Inventory, Characterization, and Classification of Minesoils in the Big South Fork National River and Recreation Area

A Thesis Presented for the Master of Science Degree

The University of Tennessee, Knoxville

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DEDICATION

To my Lena Bear,

you satisfy my soul.

To my ninja/husband,

for being more supportive

than my favorite bra.

To my parents,

who first realized I'm not crazy,

just *eccentric.*

To Brian and Roy,

for being the biggest jerks

I've ever known.

To Tom/world's best advisor,

this is just another damn soil science thesis.

To Amy and Michael,

for the second chances.

And to you,

for being one of six people

who will ever read this thesis.

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ABSTRACT

The aim of Part One was to discover and investigate the physical and chemical properties of coal minesoils occurring within the Big South Fork National River and Recreation Area (BSF) in order to better understand the nature of these anthropogenic soils. In particular, this information was to identify which, if any, un-reclaimed or recently reclaimed minesoils were actively producing acid mine drainage (AMD) and what properties were inhibiting revegetation. Historical knowledge and maps were used to locate more than 30 un-reclaimed and reclaimed minesoil sites, which were mapped with GPS. Soil profiles were exposed on 18 sites and grab samples taken on another 12. The morphological properties of each full profile were described according to the National Soil Survey Handbook and samples were taken from each horizon. Chemical properties analyzed for include: particle size, acid-base account, pH, exchangeable aluminum, manganese oxides, soil organic carbon, cation-exchange capacity, exchangeable bases, Mehlich I-extractable elements, and total elemental concentrations.

Significant differences in the following properties (averaged) were discovered between the un-reclaimed and reclaimed minesoils: slope, percent rock fragments, dominant lithology, net neutralization potential, pH, extractable aluminum, base saturation, several Mehlich I-extractable nutrients and total elemental concentrations. Hierarchical clustering analysis revealed similar findings and also highlighted instances where reclaimed minesoils were statistically more similar to un-reclaimed minesoils than to other reclaimed minesoils. This indicated that reclamation efforts may not have been completely successful on these sites.

In Part Two, minesoil profiles were classified according to *Soil Taxonomy* and according to proposed amendments by the International Committee for Anthropogenic Soils (ICOMANTH). The ICOMANTH amendments provided more informative classifications for coal minesoils in the BSF however, shortcomings were noted. Additional recommendations were made and the minesoils were again classified according to these recommendations. Compared to both the *Soil Taxonomy* and the ICOMANTH classifications, those according to the proposed additional amendments revealed more of the unique properties of the minesoils studied in this project. The results of this study can aid the National Park Service with future land management of the minesoils located within the BSF boundaries and other users of drastically disturbed minesoils.

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INTRODUCTION

Overview of history and properties of coal minesoils in the Big South Fork National River and Recreation Area and their classification.

Introduction

With the onset of the Industrial Revolution during the late 18th and early 19th centuries, the demand for coal sharply increased in the United States (US) and worldwide. The discovery and exploitation of vast coal deposits in the Appalachian mountain regions of the eastern US fueled an explosion of industry which propelled this fledgling nation into a position of prominence in the global economy. During the early days of coal mining, little to no state or federal laws existed to regulate the industry, allowing for large-scale and long-term environmental damage to many communities, including large areas of the Cumberland Plateau, stretching from north Alabama and Georgia, through Tennessee, up to Kentucky and Virginia. Often before mining, timber was removed from heavily forested areas and hundreds of tons of overburden and refuse materials, those geologic strata above and/or below a coal seam, were blasted apart and left on the surface in large, steep, unstable piles. These decimated landscapes were unattractive and often hazardous to the environment and/or human health. After decades of debate over how to regulate such a powerful industry, Congress passed the Surface Mining Control and Reclamation Act (SMCRA) in 1977. Among other regulations, coal mining companies were henceforth required to determine the acid-producing potential of geologic materials to be unearthed; this refers to the balance between acid-neutralizing (e.g. carbonates) and acid-producing constituents (e.g. metal sulfides that can become oxidized, releasing protons and/or generating sulfuric acid) of a geologic material. Further, a plan must be submitted before mining can begin stipulating how the land iss to be reclaimed once mining ceases.

Just before the passage of SMCRA, a large tract of formerly mined lands covering over 50,000 hectares of land in parts of Tennessee and Kentucky along the Big South Fork River was recognized as having historical and environmental significance; it was deemed to become the “Yellowstone of the East”. In 1974, it was officially recognized as the Big South Fork National River and Recreation Area, which contains one of only two recognized national rivers and is the nation’s only *River and Recreation Area*. After the passage of the SMCRA laws, the National Park Service began receiving funds to reclaim areas of the park which were once large coal mine refuse dumps. While many improvements have been made over the past three decades, environmental challenges associated with the previous mining activities in this area are still present. Because the terrain is so rugged and steep, the most common method of coal mining was a form of underground mining called “punch mining”. As suggested by the name, miners would remove over burden from the face of a coal seam and follow it back into the

mountain until the oxygen supply became too low for men to operate. They would then continue along the contour of the mountainside and repeat the process again. The low-quality coals and high carbon shales lining the roof and floor of the coal seams were sorted from the high-quality coals directly outside of the mine entrances and were simply dumped down the side of the narrow rail benches (created to haul men and materials in and high-quality coal out), along with overburden materials, and left in large unstable piles.

Environmental hazards were created by the weathering of any geologic materials present in the spoil piles containing pyrite or other metal sulfides. Once exposed to oxygen and water, these materials begin to oxidize, generating sulfuric acid and solubilizing heavy metals present in the parent materials. The acidic, metal rich leachates are called acid mine drainage (AMD) and though many efforts have been made to neutralize large spoil piles within the park boundaries, problem areas still exist because many areas mined before the SMCRA laws went into effect were unmapped and relatively small in scale, remaining low on the priority list of areas to be reclaimed. These spoil piles and the minesoils forming therein can be found throughout the park beneath former rail benches that line many hillsides, but remain hidden by the adjacent forested areas growing in native soils. In Part One of this research project, the National Park Service (NPS) provided funds to seek out these hidden spoil piles and minesoils and analyze their physical and chemical properties in order to determine which may still be actively producing acid mine drainage and to determine which, if any, properties may be inhibiting revegatation. Further, the NPS desired the same analysis to be made on soils previously reclaimed to judge the effectiveness of the reclamation techniques used. By doing so, they hope to outline future steps that can be taken to further protect the water quality of the Big South Fork River, into which any AMD being produced within the park boundaries drains.

The physical and chemical properties of mined lands are of vital interest to future land users because the properties of coal minesoils are unique compared to surrounding native soils. For many land planners, soil surveys provide the classifications of soils in a particular area, which are intended to provide important information about the properties of a given soil. For decades, however, land users have complained that classifications according to *Soil Taxonomy,* the classification scheme used in the US, of minesoils and other anthropogenically-altered soils are non-descript and do not reflect the unique properties of these soils. In Part Two, minesoils discovered in the BSF were classified according to *Soil Taxonomy* to judge how well their classifications describe the soils. Further, they were classified according to recently proposed amendments to *Soil Taxonomy* by the International Committee of

Anthropogenic Soils (ICOMANTH) because several of the recommendations of this group have been accepted by the Soil Survey Staff and incorporated into *Soil Taxonomy* over the past several years. Because the goal of ICOMANTH is to, as seamlessly as possible, adjust *Soil Taxonomy* to include anthropogenically-altered soils in general, it was important to assess whether the amendments were suited to descriptively classify coal minesoils, which sprawl over large tracts of land in the US. The results of this effort will provide ICOMANTH and the Soil Survey Staff with field validation of the proposed amendments and possibly with suggestions for further improvement.

Part One

Chemical and Physical Characterization of Minesoils in the Big South Fork National River and Recreation Area

ABSTRACT

Just before the passage of the Surface Mining Control and Reclamation Act in 1977, a large tract of formerly coal-mined lands covering over 50,000 hectares in Tennessee and Kentucky was officially recognized as the Big South Fork National River and Recreation Area (BSF). In the 1980s, the National Park Service (NPS) began receiving funds to reclaim former coal refuse dumps within the park, all of which were created before regulations were enacted. Environmental challenges associated with previous mining activities stem from the weathering of geologic materials containing pyrite or other metal sulfides, which upon oxidation, begin generating sulfuric acid and solubilizing metal cations. These metal rich, acidic leachates are called acid mine drainage (AMD). Problem areas still exist in the BSF because many refuse piles were unmapped, and remained hidden by forested areas growing in native soils. In Part One, the NPS provided funds to map these hidden minesoils and analyze their physical and chemical properties to determine which may be producing acid mine drainage and to determine which properties may be inhibiting revegatation. The same analyses were to be made on soils previously reclaimed to judge the effectiveness of the reclamation techniques used.

Field descriptions for physical properties were completed according to National Cooperative Soil Survey Standards and sample were taken from each horizon. Chemical properties analyzed included: particle size, acid-base account, pH, exchangeable aluminum, manganese oxides, soil organic carbon, cation-exchange capacity, exchangeable bases, Mehlich I-extractable elements, and total elemental concentrations.

Significant differences in the following properties (averaged) were discovered between the un-reclaimed and reclaimed minesoils: slope, percent rock fragments, dominant lithology, net neutralization potential, pH, extractable aluminum, base saturation, several Mehlich I-extractable nutrients and total elemental concentrations. Hierarchical clustering analysis revealed similar findings and also highlighted instances where reclaimed minesoils were statistically more similar to un-reclaimed minesoils than to other reclaimed minesoils. This indicated that reclamation efforts may not have been completely successful on these sites. The results of this study can aid the National Park Service with future land management of the minesoils located within the BSF boundaries.

Introduction

For nearly three thousand years, coal has been used as an energy source by many human civilizations. As far back as 1000 BCE, the Chinese were using coal to smelt copper from which they made their national currency. In ancient Greece, Aristotle described coal as a charcoal-like rock and archaeological evidence has revealed that the early Romans burned coal for energy as well. During the middle ages, England began mining coal and used it to trade internationally with other European countries such as Belgium. Coal was first mapped in what would become the United States (US) in 1673 by Louis Joliet, labeling areas of the Illinois Basin as "carbon de terra". In the 18^{th} and 19^{th} centuries, the demand for coal exploded worldwide with the invention of the coal-powered steam engine and the onset of the Industrial Revolution (World Coal Institute, 2005). The demand for coal has risen steadily for over 200 years, giving countries with large coal deposits the energy supply needed to produce and sell more goods, imparting wealth and higher standards of living.

The progress of America is irrefutably tied to the use of coal, its most abundant energy source. Found in 38 states, coal deposits lie beneath 1.2 million km^2 or over 13% of the US total land area (Energy Information Administration, 1995). Mining for coal in the US dates back to the early 1700s. The first commercial coal mines opened near Richmond, Virginia in 1748. By the 1800s, coal was being used to power a variety of steam engines as well as large manufacturing plants, essentially making all military efforts during this time possible, including the American Civil War. Using coal to produce iron and steel sparked the Industrial Revolution in America, ensuring the fledgling nation a position of power on the global stage. The demand for coal has steadily increased since that time and now accounts for 23% of energy consumption in the USA, mostly providing energy to produce electricity. In 1997, a record 1.1 billion short tons of coal were produced in the US. Fifty-six percent of this was extracted from the top three coal-producing states: Wyoming, Kentucky, and West Virginia (Office of Water, 2000).

Sometimes called "Nature's Black Diamond", coal is an organic sedimentary rock that is ignitable and composed mostly of hydrogen, carbon, and oxygen (WCI, 2011). It contains more than fifty percent carbonaceous material by weight. Coal was created from the remains of plants that lived and died 360 to 290 million years before present (BP), during the aptly named Carboniferous Period- also known as the first age of coal. During this time, vast swamplands dominated large portions of the globe, serving as home to a host of plant life. After death, the remains of these plants sank into the swamps, at

the bottom of which were anoxic conditions. The process of decay was greatly slowed by the absence of oxygen, trapping energy once harnessed through photosynthesis and stored in plant tissues, which would normally be released into the environment. The energy-rich organic materials were quickly covered by sediments; over large periods of time and under extreme pressures, physical and chemical conversions including the release of structural oxygen eventually transformed large deposits of hydrocarbons into coal (Crowell, 2008).

There are four major types of coal, separated on the basis of percent carbon as well as the amount of energy released upon burning. The various types of coal also have different uses (Figure 1). Anthracite has the largest heating value and percent carbon (86-98%), but occurs rarely compared to the other three. Anthracite produces very little pollution and ash. Bituminous coal is second in value, with a carbon content ranging from 45-85%. This is the most prevalent form of coal found in the US, but is problematic environmentally. This coal was formed from swamps that were flooded with seawater, which is high in sulfur. The high sulfur content of bituminous coal causes sulfur dioxide gas to be released upon ignition, mixing with water vapor in the atmosphere to form sulfuric acid rain. Mining bituminous coal also has the potential for producing acidic leachates that can affect local watersheds. Subbituminous coal contains between 35-45% carbon and is most often strip-mined because it is often found nearer to the surface. Lignite, the last and lowest valued coal, is also found close to the surface. It contains only between 25-35% carbon (US Dept. of Energy, 2008).

In the US, 93% of all coal that is produced originates from five regions: Gulf Coast, Illinois Basin, northern and central Appalachian Basins, Colorado Plateau, and Northern Rocky Mountains and Great Plains Region. Of this, more than 40% is produced in the northern and central Appalachian Basin coal region (Figure 2), where both underground and surface mining techniques are used (Ruppert, 2000). Underground, or deep, mining extracts coal seams located hundreds of meters beneath the surface, with some mine shafts reaching as deep as 300 meters. Underground mining accounts for around 30% of total production in the US, but around 50% of that produced in the Appalachian regions (EIA, 2009).

To begin either surface or underground coal mining, first the soil and rock covering the coal seam- called overburden- is removed and stored. Large earth-moving equipment then exposes and extracts the coal seam. After the mining operation ceases, the overburden materials are replaced, regraded, topsoiled, and seeded- a process called reclamation. This last step was not always required by law and before the mid-1970s was rarely completed. In most cases, the excavation of a bench just beneath the elevation of the coal seam is required in order to allow equipment to be brought in and coal

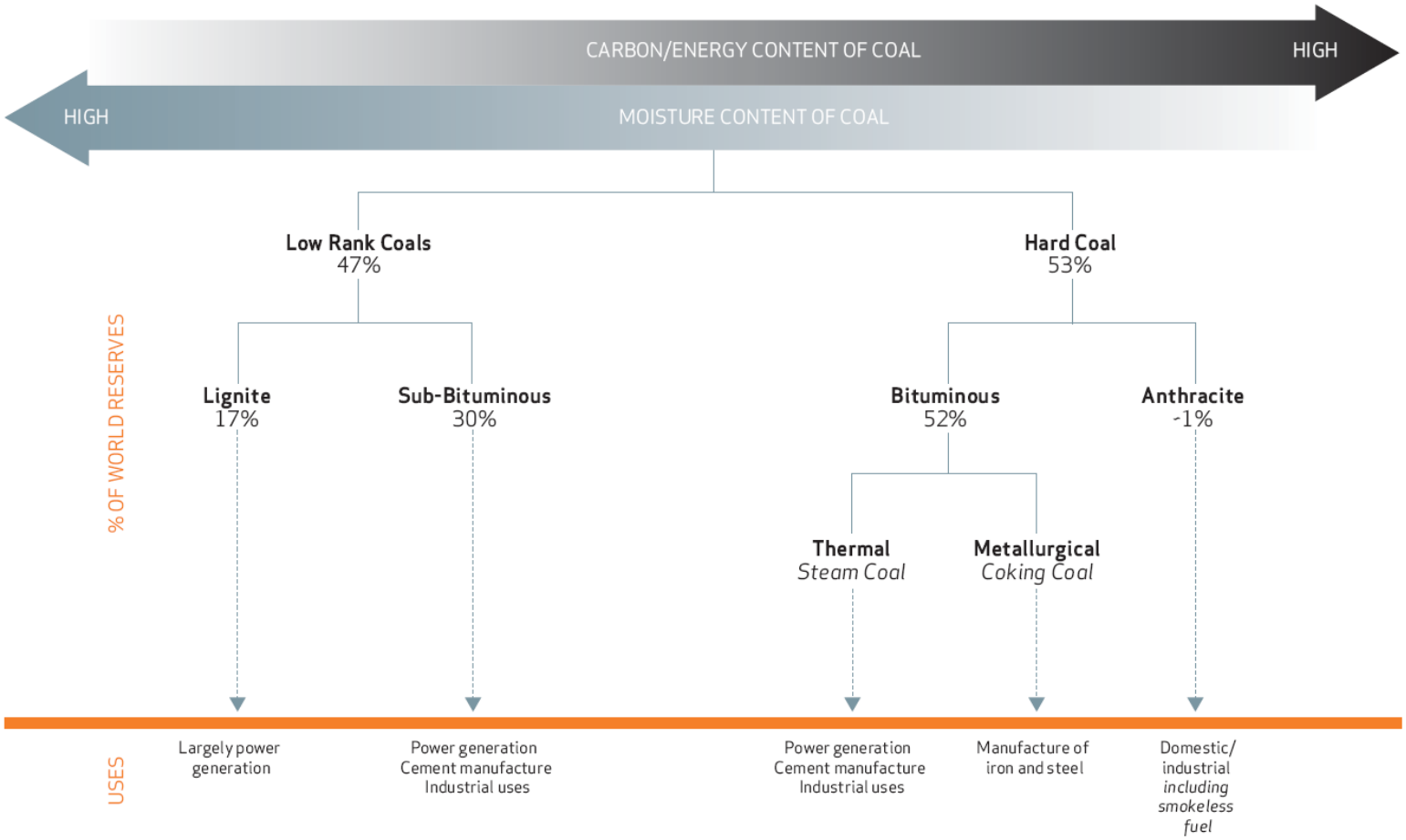


Figure 1. The four types of coal and their various uses (World Coal Institute, 2005).

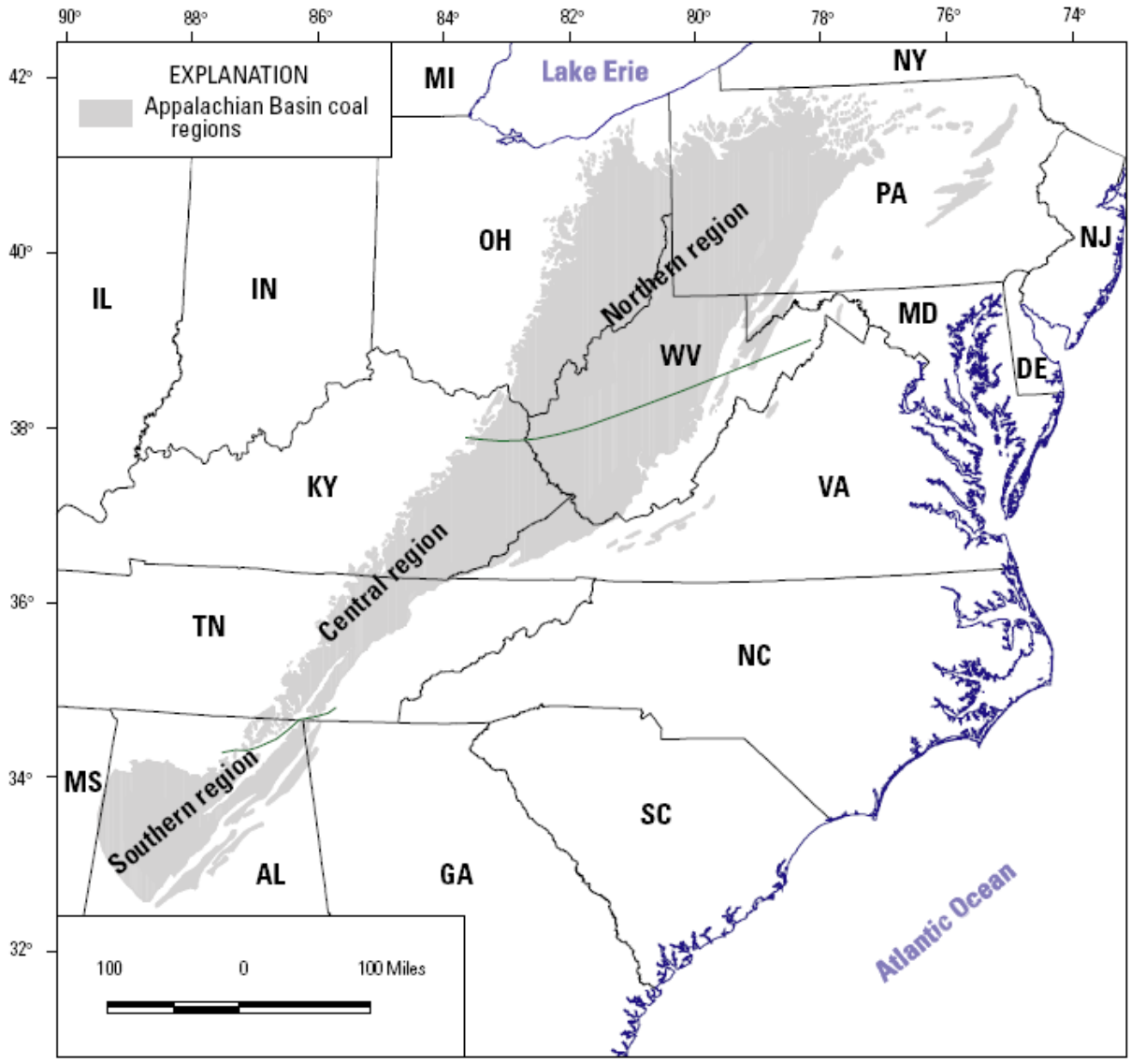


Figure 2. States in the northern, central, and southern Appalachian Basin coal regions

to be carried out. Overburden materials are blasted off, sorted by size and stored to be replaced later to their approximate original location (EIA, 1995). Mine refuse (or the low-grade coals, high carbon shales, and mudstones/claystones that line the upper and lower portions of the coal seam) can either be mixed with or buried beneath overburden materials (Lottermoser, 2010). Mine refuse and overburden materials are collectively referred to as "mine spoil" or simply "spoil".

After a mining operation ceases, the area which was mined becomes known as "disturbed land". This refers to land that has been disrupted by human activities at least to the depth of 1 m. Often the original soils present have been completely removed and are partially or entirely supplanted by geologic materials that were once located underneath the surface. To use the terms of soil scientists, the pedologic clock is set back to "Time 0" (Jenny, 1941; Soil Surv. Staff, 1975), meaning that soil formation has begun anew. As the disturbed geologic materials weather, soil begins to develop in the surface and near-surface layers, or horizons, often at an accelerated rate. This rapid breakdown is due to the increase in surface area created by blasting the materials apart upon extraction. Since the surface is now composed of materials that can be very different than those from which the original soil profiles developed, the newly forming soils can be markedly different than native soils nearby. After many years of research, some general properties of these "minesoils" have been recognized (Sencindiver and Ammons, 2000).

Physical Properties of Minesoils

Minesoils are typically young and form from mixtures of soil and blasted rock fragments. The texture of minesoils varies with location on the landscape, often within short distances depending on the type of parent materials present. In the Appalachian coal mining region, sedimentary rocks exposed during mining often include mudstone, sandstone, limestone, and countless combinations of these (Grube et al, 1982). Most minesoils in this region are loamy but can range from sandy to clayey in texture (Bussler et al., 1984; Haering et al., 2004; Johnson and Skousen, 1995; Sencindiver and Ammons, 2000). In many cases, a thin surface horizon will be present that has a finer texture than subsurface horizons. Minesoils typically have a weak to moderate grade structure with granular or subangular blocky shape, even those which are very young (1 to 2 years). Soil development depends on the type of material left on the surface after mining and the extent of reclamation efforts if any.

Color mottling, which is not caused by pedogenic horizonation, is a common characteristic of minesoils (Smith and Sobek, 1978). This is often the result of depositing different parent materials together (relic mottling) or can be caused by the sulfuricization of the parent materials as they weather (Fanning and Fanning, 1989). Sulfuricization is a very important process of soil-formation in minesoils occurring from pyritic spoil materials. It is a process in which spoil minerals are weathered by sulfuric acid being produced by the oxidation of pyrite and, through dissolution, new mineral phases are formed. These are called acid sulfate soils and often have a very low pH, an accumulation of sulfate ions and other cations (e.g. Ca^{2+}, Mg^{2+}, K^{+}, and Al^{3+}), and mottles of precipitated yellow jarosite [$KFe_3(SO_4)_2(OH)_6$] (Sencindiver and Ammons, 2000). Dark colors occurring in subsurface horizons can be caused by high carbon rock fragments or fine coal materials. These coal fragments also create another common characteristic of minesoils (and of young soils in general), as described by Sobek et al. (1978): the irregular distribution of oxidizable organic carbon with depth.

Minesoils typically have high rock fragment content (35 to 70%) when compared to surrounding native soils. Coarse fragments can be splintered on the edges and highly disordered, commonly creating bridging voids. These voids are created by overlapping rock fragments which do not allow all spaces to be filled with fine-earth material. They can range from small to quite large in size (1mm to > 0.5m) and are uncommon in undisturbed native soils (Sencindiver and Ammons, 2000).

Chemical Properties of Coal Minesoils

The type of parent material, or the geologic material from which soil develops, as well as the rate of weathering have the heaviest influence on the chemical properties of minesoils (Sencindiver and Ammons, 2000). In highly weathered, humid regions like the southeastern US, it has been shown that overburden strata at or near the earth's surface are more highly weathered and oxidized than rock strata farther down in the geologic column (Grube et al., 1982; Smith and Sobek, 1978). This "zone of oxidative weathering" (Figure 3) varies in depth depending on factors including slope and rock type and generally has a chroma ≥ 3. Because this zone has been stripped of many nutrients important for plant growth, minesoils composed mostly of materials from this zone exhibit low fertility (Grube et al., 1982; Sobek et al., 2000). Strata from deeper in the geologic column are unweathered and un-oxidized with

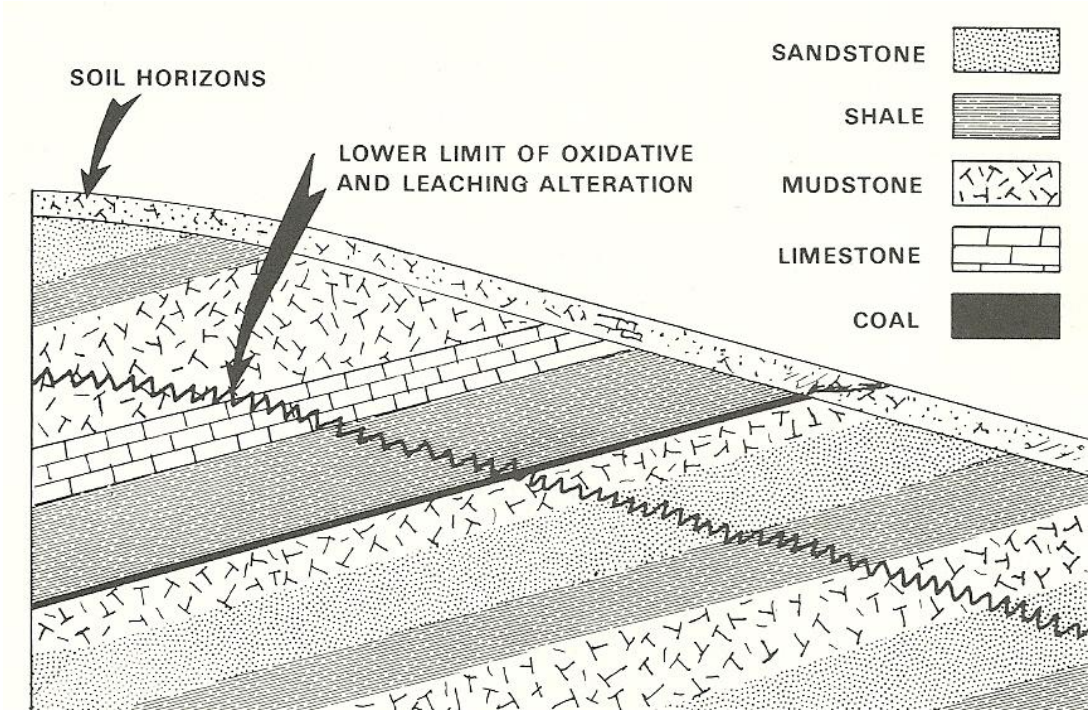


Figure 3. Zone of Oxidative Weathering (Grube et al., 1982).

chroma ≤ 2.5 (Sobek et al., 2000). Upon being brought to the surface and exposed to oxygen and water, unweathered materials from this zone begin to oxidize. Depending on the mineralogical makeup of the spoil materials, oxidation can be problematic for reclamation efforts and for the local environment. This is because bituminous coal seams (and the geologic strata above and below), if formed in environments inundated with sulfur-rich seawater, can contain minerals bearing various forms of reduced divalent metallic sulfides [e.g., chalcopyrite ($CuFeS_2$), galena (PbS), sphalerite (ZnS), and pyrite (FeS_2)]. The most prevalent sulfide by far in coal and overburden strata comes from the pyrite group (FeS-FeS_2). The oxidation of pyrite is the main cause of acid-forming reactions in refuse piles and minesoils. From this point forward, all metallic sulfides will be referred to collectively as pyrite (Geidel & Caruccio, 2000).

Minesoil Acidity

Soil pH has been described as “probably the single most important chemical characteristic of a soil” (Bloom et al., 2005). Because many chemical reactions are controlled by proton activity, soil

solution pH is regarded as a master chemical variable (Essington, 2004). Understanding soil pH is crucial to understanding chemical processes including precipitation dissolution reactions, ion mobility, and equilibria of metal ions. With knowledge of soil pH, the relative availability of P and of many minor elements can be approximated, including B, Cu, Fe, Mn, Mo, Zn, and others. The major cations existing on exchange sites of soil materials can be roughly predicted. For example, soil pHs in the range of 2-3 point to the occurrence of free mineral acid (typically H_2SO_4). As stated by Thomas (1996), "a pH value much below 4.0 is impossible to achieve with Al^{3+}-saturation so that acidity 10 to 100 times more intense (pH 2-3) indicates not only the presence of H^+ but also a continuing source of them." In a soil saturated with H^+, this continuing source is a result of exchangeable H^+, from H_2SO_4, rapidly dissolving minerals. Thus, a large amount of free acid will always be present in soils with a pH of 2 to 3 (Thomas, 1996). Pyritic-S bearing minerals are often the source of this excess acid which, as discussed earlier, oxidize to form H_2SO_4. The occurrence of free acid in soils suggests three significant problems. First, most plants will not grow, as the growth of roots becomes inhibited and absorption of nutrients across the cell wall decreases significantly. Second, the pyritic-S bearing minerals are being dissolved. Finally, mitigating this soil acidity using lime will most likely be costly. In many efforts to reclaim highly acidic mine spoils, the cost of the lime can equal the value of the land itself (Thomas, 1996).

The element of greatest concern in relation to potential acid-production in mine spoils is sulfur (S). More importantly, it is the oxidation state of S. Three general forms of S are present in spoil materials: organic-S, sulfate (SO_4)-S, and pyritic-S. Organic-S consists of oxidized and reduced forms of S, such as sulfate esters [S(VI)] and sulfhydryls [S(-II)]. Organic-S usually has a negligible impact on acid production due to its low abundance. Coal and organic soils can contain as much as 0.5% organic sulfur, on a weight basis (Sobek et al., 2000). Sulfate-S is also of little to no concern because it is already in its fully oxidized state. In Appalachian overburden, sulfide found in pyrite is the dominant form of sulfur (Smith et al., 1976). The oxidation of reduced pyrite can commonly lower the pH of minesoils to < 4 and sometimes even to <2 (Mays & Bengston, 1978).

A summary of the reactions that describe the oxidation of FeS_2 and the production of acidity in minesoils are given as follows (Essington, 2004; Grishin, Bigham, and Tuovinen, 1988):

[1] $FeS_2(s) + \frac{7}{2}O_2\,(g) + H_2O(l) \rightarrow Fe^{2+}(aq) + 2SO_4^{2-}(aq) + 2H^+(aq)$

[2] $Fe^{2+}(aq) + \frac{1}{4}\,O_2(g) + H^+(aq) \rightarrow Fe^{3+}(aq) + \frac{1}{2}H_2O(l)$

[3] $3Fe^{3+}(aq) + X^+ + 2HSO_4^-(aq) + 6H_2O(l) \rightarrow XFe_3(SO_4)_2(OH)_6(s) + 8H^+(aq)$

where X = K^+ (potassium jarosite), Na^+ (natrojarosite), NH_4^+ (ammoniojarosite), or H_3O^+ (hydronium jarosite)

[4] $FeS_2(s) + 14Fe^{3+}(aq) + 8\ H_2O(l) = 15Fe^{2+}(aq) + 2SO_4^{2-}(aq) + 16H^+(aq)$

[5] $Fe^{3+}(aq) + 3H_2O(l) \rightarrow Fe(OH)_3\ (s) + 3H^+(aq)$

Pyrite is itself is only sparingly soluble in water; however, the oxidation of FeS_2 by O_2 (Eq. 1) produces soluble Fe^{2+}, SO_4^{2-}, and 2 moles of acidity (protons). *Thiobacillus thiooxidans*, a bacterium that can oxidize elemental-S and sulfide-S, can mediate this reaction when present. The further oxidation of Fe^{2+} to Fe^{3+} (Eq. 2) consumes acidity but is nonetheless important to the production of AMD. *Thiobacillus ferrooxidans* catalyzes the oxidation of Fe^{2+} by O_2 and may speed the reaction by 60-95% (Eq.2). From here, the Fe^{3+} can either precipitate into minerals or begin to directly oxidize pyritic-S. The precipitation and dissolution of Fe(III)minerals such as iron(III)sulfate ($Fe_2[SO_4]_3$), jarosite [$KFe_3(SO_4)_2(OH)_6$] (Eq. 3), and other basic sulfates regulates the oxidation of pyrite by controlling the flow of Fe^{3+} into and out of solution. During the dissolution of these minerals (sped by the leaching of SO_4), the hydrolysis of Fe^{3+} (and Al^{3+}) releases protons, helping to buffer the low pH of spoil and minesoil systems (Figure 4) (Essington, 2004). Along with this buffering, the oxidation of FeS_2 directly by Fe^{3+} makes mitigating acid-production in spoil piles challenging (Eq. 4). When the pH drops below 3 or 4, the solubility of Fe^{3+} is enhanced and becomes a better oxidizer of pyritic-S than O_2 (Geidel and Caruccio, 2000). This reaction is faster than the oxidation of Fe^{2+} by O_2, meaning that in the oxidation of pyrite, it is the rate-limiting step (Essington, 2004).

While pyrite oxidation, the precipitation of iron and aluminum sufulates and hydroxides (Eq. 5), and the dissolution of secondary minerals all generate acidity, various neutralizing reactions occur at the same time. Neutralizing reactions, unlike acid-producing reactions, do not depend on the concentration of oxidizers. Acid pH-buffering reactions in mine spoil are mostly due to the weathering of silicate minerals, carbonates, and hydroxides. Silicate minerals usually comprise the dominant reservoir of buffering capacity in natural settings, as they constitute the majority of minerals in the Earth's crust. The chemical weathering of silicates consumes hydrogen ions and produces dissolved cations, silicic acid, and forms secondary minerals (Lottermoser, 2010). Silicates can weather in one of two ways: (1) the silicate mineral is completely dissolved and the only products are soluble (Eq. 6), or (2) more commonly, the silicate mineral weathers into another phase as a secondary mineral (Eq. 7).

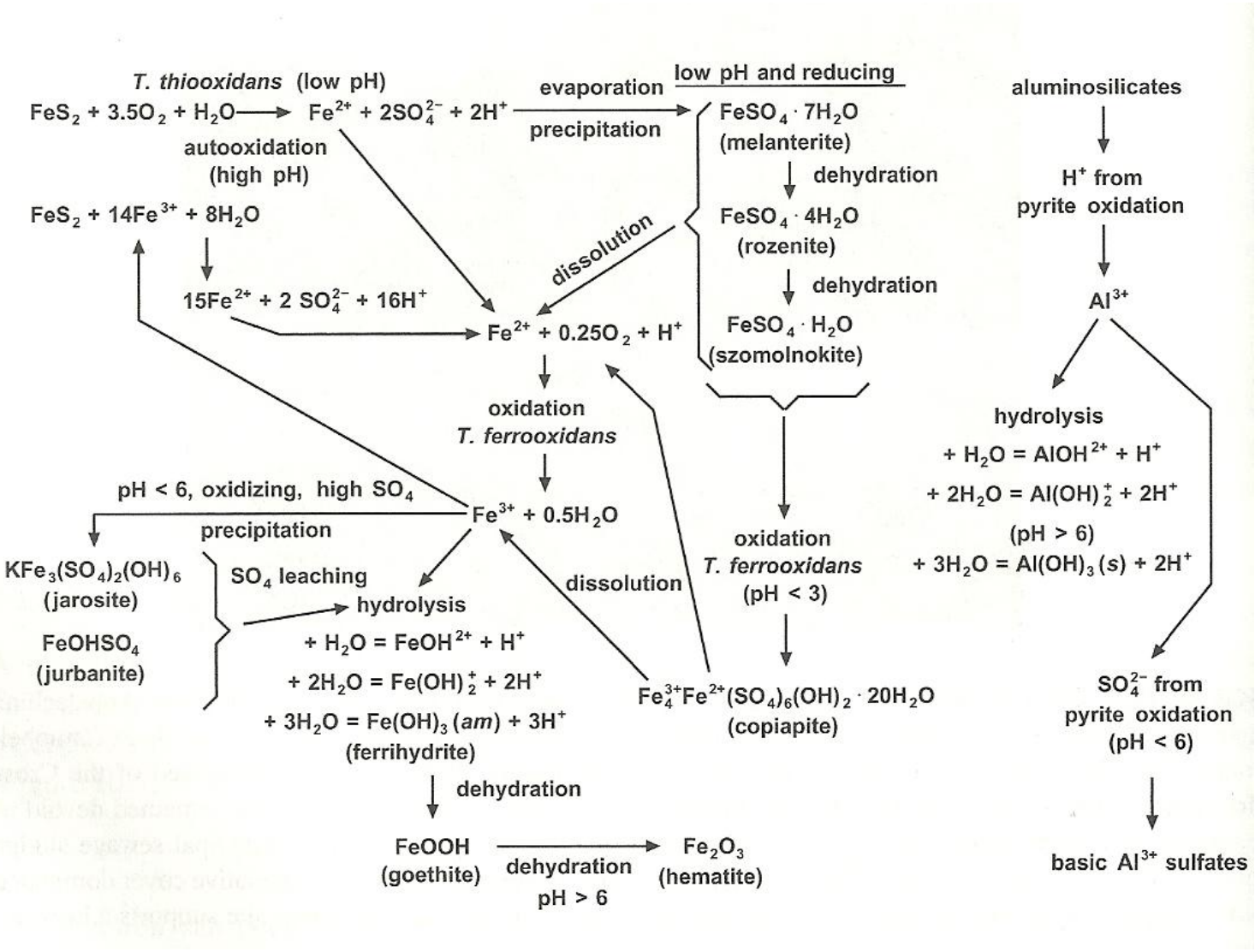


Figure 4. Processes controlling production of acidity in pyritic mine spoils (Essington, 2004).

[6] $Me^{*}AlSiO_4(s) + H^+(aq) + 3H_2O(l) \rightarrow Me^{X+}(aq) + Al^{3+}(aq) + H_4SiO_4(aq) + 3OH^-(aq)$

[7] $2Me^{*}AlSiO_4(s) + 2H^+(aq) + H_2O(l) \rightarrow Me^{x+}(aq) + Al_2Si_2O_5(OH)_4(s)$ (kaolinite)

*(Me= Ca, Fe, K, Mg, Mn, or Na)

The secondary minerals can continue to weather and consume hydrogen ions as they dissolve (Eq. 8). Equation 8 shows the further weathering of kaolinite, which consumes 6 hydrogen ions as it dissolves.However, if the Al^{3+} precipitates later as gibbsite [$Al(OH)_3$] (only if the pH has risen enough), the same amount of hydrogen is released into the system, negating this neutralization (Eq. 9).

[8] $Al_2Si_2O_5(OH)_4(s) + 6H^+(aq) \rightarrow 2Al^{3+}(aq) + 2H_4SiO_4(aq) + H_2O(l)$

[9] $2Al^{3+}(aq) + 6H_2O(l) \rightarrow 2Al(OH)_3(s) + 6H^+(aq)$

In addition to the silicate minerals, carbonate minerals such as calcite [$CaCO_3$] and dolomite [$CaMg(CO_3)_2$] are also important acid neutralizers in minesoil systems. Of the carbonates, calcite is the most important due to its rapid reaction rate. By dissolving and complexing with hydrogen ions to form bicarbonate [HCO_3^-] and carbonic acid [H_2CO_3] (Eq. 11) in weakly acidic to alkaline environments (Eq. 10), calcite neutralizes acid generated from sulfide oxidation (Lottermoser, 2010).

[10] $CaCO_3(s) + H^+(aq) \leftrightarrow Ca^{2+}(aq) + HCO_3^-(aq)$

[11] $CaCO_3(s) + 2H^+(aq) \leftrightarrow Ca^{2+}(aq) + H_2CO_3^-(aq)$

The ability of silicates and carbonates to neutralize acidity created by the oxidation of pyrite is limited by the weathering rate of the minerals in the spoil, which is dependent on several factors: (1) temperature; (2) the mineral's structure, surface area, and crystal size and shape; (3) redox conditions; (4) dissolved carbon dioxide content; and (5) the pH of the weathering solution. For example, the rate of weathering can increase or decrease depending on whether the spoil material is fine-grained or larger coarse fragments: the larger surface area of fine-grained materials can contribute a large proportion of sulfide oxidation and of silicate and carbonate dissolution (Sherlock et al., 1995).

Carbonates can weather much more quickly than even the most reactive silicate minerals, meaning that acidity can swiftly be neutralized. Calcite has even been shown to dissolve more quickly than pyrite. This can be a problem because the drainage from spoil materials bearing calcite may initially exhibit a neutral pH, but later become acidic as the calcite is completely dissolved before the pyrite (Lottermoser, 2010). The weathering rate of silicate minerals can greatly decrease their ability to significantly neutralize acid production, but in their case, it's because they weather slowly and do not usually dissolve completely compared the oxidation of pyrite (Lottermoser, 2010).

Acid Mine Drainage (AMD)

Spoil and overburden materials may contain sufficient acid-neutralizers to buffer minesoil pH; however, in the Appalachian coal mining region, this is often not true, as here an excess of oxidizable sulfur exists relative to neutralizers, creating a net acid production over time (Daniels & Stewart, 2000). The acid leachates formed as water moves through abandoned surface and deep mines as well as spoil materials is called acid mine drainage (AMD). AMD from pyritic minesoils can be much more acidic than a naturally forming acid soil environment. The pH of AMD can range to values less than 2; whereas, naturally acidic soils rarely decrease below 4 (Essington, 2004).

Under these extremely acidic conditions, many metals exhibit high solubility, potentially affecting biota in the soil surface and in local watersheds. Mine drainage can contain very high concentrations of Al, Fe, Mn, and SO_4, and the trace elements Cr, Cu, Ni, Se, and Zn. Similarly to Al, Mn becomes more available under lower pH conditions. It behaves like Fe in soils, chemically speaking, in that under either low pH or waterlogged conditions, Mn^{3+} is reduced to Mn^{2+}, which is the more mobile and plant-available form. While Mn is an essential micronutrient for plants, it can become toxic in high concentrations. Further, both Mn and Fe oxides are "strong scavenging agents for transition metal ions" (Chao, 1972) and are known to increase retention of trace and toxic metals in soils. Most terrestrial plants and aquatic organisms cannot survive once the pH drops below 4.5. Fish are directly exposed to the metals and H^+ ions through their gills resulting in decreased respiration and acute toxicity. Further, fish are exposed by eating contaminated food items and sediments (Jennnings et al., 2008). On mined lands, the concentrations of these elements can reach phytotoxic levels (Essington, 2004; Joost et al., 1983) and when coupled with extreme acidity and parent materials which lack important plant nutrients, reclamation of mined lands can be difficult.

Environmental problems persist even when AMD becomes highly diluted with freshwater because as the pH rises, dissolved metals begin to precipitate as metal hydroxides and oxyhydroxides through hydrolysis reactions. Hydrolysis is a chemical reaction in which water molecules and dissolved cations react. The cations become bonded to the hydroxy and hydrogen ions that are released. The hydrolysis reactions of the metals listed above are controlled by pH. For example, the Fe^{3+} species remains the predominate Fe(III) species when the pH is less than approximately 2. At higher pH values, however, basic iron sulfates and Fe^{3+} hydroxides will precipitate (Eq. 5), along with other metal

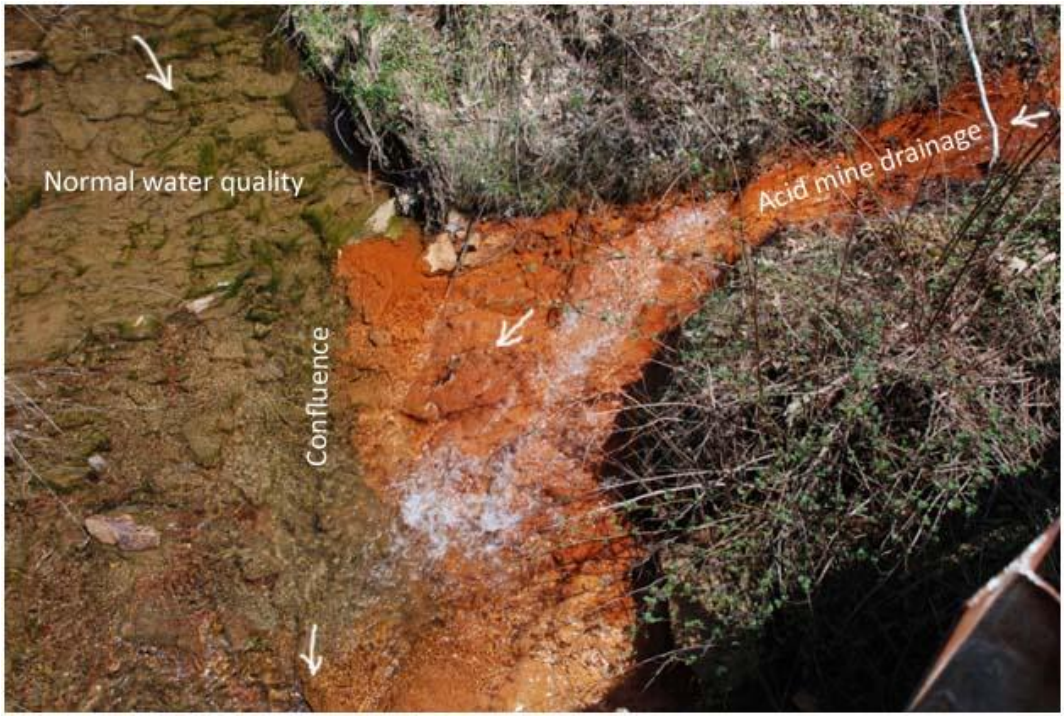


Figure 5. Precipitated metal hydroxides (yellow boy) in acid mine drainage (Bosch, 2009).

hydroxides (Eqs. 13 and 14), giving water bodies affected by AMD a characteristic reddish-orange or yellow stain, known colloquially as "yellow boy", that forms slimy sludge, coatings, or gelatinous flocculants on streambeds (Figure 5) (Lottermoser, 2010).

[13] $Al^{3+}(aq) + 3H_2O(l) \leftrightarrow Al(OH)_3(s) + 3H^{+}(aq)$

[14] $Mn^{2+}(aq) + \frac{1}{4}O_2 + \frac{5}{2}H_2O(l) \leftrightarrow Mn(OH)_3(s) + 2H^{+}(aq)$

Physically covering the bottom of water bodies can impact the availability of clean gravels used for spawning and can drastically decrease the population of benthic invertebrates, which are a food source to many aquatic organisms.

The acid or base status of spoil materials and minesoils is a key property for determining whether materials can produce acidic drainage or acid soil conditions upon weathering. The acid base account (ABA), now a standard method for assessing minesoils, was developed at West Virginia University as an attempt to classify mine spoils for revegatation potential. Two determinations are needed to complete an acid-base account: neutralization potential (NP) and maximum potential acidity

(MPA). The NP is presumed to measure carbonate minerals, weatherable silicate minerals, and exchangeable bases, providing an index of available acid neutralizers in the material (Sobek et al., 1978). The procedure does not differentiate between neutralizers and represents a theoretical maximum value for neutralization potential. The MPA is based on a measure of sulfur content of the material, the assumption being that this represents the acid-generating sulfur minerals.

As discussed previously, metal sulfides, mostly pyrite, are the main source of acid generation in Appalachian minesoils. Fractionating sulfur into total-S, organic-S, and sulfate-S allows the estimation of the pyritic-S fraction. It has been shown that very little acid is produced when pyritic-S is low or not present, so the MPA estimated from pyritic-S is considered to be more accurate than that estimated from total-S (Perry, 1998). The subtraction of NP from MPA of a sample results in the net neutralization potential (NNP). It should be recognized that the quantified NNP is based on three assumptions: (1) that all pyrite and bases are completely reacted; (2) that sulfur exists in three forms in S-bearing rocks-organic-S, sulfate-S, and sulfide-S (pyritic) with pyritic-S being the foremost producer of acid; and (3)that pyrite may oxidize more quickly or slowly than the corresponding dissolution of carbonate minerals in the geologic materials and that this method does not measure the reaction rates of either (Sobek et al., 2000).

Since the earliest applications of the acid-base account, researchers have been trying to quantify levels of significance that will accurately predict post-mining water quality. For example, research in the late 1970s concluded that rocks with NNP < -5 tons $CaCO_3$ equivalent/ 1000 tons material (T $CaCO_3$ equiv./1000T) were to be considered potentially toxic to plant rooting zones (Smith et al., 1976). One of the most recent studies (Brady et al., 1994) determined that any NNP <10 T $CaCO_3$ equiv./1000T would result in net acid production, any NNP > T $CaCO_3$ equiv./1000T would be net alkaline, and anything in between was variable meaning no prediction was possible. Ferguson and Robertson (1994) deduced that the NP/MPA ratio is a better predictor of AMD because carbonates can significantly reduce the activity of dissolved ferric iron, which in turn disturbs the self-propagating cycle of acid generation. Because there are so many contradicting studies concerning levels of significance in acid-base accounting, researchers usually label any NNP value that is negative as “potentially acid-producing” and any NNP value that is positive as “potentially acid-neutralizing”.

Other Chemical Properties of Minesoils

When reclamation is intended, the chemical properties often considered standard for assessing soil fertility must be examined. These include: soil organic carbon, cation-exchange capacity, exchangeable bases, base saturation, Mehlich-I extractable elements, and total elemental analysis. The irregular distribution of organic carbon with depth is considered to be a common property of minesoils (Sencindiver & Ammons, 2000) because they are young. In minesoils elevated amounts of oxidizable organic carbon can also be due to the presence of high-carbon rock fragments or fine coal particles. The erratic distribution of soil organic carbon presents a challenge when classifying minesoils according to *Soil Taxonomy* because this characteristic is usually associated with soils classified as "fluvents" or other great group or subgroup "fluv" taxa, indicating that the soil is forming in recent water-deposited sediments. Despite taxonomic issues, measuring soil organic carbon in minesoils is important for assessing fertility.

Another property that is important for soil fertility is the cation exchange capacity (CEC), which quantifies the ability of the soil to retain cations. Typically, clay, organic matter, and sesquioxides are responsible for CEC. The type of charge on soil particles can be separated into two categories- permanent or variable charge- depending on whether conditions of the soil environment (pH or salts) will affect the sign and magnitude of the charge. Developing as the mineral crystallizes from liquid magma or precipitates from a supersaturated solution, permanent charge, as a property of the mineral itself, is not changed by the chemistry of the environment once the mineral is formed. It is a result of isomorphic substitution and is a property specific to the phyollosilicates (Essington, 2004). Variable, or pH-dependent, charge results from the protonation or deprotonation of surface hydroxyl groups commonly found on phyllosilicates and crystalline and amorphous metal oxides, hydroxides, and oxyhydroxides (Essington, 2004). CEC strongly influences nutrient availability in soils and is thus considered one of the most important chemical properties of a soil. It is expressed as centimoles of charge from cations per kilogram of oven dried soil, or $cmol_c\ kg^{-1}$ (Tisdale et al., 1993).

Because CEC is so strongly influenced by field conditions, the methods to determine CEC vary depending on what is being studied. When trying to accurately reflect field conditions of CEC, use of an unbuffered extracting solution is required so that the pH remains that of the natural soil environment. For the purpose of soil classification, however, CEC is measured using an extracting solution buffered to a known pH, usually 7 or 8.2. This is done so that the effect of management practices such as liming or

fertilization can be minimized, as they can drastically change the CEC measurements of the same soil without such amendments (Sumner & Miller, 1996).

Because revegatation is a major goal of mine land reclamation, using Mehlich-I (Dilute Double Acid) extraction to predict plant response to fertilizers (P and K) can help land managers understand how minesoils may respond to reclamation efforts. This method was originally developed to estimate levels of available P in soils, but has since been used by many soil testing laboratories in the southern US to measure available Ca, Mg, and K (Reed and Martins, 1996). It was first found to be suitable for determining the level of available micronutrients, copper (Cu), manganese (Mn) and Zinc (Zn), in soil by Cox (1968). This information is important, along with CEC and exchangeable bases because only a small amount of macronutrients and micronutrients present in soil are available to plants and microbes at any given time, with most being tightly held in the mineral and organic matter. Plants absorb elements from the soil in ionic forms, for example, calcium, magnesium, and potassium are absorbed as the cations Ca^{2+}, Mg^{2+}, and K^{+} and phosphorus as $H_2PO_4^-$ or HPO_4^-. While a fraction of the plant available nutrients in soil exist as dissolved ions in soil water (the most readily available supply of nutrients), a much larger portion are stored on the surfaces of clay and humus particles. In order to extract these nutrients from soil particles, the Mehlich-I extractant uses a mixture of dilute HCl and H_2SO_4.

Along with Mehlich I-extractable nutrients, measuring for the total concentrations of selected elements within a soil sample can be informative. Modifications by humans can alter the natural cycling of trace elements in nature (the earth's crust is typically the dominant source in soils). Total elemental analysis is important because some elements even at trace levels can have a negative impact on plant growth, the environment, human health, etc. It should be noted that total analysis does not provide any information about the bioavailability, fate, or behavior of the elements. If background information is available for comparison, as is the case for this project, total elemental analysis can provide a preliminary indication of pollution problems. This analysis does not necessarily imply an environmental risk, however, and should only be used as an indication that further study is needed (Ammons et al., 1997).

The unique chemical and physical properties of minesoils must be taken into consideration when attempting to understand their weathering and soil-formation processes. In summary, these properties include: (1) often heterogenous mixtures of disparate parent materials, creating non-pedogenic color mottling and soil textures that can vary dramatically within short distances; (2) an increased rate of weathering resulting in thin surface horizons higher in fines than subsurface horizons,

exhibiting granular, subangular blocky, or massive structure; (3) precipitation of secondary minerals and soluble salts; (4) irregular distribution of oxidizable carbon with depth; (5) high rock fragment content; (6) bridging voids that can cause minesoils to be excessively drained; (7) varying amounts of pyritic-S which can oxidize to create minesoil acidity and AMD; and (8) potentially high concentrations of soluble metals due to low pH. Understanding how these properties and their interactions affect soil formation is essential when making plans for future land use. Soil genesis is the portion of the field of pedology that conceptualizes the processes and features that produce the physical, chemical, and mineralogical properties of soils and their spatial distribution across various landscapes. Just as minesoils can generally have similar physical and chemical properties, they also can exhibit similar pedogenic properties.

Minesoil Pedogenesis

Being relatively young soils, most minesoils exhibit A-C or A-AC-C horizonation. Ciolkosz et al. (1985) estimated that it takes 3 to 13 years for minesoils to form thin A horizons, even on most un-reclaimed sites. Roberts et al. (1988) described a 4-cm thick A horizon on a non-topsoiled 1-yr old minesoil and 6-cm thick A horizon on a 1-yr old topsoiled minesoil. When comparing minesoils forming in similar parent materials, the length of time since disturbance is directly correlated to the depth of A horizons (Bini & Gaballo, 2006; Haering et al., 1993). When considering minesoils of similar age forming in different parent materials, however, other variables including type of parent material, position in the landscape, drainage (limited and excessive), success of reclamation efforts, and possibly other factors more strongly influence the depth of A horizons (Haering et al., 2004; Sencindiver & Ammons, 2000)

Several physical and chemical properties distinguish A horizons found in minesoils from the subsoils. On unreclaimed and reclaimed mine spoils (assuming phytotoxic metal concentrations have not accumulated and aridic conditions from excessive drainage have not arisen), the growth of roots loosens soil that may have been compacted during mining activities, reducing bulk density. Organic matter accumulates on the surface upon root litter decomposition, darkening the soil color. Moreover, structural development ranging from weak granular to weak subangular blocky has been described in A horizons of minesoils, depending on factors such as slope, rate of erosion, climate, etc. (Haering et al., 2004; Roberts et al., 1988). Due to more rapid weathering in the top 10 cm of the soil profile, organic-C content can match that of native soils within 30 to 50 years. This is not true in the subsurface, where

hundreds of years may be required to reach comparable levels. Rock fragments also break down more quickly in the surface horizon, which usually exhibits a smaller rock fragment content that the subsoil horizons (Sencindiver & Ammons, 2000).

Minesoil horizons can vary from the relatively unweathered A-C-C horizonation to the development of cambic horizons, showing A-Bw-C horizonation (Haering et al., 2004; Roberts et al., 1988; Thomas et al., 2000). In several studies, weak Bw horizons were described, usually because of more evident structure, but failed to meet requirements to be cambic diagnostic horizons (Haering et al., 1993, 2004; Roberts et al., 1988). Cambic horizons were described by Daniels and Amos (1982) in minesoils forming in silty materials (15-20 yr old). In predominantly sandstone (>25%) spoil material, only A, AC, and C horizons have been described, although Bw horizons were observed in sand- and gravel-pit soils that met all requirements to be cambic except the texture (too coarse) (Sencindiver and Ammons, 2000). As in minesoil surface horizons, it seems the age of the minesoils does not influence the development of subsurface horizons as heavily as mining and reclamation method or type of parent material. Discontinuities are also a common characteristic of minesoil profiles due either to the layering of different geologic materials or because of contact with native soil materials, resulting in horizonation such as A-2Cd-3C (Haering et al., 2004) and A-Bw1-Bw2-C-2Ab (Gaither et al., 1996), respectively.

Minesoil horizonation is often markedly different than nearby native soil horizonation due to drastic disturbance caused by mining operations. When comparing native soil profiles to two 25-yr old minesoil profiles located in the same general areas, Thurman and Sencindiver (1986) found such differences. On the first site, the minesoil was described with A-C1-C2-C3 horizonation, while the native soil had A-BA-Bt-BC horizonation. On the second site, the minesoil horizonation was A-C1-C2 and the native soil horizonation was Ap-Bt-C. Similarly, Gaither et al. (1996) described two minesoil profiles with the following horizonations: A-Bw1-Bw2-C-2Ab and A-C1-C2-C3(L)-C3(R). The native profiles from areas nearby were drastically different: A-EB-Bt1-Bt2-BC-2Bt and A-BE-2Ab-3Bt. Understanding how minesoils differ from native soils is important when attempting to interpret soil surveys of mined areas because the classification of minesoils can be quite different than that of nearby native soils.

Restoring minesoils so they may eventually weather into soils with similar physical, chemical, and pedogenic properties of native or pre-mining soils is commonly the primary objective of mine land reclamation, with the goal of returning a mined area to its pre-mining uses, such as pasture-land, forest-land, or agricultural land (Shukla et al., 2004). Until the mid-1900s, however, coal mining companies

operated with little or no state or federal regulation, meaning that reclamation was not required by law and mined lands and their associated environmental hazards were left abandoned.

Surface Mining Regulation in the US

Due to its destructive nature, the rapid expansion of coal mining operations in the early 1900s created growing concerns among the public, researchers, and politicians about the economic and environmental sustainability of mining techniques being used. It is estimated that over 90% of AMD in the US originates from 450,000 ha of abandoned coal-mined lands and 6,500 ha of abandoned spoil piles. Approximately 16,000 km of streams in the US have been affected by AMD, and the EPA has stated that AMD is "the most chronic industrial pollution problem" in the Appalachian coal mining region. (Office of Water, 2000).

During the early 1900s, a large effort was mounted by academic institutions, the federal and state governments, and the mining industry to gain a better understanding of how to improve mining techniques to make restoration of disturbed lands possible. Initial information regarding the factors affecting revegatation of mined lands was obtained by small-scale, area-specific projects. For example, in 1937 the US Forest Service (USFS) began a tree planting experiment in Perry County, Ohio, offering one of the earliest assessments of the physical and chemical characteristics of mine spoil materials (Plass, 2000). Individual states began issuing laws to regulate coal mining companies within their borders, beginning with West Virginia in 1939, Indiana in 1941, Pennsylvania in 1945, Ohio in 1947, and Kentucky in 1954. Because coal companies played such a large role in the economy of these states, environmental regulations dictated by the law were nearly impossible to enforce. In the 1960s, surface mining was such a divisive issue that many proposals were made to outlaw it altogether, especially in Appalachian states where vast areas of land had been stripped and abandoned (Montrie, 2003).

The first bill introduced at the federal level to control the mining industry was presented in 1940, but resulted only in the initiation of surveys to estimate the damages done by strip mining in the 1950s and 1960s. Finally in 1968, the first full-scale congressional hearings were held on the debate, followed by more than a decade of intense congressional debates regarding how the legislation should proceed. The federal government wanted to put control of mining companies in the hands of the states, requiring them to pass their own legislation and measures of regulation. The states, having struggled

with this task for many years, argued that coal mining companies were huge conglomerates that operated nationwide and should be regulated by the federal government. Lengthy arguments over the details stretched out the debate, such as what sort of controls should be issued, what agency would be head of enforcement, and what kinds of penalties could be charged.

In the process of establishing appropriate legislation, Congress made a number of findings which guided the decision making process. First and foremost, it was recognized that coal mining operations helped meet the ever-increasing demand for energy in the US by providing coal as an energy source. Nonetheless, these same operations adversely affected public welfare, as well as that of local economies, "by destroying or diminishing the utility of land for commercial, industrial, residential, recreational, agricultural and forestry purposes" (Center for Wildlife Law, 2009). Congress found that it was appropriate and necessary to establish means to minimize these adverse social, economic, and environmental effects of coal mining. In order to do so, laws needed to ensure that competition among sellers of coal would not be used to weaken the states' ability to improve and maintain these standards on coal mining operations within their borders (Center for Wildlife Law, 2009).

The Surface Mining Control and Reclamation Act (SMCRA)

After decades of debating how to implement national and statewide coal mining standards, a consensus was finally reached, resulting in the Surface Mining Control and Reclamation Act (SMCRA) of 1977, signed into law by President Carter. While giving a nationally televised address, Carter acknowledged the ever-increasing demand for coal in the US and the positive impact the use of this energy source had on reducing our dependence on foreign energy sources. Nevertheless, he pointedly admonished coal companies and asked that they please "not plunder our environment" for short-term financial gains (Montrie, 2003). SMCRA is still regarded as one of the most comprehensive and complex pieces of legislation ever ratified. The SMCRA laws were intended to provide mandatory uniform standards for coal mining and reclamation activities on state and federal lands, including the requirement that harmful impacts on the environment be minimized (Plass, 2000).

The major guidelines and requirements enacted were to be imposed by the newly created Office of Surface Mining Reclamation and Enforcement (OSMRE) in the Department of the Interior. A short summary of the duties of this office include:

- managing programs to control surface mining operations at the state and federal level, to include the ability to impose sanctions for violations of state and federal laws;
- developing and maintaining the Abandoned Mine Reclamation Fund, whereby states can apply for federal aid to reclaim mined lands that were abandoned before the passage of the laws;
- appropriating funds to establish mining and mineral resources research at public institutions in participating states;
- establishing environmental protection performance standards, requiring that all mining and reclamation operations be overseen and permitted by the OSMRE;
- designating criterion that can exclude certain lands from being mined if reclamation is judged to be infeasible; and
- developing and implementing state and federal standards for reclamation operations on newly mined lands (Department of the Interior, 1977), to include the requirement that all mined lands be returned to their approximate original contour.

The first federal cease-and-desist order was issued to the Easton Deaton contour strip mine at Clover Fork in eastern Kentucky by Patrick Angel and Bill Hayes. Responding to a complaint by a local resident, the two men visited the mine and saw a large area covered with steeply sloping spoil piles and embankments, devoid of any life. As described by Angel, the area "looked like the aftermath of Hiroshima" (Montrie, 2003).

This type of destruction was not uncommon in eastern Kentucky. In fact, large-scale surface mining operations disturbed large tracts of land along the entire Cumberland Plateau. The Cumberland Plateau is a physiographic region that extends from Alabama and Georgia from the south, through Tennessee to Kentucky and Virginia to the north (Figure 6). This entire area is underlain by vast deposits of bituminous coal, as can be seen when comparing Figure 2 showing the Appalachian coal mining region to Figure 6 showing the Cumberland Plateau physiographic region. The environmental and geologic conditions that led to the formation of coal in this region are intimately related to the formation of the Cumberland Plateau. The geologic construction of the plateau area is critical to understanding the properties of the coal and parent materials in this area. By grasping the unique nature of these spoil materials, the physical and chemical properties of minesoils forming therein can be better understood.

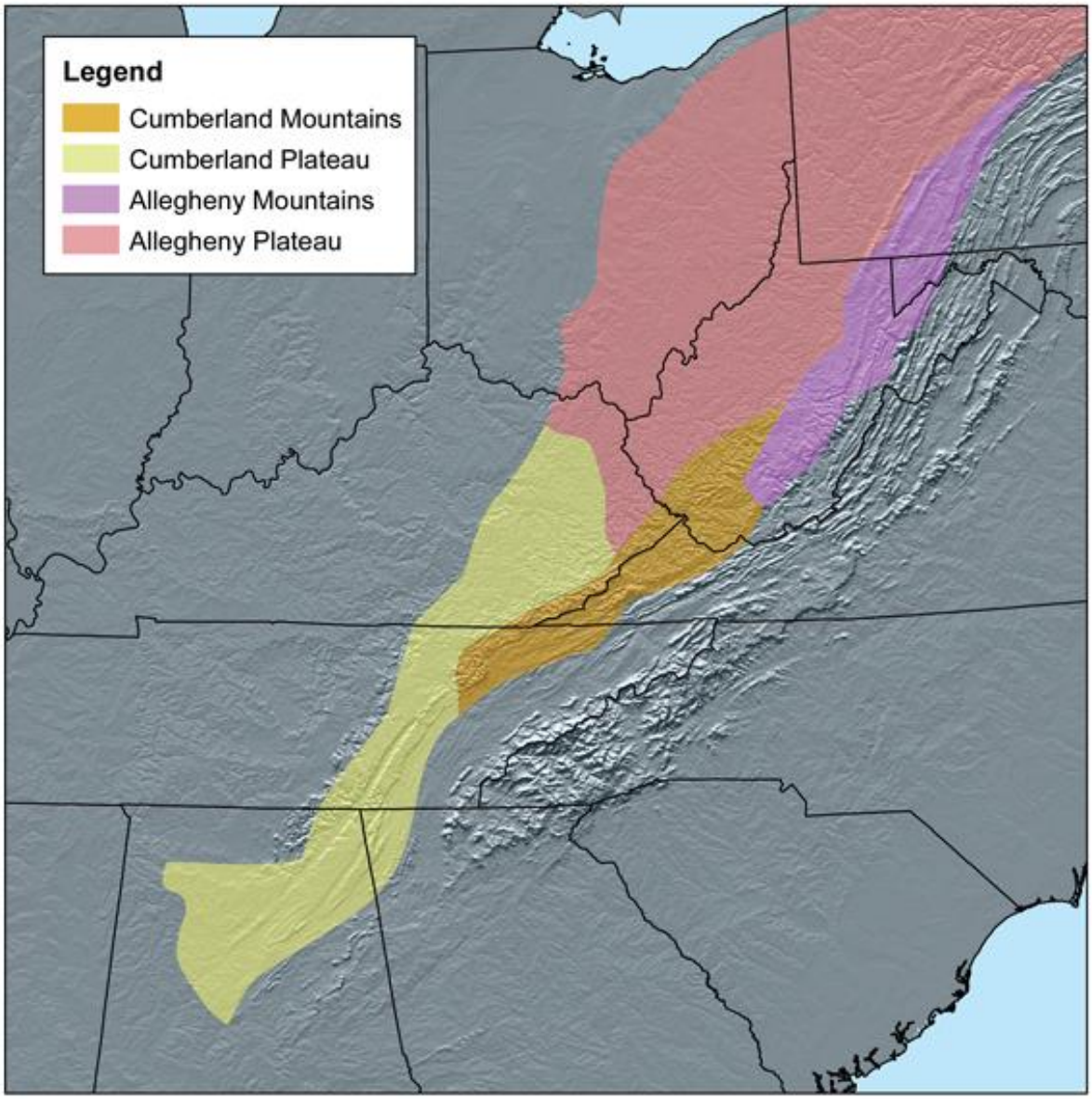


Figure 6. Cumberland Plateau physiographic region (Musser, 2007).

Geologic Overview of the Cumberland Plateau

The rocks that underlie the Cumberland Plateau were created at the bottom of an ancient shallow sea over 350 million BP. The Carboniferous period is comprised of the Mississippian (360-320 million BP) and the Pennsylvanian (320- 296 million BP) epochs of geologic time (National Park Service, 2008). During the early Carboniferous, expansive reef systems formed in the warm, shallow waters and supported large populations of aquatic life including crustaceans, mollusks, and underwater plants. These ecosystems were subjected to the effects of sea level fluctuations and storm events, as evidenced by the mixed stratigraphy present in the geologic record. The fossilized remains of marine organisms can also be found throughout the limestone and shale rock strata of this time period. These fluctuations in sea level are likely due to variations in glacial cycles (Sacks and Secor, 1999). The Pennington formation (Figure 7) was the last to be deposited in Tennessee during the Mississippian. This formation was created by clay, silt, and sands carried by rivers to the sea, which were deposited on the ocean floor forming vast dunes, deltas, sandbars, and beaches. Most strata within the Pennington are composed of shale with some siltstone, dolomite, and minor limestone (Miller, 1974).

During the Pennsylvanian epoch, this process of erosion and deposition continued, creating layers of gravel and sand sometimes thousands of feet thick, which eventually solidified into rhythmic patterns of Pennsylvanian sandstone and shale, with lesser amounts of siltstone, conglomerate, and coal (Miller, 1974). During this time, extensive swamplands, sometimes called “coal swamps”, dotted the landscape. These environments contained tropical vegetation, which upon decay, formed peat. Once this peat was compressed by layers of sediments, it became vast deposits of coal (Kentucky Educational Television, 2010). There are many complex cycles of sandstones, shales, and coals in the Pennsylvanian, which indicate oscillations in the shorelines and their adjacent environments during deposition.

The Rockcastle Conglomerate serves as a caprock over the complex layering that forms the strata of the Cumberland Plateau. This formation was created from small pebbles and coarse sands from ancient streambeds and is incredibly resistant to erosion (Finnegan, 2008). It can still be found today on the cliffs of many ridges and spurs in the Big South Fork National River and Recreation Area (BSF) and is underlain by shales, coals, fine-grained sandstones, and siltstones of the Fentress Formation. The Crooked Fork Group lies stratigraphically above the Rockcastle Conglomerate but can only be found on small, high cliff exposures. The rock formations overlying these strata, as seen in Figure 7, have been eroded away in the BSF.

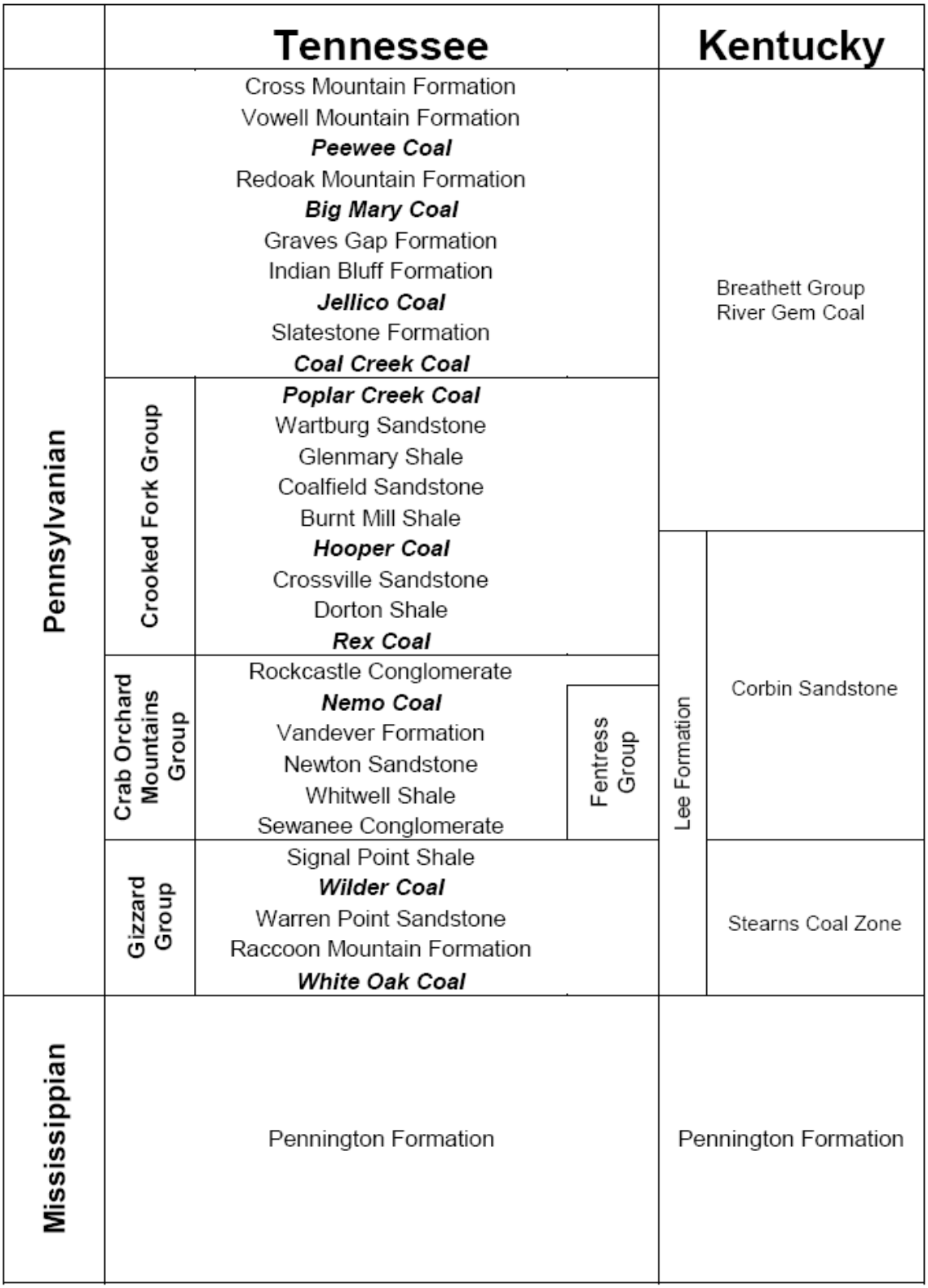


Figure 7. Approximate geologic column underlying the Cumberland Plateau.

Around 285 million BP, near the end of the Pennsylvanian Epoch, the area that is now the Cumberland Plateau was slowly pushed upwards to over 600 m above sea level by the collision of the land masses that would become Africa with that which would become North America. This collision, known as the Allegheny Orogeny, occurred over several millions of years and distorted the beds of sedimentary rocks, pushing them upward from the sea floor. This buckling and deformation created what are now the Appalachian Mountains. Over time, the area that is now the Cumberland Plateau was eroded into the Appalachian Peneplain. Around 70 million years BP, during the Cretaceous Period, the Appalachian Peneplain was uplifted into a plateau, which slants from the higher elevations in the east to the lower elevations in the west. In the millions of years since this geologic event, differential weathering has created spots of weakness in the tough Rockcastle caprock. Water has cut deeply through the softer sedimentary rocks below (mostly sandstone) in places, creating the stunning gorges, rock shelters, and arches that define the BSF today (National Park Service Staff, 2008).

Coal Mining on the Cumberland Plateau

For decades, bituminous coal on the Cumberland Plateau was mined only locally. These early "cottage industries" peaked and died out following the Civil War. With the onset of the Industrial Revolution, however, the introduction of railways and canals made access to the area's vast supplies of timber and coal possible. "Without railroads" said one Tennessee business journal in 1891, "iron and coal would have remained hidden…there would have been no way to develop or transport them…The first essential…was the construction of the railroads" (Jones, 2008). From the mid-1800s until the mid-1900s, the coal mining industry physically transformed the landscape of the Cumberland Plateau.

Despite having considerably smaller coal fields than Pennsylvania and West Virginia, the Cumberland Plateau nevertheless had sufficiently rich coal deposits to attract the attention of investors and businessmen in the mid-1800s. In just one example, the Stearns Coal & Lumber Company, which mined coal on the Cumberland Plateau, would grow to eventually own or control over 52,000 ha of land from which it extracted coal, timber, natural gas, and sand (Finnegan, 2008). Most coal resources were located in the wilderness, either on steep slopes or in creek valleys with essentially inaccessible ravines. In these early coal mining days, one method of mining used on steep terrain was an altered version of underground mining called "punch mining". Appropriately named, punch mining involved finding a coal

seam and using explosives to blast a hole in the side of the mountain to extract it. Overburden materials were removed only from the face of the mountain to expose the coal seam. Mining continued into the mountainside, following the coal seam back until the oxygen supply became too low for miners to work. Scouts would then continue ahead, finding another location where the coal seam was thick enough, typically at least 60 cm tall, and the process would be repeated.

As in typical mining operations (except on a smaller scale), the high quality coal extracted from punch mines was sorted from mine spoil materials and removed using narrow rail lines that traced the mountainside. Unsightly spoil piles characteristic of coal mining operations were spread over large areas of the Cumberland Plateau, as reclamation of these sites was rarely completed (Daniels and Zipper, 1988; Haering et al., 2004). Just as in communities across the entire Appalachian coal mining region, the social and environmental impacts of coal mining on the Cumberland Plateau prompted the public to demand change from the state and local government. Unfortunately in this region, large mining corporations capitalized and controlled entire cities. As in the case of Stearns, KY (located in McCreary County), formed by and named after the owner of Stearns Coal & Lumber, over 80% of the population was directly connected to the mining industry. Mining operations of Stearns slowly started shutting down in the 1950s and 1960s as coal supplies were dwindling. By 1976, all remaining mining operations were sold by Stearns Coal & Lumber to the Blue Diamond Mining Company, which is an international energy conglomerate. As with Stearns, KY, when the mining corporations were not based in the area, few tax revenues generated from the sale of coal wound up in local communities (Finnegan, 2008). As mining operations began to close down along the Cumberland Plateau, many areas were left in poverty.

In Scott County, Tennessee, elected official Howard Baker, Jr. had to travel door-to-door to collect enough money just to purchase the local telephone company back from Stearns Coal & Lumber Company. With the environmental movement sweeping across the United States during the 1970s, small coalitions of local activists, such as the Save Our Cumberland Mountains group, began trying to convince state and federal governments to rehabilitate large tracts of land disturbed by mining that were once rich in natural beauty and wildlife. On the Cumberland Plateau, one such area was that surrounding the Big South Fork River. Although extensive mining operations had disturbed many mountainsides in the area, the historical significance of this river gorge pushed it to the forefront of lands to be saved (Finnegan, 2008).

The Big South Fork National River and Recreation Area (BSF)

As far back as 10,000 BP, Native American tribes made temporary homes out of hundreds of naturally occurring sandstone arches in the area around the Big South Fork River, as they hunted herds of large mammals through the region. Early American settlers began arriving here in the mid-1700s, establishing permanent communities along the river banks, leaving structures behind that remain today. Further, this river gorge is home to many species of plants and animals that only exist here. Over 150 scholarly journal articles, research publications, and government documents had been written about the flora, fauna, and geology of this area by the late-1960s, when lawmakers decided to officially preserve what was to become "the Yellowstone of the East" (NPS Staff, 2008).

The Big South Fork National River and Recreation Area (BSF) was established by the U.S. Congress in 1974. It is one of only five national rivers and the only National River and Recreation Area in the US. BSF spans over 50,625 hectares in McCreary and Wayne counties in Kentucky and Scott, Fentress, Pickett, and Morgan counties in Tennessee, atop the Cumberland Plateau in the western Appalachian Mountains (Figure 8). The area lies about 160 km northwest of Knoxville, TN. The Big South Fork River begins at the confluence of the Clear Fork River and New River in Tennessee, and flows north to Kentucky through a gorge more than 182 meters deep before draining into the Cumberland River. Elevation in the park ranges from 550 meters on the plateau down to less than 244 m above sea level in the valleys. The BSF is in the mesic (8-15° C) temperature regime with mean monthly temperatures ranging from -4°C in the winter to 29°C in the summer. The area receives an average annual precipitation of about 140 cm with heavier accumulations in the spring and summer months.

Because of the extensive coal mining that took place before the creation of the park, the National Park Service (NPS) has gone to great lengths to assess the potential environmental hazards remaining within the park boundaries and to mitigate them wherever possible. Though most of the park is now heavily vegetated with mixed forests, fields, barrens, and seeps, the BSF has received state and federal grants to reclaim several of the larger abandoned spoil areas and to protect and restore kilometers of streams affected by AMD throughout the park. Many pre-SMCRA spoil banks (those created before the passage of the SMCRA laws), however, have never been reclaimed. In fact, certain areas of the park remain so isolated that many spoil embankments have never been located, mapped, or studied. In order to better understand the nature of these spoil piles (innocuous or potentially

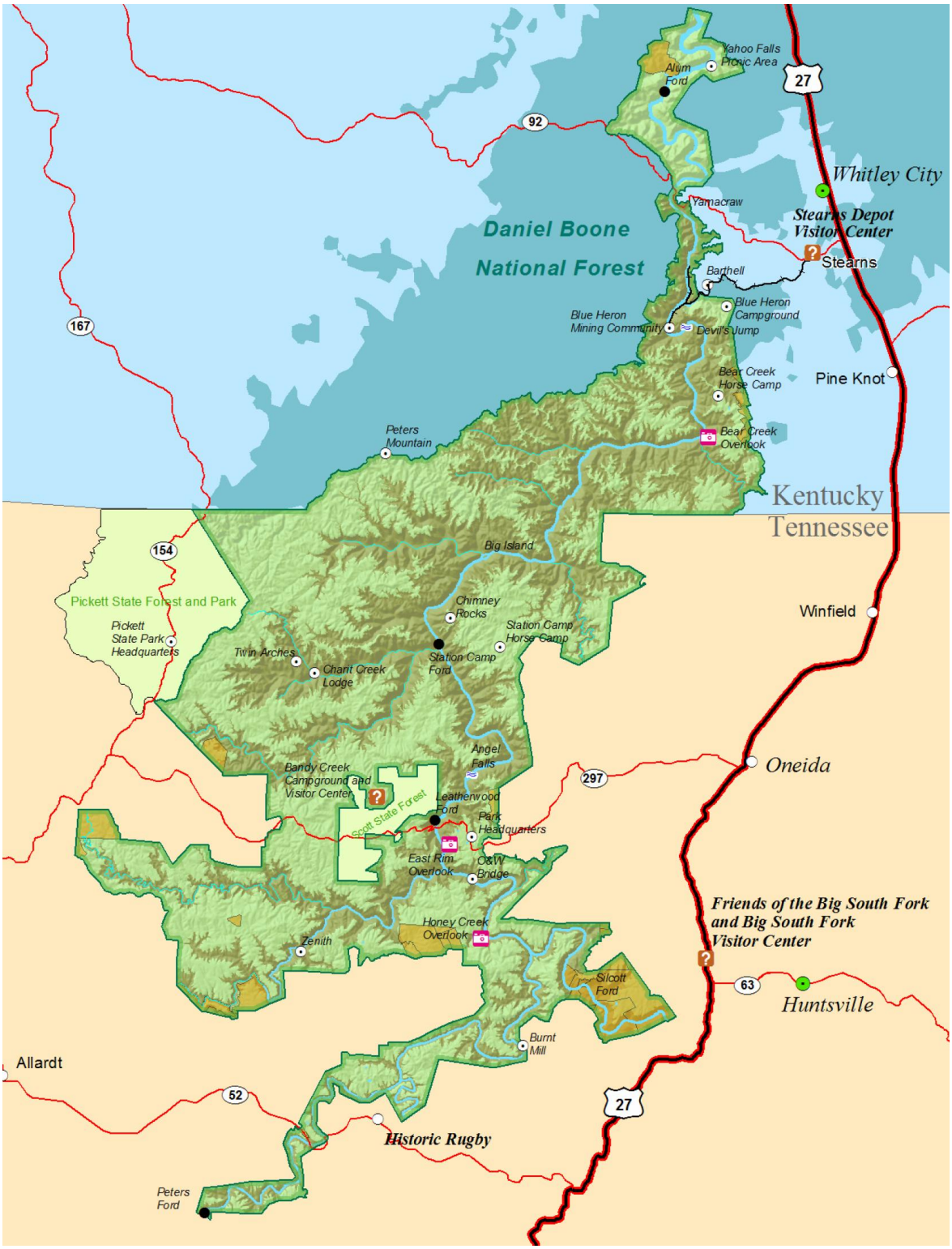


Figure 8. Map of the Big South Fork National River and Recreation Area (NPS, 2011).

hazardous), the NPS issued a grant to the University of Tennessee in 2009 to launch this research project.

Our first objective was to locate and map minesoils and spoil sites located within the BSF park boundaries. The second objective was to physically characterize the disturbed profiles, including minesoil morphological properties and determine, when quantitatively possible, if any significant differences exist between pre-SMCRA minesoils, post-SMCRA minesoils, and native soils. The third objective was to collect samples and chemically analyze the disturbed soils, including completion of an acid-base account to estimate acid-producing potential. Statistical analyses were to be conducted to determine significant differences between the three site types. These efforts will aid the National Park Service with future land use and water quality management.

Materials and Methods

Site Selection

All sampling sites were located in the Big South Fork National River and Recreation Area (BSF) either in the Nevelsville and Barthell Kentucky Topographic Quadrangles or the Barthell SW and Honey Creek Tennessee Topographic Quadrangles (USGS). Old mining roads and rail lines were located using park maps and aerial photographs (National Park Service, 2009) and with the personal knowledge of the park's Wildlife Biologist, areas where mine spoils were likely to be located were identified. Either on foot or on a John Deere 6 x 4 Gator ATV, collapsed and gated mine entrances were located and the surrounding areas physically searched for signs of spoil material.

Field Methods

Latitude and longitude for each site were recorded using a GPS unit. Samples of soil material as well as rock fragments less than 7 cm in size were collected from each horizon from selected minesoil sites. Soil morphology was completed according to National Cooperative Soil Survey standards (Soil Survey, 1994). Field notes included: horizon designation, depth, estimated rock fragment content, boundary distinctness, Munsell color, texture, structure, presence of redoximorphic features, presence

of roots and pores, and presence of clay skins. Slope, aspect, vegetation, elevation, landscape position, and other site characteristics were also recorded (Schoeneberger et al., 2002).

Grab samples were taken from selected sites, consisting of surface and subsurface samples (collected at 10 cm and 30 cm, respectively). These sites were chosen for grab samples instead of full profiles because the sites were judged to be similar in nature and in close proximity to other sites on which full profiles were described. Field notes on these sites included: lower depth of each sample, estimated rock fragment content, Munsell color, vegetation, landscape position, slope, elevation, and GPS coordinates.

Laboratory Methods

The samples were air-dried and sieved to less than 2 mm. The coarse fragments were separated and stored for further analysis. A portion of each sample was then randomly separated and ground to < 0.25 mm (60 mesh) for laboratory analyses (Soil Survey Staff, 1996). Particle-size analysis was performed using the pipette method with air-dried samples (Kilmer and Alexander, 1949). Prior to this procedure, carbonates were removed by treatment using pH 5 NaOAc and organic matter was removed using H_2O_2. The sands were fractionated into very coarse sand (vcs), coarse sand (cs), medium sand (ms), fine sand (fs), and very fine sand (vfs) (Gee and Bauder, 1986).

An acid-base account was quantified by determination of the neutralization potential (NP) and the maximum potential acidity (MPA), according to the Sobek method (Sobek et al., 1978). The first step in determining NP was the examination of the "fizz" or reaction of a sample with room temperature hydrochloric acid (HCl). It is assumed that samples with less than 20 parts per trillion (ppt) $CaCO_3$ generally will not fizz or effervesce (Sobek et al., 1978). There are four fizz ratings given based on the observed intensity of the reaction: none, slight, moderate, and strong. The volume and normality of the HCl used to digest each sample corresponded to the assigned fizz rating. If the rating was "none", 20 ml of 0.1 M HCl was reacted with the sample; if "slight", 40 ml of 0.1 M HCl; if "moderate", 40 ml of 0.5 M HCl; and if "strong", 80 ml of 0.5 M HCl.

Next, the sample and acid were heated nearly to boiling to ensure that the reaction between the acid and any neutralizers proceeded to completion. Once cooled, the mixture was titrated with standardized 0.1 M or 0.5 M NaOH (depending on the molarity of HCl used in each sample) to a pH of 7.00 using a pH meter and burette. A blank was run for each volume and molarity. To calculate the NP, a constant was calculated by dividing the amount of acid in a blank by the amount of base in that same

blank. The amount of acid consumed during the reaction was determined by subtracting the amount of base added multiplied by the constant from the amount of acid added to each sample initially. Finally, tons of $CaCO_3$ equivalent per thousand tons of material was determined by multiplying the amount of acid consumed by 25.0 and multiplying that by the molarity of the acid and base.

The MPA was determined based on the percent pyritic-S. To determine percent pyritic-S, a sequential extraction of each sample was completed. First, three subsamples of 0.500 g of each sample were separated. One was left untreated for total sulfur determination by Leco Induction Furnace. The next subsample was leached with 2:3 HCl followed by deionized water to remove chlorides. The sample was then combusted and total sulfur remaining determined again, resulting in the determination of "HCl- extractable S" which is presumed to consist mostly of sulfates. The last subsample was leached with HNO_3 followed by deionized water. This sample was combusted to determine "HNO_3-extractable S", which is subtracted from the "HCl-extractable" sulfur to determine percent pyritic-S. Organic sulfur is determined arithmetically by subtracting the HNO_3-extractable S from total sulfur. The balance between the MPA and the NP is used to determine whether a material is likely to ultimately produce acidic or alkaline drainage and soil conditions upon weathering (Sobek et al., 2000).

Because the BSF is located in a humid climate, pH using both 1:1 soil to deionized water and 1:2 soil to 0.01 M $CaCl_2$ solution was measured for each 2 mm sample using a calibrated pH meter, an Expandable IonAnalyzer EA940 (Olsen and Ellis, 1982).

Exchangeable-Al was determined by extraction with 1 M potassium chloride (KCl), as described by Lin and Coleman (1960). Because Mn and Fe oxides are easily dissolved together, using hydroxylamine hydrochloride ((NH_2)•HCl) as an extractant allowed for the selective dissolution of only the MnO_2 (Chao, 1972). ICP analysis was used to quantify both exchangeable-Al and easily-reducible Mn.

Oxidizable organic carbon was measured using the Walkley-Black method (Jackson, 1985), which is a rapid dichromate oxidation-reduction technique that proceeds according to the following general equation (Nelson & Sommers, 2000):

[15] $2\ Cr_2O_7^{2-} + 3\ C° + 16\ H^+ = 4\ Cr^{3+} + 3\ CO_2 + 8\ H_2O$

The $Cr_2O_7^{2-}$ reduced during this reaction was assumed to be a measure of the amount of organic-C in the sample. The remaining $Cr_2O_7^{2-}$ was titrated with ferrous ammonium sulfate ($Fe(NH_4)_2(SO_4)_2$•$6H_2O$) to calculate how much dichromate was reduced.

Cation-exchange capacity was determined using the Ammonium Acetate (pH 7) Method, which is a standard method for soil survey and classification. This method saturated the exchange complex

with ammonium ions with repeated washings with ammonium acetate (NH_4OAc). The solution collected after this wash with NH_4OAc was kept for determination of exchangeable bases (Na, K, Ca, and Mg) using ICP-OES, as described by Hammer and Lewis (1987). Next, the NH_4^+ adsorbed was replaced by additions of slightly acid 10% sodium chloride (NaCl) solution. The solution from these washings was saved and the NH_4^+ content was determined by estimating the amount of NH_3 liberated from the sample upon distillation of the solution with a strong base, in this case sodium hydroxide (NaOH). The NH_3 was trapped by distilling it into a boric acid solution (H_3BO_3), where the NH_3 was protonated to NH_4^+ forming ammonium borate. This ammonium borate was then titrated to boric acid and NH_4Cl by the following reaction:

[16] $NH_4^+ + H_2BO_3 + HCl \rightarrow NH_4Cl + H_3BO_3$

Because this reaction has a 1:1 stoichiometry, there is 1 mole of NH_4 present for each mole of HCl consumed. Therefore, finding the amount of NH_4 in the replacing solution allows the calculation of the CEC of the soil sample (Chapman, 1965).

The Mehlich-I, or dilute double-acid nutrient extraction (Mehlich, 1953) was completed using 5.0 g of < 2mm soil samples, which were extracted with 50 ml of the dilute double acid solution. The samples were shaken for 5 minutes, filtered, and Ca, Cu, K, Mg, Mn, P, and Zn were quantified using ICP-OES analysis.

Because Blair (2009) completed a total elemental analysis of native soils in the BSF, this information was available for comparison to the minesoils in this project. Using the same methods employed in the previous study was important for accurate comparison, so total elemental analysis was completed using the same modified microwave digestion procedure (Ammons et al., 1995) with which the following elements were quantified by ICP: As, Ba, Ca, Cd, Co, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Pb, S, Si, Sr, Ti, Zn, and Zr.

After completion of the chemical characterization, tests for statistical significance were employed to compare the following 6 groups: pre-SMCRA surface horizons to post-SMCRA surface horizons, pre-SMCRA surface horizons to native surface horizons, post-SMCRA surface horizons to native surface horizons, and the same pairs with subsurface horizons. Multiple one-way ANOVA tests in SPSS 19 software were completed to reveal statistically significant differences occurring between the mean values from each group. To reveal similarities/ differences between only the pre- and post-SMCRA profile sites which may not be directly apparent by looking at raw data or ANOVA, a hierarchical clustering analysis was completed using every data point collected on each minesoil horizon.

Clustering analysis, sometimes referred to as data segmentation, aims to group data into subsets, or "clusters", such that those within each cluster are more closely related to one another than those that lie in another cluster. Hierarchical clustering can be broken into two types of methods: *agglomerative* and *divisive*. *Agglomerative* methods, such as that employed for this project, proceed by a series of divisions which separate the data into groups. It was completed using uncentered correlation as a similarity matrix and the average linkage as the linkage criteria, as described by Eisen et al. (1998). Before the analysis, the data tables were median centered and log transformed using SAS in order to remove any effects of differences in scale or units. The "heat maps" presented were created using "TreeView" software and make understanding how pre-SMCRA minesoils differ (or are similar to) post-SMCRA minesoils.

Results and Discussion

Minesoils and spoil materials located within the BSF park boundaries weredivided into two categories: (1) sites forming in materials deposited before the passage of the SMCRA laws (pre- SMCRA sites, henceforth denoted as PRE); and (2) sites forming in materials that were reclaimed after the passage of the SMCRA laws (post-SMCRA sites, henceforth denoted as POST). The sites within each category share similar properties in many cases and separating the two facilitates discovery of the properties which reclamation efforts may have influenced. Of the PRE sites (Table 1), full profiles were described on 9 (PRE-P), grab samples (PRE-GS) taken on 7, and 9 were mapped only (PRE-MS). Full profiles were described on 9 post-SMCRA (POST-P) sites as well, along with 5 POST-GS and 3 POST-MS (Table 2). All locations were found within Scott and Fentress counties in Tennessee and McCreary County in Kentucky, as seen in Figure 9.

The majority of sites (36 out of 42) were located in McCreary County, KY because this county was home to the Stearns Coal and Lumber Company, which heavily mined McCreary County from the early to mid- 1900s. The National Park Service (NPS) negotiated the transfer of thousands of acres from Blue Diamond that were no longer being mined, slowly accumulating the more than 50,000 ha that comprise the park today. Most PRE sites were mapped with only one GPS coordinate to mark their locations, while most POST sites occurred in large reclamation areas which were marked with GPS on all

sides. Photos were taken of each site and are provided in Figures 10 through 43, along with other noteworthy pictures.

Soil Morphology

When completing morphological descriptions for each location, several types of material were identified, corresponding to the type of land disturbance including coal minesoils, reddog, sites with combinations of these two, and areas which contained these same constituents but on which reclamation efforts were made. The elevations recorded ranged from 224 to 375 meters above sea level (Tables 1 and 2).

The average slope for pre-SMCRA profile sites (PRE-P), 60%, was significantly steeper (at p=0.05) than the average slope for the post-SMCRA profile sites (POST-P), which was 43% (Tables 3 and 4). All PRE-P sites had slopes greater than 30% and 6 had a slope greater than 65%. On the 9 PRE-P, there were morphological characteristics that most shared but that differed significantly from the 9 POST-P sites. The first and most dominant influence on soil formation in the PRE-P sites was the rock fragment content and type. As seen in Table 3, depending on the estimated percent rock fragment content, a texture can be assigned the modifiers “gravelly” or “channery” if there is ≥ 15% but < 35% coarse fragments in the range of 2- 76 mm. “Channery” is assigned when the fragments are less spherical or cubical and are more flat and elongated. “Very” is added when there is ≥ 35% but < 60% coarse fragments, and “extremely” is added when there is ≥ 60% but < 90% coarse fragments (Schoeneberger et al., 2002).

Of the 33 total soil horizons sampled from PRE-P sites, only 4 were not assigned rock fragment modifiers- 3 of these were native soil horizons, not disturbed materials. The average PRE minesoil surface horizon contained 48% rock fragments by volume and the corresponding subsurface horizons, 62%. The average POST surface and subsurface horizons contained 24% and 44%, respectively. Both PRE surface and subsurface horizons contained a significantly higher volume of rock fragments than POST horizons (at p=0.05). Only 27% of POST-P horizons that received rock fragment modifiers were 60-90% rock fragments, whereas 55% of the PRE-P sites contained 60-90% rock fragments. This was expected because POST-P sites have undergone reclamation; 4 were located on sites where large-scale reclamation had been completed, including the burial or removal of pyritic-S containing materials, the addition of topsoil and fertilizers, and planted with grasses, trees, and shrubs. These were POST sites 3,

Table 1. Pre-SMCRA Inventory within BSF park boundaries.

Site*	County	Location Within Park	Site Mapped (origin)	Latitude	Longitude	Elevation (m)
1	McCreary County, KY	Barthell	Minesoil (spoil)	36.687583N	84.524917W	258
2	McCreary County, KY	Worley 1	Minesoil (refuse)	36.699622N	84.536206W	228
3	McCreary County, KY	Worley 2	Minesoil (refuse)	36.698917N	84.536306W	239
4	McCreary County, KY	West Blue Herron	Minesoil (spoil)	36.670778N	84.550444W	254
5	McCreary County, KY	Devils Creek 1	Minesoil (spoil)	36.674139N	84.551389W	231
6	McCreary County, KY	Devils Creek 2	Minesoil (spoil)	36.6745N	84.552778W	244
7	McCreary County, KY	Big Spring Hollow	Minesoil (refuse)	36.655278N	84.543028W	311
8	McCreary County, KY	Blair Creek	Minesoil (spoil)	36.657278N	84.529333W	237
9	Scott County, TN	Rough Shoals	Minesoil (refuse)	36.505861N	84.631944W	267
GS1	McCreary County, KY	Worley	Minesoil (spoil)	36.694917N	84.536528W	247
GS2	McCreary County, KY	Three West Hollow	Minesoil (refuse)	36.667056N	84.550111W	254
GS3	Scott County, TN	Bill Branch	Minesoil (refuse)	36.497778N	84.631556W	279
GS4	McCreary County, KY	Rock Creek	Minesoil (reddog)	36.713344N	84.547861W	224
GS5	McCreary County, KY	N. Dick Gap	Minesoil (refuse)	36.667167N	84.531139W	246
GS6	McCreary County, KY	Dick Gap	Minesoil (refuse)	36.663833N	84.533111W	260
GS7	McCreary County, KY	Blair Creek Drainage	Minesoil (refuse)	36.657278N	84.529389W	238
MS1	McCreary County, KY	Devils Creek	Minesoil (refuse)	36.6745N	84.552167W	270
MS2	McCreary County, KY	Devils Creek	Mine Location	36.675333N	84.552556W	257
MS3	McCreary County, KY	N. Devils Creek	Mine Location	36.67674N	84.54837W	257
MS4	McCreary County, KY	N. Devils Creek	Minesoil (refuse)	36.67675N	84.581694W	240
MS5	McCreary County, KY	Three West Hollow	Mine Location	36.665083N	84.55475W	262
MS6	McCreary County, KY	Three West Hollow	Mine Location	36.666833N	84.550333W	263
MS7	McCreary County, KY	Big Spring Hollow	Mine Location	36.656056N	84.542861W	285
	McCreary County, KY	Big Spring Hollow	Mine Location	36.655861N	84.543278W	242
	McCreary County, KY	Big Spring Hollow	Mine Location	36.656361N	84.542361W	276
	McCreary County, KY	Big Spring Hollow	Mine Location	36.656361N	84.541917W	309
MS8	McCreary County, KY	Devils Jump	Mine Location	36.671111N	84.538222W	300
	McCreary County, KY	Devils Jump	Mine Location	36.670583N	84.538389W	312
MS9	McCreary County, KY	Dick Gap	Mine Location & Refuse	36.661417N	84.533361W	260
MS10	McCreary County, KY	Worley	Mine Location	36.69865N	84.533586W	258

*GS- Grab Sample Sites, MS- Mapped Sites (no samples taken)

Table 2. Post-SMCRA Inventory within BSF park boundaries.

Site*	County	Location Within Park	Type of Disturbance	Latitude	Longitude	Elevation (m)
1	McCreary County, KY	Blue Herron Trailhead	Minesoil (refuse)	36.668361N	84.546389W	240
2	McCreary County, KY	Blue Herron Logging Road	Minesoil (refuse)	36.668583N	84.545139W	243
3	McCreary County, KY	Blue Herron Reclamation 1	Minesoil (spoil)	36.673111N	84.538722W	243
4	McCreary County, KY	Blue Herron Reclamation 2	Minesoil (spoil)	36.673139N	84.535861W	244
5	McCreary County, KY	Blue Herron Reclamation 3	Minesoil (spoil)	36.672910N	84.535486W	234
6	Fentress County, TN	Zenith Red Dog	Minesoil (reddog)	36.428083N	84.735278W	327
7	Fentress County, TN	Zenith Reclamation 1	Minesoil (refuse)	36.428806N	84.740722W	324
8	Fentress County, TN	Zenith Reclamation 2	Minesoil (refuse)	36.429139N	84.739639W	325
9	Scott County, TN	Anderson Branch Reclamation	Minesoil Reclamation	36.483694N	84.658472W	314
GS1	McCreary County, KY	Blue Herron Reclamation 4	Minesoil (spoil)	36.673139N	84.539194W	251
GS2	McCreary County, KY	Blue Herron Reclamation 5	Minesoil (spoil)	36.673111N	84.538722W	243
GS3	McCreary County, KY	Blue Herron Reclamation 6	Minesoil (spoil)	36.673083N	84.538194W	238
GS4	Fentress County, TN	Zenith	Reddog	36.428944N	84.734778W	325
GS5	McCreary County, KY	Jones Branch	Minesoil (refuse)	36.7685N	84.540861W	237
MS1	McCreary County, KY	Refuse site 3	Mine Refuse Start	36.671833N	84.532556W	288
	McCreary County, KY	Refuse site 3	Mine Refuse End	36.671833N	84.531222W	279
MS2	McCreary County, KY	Past RS3	Mine Refuse Start	36.669194N	84.528944W	265
	McCreary County, KY	Past RS3	Mine Refuse End	36.667722N	84.528583W	261
MS3	McCreary County, KY	Sheltowee Trail/Rock Creek	Minesoil (refuse)	36.714083N	84.548861W	230

*GS- Grab Sample Sites, MS- Mapped Sites (no samples taken)



Figure 9. Site locations in the BSF.



Figure 9. Continued. Site locations in the BSF.



Figure 9. Continued. Site locations in the BSF.



Figure 9. Continued. Site locations in the BSF.



Figure 9. Continued. Site locations in the BSF.

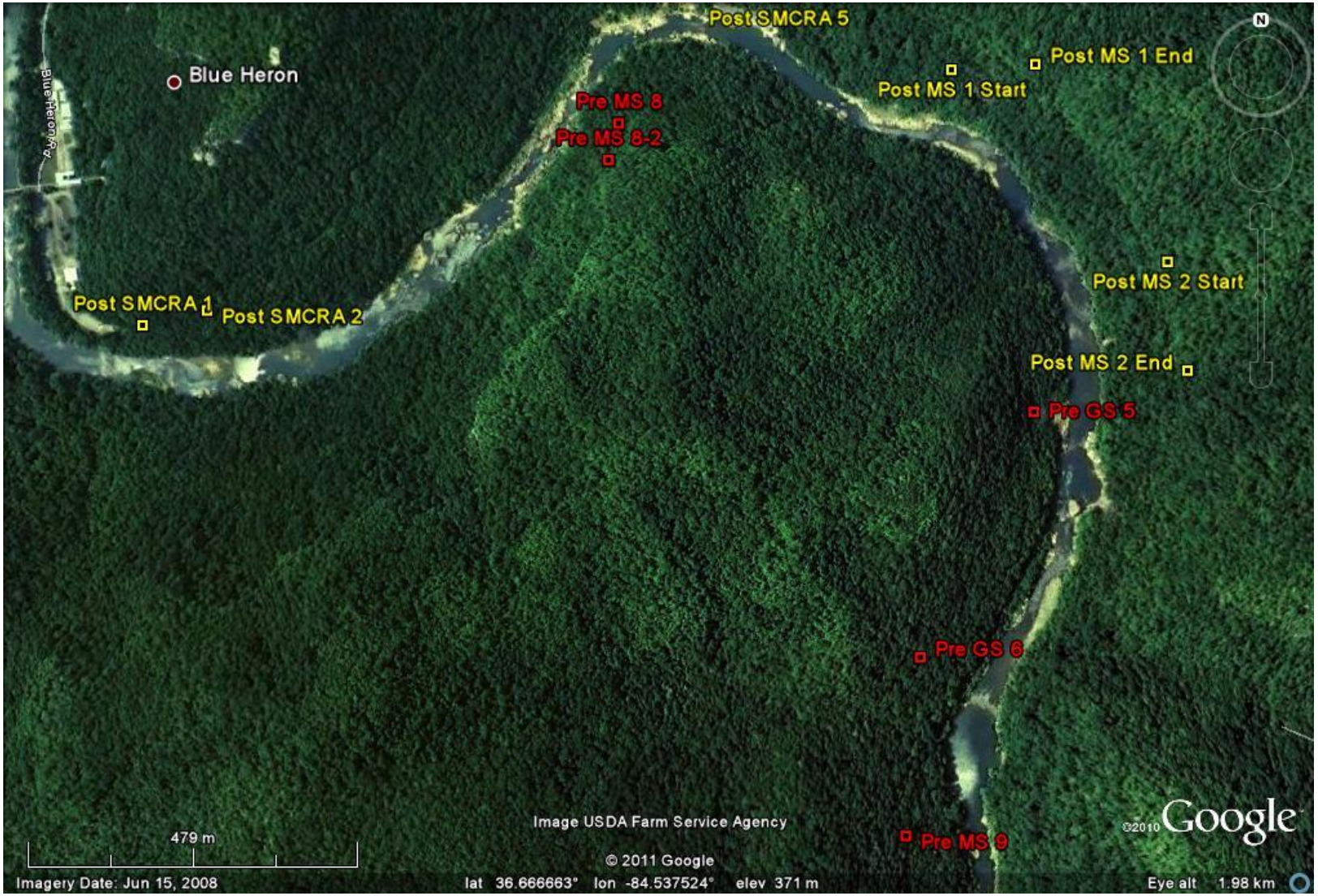


Figure 9. Continued. Site locations in the BSF.



Figure 9. Continued. Site locations in the BSF.



Figure 9. Continued. Site locations in the BSF.



Figure 9. Continued. Site locations in the BSF.

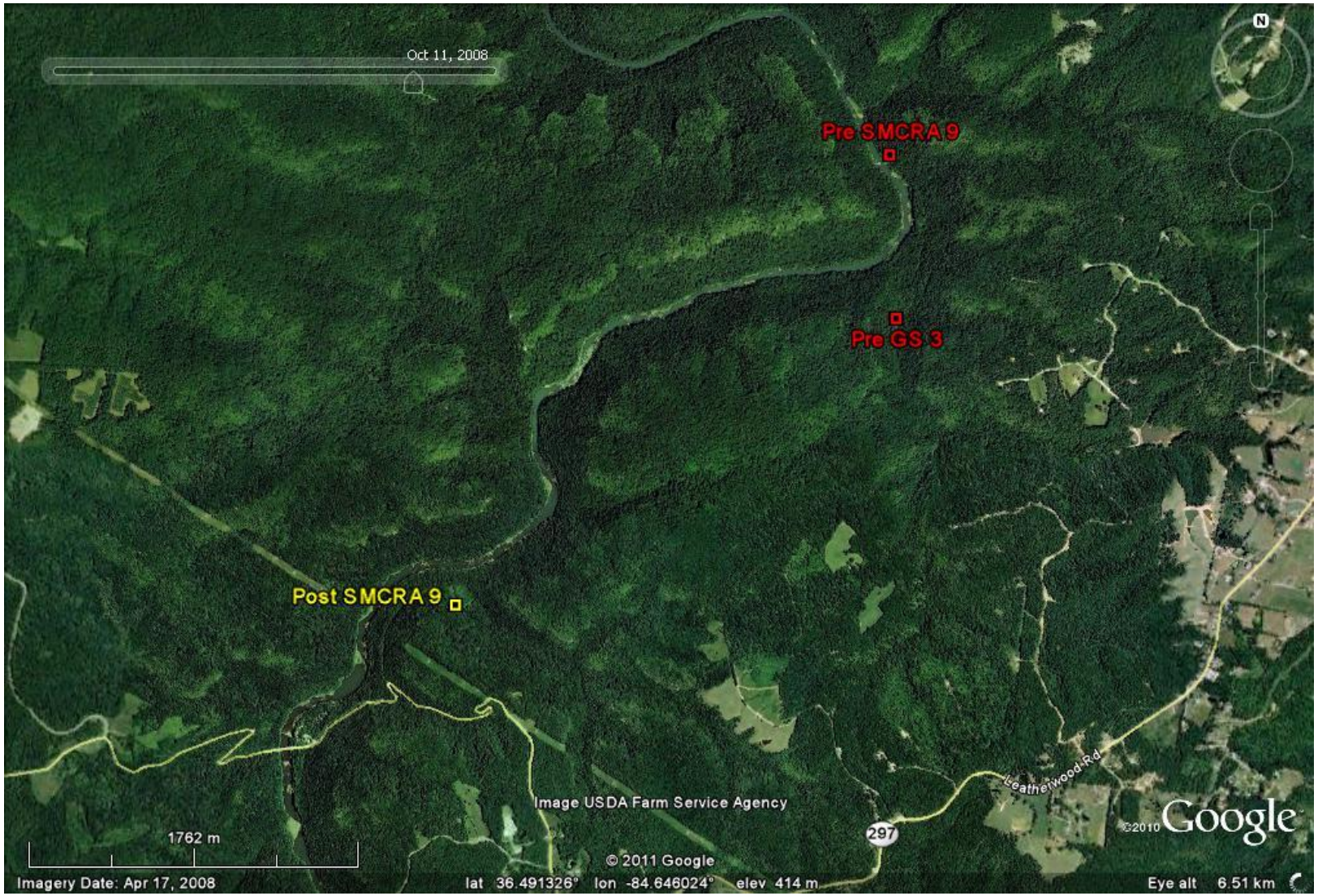


Figure 9. Continued. Site locations in the BSF.



Figure 9. Continued. Site locations in the BSF.



Figure 10. Pre-SCMRA Profile Site 2, former Worley Mining Camp.



Figure 11. Pre-SMCRA Profile Site 4.



Figure 12a. Pre-SMCRA Profile Site 5, collapsed mine opening.

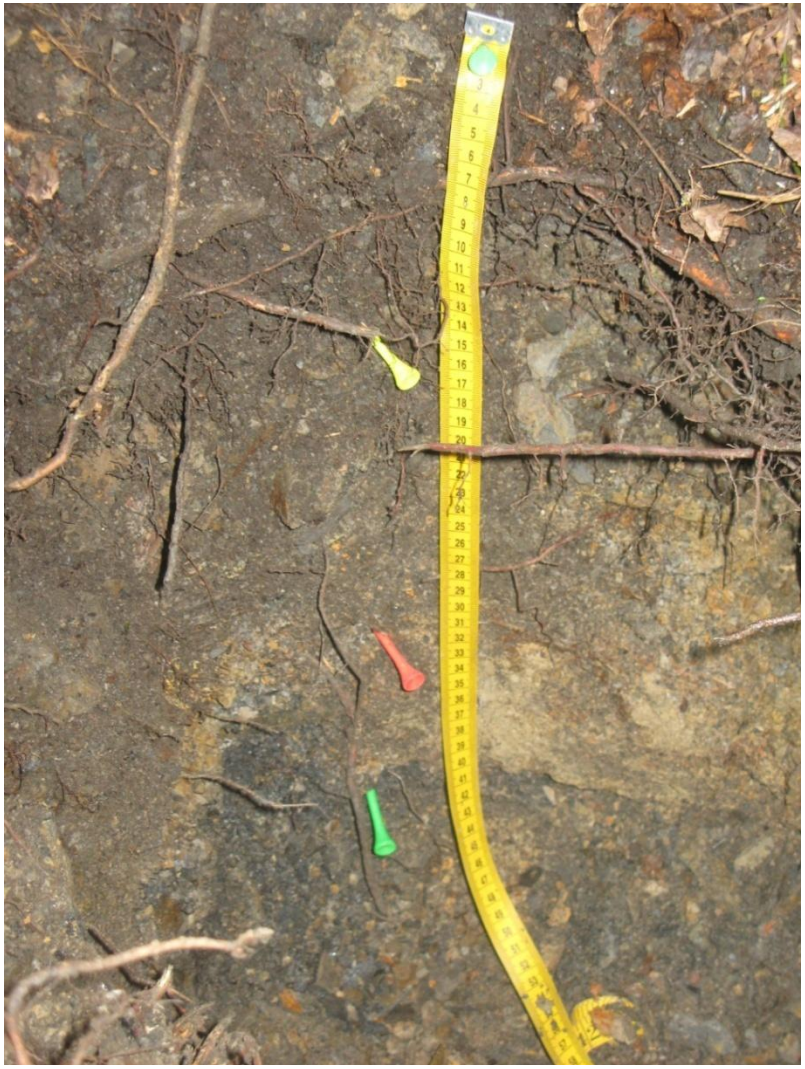


Figure 12b. Pre-SMCRA Profile Site 5.



Figure 13a. Pre-SMCRA Profile Site 6, landscape.



Figure 13b. Pre-SMCRA Profile Site 6, profile.



Figure 14. Pre-SMCRA Profile Site 7.



Figure 15a. Pre-SMCRA Profile Site 8, landscape.



Figure 15b. Pre-SMCRA Profile Site 8, profile.



Figure 16. Pre-SMCRA Profile Site 9.



Figure 17. Pre-SMCRA Grab Sample Site 1 landscape, former Worley Mining Camp.



Figure 18a. Pre-SMCRA Grab Sample Site 2, structure.



Figure 18b. Pre-SMCRA Grab Sample Site 2, surface and subsurface.



Figure 19. Pre-SMCRA Grab Sample Site 4, surface and subsurface.



Figure 20a. Pre-SMCRA Grab Sample Site 5, landscape.



Figure 20b. Pre-SMCRA Grab Sample Site 5, surface and subsurface.



Figure 21. Pre-SMCRA Grab Sample Site 6, surface and subsurface.



Figure 22. Pre-SMCRA Mapped Site 1, mining artifact.

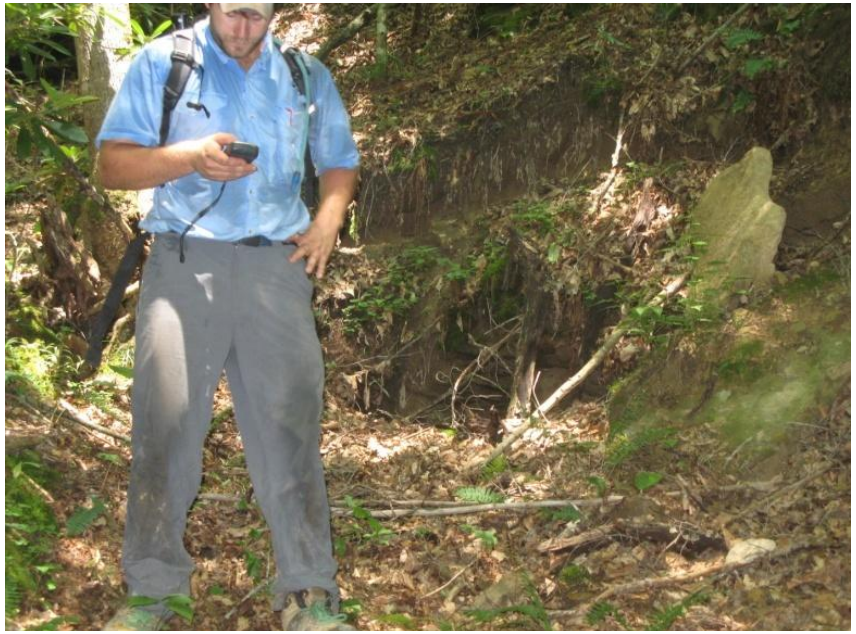


Figure 23. Pre-SMCRA Mapped Site 2, collapsed mine opening.



Figure 24a. Pre-SMCRA Mapped Site 4, landscape.



Figure 24b. Pre-SMCRA Mapped Site 4, minesoil.



Figure 25. Pre-SMCRA Mapped Site 5, mine opening.



Figure 26a. Pre-SMCRA Mapped Site 7, first mine opening.



Figure 26b. Pre-SMCRA Mapped Site 7, minesoil.



Figure 27. Pre-SMCRA Mapped Site 8, jarosite precipitation.



Figure 28. Post-SMCRA Profile Site 1.



Figure 29. Post-SMCRA Profile Site 2.



Figure 30. Post-SMCRA Profile Site 3.



Figure 31a. Post-SMCRA Profile Site 4, view from Devils Jump Overlook.

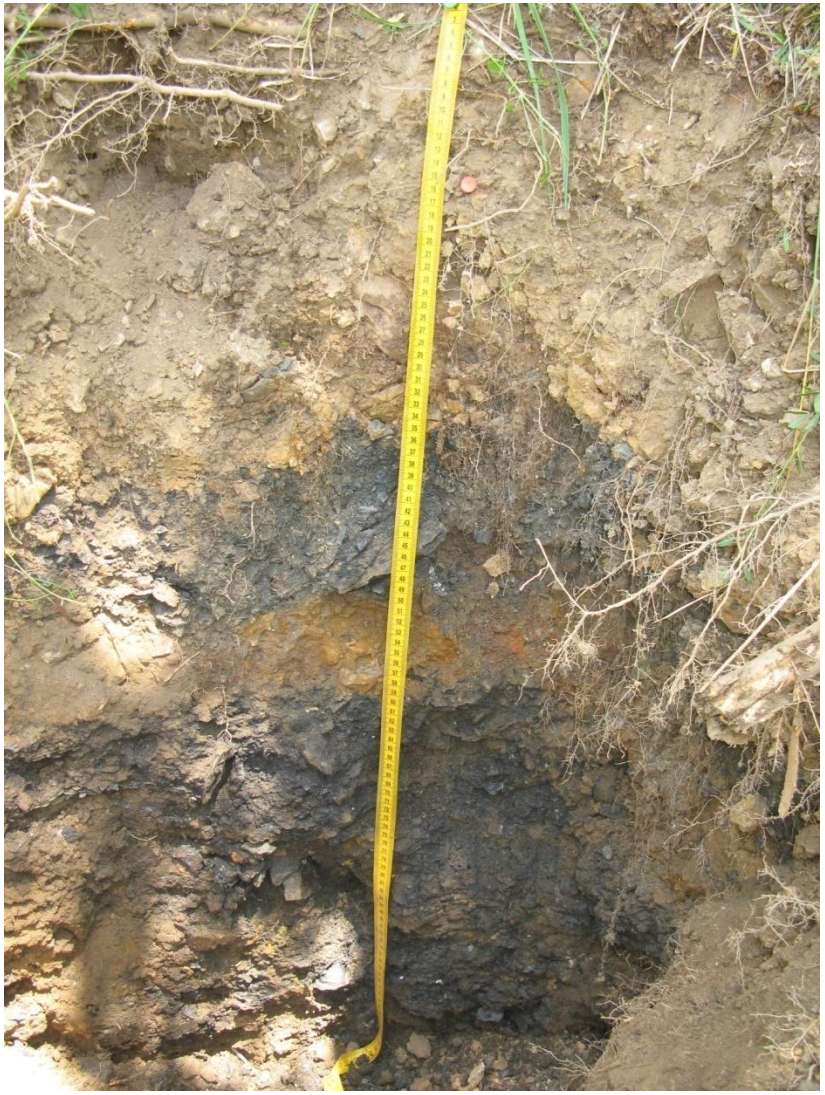


Figure 31b. Post-SMCRA Profile Site 4, profile.



Figure 32. Post-SMCRA Profile Site 5.

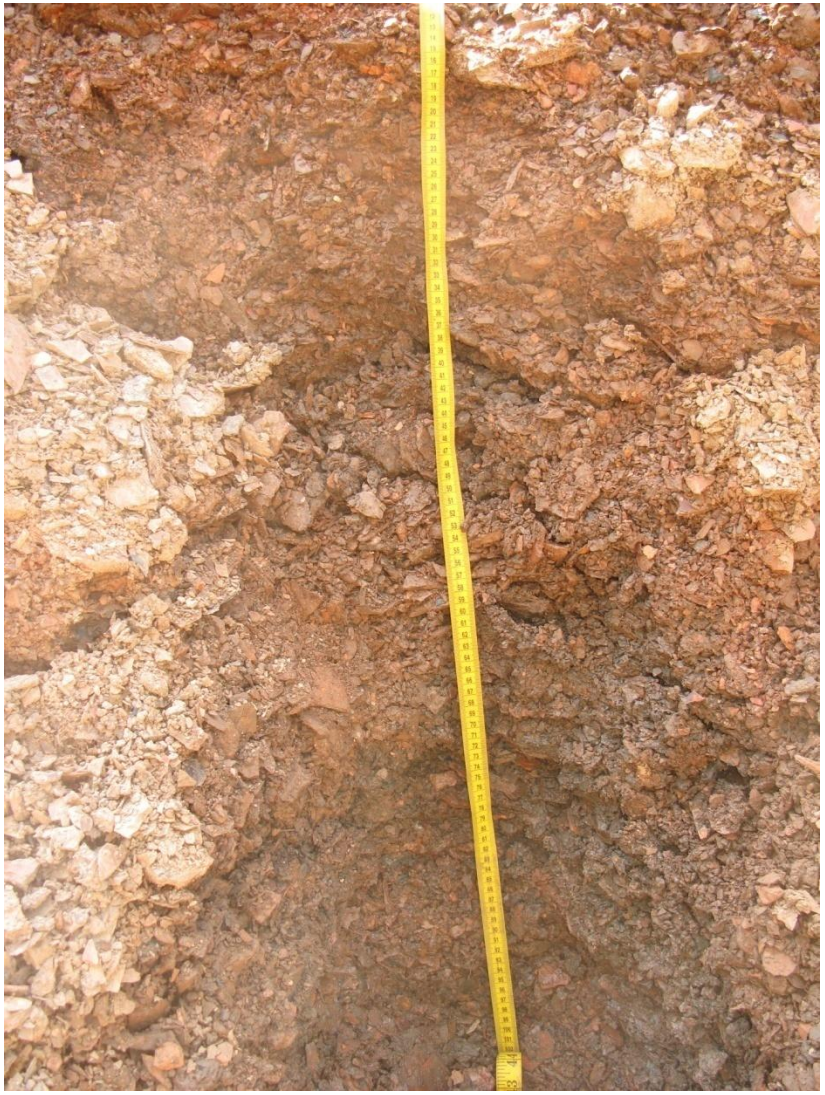


Figure 33. Post-SMCRA Profile Site 6.



Figure 34. Post-SMCRA Profile Site 7.



Figure 35a. Post-SMCRA Profile Site 8, structure.



Figure 35b. Post-SMCRA Profile Site 8, profile.





Figure 36a & b. Post-SMCRA Profile Site 9, “good reclamation” landscape (top) and “bad reclamation” (bottom).



Figure 36c. Post-SMCRA Profile Site 9, redoximorphic features.



Figure 36d. Post-SMCRA Profile Site 9, profile.

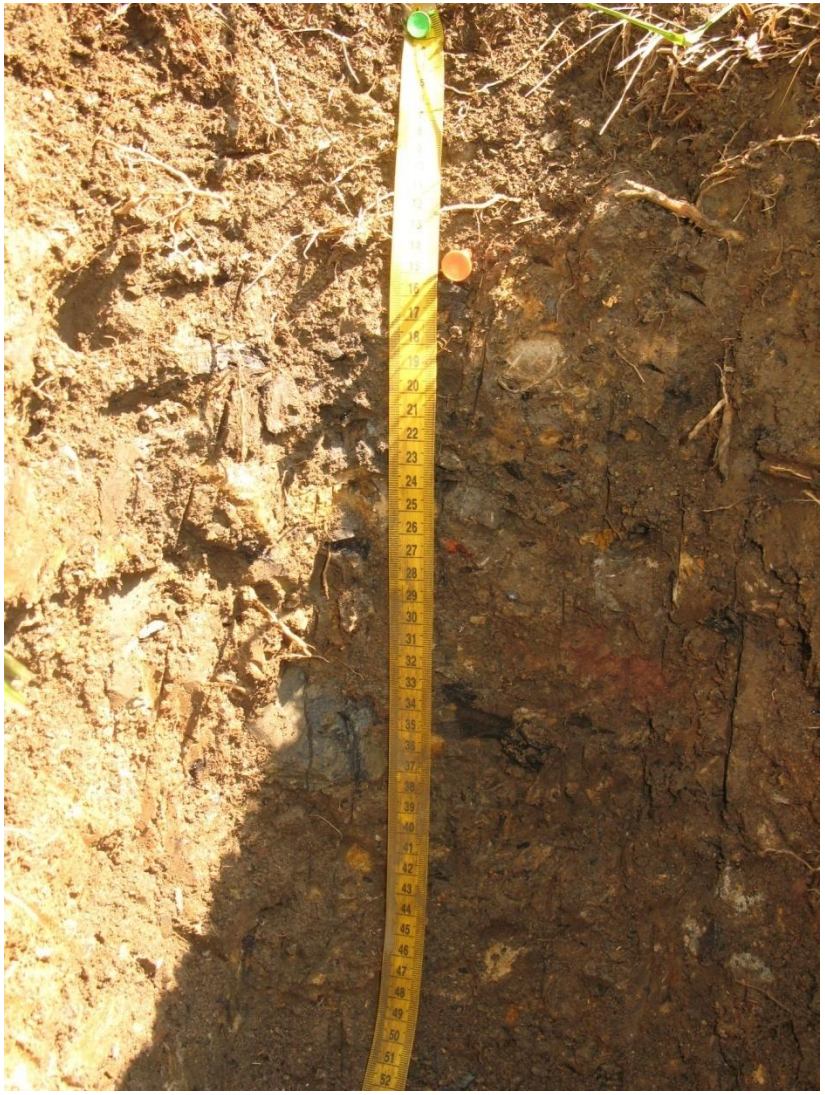


Figure 37. Post-SMCRA Grab Sample Site 1.



Figure 38. Post-SMCRA Grab Sample Site 2.



Figure 39. Post-SMCRA Grab Sample Site 3.



Figure 40. Post-SMCRA Grab Sample Site 4.



Figure 41a. Post-SMCRA Grab Sample Site 5 artifact.



Figure 42. Post-SMCRA Mapped Site 1, subsurface.



Figure 43. Post-SMCRA Mapped Site 3.

Table 3. Soil morphology for pre-SMCRA profile sites.*

Site	Slope/ Aspect	Horizon	Lower Depth (cm)	Color (Munsell)	Texture	Rock Type	Struc-ture	Boun-dary	Consis-tence	Roots	Redox Concen.	Redox Deple.	Bridging Voids	Artifacts
1	40%/ N	^Ap	23	10YR 3/1	CNV SL	COA	1 F GR	AS	L	3VF	-	-	-	-
		^Abu	39	10YR 3/1	L	-	1 F GR	AS	L	3F	-	-	-	lens
		^C1	56	10YR 2/1	CNV SCL	MSR	MA	AS	L	-	-	-	-	-
		^C2	82+	N 4/	CNV SCL	MSR	MA	-	L	-	-	-	-	-
2	70%/ NW	^Ap	10	10YR 3/1	GR L	COA	1 F GR	AS	VFR	3F&M, 1C	-	-	-	-
		^AC	33	10YR 3/1	GRV L	COA	MA	CS	FR	2F&M, 1C	-	-	-	-
		^C	55	10YR 2/1	GRV L	MSR	MA	-	FR	1M&C	-	-	-	-
3	35%/ N	^Ap	12	N 2.5/	GR SL	COA	1 F GR	AS	FR	3VF	-	-	-	-
		^Cu	24	10YR 4/2	GRV SL	COA	MA	CS	FR	1M	-	-	-	porcelain chips
		^C	50	10YR 2/2	GRX L	COA	MA	-	FR	-	-	-	-	-
4	70%/ E	^Ap	20	10YR 3/1	CNX SICL	SHA	1 F GR	AB	L	1M	-	-	-	-
		^EC	30	10YR 5/1	CNX SIL	SHA	MA	AB	L	1F, M	-	-	-	-
		^C1	80	10YR 3/1	CNX SIL	SHA	MA	AB	L	1M	-	-	1-10 cm	-
		^C2	100+	10YR 4/1	CNX SIC	SHA	MA	-	-	-	-	-	1-10 cm	-
5	30%/ N	^Ap	15	10YR 2/1	CNV L	MSR	1 F GR	AB	L	1F	-	-	-	-
		^C1	32	10YR 3/1	CNX CL	MSR	MA	AB	L	1F	-	-	4-7 cm	-
		^C2	42	2.5Y 4/2	CNX SIL	SHA	MA	AB	L	1F	-	-	4-7 cm	-
		^C3	50+	2.5Y 3/1	CNX SCL	SHA	MA	-	-	1M	-	-	4-7 cm	-

Table 3. Continued. Soil morphology for pre-SMCRA profile sites.*

Site	Slope/ Aspect	Horizon	Lower Depth	Color	Texture	Rock Type	Structure	Boun - dary	Consis- tence	Roots	Redox Concen.	Redox Deple.	Bridging Voids	Artifacts
			(cm)	(Munsell)										
6	70%/ SE	^Ap	15	2.5Y 4/1	GR CL	SHA	1 F GR	CW	L	1VF	-	-	-	-
		^C	55	10YR 4/1	GRX CL	COA	MA	CW	-	-	-	-	-	-
		2Ab	70+	10YR 5/4	L	-	2 M SBK	-	FR	-	-	-	-	-
7	80%/ N-NE	^Ap	12	7.5YR 4/1	CNV SCL	COA	1 F GR	AS	L	1F	-	-	-	-
		^C1	32	10YR 3/1	CNV L	COA	MA	CB	L	1F	-	-	4-7 cm	-
		^C2	61	7.5YR 3/1	CNV CL	COA	MA	CB	L	-	-	-	4-7 cm	-
		^C3	94	N 3/	CNV CL	COA	MA	CB	L	-	-	-	4-7 cm	-
		2C4	100+	2.5Y 4/3	CN L	SST	MA	-	-	-	-	-	-	-
8	65%/ N-NE	^Ap	17	10YR 3/1	CNV L	COA	1 F GR	AS	L	3F, 1C	-	Y	-	-
		^C1	66	N 2.5/	CNX L	COA	MA	DS	L	-	-	Y	-	-
		^C2	100+	N 2.5/	CNX L	COA	MA	-	-	-	-	Y	-	-
9	75%/ SW	^Ap	10	10YR 2/1	CN SL	COA	1 F GR	AS	L	1F	-	-	1-3 cm	-
		^C	29	10YR 2/1	CNX CL	COA	MA	AS	L	2M, 1C	-	-	1-3 cm	-
		2Ab	46	10YR 3/1	L	SST	2 M SBK	CS	FR	1C	-	-	-	-
		2Btb	65+	10YR 4/4	SCL	SST	2 M SBK	-	FR	1C, VC	-	-	-	-

*Texture (adjusted to laboratory data): CN-channery, GR- gravelly, V- very, X- extremely, L- loam, SL- sandy loam, CL- clay loam, SIL- silty loam, SCL- sandy clay loam, SICL- silty clay loam

Dominant Rock Type: COA- coal, MSR- mixed rocks, SHA- shale, SST- sandstone,

Structure: 0- structureless, 1- weak, 2, moderate, 3- strong, F- Fine, M- Medium, GR- granular, SBK- subangular blocky, MA- massive

Boundary: A- abrupt, C- clear, D- diffuse, S- smooth, W- wavy, B- broken

Consistence: L- loose, VFR- very friable, FR- friable

Roots: 1- few, 2- common, 3- many, VF- very fine, F- fine, M- medium, C- coarse, VC- very coarse

Table 4. Soil morphology for post-SMCRA profile sites.*

Site	Slope/ Aspect	Horizon	Lower Depth	Color	Texture	Rock Type	Structure	Boun-dary	Consis-tence	Roots	Redox Concen.	Redox Deple.	Bridging Voids	Artifacts
			(cm)	(Munsell)										
1	60%/ S	^Ap	12	2.5Y 2.5/1	CNV L	COA	1 F GR	DS	L	1F, M	-	-	-	-
		^C	24	2.5Y 2.5/1	CNV L	COA	MA	AS	L	1F, C	-	-	-	-
		^Cj	36	2.5Y 4/1	CN L	COA	MA	AS	L	1F, M	-	Y	-	-
		2Btb	57+	2.5Y 5/4	CL	SST	2 M SBK	-	FR	-	-	-	-	-
2	70%/ S	^Ap	16	10YR 2/1	CN SL	COA	1 F GR	DS	L	3 F, C	-	-	-	-
		^Bwj	46	10YR 2/1	CNV L	COA	1 F SBK	AS	L	3F, C, VC	-	-	-	-
		2Ab	58	2.5Y 4/2	CNV L	SST	1 M SBK	AS	FR	-	-	-	-	-
		2Btb	75+	10YR 5/4	CL	SST	2 M SBK	-	FR	-	-	-	-	-
3	20%/ SE	^Ap	14	10YR 4/2	GR L	SST	1 F GR	CS	FR	3VF, F, M	-	-	-	-
		^Cu	42	10YR 4/2	GRV L	CSS	MA	-	FR	1M, C	-	-	-	Cu wire
		^C	75	10YR 4/2	GR L	SST	MA	-	FR	1M	-	-	-	-
			100+	10YR 4/2	CBV L	SST	MA	-	FR	-	-	-	-	-
4	25%/ SW	^Ap	16	10YR 3/2	L	SST	2 M GR	CW	FR	1C, 3F	-	-	-	-
		^Bw	34	10YR 4/3	GRV SIL	MSR	1 M SBK	AS	FI	3VF, F	-	-	-	-
		^Cj	50	10YR 4/1	GRV SCL	COA	MA	AB	FR	-	-	-	3-5 cm	
		^C1	59	10YR 5/4	SCL	SST	MA	AB	FR	-	-	-	3-5 cm	-
		^C2	100+	10YR 4/1	CNX SCL	COA	MA	-	-	-			3-5 cm	-

Table 4. Continued. Soil morphology for post-SMCRA profile sites.*

Site	Slope/ Aspect	Horizon	Lower Depth (cm)	Color (Munsell)	Texture*	Rock Type	Structure	Boun-dary	Consis-tence	Roots	Redox Concen.	Redox Deple.	Bridging Voids	Artifacts
5	30%/ W	^Ap	11	10YR 5/2	L	SST	2 F GR	CS	FR	1M, 3VF	-	-	-	-
		^Bw	34	10YR 5/3	GR L	SST	1 M SBK	AS	FI	2M	-	-	-	-
		^C	41	10YR 5/4	GR SL	SST	MA	AB	FI	1M	-	-	-	-
		^Cuj	54+	10YR 3/1	CNX SCL	COA	MA	-	FI	-			-	glass
6	50%/ W	^C1	10	7.5YR 4/3	CNX SL	COA	MA	DS	FR	-	-	-	2 cm	-
		^C2	50	7.5YR 4/4	CNX SL	COA	MA	DS	FR	-	-	-	2-15 cm	-
		^C3	100+	7.5YR 3/2	CNX L	COA	MA	-	FR	-	-	-	2-7 cm	-
7	60%/ SE	^Ap	21	10YR 3/1	CN SICL	COA	2 F GR	AS	VFR	1C, 3F	-	-	-	-
		^C1	51	10YR 3/1	CNX SICL	MUD	MA	AB	VFI	2M, C	-	-	-	-
		^C2	68	N 2.5/	CNX C	COA	MA	AS	VFI	-	-	-	5-7 cm	-
		^2Cu	100+	2.5Y 4/3	SL	-	MA	-	L	-			-	Glass
8	60%/ NE	^Ap	13	10YR 2/1	L	MSR	2 M GR	CS	VFR	1F, VC	-	-	-	-
		^Bw1	40	10YR 3/1	GR L	MSR	1 M SBK	CS	L	1C	-	-	-	-
		^Bw2	66+	10YR 3/1	GRV CL	MSR	1 M SBK	-	L	1C	-	-	-	-

Table 4. Continued. Soil Morphology for post-SMCRA profile sites.*

Site	Slope/ Aspect	Horizon	Lower Depth	Color	Texture*	Rock Type	Structure	Boun- dary	Consis - tence	Roots	Redox Concen.	Redox Deple.	Bridging Voids	Artifacts
			(cm)	(Munsell)										
9	10%/ NE	^Apg	6	N 7/ (2.5Y 5/3)	L	SST	1 F GR	AS	VFR	1F	-	Y	-	-
		^Cdg	20	10YR 5/6 (N 2.5/; 7.5YR 6/6)	L	SST	MA	CW	FI	-	-	Y	-	-
		^Cd	60+	N 2.5/ (7.5YR 5/8)	L	COA	MA	-	FR	-	-	Y	-	-

*Texture (adjusted to laboratory data): CN-channery, GR- gravelly, V- very, X- extremely, L- loam, SL- sandy loam, CL- clay loam, SIL- silty loam, SCL- sandy clay loam, SICL- silty clay loam

Dominant Rock Type: COA- coal, MSR- mixed rocks, SHA- shale, SST- sandstone,

Structure: 0- structureless, 1- weak, 2, moderate, 3- strong, F- Fine, M- Medium, GR- granular, SBK- subangular blocky, MA- massive

Boundary: A- abrupt, C- clear, D- diffuse, S- smooth, W- wavy, B- broken

Consistence: L- loose, VFR- very friable, FR- friable

Roots: 1- few, 2- common, 3- many, VF- very fine, F- fine, M- medium, C- coarse, VC- very coarse

4, 5, and 9. Compaction, sometimes severe, was noted on these four sites as well. Post-SMCRA site 9 at the Anderson Branch Reclamation had been severely compacted and had obvious signs of poor drainage, such as pooled water and a saturated profile. According to Sencindiver and Ammons (2000), disturbed soils developing on coal mined lands regularly have much higher rock fragment content than the native soils nearby. This was true of both PRE and POST sites compared to native soils in the BSF characterized by Blair (2009) in a previous study, which reported native surface and subsurface horizons with an average volume of rock fragments to be 7% and 10%, significantly lower than both PRE and POST horizons ($p=0.05$).

In half of the PRE-P sites, the dominant type of rock fragment was black high carbon material (coal) (Table 3); this is why such low values and chromas appear in many of the horizons of pre-SMCRA minesoils. High-carbon and fissile shales, grey and brown sandstones, mudstones, and burned carbolithic materials known as "reddog" made up the other rock fragment types found in the PRE sites, sometimes alone and sometimes mixed. Comparatively, 42% of POST-P horizons had coal as the dominant rock type, accounting for higher values and chromas in many of the POST-P when compared to the PRE-P sites. Out of 33 PRE-P horizons, 26 had a chroma ≤ 1, compared to 15 POST-P horizons.

The nature of rock fragments is highly influential on the physical and chemical properties of minesoils because they can be weakly cemented and break down into sand, silt, and clay-sized particles within just a few decades (Sencindiver & Ammons, 2000). Soil texture, for example, depends on the type of geologic materials present. In sites where sandstone overburden is mixed with coal fragments, the textures can get as coarse as a sandy loam, as in PRE-P Site 3. In the particle-size distribution seen in Table 5, the large sand fraction (60%+) and relatively small clay fraction (< 12%) is reflective of the sandstone overburden fragments. On sites where shales and mudstones dominate, textures can be finer, such as in PRE-P Site 5 with clay loam and silty clay loam textures. In the control section (25-100cm) of PRE-P sites, textures ranged from sandy loam (PRE-P Site 3) to silty clay (PRE-P Site 4), reflecting the highly variable range of parent materials.

The weighted average of the percent clay occurring in the control sections (25-100cm) of PRE-P sites versus POST-P sites was not significantly different, being 21% and 25% respectively. The textures from POST-P horizons ranged from sandy loam (sites 5, 6, and 7) to clay (site 7). POST-P site 7 was mentioned earlier as having drainage problems and having 66% clay in the third horizon was a contributing factor (Tables 5 and 6).

Table 5. Particle size analysis for pre-SMCRA profile sites and grab samples (GS).

			USDA Particle Size Class								
Site	Horizon	Lower Boundary	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	USDA Texture*
		(cm)	----------%----------								
1	^Ap	23	10	10	8	14	19	61	26	13	CNV SL
	^Abu	39	6	11	9	12	11	51	37	12	L
	^C1	56	8	8	4	9	15	48	26	26	CNV SCL
	^C2	82+	0	5	3	8	30	58	19	23	CNV SCL
2	^Ap	10	11.5	7.1	4.2	8.9	5.6	38	49	13	GR L
	^AC	33	8.7	7.8	5.2	10.0	5.6	37	50	12	GRV L
	^C	55	9.1	9.3	6.0	10.1	5.1	40	34	26	GRV L
3	^Ap	12	15.0	13.6	7.2	1.8	21.3	60	32	7	GR SL
	^Cu	24	8.5	7.6	6.6	32.3	11.4	67	25	8	GRV SL
	^C	50	6.0	5.1	3.2	17.1	12.2	43	45	12	GRX L
4	^Ap	20	4.6	2.9	1.0	2.4	1.6	6	63	31	CNX SICL
	^EC	30	1.0	2.8	1.4	2.2	1.4	9	65	26	CNX SIL
	^C1	80	7.3	6.5	2.4	3.7	2.2	22	52	26	CNX SIL
	^C2	100+	2.4	2.4	1.0	0.9	0.0	7	48	45	CNX SIC
5	^Ap	15	8.0	9.7	4.2	9.4	6.7	39	38	23	CNV L
	^C1	32	10.7	8.3	2.6	5.4	3.6	31	40	30	CNX CL
	^C2	42	7.2	6.3	1.5	3.2	2.1	20	58	21	CNX SIL
	^C3	50+	19.2	14.5	6.2	12.3	6.2	58	18	23	CNX SCL

Table 5. Continued. Particle size analysis for pre-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Boundary	USDA Particle Size Class								USDA Texture*
			Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	
		(cm)	----------%----------								
6	^Ap	15	4.1	6.2	5.1	2.8	14.4	32	36	32	GR CL
	^C	55	2.5	3.0	3.2	9.7	7.2	26	44	30	GRX CL
	2Ab	70+	3.9	4.5	6.0	11.9	11.8	40	47	13	L
7	^Ap	12	10.0	9.8	4.1	10.6	13.6	48	24	28	CNV SCL
	^C1	32	11.4	10.0	4.7	8.6	8.4	43	33	23	CNV L
	^C2	61	3.8	3.1	1.5	3.4	2.3	21	51	28	CNV CL
	^C3	94	4.8	4.3	2.0	7.8	11.0	30	36	33	CNV CL
	2C4	100+	8.3	8.9	3.8	11.3	13.7	46	31	23	CN L
8	^Ap	17	7.4	9.5	3.6	8.9	9.3	39	41	20	CNV L
	^C1	66	19.8	10.2	3.8	4.0	11.2	50	32	19	CNX L
	^C2	100+	26.4	10.7	4.0	9.0	7.1	58	27	15	CNX L
9	^Ap	10	22.4	14.6	6.7	10.9	7.6	64	24	12	CN SL
	^C	29	7.1	5.2	2.1	2.1	12.6	30	32	37	CNX CL
	2Ab	46	3.2	5.2	4.1	6.8	10.3	30	49	21	L
	2Btb	65+	6.6	5.6	9.9	14.8	21.3	59	7	33	SCL
GS1	surface	10	1.7	4.9	3.6	7.5	7.1	27	63	10	GR SIL
	subsurface	30+	0.8	1.3	0.8	2.1	2.9	8	62	31	GRV SICL

Table 5. Continued. Particle size analysis for pre-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Boundary	USDA Particle Size Class								USDA Texture*
			Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	
		(cm)	----------%----------								
GS2	surface	10	9.8	8.0	8.6	8.3	8.6	44	37	19	CN L
	subsurface	30+	8.9	5.7	2.3	3.0	3.1	23	41	36	CNX CL
GS3	surface	10	6.2	7.0	3.6	8.7	11.3	38	33	29	CN CL
	subsurface	30+	5.4	5.1	6.5	6.8	13.2	38	40	22	CNV L
GS4	surface	10	42.8	18.2	10.4	4.6	1.0	87	12	1	CN S
	subsurface	30+	28.4	19.6	18.9	9.7	2.1	79	15	5	CNX LS
GS5	surface	10	7.6	7.2	3.5	0.9	10.3	30	39	31	CNX CL
	subsurface	30+	6.9	7.1	2.7	1.5	8.4	27	37	36	CNX CL
GS6	surface	10	3.4	5.7	2.8	3.4	9.9	26	50	24	CNV L
	subsurface	30+	3.5	3.6	1.7	6.8	17.8	31	47	22	CNX L

*Texture: CN-channery, CNV- very channery, CNX- extremely channery, GR- gravelly, GRV- very gravelly, GRX- extremely gravelly, L- loam, SL- sandy loam, CL- clay loam, SIL- silty loam, SCL- sandy clay loam, SICL- silty clay loam

Table 6. Particle size analysis for post-SMCRA profile sites and grab samples (GS).

			USDA Particle Size Class								
Site	Horizon	Lower Boundary	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	USDA Texture*
		(cm)	----------%----------								
1	^Ap	12	8.5	12.5	6.2	9.8	7.7	46	41	14	CNV L
	^C	24	7.8	11.0	6.5	4.7	9.5	41	47	12	CNV L
	^Cj	36	11.6	11.6	5.6	9.2	7.2	46	27	27	CN L
	2Btb	57+	3.2	3.0	2.1	5.5	7.7	21	44	33	CL
2	^Ap	16	14.1	22.7	12.2	11.4	4.6	65	26	9	CN SL
	^Bwj	46	10.0	12.1	6.8	9.8	4.9	44	34	21	CNV L
	2Ab	58	6.9	10.5	5.7	9.5	5.7	39	44	19	CNV L
	2Btb	75+	6.0	4.3	2.8	8.9	8.0	30	42	28	CL
3	^Ap	14	2.4	5.1	7.3	13.5	7.8	36	46	18	GR L
	^Cu	42	2.0	4.5	10.2	15.1	7.6	39	43	18	GRV L
	^C	75	1.6	6.0	12.5	18.8	7.3	46	37	17	GR L
		100+	2.8	5.3	7.8	14.9	7.1	38	43	20	CBV L
4	^Ap	16	1.8	5.4	5.2	10.3	6.3	29	48	24	L
	^Bw	34	0.7	3.1	3.1	1.2	7.5	16	60	25	GRV SIL
	^Cj	50	14.6	12.1	6.2	3.2	16.1	53	23	24	GRV SCL
	^C1	59	8.0	11.7	11.4	16.3	7.8	56	23	24	SCL
	^C2	110+	5.6	5.1	3.8	8.5	5.8	29	43	28	CNX SCL

Table 6. Continued. Particle size distribution for post-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Boundary	USDA Particle Size Class								USDA Texture*
			Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	
		(cm)	----------%----------								
5	^Ap	11	3.0	6.0	8.0	10.9	4.7	33	44	24	L
	^Bw	34	2.9	5.9	7.5	13.0	6.1	36	42	22	GR L
	^C	41	9.8	14.6	13.0	17.9	11.0	68	20	13	GR SL
	^Cuj	54+	9.6	13.5	12.5	11.1	9.6	57	17	25	CNX SCL
6	^C1	10	23.2	17.5	6.2	8.4	5.4	61	29	10	CNX SL
	^C2	50	26.1	10.9	4.3	6.7	4.6	53	30	18	CNX SL
	^C3	100+	14.7	7.5	3.2	5.0	3.8	34	43	23	CNX L
7	^Ap	21	3.2	2.5	1.4	2.5	1.6	11	58	30	CN SICL
	^C1	51	2.2	2.8	1.3	2.4	1.8	10	58	31	CNX SICL
	^C2	68	11.4	5.0	2.3	2.3	3.9	25	8	66	CNX C
	2Cu	100+	5.3	15.1	20.1	23.4	9.4	74	9	17	SL
8	^Ap	13	7.7	8.2	7.2	16.7	8.2	48	37	15	L
	^Bw1	40	7.6	10.0	6.0	2.0	14.5	40	41	19	GR L
	^Bw2	66	4.4	8.4	4.1	4.0	6.1	27	39	33	GRV CL
9	^Apg	6	1.6	3.1	5.4	11.0	14.0	35	49	16	L
	^Cdg	20	1.8	3.3	1.6	3.5	14.6	27	46	28	L
	^Cd	60+	5.7	7.5	2.4	4.9	7.3	29	46	25	L

Table 6. Continued. Particle size distribution for post-SMCRA profile sites and grab samples (GS).

			USDA Particle Size Class								
Site	Horizon	Lower Boundary	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	USDA Texture*
		(cm)	----------%----------								
GS1	surface	10	6.6	9.6	10.4	17.1	11.0	55	23	22	GR SCL
	subsurface	30+	3.6	5.0	5.6	10.7	7.5	33	41	26	GRV L
GS2	surface	10	4.8	6.8	9.4	19.8	8.5	49	33	17	L
	subsurface	30+	3.6	6.7	10.4	2.5	25.5	49	31	20	GRV L
GS3	surface	10	5.7	8.1	9.2	18.0	8.6	50	32	19	L
	subsurface	30+	1.8	6.6	11.5	19.7	9.9	49	31	20	GR L
GS4	surface	10	29.3	17.0	7.1	12.0	6.9	74	19	7	CN SL
	subsurface	30+	17.1	5.4	1.9	1.6	2.8	29	47	24	CNX L
GS5	surface	10	23.9	8.2	1.9	3.6	3.7	40	33	27	CNV L
	subsurface	30+	22.5	12.2	3.1	3.6	2.8	43	28	29	CNX CL

*Texture: CN-channery, CNV- very channery, CNX- extremely channery, GR- gravelly, GRV- very gravelly, GRX- extremely gravelly, L- loam, SL- sandy loam, CL- clay loam, SIL- silty loam, SCL- sandy clay loam, SICL- silty clay loam

Horizonation also differed between the pre- and post-SMCRA profiles. All PRE-P sites had simple horizonation resembling ^A-^C1-^C2. Variations on this horizonation included PRE-P 1 with a buried ^A horizon beneath an Ap, PRE-P site 2 had a ^CE horizon, and PRE-P sites 6, 7, and 9 had discontinuities which were denoted upon contacting native soil materials (Table 3). Three of the POST-P sites had evidence of weakly developed structure or illuviation beneath A horizons, designated ^Bw. All PRE-P A horizons exhibited weak, fine, granular structure. Most showed an accumulation of organic matter from overlying trees, which contributed to the breakdown of parent materials on the surface of the spoil piles. On PRE-P sites, all C horizons were structureless massive, showing little or no alteration by soil-forming processes. Most had at least a few fine or medium roots (although most were sparsely vegetated), suggesting the uncompacted nature of the spoil piles. On POST-P sites, however, most C horizons did not contain roots (with exceptions in POST-P 1 and 3- both of which were located in relatively well forested areas). Contrasting with the PRE-P sites, POST-P sites were typically well – vegetated (some very well), with the exception of site 6 which was a large reddog pile. Bridging voids occurred in 4 of 9 PRE-P sites and also in 3 of 9 POST-P sites. The discovery of artifacts was also evenly distributed between pre- and post- SMCRA profile sites.

Acid-Producing Potential

For the purposes of this project, if the NNP, determined by an acid-base account, was positive or neutral, the potential production of alkaline drainage from a minesoil or spoil pile was assumed. Conversely, if the NNP was negative, potential production of AMD was concluded. The NNP for all pre-SMCRA and post-SMCRA profile and grab sample sites can be seen in Tables 7 and 8. Of the PRE sites, 11/46 horizons (24%) showed the presence of carbonates by the fizz test compared to 17/44 (39%) of POST sites. The presence or absence of carbonate minerals is considered in the literature to be a critical component of predicting AMD. This is because, except for siderite, carbonate minerals can inhibit acid generation in at least three ways: (1) the dissolution of carbonates restrains the activity of *Thiobacillus ferrooxidans,* the bacteria that catalyzes the conversion of ferrous to ferric iron, by creating alkaline conditions (these bacteria are most active in a pH range of 2-4); (2) inhibit the activity of ferric iron in soil solution; and (3) as acidity decreases, the rate of carbonate dissolution increases because it is a function of H^+ activity and the partial pressure of CO_2 (Perry et al., 1998). The advanced age of the spoil

Table 7. Acid-base account for pre-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Depth	Color*	Fizz Test	Paste pH	Pyritic Sulfur	MPA	NP	NNP
		(cm)	(Munsell)			(%)	(Tons $CaCO_3$ eq/1000 T)		
1	^Ap	23	10YR 5/1	0	7.1	0.00	0.0	8.0	8.0
	^Abu	39	10YR 5/1	1	6.6	0.23	7.1	0.1	-7.0
	^C1	56	10YR 2/2	0	4.8	0.02	0.7	-3.3	-4.1
	^C2	82+	N 6/	0	4.4	0.00	0.0	-6.5	-6.5
2	^Ap	10	10YR 5/1	1	6.2	0.07	2.2	7.4	5.2
	^AC	33	10YR 5/1	1	5.7	0.00	0.0	7.9	7.9
	^C	55	10YR 4/1	1	5.3	0.09	2.9	6.9	3.9
3	^Ap	12	N 2.5/	1	6.6	0.05	1.6	9.5	8.0
	^Cu	24	10YR 5/1	0	6.6	0.17	5.2	7.3	2.1
	^C	50	10YR 5/1	1	6.3	0.18	5.7	6.2	0.5
4	^Ap	20	10YR 6/1	0	7.0	0.00	0.1	8.8	8.6
	^EC	30	10YR 7/1	0	5.5	0.00	0.0	3.7	3.6
	^C1	80	10YR 5/1	1	5.4	0.08	2.4	6.4	4.0
	^C2	100+	10YR 5/1	1	6.5	0.07	2.1	9.8	7.7
5	^Ap	15	10YR 4/1	0	5.3	0.00	0.0	2.5	2.5
	^C1	32	10YR 5/2	0	4.9	0.00	0.1	1.3	1.1
	^C2	42	2.5Y 6/2	1	5.2	0.00	0.0	4.9	4.9
	^C3	50+	2.5Y 4/1	0	5.0	0.09	2.8	1.3	-1.5
6	^A	15	2.5Y 6/2	0	4.8	0.05	1.4	-0.4	-1.8
	^C	55	10YR 6/1	0	4.9	0.04	1.1	1.5	0.4
	2Ab	70+	10YR 5/4	0	5.2	0.01	0.4	1.7	1.4
7	^Ap	12	7.5YR 2/1	0	3.9	0.00	0.0	-6.3	-6.3
	^C1	32	10YR 2/1	0	3.3	0.00	0.0	-5.5	-5.5
	^C2	61	7.5YR 2.5/1	0	3.3	0.00	0.0	-7.2	-7.2
	^C3	94	N 4/	0	3.2	0.00	0.0	-7.0	-7.0
	2C4	100+	2.5Y 6.4	0	3.0	0.03	0.8	-7.9	-8.7

Table 7. Continued. Acid-base account for pre-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Boundary	Color*	Fizz Test	Paste pH	Pyritic Sulfur	MPA	NP	NNP
		(cm)	(Munsell)			(%)	(Tons $CaCO_3$ eq/1000 T)		
8	^A	17	10YR 5/1	0	3.7	0.00	0.0	-5.7	-5.7
	^C1	66	N 4/	0	3.8	0.00	0.0	-5.3	-5.3
	^C2	100+	N 3/	0	3.9	0.00	0.0	-5.3	-5.3
9	^Ap	10	10YR 4/2	0	4.5	0.07	2.1	-8.0	-10.1
	^C	29	10YR 3/1	0	3.7	0.00	0.0	-6.0	-6.0
	2Ab	46	10YR 5/2	0	4.0	0.03	0.9	-5.5	-6.5
	2Btb	65+	10YR 7/3	0	4.1	0.01	0.4	-1.7	-2.1
GS1	surface	10	7.5YR 6/8	0	3.3	0.00	0.0	-3.2	-3.2
	subsurface	30+	2.5Y 7/3	1	3.9	0.04	1.1	1.3	0.2
GS2	surface	10	10YR 2/2	0	5.2	0.09	2.8	2.0	-0.8
	subsurface	30+	7.5YR 2/1	0	4.7	0.10	3.3	1.2	-2.0
GS3	surface	10	10YR 5/2	0	3.0	0.00	0.0	-6.0	-6.0
	subsurface	30+	10YR 6/2	0	2.9	0.00	0.0	-7.7	-7.7
GS4	surface	10	N 2.5/	0	4.5	0.00	0.0	-3.4	-3.4
	subsurface	30+	5YR 5/4	0	4.7	0.00	0.0	-3.6	-3.6
GS5	surface	10	10YR 5/1	0	2.3	0.00	0.0	-10.6	-10.6
	subsurface	30+	2.5Y 5/1	0	3.2	0.00	0.0	-8.6	-8.6
GS6	surface	10	10YR 3/2	0	3.4	0.00	0.0	-6.5	-6.5
	subsurface	30+	N 5/	2	2.6	0.00	0.0	4.1	4.1
GS7	surface		7.5YR 5/8	0	3.0	0.0	0.0	-38.3	-38.3

*Air-dried 60 mesh samples.

Table 8. Acid-base account for post-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Boundary	Color*	Fizz Test	Paste pH	Pyritic Sulfur	MPA	NP	NNP
		(cm)	(Munsell)			(%)	(Tons $CaCO_3$ eq/1000 T)		
1	^Ap	12	2.5Y 2.5/1	0	6.2	0.00	0.0	0.3	0.3
	^C1	24	2.5Y 2.5/1	0	5.3	0.25	7.8	-4.3	-12.1
	^C2	36	2.5Y 6/1	0	6.0	1.45	45.4	-1.6	-47.0
	2Btb	57+	2.5Y 7/3	0	3.7	0.00	0.0	-0.4	-0.4
2	^Ap	16	10YR 4/1	0	7.2	0.26	8.2	25.3	17.1
	^Bw	46	10YR 4/1	0	7.0	1.06	33.2	6.4	-26.9
	2Ab	58	2.5Y 6/3	0	6.5	0.20	6.4	2.2	-4.2
	2Btb	75+	10YR 6/4	0	6.2	0.00	0.0	1.3	1.3
3	^Ap	14	10YR 6/2	1	7.3	0.05	1.5	11.0	9.5
	^Cu	42	10YR 6/2	1	7.9	0.03	0.8	12.5	11.7
	^C	75	10YR 6/2	3	8.1	0.00	0.0	67.2	67.2
		100+	10YR 5/2	2	7.9	0.00	0.0	32.0	32.0
4	^Ap	16	10YR 5/2	2	7.4	0.05	1.4	38.0	36.6
	^Bw	34	10YR 6/3	1	7.9	0.04	1.4	11.7	10.3
	^C1	50	10YR 3/1	0	4.7	0.18	5.8	-5.3	-11.1
	^C2	59	10YR 4/3	0	3.7	0.07	2.1	-3.1	-5.2
	^C3	110+	10YR 2/1	0	3.3	0.20	6.1	-5.2	-11.4
5	^Ap	11	10YR 3/2	2	7.3	0.02	0.7	38.0	37.3
	^Bw	34	10YR 4/3	2	7.6	0.00	0.0	25.9	25.9
	^C	41	10YR 4/3	0	6.5	0.07	2.1	6.8	4.7
	^Cu	54+	10YR 2/1	0	4.0	0.00	0.0	-2.9	-2.9
6	^C1	10	7.5YR 6/3	1	6.9	0.07	2.1	12.5	10.3
	^C2	50	10YR 6/3	1	7.1	0.03	1.0	12.5	11.4
	^C3	100+	7.5YR 5/2	1	6.8	0.04	1.3	13.4	12.2
7	^Ap	21	10YR 5/1	1	6.2	0.01	0.3	7.6	7.3
	^C1	51	10YR 5/1	0	6.1	0.00	0.0	5.1	5.1
	^C2	68	N 4/	0	6.4	0.06	1.9	4.7	2.8
	^2Cu	100+	2.5Y 6/3	0	7.7	0.00	0.0	3.7	3.7

Table 8. Continued. Acid-base account for post-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Boundary	Color*	Fizz Test	Paste pH	Pyritic Sulfur	MPA	NP	NNP
		(cm)	(Munsell)			(%)	(Tons $CaCO_3$ eq/1000 T)		
8	^Ap	13	10YR 4/1	0	6.5	0.02	0.6	5.9	5.3
	^Bw1	40	10YR 5/2	1	6.8	0.06	1.7	7.6	5.9
	^Bw2	66	10YR 5/1	0	6.9	0.03	1.0	9.7	8.7
9	^Ap	6	2.5Y 6/3	0	7.0	0.00	-0.1	6.8	7.0
	^C1	20	10YR 6/4	1	4.4	0.01	0.4	0.1	-0.3
	^C2	60+	10YR 3/1	0	4.5	0.05	1.6	-7.7	-9.3
GS1	surface	10	10YR 5/2	0	6.8	0.02	0.5	9.5	9.0
	subsurface	30+	10YR 5/2	0	7.6	0.04	1.2	10.5	9.3
GS2	surface	10	10YR 6/2	0	7.1	0.00	0.0	8.3	8.3
	subsurface	30+	10YR 6/2	1	8.0	0.00	0.0	17.1	17.1
GS3	surface	10	10YR 5/2	1	7.6	0.00	-0.1	19.0	19.1
	subsurface	30+	10YR 6/2	1	8.1	0.03	0.8	19.5	18.7
GS4	surface	10	10YR 5/2	0	6.0	0.00	0.0	2.7	2.7
	subsurface	30+	5YR 6/6	0	6.8	0.00	-0.1	14.6	14.7
GS5	surface	10	10YR 4/1	0	4.3	0.00	0.0	3.7	3.7
	subsurface	30+	10YR 5/1	0	4.7	0.03	0.9	-4.3	-5.3

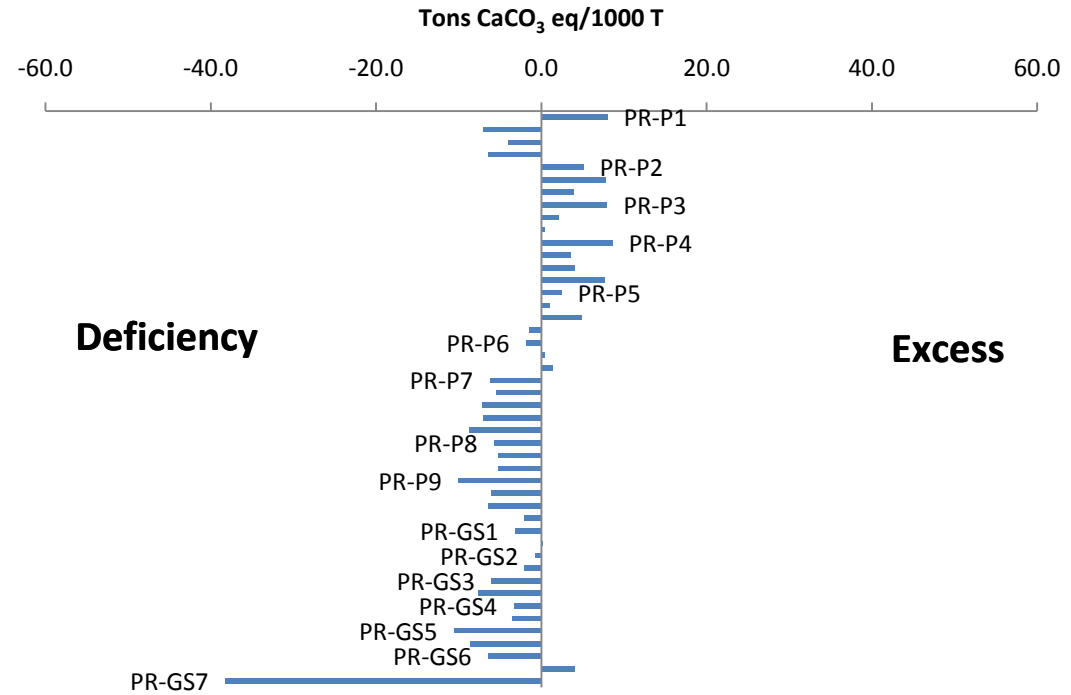
*Air-dried 60 mesh samples.

materials and minesoils in the BSF (≈ 35 – 75 years old) may suggest that even if these materials once contained significant amounts of carbonate minerals, they were leached through the years at an accelerated rate as a consequence of pyrite oxidation. The percent pyritic-S is generally low in many horizons.

Of the PRE horizons, 61% have a negative NNP, with a range from +8.6 to -38.3 tons $CaCO_3$ eq/ 1000T, compared to 27% of POST horizons with a negative NNP, having a wider range of +67 to -47. A negative NP can be produced in samples with a "0" fizz rating, meaning that no (or few) carbonates were present within the material. This is because as the sample interacts with heated HCl, acidity is released from the breakdown of minerals present. Upon titration of the sample with NaOH, it therefore takes more base to neutralize the sample than the initial amount of acid added. Again, the lack of carbonates is more indicative of acid-producing potential that the content of pyritic sulfur because even in samples with several percent pyritic-S, if enough carbonates are present acid-production can be controlled. In materials with very low percent pyritic-S, an appreciable amount of acidity can be produced if no carbonates are present to act as neutralizers (Sobek et al., 2000).

Figure 44 (a and b) are simple representations of the ABA of pre- and post-SMCRA sites in the BSF. These are adapted from traditional "Excess/Deficiency" diagrams usually applied to rock columns during pre-mining planning to determine acid/base status of various strata. The difference between the PRE and POST sites is easily seen. It should be noted that anthropogenic activities are suspected to have artificially raised the NNP on PRE-PS 2, 3, and 4. Sites PRE-P site 2 and PRE-P site 3 are both located at the former Worley Mining Camp, which was the largest ever operated by the Stearns Coal & Lumber, Co. Presently, there is a gravel road leading to the area which is used as access to fishing spots along the BSF river. It is apparent around the small parking area that fertilizers and seed have probably been added in the past to establish vegetation on slopes directly adjacent to the parking area.

PRE-P site 2 was located just past this parking area and down a steep embankment which serves as a runoff corridor from the parking area. As seen in Table 7 and Figure 44, these sites had a positive NNP. In the next section in Table 9, a base saturation of 100% is also present in the upper horizons of these sites. However, pre-SMCRA grab sample 7 (PR-GS7) was also taken from Worley, but across the small creek from the parking area where it would not have been affected by anthropogenic additions. This site had a negative NNP in the surface and only a slightly positive NNP in the subsurface, suggesting possibly a more accurate reflection of pre-SMCRA samples from this area. At Worley, large pools and small streams were noted with obvious signs of AMD which tested in the field at pH 2. Pre-SMCRA Site 4,



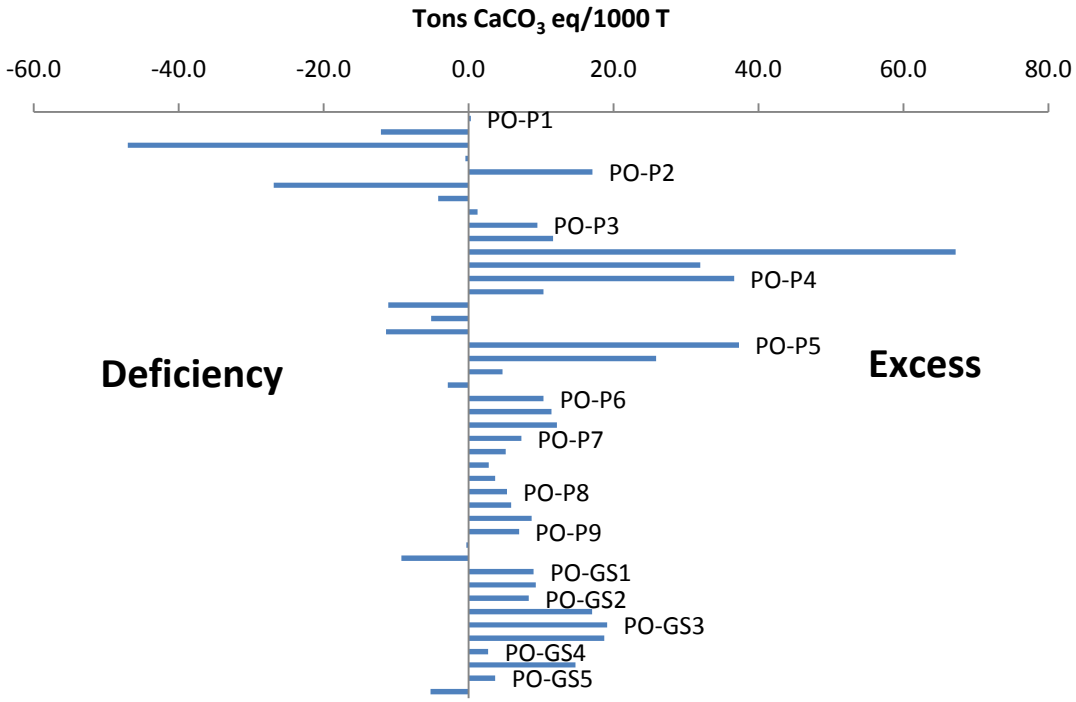


Figure 44. (a. top)Net neutralization potential from pre-SMCRA profile (PR-P) and grab sample (PR-GS) sites and (b. bottom) from post-SMCRA profile (PO-P) and grab sample (PO-GS) sites.

located on the west side of the BSF River, just across from Blue Herron, was similarly located directly off of a popular trailhead, which during its upkeep has been fertilized and seeded in the areas surrounding the signage. These anthropogenic additions are believed to be the cause of the positive NNP and high base saturation on this site as well.

Between averaged pre- and post-SMCRA ABA values for surface horizons, there was no statistically significant difference for percent pyritic sulfur or MPA based on pyritic sulfur (p=0.05). NP and NNP for the surface horizons, were statistically different, as the average NNP for PRE surface horizons was -0.8 compared to 12.4 tons $CaCO_3$ eq/1000T for POST surface horizons. The same trend was found in the subsurface horizons: average NNP for PRE horizons was -2.2 compared to 5.1 tons $CaCO_3$ eq/1000T for POST horizons. This suggests that reclamation efforts on the post-SMCRA sites have been effective at reducing the production of AMD overall.

There are a few notable exceptions for example on sites POST-P sites 1, 2, 4, and 9. In each of these profiles, the surface horizon(s) had a positive NNP value that became negative in the subsoil, some highly negative compared to other POST subsoils and even relative to PRE subsoils, as in POST-P1 and POST-P2. These pre- and post-SMCRA horizons have similar acid-producing potential because they are forming in similar parent materials, except that POST horizons were buried during reclamation efforts. On POST-P1, POST-P2, and POST-P4, there were obvious signs of AMD-generation in the form of precipitated basic sulfates coating the bottom of nearby drainage ways which emptied directly into the BSF River. This was not expected from POST-P4, as considerable efforts to reclaim this site have been made, including establishment of lush groundcover of vetch, grasses, shrubs, and trees.

Chemical Properties

Seven native soil profiles from the BSF were analyzed in a previous study (Blair, 2009) in the same laboratory using the same chemical methods as the minesoils from the BSF analyzed in this project. Thus it is possible to determine if the measured chemical properties of pre- and post- SMCRA minesoils are significantly different from each other as well as if they are significantly different from nearby native soils. The ranges and average values for native soil properties are presented at the bottom of Tables 9 and 10. These values were compared to pre-SMCRA minesoil properties separately from post-SMCRA minesoil properties.

Soil Organic Carbon

As shown in Table 9, native surface horizons in the BSF had average percent soil organic carbon (%SOC) ranging from 0.3 - 3%, with an average of 1.2%. The average in PRE surface horizons (9.7%) was not significantly different than the average %SOC in POST surface horizons (7.7%). Both, however, were significantly different than the average %SOC in native surface horizons. Likewise, the subsurface horizons from PRE and POST sites did not differ significantly from each other, but did compared to the native soil profiles. The native subsoil %SOC had an average of 0.4%, while average PRE subsurface %SOC was 7.5% and the average POST subsurface %SOC was 6.8%.

Although SOC seems to be significantly higher in the minesoils in the BSF than surrounding native soils, the commonly used Walkley-Black method for measuring SOC in soils can overestimate this value in coal minesoils (Daniels & Amos, 1982; Skjemstad & Taylor, 1999). This overestimation is a consequence of one unique property common to many coal minesoils: the presence of coal and carboniferous rock particles that occur in various sizes, amounts, and qualities. For decades, it was assumed that the oxidizing agent used in the Walkley-Black procedure, potassium dichromate, would only oxidize a negligible amount of geogenic-C compared to pedogenic-C. Depending on the size and type of coal or carbolithic geologic materials present, however, this has been proven to be a false assumption (Burger et al., 2005). A procedure for quantitatively analyzing SOC has not yet been created, but Burger et al. (2005) are actively attempting to do so, as well as trying to find a model to convert historic SOC data obtained using Walkley-Black. Thus, this data has been included in this project.

The oxidation of coal was evident in our analysis of pre- and post-SCMRA minesoils. The procedure stipulates a sample weight >0.5g and < 10g soil or sediment. If more than 75% of the dichromate is reduced (meaning that >75% of the dichromate reacted with and oxidized organic carbon in the sample and that the amount of ferroin indicator added almost equals that of the dichromate), it is recommended that the experiment be repeated with a smaller sample size. For this project, samples were first tested using 0.5 g, and then reduced to 0.25 g when only one drop of ferroin solution was needed to titrate to the endpoint. The same result was observed using this smaller sample size for many samples, suggesting that geogenic-C was being oxidized and measured.

Data for SOC derived from the Walkley-Black procedure is still useful for observing patterns of SOC with depth. Minesoils, as well as all younger soils, commonly exhibit an irregular distribution of

Table 9. Chemical properties for pre-SMCRA profile sites and grab samples (GS) including organic-C, easily-reducible-Mn, exchangeable-bases, KCl-extractable Al, cation-exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

					Exchangeable Bases								
Site	Horizon	Lower Depth	Organic Carbon	Mn	Ca	Na	K	Mg	Al (KCl)	CEC (NH_4OAc)	Base Saturation (NH4OAc)	pH 1:1 H_2O	pH 2:1 CaCl2
		(cm)	(%)	(mg/kg)	----------$cmol_c$/kg soil----------						(%)		
1	^Ap	23	5.9	36.8	7.9	0.1	0.1	0.8	0.0	6	100†	6.4	6.1
	^Abu	39	23.9	295.5	33.9	0.2	0.3	3.0	0.1	29	100†	6.0	5.7
	^C1	56	14.8	12.8	3.0	0.4	0.1	0.4	2.0	13	30	3.9	3.2
	^C2	82+	5.0	3.7	1.5	0.2	0.1	0.2	5.1	7	28	3.8	3.0
2	^Ap	10	8.9	554.0	8.5	0.1	0.4	2.5	0.1	11	100†	5.6	4.7
	^AC	33	9.1	411.5	4.8	0.1	0.3	1.5	1.8	10	69	5.0	4.1
	^C	55	9.5	306.0	2.5	0.1	0.3	1.2	5.3	12	36	4.6	3.8
3	^Ap	12	9.0	189.5	14.5	0.1	0.3	1.1	0.0	10	100†	4.8	4.3
	^Cu	24	1.6	279.0	3.9	0.1	0.1	0.4	0.0	5	94	6.0	5.7
	^C	50	3.7	351.0	6.4	0.1	0.2	0.3	0.2	8	88	5.8	5.2
4	^Ap	20	6.8	417.0	17.1	0.1	0.8	7.1	0.0	14	100†	6.9	6.2
	^EC	30	0.8	85.9	5.0	0.1	0.5	5.6	2.6	9	100†	5.1	4.1
	^C1	80	2.9	393.5	3.8	0.1	0.4	4.7	4.2	9	100†	4.8	4.0
	^C2	100+	2.1	789.0	6.0	0.1	0.4	7.6	0.0	10	100†	5.8	5.1
5	^Ap	15	8.2	454.0	6.0	0.1	0.4	3.2	4.9	16	60	4.4	4.0
	^C1	32	5.8	363.0	2.6	0.1	0.3	1.7	5.7	14	33	4.0	3.6
	^C2	42	0.9	145.7	2.0	0.1	0.3	6.2	7.6	10	85	4.3	3.9
	^C3	50+	5.6	30.1	0.9	0.1	0.2	1.6	10.8	11	25	3.9	3.5

Table 9. Continued. Chemical properties for pre-SMCRA profile sites and grab samples (GS) including organic-C, easily-reducible Mn, exchangeable bases, KCl-extractable Al, cation exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

Site	Horizon	Lower Depth	Organic Carbon	Mn	Exchangeable Bases				Al (KCl)	CEC (NH_4OAc)	Base Saturation (NH4OAc)	pH 1:1 H_2O	pH 2:1 CaCl2
					Ca	Na	K	Mg					
		(cm)	(%)	(mg/kg)	----------cmol$_c$/kg soil----------						(%)		
6	^Ap	15	3.3	23.1	1.0	0.1	0.3	0.4	14.6	10	18	4.7	3.5
	^C	55	2.2	346.5	0.9	0.1	0.2	1.0	10.4	9	25	4.8	3.5
	2Ab	70+	1.9	306.0	0.3	0.1	0.1	0.2	4.1	5	16	4.9	4.0
7	^Ap	12	13.5	19.7	0.9	0.1	0.2	0.4	2.9	12	13	3.7	3.0
	^C1	32	16.2	7.6	0.2	0.0	0.1	0.1	2.1	16	2	3.1	2.7
	^C2	61	19.9	7.3	0.1	0.1	0.1	0.0	2.9	21	1	2.8	2.6
	^C3	94	11.3	5.1	0.1	0.1	0.0	0.0	3.2	6	4	2.7	2.5
	2C4	100+	5.6	6.5	0.1	0.0	0.1	0.1	5.6	9	3	2.7	2.5
8	^Ap	17	13.1	8.8	0.2	0.2	0.2	0.3	5.3	15	5	3.4	2.9
	^C1	66	12.0	10.8	0.2	0.2	0.1	0.1	5.9	10	5	3.1	2.9
	^C2	100+	13.8	12.6	0.1	0.1	0.1	0.1	4.8	8	5	3.1	2.8
9	^Ap	10	22.9	235.8	1.2	0.1	0.4	0.3	2.4	23	9	3.9	3.4
	^C	29	12.3	9.9	0.2	0.1	0.2	0.1	5.2	13	4	3.4	2.8
	2Ab	46	9.0	26.7	0.1	0.1	0.1	0.1	3.9	17	2	3.4	3.0
	2Btb	65+	2.3	123.8	0.2	0.1	0.1	0.1	7.2	7	7	3.6	3.3
GS1	surface	10	4.4	-	0.9	0.2	0.0	0.4	0.5	8	18	3.1	2.9
	subsurface	30+	2.5	-	1.6	0.6	0.1	1.1	6.3	8	41	3.8	2.9

Table 9. Continued. Chemical properties for pre-SMCRA profile sites and grab samples (GS) including organic-C, easily-reducible Mn, exchangeable bases, KCl-extractable Al, cation exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

Site	Horizon	Lower Depth	Organic Carbon	Mn	Exchangeable Bases				Al (KCl)	CEC (NH_4OAc)	Base Saturation (NH4OAc)	pH 1:1 H_2O	pH 2:1 CaCl2
					Ca	Na	K	Mg					
		(cm)	(%)	(mg/kg)	----------cmol$_c$/kg soil----------						(%)		
GS2	surface	10	6.2	-	4.8	0.1	0.5	2.8	4.2	12	68	4.9	4.2
	subsurface	30+	6.3	-	0.9	0.1	0.1	0.9	8.5	8	24	3.9	3.7
GS3	surface	10	10.4	-	0.2	0.1	0.1	0.1	6.0	16	3	2.9	2.6
	subsurface	30+	4.2	-	0.1	0.1	0.1	0.1	6.3	9	4	2.9	2.7
GS4	surface	10	6.4	-	0.8	0.1	1.3	0.1	5.6	23	10	4.2	4.1
	subsurface	30+	4.1	-	1.1	0.1	1.1	0.2	4.6	14	17	4.6	4.3
GS5	surface	10	8.7	-	0.1	0.1	0.1	0.1	6.9	15	2	2.3	2.1
	subsurface	30+	6.6	-	0.1	0.1	0.1	0.1	2.4	12	4	3.0	2.7
GS6	surface	10	24.2	-	1.0	0.1	0.3	0.3	4.1	23	8	3.2	2.7
	subsurface	30+	8.0	-	0.2	0.1	0.1	0.1	3.2	9	5	2.8	2.5
GS7	surface	3	3.8	-	0.4	0.3	0.1	0.2	1.4	7	14	3.1	2.6
Native Soil‡	surface	-	0.3-3 (1.2)	6-1288 (383)	0-11 (4)	0.1-0.3 (.1)	0-1.4 (.5)	0-4 (1)	0-6 (3)	6-22 (12)	3-100 (45)	4-8 (4.8)	3-7 (4.4)
	subsurface	-	0.1-2 (0.3)	5-622 (231)	0.1-6 (1)	0.5-5 (1)	0-0.5 (.2)	0-6 (1)	0-7 (2)	1-15 (7)	5-85 (24)	3.5-6 (4.5)	3-8 (4)

†Percent base saturation adjusted down to 100%.

‡Native soil property ranges and averages (in parentheses) determined using same laboratory procedures (Blair, 2009).

Table 10. Chemical properties for post-SMCRA profile sites and grab samples including organic-C, easily reducible Mn, exchangeable bases, KCl-extractable Al, cation exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

					Exchangeable Bases								
Site	Horizon	Lower Depth	Organic Carbon	Mn	Ca	Na	K	Mg	Al (KCl)	CEC (NH_4OAc)	Base Saturation (NH4OAc)	pH 1:1 H_2O	pH 2:1 CaCl2
		(cm)	(%)	(mg/kg)	----------$cmol_c$/kg soil----------						(%)		
1	^Ap	12	19.9	251.0	14.5	0.2	0.4	1.5	0.0	19	86	5.7	5.1
	^C	24	18.0	64.1	7.1	0.2	0.2	0.7	0.2	23	35	4.8	4.2
	^Cj	36	9.2	27.3	8.2	0.2	0.2	0.9	0.0	11	89	5.8	5.3
	2Btb	57+	1.1	5.2	4.1	0.1	0.1	0.7	4.8	12	41	3.7	3.3
2	^Ap	16	8.8	2150.5	15.6	0.1	0.3	1.9	0.0	11	100†	7.1	6.6
	^Bwj	46	13.1	297.5	21.2	0.1	0.4	2.0	0.0	15	100†	7.2	6.5
	2Ab	58	7.0	986.5	10.6	0.1	0.3	1.7	0.0	12	100†	6.5	5.8
	2Btb	75+	2.2	24.5	7.6	0.1	0.2	1.8	0.0	8	100†	6.1	5.6
3	^Ap	14	5.0	472.5	13.2	0.1	0.3	0.9	0.0	10	100†	6.7	6.4
	^Cu	42	3.0	562.0	13.9	0.1	0.2	1.4	0.0	6	100†	7.5	7.0
	^C	75	2.4	449.0	15.4	0.1	0.1	0.5	0.0	5	100†	7.5	7.3
		100+	2.9	339.5	12.3	0.1	0.2	0.7	0.0	5	100†	7.4	7.3
4	^Ap	16	7.9	504.5	15.9	0.0	0.4	1.7	0.0	10	100†	6.8	7.0
	^Bw	34	3.0	657.0	11.3	0.1	0.3	1.4	0.0	7	100†	7.3	7.0
	^Cj	50	10.0	12.0	3.3	0.1	0.2	0.5	2.0	10	39	3.6	3.2
	^C1	59	2.8	87.4	1.8	0.1	0.1	0.5	6.3	7	36	3.0	2.8
	^C2	110+	8.2	11.1	1.6	0.1	0.1	0.3	4.6	10	20	2.7	2.5

Table 10. Continued. Chemical properties of post-SMCRA profile sites and grab samples including organic-C, easily reducible Mn, exchangeable bases, KCl-extractable Al, cation exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

					Exchangeable Bases								
Site	Horizon	Lower Depth	Organic Carbon	Mn	Ca	Na	K	Mg	Al (KCl)	CEC (NH_4OAc)	Base Saturation (NH4OAc)	pH 1:1 H_2O	pH 2:1 CaCl2
		(cm)	(%)	(mg/kg)	----------$cmol_c$/kg soil----------						(%)		
5	^Ap	11	6.6	437.0	21.9	0.1	0.3	1.3	0.0	11	100†	7.1	6.9
	^Bw	34	2.0	461.5	14.4	0.1	0.2	1.0	0.0	6	100†	7.4	7.2
	^C	41	2.4	208.6	47.1	0.1	0.2	0.6	0.0	7	100†	6.0	6.0
	^Cuj	54+	9.3	33.5	21.1	0.1	0.1	0.3	1.0	9	100†	3.6	3.5
6	^C1	10	0.6	223.5	3.5	0.2	1.0	1.6	0.0	5	100†	7.5	6.6
	^C2	50	1.3	270.0	3.1	0.1	0.8	2.5	0.0	6	100†	7.4	6.4
	^C3	100+	2.6	299.0	3.7	0.1	0.6	2.8	0.0	7	100†	7.1	6.1
7	^Ap	21	4.3	330.5	4.8	0.1	0.5	4.0	0.0	9	100†	6.1	5.2
	^C1	51	4.5	539.5	6.5	0.1	0.4	4.6	0.0	10	100†	5.9	4.8
	^C2	68	8.0	222.1	7.1	0.1	0.2	3.0	0.0	8	100†	5.8	5.4
	2Cu	100+	0.3	156.3	0.7	0.2	0.1	0.3	0.0	1	100†	6.4	5.8
8	^Ap	13	7.8	376.0	11.4	0.1	0.3	1.7	0.0	9	100†	6.3	5.9
	^Bw1	40	6.0	261.0	11.0	0.1	0.2	1.6	0.0	9	100†	6.7	6.2
	^Bw2	66	6.8	281.0	13.2	0.1	0.2	1.8	0.0	9	100†	6.8	6.4
9	^Apg	6	4.8	123.9	14.7	0.1	0.3	2.5	0.0	8	100†	7.1	6.8
	^Cdg	20	25.6	0.6	1.5	0.1	0.2	0.5	10.4	15	15	4.3	3.9
	^Cd	60+	25.5	3.5	0.6	0.1	0.2	0.4	15.2	59	2	4.3	3.9

Table 10. Continued. Chemical properties of post-SMCRA profile sites and grab samples including organic-C, easily reducible Mn, exchangeable bases, KCl-extractable Al, cation exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

Site	Horizon	Lower Depth	Organic Carbon	Mn	Exchangeable Bases				Al (KCl)	CEC (NH_4OAc)	Base Saturation (NH4OAc)	pH 1:1 H_2O	pH 2:1 CaCl2
					Ca	Na	K	Mg					
		(cm)	(%)	(mg/kg)	----------$cmol_c$/kg soil----------						(%)		
GS1	surface	10	8.8	-	16.2	0.3	0.4	2.3	0.0	14	100†	6.3	5.6
	subsurface	30+	2.8	-	12.9	0.1	0.2	1.4	0.0	9	100†	7.4	6.6
GS2	surface	10	6.3	-	14.8	0.1	0.3	1.1	0.0	12	100†	6.8	6.4
	subsurface	30+	3.2	-	12.4	0.1	0.1	0.4	0.0	6	100†	7.6	7.0
GS3	surface	10	8.9	-	20.4	0.1	0.4	1.4	0.0	12	100†	7.1	6.7
	subsurface	30+	3.5	-	13.4	0.1	0.2	0.7	0.0	6	100†	7.9	7.2
GS4	surface	10	9.1	-	3.7	0.1	1.1	1.3	1.4	12	52	5.4	4.8
	subsurface	30+	2.4	-	1.6	0.1	0.3	0.5	1.1	3	96	6.1	5.4
GS5	surface	10	9.4	-	10.7	0.1	0.8	5.7	0.1	12	100†	5.6	4.7
	subsurface	30+	8.0	-	1.3	0.1	0.3	1.4	0.0	10	32	5.0	4.3
Native Soil‡	surface	-	0.3-3 (1.2)	6-1288 (383)	0-11 (4)	0.1-0.3 (.1)	0-1.4 (.5)	0-4 (1)	0-6 (3)	6-22 (12)	3-100 (45)	4-8 (4.8)	3-7 (4.4)
	subsurface	-	0.1-2 (0.3)	5-622 (231)	0.1-6 (1)	0.5-5 (1)	0-0.5 (.2)	0-6 (1)	0-7 (2)	1-15 (7)	5-85 (24)	3.5-6 (4.5)	3-8 (4)

†Percent base saturation adjusted down to 100%.

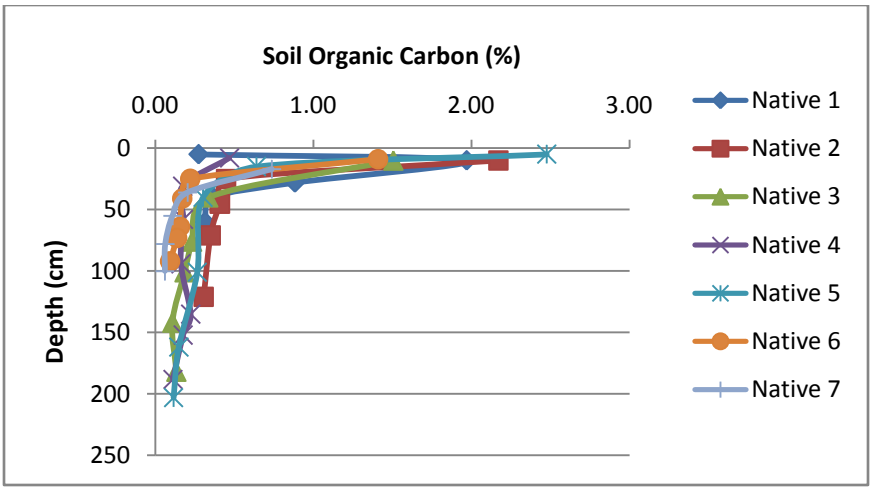
‡Native soil property ranges and averages (in parentheses) determined using same laboratory procedures (Blair, 2009).

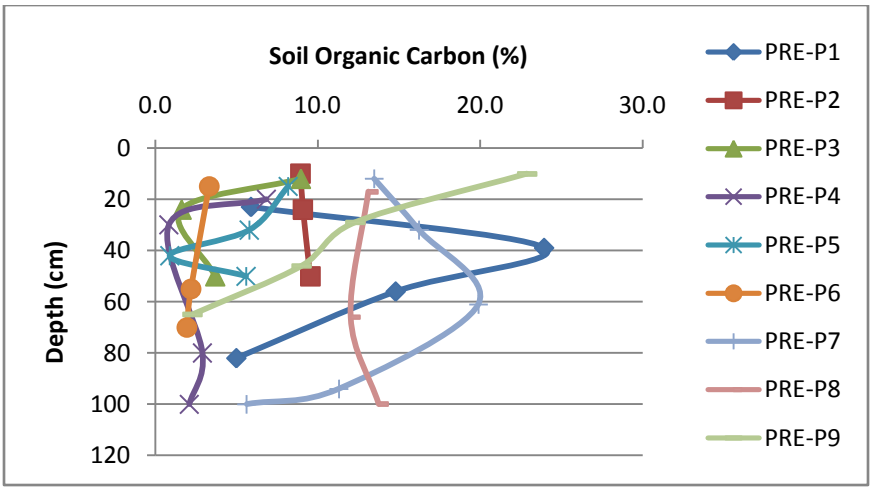
organic carbon with depth. Older soils have relatively high concentrations of SOC in surface horizons, which decrease regularly with depth (Nordt et al., 2000; Sencindiver & Ammons, 2000). All of the native soils from the BSF had a sharp decrease of SOC with depth (Figure 45 a). None of the PRE or POST profile soils displayed a typical melanization curve (Figure 45 b and c), as seen in the native soils. Although there are 2 PRE and 1 POST that show %SOC decreasing continuously with depth, the sharp decrease from surface soils into the subsoil did not occur in these sites. Again, this indicates the difference in the age of the minesoils compared to native soils.

Soil pH, Manganese, and Aluminum

In the humid Southeast, some native plants are adapted to living in strongly acid soils (4< pH < 5), such as blueberries, rhododendron, and birch trees. Below pH 4.0, however, many plant species cannot survive. It is not acidity itself which impedes plant survival. The availability of several micronutrients increases exponentially as pH decreases, including Cu, Fe, Mn, and Zn. The solubility of aluminum also dramatically rises with lowering pH. Aluminum toxicity is the most common and serious condition related to acid soil environments. Above pH of 5.2, little Al exists in solution or is exchangeable. Below this pH, however, soluble Al can inhibit the growth of roots by disrupting cell wall expansion. Mn toxicity can occur up to a pH of 5.6 and Fe becomes toxic below pH of 4.0 (Brady & Weil, 2008). From the native soil profiles from the BSF, no horizons had pH_{H2O} < 3 or pH_{CaCl2} < 3 (Tables 9 and 10). The pH of these soils ranged from 3.2 to 8.5, falling mostly between 3.5 and 5. Contrastingly, approximately 17% of the pre-SMCRA minesoil horizons had a pH_{H2O} < 3 and 43% had a pH_{CaCl2} < 3, ranging from 2.1 to 6.9 (Table 9). Only 5% of the post-SCMRA minesoil horizons had pH_{H2O} or pH_{CaCl2} < 3, ranging from 2.5 to 7.9 (Table 10).The average pH of pre-SMCRA surface horizons did not differ significantly from native surface horizons, but PRE subsurface horizons did have an average pH significantly lower than native subsurface horizons. Both PRE surface and subsurface horizon average pHs were significantly lower than those measured in POST horizons. Due to liming during reclamation, both POST surface and subsurface horizons had average pH's that were significantly higher than native surface and subsurface horizons.

Easily-reducible manganese did not differ significantly between PRE, POST, or native sites at p=0.05. PRE did differ from POST at p=0.1, meaning that there is some difference there. While it has





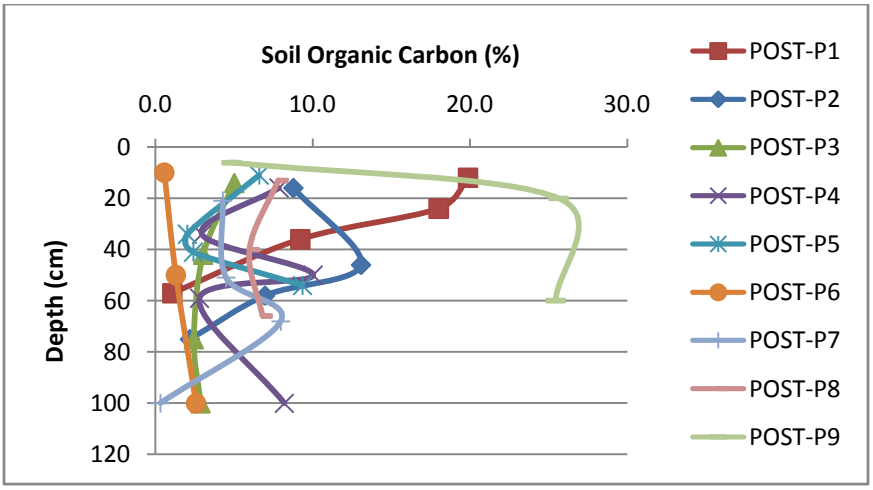


Figure 45. Distribution of soil organic carbon with depth from native profiles (Blair, 2009) (a. top), pre-SMCRA (b. middle), and post-SMCRA (c. bottom) minesoils in the BSF.

been suggested that Mn-toxicity can occur when reducible forms of Mn top 100 mg kg^{-1} soil, many of the native soil horizons from a previous study (Blair, 2009) had Mn values well over this (Tables 9 and 10). Therefore it is hard to judge whether Mn toxicity is occurring on some minesoil sites. Nonetheless, some sites differ dramatically from the average native soil values, including post-SMCRA profile site 2, which contained over 2000 mg Mn kg^{-1} soil in the surface horizon and close to 1000 mg Mn kg^{-1} soil in the second subsurface horizon (Table 10). KCl-extractable aluminum was significantly greater in PRE surface horizons than POST surface horizons (p=0.05), however PRE surface horizons were not significantly different than those of native soils. This is likely related to the pHs discussed earlier, being significantly lower between PRE and POST, but not between PRE and native sites. The POST sites have been limed and thus the pH is too high for aluminum to remain soluble. This same result is not seen in the subsurface horizons. PRE subsurface horizons had not only significantly higher concentrations of KCl-extractable Al than POST subsurfaces, but also more than native subsurface horizons. In fact, the KCl-extractable Al in POST subsurface horizons did not differ from that in native subsurface horizons. This implies that active weathering of parent materials may be taking place at an increased rate in the subsoils of PRE-SMCRA minesoils compared to POST-SMCRA or native sites (Tables 9 & 10).

Cation Exchange Capacity and Base Saturation

The averageded cation-exchange capacity (CEC) of the pre-SMCRA surface (14 ± 1 $cmol_c$ kg^{-1}) and subsurface horizons (11 ± 1 $cmol_c$ kg^{-1}) was not significantly different than POST horizons at p=0.05 (11 ± 1 and 10 ± 2 $cmol_c$ kg^{-1}, respectively) (Tables 9 and 10). There was no significant difference reflected between PRE and native surface horizons (using the same method), but there was significantly higher CEC in the subsoils of the PRE sites versus the native (8 ± 0.5 $cmol_c$ kg^{-1}). There was no significant difference found between the POST and native surface horizons, but there was significantly higher CEC in the POST subsoils versus native subsoils (p=0.1).

CEC data reflected higher values for surface horizons due to accumulated organic matter (Tables 9 and 10). In the case of post-SMCRA profile site 9 located at Anderson Branch where major reclamation efforts were made, the dramatic increase in CEC in the subsurface is probably due to the high amount of KCl-extractable Al. In some cases, the aluminum appears to be almost the only cation present on the exchange complex, as in pre-SMCRA profile site 5. The KCl-Al was 14 $cmol_c$ kg^{-1} while the total CEC was

only 10 $cmol_c$ kg^{-1}. This high aluminum along with the low base occupation of exchange sites is more than likely due to the low pH.

Base saturation was significantly different between PRE and POST surface horizons (41 ± 11% versus 95 ± 4%, respectively) and subsurface horizons (39 ± 8% versus 81 ± 6%, respectively). Both POST surface and subsurface horizons also had statistically greater percent base saturation (at p=0.05) than native surface and subsurface horizons (44 ± 13% and 26 ± 4%, respectively), even with pre-SMCRA profile sites 1-4 included, which are suspected to have anthropogenic additions of lime and/or fertilizer. No statistical difference existed between PRE and native base saturation values in the surface or subsurface (p=0.05) (Tables 9 and 10). Many of the low base saturation values were found in horizons that had correspondingly low pH. Interestingly, even on some post-SMCRA sites where extensive applications of lime and fertilizer are known to have been applied, the pH decreased in subsurface horizons with a corresponding decrease in base saturation. For example, post-SMCRA profile site 4, located near Blue Herron (Figures 31a and 31b), was once a large coal refuse pile which stretched out beneath more than ten coal mine entrances. Even after extensive reclamation efforts, the spoil buried in the subsoil appears to still be oxidizing pyrite and actively generating acidity (as reflected in the acid-base account in Table 8). On post-SMCRA profile site 9, the base saturation drops dramatically in the subsoil horizons. This along with other features of this site discussed above suggests that compaction is likely the major limiting factor for plant growth on this site. It appears that the lime and fertilizer applied to this site is not penetrating the subsoil horizons, but is likely running off.

Mehlich I Extractable Nutrients

The concentrations of Mehlich I-extractable nutrients (mg kg^{-1} soil) for all pre- and post-SMCRA samples can be seen in Tables 11 and 12. The results of the one way ANOVA comparison of means can be seen in Table 13 and Figure 46. Ca and Mg were statistically different between PRE and POST surface horizons and only Ca between PRE and POST subsurface horizons. This can be explained by the addition of lime and fertilizers to many of the post-SMCRA sites.

Table 11. Mehlich I-extractable nutrients for pre-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Depth	Ca	Cu	K	Mg	Mn	P	Zn
		(cm)	----------mg/kg soil----------						
1	^Ap	23	4151	6	75	347	41	†	9
	^Abu	39	10420	6	165	627	252	†	212
	^C1	56	1246	†	79	98	16	†	8
	^C2	82+	505	†	68	56	†	†	†
2	^Ap	10	3238	8	307	552	385	†	40
	^C1	33	1961	11	230	388	312	†	35
	^C2	55	810	14	163	267	207	†	28
3	^Ap	12	5820	†	177	224	246	†	240
	^Cu	24	1737	7	124	102	148	32	97
	^C	50	3036	8	212	87	158	165	192
4	^Ap	20	4878	†	471	1102	242	†	23
	^EC	30	1331	5	326	894	79	†	7
	^C1	80	1179	7	241	802	169	†	23
	^C2	100+	1662	†	254	1102	174	†	20
5	^Ap	15	2180	†	282	705	349	†	19
	^C1	32	733	†	155	348	191	†	16
	^C2	42	590	5	184	1065	117	†	17
	^C3	50+	311	11	145	365	53	†	39
6	^A	15	381	5	240	108	43	†	10
	^C	55	360	7	179	276	131	†	29
	2Ab	70+	94	†	77	49	124	†	7
7	^Ap	12	484	†	130	122	49	†	13
	^C1	32	91	†	†	21	†	†	†
	^C2	61	49	†	†	12	†	†	†
	^C3	94	24	†	†	8	†	†	†
	2C4	100+	31	†	†	18	†	†	†

Table 11. Continued. Mehlich I-extractable nutrients from Pre-SMCRA sites and grab samples (GS).

Site	Horizon	Lower Depth	Ca	Cu	K	Mg	Mn	P	Zn
		(cm)	----------	----------	mg/kg soil	----------	----------	----------	----------
8	^A	17	33	†	†	22	10	†	†
	^C1	66	31	†	†	13	†	†	†
	^C2	100+	26	†	†	10	†	†	†
9	^Ap	10	340	†	359	94	625	†	32
	^C	29	116	†	268	56	62	†	16
	2Ab	46	57	†	88	25	33	†	6
	2Btb	65+	61	†	75	21	126	†	5
GS1	surface	10	515	†	84	149	25	†	†
	subsurface	30+	566	†	109	257	41	†	†
GS2	surface	10	1920	†	368	684	254	†	†
	subsurface	30+	516	†	126	280	189	†	†
GS3	surface	10	86	†	60	†	†	†	†
	subsurface	30+	39	†	†	†	†	†	†
GS4	surface	10	202	†	384	25	79	†	†
	subsurface	30+	442	†	432	33	35	†	†
GS5	surface	10	28	†	†	†	†	†	†
	subsurface	30+	26	†	†	†	†	†	†
GS6	surface	10	381	†	133	85	35	†	†
	subsurface	30+	69	†	†	†	†	†	†
Native Soils†	surface		25-1600 (520)	0.5-4 (1.5)	40-220 (107)	8-400 (115)	3-445 (230)	1-20 (9)	1.5-9 (4)
	subsurface		11-1100 (165)	0-2 (1)	10-110 (49)	1-650 (106)	1-143 (43)	0-55 (6)	0-2.5 (1.5)

* Denotes measured value fell below detection limits of ICP-OES.

Table 12. Mehlich I-extractable nutrients for post-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Depth	Ca	Cu	K	Mg	Mn	P	Zn
		(cm)	----------mg/kg soil----------						
1	^Ap	12	6860	42	218	386	182	†	296
	^C1	24	2789	†	133	152	66	†	46
	^C2	36	3620	†	121	230	†	†	†
	2Btb	57+	1260	†	88	155	†	†	†
2	^Ap	16	8030	†	197	926	370	†	109
	^Bw	46	9350	†	199	710	115	†	41
	2Ab	58	4235	†	144	387	135	†	†
	2Btb	75+	2689	†	120	413	38	†	†
3	^Ap	14	5790	†	213	237	242	†	†
	^Cu	42	6130	†	112	218	138	†	†
	^C	75	8580	†	78	410	62	†	†
		100+	6900	†	163	371	150	†	†
4	^Ap	16	7550	†	311	590	276	†	†
	^Bw	34	5690	†	260	539	166	†	†
	^C1	50	1425	†	106	132	†	†	†
	^C2	59	787	†	77	135	62	†	†
	^C3	110+	646	†	†	68	†	†	†
5	^Ap	11	8770	†	217	586	170	†	†
	^Bw	34	8310	†	102	1091	76	†	†
	^C	41	11970	†	103	229	85	†	†
	^Cu	54+	10150	†	†	99	31	†	†
6	^C1	10	2513	†	797	570	65	136	28
	^C2	50	2488	†	697	714	110	83	27
	^C3	100+	2470	†	545	859	133	70	26
7	^Ap	21	2279	†	383	836	139	†	23
	^C1	51	2415	†	274	959	175	†	25
	^C2	68	2011	†	215	690	101	†	†
	^2Cu	100+	314	†	†	108	†	†	†

Table 12. Continued. Mehlich I-extractable nutrients from Post-SMCRA sites and grab samples (GS).

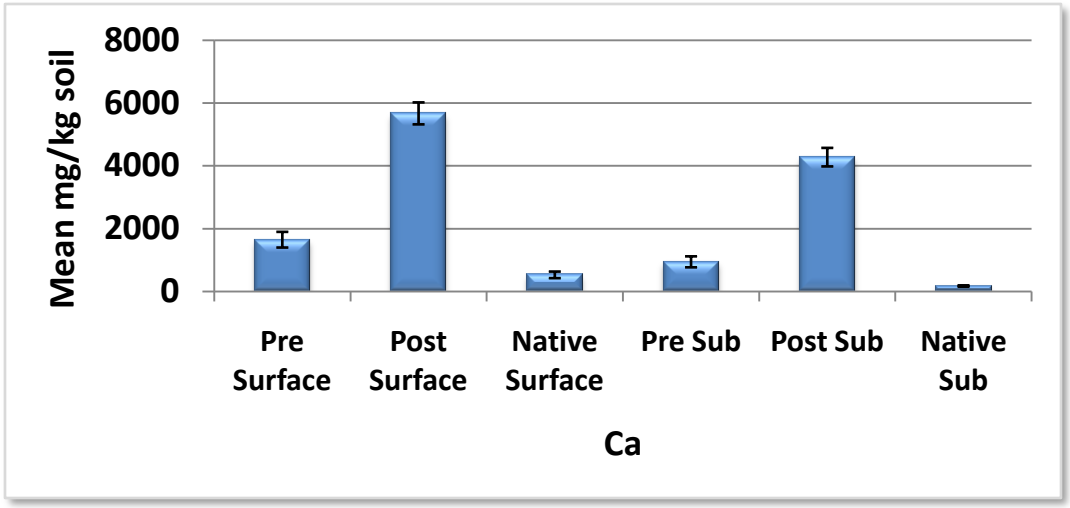
Site	Horizon	Lower Depth	Ca	Cu	K	Mg	Mn	P	Zn
		(cm)	----------mg/kg soil----------						
8	^Ap	13	4820	†	198	411	260	†	32
	^Bw1	40	4715	†	158	427	149	†	42
	^Bw2	66	5380	†	120	471	178	†	33
9	^Ap	6	5480	†	141	572	193	†	†
	^C1	20	554	†	98	102	†	†	†
	^C2	60+	231	†	102	61	†	†	†
GS1	surface	10	6840	†	336	544	309	†	26
	subsurface	30+	5300	†	129	430	183	34	†
GS2	surface	10	6230	†	242	314	344	†	†
	subsurface	30+	6920	†	88	211	204	†	†
GS3	surface	10	9610	†	243	350	279	†	†
	subsurface	30+	8880	†	139	405	170	†	†
GS4	surface	10	1498	†	378	309	78	†	†
	subsurface	30+	3271	†	247	196	226	172	225
GS5	surface	10	3062	†	341	936	500	†	38
	subsurface	30+	428	†	145	331	213	†	31
Native Soils†	surface		25-1600 (520)	0.5-4 (1.5)	40-220 (107)	8-400 (115)	3-445 (230)	1-20 (9)	1.5-9 (4)
	subsurface		11-1100 (165)	0-2 (1)	10-110 (49)	1-650 (106)	1-143 (43)	0-55 (6)	0-2.5 (1.5)

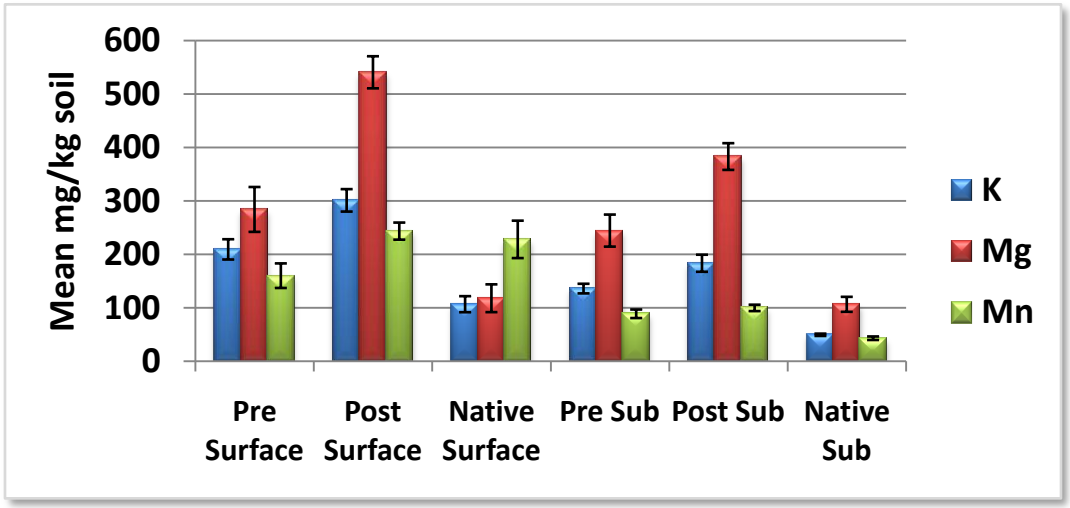
* Denotes measured value fell below detection limits of ICP-OES.

Table 13. Results from one-way ANOVA (p=0.05) for Mehlich I-extractable elements from surface and subsurface horizons of all sites.

	Surface			Subsurface		
Element	**Pre/ Post**	**Pre/ Native**	**Post/ Native**	**Pre/ Post**	**Pre/ Native**	**Post/ Native**
Ca	*** (Post)**		*** (Post)**	*** (Post)**	*** (Pre)**	*** (Post)**
Cu		*** (Pre)**			*** (Pre)**	*** (Post)**
K			*** (Post)**		*** (Pre)**	*** (Post)**
Mg	*** (Post)**		*** (Post)**		*** (Pre)**	*** (Post)**
Mn					*** (Pre)**	*** (Post)**
P						
Zn					*** (Pre)**	*** (Post)**

*Denotes a significant difference exists (p=0.05); group with significantly higher mean is in parentheses.





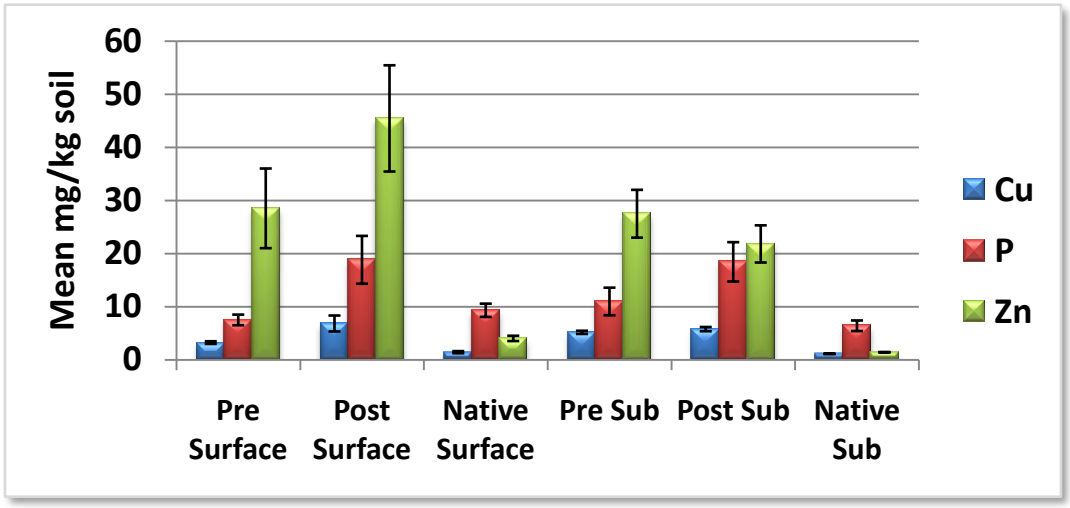


Figure 46. Comparison of means for Mehlich I-extractable nutrients for pre-SMCRA, post-SMCRA, and native surface and subsurface horizons.

The fact that copper (Cu) was the only element for which there were significant differences between pre-SMCRA and native surface horizons was not entirely unexpected. The surface horizons of pre-SMCRA minesoils after all are forming from similar materials as the native surface horizons, with much of the plant-available nutrients coming from the decomposition of forest vegetation and associated organic matter. This was also why there were many more differences between POST and native surface horizons: many of the post-SMCRA reclamation sites have been planted with legumes, grasses, and some trees, making the nature of the decomposing vegetation different.

In the subsurface there were striking differences between both pre- and post-SMCRA minesoils and native soils. Phosphorus was the only nutrient that did not differ significantly between minesoil and native subsurface horizons. P-deficiency and general infertility is common in the soils of the highly weathered and forested regions of the southeastern US. Because these soils exhibit slight to moderate acidity naturally, P is quickly adsorbed to Al/Fe oxides or clays or precipitated as Al/Fe phosphates. Thus, the low amount of extractable P in minesoils compared with that of the native soils in this region. Minesoil subsurface horizons had significantly greater Mehlich I-extractable Ca, K, Mg, Mn, and Zn than native subsurface horizons. As the PRE and POST subsurfaces did not differ in most of these, it seems that this is likely due to the stage of development of the soil profiles. Minesoils have developed within the last one hundred years and contain large fragments of fresh parent materials within the profile which are actively being broken down. Cations imbedded within the crystal structure of these minerals are released as the minerals weather, making a relatively higher concentration available for plant uptake. The native soils on the other hand have been weathering in place for a much longer period of time and are thus composed of highly weathered clay minerals such as kaolinite or simply Al/Fe oxides with little crystal structure. Most of the cations associated with the parent materials of the native soils were released long ago and have since been leached from the profile due to the high humidity, heat, and rainfall.

Total Elemental Analysis

Total elemental analysis was conducted on minesoil samples and compared to data collected from a previous study on native soils in the BSF (Blair, 2009) using the same laboratory procedures and analyzed on the same ICP instrument. The results can be seen in Tables 14 and 15, along with the results from a one-way ANOVA run in SPSS 19 in Table 16.

Table 14. Total elemental analyis for pre-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Depth	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	P	Pb	Zn
		(cm)	mg/ kg soil										
1	^Ap	23	5275	†	†	43300	10610	2205	180	1099	214	97	†
	^Abu	39	8048	†	63	28050	10520	1987	403	1678	445	67	121
	^C1	56	1187	†	†	16545	11250	1539	†	1006	229	†	†
	^C2	82+	750	53	†	22225	16920	2212	†	1439	124	55	†
2	^Ap	10	3000	101	55	41050	19380	5580	1285	1462	465	92	123
	^AC	33	1300	61	†	30950	14140	3835	751	1009	285	66	78
	^C	55	733	61	53	38950	15515	3945	504	1012	261	71	76
3	^Ap	12	8525	†	†	27400	5655	1742	894	885	854	67	300
	^Cu	24	1387	†	†	41600	6875	1059	841	732	345	86	105
	^C	50	5600	101	85	51700	15115	3355	1657	3295	1524	111	481
4	^Ap	20	2965	80	†	45250	9385	5035	550	1646	426	61	74
	^EC	30	1357	131	†	33100	21810	4965	207	1455	310	71	44
	^C1	80	1186	118	†	46050	20945	7585	705	1450	493	100	98
	^C2	100+	1695	117	†	46950	20235	5810	1135	1375	354	100	88
5	^Ap	15	1704	96	†	47400	15715	5160	670	1120	602	102	67
	^C1	32	961	100	†	56700	17465	5120	645	1366	549	117	78
	^C2	42	814	113	†	35425	22648	5535	260	1900	193	76	†
	^C3	50+	873	104	†	18990	14230	3455	73	2198	248	†	57
6	^A	15	600	116	†	42600	16970	3590	98	1251	361	85	†
	^C	55	925	110	†	33100	18290	4680	469	2417	242	74	66
	2Ab	70+	697	†	†	23430	7905	1729	552	1012	241	†	64

Table 14. Continued. Total elemental analysis for pre-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Depth	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	P	Pb	Zn
		(cm)	----------mg/ kg soil----------										
7	^Ap	12	536	†	†	20960	13475	1947	†	992	143	†	†
	^C1	32	429	†	†	9475	7705	1218	†	662	99	†	†
	^C2	61	530	57	†	18340	17005	2650	†	1362	167	†	†
	^C3	94	578	†	†	25650	7175	1256	†	579	129	61	†
	2C4	100+	459	†	†	54300	11365	1807	†	960	375	125	†
8	^Ap	17	633	†	†	33900	10065	1884	†	1308	193	83	†
	^C1	66	629	†	†	25700	10405	2105	†	1248	154	62	†
	^C2	100+	490	†	†	18150	9245	1909	†	1173	111	†	†
9	^Ap	10	1535	58	†	46900	12785	2740	854	1200	1430	106	62
	^C	29	739	97	†	73450	28400	4535	68	1701	620	162	†
	2Ab	46	794	†	†	35450	11730	2257	119	1461	328	78	†
	2Btb	65+	725	†	†	24975	9085	1768	378	990	254	58	64
GS1	surface	10	269	†	†	485500	851	203	87	241	234	1110	64
	subsurface	30+	778	98	†	63850	19410	3240	234	1315	401	135	73
GS2	surface	10	1305	86	†	45600	15845	5275	493	1194	599	97	60
	subsurface	30+	559	61	†	34950	11020	4090	513	862	409	82	†
GS3	surface	10	798	53	†	44800	12940	2595	†	2535	370	111	†
	subsurface	30+	588	60	†	42250	15640	2510	70	1486	401	103	†

Table 14. Continued. Total elemental analysis for pre-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Depth	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	P	Pb	Zn
		(cm)	----------mg/ kg soil----------										
GS4	surface	10	1880	70	104	29100	9175	2071	762	1231	491	67	93
	subsurface	30+	1508	72	262	55200	8165	1502	290	1586	613	127	69
GS5	surface	10	398	69	†	50400	15870	2750	†	1942	326	121	†
	subsurface	30+	472	158	†	89850	32250	6145	†	3820	689	199	†
GS6	surface	10	557	†	†	21380	12460	2019	†	894	302	†	†
	subsurface	30+	566	66	†	23255	18430	2610	†	1492	191	59	†
GS7	surface		322	†	†	814500	1067	302	†	335	2119	2243	70
Native Soil†	surface		530-2000 (1100)	18-76 (43)	17-44 (27)	13000-59000 (30000)	2500-17500 (9500)	600-4300 (2200)	95-520 (308)	2200-3600 (2800)	100-600 (300)	NA	25-120 (55)
	subsurface		350-1300 (650)	10-90 (50)	15-50 (30)	11000-49000 (29500)	1400-21500 (11000)	300-2600 (2500)	25-1200 (450)	1600-4500 (3000)	30-370 (215)	NA	15-100 (50)

*Denotes measured value fell below detection limits of ICP-OES.

†Native soil property ranges and averages (in parentheses) determined using same laboratory procedures (Blair, 2009).

Table 15. Total elemental analysis for post-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Depth	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	P	Pb	Zn
		(cm)	----------mg/ kg soil----------										
1	^Ap	12	5155	52	199	48100	6825	1357	456	1617	256	122	335
	^C	24	2535	†	68	24545	4935	771	150	1214	151	66	68
	^Cj	36	2472	67	74	120750	14345	1135	259	2447	181	323	†
	2Btb	57+	1202	162	†	57050	16440	3255	88	2125	359	135	63
2	^Ap	16	9900	138	150	69350	6735	3065	3460	1546	401	160	152
	^Bwj	46	6125	159	161	90200	6395	1552	627	1306	389	214	82
	2Ab	58	2805	155	174	193000	8935	1456	997	1463	697	516	106
	2Btb	75+	1840	59	62	79550	14410	2865	119	1365	602	183	60
3	^Ap	14	4825	†	†	37150	12705	2410	673	2023	344	65	†
	^Cu	42	4395	†	†	27050	9535	2108	620	943	255	65	†
	^C	75	12265	†	†	36400	11935	2290	643	955	250	71	62
		100+	4135	57	†	33350	11795	2168	512	915	243	60	†
4	^Ap	16	7680	†	†	34600	13435	3220	759	992	459	66	62
	^Bw	34	4000	61	†	41200	15060	3485	917	1471	288	88	81
	^Cj	50	1194	†	†	45450	13360	1959	†	1387	227	94	†
	^C1	59	964	†	†	63500	15700	3420	189	1248	327	126	†
	^C2	110+	894	55	†	53200	16575	2870	73	1302	345	103	†
5	^Ap	11	9890	53	†	39800	13430	3075	676	1064	391	72	69
	^Bw	34	9500	†	†	35150	13065	3075	547	1082	257	62	76
	^C	41	11460	†	†	53350	12910	3390	336	1281	337	111	63
	^Cuj	54+	6150	†	†	48150	13560	2184	69	1375	399	91	†

Table 15. Continued. Total elemental analysis for post-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Depth	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	P	Pb	Zn
		(cm)	mg/ kg soil										
6	^C1	10	4815	261	100	123850	59800	18965	1837	5735	1245	308	302
	^C2	50	2312	107	†	54450	23780	8380	850	1741	572	123	125
	^C3	100+	2033	101	†	53250	23090	8090	825	1474	506	117	119
7	^Ap	21	1672	97	†	44350	22368	8363	738	1567	406	102	122
	^C1	51	1633	95	†	46750	27250	8040	839	1387	431	113	115
	^C2	68	1814	†	†	20030	11690	3340	351	684	187	†	†
	^2Cu	100+	606	†	†	25600	1498	356	201	213	75	60	†
8	^Ap	13	3648	57	†	24010	11495	3305	551	1154	379	62	70
	^Bw1	40	4390	71	†	31550	14035	3935	504	1481	372	79	81
	^Bw2	66	4240	69	†	28900	13410	3855	450	1451	346	69	76
9	^Apg	6	859	76	†	51900	13065	2715	†	1107	210	124	†
	^Cdg	20	3265	†	†	20225	9480	2175	184	887	182	†	†
	^Cd	60+	632	83	130	26600	10920	2590	†	1126	216	68	†
GS1	surface	10	5825	53	†	37100	12595	3625	588	2805	492	88	71
	subsurface	30+	5200	61	†	40250	16260	5225	635	2242	342	92	76
GS2	surface	10	4790	†	†	27950	9620	2492	608	2725	387	66	†
	subsurface	30+	6940	†	†	27050	9910	2245	664	962	261	66	†

Table 15. Continued. Total elemental analysis for post-SMCRA profile sites and grab samples (GS).

Site	Horizon	Lower Depth	Ca	Cr	Cu	Fe	K	Mg	Mn	Na	P	Pb	Zn
		(cm)	----------mg/ kg soil----------										
GS3	surface	10	15025	72	56	40150	16125	4015	853	1462	721	100	96
	subsurface	30+	7850	†	†	32500	10685	2575	629	1025	278	74	†
GS4	surface	10	2392	110	†	52500	21040	7170	607	1989	598	123	115
	subsurface	30+	5720	279	147	103200	44000	15115	1268	6250	915	260	414
GS5	surface	10	2815	90	†	17345	10335	3855	1858	1338	568	†	64
	subsurface	30+	896	144	87	26550	14835	5240	659	2106	396	68	66
Native Soil†	surface		530-2000 (1100)	18-76 (43)	17-44 (27)	13000-59000 (30000)	2500-17500 (9500)	600-4300 (2200)	95-520 (308)	2200-3600 (2800)	100-600 (300)	NA	25-120 (55)
	subsurface		350-1300 (650)	10-90 (50)	15-50 (30)	11000-49000 (29500)	1400-21500 (11000)	300-2600 (2500)	25-1200 (450)	1600-4500 (3000)	30-370 (215)	NA	15-100 (50)

*Denotes measured value fell below detection limits of ICP-OES.

†Native soil property ranges and averages (in parentheses) determined using same laboratory procedures (Blair, 2009).

Table 16. List of calculated F values from one-way ANOVA for elemental totals from surface and subsurface horizons of all sites (calculated p-values in parentheses).

	Surface			Subsurface		
Element	**Pre/ Post**	**Pre/ Native**	**Post/ Native**	**Pre/ Post**	**Pre/ Native**	**Post/ Native**
Ca	* (Post)		* (Post)	* (Post)	* (Pre)	* (Post)
Cd		* (Pre)	* (Post)	* (Post)	* (Pre)	* (Post)
Cr		* (Pre)			* (Pre)	* (Post)
Cu	* (Post)					* (Post)
Fe				* (Post)	* (Pre)	* (Post)
K					* (Pre)	* (Post)
Mg					* (Pre)	* (Post)
Mn	* (Post)			* (Post)		
Na	* (Post)	* (Native)	* (Native)		* (Native)	* (Native)
P					* (Pre)	*(Post)
Zn						* (Post)

*Denotes a significant difference exists (p=0.1); group with significantly higher mean is in parentheses.

In Tables 14 and 15, there are several sites that stand out for having comparatively higher levels of certain elements (compared to native soils and also to other minesoils from BSF). For example, Pre-SMCRA profile sites 3 and 4 have horizons with relatively high concentrations of Cr (> 100 mg kg^{-1} soil), Mn (> 1000 mg kg^{-1} soil), and/or Zn (> 400 mg kg^{-1} soil in PRE 3). At least one horizon in each of the following Pre-SMCRA profiles had comparatively higher levels of either Cr, Fe, Mn, Pb, and/or Zn: PRE-P 9, PRE-GS 1, 2, 4, 5, and 7. Comparatively high levels of Cr, Cu, Fe, Mn, Pb, and/ or Zn were also reported in post-SMCRA profile sites 1, 2, and 6 and POST-GS sites 4 and 5, which can be seen in the table.

As reflected in Table 16, the mean total concentrations of the selected elements seem to differ in the same ways seen in the mean Mehlich I-extractable nutrients, with almost every element differing significantly in the subsurface of the minesoils compared to the native soils. Bar charts showing a comparison of means of the total elemental concentrations between PRE, POST, and native surface horizons and PRE, POST, and native subsurface horizons are provided in Figure 47. The effect of treatment can be seen between PRE and POST sites, as in the case of K, Mg, and especially calcium, which were often added as lime and fertilizer to the POST sites.

Table 16 shows that there were few significant differences between the surface horizons (at p=0.1), however, more differences occur in the subsurface horizons between the PRE/native and POST/native comparisons. This is due to the dissimilar parent materials from which the soils are developing: the native soils from highly-weathered Pennsylvanian sandstones and shales and the minesoils mostly from recently exposed Pennsylvanian coals and high-carbon shales that lined the coal seams. It is clear from this data that minesoils in the BSF contain significantly higher concentrations of the elements quantified than surrounding native soils. This is partly because the acidity and soluble acid-salt products created by the oxidation of pyritic-S bearing materials in spoils increase the solubility of metals. It is also partly because recently exposed geologic materials are being weathered. Generally, the mean concentrations of metals in new mine spoils follow the trend of Al > Fe > Mn > Pb > Zn > Cu > Ni (Ditsch & Collins, 2000).

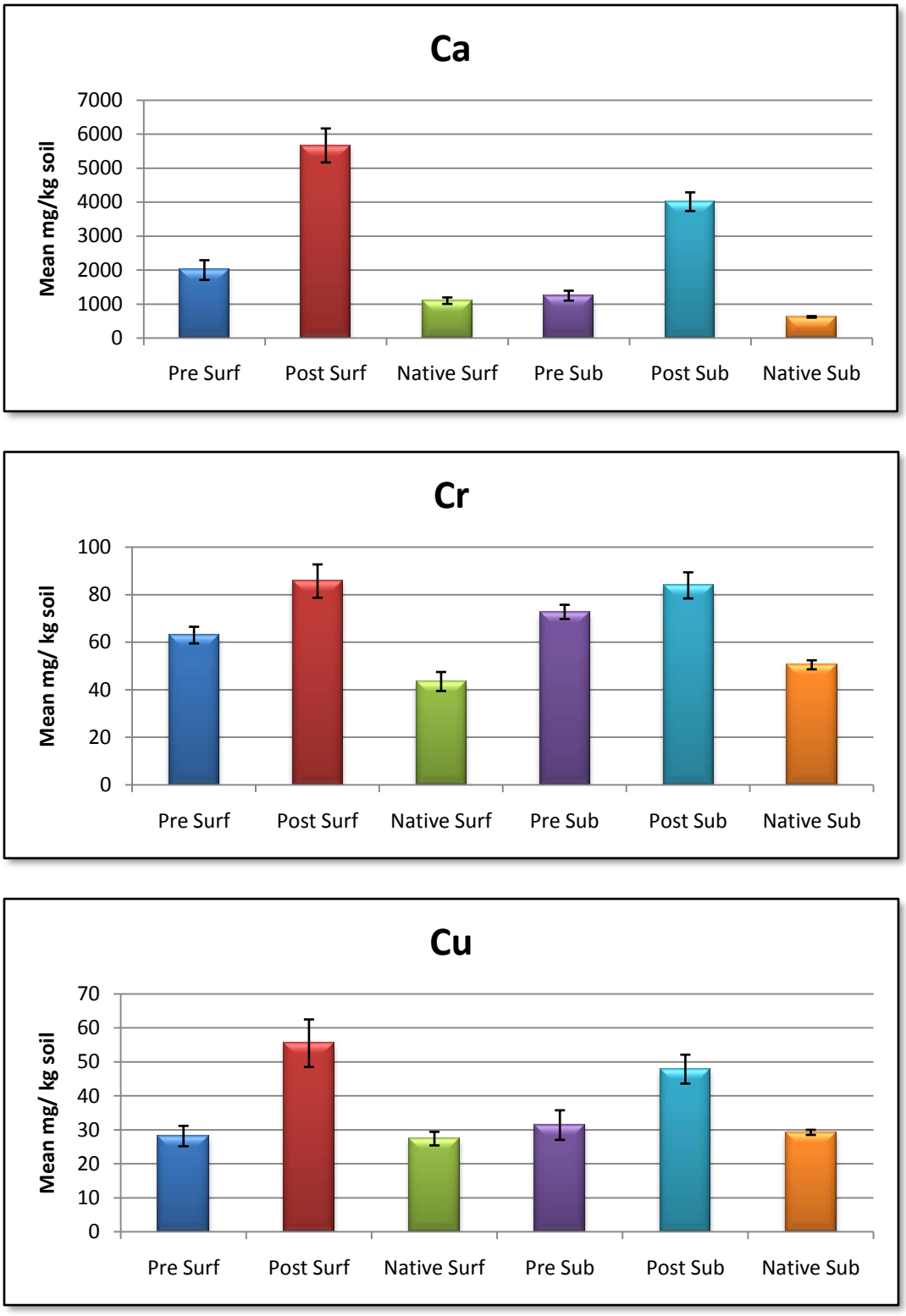
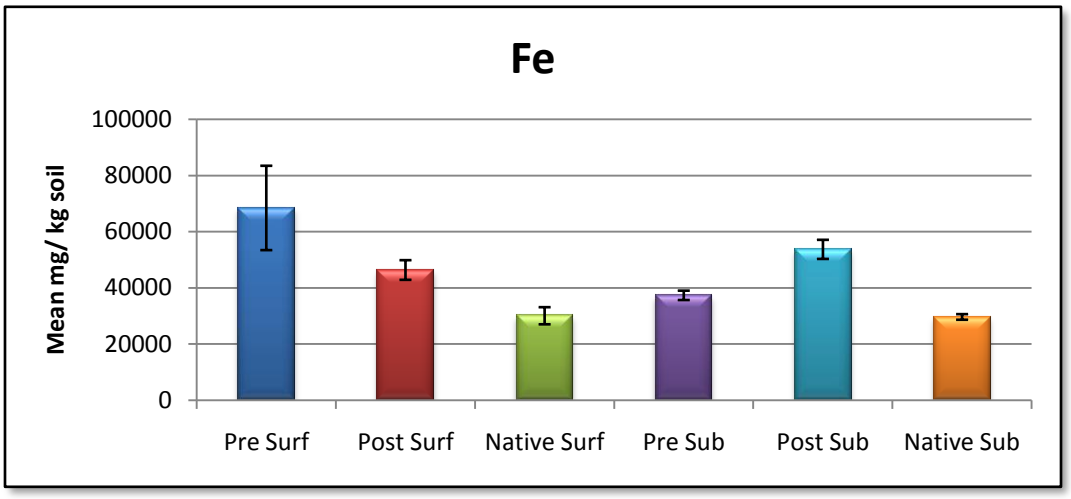
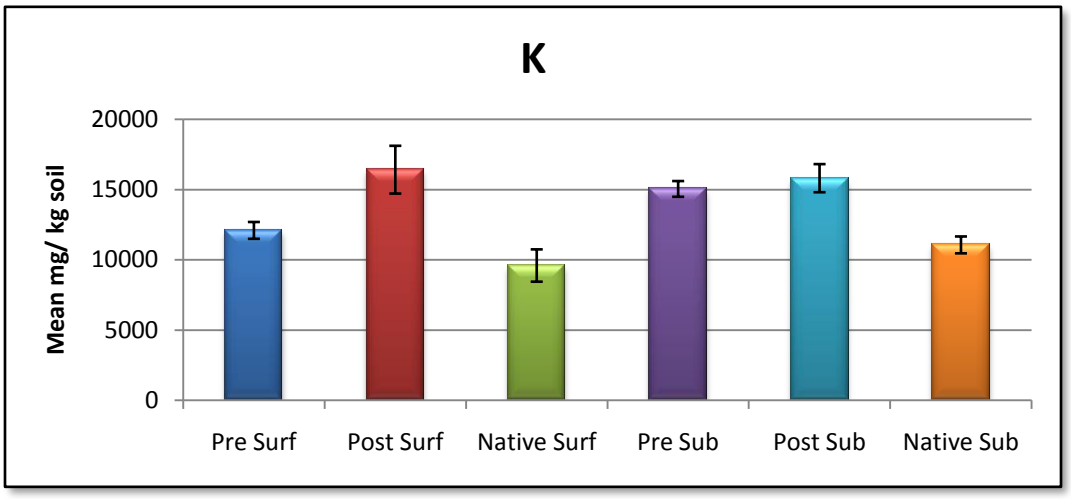
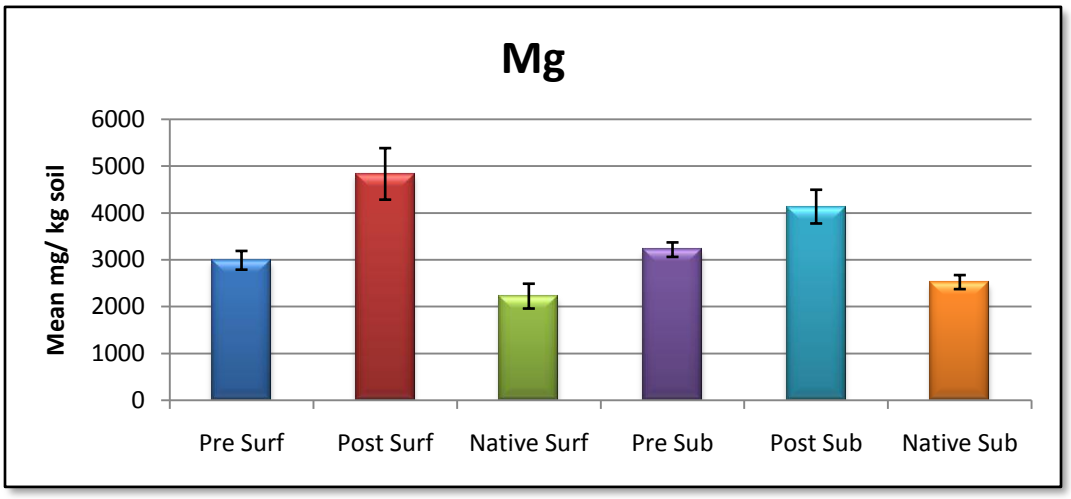


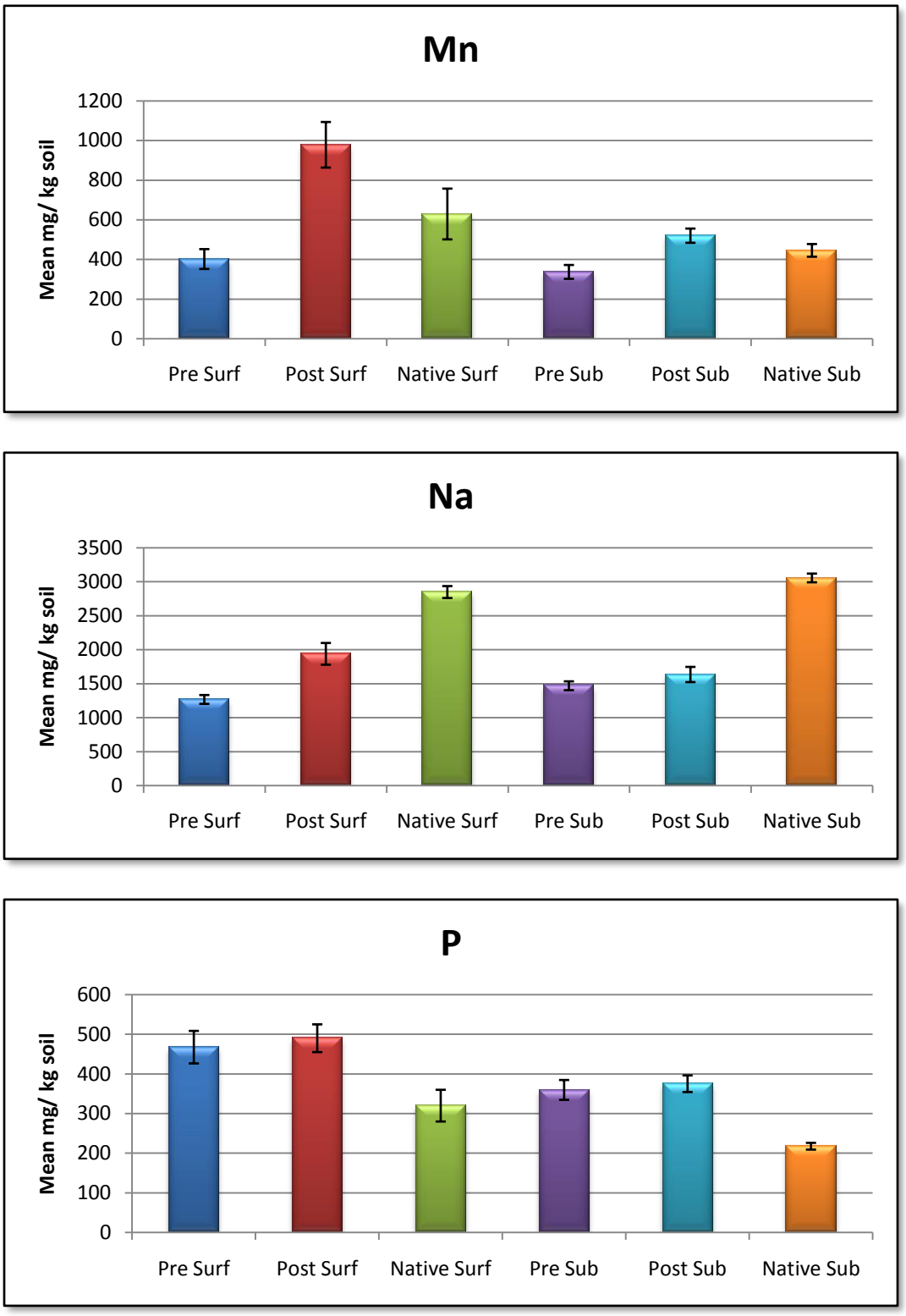
Figure 47. Comparison of means from total elemental analysis.



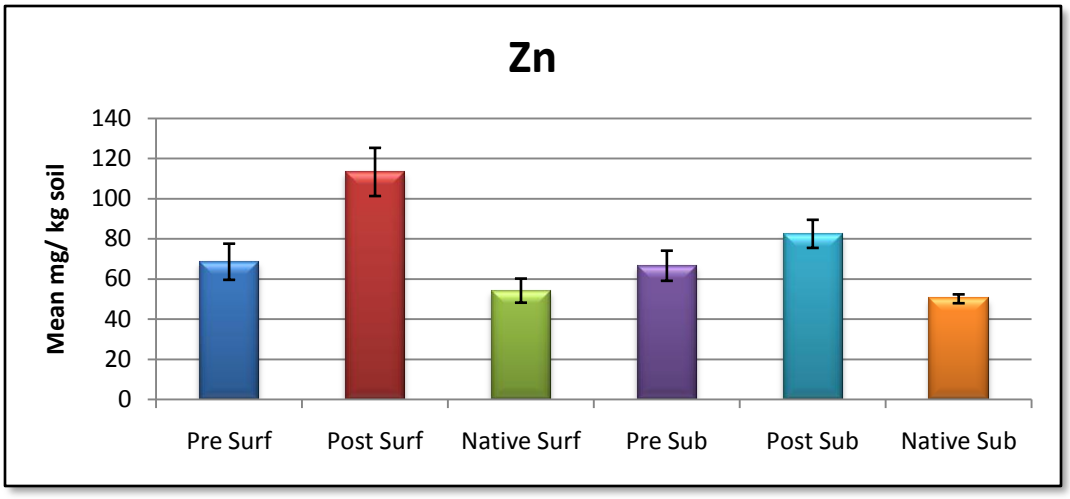




Figures 47. Continued. Comparison of means from total elemental analysis.



Figures 47. Continued. Comparison of means from total elemental analysis.



Figures 47. Continued. Comparison of means from total elemental analysis.

Clustering Analysis

The heat maps seen in Figure 48 should be thought of as *concentration* maps, as the red squares represent minesoil horizons which exhibit higher concentrations (or measured values) of a given property and green areas represent those which have less of that property. The dendrograms seen at the top and side of the cluster analysis indicate degrees of similarity between two variables. In this case, the closer together two soil horizons are linked in the dendrogram, the more similar they are to each other (as a whole, considering all properties measured). The same is true of the properties listed at the top of the cluster: the properties linked directly together are more closely related than those linked farther away or not at all. For example, in the first cluster analysis, only the properties of the A horizons from each pre- and post- SMCRA profile sites were compared. The dendrogram of related A horizons at the top of the figure indicates two main clusters and several more closely related subclusters. The two main clusters separated out PRE sites 1, 3, and 4 and POST sites 1-5 into one large cluster. The second main cluster includes POST 7, 8, 9 and PRE 1, 2, 5, 6, 7, 8, and 9. The grouping of PRE and POST A horizons in both clusters indicates that though amended or reclaimed, some POST A horizons are still more closely related to certain PRE A horizons than to other reclaimed A horizons in the BSF.

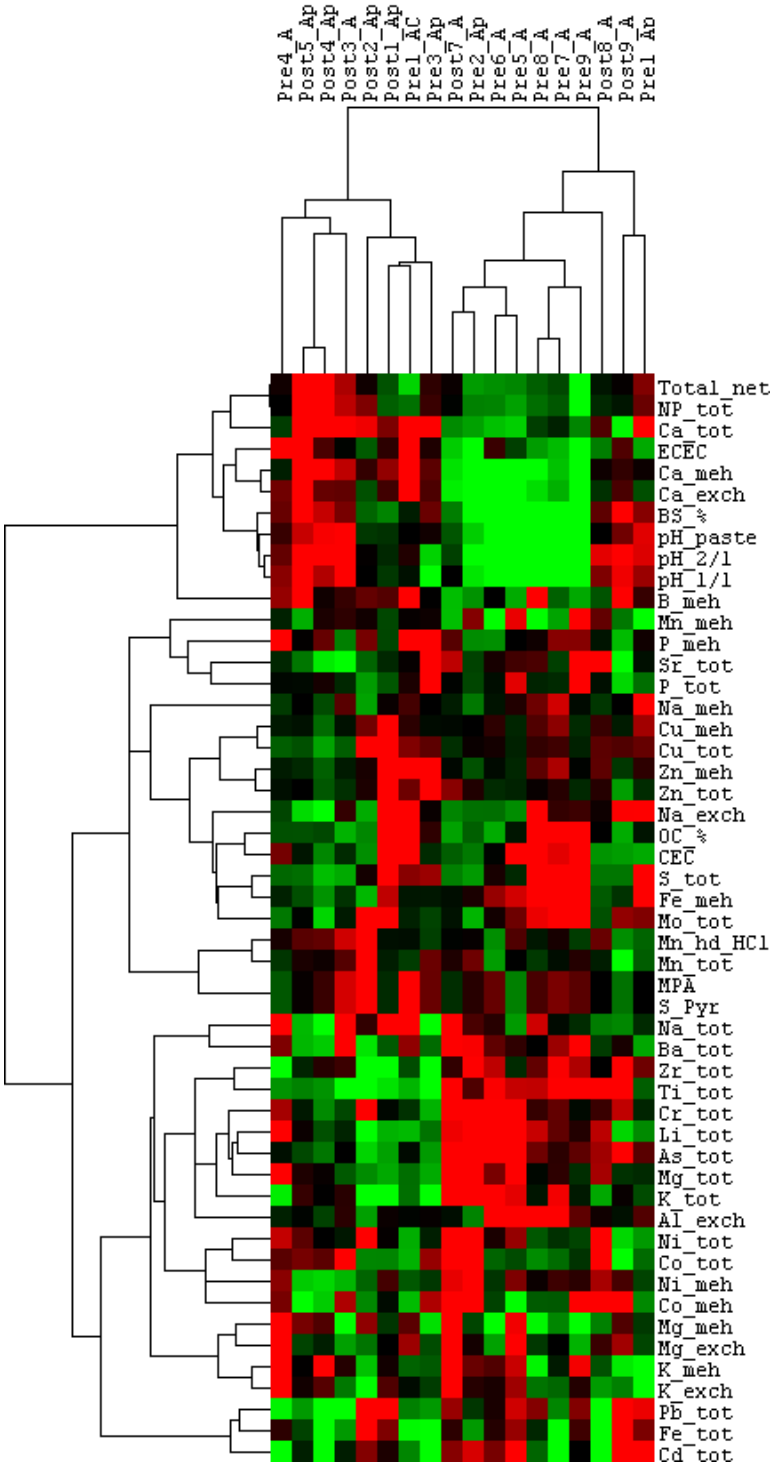


Figure 48. Hierarchical clustering analysis of pre- and post-SMCRA horizons joined by chemical properties.

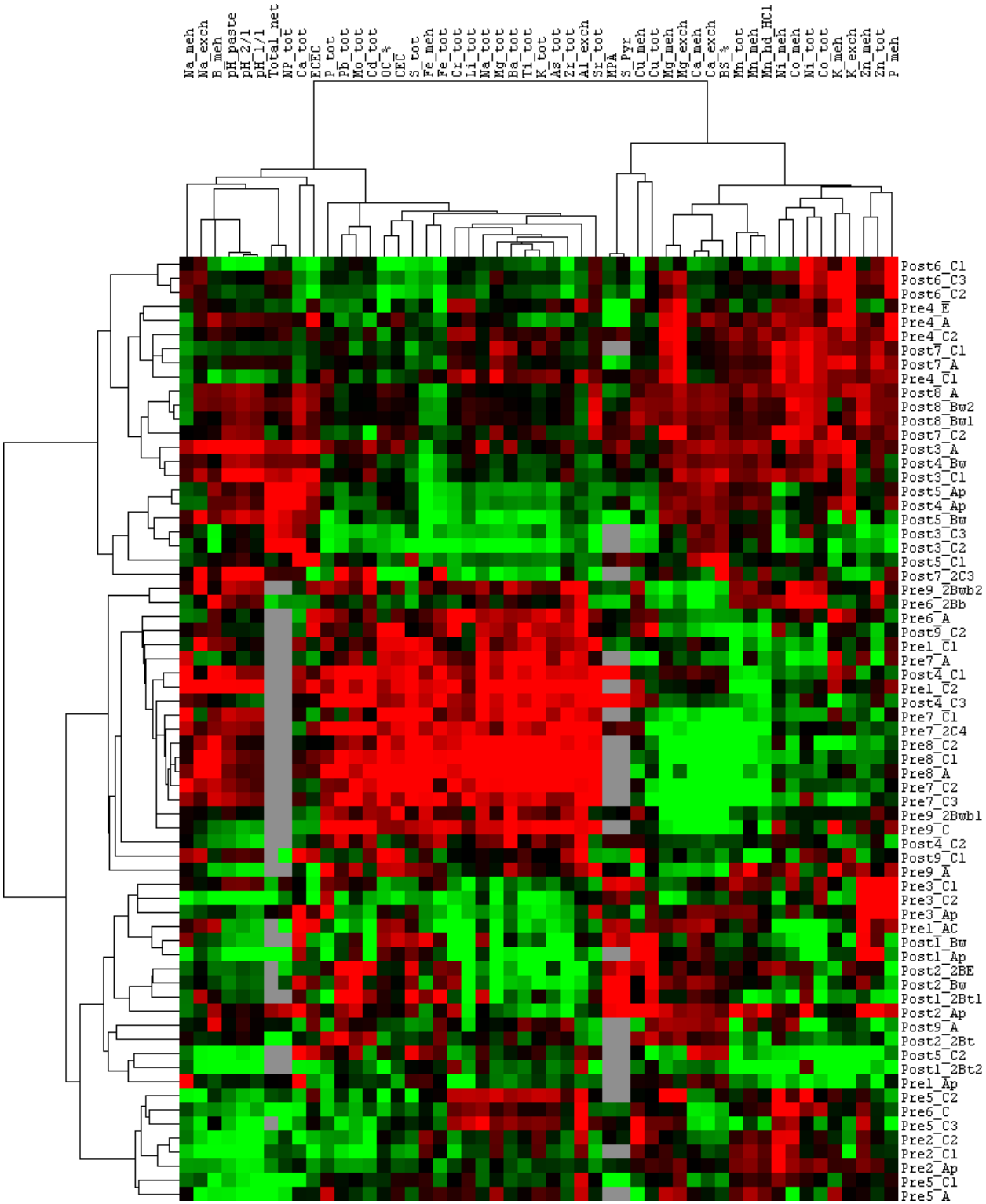


Figure 48. Continued. Hierarchical clustering analysis of pre- and post-SMCRA horizons joined by chemical properties.

The clusters showing the highest purity, or likelihood that all members of a cluster or subcluster really do belong to the same group (or are in essence truly alike for the properties tested), are the three down the center of the heat map. The level of purity is indicated by the high chroma of the squares within these clusters. The first of these high-purity subclusters is that containing POST 7 and PRE 2, 5-9, seen in a large grouping of green squares at the top of the chart. The A horizons from these sites appear to have relatively low values in the following properties: Mehlich I-extractable and exchangeable calcium, base saturation, and pH (1:1, 2:1, and paste). These sites are also quite similar in NNP, NP, and total calcium, although the chromas of many squares in these last four properties are not as rich.

Following this same cluster down, this largest subcluster splits into two more subclusters, one containing POST 7, PRE 2, 5, and 6 and the other containing PRE 7, 8, and 9. The first shares not only the properties listed above, but also has similarly high concentrations of total Ba, Zr, Ti, Cr, Li, As, Mg, K, and exchangeable-Al. This cluster seems to continue down to the bottom of the map to include total Ni, Co, Pb, Fe, and Cd, as well as Mehlich I- extractable Ni, Co, Mg, K, and exchangeable Mg and K. These, however, have many squares showing low chroma, meaning that these properties are not as similar between the members of this cluster as the other properties discussed with high chroma. The second subcluster with PRE 7-9 has high soil organic carbon, CEC, total S and Mo, and Mehlich I-Fe. These sites appear to have been split from the other subcluster to which it is linked due to lower concentrations of the metals and cations listed at the bottom of the map. The split in this cluster appears to be due to a difference in origination of the geologic materials of the minespoil piles. The subcluster with POST 7 and PRE 2, 5 and 6 had higher amounts of sandstone and shale rock fragments than the other subcluster, whose coarse fragments consisted almost entirely of black, high-C rocks.

The other main cluster is divided into two dominant subclusters, the first including PRE 4 and POST 3-5 and the second including PRE 1 and 3 and POST 1 and 2. These two clusters differed essentially in the same properties as the two subclusters discussed earlier, but with concentrations on opposite ends of the spectrum. For example, instead of having low pH and percent base saturation, these had high. These two subclusters differ from each other, however, in concentrations of Cu, Zn, SOC, total S, etc., as seen following the properties of these clusters down the map. This split is not unexpected, as the treatment of the sites within each of these subclusters is very different from one another. For example, POST 3, 4, and 5 all occurred on two of the largest reclamation areas sampled in this project. Extensive earth-moving, surface amendments, and revegatation efforts were made on these sites. It is not entirely unexpected that PRE 4 should occur in this group, as it has received anthropogenic amendments as well,

occurring directly beside a major trailhead at the Blue Herron Mining Camp. Further, the grouping of the other subcluster should not be entirely unexpected since the two POST sites only had surface amendments added and no extensive reclamation work completed and the two PRE sites have also had anthropogenic influences. As discussed earlier, pre-SMCRA profile site 1, located at the former Barthell mining community, has been affected by the construction of a parking area directly adjacent and pre-SMCRA profile site 3, occurring at the former Worley Mining Camp, has likely been affected by fertilization of the area surrounding a nearby parking area.

The second cluster analysis includes all horizons from the pre- and post-SMCRA profile sites and again includes all chemical properties measured in the lab. In this concentration map, there are two main clusters, but four dominant subclusters. The subcluster containing the two largest higher purity regions on the map (directly in the center) includes A, Bw, and C horizons from PRE sites 1, 6, 7, 8, and 9 along with C horizons from POST sites 4 and 9. These horizons share relatively higher concentrations of many of the trace element totals, along with SOC, CEC, total S and exchangeable-Al as well as similarly low concentrations of exchangeable and Mehlich I-extractable Ca and Mg, percent base saturation, Cu and Mn, along with several others properties as seen.

Again in this cluster analysis, pre-SMCRA profile site 4 was grouped with post-SMCRA sites 6, 7, and 8. Shared properties of the subsoils are similar to those of the surface horizons, including higher concentrations of exchangeable bases and base saturation as well as several total elements and Mehlich I-extractable phosphorus. The next subcluster down, occurring within the same main cluster, includes POST sites 3, 4, and 5, which were also grouped together in the first cluster analysis. As in just the surface horizons, these sites exhibit relatively higher pH, neutralization potential, and Na, and relatively lower concentrations of several trace elements, CEC, SOC, and total sulfur and aluminum. Again, these sites received extensive reclamation efforts, imparting these particular properties.

The last two subclusters in the second cluster analysis are not as tightly clustered as the previous two, with fewer and smaller high chroma areas mostly in green. The subcluster containing horizons from PRE 3 and 9 and POST 1, 2, and 9 have relatively lower pH, NNP, and concentrations of many trace elements but higher maximum potential acidity and pyritic sulfur. The final subcluster seen includes horizons from PRE 2 and 5, which showed high chroma correlations for lower pH, NNP, Ca, Pb, Mo, and Cd.

The hierarchical clustering analyses provided a quick and easy way to summarize all of the results discussed previously and indeed provided evidence for many of the previously drawn conclusions

concerning the similarities of some sites. Clustering has long been a tool of dividing data into meaningful groups for a wide variety of fields including psychology, biology, statistics, and the social sciences. In this project, as well as the first part of this study conducted by Blair (2009), clustering analysis has clearly demonstrated the relationships between many soil properties that are often taught but sometimes hard to synthesize. Blair (2009) used clustering to demonstrate the influence of parent materials and position within the landscape on the properties of a soil profile. In this project, differences amongst the sites receiving no reclamation and those which did can clearly be seen. Further, these concentration maps provide the National Park Service with a rapid glance at what reclamation efforts were not able to achieve and which pre-SMCRA sites may need reclaiming.

Conclusions

1. Thirty-three mine spoil piles and minesoils forming therein were located and mapped within the BSF park boundaries. An additional twelve mine openings were plotted using GPS as well.
2. Full minesoil profiles were exposed on eighteen sites and morphological properties were described in the field, according to the techniques of the National Cooperative Soil Survey handbook. Of the physical properties described, several were found to be statistically different between the pre-SMCRA profile sites and post-SMCRA profile sites (at p=0.05 unless otherwise stated).
    a. The average slope of pre-SMCRA sites was greater than post-SMCRA sites.
    b. The percent rock fragments in pre-SMCRA surface and subsurface horizons was greater than in post-SMCRA surface and subsurface horizons.
    c. The horizonation and development of pre-SMCRA profiles differed in general from post-SMCRA profiles. No pre-SMCRA sites had Bw and/or cambic horizons, while three post-SMCRA profiles did.
    d. Munsell values and chromas tended to be lower in pre-SMCRA horizons due to the presence of a greater quantity of coal fragments and high-carbon shales.
    e. The presence of roots was noted in many pre-SMCRA C horizons, while many post-SMCRA C horizons were highly compacted and no roots were noted.

3. The maximum potential acidity (MPA) was higher, net neutralization potential (NNP) was lower, and the paste pH was lower in pre-SMCRA surface horizons compared to post-SMCRA surface horizons, but none differed significantly in subsurface horizons. This suggests that reclamation efforts have not been successful at neutralizing the acid-production of minespoil materials.
4. The amount of soil organic carbon was significantly higher in pre- and post-SMCRA surface and subsurface horizons compared to native surface and subsurface horizons, but did not differ significantly compared to each other. This is a consequence of the presence of coal fragments and high-carbon shales in the minesoil profiles, which was not present in the native horizons.
5. Pre-SMCRA surface and subsurface horizons had lower pH than post-SMCRA horizons, but only differed from the native horizons in the subsurface. KCl-extractable aluminum followed the same trend.
6. Easily reducible manganese was found to be higher than native soils in several pre- and post-SMCRA surface and subsurface horizons.
7. Base saturation was higher in post-SMCRA sites compared to both pre-SMCRA and native profiles.
8. Mehlich-I extractable Ca, Fe, and Mg were different between PRE and POST surface horizons, and only Ca and Fe between PRE and POST subsurface horizons. Other than Fe between POST and native subsurface horizons, phosphorus was the only Mehlich-I nutrient that did not differ significantly between minesoil and native subsurface horizons. Minesoil subsurface horizons had significantly greater Ca, Cu, K, Mg, Mn, and Zn and significantly lower Na than native subsurface horizons.
9. There were few significant differences between the total elemental analysis of surface horizons (at $p=0.05$), however, a large number of differences occurred in the subsurface horizons between the PRE/native and POST/native comparisons. A few sites had relatively high levels of several metals including Cr, Cu, Mn, Ni, Pb, and Zn.
10. Hierarchical clustering analysis revealed many of the results discussed above and showed that many post-SMCRA horizons more closely resemble pre-SMCRA horizons, suggesting that reclamation efforts have not been completely successful in several cases.

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Part Two

Classifying Minesoils in the Big South Fork National River and Recreation Area

ABSTRACT

The physical and chemical properties of minesoils are of vital interest to future land users because their properties are unique compared to surrounding native soils. For many land planners, soil surveys provide the classifications of soils in a particular area, which are intended to provide important information about the properties of a given soil. For decades, however, land users have complained that classifications according to *Soil Taxonomy,* the classification scheme used in the US, of minesoils and other anthropogenically-altered soils are non-descript and do not reflect the unique properties of these soils. I

In Part Two, minesoils discovered in the BSF were classified according to the eleventh edition of *Keys to Soil Taxonomy* to judge how well the classifications described the soils. Further, the same minesoils were classified according to the recently proposed amendments to *Soil Taxonomy* by the International Committee of Anthropogenic Soils (ICOMANTH): several of the recommendations of this group have been accepted by the Soil Survey Staff and incorporated into *Soil Taxonomy* over the past several years. Because the goal of ICOMANTH is to, as seamlessly as possible, adjust *Soil Taxonomy* to include anthropogenically-altered soils in general, it was important to assess whether the amendments were suited to descriptively classify coal minesoils, which sprawl over large tracts of land in the US. Additional recommendations were made and the minesoils were again classified according to these recommendations. Compared to both the *Soil Taxonomy* and the ICOMANTH classifications, those according to the proposed additional amendments revealed more of the unique properties of the minesoils studied in this project. The results of this effort can provide ICOMANTH and the Soil Survey Staff with field validation of the proposed amendments and with suggestions for further improvement.

Introduction

Serving as the interface between the lithosphere, biosphere, and atmosphere, soils are environments capable of great stability as well as great change. The pedosphere, or soil, is defined in US *Soil Taxonomy* as:

> "a natural body comprised of solids (minerals and organic matter), liquid, and gases that occurs at the land surface, occupies space, and is characterized by one or both of the following: horizons, or layers, that are distinguishable from the initial material as a result of additions, losses, transfers, and transformations of energy and matter *or* the ability to support rooted plants in a natural environment (Soil Survey Staff, 2010)."

For introductory soil science students, soils are defined as being assemblies of natural bodies on areas of the Earth's surface that can support the growth of plant life and whose properties result from the interaction of the five soil forming factors, which are climate, biota, parent material, topography, and time (Jenny, 1941; Brady and Weil, 2008). The level of influence of any one of these factors varies from soil to soil, often within very small distances, leading to the existence of an infinite continuum of soil characteristics.

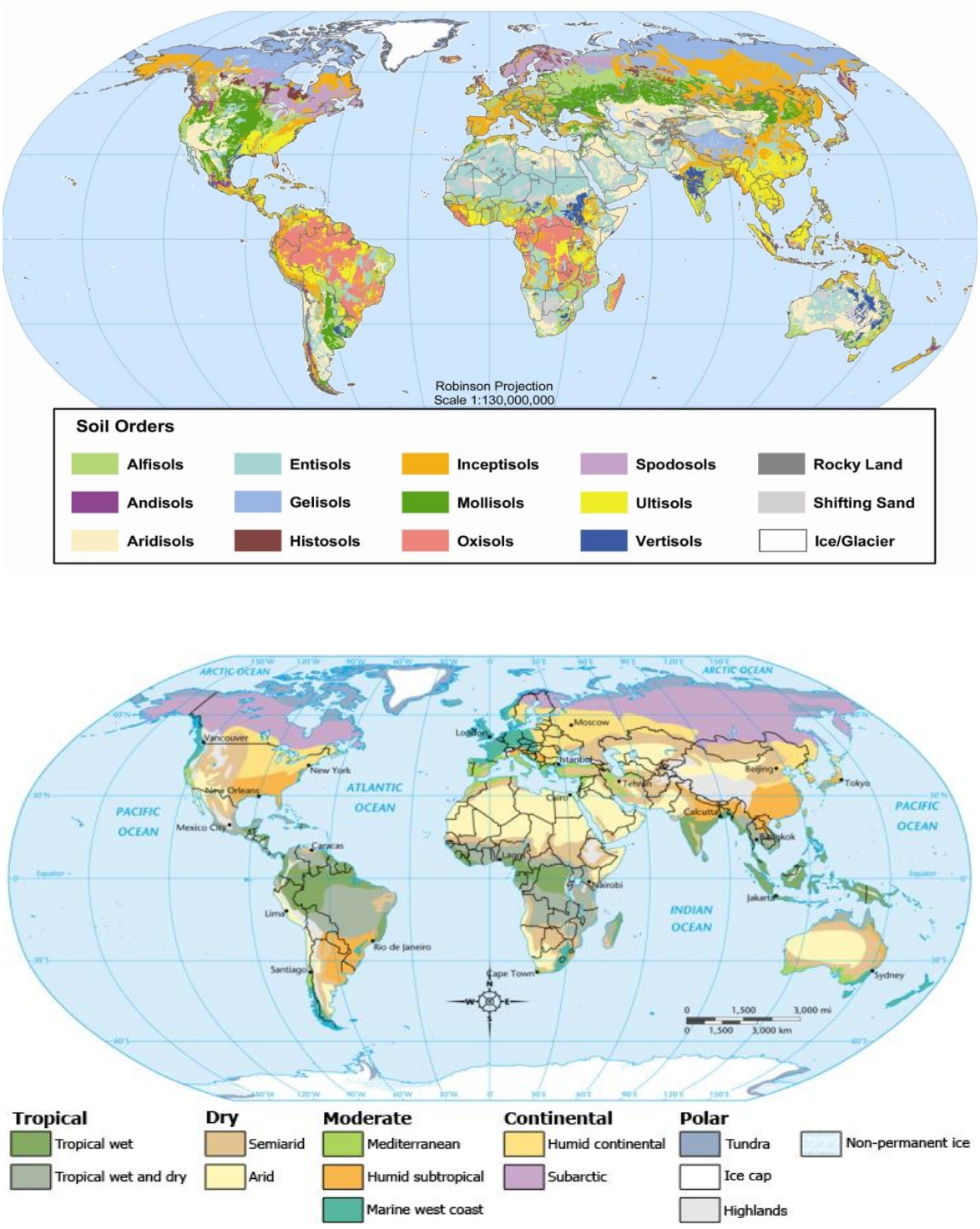
Parent materials as a soil forming factor refer to the type of geologic material from which a soil is developing. While there are three broad categories of rocks (igneous, sedimentary, and metamorphic), there are countless combinations of rock types, each with their own set of unique mineralogical and chemical properties which are imparted to soils forming therein (Buol et al., 2003; Sobek et al., 2000). Parent materials are separated into ten categories based on how they came to be situated in their current positions, including residual (formed in place from the weathering of underlying rocks), colluvial (transported by gravity downslope), alluvial (transported by water), or eolian (transported by wind) (Brady & Weil, 2008). The position of parent materials within the landscape can heavily influence the development of soil, serving as the foundation which shapes surface topography. Topography is the arrangement of the land surface in relation to slope, elevation, and landscape position. Relief has strong influence on the erosion potential and moisture content of a particular location (Buol et al., 2003). For example, steep slopes are more likely to have a high erosion potential, which in turn allows less infiltration into the soil. In most cases, soils forming on steep slopes will be

shallower with poorly developed profiles compared to more level locations. Topography also has marked influences on absorbance of solar energy, salt buildup, vegetation, and the interactions of parent materials in the process of soil formation (Brady & Weil, 2008).

Climate too has a significant impact on the nature of weathering that occurs on a local and global scale. The effects of precipitation, temperature, and sunlight on soil forming processes cannot be overstated. A map showing the global distribution of soils looks remarkably like one showing global climate regions, as seen in Figure 49. The type and amount of vegetation in a particular area depends greatly on temperature, which can increase or decrease organic matter accumulation- a key component in soil development. Water transports nutrients into and out of a soil body and makes the growth of plants and organisms possible. The fluctuations of the water table, as well as freeze-thaw or wet-dry cycles, facilitate many pedogenic processes (Buol et al., 2003). Solar radiation, or amount of energy from the sun adsorbed into the soil surface, effects soil temperature. Several properties are dependent upon soil temperature; for example, as soil temperatures increase, nitrogen and organic matter contents decrease (Jenny, 1941). Further, every 10° C rise in temperature doubles the rate of biochemical reactions (Brady & Weil, 2008). This directly affects another soil forming factor, biota.

Living organisms, or biota, have marked impacts on the rate of biochemical weathering, profile mixing, the buildup of organic matter, the cycling of nutrients, and aggregate stability in soils. As explained by Hans Jenny, an expert on the processes of soil formation in the United States, because of the interaction between the soil and organisms, they evolve together (Jenny, 1980). Small changes in the type and amount of vegetation present can cause large differences in the properties of the soils forming underneath. Microflora and fauna have profound impacts on soil development. Occurring in vast numbers and, depending on their environments, they can fix and transform nitrogen, make compounds that promote or restrain the growth of other organisms, stabilize and mobilize metallic ions and colloids, break down organic matter, and often act as the foundation of the food chain in soils (Buol et al., 2003).

Lastly, the soil forming factor time is the period through which the effects of the other factors are combined; time has highly inconsistent influences on pedogenesis at a global scale (Fanning & Fanning, 1989). Depending on the environment of a particular soil, “maturity”, or the point at which the properties of a profile are stable over time (meaning surface removal by erosion equals the break down of new parent material at the bottom of the profile), may take one hundred years in one location or one



*Sources: NRCS, 2005 (top) and Waitak, 2008 (bottom)

Figure 49. Global distribution of Soil Taxonomy soil orders (top) and global climate regions (bottom).

thousand years in another (Jenny, 1941). Nonetheless, it is agreed by the scientific community that time is required for soil formation, which in every case begins at "time zero", or the point in time "when a catastrophic event is completed and new material is exposed at the land surface, initiating a new cycle of soil development (Buol et al., 2003).

The interrelatedness of the five soil forming factors must be considered in order to understand the changes occurring in the soil continuum over the earth's surface. Understanding these changes has been attempted by mankind for thousands of years in order to better exploit all of the services provided by soils such as in the development of agriculture. Because every soil is unique, humans began grouping soils with similar properties.

Soil Classification in the United States

The earliest systems created to group soils with similar characteristics can be traced back to China around 4000 years ago, consisting of nine broad categories with descriptions such as yellow and soft, red and loose, muddy, and dark blue (Ping-Hua Lee, 1921; Wang Yun-sheng, 1979). In the late 18th and early 19th centuries, many new classification systems were developed around the world based on geology. The major developments in our understanding of soils during this period include (1) field methods that allowed the acceptance of soils as developing from underlying rocks and (2) that soils were created by the weathering of these rocks in place or by deposition of weathered rocks after being transported (Fanning & Fanning, 1989). One of the more comprehensive systems based on geology was that of Fallou in 1862 in Saxony. There were two broad classes: residual and sedimentary soils. The first was then divided into granite, limestone, and sandstone soils, etc. Subdivisions in the sedimentary class included gravelly, marly, and loamy soils, etc. Key here was that soil classification systems no longer needed to be based on their agricultural uses, an aspect common to many earlier systems (Fanning & Fanning, 1989). This method of soil classification was popular globally for another five or six decades and in fact became a major element in the classification system proposed by the soil survey program in the USA in 1899 (Coffey, 1912).

During this same time period in Russia, V.V. Dokuchaiev finally broke from the idea that soils were simply mantles of weathered rock and helped establish the field of pedology, which is the study of soil genesis, classification, and morphology (Eswaran et al., 2003). Dokuchaiev and his colleagues were the first to define soil as an "independent natural body which must not be mistaken for surface rocks

(Dokuchaiev, 1883)", and which is the result of intricate interactions between the five soil forming factors discussed above (Fanning & Fanning, 1989). This classification scheme, presented in the 1870s, was the first to be based on the genesis of soils, an idea that would not make its way into the US until several decades later. Soil classification in the United States is a relatively young science, dating back to the 1920s and a man working for the US Department of Agriculture, C.F. Marbut. He was one of the first scientists in the US to recognize the value of the work done by Dokuchaiev and one of his successors, K.D. Glinka, whose work expanded upon that of Dokuchaiev and other Russian soil scientists (Buol et al., 2003). In 1927, Marbut first presented his soil classification system at the International Congress of Soil Science in Washington. This system was composed of six categories: orders, suborders, great soil groups, families, series, and types.

After World War II, the US experienced a renewed interest in soil conservation and alternative land uses as a result of expanding global agricultural and economic markets (Eswaran et al., 2003). The zonal system being used in the US soil survey program needed to be redeveloped because of certain deficiencies within the system. These flaws included unclear definitions of classes, an overreliance on virgin soils in natural landscapes, too many theories of genesis and not enough of actual morphology, and the exclusion of some soils entirely from this system (Soil Survey Staff, 1960). According to the Soil Survey Staff concerning a classification system for US:

> "To be useful, definitions must be precise enough that different readers have approximately the same understanding of the meanings. Ideally, a definition of properties should be in such precise terms that every competent soil scientist, after making the necessary determinations, could know with assurance that the property did or did not exist in a given soil (Soil Survey Staff, 1960)".

The system of soil taxonomy presently being used in the United States was first presented in 1960 as *Soil Classification: A Comprehensive System- The 7th Approximation* by the Soil Survey Staff of the US Soil Conservation Service (now the Natural Resource Conservation Service, i.e. NRCS) under the leadership of Guy Smith (Eswaran et al., 2003). Over the next fifteen years, sweeping efforts were made to test and document the criteria lain out in this document and in 1975 a new edition was published as *Soil Taxonomy* to tackle initial shortcomings (Buol et al., 2003). There have been eleven editions since 1975, the last being published in 2010.

As stated by Eswaran et al. in 2003, the recognition that the factors of soil formation leave indicators in the forms of diagnostic horizons and features was possibly the greatest advance in the

science of soils. As described by Simonson (1968) in his general theory of soil genesis, the differentiation of soil horizons, after the deposition of parent materials, can be attributed to the following: (1) additions (e.g. additions of organic matter), (2) losses (e.g. the leaching of salts), (3) transfers within the soil (e.g. the illuviation of clay from the A to the B horizon), and (4) transformations (i.e. organic matter and mineral transformations).

Within the soil survey and classification programs in the US, a twofold system of distinguishing horizons and layers in soil profiles was established. Both methods are based upon the idea that the smallest sampling unit demonstrating the complete range of properties unique to a soil is called a *pedon*. Further, in a landscape, a soil unit is usually comprised of a group of similar pedons which are closely associated, called a *polypedon* (Brady & Weil, 2008). The first method is a detailed quantitative approach which reveals diagnostic horizons, epipedons, geologic properties, soil moisture regimes, etc. through specified field and laboratory observations and measurements as instructed in *Soil Taxonomy*, described later in more detail. The second uses more qualitative methods of defining horizon nomenclature, described as the ABC system, which is a kind of shorthand allowing prompt transmission of information about the genesis, morphology, and to a smaller extent, the classification of a soil. The current system used by the Soil Survey Staff in the US was initially modeled after the ABC system of nomenclature first published by Dokuchaiev for his descriptions of Russian Chernozems, although he admittedly designed his model after the work of Danish scientist Pierter D. Mueller (Tandarich et al., 2002). In this system, the A horizon was the first observed from the surface down and featured a consistent humus content, color, texture, and structure throughout. The B horizon was the second from the surface and essentially a transition from the A horizon to the C horizon. The C horizon was parent material unchanged by the soil forming factors (Nikiforoff, 1931).

In order to characterize a pedon in the field, a vertical exposure of the soil called a *profile* is observed or created and is the basic unit for studying soil. Next, the morphological properties of the profile are recorded. Soil morphology deals with the form, organization, and structure of the soil material. Chemical, physical, and mineralogical properties affect the composition of a soil material and are thus included in morphological descriptions, including: color, texture, structure, consistence, root quantity and size, boundary characteristics, horizon continuity, nodules or concretions, voids, and field pH (Buol et al., 2003). Once the morphological properties of a soil have been recorded, the horizons can be designated using standard nomenclature, which aides in the communication of soil properties from

one scientist to another (Buol et al., 2003). There are presently nine master horizons and layers in *Soil Taxonomy*, designated as the following:

- *O horizons*: organic soil material
- *L horizons*: limnic horizons or layers (used only in organic soils)
- *A horizons:* mineral soil materials darkened by and thoroughly mixed with humified organic matter; these can be at the soil surface or below an O horizon
- *E horizons:* mineral horizons leached of clay, iron, and aluminum, making the horizon lighter in color than those overlying and underlying; high concentrations of sand and silt sized particles; may not be present
- *B horizons:* mineral horizons forming below O, A, and/ or E horizons in which parent materials have been almost or completely broken down; and/or illuvial concentrations of silicate clay, iron, aluminum, carbonates, gypsum, or humus; and/or the removal of carbonates is evident; and/or there are either concentrations of sesquioxides or coatings of such that give the horizon lower value, higher chroma, or redder hue than overlying and underlying horizons with no evident illuviation of iron; and/or any combination of these
- *C horizons:* mineral horizons with little or no alteration by pedogenic processes; lack properties of O, A, E, or B horizons
- *R layers:* hard bedrock that underlies the horizons above and is not easily dug into with a spade
- *M layers:* root-limiting subsoil layers consisting of nearly continuous, horizontally oriented, human-manufactured materials
- *W layers:* layers of water in the soil that may be frozen or liquid (Buol et al., 2003; Brady & Weil, 2008; Soil Survey Staff, 2010).

Within master horizons, transitional horizons can be designated with a combination of capital letters, such as an AB horizon that would be more like the A than the B horizon but exhibiting properties of both. In order to more completely describe the master horizons, they are given one or more of twenty-seven possible subordinate distinctions. These are designated with lower case letters. One example could be a Bt horizon which indicates a B horizon with an accumulation of silicate clay coatings formed either by clay illuviation or movement within the horizon. Another example is a Bs, indicating an illuvial accumulation of sesquioxides and organic matter (Buol et al., 2003).

After field description and sampling of a soil profile, more quantitative determinations of properties can be determined in the laboratory. If classification of the soil is desired, specific procedures must be used, as described in *Soil Taxonomy*.

Soil Taxonomy

Taxonomy is the area of science devoted to finding, describing, naming, and classifying materials or organisms in order to understand relationships between them and the forces of their formation (Eswaran et al., 2003). The soil classification system which evolved in the US, unveiled in 1960, uses the characterization of diagnostic horizons and the presence of other soil properties to define taxa. Included in the list of desirable features of this classification system is the quantifiable identification of soil materials and horizons, meaning that some properties used to differentiate diagnostic horizons must be measured in a laboratory (Fanning & Fanning, 1989). This feature allows the comparison of one soil to another, making a soil's classification an important tool for communicating specific information about a soil (Eswaran et al., 2003).

Soil Taxonomy identifies diagnostic surface horizons called *epipedons* and diagnostic subsurface horizons. The epipedon is a horizon that develops near the surface in which the majority of parent material has been obliterated and there is evidence of eluviation or is darkened by humus. There are currently eight epipedons used in soil classification: anthropic, folistic, histic, melanic, mollic, ochric, plaggen, and umbric. Finer detail of these epipedons can be explored in *Keys to Soil Taxonomy* (Soil Survey Staff, 2010). There are nineteen diagnostic subsurface horizons that help form the building blocks of the US soil classification system. These horizons form below the surface of the soil, although they may be present directly beneath a cover of leaf litter. There are also many other diagnostic features that help define mineral soils, and others for organic soils, and still others for both mineral and organic soils.

In order to ascribe certain diagnostic properties to a soil, it is necessary to sample a site and conduct specific laboratory tests. Some commonly performed procedures include those for the following properties: cation exchange capacity (CEC), percent base saturation, exchangeable sodium percentage (ESP), pH, total organic matter or organic carbon, phosphate retention, particle-size analysis (PSA), bulk density, and soil moisture parameters, among others (Buol et al., 2003). The identification of the taxonomic class of a soil begins once all of the diagnostic properties have been extrapolated. The US system of soil classification presents a hierarchical assemblage of natural bodies of soil. Instead of being

based on the assumed mechanisms of soil formation, as was true in the past and in other countries, it is based on observable, measurable soil properties as they occur today. The genesis of a soil is not completely ignored however as it is the goal of this system to group soils of similar development (Brady & Weil, 2008). Nonetheless, the specific criteria used to classify soils into groups are those of recognizable properties.

There are six hierarchical categories of soil classification which, in descending order, are: (1) order, (2) suborder, (3) great group, (4) subgroup, (5) family, and (6) series. There are currently twelve soil orders: Alfisol, Andisol, Aridisol, Entisol, Gelisol, Histosol, Inceptisol, Mollisol, Oxisol, Spodosol, Ultisol, and Vertisol. The orders are separated based on properties reflecting the major processes of soil formation as they are understood today (Sumner, 2000). Essentially, the orders are different based on the degree of soil development observed. The existence, or lack thereof, of diagnostic horizons is hence given much emphasis. As discussed earlier, climate and topography have marked influences on the degree of weathering and development of a soil (Brady & Weil, 2008). There are sixty-four classes currently recognized at the suborder level. Suborders are separated within each order based on soil properties that are major controls on the soil-forming process. These properties include soil moisture, temperature, texture, and chemical properties, climate, wetness, vegetation, and the presence of diagnostic horizons. For example, an Ustalf is an Alfisol having an ustic soil moisture regime (Sumner, 2000).

At the great group level, around 300 classes are differentiated on the basis of soil horizons and soil features such as soil temperature or clay properties. In the case of the Ustalf from above, the suborder is divided into eight possible great groups, including for instance Natrustalfs, in which there is a natric horizon present (Soil Survey Staff, 2010). Great groups are further subdivided into more than 2400 subgroups classified on the basis of how well the soil represents the major characteristics or central concept of the great group. There are some intergrade subgroups which belong to one great group, but have some properties characteristic of another order, suborder, or great group. Here, a Vertic Torrifluvent represents a Torrifluvent that has some properties of a Vertisol. Extragrade subgroups are those that have properties which are not characteristic of the great group, but do not imply transitions to any other soil which is known. A Cryorthent, for example, in which bedrock that is strongly cemented that occurs within 50 cm of the soil surface is called a Lithic Cryorthent. A ‘typic’ member of the class does not define intergrades or extragrades (Eswaran et al., 2003; Sumner, 2000).

Soils within a family level of classification include those within a subgroup having additional properties that describe the parent materials or ambient conditions (Eswaran et al., 2003). Each family level name consists of a subgroup and three or more descriptive terms indicating particle-size class, mineralogy class (26), calcareous and reaction class (4), temperature class (8), and cation exchange activity class (4). In several families, the depth of soil (3 classes), rupture resistance (2 classes), and coatings or cracks (3 classes) are also included (Sumner, 2000). An example is a loamy (particle size), siliceous (mineralogy), subactive (cation exchange activity), mesic (soil temperature) Lithic Dystrudept (Soil Survey Staff, 2010).

There are more than 22,000 Official Soil Series Descriptions (OSDs) in the Natural Resources Conservation Service (NRCS) database with many more than that in actual existence (NRCS, 2010). Series' are those soils within a family that have additional properties which reflect comparatively small ranges of soil-forming factors and processes that depend on changes in the local physiography and that transform parent materials into soil (Eswaran et al., 2003). They typically have abstract names such as for places where the series is first described or the name of a city, county, or some other local feature.

One important feature used in the classification of soils according to *Soil Taxonomy* is the *control section*. Buol et al. (2003) describes the control section as an "arbitrary working rule, considered necessary to aid uniform soil classification". The control section is a segment of the soil profile stipulated in terms of specified depths within the family level of classification. In many soils, the control section is between 25 and 100 cm, but the depths can change based on the kind of soil as defined in *Soil Taxonomy*. The concept of the control section of a soil profile was desired within the US system of classification because it is not influenced by ordinary management practices (e.g. plowing and fertilization) and can therefore provide a volume of soil in which physical and chemical properties assumedly stay unchanged over a period of time.

Soil Taxonomy was initially intended as a tool for making and interpreting surveys of soils formed mostly under natural processes. Despite the fact that in its definition of soil, the USDA Soil Survey Staff (2010) recognizes that soils can be "modified or even made by man", the current classification system often does a poor job reflecting the true properties of soils altered by man. Anthropogenic soil-forming processes can be defined as those activities directed by humans that alter and control soil-forming processes, with humans acting not as a process in themselves, but as soil-forming factors (Pouyat & Effland, 1999). Soils heavily influenced or created by man, or anthropogenic soils, can be found on every major land mass, but mostly are found in places where humans have lived

for a long time, in areas of high population density, or in countries where large mechanical equipment is commonly used for constructive and destructive purposes. The three major land types of anthropogenic soils are transportation corridors, high-density residential, and mining areas. Although there is approximately 150 Mha of urban land, or 1% of the world's land surface area, and an equal amount of transportation corridors globally, "the major and minor surface mining of soil, rocks, and minerals is by far the most extensive anthropogenic process" (United States Central Intelligence Agency, 2000).

Surface mining for coal has drastically disturbed an estimated 4 million ha of land in the US alone. To begin surface mining, first the soil and rock covering the coal seam known as *overburden* is removed and stored. Large earth-moving equipment then exposes and extracts the coal seam. As much as half of the material initially extracted is composed of low-grade coals, high carbon shales, mudstones, and other various geologic strata that line the upper and lower portions of the coal seam; this is referred to as *coal mine refuse*. Mine refuse and overburden materials are collectively referred to as *mine spoil*, or simply *spoil*. After a surface mining operation ceases, the area which was mined becomes known as "disturbed land". This refers to land that has been disrupted by human activities at least to the depth of 1 m, with original surface materials becoming subsurface and vice versa. To use the terms of soil scientists, the pedologic clock is set back to "Time 0" (Jenny, 1941; Soil Surv. Staff, 1960), meaning that the weathering of surface and near-surface geologic materials has begun anew. The disturbed geologic materials start weathering often at an accelerated rate due to an increase in the surface area of the geologic fragments blasted apart upon extraction. Since the new surface is composed of materials which can be quite different physically and chemically from what was there before, the original landscape and ecosystem may take many decades (if ever) to return to a similar condition (Sencindiver and Ammons, 2000).

Once minespoil piles have undergone sufficient weathering to break rock fragments down into soil materials or after initial reclamation efforts including fertilization and seeding, they transition from being called mine spoils to being called *minesoils*. The difference here is that spoils are simply fragments of geologic materials, whereas soils accumulate organic matter, support the growth of plants, and serve to cycle nutrients (Daniels & Zipper, 2010). Because minesoils cover such a large portion of the global surface land area, being able to appropriately classify them for mapping purposes has become crucial to future land and resource managers. This is a problem however because minesoils have properties that can be very different from surrounding soils, often complicating their classification or lumping them into groups with native soils with disparate properties. Understanding the unique nature of minesoils is thus

vital to determine if their classification using *Soil Taxonomy* is descriptive and informative for the purposes needed. For the purposes of this project, coal minesoils in particular were examined.

Properties and Pedogenesis of Coal Minesoils

Coal minesoils are typically young and form from mixtures of soil and blasted rock fragments. The texture of minesoils varies with location on the landscape, often within short distances, depending on the type of parent materials from which they form. In many cases, a thin surface horizon is present that has a finer texture than subsurface horizons. A weak to moderate grade of structure, with granular or subangular blocky shape, is typically true of minesoils, even those which are very young (1 to 2 years). This suggests the enhanced speed of weathering that takes place in the waste materials of mining operations, a property which has been well documented in the literature. Soil development can often depend on the type of material left on the surface after mining and the extent of the reclamation efforts made (Sencindiver & Ammons, 2000; Haering et al., 2004).

Color mottling which is not caused by pedogenic horizonation is a common characteristic of minesoils (Smith and Sobek, 1978). This is often the result of different parent materials being deposited together (relic mottling) or can be caused by the sulfuricization of the parent materials as they weather (Fanning and Fanning, 1989). Sulfuricization is an important process of soil-formation in minesoils occurring from pyritic spoil materials. It is a process in which spoil minerals are weathered by sulfuric acid being produced by the oxidation of pyrite, and through dissolution, new mineral phases form. These are called acid sulfate soils and often have a very low pH, an accumulation of sulfate ions and cations, and mottles of precipitated yellow jarosite [$KFe_3(SO_4)_2(OH)_6$] (Sencindiver and Ammons, 2000). Dark colors occurring in subsurface horizons can be caused by high carbon rock fragments or fine coal materials. These coal fragments also create another common characteristic of minesoils, as described by Sobek et al. (1978): the irregular distribution of oxidizable organic carbon with depth. Minesoils typically have high rock fragment content (35 to 70%) when compared to surrounding native soils. Coarse fragments can be splintered on the edges and highly disordered, commonly creating bridging voids which can range from small to quite large in size (1mm to > 0.5m). Bridging voids are uncommon in undisturbed native soils (Sencindiver and Ammons, 2000).

The type of parent material, or the geologic material from which soil develops, as well as the rate of weathering have the heaviest influence on the chemical properties of minesoils (Sencindiver and

Ammons, 2000). In highly weathered, humid regions like the eastern US, it has been shown that overburden strata at or near the earth's surface are more highly weathered and oxidized than rock strata farther down in the geologic column (Smith and Sobek, 1978; Grube et al., 1982). Because this zone has been stripped of many nutrients important for plant growth, minesoils composed mostly of materials from this zone exhibit low fertility. Strata from deeper in the geologic column are unweathered and un-oxidized with chroma ≤ 2.5 (Sobek et al., 2000). Upon being brought to the surface and exposed to oxygen and water, unweathered materials from this zone begin to oxidize. If pyrite is present, oxidation can be problematic for reclamation efforts and for the local environment, commonly lowering the pH of minesoils to < 4 and sometimes to <2 (Mays & Bengston, 1978).

Spoil and overburden materials may contain sufficient acid-neutralizers to buffer minesoil pH; however, in some mining regions, this is commonly not true. This means an excess of oxidizable sulfur exists relative to neutralizers, creating a net acid production over time (Daniels & Stewart, 2000). The acid leachates formed as water moves through abandoned surface and deep mines as well as spoil materials is called acid mine drainage (AMD). AMD can cause pyritic minesoils to be much more acidic than a naturally forming acid soil environment. The pH of minesoils affected by AMD can range to values less than 2; whereas, naturally acidic soils rarely decrease below 4 (Essington, 2004). Under these extremely acidic conditions, many metals exhibit high solubility, potentially affecting biota in the soil surface and in local watersheds. Typically, mine drainage can contain high concentrations of Al, Fe, Mn, and SO_4, and the trace elements Cr, Cu, Ni, Se, and Zn. Most terrestrial plants and aquatic organisms cannot survive once the pH drops below 4.5. On mined lands, the concentrations of these elements can reach phytotoxic levels (Joost et al., 1983; Essington, 2004) and when coupled with extreme acidity and parent materials which lack important plant nutrients, reclamation of mined lands can be difficult.

These unique chemical and physical properties of minesoils must be taken into consideration when attempting to understand their weathering and soil-formation processes. Soil genesis is the portion of the field of pedology that conceptualizes the processes and features that produce the physical, chemical, and mineralogical properties of soils and their spatial distribution across various landscapes (Buol et al., 2003). Forming from similar pedogenic processes, many coal minesoils exhibit similar pedogenic and morphologic properties. Being relatively young soils, most minesoils exhibit A-C or A-AC-C horizonation. Ciolkosz et al. (1985) estimated that it takes 3 to 13 years for minesoils to form thin A horizons, even on most un-reclaimed sites. Roberts et al. (1988) described a 4-cm thick A horizon on a nontopsoiled 1-yr old minesoil and 6-cm thick A horizon on a 1-yr old topsoiled minesoil. When

comparing minesoils forming in similar parent materials, the length of time since disturbance is directly correlated to the depth of A horizons (Haering et al., 1993; Bini & Gaballo, 2006). When considering minesoils of similar age forming in different parent materials, however, other variables including type of parent material, position in the landscape, drainage (limited and excessive), success of reclamation efforts, and possibly other factors more strongly influence the depth of A horizons (Sencindiver & Ammons, 2000; Haering et al., 2004)

Several physical and chemical properties distinguish A horizons found in minesoils from the subsoils. On unreclaimed and reclaimed mine spoils (assuming phytotoxic metal concentrations have not accumulated and aridic conditions from excessive drainage have not arisen), the growth of roots loosens soil that may have been compacted during mining activities, reducing bulk density. Organic matter accumulates on the surface upon root litter decomposition, darkening the soil color. Moreover, structural development ranging from weak granular to weak subangular blocky has been described in A horizons of minesoils, depending on factors such as slope, rate of erosion, climate, etc. (Roberts et al., 1988; Haering et al., 2004). Due to more rapid weathering in the top 10 cm of the soil profile, organic-C content can match that of native soils within 30 to 50 years. This is not true in the subsurface, where hundreds of years may be required to reach comparable levels. Rock fragments also break down more quickly in the surface horizon, which usually exhibits a smaller rock fragment content that the subsoil horizons (Sencindiver & Ammons, 2000).

Minesoil horizons can vary from the relatively unweathered A-C-C horizonation to the development of cambic horizons, showing A-Bw-C horizonation (Roberts et al., 1988; Thomas et al., 2000; Haering et al., 2004). In several studies, weak Bw horizons were described, usually because of more evident structure, but failed to meet requirements to be cambic diagnostic horizons (Roberts et al., 1988; Haering et al., 1993, 2004). Cambic horizons were described by Daniels and Amos (1982) in minesoils forming in silty materials (15-20 yr old). In predominantly sandstone (>25%) spoil material, only A, AC, and C horizons have been described, although Bw horizons were observed in sand- and gravel-pit soils that met all requirements to be cambic except the texture (too coarse) (Sencindiver and Ammons, 2000). Discontinuities are also a common characteristic of minesoil profiles due either to the layering of different geologic materials or because of contact with native soil materials, resulting in horizonation such as A-2Cd-3C (Haering et al., 2004) and A-Bw1-Bw2-C-2Ab (Gaither et al., 1996), respectively.

Minesoil horizonation is often markedly different than nearby native soil horizonation due to the artificial resetting of the pedologic clock, with drastic disturbance by man making these young soils once more. When comparing native soil profiles to two 25-yr old minesoil profiles located in the same general areas, Thurman and Sencindiver (1986) found such differences. On the first site, the minesoil was described with A-C1-C2-C3 horizonation, while the native soil had A-BA-Bt-BC horizonation. On the second site, the minesoil horizonation was A-C1-C2 and the native soil horizonation was Ap-Bt-C. Similarly, Gaither et al. (1996) described two minesoil profiles with the following horizonations: A-Bw1-Bw2-C-2Ab and A-C1-C2-C3(L)-C3(R). The native profiles from areas nearby were drastically different: A-EB-Bt1-Bt2-BC-2Bt and A-BE-2Ab-3Bt. The lack of development can clearly be determined from such classifications. Their young age and unique properties cause coal minesoils to be classified differently than native soils which once existed and, because *Soil Taxonomy* was designed to describe natural soils, these classifications are often vague and not reflective of properties important for land use. The classification of these soils according to *Soil Taxonomy* has been highly debated for decades, with many different opinions from soil scientists concerning how to best contain them within this system.

Classification of Minesoils

There are presently several categories in *Soil Taxonomy* that distinguish anthropogenic soils from native soils, including those in the Arent suborder (result of deep plowing), those with Anthropic epipedons (formed during long continuous use by humans, either as a kitchen midden or a site for irrigated crops), and those soils with Plaggen epipedons (formed by continuous additions of manure and bedding for livestock). Agric diagnostic subsurface horizons (formed under cultivation with significant accumulations of illuvial silt, clay, and humus) and Anthraquic diagnostic conditions also separate certain anthropogenic soils from their native counterparts (Galbraith and Bryant, 1999). As in these examples, most of the remaining categories of anthropogenic soils describe agricultural soils or soils forming under agricultural processes.

Despite these inclusions, *Soil Taxonomy* is not currently equipped to accurately classify many anthropogenic soils, often resulting in these soils being oddly grouped with others that have very different characteristics or bear names that do not sufficiently describe their unique properties. For example, human-transported soils which contain or are forming in garbage, coal ash, construction debris, or mine spoil, etc. are grouped with naturally developing Entisols or Inceptisols at the subgroup

and even family levels, despite the recognized dissimilarities in their morphology and behavior (Hernandez & Galbraith, 1997; Sencindiver & Ammons, 2000). When members of a single group have greatly disparate characteristics, inherent weaknesses of *Soil Taxonomy* are revealed, considering that the purpose of the classification system is to group like soils for purposes of correlation, interpretation, and mapping (Bryant & Galbraith, 2003). Historically in the US, large areas have been incorrectly mapped or not mapped at all due to the lack of classes for anthropogenic soils and processes. Printed inside the Australian guide to soil classification it is noted that for natural sciences classification "serves as a framework for organizing our knowledge of natural systems including soils and provides a means of communication among scientists, and between scientists and users of the land" and therefore systems of classification need to be "revised periodically as knowledge increases" (Isbell, 1996).

Incorporating classes of anthropogenic soils into *Soil Taxonomy* is not as simple as it may be to incorporate them into other classification systems. In China, for example, classification is "process-based with descriptive morphology" as opposed to *Soil Taxonomy,* which is "morphology-based with implied process of formation" (Bryant & Galbraith, 2003). Process-based classification schemes emphasize the process of formation as the essential criteria for classification, thus adding soils created by anthropogenic processes as a separate order (Anthrosols) is not awkward. In *Soil Taxonomy,* however, morphology-based criteria are used for classification and although the process of soil formation is implied by the construct of the classes, using assumed knowledge of soil-forming processes is specifically avoided. This is problematic when attempting to incorporate anthropogenic soils into *Soil Taxonomy* within their own unique classes for several reasons.

Some anthropogenic soils may not bear morphological evidence of anthropogenic interference. Soils forming in mine spoil materials, for example, do have some morphological features that are unique and can be specifically related to the process of their formation; however, these features are not always present. Therefore, these features cannot be used to consistently separate these soils from native soils. Because features are inconsistent, it has been suggested that knowledge of historical land use, which usually exists for landscapes altered by humans, be allowed for classification of anthropogenic soils. This is highly debated however because it goes against the principles upon which *Soil Taxonomy* were founded. Further, reclamation of drastically disturbed lands often successfully results in reconstructed morphologies that fall into the technical description of Mollisols or other orders (Bryant & Galbraith, 2003), which is misleading when attempting to determine suitability of lands for specific purposes.

Many soil scientists have proposed changes to *Soil Taxonomy* in order to include various anthropogenic soils, some more drastic than others. The majority of these proposed changes fall within two categories. The first are those that introduce a new order for anthropogenic soils at the beginning of *Keys to Soil Taxonomy*, as is already seen in all other classification schemes that distinguish anthropogenic soil processes such as the World Reference Base (WRB) or in China. One such proposal in the US by Kosse (1988, 2001) involves the creation of a *Noosol* soil order to accommodate soils where anthropogeomorphic processes predominate. Kosse (2001) argues that all orders in *Soil Taxonomy* are constructed to reflect dominant pedogenic processes (or lack thereof) and that recognition of human-directed activities as highly-influential pedogenic processes would make separation of anthropogenic soils logical and consistent with taxonomy as it exists today.

Within the Noosol order, suborders would be distinguished by the type of noogenic soil material in which they are forming. *Noogenic materials* are defined by Kosse as soils that are the product of anthropogeomorphic processes and in most cases have not been extensively influenced by pedogenic processes. *Spolnos* for example would be the suborder into which minesoils forming in spoilic materials would fall. Anthropogenic soils forming in garbic materials would be in the *Sanos* suborder. Other noogenic soil materials proposed by Kosse are modeled after the subgroups proposed by Fanning and Fanning (1989) and several which are already used in the WRB classification of anthropogenic soils, and would include Garbic, Urbic, Dredgic, Spolic, Aric, and Technogenic. It is agreed by many soil scientists (Kosse, 2001; Bryant & Galbraith, 2003) that a separate order for anthropogenic soils would avoid the disturbance of existing classes and the creation of new classes throughout *Soil Taxonomy*. Nonetheless, many other (and some of the same) soil scientists agree that allowing the use of knowledge of the process of soil-formation cannot be allowed, even in one order, for *Soil Taxonomy* to maintain its original functionality.

The second category of proposed amendments centers on the creation of new suborders for various anthropogenic soils, including many for minesoil classification (Fanning & Fanning, 1989; Thurman et al., 1985). The addition of a new suborder of *Spolents* to the Entisol order has been proposed many times (Sencindiver, 1977; Sencindiver et al., 1978; Ammons & Sencindiver, 1990) since the late 1970's. This suborder would separate minesoils from other Orthents if they had three of the following nine properties: disordered rock fragments, color mottling not associated with horizonation, frayed edges on coarse fragments, bridging voids, local pockets of dissimilar materials, a thin surface horizon high in fines, artifacts, carbolithic coarse fragments, and irregular distribution of oxidizable

organic carbon with depth. Great groups of Spolents would be separated following the *Soil Taxonomy* soil moisture and temperature regimes, subgroups are separated by dominant lithology of the control section, and family classes distinguished by particle-size, mineralogy, soil reaction, and soil temperature, following those lain out in *Soil Taxonomy* (Sencindiver et al., 1978). Thurman and Sencindiver (1986) classified minesoils in West Virginia using the Spolent suborder and concluded that compared to *Soil Taxonomy* as it exists, the Spolent suborder aided in determining management related properties for general planning purposes. Further, Ammons and Sencindiver (1990) mapped minesoils in Missouri to the family level using the proposed Spolent amendment and found that it was effective at distinguishing and delineating the unique characteristics of minesoils when mapping or classifying.

This proposal, along with another well-known proposal to include several anthropogenic suborders within the Entisol order (Fanning & Fanning, 1989), while having the utility of distinguishing important management classes, has not been universally accepted because of the difficulties of separating some of these soils unambiguously from naturally occurring soils (Kosse, 2001). Also, minesoil series currently existing in the US (as of 2002) span not only the Entisol order (34 named series) but also are found in the Inceptisol (3 named series) and Mollisol orders (1 named series) (Galbraith, 2004). Likewise, it is unclear how many soil series of anthropogenic soils exist in total, but it likely safe to assume that they occur in just about every soil order (Eswaran et al., 2003). Limiting anthropogenic suborders to the Entisol order would leave certain anthropogenic soils in classes that do not describe their unique properties. While these types of proposals would certainly be expedient and would temporarily include most of the soils with drastic physical or hydrologic alteration, there would eventually be similar suborders added to almost all orders, or result in the addition of many suborders of Entisols (Bryant & Galbraith, 2003).

In order to address the need to accommodate anthropogenic soils in *Soil Taxonomy*, the International Committee on Anthropogenic Soils (ICOMANTH) was commissioned in 1995 to define appropriate classes that would improve understanding, classification, management, and interpretations of these soils. Included in this charge was the expectation that the introduction of anthropogenic soils into the US system should assist with mapping of urban areas, establish new materials and terms into the National Soil Information System (NASIS), simplify the creation and association of new soil series, and permit meaningful interpretations of unique soils and materials. From its inception, the committee confronted difficult questions which complicated the swift inclusion of anthropogenic soils into *Soil Taxonomy*, such as “how much difference in soil properties does it take before one recognizes

anthropogenic effects" and "under highly variable spatial and temporal soil conditions, how does one recognize and categorize the effects due to anthropogenic activities from those due to other non-anthropogenic impacts?" (Wilding & Ahrens, 2001). The committee composed seven circular letters and asked for input from soil scientists all over the world to suggest ways to minimize the impact of the incorporation of anthropogenic soils into our classification system.

Over the course of sixteen years, ICOMANTH has achieved several key changes to the eleventh edition of *Keys of Soil Taxonomy*. In *Chapter 18: Designations for Horizons and Layers*, the "M layer" was added to represent "root-limiting subsoil layers consisting of nearly continuous, horizontally-oriented, human-manufactured materials" in the soil descriptions of anthropogenic soils containing man-made materials. Based on proposals made by ICOMANTH, the suffix symbol "u" was added to indicate the "presence of human-manufactured materials (artifacts)" to help identify anthropogenically altered soil horizons, providing examples of artifacts such as "processed wood products, liquid petroleum products, coal combustion by-products, asphalt, fibers and fabrics, bricks, cinder blocks, concrete, plastic, glass, rubber, paper, cardboard, iron and steel, altered metals and minerals, sanitary and medical waste, garbage, and landfill waste" (Soil Survey Staff, 2010). Finally, the caret (^) symbol was added to be used as a prefix to master horizon designations in order to indicate human-transported materials (HTM) in either mineral or organic soils. This would make the presence of HTM obvious in the profile descriptions of anthropogenically altered soils.

These small changes however do not address the larger issues of classification of these anthropogenic soils, such as minesoils. The seventh and final ICOMANTH circular letter presented the committees' final list of proposed amendments to the twelfth edition of *Keys to Soil Taxonomy* which would add new diagnostic materials, characteristics, and terms at the subgroup and family levels. As expressly stated, the intent is to alter the current system using a "bottom-up" approach (Galbraith, 2011). According to this circular, using a "top-down" approach, such as those proposing to add a new soil order, establishing new series within that order would be complicated and drawn out. This is because lengthy reviews and supportive data must be gathered to justify the creation of new taxa to accommodate these series. The bottom-up approach would supposedly allow the creation of new choices in family classes which would differentiate urban and rural landscapes, etc., but keep the creation of new taxa in taxonomy to a minimum. Also this approach would seemingly protect existing taxa and/or concepts at higher levels, therefore avoiding the splitting of existing series and concepts. The extensive list of proposed amendments in the *7th Circular Letter* would affect every chapter and

every soil order (Appendix A). A short synopsis of the proposal includes the following, as quoted from the letter:

- "Soil series in the USDA-NRCS soil classification database reveal that established and tentative series exist in only a few taxa set up for HAHT [human-altered and human-transported] soils, primarily in Arents suborder. The Torriarents and Xerarents are deeply plowed agricultural soils, while Ustarents and Udarents form in mine or dredge soil. Arents group soils that have little in common. This proposal would move those soils to a subgroup and family level of recognition but preserve their concepts, limits, and use on existing maps.
- There are other minesoils in the Udorthents great group, many in the Typic subgroup. Series from urban surveys are tentatively set up as Typic Udorthents or Typic Dystrudepts. These proposals will allow specificity and narrow interpretation groups.
- There are HAHT soils that fit existing criteria for epipedons that they were not intended to qualify for. Proposed revisions will make the epipedons other than plaggen and anthropic exclusive of HAHT materials. The definition of the *anthropic* epipedon has been revised, but it is too broadly defined. Rather than adding four new types of anthropic epipedons, and causing revisions in existing keys, high and low carbon varieties can be recognized at subgroup levels.
- Many HAHT soils are recently altered and have buried horizons and irregular decreases in organic carbon with depth. The criteria that would lead to identification in Fluvents suborder, Fluventic, and Cumulic subgroups have been modified to prevent misleading inclusion with water-transported materials.
- New materials and characteristics are proposed for chapter 3, a major modification to the definition of buried soils, a new family class, and a standard set of subgroups are proposed that easily identify soils as HAHT" (Galbraith, 2011).

While many of the proposed amendments to *Soil Taxonomy* will have a significant effect on how minesoils (and all anthropogenic) soils are grouped and on maintaining the purity of the concepts

Table 17. Definitions of terms to be added to *Soil Taxonomy*, as proposed by ICOMANTH.

Term	Definition
Artifact	Artifacts (L. *arte,* by skill, and *factum,* to do or make) are materials created, modified, or transported from their source by humans usually for a practical purpose in habitation, manufacturing, excavation, or construction activities. Examples of artifacts include: treated and untreated wood products, liquid petroleum products, coal combustion by-products, asphalt, fibers and fabrics, bricks, cinder blocks, concrete, plastic, glass, rubber, paper and cardboard, iron and steel, altered metals and minerals, sanitary and medical waste, garbage, and landfill waste.
Human-altered material	Human-altered material (L. *humanus,* human, and *alter,* to change) is parent material for organic or mineral soil materials that have either been deeply-mixed in-place, excavated from a pedon and replaced by directed human activity, or truncated by removal of the surface soil or more. These soils may have a surface deposit of human-transported material (defined below).Many intentionally-leveled human-altered soils occur in irrigated fields. Because the soil may have been mixed deeper than all diagnostic horizons, characteristics or features (differentiae), it may be difficult to identify the human activity. However, tracing the landform laterally will reveal abrupt edges, and the leveled landform typically has geometric or linear shapes and boundaries. Tracing soil properties laterally across the landform boundary reveals abruptly contrasting materials, differentiae, or horizons at matching depths. Truncation of soil from a landform creates distinct destructive anthropogenic landforms or microfeatures, as described in ad hoc proposal to amend the National Soil Survey Handbook, 2008. Part 629: Glossary of Landform and Geologic Terms (e.g., ditches, excavated part of hillslope terraces, or leveled recreation fields). Truncated human-altered soils are composed of organic or mineral soil materials and often identified by their altered landform, absence of surface horizons, and abrupt lateral changes at the landform edge. They often contain artifacts in layers that have been moved and then replaced, and the replacement soil has an abrupt contact with the in-situ materials. Tracing the destructional landform laterally reveals an abrupt end to horizon occurrence, abrupt changes in slope, or boundary by walls, and the landform typically has geometric or linear shapes and boundaries. All of this evidence identifies profound intentional human activity and alteration. Therefore it is often the preponderance of evidence along with published or historical evidence and on-site observations that allows the most consistent identification of truncated human-altered material.
Human-transported material	Human-transported material (L. *humanus,* human, and *trans,* across, and *porto,* to carry) is parent material for soils that has been excavated from a pedon, and either mixed and replaced by directed human activity, or moved horizontally onto a pedon from a source area outside of that pedon by directed human activity, usually with the aid of machinery or hand tools. In some cases it is not possible to distinguish burial of human occupied sites and human-transported material by catastrophic or long-term erosion events without intensive on-site examination and analysis. In most cases, these characteristics do not include those that normally occur in a recently-deposited (Holocene age) alluvial, colluvial, eolian, or mass-wasting deposit. Human-transported material is composed of organic or mineral soil materials and, often contains fragments of diagnostic horizons, and may also contain artifacts such as concrete. Human-transported material often contains a lithologic discontinuity or a buried genetic horizon located beneath an individual deposit, although those properties do not diagnose the material above them as being transported by humans. Caution should be taken in several cases, where combinations of human actions and natural processes make it difficult to identify material as human-transported. Examples include material deposited by dredging adjacent to active beaches, human littering in floodplains, and where deposits from catastrophic events cover anthropogenic features (e.g., volcanic ash covering houses). Therefore it is often the preponderance of evidence along with published or historical evidence and on-site observations that allows identification.
Manufactured Layer	Manufactured layers are relatively unaltered, root-limiting layers beneath the soil surface consisting of nearly continuous, human-manufactured materials whose purpose is to form an impervious barrier. The materials used to make the layer impervious include geotextile liners, asphalt, concrete, rubber, and plastic. They are designated by the capital-letter symbol M. The presence of these materials can be used to differentiate soil series.

Table 17. Continued. Definitions of terms to be added to *Soil Taxonomy,* as proposed by ICOMANTH.

Term	Definition
Manufactured layer contact	A manufactured layer contact (L. *humanus* of or belonging to man, and *factum*, to do or make) is an abrupt contact between soil and a manufactured layer (defined above) used to form an impervious barrier. It has no cracks, or the spacing of cracks that roots can enter is 10 cm or more.
Surface mantle of new soil material	A surface mantle of new soil material is largely unaltered, at least in the lower part. A surface mantle of new soil material displays the following properties: 1. A diagnostic surface horizon (epipedon) *or* no diagnostic surface horizon; *and* 2. diagnostic subsurface horizons other than a cambic horizon; *and*, 3. A zone 7.5 cm or more thick that fails the requirements for all diagnostic horizons overlying a horizon sequence that can be clearly identified as the solum of a buried soil in at least half of each pedon. The recognition of a surface mantle of new soil material should not be based only on studies of associated soils. Buried soils may be partially identified by the presence of human-transported materials or an anthropogenic landform or microfeature such as a locally raised (constructional) or lowered (destructional) surface (e.g., a levee or a pit) as described in the ad hoc proposal to amend the National Soil Survey Handbook, 2008. *Part 629:* Glossary of Landform and Geologic Terms, or a map unit or landscape unit with geometric or artistic shape (e.g., effigy mounds).

*Copied from Galbraith, 2011.

initially intended, perhaps the most drastic changes proposed are those listed last in the synopsis above. As explained, the definitions of new materials are to be added, as seen in Table 17 (requirements for each new term can be found in Appendix A).

The additions of “human-altered” and “human-transported” materials are used to keep certain anthropogenically-influenced epipedons from being designated mollic or umbric. The original intent of designating a mollic epipedon, for example, was to identify a thick accumulation of organic matter rich in calcium which formed mostly from the dense root systems of grasses on a prairie landscape. Many coal minesoils meet the requirements of mollic or umbric epipedons, characterized by dark colors and high organic carbon, due to the presence of weathered carbonaceous spoil materials. The proposed amendments require that no artifacts be present to qualify as mollic or umbric and that the soils are not forming in HAHT materials. This forces the diagnosis of an ochric epipedon, keeping many coal minesoils from being classified in the Mollisol order, as seen in the *Conquista* series where a minesoil is classified as an Entic Haplustoll (National Cooperative Soil Survey, 2010).

Another change that is intended to improve the classification of many minesoils is the removal of the *Arents* suborder, which was originally included to separate very deeply plowed soils where

structure is destroyed and the profile often inverted and highly mixed with discernible fragments of former diagnostic horizons. As explained in the *7th Circular Letter,* the creation of a suborder that reflects a common soil-forming process (human activity) as opposed to a major property is unprecedented. Further, there are presently several minesoils classified in this suborder which contains four great groups: Ustarents, Udarents, Xerarents, and Torriarents. All of the series occurring as Xerarents and Torriarents are agricultural soils deeply mixed in place. Yet those series established in the Udarent and Ustarent great groups are all forming in human-transported materials, especially mine spoil, as in the Lenzburg series found in Illonois, Kentucky, and Ohio (National Cooperative Soil Survey, 2006).

Another diagnostic criterion that is problematic in the classification of minesoils and other anthropogenic soils is the irregular decrease of organic carbon with depth. This characteristic occurs naturally in young soils and floodplain soils and thus places those soils with this carbon requirement, a slope less than 25%, and soil temperature regime warmer than cryic into the *Fluvent* or *Fluvaquent* suborder or great group. Soils forming in HAHT materials often consist of well-mixed refuse and overburden materials or are reconstructed by the selective placement of materials on an anthropogeomorphic landscape. This can create an irregular distribution of organic carbon not only because the soils are young, but also because high-carbon materials are mixed throughout the profile. If the slope is reconstructed to be < 25%, these minesoils become classified as floodplain soils. This is often confusing and misleading to land and resource managers, as the properties of naturally-forming floodplain soils are very different from minesoils. In order to address this problem, ICOMANTH has proposed to add exclusionary statements to the Fluvent and Fluvaquent classes to keep buried soils with more than 50 cm of human-transported materials in the surface and subsurface, or that occur on an anthropogenic landform or microfeature (as described in the ad hoc proposal to amend National Soil Survey Handbook, *Part 629:* Glossary of Landform and Geologic Terms) from being grouped with naturally forming soils (Galbraith, 2011).

Perhaps the most significant additions proposed by the soil scientists of ICOMANTH are five new subgroups to be added throughout *Soil Taxonomy* meant to distinguish groups of HAHT soils. According to the *7th Circular Letter*, individuals working with soils on Anthropogenic landforms have requested for some time the separation of anthropogenically-modified soils from native soils due to their recognizable and distinct physical and chemical properties. The new subgroups and their descriptions can be seen in

Table 18. Additional extragrade subgroups to add throughout Soil Taxonomy, as proposed by ICOMANTH.

New Subgroup	Required Properties
Anthraltic (from Gr. *Anthropos*, Human and L. *alterāre*, to change)	Has, in one or more layers at a depth between 25 and 100 cm below the mineral soil surface, 3 percent or more (by volume) fragments of diagnostic horizons that are not arranged in any discernible order; or formed in 50 cm or more of human-altered material. These are used for human-altered material for subgroups of Entisols that were formerly Arents where deep plowing has destroyed former diagnostic horizons, but could be used for any human-altered material. NOTE: Thickness is subgroup specific. If the epipedon meets the meets the color and carbon requirements of the mollic or umbric epipedon throughout, the term Humic is added as well.
Anthraquic	"Other _____ that have anthraquic conditions." (These already exist in 11 subgroups but are not populated by soil series). They are surely extensive, and they are either human-altered or human-transported material or both. NOTE: Thickness is generally 50 cm or more but should be subgroup specific. If the epipedon meets the meets the color and carbon requirements of the mollic or umbric epipedon throughout, the term Humic is added as well.
Anthroportic (from Gr. *Anthropos* Human and L. *portāre* to carry)	Has, in one or more layers at a depth between 25 and 100 cm below the mineral soil surface, 3 percent or more (by volume) fragments of diagnostic horizons that are not arranged in any discernible order; or formed in 50 cm or more of human-transported material. These are used for human-transported material of dredged or mine spoil soil series that were formerly Arents, but could be used for any human-transported material. NOTE: Thickness is generally 50 cm or more but should be subgroup specific. If the epipedon meets the meets the color and carbon requirements of the mollic or umbric epipedon throughout, the term Humic is added as well.
Plaggic	"….have an plaggen epipedon." (The plaggen epipedon already exists)
Plagghaplic (Ger. plaggen, sod and Gr. haplos, simple.)	"….have a surface horizon 25 cm to 50cm thick that meets all of the requirements for a plaggen epipedon except thickness." (This concept already exists as the Plagganthreptic subgroups of Entisols and Spodosols.

*Copied from Galbraith, 2011.

Table 18. It is stated that these additional subgroups are to be added as series and are created so as not to overload every great group with unnecessary taxa. Although there are many more than five types of HAHT materials, ICOMANTH hopes these five will suffice for separation from naturally-forming soils at the subgroup level. Finer distinctions between types of HAHT soils are to be made at the family level.

In order to constrict the number of additional taxa for anthropogenically-modified soils at higher levels of classification, ICOMANTH suggests that for the purposes of mapping and interpretation, separation at the family level of classification is sufficient. Because there are so many different kinds of HAHT materials, an ongoing effort is being made by the USDA-NRCS and SUITMA group (Soils of Urban, Industrial, Traffic, Mining, and Military Areas) to help define classes of materials and possible properties (e.g. density or porosity) that can be used to further classify anthropogenic soils, to be added to *Soil Taxonomy* at some time in the future. For the time being, ICOMANTH is proposing the addition of "Human-altered and human-transported material" family classes, which are intended to be used only for soils occurring in HAHT materials or those classified under one of the five added subgroups discussed previously. For all other taxa, this class would remain omitted and the type of material would be distinguished at the soil series level. The currently proposed HAHT Material Classes can be seen in Table 19.

While the proposed amendments presented by ICOMANTH may seem elaborate compared to the short proposals made previously attempting to adjust only one order or suborder, their efforts have not gone unnoticed in the past. In fact, ICOMANTH has already played a large role in the adjustment of *Soil Taxonomy* for the inclusion of anthropogenic soils to date, as discussed previously. It is because this group has been so influential that a thorough analysis and real-world application of their proposals is necessary to make certain that all anthropogenic soils have a place in the new system were the amendments to be adopted. For the purposes of completing a thorough physical and chemical characterization of coal minesoils in the Big South Fork National River and Recreation Area (BSF) in the first half of this study, nine pre-SMCRA and nine post-SMCRA minesoil profiles were described and analyzed.

The first objective of this study is to classify eighteen coal minesoil profiles from the BSF according to *Soil Taxonomy* as it currently exists (Soil Survey Staff, 2010) with the aim of determining if and when soils are grouped with other soils that have very different properties; in other words, discovering where *Soil Taxonomy* fails to accurately describe minesoils. The second objective is to further classify the same soils using all of the amendments proposed by ICOMANTH (Galbraith, 2011). By

Table 19. Key to Human-altered and Human-transported Materials Classes, as proposed by ICOMANTH.

Family Class	Key
Methanogenic	Detectible evolution of methane from the decomposition of nonpersistant artifacts, such as garbage or other buried waste products, and which is easily detectable by its odor or readily observed by the collection and/or burning of methane gas,
	Or-
Subsidic	More than 35 percent (by volume) artifacts that are likely to decompose and cause subsidence in the soil within a realm of one hundred years from the time of burial under the current or projected effective soil climate conditions and that have diameters of 2.0 mm or more *and* at least an extremely weakly cemented rupture-resistance class,
	Or-
Spoliwastic	More than 10 percent (by volume) of garbage, waste, and debris deposited in landfills, usually mixed with and covered by earthen materials. (Comment: Middle English *spoile*, earth and rock excavated and Latin *vastus,* waste),
	Or-
Asphaltic	More than 35 percent (by volume) artifacts of asphalt that have diameters of 2.0 mm or more *and* an extremely weakly cemented to indurated rupture-resistance class,
	Or-
Concretic	More than 35 percent (by volume) artifacts of concrete that have diameters of 2.0 mm or more *and* an extremely weakly cemented to indurated rupture-resistance class,
	Or-
Gypsifactic	More than 40 percent (by weight) artifacts of synthetic gypsum products such as flue gas desulfurization gypsum, phosphogypsum, or fluorogypsum (e.g., drywall or plaster) in the fine-earth fraction,
	Or-
Combustic	More than 35 percent (by volume) artifacts of clinker and non-combustible residues of coal combustion with diameters of 2 to 75 mm,
	Or-
Ashifactic	More than 40 percent (by weight) artifacts of light-weight combustion byproducts (e.g., fly ash) in the fine-earth fraction,
	Or-
Pyrocarbonic	More than 40 percent (by weight) artifacts of products produced by pyrolysis (e.g., coke or biochar) in the fine-earth fraction,
	Or-
Aquadensic	More than 85 percent of the pedon (measured laterally) has a densic contact (e.g., a compacted mine spoil) and aquic conditions within 50 cm of the soil surface,
	Or-
Anthrodensic	More than 85 percent of the pedon (measured laterally) has a densic contact (e.g., a compacted mine spoil) within 50 cm of the soil surface, *Or*-

Table 19. Continued. Key to Human-altered and Human-transported Material Classes, as proposed by ICOMANTH.

Family Class	Key
Multiartifactic	More than 90 percent (by volume) innocuous artifacts that have diameters of 2.0 mm or more *and* at least an extremely weakly cemented rupture-resistance class,
	Or-
Medioartifactic	More than 35 percent (by volume) innocuous artifacts that have diameters of 2.0 mm or more *and* at least an extremely weakly cemented rupture-resistance class,
	Or-
Pauciartifactic	More than 10 percent (by volume) innocuous artifacts that have diameters of 2.0 mm or more *and* at least an extremely weakly cemented rupture-resistance class,
	Or-
Hypodensic	More than 85 percent of the pedon (measured laterally) has a densic contact between 50 and 100 cm of the soil surface in human-altered or human-transported material,
	Or-
Araric	More than 3 percent (by volume) of recognizable fragments of diagnostic horizons arranged in a non-discernable order due to deep-plowing of soils to a depth of at least 100 cm below the soil surface. (Comment: from L. *arāre,* to plow),
	Or-
Dredgic	More than 50 percent of the thickness (finely-stratified [less than 5 cm thick] human-transported, water-deposited sediment (e.g., dredged or irrigated) in the fine-earth fraction,
	Or-
Spolic	Other soils formed in human-transported material. (Comment: Middle English *spoile*, earth and rock excavated),
	Or-
	All other soils: No human-altered or human-transported material classes used.

*Copied from Galbraith, 2011.

doing this we can either validate changes that lead to more informative classifications of these minesoils or reject those that may introduce weaknesses in the classification scheme. The third objective is tomake additional proposals to the ICOMANTH amendments if shortcomings are found in either *Soil Taxonomy* or in the classifications of minesoils according to the ICOMANTH proposals. This will save individuals working with soil survey maps and software time and money in the future, as further efforts to adjust existing soil series for the incorporation of anthropogenic soils can be minimized.

Materials and Methods

Site Selection

All sampling sites were located in the Big South Fork National River and Recreation Area (BSF) either in the Nevelsville and Barthell Kentucky Topographic Quadrangles or the Barthell SW and Honey Creek Tennessee Topographic Quadrangles. Old mining roads and rail lines were located using park maps and aerial photographs (National Park Service, 2009) and with the personal knowledge of the park's Wildlife Biologist, areas where mine spoils were likely to be located were identified. Either on foot or on a John Deere 6 x 4 Gator ATV, collapsed and gated mine entrances were located and the surrounding areas physically searched for signs of spoil material.

Field Methods

Latitude and longitude for each site were recorded using a GPS unit. Samples of soil material as well as rock fragments less than 7 cm in size were collected from each horizon from selected minesoil sites. Soil morphology was completed according to National Cooperative Soil Survey standards (Soil Survey, 1993). Field notes included: horizon designation, depth, estimated rock fragment content, boundary distinctness, Munsell color, texture, structure, presence of redoximorphic features, presence of roots and pores, and presence of clay skins. Slope, aspect, vegetation, elevation, landscape position, and other site characteristics were also recorded (Schoeneberger, 2002).

Laboratory Methods

The samples were air-dried and sieved to less than 2 mm. Coarse fragments were separated and stored for further analysis. A portion of each sample was randomly separated and ground to pass a 60 mesh sieve for laboratory analyses (Soil Survey Staff, 2010). Particle-size analysis was performed using the pipette method with air-dried samples (Kilmer and Alexander, 1949). Prior to this procedure, carbonates were removed by treatment using pH 5 NaOAc and organic matter was removed using H_2O_2. The sands were fractionated into very coarse sand (vcs), coarse sand (cs), medium sand (ms), fine sand (fs), and very fine sand (vfs) (Gee and Bauder, 1986).

An acid-base account was quantified by determination of the neutralization potential (NP) and the maximum potential acidity (MPA), according to the Sobek (1978) method. The first step in determining NP was the examination of the "fizz" or reaction of a sample with room temperature hydrochloric acid (HCl). It is assumed that samples with less than 20 parts per trillion (ppt) $CaCo_3$ generally will not fizz or effervesce (Sobek et al., 1978). There are four fizz ratings given based on the observed intensity of the reaction: none, slight, moderate, and strong. The volume and normality of the HCl used to digest each sample corresponded to the assigned fizz rating. If the rating was "none", 20 ml of 0.1 N HCl was reacted with the sample; if "slight", 40 ml of 0.1 N HCl; if "moderate", 40 ml of 0.5 N HCl; and if "strong", 80 ml of 0.5 N HCl.

Next, the sample and acid were heated nearly to boiling to ensure that the reaction between the acid and any neutralizers goes to completion. Once cooled, the mixture was titrated with 0.1 N or 0.5 N NaOH (depending on the normality of HCl used in each sample) to a pH of 7.00 using a pH meter and burette. A blank was run for each volume and normality. To calculate the NP, a constant was calculated by dividing the amount of acid in a blank by the amount of base in that same blank. The amount of acid consumed during the reaction was determined by subtracting the amount of base added multiplied by the constant from the amount of acid added to each sample initially. Finally, tons of $CaCO_3$ equivalent per thousand tons of material was determined by multiplying the amount of acid consumed by 25.0 and multiplying that by the normality of the acid and base.

The MPA was determined based on the percent pyritic-S. To determine percent pyritic-S, a sequential extraction of the samples was completed. First, three subsamples of 0.500 g of each sample were separated. One was left untreated for total sulfur determination by Leco Induction Furnace. The next subsample was leached with 2:3 HCl followed by deionized water to remove chlorides. The sample

was then combusted and total sulfur remaining determined again, resulting in the determination of "HCl- extractable S" which is presumed to consist mostly of sulfates. The last subsample was leached with HNO_3 followed by deionized water. This sample was combusted to determine "HNO_3-extractable S", which is subtracted from the "HCl-extractable" sulfur to determine percent pyritic-S. Organic sulfur is determined arithmetically by subtracting the HNO_3-extractable S from total sulfur. The balance between the MPA and the NP is used to determine whether a material is likely to ultimately produce acidic or alkaline drainage and soil conditions upon weathering (Sobek et al., 2000). For the purpose of classification, the acid-base account will help determine if *sulfidic materials* were present in a given horizon.

In *Soil Taxonomy*, both 1:1 soil to water pH and 1:2 soil to 0.01 *M* $CaCl_2$ pH measurements are recommended. Both pH values were measured for each 2 mm sample using a calibrated pH meter, an Expandable IonAnalyzer EA940 (Olsen and Ellis, 1982). Exchangeable-Al was determined by extraction with 1 M potassium chloride (KCl) (Lin and Coleman, 1960) and quantified by inductively coupled argon plasma spectrophotometry (ICP) analysis.

Oxidizable organic carbon was measured using the Walkley-Black method (Jackson, 1985), which is a rapid dichromate oxidation-reduction technique that proceeds according to the following general equation (Nelson & Sommers, 2000):

[15] $2\ Cr_2O_7^{2-} + 3\ C° + 16\ H^+ = 4\ Cr^{3+} + 3\ CO_2 + 8\ H_2O$

The $Cr_2O_7^{2-}$ reduced during this reaction is assumed to be equal to the amount of organic C in the sample. The remaining $Cr_2O_7^{2-}$ is titrated with ferrous ammonium sulfate ($Fe(NH_4)_2(SO_4)_2 \bullet 6H_2O$) to calculate how much dichromate was reduced.

Cation-exchange capacity was determined using the ammonium acetate (NH_4OAc) (pH 7) method, which is standard for soil classification.

Classification

Once all of the morphological, physical, and chemical properties of the soil samples and profiles were determined, they were classified according the eleventh edition of *Keys to Soil Taxonomy* (Soil Survey Staff, 2010). Next, they were classified using the proposed amendments to *Keys of Soil Taxonomy* presented by the International Committee for Anthropogenic Soils (ICOMANTH) (Galbraith, 2011).

Results and Discussion

Over the course of the spring and summer of 2009, a joint effort between the National Park Service (NPS) and the Department of Biosystems Engineering and Soil Science at the University of Tennessee Knoxville led to the creation of an inventory of minesoils within the Big South Fork National River and Recreation Area (BSF), many which had never before been mapped (Table 20). Out of 42 coal minesoils mapped, full profiles and morphological descriptions were completed on eighteen (Tables 21 and 22). Each horizon of these profiles was sampled, with the soil materials and smaller coarse and rock fragments (approximately < 25 mm) being separated from larger rock fragments (approximately 25-75 mm) such that dominant lithology could be identified. Textures and particle-size distributions can be seen in Tables 23 and 24, chemical properties relevant to classification can be seen in Tables 25 and 26, and the acid-base account for all profiles can be seen in Tables 27 and 28.

Between the minesoils forming in spoil materials deposited before the passage of the Surface Mining Control and Reclamation Act (pre-SMCRA) and those forming after the passage of these laws(post-SMCRA), significant differences existed in many properties. The average slope of pre-SMCRA sites was significantly steeper (at $p=0.05$) than that of post-SMCRA sites which can impact the development of soils forming therein (Tables 21 and 22). Sites with relatively steeper slope can exhibit higher rates of surface erosion, less infiltration, and issues with stability all affecting the ability of vegetation to establish. Pre-SMCRA sites also had significantly higher rock fragment content (at $p=0.05$) than post-SMCRA sites. The nature of the rock fragments also differed, with the pre-SMCRA sites having more fragments of coal and high-carbon shales. This imparted lower chromas and values to many pre-SMCRA sites. This might have affected the classification of many of the pre-SMCRA profiles, however, the epipedons often failed to meet the required depth of 25 cm.

Table 20. Locations of coal minesoil profiles classified within BSF park boundaries.

County	Location Within Park	Site Mapped (origin)	Latitude	Longitude	Elevation (m)
McCreary County, KY	Barthell	Minesoil (spoil)	36.687583N	84.524917W	258
McCreary County, KY	Worley 1	Minesoil (refuse)	36.699622N	84.536206W	228
McCreary County, KY	Worley 2	Minesoil (refuse)	36.698917N	84.536306W	239
McCreary County, KY	West Blue Herron	Minesoil (spoil)	36.670778N	84.550444W	254
McCreary County, KY	Devils Creek 1	Minesoil (spoil)	36.674139N	84.551389W	231
McCreary County, KY	Devils Creek 2	Minesoil (spoil)	36.6745N	84.552778W	244
McCreary County, KY	Big Spring Hollow	Minesoil (refuse)	36.655278N	84.543028W	311
McCreary County, KY	Blair Creek	Minesoil (spoil)	36.657278N	84.529333W	237
Scott County, TN	Rough Shoals	Minesoil (refuse)	36.505861N	84.631944W	267
McCreary County, KY	Blue Herron Trailhead	Minesoil (refuse)	36.668361N	84.546389W	240
McCreary County, KY	Blue Herron Logging Road	Minesoil (refuse)	36.668583N	84.545139W	243
McCreary County, KY	Blue Herron Reclamation 1	Minesoil (spoil)	36.673111N	84.538722W	243
McCreary County, KY	Blue Herron Reclamation 2	Minesoil (spoil)	36.673139N	84.535861W	244
McCreary County, KY	Blue Herron Reclamation 3	Minesoil (spoil)	36.672910N	84.535486W	234
Fentress County, TN	Zenith Red Dog	Minesoil (reddog)	36.428083N	84.735278W	327
Fentress County, TN	Zenith Reclamation 1	Minesoil (refuse)	36.428806N	84.740722W	324
Fentress County, TN	Zenith Reclamation 2	Minesoil (refuse)	36.429139N	84.739639W	325
Scott County, TN	Anderson Branch Reclamation	Minesoil Reclamation	36.483694N	84.658472W	314

*Minesoils forming in spoil materials deposited before the Surface Mining Control and Reclamation Act of 1977 (pre-SMCRA).

**Minesoils forming in spoil materials deposited after the Surface Mining Control and Reclamation Act of 1977 (post-SMCRA).

Table 21. Soil morphology for pre-SMCRA minesoils.†

Site	Slope/ Aspect	Horizon	Lower Depth (cm)	Color (Munsell)	Texture	Rock Type	Struc-ture	Boun-dary	Consis-tence	Roots	Redox Conc.	Redox Deple.	Bridging Voids	Artifacts
1	40%/ N	^Ap	23	10YR 3/1	CNV SL	COA	1 F GR	AS	L	3VF	-	-	-	-
		^Abu	39	10YR 3/1	L	-	1 F GR	AS	L	3F	-	-	-	lens
		^C1	56	10YR 2/1	CNV SCL	MSR	MA	AS	L	-	-	-	-	-
		^C2	82+	N 4/	CNV SCL	MSR	MA	-	L	-	-	-	-	-
2	70%/ NW	^Ap	10	10YR 3/1	GR L	COA	1 F GR	AS	VFR	3F&M, 1C	-	-	-	-
		^AC	33	10YR 3/1	GRV L	COA	MA	CS	FR	2F&M, 1C	-	-	-	-
		^C	55	10YR 2/1	GRV L	MSR	MA	-	FR	1M&C	-	-	-	-
3	35%/ N	^Ap	12	N 2.5/	GR SL	COA	1 F GR	AS	FR	3VF	-	-	-	-
		^Cu	24	10YR 4/2	GRV SL	COA	MA	CS	FR	1M	-	-	-	porcelain chips
		^C	50	10YR 2/2	GRX L	COA	MA	-	FR	-	-	-	-	-
4	70%/ E	^Ap	20	10YR 3/1	CNX SICL	SHA	1 F GR	AB	L	1M	-	-	-	-
		^EC	30	10YR 5/1	CNX SIL	SHA	MA	AB	L	1F, M	-	-	-	-
		^C1	80	10YR 3/1	CNX SIL	SHA	MA	AB	L	1M	-	-	1-10 cm	-
		^C2	100+	10YR 4/1	CNX SIC	SHA	MA	-	-	-	-	-	1-10 cm	-
5	30%/ N	^Ap	15	10YR 2/1	CNV L	MSR	1 F GR	AB	L	1F	-	-	-	-
		^C1	32	10YR 3/1	CNX CL	MSR	MA	AB	L	1F	-	-	4-7 cm	-
		^C2	42	2.5Y 4/2	CNX SIL	SHA	MA	AB	L	1F	-	-	4-7 cm	-
		^C3	50+	2.5Y 3/1	CNX SCL	SHA	MA	-	-	1M	-	-	4-7 cm	-

Table 21. Continued. Soil morphology for pre-SMCRA minesoils.†

Site	Slope/ Aspect	Horizon	Lower Depth	Color	Texture	Rock Type	Structure	Boun-dary	Consis-tence	Roots	Redox Concen.	Redox Deple.	Bridging Voids	Artifacts
			(cm)	(Munsell)										
6	70%/ SE	^A	15	2.5Y 4/1	GR CL	SHA	1 F GR	CW	L	1VF	-	-	-	-
		^C	55	10YR 4/1	GRX CL	COA	MA	CW	-	-	-	-	-	-
		2Ab	70+	10YR 5/4	L	-	2 M SBK	-	FR	-	-	-	-	-
7	80%/ N-NE	^Ap	12	7.5YR 4/1	CNV SCL	COA	1 F GR	AS	L	1F	-	-	-	-
		^C1	32	10YR 3/1	CNV L	COA	MA	CB	L	1F	-	-	4-7 cm	-
		^C2	61	7.5YR 3/1	CNV CL	COA	MA	CB	L	-	-	-	4-7 cm	-
		^C3	94	N 3/	CNV CL	COA	MA	CB	L	-	-	-	4-7 cm	-
		2C4	100+	2.5Y 4/3	CN L	SST	MA	-	-	-	-	-	-	-
8	65%/ N-NE	^A	17	10YR 3/1	CNV L	COA	1 F GR	AS	L	3F, 1C	-	Y	-	-
		^C1	66	N 2.5/	CNX L	COA	MA	DS	L	-	-	Y	-	-
		^C2	100+	N 2.5/	CNX L	COA	MA	-	-	-	-	Y	-	-
9	75%/ SW	^Ap	10	10YR 2/1	CN SL	COA	1 F GR	AS	L	1F	-	-	1-3 cm	-
		^C	29	10YR 2/1	CNX CL	COA	MA	AS	L	2M, 1C	-	-	1-3 cm	-
		2Ab	46	10YR 3/1	L	SST	2 M SBK	CS	FR	1C	-	-	-	-
		2Btb	65+	10YR 4/4	SCL	SST	2 M SBK	-	FR	1C, VC	-	-	-	-

†Texture (adjusted to laboratory data): CN-channery, GR- gravelly, V- very, X- extremely, L- loam, SL- sandy loam, CL- clay loam, SIL- silty loam, SCL- sandy clay loam, SICL- silty clay loam

Dominant Rock Type: COA- coal, MSR- mixed rocks, SHA- shale, SST- sandstone,

Structure: 0- structureless, 1- weak, 2, moderate, 3- strong, F- Fine, M- Medium, GR- granular, SBK- subangular blocky, MA- massive

Boundary: A- abrupt, C- clear, D- diffuse, S- smooth, W- wavy, B- broken

Consistence: L- loose, VFR- very friable, FR- friable

Roots: 1- few, 2- common, 3- many, VF- very fine, F- fine, M- medium, C- coarse, VC- very coarse

Table 22. Soil morphology for post-SMCRA minesoils.†

Site	Slope/ Aspect	Horizon	Lower Depth	Color	Texture	Rock Type	Structure	Boun-dary	Consis-tence	Roots	Redox Concen.	Redox Deple.	Bridging Voids	Artifacts
			(cm)	(Munsell)										
1	60%/ S	^Ap	12	2.5Y 2.5/1	CNV L	COA	1 F GR	DS	L	1F, M	-	-	-	-
		^C	24	2.5Y 2.5/1	CNV L	COA	MA	AS	L	1F, C	-	-	-	-
		^Cj	36	2.5Y 4/1	CN L	COA	MA	AS	L	1F, M	-	Y	-	-
		2Btb	57+	2.5Y 5/4	CL	SST	2 M SBK	-	FR	-	-	-	-	-
2	70%/ S	^Ap	16	10YR 2/1	CN SL	COA	1 F GR	DS	L	3 F, C	-	-	-	-
		^Bwj	46	10YR 2/1	CNV L	COA	1 F SBK	AS	L	3F, C, VC	-	-	-	-
		2Ab	58	2.5Y 4/2	CNV L	SST	1 M SBK	AS	FR	-	-	-	-	-
		2Btb	75+	10YR 5/4	CL	SST	2 M SBK	-	FR	-	-	-	-	-
3	20%/ SE	^Ap	14	10YR 4/2	GR L	SST	1 F GR	CS	FR	3VF, F, M	-	-	-	-
		^Cu	42	10YR 4/2	GRV L	CSS	MA	-	FR	1M, C	-	-	-	Cu wire
		^C	75	10YR 4/2	GR L	SST	MA	-	FR	1M	-	-	-	-
			100+	10YR 4/2	CBV L	SST	MA	-	FR	-	-	-	-	-
4	25%/ SW	^Ap	16	10YR 3/2	L	SST	2 M GR	CW	FR	1C, 3F	-	-	-	-
		^Bw	34	10YR 4/3	GRV SIL	MSR	1 M SBK	AS	FI	3VF, F	-	-	-	-
		^Cj	50	10YR 4/1	GRV SCL	COA	MA	AB	FR	-	-	-	3-5 cm	
		^C1	59	10YR 5/4	SCL	SST	MA	AB	FR	-	-	-	3-5 cm	-
		^C2	100+	10YR 4/1	CNX SCL	COA	MA	-	-	-			3-5 cm	-

Table 22. Continued. Soil morphology for post-SMCRA minesoils.†

Site	Slope/ Aspect	Horizon	Lower Depth	Color	Texture*	Rock Type	Structure	Boun-dary	Consis-tence	Roots	Redox Concen.	Redox Deple.	Bridging Voids	Artifacts
			(cm)	(Munsell)										
5	30%/ W	^Ap	11	10YR 5/2	L	SST	2 F GR	CS	FR	1M, 3VF	-	-	-	-
		^Bw	34	10YR 5/3	GR L	SST	1 M SBK	AS	FI	2M	-	-	-	-
		^C	41	10YR 5/4	GR SL	SST	MA	AB	FI	1M	-	-	-	-
		^Cuj	54+	10YR 3/1	CNX SCL	COA	MA	-	FI	-			-	glass
6	50%/ W	^C1	10	7.5YR 4/3	CNX SL	COA	MA	DS	FR	-	-	-	2 cm	-
		^C2	50	7.5YR 4/4	CNX SL	COA	MA	DS	FR	-	-	-	2-15 cm	-
		^C3	100+	7.5YR 3/2	CNX L	COA	MA	-	FR	-	-	-	2-7 cm	-
7	60%/ SE	^Ap	21	10YR 3/1	CN SICL	COA	2 F GR	AS	VFR	1C, 3F	-	-	-	-
		^C1	51	10YR 3/1	CNX SICL	MUD	MA	AB	VFI	2M, C	-	-	-	-
		^C2	68	N 2.5/	CNX C	COA	MA	AS	VFI	-	-	-	5-7 cm	-
		2Cu	100+	2.5Y 4/3	SL	-	MA	-	L	-			-	glass
8	60%/ NE	^Ap	13	10YR 2/1	L	MSR	2 M GR	CS	VFR	1F, VC	-	-	-	-
		^Bw1	40	10YR 3/1	GR L	MSR	1 M SBK	CS	L	1C	-	-	-	-
		^Bw2	66+	10YR 3/1	GRV CL	MSR	1 M SBK	-	L	1C	-	-	-	-

Table 22. Continued. Soil morphology for post-SMCRA minesoils.†

Site	Slope/ Aspect	Horizon	Lower Depth	Color	Texture*	Rock Type	Structure	Boun- dary	Consis - tence	Roots	Redox Concen.	Redox Deple.	Bridging Voids	Artifacts
			(cm)	(Munsell)										
9	10%/ NE	^Apg	6	N 7/ (2.5Y 5/3)	L	SST	1 F GR	AS	VFR	1F	-	Y	-	-
		^Cdg	20	10YR 5/6 (N 2.5/; 7.5YR 6/6)	L	SST	MA	CW	FI	-	-	Y	-	-
		^Cd	60+	N 2.5/ (7.5YR 5/8)	L	COA	MA	-	FR	-	-	Y	-	-

†Texture (adjusted to laboratory data): CN-channery, GR- gravelly, V- very, X- extremely, L- loam, SL- sandy loam, CL- clay loam, SIL- silty loam, SCL- sandy clay loam, SICL- silty clay loam

Dominant Rock Type: COA- coal, MSR- mixed rocks, SHA- shale, SST- sandstone,

Structure: 0- structureless, 1- weak, 2, moderate, 3- strong, F- Fine, M- Medium, GR- granular, SBK- subangular blocky, MA- massive

Boundary: A- abrupt, C- clear, D- diffuse, S- smooth, W- wavy, B- broken

Consistence: L- loose, VFR- very friable, FR- friable

Roots: 1- few, 2- common, 3- many, VF- very fine, F- fine, M- medium, C- coarse, VC- very coarse

Table 23. Particle size distribution for pre-SMCRA minesoils.

			USDA Particle Size Class								
Site	Horizon	Lower Boundary	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	USDA Texture*
		(cm)	----------%----------								
1	^Ap	23	10	10	8	14	19	61	26	13	CNV SL
	^Abu	39	6	11	9	12	11	51	37	12	L
	^C1	56	8	8	4	9	15	48	26	26	CNV SCL
	^C2	82+	0	5	3	8	30	58	19	23	CNV SCL
2	^Ap	10	11.5	7.1	4.2	8.9	5.6	38	49	13	GR L
	^AC	33	8.7	7.8	5.2	10.0	5.6	37	50	12	GRV L
	^C	55	9.1	9.3	6.0	10.1	5.1	40	34	26	GRV L
3	^Ap	12	15.0	13.6	7.2	1.8	21.3	60	32	7	GR SL
	^Cu	24	8.5	7.6	6.6	32.3	11.4	67	25	8	GRV SL
	^C	50	6.0	5.1	3.2	17.1	12.2	43	45	12	GRX L
4	^Ap	20	4.6	2.9	1.0	2.4	1.6	6	63	31	CNX SICL
	^EC	30	1.0	2.8	1.4	2.2	1.4	9	65	26	CNX SIL
	^C1	80	7.3	6.5	2.4	3.7	2.2	22	52	26	CNX SIL
	^C2	100+	2.4	2.4	1.0	0.9	0.0	7	48	45	CNX SIC
5	^Ap	15	8.0	9.7	4.2	9.4	6.7	39	38	23	CNV L
	^C1	32	10.7	8.3	2.6	5.4	3.6	31	40	30	CNX CL
	^C2	42	7.2	6.3	1.5	3.2	2.1	20	58	21	CNX SIL
	^C3	50+	19.2	14.5	6.2	12.3	6.2	58	18	23	CNX SCL

Table 23. Continued. Particle size distribution for pre-SMCRA minesoils.

			USDA Particle Size Class								
Site	Horizon	Lower Boundary	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	USDA Texture*
		(cm)	----------%----------								
6	^A	15	4.1	6.2	5.1	2.8	14.4	32	36	32	GR CL
	^C	55	2.5	3.0	3.2	9.7	7.2	26	44	30	GRX CL
	2Ab	70+	3.9	4.5	6.0	11.9	11.8	40	47	13	L
7	^Ap	12	10.0	9.8	4.1	10.6	13.6	48	24	28	CNV SCL
	^C1	32	11.4	10.0	4.7	8.6	8.4	43	33	23	CNV L
	^C2	61	3.8	3.1	1.5	3.4	2.3	21	51	28	CNV CL
	^C3	94	4.8	4.3	2.0	7.8	11.0	30	36	33	CNV CL
	2C4	100+	8.3	8.9	3.8	11.3	13.7	46	31	23	CN L
8	^A	17	7.4	9.5	3.6	8.9	9.3	39	41	20	CNV L
	^C1	66	19.8	10.2	3.8	4.0	11.2	50	32	19	CNX L
	^C2	100+	26.4	10.7	4.0	9.0	7.1	58	27	15	CNX L
9	^Ap	10	22.4	14.6	6.7	10.9	7.6	64	24	12	CN SL
	^C	29	7.1	5.2	2.1	2.1	12.6	30	32	37	CNX CL
	2Ab	46	3.2	5.2	4.1	6.8	10.3	30	49	21	L
	2Btb	65+	6.6	5.6	9.9	14.8	21.3	59	7	33	SCL

Table 24. Particle size distribution for post-SMCRA minesoils.

Site	Horizon	Lower Boundary	USDA Particle Size Class								USDA Texture*
			Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	
		(cm)	----------	----------	----------	----------	%----------	----------	----------	----------	
1	^Ap	12	8.5	12.5	6.2	9.8	7.7	46	41	14	CNV L
	^C	24	7.8	11.0	6.5	4.7	9.5	41	47	12	CNV L
	^Cj	36	11.6	11.6	5.6	9.2	7.2	46	27	27	CN L
	2Btb	57+	3.2	3.0	2.1	5.5	7.7	21	44	33	CL
2	^Ap	16	14.1	22.7	12.2	11.4	4.6	65	26	9	CN SL
	^Bwj	46	10.0	12.1	6.8	9.8	4.9	44	34	21	CNV L
	2Ab	58	6.9	10.5	5.7	9.5	5.7	39	44	19	CNV L
	2Btb	75+	6.0	4.3	2.8	8.9	8.0	30	42	28	CL
3	^Ap	14	2.4	5.1	7.3	13.5	7.8	36	46	18	GR L
	^Cu	42	2.0	4.5	10.2	15.1	7.6	39	43	18	GRV L
	^C	75	1.6	6.0	12.5	18.8	7.3	46	37	17	GR L
		100+	2.8	5.3	7.8	14.9	7.1	38	43	20	CBV L
4	^Ap	16	1.8	5.4	5.2	10.3	6.3	29	48	24	L
	^Bw	34	0.7	3.1	3.1	1.2	7.5	16	60	25	GRV SIL
	^Cj	50	14.6	12.1	6.2	3.2	16.1	53	23	24	GRV SCL
	^C1	59	8.0	11.7	11.4	16.3	7.8	56	23	24	SCL
	^C2	110+	5.6	5.1	3.8	8.5	5.8	29	43	28	CNX SCL

Table 24. Continued. Particle size distribution for post-SMCRA minesoils.

Site	Horizon	Lower Boundary	USDA Particle Size Class								USDA Texture*
			Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Total Sand	Silt	Clay	
		(cm)	----------%----------								
5	^Ap	11	3.0	6.0	8.0	10.9	4.7	33	44	24	L
	^Bw	34	2.9	5.9	7.5	13.0	6.1	36	42	22	GR L
	^C	41	9.8	14.6	13.0	17.9	11.0	68	20	13	GR SL
	^Cuj	54+	9.6	13.5	12.5	11.1	9.6	57	17	25	CNX SCL
6	^C1	10	23.2	17.5	6.2	8.4	5.4	61	29	10	CNX SL
	^C2	50	26.1	10.9	4.3	6.7	4.6	53	30	18	CNX SL
	^C3	100+	14.7	7.5	3.2	5.0	3.8	34	43	23	CNX L
7	^Ap	21	3.2	2.5	1.4	2.5	1.6	11	58	30	CN SICL
	^C1	51	2.2	2.8	1.3	2.4	1.8	10	58	31	CNX SICL
	^C2	68	11.4	5.0	2.3	2.3	3.9	25	8	66	CNX C
	2Cu	100+	5.3	15.1	20.1	23.4	9.4	74	9	17	SL
8	^Ap	13	7.7	8.2	7.2	16.7	8.2	48	37	15	L
	^Bw1	40	7.6	10.0	6.0	2.0	14.5	40	41	19	GR L
	^Bw2	66	4.4	8.4	4.1	4.0	6.1	27	39	33	GRV CL
9	^Ap	6	1.6	3.1	5.4	11.0	14.0	35	49	16	L
	^C1	20	1.8	3.3	1.6	3.5	14.6	27	46	28	L
	^C2	60+	5.7	7.5	2.4	4.9	7.3	29	46	25	L

Table 25. Chemical properties of pre-SMCRA minesoils including organic-C, exchangeable bases, KCl-extractable Al, cation exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

				Exchangeable Bases								
Site	Horizon	Lower Depth	Organic Carbon	Ca	Na	K	Mg	Al (KCl)	CEC (NH_4OAc)	Base Saturation (NH4OAc)	pH 1:1 H_2O	pH 2:1 CaCl2
		(cm)	(%)	----------cmol$_c$/kg soil----------						(%)		
1	^Ap	23	5.9	7.9	0.1	0.1	0.8	0.0	6	100*	6.4	6.1
	^Abu	39	23.9	33.9	0.2	0.3	3.0	0.1	29	100*	6.0	5.7
	^C1	56	14.8	3.0	0.4	0.1	0.4	2.0	13	30	3.9	3.2
	^C2	82+	5.0	1.5	0.2	0.1	0.2	5.1	7	28	3.8	3.0
2	^Ap	10	8.9	8.5	0.1	0.4	2.5	0.1	11	100*	5.6	4.7
	^AC	33	9.1	4.8	0.1	0.3	1.5	1.8	10	69	5.0	4.1
	^C	55	9.5	2.5	0.1	0.3	1.2	5.3	12	36	4.6	3.8
3	^Ap	12	9.0	14.5	0.1	0.3	1.1	0.0	10	100*	4.8	4.3
	^Cu	24	1.6	3.9	0.1	0.1	0.4	0.0	5	94	6.0	5.7
	^C	50	3.7	6.4	0.1	0.2	0.3	0.2	8	88	5.8	5.2
4	^Ap	20	6.8	17.1	0.1	0.8	7.1	0.0	14	100*	6.9	6.2
	^EC	30	0.8	5.0	0.1	0.5	5.6	2.6	9	100*	5.1	4.1
	^C1	80	2.9	3.8	0.1	0.4	4.7	4.2	9	100*	4.8	4.0
	^C2	100+	2.1	6.0	0.1	0.4	7.6	0.0	10	100*	5.8	5.1
5	^Ap	15	8.2	6.0	0.1	0.4	3.2	4.9	16	60	4.4	4.0
	^C1	32	5.8	2.6	0.1	0.3	1.7	5.7	14	33	4.0	3.6
	^C2	42	0.9	2.0	0.1	0.3	6.2	7.6	10	85	4.3	3.9
	^C3	50+	5.6	0.9	0.1	0.2	1.6	10.8	11	25	3.9	3.5

Table 25. Continued. Chemical properties of pre-SMCRA minesoils including organic-C, exchangeable bases, KCl-extractable Al, cation exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

Site	Horizon	Lower Depth	Organic Carbon	Exchangeable Bases				Al	CEC	Base Saturation	pH 1:1	pH 2:1
				Ca	Na	K	Mg	(KCl)	(NH_4OAc)	(NH4OAc)	H_2O	CaCl2
		(cm)	(%)	----------$cmol_c$/kg soil----------						(%)		
6	^A	15	3.3	1.0	0.1	0.3	0.4	14.6	10	18	4.7	3.5
	^C	55	2.2	0.9	0.1	0.2	1.0	10.4	9	25	4.8	3.5
	2Ab	70+	1.9	0.3	0.1	0.1	0.2	4.1	5	16	4.9	4.0
7	^Ap	12	13.5	0.9	0.1	0.2	0.4	2.9	12	13	3.7	3.0
	^C1	32	16.2	0.2	0.0	0.1	0.1	2.1	16	2	3.1	2.7
	^C2	61	19.9	0.1	0.1	0.1	0.0	2.9	21	1	2.8	2.6
	^C3	94	11.3	0.1	0.1	0.0	0.0	3.2	6	4	2.7	2.5
	2C4	100+	5.6	0.1	0.0	0.1	0.1	5.6	9	3	2.7	2.5
8	^A	17	13.1	0.2	0.2	0.2	0.3	5.3	15	5	3.4	2.9
	^C1	66	12.0	0.2	0.2	0.1	0.1	5.9	10	5	3.1	2.9
	^C2	100+	13.8	0.1	0.1	0.1	0.1	4.8	8	5	3.1	2.8
9	^Ap	10	22.9	1.2	0.1	0.4	0.3	2.4	23	9	3.9	3.4
	^C	29	12.3	0.2	0.1	0.2	0.1	5.2	13	4	3.4	2.8
	2Ab	46	9.0	0.1	0.1	0.1	0.1	3.9	17	2	3.4	3.0
	2Btb	65+	2.3	0.2	0.1	0.1	0.1	7.2	7	7	3.6	3.3

Table 26. Chemical properties of post-SMCRA minesoils including organic-C, exchangeable bases, KCl-extractable Al, cation exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

Site	Horizon	Lower Depth	Organic Carbon	Exchangeable Bases				Al (KCl)	CEC (NH_4OAc)	Base Saturation (NH4OAc)	pH 1:1 H_2O	pH 2:1 CaCl2
				Ca	Na	K	Mg					
		(cm)	(%)	----------$cmol_c$/kg soil----------						(%)		
1	^Ap	12	19.9	14.5	0.2	0.4	1.5	0.0	19	86	5.7	5.1
	^C	24	18.0	7.1	0.2	0.2	0.7	0.2	23	35	4.8	4.2
	^Cj	36	9.2	8.2	0.2	0.2	0.9	0.0	11	89	5.8	5.3
	2Btb	57+	1.1	4.1	0.1	0.1	0.7	4.8	12	41	3.7	3.3
2	^Ap	16	8.8	15.6	0.1	0.3	1.9	0.0	11	100*	7.1	6.6
	^Bwj	46	13.1	21.2	0.1	0.4	2.0	0.0	15	100*	7.2	6.5
	2Ab	58	7.0	10.6	0.1	0.3	1.7	0.0	12	100*	6.5	5.8
	2Btb	75+	2.2	7.6	0.1	0.2	1.8	0.0	8	100*	6.1	5.6
3	^Ap	14	5.0	13.2	0.1	0.3	0.9	0.0	10	100*	6.7	6.4
	^Cu	42	3.0	13.9	0.1	0.2	1.4	0.0	6	100*	7.5	7.0
	^C	75	2.4	15.4	0.1	0.1	0.5	0.0	5	100*	7.5	7.3
		100+	2.9	12.3	0.1	0.2	0.7	0.0	5	100*	7.4	7.3
4	^Ap	16	7.9	15.9	0.0	0.4	1.7	0.0	10	100*	6.8	7.0
	^Bw	34	3.0	11.3	0.1	0.3	1.4	0.0	7	100*	7.3	7.0
	^Cj	50	10.0	3.3	0.1	0.2	0.5	2.0	10	39	3.6	3.2
	^C1	59	2.8	1.8	0.1	0.1	0.5	6.3	7	36	3.0	2.8
	^C2	110+	8.2	1.6	0.1	0.1	0.3	4.6	10	20	2.7	2.5

Table 26. Continued. Chemical properties of post-SMCRA minesoils including organic-C, exchangeable bases, KCl-extractable Al, cation exchange capacity (CEC), adjusted base saturation (at pH 7), and pH.

Site	Horizon	Lower Depth	Organic Carbon	Exchangeable Bases				Al (KCl)	CEC (NH_4OAc)	Base Saturation (NH4OAc)	pH 1:1 H_2O	pH 2:1 CaCl2
				Ca	Na	K	Mg					
		(cm)	(%)	----------$cmol_c$/kg soil----------						(%)		
5	^Ap	11	6.6	21.9	0.1	0.3	1.3	0.0	11	100*	7.1	6.9
	^Bw	34	2.0	14.4	0.1	0.2	1.0	0.0	6	100*	7.4	7.2
	^C	41	2.4	47.1	0.1	0.2	0.6	0.0	7	100*	6.0	6.0
	^Cuj	54+	9.3	21.1	0.1	0.1	0.3	1.0	9	100*	3.6	3.5
6	^C1	10	0.6	3.5	0.2	1.0	1.6	0.0	5	100*	7.5	6.6
	^C2	50	1.3	3.1	0.1	0.8	2.5	0.0	6	100*	7.4	6.4
	^C3	100+	2.6	3.7	0.1	0.6	2.8	0.0	7	100*	7.1	6.1
7	^Ap	21	4.3	4.8	0.1	0.5	4.0	0.0	9	100*	6.1	5.2
	^C1	51	4.5	6.5	0.1	0.4	4.6	0.0	10	100*	5.9	4.8
	^C2	68	8.0	7.1	0.1	0.2	3.0	0.0	8	100*	5.8	5.4
	2Cu	100+	0.3	0.7	0.2	0.1	0.3	0.0	1	100*	6.4	5.8
8	^Ap	13	7.8	11.4	0.1	0.3	1.7	0.0	9	100*	6.3	5.9
	^Bw1	40	6.0	11.0	0.1	0.2	1.6	0.0	9	100*	6.7	6.2
	^Bw2	66	6.8	13.2	0.1	0.2	1.8	0.0	9	100*	6.8	6.4
9	^Ap	6	4.8	14.7	0.1	0.3	2.5	0.0	8	100*	7.1	6.8
	^C1	20	25.6	1.5	0.1	0.2	0.5	10.4	15	15	4.3	3.9
	^C2	60+	25.5	0.6	0.1	0.2	0.4	15.2	59	2	4.3	3.9

Table 27. Acid-base account for pre-SMCRA minesoils.

Site	Horizon	Lower Boundary	Color*	Fizz Test	Paste pH	Pyritic Sulfur	MPA	NP	NNP
		(cm)	(Munsell)			(%)	(Tons $CaCO_3$ eq/1000 T)		
1	^Ap	23	10YR 5/1	0	7.1	0.00	0.0	8.0	8.0
	^Abu	39	10YR 5/1	1	6.6	0.23	7.1	0.1	-7.1
	^C1	56	10YR 2/2	0	4.8	0.02	0.7	-3.3	-4.1
	^C2	82+	N 6/	0	4.4	0.00	0.0	-6.5	-6.5
2	^Ap	10	10YR 5/1	1	6.2	0.07	2.2	7.4	5.2
	^AC	33	10YR 5/1	1	5.7	0.00	0.0	7.9	7.9
	^C	55	10YR 4/1	1	5.3	0.09	2.9	6.9	3.9
3	^Ap	12	N 2.5/	1	6.6	0.05	1.6	9.5	8.0
	^Cu	24	10YR 5/1	0	6.6	0.17	5.2	7.3	2.1
	^C	50	10YR 5/1	1	6.3	0.18	5.7	6.2	0.5
4	^Ap	20	10YR 6/1	0	7.0	0.00	0.1	8.8	8.6
	^EC	30	10YR 7/1	0	5.5	0.00	0.0	3.7	3.6
	^C1	80	10YR 5/1	1	5.4	0.08	2.4	6.4	4.0
	^C2	100+	10YR 5/1	1	6.5	0.07	2.1	9.8	7.7
5	^Ap	15	10YR 4/1	0	5.3	0.00	0.0	2.5	2.5
	^C1	32	10YR 5/2	0	4.9	0.00	0.1	1.3	1.1
	^C2	42	2.5Y 6/2	1	5.2	0.00	0.0	4.9	4.9
	^C3	50+	2.5Y 4/1	0	5.0	0.09	2.8	1.3	-1.5
6	^A	15	2.5Y 6/2	0	4.8	0.05	1.4	-0.4	-1.8
	^C	55	10YR 6/1	0	4.9	0.04	1.1	1.5	0.4
	2Ab	70+	10YR 5/4	0	5.2	0.01	0.4	1.7	1.4
7	^Ap	12	7.5YR 2/1	0	3.9	0.00	0.0	-6.3	-6.3
	^C1	32	10YR 2/1	0	3.3	0.00	0.0	-5.5	-5.5
	^C2	61	7.5YR 2.5/1	0	3.3	0.00	0.0	-7.2	-7.2
	^C3	94	N 4/	0	3.2	0.00	0.0	-7.0	-7.0
	2C4	100+	2.5Y 6.4	0	3.0	0.03	0.8	-7.9	-8.7

Table 27. Continued. Acid-base account for pre-SMCRA minesoils.

Site	Horizon	Lower Boundary	Color*	Fizz Test	Paste pH	Pyritic Sulfur	MPA	NP	NNP
		(cm)	(Munsell)			(%)	(Tons $CaCO_3$ eq/1000 T)		
8	^A	17	10YR 5/1	0	3.7	0.00	0.0	-5.7	-5.7
	^C1	66	N 4/	0	3.8	0.00	0.0	-5.3	-5.3
	^C2	100+	N 3/	0	3.9	0.00	0.0	-5.3	-5.3
9	^Ap	10	10YR 4/2	0	4.5	0.07	2.1	-8.0	-10.1
	^C	29	10YR 3/1	0	3.7	0.00	0.0	-6.0	-6.0
	2Ab	46	10YR 5/2	0	4.0	0.03	0.9	-5.5	-6.5
	2Btb	65+	10YR 7/3	0	4.1	0.01	0.4	-1.7	-2.1

*Air-dried 60 mesh samples.

Table 28. Acid-base account for post-SMCRA minesoils.

Site	Horizon	Lower Boundary	Color*	Fizz Test	Paste pH	Pyritic Sulfur	MPA	NP	NNP
		(cm)	(Munsell)			(%)	(Tons $CaCO_3$ eq/1000 T)		
1	^Ap	12	2.5Y 2.5/1	0	6.2	0.00	0.0	0.3	0.3
	^C	24	2.5Y 2.5/1	0	5.3	0.25	7.8	-4.3	-12.1
	^Cj	36	2.5Y 6/1	0	6.0	1.45	45.4	-1.6	-47.0
	2Btb	57+	2.5Y 7/3	0	3.7	0.00	0.0	-0.4	-0.4
2	^Ap	16	10YR 4/1	0	7.2	0.26	8.2	25.3	17.1
	^Bwj	46	10YR 4/1	0	7.0	1.06	33.2	6.4	-26.9
	2Ab	58	2.5Y 6/3	0	6.5	0.20	6.4	2.2	-4.2
	2Btb	75+	10YR 6/4	0	6.2	0.00	0.0	1.3	1.3
3	^Ap	14	10YR 6/2	1	7.3	0.05	1.5	11.0	9.5
	^Cu	42	10YR 6/2	1	7.9	0.03	0.8	12.5	11.7
	^C	75	10YR 6/2	3	8.1	0.00	0.0	67.2	67.2
		100+	10YR 5/2	2	7.9	0.00	0.0	32.0	32.0
4	^Ap	16	10YR 5/2	2	7.4	0.05	1.4	38.0	36.6
	^Bw	34	10YR 6/3	1	7.9	0.04	1.4	11.7	10.3
	^Cj	50	10YR 3/1	0	4.7	0.18†	5.8	-5.3	-11.1
	^C1	59	10YR 4/3	0	3.7	0.07	2.1	-3.1	-5.2
	^C2	110+	10YR 2/1	0	3.3	0.20	6.1	-5.2	-11.4
5	^Ap	11	10YR 3/2	2	7.3	0.02	0.7	38.0	37.3
	^Bw	34	10YR 4/3	2	7.6	0.00	0.0	25.9	25.9
	^C	41	10YR 4/3	0	6.5	0.07	2.1	6.8	4.7
	^Cuj	54+	10YR 2/1	0	4.0	0.00†	0.0	-2.9	-2.9
6	^C1	10	7.5YR 6/3	1	6.9	0.07	2.1	12.5	10.3
	^C2	50	10YR 6/3	1	7.1	0.03	1.0	12.5	11.4
	^C3	100+	7.5YR 5/2	1	6.8	0.04	1.3	13.4	12.2
7	^Ap	21	10YR 5/1	1	6.2	0.01	0.3	7.6	7.3
	^C1	51	10YR 5/1	0	6.1	0.00	0.0	5.1	5.1
	^C2	68	N 4/	0	6.4	0.06	1.9	4.7	2.8
	2Cu	100+	2.5Y 6/3	0	7.7	0.00	0.0	3.7	3.7

Table 28. Continued. Acid-base account for post-SMCRA minesoils.

Site	Horizon	Lower Boundary	Color*	Fizz Test	Paste pH	Pyritic Sulfur	MPA	NP	NNP
		(cm)	(Munsell)			(%)	(Tons $CaCO_3$ eq/1000 T)		
8	^Ap	13	10YR 4/1	0	6.5	0.02	0.6	5.9	5.3
	^Bw1	40	10YR 5/2	1	6.8	0.06	1.7	7.6	5.9
	^Bw2	66	10YR 5/1	0	6.9	0.03	1.0	9.7	8.7
9	^Ap	6	2.5Y 6/3	0	7.0	0.00	-0.1	6.8	7.0
	^C1	20	10YR 6/4	1	4.4	0.01	0.4	0.1	-0.3
	^C2	60+	10YR 3/1	0	4.5	0.05	1.6	-7.7	-9.3

*Air-dried 60 mesh samples.

Pre-SMCRA site 1, with dominantly carbonaceous lithology, met color, depth, and base saturation requirements for a mollic epipedon however, low organic carbon content in the ^Ap horizon did not meet the requirement that it be 0.6% greater than the C horizon. Both *Soil Taxonomy* and ICOMANTH classifications (Table 29) reflected many of the same family classes. With the ICOMANTH amendments, however, it is possible to distinguish that this is a soil forming in mine spoil materials > 50 cm thick and further, that these materials were transported by man. Neither classification reveals that although the surface horizons have a high base saturation and are only mildly acidic, the two C horizons have extremely low pH (> 3.2) and negative net neutralization potential (NNP). In fact, the reaction class in both systems is “non-acid”. This would be confusing to resources managers or park conservationists if they were trying to track down acidity problems in the waterway. This location was directly upslope from a stream which feeds into the Big South Fork River. Pre-SMCRA site 2 had a similar classification to Pre-SMCRA site 1, but its lower pH is revealed due to a lower pH in the surface horizons as well, despite an extremely high base saturation (created by anthropogenic additions). In both cases, the proposed amendments present a more descriptive classification than the existing *Soil Taxonomy*.

Pre-SMCRA site 3 had the highest values for % pyritic-S for pre-SMCRA sites and second highest overall, though the NNP on this site was consistently positive. This attribute is reflected in both classifications as seen in the *calcareous* reaction class. For this profile and for that of pre-SMCRA site 4 and pre-SMCRA site 5, the ICOMANTH amendments describe the properties of the soils to a much more complete extent than *Soil Taxonomy,* showing that these soils are forming in human-transported materials (HTM), specifically mine spoils, and that the epipedons meet both the color and carbon requirements of a mollic epipedon. None of this information was revealed in traditional classification.

Pre-SMCRA sites 7 and 8 have classifications similar to the other pre-SMCRA profiles. In the case of these profiles, that is somewhat disturbing. Neither classification reveals the extremely acidic nature of these soils (1:2 pH < 3.0), nor that the base saturation is correspondingly low (%BS < 5). These properties definitely impact any future land uses of almost any kind. The acidity alone at these sites is low enough to be phytotoxic. The classifications of pre-SMCRA site 9 are unreflective of some key properties as well. Not only is the extremely low pH, seen in every horizon, left unrevealed, but because the deposit of mine spoil materials was not 50 cm thick, the buried soil beneath had to be classified, leaving no indication in either classification that this soil was covered with human-transported materials.

Table 29. Classification of BSF minesoil profiles using Keys to Soil Taxonomy (2010) and proposed amendments by ICOMANTH.

Profile	*Soil Taxonomy*	ICOMANTH
Pre-1	loamy-skeletal, mixed, super-active, non-acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, super-active, non-acid, mesic Anthroportic Udorthent
Pre-2	loamy-skeletal, mixed, active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, active, acid, mesic Anthroportic Udorthent
Pre-3	loamy-skeletal, mixed, super-active, calcareous, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, super-active, calcareous, mesic Anthroportic Humic Udorthent
Pre-4	loamy-skeletal, mixed, semi-active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, semi-active, acid, mesic Anthroportic Humic Udorthent
Pre-5	loamy-skeletal, mixed, active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, active, acid, mesic Anthroportic Humic Udorthent
Pre-6	loamy-skeletal, mixed, semi-active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, semi-active, acid, mesic Anthroportic Udorthent
Pre-7	loamy-skeletal, mixed, active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, active, acid, mesic Anthroportic Udorthent
Pre-8	loamy-skeletal, mixed, active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, active, acid, mesic Anthroportic Humic Udorthent
Pre-9	fine-loamy, mixed, semi-active, acid, mesic Typic Hapludult	fine-loamy, mixed, semi-active, acid, mesic Typic Hapludult
Post-1	fine-loamy, mixed, semi-active, mesic Mollic Hapludalf	fine-loamy, mixed, semi-active, mesic Mollic Hapludalf
Post-2	fine-loamy, mixed, active, mesic Mollic Hapludalf	fine-loamy, mixed, active, mesic Mollic Hapludalf
Post-3	loamy-skeletal, mixed, semi-active, calcareous, mesic Typic Udifluvent	loamy-skeletal, spolic, semi-active, calcareous, mesic Anthroportic Udorthent
Post-4	loamy-skeletal, mixed, semi-active, mesic Typic Sulfudept	loamy-skeletal, spolic, semi-active, mesic Anthroportic Sulfudept
Post-5	loamy-skeletal, mixed, super-active, mesic Typic Eutrudept	loamy-skeletal, spolic, mixed, super-active, mesic Anthroportic Eutrudept
Post-6	fragmental, mixed, mesic Typic Udorthent	fragmental, spolic, mixed, mesic Anthroportic Udorthent
Post-7	clayey-skeletal over coarse-loamy, mixed over siliceous, subactive, non-acid, mesic Typic Udorthent	clayey-skeletal over coarse-loamy, spolic, mixed over siliceous, subactive, non-acid, mesic Anthroportic Udorthent
Post-8	loamy-skeletal, mixed, semi-active, mesic Humic Eutrudept	loamy-skeletal, spolic, mixed, semi-active, mesic Anthraltic Humic Eutrudept
Post-9	fine-loamy, mixed, super-active, acid, mesic Typic Fluvaquent	fine-loamy, aquadensic, mixed, super-active, acid, mesic Anthroportic Udorthent

While the classifications using *Soil Taxonomy* for the pre-SMCRA sites were not particularly descriptive, several of the classifications for post-SMCRA sites are simply misleading. The ^Cj horizon from post-SMCRA site 1 had the highest % pyritic-S of any other minesoil horizon studied in the BSF, being almost 50% higher than the next highest contender: the ^Bw horizon from post-SMCRA site 2. Because of the extremely high % pyritic-S (1.45%), a pH > 3.5, and the extremely negative NNP (-47.0 Tons $CaCO_3$ eq/ 1000T), the ^Cj horizon from Post-1 qualifies as having *sulfidic materials*. In fact this horizon would be called a *sulfuric horizon* if the pH were < 4.0 because jarosite concentrations were found inside a large macropore, as seen in Figure 50. This is not revealed in either classification because the surface deposit of coal mine spoil materials is less than 50 cm, requiring the soil to be classified based on the 2Btb horizon. Thus it was placed in the Alfisol order because of the argillic horizon and within a *Typic* subgroup. Post-SMCRA site 2 has the same classification as Post-1 and indeed they are quite similar. Post-2 also has diagnostic sulfidic materials present in the ^Bwj horizon and, like Post-1, this goes unrecognized in both classifications.

In the post-SMCRA site 3 profile, some of the weaknesses of *Soil Taxonomy* outlined in the *7th Circular Letter* by ICOMANTH are encountered. This site has a slope < 25% and an irregular decrease of organic carbon with depth according to standard lab techniques, placing it in the Fluvent suborder. This class was intended to represent flood-deposited soils, although this material was clearly not deposited by flood activities. Based on this soils other chemical properties, including very high concentrations of exchangeable calcium, a base saturation of 100%, a pH > 7, and a NNP > 30 in the bottom two horizons, any resource manager should be able to distinguish this site as being anthropogenically-altered. Even knowing that the soil is not a true "Fluvent" in terms of the intent behind the creation of the suborder, the classification provides very little information about the true origins of the soil materials. While the ICOMANTH classification does not differentiate the carbolithic spoil materials seen in the Post-1 and Post-2, it at least points out that this soil is forming in human-transported materials.

The classification for post-SMCRA site 4 is relatively descriptive compared to most of the other minesoils in the BSF. The presence of a cambic horizon along with a sulfuric horizon placed it into an appropriate subgroup in *Soil Taxonomy.* Nonetheless, the classification according to the ICOMANTH proposed amendments is more appropriate still, specifying that this is not an acid sulfate soil that is naturally occurring but is forming in HTM. Due to the presence of the sulfuric horizon, the extremely low pH in the subsurface horizons is distinguished because to be a sulfuric horizon, the pH ($1:1_{H2O}$) must be <



Figure 50. Jarosite accumulation (indicated by red arrow) in post-SMCRA profile 1.

4.0 if sulfides are present. The percent pyritic-S being relatively high, compared to many of the other minesoils, at 0.18% reveals the presence of active sulfides. As seen in Figure 51, the jarosite precipitates along the surfaces of a large bridging void was discovered while digging the profile, which is a common indicator of a sulfuric horizon (Soil Survey Staff, 2010).

Post-SMCRA site 5 also had an accumulation of jarosite on the surfaces of mine spoil fragments in the bottom horizon, however the horizon does not meet the requirements of a sulfuric horizon or even as having sulfidic materials. The precipitated jarosite has remained on the surfaces of rocks lining bridging voids since a time when the horizon may have been actively oxidizing pyrite and producing sulfuric acid, though it is no longer. The classifications of Post-5 and Post-6 differ in the same ways as the two classification schemes have differed in many of the BSF minesoils. The ICOMANTH amendments add descriptors for human-transported materials that do not meet the qualifications to be classified as any of the other proposed HAHT materials classes. Post-6 has a simple classification due to the fragmental particle-size class, meaning that approximately less than 10% fine materials make up the volume of this profile. Post-6 was dug from a large reddog pile, which is burned carbolithic materials that are essentially stable and inert. Because they are so stable, pyrolithic materials, as they were designated by Sencindiver (1978), weather slowly and thus often contain few fines unless soil materials are intentionally mixed in.

The more complicated classification of post-SCMRA site 7 is due to the occurrence of adjacent horizons with two strongly contrasting particle-size classes, as can be clearly seen in Figure 52. In *Soil Taxonomy,* the ability to separate horizons that would have two distinctly different particle-size classes if considered separately is important in order to distinguish important changes in “pore-size distribution or composition that are not identified in higher soil categories and that seriously affect the movement and retention of water and/or nutrients” (Soil Survey Staff, 2010). In the case of Post-7, an extremely channery clay overlies a horizon with a sandy loam texture, thus in the particle-size class, both are recognized. Both mineralogy classes are also recognized if they are different. For the cation-exchange activity class, only the horizon with the highest amount of clay is classified. The ICOMANTH classification again adds knowledge that this soil is forming in HTM falling into the spolic HAHT materials class.

Post-SMCRA site 8 was composed of soil and other materials that had been removed from the surface during mining and replaced one the operation was finished. The soil met both the requirements for base saturation and the presence of free carbonates to fall into the Eutrudept great group. The surface horizons met the color and carbon requirements for a mollic or umbric epipedon. The presence

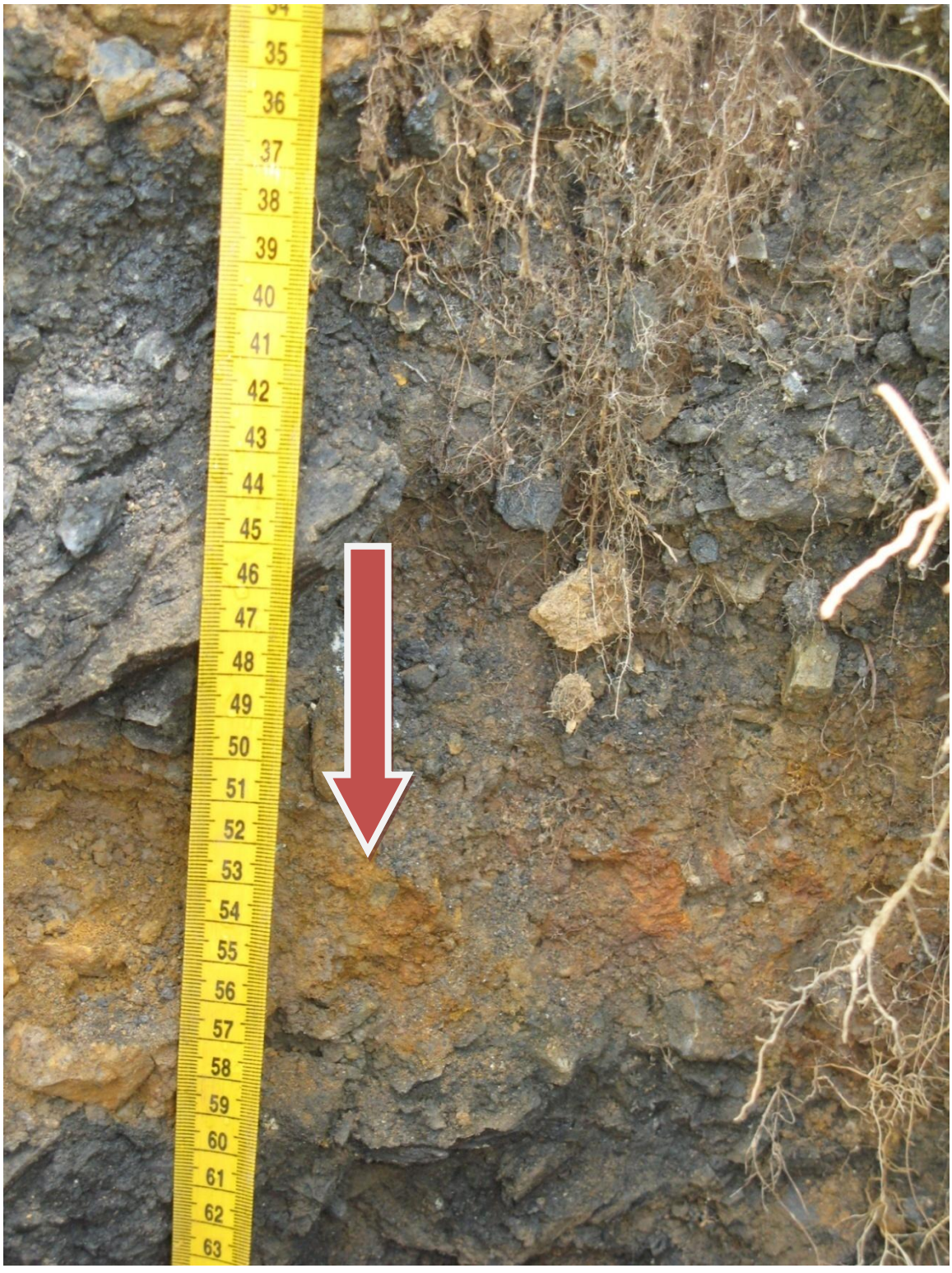


Figure 51. Jarosite accumulation (indicated by red arrow) found in bridging void from post-SMCRA profile 4.

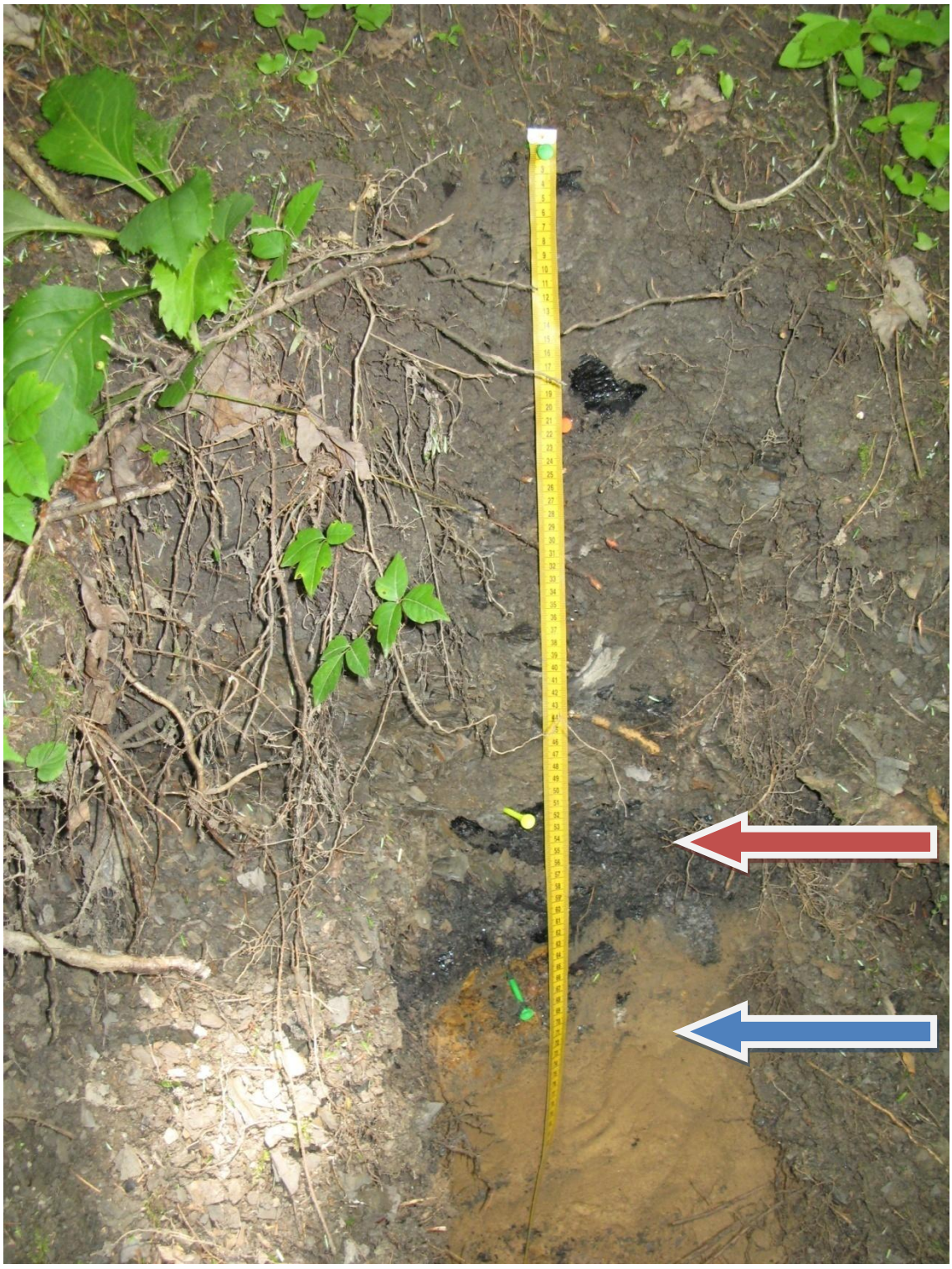


Figure 52. Strongly-contrasting horizons in post-SMCRA profile 7 (indicated by red and blue arrows).

of these properties placed this soil in the Humic subgroup. Within the ICOMANTH proposed classification, this profile was in a separate subgroup than the other minesoils thus far from this project. This profile was mostly composed of mineral soil materials with just a few sharp, splintered fragments of coal, as opposed to the Anthroportic subgroup in which buried genetic soil horizons are identified or bridging voids may occur between the loosely dumped spoil rock fragments, etc. The Anthraltic subgroup was used here because although there were only few spoil fragments within the profile, it was apparent by abrupt lateral changes at the edges of the landform that this soil material was human-altered.

Post-SMCRA site 9 was quite different than any other minesoil examined during the course of this research project. Extensive reclamation efforts had been made on this site but with few results compared to adjacent areas, as seen in Figure 53 (top). After quickly removing a thin, sludgy, gleyed surface horizon, it took much longer to dig only another 60 cm. The area had obviously been severely compacted in an effort to bury pyritic-S bearing coal mine spoils (Figure 53- bottom). Large rock structure can be easily discerned in the profile, but was so disintegrated that it was completely non-cemented. The surface horizon had a gleyed matrix, as did much of the subsurface, which began turning red almost as soon as it was exposed to air. This soil was classified in *Soil Taxonomy* as a Typic Fluvaquent, which does reflect the true nature of the aquic conditions found at the site. The pairing with a "Fluv" great group would lead one to believe that this was a floodplain soil that maintained aquic conditions through some part of the year. In the case of this soil, the ICOMANTH classification reveals several properties that the *Soil Taxonomy* classification does not. The Anthroportic subgroup reveals that this soil is forming in HTM. Because the soil is not irrigated or tilled, however, it could not fit into the Anthraquic suborder, which would have better reflected the extent of the aquic conditions. They are reflected however in the *aquadensic* family class that reflects its extensive densic contact and also aquic conditions within 50 cm of the soil surface.

Although the amendments to *Soil Taxonomy* proposed by ICOMANTH provided a more informative description of the unique properties of the coal minesoils of the BSF in almost every case, there were still instances where the amendments could be adjusted to better serve the inclusion of these soils. The first suggested amendment to those proposed in the *7th Circular Letter* is the inclusion of "Haplic" options for the Anthraltic, Anthraquic, and Anthroportic proposed subgroups to be used throughout taxonomy. Plaggic subgroups already have a proposed "Plagghaplic" subgroup option to



Figure 53. (a. top) Ineffective (red arrow) and effective reclamation (blue arrow). (b. bottom) Compacted horizons with rock-structure (green arrow).

represent soils with a thin plaggen epipedon. This is important for many minesoils whose epipedons are too thin to be classified in such a way that reflects their formation in mine spoil materials. Three of the eighteen minesoils found in the BSF ended up with classifications which in no way reflected their anthropogenic surface deposits of coal mine spoil. The proposed "Haplanthraltic", "Haplanthraquic", and "Haplanthroportic" would include the following distinction (shown in red):

> (Haplanthraltic, Haplanthraquic, Haplanthroportic) "…..have a surface horizon 25 cm to 50 cm thick that meets all the requirements for an (Anthraltic, Anthraquic, Anthroportic) subgroup except thickness."

Additional subgroups will likely be added in the future to accommodate other forms of anthropogenic soil materials.

Also proposed is the inclusion of eight additional HAHT materials classes, to be based upon the classes of dominant lithology proposed by Sencindiver and Ammons (2000) and seen in Table 30. The creation of individual HAHT materials classes to establish dominant lithology of soils forming in HAHT materials may have been avoided intentionally by ICOMANTH with the intent to make such separations within established and new soil series. As stated earlier however, the family level of classification in *Soil Taxonomy* is used to distinguish soils within a subgroup having additional properties that describe the parent materials or ambient conditions (Eswaran et al., 2003). Because parent materials have potentially the heaviest influence on the chemical properties of minesoils (Sencindiver and Ammons, 2000), along with rate of weathering, including additional information about them at the family level seems appropriate. Further, soil series are reserved for soils of small and localized extent. Minesoils, as discussed earlier, cover large areas in many different countries, but often share the same composition as those found in BSF derived from Pennsylvanian-aged geologic materials.

The next proposal is the creation of an additional reaction class for *superacid* soils that could prove useful to individuals working with soils of extremely low pH. The added class would appear on page 309 of *Keys to Soil Taxonomy* (11th ed.), *under Keys to Calcareous and Reaction Classes*, as follows (addition shown in red):

> "B. Other listed soils that, in the fine-earth fraction, effervesce (in cold dilute HCl) in all parts of the control section **Calcareous**
>
> C. Other listed soils with a pH of 3.0 or less in 0.01 M $CaCl_2$ (1:2) (about 3.5 in H_2O, 1:1) in any part of the control section
>
> **Superacid…."**

Table 30. Proposed additions to the Human-altered and Human-transported Material Classes proposed by ICOMANTH.

Family Class*	Key
Carbospolic	More than 60 percent (by volume) black, high carbon rock (e.g. coal or high carbon shales)
	Or-
Combuspolic	More than 60 percent (by volume) coarse fragments of burned carbolithic material (e.g. reddog) that have diameters of 2.0 mm or more (L. *comburere*. To burn up)
	Or-
Fissispolic	More than 60 percent (by volume) fragments of thin-bedded shale that have diameters of 2.0 mm or more
	Or-
Kalkispolic	More than 60 percent (by volume) fragments of limestone or calcareous mudstone that have diameters of 2.0 mm or more
	Or-
Regospolic	More than 60 percent (by volume) coarse fragments of sandstones with grain size greater than 0.05 mm and have interior chroma greater than 2.
	Or-
Plattispolic	More than 60 percent (by volume) coarse fragments of sandstones with grain size greater than 0.05 mm
	Or-
Schlickispolic	More than 60 percent (by volume) coarse fragments of nonfissile mudstones greater than 2.0 mm or more
	Or-
Matrispolic	Less than 10 percent (by volume) coarse fragments that have diameter of 2.0 mm or more
	Or-
Spolic	Other soils formed in human-transported material.
	Or-
	All other soils: No human-altered or human-transported material class required.

*** Based on classes of dominant lithology presented by Sencindiver & Ammons (2000).**

This amendment would help emphasize high acidity in soils with extremely low pHs in the control section. In soils, pH is a master variable meaning that it controls many of the chemical and biological reactions that speed or slow the development of soil. Once the pH falls below 4.5, root growth in most plants stops; many of acidic minesoils can have a pH below 3. When this extreme acidity reacts with the spoil and overburden materials nearby, any metals that are present can be solubilized and either precipitate into the soil environment or, if the pH remains sufficiently low, leach into the local watershed. Waters and soils affected by acid mine drainage can contain high concentrations of elements including Fe, Mn, Al, SO4, along with trace elements including Cr, Cu, Ni, Se, and Zn. Several of these can reach phytotoxic levels even in relatively small concentrations. For all of these reasons, knowledge of a horizon with extremely low pH within the control section of a soil should be reflected in its classification.

Because many minesoils contain buried genetic horizons or are themselves covered with a surface mantle of new soil materials, the reaction class that gets added to the family name may be a poor representation for parts of the minesoil profile if the buried soil or mantle has a reaction class significantly different than the soil. This is because depending on the depth of the surface mantle of new material, one may classify the new soil or the original buried soil. In the particle-size classes, this problem is handled by the ability to distinguish *strongly contrasting* particle size classes by determining the class for each and listing them both. The use of *strongly contrasting* classes is also applied to mineralogy classes. The next proposed addition to the ICOMANTH amendments would be included on page 308 to be placed between *Calcareous and Reaction Classes of Mineral Soils* and *Use of the Calcareous and Reaction Classes* (additions shown in red):

> "….There are five classes-calcareous, super-acid, acid, non-acid, and allic. These are defined later, in the key to calcareous and reaction classes. If two or more soil horizons within the control section have strongly contrasting pH (differ by more than 2.5 pH units [1:2_{Cacl2}] and if considered individually would fall into separate reaction classes), the calcareous and reaction classes are to be determined for each horizon and are to be listed as one "over" the other (e.g. calcareous over super-acid). If horizons would fall into separate classes but do not differ by more than pH 2.5, the pH to determine family class by is the weighted average of those in the control section. For example, within 25-100 cm of the soil surface, there occurs horizonation with descending pHs of 5.8, 3.4, and 2.4; the family name would be listed as *non-acid over super-acid*….."

Directly beneath this in the explanations of which families and orders are to be assigned this family class, the following addition is proposed (additions shown in red):

> "…The calcareous, super-acid, acid, and non-acid classes are used in the names of the families of Entisols, Gelisols, Aquands, Aquepts, and all Gelic suborders and Gelic great groups, as well as in all Anthraltic, Haplanthraltic, Anthraquic, Haplantraquic, Anthroportic, Haplanthroportic, Plaggic, and Plagghaplic subgroups, except they are not used in any of the following…"

This amendment would change the family-level classifications of several of the minesoils found in the BSF (as seen in Table 31), including those of Pre-9, Post-1, and Post-2.

These simple and small additions, if approved along with the proposed amendments made by ICOMANTH, could make the classification of coal minesoils in the Appalachian coal mining regions much more descriptive and informative. Table 31 shows the classifications for all eighteen minesoils studied in the BSF according to *Soil Taxonomy,* according to the proposed ICOMANTH amendments (shown in red), and according the additions proposed in this project (shown in green). For most sites, the classification is adjusted to include a more descriptive human-altered and human-transported materials class, except for pre-SMCRA site 5 and post-SMCRA sites 5, 8 and 9. The first three were not adjusted from the ICOMANTH proposals because the spoil materials were highly mixed and variable, with no dominant rock type. The last one, post-SMCRA site 9, was not adjusted because its HAHT materials class fell out into the aquadensic class, occurring before those for spolic materials. The slight modifications providing the dominant lithology (where one occurs) is an important feature for those working with these mined and/ or reclaimed lands. As discussed earlier, the nature of the parent materials has a large impact on the development of young soils due to their breakdown and the release of nutrients and/or metals into the soil. Depending on the materials breaking down, the pH of the soil can be greatly impacted which again, is a master variable and controls much of the soil chemistry.

The adjustments to the calcareous and reaction classes can also be seen in many classifications: pre-SMCRA sites 1, 7, 8 and 9, and post-SMCRA sites 1, 2, 4, 5, 8, and 9. Some are the same classes into which the profiles would be classified in *Soil Taxonomy* as it currently exists (and also according to the proposals by ICOMANTH), but the order, great and subgroups of the soils keep this class from being assigned, as in pre-SMCRA site 9 and post-SMCRA sites 1, 2, and 8. Post-SMCRA sites 4 and 5 also would

Table 31. Classification of BSF minesoils using Keys to Soil Taxonomy (2010),propsed amendments by ICOMANTH (Galbraith, 2011) (shown in red), and additional amendments by Jones (shown in green).

Profile	*Soil Taxonomy*	ICOMANTH	Jones et al.
Pre-1	loamy-skeletal, mixed, super-active, non-acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, super-active, non-acid, mesic Anthroportic Udorthent	loamy-skeletal, carbospolic, mixed, super-active, non-acid over super-acid, mesic Anthroportic Udorthent
Pre-2	loamy-skeletal, mixed, active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, active, acid, mesic Anthroportic Udorthent	loamy-skeletal, carbospolic, mixed, active, acid, mesic Anthroportic Udorthent
Pre-3	loamy-skeletal, mixed, super-active, calcareous, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, super-active, calcareous, mesic Anthroportic Humic Udorthent	loamy-skeletal, carbospolic, mixed, super-active, calcareous, mesic Anthroportic Humic Udorthent
Pre-4	loamy-skeletal, mixed, semi-active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, semi-active, acid, mesic Anthroportic Humic Udorthent	loamy-skeletal, fissispolic, mixed, semi-active, acid, mesic, Anthroportic Humic Udorthent
Pre-5	loamy-skeletal, mixed, active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, active, acid, mesic Anthroportic Humic Udorthent	loamy-skeletal, spolic, mixed, active, acid, mesic Anthroportic Humic Udorthent
Pre-6	loamy-skeletal, mixed, semi-active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, semi-active, acid, mesic Anthroportic Udorthent	loamy-skeletal, carbospolic, mixed, semi-active, acid, mesic Anthroportic Udorthent
Pre-7	loamy-skeletal, mixed, active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, active, acid, mesic Anthroportic Udorthent	loamy-skeletal, carbospolic, mixed, active, super-acid, mesic Anthroportic Udorthent
Pre-8	loamy-skeletal, mixed, active, acid, mesic Typic Udorthent	loamy-skeletal, spolic, mixed, active, acid, mesic Anthroportic Humic Udorthent	loamy-skeletal, carbospolic, mixed, active, super-acid, mesic Anthroportic Humic Udorthent
Pre-9	fine-loamy, mixed, semi-active, mesic Typic Hapludult	fine-loamy, mixed, semi-active, mesic Typic Hapludult	fine-loamy, regospolic, semi-active, acid, mesic, Haplanthroportic Hapludult

Table 31. Continued. Taxonomic classification of BSF minesoil profiles using *Soil Taxonomy,* proposed amendments by ICOMANTH (shown in red), and additional proposed amendments by Jones et al. (2011) (shown in green).

Profile	*Soil Taxonomy**	ICOMANTH†	Jones et al.‡
Post-1	fine-loamy, mixed, semi-active, mesic Mollic Hapludalf	fine-loamy, mixed, semi-active, mesic Mollic Hapludalf	fine-loamy, carbospolic, semi-active, acid, mesic Haplanthroportic Mollic Hapludalf
Post-2	fine-loamy, mixed, active, mesic Mollic Hapludalf	fine-loamy, mixed, active, mesic Mollic Hapludalf	fine-loamy, carbospolic, active, non-acid, mesic Haplanthroportic Mollic Hapludalf
Post-3	loamy-skeletal, mixed, semi-active, calcareous, mesic Typic Udifluvent	loamy-skeletal, spolic, semi-active, calcareous, mesic Anthroportic Udorthent	loamy-skeletal, plattispolic, semi-active, calcareous, mesic Anthroportic Udorthent
Post-4	loamy-skeletal, mixed, semi-active, mesic Typic Sulfudept	loamy-skeletal, spolic, semi-active, mesic Anthroportic Sulfudept	loamy-skeletal, carbospolic, semi-active, calcareous over super-acid, mesic Anthroportic Sulfudept
Post-5	loamy-skeletal, mixed, super-active, mesic Typic Eutrudept	loamy-skeletal, spolic, mixed, super-active, mesic Anthroportic Eutrudept	loamy-skeletal, spolic, mixed, active, calcareous over acid, mesic Anthroportic Eutrudept
Post-6	fragmental, mixed, mesic Typic Udorthent	fragmental, spolic, mixed, mesic Anthroportic Udorthent	fragmental, combuspolic, mixed, non-acid, mesic Anthroportic Udorthent
Post-7	clayey-skeletal over coarse-loamy, mixed over siliceous, subactive, non-acid, mesic Typic Udorthent	clayey-skeletal over coarse-loamy, spolic, mixed over siliceous, subactive, non-acid, mesic Anthroportic Udorthent	clayey-skeletal over coarse-loamy, carbospolic, mixed over siliceous, subactive, non-acid, mesic Anthroportic Udorthent
Post-8	loamy-skeletal, mixed, semi-active, mesic Humic Eutrudept	loamy-skeletal, spolic, mixed, semi-active, mesic Anthraltic Humic Eutrudept	loamy-skeletal, spolic, mixed, semi-active, non-acid, Anthraltic Humic Eutrudept
Post-9	fine-loamy, mixed, super-active, acid, mesic Typic Fluvaquent	fine-loamy, aquadensic, mixed, super-active, acid, mesic Anthroportic Udorthent	fine-loamy, aquadensic, mixed, super-acid, mesic Anthroportic Udorthent

not be assigned calcareous and reaction class names based on their orders but do according to the proposals from this project. They also have strongly contrasting pH classes (as proposed above) so they are assigned both class names. These changes are important because soils forming in HAHT materials can still be classified in orders other than Entisols based on the properties of a buried soil which may not reveal important information regarding the pH-status of these materials.

Finally, the adjustments proposed to the ICOMANTH amendments would alter the ICOMANTH classifications of pre-SMCRA site 9 and post-SMCRA sites 1 and 2 because these soils were classified based on the properties of a buried soil beneath a surface mantle of new soil materials. These did not previously qualify to be included in the proposed HAHT subgroups of the *7th Circular Letter* based on the depth of the HAHT materials, which could greatly impact the interpretation of these soils in survey and mapping uses. For example, in the classifications of post-SMCRA sites 1 and 2, a land user reading the soil survey or map of this area would believe, according to the current *Soil Taxonomy* and the ICOMANTH classifications, that they were dealing with a naturally forming Alfisol (higher base than Ultisols but still relatively well weathered) that had a deep or dark epipedon forming from the breakdown of large quantities of organic materials which has imparted the dark colors required for the Mollic subgroup. This is corrected by classifying the soils using the proposals from this project by the inclusion of these soils in the Haplanthroportic subgroups. The surface mantle of new soil materials (mine spoils) was less than 50 cm deep and therefore did not qualify to be in the anthropogenic subgroups proposed by ICOMANTH. Further, this same 50 cm requirement kept them from receiving even a HAHT materials class assignment.

While the proposals of ICOMANTH and the additional proposals seen here will certainly not guarantee accurate, informative, and descriptive classifications for all anthropogenic soils, it is clear that they would at least provide an improvement to the classifications of the coal minesoils in the BSF, and likely those of coal minesoils elsewhere. The proposals made here are not revolutionary in that they would not change many of the concepts and intentions of *Soil Taxonomy* as it exists today. One major way in which the original intent would change, however, is the acceptance of the use of historical record for the identification of certain anthropogenically-created or altered soils. This should be acceptable, however, if restricted to be used only in soils falling within the anthropogenic suborders and HAHT materials classes. This exception should be made because of the outcry from land users and resource managers to be able to differentiate these HAHT soils from native soils during soil surveys and soil mapping.

Conclusions

1. The current classification scheme presented in the second edition of *Soil Taxonomy* and the eleventh edition of *Keys to Soil Taxonomy* used in the United States is inadequately equipped to descriptively classify anthropogenically-altered or created soils, including coal minesoils.
2. The addition of new terms and diagnostic features, five new subgroups, and a new family class of human-altered and human-transported materials, as proposed by the International Committee for Anthropogenic Soils (ICOMANTH) in their *7th Circular Letter*, more descriptively classifies anthropogenic soils than *Soil Taxonomy* as it currently exists. Nonetheless, weaknesses were found when classifying coal minesoils of the BSF, including:
    a. the exclusion of soils with a surface mantle of HTM < 50 cm thick from being recognized as forming in HAHT materials;
    b. the lack of information concerning the dominant lithology of soil materials;
    c. and the recognition of extremely acidic horizons within the control sections of soils.
3. To address the inadequacies of the ICOMANTH proposals to accurately reflect important properties of a soil to land users, recommendations based on the data collected in this project include:
    a. addition of another three subgroups to the new five subgroups proposed by ICOMANTH: Haplanthraltic, Haplanthraquic, and Haplanthroportic. These would ensure the separation of anthropogenic soils which must be classified according the properties of buried soils, but which have significant depositions of human-altered and/or human-transported (HAHT) materials in surface horizons;
    b. require soils within Haplanthraltic, Haplanthraquic, and Haplanthroportic subgroups, as well as those within the proposed Anthraltic, Anthraquic, and Anthroportic subgroups (as proposed by ICOMANTH) and all soils containing HAHT diagnostic materials to receive reaction class family names;
    c. addition of a new reaction class at the family level of *super-acid*, which would reveal to land users that some horizon within the upper 100 cm of a soil has a pH less than or equal to 3.0 by $1:2_{CaCl2}$ (this is useful because many land users are not agriculturalists

and may be interested in establishing deeply-rooted plant species such as forests or tall-grass prairies); and finally

d. addition of eight new HAHT materials classes to be added to those created by ICOMANTH, which would specify the dominant lithology of spolic materials.

4. Classifying coal minesoils in the BSF according to the proposed changes to *Soil Taxonomy* by ICOMANTH and the new amendments in this project resulted in the more accurate, descriptive, and informative classification of these anthropogenic soils.

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CONCLUSION

The Big South Fork National River and Recreation Area (BSF) is host to thousands of visitors every year. This "Yellowstone of the East" spans more than 100,000 ha across Tennessee and Kentucky and provides many outdoor adventure opportunities including hiking, horseback riding, kayaking, fishing, hunting, and much more. Because the Big South Fork River is one of only two recognized national rivers, and because it is the only home to several endangered aquatic species, protecting this river has been a priority of the National Park Service for more than three decades. This has been challenging because much of the park was mined for coal in the early to mid-1900s, during which time hundreds of spoil piles and refuse dumps were abandoned and acid mine drainage left untreated. In Part One of this research project, the physical and chemical characterization of the more than thirty minesoils and spoil piles located within the park boundaries identified many unique properties of these soils when compared to native soils nearby. Important findings included the discovery that several former spoil dump areas which had been reclaimed still had many properties similar to those minesoils which have not been reclaimed. This indicated that reclamation efforts on these sites were not completely successful and that future efforts may need to be made. Further, findings indicated that although many pre-SMCRA minesoils have never been reclaimed, most do not post environmental or human health hazards and are not actively producing acid mine drainage. Because some of these piles are surrounded by well-forested areas, the recommendation is to leave them undisturbed to avoid re-exposure of pyritic-sulfur containing materials that may begin to produce acid mine drainage again if exposed. This information provided the NPS with information that is crucial to creating an informed priority list of sites that need to be reclaimed in the future due to their acid-producing potential.

In Part Two, it was determined that *Soil Taxonomy* does not provide adequately informative classifications of the coal minesoils in the BSF. It was further determined that implementing the recommendations of the International Committee of Anthropogenic Soils to amend *Soil Taxonomy* does provide more descriptive classifications, however several shortcomings were noted. New amendments to be added to those presented by ICOMANTH in order to improve the classifications of coal minesoils included the creation of three additional extragrade subgroups to be added to those proposed which would be added throughout *Soil Taxonomy*. Further, any soil forming in human-altered or human-transported materials (as defined by ICOMANTH) should receive a reaction class name to the family name. A new reaction class of *superacid* is also proposed because any soil horizon within the control

section of a soil with a pH less than 3 would present challenges to reclamation or revegatation and should be recognized at the family, not the series level of classification. Finally, eight new human-altered and human-transported materials sub-classes to distinguish dominant lithology of those soils falling within the *spolic* class would be helpful to land users, as these materials heavily influence the development of soils and potential land uses.

APPENDIX A

Proposed Revisions to the future 12th Edition of Keys to Soil Taxonomy
Based on: ICOMANTH (International Committee for Anthropogenic Soils) Circular Letter 7. Dr. John M. Galbraith, Virginia Tech
May 16, 2011

Proposed Revisions to the future 12th Edition of Keys to Soil Taxonomy
Based on: ICOMANTH (International Committee for Anthropogenic Soils) Circular Letter 7. Dr. John M. Galbraith, Virginia Tech.

Black text in quoted text marks existing text in the 11th Ed. of the Keys, red text marks proposed insertions, and strikethrough mark proposed deletions.

Chapter 1. Changes Within the Definition of Buried Soils1Chapter 3. Changes to Horizons and Characteristics of Mineral soils
Revise: Epipedons 1

Changes to Diagnostic Horizons and Features for Both Organic and Mineral Soils
Add: Artifacts 6
Add: Human-altered Material 6
Add: Human-transported Material 7
Add: Manufactured Layer 10
Add: Manufactured Layer Contact 10
Add: Surface Mantle of New Soil Material 10

Chapter 4. Changes to the Key to Soil Orders 11

Chapter 5-16. Changes to Keys of Multiple Orders 12

Throughout Soil Taxonomy
Modify: Irregular Decrease in OC Criteria 16
Add: New Subgroups for Human-Altered and Human–Transported Soils 17

Chapter 17. Changes to Family Criteria
Add: Human-altered or Human-transported Material Class 18
Modify: List of Root-limiting Layers 22

Appendix. Add: Literature Cited Reference 23

Background:

These proposals originate from Circular Letter 7 of ICOMANTH (International Committee for Anthropogenic Soils), a committee commissioned by USDA NRCS in 1988 to introduce differentiae and taxa for classification and survey of observed human-altered and human-transported (HAHT) soils. These soils form through profound, intentional alteration or transportation of materials, and do not include soils altered unintentionally or chemically treatment standard production agriculture practices. The charge of the committee was to introduce what have been called *anthropogenic soils* by others into US Soil Taxonomy, to facilitate mapping of urban areas, introduce new terms and materials into NASIS, allow meaningful interpretations for unique materials and soils, and ease establishment and correlation of new soil series. The adjectives human-altered and human-transported are preferred because all soil genesis processes are natural. Humans may generate new materials and add them to the environment, but humans only affect, they do not generate biogeochemical processes in natural settings where soils form (pointed out by Hari Eswaran, personal communication). These proposals attempt to distinguish HAHT soils from other soils based on field properties, a challenge posed by Richard "Dick" Arnold.

An important aspect of Soil Taxonomy is that establishing soil series is easier if no new taxa above the family level must be created beforehand. Proposing a new series while proposing a new taxa at order, suborder, great group, or subgroup level requires supportive data and lengthy review, and still requires additions of classes at the family level to support important separations and produce unique interpretations. Interpretations for mapping are not based on higher taxa, but rather on properties recognized at the family level and below.

Meanwhile, tentative series are "misclassified" into a taxon that is seldom appropriate, then they are reclassified at establishment. This is not conducive to progressive correlation during soil mapping. Adding a new family class for HAHT soils rather than trying to make them fit into classes created for prototypic (from Greek *prōtos,* first, ancestral, original) soils. Proposing new soil series by choosing among HAHT family classes, however, can be done easily and rapidly, with correlation and review conducted in a regionally-structured USDA-NRCS setting. Once established and data collection begins, the appropriate subgroup from a proposed set of standard choices is possible, and is supported by data.

There is no intent to introduce a new soil order (a top-down approach). A top-down approach leads to branching and proliferation of taxa in order to reach the series level. The HAHT soils undoubtedly occur in all orders except Mollisols. The proposed changes will take place by adding new diagnostic materials characteristics and terms, at the subgroup and family level, leading to easy establishment of soil series. The intent of these proposals are to introduce taxa at family and subgroup levels only, a bottom-up approach. The bottom-up approach allows multiple choices of family classes to differentiate series in urban and rural landscapes, yet minimizes proliferation of new taxa. The bottom-up approach preserves existing taxa and concepts at higher levels that are proven, and does not lead to the splitting of existing series concepts. However, as we correlate and add new series, produce soil surveys, populate data in NASIS, and add standards in the USDA-NRCS soil survey program, the subgroups for HAHT soils *can later* be separated at higher levels of the classification system.

Although emphasis is placed on the USDA-NRCS soil survey program, the proposed changes should apply globally. Supporting and improving the system that supports and updates soil taxonomy has allowed it to be useful in increasingly more countries, proof that the concept is valid and not exclusive to global use. The proposals will make it easier for new users of soil taxonomy to begin using the system and propose soil series and produce interpretive maps. A very important basis for these proposals is that when a Universal Soil Classification system is created, it will require correlation between systems. Finding HAHT soils would be confusing if almost all are classified at various levels of taxa from suborder through subgroup. Finding HAHT soils would be even more difficult if they are recognized only at the series level. There are almost 24,000 series and no facility to consistently identify to identify if they contain evidence of human-altered or human-transported properties besides individual inspection. However, it will be easy to query for and then correlate these soils if they occur in meaningful family classes and a few standard subgroups.

Summary of proposed changes:

1. Soil series in the USDA-NRCS soil classification database reveal that established and tentative series exist in only a few taxa set up for HAHT soils, primarily in Arents suborder. The Torriarents and Xerarents are deeply plowed agricultural soils, while Ustarents and Udarents form in mine or dredge soil. Arents group soils that have little in common. This proposal would move those soils to a subgroup and family level of recognition but preserve their concepts, limits, and use on existing maps.
2. There are other mine soils in the Udorthents great group, many in the Typic subgroup. Series from urban surveys are tentatively set up as Typic Udorthents or Typic Dystrudepts. These proposals will allow specificity and narrow interpretation groups.
3. There are HAHT soils that fit existing criteria for epipedons that they were not intended to qualify for. Proposed revisions will make the epipedons other than plaggen and anthropic exclusive of HAHT materials. The definition of anthropic epipedon has been revised, but it is too broadly defined. Rather than adding four new types of anthropic epipedons, and causing revisions in existing keys, high and low carbon varieties can be recognized at subgroup levels.
4. Many HAHT soils are recently altered and have buried horizons and irregular decreases in organic carbon with depth. The criteria that would lead to identification in Fluvents suborder, Fluventic, and Cumulic subgroups have been modified to prevent misleading inclusion with water-transported materials.
5. New materials and characteristics are proposed for chapter 3, a major modification to the definition of buried soils, a new family class, and a standard set of subgroups are proposed that easily identify soils as HAHT.

There have been 7 circular letters distributed internationally. The 7th Circular letter, and any revisions to the proposals within, is the last circular letter. Earlier letters introduced new terms, new horizon nomenclature, and new standards into NASIS that complimented existing standards or added to them. Those changes have been tested and found acceptable. This set of proposed changes includes reference to changes in an ad-hoc proposal to amend Part 629 (Glossary of geomorphic Terms) in the National Soil Survey Handbook and NASIS. With these proposals, ICOMANTH will conclude activity. The 7th Circular is the cumulative endpoint of over 14 years of efforts, numerous publications, and several soil surveys from many contributors. Further work will be needed to improve the proposed HAHT family classes, clarify how they are to be measured and identified, revise their order or add new ones, and refine description of artifacts. These proposals must be tested to see if they support a system for making and interpreting soil surveys.

CHAPTER 1. CHANGES TO THE DEFINITION OF "BURIED SOILS"

Purpose: Update the definition of buried soils. Background: The changes are to clarify the three distinct types of materials and deposits that overlie a buried soil. The three types are: a plaggen epipedon (always 50 cm or more thick); a deposit of human-transported material 50 cm or more thick; or a surface mantle of new soil material of 30 to 50 cm thickness. The first two of these are human -transported materials, the last is a recent deposit of soil material (e.g., a recent floodplain deposit) that meets the definition of a "surface mantle" in Soil Taxonomy. Presently, only the mantle and a plaggen epipedon are part of the definition of material above buried soils. The plaggen epipedon as defined meets the definition of human-transported material as proposed in this document. Other human-transported materials over buried diagnostic horizons fulfills the same intent in identifying buried soils as originally defined in Soil Taxonomy, and should be added to the list, with a minimum thickness the same as the plaggen epipedon. A sliding thickness is set up for a mantle of new material, and the definition of a mantle requires the presence of C horizon material at the base. No such requirement is needed for plaggen epipedon or human-transported material because they contain other diagnostic evidence. It seems simpler to users to set the minimum thickness of materials to a standard 50 cm. I do not anticipate any changes to existing soil series or splitting of existing series.

Proposed Action 1: Change the following parts of the definition of buried soils on page 2.

"A buried soil is composed of one or more genetic horizons which are covered with *one* of the following:
1. A plaggen epipedon; *or*
2. A deposit of human-transported material 50 cm or more thick; *or*
3. A surface mantle of new soil material (defined below). ~~a surface mantle of new soil material that either is 50 cm or more thick or is 30 to 50 cm thick and has a thickness that equals at least half the total thickness of the named diagnostic horizons that are preserved in the buried soil.~~ The minimum thickness of the ~~a~~ mantle is *either*:
   a. 50 cm~~or more~~; *or*
   b. 30 to 50 cm, and this thickness equals at least half the total thickness of the named diagnostic horizons that are preserved in the sequence of buried genetic soil horizons.

A surface mantle of new soil material that does not meet the minimum thickness for buried soils can be used to establish a phase of the mantled soil or even another soil series if the mantle affects the use of the soil.

~~Any horizons or layers underlying a plaggen epipedon are considered to be buried.~~"

CHAPTER 3. CHANGES TO HORIZONS AND CHARACTERISTICS OF MINERAL SOILS

1) **Purpose: Update and standardize definitions of anthropic, mollic, plaggen and umbric epipedons with regards to artifacts and phosphorus**. Background: All parts of anthropic epipedons are required to be moist for less than 90 days (cumulative) in normal years during times when the soil temperature at a depth of 50 cm is 5 ^{o}C or higher, unless the soil is irrigated. Mollic epipedons are required to be moist for 90 days (cumulative) or longer without irrigation. This was introduced to prevent some irrigated fields in arid areas from being mollic, even if they met all

other mollic criteria. Human-transported materials with properties of a mollic epipedon were also meant to be excluded. However, the definition of mollic and anthropic epipedons are not exclusive as now written. The moisture requirement does not allow anthropic epipedons to be identified on kitchen middens or shell mounds in areas where they are moist and are not irrigated, even though theses soils are known to occur in moist climates. Since mollic epipedons must be moist if not irrigated, there is no need to limit anthropic epipedons by moisture or irrigation criteria.

Artifact presence is part of the definition of a plaggen epipedon, but not an anthropic epipedon, where they are often found in even greater abundance. Anthropic and mollic epipedons have considerable overlap in physical and chemical properties, and absence of artifacts in mollic epipedons can be used to distinguish the two more reliably than measuring Phosphorus (P) content. Artifact presence should be added to Anthropic epipedons in place of P criteria, and prevented in mollic epipedons in place of P criteria. There is no evidence that any P content limit can reliably separate anthropic from mollic and umbric epipedons, especially because of high rates of manure (e.g., poultry litter) being applied in some fields, and because some soils form over high-phosphate bedrock.

There is an apparent flaw in logic where mollic and umbric are allowed to have irregular decrease in P with increasing depth below the epipedon, whereas the anthropic is not. Lab data demonstrates that an irregular change in P content below the surface is normal for kitchen midden soils by their nature of deposition and formation, so a revision is needed. An original intent of Soil Taxonomy was to identify anthropic epipedons based on higher P content due to human inputs relative to epipedons like mollic and umbric. As currently written, there is no upper P limit on mollic or umbric provided that either the P content decreases irregularly with increasing depth below the epipedon, or nodules are within the epipedon. The problem is exposed when an anthropic epipedon with extremely high P content in a thick humid kitchen midden soil may meet all parts of the definition of a mollic epipedon but fail to meet the definition of an anthropic epipedon. Using P content to separate some mollic and umbric epipedons from some anthropic epipedons now seems to be a moot point that manures, biosolids, biochar, and P fertilizer are being applied at high rates on agricultural soils. The P criteria should be removed from both mollic, umbric, and anthropic and replaced with archaeological evidence (e.g., presence of artifacts) to separate profoundly human-altered or human–transported epipedons from mollic and umbric epipedons.

The properties of the anthropic epipedon are highly variable since they occur across the globe and form by a variety of processes over variable amounts of time. Therefore it does not seem necessary to limit the color or organic carbon properties of the diagnostic horizon or layer. The properties can be defined at the subgroup level or below (as they are for the ochric epipedon).

The following modifications preserves the intent of the definition of the former anthropic, mollic, plaggen, and umbric epipedons but are proposed to clearly separate the epipedons. The following changes keep recent over-application of manures and P fertilizers from changing epipedons and classification at the soil series and higher levels. Preservation of the classification of existing soil series and prevention of changing the classification of a soil by an agricultural practice in the plow layer is followed here.

<u>Proposed Action 2</u>: Insert the following definition before the required characteristics for the anthropic epipedon on page 5, inserted between the headers labeled “Anthropic Epipedon” and “Required Characteristics”.

Anthropic epipedons form in human-altered or human-transported material (defined below). They often occur on anthropogenic landforms and microfeatures as described in an ad hoc proposal to amend the National Soil Survey Handbook, *Part 629:* Glossary of Landform and Geologic Terms (e.g., fill or middens) or occur in human-transported materials above them. They may also occur in soils that have long-term usage for agriculture. The material that the anthropic epipedon forms in has not been modified by long-term manuring as the material in the plaggen epipedon has. A map unit delineation of soils with anthropic epipedons often have straight-sided, rectangular or geometric landscape units, or are higher than the adjacent soils by as much as or more than the thickness of the anthropic epipedon. The anthropic epipedon formed at the surface, but may now be old enough or buried so that some part now meets the definition of some other diagnostic horizon.

Proposed Action 3: Modify the definition of the anthropic epipedon on pages 5 and 6.

Anthropic Epipedon
Required Characteristics

The anthropic epipedon consists of mineral soil material that shows ~~some~~ evidence of ~~disturbance~~ intentional alteration by human activity. After mixing the properties of the upper 18 cm of the mineral soil, or of the whole mineral soil if its depth to a densic, manufactured layer, lithic, or paralithic contact, a petrocalcic horizon, or a duripan (all defined below) is less than 18 cm, the anthropic epipedon has the following properties:

1. When dry, has ~~*either or*~~ *both* of the following:
   a. Structural units with a diameter of 30 cm or less~~ or secondary structure with a diameter of 30 cm or less; *or*~~
   b. ~~A moderately hard or softer rupture-resistance class~~; *and*

~~2. Rock structure, including fine stratifications (5 mm or less thick), in makes up less than one-half of the volume of all parts, *and*~~ any rock structure present does not directly underlie either a plow player or a depth of 18 cm, whichever is deeper; *and*

2. Evidence of long-continued manuring in a human-made surface layer 50 cm or more thick is absent (i.e., does not meet the requirements of a plaggen epipedon); *and*
3. Consists of human-altered or human-transported material (defined below), and has *one or more* of the following:
   a. Artifacts in some part; *or*
   b. Evidence that being modified by human-applied organic amendments (e.g., surface applications of char, charcoal, or cooking ashes were made to enhance fertility or water-holding capacity) has sustainably altered the physical and chemical properties; *or*
   c. Anthraquic conditions; *and* …

~~5~~4. The minimum thickness of the epipedon is as follows:
   a. ~~10 cm if it is directly~~ The entire thickness of material above a densic contact, manufactured layer contact, lithic contact, paralithic contact, petrocalcic horizon, or duripan (all defined below) if one of these occurs within 25 cm of the soil surface; *or*
   b. 25 cm; *and*
   c. The horizon or layer directly beneath 18 cm or the plow layer (whichever is deeper) meets one of the requirements in part 3 of this definition; *and*
5. The soil does not meet both the color and organic-carbon content requirements of a mollic epipedon; *and*

~~6. ….~~

6. Has more organic carbon (excluding carbon older than Pleistocene-age) than a horizon below; and
7. The n value (defined below) is less than 0.7."

Proposed Action 4: Change item 7 of the definition of the mollic epipedon on page 8 **and the umbric epipedon** on page 9.

"**Mollic Epipedon**
Required Characteristics
The mollic epipedon consists of mineral soil materials not human-altered or human-transported material (defined below) and, …."

~~7. Phosphate:~~
~~a. Content less than 1,500 milligrams per kilogram by citric-acid extraction; *or*~~
~~b. Content decreasing irregularly with increasing depth below the epipedon; *or*~~
~~c. Nodules are within the epipedon; *and*~~

7. Does not contain *any* of the following:

a. Artifacts (more than incidental debris or trash) in some part; *or*
b. Evidence of being modified such that human-applied organic amendments (e.g., surface applications of bone for raising P levels, or char and charcoal produced by pyrolysis added to enhance fertility or water-holding capacity) profoundly altered the physical and chemical properties; *or*
c. Anthraquic conditions; *and*"

"**Umbric Epipedon**
Required Characteristics
The umbric epipedon consists of mineral soil materials not human-altered or human-transported material (defined below) and, …."

~~7. Phosphate:~~
~~a. Content less than 1,500 milligrams per kilogram by citric-acid extraction; *or*~~
~~b. Content decreasing irregularly with increasing depth below the epipedon; *or*~~
~~c. Nodules are within the epipedon; *and*~~
7. Does not contain *any* of the following:
a. Artifacts (more than incidental debris or trash) in some part; *or*
b. Evidence of being modified such that human-applied organic amendments (e.g., surface applications of bone for raising P levels, or char and charcoal produced by pyrolysis added to enhance fertility or water-holding capacity) profoundly altered the physical and chemical properties; *or*
c. Anthraquic conditions; *and*"

Proposed Action 5: Change the following parts of the definition of plaggen epipedon on page 8.

"The plaggen epipedon consists of mineral soil materials and meets the following:
1. ~~It~~ Occurs on l~~L~~ocally raised landforms ~~surfaces~~ (as described in an ad hoc proposal to amend the National Soil Survey Handbook, *Part 629:* Glossary of Landform and Geologic Terms) produced by long-term additions of manure *and* contains *one or both* of the following:
   a. Artifacts ; *or*
   b. Spade marks ~~below a depth of 30 cm~~throughout; *and*
2. Colors with a value of 4 or less, moist, 5 or less, dry, and chroma of 2 or less; *and*
3. An organic-carbon content of 0.6 percent or more throughout; *and*
4. A thickness of 50 cm or more of human-altered or human-transported materials derived from manure; *and*
5. Some part of the epipedon is moist for 90 days or more (cumulative) in normal years during times when the soil temperature at a depth of 50 cm below the soil surface is 5 ^{o}C or higher, if the soil is not irrigated."

Proposed Action 6: Change the following parts of the definition of folistic, histic, and melanic epipedons starting on page 6.

"Folistic Epipedon
Required Characteristics
The folistic epipedon is defined as a layer (one or more horizons) that is saturated for less than 30 days (cumulative) in normal years (and is not artificially drained) and *either*:
1. ….
   c. 8 + (clay percentage divided by 7.5) percent or more if the mineral fraction contains less than 60 percent clay; *and*
3. Does not meet the definition of an anthropic epipedon (i.e., is not human-altered or human-transported material)."

"Histic Epipedon

Required Characteristics

The histic epipedon is a layer (one or more horizons) that is characterized by saturation (for 30 days or more, cumulative) and reduction for some time during normal years (or is artificially drained) and *either*:

1. …
   c. 8 + (clay percentage divided by 7.5) percent or more if the mineral fraction contains less than 60 percent clay*; and*

3. Does not meet the definition of an anthropic epipedon (i.e., is not human-altered or human-transported material)."

"Melanic Epipedon

Required Characteristics

The melanic epipedon has ~~*both*~~ *all* of the following:

1. …
   c. 6 percent or more organic carbon as a weighted average and 4 percent or more organic carbon in all layers*; and*

3. Does not meet the definition of an anthropic epipedon (i.e., is not human-altered or human-transported material)."

2) **Purpose: Add definition of Artifacts.** Background: Artifacts may be added to the soil and occur in or on the soil and should be described if they become part of the soil and are durable enough to persist (resist weathering and leaching) for a few decades or more, to prevent soil descriptions become outdated and soil series concepts become based on transient properties. From a practical purpose, artifacts that become part of the soil should be first split into categories that relate to human safety concerns, and then into categories that relate to their properties and behavior as part of the soil. These categories are defined below and may lend themselves to the creation of new differentiae and new classes in Soil Taxonomy in the future.

Proposed Action 7: Add definition of Artifacts to Chapter 3.

Artifacts

Artifacts (L. *arte*, by skill, and *factum*, to do or make) are materials created, modified, or transported from their source by humans usually for a practical purpose in habitation, manufacturing, excavation, or construction activities. Examples of artifacts include: treated and untreated wood products, liquid petroleum products, coal combustion by-products, asphalt, fibers and fabrics, bricks, cinder blocks, concrete, plastic, glass, rubber, paper and cardboard, iron and steel, altered metals and minerals, sanitary and medical waste, garbage, and landfill waste. Artifacts are already mentioned in Soil Taxonomy in the description of the epipedons (Soil Survey Staff, 1999, p. 26-28) but are not yet defined.

3) **Purpose: Add definition of Human-altered materials** to Chapter 3. Background: Human-altered materials are required for the definition of the proposed new family of Human-altered or -transported Material Class (below). Therefore it should be identified in Chapter 3 under Horizons and Characteristics Diagnostic for Both Mineral and Organic Soils starting on page 23. There are proposed additional uses of the term in the Keys that would be facilitated by the definition.

Proposed Action 8: Add: **Definition of Human-altered Material** to Chapter 3 between Glacic Layer and Human-transported Material.

Human-altered Material

Human-altered material (L. *humanus,* human, and *alter,* to change) is parent material for organic or mineral soil materials that have either been deeply-mixed in-place, excavated from a pedon and replaced by directed human activity, or truncated by removal of the surface soil or more. These soils may have a surface deposit of human-transported material (defined below).

Many intentionally-leveled human-altered soils occur in irrigated fields. Because the soil may have been mixed deeper than all diagnostic horizons, characteristics or features (differentiae), it may be difficult to identify the human activity. However, tracing the landform laterally will reveal abrupt edges, and the leveled landform typically has geometric or linear shapes and boundaries. Tracing soil properties laterally across the landform boundary reveals abruptly contrasting materials, differentiae, or horizons at matching depths.

Truncation of soil from a landform creates distinct destructive anthropogenic landforms or microfeatures, as described in ad hoc proposal to amend the National Soil Survey Handbook, 2008. *Part 629:* Glossary of Landform and Geologic Terms (e.g., ditches, excavated part of hillslope terraces, or leveled recreation fields). Truncated human-altered soils are composed of organic or mineral soil materials and often identified by their altered landform, absence of surface horizons, and abrupt lateral changes at the landform edge. They often contain artifacts in layers that have been moved and then replaced, and the replacement soil has an abrupt contact with the in-situ materials. Tracing the destructional landform laterally reveals an abrupt end to horizon occurrence, abrupt changes in slope, or boundary by walls, and the landform typically has geometric or linear shapes and boundaries. All of this evidence identifies profound intentional human activity and alteration. Therefore it is often the preponderance of evidence along with published or historical evidence and on-site observations that allows the most consistent identification of truncated human-altered material.

Required Characteristics

Human-altered material meets *one or more* of the following:

1. Occurs on an anthropogenic landform or microfeature, as described in ad hoc proposal to amend the National Soil Survey Handbook, 2008. *Part 629:* Glossary of Landform and Geologic Terms (e.g., leveled irrigated fields or construction excavation areas) or in transported material above one of them and meets the definition of human-transported material (defined below) or and has evidence of intentional alteration in *one* of the following:
   a. Has an abrupt lateral discontinuity of horizons and layers at the edge of a farming terrace or field (e.g., no continuous diagnostic surface or subsurface horizons extend across the boundary edge of the field at similar depths below the current surface); *or*
   b. Have been irrigated and farmed in arid regions for a long enough period of time that they now have either an anthropic epipedon (yet fail to have anthraquic conditions); *or*
   c. Anthraquic conditions; *or*
   d. Meets the definition of an agric horizon; *or*
   e. Meets the definition of anthropic or plaggen epipedon; *or*
   f. Overlies humilluvic materials; *or*
   g. Overlies bones arranged in ceremonial position or human body parts prepared to prevent decay; *or*
   h. Contains 3 percent or more (by volume) detached pieces of diagnostic horizons between 25 cm or the bottom of the active plow layer, whichever is deeper, and 100 cm but no laterally continuous diagnostic horizons other than the lower part of an epipedon, or an albic, calcic, cambic, gypsic, salic, or sulfuric horizon within that depth; *or*

2. Occurs within the boundaries of a destructional (excavated) anthropogenic landform or microfeature (e.g., within pit walls), as described in the ad hoc proposal to amend the National Soil Survey Handbook, 2008. *Part 629:* Glossary of Landform and Geologic Terms and has evidence of intentional alteration in *one or more* of the following:
   a. An abrupt lateral discontinuity of horizons and layers at the edge of the anthropogenic landform or microfeature (e.g., no continuous diagnostic surface or subsurface horizons extend across the boundary edge of the anthropogenic landform or microfeature at similar depths below the current surface); *or*

b. A subsurface diagnostic horizon, diagnostic subsurface characteristic, pedogenic root-limiting layer, or bedrock occurs at the soil surface; *or*
c. Microfeatures that indicate excavation by mechanical tools (e.g., scrape marks on rocks or in soil from tools or machinery); *or*
d. A densic contact occurs either at the surface or between replaced surface soil and the in-situ subsoil; *or*
e. Anthraquic conditions; or
f. Artifacts or manufactured layers.

4) **Purpose: Add definition of Human-transported materials** to Chapter 3. Background: Human-transported materials are required for the use of the caret symbol (^) in Chapter 18, Designations for Horizons and Layers. Therefore it should be identified in Chapter 3 under Horizons and Characteristics Diagnostic for Both Mineral and Organic Soils starting on page 23. There are proposed additional uses of the term in the Keys that would be facilitated by the definition.

Proposed Action 9: Add definition of Human-transported Material to Chapter 3 between Human-altered Material and Lithic Contact.

Human-transported Material

Human-transported material (L. *humanus,* human, and *trans,* across, and *porto,* to carry) is parent material for soils that has been excavated from a pedon, and either mixed and replaced by directed human activity, or moved horizontally onto a pedon from a source area outside of that pedon by directed human activity, usually with the aid of machinery or hand tools. In some cases it is not possible to distinguish burial of human occupied sites and human-transported material by catastrophic or long-term erosion events without intensive on-site examination and analysis. In most cases, these characteristics do not include those that normally occur in a recently-deposited (Holocene age) alluvial, colluvial, eolian, or mass-wasting deposit. Human-transported material is composed of organic or mineral soil materials and, often contains fragments of diagnostic horizons, and may also contain artifacts such as concrete. Human-transported material often contains a lithologic discontinuity or a buried genetic horizon located beneath an individual deposit, although those properties do not diagnose the material above them as being transported by humans. Caution should be taken in several cases, where combinations of human actions and natural processes make it difficult to identify material as human-transported. Examples include material deposited by dredging adjacent to active beaches, human littering in floodplains, and where deposits from catastrophic events cover anthropogenic features (e.g., volcanic ash covering houses). Therefore it is often the preponderance of evidence along with published or historical evidence and on-site observations that allows identification.

Required Characteristics

Human-transported material often contains a lithologic discontinuity or a buried horizon at the bottom of an individual deposit, and meets *one or more* of the following:

1. Occurs on a constructional anthropogenic landform or microfeature, as described in ad hoc proposal to amend the National Soil Survey Handbook, 2008. *Part 629:* Glossary of Landform and Geologic Terms (e.g., fill, mounds, dredged spoil banks, or levees); *or*

2. Occurs within the boundaries of a destructional (excavated) anthropogenic landform or microfeature (e.g., within pit walls), as described in the ad hoc proposal to amend the National Soil Survey Handbook, 2008. *Part 629:* Glossary of Landform and Geologic Terms or occur in human-transported materials above them and meets *one or more* of the following:

a. Directly and abruptly overlies a genetic soil horizon, saprolite, or a densic, lithic, manufactured layer, or paralithic contact; *or*

b. Overlies or adjoins any anthropogenic landform or microfeature that indicate excavation by mechanical tools (e.g., scrape marks on rocks or in soil from tools or machinery); *or*

c. Has an abrupt change in level at the edge of any anthropogenic landform or microfeature (e.g., the excavation is bounded by pit walls); *or*

d. Genetic and diagnostic horizons or characteristics traced laterally end abruptly at the destructional landform edge (e.g., some horizon or characteristic does not cross the boundary of the excavation); *or*

3. Does not have the characteristics of Holocene age transported parent materials (e.g., colluvium) that are deposited in-place by natural processes, and the evidence of transportation by human activity exists by meeting *one or more* of the following:

a. Contains *one or more* of the following:

(1) Artifacts; *or*

(2) Detached pieces of diagnostic horizons and/or characteristics which often have sharply-defined or abrupt edges, random orientation relative to each other, and that contrast noticeably in texture or color to the surrounding matrix; *or*

(3) A manufactured layer contact; *or*

(4) Freshly fractured rock fragments with splintered or sharp edges, sometimes cutting through rather than separating between minerals; *or*

(5) Mechanical abrasion marks on surfaces of randomly-oriented rock-fragments; *or*

(6) Bridging voids[1] between rock fragments caused by mechanical dumping of extremely coarse textured materials such as fragmental mine spoil; *or*

(7) Pararock fragments or saprolite unlikely to occur in or undocumented in the region; *or*

(8) An irregular structure shape in densic material (surfaces intersect irregularly in tangential or divergent directions) caused by traffic exceeding the shear strength of the compressed layer; *or*

(9) Distortions in material with fine stratifications (5 mm or less thick) in areas never known to be subject to cryoturbation. The patterns are caused by mechanically exceeding the shear strength of the layer (e.g., the weight of heavy equipment wheels or tools sinking into and compacting or mixing a wet soil), causing swirling, overturned, or broken patterns; *or*

b. Has an irregular distribution pattern with depth (unexplained by natural parent material formation or transportation processes alone) of *one or more* of the following:

(1) Organic-carbon content (Holocene age); *or*

(2) Airborne combustion byproducts (e.g., fly ash); *or*

(3) Combustion or manufacturing by-products (e.g., particulate charcoal or organic ash produced by pyrolysis, coal ash, bottom ash, slag, etc.); *or*

(4) Refined or raw hydrocarbons (e.g., buried refined or crude oil spills) not associated with a recorded spill at the site; *or*

(5) Radioactive fallout; *or*

(6) Aerosols and particulates manufactured, released, or produced by manufacturing; *or*

(7) Minerals or rock fragments that are rapidly weatherable in the current effective soil property and soil climatic setting; *or*

(8) Heavy metals (e.g., Pb) associated with human mining or manufacturing activity, feeding, application, pollution, dumping, or biosolid or manure-spreading; *or*

[1] A void created when fragmental material is transported and deposited without packing or sorting so that a trio of rock fragments stack in a way that prevents fine material from filling the void.

5) **Purpose: To identify a manufactured layer.** Background: Manufactured layers are currently described with the new master layer letter "M" but are not defined in Chapter 3. Intentionally-compacted soils (e.g. subsoils compacted to cause episaturation in rice fields or constructed wetlands) will be recognized by their densic contact in the new family class for human-altered and human-transported soils.

Proposed Action 10: Add Manufactured Layer to Chapter 3.

Manufactured Layer
Manufactured layers are relatively unaltered, root-limiting layers beneath the soil surface consisting of nearly continuous, human-manufactured materials whose purpose is to form an impervious barrier. The materials used to make the layer impervious include geotextile liners, asphalt, concrete, rubber, and plastic. They are designated by the capital-letter symbol M. The presence of these materials can be used to differentiate soil series.

6) **Purpose: Add Manufactured Layer Contact** to identify a contact with an impervious, root-limiting layer beneath the soil surface that profoundly affects soil depth class, rooting depth, water-holding capacity, and other important properties. Other contacts are identified in Chapter 3, and this one will be added to the list of root-limiting contacts, so it must be defined.

Proposed Action 11: Add definition of Manufactured Layer Contact to Chapter 3**.** Manufactured layer contacts are not currently listed as a root-limiting layer in Chapter 17 and are also not currently defined in Chapter 3 of the Keys to Soil Taxonomy.

Manufactured Layer Contact
A manufactured layer contact (L. *humanus* of or belonging to man, and *factum*, to do or make) is an abrupt contact between soil and a manufactured layer (defined above) used to form an impervious barrier. It has no cracks, or the spacing of cracks that roots can enter is 10 cm or more.

7) **Purpose: Add definition of Mantle.** Background: To identify a buried soil, it is necessary to recognize a mantle of new soil material. This is the only material that is diagnostic to identifying the taxonomic class of a soil that is not listed in Chapter 3. Mantle definition is embedded in a paragraph in Chapter 1.

Proposed Action 12: Modify and move: Surface Mantle of New Soil Material from Chapter 1 to Chapter 3**.**

Surface Mantle of New Soil Material

A surface mantle of new soil material~~, as defined here,~~ is largely unaltered, at least in the lower part. A surface mantle of new soil material displays the following properties:

1. ~~It may have a~~ A diagnostic surface horizon (epipedon) ~~and/~~*or* no diagnostic surface horizon; *and*
2. ~~n~~No ~~other~~ diagnostic subsurface horizons other than a cambic horizon; *and*, ~~all defined later.~~
3. ~~However, there remains a~~ A zone 7.5 cm or more thick that fails the requirements for all diagnostic horizons, ~~as defined later,~~ overlying a horizon sequence that can be clearly identified as the solum of a buried soil in at least half of each pedon.

The recognition of a surface mantle of new soil material should not be based only on studies of associated soils. Buried soils may be partially identified by the presence of human-transported materials or an anthropogenic landform or microfeature such as a locally raised (constructional) or lowered (destructional) surface (e.g., a levee or a pit) as described in the ad hoc proposal to amend the National Soil Survey Handbook, 2008. *Part 629:* Glossary of Landform and Geologic Terms, or a map unit or landscape unit with geometric or artistic shape (e.g., effigy mounds).

CHAPTER 4. MODIFICATION TO THE KEY TO SOIL ORDERS

Purpose: To modify the key to Inceptisols so that folistic epipedons would be allowed as well as histic, mollic, plaggen, or umbric epipedons. Background: Adding folistic to the list of epipedons that qualify a soil as Inceptisols would achieve the same rationale as that used for histic epipedons.

Proposed Action 13: Modify the Key to Soil Orders for Inceptisols as follows:

"2. No sulfidic materials within 50 cm of the mineral soil surface; *and both*:
a. In one or more horizons between 20 and 50 cm below the mineral soil surface, either an *n* value of 0.7 or less or less than 8 percent clay in the fine-earth fraction;
and
b. *One or ~~both~~more* of the following:
(1) A salic horizon or an folistic, histic, mollic, plaggen, or umbric epipedon; *or* …
(2) In 50 percent or more…"

CHAPTER 5-16: CHANGES IN KEYS IN MULTIPLE PLACES

A. Changes to Chapter 7: Key to Aridisols: staring on page 97.

Purpose: Delete Anthracambids great group and Typic Anthracambids subgroup on page 108. There are no soil series in this great group or subgroup, and only Typic subgroup taxa. If soil series are established, they can be added in the proposed Anthropic or Anthropic Humic subgroups of Haplocambids.

a. **Proposed Action 14: Delete Anthracambids great group and Typic Anthracambids subgroup** on page 108. If soil series are proposed, they can be recognized in Anthropic Humic, Anthropic, or Anthroportic subgroups and the materials recognized with an HAHT family class.

B. Changes to Chapter 8: The Key to Entisols, page 123.

1) **Purpose: Move Torriarents and Xerarents from a suborder to subgroup level**. Background: These soils were identified and are mapped in very deeply plowed soils of the Central Valley of California. Soil series exist to recognize soils that were deeply plowed and amended chemically to destroy root-limiting layers or abrupt textural changes, or both, that limited agricultural production. The Torriarents and Xerarents are mixed in place. The basis of placing a soil at the suborder level because of a soil forming process (human activity) rather than a major property has no parallel in Soil Taxonomy. The presence of 3 percent or more fragments of diagnostic horizons may have a very minor affect of the behavior of a soil, so the threshold of recognition at a level as high as suborder seems unjustified. The 3 percent minimum of diagnostic material seems too low to be important at making interpretive maps. However, since soil series of deeply mixed soils already exist, recognizing the action of "anthroturbation" and reclassifying them at the subgroup level seems appropriate. The suggested subgroup name is Anthraltic (from Gr. *Anthropos,* Human and L. *alterāre,* to change). Finer divisions can be made at the family and series levels or as phases of series. For example, soil series of Sodic Torriarents would still be separated from soil series of Duric Torriarents.

Proposed Action 15: Delete the Key to Arents, part LC. on page 123; and the Key to Great Groups of Arents, page 127. These deleted groups of Torriarents and Xerarents will go through into their respective "Anthraltic Torriorthents" and "Anthraltic Xerorthents" and fall out between Oxyaquic and Duric subgroups in Torriorthents and between the Oxyaquic and Durinodic subgroups in Xerorthents.

2) **Purpose: Move Ustarents and Udarents from a suborder to subgroup level recognition.** Background: The Ustarents and Udarents are human-transported material rather than deeply plowed farmland soils, mostly mine spoil but some dredged spoil. Transportation of soil by humans onto or away from a pedon using tools or machinery is a common practice in urban areas, mining areas, and where sediments are dredged. The presence of thin strata from dredging, buried garbage in a landfill, or a densic horizon formed from mechanical compaction are important physical properties. The Ustarents and Udarents may become a very large group of soils once urban soils with fragments start being proposed and mapped. The basis of placing a soil at the suborder level because of a soil forming process (human activity) rather than a major property has no parallel in Soil Taxonomy. The presence of 3 percent or more fragments of diagnostic horizons may have a very minor affect of the behavior of a soil, so the threshold of recognition at a level as high as suborder seems unjustified. The 3 percent minimum of diagnostic material seems too low to be important at making interpretive maps. However, since soil series of transported soils already exist, recognizing the action of "anthrotransportation" and reclassifying them at the subgroup level as seems appropriate. The suggested term is Anthroportic (from Gr. *Anthropos* Human and L. *portāre* to carry). Finer divisions can be made at the family and series levels, or as phases of series. For example, soil series of Alfic Udarents would still be separated from soil series of Mollic Udarents.

Proposed Action 16: Delete the Key to Arents, part LC. on page 123; and the Key to Great Groups of Arents, page 127. These deleted groups of Udarents and Ustarents will go through into their respective "Anthroportic Udorthents" and "Anthroportic Ustorthents" and fall out between Oxyaquic and Durinodic subgroups in Ustorthents and between the Oxyaquic and Vermic subgroups in Udorthents.

Proposed Action 17: Delete the Plagganthreptic intergrade subgroup of Udipsamments on page 141. This subgroup intergrade cannot exist if the Anthrepts suborder is deleted. There are no series in this suborder. If series are set up, they can use the subgroups of Plagghaplic proposed below.

3) **Purpose: Delete the subgroup of Anthropic Torrifluvents** on page 130. There are no existing series. If one is added, it can be named using the Anthropic or Anthropic Humic subgroups proposed below.

Proposed Action 18: Delete the subgroup of Anthropic Torrifluvents on page 130. If a series is developed, it can be named using the Anthropic or Anthropic Humic subgroups proposed below.

4) **Purpose:** Add an exclusion statement to prevent soils with irregular carbon decrease caused by human-transportation of material from qualifying as Fluvaquents or Fluvents along with naturally-deposited soils. Background: The physical properties associated with human-transportation of material give these soils different properties and interpretations. Organic carbon decrease with depth is predictably irregular in human-transported material. However, human-transported materials can be identified separately from flood-deposited material and they occur on different (Anthropogenic) landforms (as described in an ad hoc proposal to amend the National Soil Survey Handbook, *Part 629:* Glossary of Landform and Geologic Terms). Dredged material would be recognized at the family level. This preserves the concept of Fluvents occurring on natural landforms and places human-transported material that buries a soil in separate taxa. The exclusion statement would cause reclassification of soil series but the correction should not cause soil series to be split.

Proposed Action 19: Add an exclusionary statement to Fluvents on page 123 to prevent human-transported soils from being classified as Fluvents. These soils would then be classified as Orthents.

Page 123
"LE. Other Entisols that do not have either a densic, lithic, or paralithic contact within 25 cm of the mineral soil surface or 50 cm or more of human-transported material in the surface and subsurface horizons; *and* ~~and have~~:
1. Meet *all* of the following:

a. Do not occur on an anthropogenic landform as described in the ad hoc proposal to amend National Soil Survey Handbook, *Part 629:* Glossary of Landform and Geologic Terms; *and*
b. Do not occur on or above an anthropogenic microfeature as described in the ad hoc proposal to amend the National Soil Survey Handbook, *Part 629:* Glossary of Landform and Geologic Terms; *and*

~~1~~2. Have a slope of less than 25 percent; *and*
~~2~~3. Have *one or both* of the following: ……. *and*

~~3~~4. Have a soil temperature regime: …….**Fluvents**…"

Proposed Action 20: Add an exclusionary statement to Fluvaquents on page 124 to prevent human-transported soils from being classified as Fluvaquents. These soils would then be classified as Epiaquents or Endoaquents.

Page 124
"LBF. Other Aquents that ~~have *both:*~~ do not have 50 cm or more of human-transported material in the surface and subsurface horizons; *and*
1. Meet *all* of the following:
   a. Do not occur on an anthropogenic landform as described in the ad hoc proposal to amend National Soil Survey Handbook, *Part 629:* Glossary of Landform and Geologic Terms; *and*
   b. Do not occur on or above an anthropogenic microfeature as described in the ad hoc proposal to amend the National Soil Survey Handbook, *Part 629:* Glossary of Landform and Geologic Terms; *and*

~~1~~2. Have a slope of less than 25 percent; *and*
~~2~~3. Have *one or both* of the following: …….. **Fluvaquents**…"

C. Changes to Chapter 11: Key to Suborders of Inceptisols: Anthrepts on page 161.

Purpose: Move Anthrepts from a suborder to subgroup level recognition. Background: The Anthrepts are human-altered or human-transported material epipedons that have unique physical properties compared to regional soils because of their material, age, and mode of deposition. However, there are no soil series set up to recognize or interpret these differences. There are no soil series in Anthrepts, Plagganthrepts, Haplanthrepts, Typic Plagganthrepts or Typic Haplanthrepts. There are no soil series in any of the five intergrade subgroups to Anthrepts, or . Plagganthreptic Udipsamments LDFF on page 141, Plagganthreptic Fragiaquods CACB on page 259, Plagganthreptic Haplohumods CDDC on page 262, Plagganthreptic Alorthods CEDG on page 263, or Plagganthreptic Fragiorthods CECD on page 263. Soil series that may be proposed can be proposed the subgroup level using one of the proposed extragrade subgroup choices Anthraltic, Anthraquic, Anthropic, Anthroportic, Plaggic, or Plagghaplic extragrade, or using the proposed human-altered and human-transported family class if the material is thick enough and fits better there than with one of the currently proposed subgroups. Other subgroups could also be proposed. For example, a Typic Plagganthrepts with aquic conditions in the upper 50 cm is not captured in the current name. However, we could tell those properties if we identified Plaggic Aquic Dystrudepts. Anthropic epipedons where humans added char and kitchen refuse are likely to be more fertile than surrounding soils (e. g., Terra Preta soils) and of archaeological importance in arid to humid regions. Typic Haplanthrepts tells us little about the soil but Anthropic Petrocalcic Eutrudepts tells us much more.

Proposed Action 21: Eliminate Anthrepts on page 161. There are no soil series in this suborder. If a series is developed, it can be named using the Anthropic or Anthropic Humic subgroups proposed below.

D. Changes to Chapter 14: Key to Spodosols: staring on page 257.

Purpose: After eliminating the suborder of Plagganthrepts, there is no need for the Plagganthreptic intergrade subgroups in Spodosols. There are no soil series in any of the subgroups.

Proposed Action 22: Eliminate Plagganthreptic Fragiaquods on page 259. There are no soil series in this subgroup. This subgroup intergrade cannot exist if the Anthrepts suborder is deleted. If series are set up, they can use the subgroups of Plagghaplic proposed below.

Proposed Action 23: Eliminate Plagganthreptic Haplohumods on page 262. There are no soil series in this subgroup. This subgroup intergrade cannot exist if the Anthrepts suborder is deleted. If series are set up, they can use the subgroups of Plagghaplic subgroups proposed below.

Proposed Action 24: Eliminate Plagganthreptic Alorthods on page 259. There are no soil series in this subgroup. This subgroup intergrade cannot exist if the Anthrepts suborder is deleted. If series are set up, they can use the subgroups of Plagghaplic proposed below.

Proposed Action 25: Eliminate Plagganthreptic Fragiorthods on page 259. There are no soil series in this subgroup. This subgroup intergrade cannot exist if the Anthrepts suborder is deleted. If series are set up, they can use the subgroups of Plagghaplic proposed below.

E. Changes to Chapter 15 Ultisols on page 267.

1) **Purpose: Delete the subgroup of Anthropic Kandihumults** on page 272. There are no existing series. If a series is developed, it can be named using the Anthropic or Anthropic Humic subgroups proposed below.

Proposed Action 26: Delete the subgroup of Anthropic Kandihumults on page 272. If a series is developed, it can be named using the Anthropic or Anthropic Humic subgroups proposed below.

2) **Purpose: Delete the subgroup of Anthropic Kanhaplohumults** on page 273. There are no existing series. If a series is developed, it can be named using the Anthropic or Anthropic Humic subgroups proposed below.

Proposed Action 27: Delete the subgroup of Anthropic Kanhaplohumults on page 273. If a series is developed, it can be named using the Anthropic or Anthropic Humic subgroups proposed below.

Changes throughout Soil Taxonomy

A. Irregular Decrease in OC

Purpose: Add an exclusion statement to prevent soils with irregular carbon decrease caused by human-transportation of material from qualifying as Fluventic and Fluvaquentic taxa along with naturally-deposited soils. Background: The physical properties associated with human-transportation of material give these soils different properties and interpretations. Organic carbon decrease with depth is predictably irregular in most human-transported material. Human-transported material is excluded from being a mollic or umbric epipedon in a separate proposal. Dredged material with irregular decrease in carbon or high carbon at 125 cm would be recognized at the family level. However, most human-transported materials can be identified if they occur on anthropogenic landforms (as described in an ad hoc proposal to amend the National Soil Survey Handbook, *Part 629:* Glossary of Landform and Geologic Terms). The exclusions statement would cause reclassification of soil series but the correction should not cause soil series to be split.

Keys to Subgroups that require within a depth of 125 from the mineral soil surface an irregular decrease in OC with depth or 0.2 percent or more of OC. Note that subgroups that contain the Cumulic name are excluded in the proposed modified definition of the mollic and umbric epipedon and by the definition of buried soils.

Proposed Action 28: Add an exclusionary statement to subgroups that contain the terms Fluventic or ____fluventic throughout the Keys to prevent human-transported soils from being classified in those taxa. There are several combinations of criteria but the fragment in question is always similar. An example is given for some variations found.

"GGAG. Other Aquicambids that have less than 50 cm of human-transported material in the surface subsurface horizons and an irregular decrease in organic-carbon content (Holocene age) between a depth of 25 cm and either a depth of 125 cm below the mineral soil surface or a densic, lithic, or paralithic contact, whichever is shallower. **Fluventic Aquicambids**"

"LAAE. Other Frasiwassents that have less than 50 cm of human-transported material in the surface and subsurface horizons and one or both of the following:
1. At a depth of 125 cm below the mineral soil surface, an organic-carbon content (Holocene age) of 0.2 percent or more and no densic, lithic, or paralithic contact within that depth; *or*
2. An irregular decrease in organic-carbon content (Holocene age) between a depth of 25 cm and either a depth of 125 cm below the mineral soil surface or a densic, lithic, or paralithic contact, whichever is shallower.
Fluventic Frasiwassents"

COMMENT: All other examples follow the same principal: Add the phrase "less than 50 cm of human-transported material in the surface and subsurface horizons" directly before the phrase "one or both of the following:" in all Fluvaquentic, Fluvaquentic ____, Fluventic or ____fluventic taxa.

B. Add New Subgroups for Human-Altered and Human–Transported Soils

Purpose: Add five new subgroup terms to identify distinct groups of human-altered and human–transported soils. Background: The physical and chemical properties associated with human alteration or transportation of material give these soils different properties than existing taxa and series. Humans that work with soils on evident Anthropogenic landforms recognize the soil behavioral differences and request this recognition in Soil Taxonomy. However, to avoid populating Soil Taxonomy with an almost unlimited number of potential taxa based on estimated needs, the following shorter list should be able to accomplish these goals. This change can be accomplished with five new subgroup terms, used alone or in combination with other subgroup terms. All other additions of taxa to recognize soils above the soil series level can be accomplished by using the proposed new human-altered soils classes.

Proposed Action 29: Additional terms for extragrade subgroups throughout Soil Taxonomy, to be added as soil series are established.

a. Anthraltic (from Gr. *Anthropos,* Human and L. *alterāre,* to change). Has, in one or more layers at a depth between 25 and 100 cm below the mineral soil surface, 3 percent or more (by volume) fragments of diagnostic horizons that are not arranged in any discernible order; or formed in 50 cm or more of human-altered material. These are used for human-altered material for subgroups of Entisols that were formerly Arents where deep plowing has destroyed former diagnostic horizons, but could be used for any human-altered material. NOTE: Thickness is subgroup specific. If the epipedon meets the meets the color and carbon requirements of the mollic or umbric epipedon throughout, the term Humic is added as well.
b. Anthraquic: "Other _____ that have anthraquic conditions." (These already exist in 11 subgroups but are not populated by soil series). They are surely extensive, and they are either human-altered or human-transported material or both. NOTE: Thickness is generally 50 cm or more but should be subgroup

specific. If the epipedon meets the meets the color and carbon requirements of the mollic or umbric epipedon throughout, the term Humic is added as well.

c. Anthroportic (from Gr. *Anthropos* Human and L. *portāre* to carry): Has, in one or more layers at a depth between 25 and 100 cm below the mineral soil surface, 3 percent or more (by volume) fragments of diagnostic horizons that are not arranged in any discernible order; or formed in 50 cm or more of human-transported material. These are used for human-transported material of dredged or mine spoil soil series that were formerly Arents, but could be used for any human-transported material. NOTE: Thickness is generally 50 cm or more but should be subgroup specific. If the epipedon meets the meets the color and carbon requirements of the mollic or umbric epipedon throughout, the term Humic is added as well.
d. Plaggic: "….have an plaggen epipedon." (The plaggen epipedon already exists)
e. Plagghaplic: "….have a surface horizon 25 cm to 50cm thick that meets all of the requirements for a plaggen epipedon except thickness." (This concept already exists as the Plagganthreptic subgroups of Entisols and Spodosols. The formative elements for the plagghaplic subgroup are from the Ger. *plaggen*, sod and Gr. *haplos*, simple.)

CHAPTER 17: FAMILY AND SERIES DIFFERENTIAE AND NAMES

1) **Add Human-altered and human–transported Material Family Class**

a) **Purpose:** Modify family classes. Background: Separating human-altered or human-transported soils can be accomplished at many levels in Soil Taxonomy, yet the goal must be to make meaningful separations that can be used to make useful maps and interpretations for soil use. Proliferation of anticipated taxa would occur if these separations are made at a high categorical level. We propose to add differentiae at the family level in the form of a human-altered or human-transported materials class to minimize the number of taxa at higher levels. The new family class is reserved for soils with a significant thickness of human-transported materials, at least in the upper part. This family class will identify all human-altered or human–transported soils not recognized at higher category levels, and will separate soils with significantly different management considerations. Meaningful limits must be identified from these draft starting levels, and this list should expand over time. Many of the materials have unknown or variable density or are porous or hollow. An effort is being undertaken by USDA-NRCS and SUITMA to help define material classes and representative densities. We must also identify methods to separate organic carbon from black carbon (char and coal).

<u>Proposed Action 30</u>: Add the following classes in Chapter 17, page 299 and 308.
Family Differentiae for Mineral Soils and Mineral Layers of Some Organic Soils

"The following differentiae are used to distinguish families of mineral soils and the mineral layers ….. in the family names.

Particle-size classes and their substitutes
Human-altered and human–transported material classes
Mineralogy classes
Cation-exchange activity classes
Calcareous and reaction classes
Soil temperature classes
Soil depth classes
Rupture-resistance classes
Classes of coatings on sands
Classes of permanent cracks"

Human-altered and Human–transported Material Classes

Human-altered or –transported material classes are intended to provide useful information on the behavior and interpretations for use of soils formed in human-altered or human-transported material (defined above). Human-altered or human–transported material classes are only used in taxa where either one of the following occurs: human-altered or human-transported material extend from the soil surface to the shallower of a root-limiting layer that occurs within 50 cm of the soil surface, or 50 cm, or the soil occurs in an Anthraltic, Anthraquic, Anthroportic, Plaggic or Plagghaplic extragrade subgroup. In other taxa, the class is omitted from the family name and the material identified at the soil series level. The following key to human-altered or human–transported material classes is designed to make important distinctions in the order of most importance to human health and safety.

Control Section for Human-altered and Human–transported Material Classes

The control section for the human-altered and human-transported material classes is one of the following:

1. Mineral soils that have a paralithic or lithic contact 50 cm or less below the mineral soil surface: The zone from the mineral soil surface to the paralithic or lithic contact.
2. All other soils: The zone from the mineral soil surface to a depth of 100 cm or to a paralithic or lithic contact that is below 50 cm, whichever is shallower.

Key to Human-altered and Human–transported Material Classes

Mineral soils that in some part of the human-transported material control section have:

1. Detectible evolution of methane from the decomposition of nonpersistant artifacts, such as garbage or other buried waste products, and which is easily detectable by its odor or readily observed by the collection and/or burning of methane gas.

Methanogenic

or

2. More than 35 percent (by volume) artifacts that are likely to decompose and cause subsidence in the soil within a realm of one hundred years from the time of burial under the current or projected effective soil climate conditions and that have diameters of 2.0 mm or more *and* at least an extremely weakly cemented rupture-resistance class.

Subsidic

or

3. More than 10 percent (by volume) of garbage, waste, and debris deposited in landfills, usually mixed with and covered by earthen materials. (Comment: Middle English *spoile*, earth and rock excavated and Latin *vastus,* waste)

Spoliwastic

or

4. More than 35 percent (by volume) artifacts of asphalt that have diameters of 2.0 mm or more *and* an extremely weakly cemented to indurated rupture-resistance class.

Asphaltic

or

5. More than 35 percent (by volume) artifacts of concrete that have diameters of 2.0 mm or more *and* an extremely weakly cemented to indurated rupture-resistance class.

Concretic

or

6. More than 40 percent (by weight) artifacts of synthetic gypsum products such as flue gas desulfurization gypsum, phosphogypsum, or fluorogypsum (e.g., drywall or plaster) in the fine-earth fraction.

Gypsifactic

or

7. More than 35 percent (by volume) artifacts of clinker and non-combustible residues of coal combustion with diameters of 2 to 75 mm.

Combustic

or

8. More than 40 percent (by weight) artifacts of light-weight combustion byproducts (e.g., fly ash) in the fine-earth fraction.

Ashifactic

or

9. More than 40 percent (by weight) artifacts of products produced by pyrolysis (e.g., coke or biochar) in the fine-earth fraction.

Pyrocarbonic

or

10. More than 85 percent of the pedon (measured laterally) has a densic contact (e.g., a compacted mine spoil) and aquic conditions within 50 cm of the soil surface.

Aquadensic

or

11. More than 85 percent of the pedon (measured laterally) has a densic contact (e.g., a compacted mine spoil) within 50 cm of the soil surface.

Anthrodensic

or

12. More than 90 percent (by volume) innocuous artifacts that have diameters of 2.0 mm or more *and* at least an extremely weakly cemented rupture-resistance class.

Multiartifactic

or

13. More than 35 percent (by volume) innocuous artifacts that have diameters of 2.0 mm or more *and* at least an extremely weakly cemented rupture-resistance class.

Medioartifactic

or

14. More than 10 percent (by volume) innocuous artifacts that have diameters of 2.0 mm or more *and* at least an extremely weakly cemented rupture-resistance class.

Pauciartifactic

or

15. More than 85 percent of the pedon (measured laterally) has a densic contact between 50 and 100 cm of the soil surface in human-altered or human-transported material.

Hypodensic

or

16. More than 3 percent (by volume) of recognizable fragments of diagnostic horizons arranged in a non-discernable order due to deep-plowing of soils to a depth of at least 100 cm below the soil surface. (Comment: from L. *arāre,* to plow)

Araric

or

17. More than 50 percent of the thickness (finely-stratified [less than 5 cm thick] human-transported, water-deposited sediment (e.g., dredged or irrigated) in the fine-earth fraction.

Dredgic

or

18. Other soils formed in human-transported material. (Comment: Middle English *spoile*, earth and rock excavated)

Spolic

or

19. All other soils: No human-altered or human-transported material classes used.

2) **Modify the List of Root-Limiting Contact Features** on page 300.

a) **Purpose: Modify the list of root-limiting contact features on page 300.** Background: The change is made to add the manufactured layer contact to the list of other root-limiting layers on page 300. Presently, the manufactured layer contact is not listed. A manufactured layer (i.e., the M layer) is a root-limiting layer and therefore the uppermost part is a contact that defines the effective rooting depth of the soil much as the top of a petrocalcic horizon does.

<u>Proposed Action 31</u>: Modify the following sentence: on page 300 under Root-limiting layers.

"Unless otherwise indicated, the following are considered root-limiting layers in this chapter: a duripan; a fragipan; petrocalcic, petrogypsic, and placic horizons; continuous ortstein (90 percent or more); and densic, manufactured layer, lithic, paralithic, and petroferric contacts."

b) **Purpose:** The change is made to **add the contact to a manufactured layer to the list of root-limiting contact features in mineral soils and Histels** on page 310 under Soil Depth Classes.

Proposed Action 32: Modify the following sentence on page 310.

"The root-limiting layers included in soil depth classes are duripans; petrocalcic, petrogypsic, and placic horizons; continuous ortstein (90 percent or more); and densic, manufactured layer, lithic, paralithic, and petroferric contacts."

c) **Purpose:** The change is made to **add the contact to a manufactured layer to the list of other root-limiting contacts in Histosols** on page 313.

Proposed Action 33: Modify the following sentence on page 313 under Soil Depth Classes [for Histosols]:

"The root-limiting layers included in soil depth classes of Histosols are duripans; petrocalcic, petrogypsic, and placic horizons; continuous ortstein (90 percent or more); and densic, manufactured layer, lithic, paralithic, and petroferric contacts."

APPENDIX

1. **Purpose: Add an important reference** to Literature Cited on page 328.

Proposed Action 34: Add the following references:

Hester, T.R.; R.F. Heizer, and J.A. Graham, 1975. Field Methods in Archaeology. Palo Alto, CA: Mayfield Publishing.

U.S. Department of Agriculture, Natural Resources Conservation Service, 2008. National Soil Survey Handbook, title 430-VI. [Online] Available: http://soils.usda.gov/technical/handbook/ *Part 629:* Glossary of Landform and Geologic Terms [Online] Available: ftp://ftp-fc.sc.egov.usda.gov/NSSC/Soil_Survey_Handbook/629.doc

2. **Purpose: Delete this reference to citric acid** on page 325. It is no longer used in the definition of the anthropic epipedon.

Proposed Action 35: Delete this reference to Citric Acid on page 325.
Citric-acid-extractable phosphorus (acid-soluble phosphate) is used to separate the mollic epipedon (less than 1,500 mg/kg P2O5) from the anthropic epipedon (equal to or more than 1,500 mg/kg).

VITA

Cassi Lynn Savage Jones was born in Fort Payne, AL to Drs. Jim and Sherri Savage and has one older brother, Wes. She attended elementary school at Vernon Elementary in Vernon, AL. She moved to Birmingham, AL in 1994 where she attended W.J. Christian Middle School and Jefferson County International Baccalaureate High School, graduating in 2001. She moved to Maryville, TN in 2001 to attend Maryville College. She later transferred to the University of Tennessee in the fall of 2005, where she graduated with her Bachelor's of Science in Environmental and Soil Science in 2008 and accepted a graduate research assistantship in August of 2009. She received her Master's of Science in Environmental and Soil Science under the guidance of Dr. Tom Ammons in August 2011. She accepted a graduate research assistantship to Auburn University in Auburn, AL in July 2011 and began study toward a Doctor of Philosophy in Soil Science in August 2011. Cassi is a member of Phi Kappa Phi, Gamma Sigma Delta, the Soil Science Society of America, and the American Society of Agronomy.