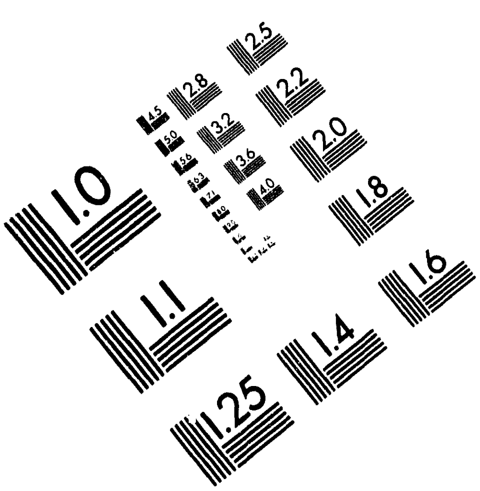

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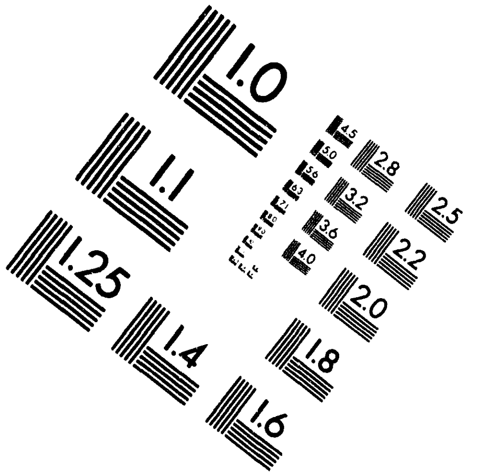

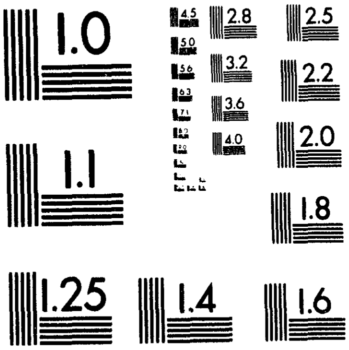

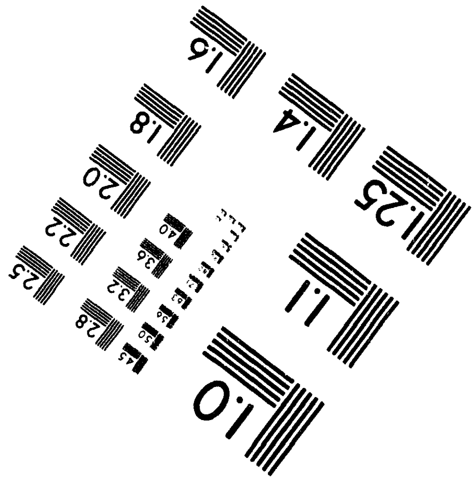

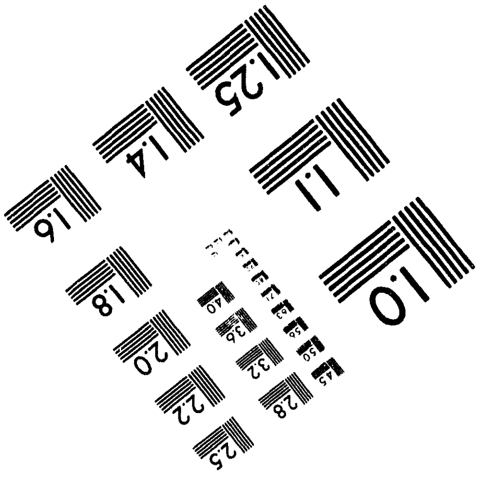

1 of 2

ORNL/TM-12258

X-231B Technology Demonstration for In Situ Treatment of Contaminated Soil:

Contaminant Characterization and Three Dimensional Spatial Modeling

O. R. West [1]
R. L. Siegrist [1]
T. J. Mitchell [2]
D. A Pickering [3]
C. A. Muhr [3]
D. W. Greene [3]
R. A. Jenkins [4]

Environmental Sciences Division
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Prepared By
OAK RIDGE NATIONAL LABORATORY
P.O. Box 2008
Oak Ridge, Tennessee 37830-6036

Managed by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
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---

[1] Environmental Sciences Division, ORNL

[2] Engineering Physics & Mathematics Division, ORNL

[3] Health and Safety Research Division, ORNL

[4] Analytical Chemistry Division, ORNL

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ACRONYMS AND ABBREVIATIONS

ACD - Analytical Chemistry Division
ASI - Advanced Sciences, Inc.
ASTM - American Society Testing Materials
bgs - below ground surface
C - center
CT - carbon tetrachloride
DCA - 1,2-dichloroethane
DCE - 1,2-dichloroethylene
DOE - United States Department of Energy
EB - ethylbenzene
EPA - United States Environmental Protection Agency
ESD - Environmental Sciences Division
FID - flame ionization detector
GC - gas dhromatograph
GP - Geoprobe®
GW - groundwater
ID - inner diameter
K - hydraulic conductivity
MC - methylene chloride
MeOH - methanol
MMES - Martin Marietta Energy Systems, Inc.
MP&T - modified purge and trap vial
MS - mass dpectrometer
MSL - mean sea level
MW - monitoring well
nd, ND - not detected
NE - northeast
NEPA - National Environmental Policy Act
NPDES - National Pollutant Discharge Elimination System
OD - outer diameter
OEPA - Ohio Environmental Protection Agency
ORNL - Oak Ridge National Laboratory
OSHA - Occupational Safety and Health Administration
PCE - perchloroethylene (Tetrachloroethylene)
PID - photoionization detector
PORTS - Portsmouth Gaseous Diffusion Plant
ppm$_v$ - parts per million Volumetric
QA/QC - quality assurance/quality control
QAPP - quality assurance project plan
RCRA - Resource Conservation and Recovery Act
RFI - RCRA Facilities Investigation
SB - soil boring
SW - douthwest
TCE - trichloroethylene
TOC - total organic carbon
TOL - toluene
TCA - 1,1,1-trichloroethane
USDA - U.S. Department of Agriculture
VOA - volatile organic analysis
VOC - volatile organic compound
XYL - xylenes (total)

PREFACE

Fine-textured soils and sediments contaminated by trichloroethylene (TCE) and other chlorinated organics present a serious environmental restoration challenge at U.S. Department of Energy (DOE) sites. Although in situ processes such as bioremediation and soil vapor extraction are feasible at sites with permeable soils (e.g., hydraulic conductivity K $>10^{-3}$ cm/s), their application is normally infeasible in wet, clay soils, and sediments. Environmental restoration of these sites has normally consisted of either (1) excavation and on-site storage, off-site land filling, or thermal treatment; or (2) in-place containment by capping and slurry wall emplacement.

In November 1990, DOE and Martin Marietta Energy Systems, Inc. (MMES) initiated a research and demonstration project at Oak Ridge National Laboratory (ORNL). The goal of the project was to demonstrate a feasible and cost-effective process for closure and environmental restoration of the X-231B Solid Waste Management Unit at the DOE Portsmouth Gaseous Diffusion Plant located in southern Ohio. The X-231B Unit was used from 1976 to 1983 as a land disposal site for waste oils and solvents. Silt and clay deposits (K $<10^{-6}$ cm/s) beneath the unit were contaminated with volatile organic compounds (VOCs) such as TCE (approx. 1–100 ppm range) and low levels of radioactive substances. The shallow groundwater (water table at approx. 12–14 ft depth) was also contaminated, and some contaminants were at levels well above drinking water standards.

After an initial technology evaluation and screening phase, the X-231B project focused on research and demonstration of in situ vapor stripping, chemical oxidation, and solidification; reagent delivery to the subsurface was achieved by soil mixing techniques. The primary objectives of the project were to develop processes as necessary and appropriate and to characterize the operation and performance of each process with regard to in situ treatment of VOCs in clay soils. Secondary objectives were to determine the treatment process zone of influence; the treatment process effects on air emissions, soil chemistry, and microbiology properties; and the fate of heavy metal and radioactive materials. Soil homogenization and translocation were also studied.

Since July 1991 varied research activities have been conducted. Site characterization and contaminant modeling work has included use of a hydraulic probe for collection of nearly 200 soil samples with on-site laboratory analysis for target VOCs. These data were used for statistical simulation and three dimensional modeling of contaminant distribution. A series of laboratory experiments were completed using bench-scale apparatus as well as a pilot-scale soil mixing system in which soil cores from the site were treated. A full-scale field demonstration was completed at the X-231B site in June 1992. Replicated tests of in situ vapor stripping, peroxidation, and solidification were made in soil columns measuring 10 ft in diameter and 15 to 22 ft deep. A computerized data acquisition system linked to approximately 60 sensors enabled near-continuous monitoring of process operation and performance (e.g., recording intervals of 0.2 to 2 min for auger position, off-gas air flow rate and VOC content, soil vapor pressure and temperature). In addition, nearly 500 soil and gas samples were collected before, during, and after soil treatment, for analyses of physical, chemical, and biological parameters. Soil matrix, soil vapor, and off-gas VOC measurements were made by multiple methods.

The X-231B project has been a multidisciplinary and multi-institutional, fast-track, applied research and demonstration effort. Directed by ORNL, the project has benefited from the significant contributions of research staff from six divisions at ORNL, technical and management staff at Portsmouth and Energy Systems, and principal collaborators from two universities (The University of Tennessee and Michigan Technological University) and several private industries (e.g., Chemical Waste Management, Millgard Environmental, Envirosurv, and NovaTerra).

Results of the project have been very insightful regarding in situ environmental restoration of contaminated clay soils. For example, the use of a hydraulic probe for soil sampling with on-site VOC analyses, followed by three dimensional visualization, provided enhanced information compared with conventional sampling, off-site analyses, and routine data treatment. In situ treatment of VOCs in clay soils was effectively (e.g., >85% reduction) and rapidly accomplished (e.g., >15 yd^3/h), and the fate of VOCs and radioactive substances was controlled. Moreover, in situ treatment costs were acceptably low. Operation and performance did vary for the different processes evaluated, and there were advantages and disadvantages associated with each. Ancillary study results indicated interesting changes in soil properties following treatment. For example, soil bacteria levels were increased by several orders of magnitude following ambient air stripping. The favorable project results are being used to design and implement a cost-effective in situ treatment process for full-scale closure of the X-231B Unit.

This report describes the methods and results of one part of the X-231B project. Details regarding other aspects of the work are available in other project publications. Information regarding these publications may be obtained by contacting Dr. Robert L. Siegrist, Oak Ridge National Laboratory, P.O. Box 2008, Oak Ridge, TN, 37831-6036; 615-574-7286.

ACKNOWLEDGMENTS

Many individuals and organizations have contributed to the successful completion of the overall X-231B Technology Demonstration project. Technical staff at ORNL and Energy Systems provided outstanding support in completing laboratory and field work in a timely and effective manner. The contributions of university research collaborators and private industry participants were also significant. Without the financial support and management assistance provided by the DOE Office of Environmental Restoration and the Energy Systems Portsmouth Gaseous Diffusion Plant (PORTS), this project could not have been accomplished. In addition, the support and assistance provided by technical and management staff at Portsmouth were invaluable to the completion of the project. The support of the Ohio Environmental Protection Agency was also important to the completion of the work.

The following individuals are recognized for their contributions to completion of the work described in this report.

Oak Ridge National Laboratory

O. R. West	Environmental Sciences Division
R. L. Siegrist (Project Technical Director)	Environmental Sciences Division
T. J. Mitchell	Engineering Physics & Mathematics Division
D. A. Pickering	Health and Safety Research Division
C. A. Muhr	Health and Safety Research Division
D. W. Greene	Health and Safety Research Division
R. A. Jenkins	Analytical Chemistry Division
S. H. Harmon	Analytical Chemistry Division
S. E. Herbes	Environmental Sciences Division
M. I. Morris (Demonstration Coordinator)	Chemical Technology Division
T. L. Donaldson	Chemical Technology Division
R. M. Schlosser	Oak Ridge Associated Universities
J. L. Zutman	Oak Ridge Associated Universities
Y. I. Jager	Environmental Sciences Division
M. D. Morris	Engineering Physics & Mathematics Division

Private Industries

J. Tuttle, H. Chapman	Envirosurv, Inc.

Martin Marietta Energy Systems, Inc.

D. T. Davenport (Site Representative)	Environmental Restoration, PORTS
J. S. Watson	Environmental Restoration Division, K-25
T. M. Koepp	Environmental Restoration Division, K-25
C. G. Cowart	Waste Research and Development Programs

U.S. Department of Energy

D. Dollins	DOE, PORTS
J. O. Moore	DOE Field Office, Oak Ridge

EXECUTIVE SUMMARY

The X-231B Solid Waste Management Unit, located in the Portsmouth Gaseous Diffusion Plant in Piketon, Ohio, consists of ~0.8 acres of level land used for the disposal of waste oils and degreasing solvents from 1976 to 1983. Since then, waste disposal operations have ceased and caps have been installed over the Unit to hydrologically isolate the contaminated soil. However, site characterization activities conducted after the caps were installed revealed the presence of several volatile organic compounds (VOCs) in the fine-textured soils underlying the Unit as well as in groundwater directly beneath and downgradient from the site. As a result of these findings, the Ohio Environmental Protection Agency (Ohio EPA) required that soil remediation be included in the closure of the X-231B Unit.

A team of scientists and engineers from Oak Ridge National Laboratory (ORNL) was assembled to identify technologies for the effective removal of VOCs from fine-textured soils such as those that underlie the X-231B Unit. A group of technologies were selected and subsequently evaluated through laboratory-scale treatability studies using X-231B soil, and field-scale process implementations that were conducted within the X-231B Unit. This document contains contaminant characterization and distribution modeling that was performed in support of the technology demonstration.

The primary objective of contaminant characterization at the X-231B Unit was to locate highly contaminated regions where the field-scale process implementations were to be conducted. To fulfill this objective, three dimensional models of the VOC distribution were developed from a spatially extensive baseline VOC data set collected in January 1992. During this sampling event, soil samples were collected from ~190 locations to depth of 22ft within the Unit and analyzed for target VOCs using an on-site heated headspace technique. Duplicate samples were collected from several sampling locations to investigate short-range spatial variability which turned out to be rather significant. Off-site analyses following EPA Method SW5030/8240 were also performed on samples taken from 20% of the sampling locations. Comparisons between on-site and off-site analyses of corresponding samples (i.e., samples located within 1-ft of each other) showed predominantly higher VOC levels measured by the on-site heated headspace technique.

Spatial models were developed from the VOC data set using three different interpolation techniques: (1) a three dimensional interpolator which was an extension of a minimum tension, two-dimensional contouring method, (2) a smoothing routine that compromises between minimizing curvature and residual sum of squares, and (3) a version of kriging. Visualizations of the spatial models from the three methods were very similar, and all indicated a highly contaminated region close to the eastern edge of the north plot where all technology demonstrations were subsequently conducted.

The predictive capability of the various spatial modeling methods were evaluated through cross-validation exercises in which a subset of the January data set was used to predict VOC measurements at excluded sampling points (i.e., either excluded all sample depths within a few borings or excluded a few sample depths within all borings). There were no remarkable differences among predictions from the three different methods and all three methods gave similar trends in differences between predicted and measured values. The cross-validation exercise in which VOC measurements at given depths were eliminated resulted in smaller prediction errors when compared to that in which samples from entire borings were eliminated. This indicates that to define the contaminant distribution within the X-231B Unit, more information is gained by collecting samples from a greater number of borings (i.e., greater horizontal sampling density) than collecting samples from more depth intervals (i.e., greater vertical sampling density). This observation is important in designing sampling activities at X-231B and similar sites.

The three spatial modeling methods were also evaluated by comparing model predictions with VOC measurements made four months after the baseline samples were collected (April/May 1992). Large prediction errors, which were sometimes as high as two orders of magnitude, highlight the inherent difficulty of characterizing an in-place soil volume on the basis of a limited number of discrete soil samples. Although all three methods gave similar trends in ratios between predicted and measured values, the three dimensional kriging method was judged to be most suitable for use with spatially distributed VOC data sets since that method alone incorporates uncertainty due to spatial heterogeneity. Confidence intervals for predicted VOC levels at unsampled points are easily obtained when using the kriging method but are not defined under the other spatial modeling techniques.

A simulation technique coupled with three-dimensional kriging was used to estimate the mass of total VOCs in the north plot of the X-231B Unit to a depth of 22 ft. Mass estimates could also have been calculated from the contaminant distribution models developed from the other spatial modeling methods evaluated in this study. However, as mentioned previously, interval estimates given by the kriging method better reflect the uncertainty in the spatial modeling process when dealing with heterogeneous contaminant distributions. Simulations using the kriging model resulted in a best total VOC mass estimate in the north plot of 335 kg, with a 90% confidence interval of 229 to 488 kg, and a mass estimate in the south plot of 29 kg, with a 90% confidence interval of 16 and 76 kg.

1. INTRODUCTION

1.1 BACKGROUND

The X-231B Solid Waste Management Unit is located in the Portsmouth Gaseous Diffusion Plant (PORTS), a U.S. Department of Energy (DOE) production facility in Piketon, Ohio. The X-231B Unit consists of two plots (see Figs. 1.1 and 1.2), which together encompass ~0.8 acres. It was reportedly used for the treatment and disposal of waste oils and degreasing solvents from 1976 to 1983. From 1989 to 1990, efforts were made to close the X-231B Unit in compliance with Resource Conservation and Recovery Act (RCRA) requirements. In 1987, geomembrane caps were placed over both plots to hydrologically isolate the contaminated soil. Site characterization activities conducted within the Unit after the caps were installed revealed the presence of several volatile organic compounds (VOCs) [e.g., trichloroethylene (TCE) and 1,1,1-trichloroethane (TCA)] in fine-textured soils from the ground surface to a depth of ~25 ft [1,2]. Furthermore, TCE at levels higher than the Federal drinking water standard (> 5 ppb) were measured in the shallow groundwater directly beneath and 750 ft downgradient from the unit.

Concerned over the continuous release of contaminant VOCs into the ground water, the Ohio Environmental Protection Agency (Ohio EPA) required that soil remediation be included in the closure of the X-231B Unit. A team of scientists and engineers from Oak Ridge National Laboratory (ORNL) was assembled by Martin Marietta Energy Systems, Inc. (MMES), the PORTS management contractor, to identify technologies for the effective removal of VOCs from fine-textured soils such as those that underlie the X-231B Unit (see Table 1.1 for characteristics). The ORNL project team selected the following in situ technologies for potential application at the X-231B unit: (1) vapor stripping, (2) solidification/stabilization, and (3) peroxidation. All three technologies were to be coupled with soil mixing in order to overcome problems associated with delivering treatment fluids to low-permeability soils (i.e., air for vapor stripping, grout for solidification/stabilization, and hydrogen peroxide for peroxidation). These technologies were evaluated through laboratory-scale treatability studies using X-231B soil, and field-scale process implementations that were conducted within the X-231B Unit. This document contains details of contaminant characterization and distribution modeling that were performed in support of the technology demonstration. Other aspects of the overall X-231B technology demonstration project can be found in other project publications [3-7].

1.2 OBJECTIVES AND SCOPE

The primary objective of contaminant characterization at the X-231B Unit was to locate highly contaminated regions where the field-scale process implementations were to be conducted. To fulfill this objective, a baseline sampling event was conducted in January 1992 in which soil samples were collected from ~190 locations within the Unit and analyzed for target VOCs. Aside from VOC samples, soil cores for laboratory treatability studies were also obtained during this sampling event. Additional sampling and analysis activities were completed during the field-scale testing in April-June 1992 [7]. This report focuses on the results of the January 1992 baseline sampling event, but also includes a summary of previous site characterization activities conducted at X-231B.

This document begins with a summary of the subsurface physical and contaminant characteristics obtained from investigative studies conducted at the X-231B Unit prior to January 1992 (Sect. 2). This is then followed by a description of the sample collection and analysis methods used during the baseline sampling conducted in January 1992 (Sect. 3). The results of this sampling event were used to develop spatial models for VOC contaminant distribution within the X-231B Unit.

Visualizations of these spatial models as well as VOC mass estimates calculated from these models are given in Sect. 4. Conclusions regarding the characterization data and the various approaches used to model the VOC distribution are given in Sect. 5.

Table 1.1. Characteristics of subsurface soil at X-231B as measured in samples collected by ORNL in December 1990 [3]. Range of values taken from several samples.

	Nominal depth	
Characteristic	Shallow (7 ft)	Deep (15 ft)
Grain size distribution		
Clay: <0.002 mm (wt %)	22.5 – 25.0	12 – 15
Silt: 0.002–0.05 mm (wt %)	65.5 – 67.0	39 – 64
Sand: 0.05–2.0 mm (wt %)	8 – 12	22 – 46
USDA Texture	Sandy clay loam	Silt loam
Water content (wt%)	13.4 – 19.0	18.8 – 19.0
Total organic carbon (mg/kg)	579–1190	184–472

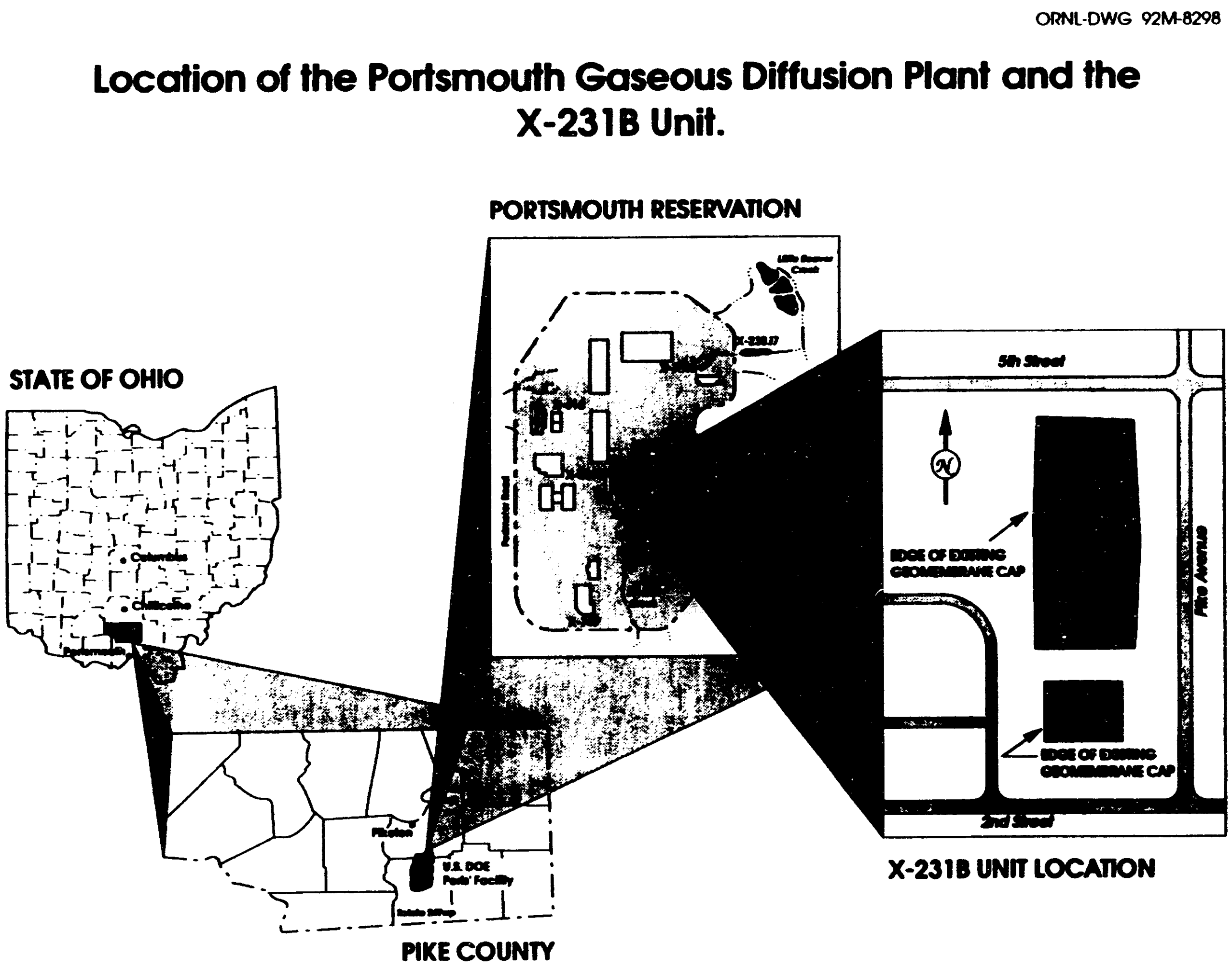

Fig. 1.1 Location of the DOE Portsmouth Gaseous Diffusion Plant and the X-231B Unit. (ORNL DWG 92M-8298)

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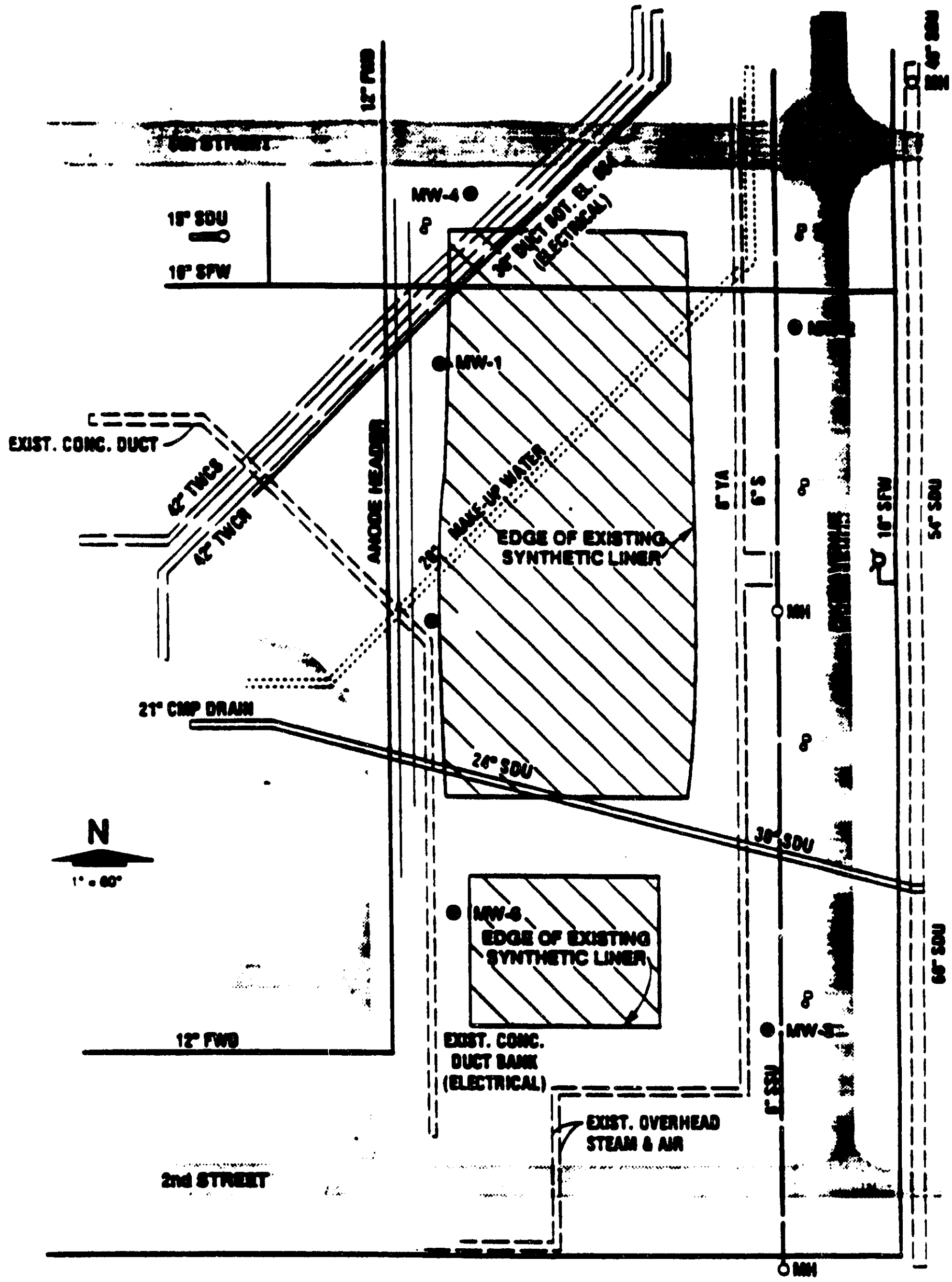

Fig. 1.2. Map of the X-231B unit indicating its areal extent and the location of various utilities. (Source: Morrison and Knudsen, 1990 [2])

2. PHYSICAL SETTING AND REPORTED CONTAMINATION

Conditions at and around the X-231B unit have been characterized as part of several investigations over the past 8 years (Table 2.1). A synopsis of the existing conditions at the site is provided below; further details may be found in other published reports [8-16].

2.1 SITE PHYSICAL CHARACTERISTICS

2.1.1 Setting

The X-231B unit at PORTS consists of two separate plots (see Fig. 1.1). The larger, northern plot is ~265 ft long by 110 ft wide. The smaller, southern plot is 100 ft long by 70 ft wide. The overall site and the immediate vicinity are level. Underground and overhead utility lines around and within X-231B (see Fig. 1.2) include storm and sanitary sewers, water supply lines, cooling tower supply and return lines, air and steam lines, and electrical lines. The existence of these underground structures may hinder some forms of in situ remediation such as soil mixing. However, it is possible that these utilities will be relocated prior to full-scale soil remediation activities at the site.

2.1.2 Soil and Unconsolidated Units

Five geologic units exist in the shallow subsurface beneath the PORTS plant site, including X-231B. These units consist of the unconsolidated Quaternary age Minford and Gallia members of the Teays formation, followed in descending order by three formations: Sunbury Shale, Berea Sandstone, and Bedford Shale (Fig. 2.1), all of Mississippian age.

The Minford Unit is divided into an upper clay and a lower silty zone. The Minford upper zone ranges in thickness from 12 to 20 ft in the X-231B area and generally consists of a stiff, silty clay (SC on Unified Soil Classification System) which is predominantly yellow to yellow-brown (10YR5/6, 10YR6/4 using the Munsell Soil Color chart) to olive-brown in some areas [8]. The Minford lower silt layer is 8.5 to 18 ft thick (also based on logs from MW-1 through MW-6), classified as SM (inorganic, micaceous, and elastic), and commonly brown to yellow-brown (10YR5/8 to 10YR6/8). The silt contains occasional light brown-gray silt zones in desiccation cracks; occasional very fine, unconsolidated sand; scattered very poorly graded, clear, quartz sand particularly within the lower end of the unit; black iron oxide staining; and scattered micaceous intervals also within the lower end of the unit.

The Gallia Unit, which lies beneath the Minford, is composed of reddish-brown silty, clayey sand and gravel. This unit which has a thickness ranging from 1.8 to 4.4 ft within the X-231B area, is generally loosely consolidated but can be semiplastic, depending on clay content [12]. The Gallia Unit is not continuous beneath the PORTS plant site. This discontinuity may be the result of deposition by a river system that did not cover the entire plant site. Alternatively, the river may also have changed course and removed the previously deposited material. Particle size distributions for the Minford clay, Minford silt and Gallia sand layers are presented in Table 2.2.

Table 2.1 Summary of soil sampling and analysis studies conducted at the X-231B site prior to the Technology Demonstration.

Sampling party	Time of study	Description of activity and results	Reference
CTL Engineering, Inc.	September 1985	Drilled monitoring wells (~30 ft deep) MW-1 through 6 (Fig. 2.1). Initial discovery of VOCs in groundwater.	8
Goodyear Atomic	February 1986	Twelve, shallow (3 ft), hand-augured soil borings and additional groundwater sampling from MW-1 through 6 (Fig. 2.1). Confirmed presence of VOCs in soil and groundwater.	9
Geraghty and Miller	March 1986	Fourteen, 10 ft deep hand-auger soil borings. Max. TCE in soil was 12,000 ug/kg but most were less than 10 ug/kg (detection limit).	9
IEP, Inc.	1986	Ten, 10-ft deep boreholes. 5 samples (4 at 3.5 ft., 1 at 7 ft) were analyzed for RCRA Appendix VIII contaminants. TCE and TCA present at highest levels (8,900 and 7,200 ug/kg, respectively).	2
Advanced Sciences, Inc.	June, 1987	Sixteen, drilled borings to 30 ft depth with analysis for or VOCs, metals, herbicides, and PCBs. General contamination by VOCs with TCE and TCA predominating.	11
Oak Ridge National Laboratory	December, 1990	Three 24 ft-soil borings. Max. TCE was 7,700 ug/kg.	3

Table 2.2. Particle size distributions reported for the unconsolidated deposits at Portsmouth [8].

Particle	Diameter (mm)	Minford Clay (wt%)	Minford Silt (wt%)	Gallia Sand (wt%)
Aggregate	> 2.000	0 - 1%	0 - 1%	20 - 36%
Coarse sand	0.500 - 2.000	0 - 1%	0 - 2%	0 - 7%
Medium sand	0.250 - 0.500	1 - 6%	0 - 3%	7 - 20%
Fine sand	0.050 - 0.250	1 - 6%	2 - 36%	14 - 20%
Silt	0.002 - 0.050	34 - 54%	33 - 66%	13 - 33%
Clay	<0.002	32 - 64%	17 - 45%	11 - 22%

2.1.3 Bedrock Units

The existence of the Sunbury Shale, Berea Sandstone, and Bedford Shale formations beneath X-231B has been inferred from logs taken from soil borings drilled in the surrounding areas. The Sunbury unit is a black, very carbonaceous, fissile shale that is highly fractured in outcrops. It was found to be coherent, semiplastic and clayey in some cores obtained during the Groundwater Quality Assessment drilling program [13]. The Sunbury ranges in thickness from 0 to 20 ft and averages about 10 ft thick beneath most of the plant [14].

The Berea unit is a light-gray, hard, thickly-bedded, fine-grained sandstone with scattered thin shale laminations. The average thickness is 30 ft; however, the lower 10 ft has numerous shale laminations and is very similar to the underlying Bedford Shale. This gradational contact does not allow for a concise determination of the thickness of the Berea [14].

The Bedford Shale, which has an average thickness of 100 ft, is composed of thinly bedded shale with interbeds and laminations of hard, gray, fine-grained sandstone and siltstone. One-third to one-half of the formation is sandstone [14].

The Mississippian bedrock sequence (i.e., Sunbury Shale, Berea Sandstone, and Bedford Shale) has a regional dip of about 30 ft per mile to the east. The bedrock surface at X-231B is generally flat, with a slight to moderate slope to the southeast. The Sunbury Shale, which is the shallowest bedrock unit, is slightly fractured and is 10 to 12 ft thick. Directly under the Sunbury is the Berea, a hard, thick-bedded, fine-grained sandstone averaging 30 ft in thickness. The upper surface of the Berea dips gently to the southeast.

ORNL-DWG 93-15544

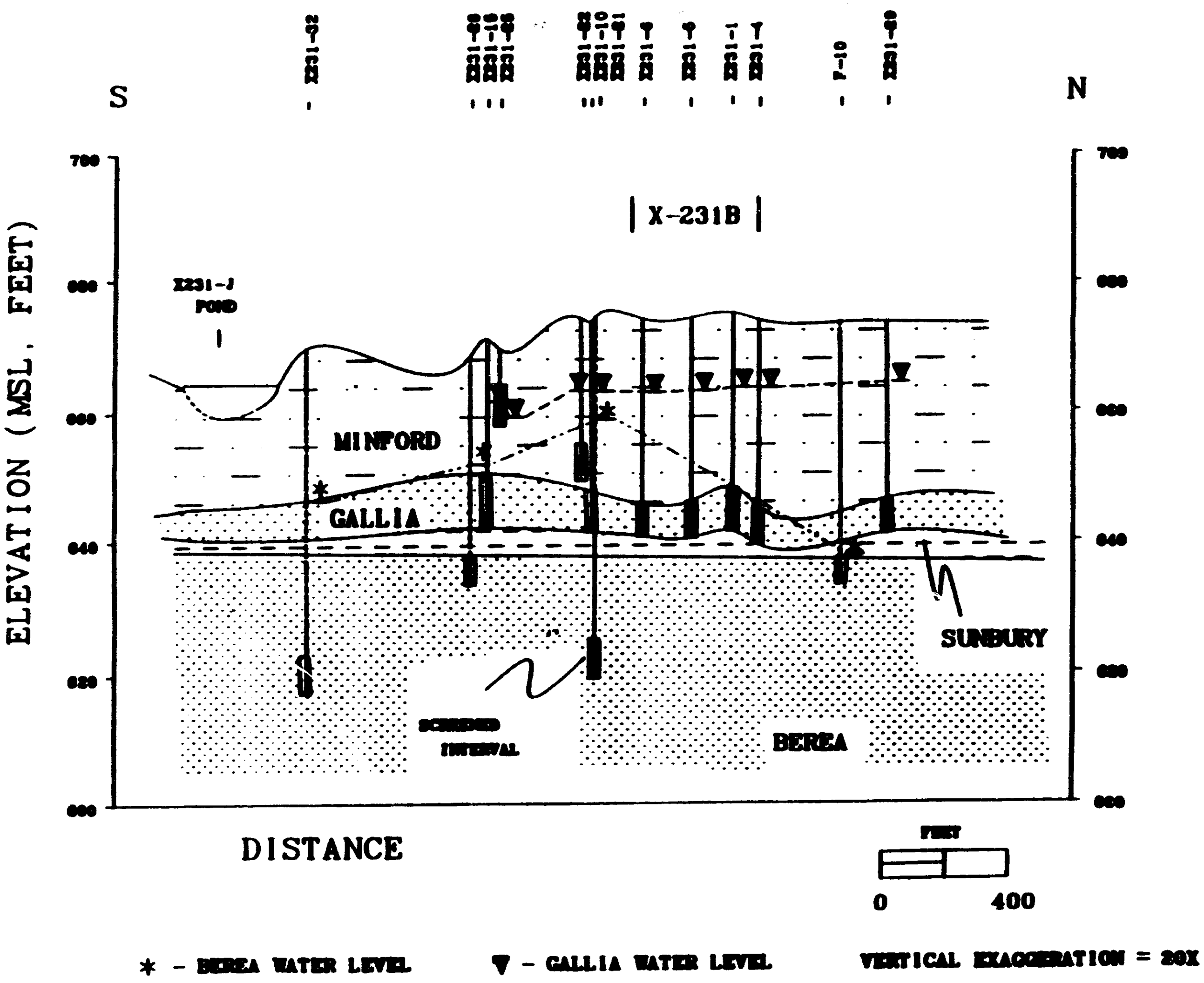

Fig. 2.1. Stratigraphic cross-section of the X-231B site. (Source: Geraghty & Miller, 1989 [13])

2.1.4 Hydrogeology

Groundwater underneath the X-231B unit occurs in two aquifer systems: the Minford/Gallia members and the Berea sandstone (see Fig. 2.1). The depth to the water table underneath the site is ~10 to 14 ft. The hydraulic conductivity values of all geologic units are relatively low (Table 2.3) [9]. Laboratory measurements revealed a saturated hydraulic conductivity (K_{sat}) in the range of 8.1×10^{-8} cm/sec (0.00023 ft/d) for the Minford clay and 1.5×10^{-6} cm/sec (0.0043 ft/d) for the Minford silt. Field pumping tests yielded a substantially higher mean K_{sat} for the Gallia deposit of 2.5×10^{-3} cm/sec (7.1 ft/d). The lower portion of the Minford is reportedly in hydraulic continuity with the Gallia [13]. The permeability of the Sunbury Shale is believed to be very low. Although thin and slightly fractured, the Sunbury when present appears to hydraulically isolate the underlying Berea from the overlying unconsolidated aquifer (i.e., Minford/Gallia).

Thirty-six groundwater monitoring wells have been installed in the vicinity of the X-231B unit over the past few years. Twenty-five wells have been installed and screened within the Gallia deposit, but only three wells have been screened in the overlying Minford. Eight wells penetrate into the underlying bedrock (i.e., Sunbury or Berea). Based on observations within these wells, groundwater movement in the area surrounding X-231B is predominantly vertical in the Minford unit and horizontal in the Gallia. Horizontal hydraulic gradients in all three units at X-231B (i.e., Minford, Gallia, and Berea) indicate a southeasterly flow. The hydraulic gradients are low, however. Vertical gradients between the Gallia and Minford indicate potential for upward flow in the vicinity of the X-231B site [14]. The interaction between the flow systems in the Gallia Unit and the Berea Sandstone is controlled by the thickness of the Sunbury Shale that exists between the two aquifers. Vertical gradients between the Gallia and Berea indicate downward flow in the vicinity of the X-231B site [14].

Table 2.3 Hydraulic conductivities of geologic units at Portsmouth [14].

Subsurface unit	Hydraulic conductivity (cm/sec)
Minford Clay	8.1×10^{-8}
Minford Silt	1.5×10^{-6}
Gallia	1.2×10^{-3}
Sunbury	not measured
Berea	5.6×10^{-5}
Bedford	2.1×10^{-5}

2.2 SITE CONTAMINATION CHARACTERISTICS

2.2.1 Soil Contamination

Several field investigations have been conducted within and around the X-231B Unit during the past 5 years (See Table 2.1). An early study was conducted by Goodyear Atomic Corporation in January 1986 [2]. This study was limited to hand auger borings to ~3-ft depth at 12 locations within the X-231B unit boundaries (see Fig. 2.2). High levels of VOCs were detected in the samples. Polychlorinated biphenyls (PCBs) were also detected, but only in 6 of 12 borings and at concentrations of only 1 to 7 mg/kg (ppm).

A subsequent investigation was conducted by Geraghty & Miller, Inc., in April 1986 [9]. This study consisted of hand auger borings in 14 locations within the unit (see Fig. 2.3). Soil samples were collected at depth zones of 0 to 2, 4 to 6, and 8 to 10 ft. This study found a maximum VOC concentration of 12,000 µg/kg (ppb) in the 0 to 2 ft depth zone and a general trend of declining VOC concentrations with depth. TCE and TCA were the primary contaminants.

Another study was conducted by IEP, Inc. in 1986 [2]. Soil samples collected from ten, 10-ft deep boreholes were analyzed for RCRA Appendix VIII contaminants. Five samples were selected for this analysis based on those with the highest field readings for VOCs. Four of the five samples were from 3.5 ft deep, and one was from 7.0 ft. Of the seven VOCs analyzed as part of the RCRA Appendix VIII list, TCA and TCE were present at the highest concentrations (8900 and 7200 µg/kg, respectively). However, the concentrations varied widely among borings. Other VOCs detected included, methylene chloride, 1,1-dichloroethene, tetrachloroethene, chloroform, and freon. Analyses for pesticides and heavy metals revealed nondetectable or very low concentrations. Total alpha and total beta radiation was below 100 cpm, except in two samples which measured ~100 to 200 cpm (~2200 cpm = 1 nCi).

A more extensive study was conducted by Advanced Sciences, Inc. (ASI) from June 1987 through January 1988 [11]. This study consisted of 16 test borings drilled to the Sunbury Shale at a depth of 30 ft. Soil samples were collected at selected intervals and analyzed for VOCs, metals, herbicides and PCBs, and radioactivity (Table 2.4). The results of this study showed general contamination of the soil by VOCs, with TCE and TCA being the primary contaminants. Soil concentrations ranged from nondetectable to 17,000 µg/kg for TCA and nondetectable to 13,000 µg/kg for TCE. Acetone and Freon-113 were also prevalent at appreciable concentrations. The highest VOC concentrations were typically found at or just above the groundwater table (see Fig. 2.4). Metal contamination was generally low and within probable background or normal soil levels. No pesticides, herbicides or PCBs were detected in this study. Total alpha activities were generally low. Only 12 of 69 samples exhibited alpha levels above the detection limit of 10 nCi/kg. This contamination was largely confined to the top 12 ft of soil. This compared with a reported background level of 3 to 6 nCi/kg. Total beta activities were measured in all boreholes, but levels were normally below 30 nCi/kg. Total uranium concentrations averaged 3 mg/kg.

2.2.2 Groundwater Contamination

Samples collected by IEP, Inc. from three groundwater monitoring wells located near X-231B were analyzed for RCRA Appendix IX contaminants [2]. Wells MW-1, MW-5, and MW-6 were selected for this sampling based on previous work which showed them to be within the area of highest contaminant concentrations around X-231B. These analyses revealed that all three wells were contaminated with TCE (308 to 696 µg/L), TCA (62 to 3910 µg/L), and 1,1-dichloroethene (DCE) (67 to 924 µg/L) at levels well above federal drinking water standards (see Table 2.5). Lower levels of seven other organics were found in some of the wells. Metals were detected, but concentrations were within drinking water standards, except for of iron, which was present at high concentrations.

Additional analyses of groundwater samples from monitoring wells into the Gallia deposit around X-231B identified 12 VOCs above detection limits. Six VOCs were widespread: TCE, TCA, 1,1-dichloroethane (DCA), chloroform, 1,1-DCE, and 1,2-dichloroethene (1,2-DCE). VOC concentrations were generally in the 100-to 1000-µg/L range. A site map depicting the extent of the groundwater plume, as illustrated by an isoconcentration contour map for TCE in the Gallia, is presented in Fig. 2.5. This indicates the plume has spread ~750 ft southeast of the southeast edge of X-231B.

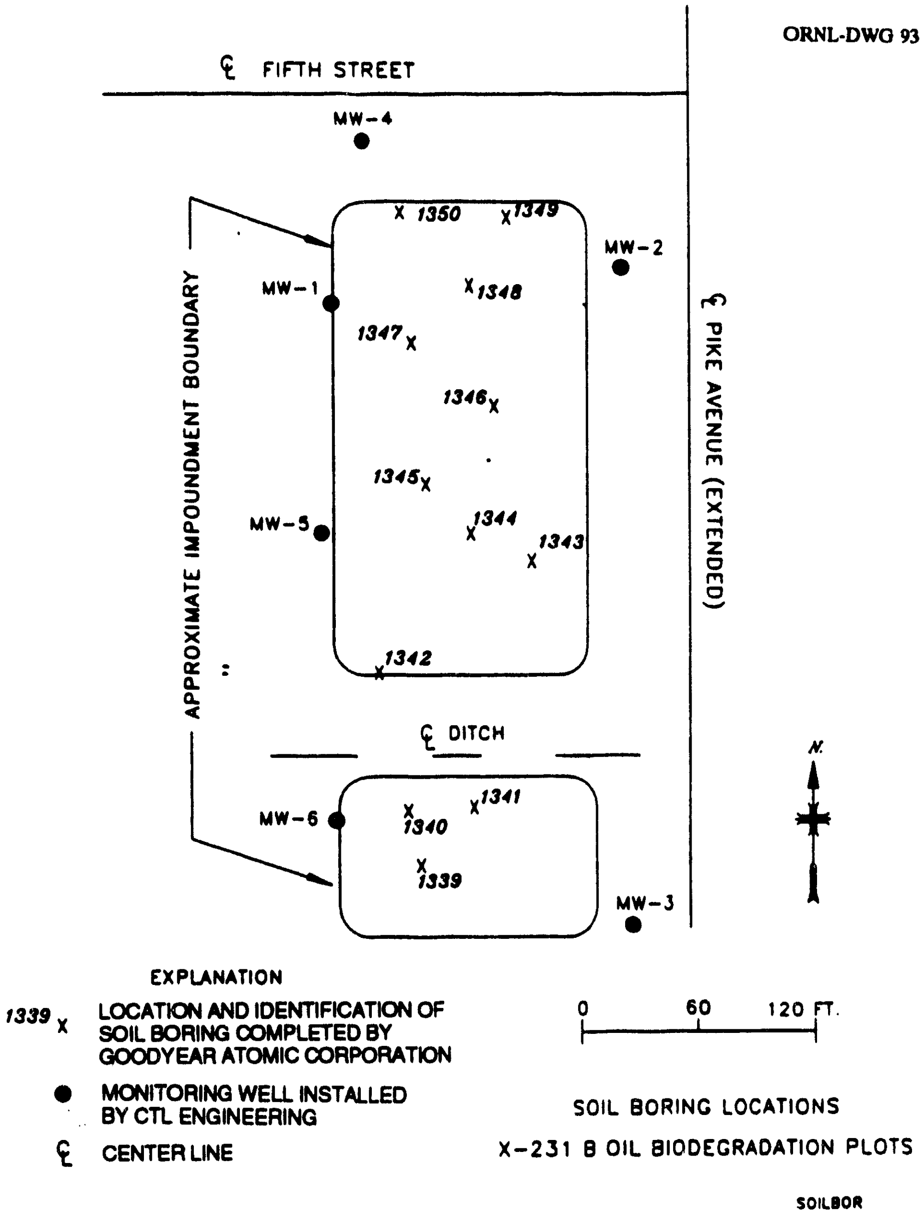

Fig. 2.2. Location of borings and monitoring wells installed by CTL Engineering and soil borings drilled by Goodyear Atomic in 1986.
(Source: Geraghty & Miller, Inc., 1986 [8, 9])

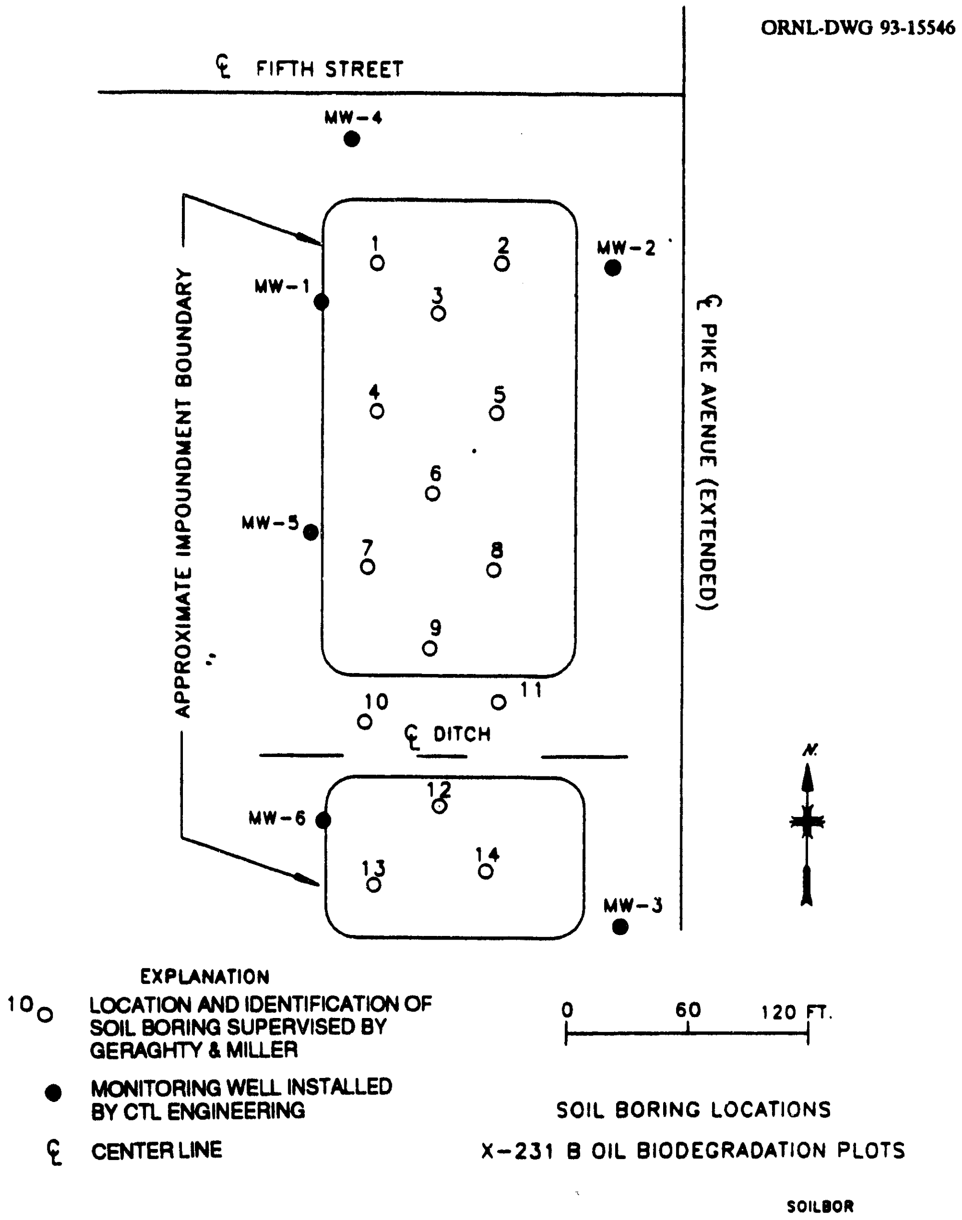

Fig. 2.3. Location of soil borings drilled by Geraghty & Miller, Inc. in 1986. (Source: Geraghty & Miller, Inc., 1986 [9])

Table 2.4. Summary of soil contamination levels with depth below X-231B. (Source: Advanced Sciences, Inc., 1988 [11])

	Depth below ground surface (ft)					
Constituent	0-2	8-10	12-14	16-18	20-22	24-26
Volatile Organics, µg/kg						
1,1-Dichloroethane [50] [a]	nd [b]	nd	nd	nd-150	nd-120	nd-240
1,2-Dichloroethane [50]	nd	nd	nd	nd	nd	nd
1,2-Trans-dichloroethene [50]	nd	nd	nd	nd	nd	nd
1,1-Dichloroethene [50]	nd	nd-83	nd-1800	nd-410	nd-5500	nd-230
Methylene chloride [50]	nd-160	nd	nd-500	nd-55	nd-160	nd
1,1,1-Trichloroethane [50]	nd-200	nd-10000	nd-4100	nd-5000	nd-17000	nd-810
1,1,2-Trichloroethane [50]	nd-	nd	nd-130	nd-140	nd-140	nd
Trichloroethene [50]	nd-120	nd-7300	nd-5300	nd-4800	nd-13000	nd-4500
Acetone [50]	nd-23000	nd-6200	nd-3800	nd-12000	nd-1000	nd-2900
Trichlorofluoromethane [50]	nd	nd	nd	nd	nd	nd
Freon 113 [50]	nd-2200	nd-11000	nd-7000	nd-5900	nd-4900	nd-2600
Chloroform [50]	nd	nd	nd-580	nd-57	nd-240	nd-110
Metals, Herbicides, and PCBs, mg/kg						
Arsenic [10]	nd	nd	[c]	nd	[c]	nd
Barium	38-86	24-51	[c]	19-44	[c]	17-24
Cadmium [01]	nd	nd	[c]	nd	[c]	nd
Chromium	14-31	9-20	[c]	7-14	[c]	9-18
Lead	20-28	16-23	[c]	10-18	[c]	13-20
Mercury [0.02]	nd-0.84	nd-0.04	[c]	nd	[c]	nd
Nickel	8-18	7-20	[c]	9-15	[c]	13-21
Beryllium [01]	nd	nd	[c]	nd	[c]	nd
2,4-D	nd	nd	[c]	nd	[c]	nd
2,4,5-TP (Silvex)	nd	nd	[c]	nd	[c]	nd
Polychorinated biphenyls	nd	nd	[c]	nd	[c]	nd
Radioactivity						
Total Alpha, nCi/kg [10]	nd-150	nd	nd	nd	nd	nd
Total Beta, nCi/kg [10]	nd-200	nd-22	nd-31	nd-33	nd-34	nd-34
Total Uranium, mg/kg	2-150	2-8	1-3	2-3	2-3	2-3
Technetium, nCi/kg [2]	nd-380					

[a] The number in brackets is the method detection limit. Pairs of numbers denote a range of values.

[b] "nd" indicates constituent not detected at detection limit shown.

[c] indicates analyses not performed.

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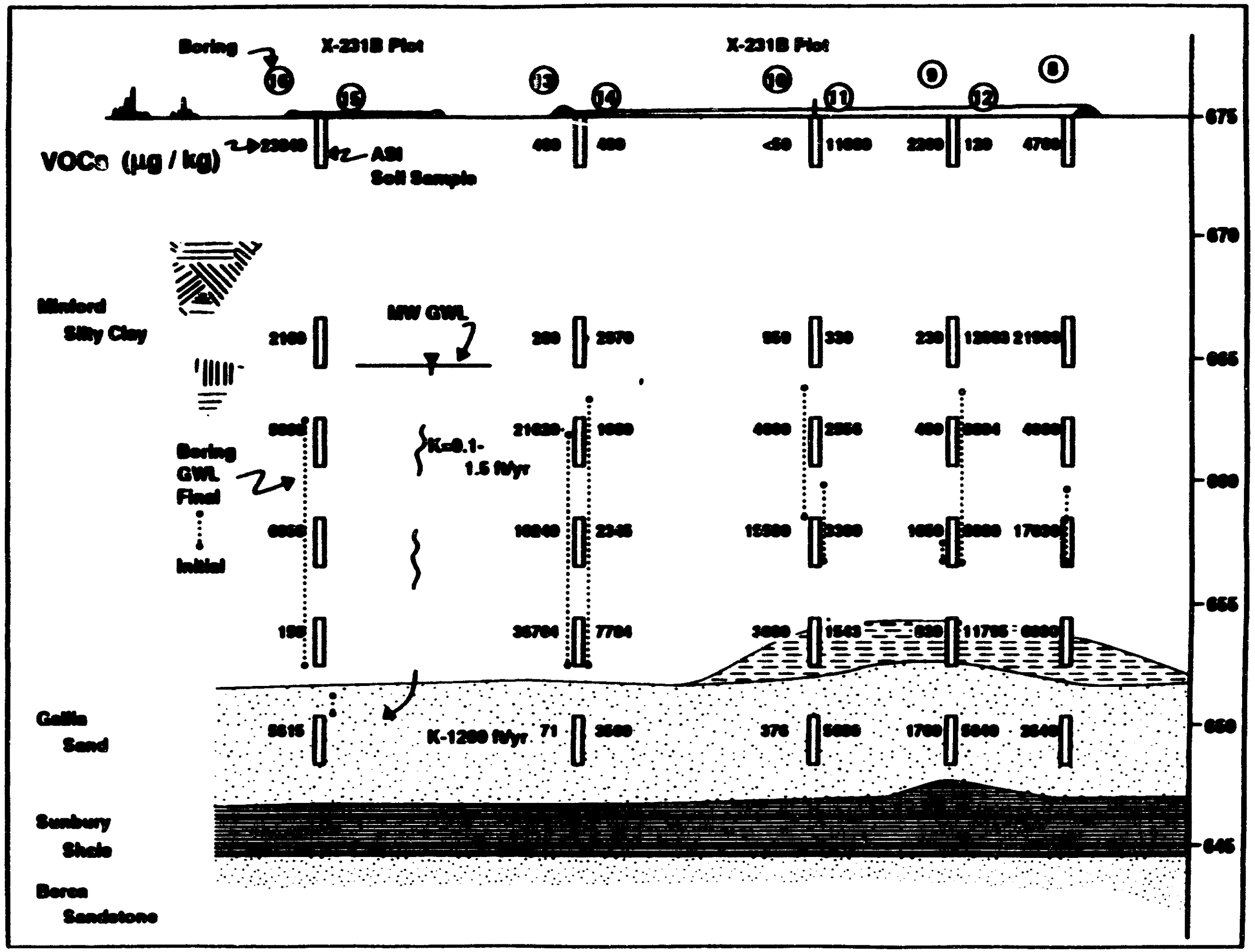

Fig. 2.4. Spatial variability of soil VOC concentrations determined in 1987 (after [11]).

Table 2.5. Summary of groundwater contaminant concentrations at X-231B. (Source: Morrison Knudsen, 1990 [2])

Constituent [a]	Units	Concentrations [b] Average [c]	 Min.	 Max.	Comments
Trichloroethene	µg/L	464.0 {5} [d]	180	1400	Detected in every well
1,1-Dichloroethane	µg/L	9.4 {-}	5	27	Detected only in wells MW1, MW5, MW6 and MW10
1,1-Dichloroethene	µg/L	88.3 {7}	5	320	Not detected in wells MW2 MW4 and MW17
1,2-Dichloroethene	µg/L	9.6 {70, 100}	5	26	Detected only in wells MW5, MW6, MW10 and MW17
1,1,1-Trichloroethane	µg/L	188.0 {200}	5	790	Not detected in wells MW2 MW4 and MW17
Chloroform	µg/L	17.6 {-}	5	110	Detected only in wells MW1 and MW5
Aluminum	mg/L	4.1 {-}	1.4	8.7	Not detected in well MW6 [e]
Iron	mg/L	10.9 {300}	3.3	23.6	[e]
Manganese	mg/L	0.37 {50}	0.27	0.44	[e]
Alpha	pCi/L	35.2 {15}	30	76	Detected only in wells MW1 and MW4 (Qualitative data)
Beta	pCi/L	64.2 {4 mrem/yr}	60	80	Detected only in wells MW4 and MW6 (Quantitative data)
Uranium	µg/L	12.9 {-}	1	39	Not detected in wells MW6 and MW17
Technetium, beta	pCi/L	41.1 {4 mrem/yr}	25	88	Detected only in wells MW1, MW2, MW4 and MW6

[a] The only constituents shown are those which were detected in more than one well.

[b] The analyses provided in this table were performed in November-December 1988.

[c] The average concentrations were computed using the individual concentrations measured at all wells divided by the number of wells. For samples with no detects, the method detection limit was used in the computation and is shown as the minimum concentration.

[d] The numbers in brackets are equal to Federal Maximum Contaminant Limits or Goals for drinking water.

[e] The concentrations of aluminum, iron and, manganese were measured in wells MW1, MW5 and MW6 in April 1989.

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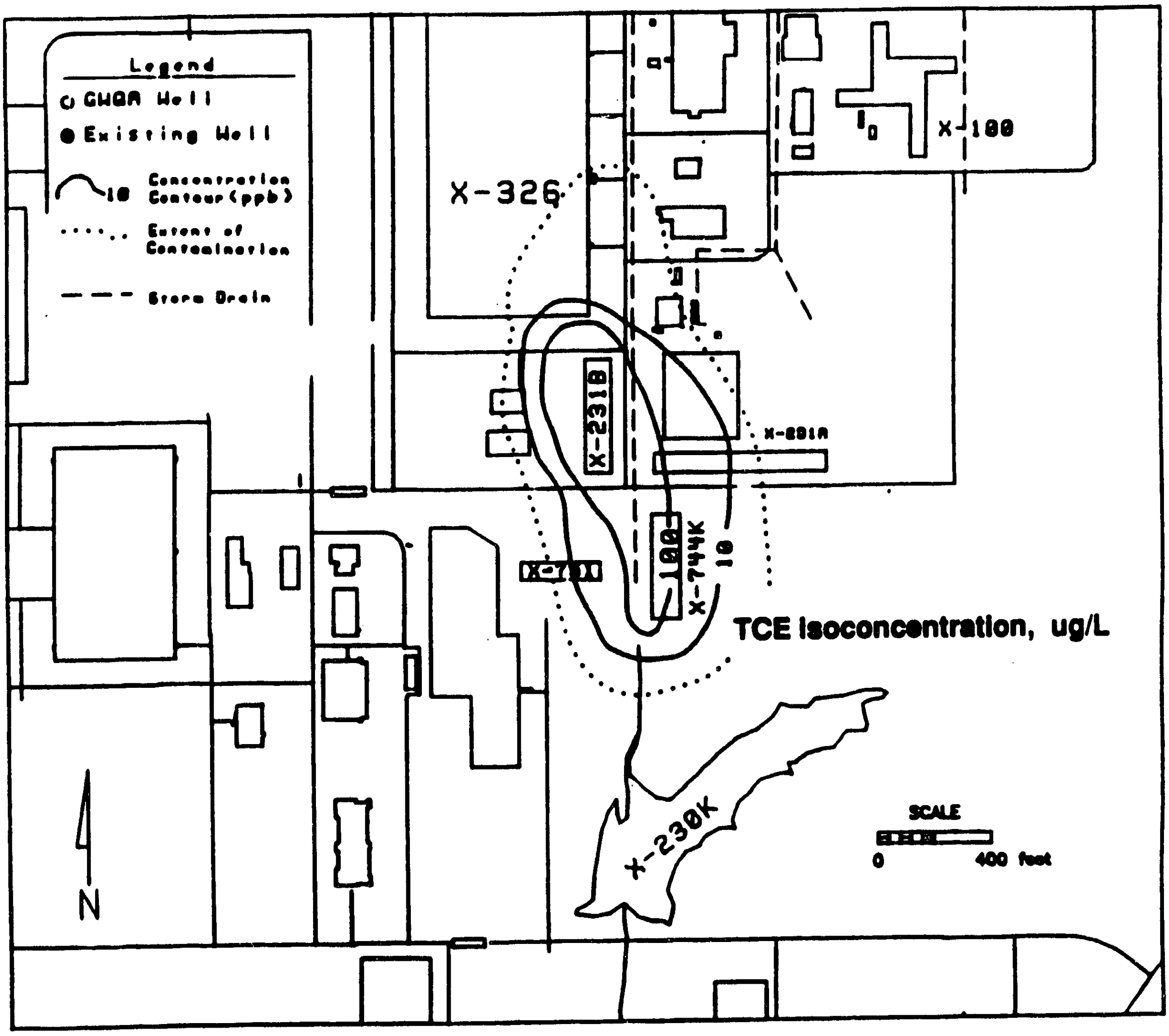

Fig. 2.5. Map of X-231B indicating extent of groundwater contamination by TCE in the Gallia deposit under and around X-231B. (Source: Geraghty & Miller, Inc., 1989 [13])

3. BASELINE SAMPLING AND CONTAMINANT CHARACTERIZATION

3.1 INTRODUCTION

During the sampling event conducted at the X-231B site in January 1992, soil samples were collected from ~190 locations within the X-231B Unit. The primary purpose of this sampling event was to obtain sufficient data for spatially modeling the distribution of VOCs within the X-231B Unit. Other objectives were (1) to collect soil cores for the laboratory treatability studies, (2) to investigate short-range spatial variability in the VOC distribution, and (3) to compare measurements made using the on-site heated headspace technique and the EPA method SW5030/8240 conducted at an off-site laboratory. This section focuses on the field methods used in collecting soil samples for VOC analysis and cores for the treatability studies. Statistical analysis of the VOC data are presented in this section, as well as the results of the spatial variability study and the comparison between on-site and off-site VOC analysis methods.

3.2 METHODS

3.2.1 Mapping of Utilities and Borings

Before drilling, a complete utilities survey was conducted on the X-231B site. This survey was done by ORNL staff using a hand-held utility locator to confirm previously mapped utilities in the area and to physically identify and mark the utility locations on the ground surface before invasive sampling began.

3.2.2 Soil Probe and Boring Installation and Sampling

Collection of baseline soil samples from 24 locations was accomplished using a truck-mounted hydraulic probe system (Geoprobe®) [16]. The probe sampling system is designed for interval sampling from ground surface to a maximum depth of approximately 40 ft. In order to obtain a baseline subsurface sample, the sampler is connected to the drive rod assembly, and activated at each desired sample depth. The sampler is 1 ft long by 1 in. OD (ID is 0.5 in.) and is able to obtain a relatively undisturbed 100 g soil sample inside the sample collection tube (see Fig. 3.1). After withdrawal from the subsurface, the soil sample is extracted from the sampler tube and placed into appropriate sample containers, labeled, and packaged with completed documentation for both on-site and off-site laboratory analysis. The sample was visually inspected, and the lithology and physical characteristics were logged. After the soil sample was removed, the sample tube was decontaminated before being reattached to the drive-rod assembly. To expedite sampling, at least two soil tube samplers were used alternately.

The 24 Geoprobe® sampling locations are shown in Fig. 3.2 and are designated by GPn where n is the probe number. Soil samples were collected at 3 ft intervals to a depth of approximately 22 ft (e.g., 0-1, 3-4, 6-7, 9-10, 12-13, 15-16, 18-19, and 21-22 ft bgs) at each of 24 soil probe locations in order to characterize both the vertical and horizontal extent of VOCs in the X-231B Unit. Given that the thickness of the Minford layer is ~25 ft beneath X-231B (see Sect. 2), all of the baseline samples were collected within either the Minford silt or clay zone. Sample collection (and on-site analysis) was conducted by Envirosurv, Inc. (Arlington, VA) working collaboratively with ORNL [16].

Core samples were collected from seven borings using two sizes of split samples. Four small diameter soil borings were drilled using 7-5/8-in.-OD hollow stem augers. A number of small soil cores were obtained using a 3-in. OD by 2-ft long split spoon, containing four 6-in.-long by 2.5-in.-OD stainless steel sleeves. Soil samples were collected continuously from each soil boring from depths of approximately 4 ft to 12 ft. The goal was to collect a minimum of 40 soil samples in the 2.5-in. sleeves. Three large diameter soil borings were drilled using 11-5/8-in. hollow stem augers with a center bit. Large cores were collected from these locations using an 8-in.-ID by 2-ft-long split spoon containing one 8-in.-OD by 24-in. long stainless steel sleeve. Samples were collected from depths of approximately 4 to 6 ft, 6 to 8 ft, 8 to 10 ft, and 10 to 12 ft in each boring. These borings were drilled to depth with the large augers, the augers were then removed from the boring, and the sampler was inserted and driven 2 ft into the soil and withdrawn. Locations for both small and large-diameter borings are shown in Fig. 3.2 and are designated by SBn where n is the boring number.

A soil boring log was completed for each probe and each boring location by an on-site ORNL geologist. The soil boring log contained the type of sampling equipment used, the sample depths, the lithology encountered, and any unusual occurrences during the soil boring.

The soil sample tube and all other downhole drilling equipment were decontaminated prior to use by detergent wash and steam cleaning. All downhole equipment was decontaminated between boreholes by steam-cleaning.

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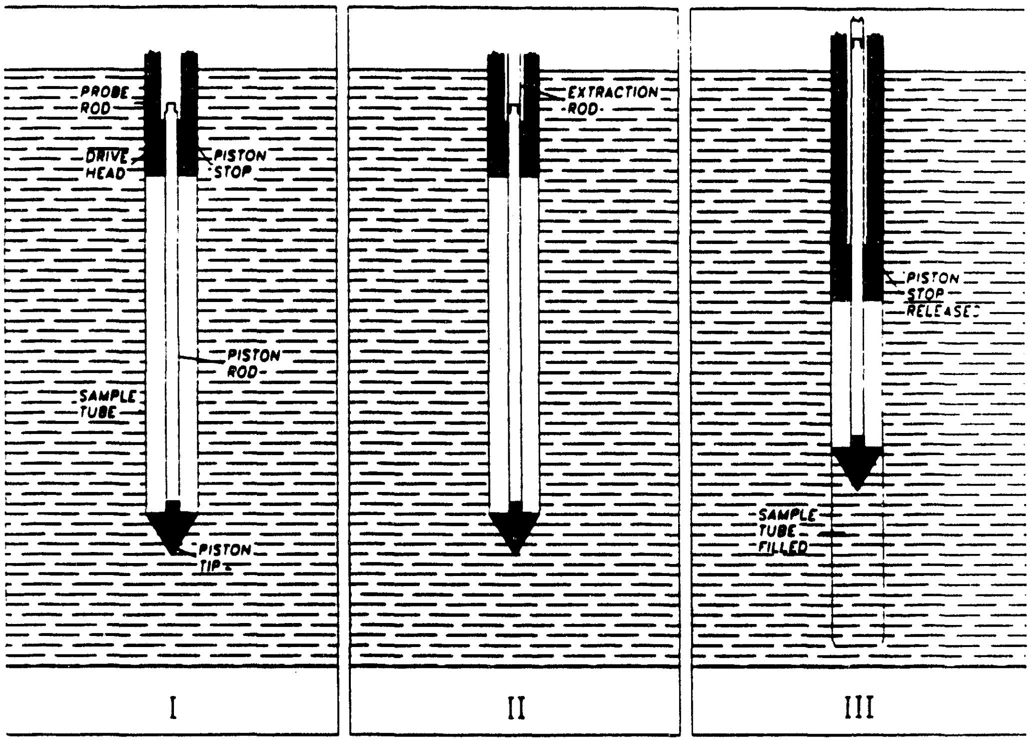

Fig. 3.1 Schematic of Geoprobe® soil sampling probe.

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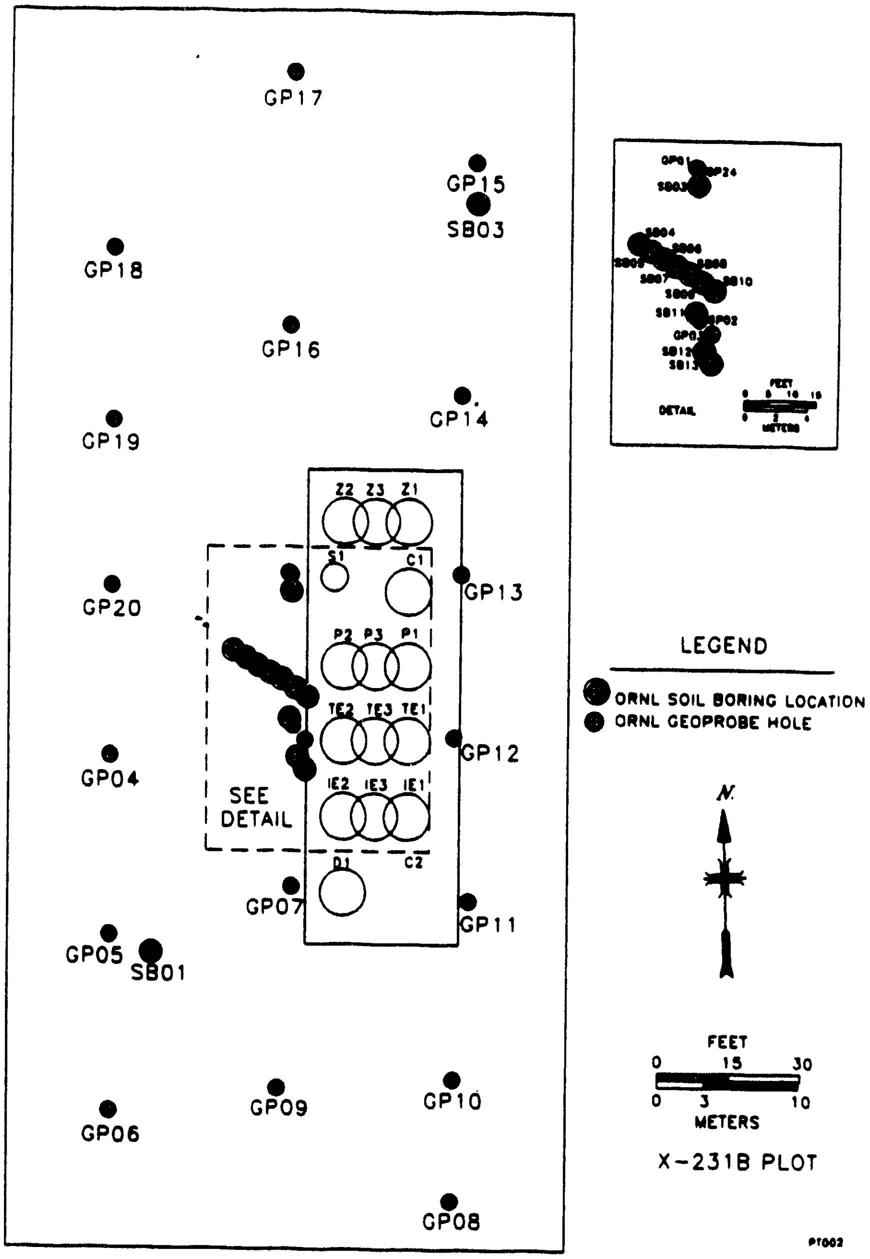

Fig. 3.2. Locations within the X-231B site where Geoprobe® and soil core samples were collected in January 1992.

3.2.3 On-Site VOC Analyses

Upon collection, each soil probe or core was screened for radioactivity using hand-held detectors (alpha, beta, gamma). All probe samples and some of the soil cores were then subsampled for on-site VOC analyses as follows. Immediately after collection, ~100 g of intact soil was extruded from the sampler into a zip-closure polyethylene bag from which a small aliquot of soil (10 to 20 g) was placed into a Teflon-sealed, 40-mL glass vial. Soil sample weights were measured to the nearest 0.01 g. Within 24 h of collection, a heated-headspace technique was used to measure the VOC content of samples collected from all the baseline sampling locations and the majority of the core samples [16-17]. In this on-site analysis, the 40-mL VOA vial containing the soil sample is heated to 60°C in a water bath for ≥30 min. During this time, the VOCs within the soil are thermally desorbed, diffused, and volatilized into the headspace of the vial. A sample of the headspace is withdrawn in a syringe and injected into a laboratory-grade gas chromatograph (GC) (Shimadzu 14A) equipped a 30 m Restek Rtx-volatiles megabore capillary column with an electron capture detector (ECD). For this study, the GC was calibrated to quantify seven chlorinated organics known to be the predominant VOCs present within deposits beneath the X-231B site: trichloroethene (TCE), 1,1,1,-trichloroethane (TCA), 1,1-dichloroethene (1,1-DCE), 1,1-dichloroethane (DCA), cis-1,2-dichloroethene (c-1,2-DCE), trans-1,2-dichloroethene (t-1,2-DCE), and methylene chloride (MC). The concentration measured in the headspace sample was converted to mass of target compound, which was then expressed as μg of target VOC per kg of field moist soil (ppb).

The GC was initially calibrated using four standard concentrations that bracketed the expected contaminant levels for each target compound to document method linearity. Sample concentrations that fell outside this bracketed range are diluted and reanalyzed. Initial calibration factors are determined using the least squares method to calculate a slope formula. The best fit line has to produce a correlation coefficient of no less than 0.980 to be an acceptable calibration. A continuing calibration was preformed prior to each day's sampling to verify instrument calibration. The Relative Percent Difference (RPD) between the initial and continuing calibration standards were within 30%. Retention times of standards were used to identify chromatogram peaks, and response factors were used to calculate concentrations for the target compounds of interest. All standards preparations were documented in the field logbook and are traceable back to the National Institute of Standards and Technology (NIST).

Method blanks were run at the beginning of each day to check for potential contaminants in the analytical system. Blanks were taken by withdrawing a headspace sample from a 40-mL vial containing deionized water. The blank sample was injected into the GC in the same manner as the headspace samples. Syringe and instrument blanks were also run as needed to document that the analytical system is free of contamination. As a check on field sampling quality assurance and quality control (QA/QC), trip blanks, field blanks, and equipment rinsate samples were prepared and analyzed. In addition to the analysis blanks, field duplicate soil samples were collected. These consisted of two soil subsamples collected adjacent to each other from the same sample. Field duplicate samples were collected from approximately 10% of the soil samples and analyzed onsite for VOCs with a subset submitted to ORNL Analytical Chemistry Division (ACD) for VOC analysis.

A majority of the soil core samples were also subsampled and analyzed for VOCs on-site. A micro-coring device was used to obtain a plug (2 to 5 g) of soil from the exposed end of a core. This plug was extruded into a Teflon-sealed, 40-mL VOA vial and analyzed as described above.

3.2.4 Soil Core Handling and Disposition

Immediately after core collection, labeling and subsampling, the sleeve containing each core was sealed with Teflon liners and plastic caps. The time between core removal from the borehole and sealing was minimized (e.g., <15 min) to prevent loss of VOCs. Each sealed core was placed in hard plastic or metal coolers containing vermiculite or similar packing material. Ice substitutes (e.g. Blue Ice®) were added to maintain temperatures near 4°C. The coolers were labeled, chain of custody documentation placed inside, and then shipped to the ORNL and to the technology vendors conducting the treatability studies without being disturbed or transferred to other sample containers. Based on the field VOC analyses, the small core sleeves were ranked from low to high VOC concentration and divided sequentially into 10 groups of 4 sleeves each, from low to high VOC concentrations. Then, each group of 4 sleeves (each sleeve containing a 2.5 in. by 6 in. core) was randomized and 2 sleeves were assigned to Vendor A, 1 sleeve to Vendor B and 1 sleeve to Vendor C as follows: 20 cores to Vendor A for hot air/steam extraction testing, 10 cores to Vendor B for solidification testing, and 10 cores to Vendor C for solidification testing. The 12 large cores were labeled and shipped together to ORNL for use in testing vapor stripping and peroxidation [5-6].

3.2.5 Off-Site Laboratory Analyses

A subset of the baseline soil probe samples were sent to ORNL for laboratory analysis of soil VOCs. The subset was collected in parallel to samples from each of several borings in the south, center, and north portion of the X-231B site. These soil samples were collected using the Geoprobe® and a micro-coring device. A plug of soil weighing approximately 5 to 10 g was removed from the Geoprobe® and containerized in Dynatech purge and trap vials (or back-up 40-mL VOA vials). Soil samples were taken from about 20% of the baseline sampling locations, and approximately 20% of the small cores (or 8 subsamples from the small sleeves) and all large cores (or 12 subsamples). These subsamples were individually wrapped in "bubble pack" or foam, or embedded in vermiculite within hard plastic or metal coolers. Ice substitutes (e.g. Blue Ice®) were added to maintain temperatures near 4°C. The coolers were labeled, chain of custody documentation placed inside, and then shipped to ORNL.

The off-site analyses were performed at the ORNL ACD following methods outlined in EPA method 5030/8240 as prescribed in SW-846 within the required 14-day holding time [18]. Table 3.1 lists the target VOC analytes and their respective detection limits. The ORNL ACD laboratory ran QA samples (i.e., duplicates, laboratory reruns, spikes and blanks) to monitor performance. Two matrix spike and matrix spike duplicate (MS/MSD) samples were analyzed to determine if matrix interferences were present. These samples were prepared in the laboratory from an additional set (2) of soil samples collected from two of the locations.

In addition to the VOC analyses, samples from both the baseline probes and the soil cores were collected and containerized in 1-L polyethylene bags. These samples were transported to ORNL for analysis of water content [19].

Table 3.1. Summary of VOC target analytes and method detection limits.

Volatile Organic Compound[a]	Detection limit	
	Water (µg/L)	Soil (µg/kg)
Chloromethane	10	10
Bromomethane	10	10
Vinyl chloride	10	10
Chloroethane	10	10
Methylene chloride	5	5
Acetone	100	100
Carbon disulfide	5	5
1,1-Dichloroethene	5	5
1,1-Dichloroethane	5	5
1,2-Dichlorothene (total)	5	5
Chloroform	5	5
1,2-Dichloroethane	5	5
2-Butanone	100	100
1,1,1-Trichloroethane	5	5
Carbon tetrachloride	5	5
Vinyl acetate	10	50
Bromodichloromethane	5	5
1,2-Dichloropropane	5	5
cis-1,3-Dichloropropene	5	5
Trichloroethene	5	5
Dibromochloromethane	5	5
1,1,2-Trichloroethane	5	5
Benzene	5	5
trans-1,3-Dichloropropene	5	5
2-Chloroethylvinyl ether	10	10
Bromoform	5	5
4-Methyl-2-pentanone	50	50
2-Hexanone	50	50
Chlorodibromoethane	5	5
1,1,2,2-Trichloroethane	5	5
Toluene	5	5
Chlorobenzene	5	5
Ethylbenzene	5	5
Styrene	5	5
Total xylenes	5	5

[a] The target compounds for on-site analyses are underlined. The detection limits for the field analyses are 10 ug/L or 10 ug/kg, for water and soil, respectively.

3.3 RESULTS AND DISCUSSION

3.3.1 Subsurface Lithology

A compilation of stratigraphic cross sections interpreted from the boring logs for each of the baseline probe locations (see Fig. 3.2) is shown in Fig. 3.3. The boring logs themselves and several additional stratigraphic cross sections are presented in Appendix A. Subsurface conditions observed from ground surface to 22 ft depth were generally consistent with those reported previously. The shallow unconsolidated deposit beneath the X-231B site consists of a 5- to 10-ft layer of brownish yellow (10YR6/6) silty clay with a trace of very fine sand. This is underlain by an 8- to 10-ft layer of yellowish brown (10YR5/8) clay. Mottles within the clay layer indicate seasonal saturation. Beneath the clay layer is a 0- to 8 ft lay ellow (10YR6/8) silt.

3.3.2 Target Compound Concentrations

Concentrations of TCE, 1,1,1-TCA, MC, 1,1-DCE, cis-1,2-DCE, trans-1,2-DCE, and 1,2-DCA were measured in soil samples collected from 8 depths in each of 24 locations using a Geoprobe® (see Appendix B for complete data set). Concentrations of TCE, MC, and 1,1-DCE predominated, representing ~90% of the total VOCs measured (Table 3.2). The average concentration of individual VOCs ranged from 25 to ~2400 µg/kg (ppb). For each VOC, there were wide fluctuations in the measured concentrations, with the range spanning four to five orders of magnitude. The wide ranges and high relative error (typically 200 to 400%) were exhibited by all of the target compounds.

When compared with the summation of the average concentrations of each of the target compounds, TCE and MC represented approximately 38 and 42% of the total, respectively (Table 3.2). There was also a strong linear relationship between these two principal compounds and the summation, with Pearson correlation coefficients *r* equal to 0.91 for TCE vs summation, 0.95 for MC vs summation, and 0.77 for TCE vs MC, respectively. This strong correlation suggested that a summation of the target compounds could be used for analysis of VOC characteristics and spatial modeling.

Samples from two borings were also analyzed for gross alpha, gross beta, and total uranium. Radiological measurements yielded concentrations similar to background levels for the Portsmouth site (Appendix C, Table C.3).

3.3.3 Summary Statistics for Total VOC Levels

Since the northern plot of the X-231B Unit represented over 80% of the surface area of the complete Unit, VOC analyses, interpretation, and modeling efforts were concentrated on that plot. Within the northern plot, 164 soil samples were collected from up to 8 depths in each of 21 locations using a Geoprobe® (see Fig. 3.2 for probe locations). In addition, there were 12 duplicates (i.e., two adjacent subsamples from the same Geoprobe® 1-ft sample interval). For the analysis and modeling efforts, the VOC data set was reduced by summing the concentrations of the seven target VOCs measured in each sample. This was judged appropriate since it would simplify and expedite analysis and modeling efforts required for the X-231B Technology Demonstration. Furthermore, the performance goal for remediation of the X-231B Unit was based on total VOC concentration. There was also a strong linear correlation among the predominant VOCs. For these reasons, analyses, interpretation and modeling of this VOC data set were limited to the sum of the concentrations of target compounds: TCE, MC, 1,1-DCE, 1,1,1-TCA, cis- and trans-1,2-DCE, and 1,2-DCA. In the following discussions, this sum will be referred to as "total VOCs".

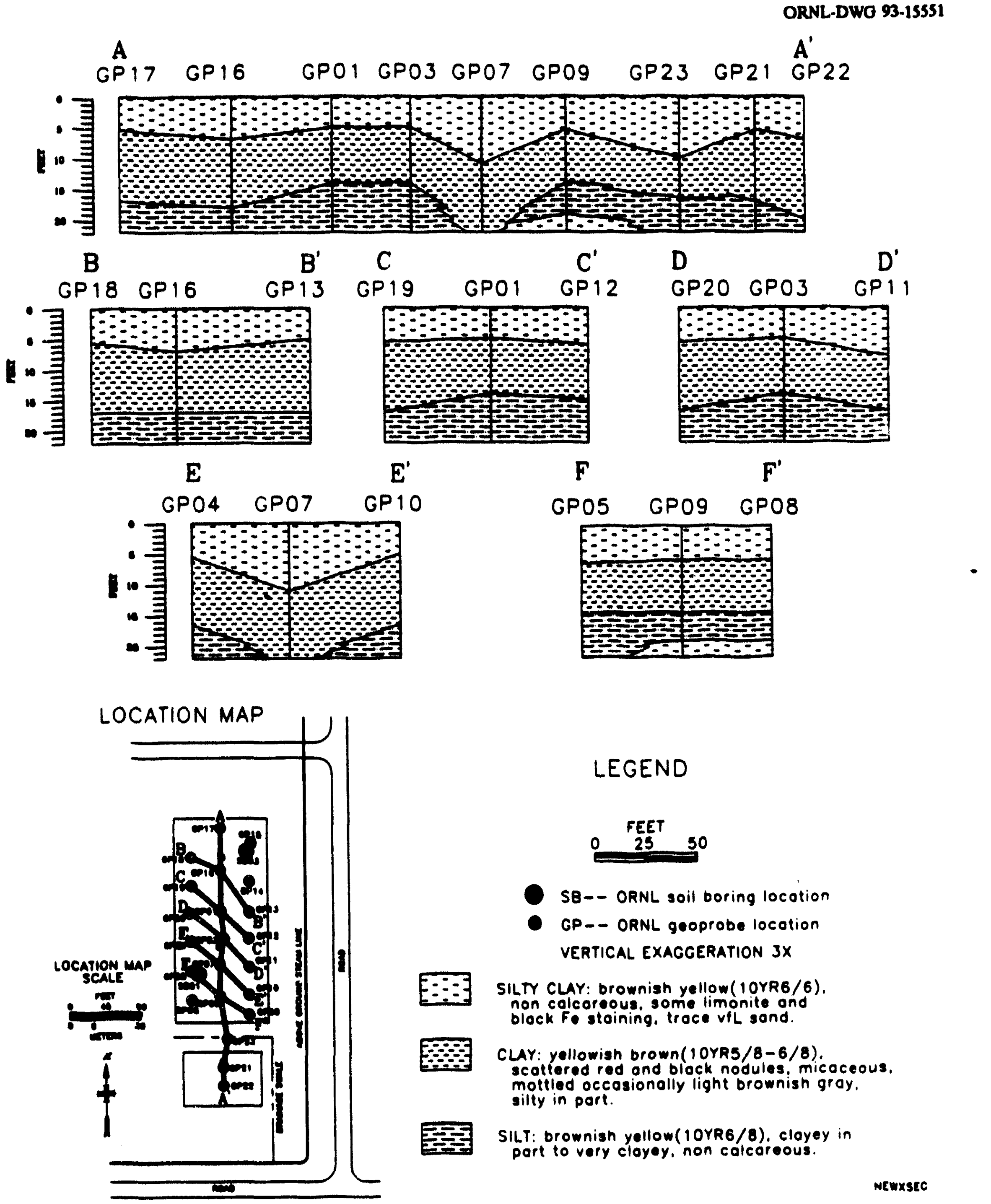

Fig. 3.3. Stratigraphic cross-sections interpreted from boring logs prepared during Geoprobe® soil sampling in January 1992 (refer to Appendix A for boring logs).

Table 3.2 Summary of target compound concentrations determined in Geoprobe® soil samples collected and analyzed on-site in January 1992 [a]

Statistic	TCE	1,1,1-TCA	MC	1,1-DCE	1,2-DCE [b]	1,1-DCA	Summation
Count	187	187	187	187	187	187	187
Average	2126	292	2392	535	274	25	5644
Std. dev.	7046	600	9173	1661	1216	37	15727
% Relative error	331	206	384	310	443	144	279
Minimun	0	0	2	1	2	1	9
25th quartile	61	21	32	5	14	5	648
Median	380	110	150	25	32	13	1340
75th quartile	1000	325	565	300	109	29	4133
Maximum	20000	4200	40000	14000	7808	130	64014
Compound avg. conc. % of summation	37.7	5.2	42.4	9.5	4.9	0.5	100
Correlation of compound with summation [c]	0.91	0.59	0.95	0.02	0.15	0.67	1.00

[a] Results of analyses of 187 soil samples collected from 8 depths in each of 24 locations using a Geoprobe® and analyzed on-site by heated headspace GC methods (see Appendix B). For this analysis, non-detects were set equal to the reported detection limit. Results are reported on the basis of field moist soil weight.

[b] Summation of cis- and trans-1,2-DCE isomers.

[c] Pearson correlation coefficient, *r*.

Table 3.3 Summary statistics for the total VOC concentrations in the north plot of the X-231B Unit [a]

Statistic	Total VOC concentration (ug/kg)	Log-transformed total VOC concentration[b] (log (ug/kg))
Mean	5731	3.15
Std. deviation	16208	0.72
Std. error of mean	1222	0.054
Minimum	6	0.78
5th percentile	94	1.97
25th percentile	538	2.73
50th percentile	1320	3.12
75th percentile	3796	3.58
95th percentile	20101	4.30
Maximum	154410	5.19

[a] Results of analyses of 164 soil samples collected from up to 8 depths in each of 21 locations within the north plot of the X-231B Unit using a Geoprobe® with VOC analyses made on-site by heated headspace GC methods (see Appendix B). For this analysis, nondetects were excluded from the summation of TCE, MC, TCA, 1,1-DCE, 1,2-DCE (sum of cis- and trans-1,2-DCE isomers), and 1,1-DCA. At 12 sample locations where duplicates were collected, the observation is the average of the two. Results are reported on the basis of field moist soil weight.

[b] Total VOC values were log-transformed prior to calculating statistics.

Summary statistics for the total VOC concentrations measured in the north plot are given in Table 3.3. Analysis of the total VOC concentrations revealed that the data set was highly skewed and not normally distributed. However, the log-transformed (base 10) data set did not differ significantly from a normal distribution (see Fig. 3.4 and 3.5). As a result, in many of the following data analyses, log-transformation was employed to normalize the data set.

3.3.4 Short-range Spatial Variability in VOC Concentrations

To quantify short-range variability of VOCs within the deposits beneath the X-231B Unit, VOC measurements were made on 12 pairs of duplicate soil samples collected from the same 1-ft Geoprobe® sampling interval. The total VOC values for these duplicate measurements are shown in Table 3.4. The ratio of the largest to the smallest total VOC value in each duplicate pair ranged from 1.1 to 8.7. The mean of the squared difference between the log VOC values in these pairs was 0.194. This indicates that the log VOCs within a 1-ft interval have a standard deviation of 0.311. Assuming that 95% of the log VOC values within a given core fall within two standard deviations of the mean, a variability of more than one order of magnitude within a 1-ft interval is not unusual. The duplicate measurements given in Table 3.4 were used to estimate parameters in a kriging-based VOC model that included definition of the short-range variability of the VOC contaminant distribution (see Sect. 4).

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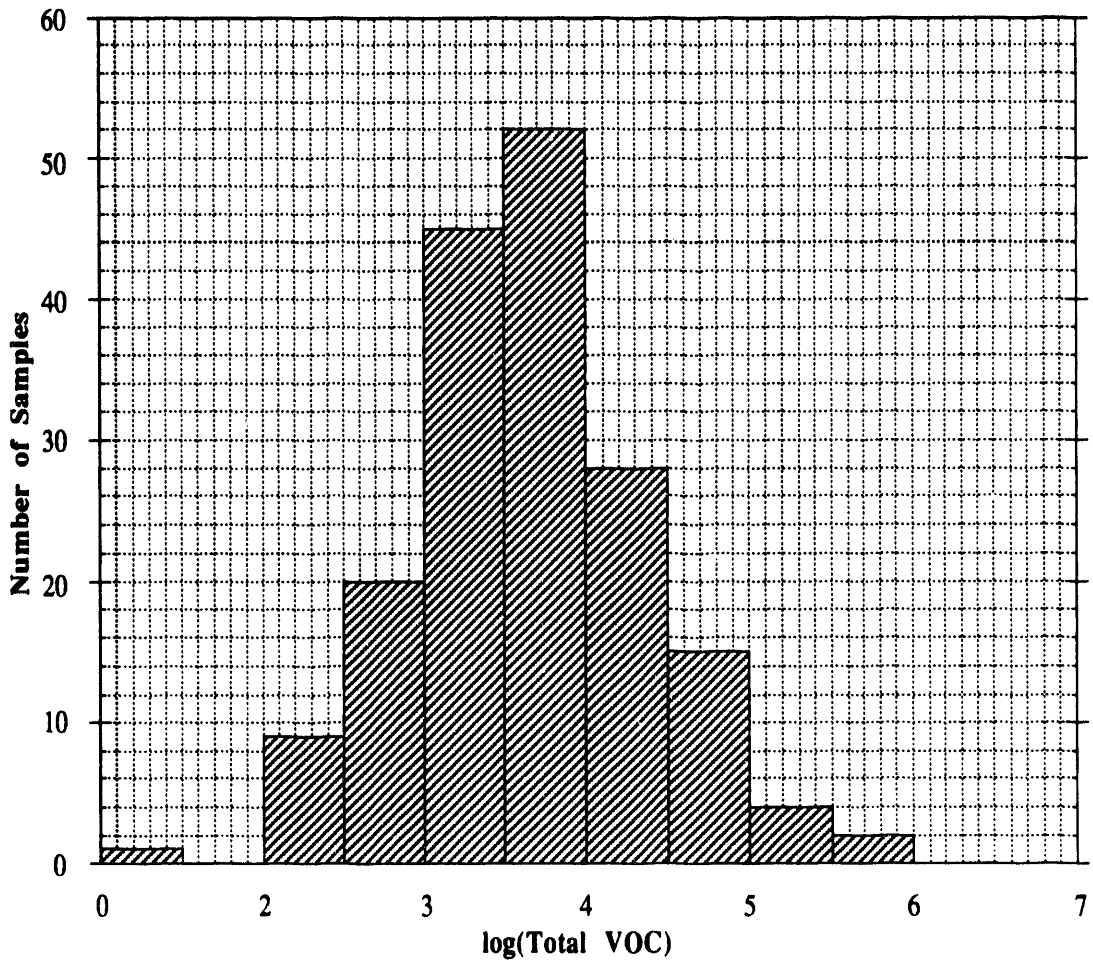

Fig. 3.4 Distribution of log-transformed total VOC concentrations in the north plot of the X-231B site.

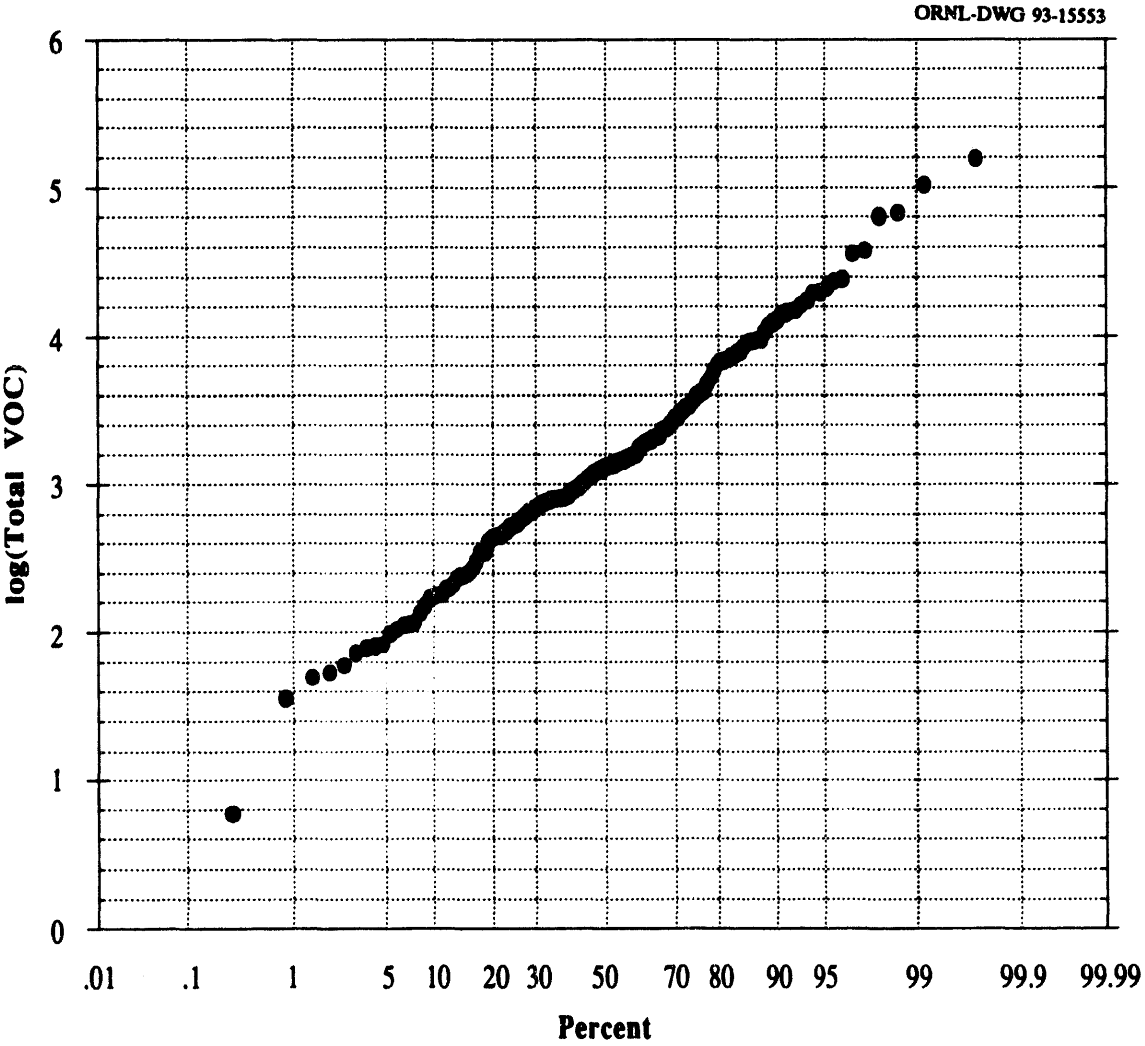

Fig. 3.5 Normal plot of log-transformed total VOC concentrations in the north plot of the X-231B site.

Table 3.4 Total VOC concentrations in duplicate soil samples taken from the same 1-ft Geoprobe® sampling interval [a]

Probe no.	Depth (ft)	Higher VOC concentration in duplicate pair (ug/kg)	Lower VOC concentration in duplicate pair (ug/kg)	Ratio of higher to lower concentration
GP03	9 - 10	4195	2792	1.50
GP03	12 - 13	3992	571	6.99
GP04	3 - 4	830	700	1.19
GP08	21 - 22	345	181	1.91
GP09	3 - 4	938	531	1.77
GP09	21 - 22	298	174	1.71
GP14	18 - 19	1848	784	2.36
GP14	21 - 22	6760	5290	1.28
GP15	12 - 13	14117	4725	2.99
GP16	3 - 4	1324	152	8.71
GP16	12 - 13	112	50	2.24
GP24	15 - 16	520	477	1.09

[a] Results of analyses of soil samples collected from locations within the north plot of the X-231B Unit using a Geoprobe® with VOC analyses made on-site by heated headspace GC methods (see Appendix B). For this analysis, non-detects were excluded from the summation of TCE, MC, TCA, 1,1-DCE, 1,2-DCE (sum of cis- and trans-1,2-DCE isomers), and 1,1-DCA. Results are reported on the basis of field moist soil weight.

3.3.5 Analytical Variability in VOC Concentrations

Analytical variability in the headspace GC analysis of VOCs is relatively small as determined from nine pairs of "on-site lab duplicates" (i.e., duplicate headspace samples collected from the same 40-mL soil sample vial) (Table 3.5). The ratio of the largest to the smallest VOC concentration in each pair ranged from 1.03 to 1.69. The mean of the squared difference between the log VOC values in these pairs was 0.0115. This indicates that the analytical variability of log VOC has a standard deviation of 0.0760, which is low relative to short-range variability (see Sect. 3.3.4).

Table 3.5 Total VOC concentrations in duplicate headspace samples taken from the same 40-mL sample vial. [a]

Probe no.	Depth (ft)	Higher VOC concentration in duplicate pair (ug/kg)	Lower VOC concentration in duplicate pair (ug/kg)	Ratio of higher to lower concentration
GP12	3 - 4	1977	1977	1.00
GP15	12 - 13	14117	14117	1.00
GP17	12 - 13	79	54	1.46
GP19	3 - 4	758	613	1.24
GP19	9 - 10	1645	1520	1.08
GP19	15 - 16	1423	1142	1.25
GP19	21 - 22	2780	2598	1.07
GP20	12 - 13	94	81	1.16
GP20	15 - 16	452	440	1.03

[a] Results of analyses of soil samples collected from locations within the north plot of the X-231B Unit using a Geoprobe® with VOC analyses made on-site by heated headspace GC methods (see Appendix B). For this analysis, nondetects were excluded from the summation of TCE, MC, TCA, 1,1-DCE, 1,2-DCE (sum of cis- and trans-1,2-DCE isomers), and 1,1-DCA. Results are reported on the basis of field moist soil weight.

3.3.6 Comparison Between On-site and Off-site VOC Analyses

Duplicate soil samples were collected from approximately 20% of the sampling locations and sent to ORNL where they were analyzed by direct purge-and-trap GC/MS VOC analysis following EPA method SW5030/8240. The samples sent off-site consisted of a plug of soil taken from either a Geoprobe® sample or a split-barrel core sample, with a stainless steel, micro-coring device. The plug (ca. 5 g) was immediately extruded directly into a 40-mL Dynatech purge-and-trap vial (Dynatech Precision Sampling Corporation). In the laboratory, the Dynatech vial was connected directly to a Tekmar purge and trap instrument without any additional sample transfer.

The concentrations of TCE and total VOCs as measured on-site vs off-site in corresponding duplicate samples are listed in Table 3.6. The comparative concentrations of total VOCs are graphically depicted in Fig. 3.6. There was clearly a large, variable discrepancy between the two sets of measurements. The median ratio of on-site to off-site measurements of total VOCs was 8.35, which corresponds to an 88% loss. The losses are quite variable: one-fourth of them are <69%, and one fourth are >95%.

Table 3.6 Comparison of VOC concentrations measured in an on-site laboratory versus off-site laboratory. [a]

				Total VOCs (ug/kg)			TCE (ug/kg)		
Dupl. pair	Sample no.	Boring or probe no.	Depth (ft)	On-site GC	Off-site GC/MS	Ratio on-site/ off-site	On-site GC	Off-site GC/MS	Ratio on-site/ off-site
1	2065	GP21	12 - 13	3133	312	10	670	139	4.8
2	2066	GP21	15 - 16	955	40	23.9	260	8	32.5
3	2067	GP21	18 - 19	796	36	22.1	210	5	42
4	2068	GP21	21 - 22	540	100	5.4	110	28	3.9
5	2069	GP22	0 - 1	191	33	5.8	11	5	2.2
6	2070	GP22	3 - 4	244	30	8.1	13	5	2.6
7	2071	GP22	6 - 7	408	30	13.6	99	5	19.8
8	2129	GP17	0 - 1	3314	30	110.5	1800	5	360
9	2130	GP17	3 - 4	126	30	4.2	35	5	7
10	2131	GP17	6 - 7	138	30	4.6	76	5	15.2
11	2132	GP17	9 - 10	85	332	0.3	52	238	0.2
12	2133	GP17	12 - 13	57	30	1.9	21	5	4.2
13	2134	GP17	15 - 16	43	42	1	8.9	15	0.6
14	2135	GP17	18 - 19	180	30	6	13	5	2.6
15	2185	GP24	0 - 1	5849	61	95.9	3000	26	115.4
16	2186	GP24	3 - 4	16181	345	46.9	3500	275	12.7
17	2187	GP24	6 - 7	14360	137	104.8	9600	109	88.1
18	2188	GP24	9 - 10	19799	343	57.7	5700	318	17.9
19	2189	GP24	12 - 13	1877	80	23.5	1800	55	32.7
20	2190	GP24	15 - 16	521	32	16.3	390	7	55.7
21	2191	GP24	18 - 19	719	151	4.8	440	123	3.6
22	2192	GP24	21 - 22	1037	64	16.2	800	39	20.5
23	1035	SB06	9.5	43	30	1.4	2.4	5	0.5
24	1049	SB07	9.5	106	50	2.1	30	6	5
25	1051	SB07	10.5	56	30	1.9	17	5	3.4
26	1064	SB08	9.0	85	30	2.8	15	5	3
27	1072	SB09	5.0	2296	742	3.1	590	549	1.1
28	1074	SB09	7.0	1000	38	26.3	420	7	60
29	1075	SB09	9.0	201	277	0.7	130	112	1.2
30	1077	SB10	3.0	4674	546	8.6	3400	85	40
31	1078	SB10	7.0	5956	372	16	3600	306	11.8
32	1080	SB10	9.0	384	51	7.5	82	26	3.2
33	1083	SB11	4.5	4824	60	80.4	860	23	37.4
34	1086	SB11	6.5	546	30	18.2	180	5	36
35	1097	SB12	4.0	428	131	3.3	120	48	2.5
36	1101	SB12	6.5	523	32	16.3	320	5	64

[a] Results of analyses of soil samples collected from locations within the north plot of the X-231B Unit with VOC analyses made on-site by heated headspace GC methods (see Appendix B) and off-site by direct purge-and-trap GC/MS methods (see Appendix C). For this analysis, non-detects were set equal to the detection limit and included in the summation of TCE, MC, TCA, 1,1-DCE, 1,2-DCE (sum of cis- and trans-1,2-DCE isomers), and 1,1-DCA. Results are reported on the basis of field moist soil weight.

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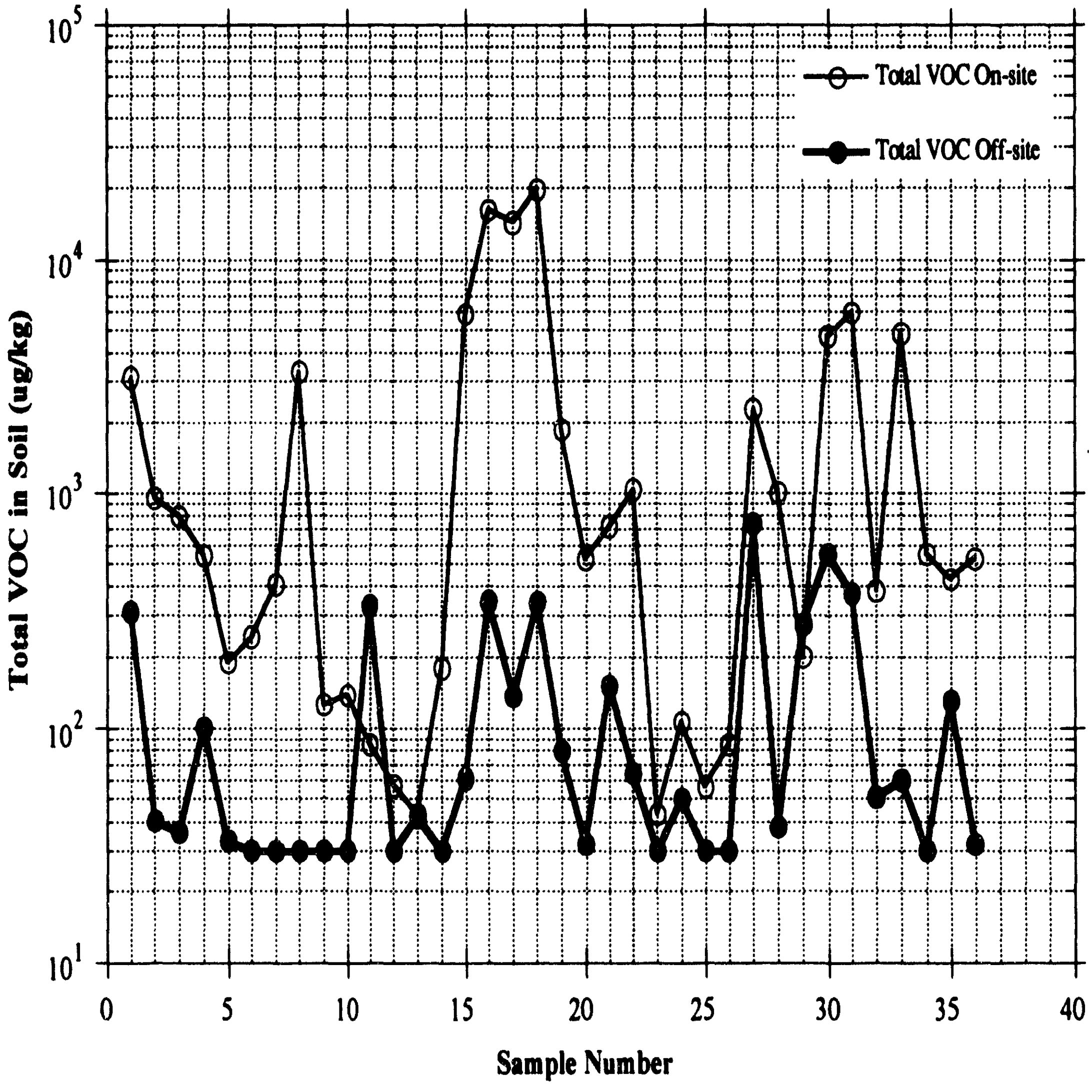

Fig. 3.6 Comparison of on-site (field) and off-site (laboratory) measurements of total VOCs in soil samples collected during January 1992.

A linear regression analysis was done for the log-transformed (natural log basis) concentrations of TCE and total VOCs measured on-site vs off-site. For total VOCs, the least squares fit of log(on-site) to log(off-site) yielded log(on-site VOCs) = 2.409 + 0.943 log(off-site VOCs), with a S.E. of slope = 0.243 (34 df) and a residual S.D. = 1.48. For TCE only, the least squares fit of log(on-site) to log (off-site) yielded log(on-site TCE) = 2.750 + 0.0.822 log(off-site TCE), with a std. error of slope = 0.182 (34 df) and a residual s.d. = 1.70. The analysis indicated that the slopes were significantly different from 0 but not from 1. Furthermore, the non-zero (positive) intercept reflects the trend of on-site measurements being generally higher than the off-site measurements. It is reasonable to conclude that the ratio of field to lab concentrations is independent of concentration level, although subject to considerable random variation.

The estimated variance of the difference between log-transformed (base 10 log basis) concentrations measured on-site versus off-site was 2.13. This is considerably larger than the variance (0.097) estimated based on on-site analyses of duplicate soil samples and confirms that the on-site versus off-site discrepancies were not due to short-range spatial variability within duplicate pairs. The observed differences between on-site and off-site VOC measurements are speculated to be due to volatilization losses of the target analytes during sample storage and pre-analytical preparation [20].

3.3.7 Tests for Spatial Dependence

A two-way analysis of variance (depth and boring) was performed to clearly demonstrate that the VOC concentrations do not simply reflect uncorrelated noise but possess an underlying spatial structure. The sources of variation included in this study were sample boring location, sample depth, and interaction between boring location and depth. The results of this analysis are presented in Table 3.7.

As shown in Table 3.7, the mean square, which is the ratio of the sum of squares to the degrees of freedom, is a measure of the variability attributed to the corresponding source of variation. The mean square for the error is the variability between samples taken at the same location and was calculated from the duplicate measurements (see Table 3.4). The F-value, which is the ratio of the mean square for a given source to the error mean square, provides a test for the statistical significance of that source. The higher the F-value, the more statistically significant is the variability due to that source. The P-value is the probability of observing an F-value as large as the one given, if the variability of the corresponding source were the same as that due to error. Small P-values imply that the variability in VOC concentrations due to the corresponding source is significantly larger than the variability among samples at the same location (i.e., small-scale variability). Both sample boring location and depth contribute significantly to the variation in the VOC data set. In addition, there is a significant interaction between sample boring location and depth as indicated by the relatively small P-value calculated for this source of variation. This means that the trend due to depth varies from boring to boring (i.e., "low" values do not always occur at the same depth for different borings).

A visual inspection of boring-averaged VOC concentration plotted against depth (Fig. 3.7 and Table 3.8) shows a general trend of decreasing VOC levels with increasing depth. However, the significant interaction in the analysis of variance (Table 3.7) indicates that the effect of depth was not consistent among borings. The results of the two-way analysis of variance showed that the VOC data contained a spatial structure, albeit very complex, which can be modeled using the techniques described in Sect. 4.

Table 3.7 Analysis of variance table for estimating the contribution of sample boring location and depth to total VOC concentrations [a]

Source of variation	Degrees of freedom	Sum of squares	Mean square	F-value	P-value
Sample boring location	20	30.15	1.51	15.57	9.78×10^{-6}
Sample depth	7	11.79	1.68	17.32	2.18×10^{-5}
Interaction between boring location and depth	136	46.45	.34	3.52	0.90×10^{-2}
Error	12	1.16	0.097	-	-

[a] Analysis of variance performed on log-transformed data set consisting of results of analyses of soil samples collected from locations within the north plot of the X-231B Unit with VOC analyses made on-site by heated headspace GC methods (see Appendix B). For this analysis, non-detects were set equal to the detection limit and included in the summation of TCE, MC, TCA, 1,1-DCE, 1,2-DCE (sum of cis- and trans-1,2-DCE isomers), and 1,1-DCA. Results are reported on the basis of field moist soil weight.

Degrees of freedom deduced from 21 boring locations in the north plot of X-1231B, and B sampling depth intervals.

Table 3.8 Summary statistics of total VOC and log VOC concentrations grouped by depth interval [a]

		Total VOC (ug/kg)			Log Total VOCs (log ug/kg)		
Depth (ft)	Samples	Mean	Std.dev.	Std. error of mean	Mean	Std. dev.	Std. error of mean
0 - 1	21	9931	15603	3405	3.57	0.69	0.15
3 - 4	24	17812	38126	7782	3.38	0.89	0.18
6 - 7	21	5348	7154	1561	3.33	0.67	0.15
8 - 9	20	4294	5666	1267	3.25	0.64	0.14
12 - 13	23	2777	3917	817	2.83	0.9	0.19
15 -16	22	1801	4116	878	2.81	0.61	0.13
18 - 19	22	1508	1451	309	3.02	0.39	0.08
21 - 22	23	1642	1694	353	2.99	0.50	0.10

[a] Analysis performed on results of analyses of soil samples collected from locations within the north plot of the X-231B Unit with VOC analyses made on-site by heated headspace GC methods (see Appendix B). For this analysis, nondetects were set equal to the detection limit and included in the summation of TCE, MC, TCA, 1,1-DCE, 1,2-DCE (sum of cis- and trans-1,2-DCE isomers), and 1,1-DCA. Results are reported on the basis of field moist soil weight.

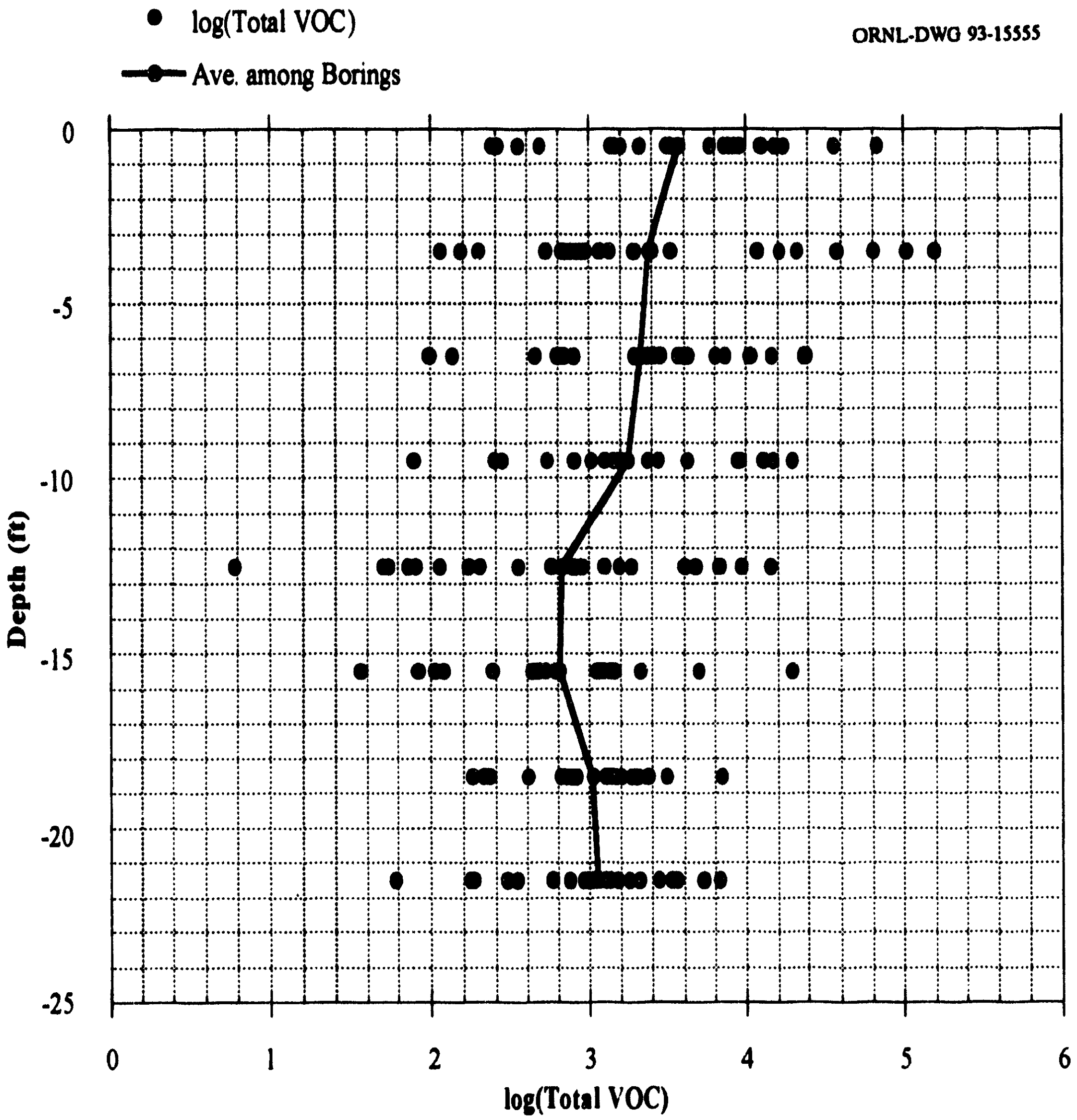

Fig. 3.7 VOC concentrations (log transformed) as a function of depth.

4. SPATIAL MODELING OF TOTAL VOC DISTRIBUTION

4.1 INTRODUCTION

Mathematical functions that can describe the distribution of total VOCs within the north plot of the X-231B Unit were developed from the on-site VOC data set given in Sect. 3. Three interpolation methods, described in Sect. 4.2, were used to derive the spatial models, and the resulting functions are visualized and compared in Sect. 4.3. A cross-validation study was conducted to evaluate the interpolation functions (Sect. 4.3.2). In addition, the spatial models were used to predict the results of a sampling event conducted in April/May 1992, immediately prior to the field-scale technology demonstrations. Comparisons between the predictions and the actual VOC values are given and discussed in Sect. 4.3.3. The spatial models were also used to estimate the toal mass of VOCs within the north and south plots of X-231B, which served as a basis for developing performance goals for the full-scale remediation of the site.

4.2 METHODS

Spatial modeling is the process of applying interpolation/smoothing methods to select a three-dimensional response function, $u(x,y,z)$, that is compatible with measurements made at discrete points within the region of interest. The spatial modeling conducted in support of the X-231B Technology Demonstration was aimed at seeking a function $u(x,y,z)$ = log(VOC concentration), where x,y,z are spatial coordinates, that best represented the data set consisting of on-site VOC measurements described in Sect. 3. The selected three-dimensional response functions, or VOC spatial models, were then visualized by commercially available three-dimensional computer software (Dynamic Graphics [21]). This facilitated the identification of relatively uniform and highly contaminated areas within the north plot of the X-231B site.

Three interpolation/smoothing methods were used to develop the VOC spatial models: (1) a three-dimensional interpolator that is an extension of a minimum tension, two-dimensional contouring method, (2) a smoothing routine that compromises between minimizing curvature and residual sum of squares, and (3) a version of kriging. A description of each method follows.

Method I is a commercially available, three-dimensional interpolator that is an extension of the "minimum tension" two-dimensional contouring method due to Briggs [22]. This method is implemented in the Dynamic Graphics software [21] that was used to visualize the VOC spatial models. The source code is not available, and documentation, aside from the reference to Briggs, is limited primarily to advertising. The original method described by Briggs is essentially a two-dimensional interpolator that selects the function $u = \hat{u}$ with "minimum curvature" that agrees with the observed concentration values. In two dimensions, the total squared curvature was defined to be

$$C(u) = \iint \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right)^2 dx\,dy, \tag{1}$$

where u is the response and x and y are the two spatial variables [22]. It was assumed that extension to three spatial dimensions is done simply by adding another term inside the brackets and integrating over three dimensions. In numerical implementation, C is replaced by a discrete approximation on a rectangular grid. The data locations need not be restricted to the grid, but for those that are not, the method does not quite produce true interpolations (i.e., the selected response function does not "pass through" observed concentrations that are not on the grid points).

Method II is a smoothing routine due to Wahba and Wendelberger that is implemented in the public-domain software RKPACK [23,25]. This method seeks the function $u = \hat{u}$ that best compromises between minimizing the curvature and minimizing the residual sum of squares. Here, the total squared curvature is defined to be

$$C(u) = \sum_{\alpha_1+\alpha_2+\alpha_3=2} \frac{2!}{\alpha_1!\alpha_2!\alpha_3!} \iint \left(\frac{\partial^2 u}{\partial x^{\alpha_1} \partial y^{\alpha_2} \partial z^{\alpha_3}} \right)^2 dxdydz \qquad \alpha_1, \alpha_2, \alpha_3 = 0,1,2. \tag{2}$$

The algorithm searches for the function u = $\hat{u}$ that minimizes

$$Q(u) = S(u) + \lambda C(u), \tag{3}$$

where $S(u)$ is the average residual sum of squares at the observed locations and λ is a weighting factor applied to the "penalty" C. For λ near 0, the fitted function $\hat{u}$ will be very nearly a true interpolator; for larger values of λ, $\hat{u}$ will have smaller curvature but will not agree exactly with the observed concentrations.

Although the user can specify λ, RKPACK provides a couple of options for automatic selection. In the work described herein, the generalized cross-validation (GCV) method of Craven and Wahba was chosen from the options [26].

Method III is a version of kriging, a spatial prediction method commonly used in geostatistics [27-29]. The response function u is viewed as a realization of the stationary Gaussian random function U. The fitted function $\hat{u}$ is taken to be the conditional expectation of U given the values of u at the observed locations. The function U was represented as the sum of three components:

U_1, a smooth function that captures the major global features of the response,
U_2, a rough function that captures local, short-range, variability, and
U_3, independent random "noise" which represents very short-range variability (e.g., variability among samples within the same core)

Each of these functions is a stationary Gaussian process. U_1 has mean, μ, and a Gaussian covariance function:

$$Cov\left(U_1(x_1, y_1, z_1), U_1(x_2, y_2, z_2)\right) = \sigma^2 e^{-\theta_x (x_1 - x_2)^2 - \theta_y (y_1 - y_2)^2 - \theta_z (z_1 - z_2)^2}, \tag{4}$$

U_2 has mean, 0, and an isotropic exponential covariance function:

$$Cov\left(U_2(x_1,y_1,z_1),U_2(x_2,y_2,z_2)\right)=\omega^2 e^{-\psi\sqrt{(x_1-x_2)^2+(y_1-y_2)^2+(z_1-z_2)^2}}, \quad (5)$$

U_3 has mean, 0, and variance α^2.

The adjustable (or fitting) parameters (μ, σ^2, θ_x, θ_y, θ_z, ω^2, ψ, and α^2) were determined by the method of maximum likelihood [30].

4.3 RESULTS

4.3.1 Visualization of Total VOC Spatial Models

Visualizations of the prediction function $\hat{u}\ (x,y,z)$ were obtained by means of Dynamic Graphics, Inc. software [21]. They are shown in Figs. 4.1 and 4.2, for the predictions based on Methods I and III, respectively. Although there are differences in smoothness of the representations, the two consistent impressions are (1) higher VOC concentrations exist nearer the surface and (2) higher VOC concentrations exist near the middle of the eastern part of the region. These impressions become clearer by examining the estimate of the smooth, underlying function U_1 available from Method III and visualized in Fig. 4.3.

The appearance of "hot" and "cold" spots in the visualizations should be interpreted with caution since these invariably appear at sampled locations. At other locations, because of the considerable short-range variability, it is essentially unknown whether a location is extremely hot or extremely cold. In general, the prediction at an unsampled location is an unremarkable intermediate value.

It should also be noted that all of these representations of the concentration function are likely to be much smoother than the true concentration. Smoothness is incorporated explicitly in Methods I and II (through minimizing curvature subject to constraints on the residual sum of squares). In Method III the prediction function is essentially an average of all realizations of the postulated random functions that agree with the data and is therefore smoother than a typical realization.

The geostatistical approach that underlies the kriging method provides a basis for simulating "typical" representations of the true concentration function u. As mentioned previously, the function u is considered to be a realization of the stationary Gaussian random function U. In essence, U is a large population of functions and u is one of them. The conditional random function U_C consists of that subpopulation of U that agrees with the data at all sampled points. Conditional simulation is the process of randomly generating functions from U_C. The procedure used is described in Journel and Huijbregts [27]. One first generates a member of U (e.g., u_S) by an ingenious approximation called the "turning bands" method and then modifies it according to the following equation [28-29, 31]:

$$u_{cs}(x,y,z)=\hat{u}(x,y,z)+u_s(x,y,z)-\hat{u}_s(x,y,z) \quad (6)$$

where $\hat{u}(x,y,z)$ is the predicted concentration at the point x,y,z based on the observed data and $\hat{u}_s(x,y,z)$ is the predicted concentration at x,y,z based on the simulated data u_S.

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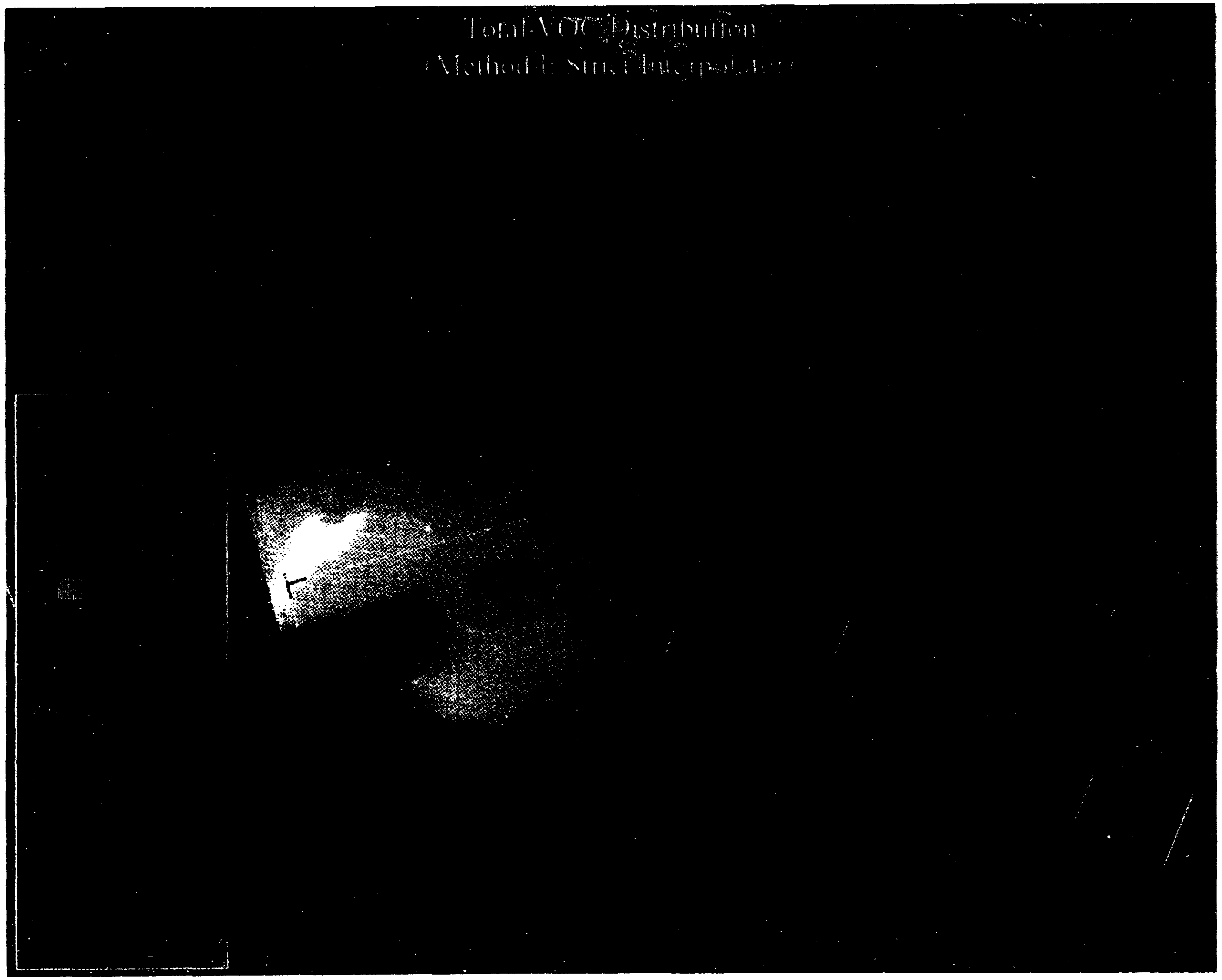

Fig. 4.1. Spatial model of VOC distribution in the north plot of the X-231B Unit based on the Briggs method (Method I). (Note: North to south orientation is right to left in the image displayed)

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Fig. 4.2. Spatial model of VOC distribution in the north plot of the X-231B Unit based on a 3-D kriging model (Method III). (Note: North to south orientation is right to left in the image displayed)

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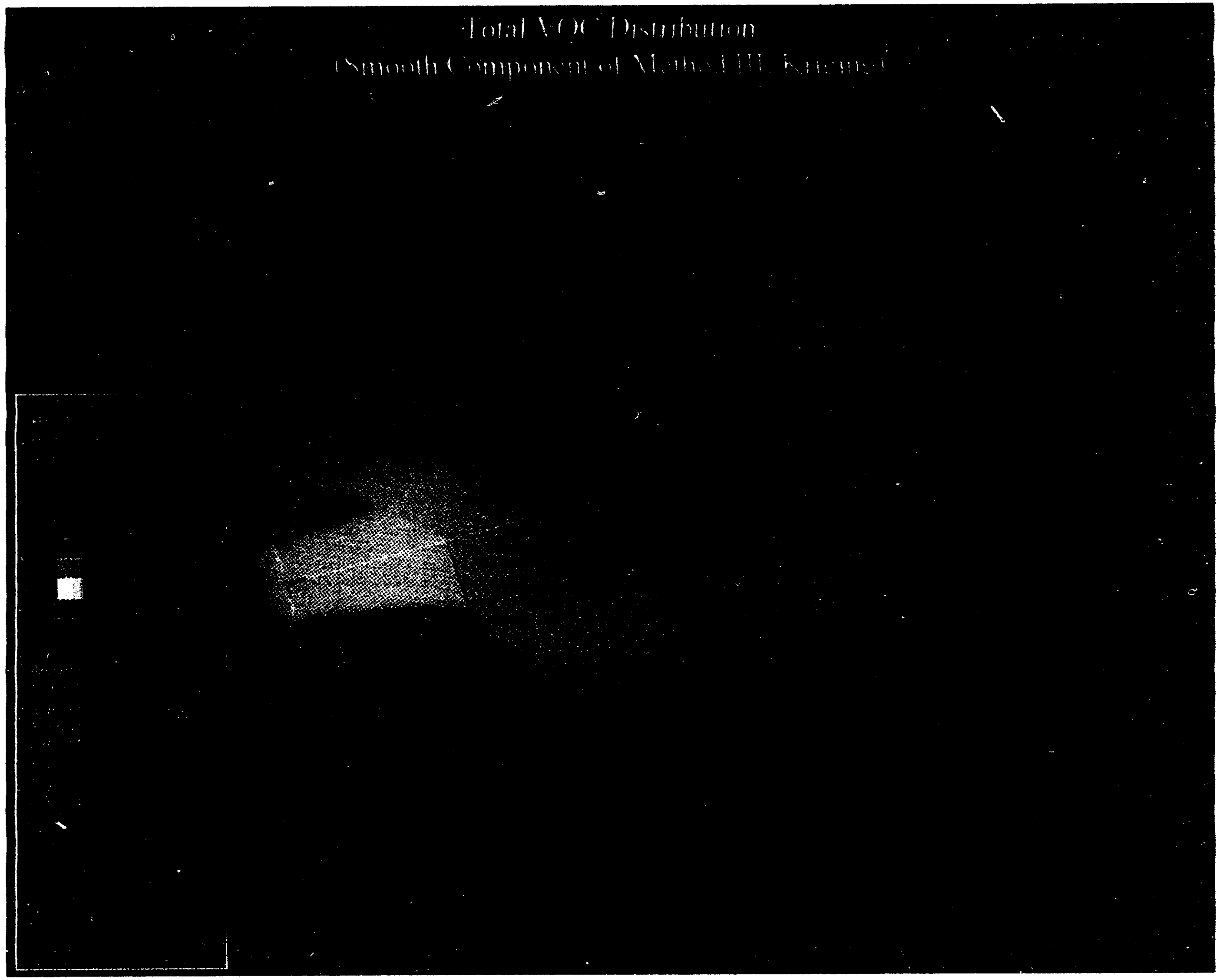

Fig. 4.3 Three-dimensional visualization of the smooth component of the kriging spatial model (Model III). (Note: North to south orientation is right to left in the image displayed.)

For practical reasons, u_{CS} cannot be generated at every point in its domain, which is the three dimensional spatial region of interest. Instead, the same grid used for the previous visualizations was chosen, and the function values $u_{CS}(x)$ was generated only for those $(x,y,z)'$ s that are on the grid.

A computer visualization of one of these simulated concentration functions is shown in Fig. 4.4. Note that it is much rougher, with many more "hot" and "cold" spots, than is the predicted function $\hat{u}$ shown in Fig. 4.2. Other simulations would give a similar impression, but the locations of many of the hot and cold spots would be different. The prediction function is the function one would arrive at if one were to average many such simulated functions.

Fig. 4.4 emphasizes the point that the spatial variability here is such that the sampling of 8 depths at each of 21 locations is quite inadequate to identify all (or even most) of the hot spots. A more relevant concern from the point of view of remediation, however, is the estimation of the total mass of VOCs in the volume of interest which is described in Sect. 4.3.4.

4.3.2 Cross-Validation of Total VOC Spatial Models

To evaluate the three spatial prediction methods, a couple of cross-validation exercises were conducted using the on-site VOC data generated during January 1992.

In the first exercise, the VOC data at three depths (i.e., 3 to 4, 9 to 10, and 15 to 16 ft) were excluded from each of 21 borings leaving 5 depths upon which to base the prediction. The predicted VOC values at these excluded locations were then compared with the observed values (those that were actually measured), and the errors of prediction were computed. Summaries of these errors are shown in Table 4.1. A visual comparison of prediction errors among the three methods are shown in the box plots in Fig. 4.5. It is evident from this figure that there is not much difference among the apparent prediction error of the three methods.

The second exercise was carried out as in the first, except that the excluded data set consisted of 4 of the 21 Geoprobe® locations (i.e., all depths in probe locations GP04, GP07, GP12, and GP16) (see Fig. 3.2 for probe locations). The remaining samples (total of 143) were used to predict the VOC concentrations in the excluded set. In the second exercise, a two-dimensional kriging program (SURFER, Golden Graphics Corp., Golden, CO), was also used. This two-dimensional kriging method interpolates each of the eight depths separately. The kriging model used linear (presumably isotropic) covariances. Summaries of the prediction errors for all four methods are shown in Table 4.2 and Fig. 4.6. Although there is again not much difference in the predictions of the methods, the three-dimensional kriging method appeared to have an advantage over the other approaches.

It was also observed that smaller errors between predicted and measured values were seen in the first cross-validation exercise (wherein measurements were removed from some depths in all borings) when compared with the second exercise (where all measurements were removed from some borings). This indicates that, for th [illegible] -231B site, if sampling density were to be increased and a choice had to be made between more probe locations or more samples with depth, it would be more efficient to increase the number of probe or boring locations instead of increasing the number of sampling depths. This observation is relevant for additional sampling that will be conducted at the site prior to full-scale remediation.

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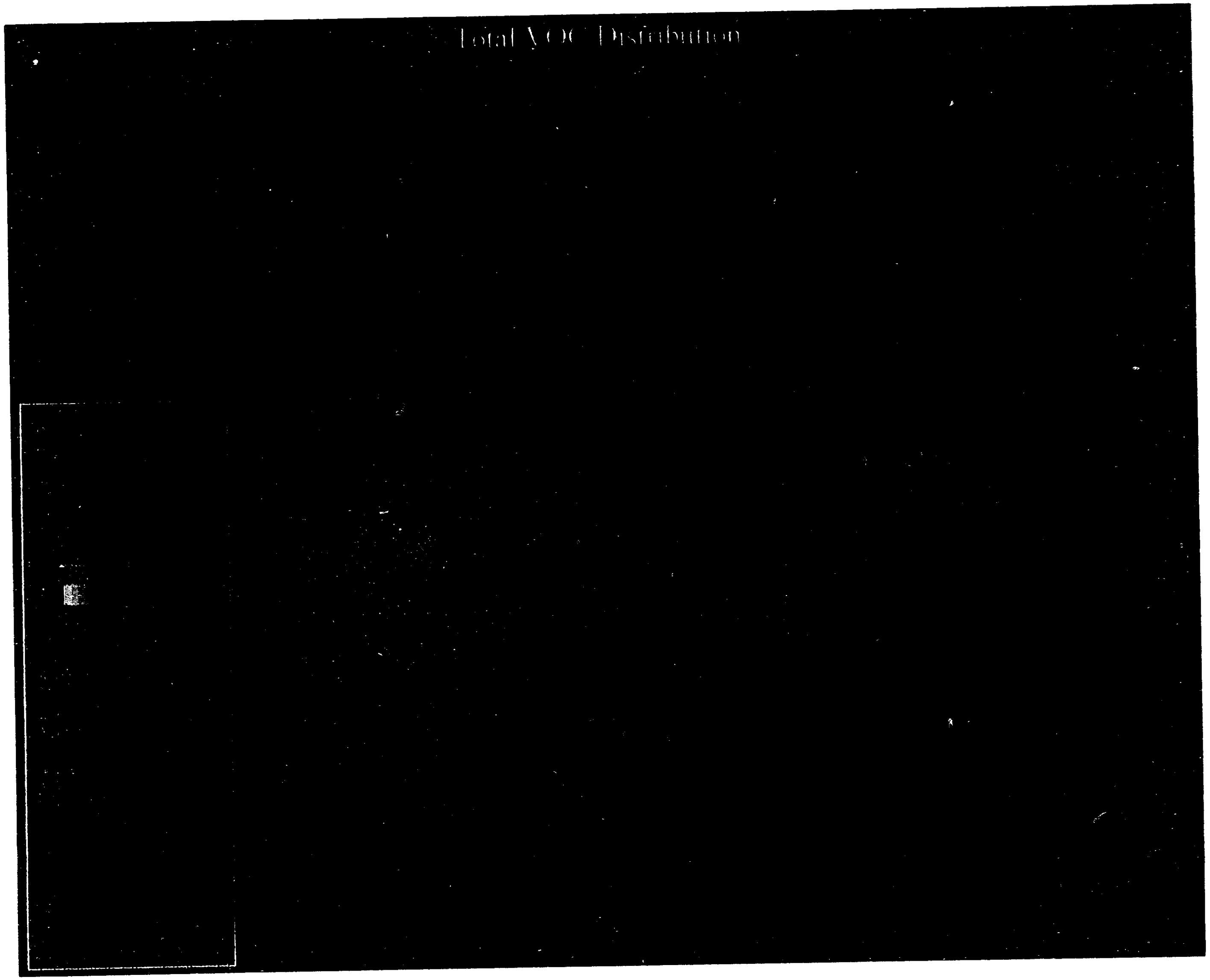

Fig. 4.4. Conditional simulation of VOC distribution in the north plot of the X-231B Unit based on a "turning bands" algorithm applied to the three-dimensional kriging model.

Table 4.1 Error summaries for three smoothing/interpolation methods in the first cross-validation exercise [a]

	Error = Predicted VOCs - Observed VOCs (ug/kg)			Error = Log(Predicted VOCs) - Log(Measured VOCs) (Log ug/kg)		
Error statistic	Method I	Method II	Method III	Method I	Method II	Method III
Minimum error	-145202	-142562	-145454	-1.22	-1.12	-1.24
25th Percentile	-549	-511	-868	-0.22	-0.22	-0.24
Median error	15	53	70	0.02	0.05	0.04
75th Percentile	944	1079	797	0.31	0.35	0.34
Maximum error	3813	3639	3206	1.42	1.4	1.34
Median absolute error	816	834	818	0.28	0.3	0.32
Root mean squared error	23082	22860	23272	0.52	0.52	0.53

[a] Cross-validation exercise performed on results of January 1992 on-site VOC analyses, the results of which were reported on the basis of field moist soil. The VOC data at three depths (i.e., 3-4, 9-10, and 15-16 ft) were excluded from each of 21 borings leaving five depths upon which to base the prediction. The predicted VOC values at these excluded locations were then compared with the observed values (those that were actually measured) and the errors of prediction were computed. Method I = Dynamic Graphics interpolation. Method II = RKPACK smoother. Method III = three-dimensional kriging.

Table 4.2 Error summaries for four smoothing/interpolation methods in the second cross-validation exercise [a]

	Error = Predicted VOCs - Observed VOCs (ug/kg)				Error = Log(Predicted VOCs) - Log(Measured VOCs) (Log ug/kg)			
Error statistic	Method I	Method II	Method III	Method IV	Method I	Method II	Method III	Method IV
Minimum error	-32118	-33909	-33228	-34787	-0.96	-1.22	-1.1	-1.45
25th percentile	-432	468	-126	-467	-0.16	0.12	-0.05	-0.09
Median error	515	1170	483	622	0.3	0.29	0.13	0.35
75th percentile	2612	2206	1708	2157	0.69	0.74	0.62	0.61
Maximum error	16274	16438	7573	25767	1.33	1.46	1.32	1.34
Median absolute error	1030	1323	832	916	0.32	0.38	0.23	0.43
Root mean squared error	7083	7364	6464	9139	0.62	0.65	0.57	0.65

[a] Cross-validation exercise performed on results of January 1992 on-site VOC analyses, the results of which were reported on the basis of field moist soil. The VOC data at four of the 21 Geoprobe® locations (i.e., all depths in probe locations GP04, GP07, GP12, and GP16) were excluded leaving 17 borings upon which to base the prediction. The predicted VOC values at the excluded locations were then compared with the observed values and the errors of prediction were computed. Method I = Dynamic Graphics interpolation. Method II = RKPACK smoother. Method III = three-dimensional kriging. Method IV = two-dimensional kriging.

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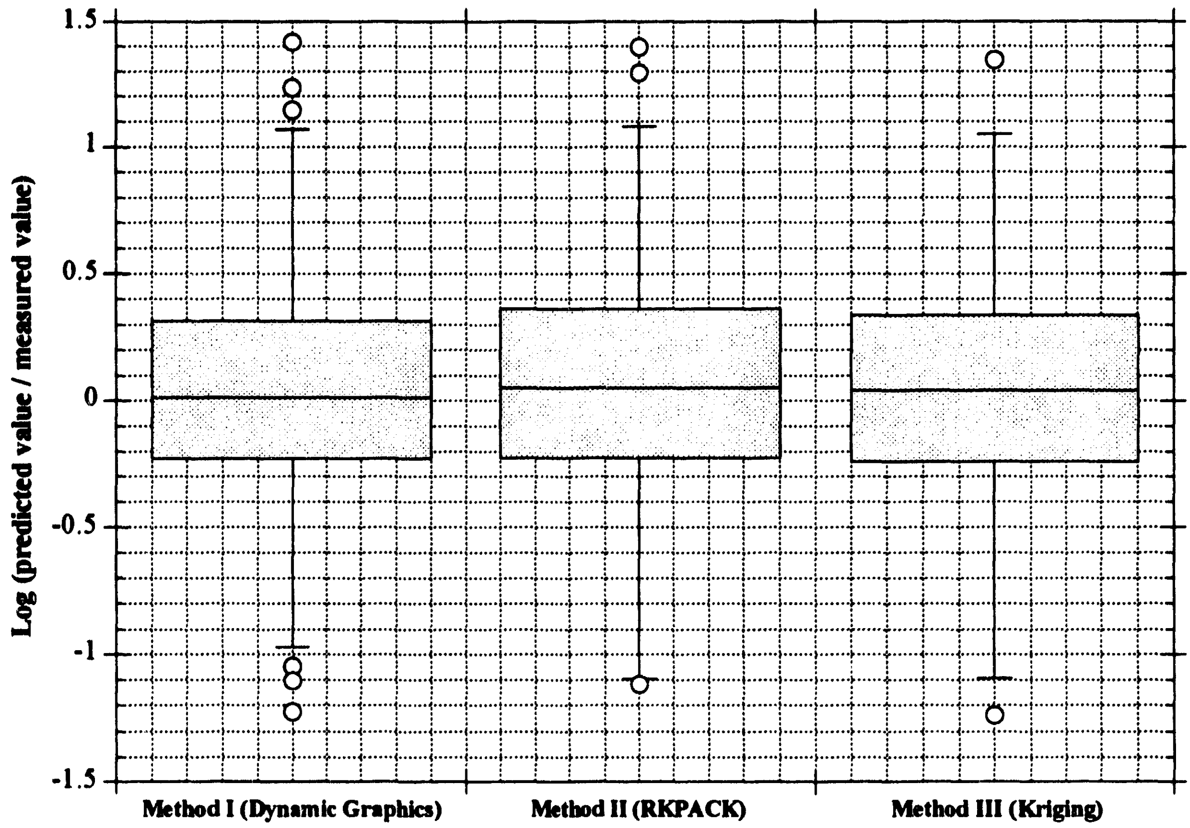

Fig. 4.5 Log ratio of predicted to observed VOC concentrations at deleted sample depths as determined during the first cross-validation exercise.
(Note: The tops and bottoms of the boxes mark the limits of ±25% of the computed ratios for each method. The line in the box represents the median ratio; the vertical lines mark the range of ratios while the circles represent outliers.

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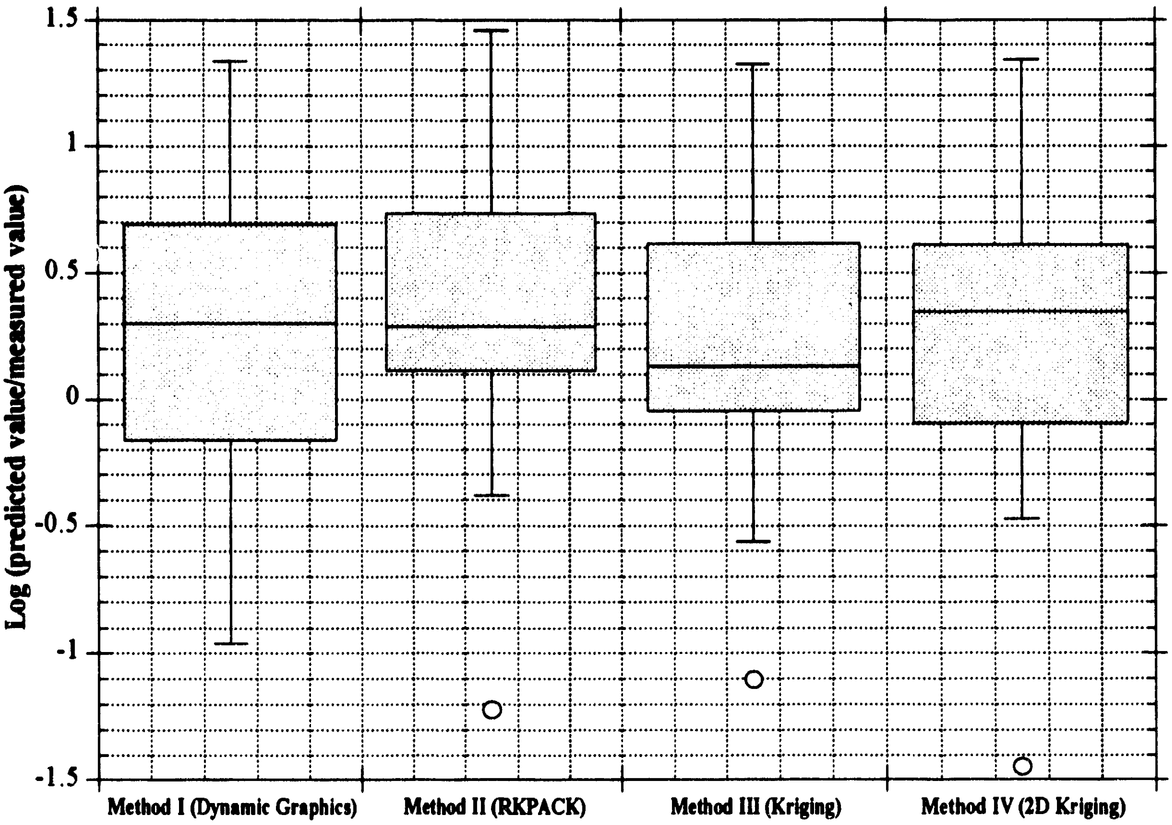

Fig. 4.6 Log ratio of predicted to observed VOC concentrations at deleted sample probe locations as determined during the second cross-validation exercise.
(Note: The tops and bottoms of the boxes mark the limits of ±25% of the computed ratios for each method. The line in the box represents the median ratio; the vertical lines mark the range of ratios while the circles represent outliers.

4.3.3 Prediction of a Subsequent Data Set

Another opportunity to evaluate the predictive ability of the spatial modeling methods came about in April 1992, four months after the baseline data had been collected in January 1992. At this time, soil samples were collected and analyzed on-site in a fashion identical to that employed in January 1992; all methods were the same. These data were required to establish pretreatment VOC concentrations within a small portion of the north plot of the X-231B Unit where field testing of in situ treatment technologies was to occur. The field test area was in the central part of the north plot of the X-231B Unit and represented approximately 10% of the area of the north plot (Fig. 4.7).

In total, 204 soil samples were collected from the field test area in late April and early May 1992. Analyses were made on-site for the target VOCs. Using the spatial models developed with the January 1992 VOC dates were used to predict VOC concentrations in each of the April 1992 sampling locations. The errors of prediction for each of the three spatial modeling methods are given in Table 4.3, and box plots of these errors are shown in Fig. 4.8. Comparison of the three modeling methods revealed that there was no substantial difference among the methods. The height of each box in Fig. 4.8 (which contains the middle 50% of the errors) is virtually the same for each method, although there is a slight difference in their locations.

A scatter plot of the VOC concentrations observed vs the values predicted by the RK method is shown in Fig. 4.9. The "ideal line" shown in Fig. 4.9 corresponds to perfect prediction, whereas the "least-squares line" was derived by fitting the logs of the observed concentrations to the logs of the predicted concentrations. This figure shows that the distribution of observed values at a particular predicted value is reasonably well centered on the predicted value, but has a scatter of 2 to 3 orders of magnitude. In addition, the range of predicted values is narrower than the range of measured values.

A useful property of the kriging methodology (Method III) is that it provides estimates of uncertainty (in the form of posterior or conditional standard deviations) with each prediction. Fig. 4.10 shows the April VOC concentrations relative to the 95% prediction intervals based on the January 1992 data. Even though these intervals are wide (the upper limit is 200 to 300 times the lower limit), they still failed to cover 28 of the 204 observed values. In nearly all of these cases, the observed value was higher than expected. It is not clear whether this is a temporal or a spatial effect. This demonstrates that given a sufficient number of samples, prediction of VOC concentrations within a region of interest can be achieved with reasonable certainty. However, prediction of concentrations at a discrete point or in a small region is very imprecise.

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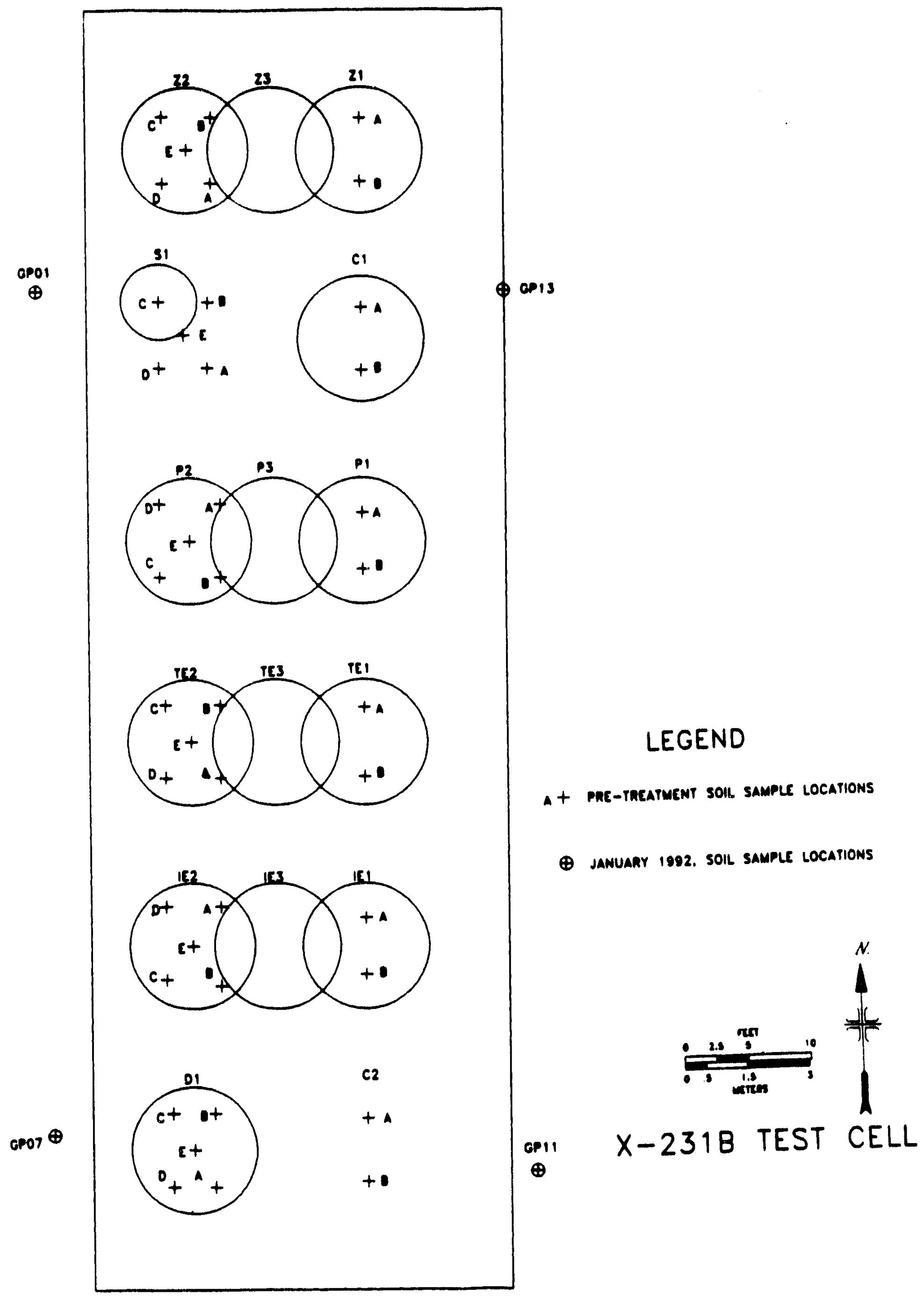

Fig. 4.7 Location of Geoprobe® sampling points within the field test sub-region of the north plot of the X-231B Unit from soil samples were collected during April 1992. (Note: Refer to Fig. 3.2 for the location of this sub-region within the X-231B Unit. Circles represent demonstration test cells.)

Table 4.3 Error summaries for prediction of the April/May 1992 subregion data set based on the January 1992 region data set [a]

	Error = Predicted VOCs - Observed VOCs (ug/kg)			Error = Log(Predicted VOCs) - Log(Measured VOCs) (Log ug/kg)		
Error statistic	Method I	Method II	Method III	Method I	Method II	Method III
Minimum error	-566179	-566625	-568491	-2.03	-2.07	2.28
25th percentile	-18510	-20817	-22537	-0.51	-0.74	-0.85
Median error	835	-277	-2156	0.13	-0.02	-0.19
75th percentile	6767	2333	1114	0.65	0.46	0.3
Maximum error	69526	32847	10724	1.82	1.73	1.57
Median absolute error	10674	4952	4096	0.62	0.57	0.55
Root mean squared error	86135	86722	87625	0.8	0.78	0.83

[a] Validation exercise where the results of the January 1992 on-site VOC analyses, the results of which were reported on the basis of field moist soil, were used to predict the VOC concentrations within a subregion of the north plot of the X-231B Unit. The predicted VOC concentrations were then compared with the observed values and the errors of prediction were computed. Method I = Dynamic Graphics interpolation. Method II = RKPACK smoother. Method III = three-dimensional kriging.

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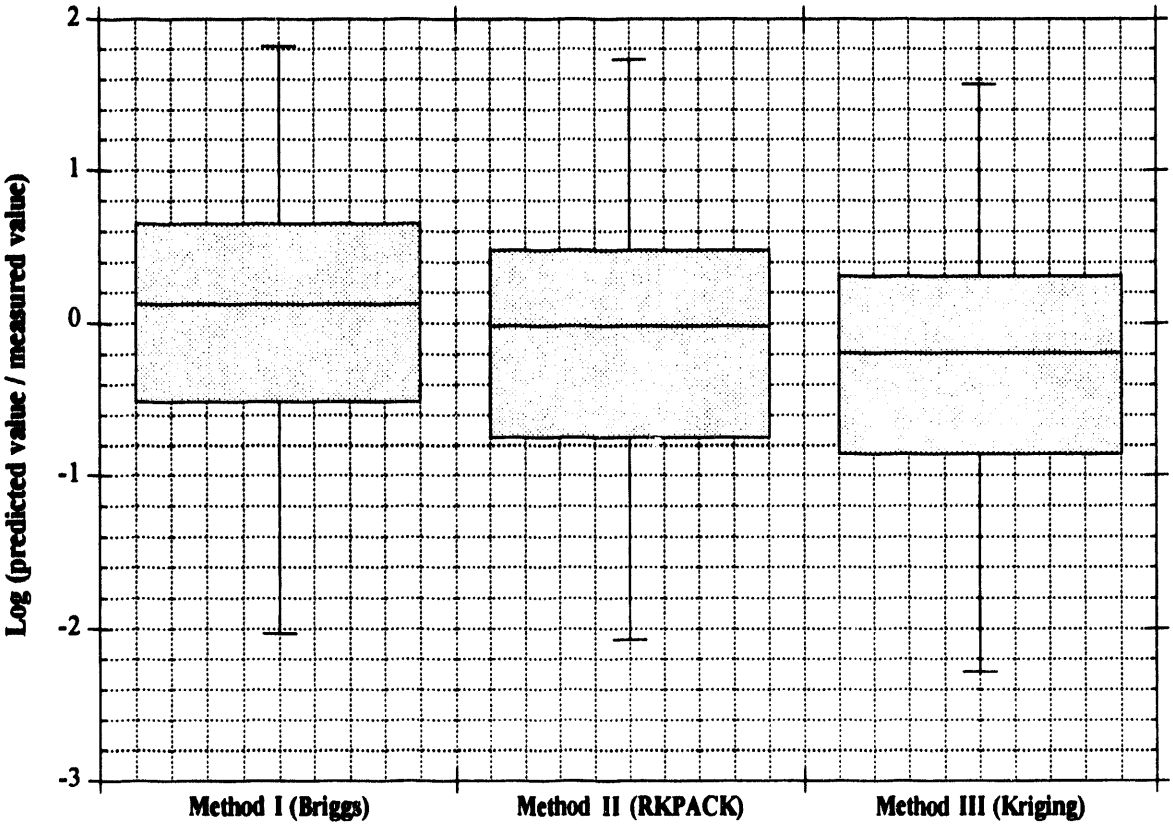

Fig. 4.8 Log ratio of predicted to observed VOC concentrations in subregion April 1992 data set based on the January 1992 region data set.
(Note: The tops and bottoms of the boxes mark the limits of ±25% of the computed ratios for each method. The line in the box represents the median ratio; the vertical lines mark the range of ratios while the circles represent outliers.)

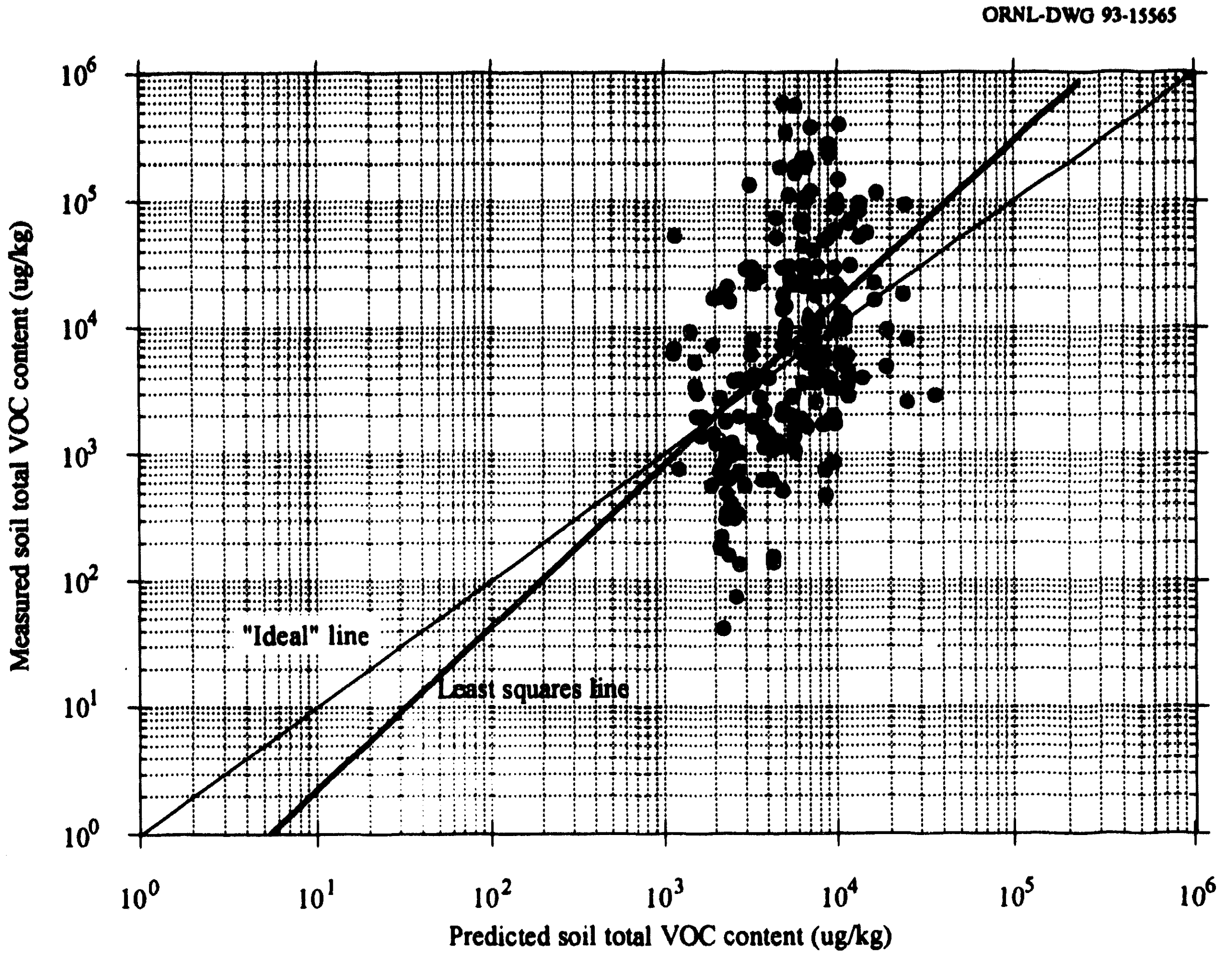

Fig. 4.9 Predictions of the April sub-region data based on the region data set observed in January 1992 and modeled using Method II.

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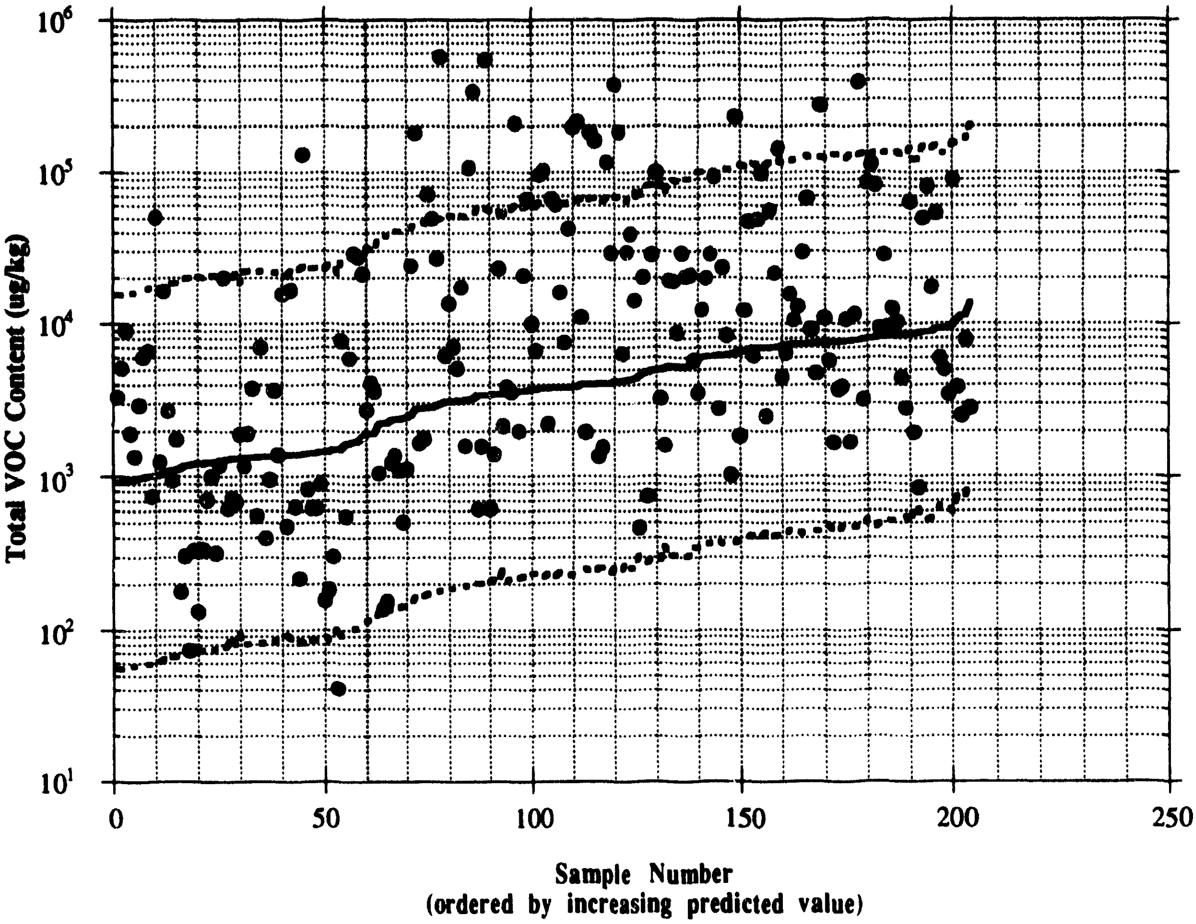

Fig. 4.10 Prediction of the April sub-region VOC concentrations based on the 3-D kriging model developed from the January 1992 region data.
(Note: The predicted concentrations are depicted by the solid line with the 95% confidence interval indicated by the dashed lines. The individual observed data points are displayed as filled circles).

4.3.4 Mass Estimates Of Total VOC In The X-231B Unit

To this point, the discussion has focused on the estimation of the spatial distribution of the VOC concentrations. For the purpose of eventual remediation, it was also of interest to estimate the total mass of VOCs in the north plot and the south plot to a depth of 22 ft.

Mass estimates for the north and south plots of the X-231B Unit were conducted using the stochastic simulation method described in Sect. 4.3. The method starts with the random selection of 2000 points within the volume of interest. This is then followed by the generation of 200 simulations of the total VOC distribution using parameters of three-dimensional kriging models developed from the 199 VOC measurements taken in January 1992 (samples from probes in the north and south plot), and from the 204 VOC measurements taken in April 1992 prior to the field-scale demonstration. For a given simulation, the average of the concentrations over these points is an estimate of the mean VOC concentration over the region of interest. The mass estimate for a simulation is equal to the average VOC concentration multiplied by the mass of soil in the volume of interest. The average concentration and, consequently, the mass estimate will vary from one simulation to the next in accordance with the uncertainty of VOC concentrations at the unsampled points which was incorporated into the geostatistical model. The histogram of average VOC concentrations in the north plot generated by the simulations is shown in Fig. 4.11.

Two different three-dimensional kriging models were used in the simulations for the mean VOC concentrations, one for the 0-16 ft depth zone and another for the 16 -22 ft depth zone. This was necessary to allow for the smaller variability of the log concentrations in the deeper zone.**

Fig. 4.12 shows a plot of the 200 mass estimates for the north plot. The mass estimates for the north and south plots were calculated by multiplying the simulated mean concentrations by the contaminated soil mass, which was determined from an estimated volume of soil underlying the north and south plots, and an assumed soil density of 1.8 g/cc. The quantiles of the 200 mass estimates for total VOCs in north and south plots of X-231B are given in Table 4.4. The median values (50%) can be used as the "best" mass estimate for each depth zone, with the 5% and 95% values as the 90% confidence limit.

Stochastic simulations following the method described above were also performed on a data set that only included the VOC measurements taken in January 1992 from the north plot (176 samples). The simulated mean VOC concentrations and estimated mass in the north plot were lower than those obtained from simulations based on data from both the January and April/May 1992 sampling events (compare Figs. 4.11 and 4.13, Figs. 4.12 and 4.14). This is probably due to higher VOC levels measured in the April/May 1992 samples; the mean of the 204 VOC measurements from this sampling event was 36,715 ug/kg while the mean of the 199 VOC levels taken in January 1992 was only 5393 ug/kg. This is not entirely surprising given that the April samples were collected from the eastern edge of the north plot, a region that was identified as being highly contaminated in spatial models developed from the January 1992 data set (see Figs. 4.1 and 4.2).

The mass estimates based on both the January and April/May 1992 data sets (shown in Table 4.4) are believed to be more reliable than estimates from the January data set alone since the former values are based on a larger number of samples.

** Because the log concentrations must be exponentiated before averaging over a region, the variability of the log concentrations significantly affects the estimate of the mean VOC concentration.

Table 4.4 Estimated mass of total VOCs within the north and south plots of the X-231B Unit to a depth of 22-ft. [a]

Quantile	Estimated Total VOC mass in the north plot (kg)	Estimated Total VOC mass in the south plot (kg)
5%	229	16
25%	273	23
50%	335	29
75%	382	46
95%	488	76

[a] Estimates were made using a spatial model based on three-dimensional kriging developed from the results of on-site VOC analyses made in January and April/May 1992. 200 simulations were made yielding the quantiles listed.

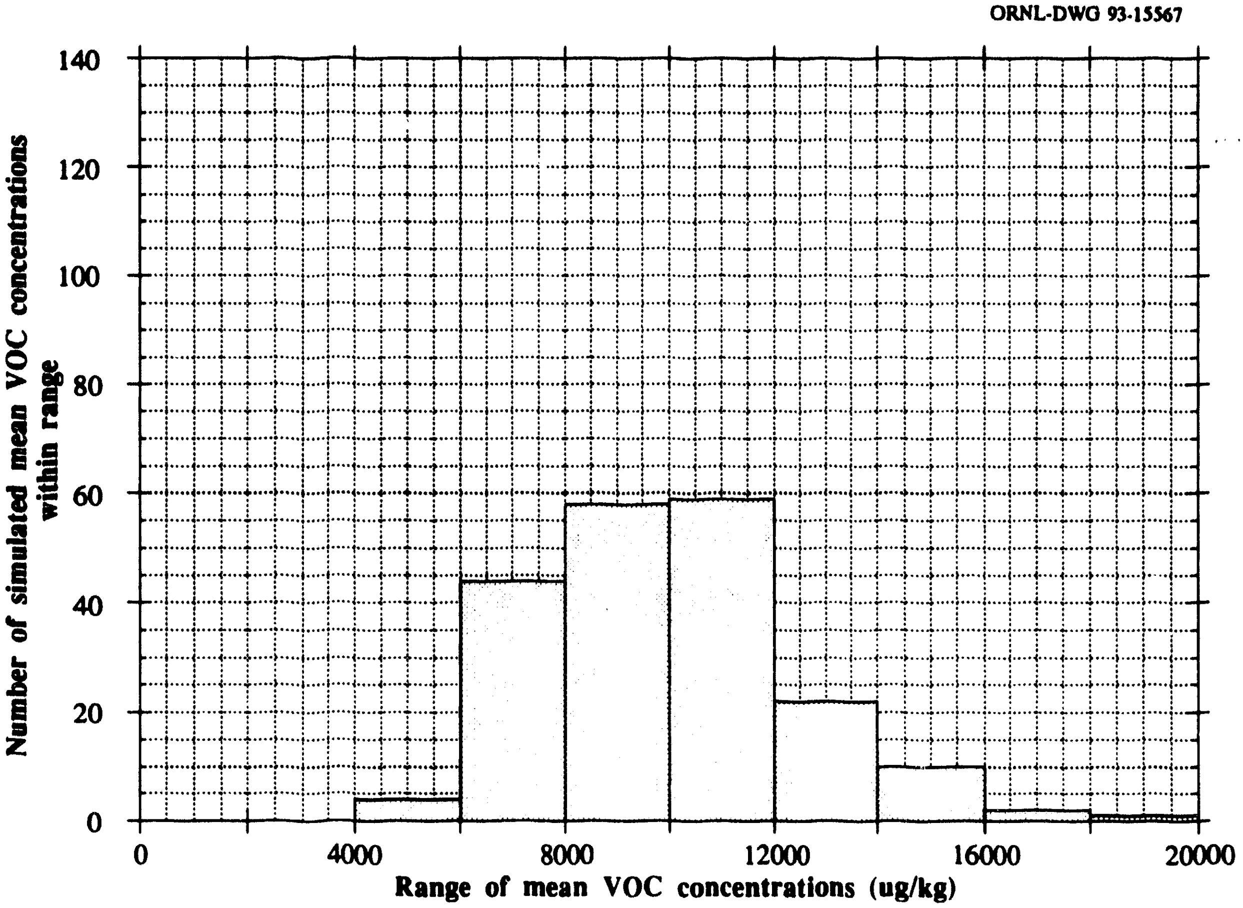

Fig. 4.11 Distribution of 200 simulated estimates of mean VOC concentration in the north plot using both January and April data sets.

ORNL-DWG 93-15568

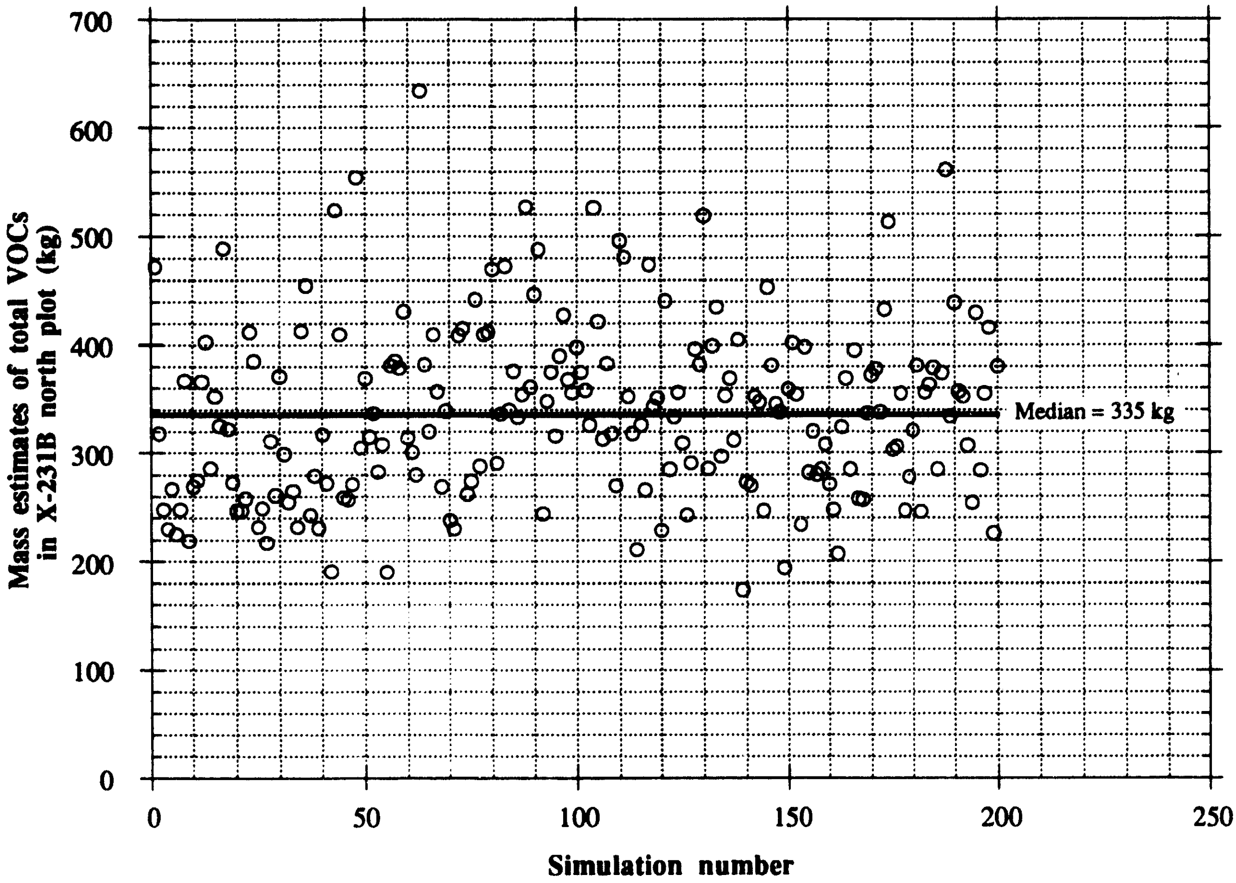

Fig. 4.12 Estimates of total VOC mass calculated from simulations of VOC distribution in the north plot of the X-231B Unit using both January and April data sets.

ORNL-DWG 93-15571

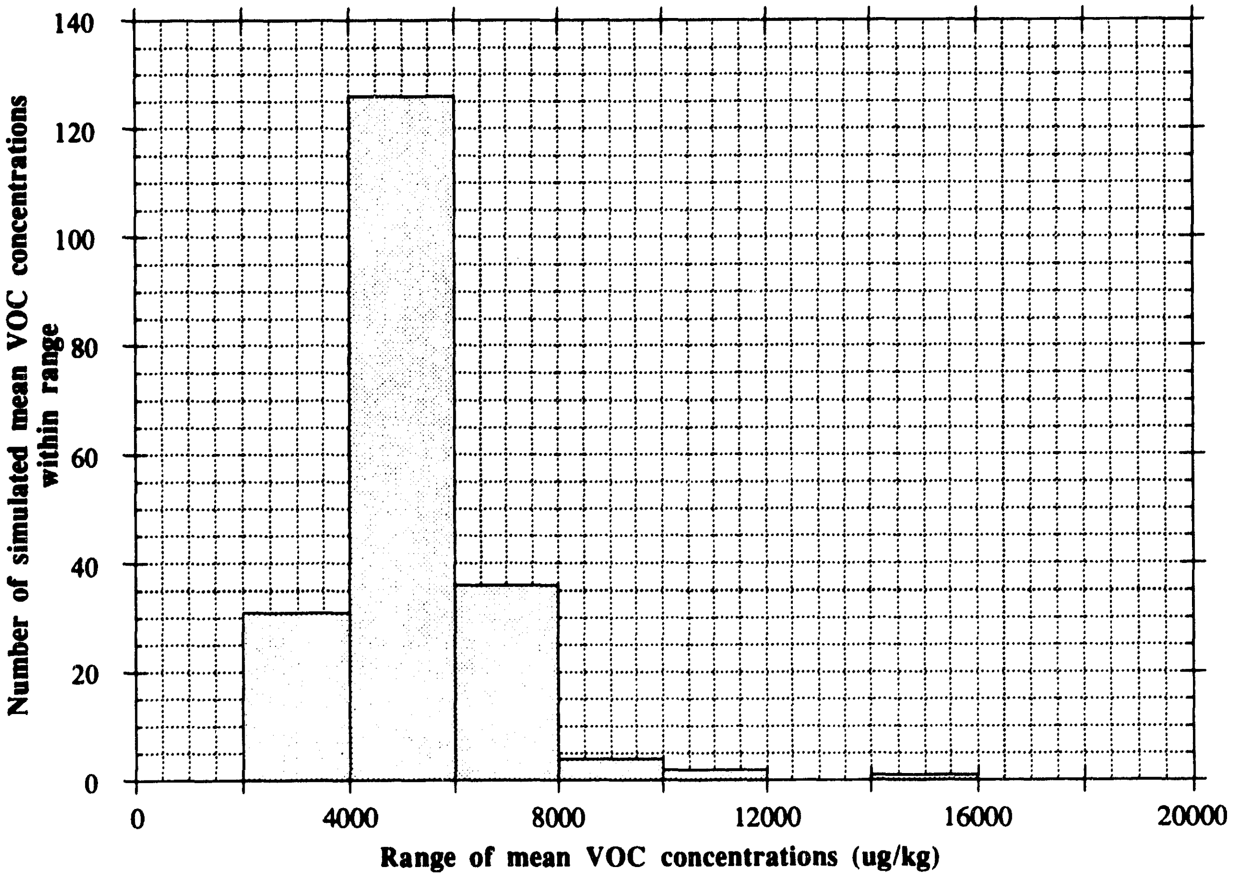

Fig. 4.13 Distribution of 200 simulated estimates of mean VOC concentration in the north plot based on the January data set alone.

ORNL-DWG 93-15572

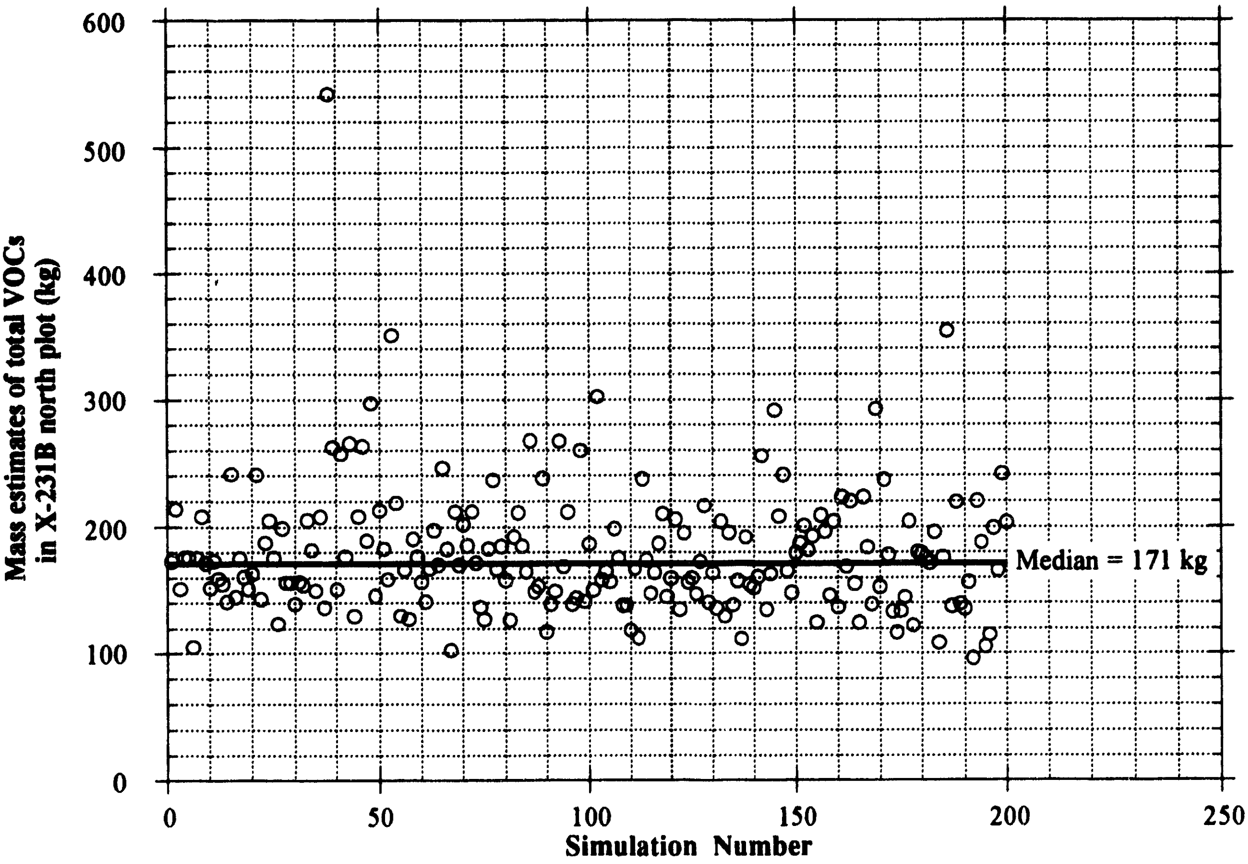

Fig. 4.14 Estimates of total VOC mass calculated from simulations of VOC distribution in the north plot of the X-231B Unit based on the January data set alone

5. SUMMARY AND CONCLUSIONS

The primary objective of contaminant characterization at the X-231B Unit was to locate highly contaminated regions where the field-scale process implementations were to be conducted. To fulfill this objective, three dimensional models of the VOC distribution were developed from a spatially extensive baseline VOC data set collected in January 1992. Using an on-site technique, VOC levels were measured in soil samples collected from up to 8 depths (ground surface to 22-ft depth) in each of 24 locations, with a majority of the samples collected from the north plot of the X-231B Unit. Analysis of the data set revealed several components contributing to the variation in the VOC observations. Models for the spatial distribution of the VOC data were developed using three interpolation methods and visualizations of these VOC distribution models were used to locate the more highly contaminated areas within the plot wherein the technology demonstrations were subsequently conducted.

The following conclusions can be made based on the data collected in January 1992 and the subsequent analyses of this data set:

1. The short-range spatial variability of soil VOC concentrations can be more than one order of magnitude, as determined from samples that were collected within 1-ft of each other.

2. VOC measurements obtained from an on-site headspace technique were consistently and significantly higher than values obtained from off-site analyses following EPA Method SW5030/8240. The median ratio between on-site and off-site measurements was 8.35, which corresponds to an 88% discrepancy between analyses results. The variance between on-site and off-site measurements was larger than the variance of the field duplicates, which indicates that spatial variability was not the reason behind these discrepancies. Losses of target analytes by volatilization during storage and preanalytical preparation were speculated to be responsible for the discrepancies observed.

3. A two-way analysis of variance suggests that the VOC data do not simply reflect uncorrelated noise but possess an underlying spatial structure. The analysis showed that the variation of VOC levels was a function of sample probe location and sample depth. In general, VOC concentrations were highest near the shallower and more central portion of the X-231B Unit, with concentrations declining toward the edges of the Unit and with depth.

4. Cross-validation exercises, wherein subsets of the January 1992 data set were used to predict the excluded data points, showed that three spatial modeling methods did not result in significantly different predictions. Lower prediction errors (difference between predicted and observed value) were obtained when samples were eliminated from given depths vs when samples were eliminated from borings. This is an indication that it is better to have more horizontally dispersed sample points (i.e., more probe locations) vs vertically dispersed points (i.e., more sample depths).

5. The three different spatial modeling methods performed equally at predicting VOC concentrations within a subregion of the site (i.e., ~10% of the modeled region). When compared to actual observations made four months after the January 1992 samples were collected, some predictions were off by as much as two orders of magnitude. These large predictions errors highlight the inherent difficulty of characterizing a subsurface soil region on the basis of a finite number of discrete samples.

6. The main advantage of using three-dimensional kriging for developing contaminant spatial models lies in the method's ability to capture uncertainty brought about by heterogeneous data sets that possess substantial short-range variability. Similar uncertainty estimates can not be obtained from deterministic spatial modeling methods.

7 Stochastic simulations using the 3-dimensional kriging model resulted in a best mass estimate of total VOCs in the north plot equal to 335 kg, with a 90% confidence interval of 229 to 488 kg, and a mass estimate in the south plot of 29 kg, with a 90% confidence interval of 16 and 76 kg.

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APPENDIX A. BORING LOGS AND CROSS-SECTIONS

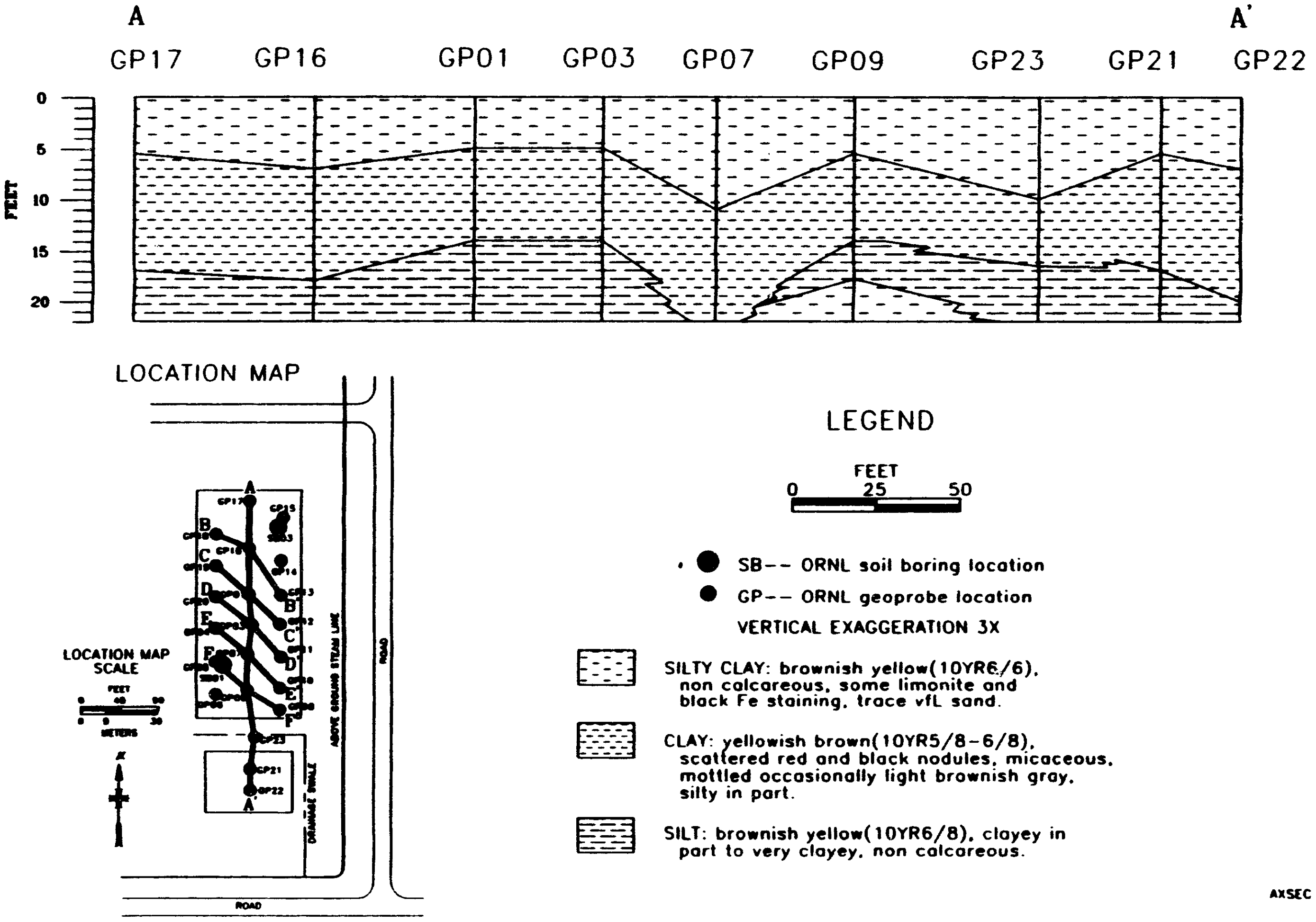


Fig. A.1 Stratigraphic profile through section A-A'.

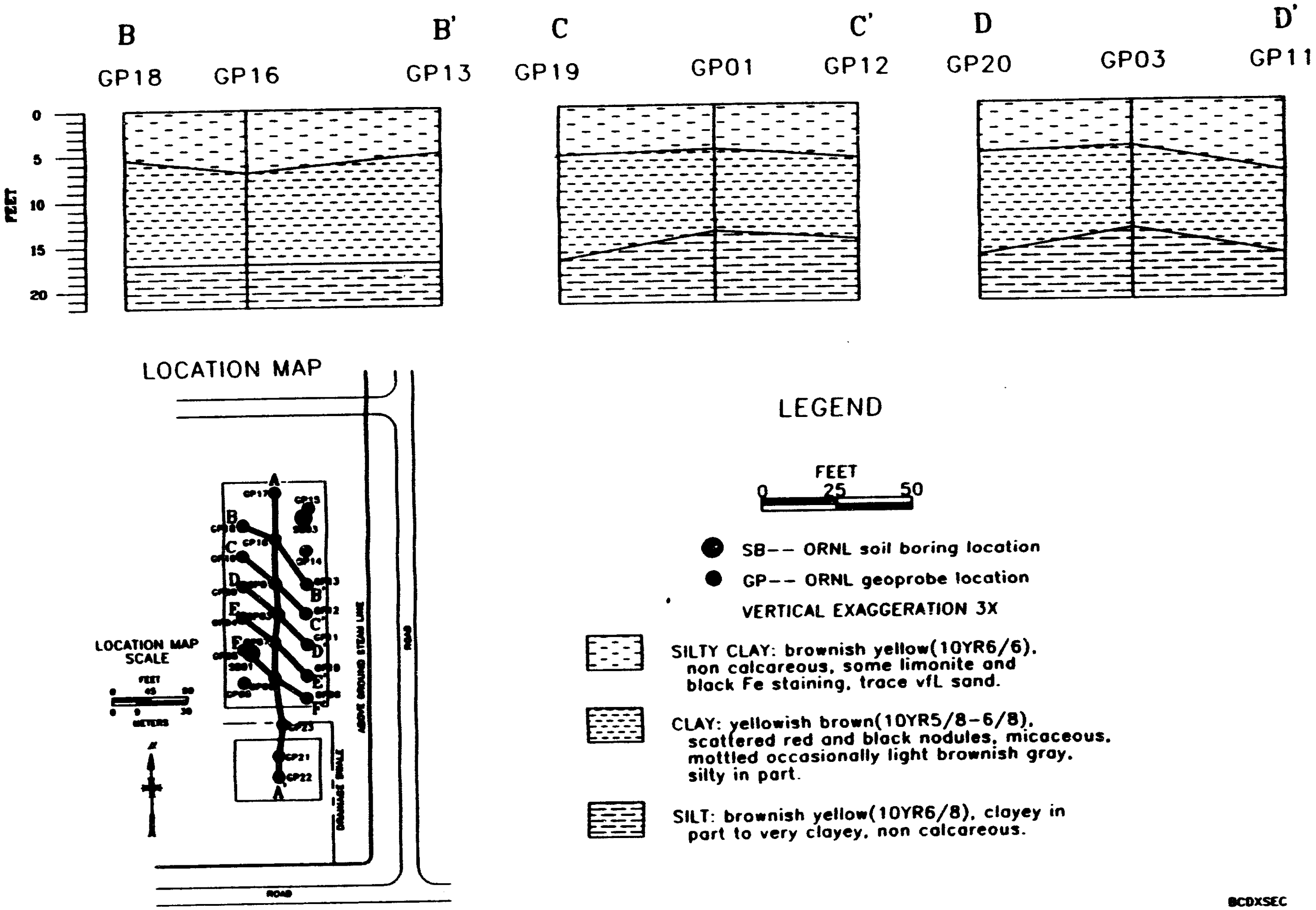


Fig. A.2 Stratigraphic profile through section B-B', C-C' and D-D'.

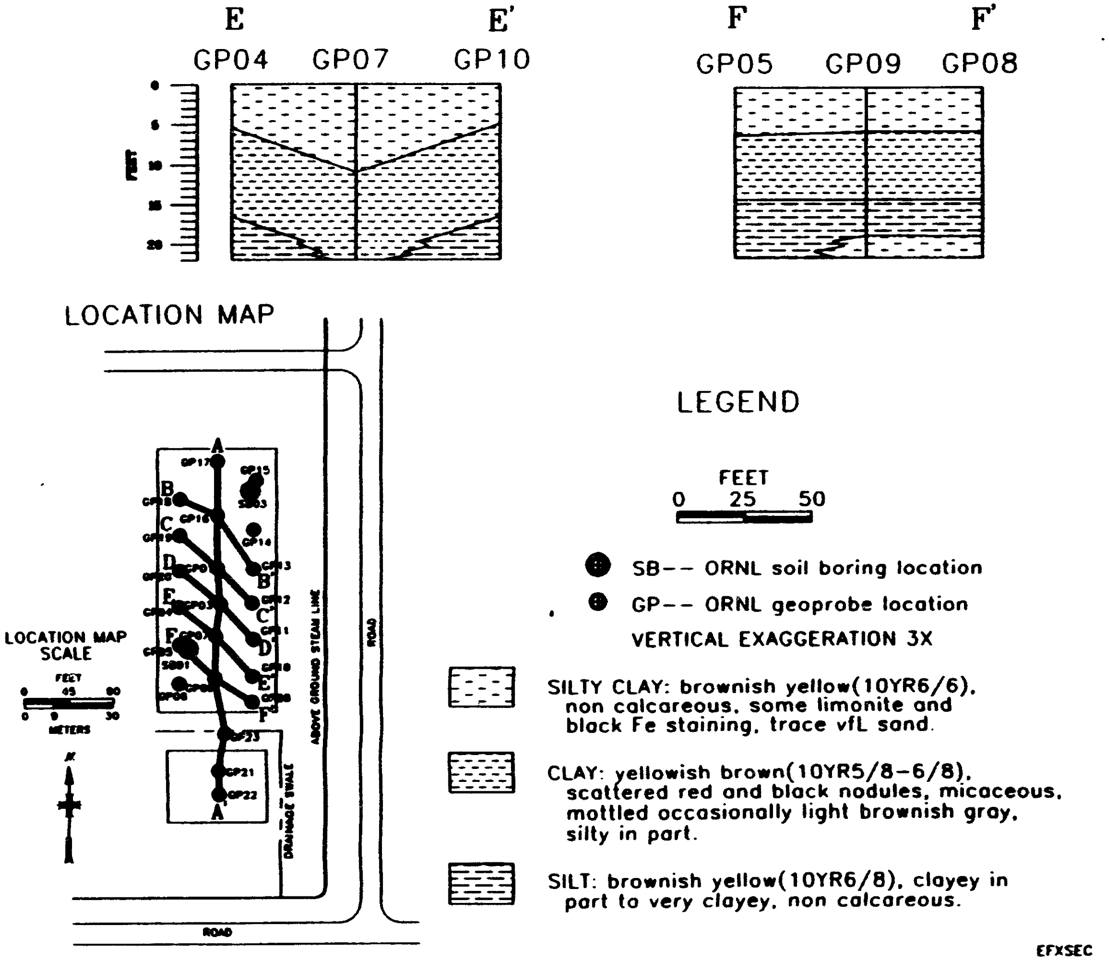


Fig. A.3 Stratigraphic profile through section E-E' and F-F'.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

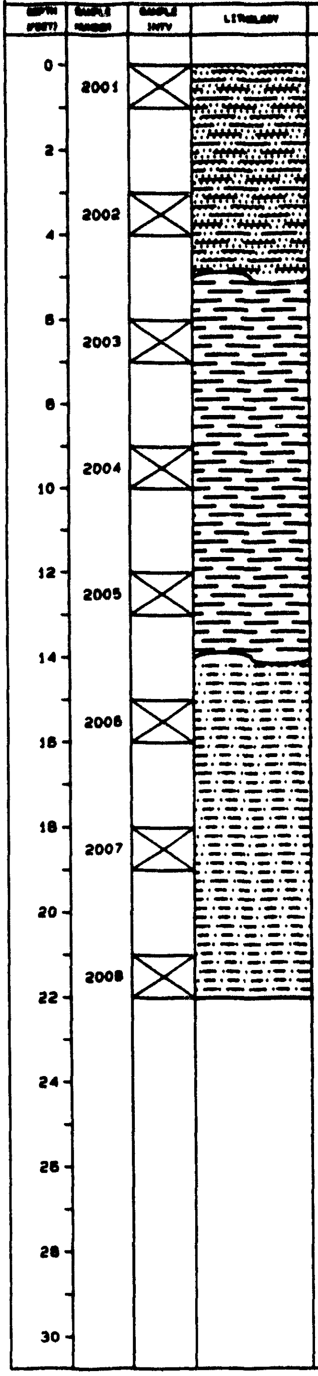
Prepared By: R.M. Schlosser Date: 01/15/92 Page: 1 OF 1

Hole No.: GP01 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-231B

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: Doug Pickering Date: 03/19/92



DESCRIPTION

SC SILTY CLAY: brownish yellow (10YR6/6), dry, compact, 10% vfU sand, subangular, non calcareous.

SC SILTY CLAY: as above, some root hairs, 1% dark minerals, non calcareous, dry.

CL CLAY: yellowish brown (10YR5/6), soft, damp, some scattered cU clear quartz sand, angular, some occasional dark accessory minerals, silty in part.

CL CLAY: color as above, mottled light brownish gray (10YR6/2) in 1-2mm beds with occasional mottling throughout, damp, some occasional common limonite staining. OVA 0ppm.

CL CLAY: yellowish brown (10YR5/6), stiff, scattered vcU common pebbles, round, micaceous, scattered dark soft organics in very thin discontinuous beds, mottled occasionally light brownish gray as above which appears to be silt, slightly calcareous, damp.

SM SILT: brownish yellow (10YR6/8), mottled yellowish brown (10YR5/8) with occasional light brown silt zones appearing in desiccation cracks, damp, some vfU sand scattered throughout.

VPS VERY POOR SAMPLE: sample appears to be silt as above, saturated.

SM SILT: brownish yellow (10YR6/8), vfL with some scattered fL, very poorly graded, predominantly clear quartz, subangular with some subrounded, <1% dark accessory minerals, slightly calcareous OVA pegged on highest scale in borehole.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: B.M. Schlosser Date: 01/15/92 Page: 1 OF 1

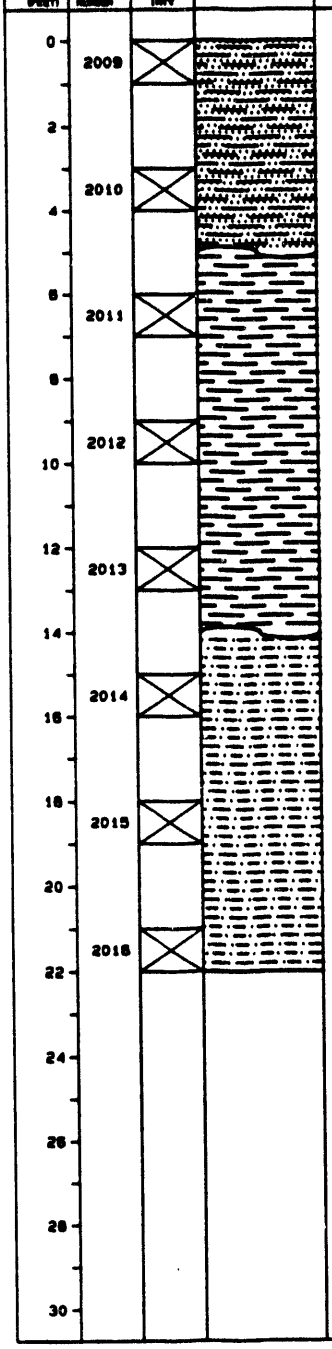
Hole No.: GP02 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-231B

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92

DEPTH (FEET) | SAMPLE NUMBER | SAMPLE INTV | LITHOLOGY | DESCRIPTION



SC SILTY CLAY: light yellowish brown to brownish yellow (10YR6/4-6/6), some scattered vfL sand, salt deposits, compact, dry, root hairs.

SC SILTY CLAY: brownish yellow (10YR6/6), 1% dark accessory minerals, non calcareous, dry.

CL CLAY: brownish yellow (10YR6/6), mottled light brownish gray (10YR2/2) abundant dark organics, tight, dry, some limonite staining, crumbly.

CL CLAY: color as above, slightly micaceous, some scattered silt.

CL CLAY: brownish yellow to yellowish brown (10YR6/8-5/8) some scattered mU sand, round, slightly calcareous.

SM SILT: brownish yellow (10YR6/8), some scattered fU-mL sand, arkosic, <1% dark accessory minerals very slightly calcareous, tight, damp.

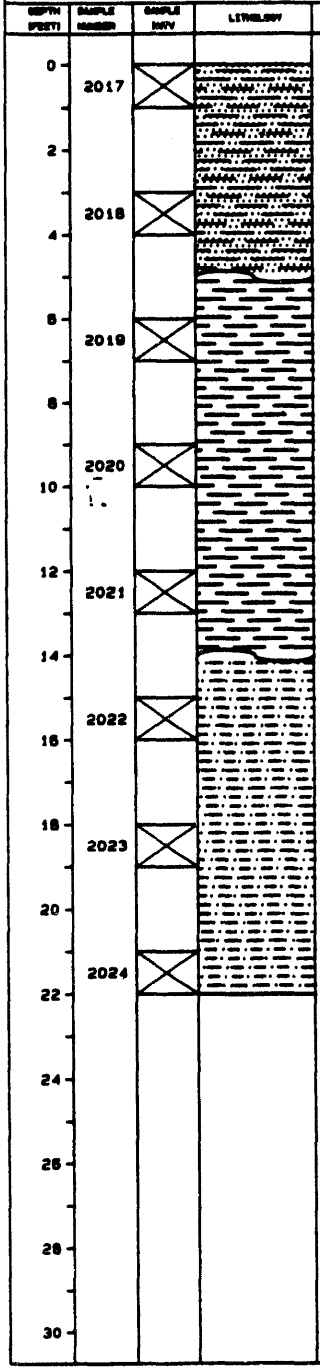
SM SILT: brownish yellow (10YR6/6-6/8), no sand, some common black Fe oxides locally, occasional mottling yellowish brown (10YR5/6), scattered micaceous content, wet.

SM SILT: VPS, silt as above, saturated.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 01/16/92 Page: 1 OF 1
Hole No.: GP03 Ground Elevation:
Total Depth: 22' Rig Type: Geoprobe Location: X-231B
Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube
Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC SILTY CLAY: brownish yellow (10YR6/6), mottled light brownish gray (10YR6/3), some scattered fU quartz sand, 5-15mm common pebbles, non calcareous, dry, tight.

SC SILTY CLAY: as above, abundant root hairs, some limonite staining, root pores, dry.

CL CLAY: yellowish brown (10YR5/6), mottled light brownish gray (10YR6/2) abundant dark organics and black Fe staining, some mottled brownish yellow (10YR6/8), plastic, tight, stiff, silty in part, HNU 190ppm in borehole.

CL CLAY: color as above, becoming silty, higher % black Fe oxides and common limonite staining, stiff, dry, HNU 160 ppm in borehole.

CL CLAY: brownish yellow to yellowish brown (10YR6/8-5/6) scattered 3-5mm pebbles, non calcareous, HNU 200 ppm in borehole.

SM SILT: color as above, some scattered clay.

SM SILT: light yellowish brown to brownish yellow (10YR6/4-6/6), some scattered mU sand, 1% dark accessory minerals, HNU 100 ppm in borehole.

SM SILT: color as above, some clay, micaceous, wet, slightly plastic, very soft, HNU 110 in borehole

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

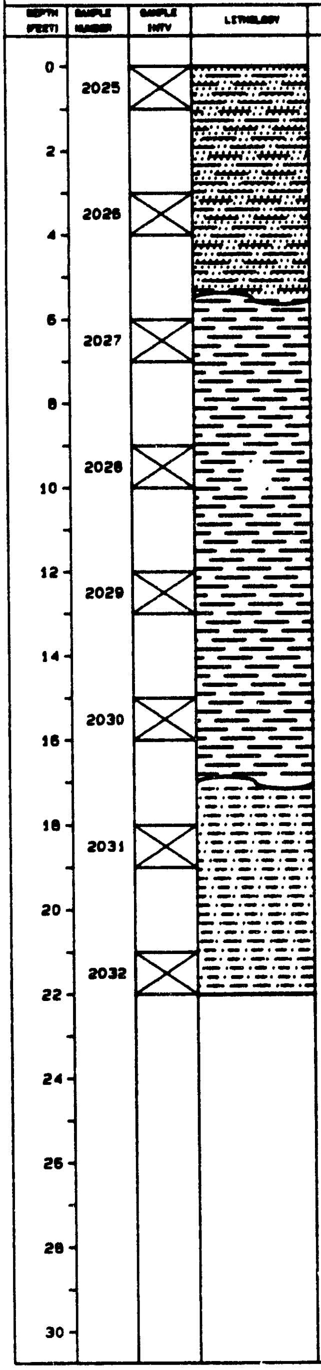
Prepared By: R.M. Schlosser Date: 01/16/92 Page: 1 OF 1

Hole No.: GP04 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-231B

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



SAMPLE NUMBER	DESCRIPTION
2025	SC **SILTY CLAY:** light yellowish brown to brownish yellow (10YR6/4-6/6) mottled light brownish gray (10YR6/2), occasional root hairs and common 2-6mm pebbles, very round, very silty
2026	SC **SILTY CLAY:** yellowish brown (10YR5/6), mottled as above throughout, abundant root hairs, some dark Fe oxides, becoming less silty. HNU 70ppm in borehole.
2027	CL **CLAY:** predominantly brownish yellow (10YR6/6), mottled light brownish gray as above, one 5mm band of brown (10YR5/3). HNU 30ppm in borehole.
2028	CL **CLAY:** as above.
2029	CL **CLAY:** yellowish brown (10YR5/6-5/8), some silt, <1% dark accessory minerals, non calcareous.
2030	CL **SILTY CLAY:** brownish yellow (10YR6/6-6/8), dry, crumbly, becoming damp.
2031	SM **SILT:** brownish yellow (10YR6/8), very little clay wet.
2032	SM **SILT:** as above, saturated.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

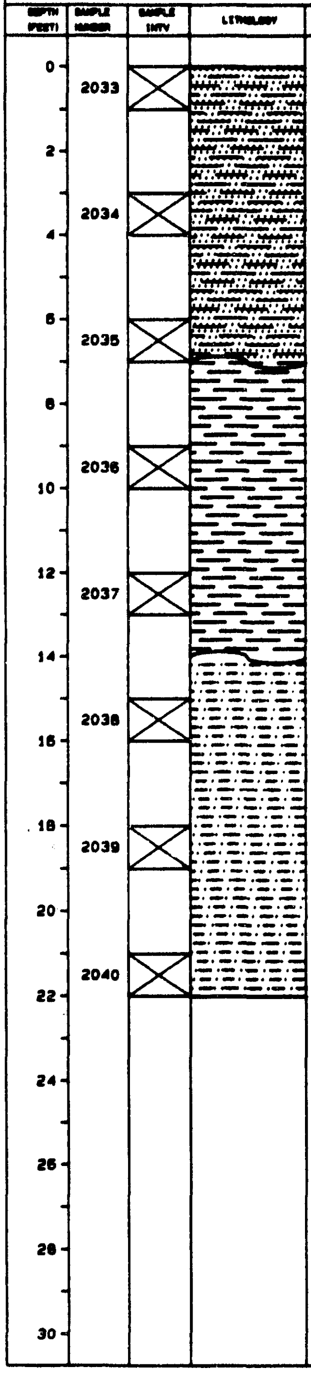
Prepared By: R.M. Schlosser Date: 01/17/92 Page: 1 OF 1

Hole No.: GP05 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-231B

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC **SILTY CLAY:** brown to brownish yellow (10YR5/2-5/4 hard, compacted, scattered 3-5mm pebbles, abundant fines, very calcareous, trace vfU clear quartz sand, HNU 30ppm in borehole.

SC **SILTY CLAY:** yellowish brown (10YR5/6-5/8), mottled light brownish gray (10YR6/2), abundant root hairs, soft, crumbly.

SC **SILTY CLAY:** color as above, <1% dark accessory minerals. HNU 40ppm in borehole.

CL **CLAY:** brownish yellow (10YR6/6-6/8), mottled light brownish gray (10YR6/2), root pores, dry, crumbly, non calcareous. HNU 50ppm in borehole.

CL **CLAY:** yellowish brown (10YR6/8), mottled light brownish gray, silty in part to very silty locally, some limonite and black Fe staining, stiff, damp.

SM **SILT:** brownish yellow (10YR6/8), mottled light brownish gray (10YR6/2), clayey and calcareous in part.

SM **SILT:** as above, scattered black Fe oxides. HNU in borehole 15ppm.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

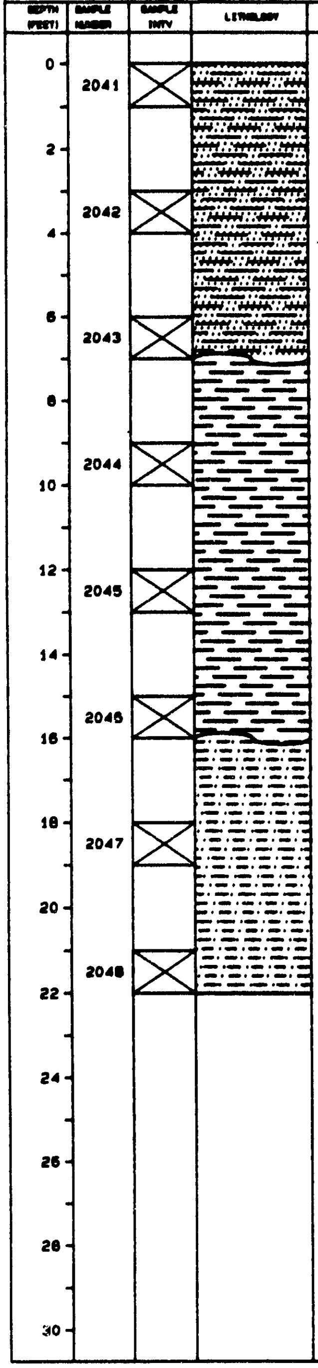
Prepared By: R.M. Schlosser Date: 01/17/92 Page: 1 OF 1

Hole No.: GP06 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-231B

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC SILTY CLAY: brownish yellow (10YR6/8) mottled light brownish gray, dry, non calcareous, some salt, dark brown mottling by Fe oxides, slightly calcareous.

SC SILTY CLAY: yellowish brown (10YR5/6-5/8), root hairs, abundant limonite staining and black Fe oxides, non calcareous. HNU 5ppm in borehole.

SC SILTY CLAY: brownish yellow (10YR6/6-6/8), some scattered 2-5mm pebbles. HNU 50ppm in borehole.

CL CLAY: yellowish brown (10YR5/8-6/8), mottled between these two colors, dry, non calcareous.

CL CLAY: as above, some scattered 3-6mm nodules, non calcareous.

SM CLAYEY SILT: brownish yellow (10YR6/8), abundant limonite staining and occasional nodules, often mottled light brownish gray (10YR6/2), moist. HNU 10ppm in borehole.

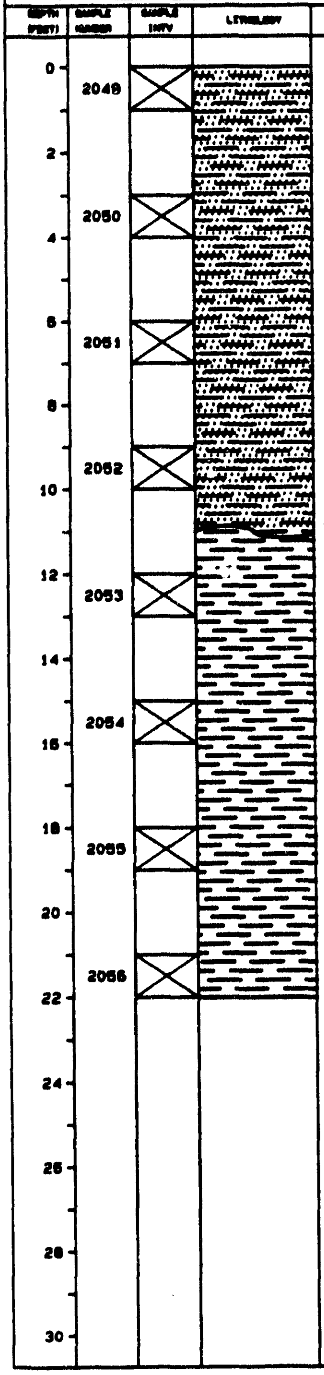
SM SILT: as above, less clayey, damp to wet.

VPS SILT: as above. HNU 70ppm.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: C.A. Muhr Date: 01/17/92 Page: 1 OF 1
Hole No.: GP07 Ground Elevation:
Total Depth: 22' Rig Type: Geoprobe Location: X-231B
Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube
Project: Portsmouth Date Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC SILTY CLAY: brownish yellow (10YR6/6), some root hairs, black Fe oxides. HNU 10ppm in borehole.

SC SILTY CLAY: yellowish brown (10YR5/6), root hairs, non calcareous. HNU 0ppm in borehole.

SC SILTY CLAY: color as above, non calcareous, limonite staining. HNU 10ppm in borehole.

SC SILTY CLAY: yellowish brown (10YR5/6-5/8), non calcareous, very har , siliceous silty layer at about 10', very pale brown (10YR7/6). HNU 10 ppm in borehole.

NO SAMPLE RECOVERY:

CL CLAY: brownish yellow (10YR6/8-5/6), very homogeneous. HNU 4ppm in borehole.

CL CLAY: brownish yellow (10YR6/8-5/6), homogeneous, HNU 2ppm in borehole.

CL CLAY: color as above, homogeneous, wet, HNU 1 prm in borehole.

ornl OAK RIDGE NATIONAL LABORATORY

Borehole Summary Information

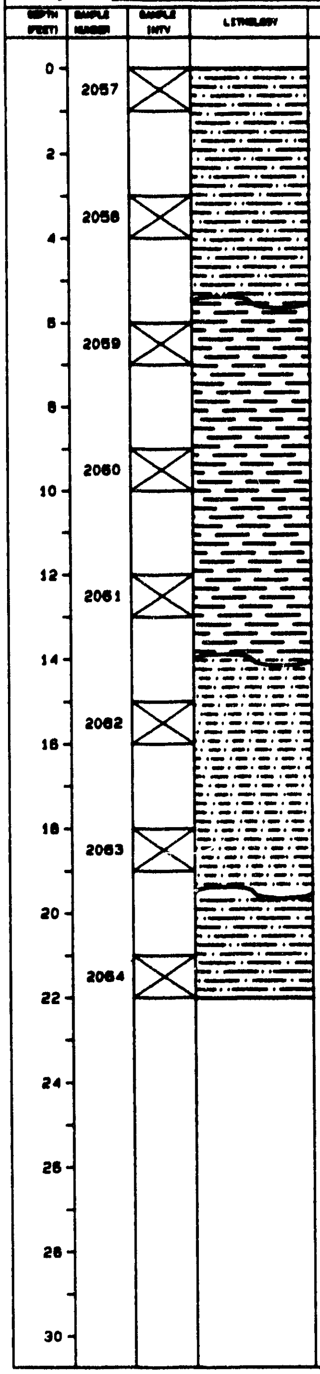
Prepared By: R.M. Schlosser Date: 01/18/92 Page: 1 OF 1

Hole No.: GP08 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-231B

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC SILTY CLAY: yellowish brown (10YR5/4-5/6), clear quartz vfL sand occasionally, root hairs, some limonite staining along root pores, some nodules. HNU 9ppm in borehole.

SC SILTY CLAY: yellowish brown (10YR5/6), mottled light brownish gray, dry to slightly moist, some black Fe oxides locally. HNU 10ppm in borehole.

CL CLAY: color as above, with occasional yellowish brown mottling (10YR5/8). HNU 10ppm in borehole.

CL CLAY: as above mottled light brownish gray (10YR) occasional nodules and black Fe oxides, silty as above, becoming less silty with depth, damp.

CL CLAY: yellowish brown (10YR5/8), mottled light brownish gray, homogeneous, silty in part, few nodules, <1% dark accessory minerals; silt size, HNU 10ppm in borehole.

SM SILT: brownish yellow (10YR6/6-6/8), clayey in part, homogeneous, no mottling.

SM SILT: as above, clayey in part to very clayey, non calcareous, wet, HNU 10ppm in borehole.

SC CLAYEY SILT: color as above, 50% clay, HNU 14ppm in borehole.

ornl OAK RIDGE NATIONAL LABORATORY

Borehole Summary Information

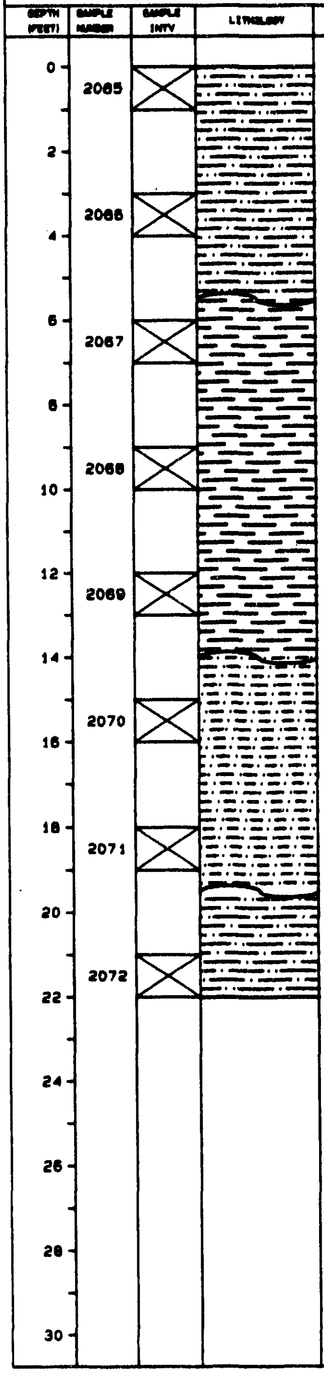
Prepared By: C.A. Muhr Date: 01/18/92 Page: 1 OF 1

Hole No.: GP09 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-2318

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC **SILTY CLAY:** brown (10YR5/3), numerous root hairs, some salt, non calcareous. HNU 170ppm in borehole.

SC **SILTY CLAY:** yellowish brown (10YR5/6), mottled brown and gray, some black Fe oxide content. HNU 120ppm in borehole.

SC **SILTY CLAY:** (10YR5/6). HNU 120ppm in borehole.

CL **CLAY:** as above mottled light brownish gray brownish yellow (10YR6/2-6/8), occasional nodules and Fe staining. HNU 40ppm in borehole.

CL **CLAY:** brownish yellow (10YR5/6), HNU 150ppm in borehole.

SM **SILTY CLAY:** yellowish brown (10YR5/6), HNU 150ppm in borehole.

SC **CLAYEY SILT:** brownish yellow (10YR6/6), wet, HNU in borehole, 220ppm.

SC **CLAYEY SILT:** clayey silt, very wet. HNU 40ppm in borehole.

ornl OAK RIDGE NATIONAL LABORATORY

Borehole Summary Information

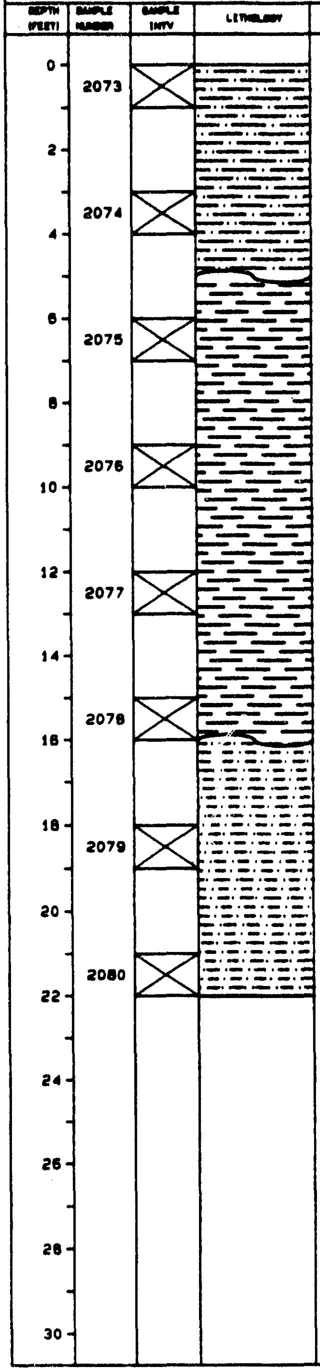
Prepared By: R.M. Schlosser Date: 01/19/92 Page: 1 OF 1

Hole No.: GP10 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-231B

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC SILTY CLAY: yellowish brown (10YR5/6), mottled light brownish gray (10YR6/2), root hairs, some nodules, limonite and black Fe oxide stains, dry crumbly. HNU 50ppm in borehole.

SC SILTY CLAY: as above, predominantly brownish yellow (10YR6/6), nodules, staining and nodules as above, trace vfL sand. HNU 120ppm in borehole

CL CLAY: brown to yellowish brown (10YR5/3-5/4) plastic, mottled light brownish gray (10YR6/2), silty in part, non calcareous to slightly calcareous. HNU 200ppm in borehole.

CL CLAY: as above mottled light brownish gray to brownish yellow (10YR6/2-6/8), occasional nodules and Fe staining. HNU 40ppm in borehole.

CL CLAY: brownish yellow (10YR6/8), occasional very hard silt zones, predominantly dry, crumbly, non calcareous. HNU 10ppm in borehole.

CL CLAY: very poor sample, very silty. HNU 5ppm in borehole.

SM SILT: brownish yellow (10YR6/8), homogeneous, <1% black accessory minerals, wet, firm, HNU 55ppm in borehole.

SM SILT: as above, HNU 60ppm in borehole.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

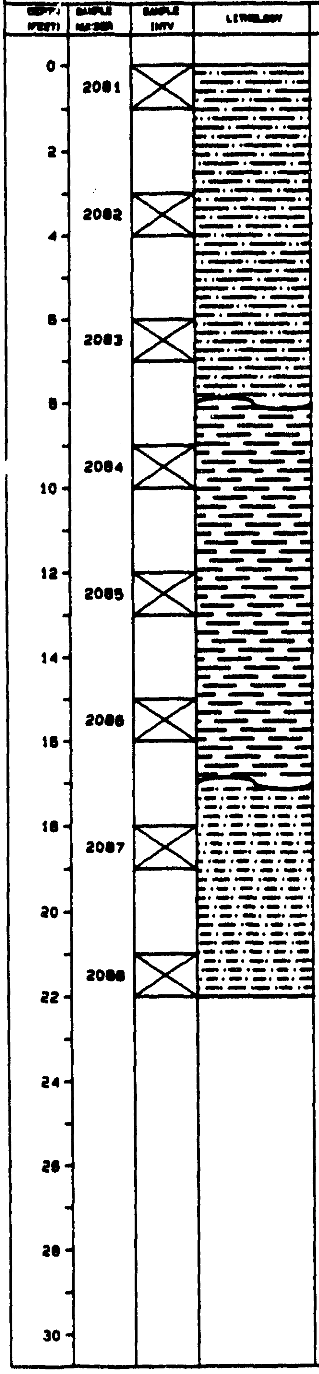
Prepared By: R.M. Schlosser Date: 01/19/92 Page: 1 OF 1

Hole No.: GP11 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-2318

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC SILTY CLAY: yellowish brown (10YR5/6-5/8), abundant root hairs, trace vfL sand, tight, compacted, non calcareous. HNU 150ppm in borehole.

SC SILTY CLAY: as above, becoming brownish yellow (10YR6/2) which is silt, some limonite and black Fe oxides, occasional nodules, tight, some root hairs. HNU 180ppm in borehole.

SC SILTY CLAY: higher percent clay, color as above with occasional mottling, slightly calcareous.

CL CLAY: brown to brownish yellow (10YR5/3-5/4), silty in part, mottled light brownish gray (10YR-6/2) and yellowish brown (10YR5/8), occasional red (2.5YR4/6) nodule, nodules moderately soft to firm. HNU 45ppm in borehole.

CL CLAY: brownish yellow (10YR6/6), mottled as above with black and red nodules, firm, some dark accessory minerals, slightly to very calcareous.

CL CLAY: very poor sample, very silty, HNU 5ppm in borehole.

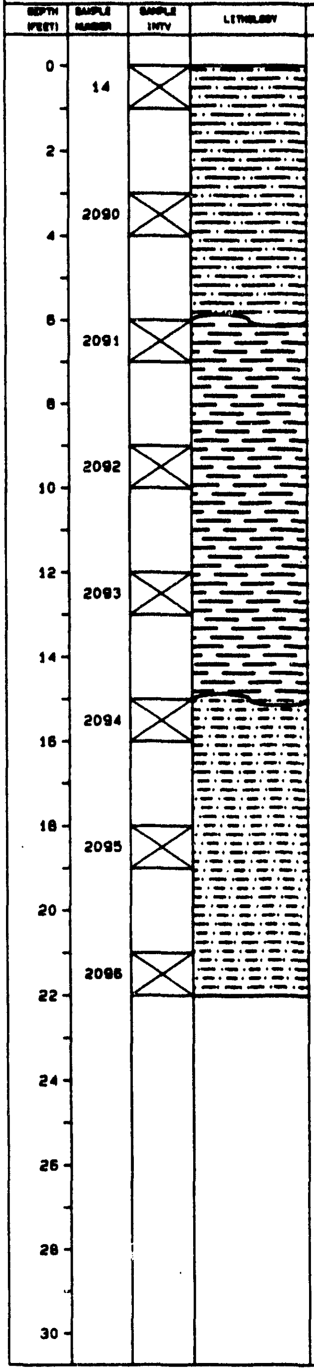
SM SILT: brownish yellow (10YR6/8), abundant moderately hard nodules, reddish brown, occasional clay. HNU 155ppm in borehole.

SM SILT: as above, some brown clay. HNU 60ppm in borehole.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 01/20/92 Page: 1 OF 1
Hole No.: GP12 Ground Elevation:
Total Depth: 16' Rig Type: Geoprobe Location: X-231B
Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube
Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC **SILTY CLAY:** yellowish brown (10YR5/4), dry, crumbly, trace vfL sand, compact. HNU 40ppm in borehole.

SC **SILTY CLAY:** as above, becoming brownish yellow (10YR6/6), <1% dark accessory minerals, some black Fe oxides and trace limonite staining, root hairs. HNU 40ppm in borehole.

CL **CLAY:** color as above, silty in part to very silty, moist, slightly plastic, sticky. HNU 10ppm in borehole.

CL **CLAY:** as above, more silty, mottled light brownish gray (10YR6/2) which is silt, slightly calcareous. HNU 12ppm in borehole.

CL **CLAY:** brownish yellow (10YR6/6-6/8), mottled strong brown (7.5YR5/6), mottled with silt, light brownish gray (10YR6/4), abundant red and black nodules. HNU 15ppm in borehole.

SM **SILT:** very clayey, predominantly brownish yellow (10YR6/5). HNU 20ppm in borehole.

SM **SILT:** as above, homogeneous. HNU 60ppm in borehole.

SM **SILT:** as above.

ornl OAK RIDGE NATIONAL LABORATORY

Borehole Summary Information

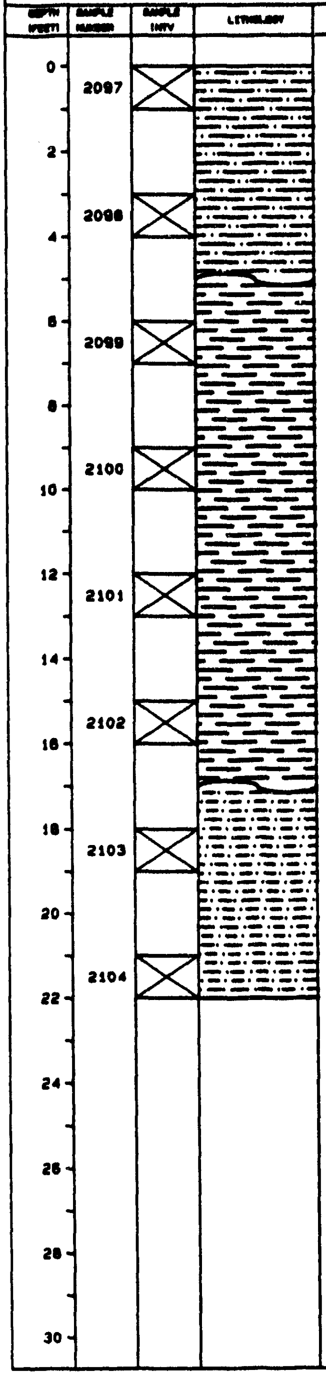
Prepared By: R.M. Schlosser Date: 01/20/92 Page: 1 OF 1

Hole No.: GP13 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-231B

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC SILTY CLAY: yellowish brown (10YR5/4), dry, compacted.

SC SILTY CLAY: yellowish brown (10YR5/6) mottled light brownish gray (10YR6/2-6/3). HNU 130ppm in borehole.

CL CLAY: yellowish brown (10YR5/6-5/8), silty in part to very silty, occasional nodules and black staining, dry.

CL CLAY: as above, less silty.

CL CLAY: as above, mottled very pale brown (10YR7/3), tight, moist. HNU 130ppm in borehole.

CL CLAY: becoming silty, abundant nodules.

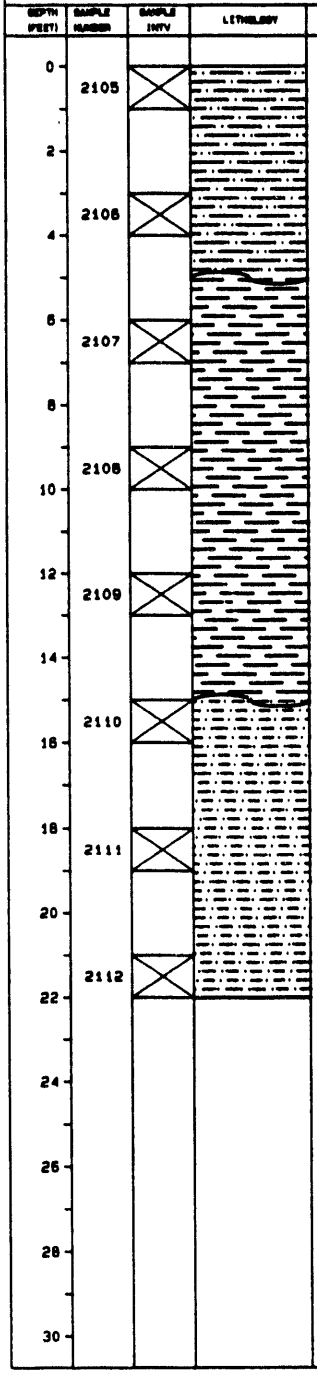
SM SILT: yellowish brown, homogeneous.

SM SILT: as above, homogeneous, wet.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 01/21/92 Page: 1 OF 1
Hole No.: GP14 Ground Elevation:
Total Depth: 22' Rig Type: Geoprobe Location: X-231B
Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube
Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC SILTY CLAY: brown to yellowish brown (10YR5/3-4) abundant pebbles and nodules, limonite and black Fe oxide staining. HNU 250ppm in sample bag.

SC SILTY CLAY: yellowish brown (10YR5/6-8) mottled light brownish gray (10YR6/2), root hairs, limonite staining, scattered nodules, crumbly. HNU 300ppm in sample bag.

CL CLAY: yellowish brown (10YR5/6), mottled as above slightly cohesive, silty in part, non calcareous to slightly calcareous. HNU 200ppm in sample bag

NO SAMPLE: hit vug.

CL CLAY: yelluwish brown (10YR5/6) and light brownish gray (10YR6/2), crumbly, occasional nodule. HNU 2ppm in sample bag.

SM SILT: yellowish brown (10YR5/8), clayey in part, mottled vericaliy along desiccation cracks light brownish gray (10YR6/2), 1-2mm red and black nodules, some limonite staining. HNU 5ppm in sample bag.

SM SILT: very little clay, <1% dark accessory minerals. HNU 10ppm in sample bag.

SM SILT: as above, homogeneous, wet. HNU 50ppm in sample bag.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

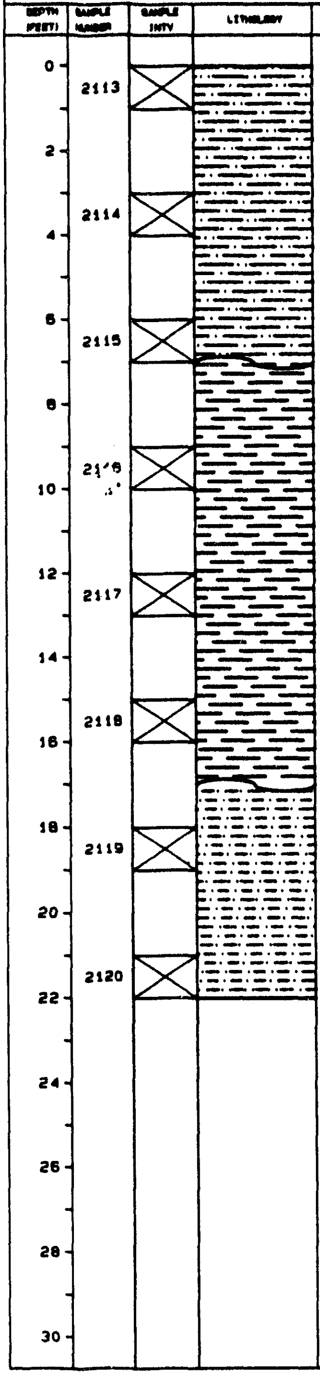
Prepared By: R.M. Schlosser Date: 01/21/92 Page: 1 OF 1

Hole No.: GP15 Ground Elevation:

Total Depth: 22' Rig Type: Geoprobe Location: X-231B

Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube

Project: Portsmouth Data Verified By: D.A. Pickering Date:



DESCRIPTION

SC **SILTY CLAY:** light yellowish brown to brownish yellow (10YR6/4-6), abundant black Fe oxide staining, root hairs, crumbly, dry. HNU 30ppm in sample bag.

SC **SILTY CLAY:** as above, high % fines, dry. HNU 4ppm in sample bag.

SC **SILTY CLAY:** as above.

CL **CLAY:** predominantly yellowish brown (10YR5/8), mottled light gray and brownish yellow, very slightly calcareous, tight, HNU 70ppm in sample bag.

CL **CLAY:** yellowish brown (10YR5/6-8) and light brownish gray (10YR6/2), cohesive, damp, homogeneous, tight, HNU 80ppm in sample bag.

CL **CLAY:** as above, higher % silt, wet HNU, 60ppm in sample bag.

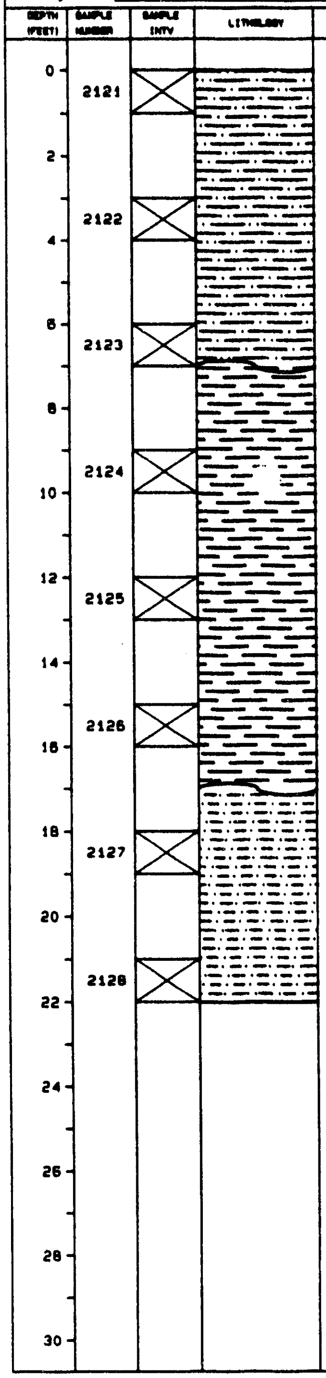
SM **SILT:** yellowish brown (10YR5/6), trace clay, micaceous, trace vfL clear quartz sand, angular, HNU 20ppm in sample bag.

SM **SILT:** as above, very well consolidated, trace clay, HNU 2ppm in sample bag.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 01/21/92 Page: 1 OF 1
Hole No.: GP16 Ground Elevation:
Total Depth: 22' Rig Type: Geoprobe Location: X-231B
Auger Size: 1" drive tube Sample Type: 1"x1' Shelby tube
Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

SC **SILTY CLAY:** brown to brownish yellow (10YR5/3-4), dry, compacted, crumbly. HNU 20ppm in sample bag.

SC **SILTY CLAY:** yellowish brown (10YR/5/6-8), mottled occasionally light brownish gray to pale brown (10YR6/2-3), occasional black Fe oxide staining, occasional nodule, HNU 3ppm in sample bag.

SC **SILTY CLAY:** as above, higher % clay, cohesive, abundant light brownish gray mottling in desiccation cracks. HNU 2ppm in sample bag.

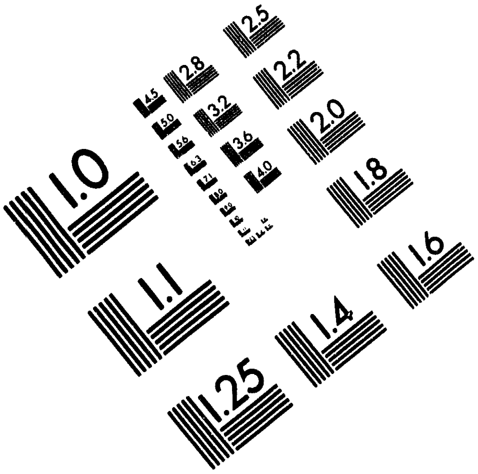
NO SAMPLE:

CL **CLAY:** intermittent beds of yellowish brown (10YR6/6) and very pale brown (10YR7/3-6/3), very plastic, moist, yellow brown moist but not as plastic, occasional black Fe oxides and nodules. HNU in sample bag, 5ppm.

CL **CLAY:** as above, silty in part, no bedding as above, just yellow brown mottled light brownish gray.

SM **SILT:** brownish gray (10YR6/8), occasional clay, some nodules, occasional black Fe oxide staining, wet.

SM **SILT:** as above, saturated.



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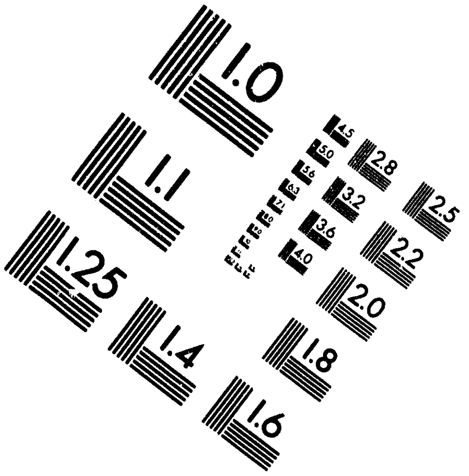

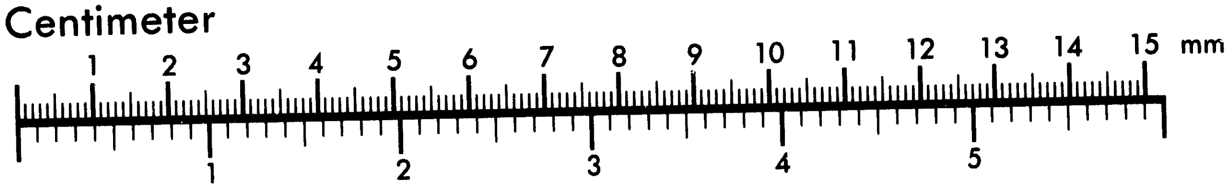

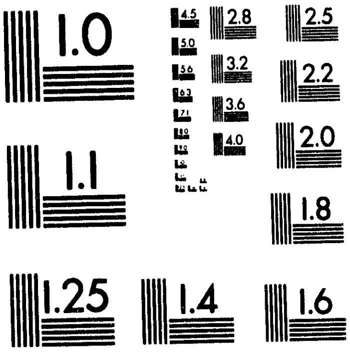

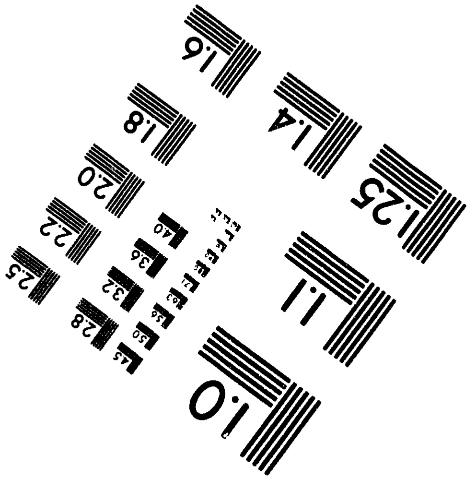

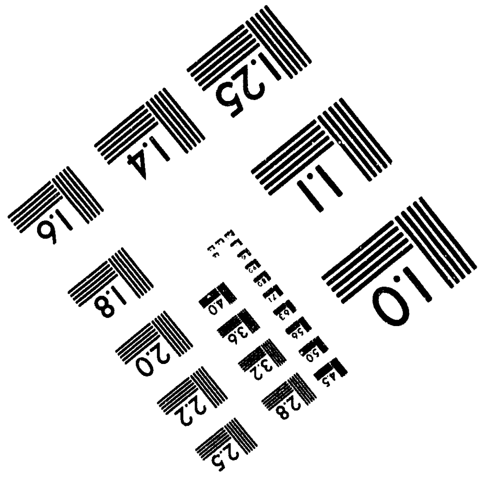

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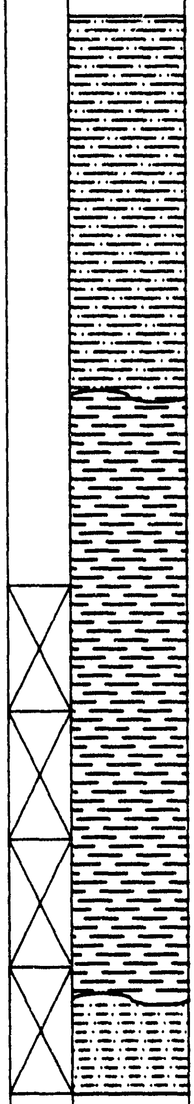
Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 01/21/92 Page: 1 OF 1
Hole No.: SB08 Ground Elevation:
Total Depth: 17' Rig Type: Acker AD-2 Location: X-231B
Auger Size: 11 5/8" O.D. Sample Type: 8"x2' Shelby tube "Calif. method"
Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92

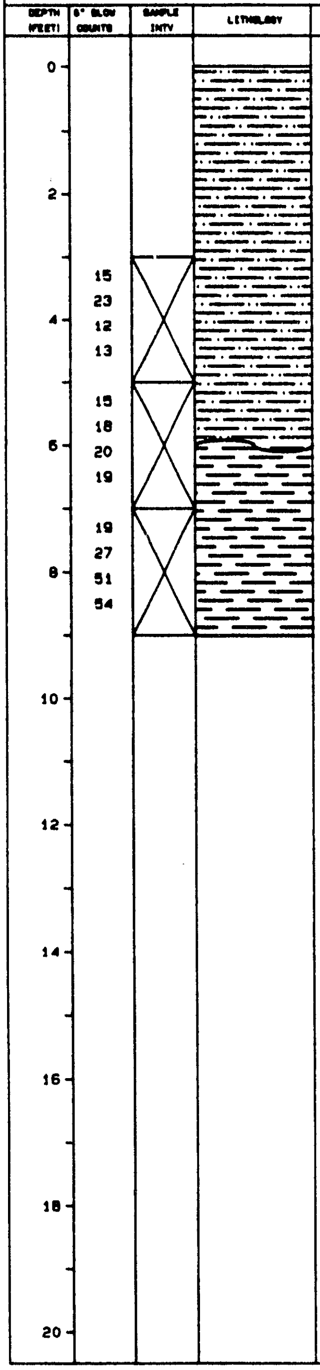


DEPTH (FEET)	6" BLOW COUNTS	SAMPLE INTV	LITHOLOGY	DESCRIPTION
0				
2				
				AUGER TO 9'
4				**SC SILTY CLAY:** logged from cuttings, higher clay content with depth, scattered large nodules.
6				
8				
	5			
	10			
10	33			**CL CLAY:** yellowish brown mottled light brownish gray (10YR6/2), black and reddish brown limonite staining. Stainless steel sleeve.
	50			
	47			
	35			
12	117			**CL CLAY:** as above. Stainless steel sleeve.
	100			
	PUSH			
	31			
14	42			**CL CLAY:** as above, some nodules of concreted vfL clear quartz sand, subangular to subround, very poorly graded. Acrylic glass sleeve.
	50			
	14			
	19			
16	18			
	24			**SM SILT:** clayey in part. Stainless steel sleeve.
18				
20				

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 01/22/92 Page: 1 OF 1
Hole No.: S809 Ground Elevation:
Total Depth: 9' Rig Type: Acker AD-2 Location: X-2318
Auger Size: 11 5/8" O.D. Sample Type: 8"x2' Shelby tube "Calif. method" SS sleeve
Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

AUGER TO 3'

SC SILTY CLAY: logged from cuttings, yellow brown crumbly.

SC SILTY CLAY: as above, 80% recovery, sample very loose.

SC SILTY CLAY: yellow brown, crumbly.

CLAY: color as above, silty in part.

ornl OAK RIDGE NATIONAL LABORATORY

Borehole Summary Information

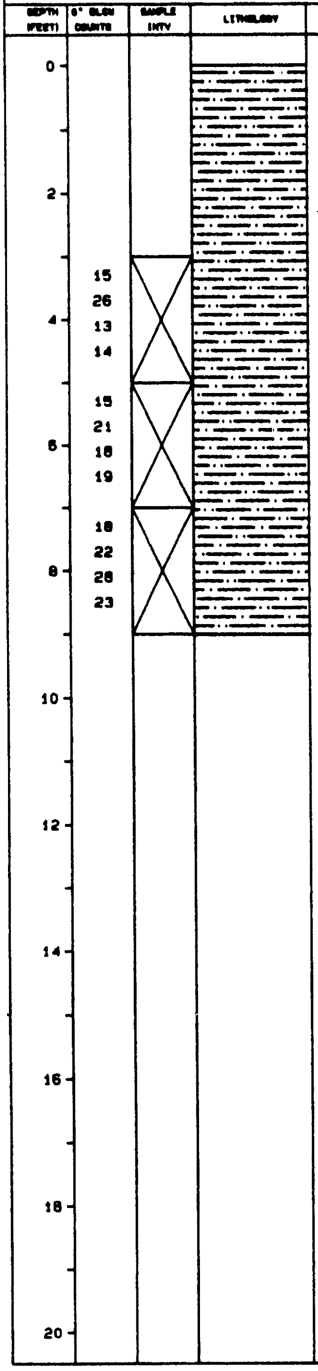
Prepared By: R.M. Schlosser Date: 01/22/92 Page: 1 OF 1

Hole No.: SB10 Ground Elevation:

Total Depth: 9' Rig Type: Acker AD-2 Location: X-231B

Auger Size: 11 5/8" I.D. Sample Type: 8"x2' Shelby tube "Calif. method" SS sleeve

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

AUGER TO 3'

SC SILTY CLAY: logged from cuttings, yellow brown crumbly.

SC SILTY CLAY: as above, mottled light brownish gray (10YR6/2).

SC SILTY CLAY: as above, appears altered to brownish gray at 6'.

SC SILTY CLAY: as above, higher clay content.

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

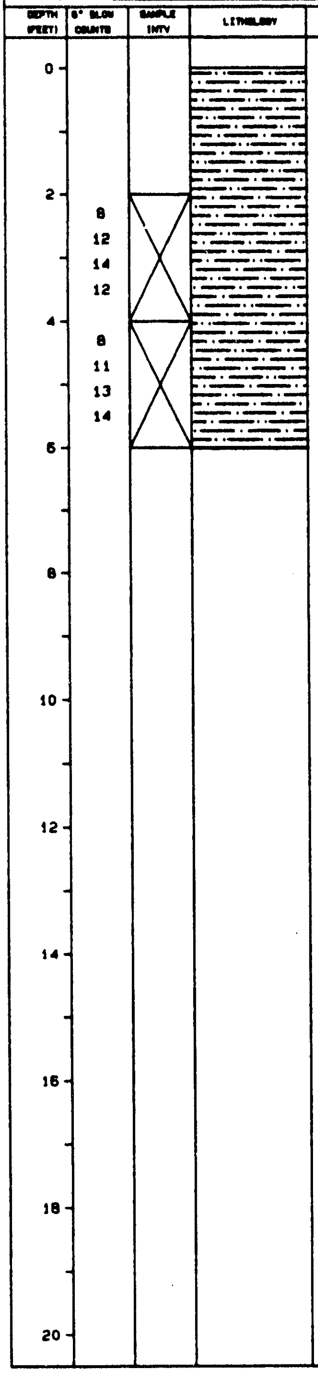
Prepared By: R.M. Schlosser Date: 01/22/92 Page: 1 OF 1

Hole No.: SB11 Ground Elevation:

Total Depth: 6' Rig Type: Acker AD-2 Location: X-2318

Auger Size: 4.25" I.D. Sample Type: 3"x2' Splitspoon "Calif. method" SS sleeves

Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

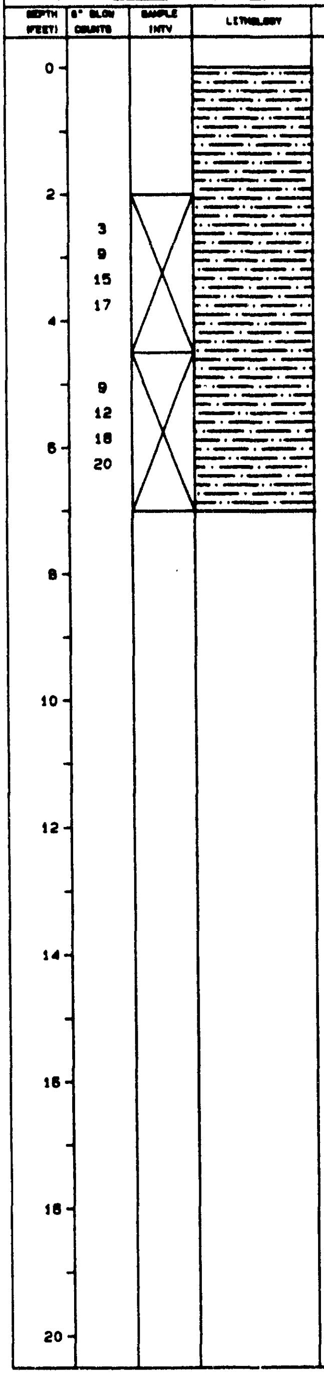
AUGER TO 2'

SC SILTY CLAY: yellowish brown (10YR6/8), mottled light brownish gray (10YR6/2).

Borehole Summary Information

ornl OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 01/23/92 Page: 1 OF 1
Hole No.: SB12 Ground Elevation:
Total Depth: 7' Rig Type: Acker AD-2 Location: X-231B
Auger Size: 4.25" I.D. Sample Type: 3"x2' Splitspoon "Calif. method" SS sleeves
Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

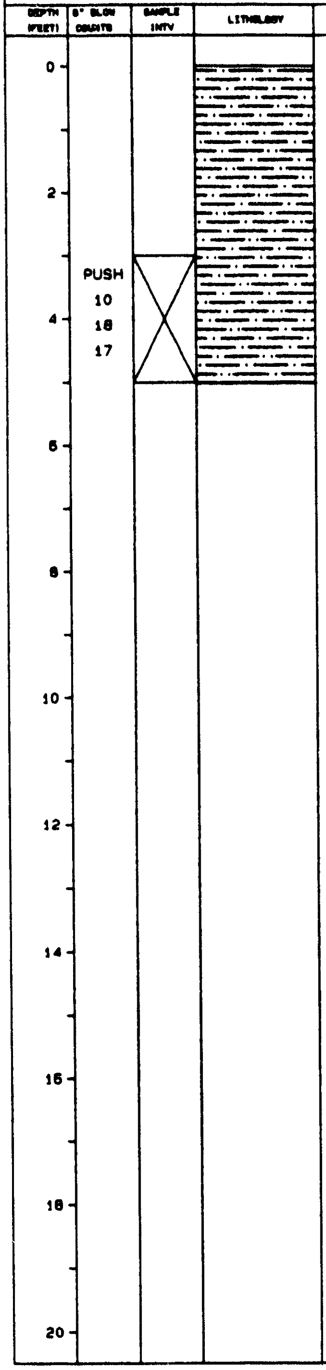
AUGER TO 2'
Drive sampler to 4.5' for recovery.

SC SILTY CLAY: yellowish brown (10YR6/8), silty in part to very silty.

Borehole Summary Information

orn1 OAK RIDGE NATIONAL LABORATORY

Prepared By: R.M. Schlosser Date: 01/23/92 Page: 1 OF 1
Hole No.: SB13 Ground Elevation:
Total Depth: 5' Rig Type: Acker AD-2 Location: X-231B
Auger Size: 11 5/8" O.D. Sample Type: 8"x2' Shelby tube "Calif. method"
Project: Portsmouth Data Verified By: D.A. Pickering Date: 03/19/92



DESCRIPTION

AUGER TO 5'

SC SILTY CLAY: logged from cuttings, yellowish brown (10YR6/8), silty in part to very silty, occasionally mottled light brown.

SC SILTY CLAY: as above, drove Acrylic glass sleeve which was recovered broken, no sample taken.

APPENDIX B. RESULTS OF ON-SITE VOC ANALYSES IN JANUARY 1992

Table B.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in January 1992.

Probe and sample no.		TCE (ug/kg)	1,1,1-TCA (ug/kg)	MC (ug/kg)	1,1-DCE (ug/kg)	1,1-DCA (ug/kg)	1,2-DCE (ug/kg)	Summation of VOCs (ug/kg)
GP01	2001	6500	1400	3700	11	110	576	12297
	2002	25000	4400	73000	110	280	1260	104050
	2003	8700	830	1000	6.6	72	20	10629
	2004	14000	120	540	22	57	114	14853
	2005	6600	93	100	31	68	136	7028
	2006	760	55	330	7.9	6.1	58	1217
	2007	650	22	57	24	15	10	778
	2008	40	3.8	9.8	6.3	1.2	2	63
GP02	2009	370	130	1000	11	58	37	1606
	2010	1200	380	36000	9.6	77	19	37686
	2011	150	54	340	56	29	164	793
	2012	110	10	130	1.3	5.3	22	279
	2013	95	17	390	8700	13	243	9458
	2014	23	13	340	66	5.0	3	450
	2015	340	3.1	180	1800	1.6	74	2399
	2016	910	22	1800	800	4	48	3584
GP03	2017	39000	630	28000	27	67	134	67858
	2018	77000	1200	76000	27	210	134	154571
	2019	17000	700	6300	30	230	142	24402
	2020	2700	95	1400	25	62	124	4406
	2021	190	61	320	20	49	98	738
	2022	160	85	360	24	61	122	812
	2023	120	49	61	8.5	8.5	17	264
	2024	200	120	560	4.3	37	22	943
GP04	2025	160	310	1500	21	130	106	2227
	2026	280	350	200	25	63	126	1044
	2027	890	530	130	360	38	14	1962
	2028	590	320	140	570	15	13	1648
	2029	240	120	53	790	5.9	29	1238
	2030	300	200	68	520	6.3	23	1117
	2031	430	350	160	470	16	33	1459
	2032	170	140	70	180	5.7	19	585

Table B.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in January 1992. (continued)

Probe and sample no.		TCE (ug/kg)	1,1,1-TCA (ug/kg)	MC (ug/kg)	1,1-DCE (ug/kg)	1,1-DCA (ug/kg)	1,2-DCE (ug/kg)	Summation of VOCs (ug/kg)
GP05	2033	140	62	8400	540	1.6	17	9161
	2034	50	9.9	120	420	18	44	662
	2035	120	13	46	510	7	14	710
	2036	350	17	8.1	370	4.8	52	802
	2037	380	19	14	360	5.1	11	789
	2038	1000	16	420	1.6	4.4	7	1449
	2039	730	82	35	250	5.2	185	1287
	2040	510	74	30	220	4.8	413	1252
GP06	2041	20	39	160	240	24	10	493
	2042	46	48	270	110	23	29	526
	2043	54	11	38	300	5.8	53	462
	2044	750	170	410	130	5.3	125	1590
	2045	370	90	70	320	5	43	898
	2046	530	160	160	240	4.7	49	1144
	2047	1400	160	1100	220	12	232	3124
	2048	1000	330	1900	6.7	33	101	3371
GP07	2049	320	250	180	210	5.5	14021	14987
	2050	1200	830	430	19	67	3	2549
	2051	960	820	360	150	78	30	2398
	2052	740	890	320	300	47	104	2401
	2054	120	610	170	380	9.4	93	1382
	2055	28	610	250	350	15	111	1364
	2056	87	330	250	280	8.3	39	994
GP08	2057	9.4	7.8	34	300	12	24	387
	2058	9.4	15	77	78	5.6	25	210
	2059	3.3	3.6	12	79	4.9	10	113
	2060	3.7	2.1	9.8	220	0.93	12	249
	2061	0.32	0.45	4.9	0.79	0.79	2	9
	2062	5.1	2.6	6.6	400	0.95	15	430
	2063	20	2.8	3.5	1900	3.5	134	2064
	2064	16	3.3	2.5	290	3.8	7	323

Table B.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in January 1992. (continued)

Probe and sample no.		TCE (ug/kg)	1,1,1-TCA (ug/kg)	MC (ug/kg)	1,1-DCE (ug/kg)	1,1-DCA (ug/kg)	1,2-DCE (ug/kg)	Summation of VOCs (ug/kg)
GP09	2065	670	290	2100	31	29	13	3133
	2066	260	160	150	330	38	17	955
	2067	210	180	170	180	34	22	796
	2068	110	110	110	170	15	25	540
	2069	11	5.7	14	140	6.8	14	192
	2070	13	15	9.3	170	2.1	35	244
	2071	99	61	49	160	5.2	34	408
	2072	27	21	22	79	1.7	25	176
GP10	2073	1000	330	7000	3.7	59	21	8414
	2074	380	120	340	1.9	31	22	895
	2075	510	51	61	1.9	17	20	661
	2076	620	150	180	1.8	28	46	1026
	2077	520	150	84	3.2	16	35	808
	2078	68	37	8.9	8.9	22	44	189
	2079	800	230	1200	2.9	28	85	2346
	2080	700	200	410	2.7	16	8	1337
GP11	2081	1800	400	4900	2.2	48	116	7266
	2082	2400	680	110	5.2	23	97	3315
	2083	3500	280	200	4.2	21	28	4033
	2084	3400	15	32	9300	10	9	12766
	2085	8600	20	250	500	9.1	18	9397
	2086	1400	9.8	21	670	13	41	2155
	2087	710	6.9	11	76	11	22	837
	2088	450	41	20	940	4.6	60	1516
GP12	2089	610	230	560	2.2	50	11	1463
	2090	800	400	590	5.2	75	62	1932
	2091	1600	460	1600	4	80	490	4234
	2092	620	160	550	4.3	58	36	1428
	2093	170	61	120	4.3	11	22	388
	2094	1000	130	160	3.9	26	20	1340
	2095	920	70	110	1.5	19	127	1248
	2096	580	94	380	3.4	9.7	10	1077

Table B.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in January 1992. (continued)

Probe and sample no.		TCE (ug/kg)	1,1,1-TCA (ug/kg)	MC (ug/kg)	1,1-DCE (ug/kg)	1,1-DCA (ug/kg)	1,2-DCE (ug/kg)	Summation of VOCs (ug/kg)
GP13	2097	10000	2400	3200	3.6	30	1609	17243
	2098	5100	820	15000	4.5	18	151	21094
	2099	20000	2700	660	60	10	18	23448
	2100	7200	130	1000	150	51	437	8968
	2101	5700	60	360	26	20	520	6686
	2102	4500	38	38	330	25	50	4981
	2103	370	28	25	430	25	50	928
	2104	330	26	23	390	23	46	838
GP14	2105	5200	630	1500	4.8	50	312	7697
	2106	19000	4200	40000	4.7	47	762	64014
	2107	2500	590	4000	3.8	32	250	7376
	2109	25	17	31	3.4	8.5	17	102
	2110	220	120	110	3.7	9.2	18	481
	2111	520	14	140	2.4	5.9	116	798
	2112	2600	160	2600	5.5	11	1414	6791
GP15	2113	370	210	750	2.5	11	21	1365
	2114	430	250	380	50	18	26	1154
	2115	1100	370	1200	71	24	94	2859
	2116	1000	240	6100	460	15	1405	9220
	2117	2300	410	7700	92	15	3606	14123
	2118	2100	350	8800	550	23	7808	19631
	2119	1900	540	3000	25	85	1414	6964
	2120	280	100	220	94	28	35	757
GP16	2121	2000	1100	32000	98	130	763	36091
	2122	13	74	57	8.3	7.2	14	174
	2123	39	410	170	12	31	62	724
	2125	11	5.6	4.3	29	1.6	3	55
	2126	33	24	8.6	52	2	4	124
	2127	28	28	12	140	3.7	4	216
	2128	400	510	810	3.9	63	20	1807
GP17	2129	1800	500	7.7	1	2.5	1003	3314
	2130	35	42	20	8.6	2.1	18	126
	2131	76	19	30	0.86	3.8	8	138
	2132	52	2.3	15	9.2	2.1	4	85
	2133	21	1.6	22	8.0	1.5	3.0	57
	2134	8.9	2.3	14	11	2.4	5	44
	2135	13	3.5	140	18	1.7	4	180

Table B.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in January 1992. (continued)

Probe and sample no.		TCE (ug/kg)	1,1,1-TCA (ug/kg)	MC (ug/kg)	1,1-DCE (ug/kg)	1,1-DCA (ug/kg)	1,2-DCE (ug/kg)	Summation of VOCs (ug/kg)
GP18	2137	67	130	27	7.8	8.3	5	245
	2138	6100	3500	850	6.2	21	1203	11680
	2139	1200	550	1100	4.7	21	872	3748
	2140	640	170	99	4.7	12	342	1268
	2141	1200	110	210	5.8	16	30	1572
	2142	32	25	26	4.9	12	24	124
	2143	800	200	510	4	33	54	1601
	2144	840	330	510	4.8	62	342	2089
GP19	2145	23	180	31	6.7	26	34	301
	2146	360	320	42	6.5	36	32	797
	2147	1700	450	400	5.4	18	39	2612
	2148	1000	190	280	5.1	25	38	1538
	2149	130	22	48	4.8	12	24	241
	2150	88	49	86	1200	2.7	5	1431
	2151	290	85	100	1500	2.3	10	1987
	2152	400	120	140	2100	10	13	2783
GP20	2153	3400	900	3400	8.3	55	42	7805
	2154	1400	370	150	5.5	30	29	1985
	2155	900	200	5200	1	15	44	6360
	2156	630	54	94	2.1	17	11	808
	2157	54	14	10	2.2	3.0	11	94
	2158	330	51	52	1	4.0	5	443
	2159	290	28	17	1	12	303	651
	2160	490	130	290	5.6	9.2	15	940
GP21	2161	2.8	44	10	3.6	17	263	340
	2162	250	160	190	1	14	29	644
	2163	390	170	380	1.3	16	47	1004
	2165	140	140	570	1	12	36	899
	2166	94	120	110	1	6.7	29	361
	2167	630	160	2200	2.4	14	95	3101
	2168	190	770	580	9.1	10	87	1646

Table B.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in January 1992. (continued)

Probe and sample no.		TCE (ug/kg)	1,1,1-TCA (ug/kg)	MC (ug/kg)	1,1-DCE (ug/kg)	1,1-DCA (ug/kg)	1,2-DCE (ug/kg)	Summation of VOCs (ug/kg)
GP22	2169	7.6	3.7	38	7900	2.6	34	7986
	2170	3.1	8.9	7.7	970	7.1	13	1010
	2171	330	170	61	1300	13	8	1882
	2172	150	23	130	430	21	19	773
	2173	2.7	23	40	51	6.5	10	133
	2174	4.7	58	81	360	6.7	6	516
	2175	16	4.8	2.1	4300	2.1	4	4329
	2176	1.8	4.8	16	670	4.5	9	706
GP23	2177	6.2	4.6	4.6	4400	4.6	9	4429
	2178	26	13	13	14000	13	32	14097
	2179	7.6	4.4	4.3	4300	4.3	9	4330
	2180	1.5	5.5	5.5	4800	5.5	11	4829
	2181	16	2.6	2.3	4200	2.3	9	4232
	2182	7.6	7.2	5.9	280	4.1	8	313
	2183	26	17	13	3700	4.3	24	3784
	2184	14	4.8	4	3500	4	8	3535
GP24	2185	3000	760	1700	7.2	24	358	5849
	2186	3500	540	11000	3.5	29	1109	16182
	2187	9600	1200	2900	13	57	590	14360
	2188	5700	900	12000	6.8	75	1117	19799
	2189	1800	14	29	3.8	9.3	21	1877
	2190	390	21	66	5.3	13	26	521
	2191	440	170	85	1.6	3.9	19	720
	2192	800	67	130	1.9	4.8	33	1037

Table B.2 Statistics of on-site VOC measurements collected in January 1992

Statistics of VOC levels

	TCE (ug/kg)	1,1,1-TCA (ug/kg)	MeCl (ug/kg)	1,1-DCE (ug/kg)	1,1-DCA (ug/kg)	1,2-DCE (ug/kg)	Summation of VOCs (ug/kg)
Count	187	187	187	187	187	187	187
Average	2126	292	2392	535	25	274	5644
Std. Dev.	7046	600	9173	1661	37	1216	15727
%RE	331	206	384	310	144	443	279
Minimum	0	0	2	1	1	2	9
25th%	61	21	32	5	5	14	648
Median	380	110	150	25	13	32	1340
75th%	1000	325	565	300	29	109	4133
Maximum	20000	4200	40000	14000	130	7808	64014
Average conc.	(%)	(%)	(%)	(%)	(%)	(%)	(%)
as % of total	37.7	5.2	42.4	9.5	0.5	4.9	100

Correlation matrix of target compounds

	TCE	TCA	MeCL	1,1-DCE	1,1-DCA	1,2-DCE	Summation
TCE	1.00	0.48	0.77	-0.07	0.59	0.04	0.91
TCA	0.48	1.00	0.59	-0.13	0.52	0.14	0.59
MeCL	0.77	0.59	1.00	-0.07	0.68	0.10	0.95
1,1-DCE	-0.07	-0.13	-0.07	1.00	-0.14	-0.04	0.02
1,1-DCA	0.59	0.52	0.68	-0.14	1.00	0.04	0.68
1,2-DCE	0.04	0.14	0.10	-0.04	0.04	1.00	0.15
Summation	0.91	0.59		0.02	0.67	0.15	1.00

Correlation of compound with summation of VOCs

r2	0.83	0.35	0.90	0.00	0.45	0.02	1.00
Pearson, r	0.91	0.59	0.95	0.02	0.67	0.15	1.00

Notes:

(1) The data presented are a major subset of the Geoprobe samples collected in January 1992.

(2) The VOC results are reported on the basis of field moist soil weight.

(3) The VOCs were measured on-site using a heated headspace GC method.

(4) In this tabulation and analysis, non-detects were set equal to the MDL.

APPENDIX C. RESULTS OF OFF-SITE VOC ANALYSES IN JANUARY 1992

C.1 Explanatory Notes on Off-site Laboratory Analysis of VOCs

In the January 1992 baseline characterization study, soil samples were collected from approximately 20% of the sample locations for analysis for VOCs by ORNL ACD using GC/MS methods. For these samples, 40-mL Dynatech vials were utilized to containerize samples for shipment to ORNL ACD. These 40-mL vials are specifically designed to be directly connected to a purge-and-trap instrument. The vials have Teflon septa on both ends and a porous disk within the vial for distribution of the purge gas. The vials are intended to be used on an autosampler. The purge gas is injected into the vial through the bottom septa and flows out of the vial through the top septa. This configuration is reported to enhance the recovery efficiency of soil VOCs. The infield containerization in these vials also is intended to eliminate the need for soil sample transfer in the laboratory, a known mechanism for loss of volatile analytes such as TCE. In this work, however, ORNL ACD did not have a functioning autosampler and the Dynatech vials were necessarily opened in the laboratory, the top and bottom caps removed, and the vials then attached to the purge-and-trap instrument. The soil sample was not removed from the vial or otherwise disturbed.

In the field, ~ 5 mL of moist soil was collected using a stainless steel coring device and extruded into each Dynatech vial. The vials were sealed and cooled to 4°C during shipment off-site and for pre-analytical storage at ORNL. The tare weights of the empty vials had been measured and it was intended that the laboratory would weigh the vial filled with sample. However, due to a miscommunication, the loaded vials were not reweighed and the ORNL ACD lab analyst assumed that each vial contained exactly 5 g of field moist soil, and the concentrations of VOCs were reported on that basis. When this error came to light, an effort was made to estimate the soil sample weights after the fact as follows.

The samples analyzed for VOCs were recovered, dried (in their vials), and weighed in their containers. Information on the moisture content was available from companion samples, taken at the same place and time. In each case, the lab VOC sample and the companion sample were collected adjacent to each other in the same Geoprobe® 1-ft sample interval. These soil samples were weighed in their vials before and after drying; subtraction of the tare weights of their respective containers then yielded the moist and dry sample weights for the companion samples. Under the assumption that the ratios fo these wieghts were the same for the corresponding lab samples at the time of analysis, multiplication of the dry lab samples by the respective weight ratio yielded the estimated moist weights of the lab VOC samples.

Since the VOC concentrations reported by ORNL ACD were based on an assumed moist sample weight of 5 g, the reported VOC concentrations had to be corrected by the following equation:

$$\textit{actual ug VOC per kg moist soil} = \textit{correction factor} * \textit{reported ug VOC per kg moist soil} \quad (C.1)$$

where,

$$\textit{correction factor} = (\textit{assumed 5 g weight}) / (\textit{moist weight of lab sample}) \quad (C.2)$$

Thus, the corrected VOC concentrations shown in Table C.2 were computed from the lab reported VOC concentrations shown in Table C.1 multiplied by the corresponding correction factor determined according to Eq. C.2. The computed correction factors are shown in Table C.2.

Table C.1. Summary of reported results of off-site VOC analyses of soil samples collected in January 1992.

(Sample results reported on a field moist basis, assuming 5 g of soil was containerized in the analysis vessel. Refer to Table C.2 for correction).

SAMPLE NO.	SAMPLE DATE	SOIL BORING OR PROBE	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Acetone (ug/kg)	CT (ug/kg)	1,2-DCA (ug/kg)	PCE (ug/kg)	TOL (ug/kg)	EB (ug/kg)	XYL (ug/kg)	OTHER VOCS	(ug/kg)
1035	1/20/92	SB06	9-10	5 U	5 U	5 U	5 U	5 U	5 U	637 B	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	10
1049	1/20/92	SB07	9-10	30	5 U	5 U	5 U	5 U	8	28 B	5 U	5 U	5 U	5 U	5 U	5 U		
1051	1/20/92	SB07	10-11	5 U	5 U	5 U	5 U	5 U	5 U	80 B	5 U	5 U	5 U	5 U	5 U	5 U		
1064	1/21/92	SB08	9-11	5 U	5 U	5 U	9	5 U	5 U	21 B	5 U	5 U	5 U	5 U	5 U	5 U		
1072	1/22/92	SB09	3-5	87	10	5 U	46	113	750 E	44 B	18	5 U	5 U	5 U	5 U	5 U		
1074	1/22/92	SB09	5-7	5 U	10	5 U	5 U	5 U	6	350 BE	5 U	5 U	5 U	5 U	5 U	5 U		
1075	1/22/92	SB09	7-9	93	6	5 U	113	5 U	153	61 B	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	12
1077	1/22/92	SB10	3-5	72	5 U	5 U	54	533 E	125	67 B	5 U	5 U	18	7	43	113	2-Butanone	12
1078	1/22/92	SB10	5-7	9	7	5 U	29	22	331 E	148 B	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	18
1080	1/22/92	SB10	7-9	5 U	6	5 U	5 U	5 U	38	297 BE	5 U	5 U	5 U	5 U	5 U	5 U		
1083	1/22/92	SB11	4-5	5 U	5	5 U	5 U	24	32	406 BE	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	10
1086	1/22/92	SB11	6-7	5 U	5 U	5 U	5 U	5 U	5	46 B	5 U	5 U	5 U	5 U	5 U	5 U		
1097	1/23/92	SB12	4-5	13	9 B	5 U	26	44	56	609 BE	7	5 U	5 U	5 U	5 U	5 U	2-Butanone	16
1101	1/23/92	SB12	6-7	5 U	5 U	5 U	5 U	12	5 U	74 B	5 U	5 U	5 U	5 U	5 U	5 U		
2065	1/18/92	GP09	0-1	19	5 U	5 U	18	284 E	275 E	2118 BE	5 U	5 U	9	16	5 U	5 U	2-Butanone	174
2066	1/18/92	GP09	3-4	5 U	5 U	5 U	5 U	26	16	1162 BE	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	33
2067	1/18/92	GP09	6-7	5 U	5 U	5 U	5 U	25	12	1219 BE	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	15
2068	1/18/92	GP09	9-10	43	5 U	5 U	17	136	89	48 B	23	5 U	5 U	5 U	5 U	5 U	2-Butanone	10
2069	1/18/92	GP09	12-13	6	5 U	5 U	5 U	18	8	723 BE	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	11
2070	1/18/92	GP09	15-16	5 U	5 U	5 U	5 U	5 U	5 U	707 BE	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	10
2071	1/18/92	GP09	18-19	5 U	5 U	5 U	5 U	5 U	5 U	23 B	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	6 B
2129	1/22/92	GP17	0-1	5 U	6	5 U	5 U	6	6	19 B	5 U	5 U	5 U	5 U	5 U	5 U		
2130	1/22/92	GP17	3-4	5 U	5 U	5 U	5 U	6	5 U	47 B	5 U	5 U	5 U	5 U	5 U	5 U		
2131	1/22/92	GP17	6-7	5 U	6 U	5 U	5 U	5 U	5 U	290 BE	5 U	5 U	5 U	5 U	5 U	5 U	Chloroform	9
2132	1/22/92	GP17	9-10	131	5 U	5 U	5 U	5 U	422 E	79 B	5 U	5 U	5 U	5 U	5 U	5 U		
2133	1/22/92	GP17	12-13	5 U	5 U	5 U	5 U	5 U	5 U	11 B	5 U	5 U	5 U	5 U	5 U	5 U		
2134	1/22/92	GP17	15-16	12	5 U	5 U	5 U	5 U	27	26 B	5 U	5 U	5 U	5 U	5 U	5 U		
2135	1/22/92	GP17	18-19	5 U	5 J	5 U	5 U	5 U	5 U	23 B	5 U	5 U	5 U	5 U	5 U	5 U		
2185	1/24/92	GP24	0-1	5 U	5 U	5 U	5 U	21	37	116 B	5 U	5 U	5 U	5 U	5 U	5 U		
2186	1/24/92	GP24	3-4	5 U	5 U	5 U	5 U	104	571 E	671 BE	5 U	5 U	19	5 U	5 U	5 U	2-Butanone	26
2187	1/24/92	GP24	6-7	5 U	5 U	5 U	5 U	10	141	482 BE	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	17
2188	1/24/92	GP24	9-10	5 U	5 U	5 U	5 U	5 U	613 E	39 B	5 U	5 U	5 U	5 U	5 U	5 U	2-Butanone	20
2189	1/24/92	GP24	12-13	5 U	5 U	5 U	5 U	5 U	77	434 BE	5 U	5 U	5 U	5 U	5 U	5 U		
2190	1/24/92	GP24	15-16	5 U	5 U	5 U	5 U	5 U	12	293 BE	5 U	5 U	5 U	5 U	5 U	5 U		
2191	1/24/92	GP24	18-19	5 U	5 U	5 U	5 U	15	230 E	10 U	5 U	5 U	5 U	5 U	5 U	5 U		
2192	1/24/92	GP24	21-22	5 U	5 U	5 U	5 U	6	67	30 B	5 U	5 U	5 U	5 U	5 U	5 U		

NOTES:

(1) VOCs identified soil samples collected from the X-231B Unit during January 1992 and sent to ORNL ACD for analysis by GC/MS according to EPA method SW5030/8240.

(2) Qualifiers shown by the numbers: "U" indicates VOC analyzed for but not detected at quantitation limit shown. "J" indicates that the quantitative value is estimated.

"B" indicates the compound was detected in both the sample and its associated blank. "E" indicates that the reported concentration exceeded the calibration range.

(3) Results are reported on the basis of field moist soil weight.

Table C.2. Summary of corrected results of off-site VOC analyses of soil samples collected in January 1992.

SAMPLE NO.	SOIL BORING/ PROBE	DEPTH (ft)	WEIGHT CORR. FACTOR	1,1-DCE	MC	1,2-DCE	1,1-DCA	1,1,1-TCA	TCE	Summation of VOCs (ug/kg)
1035	SB06	9-10	0.82	5	5	5	5	5	5	30
1049	SB07	9-10	0.8	24	5	5	5	5	6	50
1051	SB07	10-11	0.49	5	5	5	5	5	5	30
1064	SB08	9-11	0.58	5	5	5	5	5	5	30
1072	SB09	3-5	0.73	64	7	5	34	83	549	742
1074	SB09	5-7	1.15	5	11	5	5	5	7	38
1075	SB09	7-9	0.73	68	5	5	82	5	112	277
1077	SB10	3-5	0.68	49	5	5	37	365	85	546
1078	SB10	5-7	0.92	8	6	5	27	20	306	372
1080	SB10	7-9	0.68	5	5	5	5	5	26	51
1083	SB11	4-5	0.71	5	5	5	5	17	23	60
1086	SB11	6-7	0.87	5	5	5	5	5	5	30
1097	SB12	4-5	0.85	11	8	5	22	37	48	131
1101	SB12	6-7	0.57	5	5	5	5	7	5	32
2065	GP09	0-1	0.51	10	5	5	9	144	139	312
2066	GP09	3-4	0.48	5	5	5	5	12	8	40
2067	GP09	6-7	0.42	5	5	5	5	11	5	36
2068	GP09	9-10	0.32	14	5	5	5	43	28	100
2069	GP09	12-13	0.44	5	5	5	5	8	5	33
2070	GP09	15-16	0.58	5	5	5	5	5	5	30
2071	GP09	18-19	0.31	5	5	5	5	5	5	30
2129	GP17	0-1	0.39	5	5	5	5	5	5	30
2130	GP17	3-4	0.51	5	5	5	5	5	5	30
2131	GP17	6-7	0.57	5	5	5	5	5	5	30
2132	GP17	9-10	0.56	74	5	5	5	5	238	332
2133	GP17	12-13	0.58	5	5	5	5	5	5	30
2134	GP17	15-16	0.56	7	5	5	5	5	15	42
2135	GP17	18-19	0.48	5	5	5	5	5	5	30
2185	GP24	0-1	0.71	5	5	5	5	15	26	61
2186	GP24	3-4	0.48	5	5	5	5	50	275	345
2187	GP24	6-7	0.78	5	5	5	5	8	109	137
2188	GP24	9-10	0.52	5	5	5	5	5	318	343
2189	GP24	12-13	0.71	5	5	5	5	5	55	80
2190	GP24	15-16	0.62	5	5	5	5	5	7	32
2191	GP24	18-19	0.53	5	5	5	5	8	123	151
2192	GP24	21-22	0.58	5	5	5	5	5	39	64

Notes:

(1) Target VOCs identified in soil samples collected from the X-231B Unit during January 1992 and sent to ORNL ACD for analysis by GC/MS according to EPA method SW5030/8240.

(2) Sample results are reported on a field moist basis, after correcting for actual weight of sample containerized in the analysis vessel.

(3) Correction = Reported ug/kg * (analyst assumed 5 g moist wt.)/(measured moist sample wt.)

(4) For non-detects ("U"), any reported value was set equal to the uncorrected MDL after sample weight correction was made (MDL typically 5 ug/kg).

Table C.3. Summary of off-site analyses made for radiological contamination in soil samples collected during January 1992.

Probe no.	Sample no.	Depth (ft)	Gross alpha (Bq/kg)	Gross beta (Bq/kg)	Total uranium (mg/kg)
GP01	2001	0-1	540 +/- 350	950 +/- 410	1.191
GP01	2002	3-4	800 +/- 400	1100 +/-400	1.086
GP01	2003	6-7	620 +/- 420	1500 +/- 600	1.158
GP01	2005	12 - 13	500 +/- 420	1000 +/- 600	0.845
GP24	2185	0 - 1	1100 +/- 700	970 +/- 7400	1.245
GP24	2186	3 - 4	850 +/- 500	1200 +/- 600	0.862
GP24	2187	6 - 7	830 +/- 380	980 +/-360	0.612
GP24	2189	12 - 12	580 +/- 360	1300 +/- 500	1.048

APPENDIX D. RESULTS OF ON-SITE VOC ANALYSES IN APRIL 1992

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3001	4/22/92	S1C-02	1-2	2000	50	< 3.1	89	940	150	230	3459
3002	4/22/92	S1C-05	4-5	4900	< 13	< 13	190	420	27	400	5937
3002 Dup	4/22/92	S1C-05	4-5	4300	< 12	< 12	180	350	13	190	5033
3003	4/22/92	S1C-09	8-9	1500	30	< 12	28	7.0	5.9	37	1607.9
3004	4/22/92	S1C-14	13-14	20	5.3	< 1.0	5.1	1.5	1.5	7.5	40.9
3005	4/22/92	S1B-02	1-2	1400	8000	< 11	170	380	50	300	10300
3006	4/22/92	S1B-05	4-5	3000	< 9.5	< 9.5	130	220	23	520	3893
3007	4/22/92	S1B-09	8-9	1100	33	< 11	75	43	21	280	1552
3007Dup.	4/22/92	S1B-09	8-9	930	30	< 7.7	61	39	21	280	1361
3008	4/22/92	S1B-14	13-14	82	48	< 9.1	< 9.1	< 9.1	3.1	24	157.1
3009	4/23/92	S1B-BI-42392-1	Equip Blk.	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 0.2	< 0.2	0
3010	4/23/92	S1D-02	1-2	26000	< 29	< 29	310	760	510	850	28430
3010Dup.	4/23/92	S1D-02	1-2	8000	68	< 20	130	220	310	600	9328
3011	4/23/92	S1D-05	4-5	3500	< 20	< 20	230	160	360	230	4480
3012	4/23/92	S1D-09	8-9	620	600	31	160	17	200	590	2218
3013	4/23/92	S1D-14	13-14	400	< 10	14	90	7.7	35	280	826.7
3014	4/23/92	S1A-02	1-2	1100	880	140	110	98	230	640	3198
3015	4/23/92	S1A-05	4-5	4300	< 20	< 20	200	190	380	1100	6170
3016	4/23/92	S1A-09	8-9	280	530	34	140	42	170	790	1986
3017	4/23/92	S1A-14	13-14	300	< 20	51	26	6.2	23	220	626.2
3017 Dup.	4/23/92	S1A-14	13-14	320	< 24	< 24	45	7.1	25	230	627.1
3018	4/23/92	S1E-02	1-2	10000	< 22	< 22	240	510	720	1100	12570
3019	4/23/92	S1E-05	4-5	4000	< 20	37	190	190	420	900	5737
3020	4/23/92	S1E-09	8-9	910	< 20	< 20	230	14	130	680	1964
3021	4/23/92	S1E-14	13-14	400	280	63	26	21	31	75	896

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992 (continued)

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3022	4/23/92	P2C-02	1-2	2700	< 22	< 22	350	65	280	480	3875
3023	4/23/92	P2C-05	4-5	350	120	< 19	120	22	63	170	845
3023 Dup.	4/23/92	P2C-05	4-5	700	800	< 20	130	21	94	200	1945
3024	4/23/92	P2C-09	8-9	730	370	51	290	35	110	560	2146
3025	4/23/92	P2C-14	13-14	540	250	49	310	38	180	540	1907
3026	4/23/92	P2E-02	1-2	7700	< 21	< 21	200	220	580	750	9450
3027	4/23/92	P2E-05	4-5	1600	18	< 19	210	41	140	485	2494
3028	4/23/92	P2E-09	8-9	350	255	34	220	27	30	490	1406
3029	4/23/92	P2E-14	13-14	270	220	28	240	37	110	490	1395
3030	4/24/92	P2E-RI42492-1	Rinseate	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 0.2	< 0.2	0
3031	4/24/92	P2D-02	1-2	11000	< 26	< 26	310	240	690	710	12950
3031 Dup.	4/24/92	P2D-02	1-2	8900	< 21	< 21	220	230	610	630	10590
3032	4/24/92	P2D-05	4-5	1800	< 22	< 22	220	59	250	450	2779
3033	4/24/92	P2D-09	8-9	320	200	23	530	160	13	350	1596
3034	4/24/92	P2D-14	13-14	220	< 17	< 17	120	< 17	66	150	556
3035	4/24/92	P1A-02	1-2	2200	< 26	< 26	180	120	570	660	3730
3035 Dup.	4/24/92	P1A-02	1-2	770	< 19	< 19	150	54	300	400	1674
3036	4/24/92	P1A-05	4-5	550	340	< 33	81	57	85	730	1843
3037	4/24/92	P1A-09	8-9	680	< 29	< 29	370	420	600	1800	3870
3038	4/24/92	P1A-14	13-14	42	99	55	< 29	< 29	16	93	305
3039	4/24/92	P1B-02	1-2	4000	190	< 30	160	280	940	840	6410
3040	4/24/92	P1B-05	4-5	290	38	< 28	160	22	89	430	1029
3041	4/24/92	P1B-09	8-9	270	320	< 27	100	260	53	580	1583
3041 Dup.	4/24/92	P1B-09	8-9	32	93	< 31	31	140	< 3.1	320	616
3042	4/24/92	P1B-14	13-14	< 28	120	30	< 28	< 28	3.7	31	184.7

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992 (continued)

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3043	4/24/92	TE2C-02	0-2	1800	210	< 29	110	31	410	260	2821
3044	4/24/92	TE2C-05	4-5	5900	< 28	< 28	390	60	980	530	7860
3044 Dup.	4/24/92	TE2C-05	4-5	760	120	< 31	360	52	810	410	2512
3045	4/24/92	TE2C-09	8-9	110	82	< 29	130	< 29	76	70	468
3046	4/24/92	TE2C-14	13-14	220	110	< 29	130	< 29	140	120	720
3047	4/25/92	TE2D-02	1-2	3100	< 31	< 31	180	86	1000	360	4726
3047 Dup.	4/25/92	TE2D-02	1-2	7000	< 26	< 26	270	170	1200	540	9180
3048	4/25/92	TE2D-05	4-5	77000	< 31	< 31	570	540	11000	3800	92910
3049	4/25/92	TE2D-09	8-9	< 27	3900	< 27	160	54	870	140	5124
3050	4/25/92	TE2D-14	13-14	< 30	520	< 30	< 30	< 30	150	14	684
3051	4/25/92	TE2C-RI42492-1	Rinseate	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 0.2	< 0.2	0
3052	4/25/92	TE2E-02	1-2	15000	< 27	< 27	550	130	1300	530	17510
3053	4/25/92	TE2E-05	4-5	13000	< 30	< 30	320	110	1600	690	15720
3054	4/25/92	TE2E-09	8-9	2000	< 30	< 30	220	75	1000	280	3575
3055	4/25/92	TE2E-14	13-14	2000	31	< 26	200	81	1100	260	3672
3056	4/25/92	IE2C-02	1-2	12000	140	< 44	540	190	6500	1000	20370
3057 Dup.	4/25/92	IE2C-05	4-5	35000	< 38	< 38	440	370	29000	2500	67310
3058	4/25/92	IE2C-09	8-9	380	182	63	46	< 33	360	22	1053
3059	4/25/92	IE2C-14	13-14	< 34	150	< 34	< 34	< 34	150	5.9	305.9
3060	4/25/92	IE2D-02	1-2	12000	150	180	320	310	5400	670	19030
3060 Dup.	4/25/92	IE2D-02	1-2	6700	240	< 42	220	170	11000	840	19170
3061	4/25/92	IE2D-05	4-5	1400	150	< 40	170	200	3600	830	6350
3062	4/25/92	IE2D-09	8-9	220	< 43	< 43	< 43	< 43	270	16	506
3063	4/25/92	IE2D-14	13-14	< 9.0	120	< 9.0	< 9.0	< 9.0	4.1	9.1	133.2
3064	4/25/92	IE2E-02	1-2	700	39	< 39	140	76	2000	300	3255

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992 (continued)

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3065	4/25/92	IE2E-05	4-5	850	68	< 41	190	160	9100	670	11038
3066	4/25/92	IE2E-09	8-9	500	160	< 41	< 41	< 41	550	24	1234
3067	4/25/92	IE2E-14	13-14	52	110	79	< 19	< 19	87	6.4	334.4
3068	4/26/92	D1D-02	1-2	34000	< 31	< 31	660	170	15000	17000	66830
3069	4/26/92	D1D-05	4-5	33000	< 20	< 20	280	240	17000	21000	71520
3069 Dup.	4/26/92	D1D-05	4-5	25000	< 23	< 23	410	240	12000	12000	49650
3070	4/26/92	D1D-09	8-9	20000	< 20	< 20	170	170	4100	3200	27640
3071	4/26/92	D1D-14	13-14	13000	< 18	< 18	110	110	2800	360	16380
3072	4/26/92	D1D-18	17-18	8000	< 24	< 24	24	28	900	80	9032
3073	4/26/92	IE2E-42492-1	Rinseate	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	0.37	< 0.2	0.37
3074	4/26/92	C2B-02	1-2	47000	< 20	< 20	600	670	12000	21000	81270
3075	4/26/92	C2B-05	4-5	3200	38	< 25	330	32	760	11000	15360
3076	4/26/92	C2B-09	8-9	65	< 22	< 22	25	< 22	35	29	154
3076 Dup.	4/26/92	C2B-09	8-9	66	26	40	< 19	< 19	36	29	197
3077	4/26/92	C2B-14	13-14	62	< 22	< 22	< 22	< 22	33	12	107
3078	4/26/92	C2A-02	1-2	6900	130	< 26	390	76	6000	11000	24496
3078 Dup.	4/26/92	C2A-02	1-2	6600	210	< 19	270	340	6100	11000	24520
3079	4/26/92	C2A-05	4-5	290	< 27	< 27	290	200	370	280	1430
3080	4/26/92	C2A-09	8-9	70	45	< 24	84	30	52	140	421
3081	4/26/92	C2A-14	13-14	22	28	< 12	< 12	< 12	13	7.8	70.8
3082	4/26/92	IE1A-02	1-2	18000	< 22	< 22	290	270	6300	4500	29360
3082 Dup.	4/26/92	IE1A-02	1-2	14000	< 21	< 21	230	170	3800	2300	20500
3083	4/26/92	IE1A-05	4-5	7800	< 20	< 20	230	110	3200	2900	14240
3084	4/26/92	IE1A-09	8-9	17000	< 20	< 20	200	180	4000	2900	24280
3085	4/26/92	IE1A-14	13-14	15000	< 18	< 18	80	120	4600	290	20090

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992 (continued)

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3086	4/27/92	IE1A-42792-1	Rinseate	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 0.2	< 0.2	0
3087	4/27/92	IE1B-02	1-2	61000	< 22	< 22	500	690	22000	16000	100190
3088	4/27/92	IE1B-05	4-5	14000	< 26	< 26	460	300	5000	9500	29260
3089	4/27/92	IE1B-09	8-9	610	< 23	< 23	86	23	270	110	1099
3089 Dup.	4/27/92	IE1B-09	8-9	800	< 25	< 25	88	25	330	135	1378
3090	4/27/92	IE1B-14	13-14	710	< 13	< 13	50	22	340	75	1197
3091	4/27/92	C1A-02	1-2	6300	53	< 23	220	440	1100	42000	50113
3091 Dup.	4/27/92	C1A-02	1-2	13000	< 23	< 23	220	86	1800	66000	81106
3092	4/27/92	C1A-05	4-5	21000	< 25	< 25	140	930	8300	360000	390370
3093	4/27/92	C1A-09	8-9	1150	42	< 23	76	630	1300	180000	183198
3094	4/27/92	C1A-14	13-14	310	< 21	< 21	< 21	35	160	5400	5905
3095	4/27/92	C1B-02	1-2	14000	< 22	< 22	260	360	2400	47000	64020
3096	4/27/92	C1B-05	4-5	20000	< 24	< 24	240	660	2900	250000	273800
3097	4/27/92	C1B-09	8-9	330	77	46	170	460	470	180000	181553
3097 Dup.	4/27/92	C1B-09	8-9	300	< 25	57	74	460	220	160000	161111
3098	4/27/92	C1B-14	13-14	62	< 25	340	< 25	< 25	0.56	150	552.56
3099	4/27/92	P2A-02	1-2	960	42	< 21	130	130	130	300	1692
3100	4/27/92	P2A-05	4-5	4700	< 23	< 23	270	130	310	6800	12210
3101	4/27/92	P2A-09	8-9	110	41	< 23	180	< 23	6.5	280	617.5
3102	4/27/92	P2A-14	13-14	45	79	< 20	33	< 20	6.1	55	218.1
3102 Dup.	4/27/92	P2A-14	13-14	44	< 20	510	28	< 20	5.5	51	638.5
3103	4/28/92	P2B-02	1-2	38000	< 27	< 27	280	420	1300	14000	54000
3104	4/28/92	P2B-05	4-5	5300	< 34	< 34	300	74	430	4600	10704
3105	4/28/92	P2B-RI42892-1	Rinseate	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	0.21	< 0.2	0.21
3106	4/28/92	P2B-09	8-9	680	< 26	< 26	300	53	190	8800	10023

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992 (continued)

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3106 Dup.	4/28/92	P2B-09	8-9	700	27	< 25	250	41	120	5500	6638
3107	4/28/92	P2B-14	13-14	930	25	< 12	220	59	400	15000	16634
3108	4/28/92	TE2B-02	1-2	64000	< 23	< 23	370	510	7400	18000	90280
3109	4/28/92	TE2B-05	4-5	67000	< 19	< 19	320	340	11000	34000	112660
3110	4/28/92	TE2B-09	8-9	8900	< 24	< 24	340	110	1100	5600	16050
3110 Dup.	4/28/92	TE2B-09	8-9	3500	59	< 19	230	64	780	2900	7533
3111	4/28/92	TE2B-14	13-14	6800	< 19	< 19	210	110	2000	6400	15520
3112	4/28/92	TE2A-02	1-2	14000	270	< 22	320	300	2700	4100	21690
3113	4/28/92	TE2A-05	4-5	3100	45	< 27	330	200	1800	290	5765
3114	4/28/92	TE2A-09	8-9	4000	< 25	< 25	160	150	1600	260	6170
3115	4/28/92	TE2A-14	13-14	700	120	< 20	71	82	860	86	1919
3115 Dup.	4/28/92	TE2A-14	13-14	1900	140	< 25	99	100	1400	140	3779
3116	4/28/92	TE1B-02	1-2	1800	120	< 27	310	49	1100	150	3529
3117	4/28/92	TE1B-05	4-5	14000	< 18	< 18	310	400	2000	12000	28710
3118	4/28/92	TE1B-09	8-9	540	140	< 26	420	81	220	370	1771
3118 Dup.	4/28/92	TE1B-09	8-9	650	93	120	59	92	300	350	1664
3119	4/28/92	TE1B-14	13-14	44	< 21	760	< 21	53	120	200	1177
3120	4/28/92	TE1A-02	1-2	6200	30	290	260	61	1200	360	8401
3120 Dup.	4/28/92	TE1A-02	1-2	19000	62	< 20	310	110	1400	2500	23382
3121	4/28/92	TE1A-05	4-5	3300	< 35	440	180	180	820	3800	8720
3122	4/28/92	TE1A-09	8-9	4300	< 26	< 26	270	480	870	21000	26920
3123	4/28/92	TE1A-14	13-14	440	990	110	53	190	310	4900	6993
3124	4/29/92	D1A-02	1-2	100000	< 31	< 31	700	64	43000	65000	208764
3125	4/29/92	D1A-05	4-5	79000	< 21	< 21	410	500	38000	62000	179910
3126	4/29/92	D1A-09	8-9	23000	< 22	< 22	250	150	2300	3200	28900

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992 (continued)

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3127	4/29/92	D1A-14	13-14	640	< 19	88	29	< 19	450	41	1248
3128	4/29/92	D1A-18	17-18	3900	< 22	< 22	< 22	< 22	1200	40	5140
3128 Dup.	4/29/92	D1A-18	17-18	2600	< 16	< 16	< 16	21	688	24	3333
3129	4/29/92	D1A-22	21-22	4100	68	< 26	420	80	1100	270	6038
3130	4/29/92	TE1A-R142992-1	Rinseate	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 0.2	< 0.2	0
3131	4/29/92	D1B-02	1-2	48000	180	< 19	390	390	28000	39000	115960
3132	4/29/92	D1B-05	4-5	39000	< 20	< 20	370	260	30000	38000	107630
3133	4/29/92	D1B-09	8-9	1600	74	< 22	180	23	730	110	2717
3134	4/29/92	D1B-14	13-14	790	99	160	28	< 23	620	53	1750
3134 Dup.	4/29/92	D1B-14	13-14	360	100	170	< 19	< 19	290	23	943
3135	4/29/92	D1B-18	17-18	550	66	77	72	23	520	43	1351
3136	4/29/92	D1B-22	21-22	< 29	330	< 29	67	< 29	320	29	746
3137	4/29/92	D1E-02	1-2	110000	< 25	< 25	630	610	58000	44000	213240
3137 Dup.	4/29/92	D1E-02	1-2	100000	< 23	< 23	600	570	54000	42000	197170
3138	4/29/92	D1E-05	4-5	160000	< 19	< 19	490	1000	230000	180000	571490
3139	4/29/92	D1E-09	8-9	18000	< 19	< 19	260	110	2100	880	21350
3140	4/29/92	D1E-14	13-14	1600	58	110	40	< 20	810	78	2696
3141	4/29/92	D1E-18	17-18	970	90	170	< 21	< 21	660	28	1918
3142	4/29/92	D1E-22	21-22	4200	47	< 15	58	42	2200	46	6593
3143	4/29/92	DIE-02	1-2	170000	< 23	< 23	640	920	140000	61000	372560
3144	4/29/92	D1E-05	4-5	110000	< 18	< 18	410	560	150000	77000	337970
3145	4/29/92	D1E-09	8-9	2400	39	< 25	99	39	960	66	3603
3145 Dup.	4/29/92	D1E-09	8-9	2800	< 31	< 31	95	39	1100	62	4096
3146	4/29/92	D1E-14	13-14	36	45	< 22	< 22	< 22	94	4.2	179.2
3147	4/29/92	DIE-18	17-18	1900	< 15	< 15	26	20	960	19	2925

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992 (continued)

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3148	4/29/92	D1E-22	21-22	42000	< 14	< 14	94	160	8700	110	51064
3149	4/30/92	IE2A-02	1-2	7500	110	< 21	280	310	9500	3300	21000
3150	4/30/92	IE2A-05	4-5	9700	< 25	< 25	< 25	350	25000	4100	39150
3151	4/30/92	IE2A-09	8-9	270	< 28	< 28	< 28	< 28	860	4.0	1134
3152	4/30/92	IE2A-14	13-14	95	37	81	< 15	< 15	490	1.9	704.9
3152 Dup.	4/30/92	IE2A-14	13-14	44	110	480	< 24	< 24	370	1.7	1005.7
3153	4/30/92	IE2B-02	1-2	37	< 23	< 23	< 23	< 23	680	27	744
3154	4/30/92	IE2B-05	4-5	7800	< 20	< 20	340	240	26000	8200	42580
3155	4/30/92	IE2B-09	8-9	< 22	53	< 22	< 22	< 22	84	1.2	138.2
3155 Dup.	4/30/92	IE2B-09	8-9	< 21	43	< 21	< 21	< 21	110	1.2	154.2
3156	4/30/92	IE2B-14	13-14	< 13	43	< 13	< 13	< 13	29	0.69	72.69
3157	4/30/92	DI-42992-1	Rinseate	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 0.2	< 0.2	0
3158	5/11/92	Z1Aa-02	1-2	6200	< 20	< 20	260	4700	2800	54000	67960
3158 Dup.	5/11/92	Z1Aa-02	1-2	2500	< 20	< 20	110	2000	1200	24000	29810
3159	5/11/92	Z1Aa-05	4-5	11000	< 24	< 24	170	12000	7600	200000	230770
3160	5/11/92	Z1Aa-09	8-9	22000	< 20	990	130	18000	46000	460000	547120
3161	5/11/92	Z1Aa-14	13-14	2300	< 26	67	85	7200	1100	120000	130752
3162	5/11/92	Z1Ab-02	1-2	4500	< 18	< 18	240	1900	1300	75000	82940
3163	5/11/92	Z1Ab-05	4-5	5900	< 23	< 23	1600	2400	4000	130000	143900
3164	5/11/92	Z1Ab-05	8-9	490	< 29	180	73	2500	1400	92000	96643
3164 Dup.	5/11/92	Z1Ab-09	8-9	2100	< 20	< 20	150	2900	780	97000	102930
3165	5/11/92	Z1Ab-14	13-14	120	< 20	< 20	< 20	64	140	7400	7724
3166	5/11/92	Z1Bb-02	1-2	24000	< 22	< 22	310	8000	10000	57000	99310
3167	5/11/92	Z1Bb-05	4-5	2300	< 26	< 26	180	1900	730	7200	12310
3168	5/11/92	Z1Bb-09	8-9	4600	67	< 20	110	200	82	2000	7059

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992 (continued)

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3168 Dup.	5/11/92	Z1Bb-09	8-9	7300	< 20	< 20	120	240	120	5800	13580
3169	5/11/92	Z1Bb-14	13-14	< 22	68	120	< 22	26	13	95	322
3170	5/11/92	Z1Bb-RI51192-1	Rinseate	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	0.2	< 0.2	0.2
3171	5/11/92	Z1Ba-02	1-2	2400	< 19	< 19	150	3000	1000	5000	11550
3172	5/11/92	Z1Ba-05	4-5	7000	< 24	< 24	250	22000	1900	18000	49150
3173	5/11/92	Z1Ba-09	8-9	17000	< 24	< 24	93	1800	140	1800	20833
3174	5/11/92	Z1Ba-14	13-14	610	71	< 19	< 19	50	34	190	955
3174 Dup.	5/11/92	Z1Ba-14	13-14	62	69	< 20	< 20	44	35	190	400
3175	5/12/92	Z1Be-RI51292-1	Rinseate	< 2.0	< 2.0	< 2.0	< 2.0	< 2.0	< 0.2	< 0.2	0
3176	5/12/92	Z1Be-02	1-2	2500	< 19	100	170	3100	600	4400	10870
3177	5/12/92	Z1Be-05	4-5	15000	< 20	< 20	180	12000	1200	19000	47380
3178	5/12/92	Z1Be-09	8-9	17000	< 25	74	81	4400	70	1600	23225
3179	5/12/92	Z1Be-14	13-14	< 19	34	< 19	< 19	260	50	280	624
3180	5/12/92	Z1Bc-02	1-2	16000	< 22	< 22	210	4300	2200	34000	56710
3181	5/12/92	Z1Bc-05	4-5	3100	< 24	99	86	2100	660	14000	20045
3181 Dup.	5/12/92	Z1Bc-05	4-5	7500	< 25	80	140	2400	710	18000	28830

Table D.1. Results of on-site analyses for VOCs conducted on Geoprobe samples collected by Envirosurv, Inc. in April 1992 (continued)

SAMPLE NO.	SAMPLE DATE	PROBE LOCATION	DEPTH (ft)	1,1-DCE (ug/kg)	MC (ug/kg)	t-1,2-DCE (ug/kg)	1,1-DCA (ug/kg)	c-1,2-DCE (ug/kg)	1,1,1-TCA (ug/kg)	TCE (ug/kg)	Total VOC (ug/kg)
3182	5/12/92	Z1Bc-09	8-9	6000	< 21	< 21	160	2100	270	8900	17430
3183	5/12/92	Z1Bc-14	13-14	< 16	68	120	< 16	23	8.4	120	339.4
3184	5/12/92	Z1Bd-02	1-2	200	130	110	80	1600	290	2000	4410
3184 Dup.	5/12/92	Z1Bd-02	1-2	110	120	120	55	1000	190	1200	2795
3185	5/12/92	Z1Bd-05	4-5	8500	< 21	< 21	200	43000	1200	33000	85900
3186	5/12/92	Z1Bd-09	8-9	9300	< 20	< 20	84	18000	200	2100	29684
3187	5/12/92	Z1Bd-14	13-14	< 24	55	310	< 24	42	4.7	64	475.7

Notes:

(1) The soil samples were collected by Envirosurv, Inc. using a Geoprobe and were analyzed on-site using heated headspace GC methods.

(2) All soil samples were collected to established a pre-treatment concentration level prior to field testing of in situ remediation technologies.

(3) The VOC results are reported on the basis of field moist soil weight.

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