To the Graduate Council:

I am submitting herewith a thesis written by Marjorie J. Boyce entitled "Characterization of Mineralogy and Permeability of the Proposed Hard Labor Soil Series (fine, kaolinitic, thermic Oxyaquic Kanhapludults)". I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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CHARACTERIZATION OF MINERALOGY AND PERMEABILITY OF THE PROPOSED HARD LABOR SOIL SERIES (FINE, KAOLINITIC, THERMIC OXYAQUIC KANHAPLUDULTS)

A Thesis
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Marjorie J. Boyce
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ABSTRACT

In the Piedmont of Georgia, many homes have been built on the Appling soil series (fine, kaolinitic, thermic Typic Kanhapludults). This soil is well drained and well suited for in-situ household waste disposal. Some areas that are included in the Appling units are moderately well drained with redoximorphic features within 80 cm of the soil surface. The proposed Hard Labor series (fine, kaolinitic, thermic Oxyaquic Kanhapludults) will recognize these features. The objectives of this study are to characterize the morphology and mineralogy of the redoximorphic features and to determine saturated hydraulic conductivity above and in the redoximorphic zones of the Hard Labor soil series. Two representative sites were chosen and sampled. Classification of the profiles was fine, kaolinitic, thermic Oxyaquic Kanhapludults. Redoximorphic features can be correlated with increases in bulk density and decreases in structure. Mineralogy of the pedons is kaolinitic, but shows a small expandable clay component in the lower horizons. Saturated hydraulic conductivity (Ksat) was measured on five representative sites. Ksat decreases with depth. Soil morphology described in the zones of interest proved to be a good indicator of low hydraulic conductivity (Ksat).

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Part 1.

Introduction and Objectives

Introduction

Soil is "the collection of natural bodies on the earth's surface containing living matter and supporting or capable of supporting plants out-of-doors" (Soil Survey Staff, 1975). Buol, Hole, and McCracken (1989) define soils as the "natural body of mineral and organic matter that changes, or has changed, in response to climate and organisms" (Buol et al., 1989). Sposito, on the other hand, defines soils as "porous media created at the land surface by weathering processes derived from biological, geological, and hydrological phenomena" (Sposito, 1989). Soils are important to different groups of people for different reasons. The farmer is concerned about soil fertility and productivity; the engineer about shear strength and load bearing ability; the archaeologist about artifacts buried in it; and the soil scientist about genesis and classification.

The USDA Natural Resources Conservation Service uses a soil's taxonomic classification and series characteristics to write interpretations for their use. These interpretations describe the soil's limitations with regard to sanitary facilities, such as septic tanks, sewage lagoons, and landfills; construction materials including fill dirt; building sites - roads and excavations; water management, such as ponds and irrigation; and recreational development including camping sites and trails. These interpretations also rate the soil's capability for producing agricultural and forestry products.

In the Piedmont, many homes have been built on areas that are mapped as the Appling series (fine, kaolinitic, thermic Typic Kanhapludults). Because of Appling's moderate permeability, greater than 150 cm to bedrock, and greater than 180 cm to a seasonal high water table, it is described as being well suited as a medium for the treatment of household septic waste.

There are many soil properties that are evaluated when siting a septic tank absorption field, including permeability, depth to a seasonal high water table, depth to bedrock, and depth to a cemented pan. These properties affect the degree of excavation difficulty, rate and efficiency of effluent absorption, and the protection of ground water purity (Soil Survey Staff, 1996b). The different effects of these properties are stated in Table 1 (Soil Survey Staff, 1996b). One of the most important concerns is permeability and saturated hydraulic conductivity of the subsoil and saprolite (Vepraskas and Williams, 1995). The transitional zone between soil and saprolite, the BC horizon, is often slowly permeable (Vepraskas et al., 1996). This is the area where the drain lines for septic fields are often placed. If this zone moves waste too slowly, the probability of at least seasonal failure is high.

Appling is a well-drained soil that formed in residuum from felsic igneous and metamorphic rocks. It was first correlated in Columbia County, Georgia, in 1911. It has a sandy or loamy epipedon and a clayey argillic horizon that ranges in color from 5YR to 2.5Y hue. High chroma mottles are allowed in the lower part of the argillic (Natural Resources Conservation Service, 1997a). These mottles are attributed to parent material and not to redoximorphic conditions in the soil. No chroma < 4 redoximorphic features are described. Appling has well formed subangular to angular blocky structure in the Bt horizons so the permeability is moderate. With regards to interpretations for septic tank absorption fields, Appling is rated as moderate because of permeability in the subsoil (Natural Resources Conservation Service, 1997c).

Some areas historically included in Appling map unit delineations throughout the Piedmont have soils with redoximorphic features such as gray colors and zones of iron accumulation which indicate a seasonal high water table. This water table has led to failure of some septic systems installed on this moderately well drained Appling. These areas are difficult to predict on the landscape, as they do not appear to be tied to a particular geomorphic position. Powell and Springer (1965) documented some of these moderately well drained inclusions. Their study measured the accuracy of map unit composition for the Walton County, Georgia Soil Survey. Walton County joins Morgan

Table 1. Soil properties and their effects on septic tank absorption fields.

PROPERTY	LIMITS			RESTRICTIVE FEATURE
	SLIGHT	MODERATE	SEVERE	
USDA Texture	--	--	ice	permafrost
Total subsidence (in)	--	--	>24	subsides
Flooding	none	rare	frequent occasional	flooding
Depth to bedrock (in)	>72	40 to 72	<40	depth to rock
Depth to cemented pan (in)	>72	40 to 72	<40	cemented pan
Ponding	--	--	+	ponding
Depth to high water table (ft)	>6	4 to 6	<4	wetness
Permeability (24 to 60 in, in/hr)	2.0 to 6.0	0.6 to 2.0	<0.6	percs slowly
Permeability (24 to 60 in, in/hr)	--	--	>6.0	poor filter
Slope (%)	<8	8 to 15	>15	slope
Weight percent >3 in (weighted avg. to 40 in)	<25	25 to 50	>50	large stones

County to the northwest. The Appling map units commonly had inclusions of other soils from 17 to 30 percent. The included soils usually were Louisburg (coarse-loamy, mixed, thermic Ruptic-Ultic Dystrochrepts) on the convex sideslopes, and Colfax (fine-loamy, mixed, thermic Aquic Fragiudults) on the toe slopes. These inclusions are important because of the limitations they place on interpretations, especially urban interpretations.

The proposed Hard Labor series (fine, kaolinitic, thermic Oxyaquic Kanhapludults) will recognize redoximorphic features found in the lower part of the argillic horizon below a depth of 75 cm, which are not allowed in Appling. The Hard Labor soil series is a moderately well drained soil with a seasonal perched water table at depths of 120 to 180 cm (NRCS, 1997b). Redoximorphic features with chroma < 3 are described in the lower Bt and BC below 60 centimeters. It has platy structure in this zone. Water is removed somewhat slowly during some periods of the year, and free water in the soil is moderately deep (Soil Survey Staff, 1993b). In a preliminary evaluation of Appling map units across the Piedmont, Hard Labor is the major component of Appling map units, with Appling serving as a non-limiting dissimilar inclusion (George and Evon, 1997). The Hard Labor series, therefore, is of wide extent and urban interpretations for these map units will differ greatly from the Appling map units. The cropland interpretations for Hard Labor will be the same as for Appling, but the urban interpretations, which often require investigations to greater soil depths need to be updated. There are currently no data to support this need.

The objectives of this study were to characterize the morphology and mineralogy of the redoximorphic features and to determine saturated hydraulic conductivity above and in the redoximorphic zones of the Hard Labor soil series.

Literature Review

Historical Overview

The Piedmont of Georgia begins at the fall line of the major rivers in the state, roughly from Columbus to Macon to Augusta, and extends north where it meets the foothills of the Appalachian Mountains. It is characterized by rolling hills that are dissected by many small streams. It is part of the Southern Piedmont Major Land Resource Area, which stretches from Virginia to Alabama.

The Piedmont plays an important role in Georgia's agricultural history. Until recently most of the Piedmont was farmed, either in row crops, such as cotton, or used for hay and pasture. With the growing urban presence from Atlanta in northern Georgia, the land use is rapidly shifting from crops to forestry and urban land.

Morgan County

Morgan County is located in the north-central part of the state (Fig. 1). Madison is the county seat. Agriculture and forestry have always been important to the Morgan County economy. Before the Civil War most farmers grew only what they needed. Only a small number of livestock were raised. Cotton production increased sharply after the Civil War until 1921 when the boll weevil virtually wiped out the cotton crop (Payne, 1965). Since the late 1980's cotton has made a steady comeback, with the eradication of the boll weevil, and this increase is evident in Morgan County. Agricultural interpretations are very important; however, urban interpretations for land use are becoming more prevalent because of the close proximity to Atlanta via Interstate 20 (Wheat, 1997).

Soils in Morgan County were first mapped in 1915 by the Bureau of Soils, then again in 1965 by the Soil Conservation Service. The 1965 survey was updated and completed in August 1997. The final, digitized product should be available in 1998.

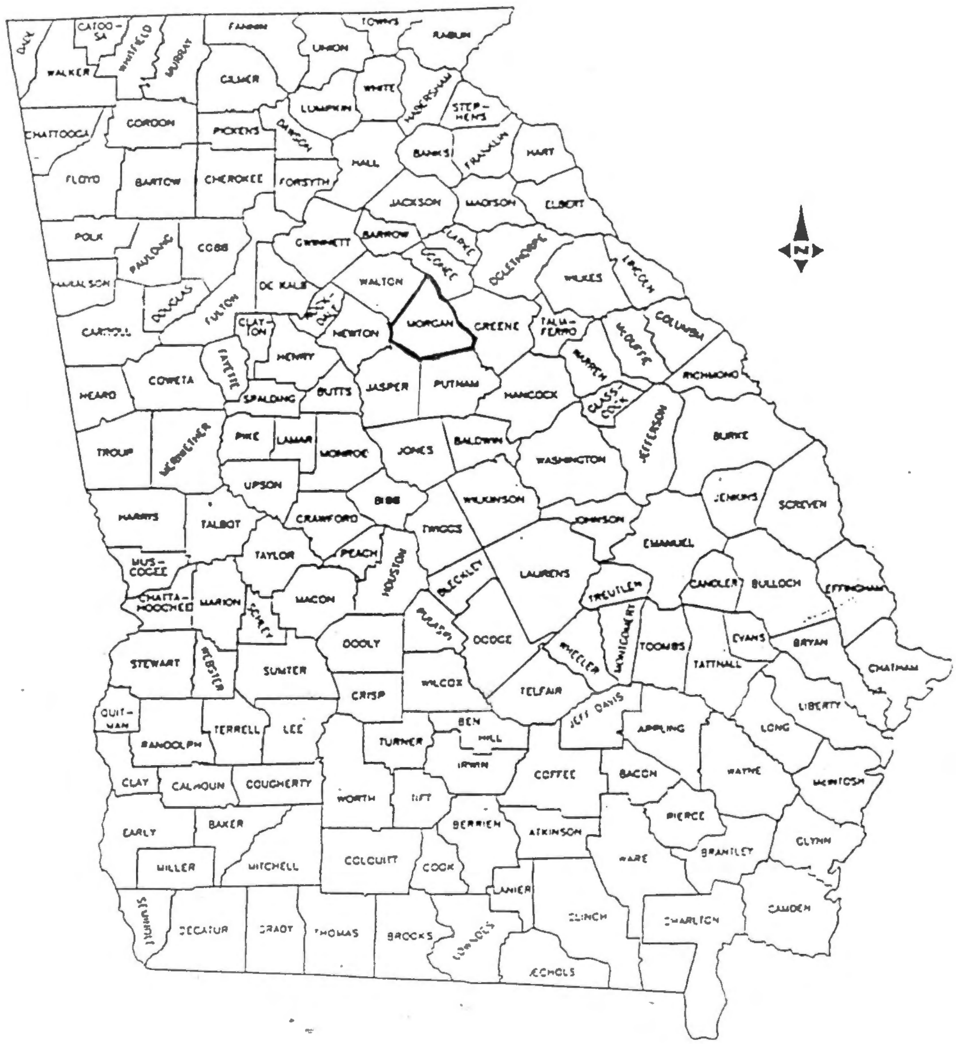

Fig. 1. County map of Georgia showing the location of Morgan County.

Materials and Methods

Site Selection

The Morgan County sites were chosen as a result of the soil survey update field investigations. The survey used the point-transect method of investigating and evaluating the mapping accuracy and map unit composition of the 1965 survey (Soil Survey Staff, 1993a). The choice of these sites was based on the Hard Labor soils found during transect observations. This method is not the most statistically correct; however, it does provide adequate information for the production soil survey (Young et al., 1997).

Five sites were chosen for saturated hydraulic conductivity measurements. Two of these were then selected for sampling and lab characterization. Figure 2 shows the location of the study sites in Morgan County.

Land use was also considered in selection of the sites. None of the sites were forested, as the Appling soil is considered by local farmers to be the best soil for cultivation (Wheat, 1997). Sites 2A and 5A are located in active cotton (*Gossypium hirsutum* L.) fields. Site 3A is located in a fescue (*Festuca arundinacea* L.) hay field. Site 1A is located in an alfalfa (*Medicago sativa* L.) field. Site 4A is located in an abandoned hay field that is being subdivided for houses.

A cross-section of eroded and non-eroded units was also desired. Sites 1A, 3A, and 5A were located in Appling loamy coarse sand, 2 to 6 percent slopes, eroded units. Sites 2A and 4A were located in Appling loamy coarse sand, 2 to 6 percent slopes units. With correlation in the update survey, these units have been combined into a Hard Labor loamy coarse sand, 2 to 6 percent slopes unit.

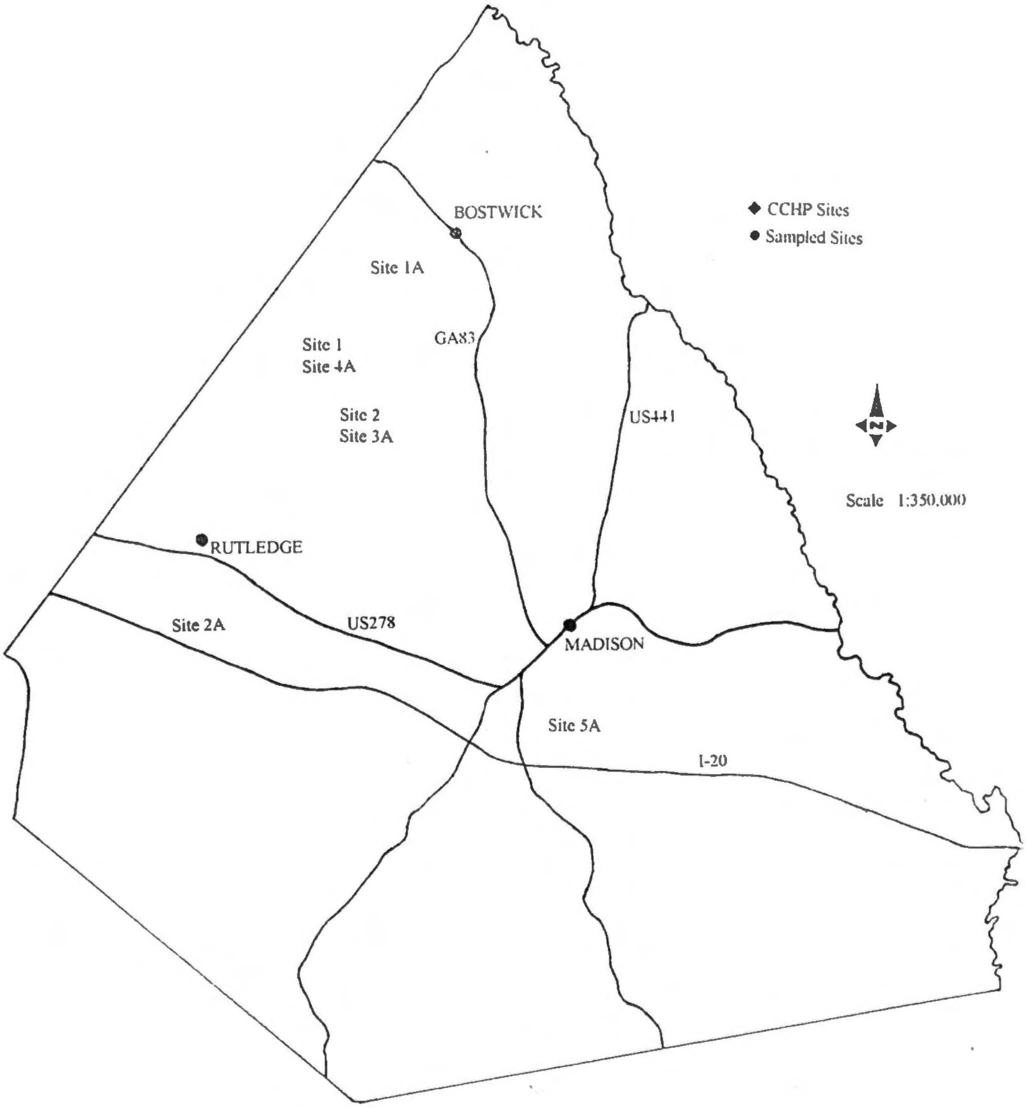

Fig. 2. Map of Morgan County, Georgia showing the location of the study sites.

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Part 2.

Mineralogy and Redoximorphic Features

of Two Hard Labor Pedons (fine, kaolinitic, thermic Oxyaquic Kanhapludults)

in Morgan County, Georgia

Introduction

Redoximorphic features in soils are an indicator of either the past or present soil moisture condition (Vepraskas, 1995). Relict redoximorphic features often have sharp, thin boundaries while features that are still developing have thicker, more diffuse boundaries. The proposed Hard Labor soil series describes redoximorphic concentrations below a depth of 20 cm and redoximorphic depletions below a depth of 75 cm. The soil structure in this zone is described as platy parting to subangular blocky.

The objective of this chapter was to characterize the morphology and mineralogy of the redoximorphic features in the Hard Labor soil.

Literature Review

Soil Genesis and Pedogenic Features

Soil is formed by interactions of five factors: climate, organisms, relief or topography, parent material, and time (Jenny, 1941). This process is not controlled by genes, as in animals or plants, but by the degree of activity of these five factors (Buol et al., 1989). These factors influence soils in different ways in different parts of the world. Parent material influences how quickly a soil develops and what kind of soil develops. Soil formation is directly related to landscape position with regard to variability across the landscape. Geomorphic and hydrologic processes on the landscape control this variability (Tomer and Anderson, 1995).

Hunckler and Schaetzl (1997) found that in Spodosol development the aspect of the site had a large impact on the amount of development of the B horizon. The north-northeast facing slopes repeatedly had thicker sola and horizons and darker colors indicating greater podzolization (development). This finding was due to more available moisture and higher infiltration on these slopes versus the south-southwest slopes. Deep soils that are formed in place in fine-grained crystalline rock take millions of years to develop (Harpstead, 1989). This rock weathers in place to form saprolite, which loses the parent rock structure and begins to develop soil structure (O'Brien and Buol, 1984). Mineral composition of the parent rocks will influence the mineralogy and fertility of the soil that develops. Texture is also influenced by the parent material (Stolt et al., 1993a). Topography influences the amount of organic matter and climatic zones of the soil. Brady (1990) stated that organisms living in the soil have a direct effect on the accumulation of organic matter, profile mixing, cycling of nutrients, and structural stability of the soil. Organic matter content is lowest in the highest part of the landscapes. Weathering of a soil's parent material is dictated by the climate of an area (Cady, 1950). Climate also will influence the chemical nature of a soil. Warm, humid climates will not show the chemical variations in the parent material as much as a cool or dry climate (Jenny, 1941). Mountainous areas often have the soil climate of a more northern region.

Aspect in mountainous areas influences the types of soil that develop because of different microclimates (Hunckler and Schaetzl, 1997). The amount of solar radiation a site receives can change soil temperature and atmospheric temperature. Wind velocity and moisture are also affected (Hunckler and Schaetzl, 1997). Franzmeier et al. (1969) in studying north and south slopes in eastern Kentucky and Tennessee found that the north slopes had a higher percentage of organic matter. Losche et al. (1970) found that soils on south slopes were redder, were more clayey in the Bt horizon, had higher iron contents, and were deeper than those on north facing slopes.

In the Piedmont of Georgia, the long, hot summers and mild winters hasten chemical, physical, and biological weathering. Microbial activity is non-stop, even during the cool season (Buol, 1973). In this area regional climate and parent material are more important than the other factors for controlling soil formation (Stolt et al., 1993a). Birkeland (1974) also states that the soil forming factors control the limits and directions that soil can go in its development, but the pedogenic processes are responsible for the actual formation of the soil.

Along with the five factors of formation, pedogenic processes help shape the soil. Pedogenic processes or soil forming processes are "any reaction taking place in soil that is functionally related to soil-forming factors" (Jenny, 1941). These processes and reactions include addition and subtraction of minerals and organic materials and translocation and transformation of these materials in the soil (Buol et al., 1989). Additions to soils include mostly organic matter from plants and animals. Volcanic eruptions and loess depositions are not necessarily considered additions because they deposit parent material (Jenny, 1941). Soil surface erosion and leaching of nutrients are the most important losses that occur in soils. Soils occurring on summits are not as affected by erosion as those in backslope or shoulder positions. Losses from the summit position occur in the sand fraction as sand weathering and leaching of the weathered materials (Stolt et al., 1993b).

Climate can have a large effect on these soil reactions. As temperature increases 10 degrees Celsius, chemical and biochemical reaction rates generally double (Jenny, 1941). Organic acids from decaying plant and animal material often speed this process, solubilizing minerals in the parent material and chemically altering it. These minerals then can accumulate in a lower horizon or be lost from the soil into the ground water (Hunckler and Schaetzl, 1997).

Transformations in soils include biochemical processes of decomposition and then synthesis to make new compounds. Translocation of clays and minerals is the process that affects the mineralogy of a soil (Schoeneberger et al., 1992). Table 2 presents a complete listing of the sub-processes within the four main pedogenic processes (Buol et al., 1989).

The major soil-forming processes at work in the Piedmont of Georgia are

Table 2. Pedogenic processes in soils.

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

weathering of the sand and silt fraction, transport and leaching of these weathering products, illuviation of clay, and iron oxide accumulation (Stolt et al., 1993b). Important to this study is the reduction, then translocation, and finally oxidation of iron and manganese oxides (Vepraskas, 1995). These processes develop the reticulate mottling pattern associated with the Hard Labor soil. Stolt et al. (1994) described these as Strongly Contrasting Redoximorphic Patterns (SCRP).

Geology

Felsic igneous and metamorphic rocks dominate the geology of the Piedmont in Georgia. These rocks are approximately dated in the late Precambrian or early Paleozoic age. The Piedmont looks like a former peneplain surface that has been dissected. Deposition occurred as alternating shales and basaltic flows (Lawton, 1969). The region undergoes continuous mineral alterations in the saprolite, continuous erosion, and continuous down-wasting along upland, intermittent drainageways (Mills et al., 1987). The surface drainage of the area is not structurally controlled and the geomorphic form of the Piedmont does not change among rock types (Daniels et al., 1973).

Morgan County is located entirely within the Piedmont. Figure 3 is the geology map of Morgan County. Most of Morgan County is underlain by granite and granite gneiss with bands of mica schist and biotite gneiss trending from northeast to southwest (Pickering and Murray, 1976).

Lawton (1969) describes this banding in greater detail. The biotite gneiss present in the Hard Labor Creek area of Morgan County varies from veined to porphyritic to homogeneous. These different rock types occur in gradations and are not mappable from the extremely weathered saprolite. Felsic and mafic bands also alternate within the gneiss, but they are not continuous or mappable. Large crystals of microcline, plagioclase, and quartz distinguish the porphyritic gneisses. These gneisses were formed by low pressure local metamorphism.

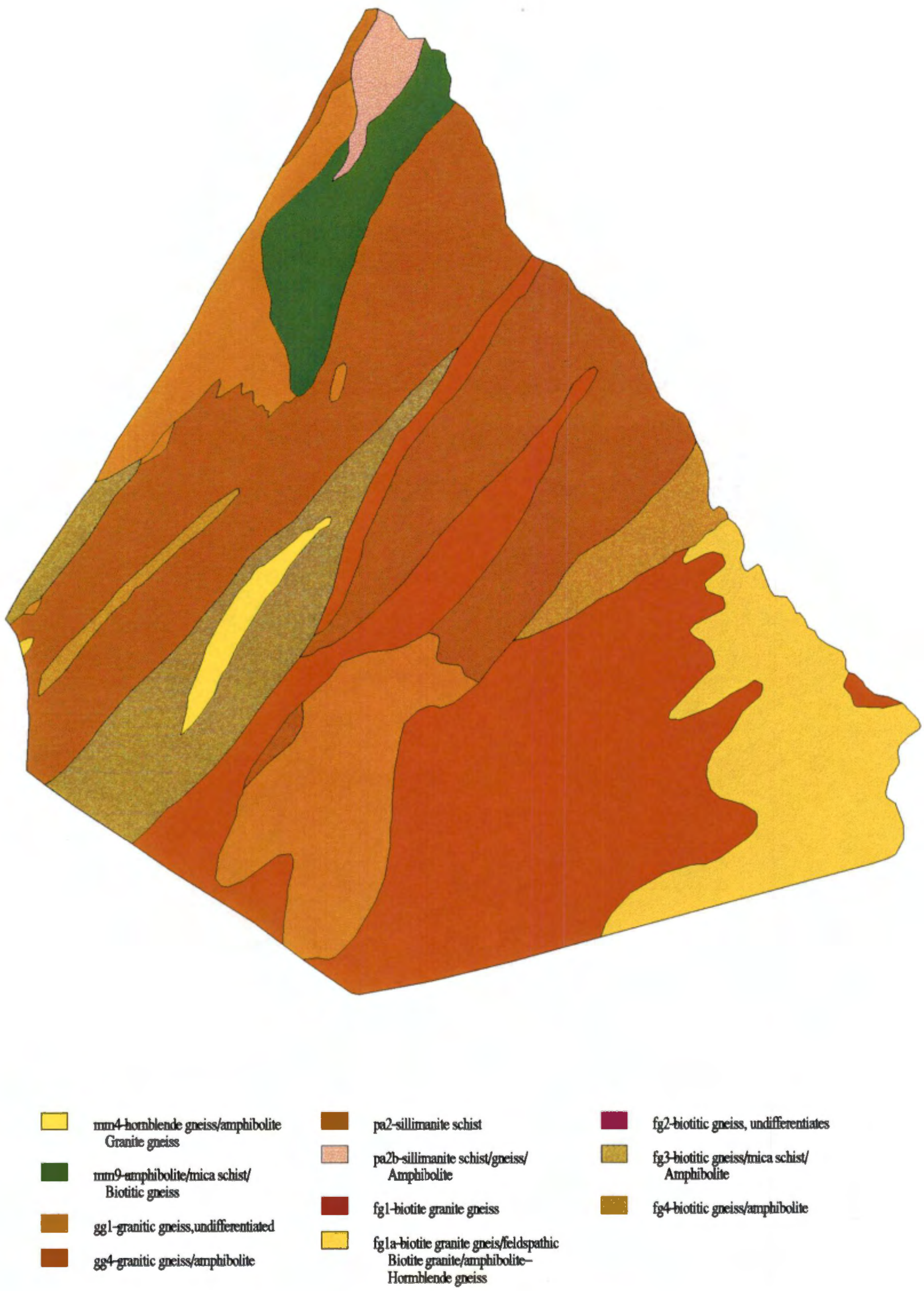


Fig. 3 Geology map of Morgan County, Georgia

Biotite and granitic gneiss tend to form a coarse-loamy saprolite and, therefore, a soil with low nutrient levels. Saprolite is defined as "soft, friable, isovolumetrically weathered bedrock that retains the fabric and structure of the parent rock" (Schoeneberger et al., 1995). This saprolite is mostly Quaternary in age (Mills et al., 1987). It is banded, with textures varying from silt loam to gravelly sandy loam. These textures in the saprolite reflect the parent material (Schoeneberger et al., 1995).

The high iron, red soils of the Piedmont are formed in a mixture of gneiss and schist. The schist adds clay minerals, such as kaolinite and hydroxy interlayered vermiculite (HIV) (Buol et al., 1989).

Redoximorphic Features

The redoximorphic features described in the Hard Labor soil are the result of oxidation and reduction reactions. These reactions result in the complete transfer of electrons from one ionic species to another. The oxidized species loses electrons and the reduced species gains electrons (Sposito, 1989). This exchange of electrons in the iron fraction of a soil results in the mottling patterns that are evident in soils with a fluctuating water table. The water table is influenced by soil physical properties, such as texture, structure, hydraulic conductivity, and porosity (Khan and Fenton, 1994). The pattern is formed by iron and manganese oxide reduction, translocation and oxidation (Vepraskas, 1995).

Franzmeier et al. (1983) studied the correlation between soil color and water table depth in several soil catenas in Indiana. They found that horizons with chroma ≤ 2 matrices are periodically saturated. The degree of the "grayness" often shows the length of the saturation. Soils with horizons that have chroma 3 features, such as matrix color or mottles, are also periodically saturated, but the reduction is not as complete as soils with a chroma 2 matrix. This distinction is not extremely important for agricultural interpretations, but is very important for on-site waste disposal. In these situations of increased organic waste material and added wetness, these chroma 3 soils are interpreted the same as a chroma 2 soil.

Schoeneberger et al. (1992) described redoximorphic features in a gneiss saprolite. These features are associated with fractures and bedding planes of the saprolite and they exhibited a color "zonation" with a red matrix, then yellow and then a white zone. The smallest zone is a thin, black coating of mainly iron and manganese oxides. The color zones are not inherent in the rock and therefore are pedogenic with the formation of the saprolite. The dominant mineralogy of the zones is as follows: red – hematite, yellow – goethite, white- aluminum and silica, black – manganese oxides. They also concluded that the color zones were a result of past redoximorphic conditions. Figure 4 illustrates the configuration of the redoximorphic zones (Vepraskas, 1995).

It is not known exactly how rapidly soil colors can respond to changes in the water table. It is also difficult to tell if the colors represent the present condition or a past soil water condition (Franzmeier et al., 1983). Vepraskas (1995) stated that soils can retain their old redoximorphic features even when events such as stream down-cutting remove the water that formed those features and the soils are now better drained.

The redoximorphic features in the Hard Labor soil follow a reticulate mottling pattern (George and Evon, 1997). Foth (1978) identified reticulate mottling as a streaky network of different colors. These Strongly Contrasting Redoximorphic Patterns (SCRP) are defined to be differing from the matrix in hue by at least two Munsell pages (five

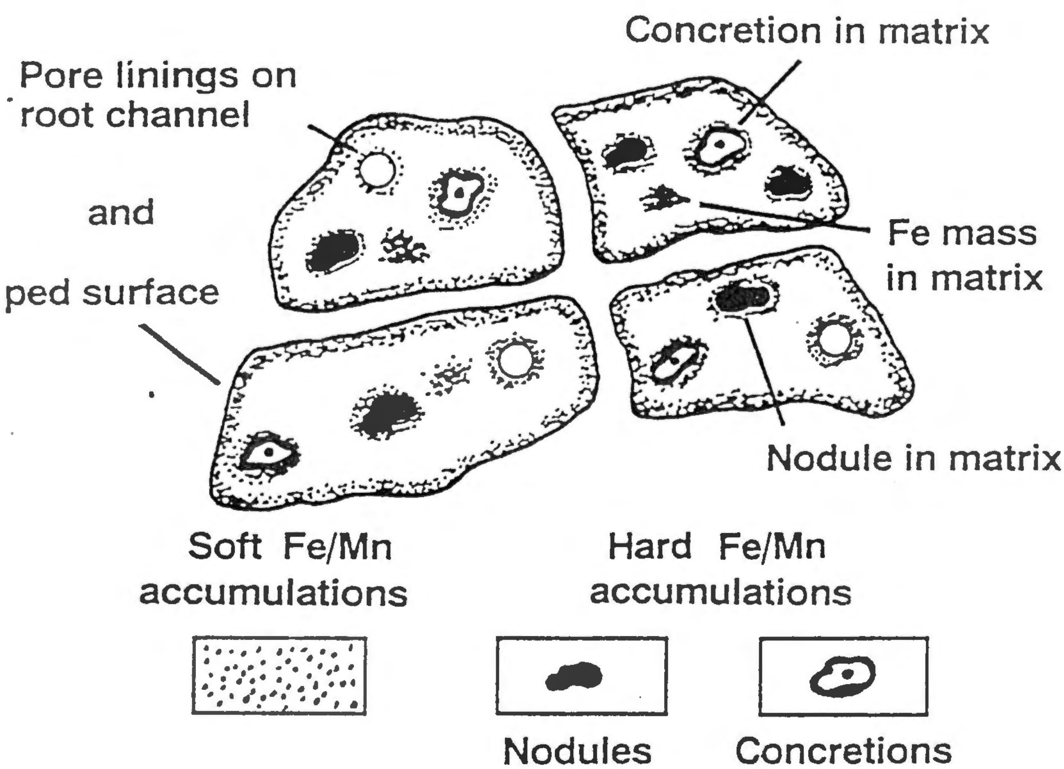


Fig. 4. Configuration of redoximorphic features in the Hard Labor soil

hues); if the hue is the same, differing from the matrix by at least four units of value or chroma or if the hue differs by one Munsell page (2.5 hues), differing from the matrix by one unit of chroma or two units of value (Stolt et al., 1994). These zones of accumulation and depletion are the result of iron movement. Not much is known about the processes that form these horizons. Generally, the slow permeability of a soil horizon, or the presence of a fluctuating water table are responsible for the segregation of iron. SCRP occur in soils on stable landscapes that may contain plinthite (Stolt et al., 1994).

Clay is also associated with the moving of the iron (McDaniel et al., 1992). The gray (Munsell) parts of the matrix have a clay texture and the red and yellow (Munsell) parts are sandy clay loam. The depletions in these horizons are defined as having chroma of two or less and also a value of four or more (Vepraskas, 1995). Within the redoximorphic zones, the soil structure is commonly platy (Daniels et al., 1978).

There are several types of redoximorphic features. Vepraskas (1995) defined the following types of redoximorphic features.

1. Redox concentrations - these include areas of accumulation of iron and manganese oxides. They can be described as nodules, concretions, masses, and pore linings. Nodules and concretions are firm to extremely firm segregations. Concretions commonly have regular concentric layers, whereas nodules are more uniform internally.
2. Redox depletions – these include areas of low chroma (≤ 2) where iron and manganese (Fe-Mn) oxides or Fe-Mn oxides and clay have been stripped. They can be described as iron depletions or clay depletions. In the past, iron

depletions have been called gray mottles. Clay depletions are gray mottles that have a lighter texture than the surrounding matrix.

3. Reduced matrices – these include entire horizons in which the iron has been reduced and will change color from grey or blue to brown when exposed to air.

Materials and Methods

Field Methods

Two representative pedons were chosen for sampling. Saturated hydraulic conductivity sites 3A and 4A were chosen because they were in different map units and different erosion phases (see Part 2 of this thesis). Profile description followed the National Cooperative Soil Survey Standards (Soil Survey Staff, 1993). Site descriptions and morphology were described in the field. Site description included latitude, longitude, elevation, vegetation, slope, and aspect. Horizon designation, horizon depth, boundary, texture, color, structure, consistence, and redoximorphic features were described for morphology. The soil profiles were classified according to the Keys to Soil Taxonomy (Soil Survey Staff, 1996).

Laboratory Sample Preparation

Each sample was air dried, crushed and sieved through a 2 mm sieve. Coarse fragments, if present, were then separated and weighed to determine their percent by weight and volume. Part of each 2 mm sample was ground to 60 mesh for other laboratory analyses (Soil Survey Staff, 1993).

Particle size, pH, CEC, and carbon analysis were performed on all samples. In addition x-ray diffraction and bulk density were measured on selected samples from the pedons.

Particle size analysis was determined by the pipette method (Kilmer and Alexander, 1949; Gee and Bauder, 1986). This is a modified method using 400 ml of solution and a 5 ml pipette. This method has been checked numerous times against the original 1000 ml of solution with a 25 ml pipette. The results are the same (West, 1998). The sand fraction was then sieved to separate the very coarse, coarse, medium, fine, and very fine sand fractions. A glass electrode pH meter method using a 1:1 soil to water ratio was used to determine pH (McLean, 1982).

Cation exchange capacity was determined using the ammonium acetate auto extractor method. The bases determined include Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}. The extract was then analyzed on a Perkin-Elmer Atomic Absorption Spectrophotometer (Thomas, 1982). Total carbon was analyzed using a LECO SC-444 carbon analyzer. This was accomplished by weighing 0.2 to 0.5 grams of each sample into combustion boats and loading into the analyzer (Nelson and Sommers, 1982; NRCS, 1996). Bulk density was determined on selected samples by the saran-coated clod method. The clod was weighed in air to determine mass, and immersed in water to determine volume. Then it was oven-dried and weighed again (Blake and Hartage, 1986).

X-ray diffraction was done using the thin film on glass technique. The clay fraction was separated and placed on glass slides. The slides were then treated in two ways: either saturated with magnesium and ethylene glycol or saturated with potassium chloride. These slides were then x-rayed. The KCl slides were further analyzed by heating to 300 and 550 degrees centigrade and x-raying again (Whittig and Allardice, 1986; NRCS, 1996).

Results and Discussion

Both sites that were described are located on the Rutledge North USGS quadrangle (Fig. 5). The sites are represented by the proposed typical pedon, which is also Site 2 (Fig. 6).

The lab data showed a distinct clay bulge in both pedons indicating advanced pedogenesis (Fig. 7). The potassium chloride extractable aluminum increased dramatically with the clay, as another indicator of advanced pedogenesis. The pH in the soil decreased with depth and was very acid in the subsoil (Table 3). This indicated a parent material that was not very high in basic cations initially.

The redoximorphic features in both sites were recognized as relict and contemporary features. The dark red and red features in the BEt and Bt horizons of Site 1 and the EB and Bt horizons of Site 2 had sharp boundaries. This indicated a past moisture regime with a much higher water table (Vepraskas, 1995). These colors were very high in chroma and indicate highly oxidized iron (hematite). Also Site 1 had three percent plinthite nodules in the BEt and Bt horizons. These relict features are irreversible, regardless of future changes in the moisture regime.

The redoximorphic depletions appeared in the lower parts of both sites (Fig. 8). These features and the accompanying concentrations did not exhibit the sharp boundaries of the upper features. These features were best described as streaks, bands, and masses. In Site 1 the depletions start at the BCt1 horizon. They begin in the Bt2 horizon in Site 2.

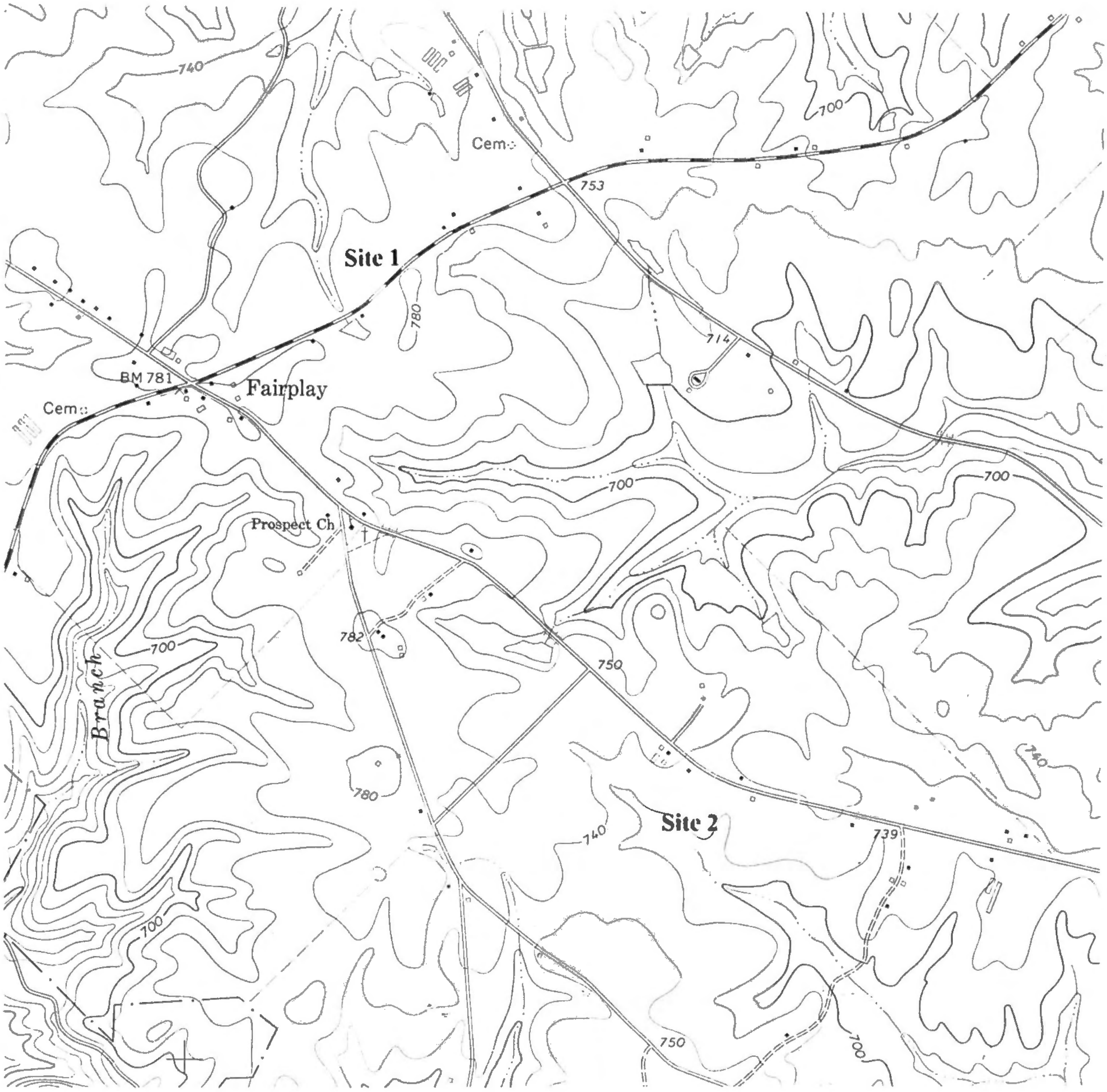


Fig. 5. Section of Rutledge North Quadrangle showing the location of Sites 1 and 2.

Fig. 6. Soil profile of proposed Hard Labor soil series.

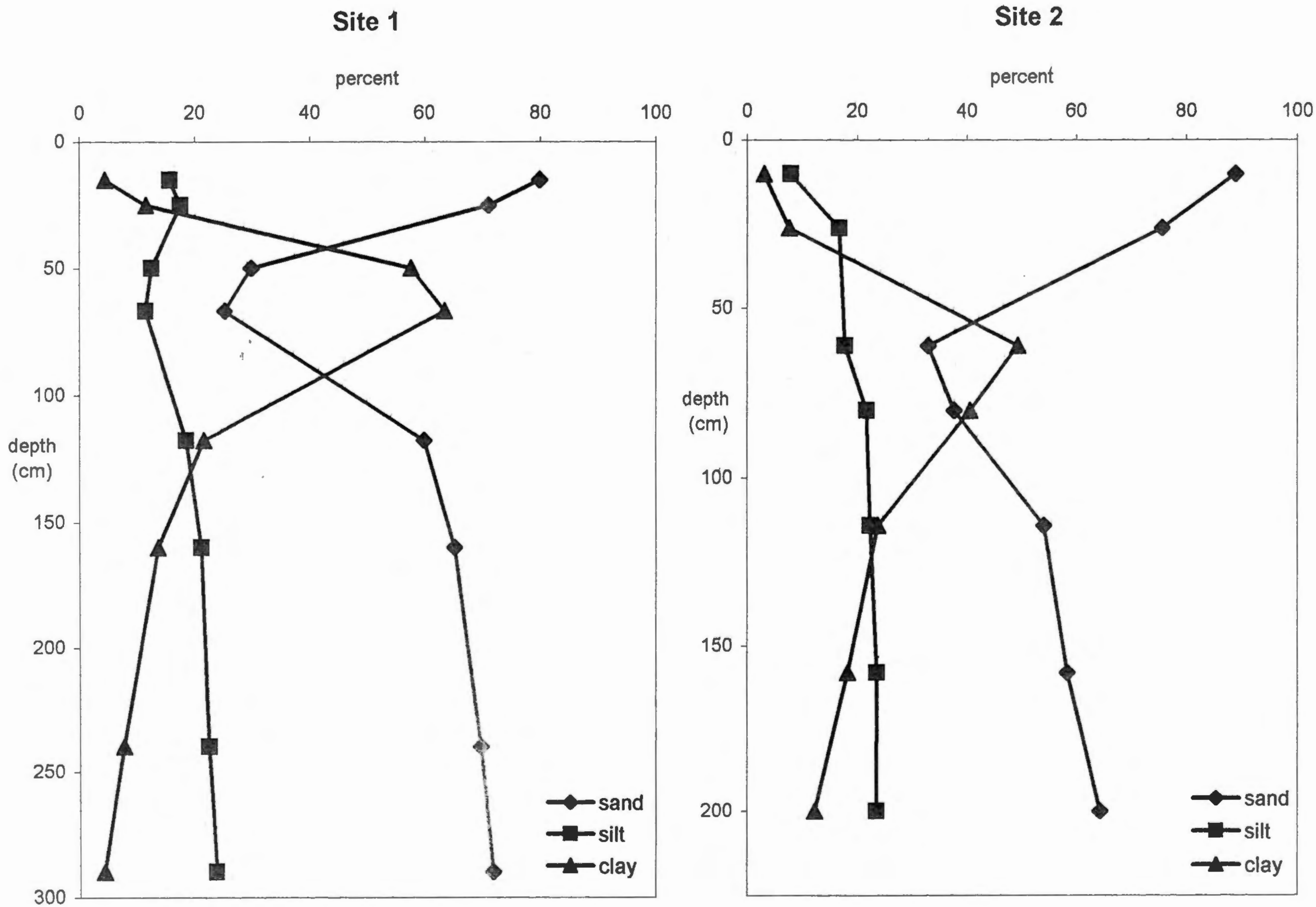


Fig. 7. Particle size distribution of Sites 1 and 2.

Table 3. Laboratory data for Sites 1 and 2 by depth showing texture, percent clay, KCl extractable aluminum, and pH.

Horizon	Depth	Texture	% clay	KCl Al	pH
	cm			cmol/kg	
		Site 1			
Ap	0-15	LS	4.4	0.1	6.0
BEt	15-25	COSL	11.5	0.2	5.6
Bt1	25-50	C	57.6	1.9	4.8
Bt2	50-67	C	63.4	2.5	4.9
BCt1	67-118	SCL	21.6	1.0	4.7
BCt2	118-160	COSL	13.6	2.6	4.6
BC	160-240	FSL	7.7	3.0	4.7
C	240-290	COSL	4.3	2.4	4.8
		Site 2			
Ap	0-10	COS	3.2	0.5	5.4
EB	10-26	COSL	7.7	0.4	5.7
Bt1	26-61	C	49.3	0.4	5.7
Bt2	61-80	C	40.6	2.5	5.3
BCt	80-114	SCL	23.7	3.1	4.9
CB	114-158	FSL	18.2	4.1	4.8
C	158-200	FSL	12.3	2.4	4.5

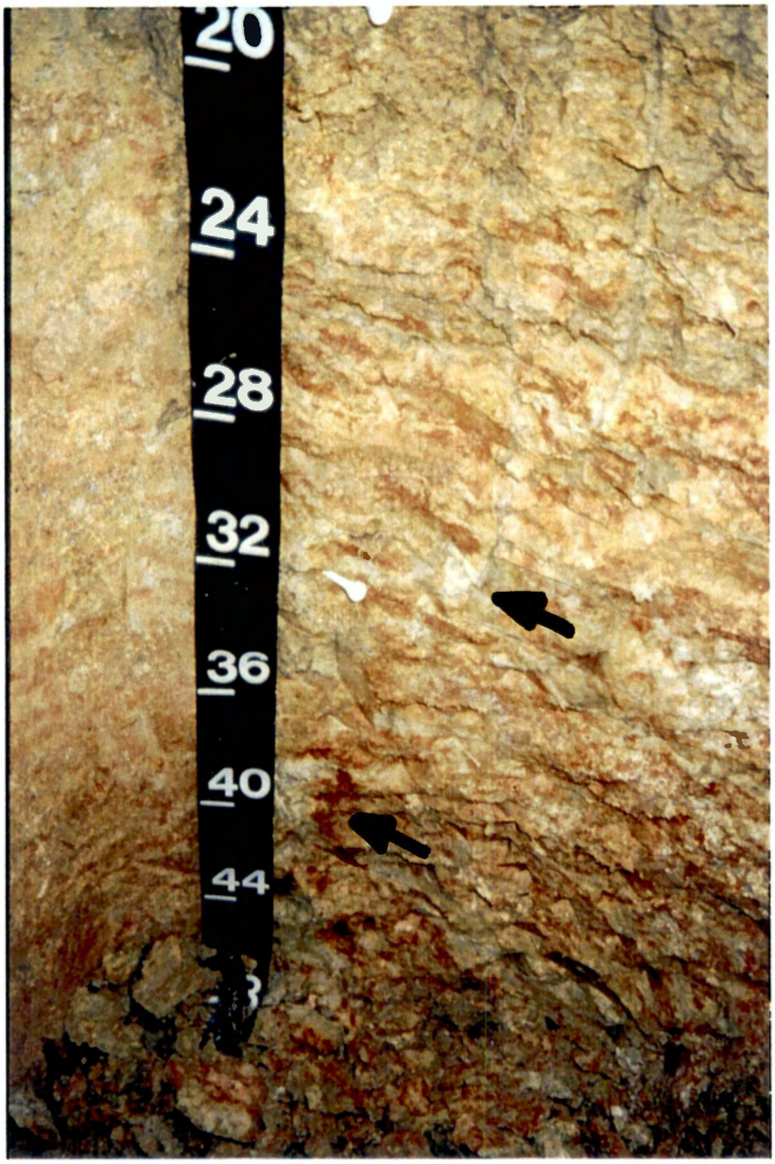
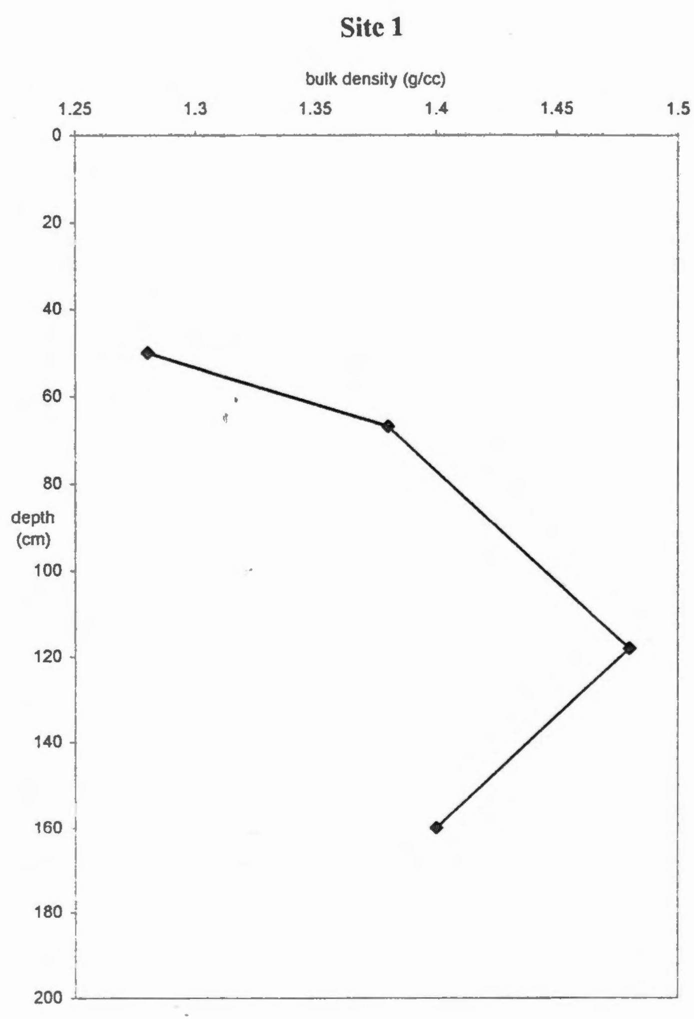


Fig. 8. Redoximorphic features in the Hard Labor soil.

Bulk density was determined for all horizons below the Ap in both sites except for the BC and C horizons of Site 1. This part of the pedon was sampled by hand augering into the bottom of the pit therefore no bulk density clods were obtained. Site 1 bulk density shows a bulge increasing to 1.48 g/cc at 118 cm, then decreasing again as depth increases (Fig. 9). This depth corresponds with the BCt1 horizon. The texture of this horizon is sandy clay loam with weak medium platy structure parting to weak fine subangular blocky (Table 4). This increase in bulk density is the result of pores being blocked by clay particles illuviated from the horizons above. Redoximorphic depletions (2.5Y 7/2) in this site also correspond with the increase in bulk density.

The bulk density in Site 2 does not show a bulge with depth, but indicates a plateau from 80 to 150 cm with the bulk density measuring 1.47 to 1.45 g/cc (Fig. 9). After this point the measurements decrease to the bottom of the pit. This plateau in bulk density can be attributed to the same cause as in Site 1. These depths correspond to the BCt and CB horizons. These horizons have textures of sandy clay loam and fine sandy loam, respectively. The structure in the BCt horizon is moderate very thick platy (Table 4). Massive and weak very thick platy structure are described in the CB horizon. Redox depletions also occur concurrently with the plateau in bulk density.

The percent organic carbon in the sites follows a normal curve, high in the surface then decreasing gradually through the pedon. However, Site 1 shows a slight bulge in organic carbon in the subsoil (Fig. 10). The bulge in Site 1 occurs at 150 cm. This is in the BCt2 horizon. This possibly indicates wetness in this horizon. Site 2 has a slight plateau in the organic carbon from 30 cm to 70 cm (Fig. 10). Then the carbon falls off drastically. This plateau occurs in the Bt1 and Bt2 horizons. This could be a function of



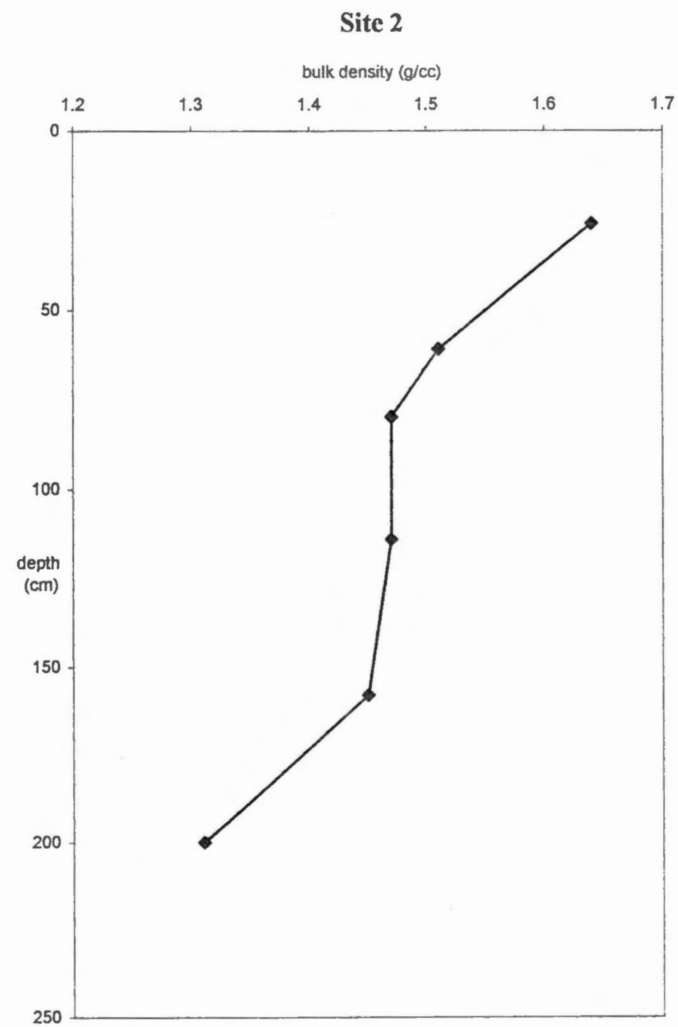


Fig. 9. Bulk density vs. depth for Sites 1 and 2.

Table 4. Soil morphology of Sites 1 and 2.

Horizon	Depth	Structure†	Redox features‡
	cm		
		Site 1	
Ap	0-15	1fmgr & 1fmsbk	--
BEt	15-25	1msbk	c2p 2.5YR 4/6
Bt1	25-50	3tkpl to 2msbk,abk	c2p 2.5YR 4/6
Bt2	50-67	2mpl to 1fsbk	c23p 10R 4/3 &10R 4/6
BCt1	67-118	1mpl & 1fsbk	m23d 10R 4/6, c1p10YR 8/1 & 2.5Y 7/2
BCt2	118-160	1co&msbk	c1d 2.5YR3/4 & m2d 10YR 8/1
BC	160-240	1cosbk	c2p 5YR 7/2
C	240-290	ma	f12p 10R 4/6
		Site 2	
Ap	0-10	2fgr	--
EB	10-26	1msbk	f1p 7.5YR 3/2
Bt1	26-61	2copr to 3mpl	m3d 2.5Y 6/6 & m2p 2.5YR 4/6
Bt2	61-80	2mtkpl	m2p 2.5YR 4/6 & c2p 2.5Y 7/2
BCt	80-114	2vtkpl	m23p 2.5YR4/6 & 2.5YR 7/2,c2p 2.5Y 6/2
CB	114-158	1vtkpl & ma	m2p 2.5YR 4/6 & c2d 2.5Y 6/6
C	158-200	ma	c2p 2.5YR 4/6, c2p 2.5Y 6/6 &5YR 4/6

† Grade: 1 = weak, 2 = moderate, 3 = strong; size: f = fine, m = medium, co = coarse, tk = thick, vtk = very thick; kind: gr = granular, sbk = subangular blocky, abk = angular blocky, pr = prismatic, pl = platy, ma = massive.

‡ Abundance: f = few, c = common, m = many; size: 1 = fine, 2 = medium, 3 = coarse; contrast: d = distinct, p = prominent.

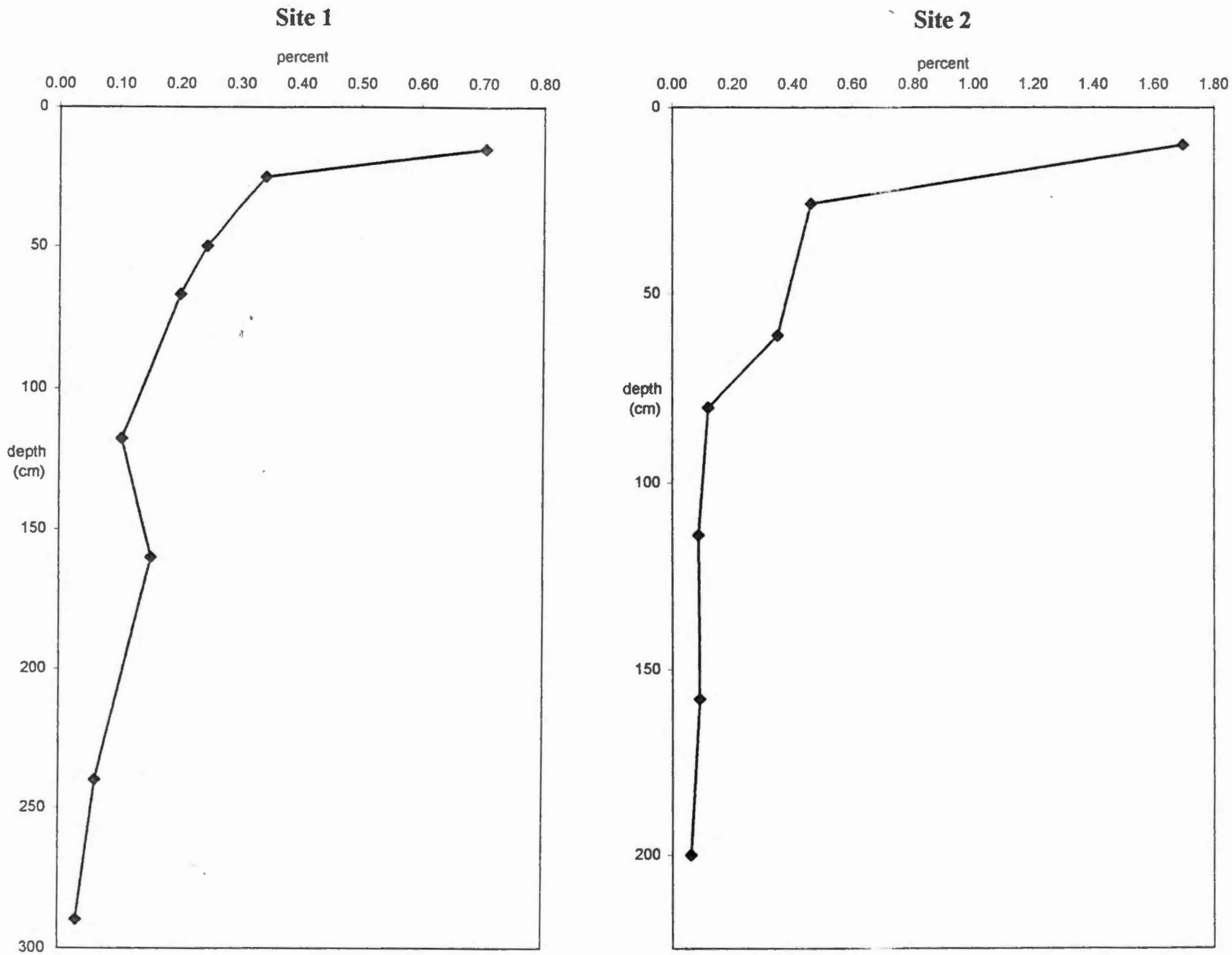


Fig. 10. Organic carbon percentage for Sites 1 and 2.

well developed structure in these horizons, which allows some carbon from the surface to be illuviated, or from surface creep from past agricultural activities.

Clay-free particle size was calculated to check for indications of a lithologic discontinuity. The clay-free graph of Site 1 shows a silt bulge at 60 cm (Fig. 11). The silt decreases with depth and does not show any more changes in the pedon. This increase in silt percentage occurs approximately at the top of the Bt2 horizon and this may indicate advanced degradation of the coarser grains in the parent material. The clay-free sand fraction of this site shows the medium and fine sand predominating in the very top of the pedon, then decreasing dramatically to a depth of 25 cm (Fig. 12). From there the fractions show no identifiable pattern until 200 cm. At this depth the fine sand increases to become the dominant fraction while the coarse and very coarse sand decrease. At 250 cm this trend is reversed, with fine and very fine sand decreasing to the bottom of the pit, and coarse and very coarse sand increasing to the base of the sampled profile.

The clay-free graph of Site 2 shows the same trends as Site 1 except the increase in silt percentage occurs lower in the profile at approximately 70 cm (Fig. 13). This again occurs in the Bt2 horizon and possibly is caused from higher degradation of the coarse parent material grains. The clay-free sand fractions show a dramatic reversal of fine and very fine sand at 15 cm with very fine sand increasing to a high at 26 cm (Fig. 14). The very fine sand drops in percentage then shows another small bulge at 80 cm. This bulge coincides with the beginning of the BC horizon, which has many mica flakes. The fine sand then rebounds and becomes the predominant sand fraction at 114 cm. This depth coincides with the start of the CB horizon, which also has many mica flakes.

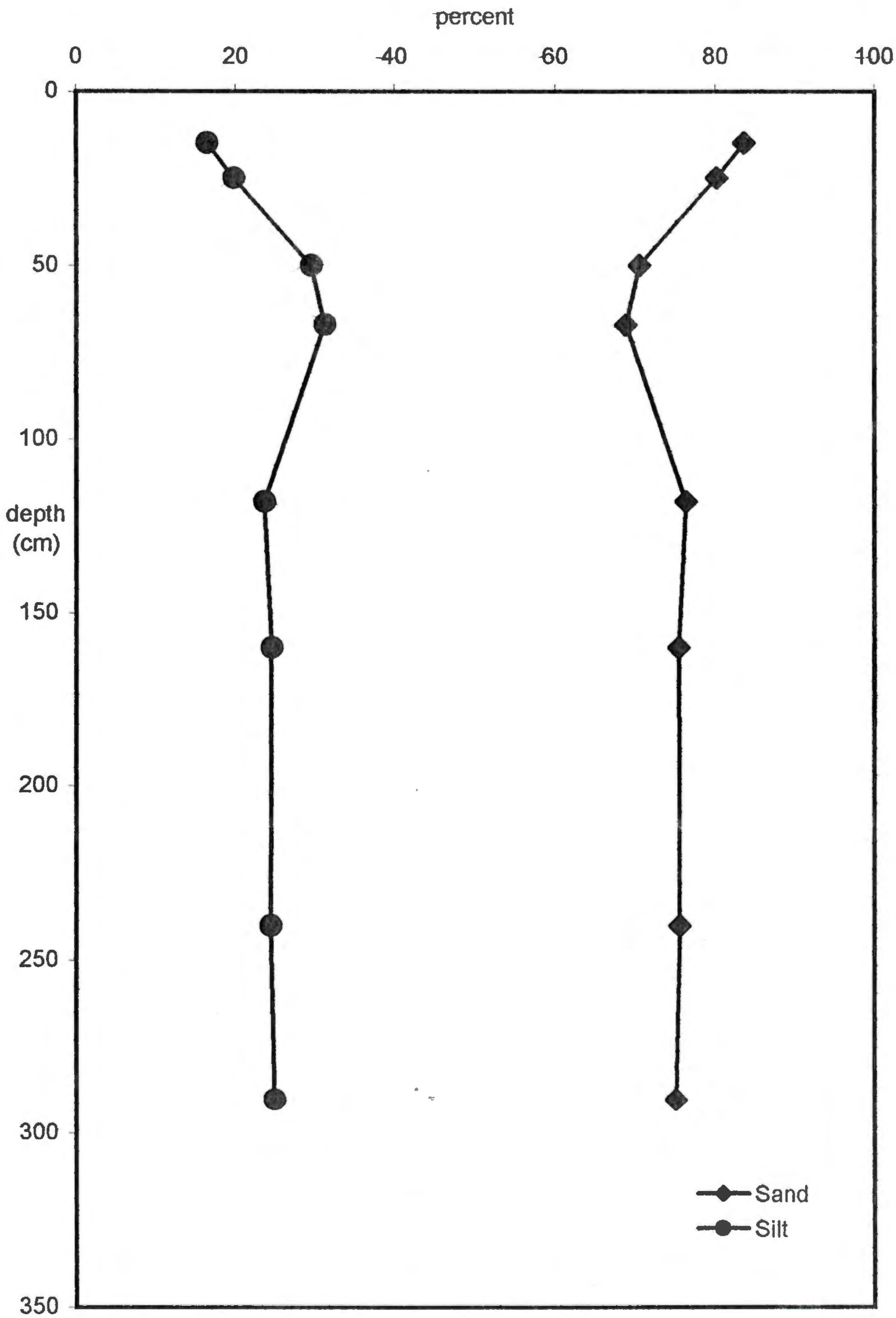


Fig. 11. Clay-free particle size distribution – Site 1.

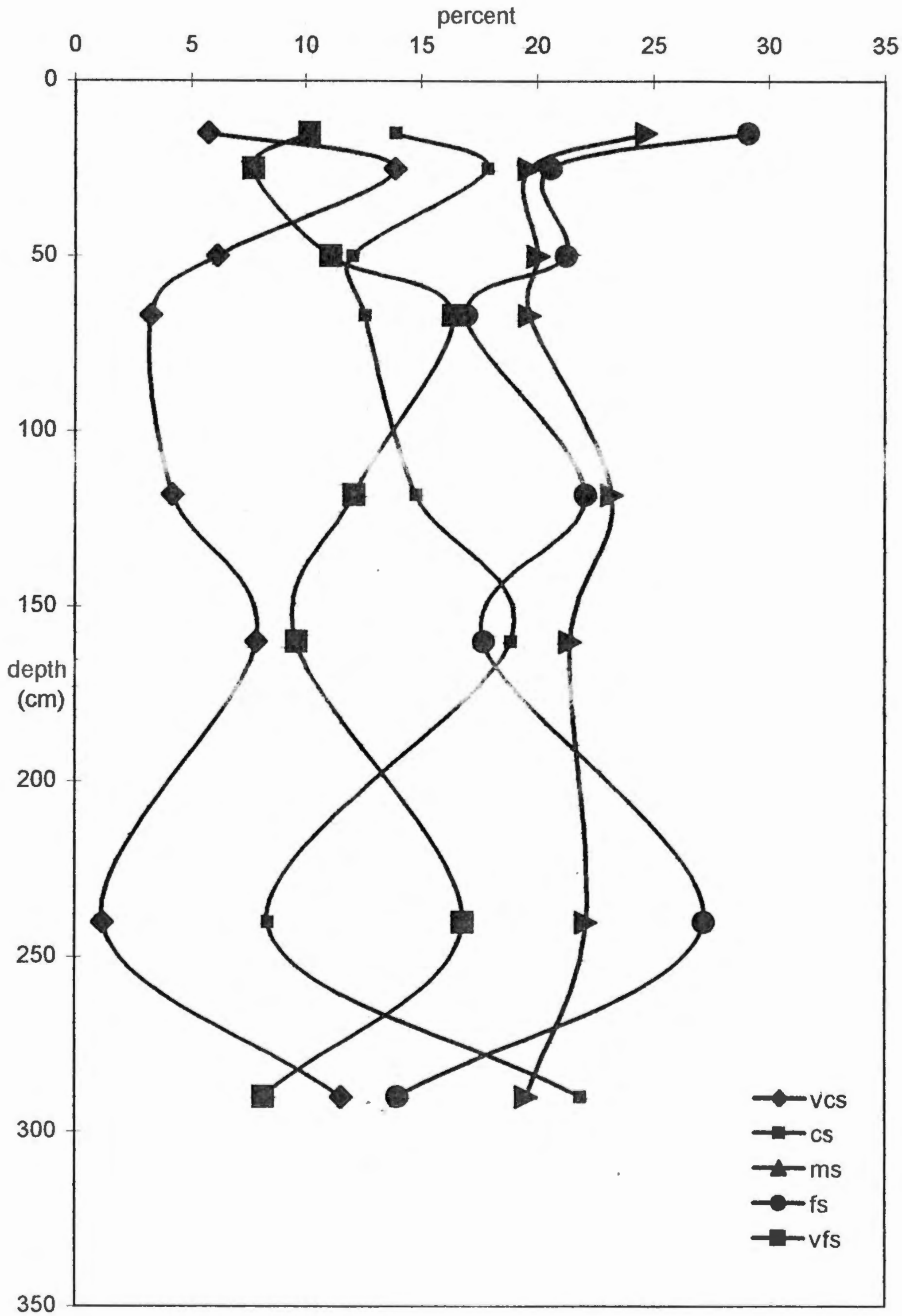


Fig. 12. Clay-free sand distribution – Site 1.

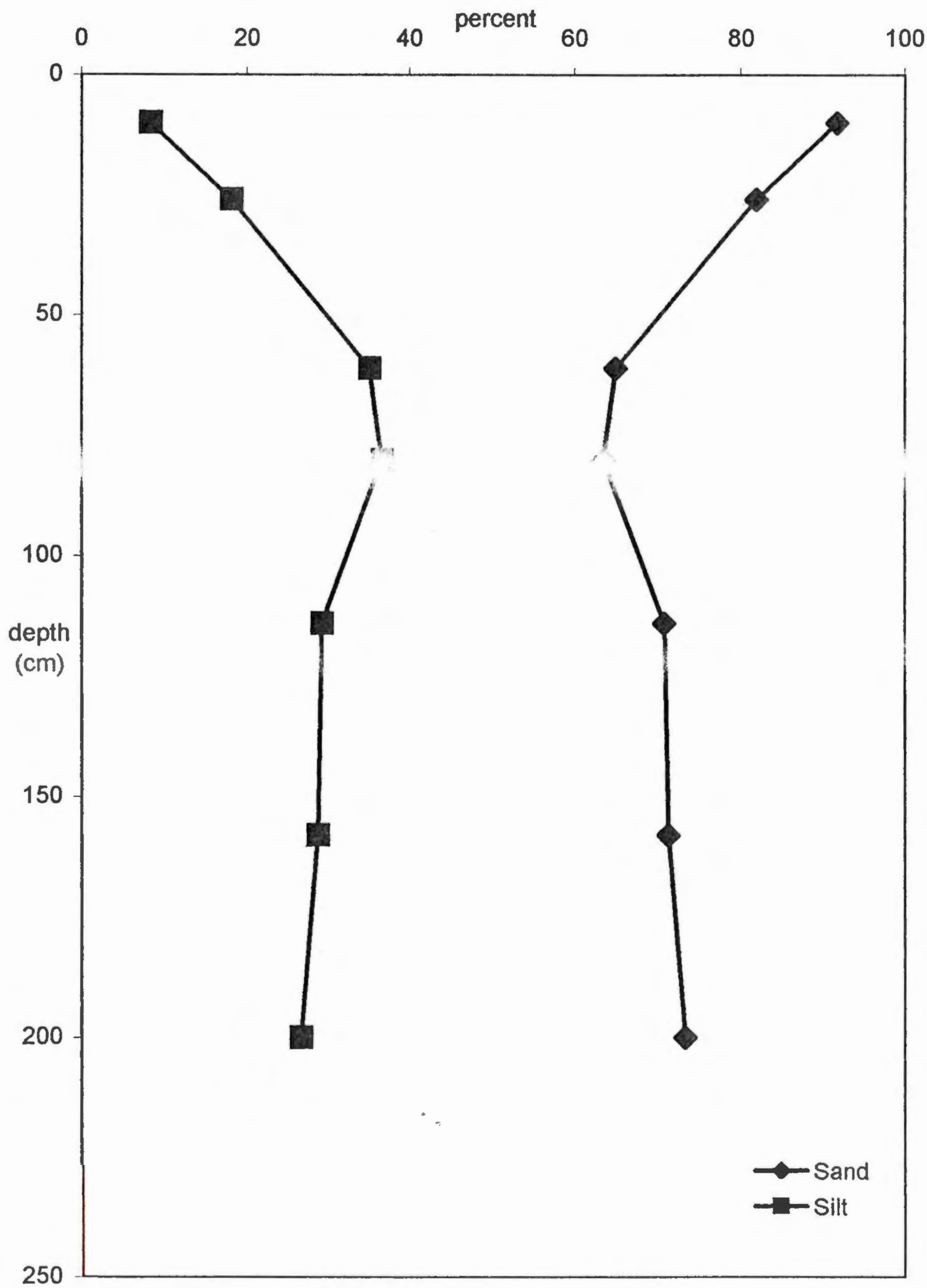


Fig. 13. Clay-free particle size distribution – Site 2.

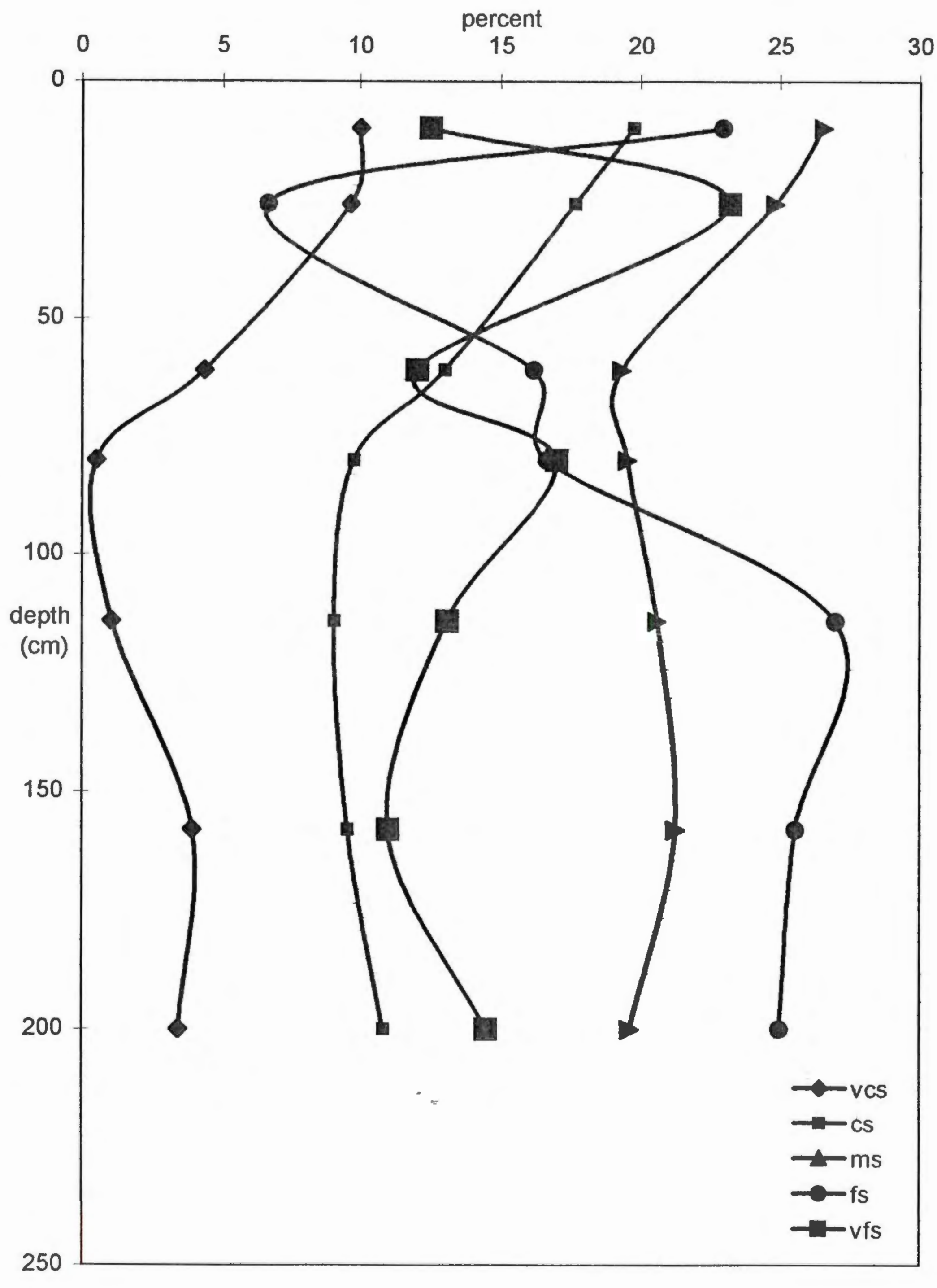


Fig. 14. Clay-free sand distribution – Site 2.

X-ray diffraction

X-ray diffraction was completed on four samples from each site using magnesium and ethylene glycol, potassium chloride (KCl), KCl heated to 300 degrees centigrade and KCl heated to 550 degrees centigrade. Using the patterns generated from these treatments, the kind and amount of clay minerals were determined (University of Georgia, 1998). The Ap, Bt1, BCt, and C horizons were evaluated.

Kaolinite was the dominant mineral in all of the samples. It appeared as a large, sharp peak at 7.2 angstroms and 3.6 angstroms. This peak remained strong with all of the treatments but was destroyed by heating to 550 degrees centigrade.

The other dominating mineral was quartz. The first order peak was sharp at 3.3 angstroms with a smaller second order peak at 4.2 angstroms. Quartz was not affected by any of the treatments.

Other peaks of interest that appeared were small peaks around 14 to 15 angstroms that were probably hydroxy-interlayered vermiculite (HIV). This peak became fairly distinct at 10 angstroms with heat treatment to 300 degrees. There was a small illite peak at 10 angstroms, and gibbsite (4.8 angstroms) appeared in the upper horizons. There was also a low angle shoulder on the 14 angstrom peaks that indicated that there was a minor expandable component. The expandable minerals became a larger component in the lower horizons, as the 14 angstrom peak was less distinct. This increase was also reflected in the CEC/clay ratio, indicating higher clay activity. The 4.8 angstrom gibbsite peak decreased into the lower horizons. Goethite was also present in each horizon in small amounts. This was confirmed by the disintegration of the 4.1 angstrom peak with heat treatment. (West, 1998).

In Site 1 the quartz peak was large in the Ap horizon then decreased from the Ap to the Bt1 horizon (Fig. 15). The HIV-vermiculite peak at 14 angstroms also decreased. Illite showed up at 10 angstroms in the Ap and was missing or very small in the Bt1. The goethite peak at 4.1 angstroms became broader and flatter. A shoulder also appeared on the HIV-vermiculite peak in the Bt1 horizon. Moving from the Bt1 to the BCt1, the shoulder became more apparent at 14A. A small illite peak became visible again in the BCt1. Goethite became even broader and flatter. The pattern remained relatively constant from the BCt1 to the C, which indicated a relatively stable weathering environment.

In Site 2 quartz decreased dramatically from the Ap to the Bt1 (Fig. 16). The HIV-vermiculite peak remained small but constant. The Ap had a small broad gibbsite peak that became a bit sharper in the Bt horizon. Goethite decreased from medium to small and became broader. The gibbsite peak disappeared when moving from the Bt1 to the BCt horizon. Goethite became broader and less distinct. Quartz again decreased in size. As in Site 1 the peaks remained relatively constant from the BCt to the C horizon.

When looking at the changes in clay minerals with the different potassium chloride (KCl) treatments, the distinction of the minerals became clearer (Figs. 17 & 18). Kaolinite disintegrated at around 530 degrees centigrade. Quartz remained constant. The expandable minerals, such as hydroxy-interlayered vermiculite and vermiculite, moved from a 14 angstrom spacing to a 10 angstrom spacing (Moore and Reynolds, 1989; NRCS, 1996). Gibbsite was destroyed at 300 degrees centigrade. All of these trends were shown by the KCl treatment plots for each horizon that was scanned which indicated an expandable component in these samples.

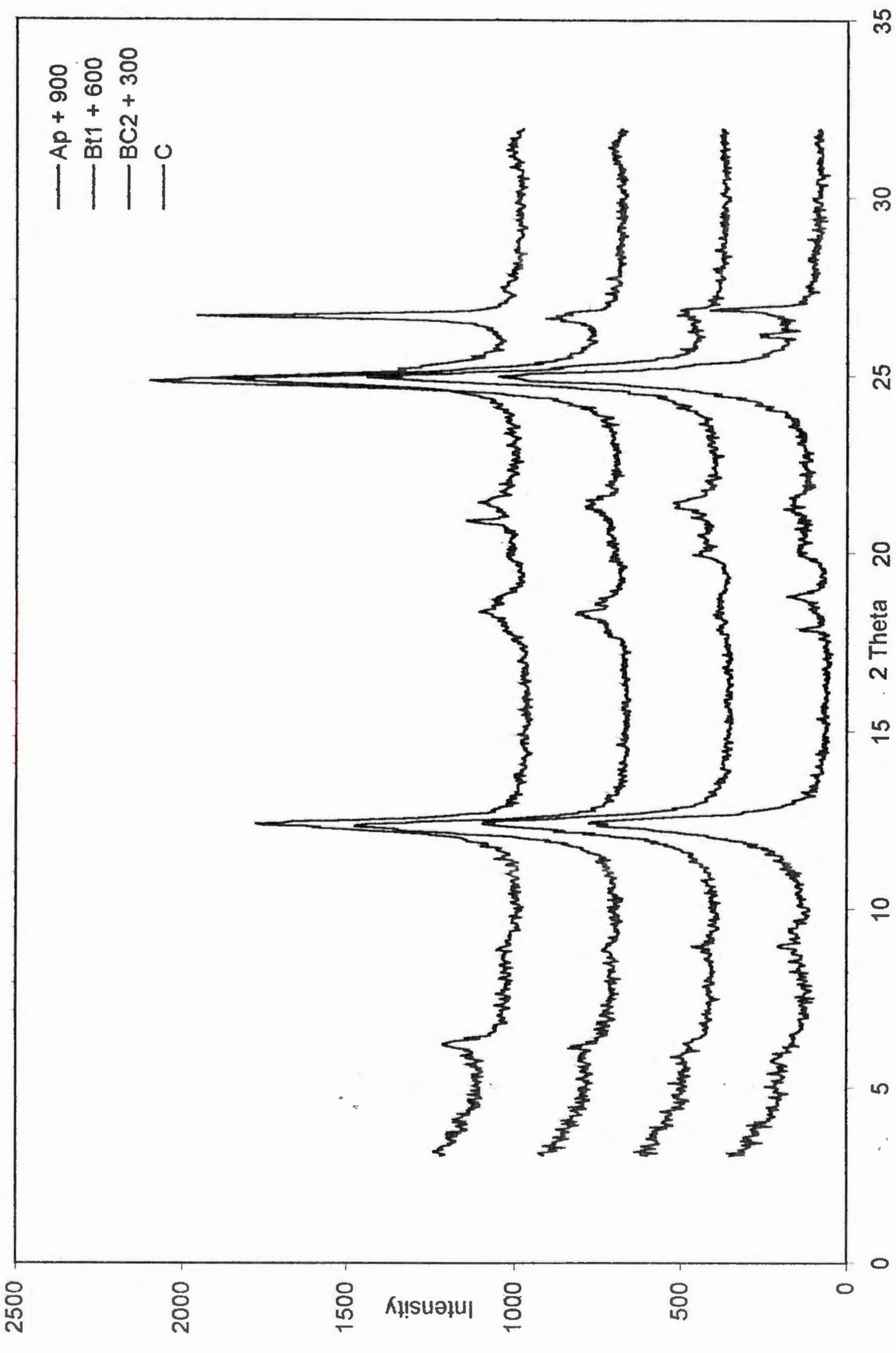


Fig. 15. Site 1 – Xray diffraction pattern with magnesium glycolation.

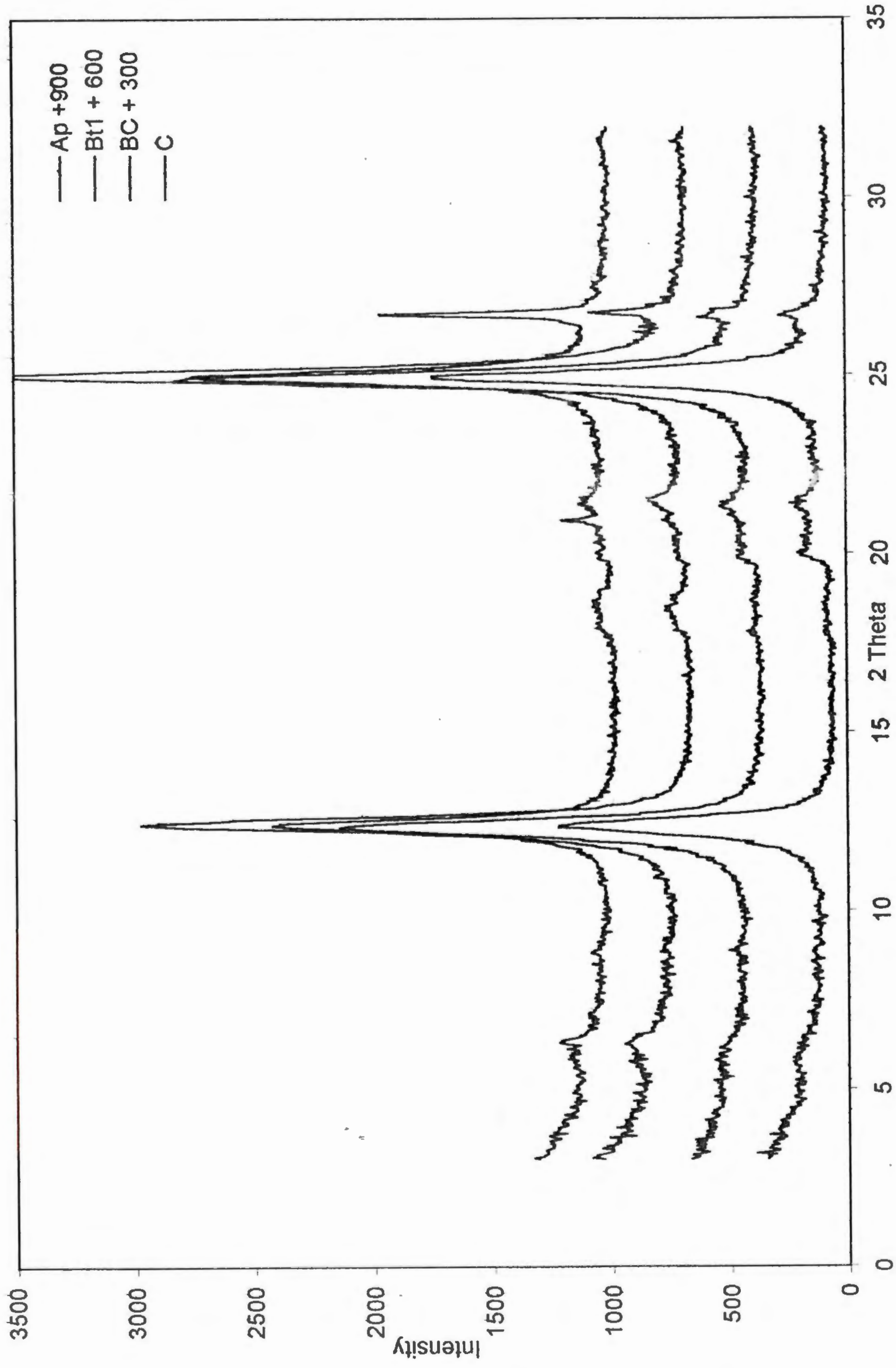


Fig. 16. Site 2 – Xray diffraction pattern with magnesium glycolation.

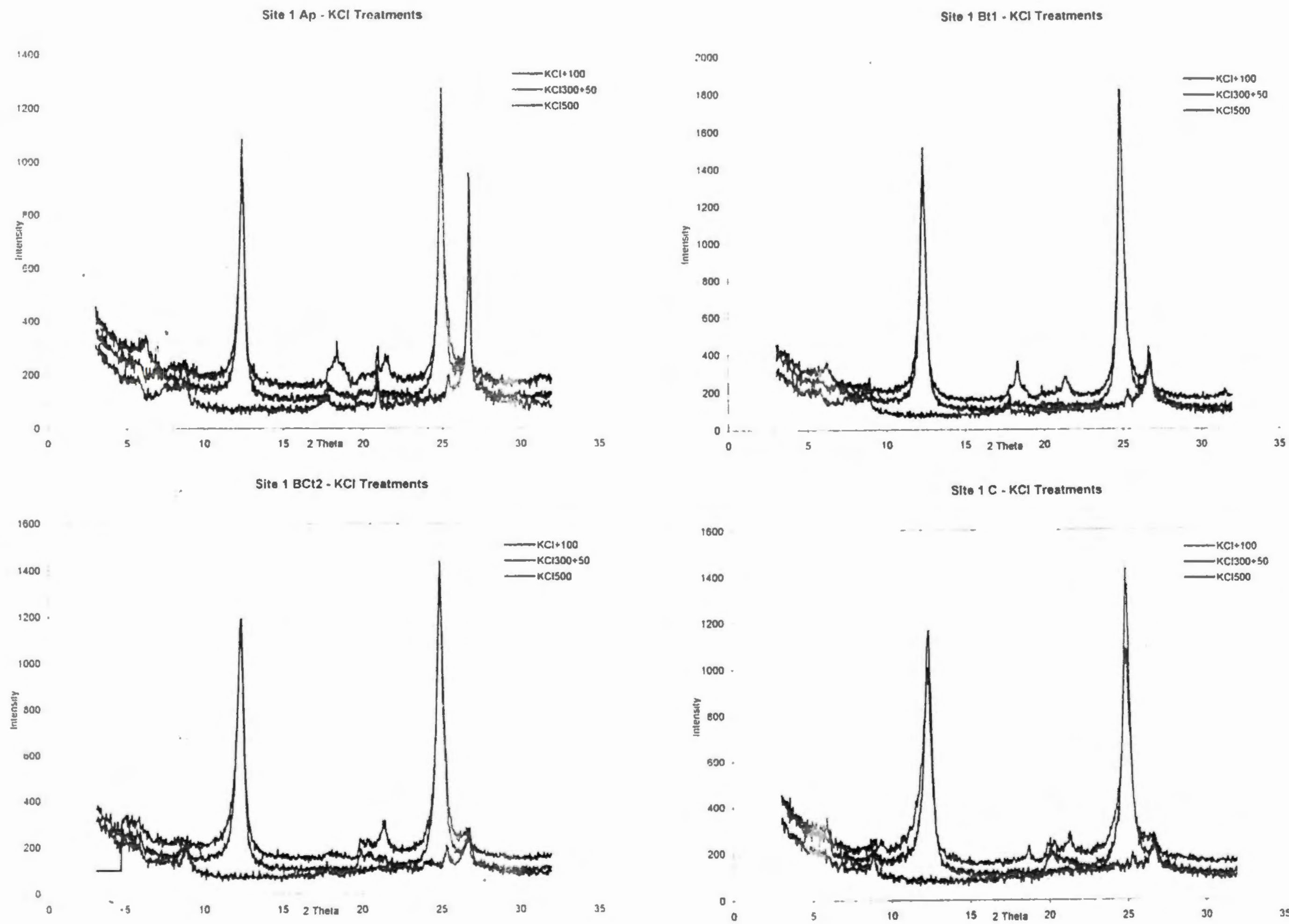


Fig. 17. Site 1 – Xray diffraction patterns for each sample showing the three potassium chloride treatments.

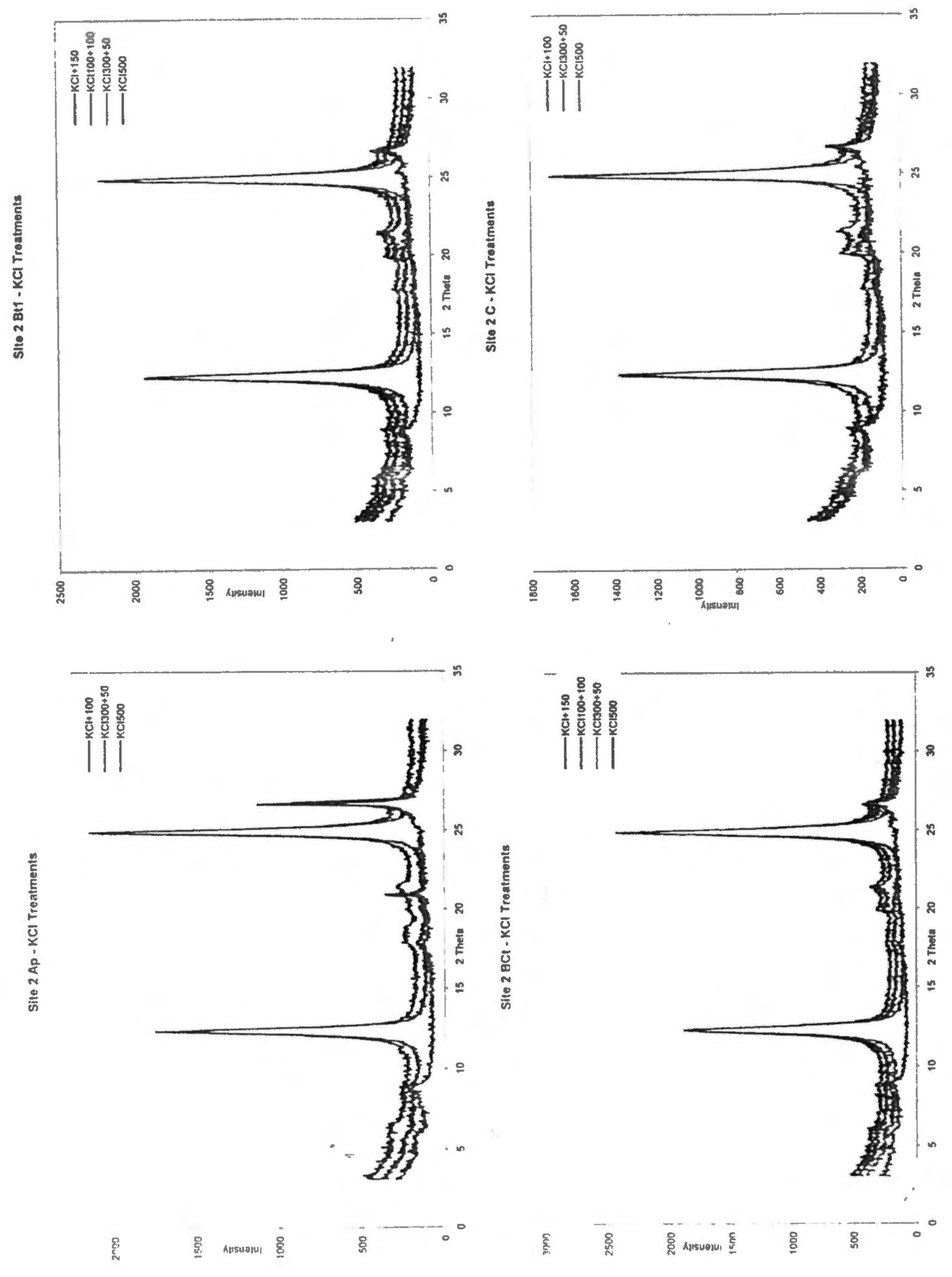


Fig. 18. Site 2 – Xray diffraction patterns for each sample showing the three potassium chloride treatments.

Classification of the sites

Both Site 1 and Site 2 were located in a broad flat upland summit with a slightly convex surface. The slope of the sites was 4 percent for Site 1 and 3 percent for Site 2. The parent material for the sites was a coarse grained acid metamorphic rock. Both sites were in the udic moisture regime and thermic temperature regime. Neither site used the cation exchange capacity activity class because they were classified as kanhap great groups.

Site 1 was classified as fine, kaolinitic, thermic Oxyaquic Kanhapludults. The base saturation at 125 cm below the top of the argillic was 14 percent (Table 5). It was oxyaquic because the site did not meet aquic conditions in most years, but did have redoximorphic depletions starting at 67 cm. Epipedon and diagnostic horizons found were ochric, argillic, and kandic. It met the required increase in clay for an argillic horizon starting at 15 cm. The site also met the requirements for a kandic diagnostic horizon by having CEC and ECEC of below 16 and 12, respectively. These conditions existed throughout the site. The family particle size class was fine with an average of 48 percent clay. An abrupt textural change existed between the Ap and BEt horizons. Mineralogy was kaolinitic by results of x-ray diffraction analysis.

Site 2 was also classified as fine, kaolinitic, thermic Oxyaquic Kanhapludults. The base saturation was 18 percent at 125 cm below the top of the argillic (Table 5). Again it was oxyaquic with redoximorphic depletions beginning at 61 cm. An ochric epipedon existed, along with argillic and kandic diagnostic horizons. The argillic horizon did not begin until 26 cm even though the increase in clay is met in the EB horizon

Table 5. Laboratory data for Sites 1 and 2 showing percent base saturation, CEC, and ECEC.

Horizon	Depth	% bs	CEC	ECEC
	cm		cmol/kg	cmol/kg
		Site 1		
Ap	0-15	76	1.7	1.4
BEt	15-25	71	1.4	1.2
Bt1	25-50	33	8.7	4.8
Bt2	50-67	30	7	4.6
BCt1	67-118	30	2	1.6
BCt2	118-160	14	3.5	3.1
BC	160-240	11	3.7	3.4
C	240-290	3	3	2.5
		Site 2		
Ap	0-10	51	3.9	2.5
EB	10-26	48	4.6	2.6
Bt1	26-61	75	5.9	4.8
Bt2	61-80	31	5.8	4.3
BCt	80-114	19	5.2	4.1
CB	114-158	18	6.5	5.3
C	158-200	18	4.9	3.3

above. This is because the horizon from 10 to 26 cm was called EB; therefore, the eluvial condition dominated. The family particle size class was fine, with 46 percent clay. There was an abrupt textural change between the Ap and EB horizons. The mineralogy again was kaolinitic.

Conclusions

1. Classification of the sites was:

    Site 1: fine, kaolinitic, thermic Oxyaquic Kanhapludult

    Site 2: fine, kaolinitic, thermic Oxyaquic Kanhapludult

2. High bulk density, platy structure, and formation of redoximorphic features can be correlated in the BC horizons. Bulk density did not decrease with clay content in this zone. Instead bulk density increased, as in Site 1, or plateaued, as in Site 2, before decreasing into the C horizons. The structure in both sites in the BC contained a platy component that retards permeability further and allows the depletions to form.
3. Kaolinite was the dominant mineralogy in both sites; however, an expandable component in the form of vermiculite or hydroxy-interlayered vermiculite existed in small amounts in the BCt and C horizons.

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Part 3.

Saturated Hydraulic Conductivity and Permeability

of Five Hard Labor Sites (fine, kaolinitic, thermic Oxyaquic Kanhapludults)

in Morgan County, Georgia

Introduction

Saturated hydraulic conductivity is a good measure of the permeability of a particular horizon. When several measurements are taken with depth through a profile, the rate of water movement through that soil can be predicted. Horizons that impede the flow of water are also recognized.

The proposed Hard Labor soil series has features that indicate slow hydraulic conductivity through the BC and C horizons. These features include platy structure, higher bulk densities, and redoximorphic features (see Part 1 of this thesis).

The objective of this chapter was to determine the saturated hydraulic conductivity of the redoximorphic zones of the proposed Hard Labor soil series and how these features are related to field soil morphology.

Literature Review

Saturated Hydraulic Conductivity

The saturated hydraulic conductivity (K_{sat}) of a soil is the measurement of the amount of water that will move through a certain amount of saturated soil under a hydraulic gradient in a certain amount of time (Soil Survey Staff, 1993b). Hydrologic properties of a soil horizon are dominantly influenced by structure and texture (Nimmo, 1997). Many soil properties are combined and inferred by K_{sat}, including soil structure, texture, porosity, bulk density, and clay mineralogy (Schoeneberger et al., 1995). It is very important in determining suitability for waste disposal (Vepraskas et al., 1996). Schoeneberger et al. (1995) found that saturated hydraulic conductivity, water retention, and bulk density of a Typic Kanhapludult (Cecil series) changed rapidly and unpredictably across the Piedmont landscape. Figure 19 shows the relationship of K_{sat} as a function of bulk density and texture (Soil Survey Staff, 1993b). These drastic soil property changes are due to macropores in various orientations within the soil. In

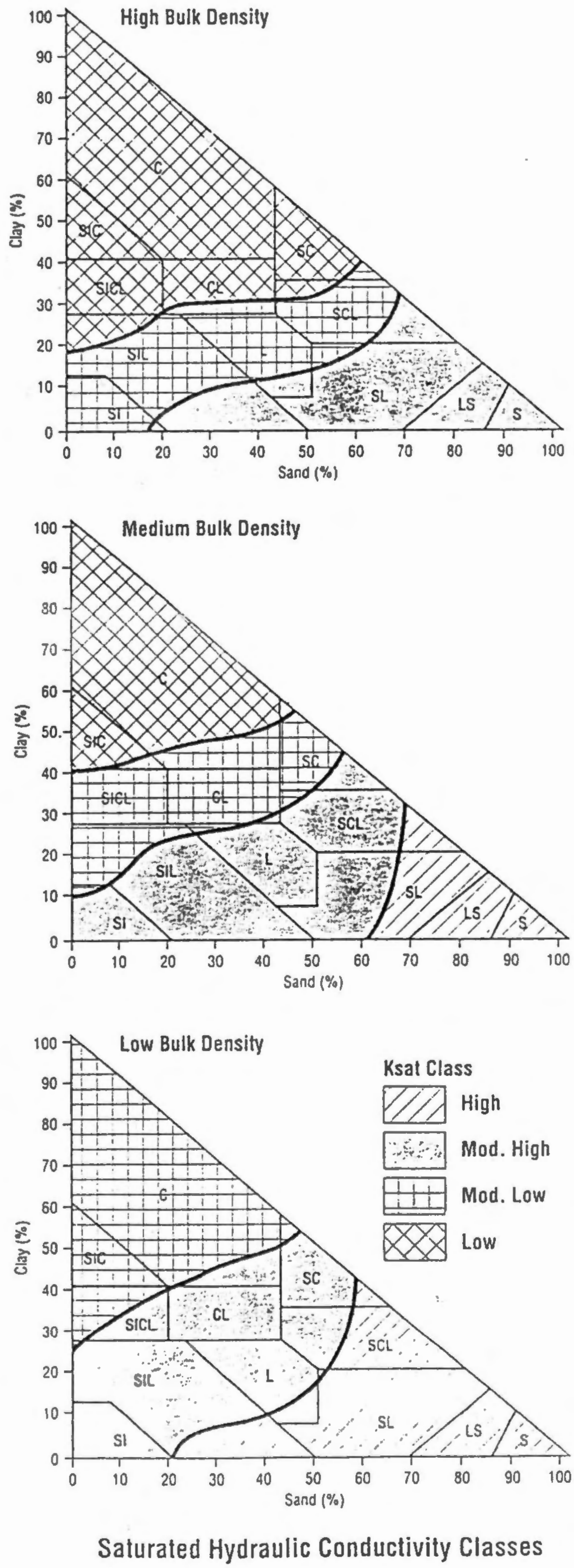

Fig. 19. Saturated hydraulic conductivity as a function of bulk density and texture.

transitional horizons, such as the BC, many of the smaller pores are blocked with illuviated clay particles (Vepraskas et al., 1996).

O'Brien and Buol (1984) found in studying the soil-saprolite sequence of the Pacolet series (fine, kaolinitic, thermic Typic Hapludults) that the saprolite had a significantly lower saturated hydraulic conductivity than the overlying Bt horizon. The K_{sat} in this zone decreases from 2.2 μm/s to 1.1μm/s. Differences in structure between the Bt and saprolite are also reflected in the saturated hydraulic conductivity. Lateral flow can also occur at these contacts. This reduced flow and perching of water occurs mainly after a rain that saturates the soil.

Vepraskas et al. (1991) studied the effects of shear and foliation planes in saprolite on the conductivity of transitional zones in soil. These planes are often found in the gneiss saprolite that is typical of the Piedmont. They are caused by bands of quartz or by muscovite. The results of the study showed that soil water flowed primarily through the mica veins and not the quartz. The quartz veins often were tightly packed and contained iron and manganese oxides in the interparticle space. Soil water also moved along macropores and channels. These channels did not increase the K_{sat} appreciably; therefore it was concluded that they were partially or completely blocked by clay or iron and manganese oxides.

Vepraskas et al. (1996) followed up the earlier research in soil/saprolite conductivity by studying the porosity of these zones. They found that the transition zone had less inter/intraparticle pores than the zones both above and below. The Bt horizon above the transition usually had medium, subangular blocky structure. In the transition zone, the clay percentage began to decrease and the structure became weaker. In addition to having fewer pores and intraparticle spaces, plugging with clay and iron oxides occurred (Vepraskas et al., 1991). As the texture and structure gradually changed to rock-controlled, the amount of plugged pores decreased, and the K_{sat} increased in this zone.

Saturated hydraulic conductivity changes can be correlated with horizon changes. The K_{sat} was highest in the clayey Bt horizons, decreased into the BC and increased into the upper part of the saprolite (Schoeneberger et al., 1995). Many times the lowest K_{sat} value for a soil will be in the soil-saprolite transition zone (BC horizon). Location of this slowly permeable layer is accomplished best by in-situ K_{sat} measurements (Vepraskas et al., 1996).

Materials and Methods

Saturated Hydraulic Conductivity Measurements

Saturated hydraulic conductivity was measured in duplicate at each site using the constant-head well permeameter technique (Amoozegar, 1989a). This measurement was accomplished using the Compact Constant Head Permeameter (CCHP), also called an "Amoozemeter" (Fig. 20). Figure 21 shows the configuration of the CCHP (Amoozegar, 1992). An 8-cm diameter auger hole was bored to approximately the middle of the horizon of interest. A 20-cm head of water was maintained in the hole and the outflow was measured.

At each site measurements were taken in three zones: above the gray (chroma ≤ 2) colors, in the gray colors, and in the lower BC or C horizon where the clay content significantly decreased. These depths varied with the morphology of the site. The "above gray" measurement was taken at least 10 cm above the horizon boundary containing gray redoximorphic features. The "in gray" measurement was taken at least 10 cm above a noticeable decrease in clay content and weakening of the structure, which indicated a transitional zone or saprolite. The lower BC/C measurement was taken at least 20 cm below the noticeable texture or structure decrease.

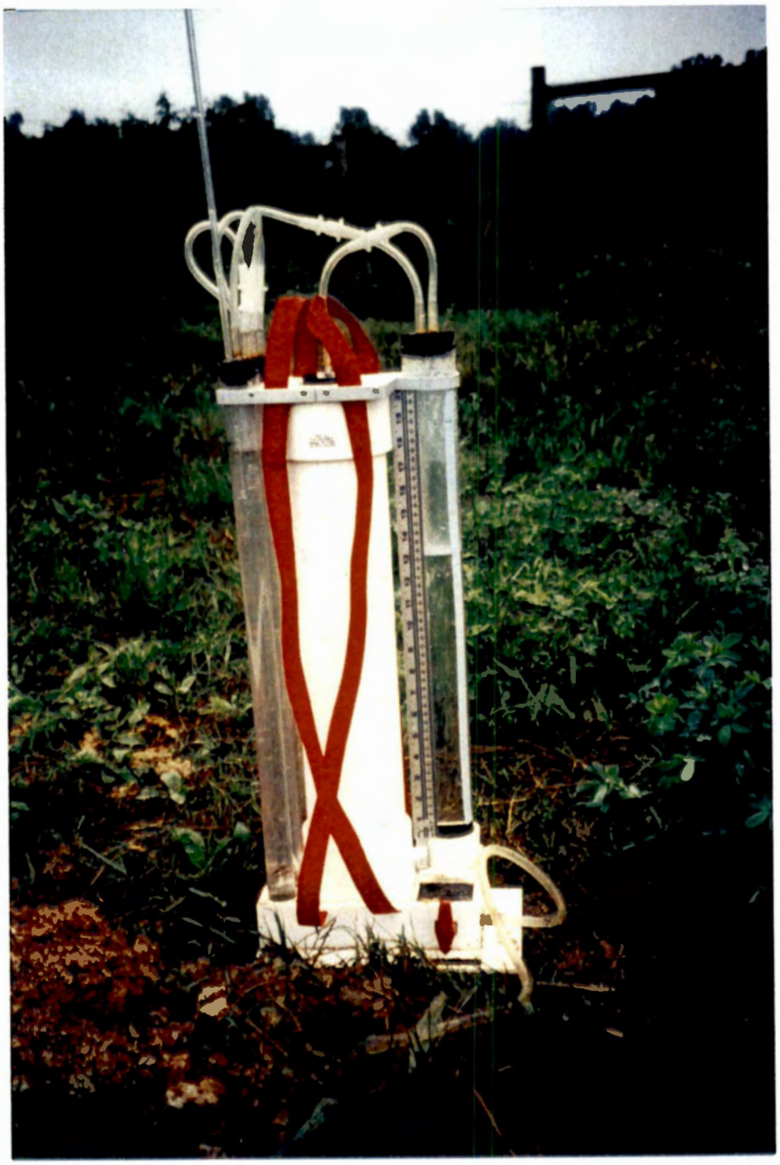

Fig. 20. Compact Constant Head Permeameter (Amoozemeter) at Site 1A.

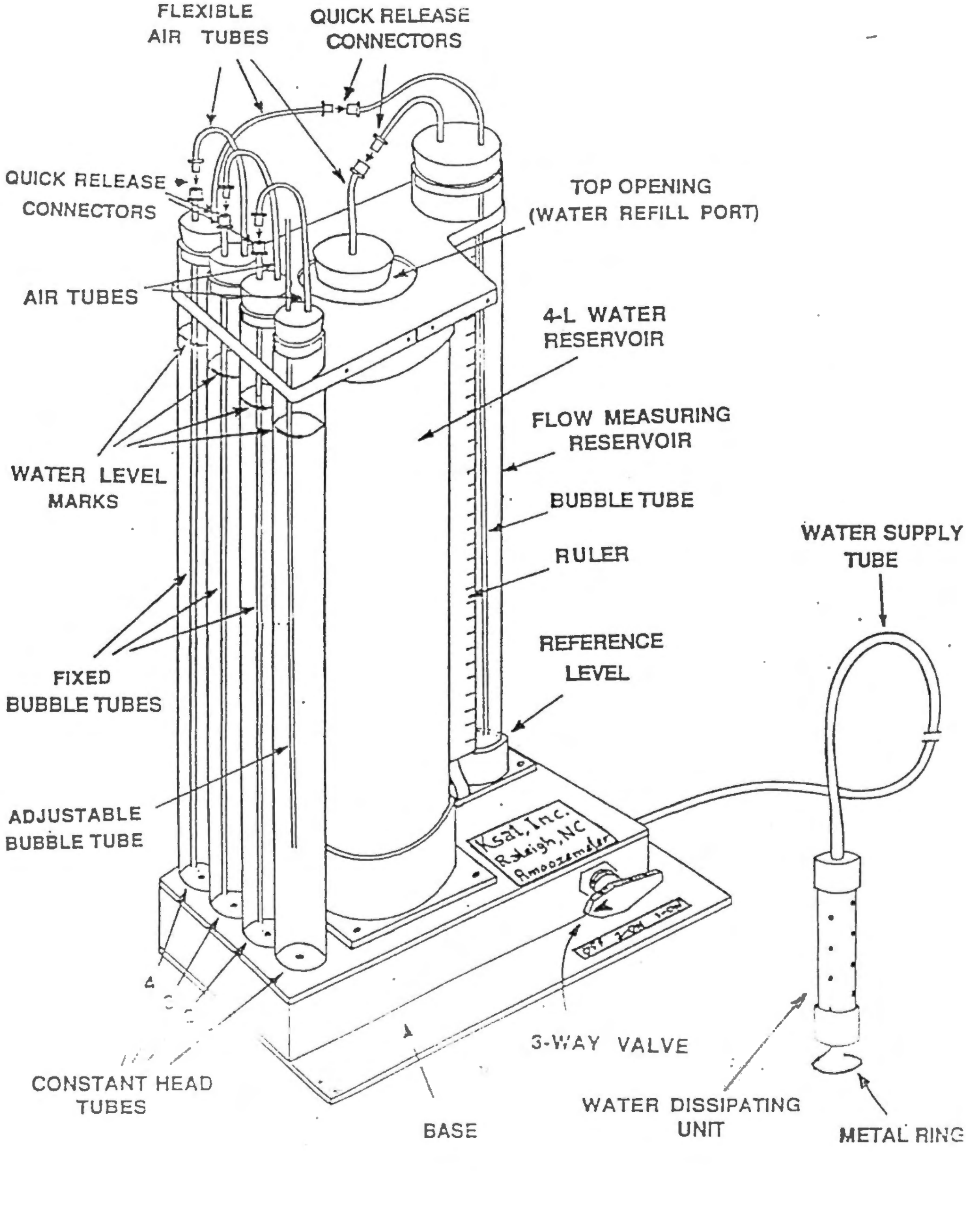

Fig. 21. Configuration of the Compact Constant Head Permeameter.

The K_{sat} was then calculated using the Glover Solution (Schoeneberger et al., 1995). The Glover solution is stated as:

$$K_{sat} = QA$$

where:

$$Q = \text{steady state flow rate}$$

$$A = \{\sinh^{-1}(H/r) - [(r/H)^2 + 1]^{1/2} + r/H\} / [2\pi H^2]$$

$$H = \text{depth of water in the hole}$$

$$r = \text{radius of the hole}$$

This equation depends only on those measurements determined in the field and is therefore easily solved (Amoozegar, 1989b). The measurements obtained from this equation then can be used to assign a USDA K_{sat} class to a particular horizon of a soil.

Results and Discussion

Site Location

The five CCHP sites were located in the western part of Morgan County, where the bulk of the Hard Labor map units are located. Table 6 shows the location and position of the sites on the landscape. Figures 22 through 25 show the locations of the sites on the USGS topographic quadrangles.

CCHP Data

The five sites measured for saturated hydraulic conductivity exhibited a wide range of conductivities; however, some general trends were observed among the three zones of interest (Fig. 26). Saturated hydraulic conductivity was highest in the shallower depths, the "above gray" zone. No redoximorphic depletions were observed in the "above gray" zone at any of the sites. From here, K_{sat} decreased dramatically to the "in gray" zone. Redox depletions were first observed in the "in gray" zone. The exception to this pattern was Site 4A, which will be discussed later. In the "lower BC/C" zone, K_{sat} rebounded slightly in Sites 1A, 3A, and 4A, while it continued to decrease in Sites 2A and 5A.

Table 6. Location and landscape position of sites.

Site	Latitude	Longitude	Elevation (ft.)	Position	Slope (%)
Site 1	3343'51"N	8331'49"W	690	sideslope	2
Site 2	3335'44"N	8337'25"W	730	summit	1
Site 3	3340'29"N	8333'51"W	730	summit	2
Site 4	3341'30"N	8334'33"W	770	summit	4
Site 5	3333'28"N	8328'12"W	680	summit	4

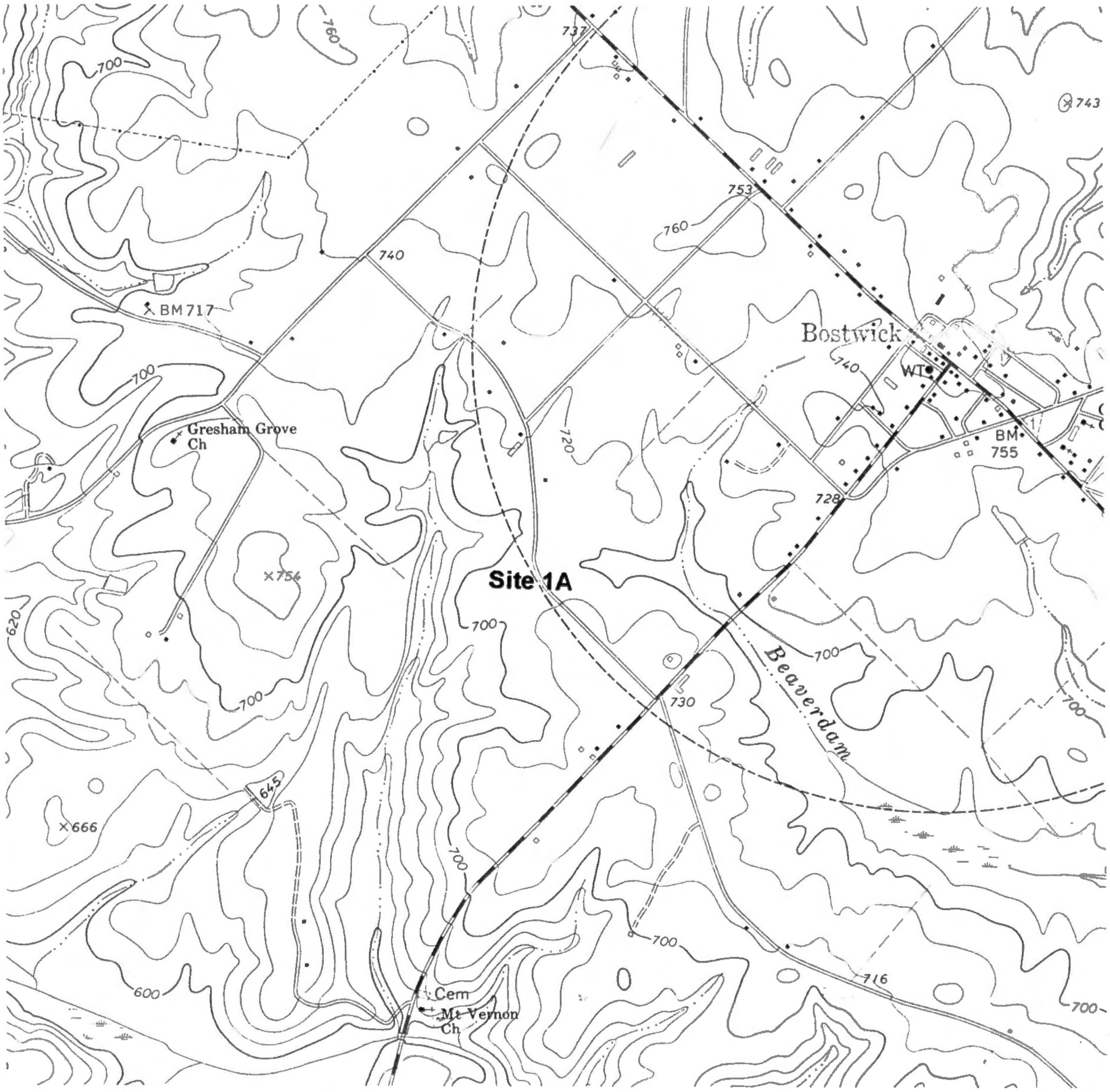

Fig. 22. Section of the Rutledge North Quadrangle showing the location of Site 1A.

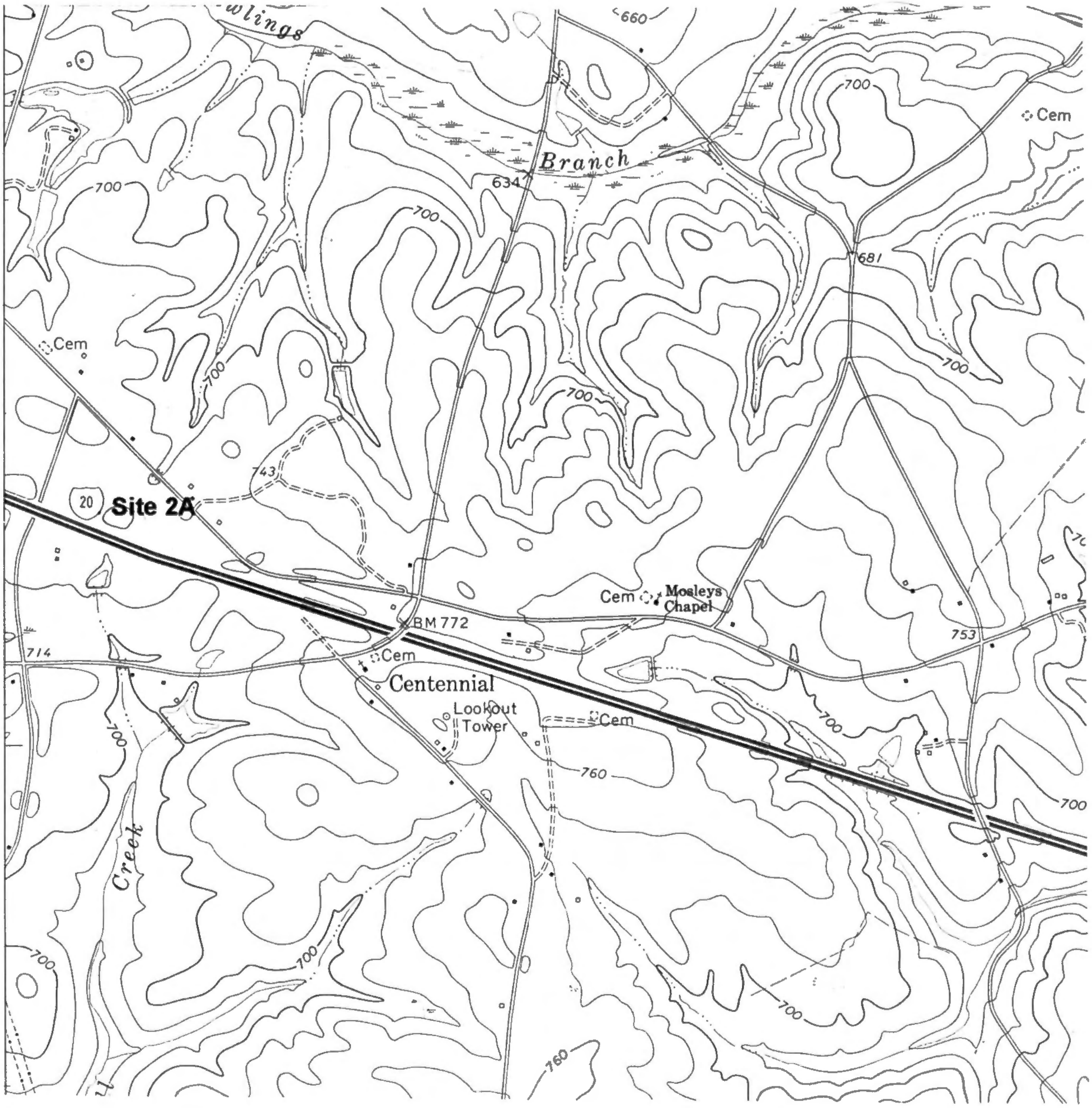

Fig. 23. Section of the Rutledge South Quadrangle showing the location of Site 2A.

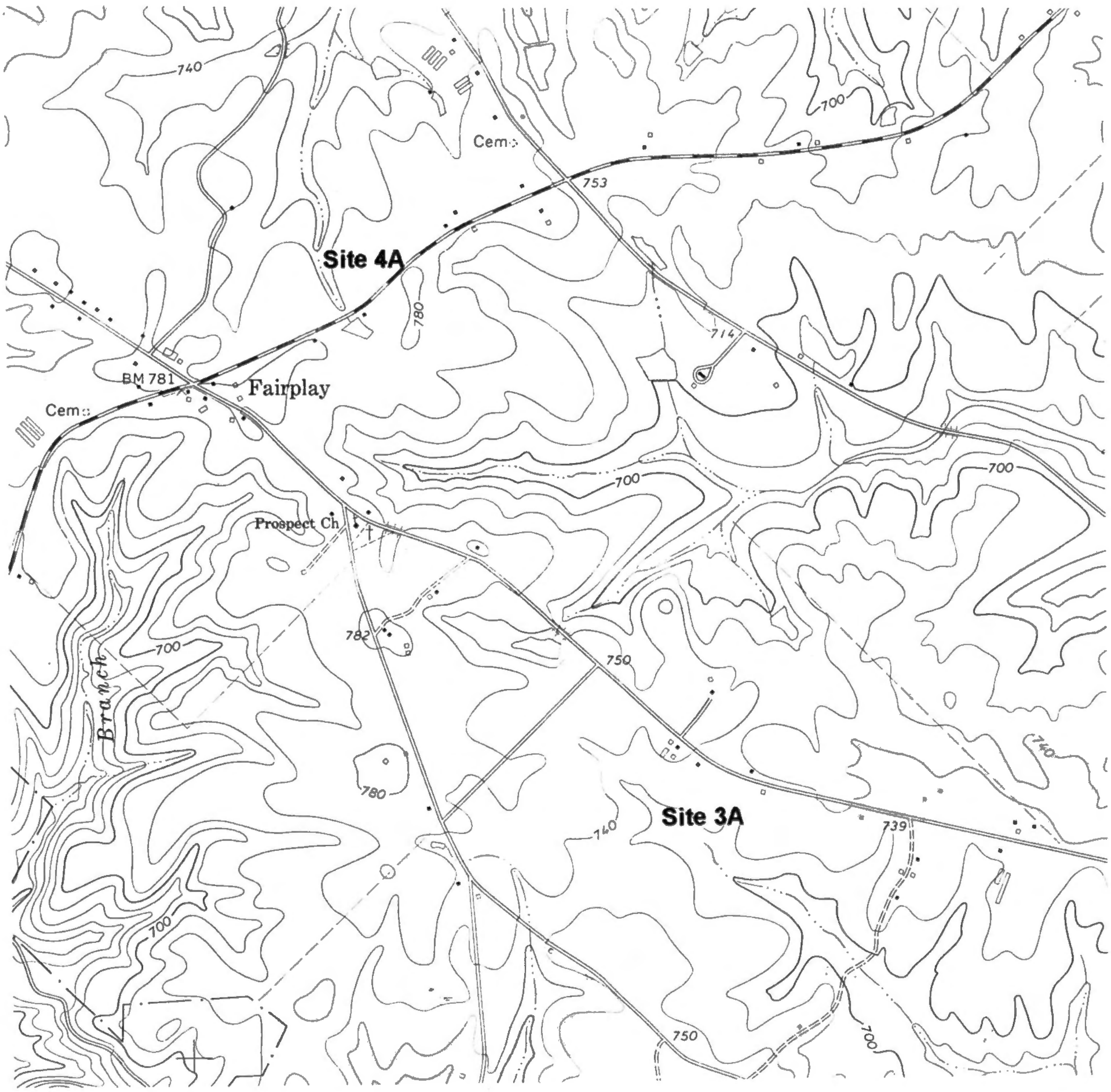

Fig. 24. Section of the Rutledge North Quadrangle showing the location of Sites 3A and 4A.

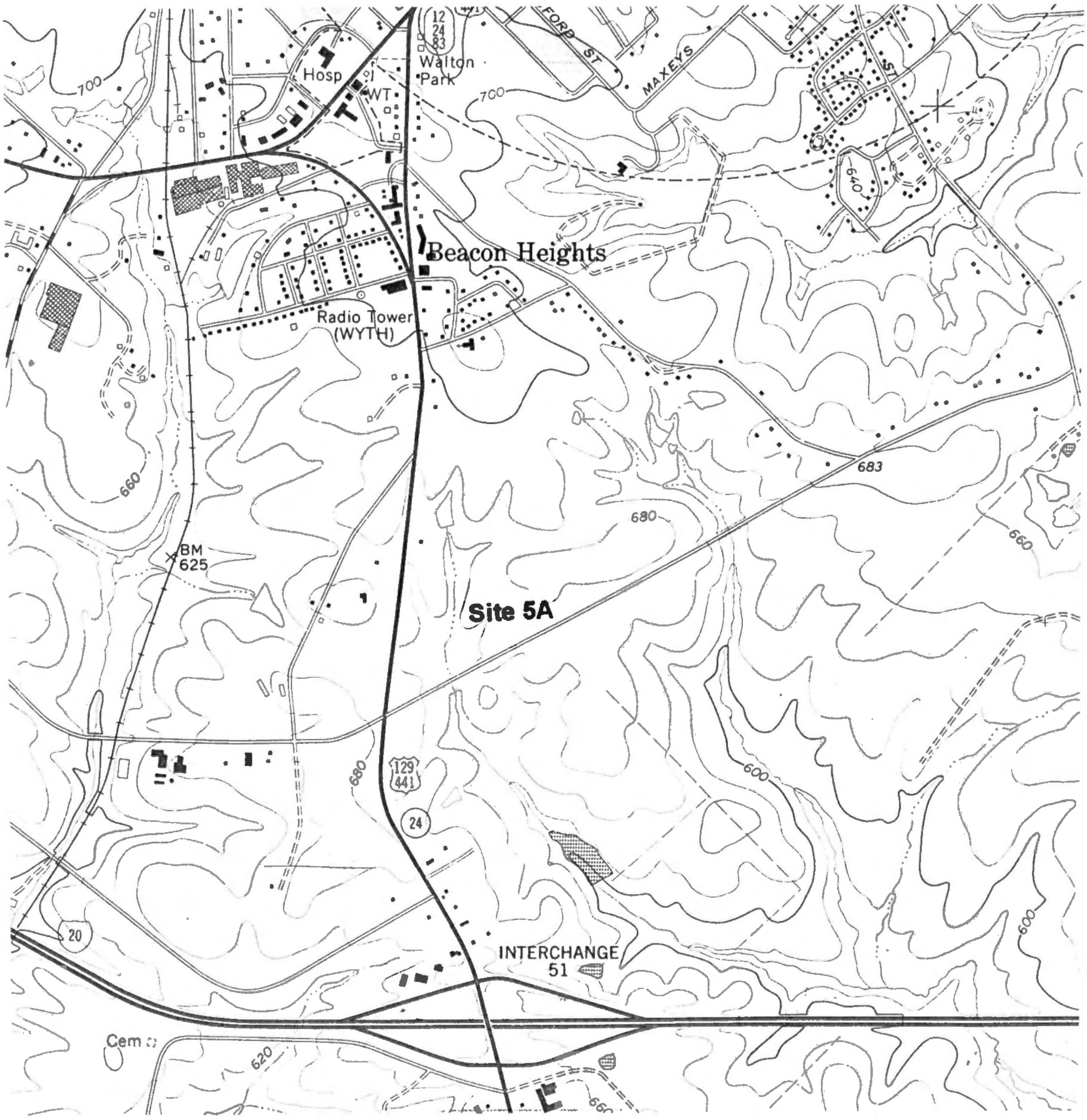

Fig. 25. Section of the Madison Quadrangle showing the location of Site 5A.

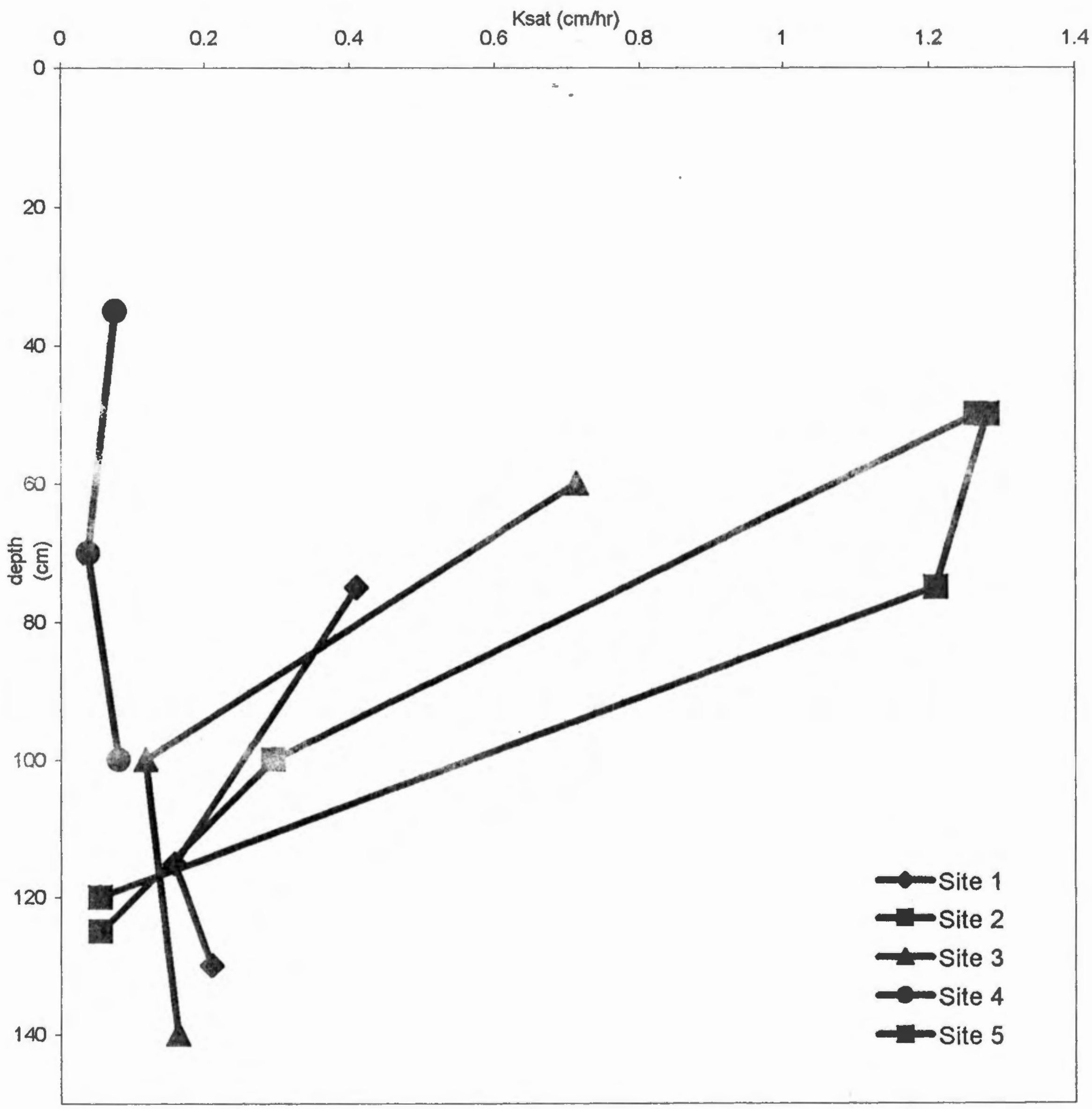

Fig. 26. Comparison of Ksat values for Sites 1A through 5A.

Soil structure exhibited a large influence on the conductivity of a horizon. At Site 2A the K_{sat} drastically decreased from the zone above gray colors to the gray zone. Simultaneously the structure changed from a moderate, medium subangular blocky to a moderate medium platy.

Table 7 presents the CCHP data by site, with averages for each site and overall averages for each zone of the Hard Labor soil. In the "above gray" zone (chroma ≤ 2) the mean K_{sat}, as expressed in cm h^{-1}, was 0.7489. The zone where gray redoximorphic features or matrix colors occurred ("in gray") had a K_{sat} of 0.364 cm h^{-1}. The lower BC transitional horizon ("lower BC/C") had a mean K_{sat} of 0.1132 cm h^{-1}. Vepraskas et al. (1996) found that the lowest K_{sat} measurements were observed in the soil/saprolite transitional zone. These values were often less than or equal to 0.05 cm h^{-1}. Measurements in this zone rate as moderately low according to the Natural Resources Conservation Service guide for saturated hydraulic conductivity (Table 8; Soil Survey Staff, 1993). These findings agree with studies by Vepraskas et al. (1991 and 1996), Schoeneberger and Amoozegar (1990), Williams and Vepraskas (1994) and Schoeneberger et al. (1995).

The sites showed much variability. Data from site 1A showed a large decrease of Ksat into the redoximorphic zone, which then rebounded slightly into the lower transitional horizon (Fig. 27). This was probably a function of structure and texture of the Bt4 and BC horizons. The structure changed from fine and medium angular blocky with a clay texture to coarse subangular blocky with a clay loam texture. Redox features were essentially the same as the other sites (Table 9).

Saturated hydraulic conductivity data for Site 2A decreased steadily from the upper horizons into the lower part (Fig. 28). This was attributed to the degradation of structure from the Bt1 (medium subangular blocky) to the Bt3 (medium subangular

Table 7. CCHP data for Sites 1A through 5A including averages for each site.

Site No.	Above gray (cm/hr)	In gray (cm/hr)	Lower BC/C (cm/hr)
Site 1A	0.215	0.207	0.111
	0.606	0.111	0.310
Average	0.4105	0.159	0.2105
Site 2A	1.11	0.192	0.074
	1.42	0.399	0.037
Average	1.265	0.2955	0.0555
Site 3A	0.074	0.042	0.017
	**	**	0.038
	0.078	0.034	0.188
Average	0.076	0.038	0.081
Site 4A	0.200	2.19	0.0443
	2.36	0.229	0.066
Average	1.28	1.2095	0.0551
Site 5A	0.916	0.029	0.033
	0.510	0.207	0.295
Average	0.713	0.118	0.164
Overall average	0.7489	0.364	0.1132

** measurements were not needed

Table 8. Saturated hydraulic conductivity classes.

Ksat classes	cm/hr
Very high	>36.0
High	3.6 to 36.0
Moderately high	0.36 to 3.6
Moderately low	0.036 to 0.36
Low	0.0036 to 0.036
Very low	<0.0036

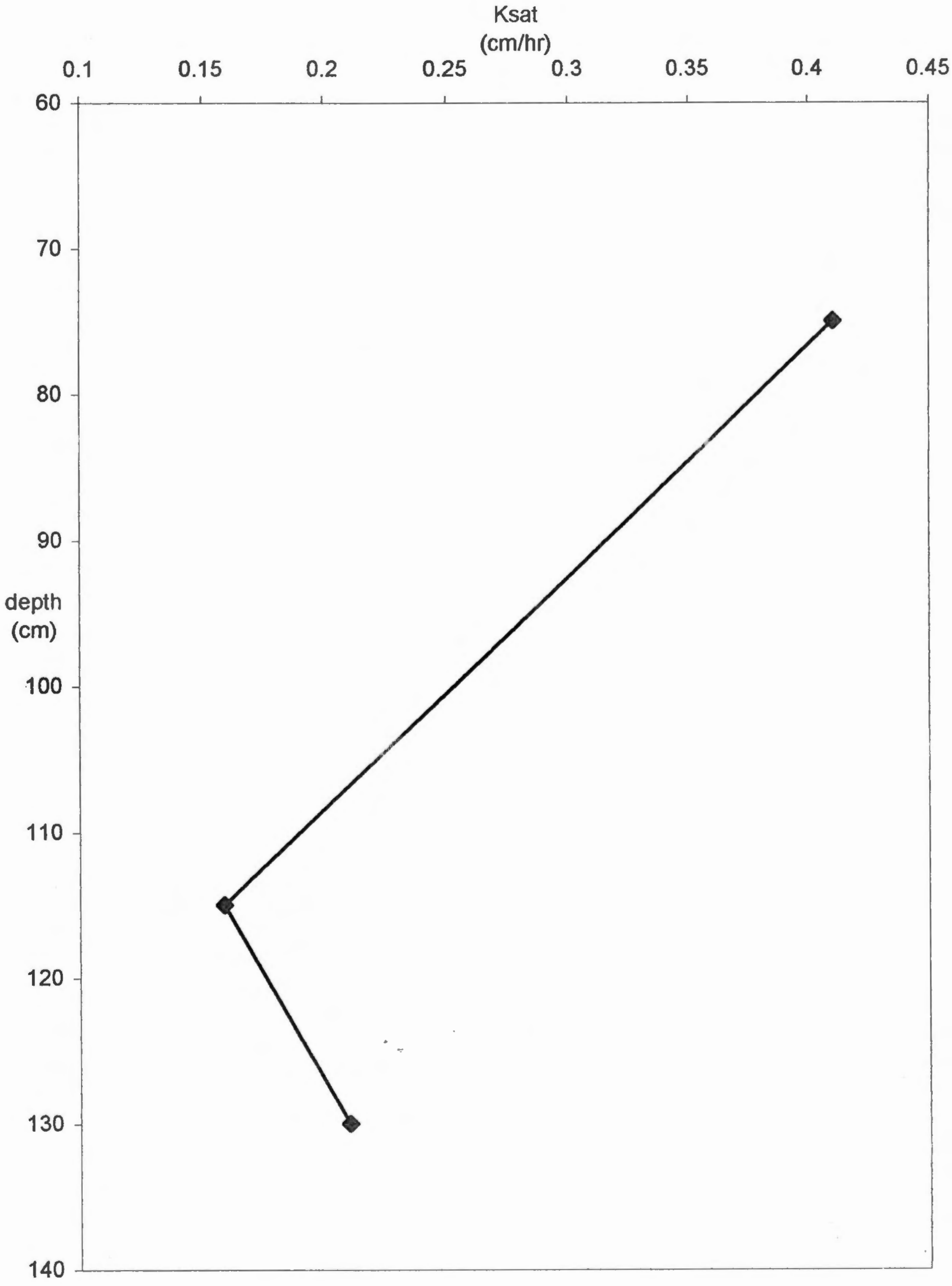

Fig. 27. Saturated hydraulic conductivity by depth for Site 1A.

Table 9. Soil morphology of Sites 1A, 2A, and 3A.

Horizon	Depth (cm)	Zone	Texture†	Structure‡	Redoximorphic Features§
			Site 1A		
Bt2	71	Above	SC	2msbk	c2p 2.5YR 5/8
Bt4	107	Gray	C	2fmabk	m2p 10R 4/8
					c2d 2.5Y 6/3
BC	138	BC/C	CL	2cosbk	m23p 10R 4/8
					c2d 2.5Y 7/2
					c1f 7.5YR 6/8
			Site 2A		
Bt1	54	Above	SC	2msbk	--
Bt3	100	Gray	C	2msbk	c23p 2.5Y 6/2
BC	128	BC/C	C	2mpl	m23p 10R 4/8
					c23p 2.5Y 6/8
					c1d 2.5Y 7/2
			Site 3A		
Bt3	50	Above	C	3mpl to	m23p 2.5YR 4/6
				1cosbk	m2p 10YR 8/4
BC	102	Gray	SCL	1msbk	c1p 10YR 8/1
C	152	BC/C	SCL	ma	c1p 10YR 8/1

† SCL = sandy clay loam, CL = clay loam, SC = sandy clay, C = clay.

‡ Grade: 1 = weak, 2 = moderate, 3 = strong; size: f = fine, m = medium, co = coarse; kind: sbk = subangular blocky, abk = angular blocky, pl = platy, ma = massive.

§ Abundance: c = common, m = many; size: 1 = fine, 2 = medium, 3 = coarse; contrast: f = faint, d = distinct, p = prominent.

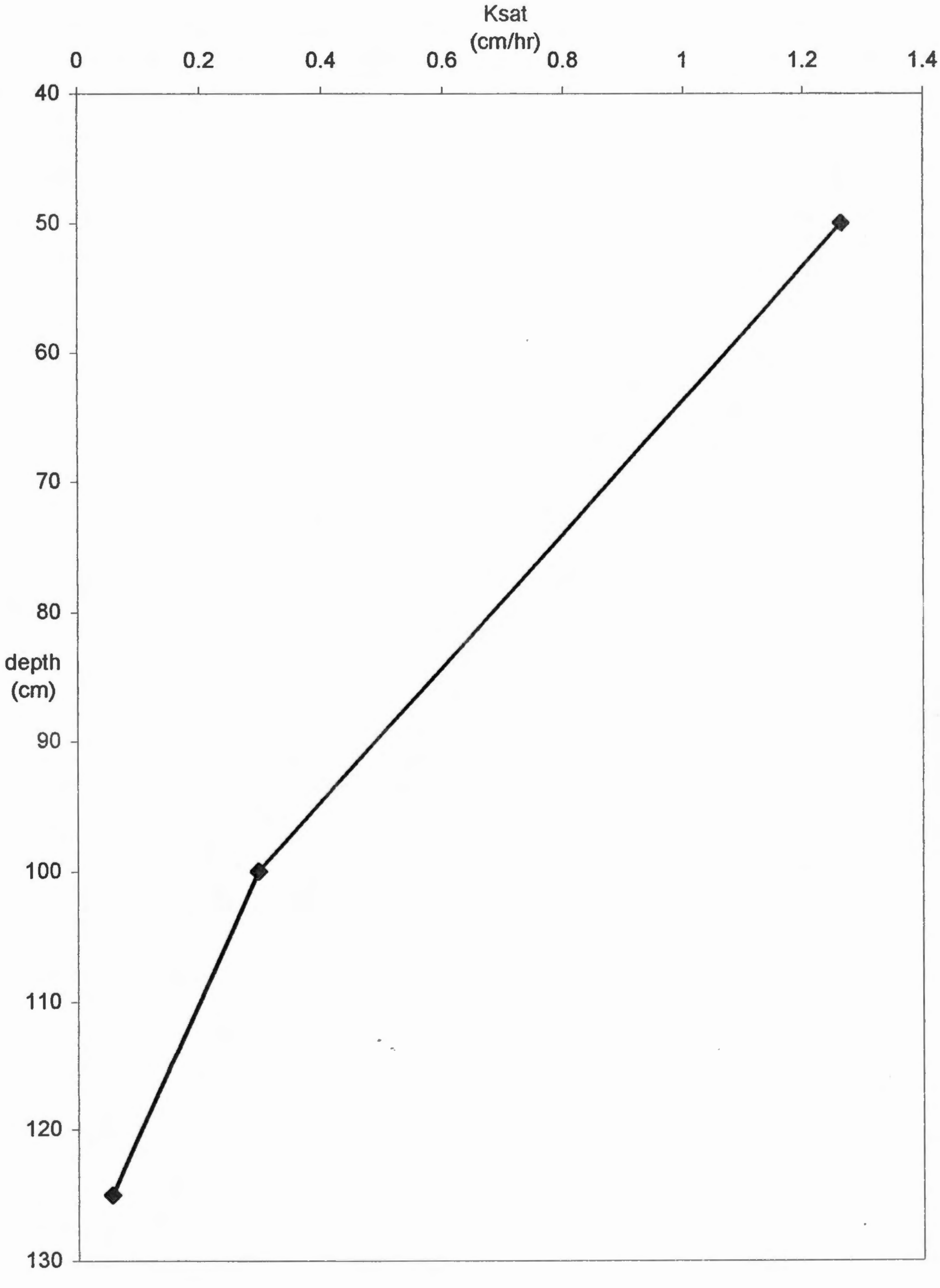

Fig. 28. Saturated hydraulic conductivity by depth for Site 2A.

blocky) to the BC (medium platy). As a result, the amount of redox features increased steadily into the C horizon (Table 9).

Site 3A followed a similar pattern of Site 1A (Fig. 29). There was a very slight rebound of Ksat in the C horizon, even though the structure in this zone was massive. This slight increase was attributed to a decrease in texture, from a clay loam to a sandy loam (Table 9).

The averages for Site 4A were low for all horizons. Site 4A had the heaviest textures in each of the zones of interest of all of the sites. When the scale was adjusted on the plot, a large difference emerged from the Bt2 to the Bt4 horizon (Fig. 30). Platy structure was found in the "above gray" zone, but not in the lower zones. No other morphology could be correlated to this difference (Table 10).

Site 5A had a similar plot to Site 2A in that the Ksat decreased with depth through the pedon; however, upon examination of the scale-adjusted plot, a slight increase was noticed from the Bt2 to the Bt4 horizon (Fig. 31). This appears on the plot to be a plateau. No morphology could be definitively tied to this event (Table 10). The Ksat then decreased with depth to the BC horizon, where it was the lowest for this site.

Conclusions

1. Saturated hydraulic conductivity decreases with depth to a point, then steadies. All sites exhibit this behavior.
2. Morphology is a good indicator of a low conductivity zone. Properties such as structure and presence of redoximorphic features can predict where saturated hydraulic conductivity, and therefore permeability, is low.

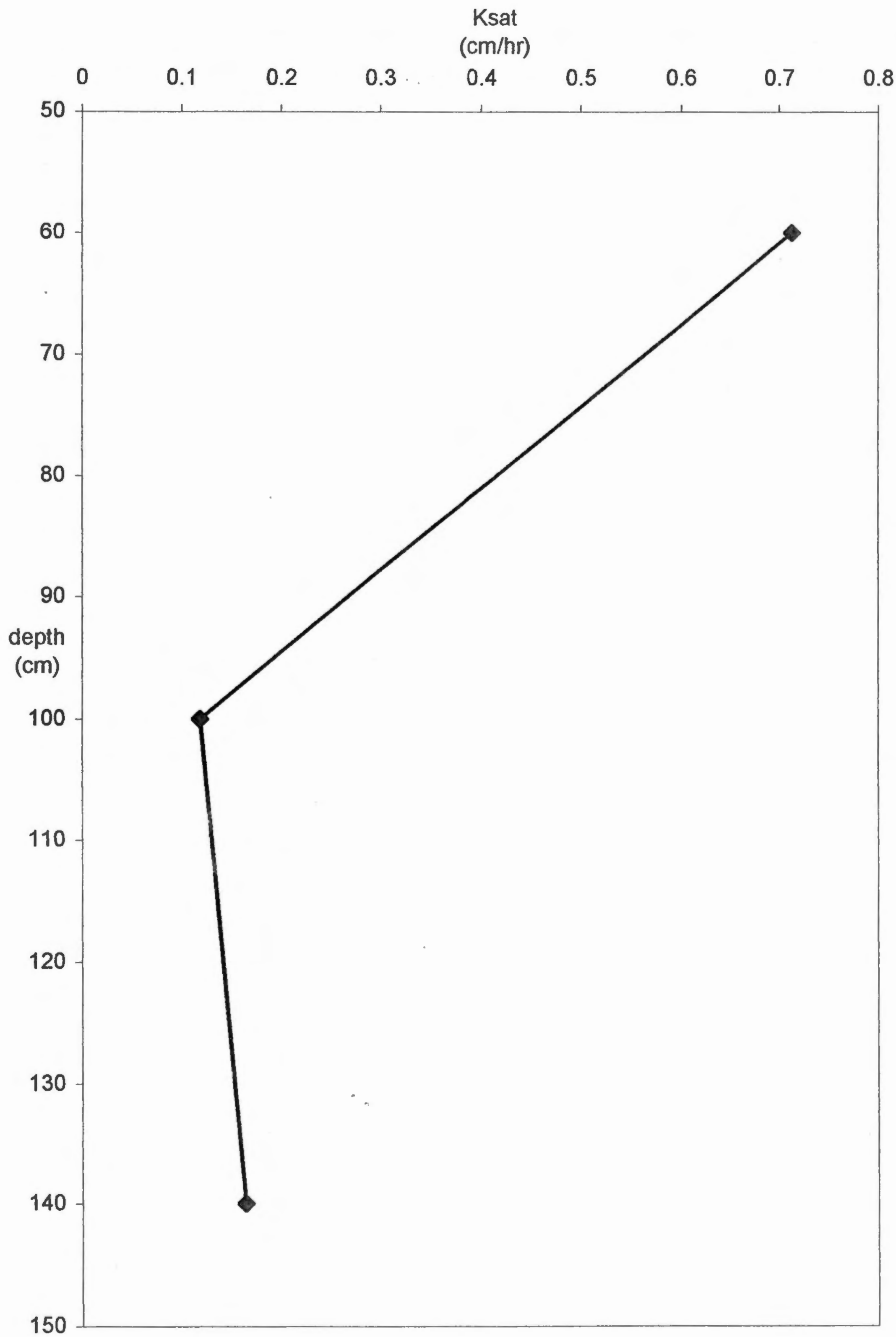

Fig. 29. Saturated hydraulic conductivity by depth for Site 3A.

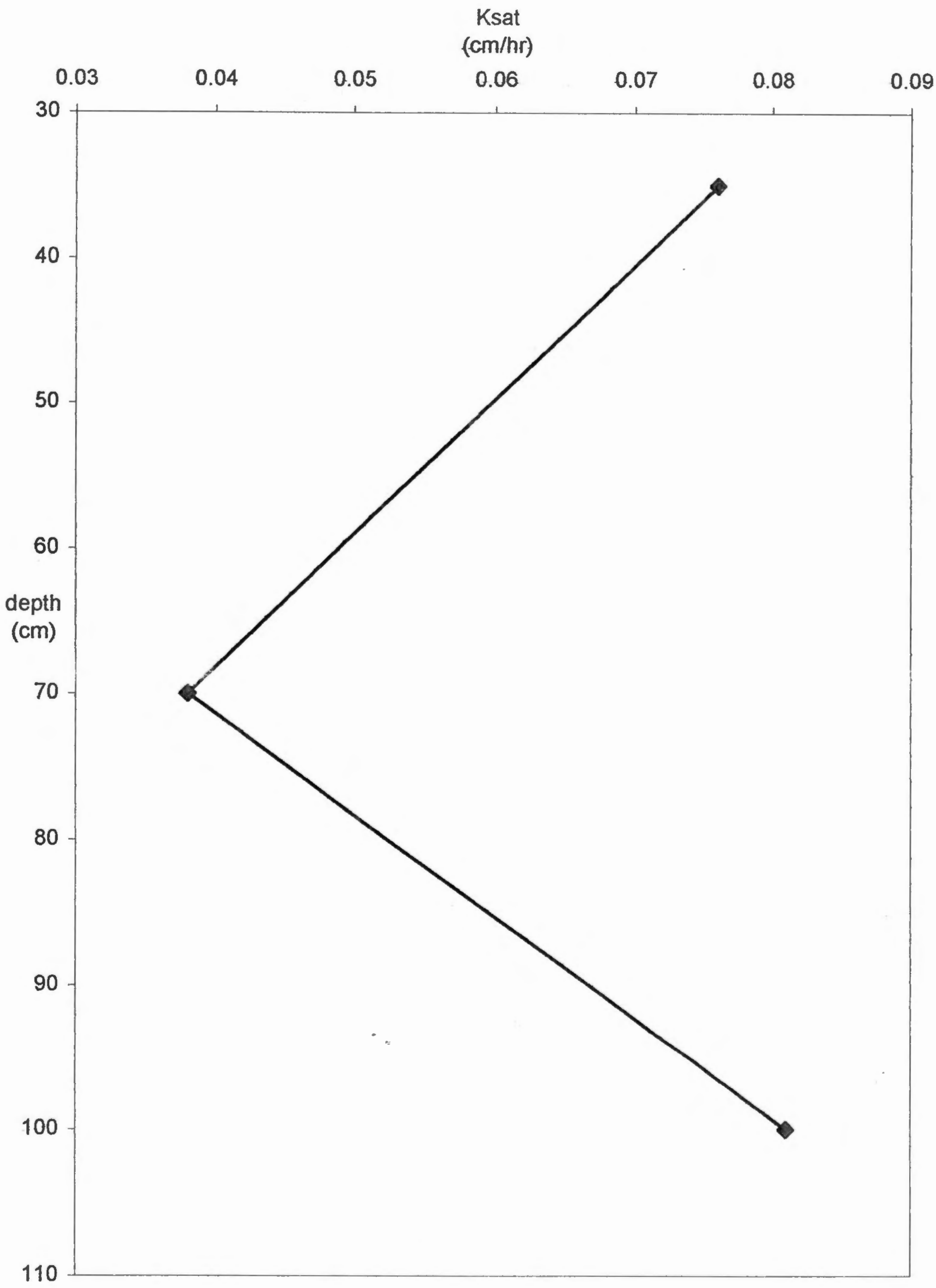

Fig. 30. Saturated hydraulic conductivity by depth for Site 4A.

Table 10. Soil morphology of Sites 4A and 5A.

Horizon	Depth (cm)	Zone	Texture†	Structure‡	Redoximorphic Features§
			Site 4A		
Bt2	32	Above	C	1mpl to 2mabk	f2p 2.5yR 4/8 c2d 2.5Y 6/6
Bt3	73	Gray	C	2msbk	c2p 2.5YR 4/8 f1p 10YR 7/2 f1p 2.5Y 6/4
BC	103	BC/C	CL	1msbk	c2p 2.5Y 7/2 c2p 10YR 6/8 f2d 5YR 5/6
			Site 5A		
Bt2	46	Above	C	2msbk	c2p 2.5YR 4/8
Bt4	88	Gray	CL	2mpl	--
BC	126	BC/C	L	1msbk	--

† C = clay, CL = clay loam, L = loam.

‡ Grade: 1 = weak, 2 = moderate; size: m = medium; kind: sbk = subangular blocky, abk = angular blocky, pl = platy.

§ Abundance: f = few, c = common; size: 1 = fine, 2 = medium; contrast: d = distinct, p = prominent.

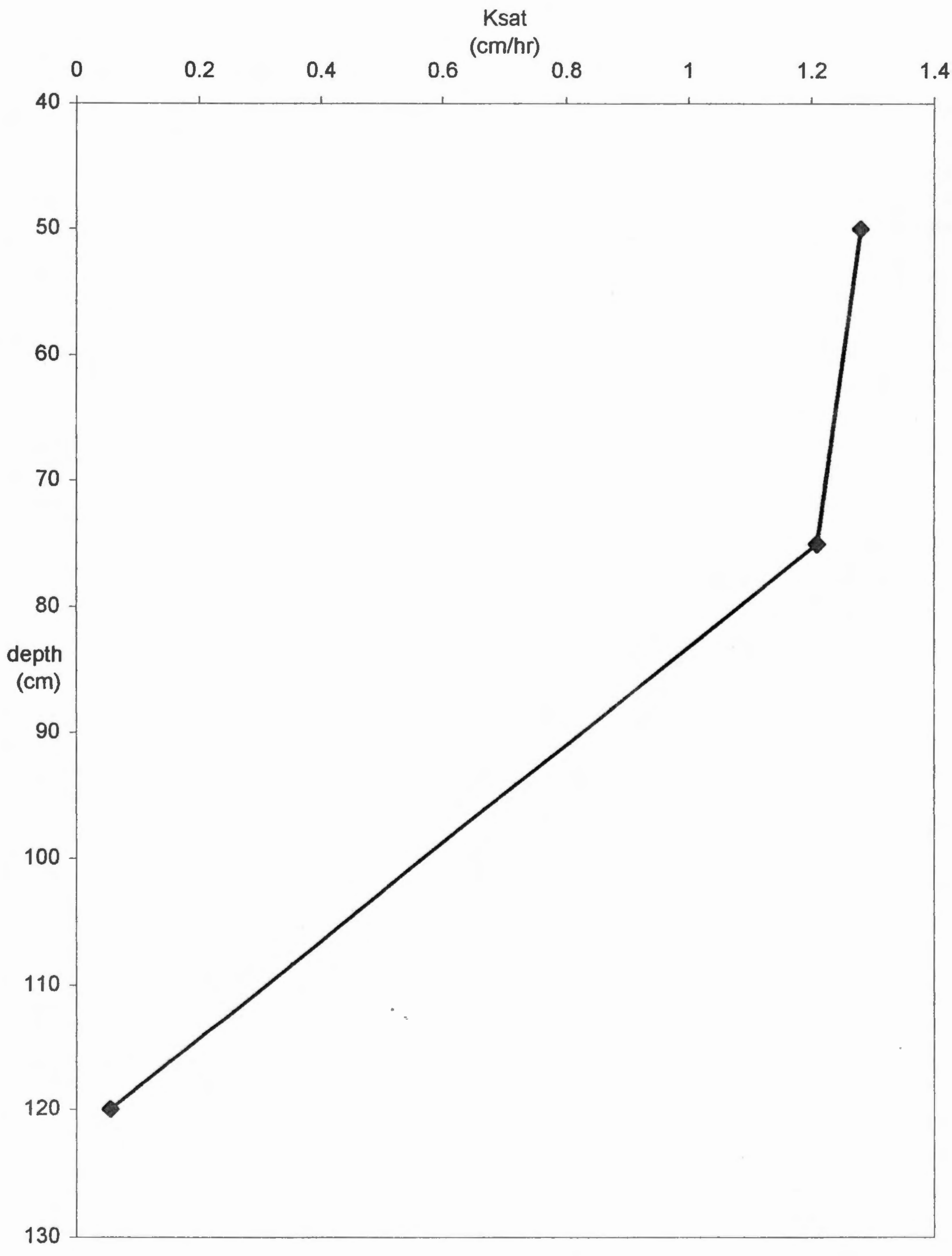

Fig. 31. Saturated hydraulic conductivity by depth for Site 5A.

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APPENDICES

Appendix A. Narrative Soil Descriptions - Characterization Sites

Characterization Site 1
Location: Rutledge North, Georgia quadrangle
Latitude: 33 degrees, 41 minutes, 31.0 seconds
Longitude: 83 degrees, 34 minutes, 34.0 seconds
Slope: 4 percent
Vegetation: bemuda grass, dog fennel, mixed forbs
Classification: fine, kaolinitic, thermic Oxyaquic Kanhapludults

Ap—0 to 15 cm; dark yellowish brown (10YR 4/4) loamy sand; weak fine and medium granular and weak fine and medium subangular blocky structure; very friable; common fine and medium roots; 2 percent gravel; pH 5.98; abrupt smooth boundary.

BEt—15 to 25 cm; strong brown (7.5YR 5/6) coarse sandy loam; weak medium subangular blocky structure; hard, friable; common fine roots; 5 percent faint brown (7.5YR 5/4) clay films; 3 percent medium red (2.5YR 4/6) plinthite segregations; 2 percent gravel; pH 5.58; clear wavy boundary.

Bt1—25 to 50 cm; strong brown (7.5YR 5/8) clay; 12 percent medium yellow (10YR 7/6) mottles; strong thick platy structure parting to moderate medium subangular blocky and moderate medium angular blocky; firm; common very fine roots; 30 percent faint strong brown (7.5YR 5/6) clay films; 3 percent medium red (2.5YR 4/6) plinthite segregations; pH 4.83; clear wavy boundary.

Bt2—50 to 67 cm; strong brown (7.5YR 5/8) clay; 25 percent medium and coarse yellow (10YR 7/6) mottles; moderate medium platy structure parting to weak fine subangular blocky; firm; common very fine roots; 33 percent faint strong brown (7.5YR 5/6) clay films; 3 percent medium and coarse weak red (10R 4/3) and red (10R 4/6) horizontally oriented plinthite segregations; pH 4.88; quartz grains in seams associated with yellow mottles; gradual wavy boundary.

BCt1—67 to 118 cm; red (2.5YR 5/6) sandy clay loam; 10 percent medium yellow (10YR 7/6) mottles; weak medium platy and weak fine subangular blocky structure; friable; 30 percent faint red (2.5YR 5/6) clay films in pores and on horizontal ped faces; 25 percent medium and coarse red (10R 4/6) concentrations in streaks and 10 percent fine white (10YR 8/1) and light gray (2.5Y 7/2) depletions; pH 4.7; quartz and mica seams, 2 to 4 cm thick, associated with white and light gray depletions, spaced 25 to 30 cm apart; gradual wavy boundary.

BCt2—118 to 160 cm; 50 percent reddish brown (2.5YR 5/4) and 50 percent yellow (10YR 7/6) coarse sandy loam; weak medium and coarse subangular blocky structure; friable; 5 percent faint red (2.5YR 5/6) clay films; 15 percent fine dark reddish brown (2.5YR 3/4) concentrations and 30 percent medium white (10YR 8/1) depletions; 2 percent gravels; pH 4.62; gradual wavy boundary.

BC—160 to 240 cm; red (10R 4/6) fine sandy loam; 1 percent medium yellow (10YR 7/6) mottles; weak coarse subangular blocky structure; friable; 15 percent medium pinkish gray (5YR 7/2) depletions; pH 4.73; gradual wavy boundary.

C—240 to 290 cm; 35 percent light reddish gray (2.5YR 7/1), 35 percent white (2.5YR 8/1) and 30 percent very dark gray (5YR 3/1) coarse sandy loam; massive; friable; 2 percent fine and medium red (10R 4/6) bands extending along fractures in the saprolite; pH 4.79.

Characterization Site 2
Location: Rutledge North, Georgia quadrangle
Latitude: 33 degrees, 40 minutes, 38.0 seconds
Longitude: 83 degrees, 33 minutes, 50.0 seconds
Slope: 3 percent
Vegetation: fescue hay
Classification: fine, kaolinitic, thermic Oxyaquic Kanhapludults

Ap—0 to 10 cm; dark brown (7.5YR 3/2) coarse sand; moderate fine granular structure; very friable; many very fine and fine and common medium roots; pH 5.35; abrupt smooth boundary.

EB—10 to 26 cm; light yellowish brown (10YR 6/4) coarse sandy loam; weak medium subangular blocky structure; slightly hard, friable; common very fine and fine and few medium roots; dark brown (7.5YR 3/2) organic stains; 2 percent gravel; pH 5.74; clear wavy boundary.

Bt1—26 to 61 cm; yellowish brown (10YR 5/6) clay; moderate coarse prismatic structure parting to strong medium platy; firm; common very fine and fine and few medium roots; 60 percent prominent yellowish brown (10YR 5/4) clay films; 30 percent coarse olive yellow (2.5Y 6/6) and medium red (2.5YR 4/6) concentrations; pH 5.72; clear wavy boundary.

Bt2—61 to 80 cm; brownish yellow (10YR 6/8) clay; moderate thick platy structure; firm; few very fine and fine roots; 70 percent prominent yellowish brown (10YR 5/4) clay films; 30 percent medium red (2.5YR 4/6) concentrations and 15 percent medium light gray (2.5Y 7/2) depletions; 1 percent gravel; pH 5.31; redox feature configuration is red ped interior, surrounded by yellow, with light gray in macropores; clear wavy boundary.

BCt—80 to 114 cm; brownish yellow (10YR 6/8) sandy clay loam; moderate very thick platy structure; slightly hard, friable; few very fine and fine roots; 5 percent faint yellowish brown (10YR 5/4) clay films; 30 percent medium and coarse red (2.5YR 4/6) and pale red (2.5YR 7/2) horizontally oriented concentrations and 15 percent medium light brownish gray (2.5Y 6/2) depletions; many mica flakes; pH 4.88; clear wavy boundary.

CB—114 to 158 cm; light gray (2.5YR 7/2) fine sandy loam; weak very thick platy structure and massive; friable; 30 percent medium red (2.5YR 4/6), 12 percent medium olive yellow (2.5Y 6/6) and yellowish red (5YR 4/6) concentrations in thin seams and pockets; many mica flakes; pH 4.76; abrupt wavy boundary.

C—158 to 200 cm; light gray (2.5YR 7/2) fine sandy loam; massive; very friable; 15 percent medium red (2.5YR 4/6) and 2 percent medium olive yellow (2.5Y 6/6) concentrations; pH 4.48.

Appendix B. Narrative Soil Descriptions – Amoozemeter Sites

Amoozemeter Site 1A
Landscape Position: upland sideslope
Slope: 2%
Parent Material: residuum
Vegetation: alfalfa and bermuda grass pasture
Drainage: moderately well drained
Classification: fine, kaolinitic, thermic Oxyaquic Kanhapludults

Ap—0 to 10 cm; brown (10YR4/3) loamy sand; weak medium granular structure; very friable; abrupt smooth boundary.

E—10 to 20 cm; yellowish brown (10YR 5/4) loamy sand; weak medium subangular blocky structure; very friable; abrupt smooth boundary.

BE—20 to 50 cm; yellowish brown (10YR 5/4) sandy loam; weak coarse subangular blocky structure; friable; gradual smooth boundary.

Bt1—50 to 66 cm; brownish yellow (10YR 6/6) clay loam; moderate medium subangular blocky structure; firm; gradual smooth boundary.

Bt2—66 to 89 cm; yellowish brown (10YR 5/6) sandy clay; moderate medium subangular blocky structure; firm; common medium red (2.5YR 5/8) concentrations; gradual smooth boundary.

Bt3—89 to 101 cm; brownish yellow (10YR 6/6) sandy clay; moderate medium subangular blocky structure; firm; common medium red (10R 4/8) concentrations and common medium light yellowish brown (2.5Y 6/3) depletions; gradual smooth boundary.

Bt4—101 to 122 cm; brownish yellow (10YR 6/6) clay; moderate fine and medium angular blocky structure; firm; many medium red (10R 4/8) concentrations and common medium light yellowish brown (2.5Y 6/3) depletions; gradual smooth boundary.

BC—122 to 200 cm; brownish yellow (10YR 6/8) clay loam; moderate coarse subangular blocky structure; firm; many medium and coarse red (10R 4/8) and common fine reddish yellow (7.5YR 6/8) concentrations and common medium light gray (2.5Y 7/2) depletions; few thin discontinuous lenses of kaolinite.

Amoozemeter Site 2A
Landscape Position: summit
Slope: 1%
Parent Material: residuum
Vegetation: cotton
Drainage: moderately well drained
Classification: fine, kaolinitic, thermic Oxyaquic Kanhapludults

A—0 to 15 cm; brown (10YR 4/3) coarse sandy loam; weak fine granular structure; very friable, slightly sticky and nonplastic; gradual wavy boundary.

BA—15 to 35 cm; olive brown (2.5Y 4/3) sandy clay loam; weak medium subangular blocky structure; friable, slightly sticky and slightly plastic; clear wavy boundary.

Bt1—35 to 66 cm; yellowish brown (10YR 5/6) sandy clay; moderate medium subangular blocky structure; firm, slightly sticky and plastic; 5 percent fine gravel; clear wavy boundary.

Bt2—66 to 94 cm; yellowish brown (10YR 5/8) clay; moderate medium subangular blocky structure; firm, slightly sticky and plastic; 2 percent fine gravel; few medium yellowish red (5YR 5/6) concentrations; clear wavy boundary.

Bt3—94 to 106 cm; yellowish brown (10YR 5/6) clay; moderate medium subangular blocky structure; firm, slightly sticky and plastic; common medium and coarse light brownish gray (2.5Y 6/2) depletions; clear wavy boundary.

BC—106 to 130 cm; brownish yellow (10YR 6/6) sandy clay; moderate medium platy structure; firm, slightly sticky and plastic; many medium and coarse dark red (2.5YR 4/8) and common medium and coarse olive yellow (2.5Y 6/8) concentrations and common fine light gray (2.5Y 7/2) and common medium white (10YR 8/1) depletions; gradual wavy boudary.

C—130 to 150 cm; brownish yellow (10YR 6/6) clay; massive; very firm, sticky and plastic; many medium and coarse red (10R 4/8) and common medium and coarse olive yellow (2.5Y 6/8) concentrations and common fine light gray (2.5Y 7/2) and common medium white (10YR 8/1) depletions.

Amoozemeter Site 3A
Landscape Position: summit
Slope: 2%
Parent Material: residuum
Vegetation: fescue and bermuda hayfield
Drainage: moderately well drained
Classification: fine, kaolinitic, thermic Oxyaquic Kanhapludults

A—0 to 7 cm; very dark grayish brown (10YR 3/2) coarse sandy loam; moderate medium granular structure; very friable; clear smooth boundary.

E—7 to 18 cm; light olive brown (2.5Y 5/3) loamy coarse sand; moderate medium granular structure; very friable; clear wavy boundary.

Bt1—18 to 33 cm; yellowish brown (10YR 5/6) clay; moderate coarse subangular blocky structure; firm, slightly sticky and plastic; common medium light yellowish brown (2.5Y 6/3) clay films; few fine dark red (2.5YR 4/6) concentrations; few mica flakes; gradual wavy boundary.

Bt2—33 to 48 cm; yellowish brown (10YR 5/6) clay; moderate thick platy structure parting to moderate coarse angular blocky; firm, slightly sticky and plastic; common medium light yellowish brown (2.5Y 6/3) clay films; few fine dark red (2.5YR 4/6) concentrations; few mica flakes; gradual wavy boundary.

Bt3—48 to 81 cm; yellowish brown (10YR 5/8) clay; strong medium platy structure parting to weak coarse subangular blocky; firm, slightly sticky and slightly plastic; common fine and medium light yellowish brown (10YR 6/4) clay films; many medium and coarse dark red (2.5YR 4/6) concentrations and many medium very pale brown (10YR 8/4) depletions; few mica flakes; gradual wavy boundary.

BC—81 to 122 cm; 35 percent yellowish brown (10YR 5/8), 35 percent dark red (2.5YR 4/6) and 30 percent dark yellowish brown (10YR 4/8) sandy clay loam; weak medium subangular blocky structure; friable, slightly sticky and slightly plastic; common medium light yellowish brown (2.5Y 6/3) clay films; common fine white (10YR 8/1) depletions; common mica flakes; gradual wavy boundary.

C—122 to 160 cm; 35 percent yellowish brown (10YR 5/8), 35 percent dark red (2.5YR 4/6) and 30 percent dark yellowish brown (10YR 4/8) sandy clay loam; massive; very friable; common fine white (10YR 8/1) depletions; many mica flakes.

Amoozemeter Site 4A
Landscape Position: convex summit
Slope: 4%
Parent Material: residuum
Vegetation: dogfennel and other mixed forbs
Drainage: moderately well drained
Classification: fine, kaolinitic, thermic Oxyaquic Kanhapludults

Ap—0 to 15 cm; dark yellowish brown (10YR 4/4) loamy coarse sand; moderate medium granular structure; friable; abrupt smooth boundary.

Bt1—15 to 25 cm; yellowish brown (10YR 5/6) sandy clay; weak medium subangular blocky structure; firm, slightly sticky and plastic; common coarse dark red (2.5YR 4/8) soft plinthite segregations; clear smooth boundary.

Bt2—25 to 46 cm; yellowish brown (10YR 5/8) clay; weak medium platy structure parting to moderate medium angular blocky; firm, sticky and plastic; common yellowish brown (10YR 5/6) clay films; common medium olive yellow (2.5Y 6/6) depletions; few medium dark red (2.5YR 4/8) soft plinthite segregations; few mica flakes; gradual smooth boundary.

Bt3—46 to 73 cm; yellowish brown (10YR 5/6) clay; moderate medium subangular blocky structure; firm, slightly sticky and plastic; few fine light gray (10YR 7/2) and light yellowish brown (2.5Y 6/4) depletions; common medium dark red (2.5YR 4/8) soft plinthite segregations; few mica flakes; gradual smooth boundary.

Bt4—73 to 86 cm; strong brown (7.5YR 5/6) clay; moderate medium subangular blocky structure; firm, slightly sticky and plastic; common medium dark red (2.5YR 4/8) concentrations and few fine light gray (2.5Y 7/2) and light yellowish brown (2.5Y 6/4) depletions; few mica flakes; gradual smooth boundary.

BC—86 to 114 cm; dark red (2.5YR 4/8) clay loam; weak medium subangular blocky structure; friable; common medium brownish yellow (10YR 6/8) and few medium yellowish red (5YR 5/6) concentrations and common medium light gray (2.5Y 7/2) depletions; common mica flakes; gradual smooth boundary.

C—114 to 150 cm; dark red (2.5YR 4/8) sandy loam; massive; friable; common medium yellowish red (5YR 5/6) concentrations and common medium light gray (2.5Y 7/2) depletions; few clear quartz grains surrounded by depletions.

Amoozemeter Site 5A
Landscape Position: summit
Slope: 4%
Parent Material: residuum
Vegetation: cotton
Drainage: moderately well drained
Classification: fine, kaolinitic, thermic Oxyaquic Kanhapludults

A—0 to 20 cm; strong brown (7.5YR 5/6) sandy clay loam; weak fine granular structure; friable; 5 percent fine gravel; clear smooth boundary.

Bt1—20 to 38 cm; strong brown (7.5YR 5/8) sandy clay; moderate medium subangular blocky structure; firm, nonsticky and slightly plastic; 5 percent fine gravel; common fine dark red (2.5YR 4/6) concentrations; gradual wavy boundary.

Bt2—38 to 71 cm; yellowish brown (10YR 5/8) clay; moderate medium subangular blocky structure; firm, slightly sticky and slightly plastic; 2 percent fine quartz grains; common medium pale brown (10YR 6/3) clay films; common medium dark red (2.5YR 4/8) concentrations; gradual wavy boundary.

Bt3—71 to 86 cm; yellowish brown (10YR 5/8) clay; weak thin platy structure parting to weak medium subangular blocky; firm, slightly sticky and slightly plastic; 2 percent fine quartz grains; common medium light yellowish brown (10YR 6/4) clay films; common coarse dark yellowish brown (10YR 4/6) concentrations and common medium light gray (10YR 7/2) depletions; gradual wavy boundary.

Bt4—86 to 114 cm; 40 percent yellowish brown (10YR 5/8), 40 percent red (10R 4/6) and 20 percent light gray (10YR 7/2) clay loam; moderate medium platy structure; firm, nonsticky and slightly plastic; 2 percent fine quartz grains; common medium light yellowish brown (10YR 6/4) clay films; gradual wavy boundary.

BC—114 to 152 cm; 40 percent red (10R 5/6), 30 percent very pale brown (10YR 8/2) and 30 percent yellowish brown (10YR 5/6) loam; weak medium subangular blocky structure; friable; fine mica flakes.

Appendix C. Laboratory Data for Site 1

Horizon	Depth	vcs	cs	ms	fs	vfs	total sand	total silt	total clay	Text†	pH	Bulk density	KCl Al	CEC	CEC/ clay	% base saturation	ECEC
	cm											g/cc	cmol/ kg	cmol/ kg			cmol/kg
Ap	0-15	5.5	13.3	23.6	27.8	9.7	79.9	15.7	4.4	LS	6.0	--	0.1	1.7	0.39	76	1.4
BE	15-25	12.8	15.8	17.4	18.2	6.8	71.0	17.5	11.5	COSL	5.6	--	0.2	1.4	0.12	71	1.2
Bt1	25-50	2.6	5.1	8.5	9.0	4.7	29.9	12.5	57.6	C	4.8	1.28	1.9	8.7	0.15	33	4.8
Bt2	50-67	1.2	4.6	7.2	6.2	6.0	25.2	11.4	63.4	C	4.9	1.38	2.5	7.0	0.11	30	4.6
BCt1	67-118	3.3	11.6	18.2	17.3	9.5	59.9	18.5	21.6	SCL	4.7	1.48	1.0	2.0	0.09	30	1.6
BCt2	118-160	6.8	16.3	18.5	15.3	8.3	65.2	21.2	13.6	COSL	4.6	1.40	2.6	3.5	0.26	14	3.1
BC	160-240	1.1	7.7	20.4	25.1	15.5	69.8	22.5	7.7	FSL	4.7	--‡	3.0	3.7	0.48	11	3.4
C	240-290	11.1	20.9	18.7	13.4	7.8	71.9	23.8	4.3	COSL	4.8	--‡	2.4	3.0	0.70	3	2.5

† LS = loamy sand, COSL = coarse sandy loam, C = clay, SCL = sandy clay loam, FSL = fine sandy loam.

‡ Bulk density was not measured on these horizons because they were sampled from the base of the pit with an auger.

Appendix D. Laboratory Data for Site 2

Horizon	Depth	vcs	cs	ms	fs	vfs	total sand	total silt	total clay	Text†	pH	Bulk density	KCl Al	CEC	CEC /clay	% base saturation	ECEC
	cm											g/cc	Cmol/ kg	Cmol/ kg			cmol/kg
Ap	0-10	9.7	19.1	25.7	22.2	12.1	88.8	8.0	3.2	COS	5.4	--	0.5	3.9	1.22	51	2.5
EB	10-26	8.9	16.3	22.9	6.1	21.4	75.6	16.7	7.7	COSL	5.7	1.64	0.4	4.6	0.60	48	2.6
Bt1	26-61	2.2	6.6	9.8	8.2	6.1	32.9	17.8	49.3	C	5.7	1.51	0.4	5.9	0.12	75	4.8
Bt2	61-80	0.3	5.8	11.6	9.9	10.1	37.7	21.7	40.6	C	5.3	1.47	2.5	5.8	0.14	31	4.3
BCt	80-114	0.8	6.9	15.7	20.6	10.0	54.0	22.3	23.7	SCL	4.9	1.47	3.1	5.2	0.22	19	4.1
CB	114-158	3.2	7.8	17.4	20.9	9.0	58.3	23.5	18.2	FSL	4.8	1.45	4.1	6.5	0.36	18	5.3
C	158-200	3.0	9.5	17.2	21.9	12.7	64.3	23.4	12.3	FSL	4.5	1.31	2.4	4.9	0.40	18	3.3

† COS = coarse sand, COSL = coarse sandy loam, C = clay, SCL = sandy clay loam, FSL = fine sandy loam.

Appendix E. Amoozemeter Data for Site 1A

Location: Site 1A - 1
Date: 5/23/97
Horizon: Bt2
Hole Depth: 73 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	9:30	0	-	-
0.3 cm	105	10:00	0.5	63	0.0665
1.7 cm	105	10:30	0.5	357	0.377
4.4 cm	105	11:00	0.5	924	0.976
2.7 cm	105	11:30	0.5	567	0.599
2.7 cm	105	12:00	0.5	567	0.599
2.8 cm	105	12:30	0.5	588	0.620

Mean K: 0.606 cm/hr

Location: Site 1A - 2
Date: 5/23/97
Horizon: Bt2
Hole Depth: 69 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	9:30	0	-	-
0 cm	105	10:00	0.5	0	0
0.3 cm	105	10:30	0.5	63	0.0665
5.8 cm	105	11:00	0.5	1218	1.286
0.3 cm	105	11:30	0.5	63	0.0665
0.3 cm	105	12:00	0.5	63	0.0665
0.9 cm	105	12:30	0.5	189	0.200
1.0 cm	105	13:00	0.5	210	0.222
1.0 cm	105	13:30	0.5	210	0.222

Mean K: 0.215 cm/hr

Location: Site 1A - 3
Date: 5/23/97
Horizon: Bt4
Hole Depth: 109 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	13:20	0	-	-
0.5 cm	105	13:50	0.5	105	0.111
0.3 cm	105	14:20	0.5	63	0.066
0.5 cm	105	14:50	0.5	105	0.111
0.5 cm	105	15:20	0.5	105	0.111
0.5 cm	105	15:50	0.5	105	0.111

Mean K: 0.111 cm/hr

Location: Site 1A - 4
Date: 5/23/97
Horizon: Bt4
Hole Depth: 104 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	13:50	0	-	-
0.2 cm	105	14:20	0.5	42	0.044
0.2 cm	105	14:50	0.5	42	0.044
0.9 cm	105	15:20	0.5	189	0.200
1.0 cm	105	15:50	0.5	210	0.222
0.9 cm	105	16:20	0.5	189	0.200

Mean K: 0.207 cm/hr

Location: Site 1A - 5
Date: 8/19/97
Horizon: BC
Hole Depth: 137 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	8:35	0	-	-
1.7 cm	105	9:05	0.5	357	0.377
1.4 cm	105	9:35	0.5	294	0.310
1.4 cm	105	10:05	0.5	294	0.310
1.4 cm	105	10:35	0.5	294	0.310

Mean K: 0.310 cm/hr

Location: Site 1A - 6
Date: 8/19/97
Horizon: BC
Hole Depth: 139 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	8:35	0	-	-
0.6 cm	105	9:05	0.5	126	0.133
0.5 cm	105	9:35	0.5	105	0.111
0.5 cm	105	10:05	0.5	105	0.111
0.5 cm	105	10:35	0.5	105	0.111

Mean K: 0.111 cm/hr

Appendix F. Amoozemeter Data for Site 2A

Location: Site 2A - 1
Date: 5/13/97
Horizon: Bt1
Hole Depth: 52 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	10:25	0	-	-
2.2 cm	105	10:55	0.5	462	0.49
5.1 cm	105	11:25	0.5	1071	1.13
5.5 cm	105	11:55	0.5	1155	1.22
6.6 cm	105	12:25	0.5	1386	1.46
6.3 cm	105	12:55	0.5	1323	1.40
5.3 cm	105	13:20	0.42	1325	1.40

Mean K: 1.42 cm/hr

Location: Site 2A - 2
Date: 5/13/97
Horizon: Bt1
Hole Depth: 56 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	10:25	0	-	-
3.1 cm	105	10:55	0.5	651	0.69
3.3 cm	105	11:25	0.5	693	0.73
4.0 cm	105	11:55	0.5	840	0.89
5.0 cm	105	12:25	0.5	1050	1.11
4.7 cm	105	12:55	0.5	987	1.04
5.1 cm	105	13:25	0.5	1071	1.13
3.4 cm	105	13:45	0.5	1081	1.14

Mean K: 1.11 cm/hr

Location: Site 2A - 3
Date: 5/23/97
Horizon: Bt3
Hole Depth: 99 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	14:00	0	-	-
1.5 cm	105	14:30	0.5	315	0.333
0.6 cm	105	15:00	0.5	126	0.133
0.5 cm	105	15:30	0.5	105	0.111
0.7 cm	105	16:00	0.5	147	0.155

Mean K: 0.133 cm/hr

Location: Site 2A - 4
Date: 5/23/97
Horizon: Bt3
Hole Depth: 101 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	14:00	0	-	-
2.9 cm	105	14:30	0.5	609	0.643
1.7 cm	105	15:00	0.5	357	0.377
0.9 cm	105	15:30	0.5	189	0.200
0.8 cm	105	16:00	0.5	168	0.177
0.9 cm	105	16:00	0.5	189	0.200

Mean K: 0.192 cm/hr

Location: Site 2A - 5
Date: 5/27/97
Horizon: BC
Hole Depth: 127 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	9:45	0	-	-
1.6 cm	105	10:15	0.5	336	0.355
0.5 cm	105	10:45	0.5	105	0.111
0.2 cm	105	11:15	0.5	42	0.044
0.1 cm	105	11:45	0.5	21	0.022
0.2 cm	105	12:15	0.5	42	0.044

Mean K: 0.037 cm/hr

Location: Site 2A - 6
Date: 5/27/97
Horizon: BC
Hole Depth: 129 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	9:45	0	-	-
2.9 cm	105	10:15	0.5	609	0.643
1.1 cm	105	10:45	0.5	231	0.244
0.4 cm	105	11:15	0.5	84	0.089
0.3 cm	105	11:45	0.5	63	0.066
0.3 cm	105	12:15	0.5	63	0.066

Mean K: 0.074 cm/hr

Appendix G. Amoozemeter Data for Site 3A

Location: Site 3A - 1
Date: 8/22/97
Horizon: Bt3
Hole Depth: 47 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	8:00	0	-	-
4.5 cm	105	8:30	0.5	945	0.998
3.0 cm	105	9:00	0.5	630	0.665
2.4 cm	105	9:30	0.5	504	0.532
2.2 cm	105	10:00	0.5	462	0.488
2.3 cm	105	10:30	0.5	483	0.510

Mean K: 0.510 cm/hr

Location: Site 3A - 2
Date: 8/22/97
Horizon: Bt3
Hole Depth: 53 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	8:00	0	-	-
11.1 cm	105	8:30	0.5	2331	2.42
7.8 cm	105	9:00	0.5	1638	1.73
4.2 cm	105	9:30	0.5	882	0.931
4.1 cm	105	10:00	0.5	861	0.909
4.1 cm	105	10:30	0.5	861	0.909

Mean K: 0.916 cm/hr

Location: Site 3A - 3
Date: 8/22/97
Horizon: BC
Hole Depth: 101 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	10:30	0	-	-
0.8 cm	105	11:00	0.5	168	0.177
0.9 cm	105	11:30	0.5	189	0.200
1.0 cm	105	12:00	0.5	210	0.222
0.9 cm	105	12:30	0.5	189	0.200

Mean K: 0.207 cm/hr

Location: Site 3A - 4
Date: 8/22/97
Horizon: BC
Hole Depth: 102 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	10:30	0	-	-
0 cm	105	11:00	0.5	0	0
0.1 cm	105	11:30	0.5	21	0.022
0.2 cm	105	12:00	0.5	42	0.044
0.1 cm	105	12:30	0.5	21	0.022

Mean K: 0.029 cm/hr

Location: Site 3A - 5
Date: 8/22/97
Horizon: C
Hole Depth: 155 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	12:45	0	-	-
1.3 cm	105	13:15	0.5	273	0.288
1.4 cm	105	13:45	0.5	294	0.310
1.3 cm	105	14:15	0.5	273	0.288

Mean K: 0.295 cm/hr

Location: Site 3A - 6
Date: 8/22/97
Horizon: C
Hole Depth: 154 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	12:45	0	-	-
0.1 cm	105	13:15	0.5	21	0.022
0.1 cm	105	13:45	0.5	21	0.022
0.2 cm	105	14:15	0.5	42	0.044
0.2 cm	105	14:45	0.5	42	0.044

Mean K: 0.033 cm/hr

Appendix H. Amoozemeter Data for Site 4A

Location: Site 4A - 1
Date: 5/7/97
Horizon: Bt2
Hole Depth: 30 cm
Chambers used: small

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	20	11:15	0	-	-
0.7 cm	20	11:30	0.25	56	0.059
0.8 cm	20	11:45	0.25	64	0.068
0.7 cm	20	12:00	0.25	56	0.059
0.5 cm	20	12:15	0.25	40	0.042
0.9 cm	20	12:30	0.25	72	0.076
2.0 cm	20	13:00	0.5	80	0.084
0.9 cm	20	13:15	0.25	72	0.076
0.9 cm	20	13:30	0.25	72	0.076

Mean K: 0.078 cm/hr

Location: Site 4A - 2
Date: 5/6/97
Horizon: Bt2
Hole Depth: 33 cm
Chambers used: small

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	20	10:40	0	-	-
0.3 cm	20	10:55	0.25	24	0.025
9 cm	20	11:10	0.25	720	0.760
1.2 cm	20	11:25	0.25	96	0.101
1.0 cm	20	11:40	0.25	80	0.084
0.9 cm	20	11:55	0.25	72	0.076
0.8 cm	20	12:10	0.25	64	0.067
0.9 cm	20	12:25	0.25	72	0.076
0.9 cm	20	12:40	0.25	72	0.076

Mean K: 0.074 cm/hr

Location: Site 4A - 3
Date: 5/6/97
Horizon: Bt3
Hole Depth: 76 cm
Chambers used: small

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	20	12:00	0	-	-
0.1 cm	20	12:15	0.25	8	0.0084
0.3 cm	20	12:30	0.25	24	0.025
0.1cm	20	12:45	0.25	8	0.0084
0.7 cm	20	13:00	0.25	56	0.059
0.4 cm	20	13:15	0.25	32	0.034
0.4 cm	20	13:30	0.25	32	0.034
0.4 cm	20	13:45	0.25	32	0.034

Mean K: 0.034 cm/hr

Location: Site 4A - 4
Date: 5/6/97
Horizon: Bt3
Hole Depth: 71 cm
Chambers used: small

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	20	12:55	0	-	-
0.3 cm	20	13:10	0.25	24	0.025
0.1 cm	20	13:25	0.25	8	0.0084
0.3cm	20	13:40	0.25	24	0.025
0.1 cm	20	13:55	0.25	8	0.0084
0.2 cm	20	14:10	0.25	16	0.017
0.5 cm	20	14:25	0.25	40	0.042
0.5 cm	20	14:40	0.25	40	0.042
0.5 cm	20	14:55	0.25	40	0.042

Mean K: 0.042 cm/hr

Location: Site 4A - 5
Date: 5/7/97
Horizon: BC
Hole Depth: 104 cm
Chambers used: small

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	20	9:15	0	-	-
29 cm	20	9:30	0.25	2320	2.45
2.4 cm	20	9:45	0.25	192	0.202
2.6 cm	20	10:00	0.25	208	0.219
2.2 cm	20	10:15	0.25	176	0.186
2.3 cm	20	10:30	0.25	184	0.194
2.2 cm	20	10:45	0.25	176	0.186
2.2 cm	20	11:00	0.25	176	0.186

Mean K: 0.188 cm/hr

Location: Site 4A - 6
Date: 5/7/97
Horizon: BC
Hole Depth: 106 cm
Chambers used: small

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	20	9:20	0	-	-
38.5 cm	20	9:35	0.25	3080	3.25
0.4 cm	20	9:50	0.25	32	0.034
0.2 cm	20	10:05	0.25	16	0.017
0.1 cm	20	10:20	0.25	8	0.0084
0.3 cm	20	10:35	0.25	24	0.025
0.2 cm	20	10:50	0.25	16	0.017
0.2 cm	20	11:05	0.25	16	0.017
0.2 cm	20	11:20	0.25	16	0.017

Mean K: 0.017 cm/hr

Location: Site 4A - 7
Date: 5/7/97
Horizon: BC
Hole Depth: 100 cm
Chambers used: small

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	20	11:40	0	-	-
0.7 cm	20	11:55	0.25	56	0.059
0.3 cm	20	12:10	0.25	24	0.025
0.5 cm	20	12:25	0.25	40	0.042
0.2 cm	20	12:40	0.25	16	0.017
0.3 cm	20	12:55	0.25	24	0.025
0.3 cm	20	13:10	0.25	24	0.025
0.5 cm	20	13:25	0.25	40	0.042
0.4 cm	20	13:40	0.25	32	0.034
0.5 cm	20	13:55	0.25	40	0.042
0.4 cm	20	14:10	0.25	32	0.034

Mean K: 0.038 cm/hr

Appendix I. Amoozemeter Data for Site 5A

Location: Site 5A - 1
Date: 7/3/97
Horizon: Bt2
Hole Depth: 46 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	10:00	0	-	-
7.9 cm	105	10:30	0.5	1659	1.75
10.8 cm	105	11:00	0.5	2268	2.39
10.0 cm	105	11:30	0.5	2100	2.22
5.1 cm	105	12:00	0.5	1071	1.13
10.2 cm	105	12:30	0.5	2142	2.26
11.1 cm	105	13:00	0.5	2331	2.46
10.7 cm	105	13:30	0.5	2247	2.37

Mean K: 2.36 cm/hr

Location: Site 5A - 2
Date: 7/3/97
Horizon: Bt2
Hole Depth: 46 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	12:45	0	-	-
1.3 cm	105	13:15	0.5	273	0.288
1.2 cm	105	13:45	0.5	252	0.266
0.8 cm	105	14:15	0.5	168	0.177
1.0 cm	105	14:45	0.5	210	0.222
0.9 cm	105	15:15	0.5	189	0.200

Mean K: 0.200 cm/hr

Location: Site 5A - 3
Date: 8/15/97
Horizon: Bt3
Hole Depth: 82 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	9:00	0	-	-
1.6 cm	105	9:30	0.5	336	0.355
1.1 cm	105	10:00	0.5	231	0.244
1.0 cm	105	10:30	0.5	210	0.222
1.0 cm	105	11:00	0.5	210	0.222

Mean K: 0.229 cm/hr

Location: Site 5A - 4
Date: 8/15/97
Horizon: Bt3
Hole Depth: 93 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	9:00	0	-	-
14.7 cm	105	9:30	0.5	3087	3.26
10.5 cm	105	10:00	0.5	2205	2.33
9.8 cm	105	10:30	0.5	2058	2.17
10.0 cm	105	11:00	0.5	2100	2.22
9.9 cm	105	11:30	0.5	2079	2.19

Mean K: 2.19 cm/hr

Location: Site 5A - 5
Date: 8/15/97
Horizon: BC
Hole Depth: 131 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	11:15	0	-	-
0.4 cm	105	11:45	0.5	84	0.089
0.3 cm	105	12:15	0.5	63	0.066
0.3 cm	105	12:45	0.5	63	0.066
0.3 cm	105	13:15	0.5	63	0.066

Mean K: 0.066 cm/hr

Location: Site 5A - 6
Date: 7/3/97
Horizon: BC
Hole Depth: 122 cm
Chambers used: both

Change in water level	Chamber Factor	Clock Time	Elapsed Time (hr)	Q (cm3/hr)	K (cm/hr)
0 cm	105	9:45	0	-	-
1.2 cm	105	10:15	0.5	252	0.266
0.3 cm	105	10:45	0.5	63	0.0665
0.2 cm	105	11:15	0.5	42	0.0443
0.2 cm	105	11:45	0.5	42	0.0443
0.2 cm	105	12:15	0.5	42	0.0443

Mean K: 0.0443 cm/hr

VITA

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