To the Graduate Council:

I am submitting herewith a thesis written by Jason D. Windingstad entitled "Pedologic investigations in the Red River region of Eastern Kentucky: Relationship of soil properties to lithology, slope aspect, and soil quality to prehistoric indigenous food plot locations." I have examined the final paper 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 Environmental Soil Science.

Neal Eash, Major Professor

We have read this thesis
And recommend its acceptance:

Accepted for the Council:

Vice Chancellor and
Dean of Graduate Studies

AG-VET-MED.

Thesis
2005
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PEDOLOGIC INVESTIGATIONS IN THE RED RIVER REGION OF EASTERN KENTUCKY: RELATIONSHIP OF SOIL PROPERTIES TO LITHOLOGY, SLOPE ASPECT, AND SOIL QUALITY TO PREHISTORIC INDIGENOUS FOOD PLOT LOCATIONS

A Thesis

Presented for the

Master of Science

Degree

University of Tennessee, Knoxville

Jason D. Windingstad

December, 2005

ACKNOWLEDGMENTS

This thesis would not have been possible without the support and assistance of friends, colleagues, and family. First I would like to acknowledge Dr. Neal Eash for asking me to be his graduate student. I am thankful for his guidance and his willingness to allow me to pursue my own interests.

I would also like to thank my committee members, Dr. Sarah Sherwood for giving a Midwestern farm kid a chance and Dr. John T. Ammons for his guidance during lab work. I am grateful to Dr. Sarah Sherwood for her feedback and support throughout the drafts of this thesis.

A special thanks goes out to the landowners, the Skidmores, the Andersons, and the Whites for allowing us access to their property. This research would not have been possible without their kindness. A special thanks goes out to Tee Skidmore for the after work refreshments.

I owe many thanks to my friends and colleagues at the University of Tennessee, Melanie Stewart, Jessie Journey, Dustin Eash and Paul Seger for there input and contributions to this thesis.

I would like to acknowledge my family especially the undying support of my mother and father who supported me even when I failed. Thank you for installing in me a great respect for nature and a strong work ethic that allowed me to achieve my goals.

Finally, I would like to thank my wife Sunny for her patience, support, and kindness. It was her strength as much as mine that saw me through to the end. It is to her that I dedicate this thesis.

ABSTRACT
Part 1

The Red River Valley of Eastern Kentucky contains cultural remains that point to the independent development of agriculture during the Late Archaic cultural period. The objective of this study is to gather quantitative data through the chemical and physical analysis of soils collected within a valley transect to gain insights into landscape processes and soil quality that may have played a role in the development of plant domestication. National Cooperative Soil Survey standards were used for field descriptions and the chemical and physical analysis of all samples. Soil quality values such as ECEC (ammonium acetate pH 7), pH (1:1 soil, water), Available P (Bicarbonate), Organic C and N (dry combustion C analyzer), and particle-size (pipette method) are plotted versus landscape position to determine what slope position contains soils suitable for hillside food plots. Relative soil age indicators such as extractible iron (citrate-dithionite method), B horizon thickness, and clay accumulation are used to interpret landscape processes and relative age of the numerous slope failures in the region. Upland soils had the highest ECEC and base saturation compared to other landscape positions. Outcrops of Mississippian carbonate bedrock are contributing basic cations to upland soils resulting in high base saturation. Soil morphology indicates that the landslides encountered within the transect are late-Holocene in age. These slides were likely generated by mid to late-Holocene climatic shifts in which the frequency and intensity of summer precipitation increased across the southeastern United States. These landslides may have contributed to the development of plant domestication by providing disturbed soils in which weedy plants (such as those domesticated by indigenous people) thrive.

ABSTRACT
Part 2

The Western Cumberland Escarpment in Eastern Kentucky has slopes developed in sedimentary bedrock of Mississippian and Pennsylvanian age. This study was conducted in order to determine the affects of slope position, aspect, and changes in bedrock on soils developed in these lithology segmented slopes. Chemical and physical soil characteristics such as ECEC, base saturation, pH, soluble cations, organic C, particle size, and free iron are plotted versus slope position in order to determine the relationship between pedologic and geomorphic processes and slope position in this landscape. Correlation coefficients are then calculated and trend lines plotted in order to determine if a correlation exists. The soils of the SW facing slope had a moderate to strong statistical fit (r^2>0.60) for solum depth, extractable Fe, base saturation, soluble cations, organic C, sand content in the A horizon, and Profile Darkness Index (PDI). Poor correlations existed for clay ratios and pH. Soils of the NE facing slope had a moderate statistical fit (r^2>0.60) for solum depth, extractable Fe, base saturation, soluble cations, fine silt content in the A horizon, ECEC, and PDI. Poor correlations existed for pH, sand content of the A horizon and organic C. Carbon accumulation index indicated that carbon is being retained at the summit of the SW facing slope and is accumulating at the base of NE facing slope. The influence of changes in bedrock lithology is apparent in the base status of upland soils as outcrops of carbonate bedrock contribute basic cations. The NE facing slope had thinner sola, less extractable Fe, lower clay ratios, lower base saturation, and lower pH than the soils of the SW slope. Increased moisture contents on the NE facing slope may have contributed to the landslides found in the lower slope positions.

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Part 1
Soil Quality and Indigenous Foodplot Locations In Eastern Kentucky

Introduction

Many studies have been conducted concerning the rich ethnobotanical deposits preserved in the rockshelters inhabited along the Western Escarpment of the Cumberland Plateau in eastern Kentucky revealing early plant husbandry and domestication during the Terminal Archaic and Woodland cultural periods (Gremillion 1996, Smith 1989, 1992). Previous research has primarily focused on the carbonized plant remains found within storage pits or paleofecies recovered in rockshelters such as Cloudsplitter, (Cowan 1985), Newt Kash and Hooten Hollow, Menifee County (Gremillion 1996), and Cold Oak Shelter, Lee County (Gremillion 1993, 1996). Among the macrobotanicals recovered are Pre-maize domesticates such as *Chenopodium berlandieri* (goosefoot), and *Iva annua* (sumpweed) which have been recognized as contributions to the Native diet (Gremillion 1993, Smith 1989) and were likely cultivated in garden plots either on hillslopes in close proximity to the rockshelter and/or in the alluvium of the Red River Valley.

In addition to the question of foodplot location, it is unclear how plant domestication occurred in such a rugged landscape. The study area (Fig. 1 and 2) lies along the North Fork of the Red River in the Western Cumberland Escarpment (Potsville Escarpment) of east central Kentucky (Fenneman, 1938). The Potsville escarpment is characterized by steeply dissected gorges with canyon-like valley margins and limited aerial extent of alluvium. Resistant beds of sandstone and conglomerate within lower strata of Pennsylvanian age form the cap rock of the escarpment. The Red River, as the primary drainage for the region, flows from east to west to its confluence with the North Fork of the Kentucky River. Drainage type is dendritic with watershed topography

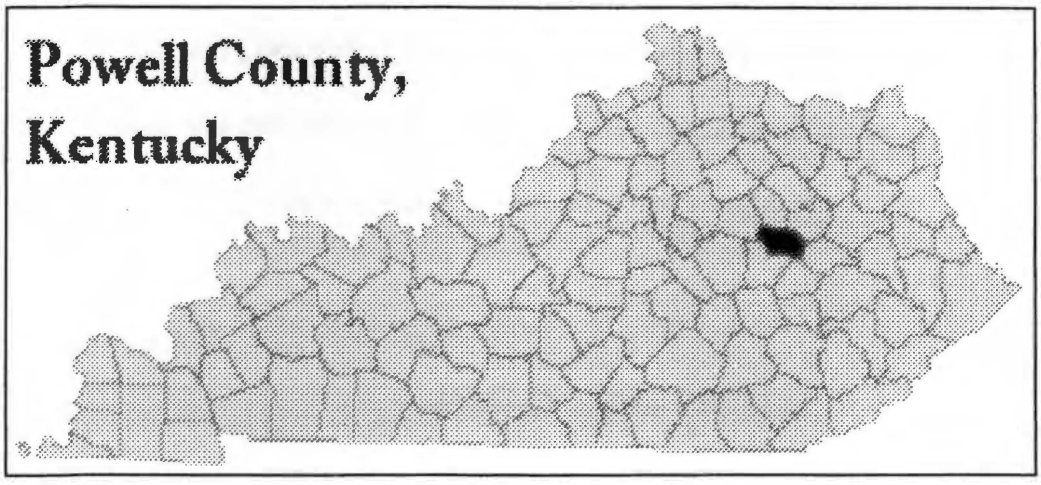


Figure 1: Location of Study Area

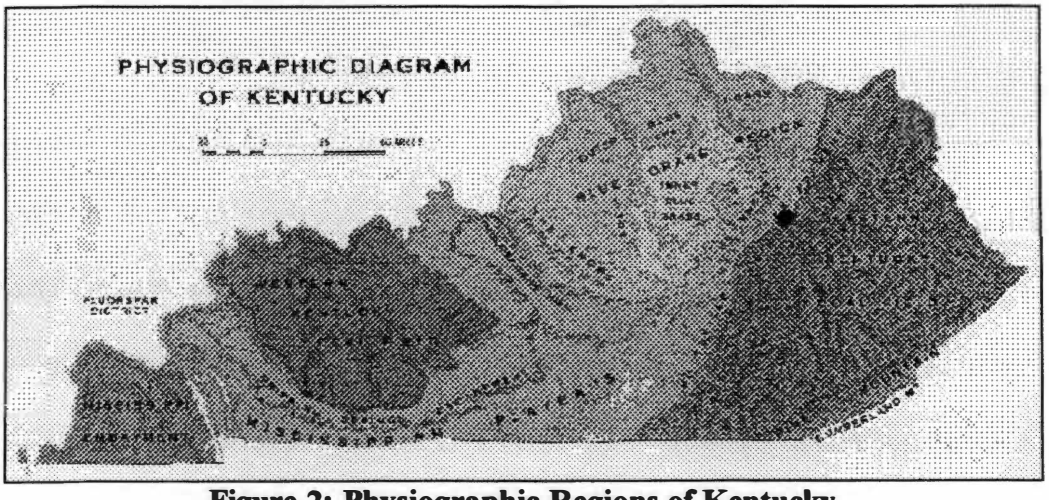


Figure 2: Physiographic Regions of Kentucky
Black Region indicates study area

controlled predominately by the lithology of the Pennsylvanian and Mississippian bedrock. Slope gradients can exceed 60% yielding erodible soils that are shallow and in general acidic. Why cultivation of plants became a means of sustainability in such an environment is unknown.

The suitability of the various locations for garden plots has been debated by researchers such as Ison (1991) who believe upland settings would have been preferred over alluvial settings on the basis of exposure to sunlight, warmer temperatures on slopes from temperature inversions and the close proximity to the settlement site (rockshelter). A strong case for an alluvial setting can also be made as the affects of soil erosion are limited and the soils are believed to be, in general, more fertile. However, a tradeoff exists between these two localities in the amount of energy expended by the harvester in travel costs versus the amount of energy gained by consumption of the harvest (Gremillion, 2002). *Central place foraging theory* is a concept from behavioral ecology that assumes food is transported to a secure area prior to being consumed and the amount of food delivered is sufficient to account for the energy expended during delivery (Krebs, 1978; Jones and Madsen, 1989; Orians and Pearsons, 1979; Gremillion, 2002). This model has been applied to a portion of the Red River drainage in order to predict where foodplots were located in relation to the central place (rockshelter). Yield estimates from the Powell and Wolfe County Soil Survey were incorporated into the model to determine the relative fertility of upland and alluvial soils. The conclusions of the study acknowledged that both upland and floodplain habitats could have played a role in food production and that more studies should be conducted concerning the environmental circumstances under which specific locations would prevail (Gremillion, 2002). The

specific question of foot plot location (uplands vs. floodplain), is a function of energy costs of the harvester, the crop species in question, and the suitability of the soil to support plant growth (Gremillion, 2002). It is believed that return rates between hillside and floodplain plots would not have been equivalent due to habitat characteristics (namely soil quality) and a sacrifice in travel costs would have been made to exploit more productive areas (Gremillion, 2002).

The productivity of a given area is largely determined by the chemical and physical attributes of the underlying soil. According to Carter et al, (1997) the quality of any soil is dependent on the soils inherent composition which is a function of soil state factors (climate, parent material, time, topography, organisms). Chemical soil attributes of specific interest are ECEC, base saturation, pH, and organic C as these will determine nutrient availability (Heil and Sposito, 1997). Soil texture and water holding capacity are also of considerable importance as these will have influence over many of the chemical properties identified. Numerous researchers have studied the relationship and distribution of soils across hillslopes identifying a certain degree of predictability between specific soil characteristics and slope position (Birkeland, 1999; Gerrard, 1981; Ruhe and Walker, 1968; Conacher and Darymple, 1977; Carter and Ciolkosz, 1990; Finney et al, 1962; Kliess, 1970; Losche et al. 1970; Milne 1935). This relationship is the result of specific geomorphic processes inherent to individual slope elements which are characterized by steepness and the predomination of erosional or depositional processes. Milne (1935) recognized the soil-geomorphic relationship with hydrologic sequences and outlined the original concept of the catena. Gerrard (1981) describes the catena as soil variation related to differences in slope position with emphasis on the difference between the freely

drained upper slope and the poorly drained lower slope. The catena concept forms the basis of the approach taken in this study as the majority of the soils in this landscape formed on sloping terrain.

The inherent quality of a soil is a function of state factors (parent material, organisms, climate, topography, and time) that combine to form a specific soil attribute (Carter et al. 1997). This study focuses on chemical soil variables that affect the ability of a soil to support plant growth. B horizon variables such as effective cation exchange capacity (ECEC), base saturation and texture are considered to be less dynamic and change over longer time spans while surface horizon attributes such as organic carbon content, available phosphorus, and pH can fluctuate over several years to less than month and can easily be altered by human influence. Therefore, the soil in its entirety must be described and analyzed in order to draw legitimate conclusions regarding past soil conditions. Correlations between slope position and soil properties is expected to exist if soil formation processes are in some form of equilibrium with slope processes while no correlation is expected on slopes that are morphologically young. Changes in climate and vegetation will upset the equilibrium and result in a poor correlation between slope position and soil characteristics (Gerrard, 1981).

Research has also been conducted in the Red River drainage using GIS (Geographic Information System) by Mickelson (2002) who correlated archaeological site location with elevation, slope aspect, and ecological setting. This revealed a shift in settlement patterns occurring within the time period associated with plant domestication. Mickelson's findings indicate that during the Late Archaic and Early Woodland cultural periods the number of archaeological sites increases on upland slope and upland level

areas (Mickelson, 2002). Additionally, mean slope angle for sites increases from 4 degrees in the Middle Archaic to over 9 degrees in the Early Woodland. Mickelson concluded that a shift in land use was observed between the Middle Archaic and Late Archaic to Early Woodland periods; specifically greater assemblage diversity and the occupation of a wide variety of landform types (Mickelson, 2002). This shift in land use may be related to habitat quality (soil type, aspect etc.), as suitable locations for foodplots were exploited during these periods.

This study is intended to shed more light on the inception of plant domestication and the suitability of hillslope versus alluvial settings for foodplots using quantitative soil data gathered in a cross valley transect within the Red River valley. This will provide data on the variation of specific soil attributes with landscape position that are essential for plant growth and provide it on a more reliable scale than is currently available within soil surveys. Modern county soil surveys provide yield estimates for most soil series and can be used as a general guide to soil quality; however, these yields are those that can be expected under high levels of management (i.e. application of fertilizers). Additionally, soil surveys are mapped on a 1:20000 scale with each soil series based off a type location/pedon. This often results in a misrepresentation of soil variability with subtle variations in landscape position. Additionally, soil morphology and soil-slope relationships will provide information regarding slope evolution and slope processes that may have influenced land use practices.

Field and Laboratory Methods

The mean annual precipitation for the study area is 117 cm with a mean winter temperature of 2 degrees C and a mean summer temperature of 23 degrees C. The

dominant vegetation on the valley slopes is mixed mesophytic forest with beech, tulip poplar, sugar maple, birch, black walnut, hickory, oak, and ash while the vegetation in the sandstone parent materials of the caprock are dominated by pines and oak (Delcourt, 1998; Muller, 1982).

The bedrock geology is comprised entirely of Pennsylvanian and Mississippian systems (Weir, 1974) (Fig. 3). The cap rock is Pennsylvanian in age and consists of the upper member of the Breathitt formation, the Corbin sandstone member of the Lee formation, and the lower tongue of the Breathitt formation. The lower tongue of the Breathitt formation has an unconformable contact with the rocks of the Mississippian system and consists of 90% shale and siltstone with 10% sandstone or conglomaritic sandstone (Weir, 1974). The dominant cap rock of the study area is the Corbin sandstone member which consists of 60% sandstone, 35% conglomaritic sandstone, and 5% inter-bedded shales. The upper member of the Breathitt formation crops out predominately to the east of the study site and is comprised of 90% shale and siltsone with 10% sandstone (Weir, 1974). The resistant nature of this bedrock creates the cliff topography in the upper reaches of the watersheds in the region.

The Mississippian system contains the Newman limestone and the Renfro, Nada, Cowbell, and Nancy members of the Borden formation (Weir, 1974). These formations make up the steep backslopes and the upland benches within the study area. The Newman limestone lies directly below the Pennsylvanian strata and is comprised of 90% limestone with 10% shale and some chert. The Newman can be further subdivided into the upper member, St. Genevieve member, and the St. Louis member. The Renfro and Nada members are mostly comprised of dolomite or dolomitic siltstone. The more resistant

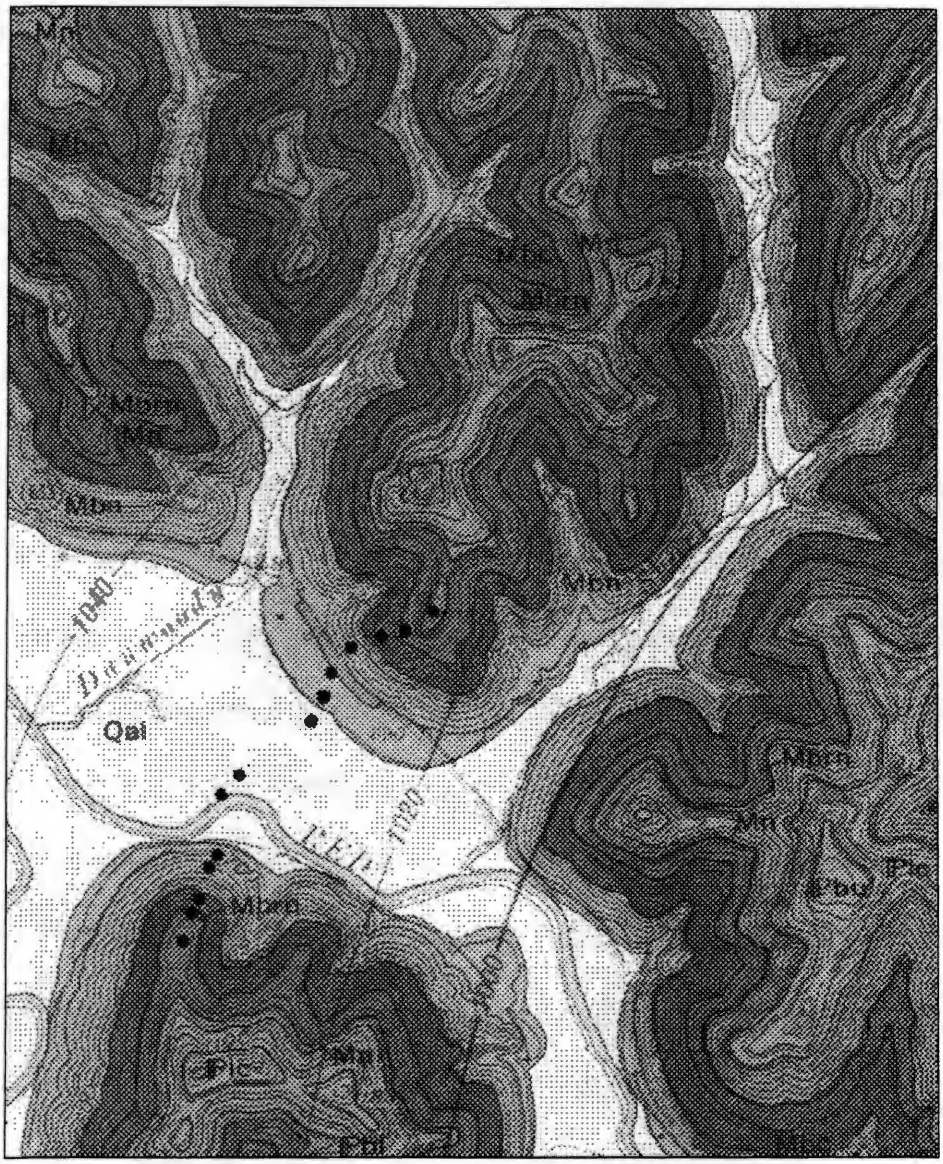


Figure 3: Pedon Locations Geologic 7.5' Quad
Slade USGS Geologic 7.5' Quad Slade, KY (1974)
Black dots indicate pedon locations

nature of this formation has resulted in the lower gradient upland benches found in the region. The Cowbell and Nancy members of the Borden formation are the slope forming bedrock of the area. The Cowbell is 70% siltstone and 30% shale while the Nancy is 90% shale and 10% siltstone (Wier, 1974).

Sampling

Sampling sites were selected on a slope/landscape position basis across a northeast to southwest trending transect (Fig. 3 and 4). Each pedon was chosen in an area that represented a high degree of expression of the landform type. The slope model of Ruhe and Walker (1968) was used to differentiate slope elements. In total, fourteen pedons were described from hand dug pits, bucket auger cores, or cores taken using a Giddings Geoprobe. All pedons were described using standard soil survey procedures (Soil Survey Division Staff, 1993) with samples taken for each genetic horizon.

Samples were air dried and passed through a 2-mm sieve. Subsamples of the 2mm fraction were collected and passed through a 60-mesh sieve for use in the determination of total organic C, and total N using dry combustion. Particle-size was done using the pipette method as described in Kilmer and Alexander, (1949). The following methods refer to the Soil Survey Laboratory Staff (2004) unless otherwise noted. Available P was determined using the Olsen Bicarbonate method (Method 4D5), exchangeable bases were extracted using NH_4OAc at pH 7 (Method 4B) and determined through ICAP analysis. Exchangeable Aluminum and extractable acidity were determined through 1N KCl extraction (method 4B3). Extractable acidity was then determined through NaOH titration and exchangeable Aluminum through 1N KF titration (Sparks, 1996). Effective cation exchange capacity (ECEC) was determined through summation of cations plus

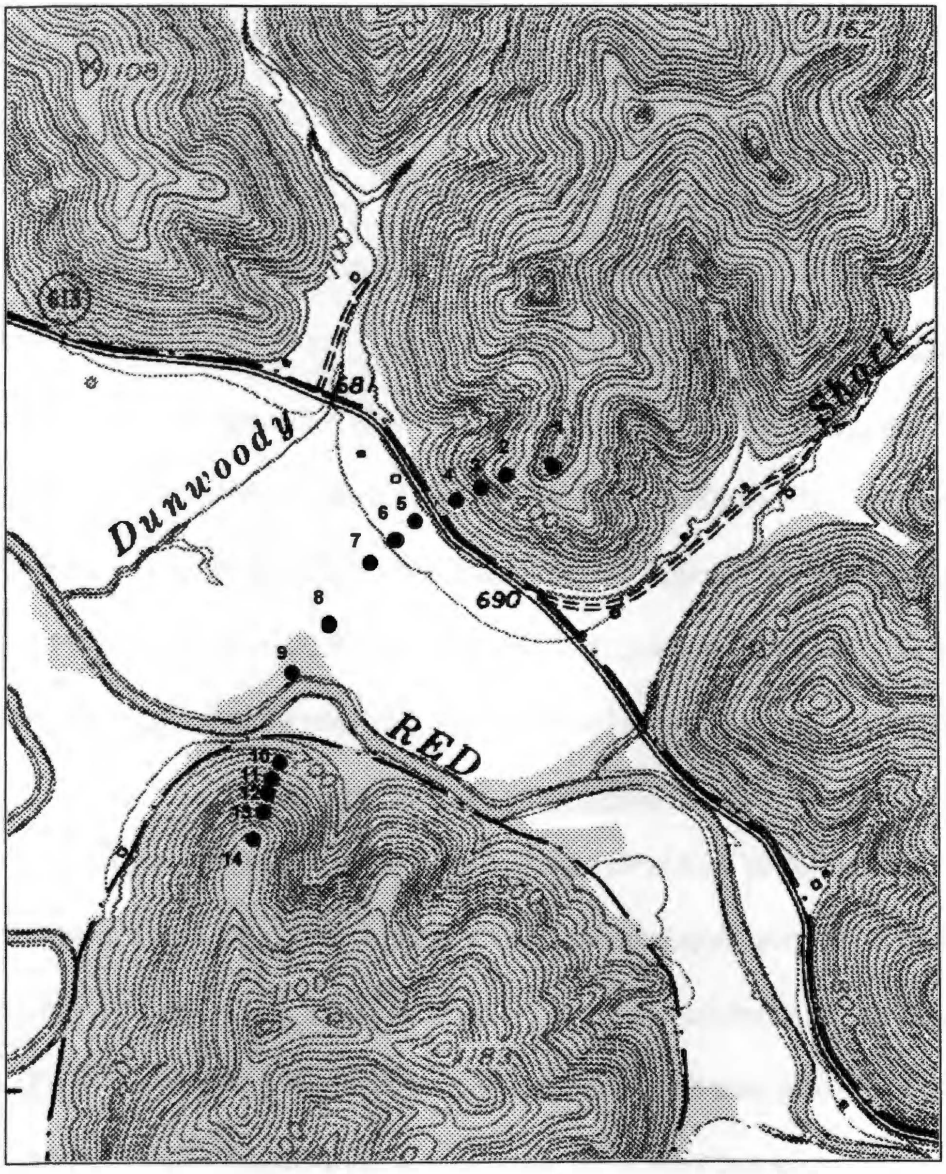


Figure 4: Pedon Locations 7.5' Topographic Quad
Slade Topographic 7.5' Quad
Black dots indicate pedon locations

exchangeable aluminum. Base saturation was determined mathematically from ECEC data.

Data Analysis

Soils were placed into groups based on taxonomic classification at the great group level and their position on the landscape. Values for ECEC and base saturation were averaged within the control section which for Hapludalfs is the upper 50 cm of the argillic horizon or if the argillic is less than 50 cm the entire argillic. For Dystrudepts, Eutrudepts, and Fluvents averages for the control section are from 25 cm to a depth of 100 cm or a paralithic/lithic contact. (Soil Survey Staff, 1999). Group 2 soils are not graphed as they are very shallow and only two samples were collected for these pedons.

Results and Discussion

The distribution of soils within the northeast to southwest trending transect reflect the lithologic control over slope steepness in the upland bench and slope topography in this portion of the Cumberland escarpment (Fig. 4, Table 1). The soils of the summit, formed over the Renfro member dolomite have moderately deep Alfisols with silty clay to clay argillic horizons and loam to silt loam surface horizons. Shoulder positions were predominately comprised of rock outcrops or extremely shallow soils. The back slope positions contained shallow Inceptisols with silt loam textured horizons over shale and siltstone residuum of the Cowbell member. The soils of the footslope and alluvial toeslope were Alfisols (North side) or Inceptisols (South side) with silty clay loam to silt loam argillic or cambic horizons and silt loam A horizons. The shales of the Nancy member form the residual material below the colluvium on the footslope position.

Table 1: Soil Groups

Group # *Position*	*Classification*	*Series*	*Landscape*
Group 1	Hapludalfs	Carpenter	Summits
Group 2	Dystrudepts	Berks	Backslopes
Group 3	Hapludalfs	Bledsoe	Foot/toeslope N
Group 4	Dystrudpets	Berks	Foot/toeslope S
Group 5	Eutrudpets/Fluvaquents	Grigsby/Newark	Floodplain

Group 1 Summits

The soil morphology of the summit positions, or upland benches, on both sides of the valley indicates relative stability with respect to erosional processes. Clay accumulation along with leaching of basic cations and the presence of BE horizons indicate long periods of stability (Fig. 5). Compared to other groups the soils in group 1 have higher organic C, ECEC, available P, and C:N ratios (Fig. 6). Both summit positions had slopes of 20-30% which may allow for mixing of fresh organic matter due to the downslope movement of materials. This would account for the higher levels of organic C and C:N ratios as in-situ decomposition without fresh inputs would result in lower levels. These findings are similar to catena studies with multiple parent materials conducted on loess-mantled slopes in Missouri. Young and Hammer (2000) discovered higher levels of organic C on the summit versus the shoulder or backslope positions. They attributed this to an increase in prairie type vegetation on the summit versus the backslopes. In contrast, Norten et al. (2003) found that organic C was low on the summits and highest on the backslopes in a lithologically segmented catena on the Colorado Plateau. The lower slope gradients (20%) of the upland benches created by differential weathering processes within the Mississippian limestone/dolomites act as temporary catchments for upslope

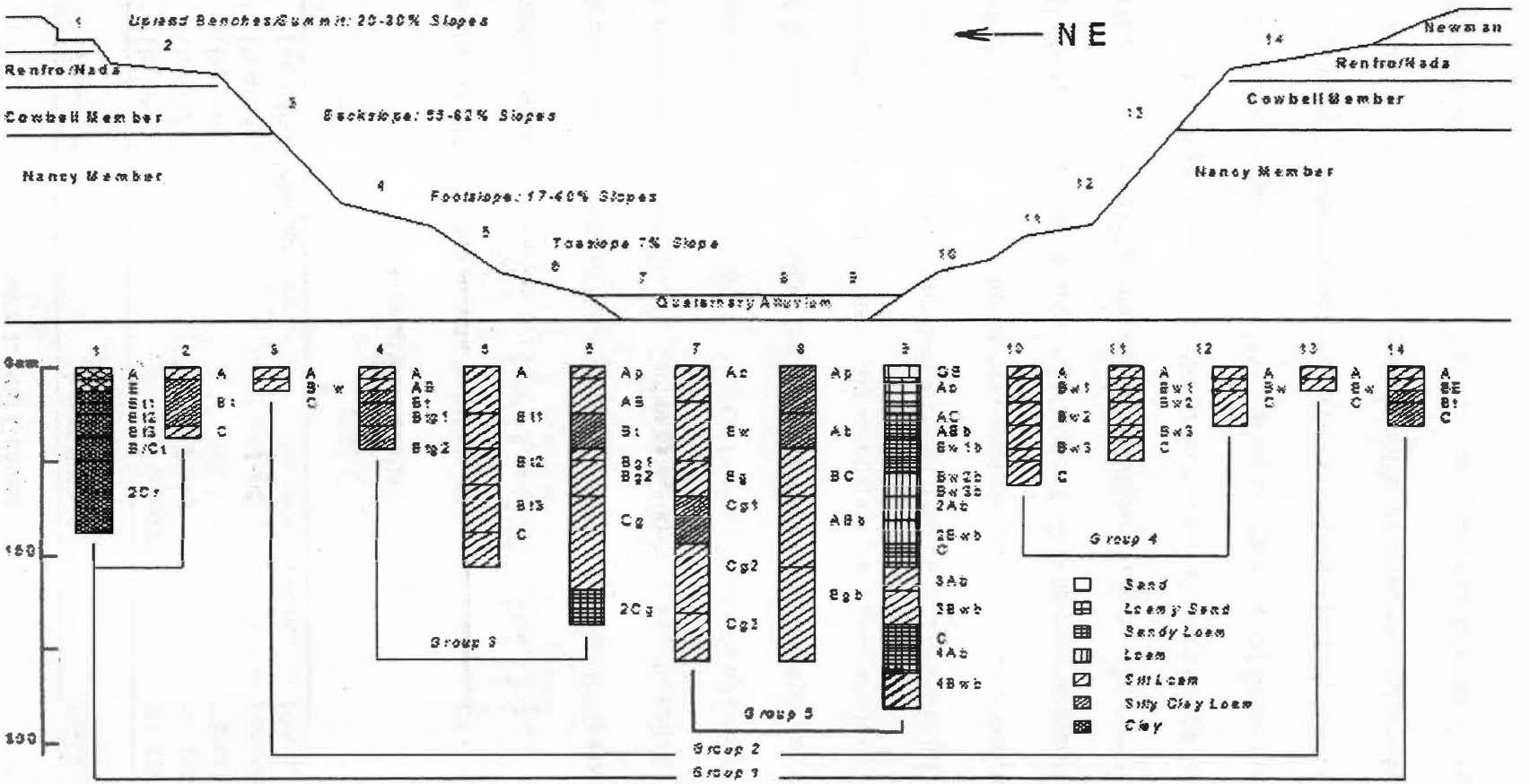


Figure 5: Valley Cross Section and Profile Descriptions

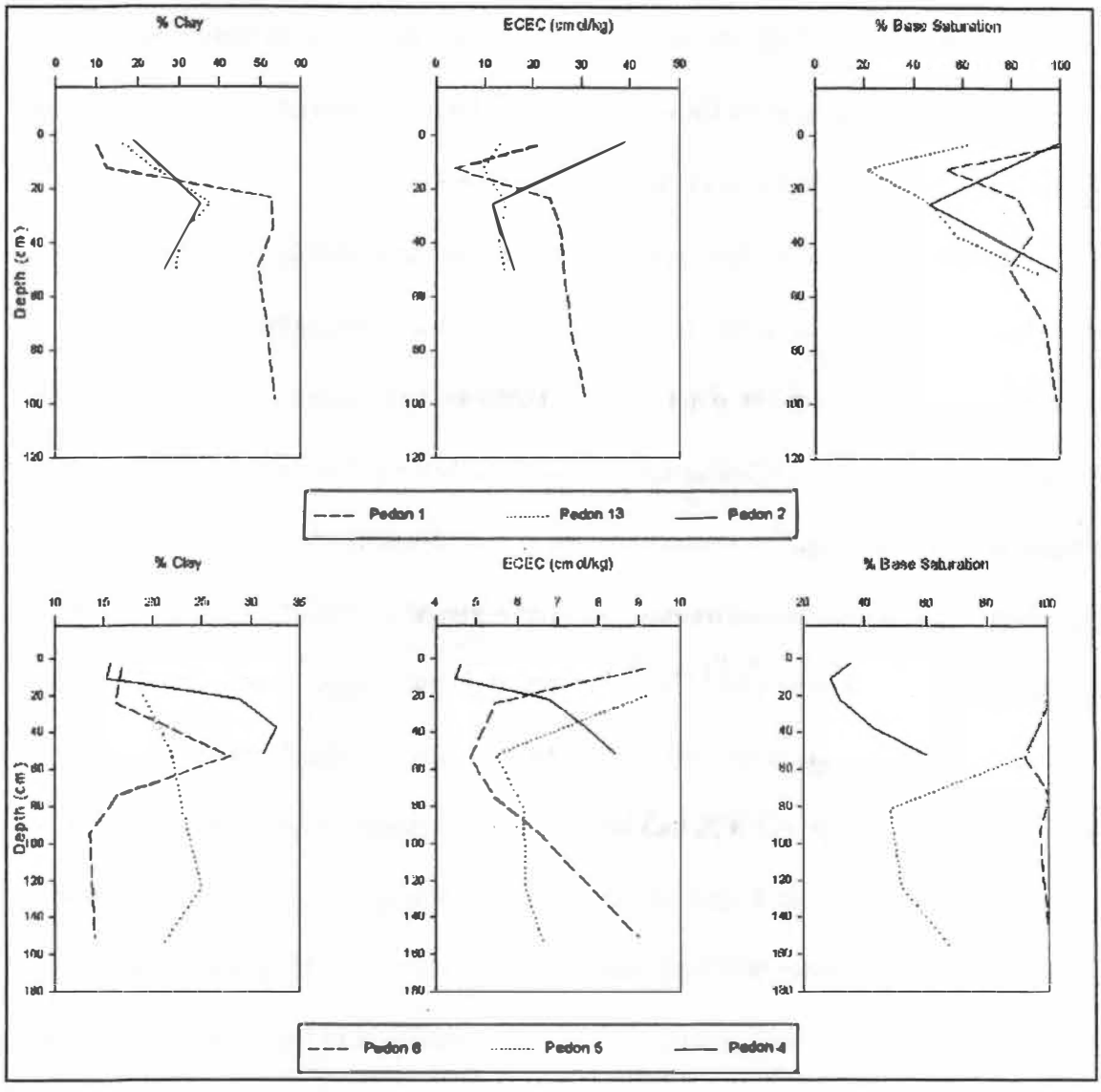


Figure 6: Soil Properties with Depth Group 1 & Group 3 Soils
Group 1 = Upper Group 3 = Lower

mineral and organic matter but still allow for downslope movement of materials on the bench itself. This would explain the high organic C, total N and available P in relation to the backslope which has slope gradients exceeding 55%.

Nutrient availability is largely determined by cation exchange capacity. Base Saturation is the ratio of basic cations to acidic cations on the exchange sites. Organic matter is a significant source of plant essential nutrients and a major contributor of ECEC especially in surface soils (Johnson et al., 2002). Divalent cations such as Ca^{2+} and Mg^{2+} compete with Al^{3+} for position on exchange sites in acidic soils. As a soil progresses in age, soluble cations are leached form the soil and replaced with acidic cations such as Al^{3+} and H^{+} which are more tightly held due to aluminums' higher charge and the small ionic radius of H^{+} (Tisdale et al., 1993). Base saturation within the A horizon on the summit of the north slope is 100% indicating that all exchange sites are occupied by basic cations (Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}), thus, nutrient availability would be high, as the availability of nutrient cations increases with base saturation (Tisdale et al., 1993). ECEC is a measure of total negative charge within a soil and an indicator of the soils ability to retain cations, most of which are essential for plant growth. Summit soils had the highest average ECEC within the control section compared to all other groups, primarily due to the increased clay content in the argillic (Bt) horizons leading to a greater permanent charge. With increasing depth in Group 1 soils, both base saturation and ECEC decrease. This is a result of the changing source of negative charge (organic matter to clays) and the amount of leaching that has taken place. It does appear that more intensive leaching has occurred on the southern summit which is likely due to the influence of slope aspect. NE facing slopes have higher moisture contents and lower temperatures due to a decrease

in potential direct solar radiation. The resulting increase in moisture leads to increased eluvial-illuvial processes yielding lower base saturation and pH (Franzmeier et al., 1969; Carter and Ciolkosz, 1991).

Pedon 1 on the north summit (Fig. 4) had a more easterly slope aspect than the rest of the pedons described on the SW facing slope. This soil is extremely weathered with intensive clay accumulation in the B horizons, strong blocky structure, and an E horizon. This pedon has developed in the Newman limestone which contains the St. Genevieve and St. Louis limestone members. Typically a soil at this stage of development has low ECEC and low base saturation due to long periods of weathering and leaching processes; however, this pedon had high ECEC and high base saturation making it relatively fertile. This is likely explained by a limestone outcrop just above the sample location which is contributing basic cations (Ca^{2+}, Mg^{2+}) as it weathers through dissolution. This geologic control may have a contributing influence over the upland soils that have developed in calcareous parent materials with upslope outcrops of limestone.

The predominant acidic cation in this system is Al^{3+} which is toxic to plants at high levels and can limit phosphorus availability (Brady and Weil, 2002). Aluminum toxicity is generally not considered to be a problem at pHs above 5.2 as little Al^{3+} exists in solution or on exchange sites. The average A horizon pH for group 1 soils was 5.3 indicating that within the surface Al^{3+} toxicity would not be a factor in maintaining food plots. However, the depth of the A horizon was 5cm or less for both summit positions and the pH falls to 4.5 in the B horizons. Additionally, the southern summit (NE facing slope) had a significantly lower base saturation in the subsurface and a lower pH than the

northern summit (SW facing slope). Organic C content, ECEC, pH and base saturation of the A horizon were all lower on the southern summit.

Group 2 Backslopes

The soils in Group 2 are found on slopes with gradients exceeding 50% and represent zones of maximum erosion. Group 2 soils exhibited higher C:N ratios on both slope aspects indicating the influx of fresh organic matter from the summit and shoulder. ECEC and base saturation are low and decreases dramatically with depth compared to the summit, footslope and toeslope positions on both sides of the valley. This likely reflects the erosional nature of the steep backslope position and low clay contents of the subsurface horizon. These soils are very thin, less than 20cm thick on the north slope and less than 8 cm on the south. The presence of weakly developed B horizons indicates the most dynamic part of these profiles is the A horizons while the slightly more clay rich subsurface is more static. Additionally, through flow of water likely removes soluble cations from the subsurface horizons. This is in agreement with other studies that indicate decreasing pH, base saturation, organic C and total N with increasing slope gradient in acidic soils (Gerrard, 1981; Furley 1968).

Base saturation in the Bw horizons is below 20% and pHs are less than 4 indicating a predomination of Al^{3+} on the exchange sites. In contrast the surface horizons have greater than 80% base saturation, high levels of organic C and moderate P availability. This is a strong indication that fresh organic matter is continuously being supplied to these backslopes and has short residence times which does not allow for much decomposition to occur. This process is significant as it supplies both the lower slope elements and the floodplain with nutrients essential to ecosystem productivity.

Group 3 Footslope and Toeslope North Side of Valley

The lower slope gradients in the footslope and toeslope positions have resulted in relative stability facilitating soil development. These soils are classified as Hapludalfs with textures range from silty loam at the surface to silty clay loam in the Bt horizons. Base saturation increases form Group 2 (backslope) as does ECEC within the control section and surface horizon pH (Table 2). The most striking difference is the sharp decrease in the organic C content and C:N ratio in the A horizons from group 1 and 2 soils. The decrease in slope gradient may be influencing the mixing of fresh organic matter and promoting in-situ decomposition. Norten et al. (2003) identified lower C:N and organic C levels on lower gradient slope positions in the Colorado Plateau and related it to a lower influx of organic matter resulting in an immobilizing microbial environment in which nutrients are being taken out of the soil by microbes to facilitate decomposition. Many traditional hillslope studies identify increasing organic C levels with distance from the summit (Kleiss, 1970; Honneycutt et al., 1990; Finney, 1962; Bell, 2003) however, these studies were conducted in closed systems in which slope materials collected on the toe in a closed drainage basin. Within the surface horizon Group 3 soils have lower organic C, C:N ratios, and available P, however; the A horizon is much thicker, resulting in higher base saturation with depth than what is observed in summit

Table 2: Mean Values for Soil Properties Across Groups

Soil Group	%BS*	ECEC*†	pH**	O.C.**	C:N**	Avail P**††	n
Group 1 (Summits)	46.9	12.9	5.0	8.3	15	4.6	3
Group 2 (Backslopes)	15.9	4.5	4.9	8.0	17	2.4	2
Group 3 (Foot/toeslope N)	66.9	5.8	5.2	2.1	11	1.0	3
Group 4 (Foot/toeslope S)	29.7	5.0	4.6	2.7	14	1.6	3
Group 5 (Floodplain)	72.0	5.7	5.3	1.1	13	0.7	3

*values for A horizons ** values averaged within control section †units=cmol/kg ††units=mg/kg

(Group 1) soils. Thickening of A horizons with distance from the summit indicates that Group 3 soils occupy a slope position that is dominated by deposition rather than erosion.

Group 4 Footslope and Toeslope South Side Valley

Group 4 soils have developed within the lower slope elements on the south side of the valley. These soils are classified as Dystrudepts exhibiting weakly developed B horizons and low base saturation. The soils of Group 4 have developed in a landslide deposit on the south side of the valley. The increased moisture contents due to the influence of slope aspect have lead to a greater loss of soluble cations resulting in a nutrient poor slope. The base saturation within the control section drops below 15% in some of these soils indicating that Al^{3+} and H^{+} dominate the exchange sites (Fig. 7). Additionally, ECEC is low in the control section due to the low clay contents. These soils show little clay accumulation with depth indicating relative pedogenic immaturity (Fig. 5 and 7). Pedon 11 does show a clay increase with depth however the value falls short of the requirements for an argillic (Bt) horizon. The most interesting attribute is the difference in ECEC with depth between pedon 10 and 11 (Fig. 7). Pedon 11 has a much higher surface ECEC than pedon 10. Pedon 11 also has a surface pH of 5.2 while pedon 10 has a pH of 4.45. The ECEC of surface horizons is pH dependent with high pH values yielding higher ECEC due to dissociation of functional groups leaving negatively charged sites on organic molecules (Brady and Weil, 2002). The surface horizon pH of pedon 9 is nearly 10x more acidic than the pH of pedon 10 resulting in H^{+} dominating the exchange sites on the organic molecules limiting there ability to retain other plant

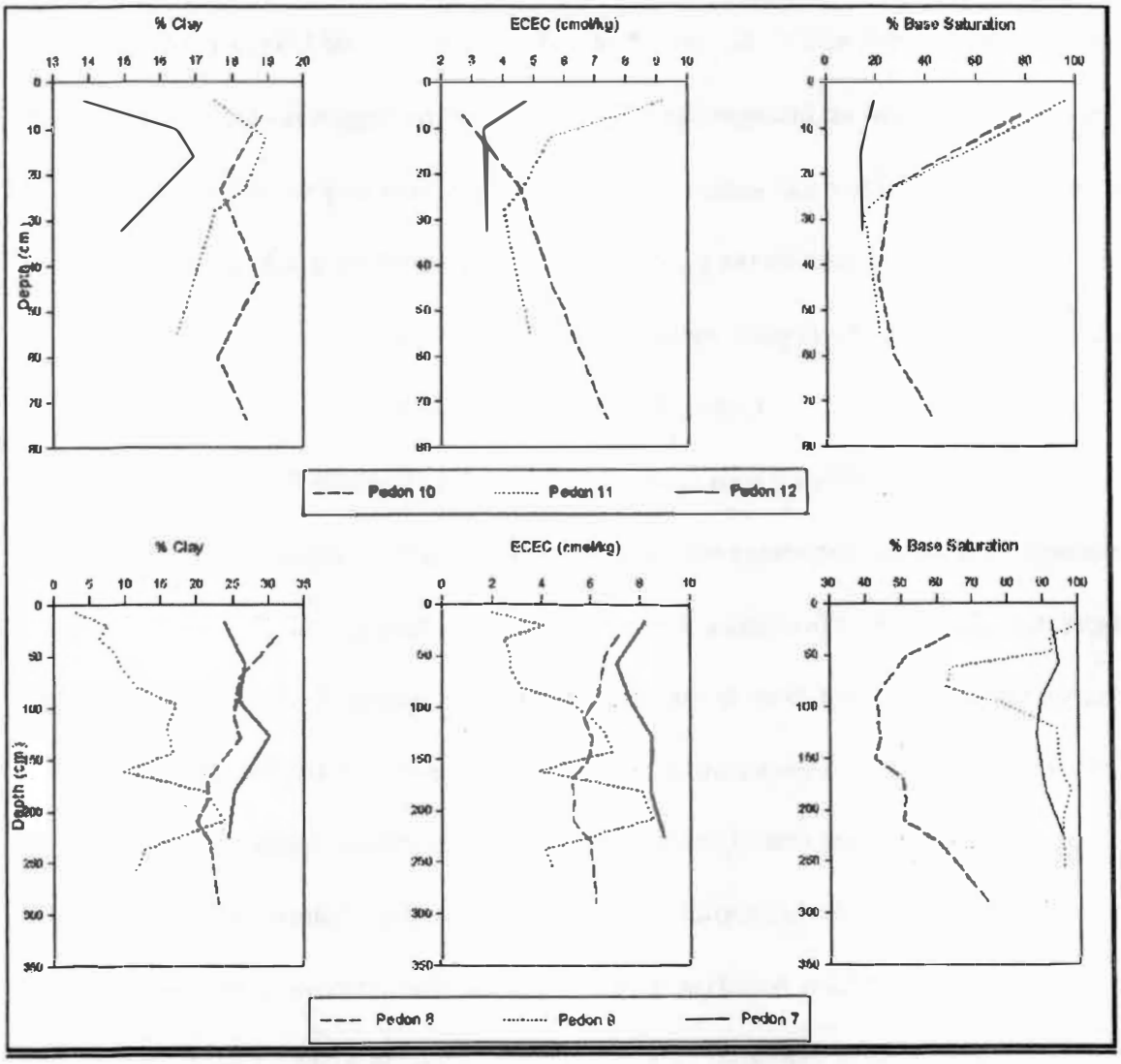


Figure 7: Soil Properties with Depth Group 4 & 5 Soils
Group 4 = Upper Group 5 = Lower

essential cations such as Ca^+, K^+, etc. Organic C, available P and C:N ratios of the surface horizon show an increase from Group 3 indicating these soils are receiving fresh inputs of organic matter and some mixing is occurring. This may be influenced by the decrease in slope gradient on the tops of the debris flows which would act as more affective catchments for organic matter moving downslope.

Group 5 Floodplain Alluvium

Variation in Group 5 soils is largely a function of distance from the modern river channel. Sand content increases with decreasing distance from channel while silt content decreases. This reflects floodplain deposition processes during peak flow events in which coarser textures drop out close to the channel creating a natural levee and finer grained sediments accumulate in the slower moving floodwaters away from the channel (Ritter et al. 2002). This processes other wise known as vertical accretion appears to be the dominant process within this portion of the Red River valley. Nanson and Crooke (1992) have classified floodplains based on stream power and the cohesive or non-cohesive nature of the floodplain sediments. The soil textures adjacent to the modern channel are predominately sandy loams and are largely non-cohesive. Silt content increases quickly with distance from the channel with silt loam textures dominating. According the genetic classification of floodplains outlined by Nanson and Crooke (1992), this portion of the Red River valley closely matches the confined vertical-accretion sandy floodplain model. This floodplain type is confined by a bedrock valley that in effect concentrates the erosional power of extreme flooding events. Overbank deposition builds a sandy-silty floodplain over thousands of years, with catastrophic flood events occasionally stripping the floodplain (Nanson and Crooke, 1992). This would explain the absence of Pleistocene

terraces within this portion of the valley. Vertical-accretion dominates this floodplain because channel migration is restricted by bedrock valley margins. The radiocarbon date in the north toeslope indicates that the channel has not been on this side of the valley for over 2500 years, or possibly longer due to the time hiatus present between the colluvial and alluvial deposits. Additionally, since the modern channel is very close to the southern margin of the valley, it can be concluded that it has taken over 2500 years for the Red River to transverse this distance through lateral migration. This is further validated by buried cultural deposits within the floodplain dating to the Late Archaic (Cowan, 1976).

The absence of argillic horizons in these soils, also indicate that the alluvium is fairly young. This correlates well with other studies in the southeast which have identified Holocene terraces/floodplains having cambic horizons with little clay accumulation (Leigh, 1996; Delcourt, 1980; Mills, 2004). Buried surface horizons within the bank profile and pedon 8, indicate active vertical accretion and mark this area as the active floodplain in which sediment accumulation periodically outpaces pedogenesis (Birkeland, 1999). Pedon 7 which is near the valley margin to the north does not have buried horizons but does have an irregular distribution of carbon with depth. The deep sequence of silty loam soils and sediment down to 4 meters indicate that this area has been collecting fine grained backwater deposits.

It is important to consider that alluvial soils within this transect have undergone some level of disturbance within a modern agro-ecosystem. Currently the valley is being used as pasture for cattle and vegetation is composed largely of grasses. Trees occasionally dot the valley bottom but have largely been cleared. This represents a managed ecosystem in which soil nutrient dynamics will differ from those on the forested

slopes. Soil variables such as organic C, total N, and available P will largely be function of management practices instead of natural soil conditions, especially in the surface horizons. Closer to the modern channel periodic flood events may negate some of these effects. Soil characteristics that are more static such as particle size and cation exchange capacities are not as easily affected by anthropogenic disturbance, thus these variables may still shed some light on the quality of alluvial soils versus hillslopes.

The low levels of organic C, total N, and available P compared to upland sites is both a function of floodplain activity and human disturbance (Table 2, Fig. 8). Harvest of biomass by livestock and the loss of forest vegetation have likely influenced the levels of these nutrients. However, ECEC is low compared to the uplands due to the influence of texture. The upland benches had higher clay contents and higher levels of organic matter, both of which act as soil colloids that retain basic cations. The sandier textures in combination with lower levels of organic matter have influenced the ECEC of floodplain soils. In contrast, base saturation and pH are higher in the alluvium reflecting the low levels of soil development.

Archaeological Implications

Out of the soils encountered on the transect Groups 1, 3, and 5 would be considered the most likely candidates for food plots based on the observed data. Group 1 (summit) soils have high ECEC's, high organic C content, and high available P compared to all other groups (Fig. 8). High ECEC values indicate that this soil can retain high levels of exchangeable cations. Base saturation is 100% in the surface horizon with an average in the control section of 46.9% on the north summit. On the southern summit more

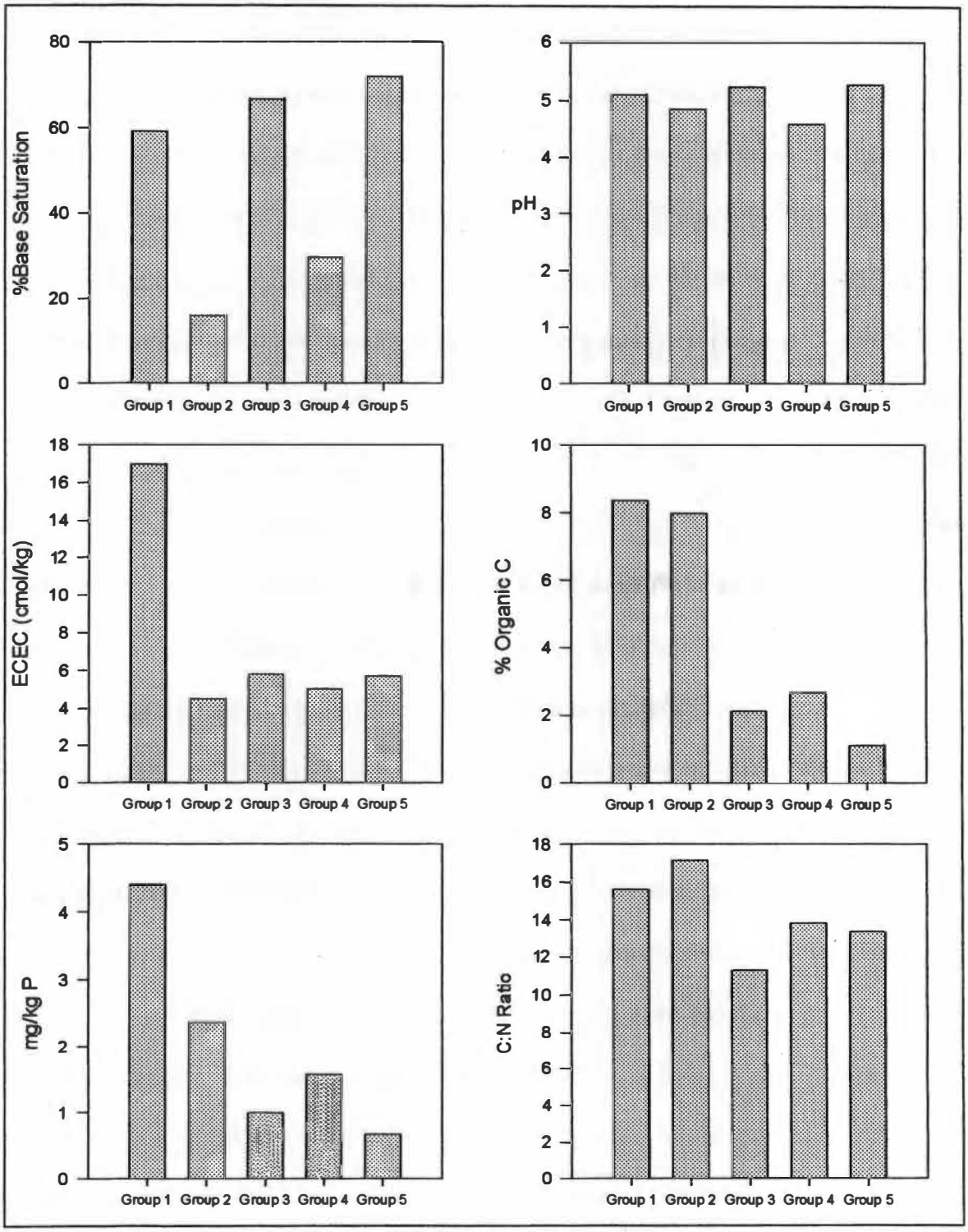


Figure 8: Comparison of Mean Values for Soil Groups

Base Saturation and ECEC are averaged within the control section for each pedon
All other variables are for surface horizons

leaching has taken place and base saturation is 60% at the surface and 47.4% in the control section. Additionally, high organic C contents indicate higher levels of organic matter which is the main source of plant nutrients. This indicates that these soils are capable of supplying essential nutrients to plants and that there is likely a sufficient supply. The silt loam to silty clay loam textures are capable holding a large amount of available water however due to the shallow nature of the soil and its well drained slope position this soil could potentially dry out quickly. The primary concern regarding the suitability of Group 1 soils for food plots is the potential erosion hazard. Deforestation would result in destabilization of this slope position and the relatively thin surface horizon would mobilize resulting in loss of organic matter and consequently soil nutrient levels would decline. Delcourt et al. (1998) through pollen core analysis provide evidence that suggests widespread forest clearance and in increase in fire tolerant tree species after 1200 cal yrs BC. The aerial extent of Group 5 soils is limited to Renfro and Nada member outcrops found within the study region. Differential weathering between these members has created the upland benches that separate the summit of the escarpment from the valley floor. These benches are more extensive further west in the escarpment where the Pennsylvanian caprock has been more extensively eroded (Weir, 1974).

Group 3 soils, located in the footslope and toeslope on the north side of the valley, have lower ECEC than group 1 soils however base saturation within the control section is higher. This would indicate that though these soils have lower ECEC, they may still have a high nutrient availability as basic cations dominate the exchange sites. Organic C and available P within the surface horizon decline from Group 1 soils due to the relative stability of these slope positions resulting in a greater extent of decomposition.

Additionally, A horizons are thicker and high base saturation extends to a greater depth in these soils when compared to group 1. These soils have silt loam to silty clay loam textures and are capable of holding a large volume of available water. Poor drainage conditions do exist for some of the soils in this group as water tables are near the surface during parts of the year.

Group 5 soils which are found in the floodplain have high base saturation within the control section and ECEC levels comparable to Group 3 soils. Organic C, C:N and available P are low at the surface however due periodic flooding these attributes are found at depth within these soils at relatively high values. Due to the high base saturation nutrient availability would be very high and the distribution of organic C and available P with depth make these soils fertile. Regular deposition of organic materials originating from the valley sides give these soils there inherent quality.

The strong correlation (r^2 = 0.71-0.90) between slope position and base saturation (Fig. 9) indicate that some level of equilibrium has been reached between the soil and the environment (Gerrard, 1981). If these soils had been recently disturbed a correlation would not exist between slope position and soil characteristics. Additionally, the presence of argillic horizons and the radiocarbon date indicate that the lower gradient portions of theses slopes have been relatively stable for at least 2500 years. It is believed then that the data presented in this study is relevant to soil conditions that existed during the Late Archaic and Early Woodland cultural periods.

A correlation between site location and soil quality during the Late Archaic and Early Woodland may exist, specifically regarding slope aspect and site elevation. Mickelson (2002) performed a one sample t-test of the population mean for elevation of

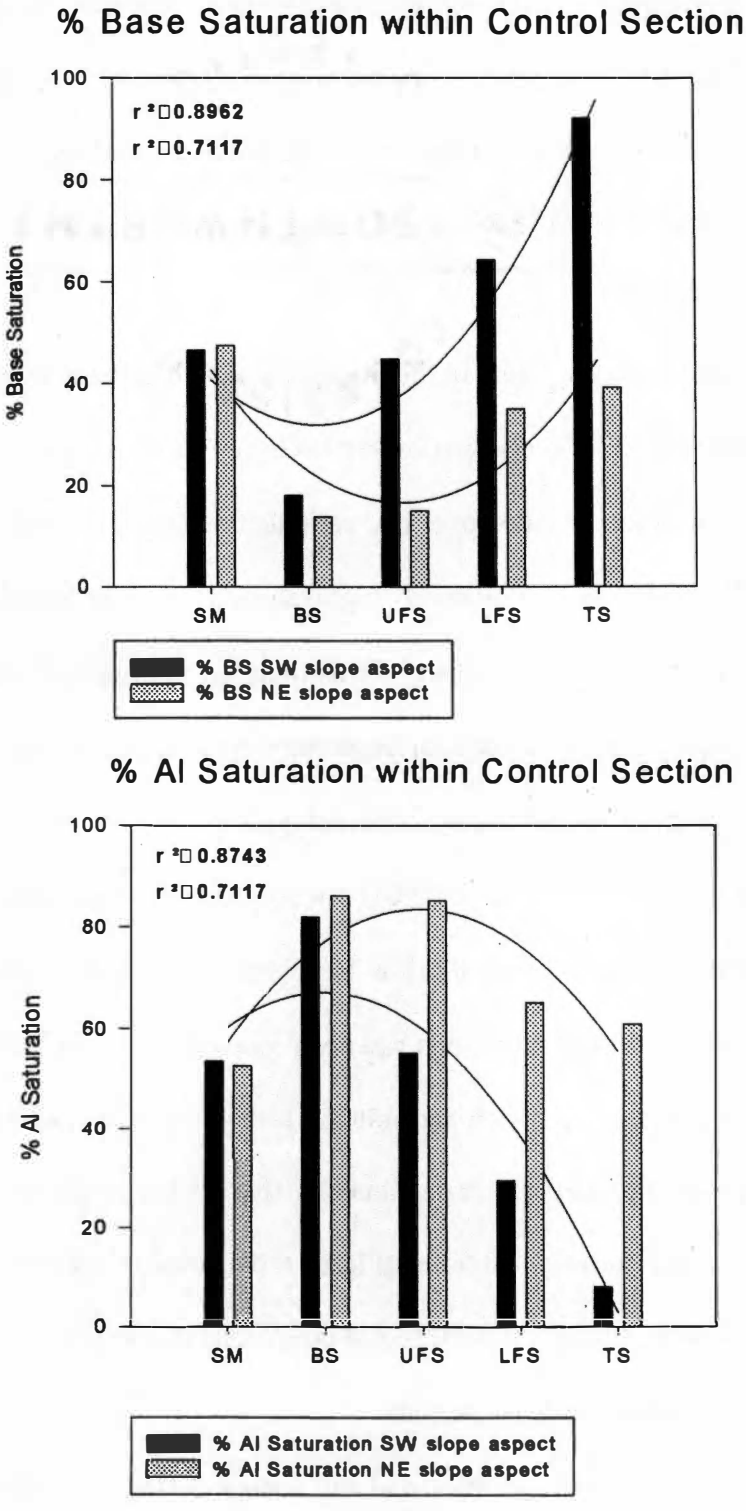


Figure 9: Base and Al^{3+} Saturation Across Slopes

SM=summit, BS=backslope, UFS=upper footslope, LFS=lower footslope, TS=toeslope

Base Saturation Averaged within Soil Control Section

Upper correlation coefficient (r^2) is for SW slope aspect

archaeological sites tested at alpha=0.05 which indicated that elevation of sites significantly deviates from the mean background elevation. This reveals that many sites are located in upland settings. Additionally, the number of upland sites (rockshelter sites) increases during the late Archaic and early Woodland which corresponds to the introduction of domesticated plants (Mickelson, 2002). From the data collected in this study, upland soils occurring on benches formed in the Renfro dolomites and Newman limestones have inherent soil qualities that make them suitable for food plots as long as deforestation does not destabilize the slope.

Slope aspect has also had an affect on the soil attributes observed in this study. The NE facing slope is overall nutrient poor with low base saturation that is likely the result of increased moisture contents enhancing the leaching of basic cations (Fig. 9). Aluminum saturation is considerably greater in the lower slope elements of the NE facing slope. This would likely have an affect on potential yields if foodplots were located on the lower slopes. Base and aluminum saturation are comparable on the summit position indicating that slope aspect would not play as significant a role between slope aspects for this slope position. Aluminum toxicity is the most common problem associated with acid soils and can affect not only plants but bacterial populations that are critical to the Nitrogen cycle (Brady and Weil, 2002). Additionally, pH of the surface horizons is lower for all slope positions on the NE facing slope. Mickelson (2002) conducted a one sample t-test on a large sample size for facing aspect of archaeological sites and determined that south facing slopes were preferred. In the northern hemisphere south facing slopes receive more solar radiation especially during the winter months and according to Franzmeier et al (1969) a 2C lower mean annual temperature was discovered on north-

facing slopes of the Cumberland Plateau in Kentucky and Tennessee. These conditions may have played a role in site selection by indigenous peoples however it has been found in other studies that south facing slopes are commonly preferred (Hall and Kleppel, 1988).

The inception of plant domestication in this landscape likely has many contributing factors that extend beyond the environmental conditions present at the time. This study does not take into account the cultural influences that potentially influenced subsistence patterns. Nevertheless, landscape processes controlled by geologic and climatic conditions certainly had some level of influence and are worthy of some discussion.

The presence of numerous landslides in the area is of particular significance as the occurrence of these events plays a considerable role in the evolution of this landscape. Outerbridge (1982) mapped landslides and debris flow deposits in the Slade Quadrangle (Fig. 10) including several within the transect. These slide deposits are represented in the data collected for the group 4 soils. The morphology of the soils developed in the landslides occurring within the study transect indicate that they have been stable long enough to develop cambic (Bw) subsurface horizons and weak blocky structure. The radiocarbon date on the opposite side of the valley indicated that a soil with an argillic (Bt) subsurface horizon can develop in colluvial deposits within 2500 years in this environment. Knowing this, it is then appropriate to assume that these slides are less than 2500 years in age as they have not developed argillic (Bt) horizons. Some clay accumulation was present but the difference between the clay percentage in the A horizon versus the B horizon fell short of the argillic diagnostic subsurface horizon requirement.

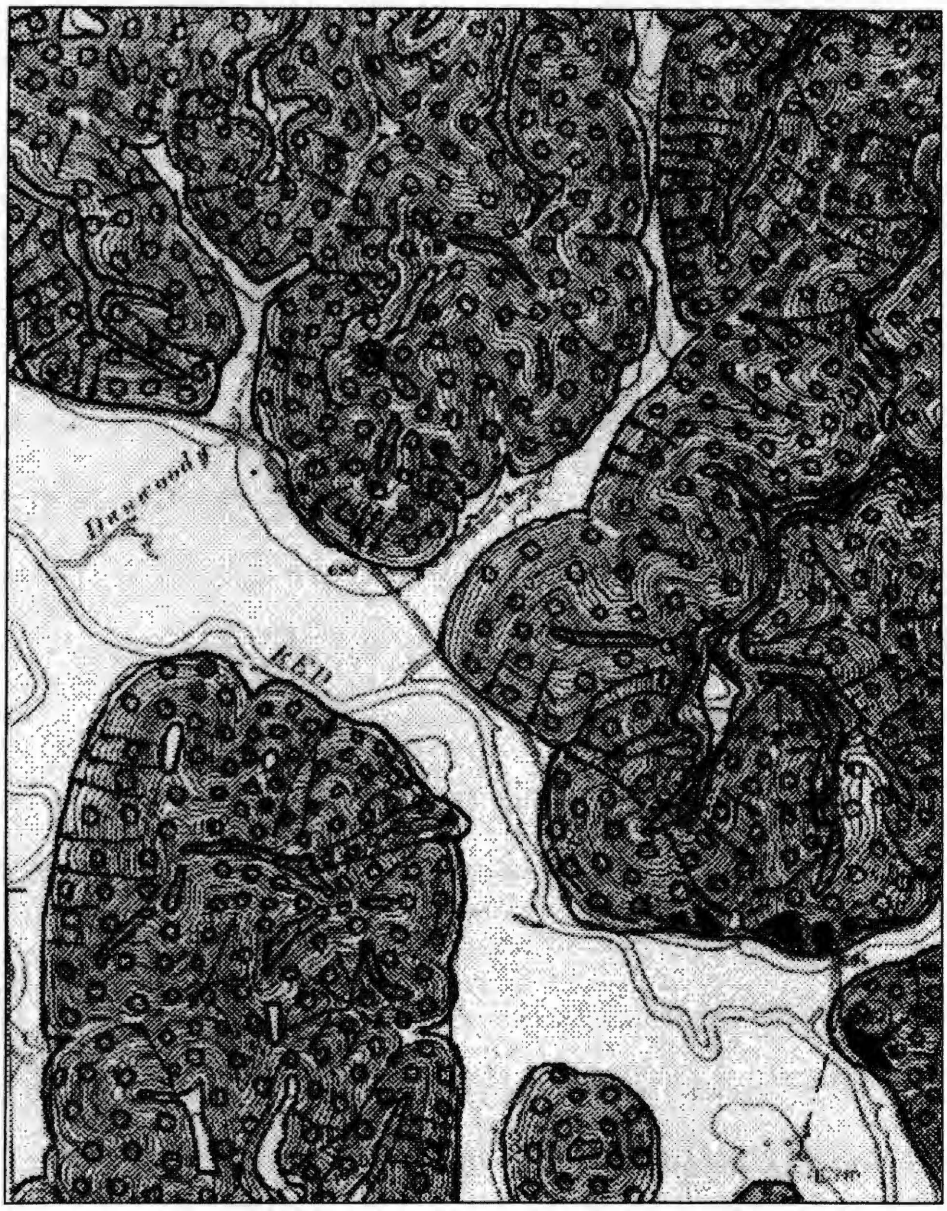


Figure 10: Landslide Map for Study Region
Detail from USGS 7.5' Quad Slade, KY
Outerbridge (1982)
Each Circle Represents a Mapped Landslide
Red Dots Indicate Locations of Pedon 10 & 11

The exact age of the slides is difficult to ascertain, because very few absolute age dates are available for colluvial deposits in the Cumberland Plateau; however, several dates are available for soils with cambic horizons within terrace sequences in the southeastern United States. Leigh (1996) discovered a radiocarbon date of 600-1900 yr BP for a late Holocene terrace with cambic horizons in the Blue Ridge of Northern Georgia. This region receives similar rainfall (MAP=150cm) and has a similar average temperature (13 C) has the study area. It is expected however; that soil development would proceed at a faster rate in previously weathered material such as is found in the colluvium that makes up the landslide deposits (Birkeland, 1999). I believe these landslide deposits fall within the time range discovered for the Late Holocene terrace in Leigh's study.

Delcourt and Delcourt (1984) studied Late Quaternary paleoclimates in Eastern North America interpreted from palynological records and marine Foraminifera in the western North Atlantic Ocean. A major increase in the frequency and magnitude of summer tropical storms in the southeastern United States during the mid-Holocene and late-Holocene (6000 yrs-present) was interpreted from the data. This climatic shift would facilitate slope failure and the destabilization of river systems (Delcourt, 1984; Knox, 1983). The numerous landslide deposits found in the study area are likely the result of this occurrence especially on slopes that have formed over the Cowbell and Nancy member shales and siltstones, as these slopes exceed 50% gradients and have impermeable bedrock beneath. Kochel (1987) also attributed Holocene debris flows in the Appalachians of Virginia to catastrophic storm events. Additionally, Cremeens et al. (2003) identified Holocene colluvial soils in the unglaciated Appalachian Plateau of West

Virginia with buried surface horizons overlain by poorly-sorted colluvium and concluded that this sequence was the result of similar climatic events.

The timing and presence of these landslides is believed to be significant in this study as weedy plants such as the ones discovered within the rockshelter sites, thrive in disturbed contexts (Gremillion, 1993). It is conceivable that this climatic shift during the mid to late-Holocene resulted in a geomorphic response (landslides) that provided an increased area of disturbed soils in which weedy plants would dominate. Even though the soil morphology of the slides encountered within this study indicate that they probably did not occur during the periods in which plant domestication occurred, other slides of the area may date to this period. Potentially, this landscape processes played a critical role in the development of agricultural practices in such a rugged landscape.

Conclusions

The horizontally bedded sedimentary rock of the western Cumberland escarpment has created unique slope topography with low gradient upland benches grading into steep sided backslopes. This has resulted in discrete zones of soil formation that have a profound influence on soil chemistry and the distribution of organic C, N and available P across the slope. Upland benches formed in resistant limestones of the Renfro and Nada members have had the affect of lessening slope gradient and facilitating soil development. These upland soils (Group 1 soils) have well developed argillic horizons and are high in basic cations, organic carbon, and available P compared to other slope positions (Fig. 11). Backslope positions (Group 2 soils) with steep gradients formed in less resistant shales and siltstones have very thin soils with low base saturation, low pH, and low ECEC. Footslopes and alluvial toeslopes on the north side of the valley (Group 3

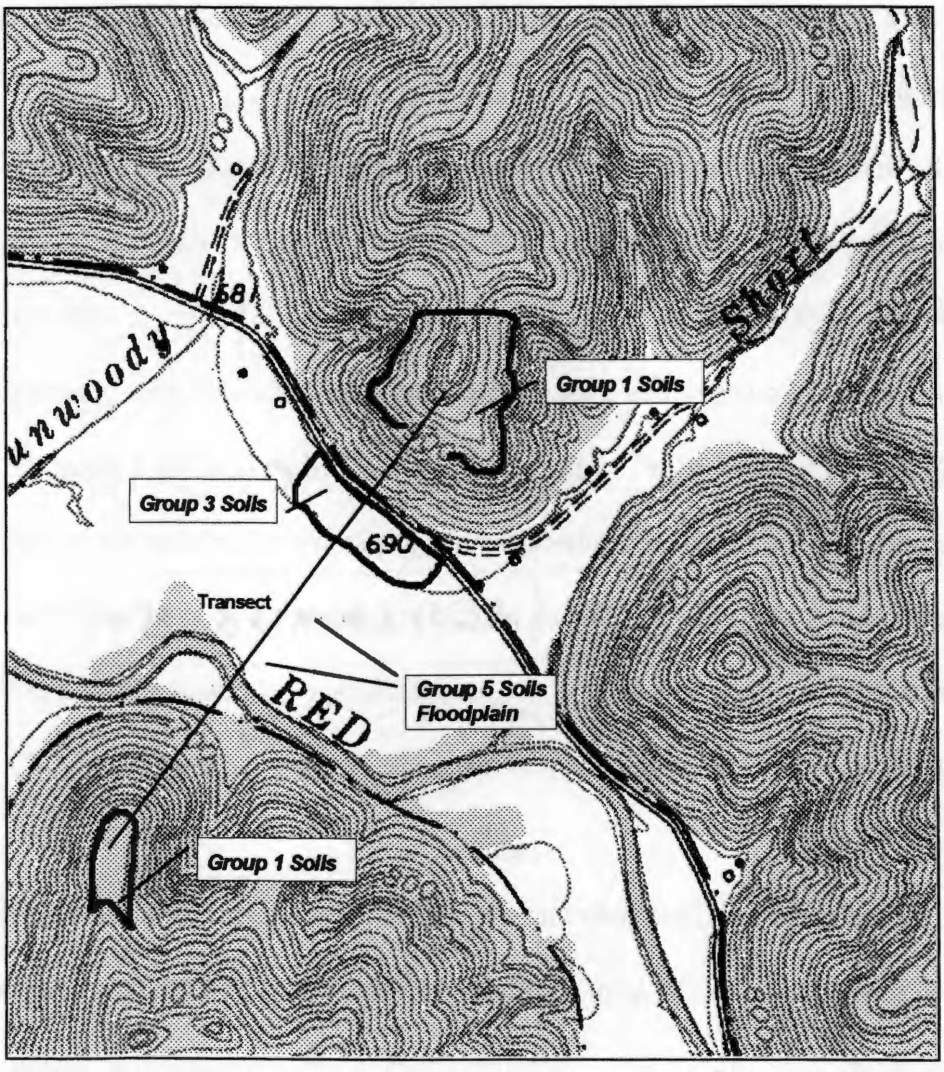


Figure 11: Suitable Foodplot Locations Based on Soils Data
Detail from USGS 7.5' Quad Slade, KY (1983)

soils) show a decrease in slope gradient and have higher base saturation and an increase in ECEC over the backslope. Footslope and toeslopes on the south side of the valley (Group 4 soils) have lower base saturation and lower pH than soils that occupy the same slope position on the opposite side of the valley. This is believed to be a function of landslide events and increased moisture contents on this NE facing slope leading to enhanced leaching processes. Alluvial soils are rich in basic cations however surface horizon organic C and available P content are low compared to other soils.

The geology of the region is exhibiting a high degree of control over soil characteristics. Upland soils developed in the Newman, Renfro and Nada limestones/dolomites have lessened slope gradients due to the resistant nature of the rock type and have high base saturation resulting from the weathering of basic cations from the carbonate rock outcrops in this slope position. This result is soils exhibiting the physical characteristics of a highly weathered (low base status) soil with high levels of basic cations that are essential for plant growth. These upland soils are capable of supporting small scale agriculture as long as extensive deforestation did not result in increased erosion.

The shales and siltstones of the Nancy and Cowbell members have weathered to form steep slope gradients (> 50%) with shallow erosive soils and a high potential for landslide activity. An increase in the frequency and intensity of summer precipitation events during the mid to late Holocene resulted in numerous landslides occurring on these slopes. Many of the weedy plants that were used as contributions to the Native diet thrive in the disturbed soils that these landslides created. These landslides may have influenced the subsistence patterns observed in the archaeological record.

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Part 2
The Affects of Slope Position, Apsect, and Changes in Bedrock on Soils Developed in Lithologically Segmented Slopes

Introduction

The linkage of pedogenic variables with changing slope position has been widely discussed by researchers such as Ruhe and Walker (1968), Conacher and Dalrymple (1977), Kleiss (1969), Birkland (1999), Gerrard (1990) and others. These studies have both identified soil variation with slope position in numerous climates and further refined the original concept of the catena as originally outlined by Milne (1935). Milne (1935) recognized soil-geomorphic relationships within hydrologic sequences; however, the model was imprecise and included uniform and multiple parent materials. The early models of Milne (1935) and Bushnell (1943) characterized soil features in relation to erosional and hydrological conditions but used it more as a mapping convenience instead of an identification of pedogenic and geomorphic relationships.

Gerrard (1981) outlines the catena as soil variation related to differences in slope position with emphasis on the difference between the freely drained upper slope and the poorly drained lower slope. Further differentiation is related to geomorphic processes inherent to the individual slope elements such as surface wash, mass movements, and soil creep (Gerrard, 1981; Birkeland 1999; Ruhe 1960). From the previous definition it is clear that the catenary concept is dependent upon several factors. First in order for a true correlation to exist the soils of a slope must be erosionally linked and form a hydrologic continuum from summit to toeslope. As stated by Gerrard (1981: p. 61), "the real significance of catenas lies in the recognition of the essential processes involved in catenary differentiation and not in the formal appearance of its product." The product or pedon cannot be isolated and described as an independent unit, it is linked through an open system of both gains and losses of energy and materials. Additionally, other state factors

(Jenny, 1941) such as climate, vegetation, and parent materials are not considered to play a dominant role in pedogenic processes occurring on the slope and are considered to be relatively constant. Intra-catena variation in these factors complicates the relationship between slope position and soils.

Many studies identifying pedogeomorphological processes and topographical relationships have been conducted on slopes with little intra-catena variation (Park and Burt 2002, Honeycutt et al. 1990, Young and Hammer 2000, Kliess 1969, and Ruhe and Walker 1968). All of these studies identified soil attributes that vary as a function of the distribution of sediments, organic matter, and dissolved materials down slope. Less research has been conducted on slopes with intra-catena variation in bedrock. Conacher and Dalrymple (1977) discuss environmental changes occurring within a catena and conclude that despite the spatial variation in these factors the relationship between soils, water, and erosion still apply. Norten et al. (2002) studied soil nutrient dynamics occurring on a lithologically segmented hillslope in the Colorado Plateau and identified a distribution of soils in relation to lithologically controlled slope positions.

In addition to intra-catena variation of bedrock, slope aspect has been found to have a certain level of control over pedogenesis. Losche et al. (1970) studied slope aspect in the southern Appalachian Mountains of Virginia and North Carolina and concluded that slope aspect played a more significant role in the soils found in North Carolina due to the differences in parent materials and precipitation between the two sites. Franzmeier et al. (1969) related a 2 C lower mean annual temperature on the north slope to higher levels of organic matter, darker soil colors, and longer periods of moist soil conditions when compared to the south facing slope within the Cumberland Plateau in southern Kentucky

and Tennessee. Carter and Ciolkosz (1991) found the variation in evaporation and moisture content to be the primary control over pedogenic variables such as organic carbon content, and soil morphology on NW versus SW slope aspects in Pennsylvania.

Relative-age dating techniques such as free iron, clay ratios (Jenny, 1941), carbon accumulation index (SSL, 1995), profile darkness index (PDI) (Thompson and Bell, 1996) and solum thickness have been widely used in chronosequence studies and to a lesser extent on colluvial deposits. Liebens and Schaetzl (1997) and Mills (2004) have utilized relative age dating techniques in the Appalachian region and have proven that these techniques can provide a better understanding of hillslope evolution. The time factor is of importance as differentiation of soil properties between slope positions is time transgressive and not solely a function of topography (Gerrard, 1981). These studies indicate that relative age indicators can be used in humid temperate environments and consistent results can be achieved. Relative ages of hillslope colluvium aid geomorphic and pedologic interpretations by incorporating a temporal framework into the study of landscape evolution and soil genesis (McFadden and Knuepfer, 1990; Mills, 2004; Gerrard, 1990).

This study identifies soil variation with slope position and slope aspect on hillslopes with intra-catena variation in bed rock. Additionally, soil attributes that may differ with relative age of slope deposits is examined. The objective is to construct a general soil landscape model focusing on relative age of landform stability and soil variability with aspect and changes in lithology on hillslopes with intra-catena variation in bedrock.

Methods

Study Area

The study area is located on the North Fork of the Red River, within the western Cumberland escarpment in Powell county, Kentucky (Fenneman, 1938) (Fig. 1 and 2). The area is characterized by a highly dissected dendritic drainage pattern formed in Mississippian and Pennsylvanian sedimentary bedrock sequences. The deeply dissected drainages have limited extent of alluvium in narrow floodplains and steep sided valley margins. Relief ranges from 680' at the modern channel to 1200' on the summits with some slopes exceeding gradients of 55%. Mean annual rainfall is 46" with 25" (55%) falling between April and September. The average winter temperature is 36 degrees F and the average summer temperature is 74 degrees F. Vegetation on slopes is dominated by mixed mesophytic forest comprised of oak, hemlock, beech, basswood, and tulip poplar (Delcourt, 1998).

Soils are described on the nose section of the valley margins (Fig. 2) with slope profiles divided into convex upland benches (20-30% gradient) grading to a flat steep backslope (56-62% gradient) which grades to a concave upper footslope (40% gradient) grading into convex lower footslope (10-17%) which grades into a concave toeslope (7% gradient) (Fig. 3). Slopes are under mixed mesophytic forests that have not been intensively logged since the 1920's according to Powell county records.

Soils formed in Mississippian limestones and dolomites in the uplands while soils on the lower slopes formed in Mississippian siltstones and shales (Fig. 2). All hillslope soils are either mapped as Bledsoe-Berks-Rock outcrop complex or Carpenter-Bledsoe-Berks complex. These soils range from Typic Dystrudepts to Typic Hapludalfs or Ultic

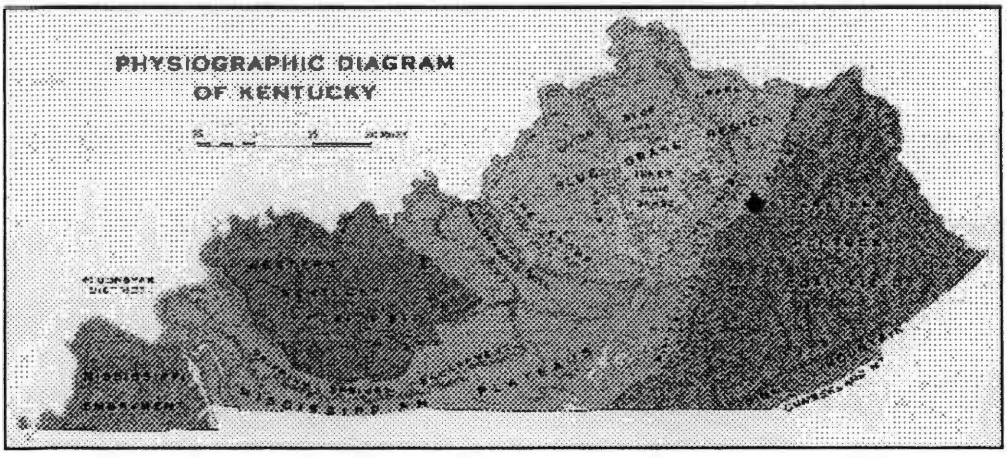


Figure 1: Physiographic Regions of Kentucky Showing Study Region
Shaded area indicates study region

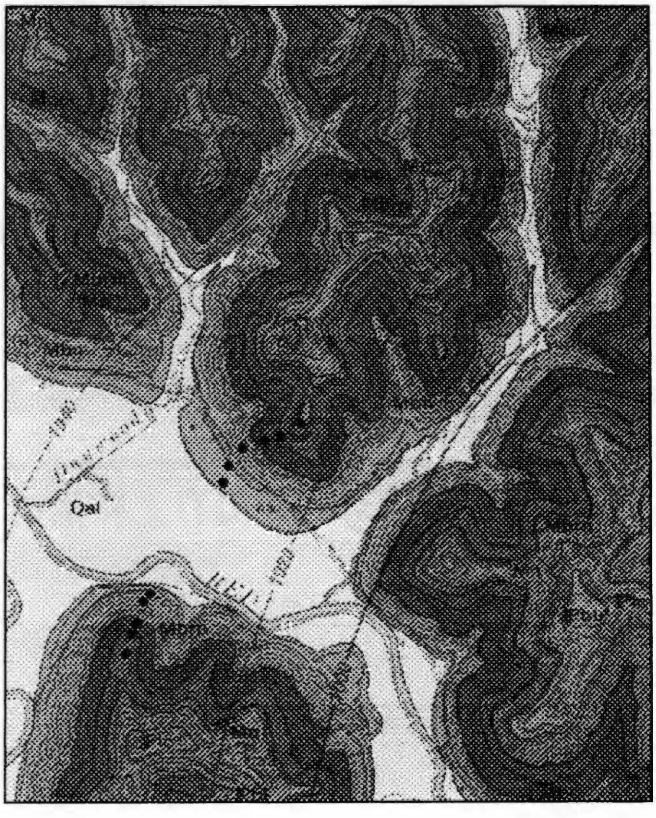


Figure 2: Pedon Locations 7.5' Geologic Quad
USGS Slade 7.5' Geologic Quad, 1974
Black dots indicate core locations

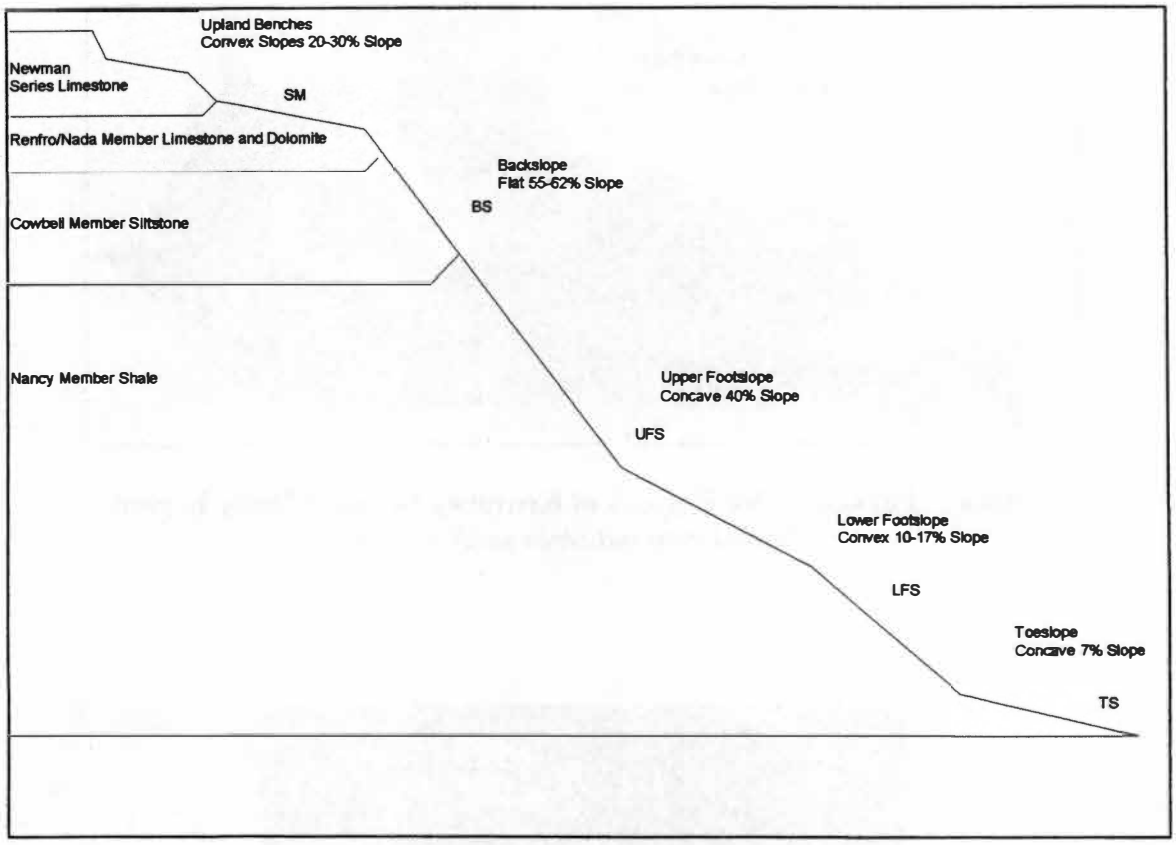


Figure 3: Slope Cross Section

SM=summit, BS=backslope, UFS=upper footslope, LFS=lower footslope, TS=toeslope
Not to Scale

Hapludalfs according to the Wolfe and Powell county soil survey. The underlying bedrock on both sides of the valley is identical, including the location of intra-catena variation. This allows for direct comparison of soil variables with slope aspect as parent material differences are minimal.

Sampling

Slope sections are stratified according to the landscape model developed by Ruhe and Walker (1968) with upland, backslope, footslope, and toeslope elements (Fig. 3 and 4). Sampling sites were selected based on landform type so each landform encountered along the transect has at least one complete pedon description. The transect consisted of a straight line trending from northeast to southwest and ended on the first upland bench formed in the Nada dolomite on both sides of the valley. This sampling method was selected due to the extremely rugged terrain that excluded the possibility of using hydraulic probes thus limiting the amount of ground that could be covered. All pedons were described using hand dug pits and or a bucket auger with individual samples taken for each genetic horizon. All pedons were described using national cooperative soil survey standards, noting horizon depths, color, structure, texture, slope shape and gradient and the absence or presence of clay skins. All samples were air-dried and passed through a 2-mm sieve in preparation of analysis.

Chemical and Physical Analysis

All ten pedons were analyzed per genetic horizon using the following methods. These methods refer to the Soil Survey Laboratory manual unless otherwise stated.

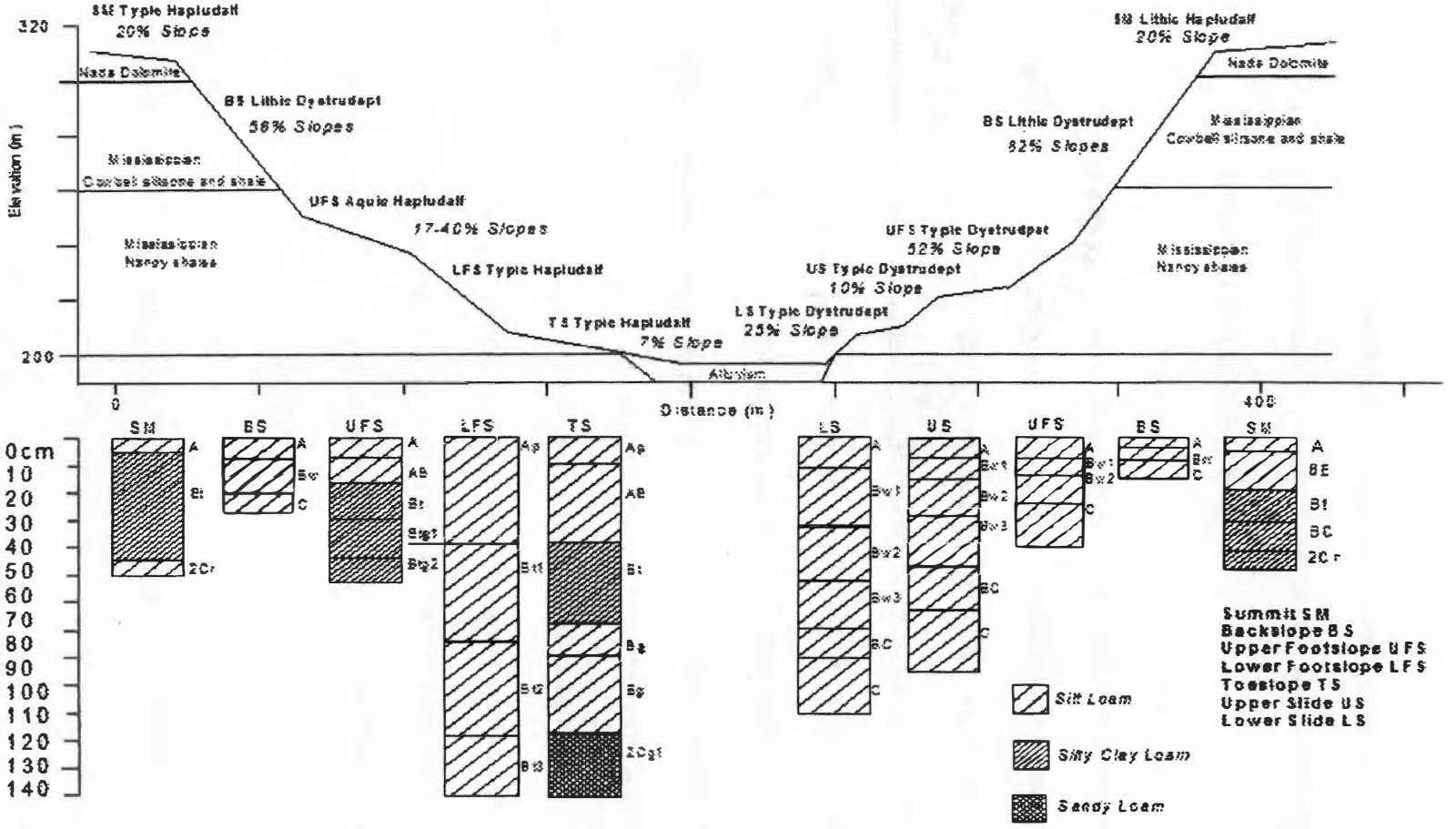


Figure 4: Valley Cross Section

Particle size was determined using the pipette method (Kilmer and Alexander, 1949), pH was analyzed in a 1:1 soil water mixture (4Cla), ECEC was determined by NH_4OAc at pH 7.0 and automatic vacuum extraction (4Bla) exchangeable cations were analyzed through ICP. Extractable acidity and exchangeable aluminum were determined through KCl extractions (4B3) and titration with NaOH for extractable acidity and 1N KF for exchangeable aluminum (Sparks, 1996). Base saturation was determined mathematically from summation of cations + KCl extractable aluminum. Total organic C was determined on a – 60-mesh sample and was analyzed through dry combustion (6a4a1). Extractable (or free Fe) was determined through dithionite-citrate extraction and quantified using atomic absorption (AA) (Perkin Elmer 5100) (Holmgren, 1967). Profile darkness indicator as described by Thompson and Bell (1996), accumulation index (SSL, 1995) and clay ratios as described by Jenny (1941) were calculated as follows:

$$PDI: \sum_{i=1}^{n} = \frac{\text{A horizon thickness}_i}{(V_i C_i) + 1} \text{ (Thompson and Bell, 1996)}$$

V = color value
C = color chroma

$$\text{Clay Ratio: } \frac{\%\text{Clay B horizon}}{\%\text{Clay A horizon}} \text{ (Jenny, 1994)}$$

$$\text{Organic C kg/m}^2 = Wt_{OC} \times 0.1 \times {}^*Db_{1/3} \times Hcm \times Cm \text{ (SSL, 1995)}$$

Wt_{OC} = Weight percentage of organic C on a <2mm base
0.1 = Conversion factor, constant
$Db_{1/3}$ = Bulk density at 1/3-bar water content on a <2mm base (g cc^{-1})
Hcm = Horizon thickness (cm).
Cm = Coarse fragment conversion factor
**Bulk Density was assumed as 1.33 g/cm^3 for all horizons*

Statistical Analysis

Five pedons are described for each slope aspect, one for each slope position (summit/shoulder, backslope, upper footslope, lower footslope, toeslope). Descriptions for each slope position are grouped and plotted on an XY axis with the X axis being slope position and Y axis being the soil variable under study. Trend lines, predictor equations, and regression coefficients were calculated for both slope aspects using Sigma Plot 9.0.

Once soil characteristics have been plotted versus slope position the shape of the observed trend line, whether it's linear or parabolic, can be used to delineate slopes into erosional and depositional sections. According to Furley (1971) the axis of a positive parabolic trend line is the division between the predominantly erosional upslope and predominantly depositional footslope. Additionally, if portions of the slope show a high degree of variability within the trend line it would indicate that irregular erosional and depositional processes have occurred (Gerrard, 1981).

Results and Discussion

Soil Classification

Summit and backslope positions have similar taxonomic classifications for both slope aspects with Hapludalf to Dystrudept sequences (Table 1). Variation in classification begins at the subgroup level for the different slope aspects. The NE slope summit is within the lithic subgroup while the SW slope summit exhibits slightly deeper soils. Both backslope positions are classified as Lithic Dystrudepts exhibiting shallow depths to bedrock and gravelly horizons. Slight variation exists at the family level due to variations in particle size within the control section.

Table 1: Soil Taxonomy on Slope Segments

Southwest slope aspect	
Landscape position	Taxonomic classification†
Summit	Fine-silty, mixed, mesic Typic Hapludalf
Backslope	Loamy-skeletal, mixed, mesic Lithic Dystrudept
Upper footslope	Fine-silty, mixed, mesic Aquic Hapludalf
Lower footslope	Fine-loamy, mixed, mesic Typic Hapludalf
Toeslope	Fine-silty, mixed, mesic Aquic Hapludalf

Northeast slope aspect	
Landscape position	Taxonomic classification†
Summit	Clayey, mixed, mesic Lithic Hapludalf
Backslope	Loamy-skeletal, mixed, mesic Lithic Dystrudept
Upper footslope	Coarse-silty, mixed, mesic Typic Dystrudept
Upper slide (*lower footslope*)	Fine-silty, mixed, mesic Typic Dystudept
Lower slide (*toeslope*)	Fine-silty, mixed, mesic Typic Dystrudept

†Mineralogy is assumed based on soil series descriptions.

A higher degree of variability exists on the lower slope elements between aspects all the way up to the soil order level. The lower elements of the SW slope are classified as Hapludalfs while the soils of the NE slope are Dystrudepts. This variation is due to landslide events that have occurred on the NE slopes within the lower slope elements which has interrupted pedogenesis (Outerbridge, 1982). At the subgroup level the soils on the SW slope are aquic in the upper footslope and toeslope positions while those on the NE slope are Typic. This variation is, again, likely due to the landslides that have occurred on the NE slope interrupting through flow of water. Variation at the family level for the lower slope elements is, again, due to the control section differences in particle size.

The differences in classification arise primarily on the lower footslope elements between aspects. This is a result of landslide events that have occurred at some point in the past on the NE slope. This has interrupted pedogenesis and left immature soils with minimal expression of B horizon development. Soil moisture conditions which show up at

the subgroup level indicate that the movement of materials on the NE slope has influenced not only soil development but through flow of water down slope. The SW slope has aquic conditions within the upper footslope which is unusual in the fact that it lies on a 40% slope gradient. The NE slope does not exhibit aquic conditions at a depth that would influence taxonomic classification. This may be due, in part, to the increased clay content on the SW slopes from argillic horizon formation. Illuvial, eluvial processes have been interrupted on the NE slope resulting in lower clay contents in the subsurface horizons which may allow for more through flow of water.

Particle Size

Total sand contents of the A horizons for both slope aspects exhibit a negative parabolic trend with slope position (Fig. 5). Backslopes and upper footslopes have higher sand contents than the summits and toeslopes within the upper horizons. Fine silt contents within the same horizons have a positive parabolic trend with slope position and in general are negatively correlated to sand content. This is likely a function of sedimentation processes currently acting on the surfaces of these slopes. Kleiss (1970) identified a decrease in mean particle size with distance from the summit in Iowa that was interpreted as a result of a particle sorting process. Similarly, Franzmeier et al. (1969) found higher sand contents on backslope positions in the Cumberland Plateau of Kentucky and Tennessee versus the lower slope positions within the particle size control section. The sorting of materials due to erosional processes is highest within the backslope positions for both slope aspects. This is indicated by the decrease in the easily eroded silt content

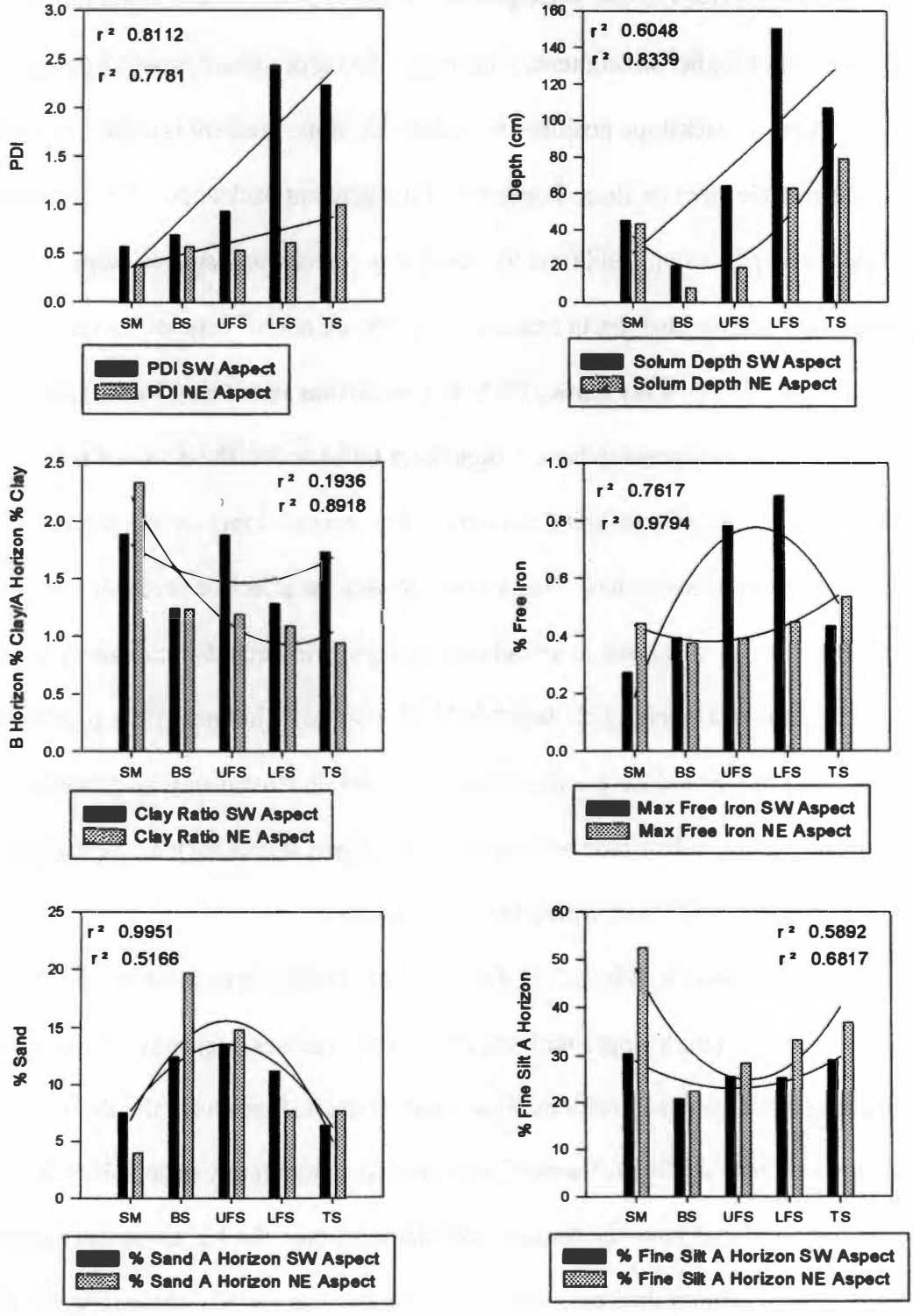


Figure 5: Relationship between Physical Soil Variables, Free Iron and Slope Position
Upper correlation coefficient (r^2) is for SW slope aspect

within the surface horizon of this slope position. Summit positions and lower slope elements both have higher silt contents indicating a fining of materials both upslope and downslope from the backslope position. It is clear that slope gradient is exhibiting some control over particle sizes on these slopes with high gradient backslopes (55-62%) having the highest levels of erosion. Additionally, the strong correlation between slope position and particle indicate the changes in bedrock lithology are not influencing texture.

Solum Depth, Clay Ratio, PDI, Accumulation Index and Free Iron

Slope gradient appears to have a significant influence on the depth of soil formation. According to Carter and Ciolkosz (1991), steeper slopes have a higher effective surface area due to the cosine law. This, in turn, lowers the effective precipitation per unit area on steeper slopes as rainfall is spread over a larger area such that compared to a 0% slope a 55% slope will receive 12% less rainfall (Carter and Ciolkosz, 1991 p. 208). Over a number of years this would have a significant influence on eluvial-illuvial processes and limit the expression of subsurface horizons on the steepest slopes such as the backslopes (55-62% slope gradients) found within the study transect.

Solum thickness (A, AB, BE, B, BC horizons) exhibits a positive parabolic trend with slope position on both slopes with the greatest thicknesses occurring on the summit, lower footslope and toeslope positions (Fig. 3 and 4). Backslopes have the thinnest sola with shallow depths to bedrock. Summit positions have moderately deep soils while footslopes and toeslopes have the thickest sola. Interestingly, the NE slope has a stronger correlation between solum thickness and slope position than the SW slope (Fig. 5). This is likely an expression of the increased erosional processes occurring on the NE slope that has created relatively young geomorphic surfaces with thicker deposits and lower slope

gradients in the footslope and toeslope position. Consequently, the upslope soils are then thinner due to soil loss from landslide activity. The predictability of soil depth with slope position then becomes a function of the relatively recent erosional processes rather than long term slope stability as is seen on the SW slope. This stability has resulted in a higher degree of differentiation between soil properties for the various slope positions on this slope aspect.

The ratio of the % clay in the B horizon divided by the % clay in the A horizon is a good indicator of the degree to which illuviation has taken place (Jenny, 1941) (Fig. 4). The summit positions for both slope aspects exhibited the highest ratios with the NE slope having the highest value. The SW slope has an unpredictable trend with the upper footslope and toeslope having ratios as high as the summit ratio. The backslope and lower footslope had the lowest ratios for the SW slope. The NE slope showed a continual decrease in clay ratios from the summit to the toeslope and a strong correlation between slope positions.

The presence of a BE horizon indicating a higher degree of illuvation on the NE slope summit is indicative of higher moisture contents (Fig. 3). Carter and Ciolkosz (1991) discovered a similar occurrence within soils developed from sandstone in Pennsylvania. They attributed this to decreased evapotranspiration and consequently higher moisture levels on a NE slope aspect. This increase in moisture content on the NE slope would have increased the effectiveness of illuvial-eluvial processes resulting in the weakly expressed eluvial horizon. The extents to which translocation processes are expressed within a soil are strongly related to the depth of the groundwater table (Jenny, 1941). Summit positions are well drained and have a more pronounced accumulation of clays in the illuvial horizons

while alluvial toeslopes tend to show the opposite affect (impeded flow) and have more isotropic properties.

Profile darkness index (PDI) increases for both slope aspects from summit to toeslope with a strong positive correlation existing between PDI and solum thickness and a weak to moderate negative correlation existing between PDI and organic C (Fig. 5,6 and 7). This indicates that the PDI values are more a function of erosional and depositional process rather than accumulation of organic C. Profile darkness index (PDI) is a measure of both A horizon thickness and Munsell color. PDI increases with darker colors which can be viewed as an indicator of organic C accumulation and drainage conditions (Ruetter and Bell, 2003). A horizons tend to form relatively quickly until eventually a steady state is reached between gains and losses of organic materials (Simonson, 1958). This time required to reach this steady state is depended upon soil forming factors however Birkeland (1999) believes this steady state is reached most commonly between 5 and 20 ky. Carbon accumulation index exhibits opposite trends with slope aspect with the SW slope having the highest values near the summit and the NE slope having the highest values in the lower slope elements (Fig. 7). The accumulation index can provide insight into the direction of soil formation processes, specifically the physical movement of materials on these slopes (Kononova, 1966; SSL, 1995 p. 25). The increased accumulation index at the base of the NE slope indicates that recent slope processes have deposited organic materials. On the SW slope the accumulation index is highest near the summit and lowest at the base of the slope. This is an indication that the physical movement of slope material has not recently occurred on this slope.

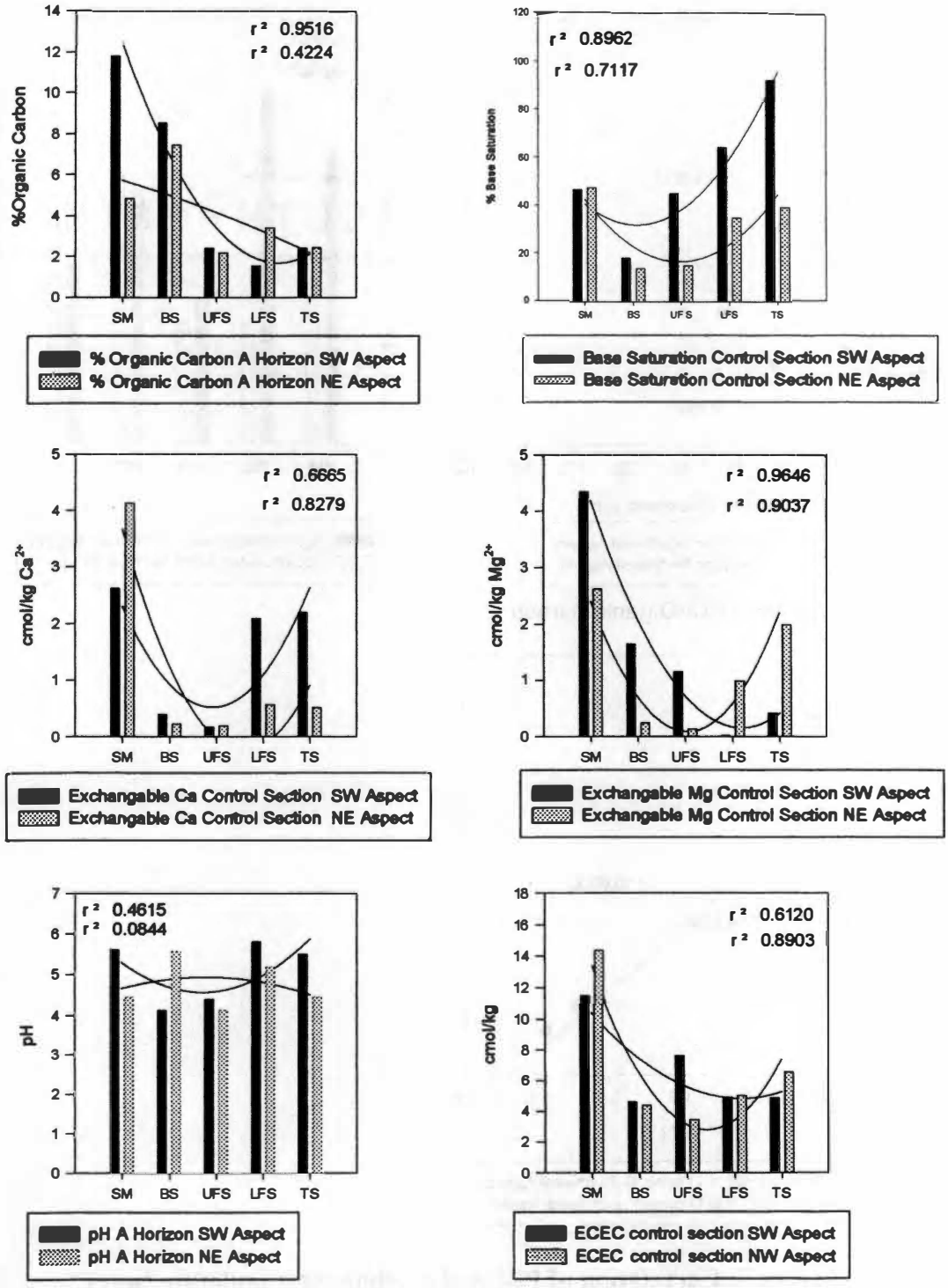


Figure 6: Relationship Between Chemical Soil Variables and Slope Position
Upper correlation coefficient (r^2) is for SW slope aspect

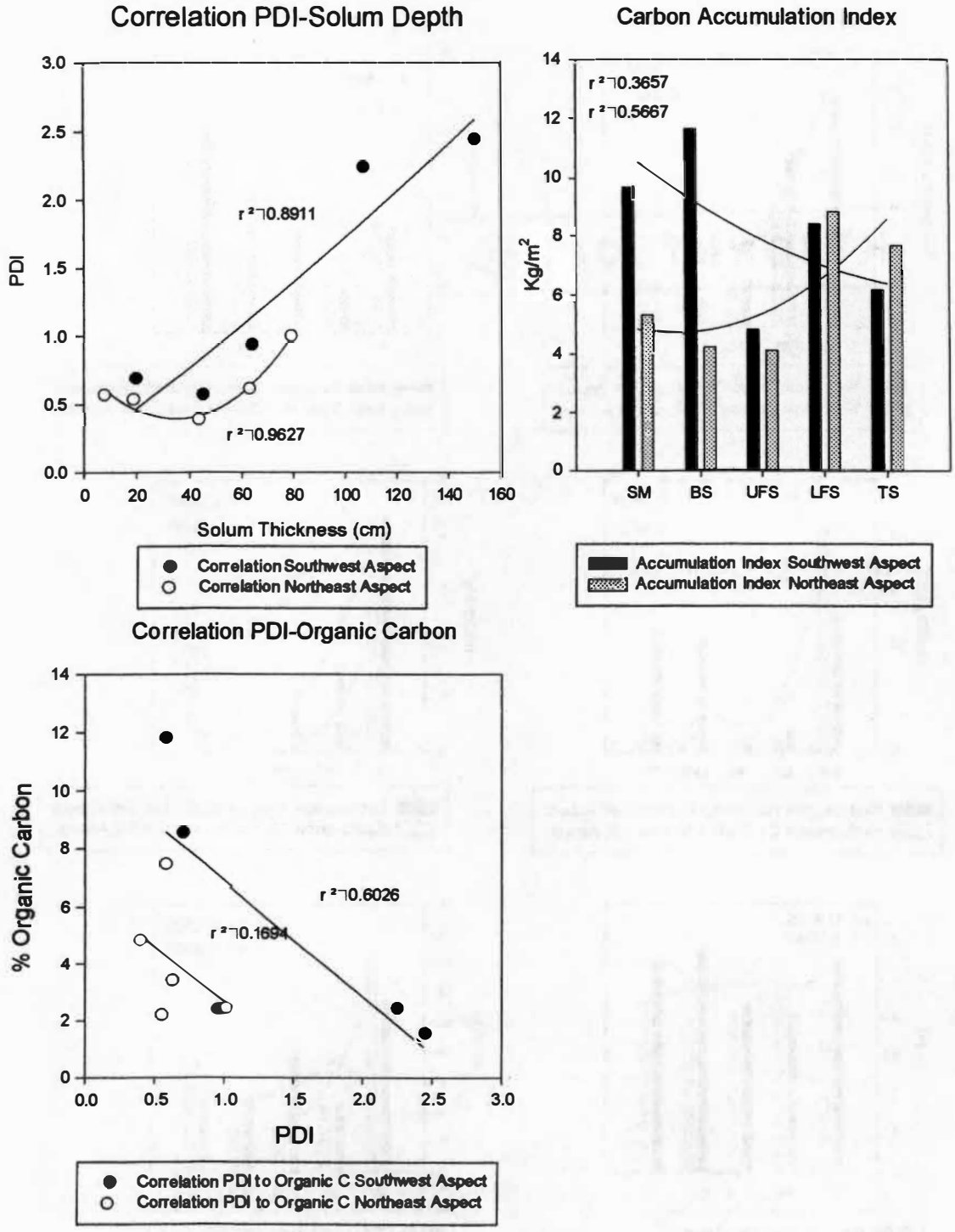


Figure 7: Correlation of PDI and Carbon Accumulation Index

Bulk Density for calculation of carbon accumulation index was assumed as 1.33 g/cm³

Maximum extractable Fe content within the subsurface horizons is highest on the upper and lower footslopes on the SW slope and lowest at the summit (Fig. 4). On the NE slope the toeslope has the highest extractable Fe and the backslope has the lowest. The maximum extractable Fe content was well correlated to slope position fitting either a positive or negative parabolic correlation. The SW slope fit a negative parabolic correlation while the NE fit a positive one. Additionally, the SW slope had higher Fe contents for all mid-slope positions compared to the NE slope while all other positions were comparatively equal.

Free or extractable Fe is largely used as a relative age indicator as the proportion of Fe released as a weathering product increases with age (Birkeland, 1999; Buol et al. 2003; Liebens and Schaetzl, 1997; Mills, 2004). Drainage, landscape position and parent materials can also contribute to the extractable Fe content (Buol et al., 2003). The extractable Fe content on these slopes is an indicator of both relative age and landscape stability. The SW slope summit has the lowest free Iron content yet it has nearly the highest clay ratio between the A and B horizons. This may indicate loss of Fe downslope from lateral movement and or soil creep. Conacher and Dalrymple (1977) consider lateral subsurface water flow and soil creep critical processes on steeply sloping convex slopes. This process may contribute to the increase in extractable Fe downslope however, in addition to lateral movement the footslope position on the SW slope has very high free Fe compared to all other slope positions and aspects. This landform also has high clay ratios and relatively deep sola which indicate that this geomorphic surface has been stable for

some time. Other studies in the southeastern United States indicate that argillic horizon formation requires 5000 years to develop (Leigh, 1996). Although this study was conducted in alluvial parent materials in the Blue Ridge of northern Georgia, precipitation and temperature are similar (MAP=150cm, MAT=13C). Additionally, theradiocarbon date within the toeslope indicates that argillic horizon formation has taken place in the weathered colluvium within 2500 years.

Extractable Fe on the NE slope displays a somewhat similar trend however the distribution of Fe shows less variability. The toeslope has the highest maximum extractable Fe content while the backslope and upper toeslope have the lowest. This indicates that the midslope position is pedogenically young and is a source area for eroded materials moving downslope. The toeslope and footslope is receiving partially weathered materials from the backslope position with free iron moving physically within the colluvial material.

The overall comparison between slope aspects reveals that the NE slope has considerably lower extractable Fe contents than the SW slope. This is believed to largely be a function of slope stability that may potentially be a result of microclimatic differences in moisture content and temperature. Franzmeier et al. (1969) collected temperature data for north and south facing slopes on the Cumberland Plateau in Kentucky and Tennessee and discovered that the mean annual temperature difference caused by differences in solar radiation were 1.5 C to 1.9 C between slope aspects. Additionally, it was discovered that the lowest sites tended to be the coolest and had higher moisture contents as they are shaded in the morning and evening by adjacent hills. It is conceivable then that the mass wasting events that have occurred on the NE slope may have been a result of these microclimatic differences.

pH, Base Saturation and Exchangeable Bases

On the SW slope the highest pH in the surface horizon occurred within the lower footslope and the lowest pH was found on the backslope (Fig. 6). Base saturation within the control section was highest on the lower footslope and toeslope and the lowest was at the backslope fitting a positive parabolic trend. Exchangeable calcium in the control section was highest on the summit and lowest at the upper footslope. Exchangeable magnesium was also highest on the summit; however, the lowest was found in the lower footslope instead of the upper footslope as in calcium. The exchange sites for these soils are largely dominated by calcium and magnesium as these cations are more difficult to leach (Birkeland, 1999). Because of this ECEC is closely related to the cmol/kg of exchangeable calcium present.

The predictability of surface horizon pH with slope position is poor (r^2=0.4615) for the SW slope (Fig. 6). However, some correlation does exist between pH and percent organic C and clay content in the surface horizons. Summit and Footslope positions have higher clay and organic C contents and thus higher pHs due to an increase in buffering capacity for these soils. Base saturation within the control section is a good measure of the degree to which leaching of basic cations has taken place. This process is enhanced in soils with low CEC's and higher moisture contents. The base saturation on the SW slope shows a strong correlation with slope position (r^2=0.8962) fitting a positive parabolic trend. Exchangeable calcium within the control section is moderately correlated with slope position (r^2=0.6665) and for most slope positions is highly correlated to clay content. The exception to this is in the upper footslope where matrix colors with chroma of two or less were encountered at a depth of 15cm. Hydrology has become the dominant control over

chemical characteristics with high moisture contents more intensively leaching this soil of basic cations.

The NE slope has the highest pH in the surface horizons occur in the backslope and the lowest in the upper footslope (Fig. 6). Base saturation within the control section was highest on the summit and lowest in the backslope. Exchangeable calcium and magnesium within the control section was highest on the summit and lowest in the upper footslope position.

On the NE slope no correlation exists between slope position and surface horizon pH (r^2=0.0844) but again is well correlated to the clay and organic C content (r^2=0.7112). Base saturation within the control section has a moderate correlation to slope position (r^2=0.7117) fitting a positive parabolic trend. As on the SW slope this reflects the ability of the soil to buffer inputs of acidic cations due to the absence or presence of soil colloids (clays, O.M.). The summit and lower slope elements have higher clay contents and thus higher base status. Exchangeable calcium and magnesium both show a strong correlation to slope position (r^2>0.83) and again is a reflection of the clay content within the control sections in these soils.

Overall base saturation and surface horizon pH are higher on the SW slope with the exception of the backslope where pH is higher on the NE slope (Fig. 6). This is likely due to the increased moisture content on the NE slope enhancing leaching processes and the higher clay contents present on the SW slope. Exchangeable calcium was higher on the SW summit and magnesium was higher on the NE summit. This may indicate the degree of leaching that has taken place as calcium is more tightly held to soil colloids than magnesium due to its larger hydrated radius (Brady and Weil, 2002). More intense leaching

from higher moisture contents on the NE summit would result in a higher degree of magnesium loss on the exchange sites. Carter and Ciolkosz (1991) also explained higher levels of eluvial-illuvial processes occurring on N slopes in Pennsylvania by increased moisture contents on this slope aspect. Finney et al. (1962) on the Allegheny Plateau in Ohio found the opposite trend where the SW facing slope had lower base saturation and lower pH. This was explained by the change in vegetation with slope aspect where the NE slope consisted of mixed mesophytic and the SW slope was dominated by oak. The higher occurrence of fire on the dry SW slope is also believed to have contributed to the lower base content and pH as nitrogen is lost through volatization and calcium, potassium, and nitrogen in the ash is quickly lost through leaching processes (Finney et al., 1962).

Hillslope Processes, Relative Time of Stability and Geologic Influence

Both contemporary and past hillslope processes (erosion, deposition, mass wasting) along with changes in bedrock lithology have resulted in the distribution of soils observed on these slopes. Properties associated with A horizons (organic C, pH) tend to form quickly and thus represent more current processes (Birkeland, 1999). B horizon characteristics (lessivage, base saturation, thickness) take considerably more time to develop and require long periods of landform stability. The correlation between soil properties and slope position is expected to be poor if erosive processes are vigorous or the geomorphic surface is young (Gerrard, 1981). Additionally, a strong correlation between slope position and soil properties indicates that the soils have reached some kind of steady-state condition whereas a poor correlation would indicate a steady-state has not been reached and there is little differentiation between slope positions (Gerrard, 1981).

Nearly all soil variables observed in this study had a moderate to strong statistical fit with a parabolic trend line. The axis of the curve fell either in the backslope or upper footslope position indicating that this is the point of maximum erosion and loss of soluble cations. B horizon properties for the SW slope tend to show moderate to strong correlations with slope position with the exception of clay ratios. Maximum extractable Fe, solum depth, base saturation, and exchangeable calcium all had regression coefficients of ≥ 0.60. Clay ratios exhibited a poor statistical fit to both a parabolic and linear trend (r^2=0.18). Total sand within the A horizons had a strong fit (r^2=0.99) with the axis of the curve on the backslope position. Fine silt content in the A horizons have a moderate fit (r^2=0.59) and display a positive parabolic trend with the axis of the curve between the backslope and upper footslope.

The observed trend lines (Table 2) delineate three distinct zones of geomorphic process and soil formation on the SW slope (Fig. 5 and 6). Fine silt, base saturation, exchangeable calcium and clay ratios fit a positive parabolic trend with the axis either on the backslope or upper footslope position. Free Fe and sand fit a negative parabolic trend with the axis on the upper footslope for sand and the lower footslope for free Fe. Solum depth displayed a positive linear trend with the max depth on the lower footslope. Clay ratios had a weak statistical fit mainly due to a high degree of variation in the lower slope elements. This may be an indication of irregular deposition particularly in the lower footslope which had a low clay ratio but a high maximum free Fe content. From the observed trend lines for this slope it is apparent that the summit and backslopes are dominated by erosional processes with the area of maximum erosion occurring in the

Table 2
Parabolic Predictor Equations[a] for Soil Properties with Slope Position and Aspect

Soil Property	*SW slope*		*NE slope*	
	Prediction equation	r^{2b}	Prediction equation	r^{2b}
Clay Ratio	$y=0.067x^2-0.29x+1.79$	0.18	$y=0.13x^2-0.82x+2.20$	0.89
Max free Fe	$y=-0.10x^2+0.49x+0.19$	0.76	$y=0.03x^2-0.08x+0.44$	0.98
A horizon sand	$y=-1.66x^2+6.28x+7.63$	0.99	$y=-2.41x^2+9.18x+6.85$	0.52
A horizon fine silt	$y=1.58x^2-6.10x+29.13$	0.59	$y=4.692x^2-20.73x+48.07$	0.68
%O.C. A horizon	$y=0.97x^2-8.39x+19.84$	0.95	$y=-0.051x^2-0.58x+6.35$	0.42
Solum Depth	$y=0.43x^2+23.69x+27.25$	0.60	$y=9.64x^2-25.87x+36.28$	0.83
Base Saturation	$y=7.49x^2-16.29x+40.67$	0.90	$y=6.75x^2-26.53x+42.62$	0.71
Exch. Ca^{2+}	$y=0.49x^2-1.86x+2.298$	0.67	$y=0.83x^2-3.01x+3.66$	0.83

[a]y are values of soil properties predicted for slope position x
[b]r^2 is the correlation coefficient
n=5 for all soil properties
%O.C.= organic carbon

backslope or upper footslope while the lower footslope and toeslope are dominated by deposition. Some irregularity in soil variables such as clay ratio and solum depth occurs primarily in the lower slope elements. Clay ratios have a poor statistical fit to both linear and parabolic trends due to a high degree of variability in the footslope position. The clay ratio decreases rapidly from the summit then shows a marked increase from the backslope until the lower footslope is reached where it shows a drastic decrease again.

The lower footslope also has high max free Fe which would normally indicate a high degree of soil development. This likely reveals that previously weathered material with some free Fe is periodically being deposited in this slope position followed by a period of stability allowing for the translocation of clay. This is further verified as solum thickness is highest on this slope position indicating that this a zone dominated by deposition with pedogenesis outpacing accumulation.

In general B horizons of the SW slope exhibit a high degree of differentiation and a moderate to strong correlation between slope positions indicating this slope has been stable for some time, however some irregular deposition has occurred in the lower footslope. A radiocarbon date on charcoal found between 80-107cm in the toeslope revealed a calibrated age of between 2740 to 2370 Cal BP. Above the sample depth an argillic horizon has formed and below a discontinuity separates colluvial and alluvial parent materials. This indicates that argillic horizon formation in previously weathered colluvium can occur within 2500 years in this environment. Unfortunately since these are erosive slopes, it is unlikely that the soils across its surface are of the same age (Birkeland, 1999). A more likely scenario is that the relative age of the summit is old (> 2500 BP) and the backslope is young (< 2500 BP) and the lower slope elements are intermediate in age (2500 BP).

The trends observed for total sand and fine silt within the A horizons indicate that under contemporary conditions the zone of maximum erosion lies on the backslope and upper footslope. Upslope and downslope from this point sand content decreases and silt content increases. Organic C content had a strong statistical fit (r^2=0.95) in a positive parabolic trend with a steep curve on the upslope positions and a flat curve in the lower slope elements (Table 2). The flatness of this curve indicates that organic C is being lost in an open system instead of accumulating on the lower slope elements. Many studies indicate organic C increasing downslope (Walker and Ruhe, 1968; Kliess, 1970) however Young and Hammer (2000) also found decreasing organic C with distance from the summit and concluded that many of these earlier studies were conducted within closed drainages or depressions which cause organic C to accumulate downslope.

Like the SW slope the B horizon variables on the NE slope tend to have a moderate to strong statistical fit within a parabolic trend line (Table 2). However less differentiation exists between slope positions due to the landslide activity that has occurred on the lower slope. The type of mass wasting these deposits represent is difficult to ascertain; however, they appear to be of the debris flow type and have formed a unique scarp and terrace-like topography on the lower slope. This process has had a profound impact on the distribution of soils across this slope.

Solum depth and maximum free Fe fit positive parabolic trends on the NE slope with the curve axis on the backslope position. The free Fe curve is relatively flat with slight increases in the summit and lower slope elements. This type of trend would be expected on slopes that have not been stable long enough for weathering to release significant amounts of Fe. Solum depth fits a positive parabolic trend with the axis on the backslope. The terrace-like deposits formed from the landslide have reduced the slope angle on the tops of these landforms. This decrease in angle would increase the effective precipitation the tops of these flows receive which in turn would result in thicker soils through enhanced eluvial-illuvial processes. It is likely that if soils were described on the scarps of these flows and not just the tops a much higher degree of sinuosity would have been observed in the trend lines in the lower slope positions. Clay ratios fit a positive parabolic trend with the axis on the lower footslope. This curve is flat in the lower slope and increases sharply in the upslope positions. It is apparent that the summit has a much higher degree of lessivage than the lower slope positions which also indicates the time of relative stability is greater in the summit position than for the footslope and toeslope position. If pedogenesis was

interrupted in the lower slope positions from the landslide this would indicate that the soils of the summit are significantly older than those developed in the slide.

Base saturation and exchangeable calcium both fit positive parabolic trends with the axis near the upper footslope (Fig. 6). Unlike clay ratios the curve begins to increase in the lower slope indicating soluble cations are being retained. Even though the base saturation shows an increase from the backslope it is still below 40% which likely indicates that previously leached, nutrient poor material was deposited in the debris flow.

A horizon variables tend to show a poor statistical fit compared to the properties of the B horizon. Total sand fits a negative parabolic trend with the axis on the upper footslope however the correlation coefficient is low (r^2=0.52). Fine silt fits a positive parabolic trend with a better fit (r^2=0.68) and shows a steady increase in the lower slope positions. Organic C has a poor statistical fit due to an increase in the backslope and the lower footslope. The trend indicates that organic C is accumulating in the lower footslope and toeslope (slide areas) and the zone of maxium erosion is in the upper footslope. Many of the observed trends had their axis occurring over the upper backslope position. This slope position likely represents the source area for much of the material deposited in the lower slope. The junction between the depositional and erosional areas will fluctuate up and down slope in response to changes in the system from climatic or vegetational shifts (Gerrard, 1981). The poor correlation between slope position and A horizon variables is an indication that a shift of this nature has taken place as evidenced by the landslide deposits.

The landslides themselves are pedogenically young with little clay accumulation, and low extractable Fe. A closer look at the distribution of organic C and extractable Fe with depth (Fig.8) in the upper and lower slide indicate that extractable Fe is comparable

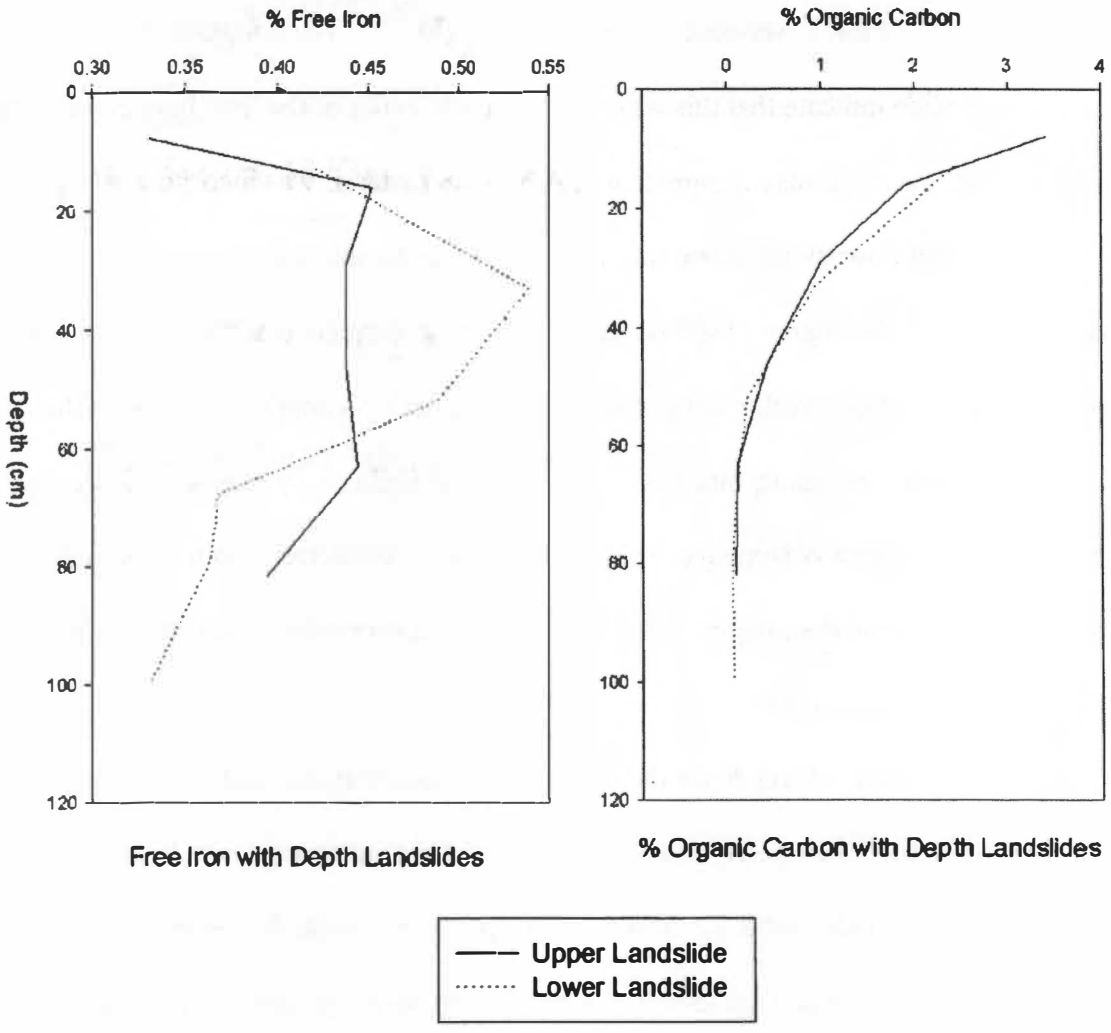


Figure 8: Organic Carbon and % Free Iron with Depth Landslides

between slides and organic C shows a gradual decrease (Fig. 8). The similarity between the upper and lower slide indicate that this was either a single event or the time between events was limited. The organic C may designate that A horizon material was incorporated into the flow as it moved downslope. Assuming that the pedogenic clock was reset when theseslides occurred, the degree of soil development would indicate that these deposits are late Holocene in age. The development of the soils that occupy a similar position on the SW slope have argillic horizons, more extractable Fe, and higher clay ratios. Additionally, since the toeslope on the SW slope has had argillic horizon formation within 2500 years it seems unlikely that these flow deposits are of a greater age even when you consider the potential affects of slope aspect.

Overall the observed trends for the NE slope indicate that relatively recent disturbance has altered hillslope processes. Solum thickness increases downslope however clay accumulation and extractable Fe does not. This points to the landslides on the lower slope not being stable long enough to show an increase in lessivage and weathering products. The relative duration of stability for all slope positions below the summit is brief and consequently the relative soil age is likely young. The summit position has a high clay ratio and an increase in exchangeable Fe over the backslope and upper footslope positions. This indicates a long period of stability and an intermediate-old relative age.

Variation in bedrock is playing a considerable role in the observed soil trend lines and the overall evolution of the slopes in this region. Differential weathering processes between the horizontally bedded Mississippian and Pennsylvanian sedimentary bedrock have resulted in an interruption of the slope continuum from summit to toeslope. Upper

Mississippian limestones and dolomites of the Renfro and Nada members and the Newman series have formed upland "benches" with decreased slope gradients that have resulted in discrete zones of increased soil development. These slope positions represent individual slopes within the overall slope and thus disrupt the physical and chemical movement of materials downslope. Underlying shales of the Nancy member in the lower backslope and foot/toe slope appear to be relatively impermeable as evidenced by low chromas in the upper footslope position on the SW slope. This is especially unusual in the fact that this slope segment has a 40% gradient thus aquic soil conditions were not expected to be found. These shales are influencing the flow of water downslope and may be contributing to the landslide activity that is so prominent in the region (Outerbridge, 1982).

Conclusion

This study reveals that soil chemical and physical characteristics across these slopes are related to slope position, slope aspect, geology and relative time of stability. Additionally, the relationships between soil variables and slope position can have a strong correlation even on slopes with intra-catena variation in the underlying bedrock. The soils of the SW slope had a moderate to strong statistical fit (r^2>0.60) for solum depth, extractable Fe, base saturation, exchangeable cations, organic C, % sand in the A horizon, and PDI. Poor correlations existed for pH and clay ratios. Some of the observed trend lines showed higher degrees of variability in the lower footslope (clay ratio) pointing to a disruption in depositional processes. The time of relative stability allowing for soil development is highest on the summit and footslope positions. The summit and backslope are dominated by erosional processes while the footslope is dominated by deposition. The carbon accumulation index indicates that on the NE slope carbon has accumulated at the

base of the slope due to recent (late-Holocene) landslide activity while on the SW slope carbon is remaining near the summit.

The soils on the NE slope had a moderate to strong statistical fit (r^2>0.60) for solum depth, extractable Fe, base saturation, exchangeable cations, fine silt content in the A horizon, CEC, and PDI. A poor correlation existed for pH, sand content of the A horizon and organic C content in the A horizon. The presence of a recent (late Holocene) debris flow in the lower footslope and toeslope positions resulted in poorly developed soils that influenced the observed trend lines. Changes in bedrock lithology have influenced slope gradients and shales of the Nancy member in the lower slope elements is affecting the flow of water downslope and contributing to landslide activity.

Soils on the NE slope had thinner sola, less extractable Fe, lower clay ratios, lower base saturation, and lower pH than the soils on the SW slope. Clay ratios on the NE summit were higher indicating greater eluvial-illuvial processes from increased moisture contents on this slope aspect. The presence of recent landslide deposits on the lower footslope and toeslope may be related increased moisture contents on the NE facing slope however many landslides have been mapped in the area and further study is required to determine if slope aspect is a significant factor in the orientation of these deposits.

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Appendices

Appendix A – Pedon Descriptions

Horizon	Depth(cm)	Color(moist)	Mottles	Sand	Silt	Clay	Structure	Boundary
Soils on Southwest Facing Slope				——%	——			
Core #8 (Typic Hapludalf) 30% slope, Upper Summit (SM)								
A	0-7	7.5YR 3/2	--	46	44	10	2gr	c
E	7-17	10YR 5/6	--	47	40	13	2sbk	c
Bt1	17-29	5YR 4/6	--	19	28	53	2abk	c
Bt2	29-41	5YR 4/6	--	18	29	53	3abk	c
Bt3	41-60	5YR 4/6	--	18	32	49	2sbk	c
B/Ct	60-80	7.5YR 5/6	--	17	31	52	1sbk	c
2Cr	80+	--	--	13	33	54	m	--
Core #9 (Typic Hapludalf) 20% slope, Lower Summit (SM)								
A	0-4	10YR 3/2	--	7	74	19	1gr	c
Bt	4-45	2.5Y6/4	--	3	62	35	1sbk	c
C	45-54	--	--	9	65	27	m	c
2Cr	54+	--	--	-	-	-	--	--
Core #10 (Lithic Dystrudept) 56% slope, Backslope (BS)								
A	0-9	10YR 4/3	--	13	76	11	2gr	c
Bw	9-20	2.5Y 5/3	--	13	73	14	1sbk	c
2Cr	20+	--	--				m	--
Core #11 (Aquic Hapludalf) 40% slope, Upper Footslope (UFS)								
A	0-6	10YR 5/3	--	14	71	16	1gr	c
AB	6-15	10YR 5/3	10YR 5/6	13	71	15	1sbk	c
Bt	15-29	2.5Y 6/2	10YR 5/6	4	67	29	1sbk	c
Btg1	29-44	10YR 6/2	--	3	65	32	1sbk	c
Btg2	44+	10YR 5/2	--	2	67	31	1sbk	--
Core #6 (Typic Hapludalf) 17% slope, Lower Footslope (LFS)								
Ap	0-39	10YR 5/3	--	11	70	19	1gr	a
Bt1	39-65	10YR 5/4	--	19	59	22	1sbk	c
Bt2	65-98	10YR 5/6	--	12	65	23	2sbk	c
Bt3	98-150	10YR 4/6	10YR 6/2	8	67	25	2sbk	c
C	150-160	10YR 5/4	--	16	63	21	m	--
Core # 5 (Aguic Hapludalf) 7% slope, Toeslope (TS)								
Ap	0-10	10YR 5/3	--	6	77	17	1gr	a
AB	10-38	10YR 4/4	10YR 5/2	8	76	16	1gr	c
Bt	38-67	10YR 5/4	--	4	68	28	1sbk	c
Bg	67-80	10YR 6/2	10YR 4/6	8	76	16	1sbk	c
Bg	80-107	2.5Y 6/1	10YR 5/6	9	78	14	1sbk	c
2Cg1	107-195	10YR 6/2	10YR 5/8	14	72	14	sg	a
2Cg2	195+	10YR 7/2	2.5Y 5/4	61	29	10	sg	--
Soils on Northeast Facing Slope								
Core #13 (Lithic Hapludalf) 20% slope, Summit (SM)								
A	0-5	10YR 4/3	--	4	80	16	1gr	c
BE	5-19	10YR 6/3	--	4	72	24	2sbk	c
Bt	19-31	2.5Y 5/3	--	2	59	38	2sbk	c
BC	31-43	10YR 5/4	10YR 6/2	2	67	30	1sbk	c
2Cr	43+	Gley 1 6/5GY	--	3	68	29	m	--
Core #14 (Lithic Dystrudept) 62% slope, Backslope (BS)								
A	0-4	2.5Y 3/2	--	20	67	13	1gr	c
Bw	4-8	2.5Y 5/4	--	14	70	16	1sbk	c
2Cr	8+	--	--	--	--	--	m	--
Core #15 (Typic Dystrudept) 52% slope, Upper Footslope (UFS)								
A	0-7	2.5Y 4/3	--	15	71	14	1gr	c
Bw1	7-13	2.5Y 5/6	--	9	75	16	1sbk	c
Bw2	13-19	2.5Y 6/4	--	9	74	17	1sbk	c
C	19-46+	--	--	9	76	15	m	--

Core #16 (Typic Dystrudept) 10% slope, Lower Footslope (LFS), Upper Slide (US)

A	0-8	2.5Y 4/3	--	8	75	18	1gr	c
Bw1	8-16	2.5Y 4/4	--	8	74	19	1sbk	c
Bw2	16-29	2.5Y 5/4	--	8	73	18	1sbk	c
Bw3	29-46	2.5Y 5/6	--	9	74	18	1sbk	c
BC	46-63	2.5Y 5/6	--	12	72	16	1sbk	c
C	63-83+	--	--	16	68	17	m	--

Core #17 (Typic Dystrudept) 25%, Toeslope (TS), Lower Slide (LS)

A	0-13	2.5Y 4/3	--	8	73	19	1gr	c
Bw1	13-33	2.5Y 5/4	--	8	74	18	1sbk	c
Bw2	33-52	2.5Y 5/4	--	9	73	19	1sbk	c
Bw3	52-68	2.5Y 6/4	--	8	74	18	1sbk	c
BC	68-79	2.5Y 6/2	10YR 5/6	8	74	18	1sbk	c
C	79-100+	--	--	5	77	18	m	--

Soils on Alluvial Surfaces

Core #7 (Dystric Fluventic Eutrudept)

Ap	0-34	10YR 5/3	--	5	71	24	1gr	c
Bw	34-82	10YR 5/3	--	6	68	27	1sbk	c
Bg	82-106	2.5Y 6/1	10YR 4/6	5	69	26	1sbk	c
Cg1	106-150	--	--	6	64	30	m	c
Cg2	150-213	--	--	7	68	25	m	c
Cg3	213-239	--	--	9	66	25	m	--

Core #2 (Dystric Fluventic Eutrudept)

Ap	0-35	10YR 4/2		10	59	31	gr	a
Ab	35-80	7.5YR 4/4		7	65	28	2sbk	c
BC	80-120	7.5YR 4/6		8	66	26	2sbk	c
ABb	120-180	7.5YR 4/4		19	57	24	1sbk	c
Bgb	180-240	7.5YR 4/4		21	58	21	2sbk	--

Cut Bank Profile (Dystic Fluventic Eutrudept)

Over Bank	0-13	----------		91	6	3	sg	a
Ap	13-26	10YR 4/3		79	14	7	1gr	a
AC	26-40	10YR 4/6		77	17	6	sg	c
ABb	40-54	10YR 3/6		57	34	9	1sbk	c
Bw1b	54-73	10YR 3/6		59	32	9	1sbk	c
Bw2b	73-87	10YR 3/6		50	38	12	1sbk	c
Bw3b	87-114	10YR ¾		42	40	17	1sbk	c
Ab	114-133	10YR 3/3		44	40	16	1sbk	c
Bwb	133-153	10YR 4/3		42	41	17	1sbk	c
C	153-172	10YR 4/3		65	25	10	sg	c
Ab	172-190	10YR 3/6		23	56	21	1sbk	c
Bwb	190-227	10YR ¾		15	61	24	1sbk	c
C	227-250	10YR 3/6		60	28	13	sg	c
Ab	250-276	10YR 3/6		53	36	12	1sbk	c
Bwb	276-290+	10YR 3/6		29	53	18	1sbk	c

Appendix B – Raw Data

ECEC Data

Core 8	ppm Ca	Blank Ca	mass extract	vol. extract	mass soil	cmol/kg Ca	Blank Mg	ppm Mg	cmol/kg Mg	Blank K	ppm K	cmol/kg K	Blank Na	ppm Na	cmol/kg Na
A 0-7	178.9	0.794	46.62	52.02	2.48	18.79	0.1737	12.08	2.87129	0.1124	10.65	0.57	1.8480	2.757	0.06
E 7-17	15.42	0.794	45.54	50.80	2.49	1.48	0.1737	1.613	0.24081	0.1124	1.907	0.09	1.8480	4.499	0.23
Bt1 17-29	162.6	0.794	47.85	53.17	2.51	17.10	0.1737	9.85	1.68840	0.1124	6.86	0.37	1.8480	2.251	0.04
Bt2 29-41	195.2	0.794	47.72	53.02	2.48	20.74	0.1737	9.46	1.63327	0.1124	5.64	0.30	1.8480	1.848	0.00
Bt3 41-60	172.2	0.794	48.67	54.30	2.51	18.50	0.1737	6.21	1.07425	0.1124	5.25	0.28	1.8480	1.848	0.00
BC 60-80	216.5	0.794	49.44	54.93	2.52	23.46	0.1737	4.888	0.80559	0.1124	6.76	0.37	1.8480	1.848	0.00
C 80-117	272.4	0.794	46.63	51.81	2.51	27.98	0.1737	4.026	0.65415	0.1124	6.65	0.35	1.8480	1.848	0.00
Core 9															
A 0-4	342.80	0.0000	44.45	49.39	2.52	33.53	0.031	27.03	4.35287	0.01	20.41	1.02	0.02	1.989	0.17
Bw 4-45	28.86	0.7200	45.81	50.88	2.52	2.62	0.180	13.17	2.15230	0.11	8.33	0.42	1.85	3.49	0.14
C 45-54	117.00	0.0000	45.82	50.91	2.52	11.80	0.031	16.9	3.13585	0.01	9.26	0.46	0.02	5.02	0.44
Core 10															
A 0-9	95.00	0.0000	42.64	47.36	2.50	8.98	0.031	10.6800	1.68017	0.01	6.21	0.30	0.02	4.9850	0.41
Bw 9-20	4.70	0.7940	46.45	51.61	2.51	0.40	0.1740	1.7710	0.27014	0.1124	3.0370	0.16	0.0000	0.73500	0.07
Core 11															
A 0-6	4.2	0.7940	45.05	50.06	2.52	0.34	0.1737	7.2200	1.15139	0.1124	3.3510	0.16	1.848	1.848	0.00
AB 6-15	2.16	0.7940	45.27	50.30	2.48	0.14	0.1737	4.8980	0.78962	0.1124	2.9010	0.14	1.848	4.5850	0.24
Bt1 15-29	2.109	0.7940	45.24	50.27	2.50	0.13	0.1737	8.7100	1.41185	0.1124	4.9420	0.25	1.848	6.0700	0.37
Btg1 29-44	2.955	0.7940	45.40	50.44	2.48	0.22	0.1737	16.7000	2.78533	0.1124	5.4400	0.28	1.848	1.848	0.00
Btg2 44-60	2.477	0.7940	45.86	50.96	2.52	0.17	0.1737	26.8000	4.42918	0.1124	6.9600	0.33	1.848	3.1440	0.11
Core 6															
A 0-39	79.0000	0.7650	46.46	53.67	2.49	8.45	0.1957	2.407	0.39353	0.0942	3.498	0.19	0.2585	1.077	0.07
39-65	45.8400	0.7650	46.23	51.37	2.49	4.84	0.1957	1.78	0.28547	0.0942	2.55	0.13	0.2585	0.857	0.05
65-98	11.8000	0.7650	47.02	52.24	2.49	1.18	0.1957	9.59	1.62149	0.0942	2.432	0.13	0.2585	0.99	0.06
98-150	5.1500	0.7650	47.58	52.87	2.50	0.46	0.1957	14.44	2.47785	0.0942	2.583	0.14	0.2585	1.528	0.11
150-180	13.0900	0.7650	47.45	52.72	2.49	1.30	0.1957	16.46	2.83285	0.0942	2.687	0.14	0.2585	2.348	0.19
Core 5															
0-10	69.6	0.0000	48.66	54.29	2.25	8.38	0.031	2.2720	0.44482	0.01	7.15	0.44	0.02	2.112	0.22
10-38cm	53.2	0.7200	45.07	50.08	2.53	5.18	0.180	1.119	0.15815	0.11	1.64	0.08	1.85	2.392	0.05
38-67cm	20.9	0.7200	49.48	54.98	2.49	2.22	0.180	10.24	1.83087	0.11	1.479	0.08	1.85	5.37	0.34
67-80	22.07	0.7200	41.09	45.65	2.48	1.96	0.180	19.84	2.98041	0.11	1.781	0.08	1.85	6.52	0.37
80-107	28.46	0.7200	42.58	47.31	2.53	2.40	0.180	22.58	3.44559	0.11	1.709	0.08	1.85	8.6	0.40
107-195	41.58	0.7200	42.97	47.74	2.54	3.83	0.180	28.65	4.43538	0.11	2.122	0.10	1.85	9.57	0.63
195-228	32.4	0.7200	42.96	47.73	2.52	2.99	0.180	11.67	1.82468	0.11	1.52	0.07	1.85	3.115	0.10
Core 7															
0-34	64.70	0.7230	44.97	49.97	2.54	6.28	0.0308	7.21	1.16180	0.1112	4.428	0.22	0.0151	1.14	0.10
34-62	48.11	0.7230	45.78	50.87	2.50	4.61	0.1812	9.31	1.53132	0.1112	3.755	0.19	1.1840	4.985	0.33
62-105	41.98	0.7230	48.18	53.53	2.48	4.44	0.1812	11.43	2.00105	0.1112	4.494	0.24	1.1840	2.621	0.13
105-150	48.04	0.7230	44.78	49.76	2.51	4.48	0.1812	15.67	2.52804	0.1112	6.07	0.30	1.1840	2.923	0.15
150-213	33.22	0.7230	49.81	55.34	2.49	3.60	0.1812	19.83	3.58535	0.1112	3.705	0.20	1.1840	3.148	0.19
213-239	37.6	0.7230	48.67	54.30	2.53	3.95	0.1812	22.53	3.94940	0.1112	2.954	0.16	1.1840	6.22	0.47
239-270	39.14	0.7230	47.45	52.72	2.53	3.89	0.0308	22.16	3.78357	0.1112	3.283	0.17	0.0151	0.912	0.08
270-289	37.25	0.7230	47.88	52.98	2.52	3.83	0.0308	20.49	3.53827	0.1112	3.412	0.18	0.0151	0.857	0.08
289-318	43.18	0.7230	48.35	53.72	2.51	4.53	0.1812	27.97	4.88634	0.1112	4.309	0.23	1.1840	3.801	0.24
328-435	83.9	0.7230	47.50	52.78	2.52	8.89	0.0308	50.2	8.64385	0.1112	8.81	0.47	1.1840	5.25	0.37
Core 2															
20-40	38.79	0.6450	47.27	52.52	2.54	3.73	0.1783	4.21	0.68381	0.0545	2.089	0.11	0.2992	0.737	0.04
40-60	28.19	0.6450	46.94	52.16	2.51	2.85	0.1783	3.814	0.62148	0.0545	1.952	0.10	0.2992	0.74	0.04
60-80	21.89	0.6450	45.76	50.84	2.50	2.14	0.1783	4.631	0.74487	0.0545	1.854	0.09	0.2992	0.793	0.04
80-100	19.28	0.6450	47.27	52.52	2.52	1.83	0.1783	4.533	0.74684	0.0545	1.773	0.09	0.2992	0.735	0.04
100-120	18.24	0.6450	45.98	51.09	2.51	1.58	0.1783	4.837	0.78006	0.0545	1.845	0.09	0.2992	0.899	0.04
120-140	16.62	0.6450	45.99	51.10	2.48	1.84	0.1783	5.51	0.91074	0.0545	1.928	0.10	0.2992	0.892	0.05
140-160	15.7	0.6450	46.36	51.53	2.53	1.53	0.1783	5.48	0.89837	0.0545	1.779	0.09	0.2992	0.717	0.04
160-180	15.73	0.6450	47.20	52.44	2.51	1.57	0.1783	5.68	0.94385	0.0545	1.61	0.08	0.2992	0.894	0.04
180-200	16.92	0.6450	45.24	50.27	2.53	1.61	0.1783	6.11	0.98850	0.0545	1.783	0.09	0.2992	0.871	0.05
200-220	18.04	0.6450	46.01	51.12	2.50	1.57	0.1783	5.93	0.98756	0.0545	1.597	0.08	0.2992	0.814	0.05
220-240	20.5	0.6450	46.68	51.87	2.49	2.06	0.1783	8.4	1.40883	0.0545	1.874	0.10	0.2992	0.785	0.04
280-300	24.26	0.6450	47.80	52.89	2.51	2.48	0.1783	10.71	1.82257	0.0545	2.11	0.11	0.2992	2.477	0.20
Bank 2															
O.B. 0-13	15.37	0.7470	50.00	55.56	2.49	1.63	0.1617	2.078	0.34815	0.0848	0.835	0.04	0.2275	0.4252	0.02
13-28	31.5	0.7470	48.46	53.84	2.51	3.29	0.1617	4.014	0.67629	0.0848	1.653	0.09	0.2275	0.626	0.04
28-40	16.3	0.7470	48.60	54.00	2.55	1.84	0.1617	3.165	0.54971	0.0848	1.679	0.09	0.2275	0.357	0.03
40-54	17.76	0.7470	48.54	53.93	2.53	1.81	0.1617	3.114	0.54123	0.0848	3.374	0.18	0.2275	0.622	0.04
54-73	13.6	0.7470	48.32	51.47	2.51	1.32	0.1617	1.987	0.30114	0.0848	2.357	0.12	0.2275	0.545	0.03
73-87	15.99	0.7470	46.26	51.40	2.53	1.55	0.1617	2.143	0.32779	0.0848	1.815	0.09	0.2275	0.569	0.03

Organic C and Total N Data

Core 8	% Nitrogen	% Carbon	C:N
A 0-7	0.5242	8.4633	16.14517
E 7-17cm	0.0547	1.0363	18.94516
Bt1 17-29	0.05911	0.7848	13.27694
Bt2 29-41	0.0473	0.5529	11.68922
Bt3 41-60	0.0378	0.3607	9.542328
BCt 60-80	0.04304	0.3738	8.684944
C 80-117	0.0349	0.1957	5.60745
Core 9			
A 0-4	0.79104	11.7936	14.90898
Bt 4-45cm	0.0771	0.5853	7.59144
C 45-54	0.0555	0.2885	5.198198
Core 10			
A 0-9	0.48339	8.5207	17.62697
Bw 9-20cm	0.0814	1.5497	19.03808
Core 11			
A 0-6	0.14543	2.396	16.47528
AB 6-15cm	0.07827	1.1358	14.51131
Bt1 15-29	0.0521	0.3321	6.37428
Btg1 29-44	0.05807	0.29231	5.033752
Btg2 44-60+	0.05191	0.1455	2.802928
Core 6			
Ap 0-39	0.2019	1.5345	7.600297
Bt1 39-65	0.02672	0.10416	3.898204
Bt2 65-98	0.02275	0	0
Bt3 98-150	0.02097	0	0
C 150-160	0.02983	0.08914	2.988267
Core 5			
Ap 0-10	0.24648	2.4085	9.771584
AB 10-38cm	0.06286	0.650197	10.34357
Bw 38-67	0.007146	0.08992	12.58326
Bg 67-80	0.00305	0.036376	11.92656
2Bg 80-107	0	0.03046	
2Cg 1 107-195	0	0	
2Cg2 195-228	0	0	
Core 7			
Ap 0-34	0.12753	1.2141	9.520113
Bw 34-82	0.06023	0.4284	7.112735
Bg 82-106	0.04743	0.2766	5.831752
Cg1 106-150	0.04496	0.24911	5.540703
Cg2 150-213	0.02962	0.09269	3.129305
Cg3 213-239	0.02604	0.057127	2.193817
Cg4 239-270	0.02432	0.04274	1.757401
Cg5 270-289	0.02312	0.03414	1.476644
Cg6 289-318	0.02864	0.06277	2.19169
Cg7 328-435	0.03553	0.14981	4.216437
Core 2			
Ap 20-40	0.0574	0.63123	10.99704
Ab 40-60	0.04712	0.54677	11.60378
60-80	0.03682	0.41056	11.15046
BC 80-100	0.0317	0.40045	12.63249
100-120	0.02115	0.291568	13.78572
ABb 120-140	0.01485	0.18947	12.75892
140-160	0.01025	0.13073	12.75415
160-180	0.00691	0.09219	13.34153
Bgb 180-200	0.007325	0.08636	11.78976
200-220	0.007512	0.10575	14.07748
220-240	0.010966	0.12915	11.77731
280-300	0.012291	0.1446	11.76471

Bank #2			
O.B. 0-13	0	0.18547	0
Ap 13-26	0.07591	1.4765	19.45067
AC 26-40	0.02023	0.46078	22.77706
BAb 40-54	0.02398	0.53934	22.49124
Bwb1 54-7	0.02137	0.43387	20.30276
Bwb2 73-8	0.03413	0.48332	14.16115
Bwb 87-11	0.07375	0.77981	10.57369
Ab 114-13	0.06351	0.77676	12.23051
Bwb 133-1	0.04686	0.63693	13.59219
C 153-172	0.007877	0.2451	31.11591
Ab 172-19	0.052798	0.6499	12.30918
Bwb 190-2	0.049718	0.5536	11.1348
C 227-250	0.008921	0.2361	26.46564
Ab 250-27	0.01146	0.2458	21.44852
Bwb 276-2	0.025678	0.3683	14.34302
Core 17			
A 0-13	0.21297	2.4241	11.38235
Bw1 13-33	0.08621	0.93736	10.87298
Bw2 33-52	0.03965	0.2152	5.427491
Bw3 52-68	0.03476	0.09854	2.834868
BC 68-79	0.03071	0.05567	1.812765
C 79-100	0.03171	0.06967	2.197099
Core 16			
A 0-8	0.2613	3.4038	13.02641
AB 8-16	0.151	1.9091	12.64305
Bw1 16-29	0.08184	1.0085	12.32283
Bw2 29-46	0.04647	0.43945	9.456639
BC 46-63	0.0287	0.11805	4.11324
C 63-82	0.0301	0.08865	2.945183
Core 15			
A 0-7	0.1296	2.1904	16.90123
Bw 7-13	0.05681	0.9174	16.14857
BC 13-19	0.03992	0.5614	14.06313
C 19-46	0.03192	0.3645	11.41917
Core 14			
A 0-4	0.4487	7.4375	16.57566
Bw4-8	0.04832	0.6675	13.81416
Core 13			
A 0-5	0.3067	4.8289	15.7447
BE 5-19	0.06665	0.6151	9.228807
Bt 19-31	0.0658	0.33797	5.136322
BC 31-43	0.05625	0.2172	3.861333
C 43-59	0.05232	0.1409	2.693043

VITA

Jason Dean Windingstad was born in Canby, Minnesota on June 19, 1975. He graduated from Dawson-Boyd High School in June 1994. He earned a Bachelor of Science in Geology and Environmental Sciences at Southwest Minnesota State University in December 2002. In the fall of 2003 Jason entered the University of Tennessee, Knoxville and in December 2005 received a Master of Science degree in Soil Science.

Mr. Windingstad is currently Employed at the Archaeological Research Laboratory at the University of Tennessee and is hoping to pursue a Doctorate in Geoarchaeology. He is a member of Gamma Sigma Delta, the Geological Society of America, and the Soil Science Society of America.

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