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A MODIFIED METHOD OF TOTAL ELEMENTAL ANALYSIS FOR DETERMINING BACKGROUND METALS IN TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Andrew O. Gallagher

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..... To Teri, for her love and patience, and for her support and encouragement during this endeavor .....

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ABSTRACT

In order to assess the impact of metal pollution, a knowledge of indigenous metal levels is required. Data for background metal concentrations for soils and parent materials in Tennessee are not available in scientific literature.

The objective of this study was to establish background metal concentrations on the major physiographic regions or Major Land Resource Areas (MLRAs) of Tennessee. Background metal concentration information will serve as a future reference for interpreting metal data. To meet this objective, it was necessary to test and evaluate an acid digestion procedure using a microwave oven for preparing soil samples for total analysis.

An acid digestion procedure for total elemental analysis was evaluated on soils of different textures to establish background metal concentrations. Samples were dissolved in 5 ml of aqua-regia and 2 ml of hydrofluoric acid (HCl-HNO_3-HF). Samples were heated in a microwave oven to facilitate reactions. Boric acid (1 gm) was then added to neutralize the hydrofluoric acid. The solutions were transfered to 100 ml volumetrics and brought to volume for analysis. The elements: Al, Ca, Fe, K, Mg, Na, P, S, Si, and Ti, were analyzed by inductively coupled argon plasma atomic emission spectrometer (ICAPAES). Recovery rates were

established by analysis of a coal fly ash standard (National Bureau of Standards). Recovery rates ranged from 88.9 percent for Fe to 101 percent for Si and Na. The procedure was tested over a broad range of textures using deep core samples. These samples were of loess, alluvium, and Tertiary Sand parent materials from the University of Tennessee Ames Plantation in Southwest Tennessee. A modification for sandy textured samples involved overnight digestion in hydrofluoric acid to achieve total dissolution.

This digestion procedure was applied to samples from thirteen selected pedons from six of the eight MLRAs in Tennessee. Total analysis for twenty-three elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Si, Sr, Ti, Zn, Zr) were then completed on these samples using ICAPAES. Generally, metal concentrations, in all regions of the state, were within the established ranges for average elemental concentrations in soils and crustal rocks.

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CHAPTER ONE

CHEMICAL CHARACTERIZATION USING TOTAL ELEMENTAL ANALYSIS

INTRODUCTION

The measurement of total elemental concentrations in soils is generally aided by acid digestion procedures. The purpose of acid digestion is to solubilize elements of interest for subsequent analysis (Kimbrough, 1992). The objective of this study was to utilize a microwave oven digestion technique to determine the total concentrations of ten elements in soils and geologic materials. The microwave dissolution technique was modified to maximize mineral dissolution. Recovery rates were validated using a coal fly ash standard. This procedure was applied to soil core samples that represented a wide range of geological and pedological weathering sequences.

LITERATURE REVIEW

Advancements in analytical instrumentation have made the preparation time, rather than the analysis time, the limiting factor in the turn-around time associated with chemical analyses (Farrell et al., 1980). Existing methods of preparing samples for elemental analysis involve

solvation in an acid or a base. Wet ashing with perchloric acid or use of aqua-regia and hydrofluoric acid in digestion bombs are two such techniques. Other methods involve fusion with bases (carbonates, borates, or hydroxides) followed by acid dissolution. These procedures are slow, tedious, and require fusion agents which may lead to volatilization losses of some metals (Hartstein, 1973).

The disadvantages of wet ashing with perchloric acid include the need for close operator attention, the need for a special hood to handle perchloric acid fumes safely, and the danger of explosion if established procedures are not strictly followed (Abu-Samra et al., 1975). Further, this digestion procedure is time consuming and requires considerable technical skill, laboratory space, and equipment (Sommers and Nelson, 1972).

Fusion techniques in platinum crucibles with carbonate, borate, or hydroxide fluxes generally result in the incomplete attack of a sample (Bernas, 1968). Decreased solubility of some metal ions and losses due to reduction, alloying, and volatilization are only a few of the disadvantages of fusion techniques. Fusion agents also prevent the determination of the cations and anions used in the flux. In addition, fusion methods use ten to twenty times as much salt flux as they do sample. This high salt content of acid digested fusion material causes problems during quantification, such as high and fluctuating

instrument background readings (Bernas, 1968).

The two principle methods of dissolving siliceous samples for total analysis are an acid digestion procedure or a base fusion technique. Of the two methods, acid digestion procedures are favored for total analysis. There is less sample contamination with the acid digestion procedure and fewer interferences during quantification. Furthermore, there are fewer steps in an acid digestion procedure (Price and Whiteside, 1977).

A new method was sought that would be rapid, simple, require only small amounts of sample, and yield a solution from which all elements present could be directly determined. The Teflon acid digestion bomb method, using aqua-regia and hydrofluoric acid (neutralized by boric acid), provides a rapid method for dissolving samples and minimizing contamination. This method also assures acceptable recovery while requiring only a small sample of fifty milligrams or less (Hartstein et al., 1973). This method eliminates the use of crucibles, prevents the loss of constituents due to alloying, reduction, or volatilization, and does not introduce cations into the system (Hendel, 1973).

Some shortcomings have been associated with the use of Teflon bombs. According to Bernas (1968), volatilization losses could not be prevented because of the dimensional instability of Teflon. After repeated use, Teflon lids tend

to become loose and this results in volatilization losses and subsequently, low recovery rates. To prevent volatilization of the dissolved constitents, the tapered edges need to be machined frequently. Also, the attack on the metallic parts of the bombs by acids could cause contamination of samples (Nadkarni, 1980).

Although there are some disadvantages, closed container digestion procedures are preferable to open vessel digestion. The Teflon bomb method minimizes contamination, speeds up decomposition, and reduces the volume of acid needed (Brzezinska et al., 1984).

Using a closed tube method, a hydrofluoric/aqua-regia system has been found to provide a favorable decomposition medium. After neutralization of the excess hydrofluoric acid with boric acid, a suitable salt-free single matrix system is obtained. This matrix diminishes or eliminates the chemical, ionization, matrix, and instrumental interferences for absorption measurements. The fluoboric-boric acid system permits contamination-free sample handling in glass equipment, ensures sample solution stability, and eliminates the need for closely matching matrix components of the sample and standard solutions. Conflicting statements appear in the literature as to the rate of attack on glass by fluoboric acid. In the presence of excess boric acid, the hydrolytic decomposition of fluoboric acid is suppressed for a period of at least two hours and during

this period only insignificant contamination occurs (Bernas, 1968).

To determine the acceptability of closed container microwave dissolution methods, standard reference materials (e.g., National Bureau of Standards) can be used to evaluate procedures (von Lehmden et al., 1974). For a hydrofluoric acid and aqua-regia digestion, precision and accuracy for most determinations are comparable to other more complex analytical techniques (Bernas, 1968). The speed of dissolution in Teflon bombs is considerably faster than for existing fusion methods (Buckley and Cranston, 1971). For a hydrofluoric acid and aqua-regia digestion, the level of recovery is quite acceptable. At the ninety-five percent confidence limit, there are no significant differences detected in the analysis in comparison with standard values. The analysis shows values to within 1.3 percent relative or better for major constituents and 4.0 percent or better for minor constituents. High overall reliability achieved by hydrofluoric acid and aqua-regia, for silicate analysis, provides satisfactory accuracy (Bernas, 1968).

Thermoplastics such as polypropylene, polyethylene, polycarbonate, and polysulfone have the necessary combination of rigidity and tensile strength to resist oxidation by strong acids and to withstand the high temperatures (100-200°C) necessary for total dissolution (Farrell et al., 1980). Use of a microwave oven instead of

a conventional oven has made possible the use of pressurized plastic tubes as dissolution vessels. The primary advantage of using a microwave oven in this process is the speed in which digestion can be carried out. Procedures which normally required one to two hours can be acheived with a microwave oven in five to fifteen minutes with little operator attention (Abu-Samra et al., 1975).

Nadkarni (1984) developed a procedure for using hydrofluoric acid and aqua-regia along with thermoplastic tubes in a microwave oven digestion method (modified from Bernas, 1968). Heating in a microwave oven in the presence of an acid mixture dissolved the metals from powdered coal, fly ash, oil shales, rocks, sediments, and biological materials. The dissolution could be achieved within three minutes with reproducible and accurate results. Using standard reference materials, results were within five percent of standard values (Nadkarni, 1984).

As environmental concerns have increased, the developement of a quick and reliable chemical analysis has become necessary. "Such an analysis must yield a determination of both major and minor elements from a single sample" (Buckley and Cranston, 1971). The objective of this study was to evaluate the microwave oven dissolution technique described by Nadkarni (1984) as applied to soils and parent material samples.

MATERIALS AND METHODS

A deep core (10.64 m) (Well # 010060240) located on the Hickory Valley topographic quadrangle at 35 degrees, 08 minutes, 13 seconds north latitude and 89 degrees, 13 minutes, 41 seconds west longitude was extracted. Core materials represented a loess, alluvium, and Tertiary Sand parent material sequence on the Ames Plantation in southwest Tennessee (Fig. 1)(Russell and Sparks, 1975). Quaternary aged loess over the Claiborne and Wilcox formations of the Tertiary age is the prevalent geology of this area (Hardeman, 1966). Samples were taken by the United States Geological Survey using a drill rig and split spoon sampler. Soil morphology was completed according to National Cooperative Soil Survey Standards (Soil Survey Staff, 1981). Field notes included: horizon designation, depth, boundary distinctness, texture, color, consistence, and structure. Elevation, aspect, vegetation, slope, and other site characteristics were also recorded. The external rind of the cores were trimmed to avoid contamination. Samples were air dried and passed through a two millimeter sieve. The samples were then quartered and one portion ground to less than sixty mesh.

Particle size analysis was determined using the pipette method (Kilmer and Alexander, 1949). Hydrogen peroxide was used to eliminate interference from organic matter in

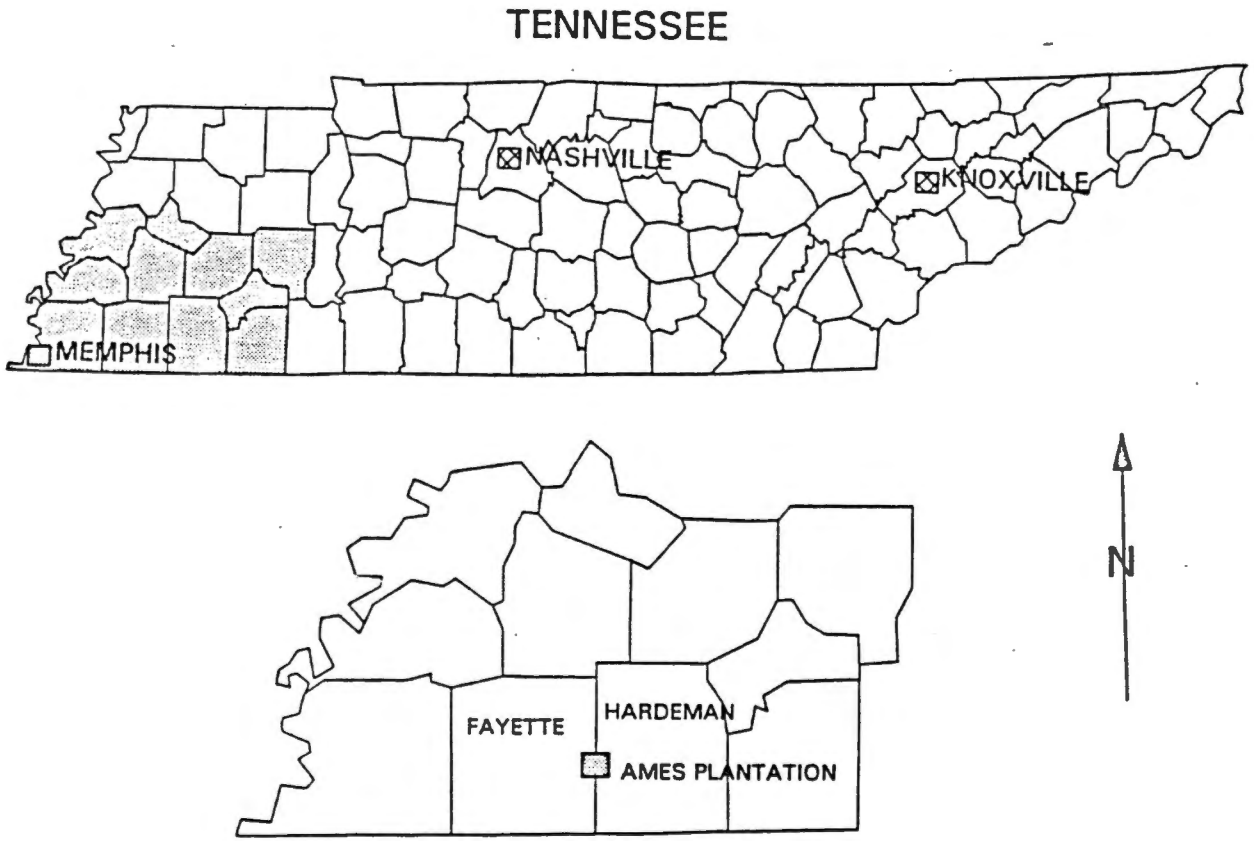


Figure 1. Location map for deep well samples.

horizons high in carbon contents. Sands were fractionated into very coarse sand (vcos), coarse sand (cos), medium sand (ms), fine sand (fs), and very fine sand (vfs) (Gee and Bauder, 1986).

MODIFIED METHOD FOR TOTAL ELEMENTAL ANALYSIS

Efforts were made to dissolve soil samples according to the microwave method described by Nadkarni (1984). In this technique, a 200 mg sample (<60 mesh) could be dissolved in 5 ml of aqua-regia and 2 ml of hydrofluoric acid when heated in a microwave oven for three minutes. This procedure was followed, but samples with greater than 45 percent sand would not dissolve completely.

After repeated attempts to dissolve the samples, certain modifications were attempted to promote sample dissolution using the microwave oven. The modifications and results are as follows:

1. The sample size was reduced from 200 mg to 100 mg without success.
2. The particle size was reduced from 60 mesh to 200 mesh. The analysis was repeated without improvement.
3. Using the 200 mg sample size, double quantities of acids and twice the microwave heating time were attempted without achieving total dissolution.

These three modifications were used in different combinations following the microwave procedure (Nadkarni, 1984) with limited success.

Based on preliminary evaluations, a total dissolution method applicable to soils (with greater than 45 percent sand) was developed. Samples with greater than 45 percent sand required pretreatment in hydrofluoric acid to achieve total dissolution. The method was revised so that a 200 mg sample of less than 60 mesh size and 2 ml of hydrofluoric acid were placed in polyallomer centrifuge tubes and allowed to react for 16 hours (overnight at room temperature). Samples with less than 45 percent sand required no overnight dissolution and needed no modification. Visual confirmation was made on the dissolution of the samples.

Following the initial 16 hour reaction period with 2 ml of hydrofluoric acid, 5 ml of aqua-regia (hydrochloric acid:nitric acid:water, 3:1:1) were added (all acids were reagent grade) and stirred with a vortex mixer. The samples were then dissolved by heating in a Tappan (800 watt) microwave for three minutes at eighty percent power to facilitate the reaction. As a result of this modification, the samples were completely dissolved. After cooling, one gram of boric acid (reagent grade, 99.99 % pure) was added to neutralize the hydrofluoric acid. The solution was then stirred and heated again in the microwave for ten minutes at twenty percent power to dissolve the boric acid. While

still hot, the solution was stirred to aid boric acid dissolution. After cooling, the solutions were transfered to 100 ml volumetrics and brought to volume for analysis. A 200 mg sample in 100 ml of solution yields a dilution factor of 500 to convert metal concentrations to units of mg/kg.

A National Bureau of Standards (NBS) coal fly ash sample (#2691) was used to establish recovery rates. Mean concentration values and associated errors were determined for Al, Ca, Fe, Mg, P, K, Si, Na, S, and Ti using sixteen replicates of the standard. A Student t-test was preformed on the sixteen replications of the coal fly ash standard (Lund, 1988). Results were used to establish the validity of the microwave oven dissolution technique.

The modified microwave oven method was tested over a wide range of textures and weathering conditions to observe how well different textures would dissolve. As shown in Table 1, the textures range from a silt loam to a sand from the deep well samples.

Ten elements for each sample were determined by inductively coupled argon plasma atomic emission spectrometer (ICAPAES), a Thermo Jarrell Ash ICAP 61.

Table 1. Morphology for loess, alluvium, Tertiary Sand parent material sequence (Livingston, 1993).

Horizon	Depth(cm)	Color	Texture*	Structure	Consistence
Ap	0-17	10YR4/4	SiL	2MGR	FR
Bt1	17-61	7.5YR4/6	SiCL	2MSBK	FR
Bt2	61-104	7.5YR4/6	SiL	2MSBK	FR
Bt3	104-119	5YR4/4	SiL	2MSBK	FR
Bt4	119-176	5YR4/4	SiL	2MSBK	FR
2Bt5	176-220	2.5YR3/4	SiCL	1MSBK	FR
2Bt6	220-251	2.5YR4/6	SiCL	1MSBK	FR
2Bt7	251-333	5YR4/6	SiCL	1MSBK	FI
2Bt8	333-357	5YR4/6	CoSL	1MSBK	FR
2Bt9	357-381	5YR4/6	CoSL	1MSBK	FR
2C	381-414	5YR4/6	LCoS	OSG	FR
3C	414-471	7.5YR5/6	CoS	OSG	FR
--	471-608	2.5YR4/8	LCoS/CoSL	OSG	FR
--	608-626	10YR6/6	FS	OSG	FR
--	626-644	10YR8/1	FS	OSG	FR
--	644-784	2.5YR4/8	FS	OSG	FR
--	784-811	5YR5/8 10YR8/1 10YR6/8	FS/LFS	OSG	FR
--	811-819	10YR8/1	FS	OSG	FR
--	819-827	5YR6/8	LFS	OSG	FR
--	827-832	10YR8/1	LFS	OSG	FR

Table 1. (continued...) Morphology for loess, alluvium, and Tertiary Sand parent material sequence (Livingston, 1993).

Horizon	Depth(cm)	Color	Texture*	Structure	Consistence
--	832-863	5YR6/8 2.5YR4/8	SL	OSG	FR
--	863-873	10YR8/1	FS	OSG	FR
--	873-912	5YR6/8 2.5YR4/8 10YR8/1	LFS	OSG	FR

* soils textures corrected from laboratory data, Si=Silt, L=Loam, C=Clay, Co=Course, S=Sand, F=Fine, 1=weak, 2=moderate, 3=strong, M=medium, GR=Granular, SBK=Subangular Blocky, OSG= Structureless Single Grain, FR=Friable, FI=Firm

During the analysis, a quality control check was monitored by analyzing samples of known concentrations after every ten samples. Three elements were checked each time and their associated errors were as follows: Ca (-1 to +6 percent), Mg (-1 to +3 percent), K (-1 to +4 percent). Blanks, after every twenty samples, and duplicates of core samples were also analyzed to ensure quality control.

RESULTS AND DISCUSSION

Table 2 shows a comparison of experimental results of metal concentrations with certified values for the NBS coal fly ash standard. Agreement between the experimental results and the NBS values were indeed favorable. With the exception of Fe, the recovery rates for all elements were within ten percent of the certified value. Averaging done by the ICAPAES introduced instrument deviations for each element represented in the standard. Table 2 shows overlapping standard deviation values for the NBS standard and the experimental values.

Table 2. Comparison of NBS coal fly ash standard (#2691) certified mean elemental composition values and those obtained through the application of a modified microwave digestion technique.

ELEMENT	CERTIFIED MEAN	EXPERIMENTAL MEAN	RECOVERY RATE
	.....Weight Percent.....		
Al	9.81 +/- 0.39[a]	9.04 +/- 1.34[b]	92.2
Ca	18.45 +/- 0.32	18.23 +/- 2.50	98.8
Fe	4.42 +/- 0.03	3.93 +/- 0.66	88.9
Mg	3.12 +/- 0.08	2.97 +/- 0.46	95.2
P	0.51 +/- 0.02	0.50 +/- 0.30	98.0
K	0.34 +/- 0.01	0.33 +/- 0.23	97.1
Si	16.83 +/- 0.12	17.02 +/- 2.47	101.0
Na	1.09 +/- 0.05	1.10 +/- 0.41	101.0
S	0.83 +/- 0.05	0.78 +/- 0.24	94.0
Ti	0.90 +/- 0.02	0.82 +/- 0.16	91.1

[a] population mean +/- 1 standard deviation for sixteen replicate determinations

[b] mean value +/- 1 standard deviation for sixteen replicate determinations

Including the error associated with the ICAPAES analysis, there was no significant difference between the experimental results and the certified values for the coal fly ash standard at the ninty-five percent confidence limit.

SUMMARY

A microwave oven digestion technique using hydrofluoric acid and aqua-regia was modified for soil and parent material samples with greater than 45 percent sand to promote total dissolution. Sandy textured sampled (greater than 45 percent) needed an overnight reaction period in hydrofluoric acid to dissolve completely. The modification of Nadkarni's method proved effective for preparing soil samples containing greater than 45 percent sands. The method is rapid with dissolution of samples (after suitable pretreatment) being achieved in three minutes and yielding analytical quality data.

In this study, the procedure was effective for dissolving soils and parent materials of all textural classes even though coarser textures of sand, sandy loam, and loamy sand required a pretreatment. The method is quick and easy and about fifty samples can be prepared in an eight hour day. One minor problem with the method is that the structural integrity of the centrifuge tubes weakens after several uses. This problem is overcome by replacing tubes

after two or three uses. The microwave oven dissolution technique has acceptable recovery rates and is accurate and reproducible, when compared to NBS standards.

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CHAPTER TWO

DETERMINATION OF BACKGROUND METALS ON SELECTED PEDONS REPRESENTING THE PHYSIOGRAPHIC REGIONS OF TENNESSEE

INTRODUCTION

Many elements, even at trace levels, are of great interest because of their potential deleterious effect on the environment (Guidoboni, 1973). Several approaches have been used to assess soil metal contamination. Most studies have evaluated "total" metal levels using results obtained from the acid digestion of soils. Such techniques have proved to be useful indicators of the gross metal content of soils and provide a preliminary indication of metal pollution. However, total elemental concentrations are of little value for assessing bioavailability, fate, or behavior (Elliot and Shields, 1988). Total elemental concentrations could better indicate pollution problems if background information were available to differentiate natural levels from potential problem levels.

Based on the lack of background metal information and the perceived need, the objective of this study was to determine the background concentrations of elements on selected pedons in Tennessee. Pedons were selected from six of the eight different physiographic regions or Major Land

Resource Areas (MLRAs). The total concentrations of twenty-three elements were determined by applying the microwave dissolution technique developed in Chapter 1 and using the extensive capabilities of inductively coupled argon plasma spectrophotometry (ICAP).

LITERATURE REVIEW

A trace element is strictly defined as a function of concentration in a natural medium. For soils, a trace element may be defined as any element whose mass concentration in a solid phase is less than or equal to 100 mg/kg (Sposito, 1989). Data in Table 3 shows that the earth's crust is the main supplier of trace elements to the soil, however, other sources, mainly anthropogenic, are modifying the natural cycle of trace elements in nature. From Table 3, the most abundant elements in soils are Si, Al, Fe, Ca, K, Na, Mg, and Ti, whereas in crustal rocks they are Si, Al, Fe, Ca, Mg, Na, K, Ti, and P.

Industrial, domestic, and agricultural activities use large quantities of elements, such as Fe, Cu, Pb, Ni, Cd, and Hg. Some of these metals are returned and become interactive with the environment (Pinta, 1978). Metal concentrations above background levels may indicate a

Table 3. Median elemental concentrations of soil and mean elemental concentrations of crustal rocks (mg kg^{-1})(modified from Bowen, 1979).

Element	Soil	Crust	Element	Soil	Crust
Al	71000	82000	Mg	5000	23000
As	6	1.5	Mn	1000	950
Ba	500	500	Mo	1.2	1.5
Ca	15000	41000	Na	5000	230000
Cd	0.35	0.11	Ni	50	80
Co	8	20	P	800	1000
Cr	70	100	Pb	35	14
Cs	4	3	S	700	260
Cu	30	50	Si	330000	277000
Fe	40000	41000	Ti	5000	5600
K	14000	21000	Zn	90	75
			Zr	400	190

problem. However, elevated concentrations of metals should only be considered as 'red flags' and in no way indicate an environmental hazard.

Many elements present in soils play an active role in plant growth. Micronutrients such as B, Co, Cu, Fe, Mn, Mo, and Zn are well established as important for plant growth (Pinta, 1978). However, at elevated concentrations, these elements can be phytotoxic and may pose a threat to human health and the environment. Even though an element may be essential, an excess of that element can be toxic even at trace levels.

SOILS AND PARENT MATERIALS

Soil has long been considered as a repository for society's waste. With increasing emphasis on detection and treatment of hazardous waste, accurate assessment of contamination becomes increasingly important (Elliot and Shields, 1988). Through mobilization by biogeochemical processes, soil contaminants can pollute water supplies or impact food crops.

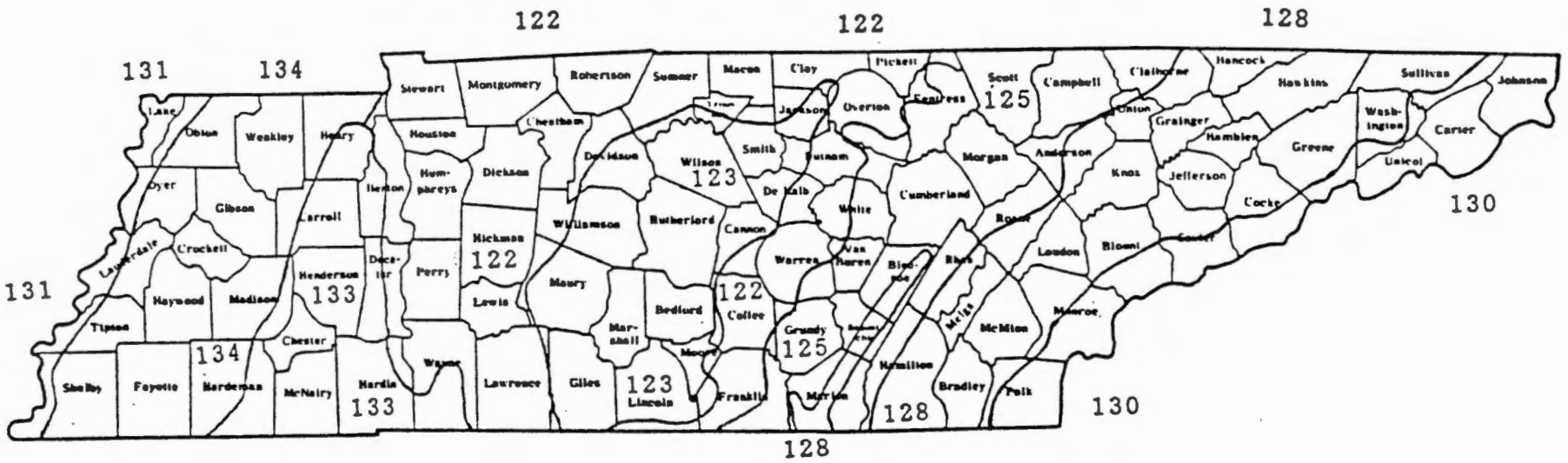
Soil is a complex biological, chemical, and physical system that responds to the many factors of its environment. Because of interaction between these factors: parent material, topography, climate, vegetation, and time, there is an almost endless variety of soils. In order to study

background elemental concentratios in soils and parent materials on a large scale, it is important to take a broad look at soils and landscapes. Based on the geology or parent materials of a given area or state, there are certain repeating patterns with predictable properties and ranges (Buol, 1973). These are general physiographic divisions or Major Land Resource Areas (MLRAs) (USDA-SCS, 1989).

Tennessee is divided into eight distinct MLRAs. From east to west, these include the Unaka Mountains or Blue Ridge, Ridge and Valley, Cumberland Plateau, Highland Rim, Central Basin, Gulf Coastal Plain, Mississippi River Valley Silty Uplands, and Mississippi River Valley Alluvium (Figure 2)(USDA-SCS, 1989).

The Unakas contain the oldest rocks in Tennessee. Rocks are from the Paleozoic Era and are of Ordovician period limestone and dolomite, Cambrian period sediments, and Precambrian period unfossiliferous granite. Major rock types are metamorphosed sediments, including quartzite, slate, schist, and marble. This MLRA is underlain by slightly metamorphosed siltstone, sandstone, and conglomerates. Natural resources of the area include metallic minerals of Au, Ag, Cu, Fe, and Mn. Non-metallic products are crushed stone, slate, marble, and building stone (Wilson, 1981).

The Ridge and Valley MLRA consists of sediments from the Paleozoic Era. These rocks include limestone,



122	HIGHLAND RIM	130	BLUE RIDGE
123	CENTRAL BASIN	131	MISSISSIPPI RIVER VALLEY ALLUVIUM
125	CUMBERLAND PLATEAU	133	GULF COASTAL PLAIN
128	RIDGE AND VALLEY	134	MISSISSIPPI RIVER VALLEY SILTY UPLANDS

Figure 2. Major Land Resource Areas of Tennessee (USDA-SCS, 1989).

sandstone, siltstone, shale, and dolomite from Ordovician, and Cambrian periods. Resources of this area include Zn, iron ore, bauxite, fluorite, and barite as well as crushed stone, marble, cement, sand, and gravel.

Conglomeratic sandstone, siltstone, shale, and coal are the major rock types of the Cumberland Plateau. These rocks, from the Paleozoic Era, are of the Pennsylvanian period and are underlain by shales, limestone, and dolomite of Mississippian period. Coal and petroleum are important natural resources of this area.

Rocks from the Paleozoic Era underlie the Eastern Highland Rim. Limestones of the Mississippian period, covered by a thin layer of loess dominate this MLRA. Products of this area are crushed limestone, road base material and agricultural lime. Some petroleum and natural gas are also produced from a few wells (Wilson, 1981).

In the Central Basin, Paleozoic Era rocks are from the Ordovician period. Shale and limestone outliers of Devonian-Mississippian periods cap the many small hills around the edge of this MLRA. Phosphates are the major resource of the Central Basin, but other products include crushed limestone and Zn (Miller, 1974).

Major rock types of the Western Highland Rim are limestones, chert, and shales of the Devonian and Mississippian periods from the Paleozoic Era. Limestones, covered by a thin layer of loess and in places by coastal

plain gravel, are exposed at the surface. Only in the southern part of this MLRA do the stream valleys erode below Devonian period rock into small areas of Silurian and Ordovician period rock. Brown iron ore deposits are the historic resource of this area. They occur in irregular masses in the residual chert and clay of limestones, or as pockets and lenses in the Cretaceous period sands and gravels from the Mesozoic Era. The ore consists of limonite, a brown or reddish-brown oxide of iron or as a hard, black variety of goethite (Wilson, 1981).

The Gulf Coastal Plain and the Mississippi River Valley Silty Uplands lie between the Western Highland Rim and the Mississippi River Valley Alluvium. Parent materials of these MLRAs consists of sand, clay, and marls of Tertiary and Cretaceous periods. These materials are from the Mesozoic and Cenozoic Era and are covered by a blanket of Quaternary loess.

The Mississippi River Valley MLRA is of recent alluvium from the Cenozoic Era. Clay deposits of the Gulf Coastal Plain and the Mississippi River Valley Alluvium MLRAs are thought to have been formed from decomposing feldspars. The feldspars were originated in mid-continent and washing into the embayment from the north during glacial melt (Wilson, 1981).

The objective of this study was to establish background metal concentrations on the Major Land Resource Areas of

Tennessee. Background metal concentration information will serve as future reference for interpreting metal data.

MATERIALS AND METHODS

SITE SELECTION

Sites were selected from previously sampled soil profiles from the University of Tennessee Soil Characterization Laboratory to obtain a preliminary estimate of twenty-three elements by MLRAs in Tennessee (Figure 3).

Some of the following soil morphology tables appear to have duplicate horizons in a single profile. These tables are abbreviations of soil morphologies and horizons may have been cut out on some property not listed in the table.

Selected pedons were from Grainger, Knox, and Anderson Counties representing the Ridge and Valley area. A pedon from Cumberland County represented the Cumberland Plateau area, while pedons from Putnam, Macon, Robertson, and Hickman Counties represented the Highland Rim area. Pedons from Jackson and Lincoln Counties represented the Central Basin, and a pedon from Wayne County represented the Gulf Coastal Plain. Gibson and Fayette pedons represented the Mississippi River Valley Silty Uplands.

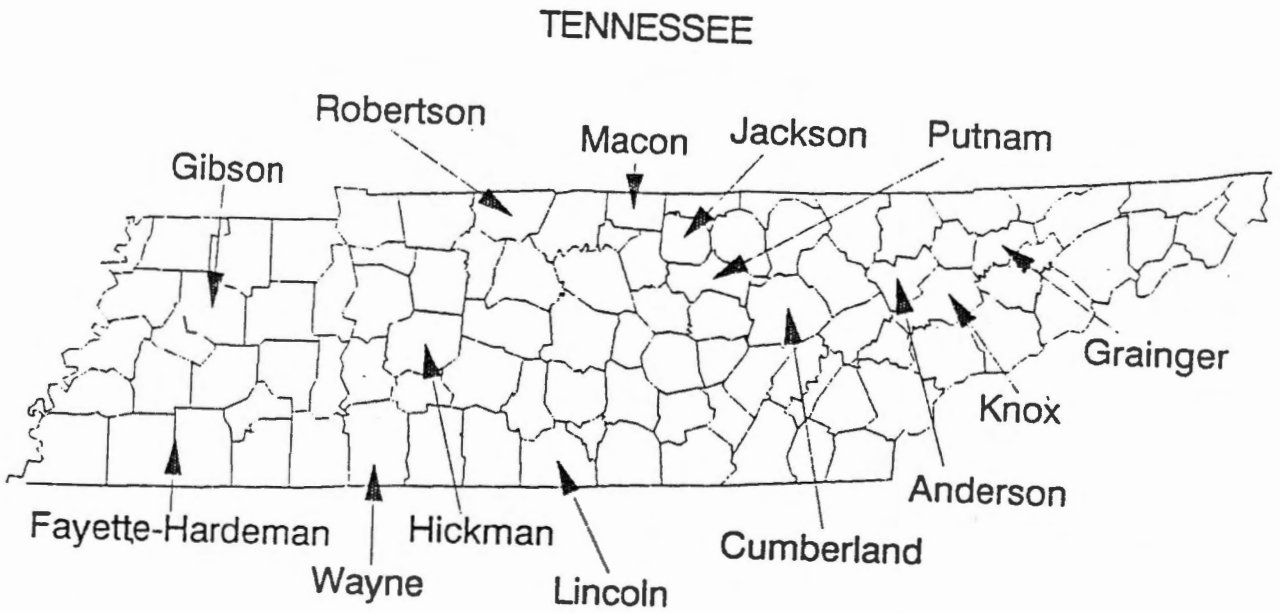


Figure 3. Location map for pedons selected for elemental analysis.

No pedons were sampled to represent the Blue Ridge MLRA or the Mississippi River Valley Alluvium.

LABORATORY METHOD

The modified method for total elemental analysis of soils and parent materials from Chapter One was used to determine background metals for selected pedons. Duplicate samples were dissolved in hydrofluoric acid and aqua-regia when heated in a microwave oven. After the dissolution, boric acid was added to neutralize the hydrofluoric acid. Solutions were then diluted in 100 ml volumetrics and analyzed for twenty-three elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Si, Sr, Ti, Zn, and Zr) using ICAP capabilities.

RESULTS AND DISCUSSION

Ridge and Valley MLRA

Pedons selected to represent the Ridge and Valley were from Grainger, Knox, and Anderson Counties. Selected from Grainger County was a pedon which had developed in deep alluvium on a stream terrace. The pedon from Knox County represented a stream terrace on the Tennessee River, and a pedon that developed in a Cambrian/Ordovician geologic

sequence was selected from Anderson County. Soil morphology, classification, and parent material are described in Tables 4, 5, and 6.

Elemental averages and ranges from the samples of the three pedons that represent the Ridge and Valley Region were obtained by compiling A, B, and C horizons of surface, subsurface, and parent material groups for each profile sampled (Table 7).

Although the soil types compared in this study have similiar classifications, their parent materials differ. The Grainger and Knox County soils are derived from limestone rock while the Anderson soil is derived from shale. Therefore, interputations should be based on the nature of parent materials (Tables 4, 5, 6). Changes in parent material may result in notable changes in the elemental content of soil.

Cumberland Plateau MLRA

The pedon selected from Cumberland County which represents the Cumberland Plateau developed in Pennsylvanian sandstone. Soil morphology, classification, and parent material are presented in Table 8. An average and range are listed in Table 9 for the elemental content representing the Cumberland Plateau by A, and B horizons. The soil profile sampled representing the Cumberland Plateau (Table 8) formed

Table 4. Soil morphology, classification, and parent material for the Grainger County pedon (Hartgrove, 1990)[1].

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
Ap	0-20	7.5YR4/4	CL	1MSBK	FR
AB	20-41	5YR4/4	CL	1MSBK	FR
Bt1	41-57	5YR5/6	C	1MSBK	FR
Bt2	57-92	2.5YR4/6	C	2FSBK	FR
Bt3	92-134	2.5YR4/6	C	2MSBK	FR
Bt3	134-167	2.5YR4/6	C	2MSBK	FR
Bt5	167-190	2.5YR4/6	C	2MSBK	FR
Bt6	190-260	2.5YR4/6	C	1MSBK	FR
Bt7	260-281	2.5YR4/6	C	1MSBK	FR
Bt8	281-302	2.5YR4/6	C	1FSBK	FR
Bt9	302-330	2.5YR4/6	C	1FSBK	FR
2BC1	330-391	5YR5/8	C	1FSBK	FR
2BC2	391-435	5YR5/8	C	1FSBK	FR
2Cb	435-518	7.5YR5/8	C	MA	FR

Taxonomic Class: fine, kaolinitic, thermic Typic Paleudalf.

Parent Material: Alluvial stream terrace

[1]Study area: 20 miles northeast of Knoxville, Tennessee on the northeast part of Luttrell, Tennessee topographic quadrangle in the Richland Valley (part of a transect), C=Clay, CL=Clay Loam, 1=Weak, 2=Moderate, F=Fine, M=Medium, SBK=Subangular Blocky, MA=Massive, FR=Friable

Table 5. Soil morphology, classification, and parent material for the Knox County pedon (Hartgrove et al., 1993)[1].

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
A	0-6	10YR3/4	SiL	2MSBK	VFR
Ap	6-20	10YR4/4	SiL	1FSBK	FR
2Bt1	20-45	7.5YR4/6	L/CL	2MSBK	FR
2Bt2	45-60	7.5YR5/6	SiCL	2MSBK	FR
2Bt3	60-100	7.5YR5/6	SiCL	2MSBK	FR
2Bt4	100-128	10YR6/8	CL	1MSBK	FR
2BC	128-236	10YR6/8	L	1FSBK	FR

Taxonomic Class: clayey, mixed, thermic Typic Halpudult.

Parent Material: Alluvial stream terrace

[1]Study area: University of Tennessee Plant Science Farm, 5 miles south of Knoxville, Tennessee at 35 degrees, 54 minutes north latitude and 83 degrees, 57 minutes, west longitude on the Knoxville, Tennessee topographic quadrangle, Si=Silt, L=Loam, CL=Clay Loam, 1=Weak, 2=Moderate, F=Fine, M=Medium, SBK=Subangular Blocky, V=Very, FR=Friable

Table 6. Soil morphology, classification, and parent material for the Anderson County pedon (Branson et al., 1993)[1].

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
E	0-17	5YR6/3	SiL	1FGr	VFR
E/Bt	17-40	2.5YR6/6 10YR5/6	L	1FGr	VFR
Bt1	40-69	5YR5/8	C	2FSBK	FR
Bt2	69-99	5YR5/8 2.5YR4/8 10YR5/6	C	2FSBK	FI
BC	99-139	10YR6/6 2.5YR4/8	SiC	1CSBK 1CABK	VFI
CB	139-187	10YR5/8 7.5YR5/6 2.5YR6/8	SiC	3CABK	VFI
C1	187-231	7.5YR5/6 10YR6/8 5YR5/8 2.5YR4/8	SiCL	3CABK	VFI
C2	231-276	5YR5/6 10YR6/8	SiCL	MA	VFI

Taxonomic Class: clayey, mixed, thermic Typic Halpudult.

Parent Material: Colluvium over residual limestone

[1]Study area: 35 degrees, 56 minutes, 12 seconds north latitude and 84 degrees, 19 minutes, 36 seconds west longitude on the Bethel Valley, Tennessee topographic quadrangle, Si=Silt, L=Loam, C=Clay, 1=Weak, 2=Moderate, 3=Strong, F=Fine, GR=Granular, SBK=Subangular Blocky, ABK=Angular Blocky, MA=Massive, V=Very, FR=Friable, FI=Firm

Table 7. Average and range for each of twenty elements analyzed from three pedons representing the Ridge and Valley MLRA.

Element	Horizon A		Horizon B		Horizon C	
	.....g/kg.....					
Al	17.3 - 28.1	(23.1)[a]	23.6 - 92.8	(67.6)	31.1 - 91.9	(75.9)
Ca	0.4 - 0.9	(0.7)	0.1 - 1.4	(0.6)	0.1 - 0.4	(0.3)
Fe	5.9 - 13.9	(11.9)	5.7 - 55.5	(37.2)	11.9 - 74.4	(48.0)
K	4.1 - 5.7	(5.1)	4.6 - 16.1	(11.4)	6.8 - 21.0	(17.0)
Mg	0.6 - 1.2	(0.9)	2.1 - 7.1	(3.3)	2.4 - 5.4	(4.0)
Na	0.5 - 1.7	(0.9)	0.1 - 3.6	(0.7)	<.01 - 0.6	(0.2)
P	<.06 - 0.2	(0.1)	<.06 - 0.3	(0.1)	<.06 - 0.2	(0.1)
Si	115.0 - 384.2	(252.9)	177.5 - 496.8	(260.9)	111.4 - 309.2	(193.2)
Ti	1.4 - 2.4	(2.0)	1.2 - 5.5	(2.8)	0.9 - 5.6	(4.1)
	.....mg/kg.....					
Ba	130 - 220	(190)	70 - 550	(300)	35 - 575	(265)

Table 7. (continued...) Average and range for each of twenty elements analyzed from three pedons representing the Ridge and Valley MLRA.

Element	Horizon A		Horizon B		Horizon C	
	.....mg/kg.....					
Co	<3 - 12	(7)	<3 - 25	(7)	<3 - 26	(13)
Cr	<5		<5		<5	
Cu	7 - 22	(14)	14 - 60	(27)	20 - 38	(27)
Mn	100 - 2000	(870)	47 - 6000	(824)	90 - 1200	(521)
Mo	<5		<5		<5	
Ni	<10 - 52	(24)	<10 - 66	(32)	<10 - 75	(41)
S	<80 - 120	(94)	<80 - 300	(112)	<80 - 105	(84)
Sr	<1 - 23	(6)	<1 - 46	(23)	<1 - 44	(14)
Zn	25 - 56	(45)	59 - 169	(96)	86 - 197	(116)
Zr	66 - 96	(81)	77 - 154	(110)	41 - 107	(76)

[a] mean value in parentheses

Table 8. Soil morphology, classification, and parent material for the Cumberland County pedon (Mote, 1993)[1].

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
A	0-7	10YR3/4	L	2MGr	VFR
AB	7-11	10YR3/4	L	1MSBK	VFR
Bw	11-28	10YR4/6	L\CL	1CSBK	VFR
Bt1	28-42	10YR4/6	SCL	1F\CSBK	VFR
Bt2	42-57	10YR4/6	SCL	1M\CSBK	FR
Bt3	57-67	10YR5/6	SCL	1F\MSBK	FR

Taxonomic Class: fine-loamy, siliceous, mesic Typic Halpudult

Parent Material: Residual sandstone

[1]Study area: Campbell Junction, Tennessee topographic quadrangle at 36 degrees, 01 minutes, 15 seconds north latitude and 85 degrees, 08 minutes, 15 seconds west longitude, L=Loam, C=Clay, S=Sand, 1=Weak, 2=Moderate, F=Fine, M=Medium, C=Coarse, GR=Granular, SBK=Subangular Blocky, V=Very, FR=Friable

Table 9. Average and range for each of twenty elements analyzed from the pedon representing the Cumberland Plateau MLRA.

Element	Horizon A	Horizon B
		.....g/kg.....
Al	16.1[a]	33.1 - 39.4 (36.2)[b]
Ca	1.4	0.6 - 1.1 (0.6)
Fe	8.2	15.6 - 19.9 (17.6)
K	2.9	5.1 - 7.2 (6.1)
Mg	0.9	1.5 - 2.0 (1.7)
Na	0.2	0.4 - 1.4 (0.8)
P	0.2	<60 - 0.2 (0.1)
Si	73.3	133.2 - 321.3 (271.7)
Ti	0.7	1.4 - 1.7 (1.6)
		.....mg/kg.....
Ba	102	162 - 242 (207)

Table 9. (continued...) Average and range for each of twenty elements analyzed from the pedon representing the Cumberland Plateau MLRA.

Element	Horizon A	Horizon B
	.....mg/kg.....	
Co	<3	<3 - 7 (5)
Cr	<5	<5
Cu	6	11 - 28 (21)
Mn	112	107 - 200 (166)
Mo	<5	<5
Ni	<10	<10 - 18 (12)
S	115	<80 - 102 (86)
Sr	14	<1 - 30 (15)
Zn	13	19 - 45 (32)
Zr	30	59 - 77 (70)

[a] A horizon was not futher partitioned
[b] mean value in parentheses

in Pennsylvanian age sandstone.

Highland Rim MLRA

Four soil profiles were sampled to represent the Highland Rim. Soil morphology, classification, and parent materials are described for the four soil profiles and these data are presented in Tables 10, 11, 12, and 13.

Elemental concentration data presented in table 14 are averages and ranges for A and B horizons of four soil profiles representing this MLRA.

The geology of the Highland Rim MLRA is dominated by Mississippian aged limestones with overlying old stream terrace remnants and thin loess mantle.

Central Basin MLRA

Representing the Central Basin MLRA were pedons from Jackson and Lincoln Counties. Soil morphology, classification, and parent materials are described for both pedons in this MLRA (Table 15 and 16). In Table 17, elemental averages and ranges are given for the A, B, and C horizons for the these pedons from.

Table 10. Soil morphology, classification, and parent material for the Putnam County pedon (Khiel, 1990)[1].

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
Ap	0-13	10YR4/3	SiL	1FGr	FR
AB	13-40	10YR4/4	SiL	1MSBK	FR
BA	40-66	10YR5/4	SiL	1MSBK	FR
Bt1	66-102	10YR5/6 7.5YR4/4 5YR4/6	SiL	2MSBK	FR
2Bt2	102-128	5YR4/6	L	2MSBK	FR
2Bt3	128-151	2.5YR4/6	L	2MSBK	FR
2Bt4	151-184	2.5YR4/6	CL	2MSBK	FR
2Bt5	184-232	2.5YR4/8	CL	1FSBK	FR
2Bt6	232-268	2.5YR4/8	CL	1FSBK	FR
2Bw	268-306	2.5YR4/6	L	1FSBK	FR
2BC	306-350	5YR5/8	L	1FSBK	FR
2C1	350-371	5YR6/8	FSL	1FSBK	FR
2C2	371-387	7.5YR5/8	FSL	1FSBK	FR

Taxonomic Class: fine-loamy, mixed, thermic Typic Paleudult.

Parent Material: Loess over alluvium

[1]Study area: Cookeville East, Tennessee topographic quadrangle at 36 degrees, 10 minutes, 13 seconds north latitude and 85 degrees, 28 minutes, 03 seconds west longitude, Si=Silt, L=Loam, C=Clay, F=Fine, S=Sand, 1=Weak, 2=Moderate, M=Medium, GR=Granular, SBK=Subangular Blocky

Table 11. Soil morphology, classification, and parent material for the Macon County pedon[1] (Soil Survey Staff, 1991).

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
Ap	0-8	5YR4/4	SiL	2F/MGr	FR
Bt1	8-14	2.5YR4/6	SiCL	2MSBK	FR
Bt2	14-28	2.5YR4/6	C	2MSBK	FR
Bt3	28-36	2.5YR3/6	C	3F/MSBK	FI
Bt4	36-64	2.5YR4/6	C	3F/MSBK	FI

Taxonomic Class: clayey, kaolinitic, thermic Typic Paleudult.

Parent Material: Alluvium over residual limestone

[1]Study area: 36 degrees, 29 minutes, 45 seconds north latitude and 85 degrees, 54 minutes, 33 seconds west longitude on the Pleasant Shade, Tennessee topographic quadrangle, Si=Silt, L=Loam, C=Clay, 2=Moderate, 3=Strong, F=Fine, M=Medium, GR=Granular, SBK=Subangular Blocky, FR=Friable, FI=Firm

Table 12. Soil morphology, classification, and parent material for the Robertson County pedon (Branson, 1992)[1].

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
Ap1	0-13	10YR4/4	SiL	1MGR	FR
Ap2	13-28	10YR4/3	SiL	1MSBK	FR
Bt1	28-51	10YR4/6	SiL	1MSBK	FR
2Bt2	51-83	2.5YR5/4	SiL	2MSBK	FR
2Bt3	83-110	2.5YR3/6	SiCL	2MSBK	FR
2Bt4	110-123	5YR4/6	SiCL	2MSBK	FR
2Bt5	123-150+	5YR4/6	SiCL	2MSBK	FI

Taxonomic Class: fine-silty, siliceous, thermic Typic Paleudult.

Parent Material: Loess over alluvium over residual limestone

Study area: 36 degrees, 28 minutes, 40 seconds north latitude and 86 degrees, 49 minutes, 30 seconds west longitude on the Greenbrier, Tennessee topographic quadrangle, Si=Silt, L=Loam, C=Clay, 1=Weak, 2=Moderate, M=Medium, GR=Granular, SBK=Subangular Blocky, FR=Friable, FI=Firm

Table 13. Soil morphology, classification, and parent material for the Hickman County pedon[1] (Soil Survey Staff, 1991).

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
Ap1	0-9	10YR3/3	SiL	2MPL	FR
Ap2	9-20	10YR4/3	SiL	MA	FR
Bt1	20-41	7.5YR4/6	SiL	1F/MSBK	FR
Bt2	41-78	5YR4/6	SiCL	2MSBK	FR
Bt3	78-102	5YR4/6	SiCL	2MSBK	FR
Bt4	102-150	2.5YR4/6	SiCL	2MSBK	FR
Bt5	150-200	2.5YR4/6	SiCL	2MSBK	FR

Taxonomic Class: clayey, mixed, thermic Typic Paleudult.

Parent Material: Alluvial stream terrace

[1]Study area: 35 degrees, 51 minutes, 36 seconds north latitude and 87 degrees, 32 minutes, 12 seconds west longitude on the Centerville, Tennessee topographic quadrangle, Si=Silt, L=Loam, C=Clay, 1=Weak, 2=Moderate, PL=Platey, MA=Massive, SBK=Subangular Blocky, FR=Friable

Table 14. Average and range for each of twenty elements analyzed from four pedons representing the Highland Rim MLRA.

Element	Horizon A		Horizon B	
	.....g/kg.....			
Al	25.9 - 53.2	(38.6)[a]	18.6 - 90.9	(64.3)
Ca	0.9 - 2.3	(1.8)	0.1 - 1.8	(0.6)
Fe	13.5 - 44.7	(20.7)	10.6 - 75.9	(38.3)
K	4.9 - 11.4	(8.8)	1.8 - 12.0	(6.0)
Mg	1.1 - 1.9	(1.4)	0.6 - 3.4	(2.0)
Na	0.5 - 2.6	(1.8)	<.01 - 3.5	(1.1)
P	<.06 - 0.2	(0.1)	<.06 - 0.6	(0.1)
Si	125.3 - 263.6	(228.8)	183.8 - 350.7	(272.5)
Ti	2.3 - 3.2	(2.6)	1.4 - 4.6	(3.3)
	.....mg/kg.....			
Ba	251 - 571	(440)	50 - 489	(225)

Table 14. (continued...) Average and range for each of twenty elements analyzed from four pedons representing the Highland Rim MLRA.

Element	Horizon A		Horizon B	
	.....mg/kg.....			
Co	<3 - 7	(4)	<3 - 20	(7)
Cr	<5		<5	
Cu	7 - 37	(17)	7 - 22	(12)
Mn	177 - 2699	(1065)	27 - 2770	(547)
Mo	<5		<5	
Ni	<10 - 15	(11)	<10 - 52	(20)
S	<80 - 240	(113)	<80 - 395	(148)
Sr	26 - 54	(40)	<1 - 55	(23)
Zn	27 - 82	(48)	8 - 148	(74)
Zr	93 - 153	(118)	51 - 171	(121)

[a] mean value in parentheses

Table 15. Soil morphology, classification, and parent material for the Jackson County pedon[1] (Soil Survey Staff, 1991).

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
A	0-4	10YR3/3	SiL	1FGR	VFR
BA	4-15	10YR4/3	grSiCL	2F/MSBK	FR
Bt1	15-35	10YR4/4	grSiCL	2M/CSBK	FR
Bt2	35-52	10YR4/4	SiCL	2M/CSBK	FR
2Bt3	52-58	10YR4/4	grSiCL	2MSBK	FR
2Bt4	58-60	10YR4/6	vgrSiL	2MSBK	FR

Taxonomic Class: fine-loamy, mixed, thermic Mollic Halpudalf.

Parent Material: Colluvium from residual limestone

[1]Study area: 36 degrees, 28 minutes, 05 seconds north latitude and 85 degrees, 39 minutes, 00 seconds west longitude on the Whitleyville, Tennessee topographic quadrangle, Si=Silt, L=Loam, C=Clay, gr=gravelly, 1=Weak, 2=Moderate, F=Fine, M=Medium, C=Coarse, GR=Granular, SBK=Subangular Blocky, FR=Friable, v/V=Very

Table 16. Soil morphology, classification, and parent material for the Lincoln County pedon[1] (Soil Survey Staff, 1991).

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
Ap	0-14	10YR3/4	L	1FGR	FR
Bt1	14-31	7.5YR4/4	CL	2MSBK	FR
Bt2	31-51	7.5YR4/6	CL	2MSBK	FR
Bt3	51-86	5YR4/6	CL	2MSBK	FR
Bt4	86-110	5YR4/6	CL	2MSBK	FR
Bt5	110-136	5YR4/6	CL	2MSBK	FR
Bt6	136-185	5YR4/6	SCL	1MSBK	FR

Taxonomic Class: clayey, mixed, thermic Typic Paleudult.

Parent Material: Alluvial stream terrace

[1]Study area: Mulberry, Tennessee topographic quadrangle at 35 degrees, 08 minutes, 18 seconds north latitude and 86 degrees, 27 minutes, 12 seconds west longitude, L=Loam, C=Clay, S=Sand, 1=Weak, 2=Moderate, F=Fine, M=Medium, GR=Granular, SBK=Subangular Blocky, FR=Friable

Table 17. Average and range for each of twenty elements analyzed from two pedons representing the Central Basin MLRA.

Element	Horizon A		Horizon B	
	.....g/kg.....			
Al	37.9 - 48.1	(43.0)[a]	47.9 - 57.7	(53.5)
Ca	1.8 - 2.8	(2.3)	1.3 - 3.1	(2.1)
Fe	24.6 - 31.6	(28.1)	30.8 - 45.1	(33.8)
K	7.0 - 17.2	(12.1)	6.8 - 20.5	(13.3)
Mg	1.5 - 3.1	(2.3)	1.9 - 3.4	(2.7)
Na	0.7 - 3.1	(1.9)	0.5 - 3.2	(1.6)
P	0.7 - 1.5	(1.1)	0.6 - 1.4	(0.9)
Si	248.4 - 322.4	(285.4)	224.6 - 465.8	(330.5)
Ti	2.0 - 2.2	(2.1)	2.1 - 2.7	(2.4)
	.....mg/kg.....			
Ba	260 - 451	(359)	199 - 541	(370)

Table 17. (continued...) Average and range for each of twenty elements analyzed from two pedons representing the Central Basin MLRA.

Element	Horizon A		Horizon B	
	.....mg/kg.....			
Co	23 - 25	(24)	16 - 35	(23)
Cr	<5		<5	
Cu	8 - 30	(19)	5 - 60	(21)
Mn	1420 - 2770	(2096)	400 - 2960	(1751)
Mo	<5		<5	
Ni	10 - 50	(30)	<10 - 62	(36)
S	179 - 638	(409)	<80 - 635	(266)
Sr	33 - 52	(43)	40 - 63	(54)
Zn	80 - 150	(113)	18 - 230	(122)
Zr	95 - 105	(99)	85 - 120	(107)

[a] mean value in parentheses

Gulf Coastal Plain MLRA

The Gulf Coastal Plain was represented by a pedon from Wayne County in a loess over Cretaceous aged sand parent material. Table 18 gives the soil morphology, classification, and parent material data for this MLRA. In Table 19, elemental averages and ranges are given for A, B, and C horizons of the profile representing this MLRA.

Mississippi River Valley Silty Uplands MLRA

The Mississippi River Valley Silty Uplands were represented by two pedons from Gibson and Fayette Counties. This area is dominated by Quaternary aged loess over Tertiary aged sands. Soil morphology, classification, and parent material data are presented for each profile in Table 20 and 21.

Data presented in Table 22 are elemental averages and ranges for A, B, and C horizons of two soil profiles representing this MLRA.

The dilution factor used in this laboratory procedure in this study influnced the reported concentrations of certain elements. In the case of As, Cd, and Pb, the detection levels were 0.1 mg/kg, 0.004 mg/kg, and 0.05 mg/kg and the dilution factor was 500. Detectable levels would be inflated and be intrepreted as being much higher due to the

Table 18. Soil morphology, classification, and parent material for the Wayne County pedon[1] (Soil Survey Staff, 1991).

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
A	0-8	10YR3/3	SiL	2FGR	VFR
BE	8-31	10YR6/3	SiL	1FSBK	VFR
Bt	31-49	7.5YR4/6	L	2MSBK	FR
BC	49-120	7.5YR4/6	SL	MA	FI
C1	120-180	2.5YR5/6	FSL	MA	FI
C2	180-200	2.5YR5/6	CoSL	MA	FI

Taxonomic Class: fine-loamy, siliceous, thermic Typic Halpudult.

Parent Material: Loess over coastal plain sand

[1]Study area: Holladay, Tennessee topographic quadrangle at 35 degrees, 50 minutes, 25 seconds north latitude and 88 degrees, 14 minutes, 56 seconds west longitude near Sand Hill, Si=Silt, L=Loam, F=Fine, Co=Coarse, S=Sand, 1=Weak, 2=Moderate, M=Medium, GR=Granular, SBK=Subangular Blocky, MA=Massive, FR=Friable, FI=Firm, V=Very

Table 19. Average and range for each of twenty elements analyzed from the pedon representing the Gulf Coastal Plain MLRA.

Element	Horizon A	B		C	
		.....g/kg.....			
Al	26.2[a]	25.8 - 49.2	(33.9)[b]	45.6 - 93.2	(69.4)
Ca	2.0	0.2 - 0.7	(0.5)	0.1 - 0.2	(0.1)
Fe	7.8	8.1 - 21.4	(13.5)	21.4 - 54.6	(38.0)
K	9.1	5.1 - 10.5	(8.0)	3.8 - 3.9	(3.9)
Mg	0.9	0.8 - 2.0	(1.6)	1.4 - 1.8	(1.6)
Na	2.6	0.5 - 2.7	(1.6)	0.1 - 0.3	(0.2)
P	<.06	<.06		<.06	
Si	351.2	247.6 - 359.9	(287.3)	257.5 - 322.9	(290.2)
Ti	2.2	2.2 - 2.8	(2.5)	2.8 - 4.0	(3.4)
		.....mg/kg.....			
Ba	462	166 - 462	(267)	143 - 145	(144)

Table 19. (continued...) Average and range for each of twenty elements analyzed from the pedon representing the Gulf Coastal Plain MLRA.

Element	Horizon A	B		C	
		.....mg/kg.....			
Co	6	6 - 9	(7)	<3 - 24	(14)
Cr	<5	<5		<5	
Cu	7	<2 - 11	(6)	10 - 27	(19)
Mn	866	87 - 127	(112)	79 - 87	(83)
Mo	<5	<5		<5	
Ni	<10	<10		<10	
S	333	<80 - 88	(83)	<80	
Sr	62	<1 - 44	(26)	<1	
Zn	47	26 - 30	(28)	47 - 85	(66)
Zr	85	83 - 106	(94)	72 - 90	(81)

[a] A horizon not futher partitioned
[b] mean value in parentheses

Table 20. Soil morphology, classification, and parent material for the Gibson County pedon[1] (Soil Survey Staff, 1991).

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
A	0-11	10YR3/3	SiL	2MGR	VFR
E	11-23	10YR5/4	SiL	2MSBK	VFR
Bt1	23-54	10YR4/6	SiL	2MSBK	FR
Bt2	54-70	10YR5/6	SiL	2M/CSBK	FR
Btx/E	70-98	10YR7/2 10YR4/4	SiL SiL	2MPR 2MSBK	FI FI
Btx1	98-129	7.5YR5/8	SiL	1CPR	FI
Btx2	129-165	7.5YR4/6 10YR5/6 10YR6/2	SiL	1CPR	FI
Btx3	165-240	7.5YR4/6 7.5YR5/6 10YR6/2	SiL	1CPR	FI
Btx4	240-290	7.5YR4/6	SiL	----	FI
2Bt	290-320	7.5YR5/8	SiCL	----	FR
2BC	320-365	7.5YR5/8	L	----	FR

Taxonomic Class: fine-silty, mixed, thermic Glossic Fragiudalf.

Parent Material: Loess over alluvium

[1]Study area: Atwood, Tennessee topographic quadrangle at 35 degrees, 56 minutes, 12 seconds north latitude and 88 degrees, 43 minutes, 06 seconds west longitude, Si=Silt, L=Loam, C=Clay, 1=Weak, 2=Moderate, M=Medium, GR=Granular, SBK=Subangular Blocky, PR=Prismatic, FR=Friable, FI=Firm

Table 21. Soil morphology, classification, and parent material for the Fayette County pedon[1] (Livingston, 1993).

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
Ap	0-17	10YR4/4	SiL	2MGR	FR
Bt1	17-61	7.5YR4/6	SiCL	2MSBK	FR
Bt2	61-104	7.5YR4/6	SiL	2MSBK	FR
Bt3	104-119	5YR4/4	SiL	2MSBK	FR
Bt4	119-176	5YR4/4	SiL	2MSBK	FR
2Bt5	176-220	2.5YR3/4	SiCL	1MSBK	FR
2Bt6	220-251	2.5YR4/6	SiCL	1MSBK	FR
2Bt7	251-333	5YR4/6	SiCL	1MSBK	FI
2Bt8	333-357	5YR4/6	CoSL	1MSBK	FR
2Bt9	357-381	5YR4/6	CoSL	1MSBK	FR
2C	381-414	5YR4/6	LCoS	OSG	FR
--	414-471	7.5YR5/6	CoS	OSG	FR
--	471-608	2.5YR4/8	LCoS/CoSL	OSG	FR
--	608-626	10YR6/6	FS	OSG	FR
--	626-644	10YR8/1	FS	OSG	FR
--	644-784	2.5YR4/8	FS	OSG	FR
--	784-811	5YR5/8 10YR8/1 10YR6/8	FS/LFS	OSG	FR
--	811-819	10YR8/1	FS	OSG	FR
--	819-827	5YR6/8	LFS	OSG	FR

Table 21. (continued...) Soil morphology, classification, and parent material for the Fayette County pedon[1] (Livingston, 1993).

Horizon	Depth(cm)	Color	Texture	Structure	Consistence
--	827-832	10YR8/1	LFS	OSG	FR
--	832-863	5YR6/8 2.5YR4/8	SL	OSG	FR
--	863-873	10YR8/1	FS	OSG	FR
--	873-912	5YR6/8 2.5YR4/8 10YR8/1	LFS	OSG	FR

Taxonomic Class: fine-silty, mixed, thermic Typic Halpudalf.

Parent Material: Loess over alluvium

[1]Study area: 35 degrees, 08 minutes, 13 seconds north latitude and 89 degrees, 13 minutes, 41 seconds west longitude on the Hickory Valley, Tennessee topographic quadrangle, Si=Silt, L=Loam, C=Clay, Co=Coarse, F=Fine, S=Sand, 1=Weak, 2=Moderate, M=Medium, GR=Granular, SBK=Subangular Blocky, OSG=Structureless Single Grain, FR=Friable, FI=Firm

Table 22. Average and range for each of twenty elements analyzed from two pedons representing the Silty Upland MLRA.

Element	Horizon A		Horizon B	
	.....g/kg.....			
Al	42.9 - 46.1	(44.5)[a]	15.6 - 86.8	(59.1)
Ca	2.5 - 6.0	(4.3)	0.2 - 5.0	(2.2)
Fe	18.2 - 20.5	(19.3)	12.9 - 48.7	(30.1)
K	16.4 - 19.1	(17.7)	2.2 - 26.9	(16.8)
Mg	0.5 - 2.5	(1.5)	0.2 - 6.9	(3.0)
Na	5.8 - 6.9	(6.4)	0.1 - 13.7	(6.1)
P	0.3 - 0.4	(0.3)	<.06 - 0.5	(0.2)
Si	246.6 - 269.2	(257.9)	131.3 - 506.9	(265.3)
Ti	2.1 - 2.7	(2.4)	0.8 - 4.0	(2.7)
	.....mg/kg.....			
Ba	596 - 961	(779)	99 - 1570	(691)

Table 22. (continued...) Average and range for each of twenty elements analyzed from two pedons representing the Silty Upland MLRA.

Element	Horizon A	Horizon B
	.....mg/kg.....	
Co	12 - 17 (14)	7 - 32 (16)
Cr	<5	<5
Cu	11 - 31 (21)	11 - 31 (21)
Mn	960 - 2470(1715)	79 - 1613(740)
Mo	<5	<5
Ni	11 - 38 (25)	6 - 40 (22)
S	119 - 370 (245)	<80
Sr	77 - 139 (108)	<1 - 197 (88)
Zn	38 - 108 (73)	11 - 250 (80)
Zr	126 - 142 (134)	31 - 226 (140)

[a] mean value in parentheses

magnification of the dilution factor.

Data for As, Cd, and Pb have been omitted from this study. Concentration values for As, Cd and Pb may be "artifacts" related to calculations derived from the large dilution factor used in this procedure or background reflections from other elements when employing the ICAP for analysis.

Tables in Appendix A list total elemental concentrations for the thirteen pedons in this chapter representing the physiographic regions (MLRAs) of Tennessee. Total elemental concentrations are given for duplicate samples for twenty-three elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Si, Sr, Ti, Zn, Zr) for each horizon throughout the profiles.

ADDITIONAL INTERPRETATIONS

For the loess, alluvium, and Tertiary Sand parent material sequence shown in Table 21, total elemental concentration values were determined. These data helped to distinguished the breaks between the different parent materials. Figures 4 and 5 show plots of elements (Ba, Ca, Fe, K, Mg, Mn, Na, and Zr) that readily exhibit the discontinuities in the loess, alluvium, and Tertiary Sand parent material sequence from Table 21. Comparing Table 21 (morphology for parent material sequence) with Figures 4 and

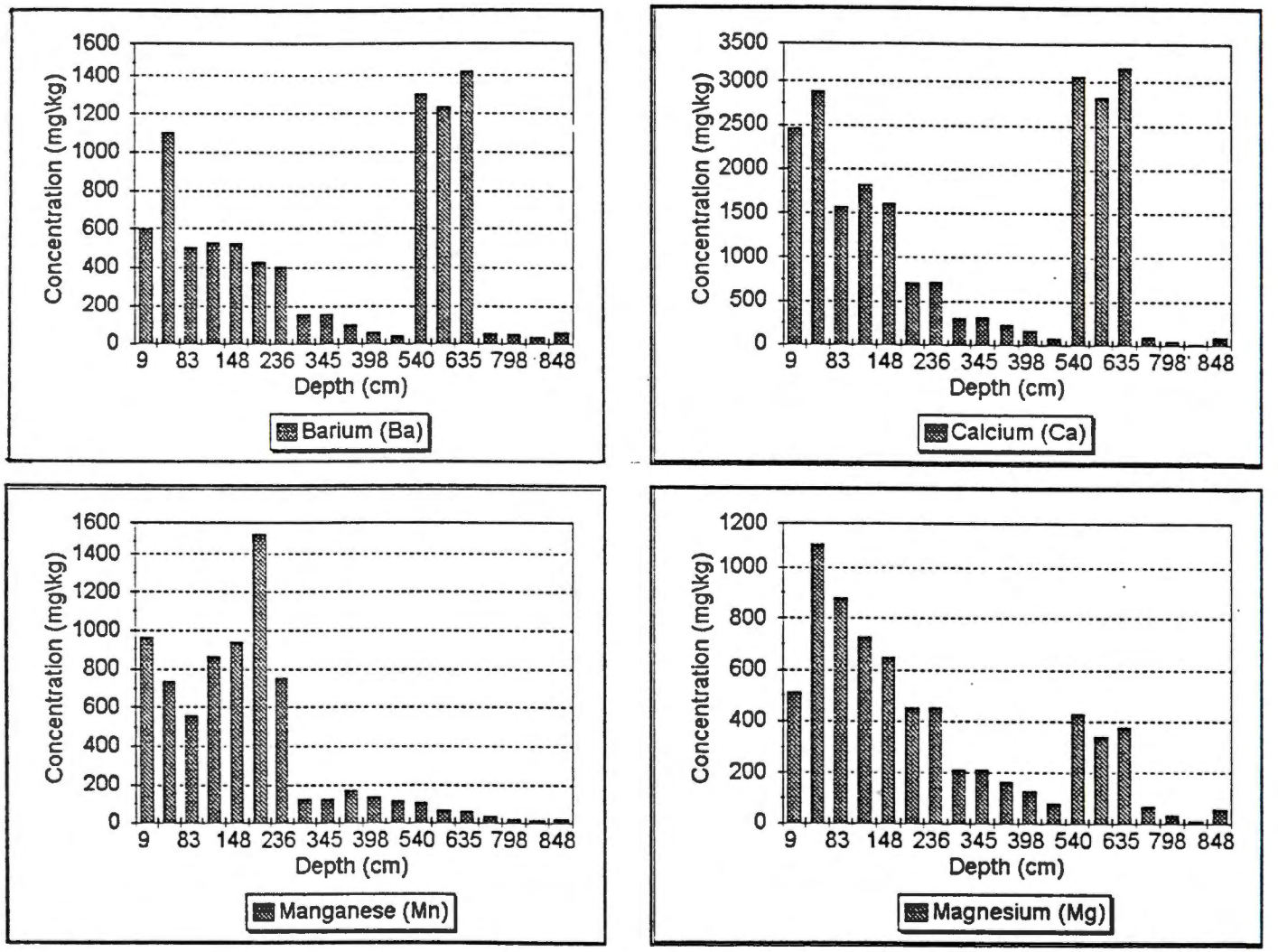


Figure 4. Total concentrations for Ba, Ca, Mg, and Mn on a loess, alluvium, and Tertiary sand parent material sequence.

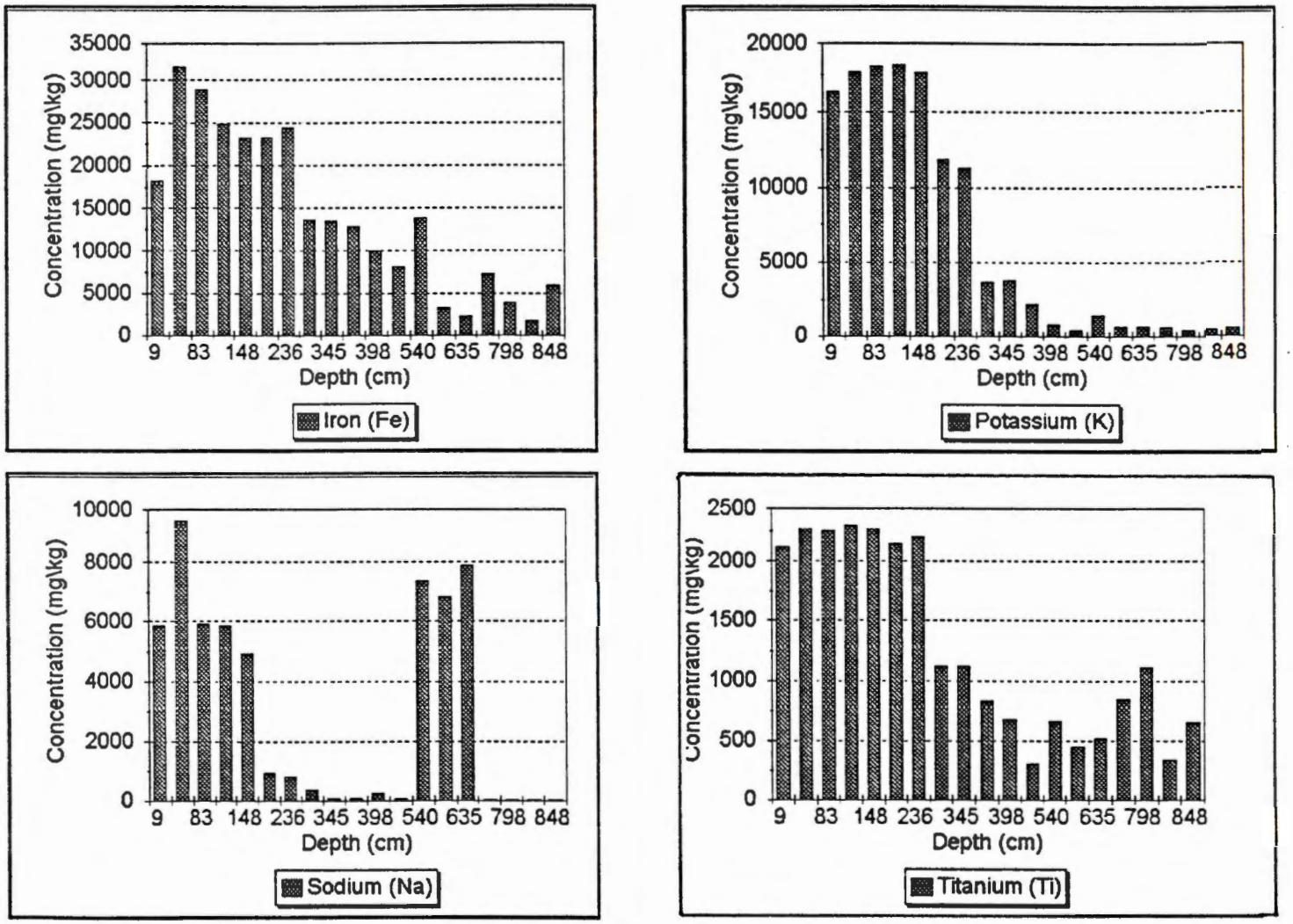


Figure 5. Total concentrations for Fe, K, Na, and Ti on a loess, alluvium, and Tertiary sand parent material sequence.

5, breaks between the loess parent material and the alluvium parent material are seen at 176 to 220 cm and a break between the alluvium parent material and the Tertiary Sand parent material at 414 to 471 cm.

SUMMARY

Table 23 gives a summary of background elemental concentrations for each region. Ranges are given for the twenty elements analyzed by averaging all horizons for each pedon representing a particular MLRA. There were thirteen pedons representing six of the eight Major Land Resource Areas from across the State of Tennessee.

Metal concentrations were within the ranges established in Table 3 for average elemental concentrations in soils and crustal rocks. Metal concentrations for Cd, Cr, Mo, and Pb were below the detection limits for the procedure used in this study.

Results from this study established background elemental concentrations for soils in the State of Tennessee. These values are in agreement with elemental concentrations of soils and geological materials established in other studies. The data presented here may be used for future site risk assessment and comparisons to aid in the identification of anthropogenically affected soils.

Table 23. Range of total elemental concentrations for six of the Major Land Resource Areas of Tennessee (average of all horizons).

Ridge and Valley

(Anderson, Knox, and Grainger County pedons)

	.....mg/kg.....		.....mg/kg.....
Al	17,000 to 92,000	Ba	35 to 570
Ca	63 to 1,360	Co	<3 to 26
Cr	<5	Cu	7 to 65
Fe	5,900 to 74,000	K	4,000 to 21,000
Mg	600 to 7,000	Mn	45 to 6,000
Mo	<5	Na	<10 to 3,500
Ni	<10 to 75	P	<60 to 275
S	<80 to 305	Si	110,000 to 490,000
Sr	<1 to 47	Ti	900 to 5,700
Zn	<4 to 200	Zr	40 to 155

Table 23. (continued...) Range of total elemental concentrations for six of the Major Land Resource Areas of Tennessee (average of all horizons).

Cumberland Plateau

(Cumberland County pedon)

	.....mg/kg.....		.....mg/kg.....
Al	16,000 to 40,000	Ba	100 to 245
Ca	180 to 1,400	Co	<3 to 7.4
Cr	<5	Cu	6 to 28
Fe	8000 to 20,000	K	2,800 to 7,300
Mg	800 to 2,000	Mn	100 to 200
Mo	<5	Na	240 to 1,350
Ni	<80	P	150 to 230
S	<80 to 115	Si	73,000 to 320,000
Sr	<1 to 30	Ti	70 to 1,700
Zn	13 to 45	Zr	30 to 76

Table 23. (continued...) Range of total elemental concentrations for six of the Major Land Resource Areas of Tennessee (average of all horizons).

Highland Rim

(Putnam, Macon, Robertson, and Hickman County pedons)

	.....mg/kg.....		.....mg/kg.....
Al	18,000 to 91,000	Ba	45 to 570
Ca	120 to 2,300	Co	<3 to 21
Cr	<5	Cu	22 to 37
Fe	10,000 to 75,000	K	1,400 to 12,000
Mg	500 to 3,400	Mn	20 to 2,700
Mo	<5	Na	<10 to 3,500
Ni	<10 to 5	P	<60 to 640
S	<80 to 395	Si	125,000 to 350,000
Sr	<1 to 55	Ti	1,400 to 4,550
Zn	7 to 150	Zr	50 to 170

Table 23. (continued...) Range of total elemental concentrations for six of the Major Land Resource Areas of Tennessee (average of all horizons).

Central Basin

(Jackson and Lincoln County pedons)

	.....mg/kg.....		.....mg/kg.....
Al	37,000 to 58,000	Ba	200 to 540
Ca	1,300 to 3,000	Co	15 to 35
Cr	<5	Cu	5 to 60
Fe	24,000 to 45,000	K	6,800 to 20,000
Mg	1,500 to 3,400	Mn	400 to 3,000
Mo	<5	Na	450 to 3,150
Ni	<10 to 62	P	600 to 1,475
S	<80 to 640	Si	220,000 to 466,000
Sr	30 to 65	Ti	1,900 to 2,700
Zn	17 to 230	Zr	85 to 120

Table 23. (continued...) Range of total elemental concentrations for six of the Major Land Resource Areas of Tennessee (average of all horizons).

Coastal Plain

(Wayne County pedon)

	.....mg/kg.....		.....mg/kg.....
Al	26,000 to 93,000	Ba	140 to 460
Ca	60 to 2,000	Co	<3 to 25
Cr	<5	Cu	<2 to 27
Fe	7,000 to 55,000	K	3,800 to 11,000
Mg	800 to 2,000	Mn	85 to 860
Mo	<5	Na	125 to 2,675
Ni	<10 to 36	P	<60
S	<80 to 330	Si	250,000
Sr	<1 to 60	Ti	2,100 to 4,000
Zn	25 to 85	Zr	70 to 100

Table 23. (continued...) Range of total elemental concentrations for six of the Major Land Resource Areas of Tennessee (average of all horizons).

Silty Uplands

(Gibson and Fayette County pedons)

	.....mg/kg.....		.....mg/kg.....
Al	3,00 to 87,000	Ba	30 to 1,900
Ca	<10 to 6,000	Co	<3 to 32
Cr	<5	Cu	3 to 31
Fe	1,745 to 49,000	K	<400 to 27,000
Mg	10 to 6,900	Mn	20 to 2,500
Mo	<5	Na	<10 to 13,700
Ni	<10 to 40	P	<5 to 570
S	<80 to 370	Si	130,000 to 790,000
Sr	<1 to 200	Ti	300 to 4,000
Zn	<4 to 250	Zr	10 to 225

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APPENDIX

APPENDIX A

TOTAL ELEMENTAL CONCENTRATIONS

Appendix A. Total elemental concentrations for Grainger County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
Ap	28131	<50	214	889	<2	5.4
AB	63223	<50	549	1363	<2	13.7
Bt1	76166	<50	467	1343	<2	25.0
Bt2	74144	<50	383	1330	<2	15.3
Bt3	76799	<50	307	1066	<2	9.1
Bt4	80411	<50	270	910	<2	7.1
Bt5	77308	<50	258	861	<2	12.6
Bt6	80634	<50	252	849	<2	9.3
Bt7	77568	<50	280	837	<2	7.9
2Bt8	79272	<50	256	845	<2	<3
2Bt9	80775	<50	261	703	<2	<3
2BC1	76664	<50	263	552	<2	<3
2BC2	74757	<50	266	450	<2	7.5
2Cb	91963	<50	221	421	<2	26.1

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
Ap	<5	7.0	13889	5604	1154	2064
AB	<5	13.7	31186	11494	2436	5915
Bt1	<5	18.0	35146	11039	2537	4942
Bt2	<5	20.0	40486	9842	2767	3974
Bt3	<5	21.1	43544	9893	2810	2500
Bt4	<5	20.5	46976	10520	2882	1585
Bt5	<5	21.8	49180	10565	2705	1764
Bt6	<5	22.6	49069	11313	2854	1251
Bt7	<5	19.7	45983	11127	2658	1431
2Bt8	<5	21.1	48733	12631	2928	574
2Bt9	<5	23.5	49331	13908	3114	604
2BC1	<5	20.9	41488	15355	3051	313
2BC2	<5	19.5	40977	16101	3081	484
2Cb	<5	38.1	74350	21058	4445	1227

(continued...) Total elemental concentrations for Grainger County pedon.

Horizon	Mo	Na	Ni	P	Pb	S
			mg/kg			
Ap	<5	442	<10	80	<25	<80
AB	<5	594	<10	78	<25	<80
Bt1	<5	386	<10	49	63	<80
Bt2	<5	148	<10	61	<25	124
Bt3	<5	138	<10	29	<25	157
Bt4	<5	436	<10	118	<25	128
Bt5	<5	102	<10	77	<25	98
Bt6	<5	345	<10	135	<25	<80
Bt7	<5	143	<10	163	<25	<80
2Bt8	<5	151	<10	131	<25	<80
2Bt9	<5	518	<10	195	<25	<80
2BC1	<5	274	<10	95	<25	<80
2BC2	<5	212	<10	46	<25	<80
2Cb	<5	89	31.6	202	<25	<80

Horizon	Si	Sr	Ti	Zn	Zr
			mg/kg		
Ap	384156	19	2397	24.8	66
AB	361275	40	2488	78.8	127
Bt1	496800	37	2381	78.6	121
Bt2	228000	39	1735	95.5	132
Bt3	256611	37	1359	75.7	134
Bt4	210760	35	1171	96.4	133
Bt5	262960	35	1310	68.5	137
Bt6	226379	33	919	68.8	124
Bt7	271345	35	650	64.1	137
2Bt8	305532	34	1437	64.3	136
2Bt9	328082	34	1135	60.0	131
2BC1	332181	33	781	56.6	128
2BC2	268116	29	1538	65.0	114
2Cb	273335	<1	5591	86.0	65

Total elemental concentrations for Knox County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
			mg/kg			
A	23942	<50	218	889	<2	3.0
Ap	53146	<50	458	1308	2.75	6.4
2Bt1	86391	138	410	1287	2.61	5.7
2Bt2	92877	89	390	773	6.36	<3
2Bt3	92679	84	401	313	3.76	<3
2BC1	87238	99	401	169	3.91	<3
2BC2	87044	57	408	109	2.90	<3
3C1b	83420	72	416	124	2.32	<3
3C2b	76807	88	495	151	<2	4.3
4Btb	76682	78	522	167	<2	13.1
4BCb	76575	65	539	180	<2	12.5
4C1b	65464	<50	533	232	2.90	10.0
4C2b	66797	56	577	283	6.22	4.9
--	51902	99	500	390	2.75	<3

Horizon	Cr	Cu	Fe	K	Mg	Mn
			mg/kg			
A	<5	12.3	13027	5724	934	441
Ap	<5	21.3	29483	11870	2157	849
2Bt1	<5	20.0	46996	11849	3004	336
2Bt2	<5	21.5	53965	12655	3134	230
2Bt3	<5	38.5	55489	13994	2810	172
2BC1	<5	26.9	51309	13535	2556	166
2BC2	<5	21.5	50804	13882	2525	369
3C1b	<5	20.2	48525	13994	2403	137
3C2b	<5	19.1	43944	17163	2893	337
4Btb	<5	29.3	42970	19846	3573	579
4BCb	<5	39.3	43266	20647	3662	594
4C1b	<5	43.6	40335	19377	3434	647
4C2b	<5	44.5	41600	20081	3786	620
	<5	65.9	36787	16997	2660	643

(continued...) Total elemental concentrations for Knox County pedon.

Horizon	Mo	Na	Ni	P	Pb	S
			mg/kg			
A	<5	1685	<10	148	<25	121
Ap	<5	2750	15.8	269	<25	97
2Bt1	<5	3571	38.4	138	<25	<80
2Bt2	<5	896	25.9	276	<25	305
2Bt3	<5	457	35.0	194	<25	<80
2BC1	<5	476	29.7	189	<25	<80
2BC2	<5	542	22.5	69	<25	<80
3C1b	<5	497	27.0	99	<25	<80
3C2b	<5	603	22.5	61	<25	<80
4Btb	<5	702	24.3	25	<25	<80
4BCb	<5	721	17.1	20	<25	<80
4C1b	<5	907	20.3	63	<25	<80
4C2b	<5	1345	4.2	138	<25	<80
--	<5	1066	11.8	33	<25	<80

Horizon	Si	Sr	Ti	Zn	Zr
			mg/kg		
A	115007	23	2259	56.1	82
Ap	177485	46	4796	94.7	151
2Bt1	171208	43	5243	168.5	154
2Bt2	288408	40	5409	120.3	116
2Bt3	255645	37	5448	121.9	107
2BC1	272394	35	5333	118.1	103
2BC2	292855	34	5326	91.9	98
3C1b	278721	35	5163	99.1	97
3C2b	285666	37	4957	97.9	84
4Btb	294752	39	4707	104.7	107
4BCb	320526	40	4773	116.0	90
4C1b	302412	41	5067	119.7	73
4C2b	158476	44	5309	191.9	87
--	309186	44	5763	103.5	88

Total elemental concentrations for Anderson County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
E	17292	361	137	348	<2	11.9
E/Bt	23578	270	145	263	<2	5.4
Bt1	58940	119	117	153	<2	6.6
Bt2	86252	<50	81	153	<2	9.9
BC	89644	<50	71	115	<2	7.2
CB	91932	<50	98	107	<2	20.3
C1	81832	<50	54	118	<2	2.9
C2	31103	<50	35	63	<2	16.5

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
E	<5	22.3	5982	4042	627	102
E/Bt	<5	48.9	8087	4584	935	51
Bt1	<5	32.7	23728	7228	2789	47
Bt2	<5	30.5	31227	11465	4901	65
BC	<5	35.8	33468	14771	6250	127
CB	<5	59.6	41320	16248	7048	1009
C1	<5	32.5	30344	13442	5362	92
C2	<5	15.9	11961	6788	2619	717

Horizon	Mo	Na	Ni	P	Pb	S
	mg/kg					
E	<5	529	51.2	<60	140	<80
E/Bt	<5	514	47.9	<60	112	<80
Bt1	<5	257	58.8	<60	122	173
Bt2	<5	167	66.0	<60	140	166
BC	<5	136	65.6	<60	111	84
CB	<5	141	74.3	<60	111	104
C1	<5	74	60.4	<60	101	<80
C2	<5	<10	18.8	<60	42	<80

Horizon	Si	Sr	Ti	Zn	Zr
	mg/kg				
E	289615	<1	1392	52.4	96
E/Bt	273720	<1	1589	59.2	102
Bt1	253715	<1	1901	98.5	98
Bt2	230673	<1	1962	110.6	99
BC	219753	<1	1779	143.3	77
CB	208129	<1	2685	196.6	90
C1	249746	<1	1807	129.5	81
C2	111435	<1	905	<4	41

Total elemental concentrations for Cumberland County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
A	16084	<50	102	1371	<2	<3
AB	33119	<50	197	1070	<2	5.5
Bw	39444	<50	240	762	<2	4.7
Bt1	37596	<50	242	437	<2	2.4
Bt2	35331	<50	196	277	<2	7.4
-	35659	<50	162	183	<2	4.7

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
A	<5	5.9	8167	2887	866	112
AB	<5	10.9	15038	5476	1599	165
Bw	<5	18.5	17440	7085	1980	177
Bt1	<5	19.6	17039	7284	1906	200
Bt2	<5	28.4	18490	5942	1610	180
-	<5	25.8	19868	5079	1537	107

Horizon	Mo	Na	Ni	P	Pb	S
	mg/kg					
A	<5	243	<10	228	<25	115
AB	<5	748	18.2	153	40	88
Bw	<5	1347	<10	<60	<25	80
Bt1	<5	939	<10	<60	<25	56
Bt2	<5	660	<10	<60	30	47
-	<5	414	<10	<60	36	102

Horizon	Si	Sr	Ti	Zn	Zr
	mg/kg				
A	73264	14	719	13.0	30
AB	133219	13	1363	44.9	59
Bw	300956	30	1630	43.7	76
Bt1	320182	29	1737	29.0	77
Bt2	321285	<1	1633	25.0	70
-	282820	<1	1505	19.0	66

Total elemental concentrations for Putnam County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
Ap	25874	53	221	854	3.62	<3
BA	18576	<50	109	219	<2	<3
Bt1	36304	71	172	263	2.90	<3
Bt2	49235	93	121	173	<2	<3
2Bt3	50954	128	117	146	<2	<3
2Bt4	51504	90	109	155	<2	<3
2Bt5	60636	157	110	143	2.61	<3
2Bw1	62452	<50	103	121	<2	4.2
2Bw2	55183	<50	93	146	<2	<3
2Bw3	45397	<50	78	133	<2	<3
2BC	30064	276	50	172	<2	<3
2C1	25283	<50	48	128	<2	<3
2C2	24406	<50	45	119	<2	<3

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
Ap	<5	36.5	14641	4930	1096	297
BA	<5	<2	10609	2769	768	81
Bt1	<5	10.8	19769	4924	1518	109
Bt2	<5	11.3	25394	3468	1573	82
2Bt3	<5	8.7	27296	3308	1591	70
2Bt4	<5	9.2	27402	3318	1557	73
2Bt5	<5	11.1	32550	3334	1538	66
2Bw1	<5	13.4	28334	3432	1438	58
2Bw2	<5	12.1	26178	3017	1309	49
2Bw3	<5	11.4	21596	2633	1021	39
2BC	<5	7.0	14718	1745	620	27
2C1	<5	5.0	13024	1571	529	23
2C2	<5	<2	11754	1482	537	24

(continued...) Total elemental concentrations for Putnam County pedon.

Horizon	Mo	Na	Ni	P	Pb	S
			mg/kg			
Ap	<5	467	<10	<60	<25	<80
BA	<5	135	<10	<60	<25	88
Bt1	<5	358	14.4	<60	<25	<80
Bt2	<5	25	29.6	<60	<25	<80
2Bt3	<5	<10	26.5	<60	<25	<80
2Bt4	<5	21	18.4	<60	<25	<80
2Bt5	<5	28	39.5	<60	<25	<80
2Bw1	<5	59	<10	<60	<25	<80
2Bw2	<5	72	<10	<60	<25	<80
2Bw3	<5	116	<10	<60	<25	<80
2BC	<5	21	<10	<60	<25	<80
2C1	<5	<10	<10	<60	<25	<80
2C2	<5	<10	<10	<60	<25	<80

Horizon	Si	Sr	Ti	Zn	Zr
			mg/kg		
Ap	125340	26	2475	62.5	93
BA	246950	13	1434	35.7	51
Bt1	220918	<1	2952	135.0	106
Bt2	285837	<1	3315	58.3	107
2Bt3	282286	<1	3464	83.1	113
2Bt4	206784	<1	3411	97.4	110
2Bt5	306151	<1	3675	81.5	121
2Bw1	187466	<1	3115	65.1	101
2Bw2	183804	<1	3119	112.8	99
2Bw3	196832	<1	2927	59.0	99
2BC	195907	<1	2468	49.4	79
2C1	164274	<1	2124	16.6	69
2C2	126018	<1	1988	17.6	68

Total elemental concentrations for Macon County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
Ap	53150	<50	251	1018	5.64	<3
Bt1	75345	134	451	1786	4.63	<3
Bt2	84420	123	175	1051	6.36	<3
Bt3	77805	146	138	749	4.77	<3
Bt4	90881	146	197	445	5.35	<3

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
Ap	<5	15.1	44710	6167	1853	422
Bt1	<5	8.9	60879	6002	2540	173
Bt2	<5	13.2	72753	4999	2412	91
Bt3	<5	9.2	75976	4145	1847	74
Bt4	<5	22.3	74301	8883	3392	62

Horizon	Mo	Na	Ni	P	Pb	S
	mg/kg					
Ap	<5	2531	14.7	140	<25	238
Bt1	<5	3480	31.5	<60	<25	219
Bt2	<5	2025	22.5	<60	<25	395
Bt3	<5	2172	44.0	<60	<25	301
Bt4	<5	2176	51.8	<60	<25	232

Horizon	Si	Sr	Ti	Zn	Zr
	mg/kg				
Ap	244645	33	3226	82.1	153
Bt1	307381	39	4186	82.7	166
Bt2	252501	32	4551	114.7	171
Bt3	202226	27	4250	89.0	169
Bt4	259570	28	3783	147.8	164

Total elemental concentrations for Robertson County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
Ap1	34190	<50	303	1368	<2	6.6
Ap2	40217	<50	312	1802	<2	7.0
Bt1	47703	<50	256	1369	<2	<3
2Bt2	42105	<50	185	913	<2	<3
3Bt3	65135	<50	141	618	<2	8.0
3Bt4	68268	<50	147	471	<2	<3
3Bt5	70839	<50	141	517	<2	<3

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
Ap1	<5	18.6	13472	9377	1125	177
Ap2	<5	17.5	19589	9470	1352	233
Bt1	<5	10.2	26376	7954	1708	166
2Bt2	<5	8.0	21426	5645	1271	110
3Bt3	<5	11.9	30704	3773	1590	65
3Bt4	<5	10.8	31757	3996	1734	56
3Bt5	<5	8.6	36675	3907	1689	49

Horizon	Mo	Na	Ni	P	Pb	S
	mg/kg					
Ap1	<5	1948	<10	93	<25	<80
Ap2	<5	1859	<10	129	<25	<80
Bt1	<5	1791	<10	<60	<25	154
2Bt2	<5	944	<10	<60	<25	173
3Bt3	<5	199	<10	<60	<25	<80
3Bt4	<5	94	<10	<60	<25	110
3Bt5	<5	111	<10	<60	<25	121

Horizon	Si	Sr	Ti	Zn	Zr
	mg/kg				
Ap1	229461	39	2310	27.4	106
Ap2	259309	38	2463	30.6	101
Bt1	252825	33	2763	7.7	106
2Bt2	350700	26	2795	42.6	105
3Bt3	254743	<1	2972	86.5	93
3Bt4	259525	<1	3115	40.2	101
3Bt5	269888	<1	3288	36.2	103

Total elemental concentrations for Hickman County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
Ap1	37582	<50	536	2272	<2	<3
Ap2	40579	53	571	1532	<2	<3
Bt1	52594	64	489	1649	<2	<3
Bt2	57986	<50	378	845	<2	16.5
Bt3	62702	<50	349	333	<2	12.3
Bt4	73922	<50	286	285	<2	14.7
Bt5	69992	<50	265	259	<2	17.2
Bt6	89141	<50	309	496	<2	20.5

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
Ap1	<5	7.7	15313	11484	1345	2561
Ap2	<5	6.9	16647	11124	1319	2699
Bt1	<5	9.4	24994	12022	2203	1118
Bt2	<5	20.4	27346	11470	2511	1408
Bt3	<5	16.8	27951	8267	2185	2770
Bt4	<5	18.4	31245	7283	2311	2012
Bt5	<5	17.1	29557	7288	2157	1411
Bt6	<5	20.8	38914	7076	2692	1593

Horizon	Mo	Na	Ni	P	Pb	S
	mg/kg					
Ap1	<5	2151	<10	153	<25	195
Ap2	<5	2093	12.4	<60	<25	87
Bt1	<5	1910	18.8	<60	<25	<80
Bt2	<5	1723	11.4	<60	58	106
Bt3	<5	687	13.4	215	39	<80
Bt4	<5	350	12.8	384	53	<80
Bt5	<5	303	17.7	276	75	<80
Bt6	<5	218	14.3	639	49	84

Horizon	Si	Sr	Ti	Zn	Zr
	mg/kg				
Ap1	263696	52	2384	37.6	122
Ap2	250486	54	2569	46.1	130
Bt1	233311	55	2827	52.9	125
Bt2	340850	45	2879	60.3	122
Bt3	263023	39	3094	78.0	117
Bt4	294062	41	3072	73.8	117
Bt5	254099	35	3054	44.6	105
Bt6	284910	55	3611	74.3	123

Total elemental concentrations for Jackson County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
A	48107	<50	451	2793	<2	24.7
BA	53278	<50	512	3044	<2	21.0
Bt1	56879	<50	513	2374	<2	20.9
Bt2	52769	56	515	2356	<2	18.6
Bt3	57657	<50	541	2412	<2	20.6
2Bt4	52166	<50	506	2384	<2	15.6
2Bt5	52418	133	457	2171	<2	21.1

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
A	<5	29.7	31609	17155	3087	2770
BA	<5	29.8	30782	19094	3303	2968
Bt1	<5	24.7	32199	18890	3361	2518
Bt2	<5	60.4	31426	18041	3129	2867
Bt3	<5	32.2	31432	20523	2943	2900
2Bt4	<5	30.5	32775	17476	3171	2779
2Bt5	<5	260.4	32352	16799	2859	2156

Horizon	Mo	Na	Ni	P	Pb	S
	mg/kg					
A	<5	3077	49.8	1475	59	638
BA	<5	3144	43.9	1379	54	521
Bt1	<5	2928	54.9	1009	58	346
Bt2	<5	2686	39.1	1116	35	360
Bt3	<5	2554	49.9	1030	56	358
2Bt4	<5	2386	48.0	1053	<25	445
2Bt5	<5	1897	62.1	618	60	635

Horizon	Si	Sr	Ti	Zn	Zr
A	322424	52	1975	146.3	95
BA	319499	58	2139	101.1	107
Bt1	326226	62	2372	108.7	109
Bt2	224621	60	2459	138.1	111
Bt3	465825	63	2534	45.6	112
2Bt4	386250	63	2328	108.1	114
2Bt5	436200	58	2089	230.1	105

Total elemental concentrations for Lincoln County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
Ap	37948	78	266	1811	<2	22.9
Bt1	47978	<50	284	1668	<2	25.8
Bt2	51505	70	223	1646	<2	28.9
Bt3	56232	59	211	1565	<2	35.3
Bt4	53544	<50	204	1511	<2	22.2
Bt5	53809	<50	202	1495	<2	17.6
Bt6	55262	96	199	1305	<2	23.6

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
Ap	<5	7.7	24558	6949	1504	1421
Bt1	<5	9.3	33100	7584	1920	1514
Bt2	<5	10.1	40111	6853	1922	1221
Bt3	<5	10.0	45119	7349	2150	1240
Bt4	<5	5.2	37071	7467	2218	872
Bt5	<5	5.2	31566	8757	2343	401
Bt6	<5	7.7	30798	10175	2539	436

Horizon	Mo	Na	Ni	P	Pb	S
	mg/kg					
Ap	<5	738	10.0	675	90	179
Bt1	<5	735	<10	826	107	<80
Bt2	<5	488	28.3	858	110	<80
Bt3	<5	452	29.7	952	129	<80
Bt4	<5	471	15.2	814	73	<80
Bt5	<5	720	26.6	608	89	111
Bt6	<5	729	34.2	648	145	174

Horizon	Si	Sr	Ti	Zn	Zr
	mg/kg				
Ap	248439	33	2142	80.0	103
Bt1	360375	40	2708	80.9	115
Bt2	343500	41	2671	79.0	98
Bt3	322131	44	2289	64.2	89
Bt4	318718	54	2432	57.8	117
Bt5	237051	56	2641	45.5	121
Bt6	394725	56	2051	17.8	88

Total elemental concentrations for Wayne County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
A	26186	91	462	2004	<2	6.1
BE	26834	131	346	727	<2	6.0
Bt	49160	<50	288	513	<2	8.8
BC	25841	<50	166	141	<2	5.9
C1	45557	<50	145	67	<2	<3
C2	93174	<50	143	110	<2	24.4

Horizon	Cr	Cu	Fe	K	Mg	Mn
	mg/kg					
A	<5	7.3	7780	9123	909	866
BE	<5	<2	8063	10533	837	121
Bt	<5	11.3	21410	8410	2042	127
BC	<5	4.4	11029	5080	978	87
C1	<5	10.4	21440	3873	1405	79
C2	<5	27.1	54578	3966	1779	87

Horizon	Mo	Na	Ni	P	Pb	S
	mg/kg					
A	<5	2614	<10	<60	48	333
BE	<5	2674	<10	<60	48	<80
Bt	<5	1490	<10	<60	46	88
BC	<5	543	<10	<60	65	<80
C1	<5	126	<10	<60	18	<80
C2	<5	332	35.7	<60	122	<80

Horizon	Si	Sr	Ti	Zn	Zr
	mg/kg				
A	351150	62	2185	47.0	85
BE	247639	44	2200	30.3	106
Bt	359850	32	2406	25.7	93
BC	254347	<1	2825	28.1	83
C1	322886	<1	2763	47.3	72
C2	257446	<1	3951	84.9	90

Total elemental concentrations for Gibson County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co
	mg/kg					
A	46123	<50	961	6032	<2	16.56
E	54581	<50	820	2861	<2	14.53
Bt1	82445	<50	1569	4992	<2	20.88
Bt2	86793	<50	770	2096	<2	21.93
E*	74565	<50	795	2598	<2	14.59
Btx*	82880	<50	802	2646	<2	31.84
Bx1	83378	<50	808	3707	<2	21.28
Bx2	79966	<50	888	5486	<2	19.37
Bx3	71143	<50	847	4526	<2	22.66
Bx4	69940	<50	737	3447	<2	17.48
2Bt	78498	<50	1912	1460	<2	9.78
2BC	53083	<50	367	1010	<2	6.98

Horizon	Cu	Fe	K	Mg	Mn	Mo
	mg/kg					
A	31.41	20458	19048	2503	2468	<5
E	14.35	20811	21404	2672	1640	<5
Bt1	28.96	40476	23263	6428	784	<5
Bt2	26.93	48727	24646	6562	1613	<5
E*	24.10	39688	26578	5563	477	<5
Btx*	30.78	42329	26908	6618	1506	<5
Bx1	26.43	41419	26069	6883	862	<5
Bx2	26.63	37533	26502	6430	922	<5
Bx3	23.14	33049	23296	5161	969	<5
Bx4	21.64	31233	21443	4443	963	<5
2Bt	11.83	41310	12289	3812	140	<5
2BC	10.81	30568	9235	2590	79	<5

(continued...) Total elemental concentrations for Gibson County pedon.

Horizon	Na	Ni	P	Pb	S	Si
	.....mg/kg.....					
A	6900	37.92	319	48	370	269214
E	7939	13.21	263	<25	<80	790076
Bt1	11766	16.81	420	<25	<80	506863
Bt2	7895	22.05	559	<25	<80	400924
E*	11375	34.68	270	<25	<80	210222
Btx*	11215	40.14	<60	<25	<80	248955
Bx1	12351	24.48	217	<25	<80	258048
Bx2	13713	33.45	356	<25	<80	296456
Bx3	9781	39.02	<60	<25	<80	284359
Bx4	7573	23.97	152	<25	<80	306867
2Bt	2939	19.88	84	<25	<80	306632
2BC	1559	6.45	<60	<25	<80	253487

Horizon	Sr	Ti	Zn	Zr
	.....mg/kg.....			
A	139	2728	108	142
E	120	3229	65	159
Bt1	129	4001	212	174
Bt2	112	3764	114	179
E*	143	3590	79	185
Btx*	145	3504	85	173
Bx1	165	3474	100	226
Bx2	197	3607	81	217
Bx3	155	3526	113	196
Bx4	126	3685	83	177
2Bt	71	3426	250	178
2BC	40	2433	22	127

* split sample from Btx\E horizon

Total elemental concentrations for Fayette County pedon.

Horizon	Al	As	Ba	Ca	Cd	Co	Cr
	.....			mg/kg	.....		
Ap	42963	<50	596	2463	<2	12	<5
Bt1	58793	<50	1104	2878	<2	14	<5
Bt2	55293	<50	504	1567	<2	12	<5
Bt3	52618	<50	527	1826	<2	12	<5
Bt4	50843	<50	522	1613	<2	14	<5
2Bt5	49878	<50	426	706	<2	17	<5
2Bt6	51393	<50	405	721	<2	15	<5
2Bt7	21158	<50	153	308	<2	7	<5
2Bt8	20990	<50	153	314	<2	7	<5
2Bt9	15580	<50	99	224	<2	8	<5
2C	10878	<50	57	165	<2	5	10
--	6043	<50	36	70	<2	<3	9
--	19058	<50	1304	3070	<2	<3	11
--	7048	<50	1234	2830	<2	<3	14
--	5365	<50	1420	3152	<2	<3	7
--	13243	<50	52	99	<2	<3	<5
--	18620	<50	49	45	<2	<3	11
--	3087	<50	34	<10	<2	3	<5
--	16738	<50	59	90	<2	<3	<5
--	11820	<50	50	57	<2	<3	<5

Horizon	Cu	Fe	K	Mg	Mn	Mo	Na
	.....			mg/kg	.....		
Ap	11	18172	16393	512	961	<5	5839
Bt1	19	31567	17740	1117	733	<5	9631
Bt2	17	28897	18100	877	560	<5	5918
Bt3	20	24857	18508	724	862	<5	5839
Bt4	20	23220	17653	647	936	<5	4916
2Bt5	19	23292	11863	450	1542	<5	918
2Bt6	18	24390	11255	450	753	<5	799
2Bt7	19	13620	3646	212	123	<5	364
2Bt8	21	13510	3780	213	123	<5	89
2Bt9	25	12880	2186	162	167	<5	95
2C	24	10010	795	127	136	<5	251
--	23	8192	<400	77	112	<5	53
--	31	13835	1388	430	103	<5	7359
--	6	3220	650	340	61	<5	6834
--	5	2301	694	377	59	<5	7891
--	7	7317	601	65	31	<5	<10
--	3	3855	404	34	19	<5	16
--	3	1745	<400	10	13	<5	16
--	6	5982	569	54	20	<5	<10
--	7	5055	<400	46	27	<5	<10

(continued...) Total elemental concentrations for Fayette County pedon.

Horizon	Ni	P	Pb	S	Si	Sr	Ti
	.....	.....	.....	mg/kg	.....	.....	.....
Ap	11	273	<25	50	246600	77	2122
Bt1	15	472	<25	119	345125	83	2323
Bt2	16	308	<25	<80	215250	82	2260
Bt3	6	238	<25	<80	289650	89	2363
Bt4	31	178	<25	<80	131325	79	2286
2Bt5	29	80	<25	<80	147500	43	2153
2Bt6	15	181	<25	<80	329375	43	2208
2Bt7	14	74	<25	<80	243250	<1	1121
2Bt8	17	<60	<25	<80	155100	<1	1122
2Bt9	16	<60	<25	<80	154200	<1	830
2C	22	<60	<25	<80	172975	<1	674
--	16	<60	<25	<80	320275	<1	312
--	16	84	<25	<80	240375	28	662
--	<10	<60	<25	<80	219075	<1	453
--	<10	<60	<25	<80	206275	<1	521
--	<10	63	<25	<80	239125	<1	845
--	<10	<60	<25	<80	218475	<1	1116
--	<10	<60	<25	<80	201925	<1	341
--	<10	60	<25	<80	344050	<1	652
--	<10	<60	<25	<80	223150	<1	1108

Horizon	Zn	Zr
	..mg/kg..	
Ap	38	126
Bt1	70	146
Bt2	80	119
Bt3	64	121
Bt4	43	113
2Bt5	70	95
2Bt6	77	111
2Bt7	11	66
2Bt8	17	44
2Bt9	13	31
2C	6	14
--	<4	11
--	10	20
--	6	12
--	8	12
--	<4	13
--	10	42
--	<4	26
--	18	19
--	9	26

VITA

VITA

Andrew O. Gallagher was born on May 2, 1961 in Winchester, Tennessee, to Mr. and Mrs. Burnie Gene Gallagher. He completed elementary and middle school at Good Shepherd Parochial School. Upon graduation from Franklin County High School in 1979, he attended Motlow State Community College in Tullahoma, Tennessee. He graduated from Motlow in 1982 with an Associate of Science Degree. In 1983, he entered the College of Engineering at Tennessee Technological University. During his studies at Tennessee Tech, he developed an interest in soils and physical sciences, and entered a major in the School of Agriculture. While at Tennessee Tech, he was active in the agronomy club, serving a term as treasurer. He was a member of the Collegiate Soil Judging team for two years, and was inducted into the Delta Tau Alpha agriculture honor society in 1985. He received his B.S. in Agriculture from Tennessee Tech University in 1986, with a major in plant and soil science and a minor in biology.

From 1986 to 1991, he worked as a soil scientist for Dickson County, Tennessee Soil Conservation District and with the USDA-Soil Conservation Service. In the fall of 1991 he entered the Institute of Agriculture at the University of Tennessee, Knoxville to pursue a Masters Degree in Plant and Soil Science. He is a present member of

Gamma Sigma Delta honor society, and a member of the Soil Scientist's Association of Tennessee. He was married in December, 1992, to Teri L. Tramel. Upon completion of the M.S. degree, the author will pursue a career as an Environmental Soil Scientist in private industry.

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