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GENESIS OF SOILS FROM ANCIENT ALLUVIUM, MARYVILLE LIMESTONE AND NOLICHUCKY SHALE IN EAST TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Debra Helen Phillips

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I dedicate this thesis to my parents, Howard and Helen Phillips, my little brother, Dennis, and to my dearest friends for their love, support, encouragement and inspiration.

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ABSTRACT

The nature and properties of soils overlying the Maryville and Nolichucky geologic formations at the Oak Ridge National Laboratory Reservation-Solid Waste Storage Area 6 (SWSA-6) were investigated to determine 1) their pedogenesis from physical, chemical, mineralogical, morphological and micromorphological properties, 2) the relationship between geological formations and soils and 3) soil genesis relationships.

Physical, chemical, mineralogical, morphological and micromorphological analyses were conducted on soils from the study area. The following physical and chemical analyses were conducted: particle size, water and KCl pH, total carbon, calcium carbonate equivalence (CCE), effective cation exchange capacity (ECEC) using sum of exchangeable bases plus KCl total acidity, exchangeable aluminum, exchangeable acidity, hydroxylamine reducible manganese and sodium dithionite (CBD) extractable manganese and iron. The mineralogy of the clay fraction was determined and micromorphological characteristics were observed.

Two Ultisols and two Alfisols were investigated and classified in the study area. Major parent materials present in the study site were ancient alluvium, Maryville Limestone and Nolichucky Shale. Some colluvial soils were present on sideslopes. Areas of ancient

alluvium were found in the southwestern portion of the Maryville Limestone area. High silt contents were predominant in the surface horizons and some Bt horizons of all soil profiles due to the deposition of fine alluvium and weathering of silty parent material. Higher sand percentages were found in the Cr horizons due to weathering of sandstone bedrock. Some fragmentation of partially weathered bedrock occurred from the sieving process during sample preparation. This may have resulted in higher sand percentages than what is present in the field. Clay content generally increased with depth and decreased after contact with partially weathered bedrock. With the exception of some surface horizons, low organic carbon values were found throughout the soil profiles and generally decreased with depth. The pH values of the soil and partially weathered bedrock ranged from 4.5 to 7.3. The pH of the carbonate bedrock of the HHMS-4B and HHMS-5A core drillings ranged from 7.5 to 8.4. The values for extractable aluminum and total acidity generally increased with depth in all soil profiles. Effective cation exchange capacity values varied from 2.38 to 52.67 cmol(+) kg^{-1} and exchangeable bases values varied from 0.01 to 44.06 cmol(+) kg^{-1} throughout all soils investigated. Ammonium acetate extractable calcium values of samples from the 4Cr and 5Cr horizons of profile four ranged from 44.06 to 30.80

cmol(+) kg^{-1} and high values were contributed from carbonates. Ammonium acetate extractable magnesium values varied from 0.07 to 7.87 cmol(+) kg^{-1} throughout all soil profiles. Magnesium values were high (6.25, 7.87 and 6.26 mg kg^{-1} respectfully) in the 3Cr, 4Cr and 5Cr horizons of profile four, which suggests the presence of dolomite in the bedrock.

Weathering sequences and soil forming processes of the soils were evaluated using x-ray diffraction (XRD) and differential scanning calorimetry (DSC). Minerals present in the clay size fraction included kaolinite, hydroxy interlayered vermiculite, vermiculite, illite, and gibbsite. Other constituents of the clay size fraction were organics, and manganese and iron oxides. High values of CBD extractable manganese and iron were found throughout most soil profiles. Microscopically, manganese and iron oxides were observed as 1) nodules, 2) granular segregated bodies, 3) crystalline forms, 4) neomangans, 5) infillings, and 6) impregnations. They were also present along with highly oriented clay coatings on pores, and faces of peds and partially weathered bedrock.

The development of soil on the interbedded Nolichucky Shale and Maryville Limestone formations exemplified how slope effects soil formation. Soil and partially weathered bedrock were deeper on the upland

position than on side slopes and footslope positions. This was due to greater stability and water infiltration which resulted in greater weathering on the upland position. The soil on the footslope was shallow due to removal of material by overland flow of water.

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CHAPTER I

INTRODUCTION

The study site is located in the Valley and Ridge physiographic province of East Tennessee in Melton Valley, southeast of Haw Ridge in Roane County, Tennessee. The general geology of the study site consists of a strata of Middle to Late Cambrian Conasauga Group rocks in the Copper Creek thrust block. Upper Maryville Limestone and Nolichucky Shale are formations of the Conasauga Group that occur within the study area. The study area is located in Solid Waste Storage Area 6 (SWSA-6) on the Oak Ridge National Laboratory Reservation. Solid Waste Storage Area 6 is a low level radioactive waste disposal site.

Knowledge of the properties of the major soils, geohydrology and landscape is important in selecting sites for disposing of low level radioactive waste. This information is used for planning the construction of shallow burial sites for radioactive waste disposal.

Little is known about the properties of the soils present at SWSA-6. A Roane County Soil Survey exists, but has out-of-date soil interpretations and classifications which cannot provide information needed for the detail necessary for planning and managing radioactive waste disposal. A recently constructed

detailed soil survey is being used to inventory the area's soils for preselection of radioactive waste disposal sites.

The objectives of this study are to 1) study the physical, chemical, mineralogical, morphological, and micromorphological properties of the major soils, 2) study relationships between soils and geological formations, and 3) develop soil genesis relationships at the study site.

CHAPTER II

LITERATURE REVIEW

History of Soil Genesis

Dokuchaev (1846-1903), a Russian geologist, laid the foundation for soil genesis (Buol et al., 1980). He stated that soil is a product of the combined activities of 1) living and dead plant and animal organisms, 2) parent rocks, 3) climate, and 4) relief. In 1879, Dokuchaev stated that soil is a self existing product of specific origin distinct from parent rock. In 1883, he published a field study on Chernozems (tall grass soils of subhumid climate with deep, dark colored organic rich layer grading downward to a lime accumulation layer), which applied developed methods of soil mapping in the field. He also developed soil cartography in the laboratory, the first classification of soils, described major soil groups, and principles of morphology of soils (Wilding et al., 1984). In 1886, Dokuchaev proposed that "soil" be recognized as a scientific term refering to "those horizons of rock which daily or nearly daily change their relationship under the joint influence of water, air, and various forms of organisms living and dead" (Buol et al., 1980). Dokuchaev used climate as the governing agency of organic production and decay (Jenny, 1941).

Another early soil scientist, Hilgard (1833-1916) recognized soil as a distinct segment of nature. He stated that soil deserved scientific inquiry and classification because of the possession of internal organization, genesis and dynamics. He hailed both theoretical and applied soil geography in his publications on soil in the southern states and alkali soils of California. He discovered the climatic element in soil formation. This brought much attention to problems in arid and humid regions. Between 1875 and 1892, Hilgard investigated the climatic action on the mineral portion of the soil. Hilgard treated climate, parent material, time, and topography (the principal soil forming factors) as independent entities (Jenny, 1961). Hilgard published his research on the interaction of parent material and climate on vegetation forms and distribution. The regional significance of climate and vegetation as agencies of change was emphasized in this material (Wilding et al., 1984). Jenny (1961) stated "If we draw a balance sheet - and why not? - We cannot escape the verdict that Hilgard and Dokuchaev are the twin fountainheads of modern pedology." Jenny's book "Factors of Soil Formation" (1941), stated that the soil forming factors are independent variables that define the state of a soil system. Common soil properties become

dependent variables and can be expressed as functions of the soil forming factors.

Fundamental Concepts of Soil Genesis

According to Buol et al., (1980), there are some fundamental concepts that prove to be useful in the understanding of soil genesis. Lyell's principle of uniformitarianism is applied to soils in reference to downward translocation of materials. The concept, "The present is the key to the past" is expressed by soil forming factors that involve timespans (Buol et al., 1980). Podzolization and laterization are examples of traditional names for general soil forming processes. They are actually combinations of specific reactions characteristic of particular timespans and conditions. Over a great period of time a succession of soils must have been formed from the earth and biota evolution. Changing conditions from the evolution of the earth are responsible for the formation of new kinds of soils. Soils of the earth are natural "clay factories" (Buol et al., 1980). There is a probability that clay particles in the sedimentary rock are products of soil forming processes. A knowledge of paleoecology, as far back as one or two million years before present, is useful in understanding soils. Although soil genesis is primarily concerned with present-day landscapes, a historical

importance exists as extentions into the past (Buol et al., 1980).

Geomorphology

Geomorphic and stratigraphic information usually improves conclusions about soil genesis based on conventional analysis and consideration of present soil forming factors. Knowledge of the stratigraphic and geomorphic history of a site is useful for interpreting soil distribution on the landscape and soil physical and chemical properties. Slope gradient appears to influence some soil properties. For example, as slope gradient increases, solum thickness and depth to carbonate decreases. From this information one can conclude that soil property changes are a true reflection of slope effect. One explanation of this conclusion is more runoff and less infiltration results from steeper slopes. This condition generally creates less leaching and soil-solution interaction resulting in less soil development per unit of time (Daniels et al., 1969).

Water Movement within Soil

One of the most important processes leading to profile differentiation is water movement within soils. The infiltration of rain water in a soil profile increases the weathering of primary minerals. When climatic conditions are favorable (warm and humid) and

the infiltration of water in a soil profile is constant, the primary minerals will eventually weather into secondary minerals (clays) and oxides. Water movement will transport the clays (illuviation) from the A and E (eluvial) horizons, to be deposited in the Bt (illuvial) horizon. Clays and other particles may eventually be removed from the profile. Water carries dissolved components to the subsoil. These components are precipitated as amorphous and crystalline minerals in the subsoil. Solids can also be moved from lower to upper horizons. During profile development such movement of materials is called pedotranslocation (McKeague and St. Arnaud, 1969).

The close connection between soil morphology, physical and chemical properties, and water table levels appear to be a cause and effect relationship. Many soil properties vary progressively as depth to water table decreases across soil topographic sequences. Clay and gibbsite contents of the Bt horizon decrease and iron and manganese minerals oxidizes as the water table depth decreases (Daniels et al., 1969).

Parent Material

The bedrock in the study area is composed of Upper Maryville Limestone and Nolichucky Shale formations of the Conasauga Group. The Upper Member of the Maryville Limestone underlies the greatest portion of the area.

The composition of this formation is dark gray, green and maroon-colored calcareous shales interbedded with gray-blue silty limestones and mudstones. The Maryville Limestone is interbedded in a transition zone with the Nolichucky Shale which contains oxidized claystones in the southernmost part of the site (Lietzke and Lee, 1986).

Two types of transported parent material present at the study site are alluvium and colluvium. Sediment transported and laid down by streams is known as alluvium. During the Pleistocene and Holocene, changes in stream discharge resulted from great climate changes. Discharge fluctuations resulting from episodes of alluviation alternated with episodes of erosion of alluvial deposits. Streams fed by snowfields and Pleistocene glacier discharge were larger and able to transport more coarse debris than present day streams (Hunt, 1972).

The mantle of loose debris that moves down hillsides by creep is called colluvium. Creep is a slow process and is caused by 1) wetting and drying of clays, 2) heaving and thawing actions of frost, 3) dissolution and crystallization of salt, 4) root growth, 5) burrowing animals, and 6) flowage of saturated ground (solifluction). An impact of any kind on particles resting on a slope will cause them to be displaced

downhill. This impact may be from a falling tree, a dislodged rolling stone, rill wash, rain or hail. Colluvial deposits generally are a chaotic mixture of coarse and fine sediments, but some sorting may be present (Hunt, 1972).

Major Soil Orders Present at the Study Site

Alfisols

Alfisols are soils that generally have an ochric epipedon, argillic horizon, and moderate to high base saturation (>35%). Ochric epipedons are light colored surface horizons with color values greater than 5.5 when dry and greater than 3.5 when moist. They are epipedons that are too thin to be mollic, umbric, anthropic, plaggen, or histic epipedons. Ochric epipedons can be hard or very hard and massive when dry. They may also be dry more than three months per year. Argillic horizons are subsurface horizons (Bt) that have at least 1.2 times as much clay than some overlying horizons. An argillic horizon can also be a horizon that has a clay content of more than 3% when the eluvial layer has less than 15% clay. Another example of an argillic horizon is when the illuvial layer has greater than 40% clay and the eluvial horizon has more than 8% clay. These horizons are formed by clay illuviation. Argillans are usually observable unless there is evidence of stress cutans. This horizon

should be 1/10 as thick as all overlying horizons or more than 15 cm (6 in.), whichever is thinner. In Alfisols, water is held at <1.5 MPa tension during at least three months each year when soil is warm enough for plants to grow. Umbric epipdons are present in a few Alfisols that are wet part of the year (Soil Survey Staff, 1975).

Where the soil temperature regime is mesic 8-15°C (47-59°F) or cooler, Alfisols generally form a belt between the grassland Mollisols and the Spodosols and Inceptisols of very humid climates. In thermic 15-22°C (59-72°F) or warmer soil temperature regimes, Alfisols generally form a belt between Aridisols of aridic regions and warm humid climate Inceptisols, Ultisols and Oxisols (Soil Survey Staff, 1975). According to the Soil Survey Staff (1975), "soil temperature regimes are used as family differentiae in all orders. Soil temperature regimes are measured at 50 cm or at lithic or paralithic contact, whichever is shallower."

Alfisols occur mostly on late-Pleistocene deposits or surfaces in regions of mesic and frigid 0-8°C (32-47°F) soil temperature regimes. They may occur on late-Pleistocene surfaces and also on older surfaces if external sources of bases are present (i.e. calcareous dust) in warmer regions (Soil Survey Staff, 1975).

Ultisols

Ultisols are soils that have one or more horizons which contain a considerable amount of translocated clay or layer silicate minerals but a small quantity of bases. These soils are usually found in mid to low latitudes. An excess of precipitation over evapotranspiration occurs at some season. Some water moves through the soil into a wet or moist substratum although the soil does not occur in a perudic soil moisture regime. Base release during weathering is normally equal to or less than that removed during leaching (Soil Survey Staff, 1975).

Ultisols are mostly found in warm humid climates that have a lower amount of precipitation during one season as compared to the rest of the year. Ultisols do not occur in aridic soil moisture regimes. They usually occur in temperature regimes warmer than frigid or isofrigid. Calcium-deficient argillic horizons are generally found in these soils within the United States (Soil Survey Staff, 1975).

Relative soil age is reflected by the developmental sequence of soils formed from the same parent material. Ultisols are located on parent materials and landforms that are geologically old. They are mainly present on Pleistocene or older surfaces. Over long periods of time, active soil formation forces have deepened soil

profiles through leaching and weathering. These deep and highly weathered soils have formed where relatively high amounts of precipitation have fallen. These soils are usually acid in reaction. When associated with warm humid climates and old terrain, these soils generally have a red color. Over a long period of time, these conditions result in a rapid and complete alteration of weatherable primary minerals into secondary clays and oxides. Kaolinite, gibbsite and hydroxy interlayered vermiculite are clay minerals formed from weathering of primary minerals. Mica is usually more prominent in coarse clay and silt fractions than in finer clay fractions (Buol et al., 1980).

Alfisol and Ultisol Formation Processes

The formation of Alfisols and Ultisols involves several individual processes. Albic and argillic horizons are the products of lessivage (Daniels et al., 1969). Lessivage is the mechanical migration of small mineral particles from A to B horizons of soils. This action generally produces B horizons relatively enriched with clay (Buol et al., 1980). The upper portion of the B horizon and the E horizon are sites of clay release in the lessivage process. Clay accumulations in the form of argillans are found in the argillic horizon, therefore the argillic horizons may be used as indicators of profile development (Buol et al., 1980). The

development of an argillic horizon generally is a slow process, but other factors besides time have great influences on the development of argillic horizons (Daniels et al., 1969). Argillic horizon morphology varies somewhat with texture. Coatings of clay on ped faces and preferred orientation of clay around sand grains and pebbles are evidence of clay illuviation (Danials et al., 1970). A soil genesis study on Indian mounds in western Iowa observed structural B horizons with clay films which had formed in 2,500 years (Parsons et al., 1962). Hallberg et al., (1978) report some translocation and accumulation of illuvial clay and fine silt in subsurface horizons of soils that developed in loess spoil material under prairie vegetation. These soils were in environments that receive about 86 cm of rainfall per year. This study suggest a clay bulge can develop under moderate rainfall in a few thousand years.

A land surface that has been stable for a long period of time can result in the formation of an argillic horizon. For example, because of the presence of an argillic horizon, Hapludults are thought to have undergone intensive weathering and/or long periods of weathering (Schumacher and Perkins, 1987).

Podzolization is also coextensive with lessivage in Alfisols and Ultisols. Podzolization is the chemical migration of aluminum and iron and/or organic matter

resulting in concentrations of silica in the eluviated layer. The eluvial horizon (E) has a low content of free iron oxide. Iron has moved from the albic to the argillic horizon. The free iron oxide to clay ratio is similar in E and Bt horizons because of the translocation of both iron oxides and clays from the E to the Bt horizons (Buol et al., 1980). Well-drained Alfisols and Ultisols have light colored surface horizons (ochric epipedon). A slight darkening of the top 10 cm or so is produced by melanization. Melanization is the darkening of light-colored unconsolidated initial mineral material by an organic matter admixture (Buol et al., 1980).

In thin sections, argillans are recognized by 1) finer and more homogenous textures than the matrix, 2) location on ped surfaces, former surfaces and grains, 3) laminated appearance, 4) birefringence, the numerical difference in values between the highest and lowest refractive index of a mineral extinction, and 5) extinction, the condition where polarized light is completely eliminated by the analyzer of the microscope. In some soils, argillans are not oriented or they have a mixed composition of clay, silt and oxides (McKeague and St. Arnaud, 1969). Argillans are usually mineralogically similar to s-matrix clay, and many constituents may be concentrated in them (Brewer and Sleeman, 1969). S-matrix is the material (plasma and/or skeleton grains and

associated voids) within the peds, or composing apedal soil material that does not occur as pedological features, other than plasma separations. Plasma is all colloidal sized and relatively soluble materials that are not bound up in skeleton grains. Plasma generally consists of mineral (amorphous and crystalline) and organic material. The soil matrix is the fine material (generally <2 um) forming a continuous phase and enclosing coarse material and/or pores (Brewer, 1976). Clay cutans in argillic horizons are higher in organic matter, clay, P, Mn, and Fe, than the matrix (McKeague and St. Arnaud, 1969). Cutans are modifications of the texture, structure, or fabrics at natural surfaces in soil materials, due to in situ modifications of plasma or concentrations of particular soil constituents. Cutans may be composed of any component of soil material (Brewer, 1976). Clay minerals occur as coatings (argillans) on void surfaces, peds and skeleton grains, and as zones separated from voids by a zone of s-matrix (quasiargillans). Skeleton grains are grains larger than colloidal size. They consist of mineral grains originally present in resistant siliceous and organic bodies and parent material (Brewer, 1976). Voids are entities interconnected through empty spaces of dissimilar shape and size, narrow necks, and intersections with empty spaces of similar size and shape

(Brewer, 1976). Ped and void argillans are usually created by illuviation (Brewer and Sleeman, 1969).

Weathering

Weathering is a combination of destruction and synthesis. There are two basic processes involved in weathering. These are mechanical and chemical. Mechanical weathering is designated as disintegration and chemical weathering is known as decomposition. Rocks are broken down by physical weathering into smaller rocks. These smaller rocks will eventually be broken down into individual minerals. Mechanical processes include freezing and thawing, erosion, deposition (by water, ice, and wind), swelling and shrinking and plant and animal influences (Brady, 1984).

The rock fragments and minerals are simultaneously attacked by chemical weathering processes. Chemical weathering of these minerals change them to new minerals either by minor alterations or by complete chemical changes. A continued decrease in particle size and release of soluble constituents contribute to the development of secondary minerals. Chemical weathering includes processes such as hydrolysis, oxidation, reduction, hydration, and dissolution (Brady, 1984).

Climate, biological activity, relief, and dissolved ion contribution of parent material is related to

chemical intensity. Mineral structure and chemical composition is related to thermodynamic susceptibility (Calvert et al., 1980). A physico-chemical regime is created by the first products of weathering. This regime affects all succeeding stages. Genesis, therefore, begins with chemical alteration of minerals at the rock-saprolite interface. Saprolite is the thoroughly decomposed igneous, metamorphic, or sedimentary rock formed in place by chemical weathering (Calvert et al., 1980). On the earth's surface, water is the primary factor influencing mineral alteration. The fundamental mechanism of mineral decomposition is hydrolysis, a form of chemical weathering, which releases exchangeable and constituent cations from soil minerals (Frenkel et al., 1983).

Under appropriate conditions electrons can be accepted (gain) or donated (loss) by all chemical elements. Hydrogen is the major electron donor and oxygen is the major electron acceptor. Electron loss by a substance is oxidation and electron gain is reduction. A substance only donates electrons if another substance accepts them and vice versa therefore, oxidation and reduction occur together. In natural electron exchange in soils, there are a limited number of elements involved because of the chemical conditions (Bohn et al., 1985). Oxidation occurs in well-aerated rock and soil materials

where biological demand is low and oxygen supply is high (Buol et al., 1980). Oxidation particulary occurs in rocks that contain iron (Brady, 1984). Ferrous to ferric iron is the most specific reaction in oxidation.

Equation 1:

$$Fe^{2+} \text{ ------> } Fe^{3+} + e^{-}$$

where e- = electron transfer

In minerals containing ferrous iron as part of their structure, oxidation is a disintegrative weathering process. Size and charge change of ferrous iron during conversion to ferric iron causes the mineral structure to break apart (Buol et al., 1980). Iron is present in the reduced ferrous [Fe^{2+}] form in some minerals. When iron is still part of the crystal lattice during oxidation structural adjustments must be made because a smaller tri-valent ion is replacing a larger di-valent ion. A less stable crystal that is subjected to both disintegration and decomposition is a result of these adjustments. Ferrous iron can also be released from the crystal and almost simultaneously oxidized to the ferric form. A example of this is the simultaneous formation of ferric oxide (goethite) from ferrous oxide released from the hydration of olivine (Bohn et al., 1985). Iron is released from the disintegration of primary mineral particles with hydroxyl and/or oxygen. This process is responsible for the formation of new oxygen to form iron

minerals. During the oxidation of primary minerals, manganese is released as a "free" form (neutral species or existing outside a chemical structure). Manganese may generally form as coatings on and within peds, and on sand grains in the soil. Manganese has a number of oxidation states which are responsible for complex chemistry (Buol et al., 1980).

Reduction occurs when soil material is water saturated (below water table level), contains a low oxygen supply and has a high biological oxygen demand. Iron is reduced to highly mobile ferrous forms. A net downward and outward movement of ground water may result in the loss of iron in this form (Buol et al., 1980).

A fluctuation from the oxidizing to reducing condition is common in C horizons and other initial soil material. This is a common cyclic response to weather variations throughout the year. During the geochemical weathering stage, initial soil material may be present in a reducing environment. This material is introduced to an oxidizing environment during the development of soil parent materials (C horizons). Lowering of land surface by erosion, coastal area uplift, lowering of regional water tables due to landscape development processes, climate change, or lowering and raising of the water table by man may cause a fluctuation from reducing to oxidizing conditions (Buol et al., 1980).

The association of water molecules or hydroxyl groups with minerals is referred to as hydration. Hydration occurs often without actual decomposition or modification of the mineral. This process occurs predominantly on surfaces and edges of the mineral grains (Buol et al., 1980). The structure and reactivity is an important property of iron oxides because reactions between iron oxide and components of the soil solution occur at the solid solution interface. Hydroxyl groups may have varying properties. They can exist between different minerals and on surfaces of the same mineral. Iron oxide surfaces in soils generally have similar properties. The adsorption of water molecules is dependent primarily on the surface area and to an extent the type of oxide (Schwertmann and Taylor, 1977). Hydration may occur throughout the entire structure of simple salts. Hydration may cause some changes in the structure of the salt. An example of this process is the case of the hydration of the mineral anhydrite which forms gypsum.

Equation 2:

$$CaSO_4 + 2H_2O \text{ ------> } CaSO_4 \cdot 2H_2O \text{ (gypsum)}$$

Water molecule sorption on mineral surfaces occurs on broken mineral edges. This reaction may occur in layer silicates on broken edges of minerals such as micas. The reaction also occurs with the association of hydroxyls

and water in the coordination sphere of aluminum and silica. A bridge or entryway for hydronium (hydrated hydrogen) ions used to attack the structure is provided by the sorbed water (Buol et al., 1980).

The dissolving of simple salts such as carbonates and chlorides is known as dissolution. The reaction occurs on mineral grains of some soil parent materials. For example, the dissolving of calcium carbonate in a calcareous glacial till or loess deposit.

Equation 3:

$$CaCO_3 + 2H^+ \text{-------} > H_2CO_3 + Ca^{++}$$

The residual phase and leached phase are two geochemical phases present in the pedogenic process. The residual phase contains the remaining in situ elements. Often after the destruction of primary minerals, the products alter to form new minerals. The leached phase encompasses all elements washed away after being liberated (Calvert et al., 1980).

Clay Size Fraction

Secondary minerals (clays) are produced by previously mentioned weathering processes. Weathering is a process that transforms unstable minerals from parent materials to more stable minerals. Clays are fine-grained minerals formed from primary minerals. They occur in forms too fine to identify optically, except by

color (Brewer and Sleeman, 1969). Due to slower weathering processes, clays are expected to remain stable for long periods of time. Common clay minerals found in soils are mica (illite), vermiculites, smectites, kaolinite and oxyhydroxide minerals weathering from parent materials (Lee and Tank, 1985). Interlayered clay minerals are characterized by a succession of stable or hydrated layers. They can also be characterized by intergrades in relation to the degree of hydroxylation or filling in the interlayers. Interlayer ions are located outside the structural units of the minerals. They can be replaced or rejected by higher hydrated cations (Na, Ca, Mg) without changing the lattice of the layer (Pedro et al., 1969).

The clay-size fraction (<2um) contains materials other than phyllosilicate minerals. Clay skins and coatings contain the highest concentrations of organic matter, clay minerals, phosphorous, manganese, and iron of any particle size fraction in Bt horizons (McKeague and St. Arnaud, 1969). Clays have a wide variety of chemical properties. The type and amount of clay minerals present are important for understanding ion exchange and adsorption mechanisms (Lutton et al., 1982).

Manganese and Iron Oxides

Manganese oxide rich ped surface coatings, concretions and nodules are common in many soils. These

black manganese oxide forms are most abundant in horizons that were seasonally saturated with water during soil formation, but may occur in any horizon. The occurrence of manganese oxides is recorded as morphological evidence of a fluctuating water table (Ross et al., 1976).

Manganese oxides, hydroxide, and hydrous oxide minerals are very complex. Manganese can exist in many oxidation states. The lowest and highest oxidation states of manganese observed in nature are 2^+ and 4^+. Manganese may have a mean valence of 3^+ to 4^+ when fixed in soils as an oxide or hydrous oxide. Many ions may be adsorbed on the manganese oxide. They become part of the crystal lattice, or possibly entrapped within crystals during crystal formation processes. These oxides are sites of important chemical reactions (Ross et al., 1976).

Many forms of manganese are found in soils. Glaebules and concretions are manganese rich plasma accumulating within the soil matrix in localized zones (1 to 10 mm dia.) (Ross et al., 1976). Glaebules are three-demensional units within the s-matrix of the soil material, and are approximately prolate (oblong) to equant (round) in shape. The morphology (size, shape, and/or internal fabric) varies greatly within soil material. This is because of a greater concentration of some constituent and/or a difference in fabric compared

with the enclosing soil material. Concretions are glaebules that generally have a concentric fabric about a center which can be a point, a line or plane. Mangans are manganese-rich plasma adhering to the soil's natural surface. Considerable intermixing of iron and manganese in concretions usually occurs in zones of predominately iron and manganese. Iron materials usually appear as drab brown or red in transmitted light (plane light through the scope) and pale brown or dark brown patches in incident light (reflected light in the microscope). When viewed under a petrographic microscope, manganese materials appear dark brown to opaque in transmitted light and mostly black in incident light (Ross et al., 1976).

Oxyhydroxides of aluminum, iron, and manganese and their mixtures are present in weathering zone pore spaces (Lutton et al., 1982). In the Conasauga group, the soil particles and weathered bedrock contain iron and manganese oxide coatings (Olsen et al., 1986).

CHAPTER III

MATERIALS AND METHODS

Nature of the Study Site

The study area is located in Solid Waste Storage Area 6 (SWSA-6) on the Oak Ridge National Laboratory Reservation. Solid Waste Storage Area 6 is found in Melton Valley, northwest of White Oak Lake and southeast of Lagoon Road and Haw Ridge in Roane County, Tennessee (see Figures 1, 2 and 3). The Oak Ridge Reservation is a part of the Valley and Ridge Province of East Tennessee. As shown in Figure 3, the study area is located on the Copper Creek thrust block and underlain by strata of Middle to Late Cambrian Conasauga Group. The Conasauga Group in the Melton Valley area is approximately 550 m thick, and composed of silty limestones, calcareous shales, and alternating siltstones and mudstones. The Upper Maryville Limestone and Nolichucky Shale are formations of the Conasauga Group that occur within the study area (Leitzke and Lee, 1986).

According to Boegly (1984), the soils in the study area are moist, strongly leached, acidic, low in organic matter, and have cation exchange capacities less than 10 cmol (+) kg^{-1} of soil. The carbonate cement found throughout most of the Conasauga Group is leached out near the surface. A thin veneer of soil, usually less

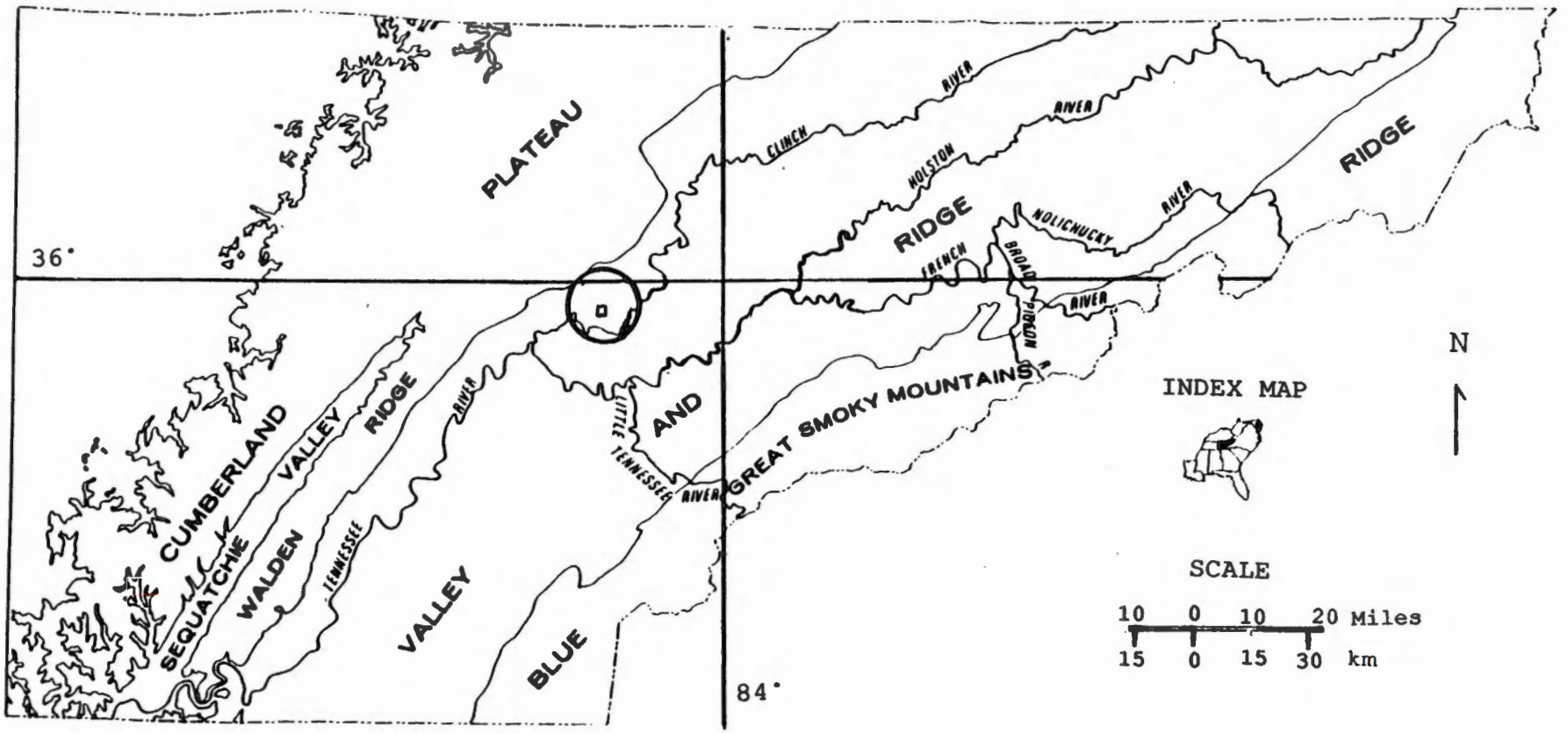
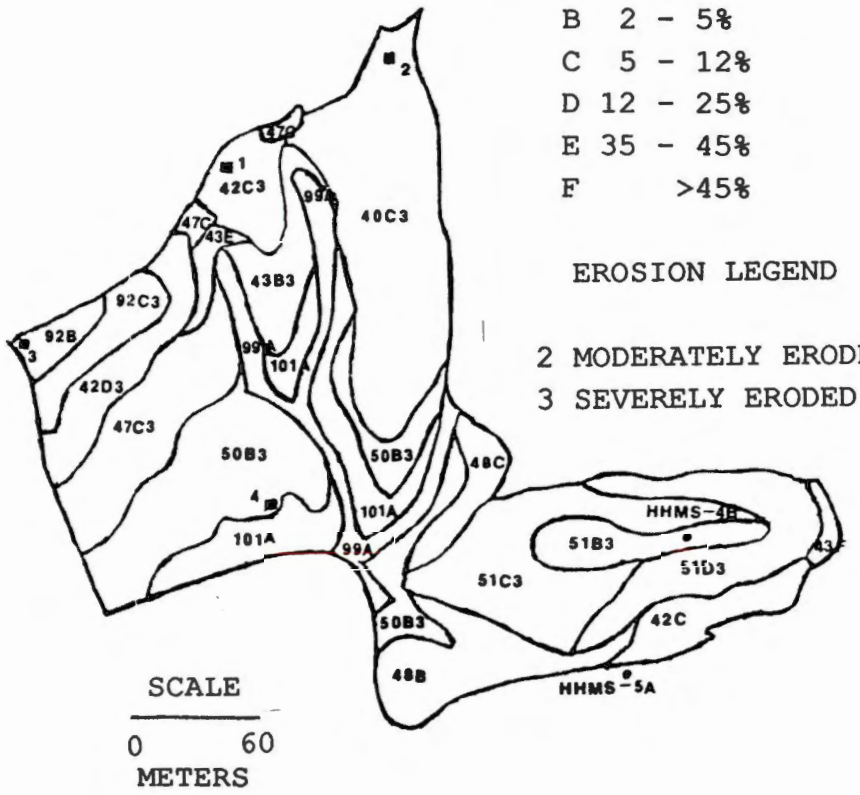


Figure 1. Location of the study site in East Tennessee.



SLOPE LEGEND

A 0 - 2%
B 2 - 5%
C 5 - 12%
D 12 - 25%
E 35 - 45%
F >45%

EROSION LEGEND

2 MODERATELY ERODED
3 SEVERELY ERODED

SOIL LEGEND

MARYVILLE SOILS

40 TYPIC HAPLUDULTS
42 RUPTIC-ULTIC DYSTROCREPTS
43 TYPIC-DYSTROCREPTS; SHALLOW

50 RUPTIC-AQUULTIC DYSTROCREPTS
51 RUPTIC-ULTIC DYSTROCREPTS

COLLUVIUM

47 TYPIC HAPLUDULTS
48 TYPIC FRAGIUDULTS

ALLUVIUM

92 TYPIC PALEUDULTS
99 TYPIC AND AERIC FLUVAQUENTS
101 AERIC OCHRAQUALFS

Figure 2. Soil map of the study site (after ORNL/TM-10013, 1986).

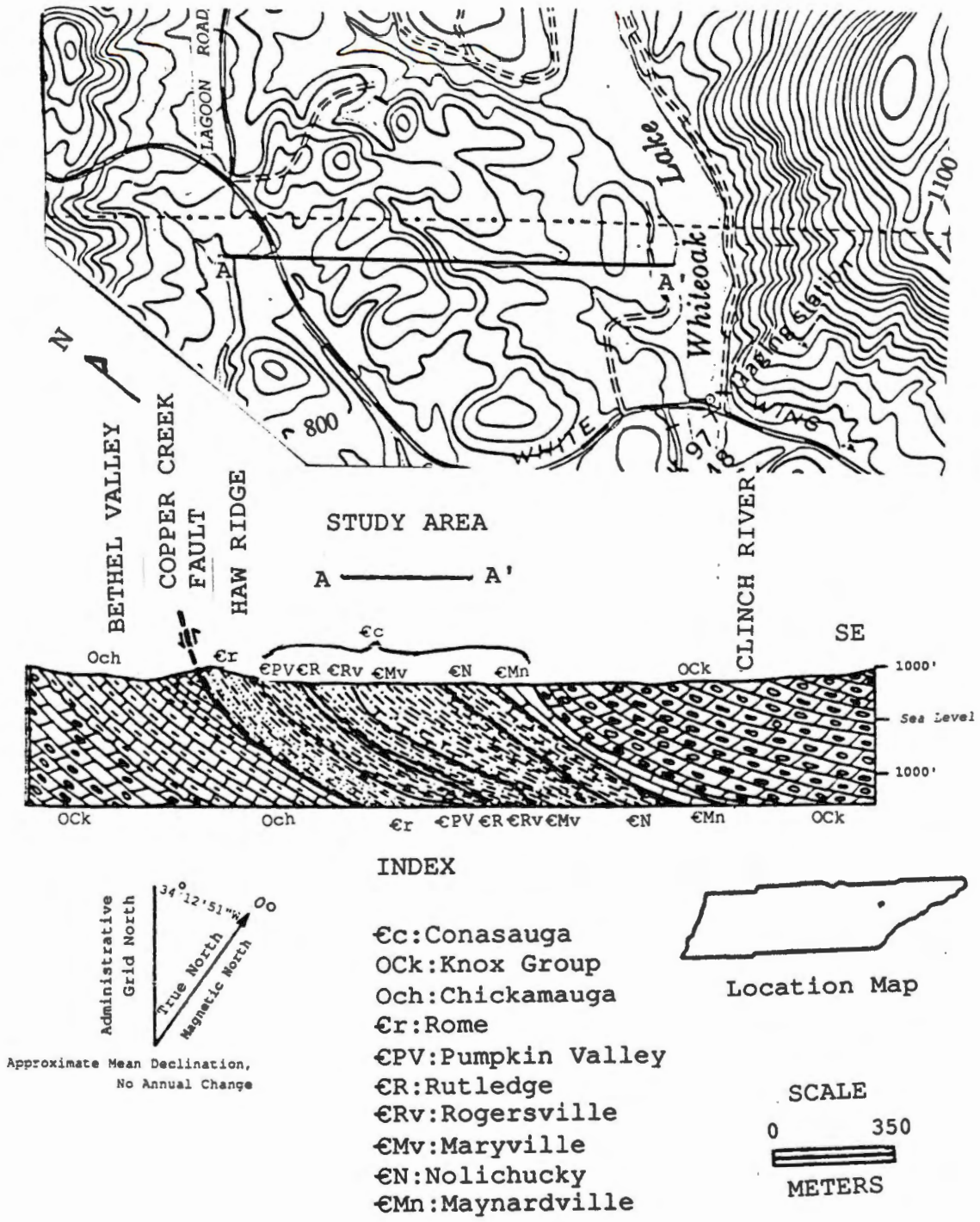


Figure 3. Topographic map and geologic cross-section of the study area (after U.S. Geological Survey, 1958).

than 1 m thick, overlies the partially weathered bedrock. The major soils found in the area are predominatly Ultisols, Alfisols and Inceptisols with small areas of Entisols. There are no distinct boundaries between the soil, partially weathered bedrock and unweathered bedrock (Boegly, 1984).

Field Methods

Soil and partially weathered bedrock samples were collected from soil profiles one, two, three, and four. All site locations are shown in Figure 2. Core drillings were collected from depths of 0 to 12.4 m approximately 250 m southeast and east of profile four (see Figure 2). Core drillings were taken by a top drive rotary drill constructed by Drill Tech. Under the operation of A.L. Clark Drilling Co., core drilling samples were collected from 56 cm diameter auger holes.

Sample Preparation

Bulk soil samples were air dried and ground to pass a 2 mm sieve. Coarse fragments (>2 mm) and fine earth materials (<2 mm) were stored in plastic bags in the Soil Sample Preparation Building on the University of Tennessee, Knoxville campus. The core drillings that contained no bedrock were sieved in order to collect the fine earth and coarse fractions. Core drillings containing bedrock were not sieved.

Laboratory Analyses

Physical and Chemical Analyses

Particle size analyses were conducted on the soil and partially weathered bedrock horizons. The pipette method was used to determine particle size distribution of the soil and partially weathered bedrock (Soil Survey Staff, 1984).

Chemical analyses were conducted on representative samples from single and combined soil horizons and partially weathered bedrock horizons as well as core drillings. Soil pH was measured using a 1:1 weight-to-volume (w/v) soil-to-solution ratio in water and 1 M KCl on the fine earth of soil profiles. The same pH procedure was used on the fine earth and the coarse fragment fractions of the core drillings. The pH of the coarse fragments was taken to determine the pH of the clay skins and surfaces of the coarse fragments. The pH of one core drilling sample (HHMS-5A) was measured in a soil/water paste due to insufficient sample (Peech, 1965).

Percent total carbon was determined by using a Leco CR12 carbon analyzer. Calcium carbonate equivalent (CCE) was determined by acid titration (Sobek et al., 1978). Exchangeable bases (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) were extracted with 1 M NH_4OAc. Exchangeable Al^{3+} was extracted with 1 M KCl. The exchangeable bases and Al^{3+} were determined

by atomic absorption spectroscopy. The effective cation exchange capacity (ECEC) was calculated from the sum of exchangeable bases plus KCl exchangeable Al^{3+} (Soil Survey Staff, 1984). Total exchangeable acidity was determined using a modified version of a method developed by Thomas (1982). The following modifications were used: 50 ml of 1 M KCl was added to 2.5 g of soil and the mixture agitated on a mechanical shaker for 30 minutes. The extract was collected by gravity filtration through a Whatman No.42 filter paper.

Reducible manganese was extracted with hydroxylamine hydrochloride, followed by determination using atomic absorption (AA) spectroscopy (Chao, 1972). Extractable iron and manganese were determined using sodium citrate sodium dithionite (Jackson, 1975).

Mineralogical Analysis

The mineralogy of soil and partially weathered bedrock clay fraction samples was determined by x-ray diffraction. The untreated clay samples were collected in conjunction with the particle size determinations. Iron was removed from the clay fraction of selected samples using sodium citrate bicarbonate dithionite (CBD) followed by saturation of split samples with 1 N KCl and 1 N $MgCl_2$ (Jackson, 1975). The untreated clay samples were oriented on ceramic tiles by suction through a Buchner funnel. Magnesium and potassium saturated clay

samples were oriented on glass slides by the filter-membrane peel technique of Drever (1973). Before the clays were oriented on the slides, they were dispersed with a ultrasonic dismembrator for 10 min. Air-dried magnesium-saturated samples were analyzed by x-ray diffraction at room temperature and after a 10% glycerol treatment. Air-dried potassium-saturated samples were analyzed at room temperature and following heat treatments at 105°C, 300°C, and 550°C.

The x-ray diffractions were conducted at the Oak Ridge National Laboratory. X-ray diffractograms were made with a Philips model 3-202 diffractometer connected to a California Scientific computer system. The radiation was CuK alpha generated at 35 kV and 15 mA. Diffractograms were completed at a scan speed of 1 degree per minute stepped at intervals of 0.02 degrees. Diffractograms began and ended at 2 and 30 degrees 2 theta, respectively (Whittig, 1965). Quantification of quartz, kaolinite, and gibbsite was achieved using differential scanning calorimetry (DSC).

Micromorphological Analysis

Petrographic analysis was conducted on 29 thin section samples using a polarizing microscope. Thin section analyses were conducted on subsamples from bulk profile samples. The descriptions, observations and measurements of the optical properties of rock and soil

forming minerals along with other crystalline and amorphous materials were completed according to FitzPatrick (1984). A scanning electron microscope (SEM), model no. ISI-40, was used to examine Cr horizon materials, especially manganese coatings (Kittrick, 1965).

CHAPTER IV

RESULTS AND DISCUSSION

Soil Morphology and Classification

Taxonomic classification for the four soils sampled are listed in Table 1. Profile descriptions of the soils are shown in Table 2. The soil profiles are illustrated in Figure 4. The soil in profile one is classified as a clayey-skeletal, mixed, thermic, Typic Hapludalf. The parent material is residuum from the Maryville Limestone. The partially weathered bedrock is variegated, with an olive color. Partially weathered siltstone and sandstone bedrock fragments are present below 100 cm. The illuvial zone (argillic horizon) of these soils is thick with a yellowish red color. The base saturation is greater than 35% throughout the control section (approximately 25 to 50 cm). The clay content is greater than 35% in the control section. Shale fragments occupy more than 50% by volume of the soil. Shale fragments are soft and disoriented to the depth of 38 cm due to some erosion but mostly to past agricultural activities. This is not enough evidence to classify the parent material as colluvium. The shale fragments below 38 cm are soft but show rock structure. Red and dark red iron oxides and black manganese oxides coat the faces of the partially weathered bedrock.

Table 1. USDA soil classification and parent material of four soil profiles described at the study site.

Profile	Classification	Parent Material
1	Typic Hapludalf; clayey-skeletal, mixed, thermic.	Maryville Limestone: Residuum
2	Typic Hapludult; clayey, mixed, thermic.	Maryville Limestone: Residuum
3	Typic Paleudult; fine-silty, mixed, thermic.	Ancient alluvium from local and distant sources
4	Aquic Hapludalf; loamy-skeletal, mixed, thermic.	Interbedded basal Nolichucky Shale and Upper Maryville Limestone: Residuum

Table 2. Field descriptions of four soil profiles at the study area.

Profile	Horizon	Depth, (cm)	Munsell Color Moist	Texture	Structure	(Moist) Consistence	Boundary	*Comments
				Typic Hapludualf; clayey-skeletal, mixed, thermic				
1	A	0 - 10	10YR 3/3	sil	2fgr	vfr	cw	9.9% shale frags; many fine roots
	E	10 - 18	10YR 6/4	sil	1fgr	vfr	cw	9.9% shale frags; common fine roots
	BE	18 - 25	10YR 5/6	sicl	2fsbk	fr	cw	8.67% shale frags; common fine roots
	Bt	25 - 38	5YR 5/6	**sh.c	2msbk/ 3fabk	fi	cw	15-20% soft shale frags (10YR 5/6) coated with yellowish-red (5YR 4/6) clay plasma
	Bt2	38 - 56	5YR 5/6	sh.c	2msbk/ 3fabk	fi	gw	20-30% soft shale frags coated with yellowish-red (5YR 4/6) clay plasma
	Bt3	56 - 68	5YR 4/6	sh.c	1csbk	fi	aw	40-60% soft shale frags (2.5Y 6/6) with yellowish-red clay plasma coatings and plug
	B/Ct	68 - 84	2.5YR 5/6	vsh.c	rock	fr	ai	70-80% shale frags with black Manganese (Mn) coatings
	C/Bt	84 - 105	2.5YR 5/6	vsh.sicl	rock	fr	ai	57.19% shale frags with dark red (2.5YR 3/6) iron (Fe) plasma coatings; thin sandstone lenses
	C	105 - 175	2.5Y 5/4-6/6	sil	rock	fr	ai	weathered shale-siltstone with dark red (2.5YR 3/6) clay and black Mn plasma coatings; few fine roots
	Cr	175 - 260	10YR 4/4	----	rock	--	--	oxidized shale coated with thin black Mn plasma and dark red (2.5YR 3/6) clay plasma; fine roots
				Typic Hapludult; clayey, mixed, thermic				
2	Ap	0 - 6	10YR 4/2	sil	2fgr	vfr	ai	10.45% shale frags; many fine roots
	E1	6 - 15	10YR 5/4	sil	1mgr	vfr	cw	10.45% shale frags; common 1-2 mm (dia.) hard Mn nodules
	E2	15 - 27	10YR 5/3	sil	1mgr	vfr	cw	10.45% shale frags; common 1-2 mm (dia.) hard Mn nodules
	Bt1	27 - 46	7.5YR 5/6	sicl	2fsbk	fi	gw	thin strong brown (7.5YR 4/4) clay plasma on ped surfaces; 14.59% shale frags; common 1-2 mm (dia.) Fe-Mn nodules; few fine roots
	Bt2	46 - 70	5YR 5/6	c	2fsbk	fi	gw	thin yellowish red (5YR 4/6) clay plasma on ped faces; few black Fe-Mn nodules; 14.59% highly weathered shale frags; few fine roots plugged with clay; few fine roots
	Bt3	70 - 84	5YR 5/8	c	1csbk	fi	cw	25.52% soft (2.5YR 5/4) shale and siltstone frags; (2.5YR 4/6) clay plasma on ped faces; horizon is highly plugged with clay; few fine roots
	C/Bt	84 - 100	2.5Y 5/6	sh.sic	rock	fi	cw	25.52% shale frags; 7.5YR 5/6, 10R 4/6, 2.5Y 5/2,5/3 clay coatings; few fine roots
	C	100 - 120	2.5Y 5/6	sh.sic	rock	fi	ci	46.69% shale frags with 7.5YR 5/6 clay coatings and dark red Fe plasma
	Cr1	120 - 208	2.5Y 5/6	v.sh.sic	rock	--	--	steeply dipping rock structure; red (10R 4/8-2.5YR 4.8) Fe plasma and black Mn plasma coatings
	Cr2	208 - 300	10YR 5/4	sh.sic	rock	--	--	shale and siltstone frags coated with black Mn plasma and yellowish-red (5YR 5/8) Fe plasma

Table 2. (continued)

Profile	Horizon	Depth, (cm)	Munsell Color Moist	Texture	Structure	(Moist) Consistence	Boundary	*Comments
			Typic Paleudult; fine-silty, mixed, thermic					
3	Ap	0 - 10	10YR 3/3	sil	2fgr	vfr	cw	many fine roots
	E	10 - 21	10YR 5/4	sil	2fgr	vfr	cw	few fine and medium roots
	Bt1	21 - 37	7.5YR 5/4	sicl	2fsbk	vfr	cw	common medium roots
	Bt2	37 - 53	7.5YR 4/4	sicl	2fsbk	vfr	aw	few 3-5 mm (dia.) chert pebbles; yellowish-red (5YR 5/6) clay plasma on peds; few medium roots
	Bt3	53 - 80	2.5YR 4/8	c	2msbk	fi	gw	few chert and sandstone pebbles; yellowish-red (5YR 5/6) and red (2.5YR 3/6) clay plasma; few medium roots
	Bt4	80 - 119	2.5YR 4/8	c	3f-msbk	vfi	dw	7.5YR 5/8, 10YR 6/3 and 2.5YR 4/6 clay plasma coats ped surfaces in water flow zones
	Bt5	119 - 190	2.5YR 4/8	c	1f-msbk	vfi	--	7.5YR 5/8, 10YR 6/3, 2.5Y 6/4 and 2.5Y 6/2 clay coatings found in flow zones
	BC	190 - 230	5YR 5/6 7.5YR 5/8	sic	--	--	--	2.5YR 6/2 and 7.5YR 4/4 clay plasma in flow zones
	CB	230 - 300	10YR 5/6	sic	--	--	--	red (2.5YR 4/8) Fe plasma and 10YR 7/2 clay coatings in flow zones
			Aquic Hapludalf; loamy-skeletal, mixed, thermic					
4	Ap	0 - 14	10YR 5/3	sil	1fgr	fr	aw	12.73% shale frags; few fine medium roots
	Bt	14 - 23	10YR 4/3	sic	2fsbk	fi	cw	16.30% shale frags; 10YR 5/4 clay plasma; few fine prominent red (2.5YR 4/8) mottles in peds; 10YR 5/4 clay coatings; few medium roots
	Btg	23 - 50	variegated 10YR 6/1 2.5YR 4/8	c	2csbk	fi	aw	54.33% shale frags; 10YR 6/2-6/3 clay plasma coats ped surfaces; few fine roots
	Cr	50 - 74	7.5YR 4/2	sh.c	rock	vfi	aw	86.96% shaly frags; 5GY 6/1 clay plasma coats steeply dipping rock structure
	2Cr	74 - 84	brown, red and gray strata	sh.c	rock	fi	aw	black Mn plasma and red Fe plasma coatings; glauconite pellets
	3Cr	84 - 120	7.5YR 4/2	sh.c	rock	fi	aw	black Mn plasma and red Fe plasma coatings; glauconite pellets
	4Cr	120 - 123	mottled brown,red and gray	sh.c	rock	fi	--	
	5Cr	123 - 150	mottled brown,red and gray	sh.c	rock	--	--	

*See Appendix B
**sh. = shaly
frags = fragments
Symbols from Soil Survey Manual, USDA Handb. no. 18, p. 139-140, 1951.

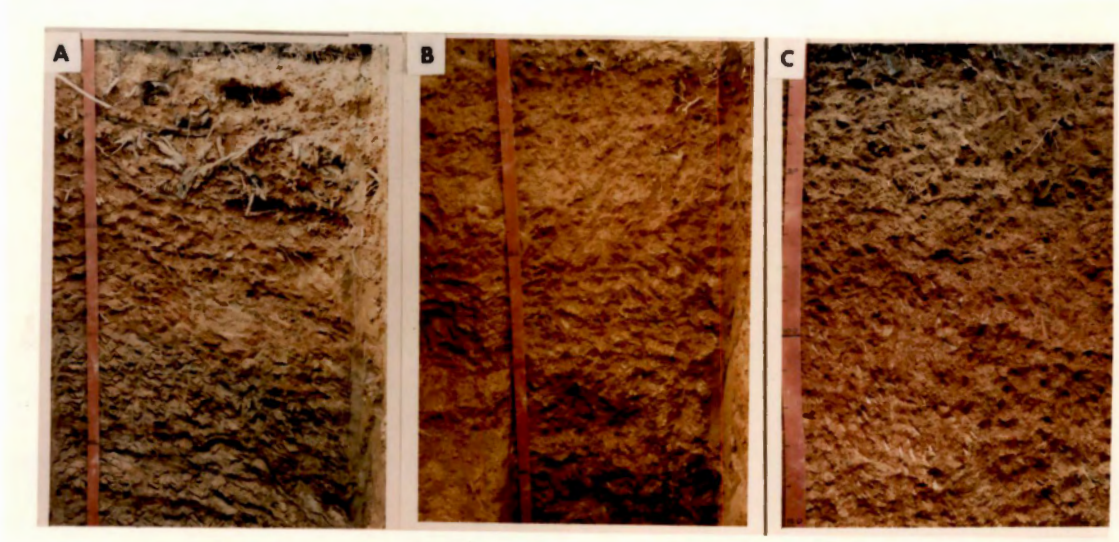


Figure 4. Photographs of soil profiles in the study area. These photographs illustrate soil and saprolite development: A) Soil profile one, B) Soil profile two, C) Soil profile three.

The soil in profile two is classified as a clayey, mixed, thermic, Typic Hapludult. This soil formed in residuum from the Maryville Limestone (see Table 1). The base saturation is less than 35% in the control section. This indicates that there has been enough leaching and weathering to remove most of the bases. A Typic Hapludult is a freely drained soil. Bright hues of 5YR (46-84 cm) are present, which suggest a high oxidation status (see Figure 4). Common hard manganese nodules (1 to 2 mm dia.) occur between 6 and 27 cm and a few black iron-manganese oxide nodules are found between 27 and 70 cm. Red to dark red iron oxide and black manganese oxide coatings are present on faces of the partially weathered bedrock.

The soil in profile three is classified as a fine-silty, mixed, thermic, Typic Paleudult. Soil profiles one, two and four have residuum as parent material, whereas, soil profile three has ancient alluvium from local and distant sources as parent material. During previous field observations, a loess deposit was suspected in the soil profile. Laboratory data (thin section observations and particle size analyses) did not provide enough evidence to support this theory. The base saturation is less than 35% in the control section. Bright red hues of 2.5YR in the Bt3 and Bt5 indicate a high oxidation status. Chert from the Knox formation

and sandstone pebbles are present between 37 and 80 cm. Red clay plasma is present as coatings on the ped surfaces (see Figure 4). The presence of rounded quartz grains (see Figure 5a) provides evidence of the alluvial nature of the parent material. Broken-up quartz grains indicate that the soil is highly weathered. Silicified oolitic material (see Figure 5b) and polycrystalline quartz (see Figure 5c) (from metamorphic sources) are additional evidence of two types of transported material present. Water flow zones are present below and within the Bt5 horizon (see Figure 5d). Surface residues were observed microscopically in these horizons (see Figure 6). These residues are the outer surfaces of aggregates from which one or more constituents have been removed. In profile three, these residues are clay and oxides. The presence of surface residues usually indicates the occurrence of water movement and weathering.

The soil in profile four is classified as a loamy-skeletal, mixed, thermic, Aquic Hapludalf. The parent material is residuum from interbedded basal Nolichucky Shale and Upper Maryville Limestone. The base saturation values for the control section are greater than 35%. Greater than 50% by volume of shale fragments is present in the soil profile. The presence of gray clay with the color of 10YR 6/1 indicates reduced conditions. Ped surfaces are coated with different shades of brown and

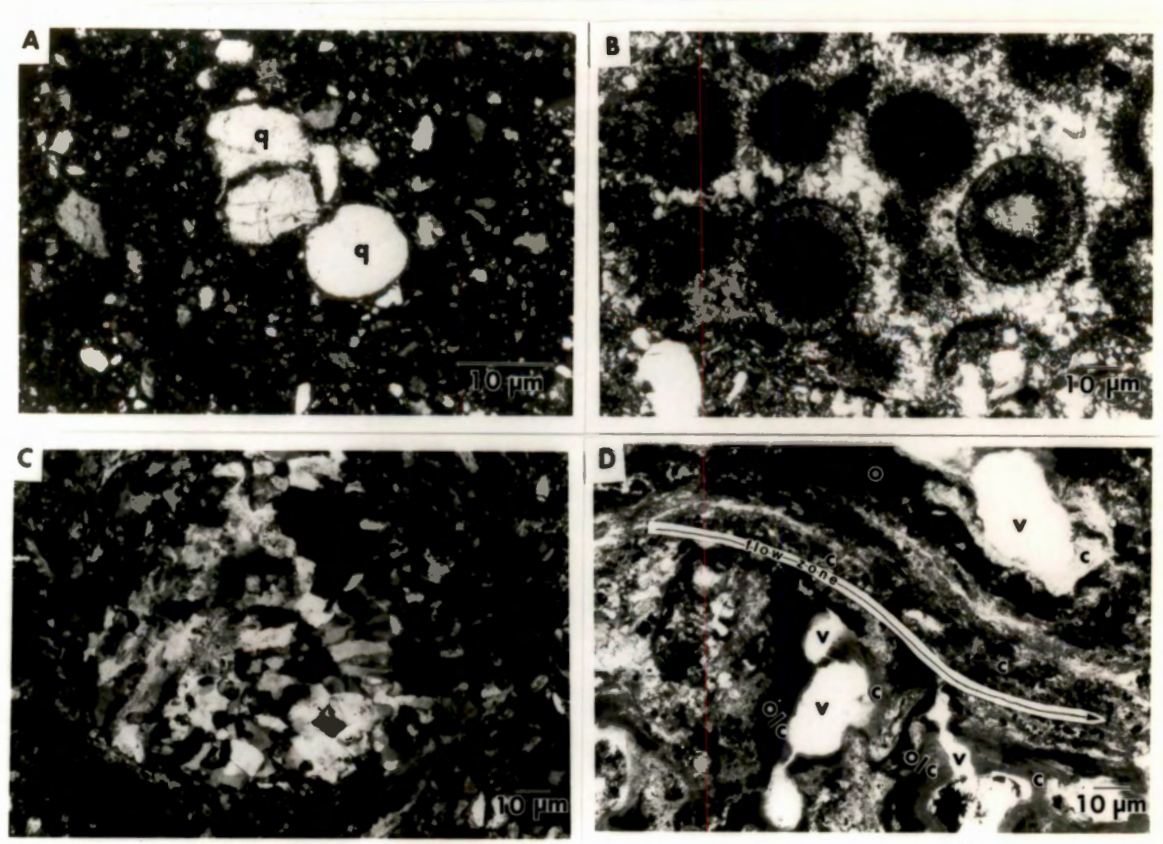


Figure 5. Photomicrographs of features in profile three. Photomicrographs illustrating: A) A rounded quartz grain (q) and a disintegrated quartz grain (q) present in the alluvial soil of profile three. The disintegrated quartz grain indicate a high degree of weathering. The round quartz grain is a product of alluvial action. B) Silicified oolitic material present in the ancient alluvium in the Bt5 horizon (130 cm) of soil profile three. C) Polycrystalline quartz grains present in the ancient alluvium in the Bt5 horizon (130 cm) of soil profile three. D) A flow zone of fine material comprised of clay (c) and manganese and iron oxides (o) in the Bt5 horizon (130 cm) of profile three. Voids (v) are also present in the area of the flow zone. The voids are coated with oxides and clay mixtures (o/c) and clay (c). The flow zone indicates illuviation of clay and oxides.

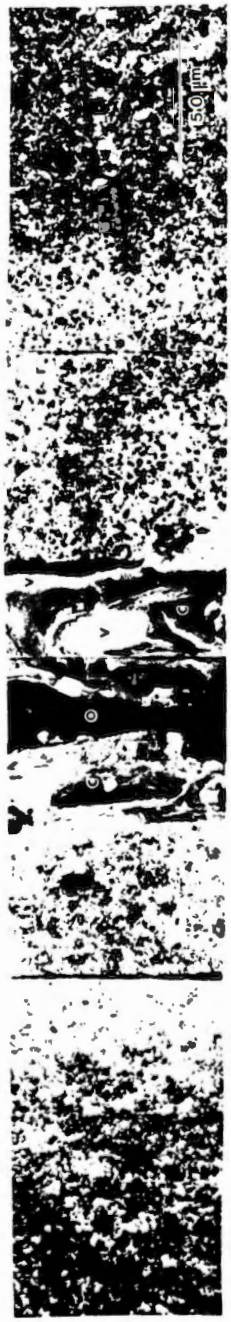


Figure 6. Photomicrograph of a surface residue. The surface residue (r) is observed adjacent to a pore that contains an infilling of highly oriented clay (C), on the side and manganese and iron oxide (o) accumulation in the center. Small voids (v) are also present. This feature was observed in the BC horizon (190-230 cm) of soil profile three.

gray clay. Black manganese oxides coat the brown colored shale between 84-120 cm. Glauconite pellets also occur within this zone. Steeply dipping rock structure is present in the 5Cr horizon. The Cr materials are quite hard below 120 cm.

Physical Properties

Particle Size Distribution

Particle size distribution for the four soil profiles is shown in Table 3. Profile one, a Typic Hapludalf, was located on a narrow and steep spur ridge. This was a residual soil, although there were deposits from overwash, erosion and pre-agricultural activities present. A notable amount of rock fragments (9.39 and 8.67%) was present in the surface and near surface horizons. Profile one had a high silt content in the surface and near surface horizons (64.9 and 51.3% respectively) due to the in situ weathering of silty bedrock. Sand size fractions remained in the 18.0 to 27.8% range from the surface to the C horizon. The sand fraction increased in the Cr horizon due primarily to the disaggregation of weathered shale, mudstone and claystone fragments during sample preparation. The clay content was low in the surface horizon due to translocation. The clay fraction percentages ranged from 23.2 to 58.2% in the subsurface horizons. The clay present was primarily

Table 3. Particle size distribution, including rock fragments, and USDA soil textures of four soils at the study site.

Profile	Horizon	Depth	Class & Particle Diameter in mm											
			VCS 2-1	COS 1-5	MS .5-2.5	FS .25-.1	VFS .1-.05	CO SI .05-.02	FSI .02-.002	SAND 2-0.05	SILT .05-.002	CLAY <0.002	Rock Frag. >2mm	Texture with Modifier
		(cm)	----------						%					
1	A	0 - 10	6.5	3.7	1.4	3.8	2.6	38.7	26.2	18.0	64.9	17.1	9.39	silt loam
	BE	18 - 25	6.7	3.1	1.3	3.3	11.1	22.5	28.8	25.5	51.3	23.2	8.67	silt loam
	CBt	84 - 105	9.7	7.0	0.5	1.0	3.2	4.6	15.8	21.4	20.4	58.2	57.19	very shaly clay
	C	105 - 132	11.5	4.5	0.9	2.4	8.5	17.4	17.4	27.8	34.8	37.4	67.00	ext. shaly clay loam
	**C	132 - 150	6.1	2.1	0.4	1.6	13.8	16.1	13.9	24.0	30.0	46.0	66.76	ext. shaly clay
	**Cr	175 - 260	23.8	9.1	1.2	3.8	6.5	10.9	17.5	44.4	28.4	27.2	78.93	ext. shaly clay loam
	Cr	201 - 213	11.6	3.0	0.5	3.1	13.4	14.5	17.9	31.6	32.4	36.0	58.61	very shaly clay loam
2	AE	0 - 27	3.2	1.9	0.6	1.9	8.8	29.8	37.6	16.4	67.4	16.2	10.45	silt
	Bt1-Bt2	27 - 70	2.3	1.5	0.5	1.8	4.0	19.5	27.1	10.1	46.6	43.3	14.59	silty clay
	Bt3-CBt	70 - 110	12.3	6.7	1.7	3.9	9.8	2.9	23.9	34.4	26.8	38.8	25.52	shaly clay loam
	C1	110 - 170	1.3	1.1	0.2	0.5	1.9	10.8	25.3	5.0	36.1	58.9	46.69	very shaly clay
	C2	170 - 190	0.8	0.5	0.3	0.9	5.0	14.3	23.1	7.5	37.4	55.1	37.75	very shaly clay
	Cr1	190 - 230	13.0	9.7	1.2	2.0	3.4	17.2	18.5	29.3	35.7	35.0	86.14	ext. shaly clay
	**Cr1-Cr2	205 - 300	2.2	2.1	0.3	2.1	9.6	14.4	21.6	16.3	36.0	47.7	72.12	ext. shaly clay
	Cr2	230 - 300	31.4	7.3	0.4	1.8	2.4	10.4	19.1	43.3	29.2	27.2	94.03	ext. shaly clay loam
	**Cr2	290 - 310	19.0	10.1	1.7	2.8	3.9	8.4	14.8	37.5	23.2	39.3	92.18	ext. shaly clay loam
	-	310 - 366	9.6	6.0	0.8	0.8	2.0	12.3	29.8	19.2	42.1	38.7	44.08	very shaly clay loam
	**-	366 - 396	16.3	8.3	1.6	4.3	9.6	12.8	8.6	40.1	21.4	38.5	49.84	very shaly clay loam
3	Ap-E	0 - 20	1.8	1.8	3.3	1.5	1.1	41.5	33.5	9.5	75.0	15.5	4.44	silt loam
	Bt1-Bt2	20 - 53	1.5	1.3	2.1	8.7	9.1	17.1	31.6	22.7	48.7	28.6	1.59	clay loam
	Bt3	53 - 80	1.7	1.5	1.9	8.6	9.2	26.8	30.6	22.9	47.4	29.7	17.42	cobbly clay loam
	Bt5	119 - 190	0.4	0.3	1.0	6.4	12.4	18.7	21.7	20.5	40.4	39.1	18.10	cobbly clay loam
4	Ap	0 - 14	2.8	2.9	1.0	2.2	2.5	21.2	34.5	11.4	55.7	32.9	12.73	silty clay loam
	Bt	14 - 23	5.2	4.2	1.7	3.1	3.8	6.1	31.2	18.0	37.3	44.7	16.30	shaly clay
	Btg	23 - 50	4.7	3.3	0.9	1.5	1.6	7.2	57.2	12.0	64.4	23.6	54.33	very shaly silt loam
	Cr	50 - 74	12.8	8.0	1.6	1.8	0.7	3.2	24.1	24.9	27.3	47.8	86.96	ext. shaly clay loam
	2Cr	74 - 84	6.2	4.5	2.2	4.8	2.9	4.5	25.3	20.6	29.8	49.6	75.71	ext. shaly clay
	3Cr	84 - 120	20.4	9.6	2.2	2.4	2.2	6.1	27.2	36.8	33.3	29.9	88.66	ext. shaly clay loam
	4Cr	120 - 123	7.3	5.0	3.2	10.4	7.0	3.9	18.3	32.8	22.2	45.0	67.85	ext. shaly clay
	5Cr	123 - 150	13.1	9.1	2.9	6.6	14.8	10.5	16.4	46.5	26.9	26.6	91.21	ext. shaly sandy clay loam

* ext. = Extremely
** = Concentration zones (See Tables 2 and 5)

in the form of coatings on the partially weathered bedrock. Petrographic examinations show most of the clay in a highly oriented state on the rock fragments, soil particles and especially in fracture zones of the partially weathered bedrock which suggest that the clay was of an illuvial nature, as illustrated in Figure 7. Some of the clay may have formed in situ from the weathering of primary minerals. Thin section examinations show in situ weathering of micas as shown in Figure 8.

Profile two, a Typic Hapludult, occurred on a geomorphically stable spur ridge. This is a highly weathered deep soil that has formed on Maryville Limestone residuum. A high silt content, 67.4%, was found in the surface horizon. The subsurface horizons had silt percentages that ranged from 21.4 to 46.6%. The presence of silt was due primarily to in situ weathering of the silty parent material. Due to removal of clays by translocation, the clay percentage for the surface horizon is low (16.2%). Clay percentages were high in subsurface horizons, especially in Bt horizons, primarily due to illuviation along with some in situ weathering of primary minerals and/or claystone. Clay percentages ranged from 27.2 to 58.9% in the subsurface horizons of profile two. The sand fraction percentages were 16.4% in the surface horizon and 5.0 and 7.0%, respectively, in

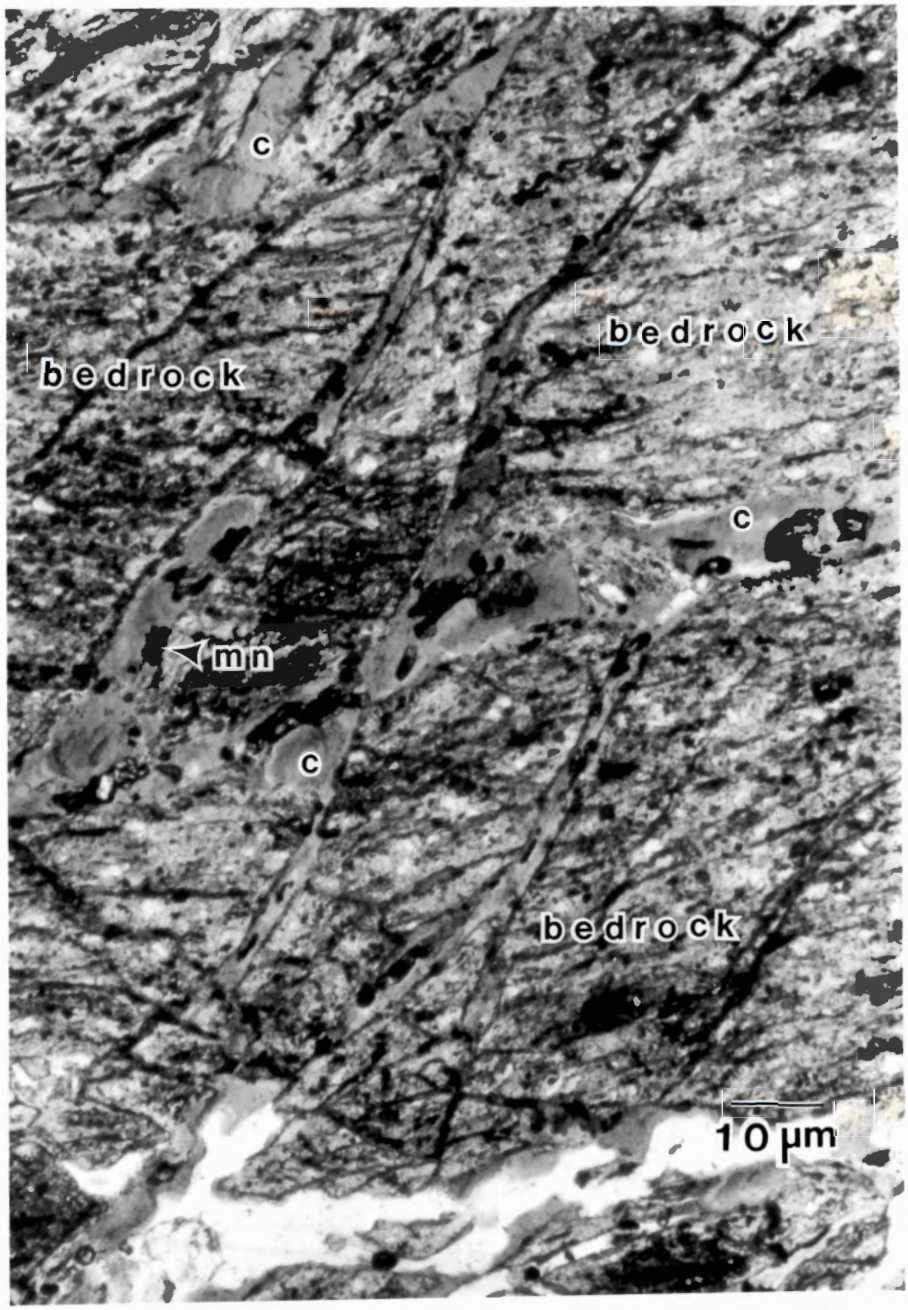


Figure 7. A photomicrograph showing illuvial highly oriented clay (c) and manganese oxide segregation (mn) within microscopic fractures of the partially weathered bedrock (bedrock) in the Cr horizon (201 to 213 cm) of soil profile one.

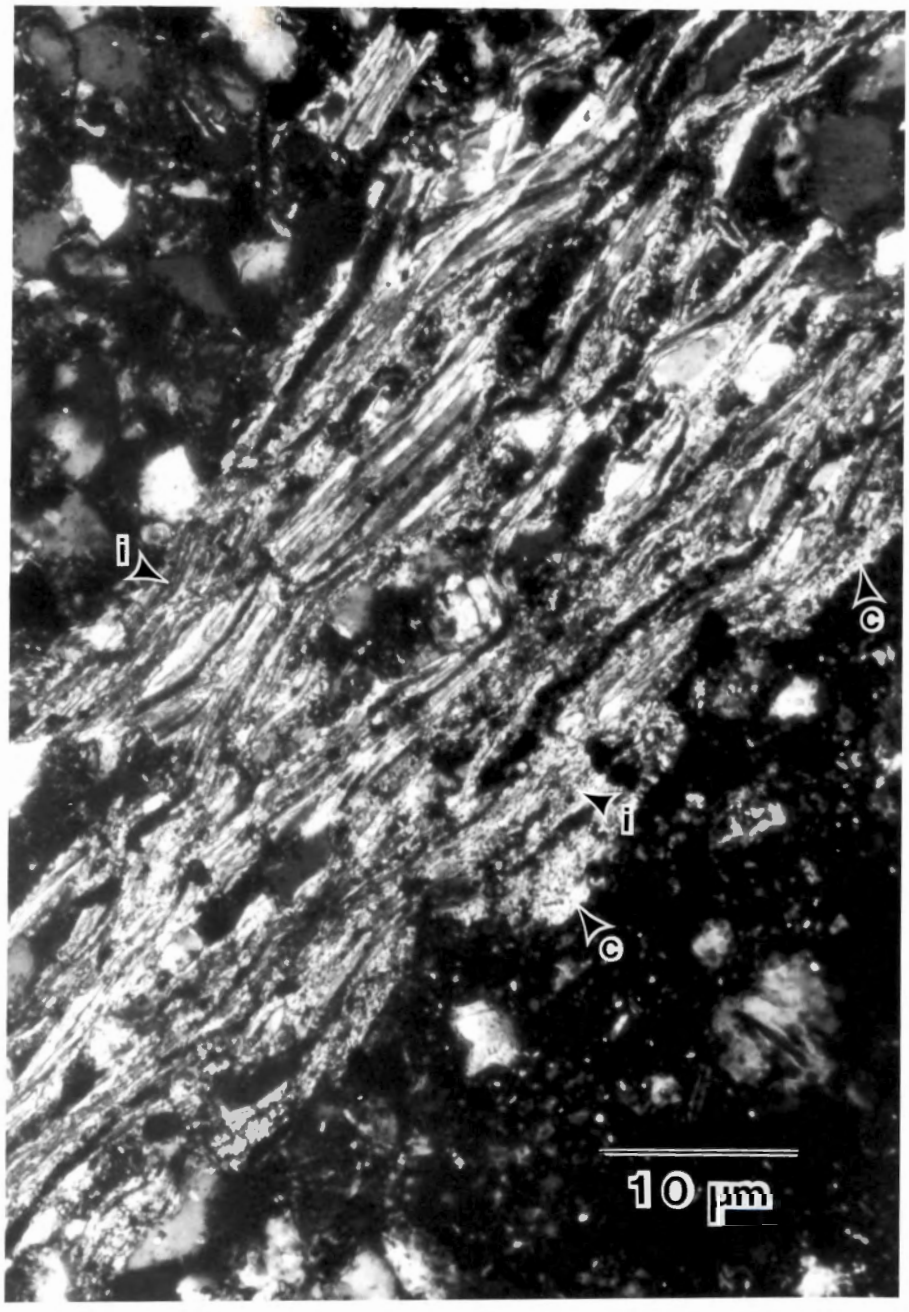


Figure 8. A photomicrograph showing <u>in situ</u> weathering of a mica grain. The grain exhibits exfoliation. The lighter areas around the grain are clay (c) and possible mica intergrades (i) which have formed from the weathering of the mica grain. These features were observed in the C/Bt horizon of soil profile one (cross-polars).

the C horizons. Large amounts of rock fragments (ranged from 14.52 to 94.03%) were present in the subsurface horizons. The coarse fragments in the A, Bt and C horizons were mainly hardened deposits of iron and manganese oxides with some rock fragments.

Profile three, a Typic Paleudult, is present on a stable summit which is the oldest landform on the site. This was a deeply weathered soil. The Ap-E horizons of profile three had a high silt content of 75.0%. Silt percentages were 48.7, 47.4 and 40.4%, respectively in the Bt1-Bt2, Bt3 and Bt5 horizons. These high silt percentages were present because of alluvial deposits of silty materials. In profile three, total sand fraction percentages were 9.5, 22.7, 22.9 and 20.5%, for the Ap-E, Bt1-Bt2, Bt3 and Bt5 respectively. The distribution of the different sand size fractions is reported in Figure 9. The data was inconclusive at this point to prove the presence of loess in the soil profile. Many sand grains were rounded and well weathered from alluvial action and intense weathering over a long period of time. Clay content was 15.5% in the surface horizon due to the eluviation of clays. The clay fraction percentages in the Bt horizons were 28.6, 29.7 and 39.1%, respectively. Most of this clay illuviated from upper horizons but some may have formed in situ. Examinations with a petrographic microscope show highly oriented clay around

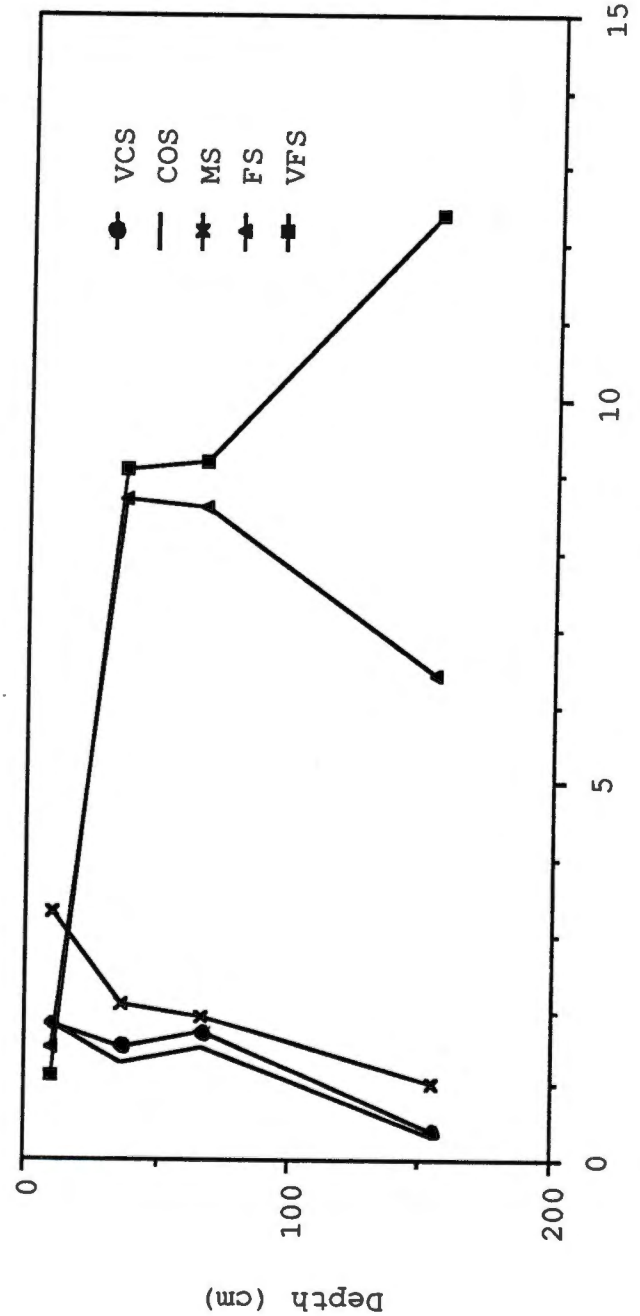


Figure 9. The distribution of the sand fraction with depth in soil profile three.

sand grains. In situ weathering of mica which generally produces clays also was observed. Coarse fragments were present in all horizons. The coarse fragments present in the surface and near surface horizons were in the form of iron and manganese oxide deposits that hardened over a long period of time. The lower subsurface horizons, Bt3 and Bt5, had cobbles and iron and manganese oxide hardened deposits present in the coarse fraction. The cobbles suggest the presence of alluvial deposits.

Profile four, an Aquic Hapludalf, is located in a low relief area. Percentages of the silt fraction varied from 22.2 to 64.4% in this profile. This silt was produced from the weathering of the silty bedrock. The clay fraction contents varied from 23.6 to 49.6% in the profile. The high clay percentages in the Cr horizons were mostly in the form of thick coatings on the partially weathered bedrock. These coatings illuviated from upper horizons in the profile. Sand fraction contents may be the result of disaggregation of weathered shale, mudstone and claystone fragments during sample preparation. Coarse fraction percentages ranged from 12.73 to 91.21%. This fraction was composed of shale, claystone and mudstone fragments.

Chemical Properties

Organic Matter

The total carbon content generally decreased with depth in the soils of the profiles (see Table 4). The surface horizon of profile one contained a large quantity of total carbon. Most of the total carbon found in subhorizons is organic material from roots or that has been leached. Organic materials illuviate with clay minerals. These clay minerals and organic particles were translocated (illuviated) through the soil into partially weathered bedrock. The accumulation of clay minerals and organic particles at 120 cm in profile four was probably a result of less permeable, partially weathered bedrock which begins at this depth. Movement of water, clay minerals and organic particles to lower depths was decreased in this zone. This resulted in the perching of water and accumulations of clay minerals and organic particles.

Hydrogen Ion Activities (pH)

The hydrogen ion activities of the soil and partially weathered bedrock samples from the various soil profile horizons and core drillings ranged from 4.5 to 7.3 (see Tables 5 and 6). Low pH values in the soil and partially weathered bedrock were the result of highly weathered conditions as demonstrated by soil profile two.

Table 4. Total organic carbon distributions in four soils at the study site.

Profile	Horizon	Depth	Total Carbon
		(cm)	(%)
1	A	0 - 10	4.10
	BE	18 - 25	0.65
	C/Bt	84 - 105	0.61
	C	105 - 132	0.17
	C **	132 - 150	0.13
	Cr **	175 - 260	0.05
	Cr	201 - 213	0.11
2	Ap-E	0 - 27	0.74
	Bt1-Bt2	27 - 70	0.28
	Bt3-C/Bt	70 - 110	0.40
	C1	110 - 170	0.10
	C2	170 - 190	0.09
	Cr1	190 - 230	0.08
	Cr1-Cr2**	205 - 300	0.05
	Cr2	230 - 300	0.01
	Cr2 **	290 - 310	0.03
	-	310 - 366	0.02
	- **	366 - 396	<0.01
3	Ap-E	0 - 20	1.80
	Bt1-Bt2	20 - 53	0.48
	Bt3	53 - 80	0.09
	Bt5	119 - 190	0.09
4	Ap	0 - 14	0.73
	Bt	14 - 23	0.45
	Btg	23 - 50	0.39
	Cr	50 - 74	0.12
	2Cr	74 - 84	0.14
	3Cr	84 - 120	0.44
	4Cr	120 - 123	0.72
	5Cr	123 - 150	0.47

** = Concentration Zones (see Tables 2 and 5)

Table 5. The distribution of pH, sodium dithionite extractable iron and manganese, and hydroxylamine reducible manganese for four soils at the study site.

Profile	Horizon	Depth	pH (1:1) (<2mm) H_2O	pH (1:1) (<2mm) KCl	CBD Fe^{2+}	CBD Mn^{2+}	Hydroxylamine Reducible Mn	Remarks*
		(cm)			mg kg $^{-1}$			
1	A	0 - 10	6.45	5.79	765.00	918.40	39.80	
	BE	18 - 25	6.11	5.18	1550.40	752.40	4.20	
	C/Bt	84 - 105	5.38	4.31	3626.10	207.20	2.40	
	C	105 - 132	4.60	3.46	3326.10	100.00	12.40	
	C	132 - 150	4.90	3.52	3886.20	1368.00	167.20	Mn Zone
	Cr	175 - 260	5.02	3.48	2172.60	874.00	156.20	Mn Zone
	Cr	201 - 213	5.20	3.61	2723.40	161.40	48.00	
2	Ap-E	0 - 27	4.81	3.75	1254.60	620.00	39.00	
	Bt1-Bt2	27 - 70	5.09	3.59	2855.29	34.90	56.00	
	Bt3-C/Bt	70 - 110	5.31	3.60	3580.20	114.00	13.00	
	C1	110 - 170	5.47	3.51	5467.20	117.80	17.40	
	C2	170 - 190	5.11	3.55	2315.40	126.00	211.40	
	Cr1	190 - 230	4.84	3.55	3480.63	988.60	125.40	
	Cr1-Cr2	205 - 300	5.21	3.61	3264.00	2834.20	609.60	Mn + Fe Zone
	Cr2	230 - 300	4.84	3.55	1876.90	1820.40	209.00	
	Cr2	290 - 310	5.28	3.69	2850.90	1950.50	116.60	Fe Zone
	-	305 - 366	5.11	3.51	1871.70	1628.00	182.40	
	-	366 - 396	4.90	3.54	1443.30	2215.60	324.00	Mn Zone
3	Ap-E	0 - 20	5.91	5.55	2683.42	13.30	29.00	
	Bt1-Bt2	20 - 53	4.49	3.79	1948.20	11.40	5.80	
	Bt3	53 - 80	5.00	3.69	2203.20	182.00	0.20	
	Bt5	119 - 190	4.90	3.48	2683.42	11.40	0.60	
4	Ap	0 - 14	4.68	3.55	2087.76	592.00	47.30	
	Bt	14 - 23	4.80	3.15	2652.00	1552.00	164.00	
	Btg	23 - 50	4.81	3.48	2641.80	520.60	44.80	
	Cr	50 - 74	4.81	3.42	2244.00	932.40	62.40	
	2Cr	74 - 84	5.05	3.45	4278.90	259.00	21.80	
	3Cr	84 - 120	6.50	5.09	2538.90	103.40	208.40	
	4Cr	120 - 123	6.95	6.19	2855.30	200.00	25.00	
	5Cr	123 - 150	7.25	6.25	2296.73	165.00	224.40	

* = Field observations (see Table 2)

Table 6. The pH, hydroxylamine reducible manganese and calcium carbonate equivalent (CCE) distributions for drill core samples from the study site.

Sample	Depth	pH (1:1 H_2O) >2mm	pH (1:1 H_2O) <2mm	pH (1:1 KCl) >2mm	pH (1:1 KCl) <2mm	Hydroxylamine Reducible Mn	CCE
	meters					(mg kg $^{-1}$)	(%)
HHMS-4B	0 -0.61	5.12	4.50	3.70	3.61	36.00	0.10
	0.61-1.22	4.80	4.74	3.51	3.48	184.00	0.61
	1.22-1.83	5.11	5.20	3.50	3.65	323.00	0.13
	1.88-2.44	5.25	4.89	3.47	3.45	308.00	0.07
	2.44-3.05	5.13	4.92	3.40	3.40	462.00	-0.03
	3.05-3.66	5.64	4.77	3.33	3.39	509.00	-0.40
	3.66-4.27	5.30	5.35	3.44	3.60	390.00	0.56
	4.27-4.88	5.74	5.45	3.80	3.87	512.00	0.62
	4.88-5.49	6.11	5.85	3.80	4.09	355.00	0.70
	5.49-6.91	7.60	-**	6.33	-**	87.00	26.17
	6.91-7.52	8.39	-	6.21	-	89.60	22.76
	7.52-8.13	8.10	-	6.73	-	91.80	28.92
	8.13-8.74	8.11	-	6.70	-	87.00	21.72
	8.74-9.35	8.30	-	6.48	-	72.80	17.10
	9.35-9.96	8.24	-	6.89	-	68.60	17.58
	9.96-10.57	8.30	-	6.69	-	70.00	16.96
	10.57-11.18	8.11	-	6.42	-	89.20	21.00
	11.18-11.79	8.25	-	6.70	-	95.60	25.33
	11.79-12.40	8.11	-	6.70	-	88.00	27.66
HHMS-5A	0-0.61	4.89	4.78	3.59	3.61	13.00	0.09
	0.61-1.22	4.82	4.73	3.38	3.49	47.30	-0.39
	1.22-1.83	5.10	5.21	3.61	3.65	261.00	0.15
	1.83-2.44	5.34	5.21	3.82	3.86	723.20	0.14
	2.44-3.05	5.69	5.80	4.24	4.08	308.00	0.65
	3.05-3.66	6.18	6.27	4.70	4.99	268.40	0.15
	6.71-7.32	-	7.70*	-	- *	125.40	31.26
	7.32-7.93	8.21	- **	6.60	- **	92.80	22.50
	7.93-8.53	7.55	-	6.70	-	68.00	13.94
	8.53-9.14	7.65	-	6.49	-	88.20	23.83
	9.14-9.75	7.92	-	6.70	-	92.40	25.81
	10.36-10.97	7.67	-	6.09	-	94.80	28.43
	10.97-11.58	8.30	-	6.95	-	89.40	20.68
	11.58-12.19	8.05	-	6.78	-	97.80	25.91

* Insufficient sample, therefore the paste method was used.
** Samples beyond this point were of bedrock and no soil was present.

Higher pH values were observed in the A and B horizons of profile one and the lower, partially weathered bedrock (horizon 5Cr) of profile four. Soil pH values ranged from 6.1 to 7.3 in these horizons. The high pH values in the surface horizon of profile one were probably due to surface applications of lime. The pH of the lower partially weathered bedrock horizon (5Cr) in profile four was high due to the presence of carbonates. The bedrock of core HHMS-4B (below 7.52 meters) had pH values >8.1 and the presence of free carbonates. Additionally, pH values of the samples from the bedrock of core HHMS-5A (below 7.32 meters) ranged from 7.6 to 8.3 and also showed the presence of free carbonates.

KCl Extractable Aluminum

Values for KCl extractable aluminum and total acidity for the soil and partially weathered bedrock in the soil profiles are shown in Table 7. The values for extractable Al and total acidity generally increased with depth in all soils. The samples in profile four had low concentrations of extractable aluminum and total acidity, due to the presence of free carbonates in the partially weathered bedrock. Low extractable Al^{3+} values (<0.2 to 8.05 cmol(+) kg^{-1}) were found in profile three, a Typic Paleudult. This is a highly weathered soil in which most of the extractable Al^{3+} has been leached out.

Table 7. NH_4OAc-exchangeable bases, KCl-extractable Al and acidity, effective cation exhange capacity (ECEC) and base saturation of four soils at the study site.

Profile	Horizon	Depth	Exchangeable bases				Extractable Al	Total Acidity	ECEC	Base Saturation
			Ca	Mg	K	Na				
		(cm)	cmol(+) kg^{-1}							(%)
1	A	0 - 10	9.10	0.66	1.26	0.10	<0.2	0.39	11.12	100
	BE	18 - 25	1.71	0.32	0.91	0.03	<0.2	0.30	2.97	100
	C/Bt	84 - 105	2.46	0.66	1.13	0.06	<0.2	0.39	4.31	100
	C	105 - 132	1.05	0.90	0.87	0.07	10.68	8.50	11.39	25
	C**	132 - 150	0.23	1.80	0.60	0.22	9.61	9.05	11.97	24
	Cr**	175 - 260	0.12	0.86	0.31	0.28	7.96	7.20	8.77	18
	Cr	201 - 213	0.23	1.12	0.25	1.43	7.11	5.75	8.77	34
2	Ap-E	0 - 27	0.60	0.07	0.16	0.05	2.13	1.50	2.38	37
	Bt1-Bt2	27 - 70	4.70	0.60	0.27	0.03	6.63	5.83	11.43	49
	Bt3-C/Bt	70 - 110	0.08	0.30	0.22	0.02	9.87	8.47	9.14	7
	C1	110 - 170	0.05	0.26	0.18	0.07	11.30	11.50	12.07	5
	C2	170 - 190	0.06	0.78	0.18	0.04	11.70	9.63	10.67	10
	Cr1	190 - 230	0.07	0.74	0.22	0.07	10.62	8.35	9.45	9
	**Cr1-Cr2	205 - 300	0.09	0.22	0.22	0.11	8.45	7.18	8.39	14
	Cr2	230 - 300	0.07	1.18	0.25	0.61	9.83	7.96	9.52	16
	Cr2**	290 - 310	0.10	1.34	0.22	0.02	8.80	7.67	9.35	16
	-	310 - 366	0.12	1.57	0.26	0.07	8.86	7.61	9.63	21
	- **	366 - 396	0.23	2.17	0.28	0.06	6.63	5.79	8.53	32
3	Ap-E	0 - 20	8.16	0.35	0.27	0.03	<0.2	0.39	9.21	96
	Bt1-Bt2	20 - 53	1.16	0.15	0.35	0.03	2.82	2.10	3.79	44
	Bt3	53 - 80	0.02	0.13	0.21	0.03	2.76	6.84	7.23	5
	Bt5	119 - 190	0.01	0.13	0.20	0.03	8.05	6.56	6.93	5
4	Ap	0 - 14	1.06	1.55	0.41	0.03	6.74	5.83	8.88	34
	Bt	14 - 23	3.72	1.40	0.37	0.04	8.00	6.53	11.56	43
	Btg	23 - 50	2.90	1.51	0.47	0.05	10.31	8.55	13.48	37
	Cr	50 - 74	0.67	2.29	0.36	0.10	9.25	8.16	11.61	27
	2Cr	74 - 84	0.62	2.35	0.21	0.11	9.20	7.81	11.10	27
	3Cr	84 - 120	2.18	6.25	0.25	0.08	<0.2	0.39	9.25	96
	4Cr	120 - 123	44.06	7.87	0.23	0.12	<0.2	0.39	52.67	99
	5Cr	123 - 150	30.80	6.26	0.15	0.16	<0.2	0.00	37.37	100

** = Concentration zones (see Tables 2 and 5)

Effective Cation Exchange Capacity (ECEC)

The effective cation exchange capacity (ECEC) values varied throughout all soils investigated (see Table 7). These values ranged form 2.38 to 52.67 cmol(+) kg^{-1}. The values reported for Cr horizons may be artificially high, due to the method of sample preparation and the presence of carbonates. The values only expressed the ECEC of the fines (<2mm), and did not include the partially weathered bedrock in the field state. Rock and/or partially weathered bedrock fragments (>2mm), comprised a large volume of the lower horizons in the soils of the study area.

Total exchangeable bases for the soil and partially weathered bedrock are reported in Table 7. Calcium values were high in surface horizons of profiles one, two and three. This was probably due to surface additions of lime and recycling of nutrients. The calcium values of samples from the 3Cr, 4Cr, and 5Cr horizons of profile four were extremely high due to the presence of free carbonates. The calcium, magnesium, potassium and sodium values varied throughout all soils. The Cr horizons in profile one contained higher concentrations of sodium than was found in any of the other soil horizons analyzed.

Calcium Carbonate Equivalent (CCE)

Calcium carbonate equivalent (CCE) values for the core drilling samples are reported in Table 6. Calcium carbonate equivalents decreased sharply in highly weathered portions of the soil where pH values are low. These values increased at the weathering front between leached and unleached bedrock.

Mineralogical Properties

Clay Size Fraction

The minerals present in the clay size fraction included kaolinite (1:1 non-expanding), hydroxy interlayered vermiculite (HIV) (2:1 non-expanding), vermiculite, illite, gibbsite and quartz. The other constituents of the clay size fraction were manganese and iron oxides.

The mineralogy of these soils are shown in Table 8. X-ray diffractograms of the clay size fraction of the soils are shown in Figures 10-17. This information was useful in determining weathering sequences and soil forming processes. Relative percentages of the minerals present in the clay size fraction of the four soil profiles were obtained from the x-ray diffractograms (XRD).

In profile one, a Typic Hapludalf, a high content (30-50%) of mica (illite) was detected in the surface

Table 8. Summation of mineralogical analysis from x-ray diffraction and differential scanning calorimetry determinations.

Profile	Horizon	Depth	Minerals present in clay fraction (<.002mm)						
			Vermiculite	HIV*	Kaolinite	Mica (illite)	Manganese Oxide	Iron Oxide	Gibbsite
		(cm)							
1	A	0 - 10	L	H	L	H	X	X	
	C/Bt	84 - 105	L	H	L	M	X	X	
	C	132 - 150	M	H	L	M	X	X	
	Cr	201 - 213	M	H	L	M	X	X	
2	Ap-E	0 - 27	L	H	L	L	X	X	
	Bt1-Bt2	27 - 70	M	H	L	L	X	X	
	Cr1	190 - 230	H	L	L	L	X	X	
	Cr2	290 - 310	M	L	L	L	X	X	
3	Ap-E	0 - 20	L	L	M¶	H		X	
	Bt1-Bt2	20 - 53	L	H	H¶	L	X	X	
	Bt3	53 - 85	L	H	H¶	L	X	X	
	Bt5	119 - 190	M	L	H¶	H	X	X	X
4	Ap	0 - 14	M	L	H¶¶	H	X	X	
	Btg	23 - 50	M	L	H¶¶	H	X	X	
	Cr	50 - 74	M	L	H¶¶	H	X	X	
	5Cr	123 - 150	H	L	H¶¶	M	X	X	

*HIV = Hydroxy interlayered vermiculite
¶ = Crystalline
¶¶ = Highly Crystalline

X = Present (<10%)
L = Low (10-20%)
M = Moderate (20-30%)
H = High (30-50%)

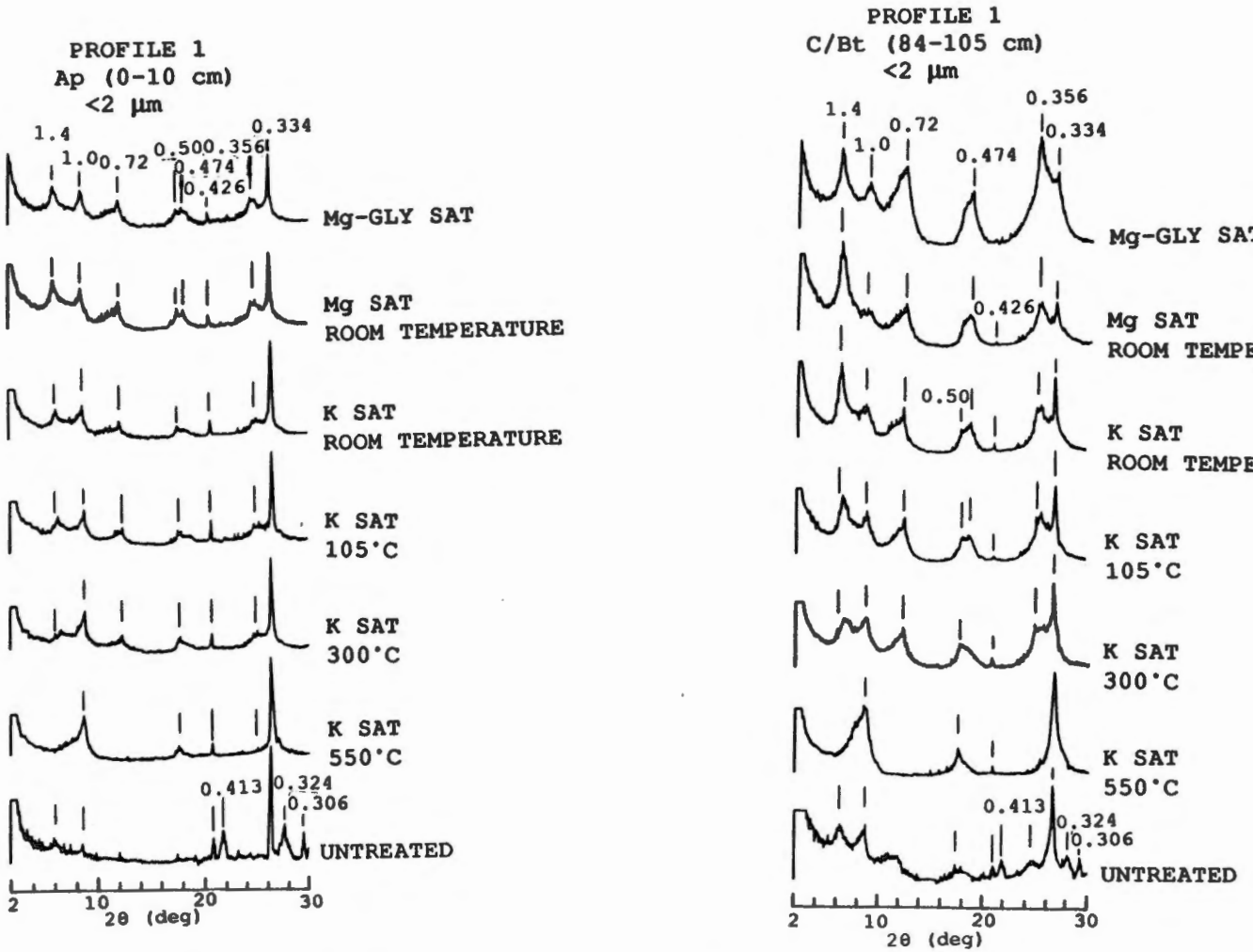


Figure 10. X-ray diffractograms of the clay fraction of the Ap and C/Bt horizons of soil profile one.

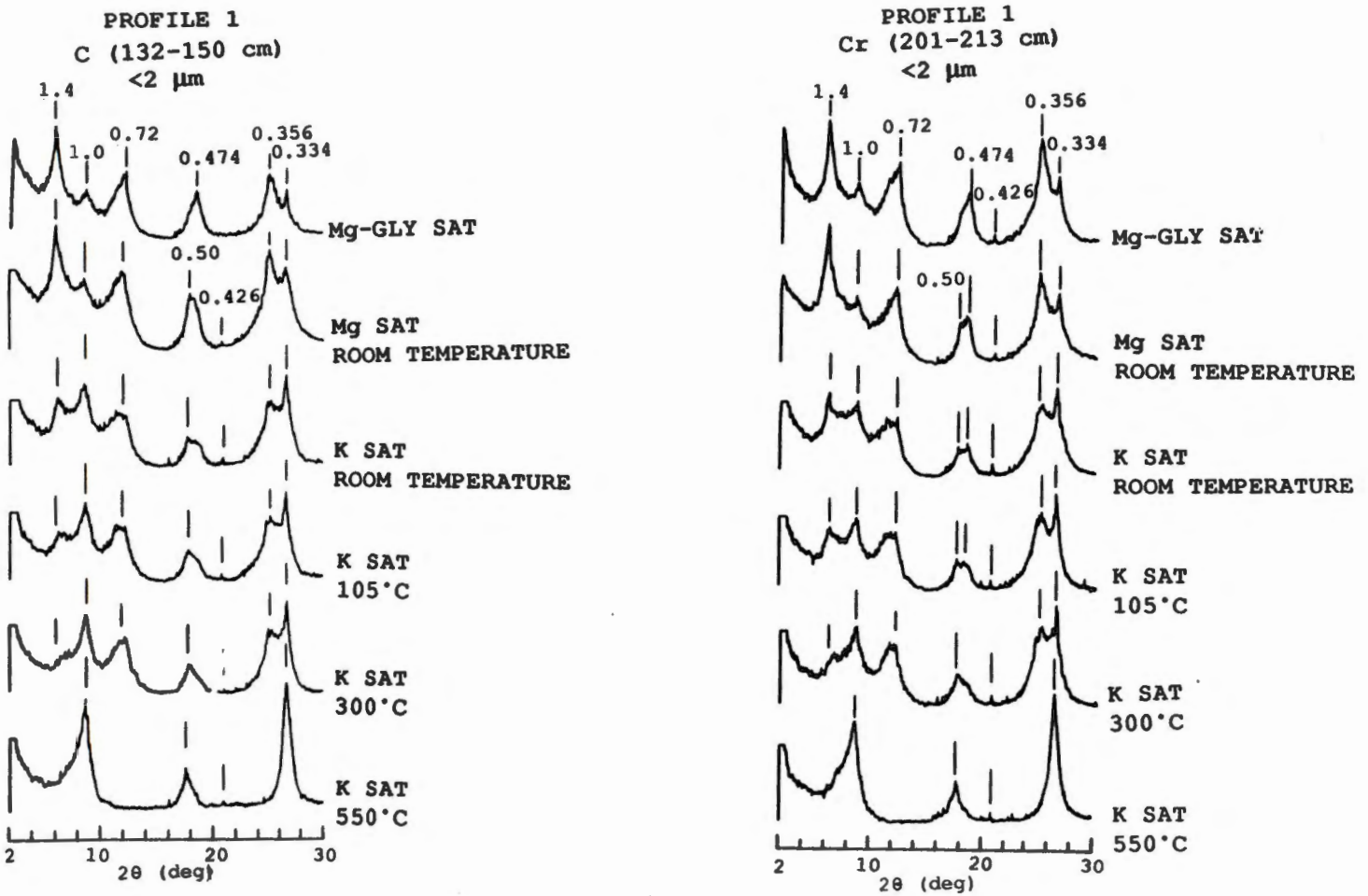


Figure 11. X-ray diffractograms of the clay fraction of the C and Cr horizons of soil profile one.

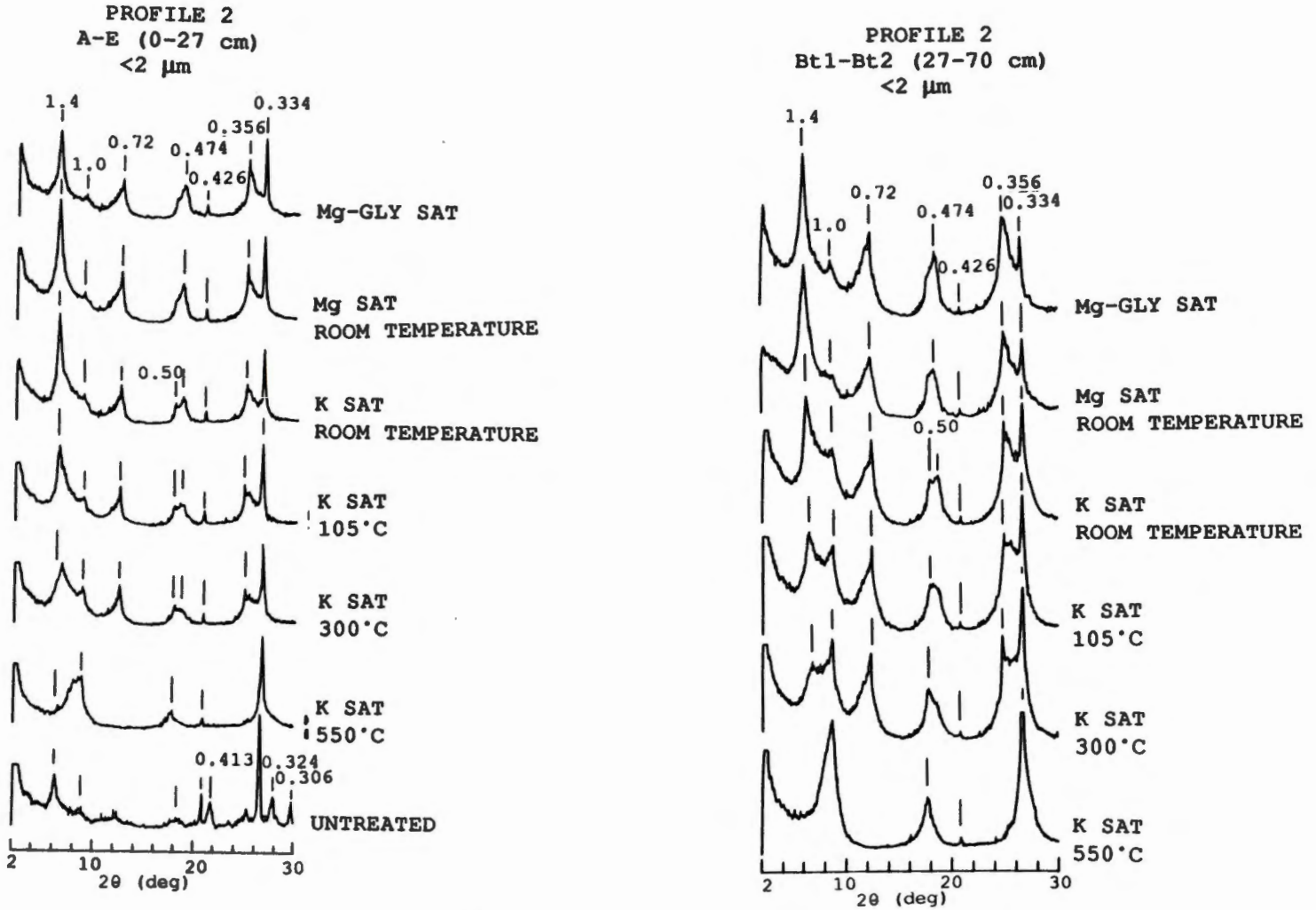


Figure 12. X-ray diffractograms of the clay fraction of the A-E and Bt1-Bt2 horizons of soil profile two.

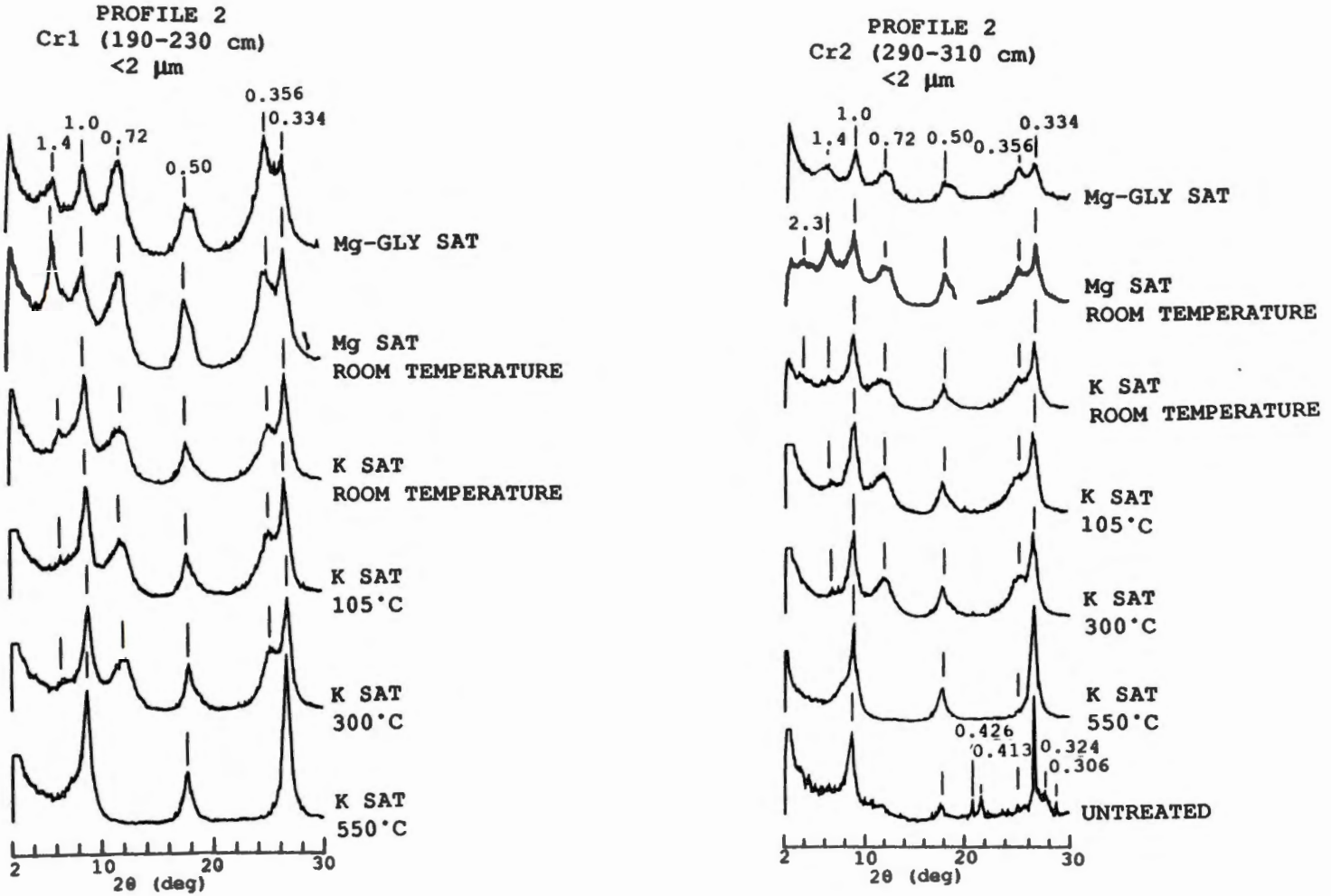


Figure 13. X-ray diffractograms of the clay fraction of the Cr1 and Cr2 horizons of soil profile two.

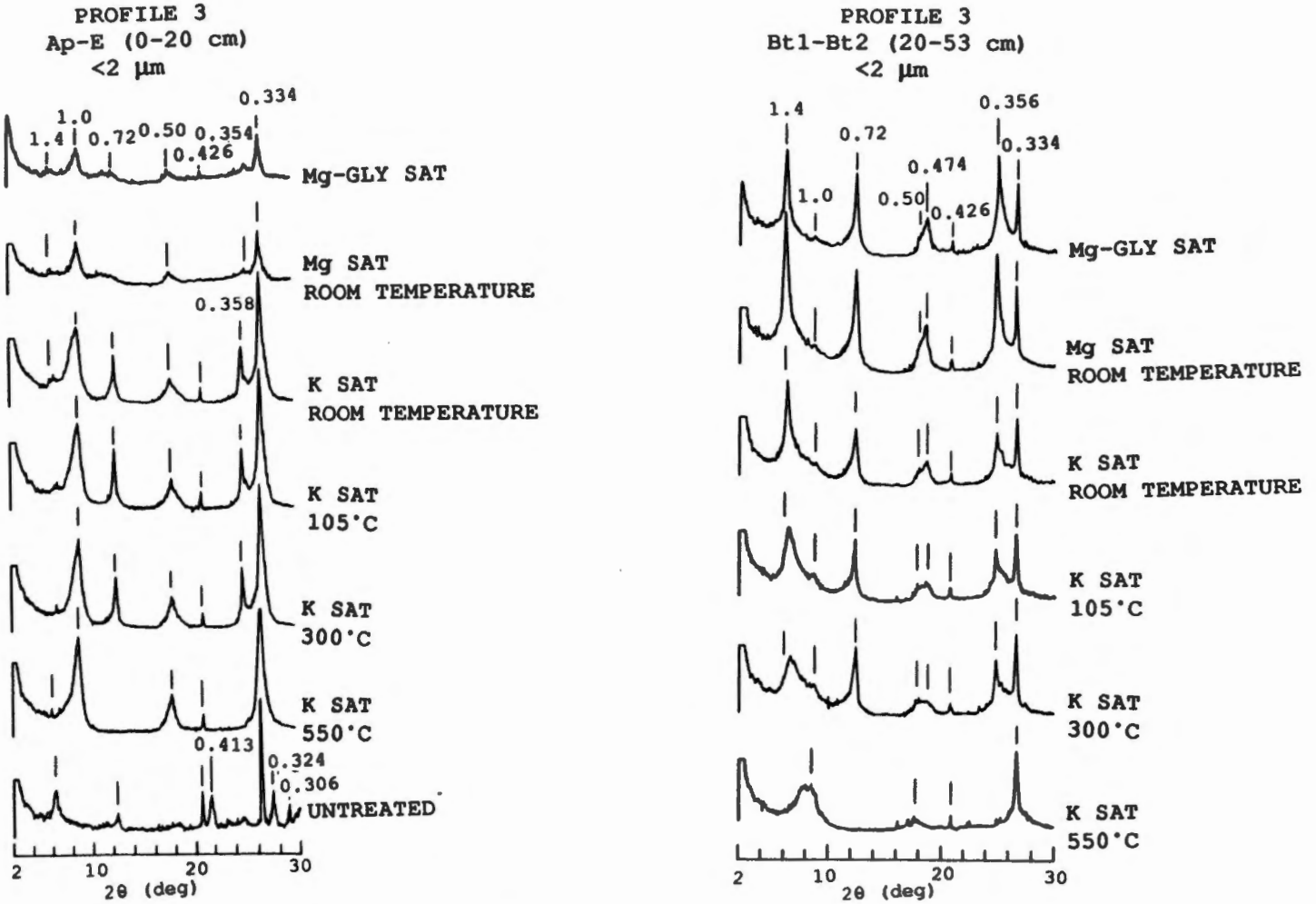


Figure 14. X-ray diffractograms of the clay fraction of the Ap-E and Bt1-Bt2 horizons of profile three.

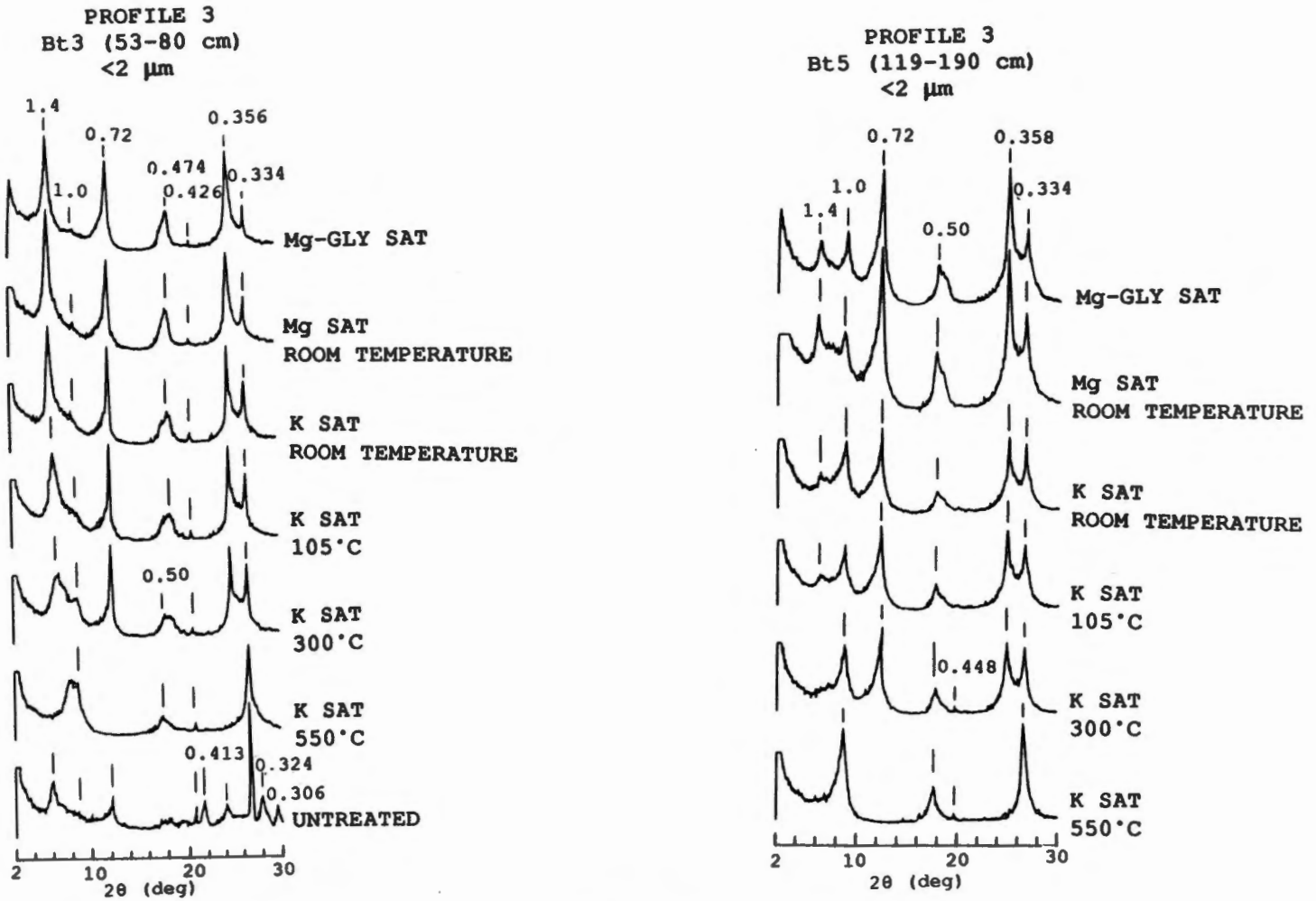


Figure 15. X-ray diffractograms of the clay fraction of the Bt3 and Bt5 horizons of profile three.

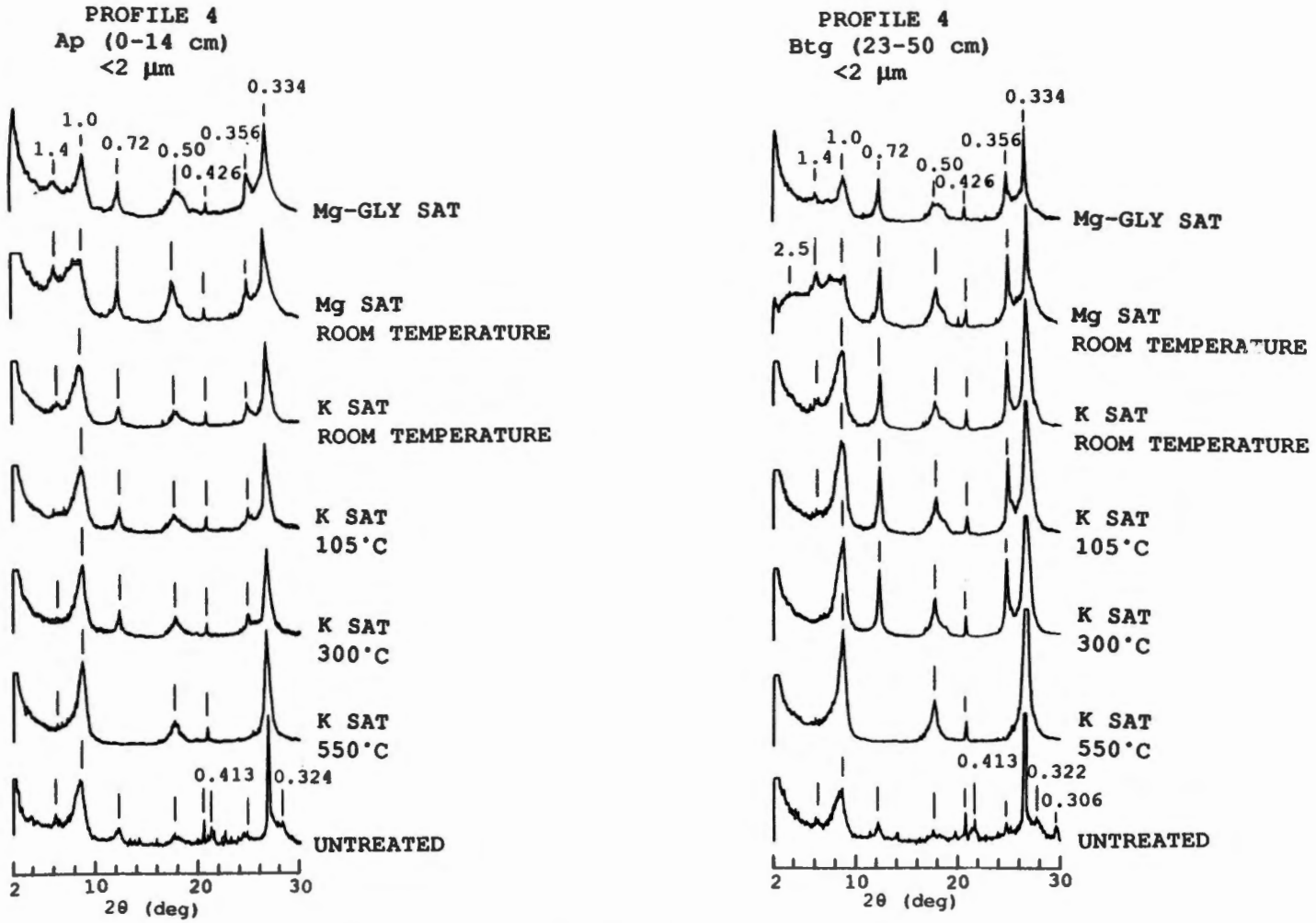


Figure 16. X-ray diffractograms of the clay fraction of the Ap and Btg horizons of profile four.

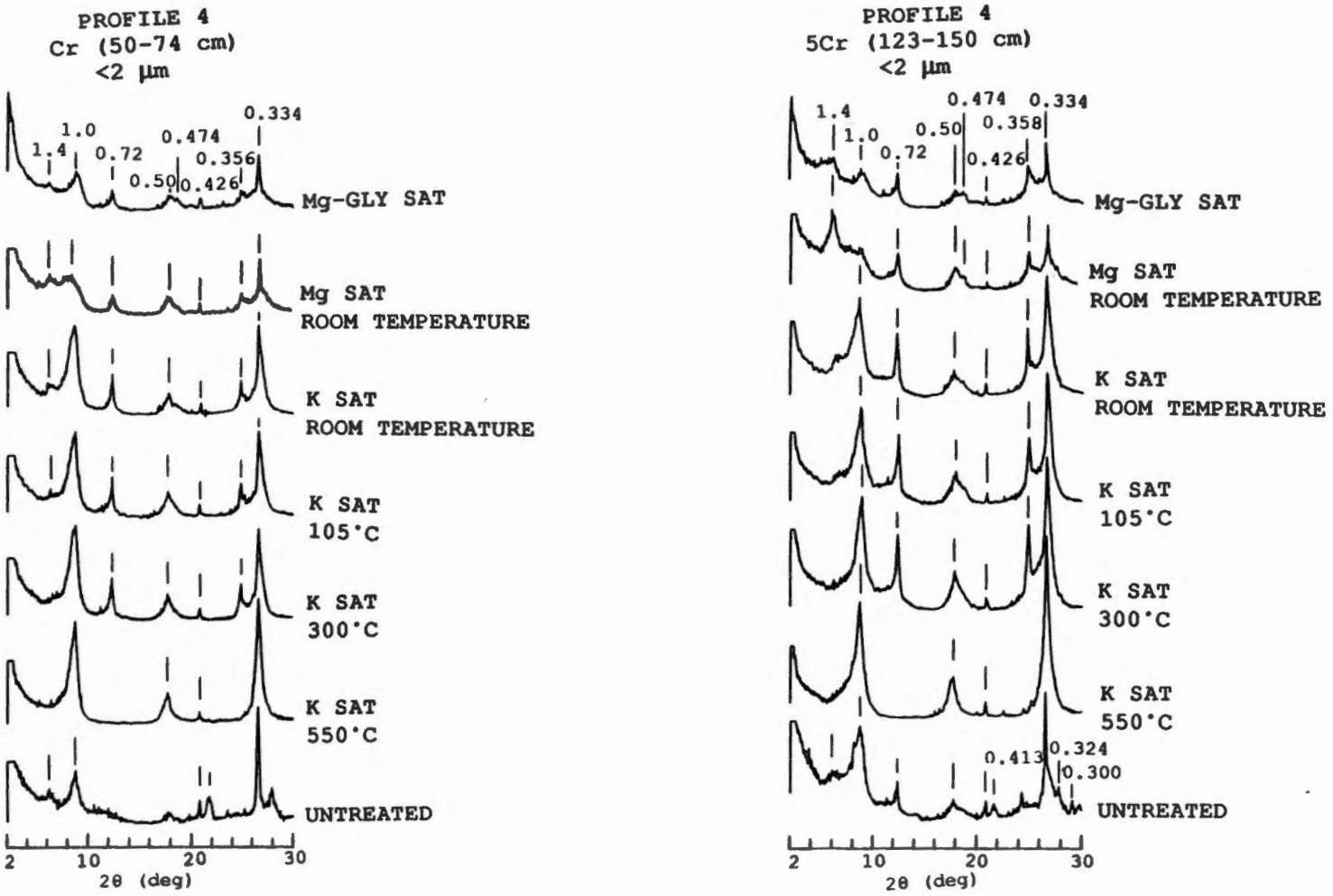


Figure 17. X-ray diffractograms of the clay fraction of the Cr1 and 5Cr horizons of profile four.

horizon and a moderate amount (20-30%) in the C/Bt through Cr horizons. Vermiculite was detected in low quantities (10%) in the A through C/Bt horizon. High amounts of HIV and low amounts of kaolinite and trace amounts of manganese and iron oxides were found throughout the soil profile.

In profile two, a Typic Hapludult, mica (illite) was identified in low amounts in the Ap-E and Bt1-Bt2 horizons and moderate amounts in the Cr horizons. Vermiculite was detected in low quantities in the Ap-E horizon, moderate amounts in the Bt1-Bt2 and Cr2 horizons and a high amount in the Cr1 horizon. HIV was found in high quantities in the Ap-E and Bt1-Bt2 horizons and low amounts in the Cr horizons. Kaolinite was found in low quantities and manganese and iron oxide were detected in trace amounts throughout the profile.

Profile three, a Typic Paleudult, exhibited a higher degree of weathering of any other soil profile. Gibbsite was found in trace amounts in the Bt5 horizon. A moderate quantity of kaolinite was found in the Ap-E horizon and a high quantity of kaolinite was found in the Bt horizons due to illuviation. Vermiculite was detected in the Ap through the Bt3 horizons in low amounts. A moderate amount of vermiculite was found in the Bt5 horizon. The degree of weathering was not so great for

this horizon as compared to upper horizons. High quantities of HIV were found at the surface and in the Bt5 horizon. Trace amounts of manganese oxides were found in the Bt1-Bt2 through Bt5 horizons. A trace amount of iron oxide was found throughout the soil profile.

Profile four, an Aquic Hapludalf, had high quantities of mica (illite) in the Ap through Cr horizon and a moderate amount in the 5Cr horizon. Vermiculite was found in moderate amounts in the Ap through Cr horizons and in high quantities in the 5Cr horizon. Low amounts of HIV were detected in all horizons of profile four. High quantities of kaolinite and trace amounts of manganese and iron oxides were found throughout the soil profile.

Mineralogy in Relation to Parent Material and Soil Age

The crystallinity of kaolinite was used as an indicator of different parent materials. Neoformed kaolinite (poorly crystalline) was identified in the clay fraction of the soils throughout profiles one and two. This was indicated by rounded peaks in the x-ray diffractograms (see Figures 10-17). Soils containing neoformed kaolinite were present on the Maryville residuum except for profile three which has alluvial parent material. A sharp x-ray diffraction peak at 0.72 nm, that indicated crystalline kaolinite, was present

throughout soil profile three (see Figures 14 and 15). Highly crystalline kaolinite was present in the clay size fraction of the soils in profile four. The soil in profile four had interbedded Nolichucky Shale and Upper Maryville Limestone as parent material.

The soil in profile three was the oldest soil in the study area. Gibbsite, an aluminum hydroxide polymorph, was found in the clay fraction of soils in the Bt5 horizon of profile three, as indicated by differential scanning calorimetry and XRD (see Figure 15 and Table 8). The presence of gibbsite indicated that advanced weathering had occurred over time in the soil of profile three.

Clay Illuviation into Partially Weathered Bedrock

Clay moved through the cracks and voids of the partially weathered bedrock present at the site as shown in Figure 18. Clay was found as coatings and plugs associated with iron and manganese oxides and organic matter in the voids and fractures of partially weathered bedrock. The clay coatings were likely deposited by water movement within the soil profile.

Iron and Manganese Oxide

Soil peds and weathered bedrock present at the study site contain iron and manganese oxide coatings.

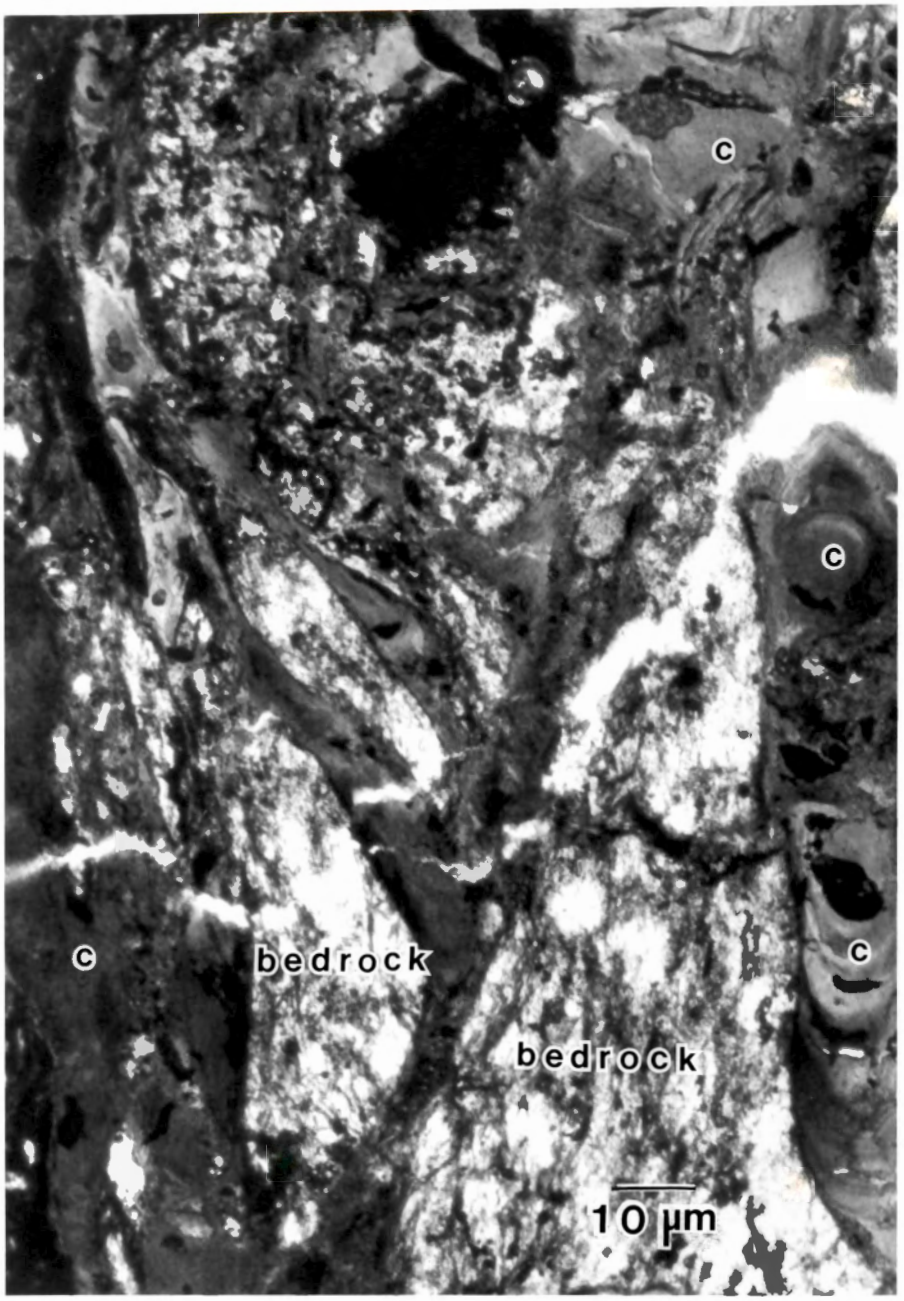


Figure 18. A photomicrograph of clay (c) in a fractured zone in the partially weathered bedrock (bedrock) (290 to 310 cm) of profile two.

Oxyhydroxides of iron and manganese, and their mixtures, are present in weathering zones and pore spaces within weathering zones.

Iron and manganese solubility in soils and partially weathered bedrock increases with increasing acidity and reducing conditions. Manganese is more reducible than iron in temporary reducing conditions and acidic pH conditions present in the soils and partially weathered bedrock at the study site. The reduced forms of manganese and iron are Mn^{2+} and Fe^{2+}, respectively. The reduced form of manganese is much more soluble than the reduced form of iron. Manganese generally accumulates in the ground water saturation zone (generally in the partially weathered bedrock) and iron tends to accumulate above the ground water saturation zone, generally in the Bt and C horizons (see Figure 19 and Tables 5 and 6).

Sodium citrate bicarbonate dithionite (CBD) extractable iron and manganese values are reported in Table 5. High manganese values were detected in the C and Cr horizons of profile two, due to high weathering and leaching of the soil profile. Sodium citrate bicarbonate dithionite extractable manganese and hydroxylamine reducible manganese values coincide. For example, where CBD extractable manganese values increased, hydroxylamine reducible manganese values increased. High iron values were found throughout all

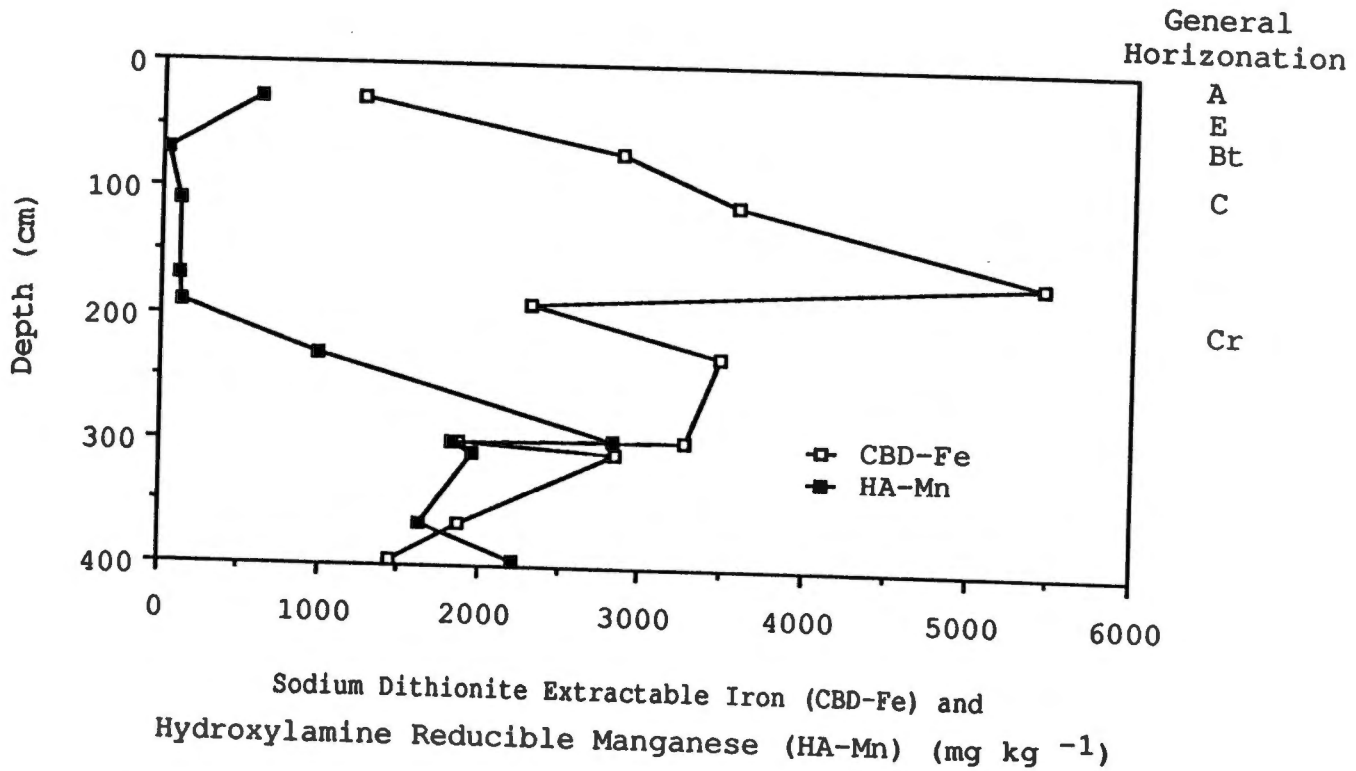


Figure 19. The distribution of sodium dithionite extractable iron and hydroxylamine reducible manganese with depth in profile two.

soil horizons investigated due to intensive weathering. Lower iron values were present in the surface horizons of profile one. Lower values were found in horizons near the surface, due to the migration of iron from these zones. Large concentrations of free iron are present in the B horizons and partially weathered bedrock zones. The CBD extractable iron values became lower in the deeper unleached and unoxidized partially weathered bedrock. High manganese concentrations were present throughout most profiles.

Hydroxylamine reducible manganese concentrations are reported in Tables 5 and 6. In samples where low CBD extractable manganese concentrations are reported, low hydroxylamine reducible manganese values also occurred. Hydroxylamine reducible manganese decreased significantly in the presence of free carbonates. High concentrations of hydroxylamine reducible manganese were present in highly weathered zones in the soil, partially weathered bedrock in the soil profiles and deep core drillings. The hydroxlamine reducible manganese procedure makes a better differentiation between manganese and iron than the CBD extractable manganese procedure. Based on the differences in behavior of manganese oxides and iron oxides toward reduction under various conditions, manganese oxides were selectively disolved in the soil with minimum attacks on coexsisting iron oxides, by the

extraction method using hydroxylamine hydrochloride ($NH_2OH \cdot HCl$). Manganese oxides in the soils were readily dissolved by hydroxylamine hydrochloride solutions. The major portion of iron oxides was left in the residue. The selective dissolution of manganese oxide from soil by acidified hydroxylamine hydrochloride is based on the difference in behavior of manganese and iron oxides toward reduction under various conditions (Chao, 1972).

Regression analyses was conducted on the hydroxlyamine reducible and CBD extractable manganese results from the four profiles to see if the two procedures yielded compatible results. Sodium citrate bicarbonate dithionite extractable manganese values served as the dependent variable and hydroxylamine reducible manganese values were the independent variable. The correlation between the two procedures was not strong. The R-squared value was 0.5429. This value, although statistically significant, showed the procedures having only a weak to moderate relationship.

The manganese mineral peaks were not present in x-ray diffractograms (XRD) of untreated clay fractions. The absence of XRD peaks suggests that these soils contained small quantities of manganese minerals that occurred probably as amorphous coatings.

Iron oxides were present throughout the four soil profiles. An iron oxide x-ray diffraction peak at 0.41

nm was observed in the untreated clay size fraction of most samples (see Figures 10-17). This x-ray peak disappeared after treatment with sodium citrate bicarbonate dithionite. A large concentration of CBD extractable iron was present in the soils of all profiles (see Table 5).

Microscopic Observations of Manganese and Iron Oxides

Manganese and iron oxides were present in microscopic amounts throughout these soils. These oxides were in many different forms and have many different associations. Manganese and iron oxides appear as 1) nodules, 2) granular segregated bodies, 3) crystalline forms 4) neo and quasi forms, 5) impregnations and 6) coatings from microscopic observations (see Figures 20a-f). Manganese and iron oxides were abundant in highly-oriented clay coatings around pores and on rock fragments. The microscopic observations of manganese and iron oxide and clay coatings on rock, partially weathered bedrock, and ped faces, indicated movement of the oxides and clay within the soil profile. This movement was primarily due to water. Large amounts of hydroxylamine reducible and CBD extractable manganese were present in the highly weathered zones of the soil and partially weathered bedrock.

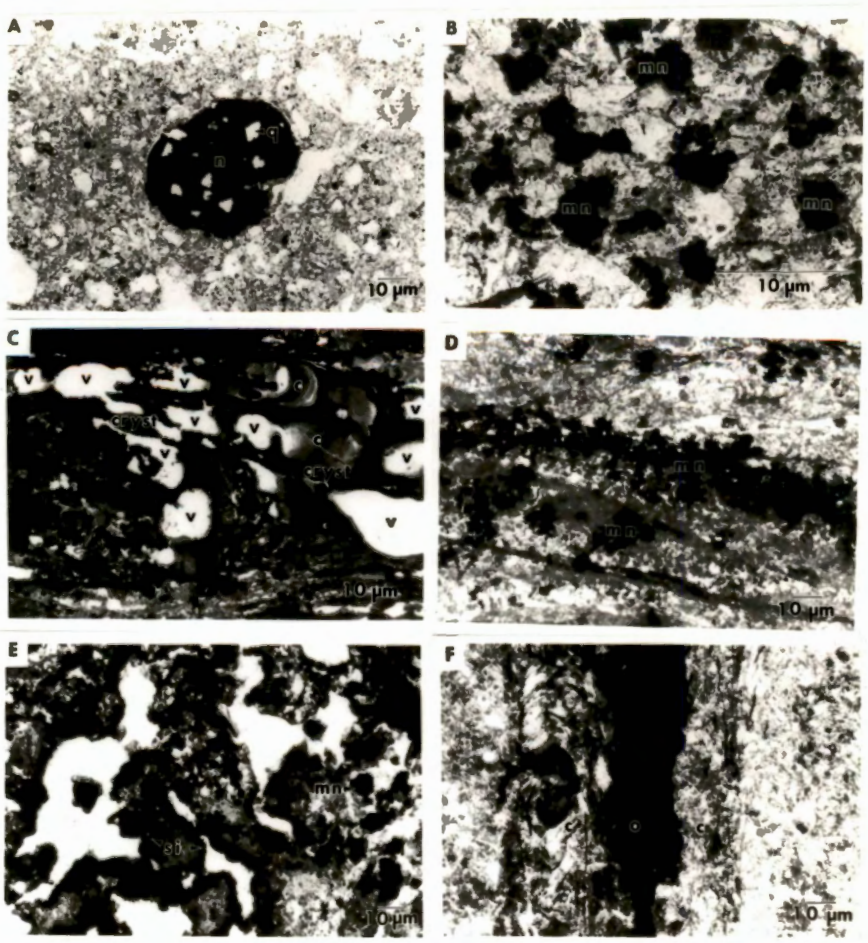


Figure 20. Photomicrographs of manganese and iron oxides forms and associations. Various forms of manganese and iron oxides and their associations: A) Manganese and iron oxide nodule (n) with quartz grain (q) inclusions in the E horizon (20 cm) of soil profile two, B) manganese oxide (mn) granular segregation present in the Cr2 horizon (290 to 310 cm) of soil profile two, C) crystalline manganese and iron oxides (cryst) are present with highly oriented clays (c) enclosed within voids (v) in the Cr2 horizon (290 to 300 cm) of soil profile two, D) neomanganferons (mn) present in the Cr horizon (290 to 300 cm) of soil profile two, E) surface impregnations (si) of manganese and iron oxide around pores and manganese segregation (mn) present in the Cr horizon (290 t0 300 cm) of soil profile two, F) pore with infillings of highly oriented clay (c) on the sides and manganese and iron oxides (o) in the center in the BC horizon (190 to 230 cm) of soil profile one.

Effect of Slope on Weathering

Geomorphology has a great influence on soil formation at the study area. A sloping landscape on interbedded Nolichucky Shale and Maryville Limestone is present in the central portion of the site. Site HHMS core drillings are present at different positions on the landscape as shown in Figure 21. Site HHMS-4B is located on the summit, and HHMS-5A is found on the sideslope. The soils are highly weathered and the partially weathered bedrock is leached. The partially weathered bedrock showed signs of thick red clay coatings on fracture faces. Depth to free carbonate bedrock is about 5.5 m for HHMS-4B (see Table 6). Carbonate bedrock was observed at about 3.7 m for HHMS-5A. The presence of free carbonate at these depths was confirmed by the great increases in calcium carbonate equivalent (CCE) values and hydrogen ion activity (pH) values (see Figures 22 and 23). High pH values were present in samples that had high concentrations of calcium. The free carbonate was produced by $CaCO_3$ present in the Maryville Limestone. There is a possibility that Maryville Limestone is present in the upper portions of the weathered bedrock where the Nolichucky Shale is found. The $CaCO_3$ that was once present has been leached to lower depths therefore resulting in low CCE values.

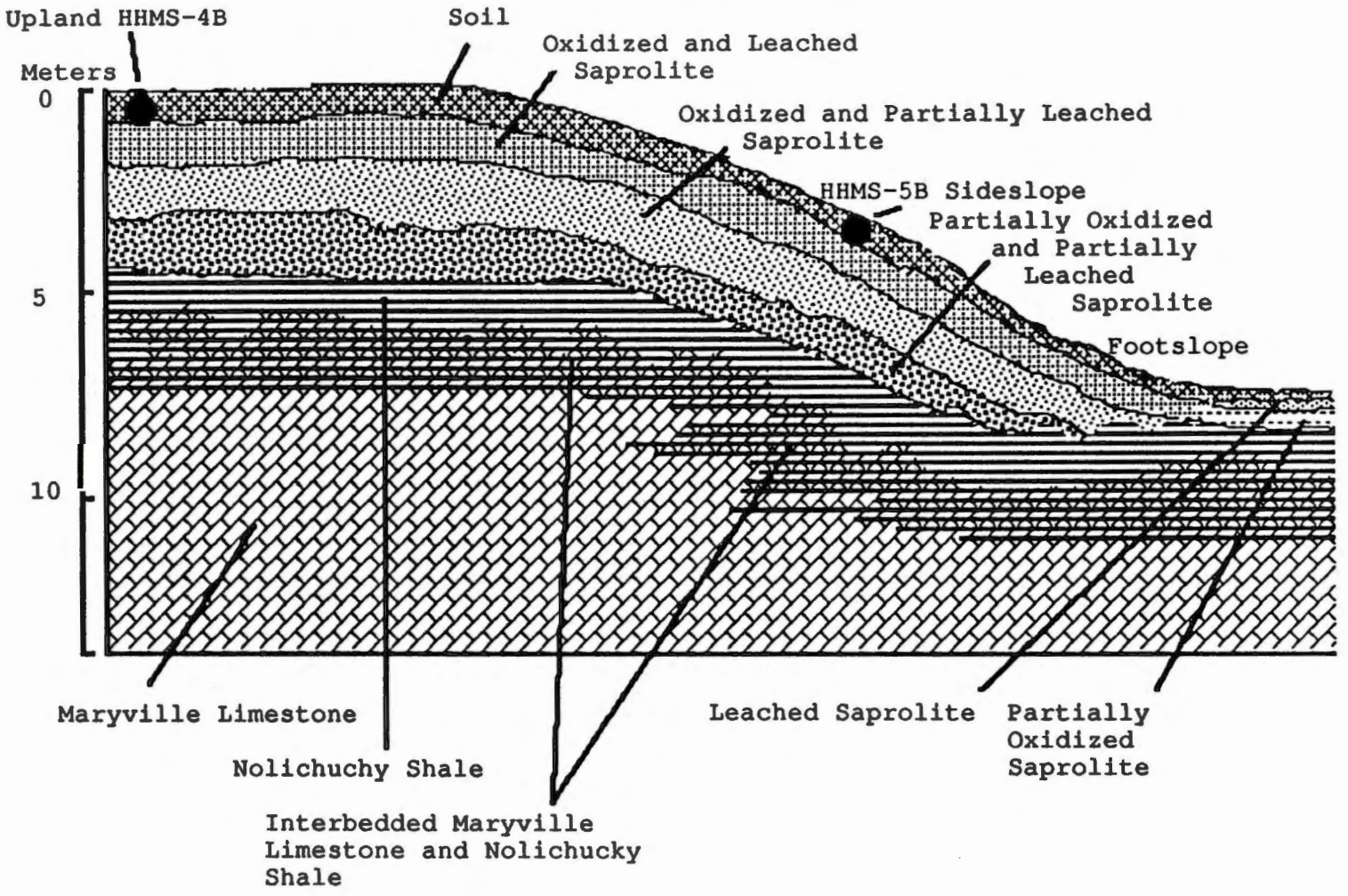


Figure 21. The distribution of soil, partially weathered bedrock (saprolite) and rock at different positions on the landscape of a Nolichucky landform at the study site.

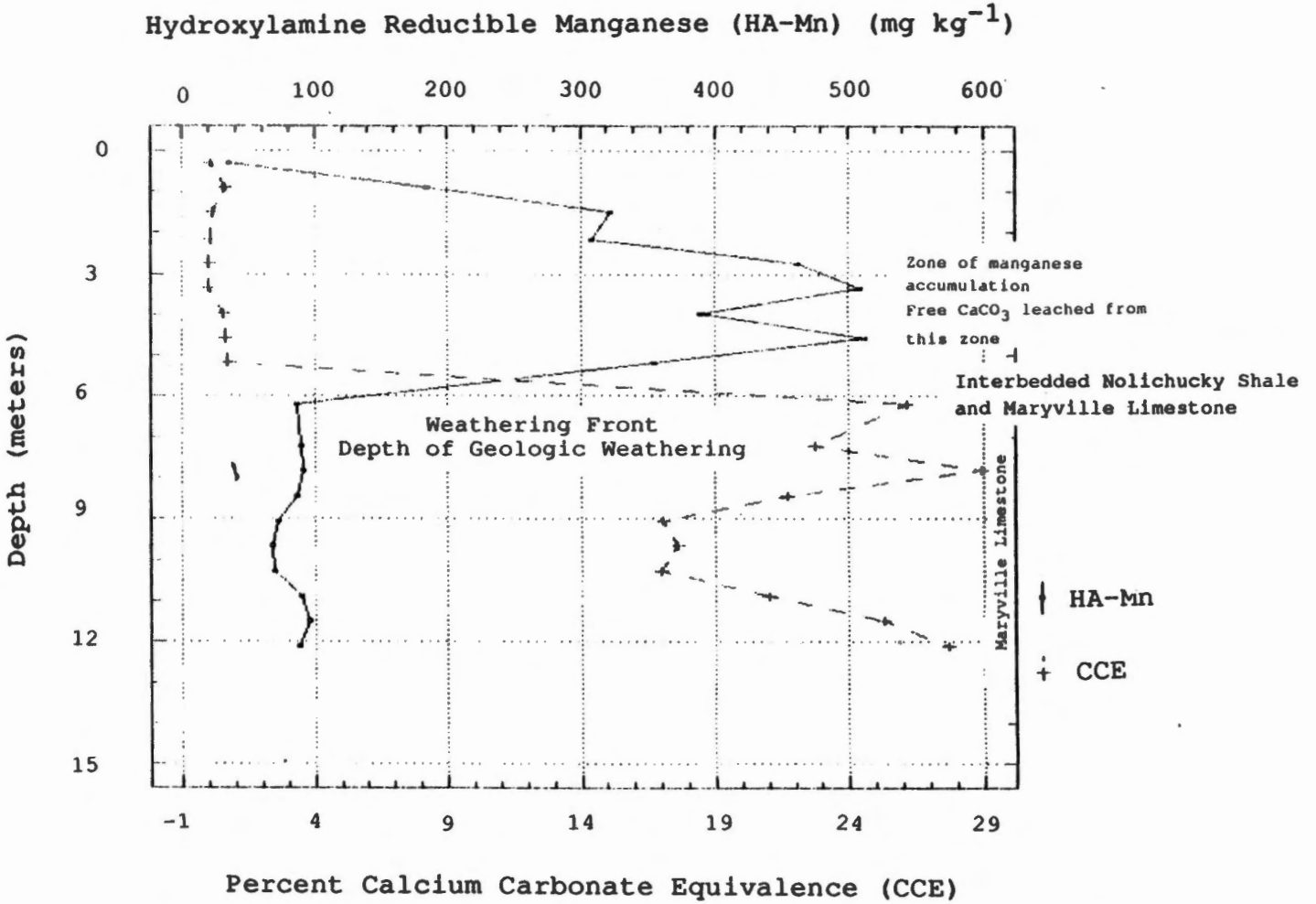


Figure 22. The distribution of percent calcium carbonate equivalence (CCE) and hydroxylamine reducible manganese with depth in core drilling HHMS-4B.

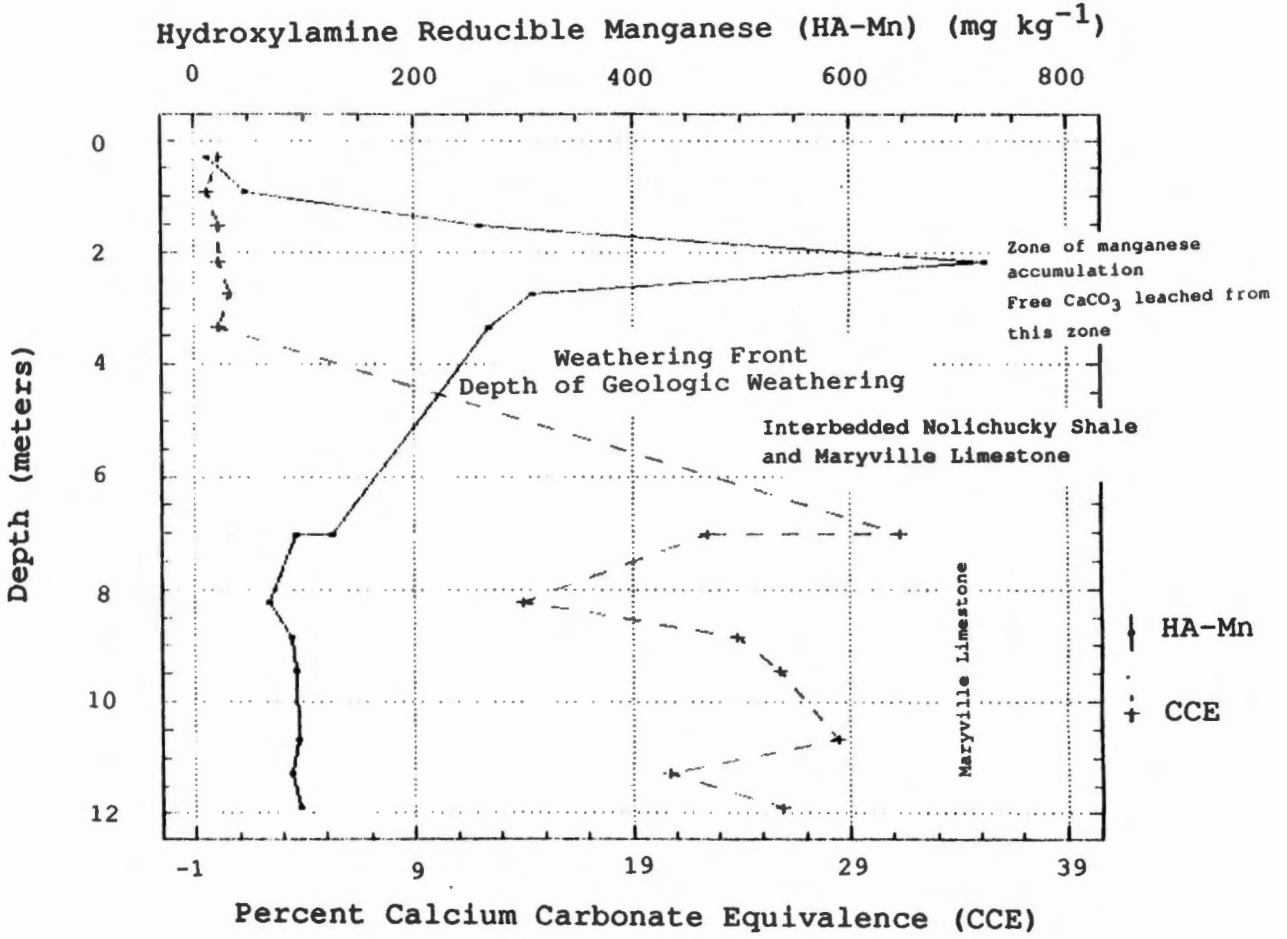


Figure 23. The distribution of percent calcium carbonate equivalence (CCE) and hydroxylamine reducible manganese with depth in core drilling HHMS-5A.

According to Lietzke and Lee (1986), soil present on a low drainageway terrace on the footslope of the sloping landscape had bedrock present at one meter. The low drainageway terraces had been removed by overland water flow. The summit where HHMS-4B was located had greater chemical weathering of rock, due to greater rainfall infiltration than the sideslope and toeslope. Hydroxylamine reducible manganese values for the HHMS samples are shown in Table 6. These data values illustrated manganese accumulations and movement in the leached, partially weathered bedrock, as shown in Figures 22 and 23. Hydroxylamine reducible manganese values were highest in the oxidized, leached zone than the partially leached zone. Manganese easily migrates through the soil and tends to settle in leached, partially weathered bedrock where the water table is present. Evidence of this was shown in higher reducible manganese values from sideslope samples than summit samples. The manganese distribution pattern indicated that manganese leached from the soil solum and migrated deeper into the upland (HHMS-4B) soil than in the sideslope (HHMS-5A) soil.

Genesis of the Soils on Ancient Alluvium and the Maryville and Nolichucky Formations

Regional Characteristics

The areal distribution of soils on the Maryville and Nolichucky formations in East Tennessee was closely associated with a rather definite combination of soil forming factors. For the purpose of orienting these soils into a unique regional environment, the pedogenic factors were described and evaluated.

Climate

The study area has a humid, warm, and temperate climate. Mean annual precipitation is 1359 mm (53.5 in) for rain and 262 mm (10.3 in) for snow. The mean January temperature varies between 3.3°C (37.9°F) and 9.3°C (48.8°F). A July average temperature varies 24.9°C (76.9°F) and 30.7°C (87.3°F). August and September have a maximum temperature as high as 30.4°C (86.7°F) and 27.5°C (81.5°F).

Present day climatic conditions are not similar to climatic conditions of the past. In the Pleistocene and Holocene, four glacial and three interglacial periods occurred. The presence of glacial and interglacial periods had a great effect on the climate of East Tennessee. The Tennessee River Valley in eastern Tennessee was greatly influenced by glacial advances and

interglacial periods. During interglacial periods, temperature increased along with an increase in rainfall. In East Tennessee, rivers deposited great amounts of sediments forming broad floodplains during these periods. These processes occurred many times during the Pleistocene and Holocene. A climatic warming and retreat of the Wisconsin glaciation occurred about 15,000 to 7,000 years ago. The most recent period of floodplain development for the Tennessee river valley followed the Wisconsin glaciation (Chapman et al., 1982).

During the Quaternary period, several changes in climate caused marked changes in the environment. These changes in environmental inputs may be the cause of wide range changes in the pattern of deposits of fluvial systems. These changes in deposits caused the mineral composition, texture and arrangement of soil horizons to vary (Chapman et al., 1982). In the study site, profile three has been greatly affected by these climatic changes. The parent material is ancient alluvium that was deposited in the Pleistocene during an interstadial period. During this period, the Clinch River was much larger and had stronger currents than present. This river deposited the alluvial sediments on the site as a terrace.

Vegetation

An early stage of old field succession was present on the site. Sagegrass and red cedar, was the dominant vegetation growing in the site. This type of vegetation was a result of severe erosion and highly weathered soils formed in an udic moisture and thermic temperature regime (Lietzke and Lee, 1986). The original vegetation growing on the site before European settlement was predominately hardwood with some coniferous trees.

Time

Geologic age and physiographic position of the soils were related at the study site. This was particularly true for the Ultisols on the study site. Profiles two (Typic Hapludult) and three (Typic Paleudult) were formed on stable landforms. These are old deep soils which have distinct profile development. They were formed in a climatic environment that was conducive to high weathering conditions. One can conclude that profile development therefore, is related to age of deposition.

All four soil profiles had high accumulations of free iron as shown in Table 5. The presence of Bt horizons were indications that these soil profiles were well developed. Free iron can be used as an indicator of soil age. This is especially true for soils from the same type of parent material. Profiles one (Typic Hapludalf) and two (Typic Hapludult), are found on the

Maryville Limestone formation. Profile two has undergone more profile development than profile one (see Figure 24). Profile two had higher free iron values with a maximum value of 5467.20 mg kg^{-1}. Profile one had a maximum free iron value at 3886.20 mg kg^{-1}. Profile three, a Typic Paleudult, which formed on ancient alluvium showed a significantly less accumulation of free iron (see Figure 25). The highest value being 2683.42 mg kg^{-1}. This could possibly be due to loss of iron to greater weathering and leaching. Profile four, an Aquic Hapludalf, which formed on interbedded Nolichucky Shale and Maryville Limestone had a maximum value of free iron at 4278.90 mg kg^{-1} in the 2Cr horizon. The clay skins that coated this bedrock were analyzed. The clay skins contained the free iron. Free iron values were high in the partially weathered bedrock. This is because the partially weathered bedrock is fractured.

Parent Material

The bedrock at the site was composed of Upper Maryville Limestone and Nolichucky Shale formations of the Conasauga Group. Soil profiles one, two and four were formed from the residuum of these formations. The saprolite material (partially weathered bedrock) still had bedding and rock structure present. Throughout the area, a few thin, weathered, pure limestone lenses were observed as thin seams of red and yellow clay. Silty

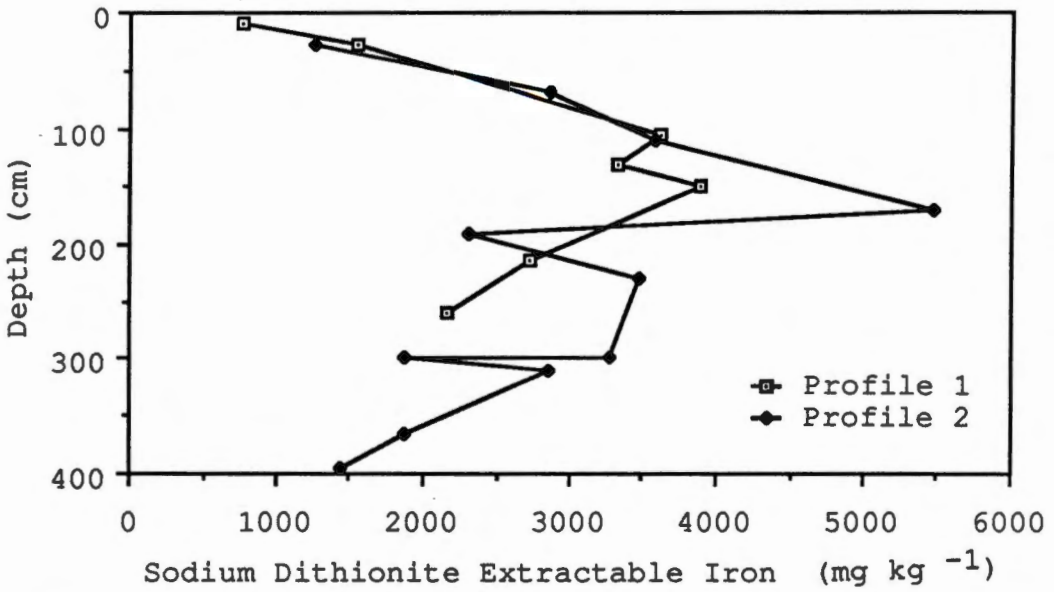


Figure 24. The distribution of sodium dithionite extractable iron (CBD-Fe) with depth in soil profile one and two on the Maryville Limestone formation.

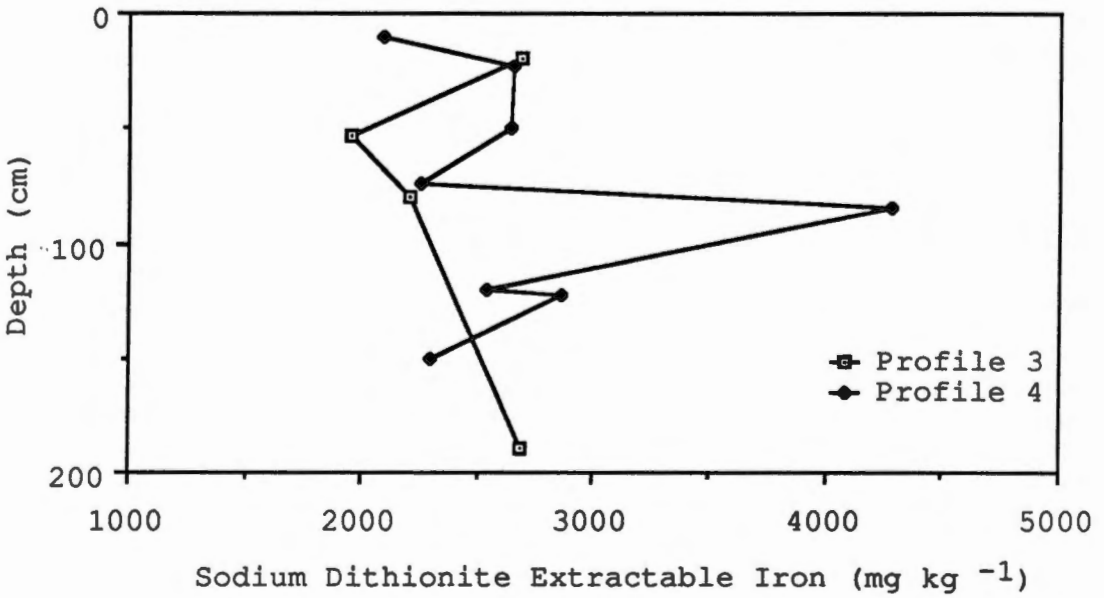


Figure 25. The distribution of sodium dithionite extractable iron (CBD-Fe) with depth in soil profile three on ancient alluvium and soil profile four on interbedded Maryville Limestion and Nolichucky Shale.

limestone members weather to porous brown siltstone blocks. Shales were known to weather to a brown or dull olive color. Fractures are also present in the partially weathered bedrock as shown in Figures 7 and 18. These features also promote greater weathering by providing an entry way for more water. Weathering also promoted well-developed joints in these siltstones and shales. At higher elevations in the site, resistant limestone lenses were found within a few feet of the surface. Soil profiles one (Typic Hapludalf) and four (Aquic Hapludalf) were greatly influenced by the parent material. Soil profile one formed on the Maryville Limestone and soil profile four formed on interbedded Nolichucky Shale and Maryville Limestone. They are from parent material that does not weather uniformly (see Figure 26). This parent material consists of a mixture of siltstone, shale and mudstone which increases the variability of the weathering of the parent material. In the exact areas where these soil profiles are located enough uniform bedrock and intense weathering occurred. Broken horizonation was not present. Directly adjacent to the soil profiles in the same parent material, broken horizonation did occur. This illustrates the variability of the resistance of the parent material to weathering. For example, profile one, a Typic Hapludalf, had field interpretations and laboratory data that supported the

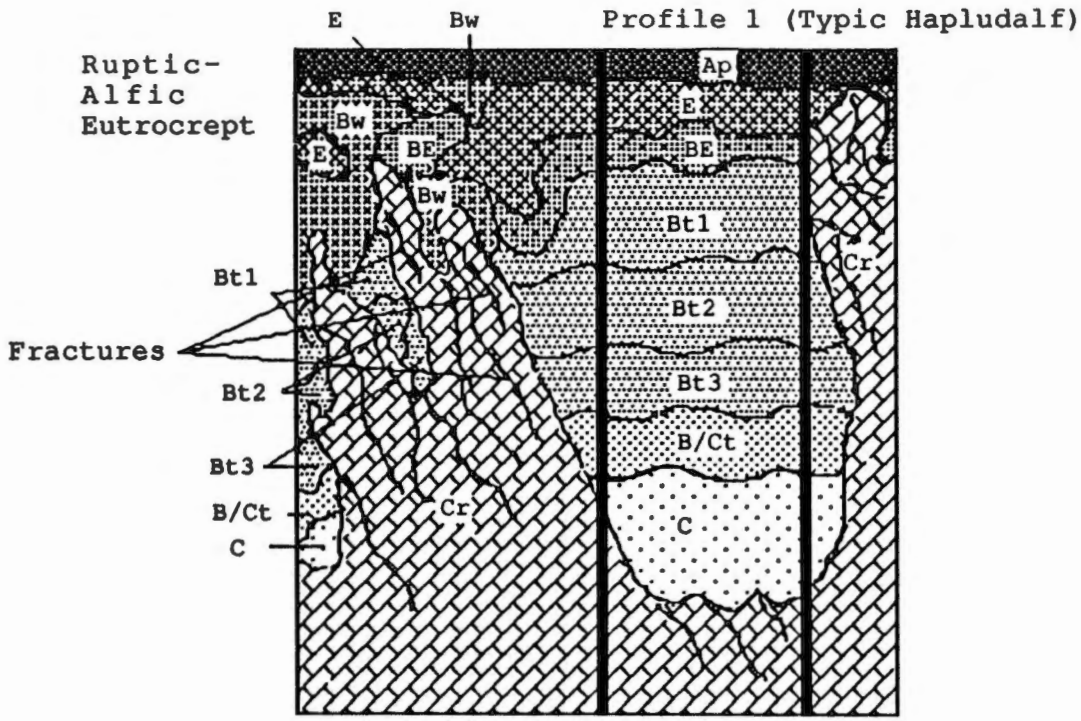


Figure 26. A generalization of soil profile 1, a Typic Hapludalf, and the variability of weathering of the adjacent parent material and soils.

given classification. Located adjacent to this soil profile is a soil that would be classified as a Ruptic-Alfic Eutrocrept based on field interpretations and laboratory data. During weathering, the material that was less resistant (limestone) weathered quicker than resistant materials (shale or claystone). This resulted in a mixing of horizons (see Figure 26). Boegly (1984) reports that the particle size data for near-surface partially weathered bedrock revealed a mean sand content of 36%, a silt content of 22% and a clay content of 42%. Due to the higher claystone content of the partially weathered bedrock, the soils of the study area had a higher clay content in the subsoil. Small faults and folds were found throughout these rock formations (Boegly, 1984).

Many geomorphic events were recorded within the landscape of the study area. Two types of transported material, alluvium and colluvium, were found in the study area. The site was positioned on a sloping landscape. East-facing slopes were much steeper than west-facing slopes, thus, causing the development of almost asymmetrical valley cross-sections. Large first-order drainageways were present (Lietzke and Lee, 1986).

Ancient alluvium was found in the western portion of the site on an upland summit that represents the highest elevation. A Typic Paleudult, profile three, is located

on the upland summit (see Figure 27). This material is a terrace created by the Clinch River about one million years ago. According to Lietzke and Lee (1986), the ancient alluvium deposits did not resemble the surrounding bedrock. This deposit was generally 0.3 m thick but on the southwestern corner of the site the thickness was about 5 m. The alluvium from soil profile three was comprised of deposits of unconsolidated sand, silt, and clay along with well-rounded cobbles and pebbles. A highly weathered shale residuum lay beneath the alluvium (Lietzke and Lee, 1986).

Physiographic

Episodes of erosion greatly influenced the formation of the landforms on the site. Drainageways were formed in areas where surface waterflow is favored. Drainageways initially formed in areas possessing close joint spacing of the bedrock. Overland water flow thus concentrated, caused soil particles to eventually be carried away in these areas. As drainageways gradually cut downward, they extended upslope over time. Present-day drainageways appear as widened parallel slopes forming as sediments accumulate on the floodplain. Depth to rock was shallower in drainageway bottoms than on interfluves because soil has been removed by overland flow. Greater rainfall infiltration and percolation occurred on interfluves. Greater chemical weathering of

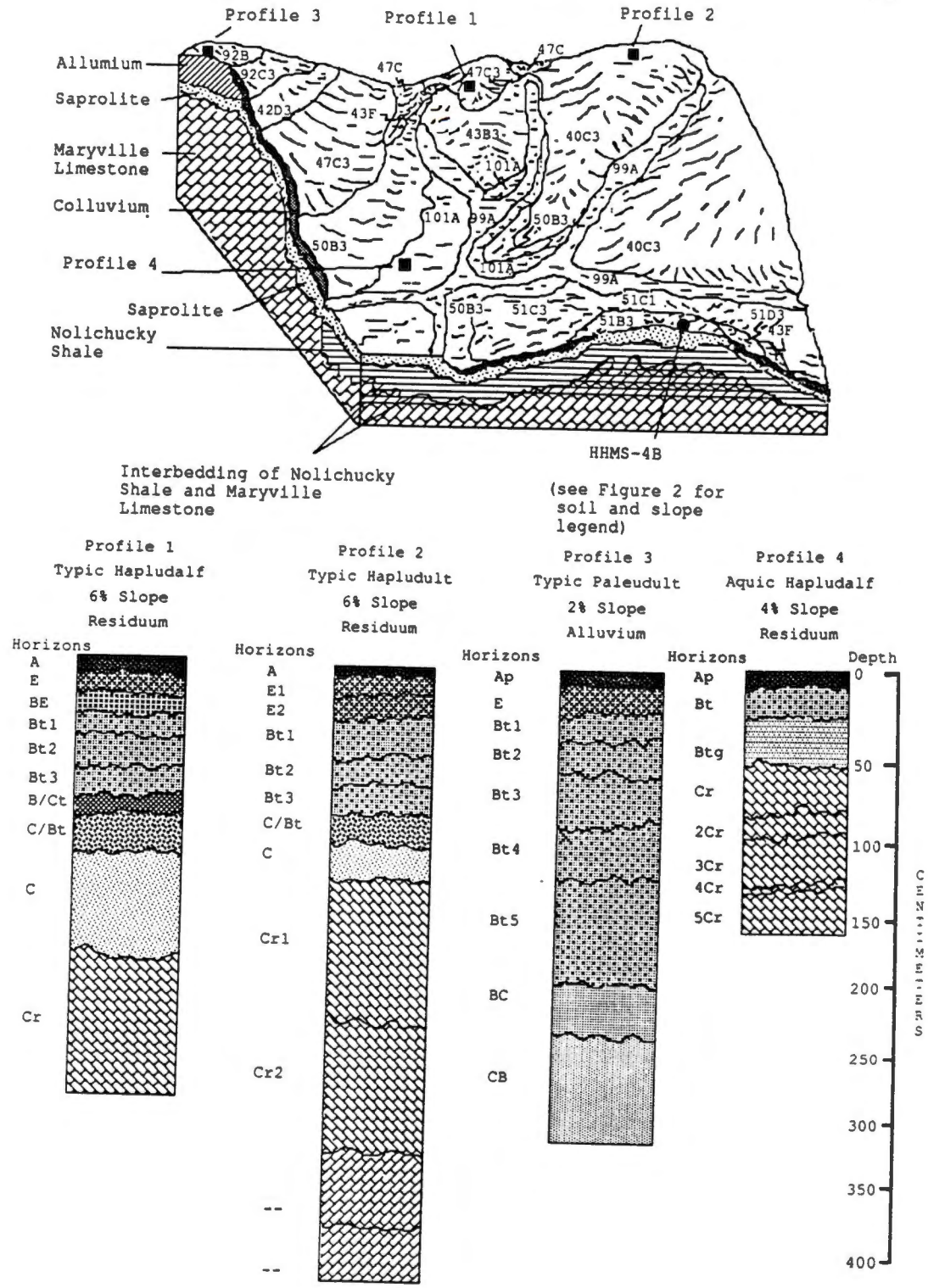


Figure 27. A block diagram of the study area showing the topographic relationship of soils and a generalized illustration of the soil profiles.

rock resulted in thicker soils as observed in profiles two and three (Lietzke and Lee, 1986).

Soil from the following soil orders at the site were characterized. Typic Hapludults occur on geomorphically stable spur ridges (see Figure 27). However, when compared to Typic Hapludults, the Typic Hapludalf, profile one, was found on a more convex, steeper and narrower spur ridge. Parent material is highly weathered surficial Maryville Limestone. The Aquic Hapludalf, profile four, occurs on a landform with low relief on the interbedded Nolichucky Shale and Maryville Limestone within the study area. These soils occur on sideslopes and footslopes in the study area. Aquic Hapludalfs are located on the interbedded Nolichucky Shale and Maryville Limestone formation and occur on footslopes of landforms whereas Maryville soils form on higher positions on the landscape (Lietzke and Lee, 1986). For example, a Typic Paleudult, profile three that formed from alluvium was located on the upland summit. This was the oldest and most weathered soil on the site.

Nolichucky landforms were usually more subdued than Maryville landforms. The Nolichucky Shale was low in permeability, so there was more surface runoff and less downward water percolation. These soils therefore, experienced a low degree of weathering (Lietzke and Lee, 1987).

CHAPTER V

SUMMARY

Two Ultisols and two Alfisols from the Maryville Limestone and Nolichucky Shale were sampled in order to study their genesis. Physical, chemical, mineralogical, morphological and micromorphological properties were investigated to understand pedogenesis and soil genesis relationships. The relationship between soil and geology was also studied.

Large amounts of silt were present throughout the surface and some upper B horizons indicating the weathering of the silty parent material. Weathering processes produced clays, which accumulate to form argillic horizons. Some clays in the upper horizons have illuviated down to eventually become coatings on partially weathered bedrock faces. Minerals found in the clay fraction of the soils at the study site were kaolinite, hydroxy interlayered vermiculite (HIV), vermiculite, mica (illite), and gibbsite. A residual soil that formed from moderately weathered Maryville Limestone (profile one) had a high amount of mica (illite). Profile three (Typic Paleudult), a soil formed from alluvium deposited on the residuum of Maryville Limestone, also had a high amount of mica (illite) in surface horizon. Hydroxy interlayered vermiculite was

high in upper horizons of profiles one and two. Kaolinite was found throughout the study area. The crystallinity of kaolinite was influenced by the parent material. Highly crystalline kaolinite was detected from the Nolichucky Shale, whereas poorly crystalline kaolinite was observed from the Maryville Limestone. A small amount of gibbsite was detected in the Bt5 horizon of soil profile three. This suggests that the soil in profile three is old and/or highly weathered. The effective cation exchange capacity values do not show any consistancy with the clay mineralogy data.

Manganese oxides were present in various quantities throughout the highly weathered soil and partially weathered bedrock. Manganese and iron oxide forms ranged from nodules, granular segregated bodies, crystalline forms, neomangans, infillings, to impregnations. With the exception of the carbonate partially weathered bedrock present in profile four, and some possible limed surface horizons, the pH values and ammonium acetate exchangeable calcium values for the soil profiles were low. This indicated high degrees of weathering. Higher amounts of CBD extractable manganese and iron also indicated the occurrence of a high degree of weathering in the soil and partially weathered bedrock at the study area. A weathering sequence was studied on a landscape on the Nolichucky formation. The soil and partially

weathered bedrock indicated conditions of high weathering and leaching. Greater weathering of the partially weathered bedrock was occurring due to the presence of fractures and voids. Due to instability, the soil on the footslope was thin. Relief was an important factor in the formation of the soil on the interbedded Nolichucky Shale and Maryville Limestone formation. Greater weathering occurred on the upland portion of the landscape than in the other positions. This was due to greater stability and a higher infiltration rate.

The variability of parent material was an important factor in the development of soil profiles one and four. These soils developed in a parent material that has a variable resistance to weathering. Profiles one and four were located in parent material where the weathering was not uniform. Directly adjacent to these profiles were Inceptisols with broken horizonation.

Climate was an important factor in the formation of profile three. During Pleistocene interglacial periods, temperature and rainfall were higher than that of the glacial period. The Clinch River was larger and had a stronger current than today. Profile three is located on a summit which has ancient alluvium present. Sediments in the form of a terrace were deposited at the study area by the Clinch River during the Pleistocene. An intense climate that promotes leaching and high weathering was

also important in the formation of profiles two and three.

Profiles two and three were also greatly affected by time. These soils are classified as Ultisols. Ultisols generally undergo intense weathering and leaching over a long period of time. This is necessary for the development of argillic horizons.

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APPENDICES

APPENDIX A

Micromorphological Description of Soil and Partially Weathered Bedrock Thin Sections

THIN SECTION DESCRIPTIONS

Sample #: 13 Profile: 1

Horizon and depth: C/Bt, illuvial clay and parent material 84-110 cm

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Angular blocky with irregular dendritic pores.

Passages: Occasional

Fecal material: None present

Organic matter: None

Particle size distribution: Very shaly clay

Fine material: Abundant reddish-orange, red and brown forming a matrix and coatings

Matrix: Abundant (15-25%) reddish-orange, red and brown anisotropic zones and random anisotropic flecks. Distinct flecks were found in the rock fragments in the lower relief areas. An area of green anisotropic clay is found adjacent to a rock fragment.

Silt: Rare (0.5-2%) quartz, rare mica, and rare feldspar
Sand: Very fine rare glauconite
Rock fragments: Very frequent (10-15%) shale

Coatings: Dominant (>50%) highly oriented clay coatings are found between rock fragments in pores and on mineral grains. Manganese and iron oxide coatings are found associated with the clay coatings.

Surface residues: None
Secondary crystalline material: None
Segregation and concretions: Dark brown to black manganese and iron oxide concretions occur in rounded to irregular forms. Granular segregations of manganese and iron oxide are observed around the concretions.

Weathering features: Micas are contorted and exfoliated, quartz grains are pitted, rock fragments are broken and exhibited rounded edges.

Microorganisms: None visible

Genesis: Deposition of clay in the form of clay coatings, weathering of rock fragments.

Sample #: 14 and 15 Profile: 1

Horizon and depth: Cr, saprolite, 201-213 cm

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Massive with occasional (2-5%) irregular pores

Passages: Occasionally

Fecal material: None

Organic matter: Rare

Particle size distribution: Very shaly clay loam

Fine material: Dominant orange and brown forming a matrix and clay embedded silt grains.

Matrix: Dominant orange and brown moderately anisotropic with embedded silt grains.

Silt: Abundant quartz, occasional feldspar and occasional highly oriented biotite grains and rare glauconite.

Rock fragments: Rare

Coatings: Very abundant (25-50%) highly oriented orange-red clay coatings are found around pores. Managanese and iron oxide coatings are found in association with the clay coatings

Surface residues: Lighter colored areas are found adjacent to areas of high clay content and manganese segregation.

Secondary Crystalline material: None visible

Segregation and concretions: Manganese and iron segregation are associated with clay coatings. Manganese and iron oxide granular segregation in dendritic growth bands and concretions are present.

Weathering features: Rare

Microorganisms: None visible

Genesis: Saprolite weathered from sedimentary rock

Sample #: 36 Profile: 1

Horizon and depth: Cr, saprolite, 160 cm (Manganese accumulation zone).

Location: Oak Ridge, Tennessee, Solid Waste Storage Area-6 (SWSA-6)

Structure and pores: Massive with very abundant dendritic and crazy plane pores.

Passages: Frequent

Fecal material: None

Organic matter: Rare, plant roots coated with iron oxide

Particle size distribution: Extremely shaly clay loam

Fine material: Abundant orange highly oriented form a matrix and clay coatings.

Matrix: Abundant orange highly oriented, low anisotropic with occasional domains and embedded silt grains.

Silt: Frequent quartz pockets in shale. In weathered areas quartz is oriented in a circle. Occasional mica, rare glauconite pellets.

Sand: Very fine quartz

Rock fragments: Abundant

Coatings: Highly oriented clays are found around pores and rock fragment along with manganese and iron oxides. They form compound coatings.

Surface residues: None

Secondary crystalline material: None visible

Segregation and concretions: Brown to black segregations and concretions of manganese and iron oxide are found in highly weathered zones and in pores.

Weathering features: Zones where fine material has been leached out are present. Mica is exfoliated and contorted, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: The saprolite is formed from weathered sandstone and shale.

Sample #: 16 and 17 Profile: 2

Horizon and depth: Cr2, saprolite, 290-300 cm, oriented parallel to the strike

Location: Oak Ridge, Tennessee, Solid Waste Storage area 6 (SWSA-6)

Structure and pores: Massive with occasional dendritic pores migrating parallel to the saprolite grain.

Passages: Occasional

Fecal material: None

Organic matter: Rare, plant tissue

Particle size distribution: Extremely shaly clay loam

Fine material: Dominant orange to orange-red and golden highly oriented clay are found as coating. Occasional golden and brown unoriented clay are found in inclusions.

Matrix: Dominant orange to orange-red and golden highly oriented clay are coating pores and occasional golden and brown unoriented clays are found within inclusions with embedded silt grains.

Silt: Frequent (5-10%) quartz, rare feldspars and occasional mica
Sand: Mica, occasional glauconite
Rock fragments: None

Coatings: Highly oriented clay is coating pores. Manganese and iron oxide coatings are found associated with the clay and iron coatings. Compound coatings of highly oriented clay and manganese and iron oxides are observed pores.

Surface residues: Lighter colored areas are found adjacent to pores and manganese oxide segregated areas.
Secondary Crystalline material: Crystalline manganese oxide.

Segregation and concretions: Granular manganese and iron oxide segregation occur in the anisotropic areas. Neomangans are present adjacent to fractures and plane pores. Manganese and iron oxide concretions and highly crystalline manganese oxide are present in passages. Tubular shaped manganese oxides are present.

Weathering features: Micas were exfoliated and contorted, oxidation of manganese and iron.

Microorganisms and organisms: Insect in a pore

Genesis: Saprolite weathered from sedimentary rock

Sample #: 18, 19, 20, 21, and 22 Profile: 2

Horizon and depth: Cr2, saprolite; 290-310 cm, oriented perpendicular to the strike.

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Massive with frequent dendritic pores migrating parallel to the saprolite grain.

Passages: Occasional

Fecal material: None

Organic matter: Rare

Particle size distribution: Extremely shaly clay loam

Fine material: Abundant orange-red forming coatings and bridges

Matrix: Abundant orange-red moderated to highly anisotropic with embedded silt grains.

Silt: Abundant quartz, abundant mica, rare feldspar and rare heavy minerals

Sand: Occasional mica

Rock fragments: Rare

Coatings: Orange-red highly oriented clays coat pores and passages along with manganese oxide. Together they form compound coatings.

Surface residues: Occasional light-colored area around pores and segregated areas.

Secondary crystalline material: Manganese oxide

Segregation and concretions: Manganese and iron oxide are found as coatings on pores. Concretions and granular segregation of manganese and iron oxide are found in fine grained area and dark bands. Neomangans occurred in the saprolitic shale.

Weathering features: Contorted and exfolated mica

Microorganisms: Rare

Genesis: Saprolite weathered from shale and siltstone

Sample #: 23 Profile: 3

Horizon and depth: E, eluvial, 20 cm

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA)-6

Structure and pores: Granular with frequent pores

Passages: Frequent

Fecal material: None

Organic matter: Occasional, plant tissue (roots) with iron oxide coatings

Particle size distribution: Silt

Fine material: Rare golden, forming coatings and rare matrix areas in the matrix.

Matrix: Rare golden, moderately anisotropic with rare random domains.

Silt: Dominant quartz, rare feldspar, occasional mica

Sand: Very fine quartz

Rock fragments: Rare

Coatings: Rare oriented clay coatings in pores

Surface residues: None

Secondary Crystalline material: None

Segregation and concretions: Very frequent, well rounded to irregular and tubular shaped manganese and iron oxide concretions

Weathering features: Quartz grains are pitted and mica grains are exfoliated and contorted, oxidation of manganese and iron.

Microorganisms: Rare

Genesis: Fine Alluvium

Sample #: 24 Profile: 3

Horizon and depth: Bt3, argillic, 70 cm

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Subangular blocky with frequent pores

Passages: Frequent

Fecal material: None

Organic matter: Rare, roots

Particle size distribution: Cobbly clay loam

Fine material: Very abundant orange, orange-red highly oriented forming a matrix and clay coatings.

Matrix: Very abundant orange, orange-red highly oriented moderately anisotropic with very frequent random domains and embedded silt and very fine sand grains.

Silt: Dominant quartz, rare feldspar, occasional mica and occasional heavy mineral

Sand: Dominate Quartz, occasional feldspar

Rock fragments: None

Coatings: High oriented clay coatings were found around pores along with manganese and iron oxide coatings forming compound coatings.

Surface residues: None

Secondary Crystalline material: None

Segregation and concretions: Orange to black colored manganese and iron oxide are found in segregated areas. Concretions contain dominant quartz grains.

Weathering features: Exfoliated and contorted mica grains, oxidation of manganese and iron.

Microorganisms: None

Genesis: Ancient alluvium and illuval zone for clays

Sample #: 25 Profile: 3

Horizon and depth: Bt5, argillic, 130 cm (above a highly mottled zone)

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Subangular blocky structure with occasional pores

Passages: Occasional

Fecal material: None

Organic matter: Rare, roots

Particle size distribution: Cobbly clay loam

Fine material: Dominant light orange-red and red forming a matrix and clay coatings.

Matrix: Dominant light orange, orange-red and rare brown and red highly anisotropic with abundant random domains and embedded silt and very fine sand grains.

Silt: Abundant quartz, occasional feldspar, rare mica, and frequent heavy mineral.

Sand: occasional quartz, siliceous oolitic fragment and polycrystalline quartz grains are discovered.

Rock fragments: None

Coatings: Very frequent highly oriented clay coatings are found around pores. Manganese and iron oxide coating are found associated with them. Together they form compound coatings.

Surface residues: None

Secondary Crystalline material: None visible

Segregation and concretions: Manganese and iron segregation are found in flow zones. Segregations and concretions were dark red and black in color.

Weathering features: Pitted quartz grains and contorted and exfoliated mica grains are present. Oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Ancient alluvium with illuvial clays present

Sample #: 26 Profile: 3

Horizon and depth: Bt5, argillic, 160 cm (bottom of highly mottled zone)

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Subangular blocky with occasional small dendritic pores

Passages: Rare

Fecal material: None

bOrganic matter: Rare, roots

Particle size distribution: Cobbly clay loam

Fine material: Dominant, orange, orange-red and red forming a matrix and crescentic clay coatings.

Matrix: Dominant, orange, orange-red and red with very abundant oriented domains and embedded silt and very fine sand.

Silt: Very frequent quartz, frequent biotite, occasional feldspar

Sand: Frequent quartz, occasional biotite

Rock fragments: None

Coatings: Thick, highly oriented, very abundant clay coatings manganese and iron oxide coatings are associated with clay coaings in pores.

Surface residues: None

Secondary Crystalline material: Goethite

Segregation and concretions: Manganese and iron oxide segregation is abundant. Manganese and iron oxide concretions are also present.

Weathering features: Rounded pitted quartz grains, exfoliated and contorted biotite, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Ancient alluvium with illuval clays

Sample #: 27 Profile: 3

Horizon and depth: BC, 190-230 cm, oriented perpendicular to the strike.

Location: Oak Ridge, Tennessee, Solid Waste Storage Area 6 (SWSA-6)

Structure and pores: Subangular blocky with very frequent pores

Passages: Rare

Fecal material: None

Organic matter: None

Particle size distribution: Cobbley clay loam

Fine material: very abundant yellow, golden orange, orange-red, red and green frequent area forming a matrix and coatings.

Matrix: Very abundant, yellow golden orange, orange-red, red and green frequent areas around pores and embedded silt and very fine sand.

Silt: Abundant quartz, occasional biotite, heavy mineral feldspar

Sand: Very fine occasional quartz, rare mica

Rock fragments: Frequent

Coatings: Abundant highly-oriented clay coatings are found in pores and on rock fragments. Iron and manganese oxides are associated with the clay coatings thus, forming compound coatings.

Surface residues: Lighter areas are observed around pores

Secondary crystalline material: Iron oxide (goethite)

Segregation and concretions: Occasionaly bright and dark red and black segregation and concretions are observed around the pores and rock fragments.

Weathering features: Pitted quartz grains exfoliated and contorted mica, oxidation of manganese and iron.

Microorganisms: None visible

Genesis: Ancient alluvium

APPENDIX B

Field Descriptions of Soil Profiles

PROFILE 1

Location:	3 m south of horizontal control point CD-3 about 3 m from the base of a very large white oak tree.
Vegetation:	Present vegetation is Kentucky 31 tall fescue. The forest regrowth prior to clearing was mixed pine-hardwood.
Parent Material:	Soft moderately weathered shale facies of Maryville Limestone (Conasauga Group).
Landform:	Narrow upland summits, shoulders and side-slopes.
Slope:	Slopes fall mostly in the range of 6 to 18%. Slope at the profile was 6%.
Elevation:	248 m.
Aspect:	mostly southerly.
Erosion:	Erosion from past agricultural activities was severe, with 20 to 30 cm removed. Recent land clearing activities stripped more of the soil profile, including most of the remaining argillic (Bt) horizon.
Classification:	Typic Hapludalf; clayey-skeletal, mixed, thermic.

PROFILE 1

Horizon	Depth	Description
A	0 to 10 cm	Dark brown (10YR 3/3) silt loam; moderate fine granular structure; friable; many fine roots; 9.39% shale fragments; clear wavy boundary.
E	10 to 18 cm	Light yellowish brown (10YR 6/4) silt loam; weak fine granular structure; very friable; common fine roots; 9.39% shale fragments; clear wavy boundary.
BE	18 to 25 cm	Yellowish brown (10YR 5/6) silty clay loam; moderate fine subangular blocky structure; friable; common fine roots; 57.19% shale fragments; clear wavy boundary.
Bt1	25 to 38 cm	Yellowish red (5YR 5/6) shaly clay; moderate medium subangular blocky structure parting to strong fine angular blocky structure; firm; few fine roots and few medium and coarse roots; 15 to 20% soft shale fragments are light yellowish brown (10YR 5/6); peds and fragments coated with yellowish red (5YR 4/6) plasma; clear wavy boundary.
Bt2	38 to 56 cm	Yellowish red (5YR 5/6) shaly clay; moderate medium subangular blocky structure parting to strong fine angular blocky structure; firm few medium roots; 20 to 30% soft light olive brown (2.5Y 5/6) shale fragments (that show rock structure); peds and shale fragments are coated with yellowish red (5YR 4/6) clay plasma; gradual irregular boundary.

Bt3	56 to 68 cm	Yellowish red (5YR 4/6) shaly clay; weak coarse subangular blocky structure; firm; few medium roots; 40 to 60% soft olive yellow (2.5Y 6/6) shale fragments; entire horizon plugged with yellowish red clay plasma; some shale fragments coated with red and dark red iron plasma; abrupt irregular boundary.
B/Ct	68 to 84 cm	Light olive brown (2.5Y 5/6) harder shale fragments plugged with yellowish red (5YR 4/6) clay plasma that crushes to a very shaly clay; rock structure; friable; no roots; some shale fragments that are larger than 2 to 3 cm have black manganese plasma coatings (this horizon restricts water flow somewhat); 70 to 80% shale fragments; abrupt irregular boundary.
C/Bt	84 to 105 cm	Light olive brown (2.5Y 5/6) weathered shale fragments plugged with yellowish red (5YR 4/6) clay plasma that crushes to very shaly silty clay loam; rock structure; 57.19% shale fragments, mostly coated with dark red (2.5YR 3/6) iron plasma; thin sandstone lenses contain fine to medium muscovite flakes; abrupt irregular boundary.
C	105 to 175 cm	Light yellowish brown (2.5Y 5/4) and olive yellow (2.5Y 6/6) weathered shale-siltstone and dark reddish brown (5YR 3/4) very soft fine grained sandstone that crushes to silt loam or very fine sandy loam; rock structure; friable; few fine roots along thin clay laminae that weathered from limestone; dark red (2.5YR 3/6) clay plasma coats fragments in water flow zones, while other fragments are coated with thin black manganese plasma abrupt irregular boundary.

Cr	175 to 260 cm	Olive brown oxidized shale and siltstone siltstone mostly coated with thin black manganese plasma; very soft sandstone stratum is dark yellowish brown (10YR 4/4); dark red (2.5YR 3/6) clay plasma moves down dip in water flow zones along with fine roots.

PROFILE 2

Location:	About 116 m north of horizontal control point CD-3 and about 299 m south-southwest of horizontal control point C-12, and 1.2 m away from the fence corner post.
Vegetation:	Kentucky 31 tall fescue. The forest regrowth outside the fence is mixed pine-hardwoods.
Parent materials:	Highly weathered Maryville Limestone (Conasauga Group).
Landform:	Broad upland summits and side-slopes that are mostly doubly convex.
Slope:	6% at the profile.
Elevation:	251 m.
Aspect:	Southerly.
Erosion:	Most areas are severely eroded from past agricultural activities. More recent land clearing activities have stripped off more of the upper part of the soil. In most areas the Ap rests in the Bt horizon. The erosion at the profile is slight.
Classification:	Typic Hapludult; clayey, mixed, thermic.

PROFILE 2

Horizon	Depth	Description
A	0 to 6 cm	Dark grayish brown (10YR 4/2) silt loam; moderate fine granular structure; very friable; many fine roots; 10.45% shale fragments; abrupt wavy boundary.
E1	6 to 15 cm	Yellowish brown (10YR 5/4) silt loam; weak medium granular structure; very friable; few fine roots; 10.45% shale fragments; common 1 to 2 mm hard manganese nodules coated with E material; clear wavy boundary.
E2	15 to 27 cm	Brown (10YR 5/3) silt loam; weak medium granular structure; very friable; few fine roots; 10.45% shale fragments; common 1 to 2 mm dia. hard manganese nodules coated with brown soil plasma; clear wavy boundary.
Bt1	27 to 46 cm	Strong brown (7.5 YR 5/6) silty clay loam; moderate fine sub-angular blocky structure; firm; few fine roots; thin strong brown (7.5YR 4/4) clay plasma on ped faces; 14.59% shale fragments.
Bt2	46 to 70 cm	Yellowish red (5YR 5/6) clay or silty clay; moderate fine subangular blocky structure; firm; few fine roots; thin yellowish red (5YR 4/6) clay plasma on ped faces, few black iron-manganese nodules; few highly weathered shale fragments; gradual wavy boundary.
Bt3	70 to 84 cm	Mottled yellowish red (5YR 5/8) and yellowish brown (10YR 5/6) clay; weak coarse subangular blocky structure parting to weak fine subangular blocky structure; firm; few fine roots; 25.52% soft light olive brown (2.5Y 5/4) shale and siltstone fragments

		that are mostly disoriented; peds are coated with red (2.5YR 4/6) clay plasma (this horizon is highly clay plugged); clear wavy boundary.
C/Bt	84 to 100 cm	Light olive brown (2.5Y 5/6) very soft and clay-plugged shale and siltstone that crushes to shaly silty clay loam 90% rock structure; firm; few fine roots; 46.69% shale fragments; the clay plasma is strong brown (7.5YR 5/6) on primary fragment faces, while secondary faces are coated with red (10R 4/6) iron plasma; water flow zones are grayish brown to brown (2.5Y 5/2-5/3); clear irregular boundary.
C	100 to 120 cm	Light olive brown (2.5Y 5/6) shale and siltstone that crushes to shaly silty clay loam; 100% rock structure; firm; few root mats in the lower boundary; 40% to 60% fragments, some which are coated with strong brown (7.5YR 5/6) clay plasma, while many are coated with red and dark red (10R 4/6 and 3/6) iron plasma; clear irregular boundary.
Cr1	120 to 208 cm	Light olive brown (2.5Y 5/6) shale and siltstone that crushes to very shaly silt loam or silty clay loam; steeply dipping rock structure; very firm; more than 95% fragments that are coated with red (10R 4/8 and 2.5YR 4/8) iron plasma coatings; clear irregular boundary.
Cr2	208 to 300 cm	Yellowish brown (10YR 5/4-5/6) shale and siltstone that crushes to very shaly silty clay loam; most fragments are coated with black manganese plasma, but water flow zones have yellowish red (5YR 5/8) plasma. (This horizon was described from auger cuttings. A remarkable feature was the change from the red

plasma to the black manganese plasma and zones of soft manganese concentrations).

PROFILE 3

Location:	SWSA-6; about 198 m south of horizonal control point CD-3, and about 198 m west of horizontal control point DS-5.
Vegetation:	Kentucky 31 tall fescue. The forest regrowth on the other side of the fence is mixed pine-hardwood with a few red cedar.
Parent materials:	Alluvium over residuum.
Landform:	Remnant of old terrace-floodplain that has undergone topographic inversion.
Slope:	0 - 2%
Elevation	260 m
Aspect:	South
Erosion:	Slight
Classification:	Typic Paleudult; fine-silty, mixed, thermic.

PROFILE 3

Horizon	Depth	Description
Ap	0 to 10 cm	Dark brown (10YR 3/3) silt loam; moderate fine granular structure; very friable; many fine roots; clear wavy boundary; 4.44% coarse fragments of hardened iron and manganese accumulations.
E	10 to 21 cm	Yellowish brown (10YR 5/4) silt loam or very fine sandy loam; moderate fine granular structure; very friable; few fine and medium roots; clear wavy boundary; 4.44% coarse fragments of hardened iron and manganese accumulations.
Bt1	21 to 37 cm	Strong brown (7.5YR 5/4) silty clay loam: moderate fine subangular blocky structure; very friable; common medium roots; no fragments; clear wavy boundary.
Bt2	37 to 53 cm	Brown (7.5YR 4/4) silty clay loam; moderate fine subangular blocky structure; very friable; common medium roots; no fragments except in the boundary where a few pea-sized chert pebbles were found; yellowish red (5YR 5/6) clay plasma on red surfaces; abrupt wavy boundary.
Bt3	53 to 80 cm	Red (2.5YR 4/6) clay; strong fine and medium subangular blocky structure; firm; very sticky; few medium roots; few chert and sand-pebbles and iron and manganese concretions; yellowish red (5YR 5/6) clay plasma covering dark red (2.5YR 3/6) clay plasma; gradual wavy boundary.

Bt5	119 to 190 cm	Variegated red (2.5YR 4/8) and yellowish red (5YR 5/6) clay; weak fine and medium subangular blocky structure; very firm and sticky; no roots or fragments; water flow zones have a sequence of colors from the outside to the inside as follows: the outer color is strong brown (7.5YR 5/8); the next color in is pale brown (10YR 6/3); in the upper part of the horizon the inner flow zone color is yellowish brown (2.5YR 6/4) while in the lower part of the horizon the inner flow zone color changes gradually light brownish gray (2.5Y 6/2).

This horizon has perched water in the past, and perched water occurred after a rain while the profile was open. Whether perched water occurs in situ cannot be determined without additional testing by neutron probe or other techniques for monitoring in situ soil water content. (The description to this depth is in a profile. The rest of the description is from a barrel auger, so only colors and textures are given.)

BC	190 to 230 cm	Variegated yellowish red (5YR 5/6), strong brown (7.5YR 5/8), and water flow zones of light brownish gray (2.5Y 6/2); silty clay loam; brown (7.5 YR 4/4) clay plasma covers some inner parts of flow zones.
CB	230 to 300 cm	Yellowish brown (10YR 5/6) silty clay loam; light gray (10YR 7/2) material coats flow zones, and the inner part of flow zones has red (10YR 4/8) iron plasma.

Based on data in ORNL/TM9442, thickness of the alluvium is about 5 m on the upland summit.

PROFILE 4

Location:	About 137 m north of horizontal control point DS-5 and about 223 m southeast of horizontal control point CD-3 in SWSA-6.
Vegetation:	Mostly Virginia pine. The ground cover in places consists of mosses and *Cladonia* sp lichens.
Parent materials:	A thin veneer of slope wash in most places over residuum from the Nolichucky Shale (Conasauga Group) or interbedded Maryville-Nolichucky.
Landform:	Low upland with mostly convex slope configuration.
Slope:	4%
Eevation:	232 m
Aspect:	South
Erosion:	Moderate to severe
Classification:	Aquic Hapludalf; loamy-skeletal, mixed, thermic.

PROFILE 4

Horizon	Depth	Description
Ap	0 to 14 cm	Brown (10YR 5/3) silt loam; weak fine granular structure; friable; few fine and medium roots; 12.73% shale fragments; abrupt smooth boundary.
Bt	14 to 23 cm	Brown (10YR 4/3) silty clay loam; moderate fine subangular blocky structure; firm; few medium roots; 16.30% shale fragments; peds coated with yellowish brown (10YR 5/4) clay plasma; few fine prominent red (2.5YR 4/8) mottles in ped interiors in the lower part of the horizon; clear wavy boundary.
Btg	23 to 50 cm	Variegated red (2.5YR 4/8) and gray (10YR 6/1) clay; moderate coarse subangular blocky structure; firm; few medium roots; 54.33% shale fragments; light brownish gray (10YR 6/2) and pale brown (10YR 6/3) clay plasma coating ped surfaces; abrupt wavy boundary.
Cr	50 to 74 cm	Brown (7.5YR 4/2) shale thickly coated with greenish gray (5GY 6/1) clay plasma that crushes to extremely shaly clay; steeply dipping rock structure; very firm; 86.96% shale fragments; abrupt irregular boundary.
2Cr	74 to 84 cm	Mottled brown, red, and gray clay strata; massive; firm; abrupt irregular boundary.

This material serves as a conduit for water flow to deeper areas in the shale. Roots also follow these soft clay strata.

3Cr	84 to 120 cm	Brown (7.5YR 4/2) shale with larger faces coated with black manganese plasma while interior faces are coated with red iron plasma; glauconite pellets occur in this stratum.
4Cr	120 to 123 cm	Mottled brown, red, and gray clay that transmits water down dip between quite hard Cr materials.
5Cr	123 to 150 cm	Same description as the 4Cr horizon.

VITA

Debra Helen Phillips, daughter of Howard and Helen Phillips was born in Augusta, Georgia on January 23, 1962. She attended elementary school in Dearing, Georgia, and Junior High school in Thomson, Georgia. She graduated from Thomson High School in May 1980. In September 1980 she entered the Bachelor of Science program in Plant and Soil Science at Tennessee Technological University. She transferred to the University of Georgia in September 1982 where she graduated with a Bachelor of Science degree in Agronomy in December 1984. After graduation she accepted a position as a soil scientist, which involved mapping soils for the USDA-SCS in South Georgia. In September 1985 she entered the Master of Science program in Plant and Soil Science at the University of Tennessee.