



**New Jersey Geological Survey
Investigation Report**



**Baseline Concentrations of
Arsenic, Beryllium and Associated Elements
in Glauconite and Glauconitic Soils in the
New Jersey Coastal Plain**

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New Jersey Coastal Plain**

by

John H. Dooley

Report
NJDEP
Information Resource Center

New Jersey Department of Environmental Protection
Division of Science, Research and Technology
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Executive Summary

Glaucanite, an iron-rich, green, phyllosilicate mineral, occurs in significant concentrations in certain sedimentary formations of marine origin that underlie the New Jersey Coastal Plain physiographic province. The glaucanite commonly is mainly sand size and where it occurs in high concentrations, the sediments are referred to as “greensands”. Soils form from the chemical weathering of the Coastal Plain sediments.

Chemical analysis of pristine glaucanite samples, from a deep core hole in the New Jersey Coastal Plain, revealed substantial concentrations of total arsenic and beryllium (Dooley, 1998). Site Remediation personnel of the New Jersey Department of Environmental Protection discovered a correlation between high concentrations of arsenic and beryllium, and soils containing glaucanite. Based on these observations, it was suggested that this mineral might be the source of the arsenic and beryllium concentrations that exceed the residential and non-residential direct contact soil cleanup criteria (RDCSCC and NRDCSCC).

The Hazardous Waste Research Fund supported the New Jersey Geological Survey to investigate the natural variations in baseline concentrations of target analyte list (TAL) elements in glaucanite-bearing soils of the New Jersey Coastal Plain. Reported herein are the results of this investigation with emphasis on the arsenic and beryllium concentrations.

The glaucanite-bearing soil series selected for this investigation are: Adelphia, Colemantown, Collington, Colts Neck, Donlonton, Freehold, Holmdel, Kresson, Marlton, Marlton and Kresson urban land complex, Shrewsbury, and Tinton. Sites obviously or potentially impacted by industrial activity were avoided. Sample stations that are cultivated, fallow, and formerly cultivated were chosen to measure the effect of agriculture on the analyte concentrations.

One hundred thirteen samples of glaucanite-bearing soil from forty five sampling stations

were collected using a mud auger for analyses. Six-inch soil samples were composited and homogenized from the 0- to 6-inch and 24- to 30-inch soil depths for each of the 45 stations. The other 23 soil samples were from the 12- to 18-inch and deeper than the 30-inch depth. Binocular microscopy was used for cursory description of the constituents in each of the 113 samples.

Three hundred to five hundred grams of each soil sample (whole soil), glauconite sand isolated from the whole soil (soil glauconite), and separates of pristine glauconite sand obtained from a deep (Ancora) core hole were submitted to a state-certified, commercial laboratory for chemical analysis using U. S. EPA SW-846 Methods 3050 and 6010A. SW-846 Method 3050, which provides a partial acid-leach of the sample and is referred to as “total recoverable”, was selected to provide chemical data that are directly compatible with chemical data submitted by the regulated community to the Department. Aliquots of select whole soils, soil glauconite isolates, and pristine glauconite isolates were sent to a commercial laboratory for total chemical analysis using various analytical methods (table 2). Comparison of total analyte concentrations with those from the EPA’s prescribed partial acid-digestion for soil provides a measure of the efficacy of the acid digestion.

Total arsenic concentrations, determined using instrumental neutron activation analysis (INAA), range from 7 to 136 ppm (parts per million) and 18 to 126 ppm for the pristine glauconite and soil glauconite isolates, respectively. These concentrations are typical for marine shale and claystone (3 to 490 ppm As, n = 53) from the western United States (Tourtelot, 1964). The 24 ppm median total arsenic concentration for pristine glauconite isolates is half that for the soil glauconite isolates (48.5 ppm). Median total arsenic concentration for the soil glauconite is four times that for marine shale and claystone.

The range in total arsenic concentration is 13 to 131 ppm with a 29.5 ppm median for the glauconite-bearing whole soils. This median is 4 to 5 times the median for United States and worldwide soils, and approximately 2.5 times that for typical marine shale. The median total

beryllium concentration in the whole soil (7.0 ppm) is enriched 8 times over the median for United States soil and 23 times that for worldwide soils.

Total arsenic in the pristine glauconite isolates has robust, positive correlations with most constituent elements in glauconite, which demonstrates that it is a constituent of pristine glauconite. Total arsenic exhibits a different association in the soil glauconite isolates. It has strong, negative correlations with the major constituent elements in glauconite and other phyllosilicate minerals, and a strong, positive correlation with total iron. The robust, positive correlation with iron suggests that arsenic is sorbed to iron (oxy)hydroxides that coat constituent minerals in the soil.

The U. S. EPA SW-846 Method 3050 acid digestion solubilizes from 11 to 57 percent (24% median), 25 to 69 percent (49.5% median), and 5 to 69 percent (40.5% median) of the total arsenic in the pristine glauconite, soil glauconite isolates, and whole soil, respectively. Percent extraction efficiency for beryllium ranges from 8.2 to 30 percent (11% median), 11 to 34 percent (18.5% median), and 1.9 to 37 percent (16% median) of the total beryllium in the pristine glauconite, soil glauconite isolates, and whole soil, respectively. These extraction efficiencies reveal that 31 to 95 percent of the total arsenic and 63 to 98 percent of the total beryllium in these glauconitic soils is not 'recoverable' using Method 3050. Matrix quality within and among the soil series appears to be the greatest variable affecting the extraction efficiency of the EPA's prescribed analytical protocol. Moreover, the non-specificity of the prescribed EPA methods for these iron-rich soils yields equivocal results. The non-specificity of, and low 'recovery' for, the EPA analytical protocol, as carried out by a state-certified, commercial, contract laboratory, provide chemical data that do not permit rigorous interpretation. Furthermore, 'recoverable' analyte concentrations provided by the EPA's partial acid-leach are not comparable to total analyte concentrations reported in the literature.

Twenty percent (23 of 113 samples) of the soil samples have 'recoverable' arsenic concentrations exceeding the 20 ppm RDCSCC. Adelphia, Kresson and Marlton series soils

account for 30, 13 and 39 percent, respectively, of these arsenic exceedances. Sixty one percent of the 23 arsenic exceedances are from Monmouth County, 26 percent are from Gloucester County, and 13 percent are from Burlington County. The 'recoverable' median and arithmetic mean arsenic concentrations for the Adelphia and Marlton soil series exceed the RDCSCC guideline.

Ten percent (11 of 113 samples) of the soil samples have 'recoverable' beryllium concentrations exceeding the 2 ppm RDCSCC. Eighty two percent (9 of 11 samples) of all beryllium exceedances are from disturbed sites. Adelphia, Colemantown and Kresson soil series each account for 18 percent of these beryllium exceedances. Sixteen percent of all samples from Gloucester County, 14 percent from Monmouth County, 8 percent from Camden County, and 5 percent from Burlington County exceed the RDCSCC guideline for beryllium.

Five percent (6 of 113 samples) of the soil samples have RDCSCC exceedances for both arsenic and beryllium.

Soil pH is a useful tool for distinguishing natural soil from soil disturbed by agriculture. Natural background pH is less than 4.7 (measured in a calcium chloride suspension) for the glauconite-bearing soil. High calcium concentrations along with relatively high pH (greater than 4.7) may be a flag that indicates a disturbed soil. The statistical method for calculating outlier concentrations suggested in the NJDEP's Field Sampling Procedures Manual (Schoenleber and Morton, 1992) successfully identified those sample stations affected by anthropogenic inputs, such as liming agents.

The results of this investigation show a wide range and elevated median values in the natural arsenic and beryllium concentrations among the various soil series and within individual soil series. A valid assessment of analyte concentrations, whether total or 'recoverable', requires basic data on the sample character, such as pH, and constituent minerals and amorphous phases (for example, iron (oxy)hydroxides) of the soil system, in addition to the historical land use.

Introduction

The New Jersey Department of Environmental Protection (NJDEP) is prohibited from requiring the remediation of soil beyond what is established as the regional natural background concentration (N.J.A.C. 58:10B-35g (4)). Guidance for determining natural background concentrations had been incorporated into the Technical Requirements for Site Remediation (N.J.A.C. 7:26E 3.10). This guidance provides methods for investigating and establishing background concentrations of suspected contaminants that result from anthropogenic inputs and naturally occurring constituents. Included are sampling procedures and stipulations for comparison of site-specific data with New Jersey background concentrations.

Following completion of site-specific, natural background investigations and submission of these data to the NJDEP by the regulated community, a correlation between elevated naturally occurring arsenic and other metals, and soils containing the mineral glauconite became apparent. To assist the NJDEP and private sector in determining the validity of this correlation and establish additional natural background reference data, funding was made available from the Hazardous Waste Research Fund for the current study.

The principal focus of this investigation is to determine a natural background concentration, using a prescribed acid-leach method of the U.S. EPA, for 24 target analyte list (TAL) metals, excluding mercury, in glauconite-bearing soils of the New Jersey Coastal Plain physiographic province (fig. 1, inset map). Natural background concentration of TAL metals represents metals that result from purely geologic processes overprinted with minor atmospheric inputs which may contain geologic (lithogenic) and anthropogenic components.

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Site Selection Criteria

Glaucanite-bearing soil series were identified based on descriptions of representative soil profiles and soil survey maps by the National Resources Conservation Service (NRCS), formerly the Soil Conservation Service (Jablonski and Baumley, 1989; Markley, 1962, 1966, 1971). Those selected for this study are: Adelphia, Colemantown, Collington, Colts Neck, Donlonton, Freehold, Holmdel, Kresson, Marlton, Marlton and Kresson urban land complex, Shrewsbury, and Tinton.

Historic aerial photographs were reviewed to facilitate selection of candidate sampling sites. Sites obviously or potentially impacted by industrial activity were avoided. A few sites thought to be relatively undisturbed were found to be disturbed. For example, bituminous coal fragments and shards of plastic were discovered approximately 1 foot below the ground surface. Some sample sites that are cultivated, fallow, or formerly cultivated were chosen to show the effect of agriculture on metal concentrations in these soils.

A narrow band of glauconite-bearing sediments trends northeast-southwest along the western portion of the New Jersey Coastal Plain (fig. 1). Soil samples were taken throughout this band in Monmouth, Burlington, Camden, and Gloucester Counties.

Soil Sampling Procedure

Maps in NRCS soil surveys for each of the four counties were used in the field as a guide to the spatial relationships among the soil series and to name the soil sampled, based on its map designation. Most samples were taken from under tree canopies in well forested land.

At each sample site surface organic debris (leaf litter, twigs, grasses) was scraped aside with a decontaminated, stainless steel shovel. A stainless steel mud auger (fig. 2), with a 2-inch (5-cm) inside diameter, was used to obtain 6-inch (15-cm) soil samples to depths down to 48 inches below ground level in accordance with NJDEP sampling protocol (Schoenleber and Morton, 1992). Before each soil sample was taken for chemical analyses the shovel and auger assembly were decontaminated in the field by:

- 1) removing visible sediment with a polythene bristle brush
- 2) thoroughly rinsing with Alconox detergent in doubly distilled, deionized water (DDDW) from the NJGS labs
- 3) rinsing with copious amounts of DDDW
- 4) rinsing with 10% v/v ultrapure nitric acid (HNO_3) in DDDW
- 5) copiously rinsing with DDDW.



Figure 2. Close-up of stainless steel mud-auger buckets. The right one is undeformed. The left one has been damaged by an attempt to penetrate a zone of refusal.

Prior to removing the 6-inch core of soil from the mud-auger bucket, the outer quarter inch or so of the core was scraped away. This reduced contamination from the overlying soil whilst entering and exiting the borehole. All soil samples were placed in unused plastic containers and stored in a cooler for transport back to the NJGS labs where they were promptly transferred to a dedicated sample refrigerator. A Trimble global positioning system (GPS) unit mounted on a stadia rod was placed in or next to the borehole to determine the location in New Jersey state plane coordinates of each sampling station. The GPS data are presented in table 1 and were used to plot the stations in figure 1.

All relevant field observations were recorded in a field notebook. A copy of the field notes are available upon request at the New Jersey Geological Survey.

Table 1. Location of soil sampling stations determined using global positioning system (GPS) methods. All positions are in survey feet, New Jersey State plane coordinates, North American Datum 1983.

Location ID	Northing	Easting	Std. Deviation (feet)
ANCORA	312998.70	393915.64	8.2
BUAD2001	391322.51	377311.89	2.9
BUAD4001	409164.39	376737.08	10.2
BUCL2001	444480.83	453569.89	3.0
BUCM2001	386691.94	380753.33	5.7
BUCM5001	430545.54	422897.96	8.2
BUDO1001	461747.61	414583.66	12.1
BUDO2001	446684.19	404989.97	18.1
BUFR2001	442797.00	431353.21	6.5
BUFR7001	407360.43	411168.15	3.3
BUHN2001	445466.00	401748.63	8.8
BUHN4001	406620.13	400036.41	6.4
BUKR3001	388334.70	383995.34	4.2
BUMR4001	444539.34	450811.94	0.8
BUSH1001	435231.89	433043.11	0.5
BUSH4001	436126.81	414170.95	8.8
CACL3001	383256.60	359716.97	9.3
CAFR3001	362235.13	336653.20	0.9
CAHN3001	391833.13	361606.95	5.3
CAKR4001	380635.69	359846.24	5.4
CAMK1001	377453.54	349733.15	5.9
CASH2001	383696.57	352689.52	5.7
GLCL4001	357012.98	321175.56	9.0
GLCM3001	322898.50	276988.43	1.3
GLCM4001	312529.23	271049.71	9.4
GLCN1001	350548.98	290294.03	1.8
GLFR4001	351340.57	283894.44	1.1

GLKR5001	327205.29	269963.85	0.9
GLMR5001	351887.98	318983.41	7.1
GLMR6001	327764.22	284864.04	1.3
MOAD1001	484328.48	506314.40	0.9
MOAD3001	477703.26	496447.07	17.1
MOCL1001	482747.91	488919.16	3.2
MOCM1001	489432.78	510640.39	7.5
MOCN2001	534508.97	595091.36	5.4
MOFR1001	482003.00	491124.47	27.5
MOFR6001	539924.14	583419.90	21.2
MOHN1001	542076.50	617386.66	5.2
MOKR1001	502813.25	549545.34	2.2
MOKR2001	471973.16	495294.19	3.9
MOMR1001	505264.95	552043.83	7.6
MOMR2001	486486.57	499677.37	4.8
MOMR3001	482799.95	507724.20	5.9
MOSH3001	537224.31	531332.92	6.0
MOTN1001	513098.23	527220.50	3.2
MOTN2001	544848.46	569148.39	7.2

Sample Preparation

The individual 6-inch soil samples were homogenized within the sample container to avoid losses and contamination. Compositing or homogenization, to the extent achievable on wet samples, was accomplished by the physical reduction of aggregates and mixing generally until the color of the sample was uniform. Sandy soil samples were fully homogenized. Samples having high clay contents were not completely homogenized, largely due to the plasticity and stickiness of the constituent clay minerals. All composited samples were kept in a dedicated refrigerator until needed.

Approximately 500-gram aliquots of each of the 113 composited soils were placed in pre-cleaned, screw-capped, glass bottles provided by the New Jersey certified analytical lab (Ecology and Environment, Inc.). All samples, packed in coolers with blue ice, were sent overnight express to Ecology and Environment (E&E) labs for analysis of TAL metals using U.S. EPA (Environmental Protection Agency) SW 846, 3rd edition, Methods 3050 and 6010A.

Aliquots from all composite soil samples and parent sediment from the Ancora core hole (fig. 1) were then air dried prior to being sent out for chemical characterization.

Aliquots of 14 soil composites, rich in glauconite sand/silt, and the six parent sediments from the Ancora core hole were wet sieved using DDDW in stainless sieves (USA Standard Testing Sieve, ASTM E-11 Specification). Sieve mesh used were #10 (2-mm openings), #60 (250-um openings), #230 (63-um openings) and the pan (<63-um openings). Gravel is retained on the #10 sieve, very coarse to medium sand on the #60 sieve, and fine to very fine sand on the #230 sieve. Silt and clay were washed into the pan. Each of the sieve fractions was air dried.

Because glauconite is paramagnetic, isolates of glauconite sand and very coarse silt from the air-dried samples were obtained by using a bench top Frantz magnetic barrier separator (Model LB-1)* interfaced with a Frantz vibration control unit on the same 14 soil composites analyzed for total metals and total organic carbon (TOC). Additional glauconite isolates were obtained from the 6 parent sediments from the Ancora core hole. These 20 glauconite isolates were analyzed for total metals by XRAL Labs. Twelve glauconite isolates from the soil composites were analyzed by E&E labs for TAL metals.

Analytical Methods

pH and Conductivity Measurements

All pHs for the 113 soil samples were measured in a 0.01M CaCl₂ solution prepared by dissolving 2.940 grams of calcium chloride dihydrate (CaCl₂·2H₂O) with DDDW in a 2-liter volumetric flask (Hendershot and others, 1993). The 0.01M CaCl₂ solution has a pH

approximating 5.6 to 5.8 and an electrical conductivity of 2.2 to 2.35 mS/cm at 21°C. Ten grams of air-dried soil were added to 50-mL glass test tubes and 20 mL of 0.01M CaCl_2 were pipetted into the test tube. This suspension was intermittently stirred with a glass rod for 30 minutes. After standing for 1 hour, a research grade (91-02 series combination glass pH electrode (Ag/AgCl filled with 4M KCl saturated with AgCl) was immersed in the supernatant. The pH was measured with an Orion Research (Model 601A)* digital ionalyzer calibrated with solutions pHs at 4.00 and 7.02 at 20°C. The pH meter was calibrated at the start and rechecked at the end of each batch of 12 soil samples.

Conductivity measurement of the soil suspensions in the 0.01M CaCl_2 solution provided only a measure of the conductance of the 0.01M CaCl_2 (specific conductivity ~ 2.27 mS/cm at 21°C). In other words, the soils provided no measurable change in the conductance of the 0.01M CaCl_2 /soil suspensions. All conductivity measurements were performed in the lab with a Yellow Springs Instrument Company (Model 32-1) conductance meter equipped with a temperature probe.

Soil Chemistry

Approximately 1-gram aliquots of each soil composite and glauconite sand isolates were digested according to SW846, 3rd edition, Method 3050 (U.S. EPA, 1995). Method 3050 prescribes sample digestion in 1:1 (v/v) nitric acid (HNO_3) and 30% hydrogen peroxide (H_2O_2). Concentrated hydrochloric acid (HCl) is added to the initial digestate and the sample is refluxed at 95°C on a hot plate.

The digestate is analyzed according to SW846, 3rd edition, Method 6010A (U.S. EPA, 1995). This method provides multielement determinations by ICP-AES (inductively coupled plasma - atomic emission spectrometry). Method 6010A employs a three-point calibration for

* Use of trade and brand names is for identification purposes only and does not constitute endorsement by the N.J. Geological Survey or the N.J. Department of Environmental Protection.

the analytes as opposed to Method 6010B which uses a one-point calibration (Kathleen Willy, E&E, Inc., oral communication, August, 1999). Ten composite soils were submitted as duplicate blind samples for QA (quality assurance) purposes.

Fourteen aliquots of composite soil samples and 20 glauconite sand isolates were sent to XRAL Labs (Canada) for total metals and total organic carbon analyses. The analytical method and detection limits used to determine each of the minor and trace analytes are listed in table 2. The major elements (Si, Al, Ca, etc.), expressed as oxides, were measured by x-ray fluorescence (XRF) methods with a minimum detection limit (MDL) of 0.01 percent.

Table 2. Analysis of minor and trace elements. Method and minimum detection limit in parts per million (ppm). Analysis of minor and trace elements by XRAL Labs. Analytical methods are: AAS, atomic absorption spectroscopy; ICP, inductively coupled plasma; ICP/MS, inductively coupled plasma/mass spectrometry; INAA, instrumental neutron activation analysis; XRF, x-ray fluorescence; CVAAS, cold vapor atomic absorption spectroscopy; DCP, direct coupled plasma.

AAS Analyte/MDL	ICP Analyte/MDL	ICP/MS Analyte/MDL	INAA Analyte/MDL	XRF Analyte/MDL	Others Analyte Method MDL
Cd 0.2	Ag 0.1	Bi 0.5	As 0.1	Ba 50	Cl coulometry 50
In 0.5	B 10	Tl 0.1	Au 0.002	Nb 2	Hg CVAAS 0.005
	Be 1		Br 1	Rb 2	Mn DCP 2
	Co 1		Cr 2	Zr 1	S Leco 50
	Cu 0.5		Cs 0.5		LOI gravimetry 100
	Ga 0.1		Hf 0.2		
	Ge 10		Sb 0.1		
	Li 1		Se 1		
	Mo 1		Ta 0.5		
	Ni 1		Th 0.2		
	Pb 2		U 0.1		
	Sc 0.05		W 1		
	Sr 1				
	V 2				

AAS Analyte/MDL	ICP Analyte/MDL	ICP/MS Analyte/MDL	INAA Analyte/MDL	XRF Analyte/MDL	Others Analyte Method MDL
	Y 1				
	Zn 0.5				

LOI, loss on ignition in weight percent.

Two composite soils and a glauconite sand isolate from the Hornerstown Formation, obtained from the Ancora core hole, were submitted as blind duplicates.

Binocular Microscopy

A binocular microscope with a maximum magnification of 60 power was used for a cursory examination of each sample sent for chemical analysis and the results are reported in Appendix 2. Microscopic examination of the composite soil samples provided information on the mineralogy and permitted an estimate of the grain size distribution. The relative proportions of sand, silt and clay in the soil samples are required to provide a textural classification for the sample. For example, sandy loam and silty clay are soil textural classes. Additionally, binocular microscopy aided in the removal of much of the nonglauconite mineral constituents (for example, bioclasts, quartz, muscovite/illite, etc.) remaining in the glauconite isolates after magnetic separation.

Sample Codification Method

Each soil sample is designated by four alpha and four numeric characters. The first two alpha characters signify the county, that is, BU is Burlington, CA is Camden, GL is Gloucester and MO is Monmouth. The last two alpha characters signify the soil series. They are:

Soil Series

AD Adelphia
CL Collington
CM Colemantown
CN Colts Neck

DO	Donlonton
FR	Freehold
HN	Holmdel
KR	Kresson
MK	Marlton-Kresson
MR	Marlton
SH	Shrewsbury
TN	Tinton

Therefore, BUAD designates a sample of the Adelphia soil series from Burlington County.

The first three numeric characters represent the sample number for the soil series. The last numeric character represents the sample depth below land surface. In all cases, ---1 indicates the sample interval is from 0 to 6 inches. Except for samples MOCL1002 (2.5 to 3.0 feet), MOCM1002 (2.0 to 3.0 feet), MOFR1002 (2.25 to 2.9 feet), MOHN1002 (3.0 to 3.5 feet), MOKR1002 (2.0 to 2.5 feet), and MOMR1002 (2.0 to 2.5 feet), ---2 indicates a sample interval from 1.0 to 1.5 feet. The sample interval from 2.0 to 2.5 feet is designated as ---3, except for those previously noted. The few samples collected below 2.5 feet are designated as ---4. For example, BUCM2001 indicates that the sample is from Burlington County(BU) from the Colemantown (CM) soil series and is the second sample (200-) covering a 0- to 6-inch depth interval (---1). BUCM2003 is the second sample of the Colemantown soil series from the 2.0 to 2.5 feet depth interval in Burlington County.

This system of sample identification is used exclusively throughout this report. Depth intervals sampled are included with the lithologic description for each sample in Appendix 2.

Soil Formation and Development

Soils are complex heterogeneous assemblies of mineral and organic solids, with aqueous and gaseous components (Alloway, 1993; Sparks, 1995), reflecting the variability of the parent

material, and organic residues from which they form (McBride, 1994). Their elemental composition, particle (grain) size, and mineralogy stem more or less systematically from the character of the parent material and the extent to which it has been weathered (chemically decomposed) (McBride, 1994). Chemical weathering dissolves or alters the parent minerals (termed *primary minerals*) to produce aluminosilicate or layer (phyllo-) silicate minerals and hydrous oxides of iron, aluminum and manganese. These weathering products, collectively termed *secondary minerals* or *materials*, are typically clay size (less than 2 μm). They possess very high surface areas and strongly influence the chemical reactivity of soils.

The formation and development of soils is highly influenced by weathering processes. According to Jenny (1941) five factors control the formation and development of soils. These are: parent material, climate, topography, soil biota, and time. Flint (1971) states that "...the greatest differences among soils now forming are related to climate and vegetation." Variations in soil weathering and vegetation are a function of variations in climate and temperature. The leaching of soil minerals results where rainfall exceeds evapotranspiration for most of the year. Such chemical weathering gradually transports the soluble salts and more readily soluble minerals into the soil. Consequently, leached soil becomes progressively more acid, as in southern New Jersey. In the dry southwestern United States where evapotranspiration exceeds rainfall, calcium tends to precipitate as a carbonate mineral in the B-soil horizon, thereby producing alkaline soils. These differences in climate and weathering form the basis for the two primary soil subdivisions: *pedalfers* (high clay and iron concentrations in the B horizon, wetter climate) and *pedocals* (calcium-rich, dryer climate).

The mineralogical composition of soils is more a function of reaction rates, determined by chemical kinetics, than the inherent stability of minerals, determined by thermodynamic properties (McBride, 1994). McBride (1994) points out that "most soils are not at equilibrium or even steady state, but mineralogic changes are not likely to be detectable except on geological time scales."

Genetic Soil Master Horizons

As soil formation (pedogenesis) proceeds, distinct layers or horizons generally develop in the soil profile. A soil horizon is defined as “a layer of soil, approximately parallel to the surface, having distinct characteristics produced by soil-forming processes” (Jablonski and Baumley, 1989). An uppercase letter represents the major genetic soil horizon, and numbers or lowercase letters that follow represent subdivisions of the major horizon. The major genetic horizons, going from the land surface, downward are:

O horizon — dominated by organic material.

A horizon — the mineral horizon situated at or near the surface, but below the O horizon. It contains an accumulation of humified organic matter intimately mixed with the mineral fraction. Includes any plowed or disturbed surface horizon.

E horizon — mineral horizon in which the principal feature is the loss of silicate clay, iron, or aluminum, or some combination of these, leaving a concentration of leached sand and silt particles.

B horizon — mineral horizon formed below an O, A, or E horizon. It is in part a layer of transition from the overlying horizon to the underlying C horizon. This horizon shows one or more of the following distinctive characteristics:

- 1) illuvial concentration of silicate clay, sesquioxides of iron and/or aluminum, humus, or a combination of these. Illuviation is defined as the deposition of leached material in a soil;

- 2) coatings of sesquioxides which impart a conspicuously lower color value, higher chroma, or redder or browner hue to the horizon without apparent illuviation of iron, than do overlying and underlying horizons;

- 3) alteration which forms silicate clay or which liberates oxides, or both, and thereby forms a granular, blocky or prismatic structure if volume changes accompany changes in moisture content.

C horizon — mineral horizon, excludes indurated bedrock, that is little affected by pedogenesis, and does not have the properties typical of the overlying horizon. It may have been modified, even if there is no evidence of pedogenesis.

General Physical Characteristics for the Soils

Eleven soil series were selected and sampled for this investigation (table 3). Those selected range widely in the concentration of glauconite, ranging from little to none in the Holmdel and Shrewsbury series to glauconite-rich in the Kresson and Marlton series. A statistical summary of the glauconite- and quartz-sand fraction in the whole soils for eight of the soil series is tabulated in table 4. Too few data preclude a meaningful statistical analysis of the glauconite- and quartz-sand fractions in the Colts Neck, Donlonton and Tinton soil series.

Table 3. Taxonomic class and general diagnostic characteristics for the soil series sampled. Source: National Cooperative Soil Survey at <http://www.statlab.iastate.edu/soils/osd/dat>.

Soil Series	Taxonomic Class	Diagnostic Characteristics
Adelphia	fine-loamy, mesic Aquic Hapludults	Ochric epipedon: 0" to 14" (A & BA horizons) Argillic hor.: 14" to 30" (Bt horizon) Aquic condition: 14" to 80" periodically saturated (endosaturation).
Colemantown	fine, glauconitic, mesic Typic Ochraqults	none listed.
Collington	fine-loamy, mesic Humic Hapludults	Ochric epipedon: 0" to 11" (Ap horizon) Argillic hor.: 11" to 29" (BA & Bt horizons)
Colts Neck	fine-loamy, mesic Humic Hapludults	Umbric epipedon: 0" to 10" (Ap horizon) Argillic hor.: 15" to 35" (Bt1 & Bt2 horizons)
Donlonton	fine, mesic Aquic Hapludults	none listed.
Freehold	fine-loamy, mesic Typic Hapludults	none listed.
Holmdel	fine-loamy, mesic Aquic Hapludults	none listed.
Kresson	fine, glauconitic, mesic Aquic Hapludults	none listed.
Marlton	fine, glauconitic, mesic Humic and Typic Hapludults	Ochric epipedon: 0" to 10" (Ap horizon) Argillic hor.: 10" to 40" (Bt horizon) Seasonal high water table: 48" to 60".
Shrewsbury	fine-loamy, mesic Typic Endoaquults and Ochraqults	Ochric epipedon: 0" to 14" (Ap & Ag horizons) Argillic hor.: 14" to 32" (Btg hoizon.) Aquic condition: 0" to 60" periodically saturated (endosaturation).
Tinton	loamy, mesic Arenic Hapludults	none listed.

Even within a particular soil series the range in glauconite concentration may vary significantly from one sample to another. For example, glauconite sand ranges from 0 to 55 percent by volume in soil samples from the Colemantown and Kresson series (table 4). Likewise, there is high variability in the silt and/or clay concentration, some of which may be glauconite, among and within particular soil series (table 5). The glauconite ranges in size from sand thru clay (that is, less than 2 μm) in the soils.

Table 4. Statistical summary of semiquantitative granulometric analyses of the mean sand fraction in whole soils. Percentage sand is divided into glauconite (g) and quartz (q) for 8 of the 11 series included.

Soil Series	Sand	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Adelphia	g	1	27.5	12.5	9.5	11.9	22.5	10
	q	12.5	77.5	41.3	20.4	44.5	65	10
Colemantown	g	0	55	5	17.7	12	35	13
	q	0.5	90	40	29.3	37.2	60	13
Collington	g	0.5	6	3.5	2.2	3.2	5.5	10
	q	35	95	73.8	18.9	71.8	95	10
Freehold	g	0	5	2	1.5	2.4	4	15
	q	30	92.5	77.5	16.9	72.1	92	15
Holmdel	g	0	3.5	1	1	1.1	1.5	9
	q	15	92.5	62.5	24	55.6	65	9
Kresson	g	0	55	5	20.1	15.3	50	11
	q	0.5	65	12.5	25.5	24.5	60	11
Marlton	g	0	50	12.5	18.1	19.7	40	15
	q	2	40	25	13	17.2	27.5	15
Shrewsbury	g	0	2.5	0.5	0.9	0.9	2	10
	q	7.5	75	56.3	23	47.3	65	10

N, number of samples.

Table 5. Statistical summary of semiquantitative granulometric analyses of the silt and clay fraction in whole soils. Percentage silt plus clay is determined by subtracting the sand fraction from 100 percent.

Soil Series	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Adelphia	21.5	70	37.5	16.4	43.8	66	10
Colemantown	4.5	91	57	22.2	50.9	65	13
Collington	4	63.5	22.3	18.7	24.9	40	10
Freehold	3	68.5	20.5	17.5	25.2	35.5	15
Holmdel	6.5	83	36.5	23.5	42.6	77	9
Kresson	32.5	90.5	60	20.5	59.4	88.5	11
Marlton	35	87.5	61.5	14.3	62.5	75	15
Shrewsbury	23	89.5	42.5	23	51.4	77.5	10

N, number of samples.

Quartz dominates the sand fraction in all but the Kresson and Marlton soil series (table 4). Mean quartz sand is slightly more abundant than glauconite sand in the Kresson soil series. Mean glauconite- and quartz-sand fractions are nearly identical in the Marlton soil series.

The estimated maximum concentration of glauconite sand (55 percent) occurs in samples from the Colemantown (BUCM2004) and Kresson (CAKR4003) soil series at depths greater than or equal to 24 inches. Estimated maximum concentration of quartz sand (95 percent) occurs in samples from below 12-inch depth in the Collington soil series (GLCL4002 and GLCL4003). Kresson and Marlton soil series have the lowest median quartz sand concentrations — 12.5 and 25 percent, respectively.

Marlton (61.5 percent) and Colemantown (57 percent) soil series have the highest median silt and/or clay concentrations, whereas the Freehold (20.5 percent) and Collington (22.3 percent) series have the lowest median silt and/or clay concentrations.

Microscopic examination shows that most samples of the Colemantown, Kresson and Marlton soils contain sand- and coarse-silt fractions imbedded in a soft, waxy, green to brown-

stained, clay matrix. The significance of this observation is discussed later in the report.

The volume percentage of sand, silt, and clay were estimated visually. These percentages are necessary to assign a textural classification, for example loam or loamy sand, to the sample. Figure 3 is the NRCS triangle (ternary diagram) illustrating the textural classification of soils. The textural classification for each sample (Appendix 2) is generally consistent with those of the NRCS's county soil surveys.

The acreage of, and percent total area, for glauconite-bearing soils mapped by the NRCS in each county in the study area are given in table 6. Forty one percent or 126,060 acres of Monmouth County contains some glauconite. Burlington (104,880 acres), Camden (31,700 acres), and Gloucester (46,950 acres) Counties are occupied by 20 to 22 percent glauconite-bearing soil. For the glauconite-bearing soil series, the Freehold series is dominant in each of the four counties. The percent Freehold soil to all glauconite-bearing soil ranges from 25 percent in Burlington County to 83 percent in Gloucester County. The Holmdel soil series is the second most abundant glauconitic soil in Burlington (19 percent) and Camden (approximately 15 percent) Counties. The Marlton soil series is the second most prevalent soil in Gloucester (approximately 9 percent) County, and it is the Tinton series in Monmouth (20 percent) County.

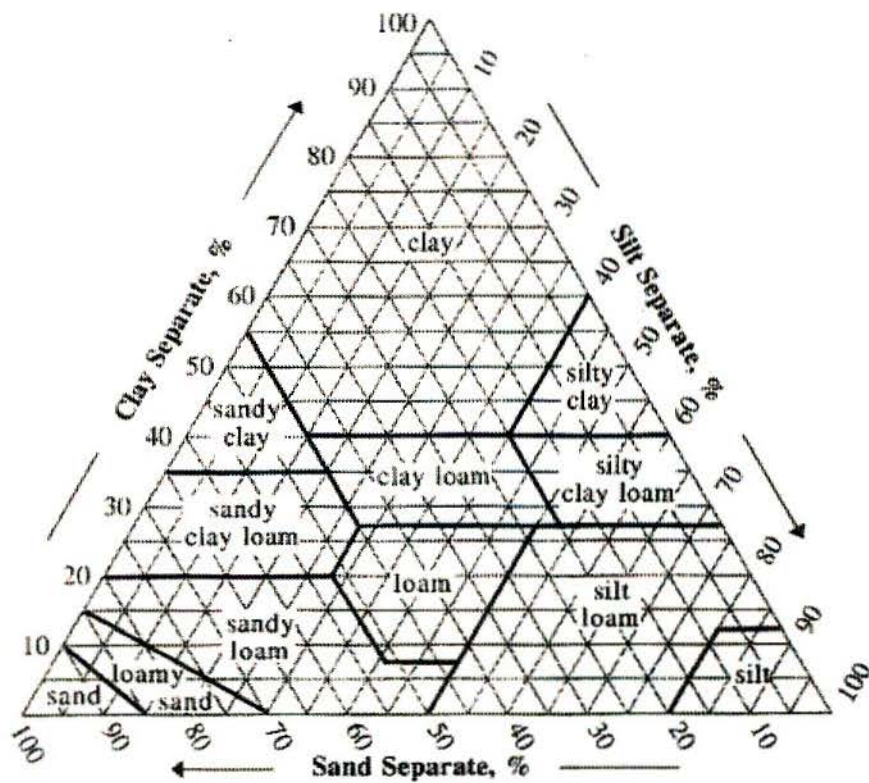


Figure 3. National Resources Conservation Service ternary diagram of soils based on texture.

Table 6. Percentage of soil mapped by the National Resources Conservation Service (NRCS) as glauconite-bearing, and the percent of total area occupied by these soils in each county. Top value is the acreage and the bottom value is the percent of the total area for the soil series relative to the acreage for glauconite-bearing soil in each county.

County	glauconite soil*	Adelphia	Colemantown	Collington	Colts Neck	Donlonton	Freehold	Holmdel	Kresson	Marlton	Shrewsbury	Tinton	Total
Burlington	20	15470 14.7	4600 4.4	12850 12.3		2790 2.7	26280 25.0	19950 19.0	3600 3.4	2370 2.3	10260 9.8	6710 6.4	104880 100
Camden	22		200 0.6	1400 4.4			22400 70.8	4700 14.8	250 0.8	1500 4.7	1250 3.9		31700 100
Gloucester	22		400 0.9	1800 3.8	1000 2.1		39000 83.1		600 1.3	4150 8.8			46950 100
Monmouth	41	5010 4.0	2240 1.8	14960 11.8	7150 5.7		49620 39.3	9310 7.4	980 0.8	2880 2.3	8550 6.8	25360 20.1	126060 100

* ratio of the acreage mapped as glauconite-bearing soils to the total acreage for soils in each county (expressed as a percentage) .

Sources: Jablonski and Baumley, 1989; Markley, 1962; 1966; 1971.

Introduction to Clay, Clay Minerals and Glauconite

Clay-size minerals and clay (layer silicate) minerals are important constituents of all soils that affect their chemical properties. Clay-size minerals, commonly referred to as *clay*, denote soil constituents that are less than 2 μm in effective diameter. The term *clay minerals* refers to minerals with sheet silicate structures of the phyllosilicate (layer silicate) group. They are called clay minerals because the clay-size fraction of soils consists principally of phyllosilicates, in addition to meager amounts of other crystalline and amorphous constituents. Because of this ambiguity, the term *phyllosilicates* is used as a descriptive name in this report.

Phyllosilicates consist of a combination of two structural units. One is an array of silicon/oxygen (Si-O) tetrahedra, referred to as the *tetrahedral sheet*. The second is an array of cations (generally Al^{+3} , Fe^{+2} , Fe^{+3} , and/or Mg^{+2}) in octahedral coordination with oxygen or hydroxyl (OH^-) anions (the *octahedral sheet*). In phyllosilicates the tetrahedral and octahedral sheets are bonded together by shared oxygen atoms.

The general chemical formula of most phyllosilicate-group minerals is:



where X represents the interlayer sites between the tetrahedral and octahedral sheets, Y the octahedral sites, and Z, the tetrahedral sites.

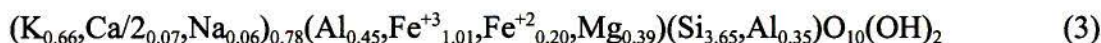
The substitution of one ion for another of similar size within a crystal lattice or framework is called *isomorphous substitution*. The substituting ion may have a lower, equal, or greater charge than the ion which it replaced. In phyllosilicate lattices, cations may substitute for coordinating cations in the tetrahedral and/or octahedral sites. A net negative charge develops on the mineral when a cation of lower valence (charge) substitutes for one of higher valence, for example, Al^{+3} for Si^{+4} or Fe^{+2} for Al^{+3} , which results in an imbalance in the negative charge of OH^- and O^{2-} ions in the mineral lattice. For this reason, isomorphic substitution is responsible for the *permanent charge* of soils.

The term *glauconite* is ambiguous (Moore and Reynolds, 1997) in that it is used to describe not only the mineral but also the rounded, earthy green pellets formed in an open marine environment (continental shelf and upper slope). The term has been used to describe earthy, green pellets that lack the mineral glauconite. Glauconite, used as a mineral name, refers to a spectrum of iron-rich (dioctahedral) clay minerals which commonly are interstratified in a range of proportions (Weaver and Pollard, 1973). A detailed discussion of the subtleties among the glauconite group minerals, which range from glauconitic smectite (a partially glauconitized precursor mineral) to glauconitic mica, the true glauconite mineral (Odin and Matter, 1981), is beyond the scope of this report. For this report, the terms glauconite, glauconitic and glauconite-bearing denote the earthy green pellets/aggregates in the samples. Based on morphological and compositional criteria, most of these sand- to coarse silt-size pellets in the sediment of the New Jersey Coastal Plain indeed consist of the mineral glauconite.

The mineral glauconite has an empirical chemical formula (Gaines and others, 1997) that can be written as:



Based on 82 chemical analyses, Weaver and Pollard (1973) report the average formula for glauconite is:



These formula show that the interlayer sites between the tetrahedral and octahedral sheets are occupied by potassium (K), sodium (Na) ± calcium (Ca) atoms. Aluminum (Al) atoms in the octahedral sites are substituted by ferric and ferrous (Fe^{+3} and Fe^{+2} , respectively) iron ± magnesium (Mg), and silicon (Si) atoms in the tetrahedral sites are substituted by Al.

Lastly, glauconite imparts a greenish color to the sediments in which it is common. These are informally referred to as *greensands*. The term *greensand marl*, found in the early literature, should be restricted to glauconite-rich sediments having significant amounts of

carbonate minerals, such as those in basal parts of the Vincentown Formation.

Results and Discussion

pH of Soils and Glauconite

All soil pHs were measured in a 0.01M CaCl₂ solution. This solution lowers the pH by about 0.5 pH unit compared to soil pH in water (Schofield and Taylor, 1955). Based on measurements of 113 composite samples, the soil pH ranges from 2.88 (CASH2001) to 6.94 (GLCN1003). Median and mean pH values are 3.7 and 3.9, respectively. These soils are appropriately categorized as being extremely to very strongly acid based on the NRCS classification scheme. Ninety percent (102 of 113) of the soil samples have pHs less than or equal to 4.7.

The lowest pH in soil occurred in the top six-inch composite sample of the Shrewsbury series soil from Camden County (CASH2001). This sample is an organic-rich, well drained, fine sandy (quartz) loam with only a trace of glauconite. The highest pH value was measured in a composite sample of the Colts Neck series from Gloucester County (GLCN1003). At this station, evidence that the soil profile was disturbed include: a manicured lawn approximately three feet north of a large, actively cultivated field with a vine crop; bituminous coal shards in the top twelve inches of the soil; and large fragments of oyster shells (possible middens?) encountered at approximately 2.2 feet below grade. This sample is a medium-to-fine, sandy (quartz) loam with approximately two percent glauconite sand.

There is no change in pH for the surface composite soil compared to the composites from the 24- to 30-inch depth interval. Median, mean, and 90th percentile pH values for the surface versus deeper soil are: 3.67 vs. 3.68, 3.90 vs. 3.91, and 4.77 vs. 4.60, respectively. pH tends to increase slightly with depth in natural soil profiles for these glauconite-bearing soil series (unpublished data, Professor J. C. F. Tedrow, Rutgers Univ.).

Outliers were identified by using the method suggested in the NJDEP's Field Sampling Procedures Manual (Schoenleber and Morton, 1992). First ($Q_{0.25}$) and third ($Q_{0.75}$) quartiles were calculated. *Mild* outliers are defined as: $Q_{0.75} + 1.5(Q_{0.75} - Q_{0.25})$, and *extreme* outliers as: $Q_{0.75} + 3.0(Q_{0.75} - Q_{0.25})$. Therefore, mild outliers have values exceeding $Q_{0.75} + 1.5(Q_{0.75} - Q_{0.25})$ but less than $Q_{0.75} + 3.0(Q_{0.75} - Q_{0.25})$. Extreme outliers are values exceeding $Q_{0.75} + 3.0(Q_{0.75} - Q_{0.25})$.

Soil samples with pH values that are mild and extreme are tabulated in table 7. With the exception of GLCM3003, all the soil samples having outlier pH values show evidence of disturbance by anthropogenic activities, that is mainly agriculture. Therefore, pH values exceeding 4.7 in glauconite-bearing soil can be used to discriminate natural soil profiles from disturbed ones. pH values exceeding 4.7, or approximately 5.2 for pHs determined using water, should flag chemical data for potential anthropogenic inputs.

The low pH values for these soils were unsettling. To assess how glauconite might affect the pH of a sample, pH was measured on essentially pure (99+ percent) glauconite from the Hornerstown Formation. pH values of 2.86 and 2.95 were measured. These low pH values are interpreted to represent an exchange reaction, commonly referred to as *cation exchange capacity* (CEC). The calcium ions (Ca^{+2}), supplied by the 0.01M $CaCl_2$ solution, exchange for two protons (hydrogen ions — H^+) on the surface of the constituent layers in glauconite. This reaction can be represented by:



where $>OH$ and $>OCa$ represent exchange sites on the edge of the sheets comprising the phyllosilicate minerals. The liberation of two protons into solution for each calcium ion exchanged results in lowering the solution pH. The cation exchange capacity for glauconite concentrates from the Hornerstown and Navesink Formations in New Jersey is 15.4 and approximately 16.6 (15.4 to 18.5) milliequivalents calcium per 100 grams, respectively (Owens and Minard, 1960). The proposed interpretation for the exchange reaction is consistent with the reported cation exchange capacity for glauconite from New Jersey.

Table 7. Soil samples having pH values that are mild or extreme outliers.

<u>Mild Outliers</u>			<u>Extreme Outliers</u>		
<u>Sample</u>	<u>pH</u>	<u>Land use</u>	<u>Sample</u>	<u>pH</u>	<u>Land use</u>
BUCM2001	4.97	former marl pit	BUCM2004	5.98	former marl pit (mine)
BUCM2002	5.44	(excavation)	CAFR3001	6.15	formerly cultivated field
BUCM2003	5.62		GLCM3003	6.14	water-logged soil
BUSH1001	4.98	cultivated field	CLCN1003	6.94	manicured lawn on edge of
MOAD1001	5.02	cultivated corn			cultivated field
MOAD1002	5.18	field	GLKR5001	6.23	open cultivated field

Total Analyte Concentrations in Glauconite-Bearing Soils and Glauconite Isolates

This section focuses on the total metal concentrations in samples of whole soils, glauconite isolated from these soils, and pristine glauconite from the Ancora core hole. Though State and Federal regulations do not require determination of total metal concentrations in soils, these data are reported here to facilitate comparisons with total metal concentrations in United States and worldwide soils, and to provide a measure of the extraction efficiency for U.S. EPA SW-846, Method 3050 (U.S. EPA, 1995).

Whole Soil

Fourteen samples of whole soils from five glauconite-rich soil series were analyzed for total metals (table 8). A statistical summary of these data is in table 9. Total arsenic concentrations in these whole soils range from 13 ppm (BUCM2003) to 131 (CAKR4003). BUCM2003, a clay loam, consists of 30- to 40-percent glauconite sand embedded in a green (glauconitic?) clay matrix, whereas CAKR4003, a medium to fine sandy clay loam, has 50- to 60-percent glauconite sand. Both samples represent a composite from 24 to 30 inches below grade, although BUCM2003 is from a former marl pit (note high calcium concentrations for BUCM2001 and 2003, table 8) and therefore is probably disturbed. Median and arithmetic mean

total arsenic concentrations are 29.5 ppm and 45.1 ± 34.9 ppm, respectively. The high standard deviation for the mean shows that the baseline arsenic concentration is highly variable in these soils. Iron-rich rocks and sediments show wide variations in their arsenic content (Boyle and Jonasson, 1973).

Total arsenic concentration in U.S. soils (N=1257) at the 20-cm (7.9 inches) depth ranges from <0.1 to 97 ppm with a median concentration of 7.2 ppm (Shacklette and Boerngen, 1984). The range in arsenic concentration for soils (N=327) from around the world is 0.10 to 40 ppm with a 6 ppm median (Bowen, 1979). The arsenic concentration in “normal soils” (N=327), on a worldwide basis, ranges from 0.1 to 55 ppm with a 7.2 ppm median (Tanaka, 1988). Therefore, the median arsenic concentration in soils is approximately 6 to 7.2 ppm. The 29.5 ppm As median for these glauconite-bearing soils is 4 to 5 times the median concentration for U.S. and worldwide soils (fig. 4). According to Walsh and others (1977), total arsenic concentration for uncontaminated New Jersey soil is 10.0 ppm (sample size and range unstated) and for soil repeatedly treated with an arsenical pesticide or defoliant is 97 to 270 ppm. The 29.5 ppm median and 45.1 ± 34.9 ppm mean arsenic concentration (table 9) for these glauconitic soils contradict Walsh and others (1977).

Table 8. Total concentration of analytes (mg/kg) in whole soils determined by various analytical methods. Concentrations for Al, Ca, Fe, Mg, Mn and Na have been converted from weight percent oxide, on a dry basis, to mg/kg.

Analyte	BUAD2001	BUAD2003	BUCL2001	BUCL2003	BUCL2001	BUCL2003	BUMR4001	BUMR4003	CAKR4001	CAKR4003	MOAD3001	MOAD3003	MOKR1001	MOKR1002
Al	46270	49130	34410	50710	52040	46690	41660	45260	48330	45370	43090	27530	44520	45580
Sb	1.9	1	2.5	1.4	1.9	1.1	1.9	2.6	2.9	4.3	2.8	1.6	4.7	4.4
As	19	29	19	30	20	13	22	23	64	131	49	41	95	77
Ba	326	221	340	238	810	352	181	69	176	161	275	132	127	56
Be	3.7	4.6	2.7	6.3	7.3	9.6	7.7	7.8	7.4	6.6	3.2	2.9	11.9	11.4
B	200	289	130	322	220	433	387	434	368	220	140	173	349	478
Cd	0.7	0.2	<0.2	<0.2	0.9	<0.2	0.5	<0.2	0.2	<0.2	0.3	<0.2	0.3	<0.2
Ca	1140	570	1720	500	12010	9010	3720	2860	2000	1790	1140	430	3570	640
Cr	125	181	155	400	327	445	503	769	292	369	300	306	826	983
Co	5	6	5	6	12	7	9	8	9	12	3	3	11	10
Cu	8	4.5	10.4	4.5	5	2.2	4.7	2.3	7.8	6.5	11.5	3.5	6.9	2.3
Fe	70630	133920	49230	120840	143920	144270	138880	174200	176080	263010	94830	80840	216150	211890
Pb	33	11	85	11	41	3	22	9	31	18	74	7	30	24
Mg	7060	13810	4100	12670	15980	22200	17310	22920	17250	11100	5130	4950	15620	20020
Mn	230	150	390	150	4110	150	310	<80	390	390	390	<80	230	<80
Mo	<1	<1	<1	<1	<1	<1	<1	<1	<1	1	<1	<1	<1	<1
Ni	10	21	16	16	24	22	19	23	17	25	14	9	21	25
K	31450	49380	21490	43320	39000	60080	55520	69380	55350	35520	23820	18760	49540	65480
Se	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Ag	0.5	0.3	0.6	0.6	0.7	<0.2	0.3	<0.2	0.8	0.4	0.3	0.2	0.5	<0.2
Na	2300	1110	1480	1040	1710	960	960	300	670	590	1260	450	670	220
Tl	0.4	0.3	0.3	0.2	0.4	0.2	0.8	0.4	0.2	0.3	0.2	<0.1	0.1	<0.1
V	81	93	88	173	137	164	146	213	113	147	130	125	386	411
Zn	69	57.4	94	105	196	187	163	191	120	114	91.3	55.1	251	276
%LOI	8.65	5.6	13.8	5.6	15.1	6.35	7.55	5.65	10.6	8.8	9.95	3.25	9.9	6.65

%LOI is loss on ignition reported as a weight percent.

Table 9. Statistical summary of total analyte concentrations for whole-soil samples.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	27530	52040	45475	6453	44328	49130	14
Sb	1.0	4.7	2.2	1.2	2.5	4.3	14
As	13	131	29.5	34.9	45.1	77	14
Ba	56	810	201	187	247	340	14
Be	2.7	11.9	7.0	3.0	6.7	9.6	14
B	130	478	306	116	296	433	14
Cd	0.2	0.9	0.3	0.3	0.4	0.7	7
Ca	430	12010	1755	3436	2936	3720	14
Cr	125	983	348	260	427	769	14
Co	3	12	7.5	3	7.6	11	14
Cu	2.2	11.5	4.9	2.9	5.7	8.0	14
Fe	49230	263010	141400	60354	144192	211890	14
Pb	3	85	23	24	29	41	14
Mg	4100	22920	14715	6359	13580	20020	14
Mn	150	4110	310	1160	626	390	11
Ni	9	25	20	5	19	24	14
K	18760	69380	46350	16387	44149	60080	14
Ag	0.2	0.8	0.5	0.2	0.5	0.7	11
Na	220	2300	960	574	980	1480	14
Tl	0.1	0.8	0.3	0.2	0.3	0.4	12
V	81	411	141	102	172	213	14
Zn	55.1	276	117	71	141	196	14
LOI	3.25	15.1	8.1	3.3	8.4	10.6	14

All concentrations are in mg/kg (ppm).

Loss on ignition (LOI) is reported as weight percent.

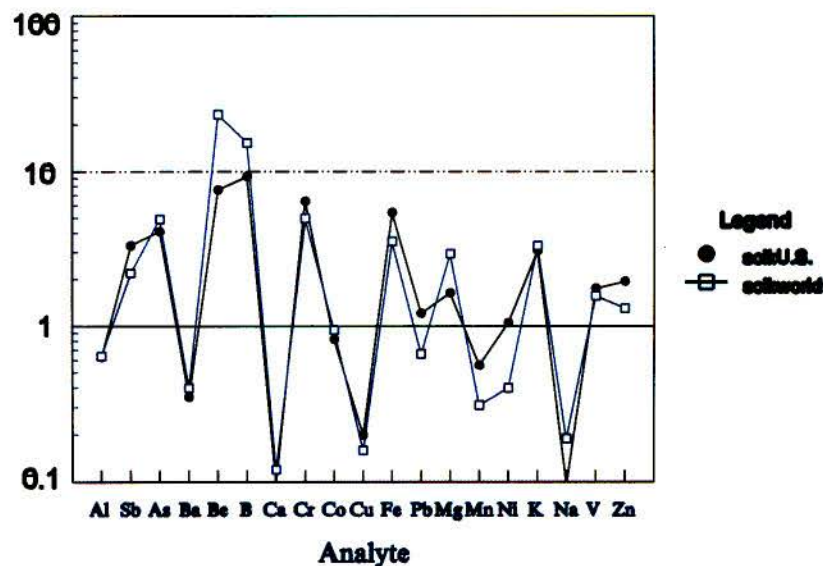


Figure 4. Ratio between the median analyte concentration in the whole soil to those for U.S. and worldwide soils. For a ratio of unity (1), the median analyte concentration for the whole soil equals the median concentration in U.S. or worldwide soil. A ratio much greater than or much less than unity indicates that the median concentration for the whole soil is higher or lower, respectively, than in U.S. or worldwide soils.

Ocean sediments can be greatly enriched in total arsenic (Boyle and Jonasson, 1973). Cronan (1972) reports total arsenic concentrations ranging from 48 to 361 ppm with a 174 ppm mean in iron-rich sediments from the Median Valley of the Mid-Atlantic Ridge near 45°N. For marine shales of Late Cretaceous age from the western United States, the total arsenic concentration ranges from 4 to 25 ppm (13 ppm mean and 12 ppm median, n = 32) in nearshore shale and claystone, and from 3 to 490 ppm (27 ppm mean and 12 ppm median, n = 53) in

offshore shale and claystone (Tourtelot, 1964). The high-end arsenic concentrations in the offshore shale and claystone occurs in pyrite-bearing sediments. Tourtelot (1964) demonstrates that the arsenic occurs in some samples principally in syngenetic pyrite but also is present in relatively high concentrations in samples containing sparse pyrite. The arsenic concentration in pyrite from rocks not effected by arsenic mineralization ranges from 100 to 1600 ppm (sample size unstated) (Boyle and Jonasson, 1973). The 131 ppm arsenic in CAKR4003 exceeds the maximum arsenic concentration for soils from around the world. It is unclear whether the high arsenic concentrations for the CAKR4000 station are totally natural or augmented by anthropogenic sources. The high arsenic concentration in the surface sample (CAKR4001 — 64 ppm) and at the 24- to 30-inch depth are confounded by the observation that the constituent soil particles are strongly coated with iron oxyhydroxides (FeOOH) in the deeper sample. The mineral vivianite ($\text{Fe}^{+2}_3(\text{PO}_4)_2 \cdot 8\text{H}_2\text{O}$), which can be common in glauconite-rich sediments, is in CAKR4003. The chemistry of arsenate and phosphate anions in soils is very similar (Roy and others, 1986; Darland and Inskeep, 1997; Peryea and Kammereck, 1997), and therefore a significant portion of the arsenic may be incorporated into the vivianite crystal lattice in addition to being sorbed onto the iron oxyhydroxide phases coating the soil particles. The apparent absence of vivianite in the surface soil sample and the relatively high arsenic concentration might represent natural (lithogenic) arsenic that was liberated by the dissolution of vivianite.

Total beryllium concentrations range from 2.7 ppm (BUCL2001) to 11.9 ppm (MOKR1001). There is approximately 5 percent glauconite sand in BUCL2001, a loamy fine sand, and 15 percent glauconite sand embedded in a soft, (glauconite?) clay matrix in MOKR1001, a clay loam. Both samples are a composite from the top six inches of soil. MOKR1001 is from an established cedar tract in a Freehold County Park. This area had been farmed in the mid 1800s through the early 1900s so the established cedar stand may be second growth on disturbed soil (Nelson “Joe” Tyberghein, Superintendent of Parks and Recreation for Freehold Township, oral communication, 1999). Additionally, the drive into the park is fill material in a swampy area. Moreover, the former superfund site, Lone Pine, is upstream of the

sample site. Therefore, this site is disturbed, although evidence of disturbance, such as a plowed soil horizon (Ap), was not observed. Median and mean beryllium concentrations are 7.0 ppm and 6.7 ± 3.9 ppm, respectively.

Total beryllium concentration at a 20-cm depth in U.S. soils ranges from < 1 to 15 ppm with a median concentration of 0.92 ppm (Shacklette and Boerngen, 1984). 479 of 1303 soil samples from the U.S. had concentrations at or exceeding the 1 ppm minimum detection limit. Beryllium concentration ranges from 0.01 to 40 ppm with a 0.30 ppm median for soils on a worldwide basis (Bowen, 1979). The 7.0 ppm median for the glauconite-bearing soil is approximately eight times the median for U.S. soil and 23 times that for worldwide soils (fig. 4). Beryllium concentration in these glauconite-bearing soils fall within the normal range for U.S. and world soils.

Relative to other soils, high median concentrations for antimony (Sb), boron (B), and chromium (Cr) occur in these glauconite-bearing soils (fig. 4). The range in Sb concentration (1.0 to 4.7 ppm) for these soils lie within the normal range (<1 to 8.8 ppm for U.S. and 0.2 to 10 ppm worldwide) for soil. The boron concentration range (130 to 478 ppm) in these soils exceeds the normal range (<20 to 300 ppm U.S. and 2 to 270 ppm world) for soil. Boron concentration in glauconite isolated from soil ranges from 345 to 662 ppm and from 350 to 691 ppm in pristine glauconite from deep core holes. Boron is a trace constituent element in glauconite. Therefore, glauconite appears responsible for the high concentration of B in these soils. The range in Cr concentration (125 to 983 ppm) in these soils falls within the normal range (1 to 2000 ppm U.S. and 5 to 1500 ppm world) for soil.

Glauconite Isolates from Soil

The total concentration of analytes in glauconite isolated from the 14 whole soils is in table 10. Note the high concentration of iron in these samples, a characteristic of glauconite. The range in arsenic concentration (18 to 126 ppm, N=10) for the glauconite isolates is

Table 10. Total concentration (mg/kg) of analytes in glauconite isolates from soils determined by various analytical methods.

Analyte	BUAD2001	BUAD2003	BUCL2001	BUCL2003	BUCL2001	BUCL2003	BUMR4001	BUMR4003	CAKR4001	CAKR4003	MOAD3001	MOAD3003	MOKR1001	MOKR1002
Al	46430	47430	48540	43890	36840	35730	38540	37590	42670	43940	57910	47960	38430	43200
Sb	NA	NA	NA	1.9	3.0	1.4	1.6	2.1	2.0	3.9	NA	2.1	5.5	3.1
As	NA	NA	NA	37	49	18	27	23	48	118	NA	79	126	58
Ba	31	87	198	28	844	127	43	40	89	104	220	57	56	22
Be	8.8	NA	NA	9.4	12.0	11.3	10.6	10.2	9.7	7.9	NA	8.1	14.6	10.8
B	582	NA	NA	566	399	598	616	585	562	345	NA	662	402	476
Cd	<0.2	<0.2	0.7	<0.2	0.4	0.6	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.4	<0.2
Ca	3720	640	2570	500	8360	6220	3070	2070	1720	400	2930	860	2720	710
Cr	NA	NA	NA	509	358	446	481	555	226	330	NA	309	755	806
Co	9	NA	NA	8	25	8	10	10	12	13	NA	6	12	10
Cu	13.4	NA	NA	12.6	6.8	2.9	6.5	4.4	7.5	7.0	NA	8.7	12.3	4.0
Fe	195100	231890	173780	191750	231890	173360	188180	183780	196430	268600	211750	232520	274900	213290
Pb	17	NA	NA	25	97	5	16	9	29	20	NA	27	75	37
Mg	18580	20570	12060	19720	19780	25510	23340	24190	21770	14350	13030	16220	18030	20930
Mn	150	770	1780	700	7750	<80	310	<80	150	310	1390	390	310	<80
Mo	<1	NA	NA	<1	<1	<1	<1	<1	<1	<1	NA	<1	<1	<1
Ni	15	NA	NA	35	29	23	33	30	24	38	NA	24	26	32
K	63650	59500	44730	61830	52530	70950	70710	74440	68710	48630	44980	54850	55100	67300
Se	NA	NA	NA	<5	<5	<5	<5	<5	<5	<5	NA	<5	<5	<5
Ag	0.6	NA	NA	0.6	1.0	0.4	0.5	1.3	0.5	1.1	NA	<0.2	0.4	<0.2
Na	450	740	1110	220	670	220	300	300	300	300	960	370	220	220
Tl	0.1	<0.1	0.3	<0.1	0.2	<0.1	<0.1	<0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1
V	171	NA	NA	226	223	167	189	190	118	149	NA	305	451	322
Zn	92.8	NA	NA	158	215	159	184	172	115	126	NA	128	294	283
%LOI	6.3	9.8	20.2	5.75	13.4	5.55	5.95	5.4	7.25	7.8	16.0	6.8	8.7	5.95

%LOI is loss on ignition reported as a weight percent.

NA indicates that insufficient quantity of sample did not permit analyses for these analytes.

essentially identical to the range for the whole soil (13 to 131 ppm). The lowest arsenic concentration for the glauconite isolates is from BUCM2003 which also has the lowest arsenic concentration for the whole soils. The isolate from MOKR1001 has the highest arsenic concentration. CAKR4003 has the second highest concentration (118 ppm) for the isolates and has the highest whole soil As concentration. Though the total arsenic concentration is identical in the glauconite-sand isolates and whole soil, glauconite sand constitutes only a fraction of the constituents in the soil. This suggests then that some of the total arsenic concentration in these soils is associated with glauconite sand.

The estimated glauconite sand content of these 14 whole-soil samples ranges from 3 to 5 percent in BUCM2003 to 50 to 60 percent in CAKR4003. MOKR1002 consists of ≥ 50 percent glauconite sand embedded in a soft, green (glauconite?), clay/silt matrix. The abundance of glauconite in the silt and clay fractions is unknown. It is possible that the glauconite concentration is high in samples where the glauconite sand is embedded in this soft, waxy, green, clay/silt matrix, as in samples from the Colemantown, Kresson and Marlton soil series (appendix 2).

A mass balance approach to account for the arsenic in whole soil, as a function of glauconite concentration, is based on the percent glauconite sand, the calculated glauconite concentration needed in the clay/silt fractions, and the arsenic concentration in the glauconite isolated from the soil. For example, BUCM2003 has 13 ppm As (table 8) and consists of 30 to 40 percent glauconite sand, less than 1 percent quartz sand, and by difference approximately 60 to 70 percent clay/silt. Glauconite sand isolated from BUCM2003 has 18 ppm As (table 10). The glauconite sand should account for approximately 7 ppm As, that is 40% glauconite sand at 18 ppm = 7.2 ppm As, in the whole soil. The 6 ppm arsenic unaccounted for by the glauconite sand in the soil may be glauconite in the clay/silt fractions. This requires that approximately half of the total clay/silt fraction consists of glauconite, that is $[0.5(60\% \text{ clay/silt in whole soil}) \times 18 \text{ ppm As in glauconite isolate} = 5.4 \text{ ppm As}]$. Therefore, the total glauconite content, by volume,

needed to fully account for the arsenic is approximately 70%. These calculations were performed on the other nine whole-soil samples. These calculations fail to account for the arsenic concentration in:

BUCL2003 — 7.4 ppm As from glauconite versus 30 ppm in whole soil.

BUMR4003 — 17.3 ppm As from a possible 75 percent glauconite maximum. Sample would need to consist entirely of glauconite which is not supported by the lithologic description (appendix 2).

CAKR4001 — approximately 5 percent quartz sand and assuming 95 percent glauconite yields 45.6 ppm As versus 64 ppm in the whole soil.

CAKR4003 — approximately 5 percent quartz sand and assuming 95 percent glauconite yields 112 ppm As versus 131 ppm As in the whole soil. Experimental error might account for this difference although it is highly unusual for mature soil to consist entirely of glauconite.

MOKR1002 — 100 percent glauconite equals 58 ppm As versus 77 ppm As in the whole soil.

Beryllium concentration in the glauconite isolates (7.9 to 14.6 ppm, N=11) is higher than in the whole soil (2.7 to 11.9 ppm). The lower beryllium concentration in whole soil results from the dilution of glauconite by other constituent minerals. In other words, none of the soil samples consists entirely of glauconite.

The median analyte concentrations in the soils and glauconite isolates, divided by the median concentration in U.S. soils, is shown in figure 5. The median analyte concentration for the glauconite isolates generally is slightly higher than for the whole soil. The lower median analyte concentration in whole soil reflects the dilution of glauconite by other constituent minerals such as quartz. The two traces are remarkably similar for most analytes. This similarity suggests that glauconite is the principal source of the TAL analytes.

Pristine Glauconite

Soil formation in a temperate climate is dominated by the chemical weathering of parent

material, in this case glauconitic sediments. Chemical weathering alters the overall chemistry of the parent material by leaching the soluble elements while the less soluble elements are retained.

Glauconite-rich parent sediment was sampled in a continuous core from an exploratory hole drilled at Ancora (fig. 1). A water-base, bentonite drill mud was used for the coring. The geologic formations and depth intervals sampled are:

Hornerstown Formation	603.5 to 603.6* and 605.0 to 605.1
Navesink Formation	641.9 to 642.0, 645.9 to 646.0, and 647.5 to 647.6
Mount Laurel Sand	659.9 to 660.0, 663.9 to 664.0, and 665.9 to 666.0
Marshalltown Formation	747.4 to 747.5 and 749.0 to 749.1
Englishtown Formation	789.3 to 789.4 and 791.9 to 792.0
Merchantville Formation	923.0 to 923.1 and 925.0 to 925.1

* depths are in feet below the surface elevation. Samples were composited for each formation.

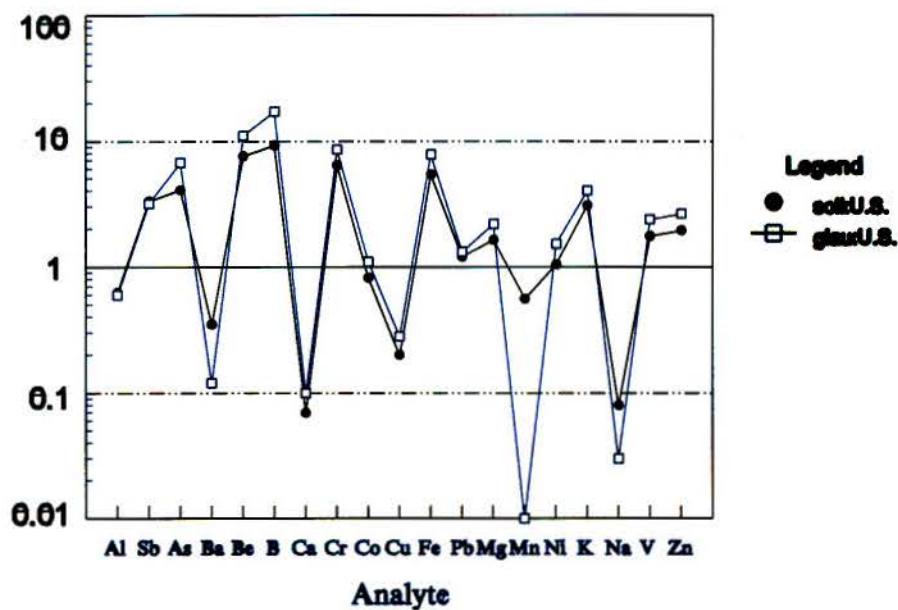


Figure 5. Ratio of the median analyte concentration in the whole soil and glauconite isolate to that in U.S. soil.

Samples of the geologic formations and the glauconite isolated from these formations are considered to be pristine, that is, unaffected by anthropogenic input. The analyte concentrations for the geologic formations and their glauconite isolates are in table 11.

Table 11. Total concentration (mg/kg) of analytes in pristine, glauconite-rich sediment from the Ancora core hole. Concentrations are for the geologic formations from the Ancora core and for the glauconite isolated from them.

Analyte	ANHRNW	ANHRNS	ANNAVW	ANNAVS	ANMTLW	ANMTLS	ANMRSW	ANMRSS	ANENGW	ANENGs	ANMERW	ANMERS
Al	51030	38060	36370	37530	25940	62890	60770	48600	67390	55160	65910	53040
Sb	1.1	1.3	0.9	1.2	0.6	5.2	0.5	0.7	0.5	0.9	NA	1.3
As	8	7	14	17	51	136	17	24	30	38	NA	55
Ba	148	31	112	48	180	120	320	35	266	45	313	69
Be	7.0	10.5	4.6	7.8	2.5	9.8	5.9	8.2	7.1	8.7	5.6	7.9
B	358	569	311	584	115	487	443	691	464	600	339	469
Cd	<0.2	<0.2	0.5	<0.2	1.3	<0.2	0.9	<0.2	<0.2	<0.2	0.3	0.3
Ca	41740	8290	204220	47030	157970	18300	32380	6720	4650	3070	28730	3930
Cr	280	351	106	121	150	1150	180	283	196	427	NA	408
Co	10	11	10	10	10	31	12	10	8	7	20	16
Cu	6.6	2.8	4.4	3.4	2.5	3.9	7.7	2.1	6.4	2.9	7.8	2.7
Fe	101890	159790	96430	144620	59790	248530	103990	155590	113920	158110	147200	179020
Pb	6	5	6	9	8	16	11	4	8	6	12	9
Mg	20750	28660	17910	26840	5430	18030	17250	24610	15740	20570	16470	18760
Mn	80	<80	310	<80	390	850	150	<80	<80	<80	150	80
Mo	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
Ni	47	33	21	21	27	71	27	13	23	10	34	23
K	49290	75680	45310	71200	19420	49290	53690	77340	53940	71620	55520	71950
Se	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	NA	<5
Ag	0.3	<0.2	0.5	0.3	<0.2	0.3	0.4	<0.2	0.2	<0.2	<0.2	<0.2
Na	2520	890	2150	960	2150	820	2820	960	2600	1040	2230	1110
Tl	0.3	<0.1	<0.1	<0.1	0.2	<0.1	0.2	<0.1	0.3	<0.1	0.1	<0.1
V	107	115	60	78	148	685	133	140	294	352	282	328
Zn	122	113	74.9	96.6	72.4	221	87.7	66.9	80.4	70.8	81.6	66.2
%LOI	7.6	5.15	18.0	5.6	14.6	7.6	7.1	5.1	6.0	5.15	8.55	5.25

The prefix AN indicates the sample is from the Ancora corehole. The suffixes W and S indicate whole and glauconite separate, respectively.

HRN is Hornerstown Formation; NAV is Navesink Formation; MTL is Mount Laurel Sand; MRS is Marshelltown Formation;

ENG is Englishtown Formation; and MER is Merchantville Formation.

%LOI is loss on ignition reported as weight percent.

To evaluate how chemical weathering has modified the chemical constituents in glauconite from soil, the chemistry of pristine glauconite can be compared to that of the soil glauconite. This statistical comparison is tabulated in table 12. Pristine glauconite from the Bass River core hole (Dooley, 1998) is included in table 12 with others from the Ancora core hole.

Table 12. Statistical summary of the total analyte concentrations (mg/kg) in glauconite isolates from soil and pristine glauconite from New Jersey. Top value in table is for the glauconite isolated from soil and the bottom value is for the pristine glauconite from the Ancora and Bass River core holes.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	35730	57910	43545	6000	43507	47960	14
	37530	62890	45530	8384	46406	55160	13
Sb	1.4	5.5	2.1	1.3	2.7	3.9	10
	0.7	7.7	1.2	2.1	1.9	1.6	13
As	18	126	48.5	38	58.3	118	10
	7	136	24	34	31.8	38	13
Ba	22	844	72	212	139	198	14
	31	120	69	29	70	100	13
Be	7.9	14.6	10.2	1.9	10.3	10.8	11
	5	10.5	7.9	1.8	7.5	8.7	13
B	345	662	566	104	527	616	11
	350	691	540	81	540	600	13
Ca	500	8360	2320	2237	2680	3720	14
	3070	61330	16510	17467	19734	39170	11
Cr	226	806	464	189	478	755	10
	121	1150	351	329	389	427	13
Co	6	25	10	5	11	13	11
	4	31	11	7.2	12.2	16	13
Cu	2.9	13.4	7	3.6	7.8	12.6	11
	1.0	8.3	2.9	2.1	3.5	3.9	12
Fe	173360	274900	204090	32380	211944	232520	14
	142730	248530	159790	27791	167320	179020	13
Pb	5	97	25	28	32	75	11
	3	31	9	8	11.2	19	11
Mg	12060	25510	19750	4087	19149	23340	14
	17850	28660	22440	3984	23273	27680	13
Ni	15	38	29	6.5	28	35	11
	10	71	23	17	29.5	46	13
K	44730	74440	60665	9935	59850	70710	14
	49290	77340	69710	7806	67500	73860	13

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
V	118	451	190	96	228	322	11
	54	685	110	219	222	352	13
Zn	92.8	294	159	66	175	283	11
	56	370	86	90	123	200	13

The ratio between the median and arithmetic mean analyte concentrations in glauconite isolated from soil and pristine glauconite is shown in figure 6. A ratio of one (unity) demonstrates that the analyte concentration in the soil glauconite equals that in the pristine glauconite, which implies chemical weathering has no net effect on the analyte concentration. A ratio greater than or less than one indicates that the analyte concentration in soil glauconite is enriched or depleted (leached), respectively, relative to the pristine (parent) glauconite. Figure 6 clearly shows that soil glauconite is enriched in arsenic (ratio = 2.0 median/1.8 mean), antimony (1.8/1.4), copper (2.5/2.2), iron (1.3/1.3), lead (2.8/2.9) and zinc (1.9/1.4). Copper and lead concentrations are consistently higher in the surface soil than deeper in the profile (table 8). Because copper and lead strongly complex with natural organic matter these two elements likely are immobilized by insoluble organics in the surface soil horizon. A significant portion of the copper and lead may be from anthropogenic sources, although the copper concentration is much lower than, and the lead concentration is similar to, the median concentration in U.S. soil (figs. 4 and 5). Calcium and sodium are more soluble elements that are leached during chemical weathering. The depletion (leaching) of calcium and sodium from glauconite produces a ratio significantly less than one. Constituent elements (Al, B, Mg and K, $\pm$ Cr, $\pm$ Be) in glauconite have ratios of approximately one, which suggests these elements remain fairly constant during chemical weathering. The ratio for silica (Si) (0.92/0.94), not shown in figure 6, is essentially identical to that for aluminum (0.96/0.94). This suggests that no silica is lost in excess of aluminum during pedogenesis. This appears to contradict reports by others (Wolff, 1967; Spoljaric and Crawford, 1980; Parron and Nahon, 1980) of the loss of silica from the glauconite crystal lattice during weathering. Glauconite is transformed into the iron oxyhydroxide phases

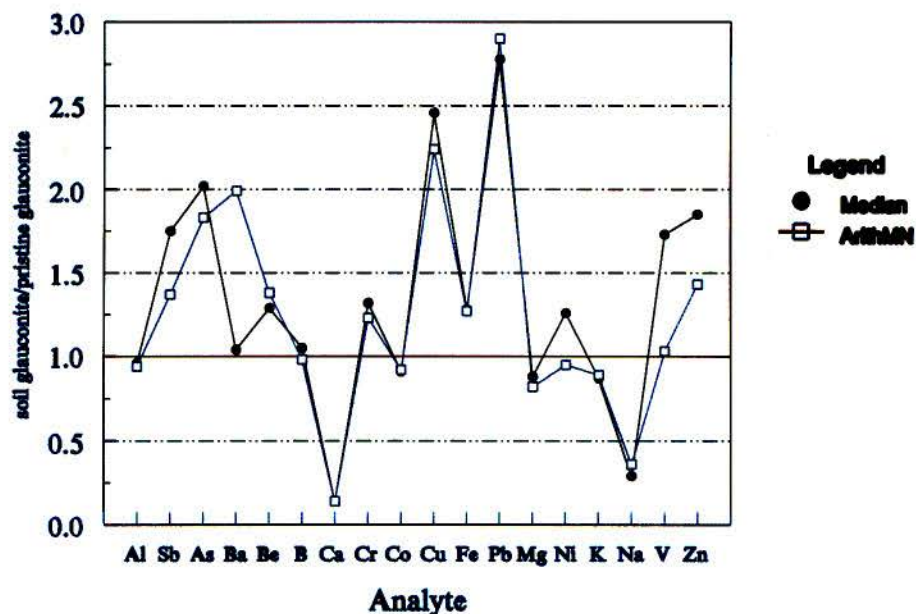


Figure 6. Ratio between the median and arithmetic mean (ArithMN) analyte concentrations in soil glauconite and pristine glauconite from the Ancora and Bass River core holes.

goethite and aluminum goethite (Parron and Nahon, 1980), mixed-layered smectite minerals (“swelling clays”), and kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$) during the weathering of soil (Wolff, 1967; Courbe and others, 1981; Loveland, 1981). Apparently, silica and aluminum are retained in the soil by incorporation into these neoformed, mixed-layered smectite minerals and kaolinite. The soft, waxy, green, clay matrix in samples from the Colemantown, Kresson, and Marlton soil series (appendix 2) may be derived from the degradation of glauconite and the neoformation of mixed-layered smectite minerals $\pm$ kaolinite. Furthermore, the weathering of glauconite to iron oxyhydroxide may account also for the iron enrichment of soil glauconite.

Implicit in the preceding mass balance approach is that the arsenic concentration is solely a function of the glauconite sand concentration in soil. The constituent minerals in most soil samples are variously coated by goethite (FeOOH) or other iron oxyhydroxide phases which resemble rust. These iron oxyhydroxide phases are effective scavengers of arsenic (Hsia and others, 1992; Bowell, 1994; Fendorf and others, 1997; Raven and others, 1998). Therefore, part of the arsenic in soil is expected to be sorbed onto these iron oxyhydroxides.

Pristine glauconite sand isolated from the Ancora core hole was used to evaluate the relationship between iron and arsenic. Chemical data for glauconite sand from the Bass River corehole were omitted from the evaluation because the glauconite sand contained significant quantities of other minerals, such as pyrite, goethite, gypsum, and quartz. The plot of arsenic as a function of iron concentration in the pristine glauconite sand is shown in figure 7. The equation for the linear regression line is: $\text{As}_{(\text{ppm})} = 0.012\text{Fe}_{(\text{ppm})} - 163.2$, with a 0.970 ($r^2 = 0.941$) correlation coefficient (r). Though this relationship is based on six data points, it suggests that a linear relationship exists between arsenic and iron in the pristine (parent) glauconite sand. To evaluate whether this linear relationship prevails in glauconite sand isolated from soil, a graphical depiction of the relationship is included in figure 7. Clearly, the strong linear relationship between arsenic and iron is maintained in the soil glauconite. Moreover, the regression line for soil glauconite ($\text{As}_{(\text{ppm})} = 0.010\text{Fe}_{(\text{ppm})} - 164.8$, $r = 0.965$) is essentially identical to that for the pristine (parent) glauconite. The shift in the regression line for soil glauconite relative to the regression line for pristine glauconite results from the increased iron in soil glauconite. This iron increase is consistent with the transformation of glauconite to goethite during weathering processes in the soil. There is also an increase in the mean arsenic concentration for soil glauconite (58.3 ppm) relative to the pristine glauconite (46.2 ppm). This increase is offset by the large increase in iron for soil glauconite (mean $\text{Fe} = 215,470$ ppm) relative to pristine glauconite (174,277 ppm), thereby shifting the regression line for the soil

glaucinite in the direction of higher iron concentration, as shown in figure 7.

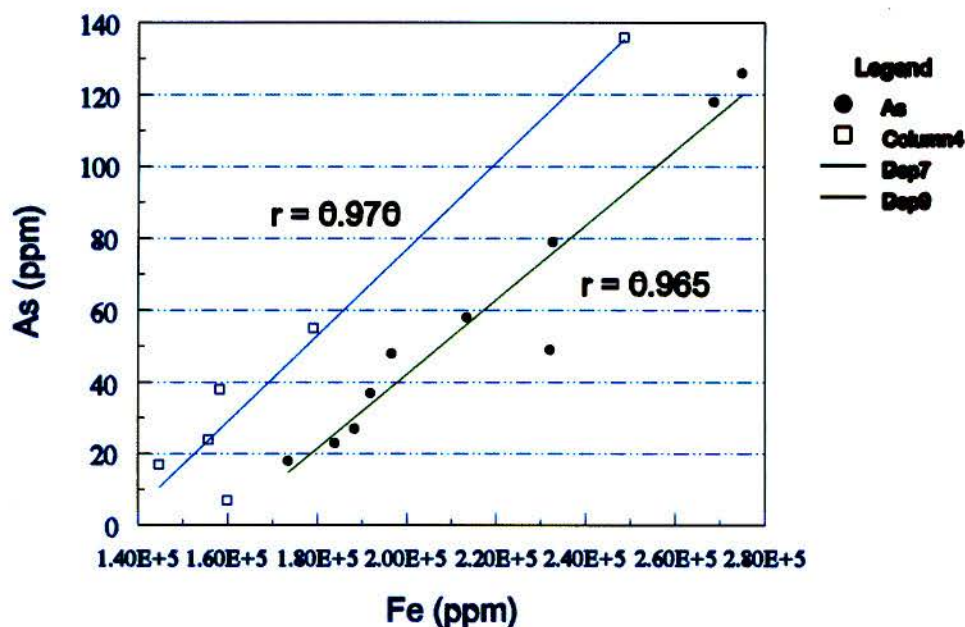


Figure 7. Arsenic as a function of iron concentration in pristine glauconite sand isolated from the Ancora core hole and for glauconite sand isolated from soil. Box is Ancora (pristine) glauconite isolates and closed circle is the soil glauconite isolates.

Correlation Analysis for Total Analyte Concentrations in Pristine Glauconite, Soil Glauconite and Whole Soil

Spearman's rank-order statistical analysis was used to determine the linear relationship, if any, among total analyte concentrations in pristine glauconite, soil glauconite and whole soil. Spearman's rank-order correlation analysis, a nonparametric statistical method, does not require

normally distributed data. This method uses the ranks of the measurements (analyte concentrations) to determine a measure of correlation between two analytes.

The Spearman's rank-order correlation coefficient (r), the measure of the strength of the linear relationship between ranks, lies between 1 and -1. Correlations of 1 and -1 imply perfect positive and negative relationships, respectively, whereas a correlation of 0 implies no linear relationship.

Pristine Glauconite

A matrix of Spearman's rank-order correlation coefficients for total analyte concentrations in pristine glauconite isolated from the Ancora core hole is in table 13. The correlation coefficients in boldface indicate strong to very strong relationships ($-0.750 \leq r \leq 0.750$) between the pairs.

Aluminum, an indicator of aluminum and/or aluminosilicate (clay) minerals, has a strong positive correlation with arsenic, chromium, vanadium and zirconium, and a strong negative correlation with magnesium. The strong positive Spearman's correlation ($r = 0.886$) between aluminum and arsenic demonstrates that total arsenic concentration increases with increasing total aluminum concentration. This strong correlation suggests that the arsenic is associated with aluminum-rich minerals such as the phyllosilicates. Chromium, zirconium, and vanadium show strong positive correlation with aluminum presumably because of isomorphous substitution in the octahedral lattice sites of phyllosilicates and/or coordination with interlayer Al-hydroxy polymers (McBride, 1989).

The strong negative correlation between aluminum and magnesium, that is, increases in aluminum concentration correspond to decreases in magnesium concentration, was unsuspected in that both are major component elements of glauconite. Weaver and Pollard (1973) report very

Table 13. Summary of Spearman's rank-order correlation for total analyte concentrations in pristine glauconite from the Ancora core hole. Top value is the robustness of the correlation and bottom value is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Ca	Cr	Co	Cu	Fe	Pb	Mg	Ni	K	Na	V	Zn	Hg	P	Si	Sr
Sb	0.319 0.4758																					
As	0.886 0.0476	0.377 0.3994																				
Ba	0.543 0.2248	0.551 0.2181	0.829 0.0639																			
Be	0.371 0.4062	0.377 0.3994	-0.029 0.9491	-0.314 0.4822																		
B	-0.257 0.5653	-0.899 0.0445	-0.429 0.3379	-0.600 0.1797	-0.086 0.8480																	
Ca	-0.429 0.3379	0.377 0.3994	-0.257 0.5653	0.200 0.6547	-0.086 0.8480	-0.143 0.7494																
Cr	0.943 0.0350	0.522 0.2433	0.771 0.0845	0.486 0.2774	0.543 0.2248	-0.429 0.3379	-0.371 0.4062															
Co	0.319 0.4758	0.882 0.0485	0.464 0.2997	0.551 0.2181	0.261 0.5596	-0.841 0.0601	0.348 0.4367	0.406 0.3642														
Cu	0.257 0.5653	0.522 0.2433	0.257 0.5653	0.543 0.2248	0.143 0.7494	-0.257 0.5653	0.543 0.2248	0.203 0.6500														
Fe	0.714 0.1102	0.812 0.0695	0.657 0.1417	0.486 0.2774	0.543 0.2248	-0.771 0.0845	-0.143 0.7494	0.829 0.0639	0.200 0.6547													
Pb	0.406 0.3642	0.721 0.1071	0.638 0.1539	0.928 0.0381	-0.174 0.6973	-0.696 0.1198	0.377 0.3994	0.464 0.2997	0.574 0.1997	0.754 0.0919	0.493 0.2705											
Mg	-0.886 0.0476	-0.377 0.3994	-1.000 0.0253	-0.829 0.0639	0.029 0.9491	0.429 0.3379	0.257 0.5653	-0.771 0.0845	-0.464 0.2997	-0.257 0.5653	-0.657 0.1417	-0.638 0.1539										
Ni	0.143 0.7494	0.928 0.0381	0.200 0.6547	0.371 0.4062	0.429 0.3379	-0.771 0.0845	0.543 0.2248	0.314 0.4822	0.928 0.0381	0.371 0.4062	0.714 0.1102	0.522 0.2433	-0.200 0.6547									
K	-0.371 0.4062	-0.522 0.2433	-0.486 0.2774	-0.771 0.0845	0.086 0.8480	0.371 0.4062	-0.429 0.3379	-0.429 0.3379	-0.261 0.5596	-0.943 0.0350	-0.257 0.5653	-0.899 0.0445	0.486 0.2774	-0.314 0.4822								
Na	-0.029 0.9483	-0.441 0.3239	0.116 0.7954	0.029 0.9483	-0.609 0.1734	0.029 0.9483	-0.696 0.1198	-0.116 0.7954	-0.412 0.3572	-0.493 0.2705	-0.232 0.6041	-0.132 0.7673	-0.116 0.7954	-0.638 0.1539	0.261 0.5596							
V	1.000 0.0253	0.319 0.4758	0.886 0.0476	0.543 0.2248	0.371 0.4062	-0.257 0.5653	-0.429 0.3379	0.943 0.0350	0.319 0.4758	0.257 0.5653	0.714 0.1102	0.406 0.3642	-0.886 0.0476	0.143 0.7494	-0.371 0.4062	-0.029 0.9483						
Zn	0.086 0.8480	0.551 0.2181	-0.086 0.8480	0.086 0.8480	0.600 0.1797	-0.143 0.7494	0.657 0.1417	0.319 0.5653	0.771 0.4758	0.257 0.0853	0.348 0.5653	0.086 0.4367	0.600 0.8480	-0.543 0.1797	-0.899 0.0445	0.086 0.8480						
Hg	-0.319 0.4758	0.176 0.6931	-0.029 0.9483	0.377 0.3994	-0.377 0.3994	-0.029 0.9483	0.899 0.0445	-0.406 0.3642	0.294 0.5108	0.406 0.3642	-0.232 0.6041	0.397 0.3746	0.029 0.9483	0.348 0.4367	-0.406 0.3642	-0.500 0.2636	-0.319 0.4758	0.377 0.3994				
P	-0.429 0.3379	0.377 0.3994	-0.257 0.5653	0.200 0.6547	-0.086 0.8480	-0.143 0.7494	1.000 0.0253	-0.371 0.4062	0.348 0.4367	0.543 0.2248	-0.143 0.7494	0.377 0.3994	0.257 0.5653	0.543 0.2248	-0.429 0.3379	-0.696 0.1198	-0.429 0.3379	0.657 0.1417	0.899 0.0445			
Si	-0.257 0.5653	-0.406 0.3642	-0.600 0.1797	-0.886 0.0476	0.429 0.3379	0.371 0.4062	-0.543 0.2248	-0.493 0.749	-0.543 0.2705	-0.200 0.2248	-0.812 0.0695	0.600 0.1797	-0.371 0.4062	0.714 0.1102	0.203 0.6500	-0.257 0.5653	-0.200 0.6547	-0.200 0.0919	-0.754 0.0919	-0.543 0.2248		
Sr	0.086 0.8480	0.290 0.5169	0.429 0.3379	0.829 0.0639	-0.600 0.1797	-0.314 0.4822	0.486 0.2774	0.029 0.949	0.203 0.6500	0.657 0.1417	-0.029 0.9491	0.841 0.0601	-0.429 0.3379	0.143 0.7494	-0.829 0.0639	0.029 0.9483	0.086 0.8480	0.143 0.1539	0.638 0.2774	0.486 0.2774	-0.886 0.0476	
Zr	0.943 0.0350	0.522 0.2433	0.771 0.0845	0.486 0.2774	0.543 0.2248	-0.429 0.3379	-0.371 0.4062	1.000 0.0253	0.406 0.3642	0.371 0.4062	0.829 0.0639	0.464 0.2997	-0.771 0.0845	0.314 0.4822	-0.429 0.3379	-0.116 0.7954	0.943 0.0350	0.257 0.5653	-0.406 0.3642	-0.371 0.4062	-0.143 0.7494	0.029 0.9491

weak negative (regression analysis) correlation coefficients between aluminum and magnesium ($r = -0.128$ for Al_2O_3 versus MgO , and $r = -0.130$ and -0.124 for octahedral Al versus octahedral Mg and tetrahedral Al versus octahedral Mg, respectively). Carson and Crowley (1993) explain the negative covariant relationship between octahedral aluminum and magnesium ($r = -0.126$ and -0.522 for tetrahedral Al versus Mg and octahedral Al versus Mg, respectively) as isomorphous substitution by magnesium for aluminum in octahedral lattice sites.

Total arsenic has a strong positive correlation with total chromium ($r = 0.771$), vanadium ($r = 0.886$) and zirconium ($r = 0.771$) in addition to barium ($r = 0.829$) while exhibiting a perfect negative correlation with magnesium ($r = -1.000$). These correlations further support the interpretation that arsenic is associated with phyllosilicates.

Though the Spearman's rank-order correlation coefficient for arsenic versus iron is moderately strong positive ($r = 0.657$), the rectilinear (straight line) correlation coefficient is very strong ($r = 0.970$), figure 7. These data indicate that as the iron concentration of glauconite sand increases so too does the arsenic concentration.

Mercury in the environment has been the focus of the NJDEP for the past decade. It is noteworthy that mercury has a strong positive correlation ($r = 0.899$) with both calcium and phosphorous. Calcium regressed against phosphorous yields a perfect positive correlation ($r = 1.000$). These two elements are the principle constituents of apatite-group minerals — authigenic phosphate minerals commonly associated with glauconite (Birch, 1979; Carson and Crowley, 1993). These data suggest that mercury is a constituent element in the apatite minerals. Individual apatite minerals should have been separated from the glauconite during the magnetic separation procedure. Therefore, the apatite mineral(s) occur as an occluded mineral within glauconite grains (Carson and Crowley, 1993).

Soil Glauconite

The matrix of Spearman's rank-order correlation coefficients for select total analyte concentrations in glauconite isolated from select soils is in table 14. The correlation coefficients in boldface indicate strong to very strong relationships ($-0.750 \leq r \leq 0.750$) between the pairs.

Total aluminum strongly correlates negatively with magnesium and beryllium. The cause for the negative relationship between aluminum and beryllium is unclear. Beryllium is a trace constituent in glauconite (tables 10 and 11).

Total arsenic shows a strong to very strong negative Spearman's correlation with major constituent elements in glauconite, magnesium, potassium and silicon, as shown by equation 2. Note the strong positive correlations among magnesium, potassium and silicon. Carson and Crowley (1993) report similar strong positive linear correlation coefficients for magnesium, potassium and silicon in glauconite, as shown in the correlation matrix below.

	Mg	K
Mg	1	
K	0.807	1
Si	0.871	0.871

Extremely strong positive correlations, Spearman's $r = 0.988$ and rectilinear (straight line) $r = 0.965$ (fig. 7), between iron and arsenic suggest that the arsenic is sorbed on iron phases in these soil glauconite separates. The apparent absence of pyrite (FeS_2), a constituent of the glauconite parent sediment, in the soil, in addition to magnesium, potassium and silicon negatively correlating with arsenic, suggest that the arsenic is mainly associated with iron oxyhydroxides, such as goethite. Part of the soil glauconite is variously coated with iron oxyhydroxides.

Mercury exhibits moderately strong negative correlations with the major constituent elements in glauconite, suggesting that mercury in the soil is not a constituent of the glauconite

Table 14. Summary of Spearman's rank-order correlation for total analyte concentrations in glauconite isolated from soils. Top value is the robustness of the correlation and bottom value is the probability. Where $-0.750 < r > 0.750$, data are shown in boldface.

	Al	Sb	As	Ba	Be	B	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni	K	Na	V	Zn	Hg	P	Si	Sr
Sb	0.231 0.4883																						
As	0.527 0.1137	0.857 0.0101																					
Ba	0.086 0.7573	-0.024 0.9418	0.055 0.8700																				
Be	-0.827 0.0089	0.109 0.7427	-0.079 0.8132	0.155 0.6250																			
B	0.082 0.7958	-0.729 0.0286	-0.552 0.0980	-0.191 0.5460	-0.173 0.5849																		
Ca	-0.354 0.2020	-0.158 0.6354	-0.297 0.3730	0.675 0.0150	0.673 0.0334	-0.027 0.9313																	
Cr	-0.248 0.4560	0.237 0.4769	-0.042 0.8987	-0.697 0.0365	0.503 0.1313	-0.091 0.7850	-0.103 0.7573																
Co	-0.327 0.3008	0.576 0.0840	0.389 0.2433	0.396 0.2101	0.300 0.3435	-0.807 0.0108	0.438 0.1662	-0.105 0.7529															
Cu	0.618 0.0506	0.243 0.4657	0.527 0.1137	-0.218 0.4902	-0.418 0.1860	-0.109 0.7301	-0.545 0.0845	-0.212 0.5245	-0.106 0.7375														
Fe	0.152 0.5841	0.845 0.0112	0.988 0.0030	-0.044 0.8739	-0.169 0.5940	-0.533 0.0919	-0.266 0.3371	-0.115 0.7298	0.370 0.2426	0.556 0.0788													
Pb	0.082 0.7958	0.626 0.0603	0.685 0.0399	0.082 0.7958	0.300 0.3429	-0.609 0.0541	-0.018 0.9542	0.042 0.8987	0.484 0.1259	0.291 0.3576	0.651 0.0394												
Mg	-0.767 0.0057	-0.657 0.0489	-0.879 0.0084	-0.376 0.1754	0.400 0.2059	0.445 0.1589	0.116 0.6745	0.200 0.5485	-0.166 0.5998	-0.627 0.0473	-0.418 0.1317	-0.536 0.0899											
Mn	0.193 0.5414	0.000 1.0000	-0.074 0.8559	0.345 0.2755	-0.024 0.9485	0.073 0.8465	0.005 0.9884	0.296 0.4677	-0.123 0.7454	0.268 0.4777	-0.083 0.7931	0.098 0.7963	-0.322 0.3088										
Ni	0.077 0.8065	0.235 0.4813	0.146 0.6616	-0.223 0.4802	-0.141 0.6552	-0.355 0.2611	-0.128 0.6867	0.304 0.3618	0.312 0.3241	-0.150 0.6345	0.014 0.9654	0.059 0.8514	-0.273 0.3874	-0.098 0.7951									
K	-0.631 0.0229	-0.632 0.0579	-0.818 0.0141	-0.508 0.0672	0.264 0.4045	0.555 0.0795	0.046 0.8678	0.309 0.3538	-0.341 0.2808	-0.509 0.1074	-0.471 0.0896	-0.600 0.0578	0.925 0.0008	-0.676 0.0326	-0.141 0.6552								
Na	0.611 0.0275	0.068 0.8381	0.103 0.7563	0.515 0.0635	-0.396 0.2108	0.105 0.7401	0.189 0.4960	-0.647 0.0524	0.135 0.6687	0.305 0.3346	0.009 0.9741	0.029 0.9279	-0.503 0.0695	0.605 0.0559	-0.313 0.3223	-0.593 0.0324							
V	0.045 0.8857	0.450 0.1772	0.442 0.1844	-0.427 0.1766	0.382 0.2273	-0.018 0.9542	-0.145 0.6455	0.636 0.0563	-0.171 0.5897	0.127 0.6873	0.323 0.3063	0.509 0.1074	-0.327 0.3007	0.317 0.4014	0.137 0.6656	-0.200 0.5271	-0.286 0.3657						
Zn	-0.582 0.0658	0.340 0.3071	0.115 0.7298	-0.082 0.7958	0.827 0.0089	-0.191 0.5460	0.473 0.1349	0.794 0.0172	0.267 0.3979	-0.436 0.1676	0.000 1.0000	0.364 0.2502	0.118 0.7086	0.098 0.7963	0.282 0.3717	0.100 0.7518	-0.467 0.1396	0.691 0.0289					
Hg	0.493 0.0756	0.317 0.3415	0.505 0.1301	0.704 0.0111	-0.073 0.8177	-0.647 0.0408	0.290 0.2950	-0.565 0.0899	0.598 0.0585	0.515 0.1035	0.161 0.5621	0.588 0.0631	-0.733 0.0082	0.357 0.2587	0.057 0.8568	-0.772 0.0054	0.641 0.0208	-0.205 0.5168	-0.214 0.4983				
P	-0.121 0.6630	0.438 0.1892	0.261 0.4343	0.349 0.2077	-0.073 0.8181	-0.291 0.3576	0.209 0.4516	-0.188 0.5730	0.641 0.0428	-0.036 0.9085	0.277 0.3175	-0.018 0.9542	-0.156 0.5737	-0.156 0.6210	0.187 0.5547	-0.178 0.5210	0.144 0.6040	-0.291 0.3576	-0.009 0.9771	0.169 0.5413			
Si	-0.367 0.1857	-0.821 0.0138	-0.964 0.0038	-0.297 0.2847	0.164 0.6048	0.618 0.0506	0.112 0.6861	0.115 0.7298	-0.406 0.1997	-0.400 0.2059	-0.761 0.0061	-0.718 0.0231	0.807 0.0036	-0.170 0.5906	-0.319 0.3132	0.811 0.0035	-0.153 0.5816	-0.382 0.2273	-0.118 0.7086	-0.515 0.0634	-0.288 0.2992		
Sr	-0.742 0.4441	-0.165 0.6203	-0.037 0.9126	0.904 0.0042	0.023 0.9424	-0.014 0.9654	0.626 0.0479	-0.646 0.0525	0.229 0.4686	-0.178 0.5733	0.082 0.7945	-0.073 0.8173	-0.068 0.8285	0.098 0.7951	-0.190 0.5481	-0.333 0.2918	0.409 0.1954	-0.466 0.1408	-0.174 0.5832	0.449 0.1561	0.205 0.5158	-0.073 0.8173	
Zr	0.793 0.0042	-0.095 0.7761	0.262 0.4315	0.295 0.2872	-0.434 0.1701	0.087 0.7838	-0.046 0.8675	-0.439 0.1878	-0.231 0.4641	0.781 0.0135	-0.011 0.9683	0.338 0.2853	-0.696 0.0121	0.447 0.1575	-0.055 0.8621	-0.645 0.0200	0.707 0.0108	0.119 0.7073	-0.416 0.1888	0.337 0.2861	0.740 0.0076	-0.284 0.3056	0.062 0.8447

or other phyllosilicates. Mercury is likely associated with soil organic matter.

Whole Soil

The Spearman's rank-order correlation coefficients matrix for total analyte concentrations in whole soils is in table 15. Correlation coefficients in boldface indicate strong to very strong relationships ($-0.700 \leq r \leq 0.700$) between the pairs.

There is a moderate to very strong, positive Spearman's correlation among the major constituent elements (K, Fe, Mg) in glauconite, except for aluminum, and a moderate to strong negative Spearman's correlation between these elements and silicon. The lack of significant correlation for aluminum with these constituent elements in whole soil may be a result of aluminum-rich (phyllosilicate) phases, such as gibbsite ($\text{Al}(\text{OH})_3$) and kaolinite ($\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$). Silicon negatively correlating with major constituent elements for glauconite demonstrates that increases in quartz sand/silt content corresponds to decreases in the glauconite ($\pm$ phyllosilicate) content in soil. In other words, the more quartz-sand-rich a soil is, the less clay/silt it contains. Support for this interpretation is in the negative correlation quartz sand has with both glauconite sand and clay/silt.

Arsenic shows a moderate to weak negative correlation with aluminum and silicon, and essentially no correlation with potassium ($r = 0.029$) and magnesium ($r = -0.062$). A moderate positive correlation exists for arsenic and iron. These correlations suggest that some of the arsenic is associated with iron oxyhydroxide phases rather than with phyllosilicate minerals.

Very strong, positive Spearman's correlations occur for beryllium and the following: boron, chromium, cobalt, iron, magnesium, potassium, vanadium, and zinc. Most of these elements are constituents of glauconite and other phyllosilicates of marine origin (Tourtelot, 1964). Also, beryllium shows a very strong, negative Spearman's correlation with silicon, which suggests that the beryllium resides primarily in the clay and/or silt fractions.

Table 15. Summary of Spearman rank-order correlation for total analyte concentrations in whole soils. Top value is the robustness of the correlation and bottom value is the probability. Data shown in boldface where $-0.700 < r > 0.700$.

	Al	Sb	As	Ba	Be	B	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Ni	K	Na	V	Zn	Hg	P	Si	Sr
Sb	-0.298 0.2826																						
As	-0.114 0.6800	0.670 0.0158																					
Ba	0.332 0.2315	-0.545 0.0493	-0.717 0.0097																				
Be	0.231 0.4054	0.373 0.1786	0.224 0.4184	-0.420 0.1301																			
B	0.277 0.3175	0.139 0.6157	0.106 0.7030	-0.471 0.0896	0.889 0.0014																		
Ca	0.110 0.6916	0.188 0.4982	-0.283 0.3075	0.563 0.3575	0.337 0.0423	0.2243																	
Cr	-0.068 0.8060	0.347 0.2114	0.330 0.2341	-0.560 0.0433	0.829 0.0028	0.757 0.0064	0.315 0.2566																
Co	0.347 0.2109	0.471 0.0897	0.350 0.2075	-0.259 0.3512	0.725 0.0090	0.522 0.0598	0.606 0.0288	0.559 0.0438															
Cu	-0.194 0.4846	0.365 0.1881	0.104 0.7086	0.319 0.2495	-0.476 0.0863	-0.679 0.0143	0.013 0.9620	-0.597 0.0314	-0.166 0.5492														
Fe	0.226 0.4144	0.576 0.0378	0.594 0.0372	-0.543 0.0503	0.820 0.0031	0.667 0.0162	0.433 0.1181	0.675 0.0150	0.853 0.0021	-0.300 0.2801													
Pb	-0.070 0.7996	0.449 0.1058	-0.002 0.9937	0.339 0.2218	-0.282 0.3099	-0.485 0.0806	0.137 0.6224	-0.411 0.1379	0.015 0.9555	0.853 0.0021	-0.233 0.4004												
Mg	0.354 0.2020	0.077 0.7806	-0.062 0.8242	-0.275 0.3219	0.873 0.0017	0.944 0.0007	0.554 0.0456	0.679 0.0143	0.568 0.0406	-0.630 0.0231	0.640 0.0211	-0.396 0.1533											
Mn	-0.202 0.5220	0.589 0.0624	0.203 0.5210	0.094 0.7658	-0.184 0.5614	-0.460 0.1456	0.373 0.2384	-0.217 0.4934	0.276 0.3834	0.609 0.0542	0.085 0.7887	0.755 0.0169	-0.217 0.4934										
Ni	0.348 0.2090	0.319 0.2502	0.220 0.4284	-0.254 0.3606	0.686 0.0134	0.597 0.0313	0.479 0.0841	0.595 0.0318	0.838 0.0025	-0.436 0.1156	0.803 0.0038	-0.183 0.5089	0.657 0.0178	0.104 0.7421									
K	0.297 0.2847	0.143 0.6049	0.029 0.9179	-0.389 0.1607	0.877 0.0016	0.977 0.0004	0.427 0.1238	0.697 0.0120	0.517 0.0622	-0.597 0.0314	0.644 0.0202	-0.392 0.1580	0.965 0.0005	-0.447 0.1572	0.624 0.0244								
Na	0.273 0.3247	-0.416 0.1997	-0.593 0.0325	0.881 0.0015	-0.520 0.0609	-0.600 0.0306	0.090 0.7444	-0.676 0.0148	-0.321 0.2469	0.574 0.0385	-0.641 0.0208	0.562 0.0426	-0.443 0.1104	0.104 0.7421	-0.403 0.1459	-0.496 0.0740							
V	0.051 0.8554	0.373 0.1786	0.400 0.1488	-0.525 0.0582	0.785 0.0047	0.702 0.0114	0.229 0.4094	0.965 0.0005	0.541 0.0509	-0.557 0.0445	0.692 0.0126	-0.389 0.1603	0.613 0.0270	-0.268 0.3960	0.611 0.0276	0.644 0.0202	-0.643 0.0204						
Zn	0.191 0.4906	0.510 0.0660	0.156 0.5733	-0.270 0.3297	0.886 0.0014	0.713 0.0101	0.651 0.0189	0.789 0.0044	0.787 0.0046	-0.308 0.2662	0.732 0.0083	0.029 0.9179	0.754 0.0066	0.193 0.5415	0.741 0.0076	0.723 0.0091	-0.381 0.1695	0.767 0.0057					
Hg	0.040 0.8865	0.150 0.5879	-0.110 0.6913	0.636 0.0219	-0.480 0.0837	-0.674 0.0151	0.187 0.4996	-0.585 0.0348	-0.117 0.6725	0.870 0.0017	-0.326 0.2404	0.781 0.0049	-0.541 0.0510	0.791 0.0124	-0.350 0.2071	-0.594 0.0322	0.699 0.0117	-0.508 0.0669	-0.229 0.4094				
P	-0.011 0.9684	0.475 0.0870	0.499 0.0717	-0.424 0.1262	0.499 0.0720	0.444 0.1091	0.433 0.1181	0.371 0.1805	0.550 0.0472	0.007 0.9810	0.741 0.0076	-0.121 0.6626	0.473 0.0884	0.240 0.4476	0.507 0.0675	0.503 0.0696	-0.458 0.0986	0.354 0.2020	0.376 0.1754	0.386 0.1641			
Si	-0.253 0.3621	-0.572 0.0393	-0.539 0.0519	0.538 0.0522	-0.833 0.0027	-0.706 0.0109	-0.427 0.1238	-0.692 0.013	-0.851 0.0026	0.335 0.2274	-0.987 0.0004	0.229 0.4094	-0.684 0.0137	-0.085 0.7887	-0.851 0.0022	-0.692 0.0126	0.628 0.0236	-0.714 0.0100	-0.758 0.0063	-0.342 0.2178	-0.714 0.0100		
Sr	0.248 0.3705	-0.461 0.0962	-0.708 0.0106	0.978 0.0004	-0.336 0.2254	-0.433 0.1181	0.378 0.1724	-0.468 0.091	-0.159 0.5662	0.350 0.2067	-0.473 0.0884	0.374 0.1775	-0.231 0.4054	0.170 0.5919	-0.183 0.5093	-0.345 0.2135	0.868 0.0018	-0.459 0.0977	-0.178 0.5210	0.190 0.4941	-0.341 0.2193	0.464 0.0945	
Zr	-0.086 0.7573	-0.492 0.0759	-0.455 0.1006	0.521 0.0604	-0.684 0.0137	-0.565 0.0415	-0.326 0.2404	-0.640 0.0211	-0.630 0.0232	0.417 0.0892	-0.842 0.0024	0.326 0.2404	-0.587 0.0344	-0.155 0.6232	-0.772 0.0054	-0.530 0.0562	0.705 0.0110	-0.657 0.0178	-0.644 0.0202	-0.445 0.1083	0.451 0.1039	0.859 0.0019	0.481 0.0827

Analyte Concentrations in Soils Determined by U.S. EPA SW-846, Methods 3050 and 6010

Introduction

Sample digestion using Method 3050 is, at best, a partial leach, particularly for samples dominated by silicate (quartz) and aluminosilicate (clay minerals) minerals as is the case here. The resultant analyte concentrations are reported as “total recoverable” (U.S. EPA, 1995). The phrase “total recoverable” is misleading. “Total recoverable” digestion protocols (Method 3050, 3051 and 3051a) do not recover all metals in the samples (Chen and Ma, 1998, citing Sawhney and Stilwell, 1994). The concentration of total recoverable metals is largely a function of the sample character (matrix), reagents used, and length of time and consistency of temperature at which the sample is digested. Lorentzen and Kingston (1996) convincingly demonstrate that temperature control of hot plates is paramount in achieving reproducible leaching of elements using EPA Method 3050B. It has been established since the early 1980s that temperature control is the most significant contributor to leach test error. That the prescribed EPA leach methods provide an assessment of the worse case scenario for solubilization and mobilization of metals has been questioned (Hamel and others, 1998, and references cited therein).

EPA SW846, Method 3050 involves filtration (Whatman 41 or equivalent) or centrifugation of the digestate. This filtrate (or supernatant) is used for metals quantification. It is known that the filter (or centrifugal) residue may contain a substantial fraction of the analytes of interest (Kimbrough and Wakakuwa, 1992). The metals associated with the filter residue are not reported as part of the “total recoverable” metals. This illustrates one of the many problems inherent in the method and the application of the term “total recoverable” metals. These inadequacies are mentioned in the discussion of the results obtained by using said EPA methods.

Extraction Efficiency of U.S. EPA SW846, Method 3050

Understanding that the EPA’s analytical methods provide ambiguous chemical data for soils, an aspect of this study was to assess that portion of the total metal concentration that is represented by the EPA’s leaching protocol. In other words, “total recoverable” metal

concentrations were compared to the true total metal concentrations in glauconite isolates and soils. This ratio of total recoverable metal to total metal concentration, expressed as a percentage, is hereafter referred to as the percent extraction efficiency.

Glauconite Separates from the Ancora Core Hole

The solubility of glauconite in nitric (HNO_3) and hydrochloric (HCl) acids directly affects the extraction efficiency, that is, metal concentration. A mineral which completely dissolves should provide $100\pm$ percent extraction efficiency. Incongruent solution produces soluble analytes in different proportions from those in the original mineral; it will result in extraction efficiencies less than 100 percent. Glauconite is reported to be “readily decomposed by HCl ” (Gaines and others, 1997, p. 1454). To evaluate the validity of this statement, samples of pristine glauconite isolated from the Hornerstown and Navesink Formations were digested in concentrated HCl at approximately 95°C for 15 to 20 minutes. The HCl turned a light pistachio green while the apparent physical integrity of the glauconite remained unchanged. Therefore, it appears that very mature glauconite, such as that from the New Jersey Coastal Plain, is not “readily decomposed by HCl ” but rather dissolves incongruently. Statements in the literature suggest that less mature and perhaps highly weathered glauconite may be decomposed by HCl , but probably not completely.

Table 16. Statistical summary of percent extraction efficiency of EPA SW846, Method 3050 for glauconite separates from the Ancora core hole.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	9.3	33	16	9.3	19	28	6
Sb	115	310	201	70.0	202	243	6
As	11	57	24	17	27	32	6
Ba	37	98	75.5	29	70	94	6
Be	8.3	30	11	9	15	22	6
B	7.6	27	13	9	16	25	6
Ca	69	111	82	15	86	94	6
Cr	4.6	44	10	16	18	30	6
Co	21	70	41	18	40	44	6
Cu	26	119	46.5	36	60	87	6
Fe	7.3	60	16	20	22	26	6
Pb	43	125	69	34	78	113	6
Mg	13	41	18.5	11	23	30	6
Ni	20	67	34	17	36	40	6
K	8.9	16	9.7	3.3	11	9.7	4
Na	52	83	65	13	68	78	5
V	3.8	143	10	54	34	31	6
Zn	22	76	41.5	22	49	75	6

Aliquots of glauconite separates from the Ancora core hole, extracted by Method 3050, are divided by total metal concentrations determined by various analytical methods and expressed as a percentage.

Six glauconite separates from the pristine glauconite-bearing formations penetrated in the Ancora core hole (table 11) were analyzed for total recoverable and total metal concentrations. The statistical summary of the percent extraction efficiency is given in table 16.

The median percent extraction efficiency for the major (Al, Fe, Mg, and K) and trace (Be, B, Cr, and V) element constituents of glauconite are less than 19 percent of the total concentration. Low median extraction efficiencies for the major and trace elements demonstrate the limited dissolution of the glauconite, that is, most of the constituent elements remain in the glauconite mineral lattice, following the acid digestion prescribed by Method 3050. The range in

percent extraction efficiency for these constituent elements is generally smaller than that for the other elements. Elements with high median and a large range in extraction efficiency may be 1) electrostatically sorbed to the glauconite, 2) coprecipitated with iron oxides, and/or 3) occur as soluble occluded minerals (for example, apatite in the case of calcium) in the glauconite aggregates.

The 201 percent median and 115 to 310 percent range in extraction efficiency for antimony (Sb) clearly indicates a problem with the analytical procedure. Soil samples with low antimony concentrations (such as those studied here) are reported to show little to no recovery of Sb from spiked environmental silicate matrices (Kimbrough and Wakakuwa, 1992; Hewitt and Cragin, 1992). Kimbrough and Wakakuwa (1992) demonstrate that Method 3050 is inaccurate and nonlinear at low and high concentrations of Sb. The unusually high percent extraction efficiency for these six pristine glauconite isolates does not appear consistent with the reported nonlinear recovery for Sb. It is unclear wherein lies the source of this discrepancy. Total Sb is measured using INAA (table 2), an analytical method that does not require acid digestion of the sample and is not subject to the solubility considerations inherent in Method 3050 extractions. Based on this consideration, it appears that the error in Sb analyses results from interferences in the quantitation procedure.

Chen and Ma (1998) compare four U.S. EPA acid digestion methods (3050, 3051, 3051a, and 3052) to evaluate the extraction efficiency and compatibility of the results on forty representative surface soil samples from Florida. Method 3052 employs nitric, hydrochloric and hydrofluoric acids with microwave-oven heating to digest soils (U.S. EPA, 1995). Method 3052 essentially provides a total digestion for TAL metals. Chen and Ma (1998) report the mean percent extraction efficiency for Sb in Florida soils is 7.8 percent (0.40 ug Sb/g mean for Method 3050 versus 5.13 ug Sb/g mean for Method 3052). It is not clear what causes the large discrepancy in Sb extraction efficiency between this study and that by Chen and Ma. Laboratory errors are suspected in addition to the inaccuracy and nonlinearity of Method 3050 for low

antimony concentrations (Kimbrough and Wakakuwa, 1992).

The percent extraction efficiency for arsenic in the six pristine glauconite separates ranges from 11 to 57 percent with a 24 percent median and a mean of 27 ± 17 percent (one standard deviation). Therefore, approximately three quarters of the total arsenic in pristine glauconite is not solubilized or extracted using Method 3050 acid digestion. The extraction efficiency for beryllium is nearly half of that for arsenic. Percent extraction efficiency for beryllium ranges from 8.3 to 30 percent with a median of 11 percent and a mean of 15 ± 9 percent. Method 3050 solubilizes most of the barium, calcium, lead and sodium in pristine glauconite.

Glauconite Separates from Soils

Glauconite separates from twelve select soil samples were analyzed for total recoverable and total metal concentrations. The statistical summary for the percent extraction efficiency is given in table 17.

Median and mean percent extraction efficiencies for beryllium, boron, magnesium and potassium in the soil glauconite are, within analytical error, essentially identical to those for pristine glauconite. The low extraction efficiency for these constituent elements in soil glauconite suggests that the crystal lattice remains little affected by the Method 3050 acid digestion.

The constituent elements aluminum, iron, chromium and vanadium, have higher extraction efficiency in the soil glauconite than in the pristine glauconite. Median percent extraction efficiency for these constituent elements is nearly twice that for pristine glauconite. The higher percent extraction efficiency for the soil glauconite likely represents solubilization of the labile portion of these constituent elements in the glauconite lattice augmented by the solubilization of amorphous and mineral phases that form from the chemical weathering

Table 17. Statistical summary of the percent extraction efficiency for EPA SW-846, Method 3050 for glauconite separates from soils.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	18	41	28	7	29	34	12
Sb	230	426	301	65	315	419	10
As	25	69	49.5	16	51	69	10
Ba	15	99	41.5	25	47	65	12
Be	11	34	18.5	7	20	26	10
B	6.9	27	16	6	15	19	10
Ca	4.8	91	63	32	50	74	12
Cr	16	64	41.5	15	40	59	10
Co	27	56	39	12	41	54	10
Cu	42	130	93	27	87	107	10
Fe	16	69	30	17	35	52	12
Pb	56	106	100	16	93	105	10
Mg	11	33	19	7	20	24	12
Mn	2.6	225	22	70	50	64	9
Ni	3	41	19	12	21	33	10
K	8.7	19	12.5	3	13	16	8
V	8	137	22	40	39	77	10
Zn	32	80	50	17	52	73	10

Aliquots of glauconite separates from select soil, analyzed according to Method 3050, are divided by total metal concentrations determined by various analytical methods and expressed as a percentage.

of primary soil minerals. Iron oxyhydroxide stains part of the soil glauconite separates (appendix 2). Chromium, vanadium and aluminum are known to isomorphously substitute for iron in iron oxides which lowers their crystallinity and thereby reduces their stability (or increases their solubility) (McBride, 1989).

The range in percent extraction efficiency for antimony is 230 to 426 percent with a 301 percent median and a mean of 315 ± 65 percent. These incredibly high extraction efficiencies for antimony are significantly higher in the soil glauconite than in pristine glauconite (table 16).

Copper and lead have median and mean percent extraction efficiencies of 93 percent and 87 ± 27 percent, and 100 percent and 93 ± 16 percent, respectively. Therefore, Method 3050 acid digestion appears to provide reasonably accurate total copper and lead concentrations in these glauconite separates from soil. Chen and Ma (1998) report percent extraction efficiency for copper and lead at 145 and 65 percent, respectively, for the quartz-sand soils they studied.

Percent extraction efficiency for arsenic in the soil glauconite ranges from 25 to 69 percent with a 49.5 percent median and a mean of 51 ± 16 percent. This extraction efficiency is approximately twice that for the pristine glauconite. The higher extraction efficiency for arsenic in the soil glauconite likely represents the combination of labile arsenic (~25 percent) in the glauconite mineral and arsenic retained in the iron oxyhydroxide that coats part of the glauconite sand grains. These results suggest that approximately half of the total arsenic associated with soil glauconite is not solubilized using the Method 3050 acid digestion.

Whole Soil Samples

Fourteen whole-soil samples were analyzed for total recoverable and total metal concentrations. They are: BUAD2001, BUAD2003, BUCL2001, BUCL2003, BUCM2001, BUCM2003, BUMR4001, BUMR4003, CAKR4001, CAKR4003, MOAD3001, MOAD3003, MOKR1001 and MOKR1002. The statistical summary for the percent extraction efficiency is given in table 18.

Median and mean percent extraction efficiency for the principal constituent elements: Al, Be, B, Cr, Mg and K, in glauconite and other phyllosilicates in the soil are less than 25 percent, with the exception of iron (28 percent median and 30 percent mean). This is additional evidence for the partial dissolution of phyllosilicate minerals using Method 3050.

The median percent extraction efficiency for glauconite separates from the Ancora core hole and whole soils, whole soil samples, and the forty Florida soils (Chen and Ma, 1998) are

compared in figure 8. The median extraction efficiency for whole soil is consistently less than that for the glauconite isolated from these soils, and generally greater than that for the pristine glauconite separates from the Ancora core hole. The quartz sand-rich soils from Florida generally show higher extraction efficiencies than the glauconite separates and the glauconite-bearing whole soil from New Jersey. Extraction efficiencies similar to those for Florida soils are expected for the quartz-rich soils covering most of the New Jersey Coastal Plain.

Table 18. Statistical summary of the percent extraction efficiency for EPA SW-846, Method 3050 for whole soils.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	6.5	62	14	16	20	25	14
Sb	28	303	188	100	181	294	12
As	4.7	69	40.5	18	39	53	14
Ba	4.6	54	7.6	14	14	25	14
Be	1.9	37	16	11	16	23	14
B	3.6	46	15	15	20	46	14
Cd	167	4670	700	1557	1300	1600	7
Ca	4.4	61	22	22	28	56	14
Cr	1.3	71	18.5	21	25	43	14
Co	14	83	38	23	42	70	14
Cu	29	218	83	47	94	130	14
Fe	3	65	28	21	30	60	14
Pb	22	280	78	63	86	101	14
Mg	1.2	49	19	16	19	29	14
Mn	1.8	53	13	16	19	41	11
Ni	2.6	67	13.5	19	21	30	14
K	0.3	67	8	19	15	22	14
V	5	91	25.5	24	34	50	14
Zn	8.9	91	39.5	25	41	73	14

Aliquots of select whole soils, analyzed according to Method 3050, are divided by total analyte concentrations determined by various analytical methods and expressed as a percentage.

The arsenic extraction efficiency in whole soil ranges from 4.7 to 69 percent with a 40.5 percent median and mean of 39 ± 18 percent. The median arsenic extraction efficiency in whole

soil is lower than for the soil glauconite separates and greater than that for the pristine glauconite separates (fig. 8). Chen and Ma (1998) show that Method 3050 is effective for solubilizing arsenic in quartz-rich soils. The low extraction efficiencies for glauconite and glauconite-bearing soils demonstrate the significant effect soil matrices have on the extraction efficiency using the Method 3050 acid digestion.

Faust and others (1987) studied the distribution of arsenic in river and lake sediments from the Maurice River drainage basin. They define “total arsenic” in sediments as the arsenic leached by concentrated nitric acid and hydrogen peroxide. Certainly, this digestion procedure is only a partial leach rather than a true total digest. The “total extractable arsenic” was determined by digestion of the sediment in 1N hydrochloric acid. Total extractable arsenic compared to their total arsenic yielded a range in the percent extraction efficiency from 13 to 53 percent with a 27.8 percent median and a mean of 30.6 ± 15.4 percent. The range, median and mean percent extraction efficiency is lower than that for the whole soils in this study. Perhaps the slightly higher extraction efficiency for the whole soils is due to the more aggressive Method 3050 acid digestion and differences in the sediment character. The extraction efficiency reported by Faust and others (1987) is similar to that for the pristine glauconite from the Ancora core hole (table 16).

Figure 8 clearly shows a low median percent extraction efficiency for, and small variability in, beryllium for all samples. This suggests that EPA methods provide only approximately 20 percent of the total beryllium in the soil.

Percent extraction efficiencies for antimony (Sb) and cadmium (Cd) are erroneously high (table 18). Median extraction efficiency for antimony and cadmium is 188 and 700 percent, respectively. Lambkin and Alloway (2000) demonstrate that cadmium analysis using ICP-OES, the instrumental method used in the EPA protocol, is subject to significant spectral interferences

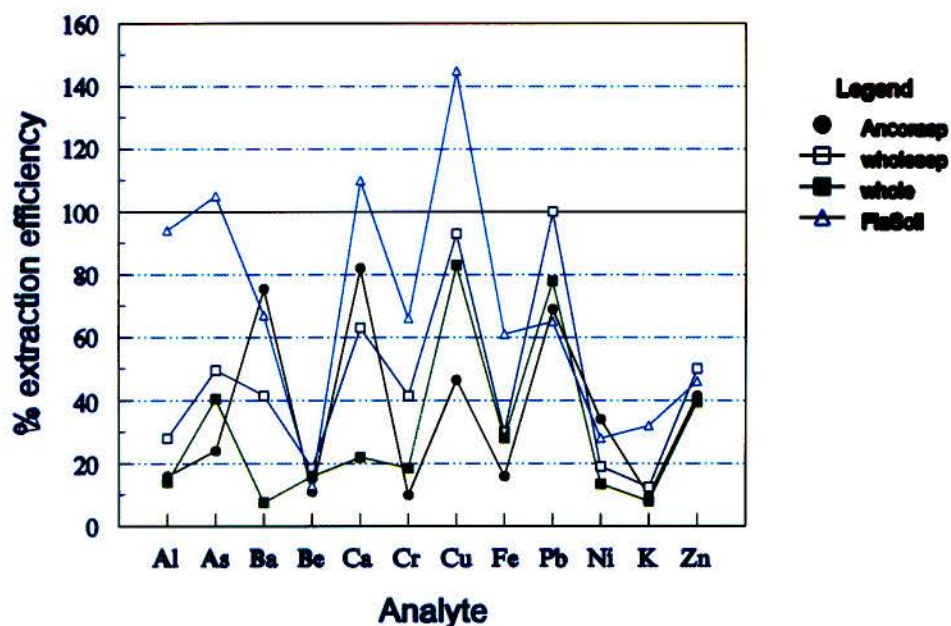


Figure 8. Median percent extraction efficiency for pristine glauconite (Ancorasap), soil glauconite separates (wholesep), whole soil (whole), and 40 Florida soils (FlaSoil) (from Chen and Ma, 1998).

when soil samples contain significant concentrations of arsenic (≥ 50 ppb) and iron. Furthermore, maximum extraction efficiencies for copper and lead are 218 and 280 percent, respectively. The 83 and 78 percent median extraction efficiency for copper and lead, respectively, suggest that the EPA method generally provides a reasonably accurate estimate of their total concentration in soils. It is likely that the copper and lead occur mainly associated with organic phases in the soil.

Percent Extraction Efficiency of Whole Soils as a Function of Depth

The design of this investigation permits evaluation of the extraction efficiency for the analytes as a function of depth in the soil. Surface soil samples from the leached (eluviated) O/A horizons might have significantly different extraction efficiencies than soil samples from the illuviated (zone of deposition) B horizon.

Composite soil samples from seven soil profiles, which represent six glauconite-rich soil series, were analyzed for total metal and total recoverable metal concentrations. A surface soil (0- to 6-inch composite) from the eluviated O/A horizons and a composite sample from 24 to 30 inches down in the profile, representing the illuviated B horizon, for seven select soil profiles were chemically analyzed. The statistical summary for percent extraction efficiency as a function of depth for whole soils is shown in table 19.

Mean and median extraction efficiencies for all analytes, except lead, are not significantly different as a function of depth in the top 30 inches of the soil profile. Mean extraction efficiencies nearly equal median extraction efficiencies, although the mean extraction efficiency generally is slightly higher than the median. Extraction data for lead suggest that its extraction efficiency increases with depth in the profile, however one deep sample yielded a 280 percent extraction efficiency, thereby strongly biasing the statistics.

A statistically insignificant higher median extraction efficiency for arsenic occurs in the surface soil, although the range in arsenic extraction efficiency is greater in the deep samples (table 19). Extraction efficiencies for iron as a function of depth mirror those for arsenic. There is no significant difference in extraction efficiencies for beryllium as a function of depth. Beryllium exhibits the lowest maximum extraction efficiency of all the analytes in table 19.

Laboratory Precision

Total Metal Analyses

To assess the reproducibility of data for total analyte analyses, the relative percent difference (RPD) was calculated for duplicate analyses. The RPD is calculated using:

$$RPD = [((A-B)/(A+B))/2] \times 100 \quad (4)$$

where A and B are the analyte concentration in the sample split.

Homogenized sample splits from the Hornerstown Formation, taken from the Ancora core hole, and two whole soils were submitted to the laboratory as blind samples for duplicate total analyte analyses. The RPD for these duplicates is given in table 20.

The overall data reproducibility is excellent for the total analyte concentrations. The mean RPD for the analytes ranges from 4.3 ± 5.6 percent for the Hornerstown Formation to 12.5 ± 20.4 percent for MOAD3003. The median RPD for the analytes ranges from 1.4 percent for BUCL2003 to 3.4 percent for MOAD3003. The high RPDs, for example 40 percent for silver in BUCL2003, and 67 and 46 percent for sodium and thallium, respectively, in MOAD3003, are attributed to one or both analytes at concentrations at or near the laboratory detection limit.

Table 19. Statistical summary of percent extraction efficiency for EPA SW-846, Method 3050 for whole-soil samples as a function of depth. Top value is for the surface (0- to 6-inch) composite and the bottom is for the 24- to 30-inch depth.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	6.5	48	13	14	19	24	7
	7.2	62	20	19	22	25	7
Sb	28	228	121	78	124	226	7
	150	303	294	65	262	300	5
As	8.3	53	44	15	40	53	7
	4.7	69	36	21	38	59	7
Ba	4.6	25	8.1	8.4	11	22	7
	6.2	54	7.1	19	17	31	7
Be	3.6	36	15	11	16	23	7
	1.9	37	17	12	15	19	7
B	6.6	46	14	16	19	21	5
	3.6	46	16	16	21	25	5
Cd	167	4670	700	1697	1359	1600	6
	NA	NA	NA	NA	NA	NA	1
Ca	8.9	57	23	21	30	51	7
	4.4	61	17	25	27	56	6
Cr	4.1	55	15	17	22	34	7
	1.3	71	25	25	28	43	7
Co	14	83	34	24	39	56	7
	18	73	52	24	44	70	7
Cu	64	136	83	24	90	104	7
	29	218	83	65	98	130	7
Fe	6.5	60	29	18	29	38	7
	3	65	25	25	30	62	7
Pb	22	98	70	25	71	90	7
	22	280	92	87	102	125	7
Mg	2.1	48	19	15	20	23	7
	1.2	49	16	17	19	29	7
Mn	1.8	41	13	16	19	36	6
	7	53	13	19	20	14	5
Ni	9.4	57	14	17	21	28	7
	2.6	67	11	23	20	30	7
K	0.3	47	7.3	16	13	19	7
	0.4	67	14	23	17	22	7
V	18	78	26	21	34	43	7
	5	91	25	29	34	50	7
Zn	13	78	40	21	41	48	7
	8.9	91	39	30	42	73	7

Table 20. Relative percent difference for duplicate analyses of total analyte concentrations in a sample of Hornerstown Formation from the Ancora core hole and two whole soils.

Analyte	ANHORNW	BUCL2003	MOAD3003
Al	0.9	3.4	0.2
Sb	22	NA	56
As	7	NA	13
Ba	1.9	0.8	5.5
Be	1.4	3	3.4
B	2.2	0.6	7.8
Ca	1.7	0	0
Cr	2	NA	1
Co	12	0	0
Cu	1.6	6.5	11
Fe	0	0.6	0.9
Pb	13	17	15
Mg	0.4	0.5	0
Mn	NA	0	NA
Ni	4.4	6.5	0
K	0.2	4.2	0.5
Ag	NA	40	NA
Na	3.2	8	67
Tl	4	0	46
V	1	0.6	9
Zn	2.7	1.9	0.6
median	2.0	1.4	3.4
mean	4.3	5.2	12.5
standard deviation	5.6	9.7	20.4

U.S. EPA SW-846, Method 3050 Results for Select Whole-Soil Duplicates

Soil composites from the surface and at depth from the Colemantown, Freehold, Kresson, Marlton and Shrewsbury soil series were submitted to the laboratory as blind samples for duplicate analyte analyses using SW-846, Methods 3050 and 6010A. The soils selected for duplicate analyses cover the range of variability in mineralogic constituents. For example, the glauconite sand ranges from a trace in MOFR6001 to 30 to 40 percent in MOMR3003. Quartz sand content in the soils ranges from approximately 2 percent in MOMR3003 to 80+ percent in MOFR6001. The RPDs are summarized in table 21. The overall data quality is poor for the total recoverable analytes.

In general, RPDs are reasonably low for BUKR3001, MOCM1001 and MOMR3001. RPDs for BUKR3003, BUSH1003, MOCM1002 and MOFR6003 generally are high, whereas BUSH1001, MOFR6001 and MOMR3003 have incredibly high RPDs.

The low RPDs are consistent with RPDs reported for background soils from Washington State (San Juan, 1994). Thirty eight soil samples from around Washington State were chemically analyzed in duplicate. The mean and range in RPDs for arsenic are 6.9 percent and 0 to 28.3 percent, respectively, for Washington State soils (San Juan, 1994, p. 12-3). RPDs for arsenic in BUKR3001(9 percent), BUKR3003(13 percent), BUSH1001(23 percent), MOCM1001(4 percent) and MOMR3001(0.5 percent) are consistent with Washington State soils. The mean and range in RPDs for beryllium are 2.4 percent and 0 to 12.3 percent, respectively, for Washington State soils. BUKR3001(2 percent), MOCM1001(13 percent) and MOMR3001(12 percent) have RPDs for beryllium that are similar to those for Washington soils.

Initially, it was suspected that those samples with the incredibly high RPDs might represent a lab error caused by not taking into account the serial dilution factor when calculating the actual analyte concentration. Ecology and Environment lab representative, Kathleen Willy (August, 1999), states that the serial dilution factor has been accounted for in all calculations.

Table 21. Relative percent difference between duplicate analyses using SW-846, Methods 3050 and 6010A for whole soils.

Analyte	BUKR3001	BUKR3003	BUSH1001	BUSH1003	MOCM1001	MOCM1002	MOFR6001	MOFR6003	MOMR3001	MOMR3003
Al	12	41	141	42	18	32	173	122	7	181
Sb	4	9	145	19	71	24	NA	NA	9	NA
As	9	13	23	NA	4	64	198	160	0.5	184
Ba	7	91	76	30	3	19	33	18	9	127
Be	2	58	124	54	13	36	168	108	12	178
B	55	81	NA	8	NA	80	NA	NA	12	NA
Cd	76	12	160	27	15	NA	188	173	3	116
Ca	37	75	137	5	12	NA	63	16	NA	NA
Cr	13	31	143	33	7	41	180	160	6	193
Co	0	30	106	20	11	27	165	35	11	144
Cu	2	24	42	18	16	59	41	8	4	109
Fe	57	64	179	36	4	34	190	156	11	165
Pb	15	32	112	29	6	30	151	59	4	186
Mg	35	43	176	57	20	30	191	150	8	186
Mn	34	57	102	26	19	0	191	25	6	78
Mo	8	34	NA	NA	19	14	NA	52	NA	NA
Ni	23	27	114	41	45	NA	133	84	13	121
K	43	78	173	52	38	59	194	186	8	192
Se	NA	98	NA	NA	NA	NA	NA	81	NA	NA
Ag	NA	NA	26	NA	0	NA	NA	NA	NA	NA
V	45	8	43	48	4	36	182	126	9	193
Zn	6	53	43	28	12	80	174	70	8	171

NA = not applicable.

The intrasample variability of lead in soils, determined using SW-846 Methods 3050A and 6010, was studied by Angle and others (1998). They conclude that it reflects routine commercial laboratory preparation.

RPDs approaching or exceeding 100 percent indicate a high intrasample variability in concentration. The range in analyte concentrations from duplicate analyses of select whole-soil aliquots is shown in table 22. Note the high intrasample variability in analyte concentrations for BUSH1001, MOFR6001, MOFR6003 and MOMR3003. Possible causes of the extreme intrasample variability in analyte concentrations include incomplete homogenization of the sample by field and/or lab personnel, variable soil matrix, U.S. EPA-mandated extraction and analytical procedures, and uneven distribution of the analyte in the soil.

The moist soil samples were homogenized as completely as feasible before 350 to 500 grams of soil were put in a bottle supplied by the laboratory. Moist, clayey and silty soil samples are nearly impossible to fully homogenize. At the analytical laboratory a few gram aliquot of the moist soil is oven dried. Method 3050 specifies that the lab technician thoroughly mix the entire sample to achieve homogeneity prior to transferring the approximately 1-gram aliquot to the beaker for digestion. Additionally, the soil aliquot selected for chemical analysis may be inherently biased by the lab technician. Angle and others (1998) state that "if the soil is clayey and/or contains pieces of gravel, organic matter, debris, etc. the technician will routinely collect a sample of the finer-grained, loose soil that is readily available in the container." Considering that only a 1- to 2-gram aliquot is taken from the 350- to 500-gram soil sample, the aliquot represents only approximately 0.5 percent of the contents in the bottle. These factors may produce a significant bias in the reported results given that such a small quantity of soil is used for the determination of the representative analyte concentration in the bottle.

Inhomogeneity in soils with an extremely variable matrix would not account for the extreme, several-order-of-magnitude concentration differences (Angle and others, 1998) reported

in table 22. For example, the arsenic concentration is reported as 2.0 and 371 ppm and the iron concentration as 2,580 and 102,000 ppm for MOFR6001. MOFR6001 consists of 80+ percent quartz sand, approximately 20 percent silt and clay, and traces of glauconite sand and illite/muscovite.

The extreme intrasample variability for analytes such as arsenic, cadmium, iron and potassium reported herein may result in large part from deficiencies in the prescribed U.S. EPA analytical methodology. Routine laboratory analysis using accepted EPA methods appears to yield inconsistent data that indicate the need for remediation actions when none are needed (Angle and others, 1998). The nonspecificity of the accepted EPA methods used for this research yields equivocal results. This in turn does not provide data which can be rigorously interpreted.

The preceding brief discussion of the inherent deficiencies in the accepted EPA analytical protocol, which produces equivocal results, is intended to illustrate to the regulators that such issues should be considered when interpreting site-specific chemical data for glauconite-bearing sediments and soils.

Table 22. Range in analyte concentrations (mg/kg) from duplicate analyses of whole-soil aliquots using SW-846 Methods 3050 and 6010A.

Analyte	BUKR3001	BUKR3003	BUSH1001	BUSH1003	MOCM1001	MOCM1002	MOFR6001	MOFR6003	MOMR3001	MOMR3003
Al	7780 - 8760	5030 - 7660	2060 - 11800	5090 - 7830	2660 - 3170	7340 - 10100	1450 - 20200	3270 - 13400	6030 - 6480	1110 - 21700
Sb	2.2 - 2.3	2.1 - 2.3	0.82 - 5.1	2.9 - 3.5	1.0 - 2.1	2.6 - 3.3	<0.78 - 5	<0.80 - 6	4.2 - 4.6	<0.83 - 17.2
As	10.9 - 11.9	14.7 - 16.7	11.6 - 14.6	<0.30	4.6 - 4.8	12.8 - 24.9	2.0 - 371	6.9 - 61.4	19.9 - 20.0	3.4 - 81.5
Ba	21.5 - 23.0	22.4 - 60.1	35.4 - 78.7	14.6 - 19.7	6.5 - 6.7	6.3 - 7.6	53.5 - 74.5	30.5 - 36.4	13.1 - 14.4	12.0 - 53.3
Be	0.98 - 1.0	0.33 - 0.6	0.26 - 1.1	0.63 - 1.1	0.07 - 0.08	0.18 - 0.26	0.2 - 2.3	0.42 - 1.4	0.98 - 1.1	0.20 - 3.5
B	16.3 - 28.6	15.1 - 35.8	7.5 - 47.8	44.1 - 83.9	<8.9	8.5 - 19.8	<8.0 - 169	<8.2 - 80.2	32.5 - 36.6	<8.4 - 119
Cd	1.3 - 2.9	2.3 - 2.6	0.86 - 7.7	2.6 - 3.4	0.51 - 0.59	<0.74 - 2.8	0.42 - 13.5	1.6 - 21.8	2.9 - 3.0	1.2 - 4.5
Ca	16.5 - 23.9	137 - 302	592 - 3190	605 - 638	35.1 - 39.6	<3.9 - 16.6	853 - 1630	546 - 640	<3.9	<4.4 - 469
Cr	40.9 - 46.7	34.9 - 47.9	14.5 - 87.1	53.6 - 75.1	15 - 16.1	75.9 - 115	5.1 - 96.1	13.7 - 124	131 - 139	12.2 - 711
Co	2.5	1.4 - 1.9	0.98 - 3.2	2.3 - 2.8	0.42 - 0.47	0.99 - 1.3	0.59 - 6.2	3.5 - 5.0	1.8 - 2.0	1.0 - 6.2
Cu	5.5 - 5.6	1.5 - 1.9	5.9 - 9.0	1.5 - 1.8	26 - 30.6	3.2 - 5.9	4.5 - 6.8	5.0 - 5.4	4.7 - 4.9	1.0 - 3.4
Fe	26000 - 46500	20000 - 38700	5750 - 105000	46100 - 66000	4200 - 4390	35700 - 50100	2580 - 102000	17100 - 137000	39100 - 43800	9020 - 92900
Pb	21.1 - 24.6	3.4 - 4.7	24 - 85.2	3 - 4	56.7 - 60	7.0 - 9.5	3.3 - 24.1	12.1 - 22.2	24.9 - 25.8	1.9 - 52.5
Mg	1180 - 1680	1020 - 1570	215 - 3400	1640 - 2940	187 - 229	633 - 860	151 - 6380	440 - 3070	1650 - 1790	205 - 5450
Mn	22.8 - 32.3	2.9 - 5.2	86.8 - 268	15.8 - 20.5	2.8 - 3.4	4.1	<0.13 - 137	143 - 184	6.1 - 6.5	6.4 - 14.5
Mo	0.71 - 0.77	0.7 - 0.99	<0.16 - 0.25	<0.14	0.33 - 0.4	0.68 - 0.78	<0.13	0.24 - 0.41	<0.14 - 0.22	<0.14
Ni	1.9 - 2.4	0.91 - 1.2	0.41 - 1.5	0.66 - 1.0	0.76 - 1.2	<0.10 - 0.24	1.2 - 6	4.6 - 11.2	0.97 - 1.1	1.7 - 6.9
K	2140 - 3320	1950 - 4430	456 - 6280	4990 - 8540	284 - 417	1280 - 2360	322 - 22000	421 - 11700	4100 - 4420	345 - 16200
Se	<3.5 - 6.7	1.6 - 4.7	<0.57 - 9.8	6.8 - 12.8	<0.67	<3.2	<0.61 - 12.2	3.3 - 7.8	<3.2	<0.64
Ag	<0.27 - 0.41	<0.26 - 0.6	0.27 - 0.35	<0.25	2	<0.25 - 0.30	<0.23	<0.24 - 0.28	<0.25	0.26 - <0.28
Na	<21.6	<20.6	<23.54 - 37.4	<20.1	<23.9	<20.2	<19.6 - 42.5	<18.7	<20.0	<20.1
Tl	<1.9	<0.37	<0.32	<1.9	<0.38	<1.8	<0.34	<1.7	<1.8	<0.36
V	36.2 - 57.2	28.6 - 30.9	14.6 - 22.5	13.4 - 21.8	12.9 - 13.4	33.4 - 35.1	1.7 - 35.8	9.7 - 42.7	104 - 114	4.3 - 250
Zn	27.7 - 29.4	18.0 - 30.9	35.3 - 54.6	19 - 25.3	8.1 - 9.1	13.6 - 19.5	6.0 - 86.4	39.0 - 80.9	38.5 - 41.5	14.1 - 181

Table 23 Analyte concentrations (mg/kg or ppm) determined using U.S. EPA Methods 3050 and 6010A in the soil samples.

Analyte	BUAD2001	BUAD2003	BUAD4001	BUAD4002	BUAD4003	BUCL2001	BUCL2002	BUCL2003	BUCM2001	BUCM2002	BUCM2003
Al	6010	4250	4270	6690*	4770*	3880*	3870*	11800*	6510	8760	3360
Sb	2.3	1.5	1.6	0.78UN*	1.8N*	2.4N*	1.5N*	4.2N*	2.3	3.1	0.74U
As	8.9	10.5	10.2	90	28	7.7	3.9	12.1	10.5	6.8E	3.6
Ba	15.1	20.6	35.5	11.9	11.7	16.3	8.6	14.8	66.3	168	25.1
Be	0.55	0.32	0.22	0.09	0.21	0.3	0.42	1.2	0.45	2.1E	0.18
Cd	2.2	1.9	2.7	1.4	1	1.1	0.94	3.5	1.5	5.2N*	0.63
Ca	102	25.1	479	39	11.3	183	3.7	4	6860	5780*	499
Cr	18.9E	21.4E	9.8E	23.9N	26.3N	34.7N	37.6N	172N	29.1N	82N*	6N
Co	1.7	1.3	1.9	0.83E	0.78E	1.5E	1.2E	3.1E	2	4.3E	1.3
Cu	6.2	1.9	11.1	3.6	2.9	6.7	1.9	2.9	6.8	0.76	4.8
Fe	19300	17300	21500	23400	21800	14500	13600	46500	17900	35300*	4380
Pb	29.6	3.7	78.2	11.4	10.4	59.1	5.6	6.6	8.9	6.3N*	8.4
Mg	1360	880	313	418	352	938	780	3640	659	3400	256
Mn	34	10.9	56.7	4	5.9	28.3	16.4	17.2	72.2	105N*	20.7
Mo	0.44	0.65	0.12U	0.13U	0.15	0.43	0.31	0.43	0.43	0.13U	0.25
Ni	1.4	0.54	2.6	0.33	0.09U	2.6	1.3	2.9	2.9	7.1	1.4
K	1600	1630	231	795E	1250E	1880E	1750E	9440E	1110	6840	251
Se	1.7	1.7	1.7	3U	3U	2.3	2.9	4.3	3.1U	3.1U	0.58U
Ag	0.24U	0.23U	0.22U	0.23U	0.23U	0.26U	0.23U	0.25U	0.24U	0.24U	0.22U
Na	331U	323U	306U	18.9U	19U	21.1U	19.1U	20.5U	19.4U	336U	33.7
Tl	0.35U	0.34U	0.32U	1.7U	1.7U	0.75U	0.68U	1.8U	1.7U	1.8U	0.32U
V	16.3N*	14.6N*	16.5N*	69.4	93.3	19.6	16.2	43	38.4N	22.5E	8.2N
Zn	27.1	14.2	53.6	19.1	11.7E	37.2E	18.6E	42.5E	44.1	85.7*	16.6
B	13.1	10.4	7.5U	8U	8.1	17.8	15.3	79.6	8.2U	38.7	7.6U

E = Reported value is estimated because of interference.

N = Spike analysis not within control limits.

U = Analyzed for but not detected.

* = Duplicate analysis not within control limits.

B = Analyte concentration in preparation blank is comparable with reported concentration, therefore value is considered estimated.

I = Initial calibration verification recovery (79.8 percent) is outside the QC limit of 90 to 110 percent.

D = Serial dilution analyses were outside the QC limit of 10 percent difference, therefore value is qualified with an unknown bias.

Note: Sample chosen for matrix spike/matrix-spike duplicate analyses was from another client's samples. Therefore, no matrix interference can be attributed to: BUCM2002; BUHN4002; MOCN2002; MOMR1002; MOSH3001; MOSH3003; MOTN1001; MOTN1003; MOTN2001; and MOTN2003.

The laboratory qualified vanadium for 0 percent spike recovery and a percent RPD outlier of 63.3 percent. However, vanadium should not be qualified for low spike recovery or duplicate outlier because the laboratory miscalculated the spike recovery of vanadium at 50.8 mg/kg whereas the correct value is 101.2 mg/kg. The dilution factor of two was not included in calculating the result for: BUAD2001; BUAD2003; BUAD4001; BUDO1003; CAFR3001; CAFR3003; GLCL4001; GLCL4002; GLCL4003; GLFR4002; GLMR5001; GLMR5003; GLMR6001; GLMR6003; MOAD3001; MOAD3003; MOSH3002; and MOTN1002.

Table 23

Analyte	BUCM2004	BUCM5001	BUCM5003	BUDO1001	BUDO1002	BUDO1003	BUDO2001	BUDO2003	BUFR2001	BUFR2003	BUFR7001
Al	6810*	7150*	4130*	6600	15700	15500	9180*	4470*	7120*	18300*	8560*
Sb	1.2N*	2.8N*	1.7N*	0.7U	0.83U	11.2	1.1N*	1.2N*	2.1N*	3.2N*	1.2N*
As	1.8	17.5	5.5	1.7	16.1	46.5	6.4	4.8	8.9	12.9	3.6
Ba	88.3	27.8	4.3	52	37	63.3	39.5	12	31	16.5	51.3
Be	1.6	0.63	0.26	0.26	0.79	2.3	0.35	0.4	0.6	0.9	0.72
Cd	1.1	3.5	1.2	0.92	7.7	52.8	1.3	1.1	1.6	4.4	1.3
Ca	5000	5	4.2U	195	131	400	463	70.2	285	543	784
Cr	57.4N	42.2N	49.3N	9.6N	46.7	85.6E	16.8N	13.1N	27.3N	83.5N	24.6N
Co	2.1E	2.8E	1.2E	3.7	6.2	73.6	2.4E	2.3E	2E	3.4E	2.1E
Cu	4.1	3.9	0.73	2.8	9.4	9.5	4.6	5.5	6.5	1.8	5.7
Fe	13200	50900	17600	7370	48500	224000	24000	15300	19600	56600	15800
Pb	6.5	29.2	2.1	2.8	14.3	29.8	17.9	5.6	23.1	7.9	17.3
Mg	1970	963	818	256	1910	2580	840	747	1400	3930	1600
Mn	37.8	13.5	5.2	19	89.3N	1240	39.2	57.8	69.3	23.1	171
Mo	0.14U	0.17U	0.14U	0.11U	0.14U	0.14U	0.14	0.12U	0.15	0.15U	0.45
Ni	7.1	4.7	1.5	3.4	6.1	14.5	3	3.8	2.5	1.8	4.6
K	4530E	2140E	2760E	322	3240	4500	985E	730E	2410E	9420E	2130E
Se	1.4	4.1U	1.6	0.64	6.2	30.3	3.1U	1.2	2.8	4.5	2.8
Ag	0.25U	0.31U	0.26U	0.23	0.25U	0.48	0.24U	0.29	0.26U	0.36	0.3
Na	20.4U	25.6U	21.3U	17U	342U	348U	19.4U	17.8U	21.1U	21.5U	18.5U
Tl	0.73U	2.3U	0.76U	0.3U	1.8U	3.6U	1.7U	0.63U	0.75U	1.9U	0.66U
V	9.6	21.9	25.2	14.1N	147	707N*	21.1	11.7	20.2	41.7	14.3
Zn	82.9E	26.8E	7.6E	6.2	52.8	146	38.9E	20.9E	43.8E	42.1E	38.2E
B	22.4	18.5	24.4	7.1U	15.1	25.3	8.2U	7.5U	17.5	75.1	15.9

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Table 23

Analyte	BUFR7002	BUFR7003	BUHN2001	BUHN2003	BUHN4001	BUHN4002	BUHN4003	BUKR3001	BUKR3003	BUMR4001	BUMR4003
Al	1890	11600*	6200	3450	2650	14200	4430	7780*	7660*	9880*	10100*
Sb	0.8	1.5N*	1.7	1.1	1.1	1	1.8	2.3N*	2.3N*	4.3N*	6.9N*
As	5.5	9.5	8.1	5.7	3.5	2.4E	6.5	10.9	16.7	8.2	6.8
Ba	14.3	20.4	15.4	13.1	11.1	43.5	18.8	23	60.1	44.8	37.5
Be	0.25	0.59	0.27	0.54	0.31	0.36E	0.42	0.98	0.6	1.8	1.3
Cd	0.8	2	2	1.4	1.4	1.5N*	2.8	1.3	2.6	3.5	3
Ca	1040	455	835	71.4	38.7	603*	38.4	16.5	137	1710	1740
Cr	16.6N	37.5N	58.9N	25.9N	25.8N	22.3N*	44.2N	40.9N	47.9N	172N	292N
Co	0.77	2.5E	1.1	1.9	1.5	1.5E	2.8	2.5E	1.9E	3.8E	4.2E
Cu	7	5.3	2.4	8.4	1.5	5.3	2.2	5.6	1.9	3.6	1.9
Fe	5450	30500	22200	16400	16000	13100*	29500	26000	38700	43800	42800
Pb	13	7.4	5.2	24.8	3.8	11.8N*	6.5	21.1	4.7	14.3	8.3
Mg	458	1780	699	306	330	1110	447	1180	1570	3810	3620
Mn	51.6	37.5	5.4	92.5	32.6	17.8N*	58.3	32.3	5.2	128	21.2
Mo	0.74	1.6	1.5	0.12U	0.12U	0.15	0.12U	0.71	0.7	0.13U	0.15U
Ni	0.77	2.5	0.1U	2.6	1.8	3.5	1.8	1.9	0.91	5.3	6.8
K	556	2490E	1210	162	246	1350	490	2140E	4430E	10300E	10100E
Se	0.63	3.2	3.2U	2.9U	2.8U	2.5	2.9	3.5U	4.7	5.1	4
Ag	0.22U	0.23	0.25U	0.22U	0.21U	0.21U	0.21U	0.41	0.6	0.24U	0.27U
Na	24.6	18.5U	20.1U	18U	17.4U	297U	17.5U	22.1U	20.6U	19.6U	22.4U
Tl	0.32U	1.6U	1.8U	1.6U	1.5U	0.31U	1.6U	2U	1.8U	1.7U	2U
V	8.1N	22.4	23.5N	29.5N	26.9N	30.3E	51.7N	36.2	28.6	38.4	56.7
Zn	15.4	26.1E	9.8	25.4	17.4	19.9*	30.4	27.7E	30.9E	71.6E	73.8E
B	7.7U	15.9	8.5U	7.6U	7.3U	8.7	7.3U	16.3	35.8	81.5	70.9

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Table 23

Analyte	BUSH1001	BUSH1003	BUSH4001	BUSH4002	BUSH4003	CACL3001	CACL3003	CAFR3001	CAFR3003	CAHN3001	CAHN3003
Al	11800*	5090*	10100	2920	6510	10500	13300	3890	7040	1730	15500
Sb	5.1N*	2.9N*	1.1	1.8	0.8U	4.7	2.7	1.1	1.3	1.6	3.3
As	14.6	0.31U	4.5E	5.2	3E	10.5	18.6E	10.5	5.6	4.1E	11.2E
Ba	78.7	19.7	51.8E	12.1	13.9E	24.4	23.8E	26.4	13.2	8E	23.4E
Be	1.1	0.63	0.35E	0.31	0.26E	0.55	0.92E	0.38	0.21	0.23E	1.7E
Cd	7.7	3.4	1.5	1.5	1.1	5.1	4	0.97	1.4	0.99	27.2
Ca	3190	605	405E	55.2	102E	52.6	901E	1330	403	370E	154E
Cr	87.1N	53.6N	14.3E	27.8N	16.2E	85.7N	67.6E	12.9E	19.5E	9.1E	72.8E
Co	3.2E	2.3E	1.4E	1	1.4E	3.9	3.3E	1.5	1.4	0.98E	5.5E
Cu	5.9	1.5	6.4	4.6	3.5	5.8	4.8	5.8	4.2	3.9	3.8
Fe	105000	46100	10300	10500	7560	41100	47500	7590	12500	7010	63700
Pb	24	3	38.6E	22.4	E	9.6	13.7E	20.7	5.2	25.2E	14.1E
Mg	3400	1640	737E	238	688E	885	2240E	737	766	222E	1420E
Mn	268	20.5	11.7E	29.5	17E	82.8	35.6E	59.8	13.4	63.2E	51.6E
Mo	0.16U	0.14U	0.15U	0.19	0.31	0.37	0.58	0.49	0.67	0.14	0.13U
Ni	0.41	0.66	3.2E	1.1	2.3E	2.3	4.4E	2.6	1.6	1.6E	10.2E
K	6280E	4990E	564E	112U	1040E	554	4910E	410	368	426E	3430E
Se	9.8	6.8	3.5	0.62U	2.4	3.1U	5.3	1.3	1.5	0.54U	24.8
Ag	0.35	0.26U	0.26U	0.24U	0.24U	0.24U	0.24U	0.21U	0.21U	0.21U	0.24U
Na	23.4U	21.3U	145	19.4U	141	19.5U	19.5U	295U	284U	21.7	19.2U
Tl	4.2U	1.9U	0.38U	0.34U	0.34U	1.7U	1.7U	0.31U	0.31U	0.3U	6.8U
V	22.5	13.4	19.2N	28N	16N	80.6N	86.7N	11.9N*	17.6N*	16.9N	636N
Zn	54.6E	19E	38.9E	13.5	12.5E	36.5	33.5E	21.3	11.9	23E	97.5E
B	47.8	44.1	9.1U	8.1U	8.8	8.2U	37.3	7.3U	7.2U	7.1U	21.7

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Table 23

Analyte	CAKR4001	CAKR4003	CAMK1001	CAMK1002	CAMK1003	CASH2001	CASH2003	GLCL4001	GLCL4002	GLCL4003	GLCM3001
Al	3150	4700	2730	4730	5340	3510	3720	1990	1850	6310	11200
Sb	0.82	0.75U	0.76U	1.3	0.89U	0.88	2.9	2	0.98	2.4	3.5
As	5.3	6.2	4.5E	5.8	7.7	7.2	10.4	7.1	5.5	15.1	13.7
Ba	14.3	10.5	13.2E	12.9	39.3	16.2	20	13.2	8.1	16.4	22.1
Be	0.27	0.46	0.31E	0.37	2	0.43	0.48	0.14	0.13	0.35	0.51
Cd	1.4	1.9	0.17U	1.3	3.3	1.3	2.3	0.62	0.57	1.8	3.3
Ca	45.1	38.6	99.5E	88.5	741	221	274	75.7	35.6	31.2	48.8
Cr	11.9N	23N	17.5E	22.3	16.6N	29N	53.4N	16.1E	17.4E	48.7E	93.9N
Co	1.3	2.2	0.87E	1.5	4	1.9	1.7	0.61	0.56	1.5	3.1
Cu	6.8	1.9	4.7	1.9	9.1	3.7	5.7	4.2	1.4	2.7	5.8
Fe	11500	18100	18.5U	10400	15500	15800	23300	5520	5210	15500	36700
Pb	19.5	4	20.5E	4.3	27.3	4.6	110	27.4	4.4	4.6	10.8
Mg	366	476	507E	769	852	566	436	260	250	601	1200
Mn	43.9	54.7	24.3E	28.8N	161	15.4	118	17.4	11.1	22.1	16.7
Mo	0.13U	0.19	0.4	0.37	0.16	0.89	0.17	0.27	0.18	0.49	0.7
Ni	1.6	2.7	2.4E	2.5	4.2	2.3	1.1	1.3	0.72	1.5	1.4
K	162	133	1090E	778	126U	290	243	227	249	681	835
Se	0.61U	3.6	2.9U	1.5	3.5U	3.1U	3.5U	0.57U	0.56U	1.7	3.4U
Ag	0.25	0.88	0.23U	0.22U	1.1	0.24U	0.27U	0.22U	0.21U	0.23U	0.27
Na	19U	18.3U	18.4U	307U	21.7U	19.5U	21.6U	305U	298U	317U	21.2U
Tl	0.34U	1.6U	0.32U	0.32U	1.9U	1.7U	2.3	0.32U	0.31U	0.33U	1.9U
V	20.3	30.2N	12.7N	19.9	31.7N	51.3N	48.8N	19.7N*	17.1N*	44.9N*	79.2N
Zn	15.1	18.3	23.1E	16.6	31.9	19.2	29.9	12.4	11.3	15.6	35.8
B	8U	7.7U	7.7U	7.6U	9.1U	8.2U	9.1U	7.5U	7.3U	7.8U	8.9U

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Table 23

Analyte	GLCM3003	GLCM4001	GLCM4003	GLCN1001	GLCN1003	GLFR4001	GLFR4002	GLFR4003	GLKR5001	GLKR5003	GLMR5001
Al	4990	7490	20700	10900	18100	9940	10600	8590	7690	7310	9570
Sb	0.86	1.4	19.3	6.1	6.6	3.1	1.3	1.4	1.1	1.4	4.7
As	6.8	7.7	92.3	16.1	14	8.2	7.1	9.5	4.4	4.7	31.4
Ba	11.3	15.5	67.9	73.6	786	278	50.6	48.2	27.9	30.2	10.1
Be	0.33	0.57	3.4	1.1	3.4	2.8	0.33	0.37	0.51	0.29	0.59
Cd	2.1	3	10.9	11.8	14.6	13.5	1.1	2.5	2.1	1.4	4.5
Ca	3.7U	3.5U	4.4U	3060	6770	6080	234	306	406	197	177
Cr	15.9	26.7	749	83.9	158	104	13.5E	19.7	22.7	9.6	63E
Co	1.8E	3E	5.5E	2.8E	22.4E	3.3E	3.6	8.1E	1.9E	4.7E	2.4
Cu	7.8	2.8	3.4	5.6	3.4	2.2	5.5	7.4	3.5	6.2	8.3
Fe	15300	23200	91800	90500	83500	46700	9870	17800	15800	11100	33100
Pb	20.3	5.9	63.9	23.7	28.1	5.5	6.3	132	5.6	48	51.2
Mg	634	910	4510	3150	5550	4030	462	805	1250	604	1820
Mn	57.1E	65.7E	13.9E	230E	4860E	55.5E	35.3	477E	51.8E	198E	28.1
Mo	0.27	0.13	0.15U	0.15U	0.17U	0.14U	0.24	0.13U	1	0.55	1.1
Ni	3.5	5.4	6.5	0.77	12.8	8.9	4.4	6.4	3.1	3.8	1.3
K	631	1250	17100	5860	11800	12300	397	1110	1370	408	4710
Se	1.8	3.5	11.1	12.7	11.3	11.5	2	2.5	2.4	2	3.4
Ag	0.23U	0.22U	0.28U	0.44	1.2	0.25U	0.22U	0.24U	0.22U	0.25U	0.28U
Na	19.1U	18.2U	22.5U	22.6U	25.3U	20.5U	304U	19.9U	17.9U	20.5U	386U
Tl	0.34U	0.32U	2U	2U	2.3U	1.8U	0.32U	0.35U	0.32U	0.37U	0.81U
V	23.4	36.4	279	27.2	69.4	25.5	16N*	48.1	15.2	18	44.1N*
Zn	21.2	27.6	183	52.9	178	96.4	18.4	48.8	18.2	25.8	33.8
B	8U	8	93.7	47.1	79.9	73.6	7.5U	8.4U	7.5U	8.6U	36.3

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Table 23

Analyte	GLMR5003	GLMR6001	GLMR6002	GLMR6003	MOAD1001	MOAD1003	MOAD3001	MOAD3002	MOAD3003	MOCL1001	MOCL1002
Al	12900	9340	15600	9530	16900	23200	6440	9450	6880	8830	6610
Sb	6.5	4.7	3.3	3.6	13.2	9	1.4	3.7	4.7	3.4	2.5
As	55.8	35.2	28.7E	25.3	32.4E	23.1E	21.7	27.7E	24.3	19E	43.1E
Ba	5.7	15.1	14.5E	7.8	74.8E	154E	19.5	14.6E	8.4	40.3E	44.7E
Be	0.92	0.83	1.1E	0.44	3.5E	3.3E	0.62	0.7E	0.49	1.1E	0.46E
Cd	4.1	5.7	5.8	4.2	19.1	22.1	4.8	13.2	5.7	4.8	3.7
Ca	66.4	264	81.3E	55.8	1810E	3220E	119	58.8E	46.6	436E	824E
Cr	166E	77.2E	84.9E	60.7E	404E	354E	44.7E	83.4E	77.5E	62.4E	45.3E
Co	3.3	1.9	2.9E	2.1	11.4E	32.4E	2.5	2.5E	2.2	4.4E	1.7E
Cu	4.8	5.4	6	5.5	8.1	5.4	9.5	4.7	4.1	8.1	5.1
Fe	32900	49000	63900	39900	210000	244000	36100	40900	49800	64500	47500
Pb	12.4	9.9	9.6E	6.3	48.4E	49.8E	63.3	9.5E	7.1	23.1E	11.5E
Mg	2820	2140	3280E	1510	2230E	4140E	979	1500E	1400	812E	1350E
Mn	10.6	27.6	30.7E	36.3	388E	756E	139	44.4E	34.7	198E	20.3E
Mo	0.14U	2.2	2.4	2.7	0.14U	0.16U	0.72	1.2	0.66	0.16U	1.4
Ni	2.8	0.09U	0.96E	0.43	26.3E	36.6E	1.8	1.7E	0.62	10.8E	1.1E
K	8780	5660	10300E	3300	5550E	5970E	1750	3890E	2610	1030E	2240E
Se	4.4	3.8	3.3U	5.2	13.1U	15.2U	2.9	14.3	5.3	5.7	3.3U
Ag	0.26U	0.21U	0.25U	0.22U	0.25U	0.29U	0.24U	0.24U	0.23U	0.29U	0.25U
Na	363U	297U	20.5U	307U	20.6U	23.9U	337U	19.4U	314U	23.6U	20.5U
Tl	0.76U	1.5U	1.8U	1.6U	7.3U	8.5U	0.7U	3.4U	1.6U	2.1U	1.8U
V	80N*	33.7N*	38.7N	24.5N*	339N	349N	55.5N*	146N	62.4N*	91.2N	50.4N
Zn	29.3	33	34.3E	23.5	261E	300E	44.2	47.1E	40	60.5E	17.6E
B	59.6	50.9	92.2	27.9	34.8	39	13.2	31.2	21.3	9.9U	12.4

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Table 23

Analyte	MOCM1001	MOCM1002	MOCM1003	MOCN2001	MOCN2002	MOCN2003	MOCN2004	MOFR1001	MOFR1002	MOFR6001	MOFR6002
Al	3170	7340	4800	11900	3410	14800	20700	9480	4470	20200	4690
Sb	2.1	2.6	2.6	1.2	1.1	2.2	2.2	0.77U	2.5	5	0.73U
As	4.8E	12.8E	15.6E	4.8	2.8E	14.2	12	2.7	72.7	371	4E
Ba	6.5E	7.6E	4.1E	36.7	10.2	54.2	60.2	17.7	27.1	53.5	11.4E
Be	0.08E	0.18E	0.17E	0.43	0.38E	0.85	0.44	0.29	0.55	2.3	0.45E
Cd	0.59	2.8	3	2	2.4N*	2.4	12.6	0.94	1.6	13.5	1.5
Ca	39.6E	16.6E	13.1E	65.1	41.2*	384	312	155	599	853	27.4E
Cr	16.1E	75.9E	79.3E	27.5	22.7N*	27.5	38.1	18.7	26.7	96.1	14.2E
Co	0.42E	0.99E	0.73E	2.1E	1.5E	2.5E	2.4E	1.5E	1.6E	6.2E	2E
Cu	30.6	3.2	3.4	11.7	1.8	17.9	6.8	3.1	26.6	6.8	1.6
Fe	4200	35700	38600	16100	16200*	17200	31300	7970	11900	102000	19500
Pb	60E	7E	6.2E	12.6	4.9N*	54.1	13.4	5.8	501	24.1	3.5E
Mg	229E	633E	510E	1170	433	1490	1250	883	919	6380	509E
Mn	3.4E	4.1E	2E	19.5E	41.2N*	37.3E	20.8E	17.3E	57.1E	137E	52.5E
Mo	0.4	0.68	0.38	0.14	0.11U	0.77	0.23	0.13U	0.38	0.13U	0.12
Ni	1.2E	0.24E	0.1UE	2.8	3	6.5	2.7	2.6	2.8	6	4.8E
K	417E	1280E	1300E	2070	420	2190	1570	1850	2210	22000	386E
Se	0.76U	3.2U	3.2U	1.8	2.3	3.1	12.3	1.6	1.7	12.2	1.1U
Ag	2	0.25U	0.24U	0.25U	0.2U	0.26U	0.26U	0.23U	0.22U	0.24U	0.22U
Na	23.9U	20.2U	19.9U	23.9	277U	21.2U	223	18.7U	18U	19.6U	17.8U
Tl	0.42U	1.8U	1.8U	0.36U	0.58U	0.38U	1.9U	0.33U	0.32U	3.5U	0.63U
V	12.9N	35.1N	30.3N	33.5	37.1E	31.9	54.2	15.4	18	35.8	30.1N
Zn	9.1E	13.6E	12E	19.9	21.7*	47.5	28.8	11.1	41.8	86.4	16.9E
B	10U	8.5	10.2	8.4U	6.8U	10.6	8.7U	13.2	15.6	169	7.5U

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Table 23

Analyte	MOFR6003	MOHN1001	MOHN1002	MOKR1001	MOKR1002	MOKR2001	MOKR2002	MOKR2003	MOMR1001	MOMR1002	MOMR2001
Al	13400	8810	1750	21400	28400	12100	15700	6280	8650	13500	7740
Sb	6	1.9	1.6	10.7	13.3	1.3	7.3	2.2	5.2	8.4	1.5
As	61.4	9.8	3.3	50.6E	53.2E	2.3	23.7	12.4	63.3E	72.3E	14.1E
Ba	36.4	19.8	9.9	27.9E	17.2E	24.7	20.2	87.9	49.4	32.9	17.4E
Be	1.4	0.53	0.06	4.3E	4.2E	0.44	0.87	0.64	1.1	1.4	0.4E
Cd	21.8	2.6	0.34	14	13.8	1.5	8.8	3.3	7.9	11.2	1.4
Ca	546	132	79.6	1810E	363E	3.5U	61.5	2120	19.5E	3.9UE	141E
Cr	124	41.7	4.6	452E	702E	29	175	28.9	177	292	60.9E
Co	5E	2.7E	1.2E	6.2E	7E	2.4E	2.8	2.4E	3.3E	3.8E	2E
Cu	5	3.3	7.6	7.2	3	3.7	6.2	3.7	9.7	5.3	6.7
Fe	137000	21500	2520	130000	138000	13000	74200	25100	168000	105000	16300
Pb	12.1	5.7	51.3	29.3E	30.1E	7.2	21.6	19.7	91.1	15.3	26E
Mg	3070	1200	129	7430E	9840E	1260	2470	1940	1720	3010	907E
Mn	143E	45.6E	11.4E	123E	71.2E	25.1E	18.5N	59.3E	18.1	40.6	22.3E
Mo	0.24	0.73	0.34	0.14U	0.15U	0.63	0.15U	0.15U	0.24	0.14U	0.42
Ni	11.2	3.5	2.2	11.9E	16.8E	4.3	0.51	3.3	1.6	3.7	3.9E
K	11700	2100	248	23100E	43800E	2240	4710	3270	5000E	8330E	1700E
Se	7.8	2.2	0.87	33U	13.7U	1.9	3.5U	2.4	7	11.8	1.5U
Ag	0.28	0.23U	0.21U	0.25U	0.26U	0.22U	0.27U	0.27U	0.26U	0.29	0.28U
Na	18.7U	18.5U	17.5U	20.7U	21.5U	17.9U	372U	22.1U	21.1U	20U	22.8U
Tl	3.3U	0.33U	0.31U	18.4U	7.7U	0.32U	1.9U	0.39U	1.9U	1.8U	0.81U
V	42.7	36.3	8.7	189N	198N	35.3	115	13.5	92.4	102	33N
Zn	80.9	25	12.6	196E	250E	21.5	55	36.3	65.7	92.7	32.6E
B	80.2	14.8	7.4U	161	219	15.8	33.5	28.1	37.5	63.6	14.8

E = Reported value is estimated because of interference.

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The laboratory qualified vanadium for 0 percent spike recovery and a percent RPD outlier of 63.3 percent. However, vanadium should not be qualified for low spike recovery or duplicate outlier because the laboratory miscalculated the spike recovery of vanadium at 50.8 mg/kg whereas the correct value is 101.2 mg/kg. The dilution factor of two was not included in calculating the result for: BUAD2001; BUAD2003; BUAD4001; BUDO1003; CAFR3001; CAFR3003; GLCL4001; GLCL4002; GLCL4003; GLFR4002; GLMR5001; GLMR5003; GLMR6001; GLMR6003; MOAD3001; MOAD3003; MOSH3002; and MOTN1002.

Table 23

Analyte	MOMR2002	MOMR2003	MOMR2004	MOMR3001	MOMR3003	MOSH3001	MOSH3002	MOSH3003	MOTN1001	MOTN1002	MOTN1003
Al	12000	11300	10400	6480	21700	2320	2260	2580	4610	5110	5900
Sb	5.4	3.5	5.6	4.6	17.2	0.73U	1.9	0.82U	2.1	2	1.5
As	19.5E	12.3E	25.6	19.9	81.5	3.3E	8.9	3.8E	4E	1.4	1.8E
Ba	10.2	12.4E	10	14.4	53.3	15.4	17.8	16.2	3.7	2.7	3.8
Be	0.81E	0.98E	0.79	1.1	3.5	0.13	0.09	0.1	0.37	0.68	0.8
Cd	4.8N*	3	4N	3N	4.5N	1.5	2	1	2.5	3.1	2.7
Ca	61.3*	46.2E	4U	4.4U	4.4U	578E	534	31.1E	3.7UE	25.3	3.4UE
Cr	148N*	154E	203*	139*	711*	13.6	15.3E	8.8	28.9	35.7E	39
Co	2.9E	3.2E	3.5	2	6.2	1.7E	1.4	0.49E	1.6E	1.9	2.7E
Cu	5.9	4.1	4.6	4.9	3.4	16.4	24.6	4	4.3	1.6	1.1
Fe	42000*	35800	55000E*	43800E*	92900E*	8670	15900	6990	16500	22100	23200
Pb	9.3N*	13.3E	10.8	25.8	52.5	85.9	168	25.9	20.7	3.5	3.2
Mg	1910	2710E	1750E	1790E	5450E	557	363	140	123	136	136
Mn	16N*	16.5E	19.5N	6.1N	14.5N	48.8	32.7	6.9	12.6	13	14.3
Mo	0.57	0.36	0.44	0.22	0.15U	0.41	0.37	0.22	0.18	0.11U	0.12U
Ni	2.6	4.4E	2.7	0.97	6.9	3.7	3.5	1.9	3.2	4.3	6
K	4270	6650E	4550E	4420E	16200E	487E	259	354E	221E	129	269E
Se	3.2U	3.3U	6.5U	3.6U	14.4U	0.57U	1.4	0.64U	2	1.7	1.3
Ag	0.25U	0.26U	0.25U	0.27U	0.28U	0.22U	0.3U	0.24U	0.23U	0.2U	0.21U
Na	346U	20.8U	20.4U	22.4U	22.6U	52.5	414U	28.3	18.8U	281U	17.3U
Tl	1.8U	1.9U	3.6U	2U	8U	0.32U	0.43U	0.36U	0.34U	0.59U	0.62U
V	83.8E	70.7N	104N*	114N*	250N*	11.7	14.7N*	7.5	41.6	58.8N*	48.3
Zn	48.2*	39.3E	39.6	41.5	181	51.7	37.8	8.5	17.6	20.9	26.3
B	35.2	63.8	37.1	36.6	119	8.1	10.2U	8.4U	7.9U	6.9U	7.3U

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Table 23

Analyte	MOTN1004	MOTN2001	MOTN2003
Al	5570	10600	8950
Sb	1.1	3.6	2.2
As	0.26U	15.4E	13.9E
Ba	4.3	23.8	21.9
Be	0.89	0.86	0.59
Cd	2.1N	5	3.7
Ca	3.4U	1000E	661E
Cr	40*	52.6	27.8
Co	2.9	4E	2.9E
Cu	1.4	8.6	3
Fe	33100E*	42800	30300
Pb	3.5	29.5	8.3
Mg	113E	1450	944
Mn	15.2N	102	62.5
Mo	0.12U	0.5	0.52
Ni	6.5	7.5	5.9
K	335E	3310E	1430E
Se	2.8U	6.1	3U
Ag	0.21U	0.25U	0.23U
Na	17.4U	20U	18.8U
Tl	1.5U	0.71U	1.7U
V	64.3N*	54.5	32.9
Zn	28.5	67.5	33.1
B	7.3U	22.4	8.1

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Analyte Concentrations in the Suite of Glauconite-Bearing Soils Using U. S. EPA SW-846, Methods 3050 and 6010A

One hundred thirteen soil samples, six inches in length, were homogenized and subjected to chemical characterization using U. S. EPA SW-846 Methods 3050 and 6010A. The soil samples selected and their lithologic descriptions are shown in appendix 2. The discussion of soil chemistry focuses on the 113 samples as a whole and on the individual soil series with particular emphasis on arsenic and beryllium.

Analyte Concentrations for all Soil Samples

Results of the chemical analyses for TAL elements and other select analytes in the 113 soil samples are presented in table 23. Mr. Joseph Sanguiliano of the Quality Assurance Section of the Bureau of Environmental Measurements and Quality Control in the Division of Publicly Funded Site Remediation provided the quality assurance review of these chemical data. His comments are included in the footnotes for table 23.

The extent to which these chemical data are qualified is unsettling. For example, consider the data quality for BUCM2002 in table 23. Only 33 percent (8 of 24) of the analytes are not qualified. Twenty-nine percent (7 of 24) of the concentrations are qualified for duplicate analysis outside the quality control limits. Seventeen percent of the chemical data are qualified for: 1) unspecified interferences which result in an “estimated” concentration; 2) serial dilution analyses not within quality control limits; and 3) matrix spike recoveries not within quality control limits.

Clay-size and phyllosilicate minerals generally have a rather high affinity for sorbing/desorbing elements. In fact, there is significant evidence in the literature that certain elements are irreversibly sorbed as inner-sphere complexes on the constituent soil minerals and amorphous phases. The exchange reaction was noted in the pH measurements where the calcium exchanged for two protons (hydrogen atoms) on the mineral surface. Moreover, glauconite has

been shown to effectively and efficiently remove metal species from landfill leachates (Spoljaric and Crawford, 1979) and metal-spiked solutions (Hao and others, 1987). Based on these considerations, it is not unusual to expect variable matrix spike recoveries from samples consisting of high concentrations of clay-size and phyllosilicate minerals. Additionally, the Method 3050 acid digestion may contribute to poor matrix spike recoveries for certain elements. In the case for lead, the hydrochloric/nitric acid digestion forms lead chloride which has a limited solubility in hydrochloric acid (Kimbrough and Wakakuwa, 1992). Filtration or centrifugation of the digestate may remove the insoluble lead chloride, thereby yielding low matrix spike recoveries for lead, as reported for BUCM2002.

The statistical summary of analyte concentrations, determined by U. S. EPA SW-846 Methods 3050 and 6010A, pH, percent organic carbon, and weight percent moisture for the whole-soil samples is shown in table 24. The statistics are calculated using only measured concentrations, that is, concentrations lower than the MDL (method detection limit) were omitted from the calculations. For example, calcium was measured in 98 (87 percent) of the 113 soil samples. Generally, minimum values reflect the reported lowest detection limit for an analyte.

The suspect 371-ppm arsenic concentration for the MOFR6001 duplicate (table 22) was not used as the maximum arsenic concentration in table 24. By taking into account the mineralogic constituents — mainly quartz sand and silt — in MOFR6001, the 2.0 ppm arsenic concentration was used for the calculations. Arsenic concentrations below the MDL for MOTN1004 (<0.26 ppm) and BUSH1003 (<0.31 ppm) were omitted from the statistical calculations. The 1.4 ppm minimum quantified arsenic concentration for MOTN1002 was used for the calculations.

Arsenic

For the 113 soil samples, the arsenic concentration ranges from <0.26 ppm (MOTN1004) to 92.3 ppm (GLCM4003) with a 9.5 ppm median and a 16.1 ± 18.8 ppm mean. Using the 371

ppm arsenic maximum reported for the MOFR6001 duplicate yields a median arsenic concentration of 9.8 ppm with a 19.4 ± 38.5 ppm mean.

Table 24. Statistical summary of pH, weight percent total organic carbon, weight percent moisture, and analyte concentrations in mg/kg, determined by U. S. EPA SW-846 Methods 3050 and 6010A, for all whole-soil samples. pH is standard units.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	2.88	6.94	3.68	0.73	3.90	4.74	113
%TOC	0.06	13.8	0.51	1.69	1.28	2.79	113
Al	1450	28400	7120	5279	8323	15500	113
Sb	0.8	19.3	2.2	3.3	3.4	6.6	99
As	0.26	92.3	9.5	18.8	16.1	35.2	111
Ba	2.7	786	19.7	79	37	60.2	113
Be	0.06	4.3	0.49	0.88	0.80	1.7	113
B	8	219	25	38	39	79.6	63
Cd	0.34	52.8	2.4	6.5	4.4	10.9	112
Ca	11.3	6860	209	1398	725	1740	98
Cr	4.6	749	37.5	132	81	172	113
Co	0.42	73.6	2.2	7.6	3.6	4.4	113
Cu	0.73	30.6	4.7	4.6	5.6	9.0	113
Fe	2520	244000	22150	42476	36858	64500	112
Pb	2.1	501	13	53	27	54.1	113
Mg	113	9840	910	1527	1446	3280	113
Mn	2	4860	33	474	112	128	113
Mo	0.12	2.7	0.42	0.51	0.56	1.00	72
Ni	0.24	36.6	2.7	4.8	4.1	7.1	109
K	126	43800	1585	5477	3350	8330	112
Se	0.63	30.3	2.9	5.2	4.6	11.3	68
Ag	0.23	2	0.33	0.47	0.55	1.1	18
Na	21.7	223	37	68	70	145	11
V	1.7	707	32	102	62	104	113
Zn	6	300	30	52	45	82.9	113
moisture	5.4	38.3	17.9	7.3	18.0	27.1	113

Using the 40.5 percent median and 69 percent maximum extraction efficiencies for arsenic in whole soil (table 18) an estimate of the total arsenic in the soil can be calculated. The

two highest leachable (“recoverable”) arsenic concentrations, 92.3 ppm (GLCM4003) and 90.0 ppm (BUAD4002), yield 228 ppm and 222 ppm total arsenic, respectively, using the 40.5 percent median extraction efficiency, and 134 ppm and 130 ppm total arsenic calculated using the 69 percent maximum extraction efficiency. The 130 ppm total arsenic lies outside the maximum arsenic concentration reported for soils from the United States and worldwide, although the concentration lies at the higher end for Late Cretaceous marine shales (Tourtelot, 1964). The calculated 130 ppm total arsenic agrees with the 131 ppm total arsenic determined for CAKR4003 (table 9).

According to Walsh and others (1977), the total arsenic concentration is 97 to 270 ppm for New Jersey soil repeatedly treated with arsenical pesticides or defoliant. Based on this investigation, the two soil samples with the highest leachable arsenic concentrations (92.3 and 90.0 ppm) can be inferred to represent the natural (lithogenic) total arsenic concentration for argillaceous (clayey) marine sediments, assuming that the maximum percent extraction efficiency provides a reasonable estimate of the total arsenic concentration. The results of this investigation do not support inferring a totally lithogenic source for the approximately 225 ppm total arsenic calculated from the median percent extraction efficiency.

Twenty three (20 percent) of the 113 soil samples have arsenic concentrations exceeding the 20 ppm Residential Direct Contact Soil Cleanup Criterion (RDCSCC). Of these 23, nine (39 percent) are from the Marlton soil series (GLMR5001 and 5003, GLMR6001, 6002 and 6003, MOMR1001 and 1002, MOMR2004, MOMR3003), seven (30 percent) samples from the Adelphia soil series (BUAD4002 and 4003, MOAD1001 and 1003, MOAD3001, 3002 and 3003), three (13 percent) from the Kresson soil series (MOKR1001 and 1002, MOKR2002), one (4 percent) each from the Colemantown (GLCM4003 — Colemantown-Matlock loam) and the Donlonton soil series (BUDO1003), and one each from the Collington (MOCL1002) and Freehold (MOFR1002) soil series. No exceedance of the arsenic criterion was found in the Colts Neck (6 samples from 2 stations), Holmdel (9 samples from 4 stations), Shrewsbury (10 samples

from 4 stations), and Tinton (6 samples from 2 stations) soil series.

The Adelphia soil series samples exceeding the RDCSCC are not from pristine soil profiles. At the sampling station for the BUAD4000 samples, a beer bottle shard and bituminous coal pieces were found approximately eight inches down in the soil. This is strong evidence for a disturbed soil. Soil samples from sampling stations MOAD1000 and MOAD3000 have been impacted by agriculture. MOAD1000 soil samples are from an actively cultivated field of row crops. MOAD3000 soil samples are from a wooded parcel bordering an actively cultivated field that is designated as Farm Land Preservation/Trust.

Six (26 percent) of the 23 soil samples with arsenic exceedance for the RDCSCC are samples from the 0- to 6-inch depth composites. These samples are from the Ap soil horizon. Four (17 percent) of the 23 samples (BUAD4002, GLMR6002, MOAD3002 and MOKR2002) are from the 12- to 18-inch depth which corresponds to the Bt soil horizon. Twelve (52 percent) of the samples are from the 24- to 30-inch depth which generally corresponds to the Bt2, B3 and C1 horizons. A sample of the Marlton soil series (MOMR2004) from 30- to 36-inches depth, corresponding to the lower Bt2 and upper Bt3 horizon, exceeds the RDCSCC for arsenic.

Gloucester County had 6 samples (26 percent) from three sampling stations and Monmouth County had 14 samples (61 percent) from nine stations in excess of the arsenic RDCSCC. Thirty-two percent (6 of 19 samples) and 33 percent (14 of 43 samples) from Gloucester and Monmouth Counties, respectively, exceed the arsenic criterion. Three (13 percent) of the 23 samples with RDCSCC exceedances for arsenic are from two sampling stations in Burlington County. There were 38 soil samples analyzed for arsenic from Burlington County. Three (8 percent) of these exceed the arsenic RDCSCC. No soil samples of the 13 samples from Camden County exceed the arsenic criterion.

The soil samples exceeding the RDCSCC for arsenic generally share some common

physical qualities. They tend to have high extractable iron concentrations. The strong positive linear correlation between total arsenic and iron concentrations is shown in figure 7. The Spearman rank-order correlation (table 25) is $r_s = 0.730$ ($p < 0.0000$) for arsenic versus iron for all 113 soil samples, which suggests that a moderately strong positive correlation is maintained when using the results for Methods 3050 and 6010A. The correlation between leachable arsenic and iron likely represents that portion of the iron occurring as: 1) secondary (rusty), amorphous $\pm$ crystalline iron oxyhydroxide coating on the constituent soil minerals, 2) iron solubilized from lattice sites in partially weathered primary minerals such as glauconite and biotite, and 3) iron-bearing, neoformed, authigenic, mainly amorphous to partly crystalline, aluminosilicates that result from the weathering of primary minerals in the soil.

These soils with greater than 20 ppm leachable arsenic are characterized by a brown (ferric iron) and/or pistachio green, soft, waxy to ooze-like, clay/silt matrix, which generally is associated with samples from the B and top of the C soil horizons. This iron-bearing, soft, waxy, clay/silt matrix likely is the neoformed, authigenic aluminosilicates previously mentioned. European investigators have noted this same matrix in the weathering profiles of glauconite-bearing soils. They refer to this clay/silt matrix as a *plasma*, which suggests that its character has not been defined. The plasma probably consists of a spectrum of mainly amorphous solid phases, solid phases transitional between noncrystalline and crystalline, and crystalline aluminosilicate minerals. The arsenic is chemisorbed by iron and aluminum oxides, noncrystalline aluminosilicates, and, to a lesser extent, phyllosilicates (McBride, 1994). The fine particle size (high surface-area-to-volume ratio) coupled with the amorphous to transitional crystalline phases are conducive to more effectively solubilizing the arsenic and iron (and aluminum) using the Method 3050 acid digestion. This soft, waxy, clay/silt matrix is common for the Adelphia, Colemantown, Kresson and Marlton soil series.

The Adelphia, Colemantown, Kresson and Marlton soil series tend to be poorly drained to waterlogged in areas with a high or perched water table. In soils that are poorly drained,

reducing (low redox potential) or anaerobic conditions become established. Under these reducing conditions the arsenic (arsenate $\{As^{+5}\}$ and arsenite $\{As^{+3}\}$) may be released into the soil solution by dissolution of iron (and manganese) oxides (McBride, 1994). The desorbed arsenate may reduce to arsenite, the more toxic arsenic specie, which may be converted to an essentially insoluble form such as a sulfide. The weak acidity of arsenite ($As(OH)_3$) causes adsorption on oxides and soils to be weaker than that for arsenate, a strong acid, when the pH is less than 7 (McBride, 1994). However, both arsenate and arsenite species are strongly retained by soils (Bohn and others, 1985). Furthermore, at pH less than 7 the thermodynamically stable species of arsenite is neutral (H_3AsO_3 , $pK_1 = 9.22$), whereas the arsenate species is anionic ($H_3AsO_4^-$, $pK_1 = 2.20$ or $H_2AsO_4^{2-}$, $pK_2 = 6.97$). Based on these considerations, the high 'recoverable' arsenic concentrations in the waterlogged glauconitic soils may in part be a function of arsenic speciation.

Repeated spraying with lead arsenate and copper acetate-arsenate ('Paris green') of apple orchards in Washington State resulted in soil arsenic concentrations that were harmful to the trees. Ceasing the application of these arsenical insecticides has resulted in decreased arsenic availability. This decrease is due to strong soil retention rather than to arsenic translocation (movement) thru the pedon (Bohn and others, 1985). Bohn and others (1985) state, "movement of arsenic through soils is minimal unless large quantities are concentrated in a small or unreactive soil volume, such as might be the case for industrial waste disposal on very coarse-textured soils", for example Collington and Freehold soil series.

Generally, the availability of toxic anions (As, Cr, Se, V) decreases somewhat with soil aluminum and iron oxyhydroxides, and increases somewhat with pH, as anion retention by soils decreases with pH increases (Bohn and others, 1985). Time decreases the availability of arsenic added to soils by permitting arsenic diffusion to the strongest sorptive sites, including arsenic incorporation into amorphous and crystalline solids. Leaching of arsenic from soils is generally negligible, because time leads to the aging of soil solids whereby the smaller and more reactive

phases redissolve to form larger and less reactive phases. Time is needed to permit the amorphous solid phases to crystallize into less reactive solid phases.

Based on these physiochemical considerations, the gradual liberation of arsenic accompanying the chemical weathering of iron-rich aluminosilicate minerals in aerobic, natural, glauconitic soil systems tends to result in low available arsenic. The Adelphia, Colemantown, Kresson and Marlton soil series have the highest glauconite concentrations in this study, tend to be poorly drained to waterlogged, and are characterized by the soft, waxy, brown and/or green, clay/silt matrix. These physical characteristics, in addition probably to a higher arsenite-to-arsenate ratio in these anaerobic sediments, lead to 'recoverable' arsenic concentrations that may exceed the 20 ppm RDCSCC for arsenic.

Beryllium

Beryllium concentrations range from 0.06 ppm (MOHN1002) to 4.3 ppm (MOKR1001) with a 0.49 ppm median and a 0.80 ± 0.88 ppm mean for the 113 soil samples (table 24). Eleven (10 percent) of the 113 samples have beryllium concentrations exceeding the 2 ppm RDCSCC. These exceedances occur in all the soil series except for the Collington (10 samples from 4 stations), Holmdel (9 samples from 4 stations), Shrewsbury (10 samples from 4 stations), and Tinton (6 samples from 2 stations).

For the 11 soil samples exceeding the RDCSCC two (18 percent) each are from the Adelphia (MOAD1001 and 1003), Colemantown (BUCM2002 and GLCM4003), and Kresson (MOKR1001 and 1002) soil series, and one (9 percent) each is from the Colts Neck (GLCN1003), Donlonton (BUDO1003), Freehold (GLFR4001), Marlton (MOMR3003), and Marlton and Kresson - urban land complex (CAMK1003) soil series.

Nine (82 percent) of the 11 samples exceeding the beryllium criterion are from disturbed sites. BUCM2002 is from a former 'marl' pit and consists of approximately 1 percent

muscovite/illite. Five samples (45 percent) are from actively cultivated fields (GLCN1003, GLFR4001, MOAD1001 and 1003, and MOMR3003). MOKR1001 and 1002 likely represent a disturbed soil. The site was cultivated from the mid 1800s through the early 1900s (Nelson “Joe” Tyberghein, park superintendent, oral communication, 1999) and is now a forested parcel with second growth cedar trees. Also the Lone Pine (former) Superfund site is upstream of this sampling station. Most other stations are being encroached upon by development, such as clearing of vegetation for dwellings, or directly border developed areas.

Three (27 percent) of the 11 samples with beryllium exceedances are in the 0- to 6-inch composites from the Ap soil horizon. One (9 percent) is from the 12- to 18-inch depth which corresponds to the B soil horizon. Seven (64 percent) are from the 24- to 30-inch depth which corresponds to the Bt2, B21t, B22, or lower B2g and upper C1 horizons.

Five (45 percent) of the 11 soil samples exceeding the beryllium criterion are from three sampling stations in Monmouth County. Five (12 percent) of the 43 total soil samples from Monmouth County exceed the beryllium RDCSCC. Gloucester County had three samples (27 percent) from three stations, Burlington County had two samples (18 percent) from two stations, and Camden County had one sample (9 percent) in excess of the beryllium RDCSCC. Sixteen percent (3 of 19 samples), 8 percent (1 of 13 samples) and 5 percent (2 of 38 samples) of the soil samples from Gloucester, Camden and Burlington Counties, respectively, exceed the beryllium criterion.

The chemistry of beryllium in soil systems has received little attention. Beryllium is widely distributed in trace concentrations in common rock-forming minerals. This wide distribution results from the substitution of beryllium for silicon in these minerals. Most of the beryllium in the world occurs in plagioclase feldspar and pyroxenes, which weather to clay (phyllosilicate) minerals, micas, and clays (Griffitts and Skilleter, 1991). Upon weathering practically all the beryllium in the original mineral is incorporated in clays. The small beryllium

concentration not incorporated in the clay minerals during rock weathering and pedogenesis is principally adsorbed on to the surfaces of mineral grains. Beryllium is strongly adsorbed by montmorillonitic soils and by bentonite (montmorillonite and bentonite are smectite-group minerals), but not by kaolinite. Magnesium, barium or calcium at high concentrations did not displace the beryllium sorbed to the montmorillonitic soil (Griffitts and Skilleter, 1991, citing Romney and Childress, 1965). The chemistry of beryllium in soil solution parallels that of Al^{+3} (McBride, 1994). Beryllium in soils exists in the +2 oxidation state only.

Soil samples exceeding the 2-ppm beryllium RDCSCC have high 'recoverable' aluminum and iron concentrations (table 23). These concentrations correspond to those soil samples that consist of the soft, waxy, brown and/or green, clay/silt matrix, that is Adelphia, Colemantown, Kresson and Marlton soil series. Solubilization or 'recovery' may be more efficient for aluminum and beryllium in this amorphous to poorly crystalline clay/silt matrix. Additionally, most soil samples having greater than or equal to 1 ppm beryllium contain traces to as much as 3 to 5 percent muscovite/illite in BUDO1003. Beryllium is probably a trace constituent in the muscovite/illite (micas).

Six (5 percent) of the 113 soil samples have RDCSCC exceedances for both arsenic and beryllium. Monmouth County has five samples (MOAD1001 and 1003, MOKR1001 and 1002, and MOMR3003) from three sampling stations, and Burlington County has one sample (BUDO1003). No RDCSCC exceedances for arsenic and beryllium occur in samples from Camden and Gloucester Counties. Twelve percent (5 of 43 samples) of all soil samples from Monmouth County, and 3 percent (1 of 38 samples) from Burlington County, exceed the criterion for arsenic and beryllium.

Exceedances of the RDCSCC for both arsenic and beryllium occur in soil series characterized by the soft, waxy, clay/silt matrix (Adelphia, Kresson and Marlton), and in a sample of the Donlonton (BUDO1003) that consists of approximately 85 to 90 percent silt and

clay with 3 to 5 percent muscovite/illite (appendix 2).

Other TAL Elements

The 39 ppm cadmium (Cd) RDCSCC is exceeded in approximately 1 percent (1 of 112) of the soil samples (BUDO1003 at 52.8 ppm). The incredibly high percent extraction efficiency for cadmium (table 18) suggests that cadmium concentrations may be more an artifact of the analytical protocol than the actual cadmium concentration for these soils. Cadmium concentrations from the EPA's prescribed analytical methods are extremely high, particularly for a partial acid leach, in comparison to total cadmium concentrations in soils, sediments and the Earth's crust (see table 2.1, p. 24 in Sparks, 1995). Therefore, exceedances of the cadmium RDCSCC are most suspect.

The 14 ppm antimony (Sb) RDCSCC is exceeded in two (2 percent) of the 99 samples with measurable antimony. GLCM4003 and MOMR3003 have 19.3 and 17.2 ppm antimony, respectively. Though MOMR3003 consists of 30- to 40-percent glauconite sand embedded in the soft, waxy, green, clay/silt matrix, the two antimony exceedances are high and suspect due to the incredibly high percent extraction efficiency (table 18) and comparatively high concentration of antimony relative to soils, sediments and the Earth's crust.

The 700 ppm barium RDCSCC is exceeded in one (0.9 percent) of the 113 samples. The 786 ppm barium for GLCN1003 is not unusual for a sample consisting of abundant mollusca debris (middens?). Also, the GLCN1000 sampling station directly borders an actively cultivated field of row crops.

The 400 ppm lead RDCSCC is exceeded in one (0.9 percent) of the 113 soil samples. MOFR1002, a sampling station on Monmouth County parkland, has 501 ppm lead and consists of moderately iron-stained clay/silt with aggregates of well-indurated ironstone.

The 370 ppm vanadium soil criterion is exceeded in two (1.8 percent) of the 113 soil samples. BUDO1003 and CAHN3003 have 707 and 636 ppm vanadium, respectively. BUDO1003 is very silty/clayey and is abundantly iron-stained. The CAHN3000 sampling station is a suburban site surrounded by housing developments and commercial parks.

For the six soil samples having exceedances of soil criterion for antimony, barium, lead or vanadium, MOFR1002 also exceeds the arsenic criterion, GLCN1003 and CAHN3003 exceed the beryllium criterion, and both arsenic and beryllium criteria are exceeded for BUDO1003, GLCM4003 and MOMR3003.

With the exception for arsenic and beryllium, these data reveal that the RDCSCC exceedances are not in the 0- to 6-inch composites, but rather occur at the 24- to 30-inch depth, that is, in the illuviated (B) horizon.

There are no RDCSCC exceedances for copper, nickel, selenium, silver, thallium or zinc.

A summary of the Spearman rank-order correlations for EPA Methods 3050 and 6010A on all soil samples is shown in table 25. The Spearman correlations for arsenic regressed against the other analytes provide rather weak relationships. The most robust Spearman correlation for arsenic is with antimony ($r_s = 0.737$, $p < 0.0000$). Antimony concentrations are suspect and therefore the relationship between arsenic and antimony is unclear. The Spearman correlation between arsenic and iron is positive and robust ($r_s = 0.730$, $p < 0.0000$), although the linear correlation coefficient ($r = 0.532$) is much less robust. Omitting those samples from known or suspected disturbed soils (BUAD4002, MOAD1001 and 1003, MOFR1002, MOMR1002), waterlogged samples (GLCM4003, MOCL1002, MOMR3003), and those below the minimum detection limit (BUSH1003, CAMK1001, MOTN1004) yields a 0.785 linear correlation coefficient and a Spearman correlation of 0.411 ($p < 0.0000$). The linear correlation between

Table 25. Summary of Spearman rank-order correlations for SW-846 Methods 3050 and 6010A for all soil samples. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V
Sb	0.617 <0.0000																			
As	0.537 <0.0000	0.737 <0.0000																		
Ba	0.430 <0.0000	0.199 0.0492	0.169 0.0750																	
Be	0.745 <0.0000	0.680 <0.0000	0.506 <0.0000	0.399 <0.0000																
B	0.707 <0.0000	0.753 <0.0000	0.379 0.0029	0.231 0.0691	0.799 <0.0000															
Cd	0.574 <0.0000	0.794 <0.0000	0.664 <0.0000	0.260 0.0061	0.769 <0.0000	0.601 <0.0000														
Ca	0.223 0.0282	0.104 0.3432	0.001 0.9894	0.684 <0.0000	0.342 0.0008	0.347 0.0133	0.166 0.1044													
Cr	0.692 <0.0000	0.855 <0.0000	0.660 <0.0000	0.137 0.1456	0.767 <0.0000	0.829 <0.0000	0.793 <0.0000	0.084 0.4063												
Co	0.749 <0.0000	0.602 <0.0000	0.429 <0.0000	0.478 <0.0000	0.806 <0.0000	0.650 <0.0000	0.719 <0.0000	0.322 0.0015	0.589 <0.0000											
Cu	0.079 0.4044	0.028 0.7807	0.256 0.0070	0.252 0.0076	-0.009 0.9230	-0.118 0.3546	0.063 0.5040	0.169 0.0961	-0.123 0.1913	0.083 0.3803										
Fe	0.704 <0.0000	0.832 <0.0000	0.730 <0.0000	0.224 0.0181	0.779 <0.0000	0.685 <0.0000	0.906 <0.0000	0.111 0.2749	0.870 <0.0000	0.693 <0.0000	-0.049 <0.0000									
Pb	0.107 0.2575	0.258 0.0108	0.370 0.0001	0.291 0.0020	0.128 0.1769	0.155 0.2236	0.179 0.0600	0.223 0.0282	0.038 0.6907	0.169 0.0737	0.744 <0.0000	0.116 0.2220								
Mg	0.817 <0.0000	0.710 <0.0000	0.584 <0.0000	0.441 <0.0000	0.804 <0.0000	0.898 <0.0000	0.717 <0.0000	0.377 0.0002	0.768 <0.0000	0.665 <0.0000	0.042 0.6566	0.736 <0.0000	0.147 0.1208							
Mn	0.161 0.0889	0.054 0.5958	0.108 0.2549	0.437 <0.0000	0.361 0.0001	0.108 0.3935	0.292 0.0021	0.487 <0.0000	0.024 0.8002	0.491 <0.0000	0.359 0.0001	0.177 0.0628	0.347 0.0002	0.237 0.01202						
Mo	0.327 0.0059	0.231 0.0690	0.423 0.0004	0.027 0.8178	0.274 0.0210	0.262 0.1106	0.351 0.0033	0.139 0.2712	0.404 0.0007	0.195 0.1000	0.049 0.6801	0.355 0.0030	-0.180 0.1290	0.481 <0.0000	-0.026 0.8297					
Ni	0.439 <0.0000	0.151 0.1442	0.041 0.6712	0.418 <0.0000	0.510 <0.0000	0.231 0.0756	0.327 0.0007	0.460 <0.0000	0.199 0.0386	0.655 <0.0000	0.015 0.8795	0.265 0.0060	0.164 0.0887	0.306 0.0015	0.432 <0.0000	-0.201 0.1004				
K	0.746 <0.0000	0.737 <0.0000	0.597 <0.0000	0.334 0.0004	0.722 <0.0000	0.973 <0.0000	0.660 <0.0000	0.302 0.0031	0.794 <0.0000	0.548 <0.0000	-0.041 0.6648	0.729 <0.0000	0.126 0.1827	0.939 <0.0000	0.099 0.2952	0.454 0.0001	0.235 0.0150			
Se	0.661 <0.0000	0.711 <0.0000	0.585 <0.0000	0.340 0.0054	0.712 <0.0000	0.596 0.0001	0.823 <0.0000	0.131 0.3229	0.738 <0.0000	0.618 <0.0000	0.024 0.8421	0.829 <0.0000	0.198 0.1053	0.694 <0.0000	0.238 0.0519	0.150 0.3438	0.177 0.1506	0.679 <0.0000		
V	0.646 <0.0000	0.659 <0.0000	0.665 <0.0000	0.043 0.6480	0.628 <0.0000	0.436 0.0006	0.736 <0.0000	-0.143 0.1590	0.772 <0.0000	0.599 <0.0000	-0.009 0.9282	0.774 <0.0000	0.122 0.1984	0.483 <0.0000	0.074 0.4306	0.144 0.2258	0.283 0.0032	0.471 <0.0000	0.655 <0.0000	
Zn	0.610 <0.0000	0.625 <0.0000	0.541 <0.0000	0.523 <0.0000	0.767 <0.0000	0.601 <0.0000	0.702 <0.0000	0.461 <0.0000	0.610 <0.0000	0.744 <0.0000	0.309 0.0010	0.673 <0.0000	0.489 <0.0000	0.694 <0.0000	0.528 <0.0000	0.148 0.2127	0.534 <0.0000	0.629 <0.0000	0.657 <0.0000	0.531 <0.0000

arsenic and iron for the filtered data is shown in figure 9. Greater variability in 'recoverable' arsenic is suggested by figure 9 at 'recoverable' iron concentrations greater than or equal to approximately 38,000 ppm. The regression line is: $\text{As (ppm)} = 3.3 \times 10^{-4} \text{Fe (ppm)} + 2.36$.

The Spearman correlation between arsenic and vanadium is 0.665 ($p < 0.0000$), whereas the linear regression coefficient is 0.423. This suggests a weak, positive correlation between arsenic and vanadium for the soils as a whole.

Note the near perfect absence of correlation ($r_s = 0.001$, $p = 0.9894$) between arsenic and calcium. Likewise, the linear regression coefficient ($r = 0.054$) shows virtually no correlation between arsenic and calcium. Moreover, the slope is negative for the linear regression. It might be inferred that a positive correlation between arsenic and calcium suggests that the soil has been amended with lime.

Beryllium, on the other hand, shows robust, positive Spearman correlations with aluminum ($r_s = 0.745$), boron ($r_s = 0.799$), chromium ($r_s = 0.769$), iron ($r_s = 0.779$), potassium ($r_s = 0.722$) and magnesium ($r_s = 0.804$) which are constituent elements in glauconite and other phyllosilicate minerals. Strong, positive linear correlation coefficients occur between beryllium and aluminum ($r = 0.745$), boron ($r = 0.762$), chromium ($r = 0.821$), iron ($r = 0.747$), potassium ($r = 0.796$) and magnesium ($r = 0.862$). Beryllium shows also a strong, positive Spearman correlation with cobalt ($r_s = 0.806$, $p < 0.0000$) and zinc ($r_s = 0.767$, $p < 0.0000$).

Spearman rank-order correlations for arsenic and beryllium regressed against soil pH, weight percent total organic carbon, and granulometric parameters for all soil samples are shown in table 26. There are no strong correlations among these parameters. Both arsenic and beryllium exhibit weak, negative Spearman correlations with percent quartz sand and weight percent total organic carbon. A weak, positive Spearman correlation occurs when arsenic and beryllium are regressed against percent glauconite sand and percent silt/clay. Arsenic shows a

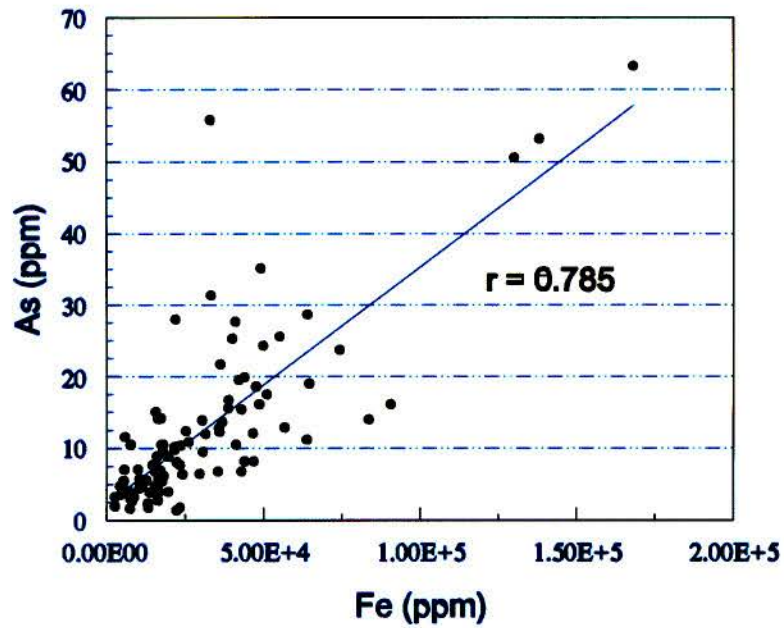


Figure 9. Linear relationship between iron and arsenic. Samples from disturbed sites, waterlogged sites, and those below the minimum detection limit are omitted.

very weak, negative Spearman correlation ($r_s = -0.100$, $p = 0.2909$) with pH, whereas beryllium has a weak, positive correlation ($r_s = 0.301$, $p = 0.0012$) with pH.

Table 26. Summary of Spearman rank-order correlations for SW-846 Methods 3050 and 6010A for all soils as a function of pH, weight percent total organic carbon (%TOC), weight percent moisture, and granulometric parameters. In each cell, top value is the correlation value and bottom is the probability.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V	Zn	
pH	0.156 0.0997	-0.147 0.1465	-0.100 0.2909	0.357 0.0002	0.301 0.0012	0.123 0.3383	0.130 0.1719	0.527 <0.0000	-0.064 0.4964	0.266 0.0049	0.020 0.8355	0.0001 0.9991	-0.047 0.6169	0.086 0.3618	0.527 <0.0000	0.011 0.9268	0.345 0.0003	0.008 0.9345	-0.018 0.8803	-0.053 0.5758	0.194 0.0397	pH
TOC	-0.074 0.4363	-0.059 0.5607	-0.061 0.5220	0.192 0.0420	-0.154 0.1027	-0.186 0.1444	-0.114 0.2334	0.093 0.3590	-0.095 0.3167	-0.118 0.2100	0.286 0.0025	-0.088 0.3536	0.274 0.0037	-0.067 0.4796	0.053 0.5717	0.003 0.9812	-0.051 0.5973	-0.056 0.5527	0.080 0.5131	-0.108 0.2536	0.099 0.2936	TOC
Moisture	0.452 <0.0000	0.539 <0.0000	0.434 <0.0000	0.386 <0.0000	0.443 <0.0000	0.503 0.0001	0.412 <0.0000	0.266 0.0088	0.507 <0.0000	0.386 <0.0000	0.250 0.0082	0.477 <0.0000	0.437 <0.0000	0.565 <0.0000	0.022 0.8180	0.107 0.3670	0.137 0.1548	0.531 <0.0000	0.420 0.0006	0.306 0.0012	0.472 <0.0000	Moisture
%glau sd	0.212 0.0248	0.337 0.0008	0.331 0.0005	0.099 0.2952	0.359 0.0001	0.379 0.0028	0.268 0.0047	0.163 0.1079	0.274 0.0038	0.302 0.0014	0.075 0.4253	0.277 0.0035	0.114 0.2256	0.420 <0.0000	0.258 0.0063	0.244 0.0399	0.061 0.5279	0.366 0.0001	0.172 0.1592	0.161 0.0878	0.292 0.0020	%glau sd
%qztz sd	-0.222 0.0186	-0.318 0.0017	-0.326 0.0006	-0.150 0.1129	-0.247 0.0088	-0.321 0.0114	-0.212 0.0255	-0.042 0.6765	-0.244 0.0098	-0.267 0.0047	-0.266 0.0048	-0.206 0.0296	-0.296 0.0017	-0.303 0.0014	-0.150 0.1112	-0.153 0.1968	-0.089 0.3546	-0.286 0.0026	-0.108 0.3769	-0.173 0.0673	-0.280 0.0031	%qztz sd
%slt-clay	0.162 0.0867	0.214 0.0345	0.275 0.0037	0.160 0.0902	0.135 0.1517	0.158 0.2130	0.135 0.1556	0.021 0.8351	0.143 0.1289	0.202 0.0329	0.352 0.0002	0.123 0.1934	0.357 0.0002	0.177 0.0611	0.120 0.2059	0.086 0.4705	0.105 0.2766	0.180 0.0579	0.061 0.6199	0.145 0.1239	0.231 0.0146	%slt-clay

Analyte Concentrations as a Function of Soil Depth

Statistical analysis of analyte concentrations for the surface soil composites, that is the A soil horizon, and for the 24- to 30-inch composites of the B horizon is shown in table 27. The median and mean pH is identical for both soil horizons. The surface soils have a median percent total organic carbon (%TOC) of 2.1 which sharply decreases to 0.3 percent in the B horizon.

The median (8.2 ppm) and mean (12.4 ± 12.6 ppm) arsenic concentration is lower in the surface soil than for the 24- to 30-inch interval with a 12.2 ppm median and 20.7 ± 23.0 ppm mean. The difference in arsenic concentration between the surface soil and that at depth is statistically insignificant. The high standard deviation for arsenic concentrations indicates its concentration varies considerably. The highest 'recoverable' arsenic concentration (92.3 ppm) is in a soil sample from the B horizon. The mean arsenic concentration (20.7 ppm) for the 24- to 30-inch soil composites exceeds the 20 ppm RDCSCC guideline. The increase in median and mean arsenic concentrations with soil depth corresponds to increases in median and mean 'recoverable' iron.

Median and mean 'recoverable' beryllium concentrations slightly increase with depth in the soil. The mean beryllium concentration (0.98 ppm) for the 24- to 30-inch soil composites is below the 2 ppm RDCSCC guideline. Maximum 'recoverable' beryllium concentration for the surface soil (4.3 ppm) and at the 24- to 30-inch depth (4.2 ppm) is virtually identical.

Table 27. Statistical summary of analyte concentrations, determined by SW846 Methods 3050 and 6010A, for whole-soil samples, discriminated by depth. Top value is the concentration for the surface (0- to 6-inches) soil composite and the bottom is the concentration in the deeper composites (>2.0 feet).

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	2.88	6.19	3.67	0.74	3.90	4.77	45
	3.05	6.94	3.68	0.76	3.91	4.60	45
%TOC	0.82	5.11	2.06	1.15	2.3	3.83	45
	0.06	2.55	0.30	0.36	0.36	0.48	45
Al	1450	21400	7490	4028	7388	10900	45
	1750	28400	6880	6232	9285	18100	45
Sb	0.82	13.2	2.1	2.5	2.9	4.7	40
	0.86	19.3	2.5	4.4	4.3	9.0	39
As	1.7	63.3	8.2	12.6	12.4	21.7	45
	1.8	92.3	12.2	23.0	20.7	53.2	44
Ba	3.7	278	24	42	34	52	45
	3.8	786	20	116	45	60.1	45
Be	0.08	4.3	0.45	0.84	0.73	1.1	45
	0.06	4.2	0.55	1.05	0.98	2.3	45
B	8	161	18	34	33	50.9	23
	8.1	219	28	45	46	79.9	29
Cd	0.42	19.1	2.0	4.0	3.5	5.7	44
	0.34	52.8	2.8	9.0	5.5	11.2	45
Ca	16.5	6860	275	1471	828	1810	40
	11.3	6770	290	1211	623	901	38
Cr	5.1	452	29	90	62	104	45
	4.6	749	45.3	182	112	292	45
Co	0.42	11.4	2.0	1.8	2.4	3.8	45
	0.49	73.6	2.5	11.8	5.5	6.2	45
Cu	1.5	30.6	5.7	4.7	6.5	9.5	45
	0.73	26.6	4.1	4.4	5.1	7.8	45
Fe	2580	210000	19450	41979	34101	50900	44
	2520	244000	29500	50385	44208	91800	45
Pb	2.8	91.1	20.7	24.1	26.9	60	45
	2.1	501	12.4	76	33.3	52.5	45
Mg	123	7430	910	1286	1250	2140	45
	129	9840	944	1894	1801	3930	45
Mn	3.1	388	34	72	61	128	45
	2	4860	36	743	203	184	45
Mo	0.13	2.2	0.4	0.4	0.5	1.0	31
	0.15	2.7	0.4	0.6	0.6	0.77	26
Ni	0.77	26.3	2.6	4.3	3.8	5.4	43
	0.43	36.6	2.9	6.2	4.9	6.9	43
K	162	23100	1370	4031	2632	5550	45
	126	43800	2210	7328	4538	9440	45
Se	0.64	12.7	2.8	3.0	3.8	6.1	24
	0.87	30.3	3.3	6.5	5.4	11.1	32
Ag	0.23	2	0.29	0.60	0.52	0.44	8
	0.23	1.2	0.42	0.36	0.57	1.1	10
Na	21.7	145	40	46	54	52.5	6
	NA	NA	NA	NA	NA	NA	NA
V	1.7	339	27	56	44	80.6	45
	7.5	707	33	147	86	198	45
Zn	6	261	33	45	42	65.7	45
	7.6	300	30	66	54	146	45
moisture	6.2	38.2	16.9	7.6	18.4	28.5	45
	5.8	35.7	20.1	7.0	18.7	26.1	45

All metal concentrations are in mg/kg (ppm).

pH is standard units.

%TOC is weight percent total organic carbon.

Moisture is reported as weight percentage.

Analyte Concentrations in the Individual Soil Series

The following section discusses the chemistry of analytes for each soil series, except for the Colts Neck, Donlonton and Tinton. Too few samples were collected for the Colts Neck, Donlonton and Tinton soil series to provide a meaningful statistical analysis.

Adelphia Soil Series

Ten soil samples from four sampling stations were analyzed according to U.S. EPA SW-846, Methods 3050 and 6010A. The statistical summary of the analyte concentrations is presented in table 28.

Soil pH for the samples ranges from 3.38 (MOAD3002) to 5.18 (MOAD1003) with a median pH of 3.45 and a 3.82 ± 0.69 mean. pH values exceeding 4.40 are extreme outliers which is defined by: $Q_{0.75} \pm 3.0(Q_{0.75} - Q_{0.25})$, where $Q_{0.25}$ and $Q_{0.75}$ are the first and third quartiles, respectively. The two extreme outliers, MOAD1001 (pH 5.02) and MOAD1003 (pH 5.18), are from a cultivated corn field that has been limed. Omitting the extreme outliers from the statistical calculation, which provides a measure of the pH in undisturbed Adelphia soil, yields a median pH of 3.42 with a 3.49 ± 0.16 mean. The two highest pHs correspond to the highest extractable calcium and aluminum concentrations.

Arsenic concentrations range from 8.9 ppm (BUAD2001) to 90 ppm (BUAD4002) with a median of 23.7 ppm and a mean of 27.7 ± 23.4 ppm. Arsenic concentration exceeding 79.3 ppm is an extreme outlier. Omitting the 90 ppm arsenic for BUAD4002 from the statistical calculation yields a 23.1 ppm median and a mean of 20.8 ± 8.7 ppm. Both the median and mean arsenic concentrations exceed the RDCSCC guideline. Based on the lithology and chemistry for BUAD4002 (12- to 18-inch depth), it is unclear why this sample has 90 ppm 'recoverable' arsenic. Arsenic concentration in the surface soil sample and the 24- to 30-inch depth composite at station BUAD4000 is 10.2 and 28 ppm, respectively (table 23). Arsenic for two samples from the 12- to 18-inch depth composite is highly enriched in BUAD4002 and slightly enriched in

Table 28. Statistical summary of analyte concentrations, determined by SW-846 Methods 3050 and 6010A, in the Adelphia soil series. All metal concentrations are in mg/kg (ppm). pH is standard units, and total organic carbon (TOC) and moisture (moist.) are expressed as weight percent.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	3.38	5.18	3.45	0.69	3.82	5.02	10
Al	4250	23200	6565	6256	8886	16900	10
Sb	1.4	13.2	2.3	4.1	4.4	9.0	9
As	8.9	90	23.7	23.4	27.7	32.4	10
Ba	8.4	154	17.3	45.7	36.6	74.8	10
Be	0.09	3.5	0.52	1.28	1.00	3.3	10
B	8.1	39	17.3	12.1	21.4	34.8	8
Cd	1.0	22.1	3.8	7.8	7.4	19.1	10
Ca	11.3	3220	80.4	1076	591	1810	10
Cr	9.8	404	35.5	146	106	354	10
Co	0.78	32.4	2.1	9.9	5.8	11.4	10
Cu	1.9	11.1	5.1	3.0	5.8	9.5	10
Fe	17300	244000	29750	84623	68410	210000	10
Pb	3.7	78.2	20.5	26.9	31.1	63.3	10
Mg	313	4140	1170	1149	1357	2230	10
Mn	4	756	39.6	243	147	388	10
Mo	0.15	1.2	0.66	0.35	0.64	0.72	6
Ni	0.33	36.6	1.7	13.6	8.0	26.3	9
K	231	5970	1690	1973	2528	5550	10
Se	1.7	14.3	2.3	5.0	4.6	5.3	6
V	14.6	349	65.9	127	116	339	10
Zn	11.7	300	42.1	106	81.8	261	10
%TOC	0.21	2.64	0.47	0.94	1.06	2.17	10
%moist.	13.1	31.8	15.1	5.7	17.5	21.9	10

MOAD3002, although the arsenic for MOAD3002 is qualified because of the presence of interference (table 23). These two samples are from the Bt soil horizon, which is the zone of silicate clay accumulation (Jablonski and Baumley, 1989).

Recoverable beryllium ranges from 0.09 ppm (BUAD4002) to 3.5 ppm (MOAD1001) with a 0.52 ppm median and a mean of 1.0 ± 1.3 ppm. For this soil series, BUAD4002 has the lowest extractable beryllium and highest arsenic concentrations. Beryllium concentrations exceeding 1.82 ppm are extreme outliers. Omitting the two (qualified) extreme outliers for beryllium, MOAD1001 (3.5 ppm) and MOAD1003 (3.3 ppm), yields a 0.41 ppm median and a 0.40 ± 0.22 ppm mean. These beryllium concentrations are well below the RDCSCC guideline.

To assess how select analyte concentrations in the Adelphia soil series compare with all the glauconite-bearing soils from this study, the median and mean concentrations for the Adelphia soils are divided by those for the entire data set. The results are shown graphically in figure 10. The median and arithmetic mean arsenic concentration for the Adelphia soil series

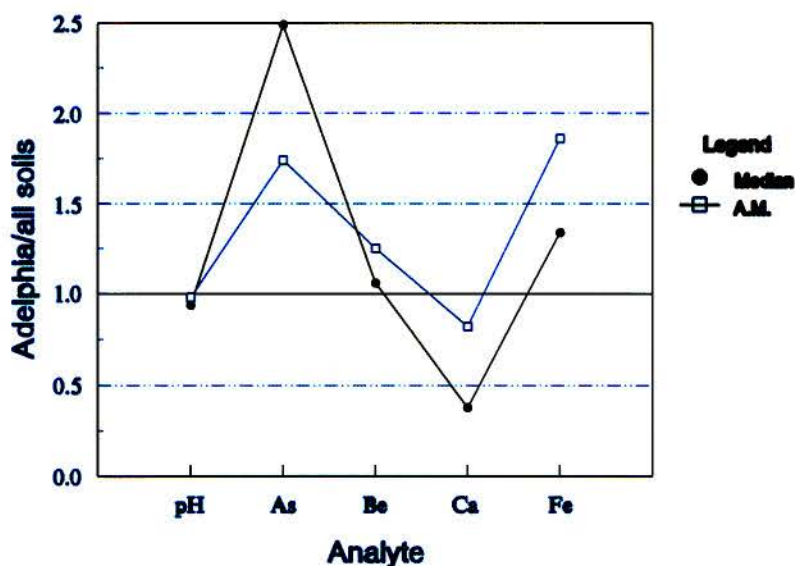


Figure 10. Ratio of median and mean analyte concentrations in the Adelphia soil series to those for the entire dataset. A.M. is the ratio of means.

are 2.5 and 1.7 times, respectively, that for the entire data set. The median beryllium concentration for the Adelphia soil mirrors that for the entire data set, and the mean is 25 percent more than the mean for all the soils. Median and mean soluble iron in the Adelphia soil is enriched compared to the entire data set.

The mean percent extraction efficiency for arsenic in four Adelphia soil samples from two sample stations is 47 ± 10 percent compared to 39 ± 18 percent for all 14 soil samples (table 18). The mean percent extraction efficiency for iron in the four samples is 35 ± 21 percent compared to 30 ± 21 percent for the 14 soil samples. The comparatively higher mean extraction efficiency for iron in Adelphia soil series may account in part for the correspondingly high percent extraction efficiency for arsenic. The mean percent extraction efficiency for beryllium in the four soil samples is 15 ± 5 percent compared to 16 ± 11 percent for all 14 samples. Mean percent extraction efficiency for aluminum (16 ± 7 percent) and potassium (7 ± 5 percent) in the Adelphia soil series is less than that for all 14 soil samples (20 ± 16 percent and 15 ± 19 percent, respectively). It might be inferred that most of the leachable arsenic is associated with the iron fraction that is solubilized using the Method 3050 acid digest.

A statistical summary of select analyte concentrations in the 0- to 6-inch and 24- to 30-inch depth composites for the Adelphia soil series is shown in table 29. For these composited depth intervals, the highest 'recoverable' arsenic (32.4 ppm) and beryllium (3.5 ppm) concentrations are in the surface soil (MOAD1001). The median and mean arsenic concentration increases with increasing depth in the soil. The median and mean background arsenic concentration for the 24- to 30-inch depth composites exceeds the RDCSCC guideline. On the other hand, the median and mean beryllium concentration decreases with increasing depth in the soil, even when the extreme outliers (MOAD1001 and 1003) are omitted.

'Recoverable' iron and potassium concentrations increase with increasing depth in the soil. The 'recoverable' aluminum appears to decrease with increasing depth in the soil. Perhaps

the higher 'recoverable' aluminum concentration in the top six inches of soil reflects a lower crystallinity or incongruent dissolution for aluminosilicate minerals caused by chemical weathering. The weathering of aluminosilicate minerals in the surface soil likely contributes to the translocation of iron and potassium into the B horizon, thereby resulting in the higher 'recoverable' concentration for these elements in the 24- to 30-inch composites

Lead is strongly enriched in the surface soil relative to the 24- to 30-inch composites. Lead strongly correlates (Spearman rank-order correlation $r = 0.867$, $p = 0.0093$) with percent total organic carbon. Lead is known to strongly complex with sulfhydryl (-SH) groups in organic matter (McBride, 1994).

Table 29. Statistical summary of analyte concentrations as a function of depth for the Adelphia soil series. Top value is the 0- to 6-inch composite and the bottom value is the 24- to 30-inch composite. Concentrations omitting the extreme outliers shown in parentheses ().

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	4270	16900 (6440)	6225 (6010)	5741 (1149)	8405 (5573)	6440 (6010)	4 (3)
	4250	23200 (6880)	5825 (4770)	9022 (1393)	9775 (5300)	6880 (4770)	4 (3)
As	8.9	32.4	16.0	11.0	18.3	21.7	4
	10.5	28.0	23.7	7.6	21.5	24.3	4
Be	0.22	3.5 (0.62)	0.59 (0.55)	1.53 (0.21)	1.22 (0.46)	0.62 (0.55)	4 (3)
	0.21	3.3 (0.49)	0.41 (0.32)	1.48 (0.14)	1.08 (0.34)	0.49 (0.32)	4 (3)
B	13.1	34.8	13.2	12.5	20.4	13.2	3
	8.1	39.0	15.9	14.1	19.7	21.3	4
Fe	19300	210000 (36100)	28800 (21500)	92484 (9130)	71725 (25633)	36100 (21500)	4 (3)
	17300	244000 (49800)	35800 (21800)	108143 (17609)	83225 (29633)	49800 (21800)	4 (3)
Pb	29.6	78.2	55.9	20.8	54.9	63.3	4
	3.7	49.8	8.8	21.5	17.8	10.4	4
K	231	5550	1675	2283	2283	1750	4
	1250	5970	2120	2148	2865	2610	4

The 'recoverable' analyte concentrations for station MOAD1000 lie within the range for mild and extreme outliers. Analyte concentrations for MOAD1001 and 1003 are mild or extreme

outliers for all elements in table 28 except for arsenic, boron, copper, lead, magnesium (MOAD1003 is the exception) and selenium.

Before discussing Spearman rank-order correlations among the various soil parameters, it is important to understand the following general concept. Though the Spearman rank-order correlation data suggest moderate to strong relation among the various analytes, special care must be exercised in evaluating the significance of the relationship. A robust correlation between analytes does not necessarily imply a causal relationship. This is due in part to the small sample size used to calculate the regression. This is true with each individual soil series.

Spearman rank-order (SRO) correlations for the metals regressed against pH, weight percent total organic carbon, weight percent moisture, and percent glauconite sand, quartz sand and silt/clay are summarized in table 30. The SRO correlation for percent total organic carbon with copper and lead is consistent with the complexation of these metals with organic matter. Organically complexed copper is bound more tightly than any other divalent transition metal (McBride, 1994). Copper tends to complex with sulfhydryl, amine and polyphenol functional groups in the soil organic matter. Like lead, copper is enriched in the A/O horizons relative to the deeper soil horizons.

Arsenic exhibits very weak, negative SRO correlations with the various parameters in table 30, except for percent quartz sand which is an extremely weak, positive correlation. Figure 11 shows arsenic plotted against percent glauconite sand in Adelphia soil series. A plot of arsenic versus the sum of glauconite sand, silt/clay and muscovite percentage shows the same relationship as figure 11. Based on this figure, the arsenic concentration is not a direct function of the percent glauconite sand or the sum of glauconite sand, silt/clay and muscovite percentage in the Adelphia soil series.

Beryllium has a very strongly negative SRO correlation with percent quartz sand, and a

very strong positive correlation with percent silt/clay. Beryllium's strong, positive SRO correlation with percent silt/clay suggests that most beryllium is in this size fraction. Potassium correlated with percent quartz sand shows a similar extremely strong negative SRO correlation. Because potassium and beryllium are constituent elements in phyllosilicates, as quartz sand content decreases the clay ($\pm$ silt) fraction correspondingly increases, thereby yielding the negative correlation.

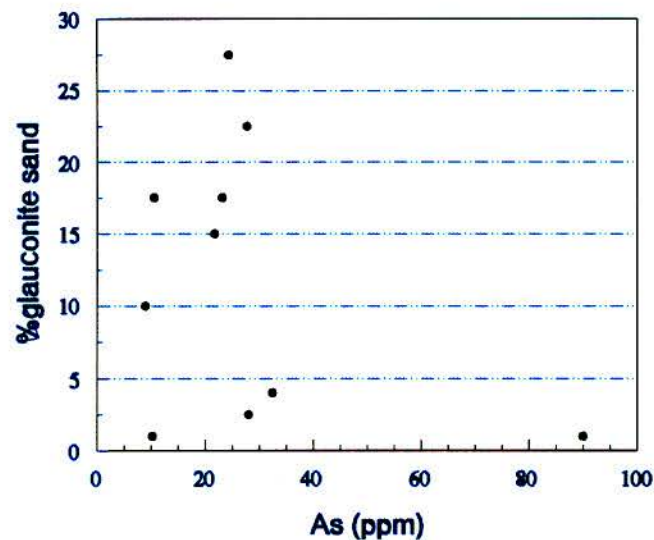


Figure 11. Arsenic concentration versus percent glauconite sand for the Adelphia soil series.

Table 30. Summary of Spearman rank-order correlation for EPA SW-846 Methods 3050 and 6010A for the Adelphia soil series as a function of pH, weight percent total organic carbon (%TOC), weight percent moisture, and granulometric parameters. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V	Zn	
pH	0.297 0.3730	0.583 0.0990	-0.103 0.7573	0.503 0.1313	0.345 0.3000	0.476 0.2077	0.467 0.1615	0.624 0.0611	0.285 0.3928	0.450 0.1772	0.418 0.2096	0.442 0.1844	0.491 0.1408	0.285 0.3928	0.612 0.0663	-0.543 0.2248	0.733 0.0381	0.297 0.3730	-0.395 0.3775	0.345 0.3000	0.564 0.0909	pH
TOC	0.030 0.9276	-0.083 0.8137	-0.321 0.3352	0.358 0.2834	0.139 0.6758	0.357 0.3447	0.188 0.5730	0.661 0.0475	-0.224 0.5011	0.286 0.3914	0.903 0.0067	0.030 0.9276	0.867 0.0093	-0.103 0.7573	0.430 0.1967	0.314 0.4822	0.400 0.2579	-0.224 0.5011	-0.273 0.5412	-0.152 0.6494	0.479 0.1509	TOC
Moisture	0.511 0.1255	0.367 0.3000	-0.049 0.8840	0.650 0.0510	0.766 0.0216	0.619 0.1015	0.571 0.0865	0.729 0.0286	0.498 0.1348	0.671 0.0442	0.541 0.1046	0.456 0.1714	0.602 0.0710	0.571 0.0865	0.723 0.0300	0.200 0.6547	0.828 0.0191	0.559 0.0934	-0.030 0.9459	0.511 0.1255	0.620 0.0629	Moisture
%glau sd	0.354 0.2887	0.234 0.5075	-0.152 0.6474	-0.116 0.7282	0.500 0.1336	0.359 0.3418	0.518 0.1200	<0.001 1.0000	0.463 0.1644	0.453 0.1745	-0.226 0.4985	0.354 0.2887	-0.506 0.1289	0.640 0.0548	0.256 0.4423	0.714 0.1102	-0.076 0.8306	0.701 0.0354	0.759 0.0900	0.079 0.8120	0.146 0.6606	%glau sd
%qtz sd	-0.636 0.0563	-0.383 0.2783	0.030 0.9276	-0.455 0.1727	-0.891 0.0075	-0.833 0.0275	-0.818 0.0141	-0.576 0.0841	-0.770 0.0209	-0.869 0.0091	-0.285 0.3928	-0.685 0.0399	-0.164 0.6235	-0.818 0.0141	-0.794 0.0172	-0.943 0.0350	-0.667 0.0593	-0.915 0.0060	-0.759 0.0900	-0.455 0.1727	-0.612 0.0663	%qtz sd
%slt-cly	0.406 0.2230	0.221 0.5313	-0.105 0.7536	0.775 0.0200	0.819 0.0140	0.627 0.0974	0.665 0.0461	0.628 0.0597	0.579 0.0826	0.750 0.0244	0.339 0.3099	0.437 0.1899	0.339 0.3099	0.609 0.0676	0.788 0.0181	0.500 0.2633	0.773 0.0288	0.726 0.0294	0.094 0.8339	0.406 0.2230	0.615 0.0648	%slt-cly

Table 31 is a Spearman rank-order correlation table for the analytes. There is significant, strong, positive correlation among aluminum, boron, beryllium, chromium, iron, magnesium and potassium. These are constituent elements in phyllosilicate, including glauconite minerals. Beryllium's strong, positive correlation with constituent elements in phyllosilicate minerals suggests that it is a constituent element in these minerals. Cobalt appears to correlate in a positive manner with the constituent elements for the phyllosilicate minerals. Arsenic does not exhibit a statistically significant correlation with any of the analytes. The 0.941 SRO correlation between arsenic and selenium is based on six points only, half of which are tightly clustered around 10 ppm arsenic.

Table 31. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A analytes for the Adelphia soil series. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V
Sb	0.800 0.0237																			
As	0.503 0.1313	0.550 0.1198																		
Ba	0.176 0.5980	0.167 0.6374	-0.309 0.3538																	
Be	0.697 0.0365	0.617 0.0811	-0.042 0.8987	0.552 0.0980																
B	0.976 0.0098	0.786 0.0376	0.310 0.4128	0.476 0.2077	0.905 0.0167															
Cd	0.794 0.0172	0.717 0.0427	0.018 0.9565	0.515 0.1222	0.891 0.0075	1.000 0.0082														
Ca	0.539 0.1056	0.400 0.2579	-0.224 0.5011	0.770 0.0209	0.721 0.0305	0.810 0.0322	0.794 0.0172													
Cr	0.879 0.0083	0.733 0.0381	0.576 0.0841	0.164 0.6235	0.733 0.0278	0.881 0.0198	0.745 0.0253	0.370 0.2674												
Co	0.754 0.0237	0.577 0.1024	-0.024 0.9418	0.590 0.0769	0.912 0.0062	0.958 0.0112	0.979 0.0033	0.845 0.0112	0.723 0.0300											
Cu	0.188 0.5730	-0.033 0.9249	-0.358 0.2834	0.515 0.1222	0.455 0.1727	0.476 0.2077	0.491 0.1408	0.830 0.0127	0.030 0.9276	0.578 0.0832										
Fe	0.939 0.0048	0.767 0.0301	0.515 0.1222	0.176 0.5980	0.648 0.0517	0.905 0.0167	0.806 0.0156	0.539 0.1056	0.915 0.0060	0.778 0.0196	0.224 0.501									
Pb	0.127 0.7026	-0.083 0.8137	-0.236 0.4783	0.588 0.0778	0.236 0.4783	0.405 0.2842	0.285 0.3928	0.770 0.0209	-0.042 0.8987	0.407 0.2217	0.867 0.0093	0.188 0.5730								
Mg	0.855 0.0104	0.817 0.0209	0.152 0.6494	0.321 0.3352	0.891 0.0075	0.976 0.0098	0.855 0.0104	0.539 0.1056	0.818 0.0141	0.815 0.0145	0.139 0.6758	0.758 0.0230	-0.042 0.8987							
Mn	0.564 0.0909	0.417 0.2386	-0.176 0.5980	0.721 0.0305	0.830 0.0127	0.929 0.0140	0.891 0.0075	0.915 0.0060	0.564 0.0909	0.942 0.0047	0.721 0.0305	0.648 0.0517	0.612 0.0663	0.624 0.0611						
Mo	0.771 0.0845	0.143 0.7494	0.086 0.8480	0.086 0.8480	0.829 0.0639	0.886 0.0476	0.886 0.0476	0.543 0.2248	0.771 0.0845	0.928 0.0381	0.429 0.3379	0.600 0.1797	-0.029 0.9491	0.714 0.1102	0.886 0.0476					
Ni	0.500 0.1573	0.452 0.2314	-0.100 0.7773	0.783 0.0267	0.717 0.0427	0.821 0.0442	0.800 0.0237	0.967 0.0063	0.450 0.2031	0.862 0.0148	0.733 0.0381	0.600 0.0897	0.733 0.0381	0.533 0.1314	0.967 0.0063	0.600 0.2301				
K	0.794 0.0172	0.700 0.0477	0.188 0.5730	0.345 0.3000	0.891 0.0075	0.976 0.0098	0.855 0.0104	0.479 0.1509	0.891 0.0075	0.833 0.0125	0.079 0.8132	0.782 0.0190	-0.079 0.8132	0.952 0.0043	0.673 0.0436	0.943 0.0350	0.533 0.1314			
Se	0.941 0.0353	0.516 0.2485	0.941 0.0353	-0.759 0.0897	0.698 0.1184	0.975 0.0513	0.941 0.0353	-0.213 0.6347	0.941 0.0353	0.832 0.0629	-0.213 0.6347	0.880 0.0490	-0.213 0.6347	0.820 0.0668	0.334 0.4552	0.872 0.0811	0.030 0.9459	0.941 0.0353		
V	0.842 0.0115	0.750 0.0339	0.697 0.0365	0.152 0.6494	0.479 0.1509	0.762 0.0438	0.564 0.0909	0.358 0.2834	0.842 0.0115	0.529 0.1126	0.030 0.9276	0.855 0.0104	0.139 0.6758	0.588 0.0778	0.430 0.1967	0.314 0.4822	0.517 0.1439	0.612 0.0063	0.941 0.0353	
Zn	0.661 0.0475	0.533 0.1314	-0.055 0.8700	0.685 0.0399	0.745 0.0253	0.976 0.0098	0.903 0.0067	0.939 0.0048	0.527 0.1137	0.912 0.0062	0.721 0.0305	0.685 0.0399	0.612 0.0663	0.612 0.0663	0.927 0.0054	0.943 0.0350	0.950 0.0072	0.588 0.0778	0.334 0.4552	0.515 0.1222

Colemantown Soil Series

Thirteen soil samples from five sampling stations were analyzed according to U. S. EPA SW-846, Methods 3050 and 6010A. The statistical summary of the analyte concentrations is presented in table 32.

Soil pH for the samples ranges from 3.05 (BUCM5003) to 6.14 (GLCM3003) with a median pH of 4.66 and a 4.46 ± 1.13 mean. The Colemantown series soil has the highest median and mean pH of all the soil series (fig. 12). In contrast to the Adelphia series, where high pH corresponds to high leachable calcium concentrations, the relation between pH and calcium is less clear for the Colemantown series samples. Station BUCM2000 samples are from a reclaimed former marl pit. By definition, marl is significantly calcareous. Calcium concentrations and pH for the BUCM2000 samples range from 499 to 6,860 ppm and approximately 5.0 to 6.0, respectively. The highest pH, 6.14 for GLCM3003, corresponds to less than the 3.7 ppm MDL for calcium. Evidence was not apparent that this site had been previously disturbed.

With the exception for station BUCM2000 samples, Colemantown soil series is waterlogged generally eight inches below grade. The soil profile is slightly moist down to the three-foot total depth at station BUCM2000.

Arsenic concentrations range from 1.8 ppm (BUCM2004) to 92.3 ppm (GLCM4003) with a 7.7 ppm median and a mean of 15.3 ± 23.6 ppm. An arsenic concentration exceeding 38.2 ppm is an extreme outlier. Omitting the 92.3 ppm arsenic for GLCM4003 from the statistical calculation yields a 7.3 ppm median and a mean of 8.9 ± 5.0 ppm. Only one of the thirteen samples exceeds the RDCSCC guideline for arsenic. As shown in figure 12, the mean arsenic concentration is nearly a factor of two less than that for the entire data set. The median arsenic concentration is approximately 1.3 times less than that for the entire data set. Median soluble iron in the Colemantown soil is nearly identical to that for the entire data set. The mean soluble

Table 32. Statistical summary of analyte concentrations, determined by SW-846 Methods 3050 and 6010A, in the Colemantown soil series. All metal concentrations are in mg/kg (ppm). pH is standard units, and total organic carbon (TOC) and moisture (moist.) are expressed as weight percent.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	3.05	6.14	4.66	1.13	4.46	5.62	13
Al	3170	20700	6810	4581	7416	8760	13
Sb	0.86	19.3	2.45	5.0	3.6	3.1	12
As	1.8	92.3	7.7	23.6	15.3	15.6	13
Ba	4.1	168	22.1	47.5	39.6	67.9	13
Be	0.08	3.4	0.45	0.98	0.80	1.6	13
B	8.0	93.7	20.5	28.4	28.1	38.7	8
Cd	0.6	10.9	2.8	2.7	3.0	3.5	13
Ca	13.1	6860	274	3025	2282	5780	8
Cr	6	749	49.3	197	102	82	13
Co	0.42	5.5	2.0	1.5	2.2	3.1	13
Cu	0.73	30.6	3.9	7.7	6.0	6.8	13
Fe	4200	91800	23200	23452	29598	38600	13
Pb	2.1	63.9	8.4	20.7	18.1	29.2	13
Mg	229	4510	818	1285	1284	1970	13
Mn	2	105	16.7	32.9	32.1	65.7	13
Mo	0.13	0.7	0.39	0.2	0.41	0.68	8
Ni	0.24	7.1	3.2	2.5	3.6	6.5	12
K	251	17100	1280	4597	3111	4530	13
Se	1.4	11.1	1.8	4.1	3.9	3.5	5
V	8.2	279	25.2	71.8	47.9	38.4	13
Zn	7.6	183	26.8	49.1	43.5	82.9	13
%TOC	0.25	5.11	0.47	1.83	1.61	3.1	13
%moist.	9.6	38.3	22.7	8.3	21.8	27.7	13

iron is a factor of 1.25 less than for the entire data set.

Waterlogged soils have low redox potential, or in other words are reducing environments (McBride, 1994; Sparks, 1995). Arsenite (As^{+3}) is the thermodynamically stable arsenic species in suitably reducing, acidic environments (Korte and Fernando, 1991). Compared to arsenate (As^{+5}), arsenite demonstrates greater solubility and mobility in both sediment and ground-water systems (Korte and Fernando, 1991). The greater mobility of arsenite under reducing conditions in acidic to neutral sediments may reflect conditions favorable to reduction of both iron and manganese (hydr)oxide sorbents. Furthermore, the stable arsenite species under these conditions is electroneutral (H_3AsO_3 , $\text{pK}_1 = 9.22$), and therefore does not have a high affinity for the charge developed at mineral surfaces. It is postulated that the labile arsenic in this soil series is predominantly the arsenite species which gradually leaches into ground water or becomes incorporated via substitution into phyllosilicate lattices and/or crystalline iron (hydr)oxide minerals. This should account for the relatively low 'recoverable' arsenic concentration for this glauconitic and clayey/silty soil series. Recoverable beryllium ranges from 0.08 ppm (MOCM1001) to 3.4 ppm (GLCM4003) with a 0.45 ppm median and a mean of 0.80 ± 0.98 ppm. The median and mean beryllium concentrations are below the RDCSCC guideline. Beryllium concentrations exceeding 1.98 ppm are extreme outliers. Omitting the two extreme

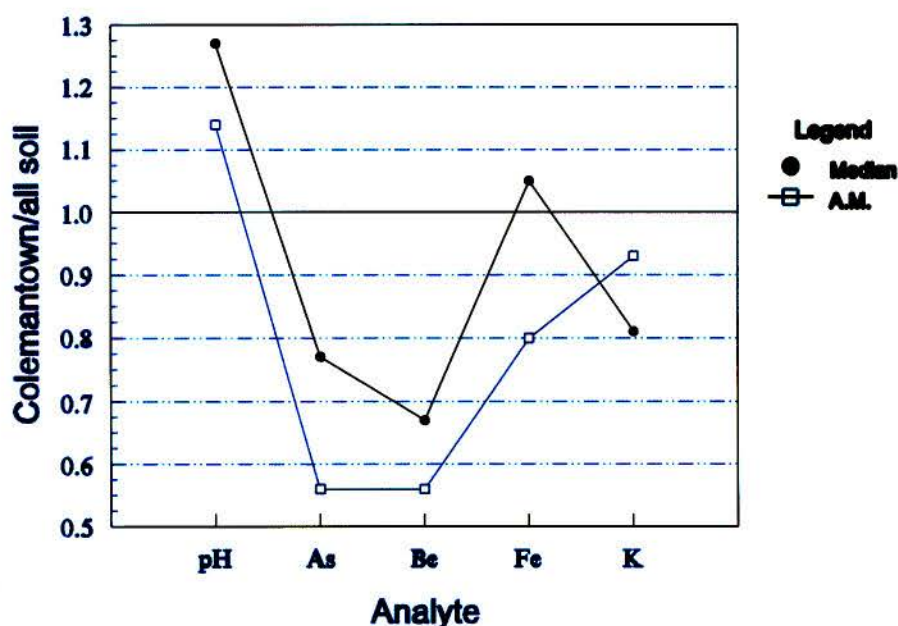


Figure 12. Ratio of median and mean analyte concentrations in the Colemantown soil series to those for the entire data set. A.M. is the ratio of means.

outliers for beryllium, BUCM2002 (a qualified 2.1 ppm) and GLKCM4003 (3.4 ppm), yields a median concentration of 0.33 ppm and a mean of 0.45 ± 0.42 ppm. Figure 12 shows the median and mean beryllium concentrations to be approximately 1.5 and 2 times, respectively, less than that for the entire data set.

Two samples (BUCM2001 and 2003) from one sample station were submitted for percent extraction efficiency analysis. The percent extraction efficiencies for aluminum, arsenic, beryllium, iron, lead and potassium are among the lowest for the 14 samples subjected to this analysis. The exception is the 280 percent extraction efficiency for lead in BUCM2003, which is

the highest extraction efficiency for the sample set (table 18). With the exception for lead, the surface soil sample has considerably higher percent extraction efficiencies than the deep sample. The percent extraction efficiency for arsenic is 53 and 28 for the surface soil sample and deep sample, respectively. The mean percent extraction efficiency for arsenic is 40.5 which is comparable to the 39 ± 18 for all 14 samples. Mean percent extraction efficiency for aluminum, beryllium, iron and potassium is 10, 4, 7.5 and 1.6, respectively. The 7.5 percent mean extraction efficiency for iron is 75 percent less than that for the 14 soil samples. This low percent extraction efficiency for iron lends support to the postulation that reducing condition convert the ferric iron (Fe^{+3}) to ferrous iron (Fe^{+2}) which is the more soluble iron species. The soluble ferrous iron too may gradually leach into the ground water thereby producing low 'recoverable' iron concentrations and percent extraction efficiencies relative to its high concentration of glauconite.

The statistical summary of analyte concentrations as a function of depth is shown in table 33. The median and mean concentrations for aluminum, arsenic, beryllium and lead are higher in the 0- to 6-inch composites in comparison to the 24- to 30-inch composites, excluding the outlier. In contrast to the Adelphia soil series, the highest 'recoverable' arsenic (92.3 ppm) and beryllium (3.4 ppm) concentrations are in the 24- to 30-inch composite (GLCM4003).

Spearman rank-order (SRO) correlations for the metals regressed against pH, weight percent total organic carbon, weight percent moisture, and percent glauconite sand, quartz sand and silt/clay are summarized in table 34. No significant SRO correlation was found among the analytes regressed against pH, total organic carbon, moisture, glauconite or quartz sand, and silt/clay. The SRO correlation between arsenic and percent glauconite sand is -0.612 ($p = 0.0340$). The simple linear regression correlation coefficient is -0.239 for arsenic regressed against percent glauconite sand. Arsenic plotted as a function of percent glauconite sand is shown in figure 13. The correlation between arsenic and percent glauconite sand remains negative, that is arsenic concentration increases with decreasing glauconite sand content, even

when the 92.3 ppm arsenic outlier for GLCM4003 is omitted.

Table 33. Statistical summary of analyte concentrations (in ppm) as a function of depth for the Colemantown soil series. Top value is the 0- to 6-inch composite and the bottom value is 24- to 30-inch composite. Concentrations omitting the extreme outliers are shown in parentheses ().

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	3170	11200	7150	2862	7104	7490	5
	3360	20700 (7340)	4990 (4560)	7198 (1724)	8104 (4955)	7340 (4990)	5 (4)
As	4.8	17.5	10.5	5.0	10.8	13.7	5
	3.6	92.3 (12.8)	6.8 (6.2)	38.2 (4.0)	24.2 (7.2)	12.8 (6.8)	5 (4)
Be	0.08	0.63	0.51	0.22	0.45	0.57	5
	0.18	3.4 (0.33)	0.26 (0.22)	1.42 (0.07)	0.87 (0.24)	0.33 (0.26)	5 (4)
Fe	4200	50900	23200	17899	26580	36700	5
	4380	91800	17600	34764	32956	35700	5
Pb	5.9	60	10.8	22.6	23.0	29.2	5
	2.1	63.9 (20.3)	8.4 (7.7)	25.3 (7.7)	20.3 (9.5)	20.3 (8.4)	5 (4)
K	417	2140	1110	638	1150	1250	5
	251	17100 (2760)	1280 (956)	7161 (1105)	4404 (1231)	2760 (1280)	5 (4)

Table 34. Summary of Spearman rank-order correlation for U.S. EPA SW-846 Methods 3050 and 6010A analytes for the Colemantown soil series as a function of pH, total organic carbon (%TOC), weight percent moisture, and granulometric parameters. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V	Zn	
pH	0.154	-0.172	-0.360	0.560	0.314	0.262	-0.088	0.714	-0.137	0.341	0.360	-0.324	0.099	0.192	0.714	-0.238	0.354	-0.165	-0.100	-0.148	0.560	pH
TOC	0.5941	0.5692	0.2119	0.0522	0.2773	0.4884	0.7604	0.0588	0.6342	0.2380	0.2119	0.2614	0.7319	0.5053	0.0133	0.5287	0.2398	0.5680	0.8415	0.6073	0.0522	TOC
	0.069	0.018	-0.018	0.256	0.098	-0.381	-0.052	0.548	-0.245	0.129	0.364	-0.105	0.239	0.019	0.270	0.443	-0.072	-0.286	-0.300	-0.113	0.146	
Moisture	0.8117	0.9537	0.9505	0.3755	0.7348	0.3135	0.8561	0.1474	0.3964	0.6542	0.2078	0.7173	0.4070	0.9468	0.3503	0.2410	0.8111	0.3216	0.5485	0.6960	0.6135	Moisture
	0.126	0.389	0.215	0.088	0.239	0.667	0.184	-0.119	0.407	0.099	-0.039	0.264	0.396	0.352	-0.456	0.786	0.091	0.473	0.100	-0.055	0.022	
%glau sd	0.6616	0.1972	0.4573	0.7607	0.4070	0.0778	0.5231	0.7528	0.1590	0.7319	0.8939	0.3609	0.1706	0.2232	0.1142	0.0376	0.7622	0.1017	0.8415	0.8490	0.9393	%glau sd
	-0.041	-0.288	-0.612	0.610	0.399	0.571	-0.271	0.719	-0.157	0.259	-0.171	-0.458	-0.234	0.306	0.618	-0.429	0.504	0.268	-0.700	-0.350	0.400	
%qtz sd	0.8860	0.3391	0.0340	0.0347	0.1667	0.1306	0.3483	0.0573	0.5860	0.3690	0.5530	0.1127	0.4166	0.2888	0.0323	0.2568	0.0943	0.3540	0.1615	0.2249	0.1659	%qtz sd
	0.220	0.245	0.638	-0.533	-0.102	0.095	0.421	-0.738	0.451	-0.077	-0.316	0.588	0.011	0.049	-0.533	0.238	-0.175	0.286	0.600	0.648	-0.242	
%slt-cly	0.4465	0.4161	0.0270	0.0649	0.7244	0.0801	0.1448	0.0508	0.1186	0.7899	0.2731	0.0417	0.9696	0.8640	0.0649	0.5287	0.5607	0.3223	0.2301	0.0247	0.4023	%slt-cly
	-0.258	-0.035	-0.330	0.297	-0.102	-0.238	-0.344	0.643	-0.516	-0.022	0.514	-0.440	0.253	-0.242	0.368	0.095	-0.189	-0.533	-0.300	-0.374	0.066	
	0.3710	0.9075	0.2528	0.3040	0.7244	0.5287	0.2336	0.0890	0.0736	0.9393	0.0748	0.1278	0.3813	0.4023	0.2022	0.8010	0.5297	0.0649	0.5485	0.1956	0.8193	

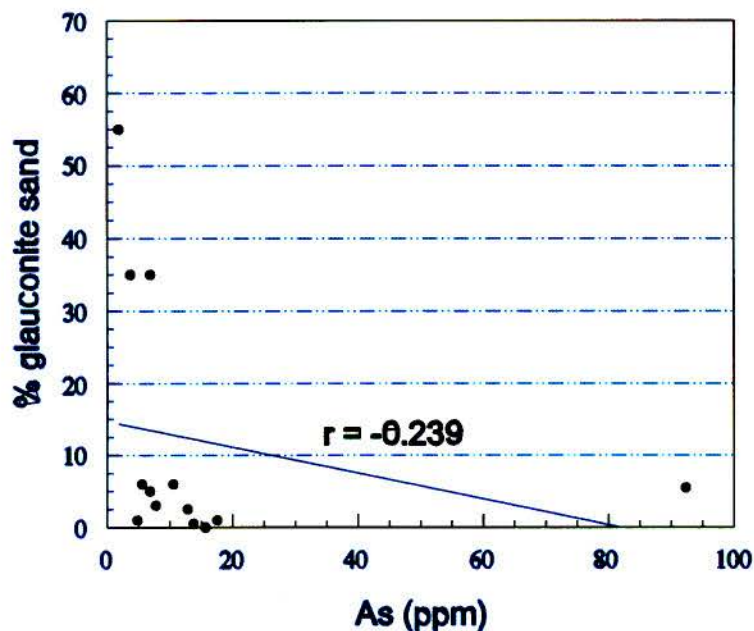


Figure 13. Arsenic concentration as a function of the percent glauconite sand in the Colemantown soil series. The linear regression line is included.

Colemantown soil series is characterized by glauconite sand embedded in a soft, waxy, greenish, clay/silt matrix (“plasma” as it is referred to by European scientists). It is unknown how much of this clay/silt matrix is true glauconite or glauconite-like. Plotting the sum of percent glauconite sand and percent silt/clay against arsenic concentration reveals a similar negative correlation. Based on these observations, the arsenic appears to associate with phases other than glauconite.

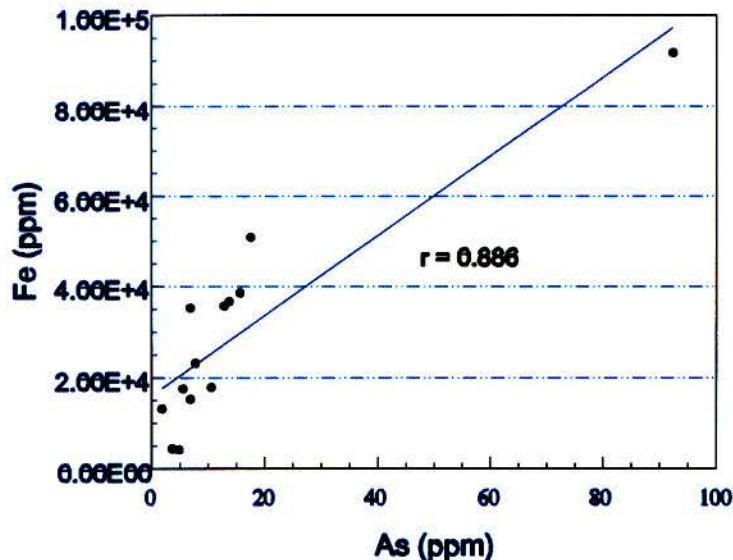


Figure 14. Arsenic concentration as a function of labile iron in the Colemantown soil series. The simple linear regression correlation line is included.

Table 35 is a SRO correlation table for the analytes. There is a very strong, positive SRO correlation (0.941, $p = 0.0011$) between arsenic and iron which suggests that the arsenic is associated with labile iron phases. This relation is consistent with the strong sorption (inner sphere coordination complex) of arsenic onto iron (hydr)oxides. Figure 14 shows the relation between arsenic and iron in Colemantown soil series. Though the linear correlation line in figure 14 shows a less clear, positive relation between arsenic and iron than the SRO correlation, it demonstrates that as extractable iron increases, arsenic concentrations increase slightly.

Figure 15 shows arsenic as a function of iron, excluding the 92.3 ppm arsenic outlier for GLCM4003. Clearly, the strong, positive correlation between arsenic and iron is shown in figure 15. It can be reasonably concluded then that the arsenic is mainly associated with labile iron (hydr)oxide constituents in Colemantown soil series. Perhaps this might explain in part why GLCM4003, which consists of 90 percent quartz sand that is pervasively coated with iron

Table 35. Summary of Spearman rank-order correlation for EPA SW-846 Methods 3050 and 6010A analytes in the Colemantown soil series. In each cell, top value is the correlation value and bottom is the probability.
Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V
Sb	0.627 0.0376																			
As	0.578 0.0454	0.726 0.0160																		
Ba	0.544 0.0595	0.291 0.3349	-0.017 0.9544																	
Be	0.779 0.0070	0.340 0.2598	0.245 0.831 0.0040																	
B	0.238 0.5287	0.539 0.1539	0.000 1.0000	0.524 0.1658	0.714 0.0588															
Cd	0.836 0.0038	0.770 0.0106	0.799 0.0056	0.338 0.2411	0.639 0.0268	0.383 0.3106														
Ca	0.214 0.5708	-0.090 0.8253	-0.500 0.1859	0.905 0.0167	0.707 0.0616	0.800 0.1659	0.024 0.9498													
Cr	0.703 0.0148	0.788 0.0090	0.558 0.0530	0.242 0.4023	0.462 0.1094	0.619 0.1015	0.693 0.0163	-0.143 0.7055												
Co	0.846 0.0034	0.487 0.1064	0.336 0.2450	0.775 0.0073	0.935 0.0012	0.524 0.1658	0.715 0.0132	0.690 0.0677	0.462 0.1099											
Cu	-0.349 0.2262	-0.195 0.5184	-0.165 0.5669	0.006 0.9848	-0.292 0.3118	-0.060 0.8741	-0.431 0.1353	0.119 0.7528	-0.443 0.1250	-0.223 0.4401										
Fe	0.703 0.0148	0.813 0.0070	0.941 0.0011	0.121 0.6754	0.421 0.1448	0.143 0.7055	0.902 0.0018	-0.381 0.3135	0.731 0.0114	0.473 0.1017	-0.407 0.1584									
Pb	0.110 0.7034	0.340 0.2598	0.303 0.2945	0.236 0.4131	0.107 0.7101	0.286 0.4497	0.113 0.6960	0.095 0.8011	-0.044 0.8790	0.159 0.5810	0.682 0.0181	0.115 0.6894								
Mg	0.813 0.0048	0.417 0.1668	0.289 0.3170	0.714 0.0133	0.957 0.0009	0.714 0.0588	0.674 0.0196	0.571 0.1306	0.648 0.0247	0.901 0.0018	-0.385 0.1821	0.495 0.0867	0.022 0.9393							
Mn	0.352 0.2232	-0.112 0.7101	-0.245 0.3964	0.698 0.0156	0.591 0.0405	0.286 0.4497	0.143 0.6202	0.952 0.0117	-0.148 0.6073	0.626 0.0300	0.019 0.9468	-0.181 0.5299	-0.115 0.6894	0.451 0.1186						
Mo	0.333 0.3778	0.811 0.0470	0.548 0.1474	0.000 1.0000	-0.060 0.8741	0.500 0.4795	0.204 0.5901	0.029 0.9491	0.690 0.0677	0.048 0.8997	0.238 0.5287	0.357 0.3447	0.357 0.3447	0.214 0.5708	-0.286 0.4497					
Ni	0.439 0.1458	-0.023 0.9426	0.016 0.9582	0.744 0.0136	0.895 0.0030	0.468 0.2512	0.460 0.1274	0.873 0.0325	0.281 0.3519	0.730 0.0155	-0.344 0.2541	0.228 0.4494	-0.158 0.6005	0.793 0.0085	0.621 0.0394	-0.595 0.1453				
K	0.522 0.0706	0.361 0.2315	0.300 0.2989	0.407 0.1590	0.671 0.0201	0.976 0.0098	0.567 0.0496	0.167 0.6592	0.709 0.0141	0.473 0.1017	-0.685 0.0176	0.538 0.0621	-0.225 0.4352	0.753 0.0091	0.033 0.9091	0.190 0.6143	0.681 0.0240			
Se	0.700 0.1615	0.500 0.3173	0.100 0.0455	0.000 1.0000	0.400 0.4237	0.400 0.4884	0.100 0.0455	-0.900 0.0374	0.100 0.8729	0.200 0.7471	-0.100 0.8415	0.900 0.0719	0.500 0.3173	0.300 0.5485	0.200 0.6892	NA NA	0.000 1.0000	0.100 0.8415		
V	0.615 0.0330	0.459 0.1281	0.707 0.0143	-0.055 0.8490	0.231 0.4234	-0.143 0.7055	0.561 0.0519	-0.071 0.8501	0.538 0.0621	0.374 0.1956	-0.184 0.5231	0.632 0.0286	0.055 0.8490	0.330 0.2534	0.038 0.8940	0.524 0.1658	-0.004 0.9907	0.192 0.5053	0.900 0.0719	
Zn	0.758 0.0086	0.389 0.1972	0.226 0.4345	0.907 0.0017	0.889 0.0021	0.476 0.2077	0.547 0.0579	0.833 0.0275	0.440 0.1278	0.885 0.0022	-0.022 0.9392	0.335 0.2456	0.231 0.4240	0.813 0.0048	0.687 0.0174	0.119 0.7528	0.761 0.0116	0.456 0.1142	0.400 0.4237	0.297 0.3040

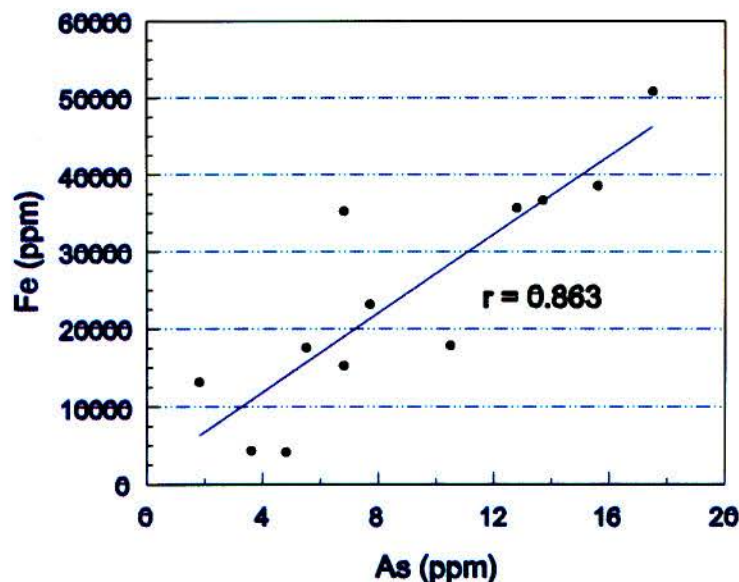


Figure 15. Arsenic concentration as a function of labile iron (excluding the 92.3 ppm arsenic outlier for GLCM4003). The simple linear regression correlation line ($\text{Fe}(\text{ppm}) = 2547\text{As}(\text{ppm}) + 1683$) is shown.

hydroxides (91,800 ppm Fe), has such an unusually high arsenic concentration. Moreover, it might be inferred that the extraction efficiency for this sample is unusually high also.

Statistically significant, strong, positive SRO correlations occur between: boron and potassium, beryllium and cobalt, beryllium and magnesium, cobalt and magnesium, and cobalt and zinc. Boron, beryllium, potassium and magnesium are constituent elements in glauconite and phyllosilicates. The strong, positive SRO correlation between constituent elements in glauconite and cobalt suggests that cobalt too is a constituent of glauconite. This positive correlation between cobalt and constituent elements in glauconite and phyllosilicates is observed in the Adelphia soil series also. Nickel and zinc also show a strong, positive correlation with

beryllium and cobalt, arguing that nickel and zinc are intimately associated with glauconite ± phyllosilicate minerals.

Cobalt and zinc have strong, positive SRO correlations with aluminum, which further supports cobalt and zinc as being constituent elements associated with glauconite and phyllosilicate minerals. There is no-to-insignificant SRO correlation between arsenic and the constituent elements in glauconite; for example: potassium, magnesium, aluminum, boron and beryllium. This is additional evidence that 'recoverable' arsenic concentrations can not be solely accounted for by glauconite.

Collington Soil Series

Ten soil series from four sampling stations were analyzed according to U. S. EPA SW-846, Methods 3050 and 6010A. The statistical summary of the analyte concentrations is presented in table 36.

Soil pH ranges from 3.24 (BUCL2001) to 4.17 (CACL3003) with a 3.65 median pH and a 3.70 ± 0.32 mean. The three highest pH values (4.17, 4.12 and 3.99) correspond to the highest calcium concentrations (901, 436 and 824) for CACL3003, MOCL1001 and MOCL1002, respectively. Based on the semiquantitative granulometric analysis of these samples (table 4), the Collington soil series is very rich in quartz sand (74 percent median and 72 percent mean).

Most of the deep soil samples from this soil series are characterized by the soft, waxy to ooze-like, clay/silt matrix.

Arsenic concentrations range from 3.9 ppm (BUCL2002) to 43.1 ppm (MOCL1002) with a median of 11.3 ppm and a 14.3 ± 11.4 ppm mean. An arsenic concentration exceeding 39.1 ppm is an extreme outlier. Omitting the 43.1 ppm arsenic for MOCL1002 from the statistical

Table 36. Statistical summary of analyte concentrations, determined by SW-846 Methods 3050 and 6010A, in the Collington soil series. All metal concentrations are in mg/kg (ppm). pH is standard units, and total organic carbon (TOC) and moisture (moist.) are expressed as weight percent.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	3.24	4.17	3.65	0.32	3.70	4.12	10
Al	1850	13300	6460	4082	6894	11800	10
Sb	0.98	4.7	2.45	1.2	2.68	4.2	10
As	3.9	43.1	11.3	11.4	14.3	19.0	10
Ba	8.1	44.7	16.4	12.5	21.1	40.3	10
Be	0.13	1.2	0.44	0.38	0.56	1.1	10
B	12.4	79.6	17.8	28.1	32.5	37.3	5
Cd	0.6	5.1	2.7	1.8	2.6	4.8	10
Ca	31.2	901	129	362	317	824	8
Cr	16.1	172	47	45	58.8	85.7	10
Co	0.56	4.4	1.6	1.4	2.2	3.9	10
Cu	1.4	8.1	4.5	2.2	4.4	6.7	10
Fe	5210	64500	28300	21425	30143	47500	10
Pb	4.4	59.1	10.6	16.9	16.6	27.4	10
Mg	250	3640	849	1038	1176	2240	10
Mn	11.1	198	21.2	57.6	44.9	82.8	10
Mo	0.18	1.4	0.43	0.36	0.50	0.58	9
Ni	0.72	10.8	1.9	3.0	2.9	4.4	10
K	227	9440	1390	2869	2296	4910	10
Se	1.7	5.7	3.6	1.6	3.7	5.3	6
V	16.2	91.2	44	29.9	46.9	86.7	10
Zn	11.3	60.5	26.1	16.1	28.6	42.5	10
%TOC	0.13	3.2	0.57	1.01	1.06	2.03	10
%moist.	6.7	31.6	16.5	7.1	17.4	22.9	10

calculation yields a 10.5 ppm median and a mean of 11.1 ± 5.6 ppm. All but one sample (MOCL1002) is in compliance with the 20 ppm RDCSCC guideline for arsenic. Based on stations BUCL2000 and GLCL4000, the arsenic concentration is slightly higher in the 0- to 6-inch samples from the A horizon than in the 12- to 18-inch composites from the Bt horizon. In all cases, soil samples from the deepest horizon (24 to 30 inches, or 30 to 36 inches for

MOCL1002) have the highest 'recoverable' arsenic concentration. The NRCS describes the Bt horizon as ranging from 13 to 29 inches in depth. Based on aluminum, magnesium and potassium concentrations in the soil profile, the top of the Bt horizon is leached to at least 18 inches in depth; below this is the illuviation horizon, that is, the zone of 'silicate clay' accumulation. Iron concentrations support this interpretation.

'Recoverable' beryllium concentrations range from 0.13 ppm (GLCL4002) to 1.2 ppm (BUCL2003) with a 0.44 ppm median and a mean of 0.56 ± 0.38 ppm. Beryllium concentrations between 0.93 ppm and 1.30 ppm are mild outliers and therefore BUCL2003 and MOCL1001 (1.1 ppm) are mild outliers.

As shown in figure 16, the arithmetic mean concentrations for pH, arsenic, beryllium, iron and potassium in the Collington soil series are considerably less than those for the entire data set. The median arsenic and iron concentrations for Collington soil series are 19 and 28 percent, respectively, higher than the data set as a whole. The median beryllium concentration is 10 percent less than the median for the entire data set, which is consistent with the low content of glauconite sand that is characteristic of this soil series (table 4).

Mean percent extraction efficiency for aluminum, arsenic, beryllium, iron, lead and potassium in the Collington soil series is nearly identical to those for the 14 soil samples (table 18). The mean percent extraction efficiency for arsenic and beryllium is 40.5 and 15 percent, respectively, for Collington soil from station BUCL2000 compared to 39 ± 18 percent and 16 ± 11 percent, respectively, for all 14 soils. The 24- to 30-inch composite soil sample (BUCL2003) has a slightly higher percent extraction efficiency for aluminum (23 vs. 11 percent), beryllium (19 vs. 11 percent), iron (38 vs. 29 percent) and potassium (22 vs. 8.7 percent) than the 0- to 6-inch composite (BUCL2001).

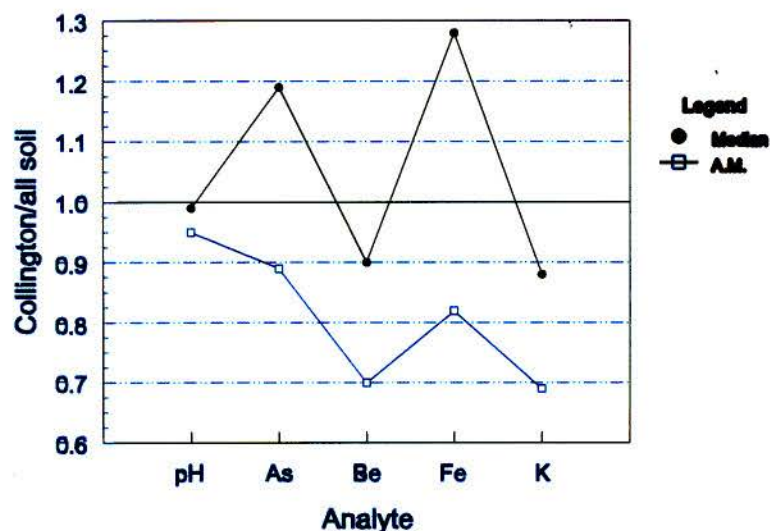


Figure 16. Ratio of median and mean analyte concentrations in the Collington soil series to those for the entire data set. A.M. is the ratio of means.

The statistical summary of select analytes in the 0- to 6-inch and 24- to 30-inch composites for the Collington soil series is shown in table 37. With the exception for lead, the median and mean 'recoverable' concentrations for the analytes in table 37 increase with increasing depth in the soil. Lead and copper concentrations (not shown in the table) are significantly higher in the surface soil than in the deep sample. In the surface soil they probably are strongly complexed with organic matter.

SRO correlations for the analytes regressed against pH, weight percent total organic carbon, weight percent moisture, and percent glauconite sand, quartz sand and silt/clay are summarized in table 38. No significantly strong SRO correlation was found for arsenic or beryllium regressed against pH, total organic carbon, moisture, glauconite or quartz sand, and

Table 37. Statistical summary of analyte concentrations (in ppm) as a function of depth for the Collington soil series. Top value is the 0- to 6-inch composite and the bottom value is the 24- to 30-inch composite. Concentrations omitting the extreme outliers are shown in parentheses ().

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	1990	10500	6355	4020	6300	8830	4
	6310	13300	9205	3571	9505	11800	4
As	7.1	19	9.1	5.5	11.1	10.5	4
	12.1	43.1 (18.6)	16.9 (15.1)	14.2 (3.3)	22.2 (15.3)	18.6 (15.1)	4 (3)
Be	0.14	1.10	0.43	0.42	0.52	0.55	4
	0.35	1.20	0.69	0.40	0.73	0.92	4
Fe	5520	64500	27800	26740	31405	41100	4
	15500	47500	47000	15840	39250	47500	4
Pb	9.6	59.1 (27.4)	25.3 (23.1)	21 (9.3)	29.8 (20.0)	27.4 (23.1)	4 (3)
	4.6	13.7	9.1	4.2	9.1	11.5	4
K	227	1880	792	718	923	1030	4
	681	9440 (4910)	3575 (2240)	3835 (2139)	4318 (2610)	4910 (2240)	4 (3)

silt/clay. The SRO correlation of 0.159 ($p = 0.6343$) for arsenic correlated to percent glauconite sand indicates essentially no relation between the two parameters. The simple linear regression correlation coefficient for arsenic correlated against percent glauconite sand is 0.293, which is a very weak, but a slightly more robust positive correlation than the SRO correlation. Arsenic as a function of percent glauconite sand is shown in figure 17, which clearly shows that the leachable arsenic concentration is virtually independent of the glauconite sand content of the soil.

Table 39 is the SRO correlation table for the analytes. Statistically significant, strong, positive SRO correlations occur between: aluminum and beryllium, aluminum and chromium, aluminum and cobalt, aluminum and iron, aluminum and magnesium, beryllium and chromium, beryllium and cobalt, and beryllium and iron. Furthermore, a strong, positive SRO correlation occurs for iron regressed against cobalt, and magnesium regressed against potassium. The strong, positive correlations between and among these analytes is expected for elements which

Table 38. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A for the Collington soil series as a function of pH, total organic carbon (%TOC), weight percent moisture, and granulometric parameters. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V	Zn	
pH	0.309 0.3538	0.134 0.6883	0.588 0.0778	0.503 0.1313	0.261 0.4343	-0.200 0.6892	0.430 0.1967	0.524 0.1658	0.212 0.5245	0.377 0.2582	0.103 0.7573	0.529 0.1126	-0.139 0.6758	0.006 0.9855	0.345 0.3000	0.377 0.2868	0.097 0.7704	0.042 0.8987	0.543 0.2248	0.636 0.0563	-0.103 0.7573	pH
TOC	-0.321 0.3352	-0.073 0.8268	-0.455 0.1727	-0.212 0.5245	-0.224 0.5011	0.200 0.6892	-0.152 0.6494	0.095 0.8011	-0.370 0.2674	-0.061 0.8553	0.442 0.1844	-0.292 0.3814	0.624 0.0611	-0.212 0.5245	0.188 0.5730	-0.628 0.0759	0.182 0.5843	-0.358 0.2834	0.200 0.6547	-0.212 0.5245	0.297 0.3730	TOC
Moisture	0.539 0.1056	0.638 0.0555	0.588 0.0778	0.685 0.0399	0.624 0.0611	-0.100 0.8415	0.648 0.0517	0.548 0.1474	0.442 0.1844	0.723 0.0300	0.830 0.0127	0.742 0.0261	0.552 0.0980	0.673 0.0436	0.612 0.0663	0.619 0.0799	0.614 0.0655	0.576 0.0841	0.600 0.1797	0.491 0.1408	0.855 0.0104	Moisture
%glau sd	0.341 0.3056	0.162 0.6268	0.159 0.6343	0.262 0.4315	0.384 0.2491	-0.872 0.0811	0.268 0.4209	0.711 0.0600	0.250 0.4532	0.248 0.4574	0.183 0.5831	0.358 0.2831	0.134 0.6874	0.646 0.0525	0.043 0.8981	0.519 0.1421	0.125 0.7068	0.744 0.0256	0.058 0.8969	-0.030 0.9271	0.378 0.2567	%glau sd
%qtz sd	-0.360 0.2805	-0.413 0.2155	-0.604 0.0701	-0.671 0.0442	-0.390 0.2417	0.300 0.5485	-0.506 0.1289	-0.831 0.0278	-0.085 0.7979	-0.535 0.1084	-0.793 0.0174	-0.645 0.0529	-0.805 0.0157	-0.390 0.2417	-0.585 0.0791	-0.456 0.1974	-0.401 0.2294	-0.226 0.4985	-0.829 0.0639	-0.622 0.0621	-0.409 0.2203	%qtz sd
%slt-cly	0.285 0.3928	0.340 0.3071	0.430 0.1967	0.491 0.1408	0.309 0.3538	0.000 1.0000	0.394 0.2373	0.738 0.0508	0.006 0.9855	0.450 0.1772	0.733 0.0278	0.498 0.1348	0.855 0.0104	0.273 0.4133	0.552 0.0980	0.218 0.5383	0.444 0.1831	0.091 0.7851	0.829 0.0639	0.552 0.0980	0.370 0.2674	%slt-cly

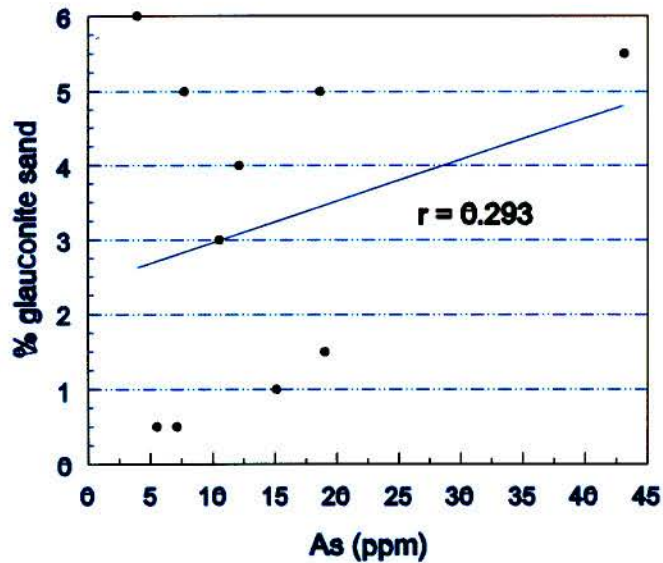


Figure 17. Arsenic concentration as a function of the percent glauconite sand in the Collington soil series. The linear regression correlation line is included.

are constituents of glauconite and phyllosilicate minerals.

SRO correlation exhibits significantly strong, positive relations for arsenic regressed against barium, iron, molybdenum and vanadium. The simple linear regression correlation coefficient is 0.600 for arsenic regressed against iron compared to the SRO correlation of 0.906 ($p = 0.0066$). Figure 18 is a graphical depiction of the relation between ‘recoverable’ arsenic and iron. Recalculating the linear regression correlation coefficient, excluding the 43.1 ppm arsenic outlier for MOCL1002, yields a 0.788 linear correlation. The relation between arsenic and iron without the extreme outlier for arsenic is shown graphically in figure 19. The positive SRO and linear correlations between arsenic and iron (figure 19) provide strong evidence that the arsenic concentration is a function of the labile iron in the Collington soil series.

Table 39. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A for Collington series soil. In each cell the top value is the correlation value and the bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V
Sb	0.890 0.0070																			
As	0.685 0.0400	0.632 0.0579																		
Ba	0.648 0.0517	0.705 0.0344	0.891 0.0075																	
Be	0.903 0.0067	0.851 0.0107	0.612 0.0663	0.564 0.0909																
B	0.600 0.2301	0.700 0.1615	-0.100 0.8415	-0.300 0.5485	0.600 0.2301															
Cd	0.867 0.0093	0.912 0.0062	0.733 0.0278	0.867 0.0093	0.806 0.0156	0.200 0.6892														
Ca	0.548 0.1474	0.431 0.2540	0.619 0.1015	0.548 0.1474	0.571 0.1306	0.500 0.4795	0.381 0.3135													
Cr	0.927 0.0054	0.888 0.0078	0.539 0.1056	0.515 0.1222	0.903 0.0067	0.600 0.2301	0.818 0.0141	0.238 0.5287												
Co	0.888 0.0078	0.927 0.0054	0.717 0.0314	0.802 0.0161	0.875 0.0086	0.600 0.2301	0.973 0.0035	0.503 0.1832	0.839 0.0118											
Cu	0.455 0.1727	0.626 0.0603	0.552 0.0980	0.758 0.0230	0.406 0.2232	0.200 0.6892	0.685 0.0399	0.524 0.1658	0.273 0.4132	0.711 0.0329										
Fe	0.845 0.0112	0.787 0.0183	0.906 0.0066	0.863 0.0096	0.857 0.0101	0.051 0.9183	0.875 0.0086	0.659 0.0814	0.729 0.0286	0.902 0.0068	0.632 0.0579									
Pb	0.164 0.6235	0.249 0.4546	0.248 0.4560	0.370 0.2674	0.103 0.7573	0.100 0.8415	0.236 0.4783	0.548 0.1474	-0.127 0.7026	0.298 0.3715	0.794 0.0172	0.292 0.3814								
Mg	0.830 0.0127	0.711 0.0329	0.552 0.0980	0.503 0.1313	0.758 0.0230	0.700 0.1615	0.612 0.0663	0.786 0.0376	0.697 0.0365	0.650 0.0510	0.442 0.1844	0.705 0.0344	0.309 0.3538							
Mn	0.600 0.0719	0.681 0.0411	0.612 0.0663	0.794 0.0172	0.467 0.1615	0.200 0.6892	0.818 0.0141	0.357 0.3447	0.467 0.1615	0.815 0.0145	0.855 0.0104	0.681 0.0411	0.552 0.098	0.333 0.3173						
Mo	0.736 0.0373	0.576 0.1035	0.921 0.0092	0.812 0.0217	0.586 0.0976	-0.205 0.6815	0.703 0.0468	0.571 0.1616	0.536 0.1298	0.634 0.0727	0.460 0.1930	0.891 0.0118	0.276 0.4348	0.711 0.0442	0.536 0.1298					
Ni	0.742 0.0261	0.695 0.0370	0.444 0.1831	0.413 0.2149	0.729 0.0286	0.900 0.0719	0.644 0.0532	0.452 0.2314	0.657 0.0489	0.780 0.0192	0.596 0.0739	0.665 0.0462	0.456 0.1714	0.563 0.0899	0.711 0.0329	0.420 0.2347				
K	0.661 0.0475	0.426 0.2017	0.467 0.1615	0.309 0.3538	0.661 0.0475	0.700 0.1615	0.370 0.2674	0.762 0.0438	0.552 0.0980	0.438 0.1892	0.188 0.5730	0.608 0.0682	0.127 0.7026	0.903 0.0067	0.091 0.7851	0.728 0.0395	0.462 0.1657			
Se	0.600 0.1797	0.638 0.1539	0.600 0.1797	0.486 0.2774	0.771 0.0845	0.600 0.2987	0.771 0.0845	0.800 0.1659	0.600 0.1797	0.812 0.0695	0.543 0.2248	0.771 0.0845	0.429 0.3379	0.486 0.2774	0.543 0.2248	0.205 0.6815	0.829 0.0639	0.314 0.4822		
V	0.770 0.0209	0.778 0.0196	0.855 0.0104	0.867 0.0093	0.673 0.0436	0.200 0.6891	0.891 0.0075	0.548 0.1474	0.648 0.0517	0.875 0.0086	0.648 0.0517	0.869 0.0091	0.309 0.3538	0.430 0.1967	0.830 0.0127	0.686 0.0523	0.620 0.0629	0.212 0.5245	0.600 0.1797	
Zn	0.673 0.0436	0.742 0.0261	0.370 0.2674	0.442 0.1844	0.782 0.0190	0.900 0.0719	0.661 0.0475	0.476 0.2077	0.661 0.0475	0.790 0.0177	0.673 0.0436	0.663 0.0468	0.418 0.2096	0.673 0.0436	0.588 0.0778	0.360 0.3088	0.851 0.0107	0.564 0.0909	0.714 0.1102	0.455 0.1727

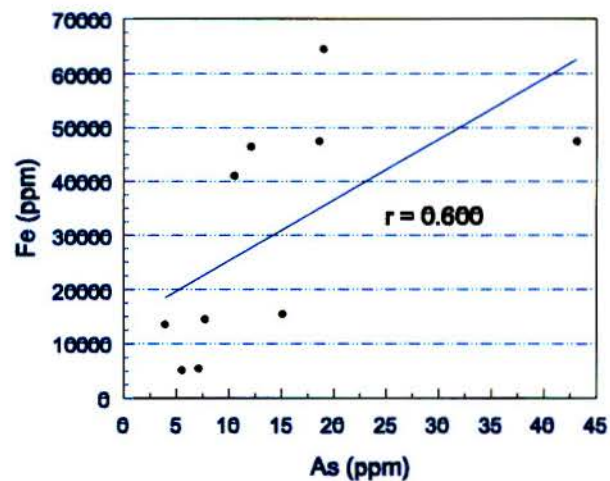


Figure 18. Arsenic concentration as a function of labile iron for the Collington soil series. The simple linear regression correlation line is shown.

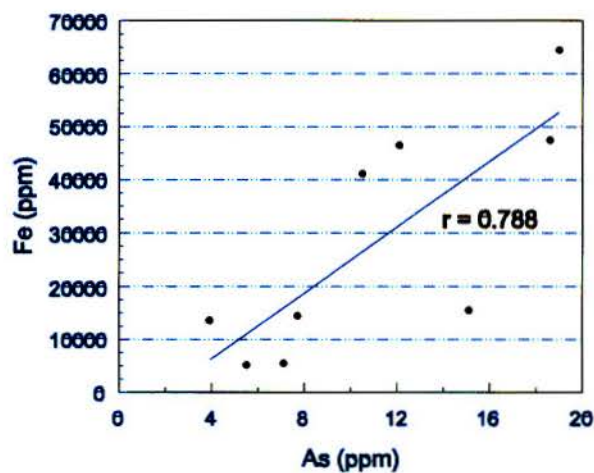


Figure 19. Arsenic concentration versus labile iron (excluding the 43.1 ppm arsenic outlier for MOCL1002). The simple linear regression correlation line ($\text{Fe (ppm)} = 3090\text{As (ppm)} - 5945$) is shown.

Freehold Soil Series

Fifteen soil samples from six sampling stations were analyzed according to U. S. EPA SW-846, Methods 3050 and 6010A. The statistical summary of the analyte concentrations is shown in table 40.

Table 40. Statistical summary of analyte concentrations, determined by SW-846 Methods 3050 and 6010A, in the Freehold soil series. All metal concentrations are in mg/kg (ppm). pH is standard units, and total organic carbon (TOC) and moisture (moist.) are expressed as weight percent.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	3.23	6.15	4.13	0.7	4.15	4.60	15
Al	1450	18300	7120	4404	7393	10600	15
Sb	0.8	3.2	1.4	0.8	1.8	3.1	11
As	2.0	72.7	7.1	17.3	11.3	10.5	15
Ba	11.4	278	27.1	66.3	47.4	51.3	15
Be	0.2	2.8	0.42	0.64	0.60	0.72	15
B	13.2	75.1	15.9	28.7	32.4	73.6	7
Cd	0.4	13.5	1.5	3.2	2.4	2.5	15
Ca	27.4	6080	543	1482	967	1330	15
Cr	5.1	104	19.5	27.6	29.2	37.5	15
Co	0.59	8.1	2.0	1.8	2.5	3.5	15
Cu	1.6	26.6	5.4	5.9	6.2	7.0	15
Fe	2580	56600	15800	15141	18764	30500	15
Pb	3.3	501	7.9	128	51.6	23.1	15
Mg	151	4030	805	1193	1258	1780	15
Mn	3.1	477	52.5	120	87.2	171	15
Mo	0.12	1.6	0.43	0.43	0.53	0.74	10
Ni	0.77	8.9	2.6	2.2	3.5	4.8	15
K	322	12300	1110	3557	2452	2490	15
Se	0.63	11.5	2.5	2.7	3.0	3.3	13
Ag	0.23	0.36	0.29	0.05	0.29	0.30	4
V	1.7	48.1	17.6	12.3	20.0	30.1	15
Zn	6.0	96.4	26.1	22.7	31.8	43.8	15
%TOC	0.18	2.47	0.46	0.75	0.87	1.58	15
%moist.	8.4	25.0	13.3	5.5	15.3	20.5	15

Soil pH ranges from 3.23 (MOFR6001) to 6.15 (CAFR3001) with a 4.13 median pH and a mean of 4.15 ± 0.70 . The relation between pH and calcium is not clearly defined. The highest pH (6.15 for CAFR3001) corresponds to 1330 ppm calcium, whereas at pH 4.29 the calcium concentration is 6080 ppm for GLFR4001, which is the highest calcium concentration for this soil series. The lowest pH (3.23 for MOFR6001) corresponds to an unusually high (1630 ppm) calcium concentration. The low pH and high calcium for MOFR6001 may be a marine aerosol overprint, considering this stations proximity to the coastline (fig. 1). The elevated concentrations of barium and sodium for this station relative to the other Freehold series samples lend support to this interpretation. The highest concentrations of calcium, barium and potassium are in GLFR4001, which is an actively cultivated field with wheat and corn.

Arsenic concentrations range from 2.0 ppm (MOFR6001) to 72.7 ppm (MOFR1002) with a 7.1 ppm median and a mean of 11.3 ± 17.3 ppm. Arsenic concentration exceeding 26.0 ppm constitutes an extreme outlier. Excluding the 72.2 ppm arsenic extreme outlier for MOFR1002 from the statistical calculation yields a 7.0 ppm median and a 6.9 ± 3.2 ppm mean. With the exception for MOFR1002, the arsenic concentration for the Freehold soil series complies with the 20 ppm RDCSCC.

'Recoverable' beryllium concentrations range from 0.2 ppm (MOFR6001) to 2.8 ppm (GLFR4001) with a 0.42 ppm median and a 0.60 ± 0.64 ppm mean. Beryllium concentration exceeding 1.49 ppm is an extreme outlier. Omitting the 2.8 ppm beryllium extreme outlier from the statistical calculation provides a 0.40 ppm median and a mean of 0.45 ± 0.20 ppm. The maximum 'recoverable' beryllium for this soil series is in the 0- to 6-inch surface soil (GLFR4001) of an actively cultivated field. It is not clear that this high beryllium concentration is a direct result of agricultural input. It may result from more aggressive weathering of the surface soil following repeated plowing of the top ten inches or so of the soil. Except for the extreme outlier, beryllium concentrations for Freehold soil series are in compliance with the RDCSCC guideline.

The ratio of select median and mean analyte concentrations in Freehold soil series to those for the entire data set is plotted in figure 20. The median and mean of arsenic, beryllium, iron and potassium for the Freehold series is less than that for the glauconite-bearing soils as a whole. The median calcium concentration for the Freehold series is 2.6 times that for the entire data set. The elevated calcium concentration results mainly from the liming of this very acidic soil. Liming may account for the slightly elevated pH for the Freehold soil series.

A statistical summary of select analytes for the 0- to 6-inch and 24- to 30-inch depth composites of the Freehold soil series is shown in table 41. Arsenic concentration increases with depth in the soil, except for station CAFR3000, which is a formerly cultivated field that now is an open, grassy field. For station CAFR3000, the 'recoverable' arsenic in the surface soil composite (10.5 ppm) is nearly twice that for the 24- to 30-inch composite (5.6 ppm). This

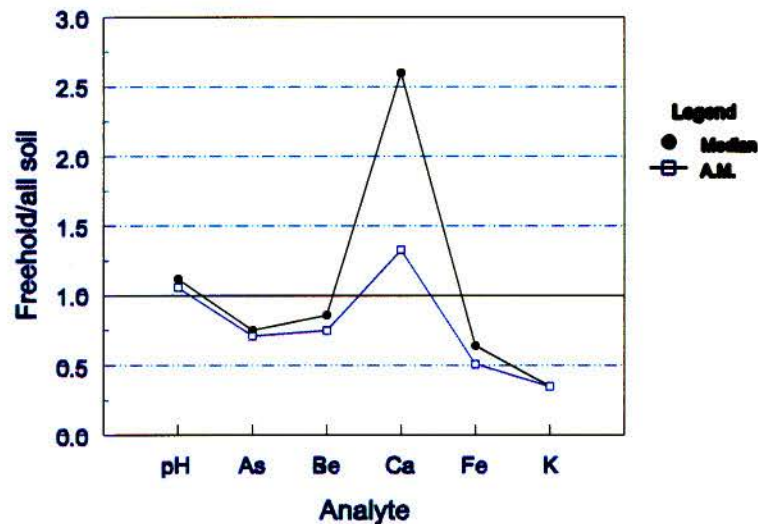


Figure 20. Ratio of median and mean analyte concentrations in the Freehold soil series to those for the entire data set. A.M. is the ratio of means.

relatively elevated arsenic in the surface soil does not appear to be an artifact of former agriculture practices, because though the calcium concentration is high, concentrations of certain other elements (for example, potassium, barium and copper) do not support agriculture inputs. Perhaps the arsenic enrichment in the surface soil results from the close proximity of the site to major urban centers. Median and mean iron concentration increases with depth in the soil, whereas potassium decreases with depth.

Table 41. Statistical summary of analyte concentrations (in ppm) as a function of depth for the Freehold soil series. Top value is the 0- to 6-inch composite and the bottom is the 24- to 30-inch composite. Concentrations excluding the extreme outliers are shown in parentheses ().

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	1450	9940	7840	3386	6740	9480	6
	3270	18300	7815	5487	8878	11600	6
As	2.0	10.5	5.9	3.6	6.0	8.9	6
	5.6	72.7 (12.9)	9.5 (9.5)	26.2 (2.8)	19.5 (8.9)	12.9 (9.5)	6 (5)
Be	0.20	2.8 (0.72)	0.49 (0.38)	0.98 (0.22)	0.83 (0.44)	0.72 (0.60)	6 (5)
	0.21	0.90	0.49	0.24	0.51	0.59	6
Fe	2580	46700	11885	15924	16707	19600	6
	11900	56600 (30500)	17450 (17100)	17139 (7493)	24400 (17960)	30500 (17800)	6 (5)
Pb	3.3	23.1	11.6	8.7	12.6	20.7	6
	5.2	501 (22.2)	15.1 (7.7)	196 (7.8)	113 (10.7)	132 (7.9)	6 (4)
K	322	12300 (2410)	1990 (1850)	4527 (987)	3237 (1424)	2410 (2130)	6 (5)
	368	9420 (2490)	1660 (1110)	3423 (990)	2670 (1320)	2490 (2210)	6 (5)

The BC soil horizon ranges from the 25- to 35-inch depth in the pedon. Excluding the extreme outlier for arsenic in MOFR1002 yields a mean of 8.9 ± 2.8 ppm arsenic for the BC horizon.

Spearman rank-order (SRO) correlations for the analytes regressed against pH, weight percent total organic carbon, weight percent moisture, and percent glauconite sand, quartz sand and silt/clay are summarized in table 42. Except for the strong, positive SRO correlation (0.771,

$p = 0.0208$) between percent glauconite sand and molybdenum, there is no significantly robust correlation among the parameters in table 42. The simple linear regression correlation is moderately strong (0.709) for percent glauconite sand regressed against molybdenum. Molybdate (MoO_4^{2-} , the stable molybdenum species at low pH) is chemisorbed in soils by oxides, noncrystalline aluminosilicates, and to a lesser extent, layer silicate clays (such as glauconite), with sorption on all these minerals increasing at lower pH (McBride, 1994). According to McBride (1994), molybdenum is least soluble in acid soils, particularly those containing iron oxides. Based on the strong correlations for molybdenum regressed against percent glauconite sand, most of the 'recoverable' molybdenum may be sorbed to the glauconite sand.

SRO correlation between arsenic and percent glauconite sand is very weak (0.105, $p = 0.6935$). The linear regression correlation is equally weak (-0.126) for these two parameters. The relation between percent glauconite sand and arsenic is illustrated in figure 21. Excluding the extreme outlier for arsenic produces a weak 0.233 linear regression correlation. The 'recoverable' arsenic apparently is independent of the percent glauconite sand in the Freehold soil series.

Table 43 is the SRO correlation table for the analytes. Magnesium, a constituent element in glauconite and certain other phyllosilicates, has a strong, positive SRO correlation with beryllium, boron, chromium and potassium, which are constituents of glauconite and phyllosilicate minerals. There is a moderately strong (0.732, $p = 0.0062$), positive SRO correlation between magnesium and aluminum. Potassium has a strong, positive SRO correlation with elements that correlate with magnesium. The strong, positive SRO correlation beryllium has with constituent elements in glauconite and phyllosilicates provides strong evidence that beryllium is a trace constituent of glauconite $\pm$ phyllosilicate minerals in the Freehold soil series.

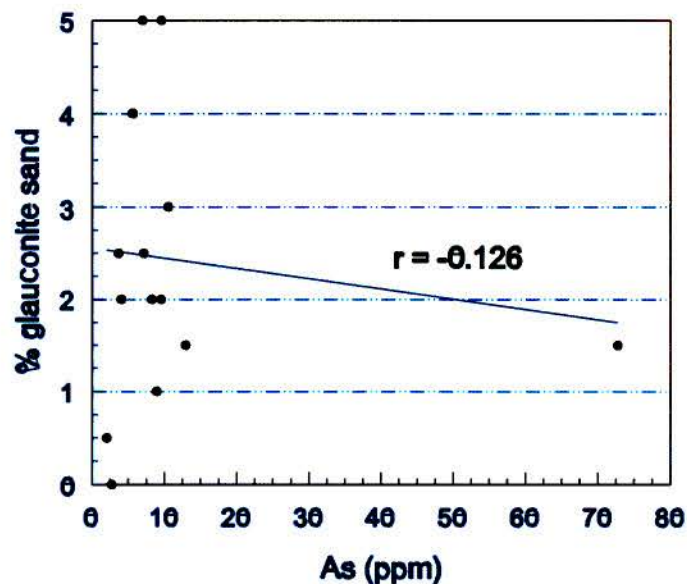


Figure 21. Arsenic concentration as a function of the percent glauconite sand in the Freehold soil series . The linear regression correlation line is shown.

Arsenic regressed against the labile iron concentration yields a moderately weak (0.434 , $p = 0.1041$), positive SRO correlation. The simple linear regression correlation is -0.011 , which indicates there is essentially no linear correlation between these analytes (fig. 22). Excluding the 72.7 ppm arsenic outlier for MOFR1002 yields a more robust linear regression correlation of 0.633 (fig. 23). Though the arsenic concentrations in figure 23 are in compliance with the RDCSCC, it has considerable variability for labile iron concentrations less than $20,000$ ppm. The moderate linear regression correlation between arsenic and iron (fig. 23) demonstrates that a significant part of the ‘recoverable’ arsenic is associated with labile iron. That part of the ‘recoverable’ arsenic not associated with iron phases is likely controlled by other (mineral) phase(s) and/or soil solution.

Table 42. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A for the Freehold soil series as a function of pH, total organic carbon (%TOC), weight percent moisture, and granulometric parameters. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V	Zn	
pH	0.132 0.6210	-0.697 0.0275	0.232 0.3846	-0.104 0.6984	0.136 0.6116	0.414 0.3100	0.068 0.7989	0.246 0.3565	0.111 0.6787	0.106 0.6929	0.246 0.3565	0.075 0.7790	0.150 0.5746	0.175 0.5126	0.296 0.2674	0.697 0.0365	0.070 0.7939	0.111 0.6787	-0.215 0.4573	0.075 0.7790	0.150 0.5746	pH
TOC	-0.193 0.4705	0.241 0.4451	-0.238 0.3738	0.486 0.0692	0.264 0.3227	0.234 0.5661	-0.165 0.5373	0.389 0.1452	0.021 0.9361	-0.247 0.3556	-0.082 0.7586	-0.079 0.7688	-0.007 0.9787	0.125 0.6400	0.071 0.7893	-0.333 0.3173	-0.021 0.9359	0.250 0.3496	0.300 0.2989	-0.339 0.2043	0.100 0.7083	TOC
Moisture	0.107 0.6885	0.301 0.3417	0.152 0.5697	0.239 0.3706	0.193 0.4705	0.667 0.1025	0.344 0.1979	0.189 0.4788	0.329 0.2189	0.174 0.5162	0.004 0.9893	0.307 0.2505	0.257 0.3360	0.246 0.3565	0.193 0.4705	0.248 0.4560	-0.079 0.7682	0.407 0.1277	0.382 0.1853	0.150 0.5746	0.464 0.0824	Moisture
%glau sd	-0.090 0.7365	-0.662 0.0363	0.105 0.69345	-0.214 0.4232	-0.050 0.8505	0.218 0.5930	0.054 0.8394	0.191 0.4756	-0.117 0.6618	0.175 0.5131	0.138 0.6043	0.034 0.8983	0.101 0.7063	-0.185 0.4882	0.225 0.4002	0.771 0.0208	0.014 0.9596	-0.153 0.5673	-0.084 0.7698	-0.189 0.4798	-0.027 0.9196	%glau sd
%qtz sd	0.032 0.9036	0.087 0.7828	-0.463 0.0834	0.072 0.7878	0.144 0.5903	0.155 0.7050	0.029 0.9139	0.270 0.3128	0.112 0.6765	-0.005 0.9839	-0.460 0.0849	0.200 0.4551	-0.484 0.0702	0.009 0.9732	-0.171 0.5226	0.287 0.3885	0.009 0.9731	0.174 0.5139	0.456 0.1138	-0.126 0.6376	-0.110 0.6814	%qtz sd
%silt-cly	-0.057 0.8305	0.050 0.8741	0.411 0.1237	0.048 0.8567	-0.143 0.5926	-0.324 0.4269	-0.045 0.8668	-0.245 0.3596	-0.109 0.6833	-0.039 0.8828	0.447 0.0945	-0.223 0.4032	0.449 0.0932	0.005 0.9840	0.172 0.5209	-0.394 0.2373	0.042 0.8748	-0.141 0.5973	-0.404 0.1612	0.132 0.6207	0.139 0.6019	%silt-cly

Table 43. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A analytes for the Freehold soil series. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V
Sb	0.597 0.0591																			
As	0.329 0.2185	0.575 0.0689																		
Ba	0.061 0.8203	0.182 0.5644	-0.034 0.8989																	
Be	0.511 0.0560	0.656 0.0380	0.481 0.0720	0.211 0.4305																
B	0.523 0.2006	0.638 0.1539	0.270 0.5079	0.126 0.7574	0.901 0.0273															
Cd	0.566 0.0341	0.890 0.0049	0.644 0.0160	0.104 0.6973	0.742 0.0055	0.800 0.0500														
Ca	-0.382 0.1528	-0.114 0.7187	0.050 0.8515	0.432 0.1059	0.107 0.6885	0.378 0.3540	-0.061 0.8197													
Cr	0.636 0.0174	0.856 0.0068	0.465 0.0821	0.036 0.8937	0.754 0.0048	0.847 0.0380	0.778 0.0036	-0.007 0.9787												
Co	0.617 0.0209	0.483 0.1267	0.415 0.1201	0.324 0.2257	0.515 0.0539	0.883 0.0306	0.698 0.0090	-0.243 0.3627	0.333 0.2131											
Cu	-0.321 0.2140	-0.337 0.2864	0.341 0.2015	0.250 0.3496	-0.129 0.6305	-0.523 0.2006	-0.125 0.6388	0.150 0.5746	-0.082 0.7586	-0.004 0.9893										
Fe	0.646 0.0156	0.811 0.0103	0.434 0.1041	-0.011 0.9680	0.804 0.0026	0.937 0.0217	0.914 0.0006	-0.200 0.4543	0.779 0.0036	0.640 0.0166	-0.354 0.1859									
Pb	-0.071 0.7893	-0.009 0.9770	0.613 0.0218	0.139 0.6023	0.300 0.2617	-0.144 0.7240	0.297 0.2657	0.046 0.8621	0.221 0.4074	0.331 0.2156	0.804 0.0026	0.093 0.7283								
Mg	0.732 0.0062	0.774 0.0143	0.459 0.0857	0.100 0.7083	0.796 0.0029	0.847 0.0380	0.681 0.0108	-0.004 0.9893	0.925 0.0005	0.317 0.2361	-0.154 0.5656	0.714 0.0075	0.164 0.5388							
Mn	-0.121 0.6496	-0.146 0.6448	0.338 0.2063	0.307 0.2505	0.443 0.0975	0.072 0.8599	0.384 0.1513	0.096 0.7182	0.146 0.5838	0.483 0.0707	0.557 0.0371	0.268 0.3162	0.771 0.0039	0.121 0.6496						
Mo	-0.055 0.8700	-0.431 0.2540	0.055 0.8700	-0.261 0.4343	-0.273 0.4133	-0.316 0.5839	-0.153 0.6454	0.612 0.0663	0.176 0.5980	-0.328 0.3247	0.018 0.9565	-0.212 0.5245	-0.103 0.7573	0.176 0.5980	-0.297 0.3730					
Ni	0.249 0.3517	0.205 0.5158	0.107 0.6899	0.387 0.1479	0.442 0.0980	-0.245 0.5477	0.465 0.0816	-0.131 0.6248	0.140 0.6013	0.661 0.0134	-0.032 0.9040	0.385 0.1498	0.186 0.4860	0.231 0.4253	0.625 0.0194	-0.634 0.0571				
K	0.604 0.0239	0.779 0.0138	0.517 0.0533	0.175 0.5126	0.814 0.0023	0.847 0.0380	0.685 0.0104	0.118 0.6592	0.893 0.0008	0.392 0.1427	0.036 0.8937	0.664 0.0129	0.386 0.1490	0.879 0.0010	0.275 0.3035	0.188 0.5730	0.188 0.4818			
Se	0.558 0.0530	0.753 0.0172	0.229 0.4283	0.487 0.0916	0.823 0.0044	0.882 0.0308	0.822 0.0044	0.107 0.7101	0.671 0.0201	0.702 0.0150	-0.473 0.1012	0.905 0.0017	-0.025 0.9317	0.613 0.0336	0.223 0.4402	-0.251 0.4777	0.442 0.1257	0.682 0.0181		
V	0.675 0.0115	0.825 0.0091	0.518 0.0525	-0.136 0.6116	0.546 0.0409	0.793 0.0521	0.814 0.0023	-0.450 0.0922	0.671 0.0120	0.564 0.0350	-0.229 0.3924	0.811 0.0024	0.082 0.7586	0.639 0.0168	0.157 0.5565	-0.382 0.2520	0.417 0.1185	0.493 0.0652	0.536 0.0631	
Zn	0.393 0.1416	0.711 0.0246	0.679 0.0110	0.386 0.1490	0.782 0.0034	0.775 0.0577	0.857 0.0013	0.125 0.6400	0.679 0.0111	0.692 0.0096	0.246 0.3565	0.721 0.0069	0.611 0.0223	0.618 0.0208	0.686 0.0103	-0.345 0.3000	0.535 0.0452	0.725 0.0067	0.710 0.0139	0.607 0.0231

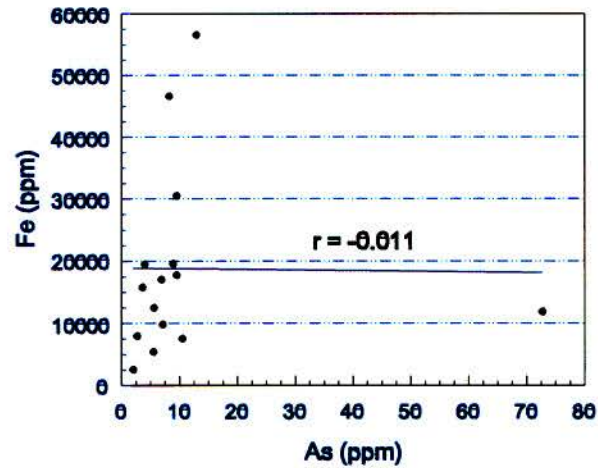


Figure 22. Arsenic concentration as a function of labile iron for the Freehold soil series. The simple linear regression correlation line is shown.

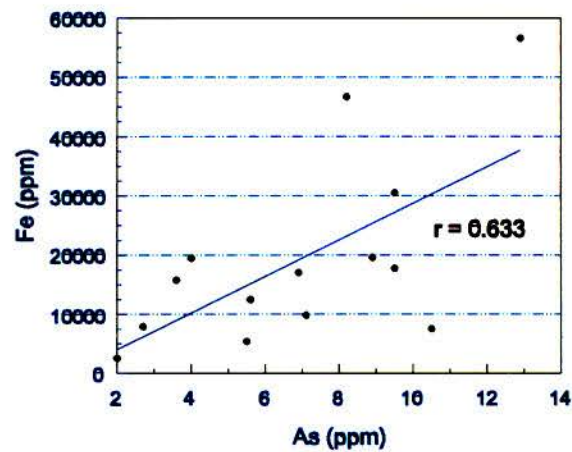


Figure 23. Arsenic concentration versus labile iron (excluding the 72.7 ppm arsenic outlier for MOFR1002) in the Freehold soil series. The simple linear regression correlation line ($\text{Fe}(\text{ppm}) = 3087\text{As}(\text{ppm}) - 2110$) is shown.

Holmdel Soil Series

Nine soil samples from four sampling stations were analyzed according to U. S. EPA SW-846, Methods 3050 and 6010A. The statistical summary of the analyte concentrations is shown in table 44.

Table 44. Statistical summary of analyte concentrations, determined by SW-846 Methods 3050 and 6010A, in the Holmdel soil series. All metal concentrations are in mg/kg (ppm). pH is standard units, and total organic carbon (TOC) and moisture (moist.) are expressed as weight percent.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	3.34	4.41	3.73	0.31	3.76	3.97	9
Al	1730	15500	4430	5237	6524	14200	9
Sb	1.0	3.3	1.6	0.7	1.7	1.9	9
As	2.4	11.2	5.7	3.1	6.1	9.8	9
Ba	8.0	43.5	15.4	10.8	18.1	23.4	9
Be	0.06	1.7	0.36	0.48	0.49	0.54	9
B	8.7	21.7	14.8	6.5	15.1	14.8	3
Cd	0.34	27.2	1.5	8.6	4.5	2.8	9
Ca	38.4	835	132	286	258	603	9
Cr	4.6	72.8	25.9	22.5	33.9	58.9	9
Co	0.98	5.5	1.5	1.4	2.1	2.8	9
Cu	1.5	8.4	3.8	2.4	4.3	7.6	9
Fe	2520	63700	16400	17826	21326	29500	9
Pb	3.8	51.3	11.8	15.4	16.5	25.2	9
Mg	129	1420	447	478	651	1200	9
Mn	5.4	92.5	45.6	28.1	42.0	63.2	9
Mo	0.14	1.5	0.34	0.57	0.57	0.73	5
Ni	1.6	10.2	2.4	2.8	3.4	3.5	8
K	162	3430	490	1099	1074	2100	9
Se	0.87	24.8	2.5	10.2	6.7	2.9	5
V	8.7	636	29.5	203	95.5	51.7	9
Zn	9.8	97.5	23	26	29	30	9
%TOC	0.06	4.59	1.01	1.41	1.35	2.32	9
%moist.	6.2	19.1	9.6	4.4	10.7	14.9	9

Soil pH ranges from 3.34 (BUHN4001) to 4.41 (CAHN3001) with a 3.73 median pH and a mean of 3.76 ± 0.31 . The relation between pH and calcium concentration is not clear. The

highest overall pH corresponds to moderate calcium concentrations (370 and 154 ppm) for station CAHN3000. Though only approximately a forty-foot swath of forest remains of the original forested parcel that lies adjacent to a former corn field, station CAHN3000 is at present a leaf-dumping site for a residential area. The highest calcium concentration (835 ppm — a mild outlier) is from a surface soil (BUHN2001) composite with a pH (3.61) less than the median and mean for this soil series. Sample BUHN4002 has a 3.70 pH with 603 ppm ‘recoverable’ calcium. Perhaps these samples of the Holmdel soil series with relatively elevated calcium and standard pHs formed from a relatively calcium-rich parent sediment. Apatite-group minerals, namely francolite $[\text{Ca}_5(\text{PO}_4, \text{CO}_3)_3\text{OH}]$, gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) and calcareous fossils (CaCO_3) can be common mineral constituents in glauconite-rich, marine sediment. Only trace amounts of these calcium minerals would be needed to account for the reported ‘recoverable’ calcium concentrations. Furthermore, the chemical weathering of these calcium minerals produces acids which would maintain the low pH for the soil.

Arsenic concentration ranges from 2.4 ppm (BUHN4002) to 11.2 ppm (CAHN3003) with a 5.7 ppm median and a 6.1 ± 3.1 ppm mean. None of the arsenic concentrations qualify as outliers, and all concentrations are in compliance with the RDCSCC guideline.

Beryllium concentration ranges from 0.06 ppm (MOHN1002) to 1.7 ppm (CAHN3003) with a median of 0.36 ppm and a mean of 0.49 ± 0.48 ppm. A beryllium concentration exceeding 1.31 ppm is an extreme outlier. Excluding the 1.7 ppm beryllium extreme outlier from the calculation yields a median beryllium concentration of 0.34 ppm and a 0.34 ± 0.16 ppm arithmetic mean. The ‘recoverable’ beryllium concentrations are in compliance with the RDCSCC.

A comparison of the median and mean concentrations for arsenic and beryllium in Holmdel soil series to those for the entire data set is shown in figure 24. The median beryllium and iron concentration in the Holmdel series soil is 1.4 times less than that for the entire data set.

The median arsenic and mean beryllium and iron concentrations are approximately 1.65 times less than that for all 113 soil samples. The mean arsenic concentration is 2.6 times less than that for the soils as a whole. These relative depletions in arsenic, beryllium and iron concentrations for the Holmdel soil series are expected for a glauconite-poor, quartz sand-rich soil (table 4).

A statistical summary for analytes in the 0- to 6-inch and 24- to 30-inch composites (36- to 42-inch composite for MOHN1002) for the Holmdel soil series is in table 45. Both the median and mean arsenic concentrations are remarkably constant in the surface-soil and deep-soil composites. Median and mean beryllium concentrations increase slightly with depth. The mean beryllium concentration remains constant with depth when the 1.70 ppm beryllium extreme outlier is omitted from the calculation. Curiously, median and mean lead concentrations increase with depth in the soil, unlike its concentration profile for the previous soil series.

Table 45. Statistical summary of analyte concentrations (in ppm) as a function of depth for the Holmdel soil series. Top value is the 0- to 6-inch and the bottom is the 24- to 30-inch composite. Concentrations omitting the extreme outliers are shown in parentheses ().

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	1730	8810	4425	3270	4848	6200	4
	1750	15500	3940	6244	6283	4430	4
As	3.5	9.8	6.1	3.1	6.4	8.1	4
	3.3	11.2	6.1	3.3	6.7	6.5	4
Be	0.23	0.53	0.29	0.13	0.34	0.31	4
	0.06	1.7 (0.54)	0.48 (0.42)	0.71 (0.25)	0.68 (0.34)	0.54 (0.42)	4 (3)
Fe	7010	22200	18750	7016	16678	21500	4
	2520	63700 (29500)	22950 (16400)	26208 (13492)	28030 (16140)	29500 (16400)	4 (3)
Pb	3.8	25.2	5.5	10.2	10.0	5.7	4
	6.5	51.3	19.5	19.6	24.2	24.8	4
K	246	2100	818	847	996	1210	4
	162	3430	369	1571	1083	490	4

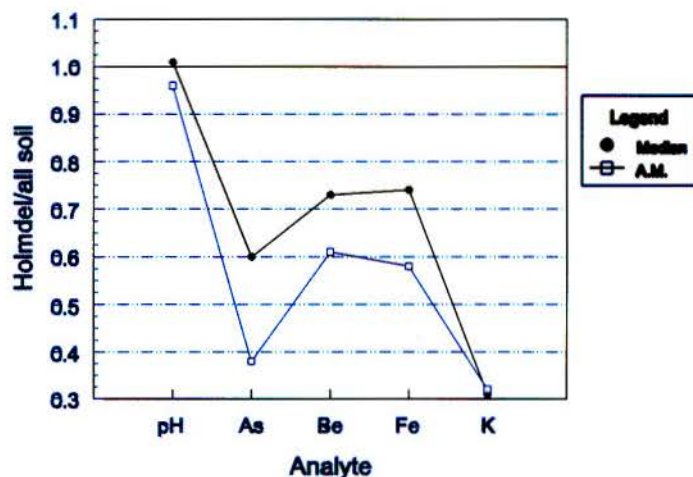


Figure 24. Ratio of median and mean analyte concentrations in the Holmdel soil series to those for the entire data set. A.M. is the ratio of means.

SRO correlations for the metals regressed against pH, weight percent total organic carbon, weight percent moisture, and percent glauconite sand, quartz sand and silt/clay are summarized in table 46. Aluminum regressed against weight percent moisture yields a strong, positive (0.833, $p = 0.0184$) SRO correlation. The linear regression correlation coefficient is a less robust, positive (0.658) relation between those two parameters. The positive relation between aluminum and percent moisture suggests that the clay (aluminosilicate) minerals are hydrated. Lead regressed against weight percent total organic carbon has a strong, negative (-0.833, $p = 0.0184$) SRO correlation, and a much less robust, negative (-0.580) linear regression correlation coefficient. The only significantly strong (0.833, $p = 0.0184$) SRO correlation for lead is with copper (table 47), which also has a moderate, negative (-0.667, $p = 0.0593$) SRO correlation with weight percent total organic carbon.

Arsenic has no significant SRO correlation with the parameters in table 46. It has a weak,

Table 46. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A for the Holmdel soil series as a function of pH, total organic carbon (%TOC), weight percent moisture, and granulometric parameters. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V	Zn	
pH	0.017 0.9624	0.571 0.1060	0.300 0.3961	0.000 1.0000	-0.050 0.8875	0.109 0.7583	0.267 0.4507	-0.083 0.8137	0.025 0.9434	0.167 0.6374	-0.050 0.8875	0.467 0.1869	0.117 0.7414	0.217 0.5400	-0.600 0.2301	0.036 0.9238	0.517 0.1439	-0.100 0.8415	0.083 0.8137	0.317 0.3704	pH
TOC	0.217 0.5400	-0.059 0.8679	0.100 0.7773	0.167 0.6374	-0.083 0.8137	0.192 0.5862	0.333 0.3458	0.217 0.5400	-0.209 0.5540	-0.667 0.0593	0.133 0.7061	-0.833 0.0184	0.417 0.2386	-0.383 0.2783	0.700 0.1515	0.024 0.9492	0.250 0.4795	0.100 0.8415	0.017 0.9624	-0.383 0.2783	TOC
Moisture	0.833 0.0184	0.361 0.3067	0.517 0.1439	0.733 0.0381	0.433 0.2203	0.636 0.0720	0.617 0.0811	0.667 0.0593	0.268 0.4488	0.083 0.8137	0.583 0.0990	-0.183 0.6041	0.733 0.0381	-0.300 0.3961	0.700 0.1615	0.916 0.0154	0.700 0.0477	0.700 0.1615	0.433 0.2203	0.100 0.7773	Moisture
%glau sd	-0.341 0.3348	-0.101 0.7743	-0.481 0.1738	-0.245 0.4886	-0.411 0.2451	-0.246 0.4868	-0.341 0.3348	-0.393 0.2658	-0.044 0.9012	0.026 0.9409	-0.297 0.4004	0.411 0.2451	-0.428 0.2256	-0.096 0.7856	-0.564 0.2591	-0.385 0.3082	-0.201 0.5695	-0.205 0.6815	-0.166 0.6384	-0.026 0.9409	%glau sd
%qtz sd	-0.203 0.5651	0.026 0.9422	-0.034 0.9236	-0.220 0.5331	-0.424 0.2307	0.026 0.9424	0.339 0.3376	0.085 0.8105	-0.443 0.2106	-0.373 0.2915	0.068 0.8479	-0.085 0.8105	-0.119 0.7372	-0.034 0.9236	-0.400 0.4237	-0.568 0.1329	0.051 0.8856	0.718 0.1509	-0.203 0.5651	-0.170 0.6316	%qtz sd
%slt-cly	0.151 0.6701	0.122 0.7293	0.234 0.5075	0.075 0.8313	0.360 0.3088	-0.021 0.9526	-0.251 0.4777	0.075 0.8313	0.332 0.3478	0.251 0.4777	0.042 0.9058	-0.025 0.9434	0.109 0.7583	-0.067 0.8498	0.700 0.1615	0.527 0.1630	-0.075 0.8313	-0.600 0.2301	0.075 0.8313	0.033 0.9246	%slt-cly

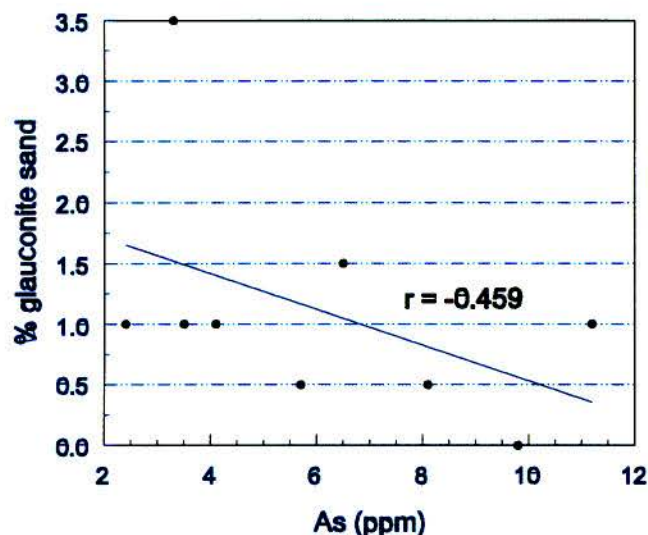


Figure 25. Arsenic concentration versus percent glauconite sand in the Holmdel soil series. The simple linear regression correlation line is shown.

negative (-0.481, $p = 0.1738$) SRO correlation with percent glauconite sand. Arsenic concentration plotted against percent glauconite sand is shown in figure 25. The simple linear regression correlation coefficient is an equally weak, negative value (-0.459) for arsenic regressed against percent glauconite sand. Beryllium exhibits no significant SRO correlation with the parameters in table 46.

Table 47 is the SRO correlation table for the analytes. Statistically significant, strong, positive SRO correlations occur between: aluminum and barium, aluminum and magnesium, aluminum and nickel, aluminum and potassium, beryllium and cobalt, chromium and iron, magnesium and barium, magnesium and potassium, arsenic and chromium, and arsenic and iron. The strong, positive SRO correlations among aluminum, chromium, iron, magnesium and vanadium, constituent elements in glauconite and/or phyllosilicates, provide strong evidence that

Table 47. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A analytes in the Holmdel soil series. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V
Sb	0.370 0.2956																		
As	0.483 0.1716	0.874 0.0134																	
Ba	0.967 0.0063	0.252 0.476	0.333 0.3458																
Be	0.683 0.0533	0.345 0.3298	0.600 0.0897	0.667 0.0593															
Cd	0.828 0.0191	0.675 0.0562	0.753 0.0332	0.795 0.0245	0.720 0.0418														
Ca	0.333 0.3458	0.000 1.0000	0.050 0.8875	0.233 0.5093	-0.217 0.5400	0.025 0.9434													
Cr	0.683 0.0533	0.672 0.0572	0.867 0.0142	0.567 0.1090	0.667 0.0593	0.895 0.0113	0.050 0.8875												
Co	0.628 0.0759	0.485 0.1699	0.536 0.1298	0.653 0.0649	0.879 0.0129	0.761 0.0315	-0.469 0.1850	0.611 0.0840											
Cu	-0.117 0.7414	-0.353 0.3181	-0.333 0.3458	-0.100 0.7773	0.000 1.0000	-0.469 0.1850	0.217 0.5400	-0.467 0.1869	-0.167 0.6359										
Fe	0.667 0.0593	0.689 0.0513	0.850 0.0162	0.583 0.0990	0.717 0.0427	0.929 0.0086	-0.083 0.8137	0.983 0.0054	0.711 0.0442	-0.483 0.1716									
Pb	-0.350 0.3222	-0.092 0.7937	-0.267 0.4507	-0.333 0.3458	-0.167 0.6374	-0.469 0.1850	0.050 0.8875	-0.500 0.1573	-0.167 0.6359	0.833 0.0184	-0.467 0.1869								
Mg	0.950 0.0072	0.487 0.168	0.600 0.0897	0.900 0.0109	0.667 0.0593	0.879 0.0129	0.317 0.3704	0.733 0.0381	0.611 0.0840	-0.333 0.3458	0.717 0.0427	-0.500 0.1573							
Mn	-0.183 0.6041	0.076 0.8306	0.233 0.5093	-0.133 0.7061	0.500 0.1573	0.075 0.8313	-0.417 0.2386	0.067 0.8504	0.360 0.3088	0.200 0.5716	0.167 0.6374	0.333 0.3458	-0.133 0.7061						
Mo	0.300 0.5485	0.718 0.1509	0.600 0.2301	0.300 0.5485	0.300 0.5485	0.600 0.2301	0.200 0.6892	0.700 0.1615	0.300 0.5485	-0.600 0.2301	0.700 0.1615	-0.700 0.1615	0.300 0.5485	-0.700 0.1615					
Ni	0.855 0.0236	0.250 0.5083	0.325 0.3894	0.819 0.0302	0.675 0.0742	0.563 0.1359	0.386 0.3077	0.458 0.2257	0.582 0.1237	0.217 0.5661	0.458 0.2257	-0.096 0.7987	0.723 0.0558	-0.229 0.5447	0.632 0.2733				
K	0.817 0.0209	0.622 0.0786	0.533 0.1314	0.767 0.0301	0.367 0.2997	0.745 0.0352	0.517 0.1439	0.533 0.1314	0.393 0.2659	-0.200 0.5716	0.517 0.1439	-0.200 0.5716	0.867 0.0142	-0.233 0.5093	0.300 0.5485	0.602 0.1109			
Se	0.700 0.1615	0.500 0.3173	0.500 0.3173	0.500 0.3173	0.700 0.1615	0.900 0.0719	0.200 0.6892	0.900 0.0719	0.900 0.0719	-0.500 0.3173	0.900 0.0719	-0.100 0.8415	0.600 0.2301	0.800 0.1096	-0.500 0.4795	0.359 0.4726	0.600 0.2301		
V	0.783 0.0267	0.471 0.1832	0.567 0.1090	0.817 0.0209	0.883 0.0125	0.895 0.0113	-0.200 0.5716	0.700 0.0477	0.921 0.0092	-0.267 0.4507	0.783 0.0267	-0.300 0.3961	0.800 0.0237	0.333 0.3458	0.300 0.5485	0.590 0.1183	0.600 0.0897	0.900 0.0719	
Zn	0.367 0.2997	0.445 0.2078	0.517 0.1439	0.400 0.2579	0.817 0.0209	0.586 0.0976	-0.367 0.2997	0.450 0.2031	0.812 0.0217	0.050 0.8875	0.567 0.1090	0.183 0.6041	0.383 0.2783	0.783 0.0267	-0.400 0.4237	0.349 0.3552	0.283 0.4229	0.900 0.0719	0.800 0.0237

these elements are associated with these mineral species.

The strong, positive SRO correlation between arsenic and iron (0.850, $p = 0.0162$), and arsenic and chromium (0.867, $p = 0.0142$) suggests that iron phases control the arsenic concentration in the Holmdel soil series. The strong, positive correlation iron has with chromium and vanadium (and aluminum) results from the known isomorphous substitution of these elements in iron oxides (McBride, 1989). These substitutions in the iron oxide lattice lower the crystallinity of the iron oxide, thereby reducing its stability, which increases its solubility (McBride, 1989). Furthermore, the weak correlation iron has with constituent elements in glauconite and/or phyllosilicates supports the interpretation that iron phases, rather than glauconite and/or phyllosilicates, control arsenic concentrations in this soil series.

Figure 26 is a graph of the arsenic concentration plotted against iron concentration. Both the SRO correlation (0.850, $p = 0.0162$) and simple linear regression correlation coefficient (0.793) demonstrate the strong, positive relation between arsenic and iron for this soil series.

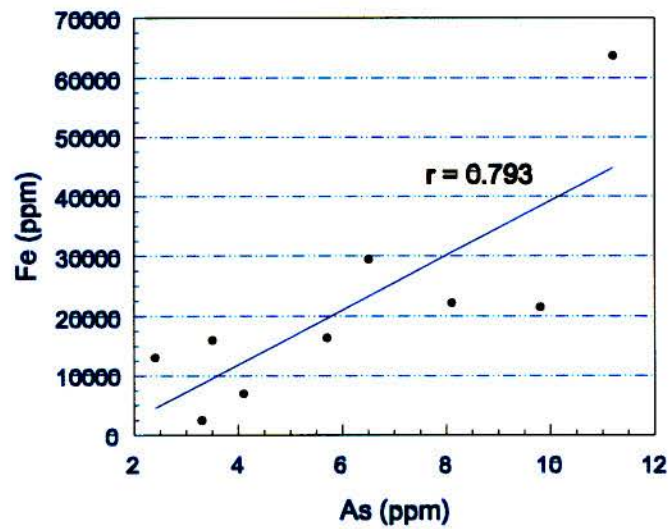


Figure 26. Arsenic concentration versus labile iron concentration in the Holmdel soil series. The simple linear regression correlation line ($\text{Fe}(\text{ppm}) = 4578\text{As}(\text{ppm}) - 6448$) is shown.

Kresson Soil Series

Eleven soil samples from five sampling stations were analyzed according to U. S. EPA SW-846, Methods 3050 and 6010A. The statistical summary of the analyte concentrations is presented in table 48.

Table 48. Statistical summary of analyte concentrations, determined by SW-846 Methods 3050 and 6010A, in the Kresson soil series. All metal concentrations are in mg/kg (ppm). pH is standard units, and percent total organic carbon (TOC) and moisture (moist.) are expressed as weight percent.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	3.35	6.19	3.63	0.82	3.89	4.38	11
Al	3150	28400	7690	7770	11106	21400	11
Sb	0.82	13.3	2.25	4.5	4.3	10.7	10
As	2.3	53.2	10.9	18.2	17.3	50.6	11
Ba	10.5	87.9	24.7	22.8	31.3	60.1	11
Be	0.27	4.3	0.60	1.51	1.23	4.2	11
B	15.8	219	33.5	82.2	72.8	161	7
Cd	1.3	14	2.1	5.0	4.7	13.8	11
Ca	16.5	2120	167	777	519	1810	10
Cr	9.6	702	29	228	140	452	11
Co	1.3	7	2.4	1.9	3.2	6.2	11
Cu	1.9	7.2	3.7	1.9	4.5	6.8	11
Fe	11100	13800	25100	47319	45591	130000	11
Pb	4	48	19.7	13.5	19.2	30.1	11
Mg	366	9840	1260	3104	2581	7430	11
Mn	5.2	198	51.8	54.9	62.1	123	11
Mo	0.19	1.0	0.67	0.26	0.63	0.71	6
Ni	0.51	16.8	3.1	5.1	4.6	11.9	11
K	133	43800	2240	13593	7797	23100	11
Se	1.9	4.7	2.4	1.1	2.8	3.6	6
Ag	0.25	0.88	0.51	0.27	0.54	0.60	4
V	13.5	198	30.2	70.1	63.6	189	11
Zn	15.1	250	27.7	80.7	63.2	196	11
%TOC	0.30	3.13	0.92	0.98	1.14	2.68	11
%moist.	10.8	26.8	21.3	5.9	20.0	26.3	11

Soil pH ranges from 3.35 (MOKR2002) to 6.19 (GLKR5001) with a 3.63 median pH and a mean of 3.89 ± 0.82 . A pH exceeding 4.72 is an extreme outlier. Excluding the 6.19 pH

extreme outlier from the calculation yields a median pH of 3.58 and a mean of 3.66 ± 0.31 . The extreme outlier pH of 6.19 for GLKR5001 is in the 0- to 6-inch composite from an actively cultivated field. The highest pH is in the surface soil composite from a cultivated field with 406 ppm calcium. The two highest 'recoverable' calcium concentrations, 2,120 ppm for MOKR2003 and 1,810 ppm for MOKR1001, in this series correspond to pH values of 3.44 and 4.38, respectively. For station MOKR2000, the pH remains constant (3.35 to 3.44) over the 0- to 30-inch depth in the soil, whereas the calcium concentration is less than the 3.5 ppm MDL in the 0- to 6-inch composite (Ap horizon), 61.5 ppm in the 12- to 18-inch composite (B21t horizon) and 2,120 ppm in the 24- to 30-inch composite (B22t horizon). Data do not support translocation of calcium from the surface soil (for example, a limed soil) to deeper in the pedon. The highest calcium concentration and relatively high barium concentration (87.9 ppm with a 19.7 ppm median and 37 ± 79 ppm mean for all 113 soil samples, table 24) may result from a local concentration of carbonate and/or apatite-group minerals. In other words, the parent sediment for this soil may have been a true marl.

Arsenic concentration ranges from 2.3 ppm (MOKR2001) to 53.2 ppm (MOKR1002) with a 10.9 ppm median and a 17.3 ± 18.2 ppm mean. An arsenic concentration exceeding 52.7 ppm is an extreme outlier. Omitting the 53.2 ppm arsenic extreme outlier from the calculation yields a 8.6 ppm median and a mean of 13.7 ± 14.5 ppm. Three (MOKR1001 with 50.6 ppm, MOKR1002 with 53.2 ppm and MOKR2002 with 23.7 ppm) of the 11 soil samples exceed the RDCSCC guideline for arsenic.

Beryllium concentration ranges from 0.27 ppm (CAKR4001) to 4.3 ppm (MOKR1001) with a median of 0.60 ppm and a mean of 1.23 ± 1.51 ppm. A beryllium concentration exceeding 2.16 ppm is an extreme outlier. Excluding the 4.30 ppm (MOKR1001) and 4.20 ppm (MOKR1002) beryllium extreme outliers yields a 0.51 ppm median and a 0.56 ± 0.24 ppm mean. Two of the 11 soil samples exceed the RDCSCC for beryllium.

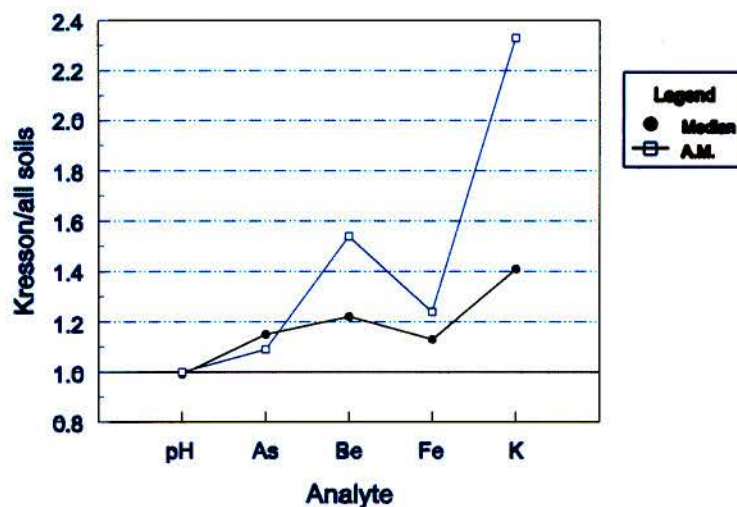


Figure 27. Ratio of median and mean analyte concentrations in the Kresson soil series to those for the entire data set. A.M. is the ratio of means.

The ratio of median and means between pH, arsenic, beryllium, iron and potassium for Kresson soil series to those for the 113 soil samples (table 24) is plotted in figure 27. The median and mean pH for the Kresson series is identical to that for all 113 soils studied herein. Arsenic concentration is slightly enriched relative to the entire data set. The median and mean beryllium concentration is enriched 1.2 and 1.5 times, respectively, over that for the entire data set. Median and mean iron concentration is enriched 1.13 and 1.24 times, respectively, over that for the 113 soil samples. The mean potassium concentration is enriched 2.33 times that for the entire data set. The high 'recoverable' potassium concentration likely results from the high concentration of clay-size phyllosilicates and glauconite that is generally characteristic of this soil series (tables 4 and 5). The B horizon of the Kresson soil series is characterized by glauconite sand embedded in a soft, waxy, greenish clay/silt matrix ("plasma").

The percent extraction efficiency in Kresson soil series was calculated for aluminum,

arsenic, beryllium, iron, lead and potassium. With the exception for beryllium, soil samples from station CAKR4000 have the lowest percent extraction efficiency for the 14 samples subjected to this analysis. On the other hand, station MOKR1000 samples have the highest percent extraction efficiency. The wide range in extraction efficiency exhibited in samples from these two stations apparently relates to matrix differences. Both samples from station MOKR1000 have the glauconite sand embedded in the soft, waxy, green silt/clay matrix, whereas those from station CAKR4000 lack this greenish silt/clay matrix. Furthermore, though both stations were well drained, the soil was moist down to 30 inches (TD) for MOKR1000 and dry to very slightly moist for CAKR4000. Therefore, even within a given soil series, the range in soil character greatly influences the efficacy of the prescribed acid-leach protocol.

The percent extraction efficiency for arsenic ranges from 5 (CAKR4003) to 69 (MOKR1002), both from the B22t horizon, with a 33.8 ± 32.2 mean. The mean percent extraction efficiency for arsenic is 39 ± 18 for the 14 soil samples (table 18). The percent extraction efficiency for beryllium ranges from 4 (CAKR4001) to 37 (MOKR1002) with a mean of 21.0 ± 17.9 . The mean percent extraction efficiency for beryllium is 16 ± 11 for all 14 samples. For the 14 samples, the lowest mean percent extraction efficiency for iron and potassium is 7 and 0.35, respectively, in soil from station CAKR4000, whereas samples from station MOKR1000 have the highest mean percent extraction efficiency for iron and potassium (62.5 and 57, respectively). The mean percent extraction efficiency for iron and potassium in the 14 samples (table 18) is 30 ± 21 and 15 ± 19 , respectively. Based on the soil character (appendix 2) and percent extraction efficiency, it appears that quality (for example, crystallinity) of the soil matrix strongly dictates the quantity of 'recoverable' analytes liberated by the prescribed acid-leach protocol.

A statistical summary of analyte concentrations in the 0- to 6-inch and 24- to 30-inch depth composites is shown in table 49. The median arsenic and beryllium concentrations increase with depth in the soil. The mean arsenic concentration increases with depth unless the

53.2 ppm extreme outlier is excluded from the calculation. The mean beryllium concentration decreases slightly with depth, with or without excluding the extreme outliers.

Table 49. Statistical summary of analyte concentrations (in ppm) as a function of depth for the Kresson soil series. Top value is the 0- to 6-inch and the bottom is the 24- to 30-inch composite. Concentrations omitting the extreme outliers are shown in parentheses ().

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	3150	21400	7780	6904	10424	12100	5
	4700	28400	7310	9867	10870	7660	5
As	2.3	50.6	5.3	20.3	14.7	10.9	5
	4.7	53.2 (16.7)	12.4 (9.3)	19.9 (5.6)	18.6 (10.0)	16.7 (12.4)	5 (4)
Be	0.27	4.3 (0.98)	0.51 (0.48)	1.7 (0.30)	1.3 (0.55)	0.98 (0.51)	5 (4)
	0.29	4.2 (0.64)	0.60 (0.53)	1.7 (0.16)	1.2 (0.50)	0.64 (0.60)	5 (4)
Fe	11500	130000 (26000)	15800 (14400)	51040 (6531)	39260 (16575)	26000 (15800)	5 (4)
	11100	138000 (38700)	25100 (21600)	52322 (11780)	46200 (23250)	38700 (25100)	5 (4)
Pb	5.6	29.3	19.5	10.0	16.5	21.1	5
	4.0	48.0	19.7	18.5	21.3	30.1	5
K	162	23100 (2240)	2140 (1755)	9705 (960)	5802 (1478)	2240 (2140)	5 (4)
	133	43800 (4430)	3270 (1839)	18757 (2123)	10408 (2060)	4430 (3270)	5 (4)

Spearman rank-order (SRO) correlations for the metals regressed against pH, weight percent total organic carbon, weight percent moisture, and percent glauconite sand, quartz sand and silt/clay are summarized in table 50. Molybdenum has a strong, positive SRO correlation with percent quartz sand. This correlation is based on only six data points. Molybdenum (MoO_4^{2-} is the thermodynamically stable species) is chemisorbed in soils by oxides (McBride, 1994), although its sorption directly onto quartz is unlikely.

Table 50. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A for the Kresson soil series as a function of pH, total organic carbon (%TOC), weight percent moisture, and granulometric parameters. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where -0.750 < r > 0.750.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V	Zn	
pH	-0.236 0.4548	-0.267 0.4223	-0.209 0.5085	0.187 0.5547	-0.173 0.5849	0.464 0.2554	-0.114 0.7187	0.200 0.5485	-0.391 0.2164	-0.215 0.4973	0.156 0.6227	-0.264 0.4045	-0.045 0.8857	-0.327 0.3007	0.418 0.1860	0.257 0.5653	0.127 0.6873	-0.327 0.3007	0.261 0.5596	-0.309 0.3284	-0.355 0.2622	pH
TOC	0.245 0.4376	-0.195 0.5595	-0.255 0.4209	-0.337 0.2864	-0.027 0.9313	-0.536 0.1894	-0.314 0.3202	-0.503 0.1313	0.136 0.6663	-0.187 0.5538	0.375 0.2353	-0.064 0.8405	-0.173 0.5849	-0.164 0.6048	-0.527 0.0954	0.543 0.2248	-0.191 0.5460	-0.045 0.8857	-0.203 0.6500	0.373 0.2385	-0.273 0.3884	TOC
Moisture	0.409 0.1958	0.693 0.0376	0.664 0.0359	0.210 0.5075	0.636 0.0442	-0.036 0.9303	0.287 0.3641	0.018 0.9565	0.573 0.0701	0.470 0.1369	0.238 0.4517	0.600 0.0578	0.527 0.0954	0.555 0.0795	-0.182 0.5653	0.371 0.4062	-0.218 0.4902	0.636 0.0442	0.029 0.9483	0.336 0.2875	0.727 0.0215	Moisture
%glau sd	-0.196 0.5347	0.196 0.5571	0.237 0.4527	-0.549 0.0824	0.041 0.8966	0.600 0.1416	0.037 0.9078	-0.122 0.7153	-0.100 0.7507	0.227 0.4727	0.080 0.7992	0.046 0.8852	0.233 0.4615	-0.196 0.5347	0.685 0.0303	-0.522 0.2433	0.329 0.2985	-0.237 0.4527	0.088 0.8436	0.178 0.5733	-0.005 0.9885	%glau sd
%qtz sd	0.118 0.7086	-0.255 0.4437	-0.300 0.3428	0.141 0.6552	0.045 0.8857	-0.571 0.1616	-0.223 0.4802	-0.236 0.4783	0.036 0.9085	-0.452 0.1528	-0.059 0.8508	-0.018 0.9542	-0.491 0.1206	-0.118 0.7086	-0.682 0.0311	0.943 0.0350	-0.455 0.1506	-0.064 0.8405	0.319 0.4758	-0.055 0.8631	-0.309 0.3284	%qtz sd
%slt-cly	-0.045 0.8857	0.061 0.8553	0.164 0.6048	0.314 0.3202	-0.091 0.7737	0.000 1.0000	0.210 0.5075	0.382 0.2520	-0.073 0.8181	0.397 0.2090	0.581 0.0661	-0.109 0.7301	0.600 0.0578	0.209 0.5085	0.364 0.2502	-0.657 0.1417	0.164 0.6048	0.200 0.5271	-0.493 0.2705	-0.100 0.7518	0.336 0.2875	%slt-cly

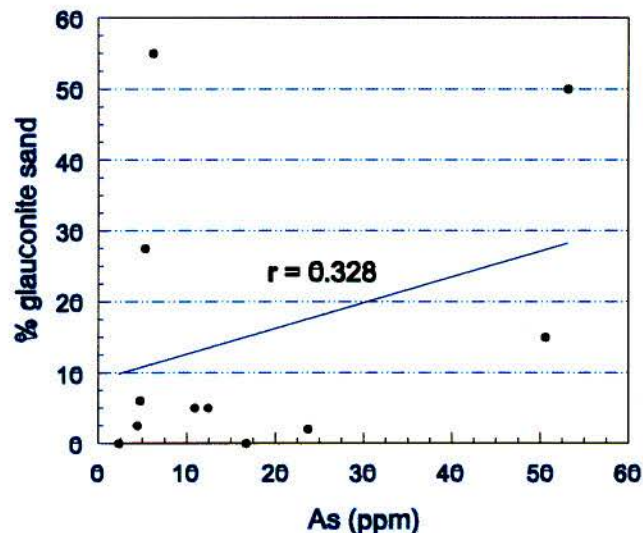


Figure 28. Arsenic concentration versus percent glauconite sand in the Kresson soil series. The simple linear regression correlation line is shown.

The point of zero charge (pzc), defined as the pH at which a surface has a net charge of zero, is approximately 2.0 pH for quartz (Sparks, 1995). The surface of quartz is electronegative at pH ~3.7 for the soil. Therefore, the anionic molybdenum species should not be adsorbed by the quartz sand because like charges repel. No statistically significant SRO correlations were found among the parameters in table 50.

Arsenic regressed against percent glauconite sand provides a weak, positive (0.237, $p = 0.4527$) SRO correlation and a weak, positive (0.328) linear regression correlation coefficient. Arsenic plotted against percent glauconite sand is shown in figure 28. The arsenic concentration shows no discernible, rational relation with percent glauconite sand in Kresson soil series. Excluding the 53.2 ppm arsenic extreme outlier yields a much weaker and negative linear regression correlation coefficient (-0.075).

Table 51 is a SRO correlation table for the analytes. Generally, there is a significant, strong to moderate, positive SRO correlation among aluminum, beryllium, boron, chromium, iron, magnesium, potassium and zinc. These are constituent elements in phyllosilicates and glauconite. Arsenic regressed against beryllium, boron, chromium, iron and zinc shows significant, moderate to strong, positive SRO correlations. The SRO correlations arsenic has with constituent elements in glauconite and phyllosilicate minerals suggest that the arsenic is associated with these minerals. This interpretation does not contradict the weak, positive correlation between arsenic and percent glauconite sand in the soil (fig. 28). It is not known how much glauconite, glauconite-like and/or phyllosilicate minerals are in the soft, waxy, greenish clay/silt matrix, which is characteristic of this soil series. Accurately knowing the total amount of glauconite in the soil samples might yield a robust, positive linear relation between arsenic and glauconite concentration, which would provide evidence to support the robust, positive SRO correlations between arsenic and constituent elements in glauconite $\pm$ phyllosilicates.

Arsenic regressed against labile iron yields a very strong, positive (0.918, $p = 0.0037$) SRO correlation. The linear regression correlation coefficient is 0.993 for arsenic regressed against iron. The linear correlation between arsenic and labile iron is shown in figure 29.

Omitting the 53.2 ppm arsenic extreme outlier yields a 0.988 linear regression correlation coefficient. This very strong, positive correlation suggests that the arsenic is intimately associated with labile iron in the Kresson series soil. It is known that the iron in this soil series occurs as: 1) amorphous to crystalline iron phases that coat or bridge constituent minerals in the soil (appendix 2), and 2) possibly neoformed, iron-bearing aluminosilicate phases, which likely have a range of crystallinity, in the soft, waxy, greenish clay/silt matrix ("plasma").

Table 51. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A analytes for the Kresson soil series. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V
Sb	0.748 0.0249																			
As	0.500 0.1138	0.894 0.0073																		
Ba	-0.009 0.9770	-0.055 0.8692	-0.036 0.9082																	
Be	0.736 0.0199	0.900 0.0070	0.818 0.0097	0.091 0.7732																
B	0.571 0.1616	0.883 0.0306	0.964 0.0182	-0.214 0.5997	0.643 0.1153															
Cd	0.560 0.0764	0.689 0.0387	0.743 0.0189	0.155 0.6234	0.670 0.0342	0.821 0.0442														
Ca	0.261 0.4343	0.142 0.6874	0.212 0.5245	0.620 0.0629	0.297 0.3730	0.371 0.4062	0.657 0.0489													
Cr	0.818 0.0097	0.900 0.0070	0.818 0.0097	-0.059 0.8514	0.864 0.0063	0.857 0.0358	0.706 0.0255	0.188 0.5730												
Co	0.721 0.0225	0.780 0.0193	0.539 0.0884	0.030 0.9251	0.626 0.0479	0.577 0.1578	0.426 0.1783	0.292 0.3814	0.557 0.0781											
Cu	0.105 0.7392	-0.073 0.8257	0.023 0.9423	0.009 0.9769	0.027 0.9308	-0.108 0.7911	-0.067 0.8334	0.110 0.7419	-0.078 0.8057	0.283 0.3712										
Fe	0.700 0.0269	0.912 0.0062	0.918 0.0037	-0.046 0.8854	0.927 0.0034	0.929 0.0230	0.770 0.0149	0.188 0.5730	0.945 0.0028	0.516 0.1027	-0.128 0.6853									
Pb	0.491 0.1206	0.523 0.1168	0.400 0.2059	0.100 0.7513	0.382 0.2273	0.607 0.1370	0.210 0.5075	0.297 0.3730	0.264 0.4045	0.845 0.0076	0.595 0.0599	0.245 0.4376								
Mg	0.800 0.0114	0.827 0.0131	0.736 0.0199	0.278 0.3795	0.800 0.0114	0.857 0.0358	0.875 0.0057	0.600 0.0719	0.855 0.0069	0.621 0.0496	-0.023 0.9423	0.827 0.0089	0.409 0.1958							
Mn	0.009 0.9771	0.097 0.7704	0.109 0.7301	0.100 0.7513	0.109 0.7301	0.393 0.3359	0.182 0.5644	0.539 0.1056	-0.164 0.6048	0.521 0.0997	0.238 0.4517	-0.055 0.8631	0.555 0.0795	0.073 0.8181						
Mo	0.600 0.1797	-0.154 0.7582	0.029 0.9491	0.257 0.5653	0.657 0.1417	0.500 0.4795	0.143 0.7494	0.300 0.5485	0.257 0.5653	-0.377 0.3994	0.058 0.8969	0.314 0.4822	0.143 0.7494	0.543 0.2248	-0.429 0.3379					
Ni	0.418 0.1860	0.249 0.4546	0.045 0.8857	0.137 0.6656	0.227 0.4723	0.357 0.3817	0.287 0.3641	0.624 0.0611	0.173 0.5849	0.584 0.0646	0.037 0.9078	0.091 0.7737	0.436 0.1676	0.373 0.2385	0.727 0.0215	-0.257 0.5653				
K	0.818 0.0097	0.900 0.0070	0.773 0.0145	0.255 0.4198	0.800 0.0114	0.929 0.0230	0.797 0.0117	0.467 0.1615	0.900 0.0044	0.607 0.0548	0.046 0.8849	0.845 0.0075	0.445 0.1589	0.973 0.0021	-0.027 0.9313	0.486 0.2774	0.291 0.3576			
Se	-0.464 0.2997	0.564 0.2591	0.812 0.0695	0.174 0.6973	0.609 0.1734	NA NA	0.609 0.1734	-0.564 0.2591	0.319 0.4758	-0.716 0.1091	-0.851 0.0571	0.841 0.0601	-0.725 0.1051	0.058 0.8969	-0.319 0.4758	1.000 0.8415	-0.986 0.0275	0.203 0.6500		
V	0.782 0.0134	0.772 0.0206	0.609 0.0541	-0.483 0.1267	0.636 0.0442	0.607 0.1370	0.396 0.2101	-0.236 0.4783	0.818 0.0097	0.635 0.0447	0.124 0.6960	0.709 0.0249	0.373 0.2385	0.527 0.0954	-0.055 0.8631	-0.143 0.7494	0.218 0.4902	0.600 0.0578	-0.116 0.7954	
Zn	0.709 0.0249	0.960 0.0040	0.873 0.0058	0.228 0.4713	0.845 0.0075	0.893 0.0287	0.747 0.0181	0.418 0.2096	0.845 0.0075	0.781 0.0135	0.064 0.8394	0.855 0.0069	0.591 0.0617	0.900 0.0044	0.191 0.5460	0.029 0.9491	0.309 0.3284	0.909 0.0040	0.116 0.7954	0.600 0.0578

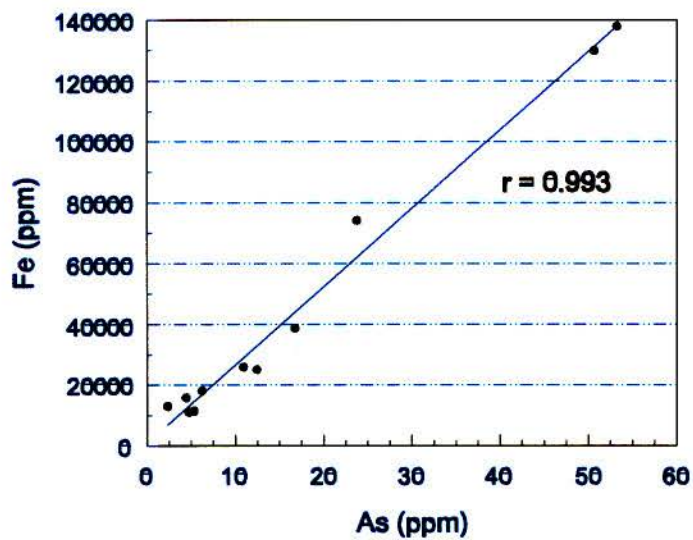


Figure 29. Arsenic concentration versus labile iron concentration in the Kresson soil series. The simple linear regression correlation line ($\text{Fe}(\text{ppm}) = 2578\text{As}(\text{ppm}) - 964$) is shown.

Marlton Soil Series

Fifteen soil samples from six sampling stations were analyzed according to U. S. EPA SW-846, Methods 3050 and 6010A. The statistical summary of the analyte concentrations is presented in table 52.

Table 52. Statistical summary of analyte concentrations, determined by SW-846 Methods 3050 and 6010A, in the Marlton soil series. All metal concentrations are in mg/kg (ppm). pH is standard units, and percent total carbon (TOC) and moisture (moist.) are expressed as weight percent.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	3.15	4.73	3.45	0.37	3.53	3.67	15
Al	6480	21700	10100	3700	11246	13500	15
Sb	1.5	17.2	4.7	3.6	5.7	6.9	15
As	6.8	81.5	25.6	23.8	33.3	63.3	15
Ba	5.7	53.3	14.5	16.4	22.4	44.8	15
Be	0.4	3.5	0.98	0.75	1.14	1.4	15
B	14.8	119	50.9	27.6	55.1	81.5	15
Cd	1.4	11.2	4.2	2.3	4.7	5.8	15
Ca	19.5	1740	81	661	397	1710	11
Cr	60.7	711	154	163	187	292	15
Co	1.9	6.2	3.2	1.1	3.2	3.8	15
Cu	1.9	9.7	5.3	1.9	5.3	6.7	15
Fe	16300	168000	43800	38125	57613	92900	15
Pb	6.3	91.1	13.3	23.7	23.7	51.2	15
Mg	907	5450	2140	1158	2550	3620	15
Mn	6.1	128	21.2	28.9	29.1	36.3	15
Mo	0.22	2.7	0.51	0.98	1.07	2.4	10
Ni	0.43	6.9	2.8	2.1	3.2	5.3	14
K	1700	16200	5660	3722	6951	10300	15
Se	3.4	11.8	4.8	2.7	5.6	7.0	8
V	24.5	250	71	56	78.0	104	15
Zn	23.5	181	39.6	39.9	56	73.8	15
%TOC	0.18	3.83	0.49	1.21	1.13	2.39	15
%moist.	9.9	28.7	22.5	6.0	22.1	27.9	15

Soil pH ranges from 3.15 (MOMR1001) to 4.73 (BUMR4001) with a median pH of 3.45 and a 3.53 ± 0.37 mean. A pH exceeding 4.26 is an extreme outlier. Excluding the 4.73 pH

extreme outlier for BUMR4001 from the calculation yields a 3.44 median pH and a mean of 3.44 ± 0.16 . The higher pHs tend to correspond to relatively high calcium concentrations, although the highest calcium concentration (1,740 ppm for BUMR4003) has a 3.38 pH. The highest pH (4.73) corresponds to 1710 ppm calcium. Station BUMR4000 has been an actively cultivated field for corn and winter wheat for the past 13 years according to the owner. The high calcium and low pH for BUMR4003 might be caused by the application of lime in addition to ammonium fertilizers. The application of ammonium fertilizers as a source for nitrogen, an essential plant nutrient, to an acid soil provides acidity (H^+) by:



The second highest pH (3.70) corresponds to 264 ppm calcium, which is the third highest calcium concentration for this soil series.

Arsenic concentration ranges from 6.8 ppm (BUMR40043) to 81.5 ppm (MOMR3003) with a 25.6 ppm median and a 33.3 ± 23.8 ppm mean. The median and mean arsenic concentration for this soil series exceed the RDCSCC guideline set at 20 ppm arsenic. Nine of the 15 soil samples (60 percent) exceed the RDCSCC guideline. Though none of the samples qualify as an extreme outlier for arsenic (greater than or equal to 98.5 ppm), two soil samples (MOMR1002 with 72.3 ppm and MOMR3003 with 81.5 ppm) qualify as mild outliers (arsenic greater than or equal to 66.85 ppm). The lowest 'recoverable' arsenic concentrations (6.8 and 8.2 ppm), and the second highest beryllium concentration, are from the actively cultivated field (station BUMR4000), which has a high concentration of glauconite sand (appendix 2).

Beryllium concentration ranges from 0.4 ppm (MOMR2001) to 3.5 ppm (MOMR3003) with a 0.98 ppm median and a mean of 1.14 ± 0.75 ppm. One of the 15 samples exceeds the RDCSCC guideline. A beryllium concentration exceeding 2.03 ppm is an extreme outlier. Omitting the 3.5 ppm beryllium extreme outlier for MOMR3003 from the statistical calculation yields a 0.96 ppm median and a 0.97 ± 0.38 ppm mean.

The ratio of select median and mean analyte concentrations in Marlton soil series to those for the entire data set is plotted in figure 30. The median and mean pH for the Marlton soil series is slightly less (more acidic) than that for the glauconite-bearing soils as a whole. A ratio of approximately two is calculated for median concentration for beryllium and iron, and for mean concentration for arsenic and potassium. This demonstrates that the median beryllium and iron concentrations, and mean arsenic and potassium concentrations in the Marlton series are enriched by a factor of two over that for all 113 soil samples. The median arsenic concentration is enriched 2.7 times over the median for the entire suite of soil samples. Median and mean potassium is enriched 3.6 and 2.1 times, respectively, over the data set as a whole. The highest mean glauconite sand (19.7 percent) and silt/clay (63.5 percent) fractions comprise this soil series and are reflected in the overall high potassium and beryllium concentrations. The Marlton soil series is characterized by having glauconite sand embedded in the soft, waxy, greenish

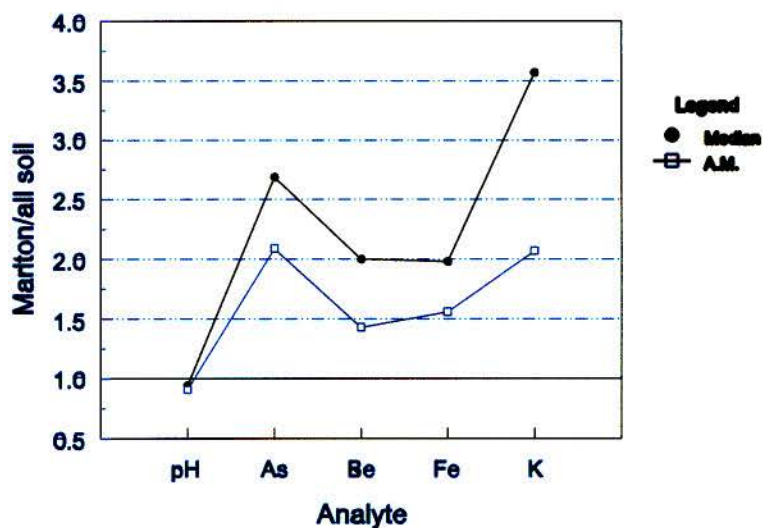


Figure 30. Ratio of median and mean analyte concentrations in the Marlton soil series to those for the entire data set. A.M. is the ratio of means.

to yellowish-brown, clay/silt matrix or “plasma” which may be neoformed phyllosilicate (?) clay

(appendix 2).

Two samples (BUMR4001 and 4003) from one sample station were submitted for percent extraction efficiency analysis. With the exception for lead, the surface soil composite has slightly higher percent extraction efficiencies than the deep composite. The mean percent extraction efficiency for aluminum, beryllium and potassium is 2 to 4 percent higher than the arithmetic mean for all 14 samples (table 18). The mean percent extraction efficiency for arsenic is 33.5 compared to the 39 efficiency for all 14 samples.

The statistical summary of analytes in the 0- to 6-inch and 24- to 30-inch composites for the Marlton soil series is shown in table 53. Except for lead, the mean analyte concentrations increase with depth in the soil. The median and mean arsenic concentrations are approximately 1.5 times higher in the 24- to 30-inch composites than in the surface soil composite, whereas the labile iron concentration remains constant over these depth intervals. The increase in aluminum, boron, and potassium concentrations for the deep samples is consistent with a well developed argillic (Bt) horizon. The median and mean lead concentration in the surface soil composite is twice that for the deep composite. Copper (not shown in table 53) shows a similar enrichment in the surface soil composite, but much less pronounced than the lead. Lead and copper in the surface soil probably are strongly complexed with organic matter. Lead (0.606, $p = 0.0234$) and copper (0.613, $p = 0.0218$) have moderately robust SRO correlations with percent total organic carbon (table 54).

Table 53. Statistical summary of analyte concentrations (in ppm) as a function of depth for the Marlton soil series. Top value is the 0- to 6-inch and the bottom is the 24- to 30-inch composite. Concentrations omitting the extreme outliers are shown in parentheses ().

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	6480	9880	8995	1293	8610	9570	6
	9530	21700 (13500)	12100 (11300)	4452 (1720)	13171 (11466)	13500 (12900)	6 (5)
As	8.2	63.3	25.7	19.8	28.7	35.2	6
	6.8	81.5	40.6	31.8	42.3	72.3	6
Be	0.4	1.8	0.97	0.49	0.97	1.1	6
	0.44	3.5 (1.4)	1.14 (0.98)	1.07 (0.38)	1.42 (1.01)	1.4 (1.3)	6 (5)
B	14.8	81.5	37.1	22.2	42.9	50.9	6
	27.9	119	63.7	29.4	67.5	70.9	6
Fe	16300	168000 (49000)	43800 (43800)	54657 (13038)	59000 (37200)	49000 (43800)	6 (5)
	32900	105000	41350	31963	58217	92900	6
Pb	9.9	91.1 (51.2)	25.9 (25.8)	30.4 (16.0)	36.4 (25.4)	51.2 (26.0)	6 (5)
	6.3	52.5	12.9	17.2	18.0	15.3	6
K	1700	10300	4855	2804	5298	5660	6
	3300	16200	8555	4278	8893	10100	6

SRO correlations for the analytes regressed against pH, weight percent total organic carbon, weight percent moisture, and percent glauconite sand, quartz sand and silt/clay are summarized in table 54. No significantly robust SRO correlations were found among the analytes regressed against these parameters. The SRO and linear regression correlations for arsenic regressed against pH, percent quartz sand and percent silt/clay are weakly negative. Arsenic regressed against percent total organic carbon and percent glauconite sand is moderately weak and positive for both the SRO and linear regression correlations. Arsenic concentration plotted against percent glauconite sand is shown in figure 31. Taking into account the amount of glauconite in the silt/clay fraction may provide a more robust, positive correlation between arsenic and glauconite. Except for beryllium regressed against percent total organic carbon,

Table 54. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A for the Marlton soil series as a function of pH, total organic carbon (%TOC), weight percent moisture, and granulometric parameters. In each cell, top value is the correlation value and bottom is the probability.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V	Zn	
pH	-0.082 0.7584	-0.426 0.1111	-0.466 0.0809	0.014 0.9573	-0.213 0.4245	-0.071 0.7891	-0.177 0.5082	0.436 0.1676	-0.272 0.3090	-0.229 0.3922	-0.091 0.7331	-0.071 0.7915	-0.424 0.1130	-0.014 0.9573	0.479 0.0731	0.370 0.2674	0.123 0.6569	-0.143 0.5923	-0.048 0.8997	-0.499 0.0621	-0.143 0.5926	pH
TOC	-0.567 0.0340	-0.267 0.3186	0.243 0.3631	0.290 0.2786	-0.106 0.6921	-0.320 0.2313	0.199 0.4559	0.127 0.6873	-0.390 0.1445	-0.455 0.0889	0.613 0.0218	0.111 0.6781	0.606 0.0234	-0.329 0.2185	0.077 0.7737	-0.224 0.5011	-0.334 0.2279	-0.250 0.3487	-0.214 0.5708	-0.097 0.7180	-0.061 0.8201	TOC
Moisture	-0.086 0.7484	0.122 0.6493	0.007 0.9787	0.107 0.6885	-0.039 0.8827	-0.068 0.7996	-0.405 0.1293	0.100 0.7518	0.100 0.7080	0.108 0.6874	0.021 0.9361	-0.311 0.2446	0.550 0.0396	-0.064 0.8099	-0.468 0.0800	-0.600 0.0719	0.248 0.3705	-0.016 0.9520	-0.310 0.4128	0.286 0.2850	0.079 0.7688	Moisture
%glau sd	0.462 0.0836	0.208 0.4363	0.375 0.1611	0.068 0.7989	0.464 0.0825	0.559 0.0364	0.312 0.2425	0.046 0.8852	0.300 0.2609	0.486 0.0692	-0.211 0.4288	0.335 0.2095	-0.059 0.8249	0.477 0.0745	0.265 0.3210	0.383 0.2506	-0.049 0.8610	0.638 0.0170	0.524 0.1658	0.029 0.9146	0.086 0.7476	%glau sd
%qtz sd	-0.479 0.0729	-0.071 0.7898	-0.429 0.1086	0.095 0.7208	-0.054 0.8391	-0.195 0.4665	-0.224 0.4029	0.341 0.2808	-0.001 0.9973	-0.273 0.3069	-0.072 0.7874	0.106 0.6905	-0.234 0.3808	-0.200 0.4542	-0.177 0.5088	-0.410 0.2189	0.024 0.9298	-0.286 0.2848	-0.108 0.7742	0.043 0.8715	0.105 0.6958	%qtz sd
%slt-cly	-0.113 0.6735	-0.055 0.8356	-0.098 0.7130	-0.173 0.5165	-0.370 0.1668	-0.479 0.0731	-0.206 0.4398	-0.255 0.4209	-0.207 0.4395	-0.233 0.3829	0.207 0.4379	-0.385 0.1501	0.279 0.2968	-0.356 0.1833	-0.188 0.4826	-0.297 0.3730	0.015 0.9557	-0.512 0.0556	0.000 1.0000	0.147 0.5834	-0.013 0.9627	%slt-cly

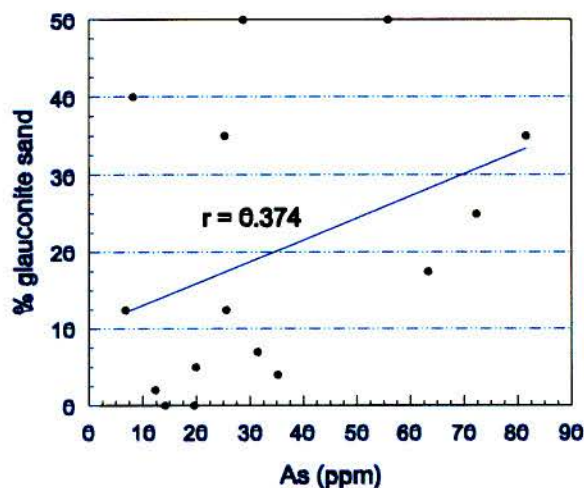


Figure 31. Arsenic concentration versus percent glauconite sand in the Marlton soil series. The simple linear regression correlation line is shown.

beryllium correlates with these parameters in the same manner as arsenic.

Table 55 is the SRO correlation table for the analytes. Arsenic has no statistically significant SRO correlation with the other analytes. Arsenic has a moderate, positive (0.508, $p = 0.0575$) SRO correlation with iron. The linear regression correlation coefficient is 0.698 for arsenic regressed against iron (fig. 32). Statistically significant, strong, positive SRO correlations occur for beryllium regressed against boron, chromium, magnesium, potassium and zinc. Significant, robust, positive SRO correlations among potassium, magnesium, beryllium and boron, and less robust, though significant, positive SRO correlations among aluminum, boron, magnesium and potassium occur for these constituent elements in glauconite and phyllosilicate minerals. Of the four glauconite-rich soil series, that is the Adelphia, Colemantown, Kresson and Marlton; the Marlton soil series has the lowest SRO correlation (0.508, $p = 0.0575$) and the second lowest linear regression correlation (0.698) for arsenic regressed against iron. This suggests that soil constituents other than amorphous to crystalline

Table 55. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A analytes for the Marlton soil series. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	B	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Se	V
Sb	0.454 0.0894																			
As	0.314 0.2396	0.484 0.0699																		
Ba	0.000 1.0000	0.188 0.4826	0.089 0.7383																	
Be	0.419 0.1166	0.436 0.1029	0.165 0.5373	0.703 0.0086																
B	0.632 0.0180	0.297 0.2669	0.143 0.5930	0.511 0.0560	0.846 0.0016															
Cd	0.357 0.1817	0.322 0.2280	0.737 0.0058	0.142 0.5960	0.191 0.4752	0.160 0.5503														
Ca	-0.027 0.9313	0.150 0.6345	-0.409 0.1958	0.273 0.3884	0.232 0.4625	0.327 0.3007	-0.305 0.3344													
Cr	0.513 0.0549	0.776 0.0037	0.227 0.3957	0.499 0.0621	0.752 0.0049	0.640 0.0167	0.126 0.6382	0.091 0.7737												
Co	0.618 0.0207	0.665 0.0128	0.120 0.6532	0.432 0.1061	0.698 0.0090	0.674 0.0117	0.077 0.7721	0.082 0.7949	0.914 0.0006											
Cu	-0.368 0.1687	-0.409 0.1257	0.264 0.3227	-0.175 0.5126	-0.552 0.0389	-0.604 0.0239	0.441 0.0987	-0.418 0.1860	-0.624 0.0196	-0.622 0.0200										
Fe	0.243 0.3631	0.394 0.1409	0.508 0.0575	0.572 0.0324	0.628 0.0188	0.479 0.0731	0.632 0.0181	0.009 0.9771	0.571 0.0327	0.411 0.1243	-0.061 0.8201									
Pb	-0.182 0.4955	0.089 0.7381	0.421 0.1148	0.454 0.0897	0.233 0.3834	0.032 0.9043	0.052 0.8457	-0.109 0.7301	0.204 0.4458	0.113 0.6727	0.204 0.4462	0.197 0.4620								
Mg	0.696 0.0092	0.408 0.1273	0.061 0.8203	0.421 0.1148	0.803 0.0027	0.907 0.0007	0.135 0.6147	0.491 0.1206	0.590 0.0273	0.658 0.0139	-0.646 0.0156	0.291 0.2757	-0.075 0.7790							
Mn	-0.025 0.9255	-0.291 0.2757	-0.096 0.7182	0.143 0.5930	-0.025 0.9252	0.061 0.8203	0.262 0.3271	0.409 0.1958	-0.222 0.4070	-0.005 0.9840	0.193 0.4705	0.118 0.6589	-0.200 0.4543	0.079 0.7688						
Mo	0.479 0.1509	-0.109 0.7427	0.260 0.4343	-0.406 0.2232	-0.374 0.2615	-0.030 0.9276	0.371 0.2659	0.452 0.2314	-0.564 0.0909	-0.213 0.5220	0.115 0.7298	-0.030 0.9276	-0.685 0.0399	0.212 0.5245	0.842 0.0115					
Ni	0.310 0.2639	0.398 0.1515	-0.209 0.4516	0.530 0.0562	0.497 0.0733	0.503 0.0696	-0.347 0.2109	0.442 0.1844	0.667 0.0162	0.702 0.0114	-0.692 0.0126	0.004 0.9873	0.187 0.5006	0.565 0.0417	-0.068 0.8060	-0.483 0.1716				
K	0.642 0.0164	0.360 0.1785	0.216 0.4184	0.477 0.0742	0.818 0.0022	0.974 0.0003	0.210 0.4319	0.374 0.2375	0.614 0.0217	0.683 0.0106	-0.549 0.0401	0.411 0.1245	0.066 0.8046	0.929 0.0005	0.095 0.7230	0.067 0.8415	0.491 0.0769			
Se	0.143 0.7055	0.204 0.5901	0.476 0.2077	0.333 0.3778	0.405 0.2842	0.095 0.8011	0.405 0.2842	-0.571 0.1616	0.419 0.2674	0.313 0.4072	0.095 0.8011	0.548 0.1474	0.190 0.6143	-0.048 0.8997	0.238 0.5287	-0.200 0.7290	-0.071 0.8611	0.000 1.0000		
V	0.336 0.2091	0.663 0.0131	0.407 0.1277	0.157 0.5565	0.466 0.0813	0.239 0.3706	0.152 0.5684	-0.409 0.1958	0.706 0.0083	0.482 0.0713	-0.300 0.2617	0.493 0.0649	0.400 0.1345	0.196 0.4624	-0.625 0.0194	-0.709 0.0334	0.169 0.5417	0.191 0.4743	0.452 0.2314	
Zn	0.336 0.2091	0.581 0.0297	0.075 0.7790	0.721 0.0069	0.814 0.0023	0.546 0.0409	0.179 0.5021	0.236 0.4548	0.831 0.0019	0.740 0.0056	-0.443 0.0975	0.645 0.0158	0.293 0.2732	0.564 0.0347	-0.064 0.8099	-0.636 0.0563	0.569 0.0401	0.497 0.0630	0.286 0.4497	0.629 0.0187

iron phases possess 'recoverable' arsenic. Part of the arsenic is likely associated with neoformed minerals in the argillic (Bt) horizon.

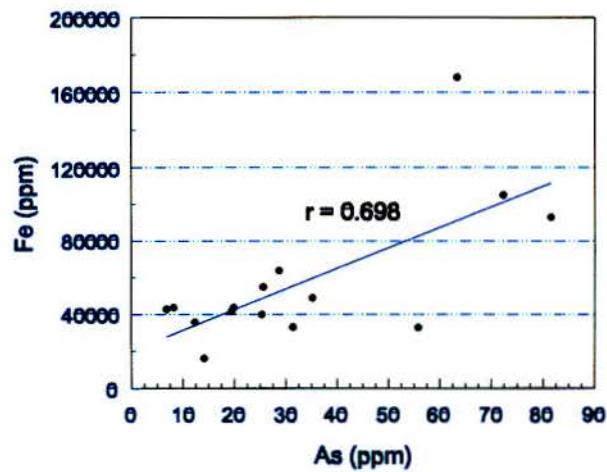


Figure 32. Arsenic concentration versus labile iron concentration in the Marlton soil series. The simple linear regression correlation line ($\text{Fe}(\text{ppm}) = 1119\text{As}(\text{ppm}) + 20309$) is shown.

Shrewsbury Soil Series

Ten soil samples from four sampling stations were analyzed according to U. S. EPA SW-846, Methods 3050 and 6010A. The statistical summary of the analyte concentration is presented in table 56.

Table 56. Statistical summary of analyte concentrations, determined by SW-846 Methods 3050 and 6010A, in the Shrewsbury soil series. All metal concentrations are in mg/kg (ppm). pH is standard units, and percent total organic carbon (TOC) and moisture (moist.) are expressed as weight percent.

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
pH	2.88	4.98	3.51	0.57	3.58	3.82	10
Al	2060	10100	3215	2532	4107	6510	10
Sb	0.82	2.9	1.8	0.9	1.8	2.9	7
As	0.31	11.6	4.85	3.6	5.8	10.4	10
Ba	12.1	51.8	17	12.3	21.9	35.4	10
Be	0.09	0.63	0.29	0.18	0.30	0.48	10
Cd	0.86	3.4	1.5	0.8	1.6	2.3	10
Ca	31.1	605	340	232	340	592	10
Cr	8.8	53.6	15.8	16.5	24.7	53.4	10
Co	0.49	2.3	1.4	0.5	1.4	1.9	10
Cu	1.5	24.6	5.2	7.2	7.9	16.4	10
Fe	5750	46100	10400	12133	15087	23300	10
Pb	3	168	32	55	55	110	10
Mg	140	1640	497	430	558	737	10
Mn	6.9	118	25	36	39	86.8	10
Mo	0.17	0.89	0.28	0.23	0.35	0.41	8
Ni	0.66	3.7	2.1	1.1	2.1	3.5	10
K	243	4990	456	1529	965	1040	9
Se	1.4	6.8	2.95	2.3	3.5	3.5	4
Na	28.3	145	52.5	57	81	141	5
V	7.5	51.3	15.4	15.5	22.5	48.8	10
Zn	8.5	51.7	24.6	14.2	26.6	38.9	10
%TOC	0.19	13.8	2.07	4.12	3.2	4.93	10
%moist.	8.1	32.9	19.8	7.5	19.4	24.7	10

Soil pH ranges from 2.88 (CASH2001) to 4.98 (BUSH1001) with a 3.51 median and a 3.58 ± 0.57 mean. pH exceeding 4.75 is an extreme outlier. Omitting the 4.98 pH extreme

outlier yields a 3.50 median pH and a mean of 3.42 ± 0.30 . Station BUSH1000 is an actively cultivated field. The two highest pH values (4.98 for BUSH1001 and 3.82 for BUSH1003) correspond to the two highest calcium concentrations (592 and 605 ppm, respectively) for this soil series. Application of lime to this agricultural plot accounts for the high pH and calcium concentrations. Station MOSH3000 most certainly has been impacted by anthropic activities as the site is littered with debris and abandoned shacks. The low pH values (3.47 for MOSH3001 and 3.14 for MOSH3002) correspond to relatively high calcium concentrations (578 and 534 ppm, respectively). This observation is ascribed to anthropic inputs rather than a soil developed from a calcareous parent sediment.

Arsenic concentrations range from 0.31 ppm (BUSH1003) to 11.6 ppm (BUSH1001) with a 4.85 ppm median and a 5.8 ± 3.6 ppm mean. No extreme or mild outlier concentrations for arsenic were found. All samples for this series have arsenic concentrations that comply with the RDCSCC. Station BUSH1000, the cultivated field, has the lowest and highest 'recoverable' arsenic concentration for the soil series. The highest arsenic concentration is in the 0- to 6-inch composite, whereas the lowest arsenic is in the 24- to 30-inch composite (Btg2 horizon). The arsenic concentration tends to remain rather constant or increases slightly with depth in the soil for samples from the other three stations. The relatively high arsenic concentration in the surface soil composite from station BUSH1000 does not imply that this arsenic is a direct result of agricultural inputs.

Beryllium concentrations range from 0.09 ppm (MOSH3002) to 0.63 ppm (BUSH1003) with a 0.29 ppm median and a 0.30 ± 0.18 ppm mean. No extreme or mild outlier beryllium concentrations were found. All the Shrewsbury soil samples are in compliance with the RDCSCC for beryllium.

The ratio of select median and mean analyte concentrations in Shrewsbury soil series to those for the entire data set is plotted in figure 33. Compared to the median and mean concentrations for the entire data set, the Shrewsbury soil series is strongly depleted in arsenic,

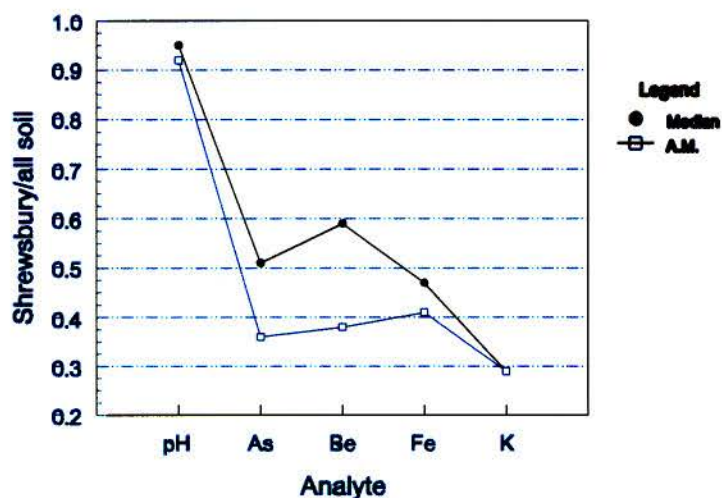


Figure 33. Ratio of median and mean analyte concentrations in the Shrewsbury soil series to those for the entire data set. A.M. is the ratio of means.

beryllium, iron and potassium. The low median and mean beryllium and potassium concentrations relative to all 113 samples results from the high concentrations of quartz sand and silt in this soil series (tables 4 and 5). In contrast to the other soil series with high contents of quartz sand, the quartz sand and silt is not pervasively coated with iron hydroxides in Shrewsbury series soil. This paucity of iron-coated mineral constituents accounts for the low labile iron concentrations. Based on the NRCS's description of the "typical pedon" from the type location in Springfield Township (Burlington County), glauconite in the A horizon ranges from 5 to 20 percent, and 10 to 20 percent in the B and C horizons. The maximum glauconite sand concentration is 2.5 percent in the Shrewsbury soil series sampled for this investigation (table 4). Furthermore, the typical pedon is described by the NRCS as having "prominent brownish yellow (10YR 6/8)" and "prominent yellowish brown (10YR 5/6 or 5/8) iron concentrations" — an atypical feature for the Shrewsbury series soil sampled herein.

Table 57. Statistical summary of analyte concentrations (in ppm) as a function of depth for the Shrewsbury soil series. Top value is the 0- to 6-inch composite and the bottom is the 24- to 30-inch composite. Concentrations excluding the extreme outliers are shown in parentheses ().

Analyte	Minimum	Maximum	Median	Standard Deviation	Arithmetic Mean	90th Percentile	N
Al	2060	10100 (3510)	2915 (2320)	3788 (773)	4498 (2630)	3510 (2320)	4 (3)
	2580	6510	4405	1701	4475	5090	4
As	3.3	11.6	5.9	3.7	6.7	7.2	4
	0.31	10.4	3.4	4.3	4.4	3.8	4
Be	0.13	0.43	0.31	0.13	0.29	0.35	4
	0.10	0.63	0.37	0.23	0.37	0.48	4
Fe	5750	15800	9485	4223	10130	10300	4
	6990	46100 (23300)	15430 (7560)	18369 (9256)	20988 (12617)	23300 (7560)	4 (3)
Pb	4.6	85.9	61.9	39.4	53.6	85.2	4
	3.0	110	15.9	50.2	36.2	25.9	4
K	290	564	472	115	449	487	4
	243	4990 (1040)	697 (354)	2250 (432)	1657 (546)	1040 (354)	4 (3)

A statistical summary of select analytes for the 0- to 6-inch and 24- to 30-inch depth composites of the Shrewsbury soil series is shown in table 57. The median and mean arsenic concentration is higher in the 0- to 6-inch composites than for the 24- to 30-inch composites. This suggests that the arsenic concentration decreases with depth in the soil. CASH2000 has higher arsenic (10.4 ppm) in the deep composite sample than in the surface composite (7.2 ppm). On the other hand, the median and mean beryllium concentrations increase slightly with depth in the soil. Median and mean lead concentrations are highly enriched in the surface soil composites relative to the 24- to 30-inch composites. The 24- to 30-inch composite for station CASH2000 has a much higher lead concentration (110 ppm) than the surface soil composite (4.6 ppm). The highest lead concentration for this soil series is 168 ppm in the 12- to 18-inch composite (lower Ag/upper Btg1 horizons) from station MOSH3000 — a disturbed site. This high lead concentration corresponds to an unusually high 13.8 percent total organic carbon — the highest total organic carbon for the 113 samples.

SRO correlations for the metals regressed against pH, weight percent total organic carbon, weight percent moisture, and percent glauconite sand, quartz sand and silt/clay are summarized in table 58. No significantly strong SRO correlations were found among the parameters in table 58. Cobalt regressed against percent quartz sand yields a significant, moderate, positive SRO correlation (0.738, $p = 0.0269$) and a 0.754 linear regression correlation coefficient. Iron has a weak, negative SRO correlation with percent silt/clay (-0.365, $p = 0.2739$) and a very weak, positive SRO correlation with percent quartz sand (0.252, $p = 0.4490$). Taken together, these correlations suggest that cobalt is co-precipitated with the iron (hydr)oxides that coat some quartz sand. According to McBride (1994), cobalt associates preferentially with iron (and manganese) oxides in strongly oxidizing conditions because of chemisorption and co-precipitation.

Arsenic regressed against percent total organic carbon (TOC) yields a moderate, positive SRO correlation (0.517, $p = 0.1211$). Analysis of this relation reveals that the high TOC concentrations, generally in the surface soil, correlate with arsenic but those soil samples with low TOC, generally the deep samples, show no correlation with arsenic. This suggests that part of the arsenic likely is complexed with sulfhydryl groups in the organic matter (humus) in this soil series. Arsenic has a weakly moderate, positive SRO correlation (0.402, $p = 0.2276$) and a 0.499 linear regression correlation coefficient with percent glauconite sand. Arsenic plotted against percent glauconite sand is shown in figure 34. Based on figure 34, little evidence supports the thesis that arsenic concentration is principally a function of the glauconite sand in the soil. Beryllium has a moderate, negative SRO correlation (-0.561, $p = 0.0924$) with percent TOC, which is practically opposite to that for arsenic and percent TOC.

Table 59 is the SRO correlation table for the analytes. Significant, moderate, with a few strong, positive SRO correlations occur between: beryllium regressed against aluminum and chromium, iron regressed against chromium and cobalt, and magnesium regressed against aluminum, cobalt and potassium. Positive SRO correlations among aluminum, beryllium, chromium, cobalt, iron and magnesium are expected among these constituent elements in

Table 58. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A for the Shrewsbury soil series as a function of pH, total organic carbon (%TOC), weight percent moisture, and granulometric parameters. In each cell, top value is the correlation value and bottom is the probability.

	Al	Sb	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Na	V	Zn	
pH	0.091 0.7851	0.036 0.9297	0.055 0.8700	0.322 0.3338	0.438 0.1892	0.117 0.7265	0.394 0.2373	0.285 0.3928	-0.111 0.7396	-0.103 0.7573	-0.018 0.9565	-0.103 0.7573	0.030 0.9276	0.418 0.2096	-0.667 0.0778	-0.683 0.0405	0.400 0.2579	0.400 0.4237	-0.067 0.8415	-0.030 0.9276	pH
TOC	-0.571 0.0865	-0.636 0.1191	0.517 0.1211	0.232 0.4870	-0.561 0.0924	-0.443 0.1838	0.097 0.7704	-0.498 0.1348	-0.380 0.2547	0.584 0.0800	-0.353 0.2902	0.347 0.2986	-0.377 0.2582	-0.109 0.7427	0.524 0.1658	0.566 0.0896	-0.351 0.3202	-0.200 0.6892	-0.043 0.8984	0.395 0.2359	TOC
Moisture	0.298 0.3715	0.649 0.1121	0.188 0.5718	0.482 0.1484	0.186 0.5769	0.591 0.0763	<0.000 1.0000	0.292 0.3814	0.191 0.5659	0.036 0.9129	0.644 0.0532	0.243 0.4657	0.170 0.6096	-0.116 0.7290	-0.228 0.5471	-0.086 0.7973	-0.400 0.2579	0.300 0.5485	0.249 0.4546	0.049 0.8840	Moisture
%glau sd	0.013 0.9690	-0.179 0.6604	0.402 0.2276	0.254 0.4464	-0.091 0.7846	-0.309 0.3544	-0.071 0.8305	-0.078 0.8153	-0.125 0.7073	0.175 0.5992	-0.305 0.3603	0.428 0.1990	-0.130 0.6971	0.350 0.2933	-0.228 0.5458	0.140 0.6738	-0.365 0.3017	0.112 0.8231	0.195 0.5593	0.091 0.7853	%glau sd
%qtz sd	0.332 0.3187	0.358 0.3808	-0.419 0.2093	-0.148 0.6567	0.244 0.4645	0.199 0.5498	0.307 0.3559	0.369 0.2679	0.738 0.0269	-0.332 0.3187	0.252 0.4490	-0.258 0.4381	0.677 0.0423	0.086 0.7960	0.587 0.1205	0.211 0.5276	0.341 0.3355	0.564 0.2591	0.062 0.8535	0.080 0.8103	%qtz sd
%slt-cly	-0.377 0.2582	-0.559 0.1712	0.334 0.3158	0.009 0.9781	-0.366 0.2724	-0.326 0.3278	-0.347 0.2986	-0.529 0.1126	-0.713 0.0324	0.383 0.2506	-0.365 0.2739	0.201 0.5473	-0.632 0.0579	-0.231 0.4883	-0.275 0.4661	0.046 0.8905	-0.276 0.4348	-0.400 0.4237	-0.079 0.8126	0.012 0.9709	%slt-cly

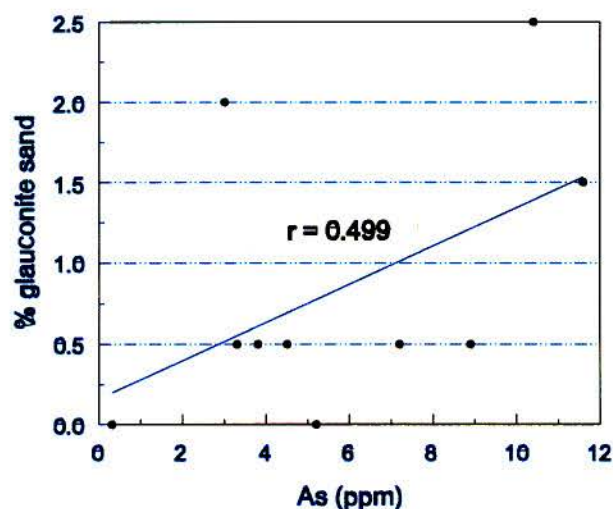


Figure 34. Arsenic concentration versus percent glauconite sand in the Shrewsbury soil series. The linear regression correlation line is shown.

glauconite and other phyllosilicate minerals.

Arsenic regressed against potassium yields a significant, robust, negative SRO correlation (-0.767 , $p = 0.0301$) and a weak, negative linear regression correlation coefficient (-0.307). Omitting the potassium extreme outlier for BUSH1003 provides a weak, positive SRO correlation (0.214 , $p = 0.6103$) and a -0.564 linear regression correlation for arsenic regressed against potassium. These correlations suggest that the arsenic concentration increases with decreasing glauconite sand content in the Shrewsbury soil. Moreover, the overall very low concentrations of glauconite sand and the negative correlations for 'recoverable' arsenic regressed against potassium are compelling evidence that the arsenic associates with mineral and/or amorphous soil constituents other than the phyllosilicate minerals. Arsenic regressed against labile iron yields a very weak, negative SRO correlation (-0.182 , $p = 0.9565$) and a weak, negative (-0.307) linear regression correlation. Arsenic plotted against labile iron is shown in figure 35. Omitting the iron extreme outlier for BUSH1003 and the 11.6 ppm arsenic for

Table 59. Summary of Spearman rank-order correlation for SW-846 Methods 3050 and 6010A analytes for the Shrewsbury soil series. In each cell, top value is the correlation value and bottom is the probability. Data shown in boldface where $-0.750 < r > 0.750$.

	Al	Sb	As	Ba	Be	Cd	Ca	Cr	Co	Cu	Fe	Pb	Mg	Mn	Mo	Ni	K	Na	V
Sb	0.414 0.3100																		
As	-0.491 0.1408	-0.306 0.4531																	
Ba	0.091 0.7844	-0.126 0.7574	0.401 0.2287																
Be	0.638 0.0555	0.487 0.2333	-0.067 0.8410	0.305 0.3604															
Cd	0.301 0.3671	0.982 0.0162	-0.141 0.6720	0.166 0.6181	0.449 0.1777														
Ca	-0.188 0.5730	0.144 0.7240	0.030 0.9276	0.547 0.1007	0.188 0.5718	0.374 0.2615													
Cr	0.382 0.2520	0.667 0.1025	0.042 0.8987	0.012 0.9709	0.772 0.0206	0.571 0.0870	0.152 0.6494												
Co	0.400 0.2301	0.545 0.1815	-0.277 0.4060	0.074 0.8241	0.630 0.0589	0.660 0.0476	0.443 0.1837	0.640 0.0548											
Cu	-0.612 0.0663	-0.270 0.5079	0.552 0.0980	0.267 0.4223	-0.553 0.0970	0.018 0.9560	0.309 0.3538	-0.515 0.1222	-0.283 0.3957										
Fe	0.321 0.3352	0.883 0.0306	-0.182 0.9565	0.134 0.6883	0.578 0.0832	0.914 0.0061	0.248 0.4560	0.770 0.0209	0.739 0.0267	-0.176 0.5980									
Pb	-0.503 0.1313	0.054 0.8947	0.576 0.0841	0.304 0.3618	-0.492 0.1396	0.129 0.6991	0.188 0.5730	-0.394 0.2373	-0.258 0.4381	0.903 0.0067	-0.066 0.8415								
Mg	0.770 0.0209	0.414 0.3100	-0.552 0.0980	0.152 0.6484	0.590 0.0769	0.472 0.1564	0.358 0.2834	0.430 0.1967	0.763 0.0221	-0.406 0.2232	0.467 0.1615	-0.442 0.1844							
Mn	-0.455 0.1727	0.252 0.5366	0.503 0.1313	0.140 0.6749	0.036 0.9129	0.301 0.3671	0.491 0.1408	0.261 0.4343	0.142 0.6711	0.503 0.1313	0.188 0.5730	0.588 0.0778	-0.224 0.5011						
Mo	-0.190 0.6143	-0.500 0.3173	-0.262 0.4884	-0.108 0.7755	-0.299 0.4283	-0.132 0.7274	0.333 0.3778	-0.190 0.6143	0.494 0.1912	0.048 0.8997	-0.024 0.9498	-0.214 0.5708	0.524 0.1658	-0.286 0.4497					
Ni	-0.183 0.5831	-0.445 0.2752	-0.043 0.8981	-0.101 0.7621	-0.621 0.0625	-0.191 0.5659	0.030 0.9271	-0.628 0.0595	-0.028 0.9334	0.567 0.0889	-0.293 0.3799	0.421 0.2069	0.073 0.8262	-0.146 0.6606	0.868 0.0217				
K	0.483 0.1716	-0.116 0.7954	-0.767 0.0301	-0.109 0.7583	0.226 0.5228	-0.025 0.9434	0.300 0.3961	0.000 1.0000	0.128 0.7180	-0.450 0.2031	-0.133 0.7061	-0.617 0.0811	0.667 0.0593	-0.300 0.3961	0.250 0.5403	-0.586 0.8684			
Na	0.700 0.1615	1.000 0.3173	-0.200 0.6892	0.100 0.8415	0.821 0.1007	0.718 0.1509	0.100 0.8415	0.500 0.3173	0.667 0.1823	-0.100 0.8415	0.800 0.1096	-0.100 0.8415	1.000 0.0455	0.000 1.0000	0.800 0.1659	0.600 0.2301	0.900 0.0719		
V	0.394 0.2373	-0.126 0.7574	0.442 0.1844	0.024 0.9418	0.529 0.1126	0.178 0.5935	-0.285 0.3928	0.576 0.0841	0.283 0.3957	-0.127 0.7026	0.406 0.2232	-0.091 0.7851	0.224 0.5011	0.079 0.8132	-0.024 0.9498	-0.134 0.6874	-0.333 0.3458	0.900 0.0719	
Zn	-0.224 0.5011	-0.252 0.5366	0.309 0.3538	0.468 0.1602	-0.085 0.7985	0.276 0.4075	0.648 0.0517	-0.236 0.4783	0.265 0.4272	0.782 0.0190	0.103 0.7573	0.624 0.0611	0.188 0.5730	0.442 0.1844	0.381 0.3135	0.567 0.0889	-0.117 0.7414	0.500 0.3173	0.018 0.9565

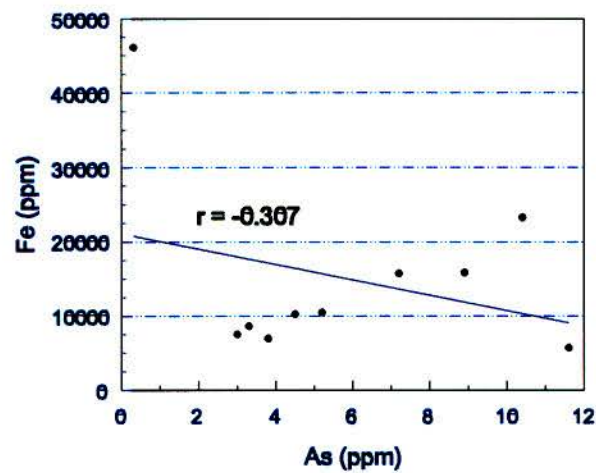


Figure 35. Arsenic concentration versus labile iron concentration in the Shrewsbury soil series. The linear regression correlation line is shown.

BUSH1001, which constitute the samples from the cultivated field, yields a very robust, positive SRO correlation (0.929, $p = 0.0009$) and a 0.964 linear regression correlation coefficient.

Arsenic plotted against labile iron, less the two values for station BUSH1000, is shown in figure 36. This strong, positive linear regression between arsenic and labile iron demonstrates that for undisturbed soil in this series the arsenic is coprecipitated or chemisorbed onto iron phases.

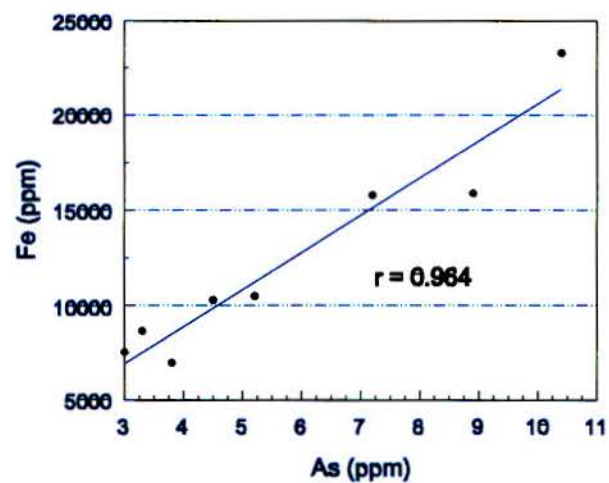


Figure 36. Arsenic concentration versus labile iron concentration in the Shrewsbury soil series (omitting station BUSH1000 data). The linear regression correlation line ($\text{Fe}(\text{ppm}) = 1954\text{As}(\text{ppm}) + 1068$) is shown.

Comparison of Arsenic and Beryllium Concentrations among the Soil Series

Statistical analyses were performed to assess significant differences in arsenic and beryllium concentrations among the Adelphia, Colemantown, Collington, Freehold, Holmdel, Kresson, Marlton, and Shrewsbury soil series. These analyses were applied on the 0- to 6-inch composites and on the total suite of composited samples for each soil series. Statistical evaluation of the 0- to 6-inch composites is important to the Department in that this sample interval is used in the initial hazardous waste site investigation to assess whether there is a problem.

Arsenic and beryllium concentrations for these soils are positively, commonly very highly skewed — a typical feature of environmental quality data (Helsel, 1990). For this reason, the Kruskal-Wallis nonparametric statistical method was selected for data analysis. The Kruskal-Wallis one-way analysis of variance is based on the rank-sum procedure which tests for independence among sample means.

Arsenic

0- to 6-inch Composites

The range, mean and median recoverable concentrations for select analytes in each of the eight soil series are summarized in table 60. The maximum recoverable arsenic concentration is 63.3 ppm in the Marlton soil series. The Adelphia, Kresson and Marlton soil series have maximum recoverable arsenic concentrations exceeding the 20-ppm RDCSCC guideline. The minimum, maximum, median and mean recoverable arsenic concentrations for the soil series are illustrated in figure 37.

Both the mean and median concentrations are nearly equal in all soil series except for the Kresson which has a 14.7 ppm mean and a 5.3 ppm median (table 60). The mean (28.7 ppm) and median (25.7 ppm) recoverable arsenic for the Marlton soil series exceed the RDCSCC guideline of 20 ppm.

Table 60. Statistical summary of analyte concentrations (ppm) determined by U.S. EPA SW-846 Methods 3050 and 6010A in the 0- to 6-inch composites for eight glauconitic soil series. Top line of cell is the mean/median and bottom line is the range in concentrations.

	Arsenic	Beryllium	Chromium	Lead	Vanadium	Zinc	N
Adelphia	18.3/16.0	1.2/0.59	119.4/31.8	54.9/55.9	106.8/36	96.5/48.9	4
	8.9 - 32.4	0.22 - 3.5	9.8 - 404	29.6 - 78.2	16.3 - 339	27.1 - 261	
Colemantown	10.8/10.5	0.45/0.51	41.6/29.1	23/10.8	37.8/36.4	28.7/27.6	5
	4.8 - 17.5	0.08 - 0.63	16.1 - 93.9	5.9 - 60	12.9 - 79.2	9.1 - 44.1	
Collington	11.1/9.1	0.52/0.43	49.7/48.6	29.8/25.3	52.8/50.2	36.7/36.9	4
	7.1 - 19	0.14 - 1.1	16.1 - 85.7	9.6 - 59.1	19.6 - 91.2	12.4 - 60.5	
Freehold	6.0/5.9	0.83/0.49	32.1/21.7	12.6/11.6	14.8/14.9	36.1/29.8	6
	2.0 - 10.5	0.20 - 2.8	5.1 - 104	3.3 - 23.1	1.7 - 25.5	6.0 - 96.4	
Holmdel	6.4/6.1	0.34/0.29	33.9/33.8	10/5.5	25.9/25.2	18.8/20.2	4
	3.5 - 9.8	0.23 - 0.53	9.1 - 58.9	3.8 - 25.2	16.9 - 36.3	9.8 - 25	
Kresson	14.7/5.3	1.3/0.51	111/29	16.5/19.5	59.2/35.3	55.7/21.5	5
	2.3 - 50.6	0.27 - 4.3	11.9 - 452	5.6 - 29.3	15.2 - 189	15.1 - 196	
Marlton	28.7/25.7	0.97/0.97	115/108	36.4/25.9	59.3/41.3	46.4/37.7	6
	8.2 - 63.3	0.40 - 1.8	60.9 - 177	9.9 - 91.1	33 - 114	32.6 - 71.6	
Shrewsbury	6.7/5.9	0.29/0.31	17.9/14.4	53.6/61.9	24.2/16.9	36.3/37.1	4
	3.3 - 11.6	0.13 - 0.43	13.6 - 29	4.6 - 85.9	11.7 - 51.3	19.2 - 51.7	

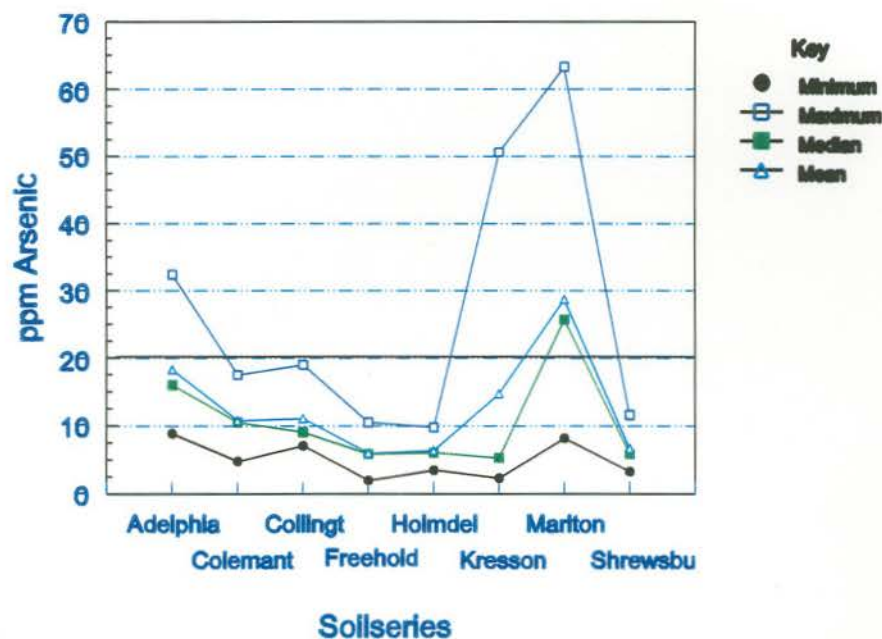


Figure 37. Minimum, maximum, median, and mean recoverable arsenic in the 0- to 6-inch composites for the eight soil series.

The mean and one standard deviation recoverable arsenic concentration for each soil series are shown in table 61, and graphically illustrated in figure 38. Unless indicated otherwise, standard deviation here refers to one standard deviation. The mean $\pm$ one standard deviation in a normal distribution accounts for approximately 68 percent of the values. All concentration data for these comparisons are positively skewed rather than normally distributed. Mean recoverable arsenic and the range in standard deviation are almost identical for the Freehold, Holmdel and Shrewsbury, and also for the Colemantown and Collington soil series (table 61). The range for the standard deviation is small for the Colemantown, Collington, Freehold, Holmdel and Shrewsbury, and large for the Adelphia, Kresson and Marlton soil series. The standard deviation for recoverable arsenic in the Adelphia, Kresson and Marlton soil series exceeds the RDCSCC guideline (fig. 38).

Table 61. Mean and one standard deviation recoverable arsenic concentration (ppm) in the 0- to 6-inch composites for the various soil series.

Soil Series	Standard		N
	Mean	Deviation	
Adelphia	18.3	11.0	4
Colemantown	10.8	5.0	5
Collington	11.1	5.5	4
Freehold	6.0	3.6	6
Holmdel	6.4	3.1	4
Kresson	14.7	20.3	5
Marlton	28.7	19.8	6
Shrewsbury	6.7	3.7	4
all samples	12.4	12.6	45

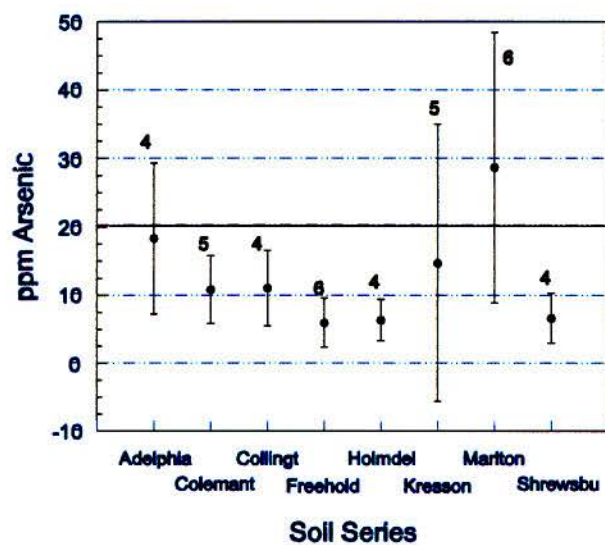


Figure 38. Mean $\pm$ one standard deviation recoverable arsenic in the 0- to 6-inch composites for each soil series. Number of measured concentrations is above the figure for each soil series.

Figure 38 shows no statistically significant difference in arsenic concentration among these soil series, based on the absence of overlap in the range for the standard deviation. A matrix for the results of the Kruskal-Wallis (K-W) test statistics is shown in table 62. K-W test values ≥ 3.84 at 95 percent confidence and one degree of freedom indicate a statistically significant difference, whereas a test value ≥ 2.71 at 90 percent confidence is significant. Results of the K-W analysis of variance for recoverable arsenic indicate that at 95 percent confidence the Adelphia soil series is statistically different from the Freehold and Holmdel series, whereas the Marlton series is statistically different from the Colemantown, Freehold, Holmdel and Shrewsbury soil series. The Adelphia soil series is significantly different from the Shrewsbury series, and the Marlton is significantly different from the Collington series at ≥ 90 percent confidence.

Table 62. Matrix for Kruskal-Wallis test statistics on arsenic concentrations in the 0- to 6-inch composites. In each cell, the upper value is the H-test value and the lower is the probability. Bold type indicates a statistically significant difference in arsenic concentration at ≥ 95 percent confidence.

	Adelphia	Colemantown	Collington	Freehold	Holmdel	Kresson	Marlton
Colemantown	0.960 0.327						
Collington	1.33 0.248	0.000 1.00					
Freehold	4.10 0.043	2.70 0.100	1.38 0.241				
Holmdel	4.08 0.043	2.16 0.142	1.33 0.248	0.045 0.831			
Kresson	0.960 0.322	0.535 0.465	0.540 0.462	0.533 0.465	0.240 0.624		
Marlton	0.409 0.522	4.03 0.045	3.68 0.055	6.16 0.013	5.50 0.019	2.70 0.100	
Shrewsbury	3.00 0.083	2.16 0.142	1.33 0.248	0.182 0.700	0.000 1.00	0.000 1.00	5.50 0.019

Composited Samples from all Depths

Summarized in table 63 are the range, mean and median recoverable concentrations for select analytes in each of the eight soil series. The maximum recoverable arsenic concentration is 92.3 ppm in the Colemantown soil series. All of the soil series, except for the Holmdel and Shrewsbury, have maximum recoverable arsenic concentrations exceeding the RDCSCC guideline. Minimum, median, mean and maximum recoverable arsenic for the soils are illustrated in figure 39. The mean and median concentrations for the suite of samples from the Adelphia and Marlton soil series exceed the arsenic RDCSCC guideline (fig. 39).

Table 63. Statistical summary of analyte concentrations (ppm) determined by U. S. EPA SW-846 Methods 3050 and 6010A in eight glauconitic soil series. Top line of cell is the mean/median and bottom line is the range in concentration.

Soil Series	Arsenic	Beryllium	Chromium	Lead	Vanadium	Zinc	N
Adelphia	27.7/23.7	1.0/0.52	106/35.5	31.1/20.5	116/65.9	81.8/42.1	10
	8.9 - 90	0.09 - 3.5	9.8 - 404	3.7 - 78.2	14.6 - 349	11.7 - 300	
Colemantown	15.3/7.7	0.80/0.45	102/49.3	18.1/8.4	47.9/25.2	43.5/26.8	13
	1.8 - 92.3	0.08 - 3.4	6 - 749	2.1 - 63.9	8.2 - 279	7.6 - 183	
Collington	14.3/11.3	0.56/0.44	58.8/47	16.6/10.6	46.9/44	28.6/26.1	10
	3.9 - 43.1	0.13 - 1.2	16.1 - 172	4.4 - 59.1	16.2 - 91.2	11.3 - 60.5	
Freehold	11.3/7.1	0.60/0.42	29.2/19.5	51.6/7.9	20/17.6	31.8/26.1	15
	2.0 - 72.7	0.20 - 2.8	5.1 - 104	3.3 - 501	1.7 - 48.1	6.0 - 96.4	
Holmdel	6.1/5.7	0.49/0.36	33.9/25.9	16.5/11.8	95.5/29.5	29/23	9
	2.4 - 11.2	0.06 - 1.7	4.6 - 72.8	3.8 - 51.3	8.7 - 636	9.8 - 97.5	
Kresson	17.3/10.9	1.23/0.60	140/29	19.2/19.7	63.6/30.2	63.2/27.7	11
	2.3 - 53.2	0.27 - 4.3	9.6 - 702	4 - 48	13.5 - 198	15.1 - 250	
Marlton	33.3/25.6	1.14/0.98	187/154	23.7/13.3	78/71	56/39.6	15
	6.8 - 81.5	0.40 - 3.5	60.7 - 711	6.3 - 91.1	24.5 - 250	23.5 - 181	
Shrewsbury	5.8/4.85	0.30/0.29	24.7/15.8	55/32	22.5/15.4	26.6/24.6	10
	0.31 - 11.6	0.09 - 0.63	8.8 - 53.6	3 - 168	7.5 - 51.3	8.5 - 51.7	

Except for the Holmdel and Shrewsbury soils, the mean concentration is higher in this suite of samples than for the 0- to 6-inch composites. In all the soil series, the mean exceeds the median concentration (fig. 39).

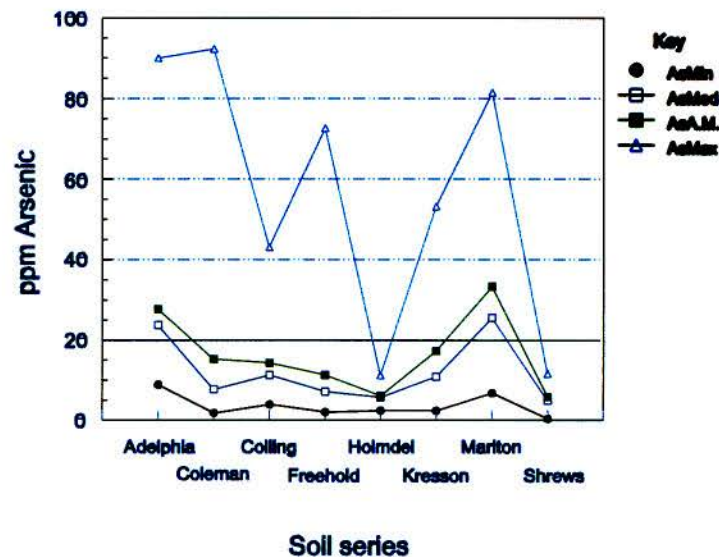


Figure 39. Minimum, median, mean and maximum recoverable arsenic in all samples from each of the eight glauconitic soil series.

The median arsenic concentration is slightly higher, compared to the suite of samples for each soil series, in the 0- to 6-inch composites from the Colemantown, Holmdel and Shrewsbury soils. Median arsenic concentration in the 0- to 6-inch composites from the Marlton soil series is almost identical to that for the entire suite of samples from this series. In comparison to the 0- to 6-inch composites, the median recoverable arsenic is higher for the entire suite of samples from the Adelphia, Collington, Freehold and Kresson soil series.

The mean and standard deviation recoverable arsenic for each soil are shown in table 64 and figure 40. With the exception for the suite of samples from the Holmdel and Shrewsbury soils, the standard deviation for recoverable arsenic in all soil series exceeds the RDCSCC guideline (fig. 40). The range for recoverable arsenic in the Holmdel and Shrewsbury varies little compared to the other soil series. The Holmdel and Shrewsbury soil series differ from the Marlton series when the overlap in the standard deviations is used as an indicator of statistical

Table 64. Mean and one standard deviation recoverable arsenic concentration (ppm) for all composites in each soil series.

Soil Series	Mean	Standard Deviation	N
Adelphia	27.7	23.4	10
Colemantown	15.3	23.6	13
Collington	14.3	11.4	10
Freehold	11.3	17.3	15
Holmdel	6.1	3.1	9
Kresson	17.3	18.2	11
Marlton	33.3	23.8	15
Shrewsbury	5.8	3.6	10
all samples	15.8	18.7	113

significance (fig. 40).

A matrix for the results of the K-W test statistics is shown in table 65. K-W analysis of variance for recoverable arsenic indicates that at ≥ 95 percent confidence statistically significant differences occur for: 1) Adelphia versus all but the Kresson and Marlton series; 2) Marlton versus all soil series except the Adelphia; and 3) Holmdel versus the Collington soil series. The Shrewsbury soil series is significantly different from the Colemantown and Kresson series at ≥ 90 percent confidence. The Adelphia series versus the Freehold and Holmdel series, and the Marlton series versus the Colemantown, Freehold, Holmdel and Shrewsbury series are significantly different at ≥ 95 percent confidence in recoverable arsenic for both the 0- to 6-inch composites (table 62) and all composited depths (table 65).

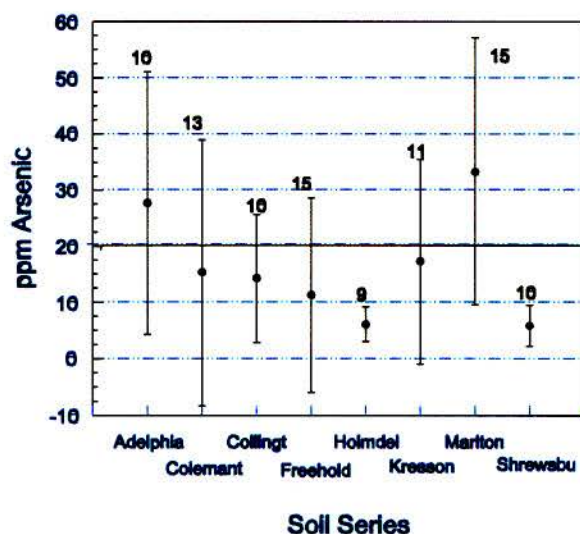


Figure 40. Mean $\pm$ one standard deviation recoverable arsenic in the suite of composite samples for each soil series. Number of measured concentrations is above the figure for each soil series.

Table 65. Matrix for Krusal-Wallis test statistics on arsenic concentration in the composites for all depths. In each cell, the top value is the H-test value and the bottom is the probability. Bold type indicates a significant difference at ≥ 95 percent confidence.

	Adelphia	Colemantown	Collington	Freehold	Holmdel	Kresson	Marlton
Colemantown	6.31 0.012						
Collington	4.01 0.045	0.809 0.369					
Freehold	10.4 0.001	0.543 0.461	2.68 0.102				
Holmdel	11.2 0.001	2.46 0.117	4.86 0.027	0.648 0.421			
Kresson	2.62 0.105	0.041 0.839	0.045 0.833	0.922 0.337	2.43 0.119		
Marlton	0.308 0.579	8.83 0.003	8.83 0.003	12.1 0.0005	13.9 0.0002	5.58 0.018	
Shrewsbury	11.3 0.001	3.01 0.082	5.85 0.016	0.942 0.332	0.015 0.903	3.35 0.067	14.2 0.0002

Beryllium

0- to 6-inch Composites

The maximum recoverable beryllium concentration is 4.3 ppm in the Kresson soil series (table 60). The Adelphia, Freehold and Kresson soil series have maximum beryllium concentrations exceeding the 2-ppm RDCSCC guideline. The minimum, median, mean and maximum recoverable beryllium concentrations are illustrated in figure 41.

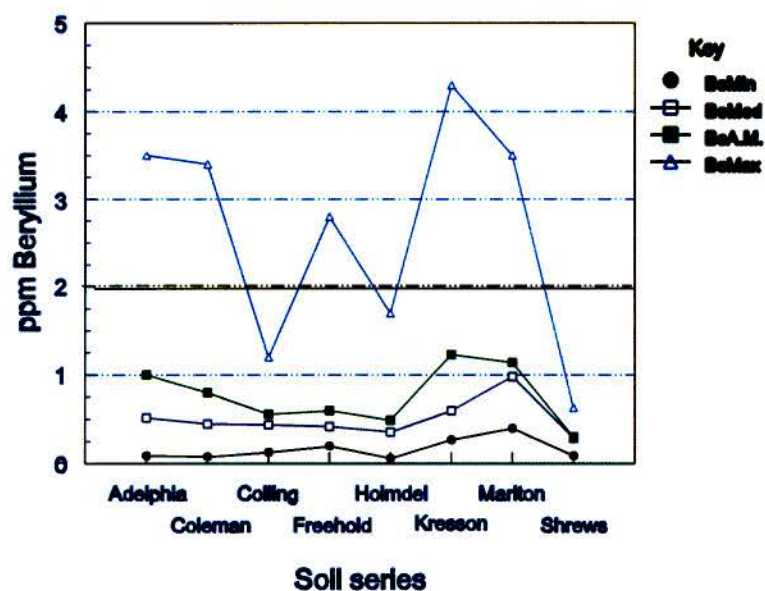


Figure 41. Minimum, median, mean and maximum recoverable beryllium in the 0- to 6-inch composites for the eight soil series.

Mean and median concentrations for all the soil series are in compliance with the RDCSCC guideline. Relatively large differences between the mean and median recoverable beryllium occur in the Adelphia, Freehold and Kresson series, whereas the difference is small to zero in the Colemantown, Collington, Holmdel, Marlton and Shrewsbury series (fig. 41).

The mean and standard deviation recoverable beryllium concentration for each soil series

are shown in table 66 and illustrated in figure 42. The range in the standard deviation about the mean is small for the Colemantown, Holmdel and Shrewsbury, moderate for the Collington and Marlton, and large for the Adelphia, Freehold and Kresson soil series. The standard deviation for recoverable beryllium in the Adelphia and Kresson soil series exceeds the RDCSCC guideline (fig. 42).

Table 66. Mean and one standard deviation recoverable beryllium concentration (ppm) in the 0- to 6-inch composites for the various soil series.

Soil Series	Standard		N
	Mean	Deviation	
Adelphia	1.2	1.5	4
Colemantown	0.45	0.22	5
Collington	0.52	0.42	4
Freehold	0.83	0.98	6
Holmdel	0.34	0.13	4
Kresson	1.3	1.7	5
Marlton	0.97	0.49	6
Shrewsbury	0.29	0.13	4
all samples	0.73	0.84	45

As it is for recoverable arsenic in the 0- to 6-inch composites, the Holmdel and Shrewsbury soil series are significantly different from the Marlton series when the overlap in the range of the standard deviation is used as an indicator of statistical significance. A matrix for the results of the K-W test statistics is shown in table 67. These analysis of variance results show that at ≥ 95 percent confidence the Holmdel and Shrewsbury differ significantly from the Marlton series, and the Shrewsbury differs from the Kresson series. The Marlton series differs significantly from the Colemantown series at ≥ 90 percent confidence.

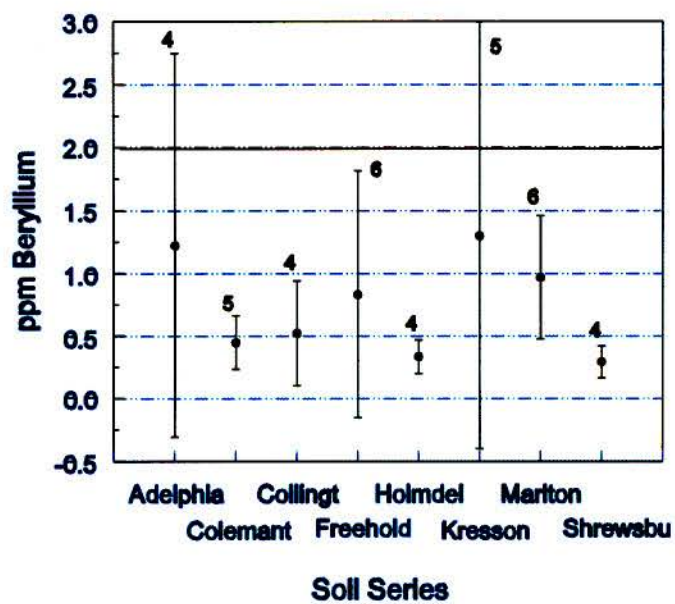


Figure 42. Mean $\pm$ one standard deviation recoverable beryllium in the 0- to 6-inch composites for each soil series. Number of measured concentrations is above the figure for each soil series.

Table 67. Matrix for Kruskal-Wallis test statistics on beryllium concentration in the 0- to 6-inch composites. In each cell, the upper value is the H-test value and the lower is the probability. Bold type indicates a statistically significant difference in beryllium concentration at ≥ 95 percent confidence.

	Adelphia	Colemantown	Collington	Freehold	Holmdel	Kresson	Marlton
Colemantown	0.540						
	0.462						
Collington	0.521	0.000					
	0.470	1.00					
Freehold	0.182	0.133	0.182				
	0.700	0.715	0.700				
Holmdel	1.33	0.960	0.333	1.14			
	0.248	0.327	0.564	0.286			
Kresson	0.000	0.175	0.240	0.300	1.82		
	1.00	0.676	0.624	0.584	0.178		
Marlton	0.409	3.33	2.23	1.64	5.50	0.533	
	0.522	0.068	0.136	0.200	0.019	0.465	
Shrewsbury	2.08	2.16	0.750	1.64	0.083	3.84	5.50
	0.149	0.142	0.386	0.201	0.773	0.050	0.019

Composited Samples from all Depths

The minimum, median, mean and maximum recoverable beryllium for the soil series are illustrated in figure 43. The maximum recoverable beryllium concentration is 4.3 ppm in a 0- to 6-inch composite from the Kresson soil series (table 63). All of the soil series, except for the Collington, Holmdel and Shrewsbury, exceed the beryllium RDCSCC guideline. Median and mean concentrations for each soil series are in compliance with the RDCSCC guideline. Except for the Shrewsbury series, the mean is greater than the median recoverable beryllium. The mean and median concentration are almost identical for the Shrewsbury soil series.

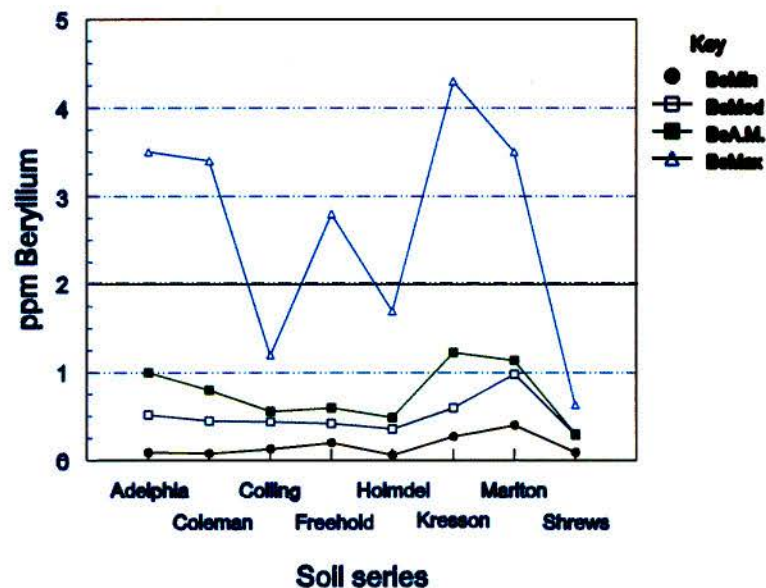


Figure 43. Minimum, median, mean and maximum recoverable beryllium in all samples from each of the eight soil series.

The mean and standard deviation recoverable beryllium for each soil are shown in table 68 and figure 44. The standard deviation for the Adelphia and Kresson soil series exceeds the 2-ppm RDCSCC. The range in the standard deviation is small for the Collington, Holmdel and Shrewsbury, moderate for the Freehold and Marlton, and large for the Adelphia, Coleman and Kresson soil series. There is no significant difference in beryllium concentration among the soil series when using overlap in the standard deviation as an indicator of statistical significance (fig. 44).

Table 68. Mean and one standard deviation recoverable beryllium concentration (ppm) for all composites in each soil series.

Soil Series	Standard		N
	Mean	Deviation	
Adelphia	1.0	1.3	10
Colemantown	0.80	0.98	13
Collington	0.56	0.38	10
Freehold	0.60	0.64	15
Holmdel	0.49	0.48	9
Kresson	1.2	1.5	11
Marlton	1.1	0.75	15
Shrewsbury	0.30	0.18	10
all samples	0.80	0.88	113

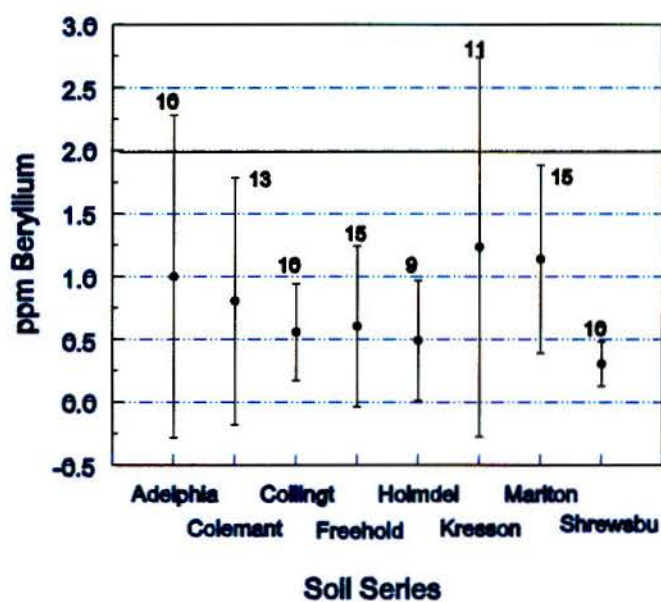


Figure 44. Mean $\pm$ one standard deviation recoverable beryllium in the suite of composite samples for each soil series. Number of measured concentrations is above the figure for each soil series.

A matrix for the K-W test statistics is shown in table 69. Except for the Kresson series, the beryllium concentration in the Marlton series is significantly different at ≥ 95 percent confidence than all other soil series. The Kresson series is significantly different from the Shrewsbury series at ≥ 95 percent confidence. At ≥ 90 percent confidence, significant differences are indicated between the Kresson and Holmdel series, and between the Freehold and Shrewsbury series. For both the 0- to 6-inch composites and all composited depths the beryllium concentration for the Kresson series differs significantly at ≥ 95 percent confidence from the Shrewsbury series, and the Marlton differs from the Holmdel and Shrewsbury soil series.

Table 69. Matrix for Kruskal-Wallis test statistics on beryllium concentration in the composites for all depths. In each cell, the upper value is the H-test value and the lower is the probability. Bold type indicates a significant difference in beryllium concentration at ≥ 95 percent confidence.

	Adelphia	Colemantown	Collington	Freehold	Holmdel	Kresson	Marlton
Colemantown	0.246 0.620						
Collington	0.091 0.762	0.004 0.951					
Freehold	0.093 0.760	0.104 0.747	0.012 0.912				
Holmdel	0.667 0.414	0.135 0.713	0.375 0.540	0.697 0.404			
Kresson	0.838 0.360	1.93 0.164	1.04 0.307	2.42 0.119	3.32 0.068		
Marlton	4.10 0.043	4.79 0.029	5.69 0.017	10.7 0.001	8.71 0.003	2.04 0.154	
Shrewsbury	2.17 0.140	1.46 0.227	2.52 0.112	2.96 0.086	0.735 0.391	7.54 0.006	14.6 0.0001

Significant Differences in both Arsenic and Beryllium Among the Soil Series

0- to 6-inch Composites

K-W analysis of variance shows that the Marlton soil series differs significantly at ≥ 95 percent confidence from the Colemantown, Collington, Freehold, Holmdel and Shrewsbury. The Kresson series differs significantly at ≥ 90 percent confidence from the Shrewsbury series.

Composites from all Depths

The Marlton soil series is significantly different at ≥ 95 percent confidence from the Holmdel and Shrewsbury series, whereas it differs from the Colemantown series at ≥ 90 percent confidence.

Results of the K-W analysis of variance for recoverable arsenic and beryllium at ≥ 95 percent confidence indicate that the Marlton soil series is significantly different from the Holmdel and Shrewsbury series in both the 0- to 6-inch composites and composited depths to 30-inches below grade. The Marlton series has the highest mean concentration of glauconite sand, whereas the Holmdel and Shrewsbury series have the lowest (table 4). The Marlton, Holmdel and Shrewsbury series represent end members within this suite of glauconite-bearing soil series. In terms of both mean recoverable arsenic and beryllium, the Marlton series is the high end member, and the Holmdel and Shrewsbury series are the low end member.

Conclusion

This chemical characterization of glauconite-bearing soils in the New Jersey Coastal Plain, employing U. S. EPA SW-846 Methods 3050 and 6010A, provides an assessment of the natural variability in the baseline concentration of TAL elements that is directly compatible with chemical data submitted to the Department in the course of site investigations conducted by the regulated community. Application of the statistical method for the calculation of outlier concentrations suggested in the NJDEP's Field Sampling Procedures Manual (Schoenleber and Morton, 1992) provides successful identification of those sample stations that were augmented by anthropogenic inputs.

Soil pH is a good tool to discriminate natural soil from disturbed soil. Natural background pH is less than 4.7 (measured in CaCl_2 solution, or approximately pH 5.3 measured in a water suspension) for glauconite-bearing soil from the New Jersey Coastal Plain. The low soil pH is due in part to the exchangeable protons on the surface of the constituent minerals.

Most native glauconite-bearing soil in New Jersey has low total and 'recoverable' calcium concentrations. High calcium concentrations along with relatively high pH (greater than 4.7) may be a flag that indicates a disturbed soil within the glauconite-bearing areas. High calcium concentration with usual pH for natural glauconite-bearing soil may represent an undisturbed soil derived from an apatite/carbonate-rich (marl) parent sediment such as the basal Vincentown Formation. The conclusion that the soil is indeed undisturbed, based solely on the high calcium/low pH criterion, requires verification in that the application of ammoniac fertilizers could account for this relation.

The range in total arsenic concentration (7 to 136 ppm) for the pristine glauconite isolates lies within the range (3 to 490 ppm, $n = 53$) for Cretaceous marine shale and claystone from the western United States. The median total arsenic concentration (24 ppm) for the pristine glauconite isolates is double that for the marine shale and claystone, whereas the means are similar (31.8 ppm for pristine glauconite and 27 ppm for marine shale and claystone).

The median total arsenic concentration in glauconite-bearing whole soil from New Jersey is enriched four to five times over the median for U. S. and worldwide soils, and enriched approximately 2.5 times over that for typical marine shale. The median total beryllium concentration in the glauconite-bearing whole soil is enriched eight times over the median for U. S. soil and twenty-three times that for worldwide soils.

Total arsenic in pristine glauconite has strong, positive Spearman rank-order correlations with total chromium, vanadium and zirconium — elements presumably isomorphously substituted in octahedral lattice sites of phyllosilicates and/or coordinated with interlayer aluminum-hydroxy polymers (McBride, 1989). The positive linear regression correlation coefficient ($r = 0.970$) between total arsenic and iron is extremely robust for the pristine glauconite. The strong, positive correlations total arsenic has with constituent elements in glauconite demonstrate that arsenic is a constituent element in pristine glauconite. Total arsenic exhibits a different association in the soil glauconite isolates. Total arsenic in the soil glauconite has strong, negative Spearman rank-order correlations with the major constituent elements (namely, magnesium, potassium and silicon) in glauconite and phyllosilicate minerals. The robust, negative correlations total arsenic exhibits with constituent elements in glauconite, in addition to its strong, positive, linear regression correlation ($r = 0.965$) with total iron suggests that the arsenic is sorbed to iron (oxy)hydroxides.

The U. S. EPA SW-846, Method 3050 acid digestion solubilizes from 5 to 69 percent of the total arsenic in the glauconite-bearing whole soil. The 40.5 percent median extraction efficiency using the Method 3050 acid digestion does not solubilize 60 percent of the total arsenic in whole soil. The median percent extraction efficiency for beryllium, using the Method 3050 acid digestion, is only approximately 20 percent of the total beryllium in glauconite isolates and select whole soils. Sixty three to ninety eight percent of the total beryllium in glauconitic whole soil is not 'recoverable' using Method 3050. The lowest maximum percent extraction efficiency for all the TAL elements in whole soil is for beryllium. Comparing 'recoverable' analyte concentrations provided by the EPA's partial-leach method to total analyte

concentrations reported in the literature is not a valid, meaningful comparison.

The non-specificity of the prescribed EPA methods for iron-rich soils provides equivocal results. Iron is an interferant for some TAL elements, such as cadmium. Incredibly high percent extraction efficiencies for antimony and cadmium reveal a problem with the EPA's analytical protocol as carried out by a state-certified, commercial laboratory. Furthermore, multiple factors, for example sample inhomogeneity and sampling biases introduced at the laboratory, affect analyte concentrations. Natural variability can be large within and among the glauconite-bearing soil series. Even within a particular soil series, the range in soil character greatly influences the efficacy of the prescribed acid-digest protocol. Matrix quality within a soil series appears to be the greatest variable affecting the extraction efficiency of the EPA's analytical method, that is the 'recoverable' analyte concentrations.

Twenty percent (23 of 113 samples) of the soil samples have 'recoverable' arsenic concentrations exceeding the 20-ppm RDCSCC. Adelphia, Kresson and Marlton soil series account for 30, 13 and 39 percent, respectively, of these arsenic exceedances. Of the arsenic exceedances, 26 percent are in the 0- to 6-inch composites (Ap horizon), 17 percent are in the 12- to 18-inch composites (Bt horizon), and 52 percent are in the 24- to 30-inch composites (Bt2, B3 and C1 horizons). Sixty one percent of the twenty three arsenic exceedances are in Monmouth County, 26 percent are in Gloucester County, and 13 percent are in Burlington County. No arsenic exceedances are found in Camden County. One third of all soil samples from Gloucester (6 of 19 samples) and Monmouth (14 of 43 samples) Counties exceed the arsenic criterion. Soil with greater than 20 ppm 'recoverable' arsenic is characterized by a brown (ferric iron) and/or pistachio green, soft, waxy to ooze-like, clay/silt matrix which generally is associated with samples from the B and top of the C soil horizons. This soft, waxy to ooze-like, clay/silt matrix is predominant in Adelphia, Colemantown, Kresson and Marlton soil series. The 'recoverable' median and mean arsenic concentrations for the Adelphia and Marlton soils series exceed the RDCSCC guideline for arsenic. Of the Adelphia, Colemantown, Collington, Freehold, Holmdel, Kresson, Marlton and Shrewsbury soil series, only the Holmdel and

Shrewsbury soil series have maximum 'recoverable' arsenic concentrations that are below the arsenic RDCSCC guideline.

Ten percent (11 of 113 samples) of the soil samples have 'recoverable' beryllium concentrations exceeding the two ppm RDCSCC. Adelphia, Colemantown, and Kresson soil series each account for 18 percent of these beryllium exceedances. Eighty two percent (9 of 11 samples) of the beryllium exceedances are from disturbed sites. Of the beryllium exceedances, 27 percent are in the 0- to 6-inch composites (Ap horizon), 9 percent are in the 12- to 18-inch composites (B horizon), and 64 percent are in the 24- to 30-inch composites (Bt2, B21t, B22, B2g horizons). Sixteen percent of all samples from Gloucester County, 12 percent from Monmouth County, 8 percent from Camden County, and 5 percent from Burlington County exceed the beryllium RDCSCC guideline. Soil samples exceeding the beryllium RDCSCC of two ppm have high 'recoverable' aluminum and iron concentrations. The high 'recoverable' concentrations correspond to those soil samples (Adelphia, Colemantown, Kresson and Marlton soil series) that consist of the soft, waxy, brown and/or green clay/silt matrix. None of the glauconite-bearing soil series had a median or mean 'recoverable' beryllium concentration exceeding the RDCSCC guideline. With the exception for the Shrewsbury and Tinton soil series, all soil series have a maximum 'recoverable' beryllium concentration that exceeds the RDCSCC.

Five percent (6 of 113 samples) of the soil samples have RDCSCC exceedances for both arsenic and beryllium.

In Adelphia, Colemantown, Collington, Freehold, Holmdel, Kresson, Marlton and Shrewsbury soil series, arsenic has moderate to strong, positive, Spearman rank-order and linear regression correlations with 'recoverable' iron, and very weak to no correlations with glauconite sand concentration. This provides strong evidence that the arsenic associates with labile iron (hydr)oxide phases in the soil. Furthermore, at the onset of this investigation, it was thought that the arsenic concentration is a direct function of the glauconite concentration in the soil. To

explain the 'recoverable' arsenic in terms of glauconite sand contents in the soil requires the soil to consist entirely of glauconite, which certainly is not true.

Beryllium, on the other hand, has robust, positive, Spearman rank-order and linear regression correlations with constituent elements for glauconite and other phyllosilicate minerals. These robust, positive correlations provide strong evidence that 'recoverable' beryllium is a function of the phyllosilicate (clay) content of the whole soil.

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Appendix 1

Site Location, Description, and Field Notes

The drainage character for the sampling station, at times, is not consistent with that for the soil series, as described in the NCRS county soil surveys. For example, the Colemantown soil series is characterized by poor drainage, whereas at station MOCM1001 the drainage is good. Global positioning system (GPS) coordinates are given in survey feet, New Jersey State Plane coordinates, North American Datum 1983.

BUAD2001 Forested area 75 feet north of Route 618 (Evesboro-Medford Road) with school and subdivision south of road. Well-developed canopy with moderate undergrowth. Thin veneer of leaf litter (oak, ash, maple) and few twigs. Below leaf litter there are very fine to fine roots and no humus layer (O-horizon). High auger resistance. Soil is very slightly moist to 2.5 feet TD (total depth) and drainage is good. Land use is suburban.

NRCS (National Resources Conservation Service) soil designation = Adelphia (AnA).

GPS (Global Positioning System) coordinates = 391322.51N and 377311.89E.

BUAD4001 Wooded tract on west side of Marter Road and approximately 0.5 mile east of the New Jersey Turnpike. Mud auger approx. 40 feet west of Marter Road in well-developed canopy with trees and shrubs not more than 40 feet tall. Very sparse undergrowth. No humus layer (O-horizon) but very fine to fine roots in surface soil. Quartz gravel persists down to 2.5 feet TD, with a bituminous coal shard at approx. 8 inches below grade. Moderate to high auger resistance. Soil is very slightly moist in top 10 inches then becomes slightly moist to TD, and has very good drainage. Land use is suburban with some farms; industrial parks in vicinity.

NRCS soil designation = Adelphia (AaA).

GPS coordinates = 409164.39N and 376737.08E.

BUCL2001 Forested tract just west of Highland Road in a “semi-wildlife preserve”. Mud auger approx. 50 feet west of road under a very well developed canopy. Thick layer (~0.2

feet) of leaf litter (oak, ash) and ~0.1 foot of humus and very fine roots which were removed prior to augering. Little undergrowth and large roots down to 2.5 feet TD. Soil becomes more argillaceous downhole and is slightly moist to TD. Drainage is outstanding with a steep (drainage) slope ~30 feet west of auger hole. Land use is rural.

NRCS soil designation = Collington (CnB).

GPS coordinates = 444480.83N and 453569.89E.

BUCM2001 Wooded tract approx. 80 feet north of Route 70; east of former “marl pit” and approx. 300 feet west of southwest branch of the Rancocas Creek. Well developed canopy with moderate undergrowth. Very thin layer of leaf litter, stems and twigs, and no humus layer. Argillaceous and compact thru pedon to 3.0 feet TD. Moderate auger resistance. Slightly moist to TD. Drainage is fair and land use is suburban.

NRCS soil designation = Colemantown (Cm).

GPS coordinates = 386691.94N and 380753.33E.

BUCM5001 Wooded tract approx. 40 feet east of Smithville Road just north of Route 537 with a very well developed canopy. Sparse undergrowth with a very thin layer of leaf litter and some twigs. No humus layer but very fine to fine roots at soil surface. Static-water level approx. 1.0 foot below grade — auger hole maintained this static-water level while augering to 2.5 feet TD. Auger hole rapidly reached static-water level. Soil is moist in top 6 inches then becomes very moist to wet — difficult to determine relative moisture of zones from ~1.0 to 2.5 feet because of the high water table. Very low auger resistance. Drainage is poor and land use is rural.

NRCS soil designation = Colemantown (Cm).

GPS coordinates = 430545.54N and 422897.96E.

BUDO1001 Wooded tract with a very well developed canopy approx. 40 feet east of Florence-Columbus Road (Co. Route 656) approx. 0.5 mile north of the New Jersey Turnpike Extension. Across from new housing development. Abundant undergrowth with a thick layer of

organic debris — mainly leaf litter with some twigs. Top soil is bioturbated with a thin layer of humus (woody matter). Some quartz gravel (lightly stained by iron) penetrated from ~1.75 to ~2.1 feet below grade. Moderate to high auger resistance. Pedon is very slightly moist to 2.5 feet TD and crumbly (silty). Drainage is good and land use is rural but quickly becoming suburbanized.

NRCS soil designation = Donlonton (DIA).

GPS coordinates = 461747.61N and 414583.66E.

BUDO2001 Wooded tract with a well developed canopy approx. 100 feet north of County 528 spur and approx. 500 feet east of I-295. No undergrowth with ~0.1 foot of leaf litter and thin humus layer with abundant fine roots. Many branches on the ground. Top of auger hole is loamy/clayey becoming sandy down hole. Soil moist to 2.5 feet TD. Soil is wet from 2.0 to 2.5 feet below grade with a static-water level approx. 27 inches below grade. Moderately light auger resistance. Drainage is poor at surface and land use is rural.

NRCS soil designation = Donlonton (DIA).

GPS coordinates = 446684.19N and 404989.97E.

BUFR2001 Forested area with a very well developed canopy approx. 150 feet south of Columbus-Jobstown Road and approx. 30 feet east of Arney's Mount-Columbus Road. Approx. 100 feet south of an old railroad bed (unused). Abundant leaf litter and branches (approx. 0.05 foot thick) with a very thin humus layer with very fine roots. Roots, some large, persist to 2.5 feet TD. Light auger resistance. Soil is moist to 2.5 feet TD. Site is well drained and land use is suburban/rural — surrounded by recent housing development.

NRCS soil designation = Freehold (FrB).

GPS coordinates = 442797.00N and 431353.21E.

BUFR7001 Right of way along power lines running thru open cultivated fields approx. 40 feet east of Eayrestown Road and north of Landing Road (Burlington Co. Route 641). Sample site on north side of treeline adjacent to cultivated field (row crops). Very thick (~0.33

foot) mat of dead wheat/straw with common wood litter. No humus development and moderate to thick roots to 2.5 feet TD. Soil is dry to very slightly moist to TD. Moderate auger resistance. Drainage is very good and land use is rural.

NRCS soil designation = Freehold (FfB).

GPS coordinates = 407360.43N and 411168.15E.

BUHN2001 Wooded tract with a well developed canopy approx. 75 feet east of Ormead Road and approx. 500 feet north of I-295. No undergrowth but common leaf litter (~0.2 foot thick) with few twigs/branches. Very thin humus layer with abundant very fine to fine roots. Quartz gravel encountered from ~1.0 to ~2.3 feet below grade. Large roots down to ~1.5 feet below grade. Soil is slightly moist to 2.5 feet TD. Light auger resistance. Drainage is good and land use is rural.

NRCS soil designation = Holmdel (HmB).

GPS coordinates = 445466.00N and 401748.63E.

BUHN4001 Wooded tract with a very well developed canopy approx. 20 feet west of Fostertown Road just north of Route 612. Ground is a bit hummocky — perhaps local soil moved for fenceline and road construction. Sparse undergrowth with mainly woody debris at surface. No humus developed but very fine to fine roots are common at the surface. Large roots are common to 2.5 feet TD. Soil is very slightly moist, tending to dry in top 15 inches, then becomes slightly to nearly moist at TD. Auger resistance is high. Drainage is fair and land use is rural with encroachment by residential subdivisions across street from sample site.

NRCS soil designation = Holmdel (HdA).

GPS coordinates = 406620.13N and 400036.41E.

BUKR3001 Wooded tract with a well developed canopy approx. 25 feet from edge of farm (corn) field and approx. 60 feet west of Elmwood Road. Sample site may have been formerly cultivated. Thin veneer of leaf litter with sparse undergrowth. Very fine to medium roots in the black topsoil with no apparent humus layer. Soil is slightly moist to 2.5 feet TD.

Auger resistance is moderate. Drainage is good and land use is suburban but is being prepared for (residential?) development.

NRCS soil designation = Kresson (KxA).

GPS coordinates = 388334.70N and 383995.34E.

BUMR4001 Cultivated field (corn and winter wheat for past 13 years according to owner), with a healthy crop of grasses and sparse wheat, approx. 400 feet east of Route 68 and approx. 20 feet south of a fence line for the dwelling. Large military (transport) jet traffic in airspace is common. No organic debris at surface of soil. Soil is very slightly moist to 2.5 feet TD. Auger resistance is high. Drainage is good and land use is rural with estate development initiated.

NRCS soil designation = Marlton (MhB).

GPS coordinates = 444539.34N and 450811.94E.

BUSH1001 Cultivated field approx. 50 feet west of Arney's Mount-Columbus Road and approx. 350 feet north of Route 537. Thick grass approx. 1-foot tall (removed prior to augering) and no surface humus layer. Top three inches of the 0- to 6-inch core is full of fine roots in a dark brown/black soil (Ap horizon). Incipient iron oxyhydroxide nodules, which are very soft (poorly indurated), occur from ~1.5 to 2.0 feet below grade. Soil remains very glauconite-rich down to 3.0 feet below grade, and is slightly moist in the top 18 inches becoming moist to 3.0 feet TD. Auger resistance is light. Drainage is good and land use is rural.

NRCS soil designation = Shrewsbury (Sx).

GPS coordinates = 435231.89N and 433043.11E.

BUSH4001 Wooded tract with a well developed canopy approx. 20 feet south of New Road (Route 639) and west of Mt. Holly-Jacksonville Road (Route 628). Sparse undergrowth (prickly vines!) and thick leaf litter (~0.15 foot) overlying a root-filled, 0.25-foot thick humus horizon. Roots range from very fine to large. Soil is very slightly moist to moist. Auger resistance is light to moderate. Drainage is poor and land use is rural.

NRCS soil designation = Shrewsbury (Sn).

GPS coordinates = 436126.81N and 414170.95E.

CACL3001 State park land with a very good canopy on the north side of Kresson Road and west of Springdale Road. Auger hole is approx. 80 feet into the trees from the clearing used to dispose of wood mulch. NRCS (SCS) soils book for Camden County (1964) shows this parcel was cultivated although now the area is wooded. Thin layer of organic debris (leaf litter/twigs) with little to no undergrowth. Fine to very fine roots in the topsoil are common. Top one foot of soil is dry and becomes very slightly moist below. Auger resistance is moderate. Drainage is excellent and land use is suburban.

NRCS soil designation = Collington (CoA, perhaps CoB).

GPS coordinates = 383256.60N and 359716.97E.

CAFR3001 Open, grassy field (formerly a cultivated farm field) approx. 100 feet southeast of back of Eckard Drugs store and behind the Mother Goose Learning Center; approx. 150 feet south of Chews Landing Road and east of Little Gloucester Road. Grass and weeds removed prior to augering. No humus layer developed at surface. Soil is dry, tending to very slightly moist. Auger resistance is moderate. Drainage is fair with some standing water in gullies (depressions) at the surface and land use is suburban.

NRCS soil designation = Freehold (FfA).

GPS coordinates = 362235.13N and 336653.20E.

CAHN3001 Church property approx. 200 feet east of Springdale Road and north of Route 70. Sample augered in a wooded (strip) parcel with a well developed canopy though only approx. 40 feet of the original wooded tract remains intact — formerly a wooded tract adjacent to a corn field. Priest says that “... neighbors dump leaves in this area”. Very thick (~0.2 foot) layer of leaves and twigs/stems overlying a thin (0.05 foot) humus layer with quartz sand (salt and pepper texture). Top two feet of soil is very sandy (quartz), strongly stained by iron and augering resistance is light. From 2 to 2.5 feet TD the soil becomes much more argillaceous and

augering resistance is moderate. Soil is very slightly moist, tending to dry. Drainage is excellent and land use is suburban — property backed by a housing development and commercial park across Springdale Road.

NRCS soil designation = Holmdel (HfA).

GPS coordinates = 391833.13N and 361606.95E.

CAKR4001 Small wooded area with a good canopy approx. 50 feet west of Springdale Road and south of Kresson Road. South of rescue squad station across from estate homes. Abundant undergrowth (vines) and leaf litter are common overlying a thin (~0.1 foot) humus layer with fine to medium roots. Gravel common to 2.5 feet TD. Soil is highly mottled with red and orange hues with occasional stringers and mottles of green glauconite in a reddish matrix of weathered(?) glauconite. Auger resistance is moderately high. Soil is dry to very slightly moist at TD. Drainage is very good and land use is suburban.

NRCS soil designation = Kresson (KrA).

GPS coordinates = 380635.69N and 359846.24E.

CAMK1001 Wooded tract with a well developed canopy approx. 275 feet west of Burnt Hill Road (County Route 670) on “Green Acres Tract”. Moderate undergrowth and 0.2-foot-thick cover of leaf litter with very fine to fine roots. No humus layer developed. No apparent horizonation in top 8 inches of soil, then horizonation becomes apparent down hole. Pedon is not the characteristic greens as for Marlton and Kresson soils, but instead mainly quartz sand strongly stained by iron with glauconite sand concentration increasing from ~1.7 to 2.5 feet TD. Auger resistance negligible to approx. 2.0 feet below grade and then moderately light to TD. Soil slightly dry to slightly moist. Drainage is very good and land use is suburban.

NRCS soil designation = Marlton and Kresson-Urban land complex (MK).

GPS coordinates = 377453.54N and 349733.15E.

CASH2001 Wooded tract with a very well developed canopy bordered on the north by Heritage Junior High School — approx. 700 feet east of the New Jersey Turnpike and approx.

300 feet west of Browning Lane. Abundant undergrowth with a 0.25-foot-thick layer of leaf litter and wood debris overlying a nicely developed 0.2-foot thick humus layer with common very fine to moderately thick roots. Auger resistance is light to moderately light. Soil is very slightly moist, tending to dry. Drainage is very good and land use is suburban.

NRCS soil designation = Shrewsbury (Sw).

GPS coordinates = 383696.57N and 352689.52E.

GLCL4001 Wooded tract with a well developed canopy approx. 150 feet east of Fox Run Road and south of Taylor Lane — across from Deptford High School. An approx. 0.2-foot thick layer of leaf litter overlies a thin layer of light brown (iron-stained quartz), sandy humus with common very fine to fine roots in topsoil. A light brown (iron-stained) quartz sand in a thin layer under the oak leaf debris overlies the blackish-brown topsoil (A horizon?) -- leached by organic acids?. There is an abrupt change from brown sand to a loamy (argillaceous) sediment from ~26 to 30 inches TD. Auger resistance is very light. Soil is dry to very slightly moist. Drainage is very good and land use is suburban.

NRCS soil designation = Collington (CmB).

GPS coordinates = 357012.98N and 321175.56E.

GLCM3001 Wooded tract along Basgalore Creek on west side of Tomlin Station Road (County Route 607). Sample taken from opening in canopy. Very dense ground cover of grasses, grape vines, wild roses, and weeds with moss at the soil surface. Topsoil is black and rich in organics with a moderate amount of medium roots. No apparent humus horizon and very glauconitic below approx. 10 inches below grade. Quartz gravel is common to 2.5 feet TD. Virtually no auger resistance. Soil is very moist to wet — water very slowly seeping into auger hole. Drainage is poor (mainly soft, muddy, water-soaked ground) and land use is rural.

NRCS soil designation = Colemantown (Ck).

GPS coordinates = 322898.50N and 276988.43E.

GLCM4001 Wooded tract with a very well developed, thick canopy near a creek approx. 30 feet west of Marl Road and south of State Route 45. Essentially no undergrowth with twig/branch debris and some leaf litter at surface. No apparent humus horizon developed. Auger resistance is light. Soil is slightly moist in top eight inches and becomes moist to approx. 1.8 feet below grade. From approx. 1.8 to 2.5 feet TD the soil is wet and very arenaceous (sandy) — within 10 minutes the borehole had 0.95 foot of standing water, that is from 1.55 to 2.5 feet below grade. Drainage is good and land use is rural.
NRCS soil designation = Colemantown-Matlock loam (CK).
GPS coordinates = 312529.23N and 271049.71E.

GLCN1001 Front yard of dwelling (vacant) on northern edge of cultivated farm field approx. 60 feet east of Cohawkin Road (Route 667) near a cemetery. Sample taken approx. 3 feet north of the cultivated field (vine crops). Bituminous coal fragments found in top one foot of soil. Large oyster shells (middens?) penetrated from 2.2 to 2.5 feet below grade. Oyster shells disappear from 2.5 to 2.9 feet TD. Auger resistance is moderate. Soil is mainly dry to very slightly moist at ~0.9 foot below grade. Drainage is excellent and land use is rural.
NRCS soil designation = Colts Neck (CoB).
GPS coordinates = 350548.98N and 290294.03E.

GLFR4001 Open, cultivated field (winter wheat, lying fallow) behind dwelling approx. 250 feet north of Harmony Road. Principal crop grown in field is tomatoes. Abundant low ground cover with wheat ~3 feet tall and no humus horizon. Quartz gravel stained by iron is common at the soil surface. Auger resistance is moderately high. Soil is dry to very, very slightly moist. Drainage is very good and land use is rural with suburban encroachment.
NRCS soil designation = Freehold (FoB).
GPS coordinates = 351340.57N and 283894.44E.

GLKR5001 Open, cultivated (wheat) field approx. 45 feet north of Swedesboro-Monroeville Road and approx. 40 west of Russell Mill Road (County Route 614). Weeds and

low ground cover is abundant with no apparent humus layer. Quartz gravel is fairly common on the soil surface and persists to 2.5 feet TD. Soil is very argillaceous at approx. 1.8 feet below grade and is mottled brick red with small (~5 mm) oxidation pockets. Samples have a very blocky structure with strange grain-size associations. Auger resistance is very high. Soil is very dry to TD. Drainage is good and land use is rural (farm).

NRCS soil designation = Kresson (KrB).

GPS coordinates = 327205.29N and 269963.85E.

GLMR5001 Wooded tract with a very developed canopy approx. 80 feet east of Fox Run Road and north of Delsea Drive (Route 47). No undergrowth with a thin (≤ 0.1 foot) layer of leaf litter and tree branches. Well developed, thin (≤ 0.1 foot) humus (O horizon) with common fine to medium roots in a greenish black top soil (A horizon). Beige, authigenic clay(?) mineral is associated with green glauconitic soil mottled orangish to brownish. Auger resistance is high. Soil is slightly moist to slightly dry from 2.0 to 2.5 feet TD. Drainage is good and land use is suburban tending toward rural.

NRCS soil designation = Marlton (MrB).

GPS coordinates = 351887.98N and 318983.41E.

GLMR6001 Wooded parcel being cleared for a subdivision (Estate homes) on south side of Mullica Hill- Swedesboro Road and west of Mullica Hill. Sample taken from open space (no canopy) near wind-break trees. Dense undergrowth of grasses and wild wheat with some leaf (oak and cedar) debris at soil surface. No humus developed with a moderate amount of very fine to fine roots in top three inches of soil. Some quartz gravel encountered at approx. 1.6 feet below grade, becoming more numerous and increasing in clast size with increasing depth in soil to 2.5 feet TD. Auger resistance is very high. Soil is very dry to dry. Drainage is excellent and land use is newly suburban (formerly rural).

NRCS soil designation = Marlton (MrB).

GPS coordinates = 327764.22N and 284864.04E.

MOAD1001 Cultivated farm field east of Olde Noah Hunt Road, approximately 400 feet north of house (Olde Noah Hunt Farm) on east side of road. Mud augered hole in corn field approx. 200 feet east of road and approx. 80 feet north of tree-/scrub-vegetation line in cultivated field. Only corn stalks and quartz sand weathered out of the soil mantle the soil surface. Iron-stained quartz gravel is common and few ironstone aggregates (~1 x 1 inch and smaller) at soil surface. Moderate to high auger resistance. Soil is gritty from ~1.5 to 2.5 feet (TD). Soil is slightly moist and drainage is excellent. Land use is rural though portions of the site are being subdivided for Ivanhoe Brook Estates.

NRCS soil designation = Adelpia (AeB).

GPS coordinates = 484328.48N and 506314.40E.

MOAD3001 Wooded tract with a very well developed canopy approx. 60 feet west of Imlaystown-Emeley's Hill Road and north of Burlington Path Road. Moderately low amount of undergrowth with a thin (≤ 0.1 foot) layer of leaf litter and twigs overlying a very thin humus horizon with abundant very fine roots. Auger resistance is moderately high. Soil is very slightly moist tending to moist to 2.5 feet TD. Drainage is good and land use is rural (farm land preservation/trust?).

NRCS soil designation = Adelpia (AeA).

GPS coordinates = 477703.26N and 496447.07E.

MOCL1001 Forested parcel with a well developed canopy in Monmouth County Park Land approx. 50 feet east of Meirs Road and north of Imlaystown-Emeley's Hill Road. Sparse low undergrowth with abundant twigs at the soil surface. No apparent humus (O horizon) development. Auger resistance is light. Soil is wet with water infilling the borehole to within three inches three inches below grade. Drainage is poor and land use is rural.

NRCS soil designation = Collington (CnB).

GPS coordinates = 482747.91N and 488919.16E.

MOCM1001 Wooded tract with a well developed canopy approx. 50 feet east of Spring Road and north of Lakewood Road (Route 526). Minor undergrowth with approx. 0.1 foot of leaf litter (oak and maple) overlying a 0.1-foot black O-horizon. Below the black O-horizon the contact is sharp with the underlying dark gray to gray sediment which grades over ~0.3 foot to light grayish green mottled with iron stained sediments. Auger refusal at approx. 2.5 feet below grade. Augered another hole approx. one foot from original borehole to approx. 3.0 feet below grade without refusal although there was chatter (grinding) around 2.5 feet depth. This suggests ironstone development at approx. 2.5 feet below grade although it does not appear to be laterally continuous. Auger resistance is moderate. Encountered water (and static water level) at approx. eight inches below grade. Drainage is good and land use is rural.

NRCS soil designation = Colemantown (Cm).

GPS coordinates = 489432.78N and 510640.39E.

MOCN2001 Wooded tract with a very well developed canopy approx. 50 feet south of Route 537 and approx. 60 feet east of Hockhockson Road. Virtually no undergrowth with approx. 0.25 foot of leaf litter and twigs overlying a 0.15-foot humus (macerated leaves) layer with abundant fine roots. Most of humus removed prior to sampling. Salt and pepper appearance to top soil. Auger resistance is light. Soil is dry to very slightly moist. Drainage is excellent and land use is rural.

NRCS soil designation = Colts Neck (CtB).

GPS coordinates = 534508.97N and 595091.36E.

MOFR1001 Forested tract with a well developed canopy on Monmouth County Park Land (Clayton Park), north of Imlaystown-Emeley's Hill Road. Sample taken approx. 40 feet into the forest from the manicured grass field. Sparse undergrowth with a veneer of leaf litter overlying a very thin humus horizon containing very fine roots. Auger resistance is moderate. Soil is moist (preceded by eleven days of precipitation). Drainage is very good and land use is rural.

NRCS soil designation = Freehold (FrC), but sampled close to Tinton (ToA).

GPS coordinates = 482003.00N and 491124.47E.

MOFR6001 Wooded tract with a very well developed, dense canopy approx. 60 feet west of Cross Road and north of Laird Road. Virtually no undergrowth but covered with approx. 0.3-foot of leaf litter and few twigs overlying a 0.15-foot humus (macerated leaves) horizon with fine to moderate roots. The humus horizon overlies approx. 0.33-foot of organic-rich, black soil. Auger resistance is light. Soil is very slightly moist tending to dry — canopy prevented significant rain throughput in spite of moderate rainfall for approx. 10 minutes prior to initiating sampling. Drainage is excellent and land use is rural with estate homes.

NRCS soil designation = Freehold (FrB).

GPS coordinates = 539924.14N and 583419.90E.

MOHN1001 Wooded parcel with a well developed canopy on an undeveloped lot in a new subdivision approx. 80 feet southeast of a newly paved road. Augered hole in a slight (muddy) depression among the trees. Very sparse undergrowth (grass and some poison ivy) with no apparent humus layer at soil surface. Auger resistance is light. Soil is moist to 3.5 feet TD. Drainage is poor at the soil surface although drainage increases below a clay at approx. 0.15 foot below grade. Water entered borehole rapidly to a static level of 2.0 feet below grade. Land use is rural/suburban.

NRCS soil designation = Holmdel (HnA).

GPS coordinates = 542076.50N and 617386.66E.

MOKR1001 Densely wooded tract with a well developed canopy in a Freehold Township Park (Liberty Oak), approx. 50 feet east of Georgia Road. Very sparse undergrowth with a thin layer of organic debris (cedar needles and twigs) on soil surface. Auger resistance is very high. Soil is moist to 2.5 feet TD. Drainage is very good and land use is rural/suburban (new development across Georgia Road).

NRCS soil designation = Kresson (KvA).

GPS coordinates = 502813.25N and 549545.34E.

MOKR2001 Wooded tract with a well developed canopy approx. 100 feet north of (Johnathon) Holmes Road. Area is surveyed for development of estate homes and there are dwellings on each side of the sample station with a fenced cedar grove across the road. Very thin undergrowth with approx. 0.05-foot of well compressed, leaf (oak, ash, maple) litter and twigs overlying a very thin layer of humus with very fine roots. Soil becomes very argillaceous from 1.5 to 2.5 feet TD. Auger resistance is moderate. Soil is slightly moist to TD. Drainage is good and land use is rural, but site is under development.

NRCS soil designation = Kresson (KvA).

GPS coordinates = 471973.16N and 495294.19E.

MOMR1001 Wooded tract with a well developed canopy approx. 250 feet south of Route 524 adjacent to the Freehold Township High School. Very sparse undergrowth with a thick (~0.1 foot) layer of leaf litter and twigs overlying a thin humus layer with very fine roots. A four inch, blackish brown, O/A-horizon is in sharp contact with the yellowish brown B-horizon. Quartz gravel is common in top 6 to 10 inches of soil and then becomes less prominent with depth. Auger resistance is very high. Soil is moist to 2.5 feet TD. Drainage is very good and land use is suburban (newly developed).

NRCS soil designation = Marlton (MIB).

GPS coordinates = 505264.95N and 552043.83E.

MOMR2001 Wooded tract with a well developed canopy west of Yellow Meeting House Road approx. 100 feet south of the cemetery (of the Quaker Meeting House?). Virtually no undergrowth with approx. 0.1 foot of leaf (oak and maple) litter overlying approx. 0.05-foot humus-rich, black, organic horizon with very fine roots. Moderate-sized roots persist to 3.0 feet TD. The black O-horizon is in moderately sharp contact with the underlying grayish green A-horizon. Soil consists of interbedded clay and sand with ironstone from approx. 1.0 to 3.0 feet TD. Auger resistance is light to moderate with depth. Soil is moist although in arenaceous sediment near TD the sediment becomes slightly drier. Drainage is very good and land use is rural.

NRCS soil designation = Marlton (MIB).

GPS coordinates = 486486.57N and 499677.37E.

MOMR3001 Forested parcel with a well developed canopy approx. 80 feet east of Olde Noah Hunt Road and approx. 50 feet south of a cultivated (corn) field. Moderate undergrowth with 0.15 to 0.2 foot of leaf (birch and oak) litter and twigs overlying a 0.1 to 0.2-foot humus horizon with plentiful very fine to fine roots. Moderate size roots persist to 2.5 feet TD. Auger resistance is moderate. Soil is moist to 2.5 feet TD. At 2 feet below grade the borehole had 2 to 3 inches of water, whereas when augering from 2.0 to 2.5 feet, the static water level rose to 0.9 to 1.0 foot below grade. Drainage is poor (wet at surface) and land use is rural, but the site is being developed into a residential subdivision.

NRCS soil designation = Marlton (MIB).

GPS coordinates = 482799.95N and 507724.20E.

MOSH3001 Wooded tract with a well developed canopy approx. 15 feet west of Wilson Avenue (Route 527) just north of Englishtown. Very dense, thick undergrowth of thorny vines with 0.15 foot of leaf litter and fine roots. No apparent humus layer developed. Large roots persist to 2.5 feet TD. The soil is a black silt and argillite from approx. 1.2 to 2.4 feet below grade becoming a greenish-gray loamy sand below 2.4 feet. Auger resistance is moderate. Soil is slightly moist from 0 to 6 inches, becoming moist to TD. Drainage is poor and land use is rural (old abandoned shacks in vicinity). Across Wilson Avenue from sample site are abandoned shacks, bottles, aluminum cans, tires, cement, etc. suggesting that this site may be impacted by anthropic activities.

NRCS soil designation = Shrewsbury (Sn).

GPS coordinates = 537224.31N and 531332.92E.

MOTN1001 Wooded tract with a very well developed canopy approx. 55 feet south of Lamb Road and east of Smithburg Road. Sparse undergrowth (shrubs) with approx. 0.1 foot of leaf litter with few twigs overlying a very thin humus layer which is a black, plastic topsoil with

very fine to fine roots. Soil is rust brown to 4.0 feet TD under the thin organic-rich top soil (O horizon). Auger resistance is very light. Soil is very slightly moist tending to dry in spite of moderately heavy rain for approx. 15 minutes prior to sampling. Drainage is excellent and land use is rural with suburban encroachment (new residential subdivision in development).

NRCS soil designation = Tinton (ToA).

GPS coordinates = 513098.23N and 527220.50E.

MOTN2001 Wooded tract with a well developed canopy approx. 40 feet west of Boundary Road and south of Newman Springs Road (Route 520). Sample taken from opening in canopy on a topographic high above the road. Very thick undergrowth of vines with virtually no underlying leaf litter or humus layer. Fine to medium roots are common in the top three inches of the soil with predominantly medium roots below three inches below grade. Auger resistance is moderate. Soil is very slightly moist in the surface soil becoming slightly moist at 2.5 feet TD. Drainage is very good and land use is rural with estate homes in vicinity.

NRCS soil designation = Tinton (ToC).

GPS coordinates = 544848.46N and 569148.39E.

Appendix 2

Cursory Description of Soil Samples Subjected to Chemical Characterization

All samples are composited for the depth interval. All ranged from slightly moist to wet. The samples were described using a Nikon SMZ-2T binocular microscope with 10- to 60-times magnification and fiberoptic illumination. The Munsell soil color chart was used for most color descriptions.

BUAD2001 [0 to 6 inches] very dark grayish brown (2.5Y 3/2), with olive yellow (2.5Y 6/6) glauconite, quartz sand and silt aggregates, fine sandy loam; most quartz sand is coated with a light beige to very light yellowish clay $\pm$ organic residue; abundant very fine, some medium, quartz sand; ~10% dull black to very, very dark green, fine to very fine, sand- to silt-size glauconite; three very coarse, sand-size aggregates of glauconite and quartz ironstone; ironstone matrix is dark red (10R 3/6); ironstone appears to be transported — well rounded, slightly larger than clasts in soil; friable; no apparent phyllosilicates.

BUAD2003 [24 to 30 inches] olive brown (2.5Y 4/4), with aggregates of grayish olive (10Y 4/2 — rock color chart is closest match), fine to medium sandy clay loam; most quartz clasts have iron staining ranging from moderate to heavy; sparse coarse quartz sand; quartz in grayish olive aggregates is coated with soft, waxy, light green (glauconite?) clay; little to no iron staining on glauconite sand; ~15 to 20% matte black to very dark green, some dark green, fine to medium, glauconite sand; plastic to slightly friable; ~1% very fine to fine muscovite/illite sand; one aggregate (5 mm) of well indurated (iron oxyhydroxide cement) quartz and glauconite sand — ironstone.

BUAD4001 [0 to 6 inches] very dark grayish brown (10YR 3/2) fine to medium sandy loam; ~10% coarse quartz sand; some very coarse quartz sand; clast size ranges from clay to very coarse sand; high organic content imparts dark gray to black color to aggregates and coated clasts; ~50:50 mixture of iron stained quartz clasts (generally the larger clast categories) — some

clasts completely and thickly coated with iron oxyhydroxide, while the smaller quartz sand has little to no iron stain; friable; glauconite concentration is most difficult to estimate because it is obscured by organics; few uncoated (clean) glauconite sand clasts; 1-cm bituminous coal clast in sample; very minor trace of muscovite/illite.

BUAD4002 [12 to 18 inches] dark yellowish brown (10YR 4/4), with dark gray (5Y 4/1) aggregates, medium sandy loam to loamy sand; prevalent yellowish brown pinpoint mottling produces the dark yellowish brown (10YR 4/4) color overall; moderate amount of fine quartz sand although quartz sand ranges up to very coarse; moderately abundant white opaque quartz clasts up to 2.5 cm. (gravel); most quartz clasts are not stained — few are lightly stained with iron oxides; zones of high permeability/porosity are where the yellowish brown clay film develops on the clasts; ~1% matte black, some very, very dark green, fine glauconite sand; no apparent iron staining on glauconite; friable and slightly plastic; trace muscovite/illite.

BUAD4003 [24 to 30 inches] yellowish brown (10YR 5/4) medium sandy clay loam -- overall appearance; aggregates are light gray (10YR 6/1) mottled with reddish yellow (7.5YR 6/8) iron oxyhydroxides; medium to fine quartz sand with few quartz clasts ranging up to 3 cm which are coated with iron-stained clay/silt; much of quartz sand is coated with iron-stained clay/silt $\pm$ iron oxyhydroxide precipitate; iron oxyhydroxide bridges many clasts; ~2 to 3% black to occasionally very, very dark green, fine to very fine glauconite sand; glauconite is smaller than overall clast size; friable; $\leq$ 1% muscovite/illite; trace heavy minerals(?).

BUCL2001 [0 to 6 inches] very dark grayish brown (10YR 3/2) loamy fine sand; salt and pepper texture; high organic content; most fine quartz sand is unstained, but ~50% is coated with a beige to brown organic residue; ~5% matte black, some very dark green, fine to occasional medium, glauconite sand; much of glauconite coated with organic residue; very friable; no apparent phyllosilicates.

BUCL2002 [12 to 18 inches] olive brown (2.5Y 4.5/4) fine sand; more than 90% of quartz sand is lightly, some moderately, iron stained; ~5 to 7% very, very dark green to matte black, fine glauconite sand; few dark green glauconite sand clasts; much of glauconite sand is coated to varying degrees with a waxy, soft, very light beige clay(?) film; friable; <1% muscovite/illite.

BUCL2003 [24 to 30 inches] olive brown (2.5Y 4/4) fine sandy loam to loamy fine sand; fine quartz sand with minor medium quartz sand; most of quartz clasts are moderately to lightly iron stained; 3 to 5% dull black to very, very dark green, some light to moderate green, glauconite sand; clay film on quartz and interstitially; plastic; trace muscovite/illite.

BUCM2001 [0 to 6 inches] brownish black (5YR 2/1 — closest match from rock color chart) clay loam to clay; very organic rich; ~5% fine to very fine quartz sand with no staining or coatings; ~5 to 7% very, very dark green to dull black, medium to fine, glauconite sand; difficult to estimate glauconite and quartz sand concentrations due to argillaceous nature of sample; most glauconite is coated with clay and/or silt; fine to very fine sand aggregates of clay and silt suggest intense bioturbation by soil-ingesting organisms; plastic and sticky; no apparent phyllosilicates.

BUCM2002 [12 to 18 inches] very dark greenish gray (no suitable match located in color charts) clay; ~2% quartz clasts; ~30 to 40% of sample is dark to very dark green, medium to fine, glauconite sand; some very, very dark green and moderately dark green glauconite sand; sparse light green, weathered(?) glauconite; glauconite sand is embedded in a very dark to dark green, soft, clay matrix; some small mottles of dark reddish brown (2.5YR 2.5/4) weathered glauconite (chamosite?); plastic and slightly sticky; <1% muscovite/illite in very fine sand thru silt fraction.

BUCM2003 [24 to 30 inches] dusky yellowish green (10GY 3/2 — closest match from rock color chart) clay loam; ≤1% fine to very fine, unstained, quartz sand; some quartz coated with deep green clay; ~30 to 40% moderate green (dark pistachio) to dark green, fine to medium, glauconite sand; some light pistachio green and few very dark green glauconite sand; glauconite

sand is embedded in a soft, waxy, slightly lighter green clay/silt(?) matrix; slightly friable to plastic; slightly sticky; minor soft brownish (amber) clay(?) — perhaps chamosite(?); no apparent phyllosilicates.

BUCM2004 [30 to 36 inches] dusky yellowish green (10GY 3/2 from rock color chart) medium sandy clay; ~1% quartz sand and silt; little to no apparent silt; dark pistachio green grading to deep dark green, medium to fine, glauconite sand; glauconite sand is in a matrix of slightly lighter green, waxy (authigenic? glauconite) clay of low porosity/permeability; much clay bridging between glauconite sand; slightly friable when slightly moist, and plastic and sticky when moist; ≤1% very fine muscovite/illite sand. Sample resembles parent material.

BUCM5001 [0 to 6 inches] black (5YR 2.5/1) loam to clay loam; high organic content; loose, very fine to medium quartz sand is stained very light brown (beige organics) grading to unstained; few clay-coated aggregates are stained deep reddish brown with iron ± organics; few obvious dull black, fine glauconite sand clasts; most glauconite sand obscured by organic coatings or incorporated in aggregates; plastic and slightly sticky; no apparent phyllosilicates.

BUCM5003 [24 to 30 inches] grayish olive (10Y 4/2 — from rock color chart), interspersed (mottled?) with yellow (10YR 7/8), submicroscopic iron oxyhydroxides (soft ooze), fine to medium sandy clay; occasional coarse quartz sand; few iron stained quartz clasts up to 1.5 cm; virtually all quartz clasts are coated with a green clay(?) or iron oxyhydroxide ooze; ~5 to 7% black to very, very dark green, very fine sand thru silt, some fine sand glauconite — may be underestimated due to matrix; glauconite grain size appears to be slightly smaller than the overall grain size of the sample; soft, green ooze may be glauconite — therefore glauconite concentration is very high; sticky and plastic; trace(?) muscovite/illite. Noted during sample processing — light glauconitic(?) sand resembles coffee with cream due to infiltration of brownish, iron-rich water from up section; therefore the chemistry for the sample may be strongly influenced by this iron-rich, muddy water in the sample.

BUDO1001 [0 to 6 inches] dark brown (10YR 4/3) clay loam overall, although relatively large aggregates are yellow (10YR 7/8) clay, quartz silt and quartz sand; quartz ranges from silt thru very fine to medium sand; most quartz sand is uncoated with few lightly stained with iron oxyhydroxide; quartz in aggregates is bridged with iron oxyhydroxides; ~1% matte black, fine to occasionally medium, glauconite sand; slightly plastic to slightly friable; trace muscovite/illite in silt fraction; black, opaque heavy minerals(?) in silt fraction — may be organic particles.

BUDO1002 [12 to 18 inches] dark yellowish brown (10YR 4/6) with many fine laminar mottles of reddish yellow (7.5YR 6/8) loam to fine sandy loam; quartz clasts are fine to medium sand with some coarse sand; most quartz sand is frosted with no to little iron stain; some iron staining on clasts especially in the reddish yellow mottles; mottles associated with coarser sand fraction which has a clearly higher permeability/porosity — lacks clay film/infillings on peds; trace glauconite; plastic to friable; slightly micaceous; small pockets of soft, black matter which does not fluoresce — perhaps a manganese mineral.

BUDO1003 [24 to 30 inches] dark yellowish brown (10YR 4/6) silty clay loam; mostly silt and clay; dark yellowish brown clay/silt coats the few quartz sand clasts; ~2% very, very dark green to black glauconite sand with virtually no iron stain; SCS (p. 98) describes the glauconite as weathered brown which would mask it (and yield an underestimate) in the matrix; few glauconite sand clasts are very soft (incipient weathering?); slightly friable to slightly plastic; ~3 to 5% muscovite/illite.

BUDO2001 [0 to 6 inches] grayish brown (10YR 5/2), predominantly mottled with reddish yellow (7.5YR 6/8), loam; quartz sand is fine to very fine; few medium quartz sand; most quartz in grayish brown aggregates is unstained and coated with clay/silt; most quartz sand in reddish mottles are moderately to lightly iron stained; trace matte black, very fine sand thru silt glauconite; slightly friable to slightly plastic; ≤1% very fine sand- to silt-size muscovite/illite; ~1% heavy minerals(?).

BUDO2003 [24 to 30 inches] yellowish brown (10YR 5/8), with light brownish gray (10YR 6/2) quartz sand and clay aggregates, fine to medium sandy clay loam; most quartz clasts are principally moderately iron stained but range from lightly to heavily stained; quartz sand brownish gray aggregates is uncoated; ~2 to 3% matte black to dark green, fine to very fine, glauconite sand; abundant lithics (very fine sand-size schist and grayish clay balls); some of these may be weathered glauconite(?) -- mottled grays and greens; few glauconite sutures appear to be weathered to deep reddish brown (rust); plastic and sticky; few ovoid phosphate (apatite minerals) pellets; no apparent phyllosilicates; trace heavy minerals.

BUFR2001 [0 to 6 inches] very dark grayish brown (10YR 3/2) fine sandy loam; most quartz sand is coated/bridged with fine silt and clay; few medium quartz sand; occasional slight brown (organic residue) or very light orangish (FeOOH) stain on quartz sand; ~1% matte black, very fine sand thru silt, glauconite; some fine glauconite sand; glauconite sand tends to be smaller than overall quartz sand; friable to slightly plastic; no apparent phyllosilicates.

BUFR2003 [24 to 30 inches] olive gray (5Y 5/2), with abundant yellowish brown (10YR 5/6) small lenticular to pinpoint mottles, fine loamy sand to some sandy loam; some medium to coarse quartz sand; most quartz clasts are translucent (frosted) to transparent with abundant clay films on peds and interstitially; yellowish brown mottles appear to be films on peds and not iron-stained quartz clasts; ~1 to 2% light pistachio green to matte black glauconite sand; plastic; ~3% muscovite/illite; small pocket of soft black matter — a manganese mineral(?).

BUFR7001 [0 to 6 inches] brown to dark brown (10YR 4/3) fine sandy loam to loamy fine sand; virtually of the quartz clasts are stained beige with organic residue; 2 to 3% matte black, some very dark green, fine to medium glauconite sand often coated with organics and minor clay; very friable; minor trace of black, opaque heavy mineral; no apparent phyllosilicates.

BUFR7002 [12 to 18 inches] dark yellowish brown (10YR 4/6) fine to medium (quartz) sand; ~10% coarse quartz sand; nearly all quartz clasts are stained dark yellowish brown with FeOOH

species; ~3 to 5% dull black to very, very dark green, very fine to medium glauconite sand; no apparent FeOOH staining on the glauconite; friable; <1% phyllosilicates; virtually no clay apparent; trace black opaque heavy minerals.

BUFR7003 [24 to 30 inches] strong brown (7.5YR 4/6) fine quartz sand; abundant very fine quartz sand; ~15% medium quartz sand; few coarse quartz sand grains that are iron stained; all quartz clasts are strongly iron stained (resembles translucent amber); ~5% very, very dark green to matte black, some dark to moderately green, mostly fine but ranges from very fine to medium, glauconite sand; some glauconite sand is iron stained and/or coated with iron-stained clay; very friable; <1% phyllosilicates.

BUHN2001 [0 to 6 inches] very dark grayish brown (10YR 3/2), with aggregates or mottles(?) of light yellowish brown (10YR 6/4), fine sandy loam; most quartz clasts are unstained; some quartz clasts are lightly stained with iron; some of the light yellowish brown aggregates consist of small zones (micro mottles) of dark reddish brown (iron) coats on the clay matrix; glauconite, if present, is obscured by aggregates and organic coatings; friable; no apparent phyllosilicates.

BUHN2003 [24 to 30 inches] light brown gray (10YR 6/1.5), with small strong brown (7.5YR 5/8) mottles apparently parallel to bedding, clay loam(?) to silty clay; fine to medium quartz sand is uncoated and unstained and embedded in a fine silt/clay matrix; few quartz clasts up to 2 cm by 2 cm with virtually no iron stain, although they are coated with gray clay $\pm$ very fine silt; many clasts are coated with clay $\pm$ very fine silt; trace of glauconite and very fine sand phosphate pellet; sticky (waxy) and plastic; ~3% very fine sand grading to silt-size muscovite/illite; one clast of dark amber heavy mineral.

BUHN4001 [0 to 6 inches] dark brown (10YR 3/3) very fine sandy clay loam; very fine quartz sand grades to quartz silt; ~5% fine quartz sand which is unstained and uncoated; most of very fine quartz sand and virtually all of the coarse quartz silt fraction is coated with fine silt and/or clay film — these aggregates are light brown likely resulting from organic residue; ~1% very,

very dark green to matte black, fine, few medium, glauconite sand; glauconite grain size larger than quartz clasts; glauconite coated like the very fine sand/silt fractions; very friable; <1% muscovite/illite in the less than fine sand fraction.

BUHN4002 [12 to 18 inches] dark grayish brown (10YR 4/2), with brownish yellow (10YR 6/8) mottled aggregates that are plastic and slightly sticky, very fine to fine sandy clay loam; most quartz sand is unstained but coated light beige from organic residue; most very fine to fine sand is coated with clay $\pm$ silt; ~1% matte black, some very, very dark green, fine to medium glauconite sand; glauconite clasts tend to be slightly larger than the quartz sand clasts; very friable; 2 to 3% muscovite/illite in the smaller than fine sand fraction.

BUHN4003 [24 to 30 inches] olive gray (5Y 5/2), with reddish yellow (7.5YR 6/8) mottles in the clay/silt/fine quartz sand aggregates, fine sandy loam; quartz sand is mainly fine to very fine and grades to coarse silt; many quartz clasts are clay coated; some quartz sand is very light beige (off white) with organic/clay residue; 1 to 2% very, very dark green to matte black, very fine to some fine, glauconite sand; glauconite sand/silt clasts tend to be smaller than the overall quartz fraction; slightly to moderately plastic; <1% muscovite/illite in sand fraction; <1% opaque, black heavy minerals (?).

BUKR3001 [0 to 6 inches] black (10YR 2/1), with aggregates of olive gray (5Y 5/2) mottled with red (2.5YR 4/8), fine sandy loam; abundant very fine, some medium and few coarse, quartz sand; most sand is iron stained to various extent $\pm$ coated with finer sediments; quartz and glauconite concentrations can not be accurately determined because of matrix; ~5% very dark green to matte black, medium to very fine, glauconite sand; most glauconite sand coated with organic-rich clay; some black glauconite silt; friable and plastic; no apparent phyllosilicates.

BUKR3003 [24 to 30 inches] dusky yellowish green (10GY 3/2 — closest match from rock color chart), extensively mottled with reddish yellow (7.5YR 6/8), fine sandy clay loam; mottles align along bedding planes (i.e. perpendicular to the core length); quartz sand is fine to medium with

abundant very fine and occasionally very coarse; quartz clasts are coated with soft, waxy, pistachio green clay; iron precipitate bridges the clasts in the oxidized sections; very glauconitic although the soft, waxy, glauconite clay (intergranular) is moderate (pistachio) green as opposed to the dark green to black, discrete, glauconite sand; few obvious dark green to very dark green, medium to fine, glauconite sand; glauconite clasts are iron stained (though appear unweathered) in oxidized sections; plastic and sticky; trace muscovite/illite and black, opaque heavy minerals.

BUMR4001 [0 to 6 inches] dark olive gray (5Y 3/2) fine to medium sandy loam; abundant very fine and few medium quartz sand; most quartz sand coated with greenish brown clay $\pm$ organic residue; very, very dark green to matte black, medium to fine, glauconite sand; occasional dull black, coarse glauconite sand; sand is ~60% glauconite and ~40% quartz; much glauconite sand coated with dark gray clay and silt; glauconite sand is larger than quartz sand clasts; friable; no apparent phyllosilicates.

BUMR4003 [24 to 30 inches] grayish olive (10Y 4/2 — rock color chart is closest match) clay loam to clay; the few quartz sand clasts are very coarse to coarse (that is much larger than the glauconite clasts) and coated with green clay; essentially 10 to 15% discrete, pistachio green, fine to medium glauconite sand embedded in a soft, waxy, lighter green clay (glauconite?) matrix; many of glauconite clasts are soft and waxy, some are moderately firm; plastic and sticky; no apparent phyllosilicates; very sparse, ovoid, phosphate (apatite-group) pellets; very tight (that is low permeability/porosity).

BUSH1001 [0 to 6 inches] black (5YR 2.5/1) clay loam (tough call); very organic rich; quartz clasts range from medium to very fine sand thru silt; occasional coarse quartz sand; quartz clasts that are loose or embedded in the black matrix generally are uncoated, clear to translucent; little quartz sand is stained with iron oxyhydroxides $\pm$ organic residue; ~1 to 2% very, very dark green, fine few medium, glauconite sand; glauconite concentration may be greatly underestimated due to matrix; friable to very slightly plastic; <1% phyllosilicates which may be underestimated also.

BUSH1003 [24 to 30 inches] grayish olive (10Y 4/2 — from rock color chart), in places mottled with strong brown (7.5YR 5/8), fine to medium sandy clay loam; most quartz sand is coated with green clay in unoxidized sample, or iron stained ± coated with iron-stained clay in oxidized sections; quartz concentration difficult to determine because of coatings and matrix; in places thin layers (laminae) of quartz sand interbedded with glauconite sand/clay; glauconite does not occur as the characteristic dark green, distinct sand/silt grains but rather is a moderate green, soft clay (ooze) matrix or very soft, fine to very fine sand thru silt particles {not sure if this is intensely weathered glauconite or merely immature glauconite}; plastic and slightly sticky; ~2% muscovite/illite.

BUSH4001 [0 to 6 inches] very dark gray (5YR 3/1) clay loam; high organic content; very fine to fine quartz sand is unstained; some light to medium gray, very fine to fine sand aggregates; some dark yellowish brown silt/clay aggregates coated with very dark gray organic-rich matrix; <1% obvious dull black glauconite sand — most obscured by matrix; friable to slightly plastic; very minor trace of phyllosilicates (two noted).

BUSH4002 [12 to 18 inches] olive gray (5Y 5/2), with prominent yellow (10YR 6/8) mottles, silty clay loam; very silty grading to very fine quartz sand; no glauconite apparent — sample consists entirely of clay/silt aggregates (balls); ~3% muscovite/illite.

BUSH4003 [24 to 30 inches] light olive gray (5Y 6/2 — no suitable match with both color charts) fine to medium sandy loam to loamy sand; a few aggregates have a moderate clay content; abundant very fine quartz sand; quartz sand is virtually free of coatings although there is a light beige (organic?) film on many clasts or light iron oxyhydroxide stain on few clasts; ~2% matte black to occasionally very, very dark green, very fine to medium, glauconite sand; friable to slightly plastic; no apparent phyllosilicates; trace very fine sand to silt-size, black, opaque heavy minerals.

CACL3001 [0 to 6 inches] brown (10YR 5/3) very fine to fine sandy loam; few medium and coarse quartz sand; most quartz sand is coated with silt ± clay; most quartz sand is unstained although a few larger (fine to medium) quartz sand clasts are lightly stained by iron; ~3% matte black to very, very dark green, fine glauconite sand; most glauconite sand coated with silt ± clay; glauconite sand appears to be slightly larger than overall grain size for the sample; very friable (loose); no apparent phyllosilicates or heavy minerals.

CACL3003 [24 to 30 inches] yellowish brown (10YR 5/4) fine to medium sandy clay loam; some very fine and few coarse quartz sand; quartz sand is moderately to lightly iron stained and/or coated with a soft, greasy, yellowish brown clay; ~5% black, few dark green, fine to very fine, glauconite sand; most glauconite sand coated with yellowish brown clay; friable to very slightly plastic; most of sample consists of blocky aggregates of sand in an iron-rich silt/clay matrix; aggregates tend to be firm; <1% muscovite/illite.

CAFR3001 [0 to 6 inches] dark grayish brown (2.5Y 4/2) loam to fine sandy loam; principally fine to very fine, some medium, quartz sand; few quartz gravel up to 3-cm length; most quartz sand is unstained although is coated with a light beige, organic residue ± silt/clay; ~3% very, very dark green to matte black, some dark to moderate green, fine to very fine, glauconite sand; some glauconite sand lightly coated with beige silt/clay; friable to slightly plastic; <1% muscovite/illite sand; trace black, opaque heavy minerals.

CAFR3003 [24 to 30 inches] light olive brown (2.5Y 5/6), locally mottled with strong brown (7.5YR 5/8), fine to very fine sandy loam to sandy clay loam; few medium quartz sand; virtually all quartz clasts are lightly to moderately stained brown by iron ± coated with iron-stained silt/clay; clasts in mottles are heavily stained by iron; ~3 to 5% black to very dark green, fine to very fine, glauconite sand grading to coarse silt; some glauconite sand maybe heavy minerals; most glauconite clasts are uncoated and unstained; slightly plastic to slightly friable; ~1% muscovite/illite in fine sand to silt fraction; heavy mineral fraction may approach 1%.

CAHN3001 [0 to 6 inches] yellowish brown (10YR 5/4) fine sand; ~7% lightly to occasionally moderately iron stained quartz sand; remainder of quartz sand is partially coated with quartz silt or uncoated and unstained; ~1% matte black to dark green, fine to medium, glauconite sand; most glauconite sand coated with quartz silt; extremely friable (loose); no apparent phyllosilicates; trace black, opaque heavy minerals.

CAHN3003 [24 to 30 inches] strong brown (7.5 4/6) fine sandy clay loam; some medium and few coarse quartz sand; iron stained quartz gravel up to 3.3-cm length; virtually all quartz sand is moderately to lightly iron stained and/or coated with iron-stained silt/clay; ~1% black to very, very dark green, fine to very fine, glauconite sand; some moderately indurated aggregates of sand in an iron-stained clay/silt matrix; very friable; no apparent phyllosilicates or heavy minerals.

CAKR4001 [0 to 6 inches] (slightly dry) dark brown (10YR 4/3) fine to medium sandy loam to loam; quartz sand ranges from very fine to medium; few quartz clasts range up thru gravel with a clast up to 3-cm length; few quartz clasts lightly iron stained; most quartz sand coated with brown silt ± clay; ~5% quartz sand; ~25 to 30% matte to shiny black, fine to medium, glauconite sand; much glauconite sand is coated with silt ± clay; glauconite sand may be slightly larger to the same size as the quartz sand; some large, moderately indurated aggregates of glauconite sand embedded in brown silt/clay matrix; few glauconite sand/silt aggregates are bridged or cemented with iron oxyhydroxide; friable to moderately indurated (firm) in places; trace muscovite/illite.

CAKR4003 [24 to 30 inches] dark brown (7.5YR 3/4) medium to fine sandy clay loam; quartz clasts range from medium sand to moderately abundant gravel (1-cm length); some fine quartz sand; most quartz is moderately to heavily stained/coated with iron oxyhydroxides ± clay; few quartz clasts coated with vivianite; ~5 to 7% of sand fraction is quartz, remainder is glauconite; ~50 to 60% black, some very, very dark green, medium to fine, glauconite sand; few coarse glauconite sand; most glauconite is moderately to heavily coated with iron oxyhydroxide ± clay; ~1% microcrystalline, pistachio green vivianite; vivianite ± gypsum (white, opaque, flattened, acicular crystals and splays) cement glauconite sand into aggregates in places; some gravel-size

aggregates consist of glauconite sand cemented with iron oxyhydroxide; friable; some moderately to well indurated aggregates; no apparent phyllosilicates or heavy minerals.

CAMK1001 [0 to 6 inches] brown (10YR 4/3) loamy fine sand; few medium quartz sand; most quartz sand stained light brown by organic residue $\pm$ clay/silt; few iron-stained quartz sand; 3 to 5% matte black to very, very dark green, fine to very fine, glauconite sand; glauconite clasts grade to silt; ~50% of glauconite is lightly coated with silt/clay; very friable (loose); no apparent phyllosilicates.

CAMK1002 [12 to 18 inches] brownish yellow (10YR 6/6) loamy fine to medium sand; some very fine quartz sand; quartz sand is lightly stained by iron; few moderately iron stained; few quartz sand unstained; ~5% black to moderately (pistachio) green, fine to medium, glauconite sand; some very fine glauconite sand; very friable; no apparent phyllosilicates or heavy minerals.

CAMK1003 [24 to 30 inches] dark yellowish brown (10YR 4/6) fine sandy loam; abundant very fine and medium quartz sand; occasional coarse and very coarse quartz sand; virtually all quartz sand is moderately stained with iron and/or coated with iron-stained silt $\pm$ clay; 5 to 7% dull black to very, very dark green, fine to medium, glauconite sand; friable to slightly plastic in places; ~1% muscovite/illite; trace opaque, black heavy minerals.

CASH2001 [0 to 6 inches] black (10YR 2/1) fine sandy loam; high organic content; loose, fine quartz sand is mainly unstained, although some is stained with organic residue and few are lightly stained with iron $\pm$ organics; most quartz sand is coated with black to dark gray silt/clay; glauconite, if present, is obscured by dark matrix; very friable to very slightly plastic in places; no apparent phyllosilicates or heavy minerals.

CASH2003 [24 to 30 inches] pale olive (5Y 6/3), locally mottled with 7.5YR hues, 5 and 6 values, and 6 and 8 chroma, fine sandy loam; abundant very fine and few medium quartz sand; most quartz sand is unstained but coated with silt $\pm$ clay; quartz sand in mottles is lightly to

moderately stained by iron $\pm$ coated with iron-stained silt/clay; ~2 to 3% black, some very, very dark green, very fine to fine glauconite sand which is coated with silt $\pm$ clay; plastic to slightly friable; much of sample consists of sand in a silt/clay matrix which forms blocky aggregates; ~1 to 2% muscovite/illite.

GLCL4001 [0 to 6 inches] dark grayish brown (10YR 4/2) fine to very fine sandy loam; much very fine, organic particulates; some medium quartz sand; quartz sand grades to silt; ~60% of quartz sand is lightly coated with beige, iron-stained, clay $\pm$ silt — small portion lightly stained by iron; rest of quartz sand is uncoated to very incompletely coated with iron-stained clay/silt; trace (?) to no apparent glauconite; very friable (loose); no apparent phyllosilicates; <1% black, opaque and transparent, orangish heavy minerals.

GLCL4002 [12 to 18 inches] brownish yellow (10YR 6/6) fine to medium sand; some coarse and few very coarse quartz sand; 95%+ of quartz sand is lightly to occasionally moderately stained with a beige (iron?) film or lightly to moderately coated with iron-stained silt $\pm$ clay; <1% matte black thru dark green, few moderately (pistachio) green, fine glauconite sand; some glauconite sand appears soft and weathered gray to greenish gray; very friable (loose); no black spherules as in GLCL4003; ~1% black, opaque heavy minerals.

GLCL4003 [24 to 30 inches] brownish yellow (10YR 6/6) fine to medium sand; some coarse and few very coarse quartz sand; 95%+ of quartz sand is lightly to occasionally moderately stained with a beige (iron?) film or lightly to moderately coated with iron-stained silt $\pm$ clay; ~1% matte black thru dark green, few moderately (pistachio) green, fine glauconite sand; some glauconite sand appears soft and weathered gray to greenish gray; very friable (loose); trace muscovite/illite; few matte black, spherical, medium sand — internal structure is microscopic, vesicular carbon (with pleochroic sheen) {flyash}; $\leq$ 1% black, opaque heavy minerals.

GLCM3001 [0 to 6 inches] very dark gray (10YR 3/1) loam; few aggregates are mottled brownish yellow (10YR 6/7) generally, organic rich; ~40% fine to medium, abundant very fine

and occasional coarse, quartz sand; quartz sand grades to quartz silt; quartz sand is unstained and coated with dark gray organic-stained silt $\pm$ clay; no apparent glauconite which may occur in trace amounts but is obscured by matrix (?); very plastic and sticky; no apparent phyllosilicates or heavy minerals; few soil ingesting worms.

GLCM3003 [24 to 30 inches] grayish olive green (5GY 3/2 — rock color chart), in places mottled with yellowish red (5YR 4/6), medium to fine sandy clay; some coarse quartz sand; few quartz gravel up to 2.9-cm. length; nearly all quartz sand is coated to varying degrees with pistachio/olive green, soft, clay $\pm$ silt; yellowish red mottles consist of iron-stained quartz sand or quartz coated with or bridged by iron-stained clay $\pm$ silt; ~5% dark green to very, very dark green, some moderate green and few black, fine to medium, glauconite sand; glauconite sand size is smaller than overall quartz sand; green clay and silt is probably glauconite; plastic and sticky in places; ~2% muscovite/illite; trace (?) black heavy minerals.

GLCM4001 [0 to 6 inches] dark brown (10YR 3/3) loam; quartz sand ranges from very fine to very coarse; sparse, moderately iron-stained, fine quartz gravel; mainly fine to medium quartz sand; most quartz sand coated with very light brown (organic residue) silt $\pm$ clay; <1% of quartz sand is moderately to lightly stained by iron; ~3% very dark green thru matte black, some dark and few moderate green, fine to very fine with little medium, glauconite sand; most glauconite sand coated with brown silt $\pm$ clay; slightly friable to slightly plastic; no apparent phyllosilicates; trace black, opaque, metallic heavy minerals.

GLCM4003 [24 to 30 inches] dark yellowish brown (10YR 4/4) medium to fine sand; occasional coarse to very coarse quartz sand; 98% of quartz sand appears very slightly stained by iron or unstained; other 2% of quartz sand is moderately to heavily stained by iron (FeOOH precipitate); 5 to 6% matte black to very, very dark green, some very dark to dark green, medium to fine, glauconite sand; few pistachio green, soft, weathered(?) glauconite sand; some glauconite with deep green to black hues is coated with pistachio to moderate green clay — altered glauconite(?) or authigenic green (glauconite?) clay?; very friable (loose); few possible phosphate (apatite

minerals) pellets; no apparent phyllosilicates; trace(?) black heavy minerals — may be underestimated.

GLCN1001 [0 to 6 inches] dark grayish brown (10YR 4/2) loamy fine sand; abundant medium and some very fine quartz sand; virtually all quartz sand is coated with films of light brown, fine silt; vitreous, black (coal?) silt adhering to quartz sand; $\leq 1\%$ matte black, very fine sand to silt-size glauconite; glauconite estimate is very uncertain; abundant very fine sand and silt-size, bituminous coal fragments may mask or be confused with glauconite; few gravel-size bituminous coal fragments; (loose) very friable; trace muscovite/illite; trace black, opaque, vitreous heavy minerals or coal?

GLCN1003 [24 to 30 inches] dark yellowish brown (10YR 4/4) medium to fine sandy loam; virtually all quartz sand is lightly stained by iron oxyhydroxides $\pm$ coated with light yellowish brown silt $\pm$ clay; quartz sand predominantly held in aggregates by yellowish brown clay bridges; $\sim 2\%$ matte black to very, very dark green, fine with few medium, glauconite sand; most glauconite sand coated with yellowish brown silt $\pm$ clay; ~ 10 to 15% oyster shells — middens(?); oyster shell fragments up to ~ 5.5 cm and very thick walled; slightly friable to plastic; no apparent phyllosilicates; trace black, opaque heavy minerals — difficult to distinguish from glauconite.

GLFR4001 [0 to 6 inches] dark yellowish brown (10YR 4/4) loamy medium sand; some fine and coarse with little very coarse quartz sand; sparse quartz gravel up to 1.7-cm length; $\sim 25\%$ of quartz sand is lightly stained by iron; most quartz sand is coated with beige silt/clay; $\sim 2\%$ dark green to matte black, medium to fine, glauconite sand; (loose) friable; no apparent phyllosilicates; $\sim 1\%$ (?) black, opaque heavy minerals.

GLFR4002 [12 to 18 inches] yellowish brown (10YR 5/4) medium sandy loam; quartz sand is mainly medium with abundant fine and a moderate amount of coarse; few quartz gravel up to 2.7 cm which are stained by iron and coated with yellowish brown clay/silt; virtually all quartz sand coated yellowish brown silt/clay; ~ 2 to 3% matte black to very dark green, some moderate and

few light pistachio green, medium to fine, glauconite sand; glauconite sand tends to be slightly smaller than overall quartz sand size; friable to very slightly plastic; trace muscovite/illite; trace iron ($\pm$ organics) stained, relatively soft, dull white sand — degraded carbonate — has satin spar (pearly) sheen and cleavage when crushed with tweezers; ~1% (?) heavy minerals — some may be glauconite(?).

GLFR4003 [24 to 30 inches] yellowish brown (10YR 5/8) medium sandy clay loam; abundant coarse and some fine quartz sand; little very coarse quartz sand and up to 1.6-cm quartz gravel; virtually all quartz sand is coated with yellowish brown (iron stained) clay $\pm$ silt; ~2% dark green thru dull black, few pistachio green, medium to fine, glauconite sand; glauconite sand is slightly smaller than overall quartz sand; ~3 to 5% very slightly iron stained, pearl white, moderately soft, fine to coarse, sand — perhaps kandite- or gypsum-group minerals; very friable (loose); trace muscovite/illite; <1% black, opaque heavy minerals.

GLKR5001 [0 to 6 inches] dark grayish brown (2.5Y 4/2) very fine to fine sandy loam; poorly sorted — quartz ranges from silt thru gravel; quartz gravel up to 1.9-cm length with very light iron stain and well coated with silt/clay; most quartz sand is fine to very fine with some medium and little coarse; majority of quartz sand is stained with light brown organic residue and coated with silt/clay; ~2 to 3% dark green to matte black, few moderately green, fine to medium, some very fine, glauconite sand; glauconite sand coated with silt $\pm$ clay; very friable; $\leq$ 1% muscovite/illite in the very fine sand thru silt fractions; $\leq$ 1% black, opaque heavy minerals. Noted during sample processing — found a 2 inch by 3 inch piece of black plastic, garbage bag.

GLKR5003 [24 to 30 inches] olive (5Y 4/3), aggregates of very dark green mottled with dark reddish brown, clay; abundant free, soft, light brown, very fine sand to silt/clay aggregates coat large aggregates; ~2 to 3% quartz clasts which are predominantly medium to coarse sand but range up to 2.5 cm, iron-stained gravel in the aggregates; quartz sand in unoxidized portion of aggregates is coated with soft, dark green clay, and heavily stained by iron in oxidized (mottles) portions; ~5 to 7% dark to very dark green, medium to fine, glauconite sand embedded in a soft,

waxy, very dark green clay matrix; firm and very friable; ~1% muscovite/illite; very sparse powdery, white particles — degraded carbonate(?).

GLMR5001 [0 to 6 inches] olive gray (5Y 5/2) clay; ~2 to 3% quartz sand ranging from very coarse to sparse very fine; most quartz sand is coarse and embedded in an olive gray clay/silt matrix; very few quartz clasts are slightly stained by iron prior to incorporation into this soil; ~7% dark to very dark green, medium to very fine, glauconite sand embedded in the olive gray clay/silt matrix (aggregates); plastic and sticky in places; ~3% muscovite/illite in the very fine sand thru silt fractions; no apparent heavy minerals.

GLMR5003 [24 to 30 inches] dark olive gray (5Y 3/2 — closest match) fine to medium sandy clay; ~3% medium to fine, occasional coarse, quartz sand; all quartz sand coated with brownish clay; few quartz sand clasts are lightly to occasionally moderately stained by iron; ~50% of sample is dark green, fine to medium, glauconite sand embedded in a soft, waxy, greenish and brownish clay; virtually all glauconite sand is coated with a soft, waxy, greenish clay; ~1% chalky white, fine to medium sand; plastic; ≤1% muscovite/illite in very fine sand thru silt fractions; no apparent heavy minerals.

GLMR6001 [0 to 6 inches] (sample is rather dry) brown (10YR 5/3) loam; quartz ranges from very coarse sand thru silt; quartz sand is mainly very fine to fine with abundant medium; very few loose quartz sand clasts are lightly stained by iron; most quartz is coated with silt ± clay; aggregates of glauconite sand (± minor quartz sand) embedded in a waxy, dark brown, clay matrix are common; some quartz sand in aggregates is stained light brown (organic residue ± iron?); ~3 to 5% very, very dark green to matte black, some dark and little moderate green, fine to occasional medium, glauconite sand; some sand/clay aggregates appear moderately weathered to iron oxyhydroxides ± bleached glauconite sand; friable; <1% muscovite/illite; trace(?) heavy minerals.

GLMR6002 [12 to 18 inches] brownish dark olive (no suitable match in available color charts) fine sandy clay loam; blocky aggregates variously mottled with reddish browns; ~3 to 5% fine to medium, occasional coarse to very coarse, quartz sand; most quartz sand coated with light greenish and brownish clay $\pm$ silt; some quartz sand appears very lightly stained by iron; ~50% dark to very dark green, fine with some medium, glauconite sand embedded in a soft, waxy, moderate greenish ($\pm$ rust brown), clay matrix; firm and friable; slightly plastic in places; 1 to 2%(?) muscovite/illite in very fine sand thru silt fractions; no apparent heavy minerals.

GLMR6003 [24 to 30 inches] olive brown (2.5Y 4/4) clay loam; ~2 to 3% fine to medium, occasional coarse, quartz sand; all quartz sand coated with light brown to brown clay $\pm$ silt; some moderately stained by iron; very abundant iron-stained quartz gravel up to 2.9-cm length; ~30 to 40% dark to very dark green, fine to medium, glauconite sand; most glauconite sand embedded in a soft, waxy, dark brown clay matrix to form blocky aggregates; few aggregates appear moderately weathered orangish brown with iron oxyhydroxides; firm and friable; ~1% muscovite/illite in fine sand thru silt fractions; no apparent heavy minerals. Noted during sample processing — clast size ranges from gravel to clay with the clay and silt encasing the frosty white, iron stained, quartz gravel. A most difficult sample to homogenize.

MOAD1001 [0 to 6 inches] dark brown (7.5YR 4/4) loam; ~30% of sample is quartz sand; quartz sand is principally fine but ranges up thru very coarse; few quartz gravel to 1.2 cm which is thickly coated with dark brown, iron-stained sand thru clay; all quartz sand is coated with or embedded in a dark brown silt/clay matrix; few quartz sand is lightly stained by iron; ~3 to 5% very, very dark green to moderate green, few dull black, fine with some medium, glauconite sand coated with or embedded in the silt/clay matrix; few fine glauconite sand embedded in the dark brown silt/clay matrix are weathered to an olive yellow (2.5Y 6/8 or 6/6) and are very soft; quartz and glauconite sand concentration is difficult to estimate because of finer matrix; may be 1 to 2% gypsiferous(?) sand ($\text{CaSO}_4 \cdot n\text{H}_2\text{O}$) based on cleavage, striations, luster, and so on; plastic to friable in places; slightly sticky; <1% muscovite/illite in sand fraction; <1% black, dull to metallic, opaque heavy minerals.

MOAD1003 [24 to 30 inches] strong brown (7.5YR 4/6) clay loam; quartz sand concentration cannot be accurately estimated because of strong brown fine matrix; ~10 to 15%(?) quartz sand ranging from fine thru very coarse — poorly sorted; all quartz sand is embedded in a soft, strong brown, iron-stained, silt/clay matrix; some quartz sand is moderately to strongly stained by deep red iron; ~15 to 20%(?) matte black thru very dark green, fine to medium, glauconite sand embedded in a soft, strong brown, iron-stained, silt/clay matrix; moderate concentration of glauconite sand weathered to varying reddish yellow/yellowish red chroma — some appear to be completely weathered to goethite with a glauconite (external) morphology; some weathered glauconite coated with a goethite crust with a core that is less weathered; all glauconite is embedded in a soft, strong brown, iron-stained silt/clay matrix; very plastic and sticky in places; no apparent phyllosilicates or heavy minerals — obscured by matrix(?).

MOAD3001 [0 to 6 inches] dark brown (10YR 3/3) loam; ~40 to 45% sand — ~20 to 25% quartz and ~15% glauconite; quartz sand is mainly fine to very fine although ranges up to few very coarse; most quartz sand is coated with or embedded in a dark brown silt ± clay matrix; ~5% quartz sand is lightly to moderately stained by iron; ~15% very, very dark green to matte black, fine to occasional medium, glauconite sand coated with or embedded in a dark brown silt ± clay matrix; plastic to very slightly friable; no apparent phyllosilicates — obscured by matrix?; ~1%(?) matte black, opaque heavy minerals in the fine to very fine sand fraction — obscured by matrix and resembles glauconite sand.

MOAD3002 [12 to 18 inches] strong brown (7.5YR 4/6) fine sandy clay loam; ~60% sand — ~35 to 40% quartz and ~20 to 25% glauconite; quartz sand is mainly fine with abundant very fine and medium; some coarse quartz sand; virtually all quartz sand is coated with or embedded in a strong brown, iron-stained, silt ± clay matrix; ~2% quartz sand is lightly to occasionally moderately stained by iron; ~20 to 25% very dark to very, very dark green, some dark green, fine with some very fine and medium, glauconite sand which is coated with or embedded in a strong brown, iron-stained, silt ± clay matrix; friable to slightly plastic; no apparent phyllosilicates or heavy minerals — obscured by iron-stained, fine matrix(?).

MOAD3003 [24 to 30 inches] dark brown (7.5YR 4/4) fine to medium sandy clay loam; some coarse and very fine quartz sand; virtually all quartz clasts are well coated with brown, iron-stained clay/silt; ~1% quartz sand is stained by iron; quartz/glaucanite sand is ~40% : 25%; ~25 to 30% very, very dark to very dark green, some matte black, fine to medium, glaucanite sand; nearly all glaucanite sand is partially to completely coated with brownish, iron-stained clay/silt; brownish interstitial clay is soft and greasy and bridges many clasts; friable; <1% muscovite/illite and a green phyllosilicate (chlorite-group mineral?); no apparent heavy minerals.

MOCL1001 [0 to 6 inches] very dark grayish brown (2.5Y 3/2) silt loam; NOTE central portion of soil core is very dark grayish brown surrounded by a brown (7.5YR 4/4) [iron-stained, oxidized] outer layer ranging in thickness from ~0.3 to 1.0 cm; quartz silt grades to very fine quartz sand; ~30 to 40% quartz sand ranging from very fine to some medium, few coarse, embedded in a silt ± clay matrix; 1 to 2% black to very, very dark green, fine to very fine sand grading to coarse silt(?), glaucanite embedded in a silt ± clay matrix; plastic and slightly sticky; no apparent phyllosilicates — obscured by matrix(?) — or heavy minerals — not distinguished from glaucanite in the very fine sand thru silt fractions.

MOCL1002 [30 to 36 inches] strong brown (7.5YR 4/6) fine to medium sandy loam; ~55 to 60% fine to medium, with some very fine and little coarse, quartz sand; nearly all quartz sand is coated with or embedded in a strong brown, iron-stained silt ± clay matrix; ~5% of quartz is lightly to moderately, occasional strongly, stained by iron; one medium gravel-size aggregate of strongly iron-stained quartz sand cemented with iron oxyhydroxides which overall is dusky red (10R 3/4); ~5 to 6% very, very dark green to matte black, some dark green, fine to medium, some very fine, glaucanite sand coated with or embedded in the strong brown silt ± clay matrix; very plastic and moderately sticky; ~3% muscovite/illite in the fine to very fine sand thru silt fraction, some iron stained; no apparent heavy minerals.

MOCM1001 [0 to 6 inches] very dark gray (10YR 3/1) silt loam; organic-rich; ~25 to 30% very fine to fine quartz sand with some medium; quartz sand grades to silt; all quartz sand is

embedded in a dark gray silt $\pm$ clay matrix; silt > clay?; ~1%(?) matte black, very fine to fine, glauconite sand grading to silt(?) is embedded in a dark gray silt $\pm$ clay matrix; dark matrix may obscure glauconite sand; friable to slightly plastic; trace(?) muscovite/illite in the very fine sand and coarse silt fractions; trace(?) Black, opaque heavy minerals; matrix is a problem!

MOCM1002 [24 to 30 inches] pale olive (5Y 6/3), mottled with reddish brown (7.5YR 6/8), medium to fine sandy clay loam; ~50 to 60% quartz sand ranging from very fine to very coarse grading up thru medium gravel; all quartz sand and gravel are embedded in a very soft (ooze), pale olive and reddish brown (iron-stained), silt $\pm$ clay matrix; 2 to 3% very, very dark green to black, some very dark green, fine to very fine sand grading into coarse silt, glauconite embedded in a very soft (ooze), pale olive and reddish brown (iron-stained) clay $\pm$ silt matrix; very plastic and sticky; trace(?) muscovite/illite in very fine sand fraction; trace(?) matte black, opaque heavy minerals; iron-stained matrix is a problem for trace constituent estimates.

MOCM1003 [30 to 36 inches] overall light olive brown (2.5Y 5/6), with large mottles(?) of olive (5Y 5/3), medium to fine sandy clay loam; some very fine and few very coarse quartz sand thru fine quartz gravel; ~70 to 80% quartz sand; virtually all quartz sand is aggregated by a soft, olive (unoxidized?) or light olive brown (oxidized) clay (ooze) film $\pm$ silt; few quartz sand is very lightly stained by iron; no apparent glauconite sand; glauconite clay may constitute the ooze; very plastic and sticky; no apparent phyllosilicates; ~1% black, opaque heavy minerals in very fine sand thru coarse silt fractions. NOTE rectangular ironstone (2.7L x 1.4W x 0.3H cm) consisting of medium to fine, unstained, quartz sand tightly cemented by goethite(?) in sample; no apparent glauconite — may be fully weathered to goethite as suggested by breaking the piece to expose a fresh surface.

MOCN2001 [0 to 6 inches] brown (10YR 4/3) medium to fine sandy loam; quartz sand (60 to 70%) ranges from moderately abundant very fine thru few very coarse; grades to quartz silt; most quartz sand is thinly coated with iron-stained silt $\pm$ clay; ~10% of quartz sand is lightly to moderately, few heavily, stained by iron; <1% very, very dark green to matte black, fine,

occasional medium, glauconite sand coated with iron-stained silt $\pm$ clay; very friable (loose); no apparent phyllosilicates; no apparent heavy minerals — obscured by fine matrix?

MOCN2002 [12 to 18 inches] strong brown (7.5YR 4/6) medium to fine sand; ~90% quartz sand; abundant very fine and few coarse quartz sand; all quartz sand is coated with a brown, iron-stained, silt $\pm$ clay film; $\leq 1\%$ of quartz sand is lightly stained by iron; ~1 to 2%(?) matte black to very, very dark green, fine to medium, few very fine, glauconite sand coated with a brown, iron-stained, silt $\pm$ clay film; very friable (loose); ~1 to 2%(?) muscovite/illite in the very fine sand thru silt fractions; $\leq 1\%$ black, vitreous to metallic, opaque heavy minerals.

MOCN2003 [24 to 30 inches] strong brown (7.5YR 4/6) loamy fine to medium sand or fine to medium sand; abundant very fine and few coarse quartz sand; all quartz sand is moderately well to well coated with a yellowish brown, iron-stained silt $\pm$ clay; $< 1\%$ quartz sand stained by iron; ~2% dull black to very, very dark green, few dark green, fine to occasional medium, glauconite sand; few glauconite sand is weathered from mottled green and gray glauconite to rusty goethite; most glauconite sand is coated with yellowish brown, iron-stained silt $\pm$ clay; very friable (loose); 2 to 3% muscovite/illite in very fine sand thru silt fractions; ~1% black, opaque, some metallic heavy minerals.

MOCN2004 [42 to 48 inches] strong brown (7.5YR 4/6) medium sand to loamy medium sand; abundant fine quartz sand; some coarse and little very coarse quartz sand; all quartz sand is well coated with orangish brown, iron-stained clay $\pm$ silt; ~3 to 4% pistachio to very dark green, medium to fine, glauconite sand; lighter green glauconite sand appears slightly weathered; most glauconite sand is coated with orangish brown, iron-stained clay $\pm$ silt; glauconite sand is smaller than quartz sand; friable (loose); $< 1\%$ iron-stained muscovite/illite in fine sand thru silt fractions; trace black, opaque, metallic heavy minerals.

MOFR1001 [0 to 6 inches] dark brown (7.5YR 4/4) medium to fine sandy loam or loamy sand; some coarse quartz sand; ~75 to 80% quartz sand; 95% of quartz sand is coated with brown,

iron-stained silt ± clay; other 5% is very sparsely coated with brown silt ± clay; no apparent glauconite; <1% matte black, fine sand carbon spheres with a very vesicular internal morphology (flyash?); very friable (mainly loose); no apparent phyllosilicates; minor trace black, opaque heavy minerals.

MOFR1002 [27 to 35 inches] strong brown (7.5YR 5/6) clay loam; predominantly medium to fine quartz sand embedded in a brown, iron-stained clay/silt matrix to form aggregates; few coarse and some very fine quartz sand; nearly all quartz sand is moderately well coated with brownish clay/silt; 1 to 2% dark to moderate (pistachio) green, some very dark to very, very dark green, fine to occasional medium, glauconite sand; some of lighter (moderate) green glauconite sand appears partially weathered (mottled) to goethite (greenish brown); slightly plastic to slightly friable; no apparent phyllosilicates; ~1% black, opaque heavy minerals in fine to occasional medium sand fraction; NOTE very angular, very well indurated ironstone gravel up to 3.2-cm length and 1.5-cm thick consists of unstained quartz sand strongly cemented by goethite — may be native to site; no apparent glauconite in ironstone.

MOFR6001 [0 to 6 inches] dark yellowish brown (10YR 4/4) loamy fine sand; abundant very fine and some medium quartz sand; ~80%+ quartz sand; quartz sand grades to coarse quartz silt; nearly all quartz sand is coated with brown, iron-stained silt ± clay(?); ~2% of quartz sand is lightly to occasionally strongly stained by iron; sparse (<<1%) dark to moderate green, fine to very fine, glauconite sand coated with brown silt ± clay(?); few carbon spherules (flyash?); very friable (loose); trace green (chlorite?) phyllosilicate and muscovite/illite in very fine sand thru silt fractions; <1% matte black to metallic, opaque heavy minerals in coarse silt to very fine sand fractions.

MOFR6002 [12 to 18 inches] strong brown (7.5YR 4/6) loamy medium sand; abundant fine to very fine quartz sand; all quartz sand well coated with light orangish brown (iron stained) silt ± clay; <1% quartz sand is moderately to lightly stained by iron; ~2% dull black to very dark green, fine to medium, glauconite sand; few moderate to light pistachio green (weathered)

glaucanite sand; most glaucanite sand is coated with light orangish brown (iron-stained) silt ± clay; friable (loose); <1% muscovite/illite in very fine sand thru silt fractions; trace black, opaque heavy minerals.

MOFR6003 [24 to 30 inches] dark brown (7.5YR 4/4) loamy fine to medium sand; some very fine quartz sand; ~80% quartz sand; all quartz sand is coated with a brown (iron-stained) silt ± clay; ~10% of quartz sand is lightly to occasional moderately stained by iron; ~5% matte black thru very dark green, fine to very fine, glaucanite sand coated with a brown (iron-stained) silt ± clay; very friable (loose); <1% black, opaque heavy minerals.

MOHN1001 [0 to 6 inches] brown (10YR 5/3) silt loam; ~10 to 20% very fine to fine quartz sand; few medium quartz sand; quartz sand is coated with and embedded in brown to grayish brown silt ± clay matrix; no apparent glaucanite sand or silt — if present, then obscured by matrix; very plastic; ~2% muscovite/illite in very fine sand and coarse silt fractions; ~2 to 5% matte black, opaque particles in coarse silt fraction — unidentified mineralogy (heavy minerals?, organics?, glaucanite?). NOTE too difficult to describe without granulometric analysis.

MOHN1002 [36 to 42 inches] overall yellowish brown (10YR 5/8), mottled light gray (5Y 7/2), medium sandy clay loam to medium sandy clay; quartz sand is mainly medium to fine although coarse sand is common; quartz clasts range from silt thru gravel up to 2.7-cm length; most quartz sand is lightly stained yellowish brown by iron; much quartz sand embedded in yellowish brown, iron-stained clay/silt matrix in oxidized portions or embedded in light gray (almost white) silt/clay matrix in more reduced sections; ~3 to 4% matte black thru moderate green, fine to medium, glaucanite sand; ~50% of glaucanite sand is lightly coated with clay/silt; plastic and sticky in places; trace muscovite/illite in finer fraction; <1% black, opaque heavy minerals.

MOKR1001 [0 to 6 inches] very dark grayish brown (2.5Y 3/2) clay loam; ~10 to 15% quartz sand and ~15% glaucanite sand; quartz sand is mainly fine to medium although ranges from very fine to few very coarse sand up to medium gravel; most quartz sand coated with a film of

greenish brown clay or embedded in a soft, waxy, greenish/brown clay $\pm$ silt matrix; some larger (medium sand thru gravel) quartz clasts are moderately to strongly, few lightly, stained by deep-red iron; ~15% very, very dark to very dark green, some moderate (pistachio) green, few black with deep red iron stain, fine to medium, glauconite sand embedded in a soft, waxy, greenish/brownish clay $\pm$ silt matrix; blocky aggregates; plastic to slightly friable in places; few phosphate (apatite-group) pellets in fine sand fraction; no apparent phyllosilicates; trace(?) black, vitreous, opaque heavy minerals — obscured by matrix.

MOKR1002 [24 to 30 inches] olive (5Y 4/3) medium to fine sandy clay; <1% fine quartz sand embedded in a soft, waxy, olive and yellowish beige clay $\pm$ silt matrix; ~50%+ dark green, medium to fine, glauconite sand coated with or embedded in a soft, waxy, olive and yellowish clay $\pm$ silt matrix; some sutures in the glauconite are infilled with iron oxyhydroxides; few small aggregates of glauconite sand bridged by iron oxyhydroxides; sparse glauconite sand altered to goethite; plastic and slightly sticky; <1% muscovite/illite in very fine sand thru silt fractions; no apparent heavy minerals.

MOKR2001 [0 to 6 inches] overall very dark grayish brown (10YR 3/2), with yellow (10YR 7/8) aggregates that are not coated with organic-rich, O-horizon sediment, loam; quartz is mainly fine to very fine sand although ranges up thru few very coarse sand; most quartz sand is coated with or embedded in a soft, yellow silt $\pm$ clay matrix; ~5% of quartz sand is lightly to moderately, few heavily, stained by iron; no apparent glauconite sand — if present, then obscured by matrix; plastic and very slightly sticky; no apparent phyllosilicates; 1 to 2% black, vitreous, opaque heavy minerals. NOTE a few ironstone aggregates up to 3.7L x 2.8W x 1.0H cm consist of medium to fine, clear to frosted, quartz sand tightly cemented with goethite(?); no apparent glauconite.

MOKR2002 [12 to 18 inches] pale olive (5Y 6/3), extensively mottled reddish yellow (7.5YR 6/8), clay loam; ~20% quartz ranging from medium to very fine sand thru silt; most quartz sand is coated with or embedded in an olive or reddish yellow clay/silt matrix; some moderate to

lightly stained by iron; ~2% matte black to very dark green, fine to occasional medium, glauconite sand embedded in mainly a soft, greasy, olive (glauconite?) clay/silt matrix; plastic; ~2% muscovite/illite in very fine sand thru silt fractions; trace(?) heavy minerals — obscured by matrix. NOTE: sample has a 4.5 x 3.5 x 1.5 cm, well indurated ironstone consisting of fine to medium quartz sand cemented with goethite; no apparent glauconite; may be exotic — no fresh fractures from auger, clast character differs from associated sediment, and so on.

MOKR2003 [24 to 30 inches] dark yellowish green (10GY 4/4 — closest match in rock color chart), intensely mottled with reddish yellow (5YR 6/8) and yellowish red (5YR 5/8), clay; ~3 to 5% very fine to medium, some coarse and few very coarse, quartz sand; mainly fine to medium quartz sand embedded in a soft, waxy, greenish and reddish yellow (iron-stained) glauconite(?) clay ± silt matrix; ~5% dark to very dark green, some moderate green and few very, very dark green, fine to very fine, glauconite sand embedded in a soft, waxy, greenish and yellowish red glauconite(?) clay ± silt matrix; glauconite sand appears slightly smaller than quartz sand; very blocky; plastic; 2 to 3%(?) muscovite/illite in the very fine to fine sand thru coarse silt fractions; no apparent heavy minerals — obscured by matrix(?).

MOMR1001 [0 to 6 inches] overall very dark brown (10YR 2/2), with yellowish brown aggregates which are coated with organic-rich sediments yielding the very dark brown overall color, loam; organic rich; quartz clasts range from very fine to very coarse sand thru gravel up to 2.2-cm length; most loose quartz sand is unstained/uncoated; <1% moderately stained by iron; quartz sand embedded in aggregates is well coated/bridged with yellowish brown, iron-stained clay/silt matrix; quartz to glauconite sand ratio in aggregates = 25% : 20%; ~15 to 20% moderate to dark green, fine to occasional medium, glauconite sand which is well coated/bridged with soft, yellowish brown clay/silt matrix; plastic; no apparent phyllosilicates and heavy minerals — obscured by dark matrix(?); NOTE two gravel-size, very well indurated ironstone fragments — largest is 3.1L x 2.7W x 0.3H cm which are very dissimilar to each other; largest one is well sorted, fine, quartz sand (no glauconite) cemented with yellowish brown goethite; the other is poorer sorted, fine to medium, quartz and glauconite sand (iron-stained quartz and weathered —

some to goethite — glauconite sand) cemented with very dark reddish brown goethite; ironstone may be exotic?

MOMR1002 [24 to 30 inches] olive (5Y 4/3), mottled with strong brown (7.5YR 5/8), clay loam to clay; ~3 to 5% quartz ranging from medium to very coarse sand up to 1.6-cm length gravel which is lightly stained by iron; quartz clasts are significantly larger than glauconite sand; quartz clasts are embedded in a soft, waxy, olive or rust brown clay ± silt matrix; ~20 to 30% dark green, few very dark green, fine to medium, glauconite sand embedded in the soft, waxy, olive or rust brown clay ± silt matrix; slightly plastic and slightly friable in places; very blocky aggregates; ~2% muscovite/illite in fine sand thru silt fractions; no apparent heavy minerals — obscured by matrix?

MOMR2001 [0 to 6 inches] dark grayish brown (2.5Y 4/2) clay loam to silt loam; ~25% quartz ranging from coarse to very fine sand thru silt; quartz sand is coated with or embedded in a grayish brown silt/clay matrix; fine silt and clay are soft and ooze-like; no apparent glauconite sand; very plastic and slightly sticky; ~3 to 5% black, some vitreous, silt particles of unidentified mineralogy (i.e. heavy minerals?, glauconite?, organic debris?); no apparent phyllosilicates; heavy minerals in silt fraction?. NOTE iron has oxidized to rust brown on the outer (2 to 3 mm) surface of the core exposed to air/light.

MOMR2002 [13 to 20 inches] light olive brown (2.5Y 5/6) clay loam; ~25 to 30% medium with some fine quartz sand; all quartz sand is embedded in a very soft, waxy, olive brown, glauconite(?) clay ± silt matrix; no apparent glauconite sand although portions of the olive brown clay ± silt matrix suggest that it consists of weathered glauconite; very plastic and slightly sticky; no apparent phyllosilicates or heavy minerals — obscured by fine matrix(?).

MOMR2003 [24 to 30 inches] olive (5Y 4/3) to grayish olive green (5GY 3/2 — from rock color chart) clay; ~10 to 15% quartz sand; quartz sand ranges from very fine to medium with few coarse; locally very fine with some fine quartz sand stringers of white with a light greenish tint;

nearly all quartz sand is embedded in or coated with a soft, waxy, olive (glauconite?) clay $\pm$ silt matrix; ~2%(?) very dark to dark green, fine, glauconite sand embedded in a soft, waxy, olive (glauconite) clay $\pm$ silt matrix; sand/silt and clay interlayers make estimation of glauconite concentration difficult; plastic and sticky; ~1% muscovite/illite in the very fine sand to coarse silt fractions; no apparent heavy minerals — obscured by matrix(?).

MOMR2004 [30 to 36 inches] olive (no suitable match in available color charts), mottled with reddish yellow (7.5YR 7/8) and pockets of white (10YR 8/1) sucrosic, very fine quartz sand/coarse silt, clay loam; ~40%(?) sand — 25 to 30% quartz and ~10 to 15% glauconite; quartz sand is mainly fine to very fine with sparse medium; most quartz sand is embedded in or coated with a soft, waxy, olive, glauconite(?) clay $\pm$ silt matrix; reddish yellow pockets of quartz sand is coated with iron-stained silt $\pm$ clay; white pockets of sucrosic very fine sand and coarse silt are clean (uncoated/unstained); ~10 to 15%(?) dark to moderate (pistachio) green, some very dark green and few brownish yellow (weathered), fine, few medium, glauconite sand embedded in a soft, waxy, olive glauconite(?) clay $\pm$ silt matrix; plastic; phyllosilicates and heavy minerals, if present, are obscured by fine, olive matrix.

MOMR3001 [0 to 6 inches] very dark gray (10YR 3/1), mottled strong brown (7.5YR 4/6), loam; ~30% quartz sand; principally fine quartz sand, although ranges from very fine thru very coarse and grades to moderately common fine to medium quartz gravel; some gravel is moderately stained by iron; most quartz sand is embedded in a dark gray and rust brown (iron-stained) silt/clay matrix; few quartz sand is moderately stained by iron; ~5% matte black to very, very dark green, fine with some medium, glauconite sand embedded in a dark gray and rust brown (iron-stained) silt/clay matrix; slightly friable to moderately plastic; no apparent phyllosilicates or heavy minerals — obscured by matrix?.

MOMR3003 [24 to 30 inches] olive (5Y 4/3) clay loam; ~30 to 40% glauconite and ~2% quartz sand; quartz sand ranges from very fine to medium; occasional coarse quartz sand; all quartz sand is embedded in an olive with little reddish yellow (iron-stained), soft, waxy, glauconite(?)

clay and silt matrix; few quartz sand is moderately to strongly stained by iron; ~30 to 40% very, very dark green to matte black, some very dark and dark green, fine to medium, glauconite sand embedded in an olive/reddish yellow (iron-stained), soft, waxy, glauconite(?) clay and silt matrix; ~1% of glauconite sand is weathered to brownish green and soft; very plastic and very slightly sticky; no apparent phyllosilicates or heavy minerals.

MOSH3001 [0 to 6 inches] brown (10YR 5/3) fine to very fine sandy loam; abundant medium and some coarse to few very coarse quartz sand; a 1.8-cm quartz gravel clast; virtually all quartz sand is coated with silt ± clay; <1% quartz sand is lightly stained by iron; ≤1% dull black to very, very dark green, fine to occasional medium, glauconite sand coated with silt ± clay; very friable (loose); three sand-size, bright yellow (elemental sulfur?), platy grains; trace muscovite/illite in very fine sand thru silt fractions; trace(?) black heavy minerals.

MOSH3002 [12 to 18 inches] black (10YR 2/1) fine sandy clay loam; salt and pepper appearance; very organic rich; ~50% total sand; abundant very fine and few medium quartz sand; occasional very coarse quartz sand; most quartz sand is partially coated with silt/clay; abundant uncoated/unstained quartz sand; <1% quartz sand lightly to heavily stained by iron; glauconite, if present, is obscured by dark matrix; bioturbation by soil ingesting organisms (worms); friable; phyllosilicates and heavy minerals, if present, are obscured by matrix. Noted during sample processing — two shards, measuring approximately one inch by one inch, of transparent cellophane (plastic) were removed from this sample. This indicates a disturbed soil!

MOSH3003 [24 to 30 inches] black (5Y 2.5/1) clay loam; very organic rich; ~20 to 25% quartz sand ranging from very fine to coarse, but principally medium to fine; sparse quartz gravel up to 2.8-cm length; most quartz sand is coated with or embedded in dark gray to black organic residue/silt/clay matrix; few quartz sand is lightly to occasionally moderately stained by iron; glauconite sand, if present, is obscured by dark matrix; friable to very slightly plastic; trace(?) — masked by matrix --muscovite/illite in silt fraction; no apparent heavy minerals.

MOTN1001 [0 to 6 inches] strong brown (7.5YR 4/6) loamy medium sand; abundant fine, some very fine, and few coarse quartz sand; ~85% quartz sand; nearly all quartz sand is coated with a film of reddish yellow, iron-stained silt $\pm$ clay; ~7 to 10% of quartz sand is lightly to moderately, few heavily, stained by iron; trace very, very to very dark green, medium to fine, glauconite sand coated with a film of reddish yellow, iron-stained silt $\pm$ clay; very friable (loose); no apparent phyllosilicates; <1%(?) black heavy minerals in the very fine sand fraction; few matte black spheres up to coarse sand size resembling flyash — vesicular internal morphology.

MOTN1002 [12 to 18 inches] strong brown (7.5YR 5/8) medium sand; 90%+ quartz sand ranging from fine thru very few very coarse; all quartz sand is coated with strong brown, iron-stained, silt $\pm$ clay; no apparent iron-stained quartz sand; no apparent glauconite sand; very friable (loose); trace iron-stained $\pm$ coated with iron-stained silt/clay muscovite/illite in the fine to medium sand fraction; trace heavy minerals (anatase?).

MOTN1003 [24 to 30 inches] (dry sample) deep rusty orange (7.5YR 4/6 — strong brown is closest match) medium sand to loamy medium sand; some fine and coarse quartz sand; all quartz sand is strongly to moderately stained with iron or coated with iron-stained silt $\pm$ clay(?); trace very, very dark green to matte black, medium to fine, glauconite sand which is coated with iron-stained silt; very friable (loose); ~1% muscovite/illite in medium thru very fine sand fraction; trace(?) heavy minerals.

MOTN1004 [42 to 48 inches] deep rusty brown (7.5YR 4/6 — strong brown is closest match) medium sand; some fine and coarse to very coarse quartz sand; all quartz sand is strongly to moderately stained with iron or coated with iron-stained silt $\pm$ clay(?); <1% dark to very dark green, fine to medium, glauconite sand; glauconite sand appears to be slightly smaller than quartz sand; glauconite sand concentration is slightly higher than in MOTN1003; $\leq$ 1% muscovite/illite in medium thru very fine sand fraction; trace(?) heavy minerals.

MOTN2001 [0 to 6 inches] dark yellowish brown (10YR 4/4) loam; ~50% total sand; quartz sand is mainly fine but ranges from very fine to medium; occasional coarse quartz sand; nearly all quartz sand is coated with dark yellowish brown, iron-stained silt $\pm$ clay; very few quartz sand is moderately stained by iron; ~5 to 7% matte black to very, very dark green, fine to some medium, glauconite sand; most glauconite sand is coated with dark yellow brown, iron-stained silt $\pm$ clay; friable to locally slightly plastic; trace slightly iron-stained muscovite/illite; trace black, opaque, metallic, heavy minerals.

MOTN2003 [24 to 30 inches] dark yellowish brown (10YR 4/4) fine to medium sandy loam; ~60% quartz sand; quartz ranges from medium thru very fine sand and grades to silt; virtually all quartz sand is coated with or embedded in a soft, yellowish brown, iron-stained, silt/clay matrix; 2 to 3% quartz sand is moderately to lightly, some strongly, stained by iron; 2 to 3% matte black thru very dark green, fine, few medium, glauconite sand coated with or embedded in a soft, yellowish brown, iron-stained, silt $\pm$ clay matrix; friable to very slightly plastic; 1 to 2%(?) muscovite/illite in the very fine sand and silt fractions; ~2% black, vitreous to matte, opaque heavy minerals and zircon. NOTE: a few ironstone blocks up to 3.2L x 2.0W x 0.5H cm consist of fine to occasional medium, slightly to moderately iron-stained, quartz sand tightly cemented by goethite — glauconite sand may be weathered to syntaxial goethite.