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Soil genesis and classification of brown iron ore spoils on the western highland rim in Tennessee

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To the Graduate Council:

I am submitting herewith a thesis written by Sonja Entrekin Gaither entitled "Soil genesis and classification of brown iron ore spoils on the western highland rim in Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

John T. Ammons, Major Professor

We have read this thesis and recommend its acceptance:

M.E. Essington, V.H. Reich

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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John T. Ammons, Major Professor

We have read this thesis and
recommend its acceptance:

Michael

Vernon H Reich

Accepted for the Council:

C W Minkel
Associate Vice Chancellor and
Dean of The Graduate School

SOIL GENESIS AND CLASSIFICATION OF BROWN IRON ORE SPOILS ON THE WESTERN HIGHLAND RIM IN TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Sonja E. Gaither

December, 1995

DEDICATION

This thesis is dedicated to Shane E. Gaither, my husband, my better half. Without his ceaseless love, patience, support, and computer skills it would not have been possible. If we were able to endure and enjoy graduate school simultaneously, then our future together is sure to be bright. Sharing life with you is the best blessing I could ever have and I thank the Lord for you everyday.

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ABSTRACT

A pedologic investigation was conducted on the Western Highland Rim in Tennessee on 140-170 year old brown iron ore spoils. The ore had formed in pockets at the interface between Mississippian Limestone and the overlying Cretaceous sands and gravels.

The objectives of this study were to 1) assess soil development on brown iron ore spoils; 2) compare properties in spoils to those in adjacent undisturbed soils; and 3) classify the spoils using *Soil Taxonomy* and the West Virginia Minesoil Classification System.

Two minesoil profiles (spoils) and two soil profiles on adjacent undisturbed soils (native) were sampled and described according to National Cooperative Soil Survey Standards. Total carbon, free iron, total elemental analysis, pH, exchangeable bases, cation exchange capacity, and exchangeable acidity were selected for laboratory chemical analysis. Variances of selected chemical properties were compared between sites using a grid sampling design and Hartley's test for homogeneity of variances.

Differences in origin of overburden material and the degree of weathering prior to disturbance accounted for morphological and chemical differences between the spoils. Spoil 1 had developed a cambic horizon and spoil 2 had not developed a diagnostic subsurface horizon. Bridging voids were observed in both spoils but not in the native soils. The spoils were enriched with iron oxides due to their association with the iron ore mining. Clay free ratios of fine sand to total sand plus silt [fs:(ts + si)] and titanium to zirconium (Ti/Zr) ratios consistently identified either differences between horizons and/or lithologic discontinuities of parent material designated by field morphology for all study sites.

Variations for total carbon, total aluminum, barium, manganese, phosphorus, titanium, and zirconium between 40-60 cm were not consistently significantly different between spoils and the native pedons at a 0.05 alpha level.

Properties defined for the Spolent suborder, of the West Virginia Minesoil Classification System, better described the spoil properties than Soil Taxonomy. Spoil 1 classified as a clayey, mixed, acid thermic Cherty Udispolept and spoil 2 classified as a clayey-skeletal, mixed, acid, thermic Cherty Udispolent using a slight modification of the West Virginia Minesoil Classification system.

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CHAPTER 1

A BRIEF HISTORY OF THE IRON ORE INDUSTRY ON THE WESTERN HIGHLAND RIM DURING THE 1800'S

Description of Tennessee's Western Highland Rim

The Highland Rim physiographic region constitutes the largest natural physiographic division in Tennessee (Fig. 1). The region is divided into Western and Eastern sections, encompasses approximately 9,300 mi^2 , and equals almost 22% of the state (Safford, 1869). Although referred to as broad and flat, the Highland Rim is actually slightly rolling and dissected by streams and valleys. Originally part of the Nashville Dome, the Highland Rim is the only portion of the Dome remaining relatively intact. Geologic uplift has occurred as indicated by the prevailing dip of the geologic beds and the higher elevations of the Highland Rim compared to the Central Basin (Safford, 1869). Subsequently, the Central Basin is believed to have formed at the center of the Dome where weakened areas eroded. Topographically, the area now resembles a shallow plate with a broad flat rim (Highland Rim) surrounding the center depression (Central Basin).

Most of the Western Highland Rim's uppermost geology is of Mississippian age, but some is of Ordovician age (Hershey and Maher, 1963). Thin quaternary-aged loess, Upper Cretaceous gravel, sand, clay, and

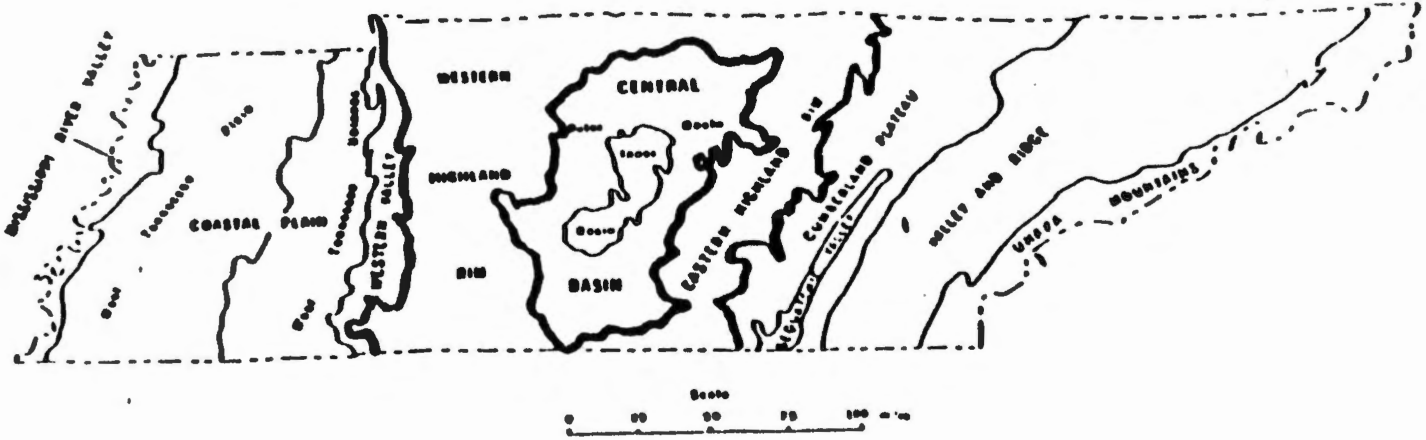


Figure 1. Physiographic map of Tennessee (Smith et al., 1988).

ferruginous conglomerate non-uniformly overlie these geologic units (Burchard, 1934; Springer and Elder, 1980) (Fig. 2). Loess is windblown material generally consisting of silt size particles and a small percentage of clay (Buol et al., 1980). Some loess deposits in Tennessee have been geologically linked to glacial floodplain origin (Springer and Elder, 1980; Livingston, 1993). The sequence of Mississippian geologic formations include St. Louis Limestone, Warsaw Limestone, Fort Payne Formation, and Chattanooga Shale (Hardeman, 1966). St. Louis Limestone, the youngest of the four, consists of coarse grained, gray crossbedded limestone and is somewhat shaley in the northeast. A karst topography is common on this formation (Hershey and Maher, 1963). Warsaw Limestone is similar but differs in thickness and is more fossiliferous (Hardeman, 1966). The Fort Payne formation is composed of bedded chert, calcareous and dolomitic silicastone, minor limestones and shale, scattered lenses of crinoidal limestone, and thin green shale at the base. Chattanooga Shale consists of carbonaceous shale (Hardeman, 1966). Some geologists consider it to be of Devonian age. Ordovician formations such as the Richmond Group and Nashville Group underlie the Chattanooga Shale. The Chattanooga Shale occurs between the Mississippian formations and Ordovician formations and marks the transition between the Highland Rim and the Central Basin.

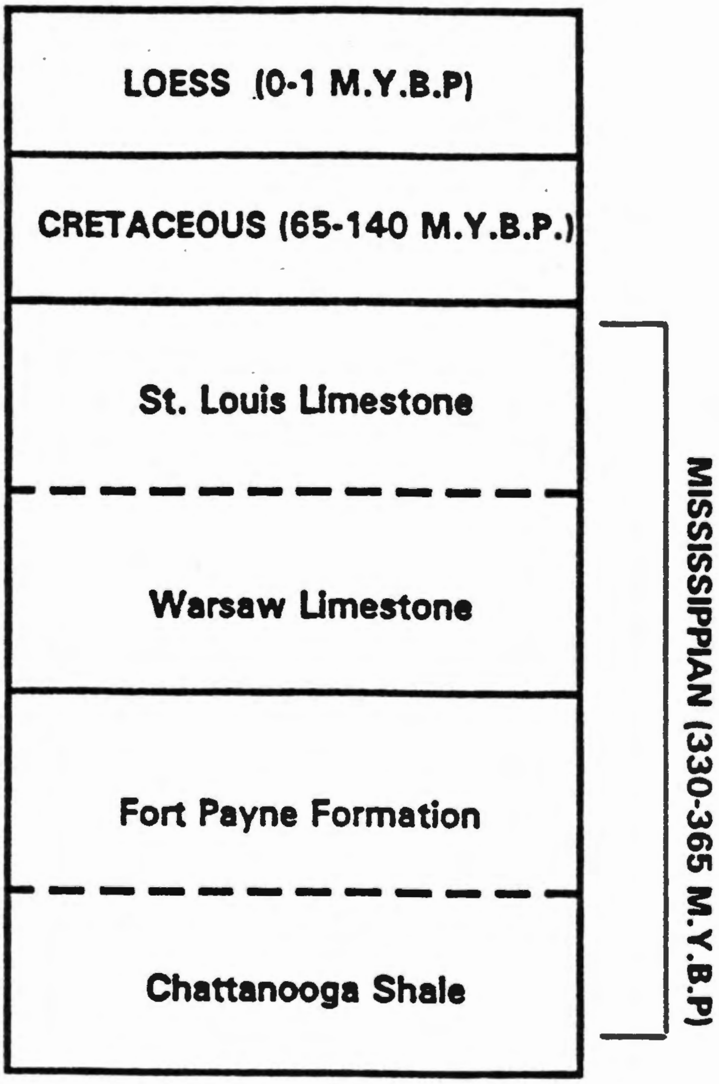


Figure 2. General geologic cross section of Tennessee's Western Highland Rim physiographic region.

Western Highland Rim's Iron Ore Resources

Iron ore is found in almost every state in the United States (Klinger, 1975). The commercially valuable sources of iron ore, deposits of coking coal, and ironmaking centers throughout the United States are shown in Figure 3 (adapted from Klinger, 1975). Tennessee's iron ore resources occur in four major divisions denoted as the Eastern, Dyestone, Cumberland Tableland, and the Western regions (Safford, 1856). The Western region occupies a strip from Kentucky through the Western Highland Rim of Tennessee into Alabama. The Western ore region includes the following counties of which the first seven listed are considered to contain the largest ore deposits: Montgomery, Stewart, Dickson, Hickman, Lewis, Wayne, Lawrence, Humphreys, Hardin, Perry, Houston, Benton, and Decatur (Burchard, 1934). The ore belt in this region averages between 15-40 miles in width and extends north to south, passing vertically through the Western Highland Rim (Safford, 1856; Burchard, 1934)(Fig. 4). The Western region covers an estimated 5,400 mi^2.

Iron Oxides and Ore Formation

Iron is the fourth most abundant element in the earth's crust and soils. Only oxygen, silicon, and aluminum are more abundant. It occurs predominantly in crystal structures as divalent ferrous iron (Fe^{2+}) or trivalent ferric iron (Fe^{3+}) (Merkle, 1955; Hem, 1972; Subcommittee, 1979). Iron enters readily into

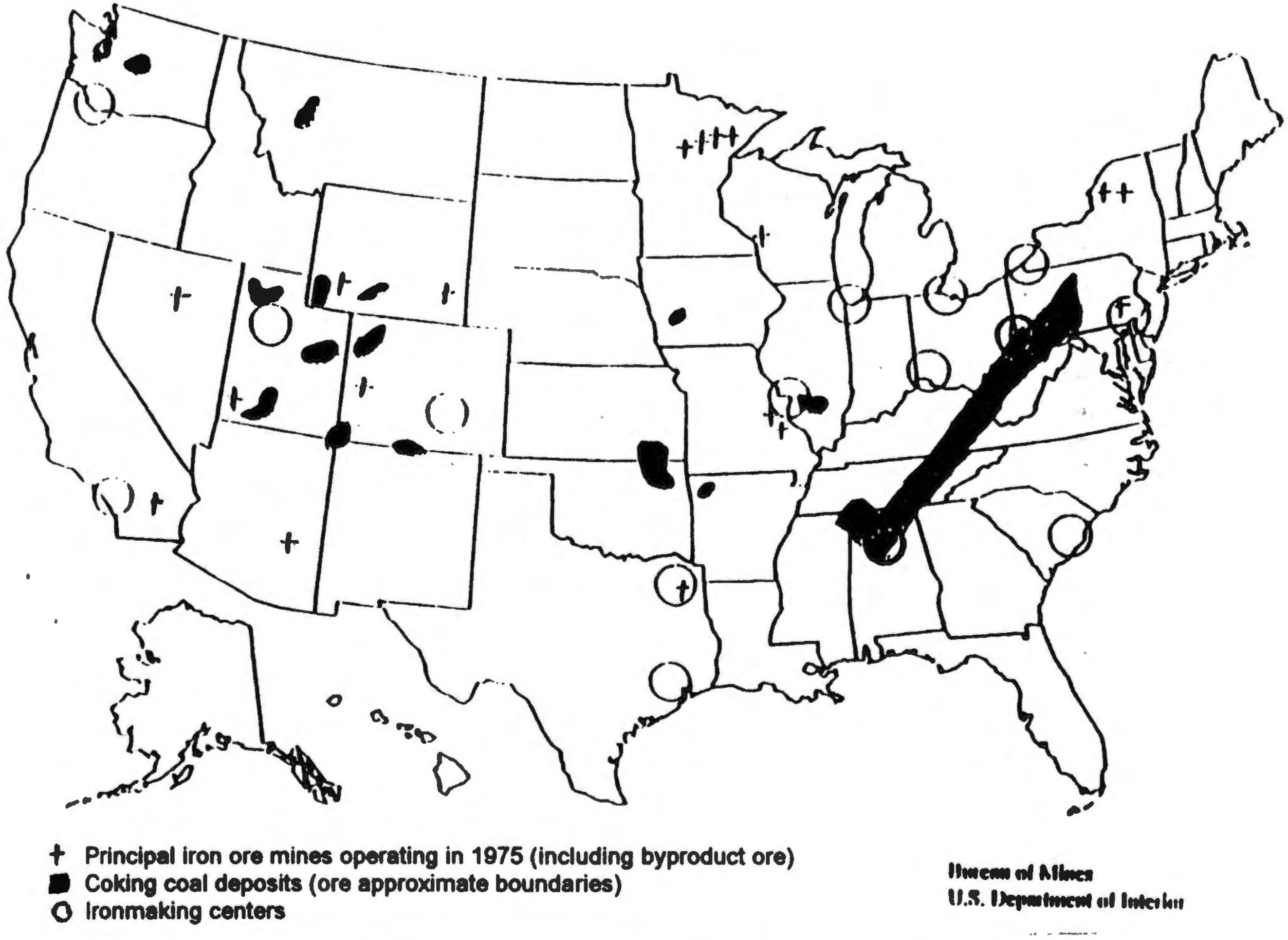


Figure 3. Sources of iron ore, deposits of coking coal, and ironmaking centers of the United States (modified from Klinger, 1975).

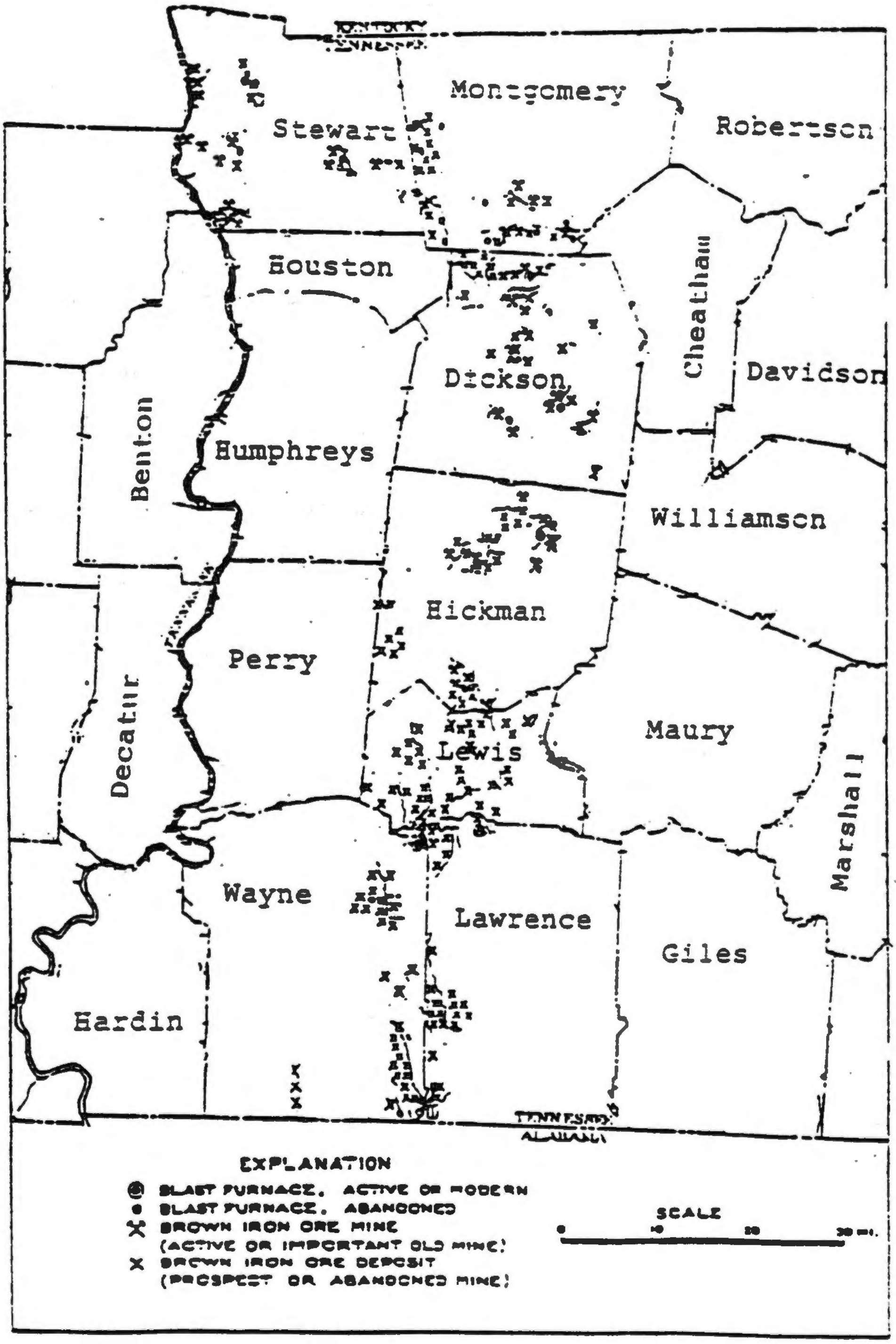


Figure 4. Map of the iron ore deposits, quarries, and blast furnaces on the Western Highland Rim in Tennessee (modified from Burchard, 1934).

hydration, complexation, and oxidation-reduction reactions (Sposito, 1989). Common forms of iron in soils include inorganic and organic ferric/ferrous complexes and ferric oxides (Subcommittee, 1979; McBride, 1994). Oxide is used as a collective term for oxides, hydroxides, and oxyhydroxides.

According to Schwertmann and Taylor (1977), iron is bound in primary minerals in the divalent state. Ferrous iron is released during the hydrolytic and oxidative weathering of iron-bearing primary minerals. Oxygen present in the soil oxidizes ferrous iron. A small portion of the resulting ferric iron will be incorporated into silicate clay minerals and/or complexed by organic matter. Most of the ferric iron will be precipitated as an oxide, hydroxide, or oxyhydroxide (McBride, 1994).

The iron minerals in the Western Highland Rim's iron ore includes a combination of ferric oxides. Most of the ore consisted of limonite, hematite (α-Fe_2O_3), and magnetite (Fe_3O_4) (Burchard, 1934). Although limonite is now a generic term, it was used to describe a variable composition of mostly fine grained goethite (α-FeOOH) and other forms, such as lepidocrocite (γ-FeOOH) (Schwertmann and Taylor, 1977). These forms share a basic crystalline octahedron structural unit of 6 O^{2-} and/or OH^- ions surrounding an Fe atom (McBride, 1994). Various oxides result from different packing arrangements of the octahedrons. A hexagonal type packing is referred to as the "α" form and cubic close packing is referred to as the "γ" form. Magnetite and maghemite have some tetrahedrally coordinated Fe sheets (Schwertmann and Taylor, 1977).

Iron oxides and organic matter are the most important pigmenting agents determining soil color (Buol et al., 1980). Organic matter contributes dark colors and iron oxides pigment from yellow to brown to red. If goethite is the dominant iron oxide present in the soil, the color will be a yellowish brown. A low concentration of hematite pigments the soil a reddish to brown color. A 5YR soil color is common with the abundant presence of hematite (Schwertmann, 1985).

In the U.S., most iron ores mined are from sedimentary formations (Subcommittee, 1979). Tennessee's Western Highland Rim iron ore is believed to have formed during the Tertiary period. Glauconitic sand beds, of Upper Cretaceous age, are postulated to have been the source of iron (Burchard, 1934). Theoretically, iron moved readily through the sand layers, precipitated as iron oxides, and accumulated as ore at the interface of cherty portions of underlying limestone (Safford, 1856; Killebrew, 1874). The ore was deposited in irregular pockets, veins, or banks of variable size and was commonly located on ridge crests in zones of clay and cherty masses. This depositional pattern may reflect areas of the limestone that had formed sink holes or areas of preferential water flow. Depth to the ore deposits varied between 30 and 100ft parallel to the surface. This was shallow enough for the ore to be mined in shallow open mine pits. Ore thickness varied and ranged from 1ft to 200ft (Safford, 1856; Killebrew, 1874; Burchard, 1934).

The Western Highland Rim iron ore contained many impurities because of associated chert, clay, gravel, and sand. Chemical impurities typically included phosphorus, silica, aluminum, and manganese. The average overall water content of the ore was between 10-12% (Burchard, 1934). Quantity and composition of impurities in the ore varied as much as ore thickness and location from the surface. Most records agree that the percent pure metallic iron recovered from the ore used in the blast furnaces averaged between 38-52% (Burchard 1934; Smith et al., 1988).

Origin of the Western Highland Rim Iron Ore Industry

The iron industry on the Western Highland Rim of Tennessee originated at the Cumberland Furnace in Dickson County in 1797. This site is recognized as the first place where iron ore was removed and processed west of the Cumberland Mountains. The furnace supplied cannon balls to General Jackson during the Battle of New Orleans (Burchard, 1934).

Montgomery Bell, a young Scotch-Irishman from Pennsylvania, bought the Cumberland Furnace from James Robertson in 1804 and increased its production by several hundred percent (Corlew, 1956). He is credited for quickly expanding the iron ore industry to neighboring counties. He is also famous for his engineering achievement of excavating a 300-ft tunnel through solid limestone to divert the Harpeth River to supply water power for the Patterson Forge (Smith et al., 1988). The tunnel is presently a highly visited historical site known as the "Narrows of Harpeth" in Cheatham County. Although Bell was known as a "shrewd exacting trader," he is remembered as a man of great enterprise that brought economic growth to this area.

In the 1800's, iron was called the "king of metals." Hardware and building materials such as mechanical tools, military weapons, sheathing for ships, railway tracks, electrical phone wires, and magnetic compasses were all iron products critical for infrastructure and enhanced technology (Safford and Killebrew, 1900). The westward movement of frontier settlers and an increased state population in Tennessee created a strong demand for these iron products. In 1809, Tennessee legislation encouraged iron industry development by offering 3,000 acre grants exempt from taxation for 99 years to proprietors who could build and operate an ironworks system within two years (Smith et al., 1988). North Carolina had enacted similar legislation in 1788, known as "An Act to Encourage the Building of Iron Works," from which the Tennessee law was modeled. Together, the frontier demand and the ironworks legislation promoted the growth of the industry in this area.

Classes of Iron Products

Cast iron, pig iron, and wrought iron were the three general classes of iron products made. Cast and pig iron required blast furnaces and were used for making most iron products (Safford and Killebrew, 1900). The cold-blast charcoal furnace was the principal type furnace used to make these products in the southern pre-Civil War iron industry (Smith et al., 1988). The Western Highland Rim iron ore industry produced mostly pig iron. By 1854, peak productions of 37,283 tons of pig iron and castings by 31 furnaces were recorded for this area (Burchard, 1934). Over time, the industry became more efficient. By 1874, 11 furnaces produced over 50,000 tons, and by 1881 a furnace built at that time could produce more pig iron than all 31 furnaces in 1854 (Killebrew, 1881; Burchard, 1934). Today, most of these furnaces and forges have been abandoned and are merely historical reminders of the great "iron industry."

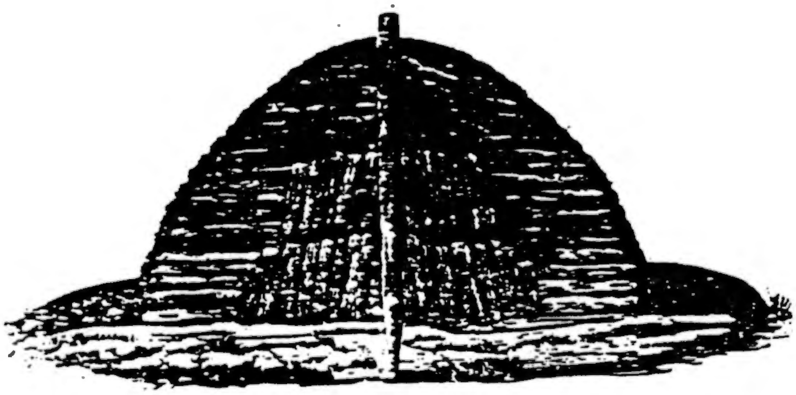
Materials Needed to Produce Pig Iron

The iron ore industrial boom was supported by a number of conditions. A successful iron industry required sizable estates with a large labor force, large tracts of timber, convenient access to limestone, railway transportation (if not proximate to major rivers), and other raw materials. This region had all of this in great abundance. A large labor force was needed because the ore was mined manually using standard tools of picks and shovels, with some horse-drawn plows and scrapers (Smith et al., 1988). Slaves made up a large portion of the labor force (Corlew, 1956).

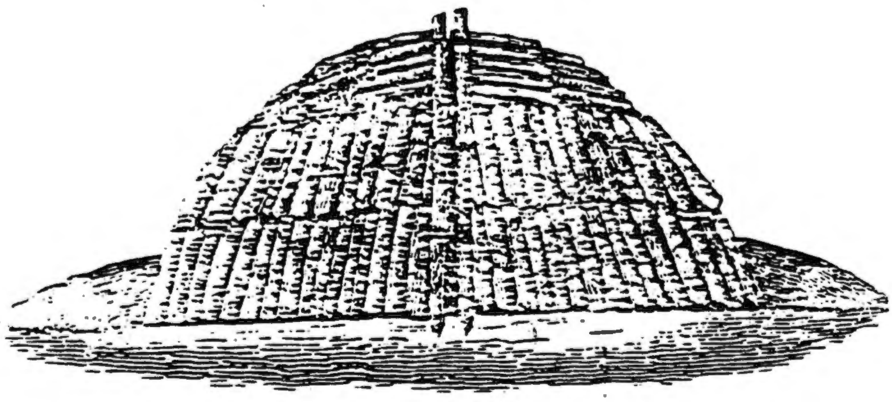
Timber was important for making charcoal to fuel the furnaces. Importing timber from long distances would not have been economically feasible, so furnaces were located near a sufficient timber source. Overman (1850) provides a diagram of how the kilns were built to char wood for making charcoal (Fig. 5) (Smith et al., 1988). Hardwoods were the preferable timber source. Killebrew (1874) was concerned with the timber source depletion of this area due to the iron industry. He stated that by the 1870's, forests had been totally cleared within a 3 to 4 mile radius of furnaces and were susceptible to repeated burning which stunted regrowth potential.

Limestone was required for the smelting process to promote separation of iron from its oxides by lowering their melting temperatures. Clay and chert were also used as a flux, but limestone was the most common. Records of the railroads in the area of the mines for this region indicated that the Louisville & Nashville Railroad (L & NR) and the Nashville, Chattanooga & St. Louis Railway (N C & St. LR) were probably the railways used for transporting the ore and other raw materials at that time (Burchard, 1934). The Cumberland River and Tennessee River were also used for transport.

Debris was removed from the ore by treatments such as washing, screening, and jigging (using a tumbler). The ore was then ready to be processed (smelted) in the furnace. The average smelting process to make pig iron used about 800 lbs (363 kg) of cleaned ore to 80 lbs (36 kg) crushed



Section of a charcoal work-piling the wood



Setting the wood for charring

Making charcoal in heaps

Figure 5. Stages in preparing charcoal from wood in a kiln (Overman, 1850; Smith et al., 1988).

limestone to 20 bu charcoal about every 20 minutes (Corlew, 1956; Safford and Killebrew, 1900). Furnace temperatures reached as high as 1,927 °C (3,500 °F) which reduced the ore and transformed limestone ($CaCO_3$) into lime (CaO). The lime bonded with impurities of the ore and formed a glass-like material called slag. Iron ore containing fewer impurities required less limestone as a flux. Slag floated on top of the molten iron, because of its lower density. The slag was periodically removed (using cinder hooks), then broken into smaller pieces, and discarded near the furnace. Much of the slag can still be found near remnants of furnaces. Slag varied in color depending on impurities in the ore (Smith et al., 1988). Sky blue slag indicated the presence of manganese while gray slag indicated high grade iron, rich in carbon.

During the 1800's, furnace operations were described as the focal point for a multitude of activities. Bining (1938) described the Pennsylvania iron operations as "feudal manors of medieval Europe" (Smith et al., 1988). This model is believed to also represent the Western Highland Rim's operation as late as the early 1860's. These plantation settings included a mansion house, homes for the workers, a charcoal house, a gristmill, a sawmill, and a blacksmith shop (Smith et al., 1988).

The advantages of producing pig iron in Tennessee during the 1800's were attributed to considerably lower timber costs and taxes compared to northern iron producing areas such as Ohio and Pennsylvania (Killebrew, 1874).

These advantages surpassed the disadvantages of higher labor costs and less feasible access to major river systems. By the early to mid 1900's, changes in technology, fuel source, and the economy in general, left Tennessee unable to compete on a large scale with other iron producing regions. Today areas such as the Great Lakes and other Northern regions are the leading miners of iron ore and producers of iron alloys such as steel.

Importance of such a study

Soil chemical and physical analysis can help clarify soil profile genesis and soil development. Characterization of the properties of minesoils is needed so that minesoils can be better managed and better decisions can be made for their profitable return under field crops, pasture, or woodland.

Soils disturbed during iron mining operations on the Western Highland Rim in the 1800's were not reclaimed. They offer an opportunity to study natural soil development from a known date of disturbance. Information gained from studying these minesoils may contribute to understanding immediate and long-term effects mining activities have on soil properties.

CHAPTER 2

SOIL GENESIS AND CLASSIFICATION OF BROWN IRON ORE SPOILS ON THE WESTERN HIGHLAND RIM IN TENNESSEE

Introduction

Soils are "the natural bodies, made up of mineral and organic materials,... and have in places been changed by human activity " (Soil Survey Staff, 1975). Although the definition of soil includes the influence of man, soils disturbed by human activities have often been misperceived as being inferior to those undisturbed. During various mining activities, i.e. surface mining for coal, clay, iron, etc., soils and geologic materials are removed, mixed, and redeposited. Catastrophic events in nature such as landslides, ice advances, tornadoes, and earthquakes cause similar changes. When man or nature disrupts soil forming processes, the pedogenic clock is reset to time zero. Conditions are then created for the formation of new soils which may or may not resemble the contiguous native soils.

Soils formed on mined land often have different properties, unique to disturbed soils, than contiguous undisturbed soils. The current *Soil Taxonomy* system used for soil mapping usually does not adequately identify soils disturbed by mining. Adopting a minesoil classification method within the *Soil Taxonomy* system should reduce mapping and land use interpretation problems often associated with mined-lands. Identifying distinguishing morphological and/or chemical properties common in minesoils, but not in undisturbed soils, is critical to develop appropriate criteria for such a classification system.

The brown iron ore spoils on the Western Highland Rim in Tennessee, resulting from iron mining in the 1800's, offered an opportunity to study soil genesis from a known date of disturbance to the present. The objectives of this study were to 1) assess soil development on 140-170 year old brown iron ore spoils; 2) compare properties in the spoils to those in adjacent undisturbed soils; and 3) classify the spoils using *Soil Taxonomy* and the West Virginia Minesoil Classification System (Ammons and Sencindiver, 1990).

Review of Literature

Definition of Soil

Soil is a natural body of mineral and organic material formed from the action and interactions of climate (cl), organism (o), parent material (p), topography/relief (r), and time (t) (Jenny, 1941). Variations of interpretations of this definition have evolved depending on specific interests of soil use (e.g. a growth medium or an engineering substrate). All approaches recognize that soils differ by measurable chemical, physical, and mineralogical characteristics. The science of studying the factors of soil genesis and resulting properties is termed the science of pedology. Pedology is derived from the greek words for pedon ‘ground’ and logos ‘science.’ Buol et al. (1980) divides pedology into two groups as 1) soil genesis and 2) soil classification. Soil genesis studies the factors and processes responsible for forming soils. Soil classification is the use of a nomenclature system that groups soils by similarity of properties and land use interpretations.

Soil Genesis and the Pedogenic Processes

Pedogenic processes are those which alter a soil's chemical, physical, and mineralogical properties. They include additions and subtractions of a soil's organic and mineral materials (in the form of solids, liquids, and gases), translocations, and transformations of such materials within the soil (Simonson, 1959; Buol et al., 1980). Terms used to delineate the different pedogenic processes are given in Table 1. These processes either form or alter soil material and the resulting soil profile reflects the balance of these processes (Simonson, 1959). Buol et al. (1980) contends that pedogenic processes are the actual building materials responsible for soil formation, and the soil forming factors set limits and directions on those processes.

Vegetation litter accounts for most of the added organic materials to soils (Simonson et al., 1952). Additions of mineral material occur most often to soils in a receiving landscape position such as a footslope, floodplain, or to those in close proximity of volcanic ash deposits. Surface erosion and the leaching of materials through a soil profile result in net losses. Transformations occur during weathering of minerals, formation of secondary minerals, and formation of

Table 1. List of soil pedogenic processes in terms of inputs, outputs, translocations, and transformations of organic and mineral material (modified from Buol et al, 1980).*

Additions	Losses	Translocation	Transformation
Cumulization	Leaching	Eluviation	Decomposition
Melanization	Erosion	Illuviation	Synthesis
Littering		Decalcification	Humification
Enrichment		Calcification	Paludization
		Salinization	Ripening
		Desalinization	Mineralization
		Alkalization	Loosening
		Dealkalization	Hardening
		Lessivage	Rubification
		Pedoturbation	
		Podzolization	Podzolization
		Desilication	Desilication
		Melanization	
		Leucinization	
		Braunification	Braunification
		Gleization	Gleization

* Definition of terms are given in appendix C.

organic compounds from decomposing organic matter. Products of transformations would include humus, clays, metal oxides, and soluble ions such as $H_4SiO^0_4$, etc. (Barshad, 1955; Buol et al., 1980). Translocations involve the movement of ions and substances with the soil's water. The soluble substances may precipitate out of solution with changes in soil chemical conditions (Birkeland, 1984). Eluviation and illuviation are the forms of translocations (Buol et al., 1980). Both terms are usually discussed in relation to a horizon, a layer approximately parallel to the soil surface that is distinguishable from adjacent layers by a set of properties derived from soil forming processes (Soil Survey Staff, 1993a). Material is either mobilized and translocated out of a horizon, (eluviated) or it is moved into and immobilized in a horizon (illuviated). Translocation occurs vertically and horizontally. In reference to horizon development, translocation is typically discussed in terms of vertical movement.

There are five master horizons recognized for soil descriptions. They are designated as O, A, E, B, and C. The E horizon is formed by intense eluviation, and the B horizon is a subsurface horizon in which intense illuviation has occurred. The type of material illuviated determines a subordinate distinction within the B horizon (Buol et al., 1980; Soil Survey Staff, 1993a). For example, if silicate clays are dominantly accumulated in the B horizon its subordinate distinction would be a lower case t. The horizon would then be termed argillic and designated as a Bt horizon.

Soil Forming Factors

Organisms

Organisms are one factor influencing soil formation and include vegetation, animals, and microbial activities. Of these, vegetation influences the rate and direction of soil formation the most (Simonson et al., 1952). Byproducts of litter decomposition include ions, elements, and solid particles that may or may not further react in the soil to form other byproducts. These products influence properties such as cation exchange capacity, base saturation, soil structure, and water holding capacity (Brady, 1990). The influence of leaf litter composition and root types differ according to plant species. Vegetation is usually grouped into three categories which include grasses, deciduous forests, and coniferous forests. In general, grasses favor higher accumulation of organic matter which gives the soil higher water holding capacity, darker color, and an increased cation exchange capacity than that observed in forest soils (Simonson et al., 1952; Brady, 1990).

Climate

Precipitation and temperature are the features of climate most often correlated to soil properties (Jenny 1941; Buol et al., 1980). Water in soil is necessary for plant growth, dissolving or altering primary minerals, and transporting material from one region of the soil to another (Buol et al., 1980; McBride, 1994). When water freezes in the soil, it physically ruptures materials, increasing the surface area available for chemical reactions. Temperature influences the type and rate of chemical reactions. Chemical reaction rates are approximately doubled for every 10° C rise in temperature (Brady, 1990). Soils exposed to higher temperatures, e.g. near the equator, weather faster than those in cooler temperatures, e.g. near the polar regions.

Topography

Topography is considered the shape of the land surface on which a soil develops (Buol et al., 1980; Brady, 1990). In general, topography influences the type of parent material exposed to the weathering zone, soil drainage ability, potential thickness of a soil profile, vegetation, and organic matter content. Elevation and gradient (relief) are the terms used to describe topography. They are measured in feet (or meters) above mean sea level and degrees of slope (angle of surface), respectively (Brady, 1990). The amount of energy from the sun reaching a soil is largely determined by elevation and aspect. Surface relief can slow or speed effects of climatic forces on soil development (Joffe, 1949). Soils on steeper slopes are more likely to have thinner profile's.

Time

The amount of time elapsed after soil materials have been subjected to weathering greatly influence the degree of soil development. Marbut (1951) referred to soil development in two basic stages as mature or immature. When pedogenic characteristics of a soil dominate over the original characteristics of the parent material, the soil is referred to as mature. Marbut emphasized that "mature" does not imply the soil has reached an endpoint. Changes may take place thereafter, but they are much slower and of a lesser magnitude. Soils may share similar characteristics at different stages of maturation, but the characteristics will be more developed in the more mature soil (Marbut, 1951). Soils, such as those formed on sideslopes, may remain relatively immature regardless of time because surface erosion rates tend to exceed the rate of soil formation (Buol et al., 1980). Poor drainage can also cause a soil to remain immature through time (Marbut, 1951).

Parent material

Parent material refers to the mineral and organic material from which soils develop. Variability of their mineral composition stems from the different possible combinations of some 70 to 80 elements (Marbut, 1951). The mineral composition influences soil pH which in turn influences base saturation, weathering rates, solubility of metals, etc.. The presence of calcite ($CaCO_3$) and dolomite [$CaMg(CO_3)_2$] in large concentrations of some rocks, such as limestone, raises soil pH and slows down acidification processes (Brady, 1990). Oxidation of minerals such as pyrite, FeS_2, increase soil acidity (McBride, 1994). Although parent material mineral composition greatly determines boundaries for potential soil chemical and mineralogical properties, it should not be considered as more important than any other soil forming factor. The Russian soil scientist credited for founding the concepts of soil genesis and mapping V.V. Dokuchaev, (1846 - 1903), reported that soils developed in the same type of parent material were not necessarily similar if they were influenced by different climatic conditions and/or different vegetation (Buol et al., 1980; Leet and Judson, 1965).

Soil forming factors and soil properties

Mathematical models have been developed to quantify the direct effect soil forming factors have on soil properties. Jenny's (1941) model attempted to predict the outcome of a soil property by defining it as a function of independent variables, the soil forming factors. This model is given as **s=*f* cl,o,r,p,t** where **s** represents any soil property such as clay content or organic matter content. It is doubtful that all the various influences soil forming factors have on soil properties could ever be dependably quantified (Barshad, 1955). The varying possibilities of interactions between the soil forming factors further complicates attempts to quantify direct influences. For the model to work as an equation, it would also have to be assumed that the factors have remained static with time.

Hans Jenny's model is still an extremely helpful qualitative conceptual tool. For example, if two soils are influenced by similar soil forming factors except "one" factor, then a difference in properties between them can be attributed to differences in that "one" factor. Relationships between each of the five soil forming factors and soil development have been repeatedly observed. The influence of landscape stability to horizon thickness is one such illustration.

Soils, in humid regions, tend to have thicker profiles on nearly level areas than on more sloping (Buol et al., 1980). There are numerous other associations of a soil forming factor to a soil property which hold true in most cases.

Soil properties can be measured using field and laboratory techniques. Soil color, structure, horizonization sequence and horizon thickness, water holding capacity, etc., are properties which can be described in the field. These features are determined by the amount and type of organic matter, amount and nature of clay minerals, amount and nature of metal oxides, the nature of exchangeable cations, particle-size distribution of fine earth (less than 2mm) fraction, concentration and type of elements present, etc.. Numerous laboratory techniques have been developed to measure chemical and physical properties of soils that can not be quantitatively determined using field techniques.

In general, clay and organic matter constitute the largest source of cation exchange capacity (CEC) in soil. In most cases, CEC has a positive correlation with clay and organic matter contents. Calcinai and Sequi (1977) studied the CEC of surface soils before and after peroxidation treatment. In 12 of the 14 samples studied, CEC decreased after peroxidation of organic matter. Calcinai and Sequi concluded that in the 2 of the 14 samples not showing an increase in CEC after peroxidation, the organic matter had been adsorbed on clay sites. Dissolution of the organic matter adsorbed on clay sites freed exchange sites. The characteristics of organic material in the presence of clay (and the type of clay) will determine if an increase in organic matter content will constitute an increase of CEC.

Clay-free ratios of sand fractions have been used to indicate parent material discontinuities in a soil profile (Timpson and Foss, 1992). Changes of clay-free ratios with soil depth are useful to identify changes in depositional energy of material in fluvial systems. Timpson and Foss (1992) recommend that clay-free ratio distribution used for pedological purposes be interpreted in the context of soil morphology.

Titanium to zirconium ratios can be used to determine parent material uniformity (Chapman and Horn, 1968; Hutton, 1977). Titanium and zirconium minerals are not considered plant nutrients and are very resistant to weathering. They undergo similar chemical reactions and are not easily leached (Hutton, 1977). These attributes make titanium and zirconium distribution in soils potentially valuable for soil development studies. A change in titanium to zirconium ratio with depth indicates a change in parent material continuity or origin or weathering stage (soil maturity). Some problems with using this ratio include determining what degree of change in the ratio value constitutes a discontinuity. The ratio value may also change with depth in a soil profile because of stratification differences within a rock formation and in material where intense eluviation has occurred (eg. an E horizon) (Chapman and Horn, 1968). To prevent misleading interpretations, titanium to zirconium distribution in a soil profile should be reviewed in the context of soil morphology.

Trace metals in a soil can be adsorbed onto clay minerals, organic matter, and complexed by residual organic compounds (Morris, 1994). Studies of soils in Roman and Native American archaeological sites found increased concentrations of trace elements such as Zn, Cu, Ni, Co, Cd, and Pb in surface horizons (Lewis et al., 1992). Elevated concentrations of extractable barium, manganese, and strontium have been found to be the most diagnostic for identifying buried surface soils (Lewis et al., 1992; Foss et al., 1990). Anthropogenic activities and biocycling effects of vegetation account for accumulation of such elements in the upper portions of soils (Foss et al., 1990). Organic material is generally more concentrated in the upper surface of soils which probably contributes to often observed higher retention levels of trace elements in surface horizons. Increased trace elements in a horizon suspected to be buried would strongly support the claim that it had once been a stable surface horizon.

Characteristics of Soils Disturbed by Mining

The terms minesoils, spoils, drastically disturbed soils, and anthropogenic soils refer to soils which have developed in material disturbed or exposed by human activities. Approximately 1.5 million ha of land in the U.S. were disturbed between 1930 and 1971 by surface and underground mining of materials such as coal, sand, clay, copper, iron, phosphate rock, etc.(Sopper, 1992; Paone et al., 1978). In Illinois alone, about 2000 ha of land were surface mined for coal annually in the 1980's (Indorante and Jansen, 1984).

In surface mining, soils overlying mined material are removed, disrupting the soil forming processes. The pedogenic clock is then reset to "time zero." Geologic material not previously in the weathering zone of soils are often exposed to surface or near surface conditions as a result of mining processes. Properties of relatively unweathered material exposed to surface conditions undergo rapid changes in a relatively short amount of time (Haering et al., 1993). The difference in characteristics of a disturbed soil from its pre-mined condition depend on several factors which include the type of equipment used for mining and reconstruction, the chemical composition of material exposed to/near the surface, the pre-weathered condition of the material prior to disturbance, site factors (i.e. slope, irregular topography, etc.), and the time since disturbance (Potter et al., 1988; Thurman and Sencindiver, 1986; Haering et al., 1993; Bell et al., 1994). Properties altered by the disturbance generally include soil horizonization, soil structure (affecting macroporosity and permeability), bulk density, coarse fragment concentration, uniformity in color and chemical properties of parent material, and hydraulic conductivity (Haering et al., 1993; Bell et al., 1994; McSweeney and Jansen, 1984; Ammons and Sencindiver, 1990; Potter et al., 1988; Indorante and Jansen, 1984).

Soil physical structure is one of the most important properties altered during the mining and reclamation processes because of its influence on the productivity potential of minesoils. Minesoil structure may show relics from its precursor, but it is mostly determined by the method of "construction" as opposed to pedogenic influences (McSweeney and Jansen, 1984;). The subsoil of newly constructed minesoils is usually massive and structureless (Haering et al., 1993; Bell et al., 1994). Moderate granular structure has been observed in the surface of minesoils within 1-2 years of disturbance (Bell et al., 1994).

McSweeney and Jansen (1984) observed soil and root patterns of reclaimed minesoils of mixed paleoloess and till origin in Illinois. They described a structure in the subsoil unique to "man-made" soils and proposed it be termed "fritted." Fritted was used to describe rounded aggregates which were loosely compressed together and similar to the size classes in *Soil Taxonomy* for blocklike and polyhedral aggregates. The organization of such structures left void spaces up to 0.02 m in width and with extensive continuity. McSweeney and Jansen observed differences in the occurrence of fritted and massive structure in relation to two types of mining operations. Methods using a mining wheel in combination with a belt for transportation favored fritted structure compared to using scrapers which resulted mostly in massive structure. Fritted structure was good for rooting proliferation and more desirable in terms of root growth compared to massive structure. McSweeney and Jansen recommended that soil structural conditions in minesoils be adequately described and, where appropriate, be used to separate soils at the series level of classification.

A study of 1 to 2 year old reconstructed prime farmland soils in western Pennsylvania also indicated that soil structure had been drastically altered to a structureless and massive condition which influenced root penetration ability (Bell et al., 1994). In 57 of the 72 (79%) profiles studied, root restrictive layers occurred within 1 meter from the surface and within 50 cm of 51% of the studied profiles. A limiting horizon was observed to be caused by soil compaction and coarse fragment concentrations greater than 50%. Subsoil was compacted by mining equipment during soil replacement operations. Scrapers had been used during reclamation of the mined-land. Bell et al. (1994) suggested morphologic examinations of horizon thickness and depth to a limiting horizon be used to evaluate the success of reclaimed minesoils, in terms of potential agricultural productivity.

Bulk density is often greater in the surface and subsoil of disturbed soils compared to an equivalent undisturbed soil (Smith et al., 1971; Thurman and Sencindiver, 1986; Potter et al., 1988). Minesoils in two different partially-reclaimed contour surface coal mine sites in West Virginia had higher overall bulk densities and lower porosities than neighboring native soils (Thurman and Sencindiver, 1986). The minesoils also had lower water retention than the native soil in all horizons. Potter et al. (1988) found that 4-11 year old constructed minesoils had increased bulk density which disrupted macropore volume and continuity. Hydraulic conductivity in the surface and subsoil of these reclaimed soils was 25% and 10%, respectively, of that in the contiguous soils. Potter et al. (1988) also found that soil macroporosity and permeability was higher in the 11 year old constructed soils compared to the 4 year old constructed soils. The activity of roots and soil fauna creates macropores. The older constructed soil had been influenced by root channel development and microorganism activity for a longer period of time which was believed to account for the differences in macroporosity volume and permeability observed between the 4yr and 11yr old constructed soils.

A study of crop productivity on reconstructed minesoils, that were at least 90cm deep, achieved as much as 90% of maximum crop yield compared to their premine productivity (Power et al., 1981). Productivity decreased with decreasing thickness of the reconstructed soils. More than likely, the crop success reflects a response to a combination of soil properties equally as important as soil depth.

A study of 6 to 8 year old mine soils suggested that immediate properties, particularly pH and extractable Ca and Mg, and weathering rates of spoil material was strongly determined by the rock type dominating the overburden and the degree of in situ weathering of that material before disturbance (Haering et al., 1993). Subsoil differentiation was discernible in 5 years of development.

Minesoil Classification

Soils formed on mined land have different properties, often unique to disturbed soils, than contiguous native soils. The current *Soil Taxonomy* system used for soil mapping usually does not adequately identify soils disturbed by mining(Thurman and Sencindiver, 1986; Schafer, 1979; Schafer et al., 1980).

Properties of minesoils often vary more within a smaller area than undisturbed soils (Schafer, 1979; Indorante and Jansen, 1981). A study of variability of soil properties in minesoils versus undisturbed soils (natural) found a higher variability in the minesoils within a 0 - 10 m lateral spacing and often a lower variability on a large landscape scale of > 500 m lateral spacing (Schafer, 1979). Variation in landscape features was highly correlated with the variation of properties in the natural soils where variability of the minesoil properties were influenced by reclamation methods.

Most disturbed soils are typically classified into various families of Typic Udorthents (Ammons and Sencindiver, 1990). Schafer (1979) classified minesoils on 400ha of mined land and natural soils on 300-ha of undisturbed land using current *Soil Taxonomy.* Fourteen different family classifications occurred on the undisturbed land and 2 family classifications occurred on the minedland. Two family classifications did not adequately reflect the variation of properties within the minedland. These results reinforce the need for a revision of the current *Soil Taxonomy* to include minesoil classification. Minesoil series have been established in most of the states having large areas of mined land. Various mine-soil classification systems, which parallel the format of *Soil Taxonomy*, have been proposed but have not been officially incorporated into *Soil Taxonomy*.

In the 1970's, researchers at West Virginia University proposed a Minesoil Classification System that defined a new suborder termed Spolent (Sencindiver, 1977; Ammons and Sencindiver, 1990). In addition, subgroup modifiers to identify dominant rock type in the particle size control section were termed as Typic, Schlickig, Matric, Fissile, Carbolithic, Pyrolithic, Kalkig, Plattic, Schlickig, and Regolithic Plattic. Typic applies to Spolents containing two or more rock types with none dominating. Schlickig applies to separate subgroups dominated by mudstones, and Matric was established for Spolents having less than 10% coarse fragments. Fissile refers to the dominant rock type being thin bedded shale and Schlickig refers to non-fissile shale. Kalkig was used for limestone or calcareous mudstone. Plattic and Regolithic Plattic described different colored sandstone (gray and brown accordingly). The criteria established for the Spolent suborder required that at least three of the following properties be met:

1) color mottling not associated with horizonization
2) disordered coarse fragments
3) splintery or sharp edges on coarse fragments
4) presence of bridging voids between coarse fragments
5) thin surface horizon higher in fines
6) pockets of contrasting materials
7) presence of artifacts

8) carbolithic coarse fragments
9) irregular distribution of oxidizable carbon

Previous Iron Ore Spoil Investigation

Most of the disturbed soils research to date, has been conducted on coal minesoils. Research data on coal minesoil material are not usually applicable to iron ore spoils. Coal minesoils typically contain pyrite and sulfur compounds, which may cause acidity problems, that are not often associated with iron ore spoils.

Soil formation research on iron ore spoils was conducted at West Virginia University by Smith et al. (1971). Physical and chemical properties of six iron ore spoils between 70 to 130 years old and of adjacent native soils were studied. Results showed the native soils had higher nitrogen content, higher organic matter content, stronger aggregation, and higher infiltration capability for the upper 3 feet. Higher CEC was noted in the native soil only in the top one to two inches, but below that higher CEC and basic nutrient concentrations occurred in the spoils. Deeper and more abundant total rooting of forest trees was observed in the spoils. Bulk density averaged 70% higher for the spoils than the native soils. The pH ranges were not significantly different between the spoils and native soils.

Smith et al. (1971) suggested the young spoils were inferior for cultivation crops or perennials sensitive to nitrogen deficiencies but were equal or superior for permanent vegetation especially deep rooted legumes or trees with low nitrogen requirements. If sulfides and other acid conducive compounds were present in the spoils and exposed to near surface conditions, the immediate quality and long term potential of the spoil would likely be inferior to the natural soils.

Materials and Methods

Site Selection and History

The study sites were located in Montgomery Bell State Park, in Dickson County near the former Laurel Furnace (Fig. 6). The Laurel furnace was a steam cold-blast charcoal type furnace, operating between 1815 and the late 1850's, established by Richard C. Napier (Smith et al., 1988). A map of furnaces in Dickson county shows the general position of the Laurel Furnace in reference to the Cumberland Furnace, rivers, and railroads (Fig. 7). The ore mined for this furnace was referred to as mostly being limonite. Plate 1 and 2 are pictures taken of ore mined near the Cumberland Furnace and is representative of the open pit mines across the region (Burchard, 1934).

Montgomery Bell State Park, 1,532 ha (3,782 acres), was deeded to the Tennessee Department of Conservation in May, 1943 (Coleman, 1967). Today, it serves as a recreational retreat. Two lakes, Lake Woodhaven (22 ha) and

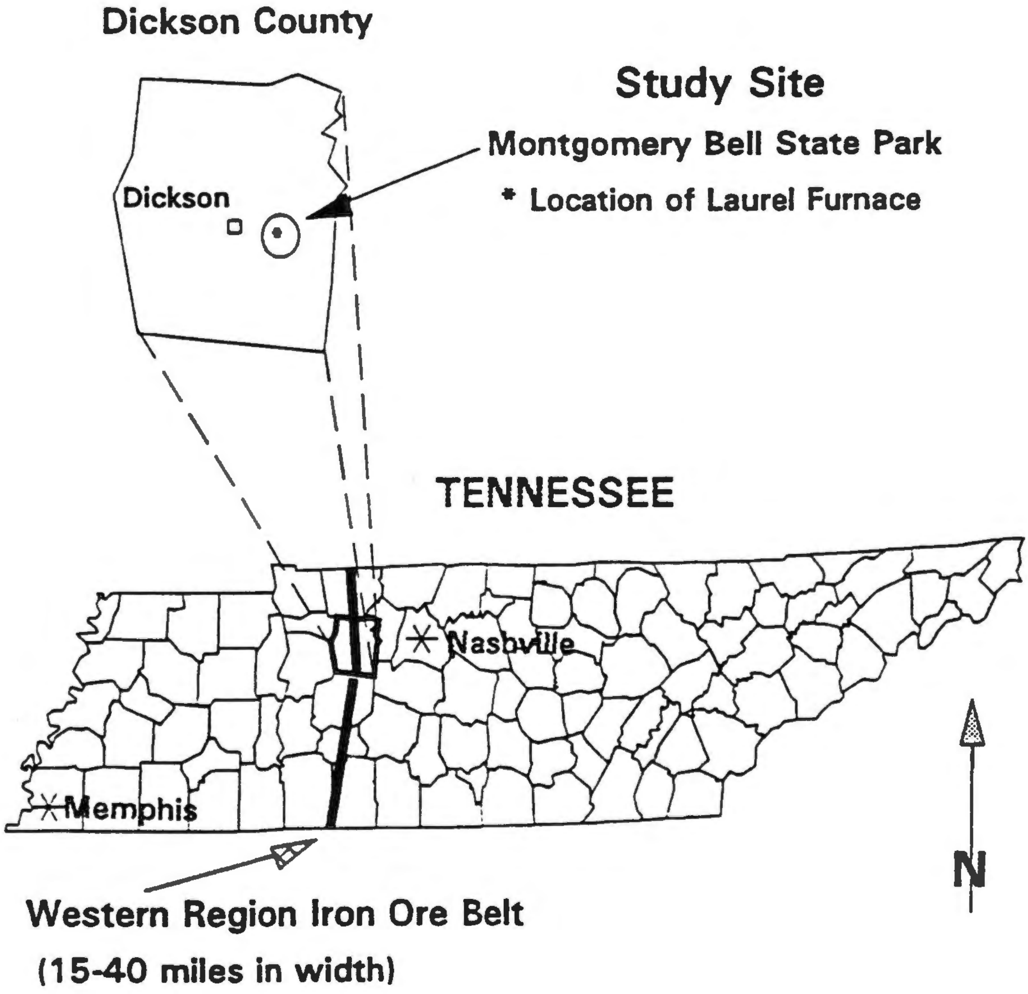


Figure 6. General location map of study area.

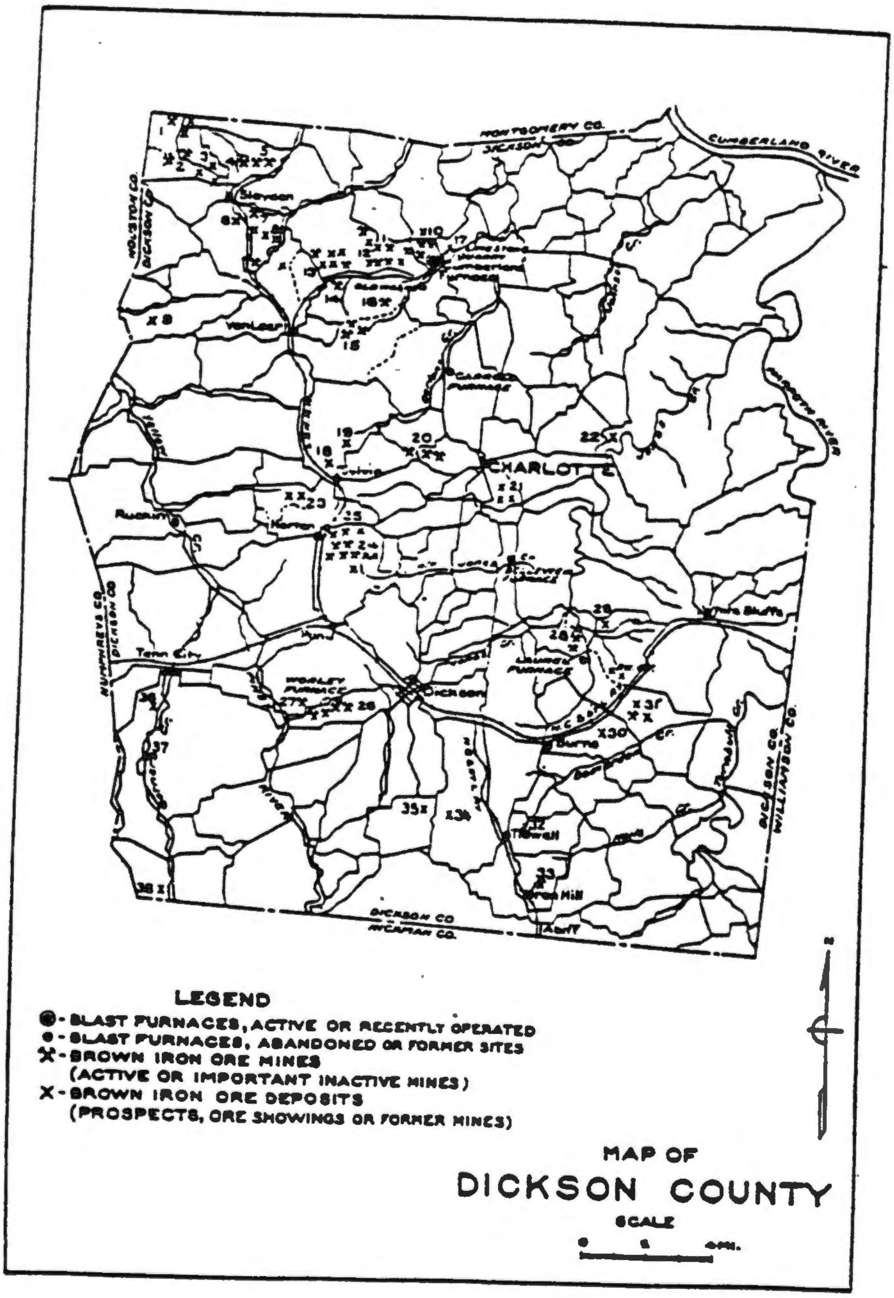


Figure 7. Map of Dickson county furnaces (Burchard, 1934).

Plate 1. Deposit of brown iron ore near Cumberland furnace being mined by hand and dry screened (Burchard, 1934).

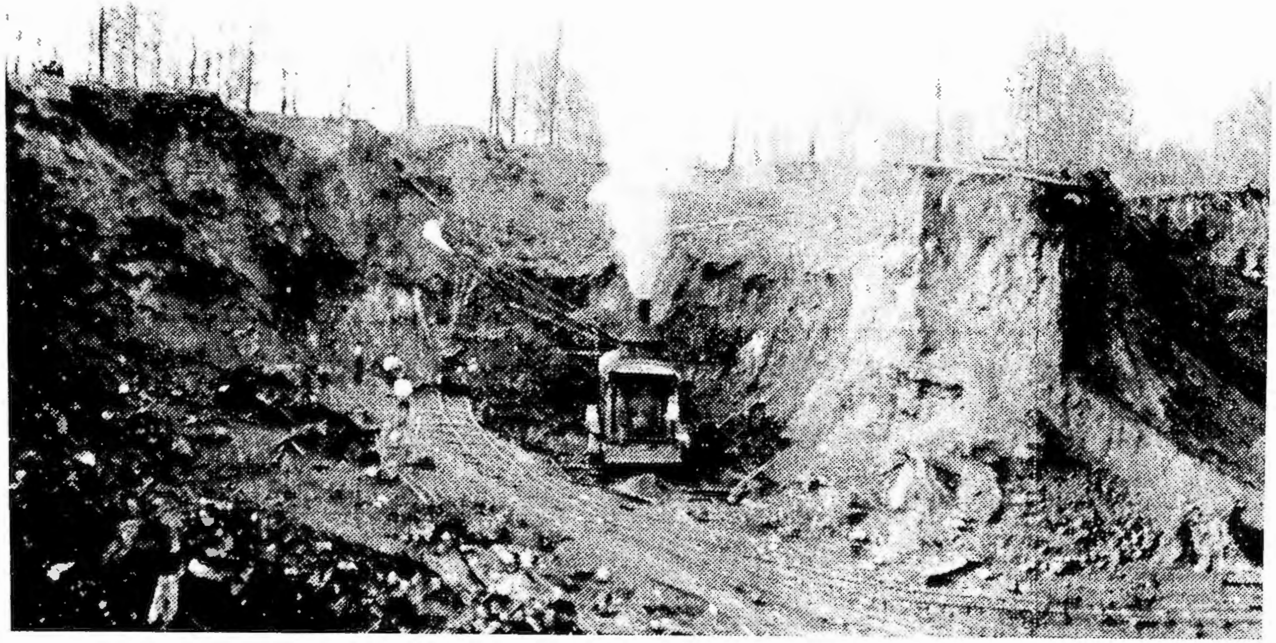


Plate 2. Bell brown iron ore mine, 3.5 miles (5.6 km) southwest of Cumberland furnace (Burchard, 1934).

Lake Acorn (11 ha), camp sites, cabins, and a hotel were constructed in the park for public use.

The spoils left from the mining operation at the Laurel furnace provided an ideal opportunity for study, because they have not been influenced by intense anthropogenic activities or natural catastrophes since the mining ceased. The time of disturbance is known (1815 through late 1850's), and the spoil piles were easily identified adjacent to excavated pits.

The study sites were mapped as Sengtown gravely silt loam on 12-20% slopes eroded (62D2), and Sengtown gravely silt loam on 5-12% slopes eroded (62C2) in the soil survey for Dickson County (Fig. 8) (Soil Survey Staff, 1993b). Sengtown is classified as a fine, mixed, thermic Typic Paleudalf. The concept of this series does not infer disturbance by mining. Spot symbols designating the presence of mines and quarries were marked for the study area. The family classification for the soil units mapped on a general soil's map for Dickson County are given in Table 2 (Springer and Elder, 1980).

Initial field observation indicated a possibility that tree growth was enhanced and species composition differed on the mined areas versus the neighboring undisturbed areas. In co-operation with the Forestry Department at The University of Tennessee, a study was conducted to determine species composition and tree age on the study area and a control section (Gaither et al., 1995). The spoil and control sites were assumed to have been similarly

Figure 8. Study area was mapped as sengtown gravelly silt loam (62C2 and 62D2) in Dickson County Soil Survey (Soil Survey Staff, 1993).

Table 2. List of family classification of the most common soil series mapped for Dickson county (modified from Springer and Elder, 1980).

Series	Family Name
Baxter	Fine, mixed, mesic Typic Paleudalf
Bodine	Loamy-skeletal,siliceous, thermic Typic Paleudult
Brandon	Fine-silty, mixed, thermic Typic Hapludult
Dickson	Fine-silty, siliceous, thermic Glossic Fragiudult
Guthrie	Fine-silty, siliceous, thermic Typic Fragiaquult
Lax	Fine-silty, siliceous, thermic Typic Fragiudult
Mountview	Fine-silty, siliceous, thermic Typic Paleudult

disturbed since most of the trees within proximity of both areas had been harvested during the mining period to provide timber for charcoal fuel as described earlier in Chapter 1. Both sites were on the same aspect and within 1 mile of each other to minimize the differences in environmental conditions. Gaither et al (1995) found greater species diversity and enhanced tree growth on the spoil sites. Core samples of dominant and codominant red oaks (*Quercus rubra* and *velutina*), indicated two age classes in the upper canopy of both sites with the oldest being between 113 - 140 years old. The older age class suggested regeneration occurred relatively soon after mining discontinued. Diameter at breast height (dbh) measured 10.2 cm (4 in) greater for the largest upper canopy trees on the spoil sites in comparison to the largest upper canopy trees on the control.

Field Methods

Study sites were located within 800 meters northwest of the Laurel Furnace remnants. Two minesoil profiles (spoils) and two soil profiles on adjacent undisturbed soils (native pedons) were described and sampled according to National Cooperative Soil Survey Standards (Soil Survey Staff, 1993a). Soil samples were taken by horizon from the entire depth of the horizon for each profile. The undisturbed soils were referred to as native 1 and 2, and the disturbed soils were referred to as spoil 1 and 2. Native 1 developed on the shoulder of a convex side slope, and native 2 developed on a nearly level portion of a ridgetop. Spoil 1 developed in overburden material on a ridgetop, and spoil 2 developed in overburden material in a drainage hollow.

Field descriptions included soil morphology and site characteristics. Morphology consisted of horizon designation, horizon depth, distinctness of horizon boundary, soil color, texture, structure, and consistence. The presence of roots, manganese concretions, mottling, and cutans were also noted. Elevation, vegetation composition, aspect, slope, and a general landscape description were noted for site characteristics (Soil Survey Staff, 1993b). Mean annual temperature regime was assumed to be thermic based on elevation and other local measurements. All study profiles were classified using the Keys to Soil Taxonomy (Soil Survey Staff, 1994; Soil Survey Staff, 1975). The spoils were also classified using the West Virginian Minesoil Classification System (Ammons and Sencindiver, 1990).

Laboratory Methods

Sample preparation

Horizon samples were air dried, sieved through a 2 mm diameter limiting sieve, and homogenized thoroughly. Coarse fragments, > 2.0 mm, were collected and weighed to determine their percent by weight. One fourth of each sample was ground to 60 mesh (Soil Survey Staff, 1984). A fizz test using 1M HCL was used to indicate the presence of free carbonates. If the sample did not fizz (react) with addition of HCL and had a soil pH of less than 7, it was assumed that free carbonates were absent. None of the soil samples reacted or had a pH above 6. Total carbon was assumed to equal organic carbon for all horizons in all study sites.

Physical analysis

A sand sieving and sedimentation-pipette method was used to determine particle size distribution of clay, silt, and sand size fractions (Kilmer and Alexander, 1949; Gee and Bauder, 1986). Sand fractions were sieved into very coarse sand (VCOS), coarse sand (COS), medium sand (MS), fine sand (FS), and very fine sand (VFS). Fine clay fractions were determined using a combination of the pipette method and centrifugation. Samples with > 0.5% organic carbon were pretreated with hydrogen peroxide (30%) to reduce potential interference of organic matter to sedimentation rates. Mineralogy was estimated on the control section using CEC to clay ratios (Soil Survey Staff, 1984).

Selected chemical analysis

Hygroscopic moisture, concentration of iron and manganese oxides, cation exchange capacity (CEC), exchangeable bases, total carbon, total concentration of 24 elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu , Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sr, Ti, Zn, and Zr), pH, and exchangeable acidity were the selected chemical analyses. All procedures included two replications of each sample. Samples were dried at 105° C for at least twelve hours to determine hygroscopic moisture (% moisture content in soil). Sample weights were corrected for moisture, using the hygroscopic data, to determine dry sample weight for all other analysis which required calculations on a dry weight basis.

Iron oxides were extracted using a citrate-dithionite (cd) method described by Olsen and Ellis (1982) and manganese oxides were extracted using an acidified hydroxylamine hydrochloride method (Gambrell and Patrick, 1982; Chao, 1972). The extracts were analyzed for Fe and Mn using a Perkin-Elmer 5000 Atomic Absorption Spectrophotometer.

Exchangeable cations were extracted by saturation with ammonium acetate at pH7 combined with a NaCl vacuum extraction procedure (Jackson, 1958; Hammer and Lewis, 1987; and Baker and Suhr, 1982). A direct displacement method and titration with 0.01 M HCL was used to determine CEC (Rhoades, 1982) which was measured with a Lab Conco distillation unit. Less than 60 mesh samples were analyzed for total carbon content using a dry combustion Leco CR-12 Carbon System Analyzer.

A modification of Nadkarni's (1984) microwave oven acid digestion technique which uses HF and an aqua regia solution (mixture of HCL and HNO_3) to digest inorganic matrices was used to solubilize the soil samples for elemental analysis (Gallagher, 1993; Ammons et al., 1995). After the neutralization of the unreacted HF with boric acid, extracts were analyzed with a

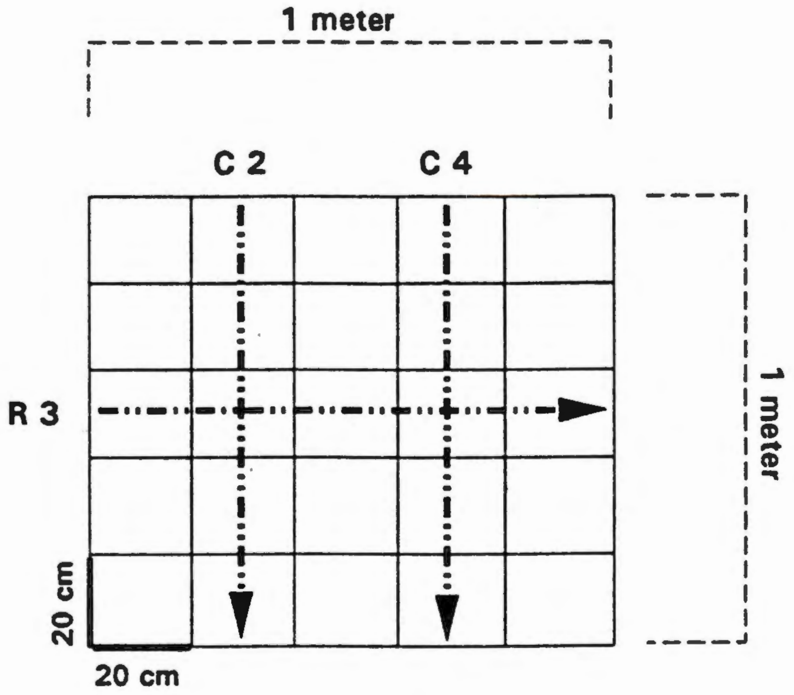
Thermo Jarrel Ash Model 61 Inductively Coupled Argon Plasma Spectrometer (ICAP-AES) for 24 elements (Al, As, Ba, Ca, Cd, Co, Cr, Cu , Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, S, Se, Si, Sr, Ti, Zn, and Zr).

A combination pH electrode and a 1:1 soil sample to water ratio was used to determine pH (McLean, 1982). A potassium chloride method was used to determine exchangeable acidity (Thomas, 1982).

For purposes of simplification, results graphed by depth were plotted by midpoint depth for each horizon so that the plot point value represents the value for the entire horizon. Clay- free ratios of fine sand to total sand plus silt [fs:(ts + si)] were calculated using particle size fraction data for all horizons of all sites and plotted as described above. Titanium to zirconium (Ti/Zr) ratios were calculated using total elemental analysis data.

Statistical Methods and Design

A grid design was sampled vertically and horizontally to allow statistical analysis for selected chemical properties. The profiles were marked off 1 meter by 1 meter and dissected into 20 cm by 20 cm sections (square) (Fig. 9). Samples were taken and homogenized from the entire squares that were in columns 2 and 4 and row 3. Row 3, at 40 - 60 cm, was chosen to be sampled because it represented the middle of the grid. As a general rule, the variability of soil properties within a row of a disturbed soil would be expected to be greater than the variability of the same soil property at the same depth (row) of a native



Key

R = Row
C = Column
*Column 2 and 4 and Row 3 were sampled

Figure 9. Grid outlay used for vertical and horizontal sampling for statistical analysis.

soil due to the mixing of material and exposure of less weathered geologic material to near surface conditions. The purpose of sampling the same row for all sites was to determine if variance of selected chemical properties at that chosen depth was significantly different between the native pedons and spoils. Variations of selected chemical analyses at a depth of 40-60 cm (row 3 in the grid) were compared between all sites. Hartley's test which compares homogeneity of two independent variances was used (Snedecor, 1956; Ott, 1993). This test is used when comparing independent random samples from two populations with possibly different means and with possibly common variance. The test compares a calculated F value (F_c) to a tabular F value (F_t). F_c is determined by dividing the larger of the two variances by the smaller as shown by the following equation

$$F_c = \frac{s^2 max}{s^2 min}$$

The null hypothesis states that $\sigma^2{}_1 = \sigma^2{}_2$ if F_c is less than or equal to F_t. If F_c is greater (>) than F_t, then the compared variances are significantly different at that chosen alpha level. Note that the degrees of freedom (n=4) were the same for both compared variances and that a 95% confidence level was used for this study.

Results and Discussion

Native 1

The parent material sequence for native pedon 1 was colluvial material over a residual paleosol described to a total depth of 116 cm. Soil textures ranged from silt loams in the surface horizon to silty clay loam and clay in the lower horizons (Tables 3 and 4). Frazee et al. (1970) found particle size distribution of loess changed as distance from the loess source increased or decreased. Coarser silts were deposited closer to the source of loess, and fine silts and clays were deposited further from the source. Loess deposits in Springfield, Tennessee, were presumed to be distant rather than local because fine silt accounted for 60-70% of total silt (Branson, 1992). The origins of the loess for this site are unknown. Fine silts made up between 50-60% of the total silt content in the upper 0.5-0.6 meters (Fig. 10). For this reason, the author assumes the West Tennessee Silty Uplands and/or Mississippi River silts were the source of loess.

Coarse fragment content ranged between 10-30% in the surface and upper argillic horizon of native 1's profile (Table 4). Coarse fragments were highest in the BC (50%). Random mottling not related to water saturation and wavy boundaries occurred in all the B horizons (Table 3). Mixing of material and accumulation of fragments during transport of the colluvial material probably attributed most to these characteristics.

Table 3. Morphology of native pedon 1.*

Horizon	Lower Depth	Color	Texture	Structure	Boundary	Consistence	Mn Concr.†	Mottles
	cm	moist				moist		
Oe	3-0							
A	16	10YR 4/4	SiL	2 mgr	cw	vfr	....	....
EB	35	7.5YR 5/6	SiL	1 mgr	cw	vfr	....	....
Bt1	60	5YR 5/6	gr. SiCL	1 msbk	cw	fr	c,f	c,d 7.5YR 5/6
Bt2	78	7.5YR 5/6	C	2 msbk	cw	fi	....	f,p 10R 4/8
BC	94	10YR 6/6	vgr. C	1 fsbk	cw	vfr	....	c,p 5YR 5/8
2Bt	116+	5YR 4/6	gr. C	2 msbk	....	fi	....	c,p 10YR 6/6

*Abbreviations for morphology designations are given in Appendix A

† Manganese concretions

Table 4. Particle size distribution and coarse fragment content for native pedons 1 and 2.

					%Coarse Fragments	
Horizon	Lower Depth	Total Sand	Total silt	Total Clay	2 - 76 mm	>76 mm
	cm	———	%	———	vol	vol
Native 1						
A	16	14.5	66.3	19.2	10	....
EB	35	16.8	59.3	23.9	12	....
Bt1	60	20.9	40.6	38.5	15	15
Bt2	78	10.1	35.2	54.7	12	....
BC	94	22.4	32.1	45.5	50	....
2Bt	116+	14.9	18.1	67.0	22	....
Native 2						
A	21	11.4	72.6	16.0	2	....
BE	32	5.7	69.2	25.1	0	....
Bt	58	8.1	58.5	33.4	4	....
2Ab	95	19.4	56.6	24.0	60	....
3Bt	108+	10.0	35.9	54.1	10	50

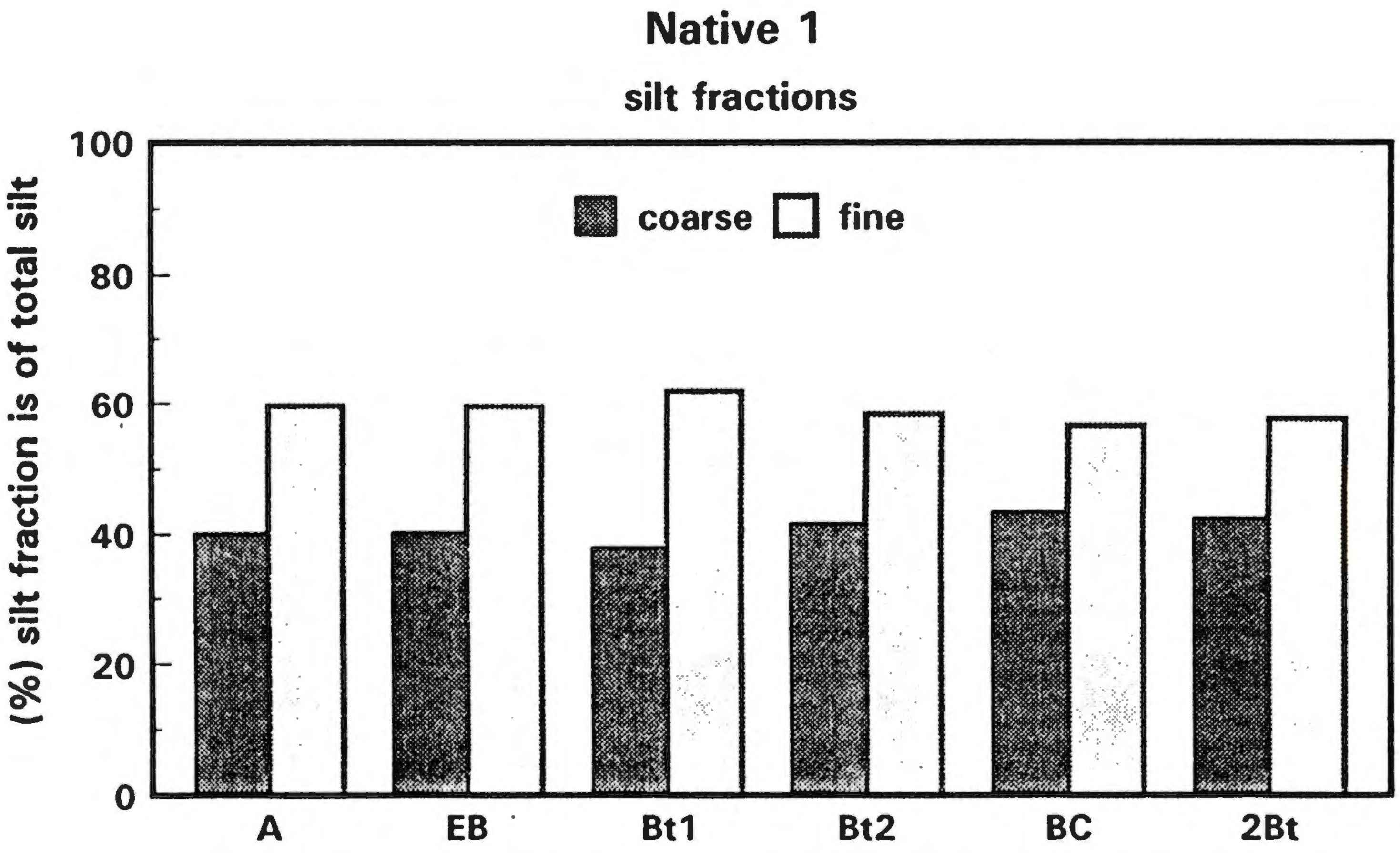


Figure 10. Coarse silt and fine silt fractions as a percent of total silt for native pedon 1.

Total clay content doubled from the A horizon to the argillic horizons, reaching a maximum in the Bt1 (Table 4). Fine clay to total clay ratios reached a maximum in the Bt1 horizon and the 2Bt horizon (Fig. 11). Free iron increased the most in the Bt2 and 2Bt horizons, reaching a maximum in the 2Bt. Free iron equaled total iron in the EB horizon (Fig. 12). This indicated that iron bearing primary minerals in this horizon have been highly weathered of iron. The formation of an EB requires the process of intense weathering and eluviation. Although iron has significantly weathered from the minerals in the EB, the underlying Bt1 did not show a large accumulation of free iron. Presence of iron oxides at that concentration were enough to maintain strong pigmentation in the EB horizon. An increased difference between free iron and total iron in the Bt1 compared to the Bt2 indicate the Bt1 is a relatively young argillic horizon. The highest clay content, free iron content, and more red colors occurred in the palesol (3Bt) (Fig. 11; Table 3). This implied that the argillic horizon (3Bt) had been highly weathered prior to being buried.

An increased clay content in the EB horizon compared to the overlying A horizon did not result in increased CEC in the EB (Table 4; Fig. 11). Cation exchange capacity decreased by half from the surface to the EB horizon and reached a maximum in the Bt2 and 2Bt horizon. Total carbon was almost 3 times higher in the A horizon compared to the EB horizon (Fig. 13). Organic matter probably constituted the largest source of CEC in the A horizon. Total

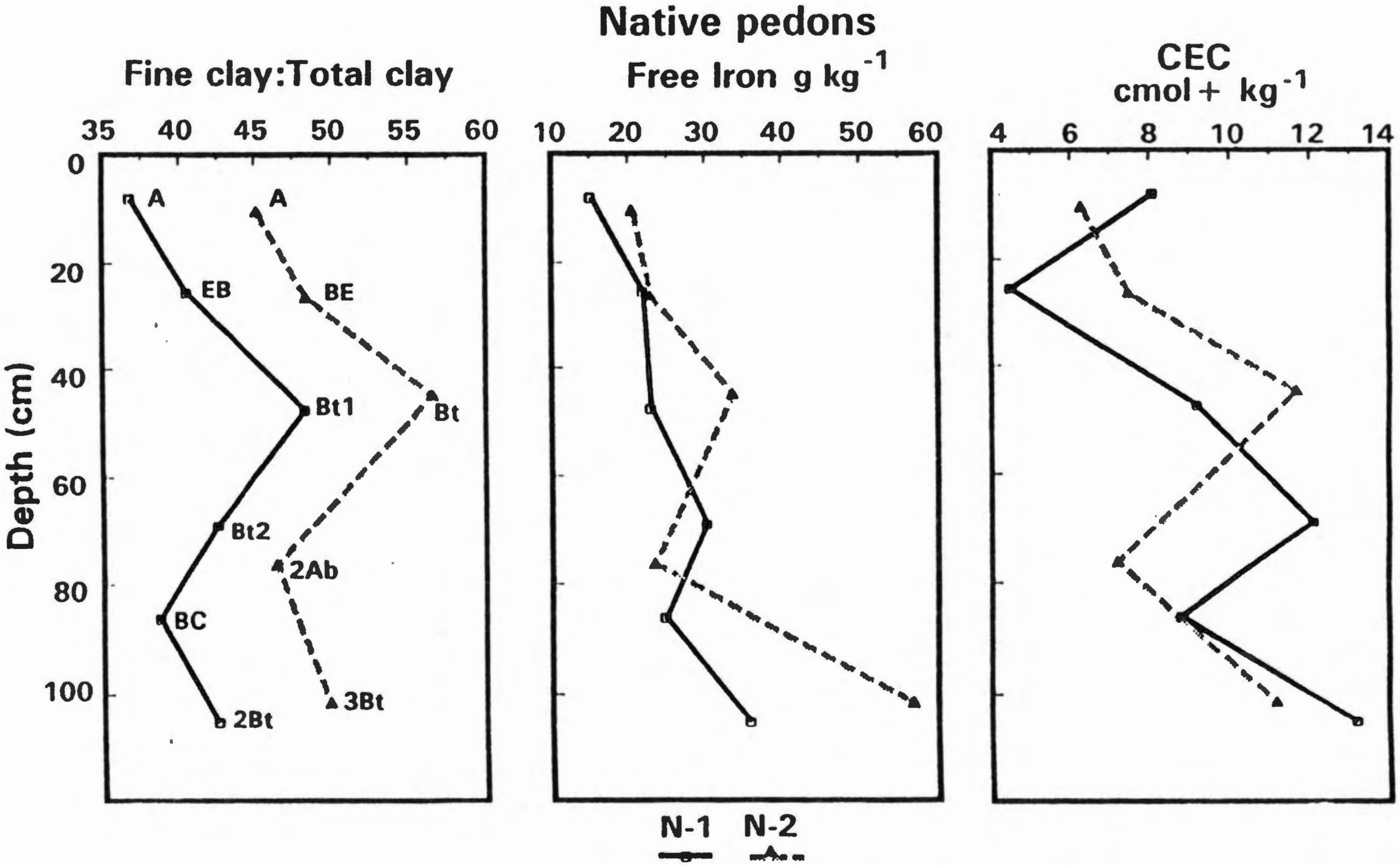
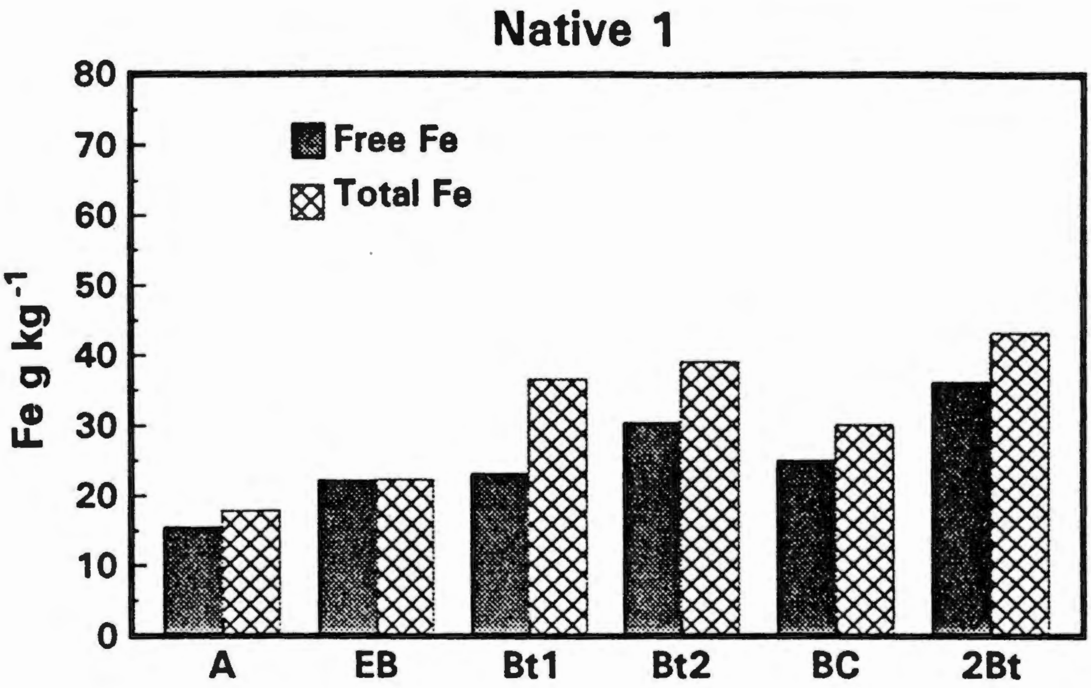


Figure 11. Fine clay to total clay ratio, free iron, and cation exchange capacity distribution by depth in native pedons 1 and 2.



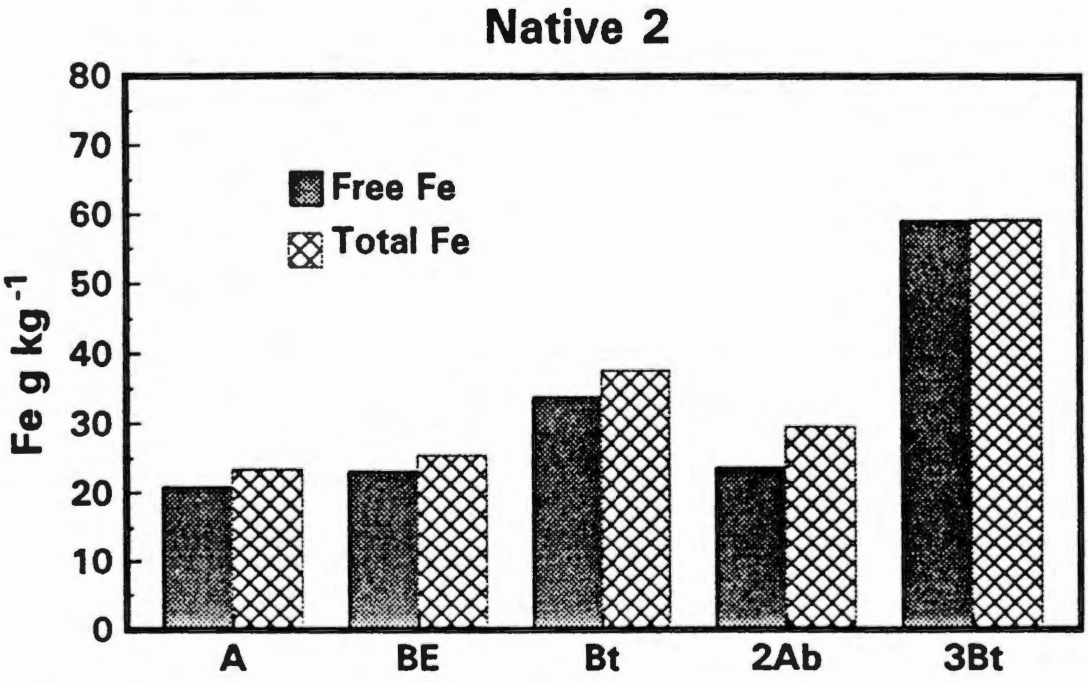
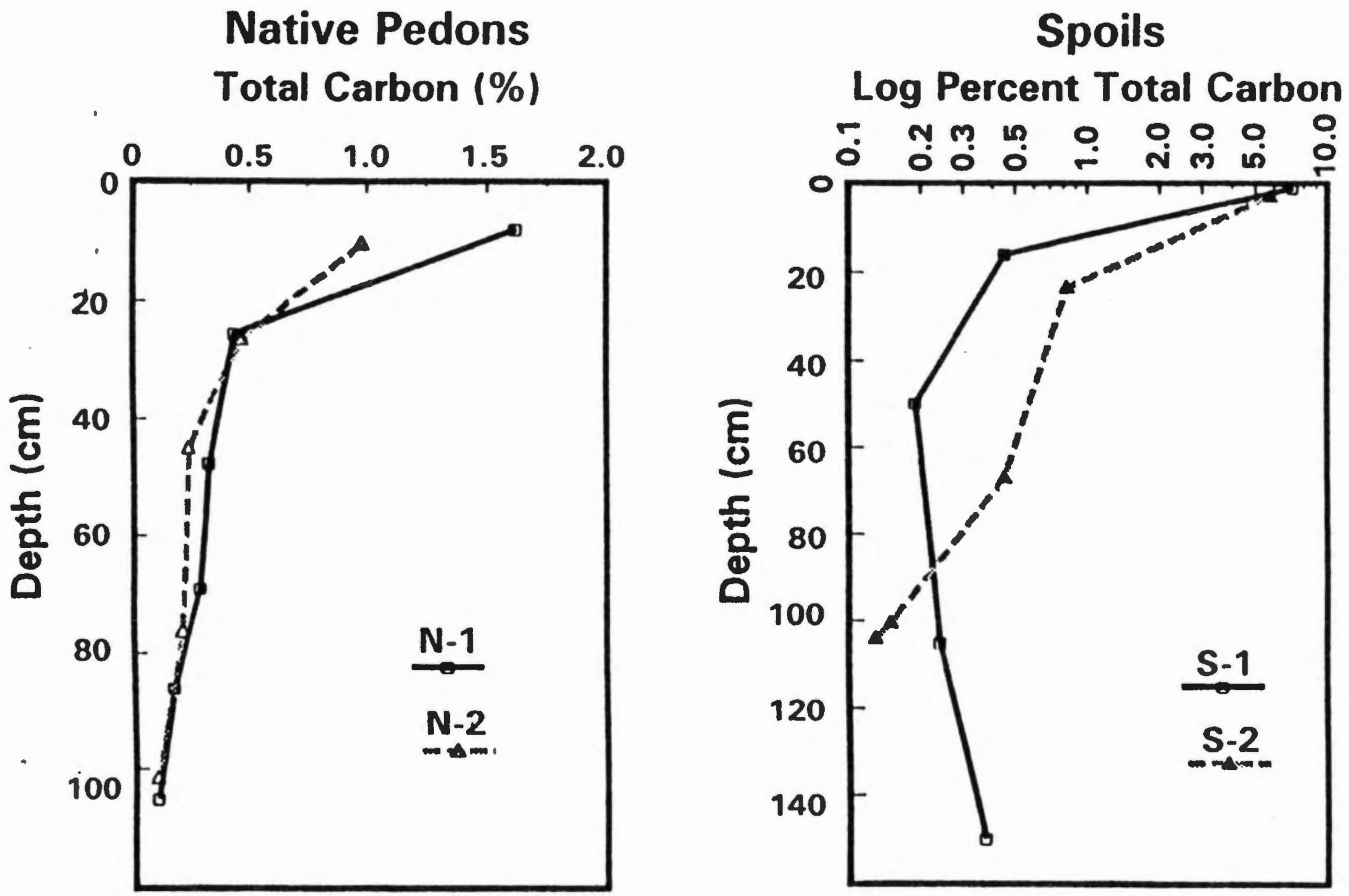


Figure 12. Free iron and total iron distribution for each horizon in native pedons 1 and 2.



Native Pedons

Spoils

Figure 13. Total carbon distribution by depth in native pedons 1 and 2 and spoil 1 and 2.

carbon content was less than 0.5% in the argillic horizons, where CEC was highest in the profile. This indicates that clay constituted the largest source of CEC in the argillic horizons.

Figure 14 shows clay free ratios [fs:(ts + si)] and titanium to zirconium (Ti/Zr) ratios by depth for both native pedons. In native pedon 1, clay free ratios almost doubled from the Bt1 to the 2Bt horizon, denoting a change in parent material between them. The most notable inflection in the graph occurred between the Bt2 and BC. This indicates a mixing zone has probably occurred between the BC and 2Bt . The Ti/Zr ratios differed between most horizons. The largest ratio changes occurred between the A and EB, followed closely by the change between the Bt1 and BC. The pattern for both graphs suggest that clay free ratios best identified lithologic changes designated by morphology while the Ti/Zr ratios was a better indication of horizon changes.

Total acidity was the lowest in the surface horizons (Table 5). The total acidity and pH for both native pedons and spoils indicate that exchangeable forms of aluminum such as Al^{3+}, $AlOH^{2+}$, and $Al(OH)_2^+$ contributed most of the salt replaceable acidity(Sposito, 1989) (Fig. 15).

Native pedon 1 was classified as a clayey, mixed, thermic Typic Hapludult (Soil Survey Staff, 1975).

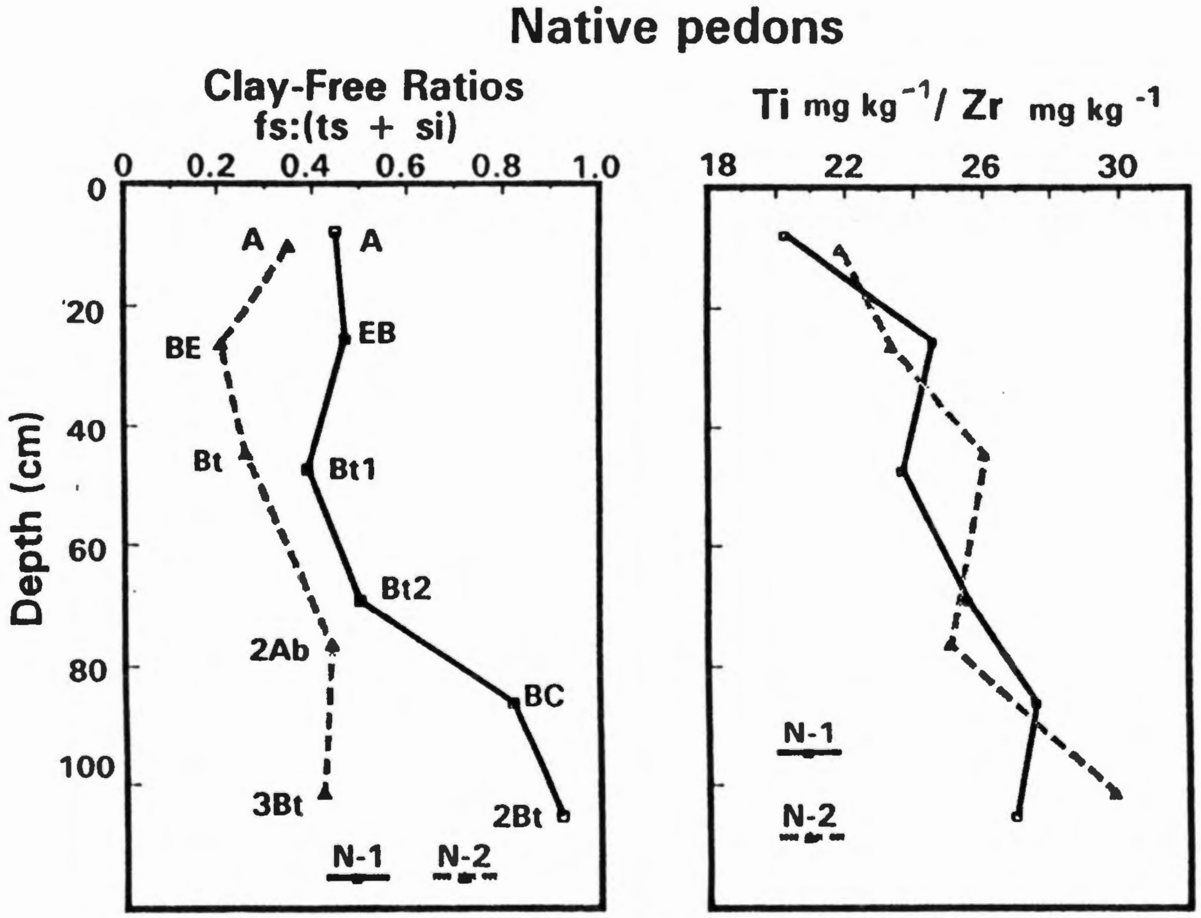


Figure 14. Clay free ratios of fine sand to total sand plus silt (fs:ts + si) and titanium to zirconium ratios for indications of lithologic discontinuities in native pedons 1 and 2.

Table 5. Chemical properties including exchangeable cations, base saturation, pH, and KCL total acidity of native pedons1 and 2.

		NH$_4$OAc Extractable Cations										
Horizon	Lower Depth	Ca	Na	K	Mg	Total Bases	NH$_4$OAc CEC	Base Saturation	pH 1:1 H$_2$O	Total Acidity	KCL Al	H+
	cm		cmol$_c$ kg^{-1}					%		cmol$_c$ kg^{-1}		
Native 1												
A	16	0.92	0.04	0.22	0.42	1.60	8.10	19.8	4.7	1.04	1.32	0*
EB	35	0.47	0.04	0.13	0.66	1.30	4.40	29.5	4.8	1.21	1.69	0*
Bt1	60	1.39	0.04	0.12	1.53	3.08	9.19	33.5	4.7	2.77	3.72	0*
Bt2	78	1.84	0.05	0.16	1.37	3.42	12.11	28.2	4.7	3.96	5.50	0*
BC	94	1.85	0.05	0.14	1.09	3.13	8.83	35.4	4.6	2.45	3.40	0*
2Bt	116+	2.13	0.05	0.20	1.51	3.89	13.23	29.4	4.6	5.28	7.46	0*
Native 2												
A	21	0.55	0.08	0.20	0.45	1.28	6.30	20.3	4.5	1.00	1.11	0*
BE	32	0.87	0.06	0.21	0.82	1.96	7.54	26.0	4.5	1.54	1.98	0*
Bt	58	2.70	0.10	0.19	1.19	4.19	11.67	35.9	4.7	1.61	1.45	0.22
2Ab	95	0.88	0.10	0.18	0.46	1.61	7.21	22.3	4.7	1.94	2.18	0*
3Bt	108+	1.91	0.05	0.25	1.04	3.25	11.24	28.9	4.7	2.83	3.07	0*

*Indicates presence of free aluminum

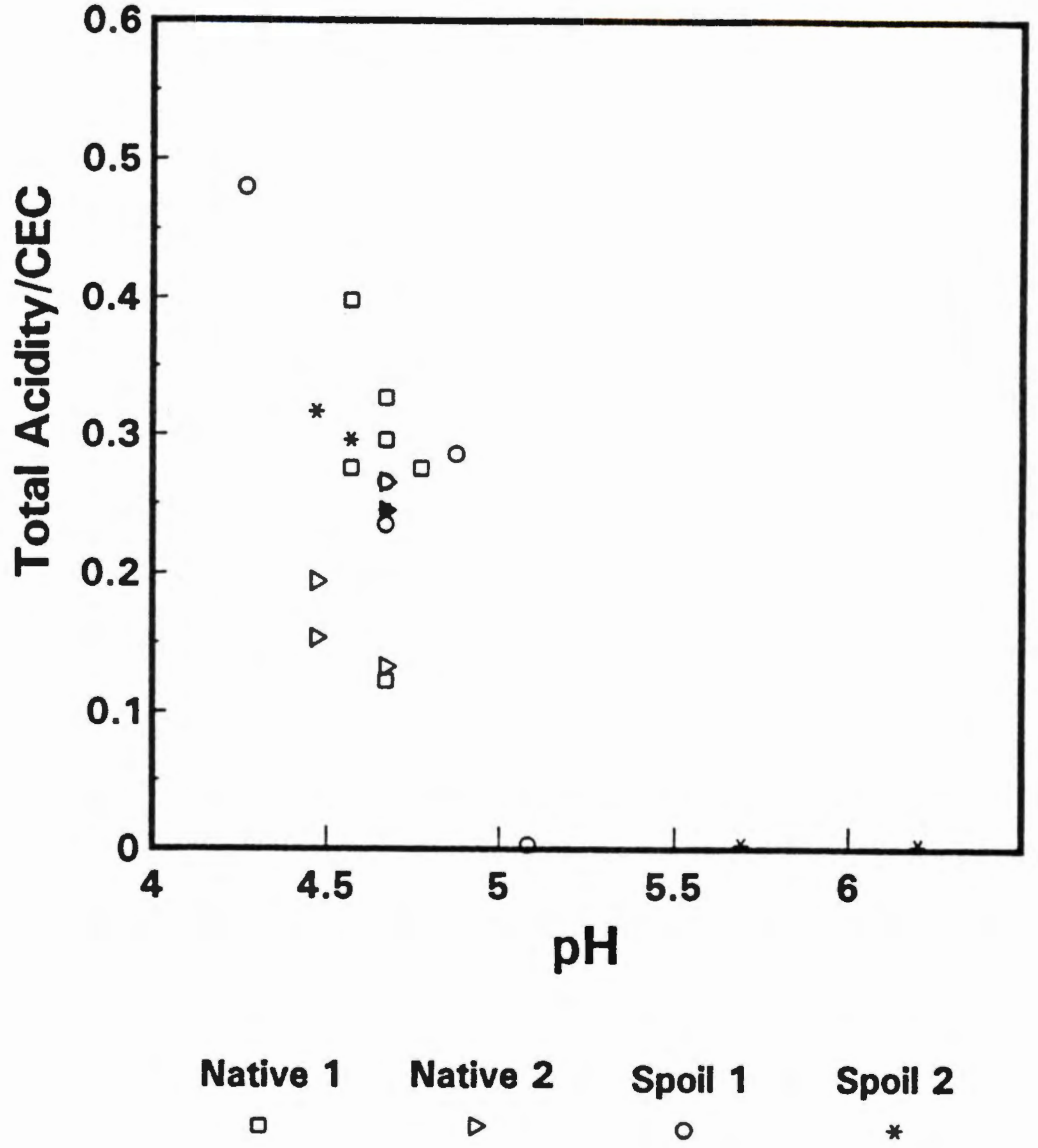


Figure 15. Salt-replaceable acidity (KCl) versus pH for all horizons in the native pedons and spoils.

Native 2

The parent material sequence for native pedon 2 included loess over a residual paleosol that was described to a total depth of 108+ cm (Table 6). Soil textures ranged from silt loam in the surface horizon (0 -32 cm) to silty clay loam (32-58 cm) and clay in the lower depth (95 - 108$^+$cm). The upper portion of this soil formed in a 0.5 to 0.6 meter loess deposit. Loess deposition was thicker in native pedon 2 than native pedon 1. Differences in landscape position accounts for the differences in loess thickness. Native pedon 1 is on a sideslope which is subject to increased surface erosion compared to the more stable upland position of native pedon 2. Textural modifiers were not observed in the loess. Coarse fragment content averaged 60% in the horizons (2Ab and 3Bt) underlying the horizons formed in loess material. Total silt content was 15% higher, on average, in the upper 0.6 meters of native pedon 2 compared to native pedon 1. Fine silt comprised between 50-60% of total silt, which is similar to native pedon 1 (Fig. 16 and 10). This suggests that the silt from loess in native pedon 1 and 2 originated from the same source.

Similar to native pedon 1, total clay, fine clay to total clay ratio, free iron, and CEC reached a maximum in the argillic horizons (Table 4; Fig. 11). Patterns for distribution of free iron, fine clay, and cation exchange capacity according to horizon and depth within native pedon 2 were almost identical. The difference between free iron and total iron was similar in the upper profile (Fig. 12). In the

Table 6. Morphology of native pedon 2.*

Horizon	Lower Depth	Color	Texture	Structure	Boundary	Consistence	Mn Concr.†	Mottles
	cm	moist				moist		
Oe	3-0							
A	21	10YR 4/4	SiL	2 mgr	cs	vfr	....	....
BE	32	7.5YR 4/6	SiL	1 msbk	cs	fr	....	....
Bt	58	7.5YR 4/4	SiCL	2 msbk	cw	fr	....	....
2Ab	95	10YR 5/4	vgr. SiL	1 fgr	cs	vfr	....	....
3Bt	108+	5YR 4/6	v.cob. C	2 msbk	....	fi	....	f,p 10YR 6/6

*Abbreviations for morphology designations are given in Appendix A

† Manganese concretions

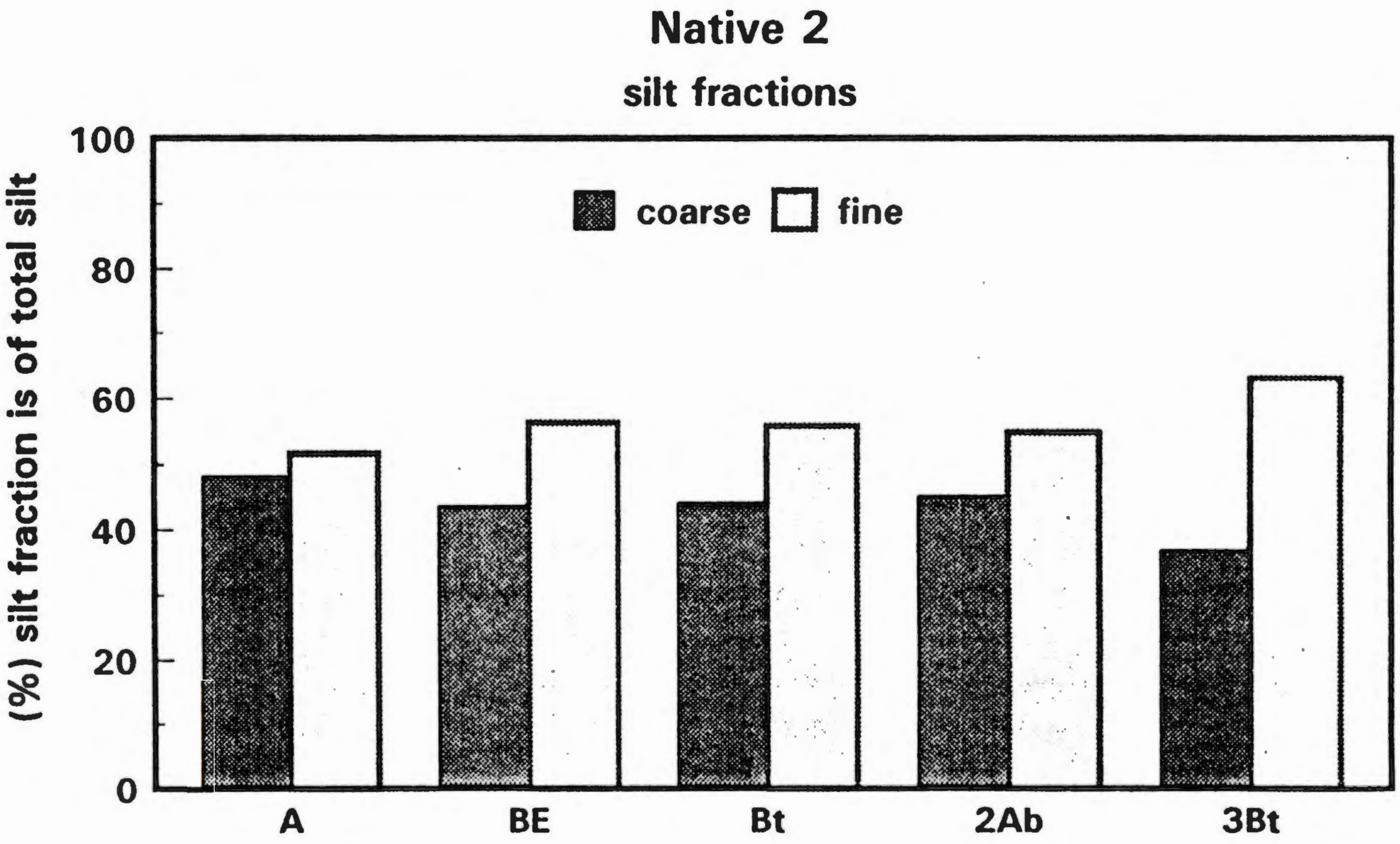


Figure 16. Coarse silt and fine silt fractions as a percent of total silt for native pedon 2.

3Bt free iron almost equaled total iron, indicating it had been highly weathered prior to being buried.

Clay free ratios almost doubled between the Bt and 2Ab, identifying the interface between the loess material and the residual material (Fig. 14). The Ti/Zr ratios did not change to the same degree between the Bt and 2Ab. Clay free ratios and Ti/Zr ratios increased and decreased at the same depths but the direction of changes were opposite. This inverse relationship between clay free ratios and Ti/Zr ratios was not observed for native pedon 1. Parent material differences may have influenced the different behaviors.

Percent base saturation and exchangeable calcium and magnesium reached a maximum in the Bt horizon (Table 5). Increased base saturation corresponded most with increases in exchangeable calcium and magnesium concentrations. Similar to native pedon 1, total acidity was lowest in the surface horizons. Total carbon was the highest in the surface horizon and its distribution was almost identical to that of native pedon 1 (Fig. 13).

Several properties in the 3Bt in native pedon 2 resembled those in the 2Bt in native pedon 1. Percent base saturation, pH, color (5YR), and clay content were similar for both paleosols, indicating that they were formed in the same residual material (Tables 3,4,5, and 6).

Native pedon 2 was classified as a fine-silty, mixed, thermic Typic Hapludult (Soil Survey Staff, 1994).

Spoil 1

Spoil 1 developed in backfill material which appeared to have been highly pre-weathered prior to deposition in a spoil. Material from a former paleosol was hypothesized to be the source of the spoil overburden (Fig. 17). Soil textures in the profile ranged from clay loam at the surface (0-2 cm) to silty clay at the middle depths (2 - 70cm) and silty clay loam at the lower depths (70- 160^{+}cm) (Table 7). Fine silt made up about 80% of total silt in the surface horizon and ranged between 50-60% for underlying horizons (Fig. 18). The difference between fine silt fractions in the surface horizon compared to the underlying horizons, indicated the surface horizon was influenced somewhat by different material. Coarse fragments ranged between 10-45% throughout the profile (Table 8).

Although the structure throughout the profile did not fit the structures defined by *Soil Taxonomy* (Soil Survey Staff, 1975), it resembled granular structure with a medium grade and medium class that was noncoherantly expressed (loose consistence)(Table 7). Most likely the handling of the material during excavation and movement account for the structure instead of pedogenic factors.

Bridging voids, averaging 1 cm in diameter, were observed between rock fragments and soil material (Plate 3). The voids were not observed in the native profiles. Mottle colors described were not associated with anaerobic conditions.

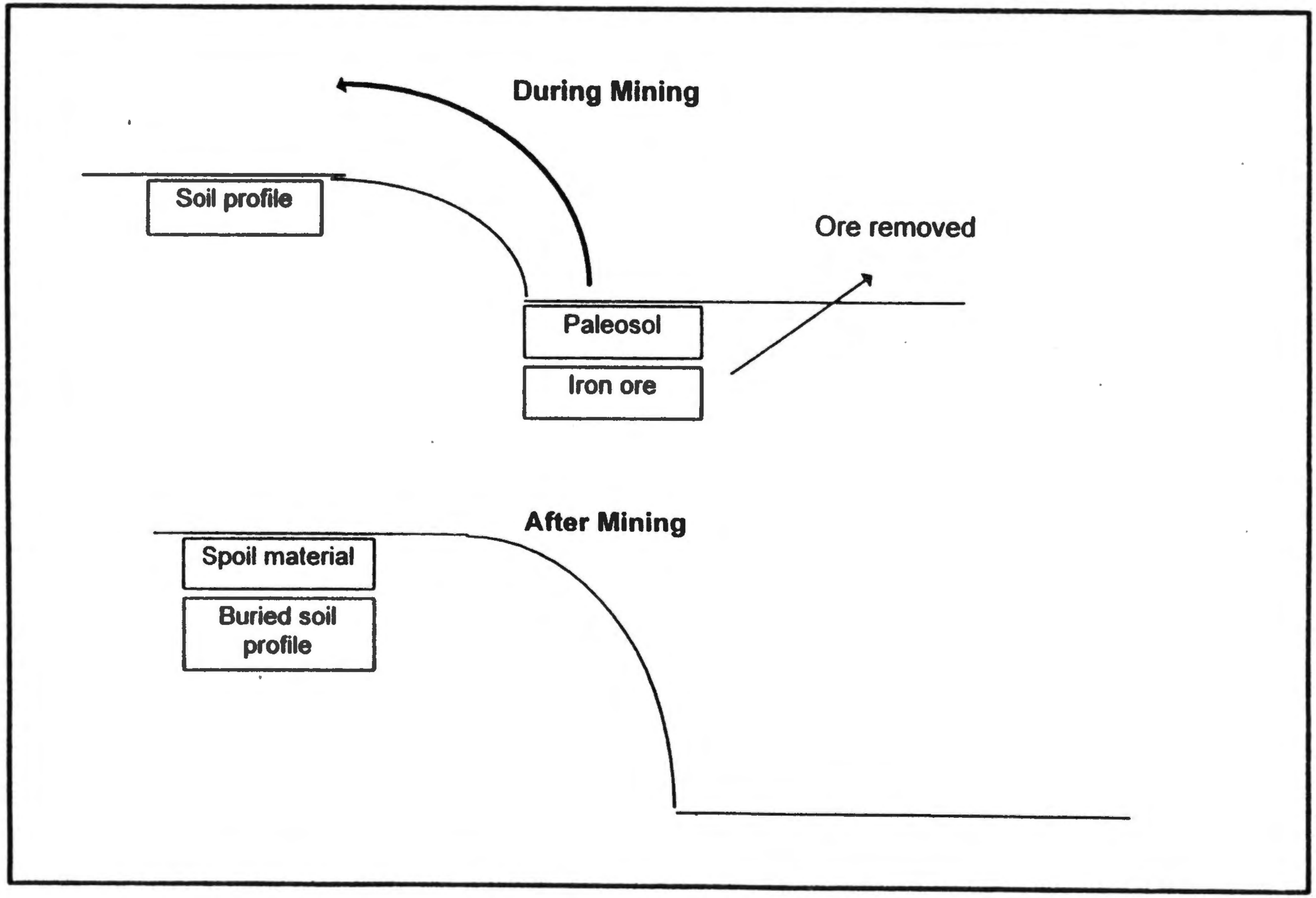


Figure 17. Hypothesized origin of spoil material for spoil 1.

Table 7. Morphology of spoil pedon 1.*

Horizon	Lower Depth	Color	Texture	Structure	Bridging Voids	Boundary	Consistence	Mn Concr.†	Mottles
	cm	moist					moist		
Oe	3-0								
A	2	7.5YR 3/1	CL	2 mgr	....	as	vfr	....	....
Bw1	30	5YR 4/6	SiC	2 mgr**	few	cs	l	c,f	c,d 7.5YR 4/4
Bw2	70	2.5YR 4/8	vgr. SiC	2 mgr**	common	gs	l	....	m,d 7.5YR 4/4
C	140	2.5YR 3/6	SiCL	2 mgr**	common	gw	l	....	c,d 7.5YR 4/6
2Ab	160+	7.5YR 4/4	SiCL	2 mgr**	....	....	fr	....	....

*Abbreviations for morphology designations are given in Appendix A

† Manganese concretions

**Material did not fit morphology structures in Soil Taxonomy. To avoid confusion of field descriptions, the Taxonomy structure the material resembled most was selected.

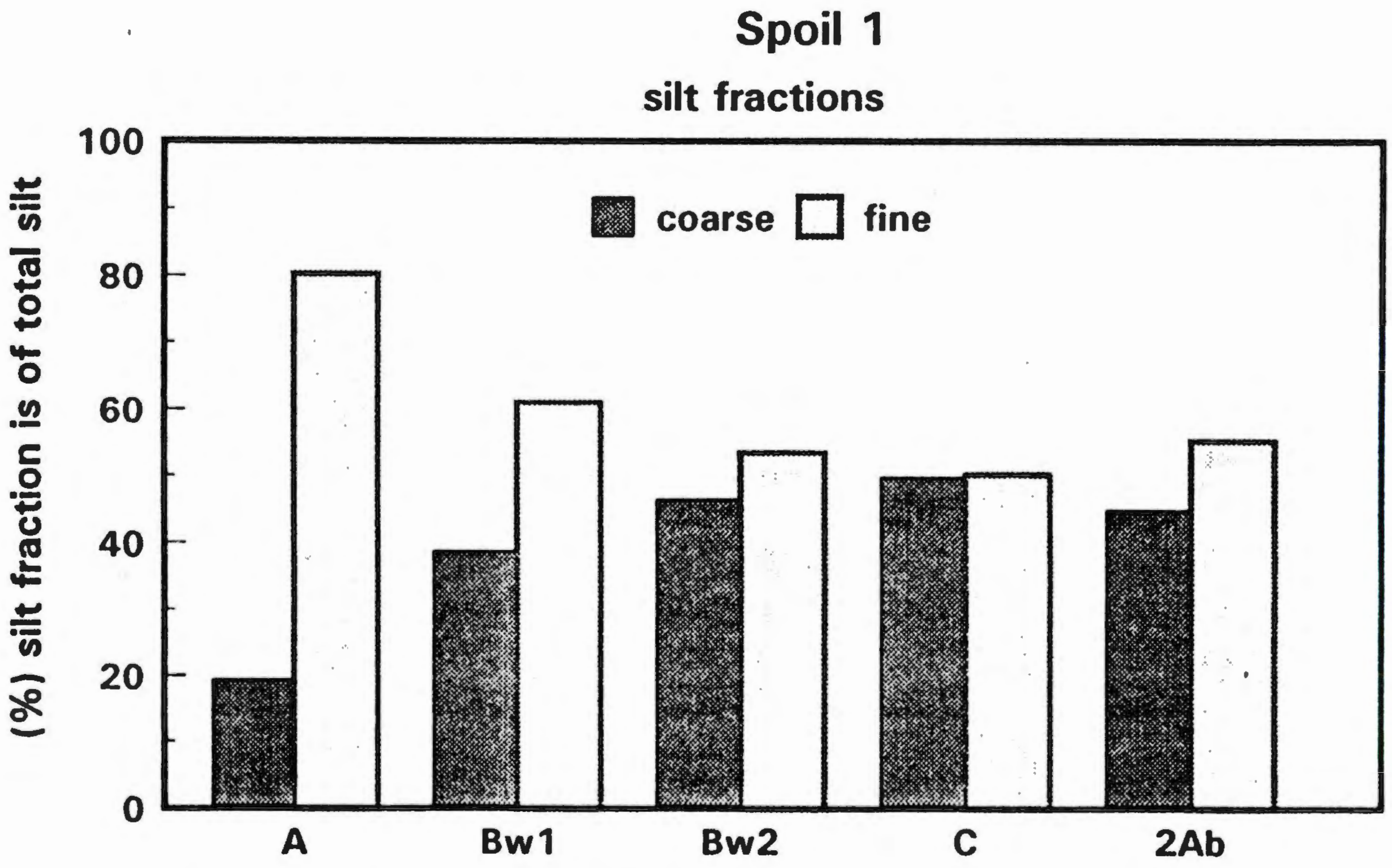


Figure 18. Coarse silt and fine silt fractions as a percent of total silt for spoil 1.

Table 8. Particle size distribution and coarse fragment content for spoils 1 and 2.

					%Coarse Fragments	
Horizon	Lower Depth	Total Sand	Total silt	Total Clay	2 - 76 mm	> 76mm
	cm		%		vol	vol
Spoil 1						
A	2	27.6	42.9	29.5	10	....
Bw1	30	14.9	39.8	45.3	12	....
Bw2	70	18.1	39.1	42.8	30	15
C	140	16.2	48.2	35.6	15	....
2Ab	160+	10.8	58.5	30.7	10	....
Spoil 2						
A	6	33.2	30.5	36.3	38	....
C1	41	19.3	27.2	53.5	50	30
C2	93	19.8	34.9	45.3	45	....
C3(L)	108+	14.1	26.7	59.2	40	....
C3(R)	108+	22.9	27.3	49.8	50	10

Plate 3. Picture of bridging voids, which averaged 1 cm in diameter, in spoil 1.

Presumably, these mottles resulted from contrasting materials mixed together during the spoil construction.

A thin 2cm surface horizon (A) with moderate medium granular structure formed in this spoil material (Table 7). Subsurface horizons included a cambic horizon (Bw1 and Bw2), a C horizon, and a buried A horizon. A cambic horizon is a diagnostic subsurface horizon changed or altered by physical movement of material or by chemical reactions (Brady, 1990). Cambic horizons have development of color or structure or both but little to no accumulation of illuvial material (Soil Survey Staff, 1993a).

Total barium more than doubled in the described buried A horizon in spoil 1 (Fig. 19). Together, an increase in total carbon, total manganese, and total barium in the buried A horizon indicated that the horizon had once been a stable surface horizon, presumably a surface horizon on the landscape prior to mining activity (Lewis et al., 1992; Foss et al., 1990) (Fig. 14 and 19).

Fine clay to total clay reached a maximum of fine clay in the Bw1 and Bw2 in spoil 1 (Fig. 20). The actual percent of fine clay to total clay in each horizon were the highest compared to all of the four pedons studied. This probably reflects the higher degree of weathering which occurred in the paleosol material prior to the spoil deposition and development.

Free iron distribution was similar to that of fine clay to total clay ratios (Fig. 20). The increase of fine clay to total clay, free iron, and free iron to total

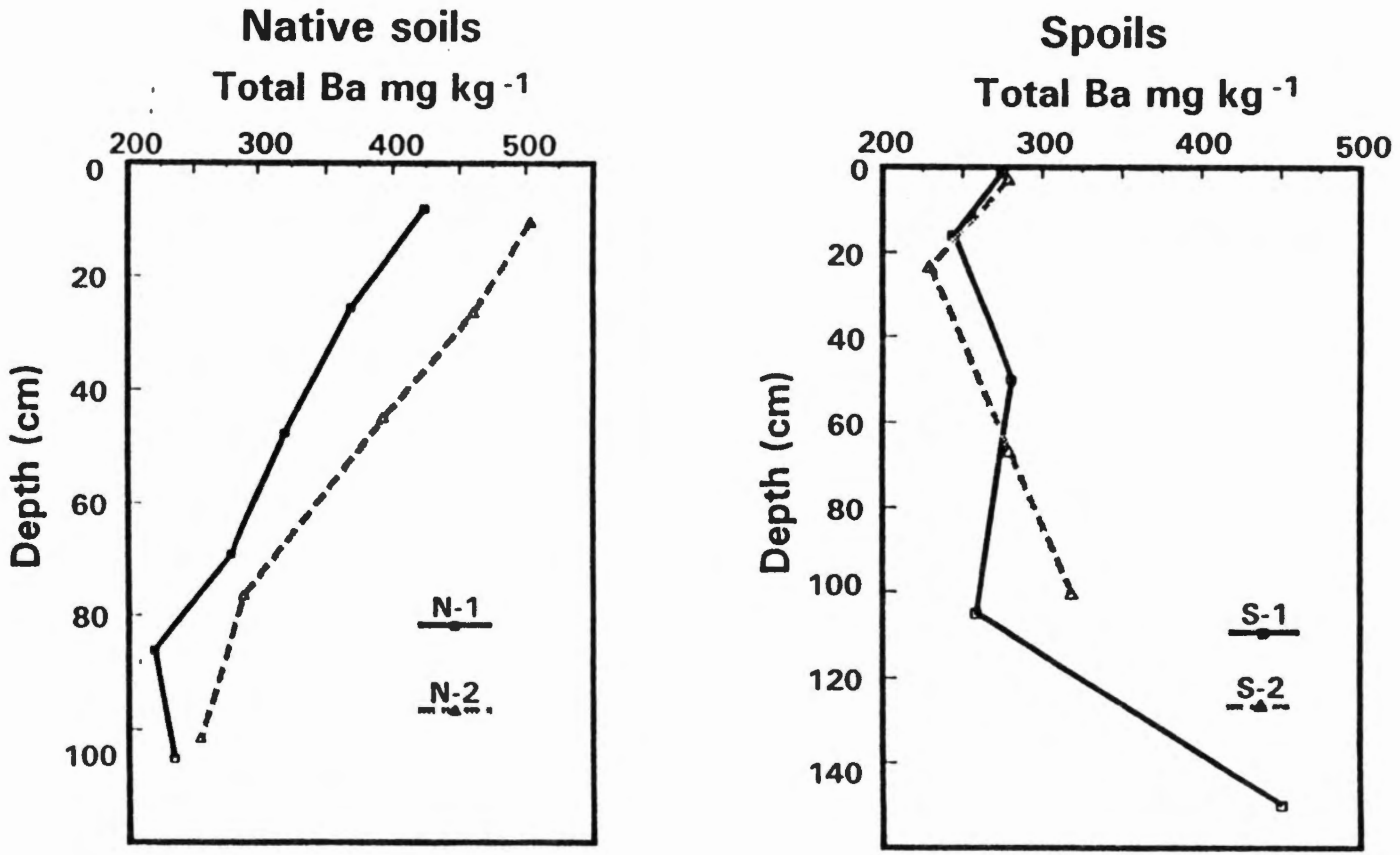


Figure 19. Total barium by depth in native pedons 1 and 2 and spoils 1 and 2.

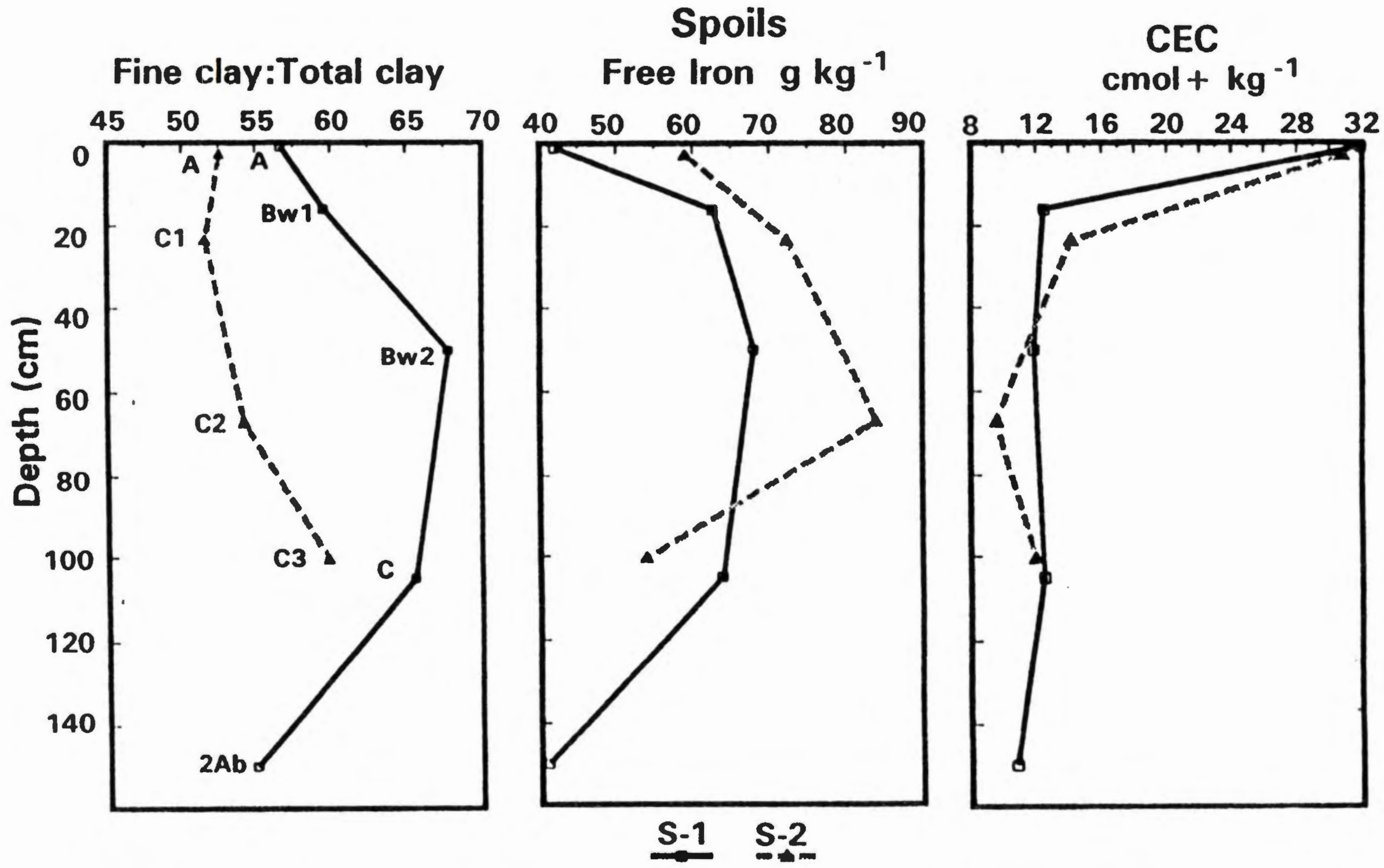


Figure 20. Fine clay to total clay ratio, free iron, and cation exchange capacity distribution by depth in spoils 1 and 2.

iron from the A horizon to the Bw1 and Bw2 horizons indicated translocation of these materials had occurred (Fig. 20 and 21). The translocation had not occurred to the degree of forming soil structure categories in *Soil Taxonomy*.

The distribution of CEC by depth did not parallel fine clay to total clay ratios or free iron distribution in spoil 1 (Fig. 20). Total carbon content and CEC followed similar patterns when graphed by depth (Fig. 13). The distribution of total carbon with depth was similar to both native pedons, but the actual percent of organic carbon in the surface horizon was more than 3 times greater than in the native surface horizons.

Clay free ratio distribution with depth identified a lithologic discontinuity at the buried A horizon (Fig. 22). Fluctuations in the graph of clay free ratios also occurred between the A and Bw1 horizon and between the Bw1 and Bw2. The largest change in the clay free ratio value was found between the Bw1 and the buried A horizon. The graph of titanium to zirconium ratio did not show the same direction or magnitude of inflections with soil depth as the graph of clay free ratios. The largest change in Ti/Zr ratio value occurred between the Bw2 and the buried A. The clay free ratio and titanium to zirconium ratios by depth both identified a contrast in material between the upper-middle portion of the profile and the buried A horizon.

Percent base saturation fluctuated among horizons but was highest in the surface (Table 9). Soil pH was highest in the surface horizon of spoil 1 and was

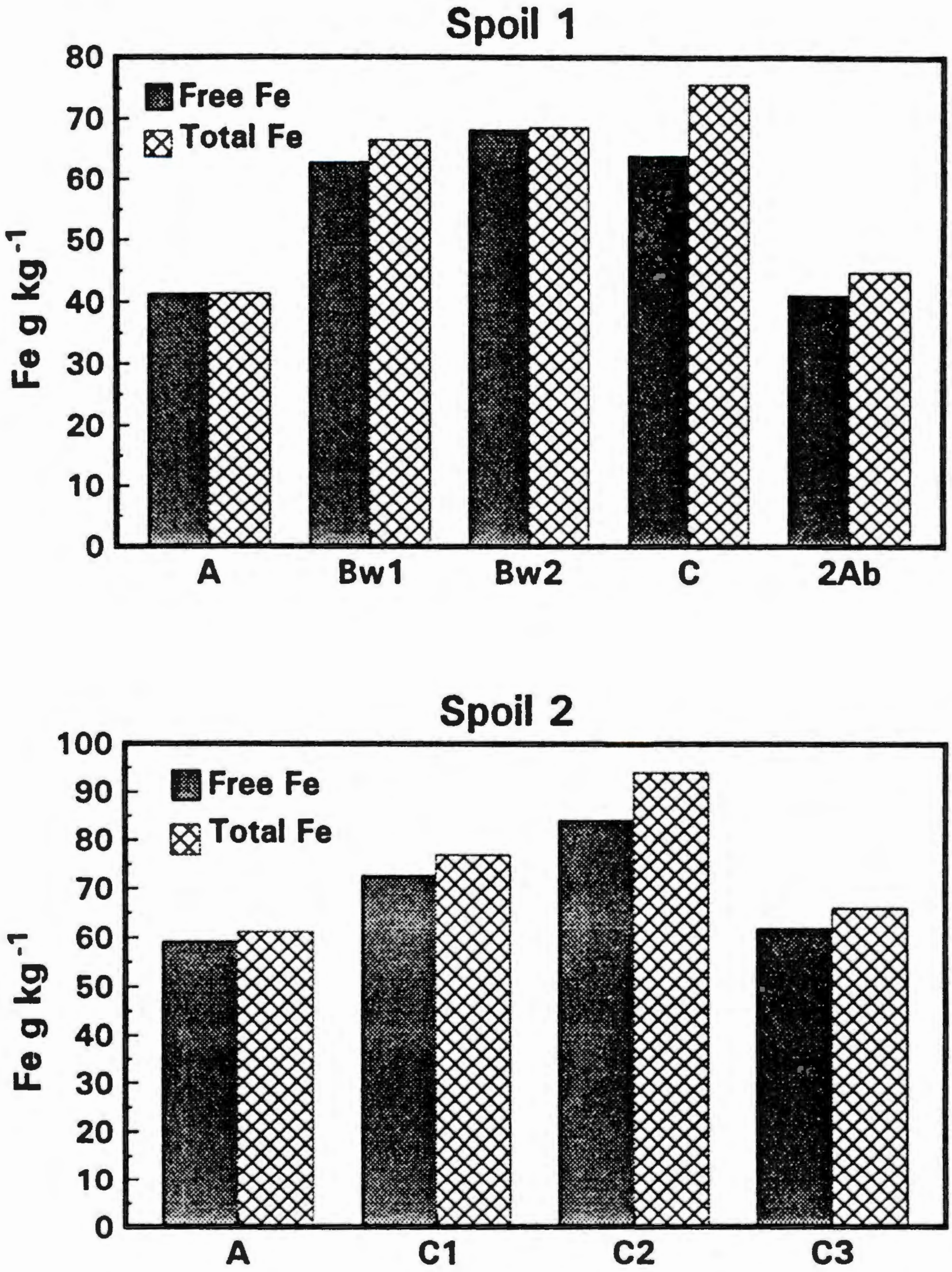


Figure 21. Free iron and total iron distribution for each horizon in spoils 1 and 2.

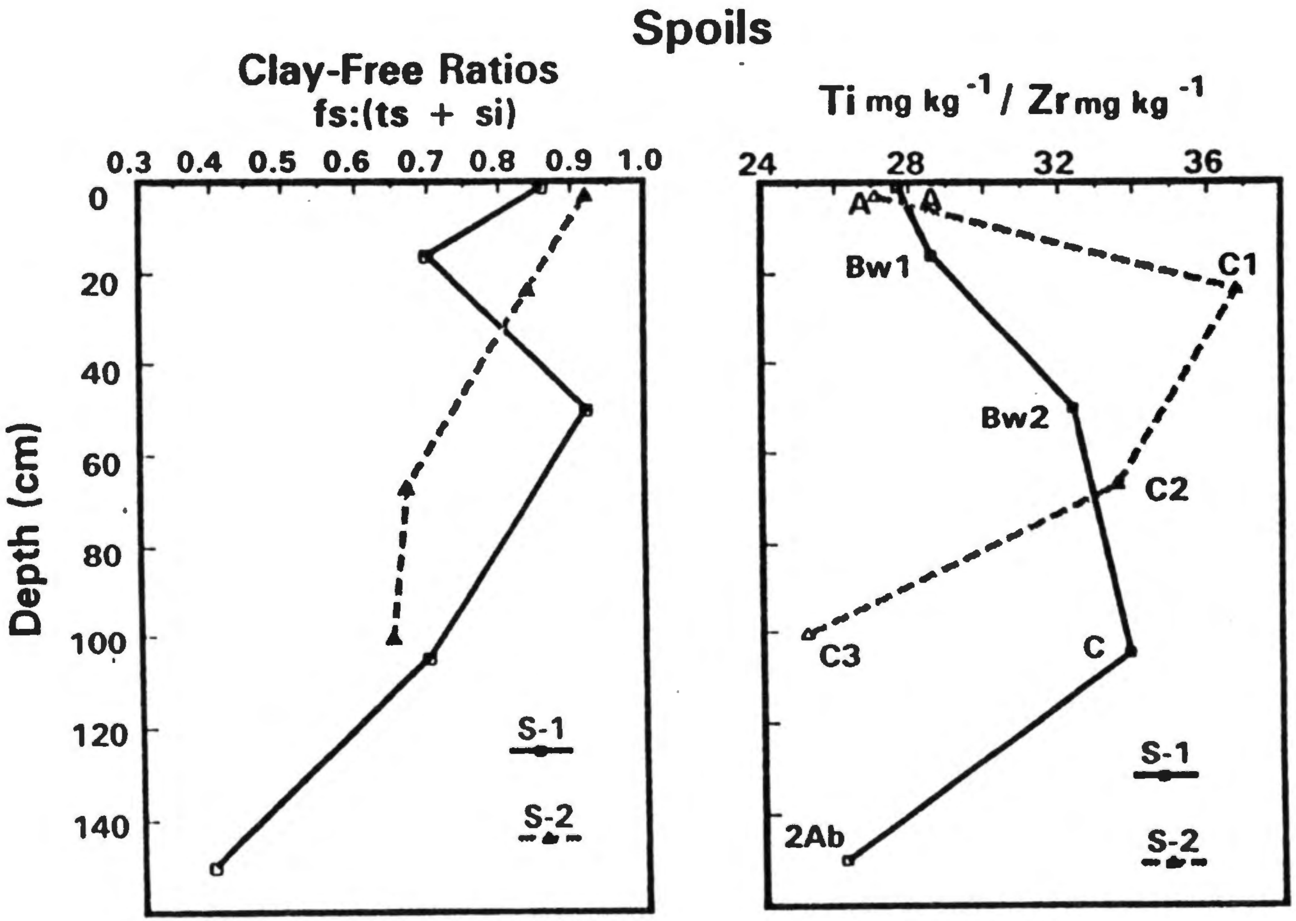


Figure 22. Clay free ratios of fine sand to total sand plus silt (fs:ts + si) and titanium to zirconium ratios (Ti/Zr) for indications of lithologic discontinuities in spoils 1 and 2.

Table 9. Chemical properties including exchangeable cations, base saturation, pH, and KCL total acidity of spoils 1 and 2.

		NH$_4$OAc Extractable Cations										
Horizon	Lower Depth	Ca	Na	K	Mg	Total Bases	NH$_4$OAc CEC	Base Saturation	pH 1:1 H$_2$O	Total Acidity	KCL Al^{3+}	H+
	cm	cmol$_c$ kg^{-1}						%		cmol$_c$ kg^{-1}		
Spoil 1												
A	2	19.71	0.27	0.46	4.19	24.64	32.54	75.7	5.1	0.06	0.08	0*
Bw1	30	0.43	0.04	0.22	0.67	1.36	12.48	10.9	4.3	5.93	8.07	0*
Bw2	70	1.63	0.22	0.22	1.95	4.02	11.92	33.7	4.7	2.80	3.74	0*
C	140	1.67	0.06	0.24	1.44	3.42	12.50	27.4	4.7	3.37	4.46	0*
2Ab	160+	0.97	0.08	0.19	1.04	2.29	10.83	21.1	4.9	3.12	4.14	0*
Spoil 2												
A	6	23.32	0.12	0.64	5.61	29.69	30.87	96.2	6.2	0.06	0.07	0.02
C1	41	5.73	0.07	0.53	3.30	9.63	14.22	67.7	5.7	0.03	0.06	0*
C2	93	1.32	0.05	0.24	0.98	2.58	9.62	26.8	4.6	2.87	3.90	0*
C3(R)	108	2.68	0.05	0.14	1.71	4.58	12.05	38.0	4.7	2.97	4.00	0*
C3(L)	108+	1.64	0.04	0.19	1.35	3.22	10.54	30.6	4.5	3.36	4.63	0*

*Indicates presence of free aluminum.

higher than the pH in the surface horizon of both native pedons. The pH throughout the rest of the profile was similar to that of the native pedons. The properties such as percent base saturation, pH, CEC, and total acidity in the A horizon of spoil 1 appear to be most strongly influenced by organic material while the same properties in the cambic and C horizon appear to be most influenced by the type of material the spoil formed in. Properties in the cambic and C horizon such as base saturation, CEC, pH, and matrix color greatly resembled those for the paleosols in native pedon 1 (2Bt) and native pedon 2 (3Bt) (Table 10). This indicates that the paleosols for both native pedons are the origin for the overburden material that spoil 1 formed in. This suggests that the red color, high clay content, high iron content, etc., in spoil 1 reflect the development of the spoil material prior to deposition in a spoil. This supports the assumption that spoil 1's overburden material originated from paleosol material.

Spoil 1 was classified as a clayey, mixed, thermic Typic Dystrochrept (Soil Survey Staff, 1994). The properties defined by the West Virginia Minesoil Classification System for Spolents described the properties in spoil 1 better than current Soil Taxonomy. An adaptation to the Spolent suborder was used to classify a minesoil, spoil 1, that met the criteria for an Inceptisol in Soil Taxonomy. The adapted suborder was termed "Spolept." The subgroup modifiers, reaction class, particle size and mineralogy categories used with Spolept were in accordance with the categories outlined for Spolents. Spoil 1

Table 10. Comparison of selected properties of the residual paleosol's in native pedons 1 and 2 to the cambic and C horizon in spoil 1.

Site	Horizon	Base Saturation	NH_4OAc CEC	pH 1:1 H_2O	Matrix color
N-1	2Bt	29.4	13.2	4.6	5YR 4/6
N-2	3Bt	28.9	11.2	4.7	5YR 4/6
S-1	Bw and C*	25.9	12.3	4.6	5YR 4/6, 7.5YR 3/1 2.5YR 4/8

*Results given are a weighted average for cambic and C horizon was classified as a clayey, mixed, acid, thermic Cherty Udispolept using the described adaptation of the West Virginia Minesoil Classification System.

Spoil 2

Spoil 2 developed in backfill material with abundant cherty coarse fragments. The chert fragments originated from limestone material originally underlying the iron ore before mining occurred. Coarse fragments in the upper portion of spoil 2 appeared less weathered than fragments at lower depths, reversing the weathering sequence expected from pedogenic processes. This suggests that during the mining process the material above the ore was removed and backfilled from higher depths to lower depths, so that material originally at a lower depth was deposited at the upper portion of the spoil, above material originally from a higher depth.

Profile textures ranged from clay loam in the surface to clay in all underlying C horizons (Table 11). Total silt made up less than 35% of total particle size distribution, the lowest of all four study pedons. The percent fine silt fractions in the surface horizon were almost identical between both spoils (Fig. 23 and 18). This suggests that the surface horizons of both spoils were influenced by similar material. Coarse fragments ranged between 38-80% throughout spoil 2' profile, with the lowest fragment content in the surface horizon (Table 8). The average coarse fragment content in the upper 1 m of spoil 2 was approximately double that in the upper 1m in native pedons 1 and 2

Table 11. Morphology of spoil pedon 2.*

Horizon	Lower Depth	Color	Texture	Structure	Bridging Voids	Boundary	Consistence	Mn Concr.†	Mottles
	cm	moist					moist		
Oe	2-0								
A	6	10YR 3/4	gr. CL	2 mgr	....	cw	vfr	....	....
C1	41	7.5YR 5/6	ex.cob. C	0 m	few	cs	fr	c,f	m,p 2.5YR 4/8
C2	93	7.5YR 4/4** 2.5YR 4/8	vgr. C	0 m	few	cw	fr	c,f	c,d 7.5YR 5/8 c.d 7.5YR 3/2
C3(L)»	108	10YR 4/6	vgr. C	0 m	....	cs	fr	c,f	c,p 7.5YR 6/8
C3(R)»	108+	7.5YR 5/6	ex.gr. C	0 m	....	....	fr	....	f,p 2.5YR 4/6

*Abbreviations for morphology designations are given in Appendix A

† Manganese concretions

**Mottled matrix color

»Material contrasted in horizon between left and right portion of the profile

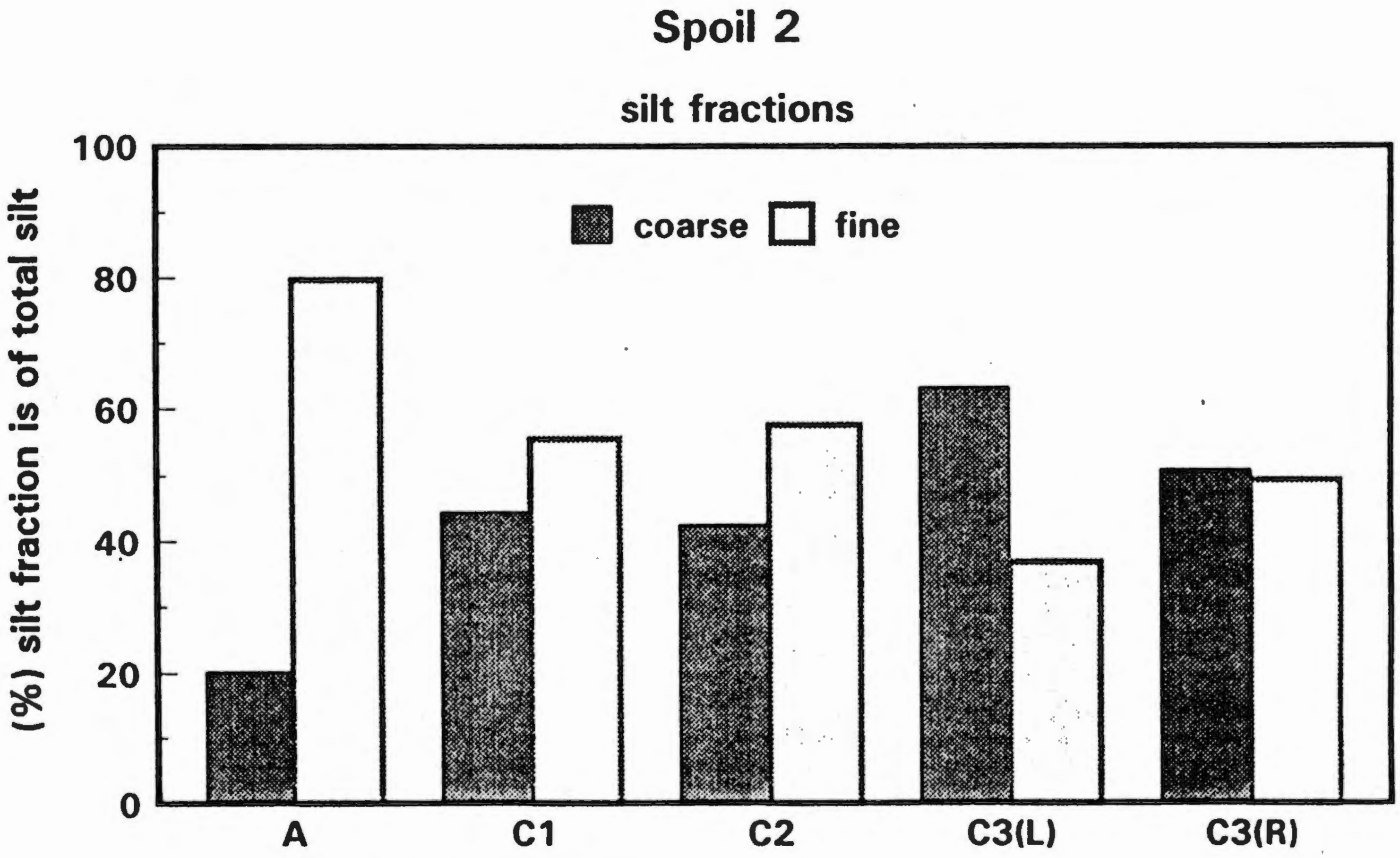


Figure 23. Coarse silt and fine silt fractions as a percent of total silt for spoil 2.

and spoil 1. Diagnostic subsurface horizons did not develop in this material. Horizonization included a thin A over three C horizons (Table 11). Moderate medium granular structure was observed in the surface horizon of spoil 2. The thickness of the surface horizon in spoil 2 was approximately 3 times that of spoil 1. Spoil 1 was positioned at the shoulder of a hollow, more susceptible to surface erosion, which most likely accounts for the difference in A horizon thickness between the spoils. Material in horizon C3 contrasted enough from the left side of the profile to the right that it was described separately as left [C3(L)] and right [C3(R)] (Table 10). Massive structure was observed in all the C horizons. Bridging voids (packing voids), averaging 1cm in diameter, were present in the C1 and C2 horizons. Voids were less abundant than in spoil 1.

Carbon fragments that appeared to have been burned were present throughout the profile. Color mottling was excessive (more abundant) in spoil 2 compared to the native pedons and spoil 1. Mottling occurred in all C horizons especially C2, which had a mottled matrix color described with two additional mottle colors. One of the mottle colors indicated possible drainage problems which were observed to be localized in pockets. Manganese concretions coincided in the areas of the low chroma mottles. The depths at which the low chroma mottles and manganese concretions occurred indicated spoil 2 had slow hydraulic conductivity while the native pedons and spoil 1 were assessed as having moderate hydraulic conductivity. Presumably, the non-low chroma mottles originated from the mixing of contrasting material during deposition of the spoil.

Distribution of fine clay to total clay ratios within spoil 2 did not change much between horizons and slowly increased with depth (Fig. 20). Translocation of free iron, and fine clay has not occurred enough in the subsoil to form soil structure or a diagnostic subsurface horizon.

Clay free ratios did not fluctuate drastically throughout the profile but slowly decreased with soil depth (Fig. 22). Titanium to zirconium ratios identified changes between each described C horizon, suggesting non-uniformity in development and/or parent material source. The magnitude of change of Ti/Zr values between horizons was greater than those for both native pedons and spoil 1. This erratic distribution with depth in spoil 2 suggests an abundant amount of contrasting material was mixed together in the spoil material during deposition.

Similar to spoil 1, total carbon content was highest in the surface of spoil 2's profile, approximately 3 times greater than the native surface horizons, and slowly decreased throughout the rest of the profile (Fig. 13). Percent base saturation was highest in the surface of spoil 2, approaching 100% (Table 9). Concentrations of exchangeable cations were also highest in the surface horizon. The surface and C1 horizon pH was higher than the highest pH in spoil

1 and higher by approximately 1 pH unit compared to the native pedons highest pH. Similar to spoil 1, properties in the surface horizon appear to be most influenced by the presence and characteristics of organic matter.

Spoil 2 was classified as a clayey-skeletal, mixed, acid thermic Typic Udorthent (Soil Survey Staff, 1994). The criteria for the Spolent suborder were applicable to spoil 2 and described them better than *Soil Taxonomy.* The following properties were observed throughout the profile: color mottling not associated with horizonization, disordered coarse fragments, sharp edges on the coarse fragments, thin surface horizon higher in fines, pockets of contrasting materials, and presence of artifacts in the form of burned carbon fragments. Seven of the nine defined properties for Spolents were met (only 3 required). Spoil 2 was classified as a clayey-skeletal, mixed, acid, thermic Cherty Udispolent using the West Virginia Minesoil Classification System.

Comparison of Morphology and Properties of All Sites

Total barium (Ba) was highest in the surface horizons of both native pedons (Table 12 and 13). Distribution of total barium with soil depth differed between the spoils and native pedons (Fig. 19). Total barium almost doubled in the buried A horizon of spoil 1 but not in the buried A horizon of native pedon 2. Total manganese (Mn) and manganese oxide (HCL-hydroxylamine) concentrations were significantly highest in the surface horizons of all four

Table 12. Total elemental concentrations determined using an acid digestion technique for native pedons 1 and 2.

Horizon	Lower Depth	Al	Fe	K	Ba	Ca	Co	Cr	Cu
	cm		g kg^{-1}				mg kg^{-1}		
Native 1									
A	16	27.2	17.7	9.3	420	4,510	50	30	70
EB	35	33.8	22.3	9.6	370	1,250	10	40	<2
Bt1	60	51.2	36.5	9.4	320	2,030	<3	70	<2
Bt2	78	61.4	38.9	10.4	280	1,190	20	70	10
BC	94	44.5	29.9	9.9	220	1,520	10	50	10
2Bt	116+	71.6	43.1	12.0	240	1,150	<3	80	<2
LSD*$_{.05}$		2.6	2.2	1.5	90	750	30	10	5
Native 2									
A	21	29.6	23.3	11.2	500	1,240	30	30	20
BE	32	42.2	25.3	13.4	460	930	20	30	20
Bt	58	49.7	37.5	11.8	390	1,200	20	40	20
2Ab	95	32.8	29.4	8.9	290	890	20	30	10
3Bt	108+	71.1	59.1	11.9	260	1,000	10	90	5
LSD*$_{.05}$		1.1	1.6	0.6	170	360	10	10	20

*LSD= Least Significant Difference calculated using PC SAS (SAS Institute Inc., 1988). If the difference between horizon values is greater than the LSD, the values are significantly different at an alpha level of 0.05.

Table 12. (continued)

Horizon	Lower Depth	Mg	Mn	Na	Ni	P	S	Sr	Ti	Zn	Zr
	cm					mg kg^{-1}					
Native 1											
A	16	1,270	1,560	5,560	30	250	870	80	1,580	80	80
EB	35	1,480	600	1,910	30	190	120	30	2,340	40	100
Bt1	60	2,700	140	1,060	60	220	270	50	1,920	210	80
Bt2	78	3,080	160	620	50	230	270	60	2,020	200	80
BC	94	2,810	110	360	60	80	650	60	1,520	130	60
2Bt	116+	3,930	80	260	60	300	470	50	2,050	220	80
LSD$_{.05}$		170	50	1,400	20	80	290	30	200	70	10
Native 2											
A	21	1,310	1,230	3,200	20	70	120	60	2,190	50	100
BE	32	1,940	620	2,840	20	50	100	50	2,600	160	110
Bt	58	2,680	510	2,040	20	<5	100	50	2,770	60	110
2Ab	95	1,670	480	1,440	20	<5	40	40	2,130	60	90
3Bt	108+	3,340	90	270	40	90	100	70	2,480	120	80
LSD$_{.05}$		200	20	870	20	30	100	20	90	160	5

Table 13. Total elemental concentrations determined using an acid digestion technique for spoils 1 and 2.

Horizon	Lower Depth	Al	Fe	K	Ba	Ca	Co	Cr	Cu
	cm		g kg^{-1}				mg kg^{-1}		
Spoil 1									
A	2	30.9	41.2	4.9	280	5,790	30	40	40
Bw1	30	66.3	66.4	8.6	250	750	10	60	5
Bw2	70	62.1	68.5	4.9	280	1,040	10	50	10
C	140	58.4	75.6	6.8	260	780	20	40	10
2Ab	160+	51.1	44.7	12.0	450	870	20	30	10
LSD$_{.05}$*		16.5	12.4	0.6	170	520	20	10	30
Spoil 2									
A	6	39.4	61.1	8.6	280	8,670	<3	60	30
C1	41	73.0	76.9	13.1	230	2,100	<3	100	<2
C2	93	72.0	94.0	9.0	280	810	20	60	<2
C3(L)	108+	92.6	65.9	11.6	360	1,200	10	120	10
C3(R)	108+	73.1	53.0	14.8	280	970	20	110	10
LSD$_{.05}$*		2.0	1.6	0.7	10	140	5	10	10

***LSD= Least Significant Difference calculated using PC SAS (SAS Institute Inc., 1988). If the difference between horizon values is greater than the LSD, the values are significantly different at an alpha level of 0.05.**

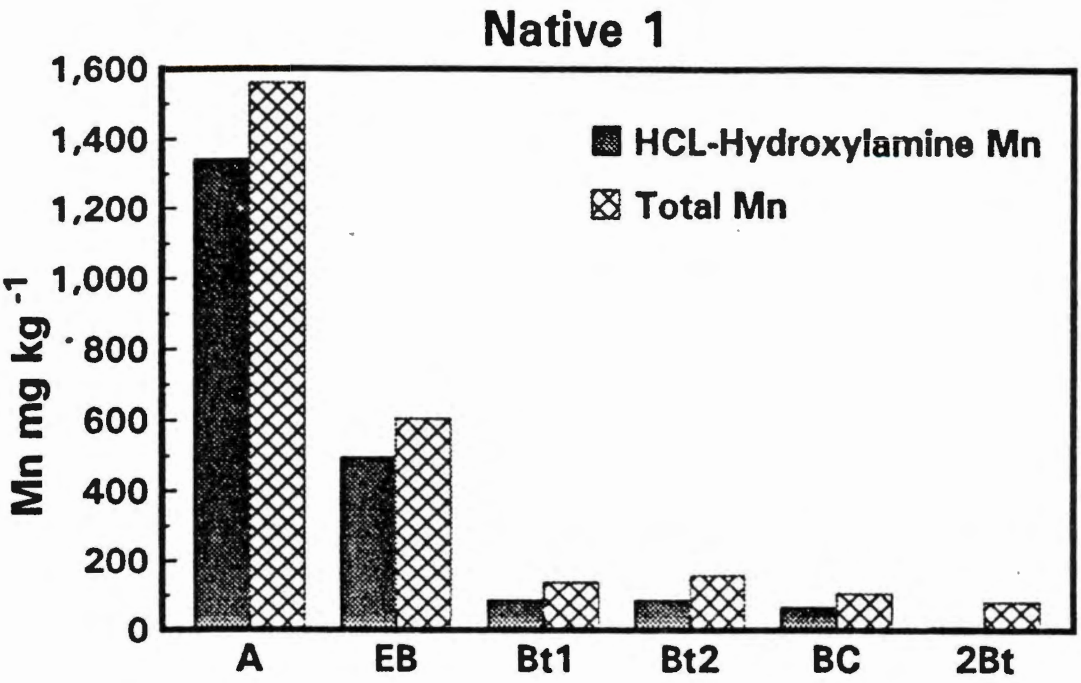
Table 13. (continued)

Horizon	Lower Depth	Mg	Mn	Na	Ni	P	S	Sr	Ti	Zn	Zr
	cm					mg kg^{-1}					
Spoil 1											
A	2	1,580	820	1,980	20	520	770	70	1,330	140	50
Bw1	30	2,400	380	990	40	110	150	40	2,660	150	90
Bw2	70	2,280	310	870	40	130	110	30	2,820	120	90
C	140	2,180	490	750	40	60	80	40	2,820	90	80
2Ab	160+	2,330	780	2,380	30	30	10	50	2,720	50	100
LSD$_{.05}$		230	120	1,090	20	140	70	30	170	60	10
Spoil 2											
A	6	2,930	1,510	3,890	40	700	1,130	60	980	240	40
C1	41	4,290	790	400	60	580	30	70	2,610	290	70
C2	93	2,180	630	1,040	30	180	110	60	2,690	160	80
C3(L)	108+	3,580	180	360	70	750	180	150	2,650	260	100
C3(R)	108+	4,290	690	320	80	530	50	70	1,900	380	80
LSD$_{.05}$		70	100	90	20	100	90	5	970	70	10

pedons and generally decreased with depth, with the exception of spoil 1 (Fig. 24 and 25). In spoil 1, total manganese and manganese oxide concentrations significantly increased in the buried A from overlying subsurface horizons. Differences in clay content, organic matter content, and coarse fragments between the buried A horizon in native pedon 2 and spoil 1 probably accounts for the differences in their trace element concentration (Table 4,6, and 7; Fig. 13). Lower clay content, lower total carbon content, differences in parent material, and higher coarse fragment contents in the buried horizon in native pedon 2 presumably reduced its ability to retain trace elements.

Total arsenic (As), cadmium (Cd), molybdenum (Mo), and lead (Pb) were below detectable levels in all samples (As=< 50, Cd=<2, Mo=< 5, and Pb=< 25) (Tables 12 and 13). Total copper (Cu) was significantly higher (α= 0.05) in the surface horizon compared to the subsurface in native pedon 1 and both spoils. Total chromium was irregularly distributed in both spoils. In the native pedons, total chromium (Cr) was significantly higher in the argillic horizons compared to adjacent horizons and more than doubled in the argillic horizons of the paleosol compared with the overlying horizons in native pedon 1 and 2.

Total iron and free iron concentrations in both spoil profile's were approximately double that of the native pedons (Fig. 12 and 21; Table 12 and 13). An "enrichment" of iron oxides was expected in the spoils due to their parent material source having been associated with mining of the iron ore.



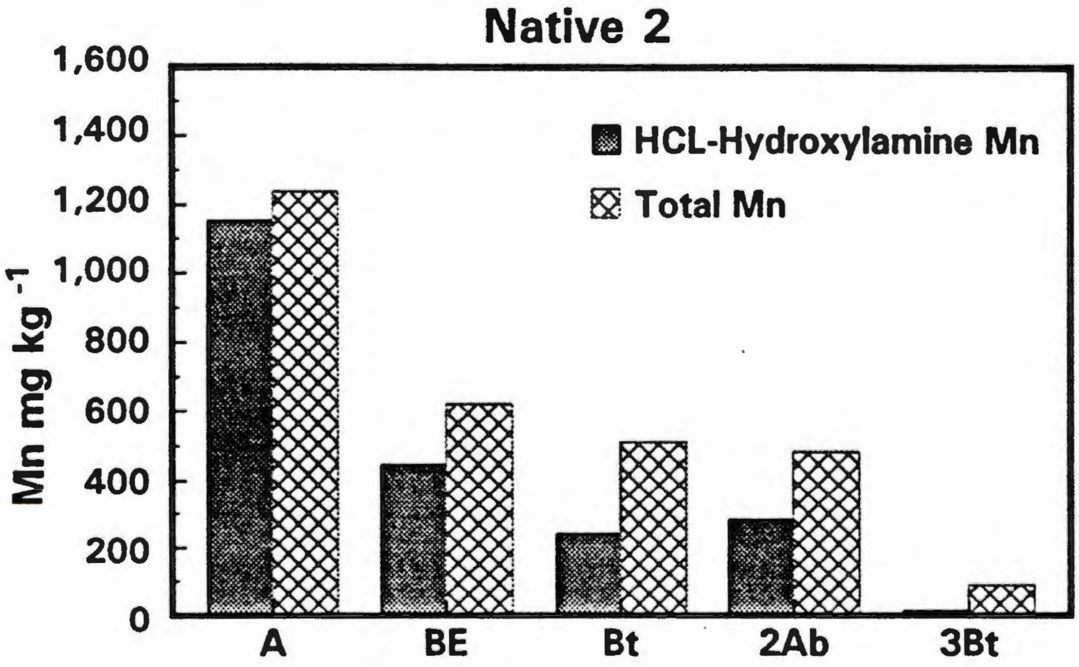


Figure 24. Total manganese and HCL-hydroxylamine manganese for each horizon in native pedons 1 and 2.

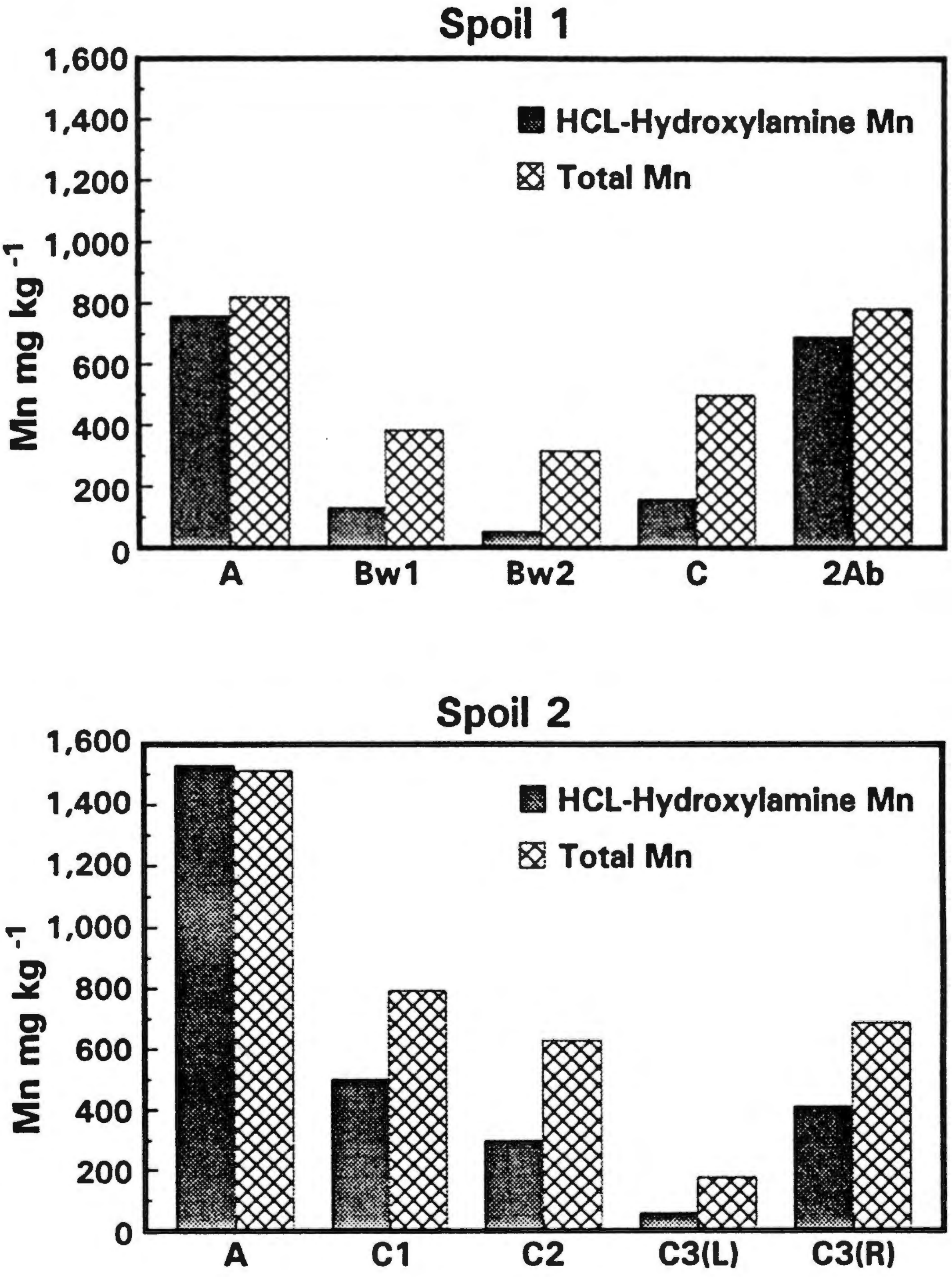


Figure 25. Total manganese and HCL-hydroxylamine manganese for each horizon in spoils 1 and 2.

Distribution of sulfur by depth differed between the native pedons and the spoils. Total sulfur (S) was significantly highest in the surface horizons of the spoils.

Morphological, physical, and chemical differences between the spoils reflected differences in source of overburden material and differences in the degree of weathering of those materials prior to placement in a spoil. Properties in the cambic and C horizon of spoil 1 which include percent base saturation, CEC, pH, and matrix color closely resembled those for the paleosols in native soil 1 (2Bt) and native 2 (3Bt) (Table 10). The paleosols in both native pedons are presumed to be the origin for the overburden material in which spoil 1 formed. The high clay content, red color, high free iron content, and total iron content in spoil 1 reflect the maturity of the material prior to placement in a spoil and not development after placement in a spoil.

Both native pedons classified differently at the family level due mostly to parent material differences which were due mostly to landscape position. The particle size class was fine-silty for native soil 2 compared to clayey for native 1. Fine clay to total clay ratios, free iron, and CEC distribution by depth were similar within native pedon 2 (Fig. 11). The same properties graphed for native pedon 1 showed a similar pattern with the exception of the EB horizon. Fine clay, free iron, and CEC reached maximum concentrations in the argillic horizons of both native pedons.

Both native profiles had similar percent base saturation. Percent base saturation in their surface horizons equaled 19.8% and 20.3% and both ranged between a low of 22% to a high of 36% throughout the rest of the profiles (Table 5). Base saturation in the surface horizons for both spoils (76% and 96%) was more than three times higher than that of the native pedons (Table 9).

Soil pH's consistently ranged between 4 and 5 for both native pedons. Soil pH in the surface of the spoils was approximately 1 unit higher than in the surface of the native pedons. Soil pH in the subsoil of the spoils was within the same range as the native pedons.

Sum of cations for the native pedons was 1.60 and 1.28 cmol$^+$ kg^{-1} soil while that for the spoils was 24.64 and 29.69 cmol$^+$ kg^{-1}(Table 5 and 9). The weighted average of total phosphorus for the upper 50 cm of spoil 2 was more than doubled that of both native pedons and higher than spoil 1 (Table 12 and 13). The weighted averages of total calcium and magnesium in the upper 50cm were almost double in spoil 2 compared to the native pedons, and higher than those for spoil 1. Higher percent base saturation and lower total acidity in the surface of the spoils corresponded with higher pH's.

Comparison of Homogeneity of Variances for Grid Samples

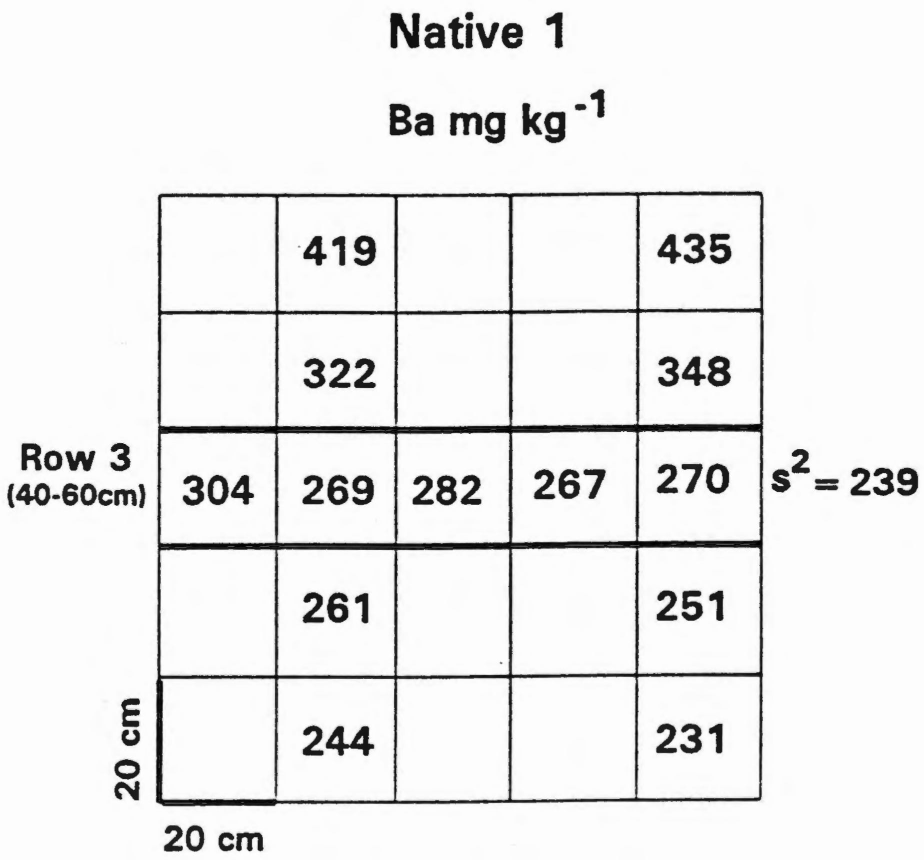
Variances for total carbon (%), total aluminum, barium, manganese, phosphorus, titanium, and zirconium for row 3 of each pedon are given in Table 14. Figure 26 provides an example of the calculation for variance of total barium

Table 14. List of variances of total elemental concentrations of selected elements for row three of the grid samples for each site.

Site	% total carbon	Al	Ba	Mn	P	Ti	Zr
N-1[*]	0.00108	36,038,756	239	1,386	3,183	20,020[>]	22[>]
N-2[*]	0.00035	2,148,152	432	3,922	998	2,277	11
S-1[*]	0.00012	1,331,036	4,296[>]	5,169	3,683	12,514	5
S-2[*]	0.00168[>]	41,007,131[>]	1,796	7,865[>]	10,564[>]	12,047	22[>]

[*] Degrees of freedom for all sites = 4 (5 - 1).

[>] Largest variation of all sites for selected elemental concentration



Native 1

Ba mg kg^{-1}

		419			435	
		322			348	
Row 3 (40-60cm)	304	269	282	267	270	$s^2 = 239$
		261			251	
		244			231	

Figure 26. The variance of total barium in row 3 (40-60cm) of the sampling grid in native pedon 1.

in row 3 of native pedon 1 which represents the method used for the other profiles. Sources of variation for the variable being measured, such as from sampling, analytical technique, instrumentation, etc., should have been similar for all four pedons. Spoil 2 had the highest variances for five of the selected 7 elemental analysis and shared the highest variance for zirconium distribution with native pedon 1. These higher variations correspond with suspected large amounts of contrasting material in spoil 2's profile, as indicated by the excessive color mottling. Note that the highest variation for each selected chemical properties measured in row 3 did not occur in native pedon 2.

Hartley's test of the homogeneity of variances between two sites indicated which of the variances given in Table 14 were significantly different from each other (Table 15). Variation of manganese and zirconium in row 3 were not significantly different at α=0.05 between any of the sites. Although the variances (α=0.05) at the chosen depth in the spoils were generally higher compared to the native pedons, they were not consistently significantly different between them. The trend of the distribution of total carbon (%), total aluminum, barium, manganese, phosphorus, titanium, and zirconium by depth (from the columns) were similar to the morphology results discussed previously.

Table 15. List of calculated F values, using Hartley's test of homogeneity of variances, between all sites.

Between Sites	% total carbon	Al	Ba	Mn	P	Ti	Zr
				F_c			
N1/N2	3.0	**16.8***	1.8	2.8	3.2	**8.8***	2.0
N1/S1	**9.0***	**27.1***	**17.9***	3.7	1.2	1.6	4.4
N1/S2	1.6	1.4	**7.5***	5.7	3.3	1.7	1.0
N2/S1	2.9	1.6	**9.9***	1.3	3.7	5.5	2.2
N2/S2	4.8	**19.0***	4.2	2.0	**10.6***	5.3	2.0
S1/S2	**14.0***	**30.0***	2.4	1.5	2.9	1.0	4.4

*Calculated F value exceeded tabular F value at a 95% confidence level ($F_{\alpha=0.05\ df\ 4,4} = 6.4$) indicating a significant difference between the variations for the two sites for that elemental concentration.

Conclusions

1. Fine clay, free iron, and CEC distribution by soil depth in the native pedons were similar. Fine clay, free iron, and CEC reached maximum concentrations in the argillic horizons of both native pedons.

2. Total carbon content was highest in the surface horizons of both native pedons and spoils. The distribution of total carbon steadily decreased from the surface to lower depths in the native pedons. Total carbon slowly decreased from the surface of the spoils to lower depths in the profile. The amount of total carbon was approximately 3 times higher in the surface horizon of both spoils than in the native pedons. Distribution of organic matter has not reached an equilibrium in the subsoil of the spoils but has reached an equilibrium in the subsurface of both native pedons.

3. Spoil 1 developed in highly pre-weathered material originating from a backfilled paleosol. Spoil 2 developed in more fragmented and less pre-weathered cherty material. The differences in origin of overburden material and the degree of weathering prior to placement in a spoil accounted for morphologic and chemical differences between spoil 1 and 2.

4. The total clay content, fine clay content, total iron, and free iron content in the paleosol of native pedon 1(2Bt) and native pedon 2 (3Bt) corresponded well with those in spoil 1. The buried paleosols in the native pedons are the origin of overburden material in which spoil 1 formed.

5. Bridging voids, averaging about 1 cm in diameter, were found in both spoils. Voids were not present in either native pedon.

6. Moderate medium granular structure formed in the surface horizons of both spoils. The same structure occurred in the surface horizons of the native pedons. Coarse fragment concentrations were the lowest in the surface horizons in both spoils compared to the subsoil.

7. Subsoil structure observed in spoil 1 was better described by the "artificial minesoil" structure termed "fritted" proposed by McSweeney and Jansen (1984) than the morphology structures outlined in *Soil Taxonomy*. Massive structure, color mottling, and high concentrations of coarse fragments (averaging 40-69%) were observed throughout spoil 2. These properties and the titanium to zirconium ratio distribution with soil depth are the result of an abundance of contrasting and fragmented material having been mixed together in the spoil material during the deposition of spoil 2.

8. Properties such as percent base saturation, CEC, pH, and color in the surface horizons of both spoils were mostly influenced by organic matter. The same properties in the argillic horizons of the native pedons were influenced mostly by mineralogical and physical properties.

9. A cambic horizon developed in spoil 1. A diagnostic subsurface horizon did not develop in spoil 2. The "fritted" structure with a loose (noncoherent) consistence observed in spoil 1, not present in spoil 2, accelerated the rate of fine clay and free iron movement to the degree of forming a weakly developed cambic horizon within 140-170 years.

10. Burned carbon fragments were found throughout spoil 2 indicating the area had probably been burned prior to or during mining processes.

11. Total iron concentrations were approximately doubled in the upper 1 meter of the spoils compared to the native pedons. The association of the spoil material with the iron ore during the mining process enriched the spoil materials with iron oxides.

12. Surface pH was approximately 1 unit higher in the spoils than in the native pedons. Higher pH's in the surface of the spoils compared to native soils corresponded well with marked higher concentrations of exchangeable and total extractable basic cations in those horizons.

13. Clay free ratios of fine sand to total sand plus silt and titanium to zirconium (Ti/Zr) ratios consistently identified either differences between horizons and/or lithologic discontinuities of parent material designated by morphology for all study sites.

14. Classification of all four pedons using Soil Taxonomy were as follows:
Native 1- clayey, mixed, thermic Typic Hapludult
Native 2- fine-silty, mixed, thermic Typic Hapludult
Spoil 1- clayey, mixed, thermic Typic Dystrochrept
Spoil 2- clayey-skeletal, mixed, acid, thermic Typic Udorthent

15. Properties defined for the Spolent suborder, of the West Virginia Minesoil Classification System, better described the spoil properties than *Soil Taxonomy*. An adaptation to the Spolent suborder was used and termed Spolept to classify a minesoil that met the criteria for an Inceptisol in *Soil Taxonomy*. A subgroup and reaction class identical to that used with Spolent was used with the Spolept suborder.

16. The methodology of classifying the spoils using the West Virginia Minesoil Classification System paralleled that of *Soil Taxonomy*. It should be relatively easy to incorporate into the current *Soil Taxonomy* because it functions within the same format (parameters).

17. Both spoils only had one type of rock group, chert fragments, which did not fit the defined subgroups of the West Virginia Classification System. A new subgroup of Cherty was used to specifically identify rock type when no more than one rock type was present in the particle size control section.

18. Spoil 1 was classified as a clayey, mixed, acid, thermic Cherty Udispolept using an adaptation of the West Virginia Minesoil Classification System. Spoil 2 was classified as a clayey-skeletal, mixed, acid, thermic Cherty Udispolent using the West Virginia Minesoil Classification System.

19. Total manganese was significantly highest in the surface horizons of both spoils and native pedons (using LSD at $\alpha = 0.05$). Total barium was highest in the surface horizon of the native pedons but was not similarly distributed by depth in the spoils. Total sulfur was significantly higher in the surface horizon of

the spoils but was not in the native pedons. Of the trace elements, total barium and manganese best identified the buried A horizon in spoil 1.

20. Variations for seven selected chemical analyses within the depth of 40-60cm were not consistently significantly different between spoils and native pedons at a 0.05 alpha level.

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APPENDICES

APPENDIX A
Definition of Abbreviations used in Soil Morphology

APPENDIX A: Definition of Abbreviations used in Soil Morphology

I. Soil Texture

A. Modifiers of soil texture
gr. = gravelly
vgr. = very gravelly
ex.gr. = extremely gravelly
v.cob. = very cobbly

B. Textural class
SiL = silt loam
SiCL = silty clay loam
SiC = silty clay
CL = clay loam
C = clay

II. Soil Structure

A. Grade of structure
1 = weak
2 = moderate

B. Class of structure
f = fine
m = medium

C. Type (shape) of structure
gr = granular
sbk = subangular blocky

III. Moist Consistence

vfr = very friable
fr = friable
fi = firm
l = loose

IV. Boundary

cw = clear wavy
cs = clear smooth
as = abrupt smooth
gs = gradual smooth
gw = gradual wavy

V. Color mottles

f, p = fine, prominent
c, p = common, prominent
c, d = common, distinct
m, p = many, prominent
m, d = many, distinct

APPENDIX B
Soil Profile Descriptions

SAMPLED BY: S. Gaither, J.T. Ammons, J.L. Branson, D.E. McMillen, and S.E. Gaither in May, 1994

TOPOGRAPHICAL QUADRANGLE: Burns, Tennessee

AREA: Montgomery Bell State Park. Within 800 meters of remnants of Laurel Furnace and Jones Creek and Jackson Cemetery

APPENDIX B-1: Soil Profile for Native 1.

PEDON: Native 1
TAXONOMY CLASSIFICATION: clayey, mixed, thermic Typic Hapludult
DOMINANT SITE VEGETATION: sugar maple, white oak, yellow poplar, and mayapple
PHYSIOGRAPHY: convex side slope
PARENT MATERIAL: colluvium over paleosol
LATITUDE/LONGITUDE: 87° 17' 18" N 36° 5' 41" W
ELEVATION: 207 m (680 ft) above mean sea level
INFILTRATION RATE: moderate
AVAILABLE WATER: borderline of moderate to high (22.5cm)
HYDRAULIC CONDUCTIVITY: moderate
SOIL WETNESS CLASS: class 1 (not wet above 150cm)
SLOPE: 24%
EROSION: none to slight
SURFACE RUNOFF: very rapid

A	0-16 cm; dark yellowish brown (10YR 4/4) silt loam; moderate, medium, granular; very friable; clear, wavy boundary; many, medium roots, and few, coarse roots, and common, fine roots; pH= 4.7
EB	16-35 cm; strong brown (7..5YR 5/6) silt loam; weak, medium, granular; very friable; clear, wavy boundary; many, medium roots; pH=4.8
Bt1	35-60 cm; yellowish red (5YR 5/6), common distinct mottles (7.5YR 5/6), gravelly silty clay loam; weak, medium, subangular blocky; friable; clear, wavy boundary; common, medium roots; common, fine manganese concretions; pH=4.7
Bt2	60-78 cm; strong brown (7.5YR 5/6)and (5YR 5/8), few prominent mottles (10R 4/8), clay; weak medium, subangular; firm; clear, wavy boundary; common, medium roots; pH=4.7
BC	78-94 cm; brownish yellow (10YR 6/6), common prominent mottles (5YR 5/8), very gravelly clay; weak, fine, subangular blocky; very friable; clear, wavy boundary; pH=4.6
2Bt	94-116+ cm; yellowish red (5YR 4/6), common prominent mottles (10YR 6/6), gravelly clay; moderate, medium, subangular blocky; firm; pH=4.6

APPENDIX B-2. Soil Profile for Native 2.

PEDON: Native 2
TAXONOMY CLASSIFICATION: fine-silty, mixed, thermic Typic Hapludult
DOMINANT SITE VEGETATION: sugar maple, chestnut oak, yellow poplar, red maple
PHYSIOGRAPHY: upland
PARENT MATERIAL: loess over residual paleosol
LATITUDE/LONGITUDE: 87^0 17' 37" N 36^0 5' 38" W
ELEVATION: 237 m (780 ft) above mean sea level
INFILTRATION: moderate
AVAILABLE WATER: moderate (18.1 cm of water)
HYDRAULIC CONDUCTIVITY: moderate
SOIL WETNESS CLASS: class 1 (not wet above 150 cm)
SOIL SLOPE: 3%
EROSION: none to slight
SURFACE RUNOFF: medium

A	0-21 cm; dark yellowish brown (10YR 4/4) silt loam; moderate, medium, granular structure; very, friable; clear, smooth boundary; many, medium roots and common, fine roots; pH=4.5
BE	21-32 cm; strong brown (7.5YR 4/6) silt loam; weak, medium subangular blocky; friable; clear, smooth boundary; few, coarse roots and common, medium roots; pH=4.5
Bt	32-58 cm; brown (7.5YR 4/4) silty clay loam; moderate, medium subangular blocky structure; friable; clear, wavy boundary; few, coarse roots and common, medium roots; pH=4.7
2Ab	58-95 cm; yellowish brown (10YR 5/4) gravely silt loam; weak, fine granular structure; very friable; clear, smooth boundary; few, medium roots; pH=4.7
3Bt	95-108+ cm; yellowish red (5YR 4/6), few prominent mottles (10YR 6/6), very cobbly clay; moderate, medium subangular blocky structure; firm; few, medium roots; pH=4.7

Additional notes: The properties in the 3Bt resembled those of the 2Bt in native pedon 1 and the cambic and C horizon in spoil 1.

APPENDIX B-3. Soil Profile for Spoil 1.

PEDON: Spoil 1
TAXONOMY CLASSIFICATION: clayey, mixed, thermic Typic Dystrochrept
MINESOIL CLASSIFICATION USING A W.VIRGINIA UNIV. SYSTEM: clayey, mixed, acid thermic Cherty Udispolept
DOMINANT SITE VEGETATION: white oak, yellow poplar, red maple, sugar maple, northern red oak, dogwood, and american hornbeam
PHYSIOGRAPHY: upland
PARENT MATERIAL: pre-weathered brown iron ore spoil material
LATITUDE/LONGITUDE: 87^{0} 17' 32" N 36^{0} 5' 42" W
ELEVATION: 219 m (720 ft) above mean sea level
INFILTRATION: moderate
AVAILABLE WATER: moderate (21.2 cm)
HYDRAULIC CONDUCTIVITY: moderate
SOIL WETNESS CLASS: class 1 (not wet above 150cm)
SOIL SLOPE: 5%
EROSION: non to slight
SURFACE RUNOFF: medium

A 0-2 cm; very dark gray (7.5YR 3/1) clay loam; moderate, medium granular structure; very friable; abrupt, smooth boundary; common, medium roots and many, fine roots; pH=5.1

Bw1 2-30 cm; yellowish red (5YR 4/6), common distinct mottles (7.5YR 4/4), silty clay; moderate, medium granular structure; loose; clear, smooth boundary; common, medium roots and few, fine roots; common, fine manganese concretions; few bridging voids; pH=4.3

Bw2 30-70 cm; red (2.5YR 4/8), many distinct mottles (7.5YR 4/4), very gravely silty clay; moderate, medium granular structure; loose; gradual, smooth boundary; few, fine roots; common bridging voids; pH=4.7

C 70-140 cm; dark red (2.5YR 3/6), common distinct mottles (7.5YR 4/6), silty clay loam; moderate, medium granular structure; loose; gradual, wavy boundary; common, fine roots; common bridging voids; pH=4.7

2Ab 140-160+ cm; brown (7.5YR 4/4) silty clay loam; moderate, medium granular structure; friable; few, fine roots; pH=4.9

Additional Notes: Overburden material in which spoil formed was highly pre-weathered prior to placement (originally paleosol material)

APPENDIX B-4. Soil Profile for Spoil 2.

PEDON: Spoil 2
TAXONOMY CLASSIFICATION: clayey-skeletal, mixed, acid, thermic Typic Udorthent
MINESOIL CLASSIFICATION USING A W.VIRGINIA UNIV. SYSTEM: clayey-skeletal, mixed, acid thermic Cherty Udispolent
DOMINANT SITE VEGETATION: yellow poplar, sugar maple, dogwood, poison ivy, and virginia creeper
PHYSIOGRAPHY: hollow of drainage way
PARENT MATERIAL: cherty clayey brown iron ore spoil
LATITUDE/LONGITUDE: 87^0 17' 40" N 36^0 5' 43" W
ELEVATION: 213 m (700 ft) above mean sea level
INFILTRATION: moderate
AVAILABLE WATER: low (11.1 cm)
HYDRAULIC CONDUCTIVITY: slow
SOIL WETNESS CLASS: class 2 (low chroma mottles within 100-150cm)
SOIL SLOPE: 35%
EROSION: none to slight (semi-receiving area)
SURFACE RUNOFF: very rapid

A 0-6 cm; dark yellowish brown (10YR 3/4) gravelly clay loam; moderate, medium granular structure; very friable; clear wavy boundary; common, fine roots; pH=6.2

C1 6-41 cm; strong brown (7.5YR 5/6), many prominent mottles (2.5YR 4/8), ext. cobbly clay; structureless massive structure; friable; clear, smooth boundary; common, coarse roots and few, medium roots and few, fine roots; common, fine manganese concretions; few bridging voids; pH =5.7

C2 41-93 cm; mixed matrix color of brown (7.5YR 4/4) and red (2.5YR 4/8), two common distinct mottles (7.5YR 3/2 and 6/8), very gravelly clay; structureless massive; friable, clear, wavy boundary; common, coarse roots and common, medium roots; common, fine manganese concretions; few bridging voids; pH =4.6

C3 (L)* 93-108+ cm; dark yellowish brown (10YR 4/8), common prominent mottles (7.5YR 6/8), very gravelly clay; structureless massive structure; friable; clear, smooth boundary; few, coarse roots; common, fine manganese concretions; pH =4.7

C3 (R)* 93-108+ cm; strong brown (7.5YR 5/6), few prominent mottles (2.5YR 4/6), extremely gravelly clay, structureless massive; friable; few, coarse roots; pH =4.5

Additional Notes: Burned carbon fragments were found throughout the profile.

APPENDIX C
Definition of Pedogenic Processes

APPENDIX C: Definition of Pedogenic Processes (Buol et al., 1980)

Alkalization- The accumulation of sodium ions on the exchange sites in a soil.

Braunification- Release of iron from primary minerals and the dispersion of particles of iron oxide in increasing amounts; their progressive oxidation or hydration, giving the soil mass brownish, reddish brown, and red colors.

Calcification- Processes including accumulation of calcium carbonate in C horizon and possibly other horizons of a soil.

Cumulization- Aeolian, hydrologic and man-made additions of mineral particles to the surface of a soil solum.

Dealkalization- The leaching of sodium ions and salts from natric horizons.

Decalcification- Reactions that remove calcium carbonate from one or more soil horizons.

Decomposition- The breakdown of mineral and organic materials.

Desalinization- The removal of soluble salts from salic soil horizons.

Desilication- The chemical migration of silica out of the soil solum and thus the concentration of sesquioxides in the solum (eg goethite) with or without formation of ironstone and concretions.

Eluviation- Movement of material out of a portion of a soil profile as in an albic horizon.

Enrichment- General term for addition of material to a soil body.

Erosion- Removal of material from the surface layer of a soil.

Gleization- The reduction of iron under anaerobic "waterlogged" soil conditions, with the production of bluish to greenish gray matrix colors, with or without yellowish brown, brown, and black mottles, and ferric and manganiferous concretions.

Hardening- Decrease in volume of voids by collapse and compaction and by filling of some voids with fine earth, carbonates, silica and other materials.

Humification- The transformation of raw organic material into humus.

Illuviation- Movement of material into a portion of soil profile as in an argillic or spodic horizon.

Leaching- General term for washing out or eluviating soluble materials from the solum.

Lessivage- The mechanical migration of small mineral particles from the A to the B horizons of a soil, producing in B horizons relative enrichment in clay (argillic horizons).

Leucinization- The paling of soil horizons by disappearance of dark organic materials either through transformation to light-colored ones or through removal from the horizons.

Littering- The accumulation on the mineral soil surface of organic litter and associated humus to a depth of less than 30cm.

Loosening- Increase in volume of voids by activity of plants, animals, and humans and by freeze-thaw or other physical processes and by removal of material by leaching.

Melanization- The darkening of light-colored mineral initial unconsolidated materials by admixture of organic matter.

Mineralization- The release of oxide solids through decomposition of organic matter.

Paludization- Processes regarded by some workers as geogenic rather than pedogenic, including the accumulation of deep deposits of organic matter as in mucks and peats (Histosol).

Pedoturbation- Biological, physical churning and cycling of soil materials, thereby homogenizing the solum in varying degrees.

Podzolization- The chemical migration of aluminum and iron and/or organic matter, resulting in the concentration of silica (i.e. silication) in the layer eluviated.

Ripening- Chemical, biological, and physical changes in organic soil after air penetrates previously waterlogged material.

Salinization- The accumulation of soluble salts such as sulfates and chlorides of calcium, magnesium, sodium, and potassium in salty horizons.

Synthesis- The formation of new particles of mineral and organic species.

APPENDIX D
Tables and Graphs

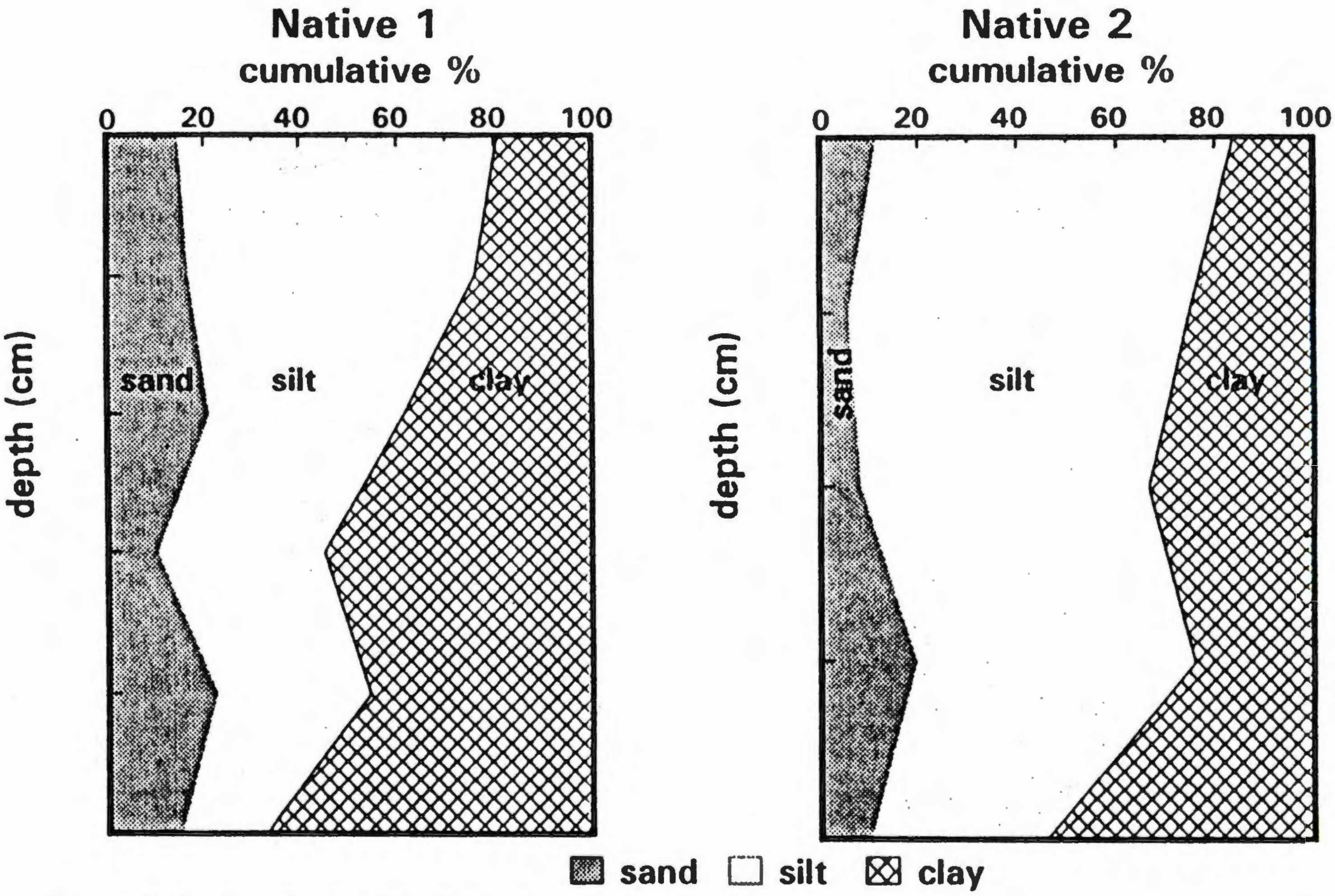

Figure D-1. Particle size distribution by depth for native pedons 1 and 2.

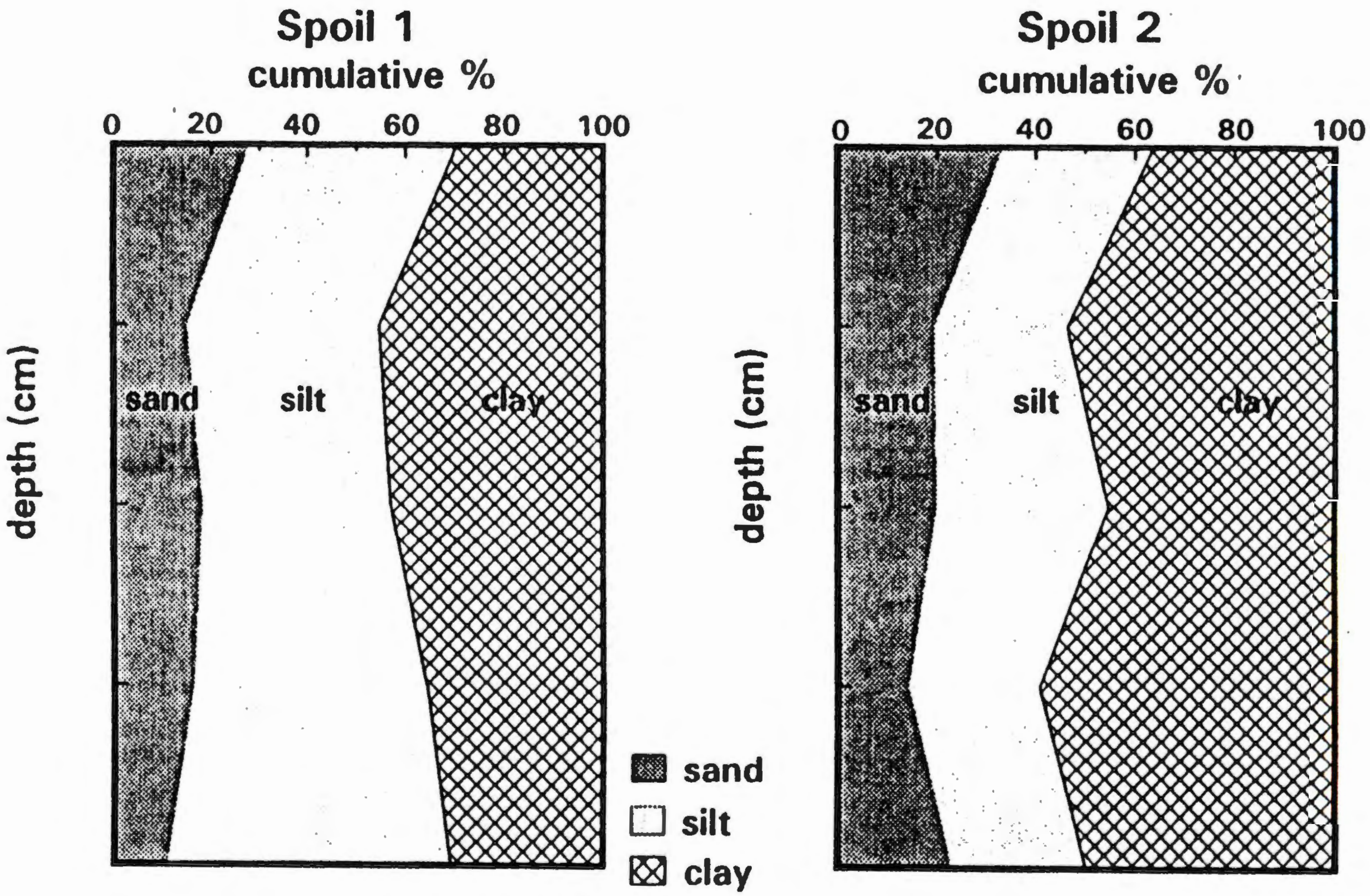

Figure D-2. Particle size distribution by depth for spoils 1 and 2.

Table D-1. Distribution of particle size fractions and clay free ratios for native pedons 1 and 2.

		Sand (2.00 - 0.05 mm)					Silt (50 - 2 *um*)		Clay (<2 *um*)		
Horizon	Lower Depth	VCOS	COS	MS	FS	VFS	CoSi	FSi	CoC	FC	FS:(TS + Si) x 100
	cm	%									
Native 1											
A	16	4.1	3.0	2.0	3.6	1.8	26.7	39.6	12.1	7.1	4.5
EB	35	4.9	3.9	2.2	3.6	2.1	24.0	35.3	14.2	9.7	4.7
Bt1	60	8.1	6.7	2.3	2.4	1.4	15.5	25.1	19.9	18.6	3.9
Bt2	78	2.6	2.2	1.2	2.3	1.8	14.7	20.5	31.4	23.3	5.0
BC	94	7.4	4.6	2.3	4.4	3.7	14.0	18.1	27.9	17.6	8.2
2Bt	116+	5.1	2.8	1.7	3.0	2.2	7.7	10.4	38.5	28.5	9.2
Native 2											
A	21	2.9	2.4	1.6	2.9	1.5	35.1	37.5	8.8	7.2	3.5
BE	32	1.1	1.4	0.8	1.6	0.8	30.2	39.0	12.9	12.2	2.1
Bt	58	2.2	2.1	0.9	1.7	1.1	25.9	32.6	14.5	18.9	2.6
2Ab	95	7.5	4.3	2.1	3.3	2.2	25.6	31.0	12.9	11.1	4.4
3Bt	108+	2.8	2.4	1.4	1.9	1.5	13.2	22.7	27.1	27.0	4.2

Table D-2. Distribution of particle size fractions and clay free ratios for spoils 1 and 2.

		Sand (2.00 - 0.05 mm)					Silt (50 - 2 *um*)		Clay (<2 *um*)		
Horizon	Lower Depth	VCOS	COS	MS	FS	VFS	CoSi	FSi	CoC	FC	FS:(TS + Si) x 100
	cm							%			
Spoil 1											
A	2	8.5	5.6	3.7	6.1	3.8	8.4	34.5	12.8	16.7	8.6
Bw1	30	3.7	3.3	2.1	3.8	1.9	15.5	24.3	18.3	27.0	7.0
Bw2	70	3.8	3.7	2.8	5.3	2.4	18.2	20.9	13.8	29.0	9.2
C	140	4.2	3.2	2.4	4.5	1.9	24.0	24.2	12.2	23.4	7.0
2Ab	160+	3.1	2.2	1.6	2.7	1.1	28.2	32.3	13.8	16.9	4.0
Spoil 2											
A	6	12.8	7.4	3.3	5.8	3.9	6.2	24.3	17.2	19.1	9.2
C1	41	5.8	4.5	2.4	3.9	2.7	12.1	15.1	25.9	27.6	8.4
C2	93	7.7	4.1	2.3	3.7	2.0	14.8	20.1	20.7	24.6	6.7
C3(L)	108+	5.1	2.8	1.4	2.7	2.1	16.9	9.8	23.6	35.6	6.5
C3(R)	108+	8.1	5.2	2.6	4.2	2.7	13.9	13.4	20.6	29.2	8.4

Table D-3. Results of chemical analysis of grid samples from row 3 (40-60cm) in native 1.

	Column				
Native 1	1	2	3	4	5
mg kg^{-1}					
Al	55756	56765	56658	47246	44057
Ba	304	269	282	267	270
Mn	225	140	135	171	145
P	417	371	426	311	307
Ti	2091	2005	2067	1790	1816
Zr	94	87	91	83	84
%T. Carbon	0.32	0.27	0.29	0.27	0.23

Table D-4. Results of chemical analysis of grid samples from row 3 (40-60cm) in native2.

	Column				
Native 2	1	2	3	4	5
mg kg^{-1}					
Al	52046	50262	49070	51369	52774
Ba	397	359	364	376	407
Mn	429	518	579	513	583
P	65	62	99	140	95
Ti	2550	2503	2428	2532	2480
Zr	115	118	111	112	110
%T. Carbon	0.29	0.25	0.28	0.25	0.28

Table D-5. Results of chemical analysis of grid samples from row 3 (40-60cm) in spoil 1.

Spoil 1	Column 1	2	3	4	5
mg kg^{-1}					
Al	64,285	62,845	64,451	64,542	66,097
Ba	190	168	190	207	332
Mn	435	329	363	249	285
P	298	239	353	245	372
Ti	2,652	2,664	2,447	2,488	2,436
Zr	96	95	94	100	97
%T. Carbon	0.18	0.16	0.16	0.15	0.16

Table D-6. Results of chemical analysis of grid samples from row 3 (40-60cm) in spoil 2.

	Column				
Spoil 2	1	2	3	4	5
mg kg^{-1}					
Al	73,608	64,800	55,928	62,116	62,374
Ba	275	315	388	313	298
Mn	833	623	771	840	731
P	564	488	315	345	453
Ti	2,422	2,492	2,300	2,244	2,253
Zr	85	93	89	86	96
%T. Carbon	0.42	0.39	0.43	0.49	0.39

VITA

Sonja Entrekin Gaither was born in Johnson City, Tennessee on May 5, 1970. Her father served in the U.S. Army, Artillery. She attended Department of Defense Dependents schools from elementary school to high school in Germany. Upon graduation from Heidelberg High School, in 1988, she entered the University of Tennessee at Knoxville. She was a member of the Gamma Sigma Delta honor society, a member of the soil judging team, participated in intramural sports, and worked part time as a student laboratory technician in the Soil Genesis and Classification Characterization Laboratory. In 1993, she graduated with a B.S. in Agriculture with a major in Plant & Soil Science and with a minor in Business Administration.

Following her graduation, she married Shane Eric Gaither of Guntersville, Alabama on August 14, 1993. She then served as a graduate research assistant in the Plant & Soil Science Department under the direction of Dr. J.T. Ammons. During that time she gained field and laboratory experience for interpreting soil genesis and the classification of soils.

Upon completion of the M.S. degree in 1995, she will be moving to Asheville, North Carolina where her husband will be working for Champion International Corporation.