
DRAFTED BY S. J. Harvey
DATE 12/12/78

FIGURE D-2

An additional seismic program was performed to provide rock contour data over a larger area than that covered by the other exploration programs previously described. This program was carried out by Geoterrex Ltd., of Lakewood, Colorado during March 1980 and observed by representatives of Golder Associates and Exxon. Individual locations for the refraction seismic survey were selected to provide spot coverage of the study area. Test locations were closer together near the proposed waste disposal areas, 1.6 to 3.2 km (1 to 2 mi.) apart, than near the perimeter of the study area, where they are up to almost 6.4 km (4 mi.) apart. Locations were also selected based on ease of site access and limitation of disruption to the public. The final locations were selected to be as far from public or private buildings as possible, over terrain with topography being as flat as possible and as close as possible to their pre-planned locations. The final 25 survey locations are shown on Figure D-1, and in detail in Ref. 8.

Data from the Geoterrex program shows the interpreted bedrock surface elevations along the line of geophones at each survey location. The average rock elevation along each survey line was determined by averaging the rock elevations at 15.2 m (50 ft.) intervals from the center of the survey line. These average elevations were used as spot data for the bedrock contour determination and are shown on Figure D-1. Details of the Geoterrex program are presented in Ref. 8.

EXXON MINERALS COMPANY, U.S.A.
POST OFFICE BOX 813 • RHINELANDER, WISCONSIN 54501

February 26, 1979

RECEIVED
FEB 28 1979
EXXON MINERALS CO., U.S.A.

MEMORANDUM

TO: C. E. Orsen

FROM: F. J. Sonderman

RE: Drill Hole Information

Per your request, the following regional drill hole data is available for incorporation in the Golder Study.

Hole No.

CUR-1	Center NE/4, SW/4, NE/4 Sec. 30, 35N, 12E. Approximate Elevation: 1,580. Vertical Depth to BR: 44'.
CUR-2	SW/4, NE/4, NW/4, NW/4 Sec. 29, 35N, 12E. Approximate Elevation: 1,545. Vertical Depth to BR: 22'.
HL-1	NE/4, NW/4, SW/4, NE/4 Sec. 36, 34N, 12E. Approximate Elevation: 1,540. Vertical Depth to BR: 154'.
HR-1	Center N1/2, NE/4, SW/4, Sec. 31, 34N, 12E. Approximate Elevation: 1,540. Vertical Depth to BR: 99'.
WRN-1	Center SE/4, SE/4, SE/4 Sec. 3, 35N, 11E. Approximate Elevation: 1,613. Vertical Depth to BR: 66'.
WRS-1	Center W/2, SW/4, NW/4, Sec. 11, 35N, 11E. Approximate Elevation: 1,607. Vertical Depth to BR: 51'.
NA-1	NE/4, NW/4, SE/4, SE/4, Sec. 1, 35N, 11E. Approximate Elevation: 1,660. Vertical Depth to BR: 153'.
CIL-1	SW/4, NE/4, SW/4, NE/4, Sec. 15, 35N, 11E. Approximate Elevation: 1,592. Vertical Depth to BR: 49'.

These are Exxon drill holes within a 10-mile radius of the Crandon site. There are a few competitor drill holes which may be available from the DNR. I will attempt to obtain the necessary data and forward it to you.

Please let me know if I can be of further assistance.

Frank J. Sonderman

FJS/jp

EXXON MINERALS COMPANY, U.S.A.
POST OFFICE BOX 813 • RHINELANDER WISCONSIN 54501

March 6, 1979

MEMORANDUM

RECEIVED
MAR 7 1979
EXXON MINERALS CO., U. S. A.

TO: C. E. Orsen

FROM: F. J. Sonderman

RE: Bedrock Elevations

The following is a summary of bedrock data for drill holes adjacent to the Crandon ore deposit:

Hole No.	Collar Elev.	Vert. Depth to B.R.	Location
134	1,583	111	Center, SE/4, NW/4, Sec. 25, T35N, R12E
135	1,590	92	Center, NE/4, SE/4, Sec. 23, T35N, R12E
136	1,616	225	NE/4, SE/4, SE/4, Sec. 26, T35N, R12E
199	1,718	303	SE/4, SE/4, NE/4, Sec. 32, T35N, R13E
200	1,676	274	NW/4, NE/4, SW/4, Sec. 32, T35N, R13E
201	1,607	230	NE/4, NE/4, NE/4, Sec. 35, T35N, R12E
202	1,607	262	NW/4, SE/4, NE/4, Sec. 35, T35N, R12E
203	1,664	238	NW/4, NW/4, NW/4, Sec. 4, T34N, R13E
204	1,704	270	NW/4, NE/4, SE/4, Sec. 32, T35N, R13E
205	1,694	272	NE/4, SE/4, SE/4, Sec. 32, T35N, R13E
206	1,698	305	SW/4, SE/4, NE/4, Sec. 32, T35N, R13E
207	1,596	268	SW/4, SW/4, NE/4, Sec. 33, T35N, R13E
208	1,608	269	NW/4, SE/4, NE/4, Sec. 35, T35N, R12E

Please advise if additional information for these holes is required.

Frank

Frank J. Sonderman

FJS/jp

United States Department of the Interior

GEOLOGICAL SURVEY

Water Resources Division
1815 University Avenue
Madison, Wisconsin 53706
608/262-2488 (FTS 262-2488)

May 8, 1980

Mr. Dave Heller
Golden Associates
5125 Peachtree Road
Atlanta, Georgia 30341

Dear Dave,

Unfortunately, I cannot send you a copy of our bedrock topo maps for the Mole Lake vicinity. It is against the policy of the USGS to release interpretive material until it has been approved by our Director.

I can, however, send you the raw data obtained during our study. It is enclosed.

If you have any questions, please feel free to call.

Sincerely,

For the District Chief

Bob Lidwin

R. A. Lidwin
Hydrologist

RAL/bjh
Enclosures

Mole Lake Seismic Data

The following is seismic results for the 21 lines indicated on the accompanying base map. Data is presented according to numbered layers. For each layer, the layer number is given, the seismic velocity of the layer in ft/sec, the depth at the "A" end of line, and the depth at the "B" end of line is given. All depths are in feet. The "A" and "B" ends of the lines are indicated on the base map. Following each layer is an interpretive remark.

LAYER	V	D_A	D_B	INTERPRETATION
LINE 1				
1	889	-	-	Unsaturated sand.
2	4866	9	12	Water table.
3	12638	135	184	Bedrock dipping toward B. Perhaps somewhat weathered.
LINE 2				
1	1176	-	-	Unsaturated till.
2	6635	17	14	Water table.
3	15238	161	169	Bedrock with zero dip component.
LINE 3				
1	1500	-	-	Surface material.
2	5400	17	22	Water table.
				Bedrock not seen, but is estimated to be deeper than 175 ft.
LINE 4				
1	1371	-	-	Glacial till.
2	5403	30	33	Water table.
3	14987	120	136	Bedrock.
LINE 5				
1	1450	-	-	Glacial till.
2	5429	8	8	Water table near surface.
3	17920	33	36	Bedrock.
LINE 6				
1	675	-	-	Sandy surface layer.
2	5405	14	11	Water table.
3	9550	115	102	Weathered bedrock? (lower velocity).
LINE 7				
1	1270	-	-	Glacial till.
2	5474	23	22	Water table.
3	12528	159	193	Bedrock.

LINE 8

Line unworkable due to seismic noise levels. Attempted on two different days.

LINE 9

1	1176	-	-	Glacial till.
2	5333	12	11	Water table.
3	11694	144	157	Bedrock.

LINE 10

1	1250	-	-	Sandy till.
2	5063	15	17	Water table.
3	9305	124	172	Weathered bedrock.

LINE 11

1	870	-	-	Sandy till.
2	5049	9	10	Water table.
3	15560	144	151	"Hard" bedrock.

LINE 12

Unworkable because of highway.

LINE 13

1	1818	-	-	Glacial till of drumlin.
2	16818	16	21	Underlain with un[illegible]athered bedrock near surface.

LINE 14

1	1000	-	-	Glacial till.
2	6388	11	11	Water table.
3	20094	243	241	Abnormally high velocity bedrock.

LINE 15

1	1250	-	-	Glacial till.
2	5037	17	22	Water table.
3	15525	111	84	Bedrock.

LINE 16

1	1416	-	-	Glacial till showing evidence of compaction.
2	22855	21	17	Layer 2 is high velocity bedrock core of drumlin. No water table apparent.

LINE 17

1	1340	-	-	Glacial till deeper than most.
2	9784	37	40	Water saturated clay? Bedrock apparent in data but depth calculation difficult. Probably greater than 125 ft.

LINE 18

1	1280	-	-	Sand.
2	6116	15	18	Water table.
3	11341	255	148	Weathered bedrock.

LINE 19

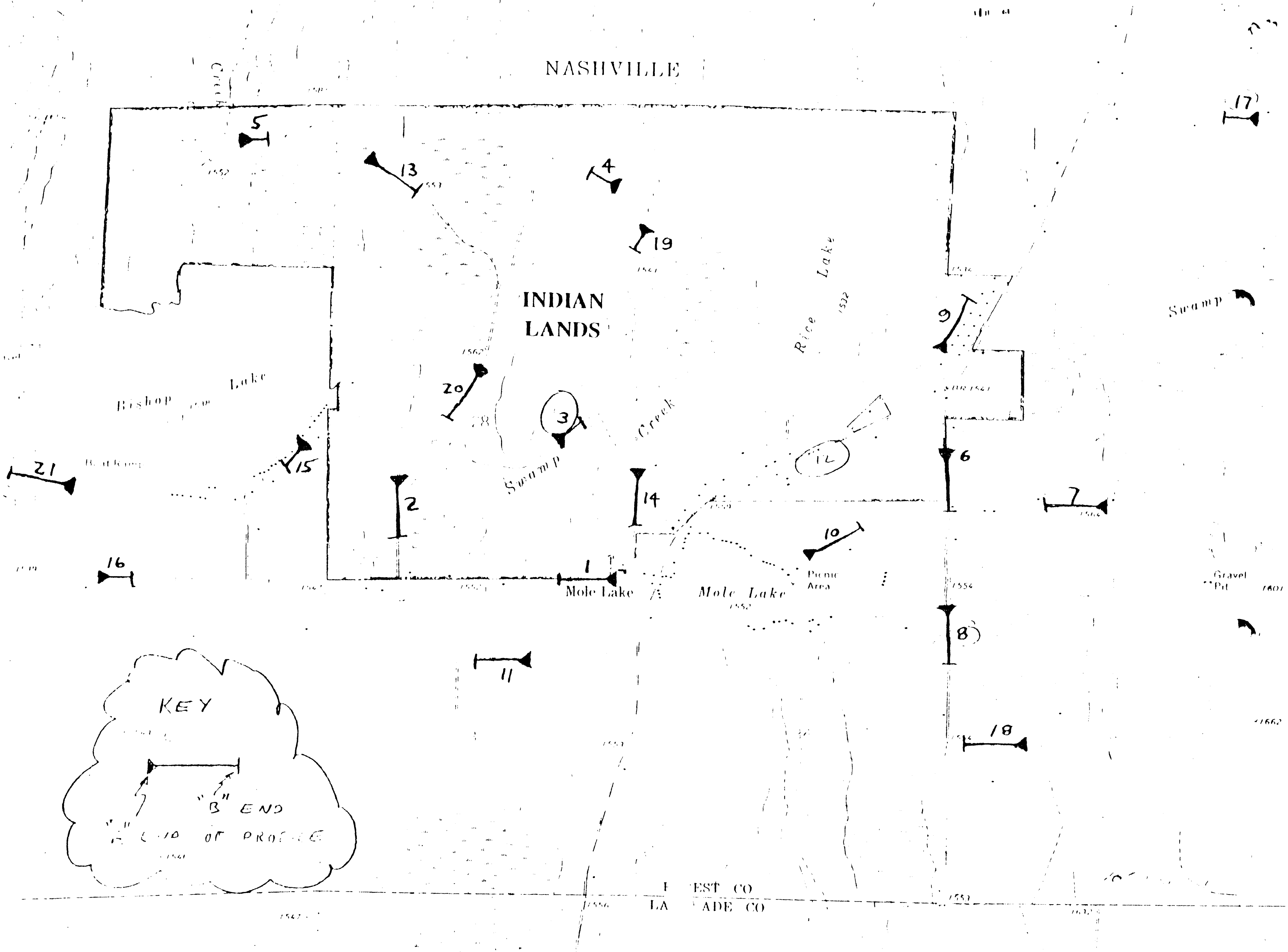
1	600	-	-	Sand.
2	5518	4	3	Water table.
3	14545	57	79	Bedrock.

LINE 20

1	17914	95	95	Glacial till of drumlin shows continuous compaction to "hard" bedrock at 95 ft. No water table apparent.

LINE 21

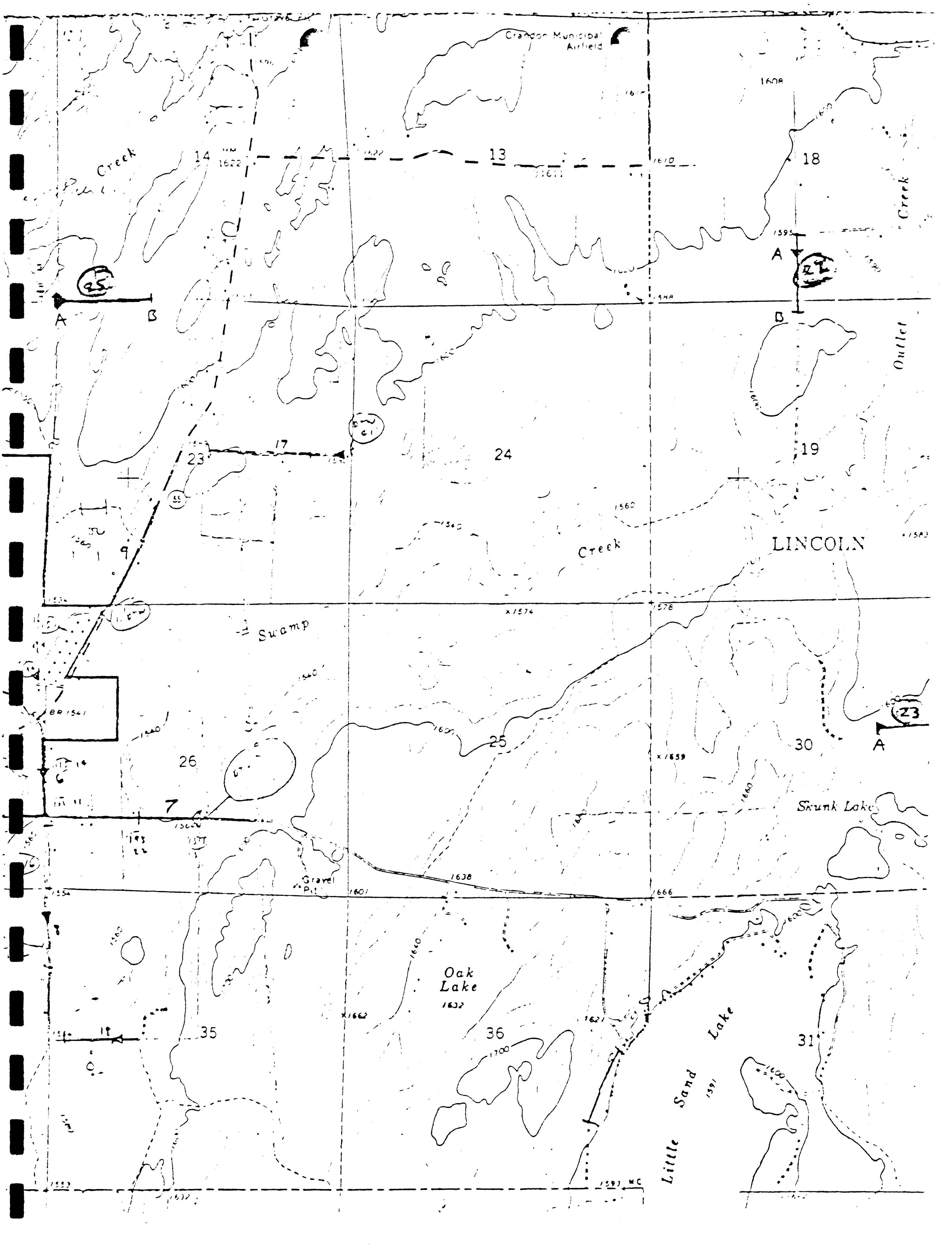
1	600	-	-	Glacial till.
2	5882	4	6	Water table.
3	15526	106	79	"Hard" bedrock dipping down toward the east.


NASHVILLE
INDIAN LANDS
Rice Lake
Bishop Lake
Swamp
Creek
Mole Lake
Mole Lake
Picnic Area
Gravel Pit
Swamp
KEY
"A" END OF PROFILE
"B" END
FOREST CO
LANGLADE CO
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21

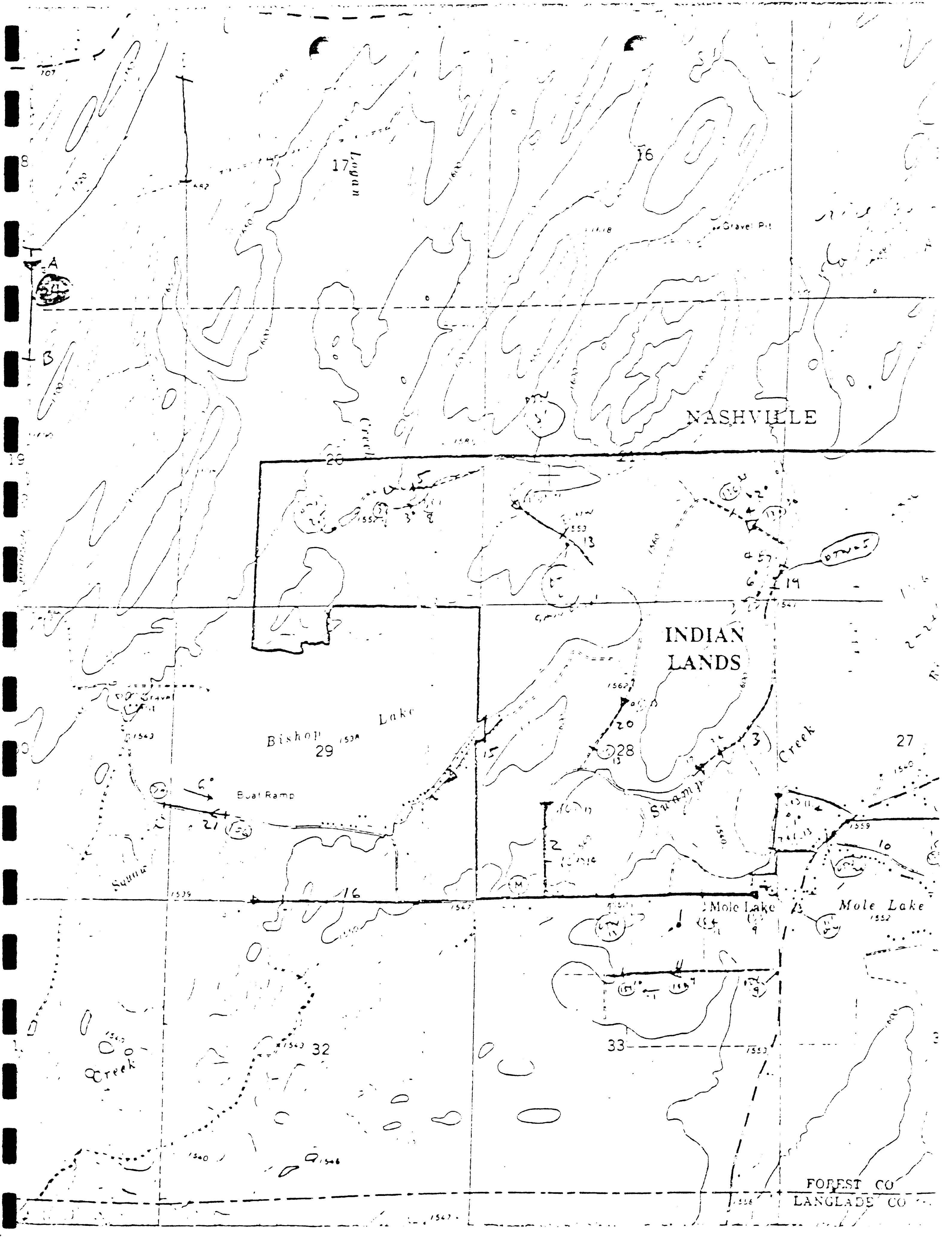
Additional Mole Lake Seismic Data

The following is seismic results for 22 to 25 lines indicated on the accompanying base map. Data is presented according to numbered layers. For each layer, the layer number is given, the seismic velocity of the layer in ft/sec, the depth at the "A" end of line, and the depth at the "B" end of line is given. All depths are in feet. The "A" and "B: ends of the lines are indicated on the base map. Following each layer is an interpretive remark.

LAYER	V	D_A	D_B	REMARKS
LINE 22				
1	1240	0	0	Glacial till.
2	6255	9	9	Water table at 9 ft.
3	?	236	168	Depth at A is maximum, may be less to bedrock.
LINE 23				
1	1756	0	0	Compact glacial till.
2	7949	24	26	Water table, saturated clay?
3	?	314	256	Depth to bedrock relatively uncertain due to short spread.
LINE 24				
1	1193	0	0	Glacial till.
2	5419	18	19	Water table.
3	18450	116	104	Good bedrock data.
LINE 25				
1	1343	0	0	Glacial till.
2	5330	44	37	Water table.
3	19360	195	121	Good bedrock data.



Crandon Municipal Airfield
Creek
14
13
18
Creek
A
B
A
B
Outlet
17
23
24
19
LINCOLN
Creek
9
Swamp
26
25
30
A
7
Skunk Lake
Gravel Pit
1638
Oak Lake
35
36
31
Little Sand Lake



NASHVILLE
INDIAN
LANDS
Bishop Lake
29
Logan
17
16
20
28
27
32
33
Boat Ramp
Gravel Pit
Swamp Creek
Mole Lake
Creek
FOREST CO
LANGLADE CO
A
B

APPENDIX E

PUMP TEST AND ANALYSES

The following pages of Appendix E contain the Management Summary portion, pages -i- through -ix-, of the Pump Test and Analyses, Crandon Project Waste Disposal System, Project Report 4, September, 1981, by Golder Associates. This summary presents a brief description of the test well installation, observation well installations, test performance, and geohydrologic model of the test site from the data analyses. Details are provided in the main text and appendices of the report.

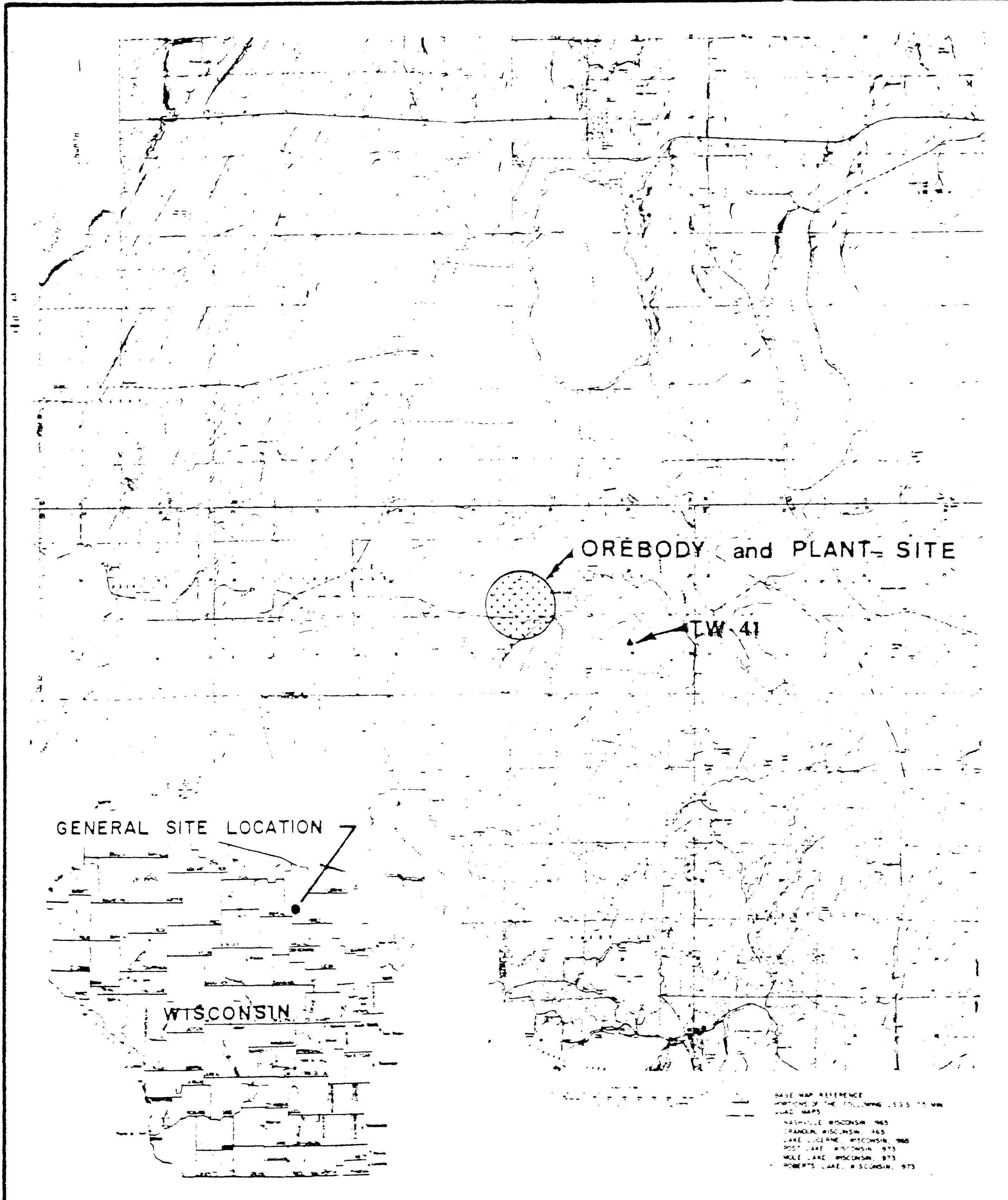
MANAGEMENT SUMMARY

Exxon Minerals Company is evaluating the feasibility of developing a waste disposal facility for a copper/lead/zinc mine and mill complex in an area south of Crandon, Wisconsin. As a part of the investigation of the geohydrologic system a major pump test was conducted in the summer of 1980 at one of the potential disposal areas known as Site 41. The location of the test site is shown on Figure S-1.

The geology of the pump test site is essentially as follows:

- An upper layer of till, 190 ft. (57.9 meters) thick, of which the lower 80 ft. (24.4 meters) is saturated.
- A middle layer of stratified drift, 70 ft. (21.3 meters) thick, of higher hydraulic conductivity than the till.
- A lower layer of till, and some fine stratified drift, 70 ft. (21.3 meters) thick, of lower hydraulic conductivity than the middle layer.
- A base of bedrock, of substantially lower hydraulic conductivity than any of the granular materials overlying it.

The installations for the pump test were comprised of a test well, 13 primary observation wells which were read regularly, and 16 secondary observation wells which were read less frequently. The test well and most of the primary observation wells were installed specifically for the test, while the remainder of the observation wells had been installed as part of previous subsurface exploration and monitoring programs. The test well and observation well locations are shown on Figure S-2.



SITE LOCATION PLAN

FIGURE S-1

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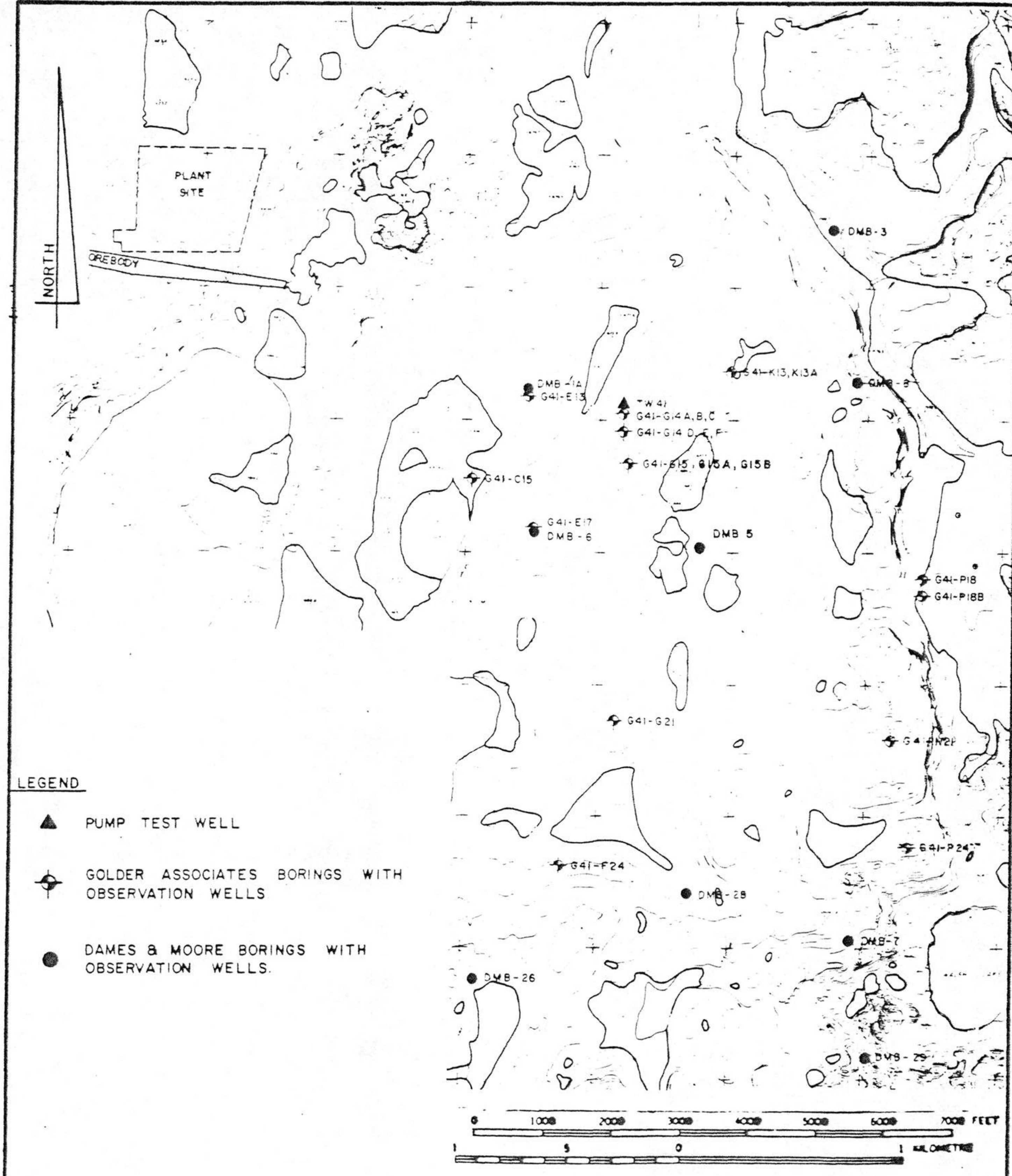
Date 7-31-81		Checked JFC
Job No. 786085		Reviewed GHC



PUMP TEST LOCATION PLAN

FIGURE S-2

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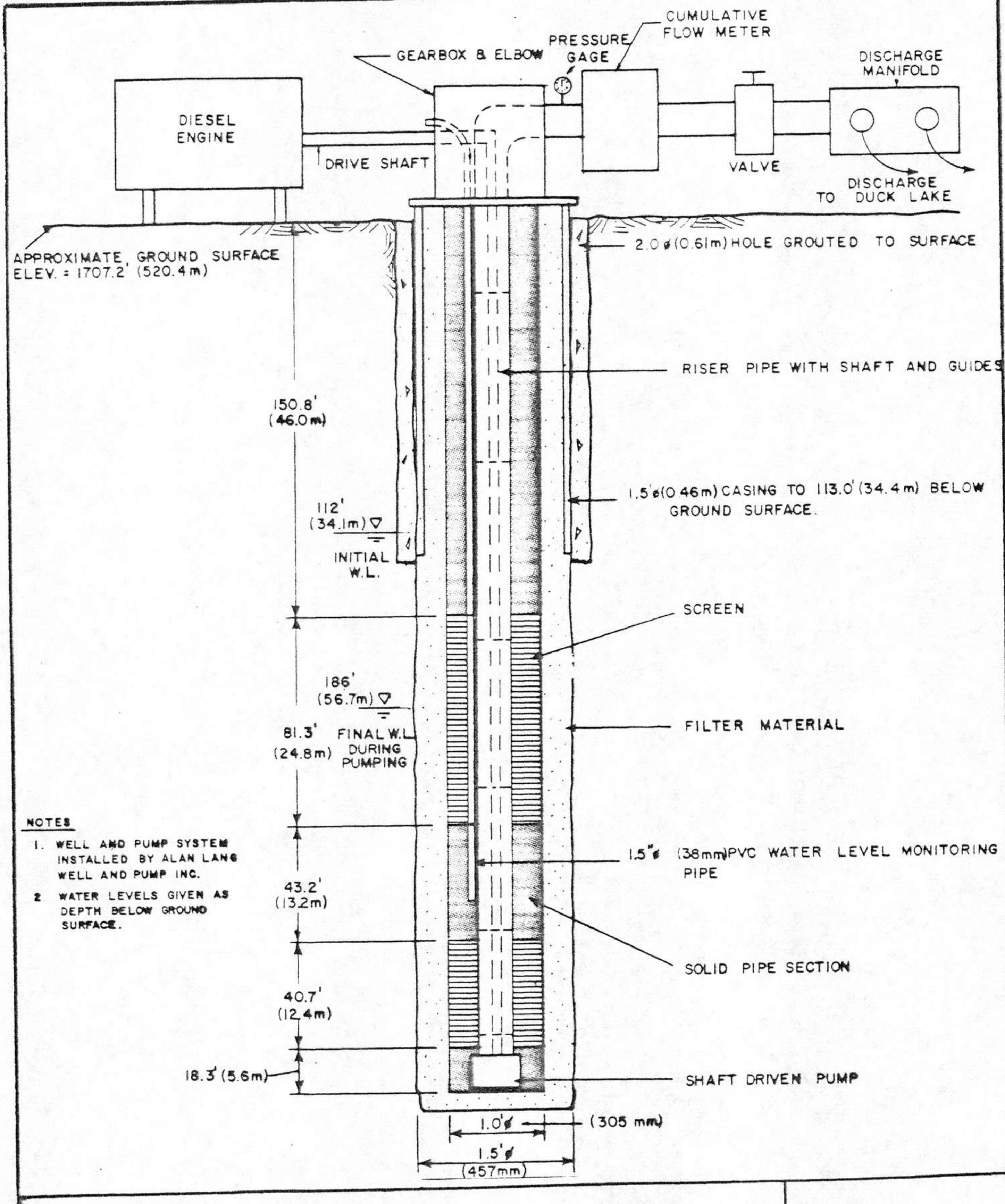
The test well construction and pump arrangement are shown in Figure S-3. The well is screened over essentially the full depth of saturated material, gravel packed, and has grouted surface casing through the unsaturated till material. A shaft driven diesel powered pump with a flow capacity of 1500 gpm (0.095 cubic meters per second) was used in the main test, while a smaller, nominal 400 gpm (0.025 cubic meters per second), submersible electric pump was used in preliminary testing.

Observation wells were completed at various elevations and various distances from the test well so as to observe the behavior of the entire system during the test. Some observation wells were completed so as to monitor water pressures at essentially one level in the groundwater system, by sealing a screened standpipe tip at that location. Typical installation details are shown in Figure S-4.

Prior to the beginning of the main pump test, a flow velocity profile of the test well was obtained in order to evaluate the hydraulic conductivity of the materials penetrated by the well. This test was performed on June 6, 1980, using the Johnson flow profiler at a well production of about 530 gpm (0.033 cubic meters per second).

The main well test was conducted over the period from June 6, 1980 to September 10, 1980. The well was pumped at an average rate of 1420 gpm (0.090 cubic meters per second) for 24 days, starting on June 27, 1980, producing a maximum drawdown of 73 ft. (22 meters) at the well. The observation



SCHEMATIC OF TEST WELL SETUP

FIGURE S-3

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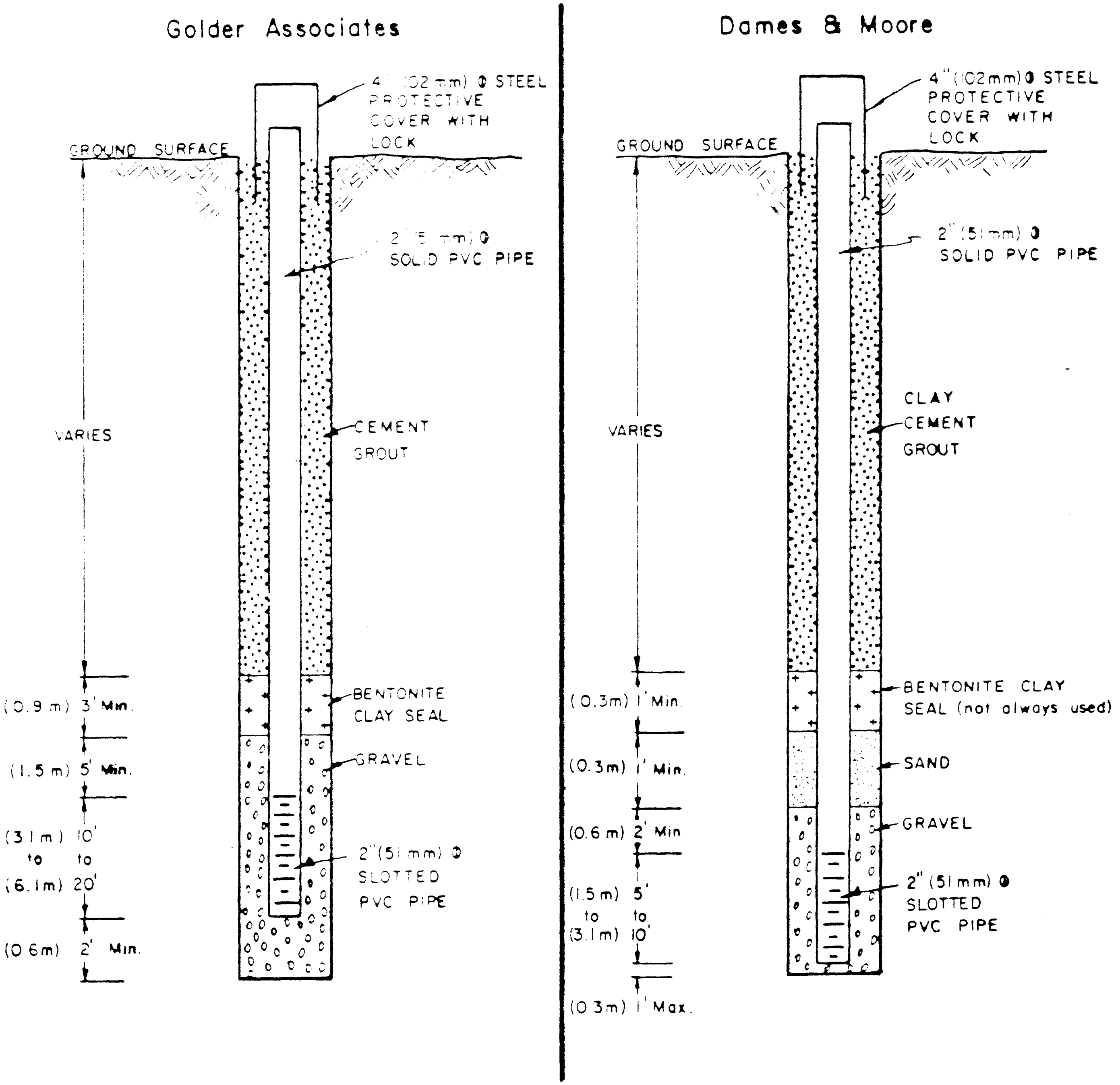

TYPICAL OBSERVATION WELL INSTALLATIONS

FIGURE S-4

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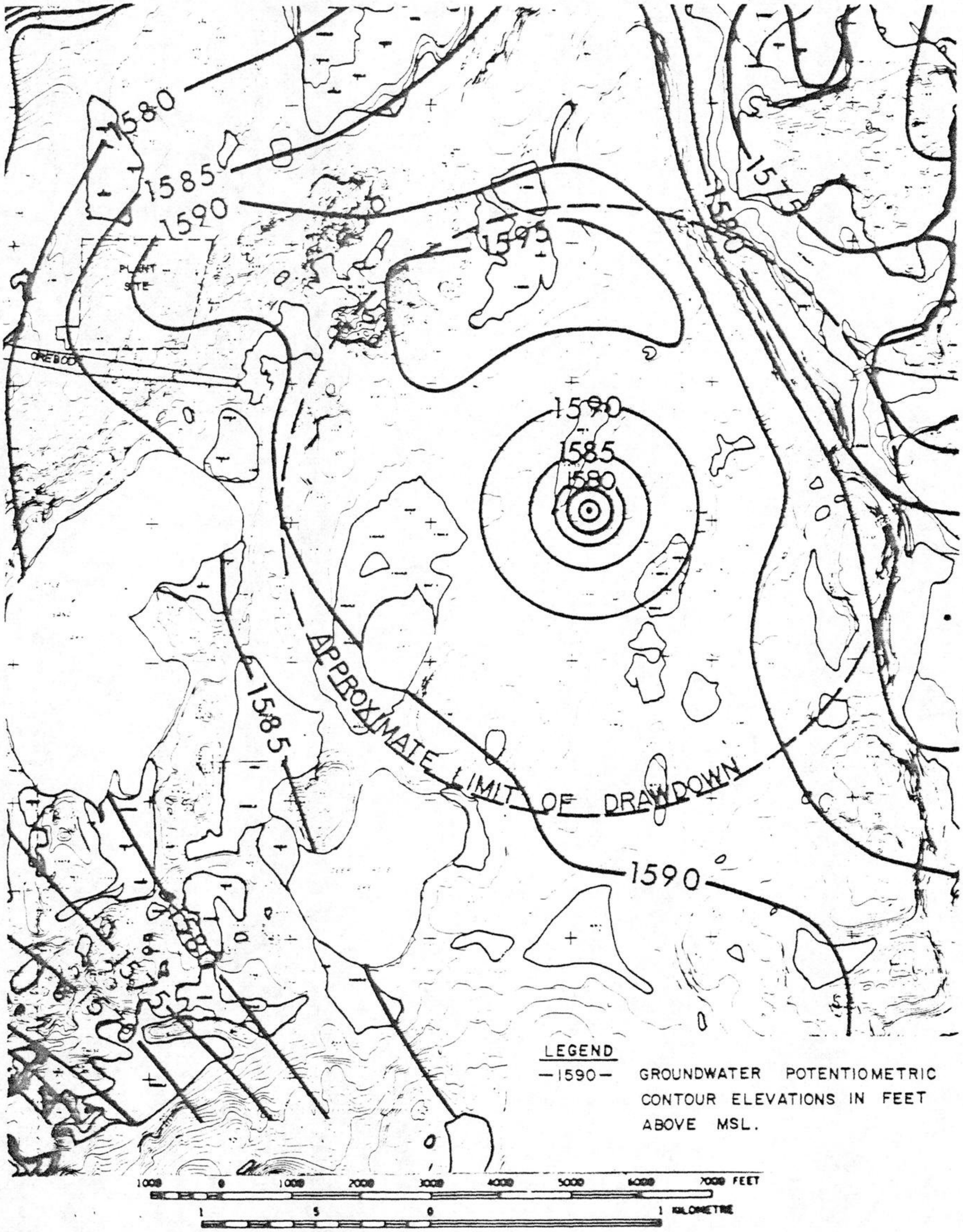
wells responded to the pumping for a distance up to 4000 ft. (1220 meters) from the well. The approximate potentiometric map in the stratified drift layer at the end of the pumping period for the test is shown on Figure S-5. Recovery was monitored for 52 days after the pump was turned off.

Detailed analyses of all the data collected during the test was performed to develop an understanding of the dynamic behavior of the groundwater system at the site, and to develop the hydrogeologic parameters which characterize each material. The results of these analyses were then combined to produce a geohydrologic model of the test site, which is presented in Figure S-6.

The performance of this pump test and analyses of the results has:

- established the geohydrologic conditions at the test site for use in regional model calibration and local seepage studies,
- demonstrated the feasibility of altering the potentiometric surface by well pumping,
- demonstrated the availability of a sustained yield of up to 950 gpm (0.060 cubic meters per second) of water from the test well, and a maximum yield of 3000 gpm (0.189 cubic meters per second),
- provided a monitoring system in one potential disposal area near the mine site.

The method of performance of the tests, and the extensive instrumentation of the groundwater system allow a high degree of confidence in the results.



EFFECT OF PUMP TEST ON POTENTIOMETRIC MAP — FIGURE S-5

Scale GRAPHIC	Golder Associates	Drawn S.K.B
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A. ENGLISH UNITS					
GEOLOGY	THICKNESS (ft)	PARAMETERS			
		k_h (ft/sec)	k_v (ft/sec)	S_s (ft^{-1})	n_d (%)
TILL	110	ABOVE NATURAL GROUNDWATER LEVEL			
TILL	80	9.3×10^{-6}	3.1×10^{-6}	4.6×10^{-6}	5.4
COARSE GRAINED STRATIFIED DRIFT	70	4.3×10^{-4}	4.3×10^{-5}	4.6×10^{-6}	7.0
TILL	70	9.3×10^{-6}	3.1×10^{-6}	4.6×10^{-6}	5.4
BEDROCK		FUNCTIONALLY IMPERMEABLE			

B. SYSTEM INTERNATIONAL					
GEOLOGY	THICKNESS (m)	PARAMETERS			
		k_h (m/s)	k_v (m/s)	S_s (m^{-1})	n_d (%)
TILL	35	ABOVE NATURAL GROUNDWATER LEVEL			
TILL	25	2.8×10^{-6}	9.4×10^{-7}	1.5×10^{-5}	5.4
COARSE GRAINED STRATIFIED DRIFT	20	1.3×10^{-4}	1.3×10^{-5}	1.5×10^{-5}	7.0
TILL	20	2.8×10^{-6}	9.4×10^{-7}	1.5×10^{-5}	5.4
BEDROCK		FUNCTIONALLY IMPERMEABLE			

LEGEND:

(1) k_h = horizontal hydraulic conductivity

k_v = vertical hydraulic conductivity

S_s = specific storage

n_d = drainable porosity (specific yield)

(2) Unshaded Values: Results obtained directly from pump test
Shaded Values: Inferred or estimated from the pump test results

BEHAVIORAL PARAMETERS AND HYDROGEOLOGIC MODEL | FIGURE S-6

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