5-2003

Identification of subsurface features that affect offsite movement of waterborne contaminants through the use of soil classification/mapping techniques, electromagnetic inductance (EM), and ground-penetrating radar (GPR)

Kevin D. Raley

To the Graduate Council:

I am submitting herewith a thesis written by Kevin D. Raley entitled "Identification of subsurface features that affect offsite movement of waterborne contaminants through the use of soil classification/mapping techniques, electromagnetic inductance (EM), and ground-penetrating radar (GPR)." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant, Soil and Environmental Sciences.

John T. Ammons, Major Professor

We have read this thesis and recommend its acceptance:

Robert S. Freeland, Ronald E. Yoder

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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

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Vice Provost and Dean of Graduate Studies

IDENTIFICATON OF SUBSURFACE FEATURES THAT AFFECT OFFSITE MOVEMENT OF WATERBORNE CONTAMINANTS THROUGH THE USE OF SOIL CLASSIFICATION/MAPPING TECHNIQUES, ELECTROMAGNETIC INDUCTANCE (EM), AND GROUND-PENETRATING RADAR (GPR)

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Kevin D. Raley
May 2003

DEDICATION

This Thesis is dedicated to my father

Charles J. Raley

For all of the support, guidance, and insight
that you have given me
throughout my life.

Acknowledgements

I wish to thank everyone who has given me guidance and support during the completion of my Master of Science Degree in Soil Science. I would like to thank Dr. Tom Ammons for making me understand the fundamental concepts of Pedology. I would also like to thank my committee members, Dr. Rob Freeland and Dr. Ron Yoder, for offering their assistance during my graduate career. I would like to thank Dr. Gary Lessman for caring enough to encourage me to attend graduate school and for being a friend.

I would also like to thank the many people that gave me help through the times that seemed agonizing: Amy Raley, Ryan Noble, Curt McDaniel, Robby Wilson, David Walker, Stephanie Harvey, Chris Raley, Lady, and Khaki. All of you gave me unconditional support and helped me through the hard times.

Abstract

Concerns regarding the quality of our water resources and how to protect them are more evident today than ever before. Many every day human activities affect the quality of this finite resource. Agricultural activity can negatively impact water supplies. By confining large-scale agriculture onto more confined plots of land, inputs are maximized and the consequences are often detrimental to the environment. Specifically, groundwater is often affected by overuse of lands that are not suitable for the production pressures put on them.

This study utilized soil classification and characterization techniques as well as mapping techniques to identify and research features known to contribute to lateral subsurface movement of water within soil bodies. In addition to this, electromagnetic inductance (EM) and ground-penetrating radar (GPR) were used to aid in the identification of such features non-intrusively. The study was conducted on sites located on Major Land Resource Area (MLRA) 134, the Southern Mississippi Valley Silty Uplands. Eight pedons were described and sampled at sites near Lynville, Kentucky and Holly Springs, Mississippi. Both EM and GPR were used at these sites in order to identify locales of subsurface features thought to contribute to lateral subsurface movement of water.

The specific objectives of this study were: 1) Complete soil morphological, chemical, and physical characterization of landforms on MLRA 134 sites near Lynville, Kentucky and Holly Springs, Mississippi. 2) Classification of these soils to the family level of Soil Taxonomy 3) Conduct non-intrusive soil investigations

using both EM and GPR 4) Assess how well this protocol works at the selected sites.

The soils encountered at the Lynville, Kentucky site consisted of fine-silty, mixed, active, thermic Typic Fragiudalfs and fine-silty, mixed, active, thermic Fragic Hapludalfs. The soils encountered at the Holly Springs, Mississippi site consisted of fine-silty, mixed, active, thermic Ultic Hapludalfs, fine-loamy, mixed, active, thermic Typic Fragiudalfs, and fine-loamy, mixed, active, thermic Typic Hapludults. The parent material sequence encountered at each of the sites consisted of loess, alluvium, and Tertiary aged coastal plain material. Loess had been eroded from two of the pedons characterized at the Holly Springs, Mississippi site.

Electromagnetic inductance provided a very useful depiction of the conductivity encountered at each of the study sites. Generally, soils at each site that contained fragipans were located in regions of higher conductivities in the resulting EM scans. The resulting ground-penetrating radar data collected at each of the sites were classified using a beta version fuzzy neural network classification program. The graphical representation of the GPR data collected at the Lynville, Kentucky site was similar to both the EM and soil maps generated for this site. The classification of GPR data taken at the Holly Springs, Mississippi Site was not as clear.

TABLE OF CONTENTS

LIST OF FIGURES

Figure | Page

LIST OF TABLES

Introduction

Concerns regarding the quality of our water resources and how to protect them are more evident today than ever before. Many every day human activities affect the quality of this finite resource. Agricultural activity can negatively impact water supplies. By confining large-scale agriculture onto more confined plots of land, inputs are maximized and the consequences are often detrimental to the environment. Specifically, groundwater is often affected by overuse of lands that are not suitable for the production pressures put on them.

In the past decade, protocols utilizing geophysical exploration of soil bodies have been researched as a means to identify naturally occurring features within soil bodies. These naturally occurring features may affect subsurface movement of water as well as contaminants dissolved in the water. In August 1990, the Ames Plantation Water Quality Project was started to "differentiate the impact of various agricultural practices on water quality," (Ames Plantation Staff, 1999). Ames Plantation was chosen due to the representative occurrence of loessial soils in this area. Loessial soils in West Tennessee and throughout the Southern Mississippi Valley are characterized as being unpredictable when investigating subsurface flow. This area is considered to be in the Southern Mississippi Valley Silty Upland Major Land Resource Area (MLRA 134), which is defined by upland terraces covered with loess and underlain by unconsolidated costal material of Tertiary and Cretaceous age (NRCS, 1999). The loessial soils in this area exhibit three characteristic parent materials which are believed to contribute to lateral movement of water due to the high contrast of texture between vertically adjacent soil horizons (Ammons *et al.*, 1994; Freeland *et al.*, 1997).

More recently, protocols have been refined in order to minimize disturbance to these lands so as to not affect the outcomes of the current research. Two methods have been used to identify soil features that may affect subsurface movement of water: 1) Traditional soil mapping and classification (intrusive) 2) The use of ground penetrating radar and electromagnetic induction to predict subsurface flow (non-intrusive). Traditional soil classification and mapping uses "pits" in order to observe *in situ* characteristics of soil bodies. By classifying soils in this manner properties and behaviors of the soil body can be observed, confirming any previous assumptions. While this practice is necessary in interpreting the behavior of specific soil types, intrusive soils mapping may drastically disturb the natural soil body and essentially the natural flow of subsurface water. Intrusive soil characterization is detrimental to investigation of subsurface flow (Freeland *et al.*, 1999) however, it is needed in order to observe the properties of the soil body that contribute to this phenomenon. Advanced technologies such as ground penetrating radar (GPR) and electromagnetic induction (EM) have provided for non-intrusive mapping, which does not disturb the natural flow paths of groundwater. All three of these techniques have been applied at Ames Plantation to develop a protocol for research on the incidence of subsurface flow of water in agriculturally managed areas.

With a functional protocol now in place, it is essential to test other areas in order to observe the limitations of the protocol. The proposed project involves testing the protocol in areas which exhibit similar characteristics to those at Ames Plantation (MLRA 134). The research was conducted on two separate sites located on the Southern Mississippi Valley Silty Upland Resource Area. Site one is located near Lynnville, in Western Kentucky and site 2 is located near Holly Springs in Northern Mississippi.

The specific objectives are: 1) Complete soil morphological, chemical and physical characterization of landforms on MLRA 134 sites near Lynville, Kentucky and Holly Springs, Mississippi 2) Classification of these soils to the family level of taxonomy 3) Conduct non-intrusive soil investigation using both GPR and EMI 4) Assess how well this protocol works at the sites located near Lynville, Kentucky and Holly Springs, Mississippi.

Chapter 1: Complete Soil Characterization of Pedons at Selected Sites near Lynnville, KY and Holly Springs, MS.

Geology

This study focuses on two locations found within the geologic feature known as the Mississippi Embayment. Figure 1 shows the portion of the Mississippi Embayment pertinent to this study. The Mississippi Embayment is a syncline that plunges southwards, with an axis that is approximately the current course of the Mississippi River (Cushing *et al.*, 1964; McDowell, 1986). The Embayment consists of two general physiographic regions: the lowlands of the Mississippi Alluvial Plain and the Coastal Plain uplands. Many physiographic regions within the Mississippi Embayment go beyond the scope of this study. The northern most apex of the Embayment is in southern Illinois, with boundaries expanding eastward and westward from about the 87th to the 95th meridians respectively. The Southern boundary of the Embayment is adjacent to roughly the 32nd parallel. Alabama, Arkansas, Illinois, Kentucky, Louisiana, Mississippi, Missouri, Tennessee, and Texas all have regions that are considered to be part of the Mississippi Embayment (Cushing *et al.*, 1964).

With reference to the geologic timescale (Table 1), the Mississippi

Figure 1. The extent of the Mississippi Embayment pertinent to this study.

Table 1: Geologic timescale.

Era	Period	Epoch	Age (m.y.b.p.)
Cenozoic	Quaternary	Holocene	0.01
		Pleistocene	2.5
	Tertiary	Pliocene	7
		Miocene	26
		Oligocene	38
		Eocene	54
		Paleocene	65
Mesozoic	Cretaceous		136
	Jurassic		190
	Triassic		225
Paleozoic	Permian		280
	Pennsylvanian		310
	Mississippian		345
	Devonian		395
	Silurian		430
	Ordivician		500
	Cambrian		570

Embayment is thought to have formed as a result of continental divergence during the late Precambrian era. The axis of this separation was in fact the ancient course of the Mississippi River. It caused the crust to thin, resulting in the subsidence of this region. Evidence of this is derived from deep well cores throughout the region which show Precambrian and Cambrian sedimentary rocks (Guccione and Zachary, 1999).

The collision of present day Africa with the eastern boundary of North America, as well as the collision of present day South America with the southern boundary of North America, during the late Paleozoic era (Mississippian and Pennsylvanian Periods) is thought to have continued the formation of the Mississippi Embayment. The result of this massive collision is the present day Appalachian and Ouichita mountains. The continued continental collision and the formation of mountains exerted great pressure on the crust immediately inland of the new mountain features. This caused vast depressions to form and, consequently, a series of basins immediately inland of the newly formed mountain ranges (Guccione and Zachary, 1999; Cushing *et al.*, 1964).

During the Jurassic period of the Mesozoic era, the southern portion of the Mississippi Embayment received sedimentary deposits. The locality of these deposits reveals that the Mississippi Embayment still had not reached its full formation because the system was still considered to have a positive gradient towards the current day Gulf of Mexico. Cretaceous formations in the Embayment extend much farther north than the Jurassic formations. This indicates that subsidence continued throughout the Mesozoic era (Cushing *et al.*, 1964). An ancient sea that at one time covered the area laid down the Cretaceous deposits and during the Late Cretaceous Epoch the Embayment occupied its northern most limit (Cushing *et al.*, 1964; McDowell, 1986).

During the Cretaceous Period, the Mississippi Embayment was covered by the Late Cretaceous Sea, which in turn deposited massive amounts of sediment that exists currently as sand, clay, marl and chalk. These deposits are thickest at the axis of the Embayment and in its southern portions (Cushing *et al.*, 1964). The onset of the Laramide Orogeny during the Late Cretaceous/Early Tertiary periods marks the formation of the modern day Rocky Mountains, as well as the start of the regression of the Late Cretaceous Sea in the Mississippi Embayment (Guccione and Zachary, 1999).

During the Tertiary Period of the Cenozoic Era, the sea that once covered the Mississippi Embayment underwent a series of transgressions and regressions. At the beginning of the Tertiary Period, during the Paleocene Epoch, the sea is thought to have occupied most of the Mississippi Embayment well into its apex in southern Illinois. Fluctuations of sea levels in the Mississippi Embayment during the Tertiary Period ultimately led to the formation of the Atlantic Coastal Plain and the Gulf Coastal Plain regions of the Untied States. The final round of invasion by the sea into the Embayment is thought to have occurred during the Jacksonian time at the end of the Eocene Epoch. Thereafter, the majority of the Embayment has been above sea level. The

Mississippi Embayment is part of the Gulf Coastal Plain region (Guccione and Zachary, 1999; Cushing *et al.*, 1964).

The Claiborne Group

Sediments of the Claiborne Group are known to exist in the two areas encompassed by this study (Lambert, 1965; Bicker, 1969; Tyer *et al.*, 1972; Cushing *et al.*, 1964; Olive and McDowell, 1986). The Claiborne Group is a formation of the Eocene Epoch during the Tertiary Period of the Cenozoic Era. Except for Illinois and Missouri, the Claiborne group is found throughout the Mississippi Embayment (Cushing *et al.*, 1964).

The Claiborne Group consists of both marine and non-marine sediments which include sand, sandy clay, clay, shale and limestone. In the southern region of the Embayment, the Claiborne Group is differentiated into separate formations based on the occurrence of the materials in different marine beds. However, in the northern part of the Embayment, the Claiborne Group is undifferentiated (Cushing *et al.*, 1964; Lambert, 1965). Olive and McDowell (1986) suggest that the Claiborne Group found in Western Kentucky is from a freshwater source. Analyses of pollen assemblages found in the undifferentiated Claiborne Group of Western Kentucky indicate a non-marine environment during the time of deposition.

In northern Mississippi, the Claiborne Group exists as the Tallahatta Formation as well as the Kosciusko Formation. The Kosciusko Formation overlies the Tallahatta Formation and is described by Bicker (1969) as irregularly bedded sand, clay and some quartzite. Tyer *et al.*, (1972) further describes the Kosciusko Formation as sand and sandstone that lies atop the Tallahatta Formation. The Tallahatta Formation, the dominant geology of the area, is comprised of sand, white shale, and lignite. These deposits have a maximum thickness of 60 meters (Tyer *et al.*, 1972).

In Western Kentucky, the Claiborne Group is undifferentiated. That is, no reason exists to believe that individual formations of the Claiborne Group occur in this area. Here, the Claiborne Group is described as sands and clays that are interbedded. The sand member is brown, yellowish-brown to white and weathers to a reddish brown ranging from fine to very coarse in particle size. The clay member is described as brown, gray, pink or white and ranges in texture from silty to sandy (Lambert, 1965).

Continental Deposits

Continental deposits occur throughout Western Kentucky, west of the *Cumberland* and *Tennessee* rivers. These deposits lay atop the Claiborne formation in the area of this study and elsewhere. The thickness ranges anywhere from zero meters up to 27 meters and is variable across the region. McDowell and Newell (1986) describe the continental deposit generally as basal gravel grading upward into sand with interbedded silt and clay. The lithology of the deposit reveals four distinct stratifications (Lambert, 1965).

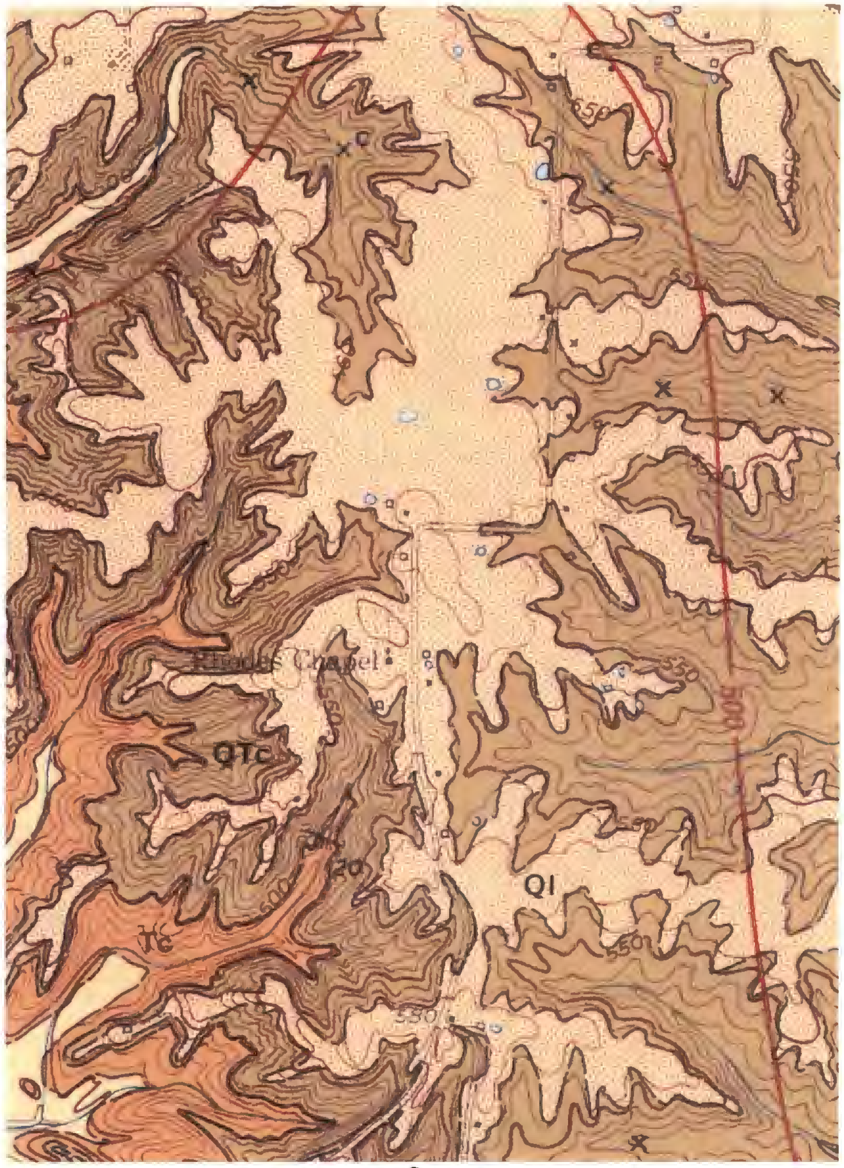
The top stratum of the continental deposit is described as gravelly sand and sandy gravel. Its color is usually dark-reddish-brown. The thickness of this layer ranges from 0 to 15 meters. The next stratum is described as gravel and sand that is brown to brick red. Along with gravel, chert pebbles are common as well as quartz pebbles. The sand fraction of this layer is described as fine to coarse, dominantly quartz, with little or no chert fragments and occurs mixed with gravel. The upper boundary of this stratum (approximately one meter) is usually brick red, silty to clayey, fine to medium quartz sand containing scattered chert pebbles. The thickness of this layer ranges from zero to 9 meters (Lambert, 1965).

The third stratum of the continental deposit found in Western Kentucky is comprised of sand, clay, silt, and gravel. The sand portion of this layer is described as brown to white. The sand is medium grained, dominantly quartz with some mica and contains one to five percent chert. The clay portion of this layer is described as light to dark gray and is mottled. The texture of this clay ranges from silty to sandy. The silt portion of this layer is described as argillaceous with a yellowish-orange color. Its texture is slightly sandy. The gravel portion of this layer is comprised of chert pebbles as well as quartz pebbles and occurs as discontinuous lenses in sand. Also found in this layer are concretions which can have a maximum length of 10 centimeters and diameter of up to 5 centimeters. The concretions are comprised of sand cemented with ferruginous material (ironstone). This layer ranges from zero to 12 meters in thickness (Lambert, 1965).

The final stratum of the continental deposit is gravel and is brown to white in color. The upper few centimeters are usually cemented by ferruginous material and, the surface of this layer, adjacent to the overlying layer, has a botryoidal appearance (resembling a bunch of grapes). Chert and quartz pebbles are common (Lambert, 1965).

There seems to be some question as to the time of origin of the continental deposit in Western Kentucky. Lambert (1965) places the origin of the continental deposit in the Pliocene and Pleistocene Epochs of the Tertiary and Quaternary Periods, respectively. The basis for this assessment comes from analysis of a pollen assemblage found in the third stratum of the continental deposit. Analysis of the pollen revealed that the species represented could in fact be found in the area at the time of this document's publication. Therefore, it was assumed that the assemblage was of Pliocene or Pleistocene age based on underlying and overlying geologies. This sample was obtained approximately one kilometer east of the study sight located in Graves County, Kentucky. Figure 2 depicts the typical geology found in Western Kentucky including the Continental and Loess deposits.

McDowell and Newell (1986) suggest the continental deposits of Western Kentucky represent two periods of deposition. At higher elevations, the continental deposits are of the Miocene and Pliocene Epochs of the Tertiary Period and at lower elevations the continental deposits are of the Pleistocene Epoch during the Quaternary Period.



2a

2b

Figure 2. The geologies typical of Graves County Kentucky including The Continental Deposits. Tc= Tertiary Claiborne Deposits, QTc= Continental Deposits, and Ql=Quaternary loess deposits. (Approximate Scale= 1:16,941; C.I.=3.05m). Figure 2b. Typical profile of the geology found in Western Kentucky. (Approximate Scale= 1:24,000). Source: Lambert, 1965.

Loess

Loess is a highly debated material in that there are many theories surrounding its formation as well as its deposition in the United States. The purpose of this discussion is not to further these debates. Generally, loess is considered silt that has been deposited over the landscape by an Aeolian process (wind deposited). The large portions of silt that was deposited throughout the Mississippi River Valley represent glacial and interglacial periods where silt has accumulated as a byproduct of glacial till and has been deposited in the river valley by fluvial action. Heavy winds during the periods of glacial activity picked up these silt particles and deposited them in a blanket that is thickest along the axis of the Mississippi Embayment (the *Mississippi River*) and thins both east and west of the present day *Mississippi River* (Lindbo *et al.*, 1997; Saucier, 1994; Rutledge *et al.*, 1996).

In the United States, the deposition of loess is believed to have occurred during the Quaternary Period of the Cenozoic Era. This recent Period of geologic history is marked by both glacial and interglacial periods during which loess was deposited. Loess depositions are marked by the development of paleosols within them. These paleosols represent separate periods of deposition (Saucier, 1994; McDowell and Newell, 1986; Lindbo *et al.*, 1997; Follmer, 1996). There are basically three depositions that are widely accepted. These are Peoria loess, which is of most recent age in relation to deposition, Roxana loess, and Loveland loess. The latter depositions are subsequently older in age based on deposition during different stages of glaciations throughout the Pleistocene Epoch.

Rutledge *et al.* (1996) and McDowell and Newell (1986) suggest that Peoria loess is of the Late Wisconsinan glacial stage in origin; Roxana loess is from the Late to Middle Wisconsinan glacial stage and, Loveland loess is from the Illinoian glacial stage. It is documented in the literature that Peoria loess occurs dominantly throughout the areas which encompass this study (Lindbo *et al.*, 1997; Lindbo *et al.*, 1995; Rutledge *et al.*, 1996; McDowell and Newell, 1986; Saucier, 1994).

Table 2 is adapted from Ammons *et al.* (1994) and shows the glacial and interglacial stages responsible for the formation and deposition of loess found throughout West Tennessee. In addition to showing Peoria, Roxana, and Loveland loess, it is suggested that there is another loess deposition found here. Farmdale loess is illustrated to be from the Wisconsinan stage and Peoria loess is actually from the early Holocene Epoch.

McDowell and Newell (1986) describe the Peoria loess found in Western Kentucky as pale yellowish gray and as much as 19 meters thick along the

Table 2: The glacial and interglacial stages responsible for the formation and deposition of loess in West Tennessee

Years Before Present	Glacial and Interglacial Stages	Tennessee Loess Depositions
10,000	Holocene (early)	Peoria
70,000	Wisconsinan	Farmdale
120,000	Sangamonian	Roxana
170,000	Illinoian	Loveland

Mississippi River and thins eastward. The Roxana loess in Western Kentucky is described as reddish brown and contains lenses of sand. It is generally less than 2 meters thick. The Loveland loess of Western Kentucky is found in an isolated pattern west of Paducah and is described as grayish orange.

Tyer *et al.* (1972) document that the soils found in Marshall County, Mississippi are those formed in coastal plain sediment and are overlain by loess. Furthermore, the authors state that the loess overlaying the Claiborne Formation is from the Pleistocene Epoch of the Quaternary Period. This indicates that based on correlations between glacial periods and loess deposits found in West Tennessee (table 2), the loess immediately adjacent to the Tertiary deposits in Mississippi may be Roxana or Loveland loess. The thick loess deposits are found extensively in bluffs west of Marshall County Mississippi and thin to the east.

Geomorphology

The regional landforms found in each of the areas of study are closely related to Saucier's (1987) discussion of terrace formation. Although Saucier confined his research to five rivers found in West Tennessee, the proximity of the study sites to these rivers warrants the discussion of his theory here.

Through the use of 1:24,000 scale topography maps as well as traditional geomorphology techniques, Saucier identified four terrace formations on the *Obion*, *Forked Deer*, *Hatchie*, *Loosahatchie*, and *Wolf Rivers* in West Tennessee. The four terrace formations are the Finley, Hatchie, Humbolt, and Henderson terraces. The Finley Terrace is the youngest in age and is three to seven meters above the present day flood plain elevation. The Hatchie Terrace is the next in age and is well preserved throughout the area of Saucier's study. At the mouths of the rivers in the area of his study, Saucier describes the Hatchie Terrace as being 10 to 15 meters above the present day flood plain elevation. The Humbolt Terrace is next in age and is more difficult to recognize due to its smaller total area and its dissection by older meandering streams. It ranges anywhere from 10 to 20 meters above present day flood plain elevation. The Henderson Terrace described by Saucier is the oldest terrace found in West Tennessee. It is limited to only the uppermost reaches of the three forks of the *Forked Deer* River, which is just south of the study area located in Kentucky. It is very dissected and is higher in elevation than the Humbolt Terrace. Saucier proposes that the original expanse of this terrace has been destroyed "during . . . valley degradation and aggradation and floodplain formation," (1987).

The Finley and Hatchie terraces observed by Saucier possess nil gradients over long stretches upstream (eastward) from the Mississippi River alluvial valley. Thus, he proposes that these two terraces are products of backwater flooding of the Mississippi River when high flood stages and rapid sedimentation at the mouths of the rivers created a damming effect. As a result, lacustrine lakes formed, and ultimately these two terraces were the result. The Humbolt and Henderson Terraces, however, do not possess these qualities, and thus, Saucier proposes that these two terraces are entirely fluvial in origin.

The rivers and their associated valleys appear to be severely under fit. That is, given the present day magnitude of the rivers and their associated valleys one would tend to believe that there is no possible way that these rivers could have formed such large valleys. However, Saucier proposes that the rivers used in his evaluation of these landforms have formed these valleys. Figure 3 illustrates one such under fit stream.

W.F. Geyl presents an alternate theory to Saucier's fluvial origin of terraces. Geyl (1996, 1968) suggests that the nil gradient streams found throughout the low-lying uplands of the Upper Mississippi Embayment are products of the regression of ancient seas and are termed tidal paleomorphs. Tidal paleomorphs are relict landforms whose current physiography are products of tidal morphogenesis. Current tidal streams are termed tidal neomorphs and possess the same characteristics as the relict tidal paleomorphs found throughout Western Kentucky, Western Tennessee and Northwestern Mississippi. These ancient tidal streams an their associated channels as well as present day tidal streams are much larger than rivers and their associated channels. Thus the tidal paleomorphs have streams that are severely under fit (figure 3).

Historical Perspective of Pedology

As a benefit to understanding any subject, it is important to know about the history that surrounds it. Pedology is a term derived from Greek ("*pedon*" meaning "ground" and "*logos*" meaning "science"). It can be thought of as the

Figure 3: The nature of under fit streams and associated valleys and interfluves found in Western Kentucky. C.I.=3.05m. Contours drawn in red are proposed contours found on erosional surfaces of Eocene aged rocks. Source: Lambert, 1965. (Approximate scale 1:23,200. C.I.= 3.05m).

study of the processes from which a soil body has formed and the grouping of soil bodies into various categories based on their properties, given a specific set of soil forming factors (Buol *et al.*, 1989).

The realization that soil properties influence the quality of life from a productivity standpoint is evident from the transformation of the human race from a purely hunting civilization to one that also farmed the land. As *Homo sapiens* depleted wild game in the environs that they populated an alternative food source was needed. Thus began the quest by humans to understand the nature of soils. Farming communities that date back as far as 3^{rd} to 2^{nd} millennium B.C. have been found in northern India where volcanic soils occur. In contrast, even further north where the soils are much less fertile, there is no evidence of human habitation (Krupenikov, 1992). Perhaps it can be stated that not only did human existence depend on the formation of civilized communities, but also a fertile land base in order to maintain a thriving society.

Another example of how long humans have been in touch with the nature and prosperity that soils possess is the written law of the Babylonian King Hammurabi (1792-1750 B.C.). In the early 1900's, a French archaeological expedition recovered a stone on which Hammurabi's laws were engraved. "If a man neglects to strengthen the dam on his land, or does not reinforce his dam, and the latter develops a breach and the water floods a neighbor's field, then he must compensate for the loss of grain," (Krupenikov, p. 56, 1992). This law illustrates how the early civilizations not only regarded their land as an asset but also the soils thereon. The conservation and fertility of their soils was essential to the prosperity and well being of their civilization.

The Ancient Greek societies also knew of soil as a property based medium which possessed certain qualities that gave rise to beneficial plants. Aristotle (384-322 B.C.) had a desire to learn about soil and did so by not only studying the soils found in Greece, but also from the people of other countries such as Egypt and Mesopotamia. Obviously, he realized that soils in these areas were very different due to climate and moisture differences. Aristotle's successor, Theophrastes (372-287 B.C.), divided most of the knowledge regarding soils into elemental characteristics and moisture. He defined soils as "a source of nutrition" for plants as well as a source of moisture (Krupenikov, 1992; Buol *et al.*, 1989).

Perhaps the most influential person in modern soil science was Vasilii Vasilevich Dokuchaev (1846-1903). He is considered the father of genetic soil science. Among his major accomplishments and contributions as a soil scientist are development of methods related to the field description and mapping of soils, description of major soil groups and their genesis, and establishment of genetic classification of soils (Krupenikov, 1992; Buol *et al.*, 1989).

In Russia, the 18^{th} and 19^{th} centuries were plagued by famine due to crop failure brought on by drought. This prompted Dokuchaev in 1877 to begin study on the Chernozem soils of Russia in order to conserve their highly productive nature. From his investigations, Dokuchaev wrote a book entitled *The Russian*

Chernozem in which he described soil as, "the surface or subsurface horizons of rocks (which, is immaterial), altered naturally by the combined influence of water, air, and various kinds of organisms both living and dead," (V.V. Dokuchaev, as quoted by Krupenikov, p. 24, 1992). Based on the study of the Chernozemic soils in Russia, Dokuchaev developed a plan to try and conserve this vital resource. Among the measures he proposed were erosion prevention, forest catchment areas on slopes, pond construction, artificial irrigation, and balance between cultivated lands, meadows, and forest in order to maintain ecological balance (Krupenikov, 1992).

If it were not for the works of K.D. Glinka (1867-1927), perhaps much of the world would not know of Dokuchaev and his major accomplishments. K.D. Glinka was a student of Dokuchaev's and among his major accomplishments was the translation of Dokuchaevian pedologic principles into German and English. Glinka wrote in detail of soil genesis and classification. One facet of Glinka's career that is often overlooked is his investigation of buried soils. The studies that he conducted on buried soils serve as a source of fact not only for pedologists but also for geologists and climatologists (Joffe, 1949; Buol *et al.*, 1989).

Since the inception of principles laid down by the forefathers of modern pedology, many have followed in their footsteps and advanced the fundamental principles. In the United States, one such person is Eugene W. Hilgard (1833-1916). Hilgard was, at the beginning of his career, a geologist. He worked in

Mississippi as State Geologist as well as a Professor of Chemistry at the University of Mississippi. He became a Soil Scientist around 1860. He had an attachment to nature that would not allow him to see soil as just unconsolidated geologic material. Often times he would raise his voice much like a preacher during sermon to get his point across. The point often being that to disregard soil, as an evolving entity that must be conserved for our future was "unchristian-like." During his career, Hilgard wrote of relationships between soil and climate and tried to implement the first U.S. system of soil and land survey. A man named Milton Whitney eventually accomplished the later in 1899; however, it was much criticized as being crude and lacking in detail (Jenny, 1961).

It was not until 1912 that attempts were made by G. W. Coffey to develop a classification system for the United States that incorporated the ideas of soil genesis developed by Dokuchaev and Glinka. His ideas on soil classification and genesis were not readily accepted due to the fact that soil was still being considered as geologic material on the immediate surface of the earth. The introduction of Dokuchaev's and Glinka's concepts of soil genesis were eventually implemented into U.S. soil survey programs and can be accredited to Curtis F. Marbut (1863-1935). Marbut was director of the U.S.D.A. Division of Soil Survey after Milton Whitney. Marbut represents a transition in U.S. soil classification. At first, early soil surveys and associated workers did not entirely realize the fundamental components and processes that should be considered when classifying a soil body. Marbut's ideas, which were rich in the teachings of

Dokuchaev and Glinka, incorporated inherent properties of the soil body (i.e. color, structure, drainage, texture, relief, parent material) and classified the soil accordingly (Joffe, 1949; Buol *et al.*, 1989).

After Marbut's death in 1935, Charles E. Kellogg (1902-1977) became his successor. Based on the principles developed both by Dokuchaev and Glinka, Kellogg published a soil survey manual in 1937 incorporating genesis and classification techniques. Kellogg said that, "the basis of soil science was the concept of soil as an independent natural body evolving as a function of the factors of soil formation," (Kellogg, as quoted by Krupenikov, p. 77, 1992).

Perhaps one of the greatest contributors to the understanding of soil genesis is Hans Jenny. He wrote in detail of the five factors of soil formation. In his book, Jenny writes, "for a given combination of climate, organisms, relief, parent material, and time, the state of the soil system is fixed; only one type of soil exists under these conditions," (1941). The earlier concept of the factors of soil formation regarded the interrelations of the factors to be casual whereas Jenny's concept regards the factors to be the defining concept of a particular soil.

The system for taxonomy in the United States today can be attributed to Guy D. Smith (1907-1981). He is the "chief architect" of *Soil Taxonomy*, which is the system of classification that will be used in this study. He developed many of the concepts that are used today in classifying soils, which are dependent upon the genesis of the soil body as supporting evidence of its classification, (Soil Survey Staff, 1975; Buol *et al.*, 1989).

Objectives

The specific objectives of this study were: 1) Complete soil morphological, chemical and physical characterization of landforms on MLRA 134 sites near Lynville, Kentucky and Holly Springs, Mississippi 2) To classify these soils to the family level of taxonomy 3) To conduct non-intrusive soil investigation using both GPR and EMI 4) To determine how well this protocol works at the sites located near Lynville, Kentucky and Holly Springs, Mississippi.

Materials and Methods

Site Selection and Field Methods

This study focused on two individual site locations in Kentucky and Mississippi. The Kentucky site is located on the Lynnville USGS 7.5 minute quad sheet at approximately 36° 32' 16.9" North latitude, 88° 35' 31.1" West longitude. The Mississippi site is located on the Holly Springs USGS 7.5 minute quad sheet at approximately 34° 49' 7.9" North latitude, 89° 26' 21.9" West longitude. At each of these locations, four pedons were described and sampled based on initial conductivity mapping using a Geonics LTD EM-31 conductivity instrument. A Giddings GSRP-S-M hydraulic probe with a 7.62cm sampling tube was used for extraction of pedons. Each pedon was described to the depth of the loess/alluvium interface. Pedon description was conducted according to methods provided by the Soil Survey Manual (Soil Survey Staff, 1993). Pedons were described by horizon, depth, color, texture, structure and consistency. Each horizon was sampled by placing approximately 3kg of soil in bags for lab analysis (Soil Survey Staff, 1996).

Laboratory Methods

Each sample was air-dried and then crushed to a 2-mm mesh sieve size. Approximately ¼ of this was ground to pass through a 60-mesh sieve. Particle size was determined by the pipette method (Kilmer and Alexander, 1949). Sand, silt and clay amounts were determined by guidelines set by the USDA system of textural classification. The sand fraction was further differentiated to very coarse, coarse, medium, fine and very fine using sieves and a CSC sieve shaker (Gee and Bauder, 1986).

Soil pH was determined using an Orion Research™ Analog Meter (model 301). Total Carbon was measured using the Leco™ 2000 Carbon System. Organic Carbon was measured using the Walkley-Black method (Jackson, 1958).

Iron oxides were extracted by the citrate-dithionite method (Olsen and Ellis, 1982). Manganese oxides were extracted by the hydroxylamine hydrochloride method (Gambrell and Patrick, 1982). These extracts were analyzed for concentration using Atomic Absorption Spectroscopy on a Perkin Elmer™ model AAnalyst 700 Spectrometer.

Total elemental analysis was conducted by extracting the samples via the aqua regia, hydrofluoric acid, microwave dissolution procedure (Ammons *et al.*, 1995). Total concentrations of calcium, copper, iron, potassium, magnesium, manganese, sodium and, zinc were measured using atomic absorption spectroscopy on a Perkin Elmer™ model AAnalyst 700 Spectrometer.

Exchangeable bases were extracted using ammonium acetate (pH 7) (Jackson, 1958) and concentrations of calcium, magnesium, sodium, and potassium were determined using atomic absorption spectroscopy.

Cation exchange capacity was determined by direct measurement using the ammonium acetate (pH 7) rapid distillation method (Chapman, 1965). Percent base saturation and exchangeable cation exchange capacity were determined mathematically (Soil Survey Staff, 1996). Exchangeable aluminum and exchange acidity was determined using the KCl-Al method (Thomas, 1982). The extracts were analyzed for aluminum using atomic absorption spectroscopy. Extractable acidity was determined by the $BaCl_2$ method.

Clay mineralogy of the control sections present at each of the eight pedons was determined using a Bruker axs™ D8 Advance™ X-ray diffractometer. Slides were prepared using a filter membrane peel technique (Drever, 1973).

Results and Discussion

Kentucky Site One

This pedon was located at N36°32'27.48", W88°35'29.92". The parent material sequence for this site is loess over alluvium over tertiary aged coastal plain material (table 3, figure 4). Loess extended from the surface to 140 cm. Beneath the loessial parent material, a coarser grained material, which is presumably the continental deposit described by Lambert (1965), extended to

Table 3: Morphology description for Kentucky Site One

Horizon	Depth (cm)	Color (moist)	Texture †	Boundary ‡	Structure §	Consistency (moist) £	Notes Ω
Ap	0-8	10YR 4/4	SiL	A	wk gr	fr	-
Bt1	8-51	7.5YR 4/6	SiCL	C	st abk	fr	-
Bt2	51-70	7.5YR 4/6	SiCL	C	mo pris/ sbk	vfr	Mn conc., stripped areas.
Bx1	70-104	7.5YR 4/6	SiL	C	st pris	fi	Mn conc., depletions, clay films, stripped areas, blind pores
Bx2	104-140	7.5YR 4/4	SiL	C	mo pris/ sbk	fi	Mn conc., depletions, clay films, stripped areas, blind pores
2BC	140-197	7.5YR 5/6	SiL	C	mo sbk	vfr	Mn conc., depletions, stripped areas
2C/BC	197-250	7.5YR 4/6	SL	C	sg/wk sbk	vfr	angular blocky, yellowish red gravel
3C1	250-287	7.5YR 5/6	SC	C	sls ma	fr	angular blocky cherty material mixed with well–rounded quartz gravel
3C2	287-344+	5YR 4/6	Gr SC	-	sls ma	vfr	well-rounded quartz gravel

† silt loam (SiL), silty clay loam (SiCL), sandy loam (SL), sandy clay (SC), gravelly (Gr)

‡ Abrupt (A), Clear (C)

§ structure-less (sls), weak (wk), moderate (mo), strong (st), granular (gr), angular blocky (abk), sub-angular blocky (sbk), prismatic (pris), single grain (sg), massive (ma)

£ friable (fr), very friable (vfr), firm (fi)

Ω Manganese (Mn), concentrations (conc.).

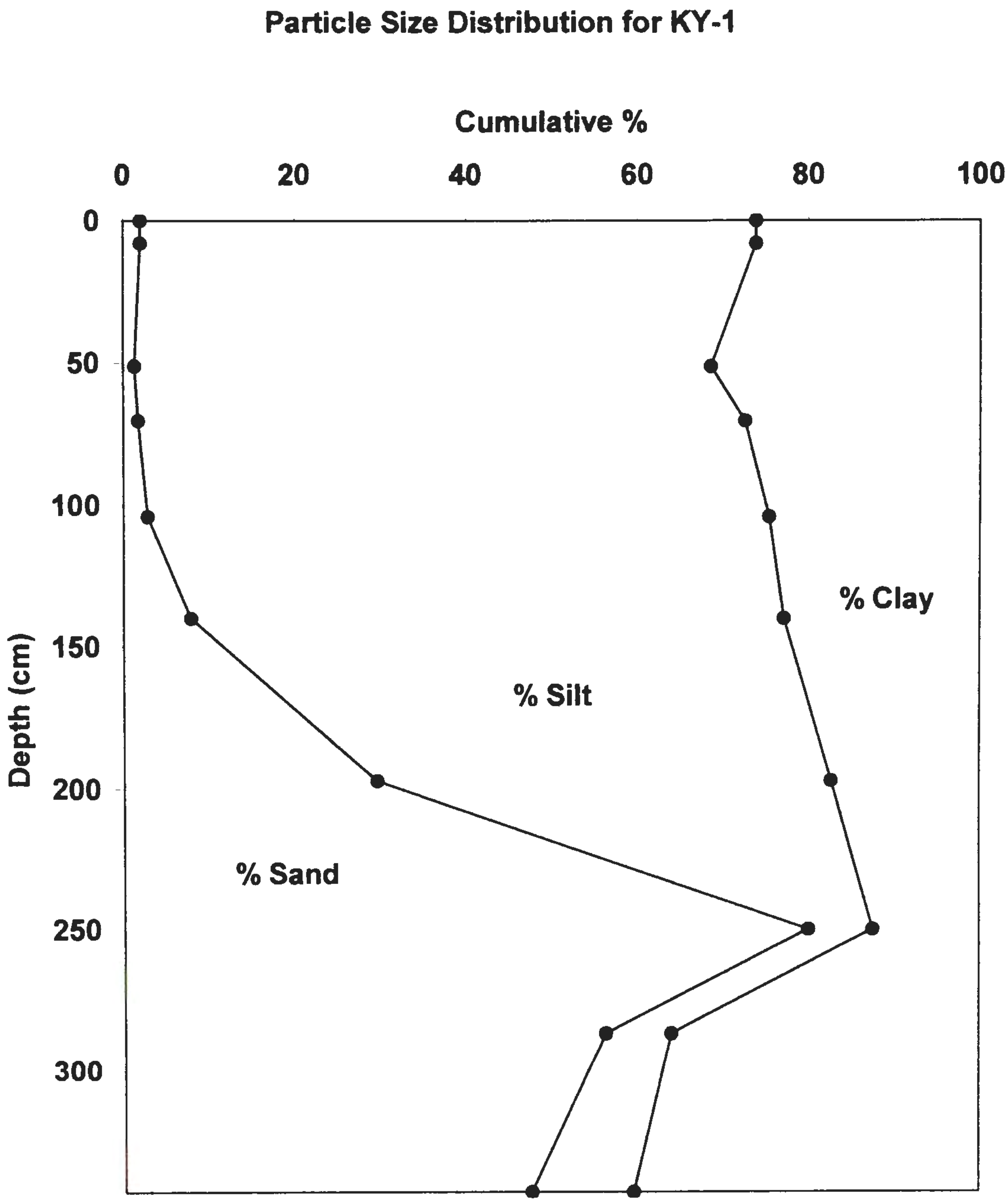


Figure 4. Particle size data by depth for Kentucky Site One.

250 cm. Figure 5 shows evidence for the lithologic discontinuities seen in this pedon. Tertiary aged coastal plain material extended from 250 to 344+ cm. This portion of the pedon was marked by a sharp increase in sand (figures 4 and 5) as well as by the development of a paleosol with red 5YR hues. Also, well rounded quartz gravel and other angular blocky coarse fragments were observed in the Tertiary material indicating that it was deposited by fluvial processes.

The diagnostic subsurface horizons in this pedon were an argillic horizon (8-70cm) and a fragipan (70-140cm) horizon. Considering the interfluve nature of this landscape position (slope=1%), the illuvial increase in clay seen in the subsurface horizon is reasonable. In the lower 70 cm of the loessial parent material (*i.e.* 70 – 140 cm), a fragipan has developed. The fragipan was marked by the characteristic brittleness required for this designation as well as by the presence of albic materials (stripped areas) within the horizon. In addition to these features, characteristic blind pores were also present.

The weathering pattern exhibited in this pedon can be seen in figure 6. The loessial parent material and underlying alluvium (0 – 250 cm) have undergone similar amounts of weathering as indicated by the difference between oxidized iron and total iron seen in figure 6. In the deeper Tertiary aged coastal plain material, there is a higher concentration of iron oxides indicating that this material is more weathered than the overlying material, and is also indicative of paleosol development. The characteristic red hues (5YR) of these horizons indicate that this material is much higher in total iron and that much of the iron

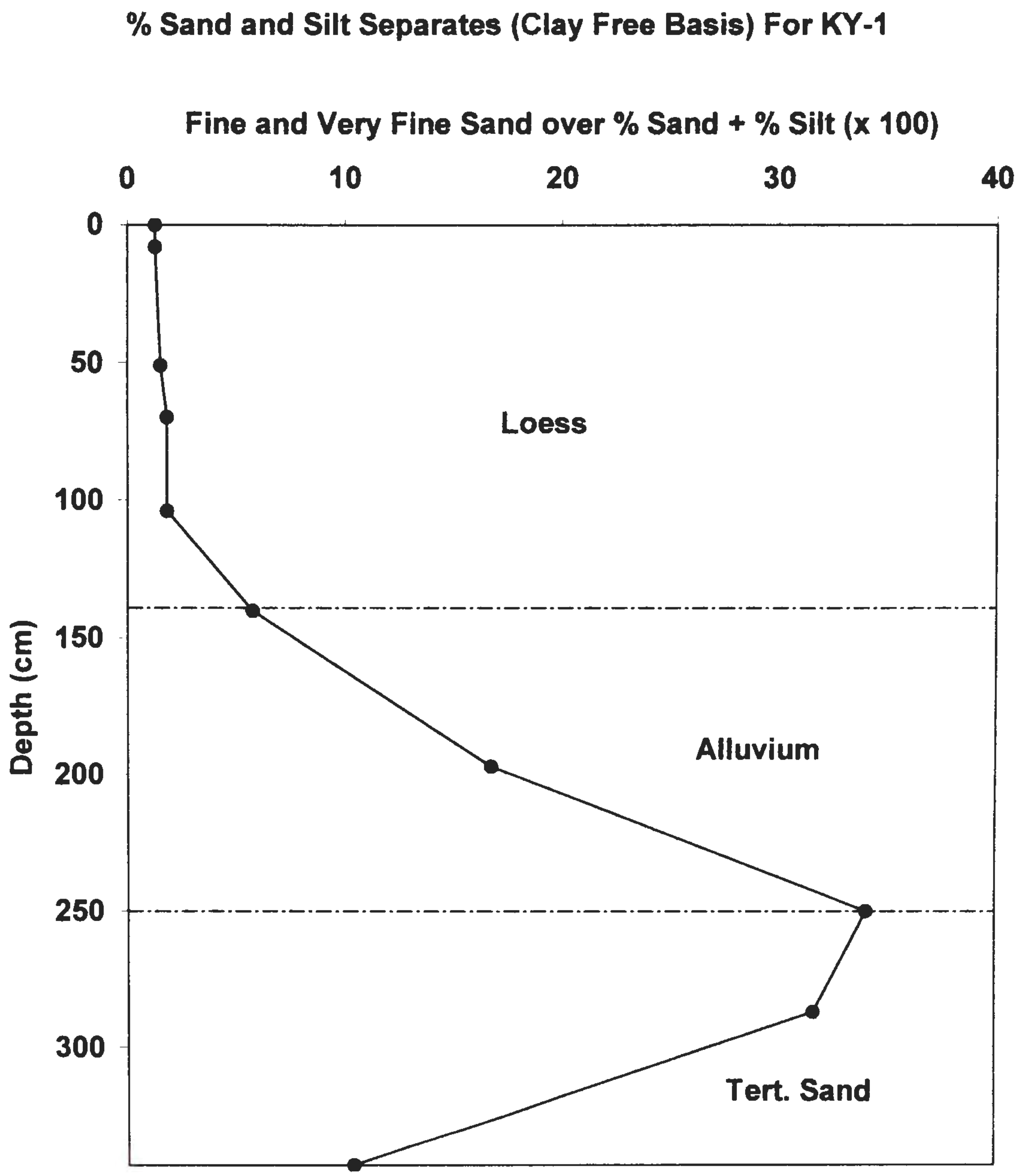


Figure 5. Sand and silt plotted on a clay free basis by depth as related to parent material for Kentucky Site One.

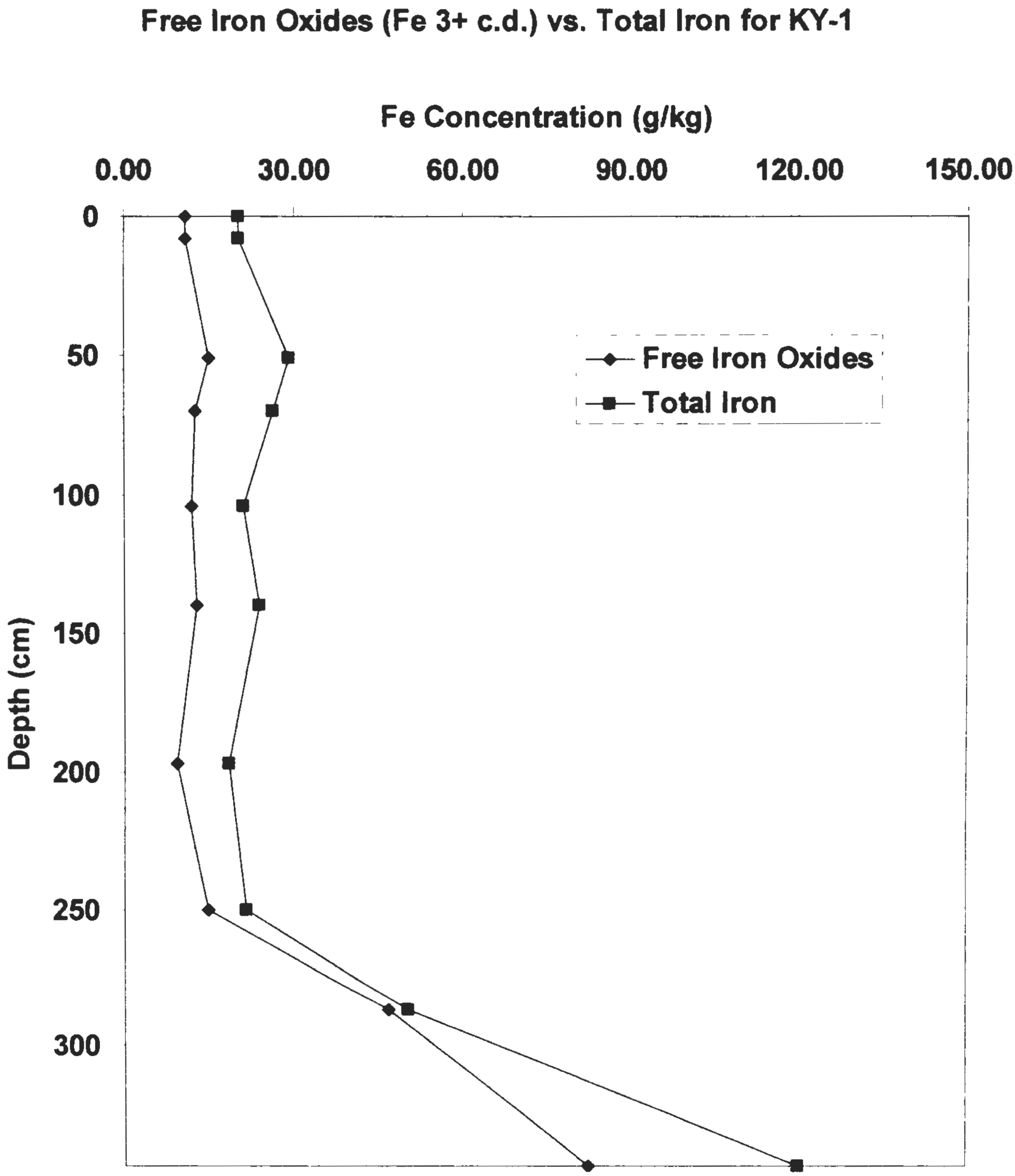


Figure 6. Free iron and total iron by depth for Kentucky Site One.

present in the $3C_1$ horizon has been oxidized. The $3C_2$ horizon has a sharp increase in total iron concentration which may be attributed to pedogenesis. At the time of excavation, a 5.08 cm saw-tooth bit was used to extract the pedon from a depth of 218 to 293cm. This indicates that this horizon may actually be a weakly cemented iron pan that has formed via the illuvial concentration (and further cementation with silica) of iron.

The carbon distribution for this pedon can be seen in figure 7. Overall, there is very little organic carbon accumulation seen throughout this profile. The higher accumulation of organic and total carbon at the surface is to be expected when considering the land use at this site as well as the liming history associated with it. There is a slight increase in organic carbon in the 2C/BC horizon (197 – 250 cm) which further indicates that this deposit may be fluvial in origin.

The classification of this pedon is a fine-silty, mixed, active, thermic Typic Fragiudalf. Lateral subsurface movement of water will be highly affected by the presence of a fragipan from 70 to 140 cm beneath the surface. It was noted at the time of description that there is evidence (in the form of redox depletions) of hindrance of water movement. Given the nature of the fragipan and its properties, water could possibly move laterally and vertically within this particular profile. The presence of a weakly cemented iron pan in the tertiary aged materials of this pedon (218 – 293 cm) could possibly hinder water movement as well. However, there is no evidence that water is being perched as indicated by the lack of redoximorphic features immediately above this horizon.

Total Carbon vs. Organic Carbon for Kentucky Site One

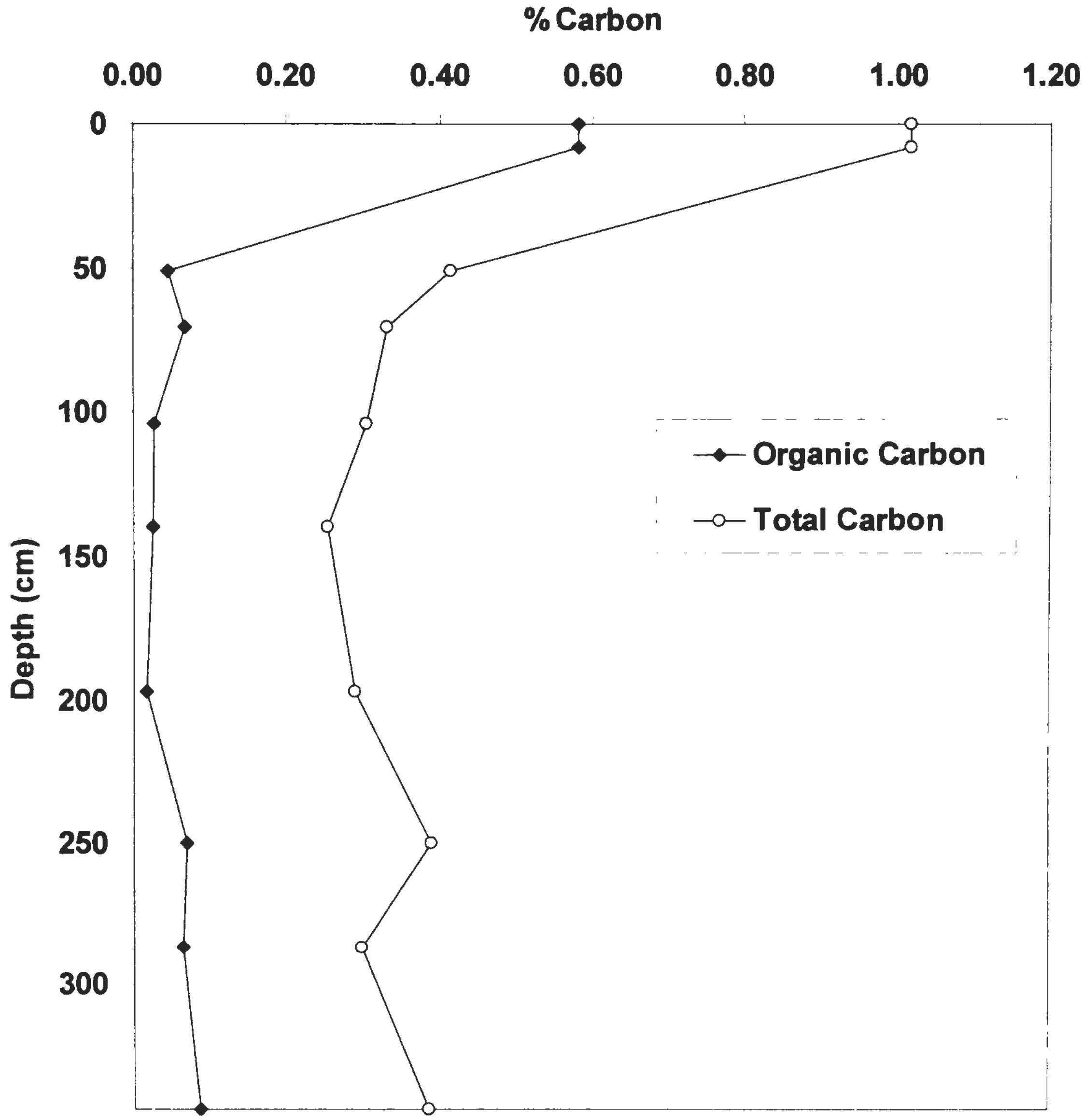


Figure 7. Organic carbon and total carbon by depth for Kentucky Site One.

Kentucky Site Two

The location of this pedon was N 36°32'27.10", W 88°35'29.60". The parent material sequence was loess over alluvium over Tertiary aged coastal plain material (table 4, figure 8). Loess extended from the surface to a depth of 110 cm. Alluvium was present from a depth of 110 cm to 280 cm. The difference in parent materials is clearly evident when observing the relative amounts of sand associated with these horizons (figures 8 and 9). Tertiary aged coastal plain material was present from a depth of 280 cm to 320+ cm. It is marked by paleosol development which is apparent from the red 5YR hues that make up this portion of the profile. This deposit is apparently fluvial in origin which is indicated by the presence of well-rounded quartz gravel and other angular blocky coarse fragments. Further evidence for the discontinuities seen in this pedon is shown in figure 9. There is a sharp increase in fine sand and very fine sand (on a clay free basis) at the depths of the lithologic discontinuities (110 cm and 280 cm).

The diagnostic subsurface horizons of this pedon are an argillic horizon (20 – 80 cm) and a fragipan (80 – 184 cm). The argillic horizon does not exhibit the typical 20 percent increase in clay from the overlying A_p horizon (figure 8). However, it was assumed that mixing of the A and B-horizons has occurred due to plowing and that the original surface horizon has been eroded. There was

Table 4: Morphology description for Kentucky Site Two

Horizon	Depth (cm)	Color (moist)	Texture †	Boundary ‡	Structure §	Consistency (moist) £	Notes Ω
Ap	0-20	10YR 4/4	SiL	A	wk gr	vfr	few Mn conc.
Bt	20-80	7.5YR 4/6	SiCL	C	mo sbk	fi	-
Bx1	80-110	7.5YR 4/6	SiL	C	mo pris	fi	Mn conc., stripped areas.
2Bx2	110-184	7.5YR 4/6	SiL	C	wk pris	fi	Mn conc., depletions, clay films, stripped areas, blind pores
2BC	184-235	7.5YR 4/6	SiL	C	mo sbk	vfr	stripped areas, blind pores
2C1	235-280	7.5YR 5/4	SL	A	sls ma	fr	few angular blocky chert frags
3C2	280-310	5YR 5/8	C	A	sls ma	fr	angular blocky chert frags and well-rounded quartz gravel common
3C3	310-320+	5YR 5/6	SC	-	sls ma	vfr	angular blocky cherty material mixed with well–rounded quartz gravel

† silt loam (SiL), silty clay loam (SiCL), sandy loam (SL), clay (C), sandy clay (SC)
‡ Abrupt (A), Clear (C)
§ structure-less (sls), moderate (mo), granular (gr), sub-angular blocky (sbk), prismatic (pris), massive (ma)
£ friable (fr), very friable (vfr), firm (fi)
Ω Manganese (Mn), concentrations (conc.).

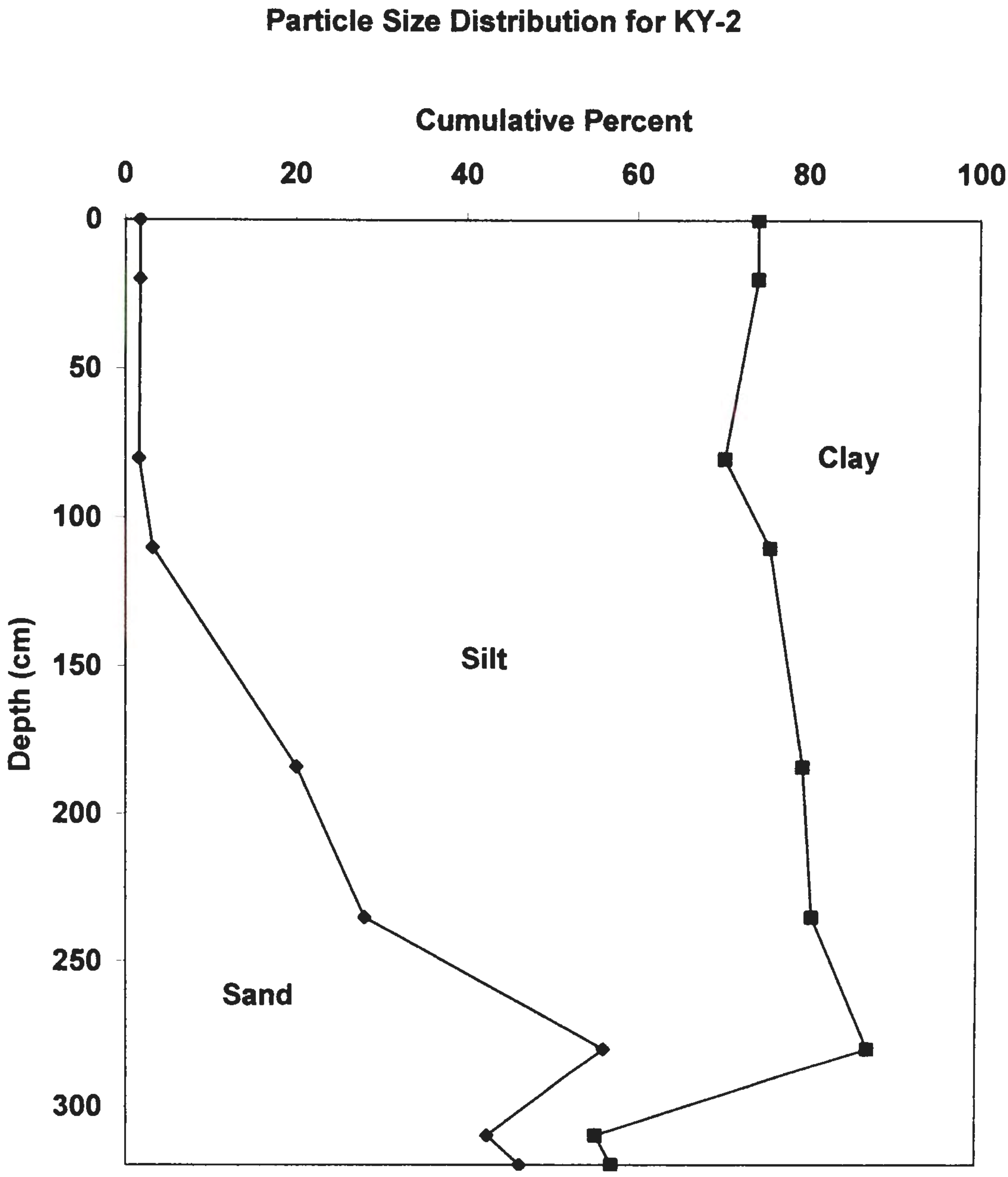


Figure 8. Particle size data by depth for Kentucky Site Two.

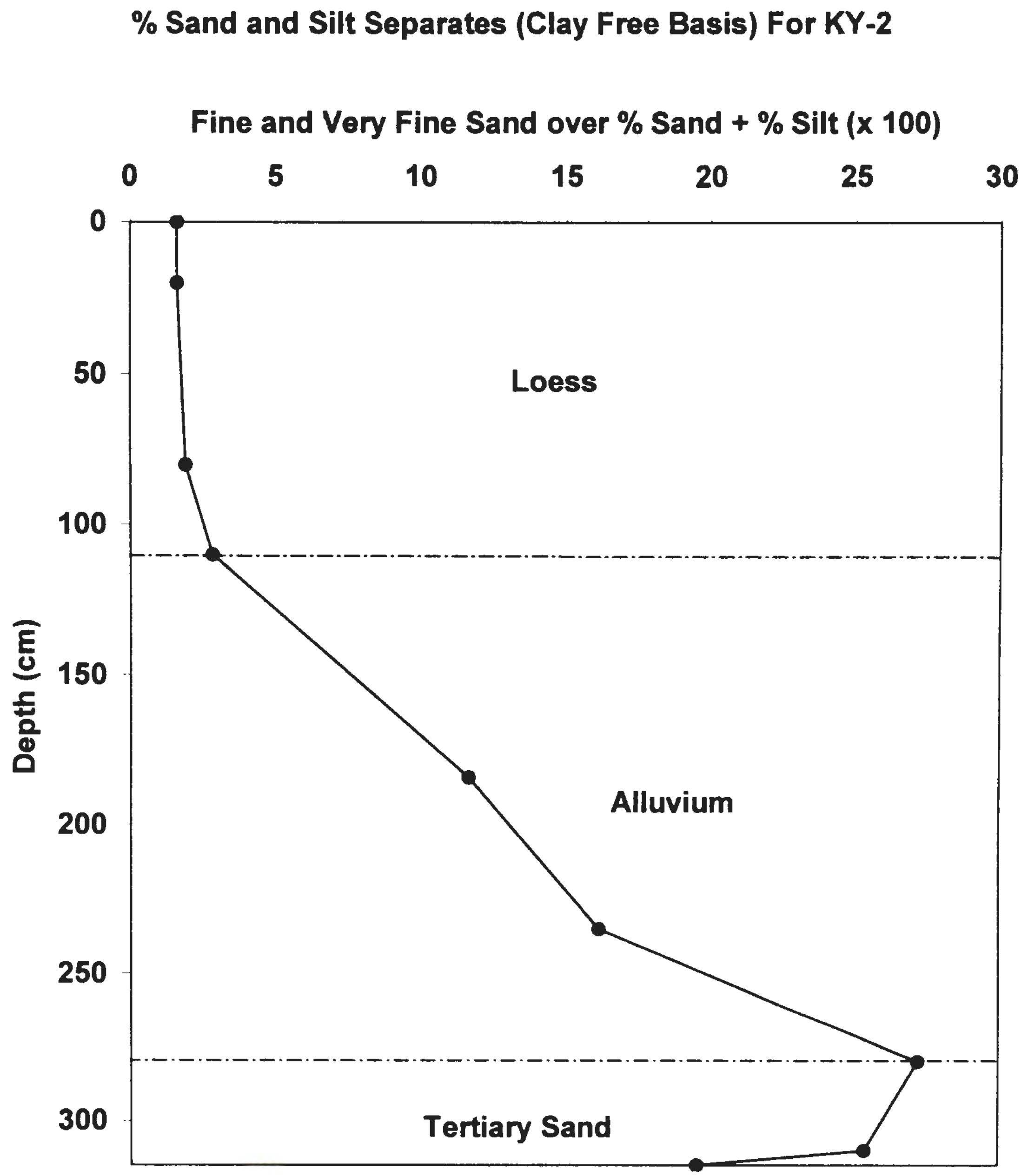


Figure 9. Sand and silt plotted on a clay free basis by depth as related to parent material for Kentucky Site Two.

further evidence of illuvial clay increase in the fragipan horizon in the form of clay films on the surfaces of peds. The fragipan exhibited typical characteristics (*i.e.* prismatic structure, brittleness, blind pores, and stripped areas) and extended beyond the depth of the lithologic discontinuity (110 cm) to a depth of 184cm.

The weathering pattern exhibited in this pedon is depicted in figure 10. Both the loess (0 – 110 cm) and the underlying alluvium (110 – 280 cm) have undergone similar amounts of weathering which is indicated by similar ratios of concentrations of oxidized iron to total iron. A much greater amount of weathering has occurred in the underlying Tertiary aged coastal plain material and has resulted in the rubification of this material (5YR hues). This is an indication of paleosol development. In this portion of the profile, the concentration of iron oxides is much closer to the total concentration of iron indicating that this material is more highly weathered than the overlying loessial/alluvial material. The lower Tertiary aged material is also much higher in total iron especially in the $3C_3$ horizon (310 – 320+cm).

The carbon distribution for this pedon can be seen in figure 11. Overall, the carbon distribution shows a normal melanization curve. There is a slight increase in organic and total carbon at a depth of 235 cm that continues to the bottom of the profile. This is highly indicative of fluvial processes which have deposited the alluvial materials found at lower depths within this profile.

The classification of this soil is a fine-silty, mixed, active, thermic Typic Fragiudalf. The presence of a fragipan from a depth of 80 cm to a depth of 184

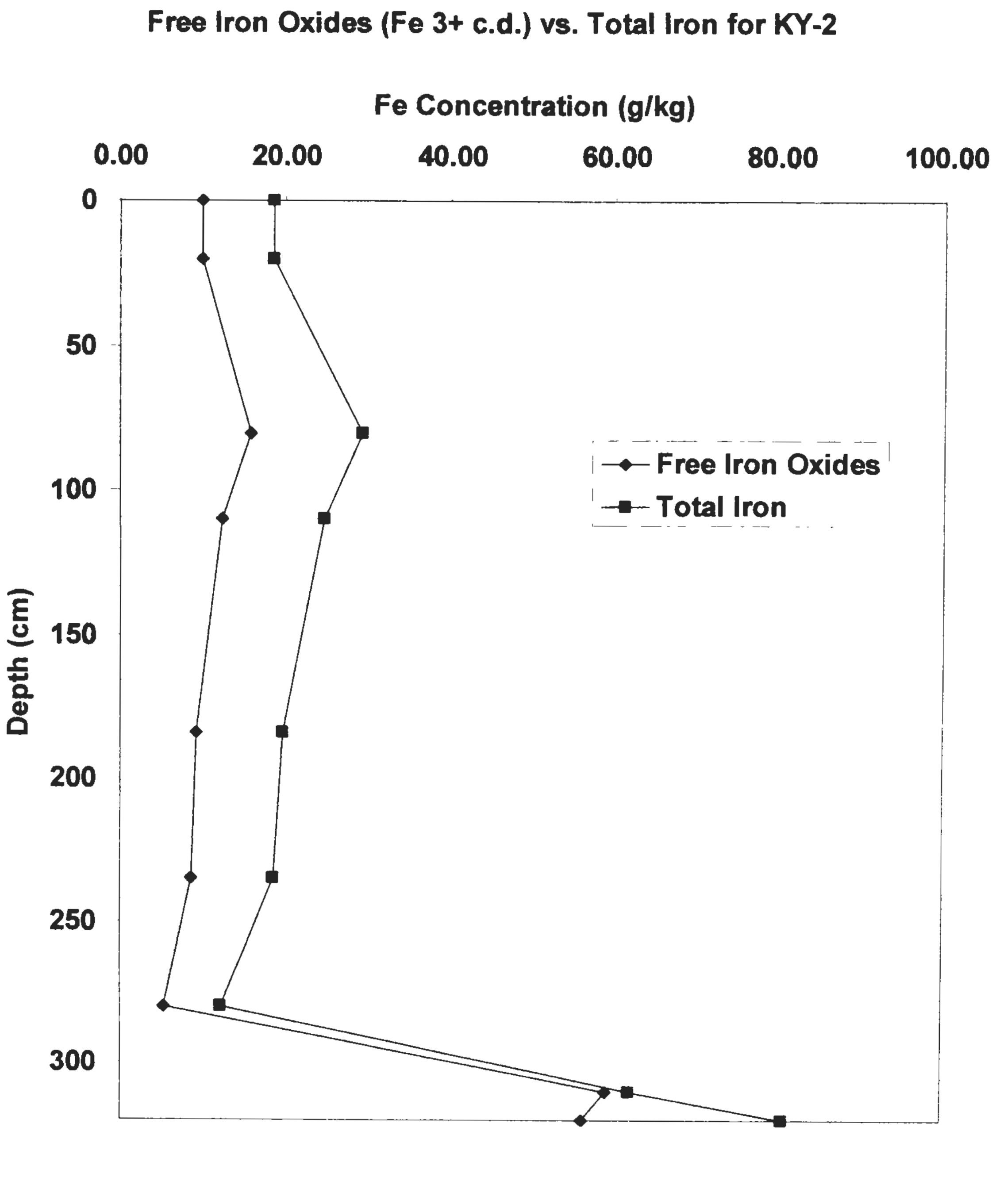


Figure 10. Free iron and total iron by depth for Kentucky Site Two.

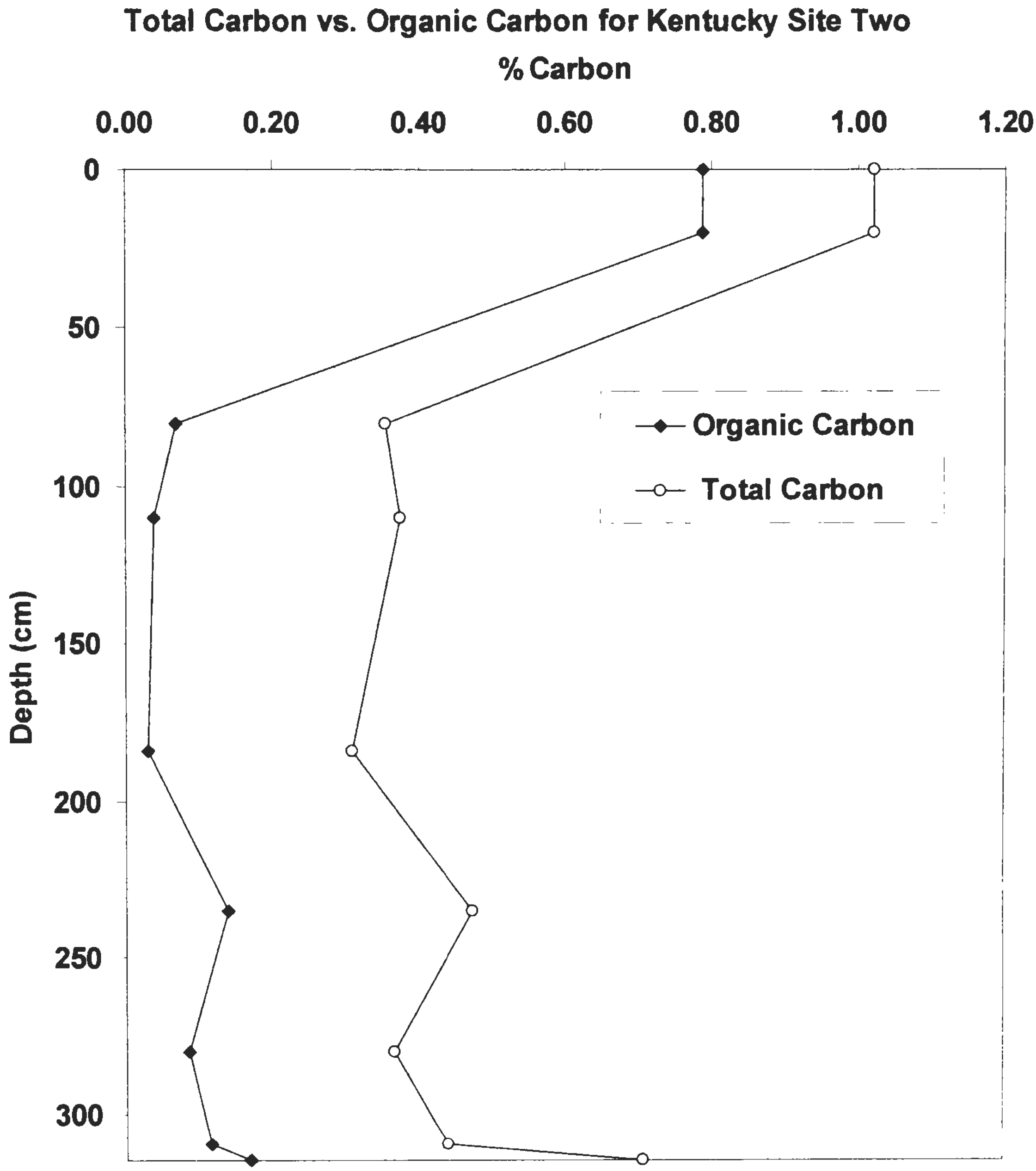


Figure 11. Organic carbon and total carbon by depth for Kentucky Site Two.

cm may cause lateral subsurface movement of water. Redoximorphic features in the form of iron depletions were common within the $2B_{x2}$ horizon (110 – 184 cm) indicating a hindrance of water movement downward through the profile. At this depth water may be migrating laterally. Lateral migration of water would continue until areas that were dominantly stripped (areas of preferential flow) were encountered. The presence of stripped areas within the fragipan horizon may cause water to further migrate downward through the profile.

Kentucky Site Three

This pedon was located at N36°32'24.30", W88°35'29.00". The parent material sequence at this site was loess over alluvium over Tertiary aged coastal plain deposits (table 5). The particle size distribution for this pedon can be seen in figure 12. Loess extended from the surface to a depth of 69 cm. The slope at this site was approximately 5% and much of the original loess has been eroded. Beneath the loessial parent material, alluvium extended from a depth of 69 cm to a depth of 194 cm. This portion of the profile is made up of a much more coarse textured material than the overlying loess. Tertiary aged coastal plain material was present from 194 cm to a depth of 343+ cm. Well rounded quartz gravel and other angular blocky type coarse fragments were found in this material as well. This material was dominantly comprised of sand and paleosol development was evident at its upper boundary as indicated by the rubification of this material (5YR hue). The diagnostic subsurface horizon present in this pedon was an argillic horizon. There was evidence of weak fragipan development in that the structure

Table 5: Morphology description for Kentucky Site Three

Horizon	Depth (cm)	Color (moist)	Texture †	Boundary ‡	Structure §	Consistency (moist) £	Notes Ω
Ap	0-15	10YR 4/4	SiCL	A	st sbk	fri	few Mn conc.
Bt	15-69	7.5YR 4/6	SiCL	C	mo pris	fi	-
2BC1	69-132	7.5YR 4/6	L	C	mo pris	fri	stripped areas
2BC2	132-174	7.5YR 4/6	SL	C	mo sbk	fri	-
2C1	174-194	7.5YR 5/6	LS	C	sls ma	vfr	-
3C2	194-253	5YR 4/6	SL	C	sls ma	fr	-
3C3	253-343+	7.5YR 5/6	SL	-	sls ma	fr	angular blocky chert frags and well-rounded quartz gravel few

† silty clay loam (SiCL), sandy loam (SL), loam (L), loamy sand (LS)
‡ Abrupt (A), Clear (C)
§ structure-less (sls), moderate (mo), sub-angular blocky (sbk), prismatic (pris), massive (ma)
£ friable (fr), very friable (vfr), firm (fi)
Ω Manganese (Mn), concentrations (conc.).

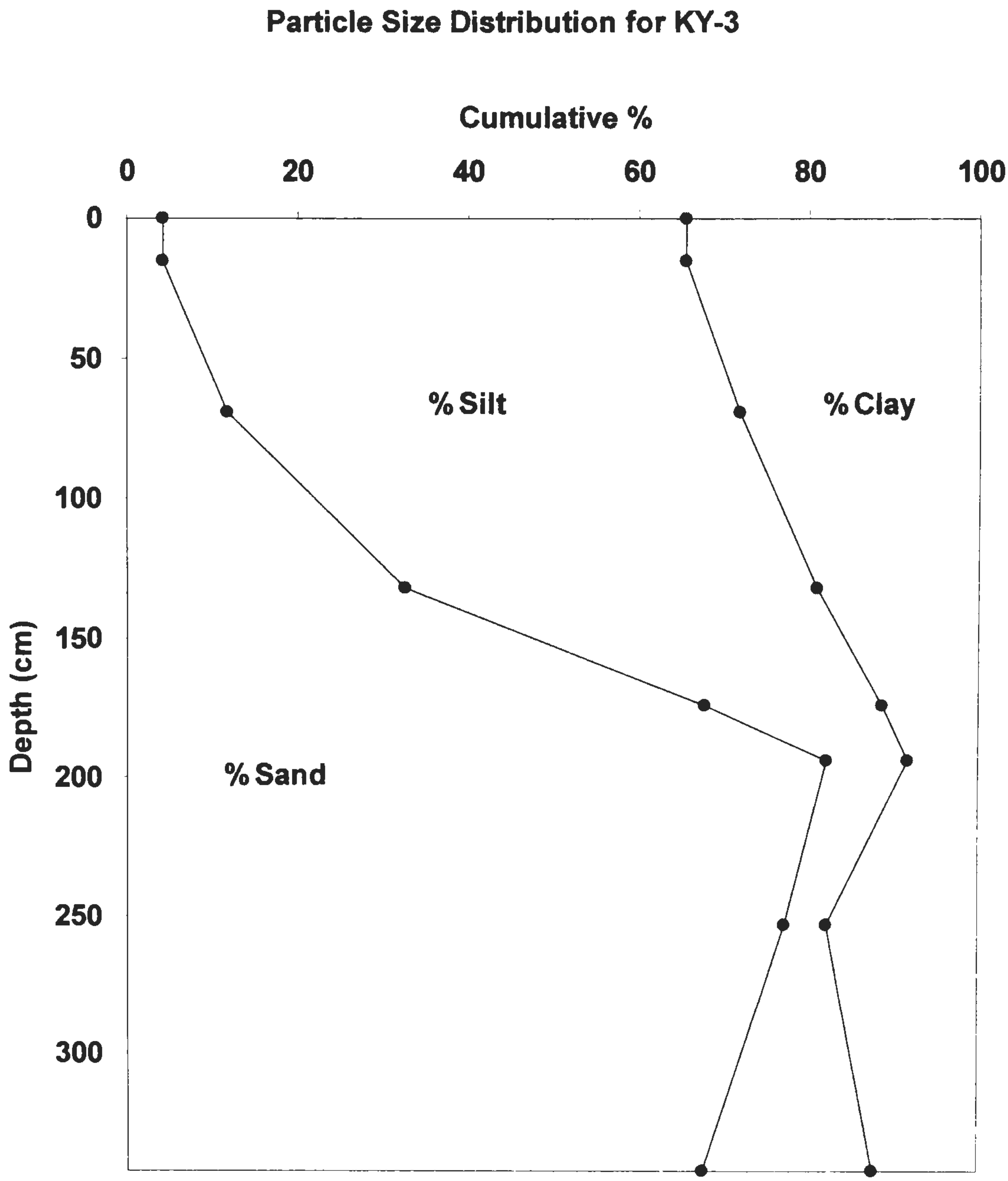


Figure 12. Particle size data by depth for Kentucky Site Three.

was moderate prismatic and stripped areas were common however many of the classic fragipan characteristics were absent (*i.e.* continuous expression of firm rupture resistance class throughout the horizon and blind pores). The absence of a true fragipan horizon in this pedon may be attributed to erosion and/or site position. There was a large amount of clay found in the surface horizon of this pedon (figure 12). It was assumed that the original surface horizon has been eroded and that plowing has resulted the mixing of surface and subsurface horizons. Therefore, the designation of argillic was given to the subsurface horizon extending from 15 to 69 cm.

The weathering pattern exhibited in this pedon can be seen in figure 13. The difference between oxidized iron and total iron is greater in the loessial and alluvial parent materials which indicates that these materials are not as weathered as the underlying Tertiary aged coastal plain material. In the coastal plain material (194 – 343+ cm), this difference is slightly less indicating that it is more weathered. Again, the amount of weathering in the Tertiary aged coastal plain material has resulted in the rubification of this material (5YR Hues).

Other than the presence of manganese concentrations, this pedon lacked redoximorphic features that would indicate a drainage impediment. Figure 14 shows the concentration of easily reducible manganese by depth. Due to the lack of redoximorphic evidence of drainage impediment (*i.e.* iron depletions), easily reducible manganese data was used to shed light on the possible fate of groundwater percolating downward through the profile. The $2BC_1$ and $2BC_2$

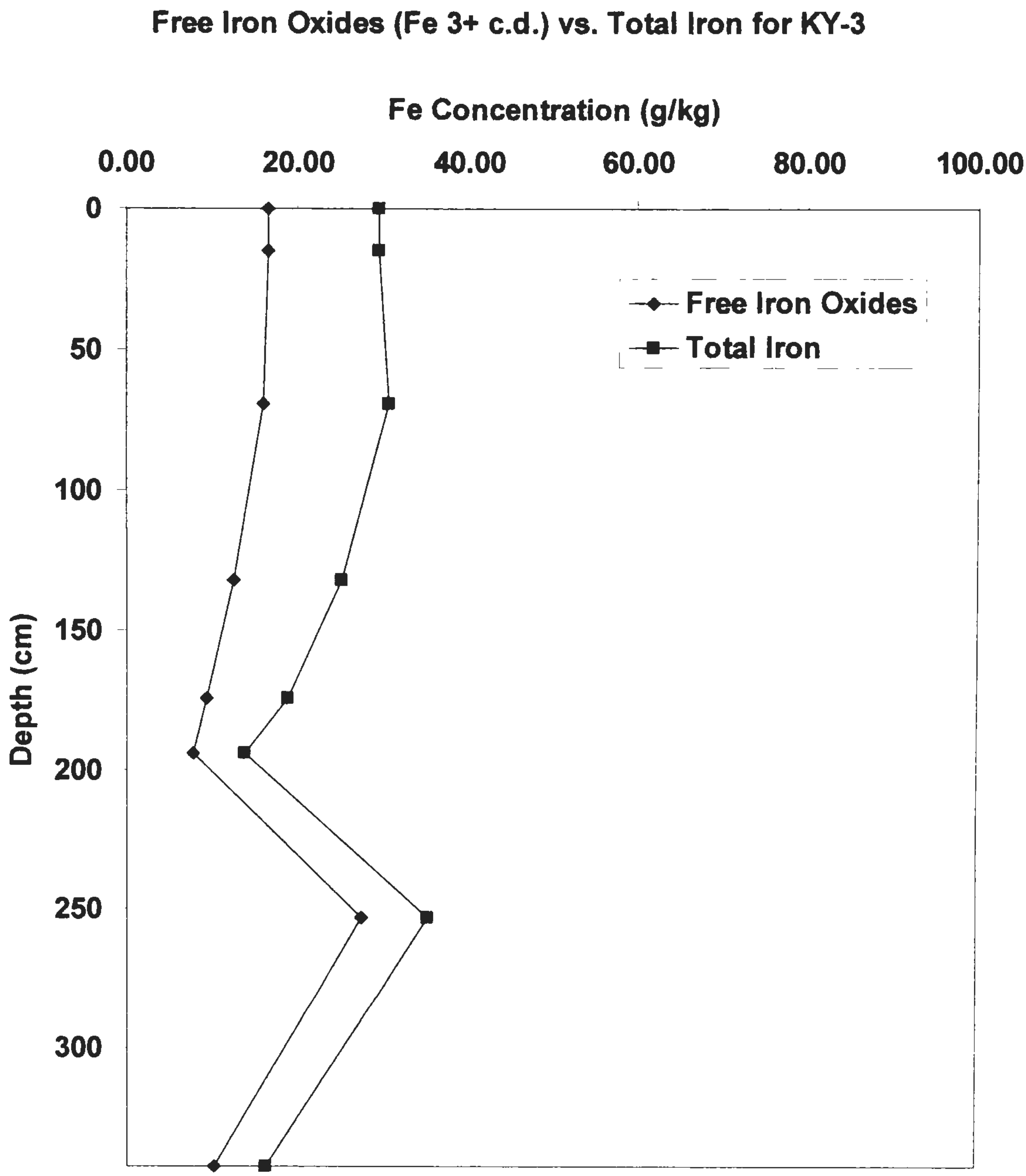


Figure 13. Free iron and total iron by depth for Kentucky Site Three.

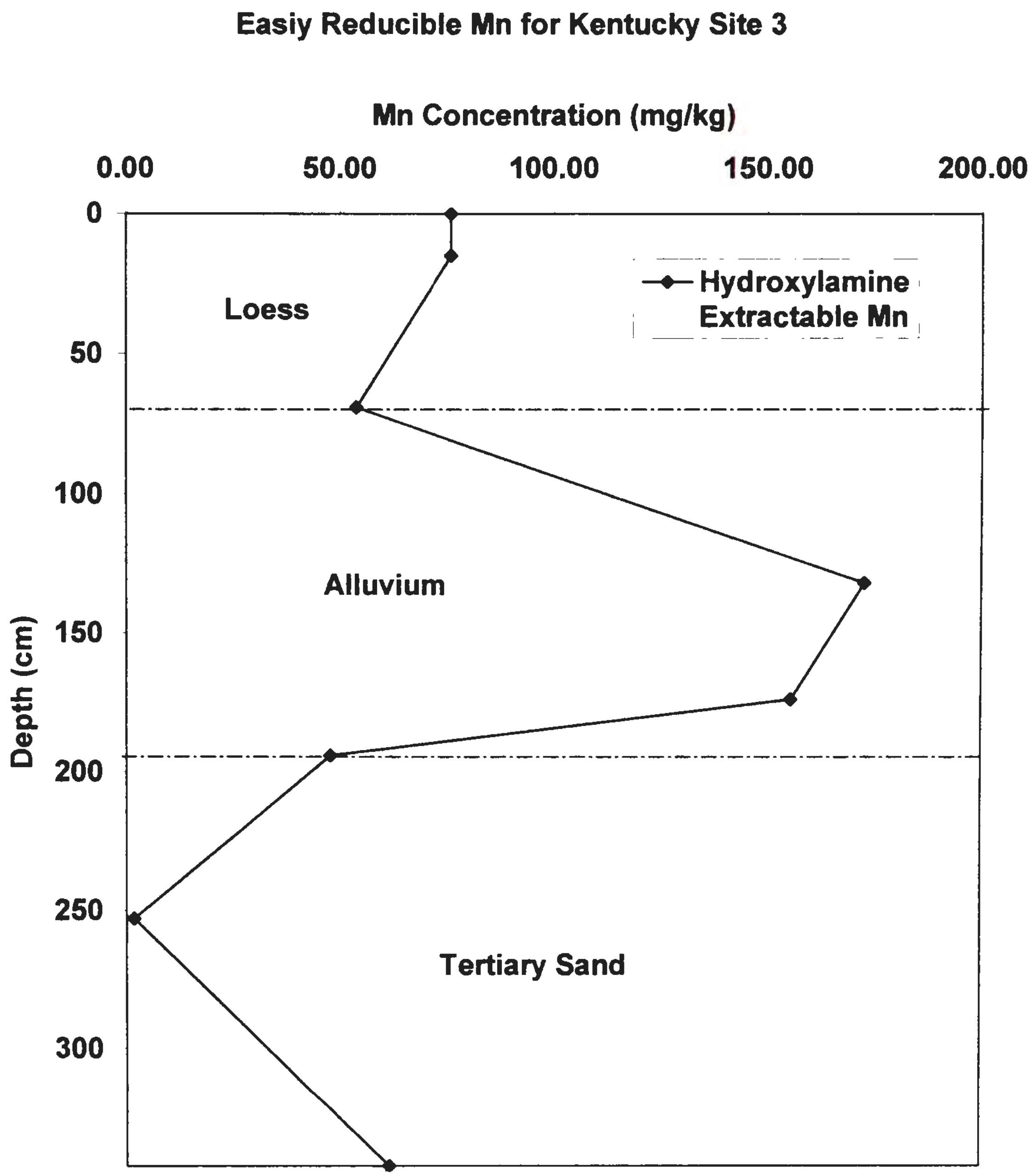


Figure 14. Easily reducible manganese data by depth as related to parent material for Kentucky Site Three.

horizons (69-132 and132 – 174 cm respectively) seems to have a greater amount of easily reducible manganese indicating that there may be a hindrance of downward movement of percolating water in this horizon. When considering the textures of the $2BC_1$ horizon and the $2BC_2$ horizon (loam and sandy loam respectively) in contrast to the loamy sand texture in the 2C1 horizon below (figure 12), a drainage impediment seems logical due to the contrast in pore size distribution (*i.e.* sharp increase in the amount of sand and decrease in the amount of clay).

The carbon distribution of this pedon can be seen above in figure 15. There is a regular decrease in both organic and total carbon with depth throughout the profile. The accumulation of organic carbon and carbonates at the surface is to be expected given the vegetation present at this site in addition to the utilization of this site for agricultural production.

This soil was classified as a fine-silty, mixed, active, thermic Fragic Hapludalf. The lack of continuous fragic materials in the subsurface results in the subgroup classification of a Fragic Hapludalf. The main contributor to lateral subsurface movement of water in this pedon can be attributed to a contrast in pore size distribution just above the depth of the lithologic discontinuity (69 – 174 cm). This is evident when evaluating the occurrence of easily reducible manganese in the subsurface (figure 14).

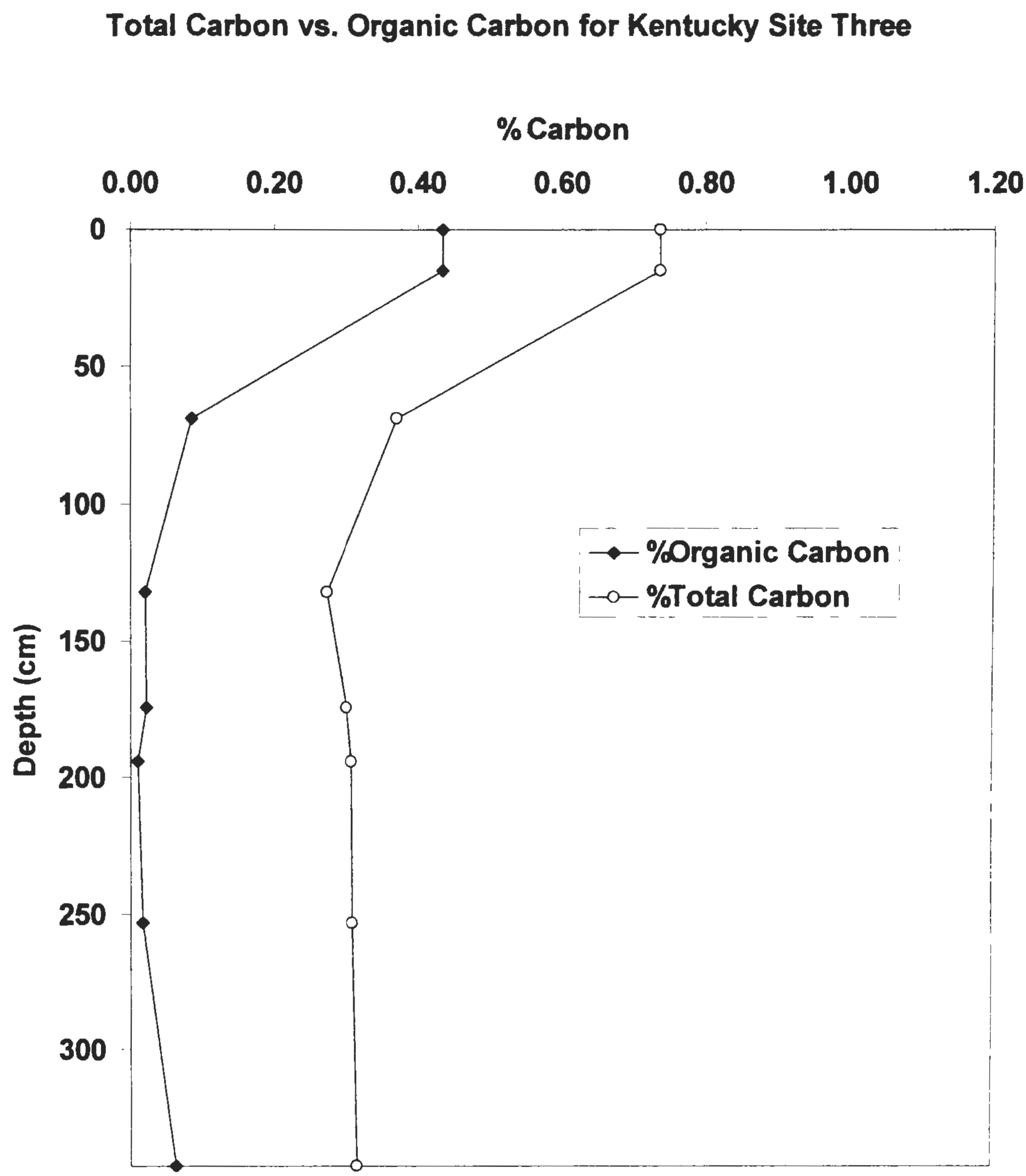


Figure 15. Organic carbon and total carbon by depth for Kentucky Site Three.

Kentucky Site Four

This pedon was located at N36°32'22.70", W88°35'27.30". The parent material sequence was loess over alluvium over Tertiary aged coastal plain material. Loess extended from the surface to a depth of 150cm. The alluvial parent material extended from a depth of 150 cm to a depth of 195 cm (table 6). The particle size distribution for this site can be seen in figure 16. The Tertiary aged coastal plain material was marked by paleosol development (2.5YR hues) in addition to the occurrence of well-rounded quartz gravel. The depths of the lithologic discontinuities are supported by not only particle size distribution (figure 16) but also by the distribution of fine sand on a clay free basis (figure 17).

The diagnostic subsurface horizon in this pedon was an argillic horizon. Again it was assumed that plowing in conjunction with erosion had resulted in the higher amount of clay at the surface. Therefore, the argillic horizon extended to a depth of 80 cm and it was noted that there was evidence of clay illuviation in the form of clay films; the Bt_2 horizon contained 29% clay (figure 16). The BC_1 horizon (80 - 150 cm) exhibited weak fragic properties. The structure of this horizon was dominantly weak prismatic and there was an abundance of stripped areas however, the characteristic brittleness and other key features of fragipan development were absent in this horizon.

The weathering pattern exhibited in this pedon is shown in figure 18. The loessial parent material and the alluvial parent material have undergone similar amounts of weathering as indicated by the difference between oxidized iron and

Table 6: Morphology description for Kentucky Site Four

Horizon	Depth (cm)	Color (moist)	Texture †	Boundary ‡	Structure §	Consistency (moist) £	Notes Ω
Ap	0-14	10YR 4/4	SiL	A	st sbk	fri	-
Bt1	14-50	7.5YR 4/6	SiCL	C	mo sbk	fi	Mn conc. common
Bt2	50-80	7.5YR 5/4	SiCL	C	mo sbk	fri	Mn conc., clay films
BC1	80-150	7.5YR 4/6	SiL	C	wk pris	fri	Mn conc., depl., clay films, stripped areas
2BC2	150-195	7.5YR 4/6	L	C	mo abk	vfr	Mn conc., stripped areas
2BC3	195-253	7.5YR 5/6	SL	C	mo sbk	fr	stripped areas, few well-rounded quartz gravel
3C	253-260+	2.5YR 4/4	SL	-	sls sg	l	stripped areas common, well-rounded quartz gravel common

† silt loam (SiL), silty clay loam (SiCL), sandy loam (SL), loam (L)

‡ Abrupt (A), Clear (C)

§ structure-less (sls), strong (st), moderate (mo), weak (wk), sub-angular blocky (sbk), prismatic (pris), angular blocky (abk), single grained (sg)

£ friable (fr), very friable (vfr), firm (fi), loose (l)

Ω Manganese (Mn), concentrations (conc.).

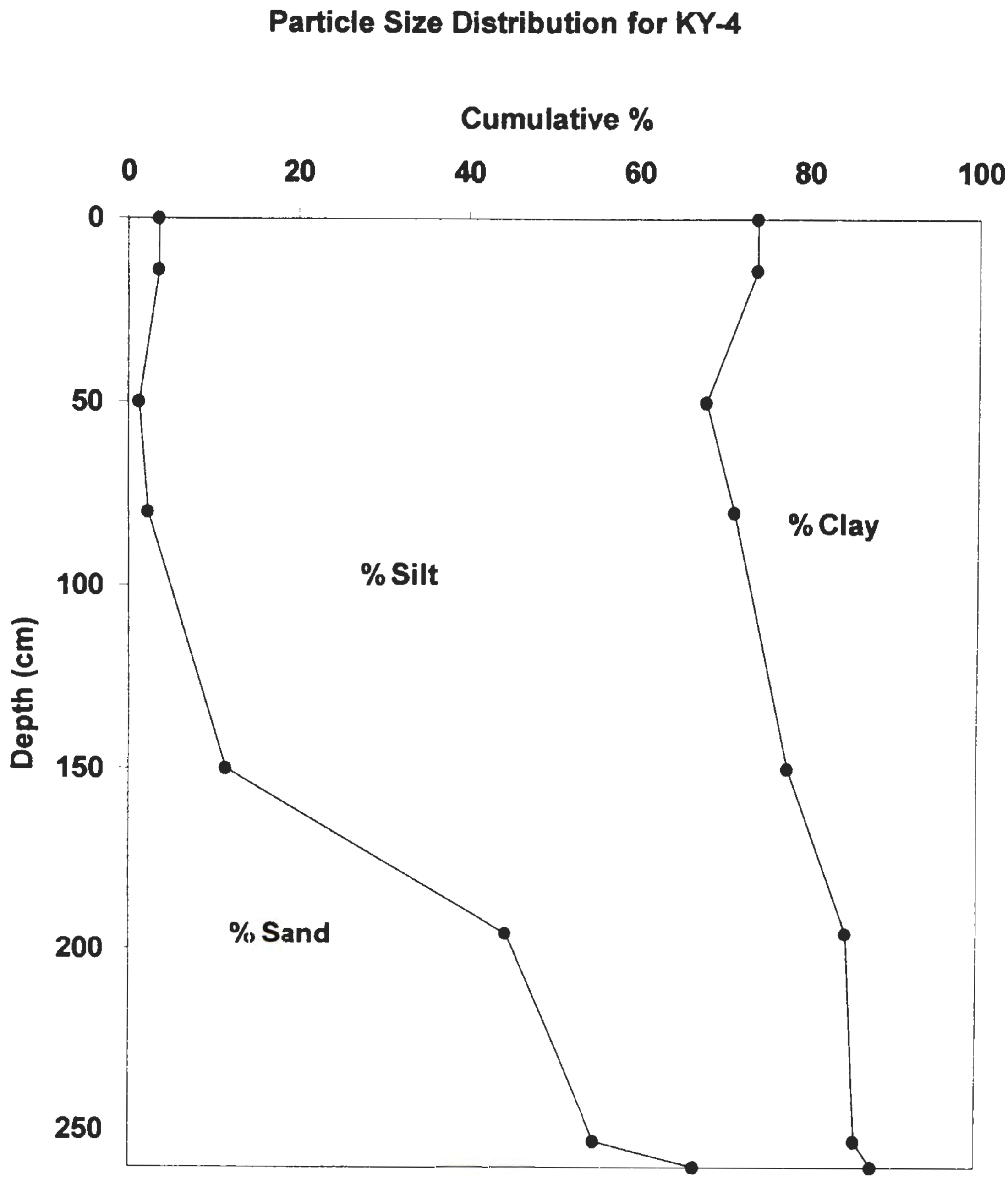


Figure 16. Particle size data by depth for Kentucky Site Four.

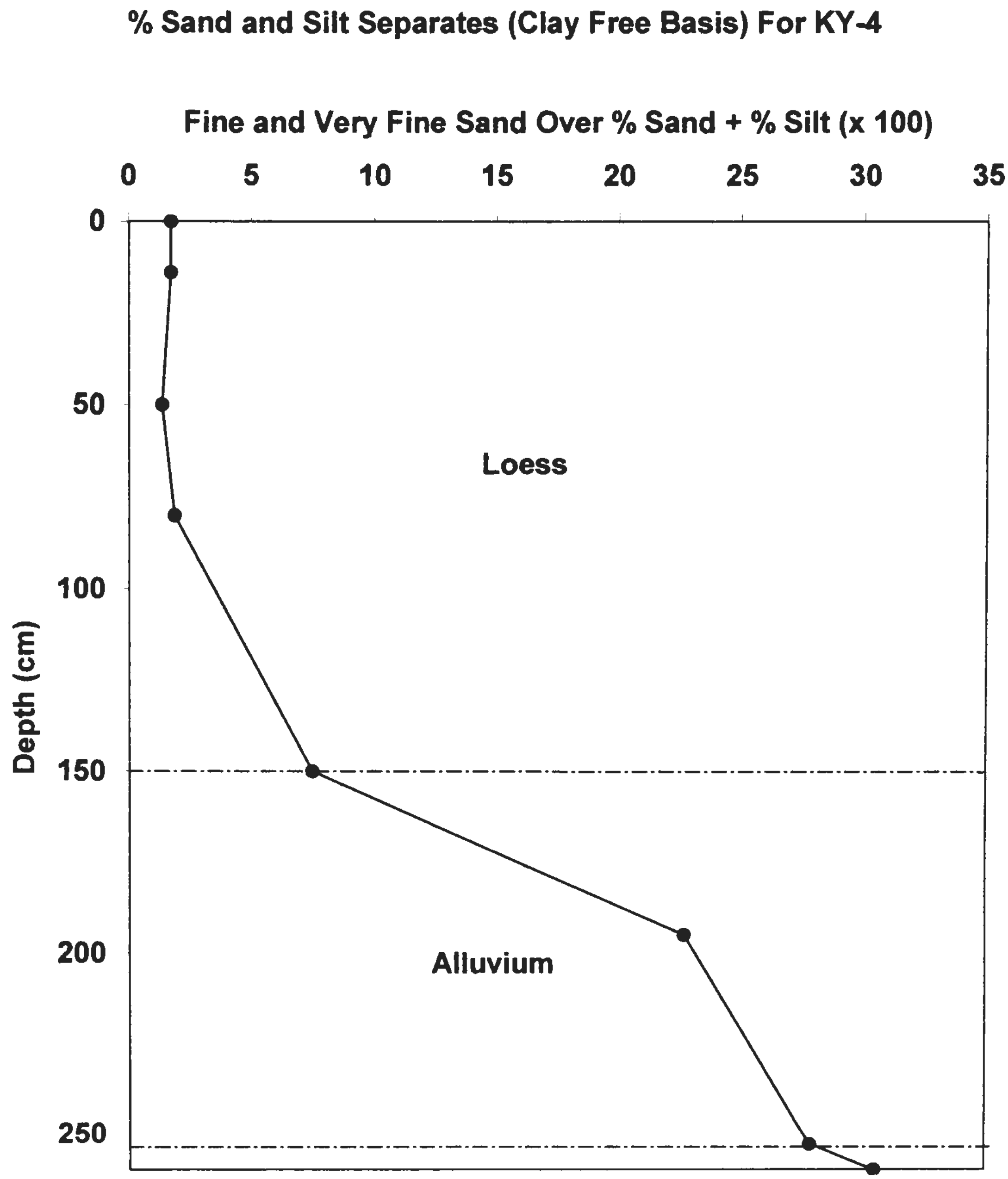


Figure 17. Sand and silt plotted on a clay free basis by depth as related to parent material for Kentucky Site Four.

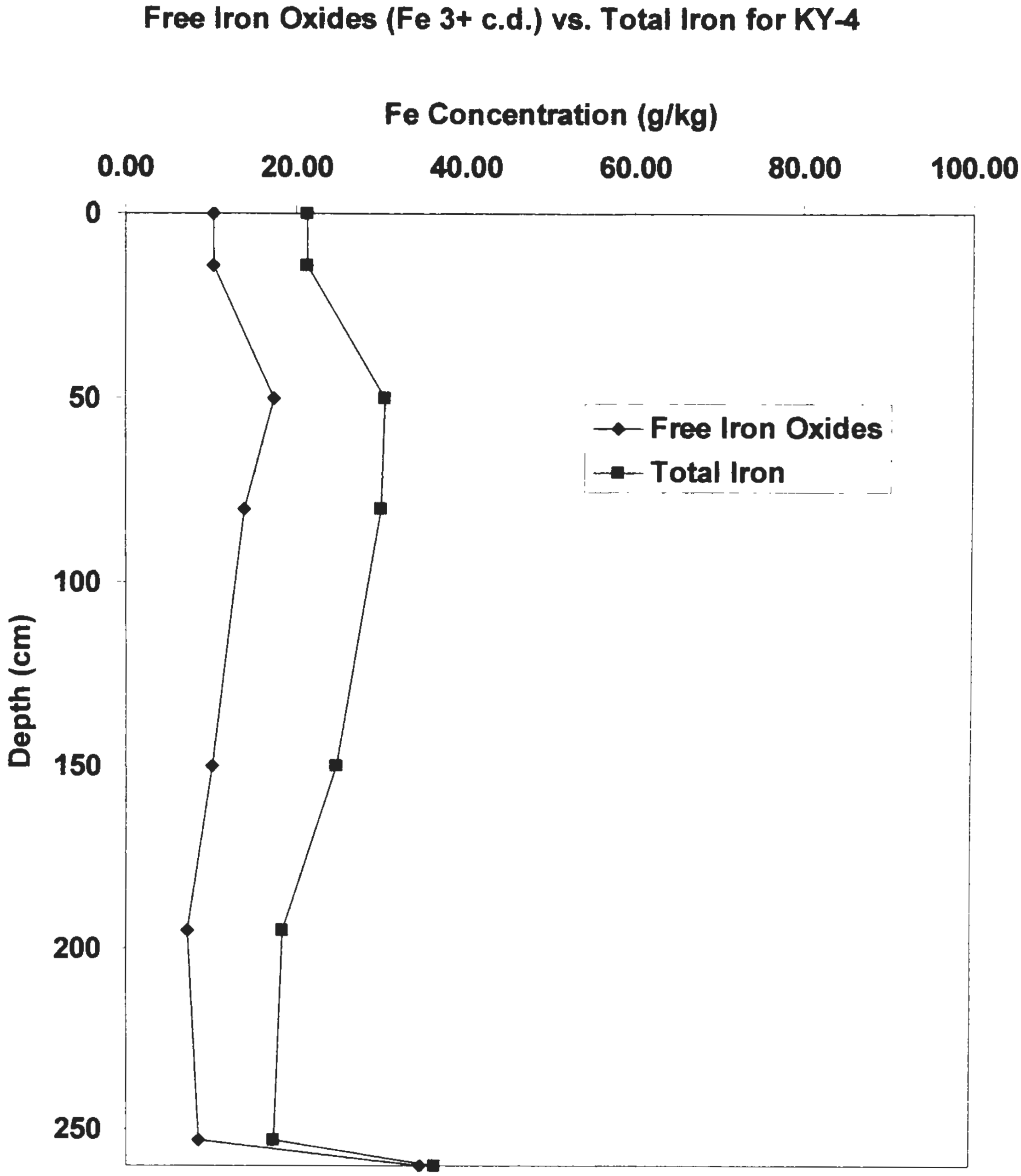


Figure 18. Free iron and total iron by depth for Kentucky Site Four.

total iron to a depth of 253 cm. A much higher amount of weathering has taken place in the 3C horizon which is presumably the Tertiary aged coastal plain material. This is also evident in the color of this horizon (2.5YR hue) which is an indication of paleosol development.

Redoximorphic features were present in the BC_1 horizon (80 – 150 cm). Hindrance of water movement at this depth is presumably being caused by the contrast in pore size distribution between the loessial parent material and the underlying alluvium. Easily reducible manganese data (figure 19) does not show evidence of drainage impediment at this depth. Therefore, any lateral movement of water within this horizon is offset when water encounters nearby areas of preferential flow.

The carbon distribution for this pedon can be seen in figure 20. Organic carbon and total carbon decrease regularly with depth. The accumulation of organic carbon and carbonates is to be expected when considering vegetation and agricultural production at this site.

This soil was classified as a fine-silty, mixed, active, thermic Fragic Hapludalf. The lack of continuous fragic properties in the subsurface has resulted in the suborder classification of Fragic Hapludalf. The subsurface does show signs of fragipan development in the BC_1 horizon (80 – 150 cm) however, these properties are much to weak to be diagnostic of a fragipan in this profile. Drainage at this site seems only to be hindered by the contrast in pore size distribution between the BC_1 and the $2BC_2$ horizons. Between these horizons,

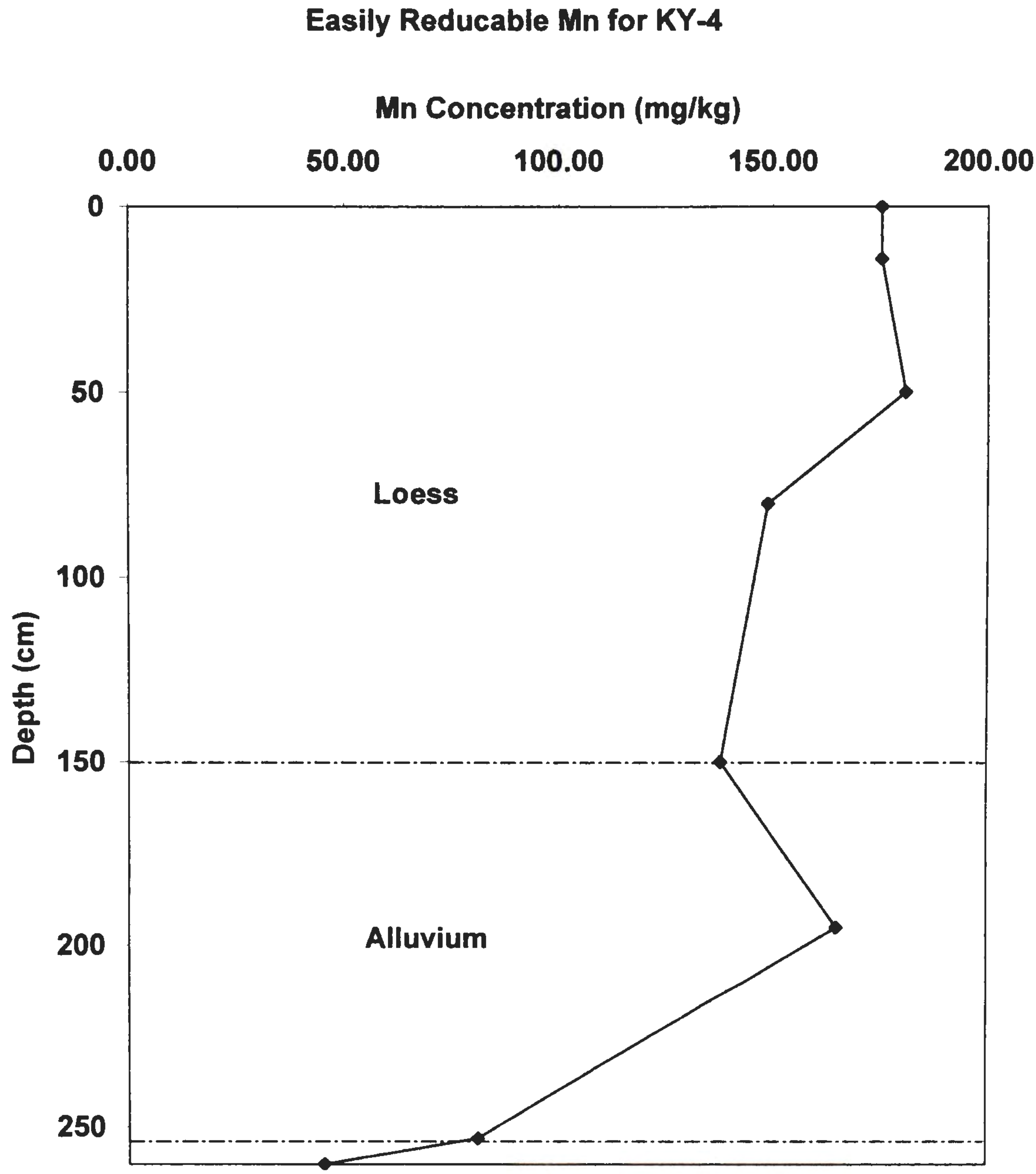


Figure 19. Easily reducible manganese concentration by depth as related to parent material for Kentucky Site Four.

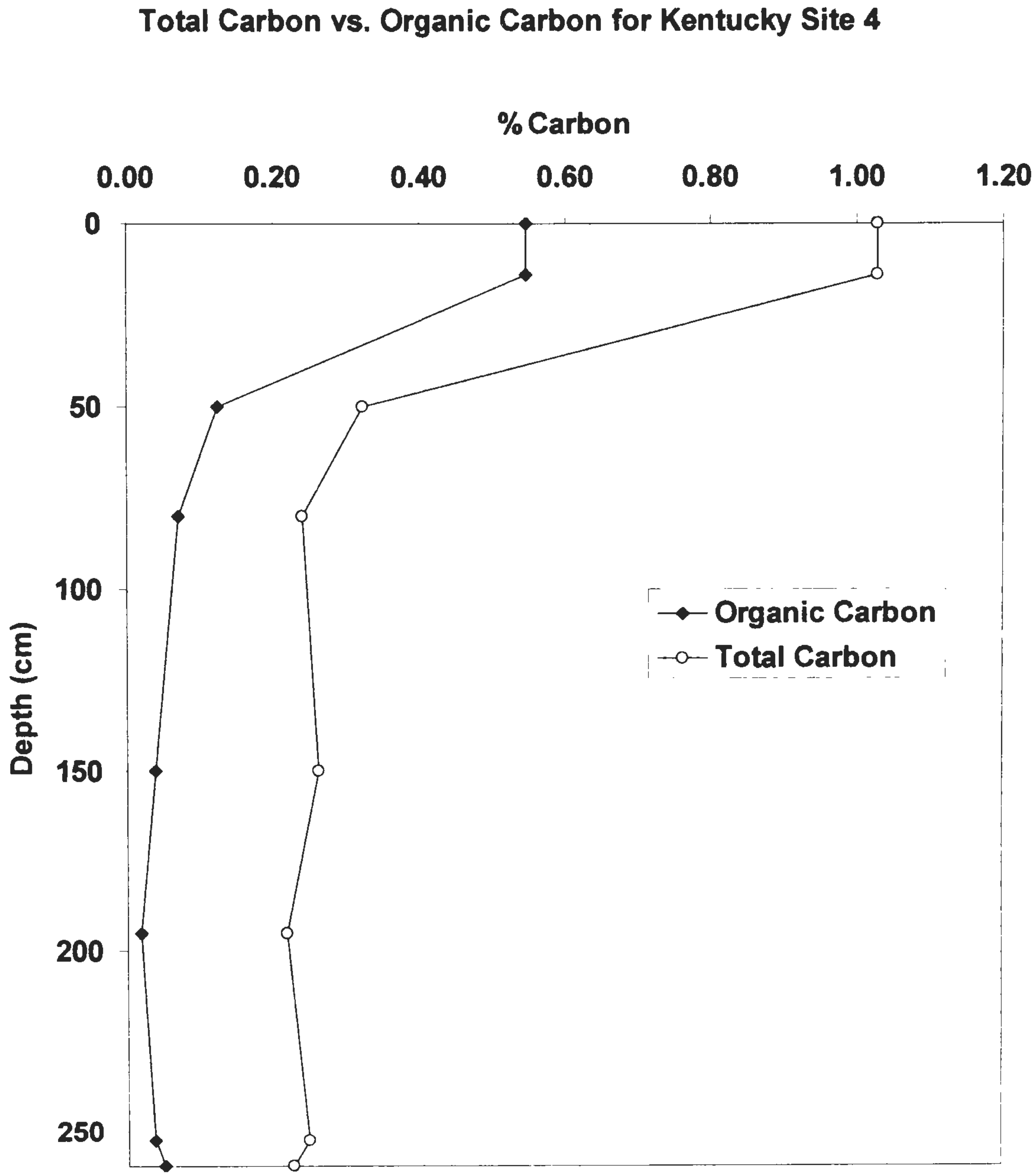


Figure 20. Organic carbon and total carbon by depth for Kentucky Site Four.

sand increases 33% (absolute). Water moving laterally in the BC_1 horizon quickly continues downward when nearby areas of preferential flow are encountered.

Conclusions for Kentucky Sites

Kentucky sites one and two were classified as fine-silty, mixed, active, thermic Typic Fragiudalfs. Kentucky sites three and four were classified as fine-silty, mixed, active, thermic Fragic Hapludalfs. Due to the occurrence of fragipans in the pedons described at sites one and two, lateral movement of water in the subsurface is likely. Sites one and two showed evidence of the hindrance of water movement within the fragipan horizons (70 – 140 cm and 110 – 184 cm respectively). Site position and erosion seem to be somewhat responsible for the lack of true fragipan development at sites three and four. At these two sites, the hindrance of water movement seems to be caused mainly by the contrast between pore size distribution of adjacent soil parent materials. Overall, the field containing these sites is a prime candidate for the movement of waterborne contaminants offsite.

Both the loess and underlying alluvium at each of these sites seem to have undergone similar amounts of weathering indicating that these materials were deposited during the same epoch (*i.e.* late Pleistocene). These materials were probably deposited during interglacial times that were somewhat close together during the Pleistocene. This is inferred by the lack of soil development in the alluvium and by the similarities in weathering patterns between the loess and the alluvium. The deeper weathering of the lower Tertiary aged coastal plain material at each of the sites is evident through paleosol development at the lower depths of each of the sites. These paleosols are marked by much redder 5YR and 2.5YR hues than the overlying loess and alluvium and are products of a much warmer/tropical climate at the time of their development. Furthermore, it is evident that the materials that make up the Tertiary aged coastal plain parent materials are products of a fluvial environment. This is most evident from the presence of well-rounded coarse fragments found in these portions of the profile. It seems likely that the landforms present in the immediate area of the Kentucky study site are in fact ancient fluvial terraces which have been inundated by alluvium from ancient streams and loess during the late Pleistocene.

Mississippi Site One

Mississippi Site One was located at N34°48'14.00", W89°26'23.00". The parent material sequence at this site was loess over Tertiary aged sand (table 7). The particle size distribution for this pedon can be seen in figure 21. There appears to be two separate loess depositions marked by paleosol development at 203 cm. Peoria loess extends from the surface to a depth of 203 cm. Clay increases just beneath the surface and decreases to the depth of the discontinuity. Loveland loess is present from a depth of 203 cm to a depth of 360 cm. This portion of the profile is dominantly silt with a slightly higher sand and clay content than the overlying Peoria loess. These findings are consistent with those of Rutledge *et al.* (1985). Beneath the loessial parent material is Tertiary

Table 7: Morphology description for Mississippi Site One

Horizon	Depth (cm)	Color (moist)	Texture [†]	Boundary [‡]	Structure [§]	Consistency (moist) [£]	Notes [Ω]
Ap	0-24	10YR 4/3	SiL	C	mo sbk	fri	-
Bt	24-80	7.5YR 4/6	SiCL	C	mo sbk	fri	-
BC1	80-130	7.5YR 4/6	SiL	C	mo sbk	fri	few Mn conc.
BC2	130-170	7.5YR 4/6	SiL	C	mo sbk	fri	Mn conc., stripped areas
BC3	170-203	7.5YR 4/6	SiL	C	mo sbk	fri	Mn conc., stripped areas
2Bt1	203-270	5YR 4/6	SiCL	C	mo sbk	fri	Mn conc., stripped areas
2Bt2	270-325	5YR 4/6	SiCL	A	mo sbk	fri	Fe conc. and depl, zone of perched water from 310 to 325cm.
2Bt3	325-360	7.5YR 5/4	SiCL	A	mo sbk	fri	Mn conc., Fe conc.
3C	360-390+	5YR 5/6	SL	-	sls ma	vfr	-

† silt loam (SiL), silty clay loam (SiCL), sandy loam (SL)
‡ Abrupt (A), Clear (C)
§ structure-less (sls), moderate (mo), sub-angular blocky (sbk), massive (ma)
£ friable (fr), very friable (vfr)
Ω Manganese (Mn), concentrations (conc.)., Iron (Fe), depletions (depl).

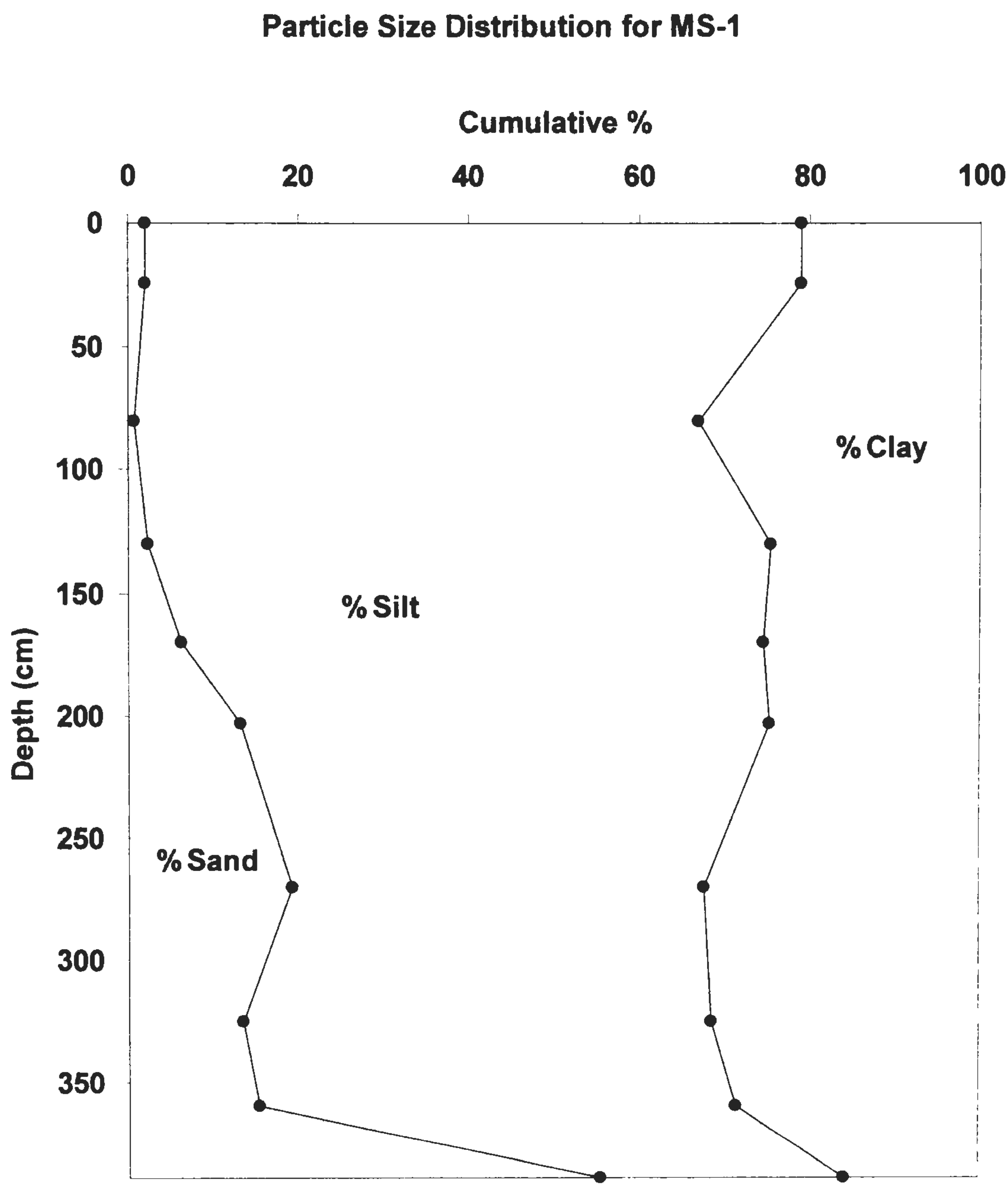


Figure 21. Particle size data by depth for Mississippi Site One.

aged coastal plain material (360 – 390+ cm) that is marked by a dramatic increase in sand (40% increase) in addition to paleosol development (5YR hues). The discontinuities observed in this pedon are further supported by fine sand data (on a clay free basis) seen in figure 22. At the depth of the first lithologic discontinuity (203 cm) the fine and very fine sand rapidly increases and then decreases with depth. The increase is seen again at the depth of the second lithologic discontinuity (360 cm).

The weathering pattern for this pedon can be seen in figure 23. The Peoria loess appears to be less weathered than the underlying Loveland loess. This is evident by a greater difference between iron oxide and total iron concentrations in the Peoria loess (0 – 203 cm). The Loveland loess deposition is slightly more weathered than the overlying Peoria loess. This can be seen in figure 23 above and is also evident by observing the 5YR hues exhibited by this portion of the profile. The additional time that the Loveland loess was exposed at the surface has resulted in the development of a paleosol. The underlying Tertiary aged coastal plain material (360 – 390+ cm) shows similar evidence of weathering.

The carbon distribution for this pedon can be seen in figure 24. Overall, carbon decreases regularly with depth. There is a slight increase in organic carbon at a depth 325 cm which may indicate that this is actually a buried surface horizon. There is no indication of secondary carbonate accumulation in this profile.

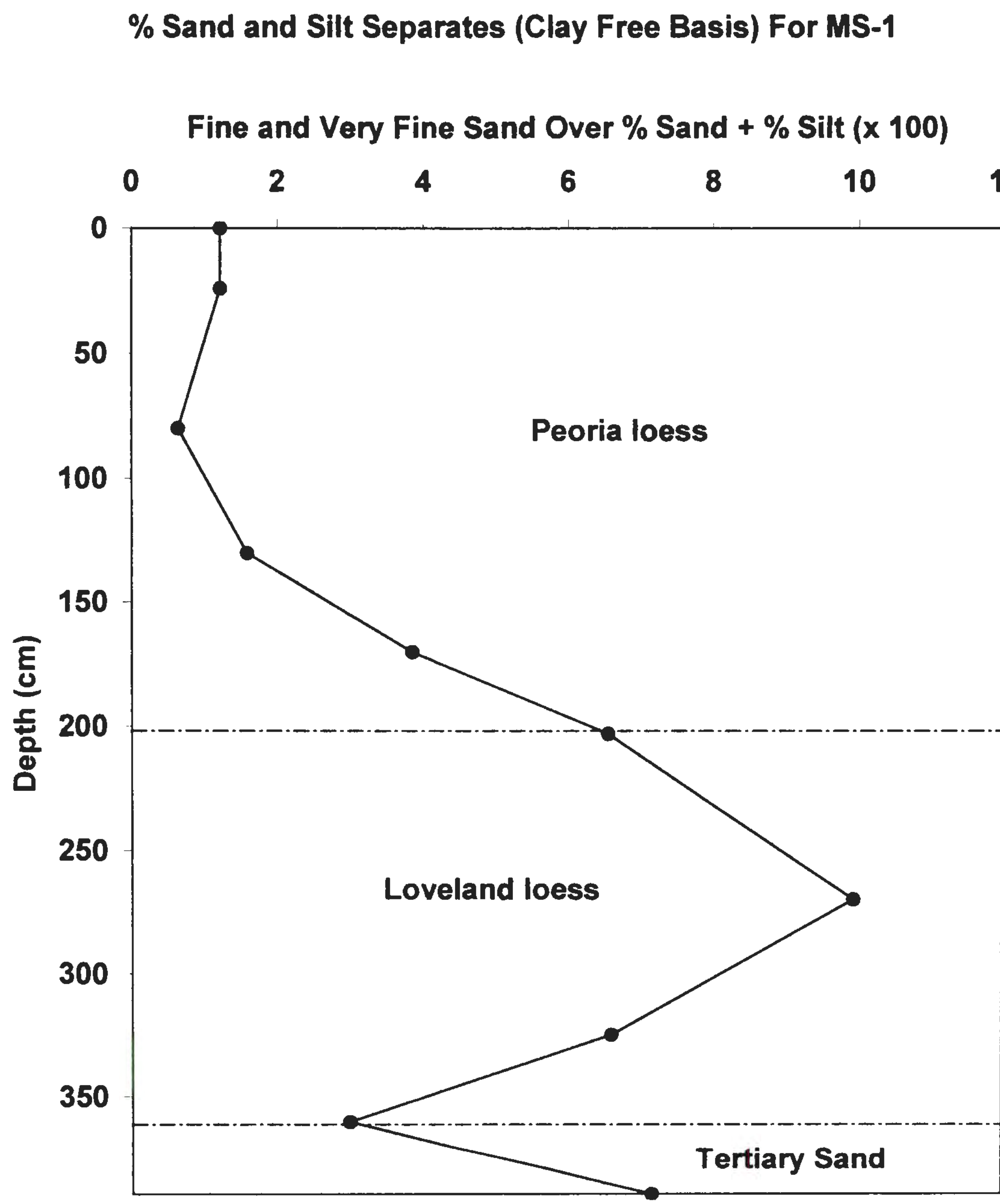


Figure 22. Sand and silt plotted on a clay free basis by depth as related to parent material for Mississippi Site One.

Free Iron Oxides (Fe 3+ c.d.) vs. Total Iron for MS-1

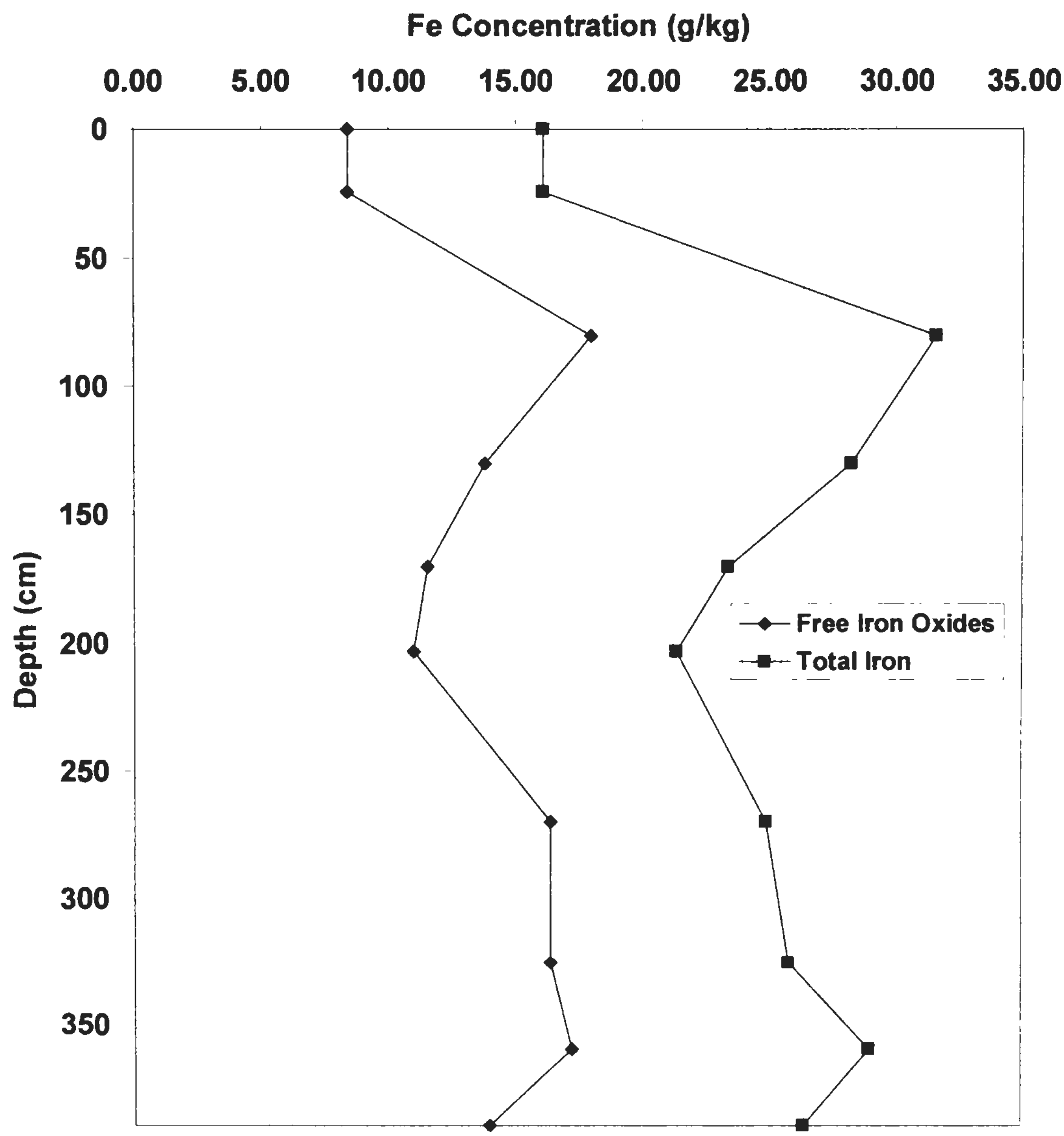


Figure 23. Free iron and total iron by depth for Mississippi Site One.

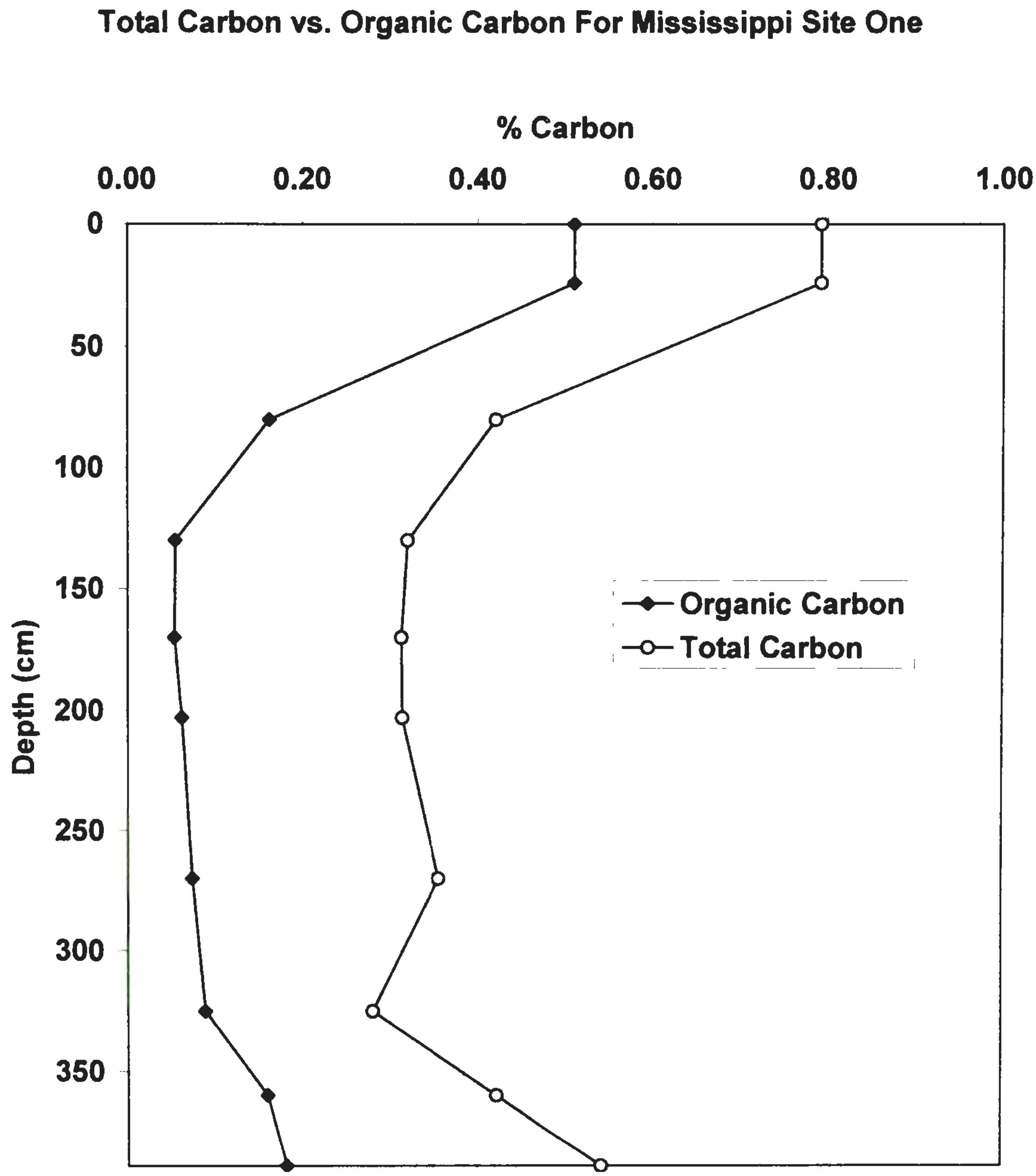


Figure 24. Organic carbon and total carbon by depth for Mississippi Site One.

There was evidence of hindrance of water movement in the lower 5 cm of the $2Bt_2$ horizon (310 – 325 cm) and redoximorphic features in the form of iron concentrations were common in the $2Bt_3$ horizon. These redoximorphic features are being caused by the contrast in pore size distribution between the loessial parent material and the underlying Tertiary aged coastal plain material. Sand increases 40% (absolute) between the loess and the underlying sandy coastal plain material. Easily reducible manganese data for this pedon can be seen in figure 25. The concentration of easily reducible manganese increases at the boundary of the first lithologic discontinuity (203 cm) indicating that there may be hindrance of downward movement of water. There is an increase in clay between the BC_3 horizon and the $2Bt_1$ horizon which may contribute to this hindrance due to decreased hydraulic conductivity.

This soil was classified as a fine-silty, mixed, active, thermic Ultic Hapludalf. The hindrance of water moving downward through the profile seems to be mainly influenced by the contrast of pore size distribution at the boundaries of the lithologic discontinuities (*i.e.* 203 cm and 360cm). Areas of preferential flow were observed in the form of stripped areas mainly from a depth of 130 to 270 cm.

Mississippi Site Two

This pedon was located at N34°49'09.60", W89°26'21.40". The parent material sequence was loess over alluvium over Tertiary aged coastal plain material (table 8). Figure 26 shows the particle size distribution for this site.

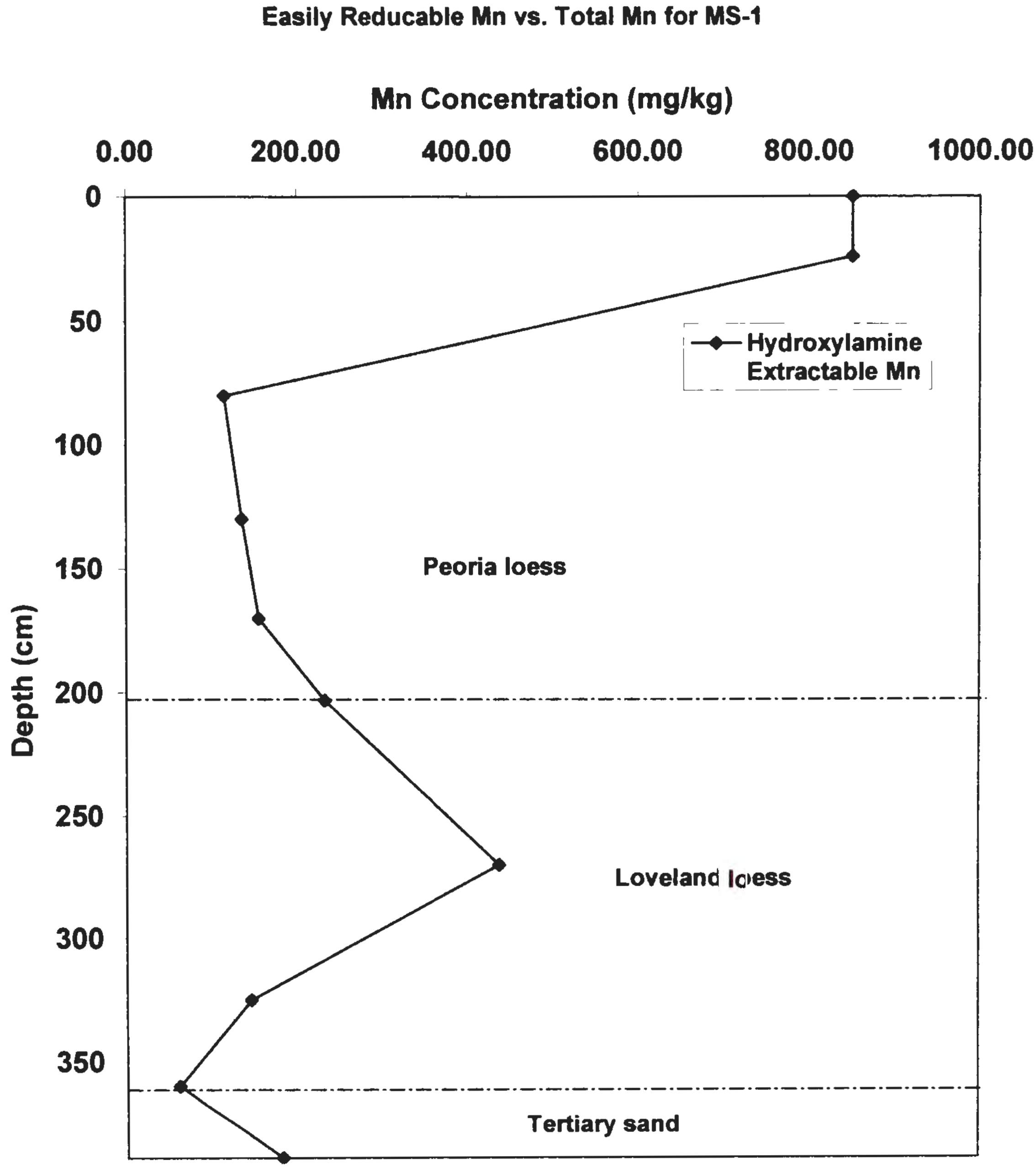


Figure 25. Easily reducible manganese concentration by depth as related to parent material for Mississippi Site One.

Table 8: Morphology description for Mississippi Site Two

Horizon	Depth (cm)	Color (moist)	Texture [†]	Boundary [‡]	Structure [§]	Consistency (moist) [£]	Notes [Ω]
Ap	0-12	7.5YR 4/3	SiL	A	mo gr	fr	-
2Bx1	12-68	7.5YR 4/6	SiCL	A	mo pris	fi	few Mn conc., few Fe conc., stripped areas common, blind pores common
2Bx2	68-120	5YR 5/6	SiL	C	mo pris	fi	Mn conc., Fe conc., stripped areas, blind pores
2Bt,x	120-155	2.5YR 3/6	CL	C	mo pris	fi	Fe depl, clay films
3BC	155-186	2.5YR 3/6	L	C	mo sbk	fri	Mn conc., Fe conc.
3C	186-230+	5YR 5/6	SL	-	sls ma	vfr	-

† silt loam (SiL), silty clay loam (SiCL), clay loam (CL), loam (L) sandy loam (SL)
‡ Abrupt (A), Clear (C)
§ structure-less (sls), moderate (mo), granular (gr), prismatic (pris), subangular blocky (sbk), massive (ma)
£ friable (fr), firm (fi), very friable (vfr)
Ω Manganese (Mn), concentrations (conc.)., Iron (Fe), depletions (depl).

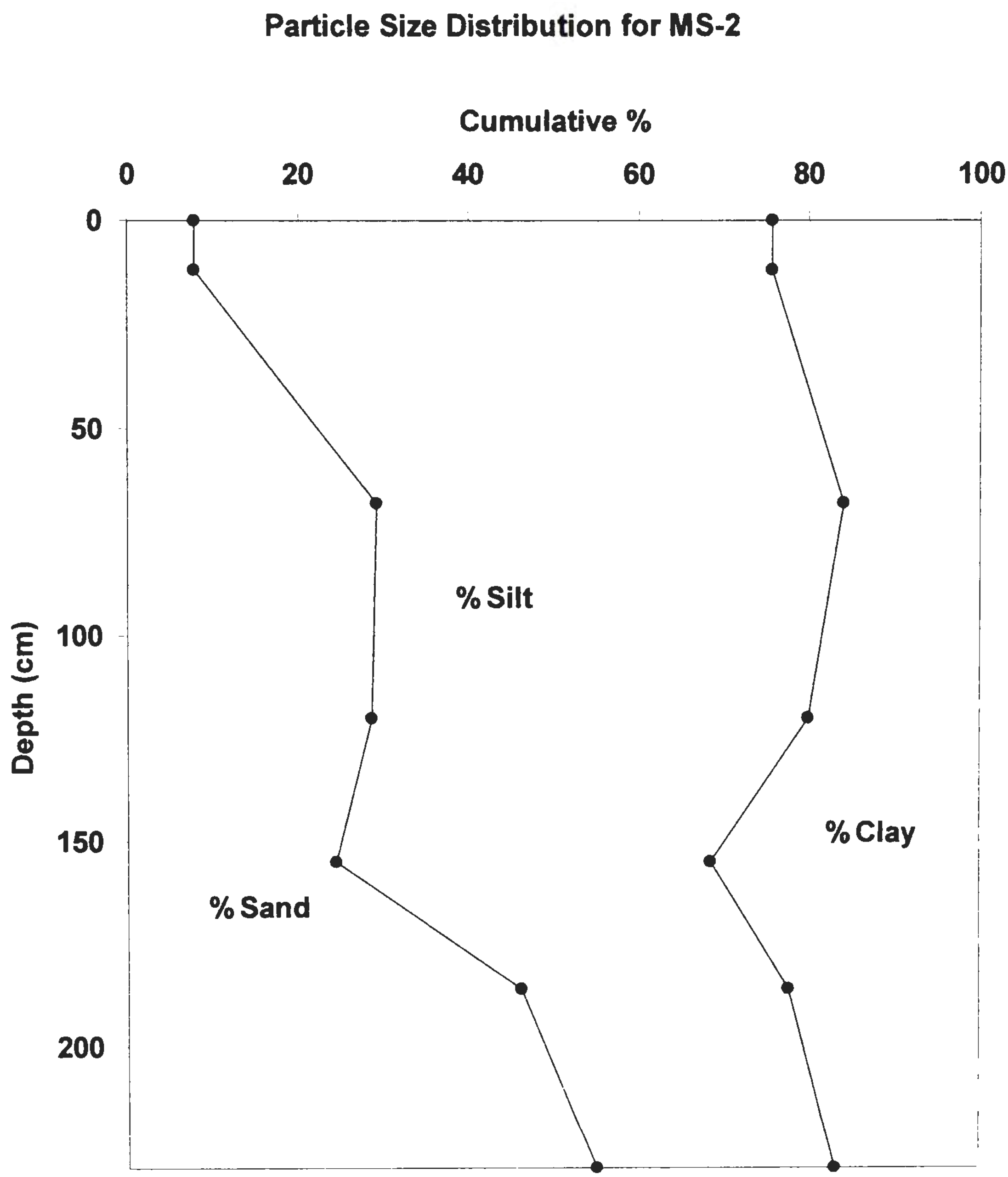


Figure 26. Particle size data by depth for Mississippi Site Two.

Loess extended from the surface to a depth of 12 cm. Most of the original loess at this site has been eroded (figures 26 and 27). The second parent material in this pedon was interpreted as alluvium due to the increase in sand content from a depth of 12 cm to a depth of 155 cm. This discontinuity was also marked by paleosol development (2.5YR and 5YR hues). Beneath the alluvium the amount of sand dramatically increased and was also marked by paleosol development. This material was interpreted to be Tertiary aged coastal plain material due to the contrast in particle size distribution in addition to evidence of pedogenesis (*i.e.* illuvial clay increase and lack of structure). Fine sand data (on a clay free basis) is shown in figure 27 and further substantiates the depths of the lithologic discontinuities observed in this pedon.

The diagnostic subsurface horizons in this pedon were a fragipan (12 – 12 cm) and an argillic horizon that was also dominantly fragic (120 – 155cm). The fragipan exhibited typical properties such as prismatic structure, brittleness, firm rupture resistance class, stripped areas, clay films, and blind pores (table 8). The surface horizon was perhaps part of the original fragipan however, erosion and plowing have resulted in its destruction.

The weathering pattern exhibited in this pedon can be seen in figure 28. The surface horizon is slightly less weathered than the underlying horizons which is evident from the difference between oxidized iron and total iron. This difference decreases in the subsurface indicating that the alluvium and Tertiary aged coastal plain material are more weathered. The colors of the subsurface

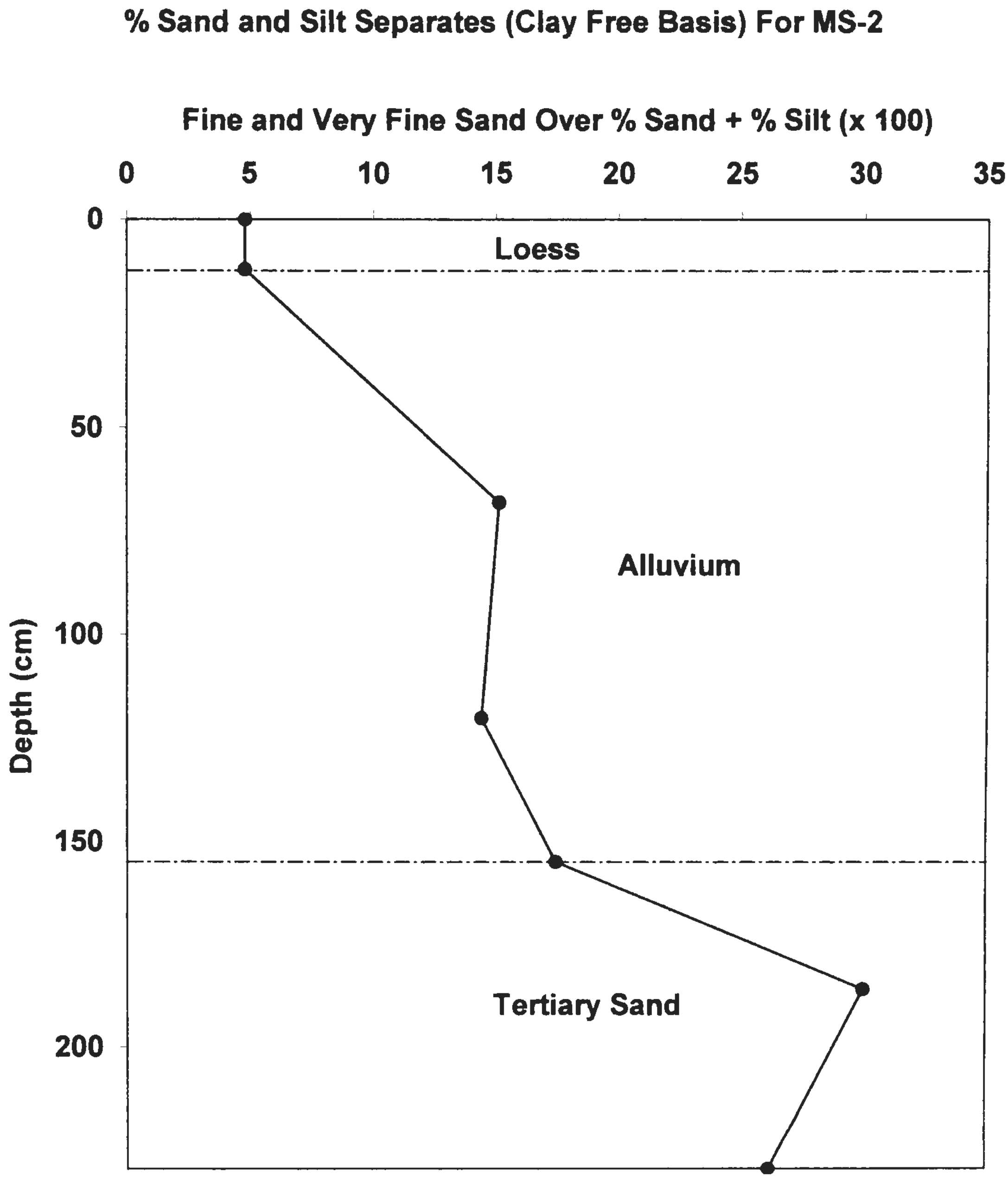


Figure 27. Sand and silt plotted on a clay free basis by depth as related to parent material for Mississippi Site Two.

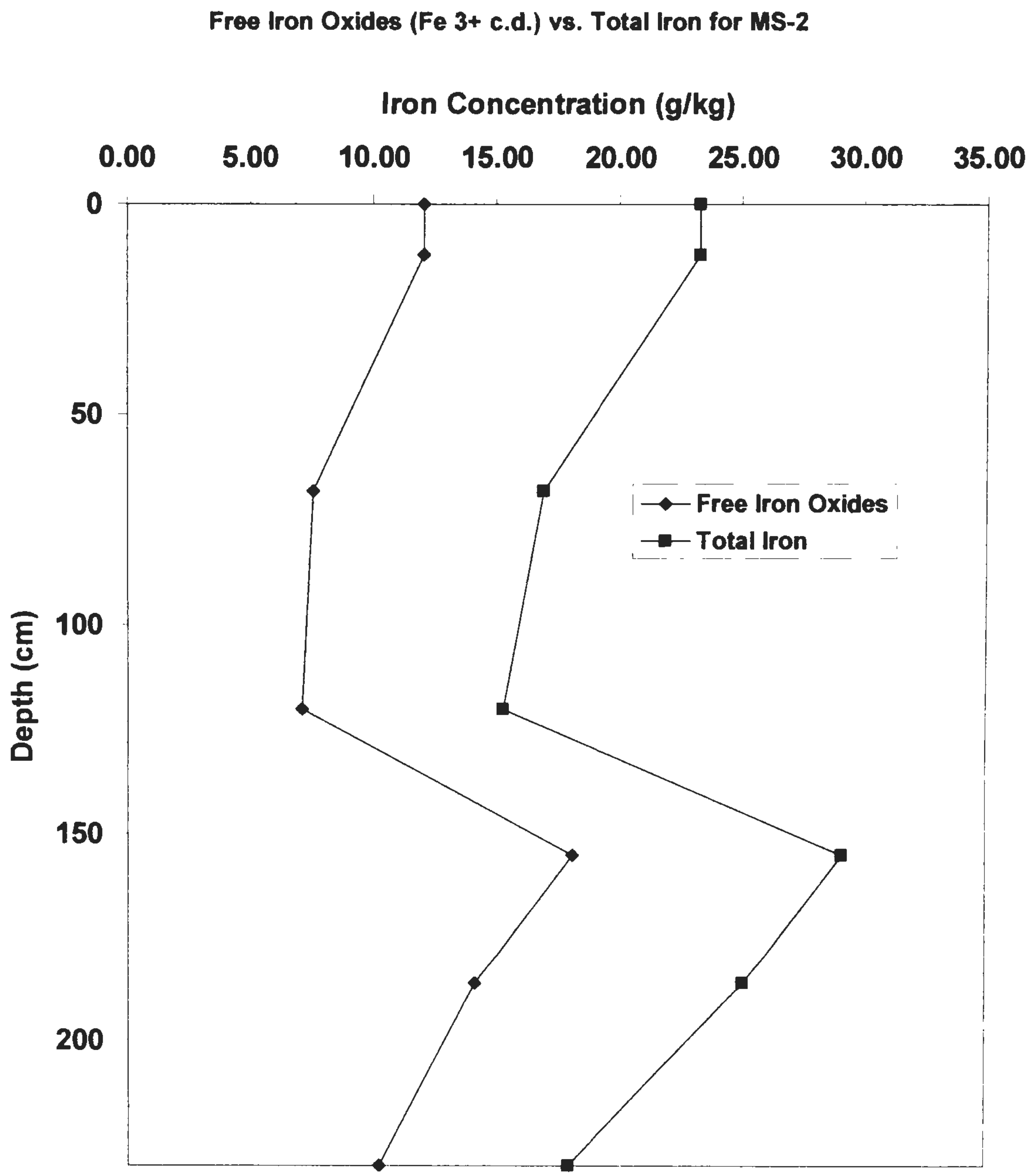


Figure 28. Free iron and total iron by depth for Mississippi Site Two.

horizons indicate that these horizons have undergone a high amount of weathering has as well (2.5YR and 5YR hues).

The carbon distribution exhibited in this pedon can be seen in figure 29. There is a regular carbon distribution with depth and no free carbonates were observed in the profile. The higher amount of organic carbon may be attributed to the addition of amendments (*i.e.* manure) in the past. In addition to this there was a higher amount of total carbon which may be attributed liming.

Redoximorphic features were observed in this profile in the 2Bt,x horizon (120 – 155 cm). This hindrance of drainage in the profile was caused by the contrast in pore size distribution between the alluvium and the underlying Tertiary aged coastal plain material in addition to the fragipan. There was a sharp increase in sand at the boundary of the discontinuity (figure 25, 155 cm). Easily reducible manganese data (figure 30) does not show a hindrance of water movement in the profile.

This soil was classified as a fine-loamy, mixed, active, thermic Typic Fragiudalf. It has developed mainly in alluvium and most of the original loess has been eroded from this site. Thus the particle size class at the family level of classification is fine-loamy. The presence of a fragipan in addition to the contrast in the distribution of parent materials that make up the profile (*i.e.* sand) contribute to the fate of downward moving water in the profile. Any lateral movement of water within the subsurface would probably occur in the 2Bt,x horizon (120-155 cm). This is evident due to the presence of redox depletions.

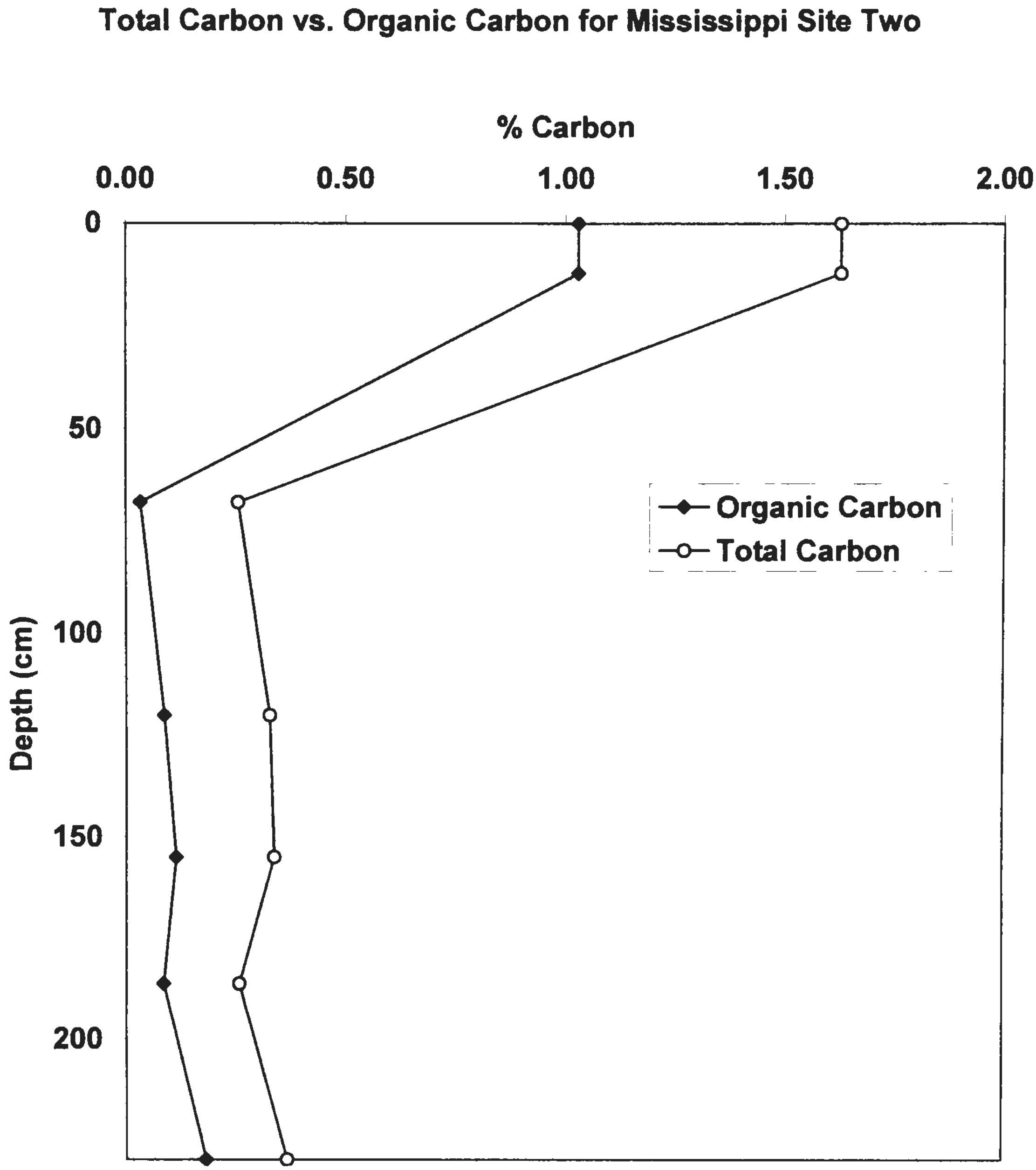


Figure 29. Organic carbon and total carbon by depth for Mississippi Site Two.

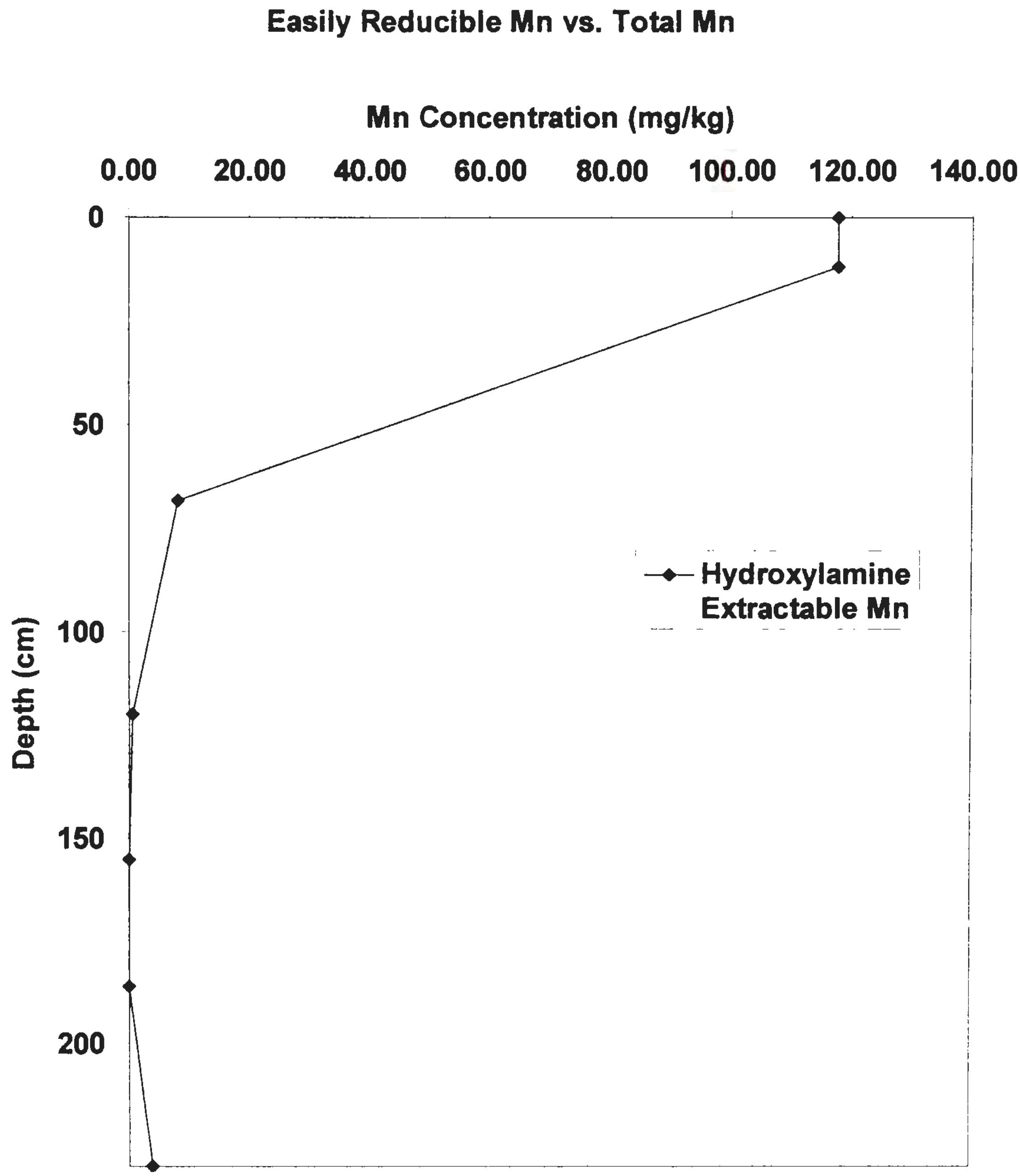


Figure 30. Easily reducible manganese concentration by depth as related for Mississippi Site Two.

Preferential flow is evident above this horizon due to the presence of stripped areas in the overlying fragipan.

Mississippi Site Three

This pedon was located at N34°49'11.50" N, W89°26'22.10". The parent material sequence was Loess over Tertiary aged coastal plain material. The particle size distribution for this pedon can be seen in table 9 and figure 31. Two loess deposits were identified in the pedon. These loess deposits are presumably Peoria loess (0 – 162 cm) and Loveland loess (162 – 250 cm). A paleosol is evident in the Loveland loess as indicated by 2.5YR Hues. Beneath the loess, a sharp increase in sand at a depth of 250 cm marks the boundary of the Tertiary aged coastal plain material. Further evidence for the lithologic discontinuities observed in this pedon is shown in figure 32. Fine sand (on a clay free basis) increases sharply at the upper depth of the Loveland loess (203 cm) and again increases at the upper boundary of the Tertiary aged coastal plain material (250 cm).

The diagnostic subsurface horizons in this pedon were argillic horizons. A significant increase in clay can be seen in the Peoria loess at a depth of 15 – 58 cm and another increase in clay is seen in the Loveland loess at a depth of 162 – 250 cm (figure 31). The accumulation of clay actually extends into the lower Tertiary aged coastal plain material in this pedon (3Bt$_3$ horizon, 250 – 283 cm). The clay increase found in the Loveland loess and the Tertiary coastal plain material is thought to be illuvial clay increase from the early Pleistocene when

Table 9: Morphology description for Mississippi Site Three

Horizon	Depth (cm)	Color (moist)	Texture [†]	Boundary [‡]	Structure [§]	Consistency (moist) [£]	Notes [Ω]
Ap	0-15	10YR 4/4	SiL	C	mo sbk	fr	few Mn conc.
Bt	15-58	7.5YR 4/6	SiCL	C	mo sbk	fr	few Mn conc.
BC1	58-108	7.5YR 4/4	SiL	C	mo sbk	fr	few Mn conc., stripped areas
BC2	108-162	5YR 4/3	SiL	C	mo sbk	fr	Mn conc., stripped areas
2Bt1	162-203	2.5 YR 3/4	SiL	C	mo sbk	fr	Mn conc., clay films, stripped areas
2Bt2	203-250	2.5YR 3/6	SiCL	C	mo sbk	fr	Mn conc., clay films, stripped areas
3Bt3	250-283	2.5YR 4/6	CL	C	mo sbk	fr	-
3C	283-397+	7.5YR 5/6	SL	-	sls ma	vfr	-

† silt loam (SiL), silty clay loam (SiCL), clay loam (CL), sandy loam (SL)

‡ Clear (C)

§ structure-less (sls), moderate (mo), subangular blocky (sbk), massive (ma)

£ friable (fr), firm (fi), very friable (vfr)

Ω Manganese (Mn), concentrations (conc.)., Iron (Fe), depletions (depl).

Particle Size Distribution for MS-3

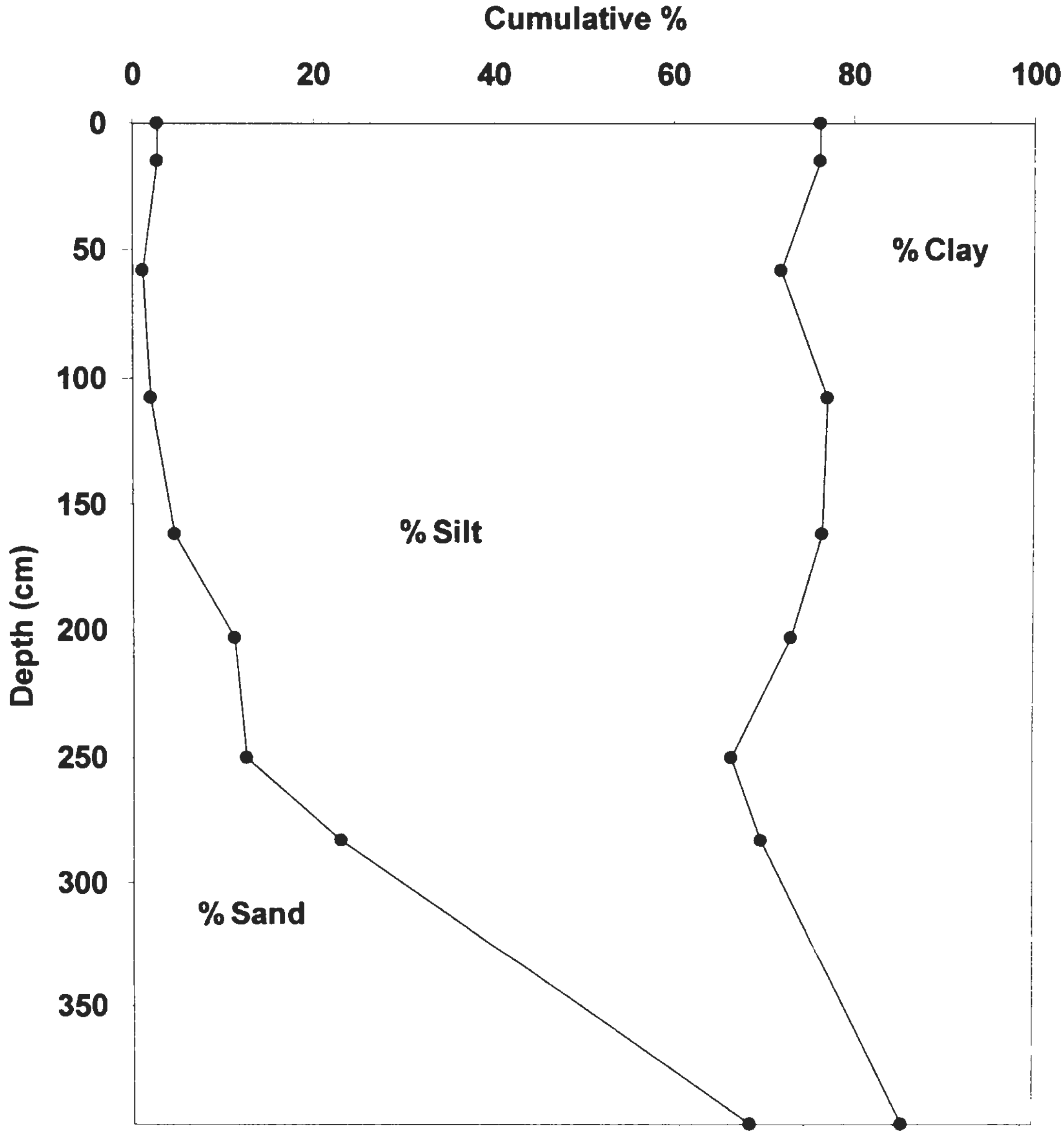


Figure 31. Particle size data by depth for Mississippi Site Three.

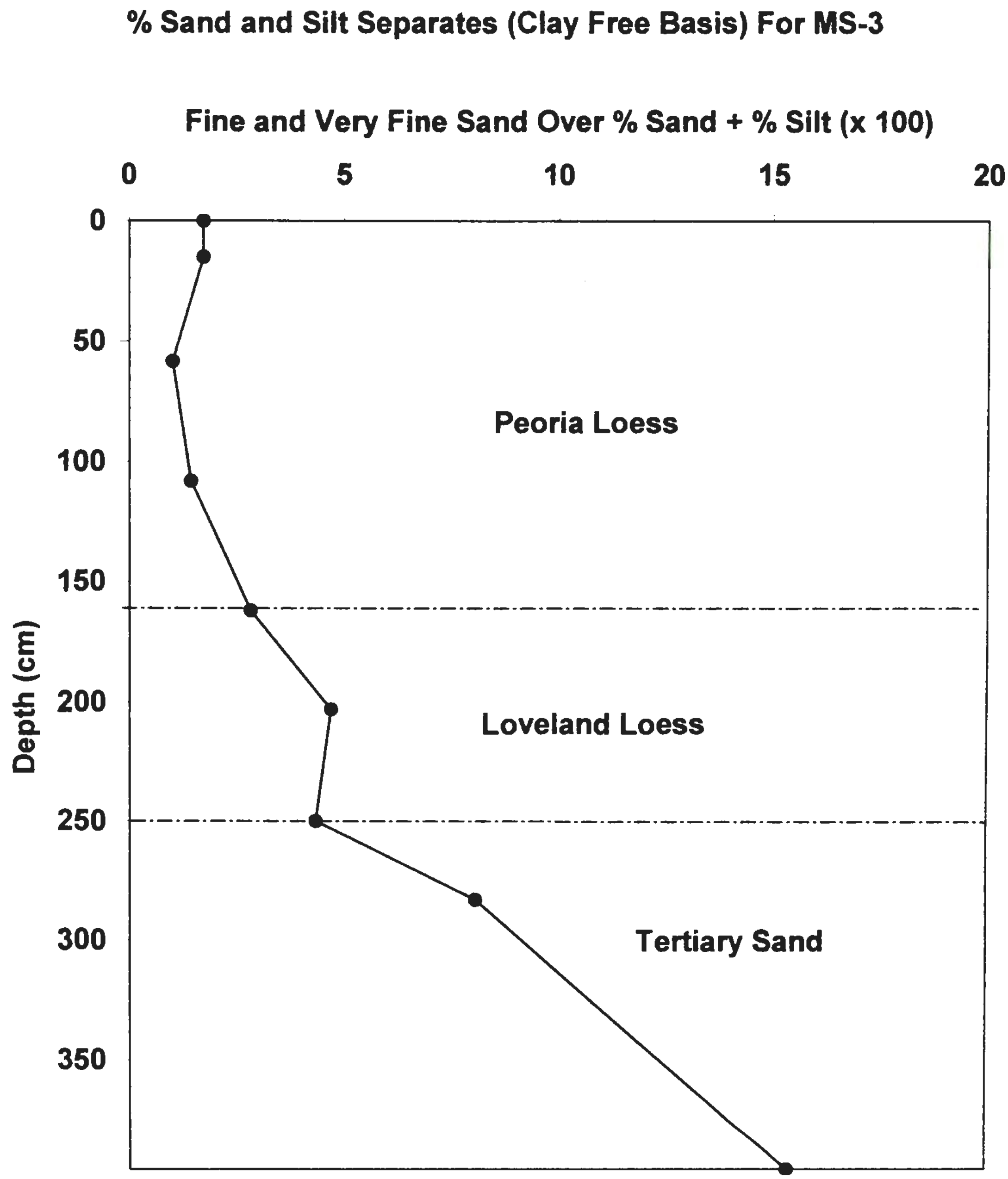


Figure 32. Sand and silt plotted on a clay free basis as related to parent material for Mississippi Site Three.

this material was actually deposited and underwent pedogenesis.

The weathering pattern exhibited in this pedon can be seen in figure 33. The Peoria loess is less weathered than the underlying Loveland loess and Tertiary aged coastal plain material. The difference between oxidized iron and total iron is greater in the Peoria loess than in the underlying material which is an indication that it is less weathered than the other parent materials in this pedon. Further evidence of paleosol development can be seen in figure 33 as well. The difference in oxidized iron and total iron seen in the Loveland loess (162 – 250 cm) is much less indicating that this material has undergone a greater amount of weathering. This is also evident in the red, 2.5YR hues exhibited in this portion of the profile.

The carbon distribution for this pedon is shown in figure 34. There is a regular decrease in carbon distribution to a depth of 203 - 250 cm. At this depth, both organic and total carbon increases. There was no indication of secondary carbonate accumulation at this depth as was evident by the lack of effervescence with 10% HCl. This horizon was probably once a surface horizon and the accumulation of plant life has resulted in organic carbon accumulation that has been buried by loess.

Significant redoximorphic features indicating a drainage impediment were not observed in this pedon. Areas of preferential flow within the Peoria and Loveland loess were evident in the form of stripped areas. The stripped areas were not observed in the Tertiary aged coastal plain material described in this

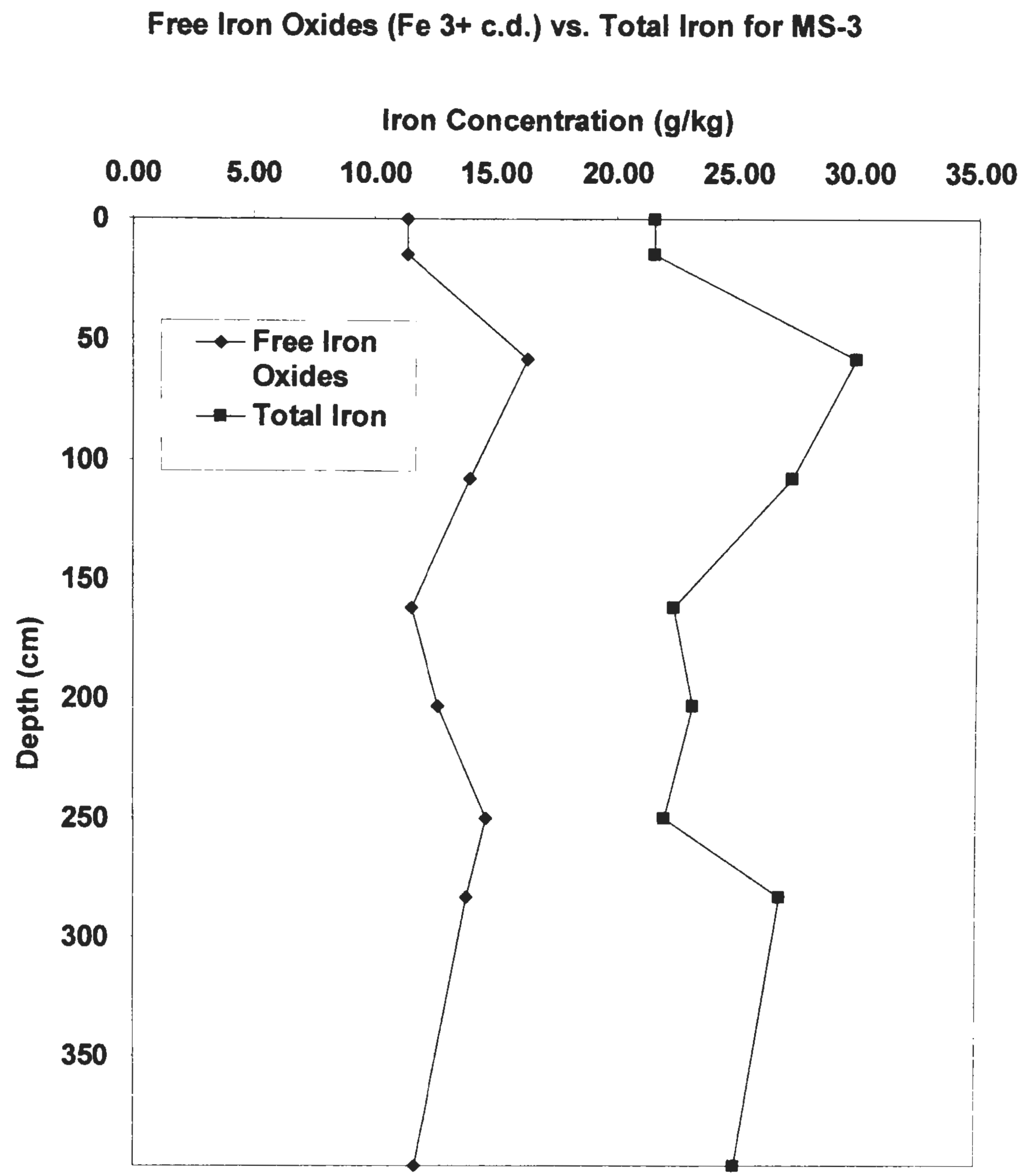


Figure 33. Free iron and total iron by depth for Mississippi Site Three.

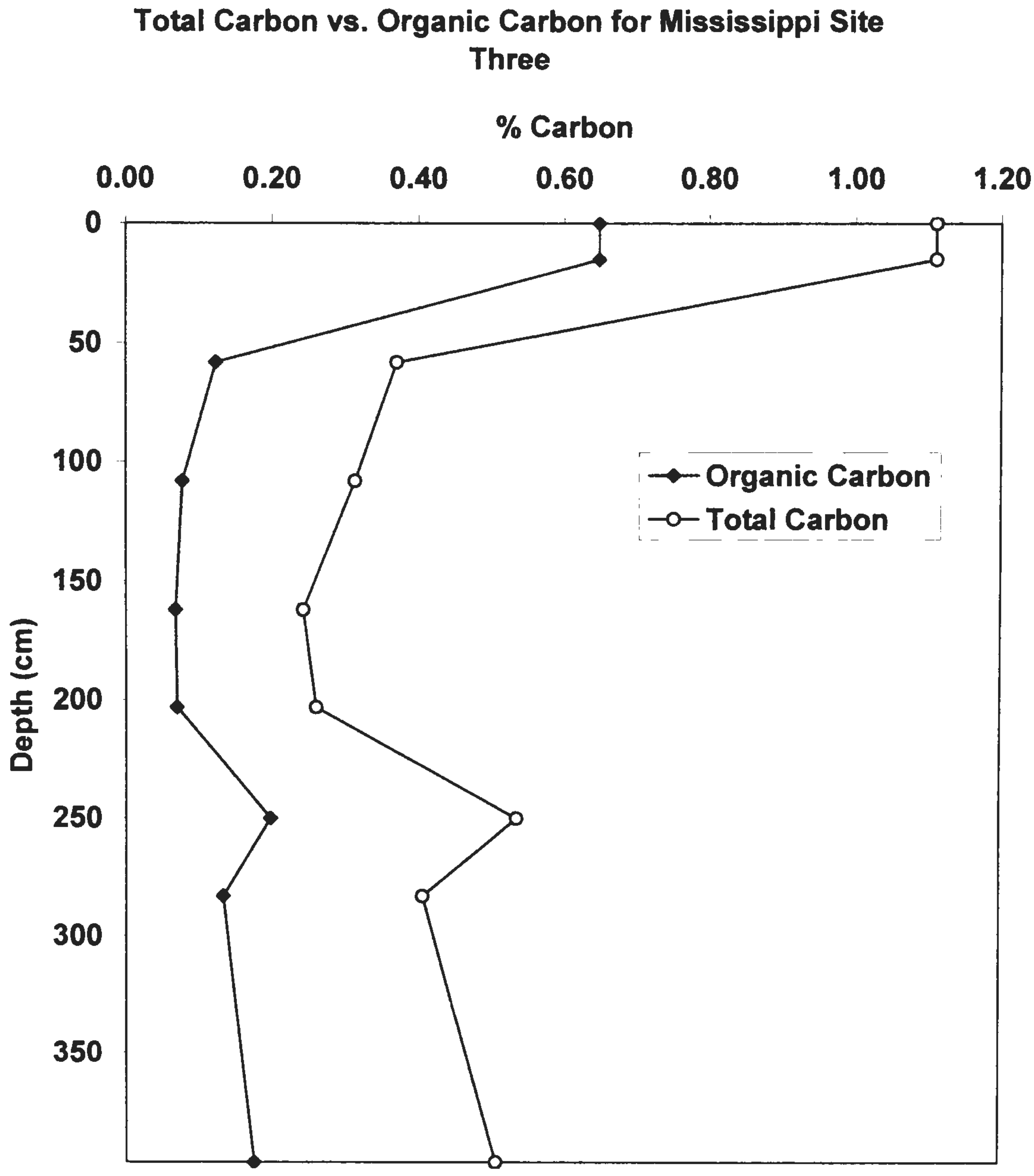


Figure 34. Organic carbon and total carbon by depth for Mississippi Site Three.

pedon. Figure 35 shows easily reducible manganese accumulation with depth for this profile. Easily reducible manganese increases significantly in the Loveland loess (162 – 250 cm). This indicates that the water moving downward through the profile is being hindered by the contrast in pore size distribution between the Loveland loess and the underlying coastal plain material.

This soil was classified as a fine-silty, mixed, active, thermic Ultic Hapludalf. The base saturation at a depth of 140 cm (1.25 meters below the top of the argillic horizon) is less than 60% which leads to the classification of an Ultic Hapludalf at the subgroup level. Redoximorphic features indicating hindrance of water movement were absent in the profile. However, easily reducible manganese accumulation in the Loveland loess indicates that the hindrance of water may occur due to the contrast in pore size distribution with the underlying coastal plain material.

Mississippi Site Four

The location of this pedon was N34°49'09.00", W89°26'21.90". The parent material sequence was alluvium over Tertiary aged coastal plain material over kaolin (table 10). The particle size distribution for this profile can be seen in figure 36. Alluvium extends from the surface to a depth of 59 cm. The original loess has been completely eroded from this pedon and is evident by the high amount of sand in the upper portion of the profile. At the depth of the first lithologic discontinuity (59 cm), the sand content increases dramatically (23% absolute). Colors of the Tertiary aged coastal plain material were much redder

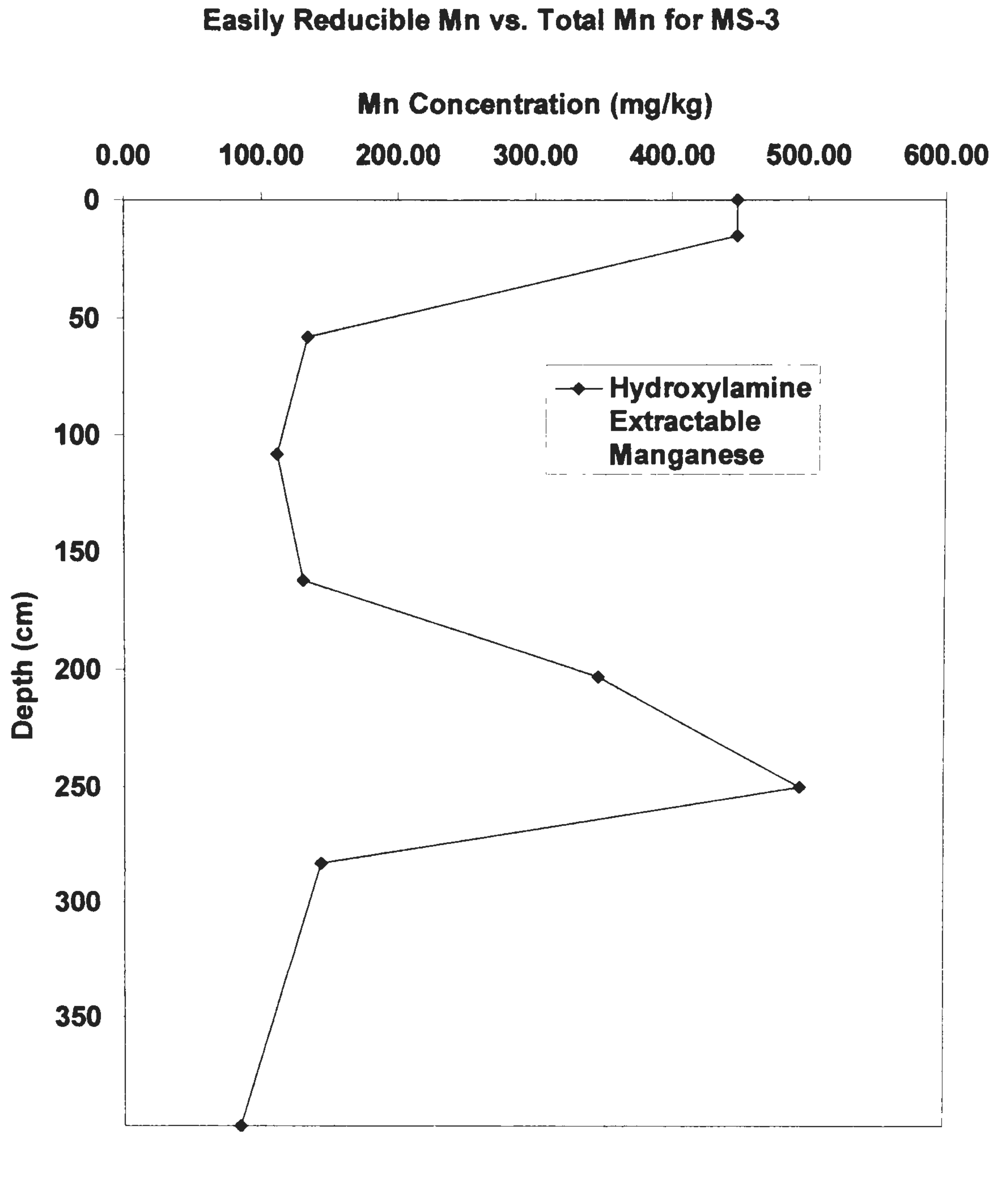


Figure 35. Easily reducible manganese concentration by depth for Mississippi Site Three.

Table 10: Morphology description for Mississippi Site Four

Horizon	Depth (cm)	Color (moist)	Texture †	Boundary ‡	Structure §	Consistency (moist) £	Notes Ω
Ap	0-11	10YR 4/4	SiL	A	mo gr	fr	-
BA	11-19	7.5YR 4/6	SiL	A	mo sbk	fr	Fe conc. common
Bt	19-59	5YR 4/4	CL	C	mo sbk	fr	clay films common
2CB	59-72	7.5YR 5/6	SL	C	wk sbk	vfr	-
2C1	72-100	2.5YR 4/8	SL	A	sls ma	vfr	-
3C2	100-114	-	-	-	-	-	-
3C3	114-136+	-	-	-	-	-	-

† silt loam (SiL), clay loam (CL), sandy loam (SL)
‡ Abrupt (A), Clear (C)
§ moderate (mo), weak (wk), structure less (sls), granular (gr), subangular blocky (sbk), massive (ma)
£ friable (fr), very friable (vfr)
Ω Fe (iron), concentrations (conc.)

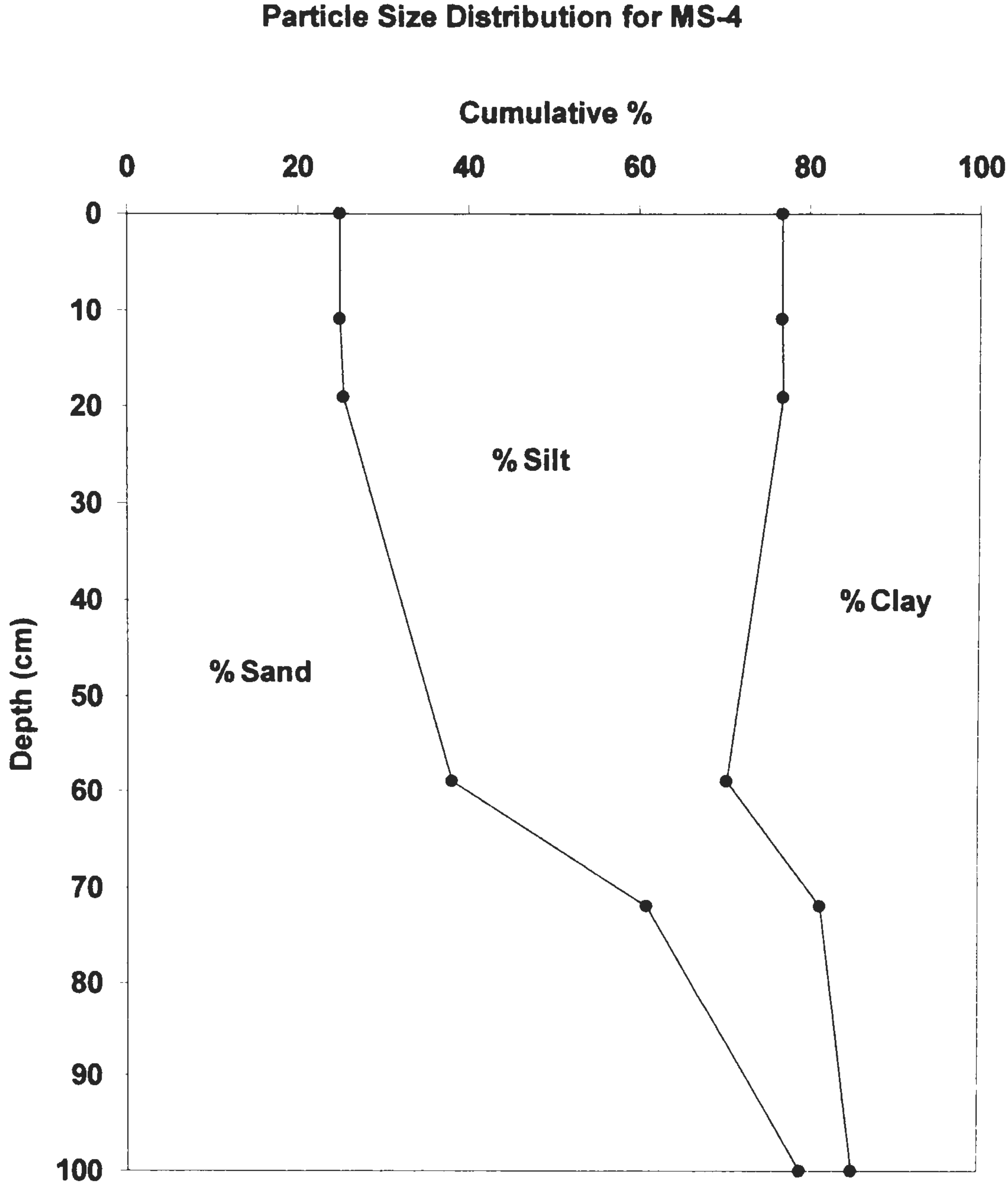


Figure 36. Particle size data by depth for Mississippi Site Four.

(2.5YR hues) than the overlying material indicating that this portion of the profile is actually a paleosol that has been washed over by local flooding during recent geologic history (presumably Pleistocene). The lower parent material in this pedon is kaolin. Further evidence of the lithologic discontinuities can be seen in the fine sand distribution (on a clay free basis) (figure 37).

The diagnostic subsurface horizon in this pedon was an argillic horizon (19 – 59 cm). Just beneath the surface is a transitional BA horizon which is common in highly eroded profiles. The remainder of the pedon was made up of sandy coastal plain material and kaolin. It is believed that Kaolin is a product of the weathering of feldspathic rocks and subsequent deposition of the weathering products into a lacustrine environment sometime during the Cretaceous or possibly the early Tertiary (Hora, 1998). The kaolin in this profile was compared to a kaolin reference standard from North Carolina in order to substantiate that this was in fact kaolin. These results can be seen in figures 38 and 39.

The weathering sequence of the parent materials in this pedon can be seen in figure 40. The alluvium parent material has undergone a considerable amount of weathering which is indicated by the difference between the concentration of iron oxides and total iron concentration. In fact, the alluvium in this pedon (0 – 59 cm) is actually more weathered than the underlying Tertiary coastal plain material. This differential weathering pattern may indicate that the overlying alluvium is actually part of the Tertiary coastal plain material. The Bt horizon (10 – 59 cm) did exhibit red hues (5YR) indicating that it was much more

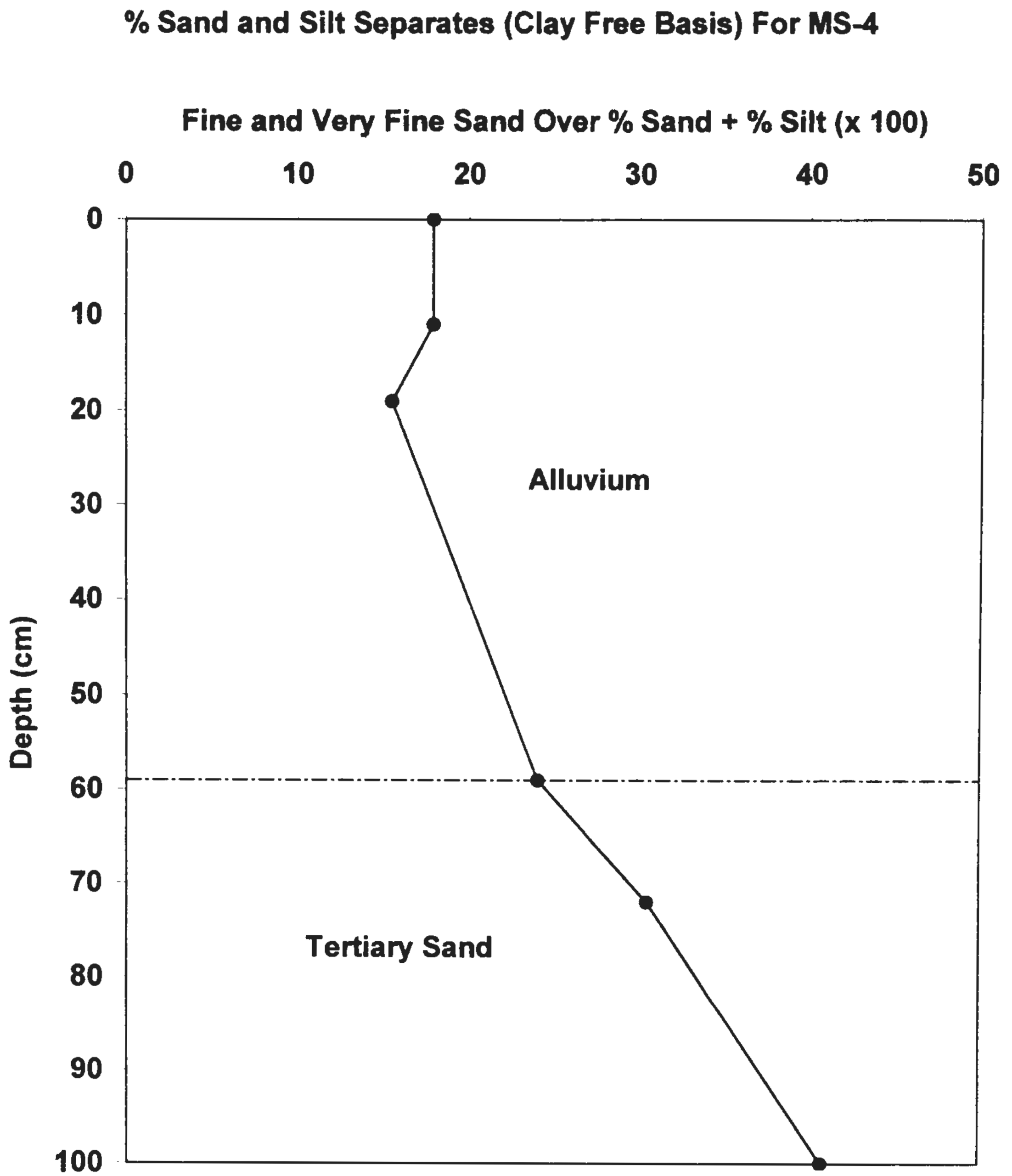


Figure 37. Sand and silt plotted on a clay free basis by depth as related to parent material for Mississippi Site Four.

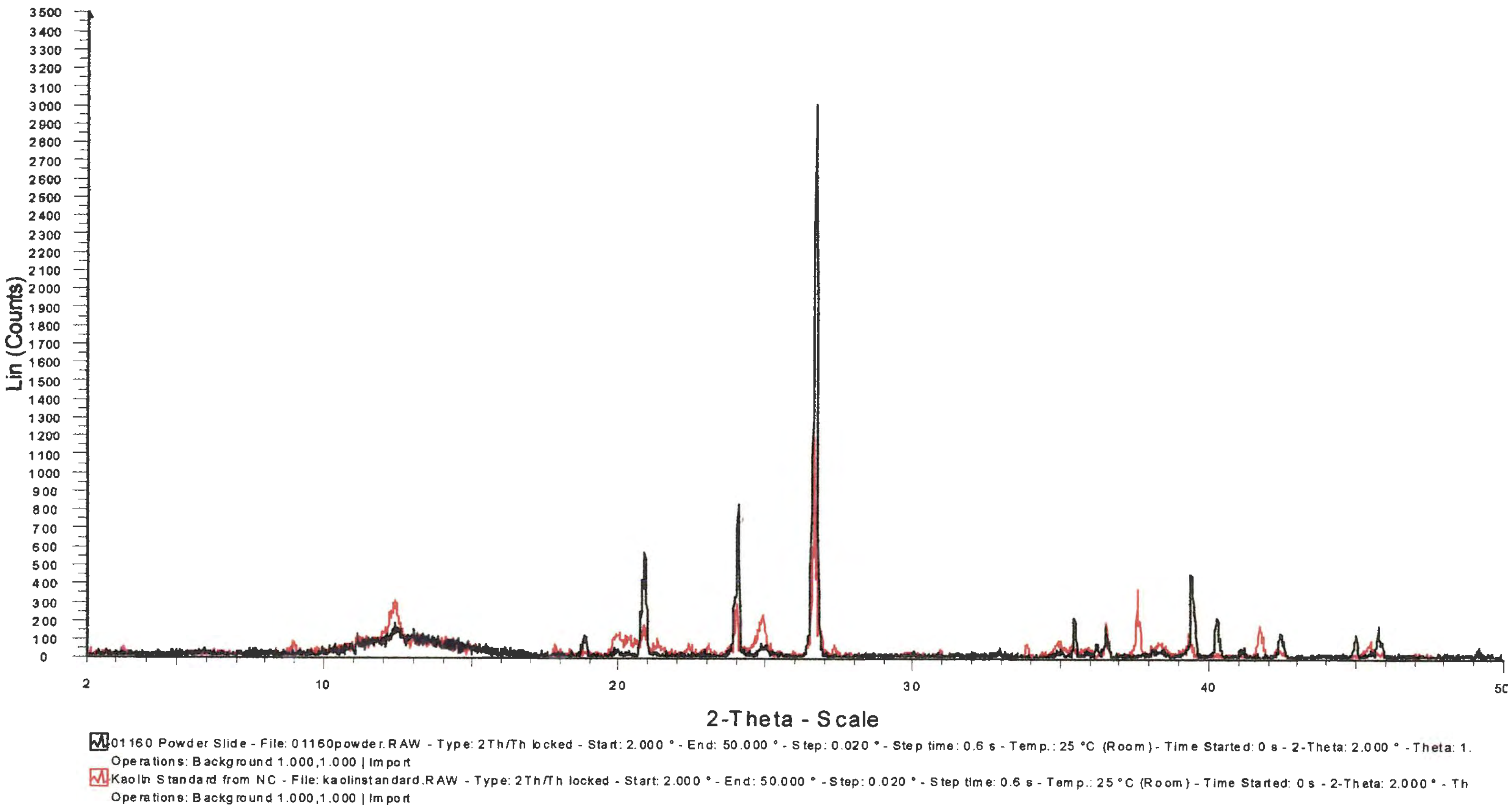


Figure 38. X-ray diffraction scan of the 3C2 horizon (100 – 114 cm) at Mississippi Site Four. Red indicates Standard Reference kaolin, Black indicates sample kaolin.

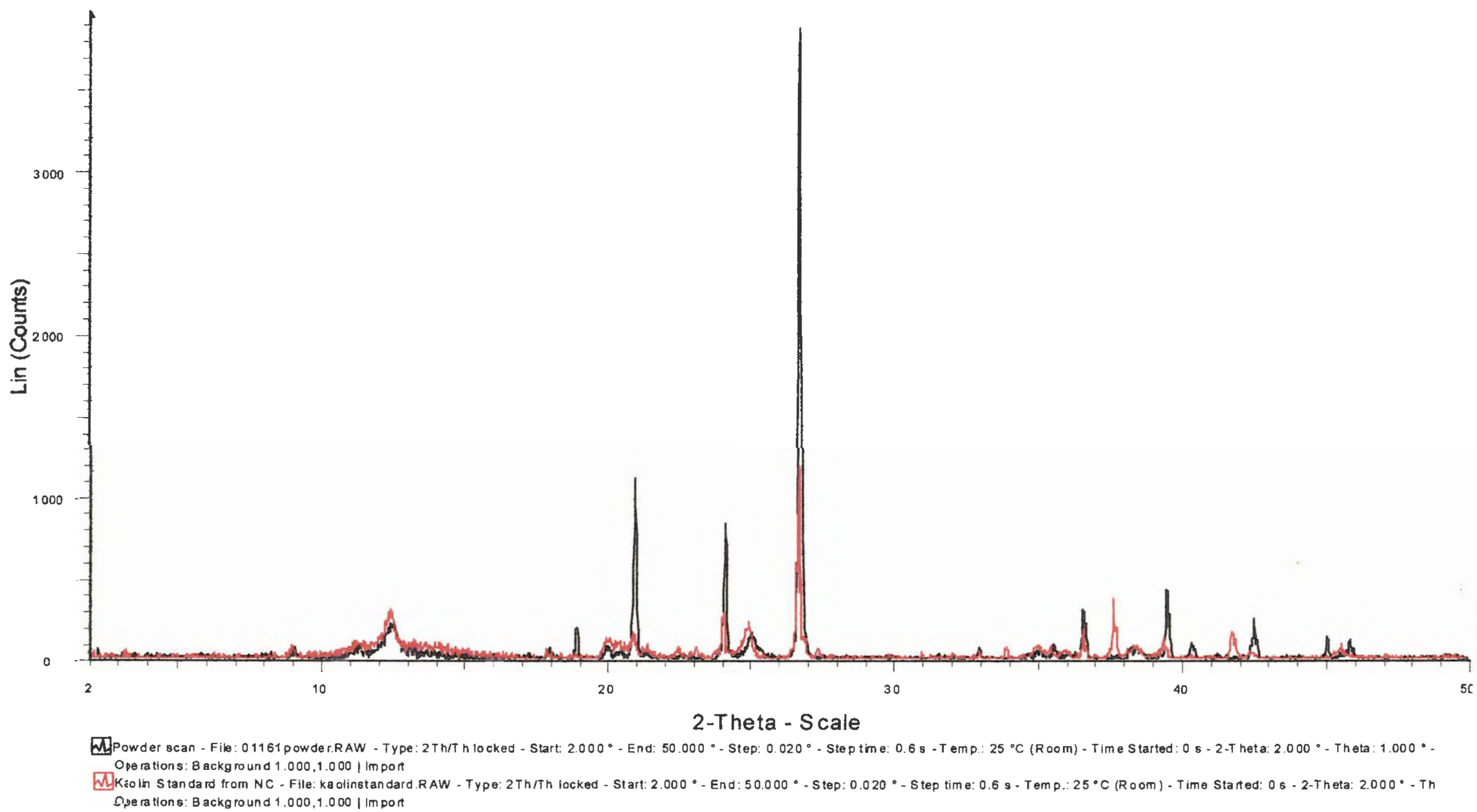


Figure 39. X-ray diffraction scan of the 3C3 horizon (114 – 136+ cm) at Mississippi Site Four. Red indicates Standard Reference kaolin, Black indicates sample kaolin.

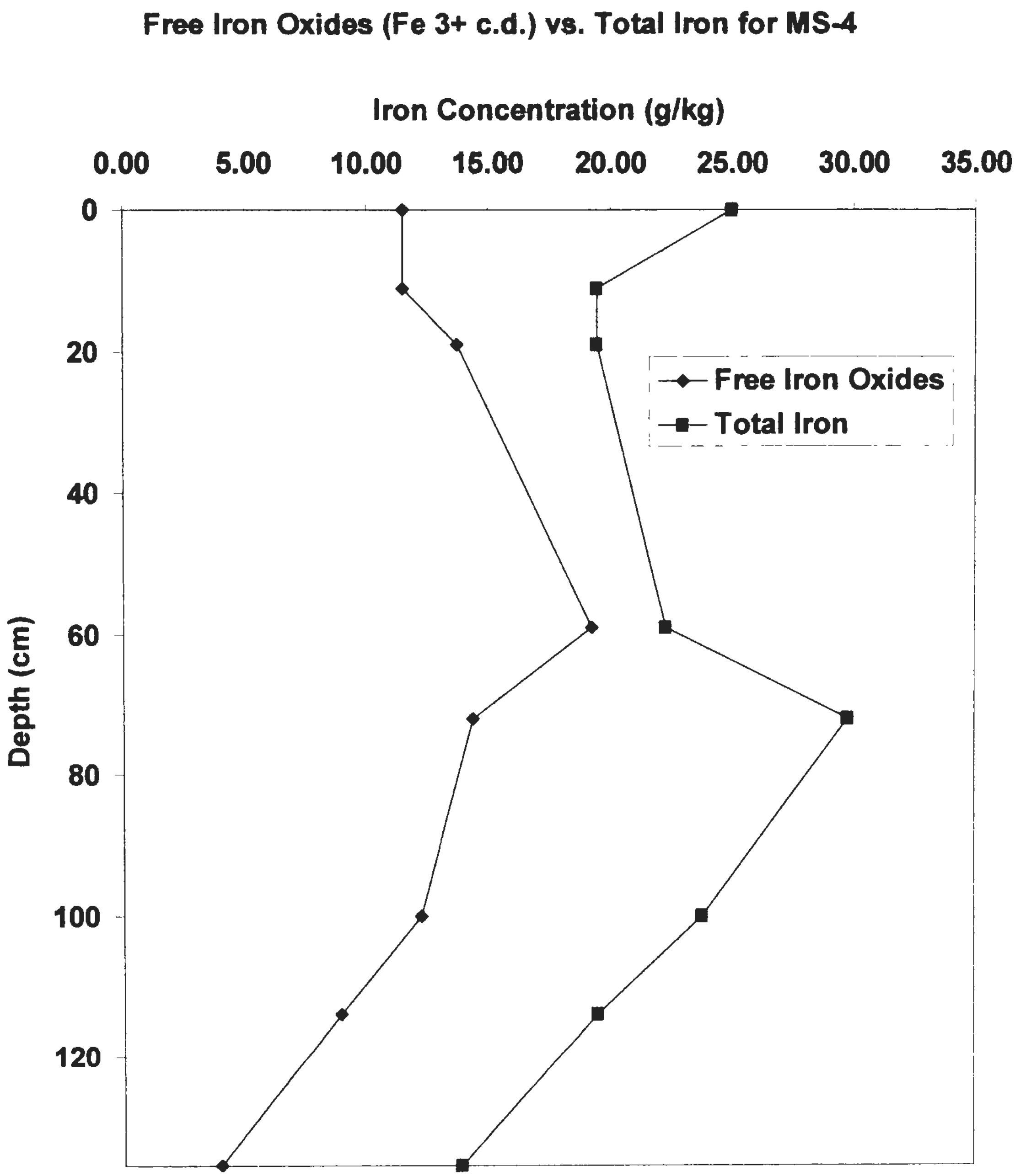


Figure 40. Free iron and total iron by depth for Mississippi Site Four.

weathered than other materials that made up the profile.

The carbon distribution for this profile can be seen in figure 41. There is a normal carbon distribution with increasing depth in this pedon. There is a slight increase in organic carbon at the depth of the first lithologic discontinuity (59 cm). This may be an indication that this horizon was once exposed at the surface and supported the development of land plants.

This profile was absent of redoximorphic features which would indicate that there was a drainage impediment. The somewhat uniformity of parent materials that make up the profile do not contribute to the hindrance of downward movement of water. This is evident by the lack of preferential flow areas in addition to a lack of redox depletions. Further evidence for this can be seen in figure 42. Easily reducible manganese does not increase with increasing depth indicating that the physical features that make up this profile do not hinder water movement.

This soil was classified as a fine-loamy, mixed, active, thermic Typic Hapludult. Erosion has eliminated the loess from this site and exposed the underlying alluvium/Tertiary coastal plain material which is much more weathered. This has resulted in the classification of Typic Hapludult at the subgroup level. There was lack of evidence indicating that downward movement of water was hindered in this profile. Easily reducible manganese data support these findings. The lower material found in this profile ($3C_2$ and $3C_3$ horizons) is kaolin.

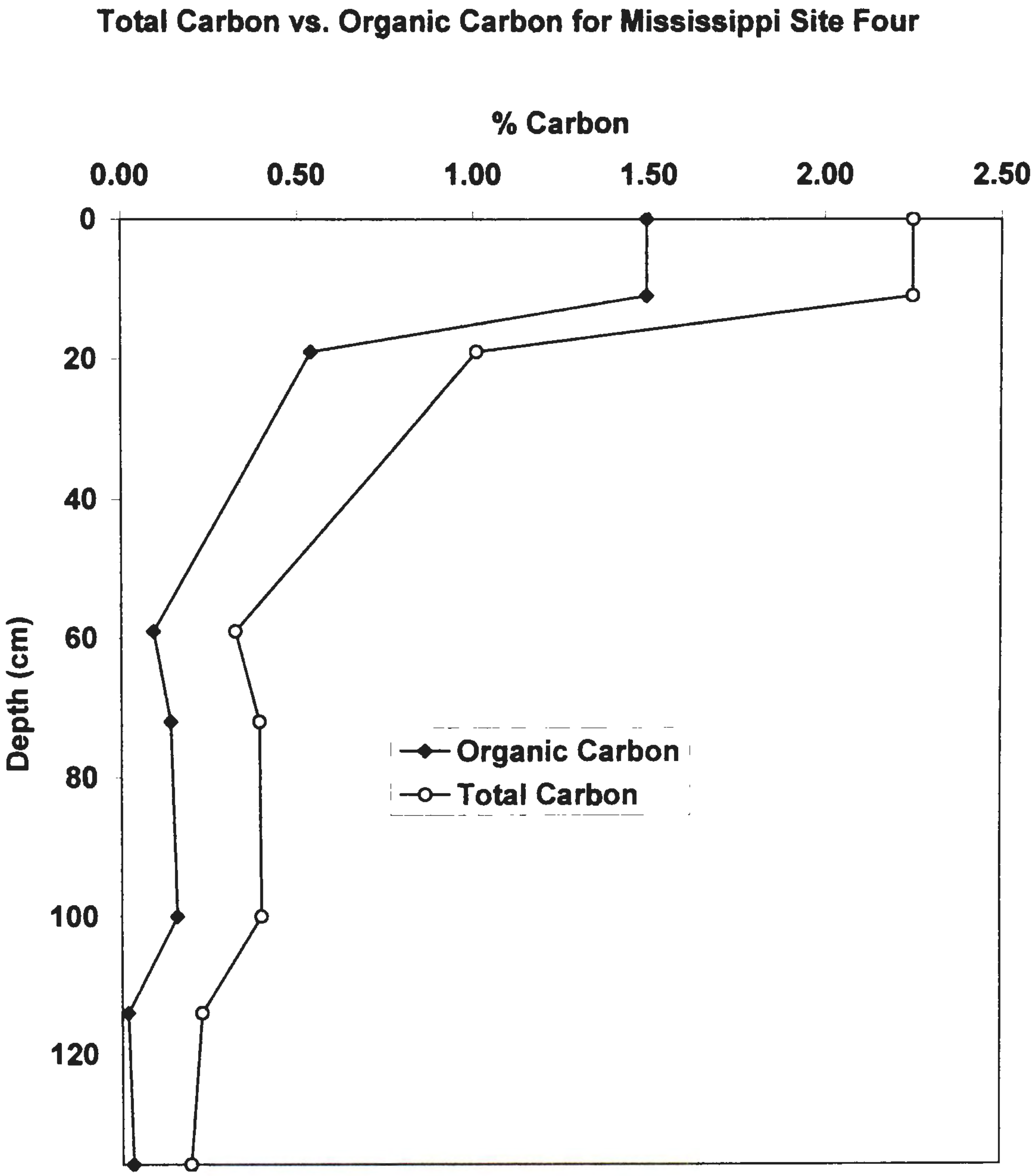


Figure 41. Organic carbon and total carbon by depth for Mississippi Site Four.

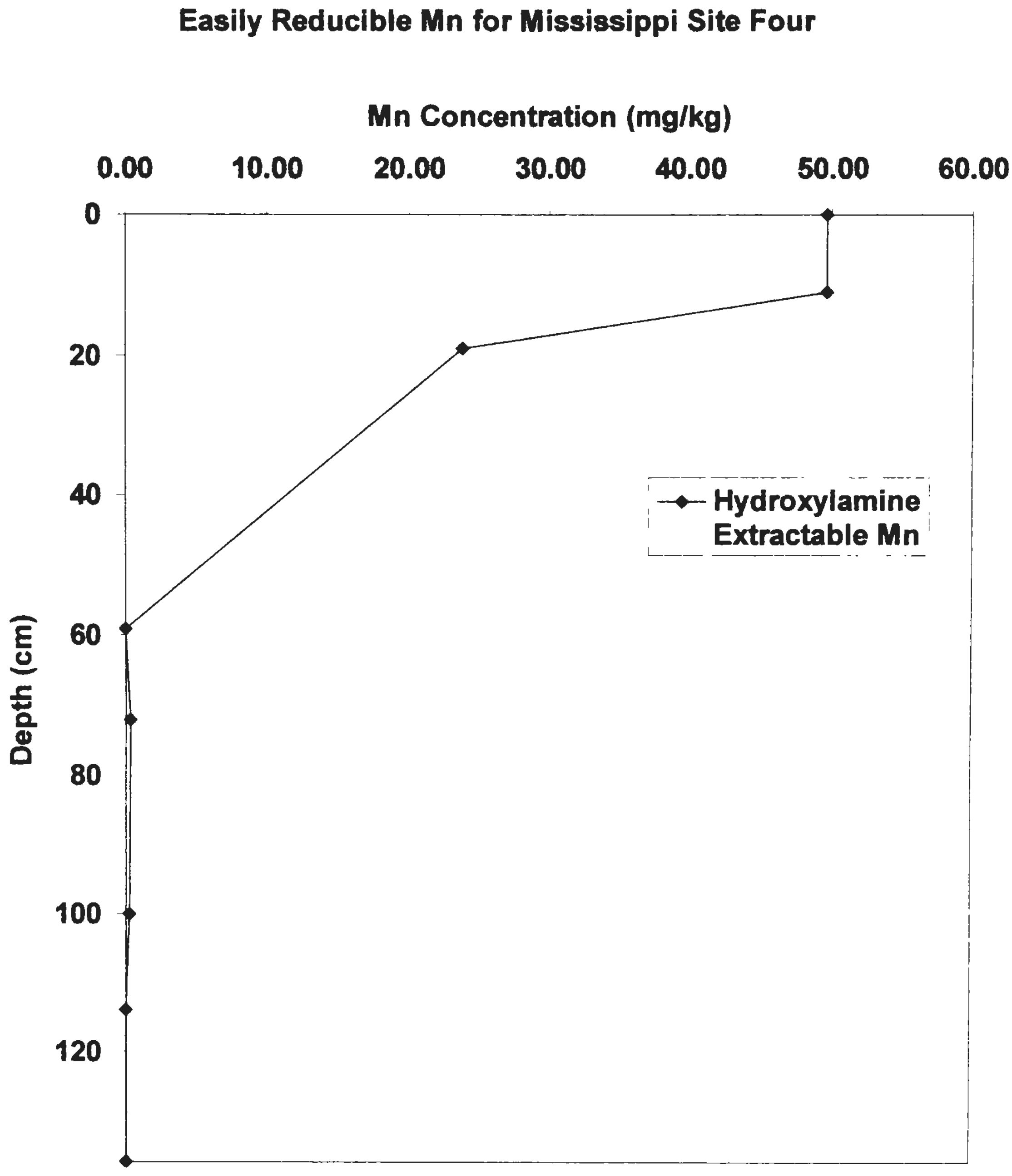


Figure 42. Easily reducible manganese concentration by depth for Mississippi Site Four.

Conclusions for Mississippi Sites

The landforms on which the Mississippi sites reside are products of not only ancient marine sediments (Tertiary) but also of local alluvium and loessial deposits. The absence of Loveland loess at sites two and four has lead to a decreased structural stability in the landscape position at each site. These sites have been subsequently eroded over time. It is unknown why such a variable nature in the presence of Loveland loess exists in this area. Perhaps heavy localized flooding during Quaternary times has removed the Loveland loess from the lower lying areas (*i.e.* sites two and four). In these areas, the Peoria loess would have been observed in direct contact with either alluvium or Tertiary aged coastal plain material however, the Peoria loess has been eroded in recent times (*i.e.* .in the past century) and only the coarser alluvial material is left. These factors all affect the high variability in the soils characterized at each of the sites.

Conclusions

Kentucky sites one and two were classified as fine-silty, mixed, active, thermic Typic Fragiudalfs. The presence of fragipans in each of these sites has dominant control over the downward movement of water. Due to this, these two sites have high potential of lateral subsurface movement of water. In addition to these features, the presence of contrasting parent materials may also contribute to lateral subsurface movement of water. Large areas of preferential flow within the fragipans further increase the risk of erratic movement of water at these sites. Kentucky sites three and four were classified as fine-silty, mixed, active, thermic

Fragic Hapludalfs. These two sites lacked true fragipan horizons however, fragic soil properties were present in some horizon (at least 30%) within the profile. These properties did not constitute a continuous phase in any horizon in the subsurface therefore these soils were classified as Fragic Hapludalfs at the subgroup level of classification. The hindrance of downward movement of water in the profile at site three seems to be caused by the contrast in particle size distribution between the alluvium and the deeper Tertiary aged coastal plain material. The hindrance of downward movement of water at site four was mainly caused by the contrast in particle size distribution between the loess and the underlying alluvium.

The presence of a two-loess sequence over Tertiary aged coastal plain material at the Mississippi sites contributes largely to the variation in the soils there. The presence of Peoria loess and Loveland loess at sites one and three may contribute to the lack of erosion seen in these two pedons. Therefore these two sites were classified as fine-silty, mixed, active, thermic Ultic Hapludalfs. Local erosion during recent geologic history (*i.e.* Pleistocene) may have removed the Loveland loess at sites two and four therefore, there was decreased structural stability in the landforms on which these two pedons resided. Erosion of the Peoria loess has resulted in a coarser particle size class (*i.e.* fine-loamy) to be given to the classification of each of these soils. In addition to this, in the case of site four, erosion has exposed more weathered parent material (alluvium) closer to the surface which results in an entirely different soil order classification.

Mississippi site two was classified as a fine-loamy, mixed, active, thermic Typic Fragiudalf and Mississippi site four was classified as a fine-loamy, mixed, active, thermic Typic Hapludult. The main cause of lateral movement of subsurface water at the Mississippi sites can be attributed to the contrast between particle size distribution in the parent materials that make up each pedon. In the case of site two, both the fragipan and the existence of contrasting particle size distribution is thought to hinder downward movement of water in the profile.

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Chapter 2: Non-intrusive Subsurface Mapping using Ground-penetrating Radar and Electromagnetic Induction.

Ground Penetrating Radar

Ground-penetrating Radar (GPR) is a popular non-intrusive instrument that allows subsurface features to be observed. Typically, a GPR unit is towed across the surface of an area and data are collected about the specific subsurface features of interest. Radar capabilities were adapted to penetrate the ground in the 1960's by the U.S. military as a way to measure suitability of soils for vehicles, to detect voids beneath the surface, and to locate buried objects (Hubbard, 1990). Currently, GPR is being used in a variety of ways by the private sector. Some of its capabilities include utility location, underground storage tank location, sediment location in ponds, and soil mapping procedures. Many of the recent studies involving the application of GPR as a means to observe soil properties have taken place in the Southern Coastal Plain region of the United States. In this region, GPR has proven to be an excellent aid in observing subsurface features as well as their horizontal extent.

Discussion of Ground Penetrating Radar Theory

The basic components of a GPR device are 1) a signal generator, 2) a transmitting antenna as well as a receiving antenna, and 3) a receiver that is capable of graphical output and recording data for interpretations. The signal generator causes the transmitting antenna to produce a series of radio waves, which penetrate downward through the ground in a broadening beam. The transmission and reception of radio waves from the antenna is in the order of 50 Hz. As the unit is pulled across the ground, the signals received are displayed as a function of their two-way travel time in the form of a radargram.

Subsurface horizons can be identified graphically by towing the transmitting and receiving antennas across the ground. Basically, the properties of the existing soil horizons possess contrasting dielectric constants (ε_r) and electrical conductivities (σ) which can be differentiated by depth given the two-way travel time of the emitted radio waves. Interpretations are made given varying radar reflection intensities that are caused by contrasting dielectric constants of adjacent soil horizons. As a horizon is encountered vertically in the profile, the GPR unit can track that horizon over horizontal distance. Some dielectric constants for selected components encountered in the field are given in table 11.

The chemical makeup of a medium and its water content contribute to the electromagnetic properties of that material. These two factors dictate the speed of radio waves through that material.

Table 11: Dielectric constants of some materials of interest. (Source: Reynolds, 1997)

Material	ε_r
Air	1
Water (fresh)	81
Coastal Sand (dry)	10
Sand (wet)	25-30
Silt (wet)	10
Clay (wet)	8-15
Clay Soil (dry)	3
Quartz	4.3

For GPR to be successful at determining pedogenic horizonization, the materials that make up the soil profile must be comprised of contrasting electrical properties. Without variability in the materials that make up the profile (*i.e.* contrast in horizonization), reflected radio waves will appear undifferentiated when looking at visual output. Also, it is essential that the material being surveyed have relatively low electrical conductivity (σ). If the medium that is being surveyed has high electrical conductivity, the radar waves will consequently degrade and static will appear in visual output at shallower depths. Media with high electrical conductivity (σ) are wet clay, wet shale, and seawater.

Fuzzy-Neural Network Classification

The interpretation process of resulting ground-penetrating radar scans often results in biased error. By visual interpretation of resulting radargrams generated from GPR data, the interpreter often introduces error into the analysis process of the research. Areas of high or low intensity radar reflections are often correlated by the interpreter as being significant in terms of the classification of such data. Often this is not the case and the grouping of classified data is not correct.

Fuzzy-neural network classification eliminates biased interpretation of radargrams by analyzing data and classifying it using network algorithms. The program takes untransformed-digital GPR data, analyzes it and returns it as an unbiased set of class groupings that differ based on relative intensities of radar reflection. There are two types of neural networks employed in order to classify data. One type is supervised neural network classifiers that employ recursive learning algorithms in order to classify data. The other type of neural network classifier is unsupervised which classifies data using only the information expressed by the existing data. This type of classifier does not rely on input/output examples in order to train the program for classification purposes. The use of fuzzy-neural network classifiers has been applied to land cover classes using remote sensing data and soil profile clustering using GPR data (Odhiambo *et al.*, 2002).

Recent Studies Involving Ground Penetrating Radar

Collins and Doolittle (1987) used GPR to determine the microvariability of diagnostic subsurface horizons within the Sapelo series (sandy, siliceous, thermic Ultic Haplaquods) found in the Atlantic Coast Flatwoods of north central Florida. A 9x10-m grid was set up on the known series and observation points were set up in one meter increments within the grid. Ground-penetrating radar was used to identify and track depths to spodic and argillic horizons within the study grid. It proved to be a useful and efficient tool in identifying the diagnostic subsurface horizons of the Sapelo soil series.

Truman *et al.* (1988) used GPR to evaluate diagnostic subsurface features and spatial variability of water tables within the soil profile in the coastal plain region of Georgia. Traditional soil morphology description and classification was used to back up the data obtained by GPR. Using GPR, depths to argillic horizons and water tables were determined as well as their spatial variability.

Rebertus *et al.* (1989) has used GPR to evaluate the variability in loess thickness in Northern Delaware. Using GPR to determine the underlying stratigraphy of landscapes within the study area (two 2.32-ha plots), it was determined that variability in loess thickness could not be predicted by looking at relief and landform because it was controlled by the underlying paleosurface. Ground penetrating radar proved to be a good and efficient tool in investigating the control that the underlying geology contributed to the variability in loess thickness.

Vellidis *et al.* (1990) used GPR to detect wetting front movement in soil profiles found in the Coastal Plain region of southern Georgia. During two separate study times (December and March), irrigation was applied to a 1.4 ha site. Ground penetrating radar was used to track the wetting front over time during each study period. GPR, coupled with water content data obtained from soil samples was determined to be effective at observing wetting front movement in sandy Coastal Plain soils. Furthermore, it was speculated that GPR might be effective in determining preferential flow paths for a given site.

Mokama and Doolittle (1993) were able to complete a detailed soil-mapping project in southwest Michigan using GPR. Within a 14-ha area, they were able to delineate map units (five total) by setting up a 15.2x36.6-m grid over the entire area and pulling GPR along gridlines. Previous soil survey mapping had determined only two map units in this area whereas Mokama and Doolittle were able to delineate five. Obviously, not only was GPR able to determine the horizontal extent of existing soil series over the study area, but it was also capable of depicting soil properties as is necessary in soil classification.

Lapen *et al.* (1996) used GPR to map shallow subsurface features in a wetland catena in southeastern Newfoundland. The study was able to determine organic soil/mineral soil contact, placic horizons, water tables and mineral soil/bedrock contact. Based on these findings and because of the efficient, nonintrusive nature of GPR, Lapen concluded that GPR was and effective tool in delineation of these subsurface features.

Branson *et al.* (2000) has used a protocol involving GPR and Electromagnetic induction (EM) at Ducktown, Tennessee (the Copper Basin) to assess its effectiveness at determining depth to shallow water tables as compared to traditional soil morphological investigations in copper mine tailings. She found that GPR and EM were able to pick up variations due to increasing electrical conductivity in the soil profile associated with presence of the water table.

Inman (2001) used ground-penetrating radar as a non-intrusive surveying tool to observe subsurface features in the loessial soils of West Tennessee at Ames Plantation. Total soil characterization coupled with GPR and EMI has proven to be an effective tool in evaluating this area where the occurrence of perched water at the loess/ancient alluvium interface is thought to impact the subsurface movement of chemicals off-site (Inman *et al.*, 2001; Inman *et al.*, 2002). Studies at Ames Plantation were the foundation for the protocol that was used in this study.

Electromagnetic Induction

Electromagnetic Induction (EM) was first used as a technique of mapping subsurface geology by Conrad Schlumberger in the early 1900's (McNeill, 1980). Not long after the First World War, Karl Sundberg developed a method using EM to explore for minerals. Other methods involving EM became commercially available after the Second World War especially during the mid 1960's. Electromagnetic Induction has a wide range of applications including mineral exploration, groundwater surveys, mapping of contaminant plumes, contaminated land mapping, location of geological faults and detection of artificial voids beneath the surface. Electromagnetic induction continues to grow as an effective tool in environmental applications.

Discussion of Electromagnetic Induction Theory

Electromagnetic induction is a means by which electrical conductivity (σ) can be measured by injecting a media with current. Based on the magnetic field that is given off by this current (secondary magnetic field), σ can be determined. The electrical conductivity of a material is a measure of the ease or difficulty by which electrical current can be conducted through that material. In soil and rock many elements contribute to the actual conductivity of the material.

Soil is considered an electrolytic conductive system. That is, the concentration of ionic forms of elements dissolved in the soil moisture component dictate σ for that soil. Electrical current travels in soil between water filled pore spaces within the matrix, which serves as the insulator (*i.e.*, sand, silt, or clay particles serve as the insulating matrix). Sand and silt are considered to be excellent insulators as well as dry clay. However, when moisture is added to the clay fraction of a soil body, conductivity increases dramatically (McNeill, 1980).

The factors that affect σ in a soil body are 1) porosity (size, shape, amount, and amount of space between pores), 2) moisture content, 3) concentration of dissolved electrolytes in the moisture fraction, 4) temperature and phase of existing moisture, and 5) the amount and type of clay that exists in the soil profile (McNeill, 1980; Doolittle *et al.*, 1994; Doolittle and Collins, 1998; Scanlon *et al.*, 1999).

Moisture occupies four stages within the soil profile. These stages can be thought to exist vertically through the soil profile in zones. The uppermost zone is called the pendular zone where soil moisture exists entirely of water vapor and, no contact of individual portions of moisture between soil particles exists. The next zone below the pendular is the funicular zone where moisture is a continuous film between adjacent soil particles and the actual pore space is beginning to fill with water. Below the funicular is the capillary stage or capillary fringe where pore space is entirely occupied by water due to water pressure within the pore space and pressure due to gravity. The pressure within the pore space is lower than the pressure caused by gravity which causes moisture to rise into the pore spaces due to capillary action. The lowest zone is the phreatic zone (or the water table) where pores are entirely saturated and, there is equilibrium between atmospheric pressure and hydrostatic pressure. The EC of a particular soil horizon is dependent on its porosity as well as the amount of water that is contained therein (McNeill, 1980).

Electromagnetic Induction has been most effective in determining EC in soils that have relatively homogenous subsurface properties and low variability between adjacent subsurface horizons. Given the effects of one factor contributing to the EC of a particular horizon, EM works well when this factor dominates all other factors contributing to EC (Doolittle *et al.*, 1994; Doolittle and Collins, 1998).

The depth of EM exploration is determined by the intercoil spacing of the transmitting and receiving coils of the instrument (Scanlon *et al.*, 1999; Reynolds, 1997). Both the transmitting and receiving coils are contained within the EM instrument. These coils function as magnetic dipole antennae. The transmitting coil of the EM instrument produces a primary magnetic field that injects currents into the material of interest. These currents subsequently produce a secondary magnetic field as a result of their interaction with the specific properties of the soil profile. The receiving coil in the instrument detects the secondary magnetic field. The signal detected by the instrument is read as a measurement of conductivity that, "represents the integrated electrical conductivity of the half space beneath the instrument," (Worby *et al.*, 1999). The depth of exploration increases with larger space between intercoils and decreased current frequency and varies with the orientation of coils given the earth's surface (Scanlon *et al.*, 1999). Table 12

Table 12: Characteristics of Geonics, Inc. EM conductivity meters. (Source: Scanlon *et al.*, 1999).

Instrument	Intercoil Spacing (m)	Frequency (Hz)	Horizontal Dipole Mode	Vertical Dipole Mode
EM38	1	14,600	0.75 meters (depth)	1.5 meters (depth)
EM31	3.7	9,800	3 meters (depth)	6 meters (depth)

shows some depths of penetration of two EM instruments given their horizontal and vertical configurations.

Recent Studies Involving Electromagnetic Induction

Ammons *et al.* (1989) has used EM in Gibson County, Tennessee in order to delineate Natraqualfs. Prior to this study, there was concern that map units initially designated Ochraqualfs might actually have been Natraqualfs. Lab analysis determining Sodium Absorption Ratios (SAR) was used to calibrate the EM38 instrument used in the study. Twelve transects were conducted within map units designated as Ochraqualfs. Based on the data obtained using EM38, only one of the map units in Gibson County needed to be reclassified.

Doolittle *et al.* (1994) used EM in Centralia, Missouri to assess its ability to determine depth to claypan as compared to conventional probing measures. The presence of a claypan subsurface horizon restricts downward movement of water in the profile and thus can contribute to lateral flow of soil water and contaminants therein. The EM38 was able to accurately detect presence and depth to claypans in the area due to the contrast in σ of clay layers in the subsurface. A high correlation was shown between depth to claypan and EM response.

Sheets and Hendricks (1995) used EM to assess its ability to measure soil water content as compared to conventional measurement techniques (neutron probe). Soil moisture measurements were taken 16 times between February 1992 and June 1993 with EM31 and a neutron probe. Data obtained were analyzed using simple linear regression and, the model described the relationship between soil water content and bulk soil EC. The regression analysis yielded an R^2 of 0.64. That is, 64 % of the variation in soil moisture content could be explained by the EC of a profile during any given month during the study.

Kitchen *et al.* (1996) used EM to map sand deposition at four sites in Missouri. The sands, deposited from the Midwest floods of 1993, were seen as a threat to the agro-economy of the state and thus the study was conducted. Using EM38 and GPS, maps were made on two field sites as part of the study. They found that the EM and GPS protocol was very efficient at determining depths of sand deposition as well as being a very useful tool for mapping.

McCauley *et al.* (1998) used EM to determine whether or not it could provide more meaningful data than actual soil testing in areas that have been damaged by oil-brine. Brine (a byproduct of oil exploration) was spilled over agricultural lands in southern Illinois and, due to this, soils had developed saline properties, which are highly variable and unpredictable. The introduction of brine can leave landscapes barren. The variable nature of salinity in brine affected areas limit the effectiveness of traditional soil sampling techniques. Therefore, EM38 was used as an alternative to see if meaningful data could be obtained in order to assess revegetation efforts. The study found that EM could be used delineate areas within fields that have oil-brine damage and that EC could be used to predict plant response.

Doolittle and Collins (1998) compared the functionality of EM and GPR in two separate areas of karst. Two sites, one in Florida and the other in Pennsylvania, were used for this study. The sites were both contrasting in soil properties. They found that GPR was effective at depicting depth of surface layers as well as buried solution features. Electromagnetic induction on the other hand was not as successful at determining these features. Electromagnetic induction was found to be effective at determining depths to bedrock in this study.

Scanlon *et al.* (1999) used both surface EM (EM31 and EM38) and subsurface EM (EM39) along with soil sampling and analysis (clay, water, and chloride content) to assess EM's ability to evaluate unsaturated flow in an arid setting. The study was conducted in the Chihuahuan Desert of Texas. Soils were extracted by use of borings and sampled for characterization. Subsurface EC was measured using EM39 and surface EC was measured using EM31 and EM 38. The study found that EM was an effective tool at evaluating and interpolating not only at borehole locations but also between the boreholes in their transect. Furthermore, EM proved useful for the characterization of unsaturated flow.

Objectives

The objectives of this portion of the study were to conduct non-intrusive soil investigations using both GPR and EMI as well as to assess how well these tools perform at identifying subsurface features that affect water movement at the sites located near Lynville, Kentucky and Holly Springs, Mississippi.

Materials and Methods

This study utilized the efforts of two teams of personnel. A geophysical team conducted the EM and GPR surveys. A team made up of soil scientists conducted pedon location, description, and sampling. Electrical conductivity was determined using an EM-31 electrical conductivity meter manufactured by Geonics, Ltd. The EM-31 instrument was towed behind a Kawasaki™ Mule™ (figure 43a) at a velocity of approximately 5 km/hr and conductivity data were logged every two seconds. In order to generate a conductivity map, an AgGPS-132™ manufactured by Trimble, Inc. was used to collect latitude and longitude data which were merged with the conductivity data. ArcGIS 8.2™ (ESRI, Inc.) was used to generate a continuous surface map so that pedon locations could be determined based on the variability of conductivity observed in the field. Given the soils characterization data and subsequent classification of the soils, a map was generated delineating soil boundaries at each of the study sites.

After conductivity maps were generated, GPR data were collected using a SIR System-10A™ manufactured by GSSI, Inc. A 200-MHz antenna was towed

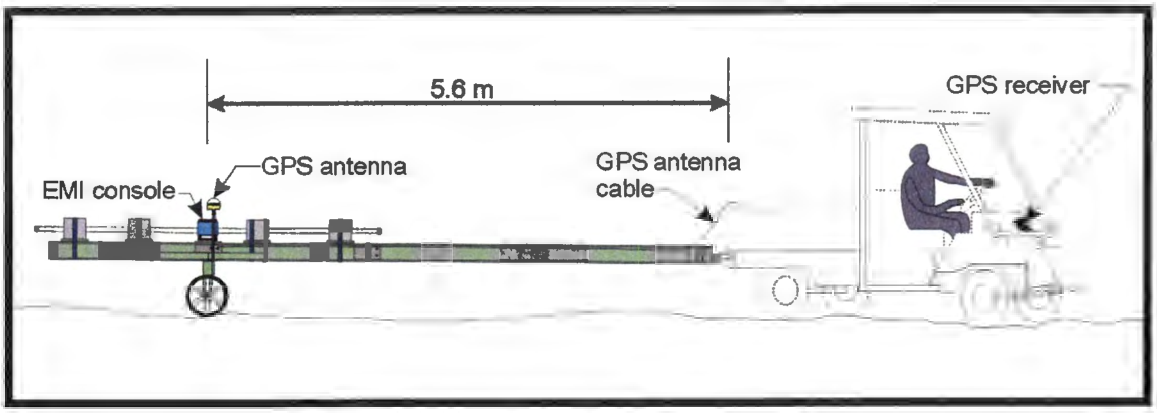


Figure 43a

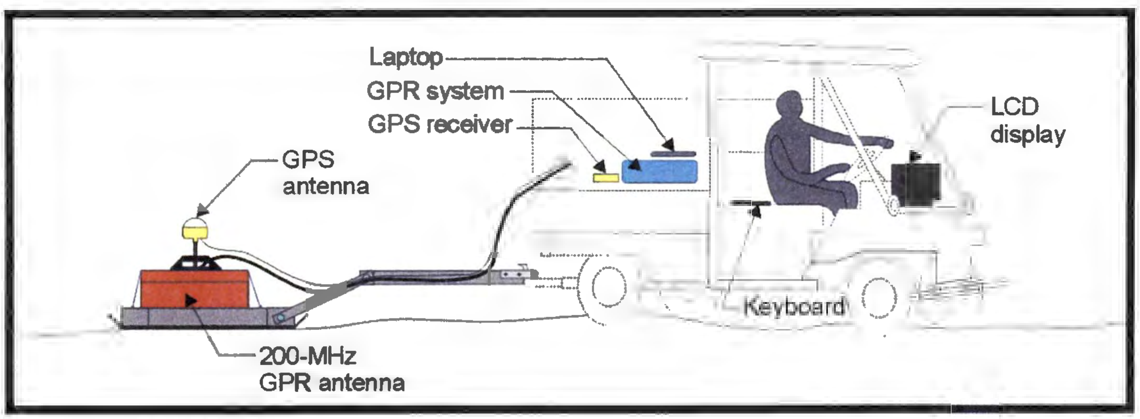


Figure 43b

Figure 43. Schematic diagram of how both the EM31 instrument (43a) and GPR instrument (43b) are attached to the Kawasaki ™ Mule™. (Source: Leonard, 2001)

by the Kawasaki™ Mule™ (which also housed the GPR SIR System-10A™) over each of the fields (figure 43b). An AgGPS-132™ was mounted atop the antenna and used to collect latitude and longitude data. The GPS data were interfaced with the GPR data in such a way that latitude and longitude were marked at a five-meter interval. The results being that GPR data were georeferenced equally throughout the continuous scan. GPR data was then combined with marker data and further analyzed by use of an unsupervised cluster fuzzy-neural network classification using MATLAB™ (The MathWorks, Inc., Natick, MA) (Odhiambo *et al.*, 2002). The unsupervised cluster fuzzy-neural network classifier used on the GPR data was a beta trial version. Based on the cluster output, classes were assigned to each of the areas of the scan where latitude and longitude were known (markers). A graphical representation of the GPR data was then generated using ArcGIS 8.2™.

Results and Discussion

A 6-m conductivity map was used to locate pedon description points at the Kentucky site. This map can be seen in figure 44. Conductivity in this field ranged from 3.18 to 7.36 mS/m. Four classes of conductivities were chosen in order to locate pedon description sites. Conductivity classes in the area of pedon 1 ranged from 6.32 to 7.36 mS/m. Clay comprised 26.19% of the total separates (*i.e.* sand, silt and clay) encountered in pedon 1. Conductivity represented in the area of pedon 2 ranged from 5.28 to 6.31 mS/m. Clay comprised 24.57% of the total separates encountered in pedon 2. Conductivity represented in the area of

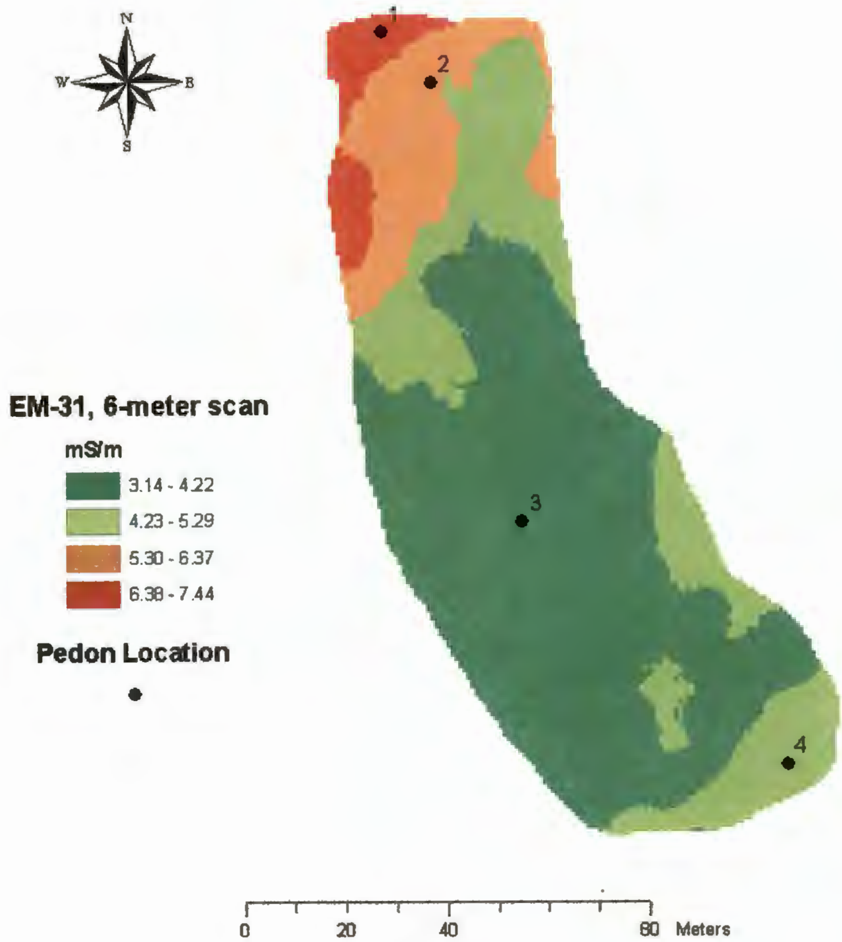


Figure 44. 6-m EM-31 map used to locate pedon description points at the Kentucky site.

pedon 3 ranged from 3.18 to 4.22 mS/m. Clay comprised 17.55% of the total separates encountered in pedon 3. Conductivity represented in the area of pedon 4 ranged from 4.23 to 5.27 mS/m. Clay comprised 21.30% of the total separates encountered in pedon 4. Generally, those pedons with a higher weighted percent of clay over the sampled depth were located in areas of higher conductivity found at the Kentucky sites.

With the aid of the conductivity map depicted in figure 44 as well as thru the aid of soils characterization/classification data (chapter 1), soil boundaries were drawn (figure 45). Generally, the Kentucky site consisted of two major soil taxons. These were: fine-silty, mixed, active, thermic Typic Fragiudalfs (pedons 1 and 2) and fine-silty, mixed, active, thermic Fragic Hapludalfs (pedons 3 and 4). The soil morphology described at pedons 1 and 2 both consisted of fragipan horizons and argillic horizons. Pedons 3 and 4 did not consist of fragipan horizons however, fragic properties were abundant in the morphology of each pedon. Pedon 3 has undergone a significant amount of erosion. The loess thickness was 69 cm and the highest clay percentage (34.43%) was in the surface horizon (0 - 15 cm). Erosion has exposed of the coarser alluvial materials closer to the surface and removed the clay and silt-sized materials. Therefore, the conductivity recorded in the area of this site was lower than any other area in the field.

The higher conductivities observed in the locations of pedons 1 and 2 are also indicative of a higher moisture content within the depth of the exploration.

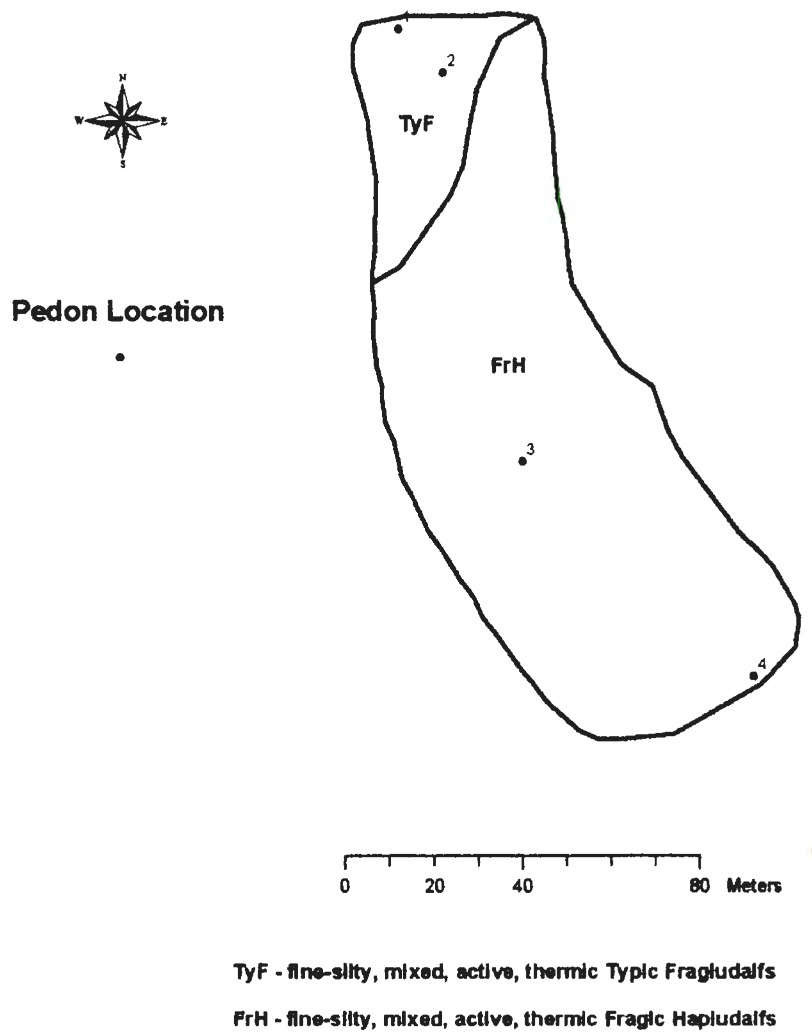


Figure 45. The soil map generated from characterization data and 6-m conductivity data.

The fragipans that make up the subsurface in the region of pedon 1 and 2 (figures 44 and 45) may be perching water. Thus, a higher conductivity was observed at these locales.

The ground-penetrating radar data collected at the Kentucky site were post processed using a fuzzy-neural networking (FNN) application. The resulting analysis was comprised of 4 class groupings for the data collected. Figure 46 shows the areas at the Kentucky site where each of the groupings occur. Distinct differences can be seen amongst the class groupings throughout the field. The northern 1/3rd of the field consists mainly of class groupings 1 and 4. These class groupings correlate to pedons 1 and 2 that were both classified as fine-silty, mixed, active, thermic Typic Fragiudalfs (figures 45 and 46). Class groupings 2 and 3 are also observed in this portion of the field and may be indicative of the highly variable nature of the soil bodies that make-up this site. The southern ½ of the Kentucky site is comprised of class grouping 3. This grouping correlates to pedons 3 and 4 that are both classified as fine-silty, mixed, active, thermic Fragic Hapludalfs (figures 45 and 46).

A 3-meter conductivity map was generated in order to delineate areas of variable conductivity at the Mississippi site. This map can be seen in figure 47. Three classes of conductivity were used in order to locate three separate pedons. Another pedon was described approximately 80 meters north of pedon 3 which was similar in morphology. No conductivity measurements were taken for the area in which this pedon was located. The conductivity class of the area

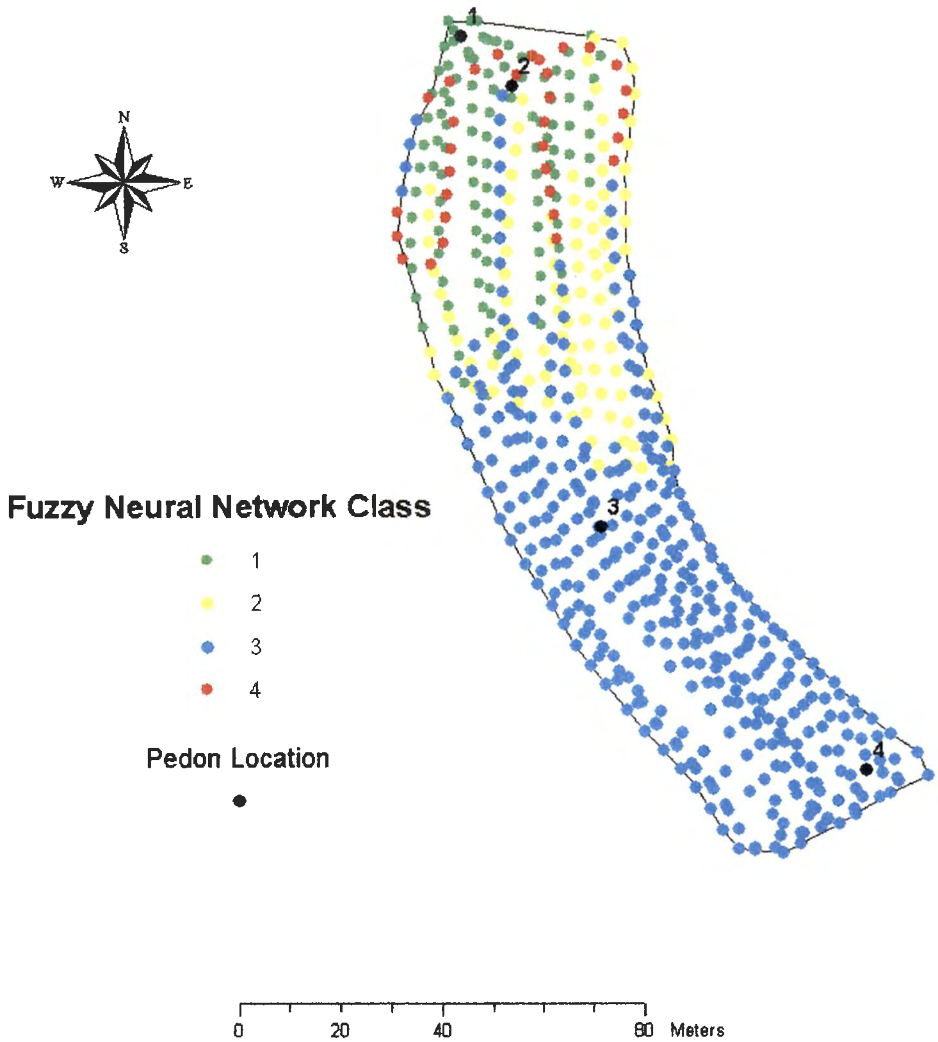


Figure 46. Class groupings produced by the fuzzy neural networking classifier based on the continuous GPR scan of the Kentucky site.

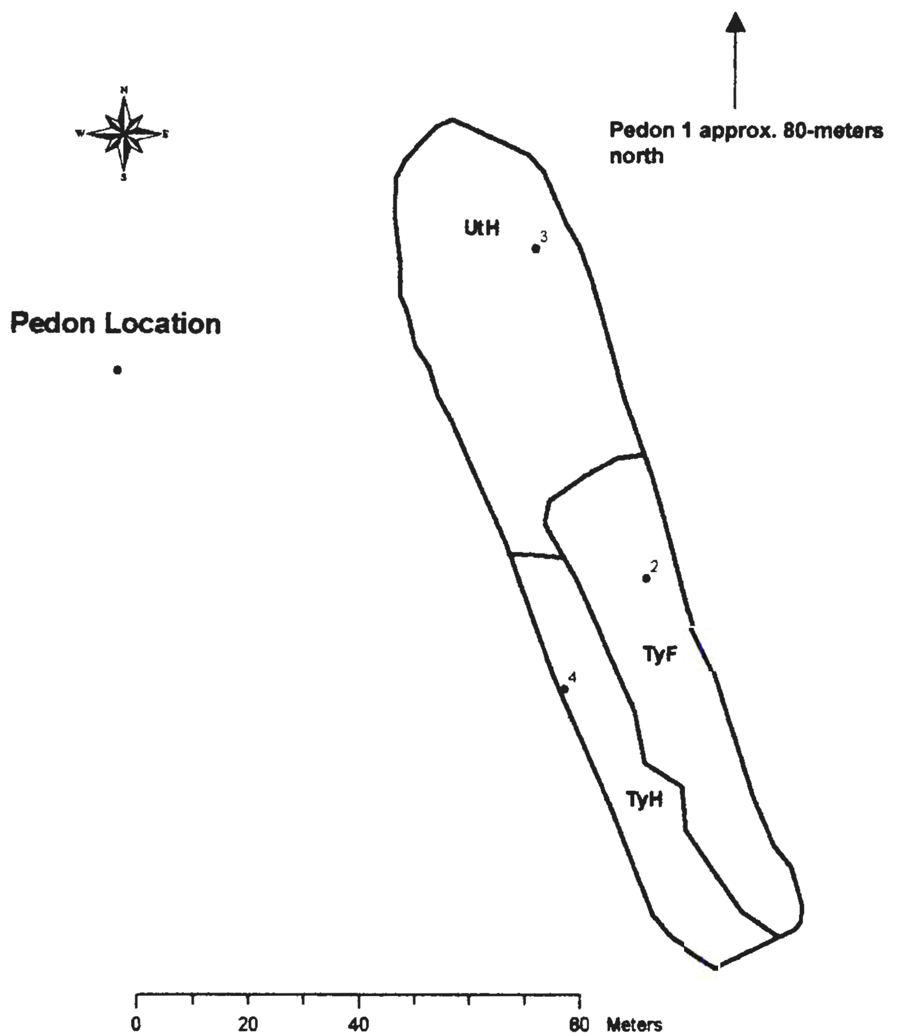
Figure 47. 3-m EM-31 map used to locate pedon description points at the Mississippi site.

represented by pedon 2 ranged from 8.87 to 11.98 mS/m. The weighted percent of clay for this pedon was 20.74%. The conductivity class of the area represented by pedon 3 ranged from 5.75 to 8.86 mS/m. The weighted percent of clay for this pedon was 25.49%. The conductivity class of the area represented by pedon 4 ranged from 2.61 to 5.74 mS/m. The weighted percent of clay for this pedon was 22.71%. The higher conductivity class observed in the vicinity of pedon 2 is likely due to higher moisture content associated with the presence of a fragipan in the subsurface rather than due to a higher weighted percent of clay determined for this pedon.

Pedon 3 consisted of argillic horizons and had a higher weighted percent of clay than any other of the pedons described in this portion of the field (25.49%). However, there was no fragipan horizon in this pedon which would hinder downward movement of water. Thus the conductivity observed this area of the field (5.75 – 8.86 mS/m) was slightly lower than that at pedon 2 due to the lack of perched water in the subsurface.

Erosion at pedon 4 has resulted in the complete removal of loess that was present at this pedon. This has resulted in the exposure of coarser alluvial materials closer to the surface, which, in turn, would result in the lower conductivity observed in the area represented by this pedon.

Using the conductivity map generated with EM-31 (figure 47) as well as with soils characterization/classification data (chapter 1), soil boundaries were drawn for the Mississippi site (figure 48). Each soil characterized at the site



TyF - fine-loamy, mixed, active, thermic Typic Fragiudalfs

UtH - fine-silty, mixed, active, thermic Ultic Hapludalfs

TyH - fine-loamy, mixed, active, thermic Typic Hapludults

Figure 48. The soil map generated from characterization data and 3-m conductivity data.

represented a different taxon. Pedon 2 was classified as a fine-loamy, mixed, active, thermic Typic Fragiudalf. Pedon 3 was classified as a fine-silty, mixed, active, thermic Ultic Hapludalf. Pedon 4 was classified as a fine-loamy, mixed, active, thermic Typic Hapludult. The morphology of each of the soils described and characterized within the study area were distinctly different. The dominant parent material that made up pedon 3 was loess whereas pedons 2 and 4 were devoid almost entirely of loess. The amount of erosion observed at pedon 4 has resulted an entirely different soil order classification (*i.e.* Typic Hapludult).

The fuzzy-neural network class groupings for the Mississippi sites can be seen in figure 49. The application of the FNN program did not result in distinct patterns. The most dominant class grouping observed in the study area was class 2. It is not known which of the pedons described at this site correlated to this class grouping. The occurrence of similar groupings tended to be more random than those observed for the Kentucky site (figure 49). The FNN program used to evaluate the ground-penetrating radar data collected at this site was not able to group similar scan patterns into distinct regions within the study site. Therefore, it is unknown whether or not a true correlation exists between the resulting class groupings and actual soils data obtained from pedons 2, 3, and 4. With this in mind and given the highly variable nature of the soils occurring on this landform, some of the randomness observed in the class groupings depicted in figure 49 may be explained. Other possibilities of the randomness observed in the FNN classifications may be attributed to the lack of data collected in the field.

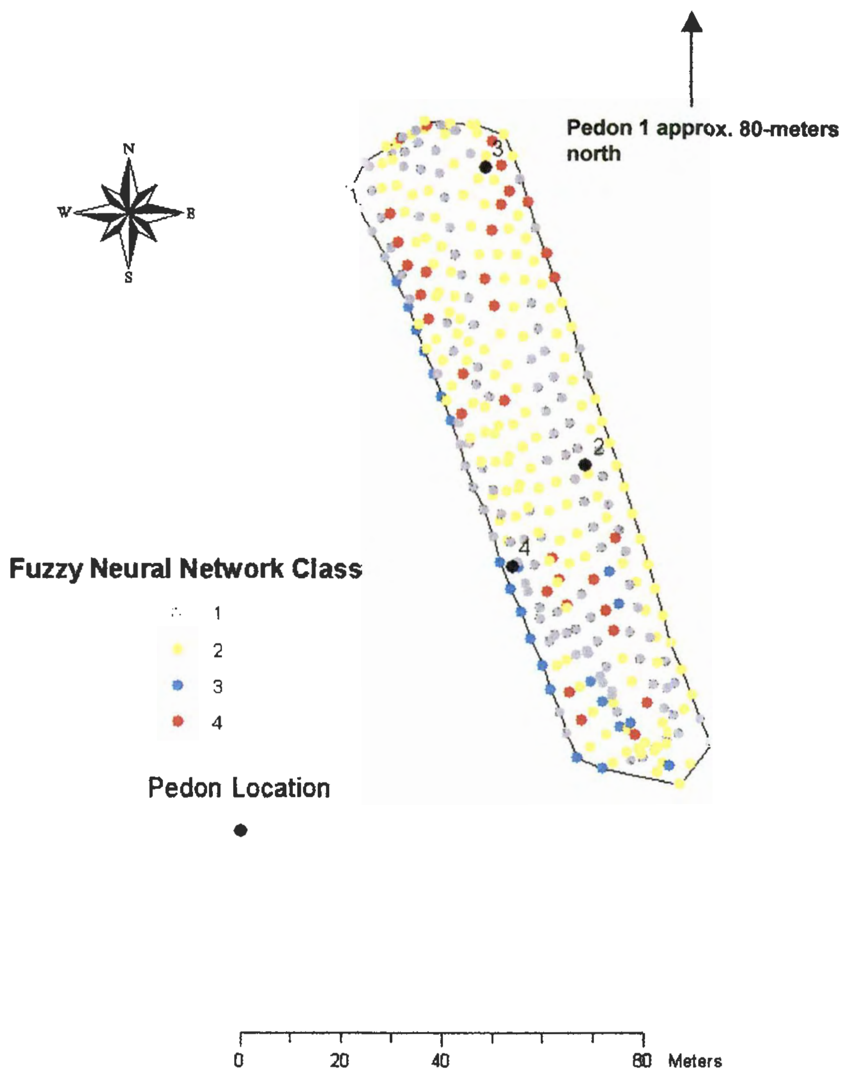


Figure 49. Class groupings produced by the fuzzy neural networking classifier based on the continuous GPR scan of the Mississippi site.

Conclusions

Overall, the use of electromagnetic induction in this study was an extremely useful tool in identifying and locating fragipans at each of the site locations. Generally, areas that had higher conductivities contained fragipans. In addition to this, EM-31 data along with soils characterization/classification data aided in delineating soil boundaries at each of the study sites. Fragipans cause water to be retained (perched) in the profile and thus a higher electrical conductivity is observed in areas containing fragipans. The use of electromagnetic induction in this study resulted in successful identification and location of such features at each study site and did so with high resolution.

The application of a fuzzy-neural network classifier to the GPR data collected at the Kentucky site resulted in a useful graphical representation of subsurface features. There was a discernable pattern observed at the study site using the resulting class groupings of the FNN classifier. Pedons 1 and 2 correlated with FNN class groupings 1 and 4 and fragipans were found in these soils. Pedons 3 and 4 correlated with FNN class grouping 3 and did not contain fragipans. The use of the FNN classifier on the GPR data collected at the Kentucky site aided in avoiding costly interpretation errors and bias and resulted in a significant depiction of subsurface features.

The application of the FNN classifier to the GPR data collected at the Mississippi site did not result in distinct patterns of class groupings across the site. There was no discernible pattern of class groupings observed at this study site. The highly variable nature of the soils found on the landscape at this site and perhaps lack of data may explain why the FNN classifier came up with no true pattern. It is unknown which of the pedons characterized at this site correlates to which of the resulting FNN class groupings.

The use of EM-31, GPR, and the fuzzy-neural network classification in this study were very useful tools in observing soil bodies in a non-intrusive manner. These tools alone can be most important in identifying areas that are at high risk of affecting the environment detrimentally by transport of water born contaminants offsite. However, without soils characterization and classification data and mapping, insight into what is actually being observed with these tools would be unknown and the user would be unable to specify exactly what is being observed. Overall, the landforms and soils evaluated in this study were effectively characterized with minimal disturbance using soils characterization/classification, mapping, EM-31, GPR, and fuzzy neural network classification.

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Appendix A: Field and Laboratory Data for Kentucky Site One.

Field Description for Kentucky Site One

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 1%
Aspect: 282°
Location: 36°32'27.48" N
88°35'29.92"W

Horizon	Depth (cm)	Color	Texture	Boundary	Structure	Consistency
Ap	0-8	10YR 4/4	SiL	A	Wk Gr	Fr
Bt1	8-51	7.5YR 4/6	SiCL	C	St Abk	Fr
Bt2	51-70	7.5YR 4/6	SiCL	C	Mo Pris/Sbk	Vfr
Bx1	70-104	7.5YR 4/6	SiL	C	St Pris	Fi
Bx2	104-140	7.5YR 4/4	SiL	C	Mo Pris/Sbk	Fi
2BC	140-197	7.5YR 5/6	SiL	C	Mo Sbk	Vfr
2C/BC	197-250	7.5YR 4/6	SL	C	Sg/Wk Sbk	Vfr
3C1	250-287	7.5YR 5/6	SC	C	SLS Mass	Fr
3C2	287-344+	5YR 4/6	GR SC	-	SLS Mass	Vfr

Notes: Manganese concentrations were observed in the 3rd, 4th, 5th, and 6th horizons. Depletions due to drainage were observed in the 4th, 5th, and 6th horizons. Stripping was observed in the 3rd, 4th, 5th, and 6th horizons. Coarse fragments were observed in the 7th, 8th, and 9th horizons in the form of chert fragments (7th and 8th) and rounded quartz gravel (9th).

Classification: fine-silty, mixed, active, thermic Typic Fragiudalf

Profile Description for Kentucky Site One

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 1%
Natural Drainage Class: Moderately Well Drained
Location: 36°32'27.48" N
88°35'29.92"W
Classification: fine-silty, mixed, active, thermic Typic Fragiudalf

Ap 0 to 8 cm; dark yellowish brown (10YR 4/4); silt loam; weak granular structure; abrupt boundary; friable; moderately acid.

Bt_1 8 to 51 cm; strong brown (7.5YR 4/6); silty clay loam; strong angular blocky structure; clear boundary; friable; strongly acid.

Bt_2 51 to 70 cm; strong brown (7.5YR 4/6); silty clay loam; moderate prismatic and subangular blocky structure; clear boundary; very friable; strongly acid; manganese concentrations common; stripped areas common (10YR 7/1).

Bx_1 70 to 104 cm; strong brown (7.5YR 4/6); silt loam; strong prismatic structure; clear boundary; firm; strongly acid; manganese concentrations common; depletions common (10YR 6/2); clay films common; stripped areas common (10YR 7/1); blind pores common.

Bx_2 104 to 140 cm; brown (7.5YR 4/4); silt loam; moderate prismatic and subangular blocky structure; clear boundary; firm; strongly acid; manganese concentrations common; depletions common (10YR 6/1); clay films common; stripped areas common (10YR 7/2); blind pores common.

2BC 140 to 197cm; strong brown (7.5YR 5/6); silt loam; moderate subangular blocky structure; clear boundary; very friable; moderately acid; manganese concentrations common; depletions common (10YR 6/1); stripped areas common (10YR 7/2).

2C/BC 197 to 250 cm; strong brown (7.5YR 4/6); sandy loam; structureless single grain and weak subangular blocky structure; clear boundary; very friable; strongly acid; angular blocky, yellowish red chert fragments (5YR 4/6) common.

$3C_1$ 250 to 287 cm; yellowish red (5YR 5/6); sandy clay; structureless massive; clear boundary; friable; strongly acid; angular blocky, dark red (2.5YR 3/6) chert material mixed with well-rounded quartz gravel common.

$3C_2$ 287 to 344+ cm; yellowish red (5YR 4/6); gravelly sandy clay; structureless massive; very friable; moderately acid; many well-rounded quartz gravels.

Base Saturation Data for Kentucky Site One

Ammonium acetate extractable bases, cation exchange capacity (pH 7.0 and pH 8.2), effective cation exchange capacity, KCl extractable aluminum and acidity, $BaCl_2$ acidity, and percent base saturation (direct measurement and by summation) for Kentucky Site One.

		cmol(+)/kg										% Base Saturation	
Horizon	Depth	Ca	Mg	Na	K	Al(KCl)	CEC pH7	ECEC	CEC pH8.2	KCl Acidity	BaCl2 Acidity	pH7	Sum of Cations
Ap	0-8	6.90	1.92	0.34	0.41	0.19	12.90	9.76		0.05		74	
Bt1	8-51	5.15	4.18	0.49	0.25	0.54	16.15	10.62		0.22		62	
Bt2	51-70	2.19	4.20	0.26	0.20	2.10	15.76	8.95		0.78		43	
Bx1	70-104	1.44	3.68	0.46	0.19	2.44	13.81	8.21		1.01		42	
Bx2	104-140	1.59	3.86	0.52	0.15	1.91	13.32	8.02	15.31	0.83	9.20	46	40
2BC	140-197	2.12	3.95	1.11	0.09	0.40	9.56	7.66		0.19		76	
2C/BC	197-250	1.35	1.74	0.53	0.05	0.95	3.40	4.62		0.08		100	
3C1	250-287	2.98	2.66	0.50	0.06	0.31	9.19	6.50		0.11		67	
3C2	287-344+	2.50	2.17	0.65	0.06	0.12	7.57	5.50		0.04		71	

Particle Size Distribution for Kentucky Site One

		USDA Particle Size Class								
	Lower	VCOS	COS	MS	FS	VFS	SAND	SILT	CLAY	FINE CLAY
Horizon	Depth	%	%	%	%	%	%	%	%	% of clay
Ap	8	0.35	0.23	0.47	0.35	0.58	1.98	71.87	26.15	37.22
Bt1	51	0.00	0.11	0.22	0.32	0.65	1.30	67.32	31.39	38.88
Bt2	70	0.00	0.23	0.23	0.56	0.68	1.69	70.95	27.36	37.06
Bx1	104	0.00	0.20	1.30	0.80	0.50	2.79	72.69	24.51	40.07
Bx2	140	0.00	0.86	2.81	3.24	0.97	7.88	69.31	22.81	42.13
2BC	197	0.21	4.01	12.22	11.20	1.95	29.58	53.09	17.33	46.21
2C/BC	250	4.28	12.12	35.26	24.85	3.55	80.06	7.50	12.44	46.35
3C1	287	1.00	9.21	27.24	17.83	1.10	56.39	7.64	35.97	60.16
3C2	344	7.27	16.52	18.11	4.78	1.00	47.68	11.97	40.36	54.51

C, N, S Data for Kentucky Site One

Sample #	Horizon	Lower Depth (cm)	Total Carbon %	Total Nitrogen %	Total Sulfur %	Organic Carbon %
01101	Ap	8	1.02	0.10	0.02	0.58
01102	Bt1	51	0.41	0.06	0.03	0.05
01103	Bt2	70	0.33	0.05	0.02	0.07
01104	Bx1	104	0.30	0.04	0.02	0.03
01105	Bx2	140	0.25	0.04	0.01	0.02
01106	2BC	197	0.29	0.04	0.02	0.02
01107	2C/BC	250	0.39	0.04	0.02	0.07
01108	3C1	287	0.30	0.03	0.02	0.06
01109	3C2	344	0.39	0.04	0.08	0.09

Free Iron Oxides (Fe3+c.d.), Total Iron, Hydroxylamine extractable Manganese, and total Manganese for Kentucky Site One.

Horizon	Lower Depth (cm)	Fe 3+ c.d.	Total Iron	Ha Mn	Total Mn
		mg/kg			
Ap	8	10934.44	20241.33	228.96	413.58
Bt1	51	15068.41	29290.57	138.70	504.50
Bt2	70	12652.97	26346.01	133.04	386.31
Bx1	104	11898.25	21163.62	80.87	294.85
Bx2	140	12813.04	24008.21	128.20	405.08
2BC	197	9439.23	18470.13	174.55	375.67
2C/BC	250	14875.30	21513.16	63.41	135.98
3C1	287	46814.01	50281.07	7.68	13.98
3C2	344	82696.35	120112.92	9.02	249.63

Concentration of selected elements for Kentucky Site One

Sample #	Horizon	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
		mg/kg							
01101	Ap	2831.58	25.20	20241.33	18284.61	3678.73	413.58	9325.05	67.36
01102	Bt1	2808.10	20.49	29290.57	19821.44	6647.63	504.50	9718.56	70.72
01103	Bt2	2588.99	21.71	26346.01	20148.14	6196.21	386.31	10728.93	62.39
01104	Bx1	2839.57	14.99	21163.62	20044.31	5424.34	294.85	11218.82	51.22
01105	Bx2	3309.40	21.67	24008.21	20277.99	5194.56	405.08	12404.54	43.85
01106	2BC	3359.86	14.72	18470.13	17925.03	4199.14	375.67	10395.26	36.67
01107	2C/BC	2417.64	5.24	21513.16	11855.76	2499.99	135.98	6732.90	25.95
01108	3C1	2131.82	13.23	50281.07	7741.44	2333.85	13.98	3882.34	31.19
01109	3C2	2326.83	45.98	120112.92	6865.35	2247.41	249.63	4124.30	101.95

pH data for Kentucky Site One

			pH	
Sample #	Horizon	Depth (cm)	1:1 pH (water)	2:1 pH (0.01M CaCl2)
01101	Ap	0-8	5.6	4.9
01102	Bt1	8-51	5.5	4.8
01103	Bt2	51-70	5.2	4.4
01104	Bx1	70-104	5.3	4.2
01105	Bx2	104-140	5.4	4.2
01106	2BC	140-197	5.7	4.5
01107	2C/BC	197-250	5.2	4.6
01108	3C1	250-287	5.4	4.6
01109	3C2	287-344+	5.6	4.8

Appendix B: Field and Laboratory Data for Kentucky Site Two

Field Description for Kentucky Site Two

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 2%
Aspect: 135°
Location: 36°32'27.10" N
88°35'29.60" W

Horizon	Depth (cm)	Color	Texture	Boundary	Structure	Consistency
Ap	0-20	10YR 4/4	SiL	A	Wk Gr	Vfr
Bt	20-80	7.5YR 4/6	SiCL	C	Mo Sbk	Fi
Bx1	80-110	7.5YR 4/6	SiL	C	Mo Pris	Fi
2Bx2	110-184	7.5YR 4/6	SiL	C	Wk Pr	Fi
2BC	184-235	7.5YR 4/6	SiL	C	Mo Sblk	Vfr
2C1	235-280	7.5YR 5/4	SL	A	SLS Ma	Fr
3C2	280-310	5YR 5/8	C	A	SLS Ma	Fr
3C3	310-320+	5YR 5/6	SC	-	SLS Ma	Vfr

Notes: Manganese concentrations were observed in the 1st, 3rd, and 4th horizons. Stripping was observed in the 3rd, 4th, and 5th. Coarse fragments were observed in the 6th, 7th, and 8th horizons in the form of blocky chert fragments (6th) and a mix of chert fragments and rounded quartz gravel was observed in the 7th and 8th horizons.

Classification: fine-silty, mixed, active, thermic Typic Fragiudalf

Profile Description for Kentucky Site Two

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 2%
Natural Drainage Class: Well Drained
Location: 36°32'27.10" N
88°35'29.60" W
Classification: fine-silty, mixed, active, thermic Typic Fragiudalf

Ap 0 to 20 cm; dark yellowish brown (10YR 4/4); silt loam; weak granular structure; abrupt boundary; friable; moderately acid; few manganese concentrations.

Bt 20 to 80 cm; strong brown (7.5YR 4/6); silty clay loam; moderate subangular blocky structure; clear boundary; firm; strongly acid.

Bx_1 80 to 110 cm; strong brown (7.5YR 4/6); silt loam; moderate prismatic structure; clear boundary; firm; strongly acid; manganese concentrations common; stripped areas common (10YR 7/2).

$2Bx_2$ 110 to 184 cm; strong brown (7.5YR 4/6); silt loam; weak prismatic structure; clear boundary; firm; strongly acid; manganese concentrations common; depletions common (10YR 7/2); clay films common; stripped areas common (10YR 7/1); blind pores common.

2BC 184 to 235 cm; strong brown (7.5YR 4/6); silt loam; moderate subangular blocky structure; clear boundary; very friable; very strongly acid; stripped areas common (10YR 7/1); blind pores common.

$2C_1$ 235to 280cm; brown (7.5YR 5/4); sandy loam; structure less massive structure; abrupt boundary; friable; strongly acid; few angular blocky chert fragments.

$3C_2$ 280 to 310 cm; yellowish red (5YR 5/8); clay; structure less massive; abrupt boundary; friable; moderately acid; few manganese concentrations; small angular blocky chert fragments and larger well-rounded quartz gravel common.

$3C_3$ 310 to 320+ cm; yellowish red (5YR 5/6); sandy clay; structure-less massive; very friable; strongly acid; blocky chert material mixed with well-rounded quartz gravel common.

Base Saturation Data for Kentucky Site Two

Ammonium acetate extractable bases, cation exchange capacity (pH 7.0 and pH 8.2), effective cation exchange capacity, KCl extractable aluminum and acidity, $BaCl_2$ acidity, and percent base saturation (direct measurement and by summation) for Kentucky Site Two.

		cmol(+)/kg										% Base Saturation	
Horizon	**Depth**	**Ca**	**Mg**	**Na**	**K**	**Al(KCl)**	**CEC pH7**	**ECEC**	**CEC pH8.2**	**KCl Acidity**	**BaCl2 Acidity**	**pH7**	**Sum of Cations**
Ap	0-20	6.78	1.76	0.47	0.30	0.14	11.69	9.45		0.03		80	
Bt	20-80	1.98	4.00	0.26	0.22	2.89	15.71	9.34		1.23		41	
Bx1	80-110	1.11	3.40	0.29	0.17	2.84	15.25	7.81		1.18		33	
2Bx2	110-184	2.33	3.81	0.60	0.09	0.59	10.86	7.42	12.07	0.27	5.23	63	57
2BC	184-235	2.40	3.53	0.61	0.09	0.59	10.06	7.22		0.28		66	
2C1	235-280	1.64	2.10	0.35	0.05	0.19	5.20	4.33		0.05		80	
3C2	280-310	4.79	3.29	0.71	0.08	0.14	11.89	9.01		0.03		75	
3C3	310-320+	4.17	3.03	0.55	0.07	0.11	10.23	7.94		0.08		76	

Particle Size Distribution for Kentucky Site Two

		USDA Particle Size Class								
Horizon	Lower Depth (cm)	VCOS %	COS %	MS %	FS %	VFS %	SAND %	SILT %	CLAY %	FINE CLAY % of clay
Ap	20	0.00	0.28	0.37	0.47	0.65	1.77	72.36	25.87	36.53
Bt	80	0.00	0.11	0.23	0.57	0.68	1.59	68.71	29.70	40.56
Bx1	110	0.00	0.32	0.85	1.27	0.74	3.19	72.47	24.34	34.86
2Bx2	184	0.10	2.75	8.47	7.24	1.53	20.10	59.48	20.42	45.22
2BC	235	0.20	4.38	11.16	10.86	1.49	28.10	52.59	19.30	43.00
2C1	280	1.11	10.11	22.44	20.21	2.43	56.29	31.06	12.65	48.59
3C2	310	3.27	9.09	17.26	11.23	1.74	42.59	12.76	44.66	61.59
3C3	320	4.72	11.91	19.41	8.94	1.44	46.42	10.80	42.78	56.88

C, N, S Data for Kentucky Site Two

Sample #	Horizon	Lower Depth (cm)	Total Carbon %	Total Nitrogen %	Total Sulfur %	Organic Carbon %
01110	Ap	20	1.02	0.09	0.03	0.79
01111	Bt	80	0.36	0.05	0.03	0.07
01112	Bx1	110	0.37	0.05	0.01	0.04
01113	2Bx2	184	0.31	0.04	0.01	0.03
01114	2BC	235	0.47	0.04	0.02	0.14
01115	2C1	280	0.37	0.03	0.01	0.09
01116	3C2	310	0.44	0.04	0.02	0.12
01117	3C3	320	0.71	0.03	0.03	0.17

Free Iron Oxides (Fe3+c.d.), Total Iron, Hydroxylamine extractable Manganese, and total Manganese for Kentucky Site Two.

	Lower	------------------------mg/kg------------------------			
Horizon	Depth (cm)	Fe 3+ c.d.	Total Iron	Ha Mn	Total Mn
Ap	20	9944.21	18552.20	269.17	481.17
Bt	80	15862.00	29337.26	210.43	580.53
Bx1	110	12442.46	24706.33	147.35	366.69
2Bx2	184	9246.61	19737.99	149.23	399.24
2BC	235	8587.06	18628.36	86.62	271.26
2C1	280	5312.58	12181.32	71.69	160.38
3C2	310	59111.99	62060.03	5.80	38.23
3C3	320	56265.00	80757.84	12.19	88.18

Concentration of selected elements for Kentucky Site Two

		mg/kg							
Sample #	Horizon	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
01110	Ap	4107.50	13.23	18552.20	19057.01	3360.21	481.17	9596.19	52.16
01111	Bt	3806.86	30.71	29337.26	18591.63	5824.73	580.53	9134.78	52.68
01112	Bx1	3874.60	18.73	24706.33	18222.31	5422.50	366.69	13153.19	35.70
01113	2Bx2	4671.32	22.70	19737.99	17601.91	4413.01	399.24	13428.97	32.67
01114	2BC	4196.08	14.46	18628.36	15565.91	3585.72	271.26	11899.80	35.15
01115	2C1	3573.31	6.74	12181.32	11984.73	2206.34	160.38	7402.26	18.99
01116	3C2	3284.78	12.99	62060.03	6874.48	2478.23	38.23	5074.54	29.99
01117	3C3	3589.78	19.74	80757.84	8092.66	2594.54	88.18	7061.68	36.22

pH data for Kentucky Site Two

			------------pH------------	
Sample #	Horizon	Depth (cm)	1:1 pH (water)	2:1 pH (0.01M CaCl2)
01110	Ap	0-20	6.0	5.2
01111	Bt	20-80	5.1	4.3
01112	Bx1	80-110	5.3	4.2
01113	2Bx2	110-184	5.4	4.4
01114	2BC	184-235	4.9	4.4
01115	2C1	235-280	5.4	4.7
01116	3C2	280-310	5.7	4.9
01117	3C3	310-315+	5.2	4.8

Appendix C: Field and Laboratory Data for Kentucky Site Three

Field Description for Kentucky Site Three

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 5%
Aspect: 90°
Location: 36°32'24.30" N
88°35'29.00" W

Horizon	Depth (cm)	Color	Texture	Boundary	Structure	Consistency
Ap	0-15	10YR 4/4	SiCL	A	Str Sbk	Fri
Bt	15-69	7.5YR 4/6	SiCL	C	Mo Pris	Fi
2BC1	69-132	7.5YR 4/6	L	C	Mo Pris	Fri
2BC2	132-174	7.5YR 4/6	SL	C	Mo Sbk	Fri
2C1	174-194	7.5YR 5/6	LS	C	SLS Ma	Vfr
3C2	194-253	5YR 4/6	SL	C	SLS Ma	Fr
3C3	253-343+	7.5YR 5/6	SL	-	SLS Ma	Fr

Notes: Manganese concentrations were observed in the 2nd and 3rd horizons. Stripping was observed in the 3rd horizon. Coarse fragments were observed in the 7th, horizon in the form of blocky chert fragments and well rounded quartz gravel.

Classification: fine-silty, mixed, active, thermic Fragic Hapludalf

Profile Description for Kentucky Site Three

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 5%
Natural Drainage Class: Well Drained
Location: 36°32'24.30" N
88°35'29.00" W
Classification: fine-silty, mixed, active, thermic Fragic Hapludalf

Ap	0 to 15 cm; dark yellowish brown (10YR 4/4); silty clay loam; strong subangular structure; abrupt boundary; friable; slightly acid; few manganese concentrations.
Bt	15 to 69 cm; strong brown (7.5YR 4/6); silty clay loam; moderate prismatic structure; clear boundary; firm; strongly acid; manganese concentrations common; stripped areas common (10YR 7/1).
$2BC_1$	69 to 132 cm; strong brown (7.5YR 4/6); loam; moderate prismatic structure; clear boundary; firm; strongly acid; stripped areas common (10YR 7/1).
$2BC_2$	132 to 174 cm; strong brown (7.5YR 4/6); sandy loam; moderate subangular blocky structure; clear boundary; friable; strongly acid.
$2C_1$	174 to 194 cm; strong brown (7.5YR 5/6); loamy sand; structureless massive structure; clear boundary; very friable; strongly acid.
$3C_2$	194 to 253cm; yellowish red (5YR 4/6); sandy loam; structure less massive structure; clear boundary; friable; moderately acid.
$3C_3$	253 to 343+ cm; strong brown (7.5YR 5/6); sandy loam; structure less massive; friable; strongly acid; few angular blocky chert fragments and larger well rounded quartz gravel.

Base Saturation Data for Kentucky Site Three

Ammonium acetate extractable bases, cation exchange capacity (pH 7.0 and pH 8.2), effective cation exchange capacity, KCl extractable aluminum and acidity, $BaCl_2$ acidity, and percent base saturation (direct measurement and by summation) for Kentucky Site Three.

		cmol(+)/kg										% Base Saturation	
Horizon	**Depth**	**Ca**	**Mg**	**Na**	**K**	**Al(KCl)**	**CEC pH7**	**ECEC**	**CEC pH8.2**	**KCl Acidity**	**BaCl2 Acidity**	**pH7**	**Sum of Cations**
Ap	0-15	9.41	3.42	0.12	0.40	0.12	16.71	13.48		0.01		80	
Bt	15-69	3.65	3.06	0.25	0.29	1.55	14.01	8.80		0.64		52	
2BC1	69-132	1.98	2.31	0.18	0.35	1.01	9.82	5.83		0.39		49	
2BC2	132-174	0.92	1.39	0.10	0.19	0.40	5.55	2.99	5.69	0.13	3.10	47	46
2C1	174-194	0.42	0.61	0.03	0.10	0.16	2.39	1.33		0.01		49	
3C2	194-253	1.18	1.31	0.06	0.12	0.09	4.05	2.77		0.01		66	
3C3	253-343+	1.07	1.00	0.07	0.05	0.12	2.78	2.32		0.04		79	

Particle Size Distribution for Kentucky Site Three

		USDA Particle Size Class								
Horizon	Lower Depth (cm)	VCOS %	COS %	MS %	FS %	VFS %	SAND %	SILT %	CLAY %	FINE CLAY % of clay
Ap	15	0.00	0.36	1.80	1.44	0.60	4.20	61.36	34.43	44.88
Bt	69	0.00	1.34	5.37	4.54	0.41	11.67	60.20	28.13	45.01
2BC1	132	0.00	4.38	14.64	12.95	0.60	32.57	48.47	18.96	44.33
2BC2	174	0.10	8.22	36.54	22.18	0.89	67.94	20.84	11.22	57.49
2C1	194	0.10	13.40	43.89	23.93	0.89	82.21	9.60	8.18	46.38
3C2	253	0.00	12.12	39.78	24.74	0.71	77.34	4.85	17.81	55.36
3C3	343	1.31	9.26	35.14	20.44	1.61	67.76	19.98	12.26	53.07

C, N, S Data for Kentucky Site Three

Sample #	Horizon	Lower Depth (cm)	Total Carbon %	Total Nitrogen %	Total Sulfur %	Organic Carbon %
01118	Ap	15	0.74	0.07	0.01	0.43
01119	Bt	69	0.37	0.05	0.02	0.09
01120	2BC1	132	0.27	0.04	0.02	0.02
01121	2BC2	174	0.30	0.04	0.01	0.02
01122	2C1	194	0.31	0.03	0.01	0.01
01123	3C2	253	0.31	0.04	0.01	0.02
01124	3C3	343	0.32	0.03	0.01	0.06

Free Iron Oxides (Fe3+c.d.), Total Iron, Hydroxylamine extractable Manganese, and total Manganese for Kentucky Site Three.

	Lower	----------------------mg/kg----------------------			
Horizon	Depth (cm)	Fe 3+ c.d.	Total Iron	Ha Mn	Total Mn
Ap	15	16534.87	29530.99	75.98	286.38
Bt	69	16047.50	30729.39	53.83	264.36
2BC1	132	12524.65	25180.03	172.82	381.66
2BC2	174	9338.37	18822.31	155.59	362.31
2C1	194	7845.45	13850.17	47.84	153.66
3C2	253	27539.75	35368.15	1.83	69.54
3C3	343	10281.19	16248.25	61.56	118.88

Concentration of selected elements for Kentucky Site Three

		mg/kg							
Sample #	Horizon	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
01118	Ap	4296.55	20.47	29530.99	18231.34	4895.78	286.38	11084.47	44.20
01119	Bt	3829.86	20.47	30729.39	19061.86	5318.62	264.36	10903.51	48.93
01120	2BC1	4221.23	16.19	25180.03	19047.35	4527.66	381.66	13115.90	38.62
01121	2BC2	3855.96	9.75	18822.31	15372.60	3122.89	362.31	12221.83	27.49
01122	2C1	3262.54	4.99	13850.17	10298.64	1851.29	153.66	7129.19	17.96
01123	3C2	3263.21	4.49	35368.15	9026.42	2077.27	69.54	5831.01	18.94
01124	3C3	3221.78	<1.00	16248.25	10320.93	1885.11	118.88	8270.98	13.74

pH data for Kentucky Site Three

			-----------pH-----------------	
Sample #	Horizon	Depth (cm)	1:1 pH (water)	2:1 pH (0.01M CaCl2)
01118	Ap	0-15	6.2	5.4
01119	Bt	15-69	5.2	4.4
01120	2BC1	69-132	5.2	4.4
01121	2BC2	132-174	5.4	4.5
01122	2C1	174-194	5.4	4.7
01123	3C2	194-253	5.6	5.0
01124	3C3	253-343+	5.2	4.8

Appendix D: Field and Laboratory Data for Kentucky Site Four

Field Description for Kentucky Site Four

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 5%
Aspect: 90°
Location: 36°32'22.70" N
88°35'27.30" W

Horizon	Depth (cm)	Color	Texture	Boundary	Structure	Consistency
Ap	0-14	10YR 4/4	SiL	A	Str Sbk	Fri
Bt1	14-50	7.5YR 4/6	SiCL	C	Mo Sbk	Fi
Bt2	50-80	7.5YR 5/4	SiCL	C	Mo Sbk	Fri
BC1	80-150	7.5YR 4/6	SiL	C	Wk Pr	Fri
2BC2	150-195	7.5YR 4/6	L	C	Mo Abk	Vfr
2BC3	195-253	7.5YR 5/6	SL	C	Mo Sbk	Fr
3C	253-260+	2.5YR 4/4	SL	-	SLS Sg	L

Notes: Manganese concentrations were observed in the 2nd, 3rd, 4th, and 5th horizons. Stripping was observed in the 5th, 6th, and 7th horizons. Coarse fragments were observed in the 6th and 7th horizons in the form of well-rounded quartz gravel.

Classification: fine-silty, mixed, active, thermic Fragic Hapludalf

Profile Description for Kentucky Site Four

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 1%
Natural Drainage Class: Moderately Well Drained
Location: 36°32'22.70" N
88°35'27.30" W
Classification: fine-silty, mixed, active, thermic Fragic Hapludalf

Ap	0 to 14 cm; dark yellowish brown (10YR 4/4); silt loam; strong subangular structure; abrupt boundary; friable; moderately acid.
Bt_1	14 to 50 cm; strong brown (7.5YR 4/6); silty clay loam; moderate subangular blocky structure; clear boundary; friable; moderately acid; manganese concentrations common.
Bt_2	50 to 80 cm; brown (7.5YR 5/4); silty clay loam; moderate subangular blocky structure; clear boundary; friable; moderately acid; manganese concentrations common; clay films common.
BC_1	80 to 150 cm; strong brown (7.5YR 4/6); silt loam; weak prismatic structure; clear boundary; friable; strongly acid; manganese concentrations common; depletions common (10YR 6/2); clay films common; stripped areas common (10YR 7/1).
$2BC_2$	150 to 195 cm; strong brown (7.5YR 4/6); loam; moderate angular blocky structure; clear boundary; friable; strongly acid; manganese concentrations common; striped areas common (10YR 7/1).
$2BC_3$	195 to 253cm; strong brown (7.5YR 5/6); sandy loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; stripped areas common (10YR 7/1); few well-rounded quartz gravel.
3C	253 to 260+ cm; reddish brown (2.5YR 4/4); sandy loam; structureless single grain; loose; strongly acid; stripped areas common (5YR 4/8 and 10YR 7/4); well rounded quartz gravel common.

Base Saturation Data for Kentucky Site Four

Ammonium acetate extractable bases, cation exchange capacity (pH 7.0 and pH 8.2), effective cation exchange capacity, KCl extractable aluminum and acidity, $BaCl_2$ acidity, and percent base saturation (direct measurement and by summation) for Kentucky Site Four.

		cmol(+)/kg										% Base Saturation	
Horizon	Depth	Ca	Mg	Na	K	Al(KCl)	CEC pH7	ECEC	CEC pH8.2	KCl Acidity	BaCl2 Acidity	pH7	Sum of Cations
Ap	0-14	6.10	1.99	0.16	0.49	0.12	12.29	8.86		0.01		71	
Bt1	14-50	6.95	4.21	0.26	0.25	0.14	16.67	11.81		0.05		70	
Bt2	50-80	4.39	0.46	0.44	0.25	0.36	16.43	5.90		0.12		34	
BC1	80-150	2.61	4.32	0.17	0.22	0.38	12.03	7.70	13.03	0.11	5.71	61	56
2BC2	150-195	1.43	2.89	0.16	0.13	0.31	7.30	4.91		0.11		63	
2BC3	195-253	1.28	2.59	0.17	0.11	0.26	6.15	4.41		0.10		67	
3C	253-260+	0.55	1.30	0.21	0.10	0.21	3.54	2.37		0.04		61	

Particle Size Distribution for Kentucky Site Four

		--USDA Particle Size Class--								
	Lower	VCOS	COS	MS	FS	VFS	SAND	SILT	CLAY	FINE CLAY
Horizon	Depth (cm)	%	%	%	%	%	%	%	%	% of clay
Ap	14	0.37	0.92	1.10	0.73	0.46	3.57	70.37	26.06	39.79
Bt1	50	0.00	0.32	0.11	0.32	0.54	1.29	66.71	32.00	37.94
Bt2	80	0.00	0.34	0.68	0.68	0.57	2.27	69.12	28.61	34.44
BC1	150	0.10	1.42	4.37	4.68	0.81	11.39	66.28	22.34	41.84
2BC2	195	0.40	8.02	17.75	16.95	1.30	44.43	40.18	15.39	49.35
2BC3	253	0.70	8.05	23.44	21.23	1.51	54.93	30.91	14.17	48.60
3C	260	5.14	11.49	24.78	20.86	4.63	66.90	20.89	12.21	43.32

C, N, S Data for Kentucky Site Four

Sample #	Horizon	Lower Depth (cm)	Total Carbon %	Total Nitrogen %	Total Sulfur %	Organic Carbon %
01125	Ap	14	1.03	0.09	0.02	0.55
01126	Bt1	50	0.32	0.05	0.01	0.12
01127	Bt2	80	0.24	0.04	0.02	0.07
01128	BC1	150	0.26	0.04	0.02	0.04
01129	2BC2	195	0.22	0.03	0.01	0.02
01130	2BC3	253	0.25	0.03	0.01	0.04
01131	3C	260+	0.23	0.03	0.01	0.05

Free Iron Oxides (Fe3+c.d.), Total Iron, Hydroxylamine extractable Manganese, and total Manganese for Kentucky Site Four.

	Lower	----------mg/kg----------			
Horizon	Depth (cm)	Fe 3+ c.d.	Total Iron	Ha Mn	Total Mn
Ap	14	10277.75	21403.61	175.31	377.96
Bt1	50	17375.41	30493.51	180.90	474.29
Bt2	80	13976.07	30059.24	148.88	418.15
BC1	150	10175.84	24856.82	137.88	400.80
2BC2	195	7269.99	18431.77	164.96	334.42
2BC3	253	8582.52	17419.72	81.19	225.82
3C	260+	34714.36	36435.78	45.42	140.29

Concentration of selected elements for Kentucky Site Four

		mg/kg							
Sample #	Horizon	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
01125	Ap	3866.10	11.73	21403.61	18849.38	3533.72	377.96	14090.00	48.39
01126	Bt1	4055.92	14.98	30493.51	18440.34	5616.58	474.29	11946.83	54.92
01127	Bt2	3873.55	13.50	30059.24	18653.42	5259.22	418.15	13977.27	43.74
01128	BC1	4421.25	8.25	24856.82	18895.31	4638.56	400.80	16089.28	30.24
01129	2BC2	3921.70	16.72	18431.77	15102.55	3201.38	334.42	12054.21	32.94
01130	2BC3	3509.98	24.18	17419.72	13951.59	2920.73	225.82	10154.30	28.41
01131	3C	2980.53	11.23	34671.49	8072.39	1881.18	140.29	8916.87	20.97

pH data for Kentucky Site Four

			-------------pH------------------	
			1:1 pH	2:1 pH
Sample #	Horizon	Depth (cm)	(water)	(0.01M CaCl2)
01125	Ap	0-14	5.8	5.1
01126	Bt1	14-50	5.9	5.2
01127	Bt2	50-80	5.6	4.9
01128	BC1	80-150	5.5	4.8
01129	2BC2	150-195	5.5	4.7
01130	2BC3	195-253	5.4	4.7
01131	3C	253-260+	5.3	5.8

Appendix E: Field and Laboratory Data for Mississippi Site One

Field Description for Mississippi Site One

Landscape Position: Upland
Parent Material Sequence: Loess/Tertiary Sand
Slope: 2%
Aspect: 211°
Location: 34°48'14.00" N
89°26'23.00" W

Horizon	Depth (cm)	Color	Texture	Boundary	Structure	Consistency
Ap	0-24	10YR 4/3	SiL	C	Mo Sbk	Fri
Bt	24-80	7.5YR 4/6	SiCL	C	Mo Sbk	Fri
BC1	80-130	7.5YR 4/6	SiL	C	Mo Sbk	Fri
BC2	130-170	7.5YR 4/6	SiL	C	Mo Sbk	Fri
BC3	170-203	7.5YR 4/6	SiL	C	Mo Abk	Fri
2Bt1	203-270	5YR 4/6	SiCL	C	Mo Sbk	Fri
2Bt2	270-325	5YR 4/6	SiCL	A	Mo Sbk	Fri
2Bt3	325-360	7.5YR 5/4	SiCL	A	Mo Sbk	Fri
3C	360-390+	5YR 5/6	SL	-	SLS Ma	Vfr

Notes: Manganese concentrations were observed in the 3rd, 4th, 5th, 6th and 8th horizons. A zone of perched water was observed within the 7th horizon. This zone extended from 310 cm to 325cm. Iron concentrations and depletions were observed. Stripping was observed in the 4th, 5th, and 6th horizons.

Classification: fine-silty, mixed, active, thermic Ultic Hapludalf

Profile Description for Mississippi Site One

Landscape Position: Upland
Parent Material Sequence: Loess/Tertiary Sand
Slope: 1%
Natural Drainage Class: Well Drained
Location: 34°48'14.00" N
89°26'23.00" W
Classification: fine-silty, mixed, active, thermic Ultic Hapludalf

Ap 0 to 24 cm; brown (10YR 4/3); silt loam; moderate subangular and moderate granular structure; clear boundary; friable; moderately acid.

Bt 24 to 80 cm; strong brown (7.5YR 4/6); silty clay loam; moderate subangular blocky structure; clear boundary; friable; slightly acid.

BC_1 80 to 130 cm; strong brown (7.5YR 4/6); silt loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; few manganese concentrations.

BC_2 130 to 170 cm; strong brown (7.5YR 4/6); silt loam; moderate subangular blocky structure; clear boundary; friable; very strongly acid; few manganese concentrations; stripped areas common (10YR 7/2).

BC_3 170 to 203 cm; strong brown (7.5YR 4/6); silt loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; few manganese concentrations; stripped areas common (10YR 7/2).

$2Bt_1$ 203 to 270 cm; yellowish red (5YR 4/6); silty clay loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; manganese concentrations common; few stripped areas (10YR 7/1).

$2Bt_2$ 270 to 325 cm; yellowish red (5YR 4/6); silty clay loam; moderate subangular blocky structure; abrupt boundary; friable; strongly acid; iron concentrations common; Iron depletions common (7.5YR 6/2); zone of perched water (approximately 5 cm thick) extended from 310 to 325 cm.

$2Bt_3$ 325 to 360 cm; brown (7.5YR 5/4); silty clay loam; moderate subangular blocky structure; abrupt boundary; friable; strongly acid; manganese concentrations common; iron concentrations common.

3C 360 to 390+ cm; yellowish red (5YR 5/6); sandy loam; structureless massive; very friable; very strongly acid.

Base Saturation Data for Mississippi Site One

Ammonium acetate extractable bases, cation exchange capacity (pH 7.0 and pH 8.2), effective cation exchange capacity, KCl extractable aluminum and acidity, $BaCl_2$ acidity, and percent base saturation (direct measurement and by summation) for Mississippi Site One.

		cmol(+)/kg										% Base Saturation	
Horizon	**Depth**	**Ca**	**Mg**	**Na**	**K**	**Al(KCl)**	**CEC pH7**	**ECEC**	**CEC pH8.2**	**KCl Acidity**	**BaCl2 Acidity**	**pH7**	**Sum of Cations**
Ap	0-24	5.40	0.27	0.11	0.12	0.42	8.82	6.33		0.01		67	
Bt	24-80	8.39	3.02	0.17	0.21	0.09	14.88	11.88		0.03		79	
BC1	80-130	0.68	3.51	0.14	0.16	1.90	11.91	6.38		0.78		38	
BC2	130-170	1.28	3.29	0.13	0.21	1.67	10.61	6.58	13.55	0.65	8.64	46	36
BC3	170-203	0.78	2.91	0.27	0.15	1.21	10.49	5.31		0.48		39	
2Bt1	203-270	1.44	2.81	0.26	0.20	0.78	10.06	5.50		0.32		47	
2Bt2	270-325	2.11	3.06	0.17	0.19	0.82	10.82	6.36		0.31		51	
2Bt3	325-360	1.16	3.31	0.33	0.18	0.81	11.58	5.80		0.32		43	
3C	360-390+	1.34	1.89	0.19	0.09	0.40	6.00	3.91		0.18		58	

Particle Size Distribution for Mississippi Site One

		USDA Particle Size Class								
	Lower	VCOS	COS	MS	FS	VFS	SAND	SILT	CLAY	FINE CLAY
Horizon	Depth (cm)	%	%	%	%	%	%	%	%	% of clay
Ap	24	0.11	0.46	0.57	0.46	0.46	2.05	76.97	20.98	35.38
Bt	80	0.00	0.40	0.00	0.00	0.40	0.80	66.20	33.00	37.23
BC1	130	0.00	0.57	0.68	0.79	0.34	2.38	73.23	24.40	35.06
BC2	170	0.10	1.51	1.92	1.92	0.81	6.26	68.44	25.30	45.53
BC3	203	0.20	3.66	4.58	3.97	0.71	13.12	62.31	24.57	48.38
2Bt1	270	0.70	5.12	7.12	5.62	0.70	19.27	48.44	32.29	53.63
2Bt2	325	0.61	3.85	4.76	3.65	0.61	13.47	55.07	31.46	49.49
2Bt3	360	1.62	7.07	4.64	1.72	0.30	15.35	56.11	28.54	29.45
3C	390	13.30	24.89	11.69	4.64	1.11	55.63	28.54	15.83	35.15

C, N, S Data for Mississippi Site One

Sample #	Horizon	Lower Depth (cm)	Total Carbon %	Total Nitrogen %	Total Sulfur %	Organic Carbon %
01132	Ap	24	0.79	0.09	0.02	0.51
01133	Bt	80	0.42	0.06	0.01	0.16
01134	BC1	130	0.32	0.05	0.01	0.05
01135	BC2	170	0.31	0.05	0.01	0.05
01136	BC3	203	0.31	0.05	0.01	0.06
01137	2Bt1	270	0.36	0.05	0.01	0.07
01138	2Bt2	325	0.28	0.04	0.01	0.09
01139	2Bt3	360	0.42	0.04	0.02	0.16
01140	3C	390+	0.54	0.04	0.00	0.18

Free Iron Oxides (Fe3+c.d.), Total Iron, Hydroxylamine extractable Manganese, and total Manganese for Mississippi Site One.

	Lower	mg/kg			
Horizon	Depth (cm)	Fe 3+ c.d.	Total Iron	Ha Mn	Total Mn
Ap	24	8389.50	16059.85	851.17	957.83
Bt	80	17965.09	31586.29	114.88	469.94
BC1	130	13763.75	28244.41	135.68	489.40
BC2	170	11533.76	23391.61	155.60	488.26
BC3	203	10982.38	21367.25	232.70	490.00
2Bt1	270	16381.27	24908.09	437.16	611.47
2Bt2	325	16369.47	25789.65	145.97	264.05
2Bt3	360	17231.08	28991.52	61.67	269.58
3C	390+	13979.00	26394.51	182.45	425.03

Concentration of selected elements for Mississippi Site One

		mg/kg							
Sample #	Horizon	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
01132	Ap1	3913.78	21.45	16059.85	17971.40	2323.84	957.83	10821.75	31.68
01133	Bt	3916.02	30.17	31586.29	18573.58	5434.29	469.94	10801.83	61.09
01134	BC1	3394.31	26.69	28244.41	17684.99	5079.45	489.40	13446.49	42.40
01135	BC2	3648.85	15.98	23391.61	19811.44	4279.72	488.26	12225.52	33.22
01136	BC3	2632.72	17.99	21367.25	18121.54	3571.18	490.00	11523.16	31.49
01137	2Bt1	2955.01	20.96	24908.09	14910.06	3017.86	611.47	5611.06	46.91
01138	2Bt2	2907.84	18.74	25789.65	13793.47	3122.16	264.05	5901.57	40.72
01139	2Bt3	2982.04	16.96	28991.52	16119.20	3785.54	269.58	5346.88	31.67
01140	3C	3053.90	12.74	26394.51	15842.68	3661.19	425.03	5158.20	17.24

pH data for Mississippi Site One

			pH	
Sample #	Horizon	Depth (cm)	1:1 pH (water)	2:1 pH (0.01M CaCl2)
01132	Ap	0-24	6.0	5.4
01133	Bt	24-80	6.4	5.8
01134	BC1	80-130	5.1	4.4
01135	BC2	130-170	5.0	4.3
01136	BC3	170-203	5.1	4.3
01137	2Bt1	203-270	5.2	4.4
01138	2Bt2	270-325	5.2	4.4
01139	2Bt3	325-360	5.1	4.5
01140	3C	360-390+	4.9	4.4

Appendix F: Field and Laboratory Data for Mississippi Site Two

Field Description for Mississippi Site Two

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 6%
Aspect: 254°
Location: 34°49'09.60" N
89°26'21.40" W

Horizon	Depth (cm)	Color	Texture	Boundary	Structure	Consistency
Ap	0-12	7.5YR 4/3	SiL	A	Mo Gr	Fri
2Bx1	12-68	7.5YR 4/6	SiL	A	Mo Pr	Fi
2Bx2	68-120	5YR 5/6	SiL	C	Mo Pr	Fi
2Bt,x	120-155	2.5YR 3/6	CL	C	Mo Pr	Fi
3BC	155-186	2.5YR 3/6	L	C	Mo Sbk	Fri
3C	186-230+	5YR 5/6	SL	-	SLS Ma	Vfr

Notes: Manganese concentrations were observed in the 2nd, 3rd, and 5th horizons. Iron concentrations observed in the 2nd, 3rd, and 5th horizons. Depletions were observed in the 4th horizon. Stripping was observed in the 2nd and 3rd horizons. Clay films were observed in the 4th horizon.

Classification: fine-loamy, mixed, active, thermic Typic Fragiudalf

Profile Description for Mississippi Site Two

Landscape Position: Upland
Parent Material Sequence: Loess/Alluvium/Tertiary Sand
Slope: 6%
Natural Drainage Class: Well Drained
Location: 34°49'09.60" N
89°26'21.40" W
Classification: fine-loamy, mixed, active, thermic Typic Fragiudalf

Ap	0 to 12 cm; brown (7.5YR 4/3); silt loam; moderate granular and moderate subangular blocky structure; abrupt boundary; friable; moderately acid.
$2Bx_1$	12 to 68 cm; strong brown (7.5YR 4/6); silt loam; moderate prismatic structure; abrupt boundary; firm; strongly acid; few manganese concentrations; few iron concentrations; stripped areas common (10YR 6/1); blind pores common.
$2Bx_2$	68 to 120 cm; yellowish red (5YR 5/6); silt loam; moderate prismatic and moderate subangular blocky structure; clear boundary; firm; strongly acid; manganese concentrations common; iron concentrations common; stripped areas common (10YR 6/1); blind pores common.
2Bt,x	120 to 155 cm; dark red (2.5YR 3/6); clay loam; moderate prismatic structure; clear boundary; firm; strongly acid; depletions common (5YR 5/2); clay films common.
3BC	155 to 186 cm; dark red (2.5YR 3/6); loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; few manganese concentrations; few iron concentrations.
3C	186 to 230 cm; yellowish red (5YR 5/6); sandy loam; structureless massive structure; very friable; strongly acid.

Base Saturation Data for Mississippi Site Two

Ammonium acetate extractable bases, cation exchange capacity (pH 7.0 and pH 8.2), effective cation exchange capacity, KCl extractable aluminum and acidity, $BaCl_2$ acidity, and percent base saturation (direct measurement and by summation) for Mississippi Site Two.

		cmol(+)/kg										% Base Saturation	
Horizon	**Depth**	**Ca**	**Mg**	**Na**	**K**	**Al(KCl)**	**CEC pH7**	**ECEC**	**CEC pH8.2**	**KCl Acidity**	**BaCl2 Acidity**	**pH7**	**Sum of Cations**
Ap	0-12	7.45	2.47	0.27	0.33	0.16	14.55	10.68		0.03		72	
2Bx1	12-68	1.70	4.08	0.37	0.06	0.57	9.85	6.78		0.23		63	
2Bx2	68-120	1.31	2.98	0.69	0.06	0.29	6.60	5.32	7.95	0.12	2.92	76	63
2Bt,x	120-155	2.73	4.38	1.57	0.08	0.54	12.77	9.30		0.22		69	
3BC	155-186	2.11	3.41	1.42	0.07	0.36	9.67	7.38		0.16		73	
3C	186-230+	1.47	2.46	0.97	0.07	0.23	6.18	5.22		0.09		81	

Particle Size Distribution for Mississippi Site Two

Horizon	Lower Depth (cm)	VCOS %	COS %	MS %	FS %	VFS %	SAND %	SILT %	CLAY %	FINE CLAY % of clay
		USDA Particle Size Class								
Ap	12	0.32	2.35	1.82	2.56	0.85	7.91	67.78	24.31	43.84
2Bx1	68	1.39	6.35	9.42	11.01	1.09	29.25	54.82	15.93	47.64
2Bx2	120	0.99	7.40	9.27	10.06	0.89	28.61	51.27	20.12	51.65
2Bt,x	155	0.30	3.85	9.11	10.63	0.61	24.50	44.02	31.47	45.95
3BC	186	0.40	8.02	15.85	20.97	1.10	46.34	31.32	22.33	44.07
3C	230+	1.10	11.56	21.93	19.14	1.50	55.22	27.82	16.96	42.72

C, N, S Data for Mississippi Site Two

Sample #	Horizon	Lower Depth (cm)	Total Carbon %	Total Nitrogen %	Total Sulfur %	Organic Carbon %
01141	Ap	12	1.63	0.14	0.04	1.03
01142	2Bx1	68	0.26	0.04	0.01	0.03
01143	2Bx2	120	0.33	0.04	0.01	0.09
01144	2Bt,x	155	0.34	0.04	0.02	0.11
01145	3BC	186	0.26	0.04	0.00	0.09
01146	3C	230+	0.36	0.03	0.00	0.18

Free Iron Oxides (Fe3+c.d.), Total Iron, Hydroxylamine extractable Manganese, and total Manganese for Mississippi Site Two.

Horizon	Lower Depth (cm)	Fe 3+ c.d.	Total Iron	Ha Mn	Total Mn
		----------mg/kg----------			
Ap	12	12031.66	23314.16	117.71	261.12
2Bx1	68	7551.25	16930.09	8.15	150.10
2Bx2	120	7109.32	15293.25	0.62	90.50
2Bt,x	155	18112.43	29168.74	0.00	129.08
3BC	186	14119.01	25113.84	0.00	107.70
3C	230+	10232.56	17954.11	3.96	116.87

Concentration of selected elements for Mississippi Site Two

		mg/kg							
Sample #	Horizon	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
01141	Ap	4077.95	18.49	23314.16	16763.58	3571.22	261.12	10541.91	45.48
01142	2Bx1	3498.99	13.24	16930.09	14601.10	3125.86	150.10	9477.37	33.72
01143	2Bx2	2835.00	14.25	15293.25	12587.50	2307.00	90.50	6573.00	22.75
01144	2Bt,x	2900.57	22.43	29168.74	12433.04	3524.04	129.08	6143.44	37.88
01145	3BC	2751.12	16.24	25113.84	12343.78	2917.58	107.70	7992.29	30.98
01146	3C	2982.81	11.96	17954.11	11523.56	2505.83	116.87	7905.53	27.66

pH data for Mississippi Site Two

			------------pH------------	
Sample #	Horizon	Depth (cm)	1:1 pH (water)	2:1 pH (0.01M CaCl2)
01141	Ap	0-12	5.8	5.0
01142	2Bx1	12-68	5.5	4.5
01143	2Bx2	68-120	5.2	4.4
01144	2Bt,x	120-155	5.2	4.4
01145	3BC	155-186	5.2	4.5
01146	3C	186-230+	5.2	4.4

Appendix G: Field and Laboratory Data for Mississippi Site Three

Field Description for Mississippi Site Three

Landscape Position: Upland
Parent Material Sequence: Loess/Tertiary Sand
Slope: 1%
Aspect: 270°
Location: 34°49'11.50" N
89°26'22.10" W

Horizon	Depth (cm)	Color	Texture	Boundary	Structure	Consistency
Ap	0-15	10YR 4/4	SiL	C	Mo Sbk	Fri
Bt	15-58	7.5YR 4/6	SiCL	C	Mo Sbk	Fri
BC1	58-108	7.5YR 4/4	SiL	C	Mo Sbk	Fri
BC2	108-162	5YR 4/3	SiL	C	Mo Sbk	Fri
2Bt1	162-203	2.5YR 3/4	SiL	C	Mo Sbk	Fri
2Bt2	203-250	2.5YR 3/6	SiCL	C	Mo Sbk	Fri
3Bt3	250-283	2.5YR 4/6	CL	C	Mo Sbk	Fri
3C	283-397+	7.5YR 5/6	SL	-	SLS Ma	Vfr

Notes: Manganese concentrations were observed in the 1st, 2nd, 3rd, 4th, 5th, and 6th horizons. Stripping was observed in the 3rd, 4th, 5th, and 6th horizons. Clay films were observed in the 5th and 6th horizons.

Classification: fine-silty, mixed, active, thermic Ultic Hapludalf

Profile Description for Mississippi Site Three

Landscape Position: Upland
Parent Material Sequence: Loess/Tertiary Sand
Slope: 1%
Natural Drainage Class: Well Drained
Location: 34°49'11.50" N
89°26'22.10" W
Classification: fine-silty, mixed, active, thermic Ultic Hapludalf

Ap 0 to 15 cm; dark yellowish brown (10YR 4/4); silt loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; few manganese concentrations.

Bt 15 to 58 cm; strong brown (7.5YR 4/6); silty clay loam; moderate subangular blocky structure; clear boundary; friable; slightly acid; few manganese concentrations.

BC_1 58 to 108 cm; brown (7.5YR 4/4); silt loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; few manganese concentrations; few stripped areas (10YR 7/3).

BC_2 108 to 162 cm; reddish brown (5YR 4/3); silt loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; manganese concentrations common; stripped areas common (10YR 7/3).

$2Bt_1$ 162 to 203 cm; dark redish brown (2.5YR 3/4); silt loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; manganese concentrations common; clay films common; stripped areas common (10YR 7/3);

$2Bt_2$ 203 to 250 cm; dark red (2.5YR 3/6); silty clay loam; moderate subangular blocky structure; clear boundary; friable; very strongly acid; manganese concentrations common; clay films common; stripped areas common (10YR 7/3).

$3Bt_3$ 250 to 283 cm; red (2.5YR 4/6); clay loam; moderate subangular blocky structure; clear boundary; friable; strongly acid.

3C 283 to 397+ cm; strong brown (7.5YR 5/6); sandy loam; structureless massive; very friable; very strongly acid.

Base Saturation Data for Mississippi Site Three

Ammonium acetate extractable bases, cation exchange capacity (pH 7.0 and pH 8.2), effective cation exchange capacity, KCl extractable aluminum and acidity, $BaCl_2$ acidity, and percent base saturation (direct measurement and by summation) for Mississippi Site Three.

		cmol(+)/kg										% Base Saturation	
Horizon	Depth	Ca	Mg	Na	K	Al(KCl)	CEC pH7	ECEC	CEC pH8.2	KCl Acidity	BaCl2 Acidity	pH7	Sum of Cations
Ap	0-15	5.39	1.21	0.11	0.35	0.21	11.20	7.26		0.08		63	
Bt	15-58	6.47	4.28	0.13	0.19	0.07	13.50	11.13		0.01		82	
BC1	58-108	1.95	3.86	0.25	0.16	1.03	10.97	7.25		0.41		57	
BC2	108-162	1.18	3.31	0.15	0.21	1.26	10.81	6.11	12.22	0.50	7.37	45	40
2Bt1	162-203	0.96	2.99	0.16	0.28	1.01	8.83	5.41		0.38		50	
2Bt2	203-250	1.26	3.04	0.23	0.33	0.56	8.55	5.44		0.24		57	
3Bt3	250-283	1.20	2.94	0.13	0.27	0.64	9.41	5.18		0.25		48	
3C	283-397+	0.80	1.62	0.11	0.12	0.56	4.74	3.21		0.20		56	

Particle Size Distribution for Mississippi Site Three

		USDA Particle Size Class								
	Lower	VCOS	COS	MS	FS	VFS	SAND	SILT	CLAY	FINE CLAY
Horizon	Depth (cm)	%	%	%	%	%	%	%	%	% of clay
Ap	15	0.00	0.77	0.77	0.77	0.48	2.78	73.48	23.75	40.73
Bt	58	0.00	0.25	0.25	0.34	0.34	1.19	70.75	28.06	38.73
BC1	108	0.00	0.47	0.47	0.47	0.57	1.99	75.09	22.92	44.19
BC2	162	0.19	1.21	1.21	1.21	0.84	4.65	71.89	23.46	43.00
2Bt1	203	1.18	4.51	2.36	2.36	0.88	11.29	61.82	26.89	51.25
2Bt2	250	1.74	5.22	2.80	2.03	0.68	12.48	54.03	33.49	54.95
3Bt3	283	4.00	9.10	4.60	3.70	1.60	22.99	46.84	30.17	47.17
3C	397+	8.53	31.63	15.96	11.50	0.99	68.61	16.85	14.53	37.60

C, N, S Data for Mississippi Site Three

Sample #	Horizon	Lower Depth (cm)	Total Carbon %	Total Nitrogen %	Total Sulfur %	Organic Carbon %
01147	Ap	15	1.11	0.12	0.05	0.65
01148	Bt	58	0.37	0.05	0.02	0.12
01149	BC1	108	0.31	0.05	0.02	0.08
01150	BC2	162	0.24	0.05	0.01	0.07
01151	2Bt1	203	0.26	0.05	0.00	0.07
01152	2Bt2	250	0.53	0.06	0.02	0.20
01153	3Bt3	283	0.41	0.05	0.02	0.13
01154	3C	397+	0.51	0.04	0.01	0.18

Free Iron Oxides (Fe3+c.d.), Total Iron, Hydroxylamine extractable Manganese, and total Manganese for Mississippi Site Three.

	Lower	----------mg/kg----------			
Horizon	Depth (cm)	Fe 3+ c.d.	Total Iron	Ha Mn	Total Mn
Ap	15	11325.68	21566.82	447.70	627.16
Bt	58	16342.04	29975.68	134.30	481.47
BC1	108	13971.58	27336.75	111.43	430.25
BC2	162	11527.55	22453.18	130.18	405.60
2Bt1	203	12639.50	23248.72	347.02	522.68
2Bt2	250	14652.45	22082.46	494.24	572.48
3Bt3	283	13859.12	26870.34	143.25	324.75
3C	397+	11707.50	25037.17	84.53	258.83

Concentration of selected elements for Mississippi Site Three

		mg/kg							
Sample #	Horizon	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
01147	Ap	3685.05	14.47	21566.82	18260.06	3110.12	627.16	13003.42	46.67
01148	Bt	3619.46	19.93	29975.68	18678.38	5058.63	481.47	12877.35	59.03
01149	BC1	3817.50	17.50	27336.75	19085.50	4599.00	430.25	14217.00	46.75
01150	BC2	3482.60	16.23	22453.18	20803.63	3782.29	405.60	12655.76	37.96
01151	2Bt1	3233.54	15.98	23248.72	17462.30	3152.68	522.68	10886.05	29.71
01152	2Bt2	2991.82	15.96	22082.46	15895.96	2813.70	572.48	7850.95	42.66
01153	3Bt3	3092.16	14.99	26870.34	15862.60	2936.25	324.75	6998.34	40.47
01154	3C	2564.59	11.47	25037.17	14320.32	3272.17	258.83	9851.45	127.65

pH data for Mississippi Site Three

			-----------pH---------------	
			1:1 pH	2:1 pH
Sample #	Horizon	Depth (cm)	(water)	(0.01M CaCl2)
01147	Ap	0-15	5.5	4.8
01148	Bt	15-58	6.4	5.8
01149	BC1	58-108	5.3	4.6
01150	BC2	108-162	5.2	4.4
01151	2Bt1	162-203	5.2	4.4
01152	2Bt2	203-250	5.0	4.5
01153	3Bt3	250-283	5.1	4.4
01154	3C	283-397+	4.8	4.3

Appendix H: Field and Laboratory Data for Mississippi Site Four

Field Description for Mississippi Site Four

Landscape Position: Upland
Parent Material Sequence: Alluvium/Tertiary Sand/Kaolin
Slope: 6%
Aspect: 220°
Location: 34°49'09.00" N
89°26'21.90" W

Horizon	Depth (cm)	Color	Texture	Boundary	Structure	Consistency
Ap	0-11	10YR 4/4	SiL	A	Mo Gr	Fri
BA	11-19	7.5YR 4/6	SiL	A	Mo Sbk	Fri
Bt	19-59	5YR 4/4	CL	C	Mo Sbk	Fri
2CB	59-72	7.5YR 5/6	SL	C	Wk Sbk	Vfr
2C1	72-100	2.5YR 4/8	SL	A	SLS Ma	Vfr
3C2	100-114	-	-	-	-	-
3C3	114-136+	-	-	-	-	-

Notes: Iron concentrations were observed in the 2nd horizon; clay films were observed in the 2nd and 3rd horizons.

Classification: fine-loamy, mixed, active, thermic Typic Hapludult

Profile Description for Mississippi Site Four

Landscape Position: Upland
Parent Material Sequence: Alluvium/Tertiary Sand/Kaolin
Slope: 6%
Natural Drainage Class: Well Drained
Location: 34°49'09.00" N
89°26'21.90" W
Classification: fine-loamy, mixed, active, thermic Typic Hapludult

Ap 0 to 11 cm; dark yellowish brown (10YR 4/4); silt loam; moderate granular; abrupt boundary; friable; very strongly acid.

BA 11 to 19 cm; strong brown (7.5YR 4/6); silt loam; moderate subangular blocky structure; abrupt boundary; friable; moderately acid; iron concentrations common.

Bt 19 to 59 cm; reddish brown (5YR 4/4); clay loam; moderate subangular blocky structure; clear boundary; friable; strongly acid; clay films common.

2CB 59 to 72 cm; strong brown (7.5YR 5/6); sandy loam; weak subangular blocky structure; clear boundary; very friable; very strongly acid.

2C1 72 to 100 cm; red (2.5YR 4/8); sandy loam; structureless massive structure; abrupt boundary; very friable; extremely acid.

3C2 100 to 114 cm.

3C3 114 to 136+ cm.

Base Saturation Data for Mississippi Site Four

Ammonium acetate extractable bases, cation exchange capacity (pH 7.0 and pH 8.2), effective cation exchange capacity, KCl extractable aluminum and acidity, $BaCl_2$ acidity, and percent base saturation (direct measurement and by summation) for Mississippi Site Four.

		cmol(+)/kg										% Base Saturation	
Horizon	**Depth**	**Ca**	**Mg**	**Na**	**K**	**Al(KCl)**	**CEC pH7**	**ECEC**	**CEC pH8.2**	**KCl Acidity**	**BaCl2 Acidity**	**pH7**	**Sum of Cations**
Ap	0-11	4.83	1.25	0.20	0.32	0.31	10.70	6.92		0.15		62	
BA	11-19	5.33	1.50	0.10	0.15	0.21	11.67	7.29		0.05		61	
Bt	19-59	0.64	1.96	0.12	0.10	2.77	9.85	5.59		0.98		29	
2CB	59-72	0.01	1.30	0.10	0.07	2.16	6.45	3.64		0.82		23	
2C1	72-100	0.07	0.80	0.09	0.05	1.82	4.33	2.84	6.35	0.66	5.33	24	16
3C2	100-114	0.09	1.28	0.14	0.06	1.96	5.69	3.53		0.77		28	
3C3	114-136+	0.00	1.75	0.23	0.04	2.16	5.74	4.18		0.89		35	

Particle Size Distribution for Mississippi Site Four

Horizon	Lower Depth (cm)	VCOS %	COS %	MS %	FS %	VFS %	SAND %	SILT %	CLAY %	FINE CLAY % of clay
		USDA Particle Size Class								
Ap	11	0.71	4.56	6.69	11.55	1.42	24.92	51.85	23.22	44.48
BA	19	1.37	5.15	7.57	9.78	1.47	25.35	51.70	22.95	51.13
Bt	59	2.12	10.39	9.68	14.42	1.51	38.12	32.38	29.50	45.20
2CB	72	2.60	15.98	18.87	21.87	1.70	61.02	20.52	18.46	46.87
2C	100	2.53	19.70	23.84	30.51	2.53	79.10	6.18	14.72	60.87
3Cr1	114	-	-	-	-	-	-	-	-	-
3Cr2	136	-	-	-	-	-	-	-	-	-

C, N, S Data for Mississippi Site Four

Sample #	Horizon	Lower Depth (cm)	Total Carbon %	Total Nitrogen %	Total Sulfur %	Organic Carbon %
01155	Ap	11	2.25	0.17	0.05	1.49
01156	BA	19	1.01	0.10	0.03	0.54
01157	Bt	59	0.32	0.04	0.02	0.09
01158	2CB	72	0.39	0.04	0.02	0.14
01159	2C1	100	0.40	0.03	0.02	0.16
01160	3C2	114	0.23	0.03	0.01	0.02
01161	3C3	136+	0.19	0.02	0.01	0.03

Free Iron Oxides (Fe3+c.d.), Total Iron, Hydroxylamine extractable Manganese, and total Manganese for Mississippi Site Three.

	Lower	---------------------	mg/kg	---------------------	
Horizon	Depth (cm)	Fe 3+ c.d.	Total Iron	Ha Mn	Total Mn
Ap	11	11482.00	19491.63	49.68	150.66
BA	19	13748.20	22307.84	23.77	136.70
Bt	59	19296.36	29802.03	0.00	110.33
2CB	72	14361.41	23805.79	0.36	122.38
2C	100	12221.54	19510.05	0.30	96.70
3Cr1	114	8943.54	13909.80	0.00	53.87
3Cr2	136	3995.35	8781.43	0.00	40.92

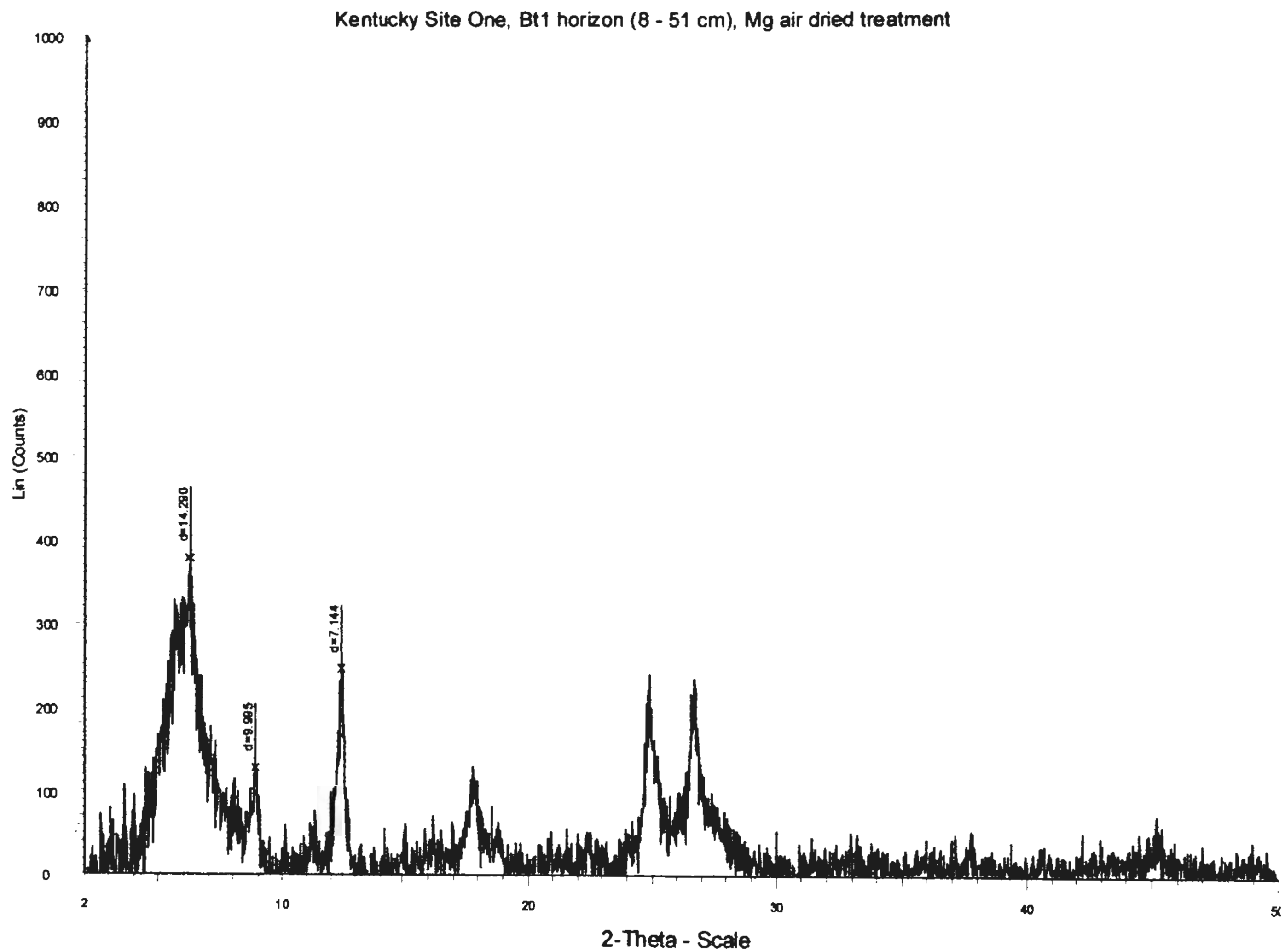
Concentration of selected elements for Mississippi Site Four

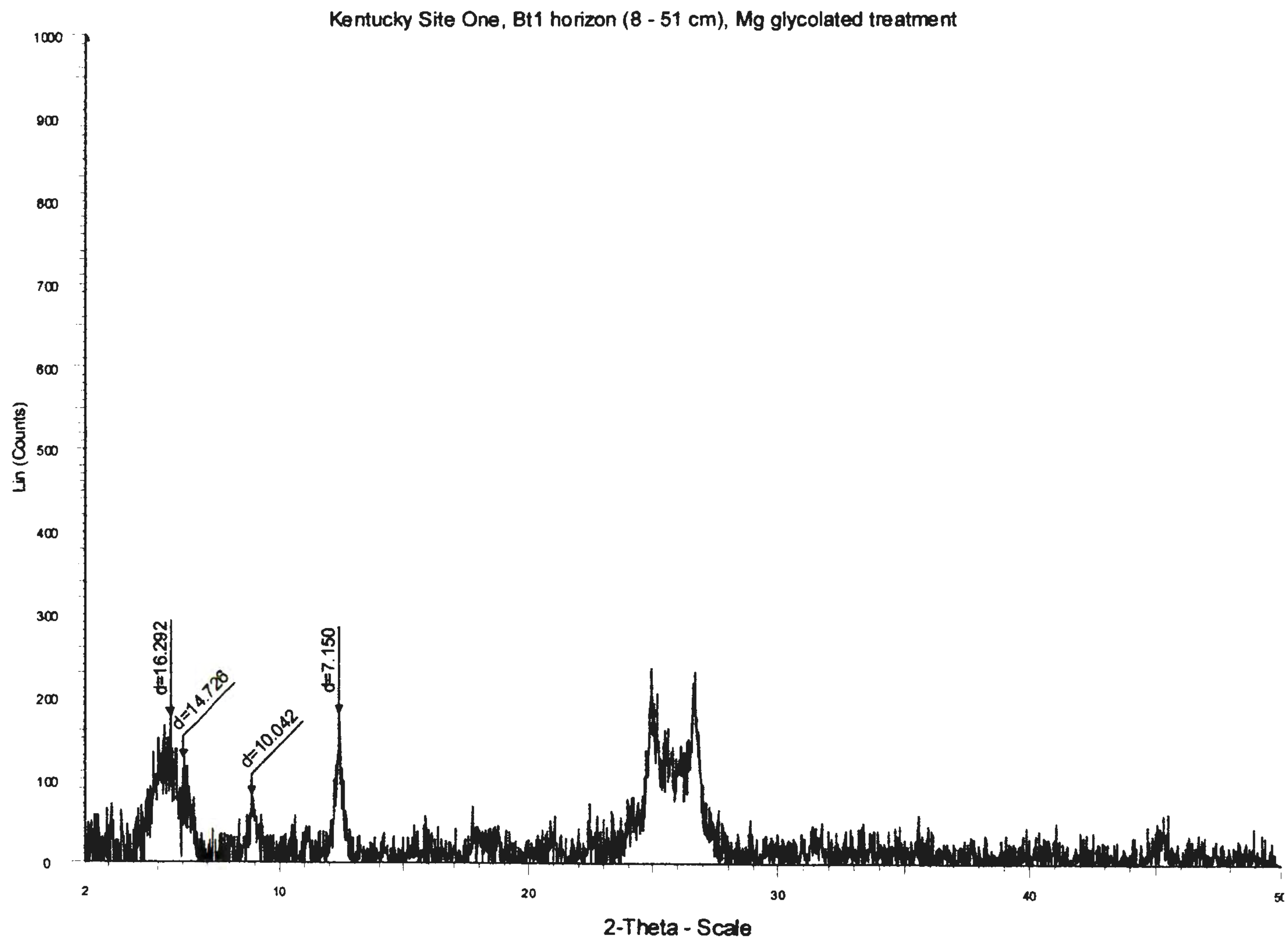
		mg/kg							
Sample #	Horizon	Ca	Cu	Fe	K	Mg	Mn	Na	Zn
01155	Ap	3178.79	8.73	19491.63	14440.81	2521.88	150.66	11650.34	118.24
01156	BA	3333.16	7.22	22307.84	15517.93	2781.86	136.70	9480.70	125.49
01157	Bt	2267.73	20.47	29802.03	12853.12	2898.17	110.33	7000.11	78.20
01158	2CB	2437.70	13.96	23805.79	12374.66	2531.91	122.38	6239.16	25.92
01159	2C1	2448.23	11.50	19510.05	9993.91	1917.58	96.70	5661.82	30.24
01160	3C2	2374.66	5.24	13909.80	8969.84	1539.56	53.87	7397.76	15.21
01161	3C3	2404.22	2.99	8781.43	9476.17	1661.68	40.92	7299.00	12.72

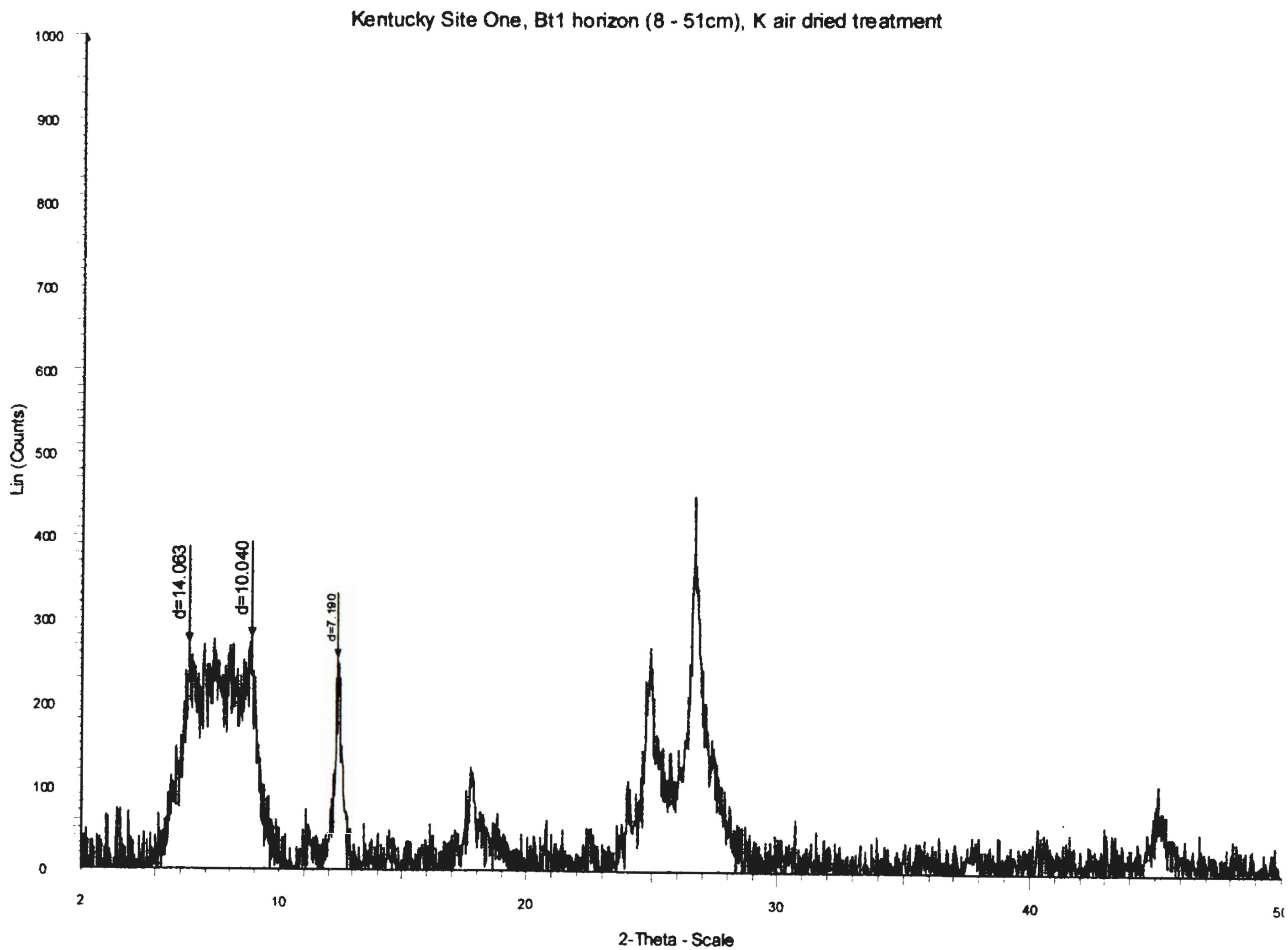
pH data for Mississippi Site Four

			------------pH------------	
Sample #	Horizon	Depth (cm)	1:1 pH (water)	2:1 pH (0.01M CaCl2)
01155	Ap	0-11	5.0	4.6
01156	BA	11-19	5.8	4.0
01157	Bt	19-59	5.1	3.9
01158	2CB	59-72	4.6	4.0
01159	2C1	72-100	4.3	3.9
01160	3C2	100-114	4.6	3.9
01161	3C3	114-136+	4.4	3.6

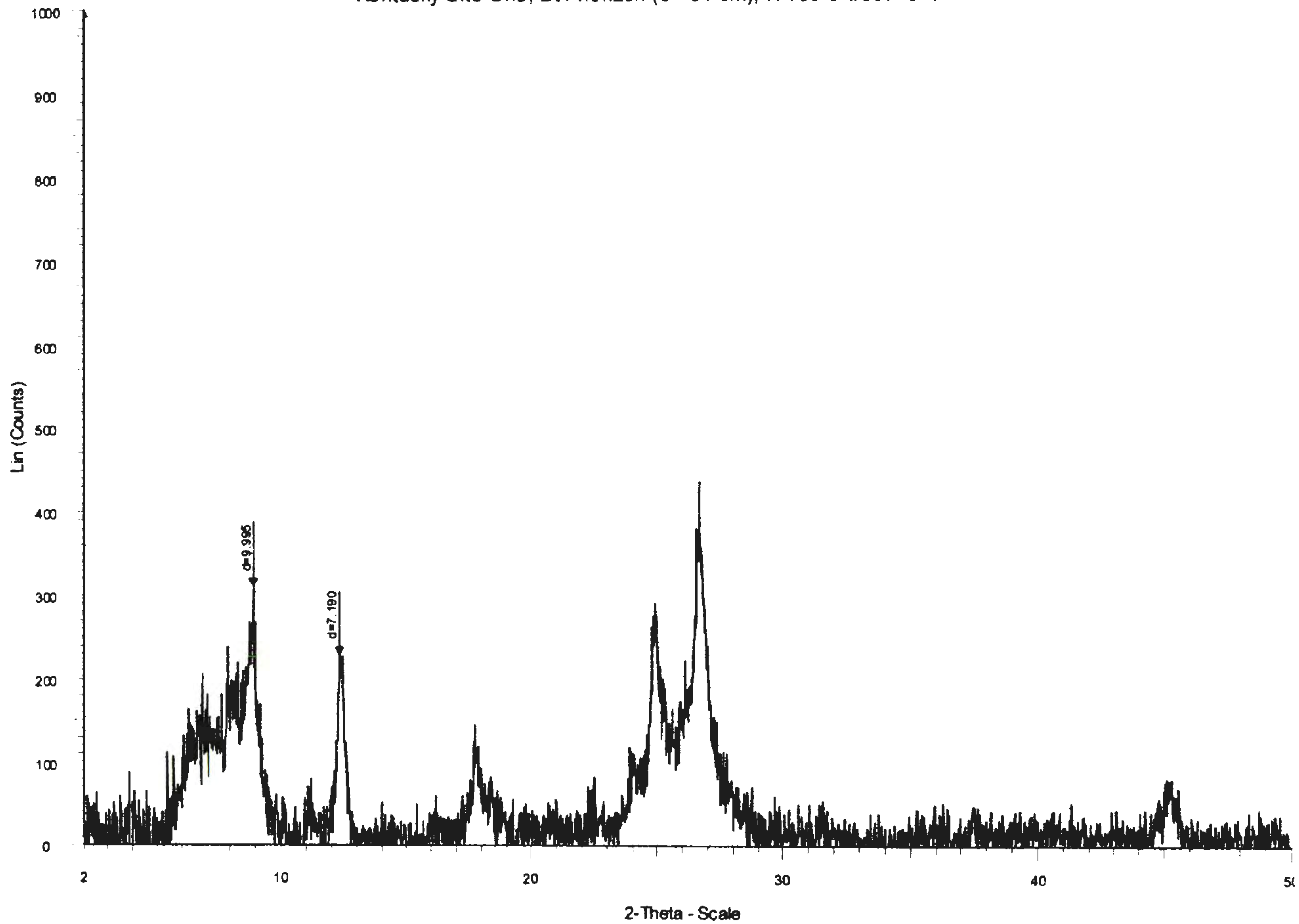
Appendix I: X-ray Diffractograms of Control Sections

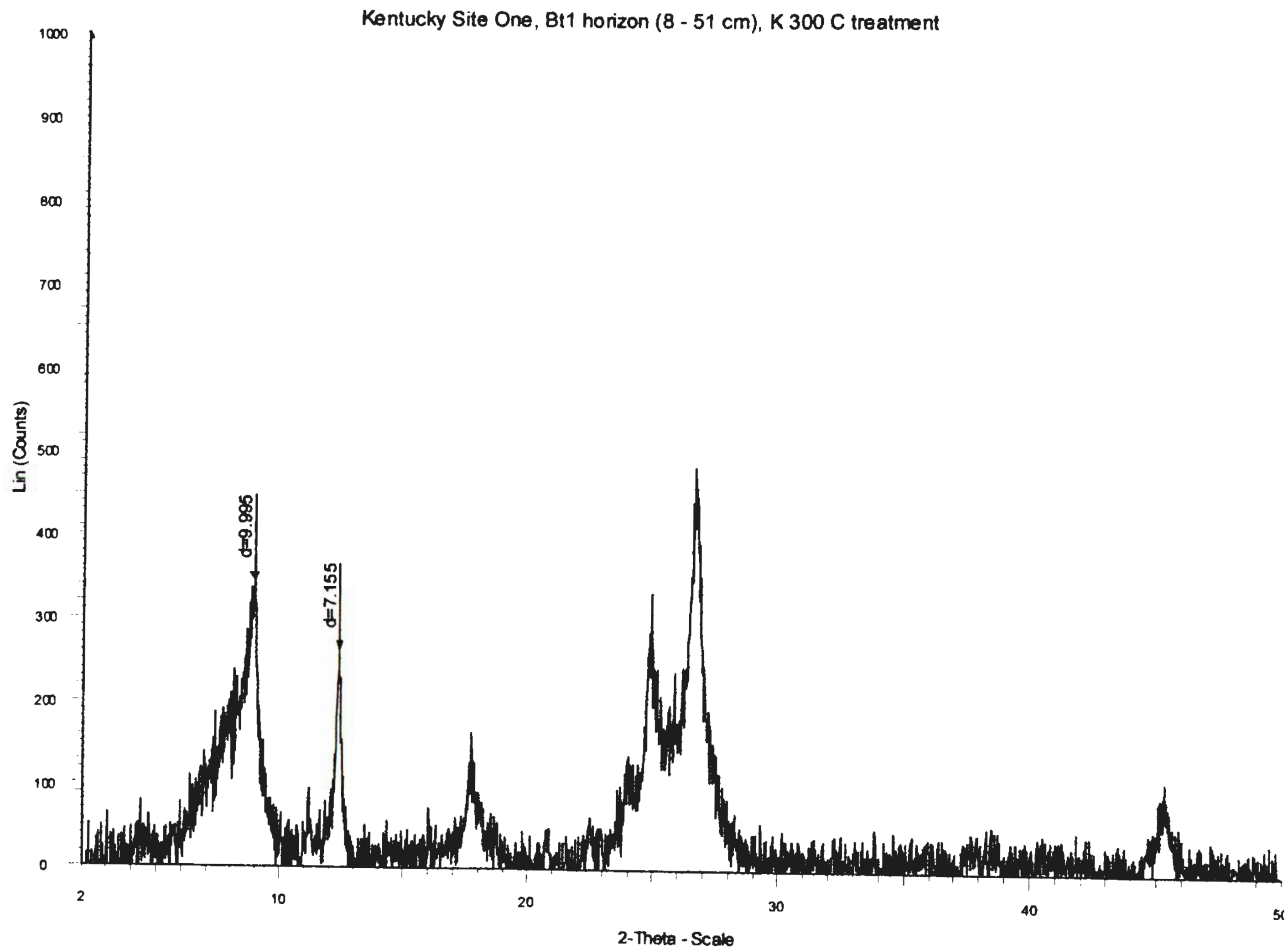

Kentucky Site One, Bt1 horizon (8 - 51 cm), Mg air dried treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=14.290
d=9.995
d=7.144
2
10
20
30
40
2-Theta - Scale


Kentucky Site One, Bt1 horizon (8 - 51 cm), Mg glycolated treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
2
10
20
30
40
50
2-Theta - Scale
d=16.292
d=14.728
d=10.042
d=7.150

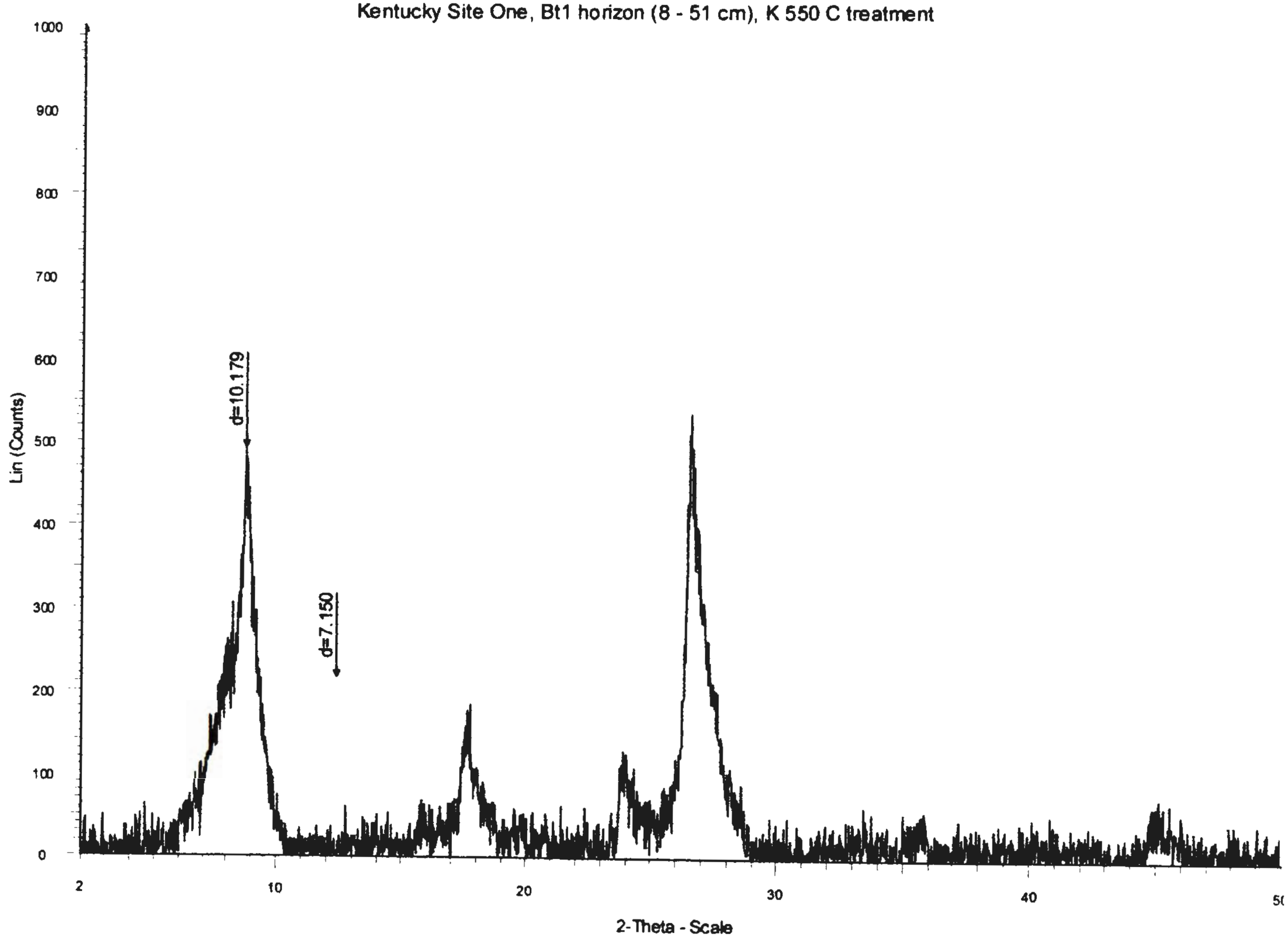

Kentucky Site One, Bt1 horizon (8 - 51cm), K air dried treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=14.063
d=10.040
d=7.190
2
10
20
30
40
50
2-Theta - Scale

Kentucky Site One, Bt1 horizon (8 - 51 cm), K 105 C treatment

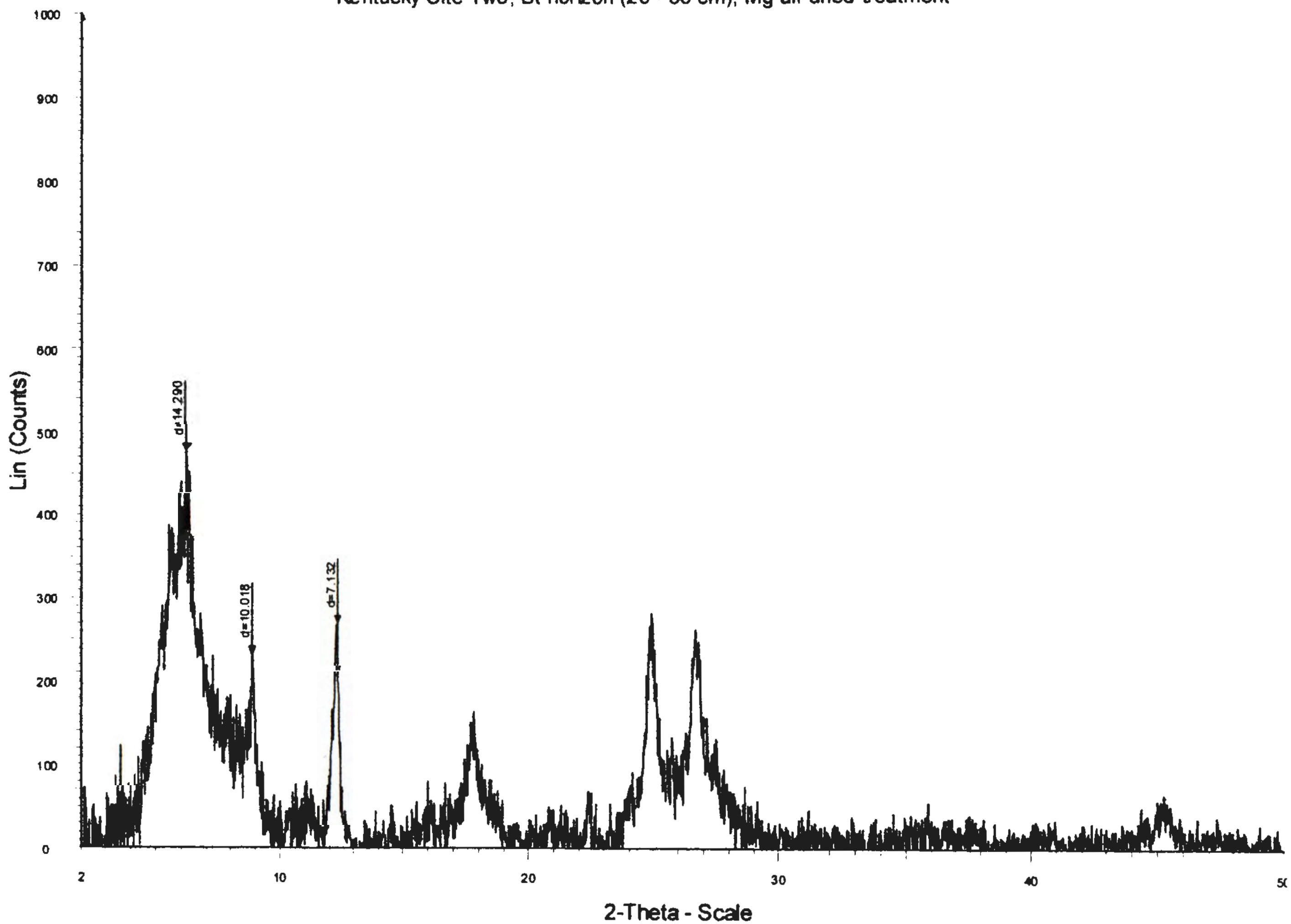



Kentucky Site One, Bt1 horizon (8 - 51 cm), K 300 C treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=9.995
d=7.155
2
10
20
30
40
2-Theta - Scale

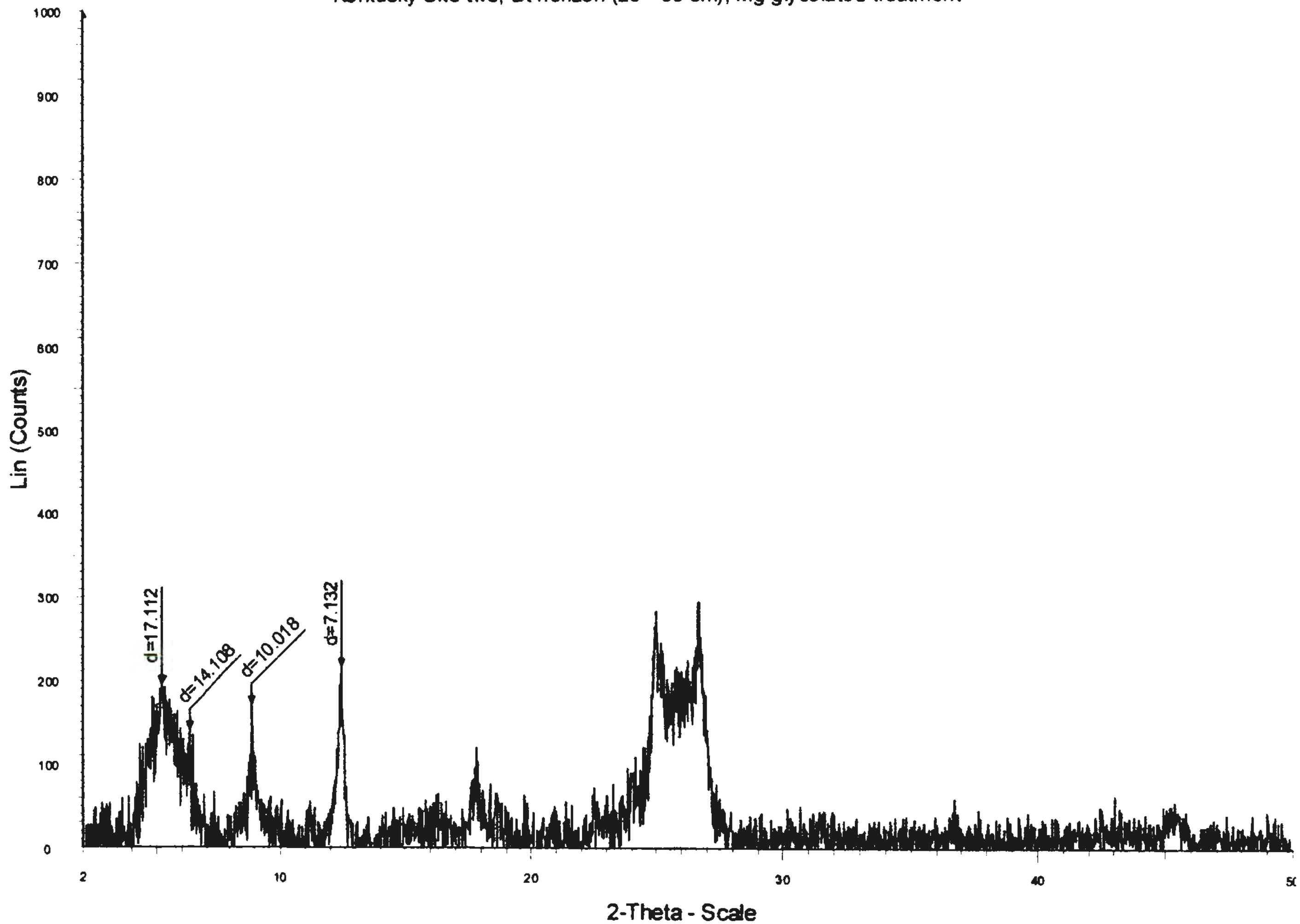
Kentucky Site One, Bt1 horizon (8 - 51 cm), K 550 C treatment



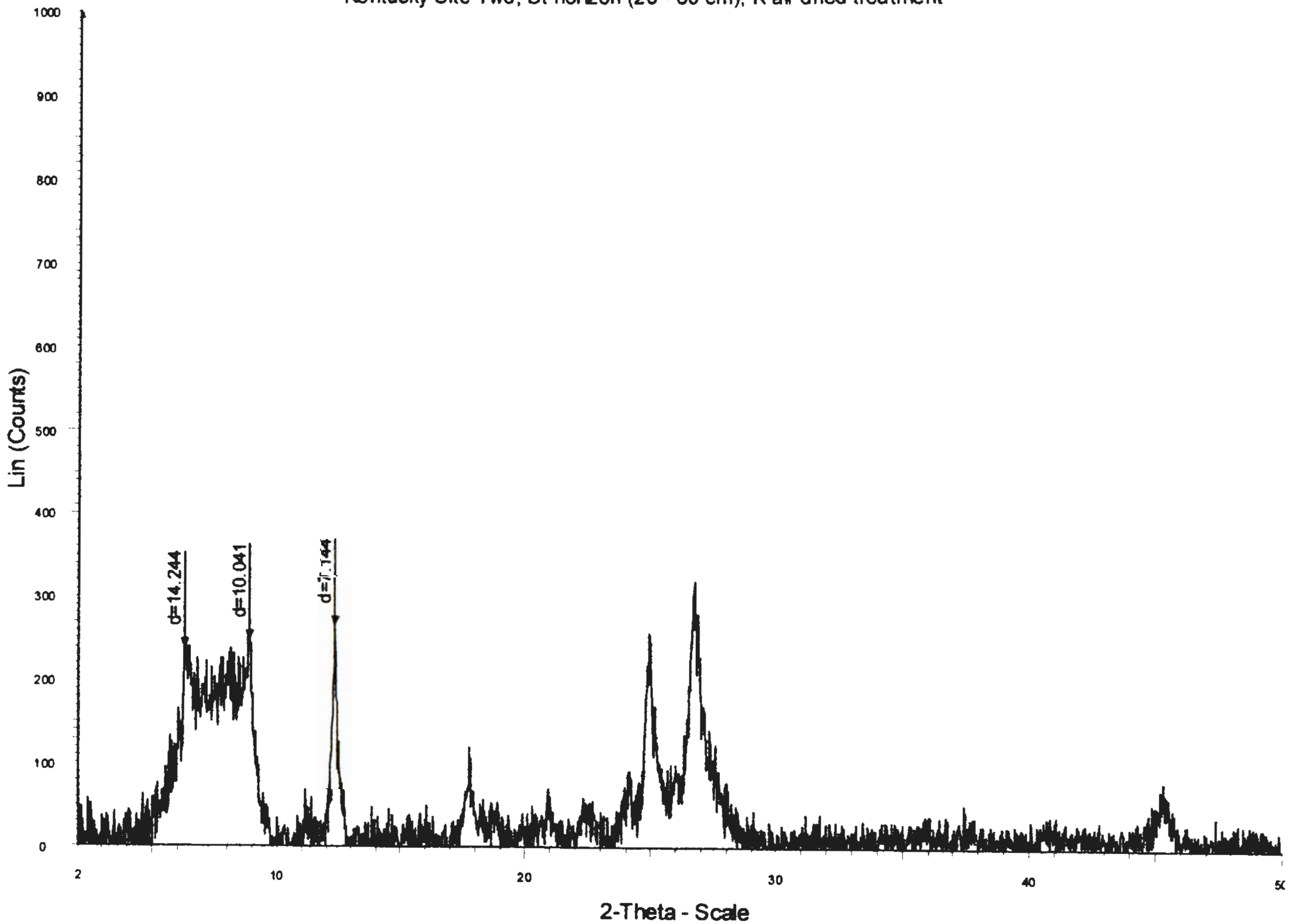
Kentucky Site Two, Bt horizon (20 - 80 cm), Mg air dried treatment

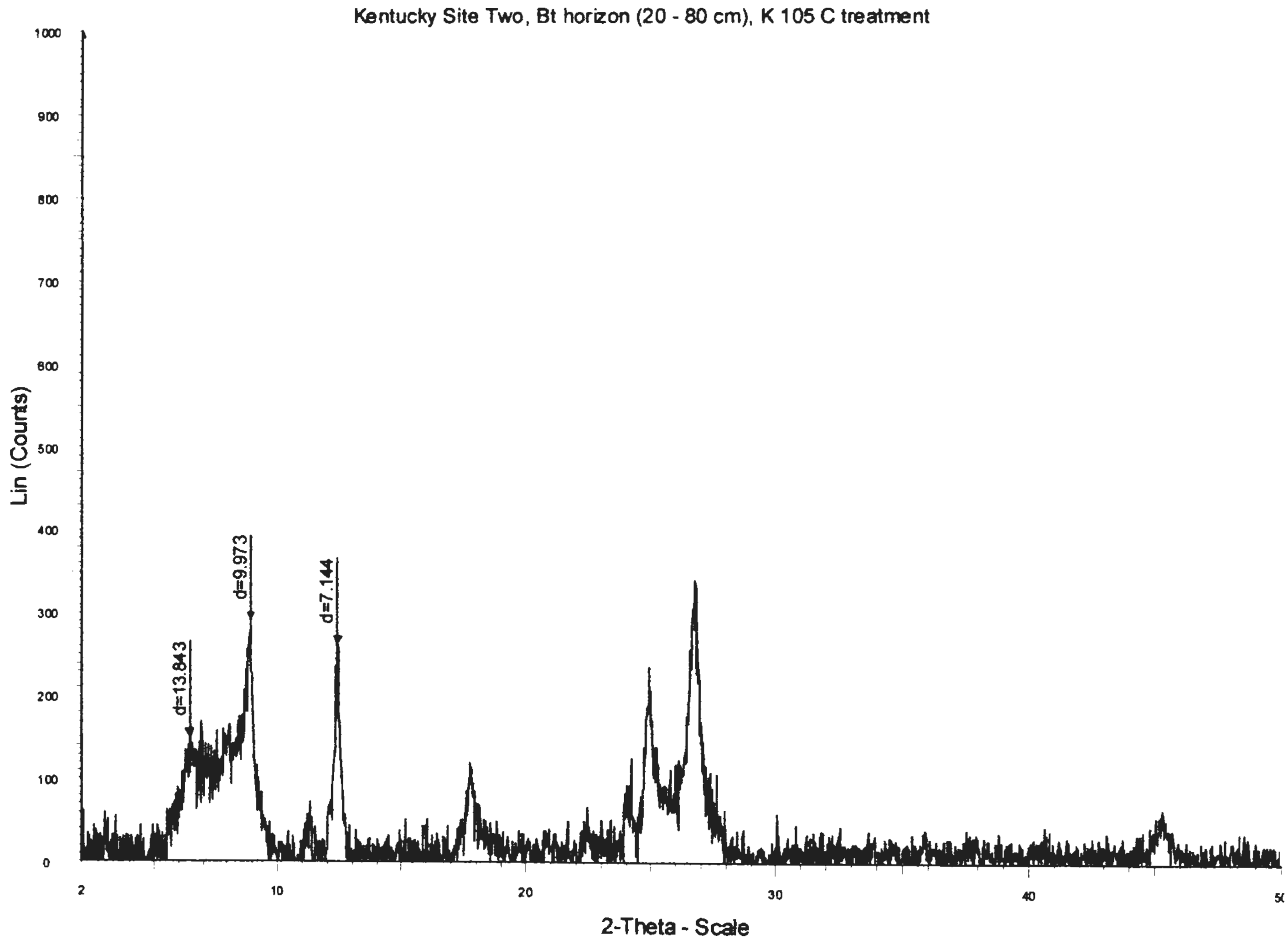


Kentucky Site two, Bt horizon (20 - 80 cm), Mg glycolated treatment

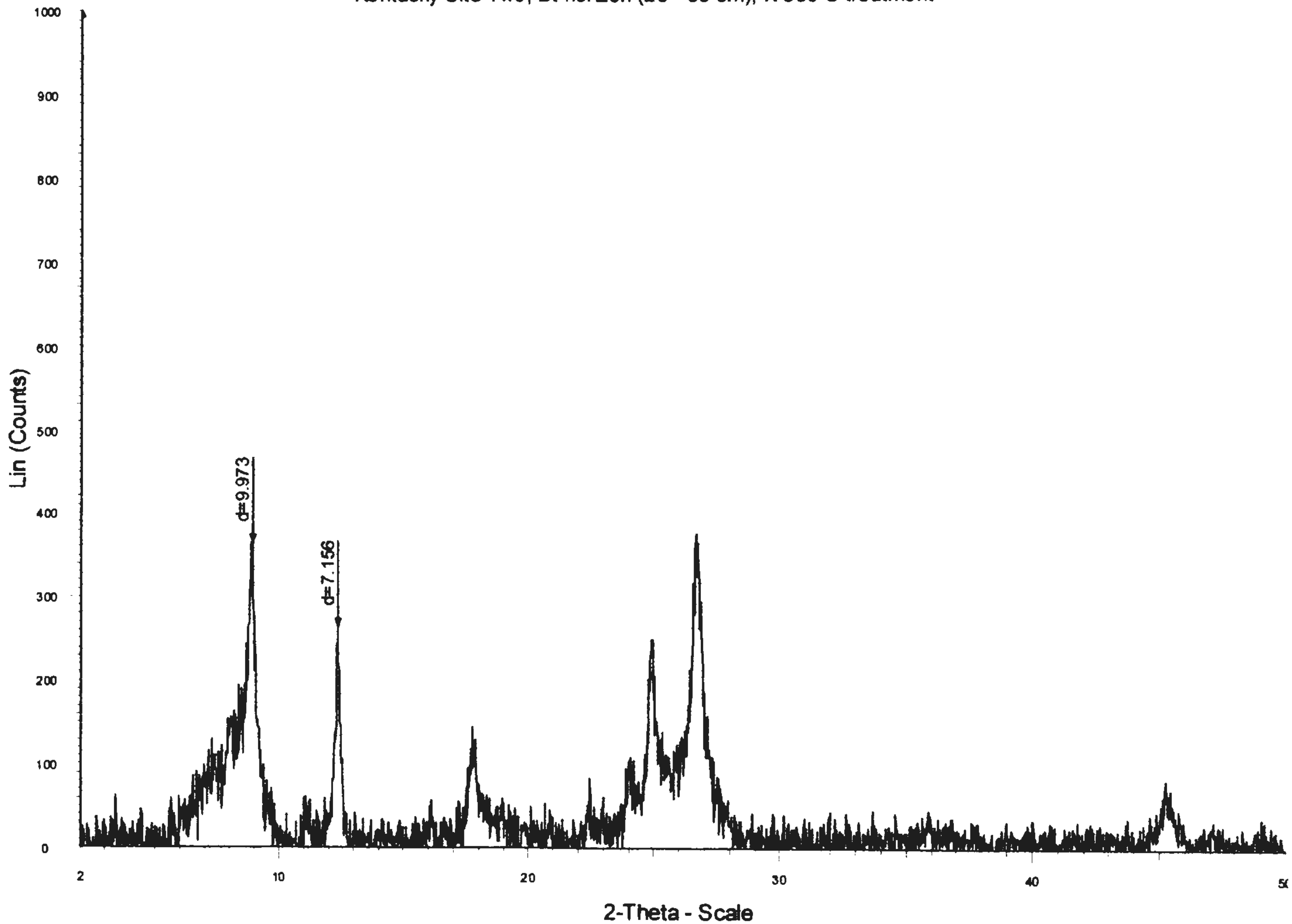


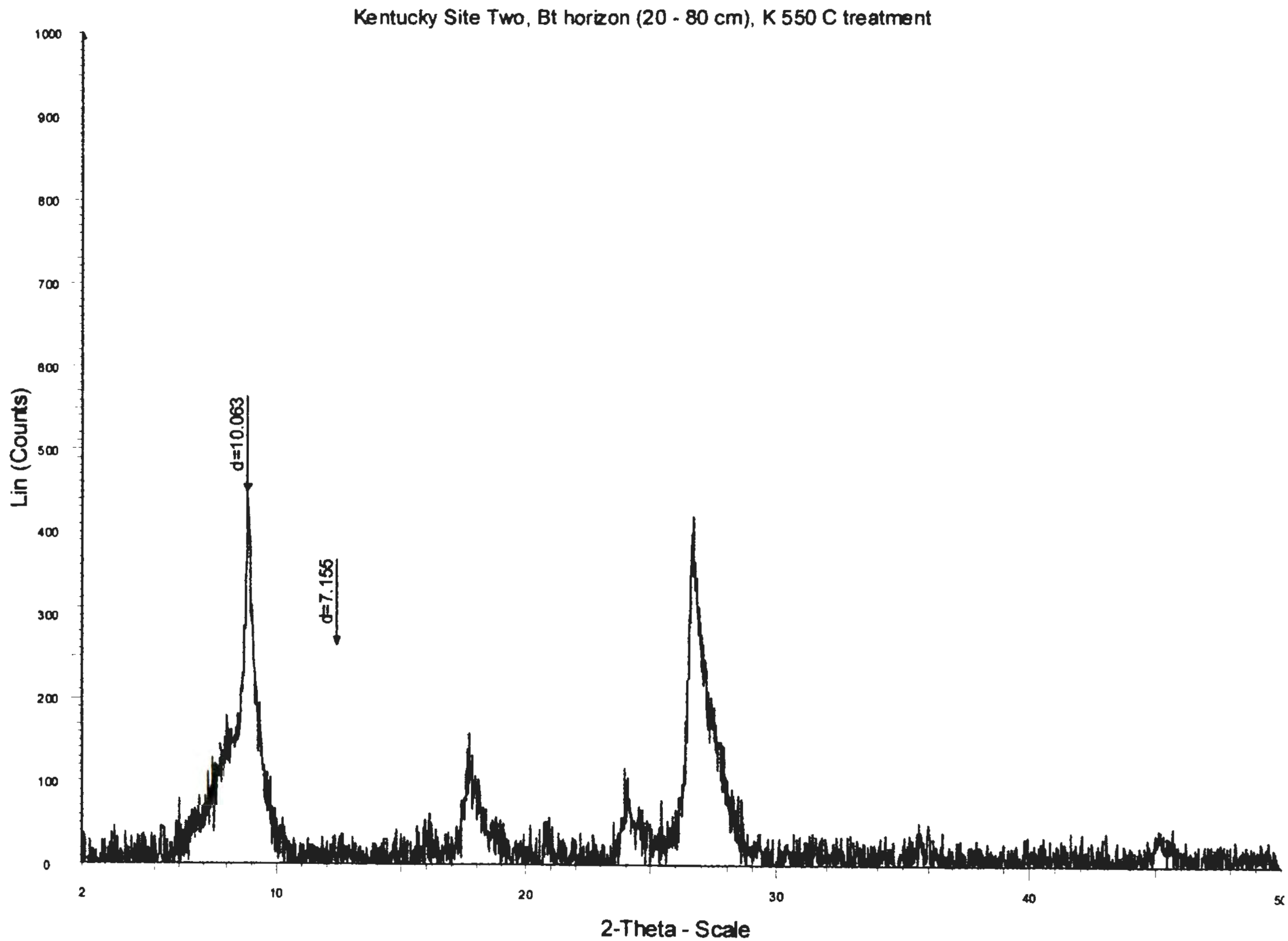
Kentucky Site Two, Bt horizon (20 - 80 cm), K air dried treatment



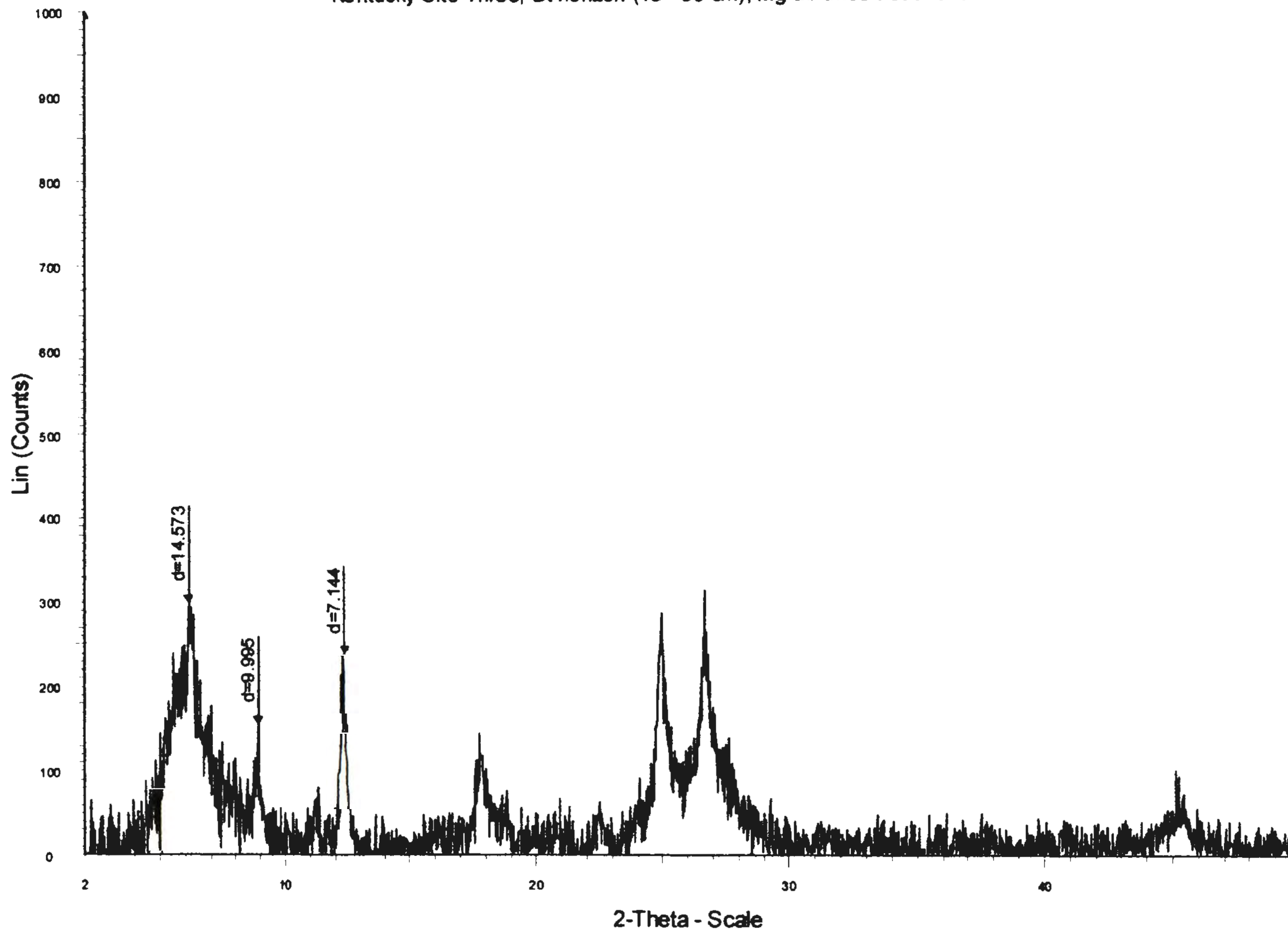

Kentucky Site Two, Bt horizon (20 - 80 cm), K 105 C treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=13.843
d=9.973
d=7.144
2
10
20
30
40
2-Theta - Scale

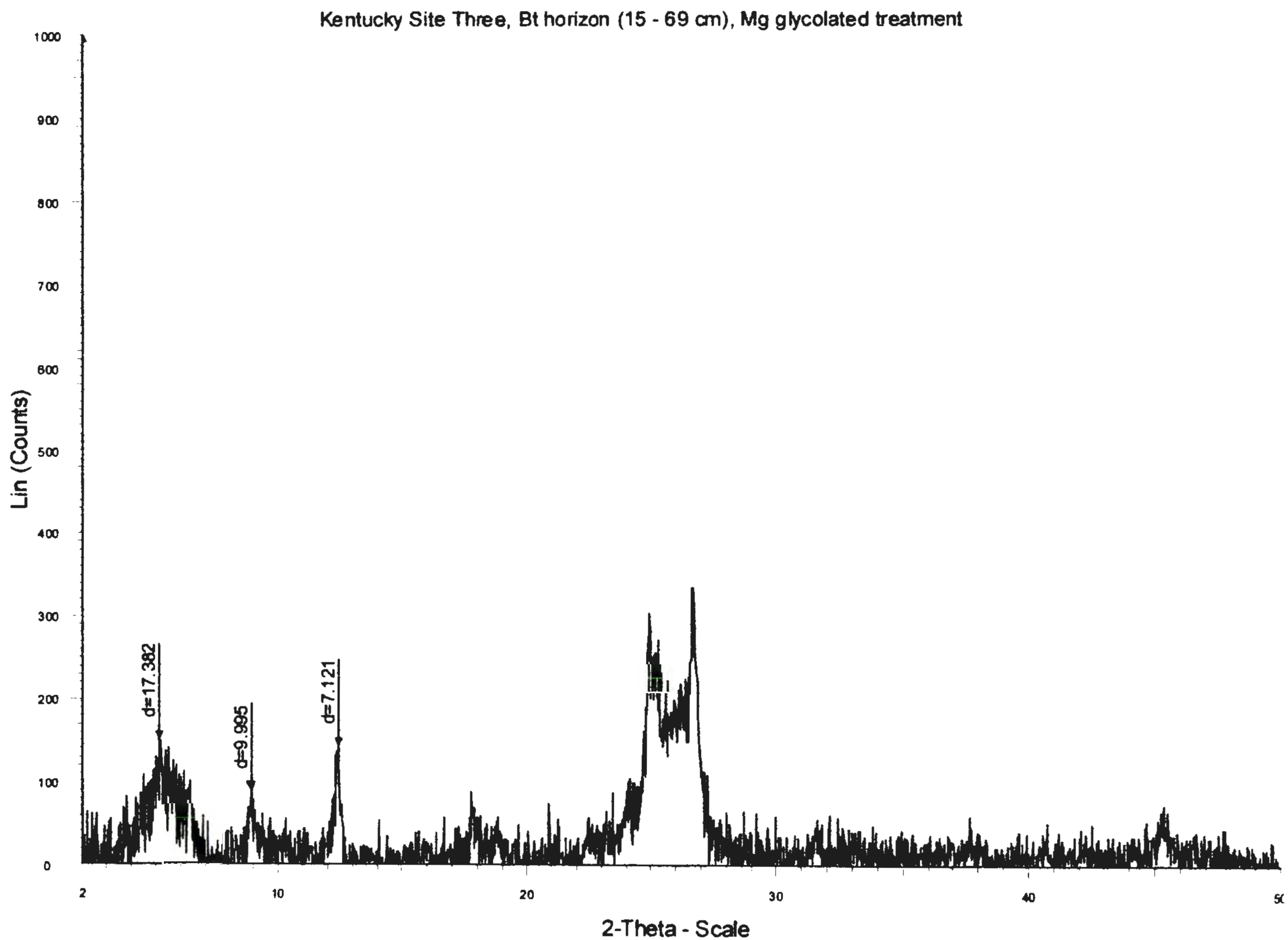
Kentucky Site Two, Bt horizon (20 - 80 cm), K 300 C treatment



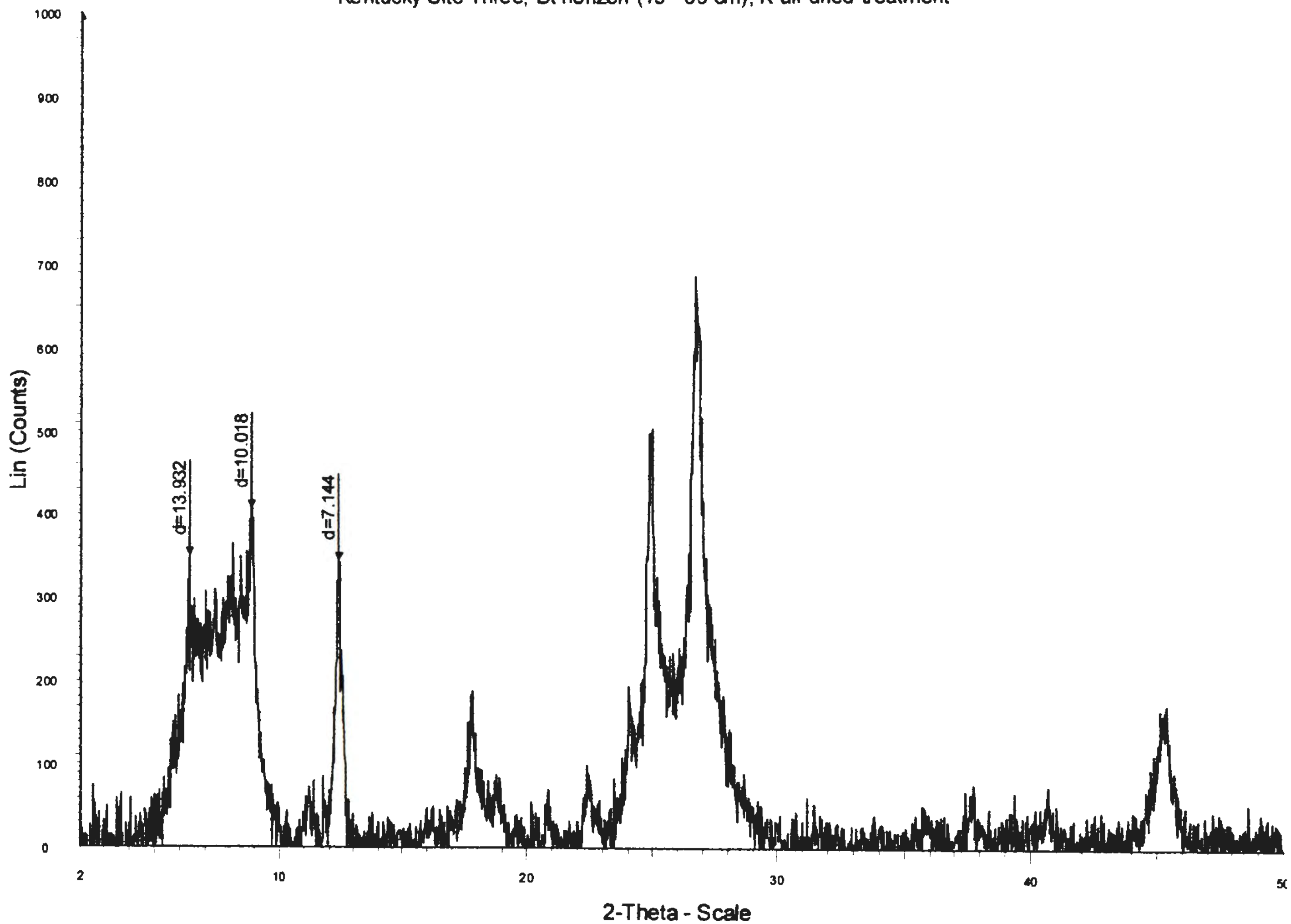

Kentucky Site Two, Bt horizon (20 - 80 cm), K 550 C treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=10.063
d=7.155
2
10
20
30
40
50
2-Theta - Scale

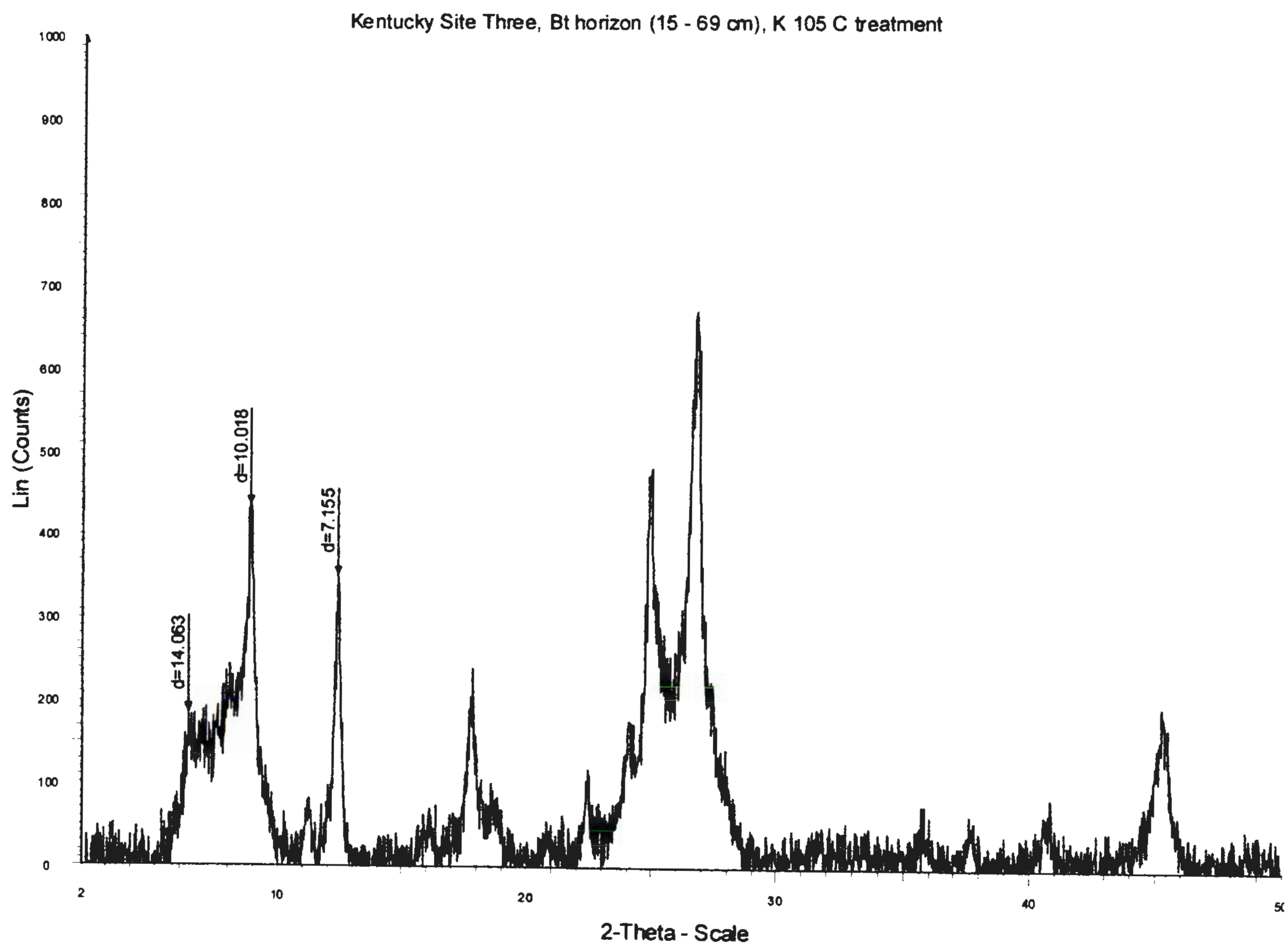
Kentucky Site Three, Bt horizon (15 - 69 cm), Mg air dried treatment.

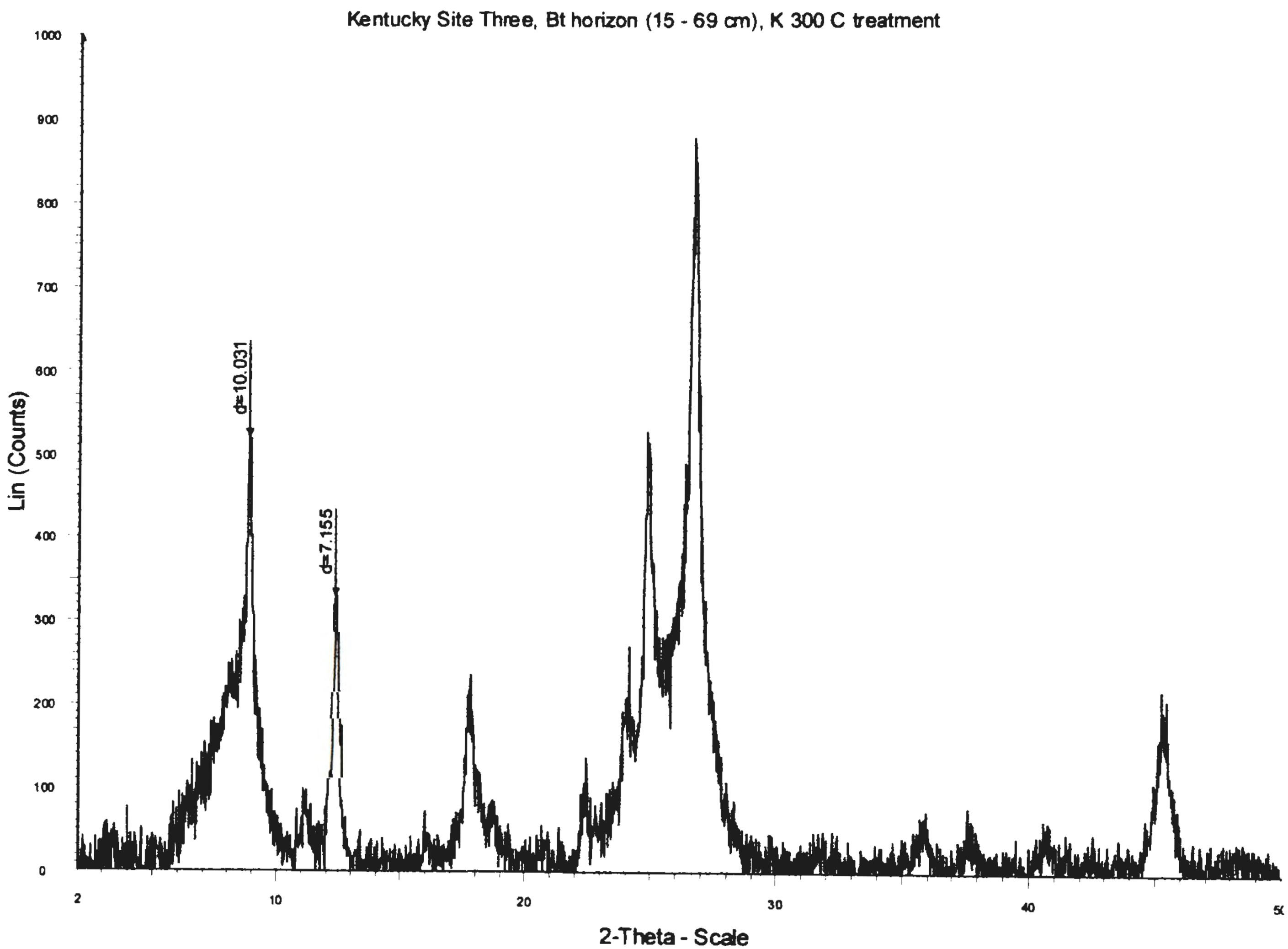



Kentucky Site Three, Bt horizon (15 - 69 cm), Mg glycolated treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=17.382
d=9.995
d=7.121
2
10
20
30
40
50
2-Theta - Scale

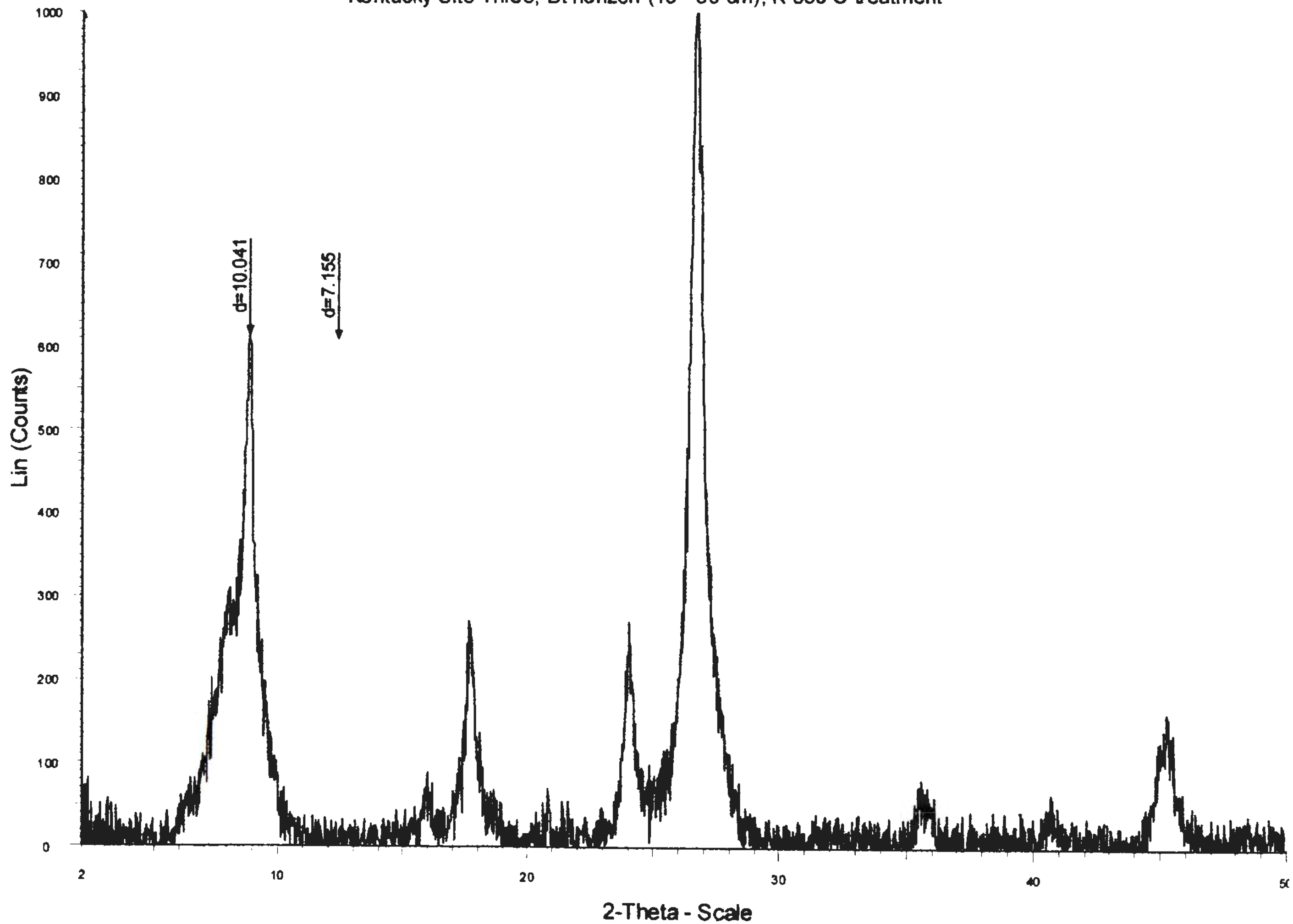
Kentucky Site Three, Bt horizon (15 - 69 cm), K air dried treatment



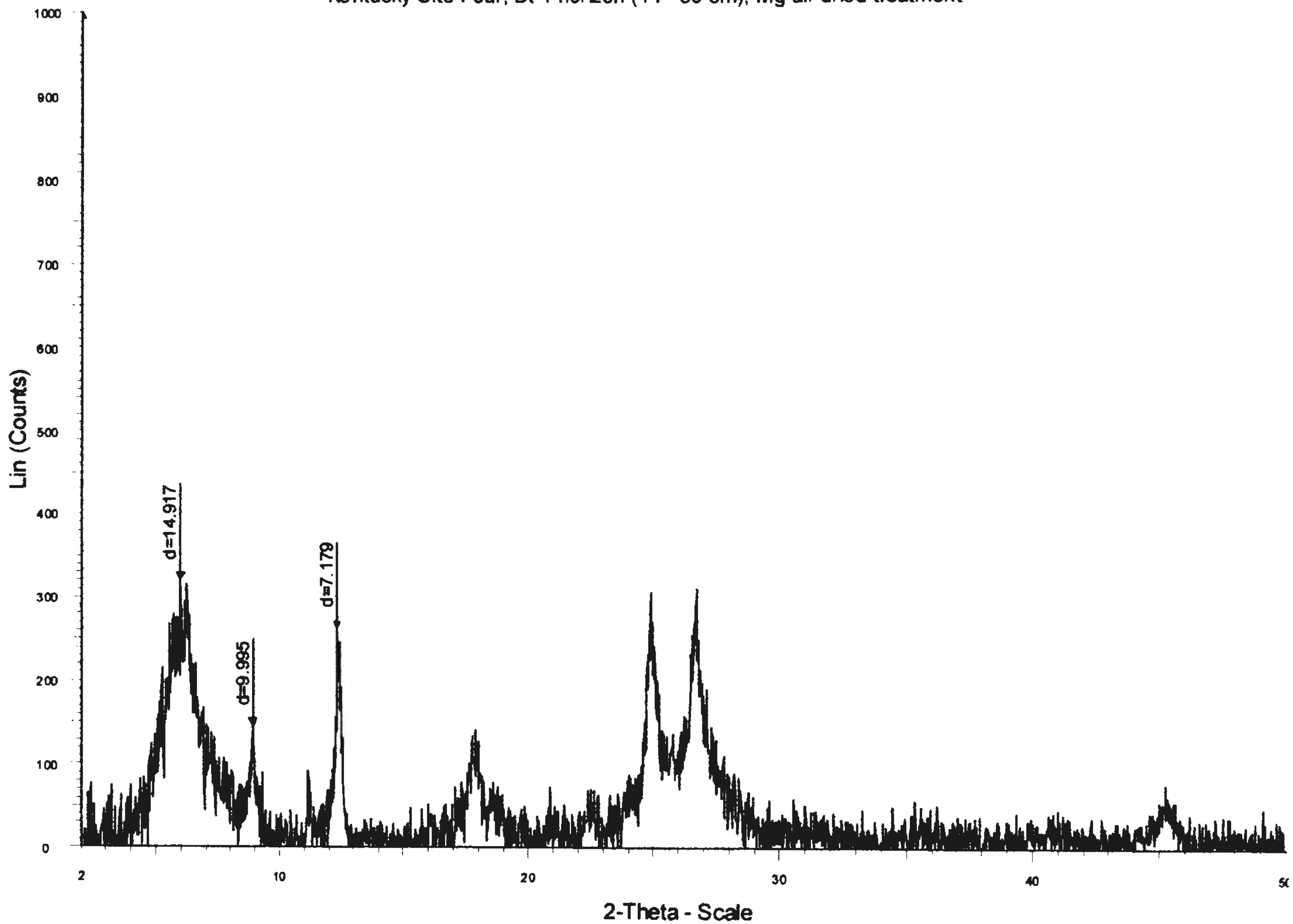

Kentucky Site Three, Bt horizon (15 - 69 cm), K 105 C treatment
Lin (Counts)
0
100
200
300
400
500
600
700
800
900
1000
d=14.063
d=10.018
d=7.155
2
10
20
30
40
2-Theta - Scale

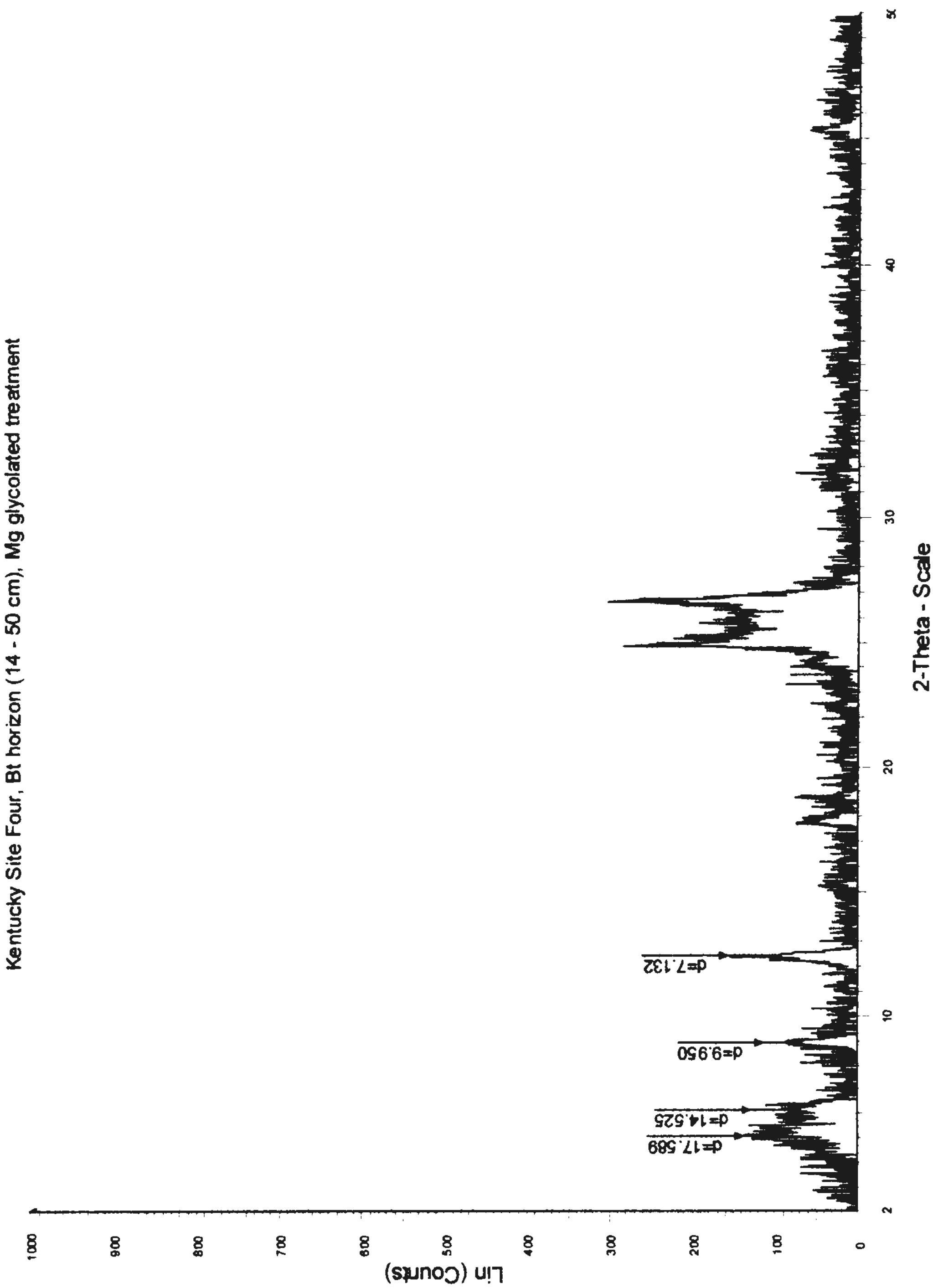

Kentucky Site Three, Bt horizon (15 - 69 cm), K 300 C treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=10.031
d=7.155
2
10
20
30
40
50
2-Theta - Scale

Kentucky Site Three, Bt horizon (15 - 69 cm), K 550 C treatment

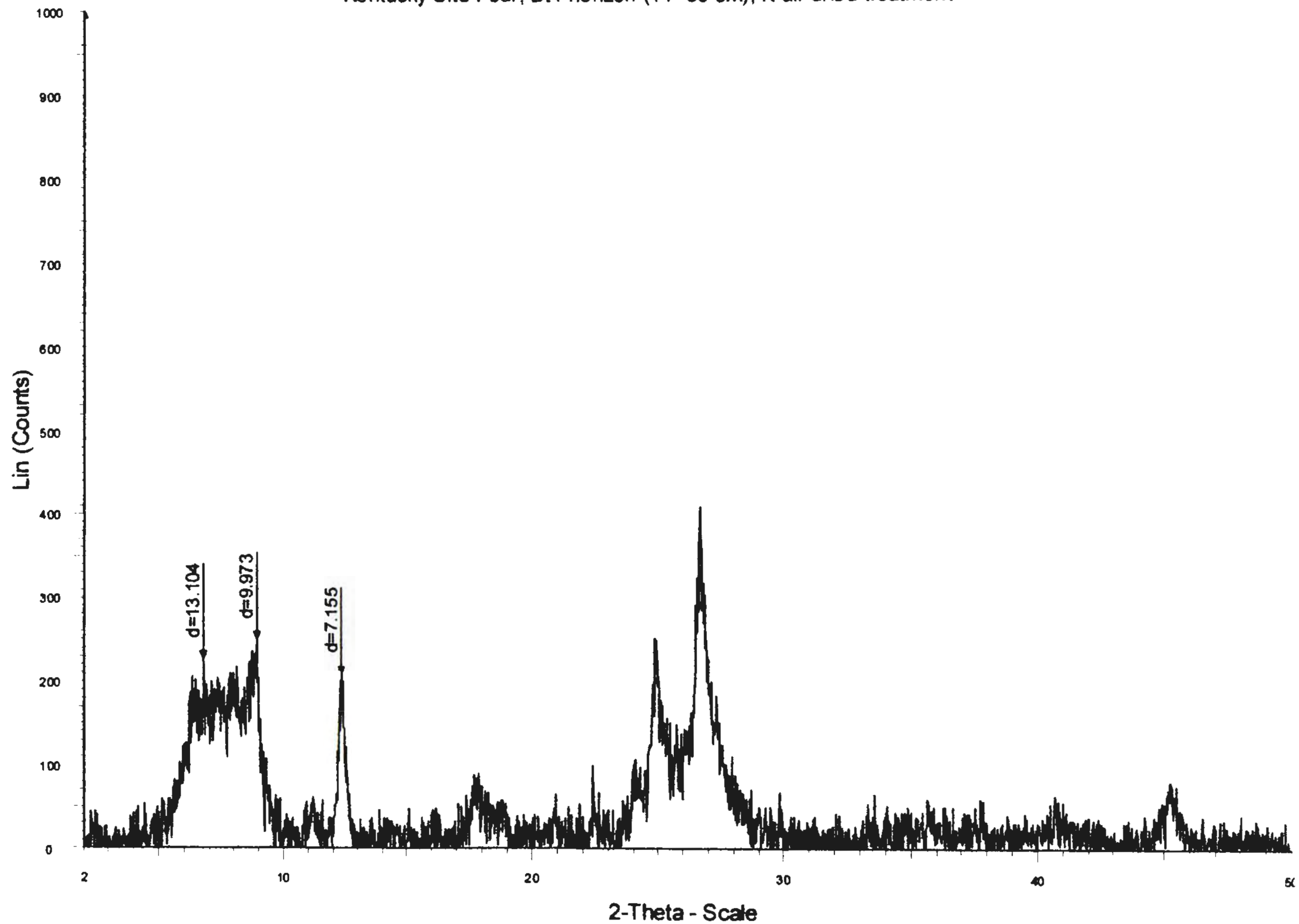


Kentucky Site Four, Bt 1 horizon (14 - 50 cm), Mg air dried treatment

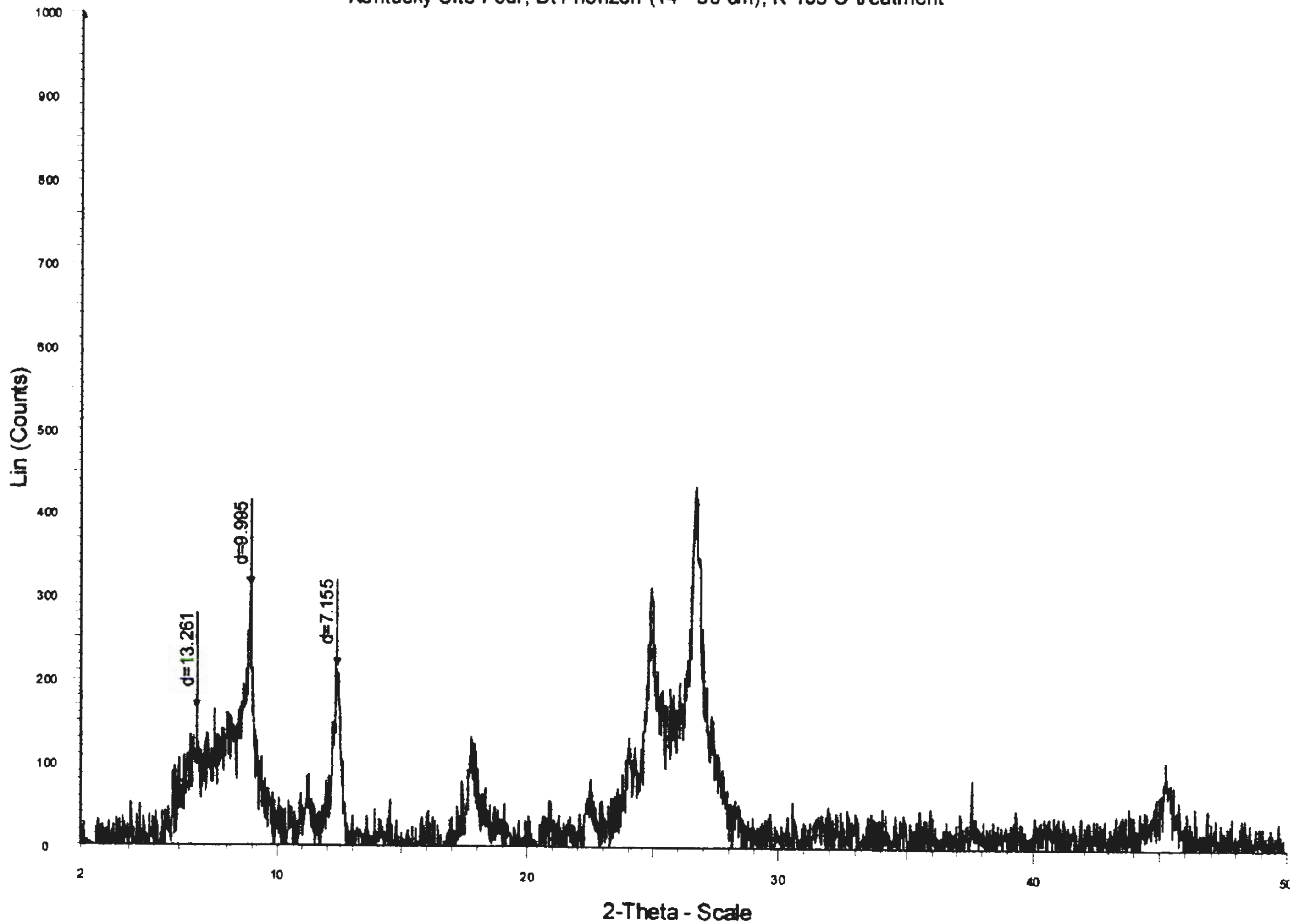



Kentucky Site Four, Bt horizon (14 - 50 cm), Mg glycolated treatment
Lin (Counts)
0
100
200
300
400
500
600
700
800
900
1000
2-Theta - Scale
2
10
20
30
40
50
d=17.589
d=14.525
d=9.950
d=7.132

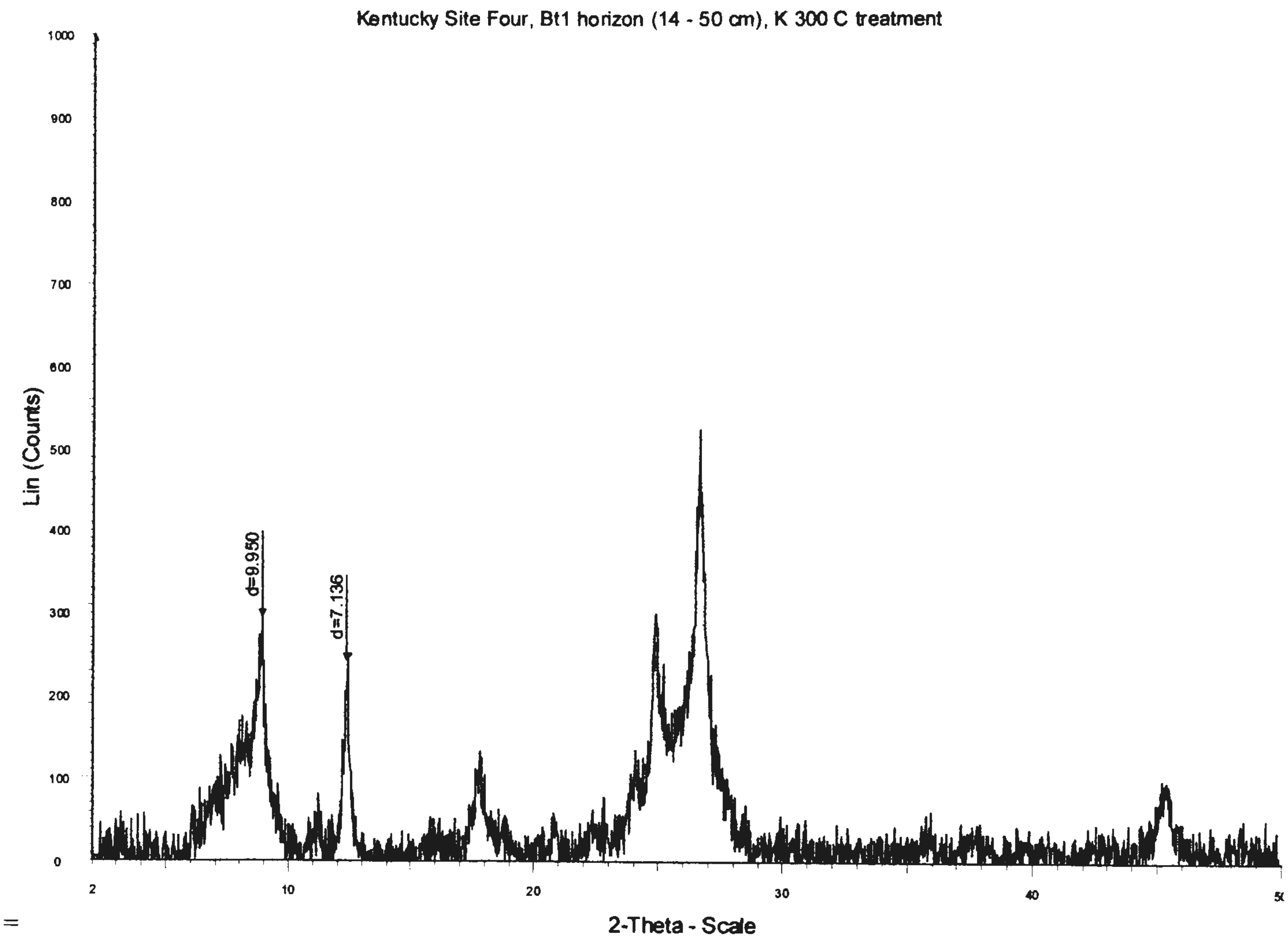
Kentucky Site Four, Bt1 horizon (14- 50 cm), K air dried treatment



Kentucky Site Four, Bt1 horizon (14 - 50 cm), K 105 C treatment

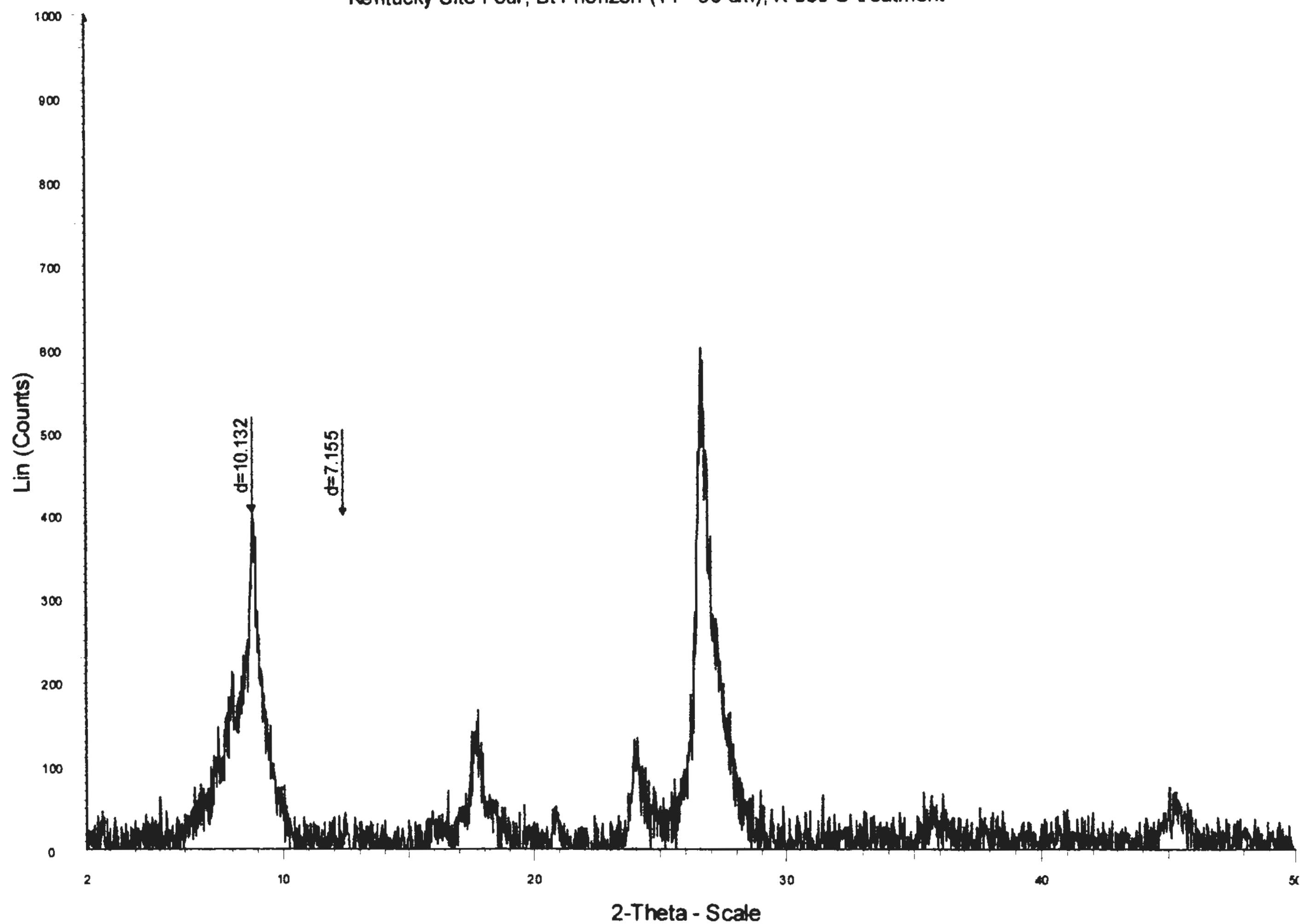


234

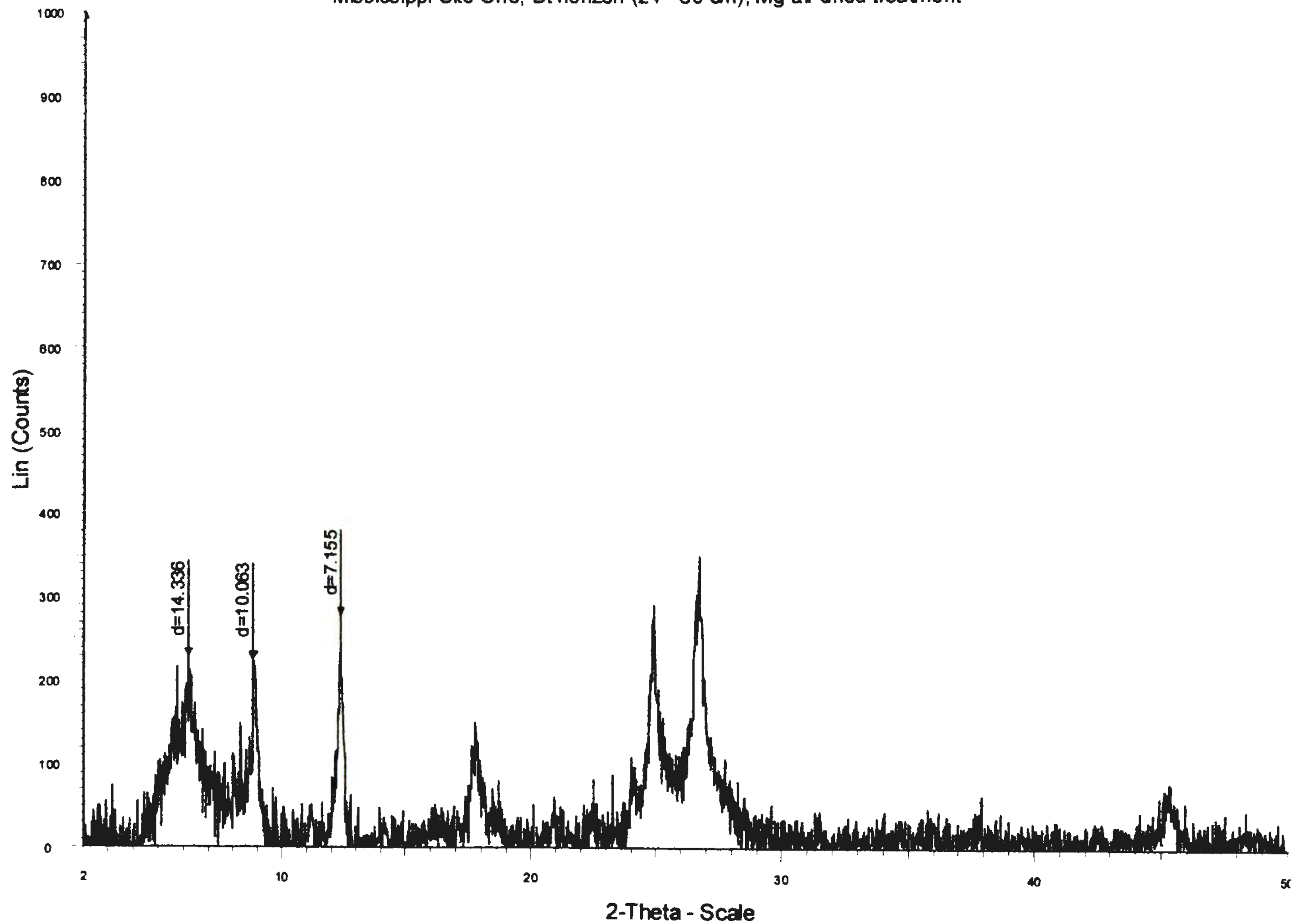


Kentucky Site Four, Bt1 horizon (14 - 50 cm), K 300 C treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=9.950
d=7.136
2
10
20
30
40
50
2-Theta - Scale

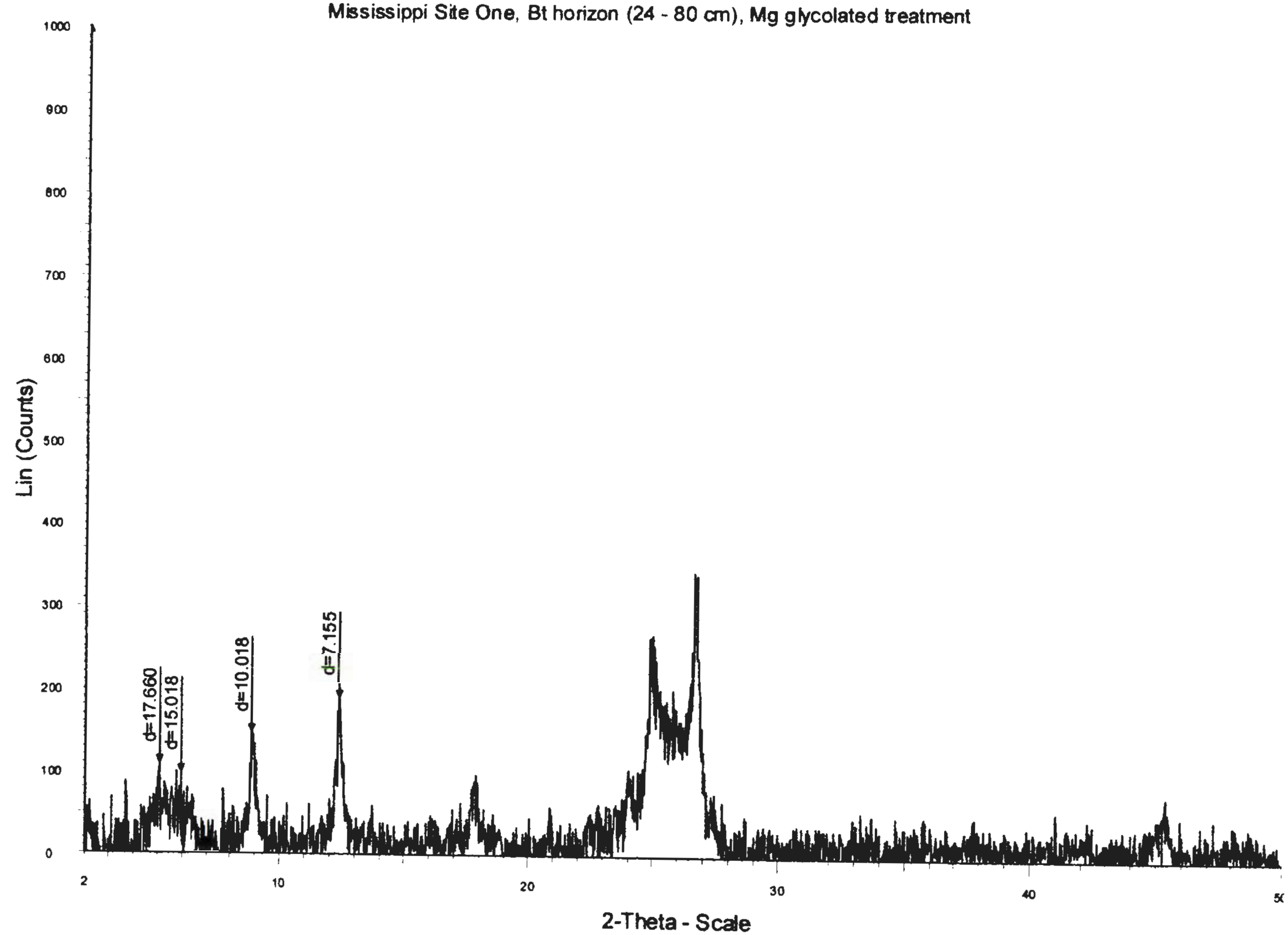
Kentucky Site Four, Bt1 horizon (14 - 50 cm), K 550 C treatment

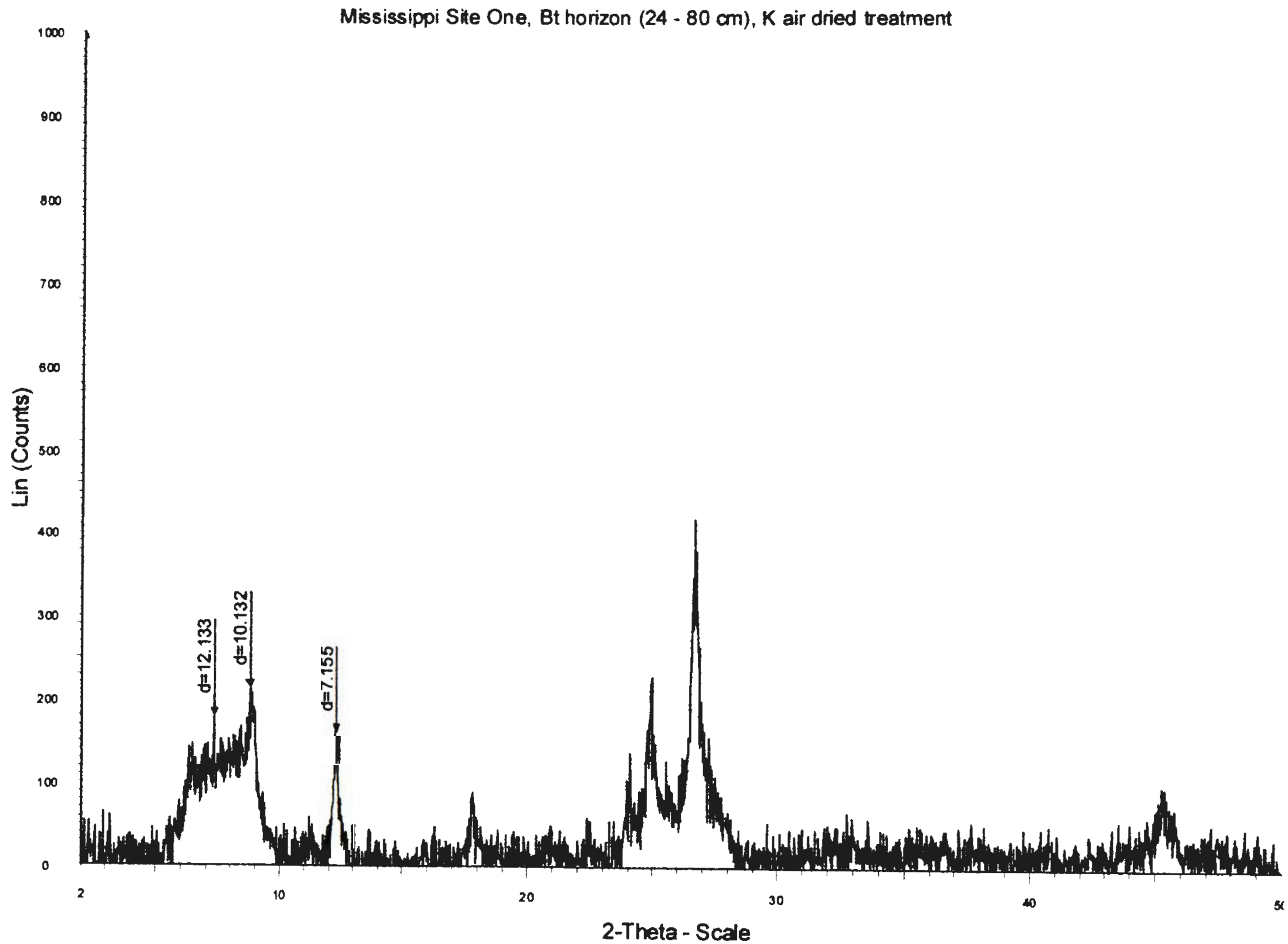


Mississippi Site One, Bt horizon (24 - 80 cm), Mg air dried treatment

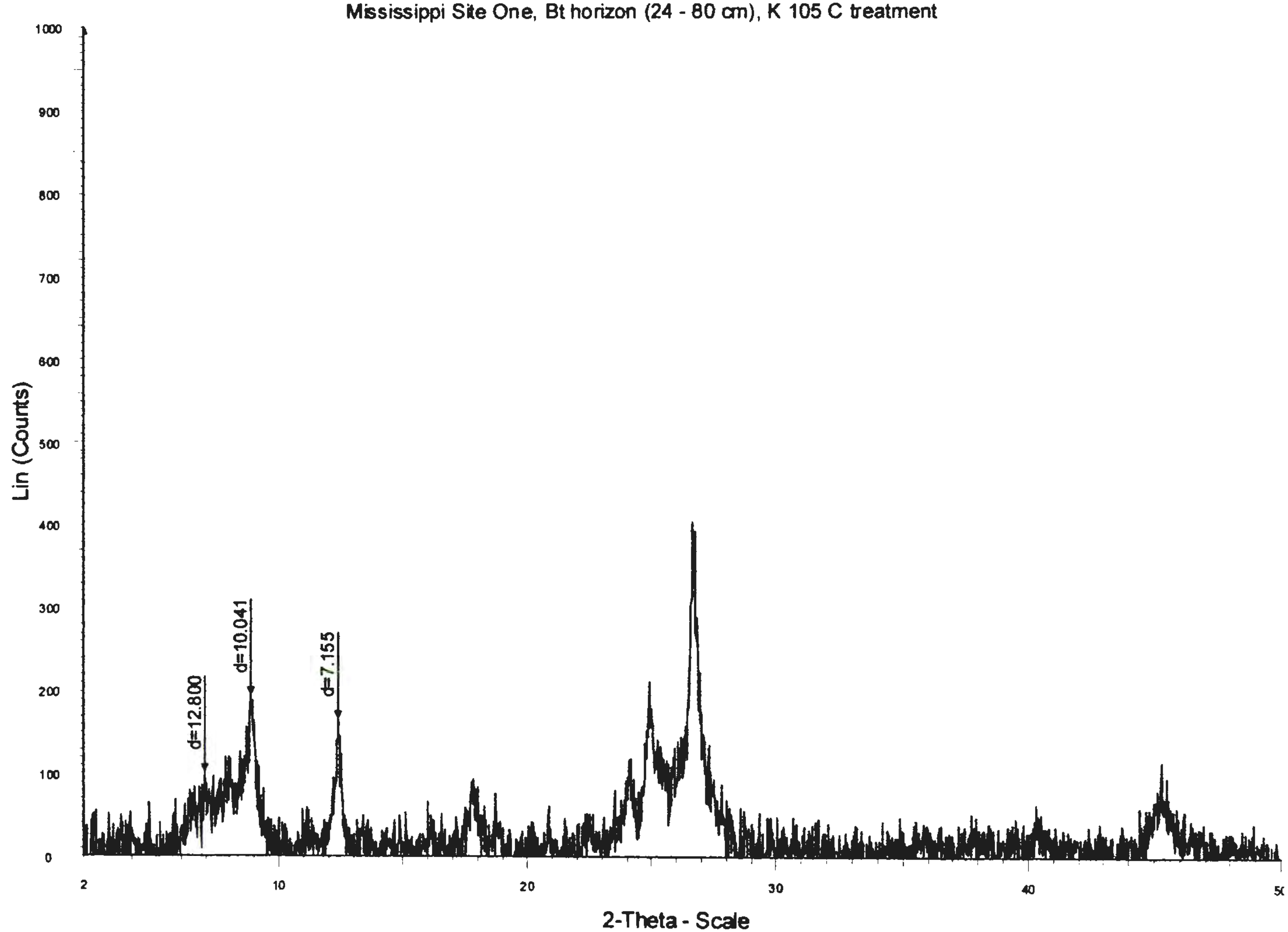


Mississippi Site One, Bt horizon (24 - 80 cm), Mg glycolated treatment

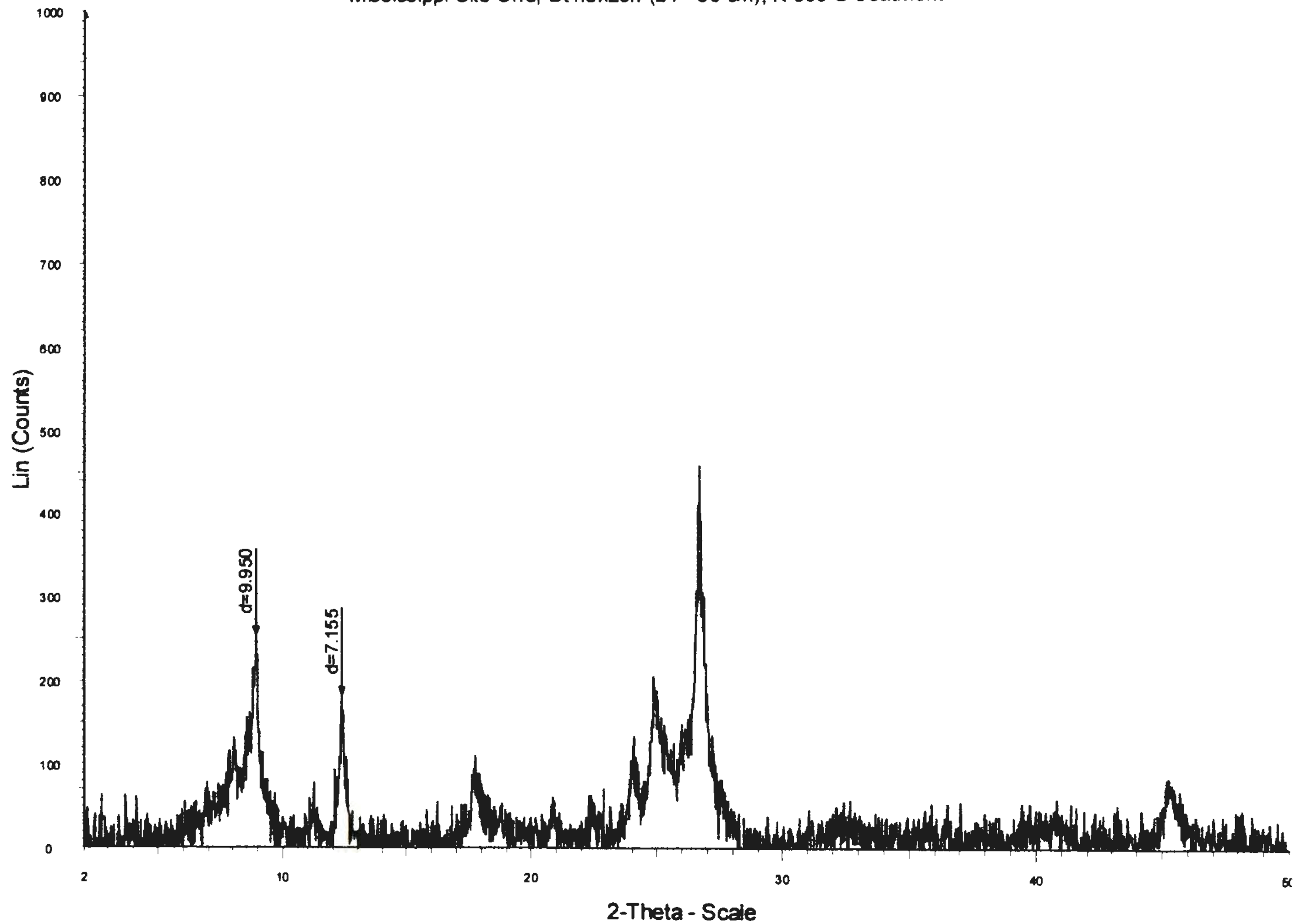


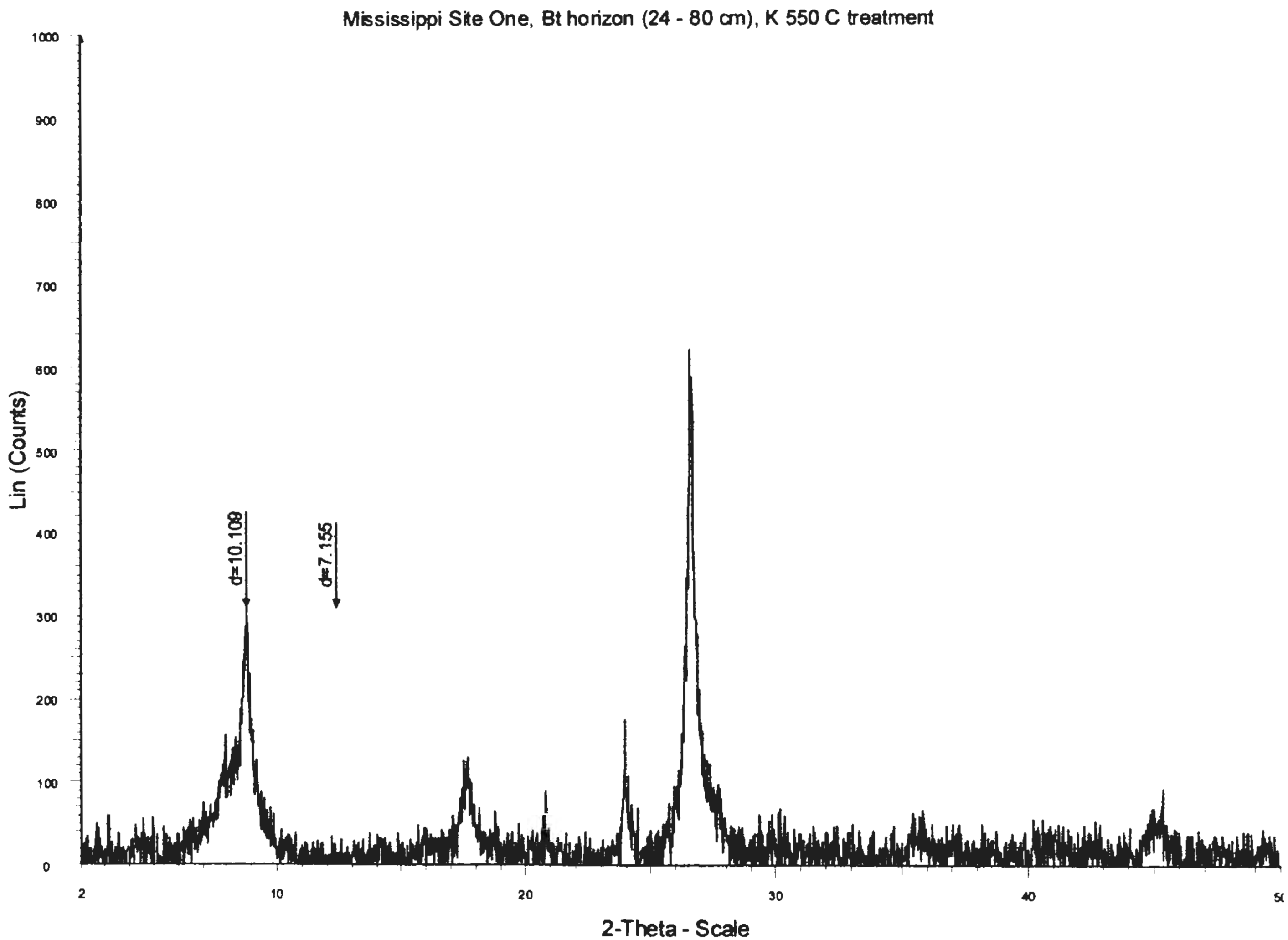

Mississippi Site One, Bt horizon (24 - 80 cm), K air dried treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=12.133
d=10.132
d=7.155
2
10
20
30
40
50
2-Theta - Scale

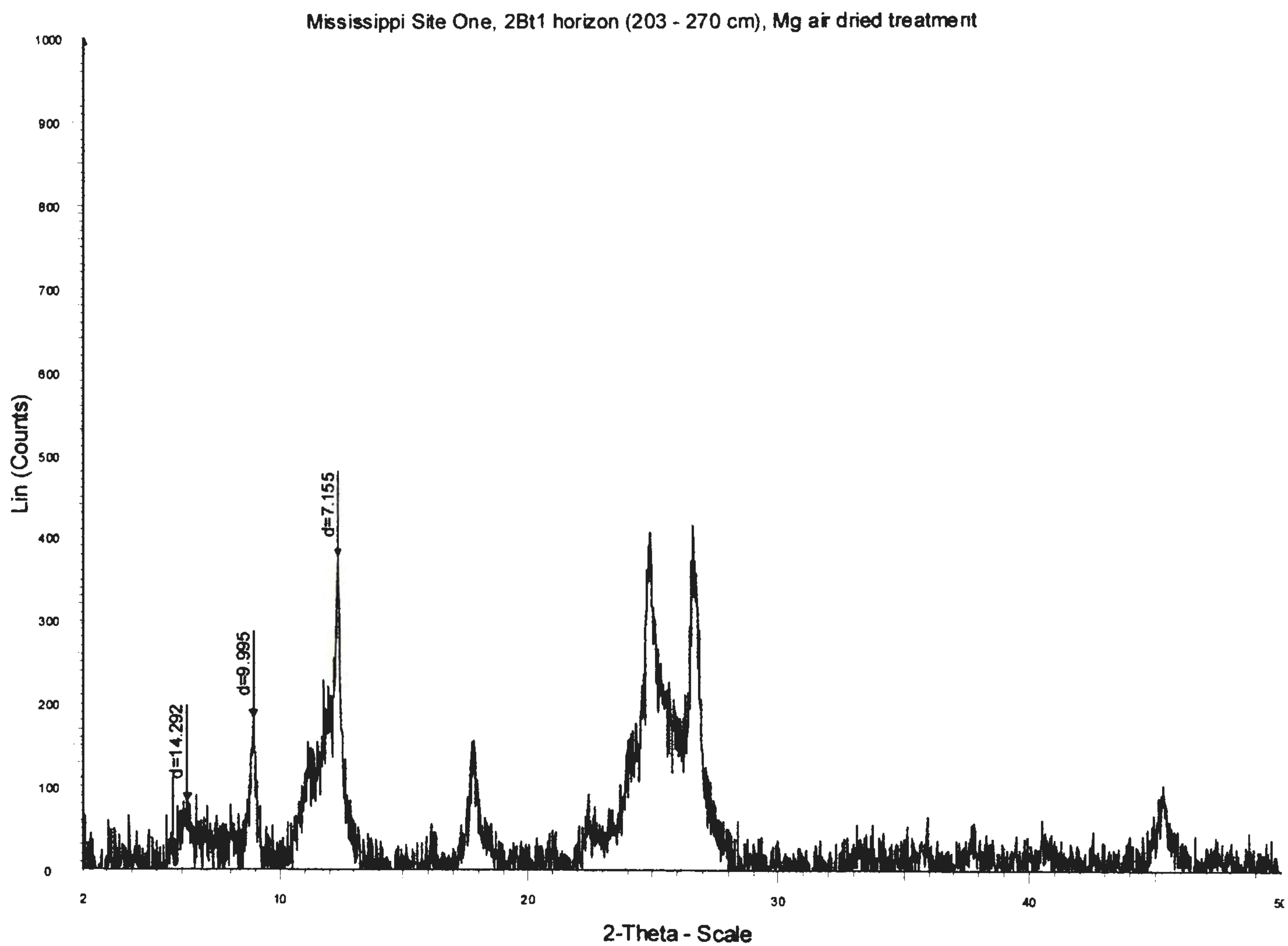
Mississippi Site One, Bt horizon (24 - 80 cm), K 105 C treatment

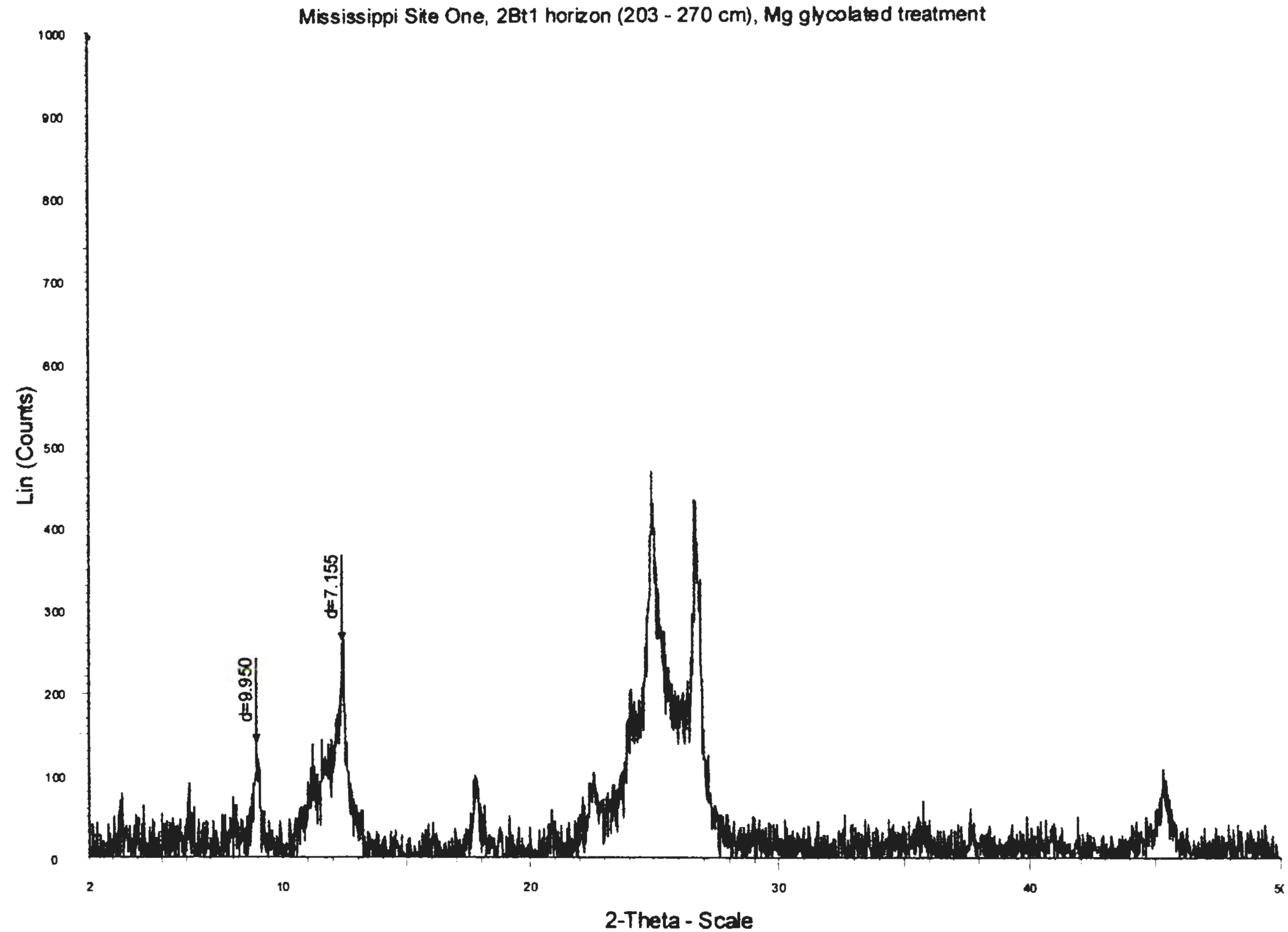


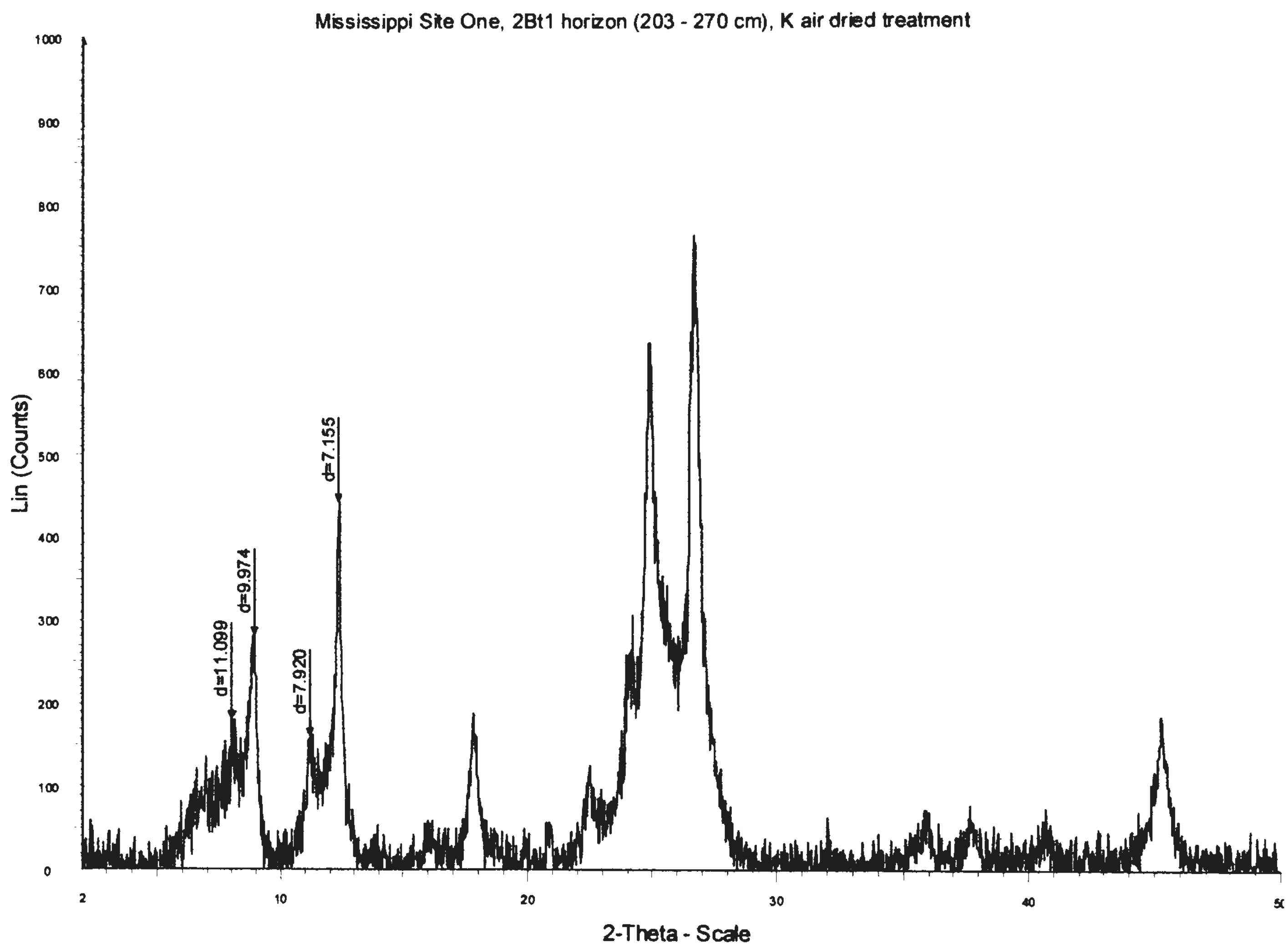
Mississippi Site One, Bt horizon (24 - 80 cm), K 300 C treatment



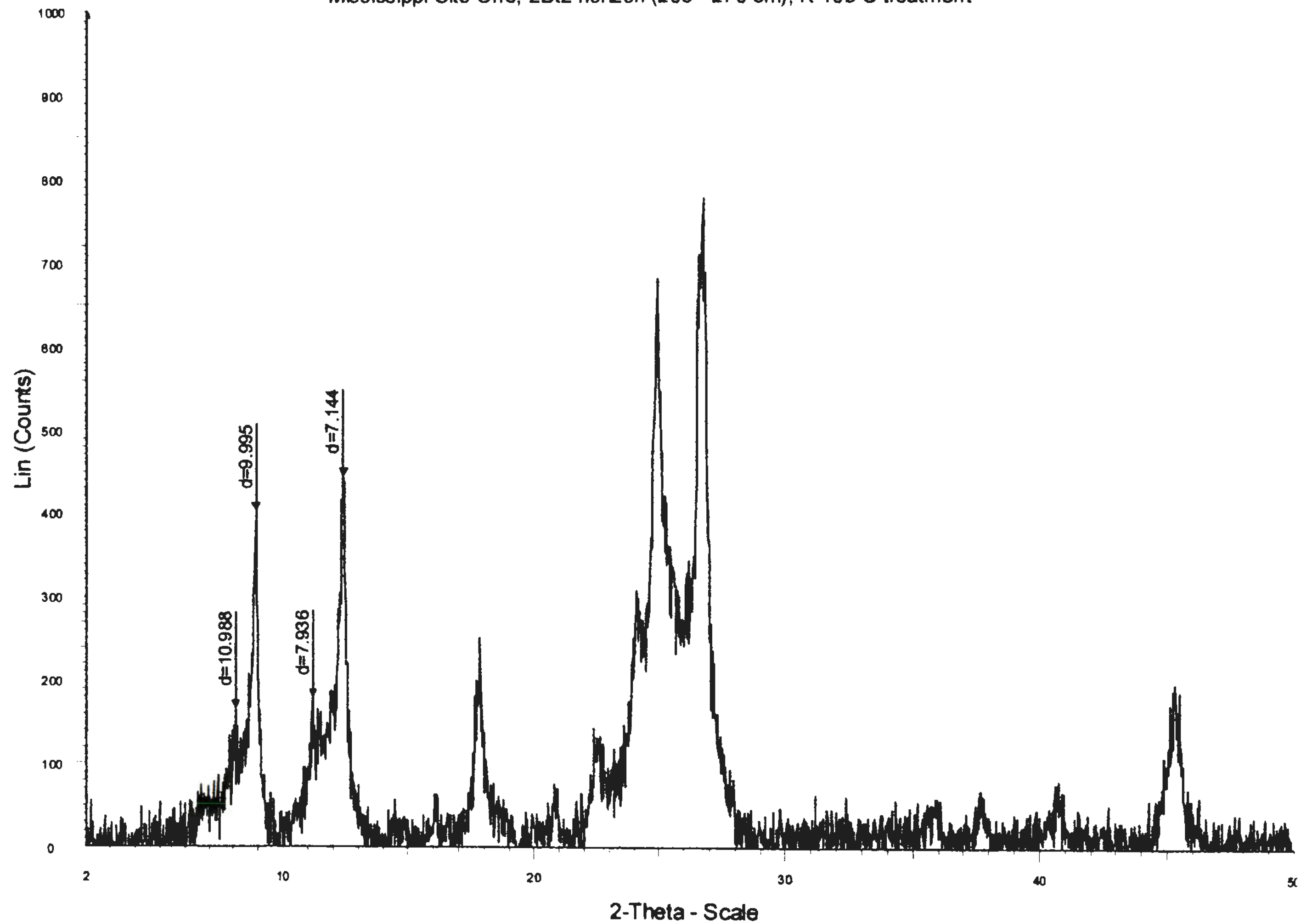

Mississippi Site One, Bt horizon (24 - 80 cm), K 550 C treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=10.109
d=7.155
2
10
20
30
40
50
2-Theta - Scale

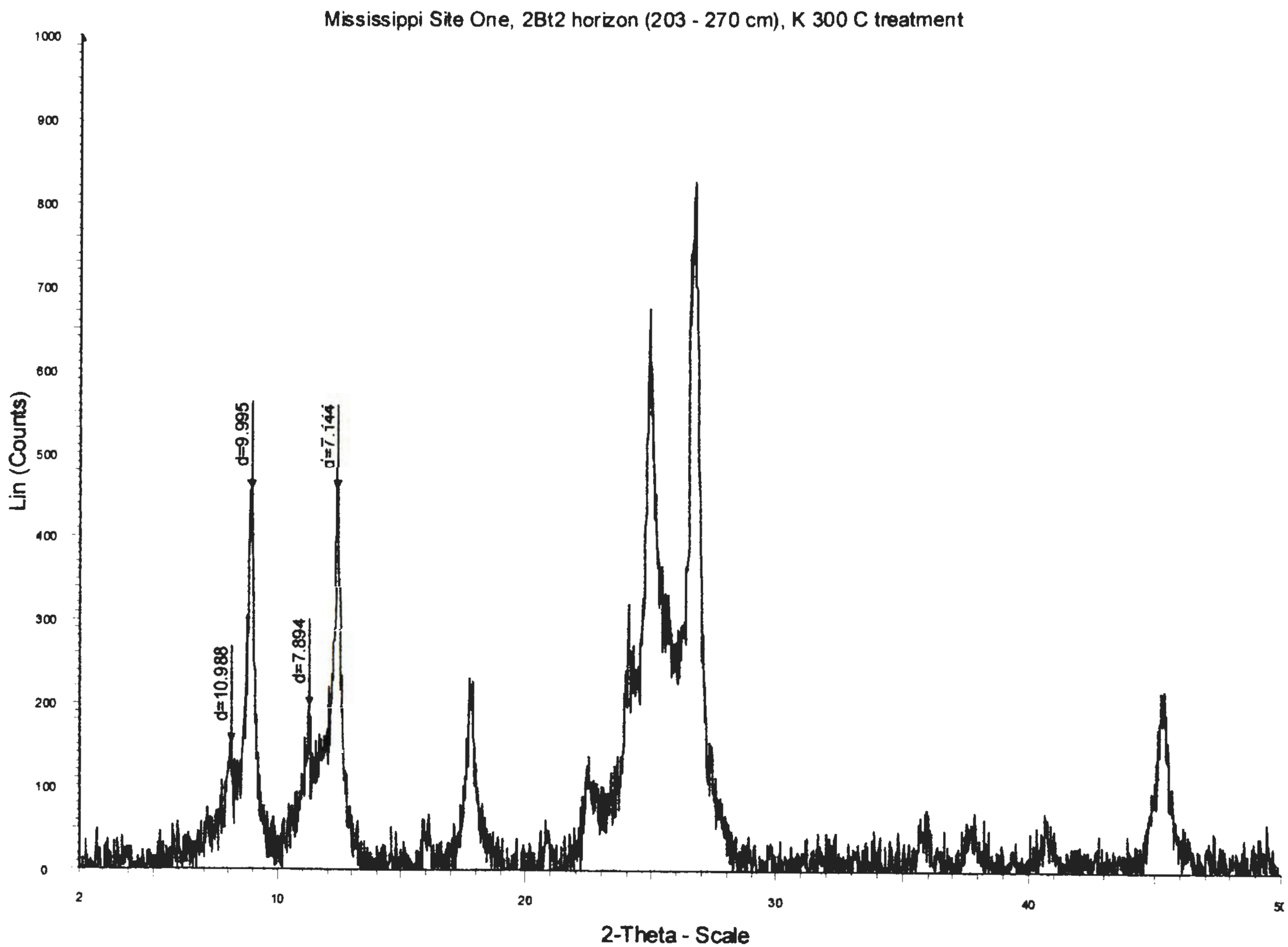

Mississippi Site One, 2Bt1 horizon (203 - 270 cm), Mg air dried treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=14.292
d=9.995
d=7.155
2
10
20
30
40
50
2-Theta - Scale


Mississippi Site One, 2Bt1 horizon (203 - 270 cm), Mg glycolated treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=9.950
d=7.155
2
10
20
30
40
50
2-Theta - Scale

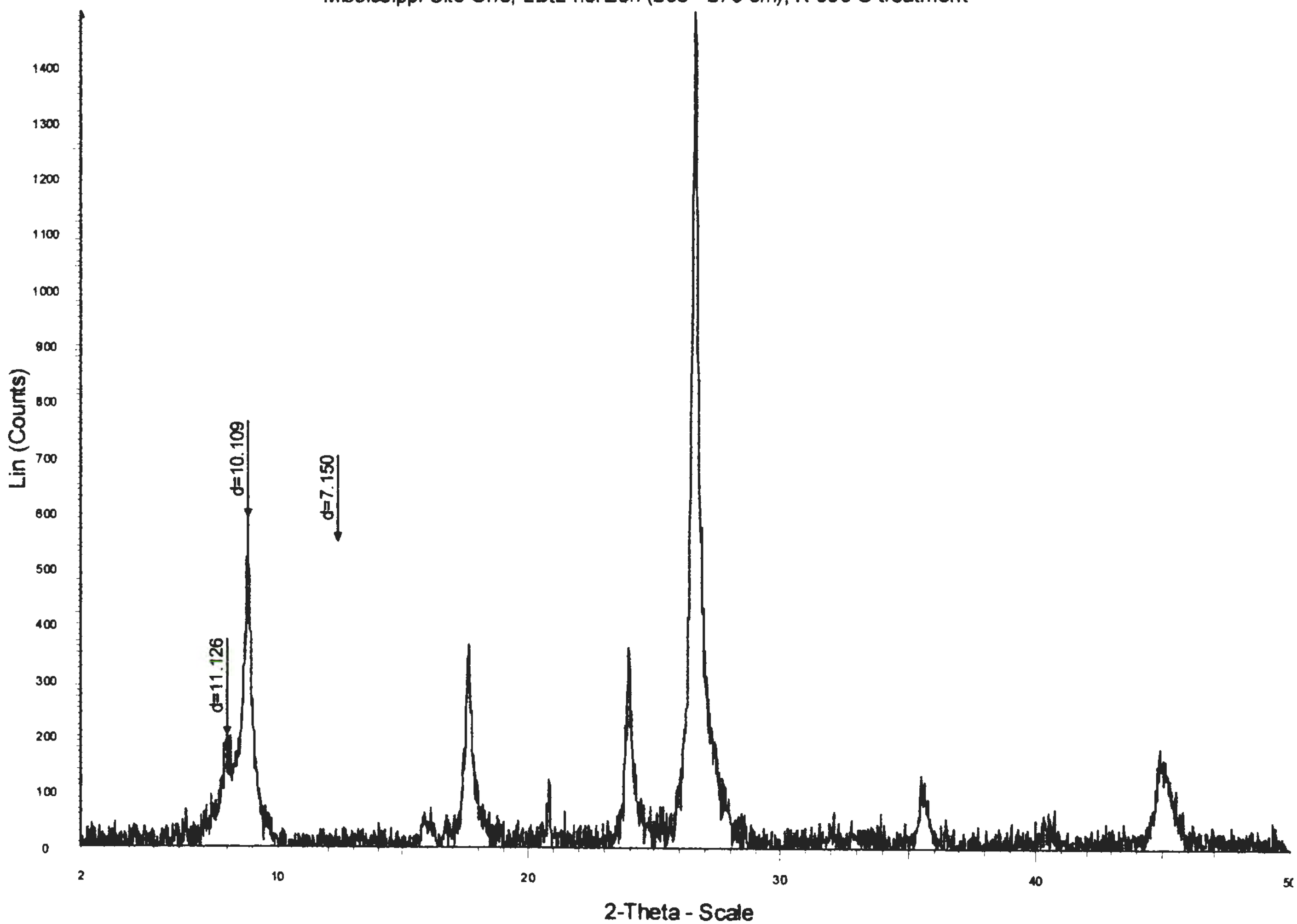

Mississippi Site One, 2Bt1 horizon (203 - 270 cm), K air dried treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=11.099
d=9.974
d=7.920
d=7.155
2
10
20
30
40
2-Theta - Scale

Mississippi Site One, 2Bt2 horizon (203 - 270 cm), K 105 C treatment

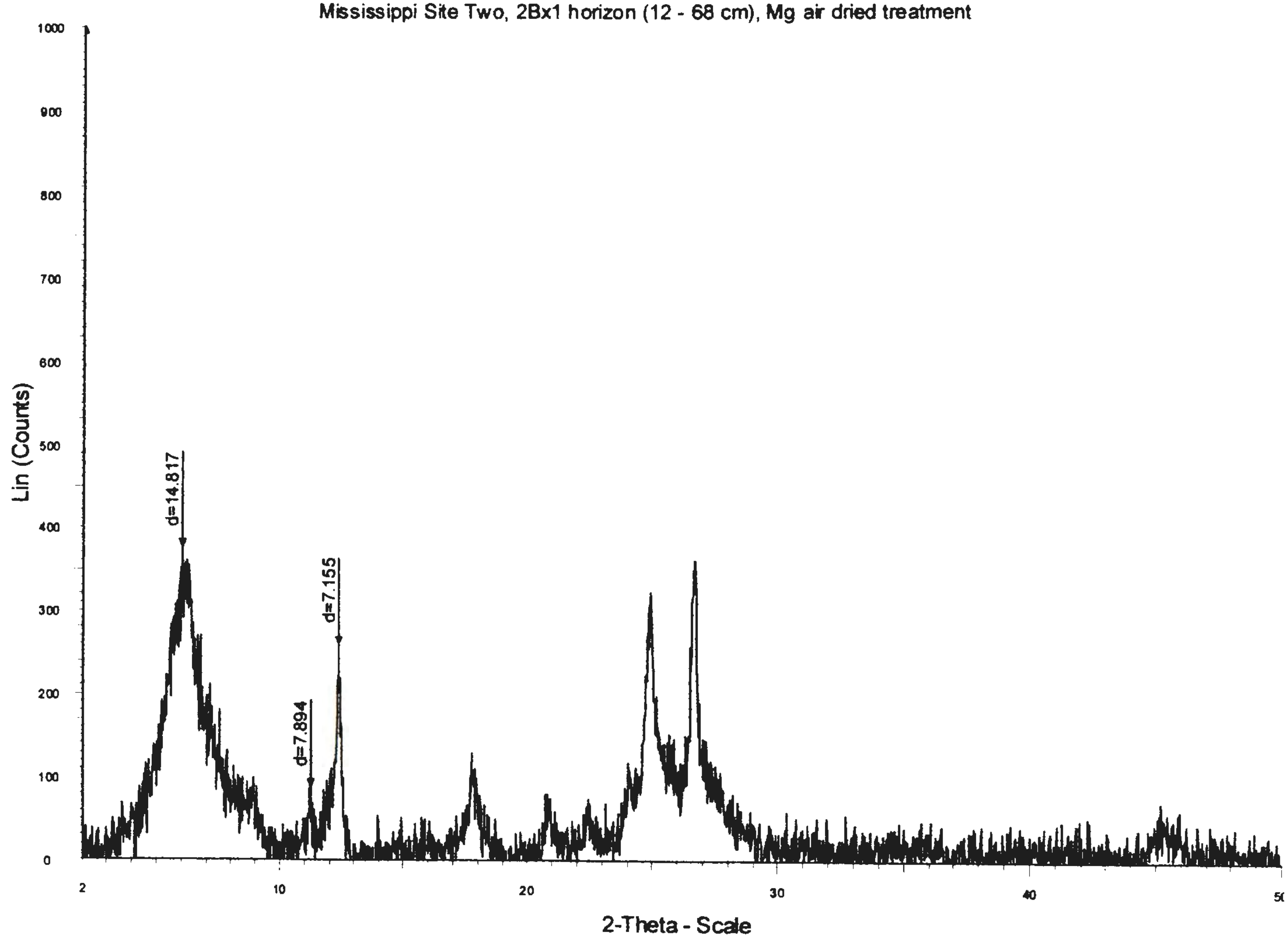



Mississippi Site One, 2Bt2 horizon (203 - 270 cm), K 300 C treatment
Lin (Counts)
0
100
200
300
400
500
600
700
800
900
1000
d=10.988
d=9.995
d=7.894
d=7.144
2
10
20
30
40
50
2-Theta - Scale

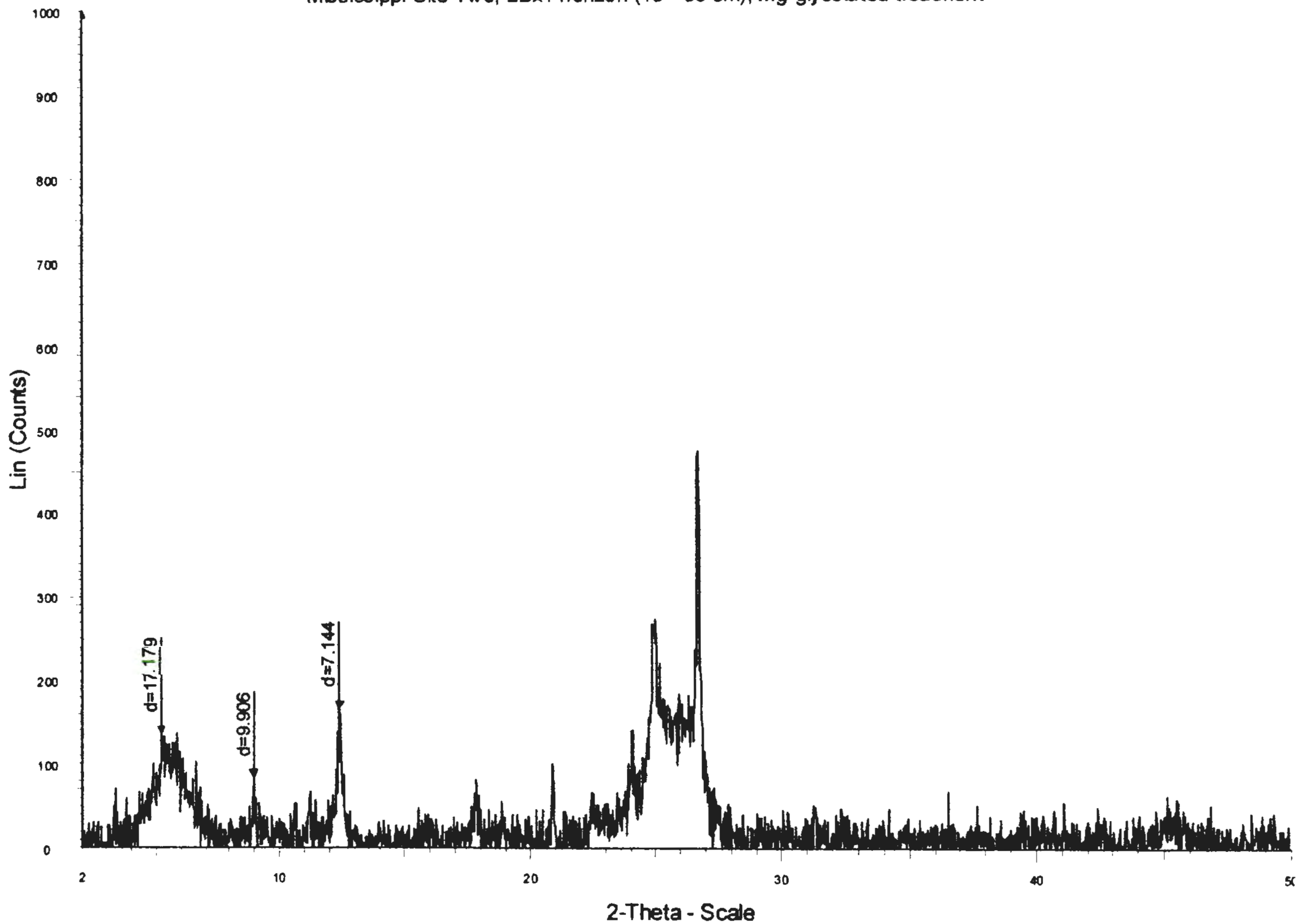
Mississippi Site One, 2Bt2 horizon (203 - 270 cm), K 550 C treatment

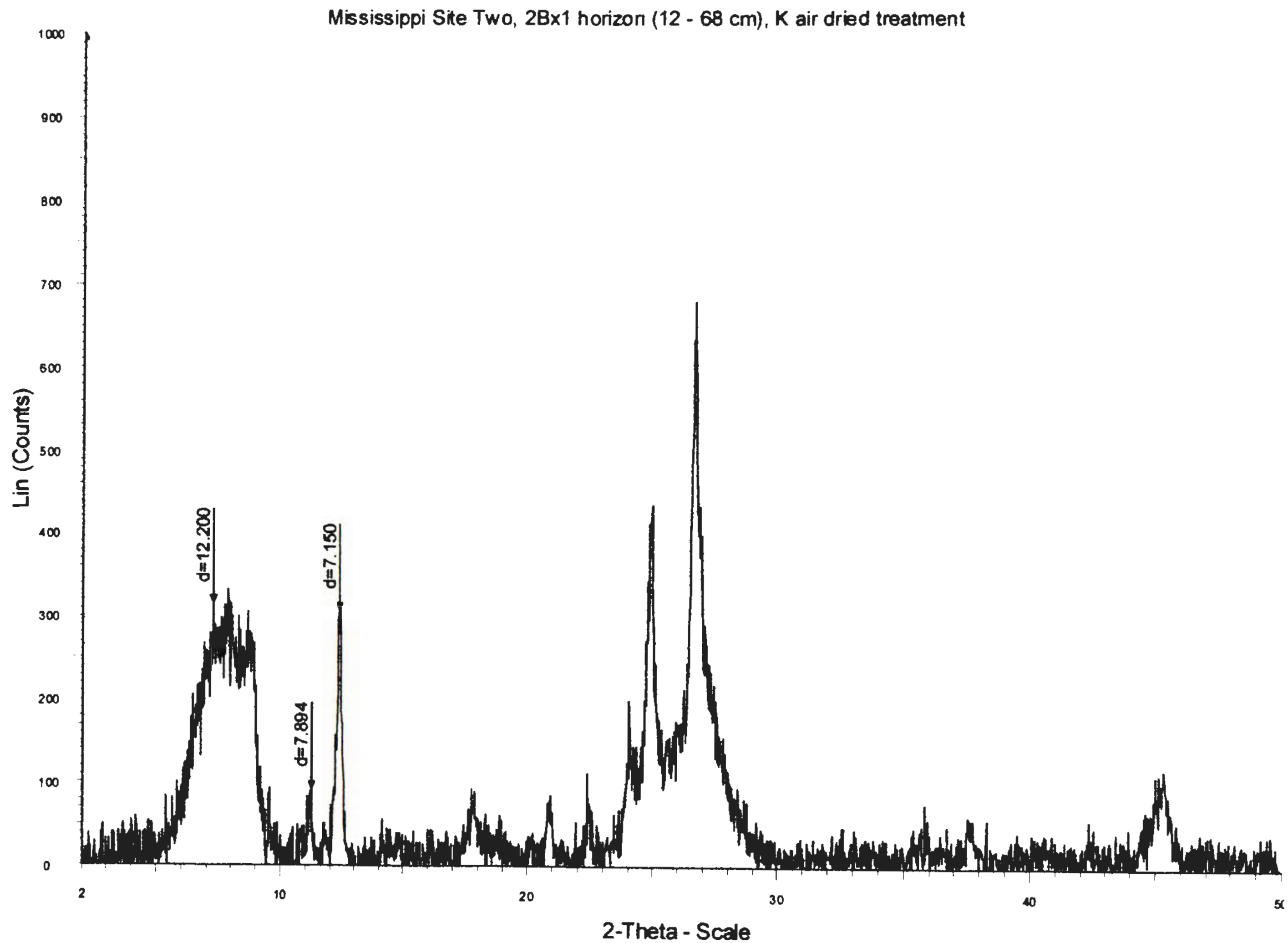


Mississippi Site Two, 2Bx1 horizon (12 - 68 cm), Mg air dried treatment

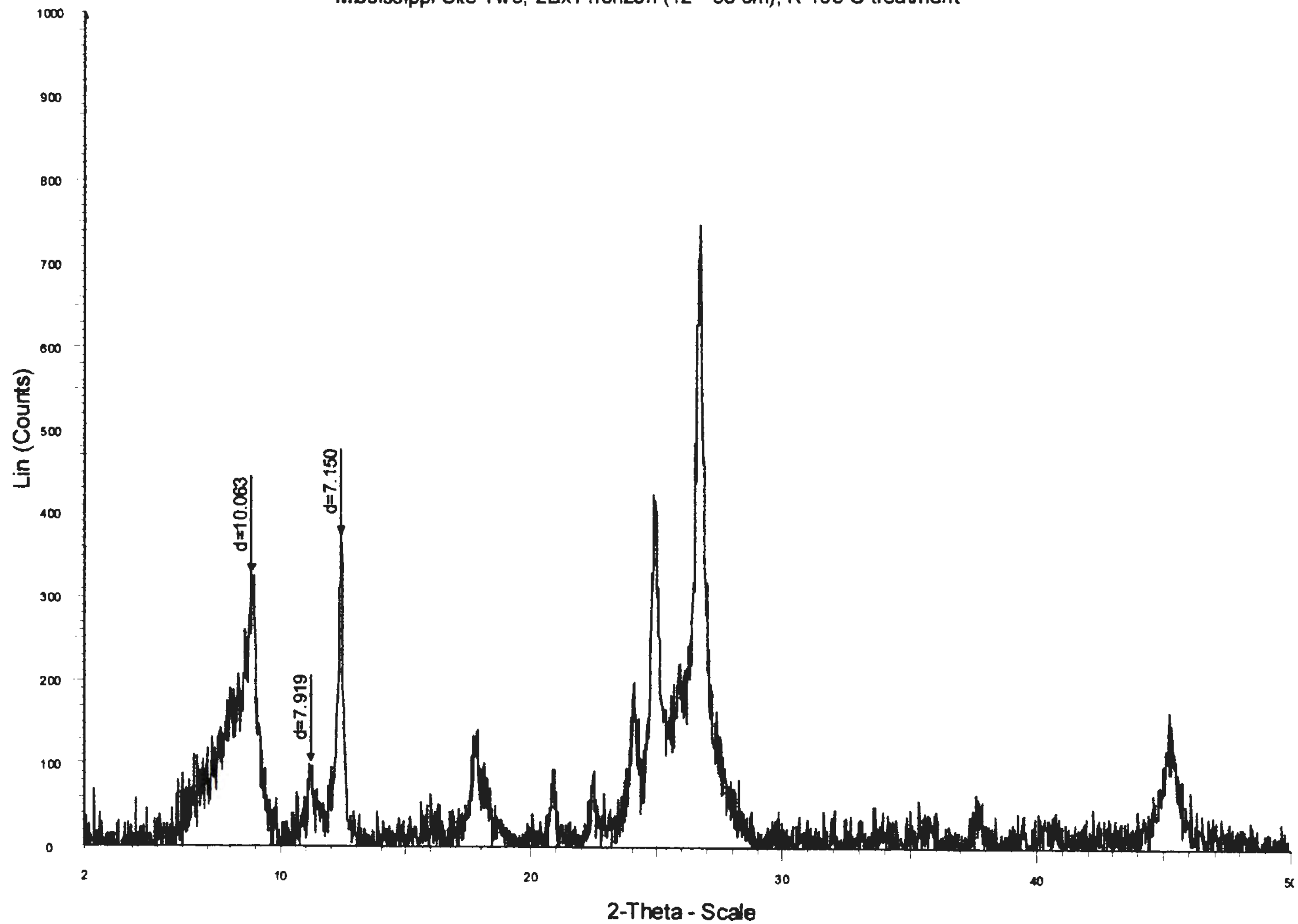


Mississippi Site Two, 2Bx1 horizon (16 - 68 cm), Mg glycolated treatment

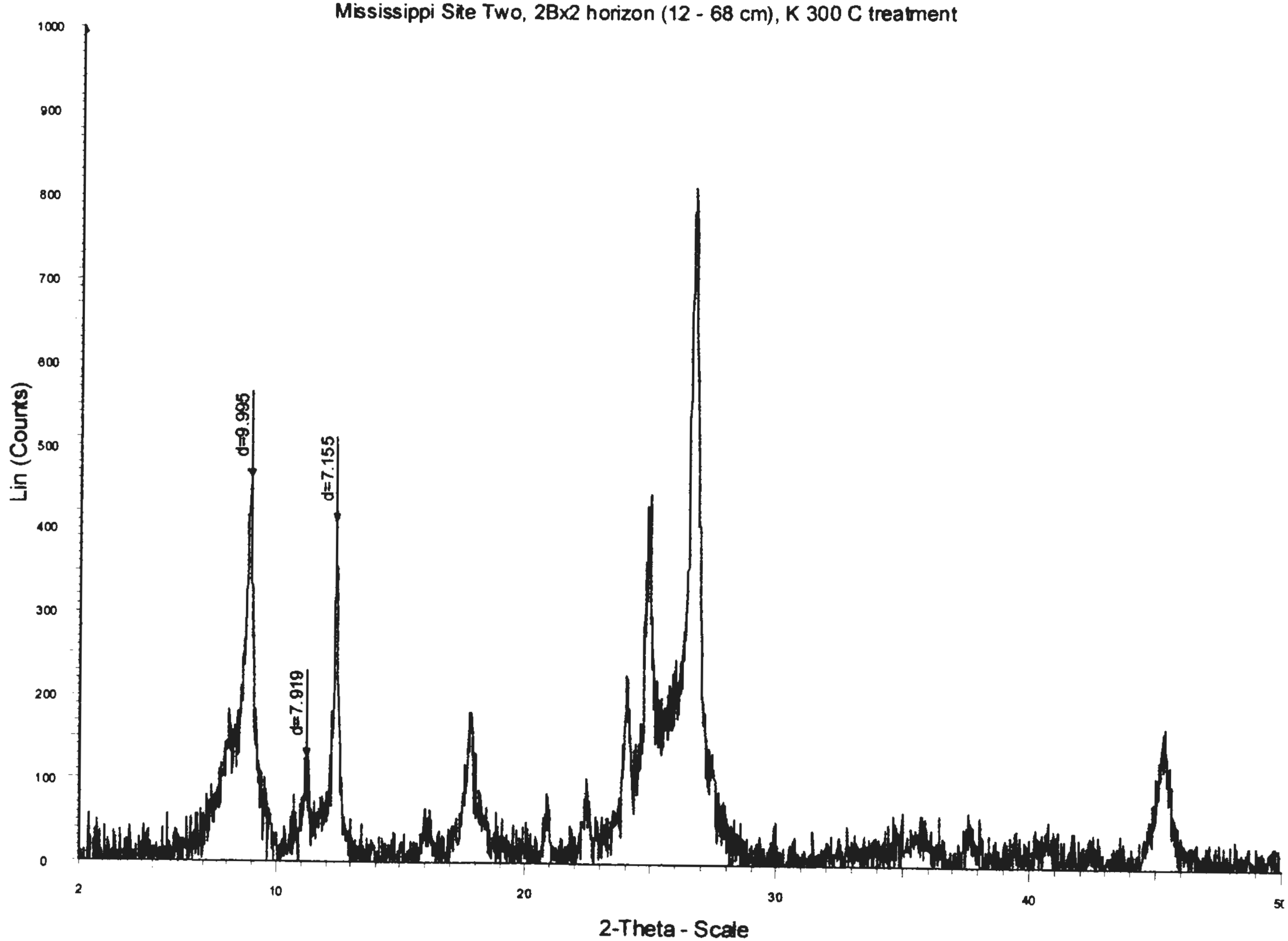



Mississippi Site Two, 2Bx1 horizon (12 - 68 cm), K air dried treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=12.200
d=7.894
d=7.150
2
10
20
30
40
50
2-Theta - Scale

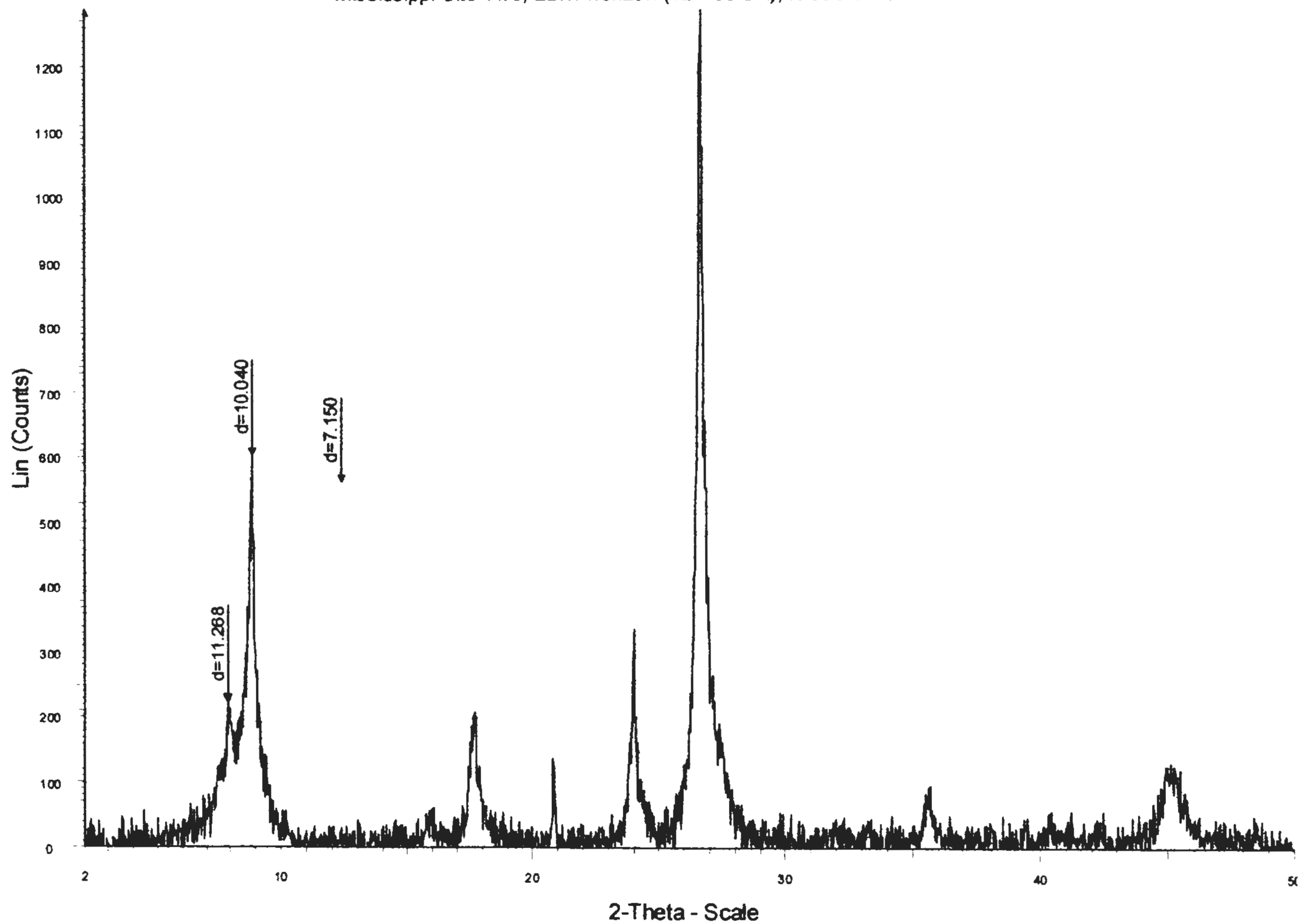
Mississippi Site Two, 2Bx1 horizon (12 - 68 cm), K 105 C treatment

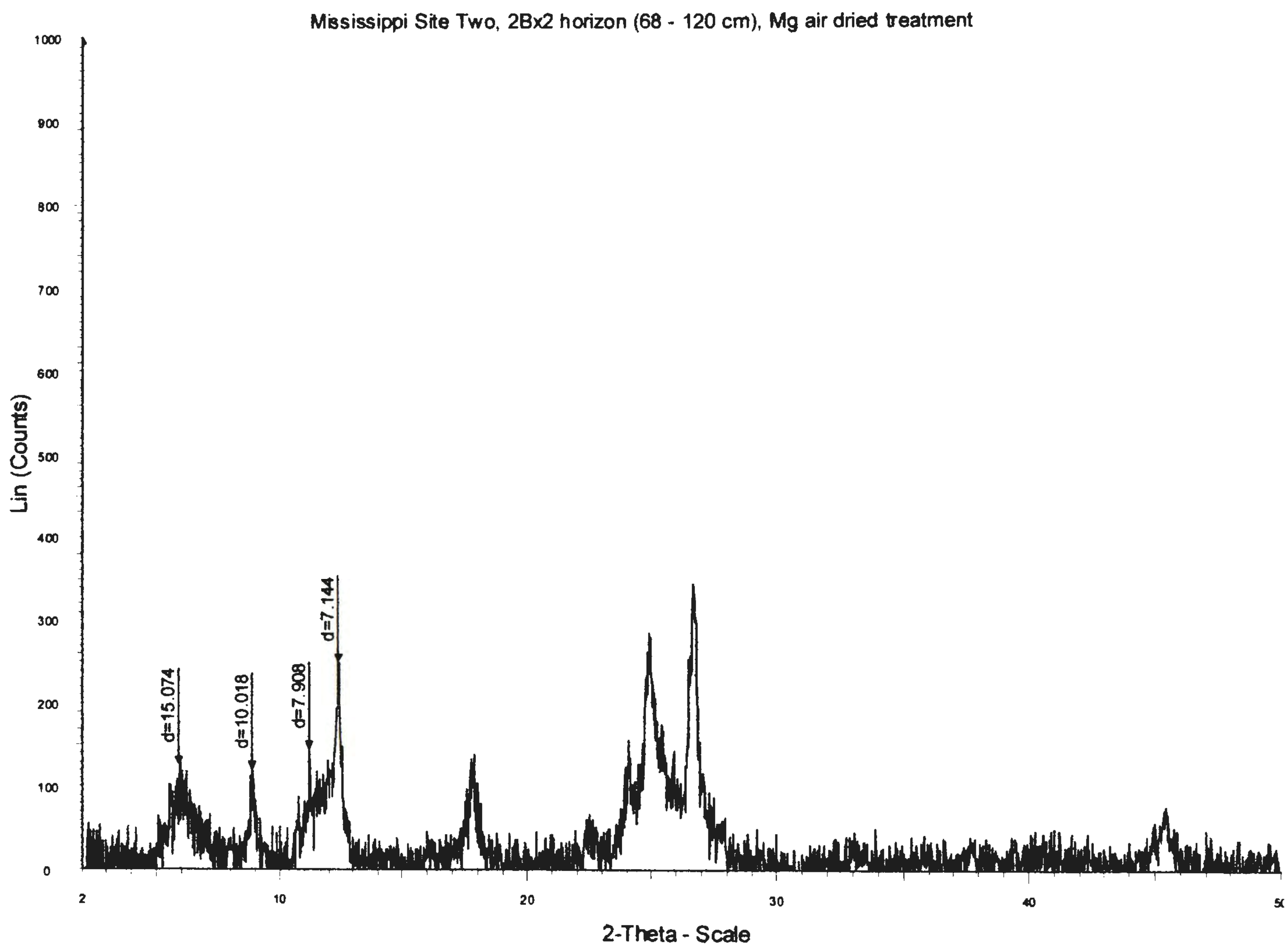


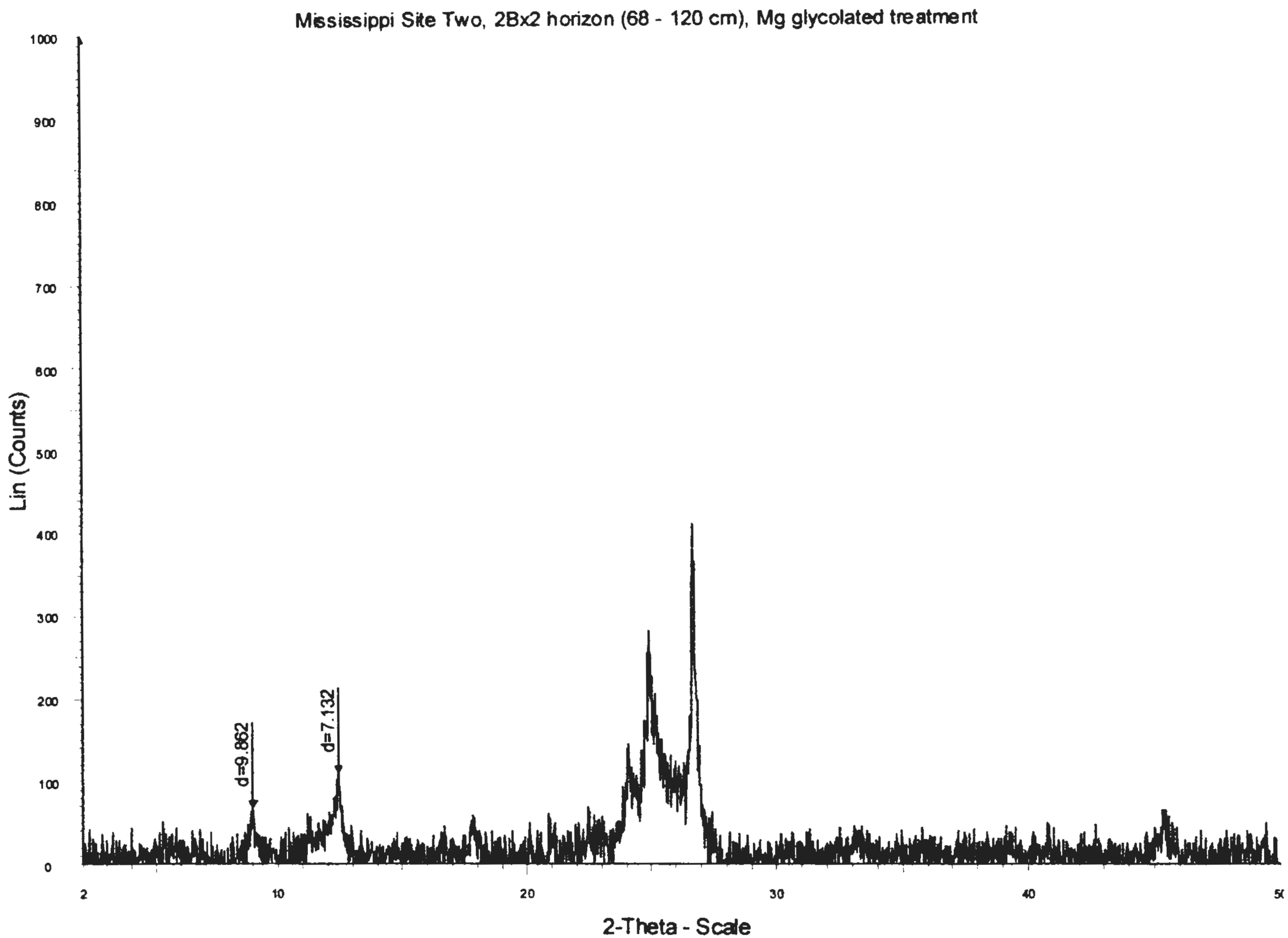
Mississippi Site Two, 2Bx2 horizon (12 - 68 cm), K 300 C treatment

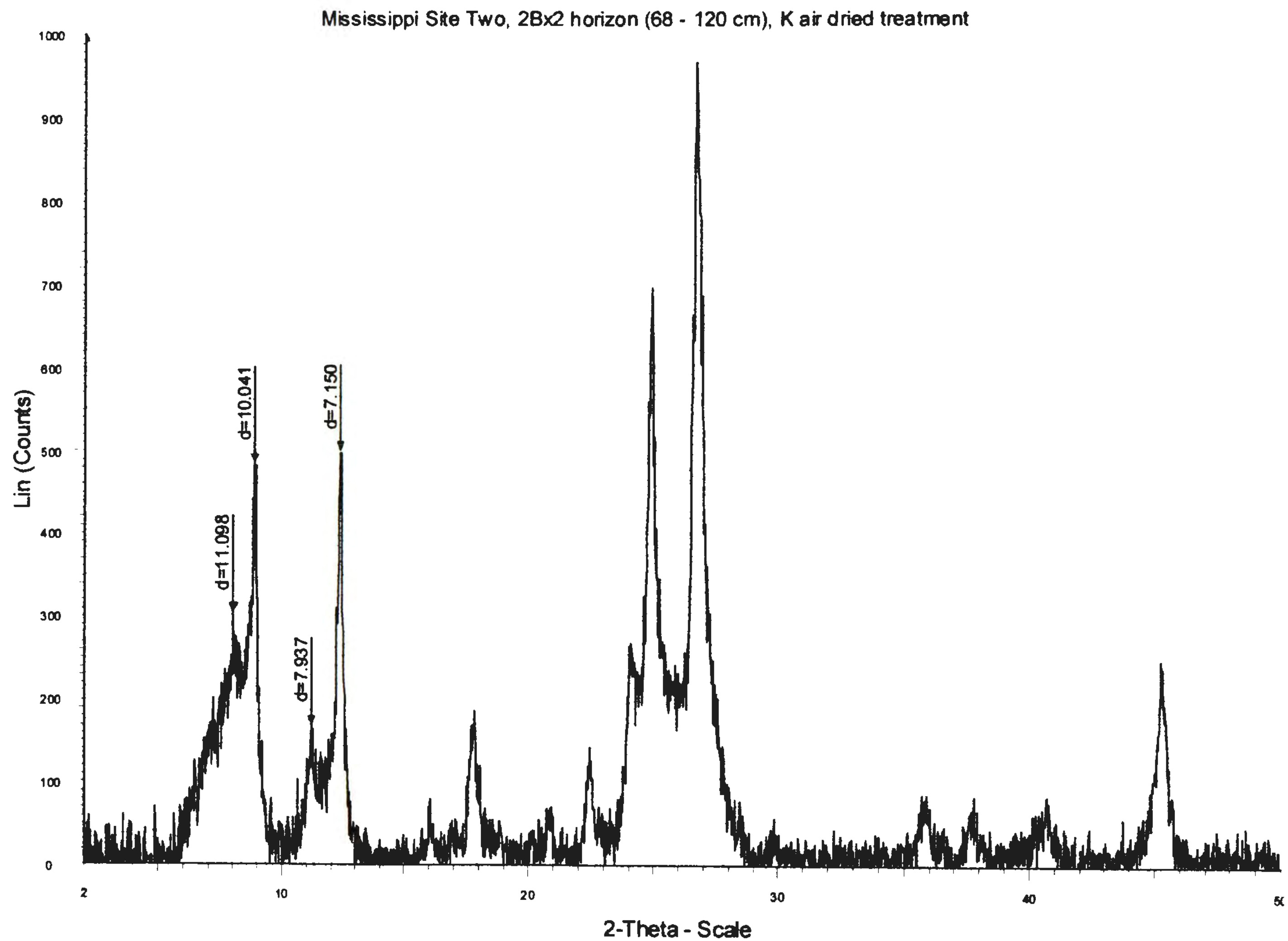


Mississippi Site Two, 2Bx1 horizon (12 - 68 cm), K 550 C treatment



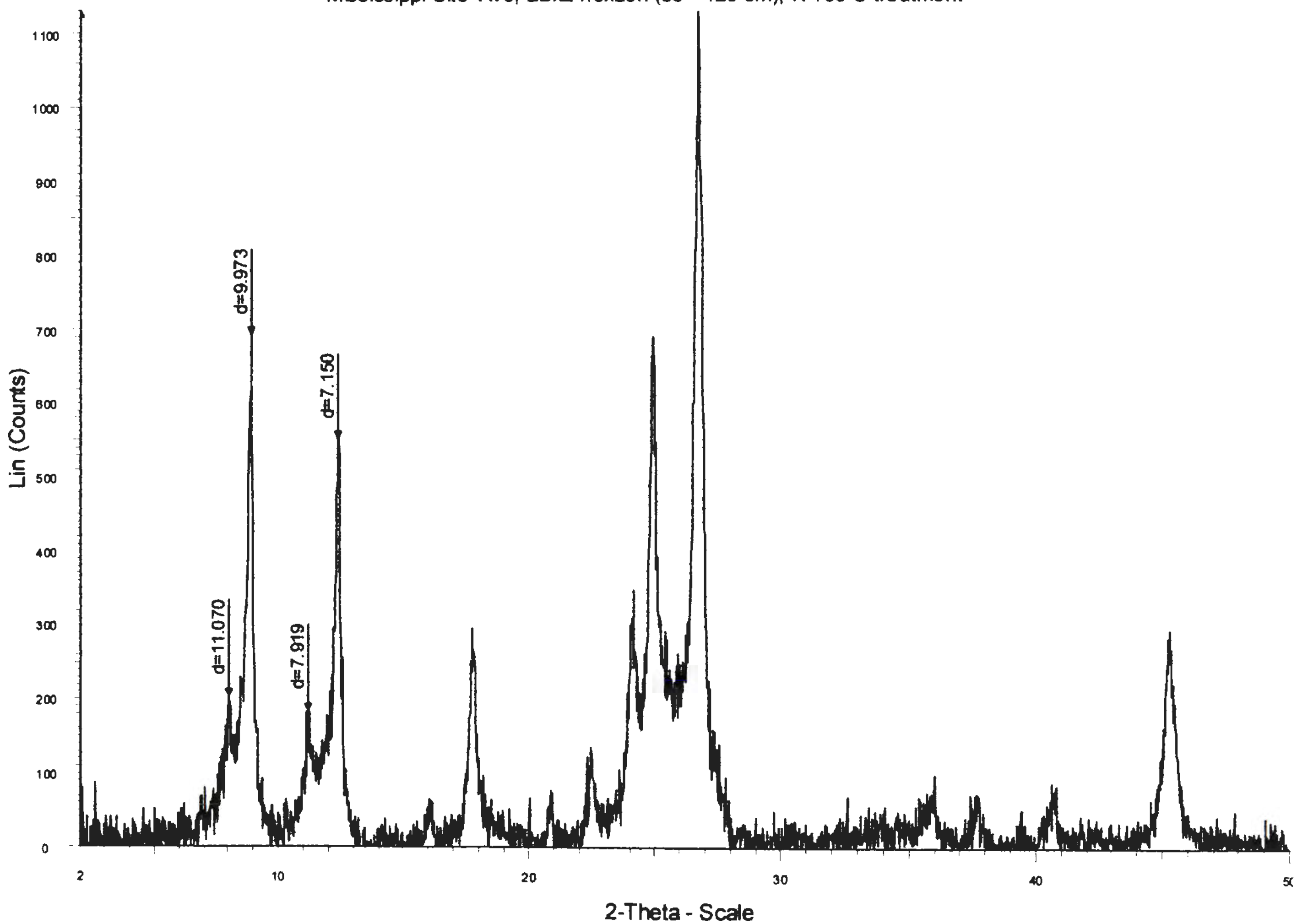

Mississippi Site Two, 2Bx2 horizon (68 - 120 cm), Mg air dried treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=15.074
d=10.018
d=7.908
d=7.144
2
10
20
30
40
2-Theta - Scale


Mississippi Site Two, 2Bx2 horizon (68 - 120 cm), Mg glycolated treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=9.862
d=7.132
2
10
20
30
40
2-Theta - Scale

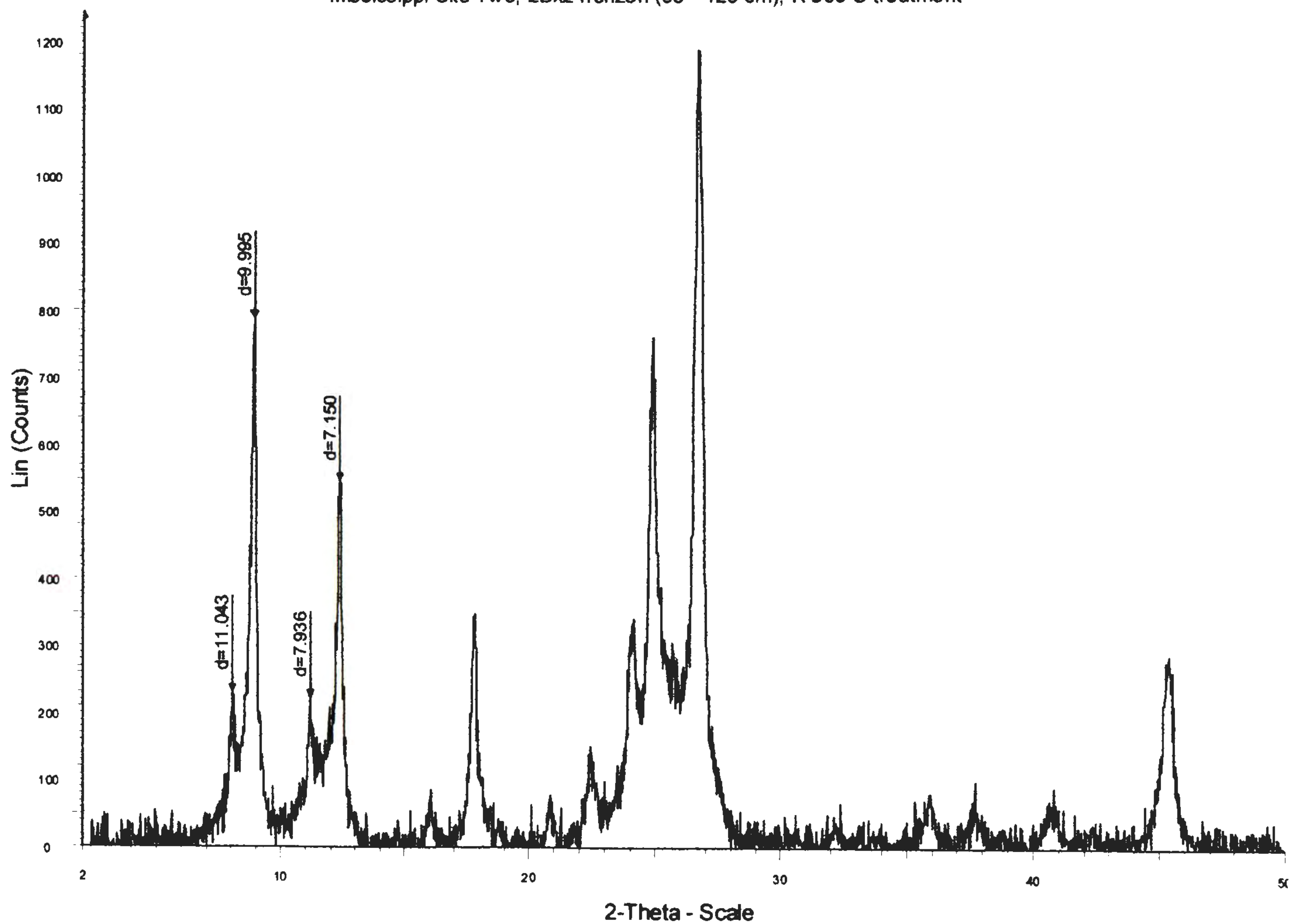


Mississippi Site Two, 2Bx2 horizon (68 - 120 cm), K air dried treatment
Lin (Counts)
2-Theta - Scale
d=11.098
d=10.041
d=7.937
d=7.150
1000
900
800
700
600
500
400
300
200
100
0
2
10
20
30
40

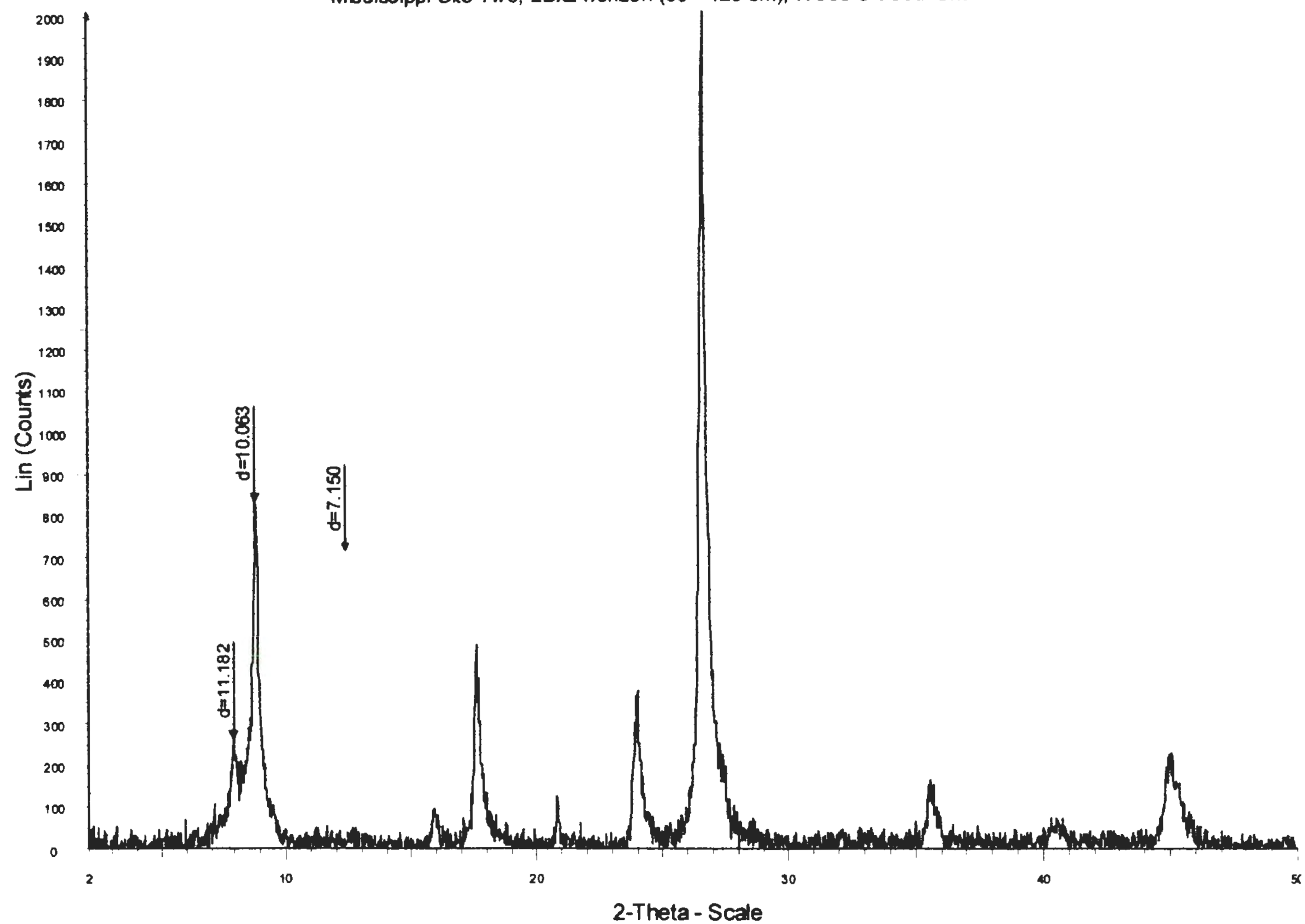
Mississippi Site Two, 2Bx2 horizon (68 - 120 cm), K 105 C treatment



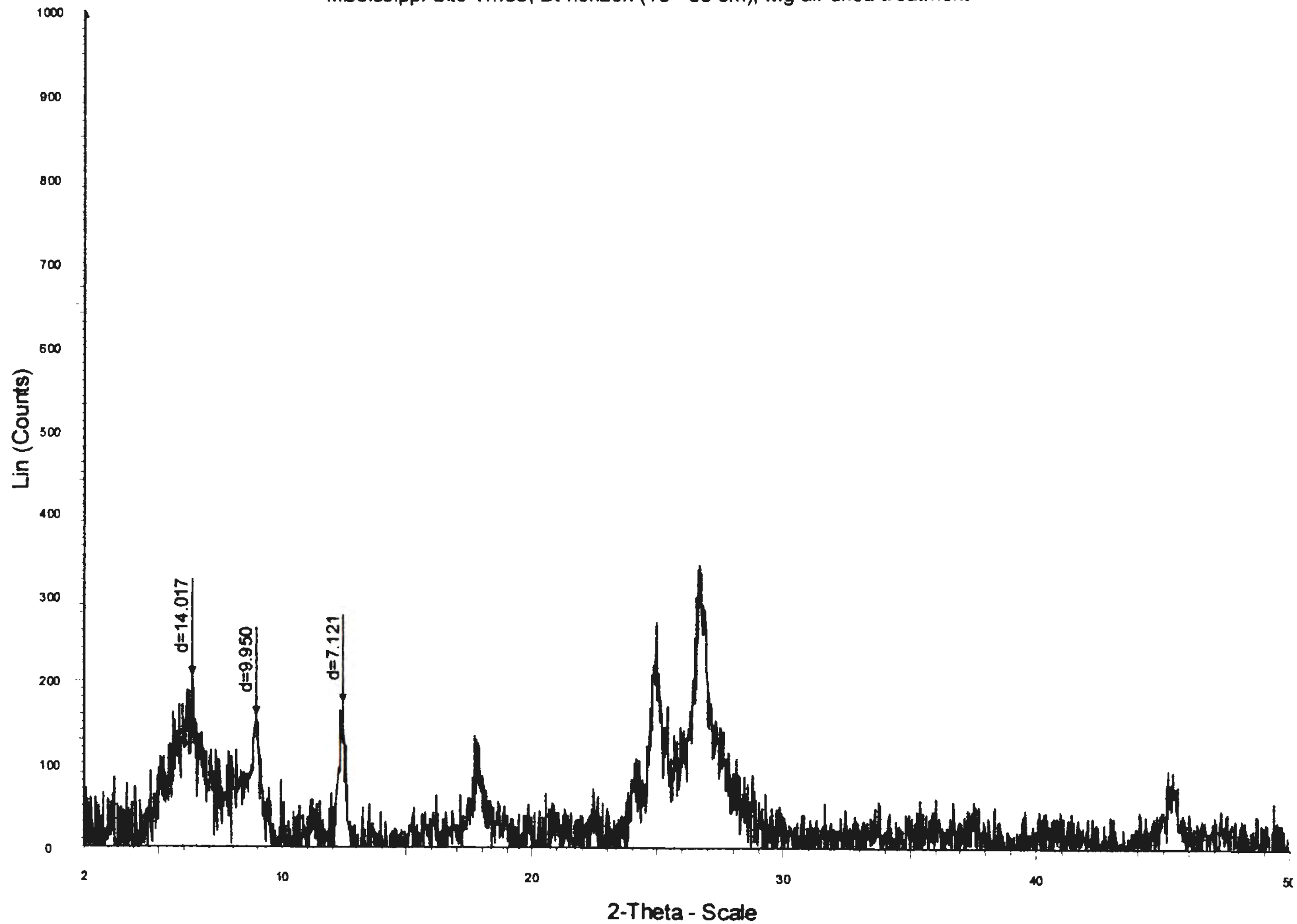
Mississippi Site Two, 2Bx2 horizon (68 - 120 cm), K 300 C treatment

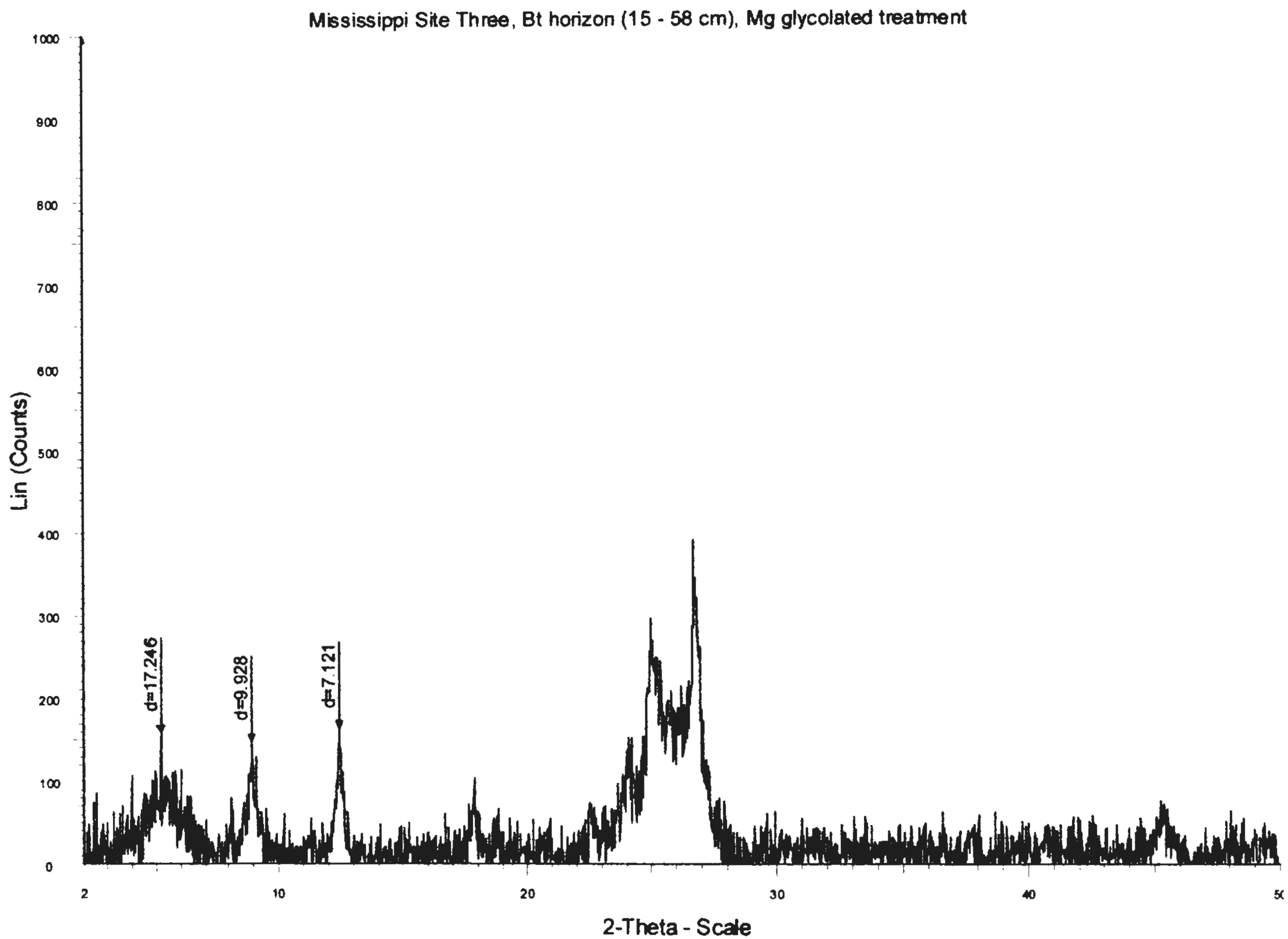


Mississippi Site Two, 2Bx2 horizon (68 - 120 cm), K 550 C treatment

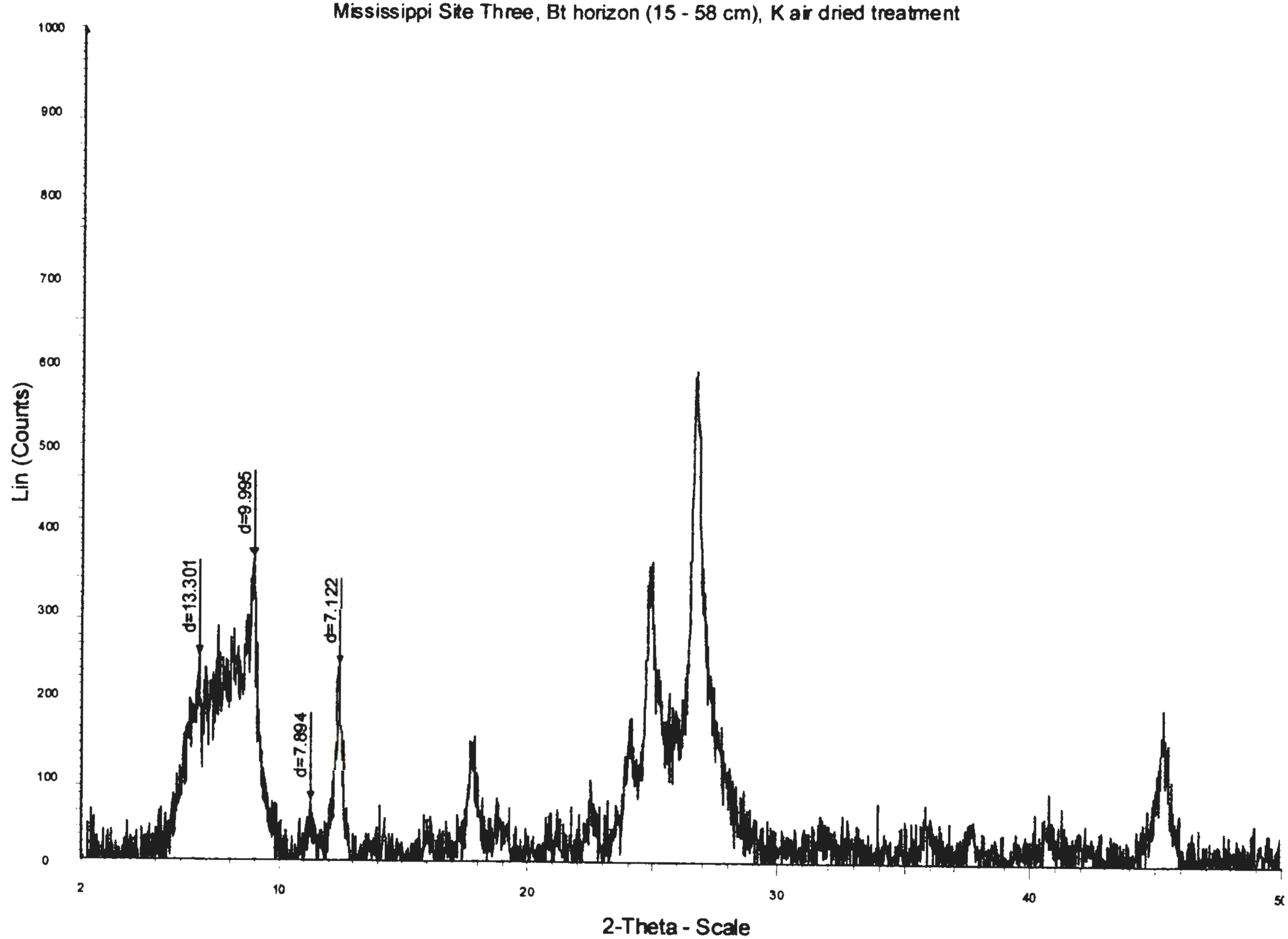


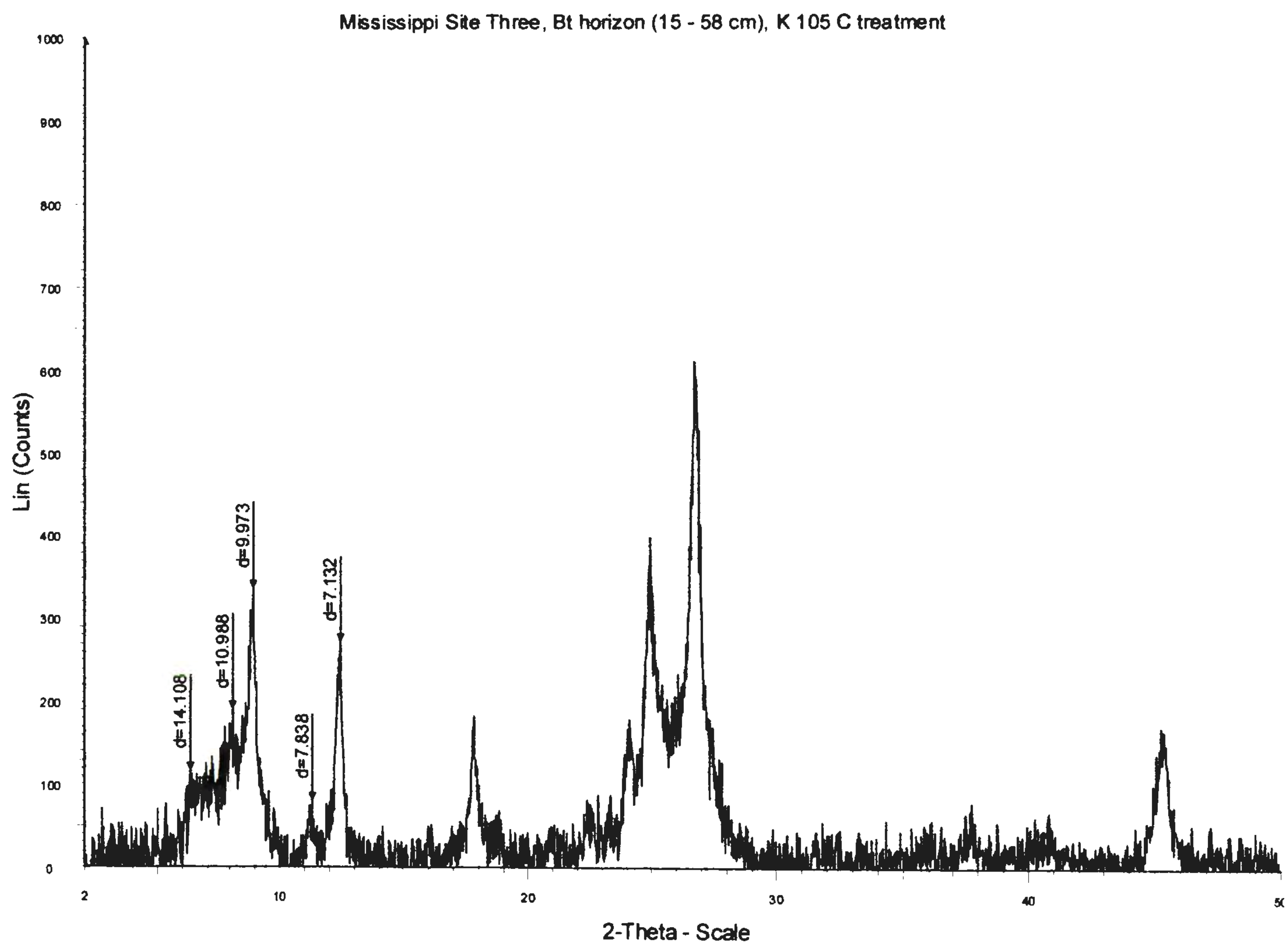
Mississippi Site Three, Bt horizon (15 - 58 cm), Mg air dried treatment



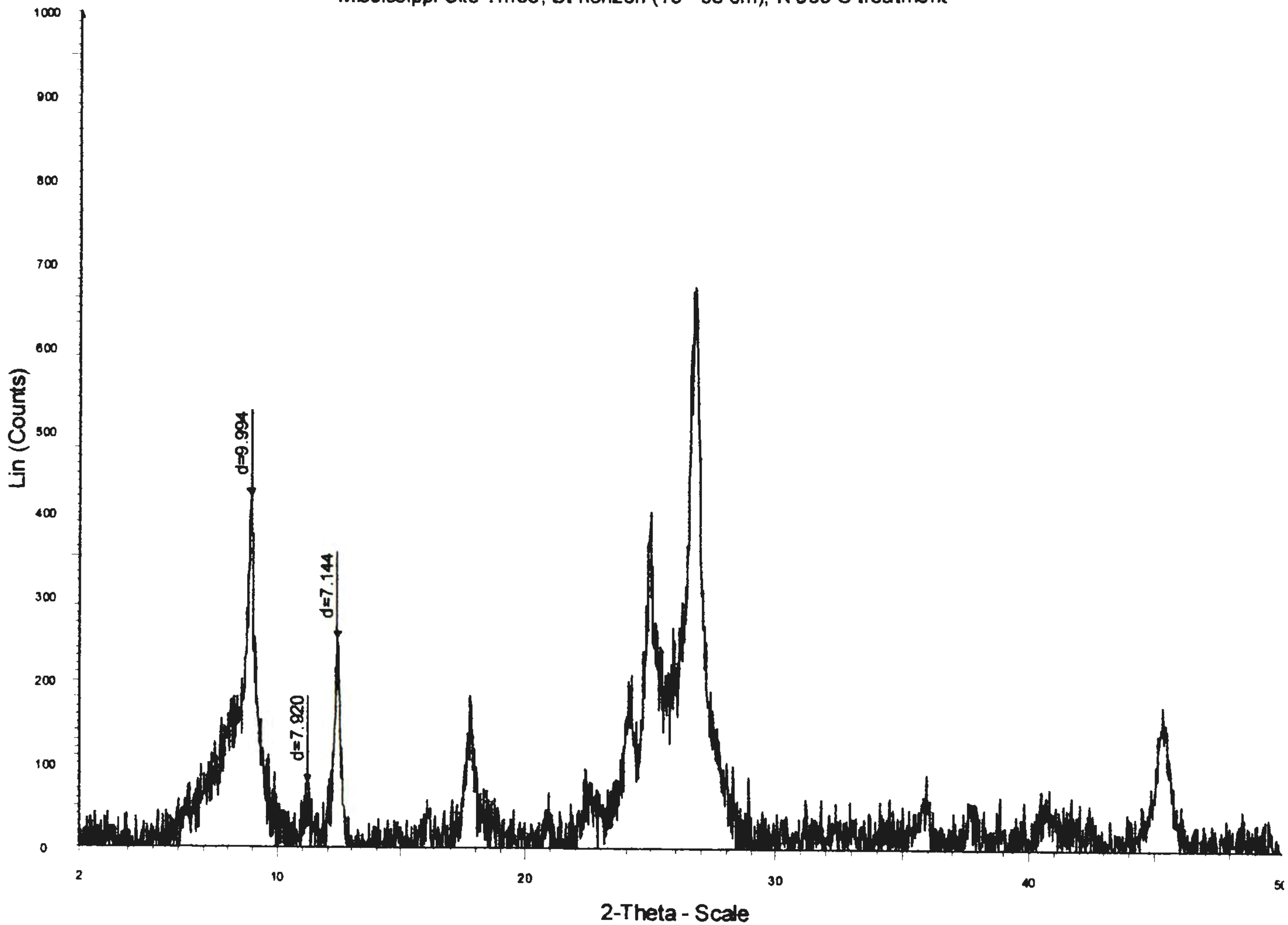

Mississippi Site Three, Bt horizon (15 - 58 cm), Mg glycolated treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=17.246
d=9.928
d=7.121
2
10
20
30
40
50
2-Theta - Scale

Mississippi Site Three, Bt horizon (15 - 58 cm), K air dried treatment

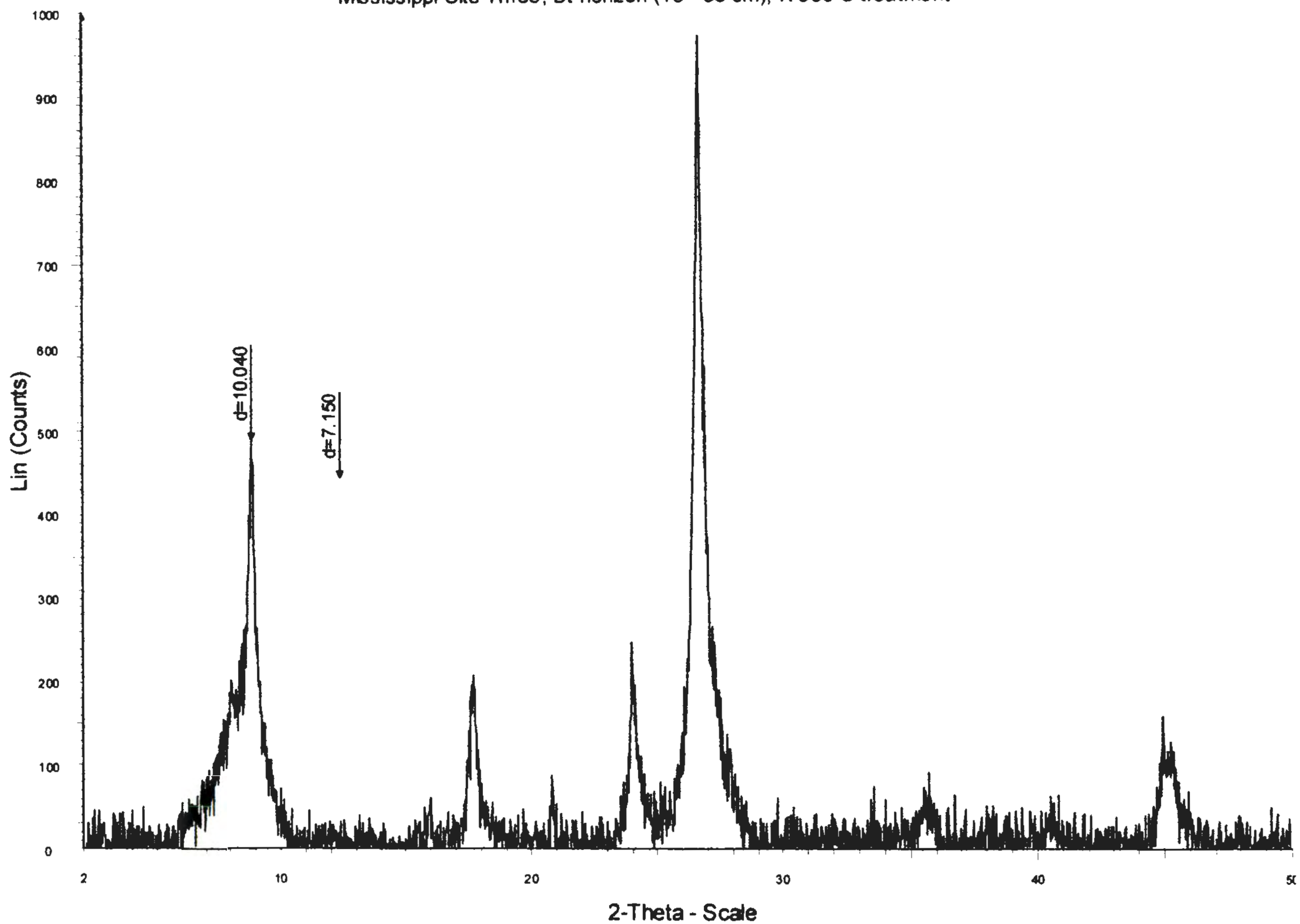



Mississippi Site Three, Bt horizon (15 - 58 cm), K 105 C treatment
Lin (Counts)
0
100
200
300
400
500
600
700
800
900
1000
d=14.108
d=10.988
d=9.973
d=7.838
d=7.132
2
10
20
30
40
2-Theta - Scale

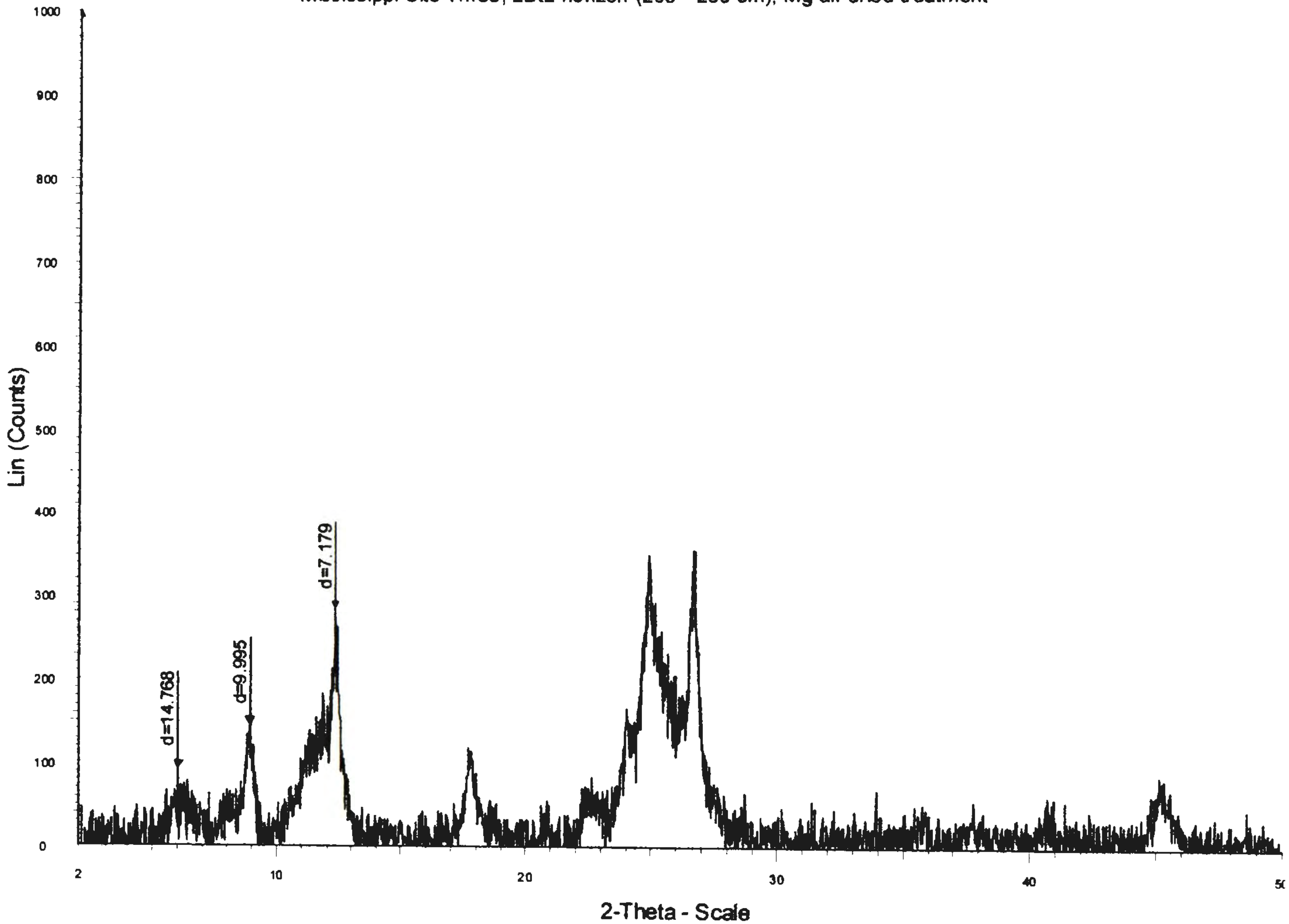
Mississippi Site Three, Bt horizon (15 - 58 cm), K 300 C treatment



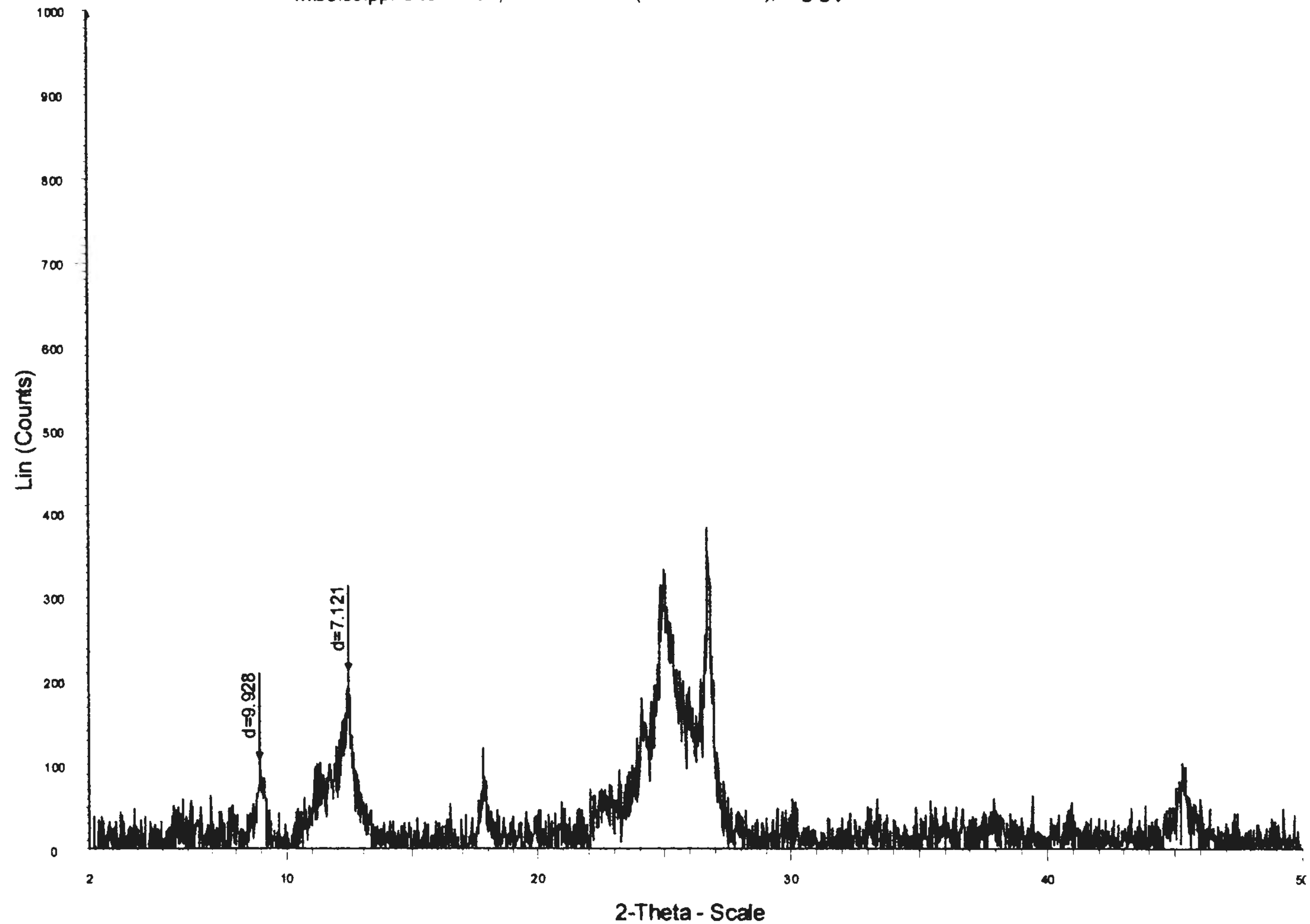
Mississippi Site Three, Bt horizon (15 - 58 cm), K 550 C treatment



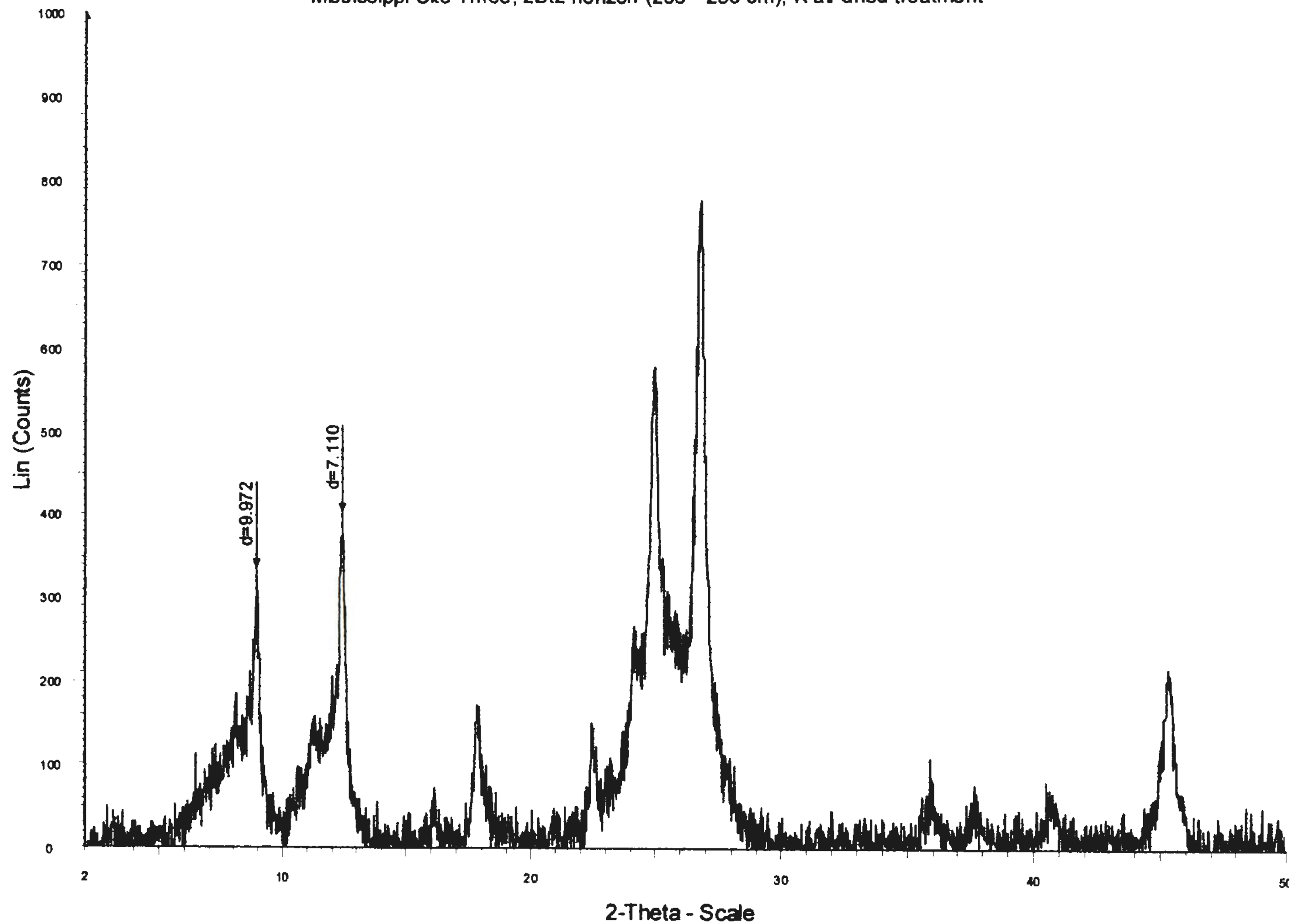
Mississippi Site Three, 2Bt2 horizon (203 - 250 cm), Mg air dried treatment



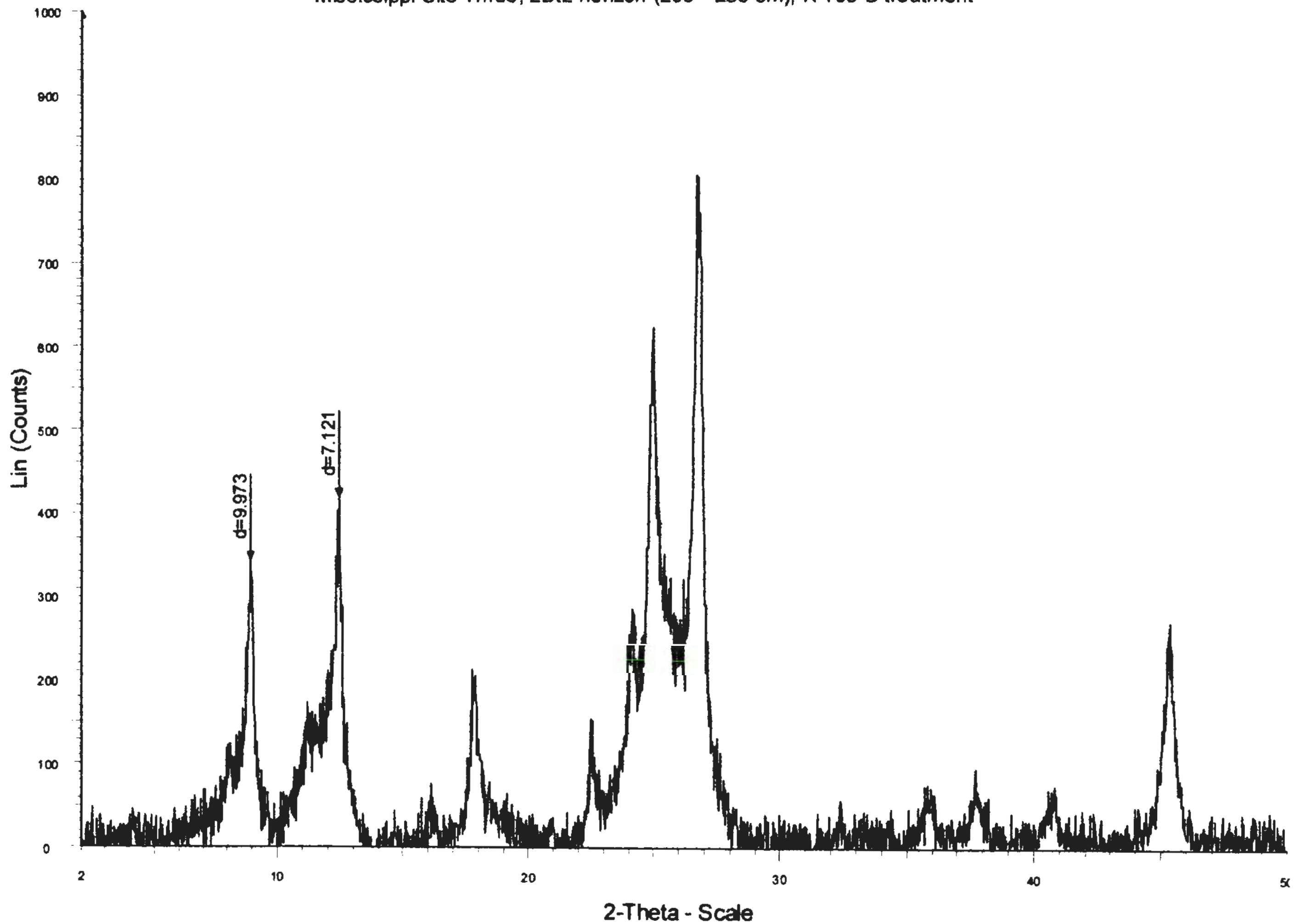
Mississippi Site Three, 2Bt2 horizon (203 - 250 cm), Mg glycolated treatment

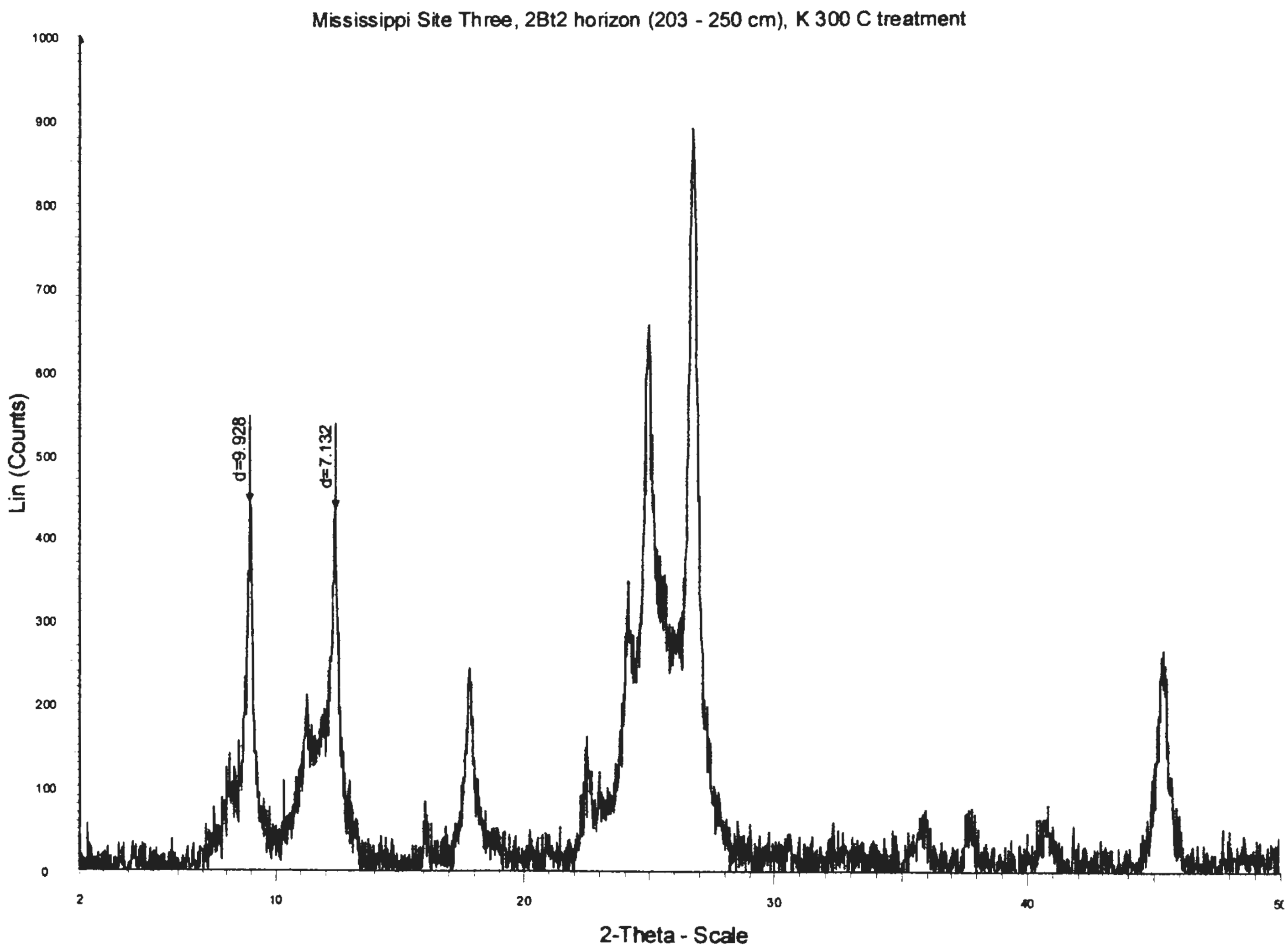


Mississippi Site Three, 2Bt2 horizon (203 - 250 cm), K air dried treatment



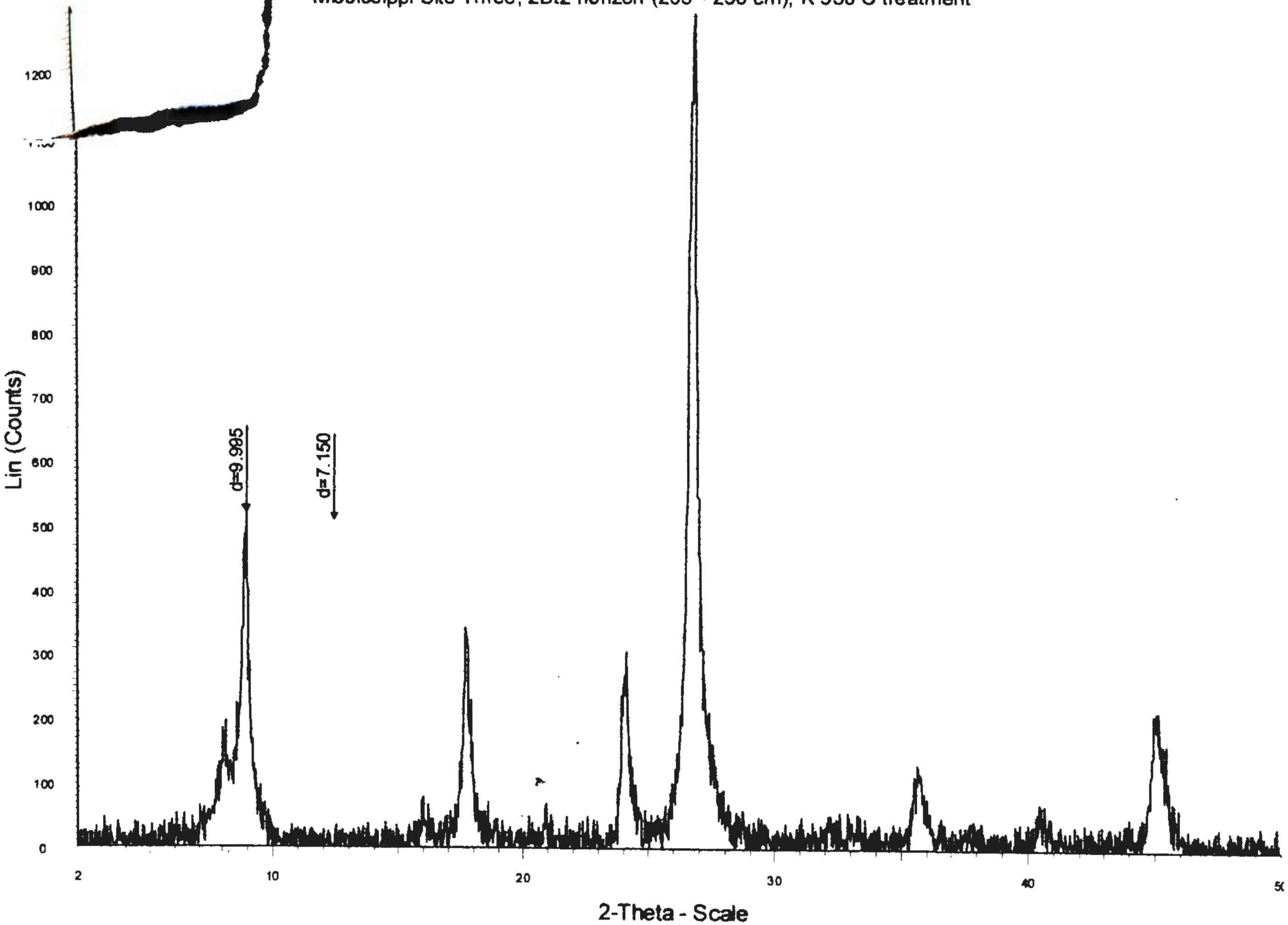
Mississippi Site Three, 2Bt2 horizon (203 - 250 cm), K 105 C treatment



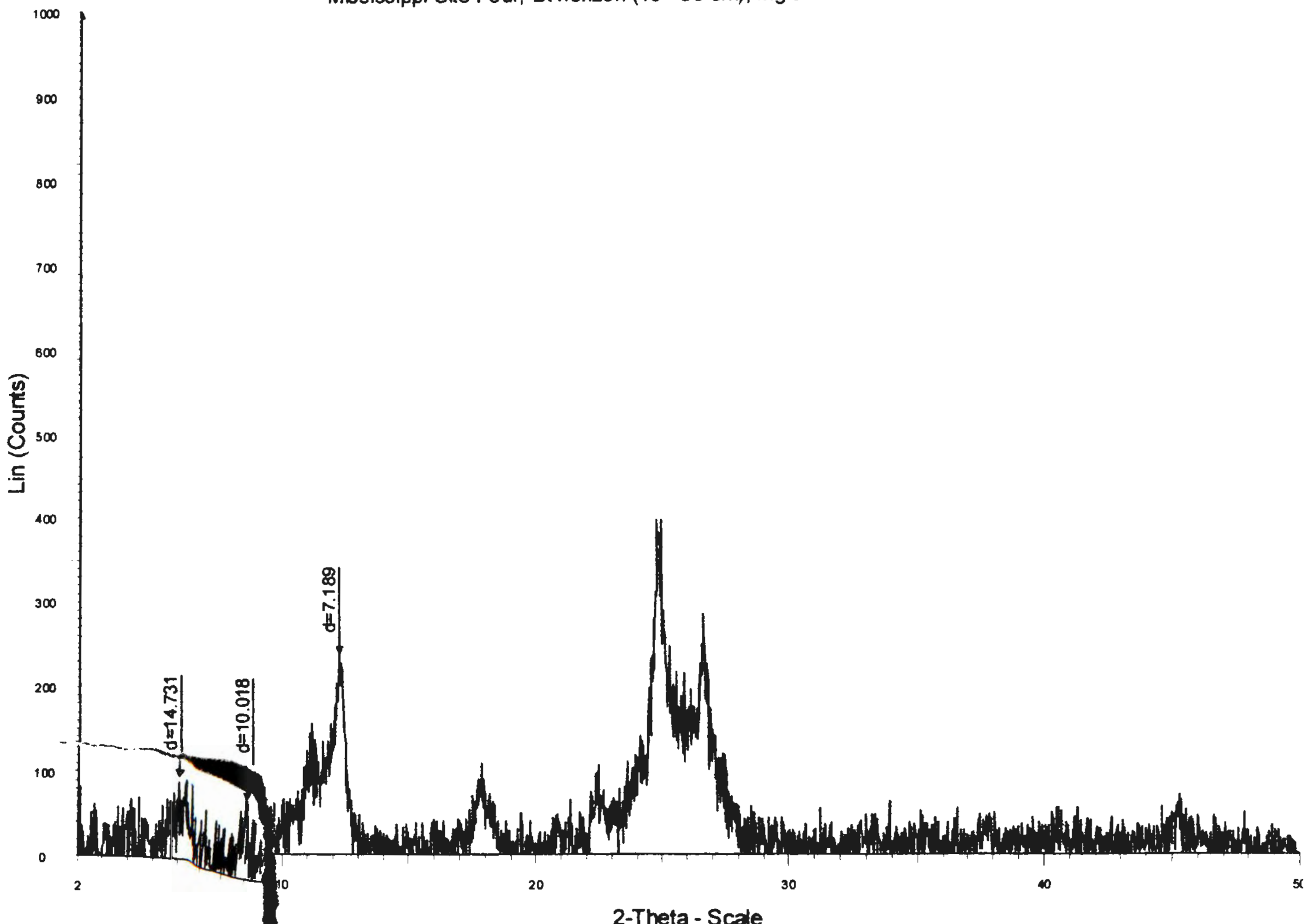


Mississippi Site Three, 2Bt2 horizon (203 - 250 cm), K 300 C treatment
Lin (Counts)
1000
900
800
700
600
500
400
300
200
100
0
d=9.928
d=7.132
2
10
20
30
40
2-Theta - Scale

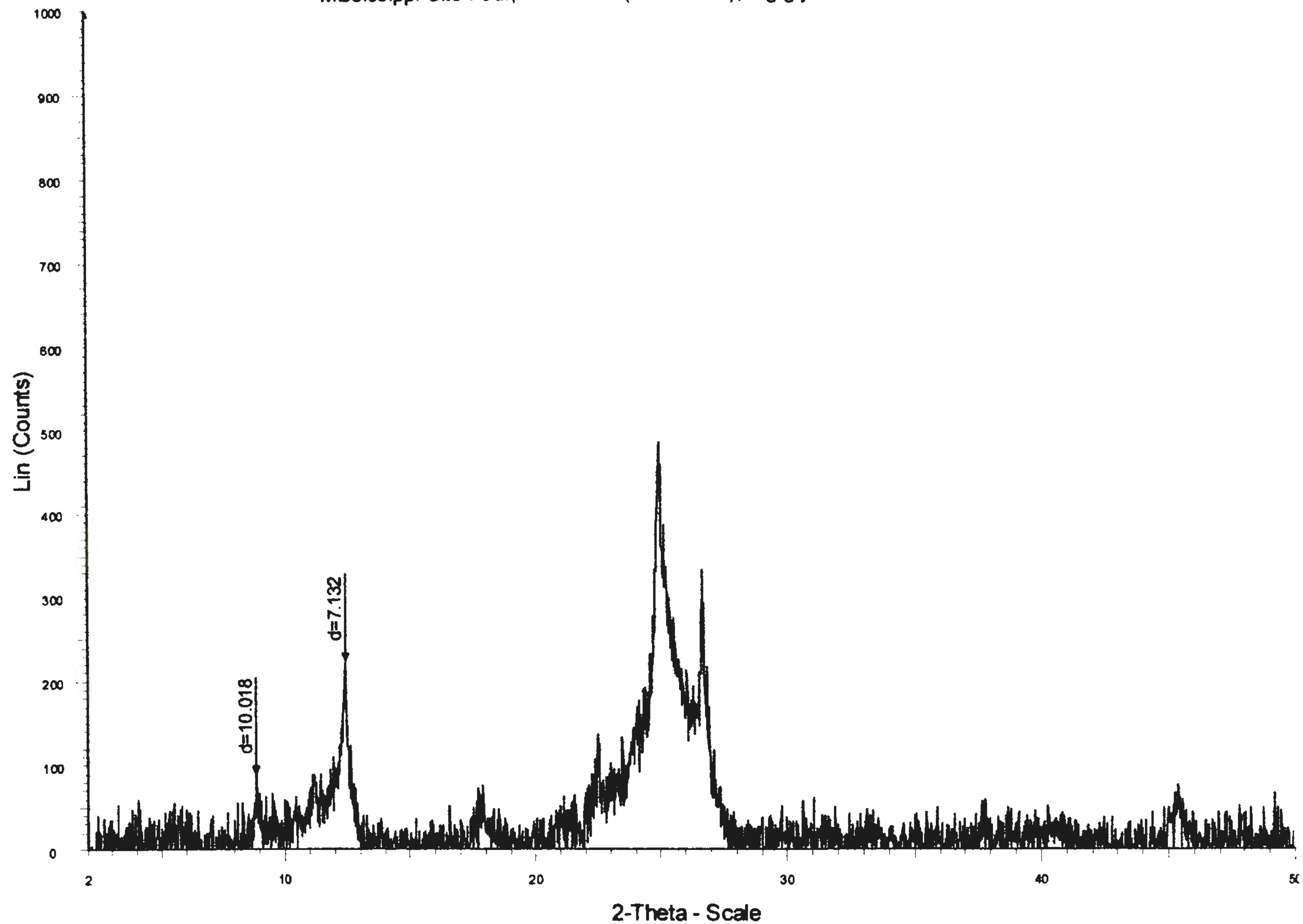
Mississippi Site Three, 2Bt2 horizon (203 - 250 cm), K 550 C treatment



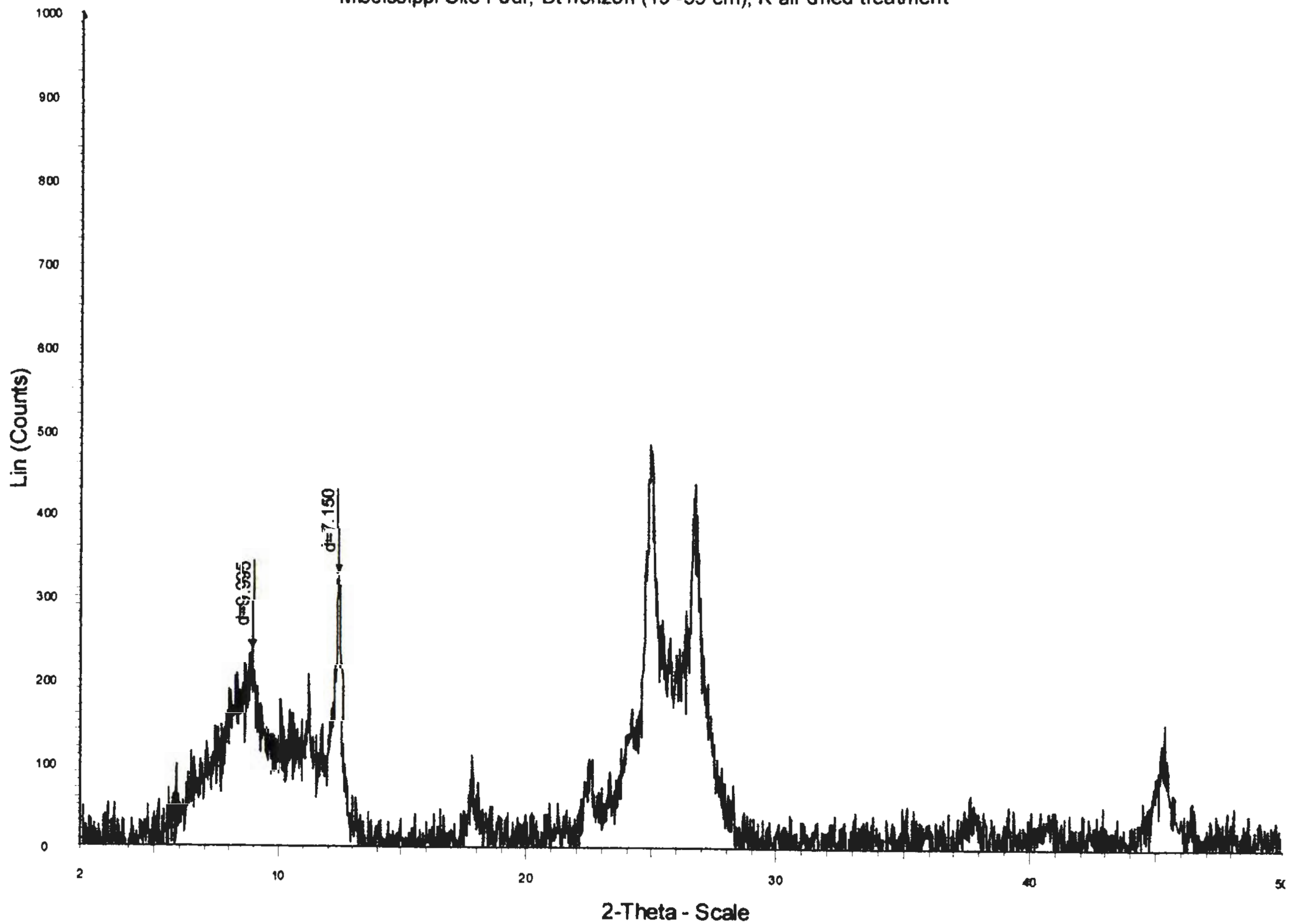
Mississippi Site Four, Bt horizon (19 - 59 cm), Mg air dried treatment



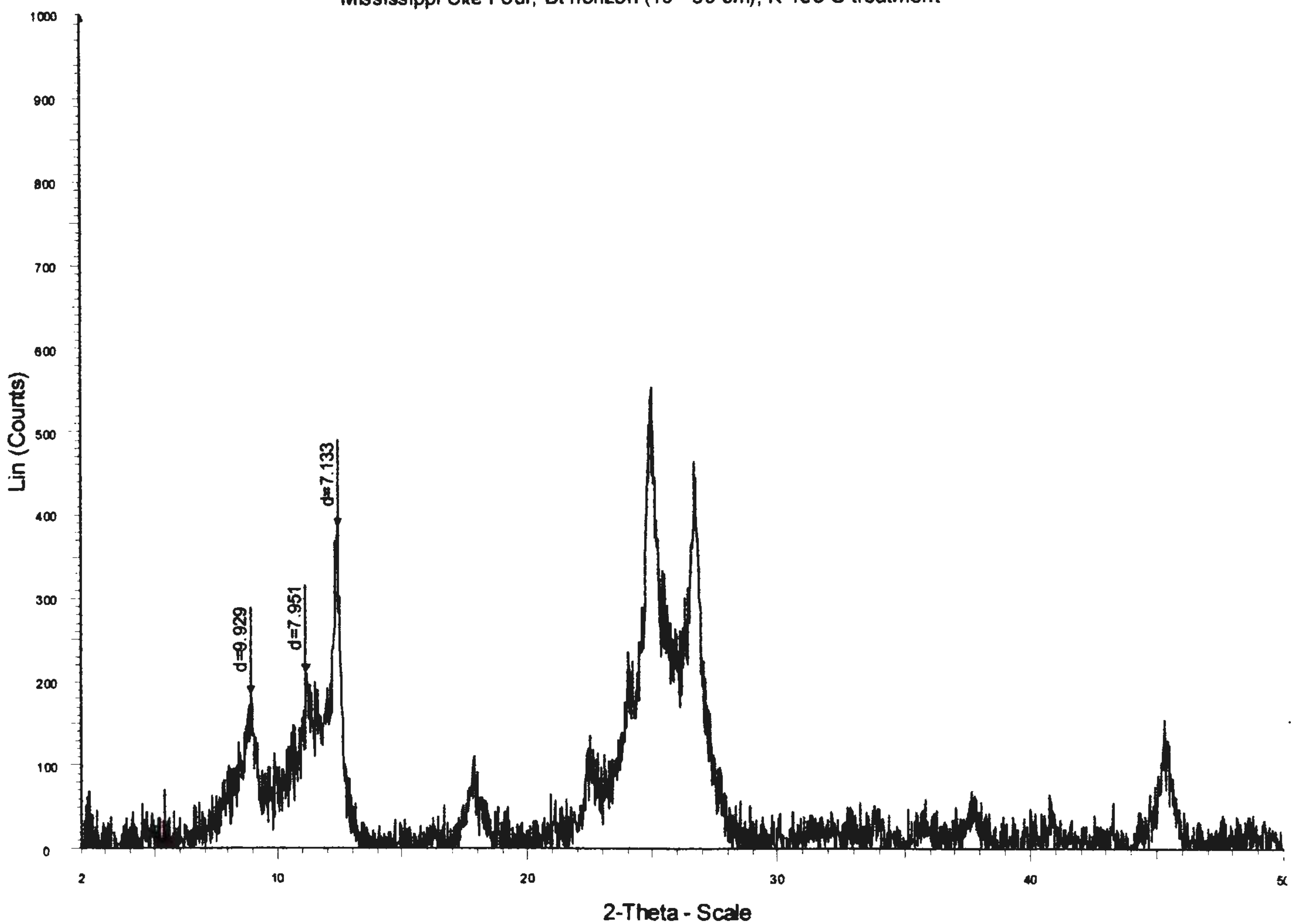
Mississippi Site Four, Bt horizon (19 - 59 cm), Mg glycolated treatment



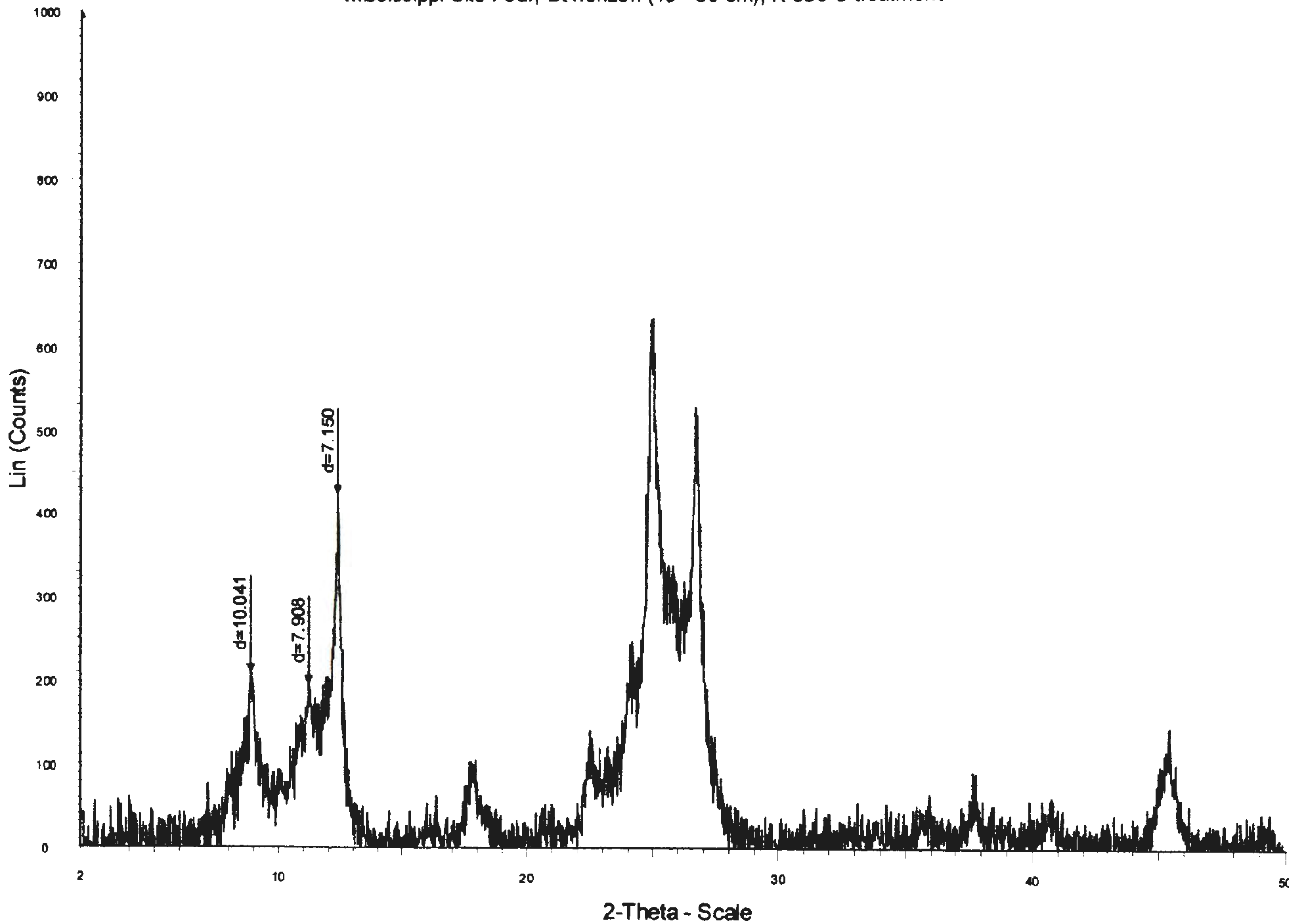
Mississippi Site Four, Bt horizon (19 -59 cm), K air dried treatment



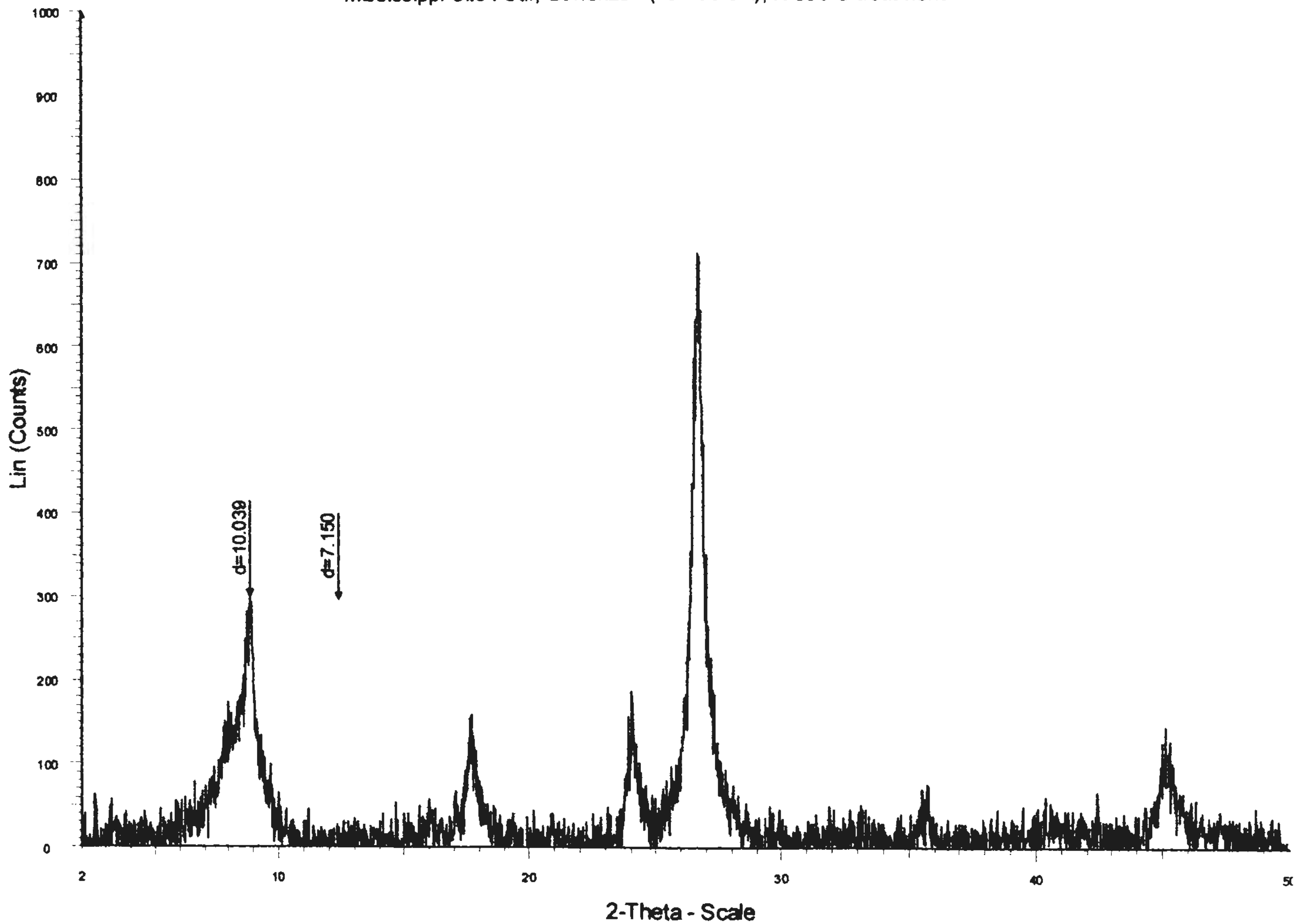
Mississippi Site Four, Bt horizon (19 - 59 cm), K 105 C treatment



Mississippi Site Four, Bt horizon (19 - 59 cm), K 300 C treatment



Mississippi Site Four, Bt horizon (19 - 59 cm), K 550 C treatment



VITA

Kevin D. Raley was born in Chattanooga, Tennessee on March 21, 1975. His elementary education was completed in the Hamilton County Public School System and he began attending a private school, the McCallie School for Boys, shortly thereafter. He graduated from East Ridge High School in May, 1993. He began his attending The University of Tennessee, Knoxville in August 1993 where he completed his Bachelor of Science degree in Agriculture in December 1997. After his graduation, he began working as a Soil Scientist in the Land Between the Lakes region of Tennessee. In January 2001, he began graduate school at The University of Tennessee, Knoxville in pursuit of his Master of Science Degree. He graduated in May, 2003.