

APPENDIX D

CPT Logs

FUGRO GEOSCIENCES, INC.



6105 Rookin
Houston, TX 77074
Phone : 713-778-5580
Fax : 713-778-5501

December 5, 1997
Report Number: 0301-7257

Baker Environmental
AOP # 3
420 Brauser Rd.
Corapolis, PA 15108

Attention: Mr. John Andy

**REPORT FOR
CONE PENETRATION TESTING
AND RELATED SERVICES
CAMP LEJEUNE, NORTH CAROLINA**

Dear Mr. Andy:

Please find enclosed herewith the final results of the cone penetrometer tests conducted at the above referenced location.

For your information, the soil stratigraphy was identified using Campanella and Robertson's Simplified Soil Behavior Chart. Please note that because of the empirical nature of the soil behavior chart, the soil identification should be verified locally.

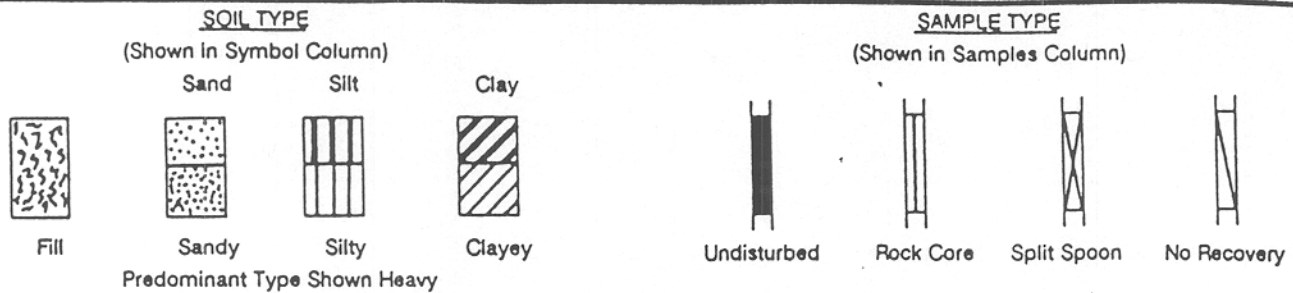
Fugro Geosciences appreciates the opportunity to be of service to your organization. If you should have any questions, or if we can be of further assistance, please do not hesitate to contact us. We look forward to working with you in the future.

Very truly yours,
FUGRO GEOSCIENCES, INC.

Jeffery L. Ness
General Manager
CPT Operations

JLN/mw

Key To Soil Classification and Symbols



TERMS DESCRIBING CONSISTENCY OR CONDITION

COARSE GRAINED SOILS (Major portion Retained on No. 200 Sieve)

Includes (1) clean gravels and sand described as fine, medium or course, depending on distribution of grain sizes (2) silty or clayey gravels and sands and (3) fine grained low plasticity soils ($PI < 10$) such as sandy silts. Condition is rated according to relative density, as determined by lab tests or estimated from resistance to sampler penetration.

<u>Descriptive Term</u>	<u>Penetration Resistance*</u>	<u>Relative Density</u>
Loose	0 - 10	0 to 40%
Medium Dense	10 - 30	40 to 70%
Dense	30 - 50	70 to 90%
Very Dense	Over 50	90 to 100%

* Blows/Foot, 140# Hammer, 30" Drop

FINE GRAINED SOILS (Major Portion Passing No. 200 Sieve)

Includes (1) inorganic and organic silts and clays, (2) sandy, gravelly or silty clays, and (3) clayey silts. Consistency is rated according to shearing strength, as indicated by penetrometer readings or by unconfined compression tests for soils with $PI \geq 10$.

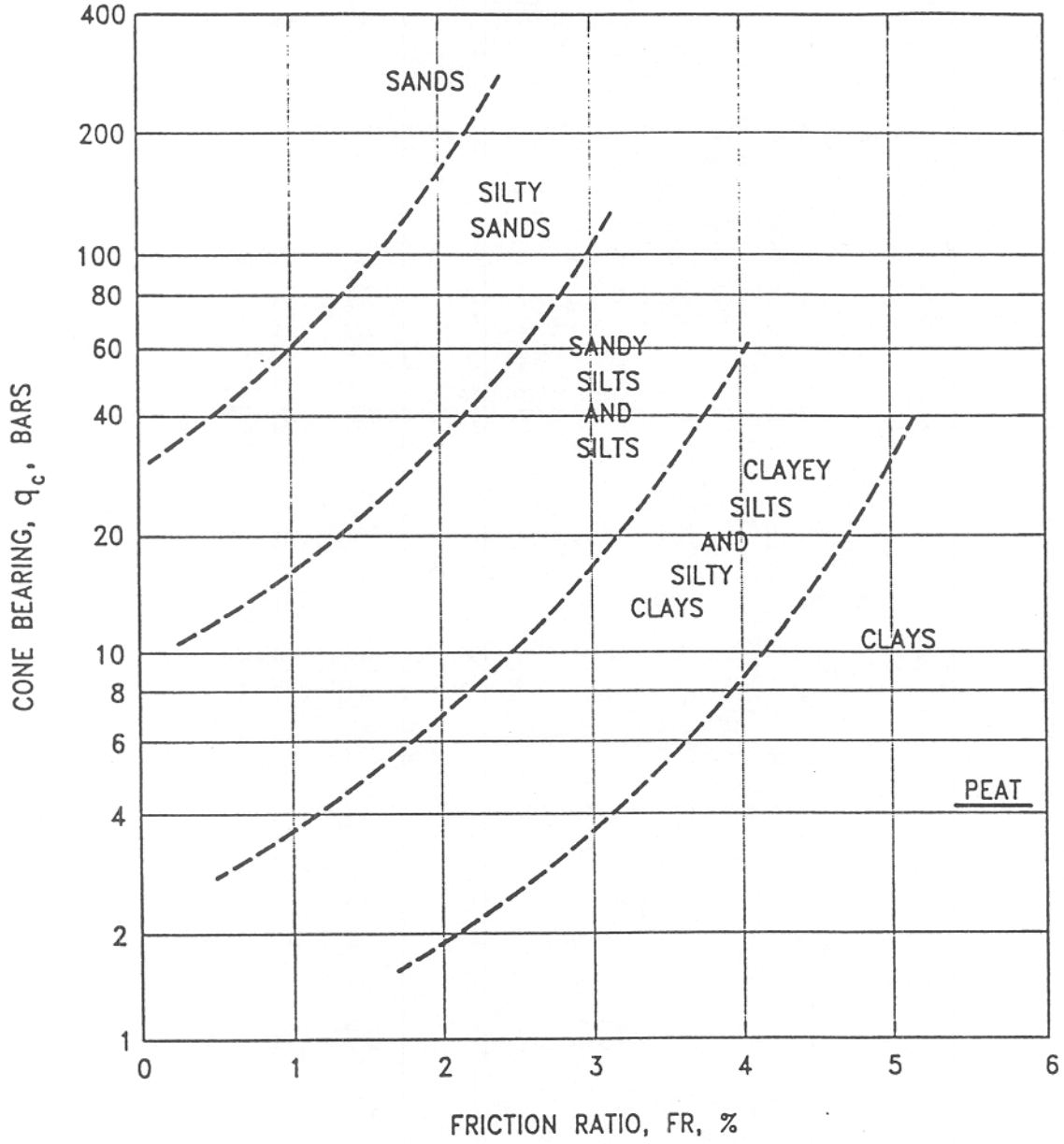
<u>Descriptive Term</u>	<u>Cohesive Shear Strength Tons/Square Foot</u>
Very Soft	Less Than 0.125
Soft	0.125 to 0.25
Firm	0.25 to 0.50
Stiff	0.50 to 1.00
Very Stiff	1.00 to 2.00
Hard	2.00 and Higher

Note: Slickensided and fissured clay may have lower unconfined compressive strengths than shown above because of planes of weakness or shrinkage cracks; consistency ratings of such soils are based on hand penetrometer readings.

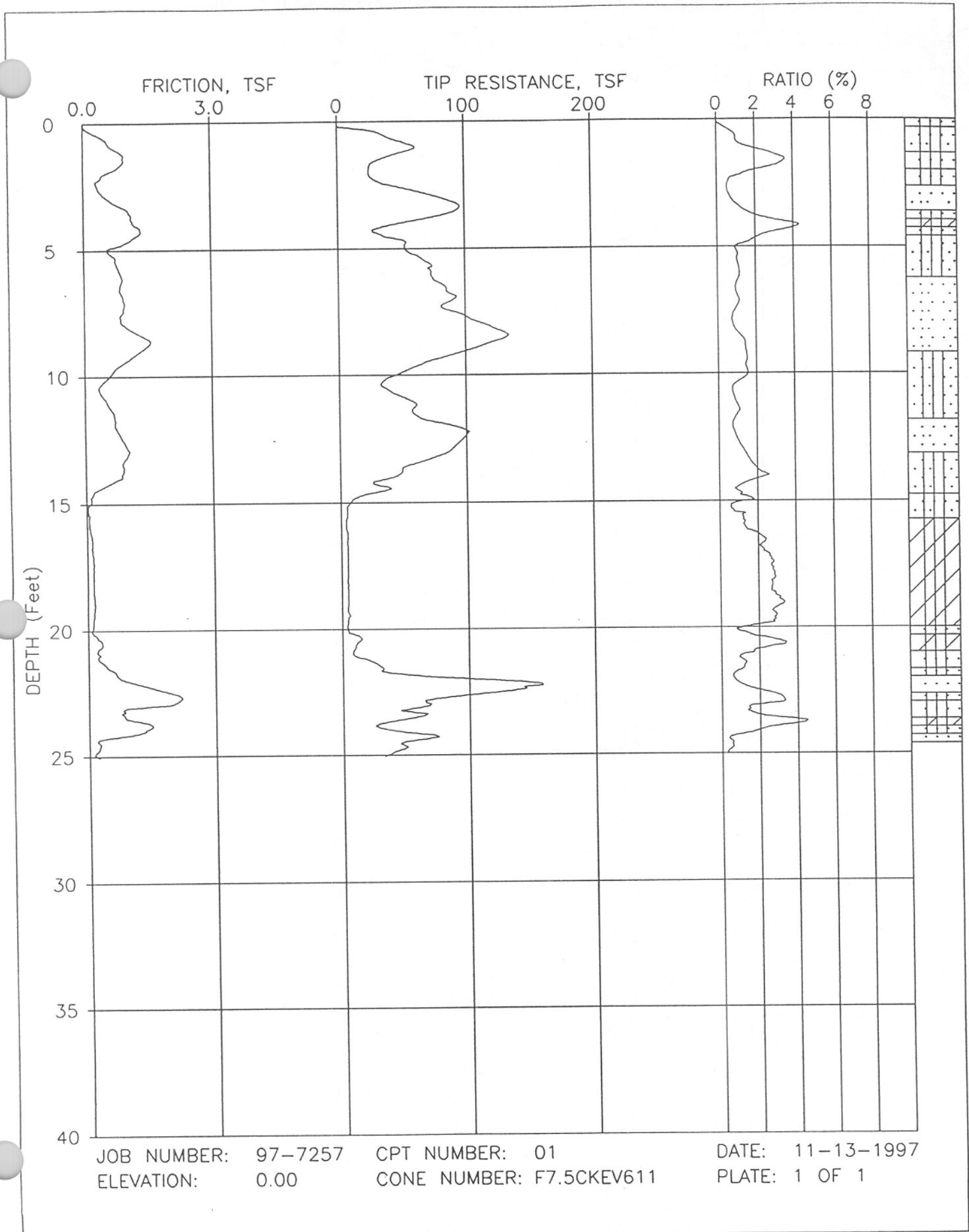
TERMS CHARACTERIZING SOIL STRUCTURE

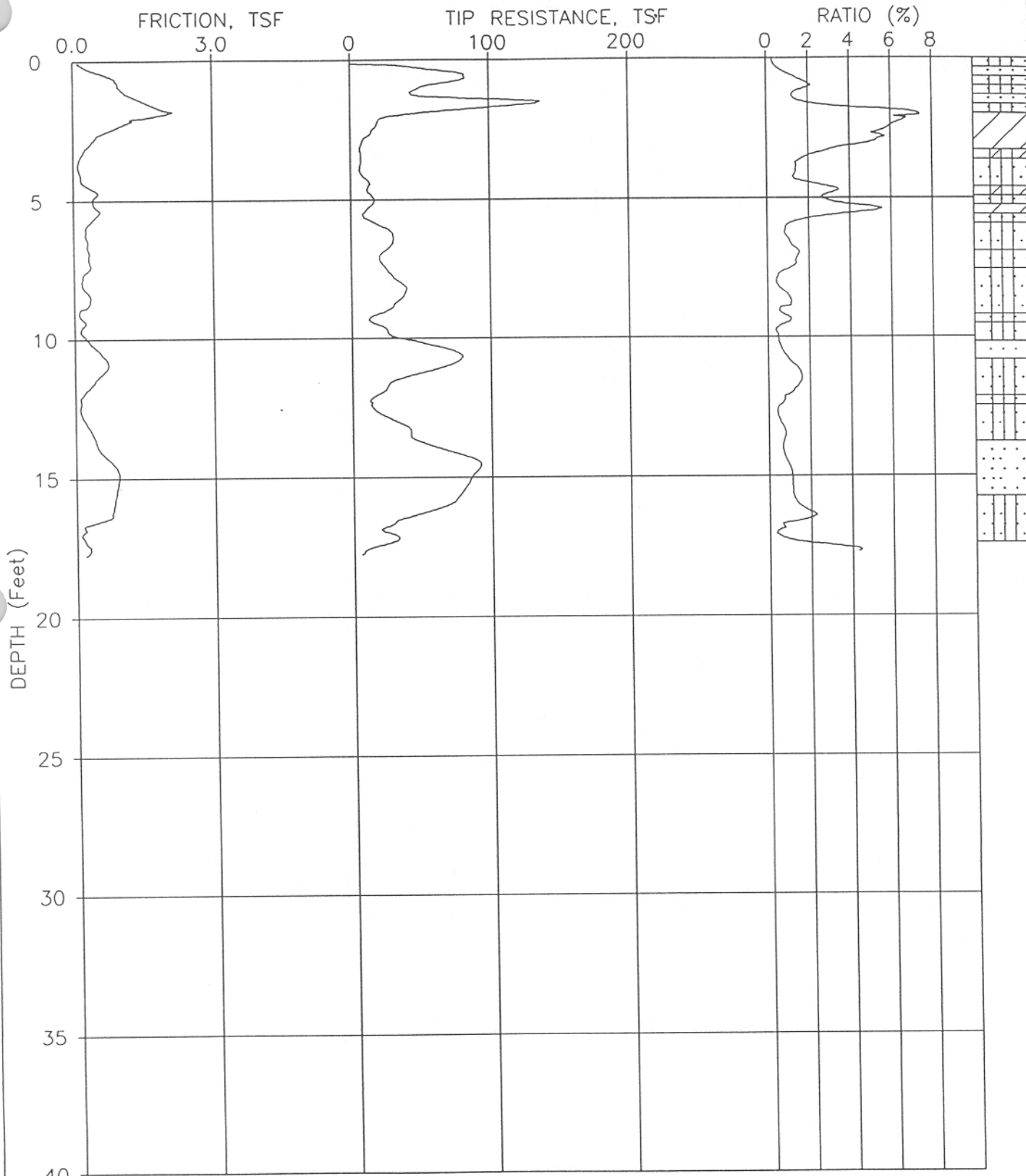
<p>Parting: paper thin in size</p> <p>Seam: 1/8" to 3" thick</p> <p>Layer: greater than 3"</p> <p>Fissured: containing shrinkage cracks, frequently filled with fine sand or silt, usually more or less vertical</p> <p>Sensitive: pertaining to cohesive soils that are subject to appreciable loss of strength when remolded</p> <p>Interbedded: composed of alternate layers of different soil types</p> <p>Laminated: composed of thin layers of varying color and texture</p> <p>Calcareous: containing appreciable quantities of calcium carbonate</p> <p>Well Graded: having wide range in grain sizes and substantial amounts of all intermediate particle sizes</p> <p>Poorly Graded: predominantly of one grain size, or having a range of sizes with some intermediate size missing</p>	<p>Flocculated: pertaining to cohesive soils that exhibit a loose knit or flakey structure</p> <p>Slickensided: having inclined planes of weakness that are slick and glossy in appearance.</p> <p style="text-align: center;"><u>Degree of Slickensided Development</u></p> <p>Slightly Slickensided: slickensides present at intervals of 1' to 2', soil does not easily break along these plates</p> <p>Moderately Slickensided: slickensides spaced at intervals of 1' to 2', soil breaks easily along these planes</p> <p>Extremely Slickensided: continuous and interconnected slickensides spaced at intervals of 4" to 12', soil breaks along the slickensides into pieces 3" to 6" in size</p> <p>Intensely Slickensided: slickensides spaced at intervals of less than 4", continuous in all directions; soil breaks down along planes into nodules 1/4" to 2" in size.</p>
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1 BAR=100 kPA=1.02 KG/CM²

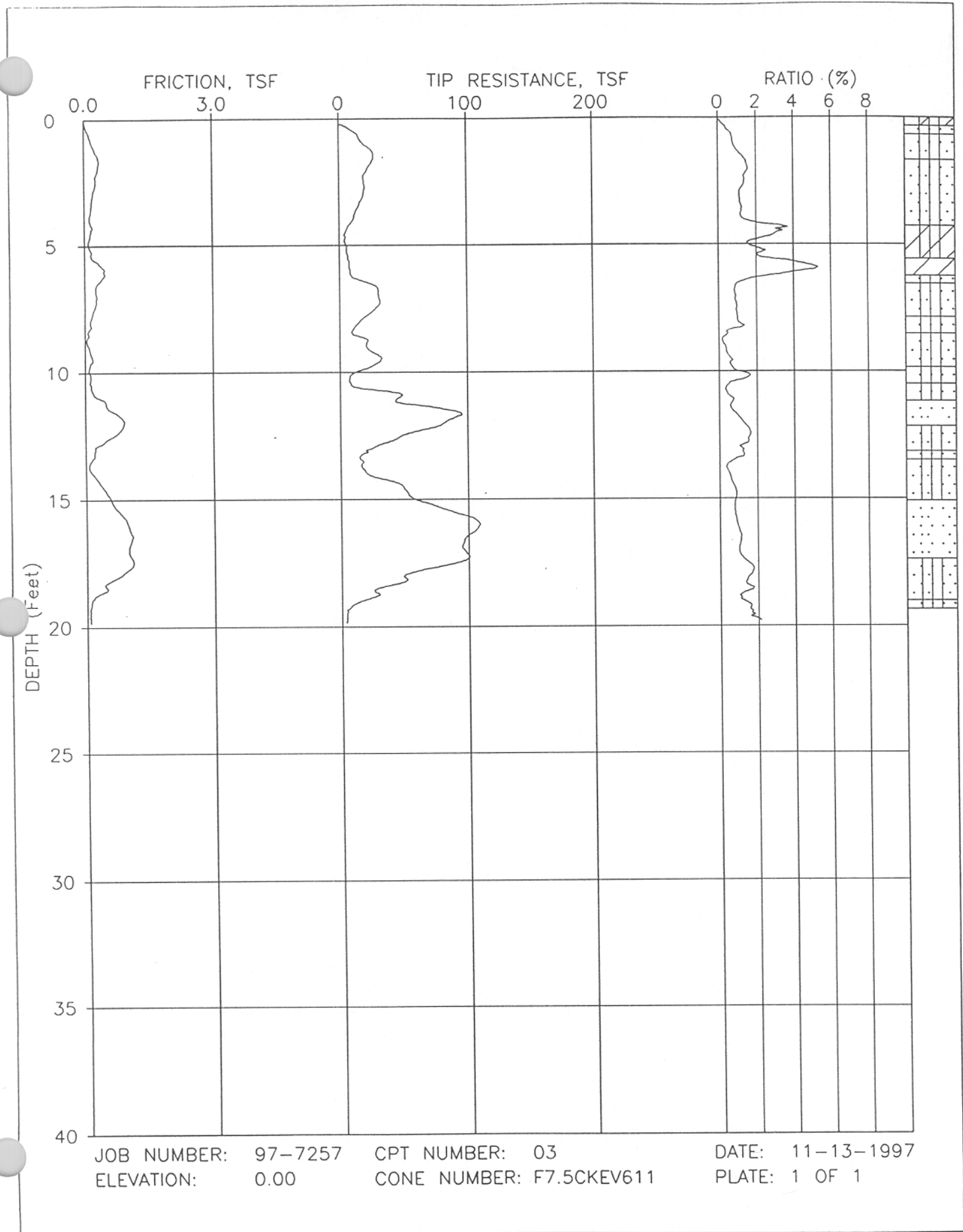


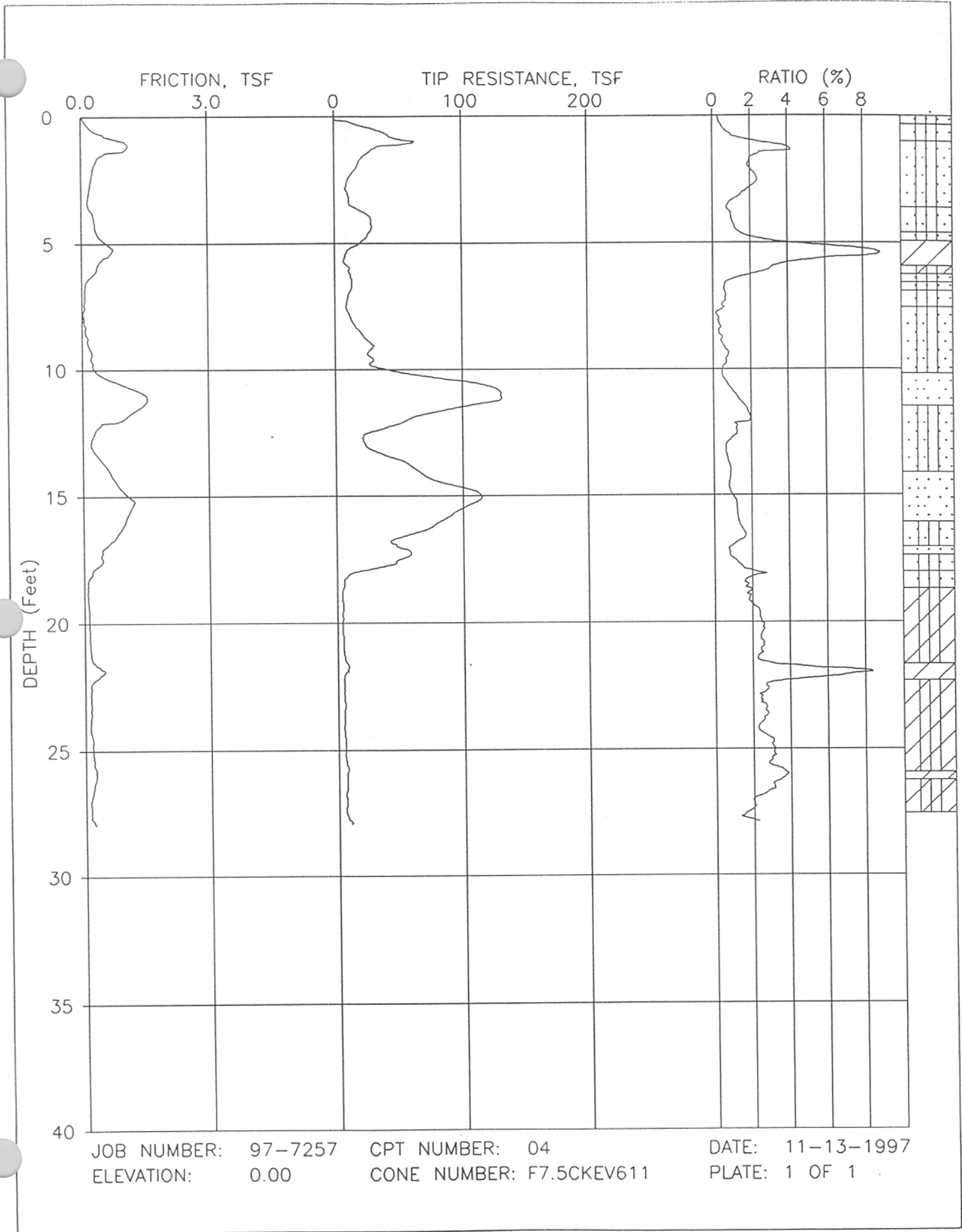
CAMPANELLA AND ROBERTSON CLASSIFICATION CHART (1983)

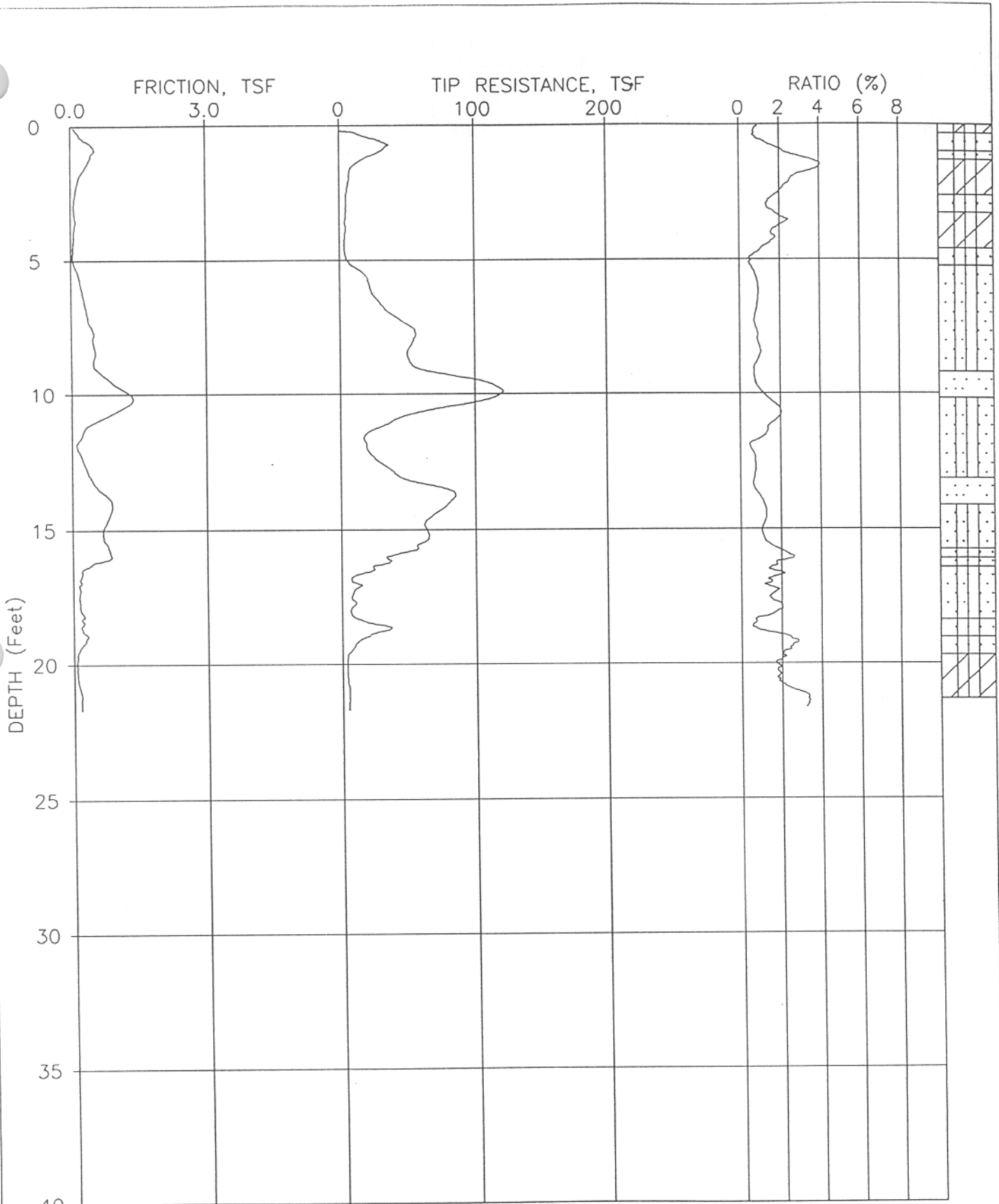




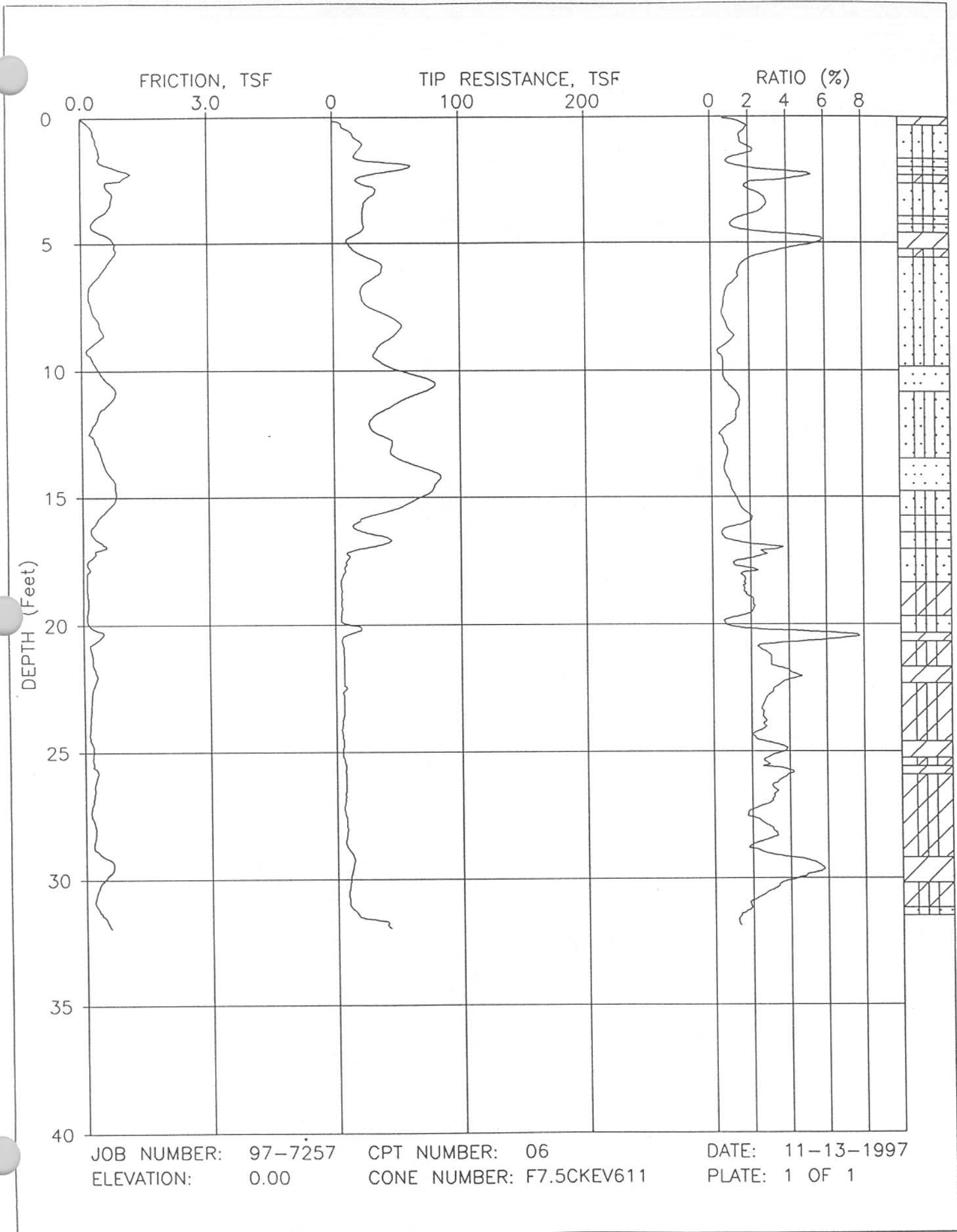
JOB NUMBER: 97-7257 CPT NUMBER: 02 DATE: 11-13-1997
 ELEVATION: 0.00 CONE NUMBER: F7.5CKEV611 PLATE: 1 OF 1

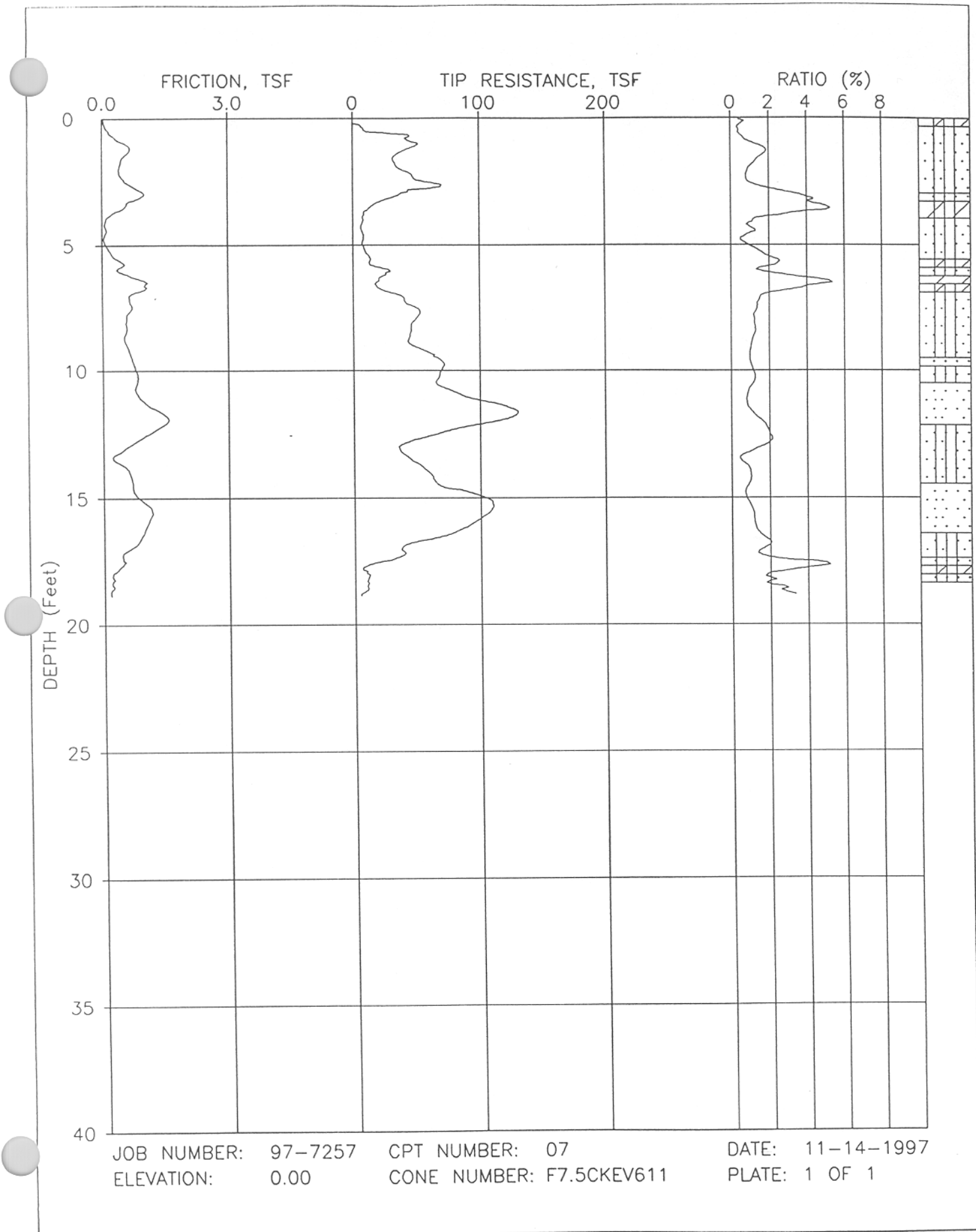


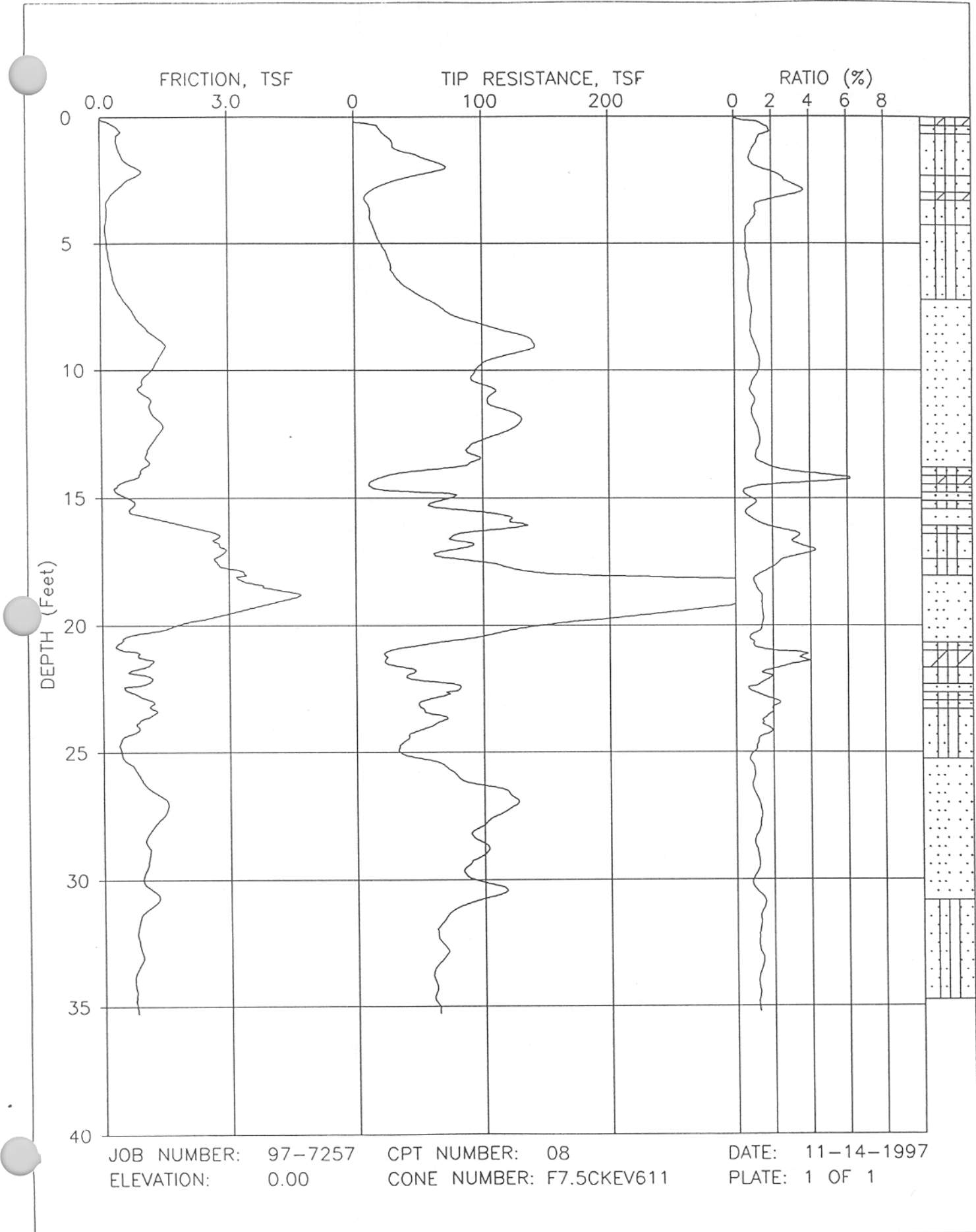


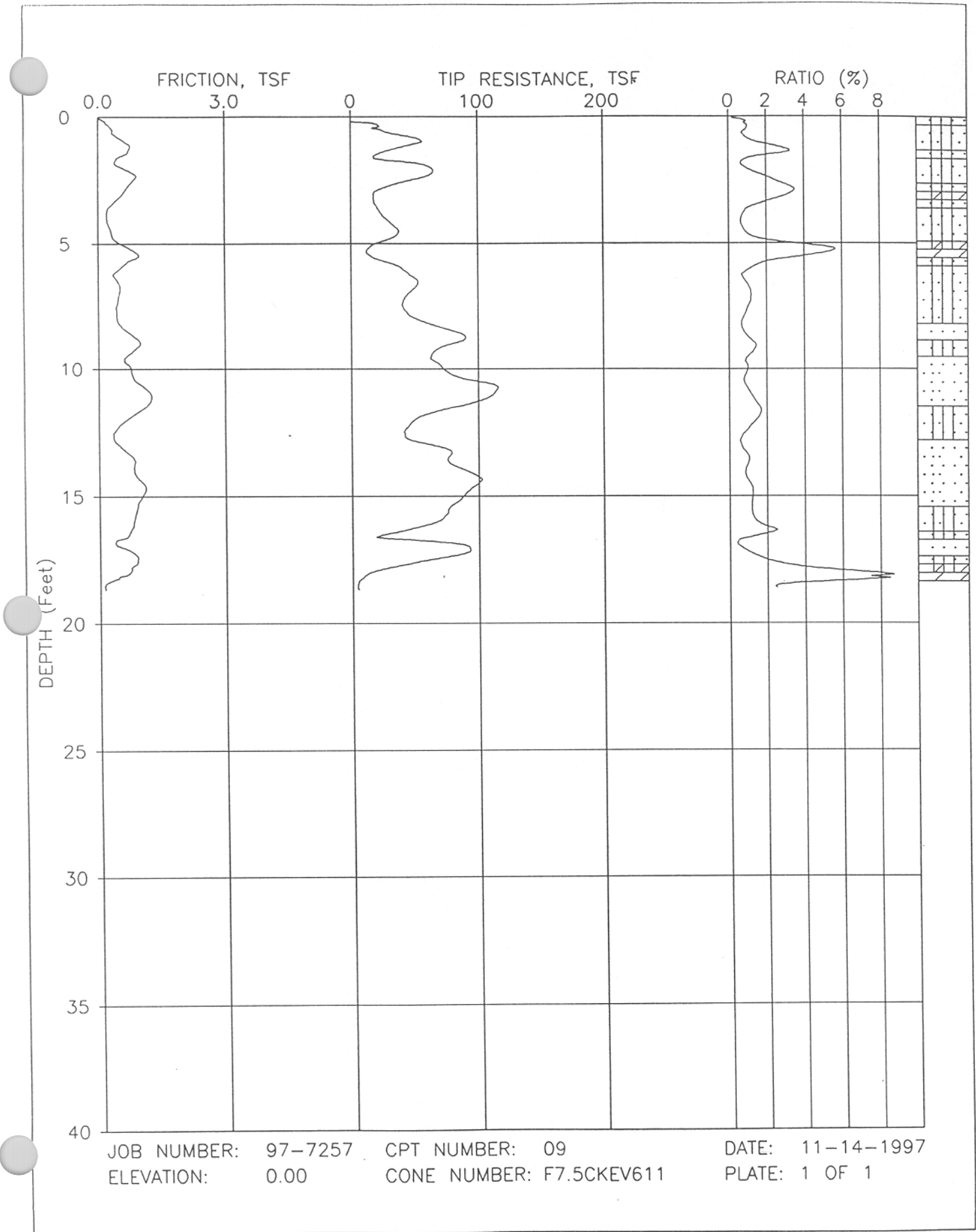


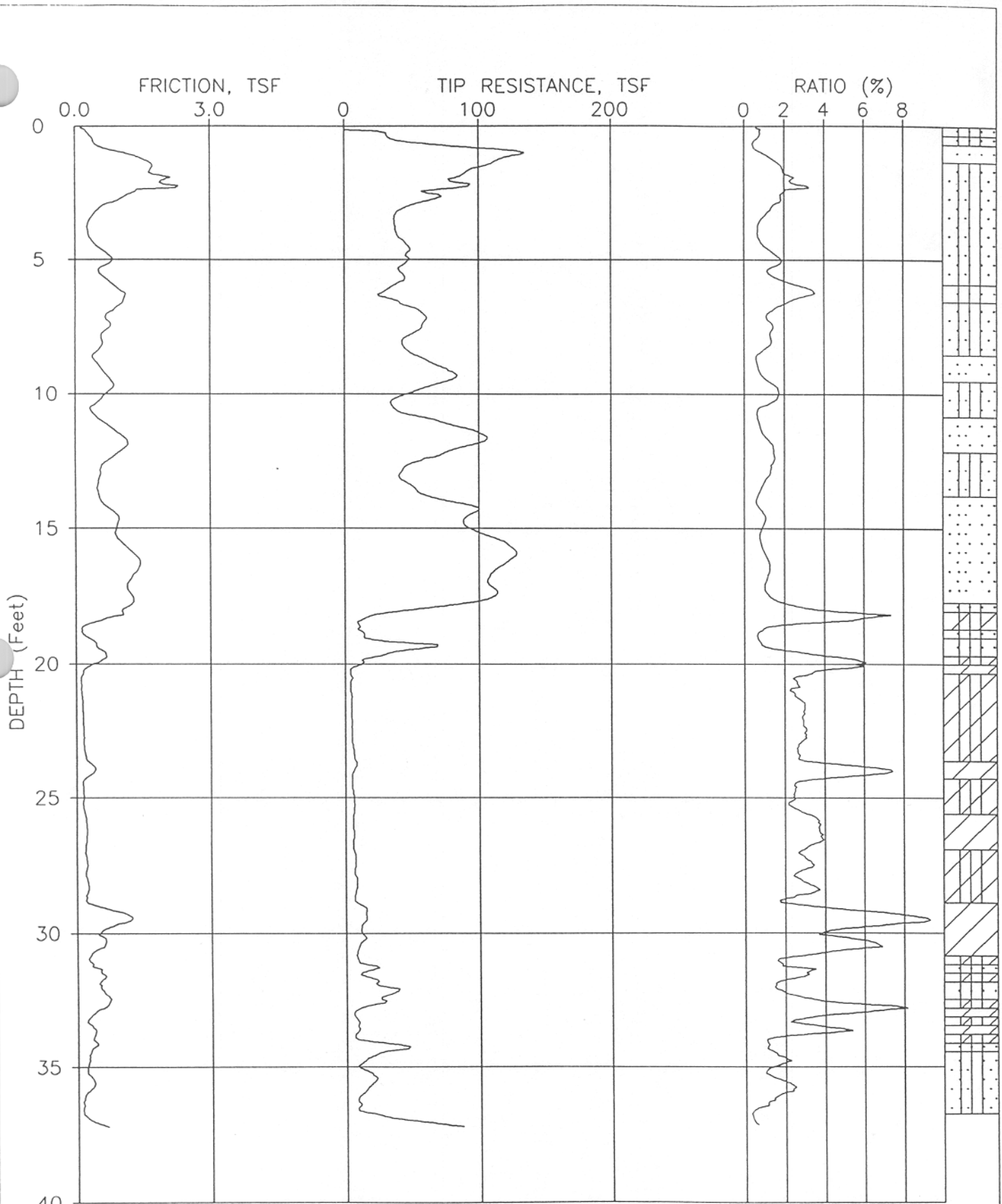
JOB NUMBER: 97-7257 DEPT NUMBER: 05 DATE: 11-13-1997
 ELEVATION: 0.00 CONE NUMBER: F7.5CKEV611 PLATE: 1 OF 1







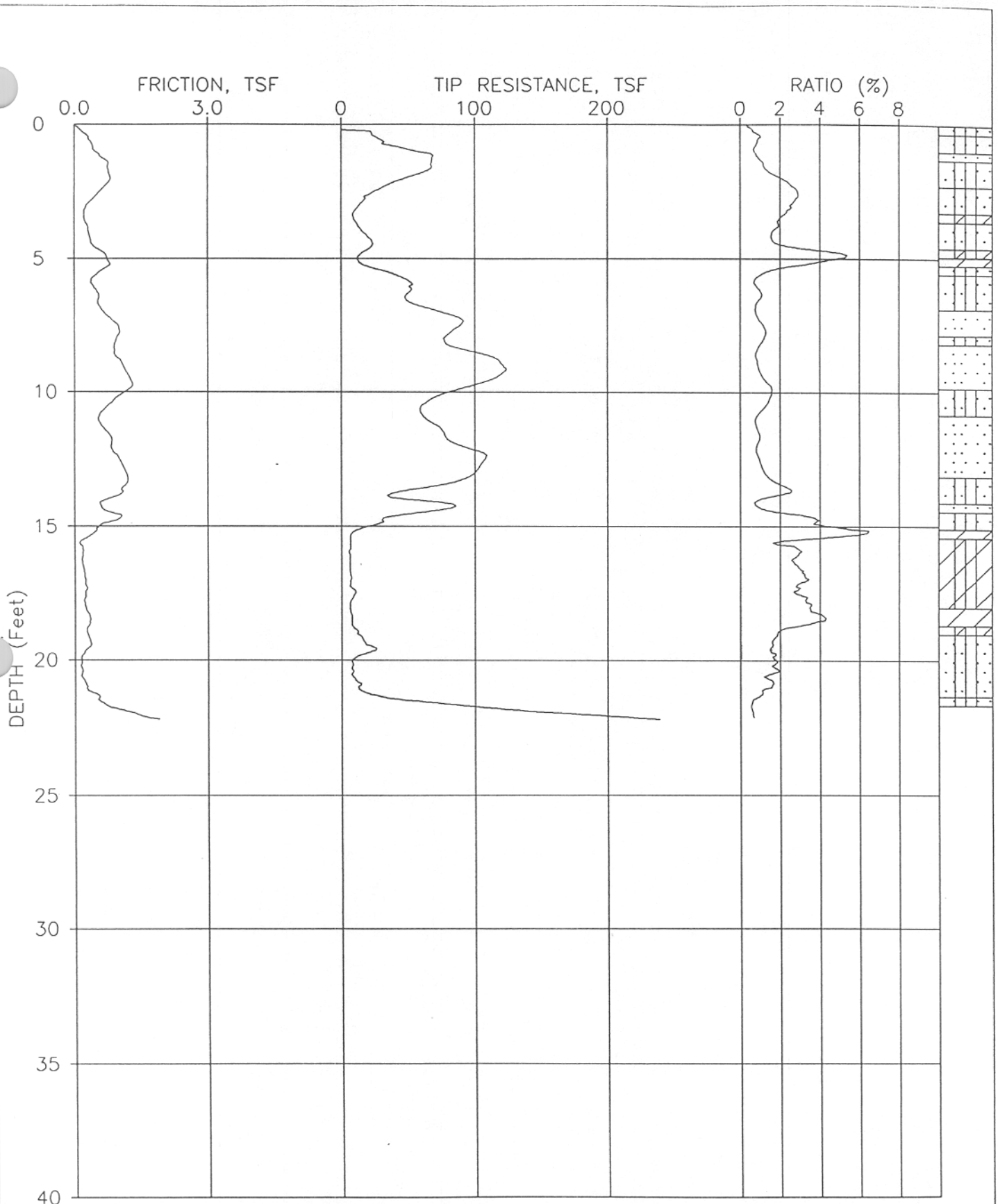




JOB NUMBER: 97-7257
 ELEVATION: 0.00

CPT NUMBER: 10
 CONE NUMBER: F7.5CKEV611

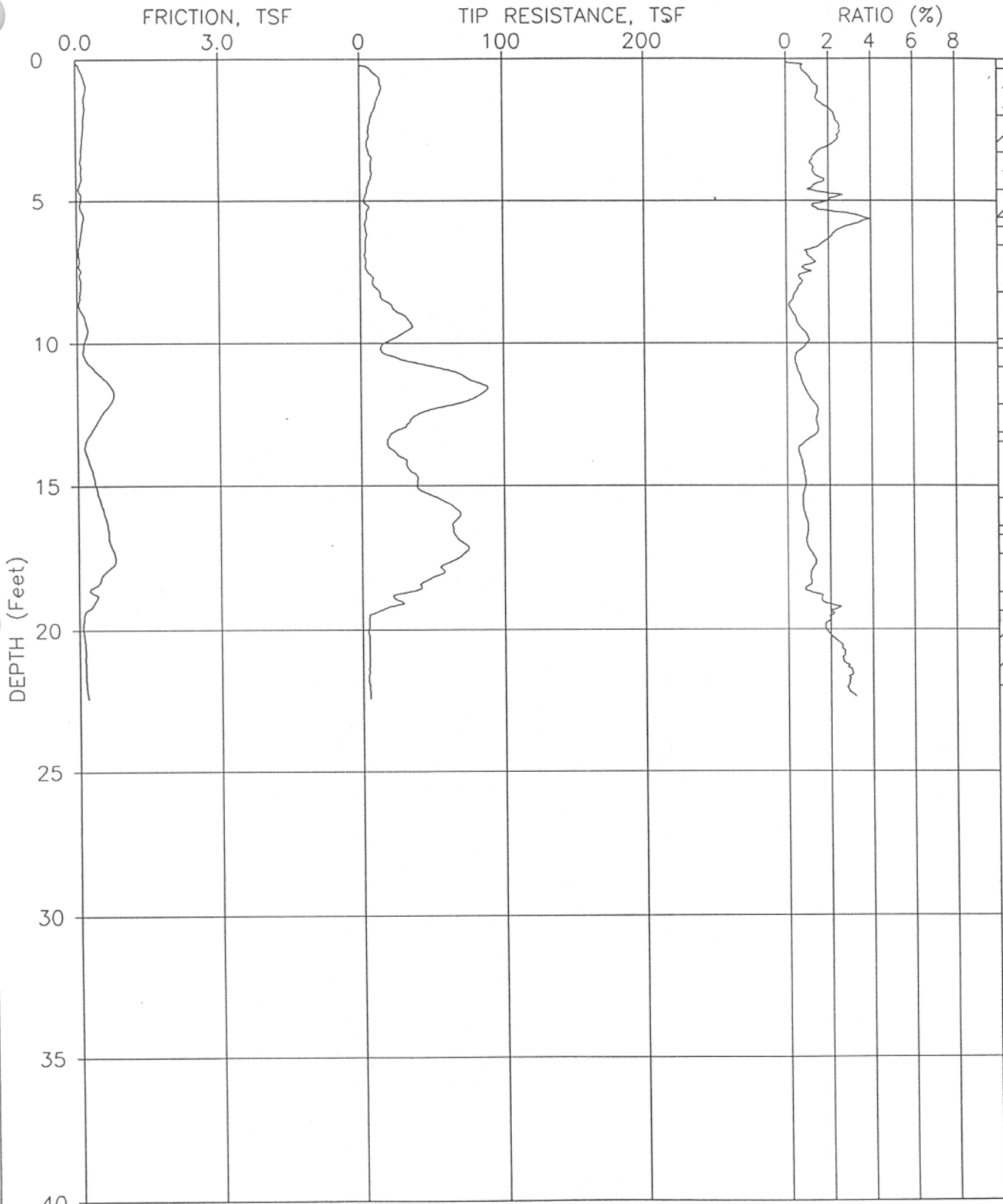
DATE: 11-14-1997
 PLATE: 1 OF 1



JOB NUMBER: 97-7257
 ELEVATION: 0.00

CPT NUMBER: 11
 CONE NUMBER: F7.5CKEV611

DATE: 11-14-1997
 PLATE: 1 OF 1



JOB NUMBER: 97-7257 CPT NUMBER: 12 DATE: 11-15-1997
 ELEVATION: 0.00 CONE NUMBER: F7.5CKEV611 PLATE: 1 OF 1

APPENDIX E
Non-VOC Analyses (Soil
Moisture, f_{oc} , XRD)

Major Ion Analyses (Ground Water
And Source Water)

Ground-Water VOC Analyses

Client: Duke Engineering & Services
Attn: Fred Holzmer
Address: 9111 Research Blvd
Austin, Tx 78758
Phone: 425-2000 **FAX:** 425-2099

Report #/Lab ID#: 87533 **Report Date:** 12/9/97
Project ID: MCB Camp Lejeune
Sample Name: IS26-04
Sample Matrix: soil
Date Received: 12/5/97 **Time:** 16:30:00
Date Sampled: 11/21/97 **Time:** 00:00:00

REPORT OF ANALYSIS

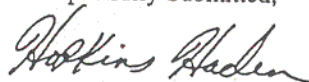
QUALITY ASSURANCE DATA¹

Parameter	Result	Units	RQL ⁵	Blank	Date	Method	Prec. ²	Recov. ³	CCV ⁴	LCS ⁴
Total organic carbon (TOC)	1510	mg/Kg	200	<200	12/9/97	ASA 29-3.5.2	11.34	119.62	111.25	111.24

@ 16.5 ft in f. SAND

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Respectfully Submitted,



Hopkins Haden

1. Quality assurance data reported is for the lot analyzed which included this sample.
2. Precision (Prec.) is the absolute value of the relative percent (%) difference between duplicate measurements.
3. Recovery (Recov.) is the percent (%) of analyte recovered from a spiked sample.
4. Calibration Verification (CCV) and Lab Control Sample (LCS) results expressed as the percent (%) recovery of analyte from a known standard.
5. Reporting Quantitation Limit. The Practical Quantitation Limit (PQL) or the Method Detection Limit (MDL) reported for the analyte.
6. Method numbers typically denote USEPA procedures. Less than (" $<$ ") values reflect nominal quantitation limits, adjusted for any required dilution.

Client: Duke Engineering & Services
Attn: Fred Holzmer
Address: 9111 Research Blvd
Austin, Tx 78758
Phone: 425-2000 **FAX:** 425-2099

Report #/Lab ID#: 87534 **Report Date:** 12/9/97
Project ID: MCB Camp Lejeune
Sample Name: IS26-05
Sample Matrix: soil
Date Received: 12/5/97 **Time:** 16:30:00
Date Sampled: 11/21/97 **Time:** 00:00:00

REPORT OF ANALYSIS

QUALITY ASSURANCE DATA¹

Parameter	Result	Units	RQL ⁵	Blank	Date	Method	Prec. ²	Recov. ³	CCV ⁴	LCS ⁴
Total organic carbon (foc)	5560	mg/Kg	400	<200	12/9/97	ASA 29-3.5.2	11.34	119.62	111.25	111.24

@ 18.0 ft in cl-SILT

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Respectfully Submitted,
Hopkins Haden
Hopkins Haden

1. Quality assurance data reported is for the lot analyzed which included this sample.
2. Precision (Prec.) is the absolute value of the relative percent (%) difference between duplicate measurements.
3. Recovery (Recov.) is the percent (%) of analyte recovered from a spiked sample.
4. Calibration Verification (CCV) and Lab Control Sample (LCS) results expressed as the percent (%) recovery of analyte from a known standard.
5. Reporting Quantitation Limit. The Practical Quantitation Limit (PQL) or the Method Detection Limit (MDL) reported for the analyte.
6. Method numbers typically denote USEPA procedures. Less than (" $<$ ") values reflect nominal quantitation limits, adjusted for any required dilution.

Client: Duke Engineering & Services
Attn: Fred Holzmer
Address: 9111 Research Blvd
Austin, Tx 78758
Phone: 425-2000 FAX: 425-2099

Report #/Lab ID#: 87535 Report Date: 12/9/97
Project ID: MCB Camp Lejeune
Sample Name: IS26-06
Sample Matrix: soil
Date Received: 12/5/97 Time: 16:30:00
Date Sampled: 11/21/97 Time: 00:00:00

REPORT OF ANALYSIS

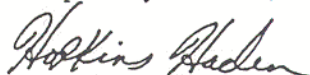
QUALITY ASSURANCE DATA¹

Parameter	Result	Units	RQL ⁵	Blank	Date	Method	Prec. ²	Recov. ³	CCV ⁴	LCS ⁴
Total organic carbon (foc)	6420	mg/Kg	400	<200	12/9/97	ASA 29-3.5.2	11.34	119.62	111.25	111.24

@ 19.0 ft in si-CLAY

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Respectfully Submitted,



Hopkins Haden

1. Quality assurance data reported is for the lot analyzed which included this sample.
2. Precision (Prec.) is the absolute value of the relative percent (%) difference between duplicate measurements.
3. Recovery (Recov.) is the percent (%) of analyte recovered from a spiked sample.
4. Calibration Verification (CCV) and Lab Control Sample (LCS) results expressed as the percent (%) recovery of analyte from a known standard.
5. Reporting Quantitation Limit. The Practical Quantitation Limit (PQL) or the Method Detection Limit (MDL) reported for the analyte.
6. Method numbers typically denote USEPA procedures. Less than ("<") values reflect nominal quantitation limits, adjusted for any required dilution.

X-RAY DIFFRACTION MINERAL PERCENTAGES

Project Name: MCB Camp Lejeune

Sample ID	BULK METHOD									CLAY METHOD							
	Qtz (%)	Feld (%)	Cal (%)	Dol (%)	Sid (%)	Pyr (%)	Bar (%)			Total Bulk (%)	Kao (%)	Ill (%)	Chl (%)	Sme (%)	EML	Total Clay (%)	Total (%)
IS25-05	81	11	*	*	*	1				93	3	2	1	1		7	100
IS25-06	85	2	*	*	*	4	*			91	4	2	1	2	*	9	100

* Denotes a trace percentage

Legend

- | | | | | | |
|-----|---|-----------------------------|---------------|---|--|
| Qtz | = | Quartz, SiO ₂ | Feld | = | Feldspar, (K, Na, Ca, Ba) (Al, Si) ₃ O ₈ |
| Cal | = | Calcite, CaCO ₃ | Dol | = | Dolomite, CaMg(CO ₃) |
| Sid | = | Siderite, FeCO ₃ | Pyr | = | Pyrite FeS ₂ |
| Bar | = | Barite BaSO ₄ | EML | = | Expandable Mixed Layer Illite/Smectite) |
| | | | Clay Minerals | = | Phyllosilicates |

QUANTERRA INCORPORATED

PRELIMINARY DATA SUMMARY

The results shown below may still require additional laboratory review and are subject to change. Actions taken based on these results are the responsibility of the data user.

Lot #: H7H220200

Baker Environmental
Camp LeJeune
Project Number: CTO-356

Date Reported: 8/29/97

PAGE

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
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Client Sample ID: IR88IW01-04
Sample #: 001 Date Sampled: 08/20/97 08:10 Date Received: 08/22/97 Matrix: SOLID

Inorganic Analysis				Reviewed
Percent Moisture	17.3	0.10	%	MCAWW 160.3 MOD
N-Hexane Ext. Material, Silica Gel Treated (1664)	ND	330	mg/kg	CFR136A 1664 SGT

Client Sample ID: IR88RW01-05
Sample #: 002 Date Sampled: 08/19/97 12:39 Date Received: 08/22/97 Matrix: SOLID

Inorganic Analysis				Reviewed
Percent Moisture	17.5	0.10	%	MCAWW 160.3 MOD
N-Hexane Ext. Material, Silica Gel Treated (1664)	ND	330	mg/kg	CFR136A 1664 SGT

Client Sample ID: IR88RW02-04
Sample #: 003 Date Sampled: 08/19/97 16:29 Date Received: 08/22/97 Matrix: SOLID

Inorganic Analysis				Reviewed
Percent Moisture	18.1	0.10	%	MCAWW 160.3 MOD
N-Hexane Ext. Material, Silica Gel Treated (1664)	ND	330	mg/kg	CFR136A 1664 SGT

Client Sample ID: IR88IS13-08
Sample #: 004 Date Sampled: 08/20/97 11:15 Date Received: 08/22/97 Matrix: SOLID

Inorganic Analysis				Reviewed
Percent Moisture	21.2	0.10	%	MCAWW 160.3 MOD
N-Hexane Ext. Material, Silica Gel Treated (1664)	ND	330	mg/kg	CFR136A 1664 SGT

Client Sample ID: IR88IW01-09
Sample #: 005 Date Sampled: 08/20/97 08:50 Date Received: 08/22/97 Matrix: SOLID

(Continued on next page)

QUANTERRA INCORPORATED
PRELIMINARY DATA SUMMARY

results shown below may still require additional laboratory review and are subject to
change. Actions taken based on these results are the responsibility of the data user.

#: H7H220200 Baker Environmental PAGE 2
 Camp LeJeune Date Reported: 8/29/97
 Project Number: CTO-356

<u>PARAMETER</u>	<u>RESULT</u>	<u>REPORTING LIMIT</u>	<u>UNITS</u>	<u>ANALYTICAL METHOD</u>
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Client Sample ID: IR88IW01-09
Sample #: 005 Date Sampled: 08/20/97 08:50 Date Received: 08/22/97 Matrix: SOLID

Inorganic Analysis				Reviewed
Percent Moisture	20.2	0.10	%	MCAWW 160.3 MOD
N-Hexane Ext. Material,	ND	330	mg/kg	CFR136A 1664 SGT
Silica Gel Treated (1664)				

QUANTERRA INCORPORATED
PRELIMINARY DATA SUMMARY

 Results shown below may still require additional laboratory review and are subject to change. Actions taken based on these results are the responsibility of the data user.

Lot #: H7H2S0122 Baker Environmental, Inc. PAGE 1
 Camp LeJeune Date Reported: 9/03/97
 Project Number: CTO-356

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
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Client Sample ID: IR88-RW01-97C

Sample #: 001 Date Sampled: 08/21/97 12:20 Date Received: 08/25/97 Matrix: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD	
Inductively Coupled Plasma					In Review
Silver	ND	10.0	ug/L	ICLP ILM03.0	
Aluminum	273	200	ug/L	ICLP ILM03.0	
Barium	141 B	200	ug/L	ICLP ILM03.0	
Beryllium	ND	5.0	ug/L	ICLP ILM03.0	
Calcium	15600	5000	ug/L	ICLP ILM03.0	
Cadmium	ND	5.0	ug/L	ICLP ILM03.0	
Cobalt	4.5 B	50.0	ug/L	ICLP ILM03.0	
Chromium	8.9 B	10.0	ug/L	ICLP ILM03.0	
Copper	ND	25.0	ug/L	ICLP ILM03.0	
Iron	15100	100	ug/L	ICLP ILM03.0	
Potassium	2080 B	5000	ug/L	ICLP ILM03.0	
Magnesium	4510 B	5000	ug/L	ICLP ILM03.0	
Manganese	126	15.0	ug/L	ICLP ILM03.0	
Sodium	12200	5000	ug/L	ICLP ILM03.0	
Nickel	75.1	40.0	ug/L	ICLP ILM03.0	
Antimony	ND	60.0	ug/L	ICLP ILM03.0	
Vanadium	ND	50.0	ug/L	ICLP ILM03.0	
Zinc	14.7 B	20.0	ug/L	ICLP ILM03.0	

Mercury (Cold Vapor Technique)					In Review
Mercury	ND	0.20	ug/L	ICLP ILM03.0	

Inductively Coupled Plasma					In Review
Arsenic	4.3 B	10.0	ug/L	ICLP ILM03.0	
Lead	1.4 B	3.0	ug/L	ICLP ILM03.0	
Selenium	ND	5.0	ug/L	ICLP ILM03.0	
Thallium	ND	10.0	ug/L	ICLP ILM03.0	

B Estimated result. Result is less than RL.

Volatile Organics by GC/MS					In Review
Benzene	ND	10000	ug/L	SW846 8260A	
Bromobenzene	ND	10000	ug/L	SW846 8260A	
Bromochloromethane	ND	10000	ug/L	SW846 8260A	
Bromodichloromethane	ND	10000	ug/L	SW846 8260A	
Bromoform	ND	10000	ug/L	SW846 8260A	

(Continued on next page)

QUANTERRA INCORPORATED
PRELIMINARY DATA SUMMARY

 e results shown below may still require additional laboratory review and are subject to
 change. Actions taken based on these results are the responsibility of the data user.

Lot #: H7H250122 Baker Environmental, Inc. PAGE 2
 Camp LeJeune Date Reported: 9/03/97
 Project Number: CTO-356

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
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Client Sample ID: IR88-RW01-97C
 Sample #: 001 Date Sampled: 08/21/97 12:20 Date Received: 08/25/97 Matrix: WATER

Volatile Organics by GC/MS

In Review

Bromomethane	ND	20000	ug/L	SW846 8260A
n-Butylbenzene	ND	10000	ug/L	SW846 8260A
sec-Butylbenzene	ND	10000	ug/L	SW846 8260A
tert-Butylbenzene	ND	10000	ug/L	SW846 8260A
Carbon tetrachloride	ND	10000	ug/L	SW846 8260A
Chlorobenzene	ND	10000	ug/L	SW846 8260A
Chlorodibromomethane	ND	10000	ug/L	SW846 8260A
Chloroethane	ND	20000	ug/L	SW846 8260A
Chloroform	ND	10000	ug/L	SW846 8260A
Chloromethane	ND	20000	ug/L	SW846 8260A
2-Chlorotoluene	ND	10000	ug/L	SW846 8260A
4-Chlorotoluene	ND	10000	ug/L	SW846 8260A
1,2-Dibromo-3-chloro- propane	ND	20000	ug/L	SW846 8260A
1,2-Dibromoethane	ND	10000	ug/L	SW846 8260A
Dibromomethane	ND	10000	ug/L	SW846 8260A
1,2-Dichlorobenzene	ND	10000	ug/L	SW846 8260A
1,3-Dichlorobenzene	ND	10000	ug/L	SW846 8260A
1,4-Dichlorobenzene	ND	10000	ug/L	SW846 8260A
Dichlorodifluoromethane	ND	20000	ug/L	SW846 8260A
1,1-Dichloroethane	ND	10000	ug/L	SW846 8260A
1,2-Dichloroethane	ND	10000	ug/L	SW846 8260A
1,1-Dichloroethene	ND	10000	ug/L	SW846 8260A
cis-1,2-Dichloroethene	11000	5000	ug/L	SW846 8260A
trans-1,2-Dichloroethene	ND	5000	ug/L	SW846 8260A
1,2-Dichloropropane	ND	10000	ug/L	SW846 8260A
1,3-Dichloropropane	ND	10000	ug/L	SW846 8260A
2,2-Dichloropropane	ND	10000	ug/L	SW846 8260A
1,1-Dichloropropene	ND	10000	ug/L	SW846 8260A
Ethylbenzene	ND	10000	ug/L	SW846 8260A
Hexachlorobutadiene	ND	10000	ug/L	SW846 8260A
Isopropylbenzene	ND	10000	ug/L	SW846 8260A
p-Isopropyltoluene	ND	10000	ug/L	SW846 8260A
Methylene chloride	ND	10000	ug/L	SW846 8260A
Naphthalene	ND	10000	ug/L	SW846 8260A
n-Propylbenzene	ND	10000	ug/L	SW846 8260A
Styrene	ND	10000	ug/L	SW846 8260A

(Continued on next page)

QUANTERRA INCORPORATED

PRELIMINARY DATA SUMMARY

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Lot #: H7H250122
 Baker Environmental, Inc.
 Camp LeJeune
 Project Number: CTO-356
 Date Reported: 9/03/97
 PAGE 4

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
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Client Sample ID: IR88-RW02-97C
 Sample #: 002 Date Sampled: 08/22/97 09:12 Date Received: 08/25/97 Matrix: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD	
Volatile Organics by GC/MS					In Review
Chloroethane	ND	20000	ug/L	SW846 8260A	
Chloroform	ND	10000	ug/L	SW846 8260A	
Chloromethane	ND	20000	ug/L	SW846 8260A	
2-Chlorotoluene	ND	10000	ug/L	SW846 8260A	
4-Chlorotoluene	ND	10000	ug/L	SW846 8260A	
1,2-Dibromo-3-chloro-propane	ND	20000	ug/L	SW846 8260A	
1,2-Dibromoethane	ND	10000	ug/L	SW846 8260A	
Dibromomethane	ND	10000	ug/L	SW846 8260A	
1,2-Dichlorobenzene	ND	10000	ug/L	SW846 8260A	
1,3-Dichlorobenzene	ND	10000	ug/L	SW846 8260A	
1,4-Dichlorobenzene	ND	10000	ug/L	SW846 8260A	
Dichlorodifluoromethane	ND	20000	ug/L	SW846 8260A	
1,1-Dichloroethane	ND	10000	ug/L	SW846 8260A	
1,2-Dichloroethane	ND	10000	ug/L	SW846 8260A	
1,1-Dichloroethene	ND	10000	ug/L	SW846 8260A	
cis-1,2-Dichloroethene	10000	5000	ug/L	SW846 8260A	
trans-1,2-Dichloroethene	ND	5000	ug/L	SW846 8260A	
1,2-Dichloropropane	ND	10000	ug/L	SW846 8260A	
1,3-Dichloropropane	ND	10000	ug/L	SW846 8260A	
2,2-Dichloropropane	ND	10000	ug/L	SW846 8260A	
1,1-Dichloropropene	ND	10000	ug/L	SW846 8260A	
Ethylbenzene	ND	10000	ug/L	SW846 8260A	
Hexachlorobutadiene	ND	10000	ug/L	SW846 8260A	
Isopropylbenzene	ND	10000	ug/L	SW846 8260A	
p-Isopropyltoluene	ND	10000	ug/L	SW846 8260A	
Methylene chloride	ND	10000	ug/L	SW846 8260A	
Naphthalene	ND	10000	ug/L	SW846 8260A	
n-Propylbenzene	ND	10000	ug/L	SW846 8260A	
Styrene	ND	10000	ug/L	SW846 8260A	
1,1,1,2-Tetrachloroethane	ND	10000	ug/L	SW846 8260A	
1,1,2,2-Tetrachloroethane	ND	10000	ug/L	SW846 8260A	
Tetrachloroethene	150000	10000	ug/L	SW846 8260A	
Toluene	ND	10000	ug/L	SW846 8260A	
1,2,3-Trichlorobenzene	ND	10000	ug/L	SW846 8260A	
1,2,4-Trichlorobenzene	ND	10000	ug/L	SW846 8260A	
1,1,1-Trichloroethane	ND	10000	ug/L	SW846 8260A	

(Continued on next page)

QUANTERRA INCORPORATED

PRELIMINARY DATA SUMMARY

The results shown below may still require additional laboratory review and are subject to change. Actions taken based on these results are the responsibility of the data user.

Lot #: H7H250122 Baker Environmental, Inc. Camp LeJeune Date Reported: 9/03/97
 Project Number: CTO-356

Client Sample ID: IR88-RW02-97C
 Sample #: 002 Date Sampled: 08/22/97 09:12 Date Received: 08/25/97 Matrix: WATER

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
In Review				
Volatile Organics by GC/MS				
1,1,2-Trichloroethane	ND	10000	ug/L	SW846 8260A
Trichloroethene	3500 J	10000	ug/L	SW846 8260A
Trichlorofluoromethane	ND	20000	ug/L	SW846 8260A
1,2,3-Trichloropropane	ND	10000	ug/L	SW846 8260A
1,2,4-Trimethylbenzene	ND	10000	ug/L	SW846 8260A
1,3,5-Trimethylbenzene	ND	10000	ug/L	SW846 8260A
Vinyl chloride	ND	20000	ug/L	SW846 8260A
o-Xylene	ND	5000	ug/L	SW846 8260A
m-Xylene & p-Xylene	ND	5000	ug/L	SW846 8260A

J Estimated result. Result is less than RL.

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
In Review				
Inorganic Analysis				
Carbonate Alkalinity	ND	5.0	mg/L	SM18 2320 B

Client Sample ID: IR88-DRM01
 Sample #: 003 Date Sampled: 08/22/97 16:40 Date Received: 08/25/97 Matrix: SOLID

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
In Review				
Volatile Organics by GC/MS TCLP				
Benzene	ND	0.62	mg/L	SW846 8260A
Carbon tetrachloride	0.50 J	0.62	mg/L	SW846 8260A
Chlorobenzene	ND	0.62	mg/L	SW846 8260A
Chloroform	ND	0.62	mg/L	SW846 8260A
1,2-Dichloroethane	ND	0.62	mg/L	SW846 8260A
1,1-Dichloroethylene	ND	0.62	mg/L	SW846 8260A
Methyl ethyl ketone	ND	3.0	mg/L	SW846 8260A
Tetrachloroethylene	37	0.62	mg/L	SW846 8260A
Trichloroethylene	0.42 J	0.62	mg/L	SW846 8260A
Vinyl chloride	ND	1.2	mg/L	SW846 8260A

J Estimated result. Result is less than RL.

(Continued on next page)

QUANTERRA INCORPORATED

PRELIMINARY DATA SUMMARY

 The results shown below may still require additional laboratory review and are subject to change. Actions taken based on these results are the responsibility of the data user.

Lot #: H7K180134 Baker Environmental Camp LeJeune Date Reported: 12/15/97 PAGE 4
 Project Number: CTO-356

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
Client Sample ID: IR88-RW01-87D				
Sample #: 012 Date Sampled: 11/17/97 12:20 Date Received: 11/18/97 Matrix: WATER				
Aluminum	0.28	0.20	mg/L	SW846 6010A
Barium	ND	0.20	mg/L	SW846 6010A
Beryllium	ND	0.0050	mg/L	SW846 6010A
Calcium	15.7	5.0	mg/L	SW846 6010A
Cadmium	ND	0.0050	mg/L	SW846 6010A
Cobalt	ND	0.050	mg/L	SW846 6010A
Chromium	ND	0.010	mg/L	SW846 6010A
Copper	ND	0.025	mg/L	SW846 6010A
Iron	25.8	0.10	mg/L	SW846 6010A
Potassium	ND	5.0	mg/L	SW846 6010A
Magnesium	ND	5.0	mg/L	SW846 6010A
Manganese	0.094	0.015	mg/L	SW846 6010A
Sodium	19.7	5.0	mg/L	SW846 6010A
Nickel	ND	0.040	mg/L	SW846 6010A
Antimony	ND	0.060	mg/L	SW846 6010A
Vanadium	ND	0.050	mg/L	SW846 6010A
Zinc	0.023	0.020	mg/L	SW846 6010A

Mercury in Liquid Waste (Manual Cold-Vapor)					Reviewed
Mercury	ND	0.00020	mg/L	SW846 7470A	

Inorganic Analysis					Reviewed
Alkalinity, Total	28.2	5.0	mg/L	SM18 2320 B	
Alkalinity, Total	31.5	5.0	mg/L	SM18 2320 B	
Bromide	0.84	0.50	mg/L	MCAWW 300.0A	
Chloride	66.0	5.0	mg/L	MCAWW 300.0A	
Fluoride	ND	1.0	mg/L	MCAWW 300.0A	
Nitrite as N	ND	0.50	mg/L	MCAWW 300.0A	
Nitrate as N	ND	0.50	mg/L	MCAWW 300.0A	
o-Phosphate as P	ND	1.0	mg/L	MCAWW 300.0A	
Sulfate	16.1	1.0	mg/L	MCAWW 300.0A	

(Continued on next page)

QUANTERRA INCORPORATED

PRELIMINARY DATA SUMMARY

The results shown below may still require additional laboratory review and are subject to change. Actions taken based on these results are the responsibility of the data user.

Lot #: H7K180134 Baker Environmental Camp LeJeune Project Number: CTC-356 Date Reported: 12/15/97 PAGE 5

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
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Client Sample ID: IR88-RW02-97D

Sample #: 013 Date Sampled: 11/17/97 12:35 Date Received: 11/18/97 Matrix: WATER

Trace Inductively Coupled Plasma (ICP) Metals

Arsenic	ND	0.010	mg/L	SW846 6010A
Lead	ND	0.0030	mg/L	SW846 6010A
Selenium	ND	0.0050	mg/L	SW846 6010A
Thallium	ND	0.010	mg/L	SW846 6010A

Reviewed

Inductively Coupled Plasma (ICP) Metals

Silver	ND	0.010	mg/L	SW846 6010A
Aluminum	0.33	0.20	mg/L	SW846 6010A
Barium	ND	0.20	mg/L	SW846 6010A
Beryllium	ND	0.0050	mg/L	SW846 6010A
Calcium	15.1	5.0	mg/L	SW846 6010A
Cadmium	ND	0.0050	mg/L	SW846 6010A
Cobalt	ND	0.050	mg/L	SW846 6010A
Chromium	ND	0.010	mg/L	SW846 6010A
Copper	ND	0.025	mg/L	SW846 6010A
Iron	6.1	0.10	mg/L	SW846 6010A
Potassium	9.9	5.0	mg/L	SW846 6010A
Magnesium	5.3	5.0	mg/L	SW846 6010A
Manganese	0.10	0.015	mg/L	SW846 6010A
Sodium	30.9	5.0	mg/L	SW846 6010A
Nickel	ND	0.040	mg/L	SW846 6010A
Antimony	ND	0.060	mg/L	SW846 6010A
Vanadium	ND	0.050	mg/L	SW846 6010A
Zinc	0.039	0.020	mg/L	SW846 6010A

Reviewed

Mercury in Liquid Waste (Manual Cold-Vapor)

Mercury	ND	0.00020	mg/L	SW846 7470A
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Reviewed

Inorganic Analysis

Alkalinity, Total	ND	5.0	mg/L	SM18 2320 B
Bromide	ND	0.50	mg/L	MCAWW 300.0A
Chloride	45.5	5.0	mg/L	MCAWW 300.0A
Fluoride	ND	1.0	mg/L	MCAWW 300.0A
Nitrite as N	ND	0.50	mg/L	MCAWW 300.0A
Nitrate as N	1.0	0.50	mg/L	MCAWW 300.0A
o-Phosphate as P	ND	1.0	mg/L	MCAWW 300.0A

Reviewed

(Continued on next page)

QUANTERRA INCORPORATED

PRELIMINARY DATA SUMMARY

 The results shown below may still require additional laboratory review and are subject to change. Actions taken based on these results are the responsibility of the data user.

Lot #: H7K180134 Baker Environmental. Camp LeJeune Project Number: CTO-356
 Date Reported: 12/15/97 PAGE 7

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD
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Client Sample ID: IR88-FB02

Sample #: 014 Date Sampled: 11/17/97 14:20 Date Received: 11/18/97 Matrix: WATER

Inorganic Analysis

Alkalinity, Total	63.9	5.0	mg/L	SM18.2320 B	Reviewed
Bromide	ND	0.50	mg/L	MCAWW 300.0A	
Chloride	12.4	1.0	mg/L	MCAWW 300.0A	
Fluoride	ND	1.0	mg/L	MCAWW 300.0A	
Nitrite as N	ND	0.50	mg/L	MCAWW 300.0A	
Nitrate as N	ND	0.50	mg/L	MCAWW 300.0A	
o-Phosphate as P	ND	1.0	mg/L	MCAWW 300.0A	
Sulfate	5.4	1.0	mg/L	MCAWW 300.0A	

QUANTERRA INCORPORATED

PRELIMINARY DATA SUMMARY

The results shown below may still require additional laboratory review and are subject to change. Actions taken based on these results are the responsibility of the data user.

Lot #: H7K180134 Baker Environmental Camp LeJeune Project Number: CTO-356 Date Reported: 12/15/97 PAGE 6

PARAMETER	RESULT	REPORTING LIMIT	UNITS	ANALYTICAL METHOD	
Sulfate	46.7	5.0	mg/L	MCAWW 300.0A	Reviewed

Client Sample ID: IR88-RW02-97D

Sample #: 013 Date Sampled: 11/17/97 12:35 Date Received: 11/18/97 Matrix: WATER

Client Sample ID: IR88-FB02

Sample #: 014 Date Sampled: 11/17/97 14:20 Date Received: 11/18/97 Matrix: WATER

Trace Inductively Coupled Plasma (ICP) Metals

Arsenic	ND	0.010	mg/L	SW846 6010A	Reviewed
Lead	ND	0.0030	mg/L	SW846 6010A	
Selenium	ND	0.0050	mg/L	SW846 6010A	
Thallium	ND	0.010	mg/L	SW846 6010A	

Inductively Coupled Plasma (ICP) Metals

Silver	ND	0.010	mg/L	SW846 6010A	Reviewed
Aluminum	0.20	0.20	mg/L	SW846 6010A	
Barium	ND	0.20	mg/L	SW846 6010A	
Beryllium	ND	0.0050	mg/L	SW846 6010A	
Calcium	26.9	5.0	mg/L	SW846 6010A	
Cadmium	ND	0.0050	mg/L	SW846 6010A	
Cobalt	ND	0.050	mg/L	SW846 6010A	
Chromium	ND	0.010	mg/L	SW846 6010A	
Copper	ND	0.025	mg/L	SW846 6010A	
Iron	ND	0.10	mg/L	SW846 6010A	
Potassium	ND	5.0	mg/L	SW846 6010A	
Magnesium	ND	5.0	mg/L	SW846 6010A	
Manganese	ND	0.015	mg/L	SW846 6010A	
Sodium	9.0	5.0	mg/L	SW846 6010A	
Nickel	ND	0.040	mg/L	SW846 6010A	
Antimony	ND	0.060	mg/L	SW846 6010A	
Vanadium	ND	0.050	mg/L	SW846 6010A	
Zinc	ND	0.020	mg/L	SW846 6010A	

Mercury in Liquid Waste (Manual Cold-Vapor)

Mercury	ND	0.00020	mg/L	SW846 7470A	Reviewed
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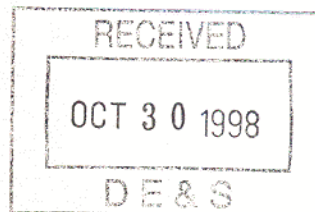


Duke Engineering & Services 9111 Research Blvd. Austin, TX 78758	Project: MCB Camp Lejune - Site 88 Sear Project Number: none Project Manager: Fred Holzmer	Sampled: 9/24/98 Received: 9/25/98 Reported: 10/21/98 13:13
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ANALYTICAL REPORT FOR SAMPLES:

Sample Description	Laboratory Sample Number	Sample Matrix	Date Sampled
88 Source - 98	8090283-01	Water	9/24/98
88 Source - 98	8090283-02	Water	9/24/98

Source Water: Major ion analysis



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*The results in this report apply to the samples analyzed in accordance with the chain of custody document.
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Duke Engineering & Services 9111 Research Blvd. Austin, TX 78758	Project: MCB Camp Lejune - Site 88 Sear Project Number: none Project Manager: Fred Holzmer	Sampled: 9/24/98 Received: 9/25/98 Reported: 10/21/98 13:13
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Total Metals by EPA 200 Series Methods Star Analytical, Inc.

Analyte	Batch Number	Date Prepared	Date Analyzed	Specific Method	Reporting Limit	Result	Units	Notes*
88 Source - 98				8090283-01			Water	
Magnesium	10V8211	10/11/98	10/14/98	EPA 200.7	0.500	2.00	mg/l	
Calcium	"	"	"	EPA 200.7	2.00	21.0	"	
Potassium	10V8323	"	10/20/98	EPA 200.7	0.500	1.40	"	
Sodium	"	"	"	EPA 200.7	5.00	8.00	"	

Star Analytical, Inc.

**Refer to end of report for text of notes and definitions.*

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Duke Engineering & Services 9111 Research Blvd. Austin, TX 78758	Project: MCB Camp Lejune - Site 88 Sear Project Number: none Project Manager: Fred Holzmer	Sampled: 9/24/98 Received: 9/25/98 Reported: 10/21/98 13:13
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Conventional Chemistry Parameters by APHA/EPA Methods Star Analytical, Inc.

Analyte	Batch Number	Date Prepared	Date Analyzed	Specific Method	Reporting Limit	Result	Units	Notes*
88 Source - 98				8090283-02			Water	
Chloride	10V8138	10/8/98	10/8/98	EPA 325.3	0.30	13	mg/l	
Fluoride	10V8074	10/2/98	10/2/98	EPA 340.2	0.100	ND	"	
Nitrate-Nitrogen	09V8385	9/28/98	9/25/98	EPA 352.1	0.20	ND	"	
Nitrate/Nitrite-Nitrogen	09V8397	9/18/98	"	EPA 353.3	0.10	ND	"	
Phosphorus	10V8120	10/5/98	10/1/98	EPA 365.2	0.10	ND	"	
Sulfate	09V8456	9/29/98	9/29/98	EPA 375.4	1.0	7.7	"	
Bicarbonate Alkalinity	10V8194	10/7/98	10/7/98	SM 2320B	10	33	"	

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Duke Engineering & Services 9111 Research Blvd. Austin, TX 78758	Project: MCB Camp Lejune - Site 88 Sear Project Number: none Project Manager: Fred Holzmer	Sampled: 9/24/98 Received: 9/25/98 Reported: 10/21/98 13:13
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Total Metals by EPA 200 Series Methods/Quality Control Star Analytical, Inc.

Analyte	Date Analyzed	Spike Level	Sample Result	QC Result	Units	Reporting Limit Recov. Limits	Recov. %	RPD Limit	RPD %	Notes*
Batch: 10V8211			Date Prepared: 10/11/98			Extraction Method: General Preparation				
Blank 10V8211-BLK1										
Calcium	10/14/98			ND	mg/l	0.200				
Magnesium	"			ND	"	0.100				
Blank 10V8211-BLK2										
Calcium	10/14/98			ND	mg/l	0.200				
Magnesium	"			ND	"	0.100				
LCS 10V8211-BS1										
Calcium	10/14/98	1.00		1.30	mg/l	80.0-120	130			
Magnesium	"	1.00		1.20	"	80.0-120	120			
LCS 10V8211-BS2										
Calcium	10/14/98	1.00		1.10	mg/l	80.0-120	110			
LCS Dup 10V8211-BSD1										
Calcium	10/14/98	1.00		1.10	mg/l	80.0-120	110	20.0	16.7	
Magnesium	"	1.00		1.10	"	80.0-120	110	20.0	8.70	
LCS Dup 10V8211-BSD2										
Calcium	10/14/98	1.00		1.30	mg/l	80.0-120	130	20.0	16.7	
Batch: 10V8323			Date Prepared: 10/11/98			Extraction Method: General Preparation				
Blank 10V8323-BLK1										
Potassium	10/20/98			ND	mg/l	0.500				
Sodium	"			ND	"	0.500				
LCS 10V8323-BS1										
Potassium	10/20/98	10.0		10.0	mg/l	80.0-120	100			
Sodium	"	1.00		0.960	"	80.0-120	96.0			
LCS Dup 10V8323-BSD1										
Potassium	10/20/98	10.0		9.70	mg/l	80.0-120	97.0	20.0	3.05	
Sodium	"	1.00		0.900	"	80.0-120	90.0	20.0	6.45	

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Conventional Chemistry Parameters by APHA/EPA Methods/Quality Control Star Analytical, Inc.

Analyte	Date Analyzed	Spike Level	Sample Result	QC Result	Units	Reporting Limit Recov. Limits	Recov. %	RPD Limit	RPD %	Notes*
Batch: 09V8385	Date Prepared: 9/18/98		Extraction Method: General Preparation							
Blank	09V8385-BLK1									
Nitrate-Nitrogen	9/18/98			ND	mg/l	0.20				
Duplicate	09V8385-DUP1	8090192-02								
Nitrate-Nitrogen	9/28/98		ND	ND	mg/l					
Batch: 09V8397	Date Prepared: 9/18/98		Extraction Method: EPA 1311/3010							
Blank	09V8397-BLK1									
Nitrate/Nitrite-Nitrogen	9/25/98			ND	mg/l	0.10				
LCS	09V8397-BS1									
Nitrate/Nitrite-Nitrogen	9/18/98	0.80		0.85	mg/l	70-130	110			
LCS Dup	09V8397-BSD1									
Nitrate/Nitrite-Nitrogen	9/18/98	0.80		0.85	mg/l	70-130	110	30	0	
Duplicate	09V8397-DUP1	8090283-02								
Nitrate/Nitrite-Nitrogen	9/25/98		ND	ND	mg/l			30		
Batch: 09V8456	Date Prepared: 9/29/98		Extraction Method: General Preparation							
Blank	09V8456-BLK1									
Sulfate	9/23/98			1.8	mg/kg	1.0				
LCS	09V8456-BS1									
Sulfate	9/23/98	20		9.8	mg/kg	70-130	49			
LCS Dup	09V8456-BSD1									
Sulfate	9/29/98	20		9.5	mg/kg	70-130	48	30	2.1	
Duplicate	09V8456-DUP1	8090283-02								
Sulfate	9/29/98		7.7	7.7	mg/kg			30	0	
Batch: 10V8074	Date Prepared: 10/2/98		Extraction Method: General Preparation							
Blank	10V8074-BLK1									
Fluoride	10/2/98			ND	mg/l	0.100				
LCS	10V8074-BS1									
Fluoride	10/2/98	0.100		0.100	mg/l	78.0-113	100			
Duplicate	10V8074-DUP1	8090283-02								
Fluoride	10/2/98		ND	ND	mg/l			25.0		

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Duke Engineering & Services
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Austin, TX 78758

Project: MCB Camp Lejune - Site 88 Sear
Project Number: none
Project Manager: Fred Holzmer

Sampled: 9/24/98
Received: 9/25/98
Reported: 10/21/98 13:13

Conventional Chemistry Parameters by APHA/EPA Methods/Quality Control Star Analytical, Inc.

Analyte	Date Analyzed	Spike Level	Sample Result	QC Result	Units	Reporting Limit Recov. Limits	Recov. %	RPD Limit	RPD %	Notes*
Batch: 10V8120			Date Prepared: 10/5/98			Extraction Method: General Preparation				
Blank	10V8120-BLK1									
Phosphorus	10/1/98			ND	mg/l	0.10				
Duplicate			10V8120-DUP1			8090304-06				
Phosphorus	10/1/98		1.5	1.8	mg/l			30	18	
Batch: 10V8138			Date Prepared: 10/8/98			Extraction Method: General Preparation				
Blank	10V8138-BLK1									
Chloride	10/8/98			ND	mg/l	0.30				
LCS			10V8138-BS1							
Chloride	10/8/98	890		910	mg/l	90-110	100			
Duplicate			10V8138-DUP1			8090283-02				
Chloride	10/8/98		13	12	mg/l			16	8.0	
Batch: 10V8194			Date Prepared: 10/7/98			Extraction Method: General Preparation				
Blank	10V8194-BLK1									
Bicarbonate Alkalinity	10/7/98			ND	mg/l	1.00				
Duplicate			10V8194-DUP1			8090283-02				
Bicarbonate Alkalinity	10/7/98		33	26	mg/l			30.0	24	



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Duke Engineering & Services 9111 Research Blvd. Austin, TX 78758	Project: MCB Camp Lejune - Site 88 Sear Project Number: none Project Manager: Fred Holzmer	Sampled: 9/24/98 Received: 9/25/98 Reported: 10/21/98 13:13
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Notes and Definitions

#	Note
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- D Data reported from a dilution.
- DET Analyte DETECTED
- ND Analyte NOT DETECTED at or above the reporting limit
- NR Not Reported
- dry Sample results reported on a dry weight basis
- Recov. Recovery
- RPD Relative Percent Difference

Star Analytical, Inc.

Lari Hall, Project Manager

APPENDIX F

Soil Concentration Correction Calculations: Extract Volume Calculation and Soil Concentration Conversion

Appendix F

Extract Volume Calculation and Soil Concentration Conversion

Extract Volume Correction Calculation (VE)

$$VE = V_{\text{meoh}} + V_{\text{sw}}$$

Where:

- VE = Extract Volume (mL)
- V_{meoh} = Volume of methanol (mL)
- V_{sw} = Volume of soil water (mL)

$$V_{\text{meoh}} = M_{\text{meoh}} \rho_{\text{meoh}}$$

Where:

- M_{meoh} = mass Methanol (gms)
- ρ_{meoh} = density of methanol (0.79 gms/mL)

$$M_w = \% \text{ soil moisture } (M_s)$$

Where:

- M_w = Mass soil water (gms)
- M_s = Mass soil (gms)

Since density of water = 1 gm/ml then mass in grams is equal to volume in ml.

Sample calculation for sample IS07-02

Volume of methanol	$(57.0\text{gms} - 126.9\text{gms}) / 0.79\text{gm/ml} = 38.1\text{ml}$
Mass of Soil	$303.0\text{ gms} - 157.0\text{ gms} = 146\text{ gms}$
Mass of Water	$146\text{gms} (0.2) = 29.2\text{ gms}$ percent soil moisture = 20%
Volume of water	29.2 ml assuming density of water = 1 gm/ml
Extract Volume	$38.\text{ml} + 29.2\text{ ml} = 67.3\text{ ml}$

Extract Concentration from Reported Soil Concentration

$$RO\ OCC\ (df)\ (V_{meoh})/[1,000(M_s)]$$

Where:

RC = Reported soil concentration ($\mu\text{g}/\text{kg}$)

OCC = On column concentration ($\mu\text{g}/\text{L}$)

df = sample dilution factor

M_s = Mass of soil (gms)

1,000 = unit conversion factor

$$EC = OCC(df)$$

Where:

EC = extract concentration ($\mu\text{g}/\text{L}$)

Then:

$$EC\ RC(M_s)(1000)N_{meoh}$$

Sample calculation for sample IS07-02

Extract concentration ($\mu\text{g}/\text{L}$)

$$110,830\mu\text{g}/\text{kg}(146\text{gms})(1,000)/38,100\mu\text{l} = 424,703\ (\mu\text{g}/\text{L})$$

Soil Concentration Conversion

$$M_{pce} = EC(V_E)(1,000)$$

Where:

M_{pce} = mass of POE (mg)

$$SC = M_{pce}(1000)/M_s$$

Where:

SC = concentration of PCE in soil ($\mu\text{g}/\text{kg}$)

Sample calculation for sample IS07-02

Mass of PCE (μg)

$$424,703\ (\mu\text{g}/\text{L})\ (67.3\ \text{ml})/(1,000\ \text{ml}/\text{L})\ 28582.5\ \mu\text{g}$$

Concentration in soil ($\mu\text{g}/\text{kg}$)

$$28582.5\ \mu\text{g}\ (1,000\ \text{gms}/\text{kg})/146\ \text{gms} = 195,771\mu\text{g}/\text{kg}$$

Soil VOC Concentration Correction Calculations

The reason for the correction to the lab-reported soil VOC concentrations is explained as follows. As discussed in Section 3.1.1, the soil samples collected for VOC analysis were preserved in the field with methanol to minimize volatile losses of VOCs from the samples during sample collection, shipment, and analysis. In addition to acting as a VOC preservative for the samples, the methanol also functions as a solvent to extract VOCs from the soil samples. The liquid extract in each soil sample jar, “as received” by the lab, was then analyzed for VOCs by the lab. The soil concentration results reported by the laboratory were incorrect because the calculations to determine soil VOC concentrations were based on the assumption that the total volume of liquid extract in each sample jar was composed only of methanol and VOCs. However, since water is also miscible with methanol, along with the VOCs, the total liquid volume in the soil samples received by the lab consisted of methanol, soil water, and VOCs. Soil water can account for as much as 45% of the total liquid volume in a methanol-preserved soil sample, and therefore, must be accounted for in the analysis in order to accurately convert to soil VOC concentrations. The volume of water in the soil samples can be calculated if the percent soil moisture (by weight) is known. The soil moisture values in Table 3.3 indicates that 20% is generally representative of the moisture content of the soil samples collected at Site 88. The laboratory-reported analytical values were corrected for the sample volume error by assuming 20% moisture content for all samples. The corrected raw analytical results were then converted from a concentration of VOC in $\mu\text{g/L}$ of extract solution to $\mu\text{g/Kg}$ of wet soil.

The correction calculations are a 3-part calculation process:

- 1) Extract volume correction;
- 2) Extract concentration from misreported soil concentration;
- 3) Soil concentration conversion

The process is shown below and includes a sample calculation.

1) Extract Volume Correction (V_E)

$$V_E = V_{\text{meoh}} + V_{\text{sw}}$$

Where:

$$\begin{aligned} V_E &= \text{Extract Volume (mL)} \\ V_{\text{meoh}} &= \text{Volume of methanol (mL)} \\ V_{\text{sw}} &= \text{Volume of soil water (mL)} \end{aligned}$$

$$V_{\text{meoh}} = M_{\text{meoh}} / \rho_{\text{meoh}}$$

Where:

$$\begin{aligned} M_{\text{meoh}} &= \text{mass Methanol (gms)} \\ \rho_{\text{meoh}} &= \text{density of methanol (0.79 gms/mL)} \end{aligned}$$

$$M_w = \% \text{ soil moisture (} M_s \text{)}$$

Where:

$$\begin{aligned} M_w &= \text{Mass soil water (gms)} \\ M_s &= \text{Mass soil (gms)} \end{aligned}$$

Since density of water = 1 gm/ml then mass in grams is equal to volume in ml.

Sample calculation for sample IS07-02

Volume of methanol	(157.0gms - 126.9gms) / 0.79gm/ml = 38.1ml
Mass of Soil	303.0 gms - 157.0 gms = 146 gms
Mass of Water	146gms (0.2) = 29.2 gms percent soil moisture = 20%
Volume of water	29.2 ml assuming density of water = 1 gm/ml
Extract Volume	38.1ml + 29.2 ml = 67.3 ml

2) Extract Concentration from Misreported Soil Concentration

$$RC \text{ OCC (df)} = (V_{\text{meoh}}) / [1,000(M_s)]$$

Where:

RC = Reported soil concentration ($\mu\text{g}/\text{kg}$)
 OCC = On column concentration ($\mu\text{g}/\text{L}$)
 df = sample dilution factor
 M_s = Mass of soil (gms)
 1,000 = unit conversion factor

$$EC = OCC(df)$$

Where:

EC = extract concentration ($\mu\text{g}/\text{L}$)

Then:

$$EC = RC(M_s)(1000)/V_{\text{meoh}}$$

Sample calculation for sample IS07-02

Extract concentration ($\mu\text{g}/\text{L}$)

$$110,830\mu\text{g}/\text{kg}(146\text{gms})(1,000)/38,100\mu\text{l} = 424,703 (\mu\text{g}/\text{L})$$

3) Soil concentration Conversion

$$M_{\text{pce}} = EC(V_E)(1,000)$$

Where:

M_{pce} = mass of PCE (mg)

$$SC = M_{\text{pce}}(1000)/M_s$$

Where:

SC = concentration of PCE in soil ($\mu\text{g}/\text{kg}$)

Sample calculation for sample IS07-02

Mass of PCE (p.g)

$$424,703 (\mu\text{g}/\text{L}) (67.3 \text{ ml}) / (1,000 \text{ ml/L}) = 28582.5 \mu\text{g}$$

Concentration in soil ($\mu\text{g}/\text{kg}$)

$$28582.5 \mu\text{g} (1,000 \text{ gms}/\text{kg}) / 146 \text{ gms} = 195,771 \mu\text{g}/\text{kg}$$

SOIL SAMPLES PRESERVATIVE LOG

Sample Number	Tare (gm)	Tare + Methanol (gm)	Final Weight (gm) Soil + methanol	Volume Added (ml)
1501-1	127.3	156.8	264.7	
1501-2	127.3	150.5	291.3	
1501-3	128.6	161.2	285.9	
1501-4	127.5	152.7	271.9	
1502-1	126.6	153.0	297.0	
1502-2	126.3	152.8	302.3	
1502-3	128.4	161.5	274.9	
1503-1	127.6	150.8	251.2	
1503-2	128.6	163.2	288.2	
1503-3	126.6	152.8	280.3	
1502-4	127.6	159.5	232.1	
1504-1	127.6	157.8	299.3	
1505-1	127.3	156.6	268.6	
1505-2	127.1	156.2	279.5	
1505-3	128.2	158.7	287.1	
1505-4	127.0	155.7	280.3	
1506-1	127.4	159.2	317.9	
1507-1	127.4	156.9	292.3	
1507-2	126.9	157.0	303.0	
1507-3	125.6	156.1	311.9	
1507-4	126.0	152.7	250.6	
1508-1	126.5	156.6	241.1	
1508-2	127.5	153.7	229.8	
1508-3	126.0	151.8	225.3	
1508-4	126.3	159.2	280.0	

MILW
SPLASH

BAKER ENVIRONMENTAL

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) SOLID

Lab Sample ID:H7G290134 019

Method: SW846 8260A

Volatile Organics, GC/MS (8260A)

Sample WT/Vol: 5 / mL

Date Received: 07/29/97

Work Order: CC006202

Date Extracted:08/03/97

Dilution factor: 870

Date Analyzed: 08/03/97

Moisture %:

QC Batch: 7215125

Client Sample Id: IS07-2 -RE 1

CAS NO.	COMPOUND	CONCENTRATION UNITS:	
		(ug/L or ug/kg)	ug/kg
71-43-2	Benzene	4400	U
108-86-1	Bromobenzene	4400	U
74-97-5	Bromochloromethane	4400	U
75-27-4	Bromodichloromethane	4400	U
75-25-2	Bromoform	4400	U
74-83-9	Bromomethane	8700	U
104-51-8	n-Butylbenzene	4400	U
135-98-8	sec-Butylbenzene	4400	U
98-06-6	tert-Butylbenzene	4400	U
56-23-5	Carbon tetrachloride	4400	U
108-90-7	Chlorobenzene	4400	U
124-48-1	Chlorodibromomethane	4400	U
75-00-3	Chloroethane	8700	U
67-66-3	Chloroform	4400	U
74-87-3	Chloromethane	8700	U
95-49-8	2-Chlorotoluene	4400	U
106-43-4	4-Chlorotoluene	4400	U
96-12-8	1,2-Dibromo-3-chloropropane	8700	U
106-93-4	1,2-Dibromoethane	4400	U
74-95-3	Dibromomethane	4400	U
95-50-1	1,2-Dichlorobenzene	4400	U
541-73-1	1,3-Dichlorobenzene	4400	U
106-46-7	1,4-Dichlorobenzene	4400	U
75-71-8	Dichlorodifluoromethane	8700	U
75-34-3	1,1-Dichloroethane	4400	U
107-06-2	1,2-Dichloroethane	4400	U
75-35-4	1,1-Dichloroethene	4400	U
156-59-2	cis-1,2-Dichloroethene	46000	
156-60-5	trans-1,2-Dichloroethene	2200	U

BAKER ENVIRONMENTAL

Lab Name:QUANTERRA

SDG Number:

Matrix: (soil/water) SOLID

Lab Sample ID:H7G290134 019

Method: SW846 8260A

Volatile Organics, GC/MS (8260A)

Sample WT/Vol: 5 / mL

Date Received: 07/29/97

Work Order: CC006202

Date Extracted:08/03/97

Dilution factor: 870

Date Analyzed: 08/03/97

Moisture %:

QC Batch: 7215125

Client Sample Id: IS07-2 -RE 1

CAS NO.	COMPOUND	CONCENTRATION UNITS:	
		(ug/L or ug/kg)	ug/kg
78-87-5	1,2-Dichloropropane	4400	U
142-28-9	1,3-Dichloropropane	4400	U
594-20-7	2,2-Dichloropropane	4400	U
563-58-6	1,1-Dichloropropene	4400	U
100-41-4	Ethylbenzene	4400	U
87-58-3	Hexachlorobutadiene	4400	U
98-82-8	Isopropylbenzene	4400	U
99-87-6	p-Isopropyltoluene	4400	U
75-09-2	Methylene chloride	4400	U
91-20-3	Naphthalene	4400	U
103-65-1	n-Propylbenzene	4400	U
100-42-5	Styrene	4400	U
630-20-6	1,1,1,2-Tetrachloroethane	4400	U
79-34-5	1,1,2,2-Tetrachloroethane	4400	U
127-18-4	Tetrachloroethene	110000	
108-88-3	Toluene	4400	U
87-61-6	1,2,3-Trichlorobenzene	4400	U
120-82-1	1,2,4-Trichlorobenzene	4400	U
71-55-6	1,1,1-Trichloroethane	4400	U
79-00-5	1,1,2-Trichloroethane	4400	U
79-01-6	Trichloroethene	3900	J
75-69-4	Trichlorofluoromethane	8700	U
96-18-4	1,2,3-Trichloropropane	4400	U
95-63-6	1,2,4-Trimethylbenzene	3800	J
108-67-8	1,3,5-Trimethylbenzene	1700	J
75-01-4	Vinyl chloride	4800	J
95-47-6	o-Xylene	2200	U
136777-61-2	m-Xylene & p-Xylene	2200	U

Data File: /chem/gcms/mw.i/W080397.b/CC006202.d
 Report Date: 03-Aug-97 17:46:16

Quanterra - Knoxville

SW-846 Method 8260A - Volatile Organics
 Data file : /chem/gcms/mw.i/W080397.b/CC006202.d
 Lab Smp Id: CC006202
 Inj Date : 03-AUG-97 16:12:00
 Operator : 60487
 Smp Info : CC006202,870,0,,,
 Misc Info : W080397,MS8260_L,
 Comment :
 Method : /chem/gcms/mw.i/W080397.b/MS8260_L.m
 Meth Date : 03-Aug-97 13:19:28 wilesd Quant Type: ISTD
 Cal Date : 30-JUL-97 20:57:00 Cal File: WI0730A.d
 Als bottle: 1
 Dil Factor: 870.00000
 Integrator: HP RTE
 Target Version: 3.30
 Processing Host: hpuxcs12
 Inst ID: mw.i
 Compound Sublist: all.sub

Concentration Formula: $Vt/(Ws*1000)$

Name	Value	Description
Vt	5000.000	Sample Volume Purged
Ws	5.000	Weight of sample

Compounds	QUANT SIG MASS	RT	EXP RT	REL RT	RESPONSE	CONCENTRATIONS	
						ON-COLUMN (ug/L)	FINAL (ug/Kg)
* 1 Fluorobenzene	96	9.483	9.517	(1.000)	255535	50.0000	
* 2 Chlorobenzene-d5	117	13.833	13.900	(1.000)	237432	50.0000	
* 3 1,4 Dichlorobenzene-d4	152	17.417	17.517	(1.000)	176643	50.0000	
\$ 4 1,2-Dichloroethane-d4	65	9.100	9.133	(0.960)	86542	37.8135	37.814(a)
\$ 5 Toluene-d8	98	11.683	11.733	(0.845)	221489	46.1209	46.121(a)
\$ 6 4-Bromofluorobenzene	95	15.617	15.700	(0.897)	195307	41.3967	41.397(a)
7 Dichlorodifluoromethane	85.00	Compound Not Detected.					
8 Chloromethane (spcc)	50.00	Compound Not Detected.					
9 Vinyl Chloride (ccc)	62	3.050	3.050	(0.322)	9396	5.54636	4825.3(a)
10 Bromomethane	94.00	Compound Not Detected.					
11 Chloroethane	64.00	Compound Not Detected.					
12 Trichlorofluoromethane	101.00	Compound Not Detected.					
13 1,1-Dichloroethene (ccc)	96.00	Compound Not Detected.					
14 Carbon Disulfide	76.00	Compound Not Detected.					
15 Acetone	43	5.383	5.400	(0.568)	625	1.03861	903.59(a)
16 Methylene Chloride	84	6.017	6.033	(0.634)	2030	1.03158	897.48(a)
17 trans-1,2-Dichloroethene	96.00	Compound Not Detected.					

Data File: /chem/gcms/mw.i/W080397.b/CC006202.d
 Report Date: 03-Aug-97 17:46:16

Compounds	QUANT SIG MASS	RT	EXP RT	REL RT	RESPONSE	CONCENTRATIONS	
						ON-COLUMN (ug/L)	FINAL (ug/Kg)
18 1,1-Dichloroethane (spcc)	63.00				Compound Not Detected.		
19 2,2-Dichloropropane	77.00				Compound Not Detected.		
20 cis 1,2-Dichloroethene	96	7.917	7.950	(0.835)	108219	53.3411	46407
M 21 1,2-Dichloroethene (total)	96				108219	53.3411	46407
22 2-Butanone	43	7.967	7.983	(0.840)	736	0.58136	305.78(a)
23 Bromochloromethane	128.00				Compound Not Detected.		
24 Chloroform (ccc)	83.00				Compound Not Detected.		
25 1,1,1-Trichloroethane	97.00				Compound Not Detected.		
26 Carbon Tetrachloride	117.00				Compound Not Detected.		
27 1,1-Dichloropropene	75.00				Compound Not Detected.		
28 Benzene	78.00				Compound Not Detected.		
29 1,2-Dichloroethane	62	9.483	9.233	(1.000)	2706	1.00733	876.30(a)
30 Trichloroethene	130	9.967	10.017	(1.051)	12495	4.52553	3937.2(a)
31 1,2-Dichloropropane (ccc)	63.00				Compound Not Detected.		
32 Dibromomethane	93.00				Compound Not Detected.		
33 Bromodichloromethane	83.00				Compound Not Detected.		
34 cis-1,3-Dichloropropene	75.00				Compound Not Detected.		
35 4-Methyl-2-pentanone	43.00				Compound Not Detected.		
36 Toluene (ccc)	91.00				Compound Not Detected.		
37 trans-1,3-Dichloropropene	75.00				Compound Not Detected.		
38 1,1,2-Trichloroethane	97	12.533	12.500	(0.906)	1796	0.76042	664.37(a)
39 Tetrachloroethene	164	12.533	12.583	(0.906)	346227	127.392	110830
40 1,3-Dichloropropane	76.00				Compound Not Detected.		
41 2-Hexanone	43.00				Compound Not Detected.		
42 Chlorodibromomethane	129.00				Compound Not Detected.		
43 1,2-Dibromoethane	107.00				Compound Not Detected.		
44 Chlorobenzene (spcc)	112.00				Compound Not Detected.		
45 Ethylbenzene (ccc)	106.00				Compound Not Detected.		
46 1,1,1,2-Tetrachloroethane	131.00				Compound Not Detected.		
47 m&p-Xylene	106.00				Compound Not Detected.		
48 o-Xylene	106.00				Compound Not Detected.		
M 49 Xylene (total)	106.00				Compound Not Detected.		
50 Styrene	104.00				Compound Not Detected.		
51 Bromoform (spcc)	173.00				Compound Not Detected.		
52 Isopropylbenzene	105.00				Compound Not Detected.		
53 Bromobenzene	156.00				Compound Not Detected.		
54 1,1,2,2-Tetrachloroethane(sp)	83.00				Compound Not Detected.		
55 n-Propylbenzene	91.00				Compound Not Detected.		
56 1,2,3-Trichloropropane	75.00				Compound Not Detected.		
57 2-Chlorotoluene	91.00				Compound Not Detected.		
58 1,3,5-Trimethylbenzene	105	16.183	16.267	(0.929)	11347	1.97959	1722.2(a)
59 4-Chlorotoluene	91.00				Compound Not Detected.		
60 tert-Butylbenzene	119.00				Compound Not Detected.		
61 1,2,4-Trimethylbenzene	105	16.783	16.883	(0.964)	25716	4.33953	3775.4(a)
62 sec-Butylbenzene	105.00				Compound Not Detected.		
63 1,3-Dichlorobenzene	146.00				Compound Not Detected.		
64 p-Isopropyltoluene	119	17.233	17.333	(0.989)	3880	0.56635	492.72(a)
65 1,4-Dichlorobenzene	146.00				Compound Not Detected.		

7/28/97

APPENDIX G

**Porosity Calculation and
NAPLANAL paper
(Mariner et al, 1997)**

POROSITY FROM PERCENT SOIL MOISTURE

Assume pores are fully saturated with water, then:

$$\%w = m_p/m_t \times 100 \quad \text{and}$$

$$m_p = V_p \rho_w \quad \text{then:}$$

$$\%w = (V_p \rho_w / m_t) \times 100 \quad \text{rearranging}$$

$$V_p = \%w m_t / 100 \rho_w$$

where:

$\%w$ = percent soil moisture
 m_p = mass of water in pores
 m_t = total mass of sample
 V_p = volume of pores
 ρ_w = density of water

$$V_t = V_s + V_p \quad \text{Then}$$

$$V_t = m_s / \rho_s + V_p \quad \text{and}$$

$$m_s = m_t - m_p \quad \text{substituting}$$

$$V_t = (m_t - m_p) / \rho_s + V_p \quad \text{Finally}$$

$$V_t = (m_t - V_p \rho_w) / \rho_s + V_p$$

where:

V_T = total volume of sample
 V_s = volume of soil
 m_s = mass of soil
 ρ_s = density of soil

$$\eta = V_p / V_t \quad \text{Substituting}$$

$$\eta = (\%w m_t / 100 \rho_w) / ((m_t - V_p \rho_w) / \rho_s + V_p) \quad \text{Substitute for } V_p$$

$$\eta = (\%w m_t / 100\rho_w) / (((m_t - (\%w m_t / 100\rho_w)) / \rho_s + \%w m_t / 100\rho_w)$$

Divide top and bottom by m_t then:

$$\eta = (\%w / 100\rho_w) / (((1 - (\%w / 100\rho_w)) / \rho_s + \%w / 100\rho_w)$$

Multiply top and bottom by $100\rho_w$ then:

$$\eta = \%w / ((100\rho_w - \%w) / \rho_s + \%w)$$

where:

$$\eta = \text{porosity}$$

For soil correction calculations a value of 1 gm/ml was used for ρ_w and a value of 2.64 gm/ml was used for ρ_s . The above equation then becomes:

$$\eta = \%w / ((100 - \%w) / 2.64 + \%w)$$

Sample Calculation

Assuming soil moisture content of 20%.

$$\eta = 20 / ((100 - 20) / 2.64 + 20)$$

$$\eta = 20 / ((80) / 2.64 + 20)$$

$$\eta = 20 / (30.3 + 20)$$

$$\eta = 0.398$$

An Algorithm for the Estimation of NAPL Saturation and Composition from Typical Soil Chemical Analyses

by Paul E. Mariner, Minquan Jin, and Richard E. Jackson

Abstract

An algorithm is presented that allows estimation of the saturation and composition of a single or multi-component NAPL within a core sample. These estimates are possible because, in addition to distributing the organic chemicals between aqueous, sorbed, air, and NAPL phases according to traditional partitioning equations, the algorithm incorporates equations for the conservation of mass and volume. A unique solution is obtained by solving the set of nonlinear equations implicitly. The algorithm is built into a code called NAPEANAL, which is tested and applied to actual core samples collected in the field.

Introduction

It is an extraordinary feature of modern hydrogeological practice that estimating the mass or volume of nonaqueous phase liquid (NAPL) in a soil or rock is not deemed essential to the design of remediation systems. A brief inspection of past issues of this journal will show that NAPL volumes are seldom estimated from field data. Such a volume estimate permits the calculation of an approximate remediation period for the NAPL-contaminated soil or rock. An essential parameter for estimating NAPL volumes in a NAPL-contaminated soil or rock is the NAPL saturation of the porous medium. Mercer and Cohen (1990) have tabulated NAPL saturation data from the literature.

Paraphrasing Bear (1972), when the pore space of an aquifer sediment or fractured rock is contaminated with NAPL, the saturation (or degree of saturation) of NAPL at a particular point is defined as the fraction of pore space occupied by NAPL within a representative elementary volume (REV) around the considered point:

$$S_N = \frac{\text{volume of NAPL within REV}}{\text{total pore volume within REV}} \quad (1)$$

As pointed out by Corey (1994), "saturation can be conceptualized (but not measured) as a point property varying in space in a manner entirely analogous to porosity." The constraint of being unable to measure the saturation at a point arises from the size of the REV, which

Mayer and Miller (1992) found to vary directly with the nonuniformity of the porous medium such that "the upper range of these REV estimates (i.e., $\sim 10\text{-}10^4 \text{ cm}^3$) exceeds the scale of ... field samples typically taken to estimate NAPL residual saturation levels." It is for this reason of scale that Jin et al. (1995) have proposed using a partitioning interwell tracer test for measuring NAPL volume over a large interwell pore volume.

While soil cores cannot provide reliable NAPL saturations over large zones of the subsurface, they can provide information on the approximate volumes of NAPL present in the core samples. Furthermore, continuous coring can indicate the relative NAPL saturations with depth, which may allow an experienced observer to deduce whether pooling of NAPL may be occurring upon some capillary barrier, such as a clay lens. In addition, the analysis and interpretation of soil chemical data from cores indicate the nature of the chemical composition of the NAPL in the source zone. Finally, the chemical analysis of soil cores provides an approximate initial value of NAPL saturation which can be used in multiphase, multicomponent simulators such as UTCHEM for modeling surfactant-enhanced aquifer remediation (e.g., Brown et al. 1994) and the application of partitioning interwell tracer tests (e.g., Jin et al. 1995).

We are not aware of any published method for calculating NAPL saturation from a soil sample chemical analysis when more than one organic compound is identified in the analysis. Feenstra et al. (1991) showed how a measured organic concentration can be used to assess whether a single- or multicomponent NAPL is present in a soil sample, but not how NAPL saturation could be calculated. In addition, the method requires an a priori assumption of the NAPL chemical composition. Mott (1995) improved on the Feenstra et al. (1991) method by presenting a method that can be used to estimate multicomponent NAPL composition from a complete organic chemical soil sample analysis and to determine whether NAPL is present in the sample. The method, which is incorporated in a code called SOIL-CALC, distributes mass among all phases including the NAPL phase. However, because the method assumes that NAPL occupies no pore space, SOIL-CALC cannot be used to calculate NAPL saturation. Consequently, its calculations of NAPL composition and the concentrations of organic compounds in each phase are not accurate unless NAPL saturation is approximately two orders of magnitude lower than typical residual NAPL saturations. Typical residual NAPL saturations range from 10 percent to 20 percent in the vadose zone and from 15 percent to 50 percent in the saturated zone (Mercer and Cohen 1990).

In this paper, a model is presented for the implicit calculation of NAPL saturation, NAPL composition, and phase distribution of organic compounds in a core sample of soil or rock. This model was developed in 1993 as an extension of the model presented in Feenstra et al. (1991). In addition to the phase partitioning relationships, the model incorporates equations for the con-

servation of mass and volume. The algorithm distributes the organic chemicals among aqueous, air, sorbed, and NAPL phases so that both the NAPL saturation and the correct NAPL composition are determined regardless of the amount of NAPL in the sample.

Partitioning Theory

If NAPL exists in a core sample from the unsaturated zone, the NAPL components will be distributed among four physical phases: air, soil, water, and NAPL. Each NAPL component (i.e., each compound in the NAPL) is distributed among the phases according to thermodynamic equilibrium principles and mass transfer kinetic factors. The system reaches equilibrium when the chemical potential of any constituent is equal in all phases. Figure 1 shows a schematic representation of the equilibrium relationship.

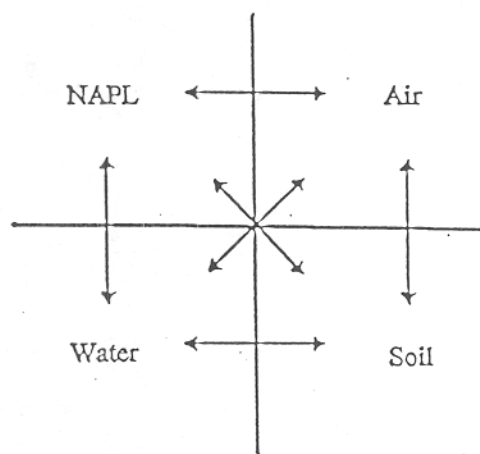


Figure 1. Schematic representation of phase equilibrium and partitioning.

To estimate the distribution of the total mass of a chemical among the phases at equilibrium, the chemical's phase partitioning behavior must be known. All nonaqueous concentrations are defined using traditional equilibrium equations that are functions of aqueous concentrations. These relationships are presented later. In each relationship, at least one chemical property of each organic compound (e.g., aqueous solubility, vapor pressure, and partition coefficient) must be known. In each case, the value of the chemical property is temperature dependent. Consequently, the values used in the model must be representative of the original soil or rock temperature. Values for these properties at specific temperatures can be found in the literature (e.g., Mercer et al. 1990) or estimated (e.g., Lyman et al. 1990; Drefahl and Reinhard 1995).

NAPL-Water Partitioning

NAPL-water partitioning depends on the aqueous solubilities of the NAPL components and the concentrations of the NAPL components in the NAPL. The relationship is analogous to Raoult's law for ideal gas mixtures. For an ideal NAPL in contact with water the

aqueous phase concentration of a NAPL component is equal to the pure phase aqueous solubility of the component multiplied by the mole fraction of the component in the NAPL mixture. Mathematically, this relationship is written as:

$$C_w^i = x_i S_i \quad (2)$$

where C_w^i is the aqueous phase concentration of component i (mass i in water per volume water); x_i is the mole fraction of the component in the NAPL mixture (mole i in NAPL per mole NAPL); and S_i is the aqueous solubility of pure component i (mass i in water per volume water). Feenstra et al. (1991) refers to C_w^i as the effective aqueous solubility of component i when the aqueous phase is at equilibrium with a NAPL. This general NAPL-water partitioning relationship has been confirmed by Banerjee (1984), Mackay et al. (1991), Cline et al. (1991), Lee et al. (1992a,b), and Broholm and Feenstra (1995) for NAPL mixtures of structurally similar compounds. This relationship is not highly dependent on temperature.

Air-Water Partitioning

The equilibrium concentration of component i in air is related to the aqueous concentration by Henry's law. Henry's law states that equilibrium water-air partitioning is described by a linear relationship. The relationship can be written as:

$$C_a^i = K_H^i C_w^i \quad (3)$$

where C_a^i is the concentration of i in air (mass i in air per volume air), and K_H^i is the dimensionless Henry's constant. The Henry's constant is often reported in the literature in its dimensional form, $K_H^{i'}$ (e.g., atm-L/mol). The dimensional Henry's constant is calculated from the equation:

$$K_H^{i'} = \frac{P_{\text{vap}}^i}{S_i} MW_i \quad (4)$$

where P_{vap}^i is the component's vapor pressure (e.g., atm), and MW_i is the component's molecular weight (mass i per mole i), which is needed to convert the previously defined mass-based aqueous solubility S_i to molar units. The two Henry's constants are related through the equation:

$$K_H^i = \frac{K_H^{i'}}{RT} \quad (5)$$

where R is the universal gas constant (0.08206 atm-L/mol-K) and T is temperature in Kelvin. As the equation reveals, air-water partitioning is highly dependent on temperature.

Soil-Water Partitioning

Sorption to soil organic matter can also be described by a linear function of the aqueous organic compound concentration. The relationship can be written as:

$$C_s^i = K_{oc}^i f_{oc} C_w^i \quad (6)$$

where C_s^i is the sorbed concentration of component i (mass i sorbed per mass soil); K_{oc}^i is the organic carbon to water partition coefficient of component i (mass i sorbed per mass organic carbon divided by mass i in water per volume water); and f_{oc} is the mass fraction of natural organic carbon within the soil matrix (mass natural organic carbon per mass soil).

The mass fraction of natural organic carbon has to be measured for the particular soil to be evaluated. Although the effect of temperature is small, the K_{oc}^i value can be highly sensitive to pH if the organic compound is ionizable (Drefahl and Reinhard 1995).

The linear isotherm model of Equation 6 has been experimentally verified for various organic compounds by Karickhoff et al. (1979), Chiou et al. (1979), Schwarzenbach and Westall (1981), and Chiou et al. (1983). It has been noted, however, that linear sorption is valid only for f_{oc} greater than about 0.001 (Schwarzenbach and Westall 1981) and greater than about 3 to 7 percent of the solid mass fraction of clay (Karickhoff 1984); otherwise, sorption of organic compounds on clays and mineral surfaces can be significant.

Conservation Equations and Relationships

Soil, water, air, and NAPL account for the total volume of a soil sample containing NAPL. The volume conservation equation is:

$$\phi_s + \phi_w + \phi_a + \phi_n = 1 \quad (7)$$

where ϕ_s is the volumetric soil content (volume soil per total volume); ϕ_w is the volumetric water content (volume water per total volume); ϕ_a is the volumetric air content (volume air per total volume); and ϕ_n is the volumetric NAPL content (volume NAPL per total volume). The soil porosity ϕ (volume void per total volume) is equal to the sum of the volumetric air, water, and NAPL contents:

$$\phi = \phi_a + \phi_w + \phi_n \quad (8)$$

Thus, the volumetric soil content ϕ_s equals $1 - \phi$.

Each NAPL component in a soil sample is distributed among the phases present. As a result, the total mass of component i in the sample equals the sum of the masses of component i in all phases. The mass conservation equation is:

$$\rho_t C_t^i = \phi_w C_w^i + \phi_a C_a^i + \phi_n C_n^i + \phi_s \rho_s C_s^i \quad (9)$$

where ρ_t is the total density of the soil sample (mass of sample per volume of sample); C_t^i is the measured total concentration of i in the sample (mass i in sample per mass of sample); C_n^i is the concentration of i in the NAPL (mass i in NAPL per volume NAPL); and ρ_s is the density of the solid (approximately 2.65 kg/L for sand). The total density, ρ_t , is approximately equal to

the weighted average of the densities of the four phases:

$$\rho_t = \phi_w \rho_w + \phi_a \rho_a + \phi_n \rho_n + \phi_s \rho_s \quad (10)$$

where ρ_w is the density of water (approximately 1.0 kg/L); ρ_a is the density of air (approximately 0.0013 kg/L at 20°C); and ρ_n is the density of the NAPL mixture (mass NAPL per volume NAPL). ρ_n can be expressed as:

$$\rho_n = \frac{\sum C_n^i}{\sum \frac{x_i MW_i}{\rho_i}} \quad (11)$$

where ρ_i is the density of pure component i in liquid form (mass i per volume i). Some components, such as vinyl chloride or anthracene, may not occur as liquid in their pure form under environmental conditions. For these components, hypothetical pure phase liquid densities are computed by extrapolation.

The mole fraction of component i in the NAPL mixture is related to mass concentration by the equation:

$$x_i = \frac{C_n^i MW_n}{\rho_n MW_i} \quad (12)$$

where MW_n is the equivalent molecular weight of the NAPL mixture (mass NAPL per mole NAPL). MW_n is approximately equal to the weighted average of the molecular weights of the NAPL components:

$$MW_n = \sum x_i MW_i \quad (13)$$

Finally, the sum of the NAPL mole fractions is equal to 1:

$$\sum x_i = 1 \quad (14)$$

Estimation of NAPL Saturation and Composition

A complete chemical analysis of a core sample provides the total mass of each component per unit mass of sample (i.e., the value of C_i^i for each component). To determine the saturation and composition of NAPL in the sample, the total mass of each component in each phase and the total volume of each phase must be determined. The partitioning theory and conservation relationships presented in the previous section can be used for this purpose. The solution allows calculation of the NAPL saturation from the equation:

$$S_N = \frac{\phi_n}{\phi} \quad (15)$$

The method presented here is a numerical solution of the partitioning and conservation equations. PC software called NAPLANAL was developed to perform the numerical simulation. NAPLANAL can be used to estimate the following: (1) the NAPL saturation and composition in a soil sample containing NAPL; (2) the concentrations of organic compounds in each phase; and

(3) the NAPL composition and NAPL volume in samples of NAPL-water emulsions ($\phi_s = 0$). A copy of NAPLANAL is available from the INTERA web site (<http://www.intera.com>) for a small fee.

The algorithm is first demonstrated by considering a hypothetical soil sample from an unsaturated formation containing NAPL with N chemical components. Calculation of NAPL saturation and composition requires the following measurements or estimates as input: total concentrations of NAPL components in the soil sample (C_i^i), volumetric water content (ϕ_w), soil porosity (ϕ), volumetric soil content ($\phi_s = 1 - \phi$), soil organic carbon content (f_{oc}), organic carbon to water partition coefficients (K_{oc}^i), Henry's law constants in dimensionless form (K_H^i), molecular weight of each component (MW_i), and densities of water, air, soil, and each NAPL component (ρ_w , ρ_a , ρ_s , and ρ_i).

Equations 2, 3, 6, and 8 through 14 provide a total of $5N+5$ independent equations that describe partitioning and conservation of organic compounds in a soil sample. Given the measurements and estimates listed in the previous paragraph, there are $5N+5$ unknowns. These unknowns are as follows: NAPL component concentrations in water, air, soil, and NAPL (C_w^i , C_a^i , C_s^i , and C_n^i); component mole fractions in the NAPL mixture (x_i); volumetric contents of air and NAPL (ϕ_a and ϕ_n); density of sample (ρ_t); and the equivalent density and molecular weight of the NAPL (ρ_n and MW_n).

An equal number of unknowns and independent equations guarantees a unique solution. NAPLANAL solves the system of equations and unknowns using an algorithm that combines the rapid local convergence of the Newton-Raphson method for a system of nonlinear equations with a globally convergent strategy. For the sample problems tested so far, the computation time for reaching a solution is less than one minute using a 486 DX66 PC.

For core samples from the saturated zone, the air volumetric content (ϕ_a) and air phase concentrations (C_a^i) are equal to zero. Thus, the terms and equations involving the air phase are dropped from the system of equations. As a result, the number of equations reduces to $4N+5$, while the number of unknowns reduces to $4N+4$. Because there are fewer unknowns than equations, a measurement for either soil porosity (ϕ) or soil volumetric water content (ϕ_w) is sufficient for estimation purposes. Users of NAPLANAL have the choice of treating either ϕ or ϕ_w as an unknown parameter. A gas chromatography method is currently being developed to allow simultaneous measurement of ϕ_w and the concentrations of organic compounds in a soil sample.

The NAPLANAL code begins with the assumption that there is no NAPL present in the sample (i.e., $\phi_n = 0$). The density of the sample can then be calculated from Equation 10 as:

$$\rho_t = \phi_w \rho_w + (\phi - \phi_w) \rho_a + (1 - \phi) \rho_s \quad (16)$$

The first approximation of the aqueous concentration can be calculated from Equation 9 by:

$$C_w^i = \frac{C_i \rho_t}{\phi_w + K_H^i (\phi - \phi_w) + f_{oc} K_{oc}^i \rho_s (1 - \phi)} \quad (17)$$

shown by Feenstra et al. (1991). If NAPL exists in the sample, then this first approximation of C_w^i should exceed the effective aqueous solubility of component i . Equations 2 and 14 imply that C_w^i equals the effective aqueous solubility when:

$$\sum \frac{C_w^i}{S_i} = 1 \quad (18)$$

Thus, a summation exceeding 1 when Equation 17 is used to estimate C_w^i implies that NAPL is present in the sample and that the NAPL saturation algorithm must be used instead to estimate C_w^i . A summation in Equation 18 equal to or less than one indicates there is no NAPL in the sample (i.e., S_N and ϕ_n equal zero). In this case, Equation 17 provides valid explicit estimates of aqueous concentrations. Air and sorbed concentrations are then calculated directly from Equations 3 and 6. When the summation in Equation 18 is less than 1, C_w^i is less than the effective aqueous solubility and calculation of x_i from Equation 2 is invalid.

Petroleum Hydrocarbon Example

In this example, the petroleum hydrocarbon data from Mott (1995) are used to compare the results of NAPLANAL and SOILCALC. The example problems consider hypothetical soil samples contaminated with C6 through C9 n-aliphatic hydrocarbons. For direct comparison of NAPLANAL and SOILCALC results, the input data are identical. The physical and chemical properties of the soil samples and the petroleum hydrocarbons used in the calculations are summarized in Table 1.

Component i	K_{oc}^i (mL/g)	K_H^i	S_i (mg/L)	ρ_i (kg/L)	MW_i (g/mol)
Hexane	6025.60	46.49	12.31	0.66	86.07
Heptane	22908.68	63.59	3.06	0.68	100.20
Octane	77624.71	95.74	0.68	0.70	114.22
Nonane	263026.8	45.80	0.47	0.72	128.26
Soil Sample Data		f_{oc}	ϕ_w	ϕ	
		0.01	0.08	0.4	

The three soil samples differ only in the total hydrocarbon component concentration. These data are shown in Table 2. The first data set represents a soil sample containing 250 mg/kg of each component. The second data set, which is a borderline case (NAPL may or may not be present based on SOILCALC results), represents a soil sample containing 192 mg/kg each component.

The third data set, which is a no NAPL case, represents a soil sample containing 100 mg/kg each component. Results from SOILCALC and NAPLANAL are summarized in Table 2. SOILCALC results are in parentheses.

SOILCALC assumes that NAPL occupies zero void space (i.e., the NAPL saturation is assumed insignificant relative to water and air content). Because of this assumption, SOILCALC does not have NAPL saturation estimation capability. In contrast, NAPLANAL implicitly calculates NAPL saturation. For the first two sets of data, the results indicate NAPL saturations of 0.15 percent and 0.02 percent, respectively. At such low NAPL saturations (i.e., approximately 1 percent or less of typical residual NAPL saturations [Mercer and Cohen 1990]), the pore space occupied by NAPL is indeed insignificant relative to pore space occupied by water and air. As a result, the two models give similar results, as shown in Table 2. However, there are still differences in the component mass distributions, especially for the mass of components in the NAPL phase. Because NAPLANAL calculates NAPL saturation, it should provide more accurate results than SOILCALC, especially at higher NAPL saturations.

Field DNAPL Examples

NAPLANAL was used to calculate the saturations and compositions of DNAPL and the phase distributions of DNAPL components in several core samples collected from a chemical plant on the Gulf Coast. DNAPL is NAPL that is denser than water. The plant has manufactured a variety of chlorinated ethanes and ethenes, such as 1,2-dichloroethane (EDC), trichloroethene (TCE), tetrachloroethene (PCE), 1,1,1-trichloroethane (1,1,1-TCA), 1,1,2-trichloroethane (1,1,2-TCA),

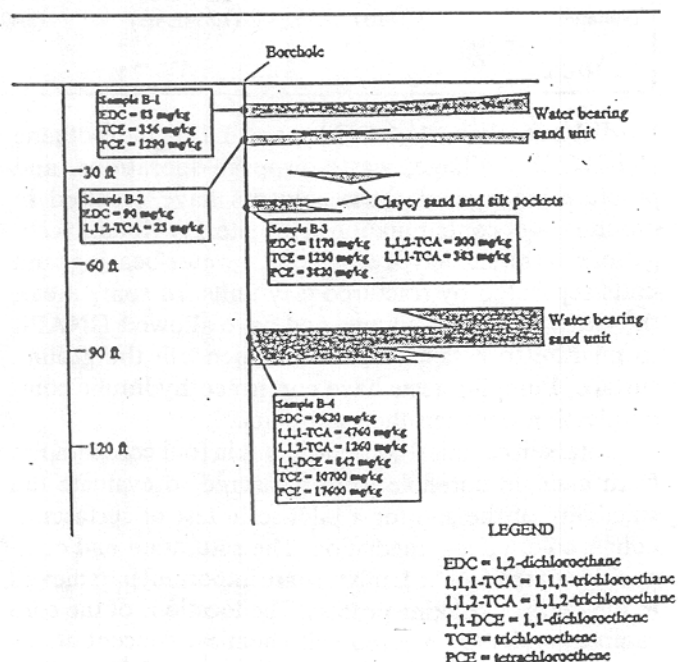


Figure 2. Cross-sectional view of soil sample location and total soil concentration.

Table 2
Comparison of NAPLANAL and SOILCALC Results
 SOILCALC Results Are in Parentheses (Mott 1995). Concentrations Are Normalized by Total Sample Mass.
 For Comparison Purposes, Calculations Are Not Rounded to Reflect Significant Figures.

Component i	Measured Sample Conc. C_i (mg/kg)	Sample Conc. in Aq. Phase $C_i^1 \phi_w \rho_i^{-1}$ (mg/kg)	Sample Conc. in Air Phase $C_i^1 \phi_a \rho_i^{-1}$ (mg/kg)	Sample Conc. Sorbed $C_i^1 \phi_a \rho_i^{-1}$ (mg/kg)	Sample Conc. in NAPL $C_i^1 \phi_a \rho_i^{-1}$ (mg/kg)	Mole Fraction in NAPL x_i
Data Set #1						
Hexane	250	1.467E-01 (1.493E-01)	2.680E+01 (2.795E+01)	1.735E+02 (1.800E+02)	4.953E+01 (4.193E+01)	0.2460 (0.2429)
Heptane	250	3.949E-02 (4.062E-02)	9.871E+00 (1.040E+01)	1.776E+02 (1.861E+02)	6.251E+01 (5.347E+01)	0.2667 (0.2663)
Octane	250	1.055E-02 (1.104E-02)	3.970E+00 (4.258E+00)	1.607E+02 (1.715E+02)	8.530E+01 (7.427E+01)	0.3193 (0.3245)
Nonane	250	3.852E-03 (3.926E-03)	6.936E-01 (6.710E-01)	1.989E+02 (2.065E+02)	5.040E+01 (4.272E+01)	0.1680 (0.1663)
NAPL saturation = 0.15%						$\sum x_i = 1.0000$ (1.0000)
Data Set #2						
Hexane	192	1.366E-01 (1.378E-01)	2.499E+01 (2.580E+01)	1.615E+02 (1.661E+02)	5.322E+00 (1.060E-02)	0.2290 (0.2241)
Heptane	192	3.894E-02 (3.968E-02)	9.749E+00 (1.016E+01)	1.751E+02 (1.818E+02)	7.114E+00 (1.445E-02)	0.2629 (0.2602)
Octane	192	1.160E-02 (1.207E-02)	4.374E+00 (4.653E+00)	1.768E+02 (1.873E+02)	1.083E+01 (2.224E-02)	0.3511 (0.3546)
Nonane	192	3.601E-03 (3.637E-03)	6.493E-01 (6.710E-01)	1.859E+02 (1.913E+02)	5.438E+00 (1.087E-02)	0.1570 (0.1540)
NAPL saturation = 0.02%						$\sum x_i = 1.0000$ (0.9929)
Data Set #3						
Hexane	100	7.316E-02 (7.177E-02)	1.339E+01 (1.344E+01)	8.654E+01 (8.648E+01)	(6.720E-15)	(0.1167)
Heptane	100	2.106E-02 (2.067E-02)	5.274E+00 (5.293E+00)	9.471E+01 (9.469E+01)	(8.132E-15)	(0.1355)
Octane	100	6.404E-03 (6.285E-03)	2.415E+00 (2.423E+00)	9.758E+01 (9.757E+01)	(1.364E-15)	(0.1847)
Nonane	100	1.930E-03 (1.894E-03)	3.481E-01 (3.495E-01)	9.965E+01 (9.965E+01)	(7.434E-15)	(0.0802)
No NAPL						$\sum x_i = 0.5171$

1,1-dichloroethane (1,1-DCA), and 1,1-dichloroethene (1,1-DCE). Spillage, waste-disposal operations, and pipeline leakage of these solvents have resulted in ground water contamination at the site. Previous investigations at the site have revealed silty water-bearing sand units separated by fractured clay units. In some areas, the clays are discontinuous and have allowed DNAPL to migrate to a sand unit 80 feet beneath the ground surface. Pumping tests have confirmed hydraulic communication between the sand units.

Total soil chemical concentrations in four core samples from a single borehole were measured to evaluate the suitability of the site for a pilot-scale test of surfactant-enhanced aquifer remediation. The saturation and composition of the DNAPL mixture are important parameters in the decision-making process. The locations of the core samples and the analyzed soil chemical concentrations are shown in Figure 2. The samples are as follows: B-1, located in a sand unit at about 10 feet below ground

Table 3
**Chemical Property Data Used in the Analysis
 of the Soil Samples**

Component i	K_{oc}^1 (mL/g)	K_H^1	S_i (mg/L)	ρ_i (kg/L)	MW_i (g/mol)
1,1-dichloroethene	65	0.87	400	1.22	97
1,2-dichloroethane	14	0.038	8690	1.26	99
1,1,1-trichloroethane	152	0.54	720	1.35	133.4
1,1,2-trichloroethane	56	0.031	4500	1.44	133.4
trichloroethene	126	0.3	1100	1.47	131.5
tetrachloroethene	364	0.54	200	1.63	165.8

surface (bgs); B-2, located in a sand unit at about 20 feet bgs; B-3, located in a unit of clayey sand with silt pockets at about 43 feet bgs; and B-4, located in a sand unit at about 80 feet bgs. The volumetric water contents of the core samples were not measured. The porosity and fraction organic carbon content of the sands were assumed

Table 4

NAPLANAL Calculations from Soil Sample Analyses
Concentrations Are Normalized by Total Sample Mass. Results Are Rounded to Two Significant Figures.

Component i	Measured Sample Conc. C_i (mg/kg)	Sample Conc. in Aq. Phase $C_w^i \phi_w \rho_i^{-1}$ (mg/kg)	Sample Conc. Sorbed $C_s^i \phi_s \rho_i^{-1}$ (mg/kg)	Sample Conc. in NAPL $C_n^i \phi_n \rho_i^{-1}$ (mg/kg)	Mole Fraction in NAPL x_i
Sample B-1					
1,2-dichloroethane	83	50	0.74	32	0.032
trichloroethene	356	46	6.4	300	0.23
tetrachloroethene	1290	27	11	1300	0.74
NAPL saturation = 0.54%					
Sample B-2					
1,2-dichloroethane	90	89	1.7		
1,1,2-trichloroethane	23	22	1.4		
No NAPL					
Sample B-3					
1,2-dichloroethane	1170	300	4.8	860	0.19
1,1,1-trichloroethane	383	8.2	1.4	370	0.063
1,1,2-trichloroethane	200	24	1.5	170	0.029
trichloroethene	1230	40	5.7	1200	0.20
tetrachloroethene	3820	18	7.6	3800	0.51
NAPL saturation = 2.3%					
Sample B-4					
1,2-dichloroethane	9620	370	6.8	9200	0.28
1,1,1-trichloroethane	4760	12	2.3	4700	0.11
1,1,2-trichloroethane	1260	19	1.4	1200	0.028
1,1-dichloroethene	842	1.6	0.14	840	0.028
trichloroethene	10700	40	6.8	11000	0.24
tetrachloroethene	17600	9.6	4.6	18000	0.32
NAPL saturation = 17%					

to be 0.375 and 0.0015, respectively. These values are equivalent to average values measured by Liljestrand and Charbeneau (1987) in similar shallow sands in the area. Table 3 lists the physical properties attributed to the chlorinated solvents in the core samples.

According to the results of the NAPLANAL calculations, presented in Table 4, only a small amount of DNAPL is present in sample B-1. The ground water in B-2 appears to contain no DNAPL. Samples B-3 and B-4 have calculated NAPL saturations of about 2.3 percent and 17 percent, respectively. The computed NAPL composition in each of these core samples is different. Although PCE appears to be the predominant NAPL component in all samples containing NAPL, the mole fraction of PCE decreases with depth while the TCE and EDC mole fractions increase. This trend suggests historical variations in the composition of infiltrating DNAPL and/or different locations of DNAPL releases having different DNAPL compositions.

In the aforementioned calculations, soil porosity was estimated. Neither porosities nor water contents had been measured for these samples. A graph relating the porosity to the calculated NAPL saturation and composition for samples B-3 and B-4 is shown in Figure 3. Samples B-3 and B-4 represent soil samples having relatively low and high NAPL saturations, respectively. The graph shows that the uncertainty of the porosity value

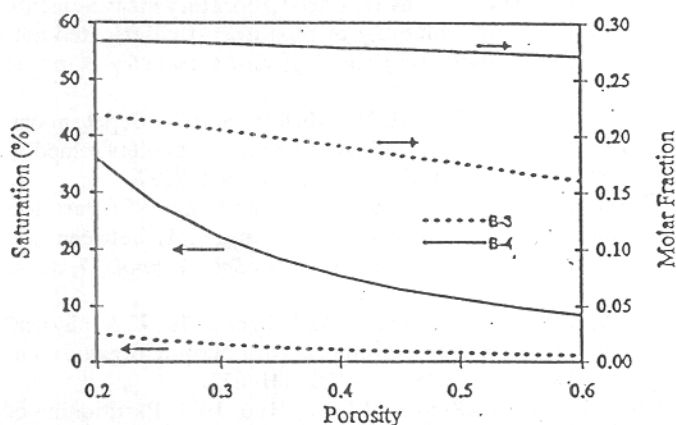


Figure 3. Effect of porosity on NAPL saturation and composition estimation results.

on the calculations of NAPL saturation and composition is small considering the relatively small possible range of soil porosity in sandy sediments.

Conclusions

The NAPL saturation algorithm presented in this paper provides a useful tool to investigators involved in site characterization studies at NAPL-contaminated sites. This algorithm allows the quantification of NAPL saturation and NAPL composition in a soil sample from

a typical soil chemical analysis. This information is useful in modeling and designing site-specific surfactant-enhanced aquifer remediation strategies (e.g., Brown et al. 1994) and partitioning interwell tracer tests (e.g., Jin et al. 1995). The calculations require only the soil information typically gathered in ground water contamination studies, specifically total chemical concentrations, water moisture content, porosity, natural organic content, and specific physical and chemical properties of the contaminants. A PC software program, NAPLANAL, was developed to perform these calculations.

The accuracy of the calculations depends on the accuracy of the input data. A sample's chemical analysis can be compromised by improper sampling and preservation, failure to identify and quantify all organic contaminants, and incomplete extraction of contaminants. In addition, the values of the physical properties of the soil sample and the chemical properties of the NAPL components affect the results. Thus, sensitivity analyses, such as the example shown for porosity, are strongly encouraged. Such sensitivity analyses can be performed easily using NAPLANAL.

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