GEOCRES No:
30M3-271-3

Final report

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Waste Management
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GEOCRES No.
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SITE ASSESSMENT
PHASE 4B:
GEOLOGY, HYDROGEOLOGY AND GEOTECHNICS, BASELINE CONDITIONS
VOLUME 2
APPENDICES A THROUGH D

Prepared for
The Ontario Waste Management Corporation

Submitted By

Gartner Lee Limited

October, 1987

Gartner Lee Limited

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October 30, 1987 GLL 87561

Mr. J.G. Micak
Manager, Environmental Projects
Ontario Waste Management Corporation
2 Bloor Street West, 11th Floor
Toronto, Ontario
M4W 3E2

Attention: Mr. D.F. Chollak,
Environmental Planner

Dear Sirs:

Re: Site Assessment Phase 4B: Geology, Hydrogeology and Geotechnics - Baseline Conditions

We are pleased to provide you with Volume 2 of the above noted three-volume report. This report is one of six Phase 4B companion reports describing baseline conditions, hydrogeologic inputs to landfill design, geotechnical inputs to facilities design, potential impacts of the landfill on ground water, potential impacts of the central operation area on ground water and ground water management strategies.

We thank you for this opportunity to be of service. Should you have any questions please do not hesitate to call.

Yours very truly,

GARTNER LEE LIMITED

for E.G. Anderson, P.Eng.
Consulting Hydrogeologist
Project Director

G.W. Reynolds, M.Sc.,
Senior Hydrogeologist,
Project Manager

GWR:emh

APPENDIX A

DRILLING, GEOLOGIC SAMPLING, INSTRUMENTATION AND HYDRAULIC TESTING PROTOCOLS

APPENDIX A

DRILLING, GEOLOGIC SAMPLING, INSTRUMENTATION AND HYDRAULIC TESTING PROTOCOLS

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A1 DRILLING AND GEOLOGIC SAMPLING

A1.1 INTRODUCTION

This Appendix describes the drilling and geologic sampling practices used to collect field data during the Phase 4B geoscience program. The major drilling and sampling activities are shown in Figure A1-1. For the most part procedures for the drilling and sampling operations, as described in the Phase 4B Protocols document (GLAL, 1986a), were adhered to throughout the drilling program. The protocol document served as a procedures manual for the field staff during the drilling program. Minor modifications to the drilling and sampling protocols were made in the field to accommodate actual field conditions. A summary of the protocol procedures (GLAL, 1986a) are discussed herein.

Details of monitor design and installation are described in Appendix A2 of this report.

Daily liaison with the Gartner Lee Markham office was maintained through a temporary field office at the site.

A1.2 DRILL SITE IDENTIFICATION

A1.2.1 PRELIMINARY DATA ANALYSIS

A preliminary review of existing water well and test hole data was completed to establish a basis for the selection of tentative drill locations. Criteria used included the following:

- the distribution of existing test holes and water wells;
- seismic survey;

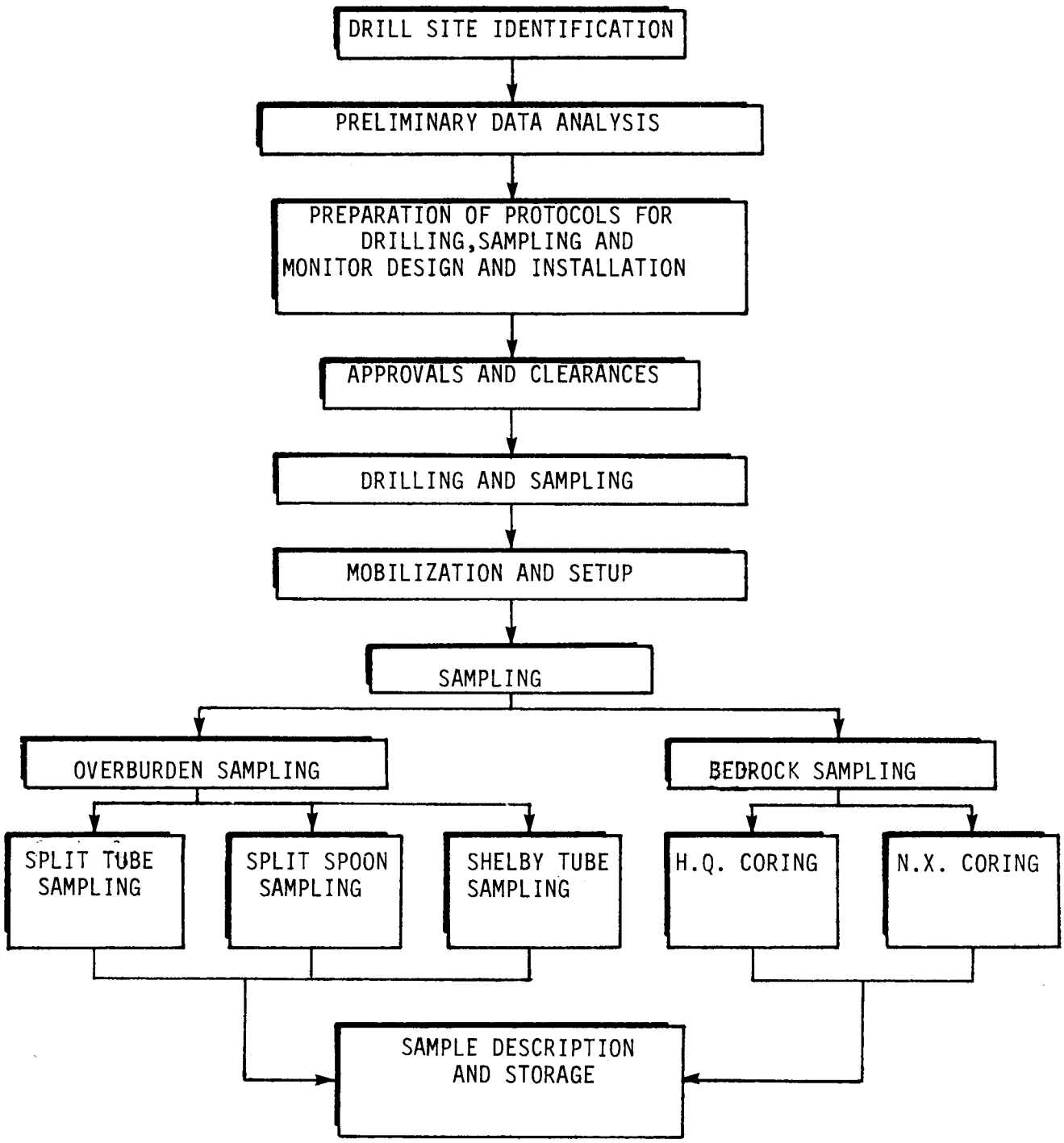

FIGURE A1-1

DRILLING & GEOLOGIC SAMPLING ACTIVITIES

- the continuity of existing data; and
- anomalous or unusual site conditions.

Monitor details including the type of installation, location and distribution of monitors are provided in Appendix A2.

A1.2.2 PROTOCOLS

Detailed protocols which described the drilling, sampling and monitor design and installation practices to be used during the Phase 4B geoscience program were developed following a preliminary review of existing data. Field data requirements were identified for major program components including geophysics, geology, geotechnics, hydrogeology, and geochemistry. These requirements were incorporated into the overall drilling and sampling program. Soil samples taken from different boreholes were dedicated to different program components; although, where possible, samples were shared between programs. The various program components are outlined in the Phase 4B, Geoscience Work Plan (GLAL, 1986b).

A1.2.3 APPROVALS AND CLEARANCES

Preliminary sketches were completed showing each drilling location and the proposed borehole arrangement at each location. Access and work area requirements were identified for each drilling location from a field visit.

All of the drilling locations, both on and off-site, were located on private property. Access and lease agreements were arranged for each drilling location. Negotiations for these agreements were completed by the Ontario Ministry of Government Services on behalf of the Ontario Waste Management Corporation.

Culverts were installed at four locations around the site to provide safe access across steep ditches. Arrangements were made directly with the Township of West Lincoln and the Ontario Ministry of Transportation and Communications for culvert installations. One culvert was required on-site to access interior drilling locations. The design specifications, installation and inspection of the culvert were carried out by M.M. Dillon Limited.

Buried services were located in the vicinity of each drilling location. Local utilities including gas, telephone, and other municipal services were cleared prior to the drilling program.

A1.3 DRILLING AND SAMPLING

A1.3.1 DRILLING EQUIPMENT AND SETUP

All Terrain Drilling Limited was retained to provide drilling services. The drilling equipment included one truck-mounted CME 75, one truck-mounted CME 55, and one track-mounted CME 75 auger drilling rig. Each rig was equipped to drill and sample both overburden and bedrock. Each rig was staffed by a two-man crew. Two additional helpers provided support services for all three rigs. Each drill rig was supervised by a Gartner Lee geologist. Drilling operations were directed from a central field office temporarily set up at the site.

The drilling operations commenced November 14, 1985 and were completed March 12, 1986. The winter operations required a heated space for logging and storing soil and bedrock samples. Heated trailers were provided at each drill rig and a heated storage space was constructed at the central field office. A record of drilling activities for each drill rig was recorded daily on Daily Activity Log forms (Figure A1-2).

FIGURE : A1-2

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DAILY ACTIVITY LOG

PROJECT: 4B Drilling & Sampling
CLIENT: OWMC

DATE: _____ DAY #: _____
BOREHOLE: _____ SITE: _____

FROM	TO	HRS.	ACTIVITY	COMMENTS
TOTAL HOURS				

CONTRACTOR QUANTITIES: By _____ (DC) By _____ (GLAL)

1) _____ 4) _____ 7) _____
2) _____ 5) _____ 8) _____
3) _____ 6) _____ 9) _____

WEATHER: _____

VISITORS: _____

OTHER: _____

DATE: _____ BY: _____ GLAL

The drill rigs were set up in accordance with standard drilling practices and in a manner that allowed the safe and efficient operation of the equipment. A safety corridor was roped off around the drill rig to limit access to the rigs. Access to the safety corridor was restricted to individuals with proper safety equipment which included steel-toed boots and a hard hat. A record was kept on a Visitor Record form (Figure A1-3) of all visitors to the field office and drill sites as well as persons entering the safety corridor.

Soil and rock samples were accessible to the general public for viewing and/or photographing as the samples were being logged by the on-site geologists. Field descriptions were recorded on Field Borehole Log forms (Figure A1-4). Samples were subsequently sealed in PVC split tubing sample containers or core boxes, labelled, and placed temporarily in the heated storage area. Samples were retrived from the storge area for re-examination and final logging by the senior GLAL geologist. Each sample was resealed in the PVC split tubing after final logging, replaced in temporary storage and subsequently sent to the permanent storage facilities of the Ontario Geological Survey in Toronto.

A1.3.2 OVERBURDEN SAMPLING

The drilling program was designed to provide continuous samples from the ground surface to and including the upper few metres of the underlying bedrock at 12 on-site locations and four off-site locations. In addition two shallow stratigraphic boreholes were completed to investigate wet depressions on-site. Drilling locations are shown in Figure A1-5. A number of split spoon and shelby tube soil samples were also collected from various depths for hydrogeologic, geochemical and geotechnical testing from a

FIGURE A1-3

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VISITOR RECORD

PROJECT: Phase 4B Drilling And Sampling
CLIENT: Ontario Waste Management Corporation

BOREHOLE _____

SITE _____

DATE	NAME	AFFILIATION	PURPOSE OF VISIT	TIME IN	TIME OUT	SITE ACTIVITIES / COMMENTS

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FIGURE A1-4

FIELD BOREHOLE LOG ____

PROJECT NAME _____ PROJECT NO. _____

CLIENT _____ DATE START _____ END _____

BOREHOLE TYPE _____ LOGGED BY _____

SAMPLE No.	TYPE	DEPTH	S.P.T. BLOWS	RECOVERY	MOISTURE TIN NO.	SAMPLE DESCRIPTION	REMARKS

Drilling Locations

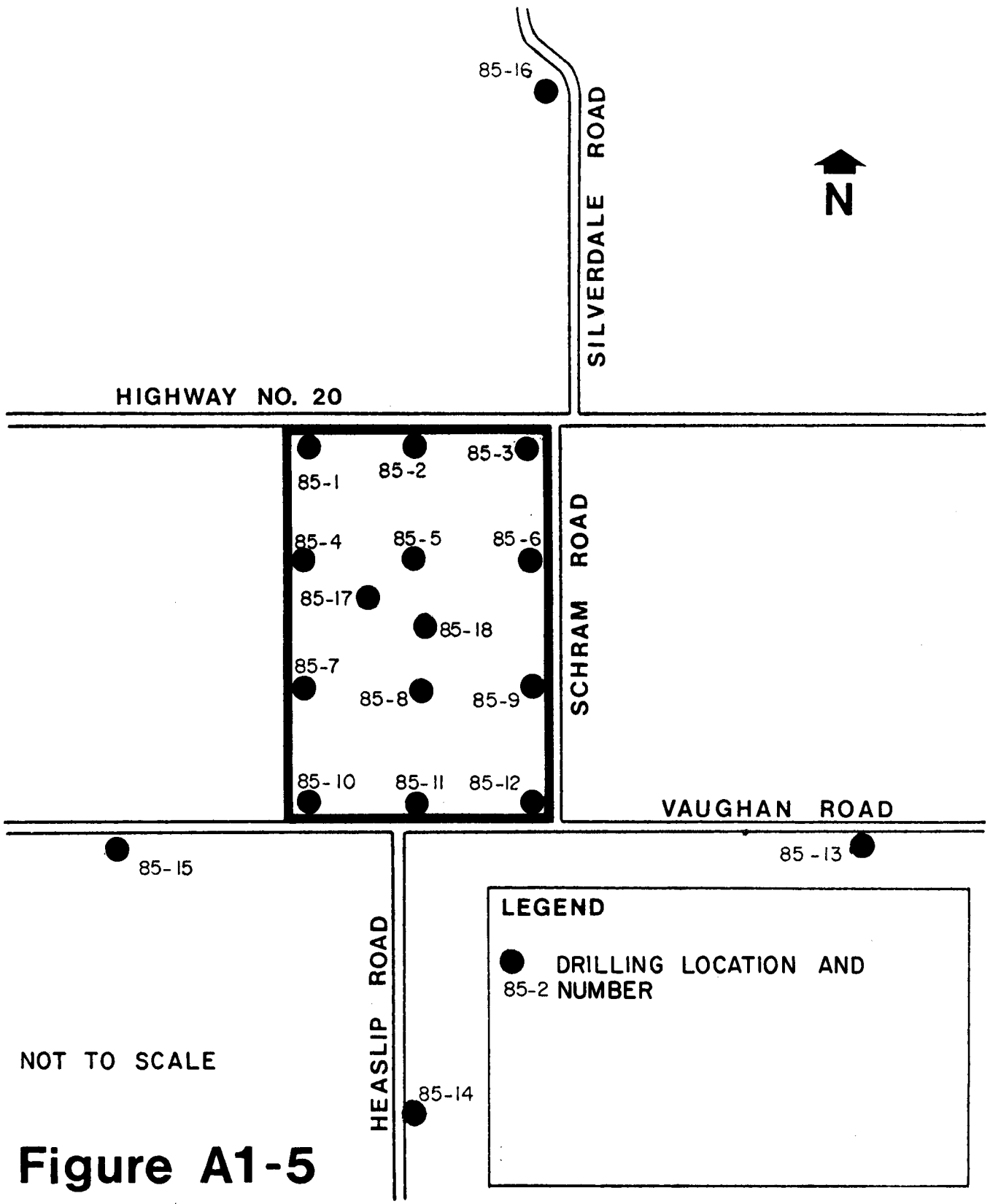

Figure A1-5

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second borehole at each location. Sampling methods are in accordance with ASTM standards and are briefly described below.

Split tube sampling

Tube samples measuring approximately 89 mm in diameter by 1.52 m in length were taken continuously from ground level to the bedrock surface. The tube sampler consisted of a split tube with a bevelled sampler tip. The split tube was threaded at both ends and fastened to the drill rods as shown in Figure A1-6. The sampler was advanced inside the hollow stem augers with the bevelled tip slightly ahead of the cutting edge of the augers. A split tube sample was obtained by advancing the sampler with the rotating augers. The augers and sampler were advanced at about 1.52 m intervals or until refusal, and the sampler was then withdrawn from the borehole. The soil sample was removed from the tube and the sampler wiped clean. Sample recovery for the tube samples was generally between 90 to 100% and was recorded in the field log. Difficult drilling conditions or large cobbles occasionally resulted in lower sample recovery.

The samples were placed in split PVC tubing, covered at each end with plastic caps and taped along the seams and at each end to minimize moisture loss.

Split tube sampling was carried out at each of the drilling locations.

Split spoon sampling

Split spoon samples were taken at 0.76 m intervals to 4.6 m and then at approximately 1.5 m intervals through the overburden at each of the on-site drilling locations. The split spoon measures 52 mm I.D. and 457 mm in length. Large diameter split spoon

Continuous Sampling With Split Tube Sampler

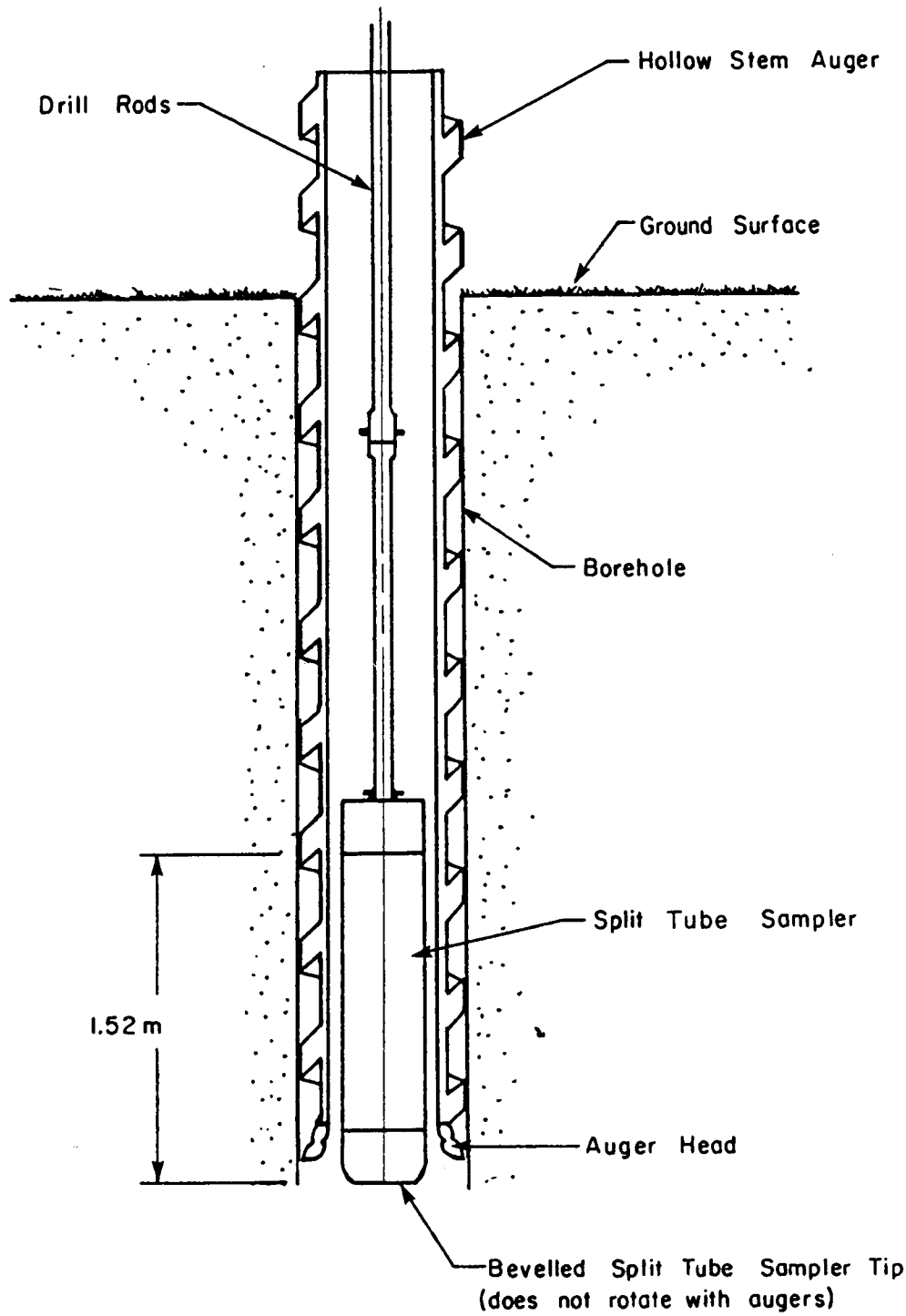

Figure A1-6

samples were taken from various depths at a number of locations on the site. These split spoons measured 102 mm I.D. and 610 mm in length.

The split spoon sampler was driven by dropping a 63.5 kg weight a distance of about 750 mm. The sampler was inserted inside the hollow stem augers in a similar fashion to the tube sampler. It was then driven into the soil below the bottom of the augers a distance of 460 mm or until refusal. The number of blows required to advance the sample for each interval of 150 mm was recorded in the field log. The split spoon was usually withdrawn when 50 or more blows were required to advance the sampler approximately 150 mm into the subsoil.

The large diameter split spoon was utilized in a similar fashion as the standard split spoon. It was driven into the soil a distance of 610 mm or refusal. The number of blows required to advance the sampler 150 mm was recorded on the field log.

At the four off-site borehole locations, split spoon sampling was carried out prior to the advancement of the split tube sampler or at 1.5 m intervals. Detailed sampling of the shallow weathered overburden (0.76 to 4.6 m) was not carried out because detailed geotechnical information was not required for the off-site locations.

Shelby tube sampling

Shelby tube samples were taken primarily for geotechnical testing. The sampler consists of a thin-walled steel sampling tube measuring 76 mm O.D. and 914 mm in length. Samples are obtained by pushing the sampling tube into the undisturbed material beneath the auger tip. The entire length of the Shelby tube is

pushed into the material or until refusal and is then withdrawn from the hole.

The lowermost portion of the Shelby tube sample was removed and placed in a plastic bag for storage. Both ends of the Shelby tubes were sealed in wax, covered with plastic caps and taped shut to minimize moisture loss. All samples were stored in a heated storage area prior to shipment to the laboratory.

Moisture tin samples

A small soil sample of approximately 100 grams was taken from the tip of each split spoon sample for laboratory determination of the soil moisture content. Soil moisture samples were placed in air tight tins immediately after they were taken from the split spoon samples. The moisture tin (sample) numbers were recorded on the field borehole logs. The samples were temporarily stored in the heated field facilities and shipped in batches to the Golder Associates (Eastern Canada) Limited laboratory for analysis.

Air rotary drilling

Air rotary drilling techniques were used to penetrate difficult soils that could not readily be drilled with hollow stem auger drilling methods. These techniques were used to drill through fractured rock at the bedrock surface. Air rotary drilling using a tricon drill bit was completed to about 3 m into bedrock for the construction of two 108 mm diameter pump wells at borehole locations 85-1 and 85-12. The air rotary drilling method utilized compressed air as a means of removing drill cuttings from the borehole. A special air filter installed on the air compressor removed trace amounts of oil from the compressed air while drilling. Water was added to the borehole where insufficient formation water was available to facilitate removal

of drill cuttings from the borehole. Water used in drilling was from the St. Catharines municipal system.

A1.3.3 BEDROCK SAMPLING

Diamond drill coring

Bedrock core samples were obtained at each of the drilling locations. Two sizes of drill core were obtained using HQ and NX size core barrels which provided 64 mm diameter and 54 mm diameter rock core, respectively. Procedures for diamond drilling are briefly described below.

The diamond drill bit and core barrel were positioned on the bedrock surface inside the hollow stem augers. Rock core was obtained by the cutting action of the rotating drill bit. Clean water was circulated in the borehole to remove cuttings from around the drill bit. About 3 m of HQ size rock core was obtained at locations 85-2 through 85-11 (Figure A1-5). At locations 85-1 and 85-12 about 30 m of NX size bedrock core was obtained. The NX size corehole was a requirement of the borehole packer testing program.

A1.3.4 SAMPLE DESCRIPTION AND STORAGE

Samples, taken from the boreholes, were described in the field and photographed. Sample descriptions were recorded on Field Borehole Log forms (Figure A1-4). These logs, together with the sample photos, form a permanent record of the samples collected.

The tube samples were transferred directly from the sampler into PVC tubular piping which was cut in half. The PVC pipe measures 89 mm inside diameter by 1.5 m long. One 'side' of the sample was scraped clean along its length with a knife or spatula to facilitate sample description. The PVC tubes were

sealed by covering the ends with plastic caps and taping the entire tube along the seams. Sample labels were affixed to each PVC tube.

The samples were stored temporarily in heated storage facilities until a sufficient number of samples were obtained for transport to permanent storage facilities in Toronto at the Ontario Geological Survey. Each shipment of samples was itemized on a Sample Packing List form (Figure A1-7). The contents of each shipment were also recorded on a Chain of Custody Record form (Figure A1-8) which showed the times and dates of sample transfer as well as the individuals involved in handling the samples.

Split spoon samples taken during the project were described in the field and moisture (moisture tin) samples taken from the base of the split spoon sampler were submitted to a laboratory for analysis. The moisture tin number was recorded on the Field Borehole Log form and on the Sample Packing List form. In cases where a split spoon sample was taken in place of the larger split tube samples, they were stored in labelled plastic bags and retained by Gartner Lee for future analysis. The top of each bedrock core segment was marked on both the core boxes and on the rock core itself with a felt marker.

Shelby tube soil samples were transferred to the Golder laboratory on a weekly basis from the heated field storage facilities. A Chain of Custody Record form accompanied each shipment of samples.

The soil and rock samples were re-examined by a senior Gartner Lee geologist at the central field office. The field descriptions were combined with the more detailed geologic log

FIGURE A1-7

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Project No. _____

SAMPLE PACKING LIST

PROJECT: _____

CLIENT: OWMC

BOREHOLE: _____

BOX NO. ___ OF ___

SAMPLE NO.	DEPTH		SAMPLE TYPE
	FROM	TO	

PACKED BY _____ DATE _____

VERIFIED BY _____ DATE _____

FIGURE A1-8

Gartner Lee Associates Limited

Project No.

CHAIN OF CUSTODY RECORD

PROJECT:
CLIENT:

BOREHOLE:
SHEET ___ OF ___

ITEM	DESCRIPTION	CONTENTS

	RELINQUISHED BY	DATE/TIME	RECEIVED BY	AT	REMARKS

prepared by the senior geologist to compile a final borehole log. All soil samples were resealed after examination.

A1.4 SITE CLEANUP

Disturbance to the area around the monitors was recorded in the form of photographs of each drilling location after completion of the drilling activities. A general site clean up was undertaken immediately following drilling. This was followed by a more comprehensive cleanup which involved the removal of small piles of drill cuttings around each monitor. Site levelling and seeding was undertaken later.

A2 MONITOR DESIGN AND INSTALLATION

A2.1 INTRODUCTION

Section A2 documents the protocols followed in the design and installation of the ground water monitors during the Phase 4B geoscience program. Included are details on:

- the distribution of monitors (Section A2.2);
- the hydrogeologic monitors (Section A2.3); and,
- the geochemical monitors (Section A2.4).

A summary of monitor details is provided in Table F1-1, Appendix F.

A2.2 MONITOR DISTRIBUTION

A2.2.1 GENERAL

Ground water monitors have been installed at 16 of the 18 drilling locations shown in Figure A2-1. Monitors are labelled as shown in the following example:

85-1-12

Year of Project — Drilling Location — Monitor Number

Monitors were not installed at locations 17 and 18. Two relatively shallow stratigraphic test holes were completed at these two locations to investigate drainage swales on the site. Monitors were installed to varying depths and distributed across the site to provide cross-sections of representative

conditions. Four off-site locations were also drilled and monitored to establish conditions adjacent to or near the site.

A total of 121 ground water monitors were installed at 16 of the 18 drilling locations shown on Figure A2-1. These consist of:

- 75 water level monitors at 12 on-site locations;
- 38 water quality monitors at five on-site locations; and
- eight water level monitors at four off-site locations.

Included with the on-site water level monitors are two pump test wells and two observation wells at each of the pump test locations. All ground water monitors are fitted with protective steel casings with locking caps. The elevation of each monitor was surveyed with respect to geodetic datum.

The drilling locations are described below with respect to the intensity of the drilling as (a) normal, (b) composite, and (c) detailed.

A2.2.2 NORMAL DRILLING LOCATIONS (ON-SITE AND OFF-SITE)

Normal on-site drilling locations include only water level monitors, with monitors completed at different depths of the hydrostratigraphic units as shown schematically in Figure A2-2.

Normal off-site drilling locations consist of two water level monitors, one completed as a water table monitor and the other completed as a piezometer into the upper 3 m of the bedrock.

Drilling Locations And Types

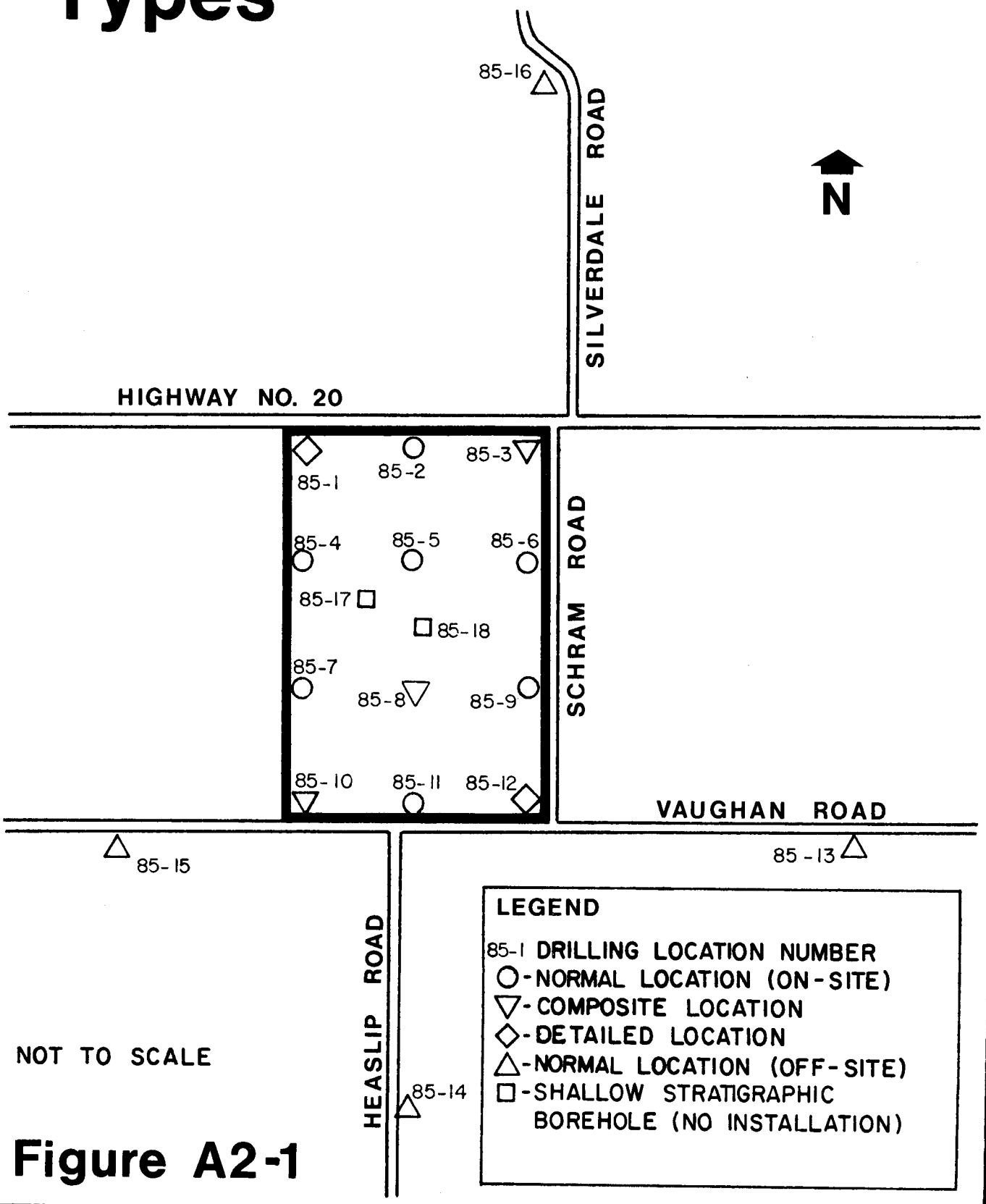

Figure A2-1

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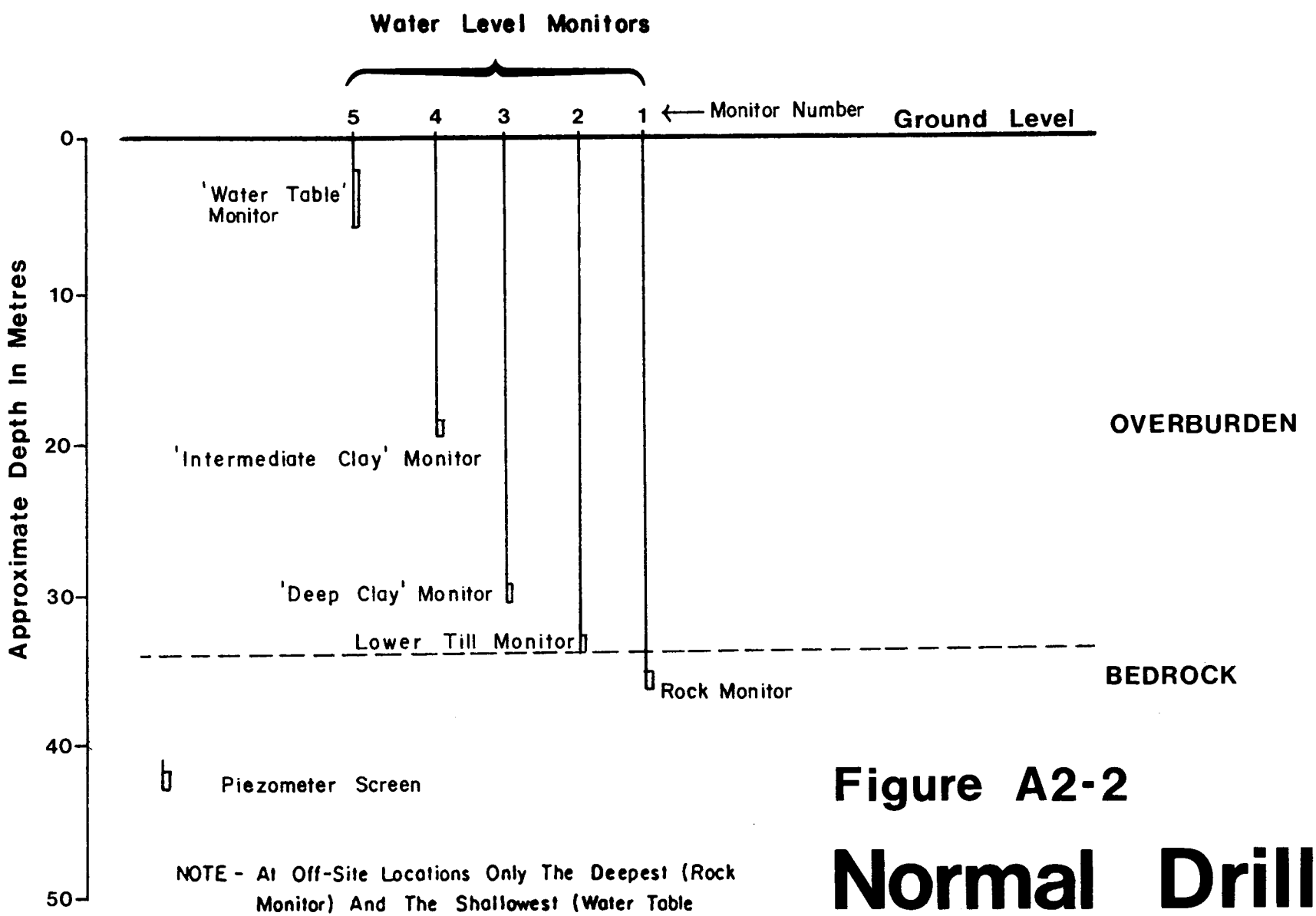

NOTE - At Off-Site Locations Only The Deepest (Rock Monitor) And The Shallowest (Water Table Monitor) Monitors Were Installed.

Figure A2-2

Normal Drilling Location (on-site)

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A2.2.3 COMPOSITE DRILLING LOCATION

There are three composite drilling locations as shown in Figure A2-1 (identified as 85-3, 85-8 and 85-10). These include both water level monitors and geochemistry monitors for a total of 11 monitors at each location (Figure A2-3). The water level monitors include two pneumatic piezometers, four standard piezometers in overburden, one standard piezometer in bedrock and one standpipe in the fractured silt and clay. There are three monitors constructed exclusively for water chemistry. The bedrock water level monitor serves as both a water level and water chemistry monitor. At drilling location 85-10 one extra shallow clay water level monitor was installed.

A2.2.4 DETAILED DRILLING LOCATION

There are two detailed drilling locations as shown in Figure A2-1, one at the northwest corner and one at the southeast corner of the site (identified as 85-1 and 85-12). These locations include all the components of the composite drilling locations plus a pump test well with bedrock observation well and a set of nine shallow overburden profile monitors. A total of 22 monitors were installed at each detailed drilling location. The arrangement of the monitors and the approximate depth of the installations are shown schematically in Figure A2-4.

A2.2.5 SHALLOW STRATIGRAPHIC DRILLING LOCATIONS

Two shallow stratigraphic drilling locations (85-17 and 85-18) are located on the site as shown in Figure A2-1. Continuous soil sampling was completed in one borehole at each of these locations and no monitor was installed. The borehole at each location was sampled in order to verify soil conditions beneath two perennially wet swales on the site.

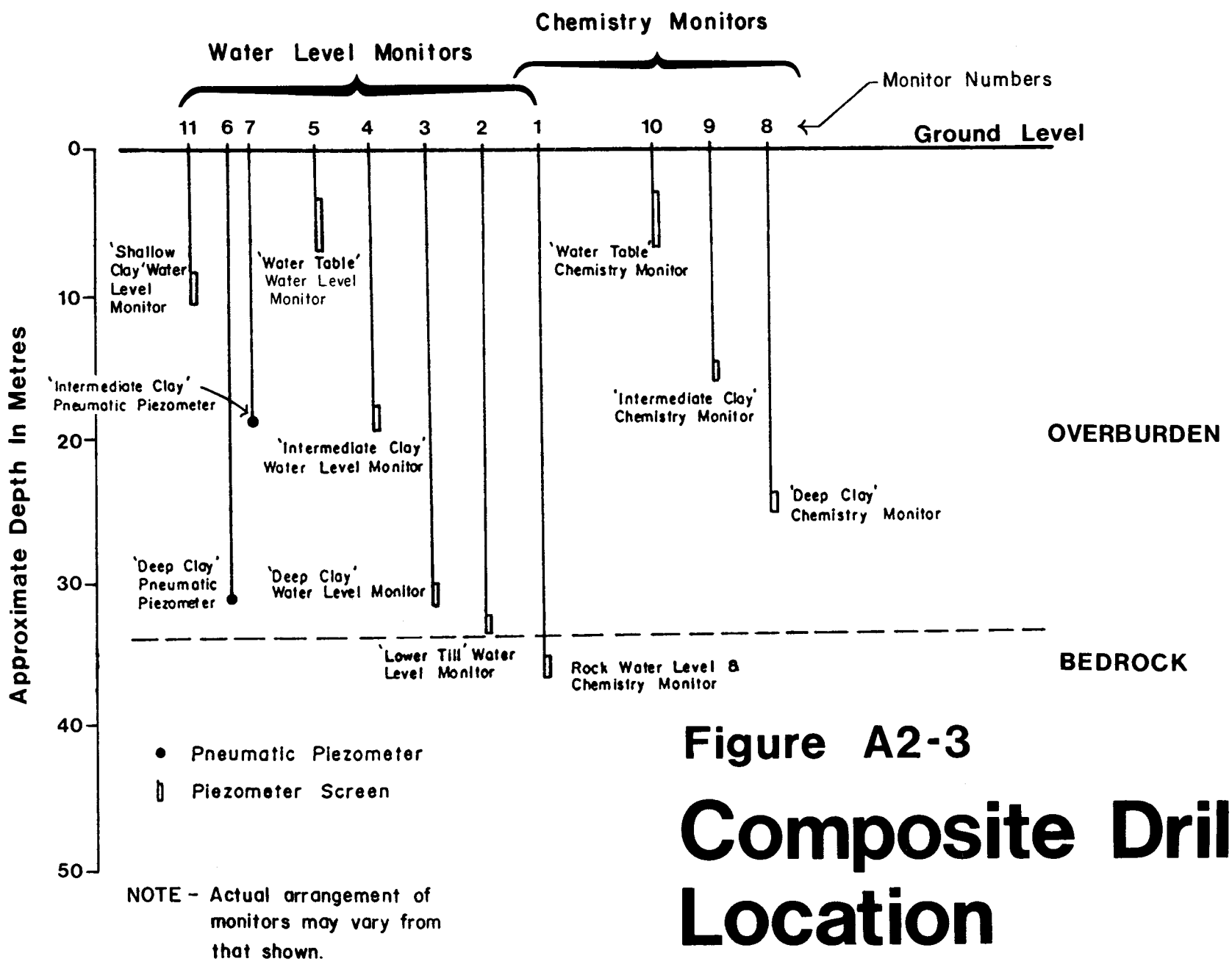

Figure A2-3

Composite Drilling Location

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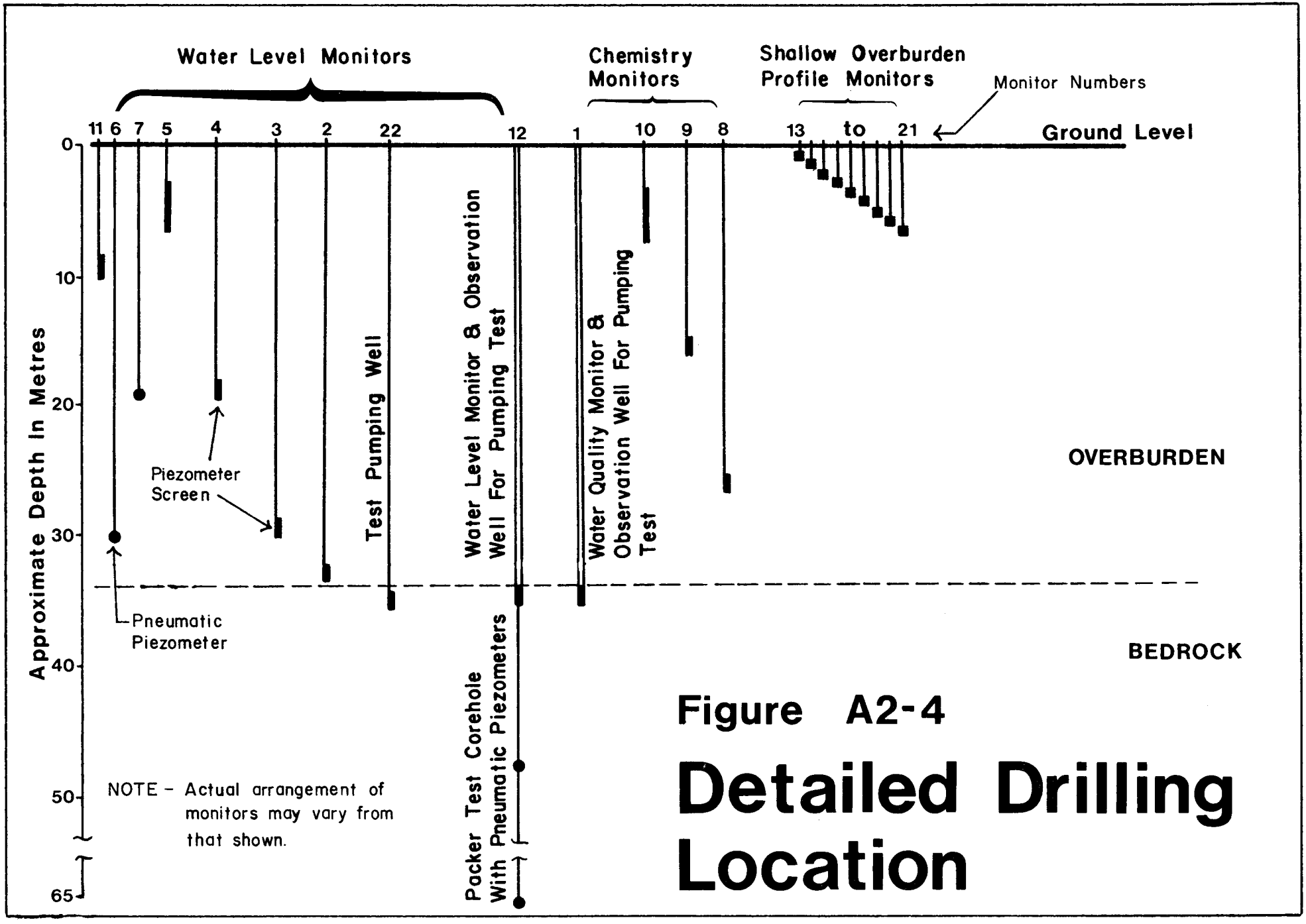

Figure A2-4

Detailed Drilling Location

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A2.3 HYDROGEOLOGIC MONITORS

Hydrogeologic monitors are designed to allow for the in situ testing of hydraulic conductivity and/or for the measurement of water levels or soil pore pressures. The monitors are completed to various depths below the surface to collect information on the bedrock and the overlying materials. Three basic types of hydrogeologic monitors were installed:

- standard piezometers;
- standpipes; and
- pneumatic piezometers.

A2.3.1 STANDARD PIEZOMETER

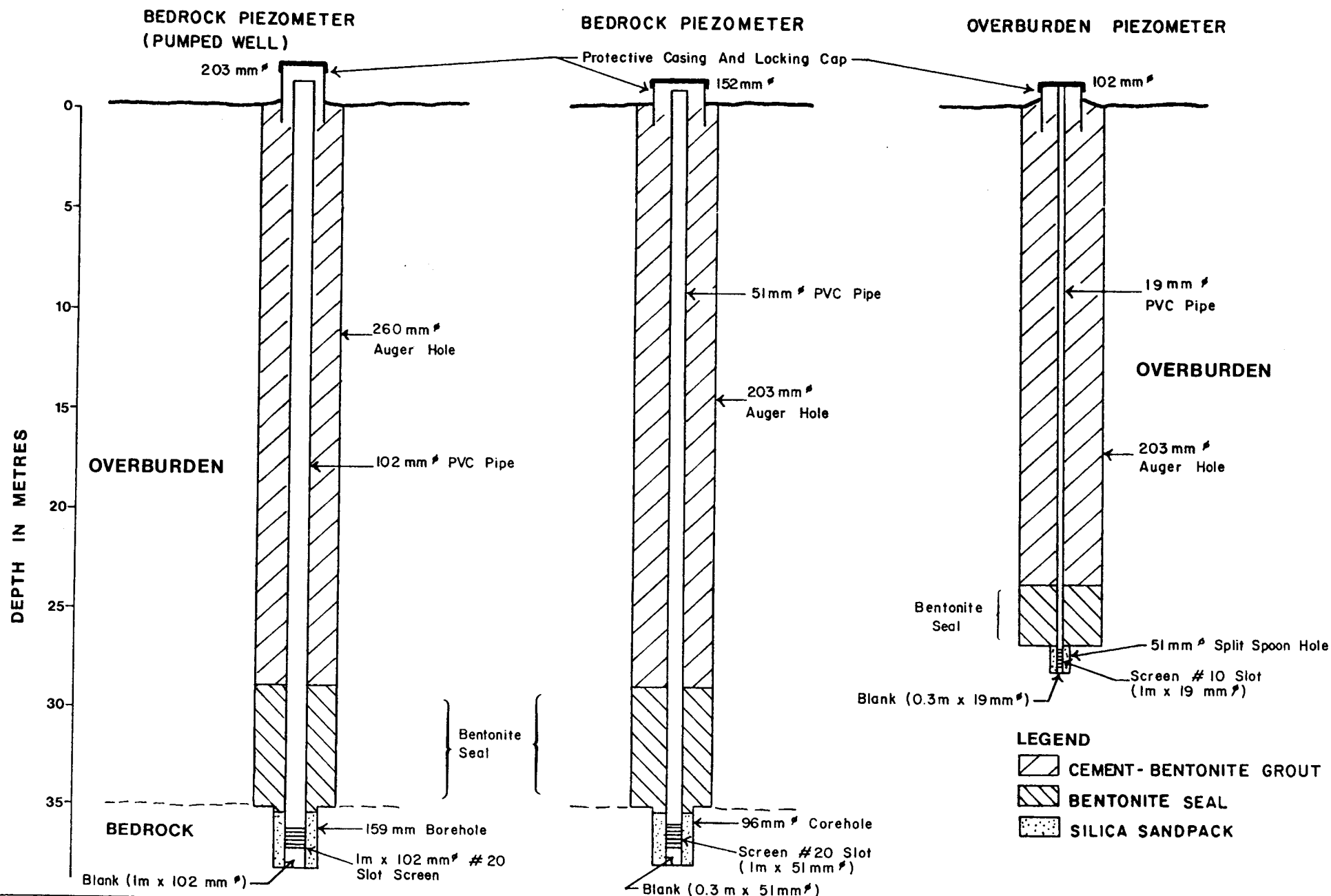
Construction details of standard piezometer installations, including the pump well, a typical bedrock piezometer, and a typical overburden piezometer are shown in Figure A2-5.

Standard piezometer ground water monitors are constructed of 102 mm and 51 mm diameter PVC for bedrock monitors and 19 mm diameter PVC for overburden monitors. The 102 mm monitors were installed at two locations for use as pump test wells. The 51 mm monitors are installed at each of the 12 on-site drilling locations and at the four off-site drilling locations. Two bedrock monitors are located near each of the pump test wells and serve as observation wells for the pump testing.

All PVC pipe is schedule 80, which was precut to 3 m lengths and equipped with threaded ends that provide flush joints. Each male threaded end was wrapped with teflon tape prior to joining the pipe lengths to ensure a water-tight seal.

Standard Piezometer Construction Details

Figure A2-5



Screens

Each monitor is equipped with either a screen or slotted interval of pipe. All screens and slotted intervals were supplied with threaded ends which provide flush joints when attached to the PVC pipe.

Machine slotted PVC screens with No. 20 slot openings were used for the 102 mm and 51 mm PVC bedrock piezometers. Machine slotted screens with No. 10 slot openings were installed on the 19 mm overburden piezometers. All screens and slotted intervals were fitted with a blank piece of pipe which acts as a sediment sump. The sump is 1 m long on the 102 mm diameter and varies in length between 0.08 and 0.3 m for the 19 mm diameter monitor. The annulus around the screens was backfilled with silica sand to about 0.3 m above the top of the screen. The bottom of each monitor was finished with a friction-fit PVC cap to prevent materials from entering the monitors.

Seals

A bentonite seal was installed directly above the sand pack. The seals are about 3 m or more in thickness in the deeper piezometers and consist of bentonite pellets ("pelltonite"), bentonite gravel ("hole plug") and bentonite powder ("quick gel"). The bentonite seals in the bedrock monitors are installed to a minimum thickness of 3 m, above the bedrock surface and are extended to above the top of the lower till. Bentonite seals installed in dry overburden boreholes were wetted with clean water to swell the bentonite and thus prevent grout from entering the silica sand pack and monitor screen. The thickness of bentonite seals in the shallowest overburden monitors will vary depending upon the depth from surface of the top of the screens.

Backfill

The annular space above the bentonite seal was backfilled to within about 0.5 m of the ground surface with a bentonite-cement grout mixture. In water-filled boreholes, the grout was installed through a tremie line from the top of the bentonite seals to within about 0.5 m of surface to displace the water in the borehole. The composition of the grout, which is similar to that used in the Phase 4A drilling program, is summarized on a per cent weight basis.

Grout Slurry Composition (% Weight)

1.5 - 3.0%	- Bentonite (Quick Gel)
40 - 60%	- Cement (Portland Type 10)
40 - 60%	- Water

Quantities of materials used in each batch of grout slurry were recorded on a Borehole Plugging Plan/Record (Figure A2-6). Chlorinated potable water from the Vineland municipal water supply system (part of St. Catharines municipal system) was used in the grout mixtures. Samples of each batch of grout were taken and retained to verify proper setting of the grout.

Surface Casing

A protective steel casing with a locking cap was installed over each monitor after the grout backfill hardened. The casing is adjusted to the proper height with silica sand placed on top of the grout backfill. The casing was then cemented in place with cement-bentonite grout. The drilling location and borehole number were stamped onto each protective casing for ease of identification. Protective casings for the 102 mm, 51 mm and 19 mm diameter monitors have respective diameters of 305 mm, 203 mm

FIGURE A2-6

Gartner Lee Associates Limited

BOREHOLE PLUGGING PLAN/RECORD

PROJECT: _____
SITE: _____
CLIENT: _____

BOREHOLE: _____ BY: _____
LOCATION: _____ CONTRACTOR: _____
DATE: _____ DRILLER: _____

VOLUME CALCULATION:

1. Hole Depth (m) = _____
2. Bit Diameter (mm) = _____
3. #2 x 1.1 (mm) = _____ = Estimated Hole Diameter
4. #3 ÷ 2 ÷ 1000 (m) = _____ = Estimated Hole Radius in Meters
5. $(\#4)^2$ x Pi(m^2) = _____ = Hole Volume/meter (m^3/m)
6. #1 (m) x #5 (m^3/m) = _____ = Hole volume (m^3)
7. Additional % = _____ = Volume for mixing (m^3)
8. Total volume = _____ = Volume for mixing (L) = _____(L)

MIXING QUANTITIES/STAGE:	TOTAL	STAGE 1	STAGE 2	STAGE 3
9. #8 Volume Grout (L)				
10. Required Cement (bags)				
11. Required Water (L)				
12. Required Bentonite (L)				

PUMPING QUANTITIES/DEPTHS:				
13. Time Initial Circulation Achieved				
14. Start Mixing Time				
15. End Mixing Time				
16. Start Pumping Time				
17. End Pumping Time				
18. Volume Grout Pumped				
19. Depth of Rods				
20. Return Achieved (Yes/No)				

21. DESCRIPTION OF UPPER METER: _____

22. COMMENTS: _____

23. WEATHER

and 102 mm. The casings are 1.5 m in length and extend 0.5 to 0.75 m below ground surface leaving 0.75 to 1.0 m of the casing above ground.

A2.3.2 STANDPIPES

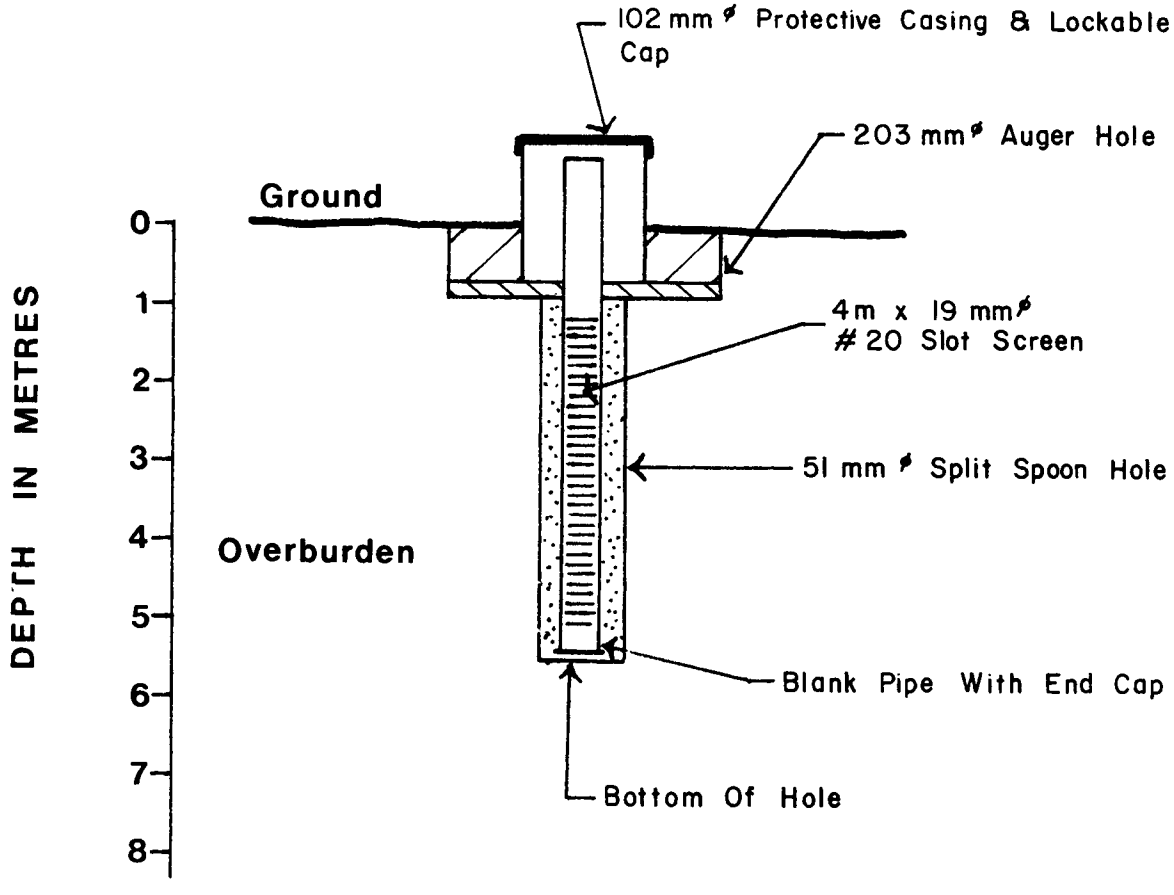
A shallow ground water monitor (standpipe) was installed at each of the 12 on-site drilling locations and four off-site drilling locations. Each standpipe was installed to a depth of between 5.5 m and 5.8 m and consists of 19 mm diameter PVC pipe. Figure A2-7 shows the construction details of a typical standpipe.

The 3 m to 4 m lower portion of the standpipes are machine slotted with No. 20 slot opening. The bottom of the standpipe has a blank segment of pipe which acts as a sediment sump and is between 0.08 to 0.3 m in length. A PVC cap was friction-fitted to the bottom of each standpipe to prevent materials from entering the pipe.

The slotted interval of the standpipe was backfilled with a silica sand pack. This material fills the annular space around the slotted interval to a maximum of about 0.8 m above the slots. A bentonite seal consisting of bentonite gravel was placed above the silica sand to a thickness of 0.1 m to 0.4 m. Under dry borehole conditions the bentonite was generally wetted with a small quantity of water to promote swelling of the bentonite prior to backfilling with grout. This inhibits the downward movement of grout into the sandpack. The annular space around the standpipe was backfilled with a cement-bentonite grout mixture to within 0.3 m to 0.5 m of the ground surface.

Figure A2-7

Standpipe Construction Details



LEGEND

CEMENT-BENTONITE GROUT

BENTONITE SEAL

SILICA SANDPACK

A protective surface casing was installed over the standpipe in the same manner as those for the piezometers. A description of the casing installation is provided in the previous section.

A2.3.3 PNEUMATIC PIEZOMETERS

A total of 14 pneumatic piezometers were installed on-site. This includes two pneumatic piezometers within the overburden at each of five locations and two pneumatic piezometers in bedrock at each of two locations. Construction details of the pneumatic piezometer installations are shown in Figure A2-8 and summarized in the following discussion.

Pneumatic piezometers are designed to measure pore water pressure within soil or rock by means of a pressure activated diaphragm. The diaphragm is mounted inside a pore pressure transducer which is installed to a predetermined depth within the borehole and sealed in place. The transducer is connected to the surface with two polyethylene tubes encased in a waterproof polyethylene jacket. Downhole pore pressures are obtained by pressurizing the diaphragm through one of the polyethylene connecting tubes and measuring the pressure by means of a pressure meter.

Transducers were supplied by Sinco Slope Indicator Company; detailed specifications (model #514178) are shown in Figure A2-9.

The transducers were wrapped in a silica sand-filled filter cloth "sock". The sock was saturated with water prior to installation to dissipate air bubbles from around the transducer. This prevents air locking around the diaphragm and also reduces the

Pneumatic Piezometer Construction Details

Figure A2-8

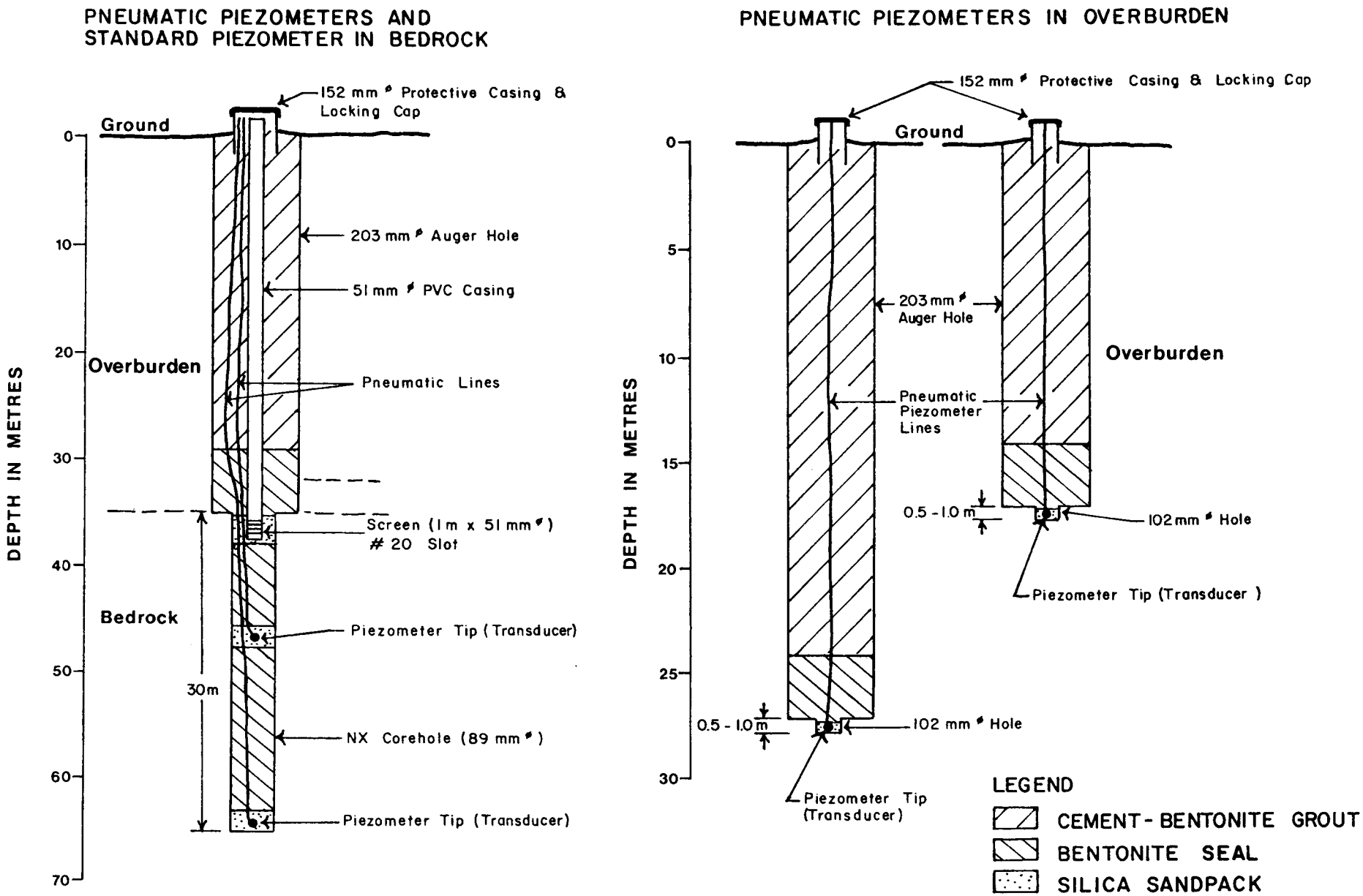


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Figure A2-9

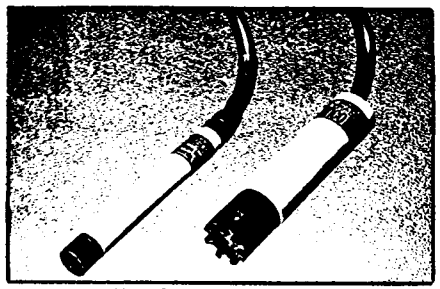
PORE-PRESSURE TRANSDUCER
514177 & 514178

Patent Applied For

The Models 514177 and 514178 are our most economical pore-pressure transducers for determining pore-water or gas pressure within embankments, foundations and slide areas. The system features high sensitivity, superior repeatability, and low diaphragm displacement. Two sizes of transducer are available: Model 514177 has a 5/8" O.D. and Model 514178 has a 1" O.D.

The transducer converts fluid pressure into pneumatic pressure which can be relayed to a remote reading station. The basic principle of operation is a hydro-pneumatic balance of forces across a flexible diaphragm.

A variety of terminal stations and portable or wall-mounted indicators provides flexibility to meet various requirements. These are coupled to the pore-pressure transducer by means of polyethylene or nylon tubing in a water-proof polyethylene jacket. This tubing is designed for direct burial and will withstand rough handling in the field. The two transducer models can both be operated with either a 2-tube or a 3-tube configuration. Accuracy is increased for longer tube lengths with a 3-tube system.



Model 514177 Model 514178

DESCRIPTION AND SPECIFICATIONS

Pore-water pressure acts upon a flexible diaphragm having negligible spring force. The force of the diaphragm due to water pressure causes a valve to close. To take a reading, when using the 3-tube arrangement, gas pressure is applied through the input tube allowing flow into the chamber and into the output tube which is connected to a high precision pressure gauge in the readout indicator. Pressure in the chamber and two tubes increases until it balances against the pore-water pressure. Excess pressure is vented to atmosphere through the opened transducer valve and third tube. The measurement may be repeated by reducing input pressure to a level just below the output pressure gauge reading at which point it will begin to decrease. The input pressure is increased again and the reading is repeated.

For the 2-tube configuration, there is no output tube. Instead, the high precision pressure gauge in the indicator measures the input pressure to the transducer. The difference between the pore pressure and the input pressure increases with longer tube lengths and higher operating pressures. However, as long as repeatable reading procedures are maintained and pore pressure changes are not extreme, high precision can be achieved.

For many applications, the flow rate may be limited by visual observation to avoid reading error. For the extremely accurate and sensitive readout pressure gauges, the flow condition is monitored with a "floating ball" flowmeter. By maintaining constant flow for each reading, the small error due to flow rate and possible operator error is eliminated. Tubing lengths for the 3-tube system may be adjusted to suit conditions with no effect to the calibration of the transducer.

Another means of operation, which also gives excellent results, is the "over pressure" method. Results are obtained by rapidly injecting gas into the input tube until gas escapes through the vent tube. When gas is detected flowing from the vent tube, the input gas is interrupted and the excess gas is slowly vented until the diaphragm valve is closed. The system pressure can then be measured in either the input tube or the gage tube. The "over pressure" method is commonly used with two-tubes, providing a more economical means of measuring pore-pressure.

This transducer does not require in-place calibration and has negligible zero shifts or changes in gauge factor. It provides a non-ambiguous measurement which is a result of the unique pneumatic-hydraulic null-balance condition. The application of this technique to measurement of pore-water pressure results in an economical, stable and sensitive transducer giving long-term repeatability for periodic measurement of fluctuating pressures. Normally, it is not necessary to refer to calibration curves at any time since the gauge factor is essentially 1.

A stainless steel disc filter is standard. Three additional types of porous filters are available. The Norton Casagrande type and the polyethylene type filters have large pore size and low air-entry pressure. The Coors filter has high air-entry pressure and permits the measurement of water pressure whenever pore-gas pressure is also present.

Fluid-pressure measurements may be continuously monitored and recorded on moving chart or digital data-logging equipment. Output signals may be compared to preset threshold values and utilized to trigger external alarms.

APPLICATION AND INSTALLATION

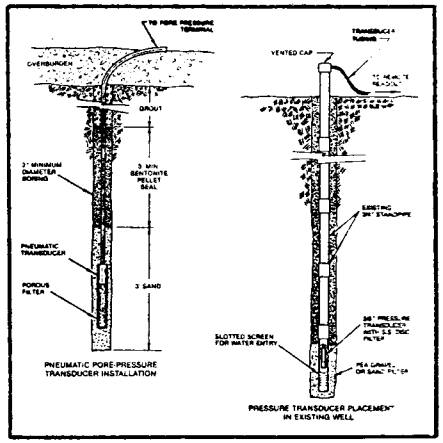
The transducer will operate in any position. It can be installed in boreholes or pressed into the soil. Well-points attached to steel pipes can be pushed into the soil and do not require drilled holes. The 5/8-inch O.D. size transducer (Model 514177) can be used in existing standpipes or placed in small size drive type well-points.

In most applications, the 1" O.D. transducer with a Norton tube filter is embedded in an open borehole and is sealed off from other water-bearing areas with Bentonite Pellets or cement grout. The tubing may be embedded directly in trenches using sand backfill to prevent rocks or other sharp objects from damaging the tubing. In cases where large lateral or vertical deformations may develop, the tubing can be protected by an outer armored conduit.

In many construction projects, it is essential to monitor pore-water pressure in both soil and rock. The transducer will provide in-situ pore-pressure data economically and reliably in support of the following objectives:

- Monitoring water-pressure changes in regard to stability of slopes.
- Control during construction of embankments and dams.
- Soil stabilization to determine seepage patterns in soil and rock.
- Surcharging of compressible foundations.
- Gauging of water table and hydrostatic pressures.
- Pumping tests to determine permeability and transmissibility coefficients.
- Measuring of pore-pressure subjected to static and dynamic transient loadings in, for example, evaluating liquefaction potential associated with earthquake accelerations.
- Stability of tailings dams and solid disposal areas.

Slope Indicator Company will be pleased to assist users with detailed installation planning.



Since this is a scientific instrument, measurements should be taken, recorded, and interpreted by qualified personnel. SINCO is not responsible for errors or omissions of such personnel.

TRANSDUCER SPECIFICATIONS:

Pressure Range:	0.5-1000 psig (3.44-6894.8 kPa)
Repeatability:	± .05 psi
Accuracy:	
Calib. Zero Offset:	−.30 psi ± .05 psi (−2.0 kPa ± .35 kPa)
Sensitivity $= \frac{\text{Output}}{\text{Input}}$:	1.007 ±0.0005
Diaphragm Displacement:	0.01 cc
Diaphragm Material:	
Standard	Buna-N Rubber
Optional:	Viton Rubber, Silicone Rubber
Body:	
Model 514177:	Nominal, ⅝" O.D. Actual, 0.625" (16 mm) O.D. ABS
Model 514178:	Nominal, 1" O.D. Actual, 1.062" (27 mm) O.D. ABS
Filters:	
Standard	S.S. Disc — 50 micron, pore size sintered stainless steel
Optional	Norton Tube — 60 micron, pore size; 1.5" (38.1 mm) O.D. x 4" (102 mm) length; .25" (6.35 mm) wall
	Polyethylene — 60 micron, pore size; 1.5" (38.1 mm) O.D. x 4" (102 mm) length; .25" (6.35 mm) wall
	Coors Tube — 1.5 to 2.2 micron, pore size; Air Entry Pressure: 18 to 28 psi (1.27 to 1.97 kg/cm²); 1.5" (38.1 mm) O.D. x 6" (152 mm) length; .25" (6.35 mm) wall

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time interval required prior to taking representative pore pressure readings.

In the case of bedrock installations, two pneumatic piezometers were installed at different depths within the same borehole. Bentonite gravel was used to backfill the borehole to the appropriate depth for the transducer installation. The transducer, wrapped in the filter cloth sock, was then installed and silica sand placed in the annular space around the transducer to 0.3 m to 0.8 m above the top of the transducer. The borehole was then backfilled with bentonite gravel to the level at which the upper transducer was to be placed. The installation and backfilling of the second transducer was completed in a similar fashion. Bentonite gravel was used to backfill and seal the borehole above the upper transducer to about 3 m below the bedrock surface. A standard piezometer was installed within the upper 3 m of bedrock in the same borehole.

Overburden pneumatic piezometers were installed using similar installation procedures. Only one transducer was installed in each borehole. Overburden boreholes were generally dry during installation of the pneumatic transducers. At drilling location 85-3 (Figure A2-1) a small amount of water was added to the borehole prior to installing the transducer. The silica sand pack and the transducer were installed under saturated conditions at the bottom of this borehole. The filter cloth sock and transducer were also saturated prior to installation. Presaturation of the borehole was only completed at location 85-3 and not at the eight other overburden pneumatic piezometer installations for comparison purposes. A bentonite gravel seal of 3 to 4 m in thickness was placed over the silica sand backfill placed around the pneumatic piezometer. The bentonite seal was

wetted with clean water after installation. Bentonite-cement grout was used to backfill the boreholes from the bentonite seal to within 0.5 to 1.0 m of the ground surface. Protective steel casings were installed at surface in a similar manner to the other piezometers.

A2.4 GEOCHEMISTRY MONITORS

A total of 38 water quality monitors were completed at five on-site drilling locations (locations 85-1, 85-3, 85-8, 85-10 and 85-12 in Figure A2-1). The water quality monitors are used for sampling of in situ ground water in both the overburden and bedrock. These monitors are constructed of 51 mm diameter PVC "Triloc" pipe and screens. The pipe which is in 3 m lengths, has specially threaded ends with rubber "O" ring seals which provide flush, water-tight joints. The screens are machine slotted with No. 20 slot openings for bedrock installations and No. 10 slot openings for overburden installations. The bottom of the screens are fitted with a blank tapered end. Three types of water quality monitors were installed.

- standard piezometers;
- standpipes; and
- shallow overburden profile monitors.

A2.4.1 STANDARD PIEZOMETERS

Bedrock monitors

Bedrock water quality monitors were installed at five on-site drilling locations. These monitors are completed within the upper 3 m of the bedrock and are similar in design to the standard hydrogeologic bedrock piezometer. The construction details are shown in Figure A2-10.

Water Quality Bedrock Piezometer, Construction Details

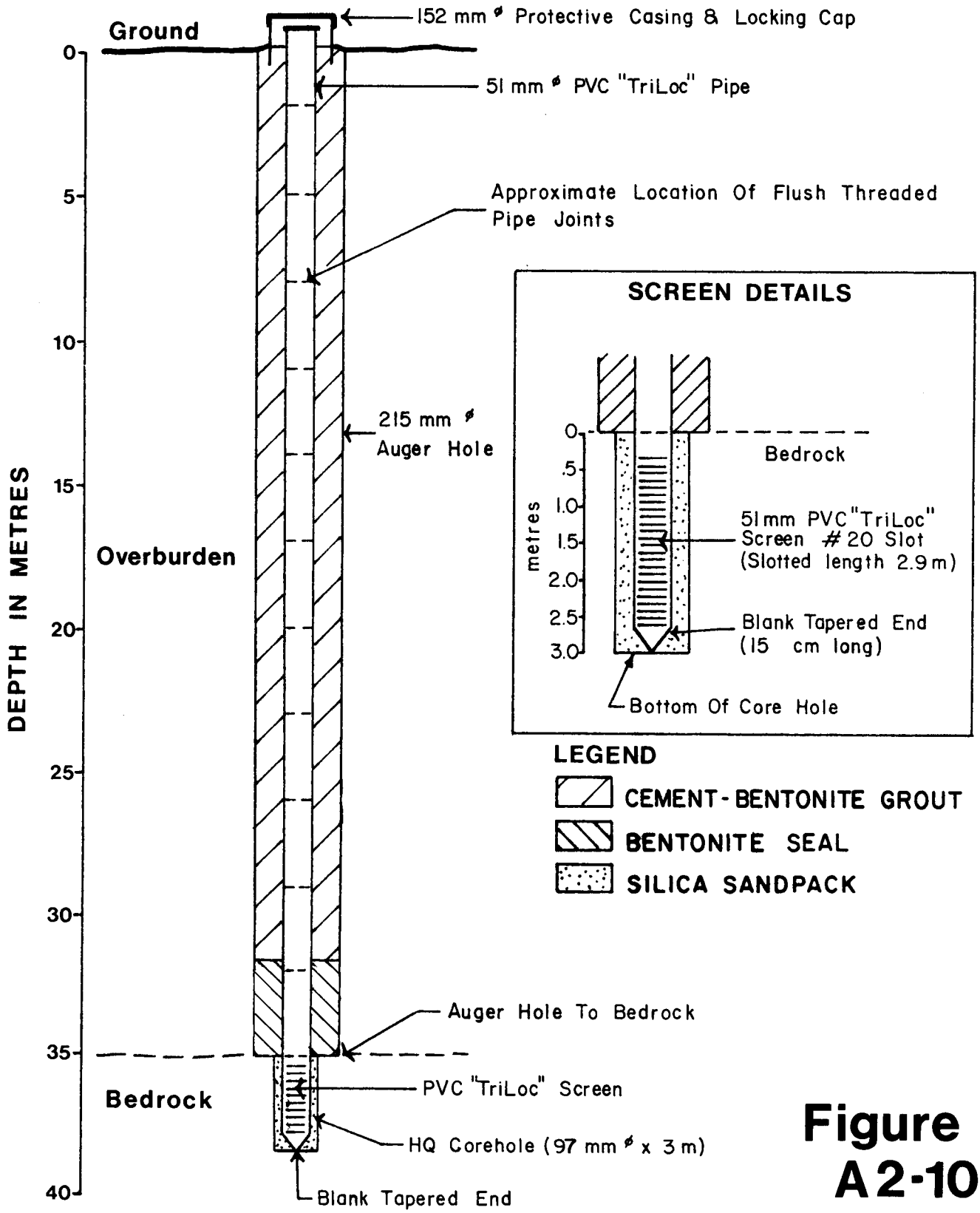


Figure A2-10

Gartner Lee Limited

The design of the bentonite seals was modified at some locations due to problems with materials clogging the inside of the borehole. This was the case in monitor 85-10-1 where a 10 m thickness of bentonite slurry was installed above 1.7 m of peltonite for a total seal thickness of 11.7 m above the silica sand pack. A thicker seal was also installed at monitor 85-12-1 to provide a secure seal above the highly fractured bedrock. The seal at 85-12-1 consists of 6 m of bentonite gravel above 2 m of bentonite pellets for a total seal thickness of about 8 m. Significant quantities of silica sand were required at 85-12-1 because the bedrock was extensively fractured. Consequently the upper 1 m of bedrock could not be backfilled with silica sand and was backfilled with caved material as the augers were pulled up.

Overburden monitors

Two water quality monitors were installed in the overburden at the five on-site locations. These monitors were installed under dry borehole conditions. They are constructed of 51 mm diameter PVC "Triloc" pipe and screens. Construction details are shown in Figure A2-11.

The screens consist of 0.6 m lengths of 51 mm diameter PVC "Triloc" machine slotted pipe with No. 20 slot openings. The screens were wrapped in a filter cloth (geotextile) sock which was fastened to the screens by three plastic clips. Silica sand was not used around the screens, instead the top of the split spoon hole in which the screens were inserted was covered with a PVC ring and rubber plug as shown in the screen details in Figure A2-11. The annular space between the screen and the sides of the split spoon hole was left empty to minimize the potential for air locking within the sand pack, which could

Water Quality Overburden Piezometer Construction Details

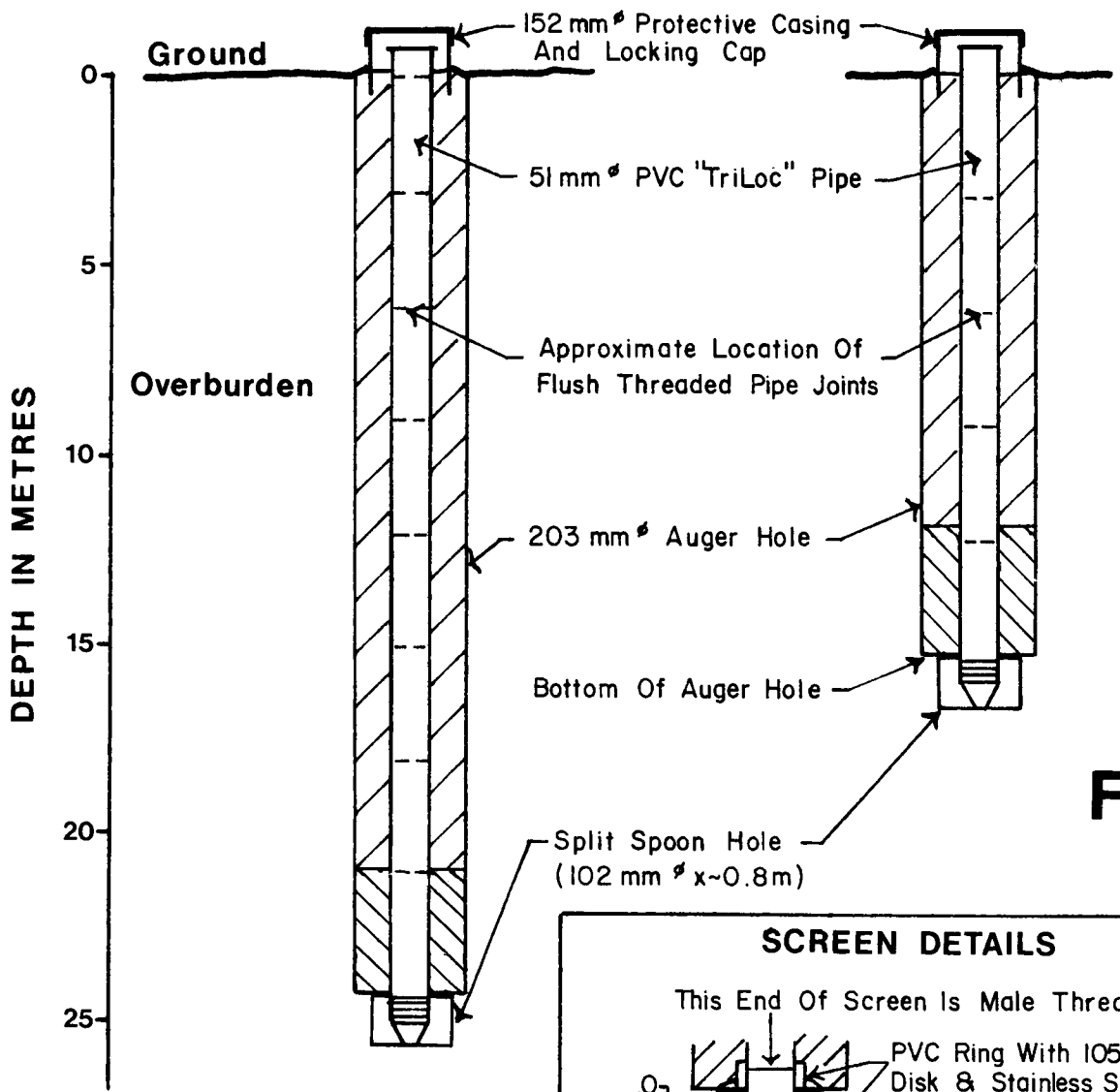


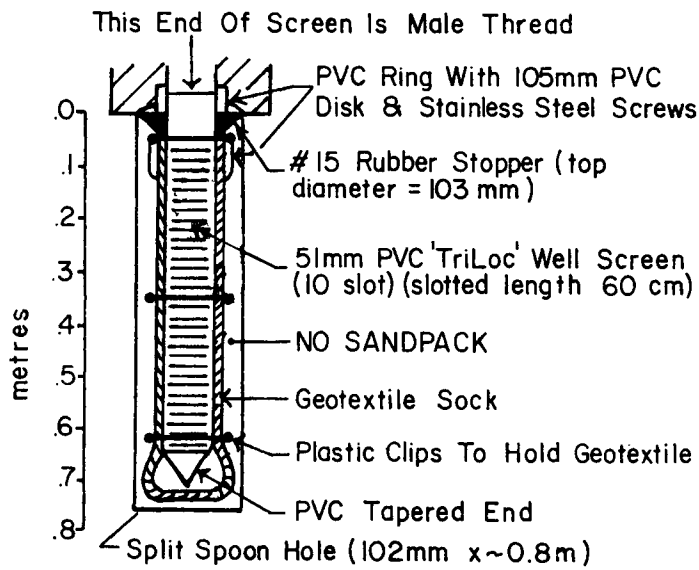
Figure A2-11

LEGEND

CEMENT-BENTONITE GROUT

BENTONITE SEAL

SCREEN DETAILS



alter the ground water chemistry. The depth of installation of the screens in the two overburden water quality monitors is about 15 m and 25 m respectively, from the ground surface.

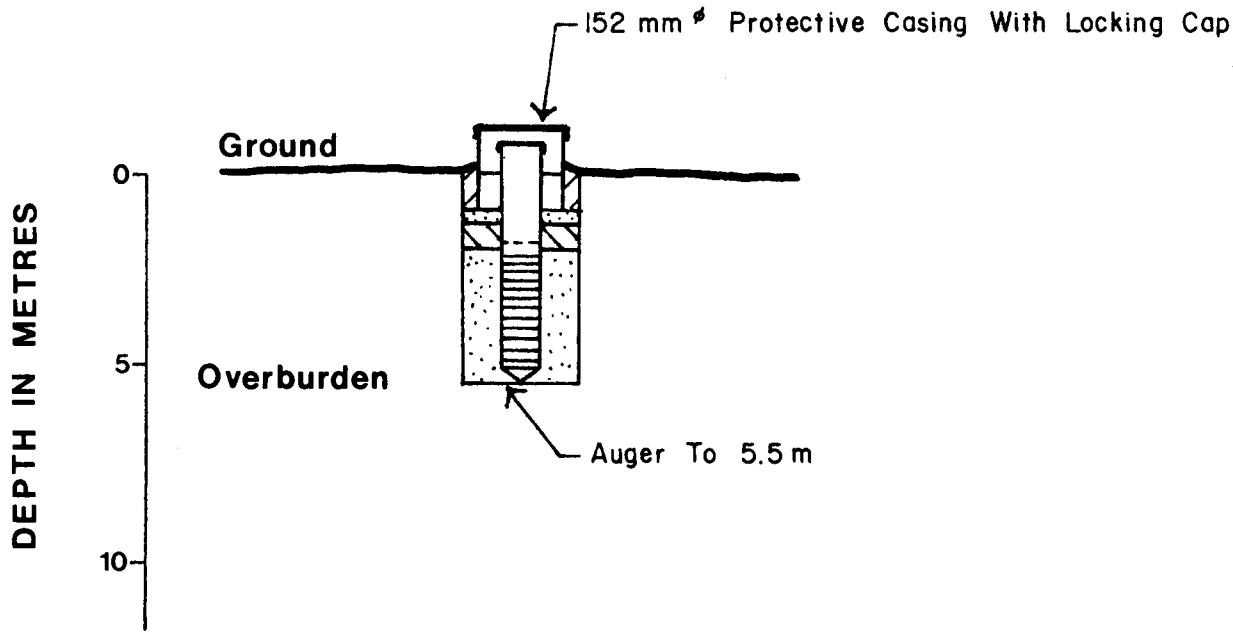
The bentonite seal installed in these monitors is layered, consisting of bentonite pellets, bentonite gravel and bentonite powder. The seal was installed above the PVC ring and rubber stopper as shown in Figure A2-11. The minimum thickness of the bentonite seals is 3.3 m. The bentonite seals were wetted with clean water prior to backfilling the hole with grout. As with all other monitors, a cement-bentonite grout mixture was used to backfill the borehole annular space above the bentonite seal to within 0.5 to 1.0 m of ground surface. The grout mixture was installed through a tremie line from the top of the bentonite seal.

The overburden water quality monitors are protected at surface with a 152 mm diameter protective steel casing with locking cap. These casings were grouted in place after being adjusted to a convenient height. The protective casing installation was completed in a similar fashion to that described previously for the hydrogeologic monitors.

A2.4.2 STANDPIPES

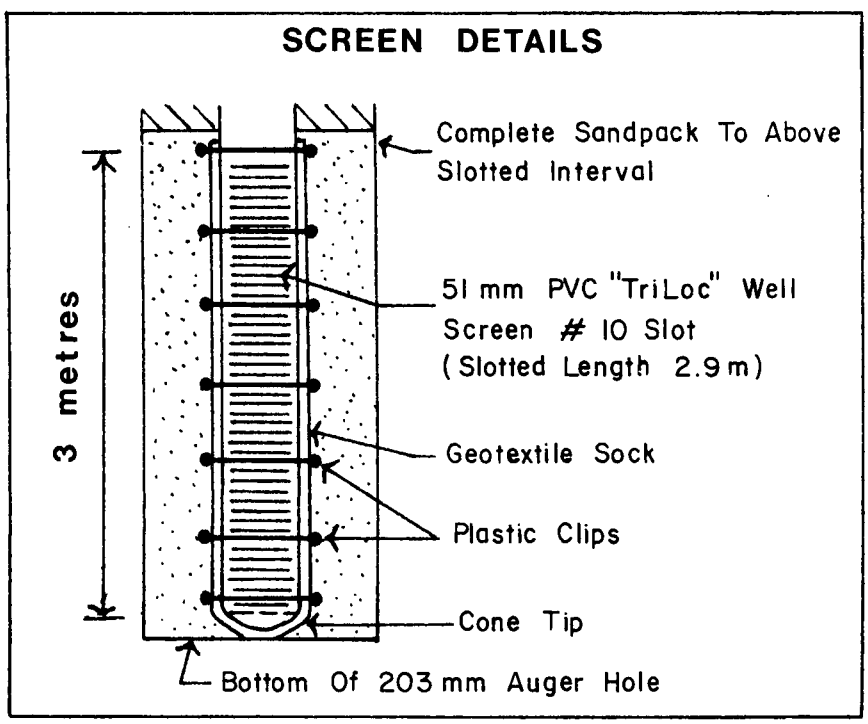
Water quality standpipes are installed at five drilling locations (locations 85-1, 85-3, 85-8, 85-10 and 85-12 in Figure A2-1). The standpipes are constructed of 51 mm diameter "Triloc" PVC pipe and screens. They are completed to a depth of 5.5 m below ground surface. Construction details are shown in Figure A2-12.

Figure A2-12
Water Quality Standpipe, Construction Details



LEGEND

- CEMENT-BENTONITE GROUT
- BENTONITE SEAL
- SILICA SANDPACK



The screens are machine slotted "Triloc" pipe with No. 10 slots over a 3 m segment. The bottom end of the screen was fitted with a tapered cone tip and the slotted interval was wrapped in a filter cloth sock which was fastened to the screen with several plastic clips. Silica sand pack backfilled around the screen to just above the top of the slotted interval.

Bentonite powder was added to the top of the silica sand pack as a seal to prevent surface water from entering the screen. The seal has a minimum thickness of 0.4 m. No water was added to the bentonite powder. Silica sand was placed above the bentonite to level and support the protective surface casing as it was being grouted in place.

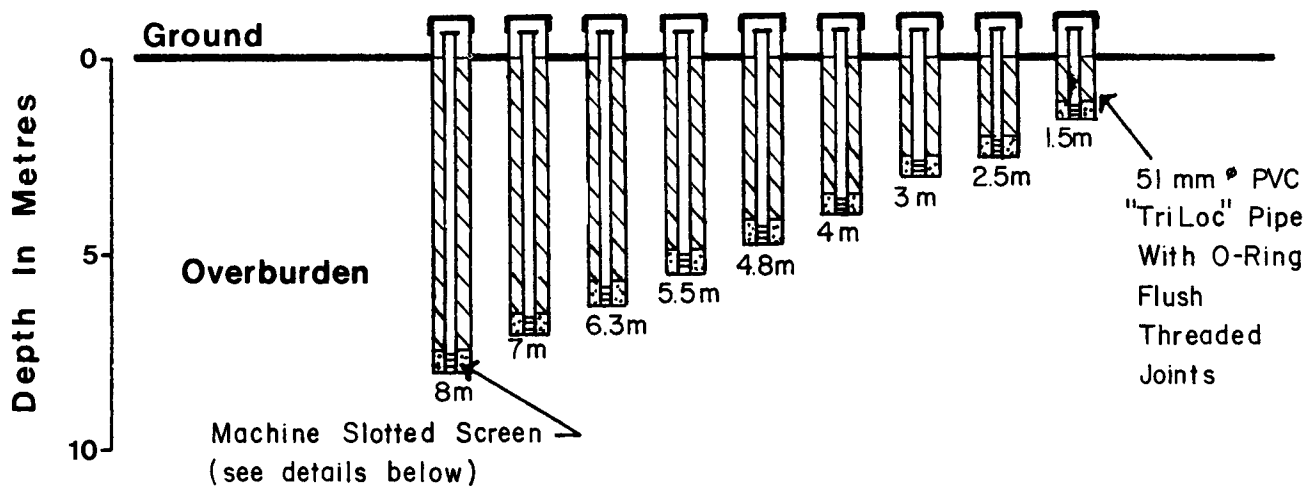
A cement-bentonite grout mixture was placed above the bentonite seal to fill the annular space around the monitor to within about 1 m of the ground surface.

A2.4.3 SHALLOW OVERBURDEN PROFILE MONITORS

A set of nine shallow water quality monitors were installed at each of the two detailed drilling locations, 85-1 and 85-12 (Figure A2-1). These monitors are constructed of 51 mm diameter PVC "Triloc" pipe with machine slotted screens. The purpose of these monitors is to allow for the sampling of ground water at various shallow depths between 1.5 and 8.0 m. Construction details for these monitors are shown in Figure A2-13.

The screens consist of 51 mm diameter PVC "Triloc" pipe with No. 10 sized machine slotted perforations extending over a 0.3 m length. The bottom of the monitor was capped with a friction-fitted PVC cap. The slotted interval was covered with a filter cloth (geotextile) sock held in place with two plastic clips.

Shallow Overburden Profile Monitors, Construction Details



LEGEND

Bentonite Seal

Silica Sandpack

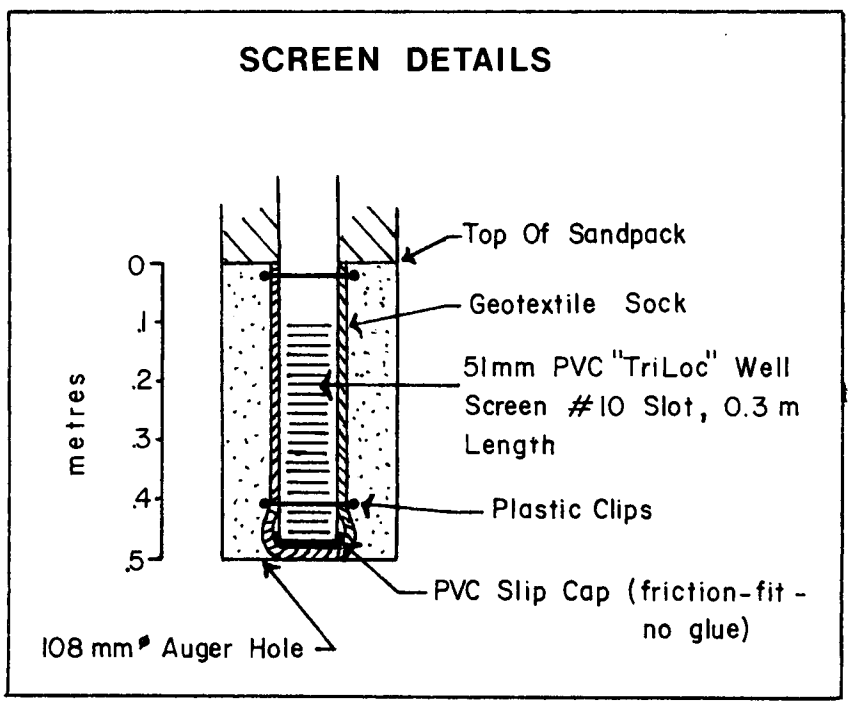


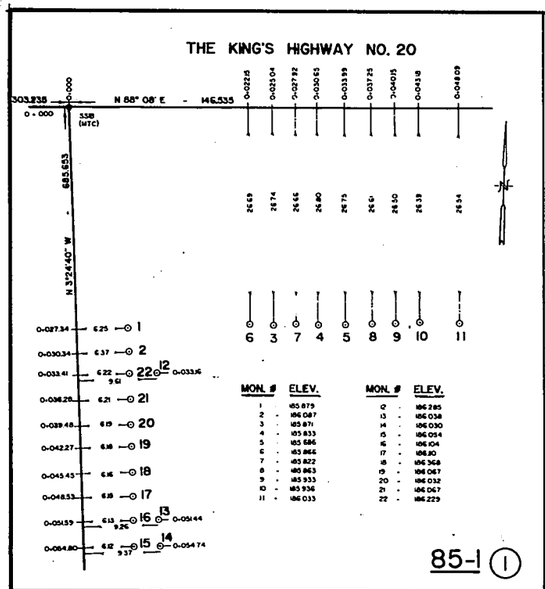
Figure A2-13

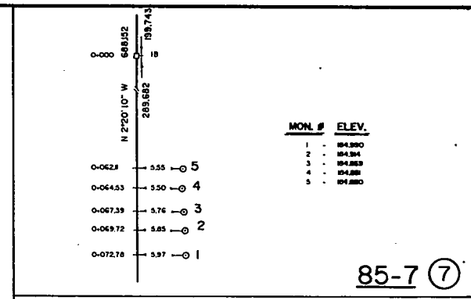
The annular space around the slotted interval was backfilled with silica sand to just above the top of the slotted interval.

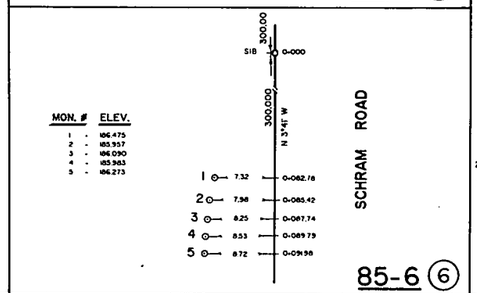
The bentonite seals extend from above the silica sand pack to within less than 1 m of ground surface. The seals consist of bentonite pellets, bentonite gravel and bentonite powder.

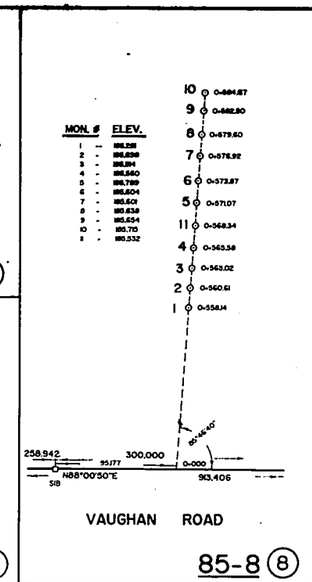
Protective steel surface casings measuring 152 mm in diameter and 1.5 m in length were installed over each monitor. Each casing was installed to a depth of 0.6 to 1.0 m and was fitted with a locking cap. A surface seal was achieved by pushing the casing into the 108 mm diameter auger hole.

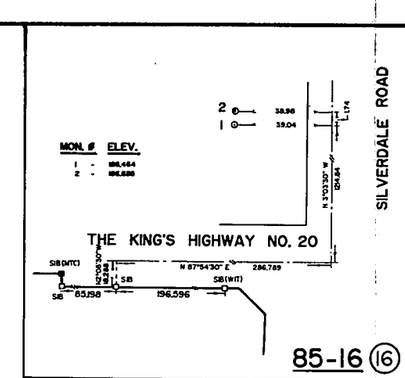
A legal survey of all monitors described above was completed by Matthews and Cameron Limited and their location relative to surveyed benchmarks are shown on Figure A2-14.

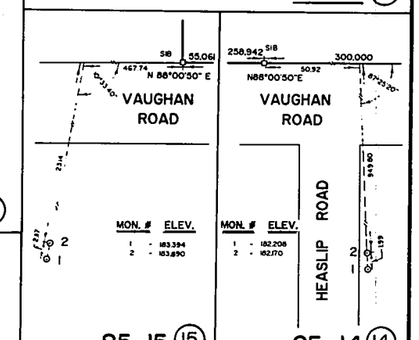


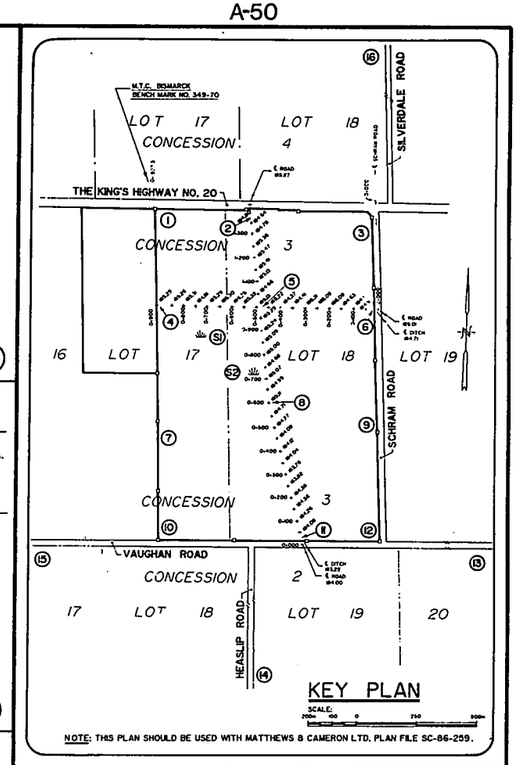


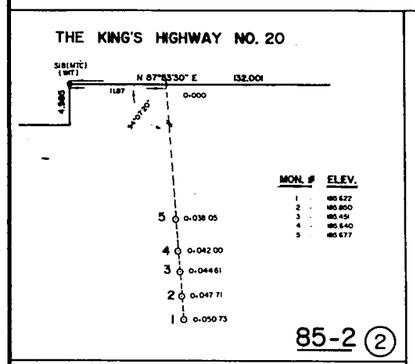


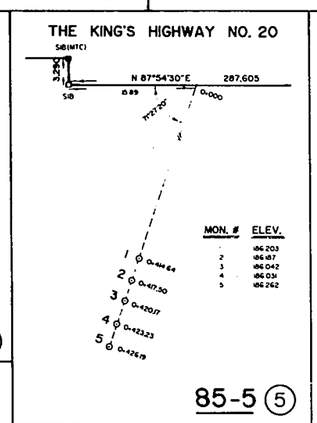


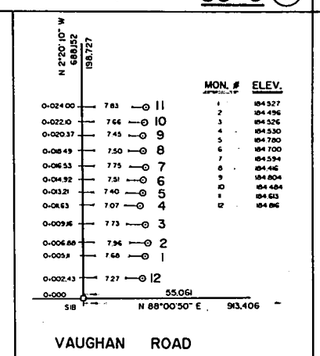


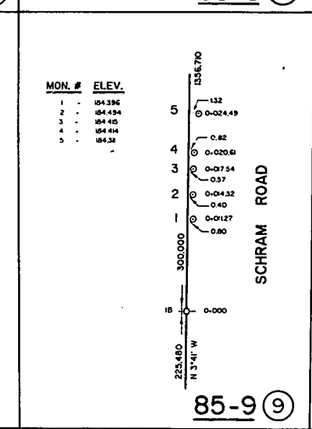


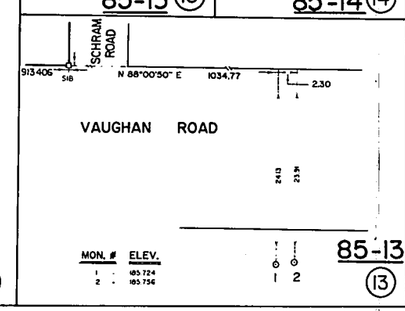


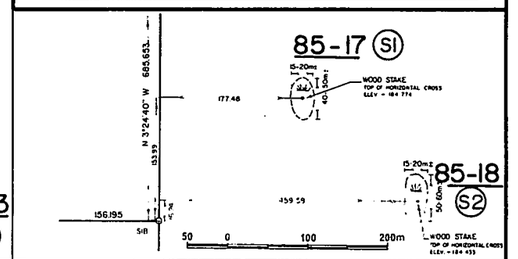


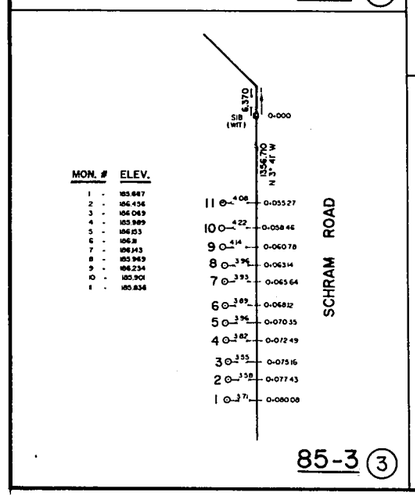


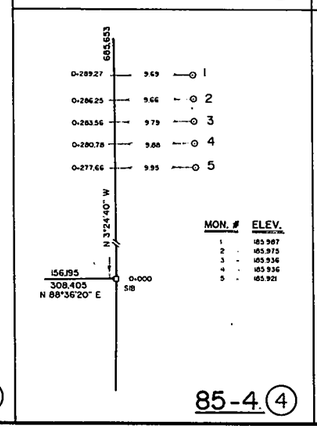


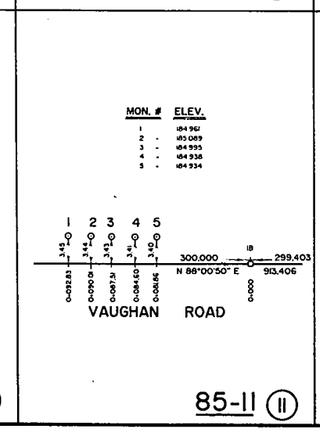


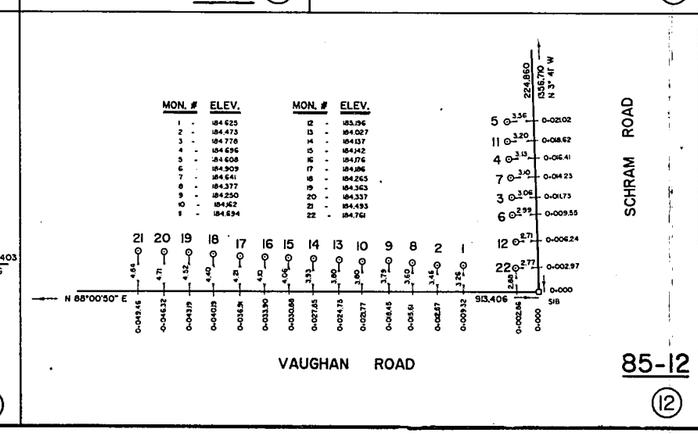












BENCH MARK

"BISMARCK"
M.T.C. BENCH MARK NO. 349-70
ELEVATION - 186.351
TABLET IS SET HORIZONTAL IN WEST FACE OF CONC. FOUNDATION, BEING 2.9m N. OF S.W. CORNER & 0.3m BELOW FRAMEWORK 1½ STY DWELLING.
SEE M.T.C. HORIZONTAL AND VERTICAL CONTROL PLATES NO. 227-20165-O AND NO. 227-20131-O

LEGEND

① DENOTES MONITORING LOCATION GROUP NO.
(S) - SWAMP AREA NO.
+184.08 - EXISTING ELEVATIONS
85-1 GARTNER LEE ASSOCIATES LIMITED DRILLING LOCATION NUMBER

METRIC

DISTANCES SHOWN ON THIS PLAN ARE IN METRES AND CAN BE CONVERTED TO FEET BY DIVIDING BY 0.3048.

NOTES

FIGURE A2-14
Monitor Locations

DATE JULY 2, 1986 — THOMAS G. CAHILL, ONTARIO LAND SURVEYOR

PLAN SHOWING LOCATION & ELEVATION OF MONITORS

PARTS OF LOTS 17 & 18, CONCESSION 3
FORMERLY IN THE TOWNSHIP OF GAINSBOROUGH, NOW
TOWNSHIP OF WEST LINCOLN
Regional Municipality of Niagara

SCALE: (EXCEPT WHERE NOTED OTHERWISE)

MATTHEWS & CAMERON LTD.
Ontario Land Surveyors -- Professional Engineers
R. J. MATTHEWS O.L.S.
ANDREW CAMERON O.L.S., P. ENG. — T. G. CAHILL O.L.S.
5252 MURRAY ST. NIAGARA FALLS, ONT. L2E 3V7 Phone (416) 356-3693
27 WILLIAM ST. ST. CATHARINES, ONT. L2R 5H2 Phone (416) 988-8841

DRAWN BY	CHECKED BY	SCALE
A.J.L.	T.G.C.	1:300
YEAR 1986	L.L.N. 50350	FILE SC-86-266

A3 WATER LEVEL MEASUREMENT AND HYDROGEOLOGIC TESTING

Protocols for conducting water level measurements and field and laboratory testing to establish hydrogeologic parameters are described in this Appendix.

This Appendix is organized as follows:

- water level measurement (Appendix A3.1);
- slug testing (Appendix A3.2);
- packer testing (Appendix A3.3);
- pump testing (Appendix A3.4); and
- laboratory testing (Appendix A3.5).

A3.1 WATER LEVEL MEASUREMENT

A3.1.1 PIEZOMETERS AND STANDPIPES

Water levels in all piezometers and standpipes, other than pneumatic piezometers, were measured using a Solinst Compact Water Level Meter (Model No. 1W4). The procedure for taking water level measurements is described below:

(1) Remove protective casing cap and monitor cap.

(2) Switch water level meter to "on"; test the battery using battery test button (if a "beep" is heard then batteries are charged). Ensure that the probe and cable are clean.

(3) Lower the probe into the monitor slowly until a "beep" is heard indicating water.

(4) Read the depth, to the nearest centimetre (0.01 m), from the graduated cable at the highest point on the top of the monitor pipe.

(5) Repeat the measurement for confirmation.

(6) Remove the probe from the monitor.

(7) Replace monitor cap and lock the protective casing cap in place.

Measurements in the geochemistry monitors were undertaken using a water level meter which was dedicated for use in these monitors. The water level measurements are presented in Appendix F2.

A3.1.2 PNEUMATIC PIEZOMETERS

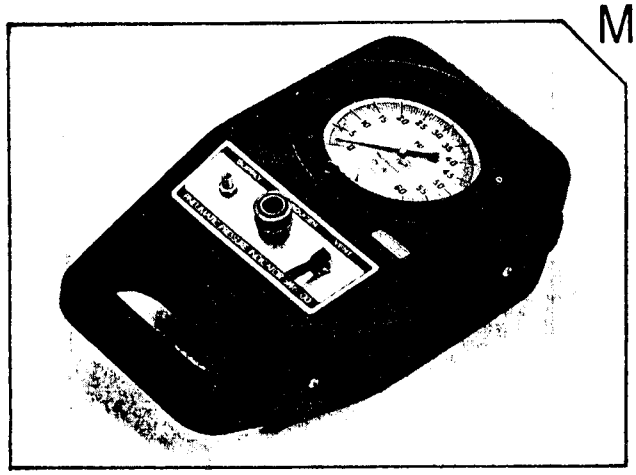
The specifications and the procedure for use of the Sinca Model 514196 Pressure Indicator are described in Figure A3-1. This instrument is used to measure the ground water pressure at the pneumatic piezometers, described in Appendix A2.3.3. The pressure measurement is converted into an equivalent water level elevation using the following formula:

equivalent water level elevation (m)	=	elevation of pneumatic piezometer (m)	+	pneumatic pressure x 0.704 reading (psi)

The 0.704 value is a constant which converts pressure in pounds per square inch (psi) to metres of hydraulic head. Equivalent water level elevations are presented in Appendix F2.

Figure A3-1

Pneumatic Pressure Indicator
Model 514196



The Model 514196 Pressure Indicator was designed to be economically priced and simple to operate. This unit incorporates the same high quality components as our other pneumatic pressure indicators into a custom-made, easy to handle ABS plastic case.

When combined with the Models 514177 and 514178 piezometers, the system is used for studies relating to hydrogeology, geotechnical and geophysical applications.

The indicator operates on a simple over-pressurizing technique for reading the transducer, which reduces operator error. The pressure gauge (0-60 psi with ½% accuracy) responds directly to the input supply, which can be a bicycle pump, automative air supply, or portable pressure bottle.

To operate the system, simply connect the transducer to the quick connector, and the air supply to the tire valve. Input pressure should be continued until air escapes from the vent tube of the transducer. The operator then shuts down the supply and waits for the pressure on the gauge to stabilize. This method will result in accurate, repeatable readings. A vent valve on the indicator can be used to bleed the air from the gauge and transducer.

SPECIFICATIONS

Size: 13.5 x 7.25 x 5 in (343 x 184 x 127 mm)

Weight: 5 lb (2.3 kg)

Maximum Operating Pressure: 60 psi (700 kPa)

Accuracy: 0.50% Full Scale

Gas Source: Bicycle Pump, Automotive Air Supply or Portable Pressure Bottle

LIMITED WARRANTY: The Slope Indicator Company warrants all products sold by it to be free of defects of workmanship and material for a period of one year from the date of delivery by it. The **OBLIGATION OF THE SLOPE INDICATOR COMPANY** is hereafter **LIMITED** to **REPLACEMENT** or, **AT ITS OPTION, REPAIR** of products returned to it **WITH TRANSPORTATION CHARGES PREPAID** and which its examination shall disclose, to its satisfaction, was/were not free from such defects.

IN NO EVENT SHALL THE SLOPE INDICATOR COMPANY BE LIABLE for **CONSEQUENTIAL** or **SPECIAL DAMAGES,** or for **INSTALLATION, ADJUSTMENT** or other expenses which may arise in connection with such products.

THIS WARRANTY IS EXPRESSLY IN LIEU OF ALL OTHER WARRANTIES, express or implied, whether of merchantability or fitness for any particular use, and of all other obligations and liabilities of any kind and character. **THERE ARE NO WARRANTIES WHICH EXTEND BEYOND THE DESCRIPTION ON THE FACE HEREOF.**

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Unit #5-11300 River Road, Richmond, B.C. Canada V6X 1Z5 telex: 04-352848 VCR phone: (604) 276-2545

SINCO 70001463 - 1185 Printed in USA

A3.2 SLUG TESTING

A3.2.1 INTRODUCTION

Slug tests were performed on water level monitors to determine the in situ hydraulic conductivity of the hydrostratigraphic unit. This is accomplished by analysing the water level response in the monitor following instantaneous change in water level. A more complete discussion of the background, theory, and applications of slug testing is provided in Hvorslev (1951), Cedergren (1967), and Freeze and Cherry (1979). The slug test results are presented in Appendix G2.

A3.2.2 EQUIPMENT

The following equipment was used in conducting all slug tests with the exception of those performed on bedrock monitors:

- Solinst Compact Water Level Meter;
- stopwatch or other accurate timepiece; and
- "slugs" for displacing water in the monitors.

Slug Type	Length	Diameter
Aluminium	1.825 m	0.010 m
Nylon	1.530 m	0.010 m

All data were recorded on Slug Test Field Sheets (Figure A3-2).

The following equipment was used in conducting slug tests on bedrock monitors:

FIGURE A3-2:
SLUG TEST FIELD SHEET

PROJECT: NUMBER_____ NAME_____

BOREHOLE: NO._____ MONITOR NO._____

MONITOR: NOMINAL DIA.(mm)_____ INSIDE DIA.(mm)_____ MATERIAL_____

SCREEN: LENGTH(mm)_____ INSIDE DIA.(mm)_____ MATERIAL_____

FILTER PACK: LENGTH(mm)_____ DIAMETER(mm)_____ MATERIAL_____

TEST: START DATE_____ START TIME_____

STATIC LEVEL,H (mBTOP)_____ INITIAL LEVEL,Ho (mBTOP)_____

COMPLETED BY: _____ CHECKED BY : _____

DATE	TIME t(h:m:s)	DEPTH h(mBTOP)	DATE	TIME t(h:m:s)	DEPTH h(mBTOP)

COMMENTS:

GARTNER LEE ASSOCIATES LIMITED

NOTE: (1) Test may be stopped when h = H-0.37(H-Ho)
(2) BTOP = "Below Top Of Pipe"
(3) h:m:s = hours:minutes:seconds

- Hewlett Packard HP 9816 computer with data acquisition software;
- Hewlett Packard 3456A Digital Voltmeter;
- Druck PTX160/D Pressure Transmitter, cable, and 12-volt battery;
- monitor seal apparatus with 3-way valve and pressure gauge;
- nitrogen gas cylinder and regulator
- electrical generator;
- Solinst Compact Water Level Meter; and
- nylon slug, 0.039 m diameter, 1.208 m length.

A3.2.3 METHOD

The procedure for conducting all slug tests with the exception of those performed on bedrock monitors is described below.

(1) Record appropriate initial data on the field sheet (Figure A3-2).

(2) Measure the static water level in the monitor and record on the field sheet (water level measurement is described in A3.1).

(3) Insert or withdraw an appropriately sized slug and note the time or start the stopwatch (Note: if a slug withdrawal test is performed, the slug must be placed in the monitor in advance such that the monitor has fully recovered to static prior to the test).

(4) Measure the water level in the monitor immediately on insertion or withdrawal of the slug and record as the initial level on the field sheet.

(5) Continue to measure water levels at appropriate time intervals such that sufficient data are obtained and record both the time and the water level measurement. The test may be discontinued when $Hx/Ho \leq 0.37$ (level at which curve match point reached).

The procedure for conducting slug tests on bedrock monitors is described below.

(1) Measure and record the static water level using a water level meter.

(2) Set up equipment as shown schematically in Figure A3.3.

(3) Start data acquisition program to monitor water pressure at the transmitter and record the static pressure.

(4) Seal off the top of the borehole by tightening the monitor seal apparatus and closing the 3-way valve.

(5) Pressure the borehole from atmospheric to 6 - 30 kPa using the nitrogen gas cylinder. Wait until the water level has stabilized (when the transmitter pressure is constant).

(6) Open the 3-way valve to instantaneously release the pressure in the borehole (the computer will automatically record the rise in water level at 0.5s intervals via the transmitter).

(7) Upon completion of the test unseal the monitor, leaving the pressure transmitter downhole.

Schematic Diagram Of Bedrock Slug Testing Equipment

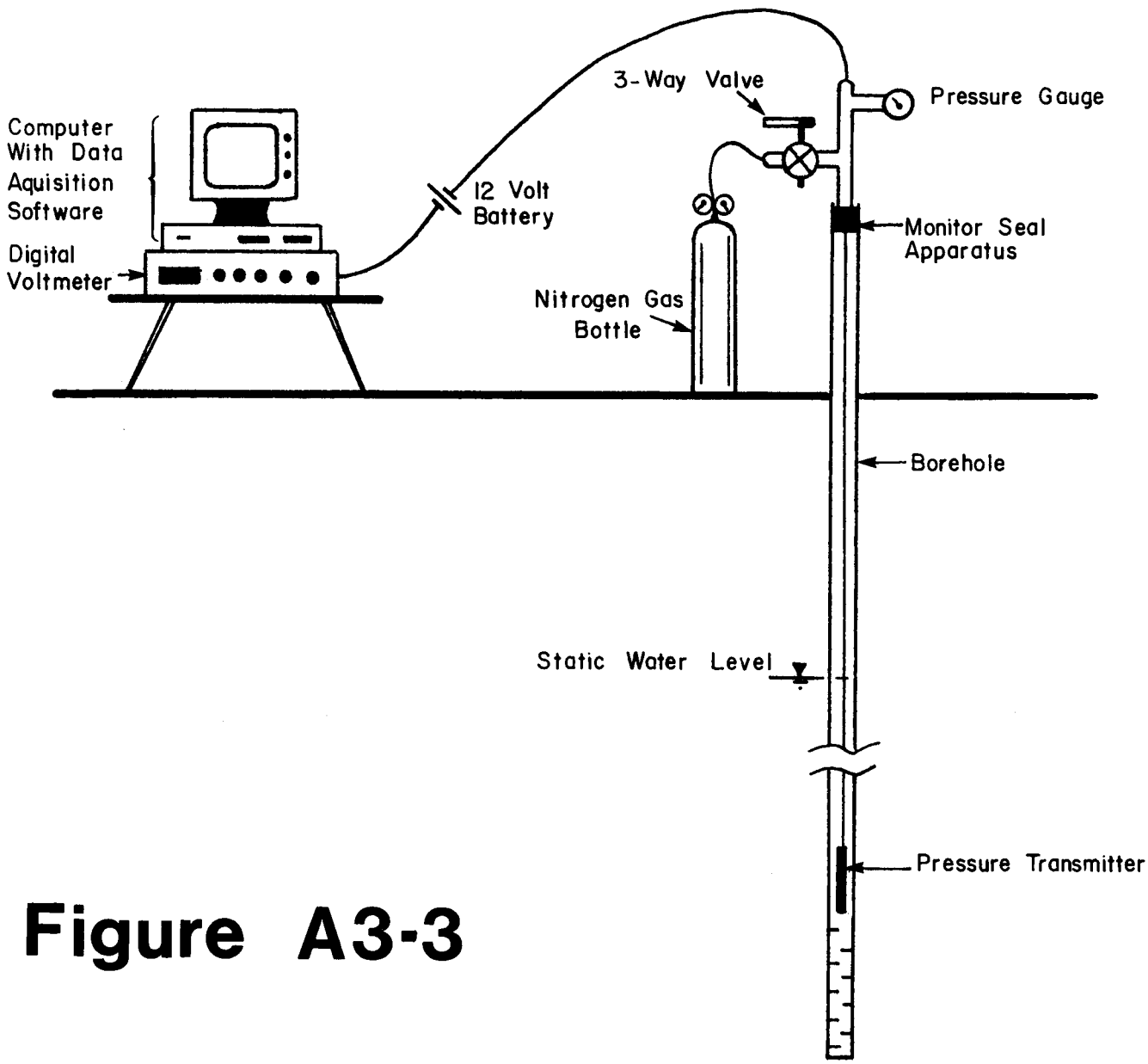


Figure A3-3

(8) Conduct a slug injection test by rapidly dropping the nylon slug into the water until the slug is completely submerged (the computer will automatically record the rise and decline of the water level at 0.5s intervals via the transmitter).

(9) Conduct a slug withdrawal test by rapidly removing the nylon slug out of the water (the computer will automatically record the decline and rise of the water level at 0.5s intervals.

(10) Stop the data acquisition program and disassemble the testing equipment.

A3.3 PACKER TESTING

A3.3.1 INTRODUCTION

Packer testing was performed to assess the hydrogeologic characteristics of the bedrock at various depths. Analysis of the test data provides values of hydraulic conductivity, storage coefficient, and static water level.

Packer testing was performed at two on-site boreholes, 85-1-1 and 85-1-12. Eleven tests were performed in borehole 85-1-1 at 3 m intervals between the depths of 39 to 72.4 m. Nine tests were performed in borehole 85-1-12 at 3 m intervals between the depths of 36 to 63 m. Specific intervals judged to be more permeable based on initial packer testing were retested using the slug-test method. Intervals judged to be less permeable were retested using a constant-head method. The testing methods are described in Section A3.3.4. The packer testing results are presented in Appendix G3.

A3.3.2 EQUIPMENT

The packer testing equipment is illustrated schematically in Figure A3-4.

The downhole equipment consists of two Roctest inflatable rubber packers separated by a perforated steel pipe. The packers are capable of sealing boreholes ranging from 63 to 114 mm in diameter. The packer system was lowered into position using a 19 mm inside diameter galvanized steel standpipe by means of a tripod and winch. The packers were inflated through 4.8 mm diameter nylon tubing which extends to the surface.

A cylinder of compressed nitrogen was used to inflate the packer and to manipulate the water level to conduct the testing. The nitrogen was fed through an adjustable manifold so that the tasks could be carried out independently at different pressures.

The data acquisition system includes:

- Hewlett Packard HP860 strip chart recorder;
- data logger; and
- Druck PTX160/D pressure sensor.

Power was supplied to the data logger and strip chart recorder by a portable generator. The generator also powered the variable direct current supply required for the pressure sensor.

A3.3.3 METHOD

A discussion of the packer testing equipment and procedure is provided in the reports prepared by Waterra Hydrogeology Inc. (Appendix G3).

Schematic Diagram Of Bedrock Packer Testing Equipment

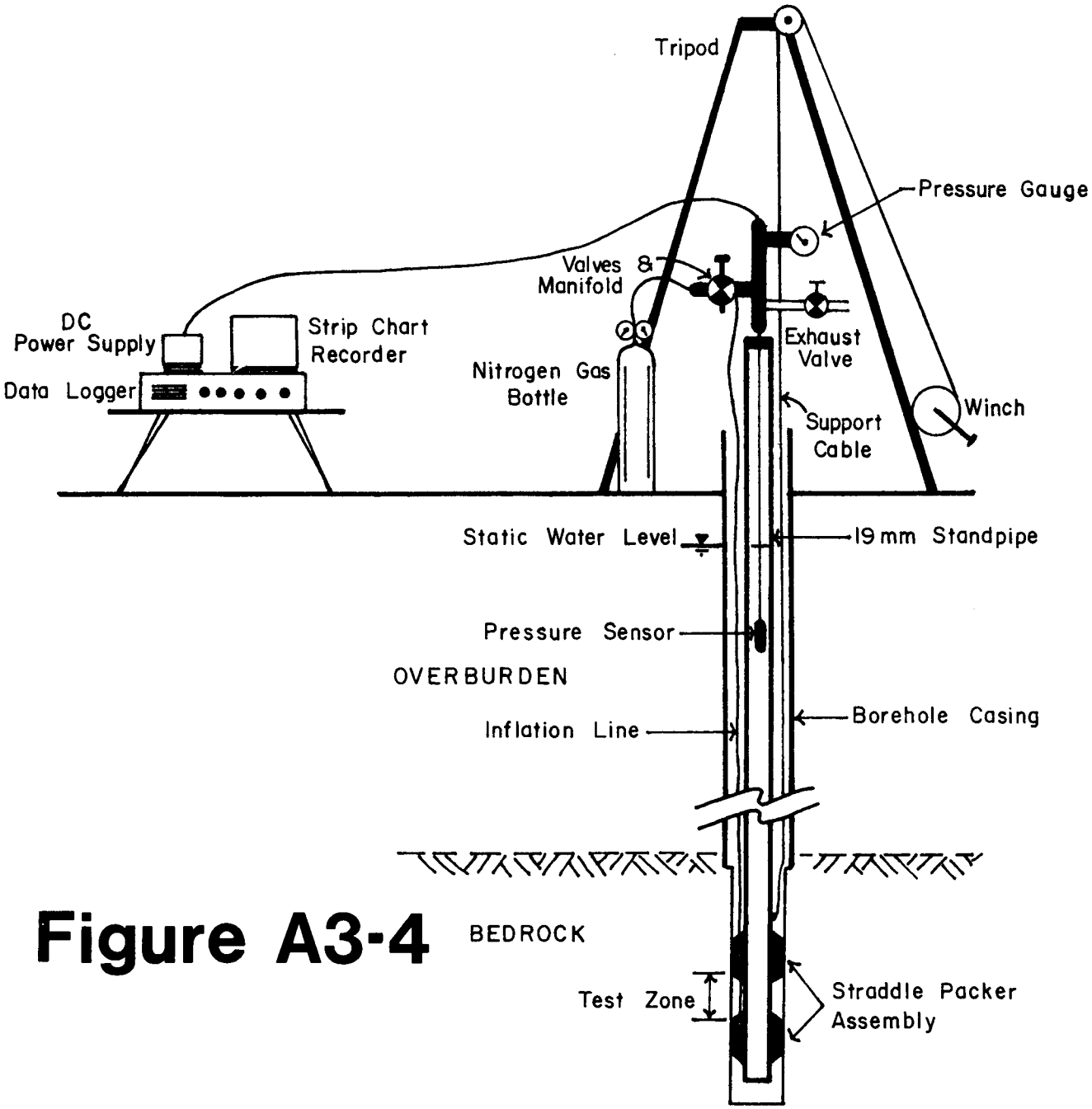


Figure A3-4

Gartner Lee Limited

A3.4 PUMP TESTING

A3.4.1 INTRODUCTION

A pump test was conducted on borehole 85-1-22 to provide hydrogeologic data on the upper 3 m of the bedrock aquifer. Ground water levels in the bedrock were monitored in a number of adjacent observation wells at the time of testing. In addition, ground water levels within the overlying Lower Till Unit were also monitored to determine the extent of hydraulic connection between the till and the bedrock.

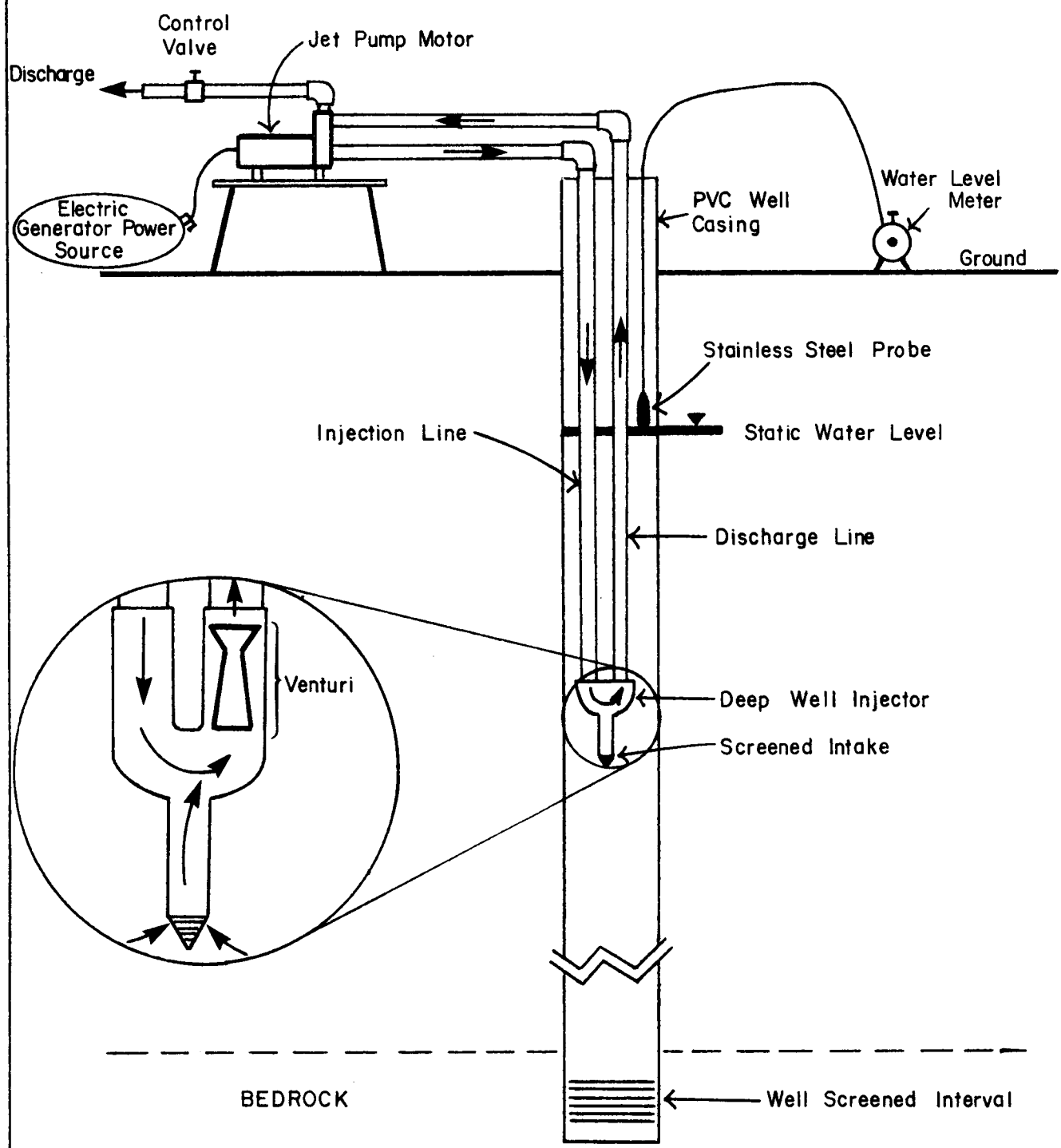
A3.4.2 EQUIPMENT

Pump testing was conducted using a narrow diameter pump to accommodate the inside diameter of the well casing. The pump selected for the pump test was a Jacuzzi jet pump (Model No. 15JH-S2). This pump was fitted with a 76 mm diameter deep well injector. The injector was installed to a depth of 15.3 m from ground surface, or about 5 m below the static water level in the well. The pump and injector assembly is shown in Figure A3-5. A 220 Volt portable electric generator was used as a power source for the pump.

A3.4.3 METHOD

Static water level measurements were taken at the pump well and all observation wells prior to testing. The observation wells included two shallow bedrock monitors (standard piezometers), two deep bedrock monitors (pneumatic piezometers), and one piezometer completed in the Lower Till Unit. In addition, water level measurements were taken at bedrock monitors at adjacent drilling locations.

Figure A3-5
Jet Pump Assembly



NOT TO SCALE

The pump and deep well injector were assembled as shown in Figure A3-5. Water taken from a nearby observation well was used to prime the pump. The water discharge hose was fitted with a control valve to regulate the pump discharge rate. Water from the well was discharged to an adjacent ditch during the pump test.

The pump was initially tested to check its operating performance and to adjust the discharge valve for the optimum discharge rate. The pump operated most efficiently under a slight back pressure with a pump rate of 0.72 L/s. Water level measurements were taken at the pump well during the initial set up test to establish potential drawdowns during the long term pump test. Adjustments were made to the depth of the injector to ensure that it would remain below the pumping water level in the well during the testing interval.

The water levels in the pump well and observation wells were allowed to recover to the initial static water levels prior to undertaking a trial pump test.

A trial pump test of one hour duration was initially conducted to determine well performance. Analysis of the test data from the pump well and the two bedrock observation wells suggested that the expected drawdown would remain relatively small during a long term pump test. The water levels were again allowed to recover to static.

The actual pump test was conducted over 18.2 h. Initially, water level measurements were taken at 10 s intervals in the pump well and the two shallow bedrock observation wells. Subsequent measurements were taken at progressively longer time

intervals. Toward the end of the pump test water level readings were taken every hour. The water level data were recorded on a Pump Test Form, an example of which is presented as Figure A3-6.

Temperature, pH, and conductivity were measured periodically on the discharge water, and pump flow rate measurements were recorded on the Pump Test Form. The flow rate was measured by recording the time required for the discharge water to fill a graduated container. Three water samples were collected during the pump test, one near the beginning of the test, another about halfway through the test and the last near the end of the test. These samples were retained in the event that chemical analysis was required.

Upon termination of the pump test, the recovery of the water level was measured in the observation wells. Measurements were taken at the same time intervals as during the pump test. The measurements were discontinued following recovery of the water levels. The tubing and injector were left in the pump well during the recovery period. The pump maintained its prime during the recovery and backflow of water into the pump well was negligible.

A3.5 LABORATORY TESTING

A3.5.1 INTRODUCTION

Laboratory tests were performed on soil samples to determine their hydraulic conductivity. A total of fifteen Shelby tube samples were tested. These are identified in Table A3-1, along with the depth and geologic unit from which the sample was collected. The laboratory tests were undertaken at Golder

FIGURE A3-6

Pump Test

PROJECT NO. _____

WELL NO. _____

ACTUAL TIME	ELAPSED TIME (MIN)	DEPTH TO WATER LEVEL FROM MEASURING POINT UNITS_____	DEPTH TO WATER LEVEL FROM STATIC LEVEL UNITS_____	PUMPING RATE UNITS___	REMARKS (eg. water colour and odour, pump test interruptions, Hach chemical analyses, etc)

Gartner Lee Associates Limited

PAGE_____ OF ___

TABLE A3-1: SAMPLES USED FOR LABORATORY PERMEABILITY TESTING

BOREHOLE NUMBER	SAMPLE NUMBER	SAMPLE DEPTH (m)	GEOLOGIC UNIT *	CONFINING PRESSURE (kPa)**
85-1-8	2	3.66- 4.27	UG	45
85-1-2	11	9.60-10.21	H	100
85-1-2	17	15.24-15.85	H	160
85-1-2	26	24.84-25.45	LG	260
85-3-2	15	18.30-18.90	LG	190
85-3-2	20	25.90-26.50	LT	270
85-8-8	2	3.61- 4.22	UG	45
85-8-8	6	21.95-22.56	LG	230
85-10-2	16	15.70-16.30	H	160
85-10-2	24	24.80-25.40	LG	260
85-12-8	1	3.05- 3.66	UG	45
85-12-8	3	10.67-11.26	H	110
85-12-22	2	15.85-16.46	H	160
85-12-8	5	21.34-21.95	H	230
85-12-22	4	28.04-28.65	LG	320

*NOTE:

UG = Upper Glaciolacustrine Unit

H = Halton Unit

LG = Lower Glaciolacustrine Unit

LT = Lower Till

** kPa = Kilopascals

Associates (Eastern Canada) Limited geotechnical laboratory.

A3.5.2 EQUIPMENT AND METHOD

Two small, cylindrical test samples were extracted from each of the Shelby tube samples listed in Table A3-1. One test sample was cut parallel to the borehole axis (vertically oriented), while the other was cut perpendicular to the borehole axis (horizontal orientation). The two orientations were used to assess any anisotropy that might exist in the materials. Each test sample was then placed in a constant head permeability testing apparatus and tested under confining pressures that correspond to the effective overburden pressures, presented in Figure 6-1 of Section 6.0. The values used for each sample are indicated in Table A3-1. The detailed testing methodology is described in Golder Associates' report (dated July 1986) presented in Appendix G5.

A4 GEOTECHNICAL TESTING

Geotechnical soil testing was conducted by the testing laboratory of Golder Associates (Eastern Canada) Limited in Mississauga, Ontario. A variety of tests were completed on soil samples using standard American Society of Testing Materials (ASTM) testing procedures. A discussion of the types of soil testing performed and their procedures is provided in Appendix E1.

APPENDIX B

GROUND WATER SAMPLING

AND

ANALYTICAL PROTOCOLS

APPENDIX B
GROUND WATER SAMPLING AND ANALYTICAL PROTOCOLS

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B1 GROUND WATER SAMPLING

B1.1 INTRODUCTION

This appendix describes the monitor flushing and ground water sampling practices used during the Phase 4B geoscience program. Flushing of the monitors was undertaken prior to sampling and involved the removal of stagnant water from the monitor casing to allow representative ground water from the surrounding geologic unit to flow into the monitor. Flushing procedures are described in Section B1.2. Ground water samples were collected from 36 monitors on two occasions, June 1986 and late August/ early September 1986, for analysis of general chemical indicators (e.g. pH, total dissolved solids), major and minor ions, dissolved organic carbon, methane, and the isotopes tritium, oxygen-18 and deuterium. Two samples were also collected near the base of the overburden for carbon-14 dating and one sample from the bedrock for a organic "priority pollutant" scan. Ground water sampling techniques are outlined in Appendix B1.4.

Ground water samples were also collected for analysis of oxygen-18, deuterium and chloride by pore water squeezing of selected soil samples. The pore water squeezing techniques are described in Appendix B1.5. Also described are Analytical Methods (Appendix B2) and the Quality Assurance/ Quality Control program (Appendix B3).

B1.2 GROUND WATER MONITOR FLUSHING PROCEDURES

All monitors were flushed prior to sampling. The purpose of flushing was to remove stagnant water standing in the monitor casing, allowing representative ground water from the surrounding geologic unit to flow into the monitor. Table B1-1 provides details on the flushing and sampling program including monitor #, average well bore volume, the date when each monitor was flushed and the amount of ground water removed during flushing and the parameters analyzed. Two different flushing methods were utilized depending on the diameter of the monitor casing. Table B1-2 identifies the method used for each monitor. Descriptions of the flushing methods are provided in the following sections.

B1.2.1 FLUSHING METHOD A

A "Waterra" hand pump was used for flushing the 51 mm diameter monitors. This pump consists of a 25 mm diameter by 150 mm long foot valve made of Delrin attached to 12.7 mm I.D. polyethylene tubing (Figure B1-1). Water is drawn to surface with this pump by oscillating the tubing up and down by hand. This draws in successive aliquots of water past the foot valve and eventually results in the discharge of water at surface.

A separate dedicated pump was installed in each monitor. In overburden monitors,the foot valve was located within about 0.1 m of the bottom of the monitor (i.e. within the screened interval). In the bedrock monitors, the foot valve was located at depths of between 22 to 23 m, or about 9 to 10 m from the bottom of the monitor. The foot valve was not placed at the bottom of the bedrock monitors because of potential depth limitations of the pump flexible polyethylene tubing.

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity F = Flushed S = Sampled	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-1-1	70.4	17-Apr-86	F	9.58	9.58	120.00	
		17-Apr-86	S	9.58	9.58	0.02	normal tritium
		12-May-86	F	9.70	9.70	120.00	
		17-Jun-86	F	9.68	9.68	120.00	
		17-Jun-86	S	9.68		2.18	list A
		20-Aug-86	F	9.94	9.97	120.00	
		26-Aug-86	F	9.91	9.91	120.00	
		26-Aug-86	S	9.91		2.07	list A & CH4
		18-Sep-86	F	9.89	9.89	120.00	
		18-Sep-86	S	9.89		0.60	CH4 & enriched trit.
85-1-3	6.4	14-Apr-86	S	7.79		0.02	normal tritium
		17-Apr-86	F	7.83	22.80	4.50	
		30-Apr-86	F	11.60	24.57	4.00	
		06-May-86	F	16.63	24.02	2.25	
		12-May-86	F	16.81	25.64	2.60	
		23-May-86	F	13.90	23.55	3.00	
		29-May-86	F	16.48	24.02	2.30	
		17-Jun-86	S	10.12		2.18	list A & normal trit.
		30-Jul-86	F	10.53	24.89	4.30	
		30-Jul-86	S	10.53		0.02	normal tritium
		26-Aug-86	S	10.97		1.07	list B
		18-Sep-86	S			0.60	CH4 & enriched trit.
85-1-10	16.5	26-Mar-86	F	1.85	5.75	25.00	
		17-Apr-86	S			0.02	normal tritium
		06-May-86	F	1.68	4.38	25.00	
		23-May-86	F	1.66	5.24	26.00	
		17-Jun-86	S	1.68		2.18	list A & normal trit.
		30-Jul-86	F	1.86	5.30	30.00	
		26-Aug-86	S	1.97		1.07	list B
		18-Sep-86	S			0.10	CH4
85-1-11	2.5	29-May-86	F	2.44	9.32	2.10	
		17-Jun-86	S	2.23		2.18	list A & normal trit.
		30-Jul-86	F	3.69	9.57	1.20	
		30-Jul-86	S	3.69		0.02	normal tritium
		26-Aug-86	S	3.72		1.07	list B
		18-Sep-86	S			0.10	CH4

NOTE: * See last page of this table for explanation of list A and list B.
* Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
* CH4 = Methane

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity F = Flushed S = Sampled	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-1-14	1.7	23-May-86	F	2.52	DRY	1.30	
		17-Jun-86	S	2.23		2.18	list A & normal trit.
		20-Aug-86	F	2.00	3.05	2.50	
		11-Sep-86	S	2.96		2.07	list B, no CH4
		18-Sep-86	S			0.10	CH4
85-1-15	3.4	01-Apr-86	F	3.35	DRY	1.00	
		17-Apr-86	S	3.20		0.02	normal tritium
		23-May-86	F	2.22	DRY	3.00	
		17-Jun-86	S	2.28		2.18	list A & normal trit.
		20-Aug-86	F	2.04	3.57	4.00	
		11-Sep-86	S	2.74		2.07	list B & enr. trit.,no CH4
		18-Sep-86	S			0.10	CH4
85-1-16	6.2	01-Apr-86	F	2.86	DRY	4.00	
		17-Apr-86	S	2.59		0.02	normal tritium
		23-May-86	F	2.09	DRY	6.00	
		17-Jun-86	S	1.95		2.18	list A & normal trit.
		20-Aug-86	F	2.27	4.56	5.00	
		11-Sep-86	S	2.53		2.07	list B & enr. trit.,no CH4
		18-Sep-86	S			0.10	CH4
85-1-17	8.3	01-Apr-86	F	2.88	DRY	5.00	
		17-Apr-86	S	2.68		0.02	normal tritium
		23-May-86	F	2.14	DRY	6.50	
		17-Jun-86	S	1.98		2.18	list A & normal tritium
		20-Aug-86	F	2.21	5.21	7.00	
		11-Sep-86	S	2.47		2.07	list B & enr. trit.,no CH4
		18-Sep-86	S			0.10	CH4
85-1-18	2.1	01-Apr-86	F	6.19	DRY	0.90	
		17-Apr-86	S	6.15		0.02	normal tritium
		23-May-86	F	5.13	6.22	3.00	
		17-Jun-86	S	5.36		2.18	list A & normal tritium
		20-Aug-86	F	4.10	6.24	4.50	
		11-Sep-86	S	5.32		1.82	list B & enr. trit.,no CH4
		18-Sep-86	S			0.10	CH4

NOTE: * See last page of this table for explanation of list A and list B.
* Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
* CH4 = Methane

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity F = Flushed S = Sampled	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-1-19	4.5	01-Apr-86	F	5.81	DRY	2.25	
		17-Apr-86	S	6.16		0.02	normal tritium
		23-May-86	F	4.85	6.69	3.70	
		17-Jun-86	S	5.51		2.18	list A & normal tritium
		20-Aug-86	F	3.97	6.74	5.00	
		11-Sep-86	S	5.60		2.07	list B & enr. trit.,no CH4
		18-Sep-86	S			0.10	CH4
85-1-20	9.1	01-Apr-86	F	4.42	7.43	5.75	
		17-Apr-86	S	5.20		0.02	normal tritium
		23-May-86	F	3.23	7.32	8.00	
		17-Jun-86	S	3.73		2.18	list A & normal tritium
		20-Aug-86	F	2.35	7.35	11.00	
		11-Sep-86	S	3.53		2.07	list B & enr. trit.,no CH4
		18-Sep-86	S			0.10	CH4
85-1-21	9.3	01-Apr-86	F	5.77	8.25	5.25	
		17-Apr-86	S	6.96		0.02	normal tritium
		23-May-86	F	4.83	8.31	7.00	
		17-Jun-86	S	6.06		2.18	list A & normal tritium
		20-Aug-86	F	4.04	8.30	9.00	
		11-Sep-86	S	6.12		2.07	list B & enr. trit.,no CH4
		18-Sep-86	S			0.10	CH4
85-2-4	4.0	29-May-86	F	3.15	15.04	3.60	
		12-Jun-86	S	6.02		1.68	list A & normal tritium
		30-Jul-86	F	5.08	15.25	3.00	
		30-Jul-86	S	5.18		0.02	normal tritium
		26-Aug-86	S	6.55		3.14	list A & enr. trit.,no CH4
		18-Sep-86	S			0.60	CH4 & enriched trit.

NOTE: * See last page of this table for explanation of list A and list B.
* Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
* CH4 = Methane

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity F = Flushed S = Sampled	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-3-1	65.8	15-Apr-86	F	9.41	9.53	120.00	
		15-Apr-86	S	9.41		0.02	normal tritium
		07-May-86	F	9.47	9.64	120.00	
		12-Jun-86	F	9.57		120.00	
		12-Jun-86	S	9.57		2.18	list A
		20-Aug-86	F	9.74	9.80	120.00	
		26-Aug-86	F	9.72	9.72	120.00	
		26-Aug-86	S	9.72		2.07	list A & CH4
		18-Sep-86	F	9.69	9.69	120.00	
		18-Sep-86	S	9.69		0.60	CH4 & enriched trit.
85-3-10	17.3	01-Apr-86	F	2.45	5.20	22.00	
		17-Apr-86	S	2.19		0.02	normal tritium
		06-May-86	F	1.92	4.13	24.00	
		22-May-86	F	1.83	4.65	25.00	
		12-Jun-86	S	1.44		2.18	list A & normal tritium
		30-Jul-86	F	1.56	4.98	30.00	
		26-Aug-86	S	1.73		1.07	list B
		18-Sep-86	S			0.60	CH4
85-8-1	77.4	15-Apr-86	F	9.06		120.00	
		15-Apr-86	S	9.06		0.02	normal tritium
		06-May-86	F	9.16	9.17	120.00	
		18-Jun-86	F	9.18	9.19	120.00	
		18-Jun-86	S	9.18		4.35	list A
		20-Aug-86	F	9.38	9.39	120.00	
		21-Aug-86	F	9.44	9.44	120.00	
		21-Aug-86	S	9.44		3.64	List A & CH4
		18-Sep-86	F	9.38	9.38	120.00	
		18-Sep-86	S	9.38		0.60	CH4 & enriched trit.

NOTE: * See last page of this table for explanation of list A and list B.
* Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
* CH4 = Methane

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity F = Flushed S = Sampled	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-8-4	3.5	15-Apr-86	S	4.69		0.02	normal tritium
		17-Apr-86	F	4.73	14.13	2.80	
		30-Apr-86	F	6.42	14.02	2.30	
		06-May-86	F	8.33	15.04	2.00	
		12-May-86	F	8.81	15.48	2.00	
		23-May-86	F	6.82	14.20	2.20	
		29-May-86	F	8.35	14.82	2.00	
		18-Jun-86	S	4.90		2.18	list A & normal tritium
		30-Jul-86	F	6.14	14.75	2.00	
		30-Jul-86	S	6.14		0.02	normal tritium
		21-Aug-86	S	6.90		1.07	list B
		18-Sep-86	S			0.60	CH4 & enriched trit.
85-8-8	17.0	01-Apr-86	F	12.20	25.42	24.00	
		30-Apr-86	F	18.09	25.40	14.50	
		23-May-86	F	19.34	25.09	11.50	
		18-Jun-86	S	18.45		4.35	list A & normal tritium
		14-Jul-86	S			15.00	Carbon 14, 13 & norm. trit
		30-Jul-86	F	21.56	25.51	8.00	
		21-Aug-86	S	19.70		3.14	list B
		18-Sep-86	S			0.60	CH4 & enriched trit.
85-8-10	13.7	01-Apr-86	F	2.68	5.44	20.50	
		15-Apr-86	S	2.41		0.02	normal tritium
		06-May-86	F	2.18	4.89	23.00	
		23-May-86	F	2.20	5.09	23.00	
		18-Jun-86	S	2.14		4.35	list A & normal tritium
		30-Jul-86	F	2.36	5.26	27.00	
		21-Aug-86	S	2.56		3.14	list B
		18-Sep-86	S			0.10	CH4
85-8-11	2.5	29-May-86	F	2.26	8.53	2.00	
		18-Jun-86	S	2.23		2.18	list A & normal tritium
		30-Jul-86	F	3.02	8.78	1.80	
		30-Jul-86	S	3.02		0.02	normal tritium
		21-Aug-86	S	3.33		1.07	list B
		18-Sep-86	S			0.10	CH4

NOTE: ‡ See last page of this table for explanation of list A and list B.
‡ Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
‡ CH4 = Methane

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity F = Flushed S = Sampled	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-10-1	82.3	15-Apr-86	F	8.31		120.00	
		15-Apr-86	S	8.31		0.02	normal tritium
		12-May-86	F	8.45	8.45	120.00	
		12-Jun-86	F	8.38	8.39	120.00	
		12-Jun-86	S	8.38		2.18	list A
		20-Aug-86	F	8.63	8.63	120.00	
		26-Aug-86	F	8.66	8.66	120.00	
		26-Aug-86	S	8.66		2.07	list A & CH4
		18-Sep-86	F	8.62	8.62	120.00	
		18-Sep-86	S	8.62		0.60	CH4 & enriched trit.
85-10-10	17.4	01-Apr-86	F	0.76	5.52	32.00	
		15-Apr-86	S	0.84		0.02	normal tritium
		07-May-86	F	1.15	4.32	28.00	
		23-May-86	F	0.83	5.09	31.00	
		12-Jun-86	S	0.94		2.18	list A
		30-Jul-86	F	1.40	5.15	30.00	
		26-Aug-86	S	1.57		1.07	list B
		18-Sep-86	S			0.10	CH4
85-11-4	4.2	29-May-86	F	4.38	16.12	3.50	
		12-Jun-86	S	5.80		2.18	list A & normal tritium
		30-Jul-86	F	7.65	16.43	2.70	
		30-Jul-86	S	7.65		0.02	normal tritium
		26-Aug-86	S	6.34		1.07	list B
		18-Sep-86	S			0.60	CH4 & enriched trit.

NOTE: ‡ See last page of this table for explanation of list A and list B.
‡ Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
‡ CH4 = Methane

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity F = Flushed S = Sampled	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-12-1	82.2	15-Apr-86	F	8.43	8.46	120.00	
		15-Apr-86	S	8.43		0.02	normal tritium
		12-May-86	F	8.85	8.56	120.00	
		10-Jun-86	F	8.53		120.00	
		10-Jun-86	S	8.53		4.35	list A
		02-Jul-86	F	8.68		120.00	
		02-Jul-86	S	8.68		2.20	see FOOTNOTE 1
		20-Aug-86	F	8.81	8.83	120.00	
		21-Aug-86	F	8.79	8.79	120.00	
		21-Aug-86	S	8.79		3.14	list A & CH4
		18-Sep-86	F	8.73	8.73	120.00	
		18-Sep-86	S	8.73		0.60	CH4 & enriched trit.
85-12-8	10.4	20-Mar-86	F	18.04	25.09	14.00	
		29-Apr-86	F	15.89	25.30	18.00	
		23-May-86	F	18.77	25.02	12.50	
		10-Jun-86	S	19.80		4.35	list A & norm. trit.
		14-Jul-86	S			15.00	Carbon 14, 13 & norm. trit
		30-Jul-86	F	20.19	25.22	10.00	
		21-Aug-86	S	19.24		3.14	list B
		18-Sep-86	S			0.60	CH4 & enriched trit.
85-12-10	17.5	26-Mar-86	F	1.18	5.38	37.00	
		15-Apr-86	S	1.10		0.02	normal tritium
		07-May-86	F	1.16	4.16	28.00	
		23-May-86	F	1.17	4.85	28.00	
		10-Jun-86	S	1.14		4.35	list A
		30-Jul-86	F	1.46	4.97	27.00	
		21-Aug-86	S	1.70		3.14	list B
		18-Sep-86	S			0.10	CH4

NOTE: * See last page of this table for explanation of list A and list B.
* Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
* CH4 = Methane

FOOTNOTE 1 : Scan for volatile and extractable, organic parameters on the U.S. E.P.A. priority pollutant list.

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity F = Flushed S = Sampled	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-12-11	2.5	29-May-86	F	1.87	9.76	2.50	
		10-Jun-86	S	1.77		2.18	list A & normal tritium
		30-Jul-86	F	3.94	9.83	1.80	
		30-Jul-86	S	3.94		0.02	normal tritium
		26-Aug-86	S	3.44		1.07	list B
		18-Sep-86	S			0.10	CH4
85-12-13	1.2	26-Mar-86	F	1.32	DRY	2.00	
		15-Apr-86	S	1.58		0.02	normal tritium
		22-May-86	F	1.25	DRY	1.50	
		10-Jun-86	S	1.60		1.00	part of list A
		16-Jun-86	S	1.60		1.00	part of list A
		20-Aug-86	F	1.71	DRY	0.50	
		11-Sep-86	S	DRY			
85-12-14	4.0	26-Mar-86	F	1.08	DRY	5.20	
		15-Apr-86	S	0.99		0.02	normal tritium
		22-May-86	F	1.16	2.96	3.50	
		10-Jun-86	S	1.19		2.18	list A
		29-Aug-86	F	1.89	3.06	3.00	
		11-Sep-86	S	2.16		1.07	list B, no CH4
		18-Sep-86	S			0.10	CH4
85-12-15	5.7	26-Mar-86	F	0.96	DRY	7.00	
		15-Apr-86	S	0.93		0.02	normal tritium
		22-May-86	F	1.07	3.43	4.50	
		10-Jun-86	S	1.26		2.18	list A
		29-Aug-86	F	2.23	2.52	3.00	
		11-Sep-86	S	2.30		1.07	list B, no CH4
		18-Sep-86	S			0.10	CH4

NOTE: * See last page of this table for explanation of list A and list B.
* Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
* CH4 = Methane

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity (F = Flushed, S = Sampled)	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-12-16	8.3	26-Mar-86	F	1.10	4.49	8.50	
		15-Apr-86	S	0.99		0.02	normal tritium
		22-May-86	F	1.12	4.43	6.50	
		10-Jun-86	S	1.31		2.18	list A
		29-Aug-86	F	2.32	4.44	4.50	
		11-Sep-86	S	2.45		1.07	list B, no CH4
		18-Sep-86	S			0.10	CH4
85-12-17	10.5	26-Mar-86	F	1.04	5.34	9.50	
		15-Apr-86	S	1.02		0.02	normal tritium
		22-May-86	F	1.11	5.26	8.30	
		10-Jun-86	S	1.34		2.18	list A
		29-Aug-86	F	2.41	5.39	5.50	
		11-Sep-86	S	2.63		1.07	list B, no CH4
		18-Sep-86	S			0.10	CH4
85-12-18	9.0	26-Mar-86	F	2.13	6.06	9.00	
		15-Apr-86	S	2.53		0.02	normal tritium
		22-May-86	F	1.80	5.96	8.30	
		10-Jun-86	S	2.38		2.18	list A
		02-Jul-86	S	2.01		1.00	low level enriched trit.
		29-Aug-86	F	2.11	6.00	7.50	
		11-Sep-86	S	3.16		1.07	list B, no CH4
		18-Sep-86	S			0.10	CH4
85-12-19	9.3	26-Mar-86	F	2.60	6.71	9.00	
		15-Apr-86	S	3.27		0.02	normal tritium
		22-May-86	F	1.98	6.60	9.30	
		10-Jun-86	S	3.09		2.18	list A
		02-Jul-86	S	2.53		1.00	low level enriched trit.
		29-Aug-86	F	2.19	6.74	10.00	
		11-Sep-86	S	4.09		1.07	list B, no CH4
		18-Sep-86	S			0.10	CH4

NOTE: * See last page of this table for explanation of list A and list B.
* Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
* CH4 = Methane

TABLE B1-1 : SUMMARY OF FLUSHING AND SAMPLING ACTIVITIES

MONITOR #	AVERAGE WELL BORE VOLUME (L)	DATE	Activity F = Flushed S = Sampled	Water Level before Activity (m below top of pipe)	Water Level after Activity (m below top of pipe)	Approximate volume of Water Removed (L)	PARAMETERS ANALYZED
85-12-20	14.2	26-Mar-86	F	1.92	7.46	14.50	
		15-Apr-86	S	1.79		0.02	normal tritium
		22-May-86	F	2.00	7.37	10.50	
		10-Jun-86	S	1.70		2.18	list A
		02-Jul-86	S	1.75		1.00	low level enriched trit.
		29-Aug-86	F	2.03	7.43	12.50	
		11-Sep-86	S	2.36		1.07	list B, no CH4
		18-Sep-86	S			0.10	CH4
85-12-21	14.8	26-Mar-86	F	2.51	7.69	14.50	
		15-Apr-86	S	2.66		0.02	normal tritium
		22-May-86	F	1.69	8.26	13.20	
		10-Jun-86	S	2.39		2.18	list A
		02-Jul-86	S	2.12		1.00	low level enriched trit.
		29-Aug-86	F	2.32	8.40	13.00	
		11-Sep-86	S	3.30		1.07	list B, no CH4
		18-Sep-86	S			0.10	CH4

NOTE: * See last page of this table for explanation of list A and list B.
* Samples collected for list B required a smaller volume of water due to reduced parameters and laboratory requirements.
* CH4 = Methane

LIST A : ANALYSES -
pH, alkalinity, total dissolved solids, dissolved inorganic carbon, dissolved organic carbon, sulphide, inductively coupled argon plasma scan for cations (Ag, Al, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sr, Th, Ti, V, Zn, Zr) and ion chromatography scan for anions (F, Cl, NO2, NO3, PO4, Br, SO4), oxygen-18,deuterium.

LIST B : ANALYSES -
All parameters listed in LIST A plus methane, except for oxygen-18 and deuterium.

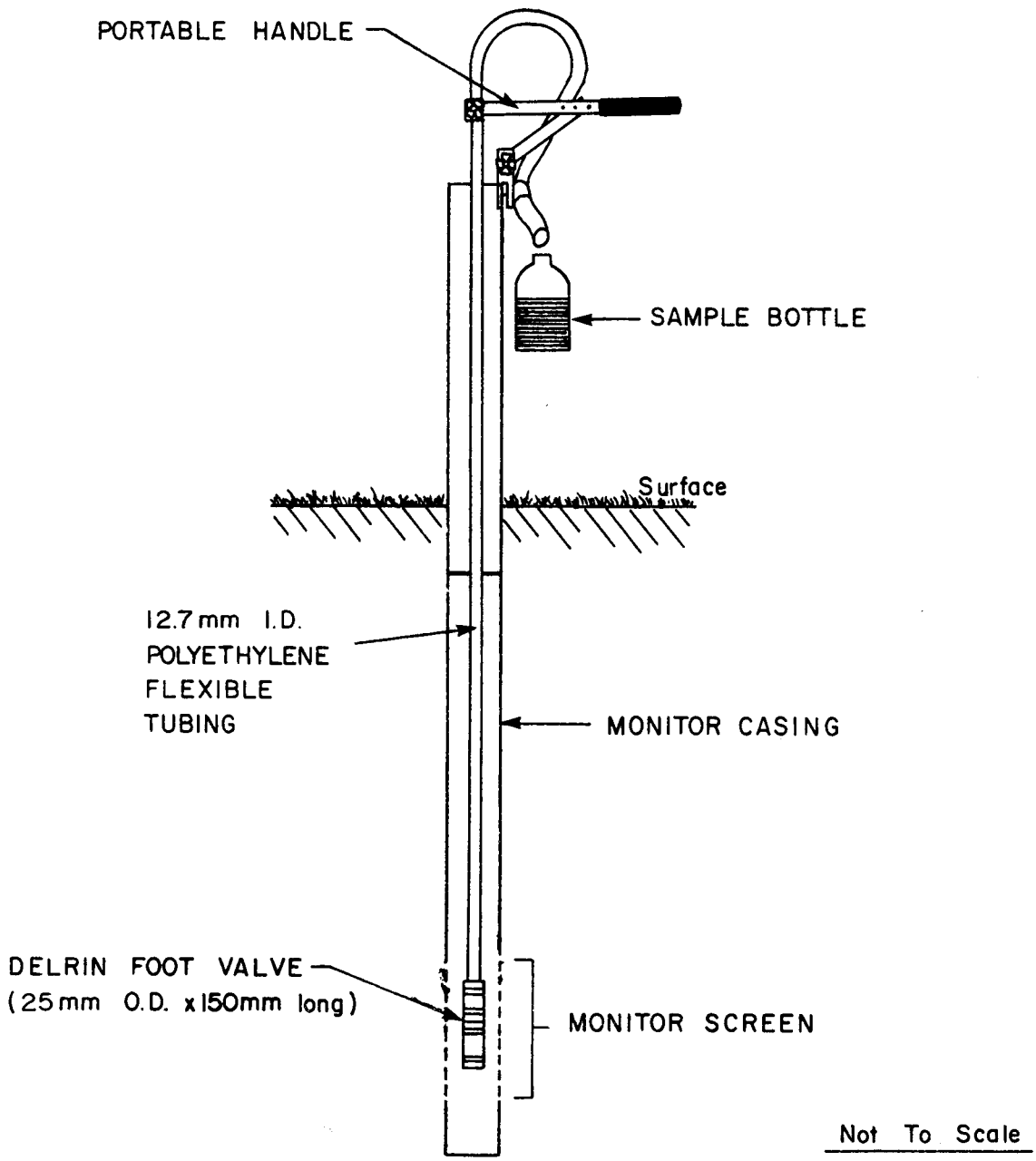
TABLE B1-2: FLUSHING METHODS USED AT EACH MONITOR

Monitor #	Flushing Method	Monitor #	Flushing Method	Monitor #	Flushing Method
85-1-1	A	85-2-4	B	85-12-8	A
85-1-3	B	85-3-1	A	85-12-10	A
85-1-10	A	85-3-10	A	85-12-11	B
85-1-11	B	85-8-1	A	85-12-13	A
85-1-14	A	85-8-4	B	85-12-14	A
85-1-15	A	85-8-8	A	85-12-15	A
85-1-16	A	85-8-10	A	85-12-16	A
85-1-17	A	85-8-11	B	85-12-17	A
85-1-18	A	85-10-1	A	85-12-18	A
85-1-19	A	85-10-10	A	85-12-19	A
85-1-20	A	85-11-4	B	85-12-20	A
85-1-21	A	85-12-1	A	85-12-21	A

N.B. See Appendix B1.2 for explanation of flushing methods.

Figure B1-1

SCHEMATIC OF THE 'WATERRA'™ HAND PUMP



Due to the low permeability of the overburden materials, most monitors in the overburden were flushed using the "Waterra" pump, by pumping until no more water could be discharged (i.e. pumped almost dry). A bailer was then used to remove the small amount of ground water remaining within the monitor. A small diameter (4.8 mm I.D.) polyethylene tube was then inserted inside and to the bottom of the tubing of the "Waterra" pump and nitrogen blown through this tube to remove the water remaining above the foot valve.

In the standpipes, where fracturing makes the near surface portion of the overburden more permeable, the monitors could not always be pumped dry. In this case the monitors were flushed by removing 21 to 30 L of water (about 1 to 2 well bore volumes).

The higher permeability of the bedrock aquifer also prevented monitors in the bedrock from being pumped dry. The bedrock monitors were flushed by removing 120 L of water (about 2 well bore volumes).

B1.2.2 FLUSHING METHOD B

Nitrogen was used for flushing the smaller 19 mm diameter monitors. Dedicated 6.4 mm I.D. polyethylene tubing was installed to the bottom of these monitors. Compressed nitrogen was then forced through this tubing, causing the ground water to rise up between the tubing and monitor casing and out of the top of the monitor. With this method, approximately 0.5 L of water remained in the monitor after flushing.

B1.3 CEMENT INTERFERENCES

Several water quality monitors had ground water with anomalously high pH (greater than 10). These monitors were: 85-1-8, 85-1-9,

85-3-8, 85-3-9, 85-8-9, 85-10-8, 85-10-9 and 85-12-9. Repeated flushings did not result in a reduction in pH.

The high pH values are likely the result of contamination by cement used to seal the upper portion of the boreholes. Ground waters in contact with partially set cement typically have very high pH values (Barcelona and Helfrich, 1986). The water quality monitors were sealed by placing a thick layer (4.1 to 7.5 m) of bentonite pellets in the borehole annulus above the screened interval. Above the bentonite pellets, cement grout was tremmied into place to seal the remainder of the borehole. Monitor construction details are described in Appendix A and tabulated in Appendix F. It appears that despite the thick bentonite seals, some of the cement penetrated through the pellets and into the area around the monitor screen. This likely occurred because of the dry condition of many of the deep overburden boreholes upon completion. As a result, the bentonite seals did not set prior to placement of the cement, nor did the fluids in the grout cause the pellets to set.

The monitors affected by cement were not used to collect ground water samples. Smaller diameter hydrogeologic monitors installed for water level measurements and hydraulic conductivity testing which were not influenced by grout, were sampled in place of the affected water quality monitors. Hydrogeologic monitors which were sampled are 85-1-3, 85-1-11, 85-2-4, 85-8-4, 85-8-11, 85-11-4 and 85-12-11.

B1.4 GROUND WATER SAMPLING PROCEDURES

Table B1-3 is a summary of the monitors at each location from which ground water samples were collected for chemical analysis. The monitoring locations are shown in Figure B1-2.

TABLE B1-3: SUMMARY OF MONITORS USED TO COLLECT GROUND WATER SAMPLES

DRILLING LOCATION	BEDROCK MONITORS	OVERBURDEN MONITORS
1	85-1-1	85-1-3, 85-1-10*, 85-1-11, 85-1-14, 85-1-15, 85-1-16, 85-1-17, 85-1-18, 85-1-19, 85-1-20, 85-1-21
2		85-2-4
3	85-3-1	85-3-10*
8	85-8-1	85-8-4, 85-8-8, 85-8-10*, 85-8-11
10	85-10-1	85-10-10*
11		85-11-4
12	85-12-1	85-12-8, 85-12-10*, 85-12-11, 85-12-13, 85-12-14, 85-12-15, 85-12-16, 85-12-17, 85-12-18, 85-12-19, 85-12-20, 85-12-21

* these monitors are standpipes screened from above the water table to a depth of approximately 5.3 m.

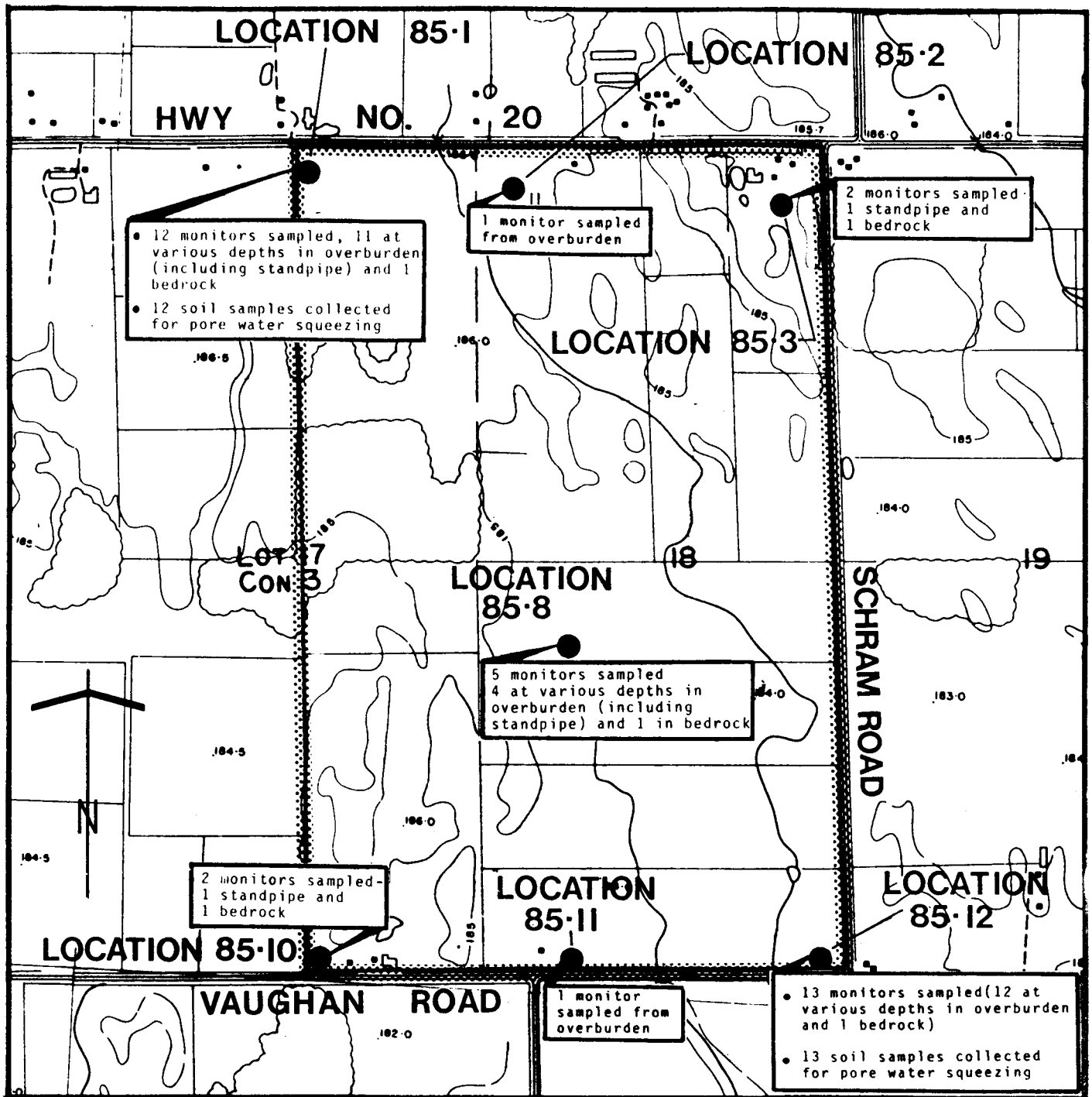


Figure B1·2
GROUND WATER SAMPLING LOCATIONS

Boundary

Sampling Location

0 500 metres

SCALE

NOTE: See appendix A1 and figure for details of each site

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Ground water samples were collected from the overburden monitors approximately three weeks after flushing. Due to the low permeability of the overburden materials, an interval of three weeks was required prior to sampling to allow a sufficient volume of ground water to flow into the monitor.

Due to the higher permeability of the bedrock, bedrock monitors were sampled immediately after flushing.

The majority of ground water samples were collected on two occasions: (1) over the period June 10 to 18, 1986 and, (2) on one of the following three days; August 21, August 26 and September 11, 1986. Occasional samplings of selected monitors for selected parameters were undertaken at other times. Table B1-1 summarizes when samples were collected from each monitor and for which parameters. The results of the chemical analyses conducted on the ground water samples are tabulated in Tables J-1 to J-4 in Appendix J.

Prior to sampling, the water level was measured and the volume of water in the monitor calculated. Approximately 3 L of ground water was required for rinsing the bottles and equipment, measuring temperature, conductivity and pH, and the sample.

Three different sampling methods were used to collect ground water samples depending on the diameter of the monitor casing and formation permeability. The method used for each monitor is listed in Table B1-4. Descriptions of the sampling methods are provided in the following sections. Also described is a separate sampling technique employed by Mr. B. Drimmie of the Isotope Laboratory, University of Waterloo to collect samples for Carbon

TABLE B1-4: SUMMARY OF SAMPLING METHODS USED AT EACH MONITOR

MONITOR #	SAMPLING METHOD	MONITOR #	SAMPLING METHOD	MONITOR #	SAMPLING METHOD
85-1-1	B	85-2-4	C	85-12-8	B
85-1-3	C	85-3-1	B	85-12-10	A
85-1-10	A	85-3-10	A	85-12-11	A
85-1-11	C	85-8-1	B	85-12-13	C
85-1-14	A	85-8-4	C	85-12-14	A
85-1-15	A	85-8-8	A	85-12-15	A
85-1-16	A	85-8-10	A	85-12-16	A
85-1-17	A	85-8-11	C	85-12-17	A
85-1-18	A	85-10-1	B	85-12-18	A
85-1-19	A	85-10-10	A	85-12-19	A
85-1-20	A	85-11-4	C	85-12-20	A
85-1-21	A	85-12-1	B	85-12-21	A

14 and 13 analyses. As well, the filtering, preservation, transportation and chain of custody protocols are outlined.

B1.4.1 SAMPLING METHOD A

A 25 mm O.D. stainless steel bailer on a wire line was used to collect ground water samples from the 51 mm diameter monitors in the overburden. The first few samples were discarded. The next sample was used to fill a beaker for immediate measurement of temperature, conductivity and pH. Sample bottles were filled after first rinsing each bottle with the water being sampled. Between monitors, the bailer was rinsed with distilled water and dried with a clean J-cloth.

B1.4.2 SAMPLING METHOD B

Ground water samples were collected from the bedrock monitors using the dedicated "Waterra" pumps which were installed in each monitor. Use of this pump is described in Appendix B1.2.1. Immediately prior to sampling, the monitors were flushed by pumping out about 120 L of water. A beaker was then filled for immediate measurement of temperature, conductivity and pH. Ground water was then collected directly into the sample bottles from the pump outlet, after first rinsing each bottle with the water being sampled.

B1.4.3 SAMPLING METHOD C

In order to sample the smaller 19 mm diameter monitors the dedicated 6.4 mm tubing was first removed and a 15 mm O.D. by 55 mm long polyethylene check valve was attached to the end of this tubing. The tubing/check valve was re-inserted to the bottom of the monitor. The tubing containing ground water from the monitor, was then pulled from the monitor. The check valve prevents the ground water sample from draining out of the

tubing. The positive pressure end of a peristaltic pump was then attached to the check valve and the water forced out the opposite end of the tubing for sample collection. This procedure was repeated until sufficient volume of sample was collected. The first 250 mL of water from each tube was discarded. The next 100 to 200 mL of the first tube was poured into a beaker for immediate measurement of temperature, conductivity and pH. The remaining water was used to fill the sample bottles, after first rinsing each bottle with the water to be sampled.

Whenever tubing was removed from the monitor, care was taken to prevent the tubing from contacting the ground. This reduced the possibility of extraneous material from getting into the monitor.

Sampling Method C was also used for the larger diameter monitors to collect samples for methane analysis because this method minimizes the loss of volatile gases.

B1.4.4 CARBON ISOTOPE SAMPLING

Two samples were collected from monitors 85-12-8 and 85-8-8 for carbon-14 and carbon-13 isotope analyses on the natural carbonate which is dissolved in the water These samples were collected on July 14, 1986 by Mr. Bob Drimmie of the Isotope Laboratory, Department of Earth Sciences, University of Waterloo. The sampling procedure was as follows:

(1) The ground water samples were collected in 20 L collapsible plastic jugs. Collapsible jugs were used because only 15 to 16 L could be obtained from each monitor. By collapsing the jug prior to sampling, minimal headspace or air contact resulted after filling even with a volume of water smaller than the 20 L jug capacity.

(2) Prior to sampling, the plastic jug was rinsed as follows: once with a 10% hydrochloric acid solution to remove any traces of carbonate; once with deionized, carbonate free water; and once with the water being sampled. The jug was then collapsed to remove as much air as possible.

(3) Ground water was removed from the monitor and poured into the sample jug using a gas driven squeeze pump. The operation of this type of pump is described by Scalf et al. (1981). The monitors were pumped dry to obtain as much water as possible.

(4) Once the jug was full, NaOH was immediately added to raise the pH to between 11 and 12. The pH was measured in the field to confirm this.

(5) A precalculated amount of $BaCl_2$ $2H_2O$ was then added immediately. The amount of $BaCl_2$ $2H_2O$ was precalculated based on alkalinity and sulphate values previously determined on ground water samples from these monitors. The amount of $BaCl_2$ $2H_2O$ added was 20% in excess of that required to precipitate all carbonate and sulphate dissolved in the sample water.

(6) The sample jug was then capped tightly and shaken.

(7) Samples were then transported back to the Isotope Laboratory at the University of Waterloo.

(8) The precipitate was allowed to settle overnight.

(9) The water was siphoned out until only the precipitate

and about 1 L of water remained. Note that the jug collapses as the water is removed, preventing air contact.

(10) The remaining precipitate and 1 L of water were then poured into a 1 L bottle with no headspace. Some air contact occurs here but the bias is considered to be minimal for dissolved carbonate younger than about 30,000 years. If bias occurs it would make the dissolved carbonate appear younger than its actual age. (personal communication with Bob Drimmie, University of Waterloo, Isotope Laboratory)

(11) To neutralize the pH, the precipitate and associated water were then rinsed several times with boiled, carbon dioxide free, distilled water.

(12) The precipitate and water were then placed in two 20 mL bottles, with no headspace. One bottle, containing approximately two-thirds of the precipitate was used for carbon-14 counting. The other bottle was used for carbon-13 analysis.

Despite the above precautions, contamination of the samples by modern carbon appears to have occurred. The source of contamination has not been identified but is likely from one of two sources, as described below.

(1) Because of the low dissolved carbonate concentrations in the deep overburden ground waters (44 to 63 mg/L HCO_3) and the low permeability of materials, only a small amount of carbon was available for dating (1.9 to 3.7 mg). Because of the small amount the sample

may have been susceptible to contamination during laboratory preparation and counting. To minimize this effect, collection of a composite sample from several sampling runs is recommended to increase the amount of carbon available for dating.

(2) To collect a sufficient volume of ground water in the low permeability materials, an interval of approximately 2 to 3 weeks was required for recovery after flushing. Geochemical speciation modelling of the ground waters at 25 m using WATEQF (Plummer et al., 1976), suggests that these deep ground waters have lower CO_2 partial pressures then the atmosphere. Consequently during the 2 to 3 week recovery period, it is anticipated that exchange and uptake of CO_2 from the atmosphere occurred. Because of the very low dissolved bicarbonate concentrations at 25 m depth (44 to 63 mg/L) it would not require much dissolved atmospheric CO_2 to significantly alter the ground water to appear near modern in age. These monitors should be resampled using a method that prevents exchange with CO_2. The recommended protocol is to purge the air in the monitor with argon after flushing and then place a one holed rubber stopper with an Ascarite trap (CO_2 trap) in the top of the monitor to prevent atmospheric CO_2 from entering the monitor during recovery.

B1.4.5 SAMPLE FILTERING

For filtered samples, the collected ground water was poured into a 4 L plastic jug, from which it was drawn using a peristaltic pump and immediately pumped through the filter. A schematic of the filtering procedure is shown in Figure B1-3. The parameters for which samples were filtered are summarized in Table B1-5.

Figure B1-3

SCHEMATIC OF SET-UP FOR FILTERING GROUND WATER SAMPLES

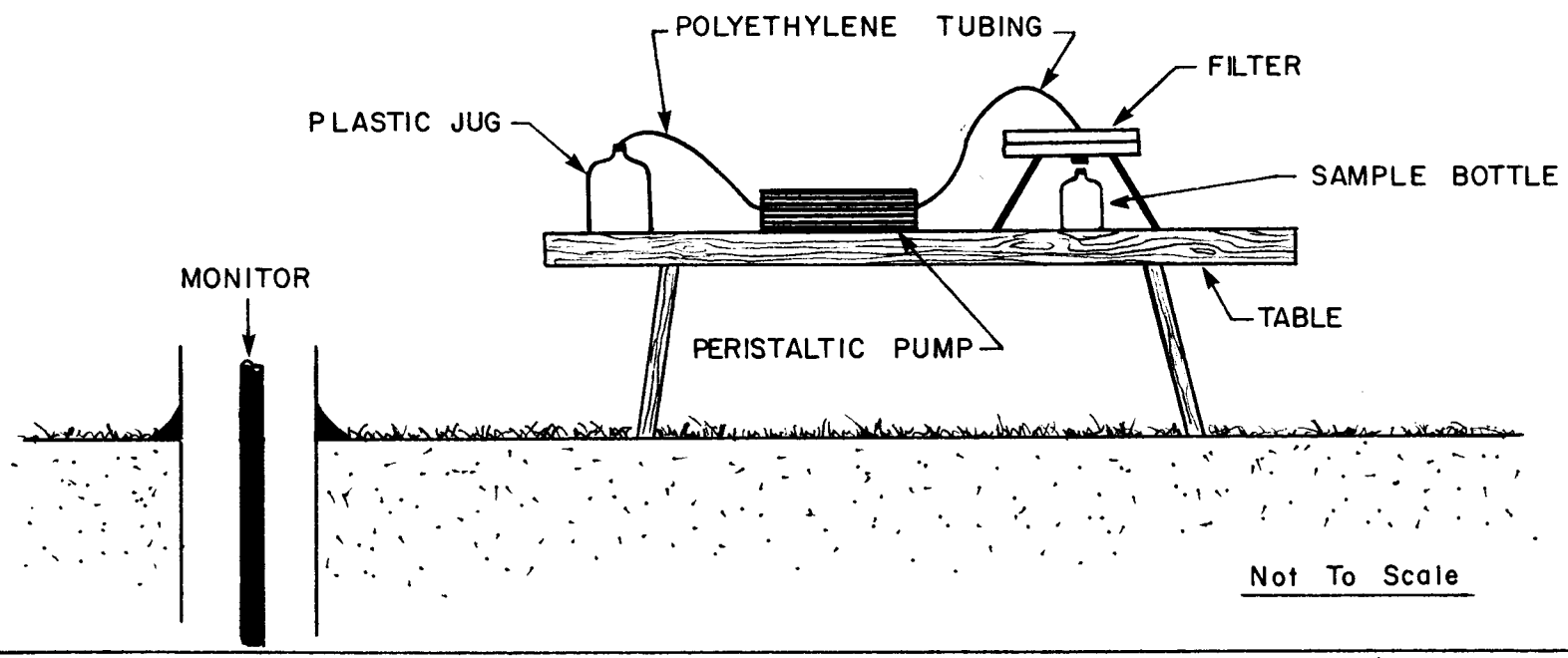

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TABLE B1-5: SUMMARY OF BOTTLE TYPES AND PRESERVATIVES FOR GROUND WATER SAMPLES

FOR ANALYSIS OF:	BOTTLE TYPE	FILTERED	PRESERVATIVE	STORAGE, TRANSPORTATION CONDITIONS	COMMENTS	LABORATORY
anion chromatography, pH, total dissolved solids	250 mL or 500 mL plastic	yes	no	cool,dark		Barringer Magenta Ltd.
inductively coupled argon plasma scan	30 or 50 mL plastic	yes	5-10 drops of nitric acid	cool,dark		Barringer Magenta Ltd.
dissolved organic carbon dissolved inorganic carbon	20 mL glass	yes	no	cool,dark		Barringer Magenta Ltd.
sulphide	500 mL plastic	no	2 mL zinc acetate and 1 mL sodium hydroxide	cool,dark		Barringer Magenta Ltd.
organic priority pollutant scan	100 mL amber for volatiles and 1 L amber for extractables	no	no	cool,dark	no headspace in volatile bottle	Mann Testing Laboratories Ltd.
dissolved methane	100 mL amber glass with septum	no	no	cool,dark	no headspace	Mann Testing Laboratories Ltd.
oxygen-18, Deuterium, enriched tritium	500 mL or 1 L glass	no	no	dark	no exposure to indoor atmosphere and fluorescent dials	Isotope Laboratory, University of Waterloo
normal tritium	20 mL plastic	no	no	dark	as above	Isotope Laboratory, University of Waterloo
low level tritium	1 L glass	no	no	dark,polyseal caps	as above	Rosentiel Isotope Laboratory, University of Miami, Florida
carbon-14, carbon-13	20 L collapsible plastic jug	no	no	dark	precipitated in field as BaCO	carbon-14 at Isotrace Laboratory, University of Toronto carbon-13 at Isotope Laboratory, University of Waterloo

B1.4.6 SAMPLE PRESERVATION AND TRANSPORTATION

Table B1-5 summarizes the types of sample containers and preservatives used for the various analytical parameters (except carbon-14 and carbon-13 which are described in Appendix B1.3.4). Sample bottles were provided pre-cleaned by the laboratories doing the analyses. Preservatives were also provided by the laboratories. After collection, all samples were immediately placed inside a cooler containing ice. Samples remained in the coolers until delivered to the laboratory for analysis. Samples were delivered to the laboratories within one to three days after sampling. Ice was replenished as required to keep sample temperature at about 4 °C.

B1.4.7 CHAIN OF CUSTODY AND FIELD RECORDS

All bottles were labelled in the field with the job, date, location, monitor, company name, sampler's name and preservatives added. All information such as water levels, water volume in monitor, pH, temperature, conductivity, colour, smell, clarity, bottles collected, filtration and weather conditions were recorded on Field Sampling Sheets (Figure B1-4)

Chain of custody forms were also completed listing the sample bottles, location and monitor, analyses to be undertaken, date sampled, sampler and company name, job, time and date of delivery to laboratory, name of laboratory, and the names of personnel delivering and receiving the samples. These forms are on file at Gartner Lee Limited.

B1.5 PORE WATER SQUEEZING

Soil samples were collected in shelby tubes from various depths at locations 85-1 and 85-12. The sample depths are listed in Table B1-6. The soil sampling and preservation protocols for shelby tubes are outlined in Appendix A1.3.2.

FIGURE B1-4 : MONITORING FIELD SHEET

PROJECT NAME _____ PROJECT NO. _____

DATE _____ SAMPLED BY _____

B.H.	MONITOR	GROUND CONDITIONS & WEATHER (TODAY & YESTERDAY)	WATER LEVEL from pipe tip (m)	COND. umhos/cm	P H	TEMP. °C	Volume of Water in Monitor (L)	Depth of Monitor (m)	COMMENTS (smell, clarity, etc.)	SAMPLE BOTTLES COLLECTED

TABLE B1-6: SOIL SAMPLES COLLECTED FOR PORE WATER SQUEEZING

Location 85-1 - Samples were collected while drilling borehole 85-1-22

Shelby Tube #	Depth Interval (m)
1	1.52 to 2.13
2	3.05 to 3.66
3	4.57 to 5.18
4	6.10 to 6.71
5	9.14 to 9.76
7	12.19 to 12.80
9	15.85 to 16.46
10	18.29 to 18.90
11	21.33 to 21.95
13	24.38 to 24.99
14	27.43 to 28.04
16	30.48 to 31.09

Location 85-12 - Samples were collected while drilling borehole 85-12-12

Shelby Tube #	Depth Interval (m)
1	1.52 to 2.13
2	3.05 to 3.65
3	4.57 to 5.18
4	6.10 to 6.71
5	9.14 to 9.75
6	12.19 to 12.80
7	15.24 to 15.85
8	18.29 to 18.90
9	21.34 to 21.95
10	24.36 to 24.99
11	27.43 to 28.04
12	30.48 to 31.08
13	33.53 to 34.14

Pore waters were extracted from these soil samples at the Department of Earth Sciences, University of Waterloo, under the direction of Dr. S.K. Frape and J. Rodvang. The pore water squeezing methodology as provided by the University of Waterloo is described below.

Squeezing was done using nine stainless steel cylinders connected in line to a tank of compressed nitrogen. Nitrogen pressure was increased gradually from 1380 kPa to a maximum of 5170 kPa. The pressure was regulated using a pressure transducer, to within 35 kPa.

Prior to being squeezed, cores were stored in waxed shelby tubes at 4° C. Upon removal from the shelby tubes for squeezing, the outer edges were trimmed from each core segment to remove parts which may have become contaminated. All parts of the squeezers were thoroughly rinsed with de-ionized water between runs, and squeezing was carried out at 4° C.

Each squeezer consisted of a hollow barrel fitted over a base (see Figure B1-5). A 65 mm long core segment was inserted into the barrel, and piston was placed on top. As pressure was applied to the piston, the clay was compressed, and water was squeezed from the pores. The water was filtered through two "Whatman 40" filter papers placed between the clay and the base before passing to a stainless steel collecting tube attached to the base. From there, the water flowed through a short segment of tygon tubing and into a 30 mL polyethylene sample bottle. A piece of parafilm stretched over the bottle prevented the water from evaporating while it was being collected. Each water sample was collected

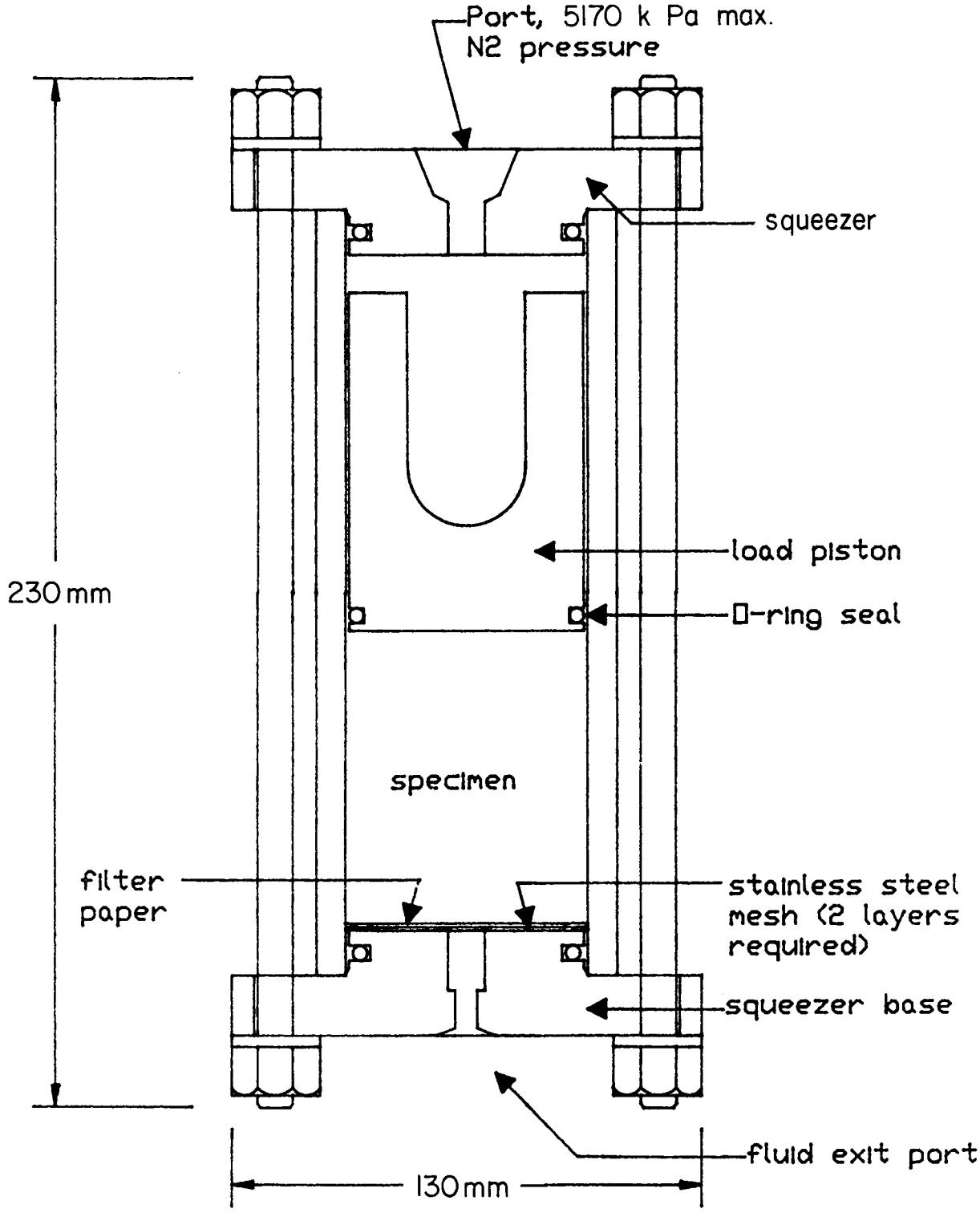


FIGURE B1-5 - Pore Fluid Extractor

Design: J.Baleshta
CAD: M. Jones

within approximately twenty-four hours. Sample bottles were then tightly capped and refrigerated until analysis

The collected pore water was analyzed for oxygen-18, deuterium and chloride. These results are summarized in Table J5 of Appendix J.

B2 ANALYTICAL METHODS

B2.1 FIELD MEASUREMENTS

B2.1.1 TEMPERATURE

Temperature measurements were made with a standard mercury thermometer after about two minutes equilibration.

For the first set of ground water samples (June 1986), temperature was measured on ground water poured into a beaker. The measurement was taken within a few minutes of being withdrawn from the monitor. However, this first method appeared to result in anomalous temperatures. Consequently, subsequent measurements were made by lowering the thermometer down the monitor on a string, into the ground water at screen level. A time period of few minutes was allowed for equilibration and then the thermometer was rapidly removed to obtain the reading. Measurements with the second method are considered to be most representative of ground water temperatures

B2.1.2 CONDUCTIVITY

Conductivity measurements were made on ground water samples using a model C45 LisleMetrix Minibridge conductivity meter. This meter provides automatic temperature compensation. Prior to each sampling run, the conductivity meter calibration was checked against standard solutions of known conductivity.

B2.1.3 pH

pH measurements were made with a Model #95 Markson Digital pH/mv/temperature meter.

Calibration of the pH meter was completed as follows:

(1) Ground water was pumped from one of the monitors into a beaker. The beaker was placed in a cooler to maintain its temperature.

(2) The calibration buffer solutions were immersed in this water to equilibrate them to ground water temperature. Equilibration took approximately 10 to 15 minutes. The temperature was then recorded.

(3) The pH electrode was rinsed thoroughly with distilled water. Excess water was removed by shaking and touching the end with a clean tissue.

(4) The pH electrode was immersed in the pH 7 buffer and the STANDARDIZE knob adjusted to a steady reading of the appropriate pH. Refer to Table B2-1 for standard buffer values at various temperatures. The solution was slowly stirred during measurement.

(5) The pH electrode was rinsed as in (3).

(6) The pH electrode was immersed in the pH 10 buffer and the TEMPERATURE knob adjusted to a steady reading of the appropriate pH. Refer to Table B2-1. The solution was slowly stirred during measurement.

(7) The pH electrode was again rinsed as in (3).

(8) The reading in the pH 7 buffer was checked and if this varied by more than 0.02 units recalibration was undertaken.

(9) Calibration was undertaken three times daily.

TABLE B2-1: STANDARD BUFFER VALUES AT VARIOUS TEMPERATURES

TEMPERATURE (degrees C)	pH OF BUFFER SOLUTIONS		
	4.01	7.00	10.00
0	4.003	7.12	--
5	3.999	7.09	10.18
10	3.998	7.06	10.15
15	3.999	7.04	10.12
20	4.002	7.02	10.05
25	4.008	7.00	10.00
30	4.015	6.99	9.96

Sample pH measurements were completed as follows:

(1) The pH electrode was rinsed as in (3) above.

(2) Ground water from the monitors was pumped into a beaker where temperature and conductivity measurements were taken followed immediately by pH.

(3) To take a measurement, the pH electrode was immersed in the ground water in the beaker until a relatively stable pH reading was obtained (about 15 minutes). The water was slowly stirred during measurement.

(4) Periodically the electrode was checked with the pH 7 buffer. If the reading was not within 0.02 units of the proper pH 7 buffer value, the pH meter was recalibrated.

B.2.2 LABORATORY ANALYTICAL METHODS

The parameters analyzed and the laboratories where the analyses were undertaken are listed in Table B2-2.

The analytical methods used by each of the laboratories are summarized in Appendices B4.1 to B4.5, provided by the laboratories. Each attachment either outlines the analysis methodologies or gives a reference where each method is outlined and indicate any modifications made to the referenced methods. Also provided in Appendices B4.1 to B4.5 are chemical parameter detection limits.

TABLE B2-2: PARAMETERS ANALYZED AND LABORATORIES WHERE THE ANALYSES WERE COMPLETED

LABORATORY	ANALYSES
1. Barringer Magenta Limited 304 Carlingview Drive, Rexdale, Ontario M9W 5G2 (416) 675-3870 (see Appendix B4.1)	pH, alkalinity, total dissolved solids, dissolved inorganic carbon, dissolved organic carbon, sulphide, inductively coupled argon plasma scan for cations (Ag, Al, B, Ba, Be, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Si, Sr, Th, Ti, V, Zn, Zr), and ion chromatography scan for anions (F, Cl, NO_3, NO_2, PO_4, Br, SO_4)
2. Mann Testing Laboratories Lt 5550 McAdam Road, Mississauga, Ontario L4Z 1P1 (416) 890-2555 (see Appendix B4.2)	. methane, scan for volatile and extractable organic parameters on the U.S. E.P.A. priority pollutant list
3. Isotope Laboratory, Department of Earth Sciences University of Waterloo, Waterloo, Ontario N2L 3G1 (519) 885-1211, ext. 2580 (see Appendix B4.3)	oxygen-18, deuterium, direct counting of tritium, enriched counting of tritium, carbon-13, and some chloride analyses
4. Rosentiel School of Marine and Atmosphere Science, Tritium Laboratory, 4600 Rickenbacker Causeway, Miami, Florida 33149-1098 (305) 361-4100 (see Appendix B4.4)	enrichment and low level counting of tritium in ultra-low activity water
5. Isotrace Laboratory, University of Toronto, 60 St. George St., Toronto, Ontario M5G 1A7 (416) 978-2241 (see Appendix B4.5)	accelerator counting of carbon-14 activity

B3 QUALITY ASSURANCE/QUALITY CONTROL

As a means of assessing the accuracy of laboratory analyses and potential biases due to ground water sampling methods, a quality assurance/quality control (QA/QC) program was implemented in both the field and laboratory.

B3.1 FIELD QA/QC

B3.1.1 VARIABILITY DUE TO SAMPLING AND ANALYTICAL METHODOLOGIES

Select split and duplicate samples were submitted to the laboratories.

Split samples were collected by dividing the same sample between two bottles. These are used to assess the reproducibility of the analytical techniques. Split sample analysis results are listed with the chemistry data in Tables J1 to J3 in Appendix J. No split samples were collected for low-level tritium counting at the University of Miami.

Duplicate samples are a separate, second set of samples collected in the same manner as the first, at approximately the same time. These act as a check on the reproducibility of sampling methodologies. Duplicate sample analysis results are listed with the chemistry data in Tables J1 to J3 of Appendix J. No duplicates were collected for low-level tritium counting at the University of Miami.

Table B3-1 presents the approximate variations in each parameter based on the split and duplicate samples. Variations between the two types of samples have not been differentiated because the variations associated with split samples were

approximately the same as the variations associated with the duplicate samples. This implies that variability during any one sampling run due to sampling methods was minimal. Estimates of percent variation were not made where more then 50% of the duplicate and split sample pairs had one or more values below detection.

Table B3-1 indicates there was good reproducibility of results for most parameters, with the average percent variation generally being 5% or less. The parameters with greater than 10% average variation were iron (10%), dissolved inorganic carbon (15%) and dissolved organic carbon (23%).

For the stable isotopes oxygen-18 (^{18}O) and deuterium (^{2}H) it is most appropriate to present analytical/sampling variability as $\pm$ 8 $^{o}/oo$ values since the values are already expressed as ratios relative to SMOW. This is the difference (δ) in the isotopic ratios ($^{18}o/^{16}o$ and $^{2}H/^{1}H$) of the sample, in parts per thousand expressed as $^{o}/oo$) with respect to Standard Mean Ocean Water (SMOW). For both oxygen-18 and deuterium results were also available from laboratory duplicate analyses as well as from the field split and duplicate samples. The range in variability of the oxygen-18 results was $\pm$ 0.0 to $\pm$ 0.16 $^{o}/oo$, averaging $\pm$0.07 $^{o}/oo$. The range in variability of the deuterium results was $\pm$ 0.0 to 2.7 $^{o}/oo$, averaging $\pm$ 0.85 $^{o}/oo$.

For tritium, the variability between split and duplicate sampling was much less then the analytical error reported by the laboratory. The analytical error for direct counting ranged from $\pm$ 6 to 8 Tritium Units (T.U). The analytical error for enriched counting ranged from $\pm$ 0.7 to 1.2 T.U. The analytical error for enriched counting of very low level activity water was $\pm$ 0.1 T.U.

TABLE B3-1: PERCENT VARIATION IN CHEMICAL RESULTS DUE TO ANALYTICAL AND SAMPLNG METHODOLOGIES BASED ON SPLIT AND DUPLICATE SAMPLES

1. General Chemical Indicators

Parameter	Average Variation(%)	Range of Variation (%)	Number of Samples
• Alkalinity (as $CaCO_3$)	3	0-9	12
• Dissolved Inorganic Carbon	15	0-57	12
• Total Dissolved Solids	5	0-17	12

2. Major Cations

Parameter	Average Variation(%)	Range of Variation(%)	Number of Samples
• Calcium (Ca)	1	0-5	12
• Magnesium (Mg)	3	0.3-16	12
• Potassium (K)	5	0-20	12
• Sodium (Na)	2	0.1-14	12
• Strontium (Sr)	2	0-6	12
• Silicon (Si)	3	0.2-9	12

3. Major Anions

Parameter	Average Variation(%)	Range of Variation(%)	Number of Samples
• Bicarbonate (HCO_3)*	3	0-9	12
• Chloride (Cl)	2	0-4	12
• Fluoride (F)	3	0.7-9	12
• Sulphate (SO_4)	1	0-5	12

* Calculated from alkalinity

TABLE 3-1 (continued)

Minor Cations*

Parameter	Average Variation(%)	Range of Variation(%)	Number of Samples
• Aluminum (Al)	-75% of data pairs have one value below detection-		
• Barium (Ba)	6	5-11	6
• Beryllium (Be)	-83% of data pairs have one value below detection-		
• Boron (B)	2	0-6	12
• Cadmium (Cd)	-67% of data pairs have one value below detection-		
• Chromium (Cr)	9	0-73	8
• Cobalt (Co)	-all but one value below detection-		
• Copper (Cu)	-83% of data pairs have one value below detection-		
• Iron (Fe)	10	0-33	12
• Lead (Pb)	-all values below detection-		
• Manganese (Mn)	2	0-14	8
• Molybdenum (Mo)	-83% of data pairs have one value below detection-		
• Nickel (Ni)	3	0-9	7
• Phosphorus (P)	2	0-5	6
• Silver (Ag)	-92% of data pairs have one value below detection-		
• Thorium (Th)	-83% of data pairs have one value below detection-		
• Titanium (Ti)	-all values below detection-		
• Vanadium (V)	-75% of data pairs have one value below detection-		
• Zinc (Zn)	-75% of data pairs have one value below detection_		
• Zirconium (Zr)	-all values below detection-		

* variations only estimated for those parameters having $\geq$ 50% of their data pairs with both values above detection

5. Minor Anions

Parameter	Average Variation(%)	Range of Variation(%)	Number of Samples
• Bromine (Br)	-all values below detection -		
• Nitrite (NO_2)	-all values below detection -		
• Nitrate (NO_3)	-all but one value below detection -		
• Phosphate (PO_4)	-all values below detection-		
• Sulphide (S)	-75% of data pairs have one value below detection-		

6. Organic Constiuents

Parameter	Average Variation(%)	Range of Variation(%)	Number of Samples
• Dissolved Organic Carbon	23	0-61	12
• Methane	7	0-31	15

B3.1.2 VARIABILITY IN DISSOLVED ORGANIC CARBON RESULTS

As indicated previous the dissolved organic carbon results exhibited the greatest variability between split and duplicate samples. There is also considerable variability between monitoring runs. For example, at monitor 85-1-11 the dissolved organic carbon concentration was reported as 62 mg/L for June 17, 1986 and 9.5 mg/L for August 26, 1986. The majority of dissolved organic carbon concentrations also appear to be elevated over the 10 mg/L or less normally observed in ground waters like those at the Preferred Site. The reason for the elevated and variable concentrations was not confirmed. Future analyses for dissolved organic carbon should carefully evaluate the analytical and field sampling errors and if required, employ alternative methodologies.

B3.1.3 VARIABILITY IN METHANE RESULTS

Methane results form the August 26, 1986 sampling were generally lower then other sampling periods. Consultation with the laboratory indicated that the samples had initially been equilibrated for only one hour, compared to the normal 24 hours. The results reported were re-run at 24 hours, but because of the lower values remain suspect.

Methane results from the deep overburden monitors with a diameter of 52 mm (85-8-8, 85-12-8), were much lower than those from monitors with a diameter of only 19 mm. (85-8-3, 85-12-3). Field testing (Table B3-2) confirmed that substantial losses of methane can occur by volatilization out of the larger diameter monitors. Consequently the higher concentrations observed in monitors 85-8-3 and 85-12-3 are considered to be most representative of actual values.

TABLE B3-2: COMPARISON OF METHANE CONCENTRATIONS IN 52 mm AND 19 mm MONITORS

MONITOR #	85-8-3	85-8-8	85-12-3	85-12-8
Diameter (mm)	19	52	19	52
Depth of screen (m)	25.83 to 26.83	24.66 to 26.38	25.90 to 6.80	24.55 to 25.15
1/2 day after flushing	46.8	4.6	171.1	0.8
1/2 after flushing	61.1	0.9	161.1	0.7
1-1/2 days after flushing	105.6	6.8	249.0	0.5
2 days after flushing	98.9	1.6	230.9	2.4
3 days after flushing	99.9	0.9	258.3	7.8

All concentrations in ppm by volume

B3.2 LABORATORY QA/QC

The internal quality assurance/quality control procedures used by the various laboratories are described in this section.

This section is organized as follows.

B3.2.1 Analytical Methods and QA/QC Procedures
Barringer Magenta Limited

B3.2.2 Analytical Methods and QA/QC Procedures
Mann Testing Laboratories Limited

B3.2.3 Analytical Methods and QA/QC Procedures
Isotope Laboratory, University of Waterloo

B3.2.4 Analytical Methods and QA/QC Procedures
Tritium Laboratory, University of Miami

B3.2.5 Analytical Methods and QA/QC Procedures
Isotrace Laboratories, University of Toronto

B3.2.1 ANALYTICAL METHODS AND QA/QC PROCEDURES

BARRINGER MAGENTA LTD.

W.D. #7754C

ANALYTICAL PROTOCOLS USED IN THE OWMC WATER QUALITY SURVEY

Prepared for:
Gartner-Lee & Associates
Toronto Buttonville Airport
Markham, Ontario
L3P 3J9

Prepared by:
Barringer Magenta Limited
304 Carlingview Drive
Rexdale, Ontario
M9W 5G2

September, 1986

1. INTRODUCTION

Barringer Magenta Limited is currently providing analytical services to Gartner-Lee & Associates with respect to a survey being performed for the Ontario Waste Management Corporation (OWMC). This document provides a brief description and summary of the analytical protocols used for the analyses of both inorganic and organic parameters for the above mentioned water quality survey.

This protocol is not designed to be a regurgitation of the analytical methods manual and, as a result, the analytical methods used are described in a very brief tabular form. In addition to the methodologies, the quality control and quality assurance protocols are also described. Once again, a general description is provided along with more detailed information as it pertains to this particular program. For the most part, the procedures used are taken from well documented sources and any in-house modifications are documented accordingly.

2. ANALYTICAL METHODOLOGIES

The analytical methods used for the water analyses provided to Gartner-Lee & Associates under this contract are summarized in Table 1. It should be noted that, for the most part, the methods are identical to those given in the listed references. If the size of sample aliquots taken or the proportions of reagents used were chosen in order to make the analyses more convenient based on the present facilities and capabilities of the laboratory then these were not considered to be major modifications to the method. In the cases where significant differences from the published methodologies are apparent, these have been noted accordingly.

Tables 2 through 4 give the detection levels that were reported for this program. In some cases, such as the ion chromatography and ICAP analyses, all of the parameters which are reportable as part of these packages have been listed. Since these services are offered as a package, results for all of the parameters are given at no additional charge.

TABLE 1

Summary of Analytical Methods

Parameter	Reference[1.]	Modified ?[2.]	Description
pH	SM-423 MOE-PC1 EPA1-150.1	No	- electrode - purchased buffer stds
Alkalinity	SM-403 MOE-AB1 EPA1-310.1		- fixed endpoint titration - to pH 4.5 - standardized H_2SO_4 (0.002-0.01 N depending upon levels expected) - standardization using NaOH and $KHC_8H_4O_4$
T.D.S.	SM-209B MOE-SD.1 EPA1-160.1	Yes	- filtration through 0.45 um membrane filter - dried at 105°C - gravimetric determination of residue
Cations	SM-305 MOE-MD54 EPA1-200.7	No	- A.R.L. Model QA-137 Inductively Coupled Argon Plasma Emission Spectrophotometer - calibration standards prepared from purchased solutions - computerized correction for spectral interferences
Anions	SM-429 MOE-CD18, NB1, SH12 EPA1-300.0	No	- Dionex Model 2110i Ion Chromatograph - Eluent: 0.0024 M Na_2CO_3 0.003 M $NaHCO_3$ - Columns: AS4A + A64 (guard column) - Detector: conductivity - Standards: prepared from salts
D.O.C./D.I.C.	Manufacturers Literature SM-505 MOE-CB20 EPA1-415.1	No	- subcontracted to Beak Consultants Ltd. - infra-red detection - Beckman system

TABLE 1 (Continued)

Summary of Analytical Methods

Parameter	Reference[1.]	Modified ?[2.]	Description
Sulphide	SM-427C MOE-SI18 EPA1-376.2	No	- Colourimetry with ferric chloride and dimethyl-p-phenylenediamine (methylene blue method) - standards from Na_2S, standardized by iodometric titration

1. SM = Standard Methods for the Examination of Water and Wastewater (16th Ed.), APHA-AWWA-WPCF (1985).

   MOE = Handbook of Analytical Methods, Ontario Ministry of the Environment (1983).

   EPA1 = Methods for Chemical Analysis of Water and Wastes, U.S. Environmental Protection Agency (revised 1983)

   EPA2 = Guidelines Establishing Test Procedures for the Analysisj of Pollutants Under the Clean Water Act; Final Rule and Interim Final Rule and Proposed Rule, Federal Register: Environmental Protection Agency, 40 CFR Part 136 (1984).

2. The methods used are similar to those listed in the references with the possible exception of the volumes taken or reagent proportions used. If significant deviations from the published methods are used, this is indicated here and the modification is flagged (*) in the "Description" column.

TABLE 2

Analytical Detection Limits
(mg/l unless otherwise noted)

pH	± 0.01 pH units
Alkalinity	0.2 mg $CaCO_3$/l
Total Dissolved Solids	1.0 mg/l
Cations	(see Table 3)
Anions	(see Table 4)
D.O.C./D.I.C.	0.5 mg/l
$S^=$	0.001

TABLE 3

I.C.A.P. Multi-element Package Detection Limits (mg/l)

Ag	0.005	Cu	0.01	Pb	0.05
Al	0.05	Fe	0.01	Si	0.05
B	0.005	K	1.0	Sr	0.001
Ba	0.005	Mg	0.01	Th	0.05
Be	0.0005	Mn	0.01	Ti	0.005
Ca	0.05	Mo	0.2	V	0.005
Cd	0.01	Na	1.0	Sn	0.05
Co	0.05	Ni	0.05	Zr	0.02
Cr	0.01	P	0.5		

TABLE 4

Ion Chromatography Package Detection Limits (mg/l)

F^-	0.005
Cl^-	0.01
NO_2^-	0.02
$PO_4^=$	0.1
Br^-	0.05
NO_3^-	0.05
$SO_4^=$	0.05

3. QUALITY ASSURANCE AND QUALITY CONTROL

In any analytical program it is vital that proper quality assurance and quality control practices be followed in order to establish credibility in the final results obtained. These practices must include both good technique and implementation as well as thorough documentation of the procedures employed. A generalized summary of the QA/QC procedures routinely employed at Barringer are presented in Appendix I. This excerpt was taken from a Manual of Standard Operating Procedures for the laboratory operations at Barringer.

In programs involving water quality analyses, the inclusion of blanks and sample replicates is a fairly easy procedure. The inclusion of reference standards, however, becomes a somewhat more difficult issue. Up until recently, the onus was on the laboratory to prepare standard solutions which could be used for this purpose, the only criteria being that their source was independent from the standards used for calibration purposes. In this way it was hoped that an independent mechanism would exist for verifying the accuracy of the calibration standards and as a monitor on recovery of various extraction processes. More recently, however, various organizations have been producing concentrates which are meant to be used for quality control and water analysis programs. These include the National Bureau of Standards, the U.S. Environmental Protection Agency and Environmental Resources Associates. Barringer has been employing the standard provided by the U.S. E.P.A. for many of its water quality tests. A list of the standards used in this program is presented in Table 5.

Control charting is a regular quanlity control procedure at Barringer. Control charts are established to monitor overall precision and accuracy of the analytical techniques used. In

TABLE 5

Reference Standards Used in O.W.M.C. Survey

Standard	Certified Parameters
EPA - Minerals	pH, Alkalinity, F^-, Cl^-, $SO_4^=$, Conductance, TOS
EPA - Nutrients	NH_3-N, TKN, Total P, NO_3^-, PO_4^{-3}
EPA - Trace Metals - I	ICAP, AA, As, Hg

order to simplify any subsequent presentation requirements it was decided that control charts be set-up specifically for this program and kept separate from the normal lab control charts. In this way the specific program can be monitored and not lost in the routine analytical work performed by the laboratory. Samples of these control charts have been presented along with the quality assurance description in Appendix I.

4. REFERENCES

More detailed information on the procedures outlined in this manual can be found in the following references.

A. Quality Control References

1. United States Environmental Protection Agency, HANDBOOK FOR ANALYTICAL QUALITY CONTROL IN WATER AND WASTEWATER LABORATORIES, Ref. EPA-600/4-79-019 (March 1979)

2. Ontario Ministry of the Environment, THE WATER QUALITY LABORATORIES, DATA QUALITY SUMMARY, D.E. King and P. Fellin (1975)

3. Ontario Ministry of the Environment, QUALITY CONTROL AND DATA EVALUATION PROCEDURES, D.E. King (1976)

4. Ontario Ministry of the Environment, PRINCIPLES OF CONTROL CHARTING, D.E. King (1984)

B. Analytical Methods Manuals

1. U.S. Environmental Protection Agency, METHODS FOR CHEMICAL ANALYSIS OF WATER AND WASTES, EPA Ref. 600/4-79-020 (May 1979)

2. Environment Canada, ANALYTICAL METHODS MANUAL (1979), Inland Waters Directorate, Water Quality Branch, Ottawa, Ontario (Aug. 1979)

3. Ontario Ministry of the Environment, HANDBOOK OF ANALYTICAL METHODS FOR ENVIRONMENTAL SAMPLES, Laboratory Services and Applied Research Branch, Rexdale, Ontario (December 1983)

4. A.P.H.A., A.W.W.A., W.P.C.F., STANDARD METHODS FOR THE EXAMINATION OF WATER AND WASTEWATER, 16th Ed., (1985)

5. U.S. Environmental Protection Agency, METHODS FOR ORGANIC CHEMICAL ANALYSIS OF MUNICIPAL AND INDUSTRIAL WASTEWATER, Ref. EPA-600/4-82-057 (July 1982)

6. U.S. Environmental Protection Agency, MANUAL OF CHEMICAL METHODS FOR PESTICIDES AND DEVICES, A.O.A.C., Ref. ISBN 0-935584-23-4 (July 1976)

7. American Society for Testing and Materials, ANNUAL BOOK OF A.S.T.M. STANDARDS, PART 31, WATERS (1979)

8. American Society for Testing and Materials, ANNUAL BOOK OF A.S.T.M. STANDARDS, Vol. 4.08, SOIL AND ROCKS: BUILDING STONES (1984)

9. Perkin-Elmer, ANALYTICAL METHODS FOR ATOMIC ABSORPTION SPECTROPHOTOMETRY (Jan. 1982)

10. Rudolf Bock, A HANDBOOK OF DECOMPOSITION METHODS IN ANALYTICAL CHEMISTRY, Halsted Press (1979)

11. A.O.A.C., OFFICIAL METHODS OF ANALYSIS OF THE ASSOCIATION OF OFFICIAL ANALYTICAL CHEMISTS (1975)

APPENDIX I

Quality Assurance/Quality Control

QUALITY ASSURANCE AND QUALITY CONTROL PRACTICES

GENERAL CONCEPTS

The purpose of a QA/QC program is to ensure consistency of data quality and accurancy in the analytical results. It must provide a routine method of monitoring the analytical process and provide a quick feedback to the analyst as to the degree of control. The then main determinants of control are background levels, precision and accuracy. These are monitored routinely by the insertion into the analytical scheme of blanks, replicates and reference standards, respectively.

With the monitoring of these three facets of the analytical process, documentation is also essential to provide a time-based monitor of the quality of the various analytical methods. This can be accomplished by centralized recording of the data obtained, and by the use of control charts. These would provide a realistic summary of analytical performance over time, enabling accurate determination of confidence and control limits. If these limits prove to be wider than is considered acceptable, it provides feedback on methods which are in need of re-evaluation and modification. It is essential that everyone involved in analytical work be aware of the importance of QA/QC protocols and adhere strictly to the accepted procedures.

BACKGROUND MONITORING

During an analytical process, backgrounds can be introduced via a number of different processes. If glassware has not been cleaned properly, contamination may be introduced from these sources. This contamination would be inconsistent and

sporadic. Another source of contamination could be from the reagents used in the analytical process. Backgrounds due to reagent contaminants would be much more consistent, showing up as a constant background in all samples.

In order to determine whether one of the former situations exist, reagent blanks are inserted in each work order at a frequency of one reagent blank for every 30 samples analyzed. It should be noted that this is not simply a calibration blank but a sample which is taken through every digestion, extraction or colour development phase of the analytical method. The only thing omitted is the sample aliquot. Reagent contaminations are easily discovered by analysis of these blanks, especially if a number of them have been included in a work order. An example is the blank observed when a poor grade of potassium permangante is used for digestions of sediments and sludges for mercury analysis. Analysis of several blanks would give a constant background reading with a very tight precision. This may represent a mercuric impurity in the reagent and should be corrected for as long as the precision is very close and the sample levels are significantly higher (at least 5x).

If some blanks give large readings and others give none, a sporadic contamination has probably occurred. This type of contamination cannot be corrected for and the analysis of that batch of samples should be terminated, the glassware rewashed and the entire analysis repeated.

MONITORING OF ANALYTICAL PRECISION

Analytical precision is simply the reproduceability of the procedure being followed. The usual method of monitoring this precision is the analysis of some samples in duplicate. This is done at a frequency of one replicate for every 30 samples

analyzed. The sample repeated is usually the one immediately following the previous blank. For example, if sample #10 was a blank, sample #20 would be a repeat of sample #11. As in the case of the reagent blank analyses, this is not simply a re-analysis of the same sample solution but involves taking a separate sample aliquot and putting it through the entire analytical process. One point to note is that poor precision observed by this process is not necessarily just an indication of a poor analysis approach. Poor precision can also occur if an inhomogenous sample is involved. In this case, the analytical precision may be excellent but, in effect, the sample aliquots being taken for analysis are not identical. This can sometimes be discerned for large work orders if the precision for a number of analyses of a reference standard show markedly better precision than that observed in the sample replicates. If this is suspected, the only recourse is to re-prepare the sample by homogenization, if feasible, and re-analyze it.

MONITORING ACCURACY

In order to measure the degree of accuracy in any analytical method several factors must be taken into account. The calibration standards used must be properly prepared, the analytical procedure must not cause any loss of analyte, interferences must be properly eliminated or accounted for and analyte recoveries must be quantitative.

To monitor calibration standard accuracy, it is necessary to have an independent lab control solution that has sufficient stability to be used over a period of time. All calibration standards should be prepared from primary standard grade reagents but the preparation process must be constantly

monitored. The first step to be taken when a new series of standard solutions is prepared is to compare the new standards to the old ones. If a discrepancy occurs, the old standards may be the problem. Subsequent to this comparison, therefore, a reference standard solution should be analyzed against the new standards and the value obtained compared to the certified or accepted value. If the value obtained does not lie within a given acceptance window, usually less than a 5% deviation from the certified value, the standards should be re-prepared. Purchased standards, such as those available for GC/MS priority pollutant work, should also be evaluated by a similar procedure before their implementation for calibration purposes.

To measure losses of analyte as a result of the analytical process, reference standards are inserted at a frequency of one standard for every 30 samples analyzed. This is inserted in every thirtieth sample position. The reference standards should be chosen so as to match the sample matrix as closely as possible, and to have an analyte level close to that expected for the samples. If the results obtained are not within the specific acceptance windows (see Section 4.5), the procedure should be reviewed, the problem corrected and the sample re-analyzed.

New reference materials are constantly being introduced as supplies of the older one are depleted. Some of the standards to be used for our routine analyses are given in Table 4.

Interferences could also be monitored in a similar manner by analyzing either synthetic or purchased interference check samples. This type of standard is especially useful for I.C.A.P. analysis where corrections for spectral interferences are performed as a routine part of the analytical process. These standards usually contain low levels of analytes with fairly substantial excesses of known interferents.

CONTROL CHARTS

Control charts are used to monitor the long-term data quality for analysis of reference standards to enable a quick visual assessment of the degree of control for a particular analytical run. They are basically a plot of analyte recovery as a function of time. Whenever a given standard is analyzed with a work order, its result is plotted on the appropriate control chart. Over a period of time, the analytical precision can be viewed directly on the chart. Control limits can be set up and acceptance criteria established. An example of a typical control chart is given in Figure 7. If the result obtained for a given standard run lies outside the given control limits, the sequence of samples associated with that standard run must immediately be scheduled for re-analysis.

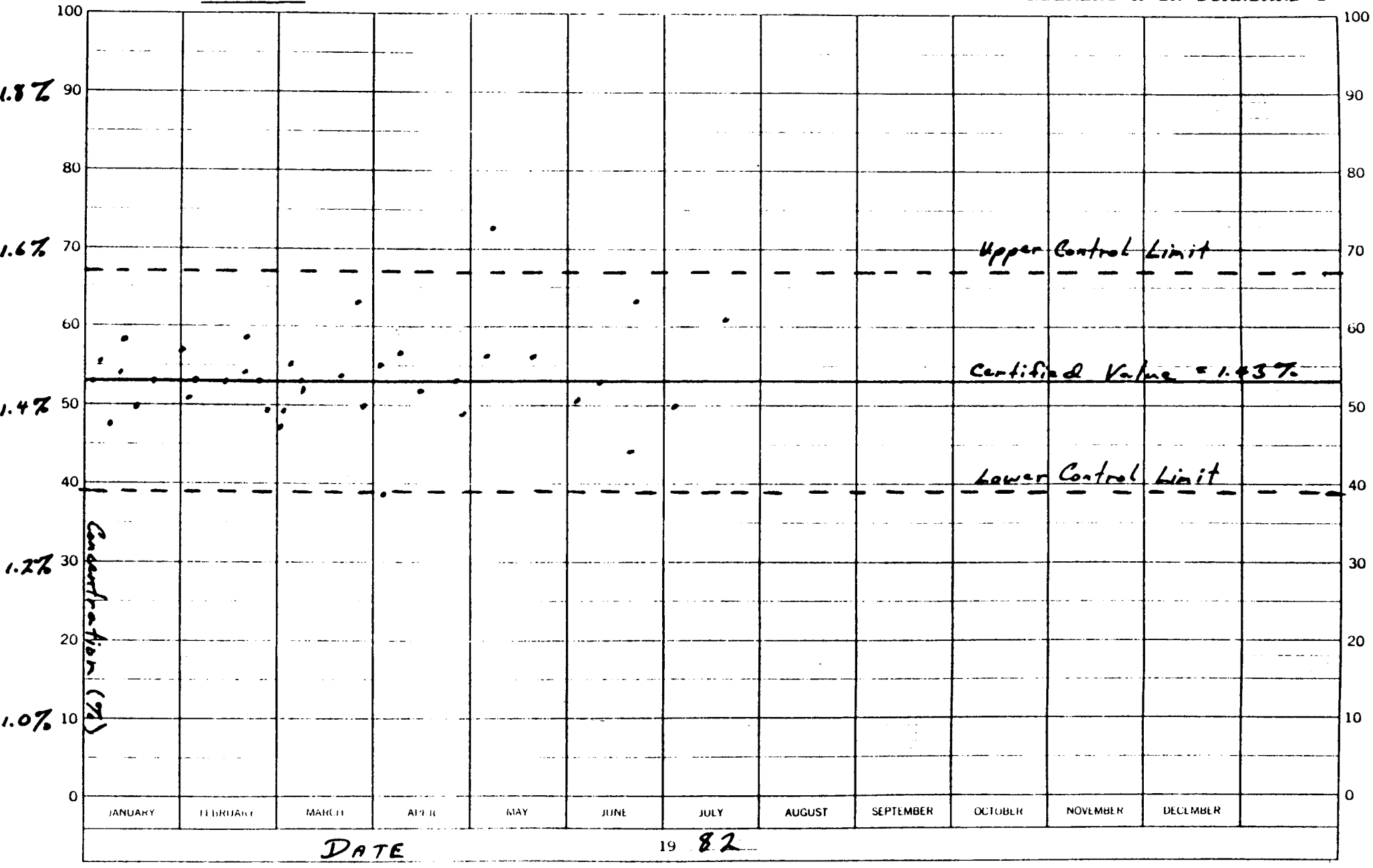
Each lab supervisor should keep a binder with all of the control charts for all standards used routinely and it should be kept as a integral part of the QA/QC process. Quality control is a vital part of the laboratory operation and the practices described here should be adhered to strictly in order to ensure the client of accurate data and to keep the laboratory's reputation held in high regard.

TABLE 4

REFERENCE STANDARDS MOST COMMONLY USED

Matrix	Standard (Source)
Rock Analysis:	SY-2 (Canmet) SY-3 (Canmet) MRG-1 (Canmet)
Soil/Sediment Analysis:	Estuarian Sediment (SRM 1646-NBS) River Sidemtn (SRM 1645-NBS) SO-1 to SO-4 (Canmet) GXR-1 to GXR-6 (U.S.G.S.) Deer Lake #1, 2 (in-house)
Vegetation Analysis:	Citrus Leaves (SRM 1572-NBS) Pine Needles (SRM 1575-NBS) Orchard Leaves (SRM 1571-NBS) Tomato Leaves (SRM 1573-NBS)
Tissue Analysis:	Bovine Liver (SRM 1577a-NBS) Oyster Tissue (SRM 1566-NBS)
Water Analysis:	WASTEWATR Set (E.R.A.) TRACE ELEMENTS IN WATER (SRM 1643a-NBS) Purchased Metals Stock Solutions (Canlab, BDH, etc.)
Miscellaneous:	TRACE ELEMENTS IN COAL-BITUMINOUS (SRM 1632a-NBS) TRACE ELEMENTS IN COAL-SUBBITUMINOUS (SRM 1635-NBS) TRACE ELEMENTS IN COAL FLY ASH (SRM 1633a-NBS) STAINLESS STEEL (SRM 101f-NBS)

FIGURE 7: EXAMPLE OF A REFERENCE STANDARD CONTROL CHART FOR ELEMENT X IN STANDARD Y



B3.2.2 ANALYTICAL METHODS AND QA/QC PROCEDURES

MANN TESTING LABORATORIES LTD.

METHANE ANALYSIS IN WATER
(Using Headspace Technique)

The samples were prepared by first removing ten (10) ml of water and replacing this volume with a like amount of pure nitrogen. The samples were then allowed to stand at room temperature (20^{0}C) for 24 hours to permit equilibrium to occur.

The analysis involved injecting 0.5uL of the headspace into a Hewlett Packard 5840A Gas Chromatogragh equipped with a Flame Ioniozation Detector (FID). The parameters of the GC were as follows:

Detector Temp.	250^{0}C
Oven Temp.	100^{0}C
Injector Temp.	100^{0}C
Column	7 ft. Poropac T
Injection Vol.	0.5uL

VOLATILE ANALYSIS - WATER SAMPLES

Sampling Preparation - Collection and Handling

Water samples for purgeable organics were collected in 50 ml capacity amber glass bottles equipped with Tuf-Bond discs and screw caps with a syringe access hole in the centre. The bottles had been previously cleaned and heated at 200°C for at least 4 hours, purged with nitrogen and sealed with PTFE coated silicone and open top caps prior to transportation to the sampling sites.

The bottles were filled to slight overflow, then sealed so that no air bubble was present in the sample. They were immediately returned to Mann Testing Labs and stored at 4°C until analysed.

Preparation of Standard Solutions

Stock standard solutions were prepared by injecting appropriate amounts of each pollutant into 25 ml of glass distilled methanol (Burdick and Jackson) in reactiflasks fitted with Minnert valves (Chromatographic Specialties Ltd.) which provide complete protection and easy access via a hypodermic needle. The resulting concentration of 1 mg/ml was further diluted to give methanolic solutions of 400 ug/ml, 40 ug/ml and 4 ug/ml for each component. Gaseous standards were prepared in a similar manner by injecting the gaseous compound from a 10 ml gas tight syringe into a pre-weighed reactiflask filled with 25 ml of methanol. The syringe needle was slightly above the ethanol meniscus while injecting, hence enabling the gas to dissolve rapidly into the methanol. The flask was re-weighed again to determine the amount

in the solution.

Aqueous composite standards were prepared by injecting appropriate aliquots of methanolic standard in 250 ml sample bottles filled with purified water.

The relative retention times (RRT) were compared to that of the internal standard, deuterated chlorobenzene (RRT = 1.00) which eluted close to the middle of the chromatogram. Detection limits were determined by purging aqueous composite standard mixture at various concentrations.

Instrumentation

Analysis of volatile organics in water was conducted using a UNACON 780B automatic concentrator (Envirochem Inc., Kemblesville, P.A.). This instrument utilized the technique developed by Bellar and Lichtenberg for the isolation and concentration of volatiles for chromatographic analysis. In general, this process involved gas stripping of the sample and adsorption of the organic compounds on a sorbent trap followed by thermal desorption and analysis by gas chromatography or gas chromatography/mass spectrometry.

The sample purging assembly included a sparger vial with a side port which was equipped with an open top screw cap and Tuf-Bond septum. A 30 ml vial was used to obtain detection limits as reported. Sample was transferred to the vial through a transfer line by pressurizing the sample bottle which was inverted and clamped on the side of the instrument. The transfer line was constructed of 1/16" teflon tubing with two Luer Lock

connectors at each end. Two 17-gauge needles were used to puncture the septa of both the bottle and the side port.

Prior to the start of the analysis, the sparger vial was purged with helium for 5 minutes by rotating the valve to "Trap-Out" mode. In this position, any contaminants that were present in the sparger vial were purged out of the system without entering the trap. An appropriate aliquot of the water was then transferred to the sparger and purged for 15 minutes at the "Trap-In" mode. The trap was heat desorbed and the organics backflushed into the second trap. When this transfer process was completed, the second trap was again heated, releasing all adsorbed organics into the capillary GC/MS system for identification and quantification.

The MDL (Method Detection Limit) listed in the volatile section is the limit that the compound can be identified and quantified in the sample matrix using the purge & trap GC/MS method.

QA/QC

Prior to sample analysis reference standards were analyzed to determine the instrument response for standards of known levels. Instrument blanks were then analyzed to determine the extent of any instrument contamination. Travelling blanks for each set of samples were analyzed to measure any possible background contamination caused by the sample container. At ten sample intervals duplicate samples were analyzed to monitor the analytical reproducibility.

TABLE I

RETENTION DATA, % RECOVERY & CHARACTERISTIC IONS OF THE VOLATILE ORGANICS

Compound	RRT	% RECOVERY	PRIMARY ION (m/e)	SECONDARY IONS (m/e)
Dichlorodifluoromethane	0.477	99.8	85	87
Chloromethane	0.486	100.3	50	52
Vinyl Chloride	0.495	106.2	62	64
Bromomethane	0.511	105.0	94	96
Chloroethane	0.516	91.9	64	96
Trichlorofluoromethane	0.545	101.6	101	103
1,1-Dichloroethylene	0.568	98.6	61	63,96
Dichloromethane	0.571	92.7	49	84
t-1,2-Dichloroethylene	0.608	92.3	61	63,96
1,1-Dichloroethane	0.614	97.2	63	65,83
Chloroform	0.661	90.5	83	85,87
1,2-Dichloroethane	0.690	80.3	62	64,98
1,1,1-Trichloroethane	0.707	102.5	97	61,99
Benzene	0.729	97.5	78	51,77
Carbon Tetrachloride	0.737	97.6	117	119,121
1,2-Dichloropropane	0.769	91.2	63	62,76
Bromodichloromethane	0.779	94.2	83	82,129
Trichloroethylene	0.782	101.2	95	130
1,3-Dichloropropene(Z)	0.827	90.8	75	110
1,3-Dichloropropene(E)	0.857	78.9	75	110
1,1,2-Trichloroethane	0.866	71.1	83	97
Toluene	0.888	91.4	91	92
Dibromochloromethane	0.914	79.7	129	127
Tetrachloroethylene	0.960	126.2	129	166,131
Chlorobenzene	1.003	92.7	112	77,114
Ethyl Benzene	1.026	93.9	91	106
m,p-Xylenes	1.038	95.4	91	105,106
Bromoform	1.042	52.5	173	171,175
o-Xylene	1.067	88.3	91	105,106
1,1,2,2-Tetrachloroethane	1.066	45.0	83	85
1,3-Dichlorobenzene	1.199	86.4	146	148,111
1,4-Dichlorobenzene	1.204	86.7	146	148,111
1,2-Dichlorobenzene	1.231	85.4	146	148,111
Acrolein	0.528	22.1	56	55
Acrylonitrile	0.551	7.9	53	52
Pentane	0.512	82.7	43	42,57
Dimethyl Sulphide	0.518	80.2	47	62,45
Methylethylketone	0.591	8.8	43	72
Hexane	0.622	84.3	57	41,43
Heptane	0.787	97.8	43	57,71
4-Methyl-2-pentanone	0.823	26.6	43	58,85

TABLE I(cont'd)

REPRODUCIBILITY OF SELECTED VOLATILE ORGANICS USING PURGE & TRAP SYSTEM

Compound	Ion (m/e)	Peak Intensity Run#1	Run#2	Run#3	SDV	% C.V.
Dichlorodifluoromethane	85	41408	46016	47488	3171.9	7.1
Chloromethane	50	19840	18560	19072	644.3	3.4
Vinyl Chloride	62	81664	83072	89728	4307.2	5.1
Bromomethane	94	49536	52608	66048	8781.8	15.7
Chloroethane	64	39872	35648	47616	6069.7	14.8
Trichlorofluoromethane	101	100992	93568	123008	15310.9	14.5
1,1-Dichloroethylene	61	22848	21600	20832	1017.5	4.7
Dichloromethane	84	24096	20512	20896	1967.8	9.0
t-1,2-Dichloroethylene	61	32032	28064	27776	2378.4	8.1
1,1-Dichloroethane	63	54272	48064	50496	3128.2	6.1
Chloroform	83	55168	52160	46528	4385.9	8.6
1,2-Dichloroethane	62	31904	31296	35840	2467.8	7.5
1,1,1-Trichloroethane	97	48256	50432	51008	1451.5	2.9
Benzene	78	99200	93184	105984	6403.8	6.4
Carbon Tetrachloride	117	37824	37248	40896	1961.2	5.1
1,2-Dichloropropane	63	21984	20768	24064	1666.8	7.5
Bromodichloromethane	83	48640	51136	51136	1441.1	2.9
Trichloroethylene	130	46208	43072	46208	1810.6	4.0
1,3-Dichloropropene(Z)	75	38272	38848	40320	1056.2	2.7
1,3-Dichloropropene(E)	75	28704	25696	30400	2382.3	8.4
1,1,2-Trichloroethane	97	36672	32416	38848	3271.6	9.1
Toluene	91	145408	140544	145664	2885.0	2.0
Dibromochloromethane	129	47808	43200	52096	4449.0	9.3
Tetrachloroethylene	129	66176	64448	66816	1224.9	1.9
Chlorobenzene	112	104960	101248	96640	4168.0	4.1
Ethyl Benzene	91	139008	124032	135168	7778.6	5.9
m,p-Xylenes	91	111104	99584	117120	8910.8	8.2
Bromoform	173	34240	30336	30528	2200.6	6.9
o-Xylene	91	121856	113152	124032	5757.2	4.8
1,1,2,2-Tetrachloroethane	83	37312	33984	31072	3122.3	9.2
1,3-Dichlorobenzene	146	99584	88192	101504	7195.8	7.5
1,4-Dichlorobenzene	146	114304	101248	118400	8957.6	8.0
1,2-Dichlorobenzene	146	94976	86144	94464	4958.0	5.4
Acrolein	56	3452	2636	2872	419.9	14.1
Acrylonitrile	53	6024	4592	4984	740.0	14.2
Pentane	43	82048	71808	71296	6065.3	8.1
Dimethyl Sulphide	62	64384	56896	60544	3744.4	6.2
Methylethylketone	43	17024	23136	20757	3080.9	15.2
Hexane	57	66944	73472	84608	8931.6	11.9
Heptane	43	117248	123648	125824	4458.0	3.6
4-Methyl-2-pentanone	43	53440	64448	51904	6842.1	12.1

TABLE I (cont'd)

GC/MS
% RECOVERY REPRODUCIBILITY
5 ppb level

	% Recovery Run #1	% Recovery Run #2	% Recovery Run #3	Ave. % Recovery	SDV
Dichlorodifluoromethane	93.6	101.6	104.1	99.8	5.5
Chloromethane	88.7	99.1	113.2	100.3	12.3
Vinyl Chloride	92.1	112.1	114.4	106.2	12.3
Bromomethane	95.4	108.6	111.0	105.0	8.4
Chloroethane	93.8	91.9	90.0	91.9	1.9
Trichlorofluoromethane	105.6	95.8	103.3	101.6	5.1
1,1-Dichloroethylene	97.1	99.1	99.7	98.6	1.4
Dichloromethane	96.2	93.1	88.7	92.7	3.8
t-1,2-Dichloroethylene	88.1	91.8	96.9	92.3	4.4
1,1-Dichloroethane	93.2	103.1	95.4	97.2	5.2
Chloroform	97.4	92.1	82.1	90.5	7.8
1,2-Dichloroethane	75.0	73.5	92.5	80.3	10.6
1,1,1-Trichloroethane	100.8	101.5	105.3	102.5	2.4
Benzene	96.3	101.2	95.0	97.5	3.3
Carbon Tetrachloride	95.5	94.0	103.2	97.6	4.9
1,2-Dichloropropane	90.0	85.1	98.6	91.2	6.8
Bromodichloromethane	99.0	92.0	91.6	94.2	4.2
Trichloroethylene	103.9	97.5	102.1	101.2	3.3
1,3-Dichloropropene(Z)	87.3	88.6	96.4	90.8	4.9
1,3-Dichloropropene(E)	81.4	72.9	82.5	78.9	5.3
1,1,2-Trichloroethane	73.7	65.1	74.6	71.1	5.2
Toluene	93.7	90.6	89.9	91.4	2.0
Dibromochloromethane	81.2	73.3	84.7	79.7	5.8
Tetrachloroethylene	127.3	125.2	126.1	126.2	1.1
Chlorobenzene	96.4	92.9	88.7	92.7	3.9
Ethyl Benzene	95.8	92.5	93.5	93.9	1.7
m,p-Xylenes	98.1	91.5	96.6	95.4	3.5
Bromoform	56.7	50.2	50.5	52.5	3.7
o-Xylene	90.5	89.7	84.7	88.3	3.1
1,1,2,2-Tetrachloroethane	46.6	42.5	46.0	45.0	2.2
1,3-Dichlorobenzene	86.4	88.4	84.3	86.4	2.1
1,4-Dichlorobenzene	86.5	88.4	85.3	86.7	1.6
1,2-Dichlorobenzene	88.8	82.6	84.7	85.4	3.2
Acrolein	24.6	19.9	21.7	22.1	2.4
Acrylonitrile	9.2	7.0	7.6	7.9	1.1
Pentane	86.1	78.8	83.2	82.7	3.7
Dimethyl Sulphide	79.3	78.9	82.4	80.2	1.9
Methylethylketone	8.5	10.9	6.9	8.8	2.0
Hexane	85.9	81.8	85.2	84.3	2.2
Heptane	99.6	95.9	97.8	97.8	1.9
4-Methyl-2-pentanone	25.4	27.8	26.6	26.6	1.2

TABLE I (cont'd)

RETENTION TIME REPRODUCIBILITY

	Run #1 RRT	Run #2 RRT	Run #3 RRT	Ave. RRT	+ Limits For RRT
Dichlorodifluoromethane	0.488	0.473	0.471	0.477	0.012
Chloromethane	0.496	0.482	0.480	0.486	0.012
Vinyl Chloride	0.506	0.491	0.487	0.495	0.012
Bromomethane	0.520	0.507	0.505	0.511	0.010
Chloroethane	0.524	0.513	0.511	0.516	0.010
Trichlorofluoromethane	0.549	0.544	0.542	0.545	0.005
1,1-Dichloroethylene	0.571	0.568	0.565	0.568	0.005
Dichloromethane	0.575	0.570	0.569	0.571	0.005
t-1,2-Dichloroethylene	0.609	0.608	0.607	0.608	0.002
1,1-Dichloroethane	0.614	0.614	0.613	0.614	0.002
Chloroform	0.660	0.662	0.660	0.661	0.002
1,2-Dichloroethane	0.694	0.682	0.693	0.690	0.009
1,1,1-Trichloroethane	0.708	0.710	0.704	0.707	0.004
Benzene	0.731	0.733	0.723	0.729	0.008
Carbon Tetrachloride	0.739	0.741	0.731	0.737	0.005
1,2-Dichloropropane	0.773	0.774	0.760	0.769	0.010
Bromodichloromethane	0.783	0.784	0.770	0.779	0.010
Trichloroethylene	0.786	0.787	0.772	0.782	0.010
1,3-Dichloropropene(Z)	0.832	0.833	0.817	0.827	0.010
1,3-Dichloropropene(E)	0.862	0.863	0.846	0.857	0.012
1,1,2-Trichloroethane	0.873	0.873	0.851	0.866	0.012
Toluene	0.892	0.892	0.881	0.888	0.005
Dibromochloromethane	0.915	0.916	0.910	0.914	0.005
Tetrachloroethylene	0.960	0.960	0.959	0.960	0.002
Chlorobenzene	1.003	1.003	1.002	1.003	0.002
Ethyl Benzene	1.027	1.026	1.026	1.026	0.002
m,p-Xylenes	1.038	1.038	1.037	1.038	0.002
Bromoform	1.042	1.042	1.041	1.042	0.002
o-Xylene	1.066	1.068	1.068	1.067	0.002
1,1,2,2-Tetrachloroethane	1.066	1.066	1.066	1.066	0.001
1,3-Dichlorobenzene	1.201	1.200	1.197	1.199	0.003
1,4-Dichlorobenzene	1.206	1.205	1.202	1.204	0.003
1,2-Dichlorobenzene	1.232	1.232	1.229	1.231	0.003
Acrolein	0.534	0.525	0.524	0.528	0.007
Acrylonitrile	0.555	0.550	0.548	0.551	0.005
Pentane	0.507	0.519	0.511	0.512	0.008
Dimethyl Sulphide	0.512	0.526	0.517	0.518	0.009
Methylethylketone	0.585	0.597	0.592	0.591	0.007
Hexane	0.617	0.626	0.623	0.622	0.006
Heptane	0.784	0.790	0.787	0.787	0.004
4-Methyl-2-pentanone	0.821	0.826	0.823	0.823	0.004

EXTRACTABLE (EPA) ANALYSIS - WATER SAMPLES

Standard Compound Characterization

A Standard solution containing approximately 1.0 ng/ul of each of the selected priority pollutants was prepared and analysed by GC/MS to determine each compound's fragmentation pattern, relative retention time (RRT) and relative response factor (RRF) compared to the internal standard D_{10} Phenanthrene. A 10 ppb dilution of this standard was routinely run prior to sample analysis to insure optimum performance of the GC/MS system. The minimum detection limit (MDL) represents the minimum level at which a compound can be detected and quantitated. Values were determined by comparison of the response of the labelled internal standards to the level of background interference in the region of the corresponding natural compound. These values are averages obtained from actual sample matrices.

Target Compound % Recovery

The % recovery of individual target compounds was determined by spiking 1 litre of purified distilled water at the 20 ppb level with a standard mixture containing all of the compounds of interest.

Recovery values and the method detection limit (MDL) are listed in Table II.

Sample Extractions

To monitor the extraction efficiency of individual sample extractions. Each sample was spiked at the 10 ppb level with a mixture of 11 deuterated acid extractables and 19 deuterated B/N compounds.

To monitor the injection efficiency all extracts were spiked with 10 ppb of D-10 Phenanthrene immediately prior to GC/MS analysis.

QA/QC Protocol

a) The use of a stock mixture of deuterated internal standards (Table III) to monitor extraction efficiency assures a high confidence level in the results of all sample extractions.

b) Travelling blanks were analysed at 10 sample intervals to insure that outside contamination was not interfering with the observed results.

c) Prior to sample analysis, reference standards at the 10 ppb level were analysed to demonstrate that the instrument was capable of the required sensitivity. Solvent blanks were run between standards and samples to monitor any possible cross contamination. Reference standards at various levels were analysed after every tenth sample.

Target Compound Identification and Quantitation

The GC/MS data files were searched for the selected pollutants using a computer program that searched successive regions of the chromatogram plotting out ion intensities of the two most abundant ions of both the target compound and labelled standards eluting in that region. The identity of detected compounds was verified by manual confirmation (mass spectra matching).

Quantitation of target compounds was achieved by comparing the peak heights of the natural compound to that of its analogous labelled standard which had been spiked into the sample at a known level. For those target compounds whose corresponding labelled standard was not available, the labelled standard that eluted closest to it was used for quantitation.

Additional Compound Identification

Additional compounds (non-targetted) present in the sample were tentatively identified by means of a computer generated mass spectra library search program. The mass spectra of the natural compound is compared to entries in the National Bureau of Standards (NBS) library containing approximately 35,000 compounds. The compounds reported as additional compounds were present in concentrations greater than 1 ppb (based on a 1:1 response to the internal standard, D_{10}-Phenanthrene) and had purity match values of greater than 800 (1000 = exact match).

TABLE II

EPA PRIORITY POLLUTANTS

MINIMUM DETECTION LIMITS & PERCENT RECOVERIES

(1 L water/20 ppb)

ACIDIC COMPOUNDS	MWT	QUANT ION	RRT	MDL	% REC
Phenol	94	94	0.270	1.6	25.0
2-Chlorophenol	142	142	0.390	3.0	40.6
2,4-Dimethyl phenol	136	107	0.431	2.5	24.5
p-Chloro-m-cresol	156	156	0.485	2.0	83.4
2,4-Dichlorophenol	176	176	0.559	2.9	47.9
2,4,6-Trichlorophenol	210	195	0.609	3.3	70.3
2-Nitrophenol	153	153	0.609	2.0	29.6
2,4-Dinitrophenol	198	91	0.772	5.0	16.5
4,6-Dinitro-o-cresol	212	265	0.921	4.0	77.5
Pentachlorophenol	280	280	0.962	3.5	80.9
4-Nitrophenol	153	153	0.652	2.1	27.0
2,4-D	234	199	0.877	2.5	94.2
Silvex	280	196	0.987	2.4	93.7

TABLE II (cont'd)

EPA PRIORITY POLLUTANTS
MINIMUM DETECTION LIMITS & PERCENT RECOVERIES
(1 L water/20 ppb)

Base/Neutral Compounds	MWT	QUANT ION	RRT	MDL	% REC
1,4-Dichlorobenzene	146	146	0.288	0.4	71.6
1,3-Dichlorobenzene	146	146	0.284	0.4	45.3
bis(2-Chloroisopropyl)ether	170	45	0.326	1.0	25.1
1,2-Dichlorobenzene	146	146	0.309	0.4	58.7
Nitrobenzene	123	77	0.348	0.5	30.3
N-Nitrosodi-n-propylamine	130	70	0.339	0.5	29.5
Hexachloroethane	234	117	0.354	2.0	83.2
Isophorone	138	82	0.389	0.4	98.2
bis(2-Chloroethoxy)methane	172	93	0.424	0.9	18.6
Naphthalene	128	128	0.460	0.4	55.9
1,2,4-Trichlorobenzene	180	182	0.454	1.3	61.7
Hexachlorobutadiene	258	225	0.506	0.5	61.6
Hexachlorocyclopentadiene	270	237	0.619	3.0	46.3
2-Chloronaphthalene	162	162	0.649	0.8	57.4
2,6-Dinitrotoluene	182	165	0.701	2.0	95.5
Dimethyl phthalate	194	163	0.712	1.0	100.0
Acenaphthylene	152	152	0.717	0.5	96.7
Acenaphthene	154	154	0.751	0.4	83.4
2,4-Dinitrotoluene	182	165	0.773	1.5	79.4
Diethyl phthalate	222	149	0.775	5.0	85.6
9H Fluorene	166	166	0.900	0.4	79.5
4-Chlorophenyl phenyl ether	204	204	0.849	1.0	97.5

TABLE II (cont'd)

BASE/NEUTRAL COMPOUNDS	MWT	QUANT ION	RRT	MDL	% REC
N-Nitrosodiphenylamine	198	169	0.868	0.4	67.0
1,2-Diphenyl hydrazine	184	77	0.877	0.6	75.9
4-Bromophenyl phenyl ether	248	248	0.937	0.5	70.7
Hexachlorobenzene	284	284	0.957	1.2	98.0
Phenanthrene	178	178	1.004	0.3	82.1
Anthracene	178	178	1.013	0.3	84.1
Di-n-butyl phthalate	278	149	1.138	0.4	76.3
Fluoranthene	202	202	1.193	0.6	88.5
Benzidene	184	184	1.211	10.0	68.0
Pyrene	202	202	1.250	0.5	88.8
Butylbenzyl phthalate	312	149	1.395	0.8	92.3
Chrysene	228	228	1.472	0.4	57.5
Benzo(a)anthracene	228	228	1.474	0.5	81.6
3,3-Dichlorobenzidene	252	252	1.470	0.7	69.6
Bis(2-ethylhexyl)phthalate	418	149	1.519	0.9	82.3
Di-n-octyl phthalate	386	149	1.637	1.5	95.3
Benzo(a)pyrene	252	252	1.657	0.3	69.7
Benzo(k)fluoranthene	252	252	1.661	0.4	63.1
Benzo(b)fluoranthene	252	252	1.712	0.6	53.4
Dibenzo(a,h)anthracene	278	278	1.967	4.0	50.2
Benzo(g,h,i)perylene	276	276	1.959	1.5	61.7
Indeno(1,2,3-CD)pyrene	276	276	1.966	1.3	71.2

TABLE II (cont'd)

ADDITIONAL COMPOUNDS

BASE/NEUTRAL COMPOUNDS	MWT	CHAR ION	RRT	MDL	% REC
4-Methyl Pyridine	93	93,92,66	.165	1.4	42.3
Benzothophene	134	134,90	.464	0.4	52.0
Benzothiazole	135	135,90	.489	0.4	33.7
Isoquinoline	129	129,102	.525	1.7	9.7
Napthalene,1-Methyl	142	142,141	.588	0.8	27.4
Napthalene,1,2-Dimethyl	156	156,141	.695	2.0	64.1
Dibenzofuran	168	168,139	.782	0.8	43.7
Napthalene-1,6,7-Trimethyl	170	170,155	.831	0.8	83.4
Diethyl Phthalate	222	149,177	.841	5.0	83.5
2-Methyl Anthracene	192	192,189	1.107	1.2	55.0
Benzo(b)fluoranthene	252	252,136	1.761	0.6	56.8
Benzo(a)pyrene	252	252,136	1.822	0.4	60.6

TABLE III

ISOTOPICALLY LABELLED INTERNAL STANDARDS

Compound	Natural Quant Ion	Deuterated Quant Ion
Acid Extractable		
4-Chloro-3-methylphenol,2.6-d_2	142	144
2-Chlorophenol-3,4,5,6-d_4	128	132
2,4-Dichlorophenol-3,5,6-d_3	162	164
2,4-Dimethylphenol-3,5,6-d_3	122	125
4,6-Dinitro-2-methylphenol-3,5-d_2	198	200
2,4-Dinitrophenol-3,5,6-d_3	184	187
2-Nitrophenol-3,4,5,6-d_4	139	143
4-Nitrophenol-2,3,5,6-d_4	139	143
Pentachlorophenol-$^{13}C_6$	266	272
Phenol-2,3,4,5,6-d_5	94	99
2,4,6-Trichlorophenol-3,5-d_2	196	198
Base/Neutrals		
Benz(a)anthracene-d_{12}	228	240
Benzyl n-Butyl Phthalate-3,4,5,6-d_4	149	153
Bis(2-chloroethoxy)-d_8-methane	93	101
Bis(2-ethylhexyl)Phthalate-3,4,5,6-d_4	149	153
Dibenzo(a,h)anthracene-d_{14}	278	292
1,2-Dichlorobenzene-d_4	146	153
1,4-Dichlorobenzene-d_4	146	153
Dimethyl Phthalate-3,4,5,6-d_4	163	167
2,6-Dinitrotoluene-a,a,a-d_3	165	168
Nitrobenzene-d_5	123	128
1,2,3-Trichlorobenzene-4,5,6-d_3	180	183
Acenaphthene-d_{10}	154	164
Anthracene-d_{10}	178	188
Benzo(k)fluoranthene-d_{12}	252	264
Bis(2-chloroethyl)-d_8 Ether	93	101
Chrysene-d_{12}	228	240
Fluorene-d_{10}	166	176
Naphthalene-d_8	128	136
Pyrene-d_{10}	202	212

EPA PRIORITY POLLUTANTS
EXTRACTABLE FRACTION - ANALYTICAL METHODOLOGY

EXTRACTION PROCEDURE

1) A 1 litre volume of sample water was spiked at the 10 ppb leve with a mixture of deuterated standards (the sample was shaken an allowed to equilibrate for 1 hr at room temperature.

2) The pH was adjusted to a pH=11 using 6N NaOH and the sampl extracted with three 50 ml volumes of CH_2Cl_2.

3) The aqueous portion was then acidified to pH=2 using 6N HCl an extracted with 3 x 50 ml volumes of CH_2Cl_2 to extract the acidi and phenolic compounds.

4) Similar organic extracts were combined and dried through a colum of solvent washed Na_2SO_4 (acidified Na_2SO_4 for acid fraction).

5) The dried extracts were collected in 1 litre Kuderna-Danis evaporators containing 2 mls of isooctane then concentrated to volume of approximately 10 ml.

6) The extracts were transferred to 15 ml graduated centrifuge tube (a 2 x 1 ml isooctane rinse) then concentrated to a 10 ml volum using a gentle stream of N_2 and spiked with 10 ppb D_{10} Phenanthrene.

Gas Chromatographic/Mass Spectrometry Instrumentation

One ul aliquots of the 10 ml extracts were analysed for the presenc of the selected priority pollutants using a Finnigan 4500 GC/MS syste set to the following condition:

All injections were performed using an on column technique.

MASS SPECTROMETER

Electron Multiplier	-	1450 e.v.
Ionization Energy	-	70 e.v.
Sensitivity	-	10^8 amps/volt
Scan Rate	-	2.25 mSec/mass unit
Scan Range	-	1-2000
Mass Range	-	60-450 a.m.u.

Varian Gas Chromatograph Conditions

Instrument	-	Varian 3500
GC Column	-	DB-5 30 M capillary
GC Temp Program		
Initial	-	50°C (0.1 min)
Final	-	285OC (20 min)
Rate	-	10°C/min
Injection Port Temp	-	250°C
Column Carrier Gas	-	Helium

EXTRACTABLE (EPA) ANALYSIS - WATER SAMPLES

Standard Compound Characterization

A Standard solution containing approximately 1.0 ng/ul of each of the selected priority pollutants was prepared and analysed by GC/MS to determine each compound's fragmentation pattern, relative retention time (RRT) and relative response factor (RRF) compared to the internal standard D_{10} Phenanthrene. A 10 ppb dilution of this standard was routinely run prior to sample analysis to insure optimum performance of the GC/MS system. The minimum detection limit (MDL) represents the minimum level at which a compound can be detected and quantitated. Values were determined by comparison of the response of the labelled internal standards to the level of background interference in the region of the corresponding natural compound. These values are averages obtained from actual sample matrices.

Target Compound % Recovery

The % recovery of individual target compounds was determined by spiking 1 litre of purified distilled water at the 20 ppb level with a standard mixture containing all of the compounds of interest.

Recovery values and the method detection limit (MDL) are listed in Table II.

Sample Extractions

To monitor the extraction efficiency of individual sample extractions. Each sample was spiked at the 10 ppb level with a mixture of 11 deuterated acid extractables and 19 deuterated B/N compounds.

To monitor the injection efficiency all extracts were spiked with 10 ppb of D-10 Phenanthrene immediately prior to GC/MS analysis.

QA/QC Protocol

a) The use of a stock mixture of deuterated internal standards (Table III) to monitor extraction efficiency assures a high confidence level in the results of all sample extractions.

b) Travelling blanks were analysed at 10 sample intervals to insure that outside contamination was not interfering with the observed results.

c) Prior to sample analysis, reference standards at the 10 ppb level were analysed to demonstrate that the instrument was capable of the required sensitivity. Solvent blanks were run between standards and samples to monitor any possible cross contamination. Reference standards at various levels were analysed after every tenth sample.

Target Compound Identification and Quantitation

The GC/MS data files were searched for the selected pollutants using a computer program that searched successive regions of the chromatogram plotting out ion intensities of the two most abundant ions of both the target compound and labelled standards eluting in that region. The identity of detected compounds was verified by manual confirmation (mass spectra matching).

Quantitation of target compounds was achieved by comparing the peak heights of the natural compound to that of its analogous labelled standard which had been spiked into the sample at a known level. For those target compounds whose corresponding labelled standard was not available, the labelled standard that eluted closest to it was used for quantitation.

Additional Compound Identification

Additional compounds (non-targetted) present in the sample were tentatively identified by means of a computer generated mass spectra library search program. The mass spectra of the natural compound is compared to entries in the National Bureau of Standards (NBS) library containing approximately 35,000 compounds. The compounds reported as additional compounds were present in concentrations greater than 1 ppb (based on a 1:1 response to the internal standard, D_{10}-Phenanthrene) and had purity match values of greater than 800 (1000 = exact match).

TABLE II

EPA PRIORITY POLLUTANTS

MINIMUM DETECTION LIMITS & PERCENT RECOVERIES

(1 L water/20 ppb)

ACIDIC COMPOUNDS	MWT	QUANT ION	RRT	MDL	% REC
Phenol	94	94	0.270	1.6	25.0
2-Chlorophenol	142	142	0.390	3.0	40.6
2,4-Dimethyl phenol	136	107	0.431	2.5	24.5
p-Chloro-m-cresol	156	156	0.485	2.0	83.4
2,4-Dichlorophenol	176	176	0.559	2.9	47.9
2,4,6-Trichlorophenol	210	195	0.609	3.3	70.3
2-Nitrophenol	153	153	0.609	2.0	29.6
2,4-Dinitrophenol	198	91	0.772	5.0	16.5
4,6-Dinitro-o-cresol	212	265	0.921	4.0	77.5
Pentachlorophenol	280	280	0.962	3.5	80.9
4-Nitrophenol	153	153	0.652	2.1	27.0
2,4-D	234	199	0.877	2.5	94.2
Silvex	280	196	0.987	2.4	93.7

TABLE II (cont'd)

EPA PRIORITY POLLUTANTS
MINIMUM DETECTION LIMITS & PERCENT RECOVERIES
(1 L water/20 ppb)

Base/Neutral Compounds	MWT	QUANT ION	RRT	MDL	% REC
1,4-Dichlorobenzene	146	146	0.288	0.4	71.6
1,3-Dichlorobenzene	146	146	0.284	0.4	45.3
bis(2-Chloroisopropyl)ether	170	45	0.326	1.0	25.1
1,2-Dichlorobenzene	146	146	0.309	0.4	58.7
Nitrobenzene	123	77	0.348	0.5	30.3
N-Nitrosodi-n-propylamine	130	70	0.339	0.5	29.5
Hexachloroethane	234	117	0.354	2.0	83.2
Isophorone	138	82	0.389	0.4	98.2
bis(2-Chloroethoxy)methane	172	93	0.424	0.9	18.6
Naphthalene	128	128	0.460	0.4	55.9
1,2,4-Trichlorobenzene	180	182	0.454	1.3	61.7
Hexachlorobutadiene	258	225	0.506	0.5	61.6
Hexachlorocyclopentadiene	270	237	0.619	3.0	46.3
2-Chloronaphthalene	162	162	0.649	0.8	57.4
2,6-Dinitrotoluene	182	165	0.701	2.0	95.5
Dimethyl phthalate	194	163	0.712	1.0	100.0
Acenaphthylene	152	152	0.717	0.5	96.7
Acenaphthene	154	154	0.751	0.4	83.4
2,4-Dinitrotoluene	182	165	0.773	1.5	79.4
Diethyl phthalate	222	149	0.775	5.0	85.6
9H Fluorene	166	166	0.900	0.4	79.5
4-Chlorophenyl phenyl ether	204	204	0.849	1.0	97.5

TABLE II (cont'd)

BASE/NEUTRAL COMPOUNDS	MWT	QUANT ION	RRT	MDL	% REC
N-Nitrosodiphenylamine	198	169	0.868	0.4	67.0
1,2-Diphenyl hydrazine	184	77	0.877	0.6	75.9
4-Bromophenyl phenyl ether	248	248	0.937	0.5	70.7
Hexachlorobenzene	284	284	0.957	1.2	98.0
Phenanthrene	178	178	1.004	0.3	82.1
Anthracene	178	178	1.013	0.3	84.1
Di-n-butyl phthalate	278	149	1.138	0.4	76.3
Fluoranthene	202	202	1.193	0.6	88.5
Benzidene	184	184	1.211	10.0	68.0
Pyrene	202	202	1.250	0.5	88.8
Butylbenzyl phthalate	312	149	1.395	0.8	92.3
Chrysene	228	228	1.472	0.4	57.5
Benzo(a)anthracene	228	228	1.474	0.5	81.6
3,3-Dichlorobenzidene	252	252	1.470	0.7	69.6
Bis(2-ethylhexyl)phthalate	418	149	1.519	0.9	82.3
Di-n-octyl phthalate	386	149	1.637	1.5	95.3
Benzo(a)pyrene	252	252	1.657	0.3	69.7
Benzo(k)fluoranthene	252	252	1.661	0.4	63.1
Benzo(b)fluoranthene	252	252	1.712	0.6	53.4
Dibenzo(a,h)anthracene	278	278	1.967	4.0	50.2
Benzo(g,h,i)perylene	276	276	1.959	1.5	61.7
Indeno(1,2,3-CD)pyrene	276	276	1.966	1.3	71.2

VOLATILE ANALYSIS - WATER SAMPLES

Sampling Preparation - Collection and Handling

Water samples for purgeable organics were collected in 50 ml capacity amber glass bottles equipped with Tuf-Bond discs and screw caps with a syringe access hole in the centre. The bottles had been previously cleaned and heated at 200°C for at least 4 hours, purged with nitrogen and sealed with PTFE coated silicone and open top caps prior to transportation to the sampling sites.

The bottles were filled to slight overflow, then sealed so that no air bubble was present in the sample. They were immediately returned to Mann Testing Labs and stored at 4°C until analysed.

Preparation of Standard Solutions

Stock standard solutions were prepared by injecting appropriate amounts of each pollutant into 25 ml of glass distilled methanol (Burdick and Jackson) in reactiflasks fitted with Minnert valves (Chromatographic Specialties Ltd.) which provide complete protection and easy access via a hypodermic needle. The resulting concentration of 1 mg/ml was further diluted to give methanolic solutions of 400 ug/ml, 40 ug/ml and 4 ug/ml for each component. Gaseous standards were prepared in a similar manner by injecting the gaseous compound from a 10 ml gas tight syringe into a pre-weighed reactiflask filled with 25 ml of methanol. The syringe needle was slightly above the ethanol meniscus while injecting, hence enabling the gas to dissolve rapidly into the methanol. The flask was re-weighed again to determine the amount

in the solution.

Aqueous composite standards were prepared by injecting appropriate aliquots of methanolic standard in 250 ml sample bottles filled with purified water.

The relative retention times (RRT) were compared to that of the internal standard, deuterated chlorobenzene (RRT = 1.00) which eluted close to the middle of the chromatogram. Detection limits were determined by purging aqueous composite standard mixture at various concentrations.

Instrumentation

Analysis of volatile organics in water was conducted using a UNACON 780B automatic concentrator (Envirochem Inc., Kemblesville, P.A.). This instrument utilized the technique developed by Bellar and Lichtenberg for the isolation and concentration of volatiles for chromatographic analysis. In general, this process involved gas stripping of the sample and adsorption of the organic compounds on a sorbent trap followed by thermal desorption and analysis by gas chromatography or gas chromatography/mass spectrometry.

The sample purging assembly included a sparger vial with a side port which was equipped with an open top screw cap and Tuf-Bond septum. A 30 ml vial was used to obtain detection limits as reported. Sample was transferred to the vial through a transfer line by pressurizing the sample bottle which was inverted and clamped on the side of the instrument. The transfer line was constructed of 1/16" teflon tubing with two Luer Lock

connectors at each end. Two 17-gauge needles were used to puncture the septa of both the bottle and the side port.

Prior to the start of the analysis, the sparger vial was purged with helium for 5 minutes by rotating the valve to "Trap-Out" mode. In this position, any contaminants that were present in the sparger vial were purged out of the system without entering the trap. An appropriate aliquot of the water was then transferred to the sparger and purged for 15 minutes at the "Trap-In" mode. The trap was heat desorbed and the organics backflushed into the second trap. When this transfer process was completed, the second trap was again heated, releasing all adsorbed organics into the capillary GC/MS system for identification and quantification.

The MDL (Method Detection Limit) listed in the volatile section is the limit that the compound can be identified and quantified in the sample matrix using the purge & trap GC/MS method.

QA/QC

Prior to sample analysis reference standards were analyzed to determine the instrument response for standards of known levels. Instrument blanks were then analyzed to determine the extent of any instrument contamination. Travelling blanks for each set of samples were analyzed to measure any possible background contamination caused by the sample container. At ten sample intervals duplicate samples were analyzed to monitor the analytical reproducibility.

TABLE I

RETENTION DATA, % RECOVERY & CHARACTERISTIC IONS OF THE VOLATILE ORGANICS

Compound	RRT	% RECOVERY	PRIMARY ION (m/e)	SECONDARY IONS (m/e)
Dichlorodifluoromethane	0.477	99.8	85	87
Chloromethane	0.486	100.3	50	52
Vinyl Chloride	0.495	106.2	62	64
Bromomethane	0.511	105.0	94	96
Chloroethane	0.516	91.9	64	96
Trichlorofluoromethane	0.545	101.6	101	103
1,1-Dichloroethylene	0.568	98.6	61	63,96
Dichloromethane	0.571	92.7	49	84
t-1,2-Dichloroethylene	0.608	92.3	61	63,96
1,1-Dichloroethane	0.614	97.2	63	65,83
Chloroform	0.661	90.5	83	85,87
1,2-Dichloroethane	0.690	80.3	62	64,98
1,1,1-Trichloroethane	0.707	102.5	97	61,99
Benzene	0.729	97.5	78	51,77
Carbon Tetrachloride	0.737	97.6	117	119,121
1,2-Dichloropropane	0.769	91.2	63	62,76
Bromodichloromethane	0.779	94.2	83	82,129
Trichloroethylene	0.782	101.2	95	130
1,3-Dichloropropene(Z)	0.827	90.8	75	110
1,3-Dichloropropene(E)	0.857	78.9	75	110
1,1,2-Trichloroethane	0.866	71.1	83	97
Toluene	0.888	91.4	91	92
Dibromochloromethane	0.914	79.7	129	127
Tetrachloroethylene	0.960	126.2	129	166,131
Chlorobenzene	1.003	92.7	112	77,114
Ethyl Benzene	1.026	93.9	91	106
m,p-Xylenes	1.038	95.4	91	105,106
Bromoform	1.042	52.5	173	171,175
o-Xylene	1.067	88.3	91	105,106
1,1,2,2-Tetrachloroethane	1.066	45.0	83	85
1,3-Dichlorobenzene	1.199	86.4	146	148,111
1,4-Dichlorobenzene	1.204	86.7	146	148,111
1,2-Dichlorobenzene	1.231	85.4	146	148,111
Acrolein	0.528	22.1	56	55
Acrylonitrile	0.551	7.9	53	52
Pentane	0.512	82.7	43	42,57
Dimethyl Sulphide	0.518	80.2	47	62,45
Methylethylketone	0.591	8.8	43	72
Hexane	0.622	84.3	57	41,43
Heptane	0.787	97.8	43	57,71
4-Methyl-2-pentanone	0.823	26.6	43	58,85

TABLE I(cont'd)

REPRODUCIBILITY OF SELECTED VOLATILE ORGANICS USING PURGE & TRAP SYSTEM

Compound	Ion (m/e)	Peak Intensity Run#1	Run#2	Run#3	SDV	% C.V.
Dichlorodifluoromethane	85	41408	46016	47488	3171.9	7.1
Chloromethane	50	19840	18560	19072	644.3	3.4
Vinyl Chloride	62	81664	83072	89728	4307.2	5.1
Bromomethane	94	49536	52608	66048	8781.8	15.7
Chloroethane	64	39872	35648	47616	6069.7	14.8
Trichlorofluoromethane	101	100992	93568	123008	15310.9	14.5
1,1-Dichloroethylene	61	22848	21600	20832	1017.5	4.7
Dichloromethane	84	24096	20512	20896	1967.8	9.0
t-1,2-Dichloroethylene	61	32032	28064	27776	2378.4	8.1
1,1-Dichloroethane	63	54272	48064	50496	3128.2	6.1
Chloroform	83	55168	52160	46528	4385.9	8.6
1,2-Dichloroethane	62	31904	31296	35840	2467.8	7.5
1,1,1-Trichloroethane	97	48256	50432	51008	1451.5	2.9
Benzene	78	99200	93184	105984	6403.8	6.4
Carbon Tetrachloride	117	37824	37248	40896	1961.2	5.1
1,2-Dichloropropane	63	21984	20768	24064	1666.8	7.5
Bromodichloromethane	83	48640	51136	51136	1441.1	2.9
Trichloroethylene	130	46208	43072	46208	1810.6	4.0
1,3-Dichloropropene(Z)	75	38272	38848	40320	1056.2	2.7
1,3-Dichloropropene(E)	75	28704	25696	30400	2382.3	8.4
1,1,2-Trichloroethane	97	36672	32416	38848	3271.6	9.1
Toluene	91	145408	140544	145664	2885.0	2.0
Dibromochloromethane	129	47808	43200	52096	4449.0	9.3
Tetrachloroethylene	129	66176	64448	66816	1224.9	1.9
Chlorobenzene	112	104960	101248	96640	4168.0	4.1
Ethyl Benzene	91	139008	124032	135168	7778.6	5.9
m,p-Xylenes	91	111104	99584	117120	8910.8	8.2
Bromoform	173	34240	30336	30528	2200.6	6.9
o-Xylene	91	121856	113152	124032	5757.2	4.8
1,1,2,2-Tetrachloroethane	83	37312	33984	31072	3122.3	9.2
1,3-Dichlorobenzene	146	99584	88192	101504	7195.8	7.5
1,4-Dichlorobenzene	146	114304	101248	118400	8957.6	8.0
1,2-Dichlorobenzene	146	94976	86144	94464	4958.0	5.4
Acrolein	56	3452	2636	2872	419.9	14.1
Acrylonitrile	53	6024	4592	4984	740.0	14.2
Pentane	43	82048	71808	71296	6065.3	8.1
Dimethyl Sulphide	62	64384	56896	60544	3744.4	6.2
Methylethylketone	43	17024	23136	20757	3080.9	15.2
Hexane	57	66944	73472	84608	8931.6	11.9
Heptane	43	117248	123648	125824	4458.0	3.6
4-Methyl-2-pentanone	43	53440	64448	51904	6842.1	12.1

TABLE I (cont'd)

GC/MS
% RECOVERY REPRODUCIBILITY
5 ppb level

	% Recovery Run #1	% Recovery Run #2	% Recovery Run #3	Ave. % Recovery	SDV
Dichlorodifluoromethane	93.6	101.6	104.1	99.8	5.5
Chloromethane	88.7	99.1	113.2	100.3	12.3
Vinyl Chloride	92.1	112.1	114.4	106.2	12.3
Bromomethane	95.4	108.6	111.0	105.0	8.4
Chloroethane	93.8	91.9	90.0	91.9	1.9
Trichlorofluoromethane	105.6	95.8	103.3	101.6	5.1
1,1-Dichloroethylene	97.1	99.1	99.7	98.6	1.4
Dichloromethane	96.2	93.1	88.7	92.7	3.8
t-1,2-Dichloroethylene	88.1	91.8	96.9	92.3	4.4
1,1-Dichloroethane	93.2	103.1	95.4	97.2	5.2
Chloroform	97.4	92.1	82.1	90.5	7.8
1,2-Dichloroethane	75.0	73.5	92.5	80.3	10.6
1,1,1-Trichloroethane	100.8	101.5	105.3	102.5	2.4
Benzene	96.3	101.2	95.0	97.5	3.3
Carbon Tetrachloride	95.5	94.0	103.2	97.6	4.9
1,2-Dichloropropane	90.0	85.1	98.6	91.2	6.8
Bromodichloromethane	99.0	92.0	91.6	94.2	4.2
Trichloroethylene	103.9	97.5	102.1	101.2	3.3
1,3-Dichloropropene(Z)	87.3	88.6	96.4	90.8	4.9
1,3-Dichloropropene(E)	81.4	72.9	82.5	78.9	5.3
1,1,2-Trichloroethane	73.7	65.1	74.6	71.1	5.2
Toluene	93.7	90.6	89.9	91.4	2.0
Dibromochloromethane	81.2	73.3	84.7	79.7	5.8
Tetrachloroethylene	127.3	125.2	126.1	126.2	1.1
Chlorobenzene	96.4	92.9	88.7	92.7	3.9
Ethyl Benzene	95.8	92.5	93.5	93.9	1.7
m,p-Xylenes	98.1	91.5	96.6	95.4	3.5
Bromoform	56.7	50.2	50.5	52.5	3.7
o-Xylene	90.5	89.7	84.7	88.3	3.1
1,1,2,2-Tetrachloroethane	46.6	42.5	46.0	45.0	2.2
1,3-Dichlorobenzene	86.4	88.4	84.3	86.4	2.1
1,4-Dichlorobenzene	86.5	88.4	85.3	86.7	1.6
1,2-Dichlorobenzene	88.8	82.6	84.7	85.4	3.2
Acrolein	24.6	19.9	21.7	22.1	2.4
Acrylonitrile	9.2	7.0	7.6	7.9	1.1
Pentane	86.1	78.8	83.2	82.7	3.7
Dimethyl Sulphide	79.3	78.9	82.4	80.2	1.9
Methylethylketone	8.5	10.9	6.9	8.8	2.0
Hexane	85.9	81.8	85.2	84.3	2.2
Heptane	99.6	95.9	97.8	97.8	1.9
4-Methyl-2-pentanone	25.4	27.8	26.6	26.6	1.2

TABLE I (cont'd)

RETENTION TIME REPRODUCIBILITY

	Run #1 RRT	Run #2 RRT	Run #3 RRT	Ave. RRT	+ Limits For RRT
Dichlorodifluoromethane	0.488	0.473	0.471	0.477	0.012
Chloromethane	0.496	0.482	0.480	0.486	0.012
Vinyl Chloride	0.506	0.491	0.487	0.495	0.012
Bromomethane	0.520	0.507	0.505	0.511	0.010
Chloroethane	0.524	0.513	0.511	0.516	0.010
Trichlorofluoromethane	0.549	0.544	0.542	0.545	0.005
1,1-Dichloroethylene	0.571	0.568	0.565	0.568	0.005
Dichloromethane	0.575	0.570	0.569	0.571	0.005
t-1,2-Dichloroethylene	0.609	0.608	0.607	0.608	0.002
1,1-Dichloroethane	0.614	0.614	0.613	0.614	0.002
Chloroform	0.660	0.662	0.660	0.661	0.002
1,2-Dichloroethane	0.694	0.682	0.693	0.690	0.009
1,1,1-Trichloroethane	0.708	0.710	0.704	0.707	0.004
Benzene	0.731	0.733	0.723	0.729	0.008
Carbon Tetrachloride	0.739	0.741	0.731	0.737	0.005
1,2-Dichloropropane	0.773	0.774	0.760	0.769	0.010
Bromodichloromethane	0.783	0.784	0.770	0.779	0.010
Trichloroethylene	0.786	0.787	0.772	0.782	0.010
1,3-Dichloropropene(Z)	0.832	0.833	0.817	0.827	0.010
1,3-Dichloropropene(E)	0.862	0.863	0.846	0.857	0.012
1,1,2-Trichloroethane	0.873	0.873	0.851	0.866	0.012
Toluene	0.892	0.892	0.881	0.888	0.005
Dibromochloromethane	0.915	0.916	0.910	0.914	0.005
Tetrachloroethylene	0.960	0.960	0.959	0.960	0.002
Chlorobenzene	1.003	1.003	1.002	1.003	0.002
Ethyl Benzene	1.027	1.026	1.026	1.026	0.002
m,p-Xylenes	1.038	1.038	1.037	1.038	0.002
Bromoform	1.042	1.042	1.041	1.042	0.002
o-Xylene	1.066	1.068	1.068	1.067	0.002
1,1,2,2-Tetrachloroethane	1.066	1.066	1.066	1.066	0.001
1,3-Dichlorobenzene	1.201	1.200	1.197	1.199	0.003
1,4-Dichlorobenzene	1.206	1.205	1.202	1.204	0.003
1,2-Dichlorobenzene	1.232	1.232	1.229	1.231	0.003
Acrolein	0.534	0.525	0.524	0.528	0.007
Acrylonitrile	0.555	0.550	0.548	0.551	0.005
Pentane	0.507	0.519	0.511	0.512	0.008
Dimethyl Sulphide	0.512	0.526	0.517	0.518	0.009
Methylethylketone	0.585	0.597	0.592	0.591	0.007
Hexane	0.617	0.626	0.623	0.622	0.006
Heptane	0.784	0.790	0.787	0.787	0.004
4-Methyl-2-pentanone	0.821	0.826	0.823	0.823	0.004

B3.2.3 ANALYTICAL METHODS AND QA/QC PROCEDURES

ISOTOPE LABORATORY, UNIVERSITY OF WATERLOO

TABLE B3-3 - SUMMARY OF ISOTOPE ANALYTICAL METHODOLOGIES

Parameter	Reference	Comments
deuterium	Thurston, W.M. (1971)	• modernization of equipment • see Fritz, P. et al (1986) for additional comments • precision is ± 1°/oo • all results as δ °/ oo relative to SMOW
oxygen-18	Moser, H. (editor) (1977)	• modernization of equipment • see Fritz, P. et al (1986) for additional comments • precision is ± 0.15°/oo • all results as δ °/oo relative to SMOW
normal tritium	Desaulniers, D.E. et al (1981)	• all samples were distilled prior to mixing with Insta-Gel • detection limit is 6±8 T.U.
enriched tritium	Taylor, C.B. (1976)	• 300 mL concentrated to 15 mL • detection limit is 0.8 ± 0.8 T.U.
carbon-13	Berry, J.C. and Drimmie, R.J. (1982)	• precision is ± 0.05°/oo • all results as δ °/oo relative to PDB

NOTES:

1. NBS standards are analyzed with every run.
2. Standards and background are analyzed with every run for tritium
3. Duplicates are analyzed every 6 to 10 samples.

REFERENCES FOR TABLE B3-3

Berry, J.C. and R.J. Drimmie. 1982. University of Waterloo, Radiocarbon Dates 1. Radiocarbon, vol. 24, pp. 68 to 82.

Desaulniers, D.E., J.A. Cherry and P. Frtiz. 1981. Origin, Age and Movement of Pore Water in Argillaceous Quaternary Deposits at Four Sites in Southwestern Ontario. Journal of Hydrogeology, vol. 50, pp. 231-257.

Fritz, P., S.K. Frape, R.J. Drimmie and A.R. Heemskerk. 1986. Reply to comments by Grabszak et al on "Water-Rock Interaction and Chemistry of Ground Waters from the Canadian Shield." Geochimica et Cosmochimica Acta, vol. 50, pp. 1561 to 1563.

Moser, H. (editor). 1977. Jahresdericht. An internal report of the Instit fur Radiohydrometric G.S.F., Munich, vol. 169, pp. 70-71.

Taylor, C.B. 1976. Procedure and Technique Critique for Tritium Enrichment by Electrolysis at the IAEA Laboratory. IAEA Technical Procedures Note #19.

Thurston, W.M. 1971. Stream Film Sampling of Water for Mass-Spec Analysis of Deuterium Content. Rev. Sci. Instr. vol. 42, pp. 700-703.

B3.2.4 ANALYTICAL METHODS AND QA/QC PROCEDURES

TRITIUM LABORATORY, UNIVERSITY OF MIAMI

SAMPLING OF ENVIRONMENTAL WATER FOR LOW LEVEL TRITIUM ANALYSIS

A. Explanation

Tritium in environmental samples will be determined with a limit of detection, of 0.1 T-units (TU) (0.0003 pli/ml). Water vapor of the open air varies from 2 to 100 TU. Indoors, the atmospheric humidity may reach 10,000 TU from various luminescent dials. Exposure of the water to such air at any temperature might give badly erroneous tritium results.

B. Sample bottles

For lowest level of tritium samples we recommend using 1 lit. (1 qt.) glass bottles with "PolySeal", conical inset, caps. The bottles should be clean and dry, preferably factory fresh. If transfer is to be made indoors, the dry bottles should first be filled with argon gas. See below.

If the very lowest detection level is not needed, heavy wall plastic bottles may be acceptable. Must have good caps. Hold a filled bottle upside-down and squeeze hard. No leakage is allowed. Remember that there are large pressure changes in air transport.

C. Sampling procedures

1. Sample transfer should be done outdoors, unless a specially vented room is available with ban on wristwatches.
2. THE PERSON PERFORMING THE SAMPLE TRANSFER IS NOT ALLOWED TO WEAR A WRISTWATCH, COMPASS OR SIMILAR WITH LUMINESCENT DIALS OR SO CALLED "BETA" LIGHTS.
3. Fill the bottle close to the neck with sample. Do not rinse. Overflow is not desirable.
4. Replace and screw cap on tightly.
5. Record bottle numbers on original field data sheets, and fill in information on bottle label.
6. If sampling indoors, never let the water be exposed to the air. Pipe the sample water into the middle of an argon-filled bottle (below the argon level). Do not pour the argon out before, by tilting an open bottle.

LOW LEVEL TRITIUM ANALYSIS

All numbers of quantities, etc., are typical only and may vary from sample to sample.

A. Distillation

300 ml of the water sample are distilled with twin reflux dropcatchers to dryness or near dryness. During the procedure, the still is vented to the ambient air through a drying agent to avoid contamination of the sample by atmospheric water vapor.

B. Electrolytic Enrichment

The object of this procedure is to reduce the volume of the sample from 275 to 3.5 ml while preserving a large fraction of the tritium.

The normal starting volume is 275 ml of which 75 ml are charged into the electrolytic enrichment cell. To that portion, 1.6 ml of concentrated sodium hydroxide solution (made from dead water and sodium peroxide or oxide) is added, and the remainder of the sample is transferred to a container on top of the cell. The sample is electrolyzed for 24 hours at 6 amps, current-regulated which removes 50 ml of water. The solution in the cell is topped up from the container to the 75 ml mark, and the procedure is continued. When a total of between 20 and 50 ml of the sample remains, electrolysis is changed to constant voltage of 3.35 V until the process stops at the lower edge of the anode, leaving 3.5 g of enriched sample. This amount of water typically contains 80% of the original amount of tritium. The enriched water sample is vacuum distilled from the sodium hydroxide, and the yield is weighed to ± 5 mg, and adjusted for hydrogen left in the sodium hydroxide.

C. Preparation of Sampling Gas

The enriched water sample is injected into a vacuum system. The water evaporates, and the vapor is reduced by hot magnesium metal to

hydrogen gas which is absorbed on activated charcoal at liquid nitrogen temperature in a stainless steel pressure cylinder. Approximately 3 lit atm of hydrogen is obtained this way.

D. Low-Level Counting

The low-level gas proportional counters have an active volume of 1 lit and are shielded by 2.5 cm of selected lead, a ring of anti-coincidence geiger counters, 10 cm of paraffin wax, boric acid and/or borated polyethylene, and at least 20 cm of iron, plus the walls and ceiling of the building. The counter is first filled with 10 psi of propane. Thereafter, the sample hydrogen gas, under pressure in its cylinder, is added to the counter for a total pressure of 40 psi. The counter is then sealed off, and the gas amplificaton is set to specifications by adjusting working voltage using an external radioactive source. After that, counting proceeds until criteria for accuracy or sensitivity have been met. The pulses are sorted into several channels, of which some are used for continuous control of gas amplification, as shown in the cosmic radiation spectrum, etc. Counting times are 6 to 20 hours. A 1 TU original sample enriched 275/3.5 ml typically shows 1 cpm in the tritium channel above a background of 0.40 cpm, known to ±0.03 cpm or better. The control of filling and counting procedures and calculation of results, as well as numerous checks on the performance of the machinery, are computerized.

E. Backgrounds and Standards

At least once weekly each counter counts dead hydrogen gas (from petroleum). In addition, water from the deep Floridan Aquifer (more than 10,000 years old water) is reduced to occasionally check on the tank hydrogen gas. This procedure sets the background count of the counting equipment. Each batch of sodium hydroxide solution is also tested for blank value. A further check on process blanks is that at least once a week a sample of dead water (from the Floridan Aquifer) goes through all the same procedures, including enrichment, as the unknown samples. In order to check on the efficiency of the enrichment procedure, at least once a week a sample of known activity, prepared from the National Bureau of Standards

(NBS) Standard Reference Material (SRM), is processed through the entire system of enrichment, reduction, and counting.

The efficiency of each counter is determined by counting standard activity hydrogen gas by reduction of standard water in our regular preparation system. This standard water is prepared from NBS SRM #4926 by dilution through weighing. The dependence of background, efficiency, etc., on pressure, gas composition, gas amplification, etc., is known, and the appropriate corrections are applied via the software of the computing system.

F. Update

Periodically, usually about every six weeks, all measurements in all counters for the preceding time period are recomputed, applying statistical tests, and scrutinized for flaws in quality. This includes all measurements of unknowns, backgrounds, blanks, enrichment factors, efficiencies, etc. Only after this step is the result considered final. The results are then reported in Data Releases, one for each project.

G. Further Technical Information

The procedures of tritium analysis are described in the following publications from this Laboratory, reprints furnished on request:

Ostlund, H.G., and H.G. Dorsey, 1977. Rapid electrolytic enrichment and hydrogen gas proportional counting of tritium, in Low-Radioactivity Measurements and Applications, Proceedings of the International Conference on Low-Radioactivity Measurements and Applications, 6-10 October 1975, The High Tatras, Czechoslovakia, Slovenske Pedagogicke Nakladatel'stvo, Bratislava.

Ostlund, H.G., H.G. Dorsey, and C.G. Rooth, 1974. GEOSECS North Atlantic radiocarbon and tritium results, Earth Planet. Sci. Lett., 23, 69-86.

Ostlund, H.G., M.O. Rinkel, and C. Rooth, 1969. Tritium in the equatorial Atlantic current system, J. Geophys. Res., 74(18), 4535-4543.

Ostlund, H.G., and E. Werner, 1962. The electrolytic enrichment of tritium and deuterium for natural tritium measurements, in Tritium in the Physical and Biological Sciences, International Atomic Energy Agency, 1962. (Describes an earlier version of the procedure).

B3.2.5 ANALYTICAL METHODS AND QA/QC PROCEDURES

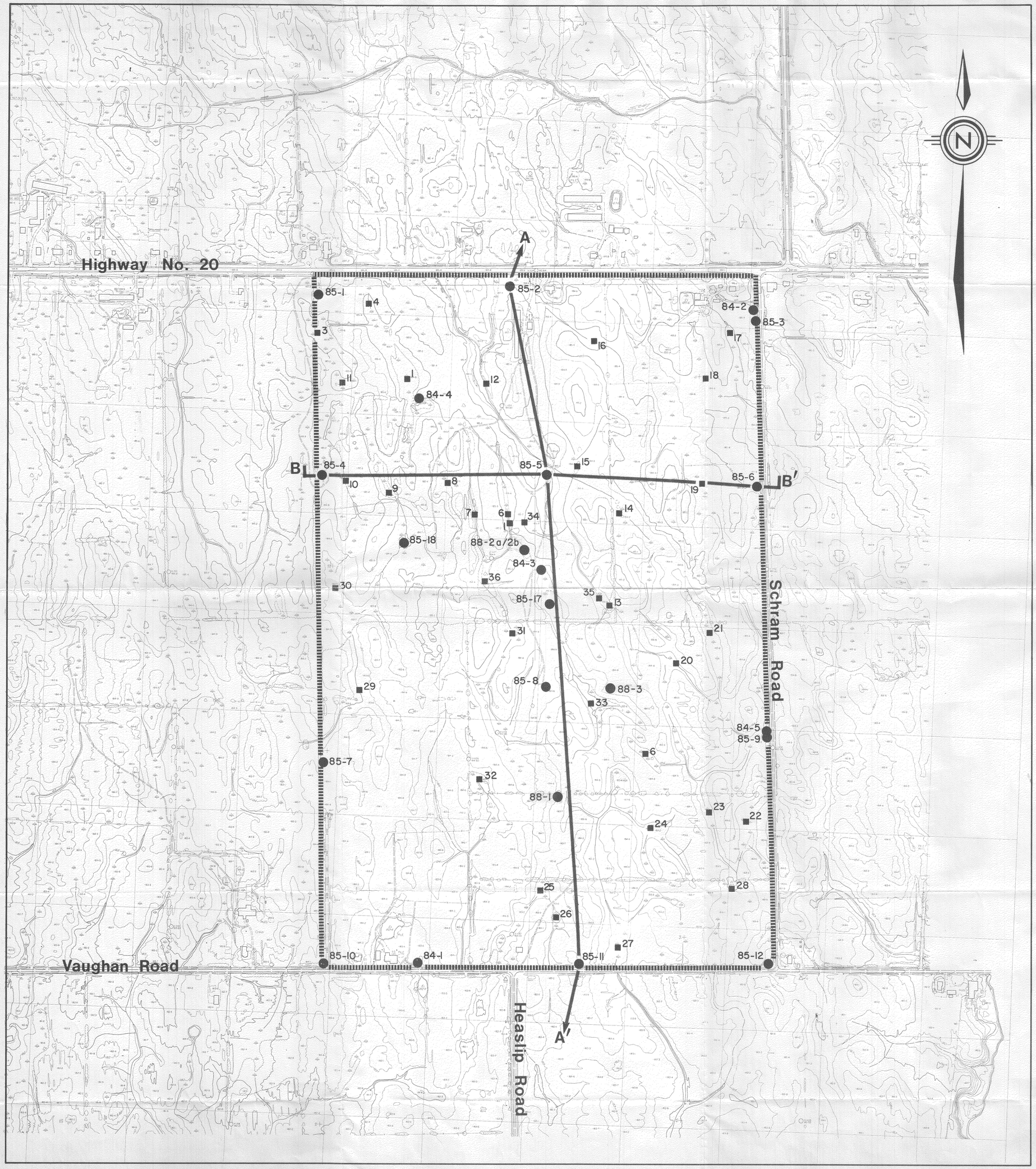
ISOTRACE LABORATORIES, UNIVERSITY OF TORONTO

A detailed description of the techniques and quality assurance/quality control program for carbon-14 dating by accelerator mass spectrometry is beyond the scope of this report. the reader is referred to the following published references:

(1) Litherland et. al. (1986),
(2) Kieser et. al. (1986) and
(3) Beukens et. al. (1986)

APPENDIX C

GEOLOGIC INFORMATION



OWMC Ontario Waste Management Corporation

Consultant

Gartner Lee

Legend

- ● 84-2 Borehole location, year and number
- ■ 24 Field station location and number
- B B' Cross section location
- Site boundary

NOTE: Cross-sections A-A' includes off-site boreholes 85-14 and 85-16

100 0 100 200 300 Metres

BOREHOLE LOCATIONS

Figure 3

APPENDIX C

GEOLOGIC INFORMATION

TABLE OF CONTENTS

LIST OF TABLES

FIGURE 3 Borehole Locations

C1 BOREHOLE LOGS

C1.1 EXPLANATION OF THE BOREHOLE LOG FORM

This explanatory section provides the user with background to assist in using the borehole logs. Each of the headings used on the borehole log is briefly explained below.

ELEVATION AND DEPTH

This column gives the elevation and depth below ground surface of interpreted geologic contacts. The elevation is surveyed in, with respect to the datum as described in the report, unless otherwise stated.

STRATIGRAPHIC DESCRIPTION

This column gives a description of the geologic materials based on visual examination of the samples and/or laboratory tests. Each stratum is described according to the following classification and terminology which is based on the proportion of individual particle sizes present.

Classification*		Terminology	Proportion
Clay	<0.002 mm	"trace" (e.g. trace sand)	<10%
Silt	0.002 to 0.06 mm	"some" (e.g. some sand)	10 - 20%
Sand	0.06 to 2 mm	adjective (e.g. sandy)	20 - 35%
Gravel	2 to 60 mm	"and" (e.g. and sand)	35 - 50%
Cobbles	60 to 200 mm	noun (e.g. sand)	>50%
Boulders	>200 mm		

* Extension of MIT Classification System

The compactness of cohesionless soils and the consistency of cohesive soils are defined by the following:

COHESIONLESS SOIL

Compactness	Standard Penetration Resistance ('N' Blows/ 0.3 m)
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	Over 50

COHESIVE SOIL

Consistency	Undrained Shear Strength (kPa)
Very soft	0 to 12
Soft	12 to 25
Firm	25 to 50
Stiff	50 to 100
Very stiff	100 to 200
Hard	Over 200

The moisture condition of cohesionless and cohesive soils is defined as follows:

COHESIONLESS SOILS	COHESIVE SOIL
Dry	DTPL - Drier than Plastic Limit
Moist	APL - About Plastic Limit
Wet	WTPL - Wetter than Plastic Limit
Saturated	MWTPL - Much Wetter than Plastic Limit

STRATA

These standard symbols are used to pictorially identify the interpreted stratigraphy of the soil and rock strata units discussed in the text.

Topsoil

Swale Sediment

Upper Glaciolacustrine Unit

Halton Unit

Lower Glaciolacustrine Unit

Lower Till

Guelph Formation

Lockport Formation

MONITOR DETAILS AND NUMBER

This column shows the location and designation of standpipe and/or piezometer ground water monitors installed in the borehole or excavation. Also shown is the water level, indicated to scale, for the date shown.

The following monitor symbols are used:

P Piezometer S Standpipe G Gas Monitor

For further data regarding seals, screens, etc., the reader is referred to the table entitled summary of monitor details.

TEST DATA

The central section of the log provides a graph which is used to plot selected field and laboratory test results at the elevation at which they were carried out. The symbols and scales for the plotting are shown at the head of the column.

Standard Penetration Resistance 'N'. The number of blows required to advance a 51 mm diameter standard split-spoon sampler 300 mm into the subsoil, driven by means of a 63.5 kg hammer falling freely a distance of 750 mm.

Water content w % . The ratio of the mass of water to the mass of oven-dry solids in the soil expressed as a percentage.

SAMPLES

These columns describe the sample number and type, the percentage recovery, 'N' value, and water content for soils (or RQD in the case of rock), of each sample obtained from the borehole or excavation. The location (depth) of each sample is plotted to scale. The legend for sample type is explained on the top left side of the form.

Where diamond drilling has been carried out the term RQD is used. The Rock Quality Designation (RQD) is an indirect measure of the number of fractures and soundness of the rock mass. It is obtained from the rock cores by summing up the length of core recovered, counting only those pieces of sound core that are 100 mm or more in length. The RQD value is expressed as a percentage and is the ratio of the summed core lengths greater than 100 mm to the total length of the core run. Then RQD classification is given below.

RQD Classification	RQD-Value (%)
Very poor quality	<25
Poor quality	25 - 50
Fair quality	50 - 75
Good quality	75 - 90
Excellent quality	90 - 100

COMMENTS

The last column describes pertinent drilling details or field observations and/or an indication of other field or laboratory tests that have been performed. The results of other tests not plotted on the form are given in an Appendix to the report.

C1.2 PHASE 4B BOREHOLE LOGS, INTRODUCTION

The borehole logs which follow, were compiled from a) field notes prepared by the drilling supervisor (Gartner Lee geologist) as the boreholes were advanced, b) a more detailed geologic log prepared by the senior project geologist during re-examination of the soil and rock samples, and c) the results of geotechnical tests conducted on selected samples. The information shown on the following borehole logs is compiled from 2 to 3 closely spaced boreholes (i.e., generally less than 3 m apart) at each drilling location on the site. One borehole provides continuous samples and the others provide geotechnical data. The boreholes used in each case are listed at the top of each borehole log (e.g., Borehole Log 85-12-1, 2 and 12 indicates that information from boreholes 85-12-1, 85-12-2 and 85-12-12 was used in compiling the borehole log). Borehole logs for drilling locations off the site are compiled from one borehole. The drilling date is indicated with the month and year. In some cases the drilling time includes more than one month.

Samples shown on the borehole logs include split-spoon (SS) and Shelby Tube (ST) samples. The split tube (T) samples are not shown. A discussion of the sampling methods is provided in Appendix A1. An explanation of the borehole log form is presented in Appendix C1.1.

BOREHOLE LOG 85-1-2 & 12

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY & FEBRUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 185.5	STRATIGRAPHIC DESCRIPTION	STRATA	MOTTLING	DENSITY & CONSISTENCY	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: dark brown, clayey silt to silt, numerous roots and twigs.										
		SILT AND CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±6.4m, silt and clay trace sand, occasional rock or silt/clay clast to 5mm, laminated to massive, occasional silt lamina to 3mm at 3.0 to 4.2m, heavily weathered to ±0.6m, numerous fractures to 2.2m, well developed black & rusty fractures 3.2, 3.6 & 3.9m, grey & rusty fracture 4.7 to 6.6m, DTPL to ±4.5m, APL below, very stiff.					1	SS	100	34	23	
							2	SS	100	27	24	
							3	SS	100	22	19	
							4	SS	100	21	20	
							5	SS	100	21	18	
5							6	SS	100	20	18	
							7	ST	100	N/A	30	V,P,GS
							8	SS	100	18	23	
	7.5	CLAYEY SILT (Till and Glaciolacustrine): brown, clayey silt trace sand and gravel, till (±65%) is massive and contains rock clasts commonly to 5mm; occasionally larger, interbedded with and gradational to laminated to massive clayey silt with rare to occasional clasts, till 7.5 to 8.5m, 9.0 to 9.2m, 10.7 to 10.9m, 13.3 to 14.0m & 14.8 to 21.8m, sharp upper contact, gradational lower contact, APL to ±12m becoming WTPL, consistency is generally very stiff to stiff becoming stiff at ±16m.					9	SS	100	17	16	
							10	SS	100	17	16	
10							11	ST	100	N/A	21	V,GS
							12	SS	100	19		
							13	SS	100	19	21	
							14	SS	100	17	22	
15							15	ST		N/A		
							16	ST	100	16	23	
							17	ST	50	N/A		
							18	SS	100	15	23	
							19	SS	100	14	22	
							20	SS	100	10	24	
							21	ST	100	N/A	22	V,GS
20							22	SS	100	14	23	
	21.8	CLAY and SILT (Glaciolacustrine): brown with red and grey banding, clay and silt grading to silty clay trace sand, rare to occasional rock or silt/clay clast to 20mm, occasional silt lamina to 2mm below ±24m, (continued)					23	SS	25	18	23	
							24	SS	5	17	26	
25							25	SS	50	24	30	

BOREHOLE LOG 85-1-2 & 12

PROJECT OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY AND FEBRUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE CONTENT & DENSITY INDICATORS	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (contiued): WTPL becoming MWTPL at ±29m, consistency is generally stiff to firm.				26 ST	100	N/A		
						27 SS	100	13	31	
						28 SS	100	15	28	
						29 SS	100	11	41	
30						30 ST		N/A	39	V,UC,γ,GS
						31 SS	100	14	37	
	32.9	SILT to VERY FINE SAND: laminated.				32 SS	100	14	39	
	33 0	SILT and SAND (Till): brown, gravelly silt and sand, numerous broken rock fragments, saturated, compact.				33 SS	100	18	7	
35	34.3	DOLOSTONE: grey, fine grained, crystalline, sugary texture, occasional dark grey horizontal banding, occasional shale lamina to 3mm thick, laminae occasionally stylolytic, occasional vug to 30mm (rarely larger), vugs commonly infilled with gypsum, occasional gypsum infilled fracture or bedding plane, mild petroliferous odour, lower contact is gradational, the rock quality is good to excellent below ±37.5m.				1 RC	100	N/A	*** 70	*** Nos. Refers to RQD
						2 RC	100	N/A	98	
40										
						3 RC	100	N/A	85	
45						4 RC	100	N/A	96	
						5 RC	100	N/A	98	
50										

BOREHOLE LOG 85-1-2 & 12

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY AND FEBRUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
		γ	Unit Weight (kN/m3)	P	Compaction Test
o---o	Water Content (w%)	C	Consolidation Test		
x	Composite of 'N' & w%	DS	Direct Shear Test		
Δ___=	Plastic & Liquid Limits	T	Triaxial Test (UC, Q, $\bar{R}$)		
_v_	Water Level (198 / /)	K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DEPTH	TEST DATA (20 40 60 80 N / 10 20 30 40 w)	SAMPLES NUMBER	SAMPLES TYPE	SAMPLES REC. (%)	N	RQD (%)	COMMENTS
		DOLOSTONE (continued):					6	RC	100	N/A	92	
55							7	RC	100	N/A	95	
							8	RC	100	N/A	95	
60	57.8	DOLOSTONE: medium grey, fine to very fine grained, sugary texture, numerous black shale laminae 1 to 3mm thick, occasional vug and vuggy zones, approximately 50% of vugs are filled with gypsum, occasional light grey chert nodule to 40mm, slight petroliferous odour, the rock quality is excellent.					9	RC	100	N/A	98	
65							10	RC	100	N/A	100	
		Borehole Terminated at 65.2 in Dolostone										
70												
75												

BOREHOLE LOG 85-2-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: NOVEMBER 1985
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 185.0	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DENIAL	TEST DATA (N 20 40 60 80; w 10 20 30 40)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: dark greyish brown, clayey silt with roots and vegetation.										
5		SILT and CLAY (Glaciolacustrine): dark greyish brown with colour banding below ±1m changing to brown at ±6.3m, silt and clay trace sand, rare rock or silt/clay clast to 5mm, occasional paper thin to 2mm thick discontinuous silt lamina, heavily weathered and fractured to ±1m, grey lined fractures 3.3 to 3.5m, WTPL to ±0.9m, DTPL to 3.5m, APL below, consistency is very stiff.					1 2 3 4 5 6 7	SS SS SS SS SS SS SS	100 100 100 100 100 60 100	24 22 27 21 22 19 19	25 23 19 20 23 26 25	
	6.7	CLAYEY SILT (Till with interbedded Glaciolacustrine): brown, clayey silt trace sand, till is massive to faintly laminated and contains up to ±5% clasts to 35mm, glaciolacustrine is indistinctly laminated with rare clasts, glaciolacustrine zones 8.7 to 10.1m and 11.1 to 11.5m, till boundaries are generally gradational, lower till boundary is sharp, APL to ±11m, WTPL below, very stiff becoming stiff at ±16m.					8 9 10 11 12 13 14 15 16	SS SS SS SS SS SS SS SS SS	100 100 2 100 100 100 100 100 100	18 33 22 21 20 26 11 13 10	18 17 20 18 19 22 21 22 23	
10 15 20												
	21.0	CLAY and SILT (Glaciolacustrine): brown with red and grey banding, clay and silt trace sand, occasional rock or silt/clay clast to 2mm thick, laminae are commonly slightly deformed, WTPL, becoming MWTPL at ±28m, generally firm, however, soft and stiff zones. (continued)					17 18 19	SS SS SS	100 100	7 7 6	30 36 23	
25												

BOREHOLE LOG 85-2-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: NOVEMBER 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
A___=	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DENTIL & NO.	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (continued):					20 ST		N/A		
							21 SS	100	16	27	
							22 SS	100	13	29	
							23 ST		N/A		
							24 SS	100	10	37	
30											
							25 SS	100	14	40	
	31.5	SILT and SAND (Till): dark greyish brown, gravelly silt and sand, uniform, massive, saturated, very dense.					26 LS	100	N/A	5	
							27 LS	100	N/A	6	GS
35	33.6	DOLOSTONE: grey, fine to medium grained, sugary texture, black shale laminae 1 to 3mm thick occur regularly throughout core, petroliferous odour, occasional zone with small (to 3mm) vugs, very poor quality.					24 Rc	100	N/A	xxx 13	xxx No. Refers to RQD
	37.0	Borehole Terminated at 37.0m in Dolostone									
40											
45											
50											

BOREHOLE LOG 85-3-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: DECEMBER 1985
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: WM/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	τ	Unit Weight (kN/m3)	P	Compaction Test
x	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 185.4	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS & DETAILS	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: dark brown, clayey silt with roots and vegetation.									
5		CLAY and SILT (Glaciolacustrine): dark greyish brown changing to brown at ±4.5m, clay and silt trace sand, occasional rock or silt/clay clast to 5mm, heavily weathered and fractured to ±1m, generally well laminated, numerous fractures to ±4m, grey lined fracture at 5.6m, DTPL to ±4.3m, APL below, firm to ±1.2m, very stiff below ±1.2m, high plasticity 4.6 to 5.2m.				1	SS	50	17	26	
						2	SS	80	40	24	
						3	SS	100	40	21	
						4	SS	100	40	20	
						5	SS	100	38	23	
					55	6	ST	100	N/A	29	UC,τ,P,GS,
					61	6	ST			31	DS
	5.9					7	ST		N/A		
10		SILT and CLAY (Till with interbedded Glaciolacustrine): brown, silt and clay trace sand and gravel, occasional rock clasts to 50mm, till is massive to indistinctly laminated, all till boundaries are gradational, laminated glaciolacustrine with silt laminae to 2mm from 7.1 to 8.0m, variable clast content and faint laminations below ±15m, APL to ±11m, WTPL below ±11m, very stiff becoming stiff at ±9m, medium plasticity.				8	SS	100	31	18	
						9	SS	100	23	19	
						10	ST	100	N/A		P
						11	ST	100	N/A	22	P,UC,τ,GS,
						11	ST			20	DS
15						12	SS	100	23	23	
						13	SS	100	22	20	
						14	SS	100	16	23	
						15	ST	100	N/A	22	UC,τ,V
20	19.9	SILT and CLAY (Glaciolacustrine): brown with red and grey bands, silt and clay trace sand, occasional rock or silt/clay clast to 2mm, well laminated, occasional silt lamina to 1mm, WTPL becoming MWTPL at ±27m, consistency is stiff to firm. (continued)				16	SS	100		39	
						17	SS	100	13	29	
						18	SS	100	10	41	
						19	ST	100	N/A	26	
25						19	ST			29	UC,τ,GS,DS

BOREHOLE LOG 85-3-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: DECEMBER 1985
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: WM/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___=	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE	DENSITY	TEST DATA (20 40 60 80 N / 10 20 30 40 w)	SAMPLE NUMBER	REC. (%)	N	w (%)	COMMENTS
		SILT and CLAY (continued):					20 ST	100	N/A		
							21 SS	100	12	36	
							22 SS	95	12	38	
30	29.9	SANDY SILT (Till): dark greyish brown, gravelly sandy silt, sand inclusion 30.0 to 30.2m, saturated, very dense.					23 SS	4	60/ .1 m	26	
	31.5	DOLOSTONE: grey, fine grained, crystalline, darker grey banding, occasional shale lamina to 1mm in lower 1.5m, occasional vug to 10mm, most vugs filled with gypsum, mild petroliferous odour, very poor rock quality.					23 Rc	100	N/A	*** 24	*** Nos. refers to RQD
35	34.7						24 Rc	100	N/A		
		Borehole Terminated at 34.7m in Dolostone									
40											
45											
50											

GARTNER LEE ASSOCIATES LIMITED

BOREHOLE LOG 85-4-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: WM/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 185.4	STRATIGRAPHIC DESCRIPTION	STRATA	MONITOR	DENIAL	NO.	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: dark brown, clayey silt with roots, organics and straw.										
5		SILT and CLAY (Glaciolacustrine): dark greyish brown changing to reddish brown at ±5.4m, silt and clay trace sand, occasional rock or silt/clay clast to 5mm (rarely larger), massive to faintly laminated with occasional well laminated zones, poorly developed textural laminae, heavily weathered with numerous fractures to ±3m, rusty black fracture 4.0m, grey lined fracture with gypsum crystals 5.5 to 7.0m, DTPL, very stiff.					1	SS	60	44	21	
							2	SS	70	52		
							3	SS	65	61	18	
							4	SS	50	37	19	
							5	SS	85	34	18	
							6	SS	100	30	28	
							7	SS	100	51	18	
							8	SS	100	60	18	
							9	SS	90	59	17	
							10	SS	70	32	19	
10	8.2	CLAYEY SILT (Glaciolacustrine with interbedded Till): brown to reddish brown, clayey silt trace sand and (locally) gravel, occasional rock or silt/clay clast to 5mm, (rarely larger), glaciolacustrine well laminated to massive, occasional well developed silt lamina to 3mm, laminations mildly disturbed ±10 to 13m, till 8.2 to 9.2m and 13.5 to 13.9m, till contains 5 to 10% sand and gravel, rock clasts to 10mm (rarely larger), sharp upper contact, other contacts gradational, grey lined fracture at 9.7 m, APL ±8 to 11m, WTPL below ±11m, consistency is generally very stiff becoming stiff at ±10m.					11	SS	90	33	23	
							12	SS	100	21	23	
							13	SS	100	13	28	
15							14	SS	100	22	24	
							15	SS	100	23	22	
							16	SS	100	26	23	
							17	SS	100	24	19	
20							18	ST	100	N/A		
							19	SS	100	22	24	
							20	SS	100	26		
25	23.5	CLAY and SILT (Glaciolacustrine): brown with red and grey banding, clay and silt trace sand, (continued)					21	SS	100	22	26	

GARTNER LEE ASSOCIATES LIMITED

BOREHOLE LOG 85-4-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: WM/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DENTAL	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (continued): rare to occasional rock or silt/clay clast to 10mm, occasional poorly developed clayey silt lamina to 3mm, WTPL, consistency is stiff to firm.					22 ST	100	N/A		
							23 SS	100	26	24	
							24 SS	100	20	30	
30							25 SS	100	17	32	
	31.3	SAND and SILT (Till): brown gravelly, sand and silt, numerous rock fragments, saturated, very dense.					26 SS	66	100/ .15m	8	
							27 SS	90	124	7	
35	35.1	DOLOSTONE: grey, fine grained, sugary textured, occasional shale lamina to 5mm (rarely larger), occasional vug to 5mm, occasional fracture cemented with gypsum, numerous fractures and breaks, poor rock quality.					24 Rc	98	N/A	*** 36	*** No. refers to RQD
	38.2	Borehole Terminated at 38.2m in Dolostone									
40											
45											
50											

BOREHOLE LOG 85-5-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: DECEMBER 1985
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊼	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 185.4	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE CONTENT & DENSITY/CONSISTENCY	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.3	TOPSOIL: dark brown, clayey silt to silty clay, with rootlets and straw.									
		SILT and CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±5.6m, silt and clay trace sand, rare rock or silt/clay clast to 5mm, generally well laminated with massive zones, clayey silt 3.1 to 4.3m, occasional silt lamina to 2mm, heavily fractured to 2.4m, fractures common to 4.0m, grey infilled fracture with gypsum crystals 5.3 to 6.0m OTPL becoming APL ±4.5m, very stiff becoming stiff at ±4.5m.				1	SS	75	22	23	
						2	SS	90	26	24	
						3	SS	100	25	27	
						4	SS	75	17	19	
						5	SS	100	22	24	
5						6	ST	100	N/A	30	γ,Q,V,P,C
						7	SS	100	12	28	
						8	SS	100	12	28	
	6.9										
		CLAYEY SILT (Glaciolacustrine with minor Till): dark reddish brown to brown, clayey silt trace sand, laminated to massive, till zones 6.9 to 7.1m, 7.6 to 7.8m, 17.5 to 19.1 m, occasional silt lamina to 1mm, occasional rock or silt/clay clast to 5mm (rarely to 30mm), contacts are gradational, APL becoming WTPL below ±12m, consistency is generally stiff, some very stiff and firm zones.				9	SS	100	11	18	
						10	ST	100	N/A	19	γ,Q,V,C
						11	ST	100	N/A		
10						12	SS	100	19	19	
						13	ST	100	N/A	19	$\bar{R}$,GS,γ
						14	SS	100	13	19	
						15	SS	100	15	21	
						16	SS	100	14	21	
15											
						17	SS	100	8	24	
						18	ST	80	N/A	24	γ,Q,V,C
						19	SS	100	11	23	
						20	SS	100	16	25	
20											
						21	SS	100	16	30	
						22	SS	100	14	24	
	22.0	CLAY and SILT (Glaciolacustrine): brown with red and grey banding, clay and silt trace sand, rare rock or silt/clay clast to 3mm, occasional silt lamina to 3mm, WTPL becoming MWTPL at ±30m, stiff, medium to high plasticity. (continued)				23	ST	100	N/A	26	γ,Q,V,C
						24	SS		8	28	
25						25	SS	100	9	28	

BOREHOLE LOG 85-5-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: DECEMBER 1985
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DENTIAL	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (continued):					26	ST	100	N/A	33	γ,Q,V,C
							26	ST			35	
						55	27	SS	100	14	22	
							28	SS	100	12	28	
							29	SS	100	20	27	
30							30	ST		N/A	31	γ,Q,V,C
											42	
							31	SS	100	13	38	
							32	SS	100	11	31	
							33	SS		9	37	
35	33.9	SILT AND SAND (Till): brown, gravelly, silt and sand, decreasing clay and increasing gravel content with depth (to ±25%gravel), saturated, very dense.					34	SS		78/ 15m	7	
	37.4	DOLOSTONE: grey, fine to medium grained, crystalline, occasional shale lamina to 2mm, occasional vugs throughout, numerous vugs to 15mm from 37.7 to 39.9m, gypsum infilling in some vugs, good rock quality.					26	Rc	100	N/A	xxx 79	xxx No. refers to RQD
40	40.4	Borehole Terminated at 40.4m in Dolostone										
45												
50												

BOREHOLE LOG 85-6-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: NOVEMBER 1985
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
&	Composite of 'N' & w%	C	Consolidation Test		
A___=	Plastic & Liquid Limits	DS	Direct Shear Test		
_v_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 185.4	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DENTAL	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: very dark brown, clayey silt, occasional roots and vegetation.									
5		SILT AND CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±4.0m, silt and clay trace sand, rare to occasional clast to 5mm, generally well laminated with occasional silt lamina to 3mm, heavily weathered to ±1.0m, heavily fractured to ±2.0m, fracture with gypsum crystals 4.8 to 5.8m, gypsum crystals along silt laminae at 7.0m, grey lined fracture with roots at 6.2m, WTPL to ±0.6m, becoming DTPL, very stiff becoming stiff at ±4.5m.				1	SS	75	22	20	
						2	SS	80	40	21	
						3	SS	100	39	23	
						4	SS	100	34	19	
						5	SS	100	30	21	
						6	SS	100	23	18	
						7	SS	100	24	23	
	7.2	CLAYEY SILT (Till and interbedded Glaciolacustrine): dark reddish grey, silt and clay trace sand and gravel (locally), occasional rock or silt/clay clast to 2mm (rarely to 80 mm), till is massive to faintly laminated and contains ±5 to 10 % sand & gravel clasts, upper till boundaries are gradational, till 7.2 to 14.3m, glaciolacustrine is indistinctly laminated to massive with occasional clayey silt laminae to 2mm, occasional till-like zones, rusty fracture at 9.0m, DTPL becoming WTPL ±14m, stiff.				8	SS	100	22	16	
10						9	SS	100	16	18	
						10	SS	100	21	17	
						11	SS	100	20	14	Samples 12 & 13 not taken
15						14	SS	100	17	21	
						15	SS	100	11	21	
						16	SS	100	15	22	
						17	SS	100	14	22	
20						18	SS	100	11	23	
						19	SS	100	14	13	
	21.8	CLAY and SILT (Glaciolacustrine): dark reddish grey with red and grey bands, clay and silt trace sand, rare to occasional rock or silt/clay clast to 20mm, well laminated with occasional silt lamina to 2mm, (continued)				20	SS	100	10	23	
25						21	SS	100	17	29	

BOREHOLE LOG 85-6-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: NOVEMBER 1985
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-6G & 85-GT
LOGGED/CHECKED BY: EJK/AJC/RDP

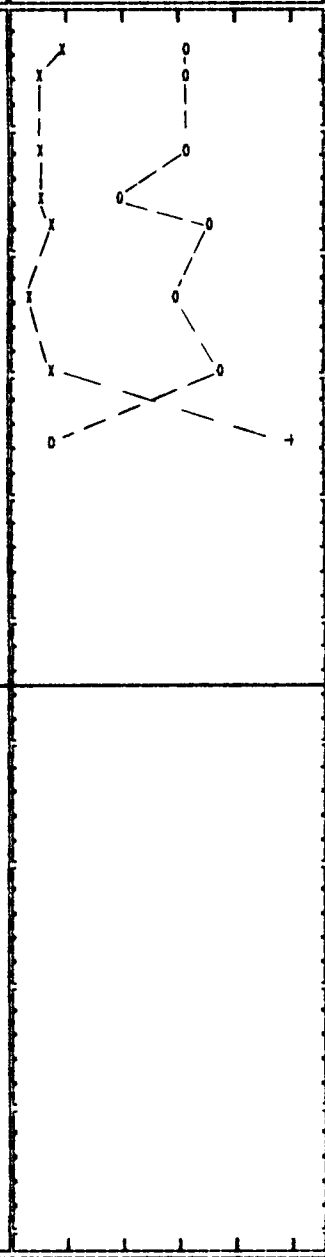
SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___=	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DENSITY & NO.	SAMPLE NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (continued): WTPL becoming MWTPL at ±29.5m, stiff.				22 ST		N/A		
						23 SS	100	20	31	
						24 SS	100	12	31	
						25 SS		12	31	
						26 ST		N/A		
						27 SS	100	13	20	
30						28 SS	100	15	36	
						29 SS	100	8	29	
						30 SS	100	14	37	
	33.6	SILT and SAND (Till): dark greyish brown, gravelly, silt and sand, increasing gravel content to bedrock, massive, saturated, very dense.				31 SS		100/ .15m	7	
35	35.5	DOLOSTONE: grey, fine grained, numerous black shale laminae to 3mm, occasional vugs commonly 10mm and occasionally to 40mm, occasional gypsum infilled fractures or vugs, petroliferous odour when freshly broken, poor rock quality.				25 Rc		N/A	xxx 25	xxx No. refers to RQD
40	38.8	Borehole Terminated at 38.8m in Dolostone								
45										
50										



BOREHOLE LOG 85-7-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 184.4	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE CONTENT & INDICATOR	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	SAMPLE NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
	0.3	TOPSOIL: dark brown, clayey silt with organics and roots.								
		SILT and CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±4.4m, silt and clay interbedded with trace clay and sand, occasional rock or silt/clay clast to 10mm, well laminated with occasional silt lamina to 5mm, 0.3 to 1.7m silt and clay trace sand, 1.7 to 2.9m silt trace sand and clay, 2.9 to 5m silt and clay trace sand, heavily weathered and fractured to 2.9m, occasional fractures to 5m, gradational lower boundary, WTPL, becoming OTPL at ±2m to ±5m then APL, stiff becoming very stiff at ±2m.				1 SS	100	24	21	
						2 SS	100	21	20	
						3 SS		25	21	
						4 ST	100	N/A		
						5 SS		35	23	
5	5.0					6 SS	100	30	19	
						7 SS	100	34	18	
						8 ST	100	N/A		
						9 SS	100	34	20	
		SILT and CLAY(Glaciolacustrine and Till): brown, silt and clay trace sand grading to clayey silt trace sand (±10 to 15m), occasional rock or silt/clay clast to 3mm, up to 10% gravel locally in till, laminated to massive glaciolacustrine ±5 to 15m, rare poorly developed silt lamina, gradational upper and lower boundaries, till ±15 to 21.8m, massive to faintly laminated with rare paper thin silt laminae, fracture 3.7 to 8.3m with grey lining and gypsum crystals, roots in fracture 6.6 to 6.7 m, faint grey lined fracture at 9.0m, till and glaciolacustrine are gradational and interbedded, APL becoming WTPL at ±13m, very stiff becoming stiff at ±10m.				10 SS	100	26	20	
10						11 SS	100	14	20	
						12 SS	100	19	20	
						13 SS	100	17	21	
15						14 SS	100	28	22	
						15 SS	100	17	27	
						16 ST	100	N/A		
						17 SS	100	20	25	
20						18 SS	100	23	25	
	21.8	CLAY and SILT (Glaciolacustrine): brown with grey and red bands, clay and silt trace sand, rare to occasional rock or silt/clay clast to 5mm, laminated with occasional silt lamina to 3 mm, WTPL, becoming MWTPL at ±31m, stiff.(continued)				19 SS	100	22	23	
						20 SS	100	17	21	
25						21 SS	100	15	32	

BOREHOLE LOG 85-7-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
±	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE & ATTERBERG LIMITS	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (continued):				22	ST	100	N/A		
						23	SS	100	15	26	
						24	SS	100	17	25	
30						25	SS	100	17	31	
						26	SS	100	19	38	
						27	ST	100	N/A		
						28	SS	100	22	36	
	33.3	SILT and SAND (Till): brown, gravelly, silt and sand, numerous dolostone clasts, saturated, very dense.				29	SS		68/ .15m	5	
35											
	35.7	DOLOSTONE: grey, fine to medium grained, sugary texture, occasional black shale lamina to 5mm (commonly styloiitic), occasional vugs to 20mm, fair rock quality.				25	Rc	100	N/A	70	xxx xxx No. refers to RQD
	38.7										
40		Borehole Terminated at 38.7m in Dolostone									
45											
50											

BOREHOLE LOG 85-8-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
✱	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 184.9	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE & NATURE	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER	SAMPLE TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: very dark greyish brown, clayey silt, with roots, straw and vegetation.									
		SILT and CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±5.3m, silt and clay trace sand, occasional rock or silt/clay clast to 5mm (rarely larger), rare red shale clast, massive to well laminated, heavily weathered to 1.4m, fractures to 3.5m, DTPL to APL, WTPL at ±5.5m, very stiff to hard becoming very stiff 4m.				1	SS	100	12	25	
						2	SS	100	30	23	
						3	SS	100	38	21	
						4	ST	100	N/A	20	V,Q,γ,$\bar{R}$,GS
5						5	SS	100	21	26	
						6	SS	100	14	27	
						7	ST	100	N/A	21	V,Q,γ,GS
						8	SS	100	23	21	
	7.2	CLAYEY SILT (Glaciolacustrine): brown, clayey silt trace sand to silt and clay trace gravel and sand, occasional rock or silt/clay clast to 2mm (rarely to 10mm), massive to laminated, rare textural laminae to 15.8m, occasional silt lamina to 1mm below 15.8m, grey fracture with gypsum crystals 8.2 to 8.5m gradational upper boundary, sharp lower boundary, APL becoming WTPL ±11.5m, very stiff becoming stiff at ±7.5m.				9	SS	100	11	20	
10						10	SS	100	14	19	
						11	SS	100	14	20	
						12	ST	100	N/A	22	V,Q,γ,GS
						13	SS	100	12	24	
15						14	SS	100	10	33	
						15	SS	100	12	30	
						16	SS	100	18	25	
						17	ST	100	N/A	27	V,Q,γ,GS
						18	SS	100	16	25	
20						19	SS	100	17	24	
	21.4	CLAY and SILT (Glaciolacustrine): brown with red and grey banding, clay and silt trace sand, rare rock or silt/clay clast to 10mm, well laminated throughout, occasional silt lamina to 2mm, laminae are mildly disturbed at 24.5 to 25.0m, (continued)				20	SS	100	12	34	
						21	SS	100	12	29	
						22	ST	100	N/A	28	
						22	ST			32	V,Q,γ,GS,$\bar{R}$
25						23	SS	100	14	32	

BOREHOLE LOG 85-8-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲---■	Plastic & Liquid Limits	DS	Direct Shear Test		
_v_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION (GEOLOGIC PROFILE)	STRATA	MONITORS	DETAIL NO.	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT: (continued) increased clast content and distorted laminations 25.2 to 26.8m, increased clast content 27.3 to 27.6m, WTPL, stiff.					24	SS	100	14	34	
							25	SS	100	15	26	
							26	SS	100	13	31	
30							27	ST	100	N/A	33	V,GS
							28	SS	100	16	27	
	32.0	SAND and SILT (Till): brown, gravelly, sand and silt trace clay, increasing gravel with depth (to 40%), numerous broken dolostone clasts to 80mm, very dense, saturated.					29	SS	100	75/ .22m	7	
35							30	SS		85	7	GS
	36.0	DOLOSTONE: grey, fine grained, sugary texture, numerous black shale laminae to 5mm, numerous fractures, ±50% of fractures infilled with calcite or gypsum, top 1.5m of core contains ±10% vugs to 10mm, below 37.5m >80% vugs filled with calcite, fair rock quality.					24	Rc		N/A	*** 58	*** No. refers to RQD
40	39.5	Borehole Terminated at 39.5 in Dolostone										
45												
50												

BOREHOLE LOG 85-9-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: NOVEMBER & DECEMBER 1985
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 183.9	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DEPTH	TEST DATA (N 20 40 60 80; w 10 20 30 40)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.3	TOPSOIL: dark brown, silty clay, with organics and vegetation.										
5		SILT and CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±4.6m, silt and clay trace sand, occasional rock or silt/clay clast to 5mm, laminated with occasional massive zones, heavily weathered to ±1m, numerous grey and rusty lined fractures to ±3m, silt and fine sand laminae (to 10mm) common 3.2 to 3.9m, DTPL becoming APL at ±4.5m, very stiff becoming stiff at ±4.5m.					1 2 3 4 5 6 7	SS SS SS SS SS SS SS	100 100 100 100 100 100 100	22 35 42 43 31 21 20	26 25 22 20 27 25 33	
10	7.6	CLAYEY SILT (Glaciolacustrine with interbedded Till): brown, clayey silt trace sand and (locally) gravel, rare to occasional rock or silt/clay clast to 4mm, laminated with massive zones, massive to faintly laminated till 9.4 to 9.6m, 14.0 to 14.7m and 19.3 to 20.3m, till boundaries are gradational over short interval (±100mm), upper contact gradational, lower contact sharp, disturbed bedding common below 15.9m, disturbed colour banded silt and clay below ±18m, 12.2 to 14.2m very silty, APL becoming WTPL at ±15m, generally stiff however, hard at ±12.2 to 14.2m.					8 9 10 11 12 13 14 15	SS SS SS SS SS SS SS SS	100 100 100 100 100 100 100 100	18 20 21 42 42 15 16 9	25 17 22 20 18 24 24 23	
20	20.3	CLAY and SILT (Glaciolacustrine): brown with red and grey banding, clay and silt trace sand, rare to occasional rock or silt clast to 5mm, undisturbed horizontal bedding, occasional silt lamina to 2mm, WTPL becoming MWTPL at ±32m, stiff. (continued)					16 17 18 19 20	SS ST SS SS SS	100 100 100 100 100	11 N/A 9 11 10	28 32 32 30	
25												

BOREHOLE LOG 85-9-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: NOVEMBER & DECEMBER 1985
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITOR & DETAILS	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (continued):				21	SS	100	11	28	
						22	ST	50	N/A		
						23	SS	100	16	27	
30						24	SS	100	13	26	
						25	SS	100	15	29	
						26	SS	100	16	39	
	32.9	SILT (Till): brown, gravelly, silt with sand and clay, medium sand 33.0 to 33.1m, saturated, very dense.				27	SS	100	86/ .2m	14	
35	34.4	DOLOSTONE: grey, fine grained, crystalline, occasional black shale lamina, mild petroliferous smell when broken, occasional vug to 10mm, gypsum infilled fracture 37.2m, poor rock quality.				24	Rc		N/A	xxx 44	xxx No. refers to RQD
	37.4	Borehole Terminated at 37.4m in Dolostone									
40											
45											
50											

BOREHOLE LOG 85-10-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: DECEMBER 1985
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 184.0	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	TEST DATA (N 20 40 60 80; w 10 20 30 40)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		SILT and CLAY (Glaciolacustrine). dark greyish brown changing to brown at ±3.4m, silt and clay trace sand, occasional rock or silt clast to 5mm, laminated with massive zones, heavily weathered to ±1m, grey lined fractures to 4.0m,DTPL to ±3.5m, becoming APL, stiff becoming very stiff at ±1.5m to ±4.6m, then stiff.				1	SS	100	17	22	
						2	SS	100	29	22	
						3	SS	100	35	19	
						4	SS	100	42	23	
5						5	SS	0	32		
						6	ST	100	N/A		
						7	SS	80	N/A	19	GS,γ,DS
						8	SS	100	13	23	
	6.5	CLAYEY SILT (Glaciolacustrine with interbedded Till): brown, clayey silt trace sand, rare to occasional rock or silt clast to 5mm, commonly laminated with massive and till zones, massive to faintly laminated till zones 14.5 to 15.3m, 16.6 to 17.3m and 19.6 to 21.9m, silt trace clay and sand 15.6 to 16.6m, till boundaries are gradational over short intervals (±100mm) to sharp, gradational upper boundary, APL becoming WTPL at ±7.6m, stiff.				9	SS	100	18	27	
10						10	SS	100	15	26	
						11	ST	100	N/A		
						12	SS	100	22	20	
						13	SS	100	19	26	
						14	SS	100	20	20	
15						15	SS	100	16	20	
						16	ST	100	N/A		GS
						17	SS	100	19	23	
						18	SS	100	14	20	
20						19	SS	100	36	18	
						20	ST	100	N/A	18	GS,γ,DS
						21	SS	100	35	19	
	21.9	CLAY and SILT (Glaciolacustrine): brown with red and grey colour banding, clay and silt trace sand, rare silt or rock clast to 2mm, well laminated throughout with occasional silt lamina to 2mm, (continued)				22	SS	100	15	36	
25						23	SS	100	18	37	

BOREHOLE LOG 85-10-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: DECEMBER 1985
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
x	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (continued): increasing gravel (to 10%) in lower 0.5m, WTPL becoming MWTPL at ±29m, stiff.				24	ST	100	N/A		
						25	SS	100	23	29	
						26	SS	100	16	36	
						27	SS	100	15	39	
30						28	ST	100	N/A	35	GS,γ,DS
						29	SS	100	10	39	
	31.5	SILT and SAND (Till): brown, gravelly silt and sand trace clay, gravel increasing to 40% with depth, massive and uniform, saturated, dense.				30	SS	100	34	7	GS
35											
	36.7	DOLOSTONE: grey, fine grained, crystalline, occasional shale lamina to 2mm, occasional vug to 5mm, several gypsum infilled fractures, fair rock quality.				25	Rc	100	N/A	xxx 61	xxx No. refers to RQD
40											
	40.0	Borehole Terminated at 40.0m in Dolostone									
45											
50											

BOREHOLE LOG 85-11-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY 1986
DRILLING METHOD. 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY. WM/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

GEOLOGIC PROFILE					TEST DATA	SAMPLES				COMMENTS
DEPTH (m)	ELEV. / DEPTH (m) 184.4	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	20 40 60 80 N / 10 20 30 40 w	NUMBER	& TYPE	REC. (%)	N	w (%)	
	0.2	TOPSOIL: dark brown, clayey silt, with roots, organics and straw.									
5		SILT and CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±4.9m, silt and clay trace sand, occasional rock or silt/clay clast to 5mm, laminated to massive, occasional silt lamina to 2mm, fracture with grey lining and gypsum crystals at 5.6m, rusty fracture 5.8 to 5.9m, lower boundary gradational, DTPL, very stiff becoming stiff at ±4.6m.				1 2 3 4 5 6	SS SS SS SS SS SS	80 80 100 100 70 66	26 31 22 22 11 11	23 24 19 23 24 31	
	6.5	CLAYEY SILT (Glaciolacustrine): brown, clayey silt trace sand, generally well laminated, laminae and beds of silt interbedded (to ±35% of total volume) 6.5 to 14.8m, occasional rock or silt/clay clast to 5mm, laminae are generally horizontally bedded with several disturbed zones (to 0.5m thick), poorly developed rusty fracture at 9.7m, till-like zone at 16.8 to 17.4 m, APL, below ±10.5m WTPL, stiff.				7 8 9 10 11 12 13 14 15 16 17 18 19	SS SS SS SS SS SS SS SS SS ST SS SS SS	100 90 100 100 100 100 100 100 100 100 100 100 100	19 16 20 16 16 26 14 15 15 N/A 17 19 12	21 21 21 21 21 20 18 25 24 24 21 35	
10											
15											
20											
	23.3	CLAY and SILT (Glaciolacustrine): dark reddish grey with well developed red and grey banding, (continued)									
25											

BOREHOLE LOG 85-11-1 & 2

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY 1986
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: WM/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
		γ	Unit Weight (kN/m3)	P	Compaction Test
o---o	Water Content (w%)	C	Consolidation Test		
⊠	Composite of 'N' & w%	DS	Direct Shear Test		
▲___■	Plastic & Liquid Limits	T	Triaxial Test (UC, Q, $\bar{R}$)		
_▽_	Water Level (198 / /)	K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DENTAL	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (continued): clay and silt trace sand, rare rock or silt/clay clast to 5mm, increasing clasts below 33.5m, occasional silt lamina to 2mm (commonly paper thin), gradational upper contact, undisturbed horizontal laminations, WTPL, stiff.					20	ST	100	N/A		
							21	SS	100	20	25	
							22	SS	33	20	33	
30							23	SS	100	11	38	
							24	SS	30	30	33	
							25	LS	100	N/A	13	
35	34.2	SAND and SILT (Till): dark greyish brown, gravelly sand and silt trace clay, increasing gravel content with depth (to 40%), three inclusions of laminated silt and clay (50mm to 130mm), saturated, very dense.					26	LS	90	N/A	22	
40	37.8	DOLOSTONE: grey, fine grained, sugary texture, numerous black shale laminae (to 8mm) and bedding planes (decreasing with depth), occasional vug to 25mm (commonly 10mm), few breaks or laminae below ±41m, fair rock quality.					25	Rc		N/A	*** 61	*** No. refers to RQD
	41.5	Borehole Terminated at 41.5m in Dolostone										
45												
50												

BOREHOLE LOG 85-12-1, 2 & 12

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY AND FEBRUARY 1986
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⧗	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 184.1	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: dark brown, clayey silt with organic material, roots and straw.									
		CLAYEY SILT (Glaciolacustrine): dark greyish brown changing to brown at ±4.1m, clayey silt trace sand, occasional rock or silt/clay clast to 10mm, generally well laminated, increasing silt content 3.0 to 7.5m with occasional silt lamina to 3mm, heavily weathered to ±1m, numerous grey lined fractures to ±5m, grey lined fractures 5.1 to 5.3m and 6.4 to 7.1m, DTPL becoming APL at ±4.2m, very stiff.				1	SS	100	38	22	
						2	SS	100	37	21	
						3	SS	100	36	21	
						4	ST		N/A	21	GS,V
						5	SS	100	45	21	
5						6	SS	100	18	28	
						7	SS	100	30	30	
	7.5	CLAYEY SILT (Glaciolacustrine): brown, clayey silt trace sand, massive to well laminated, zones of increasing and decreasing clay content throughout, rare to occasional rock or silt/clay clast to 10mm, upper contact gradational, grey lined fracture 10.1 to 12.1m (containing roots 10.1 to 11.9m), APL becoming WTPL at ±14m, very stiff.				8	SS	100	24	19	
10						9	SS	100	28	19	
						10	ST	100	N/A	18	GS,V
						11	SS	100	29	21	
						12	SS	100	22	18	
15						13	SS	100	28	21	
						14	SS	100	24	17	
						15	ST	100	N/A	21	GS,V
						16	SS	100	22	26	
						17	SS	100	23	20	
20						18	SS	100	30	27	
						19	ST	100	N/A	20	GS,V
						20	SS	100	25	24	
						21	SS	100	23	34	
25	23.8	SILT and CLAY (Glaciolacustrine): (continued)				22	SS	100	15	27	

BOREHOLE LOG 85-12-1, 2 &12

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY AND FEBRUARY 1986
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITOR DETAILS	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
		SILT and CLAY (continued): brown with red and grey banding, silt and clay trace sand, rare to occasional rock or silt/clay clast to 5mm, laminated with occasional silt lamina to 5mm (commonly 2mm), laminations horizontal and undisturbed except slightly disturbed ±27.0 to 28.0m, WTPL, stiff.				23 ST	100	N/A		
						24 SS	100	18	25	
						25 SS	100	25	28	
						26 SS	100	17	24	
30						27 ST	100	N/A	28	GS,V
						28 SS	100	17	29	
						29 SS	100	14	35	
						30 SS	100	12	37	
35						31 SS	100	46	25	
	35.3	SILT and SAND (Till): brown, gravelly silt and sand trace clay, increasing sand and gravel content with depth, saturated, dense.								
	38.1	DOLOSTONE: grey with occasional darker grey bands, fine grained, crystalline, sugary texture, occasional black shale lamina to 3mm thick (commonly less), shale occasionally stylolytic, occasional vug to 40mm, vugs are generally filled with gypsum, gypsum infilling in many fractures, petroliferous odour when freshly broken, overall rock is uniform, lower contact is approximate, rock quality ranges from poor to excellent however is generally fair.							***	*** Nos. refers to RQD
40						1 RC	100	N/A	26	
						2 RC	100	N/A	66	
45						3 RC	100	N/A	97	
50						4 RC	100	N/A	44	

BOREHOLE LOG 85-12-1, 2 & 12

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: JANUARY AND FEBRUARY 1986
DRILLING METHOD: 108 mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' Blows/0.3 m	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
x	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE CONTENT & DENSITY	TEST DATA (20 40 60 80 N / 10 20 30 40 w)	SAMPLES: NUMBER & TYPE	SAMPLES: REC. (%)	SAMPLES: N	SAMPLES: RQD (%)	COMMENTS
		DOLOSTONE (continued):								
55						5 RC	100	N/A	62	
						6 RC	100	N/A	96	
60						7 RC	100	N/A	83	
						8 RC	100	N/A	97	
65	63.5	DOLOSTONE: grey, fine to very fine grained, sugary texture, occasional shale lamina to 2mm (commonly stylolitic), vugs occasional to common, generally 3 to 5mm (rarely to 30mm), numerous fossil replacements visible, many vugs and fossil fragments are gypsum filled, overall the rock contains more unfilled vugs than elsewhere on site (maximum 2% by volume), rock quality is generally fair.				9 RC	100	N/A	76	
						10 RC	100	N/A	68	
70						11 RC	100	N/A	69	
						12 RC	100	N/A	63	
75	72.4	Borehole Terminated at 72.4m in Dolostone								

BOREHOLE LOG 85-13-1

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM, PROJECT NO.: 85-GG & 85-GT
DRILLING DATE: FEBRUARY TO MARCH, 1986 LOGGED/CHECKED BY: ASB/AJC/RDP
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES			
SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS					
x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲---▲	Plastic & Liquid Limits	DS	Direct Shear Test		
_V_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 185.1	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE & ATTERBERG LIMITS	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: very dark greyish brown, clayey silt, roots and organics.									
		SILT AND CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±5.0m, silt and clay trace sand interbedded with clayey silt trace sand to 3.1m, silt and clay trace sand 3.1 to 5.9m, heavily weathered to ±1.0 m, grey lined fractures with gypsum crystals common to ±3.0m, occasional rock or silt /clay clast to 5mm, laminated with occasional silt laminae to 2mm, gypsum crystals along silt laminae ±5.0 to ±5.5m, DTPL to 3.1m, changing to APL, very stiff to stiff.				1	SS	100	21	22	
						2	SS	100	28	24	
5						3	SS	100	17	29	
	5.9					4	SS	100	20	19	
						5	SS	100	18	18	
		CLAYEY SILT (Glaciolacustrine and Till): brown, clayey silt trace sand and (locally) gravel, massive to very faintly laminated till 5.9 to 11.5m, gradational boundaries, massive to poorly laminated glaciolacustrine 11.5 to 24.4m, occasional silt lamina to 2mm thick below 17.5m, inclusion of contorted laminated silt and clay 10.9 to 11.3m, APL to ±15m, very stiff to stiff.				6	SS	100	15	17	
10						7	SS	100	21	17	
						8	SS	100	22	20	
						9	SS	100	22	18	
15						10	SS	100	22	19	
						11	SS	100	21	23	
						12	SS	100	22	19	
20						13	SS	100	22	18	
						14	SS	100	21	21	
						15	SS	100	17	21	
25	24.4	CLAY & SILT (Glaciolacustrine):(Cont'd)				16	SS	100	18	18	

BOREHOLE LOG 85-13-1

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM, PROJECT NO.: 85-GG & 85-GT
DRILLING DATE: FEBRUARY TO MARCH, 1986 LOGGED/CHECKED BY: ASB/AJC/RDP
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲---■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOD. & NATIOL.	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY AND SILT (Glaciolacustrine): (continued) brown with red and grey banding, clay and silt trace sand, well laminated, silt laminae to 3mm thick are common throughout most of unit, rare to occasional rock or silt/clay clast to 5mm, WTPL, consistency is generally stiff to firm.				17 SS	100	15	31	
						18 SS	100	15	25	
						19 SS	100	8	26	
30						20 SS	100	26	23	
						21 SS	100	22	26	
						22 SS	100	23	36	
35						23 SS	100	21	27	
						24 SS	100	11	27	
	37.1	SANDY SILT (Till): brown, gravelly sandy silt trace clay, gravel to 35%, saturated very dense.				25 SS	100	58/ .06m	8	
	38.0	DOLOSTONE: grey, fine grained, sugary textured, frequent black shale laminae to 3mm, petroliferous odour when broken vugs to 10mm are common, ±50% of vugs are infilled with gypsum, rock quality is fair.				1 Rc	100	N/A	*** 65	*** No. Refers to RQD
40	40.9	Borehole Terminated at 40.9 m in Dolostone								
45										
50										

BOREHOLE LOG 85-14-1

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: MARCH 1986
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 181.7	STRATIGRAPHIC DESCRIPTION	STRATA	MONITOR	DENTAL	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: very dark brown, clayey silt, organic rich, numerous roots, twigs etc.										
5		SILT AND CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±4.0m, silt and clay trace sand, occasional rock or silt/clay clast to 10mm, 0.2 to 2.5m laminated and interbedded clayey silt and silty clay, 2.5 to 8.0m massive to laminated silt and clay with occasional clayey silt lamina to 10mm, heavily weathered to ±1.0m, grey lined fractures to ±3.0m, DTPL, becoming APL at ±2m, very stiff to stiff, becoming firm at ±4m.					1	SS	100	31	20	
							2	SS	100	16	31	
							3	SS	100	8	25	
							4	SS	100	7	24	
							5	SS	100	6	27	
	8.0	CLAYEY SILT (Glaciolacustrine): brown, clayey silt trace sand, rare to occasional rock or silt/clay clast to 5mm (rarely to 10mm), generally laminated with occasional massive zones (especially below 17.7m), decreased clay content 10.1 to 10.5m and 14.1 to 17.7m rare to occasional silt lamina to 2mm, silt laminae are thin and discontinous (<1mm) below 17.7m, WTPL, consistency is generally firm, some soft and stiff zones.					6	SS	100	8	20	
10							7	SS	100	6	21	
							8	SS	100	8	22	
							9	SS	100	6	24	
15							10	SS	100	10	22	
							11	SS	100	6	23	
							12	SS	100	11	27	
20							13	SS	100	12	26	
	21.2	CLAY AND SILT (Glaciolacustrine): brown with red and grey bands, clay and silt trace sand, rare rock or silt/clay clast to 5mm, well laminated with occasional silt lamina to 2 mm, (Continued)					14	SS	100	8	36	
							15	SS	100	7	29	
25							16	SS	100	8	27	

BOREHOLE LOG 85-14-1

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: MARCH 1986
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: ASB/AJC/RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE CONDITIONS	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY AND SILT (Glaciolacustrine):(cont'd) laminations are horizontal with several thin zones (maximum 0.5m thick) with slightly disturbed bedding, sharp upper and lower boundaries, WTPL, MWTPL below ±25m, firm.				17	SS	100	8	34	
						18	SS	100	7	38	
						19	SS	100	8	32	
30	29.2	SAND AND SILT (Till): brown, gravelly sand and silt trace clay, increasing gravel content with depth (to 40%), saturated, very dense.				20	SS	100	74	8	
35						22	SS		70/ .07m	6	
						23	SS		102/ .15m	8	
40	39.5	DOLOSTONE: grey, fine grained, sugary textured, numerous black bands, numerous shale partings to 1mm, occasional vugs, rock quality is fair.				24	Rc	100	N/A	*** 52	*** No. Refers to RQD
										52%	**R.Q.D.
	42.7	Borehole Terminated at 42.7m in Dolostone									
45											
50											

BOREHOLE LOG 85-15-1

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM, PROJECT NO.: 85-GG & 85-GT
DRILLING DATE: FEBRUARY TO MARCH, 1986 LOGGED/CHECKED BY: EJK/ASB/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m /RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOTTLES & DENSITY OR CONSISTENCY	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	182.8										
	0.2	TOPSOIL: very dark brown, clayey silt, numerous twigs and roots.									
		SILT AND CLAY (Glaciolacustrine): dark greyish brown changing to brown at ±6.0m, silt and clay trace sand, occasional rock or silt/clay clast to 5mm (rarely to 10mm), massive to laminated occasional silt lamina to 2mm particularly below 5.3m, heavily fractured and weathered to ±2.0m, many silt laminae are rusty to ±5.0m, black rusty or grey fractures common to ±5.0m, DTPL to 3.7m, changing to WTPL, very stiff.				1	SS	100	18	22	
						2	SS	100	31	22	
5						3	SS	100	18	22	
						4	SS	100	20	21	
						5	SS	100	31	23	
	8.2	CLAYEY SILT (Glaciolacustrine with interbedded Till): brown, clayey silt trace sand and (locally) gravel, laminated to massive, glaciolacustrine 8.2 to 18.0m, rare to occasional rock or silt/clay clast to 10mm, occasional silt lamina ((1mm) commonly discontinuous, till with interbedded laminated silt and clay 18.0 to 22.7m, massive to poorly laminated, WTPL, consistency is generally stiff, some very stiff and firm zones.				6	SS	100	17	22	
10						7	SS	100	20	21	
						8	SS	100	18	29	
						9	SS	100	11	39	
15						10	SS	100	10	28	
						11	SS	100	15	23	
						12	SS	100	16	26	
20						13	SS	100	17	24	
						14	SS	100	21	23	
	22.7	CLAY AND SILT (Glaciolacustrine): (continued)				15	SS	100	22	36	
25						16	SS	100	17	29	

BOREHOLE LOG 85-15-1

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM, PROJECT NO.: 85-GG & 85-GT
DRILLING DATE: FEBRUARY TO MARCH, 1986 LOGGED/CHECKED BY: EJK/ASB/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m /RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⁑	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE & ATTERBERG LIMITS	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY AND SILT (Glaciolacustine): (Continued) brown with red and grey banding, clay and silt trace sand, occasional silt lamina to 2mm, rare to occasional rock or silt/clay clast to 5mm, WTPL, MWTPL at ±30m, stiff to firm.				17	SS	100	23	32	
						18	SS	100	11	28	
						19	SS	100	17	30	
30						20	SS	100	11	41	
						21	SS	100	15	35	
						22	SS	100	10	37	
35	34.4	SILT (Till): brown, gravelly clayey silt trace sand, increasing gravel with depth, (to 30%), saturated, very dense.				23	SS	100	55	16	
	35.6	DOLOSTONE: grey, fine grained, crystalline, black banding and occasional black shale lamina to 2mm, occasional gypsum filled vug to 10mm, rock quality is fair.				26	Rc		N/A	*** 71	*** No. Refers to RQD
40											
	40.3	Borehole Terminated at 40.3m in Dolostone									
45											
50											

BOREHOLE LOG 85-16-1

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM, PROJECT NO.: 85-GG & 85-GT
DRILLING DATE: MARCH 1986 LOGGED/CHECKED BY: ASB/EJK/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m /RDP

SAMPLE TYPES			
SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS					
x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	r	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲---■	Plastic & Liquid Limits	DS	Direct Shear Test		
_v_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 186.0	STRATIGRAPHIC DESCRIPTION	STRATA	MOTTLES	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: very dark greyish brown, clayey silt, numerous roots									
5		SILT AND CLAY (Glaciolacustrine): dark greyish brown changing to dark grey and brown at ±4.0m, silt and clay trace sand interbedded with clayey silt trace sand, laminated with massive zones, rare to occasional rock clast to 5mm, heavily weathered and fractured to ±1.0m, fractures to 4.4m, fine sandy silt 3.9 to 4.4m, gradational lower boundary, DTPL to 2.4m, WTPL below 2.4m, very stiff to stiff, becoming firm at ±5m.				1	SS	100	26	22	
						2	SS	100	16	31	
						3	SS	100	18	27	
						4	SS	100	8	22	
						5	SS	100	6	37	
						6	SS	100	6	35	
	9.1	CLAYEY SILT (Glaciolacustrine with interbedded Till): brown, clayey silt trace sand and (in till) gravel, glaciolacustrine 9.1 to 10.4m and 11.0 to 18.1 m, laminated, occasional rock or silt/clay clast to 10mm, zones of increasing and decreasing clay content 11.0 to 18.1m, till 10.4 to 11.0m and 18.1 to 20.9m, massive to very faintly laminated, variable clast content to ±10%, contacts gradational, WTPL to non-plastic, stiff.				7	SS	100	10	21	
10						8	SS	100	12	18	
						9	SS	100	18	19	
15						10	SS	100	14	19	
						11	SS	100	17	20	
						12	SS	100	14	17	
20						13	SS	100	25	21	
	20.9	CLAY AND SILT (Glaciolacustrine): brown with red and grey banding, clay and silt trace sand, rare to occasional rock or silt/clay clast to 5mm, well laminated with occasional silt lamina to ±2mm, MWTPL, stiff to firm.				14	SS	100	17	30	
						15	SS	100	13	37	
25		(continued)				16	SS	100	8	39	

BOREHOLE LOG 85-16-1

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM, PROJECT NO.: 85-GG & 85-GT
DRILLING DATE: MARCH 1986 LOGGED/CHECKED BY: ASB/EJK/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m /RDP

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
A___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DENOTATIONS	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	SAMPLE NUMBER	SAMPLE TYPE	REC. (%)	N	w (%)	COMMENTS
	25.4	CLAY AND SILT (Glaciolacustrine)(Cont'd):				x o	17	SS	100	17	22	
	26.6	SILT (Till): brown, gravelly silt trace sand and clay, ±25% gravel, saturated, compact.										
30		DOLOSTONE: medium to dark grey, fine grained, sugary textured, occasional vug to 10mm especially below ±28.0m, occasional shale lamina to 3mm, excellent rock quality					19	Rc		N/A	xxx 95	xxx No. Refers to RQD
	30.2	Borehole Terminated at 30.2m in Dolostone										
35												
40												
45												
50												

BOREHOLE LOG 85-17

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: MARCH 12, 1986
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/AJC

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
Δ___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

GEOLOGIC PROFILE					TEST DATA	SAMPLES				COMMENTS
DEPTH (m)	ELEV. / DEPTH (m) 184.3	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE	DENSITY & CONSISTENCY	NUMBER	TYPE	REC. (%)	N	w (%)	
	0.5	ORGANICS: very dark brown, numerous fiberous fragments, roots, seeds, leaves, moss, slight decomposition, fiberous and spongy.								30	
	0.9	SILTY CLAY to CLAYEY SILT(swale sediment) grey, silty clay to clayey silt, several rock clasts to 40mm, occasional organic lamina to 2mm, WTPL, very soft.								22, 28, 24, 25	
5	5.3	SILT and CLAY (Glaciolacustrine): brown with muted red and grey bands, silt and clay to silty clay trace sand, occasional rock or silt/clay clast to 5mm, laminated, sharp upper boundary, occasional silt lamina to 1mm, laminae often discontinuous, WTPL, firm to stiff.								24, 21, 21	
10	9.9	CLAYEY SILT (Glaciolacustrine): brown, clayey silt trace sand, gradational upper boundary, massive to faintly laminated, occasional rock or silt/clay clast to 5mm, WTPL, firm to stiff.								20	
		Borehole Terminated at 9.9m in Clayey Silt									
15											
20											
25											

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BOREHOLE LOG 85-18

PROJECT: OWMC, PHASE 4B GEOSCIENCE PROGRAM,
DRILLING DATE: MARCH 12, 1986
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING

PROJECT NO.: 85-GG & 85-GT
LOGGED/CHECKED BY: EJK/AJC

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
▲---■	Plastic & Liquid Limits	DS	Direct Shear Test		
_V_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) 184.0	STRATIGRAPHIC DESCRIPTION	STRATA	MODENTIFICATION & ORIGIN	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLES NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
	0.1	ORGANICS: dark brown, fiberous.								
	2.5	SILTY CLAY to CLAYEY SILT(swale sediment) dark grey, silty clay to clayey silt, numerous black organic rich laminae to 5mm (decreasing frequency with depth), occasional silt lamina to 5mm, occasional small shell, WTPL, soft.							32, 22, 22, 34, 25	
5	4.4	SILT and CLAY (Glaciolacustrine): brown with poorly developed red and grey bands, silt and clay trace sand, rare to occasional rock or silt/clay clast (5mm), massive to faintly laminated, WTPL, firm.							26, 19	
		CLAYEY SILT (Glaciolacustrine and Till): brown, clayey silt trace sand and gravel (locally), till 4.4 to 5.7m, gradational contacts, rock clasts to 70mm, glacio-lacustrine 5.7 to 9.8m, massive to faintly laminated, occasional rock or silt/clay clast to 50mm, WTPL, stiff.							19, 21	
10	9.8	Borehole Terminated at 9.8m in Clayey Silt								
15										
20										
25										

C1.3 PHASE 4A BOREHOLE LOGS (REVISED 1986)

The five borehole logs which follow were completed as part of the 1984 Phase 4A drilling at Site LF-9C. The borehole logs were revised to reflect the expanded data base acquired during the 1985 drilling program. The revisions focused on the re-interpretation of the position of the upper and lower contacts of the Halton Unit. A discussion of the Halton Unit is provided in Section 2.3 of the accompanying report. Minor changes in the textural description to reflect greater accuracy obtained from laboratory test results have also been included. Other data remain as presented in the Phase 4A reporting (GLAL, 1985a).

BOREHOLE LOG 84-GL-1
(Revised)

PROJECT: OWMC, PHASE 4A DRILLING AND SAMPLING, PROJECT NO.: 4A
DRILLING DATE: SEPTEMBER 1984 LOGGED/CHECKED BY: EJK/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲---■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) ±185	STRATIGRAPHIC DESCRIPTION	STRATA	MOINTIOR DETAILS	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
	0.3	TOPSOIL: dark greyish brown, clayey silt to silt, with roots and vegetation.								
		CLAYEY SILT to SILTY CLAY (Glaciolacustrine): dark greyish brown to brown changing to grey at ±3.4m, clayey silt to silty clay trace sand, occasional rock or silt/clay clasts to 10mm, generally well laminated with occasional red and grey colour bands, occasional silt lamina to 1mm, heavily weathered to ±1m, fractures throughout, DTPL to 2.3m, changing to APL, stiff to very stiff.				1 SS	75	22	19	
						2 SS	75	22	23	
5						3 SS	80	22	19	
	5.1					4 SS	100	18	19	
		CLAYEY SILT (Glaciolacustrine and Till): grey to brown, clayey silt trace sand and (locally) gravel, mainly massive to poorly laminated, occasional silt lamina to 1mm, silt laminae common 8.9 to 9.2m and 11.3 to 11.8m, decreased clay content 17.1 to 17.4m, 10mm thick oblique inclusion of very fine sand at 17.9m, several grey lined fractures to 5.5m, massive to faintly laminated till 20.0 to 20.4, till contacts gradational, APL to 10m, WTPL below 10m, stiff to very stiff.				5 SS	100	26	17	
10						6 SS	100	24	19	
						7 SS	100	17	22	
						8 SS	100	11	29	
						9 SS	100	14	27	
15						10 SS	100	18	26	
						11 SS	100	18	25	
						12 SS	100	19	22	
20						13 SS	100	23	27	
	20.4	CLAY and SILT (Glaciolacustrine): brown with grey and red banding, silty clay to clayey silt trace sand, occasional rock or silt/clay clasts to 10mm, well laminated with occasional silt lamina to 1mm, very fine sand 21.2 to 21.7m, WTPL, very stiff to stiff. (continued)				14 SS	100	88	19	
						15 SS	100	21	25	
25						16 SS	100	21	26	

BOREHOLE LOG 84-GL-1
(Revised)

PROJECT: OWMC, PHASE 4A DRILLING AND SAMPLING, PROJECT NO.: 4A
DRILLING DATE: SEPTEMBER 1984 LOGGED/CHECKED BY: EJK/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_V_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE CONTENT & ATTERBERG LIMITS	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLES: NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (Glaciolacustrine): (continued)				17	SS	100	20	25	
						18	SS	100	23	26	
30						19	SS	100	17	36	
						20	SS		19	34	
	31.6	SILT (Till): brown gravelly sandy to clayey silt, saturated, very dense.				21	SS	40	15	12	
						22	SS	40	*	5	* 55/0.2m
						23	SS	0	**		** 75/0.0m
35	34.8	DOLOSTONE: light grey, fine textured, occasional vugs and shale laminae to 5mm thick, rock quality is very poor.				24	RC		N/A	*** 0	*** No. Refers to RQD
	35.6										
		Borehole Terminated at 35.6m in Dolostone									
40											
45											
50											

BOREHOLE LOG 84-GL-2
(Revised)

PROJECT: DWMC, PHASE 4A DRILLING AND SAMPLING, PROJECT NO.: 4A
DRILLING DATE: AUGUST 1984 LOGGED/CHECKED BY: EJK/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⧗	Composite of 'N' & w%	C	Consolidation Test		
▲---▲	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) ±185	STRATIGRAPHIC DESCRIPTION	STRATA	METHOD & INTERVALS	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLES NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
	0.3	TOPSOIL: very dark greyish brown, clayey silt, roots and vegetation								
5		SILTY CLAY to CLAYEY SILT: (Glaciolacustrine): dark greyish, brown changing to grey at ±4.1m, silty clay to clayey silt trace sand, occasional rock clast to 10mm, laminated, heavily weathered to ± 1m, occasional fractures with grey infilling to 5.5m, DTPL to 4.1m, APL below 4.1m, very stiff to stiff.				1 SS 2 SS 3 SS 4 SS		19 25 17 14	23 19 26 16	
	6.5	CLAYEY SILT (Interbedded and gradational Till and Glaciolacustrine): dark greyish brown to brown, clayey silt trace sand and (locally) gravel, till dominant 6.5 to 8.6m and ±13.0 to 18.7m, till is indistinctly laminated and contains variable rock clasts to ±15 %, clast banding visible, all till boundaries gradational, glaciolacustrine dominant 8.6 to ±13.0m, moderately to poorly laminated, occasional rock or silt/clay clast to 10mm, 10mm thick lamina of silty fine sand at 10.7m, APL to ±9m, WTPL below ±9m, stiff to very stiff.				5 SS 6 SS 7 SS 8 SS 9 SS 10 SS 11 SS 12 SS		11 14 17 11 14 15 13 14	16 19 19 19 19 20 22 20	
10										
15										
20	18.7	CLAY and SILT (Glaciolacustrine): brown with red and grey bands, silt and clay trace sand, occasional rock or silt/clay clast to 2mm, well laminated throughout with occasional silt lamina to 1mm (rarely to 5mm), occasional very fine sand lamina to 3mm 26.2 to 29.2m, several inclusions of reddish brown silt till to 10mm thick at 20.5m, WTPL, MWTPL below 25.5m, firm to stiff. (continued)				13 SS 14 SS 15 SS 16 SS		9 8 8 10	32 39 34 32	
25										

BOREHOLE LOG 84-GL-2
(Revised)

PROJECT: OWMC, PHASE 4A DRILLING AND SAMPLING,
DRILLING DATE: AUGUST 1984
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

PROJECT NO.: 4A
LOGGED/CHECKED BY: EJK/AJC

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲---■	Plastic & Liquid Limits	DS	Direct Shear Test		
_v_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE CONTENT & DENSITY INDICATORS	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	SAMPLE NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (Continued):				17 SS		8	35	
						18 SS		14	37	
		GRAVELLY SILT (Till): brown, sandy, clayey gravelly silt, very dense, saturated.				19 SS		10	38	
30	29.3					20 SS		*	N/A	* 25/0.15 m no sample
	30.1	DOLOSTONE: light grey, fine texture, occasional thin (to 5mm) shale laminae.				21 RC	100			
	31.4	Borehole Terminated at 31.4m in Dolostone								
35										
40										
45										
50										

BOREHOLE LOG 84-GL-3
(Revised)

PROJECT: OWMC, PHASE 4A DRILLING AND SAMPLING, PROJECT NO.: 4A
DRILLING DATE: SEPTEMBER 1984 LOGGED/CHECKED BY: ASB/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES			
SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS					
x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) ±185	STRATIGRAPHIC DESCRIPTION	STRATA	MONITOR	DEPTH & ELEVATIONS	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	SAMPLE NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
	0.3	TOPSOIL: dark yellowish brown, silt, occasional root.									
5	5.1	SILT and CLAY (Glaciolacustrine): dark greyish brown, silt and clay trace sand, laminated, occasional small red and grey colour band, occasional rock or silt/clay clast to 10mm, occasional silt lamina to 1mm, heavily weathered to ±1m, gypsum crystals 3.6 to 4.0m, occasional grey lined fracture throughout unit, DTPL, stiff to hard.					1 SS		24	21	
							2 SS		23	19	
							3 SS		12	26	
							4 SS		39	14	
		CLAYEY SILT (Glaciolacustrine minor Till): dark greyish brown changing to brown at ±5.7m, clayey silt trace sand, mainly massive to ±11m, till zone 16.8 to 17.3m, gradational contacts, occasional rock clast to 5mm, fracture with brown discolouration 8.8 to 10.3m, DTPL to 7.2m, APL 7.2 to 12m, WTPL below 12m, stiff to hard.					5 SS		34	15	
10							6 SS		24	17	
							7 SS		16	17	
							8 SS		18	21	
							9 SS		11	24	
15							10 SS		12	25	
							11 SS		11	25	
	17.9	CLAY and SILT (Glaciolacustrine): brown with red and grey banding, clay and silt trace sand, laminated with occasional silt lamina to 1mm, occasional rock or silt/clay clast to 10mm, increased rock clast content 25.0 to 28.5m, WTPL, stiff to firm.					12 SS		11	24	
20							13 SS		8	23	
							14 SS		10	31	
							15 SS		9	27	
		(continued)									
25							16 SS		10	29	

BOREHOLE LOG 84-GL-3
(Revised)

PROJECT: OWMC, PHASE 4A DRILLING AND SAMPLING, PROJECT NO.: 4A
DRILLING DATE: SEPTEMBER 1984 LOGGED/CHECKED BY: ASB/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES			
SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS					
x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_V_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITOR	DETAIL & NO.	TEST DATA (N: 20 40 60 80; w: 10 20 30 40)	NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (Continued):					17 SS		12	28	
							18 SS		11	26	
							19 SS		9	33	
30							20 SS		10	28	
							21 SS		9	34	
	32.5	GRAVELLY SILT (Till): dark greyish brown, gravelly, clayey, sandy silt, 80mm thick medium to coarse sand inclusion, saturated, dense.					22 SS		37	9	
35	33.8	DOLOSTONE: grey, fine grained, occasional shale lamina, occasional vug to 20mm, ±50% of vugs and fractures infilled with gypsum and/or calcite, fair rock quality.					23 RC	100	N/A	*** 55	*** No. Refers to RQD
	37.8	Borehole Terminated at 37.8m in Dolostone									
40											
45											
50											

BOREHOLE LOG 84-GL-4
(Revised)

PROJECT: OWMC, PHASE 4A DRILLING AND SAMPLING, PROJECT NO.: 4A
DRILLING DATE: AUGUST 1984 LOGGED/CHECKED BY: ASB/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲---■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) ±186	STRATIGRAPHIC DESCRIPTION	STRATA	MOTTLES	DENSITY	SAMPLE NUMBER	SAMPLE TYPE	REC. (%)	N	w (%)	COMMENTS
	0.2	TOPSOIL: black, silt with organics and occasional roots.									
5		SILT and CLAY (Glaciolacustrine): dark greyish brown changing to grey to brown at ±5.7m, silt and clay trace sand, occasional rock or silt/clay clast to 10mm, laminated, heavily weathered to ±1m, numerous fractures to 2.7m, DTPL to 1.5m, APL 1.5 to 3.1m, WTPL below 3.1m, firm to very stiff.				1 2 3 4	SS SS SS SS		16 11 7 5	24 23 30 22	
	6.8	CLAYEY SILT (Glaciolacustrine and Till): brown, clayey silt trace sand and (locally) gravel, till 6.8 to 10.4m, massive to faintly laminated, gradational contacts, glaciolacustrine 10.4 to 20.5m, faintly laminated to well laminated, occasional silt lamina to 1mm thick, silt laminae common 12.0 to 13.0m, occasional rock or silt/clay clast to 5mm (rarely to 20mm), several zones of increased clast content (till-like), WTPL, stiff to firm.				5 6 7 8 9 10 11 12 13	SS SS SS SS SS SS SS SS SS		11 12 13 15 10 14 9 11 12	20 13 21 21 21 23 26 30 26	
10											
15											
20											
	20.5	CLAY and SILT (Glaciolacustrine): brown with red and grey banding, clay and silt trace sand, laminated, occasional silt lamina to 1mm, silt laminae common 20.5 to 24.0m and below 30.0m, occasional rock or silt/clay clast to 10mm, WTPL, MWTPL below 28m, stiff to firm. (continued)				14 15 16	SS SS SS		8 10 14	29 30 30	
25											

BOREHOLE LOG 84-GL-4
(Revised)

PROJECT: OWMC, PHASE 4A DRILLING AND SAMPLING, PROJECT NO.: 4A
DRILLING DATE: AUGUST 1984 LOGGED/CHECKED BY: ASB/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES			
SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS					
x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
⊠	Composite of 'N' & w%	C	Consolidation Test		
▲___■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORING DETAILS	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER & TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (Continued):				17 SS		12	28	
						18 SS		13	26	
						19 SS		10	36	
30						20 SS		9	37	
	31.1	GRAVELLY SILT (Till): dark greyish brown, clayey to sandy gravelly silt, saturated, very dense.				21 SS		69	7	
						22 SS		79/ .15m	7	
35	34.4	DOLOSTONE: light grey, fine grained, finely banded with occasional shale lamina, occasional vug to 10mm, rock quality is very poor.				23 RC		N/A	*** 0	*** No. Refers to RQD
	35.5	Borehole Terminated at 35.5m in Dolostone								
40										
45										
50										

BOREHOLE LOG 84-GL-5
(Revised)

PROJECT: OWMC, PHASE 4A DRILLING AND SAMPLING, PROJECT NO.: 4A
DRILLING DATE: AUGUST 1984 LOGGED/CHECKED BY: EJK/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES			
SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS					
x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
o---o	Water Content (w%)	γ	Unit Weight (kN/m3)	P	Compaction Test
*	Composite of 'N' & w%	C	Consolidation Test		
▲---■	Plastic & Liquid Limits	DS	Direct Shear Test		
_▽_	Water Level (198 / /)	T	Triaxial Test (UC, Q, $\bar{R}$)		
		K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m) ±184	STRATIGRAPHIC DESCRIPTION	STRATA	MOISTURE CONTENT	DEPTH & NO.	TEST DATA (20 40 60 80 N; 10 20 30 40 w)	SAMPLE NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
	0.3	TOPSOIL: very dark grey, silty clay, organic rich, numerous roots.										
5		SILT and CLAY (Glaciolacustrine): dark greyish brown to dark grey changing to grey at ±5.2m, occasional red and grey colour bands, silt and clay trace sand, occasional rock or silt/clay clasts to 10mm, occasional silt lamina to 1mm, decreased clay content 1.9 to 3.6m and 4.1 to 4.4m, heavily weathered to ±1m, fractures to 3.3m, APL, firm to very stiff.					1	SS		23	25	
							2	SS	77	20	23	
							3	SS	78	16	22	
							4	SS	80	5	33	
	7.6	CLAYEY SILT (Glaciolacustrine and Till): brown, clayey silt trace sand and (locally) gravel, glaciolacustrine 9.6 to 20.5m, well laminated to faintly laminated with occasional silt lamina to 1mm, 10mm thick lamina silty fine sand at 18.2m, occasional rock clast to 10mm (rarely larger), decreased clay content 10.2 to 12.0m, till 7.6 to 9.6m, faintly laminated, gradational contacts, WTPL, firm to stiff.					5	SS	75	7	20	
10							6	SS	90	8	20	
							7	SS	60	11	19	
							8	SS	80	12	25	
							9	SS	100	8	25	
15							10	SS	100	9	22	
							11	SS	100	9	22	
							12	SS	100	18	23	
20							13	SS	100	17	26	
	20.5	CLAY and SILT (Glaciolacustrine): brown with red and grey banding, clay and silt trace sand, rare to occasional rock or silt/clay clast to 10mm, WTPL, stiff to firm. (continued)					14	SS		6	27	
							15	SS	100	11	32	
25							16	SS	100	11	29	

BOREHOLE LOG 84-GL-5
(Revised)

PROJECT: OWMC, PHASE 4A DRILLING AND SAMPLING, PROJECT NO.: 4A
DRILLING DATE: AUGUST 1984 LOGGED/CHECKED BY: EJK/AJC
DRILLING METHOD: 108mm ID HOLLOW STEM AUGERS WITH CONTINUOUS SPLIT TUBE SAMPLING AND SPLIT SPOON SAMPLES EVERY 1.5 m

SAMPLE TYPES

SS	Split Spoon (51 mm OD)	WS	Wash Sample
ST	Shelby Tube (76 mm OD)	AS	Auger Sample
T	Split Tube (102 mm OD x 1.5m)	BU	Bulk Sample
RC	Rock Core (NX size, 54 mm)	BL	Block Sample
Rc	Rock Core (HQ size, 64 mm)		
LS	Split Spoon (102 mm OD)		

SYMBOLS AND DEFINITIONS

x---x	Penetration Resistance 'N' (Blows/0.3 m)	GS	Grain Size Analysis	V	Vane Test
		γ	Unit Weight (kN/m3)	P	Compaction Test
o---o	Water Content (w%)	C	Consolidation Test		
*	Composite of 'N' & w%	DS	Direct Shear Test		
▲---■	Plastic & Liquid Limits	T	Triaxial Test (UC, Q, $\bar{R}$)		
_v_	Water Level (198 / /)	K	Hydraulic Conductivity (m/s)		

DEPTH (m)	ELEV. / DEPTH (m)	STRATIGRAPHIC DESCRIPTION	STRATA	MONITORS	DEPTH	TEST DATA (20 40 60 80 N / 10 20 30 40 w)	NUMBER	TYPE	REC. (%)	N	w (%)	COMMENTS
		CLAY and SILT (Continued):				x o	17	SS	100	10	26	
						x o	18	SS	100	17	32	
						x o	19	SS	100	11	29	
30						x o	20	SS	100	13	30	
						x o	21	SS	100	11	32	
	32.6	GRAVELLY SANDY SILT (Till): brown, gravelly sandy silt, 240mm thick inclusion medium sand, saturated, compact.				xo	22	SS		17	9	
	33.6											
35	34.6	DOLOSTONE: grey, fine grained, with shale laminae and vugs to 10mm, rock quality is poor.					23	RC	90	N/A	*** 27	*** No. Refers to RQD
		Borehole Terminated at 34.6m in Dolostone										
40												
45												
50												

C2 FIELD STATION DESCRIPTIONS

The location of the field stations are shown in Figure 2-1 (in pocket). Field stations include shallow holes completed by either a 25 mm hand soil auger, a 20 mm hand soil probe or shallow trenches completed with excavation machinery.

No geologic samples were collected at the field stations.

Field stations 1 through 5 were completed in 1984 and are from the Phase 4A report. All other stations were completed during the summer of 1986.

The field stations are generally located in the swales in order to assess the extent of the materials in these depressions. Geologic information obtained focused on factors which would assist in the identification of the boundary between the Swale Sediments and the underlying Upper Glaciolacustrine Units. The consistency of the materials, the presence of organics and the presence of glaciolacustrine silt/clay or rock clasts proved particularly useful in this regard. Other observations included the textural composition and the presence of normal geologic phenomena similar to those noted in the borehole logs.

Three of the field stations (34, 35, 36) involved digging a ± 2 m deep trench from the swale up onto the adjacent ridge.

C2 FIELD STATION LOGS, SITE LF-9C

Field Station #1 Sept. 6, 1984

Hand auger hole

0.0-0.3 m	fibrous, woody organics in a silt matrix
0.3-0.6 m	dark brown silty clay, trace of roots
0.6-1.5 m	medium grey clay, trace of roots at 0.9-1.1 m and trace of silt 1.2 to 1.5 m WTPL

Field Station #2 Sept. 6, 1984

Hand auger hole

0.0-0.3 m	medium grey clay with a trace of silt (standing water in the area)

Field Station #3 Sept. 6, 1984

Hand auger hole

0.0-0.3 m	fibrous to woody organics in a silt matrix dark grey
0.3-0.6 m	brown grey clay with silt, WTPL
0.6-1.5 m	medium grey clay, trace of silt, WTPL - water level 0.05 m below surface

Field Station #4 Sept. 6, 1984

Hand auger hole

0.0-0.6 m	grey clay, contains roots at 0.0-0.3 m oxidized, WTPL
0.6-0.9 m	medium grey to dark grey clay, WTPL
0.9-1.4 m	dark grey to blue grey clay, WTPL
1.4-1.5 m	medium grey to light grey clay, trace of silt, WTPL
1.5-1.7 m	light to medium grey clay, WTPL
1.7-1.8 m	light grey to light brown-grey clay, WTPL
1.8-2.3 m	grey clay, WTPL
2.3-2.4 m	red brown to grey clay, WTPL

Field Station #5 Sept. 6, 1984

Hand auger hole

0.0-0.3 m	topsoil, roots, silty
0.3-0.5 m	brown-grey clay
0.5-0.8 m	grey clay, APL
0.8-1.2 m	grey clay, WTPL

Field Station #6 July 14, 1986

Hand soil probe in lowest part of depression

0.0-0.3 m	silt and clay trace organics, WTPL, soft (Swale Sediments)
0.3-1.2 m	mottled grey silt and clay trace sand, occasional rock clast to 5 mm, DTPL, crumbly (Upper Glaciolacustrine Unit)

Field Station #7 July 14, 1986

Hand soil probe in depression adjacent to drainage ditch

0.0-0.3 m	mottled dark grey organic rich silt (Swale Sediments)
0.3-0.9 m	grey with rusty mottling, silt and clay trace sand, occasional rock clast to 5 mm, numerous fractures, grading to DTPL and very stiff at base of hole (Upper Glaciolacustrine Unit)

Field Station #8 July 14, 1986

Hand soil probe approximately 15 m from centre of depression (up to 1 m standing water)

0.0-0.6 m	dark brown fiberous organics, partially decomposed (Swale Sediments)
0.6-0.9 m	grey silt and clay trace sand, occasional rock clasts, indistinct laminations, APL, firm to stiff (Upper Glaciolacustrine Unit)

Field Station #9 July 14, 1986

Hand soil probe in centre of depression (up to 0.3 m standing water)

0.0-0.4 m	grey silty clay and organics, mainly organics at top grading to mainly clay (Swale Sediments)
0.4-1.0 m	grey silty clay trace sand below 0.9 m, occasional organic fragments, WTPL, firm (Swale Deposits changing to probable Glaciolacustrine at approximately 0.9 m).

Field Station #10 July 14, 1986

Hand soil probe in lowest part of long linear depression

0.0-0.5 m	dark brown fibrous organics, little decomposition (Swale Sediments)
0.5-1.0 m	grey silty clay, with organics decreasing with depth, WTPL, firm (Swale Sediments)
1.0-1.1 m	grey silty clay trace sand, occasional rock clasts, WTPL, stiff (Probable Upper Glaciolacustrine Unit)

Field Station #11 July 14, 1986

Hand soil probe in deepest and widest part of crescent shaped depression (up to 0.5 m standing water)

0.0-0.6 m	black clay and organics, partially decomposed (Swale Sediments)
0.6-1.0 m	grey silty clay with occasional organic fragments laminated, WTPL, soft (Swale Sediments)

Field Station #12 July 14, 1986

Hand soil probe in centre of elongated depression

0.0-1.0 m	silty clay and organics, mainly organics to 0.5 m then decreasing to base (Swale Sediments)
1.0-1.1 m	silt and clay, rare rock clast to 2 mm, WTPL, soft to firm (Swale Sediments)
1.1-1.2	grey clayey silt trace sand, laminated, occasional rock clast to 5 mm, WTPL, firm to stiff (Upper Glaciolacustrine Unit)

Field Station #14 July 14, 1986

Hand soil probe in lowest part of depression

0.0-0.8 m	dark grey to black organics and silty clay (Swale Sediments)
0.8-1.1 m	clayey silt trace sand, laminated, occasional rock clast, sharp change in consistency at boundary, APL, stiff (Upper Glaciolacustrine Unit)

Field Station #15 July 14, 1986

Several hand soil probe in large depression

0.0-0.7 m	black silty clay and organics (Swale Sediments)
0.7-1.0 m	grey silty clay, occasional organic fragments, WTPL, soft to firm (Swale Sediments)
1.0-1.4 m	grey clayey silt, laminated with silt laminae to 7 mm, red banding, abrupt consistency change at upper boundary, WTPL, stiff (Upper Glaciolacustrine Unit)

Field Station #16 July 14, 1986

Hand soil probe in centre of small depression

0-0-0.6 m	dark grey to black silty clay and organics (Swale Sediments)
0.6-1.2 m	clayey silt trace sand, occasional rock clast below 1.0 m, laminated (Upper Glaciolacustrine Unit)

Field Station #17 July 14, 1986

Hand soil probe at the side of elongated depression (up to 0.5 m black standing water)

0.0-0.3 m	black silty clay and organics (Swale Sediments)
0.3-0.7 m	grey silty clay trace organics, laminated, WTPL, soft (Swale Sediments)
0.7-1.1 m	silty clay trace sand, occasional rock clast to 5 mm, WTPL, stiff (Upper Glaciolacustrine Unit)

Field Station #18 July 14, 1986

Hand soil probe in elongated depression (up to 0.4 m black standing water)

0.0-0.5 m	black silty clay and organics (Swale Sediments)
0.5-1.8 m	silty clay trace organics, laminated, WTPL, soft (Swale Sediments)
1.8-1.9 m	grey clayey silt trace sand, occasional rock clasts to 3 mm, WTPL, firm to stiff (Upper Glaciolacustrine Unit)

Field Station #19 July 14, 1986

Hand soil probe in centre of depression (up to 0.4 m standing water)

0.0-0.4 m	black silty clay and organics (Swale Sediments)
0.4-1.7 m	grey silty clay, indistinct laminations, WTPL, soft (Swale Sediments)
1.7-1.8 m	grey clayey silt trace sand, occasional Queenston shale clast to 5 mm, laminated (Upper Glaciolacustrine Unit)

Field Station #20 July 14, 1986

Hand soil probe in widest part of linear depression

0.0-0.5 m	black silty clay and organics (Swale Sediments)
0.5-1.5 m	grey silt and clay, laminated, WTPL, soft (Upper Glaciolacustrine Unit)

Field Station #21 July 14, 1986

Hand soil probe in long linear depression

0.0-0.5 m	black silty clay and organics (Swale Sediments)
0.5-1.7 m	grey silty clay, laminated, WTPL, soft to firm (Swale Sediments)
1.7-1.9 m	grey clayey silt trace sand, occasional rock clast, WTPL, firm to stiff (Upper Glaciolacustrine Unit)

Field Station #22 July 16, 1986

Hand soil probe in centre of broad depression (up to 0.3 m standing water)

0.0-0.9 m	dark brown fibrous organics (Swale Sediments)
0.9-2.1 m	grey silty clay, occasional organic laminae to 2 mm thick to 1.1 m, WTPL, soft (Swale Sediments)
2.1-2.2 m	grey clayey silt trace fine sand, sharp upper boundary, massive, WTPL firm to stiff (Upper Glaciolacustrine Unit)

Field Station #23 July 16, 1986

Hand soil probe in ditched depression

0.0-0.4 m	black silty clay and organics (Swale Sediments)
0.4-0.9 m	grey clay and silt trace organics, occasional organic lamina to 4 mm, WTPL, soft to firm (Swale Sediments)
0.9-1.7 m	grey clay and silt trace sand, occasional rock clast top 10 mm, well laminated near base, WTPL, soft to firm to 1.3 m, firm to stiff below 1.3 m (Upper Glaciolacustrine Unit)

Field Station #24 July 16, 1986

Hand soil probe in broad part of linear depression (up to 0.4 m standing water)

0.0-0.8 m	brown to black fibrous organics, varying amounts of clay and silt (Swale Sediments)
0.8-1.3 m	grey clay and silt, WTPL, soft (to firm near base) (Swale Sediments)
1.3-1.5 m	grey clay and silt trace sand, occasional rock clast to 1.5 mm, sharp upper boundary, WTPL, firm to stiff (Upper Glaciolacustrine Unit)

Field Station #25 July 16, 1986

Hand soil probe in centre of small depression

0.0-0.6 m	black silty clay and organics (Swale Sediments)
0.6-0.8 m	brown fibrous organics with occasional silt clay laminae (Swale Sediments)
0.8-1.1 m	grey silty clay, WTPL, soft (Swale Sediments)
1.1-1.2 m	grey clayey silt trace sand, laminated, occasional rock clast to 10 mm, WTPL, firm to stiff (Upper Glaciolacustrine Unit)

Field Station #26 July 16, 1986

Hand soil probe near centre of wooded depression (up to 0.6 m standing water)

0.0-0.1 m	black organics and silty clay (Swale Sediments)
1.1-1.2 m	grey silty clay, WTPL, soft (Swale Sediments)
1.2-1.3 m	grey silt and clay, with silt laminae to 20 mm, occasional rock clast, WTPL, firm to stiff (Upper Glaciolacustrine Unit)

Field Station #27 July 16, 1986

Hand soil probe in centre of elongated depression

0.0-0.8 m	black clayey silt and organics, laminated (Swale Sediments)
0.8-1.2 m	grey silty clay, with occasional organic lamina to 5 mm, WTPL, soft (Swale Sediments)
1.2-1.7 m	grey silt and clay, laminated with silt interbeds, occasional reddish brown shale clast to 3 mm, WTPL to APL, stiff (Upper Glaciolacustrine Unit)

Field Station #28 July 16, 1986

Hand soil probe near centre of broad depression (up to 0.5 m standing water)

0.0-0.8 m	black silty clay and organics (Swale Sediments)
0.8-1.3 m	grey clay and silt, WTPL, soft (Swale Sediments)
1.3-1.6 m	grey silty clay and silt, laminated and interbedded, rare silt/clay clast, WTPL to APL, stiff (Upper Glaciolacustrine Unit)

Field Station #29 July 16, 1984

Hand soil probe in shallow depression

0.0-0.5 m	black silty clay and organics (Swale Sediments)
0.5-0.9 m	grey silty clay, massive, WTPL, soft to firm (Swale Sediments)
0.9-1.1 m	grey silt and clay, laminated, occasional reddish brown shale clast to 3 mm, APL, firm to stiff (Upper Glaciolacustrine Unit)

Field Station #30 July 16, 1986

Hand soil probe in linear depression in woods (up to 0.4 m standing water)

0.0-0.8 m	black organics with silty clay (Swale Sediments)

Field Station #30 (cont'd)

0.8-1.8 m	grey silty clay, laminated, silt laminae to 3 mm below 1.6 m, WTPL, firm (Swale Sediments)
1.8-1.9 m	grey clayey silt, occasional rock clast to 5 mm, WTPL-APL, stiff (Upper Glaciolacustrine Unit)

Field Station #31 July 16, 1986

Hand soil probe at centre of broad depression

0.0-0.7 M	black silty clay and organics (Swale Sediments)
0.7-1.0 m	grey silt and clay, laminated, occasional organic fragment, WTPL, firm (Swale Sediments)
1.0-1.5 m	grey clayey silt, occasional silt lamina to 10 mm, occasional rock or silt/clay clast, APL-WTPL, stiff (Upper Glaciolacustrine Unit)

Field Station #32 July 16, 1986

Hand soil probe near centre of depression (up to 0.6 m standing water)

0.0-0.5 M	black silty clay and organics (Swale Sediments)
0.5-0.9 m	grey silty clay, WTPL, soft to firm (Swale Sediments)
0.9-1.4 m	grey silt and clay, occasional rock or silt clay clast to 5 mm, occasional silt lamina to 15 mm below 1.1 m, sharp upper boundary, WTPL to APL, stiff (Upper Glaciolacustrine Unit)

Field Station #33 July 16, 1986

Hand soil probe in linear depression (up to 0.3 m standing water)

0.0-0.3 m	black to brown organics with clay (Swale Sediments)
0.3-0.8 m	grey silty clay, occasional organic lamina to 3 mm to 0.5 m, WTPL, soft to firm (Swale Sediments)
0.8-1.1 m	grey clayey silt, occasional rock or silt/clay clast to 5 mm, distinct grainsize and consistency change at upper boundary, WTPL-APL, stiff (Upper Glaciolacustrine Unit)

Field Station #34

Test Pit, approximately 22 m in length stretching from wet depression to the top of the adjacent low ridge. Excavation was by a tractor-mounted backhoe. Topographic relief is approximately 1 m (from detailed topographic maps). The test pit was dug to a depth of (approximately 2 m and extended 8 m into the depression approximately one-third of its diameter). The test pit extended in an east-west direction to the crest of the ridge approximately 11 m from the edge of the swale. A 3 m long section of trench was excavated along the crest of the trench in a north-south direction (at right angles to the main trench).

Wet conditions were encountered at surface and at depth in the depression. Both surface and subsurface water filled the pit in minutes and sides sloughed continuously. The trench was dry away from the depression in the higher land. Walls in this part of the trench were very stable over the four hour period of exposure. Small amounts (several litres total over four hours) of water entered the bottom of the trench at three fracture locations.

A sketch of the materials encountered in the trench is located on the following page and the numbered descriptions of the material units are presented below.

Unit 1: dark greyish brown to brown to grey, silt and clay trace sand, rare to occasional rock or silt/clay clast to 10 mm (rarely larger), heavily fractured and weathered to a depth of ±1 m, grey lined fractures with occasional gypsum crystals and carbonate concretions in both walls and trench bottom, massive to laminated, occasional colour bands (reddish brown to 10 mm thick), rare silt laminae (discontinuous over ±0.5 m, maximum 3 mm thick), colour bands range from horizontal undisturbed to gently undulating individual sinusoidal folding of ±100 mm amplitude, colour bands are lensoid in shape and are rarely broken. Breaks in colour bands are associated with the presence of well developed fractures, entire north-south portion of test pit displayed continuous undisturbed horizontal colour bands, generally much DTPL and stiff to very stiff except beneath swale where material is WTPL to APL and firm to stiff. (Upper Glaciolacustrine Unit).

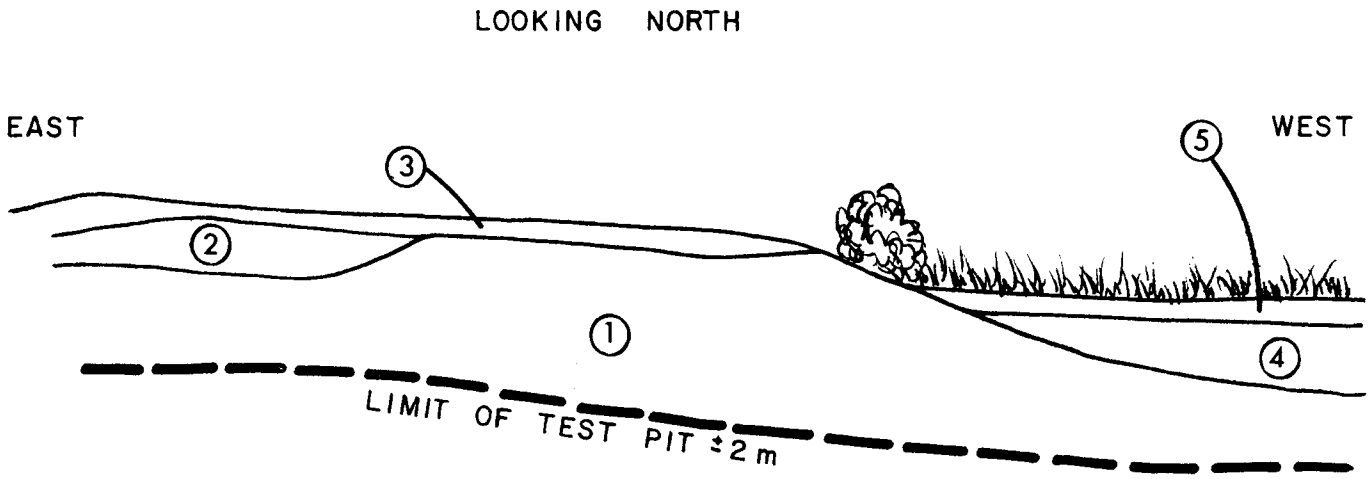
Unit 2: brown (mottled), sandy silt trace clay, heavily weathered throughout, maximum depth 0.8 m. (Upper Glaciolacustrine Unit)

Unit 3: dark brown, silt to clayey silt topsoil, vegetation and roots, maximum thickness 0.4 m (Topsoil)

Unit 4: grey, silty clay to clay and silt, massive to very faintly laminated, rare to occasional black organic particle (to 5 mm), WTPL, soft to firm. (Swale Sediments)

Unit 5: black to dark brown, organics and clay silt, abundant decaying vegetation and roots, maximum thickness ±0.5 m. (Swale Sediments)

Field Station #34: (Cross sectional sketch, not to scale)



Field Station #35 July 15, 1986

Test pit 6 m in length from centre to edge of linear swale. Excavation by a tractor-mounted backhoe. Maximum depth of excavation was 2.6 m (at centre of feature). Surface of ground was moist and spongy but there was no surface water. Water filled the test pit within minutes and sides sloughed continually.

A sketch of the materials encountered in the trench is presented below. Numbered descriptions of the materials occur below. Test pit is oriented at 65°.

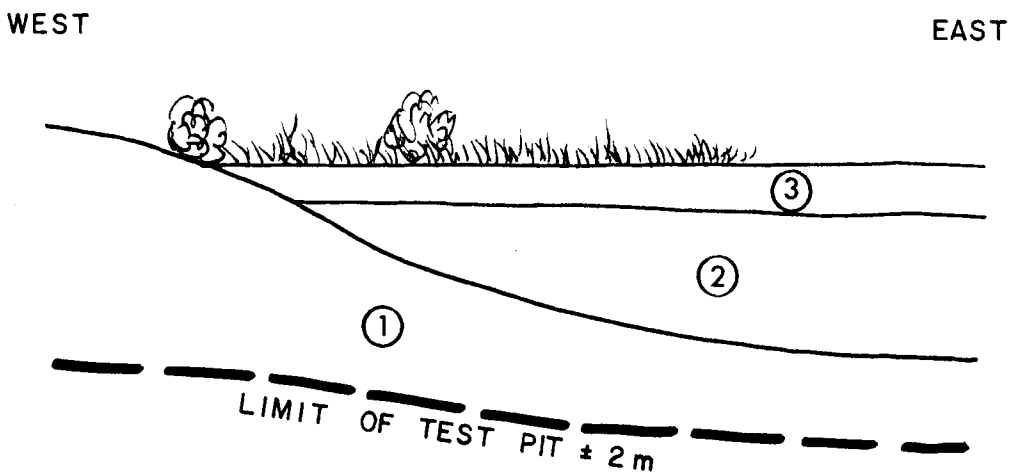
Unit 1: grey, clay and silt trace sand, well developed textural laminations, occasional rock clast to 5 mm, WTPL (with DTPL in silty zones), stiff (Upper Glaciolacustrine Unit)

Unit 2: grey, silt and clay trace organics, massive and unstructured (maximum thickness 1.1 m), WTPL, firm to stiff (Swale Sediments)

Unit 3: black, clay and organics, decaying vegetation, roots, maximum thickness 0.5 m (Swale Sediments)

FIELD STATION #35: (Cross sectional sketch – not to scale)

LOOKING NORTH



Field Station #36 July 15, 1986

Test pit 7m in length from centre of depression to edge. Excavation by a tractor-mounted backhoe. Maximum depth of excavation 2.7 m (at centre of feature). Approximately 0.1 m of water was present in the depression. Water filled the test pit within minutes and sides sloughed continuously.

A sketch of the materials encountered in the trench occurs below. Numbered descriptions of the materials are also presented. The test pit was oriented at 55°.

Unit 1: grey to greyish brown (mottled), clayey silt trace sand, occasional rock clast to 7 mm, massive to very faintly laminated, upper boundary is sharp, WTPL to DTPL, stiff (Upper Glaciolacustrine Unit).

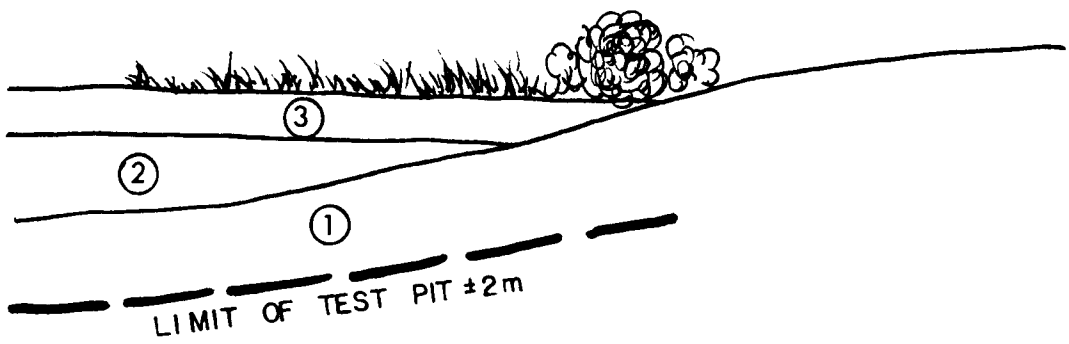
Unit 2: grey, silt and clay, massive, occasional root, maximum thickness 0.5 m, WTPL, firm to stiff (Swale Sediments).

Unit 3: black, organics and clay and silt, roots and decaying organics, maximum thickness 0.4 m (Swale Sediments)

FIELD STATION # 36 : (Cross sectional sketch — not to scale)

LOOKING NORTHWEST

SOUTHWEST NORTHEAST



C3 SUMMARY OF OIL AND GAS WELL DATA

Oil and gas well locations are shown in Figure 5-1 (in pocket at back of report) and presented on Table C3-1.

Copies of original oil and gas well records were obtained from the Ministry of Natural Resources (MNR) office in London, Ontario. Additional locations of abandoned oil and gas wells were obtained from the MNR and from local residents and numbered 1-6 in Figure 5-1 (in pocket at back of report). There is limited information available for these wells.

Imperial units are used in the original well logs and these have been changed to metric units in the summary. Where ground elevations are supplied, they have been verified using contours on 1:10 000 scale maps. Where no elevations were supplied, elevations are estimated from the base maps. All elevations are above sea level (ASL) and are shown to the nearest metre.

Copies of oil and gas well records and mapping are on file.

TABLE C3-1, SUMMARY OF OIL AND GAS WELL DATA

WELL BOREHOLE No.	LOCATION	GROUND ELEVATION (m ASL)	FROM (m)	TO (m)	MATERIALS DESCRIPTION	COMMENTS
161-3316	Con. 1, Lot 17 West Lincoln R.M. of Niagara	179	0.0 33.2	33.2 161.5	Overburden Bedrock	Abandoned
171-3118	Con. 1, Lot 17 West Lincoln Twp. R.M. of Niagara	177	0.0 32.6	32.6 167.3	Overburden Bedrock	Gas Producer
171-3166	Con. 1, Lot 17 West Lincoln Twp. R.M. of Niagara	176	0.0 31.4	31.4 163.7	Overburden Bedrock	Gas Producer
171-3254	Con. 1, Lot 17 West Lincoln Twp. R.M. of Niagara	178	0.0 32.6	32.6 166.4	Overburden Bedrock	Gas Producer
172-4289	Con. 2, Lot 17 West Lincoln Twp. R.M. of Niagara	180	0.0 36.0	36.0 160.0	Overburden Bedrock	Gas Producer
172-4632	Con. 2, Lot 17 West Lincoln Twp. R.M. of Niagara	180	0.0 30.5	30.5 161.2	Overburden Bedrock	Gas Producer
193-5489	Con. 3, Lot 19 West Lincoln Twp. R.M. of Niagara	185	0.0 30.8	30.8 159.0	Overburden Bedrock	Gas Producer
1	Con. 1, Lot 21 West Lincoln Twp. R.M. of Niagara	178				No data available, locations from MNR Petroleum Resources Map F-16 (effective date September, 1986)
2	Con. 2, Lot 20 West Lincoln Twp. R.M. of Niagara	178				No data available, locations from MNR Petroleum Resources Map F-16 (effective date September, 1986)
3	Con. 3, Lot 20 West Lincoln Twp. R.M. of Niagara	183				No data available, locations from MNR Petroleum Resources Map F-16 (effective date September, 1986)
4	Con. 1, Lot 16 West Lincoln Twp. R.M. of Niagara	176				Gas well location reported in water use survey.
5	Con. 1, Lot 21 West Lincoln Twp. R.M. of Niagara	183				Gas well location reported in water use survey.
6	Con. 1, Lot 15 West Lincoln Twp. R.M. of Niagara	174				Gas well location reported in water use survey.

Gartner Lee Associates Limited

Note: Data for above wells condensed from records on file with Ministry of Natural Resources, (MNR), London, Ontario

APPENDIX D

GEOPHYSICAL INFORMATION

APPENDIX D

GEOPHYSICAL INFORMATION

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D1 INTRODUCTION

A seismic reflection survey was undertaken by Gartner Lee Limited (GLL) in the late fall of 1985 to delineate subsurface features in the vicinity of OWMC's Preferred Site. GLL retained Waterloo Geophysics Incorporated (WGI) to collect and process the seismic data. The geophysics section of this report is a joint submission by GLL and WGI. In this regard, WGI was responsible for data processing and development of the seismic cross-sections. GLL was responsible for the geologic interpretation and reporting aspects. Both GLL and WGI were involved in data acquisition.

D1.1 PURPOSE AND SCOPE

The seismic geophysical program was undertaken to:

1) determine the continuity of subsurface overburden conditions beyond the Preferred Site boundaries;

2) determine the continuity of subsurface overburden conditions between borehole locations on-site;

3) identify anomalous subsurface conditions for selecting off-site or on-site drilling locations.

A feasibility survey was initially undertaken by GLL and WGI on October 28, 1985 under the direction of GLL with assistance from WGI and Dr. J. Hunter of the Geological Survey of Canada (GSC), to ensure site conditions were favourable for application of the seismic reflection technique. Following the

successful completion of the feasibility survey eight seismic survey lines totalling approximately 11 km in length were selected (Figure D1-1). The field program was initiated on November 14, 1985 and completed December 11, 1985.

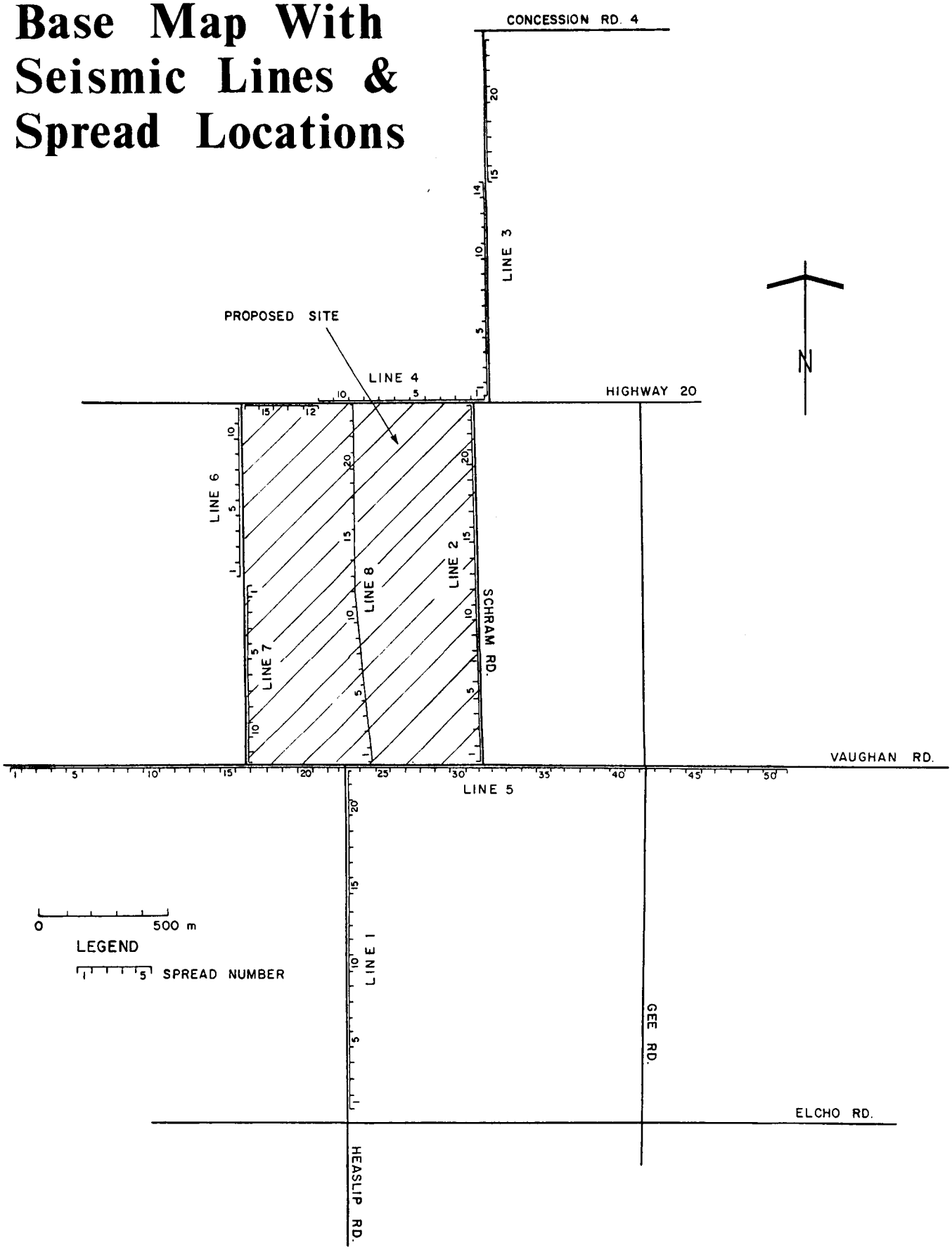
D1.2 THE SEISMIC REFLECTION TECHNIQUE

Seismic reflection has been extensively used by the petroleum industry for deep exploration over the past 50 years. Recently, the technique has been refined to allow exploration of unconsolidated sediments in a depth range of between 10 m to 200 m (Hunter and Hobson, 1977; Hunter et al., 1982b). Many of the techniques, refinements, and data processing software used in this study were developed at the Geological Survey of Canada (Dr. J.A. Hunter and staff). The details of the shallow seismic reflection technique are presented in a series of papers (Hunter et al., 1982a and 1982b, 1984; Gagne et al., 1985). A brief description of the seismic reflection technique follows.

The technique is based on the creation of a seismic pulse (ground vibration), and the measurement of the time required for the pulse to travel to, and reflect back from, a geologic boundary. The seismic pulse (source) and the detectors at surface (geophones) are moved incrementally along a line in a series of "spreads". A "spread" consists of one recording location. In this way variations in the depth to the geologic boundary are represented by the differences in reflected arrival times (Figure D1-2). Plots of the reflected arrival times of the pulse at each detector give the appearance of a geologic cross-section. The seismic interpretation of the depth to the boundaries were calculated following the determination of the velocity of the pulse through the geologic medium.

FIGURE DI-1

Base Map With Seismic Lines & Spread Locations



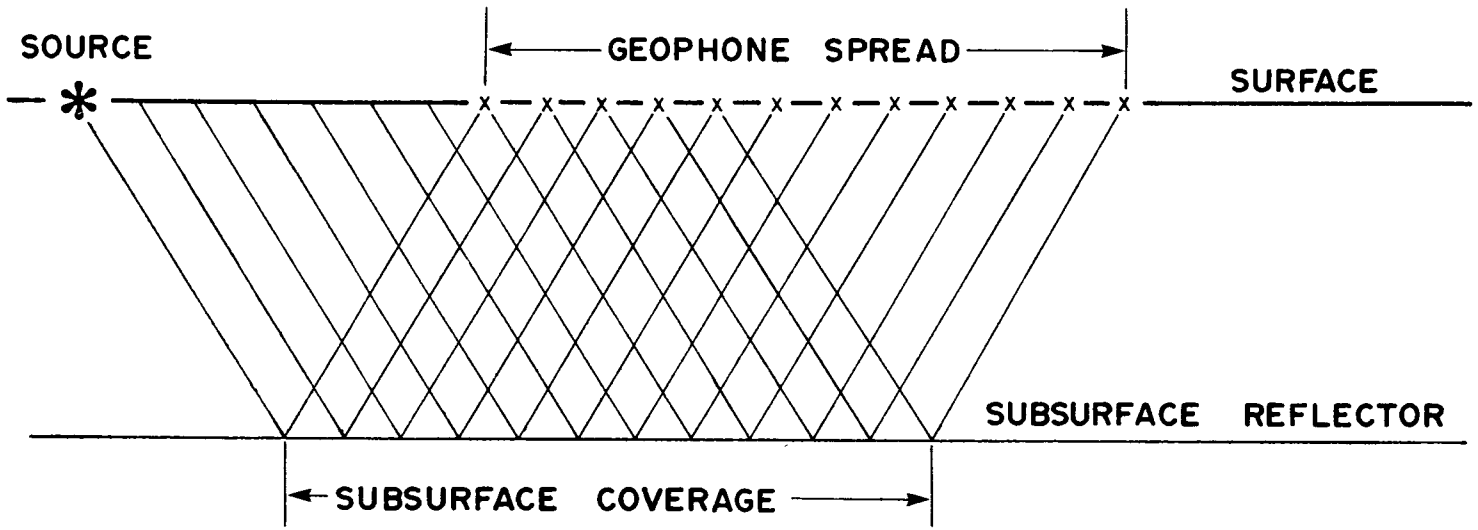


FIGURE D1-2. DIAGRAM ILLUSTRATING A FIELD SET-UP FOR "OPTIMUM OFFSET" RECORDING (from Gagne et al., 1985)

D2 DATA COLLECTION

The field program was initiated on November 14th, 1985 and completed December 11th, 1985. Figure D1-1 shows the locations of the seismic lines. Each seismic line consisted of a series of 60 m "spreads". Each spread consisted of 12 geophones placed 5 m apart and allowed subsurface conditions to be recorded at 5 m increments.

The seismic source (pulse) for this survey was a 12 gauge shotgun shell fired from a device known as a "buffalo gun" (Pullan and MacAulay, 1985). Figure D2-1 shows a schematic of the "buffalo gun". The shotgun shell is placed on the end of a hollow pipe and buried in an augered hole completed to a depth of about one metre. A firing rod, with a pin on its end, is dropped down the hollow pipe to detonate the shot gun shell. When the shell explodes a hammer switch, which is located on the gun, triggers the recording device on the seismograph.

Geophones with a natural frequency of 100 hertz (Hz) were chosen for this survey to assist with on-site filtering of data. The 100 Hz geophones heavily attenuate low frequency energy, an attribute that is beneficial in two ways. First, the preferential detection of high frequency energy tends to sharpen reflections, and thereby improves the resolution of the seismic cross-section. Secondly, the 100 Hz geophones minimize interferences caused by "ground roll" (low frequency vibrations travelling along the ground surface). The geophones were placed about 0.5 m below surface to further reduce ground roll effects. The shallow subsurface is most affected by ground roll.

12 GAUGE SHOTGUN SOURCE

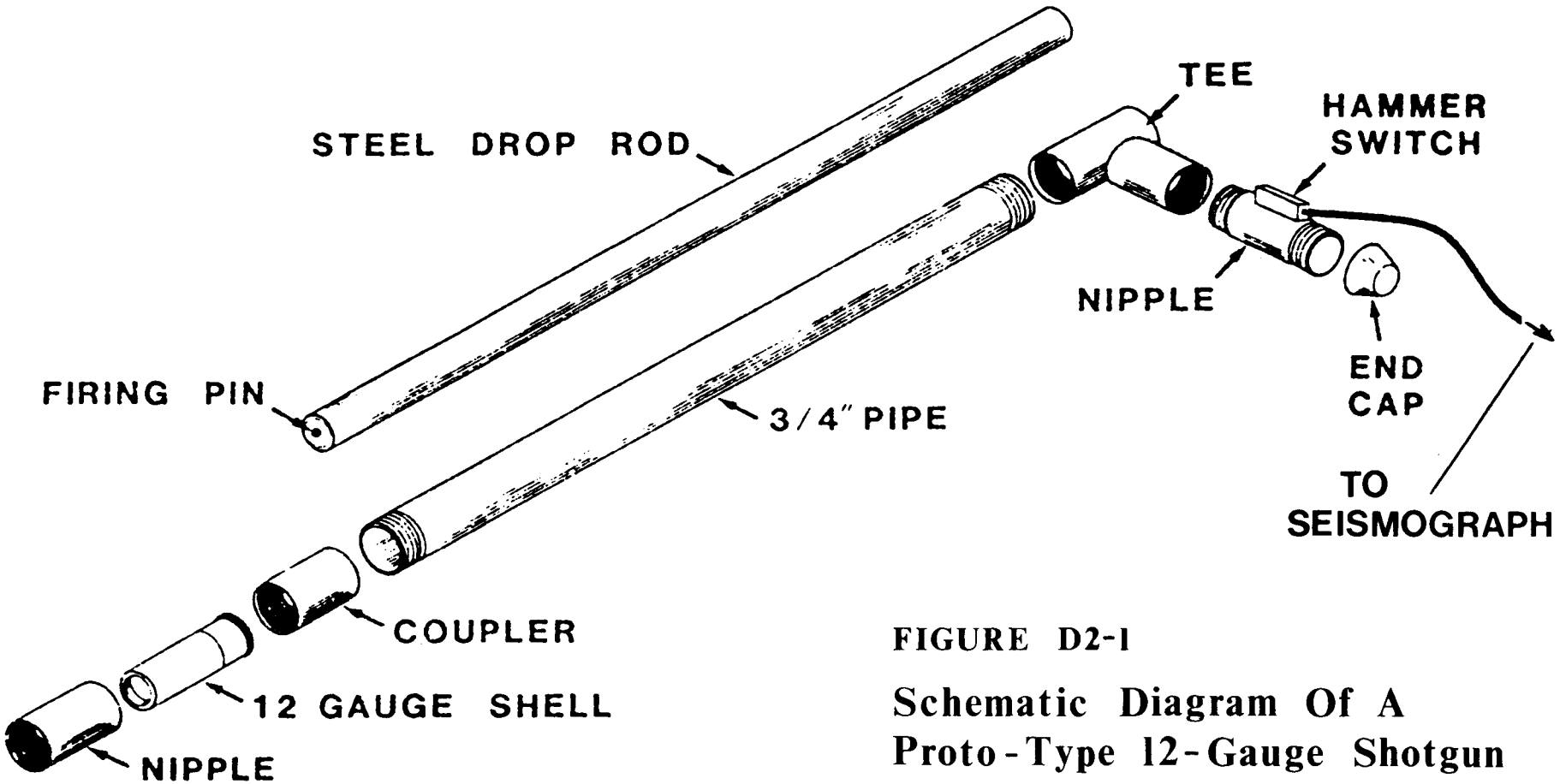


FIGURE D2-1

Schematic Diagram Of A Proto-Type 12-Gauge Shotgun Source (from Pullan and MacAulay, 1985)

Data were collected using a Nimbus 1210 F seismograph with 300 Hz high pass filters. The information was transferred from the seismograph to a cassette tape using a Nimbus G-724-S data recorder. The field data were transferred daily to a floppy disk for processing with an Apple IIe micro computer. The data acquisition system is described in Hunter et al., (1982a).

The seismic source must be located a certain distance from the geophone in order to obtain a good record of the reflected seismic pulse. The best geophone-source separations are determined from local ground roll velocities and estimated reflector depths, This separation distance known as the "common offset" falls within a range described as the "optimum window" by Hunter et al. (1982b). Wherever possible, a constant 15 m common offset distance was used in this study, however, excessive early arrival interference along some of the seismic lines necessitated increasing the common offset distance to 25 m. The common offset distances for each seismic line are listed in Table D2-1.

TABLE D2-1: SEISMIC LINE DETAILS

Seismic Line	No. of Spreads	Common Offset Distance (m)
1	22	15
2	23	25
3	23	25 (spreads 1-15) 15 (spreads 16-23)
4	16	25
5	51	15
6	11	25
7	12	25
8	23	25

Seismic refraction records were also collected during the field survey. The refraction data were used to determine surficial material velocities and to determine the depth to the water table. Seismic refraction techniques are described in Redpath (1978). In addition, a normal moveout (NMO) or common shot point record was collected from every second spread for overburden velocity analysis. This technique which is detailed in Hunter et al. (1982b) is briefly discussed in the following section.

D3 DATA PROCESSING

D3.1 DATA ENHANCEMENT AND CORRECTION

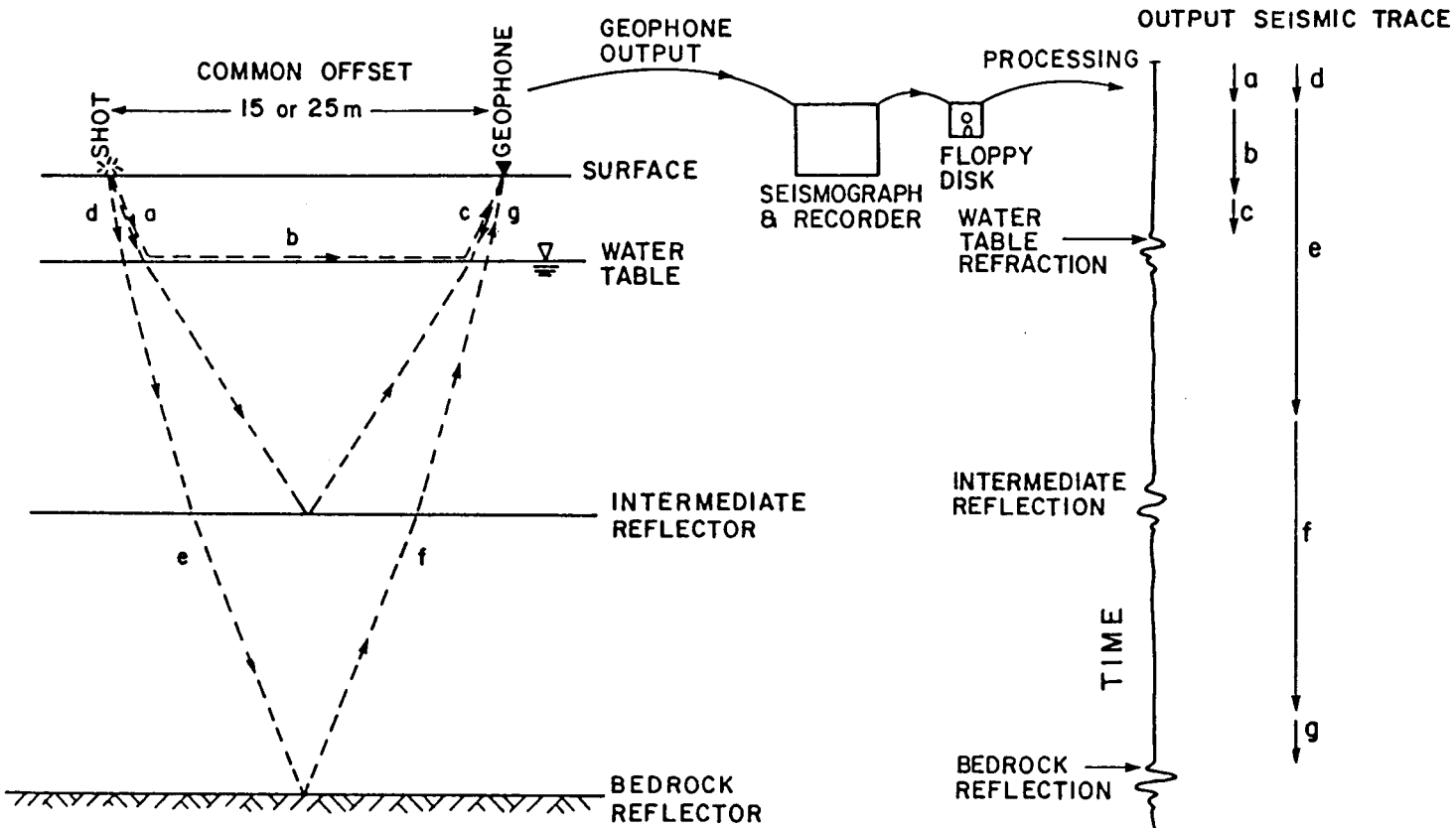
Once the seismic data were transferred to floppy disk a series of programs written by the GSC were used to process the traces. Processing involved (1) data enhancement, alignment, and correction for variations in the arrival time refracted along the water table, and (2) velocity analysis to convert the arrival times into depth measurements. The procedures are briefly described here, and in detail in Gagne et al. (1985).

Figure D3-1 is a schematic diagram which has been included to familiarize the reader with terms used in the following discussion. It is emphasized that the first signal to arrive is the refraction from the water table, and not a reflection. These initial refracted arrivals are used to correct the reflected times for surface variations.

The stages of data enhancement and correction are as follows:

i) The data were Fourier-analysed and frequencies below 500 Hz and above 1000 Hz were suppressed. This passband was chosen through trial and error so to yield the most interpretable information.

ii) Mechanical errors caused by variations in triggering time on the seismograph and errors caused by variations in near-surface velocities were eliminated by adjusting the data



ASSUMPTIONS:

a ≈ d	a + b + c	REFRACTED ARRIVAL
c ≈ g	d + e + f + g	REFLECTED ARRIVAL
b = CONSTANT	a + h + i + c	REFLECTED ARRIVAL

- - - - SEISMIC RAY PATH

FIGURE D3-1

SCHEMATIC DIAGRAM RELATING GEOPHONE OUTPUT TO PHYSICAL LAYERING

to a common first arrival time. This procedure is referred to as the "static" correction, and assumes the water table to be effectively flat and the travel time along the top of the water table to be constant. Following this correction, the data are usually ready for plotting and require no additional processing. Where data quality was poor due to ground roll, the static correction was adjusted on the raw data rather than the Fourier filtered version.

iii) Local surface features, such as road culverts, interfere with refracted arrivals from the water table. The resulting interference creates small irregularities in the reflecting boundaries down the seismic section. The irregularities were reduced as much as possible by adjusting the individual traces in time so as to smooth the refracted arrival.

iv) The data were plotted using a further series of adjustments that do not vary the information content, but simply adjust the scaling of the trace to improve clarity. These adjustments are as follows:

a) The polarity of the data is reversed. The bandpass filter (see (i) above) reverses the original polarity of the signal, making positive peaks negative and vice versa.

b) An automatic gain control (AGC) is used on the data to standardize the average amplitude of the trace along its length. Gain control is used to compensate for the natural attenuation of the signal as it travels through the ground.

c) Gain tapers are used to increase the amplitude of the

traces over the sections that detail the overburden reflectors. The velocity contrasts between overburden layers are not as large in comparison to the contrast between overburden and bedrock velocities. Consequently, overburden reflections are normally weaker than bedrock reflections. Gain tapers standardize the average trace amplitude over a specified window. By moving the window along the trace and repeating the process, overburden reflectors are highlighted without confounding the plot with strong bedrock or surface arrivals.

d) The plots are drawn using a variable area display. The positive peaks of each trace, above a background level, are highlighted to produce a "variable area" plot. This aids the eye in following a reflector laterally.

D3.2 VELOCITY ANALYSIS

Seismic velocity, as a function of depth, is estimated from the refraction arrivals from the near surface units with the normal moveout velocity analysis of the entire section. This information (supplemented with borehole data) is used to convert the seismic time-distance cross-section to a depth-distance section.

Refraction data were analysed using the "delay time" technique, which is explained by Redpath (1978). The analysis involved plotting the difference in first arrival times at each geophone, from shots at either end of the spread, against the spread distance. The inverse of the slope of the plotted line is one-half of the refracting layer's velocity. Furthermore, the sum of these same arrival times, when subtracted from the total

time taken by the pulse to travel the length of the spread, is twice the time required by the pulse to travel from the refractor to surface. Thus, the time required for the pulse to travel to the water table at each geophone was determined, and the velocities of the unsaturated zone (near surface materials) were calculated.

A normal moveout correction was applied to the reflection data recorded from a common shot point. A planar reflector will appear curved on the uncorrected record due to the increase in geophone-shot distance. A stepwise analysis begins by first assuming a velocity for the material above a reflector and correcting the records for the increasing geophone-shot distance. The velocity is incrementally increased and the procedure is repeated. The correct average velocity for the material above the reflector is selected as the velocity at which the reflector appears planar after correction. This technique is described in Gagne et al. (1985).

Three major reflections were identified from the preliminary seismic cross-sections. The three major reflectors were identified as follows:

(1) Reflective Horizon Number 1
(2) Reflective Horizon Number 2
(3) Reflective Horizon Number 3

Normal moveout velocity analysis applied to Reflective Horizons Numbers 1 and 3 was used to calculate the average velocities above these reflectors. A second step was used to partition these average velocities between the intervening horizons. This required removing the effects of the unsaturated

zone to determine the average velocity of the geologic material between the water table and Reflective Horizon Number 1. Similarly, the effects of the material above Reflective Horizon Number 1 were removed to determine the velocity of the material between Reflective Horizons 2 and 3.

The velocity analysis plots are presented in Figures D3-2 and D3-3. The values used to calculate the velocities are provided in Appendix D8. Figure D3-2 is a scatterplot showing the velocity of the materials from Reflective Horizon Number 1 to the water table and from Reflective Horizon Number 1 to Reflective Horizon Number 3 versus the intercept times. The results indicate no systematic variation in the layer velocities across the site. Histograms of the water table refractor (refraction data) and the two subdivisions of the overburden (reflection data) are shown in Figure D3-3. Several of the bedrock normal moveout records could not be used due to the irregular nature of the bedrock reflector. While the remainder of the lower subunit data is somewhat limited, it is sufficient to confirm that the velocity of 1600 m/sec is appropriate for the saturated overburden.

Figure D3-4 shows the relationship between two-way travel time based on a velocity of 1600 m/sec and depth for the 15 and 25 metre offsets (equation 1A and 1B, below).

$$\text{Depth (m)} = (.64*T^2 - 56.25)^{\frac{1}{2}} \quad \text{(15 m Offset)} \qquad 1A$$

$$\text{Depth (m)} = (.64*T^2 - 156.25)^{\frac{1}{2}} \quad \text{(25 m Offset)} \qquad 1B$$

T = 2-way travel time

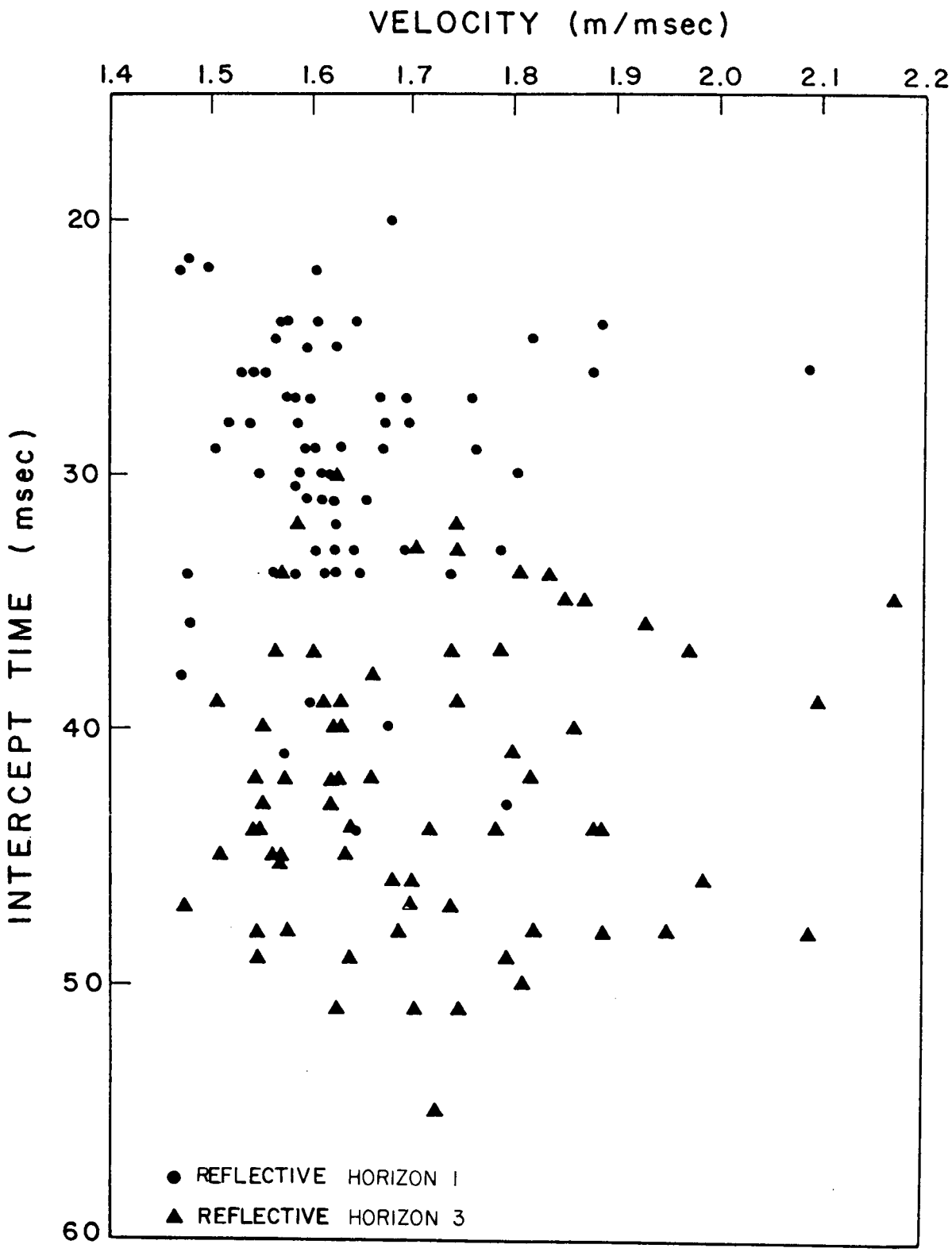


FIGURE D3-2

SCATTER OF VELOCITY ANALYSIS POINTS

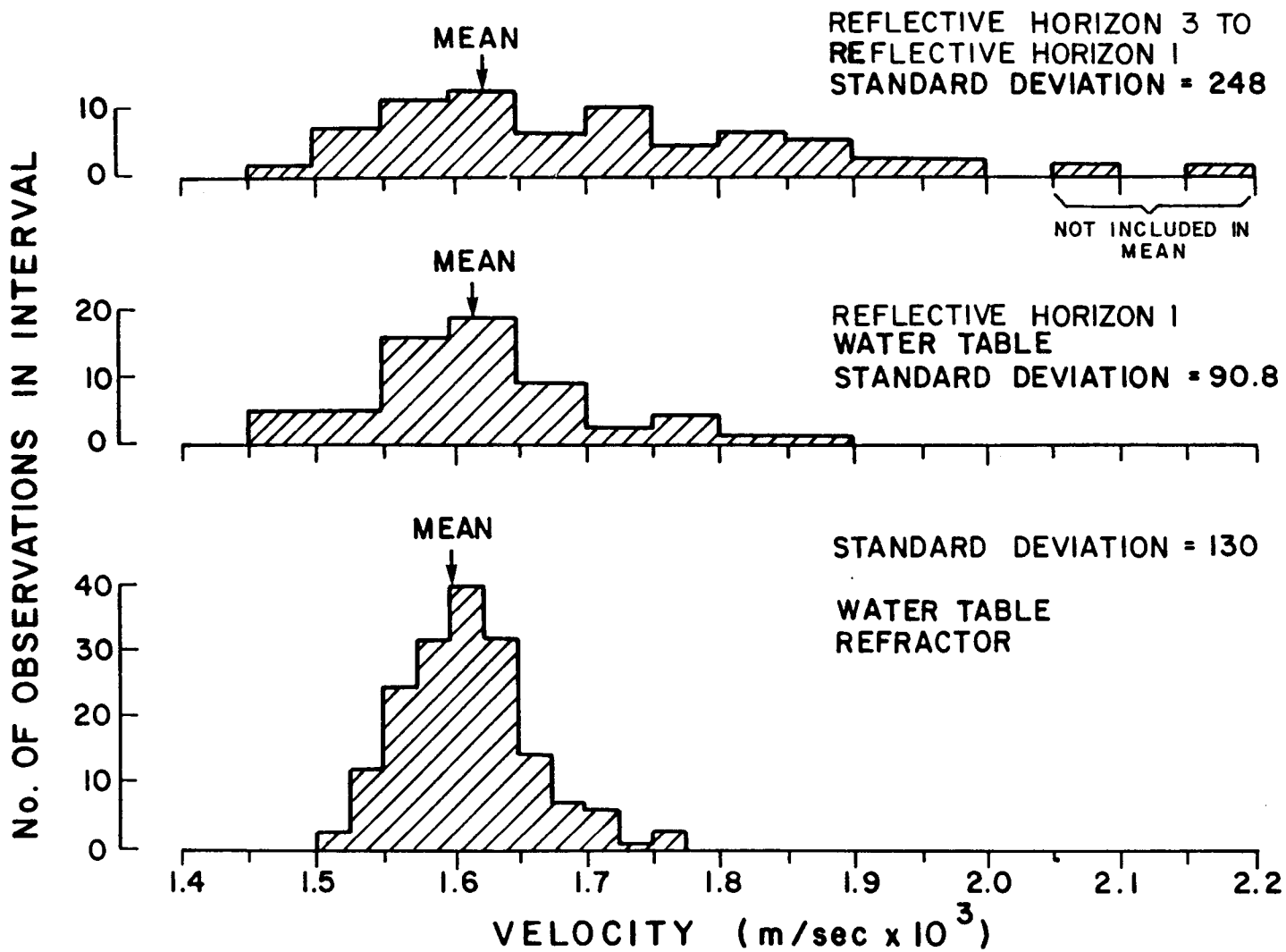


FIGURE D3-3

HISTOGRAMS FOR VELOCITY ANALYSIS

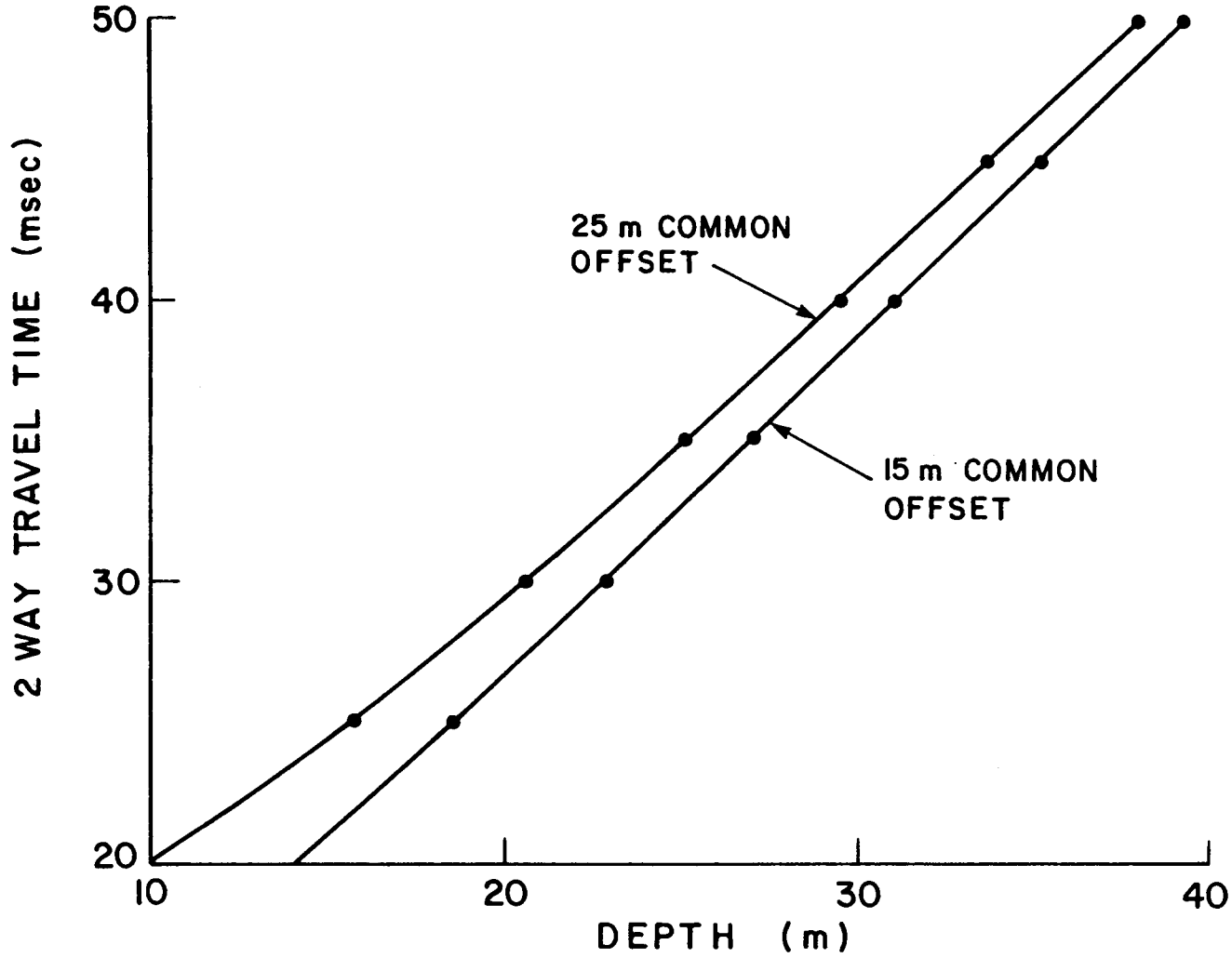


FIGURE D3-4

Plot Of Depth vs. 2 Way Travel Time

Finally the "approximate zero time" was determined for the depth scale of each record. The static corrections and bedrock smoothing had previously removed time errors due to near surface irregularities, but the corrections were related to an arbitrary time datum. To establish the zero time for depth measurement purposes, the travel time between the surface and the water table refractor (a to c) was added to the travel time (b) along the refractor for each spread. Figure D3-1 illustrates this relationship as "a" and "c" and average "b" = zero (depth scale).

D4 LIMITATIONS ON THE INTERPRETATION OF SEISMIC REFLECTION RESULTS AT THE PREFERRED SITE

The quality of the seismic data collected at the Preferred Site was very good however, some general limitations are inherent to technique and seismic record quality.

Various limitations placed on the interpretation of the seismic reflection results at the Preferred Site follow:

(i) Reflections cannot be identified above a two-way travel time of 25 to 30 msec. This is because of interference from direct waves, ground roll waves and refracted surface waves.

(ii) The final computer print (seismic cross-sections) are relative to the zero msec level. The approximate zero level for the depth scale was determined from the static correction described in Section D3. As a result, the seismic cross-sections have not been adjusted for changes in local ground surface topography. This may result in elevation differences of ± 2 m.

(iii) Local variations in the velocity of overburden materials could affect the quality of the seismic records. This would occur in areas where there was an increased depth to the water table or areas where near-surface materials have been disturbed (roads, tractor trails, culverts, etc.). These factors may result in "fuzzy" seismic responses as are evident in Line 5, Spreads 31 and 32 (Figure D5-5, Appendix D5). These local variations could cause a 10% $\pm$ error in depth determinations.

(iv) The seismic record quality was affected by noise (ground vibrations) from vehicle traffic. The traffic decreased the signal-to-noise levels and sometimes obscured reflection continuity. Line 4 along Highway 20 is the most affected (Figure D5-4, Appendix D5).

(v) Inclement weather affected the seismic record quality along certain portions of the seismic lines. The first eight spreads on Line 3 are an example of this effect (Figure D5-3, Appendix D5). These data were collected under freezing rain conditions that decreased the electrical isolation of the recording cables from the ground. The equipment would then record 60 cycle noise from nearby hydro-electric poles. This increased the inherent noise in the data.

(vi) The lateral resolution is limited by the geophone interval (5 m). In practice, a discontinuity in a reflector of less than 15 m is unlikely to be recognized on the seismic cross-sections.

(vii) Not all seismic lines were directly adjacent to drilling locations. Boreholes along Line 8 were being drilled at the same time as the seismic survey was being performed (Figure D5-7, Appendix D5). In order to minimize the effects of the seismic noise being created by the drilling rig, it was necessary to shift this survey line. Minor lateral variations in the subsurface may occur between the location of the seismic line and the nearest borehole.

D5 SEISMIC RESULTS

The seismic reflection cross-sections for the eight survey lines are shown in Figures D5-1 through D5-7. The actual seismic section is shown in the top portion of each figure and the interpreted geologic cross-section in the lower portion. The vertical depth scale is not linear but rather a function of the overburden velocity as discussed in Appendix D3.2.

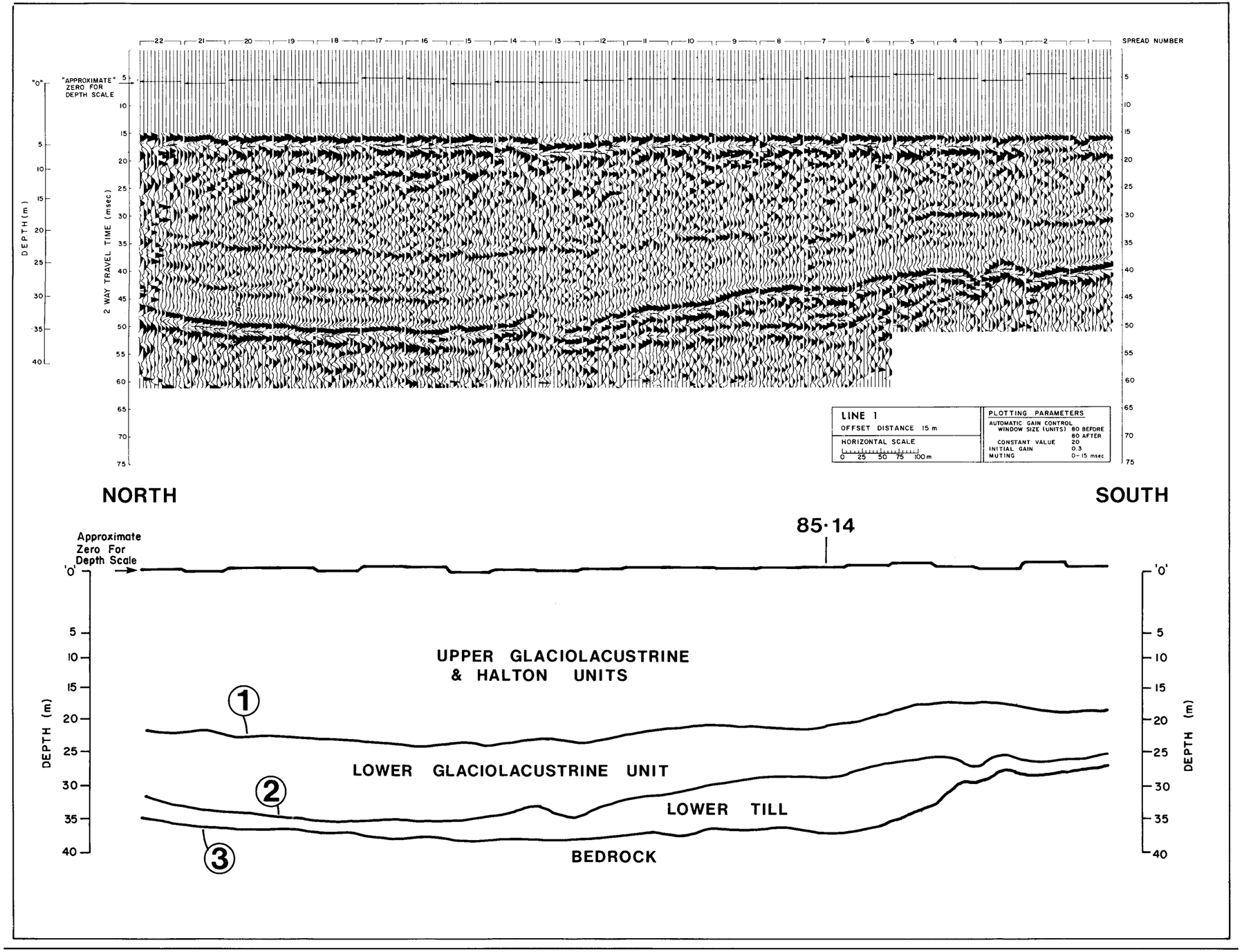
Stratigraphic control was provided by geologic logs for boreholes completed during the Phase 4A and Phase 4B programs. The logs were correlated with the seismic cross-sections upon completing the data processing stage of the geophysical program. Table D5-1 presents the depths of the geologic stratigraphic contacts and the depths of the contacts determined from the seismic reflection survey.

The continuity of the reflectors can be easily distinguished on all cross-sections. Data above the 25 to 30 msec level are uninterpretable due to masking of reflectors by other seismic waves. Three major reflectors which correspond with geologic contacts (Section 2.0) can be identified on all seismic cross-sections below the 25 to 30 msec level. The reflective horizons are indicated by number in Figures D5-1 through D5-7. A discussion of each reflector horizon follows.

D5.1 REFLECTIVE HORIZONS

D5.1.1 REFLECTIVE HORIZON NUMBER 1

The first reflective horizon (No. 1 in Figure D5-1) corresponds with a change in stratigraphy from the Halton Unit, which con-



OWMC Ontario Waste Management Corporation

Consultant:

Gartner Lee Limited

WATERLOO GEOPHYSICS

Legend:

① Reflective Horizon Number 1

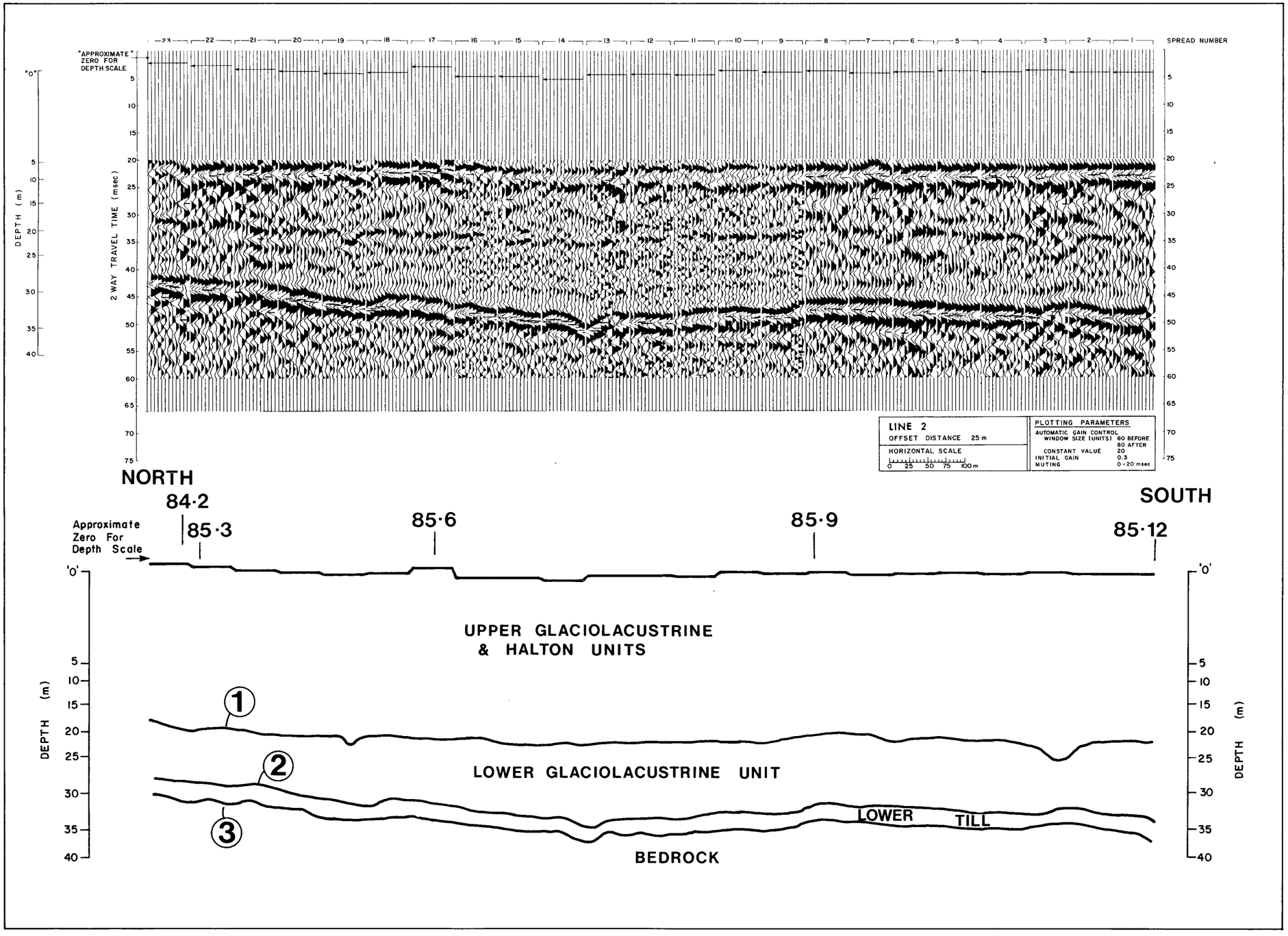
② Reflective Horizon Number 2

③ Reflective Horizon Number 3

85·14 Borehole Location

FIGURE D5-1

Seismic Cross~Section Line 1



OWMC Ontario Waste Management Corporation

Consultant:

Gartner Lee Limited

WATERLOO GEOPHYSICS

Legend:

1 Reflective Horizon Number 1

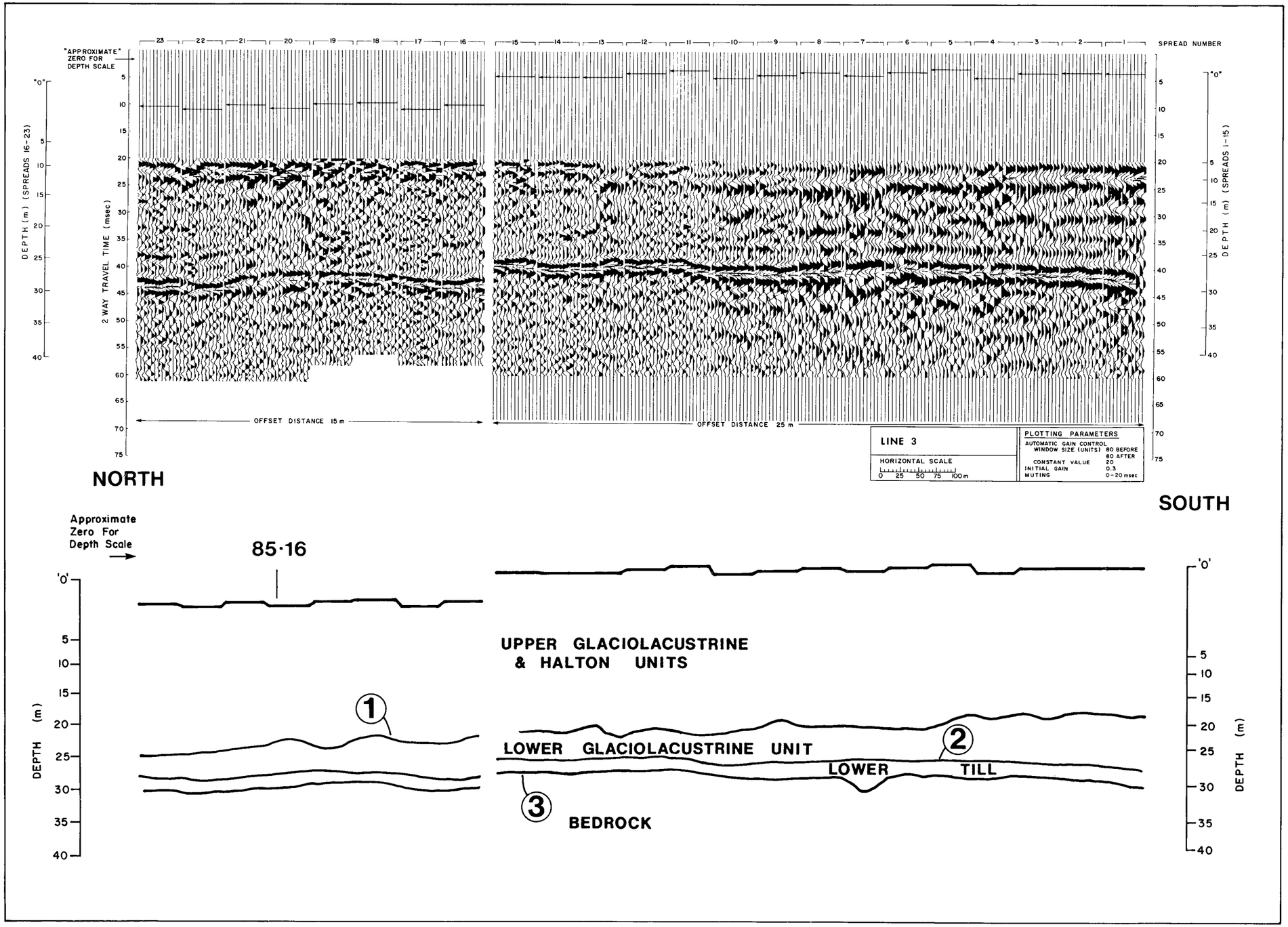
2 Reflective Horizon Number 2

3 Reflective Horizon Number 3

85·14 Borehole Location

FIGURE D5-2

Seismic Cross-Section Line 2



OWMC Ontario Waste Management Corporation

Consultant:

Gartner Lee Limited

WATERLOO GEOPHYSICS

Legend:

1 Reflective Horizon Number 1

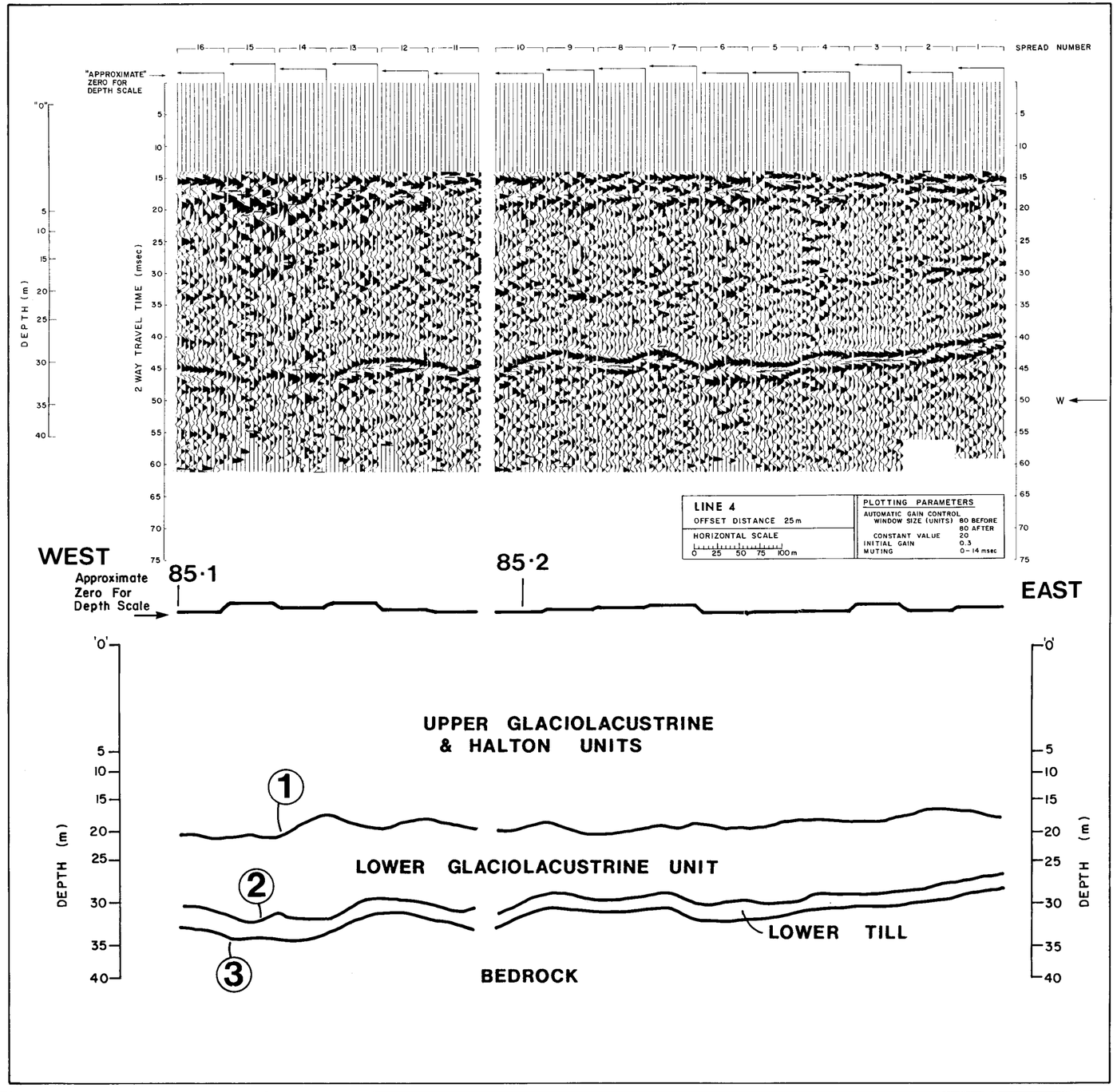
2 Reflective Horizon Number 2

3 Reflective Horizon Number 3

85·14 Borehole Location

FIGURE D5-3

Seismic Cross~Section Line 3



OWMC Ontario Waste Management Corporation

Consultant:

Gartner Lee Limited

WATERLOO GEOPHYSICS

Legend:

1 Reflective Horizon Number 1

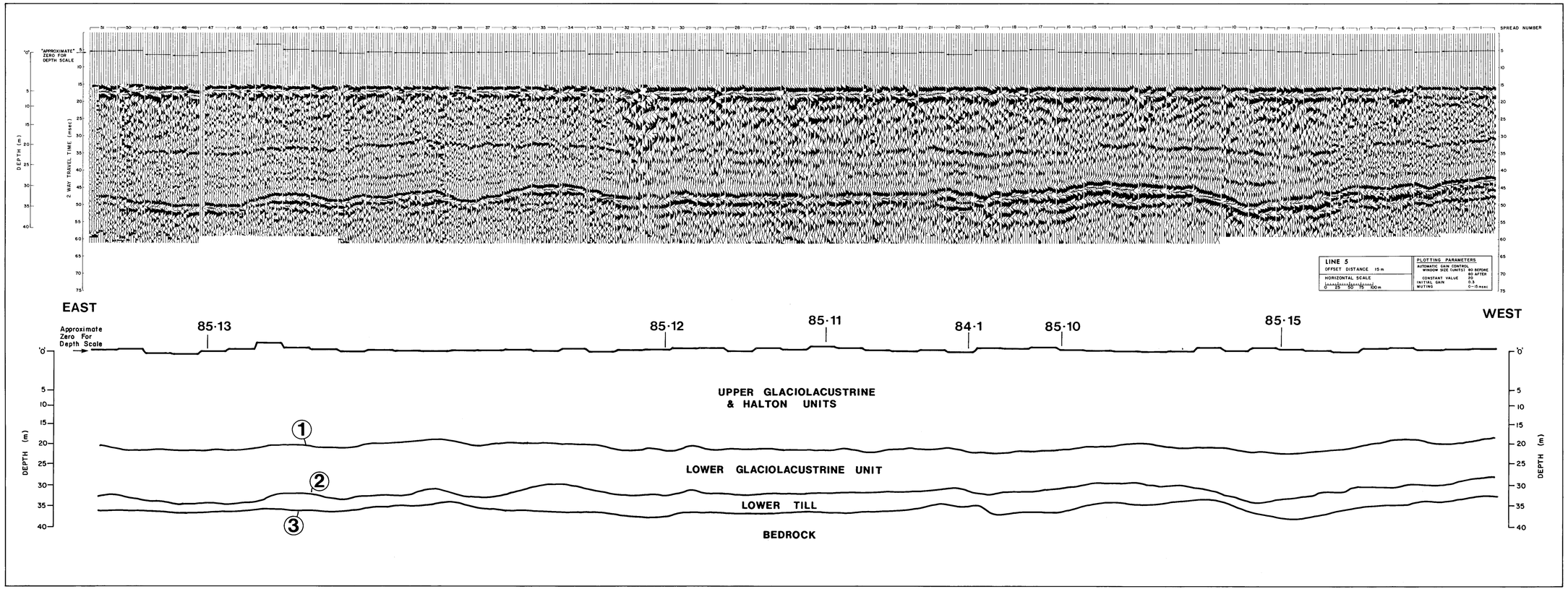
2 Reflective Horizon Number 2

3 Reflective Horizon Number 3

85·14 Borehole Location

FIGURE D5-4

Seismic Cross~Section Line 4



OWMC Ontario Waste Management Corporation

Consultant:

Gartner Lee Limited

WATERLOO GEOPHYSICS

Legend:

① Reflective Horizon Number 1

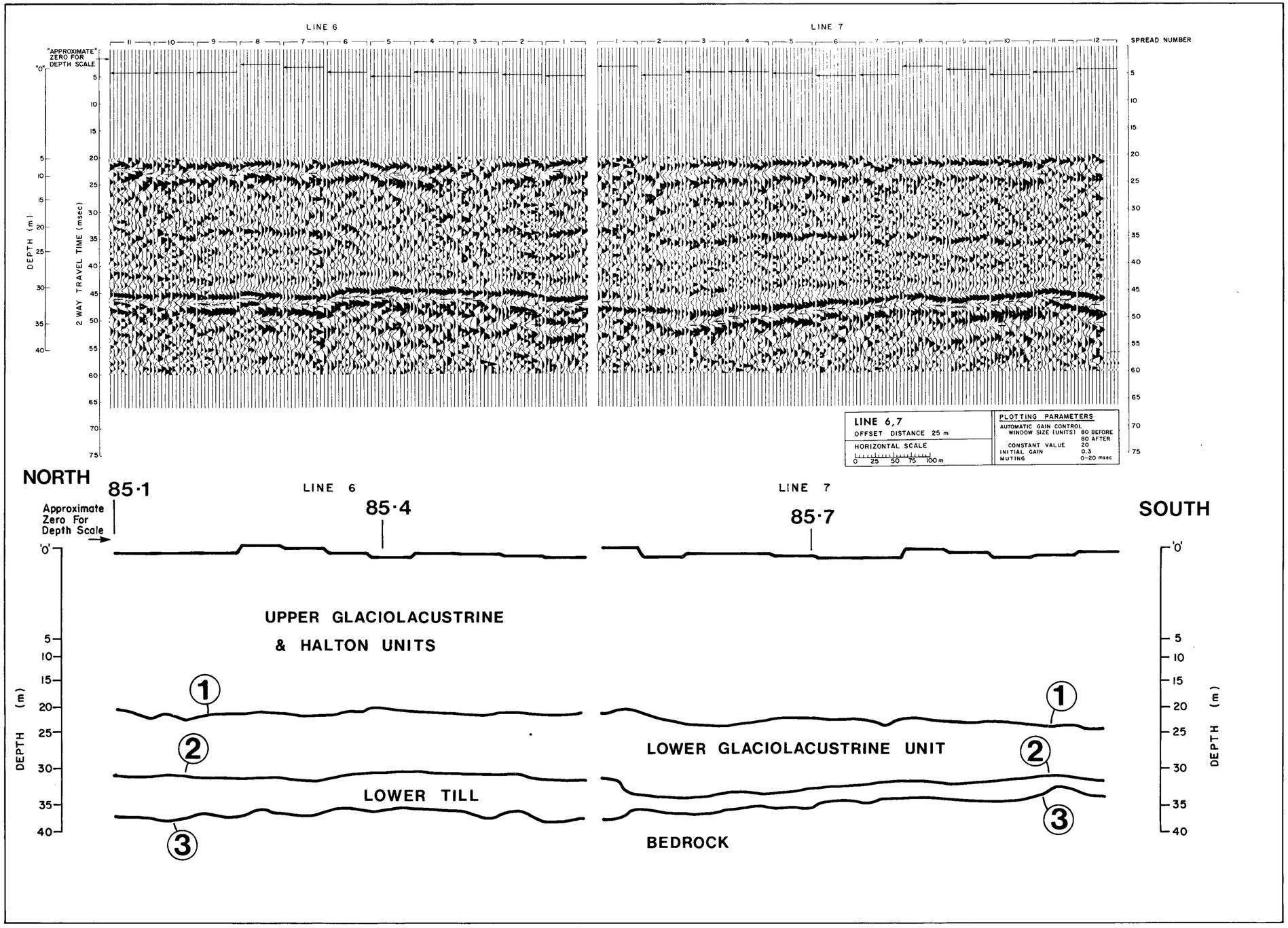
② Reflective Horizon Number 2

③ Reflective Horizon Number 3

85·14 Borehole Location

FIGURE D5-5

Seismic Cross~Section Line 5



OWMC Ontario Waste Management Corporation

Consultant:

Gartner Lee Limited

WATERLOO GEOPHYSICS

Legend:

① Reflective Horizon Number 1

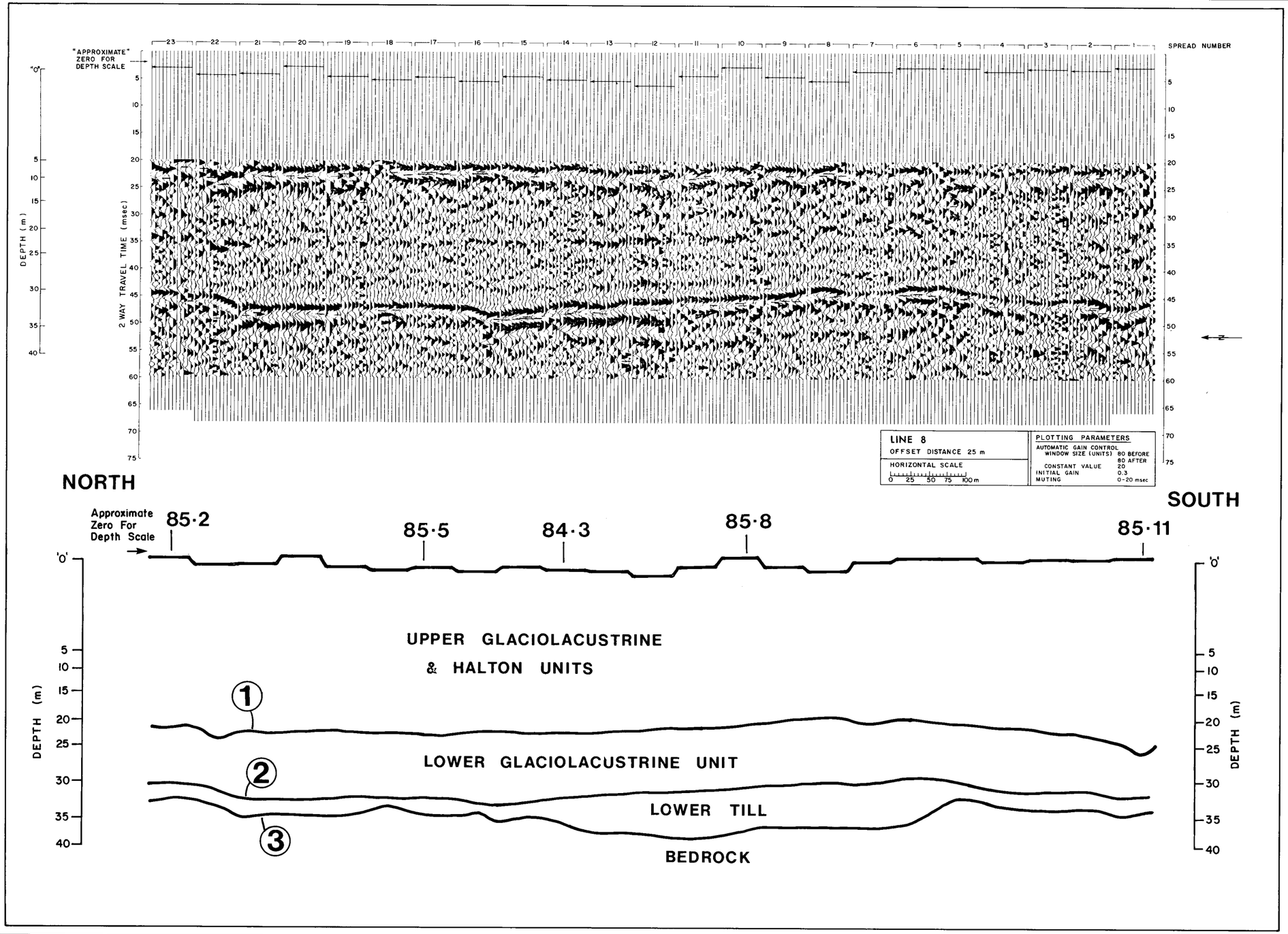
② Reflective Horizon Number 2

③ Reflective Horizon Number 3

85·14 Borehole Location

FIGURE D5-6

Seismic Cross-Section Lines 6 and 7



OWMC Ontario Waste Management Corporation

Consultant:

Gartner Lee Limited

WATERLOO GEOPHYSICS

Legend:

1 Reflective Horizon Number 1

2 Reflective Horizon Number 2

3 Reflective Horizon Number 3

85·14 Borehole Location

FIGURE D5-7

Seismic Cross~Section Line 8

TABLE D5-1: COMPARISON OF GEOLOGIC CONTACTS FROM BOREHOLE LOGS WITH GEOPHYSICAL CONTACT MEASUREMENTS

Borehole Numbers	1985																1984				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	1	2	3	4	5
Geologic Depth to:																					
Lower Glaciolacustrine Unit (m)	21.8	21.0	19.9	23.5	22.0	21.8	21.8	21.4	20.3	21.9	23.3	23.8	24.4	21.2	22.7	20.9	20.4	18.7	17.9	20.5	20.5
Lower Till (m)	33.0	31.5	29.9	31.3	33.9	33.6	33.3	32.0	32.9	31.5	34.2	35.3	39.1	29.2	34.4	25.4	31.6	29.3	32.5	31.1	32.6
Bedrock (m)	34.3	33.6	31.5	35.1	37.4	35.5	35.7	36.0	34.4	36.7	37.8	38.1	38.0	39.5	35.6	26.6	34.8	30.1	33.8	34.4	33.6
Geophysical Depth to:																					
Lower Glaciolacustrine Unit (m)	20	22	20	21	22	22	21	22	20	22	23	23	23	22	23	19	22	20	20	N/A	N/A
Lower Till (m)	30	31	29	30	31	32	32	31	32	32	34	34	35	30	34	23	31	29	31	N/A	N/A
Bedrock (m)	35	33	32	35	34	34	34	37	34	37	38	38	37	38	38	26	35	31	35	N/A	N/A

sists of interbedded till and glaciolacustrine clayey silt, to the Lower Glaciolacustrine Unit consisting of well laminated clay and silt. The boundary between the Halton Unit and the Lower Glaciolacustrine Unit was also evident from laboratory testing by the increase in plasticity and decrease in unit weight. This is described in Section 6.0. This reflector is uniformly present throughout all the seismic cross-sections.

Based on the interpretation of seismic data the depth to this reflector averages 21 m± 2 m beneath the Preferred Site. Its maximum depth of 25 m was found about 420 m south of the site boundary along Heaslip Road (Line 1, Spread 16). The reflective horizon is about 18m deep at its shallowest location about 1140 m south of the site boundary along Heaslip Road (Line 1, Spread 4).

D5.1.2 REFLECTIVE HORIZON NUMBER 2

The second major reflector is extremely strong and was identified along all seismic survey lines. This reflector corresponds to the contact between the Lower Glaciolacustrine Unit, a clay and silt, and the Lower Till, a silt and sand till with locally high gravel content. The contact between the lower Glaciolacustrine and Lower Till units is characterized by a decrease in moisture content and an increase in Standard Penetration Resistance values as described in Section 6.0.

The depth to this reflector from the seismic interpretation ranges between 29 and 35 m beneath the Preferred Site. A maximum depth of 36 m was identified about 300 m south of the site boundary on Heaslip Road (Line 1, Spreads 16 and 17). Depths on the order of 35 m, were found about 440 m west of the site boundary on Vaughan Road (Line 5, Spread 9) and about

900 m east of the site boundary on Vaughan Road (Line 5, Spreads 45 and 48). The shallowest depth of about 23 to 25 m occurs about 1000 m north of the site boundary on Silverdale Road (Line 3, Spreads 16-83).

D5.1.3 REFLECTIVE HORIZON NUMBER 3

The third reflector corresponds with the contact between the lower Till and the bedrock. This reflector, though strong over most of the site, is sometimes difficult to trace because much of the seismic energy was reflected back by the overlying Lower Till.

The depth to the bedrock reflector varies from about 31 to 38 m beneath the Preferred Site with a deepening trend to the south. Bedrock is shallowest about 1150 m north of the site boundary along Silverdale Road (Line 3, Spread 15). Bedrock is deepest about 950 to 1000 m south of the site boundary along Heaslip Road (Line 1, Spreads 6, 7 and 8).

D5.2 TOTAL THICKNESS OF THE OVERBURDEN UNITS

Based on the geophysical survey results the overburden thickness across the surveyed area varies from 28 to 38 m. The thinnest overburden found 1150 m north of the site. The thickest overburden was noted about 950 to 1000 m south of the site boundary on Heaslip Road.

D5.2.1 THICKNESS OF THE CLAY AND SILT STRATA

The clay and silt strata are composed of:

- the Upper Glaciolacustrine Unit;
- the Halton Unit; and
- the Lower Glaciolacustrine Unit.

The base of the clay and silt coincides with Reflective Horizon 2. The average thickness of these strata is about 32 m beneath the Preferred Site, and ranges between 29 and 35 m. The strata thin to 23-25 m about 1000 m north of the site boundary on Silverdale Road (Line 3, Spreads 16-23 in Figure D5-3). The thickest sequence of clay and silt occurs about 300 m south of the site boundary on Heaslip Road (Line 1, Spreads 16 and 17 in Figure D5-1). The clay and silt are about 36 m thick at this location.

D5.2.2 THICKNESS OF THE LOWER TILL

The Lower Till is identified as the sequence of materials between Reflective Horizons 2 and 3. The Lower Till overlies the bedrock and is continuous within the area mapped with the seismic survey. The Lower Till usually conforms with the bedrock topography and appears to infill depressions in the rock surface. This unit varies in thickness from a typical value of 1 to 2 m to about 6 m in depressional areas on the bedrock surface. The thickest area of the Lower Till is located about 960 m south of the site boundary along Heaslip Road. The till is about 10 m thick at this location.

D6 CONCLUSIONS

The seismic interpretation correlated well with the geologic interpretation. The seismic character of the overburden below 25 to 30 msec of two way travel time is uniform. The seismic data, in combination with borehole data, suggest continuous and correlatable geologic contacts within the overburden beneath the entire study area.

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D8 - VELOCITY ANALYSIS DATA

LINE	SPREAD	REF. VEL (m/sec)	SURF. VEL. 1 (m/sec)	SURF. VEL. 2 (m/sec)	DT (msec)	REFR. T (msec)	ZERO T (msec)
1	1	1629	505	481	1.8	8.5	9.61
	2	1627	656	707	2.2	8.3	10.17
	3	1582		353	2	8.5	9.38
	4	1633	404	326	1.8	8.8	9.62
	5	1598		640	2.6	8.4	10.48
	6	1608	533	365	3.2	8.3	10.10
	7	1596	423		1.7	8.9	9.80
	8	1585			2.2	8.6	9.57
	9	1625	416	382	2.6	8.4	9.70
	10				2.5		
	11	1571	414	431	2.4	8.7	9.97
	12	1584	352	435	3.2	8.3	9.87
	13	1661	611		1.9	8.4	9.85
	14	1640	400	403	1.6	8.6	9.40
	15	1612	379	320	2.7	8	9.18
	16	1605	783	780	1.5	8.6	10.07
	17	1649		833	1.9	8.2	10.18
	18	1670	437		1.9	8.2	9.24
	19	1638	583	718	2.2	8.2	9.99
	20	1642	577	642	2.2	8.2	9.88
	21	1643	406	610	2.8	7.6	9.38
	22	1622		512	2.6	7.9	9.56
2	1	1616	753	672	3.7	13.5	16.80
	2	1597	677	814	3.3	13.8	16.88
	3	1592	570	866	2.2	14.5	16.47
	4	1613	598	687	4.2	13.4	16.77
	5	1527	548	621	4	14.1	17.02
	6	1570	522	515	3.6	14.5	16.83
	7	1580	515	377	4.1	14.2	16.49
	8	1510	522		3.8	14.9	17.38
	9	1545		426	3.3	14.5	16.26
	10	1534	874	638	2.9	14.8	17.54
	11	1537	514	588	3.8	14.3	16.92
	12	1525	559	566	3.4	14.8	17.19
	13	1592	580	566	3.6	14.8	17.38
	14	1581	522	696	1.9	14.9	16.35
	15	1572	509	828	2.8	14.4	16.74
	16	1604	424	707	2.6	14.3	16.14
	17	1636	979	456	2.9	14	16.60
	18	1574	458	559	1.2	15.3	16.06
	19	1595	448	863	1.9	14.8	16.36
	20	1770			3.4	12.8	12.80
	21	1536	488	426	3	14.8	16.51
	22						
	23						
3	1	1609			1.9	14.8	14.80
	2	1580	546	530	2	15.1	16.45

LINE	SPREAD	REF. VEL (m/sec)	SURF. VEL. 1 (m/sec)	SURF. VEL. 2 (m/sec)	DT (msec)	REFR. T (msec)	ZERO T (msec)
3	3	1551	450	500	2.8	15	16.66
	4	1614	353	437	2.8	14.1	15.48
	5	1550	723	777	1.9	15.1	16.88
	6	1523	706	583	2	15.3	16.91
	7	1650	706		1.7	14.6	16.10
	8	1612	569	300	2.4	14.8	16.10
	9	1590	443	533	2.2	15	16.34
	10	1601	538	480	2	14.8	16.07
	11	1583	557	495	2.3	14.9	16.41
	12	1596	423	477	1.8	15	16.01
	13	1578	396	498	2.1	15	16.17
	14	1605	474		0.4	15.4	15.64
	15	1701	725	640	0.3	14.6	14.86
	16	1558	492	832	2.1	8.5	10.24
	17	1613	634	596	1.4	8.6	9.68
	18	1588	985	897	1.8	8.4	10.52
	19	1552	584	913	2	8.5	10.37
	20	1630	380	404	1.6	8.6	9.38
	21	1609	336	565	2	8.6	9.73
	22	1628	522		1.8	8.6	9.77
	23	1595	393		1.7	8.8	9.64
4	1	1578	897		1.1	15.1	16.33
	2	1627	760		2	14.1	16.00
	3	1576	1077	1077	1.5	14.8	16.82
	4	1614	529	862	1	15	15.87
	5	1631	415	706	2.1	14.3	15.77
	6	1640		517	2	14.2	15.49
	7	1547		664	1.3	15.4	16.48
	8	1609	747	840	1.8	14.5	16.29
	9	1611	745	583	1.6	14.6	15.93
	10	1610			2.5	14.1	15.80
	11	1624	756	307	1.4	14.5	15.43
	12	1577	348	423	1.2	15.4	15.98
	13	1543	554	647	3.6	15	17.70
	14	1526		470	4.8	13.4	16.22
	15	1573	760	745	4.4	13.4	17.54
	16	1634	657	815	2.1	14.2	16.13
5	1	1605	718	1166	1.7	8.2	10.20
	2	1572	467	1118	0.8	9	9.79
	3	1563	731	931	1.7	8.6	10.37
	4	1530	745		2.4	8.3	10.54
	5	1605	621		1.3	8.6	9.61
	6	1600	616	725	1.4	8.6	9.77
	7	1642	530	1118	2.6	7.5	10.18
	8	1565	1166	675	2.1	8.2	10.62
	9	1599		566	1.9	8.2	9.54
	10	1589	897	499	2.2	8.3	10.22

LINE	SPREAD	REF. VEL (m/sec)	SURF. VEL. 1 (m/sec)	SURF. VEL. 2 (m/sec)	DT (msec)	REFR. T (msec)	ZERO T (msec)
6	9	1551	1188	913	4.2	13.1	18.62
	10	1553		479	3.5	13.6	14.65
	11	1557			2.9	14	14.60
7	1	1754	529	1096	4	12.5	16.56
	2	1661	609	614	4.1	13	16.13
	3	1673	538	596	4.4	12.7	15.82
	4	1680	529	614	4.7	13	16.36
	5	1692	559	566	3.3	13.5	15.82
	6	1659	500	348	3.4	13.7	15.50
	7	1560	614	687	4.1	14.4	17.73
	8	1600			4.8	14.3	16.80
	9	1643		541	3	14	16.03
	10	1610	448	512	3.1	14.3	16.16
	11	1695	523	512	2.8	13.5	15.31
	12	1589	672			14	14.00
8	1	1626	416	671	4.8	14.9	18.16
	2	1559	657	634	5.4	13.7	18.06
	3	1581			5.3	14.6	14.60
	4	1694		645	5.5	14	18.43
	5	1682	598			14	14.00
	6	1718	656	582	3.8	14.5	17.44
	7	1716	718	609	4.2	13.7	17.18
	8	1653	731	466	3.4	13.5	16.04
	9	1674	636	819	3.6	13	16.27
	10	1559		1044	3.9	13.1	18.19
	11	1506	1177	596	3.5	13	16.88
	12	1638		1059	4.1	12.5	15.21
	13	1701	792	706	3.6	12.6	15.97
	14	1654	706	656	3.6	12.5	15.56
	15	1625	1096		3	12.4	16.51
	16	1545	745	598	2.3	12.7	14.63
	17	1560	798	728	3.3	12.8	15.95
	18	1580	583	1019	3.2	12.4	15.60
	19	1624	599		4	12.9	15.90
	20	1619	978	642	4	14	18.05
	21	1592	891	685	3.5	13	16.45
	22	1585		728	3.5	13.6	16.79
	23	1630				14	16.80