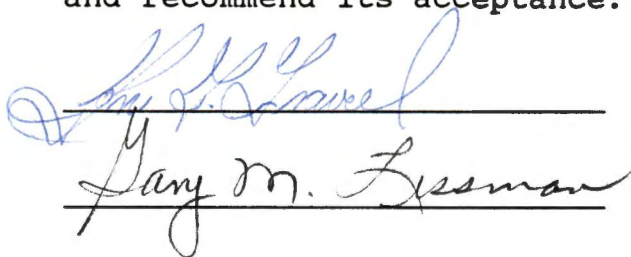


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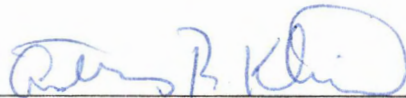
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SOIL GENESIS AND CLASSIFICATION OF THE
HIGH STREAM TERRACES ON THE
EASTERN HIGHLAND RIM IN TENNESSEE

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Anthony R. Khiel

December 1990

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DEDICATION

This work is dedicated to my wife, Mary Cay, without whose support it would not have been possible.

ACKNOWLEDGMENTS

The author wishes to thank the Institute of Agriculture and the Department of Plant and Soil Science for their support in providing the opportunity to pursue graduate studies.

A special thanks is extended to Dr. John T. Ammons for serving as the major professor and for providing direction and moral support to the author throughout the research process.

A word of thanks is offered to the members of the author's graduate committee, Dr. John Graveel and Dr. Gary Lessman, for their help and words of encouragement.

The author would also like to thank Nathan Hartgrove and Mike Timpson for their help in the field and in the laboratory.

Appreciation is extended to Carolyn and John Harris for their support.

Finally, a special word of thanks is offered to the author's parents, Omar and Marie, and brothers, Charles and Omar, for their unending support over the years.

ABSTRACT

Soils occurring on the ancient high stream terraces on the Eastern Highland Rim in Tennessee were investigated for their genesis and classification. Five sites were chosen for sampling based on the similarity of the landscapes and on the presence of krotovinas at each site. The krotovinas are believed to be the remains of ancient crayfish (*Cambarus fodiens*) burrows. The soils occurring on the five sites were described in the field, to a depth in excess of 5 meters, and analyzed for particle size distribution, cation exchange capacity, total carbon, dithionite extractable iron, hydroxylamine manganese, exchangeable bases, and clay and sand mineralogy. The soils were subsequently classified according to Soil Taxonomy. The soils classified at the Great Group level as Paleudults, Hapludalfs, and Paleudalfs.

All soils in this study formed in a parent material sequence of loess over alluvium. The loess is believed to be of local origin and approximately 10,000 years old or younger. The alluvium was deposited by an ancient stream system that was once active in this region of the Eastern Highland Rim. The disappearance of the stream that deposited this material is believed to be caused by a combination of stream meandering and stream piracy.

The paleosol that formed in the alluvial deposits is approximately 500,000 years old (mid-Pleistocene). The entire region is underlain, geologically, by Mississippian limestone of the St. Louis formation.

TABLE OF CONTENTS

CHAPTER	PAGE
1. INTRODUCTION	1
2. THE GEOMORPHOLOGY OF THE INVESTIGATED STREAM TERRACES	3
Literature Review	
Materials and Methods	
Discussion	
Conclusion	
3. SOIL GENESIS AND CLASSIFICATION	14
Literature Review	
Materials and Methods	
Results and Discussion	
Krotovina Occurrence and Formation	
Water Quality Implications of Deep Soil Investigations	
Difficulties with the Use of Soil Taxonomy	
Conclusions	
LIST OF REFERENCES	94
APPENDIXES	101
APPENDIX 1. SAND COUNT PROCEDURE	102
APPENDIX 2. X-RAY DIFFRACTOGRAMS	103
VITA	112

LIST OF TABLES

TABLE	PAGE
1. Soil morphological data for Site 1	22
2. Identification and average profile content estimation of the less than 2 micron clay samples from the soil pedons sampled as determined by X-Ray Diffraction	32
3. Quantitative mineral identification of the dominant sand fractions from the control sections of the pedons sampled	34
4. Comparison of old and new soil classification at each site sampled according to Soil Taxonomy	35
5. Exchangeable base cation content and base saturation of the soil pedon at Site 1	37
6. Soil morphological data for Site 2	38
7. Exchangeable base cation content and base saturation of the pedon at Site 2	48
8. Soil morphological data for Site 3	52
9. Exchangeable base cation content and base saturation of the pedon at Site 3	61
10. Soil morphological data for the pedon at Site 4	62
11. Exchangeable base cation content and base saturation of the pedon at Site 4	72
12. Soil morphological data for the pedon at Site 5	73
13. Exchangeable base cation content and base saturation of the pedon at Site 5	83

LIST OF FIGURES

FIGURE	PAGE
1. Relationship of the stream terrace remnants to the surrounding residual limestone surfaces	8
2. Ratio of fine and very fine sand to total sand plotted with depth of the soil profile at Site 1	23
3. Parent material sequence of the pedons sampled	24
4. Sand, silt, and clay distribution in the soil profile at Site 1	26
5. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 1	27
6. Hydroxyl Amine-Hydrochloride manganese distribution in the soil profile at Site 1	29
7. Total carbon distribution in the soil profile at Site 1	31
8. Diagram of the positioning of the sampling tube during the field investigation of Site 2	39
9. Ratio of fine and very fine sand to total sand plotted with depth of the soil profile at Site 2	40
10. Sand, silt, and clay distribution in the soil profile at Site 2	41
11. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 2	43
12. Hydroxyl Amine-Hydrochloride manganese distribution in the soil profile at Site 2	44
13. Total carbon distribution in the soil profile at Site 2	46

FIGURE	PAGE
14. Ratio of fine and very fine sand to total sand plotted with depth of the soil profile at Site 3	53
15. Sand, silt, and clay distribution in the soil profile at Site 3	54
16. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 3	56
17. Hydroxyl Amine-Hydrochloride manganese distribution in the soil profile at Site 3	57
18. Total carbon distribution in the soil profile at Site 3	58
19. Ratio of fine and very fine sand to total sand plotted with depth of the soil profile at Site 4	63
20. Sand, silt, and clay distribution in the soil profile at Site 4	64
21. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 4	65
22. Hydroxyl Amine-Hydrochloride manganese distribution in the soil profile at Site 4	68
23. Total carbon distribution in the soil profile at Site 4	69
24. Ratio of fine and very fine sand to total sand plotted with depth of the soil profile at Site 5	74
25. Hydroxyl Amine-Hydrochloride manganese distribution in the soil profile at Site 5	76
26. Sand, silt, and clay distribution in the soil profile at Site 5	77
27. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 5	78

FIGURE	PAGE
28. Total carbon distribution in the soil profile at Site 5	80
29. Comparison of the Hydroxyl Amine-Hydrochloride manganese distribution from all sampled sites	89

LIST OF PLATES

PLATE		PAGE
1.	Study area delineations and site locations marked on the Corbin topographical quadrangle	In Pocket
2.	Soil profile from excavation near site 2	49
3.	Cross sectional exposure of a krotovina	50
4.	Krotovinas exposed in a roadcut along Old Kentucky Road in Cookeville, Tennessee	84
5.	View of intact rind that formed on the boundary between the alluvial material and the krotovina fill material	85
6.	Close-up of rind showing manganese and iron segregation	86

LIST OF ABBREVIATIONS

<u>Abbreviation</u>	<u>Meaning</u>
Concr	Concentration
HIV	Hydroxyintrelayered Vermiculite
BSAT	Base Saturation
Fragr	Fragments
AD	Air Dried
Gly	Gylcol

CHAPTER 1

INTRODUCTION

This thesis is a presentations of the research findings from a project designed to investigate the genesis and classification of the soils occurring on the ancient high stream terraces on the Eastern Highland Rim in Tennessee. The objectives of the study were:

1. to determine the origin of the ancient high stream terraces;
2. to explain the genesis of the soils occurring on the terraces;
3. to delineate the extent of the terrace soils remaining on the modern landscape;
4. to classify the terrace soils according to Soil Taxonomy for use in future soil mapping endeavors.

The study area was located on the physiographic province known as the Eastern Highland Rim in middle Tennessee. The specific sites that were sampled were located in Putnam County and are marked on the Corbin topographic quadrangle (In Pocket). The sites include sampled sites, marked S1 through S5, and observation sites, marked O1 through O5. The general reasons for specific site selection included the presence of krotovinas on the

landscape and the accessibility of the site. The significance of the krotovinias will be discussed later in this report. The study involved both large scale landscape investigation using aerial photography and topographical maps.

This study was designed to link the pursuit of basic research in soil science that was needed in this region of Tennessee to applied research as it pertains to future soil survey and land use planning. The genesis of the alluvial soils on the Eastern Highland Rim has not been investigated to the knowledge of the author at the time of this writing. Also, the United States Department of Agriculture - Soil Conservation Service is conducting county soil surveys in other counties on the Eastern Highland Rim and the results of this research will be used by them in the survey procedure. Therefore, this research allows for the pursuit of knowledge for academic reasons as well as providing information for the public use.

CHAPTER 2

THE GEOMORPHOLOGY OF THE INVESTIGATED STREAM TERRACES

Literature Review

Geomorphology is defined in the Dictionary of Geological Terms (Bates and Jackson, 1984) as "the study of the classification, description, nature, origin, and development of landforms and their underlying structures, and the history of geologic changes as recorded by these geologic changes." The branch of soil science known as pedology deals with the formation of soils on present and past landscapes. These two sciences are closely related because they deal with the formation of past and present landscapes.

Stream terraces are abandoned floodplains that are not related to the existing stream and are composed of two parts, the scarp and the tread above and behind the scarp (Gerrard, 1981). The scarp is the sloping portion of the feature that once formed the stream channel wall. The tread is the level part of the feature that was once the floodplain. Howard and others (1959) have categorized terraces as erosional and depositional. Erosional terraces are those in which the tread has been formed by lateral

erosion. Depositional terraces, on the other hand, are those in which the tread represents an uneroded surface of valley fill (Ritter, 1986). The terraces investigated in this study are depositional in nature.

The formation of depositional terraces requires both a period of valley filling and subsequent entrenchment into or adjacent to the fill. The cyclic pattern is a necessity because the alluvium at the tread surface takes its form from the depositional process. The tread represents the highest level attained by the valley floor during the depositional process (Ritter, 1986). Deposition occurs when the load exceeds the stream system's ability to carry it (Leopold et al., 1964). Long term aggradation can be triggered by glacial outwash, climate change, and a change in the stream's base level or a combination of these (Ritter, 1986).

Further aspects of fluvial processes that are applicable to the formation of the high terraces in this region of Tennessee include stream meandering, and stream piracy. Stream meandering is defined by Bates and Jackson (1984) as a mature stream winding freely on a broad floodplain. Streams meander by eroding the outer banks of their meander bends and subsequently depositing the eroded material on the inside of the bend (Ritter, 1986). A meandering stream leaves its mark on the landscape in the

form of channel fill and overwash deposition. The alluvial fill in the channel position will generally be coarser and may contain a layer of large gravels sometimes called lag gravel. This is because the coarser material is able to settle out under the higher water velocity found in the channel. The overwash, or floodplain, material will be finer textured than the channel fill due to the dynamics of the finer material settling out as the velocity of the water slows (Ruhe, 1975).

Stream capture, or piracy, is the diversion of the headwaters of one stream by another stream of greater erosional capacity (Bates and Jackson, 1984). A further discussion of piracy by Ritter (1986) indicates that this process can cause spontaneous filling and cutting. The smaller tributaries rob the main channel flow by cutting headward into its path. The increased flow in the smaller channels disrupts the equilibrium and downcutting results. The removal of flow from the once main channel causes deposition of bedload and subsequent channel filling (Ritter, 1986).

Stream channel mechanical and fluvial processes lead to, in the case of this study, the formation of stream terraces that are remnants of a once active stream system.

Materials and Methods

The materials used in the geomorphic investigation into the origin of the high stream terraces included topographical quadrangle maps, both 7.5 minute quadrangles (specific quadrangles include: Burgess Falls, Cookeville-East, Cookeville-West, Dodson Branch, and Windel) and Corbin 2 degree quadrangle (USGS, current maps in issue). The methods employed for this portion of the study included the identification of the terraces at different locations on the landscape and mapping out their extent using field observations and topographical maps. The methods used to identify the actual terraces on the landscape include the location of krotvins exposed in roadcuts and subsequent soil morphological descriptions at each site.

Discussion

The geomorphic surfaces investigated in this study were located on a section of the Eastern Highland Rim that extends in a southwest to northeast direction from White County Tennessee to Wayne County, Kentucky (In Pocket). The area is bounded on the east by the Cumberland Plateau and on the west by the Central Basin of Tennessee. Geologically, the study area is underlain by Mississippian limestone of

the St. Louis formation and is influenced by strong karst topography. The landscape is typified by highly dissected rolling hills with moderate relief.

The geomorphic surfaces that were investigated fit the basic pattern of a residual surface, from the limestone, covered by a fluvial surface that was subsequently covered by loess. On these dissected landscapes, the alluvial deposits exist as remnants in some stable upland positions. Other upland positions contain a similar pattern except that the fluvial surface is not present. The presence of the water-deposited geomorphic surface was identified by the occurrence of krotovina and lag gravel in roadcuts and exposed banks (Webb et al., 1986).

Site 1 was located approximately 2 kilometers south of the Jackson-Putnam County line and 200 meters west of Route 136 at 36 degrees 15 minutes 14 seconds latitude and 85 degrees 31 minutes 19 seconds longitude in Putnam County (In Pocket). The site that was sampled for soil morphological investigation was at an elevation of 323 meters on an upland flat, with less than 3 percent slope. This portion of the terrace remnant was approximately 2 hectares in area and was surrounded by residual limestone landscapes that were at slightly higher elevations (Figure 1). When sampled for the

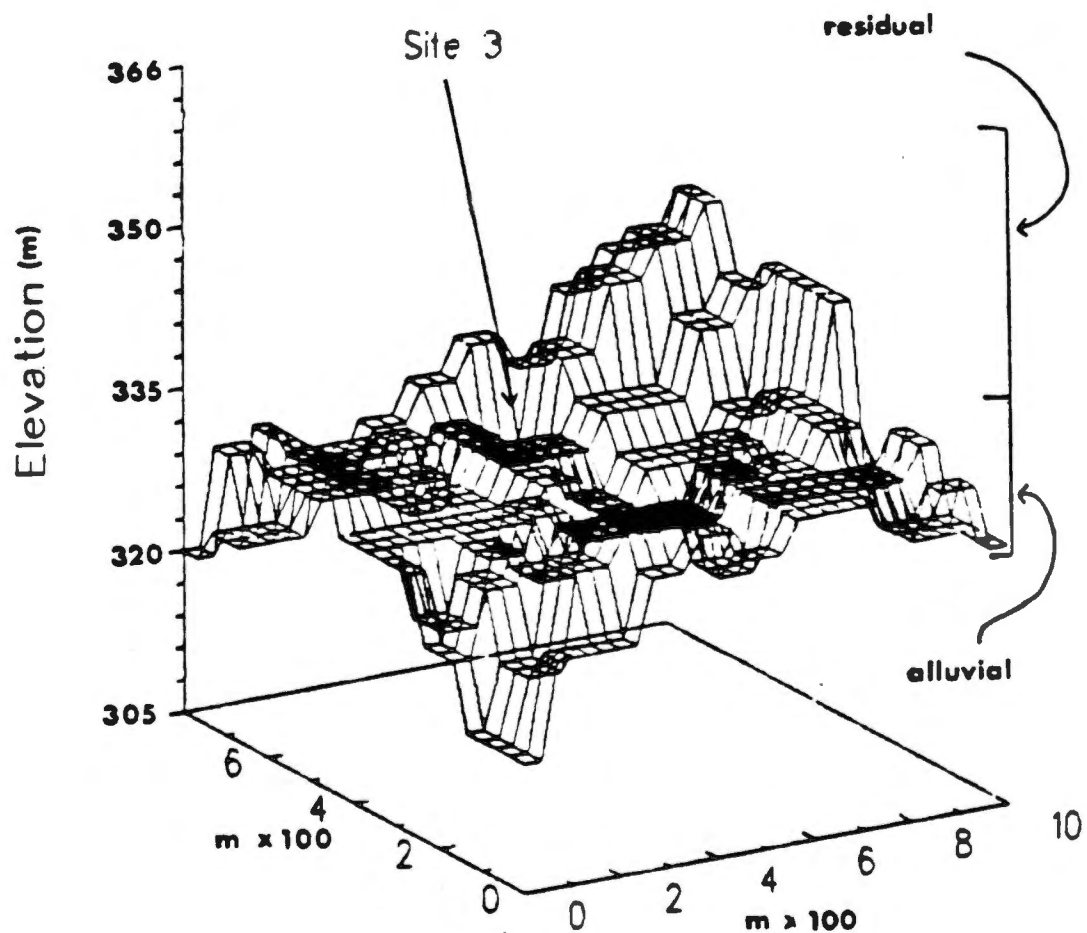


Figure 1. Relationship of the stream terrace remnants to the surrounding residual limestone surfaces.

soils investigation, three geomorphic surfaces were present, residuum, alluvium, and loess.

Site 2 was located approximately 100 meters north-northwest from the intersection of 12th street and Willow avenue at 36 degrees 10 minutes 47 seconds latitude and 85 degrees 30 minutes 51 seconds longitude in the student athletic field on the campus of Tennessee Technological University (In Pocket). The elevation of this site is 323 meters and is an upland flat less than one hectare in area. This site revealed only the fluvial and wind-blown geomorphic surfaces. The residual surface was either deeper beneath the portion investigated or it was truncated and removed when the alluvial material was deposited. Site 3 was located 50 meters south of the Northeast Elementary School in a cleared field at 36 degrees 10 minutes 13 seconds latitude and 85 degrees 28 minutes 3 seconds longitude, again in Putnam County (In Pocket). This site is positioned at an elevation of 323 meters and is a small level upland position of approximately 2 hectares in area. The field observations revealed only the fluvial and wind-blown geomorphic surfaces. The landscape is surrounded by residual limestone landscapes at a higher elevation (Figure 1).

Site 4 was located 1 kilometer south of Interstate 40 on Route 42 and 100 meters east of the road at 36 degrees 7

minutes 53 seconds latitude and 85 degrees 30 minutes 11 seconds longitude (In Pocket). This site is located on a small upland flat, less than 2 hectares in area, at an elevation of 326 meters. All three geomorphic surfaces were observed during the field investigation of this site

Site 5 was the last site sampled. This site is located on the southeast corner of West Graveyard Road and Longlane Road at 36 degrees 6 minutes 36 seconds latitude and 85 degrees 32 minutes 2 seconds longitude (In Pocket). The elevation of this site is 323 meters and it is located on an upland flat approximately 3 hectares in area. Soil morphological and laboratory data revealed fluvial and wind-blown geomorphic surfaces. The author was informed by a local landowner that level bedded limestone, typical of the Mississippian formation in this region, was present at 10 meters below the surface. This information was discovered during a water well drilling operation on land adjacent to the sampling point. This location was also surrounded by residual limestone landscapes at higher elevations (Figure 1).

Other sites used in the investigation were observation points used to determine the extent of the fluvial geomorphic surfaces. These sites are marked as observation points on the Corbin topographic quadrangle (In Pocket). Observation site 1 is a stream channel fill that was

approximately 15 meters thick and contained rounded rock fragments that ranged from 2 to 15 centimeters in diameter. Observation sites 2 and 3 are located on the western edge of the fluvial surface. The central and northern extent of the fluvial surface is established by observation sites 4 and 5, respectively.

All that is left to address is the question of where is the stream that caused these deposits. The field and map investigations have led to two scenarios as to the demise of the ancient stream system. The first scenario is the possibility of stream piracy from the west by smaller streams cutting headward across the Eastern Highland Rim. The potential areas of stream piracy are marked with arrows on the attached map. These streams, Otter Creek, Wolf River, Obey River, Spring Creek, and Falling Water River, all cut across the bench that contains the ancient fluvial deposits. It is possible to envision these smaller streams cutting across the margin of a large stream that flowed, northeast to southwest, on this portion of the Highland Rim. Once the smaller streams bridged the margin of the ancient stream, their flow would have been greatly increased. This flow could have caused the downcutting that produced the gorges that presently exist along these streams. These streams are tributaries of the Cumberland River, located approximately 50 kilometers west of Cookeville Tennessee.

The increased flow from the tributaries into the Cumberland River could have caused the entrenching seen today on the Cumberland River.

The second scenario as to the demise of the ancient stream is that the Cumberland River meandered across the bench on the Highland Rim. Change in the tributary stream and Cumberland River equilibrium caused the Cumberland to downcut to its present position. This theory could be verified if some portion of similar alluvial material could be found between the study area and the present Cumberland River. The landscape between the study area and the present river is located on the transition between the Eastern Highland Rim and the Central Basin. This region and the escarpment are highly dissected with large exposures of limestone bedrock. It is not probable that the deposits will be found. The author did not have the opportunity to search for these deposits.

The climate of the region during alluvial deposition was warm, either temperate or possibly even sub-tropical. The extent of the deposits and the depth of the channel fill support this theory. The alluvium was probably deposited during an inter-glacial period during the mid-Pleistocene.

Conclusion

Reconstruction of an ancient landscape that has been altered to a modern day form is difficult. Environmental as well as geologic factors must be reviewed when dealing with alluvial deposits that have been weathered, transported, deposited, and then weathered again. The loess deposits are approximately 10,000 years old. The paleosol that formed in the alluvial deposits is estimated to be 500,000 years old based on the extensive weathering and soil development that was observed during the field investigation. The alluvial material was deposited in the mid-Pleistocene during a warm climate period. The ancient stream that formed these terraces operated during a period when the climate did not fluctuate greatly and when ample rainfall was supplied to the region.

CHAPTER 3

SOIL GENESIS AND CLASSIFICATION

Literature Review

Jenny (1941) described soil formation as an integration of five factors. Those factors are parent material, time, climate, topography, and biological organisms. Soil genesis is the portion of soil science that deals with the factors and processes of soil formation (Buol et al., 1980). Soil classification is the process of categorizing soils based on their physical and chemical properties. When soil genesis and classification are combined into one pursuit, the field of pedology is formed (Buol et al., 1980).

The classification of any group of similar things, be it animals or soils, is important because it allows interdisciplinary communication in the subject area. It is also important to establish a standard system for the description of the subject matter. The classification system used in this study was Soil Taxonomy (Soil Survey Staff, 1975) and is the standard system used in the United States. This classification system is divided into six sections, arranged from the most broad to most descriptive are the order, suborder, great group, subgroup, family, and

series (Soil Survey Staff, 1975). A detailed field description along with laboratory data of the soil in question is needed to classify a soil correctly (Soil Survey Staff, 1990). Details concerning the actual laboratory data needed to classify soils will be included in the soil genesis section of this review.

Soil genesis can be better understood through the use of some basic concepts as proposed by Buol and others (1973). These concepts are:

1. Modern-day soil forming processes operate through space and time. This includes the thought that the old terms referring to soil formation, podzolization for instance, are in fact groups of like processes acting in different intensities and proportions at different times and places.

2. Different groups of soil-forming processes form distinctive soils.

3. Degradation of the land is modified by the soil and its vegetative cover.

4. Clay, both clay minerals and clay-sized particles, are formed in the soil.

5. Organomineral complexes are formed in the soil.

6. Soil succession occurs in the course of soil formation. This is to say that a sequence of soils is produced as successive regimes of soil forming processes act

on the soil parent material.

7. Complexity of soil formation is the norm. Complex soils are formed under two or more processes of pedogenesis as compared to simple soils which form under one general process.

8. The land surface has limited stability which has led to the thought that most soils are no older than the Tertiary.

9. Climatology is critical to understanding soil genesis.

10. A knowledge of the Pleistocene is necessary to the understanding of soil formation.

11. There are observable changes in the rates and responses of the soil to the environment.

12. An understanding of the processes of soil formation is necessary to proper soil management.

13. Paleopedology is a growing aspect of soil genesis. These concepts and ideas must be considered with the undertaking of an investigation into the genesis of the soil.

Paleopedology is where the investigation of the ancient stream terraces begins. Paleopedology is the study of the formation of ancient soils or paleosols (Bronger and Catt, 1989). Paleosols are understood to be soils buried by younger sediment thick enough so that pedogenic processes

acting on the younger sediment do not affect the buried soil (Bronger and Catt, 1989). This idea can be contrasted with that of relict soils which is defined by Nettleton, Gamble, and Allen (1989) as ancient pedogenic soils that have persisted on land surfaces of Pleistocene or greater age. The difference between the two is that paleosols are generally thought to be buried and relict soils are not. The soils investigated in this study fit the general category of paleosols.

Field recognition of paleosols can be a difficult undertaking in complex landscapes. Three main field features of paleosols have been identified by Retallack (1988) to be root traces, soil horizons, and soil structure. These have been used in field studies to distinguish ancient soils from the surrounding geological features. Retallack (1988) also listed several complications that can exist when identifying paleosols. These include erosion of parts of the soil profile, development of paleosols from erosion of preexisting paleosols, and formation of paleosols under different and successive weathering regimes. Each of these complications has been noted during the course of this study into of the stream terrace soils.

The term krotovina is defined as a filled animal burrow (Buol et al., 1980). The occurrence and formation of krotovinas has been the subject of study since the 19th

Century, with some early Russian observers regarding them as traces of tree roots (Borst, 1968). Dokuchaev, in 1883, and others recognized them as traces of filled animal burrows. This view became generally accepted after extensive study by Sukachev (1902). Krotovinas have the general morphology of elongated casting of surface-like material surrounded by the subsoil (Borst, 1968). Retallack (1987) noted that krotovinas could be filled with similar material as the subsoil but could still be distinguished by the presence of iron enriched clay at the interface between the two similar materials.

Materials and Methods

The investigation of the formation and occurrence of the stream terraces on the Eastern Highland Rim was designed to employ the use of what are considered by the soil science community to be standard field and laboratory procedures whenever possible. The study involved the analysis of selected physical and chemical properties of the soils that formed in the loessal and alluvial deposits in this region. The physical attributes studied included soil morphology, particle size analysis, and clay and sand mineralogy.

Soil morphology was determined in the field on each site that was sampled according to Soil Survey Manual (Soil

Survey Staff, 1981). Soil horizon designation, horizon thickness, moist color, field texture, structure, horizon boundary, moist consistence, and other notes that are pertinent to the field description, such as the presence of concentrations and cutans, were described during the field investigation. Particle size analysis was accomplished using the pipette method by Gee and Bauder (1986). Clay mineralogy was completed on the less than 2 micron fraction of selected samples using X-Ray diffraction (XRD). Samples were chosen from the mineralogical control section as defined by Soil Taxonomy (Soil Survey Staff, 1975). The samples were prepared into slides using the filter-membrane peel technique (Drever, 1973) for XRD analysis. The clay sample pretreatments included removal of iron, saturation with magnesium and potassium, glycolation of the magnesium saturated samples with 105, 300, and 550 °C heat treatments of the potassium saturated samples (Kunze and Dixon, 1986). X-ray diffraction analysis was performed on a Norelco x-ray diffractometer equipped with a graphite crystal diffracted beam monochromator with a 1 degree receiving slit and a copper x-ray tube. The generator settings of 35 kilovolts and 15 milliamps were used. Diffractograms of treated samples were collected with a time constant of 2 seconds, a scale factor of 1000 counts per second full scale, a scan rate of 2 degrees two-theta per minute, and a scan range of

2 to 35 degrees two-theta. A recorder paper setting of 60 inches per hour. The XRD procedure described above was used solely for the purpose of qualitative mineral identification.

The mineralogy of the dominant sand fraction was obtained from each sample using a modified procedure from Jackson (1970). The modifications to the procedure are listed in Appendix 1. This procedure allows for the determination of the mineralogy of soils that have been determined to be in the loamy particle size class according to Soil Taxonomy (Soil Survey Staff, 1975).

The chemical analyses of these soils included the determination of pH, total carbon, cation exchange capacity (CEC), manganese concentration, free iron oxide concentration, and exchangeable base determination which included calcium, potassium, magnesium, and sodium. The pH, or the negative logarithm of the hydrogen ion activity, was determined from a 1:1 water-soil paste using a combination glass electrode and an Orion ion analyzer on each horizon at every sampled site (Olsen and Ellis, 1982). Total carbon was determined on each horizon using a Leco carbon analyzer which uses the dry combustion method of carbon analysis. Cation exchange capacity and exchangeable bases were determined by the ammonium acetate method with a vacuum extractor, instead of a centrifuge (Chapman, 1969). The

concentration of the bases was determined using a Perkin-Elmer 5000 atomic absorption spectrophotometer. Manganese concentration was determined on each sample using the hydroxyl amine-hydrochloride method (Gambrell and Patrick, 1982). Free iron oxide content was also determined on each sample using the sodium citrate-bicarbonate-dithionite (CBD) method (Olsen and Ellis, 1982).

The methods employed in this research project were the standard field and laboratory methods used by the University of Tennessee's Soil Characterization Laboratory Staff.

Results and Discussion

Site 1

Soil morphology of site 1 was described to a depth of 384 centimeters (Table 1). The morphological data revealed two lithologic discontinuities, one at 88 centimeters and another at 196 centimeters (Table 1). The sand ratio plots show inflection points at these two depths which indicated that there were at least two discontinuities (Figure 2). These discontinuities are the boundaries between the loessal, alluvial and residual portions of the profile. The parent material sequence at this site was loess over alluvium over limestone residuum (Figure 3).

Parent material for the 88 centimeters of the profile was loess (wind blown silt) that is believed to be of local

Table 1. Soil morphological data for Site 1.

Horizon	Depth cm	Color	Texture	Structure	Comments
Ap	0-24	10YR4/3 brown	SIL	2agr/1fsbk	Mn concr.
BA	24-40	10YR5/4 yellowish brown	SIL	1msbk	Mn concr.
Bt1	40-57	10YR5/4 yellowish brown	SIL	1msbk	Mn concr.
Bt2	57-88	10YR4/4 dark yellowish brown	SIL	1msbk	Mn, Fe concr.
2Bt3	88-102	2.5YR4/6 red	SICL	2msbk	mottled; clay films
2Bt4	102-145	2.5YR4/6 red	C	2msbk	mottled; clay films
2Bt5	145-196	2.5YR4/6 red	C	2msbk	mottled; clay films
3Btb1	196-232	2.5YR4/6 red	C	2msbk	
3Btb2	232-268	2.5YR4/6 red	C	2msbk	
3Btb3	268-297	2.5YR4/6 red	C	2msbk	
3Btb4	297-322	2.5YR4/6 red	C	2msbk	
3BCb1	322-355	mottled	C	2msbk/OMa	few clay films
3BCb2	322-364	mottled	C	2fsbk	few clay films

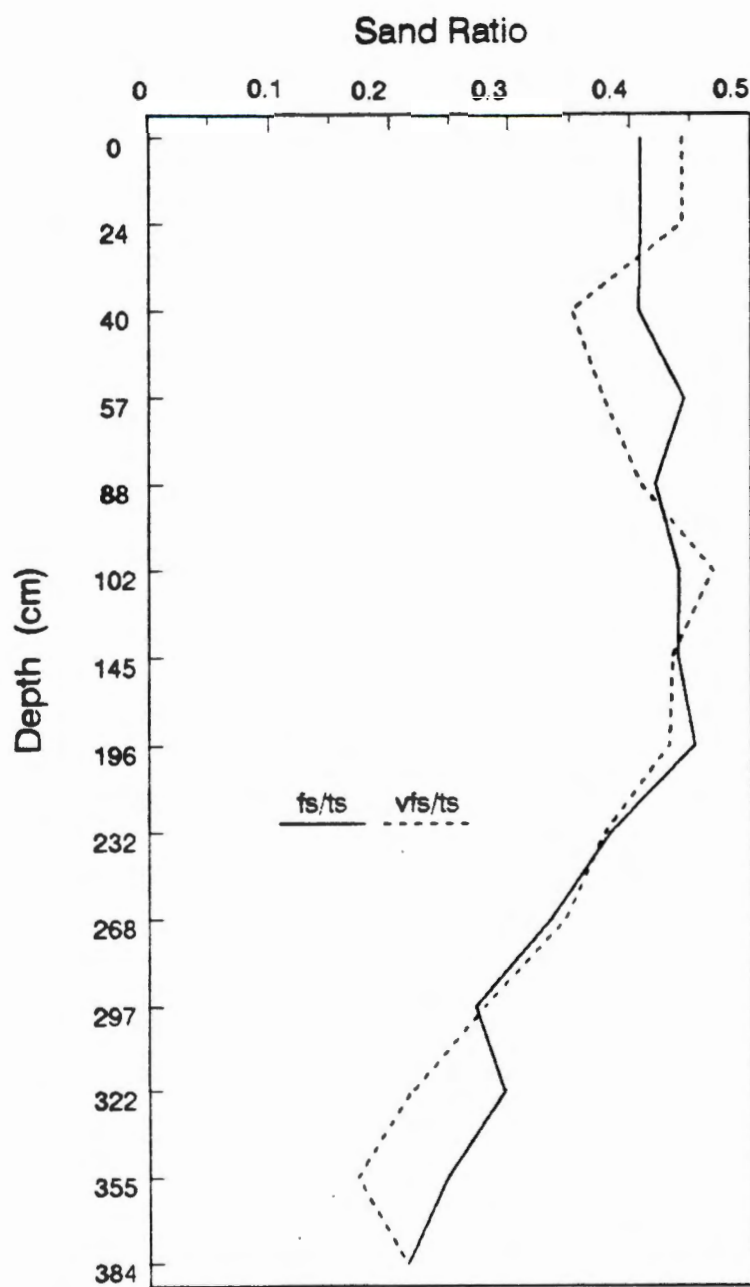


Figure 2. Ratio of fine and very fine sand to total sand plotted with depth of the soil profile at Site 1.

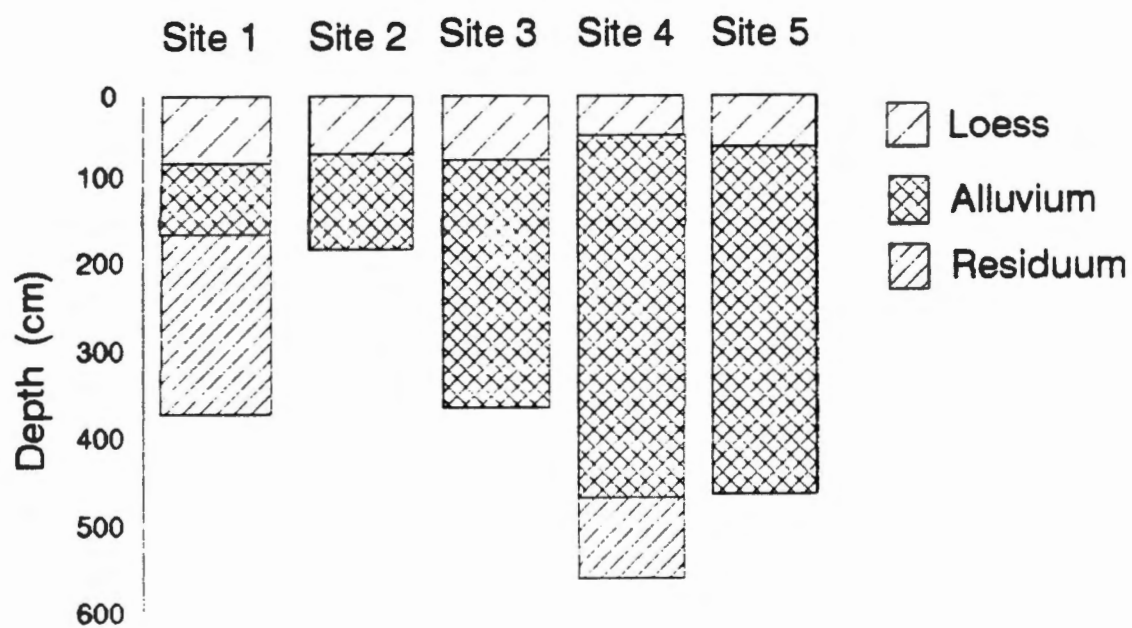


Figure 3. Parent material sequence of the pedons sampled.

origin. The speculation on the origin of the loess is based on the high content of silt and sand (Figure 4). The high sand content indicates that this material was not transported a great distance. If the material had been moved from a long distance then the sand would have settled out before it was deposited on the Eastern Highland Rim. The age of the loess deposit is approximately 10,000 years old. The loess was stable on the landscape due to the formation of an argillic horizon in this layer (Table 1).

The alluvial parent material in this profile was identified between 88 and 196 centimeters and this layer was deposited from the ancient stream system that was once, but is no longer, active in this region (Table 1). The sand ratio plot (Figure 2) shows at least two minor inflection points in this portion of the profile which gives the indication of multiple alluvial depositions at this site. The paleosol that formed from this alluvium was well-developed as indicated by the strong argillic horizon formation and the increasing of iron oxide content with depth (Figures 4 and 5). This paleosol presumably had its surface horizons truncated when the loess was deposited. The data revealed no evidence of buried surface horizons.

The portion of the soil profile that formed below 196 centimeters originated from Mississippian limestone (St. Louis formation). The presence of crinoid stems and

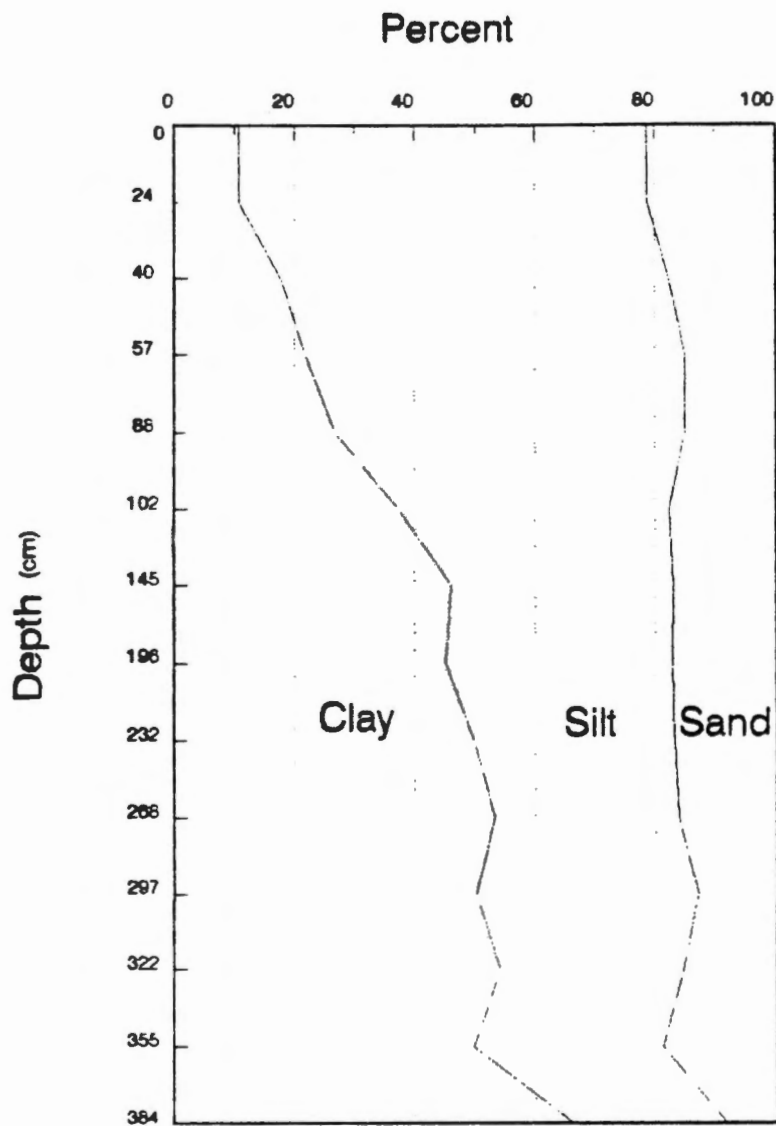


Figure 4. Sand, silt, and clay distribution in the soil profile at Site 1.

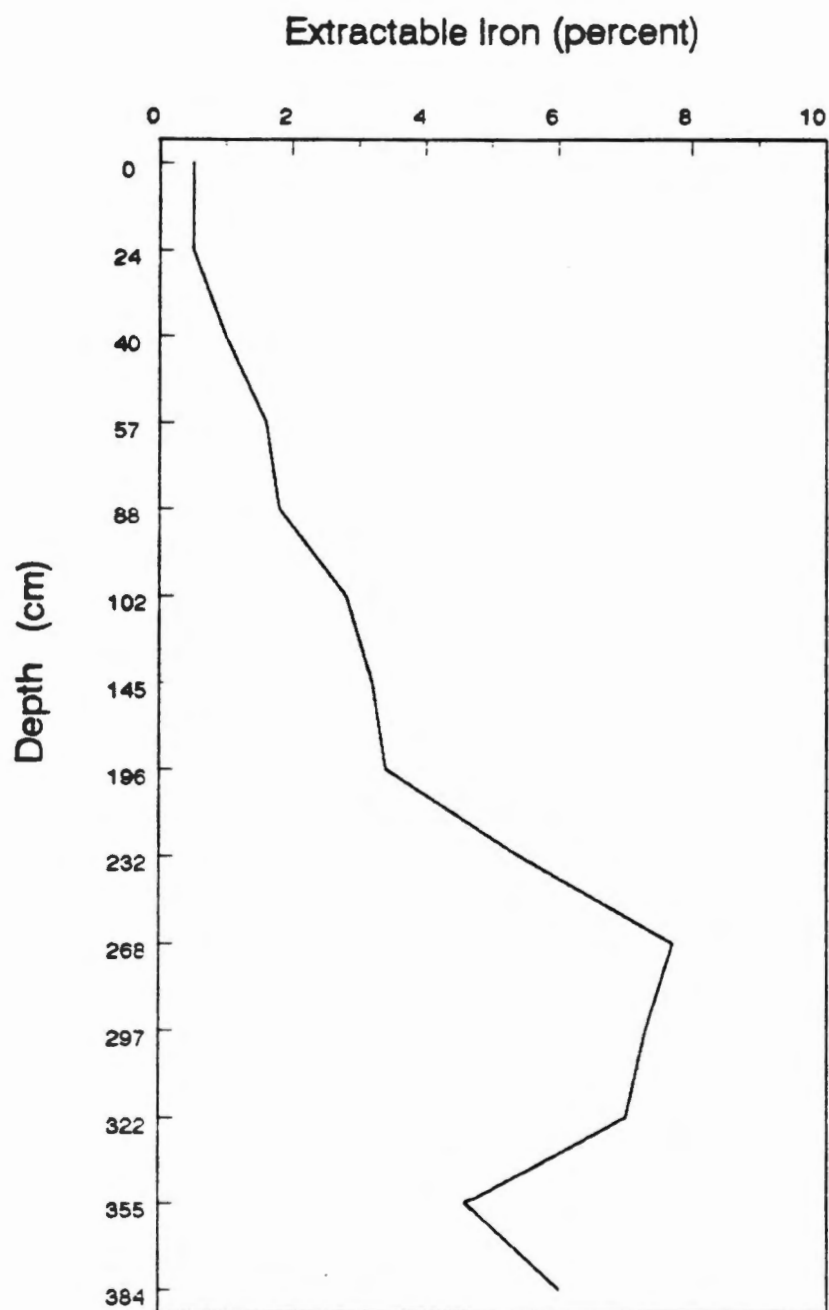


Figure 5. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 1.

other small fossils found in these horizons confirms that the soil in this layer was residual in nature. This zone was also well developed with the continuation of the argillic horizon and an increase in the iron oxide content to a depth of 322 centimeters (Figures 4 and 5). The horizons below 322 centimeters were designated transitional horizons (3BC1 and 3BC2) that were composed of a mixture of argillic horizon material and slightly altered limestone parent material (Table 1). Change in structure and a sharp change in iron oxide content was noted below this depth (Table 1 and Figure 5).

The manganese distribution curve (Figure 6) indicates that the discontinuity between the loess and the alluvium is a barrier to water movement. Manganese, which will be transported with water as it moves through the profile, is collecting on the interface between these two layers. Water movement does not seem to be impeded for any prolonged period of time. Reducing conditions were not apparent during field soil morphological observations. The data plotted on this curve shows the weathering process has continued through the alluvium and into the residual portion of the soil. The increase in manganese content at 322 centimeters indicates a pore-size discontinuity between the argillic and transitional horizons in the profile (Figure 6).

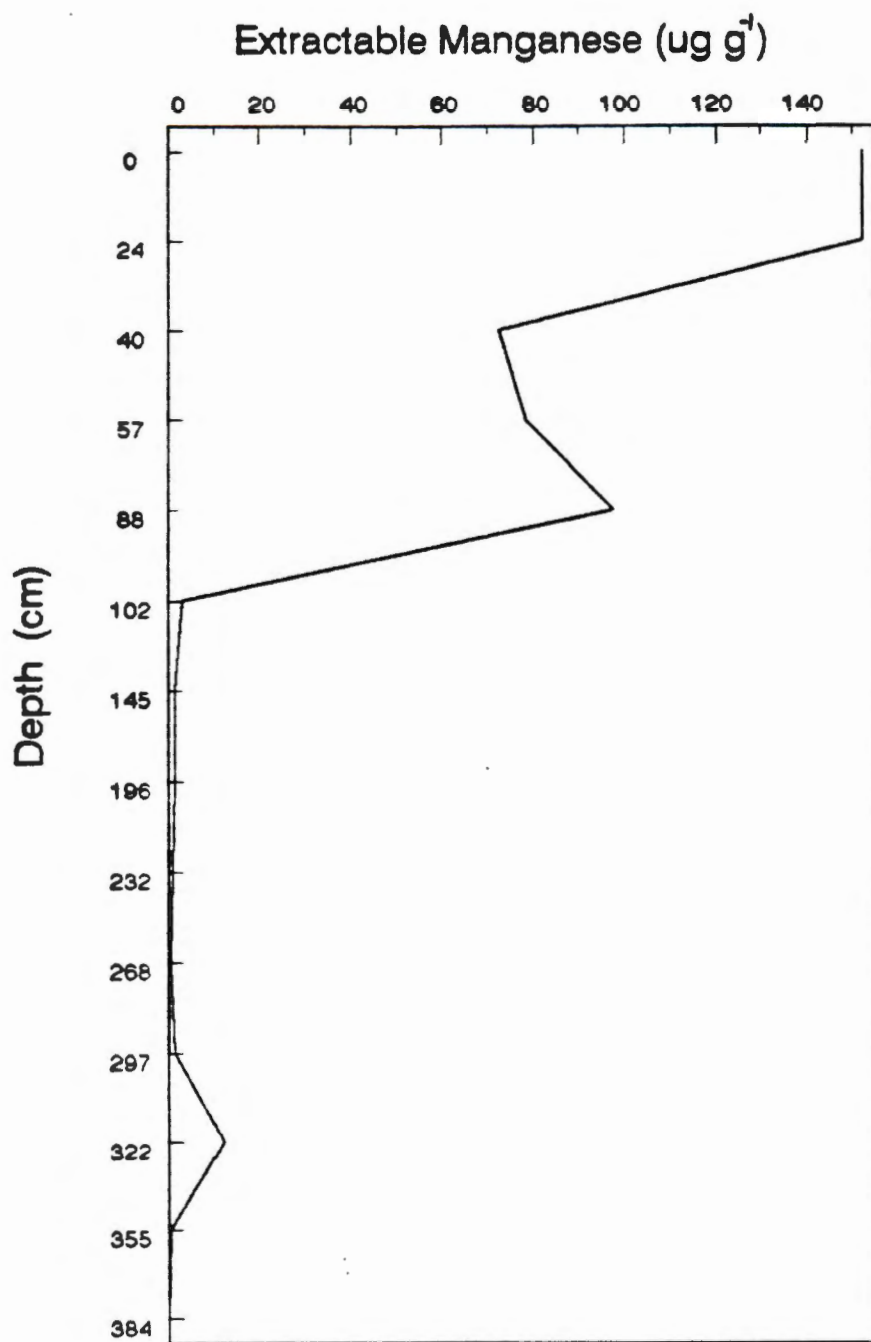


Figure 6. Hydroxyl Amine-Hydrochloride manganese distribution in the soil profile at Site 1.

The total carbon distribution curve (Figure 7) provides insight into the overall weathering pattern of the profile when there are no free carbonates present. The carbon content in this profile originated almost exclusively from organic matter accumulations on the surface. Figure 7 provides confirmation of the statement made earlier regarding the absence of buried surface horizons in the alluvial and residual portion of the profile.

Clay mineralogy on the pedon was determined on the less than 2 micron clay fraction by qualitative XRD. X-Ray diffractograms (Appendix 2) produced from the clay samples revealed that the clay mineralogy was the same throughout the profile and contained the following minerals: hydroxy-interlayered vermiculite (HIV), illite, kaolinite, and clay-sized quartz (Table 2). The uniform content throughout the profile give the indication of the extent of the weathering that has taken place. The clay minerals present are at the intermediate and advanced stage of weathering according to the weathering scheme by Foth (1984). The presence of clay-sized quartz in the loessal and alluvial parent materials gives an indication of the intensity of weathering based on the resistant nature of the quartz mineral. The peaks obtained from the XRD clay scans of the alluvial material had greater intensity and sharpness as compared to the peaks from the loessal material (Appendix 2). This indicates that

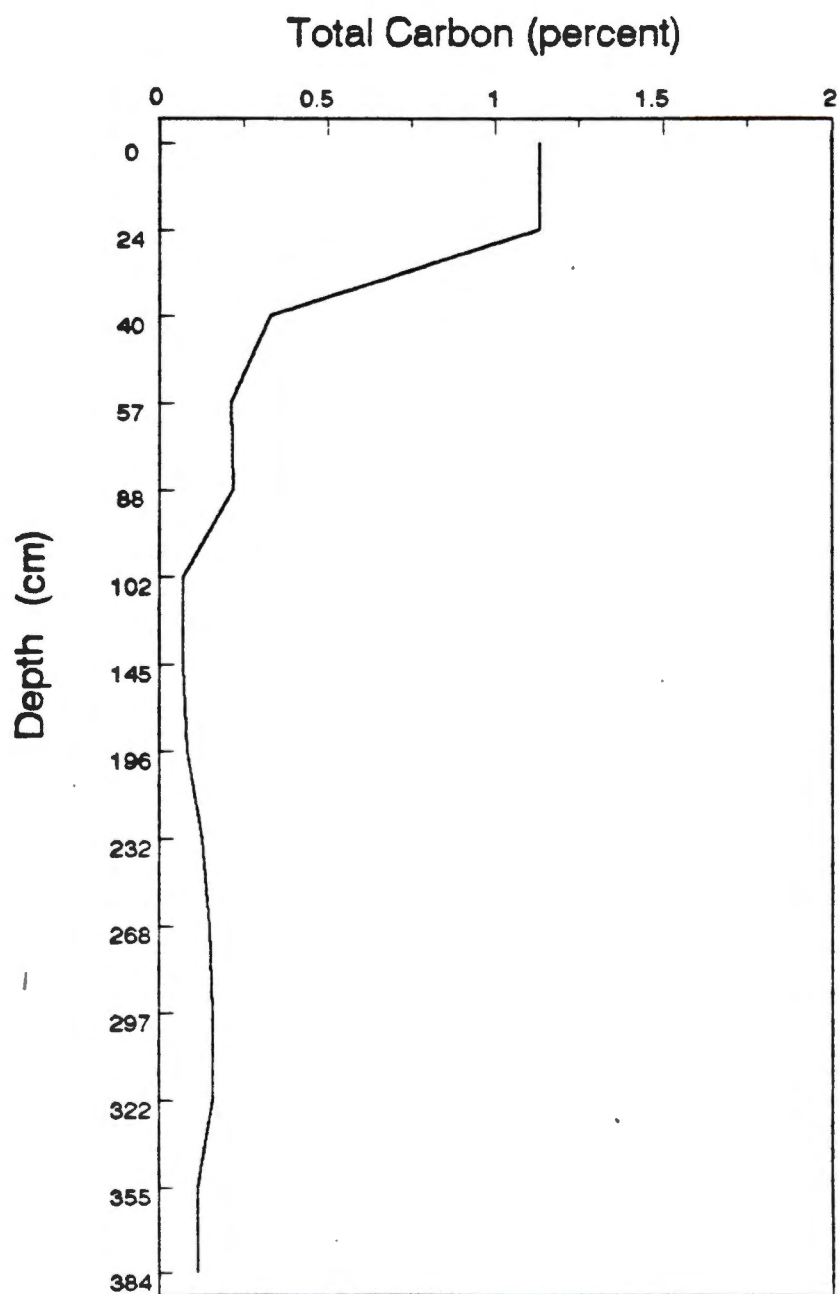


Figure 7. Total carbon distribution in the soil profile at Site 1.

Table 2. Identification and average profile content estimation of the less than 2 micron clay samples from the soil pedons sampled as determined by X-Ray Diffraction.

LOCATION	MINERALS			
	HIV	Illite	Kaolinite	Quartz
	percent			
Site 1	20-30	10-20	>30	<10
Site 2	20-30	10-20	>30	<10
Site 3	20-30	10-20	>30	<10
Site 4	20-30	10-20	>30	<10
Site 5	20-30	10-20	>30	<10

the clay minerals in the alluvial material have a higher degree of crystallinity than those from the loess. This finding supports the relative age difference between the two parent materials and supports the presence of a paleosol in the alluvial material.

Sand grain counts were used to determine the mineralogical classification of the soil. The grain counts were performed on the mineralogical control section of the profile according to Soil Taxonomy (Soil Survey Staff, 1975). The control section for site 1 was between 40 and 90 centimeters (Table 1). The control section crossed the boundary between the loessal material and the alluvial parent materials. Results of the sand grain counts averaged 75 percent quartz, 15 percent plagioclase, 0.7 percent potassium-feldspar, and 8 percent other minerals not identified (Table 3). The mineralogy of this soil would be considered mixed.

The general shape of the sand grains was also of importance to the genesis of the soil at this site. There was no overall pattern that characterized the shape of the sand grains, but some of the grains from the alluvial portion of the profile were elongated and somewhat rounded. This observation helps substantiate the presence of alluvium as a parent material at this site.

The classification of the soil (Table 4) was previously

Table 3. Quantitative mineral identification of the dominant sand fractions from the control sections of the pedons sampled.

LOCATION	MINERALS			
	Quartz	Plagioclase	K-Feldspar	Others
	-----percent-----			
Site 1	75	15	0.7	8
Site 2	75	16	0	9
Site 3	90	8	0	2
Site 4	83	14	2	0
Site 5	69	27	2	2

Table 4. Comparison of old and new soil classification at each site sampled according to Soil Taxonomy.

LOCATION	OLD CLASSIFICATION	NEW CLASSIFICATION
Site 1	fine-silty, siliceous, thermic Typic Paleudult	fine-silty, mixed, thermic Typic Paleudult
Site 2	fine-silty, siliceous, thermic, Typic Paleudult	fine-silty, mixed, thermic Typic Hapludalf
Site 3	fine-loamy, siliceous, thermic, Typic Paleudult	fine-loamy, mixed, thermic Typic Paleudult
Site 4	clayey, kaolinitic, thermic Typic Paleudult	fine, mixed, thermic Typic Paleudalf
Site 5	fine-loamy, siliceous, thermic Typic Paleudult	fine-loamy, mixed, thermic Typic Paleudalf

listed as fine-silty, siliceous, thermic Typic Paleudult (Soil Survey Staff, 1963). The base saturation data (Table 5) confirms that the soil at this site is an Ultisol. From the particle size data it was determined that there was 25 percent clay and 9 percent sand less than 0.1 millimeters, therefore the particle size class is fine silty. The mineralogy class is mixed instead of siliceous. Based on the findings of this study, the classification of the soil on this site is fine- silty, mixed, thermic Typic Paleudult (Table 4).

Site 2

The soil morphology of site 2 was described to a depth of 184 centimeters (Table 6). During the soil morphological investigation in the field, it was determined that the pedon being described included the material from the interior of a krotovina (Figure 8). From the field observations, it seemed apparent that the discontinuity between the loess and the alluvial parent materials occurred at 146 centimeters (Figure 3) . The sand ratio plot (Figure 9) substantiated this observation. Upon examination of the particle size data (Figure 10) it was determined that the discontinuity between the two parent contrasting parent materials occurred at a depth of 72 centimeters.

The parent material for the upper 72 centimeters was

Table 5. Exchangeable base cation content and base saturation of the soil pedon at Site 1.

Horizon	Depth cm	Ca	Mg	Na	K	CEC	BSAT percent
-----cmol(+) kg ⁻¹ -----							
Ap	0-24	4.12	0.24	0.43	0.30	4.5	113
BA	24-40	3.99	0.15	0.35	0.30	4.6	103
Bt1	40-57	5.82	0.24	0.33	0.30	6.6	101
Bt2	57-88	4.48	0.75	0.16	0.30	8.2	70
2Bt3	88-102	1.46	0.77	0.12	0.30	8.6	31
2Bt4	102-145	0.78	0.72	0.13	0.30	9.9	20
2Bt5	145-196	0.72	0.74	0.12	0.30	11.1	17
3Btb1	196-232	0.32	0.61	0.12	0.30	11.7	11
3Btb2	232-268	0.34	0.72	0.13	0.30	13.6	11
3Btb3	268-297	0.32	0.67	0.16	0.30	13.8	11
3Btb4	297-322	0.42	0.77	0.12	0.30	12.0	13
3BCb1	322-355	0.49	0.80	0.12	0.20	14.0	12
3BCb2	355-384	0.73	1.43	0.12	0.30	13.8	9

Table 6. Soil morphological data for Site 2.

Horizon	Depth cm	Color	Texture	Structure	Comments
Ap	0-22	10YR3/3 dark brown	SIL	1fsbk	
BA	22-50	10YR5/6 yellowish brown	SIL	1fsbk	Fe,Mn concr.
Bt1	50-72	10YR5/6 yellowish brown	SIL	1msbk	Fe,Mn concr. clay films
2Bt2	72-93	10YR6/6 brownish yellow	CL	2msbk	Fe,Mn concr. clay films
2Bt3	93-146	10YR6/4 light yellowish brown	SIL	1fsbk/ OMa	Mn concr.
2Bt4	146-184	5YR5/6 yellowish red	CL	2msbk	Mn concr. clay films

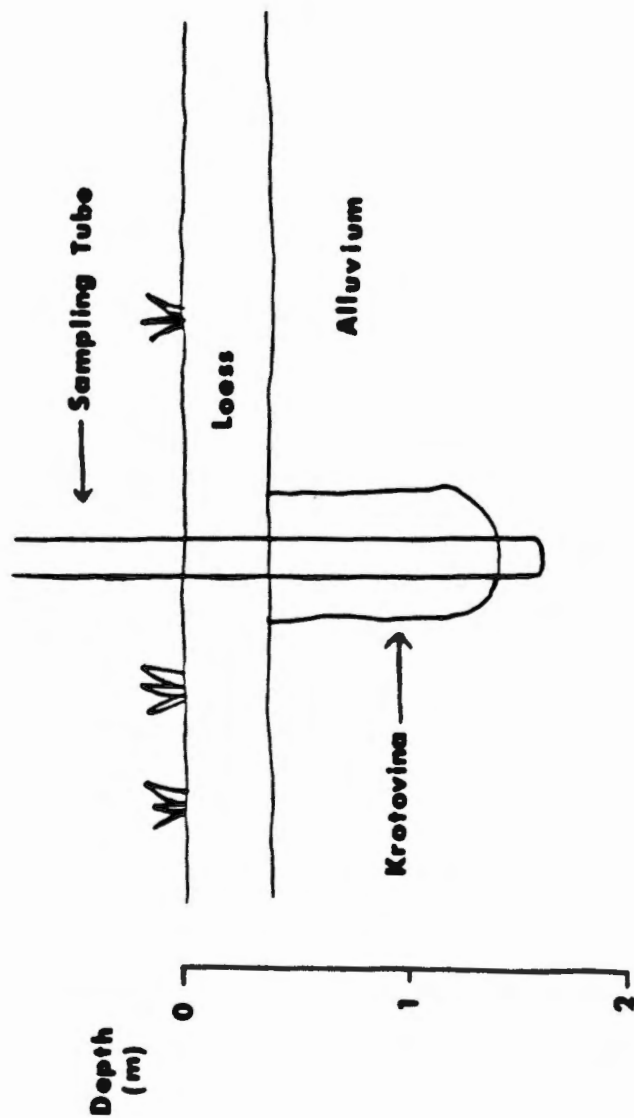


Figure 8. Diagram of the positioning of the sampling tube during the field investigation of Site 2.

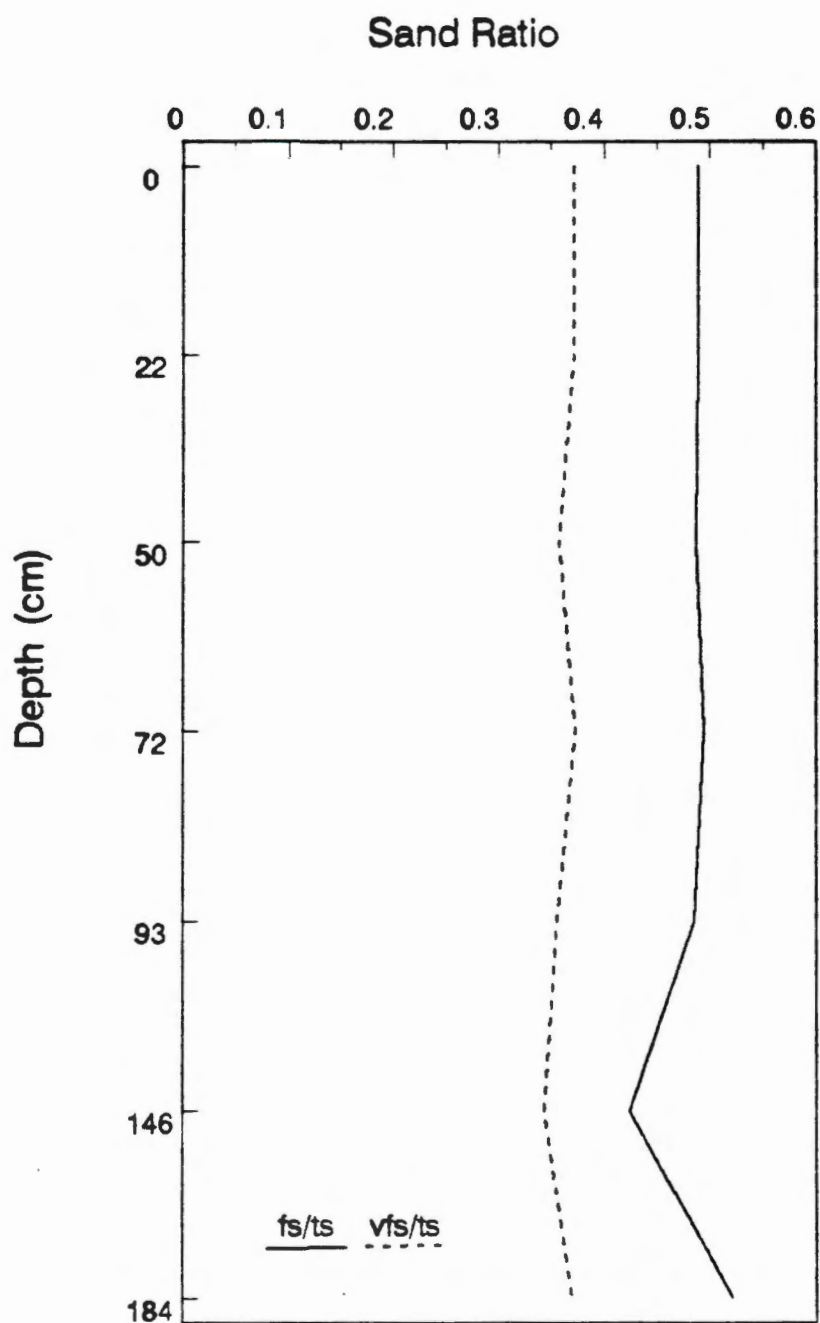


Figure 9. Ratio of fine and very fine sand to total sand plotted with depth of the soil profile at Site 2.

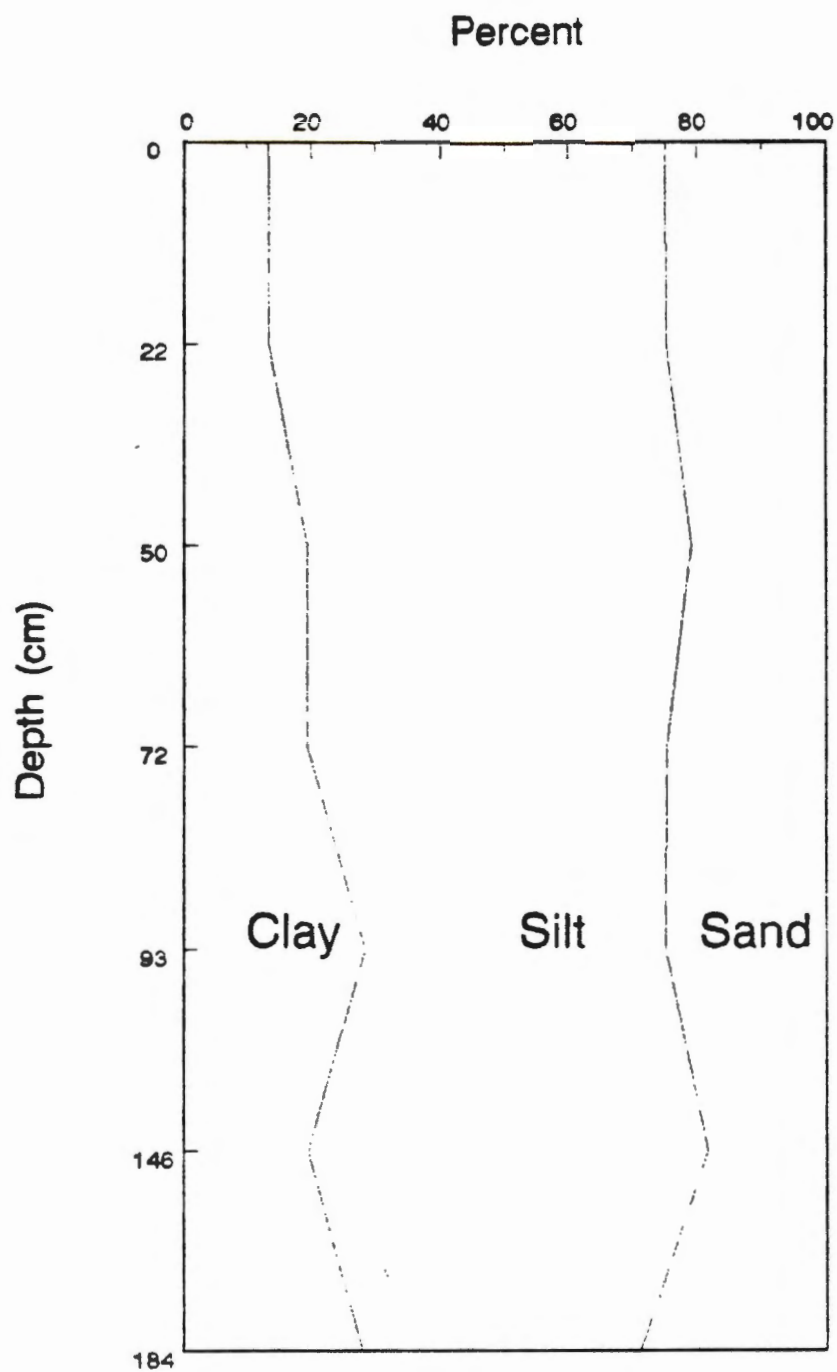


Figure 10. Sand, silt, and clay distribution in the soil profile at Site 2.

loess (Figure 3). The origin and development of this layer are similar to site 1.

The parent material of the 2Bt2 horizon is a mixture of loess and alluvium. Particle size data for the 2Bt3 horizon substantiates that the parent material for this horizon is of alluvial origin. The horizon just below, 2Bt4, contains a higher silt percentage which indicates a loessal origin (Figure 10 and Table 6). The author surmises that when the surface horizons were truncated by the arrival of the loess, the primary loessal deposition mixed with the exposed alluvial subsoil and subsequently filled the open animal burrow and formed the krotovina that is in place today. Even though this material was mixed, it was stable enough to allow for the continued formation of an argillic horizon. At the interface between the 2Bt3 and 2Bt4 horizons a dense rind composed of iron and manganese oxides exists.

The 2Bt4 horizon formed in alluvial parent material (Figure 3). This horizon was well-developed with a strong argillic horizon and increasing iron oxide content throughout (Table 6 and Figure 11).

The manganese distribution curve (Figure 12) supports the field observations described above. The surface horizons have a higher manganese content than the alluvial layer just below. The higher manganese content in the loessal material is a result of both the loessal parent

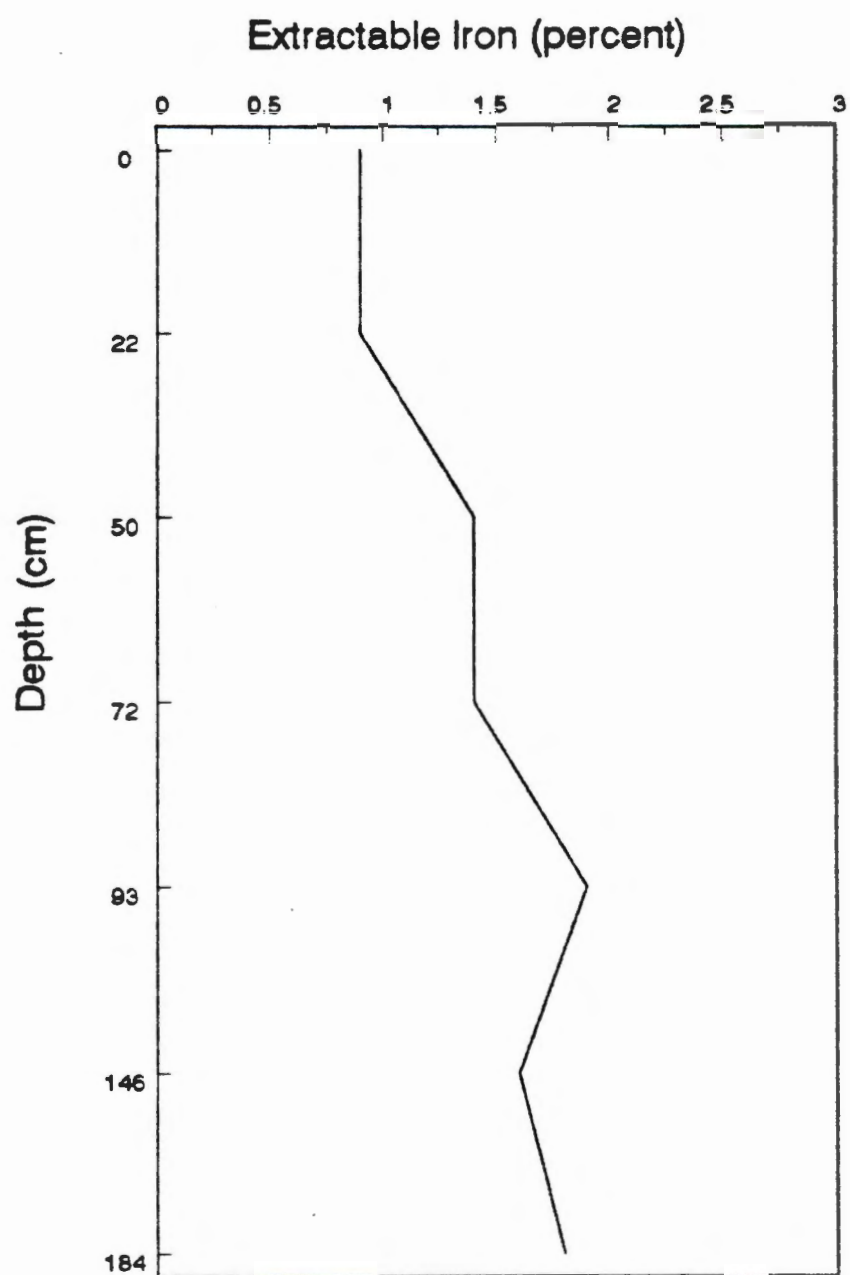


Figure 11. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 2.

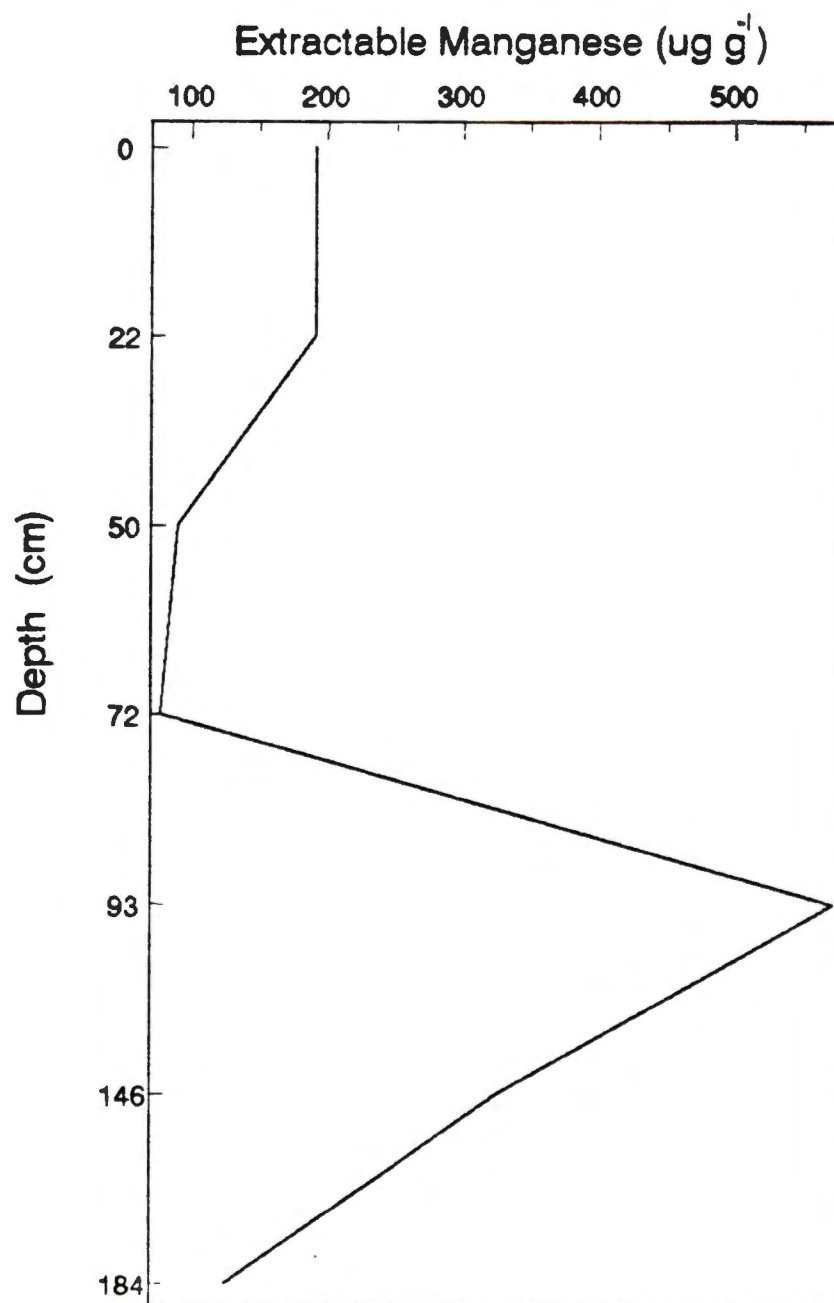


Figure 12. Hydroxyl Amine-Hydrochloride manganese distribution in the soil profile at Site 2.

material containing high amounts of the element and to recycling of the element by plants. The sharp increase in manganese content above 146 centimeters, 2Bt3 horizon, is the result of the rind impeding water movement. There was evidence, in the form of low chroma mottles, of reducing conditions in this layer.

The total carbon distribution curve (Figure 13) indicates a continuous weathering pattern throughout this profile. The content of total carbon is greatest on the surface and decreases with an increase in depth. This indicates that there is no buried surface horizon in the profile.

The mineralogy of this pedon was similar to site 1. Table 2 shows the clay minerals detected in this pedon to be HIV, illite, kaolinite, and clay sized quartz. Higher peak intensities from XRD analysis were noted in the paleosol as compared to the loessal portion of the profile. Grain counts were obtained for genesis and classification purpose. The control section for mineralogical classification was the upper 50 centimeters of the argillic horizon. The grain count data showed that the control section contained an average of 75 percent quartz, 16 percent plagioclase, and 9 percent other minerals not identified (Table 3). The family mineralogy class was mixed (Soil Survey Staff, 1975).

The sand grains in the loessal portion of the soil

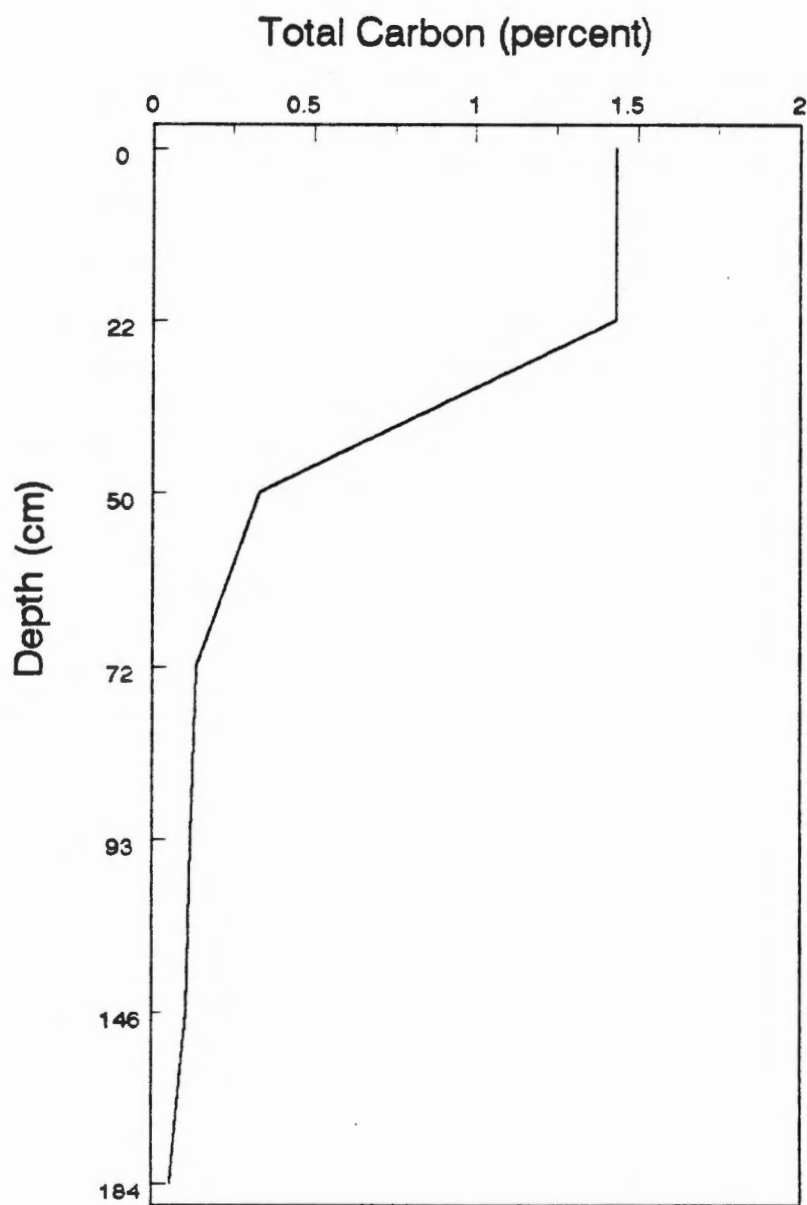


Figure 13. Total carbon distribution in the soil profile at Site 2.

showed no distinctive shape arrangement, but the sand grains observed from the alluvial portion of the profile did show elongated and slightly rounded shapes. This provides support for the presence of alluvial parent material at this site.

From the Putnam County Soil Survey, it was determined that the soil at this site was previously classified as fine- silty, siliceous, thermic Typic Paleudult (Soil Survey Staff, 1963). The particle size data revealed that the control section contained 19 percent clay and 14 percent sand less than 0.1 millimeter. The particle size class is fine silty. Based on the base saturation data (Table 7) and other information previously discussed, it was determined that the classification of this pedon was fine-silty, mixed, thermic Typic Hapludalf. The differences between the two classifications is the result of the specific site sampled. Sampling directly through a krotovina did not allow investigation of the typical sequence of soil formation on this landscape. An additional field observation was conducted approximately 4 meters from the site sampled. A fresh bank cut caused by local construction (Plate 2), showed a similar profile to the soil occurring on site 1. The krotovinas were prominent in this exposure (Plate 3).

Table 7. Exchangeable base cation content and base saturation of the pedon at Site 2.

Horizon	Depth cm	Ca	Mg	Na	K	CBC	BSAT percent
-----cmol(+) kg ⁻¹ -----							
Ap	0-22	9.75	1.65	0.28	0.30	6.8	177
BA	22-50	9.87	0.82	0.27	0.20	6.7	166
Bt1	50-72	9.63	0.60	0.26	0.20	6.3	170
2Bt2	72-93	7.68	0.52	0.25	0.20	8.3	104
2Bt3	93-146	6.22	0.65	0.25	0.20	8.0	92
2Bt4	146-184	3.60	0.71	0.28	0.20	8.0	60



Plate 2. Soil profile from excavation near Site 2.



Plate 3. Cross sectional exposure of a krotovina.

Site 3

Site 3 was described to a depth of 387 centimeters and the morphological data is presented in Table 8. The field morphology revealed one lithologic discontinuity at 102 centimeters (Table 8). The parent material sequence at this site was loess over alluvium (Figure 3). The sand ratio plot (Figure 14) shows an inflection point at 102 centimeters which indicates the presence of a boundary between different materials. The inflection points above the 102 centimeter depth may indicate some form of local variation in the loess composition. The inflections below the discontinuity occur in the alluvial material and are likely the result of different depositional events.

The upper 102 centimeters of the profile was formed from loessal parent material that is believed to be of local origin much the same as all of the sampled sites reported this study. The landscape was in a stable position for some time allowing for the formation of an argillic horizon (Table 8).

The soil horizons present below 102 centimeters originated from alluvial parent material. The horizons occurring between 102 and 268 centimeters, 2Bt2 through 2Bt6, represent part of the paleosol and exhibit well-developed morphology with the presence of an argillic horizon (Table 8). The particle size data (Figure 15) show

Table 8. Soil morphological data for Site 3.

Horizon	Depth cm	Color	Texture	Structure	Comments
Ap	0-13	10YR4/3 brown	SIL	1fgr	Mn concr.
AB	13-40	10YR4/4 dark yellowish brown	SIL	1msbk	Mn concr.
BA	40-66	10YR5/4 yellowish brown	SIL	1msbk	Mn concr.
Bt1	66-102	mottled	SIL	2msbk	clay films
2Bt2	102-128	5YR4/6 yellowish red	L	2msbk	clay films
2Bt3	128-151	2.5YR4/6 red	L	2msbk	clay films
2Bt4	151-184	2.5YR4/6 red	CL	2msbk	clay films
2Bt5	184-232	2.5YR4/8 red	CL	1fsbk	clay films. chert frags.
2Bt6	232-268	2.5YR4/8 red	CL	1fsbk	clay films
2Bw	268-306	2.5YR4/6 red	L	1fsbk	clay films
2BC	306-350	5YR5/8 yellowish red	L	1fsbk	
2C1	350-371	5YR6/8 reddish yellow	FSL	1fsbk	
2C2	371-387	7.5YR5/8 strong brown	FSL	1fsbk	Stratified sand

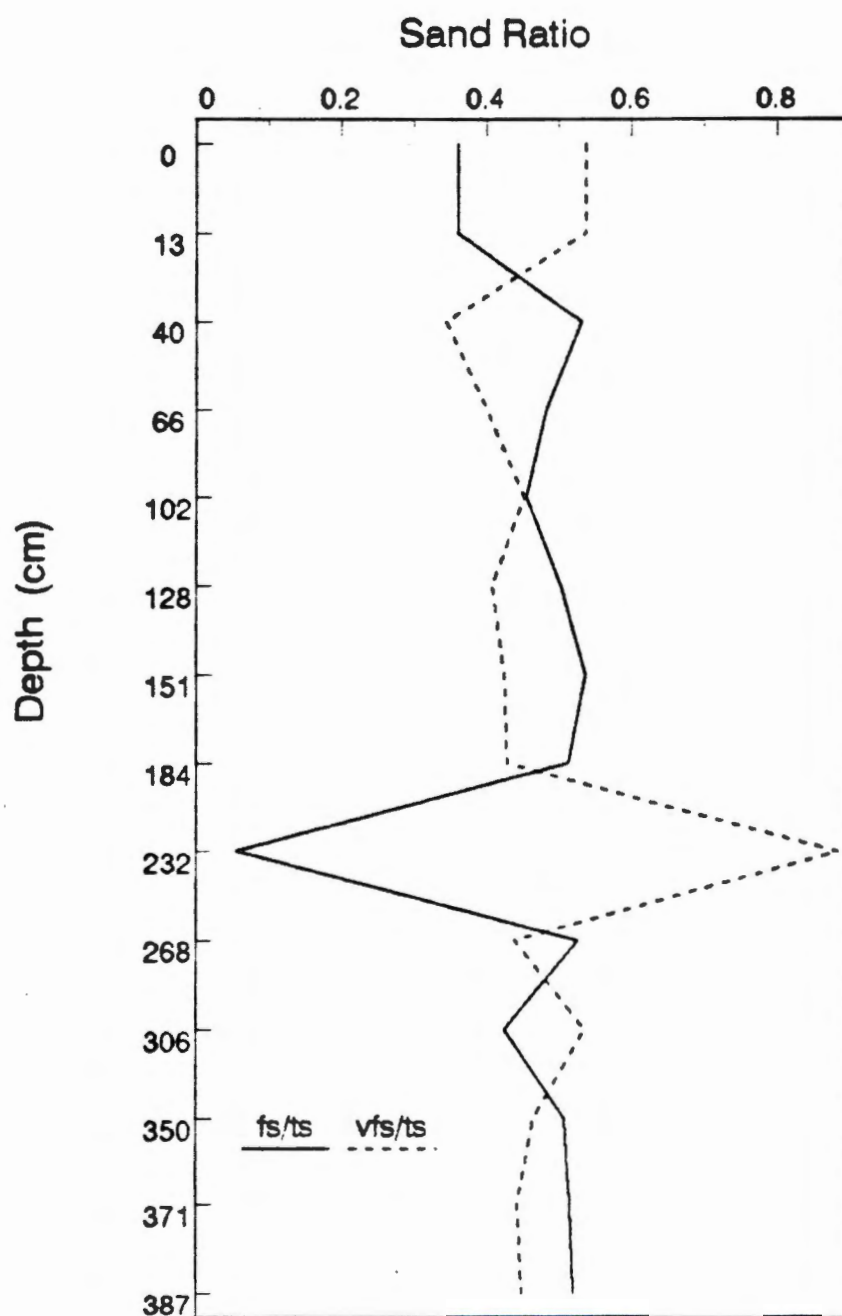


Figure 14. Ratio of fine and very fine sand to total sand plotted with depth of the soil profile at Site 3.

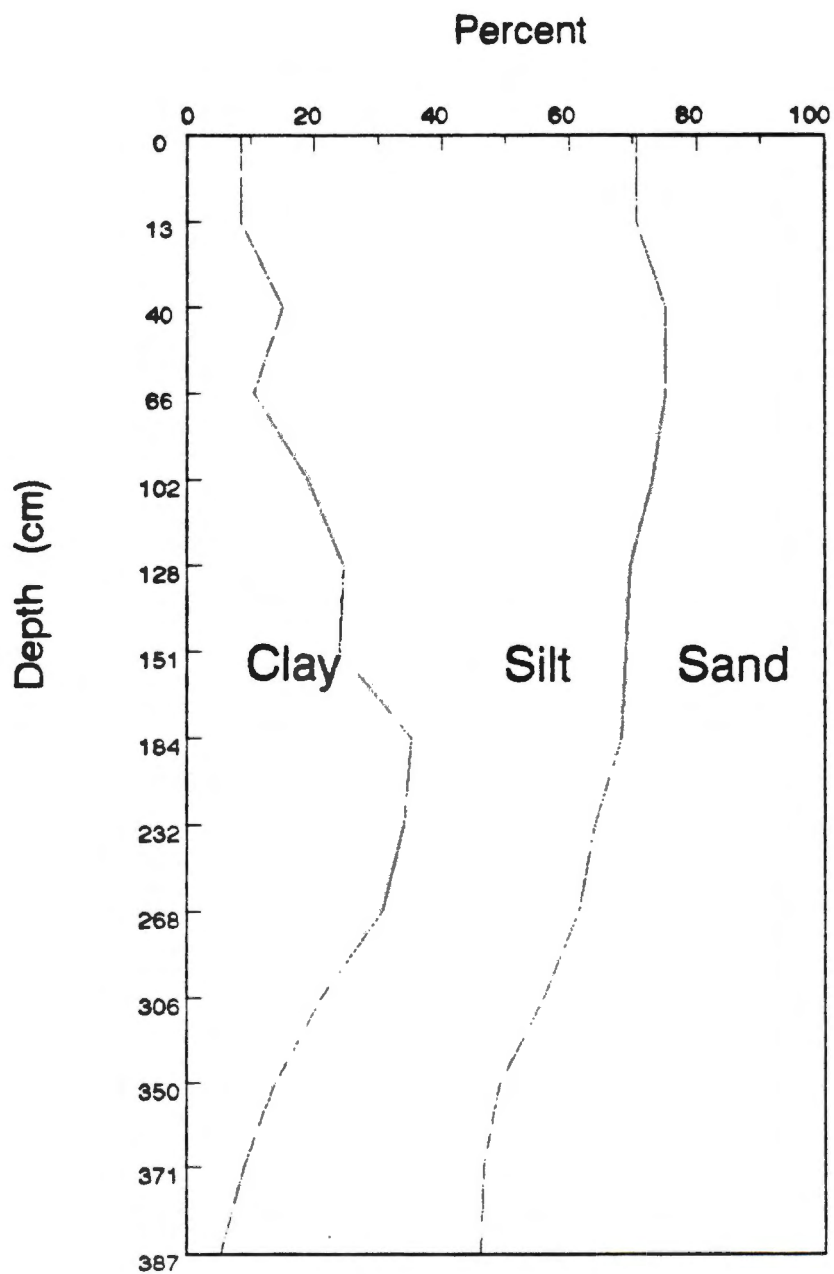


Figure 15. Sand, silt, and clay distribution in the soil profile at Site 3.

the well-developed argillic horizon with a clay bulge between 102 and 268 centimeters. Iron oxide plotted by depth (Figure 16) supports the presence of well-developed soil horizons between the depths of 102 and 268 centimeters with a similar bulge in iron content. The 2Bw horizon, 268 to 306 centimeters, is a mixing zone (Table 8). The horizon between 306 and 350 centimeters, the 2BC, is a transitional horizon between the developed subsoil above and the slightly altered parent material below. The 2C1 and 2C2 horizons consist of slightly altered parent material that contained stratified sand (Table 8). The presence of stratified sand was conclusive proof as to the presence of alluvium at this site.

The manganese distribution curve (Figure 17) shows that there was no barrier to water movement through the profile. The data indicates both the presence of the lithologic discontinuity between the two parent materials and the continuation of the weathering cycle through the entire profile. The continual decrease of manganese in the loessal portion of the profile to a constant concentration in the alluvial portion provides insight into the weathering pattern.

The total carbon distribution curve (Figure 18) shows much the same pattern as the manganese curve mentioned above (Figure 17), with a steady decrease from the surface content

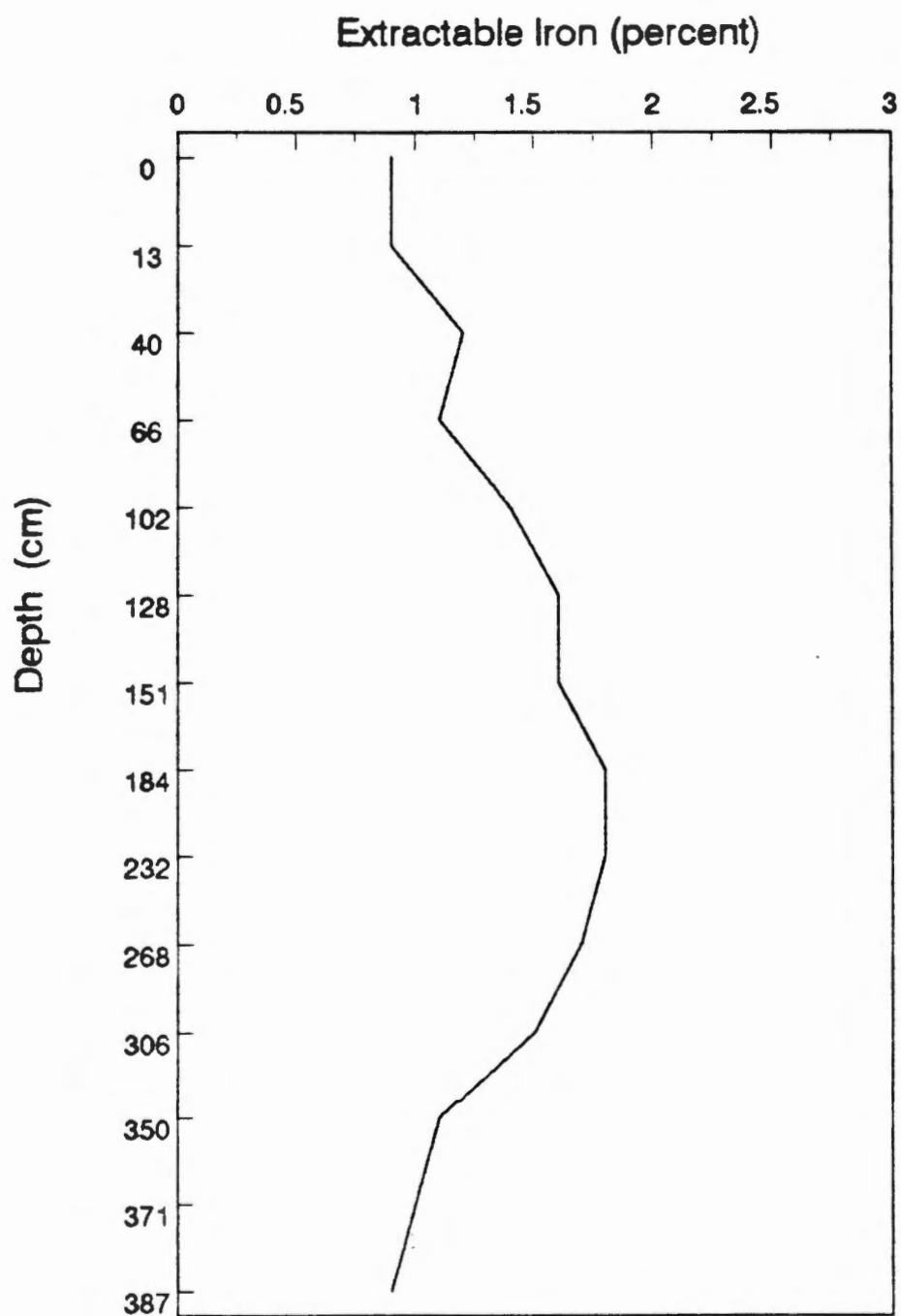


Figure 16. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 3.

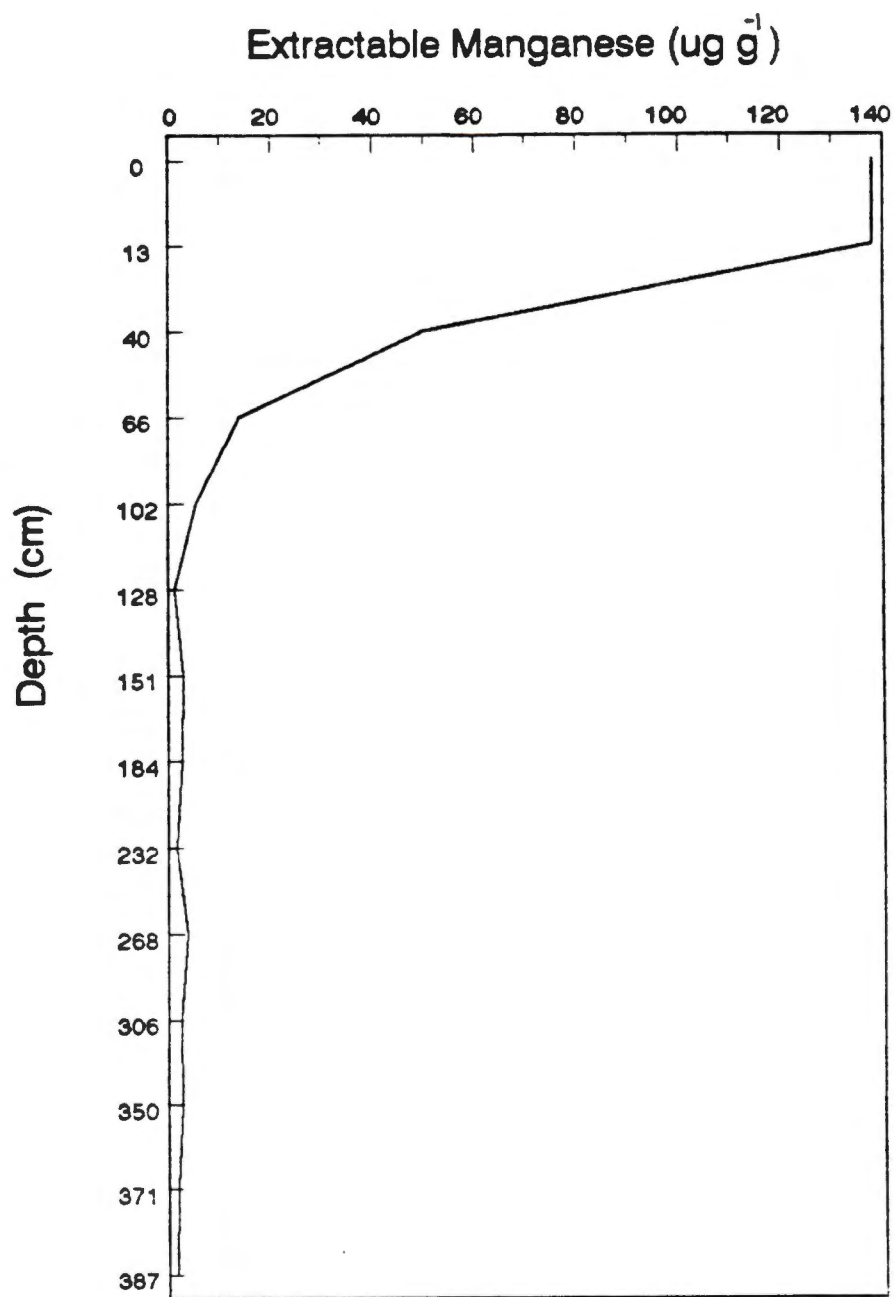


Figure 17. Hydroxyl Amine-Hydrochloride manganese distribution in the soil profile at Site 3.

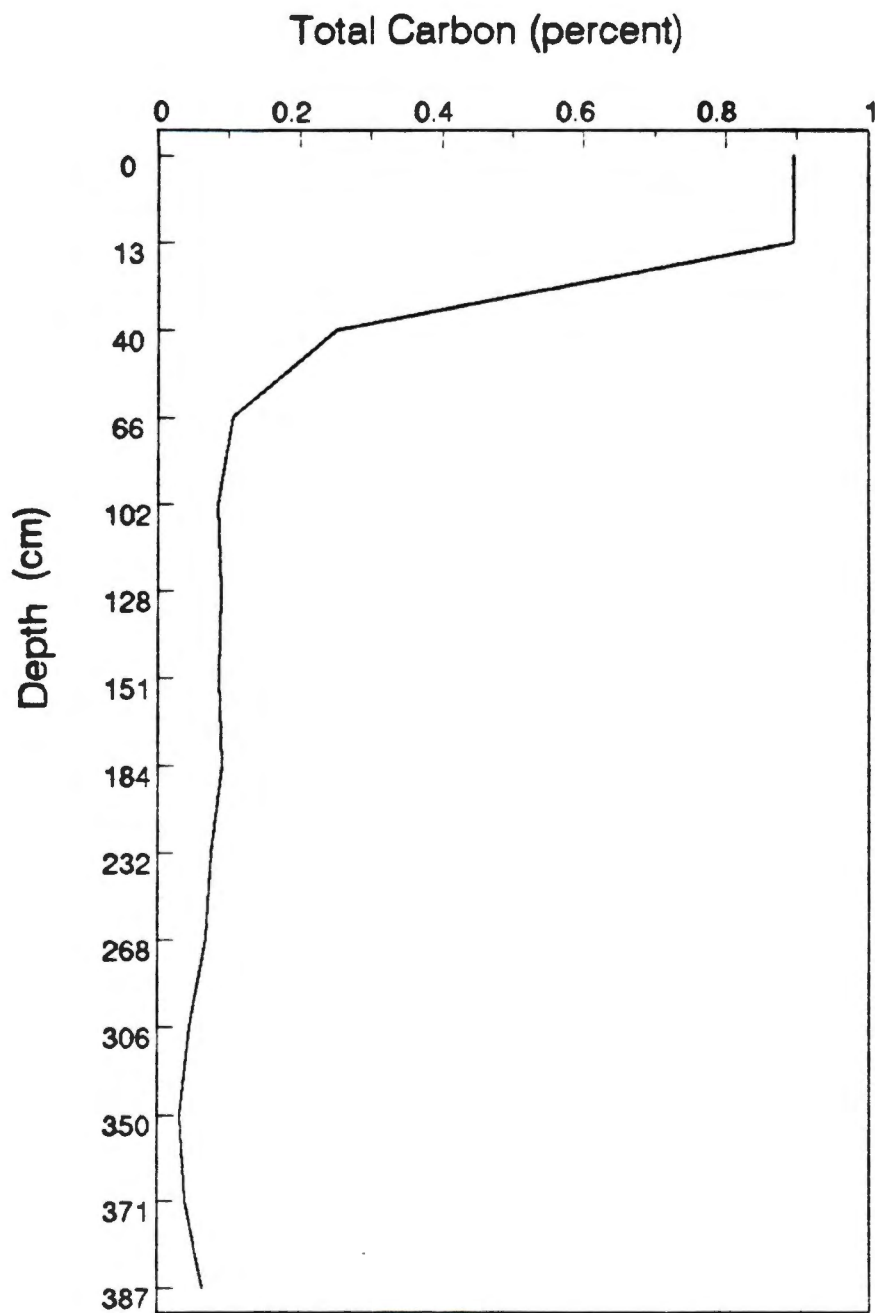


Figure 18. Total carbon distribution in the soil profile at Site 3.

to a fairly constant level throughout the subsoil. The carbon distribution also reveals the lack of buried surface horizons.

Clay mineralogical investigation showed that the same minerals were present as in the other sites (Table 2). The peak intensities were greater in the alluvial samples indicating both a higher degree of weathering and greater crystallinity in the paleosol as compared to the loessal portion of the profile (Appendix 2). The presence of clay-sized quartz in the samples (Table 2) indicates the extensive nature of the weathering processes that have taken place.

The investigation into the mineralogy of the dominant sand fractions was completed on the control section for the purpose of mineralogical classification. The grain counts showed that the control section contained an average of 90 percent quartz, 8 percent plagioclase, and 2 percent other minerals not identified (Table 3). The sand grains from the loessal portion of the profile were angular. The grains in the alluvium were elongated and rounded.

The classification of the soil at this site was a fine-loamy, siliceous, thermic Typic Paleudult (Soil Survey Staff, 1963). Based on the findings from the current study, the particle size class contains 15.5 percent sand that is coarser than 0.1 millimeters and 20 percent clay in the

control section which will place this soil in the fine-loamy particle size class. The mineralogy was determined to be mixed from the grain count data (Table 2). The sample must contain more than 90 percent quartz to be considered siliceous. The current base saturation data (Table 9) verified that the soil was an Ultisol. Therefore, based on current data, the classification of this soil at site 3 was determined to be fine-loamy, mixed, thermic Typic Paleudult.

Site 4

Soil morphology of site 4 was described to a depth of 561 centimeters (Table 10). Field data obtained from the field description (Table 10) indicated that there were two parent material discontinuities. One occurring at 36 centimeters and one at 480 centimeters. The parent material sequence of the soil at this site was loess over ancient alluvium over limestone residuum (Figure 3). The sand ratio plot show only very minor inflections at these depths and are not of much assistance in verifying lithologic discontinuities (Figure 19). The particle size and iron oxide distribution data (Figures 20 and 21) show dramatic shifts in distribution of sand, silt, and clay and iron oxide content at both 36 and 480 centimeters. These distribution shifts indicate lithologic discontinuities in the profile.

Table 9. Exchangeable base cation content and base saturation for the pedon at Site 3.

Horizon	Depth cm	Ca	Mg	Na	K	CEC	BSAT percent
		-----cmol(+) kg ⁻¹ -----					
Ap	0-13	2.35	0.27	0.06	0.30	5.5	54
AB	13-40	1.04	0.28	0.06	0.20	6.7	24
BA	40-66	0.41	0.52	0.08	0.20	6.4	20
Bt1	66-102	0.22	0.43	0.06	0.30	8.3	12
2Bt2	102-128	0.12	0.28	0.08	0.30	8.5	9
2Bt3	128-151	0.12	0.24	0.06	0.20	7.9	8
2Bt4	151-184	0.12	0.27	0.10	0.20	10.0	7
2Bt5	184-232	0.12	0.27	0.06	0.20	8.3	8
2Bt6	232-268	0.17	0.27	0.06	0.20	7.7	9
2Bw	268-306	0.14	0.23	0.06	0.20	5.6	10
2BC	306-350	0.17	0.16	0.06	0.10	3	18
2C1	350-371	0.17	0.16	0.06	0.10	2.7	19
2C2	371-387	0.17	0.16	0.06	0.10	2.7	19

Table 16. Soil morphological data for the pedon at Site 4.

Horizon	Depth cm	Color	Texture	Structure	Comments
Ap	0-16	10YR5/4 yellowish brown	L	1fsbk	
BA	16-36	5YR4/6 yellowish red	CL	2msbk	clay films
2Bt1	36-48	5YR4/6 yellowish red	C	2msbk	clay films
2Bt2	48-53	mottled	C	ND	
2Bt3	53-74	2.5YR4/6 red	C	2msbk	clay films
2Bt4	74-99	2.5YR4/6 red	C	2mpl, 2msbk	clay films
2Bw1	99-144	2.5YR4/8 red	C	2mpl	
2Bw2	144-204	2.5YR4/8 red	SC	1mpl	
2Bw3	204-284	2.5YR4/6 red	SC	1mpl	
2Bw4	284-312	2.5YR4/6 red	SC	1fsbk, 1mpl	
2Bw5	312-381	2.5YR4/8 red	SC	1fsbk, 1mpl	
2Bw6	381-419	2.5YR4/8 red	SC	1msbk	
2Bw7	419-480	2.5YR4/8 red	SCL	1msbk	
3BC1	480-498	2.5YR4/8 red	CL	1fsbk	chert frags.
3BC2	498-539	mottled	CL	1fsbk	chert frags.
3BC3	539-560	mottled	CL	1fsbk	chert frags.

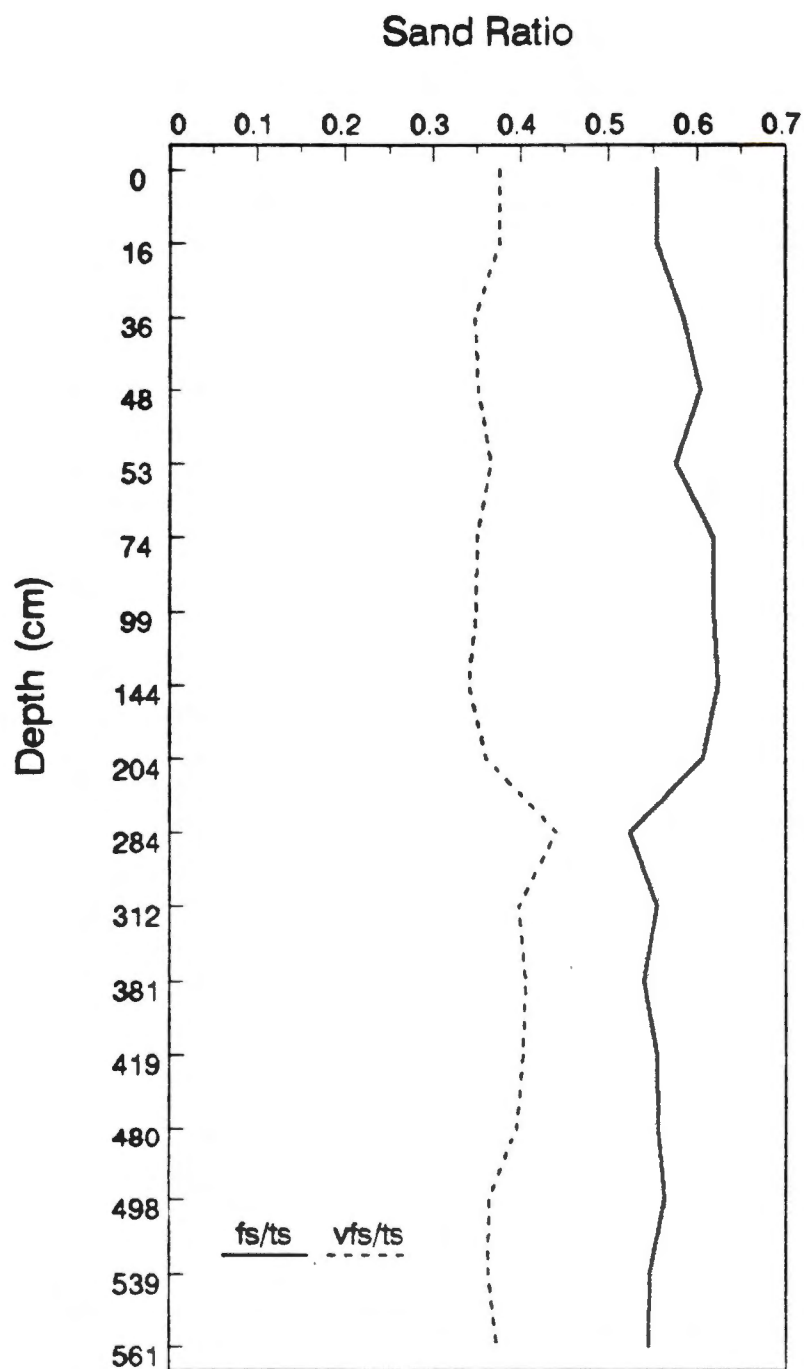


Figure 19. Ratio of fine and very fine sand to total sand plotted with depth of soil profile at Site 4

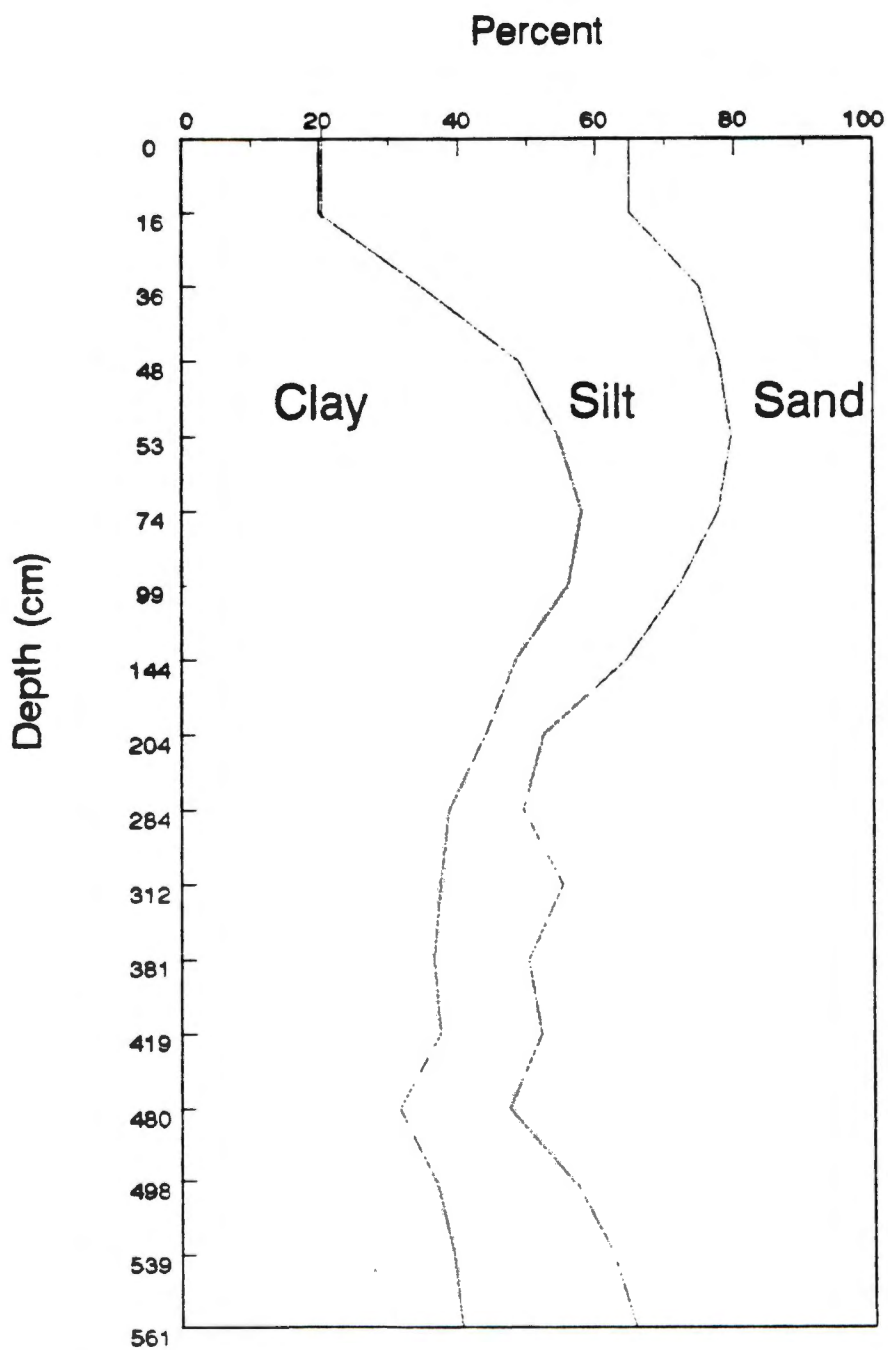


Figure 20. Sand, silt, and clay distribution in the soil profile at Site 4.

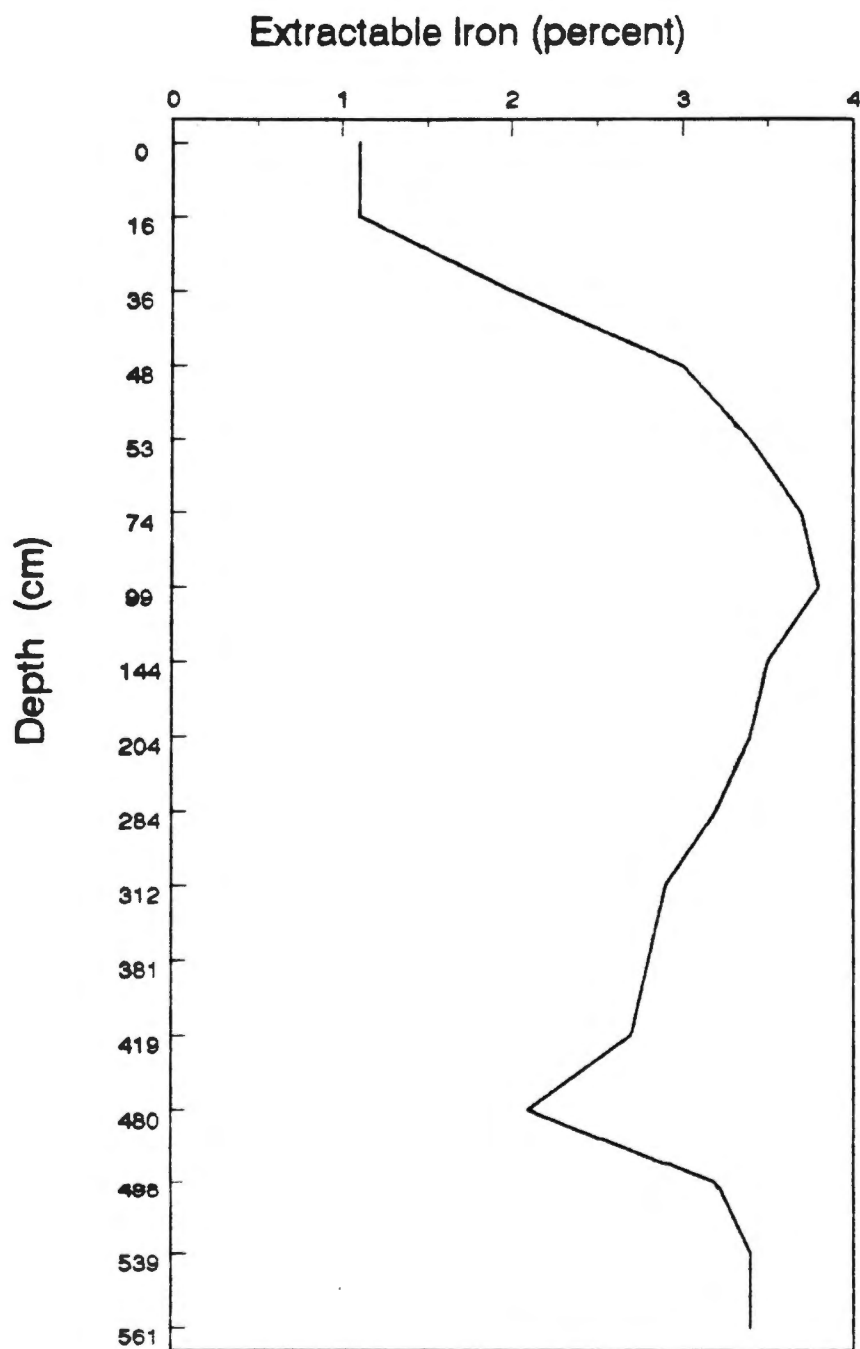


Figure 21. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 4.

The soil horizons present above 36 centimeters in this profile were formed from loess. The loessal material was in a stable landscape position for some time as denoted by the formation of moderate blocky structure and increasing iron oxide content (Table 10 and Figure 21). There was no argillic horizon formation in the loessal material at this site. This indicates that the loess deposited at this site is either younger than that of the other sites reported or that erosion of the soil at site 4 has hindered soil development in the upper horizons.

Soil horizons present between 36 and 480 centimeters originated from the alluvium deposited. Four successive Bt horizons (2Bt1 through 2Bt4) show a strongly developed argillic horizon occurring between 36 and 99 centimeters in the paleosol (Table 10). A clay bulge between these depths is characteristic of a well-expressed argillic horizon and is a feature sometimes found in paleosols (Figure 20). The iron oxide distribution curve (Figure 21) shows the characteristic increase in free iron oxides that accompanies the argillic horizon formation. The horizons that formed between 99 and 480 centimeters, 2Bw1 through 2Bw7, were less well-developed as evidenced by a weaker structure and a decrease in both clay and iron oxide content (Table 10, Figures 20 and 21).

The sand ratio plot (Figure 19) contains at least three

inflections in the alluvial layer, at 53 (2Bt3), 99 (2Bw1), and 284 (2Bw4) centimeters. These inflections presumably mark the occurrence of different episodes of deposition on the stream terrace. The data, shown in the particle size distribution plot (Figure 20), demonstrates variations in this layer which is an indication of multiple depositions.

The soil horizons present below 480 centimeters originated from residual limestone. The presence of angular chert fragments confirm residual parent material (Table 10). Presumably, there was a sequence of soil horizons that formed from the limestone parent material. These residual horizons were truncated during the deposition of the overlying alluvial material. The soil horizons described in the residual portion of the profile were transitional horizons, 3BC1 through 3BC3. These horizons were composed of a mixture of subsoil from the residual soil and slightly weathered limestone parent material. The iron oxide distribution curve (Figure 21) shows a sharp increase in oxide content in the residual layer. This increase is the result of the pedogenic weathering described in the residual parent material.

The manganese and total carbon distribution curves (Figures 22 and 23) show the same distribution pattern with depth. The higher surface concentrations of manganese and total carbon are typical of loessal material and a surface

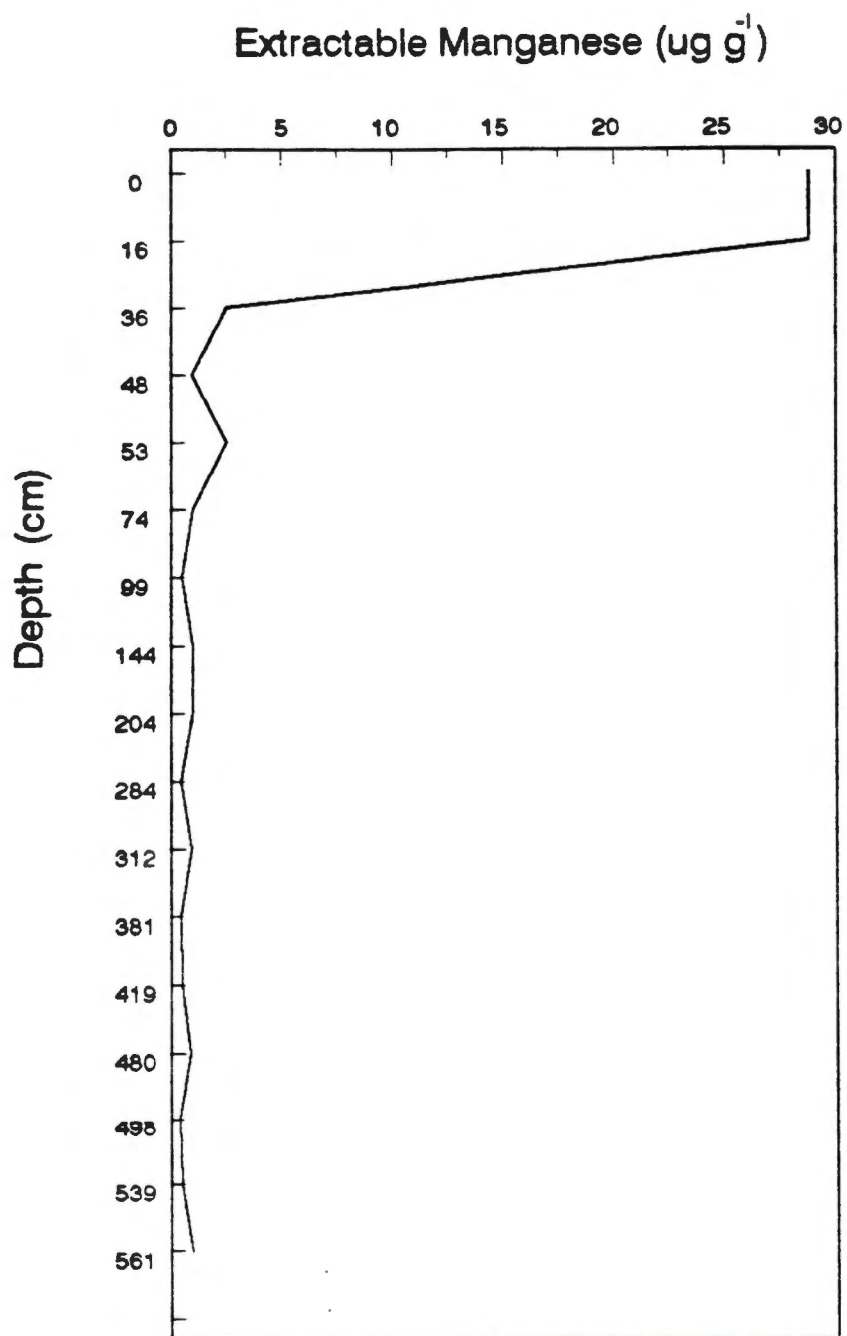


Figure 22. Hydroxyl Amine-hydrochloride manganese distribution in the soil profile at Site 4.

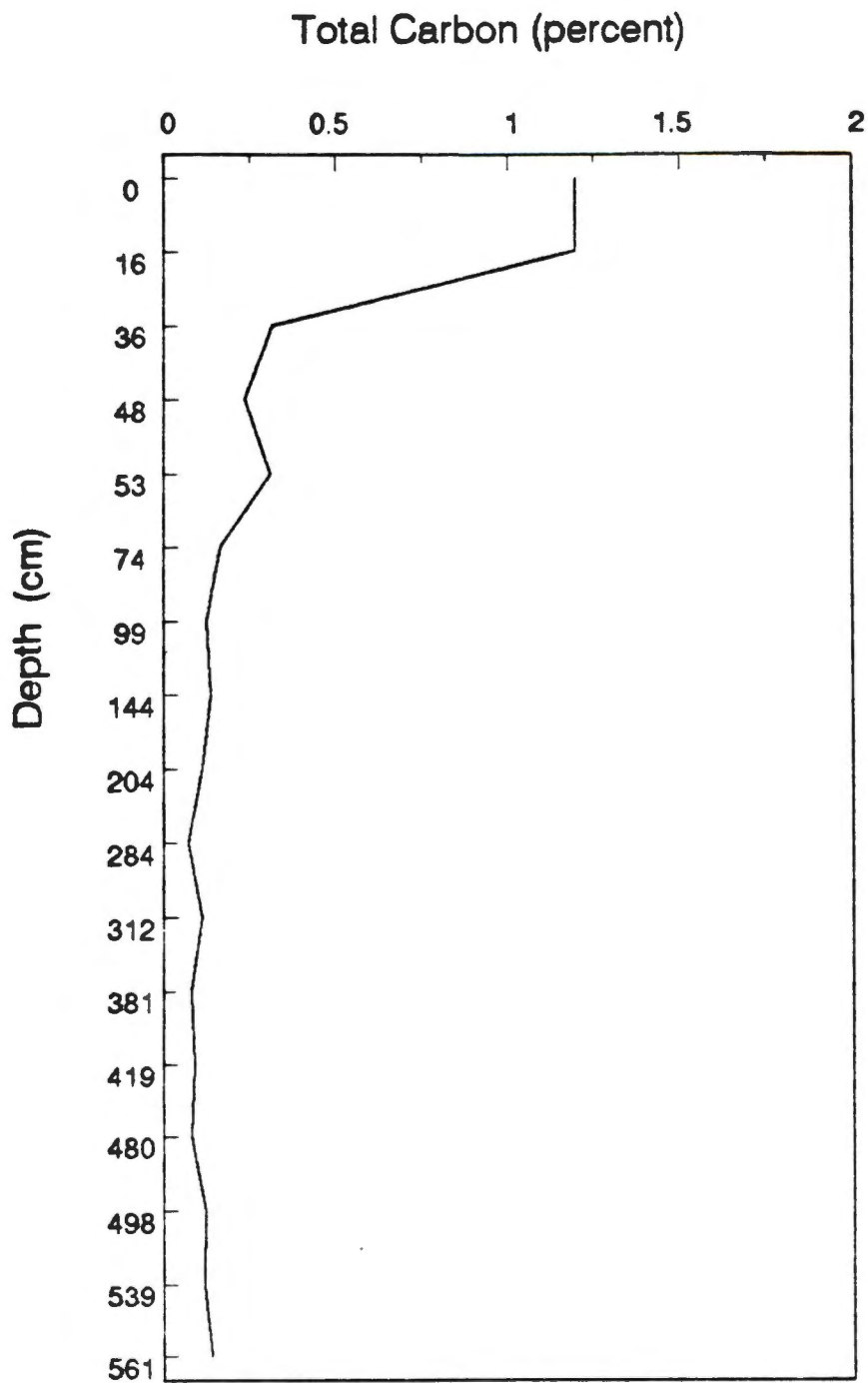


Figure 23. Total carbon distribution in the soil profile at Site 4.

horizon. This is the same pattern as demonstrated by the other sites reported in this study. The slight increase in both total carbon and manganese oxide at a depth of 53 centimeters verify the observation of an old root casing at this depth during the field investigation.

The mineralogical classification of this pedon was determined on the clay fraction from the alluvial argillic horizons (Table 10). The clay mineralogy of the 3BC2 residual horizon was determined for comparative purposes. X-ray diffractograms of the clay samples revealed the same mineral content as shown in the others sites, which included HIV, illite, kaolinite, and clay-sized quartz (Table 2). The peak intensities of the 3BC2 horizon were greater than those from the alluvial horizons. This indicates that the residual soil has undergone a higher degree of pedogenic weathering than the alluvial soil.

A grain count was conducted on the fine and very fine sand fraction from the upper argillic horizon. The sand grain mineralogy was used to investigate the genesis of the alluvial portion of the profile. The data showed an average content of 83 percent quartz, 14 percent plagioclase, and 2 percent potassium feldspar (Table 3). Some of the sand grains from these samples exhibited an elongated shape which is characteristic of water transported and deposited material.

The soil classification at this site was previously reported as a clayey, kaolinitic, thermic Typic Paleudult (Soil Survey Staff, 1963). The particle size classification was determined to be fine (46 percent clay in the control section). The mineralogy class at this site was determined on the clay fraction. The mineralogy was classified based on the qualitative clay mineralogy and was estimated to be mixed. According to the base saturation data (Table 11), the pedon that was sampled for this study was an Alfisol as opposed to the previously determined Ultisol. The current classification of this pedon is fine, mixed, thermic Typic Paleudalf.

Site 5

The morphology of site 5 was described to a depth of 491 centimeters. The field description is presented in Table 12. One lithologic discontinuity was identified from the field investigation and occurred at 56 centimeters (Table 12). The sand ratio plots (Figure 24) show only a minor inflection at this depth. The reason the ratios failed to show the discontinuity noted in the field is unclear, but the lack of fluctuation of the sand ratio curves may have resulted from homogenization of the loessal and upper alluvial portions of the profile when the loess was deposited. The discontinuity is substantiated by the

Table 11. Exchangeable base cation content and base saturation for the pedon at Site 4.

Horizon	Depth cm	Ca	Mg	Na	K	CBC	BSAT percent
-----cmol(+) kg ⁻¹ -----							
Ap	0-16	8.88	1.92	0.34	0.40	5.5	210
BA	16-36	6.97	1.93	0.23	0.20	7.8	120
2Bt1	36-48	5.82	2.93	0.24	0.30	10.4	90
2Bt2	48-53	5.51	3.19	0.25	0.30	11.9	78
2Bt3	53-74	4.52	2.45	0.17	0.30	11.9	62
2Bt4	74-99	3.65	1.76	0.22	0.30	11.2	53
2Bw1	99-144	4.16	1.26	0.09	0.20	9.4	61
2Bw2	144-204	3.80	1.04	0.09	0.20	8.0	64
2Bw3	204-284	3.58	0.83	0.11	0.10	6.6	70
2Bw4	284-312	3.75	0.78	0.08	0.10	6.6	72
2Bw5	312-381	3.49	0.67	0.09	0.10	6.3	70
2Bw6	381-419	3.86	0.74	0.08	0.10	6.7	72
2Bw7	419-480	3.74	0.62	0.08	0.10	5.4	84
3BC1	480-498	3.72	0.63	0.06	0.10	7.2	63
3BC2	498-539	3.43	0.58	0.05	0.10	7.6	55
3BC3	539-561	3.52	0.60	0.05	0.10	9.2	46

Table 12. Soil morphological data for the pedon at Site 5.

Horizon	Depth cm	Color	Texture	Structure	Comments
Ap	0-17	10YR5/4 yellowish brown	SIL	1msbk	Fe,Mn concr.
Bt1	17-41	10YR5/6 yellowish brown	SIL	2fsbk, 2msbk	Fe,Mn concr. clay films
Bt2	41-56	7.5YR5/6 strong brown	SIL	2msbk	Mn concr clay films.
2Bt3	56-79	7.5YR5/8 strong brown	SIL	2msbk	Mn concr clay films.
2Bt4	79-112	5YR5/8 yellowish red	CL	2msbk	Mn concr clay films
2Bt5	112-132	5YR5/8 yellowish red	CL	2msbk	Mn concr clay films. rounded pebbles.
2Bt6	132-201	mottled	CL	2msbk	Mn concr clay films.
2Bt7	201-237	2.5YR4/8 red	CL	2msbk	Mn concr clay films.
2Bt8	237-263	2.5YR4/8 red	CL	1msbk, 2msbk	Mn concr clay films.
2Bt9	263-284	2.5YR4/8 red	CL	1msbk, 2msbk	Mn concr clay films.
2BC1	284-371	2.5YR4/6 red	L	2msbk	Mn concr clay films.
2BC2	371-463	mottled	L	1fsbk	
2BC3	463-473	mottled	CL	OMa	
2C	473-491	mottled	CL	OMa	

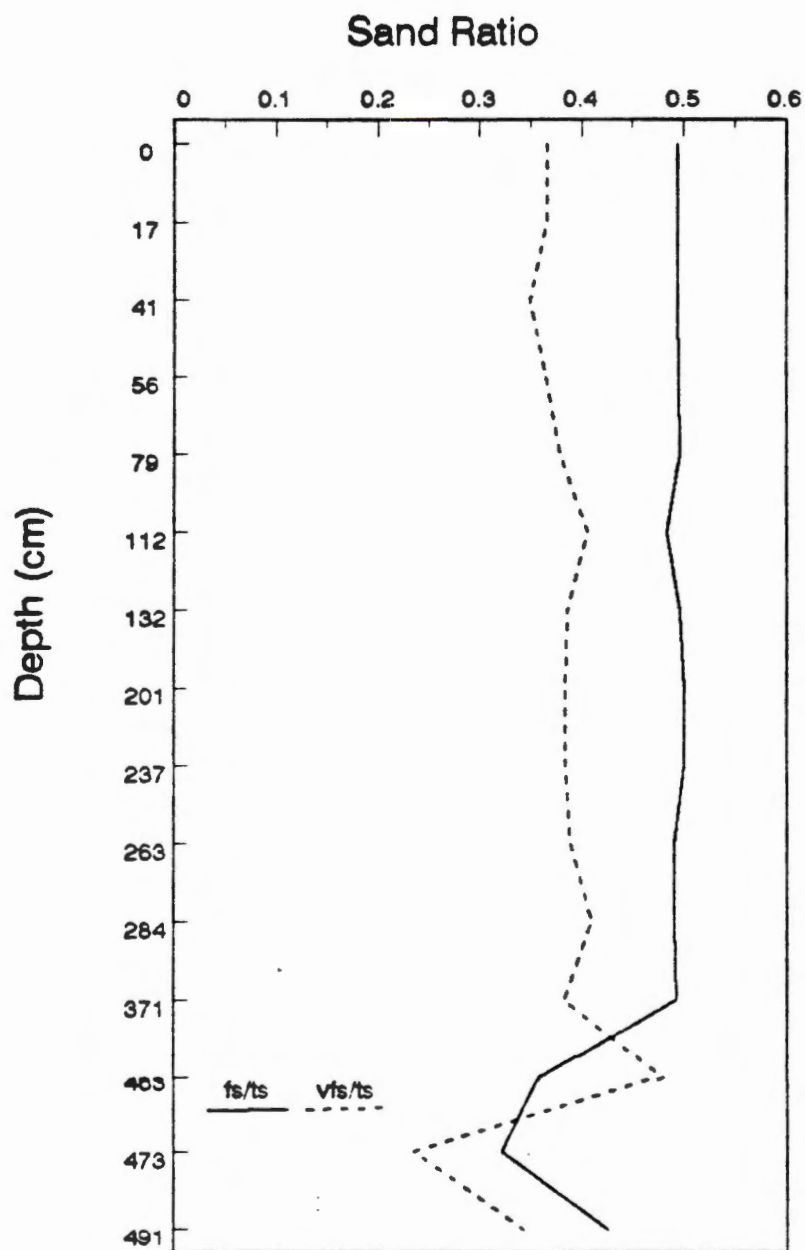


Figure 24. Ratio of fine and very fine sand to total sand plotted with depth of the soil profile at Site 5.

manganese oxide curve (Figure 25). Manganese distribution curves from the other four sites showed the loessal layer to contain a greater concentration of manganese oxide than the alluvial portion of the soil (Figures 6, 12, 17, and 22). The particle size distribution (Figure 26) also substantiates the presence of the discontinuity with an increase in clay and sand content and a decrease in silt content. The parent material sequence of this profile was loess over alluvium (Figure 3).

The soil horizons between the surface and 56 centimeters originated from a loessal parent material. The soil morphology was similar to the other sites in the study (Table 12).

The soil horizons occurring between 56 and 491 centimeters are formed from alluvial deposits (Table 12). The alluvial soil formed on a stable landscape and is estimated to be approximately 500,000 years old (mid-Pleistocene). This estimation is supported by the extensive development of an argillic horizon that formed in the alluvial material (Figure 26). The iron oxide distribution curve does not follow the clay bulge as compared to the other site reported in this study (Figure 27). The alluvial parent material is confirmed by the presence of rounded pebbles in the 2Bt5 horizon.

The soil horizons that occur between 284 and 473

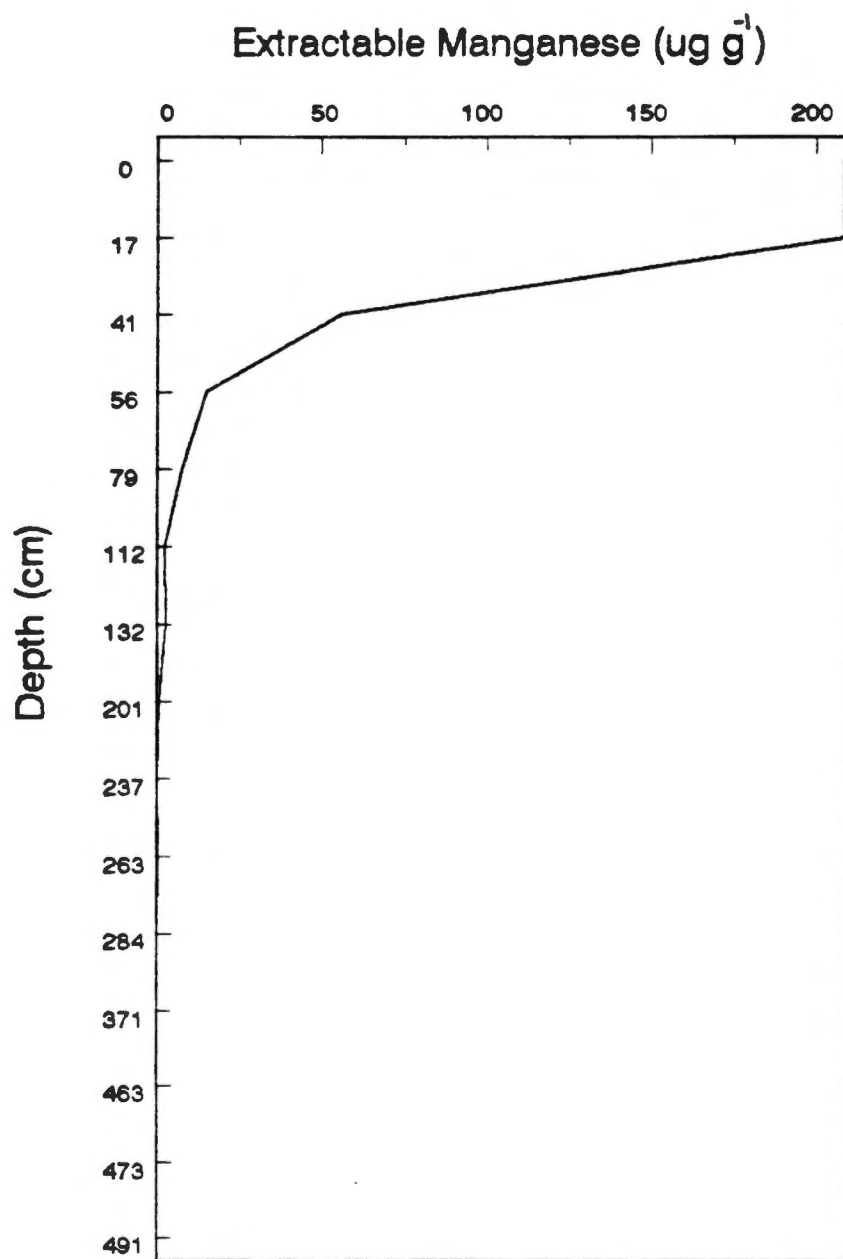


Figure 25. Hydroxyl Amine-Hydrochloride manganese distribution in the soil profile at Site 5.

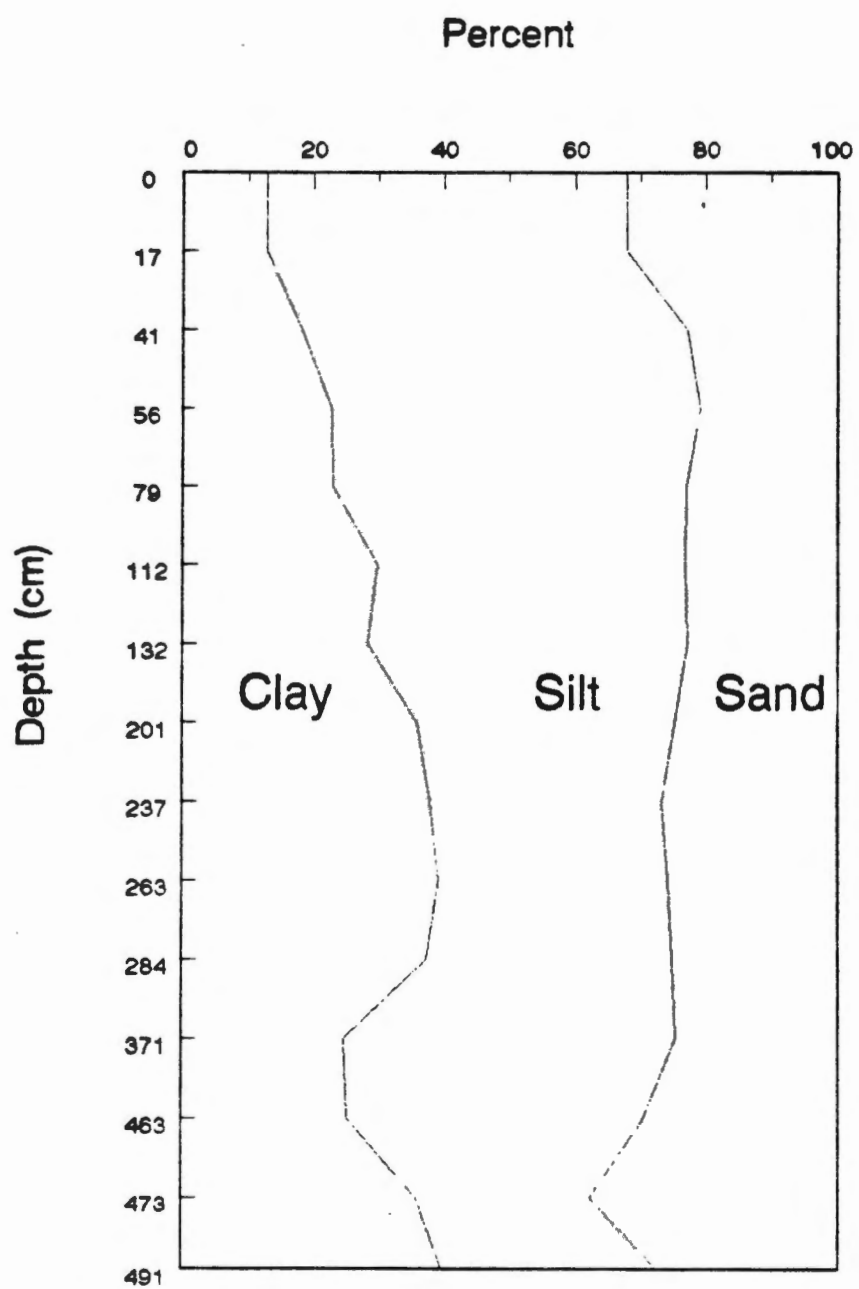


Figure 26. Sand, silt, and clay distribution in the soil profile at Site 5.

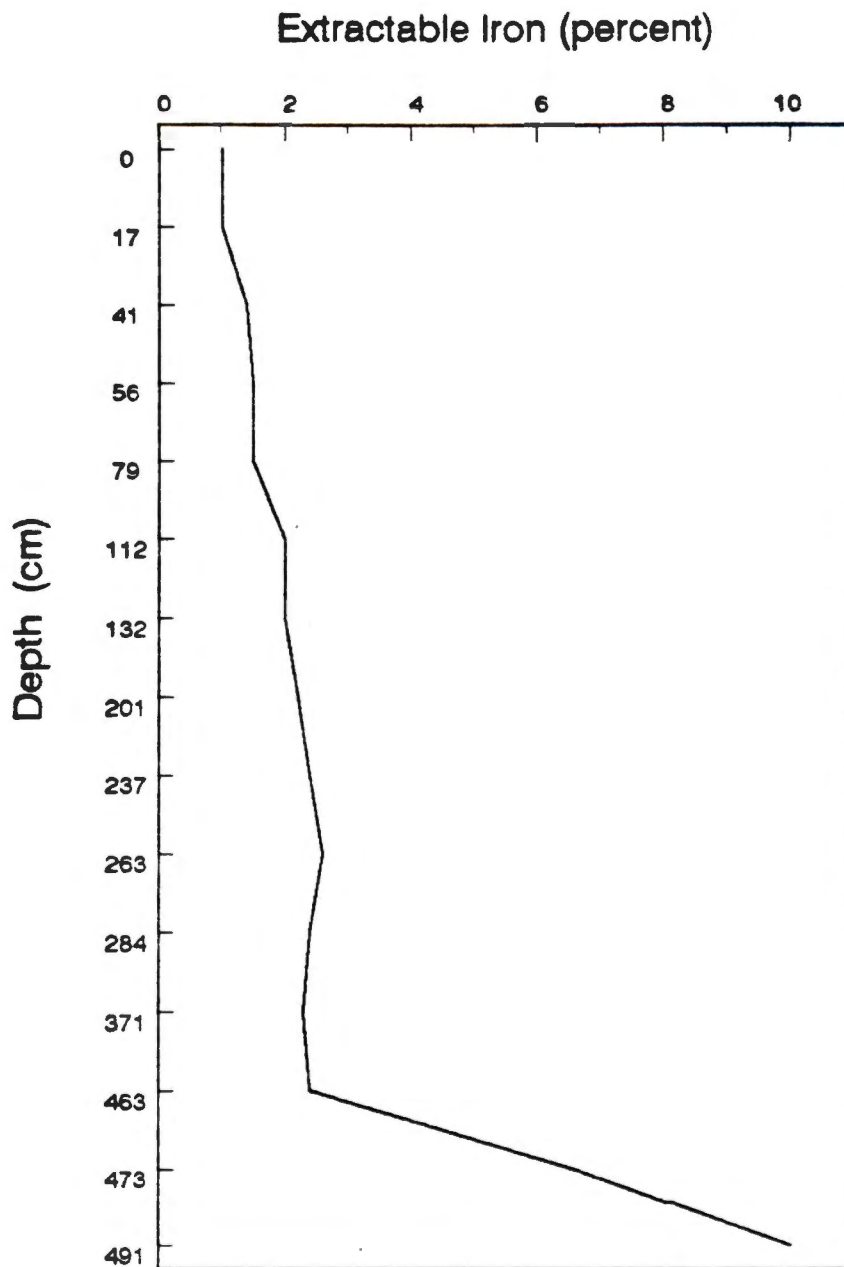


Figure 27. Citrate-Bicarbonate-Dithionite iron oxide distribution in the soil profile at Site 5.

centimeters, 2BC1 through 2BC3, are transitional horizons. These horizons were composed of a mixture of subsoil from the paleosol and slightly altered alluvial parent material (Table 12). The 2BC3 horizon contained small areas, less than 2 centimeters in diameter, of red, iron-rich concentrations that are believed to be either highly weathered rock or nodules of iron enrichment from downward iron movement as a result of argillic horizon formation.

The 2C horizon consisted of slightly weathered alluvial parent material and was described in the field as having massive structure (Table 12). This horizon also contained some iron rich areas described above which explains the increase in iron oxide content in this horizon (Figure 27). The increase in clay content (Figure 26) is caused by the nature of the alluvial material to have a high clay content and not by genetic clay formation. The alluvial parent material was weathered at least once before it was deposited in its present position. This would increase the variation in particle size distribution of the alluvial parent material.

The total carbon distribution curve shows that the surface horizons of the alluvial soil were truncated either before or during the deposition of the loess (Figure 28). The total carbon content below the parent material discontinuity of 56 centimeters is essentially constant at

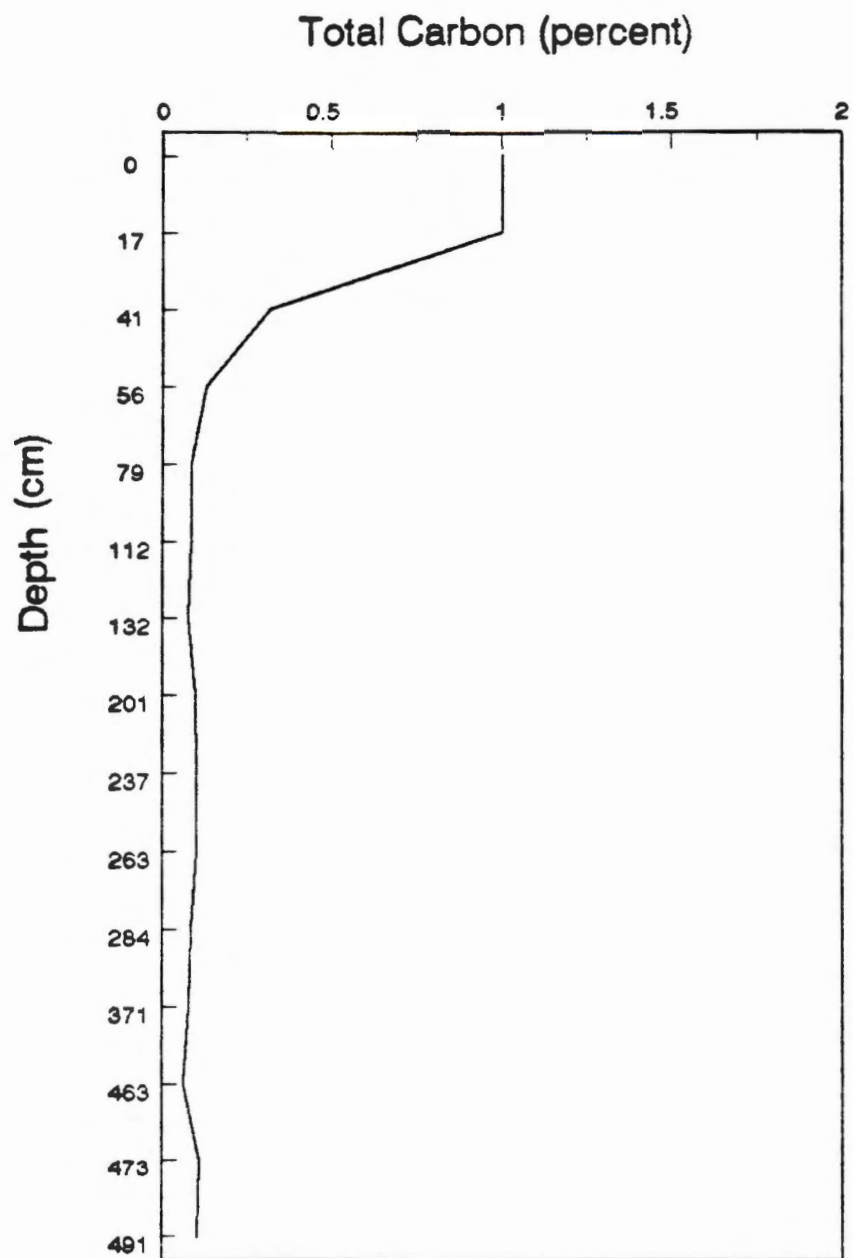


Figure 28. Total carbon distribution in the soil profile at Site 5.

0.1 percent. The importance of the manganese distribution curve was discussed earlier in this section concerning Site 5.

The clay mineralogy of the soil at this site was determined on the less than 2 micron clay samples from the loessal and alluvial portions of the profile. The X-ray diffractograms produced from the clay samples showed that the loessal and alluvial portions of the soil contained, qualitatively, the same minerals (Table 2). The peak intensities were higher in the alluvial material as compared to the loessal material. The inferences drawn from these findings are the same as those from the other sites.

Sand grain counts were completed on the mineralogical control section, the upper 50 centimeters of the argillic horizon, as defined by Soil Taxonomy (Soil Survey Staff, 1975). In this case, that portion of the soil was the Bt1, Bt2, and 2Bt3 horizons (Table 12). The mineralogy of these horizons averaged 69 percent quartz, 27 percent plagioclase, 2 percent potassium feldspar, and 2 percent minerals not identified (Table 3). The general shape of the sand grains from the alluvial portion exhibited an elongated shape that is characteristic of fluvial deposited materials.

The soil at this site was previously classified as a fine-loamy, siliceous, thermic, Typic Paleudult (Soil Survey Staff, 1963). The data from the particle size analysis

showed that the control section of the soil at this site contained 20 percent clay and 14.3 percent less than 0.1 millimeter sand. Based on this data the particle size classification of the soil would be fine-silty. The mineralogy of this soil was determined from the dominant sand fractions to be mixed. According to the base saturation data obtained from this soil (Table 13), the base saturation at 180 centimeters below the surface was 50 percent which would place this soil in the Alfisol order. Therefore, based on the field observations and laboratory data, the classification of this soil is fine-silty, mixed, thermic Typic Paleudalf.

Krotovina Occurrence and Formation

The krotovina that were present in the alluvial soils in this region were the common link between the sites that were sampled in this study. These features appeared in the alluvial portion of these soils as light brown material surrounded by red alluvial material (Plate 4).

Their formation was believed to have been caused by some form of ancient crayfish (*Cambarus fodiens*) and were the remnants of the animal's burrow (Webb et al., 1986). The feature had the shape of a long tube with a rounded bottom whose sides and bottom were lined by a resistant rind that was made up of iron and manganese oxides (Plates 5, 6).

Table 13. Exchangeable base cation content and base saturation of the pedon at Site 5.

Horizon	Depth cm	Ca	Mg	Na	K	CEC	BSAT percent
-----cmol(+) kg ⁻¹ -----							
Ap	0-17	6.76	0.73	0.23	0.20	5.7	139
Bt1	17-41	5.81	0.63	0.21	0.20	5.7	120
Bt2	41-56	4.81	1.18	0.22	0.36	6.4	101
2Bt3	56-79	3.67	1.39	0.27	0.20	6.4	87
2Bt4	79-112	2.98	1.08	0.21	0.30	7.9	58
2Bt5	112-132	2.84	0.84	0.25	0.40	7.5	57
2Bt6	132-201	2.73	0.74	0.21	0.40	8.1	50
2Bt7	201-237	2.88	0.71	0.28	0.40	8.6	49
2Bt8	237-263	2.59	0.58	0.16	0.30	8.4	43
2Bt9	263-284	2.59	0.59	0.24	0.30	9.2	40
2BC1	284-371	2.83	0.63	0.30	0.20	7.7	52
2BC2	371-463	3.45	0.62	0.27	0.10	6.5	69
2BC3	463-473	3.48	0.96	0.25	0.20	8.8	56
2C	473-491	4.12	1.23	0.25	0.20	7.5	77



Plate 4. Krotovinas exposed in a roadcut along Old Kentucky Road in Cookeville, Tennessee.



Plate 5. View of intact rind that formed on the boundary between the alluvial material and the krotovina fill material.



Plate 6. Close-up of rind showing manganese and iron segregation.

The material inside the feature was similar to the loessal surface material.

The rind formation was believed to be caused by the segregation of the iron and manganese oxides that can occur at the boundaries between contrasting materials. In this case, between the alluvial material and either water or air depending on what filled the burrow when its opening was exposed to the surface. The author believes that the rind formed a lining to the burrow prior to the formation of the krotovina. This theory is based on the idea that if the rind formed after the burrow was filled, the oxide segregation would have occurred between the loess and alluvial boundaries in the pedon. This was not seen during the field investigation.

Water Quality Implications of Deep Soil Investigations

Investigations into the genesis of the deep alluvial soils on the Eastern Highland Rim serve a multiple purpose. These investigations are important not only for providing basic information on soil genesis, but also for providing information regarding water quality associated with these soils. The purpose of this section is to point out some of the inferences that can be made regarding water quality from the data obtained from deep soil investigations.

Water movement through the soil can be traced by

observing the manganese distribution through the soil profile. Manganese, if present in the soil, will concentrate in zones in the profile that impede water movement. This has been demonstrated in the sites investigated in this study. For instance, the manganese distribution of site 1 revealed a pore size discontinuity that impeded water movement at 88 centimeters (Figure 29). As noted in that site, the water movement was not impeded long enough to cause the reduction of iron. The manganese is more sensitive to water movement than iron.

Many water contaminants, nitrates and many pesticides for instance, are mobile in the soil solution and can be transported to the ground water (Soileau, 1988). Under favorable conditions, proper Ph and ample supply of water moving through the soil profile, these substances can contaminate ground water. Environmentally, these contaminants can affect man as well as livestock and wildlife. Patterns of water movement through the soil, and therefore the potential for ground water contamination, can be identified with deep soil investigations.

Difficulties with the use of Soil Taxonomy

Soil Taxonomy was the classification system used in this study to classify the soils on the Eastern Highland Rim in Tennessee. The author employed the use of this system

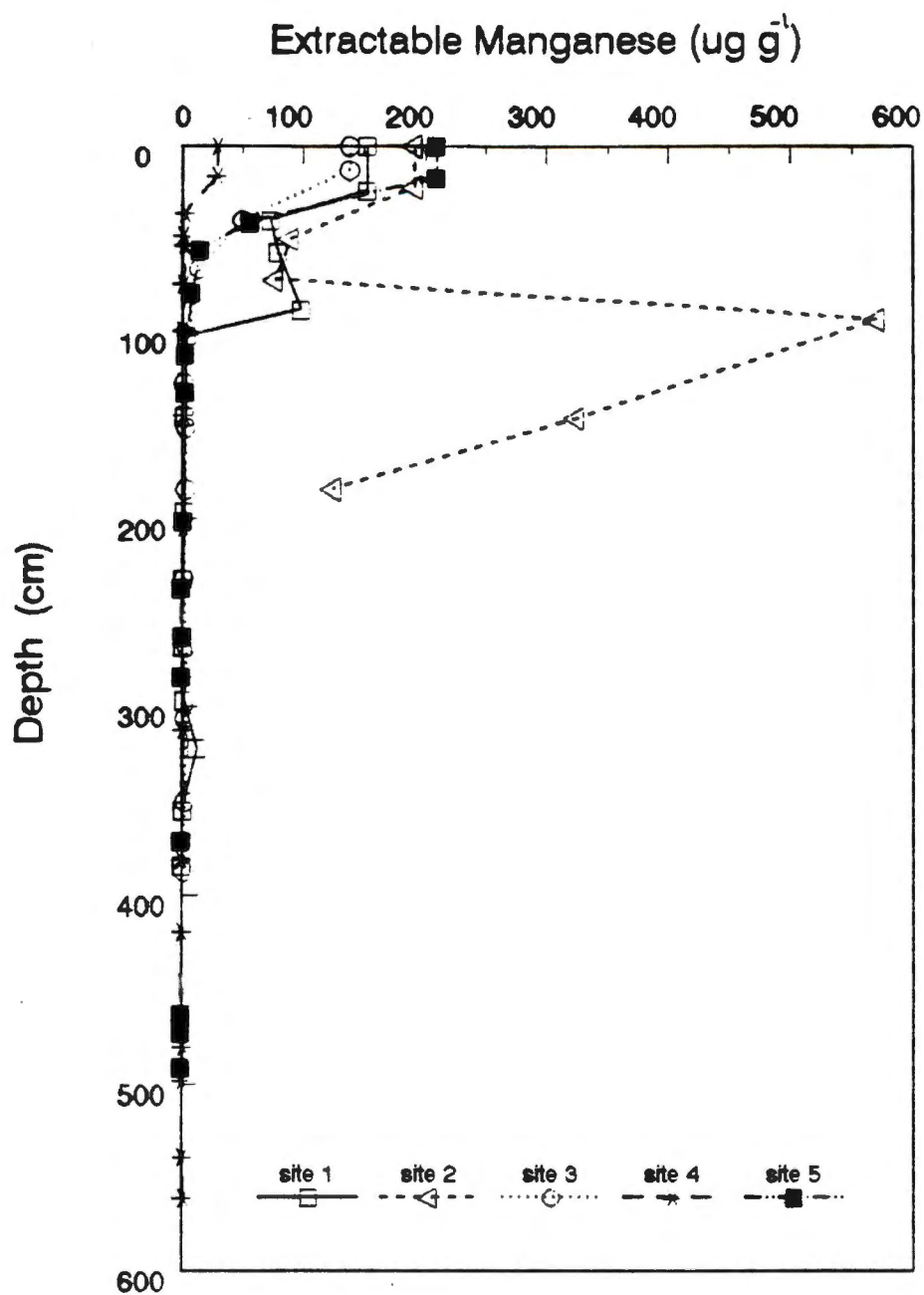


Figure 29. Comparison of the Hydroxyl Amine-Hydrochloride manganese distribution from all sampled sites.

because it is the standard for use in the United States. The purpose of this section is to present several problems that were encountered with its use during this study.

This study required soil investigations and subsequent descriptions of the terrace soils to depths in excess of 5 meters. Soil Taxonomy is mainly set up to classify soils to a depth of 2 meters. Therefore, the project was exceeding the limits of the system from the very start.

The initial problem stemming from the actual depths of the descriptions was that of horizon designations. The first part of this problem deals with the use of the designation of a buried soil, the lower case 'b'. The use of this designation is reserved for soils buried by a mantle, at least 50 centimeters thick, of new material, with new material being defined as largely unaltered. The formation of the soil at several sites used in this study was such that a residual soil formed in limestone parent material, its surface was truncated and covered by alluvium in which a well-developed soil formed. The alluvial soil was truncated and subsequently covered by loess in which a third soil developed. To complicate this situation even further, the landscapes on which these soils formed were stable enough to allow weathering to occur through the tri-sequence of soils. The problem in describing these soils is that the residual and alluvial portions of the profile are,

in essence, both buried soils formed from different parent materials. Soil Taxonomy does not allow that these be classified as buried soils by the strict definition. This limits the allowed description of the soils included in this study to the designation of lithologic discontinuities for the different parent materials.

The next problem encountered was the master horizon designation that would adequately describe a sequence of horizons between the argillic horizons and the somewhat altered parent material. The horizons in question are somewhat well-developed with structure, color, and genetic clay content and are not adequately described by either the 'Bw' or the 'BC' designation. The author used each of these designations in this study but was not satisfied with the resultant description. A possible remedy for this situation is the development of a subhorizon designation for genetic clay formation that would fill the gap between a cambic horizon and an argillic horizon.

Soil Taxonomy was set up as an open system that, through review, is capable of being changed as further knowledge is acquired. It is the wish of the author that the findings from this study be used to advance Soil Taxonomy as a complete system for the classification of soils.

Conclusion

Similar developmental patterns were revealed in the loessal and alluvial portions of the sites studied. The thickness of the alluvial layer varied somewhat at each site but some important trends were observed. First, the surface of the alluvium occurred within a narrow range of depths below the existing soil surface (from 79 to 128 centimeters). This is important in establishing the common origin of the alluvial soils at each of these sites. If the origin of the alluvium were strictly local there would be a greater fluctuation in the surface of the alluvial layers.

The second trend is that the thickness of the alluvial deposits increased with increasing proximity to the area of channel fill (observation site 1). Site 1 was probably the furthest from the actual channel because of the slight amount of alluvium present as compared to the other four sites.

The ages of the soils occurring at each of the four sites is similar. The loessal material is believed to be approximately 10,000 years old. The alluvial material is thought to be mid-Pleistocene in age, approximately 500,000 years old. The relative similarity in ages is supported by the mineralogical data that revealed the same mineral content for each site. XRD investigation provided insight that helped substantiate the relative age differences

between the loess and the alluvium. XRD results also provided insight into the extensiveness of the weathering that took place to form these soils.

Taxonomically, the soils were very similar. The base saturation differences places the soils in two orders, Alfisols and Ultisols. The data established that, at the Great Group level, the soils were Hapludalfs, Paleudalfs, or Paleudults. The basic differences were based on the clay distribution throughout the profile.

The krotovinas are believed to be the remnants of ancient crayfish burrows that formed in the alluvial material and were filled with loess. The krotovina exposures on the landscape provided a simple means of identifying the stream terrace remnants once the relationship between the two was established.

The difficulty in establishing the origin of stream terraces was discussed earlier and it must be remembered that the findings from this study are not fully conclusive. The data from the field and laboratory investigations showed that the soil included in the study were alluvial in nature and were part of the depositional events caused by a major stream system that was once active in this region of Tennessee. Further investigations and site descriptions in this region would clarify the common link that the remnants of the alluvial soils in this region have to one another.

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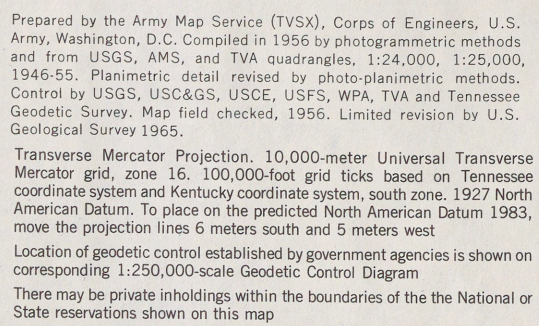
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APPENDIXES



Scale 1:250,000

0 5 10 15 20 Statute Miles

5 10 15 20 25 30 Kilometers

5 10 15 Nautical Miles

CONTOUR INTERVAL 100 FEET

1960 MAGNETIC DECLINATION FOR THIS SHEET VARIES FROM 2°30' EASTERLY FOR THE CENTER OF THE WEST EDGE TO 2°30' WESTERLY FOR THE CENTER OF THE EAST EDGE. MEAN ANNUAL CHANGE IS 0°03' WESTERLY.

FOR SALE BY U.S. GEOLOGICAL SURVEY, DENVER, COLORADO 80225, OR RESTON, VIRGINIA 22092

Plate 1. Study area delineations and site locations marked on the Corbin topographical quadrangle.



ORBIN, KY.; TENN.
1956
LIMITED REVISION 1965

APPENDIX 1. SAND COUNT PROCEDURE

Preparation of sand slides:

1. Glass slides are warmed directly on a hot plate. Spread as thin a coating as possible of the adhesive, in this case Lakeside cement, on the slide.
2. Sprinkle the sand onto the warmed, cement covered area of the slide, taking care to obtain an even coat and to avoid clumping.
3. Remove the slide from the heat and allow it to cool.

Staining of the mounted sand grains:

1. Expose the mounted sand grains to concentrated hydrofluoric acid (HF) for 1 to 2 minutes. This etches the grains so as to allow attack by the stains.
2. Wash the slide with a gentle stream of distilled water.
3. Immerse the etched slide in Na-Cobaltonitrite for 2 minutes. This stains the K-feldspars a yellowish-brown color.
4. Rinse.
5. Immerse the slide in Malachite Green for 2 minutes. This stains the plagioclases a greenish-blue color.
6. Rinse.

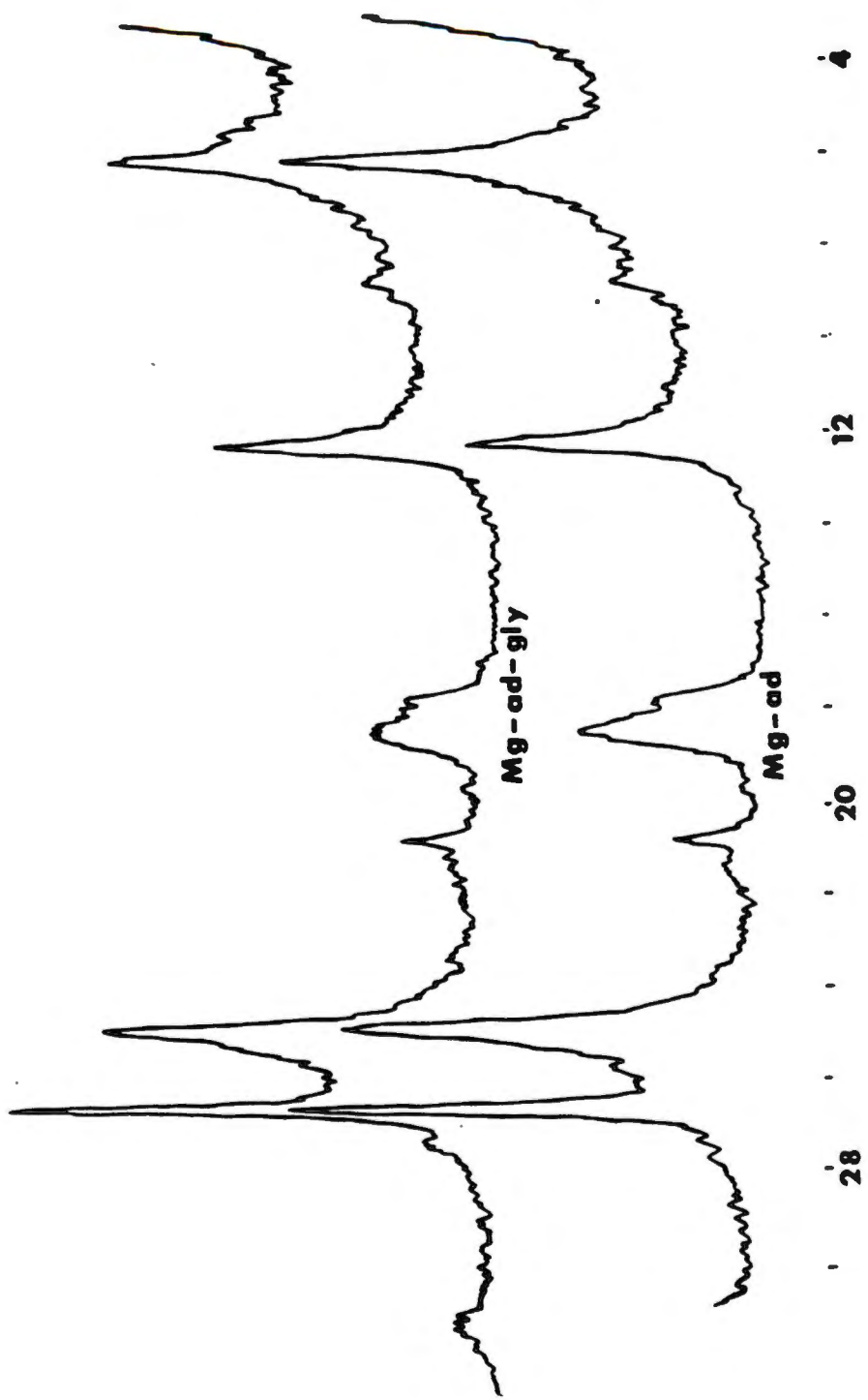
Grain Counting:

1. Place the prepared slide under the microscope, in this case a Sanyo video microscope with high resolution color monitor was used in place of the standard petrographic microscope, and adjust the zoom control so that 75 to 100 grains can be seen clearly in the field of view.
2. Count and identify grains until at least 300 grains have been recorded. To avoid biasing the count, do not change the zoom adjustment during the count of an individual slide and count full screens even if the count totals more than 300 grains.
3. Calculate the approximate weighted percentage of each mineral in the sample based on the weight percent of the fraction being used.

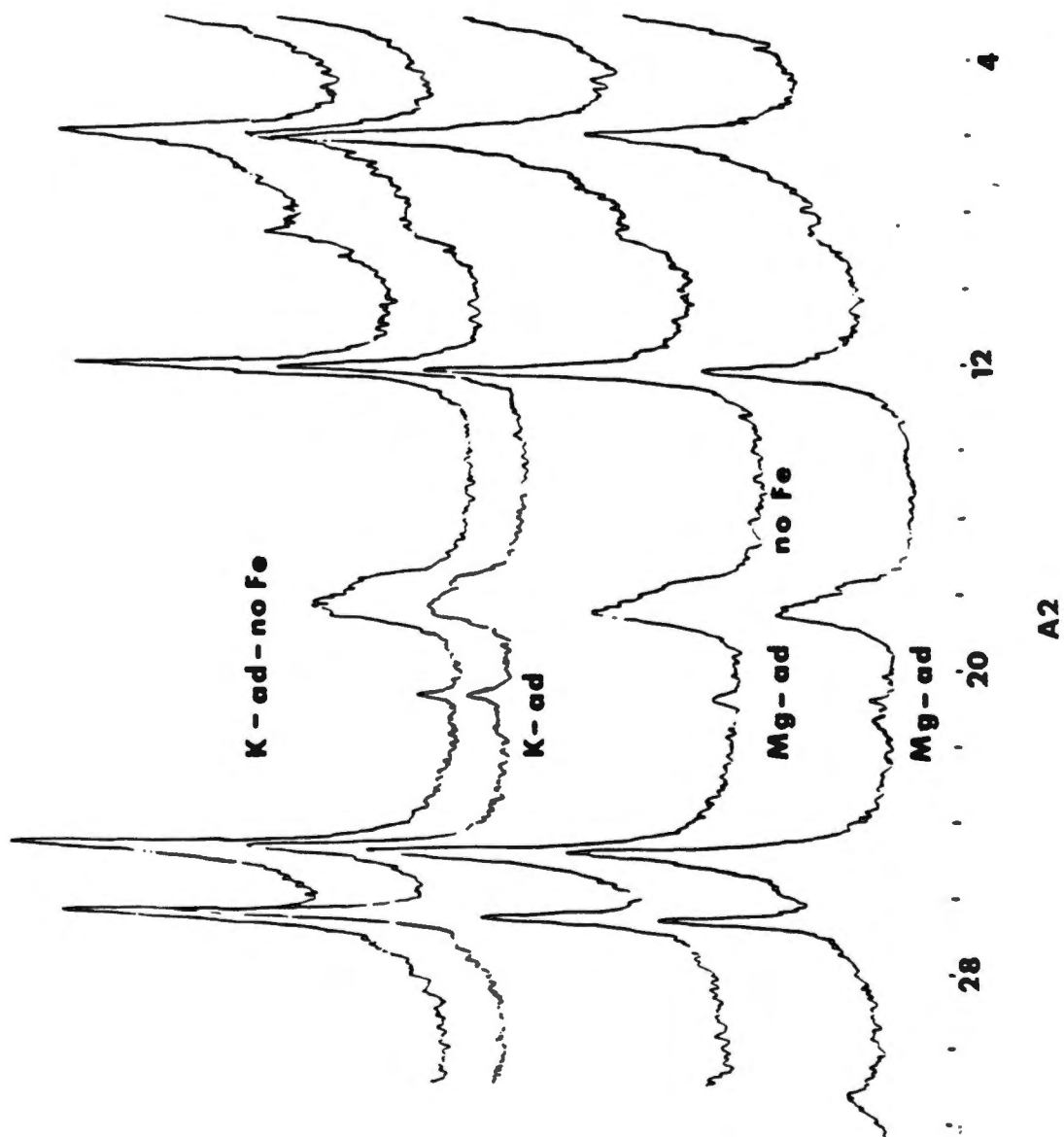
APPENDIX 2 CONTENTS

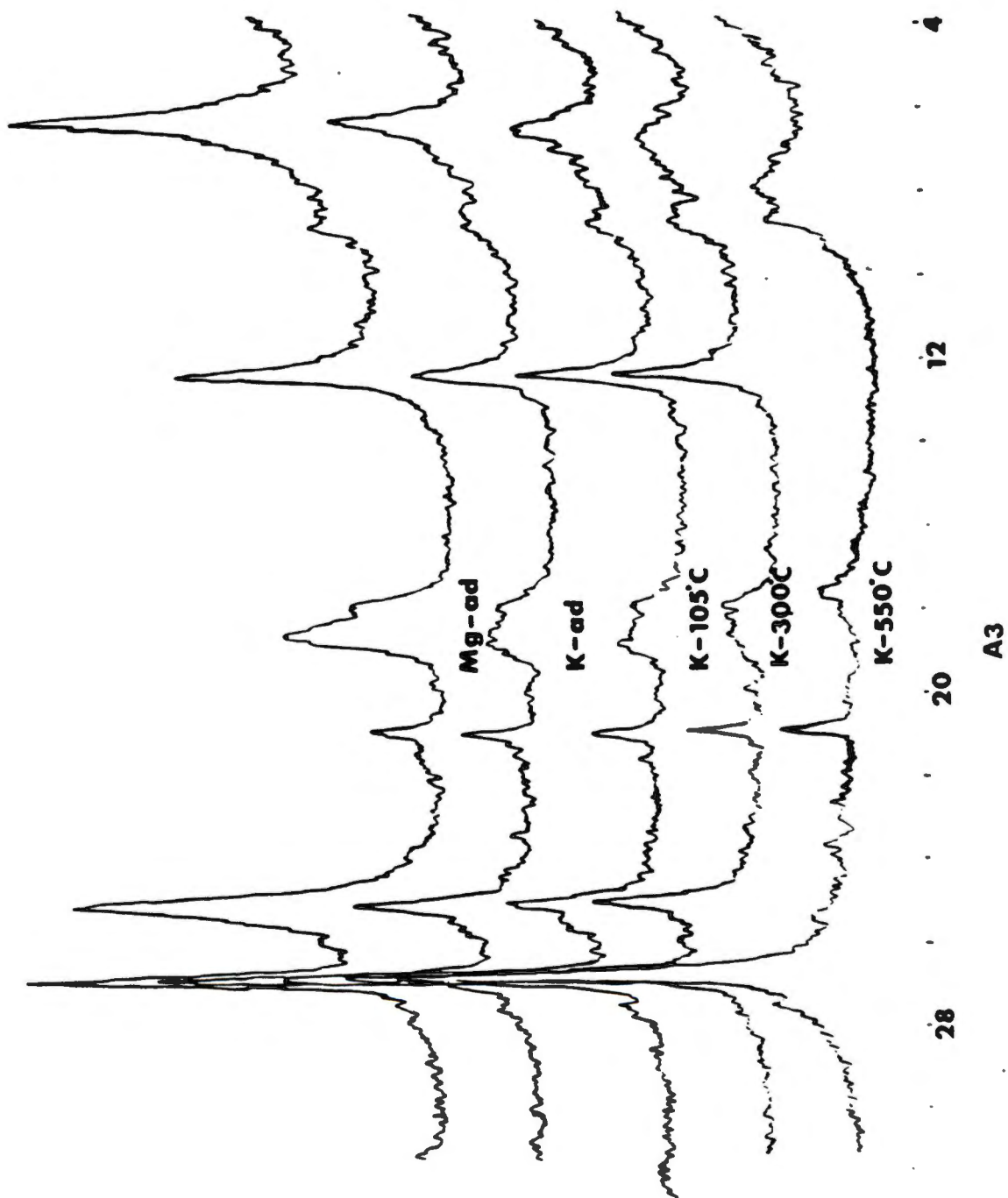
- A1. Site 1, Horizon Bt1. Shows lack of effect of the addition of ethylene glycol.
- A2. Site 3, Horizon BA. Shows the effect of iron removal.
- A3. Site 1, Horizon Bt1. XRD scan of the loessal portion of this profile.
- A4. Site 2, Horizon Ap. XRD scan of the loessal portion of this profile.
- A5. Site 2, Horizon 2Bt4. XRD scan of the alluvial portion of this profile.
- A6. Site 3, Horizon BA. XRD scan of the loessal portion of this profile.
- A7. Site 4, Horizon 2Bt1. XRD scan of the alluvial portion of this profile.
- A8. Site 5, Horizon Bt1. XRD scan of the loessal portion of this profile.

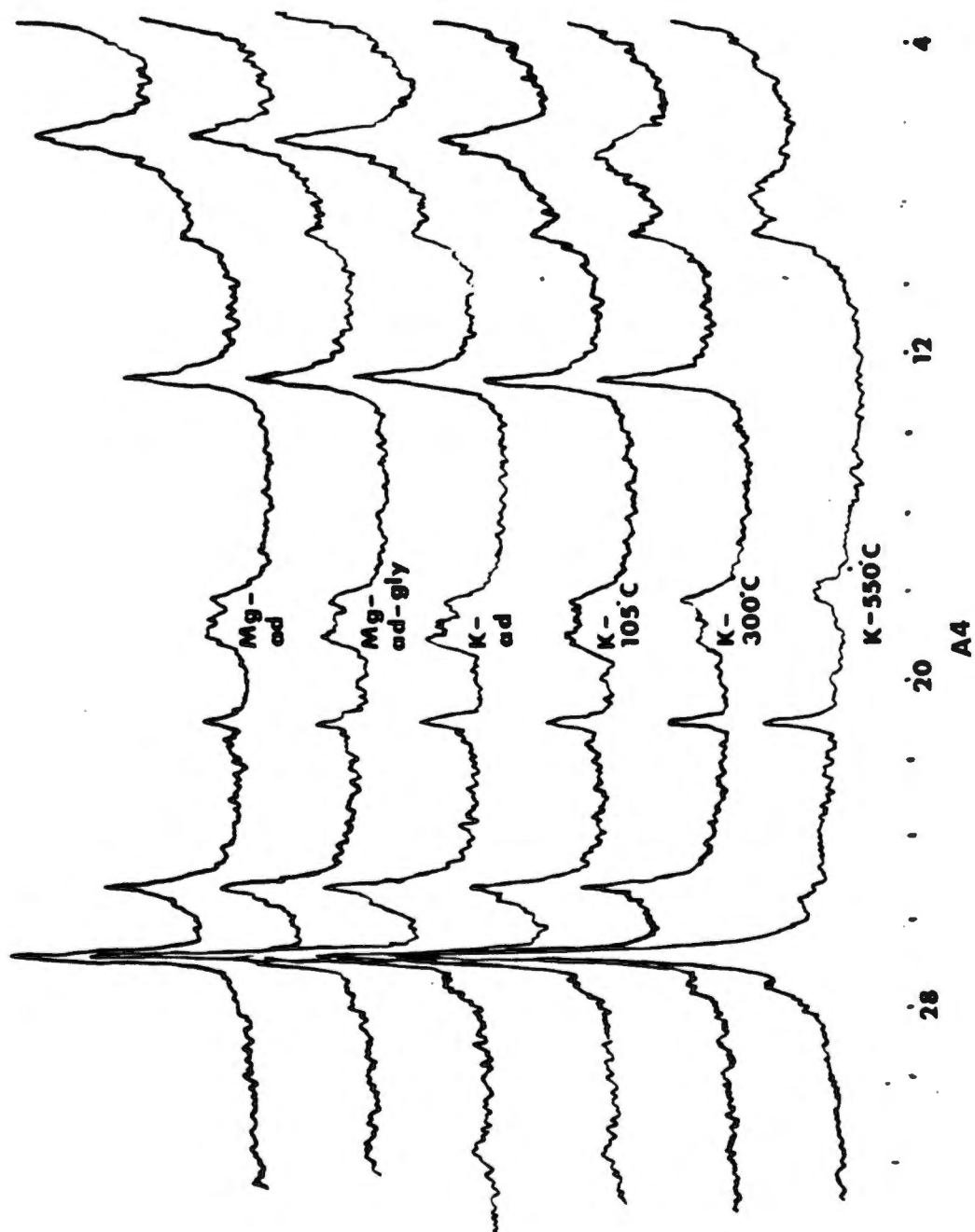
Axis scale is degrees two-theta.

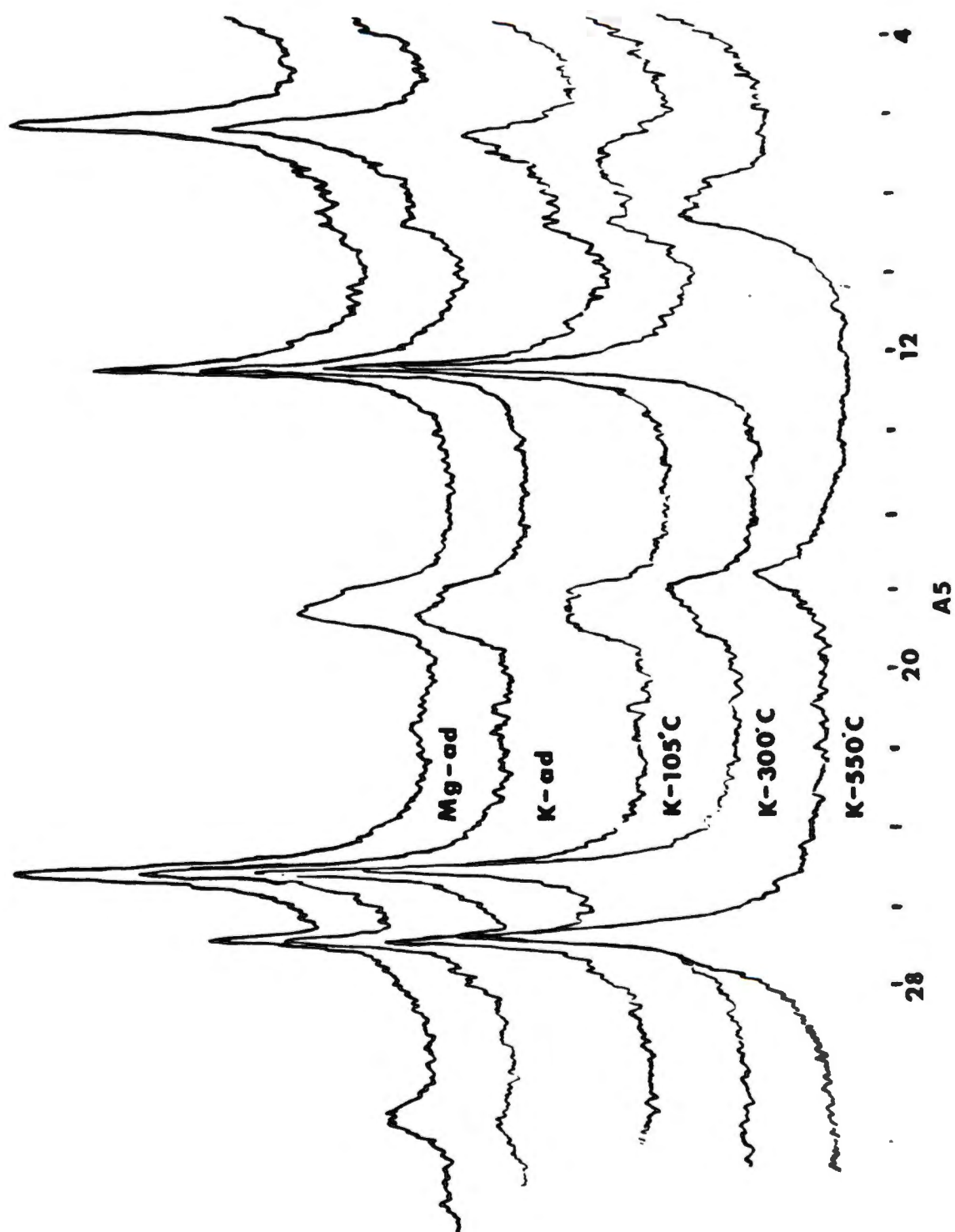


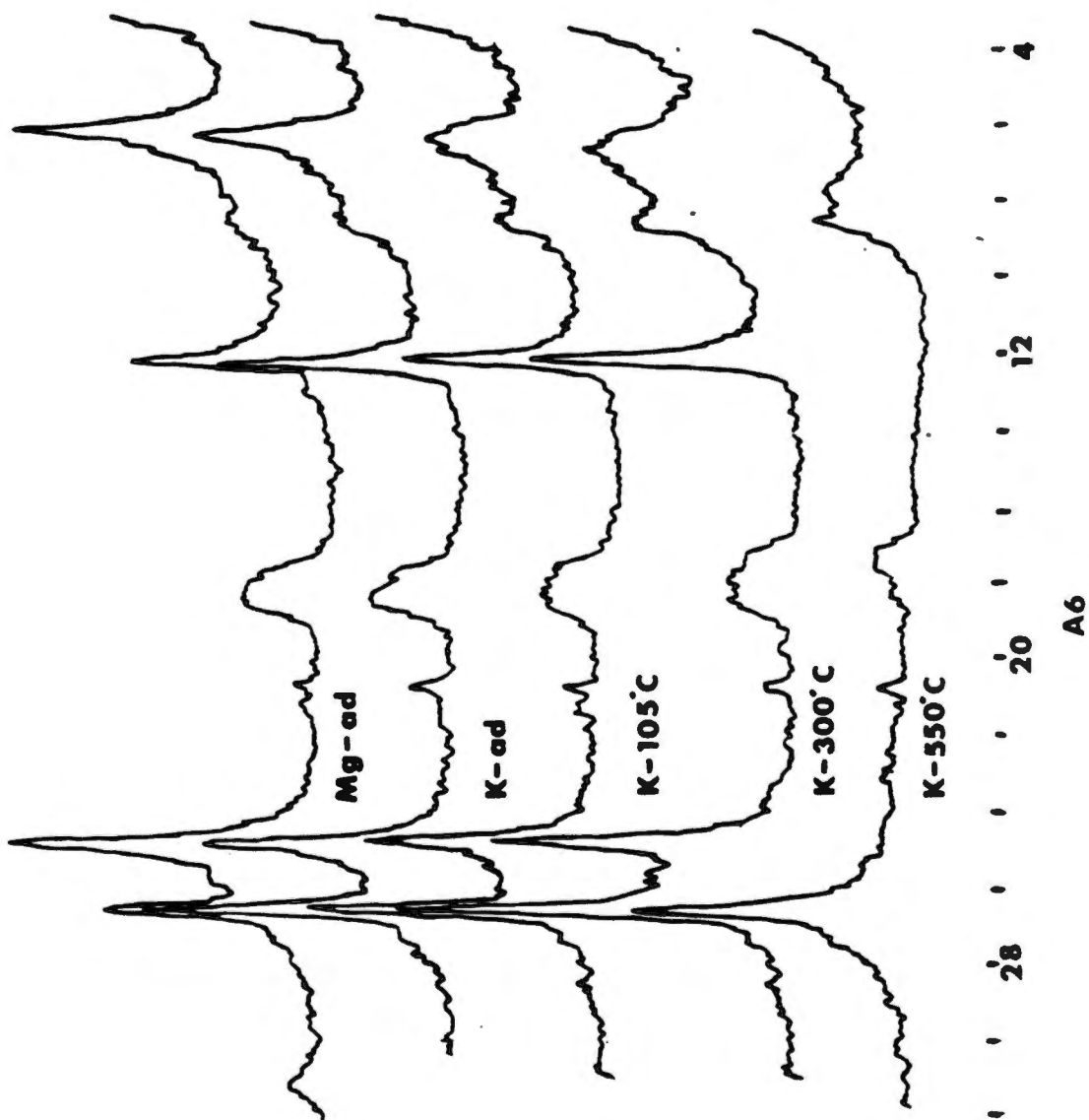
A1

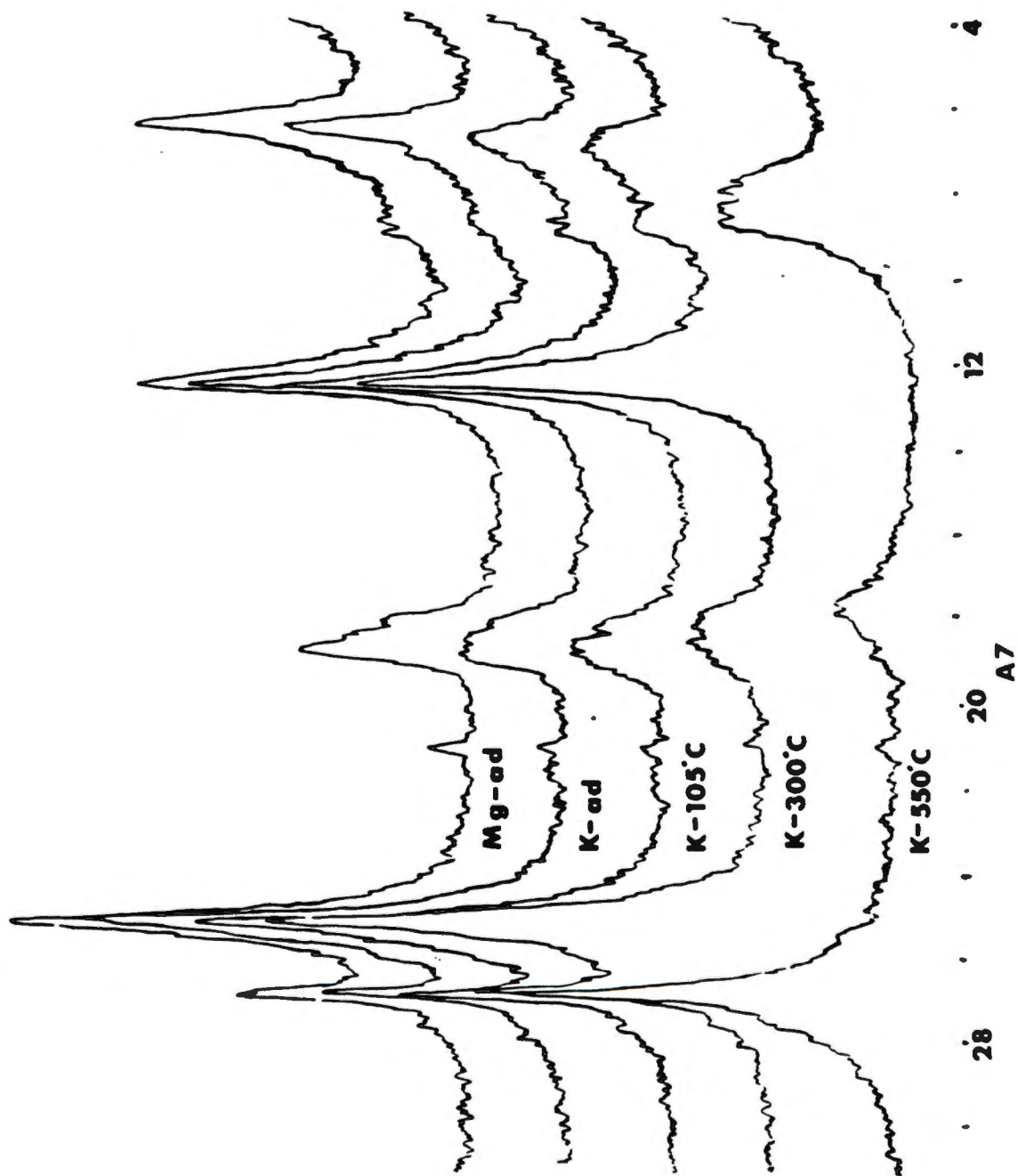


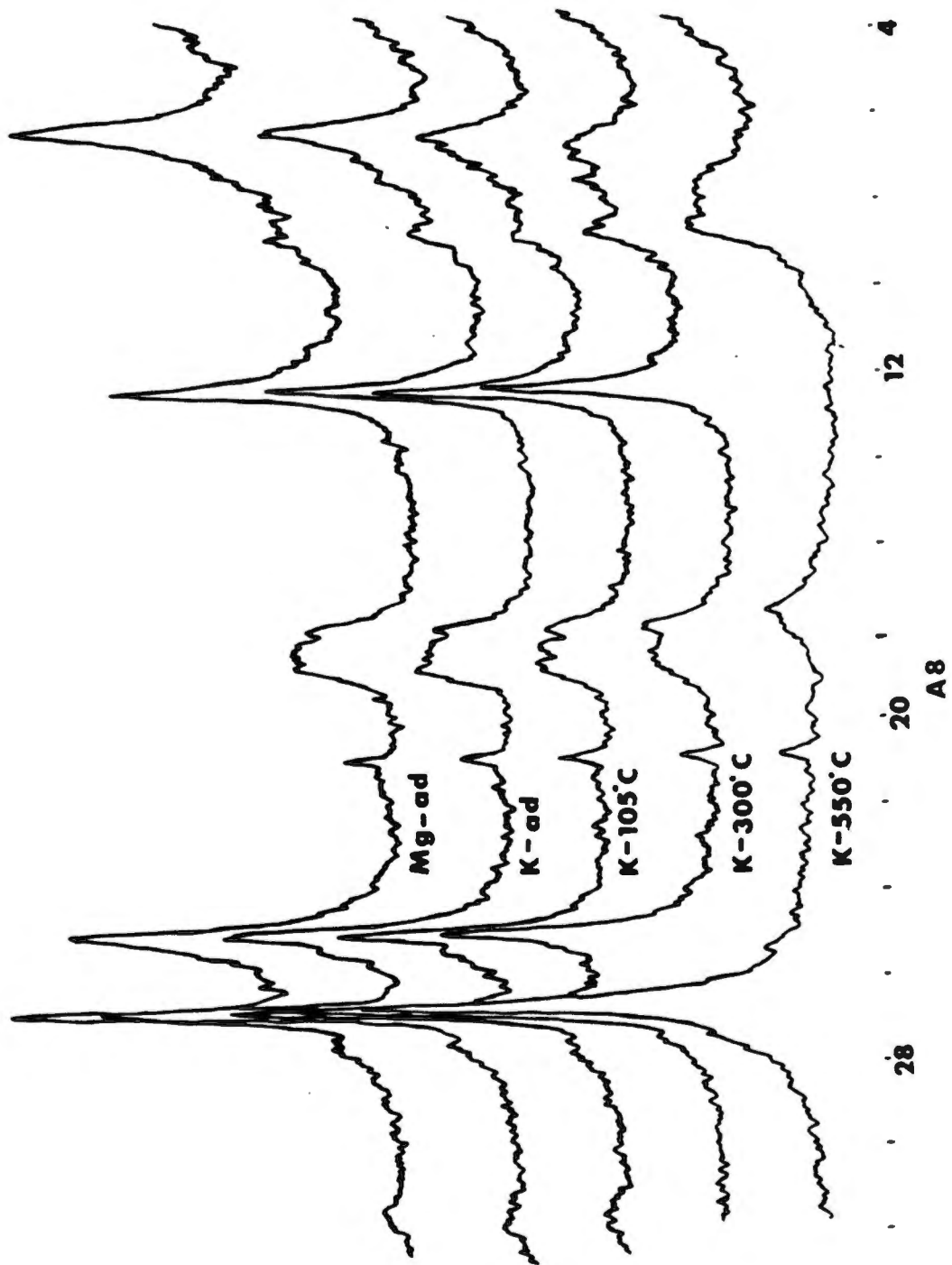












VITA

Anthony Richard Khiel was born in Washington, D.C. on March 9, 1965. He attended public schools in Montgomery County Maryland and was graduated from Montgomery Blair High School in June 1983. He entered the University of Maryland at College Park the following August. He transferred to Tennessee Technological University in the Fall of 1984 as a sophomore, and in December 1987 he received his B.S. degree in Agriculture. In the Fall of 1988, he accepted a graduate research assistantship from the University of Tennessee at Knoxville and began study toward a Master's degree in Soil Science. He received his M.S. in Soil Science in December 1990.

The author is a member of Phi Kappa Phi, Gamma Sigma Delta, Delta Tau Alpha, and the American Society of Agronomy. Mr. Khiel is employed by the Cumberland County Government, in Tennessee, and is attached to the Soil Conservation Service as a soil scientist.