THESIS

FACTORS CONTROLLING SOIL SPATIAL VARIABILITY IN A NATIVE RANGE LANDSCAPE

Submitted by

Elias Paroussis

Agronomy

In partial fulfillment of the requirements

for the degree of Master of Science

Colorado State University

Fort Collins, Colorado

Summer, 1984

COLORADO STATE UNIVERSITY

Summer 1984

WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION

BY Elias Paroussis

ENTITLED Factors Controlling Soil Spatial Variability in a Native Range Landscape

BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF

Master of Science

Committee on Graduate Work

Joseph L. Weitz

Jan E. Cipra

Rob Heil

Adviser

W F Keim

Department Head

ABSTRACT

FACTORS CONTROLLING SOIL SPATIAL VARIABILITY IN A NATIVE RANGE LANDSCAPE

Soils were characterized along three transects of the same catenary sequence within the semi-arid shortgrass (Bouteloua gracilis) steppe of northcentral Colorado. The objectives of the study were to:

1. Evaluate which factor or combination of factors (i.e. parent material, topography, biota) is/are the most important controls on soil development, soil organic matter accumulation and soil textural attributes in this environment.

2. Evaluate the spatial variability of selected soil properties and relate this variability to geomorphic form and process.

The results indicate a high degree of spatial variability in all soil properties studied. Parent material, erosional (both wind and water) processes, and topographic relationships appear to be the major controlling factors on the degree of soil development, accumulation of soil organic matter, and distribution of particle sizes within the surface horizon of the soils found on the catena.

Evaluations of organic carbon, nitrogen and phosphorus, thickness of the surface horizon and solum, depth to lime and particle size data indicate that soil development on this landscape is highly atypical when compared to soil landscape relationships reported in the literature. Soil properties are highly variable within landscape segments as well as across the transects of the same landscape.

Elias Paroussis
Department of Agronomy
Colorado State University
Fort Collins, Colorado 80523
Summer,1984.

ACKNOWLEDGEMENTS

The author expresses sincere appreciation and gratitude to Professor Robert D. Heil for his assistance, guidance and encouragement throughout the preparation of this manuscript. Appreciation is also extended to Dr. Jan E. Cipra and Dr. Joseph L. Weitz for their review of the manuscript and their advice.

Thanks are due to the Soil Survey Staff in the Agronomy department especially, Caroline Yonker coordinator of this project, Debbie Kitt, Wayne Larsen and Kathryn Beaumont for their help during all phases of this research. Thanks are also extended to Doug Kirk and Ray Souther.

The assistance of Agronomy graduate students Gene Kelly, Richard Aguilar, Mark Walthall, Wayne Honeycutt and Burkhart Franz is gratefully acknowledged.

The author wishes to express his special thanks to the Food and Agricultural Organization of the United Nations for their great financial support and the opportunity to pursue advanced studies.

Sincere and deep thanks are extended to the author's parents. Last and the most the author owes deepest gratitude to his beloved wife Georgia, and his daughters Chrysoula and Stamatia, for their encouragment, help and patience throughout his graduate studies.

TABLE OF CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Several thousand years ago man recognized the soil resource as critical to the sustenance of plant growth and nutrition (Aristotle 384-322 B.C., Theophrastus 372-287 B.C.). Heraclitus (535-475 B.C.) stated "everything changes," which suggests change must be recognized. Without exception, the dynamics of the soil resource must be understood in order to sustain and improve its ability to produce food and fiber.

Understanding the developmental history of soil, the properties which characterize it, the relationships among these properties, and how these properties are affected by external factors is prerequisite to preserving its usefulness for the future and thereby satisfying the needs of society.

Cultivation and grazing modify the direction of soil formation and raise many questions as to the degree of soil property alteration and the effect of these changes on soil productivity. The answer to these questions requires an understanding of the processes involved in these changes and the factors which affect these processes. To make reliable interpretations of the nature and significance of changes in soil properties, the physical, chemical and biological processes controlling the soil system must be understood. It is also important to study and understand how soils occur in relation to each other. Thus, our objectives were to:

(1) evaluate which factor or combination of factors (i.e. parent

material, topography, biota, is/are the most important controls on soil development, soil organic matter accumulation and soil textural attributes in this environment.

(2) evaluate the spatial variability of selected soil properties and relate this variability to geomorphic form and process.

The literature reports that there are some systematic patterns of soil property distribution on a landscape. Knowing the relationships which exist on a given hillslope provides an understanding of the occurrence and distribution of soil properties. For this reason the study area was selected on relatively undisturbed and uncultivated soils. Many studies that have been carried out in the region in the past have not found any strong relationships between different soil characteristics and other ecosystem components, more specifically vegetation. There appeared to be evidence that the reason for lack of clear relationships between soils and vegetation was due to factors outlined in the objectives of this study.

LITERATURE REVIEW

Soil Forming Factors

Jenny (1941) stated that soil forming processes are controlled by a set of external factors and described the relationships as follows:

Soil = f(climate, parent material, organisms, relief and time). This expression indicates that one or a combination of factors may be responsible for controlling soil development in a given environment. The expression also suggests that a change in any one factor will affect the influence that other factors have on soil development. In addition, the expression implies that the degree of influence of any one combination of factors varies from environment to environment, thus giving rise to many different soils with many different properties. The influence of these factors is reflected primarily in their control of the physical, chemical and biological processes which take place in soil development. Thus, an understanding of the interrelationships between soil forming factors and processes is basic to understanding how soils with given properties develop, the spatial relationship among soils and the behavioral characteristics of soils. Consistent with the objectives of this study, this literature review is a general discussion of some important interrelationships between soil forming factors and processes and how soils have been studied to better understand these interrelationships.

Many workers have studied the five recognized factors of soil formation. Climate is often considered as the major active factor affecting soil forming processes. Climatic agents such as water and wind can act to break down, erode and transport materials, and shape the landscape thus creating variability in environments of soil formation. Climate influences hydration processes, swelling and frost action, and other physical processes which mechanically break down mineral constituents of soil, as described by Wahrhaftig (1965), Eggler et al. (1969), Twidale (1968b). Effects of freezing and thawing on soil formation have been described by Russel (1943), and Williams (1964). Mass movements due to oversaturation and consequent instability of soil and geological material has been described by Carson and Kirkby (1978) and Young et al. (1969). With respect to rainfall, Rose (1961), Bennet (1939) and Chepil (1954) discussed aggregate breakdown in relation to rainfall erosivity, and Neal (1938) and Wischmeier (1966) studied runoff effects of intensive rainfall. The importance of climate to erosion is reflected in the erosion estimation index as developed by Smith and Wischmeier (1961,1962,1965). Climate also influences sediment deposition as a function of fluvial processes as reported by Happ et al. (1940), Lattman (1960), and Howard et al. (1968). The climatic factor wind has been discussed thouroughly with respect to erosion by Bagnold (1941) and Chepil and Woodruff (1963). In addition, the importance of particle movement by wind was estimated by Bagnold (1941), Kuenen (1960) and Sharp (1963).

Jenny (1980) has provided one of the most recent comprehensive reviews of the importance of climate on the chemical and biological processes which take place in soils. The literature pertaining to climate as a soil forming factor is voluminous and what has been presented here is only a brief discussion to demonstrate its importance.

Parent material is the principal control on soil development in many environments. Attributes of parent material influence such soil properties as inherent fertility, soil permeability and water holding capacity, and is the primary determinant of particle size distribution in the developing soil. Thompson, et al. (1982) studied parent material stratification and its influence on soils. Zardelman, Busrgina, Narokova, Shtinoc (1981) tested and demonstrated the effect of different parent materials on the gleying process. Distribution of parent minerals in different particle size fractions was studied by Chittleborough and Oades (1980) and Rabenhorst, et al. (1982). Parent material has been described by Jenny (1980) and others as a passive factor in soil formation. The literature clearly describes its influence on erosion, plant growth and many other processes and factors important to soil development, and must be considered in the study of soils.

The effect of topography on soil development is mainly due to modification of the microclimate. This results in the modification of erosional processes as well as weathering forces. Topography interacting with climate is effective by its steepness, aspect, length and shapes. Workers dealing with these characteristics include Weischmeier (1966), Zingg (1940), Kramer et al. (1969) and Bennet (1955). The importance of relief is discussed more in later parts of the literature review.

Organisms, including vegetation and microorganisms directly influence the chemical environment in soil formation. In addition, vegetation plays a protective role in reducing erosion and redistribution of soil material by wind and water. Beasley (1970) is one of the many workers who have studied the impact of vegetation on erosion.

Changes brought about by climate, topography and organisms acting on a deposit of parent material are carried out through time. Aspects of time as a factor of soil formation have been discussed by such authors as Bockheim (1979) and Haidouti and Yassoglou (1982). Soil chronosequences have proven to be very useful in studying the changes in soil development through time. Although it is important to study and understand the influence that any one factor (climate, parent material, relief, organisms and time) has on soil development, it is more important to understand the interrelationships among these factors, and how these interrelationships vary across landscapes.

In order to study these interrelationships for meeting the objectives of this reaserch a design for sampling the landscape had to be established. Many soil scientists, geologists and geomorphologists have tried to describe, define, and consequently name what they thought to be the elements of the landscape. Wood (1942) and many other scientists, such as Ruhe (1960,1969a,1969b), Dan et al.(1964), stated that the landscape consists of five elements which can be delineated on the basis of discordance in gradient. Those five soil landscape components are defined as the **summit**, **shoulder**, **backslope**, **footslope** and **toeslope**. Beginning with the summit, they are respectively defined as 1) the nearly level top of a hill with limited runon, runoff, 2) the convexly rounded component between the summit and the backslope, 3) the linear part of the hillslope, 4) the concave component that welds the backslope to the lower terrain, and it is in part erosional and in part depositional and 5) that component located away from the base of the hillslope which is commonly formed from depositional debris. It is not necessary for the five slope profile components to occur on every hillslope, as one or more can be missing or be present as a minor part.

These five soil-landscape elements are widely used to describe hillslopes of both closed and open systems. These two systems differ in a number of respects (Ruhe and Walker 1968). The hillslopes of closed systems are areas of enclosed drainage in which the products of superficial erosion remain within the system, usually at the toeslope position so that the record of superficial erosion is complete. The hillslopes of open systems are joined to an integrated drainage net by an alluvial channel. They represent a freely sculptured landscape from which an amount of superficial sediment passes to the more general stream system.

A framework for studying the interrelation of geomorphic and pedologic processes in soil development is provided by the hillslope model. Soil and soil properties are found to be continuous variables on the landscape. Buol et al. (1973) pointed out that specific statements about the relationships of slope to soil properties can be made only within specific geographic areas. This is probably due to variations in intensity and nature of the other soil forming factors. Within specific geographic regions, the following soil properties are commonly found to be relief related: (1) depth of the solum; (2) thickness and organic matter content of the solum; (3) relative wetness of the profile; (4) color of the profile; and (5) degree of horizon differentiation. Associated with differences in these properties are differences in chemical, physical and biological properties.

Concepts of soil development in relation to upland slopes suggest the the most highly weathered soils should exist on the highest, least sloping, and most stable land surfaces, whereas less strongly weathered soils should occur where surface drainage increases on more steeply sloping, younger surfaces formed by slope retreat. Norton and Smith (1930) found that the solum thickness and depth to carbonate decrease as slope gradient increases. They conclude that the steeper slopes result in less infiltration and more runoff, thus giving a drier site and less soil development per unit of time.

The degree of development was shown by Ruhe (1956) to be greater on the stable divides of the uplands than soils on the flanks or interfluves. He recognized a greater intensity of mineralogical weathering, or greater amount of clay accumulation, in the B horizon, and a thicker B horizon in these soils than on more sloping upland soils closely associated with stable divides. He related the observed differences among these soils to differences in erosion and land surface age.

A decrease in profile development on the steeper slopes was found by Cunningham and Drew (1962) suggesting a correlation between soil development and landscape position. They also concluded that the differences in mineralogy within these soils are due to the differences in age and source of parent materials from which these soils were formed.

Gamble et al. (1970), describing soils on interstream divides, found them to have a sola nearly three meters thick, with thick A2 horizons resulting from extensive clay translocation and destruction, but that the soils on the sideslope had a sola less than a meter thick and a thin A2 horizon. This relationship was also observed by the same workers (1970) between geomorphic surfaces and soils in the Black Creek Valley of North Carolina. Authors of this study concluded that these differences are a function of the age of the surface on which these soils occur.

Ruhe and Scholtes (1955) pointed out that soil landscapes are subjected to cyclic erosion and stability. The divides remain largely unaffected except through encroachment of slopes at the margins and through continued weathering of the soil already in place. If this weathering continues, it may result in decomposition of all minerals except those that are most resistant to weathering. They added that the flanks or interfluves are branched by erosion so that shoulder soils are completely removed, while soils on the divides remain stable and continue to weather.

Malo et al. (1974), studying soil landscape relationships in a closed drainage system developed in a glacial till plain of North Dakota, concluded that soil properties were continuous variables on the landscape. Maximum erosional activity at the shoulder position was reflected in coarser textured material while fine textured material accumulated at the lower landscape position. Sorting of particles resulted in a uniformity of material at the lower landscape position. The textural variations encountered in the profiles can be attributed more to erosional and sedimentational activity present on the hillslope than pedologic activity. The degree to which geologic processes of erosion and sedimentation affect the soils and their properties depend on landscape position.

Kleiss (1970) stated that hillslope sedimentary processes affect particle size and influence the quantity of organic material that has accumulated at various slope elevations. He found that the depth to less than 1% organic carbon decreases from the summit to the relatively unstable shoulder, while across the concave backslope, footslope, and toeslope, the depth of accumulations increases. In accordance with changes in particle size and organic carbon at various geomorphic positions, bulk density values of the surface horizons behaved similarly with the exception of an abrupt decrease in the lower slope positions in response to greater amounts of organic matter and finer texture.

Levels of OM and N vary along hillslopes. C and N accumulations are a function of either movement downslope or in situ fixation, thus it is often difficult to determine the exact reason for their accumulations. Ridgetops or slopes have lower levels of N and OM than the lowerslopes, although Barnes and Harrison (1983) suggest a reverse pattern for the sandhills. Aandahl (1984) reported a decrease at the midslope, followed by an increase and then a decrease at the toeslope.

Phosphorus is a more conservative indicator of soil formation than C or N because it has no gaseous pathway. Distribution of P was used by Smeck (1973) as an indicator of processes of movement between soils and within a profile. These movements of P are similar to that of fine textured material, thus their distribution along the landscape could be highly correlated with that of the erodible fine fraction.

Erosional processes that cause deposition of clays may lead to accumulation of phosphorus (Dong et al. 1983). That clay sized particles are richer in P than the bulk soil has been supported by the work of Sharpley (1980) and Dong et al. (1983). The redistribution of P and fine clays along hillslopes would be expected to influence the in situ turnover and steady state levels of C and N. The interaction of P with C and N accumulation was reviewed by Cole and Heil (1981). They state that although there are close linkages between nitrogen and phosphorus transformations in terrestrial ecosystems, the data do not yet enable firm conclusions about the cause and effect relationships to be made.

In summary, the literature supports what Jenny (1980) has proposed by the equation s = f(climate, parent material, relief, organisms, time), that is, soil forming factors are highly interrelated and the properties of soils at a particular site on a landscape represent the influence of the combined effects of these factors. And the relative importance of one or a combination of factors varies from site to site as a function of a change in any one of the factors. It was this background which provided the framework for this study.

GENERAL DESCRIPTION OF THE RESEARCH SITE

Location

The research area is located at the USDA-ARS Central Plains Experimental Range (CPER), which is part of the Pawnee National Grassland. The study site is approximately 80 miles northeast of Denver, Colorado, 38 miles northeast of Fort Collins, Colorado and 25 miles southeast of Cheyenne, Wyoming.

The soil landscape system investigated is located in the $E\frac{1}{2}$, $NW\frac{1}{2}$ Sec 29, T10N, R65W in Weld County, Colorado (Figure 1). Three transects were established on the native range landscape, which was selected to provide uniformity in topography, climate, parent material and vegetative cover.

Physiography

The research site lies within the Colorado Piedmont physiographic section of the Great Plains Physiographic Province. Elevation ranges from 4,500 feet (1,372 m) to 5,500 feet (1,677 m). The topography is gently rolling with a few prominent topographic features (Fenneman and Johnson, 1946; Jameson, 1969; Rasmussen et al. 1971).

History

The Central Great Plains area in which the research site is located respresents a classic example of how unsuitable land use practices play a main role in subjecting the soil to erosion and its subsequent serious economic consequences.

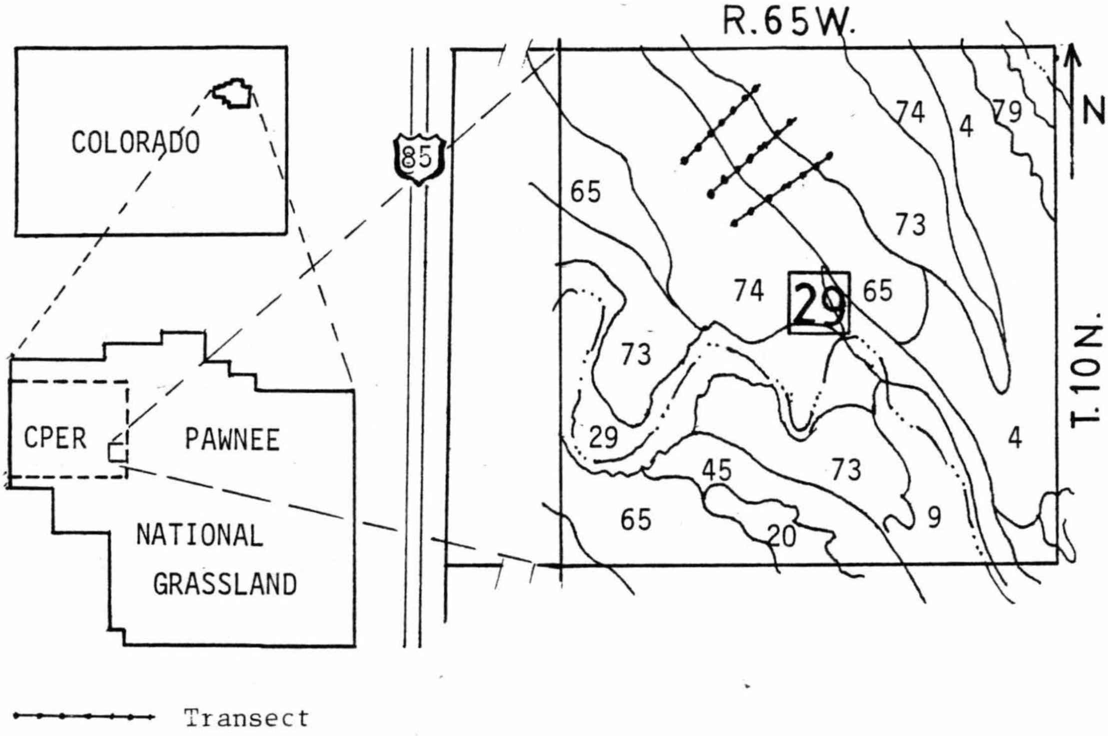

Figure 1: Topographic map of the study area.

First, the Central Great Plains region was used agriculturally for livestock grazing on the open range. Later, homesteading under quarter-section and half-section allocations brought about 90% of the land under private ownership.

The settlers from the east, accustomed to better rainfall conditions, plowed the prairie and planted wheat to the detriment of both soil and man, because although sometimes there would be good rains and good crops, there were numerous periods of drought years which would bring crop failure and dust storms. The disastrous outcome of such bad land use was the dust bowl, which occurred during the agricultural depression period from 1921 to 1939, (Hudson, 1971).

During the dust bowl years, many small farming units were forced to abandon their operations because of continuing dry years and high winds. The soil was moving from fields into fences and around buildings. Rains came in torrential downpours, washing away more unprotected soils. Therefore, land utilization projects were established as management units for this abandoned land.

These land utilization projects were first administered by the Soil Conservation Service of the USDA until the Agricultural Reorganization Act of 1953. Since that time the land has been administered by the U.S. Forest Service. The Pawnee National Grassland is therefore made up of the abandoned portions of these lands which are interspersed with private lands. At the present time, private and federal lands are frequently operated together and used for grazing by a local livestock association made up of many small ranchers in the area (Jameson, 1969).

Climate

The research site has a semi-arid continental climate. However, according to the traditional nomenclature, it would be classified as having a cool steppe climate. The Rocky Mountains, which are a very large north-south mountain range whose eastern extremity is located about 30 miles west of the research site, have probably the greatest influence on the climate of the region.

The Rocky Mountain Range is oriented perpendicular to the prevailing wind flow, causing orographic precipitation on the western slope and leaving only relatively dry air flowing down its eastern and over the grasslands. This leaves the Gulf of Mexico, which is located 1,000 miles to the southeast, to be the principal source of moisture in the region (Rasmussen et al. 1971).

Precipitation is perhaps the single most important climatic element associated with the grassland ecosystem. The annual precipitation at the CPER in the time period between 1960 and 1980 averaged 33.6 cm per year and varied between 9 cm and 65 cm. Almost 75% of the annual precipitation falls during the principal growing season of May through September. Although most of the storms are light summer thunderstorms, the greatest fluctuations in precipitation are caused by storms greater than 3 cm. Figure 2 represents the average seasonal distribution of precipitation on the research site from 1960 to 1980. Precipitation variability both within the year (summer vs. winter), and from year to year for each month is probably the most outstanding characteristic of the grassland climate. The dryness of the winter is emphasized by the fact that average total precipitation for December, January and February accounts for about 5%

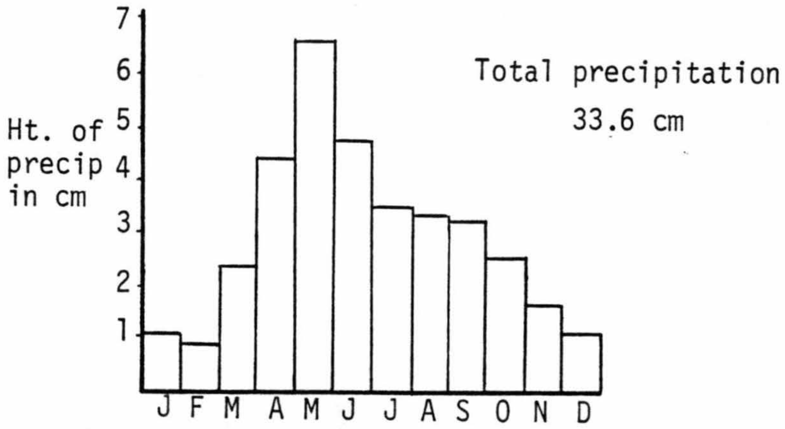

Figure 2: Mean annual precipitation (1960-1980).

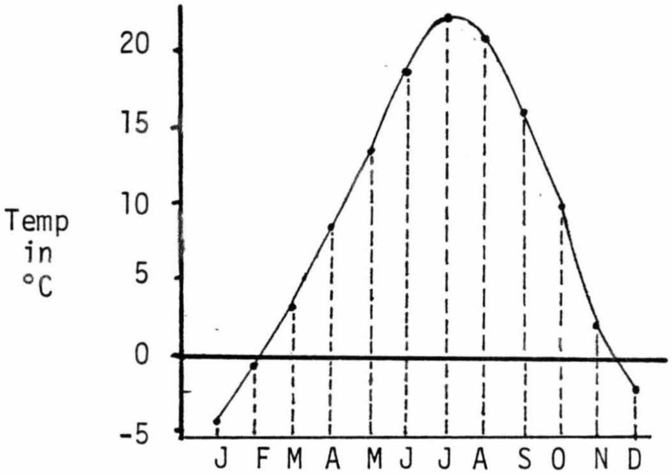

Figure 3: Mean annual temperature (1960-1980).

of the total average annual precipitation. The wet summer months of June, July and August produce approximately 48% of the total average annual precipitation. Snowfall usually makes a small contribution to the total annual precipitation, however, its variability can have a major effect depending to a great extent on when the snow occurs, its water equivalent, and its destiny (Jameson, 1969); (Smith and Striffler, 1969); (Bertolin and Rasmussen, 1969), (Rasmussen et al. 1971). Figure 3 shows the mean annual temperature for the same period 1960 to 1980.

Native vegetation

The native vegetation of the CPER site is dominated by blue grama grass (Bouteloua gracilis), and buffalo grass (Buchloe dactyloides), substituted in many areas by needle leaf sedge (Care eleocharis), and thread leaf sedge (Carex filifolia). There are many midgrasses, such as western wheat grass (Agropyron smithii), needlethread grasses (Stipa comata), little bluestem (Andropogon scoparius), side-oat grama (Bouteloua curtipendula); and tall grasses such as big bluestem (Andropogon gerardi), and prairie sandreed (Calamovilfa longifolia) that grow in association with the shortgrasses. Forbs includes Russian thistle (Salsola kali tenuifolia), Lambsquarter (chenopodium spp), scarlet globemallow (sphaer alcea coccinea), and slim flower scurpea (Psoralea teniflora). The major browse species on the area are fringed sagewort (Artemisia frigida), saltbush (Antiplex canescens), and winterfort (Eurotia lanata). Plains prickly pear (Opuntia polyacantha) is widely distributed in the area (Klipple and Costello, 1960).

Land Management

Four different grazing treatments were established on the site in 1939 for evaluating effects of long-term grazing. The four grazing treatments are heavy, moderate, light and non grazing, the latter provided for by an exclosure area of 2.5 acres which is used as control. The light, moderate, and heavy grazing treatments are based on the percent weight utilization of the current herbage growth of the major forage species, as determined by the end of the six-month grazing season (from May to October). For the heavy use grazing treatment, approximately 60% of the forage is utilized. For the moderate use, approximately 48% of the forage is utilized, while for the light use only about 20% of the forage is utilized. An estimation was made of the forage remaining at the end of the grazing season. These are 200, 300 and 400 lb. (90,136,181Kg) per acre for the heavy, moderate and light grazing treatments, respectively, (Smith and Striffler,1969). The research site lies within the moderate grazing treatment acreage.

Hydrology

The CPER area is almost an original catchment basin, most of the water available in the area comes directly from precipitation (Rasmussen et al. 1971). The research site has the characteristics of grasslands hydrology, which is the absence of stream flow. However, in order to evaluate the behavior of water, and soil-water balance of the ecosystems, eight microwatersheds (artificially bounded less than five acre area where only overland flow occurs) were installed in different locations (Smith and Striffler, 1969). Data for these microwatersheds describe the hydrological nature of the area as of the closed hillslope and flat plain systems.

Runoff events take place by storms with enough intensities to exceed the infiltration rate of the soil. In 1970 one runoff event took place in the research area, whereas in 1971 no significant runoff event occurred (Striffler, 1971, 1972).

Soils

According to the published soil map (Soil survey of Weld County) of the research site, the soils occuring on the research site belong to the Vona and Terry series. These series characterize soils that are moderately deep, well drained on moderately or highly dissected plains. Vona was formed in calcareous, sandy, alluvial and eolian material. Terry was formed in a calcareous sandy residuum derived from sandstone. These soils are coarse-loamy mixed, mesic Ustollic Haplargids. The surface layer is brown, sandy loam 6 inches (15 cm) thick. The subsoil is sandy loam 9 inches (23 cm) thick. The substratum to a depth of 60 inches (150 cm) or more is loamy sand, and in some areas the surface layer is loamy sand, too. Permeability of the Vona soil is moderately rapid. Available water capacity is moderate. Effective rooting depth is 60 inches (150 cm) or more. Runoff is slow, and the hazard of the water erosion is moderate. Soil blowing hazard is moderate. The Terry series is characterized by having a grayish brown sandy loam surface which is 5 inches (12.5 cm) thick. The subsoil is sandy loam, 12 inches (30 cm) thick. The substratum is calcareous loamy sand, 15 inches (38 cm) thick. Average depth to sandstond is 32 inches (81 cm). Depth to sandstone ranges from 20 to 40 inches (51 to 102 cm). Permeability of the Terry soil is moderately rapid. Available water capacity is moderate. Effective rooting is 20 to 40 inches (51 to 102 cm). Runoff is slow, and the hazard of erosion is moderate to high. The hazard of soil blowing is moderate. The soil at the research site is formed predominantly in fluvial outwash materials. The outwash material consists primarily of granitic sediments in which microcline is the predominant feldspar. Another partially weathered euhedral strongly-zoned alkali feldspar appears to decrease with soil depth and thus appears to be a later deposition. A relatively minor amount of volcanic glass, which also decreases with soil depth is associated with the outwash material. The euhedral zoned feldspar and volcanic glass might be part of an ashfall covering the area.

A comparatively recent wind-deposited material appears to have covered the soils at the research site. This deposition consists mainly of outwash material, but contains semirounded, iron-stained shale and siltsone fragments which indicates a mixing of the parent materials (Franklin, 1969), (Reuss, 1971).

FIELD AND LABORATORY METHODS

Field Methods

Research Layout

Three transects were laid out on the same catena based on uniformity in relief, aspect, parent material and vegetation (see figure 4). Transect 1-21 was predominantly covered by blue grama grass (Bouteloua gracilis), while the other two transects were mostly covered with blue gramma grass, with part of the 1-23 transect covered by needlethread grasses (Stipa comata) and part of the 1-22 transect was covered by a mixture of the two grasses. These transects have been labeled as shown because this data is part of a larger soils data base for the CPER. It was felt these transects should retain that labeling in order to identify these data with a large data base.

The catena was divided into five classical landscape components, namely, summit(SU), shoulder(SH), backslope(BS), footslope(FS), and toeslope(TS). The backslope appeared to be very long, thus it was necessary to break it in three zones, namely, upper backslope(UBS), middle backslope(MBS) and lower backslope(LBS). This was done to better detect the changes occurring along this part of the catenary sequence. A total of twenty one sites were described and sampled within the study area. The first step was to define, stake, and label every sampling site. Then the site was related to the map of the area.

At each site a surface description was completed including landform, position, type of the landform, shape, parent rock, parent

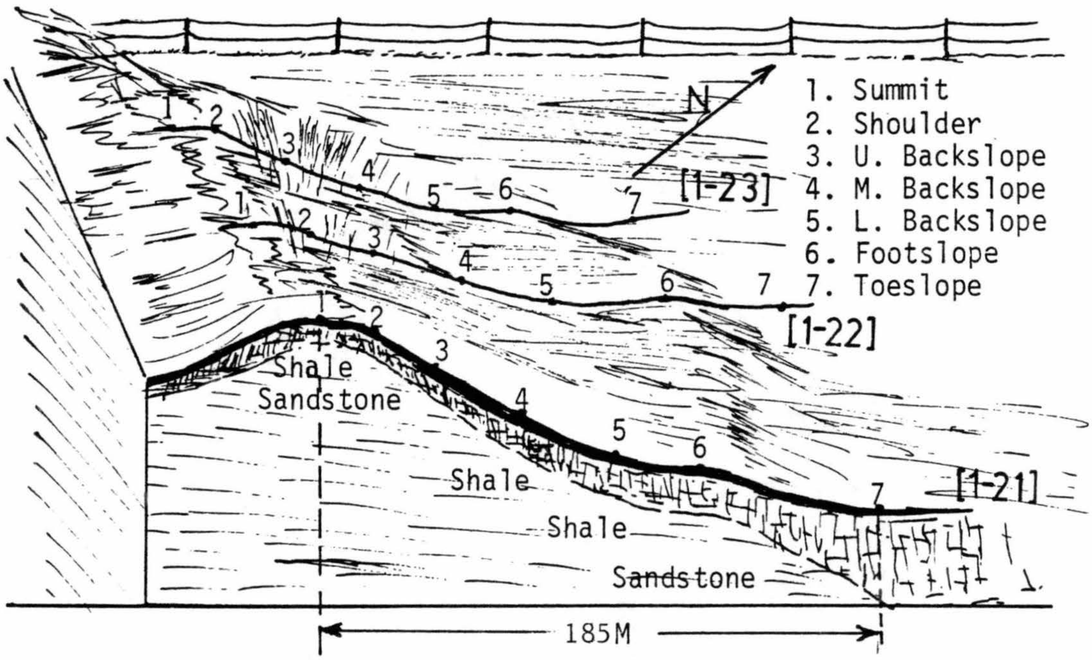

Figure 4: Layout and component description of the three transects.

material source, subsolum lithology, relative estimation of erosion, and vegetation (canopy cover) within a radius of 3 m around the located center (stake) of the site.

Field Sampling Procedure

Undisturbed soil cores were taken at each site using a hydraulic power probe mounted on a pick-up truck. At each site, four cores were collected. The first core in the center of the selected area was used for a complete field description (profile description). Another core at a distance of 20 cm was sampled for laboratory analysis. Two more cores were taken at the same elevation on the catena sites, right and left of the main core at a distance of about 2 meters, and their morphological properties were described. These observations were used to determine variability at a site. The depth of sampling was approximately 120 cm at most sites but did vary due to the presence of bedrock. Every undisturbed soil core represented a soil profile of the sampling site, which is a vertical cross section of the soil from the surface down into the parent material.

Profile Description

The soil profiles were described according to standard procedures followed by the Soil Conservation Service in the National Cooperative Soil Survey Program. The description of a soil profile consisted mainly of indentifying and characterizing the soil horizons (Soil Survey Staff, 1975). Each soil profile was described by identifying and characterizing the genetic horizons, the parent material or the other layer beneath the solum that influence the genesis and behavior of the soil.

The observations on the two additional cores at each site included the depth of the A horizon, depth of solum and depth to the carbonates. Although differentiation of soil horizons was done mainly on the basis of characteristics that could be seen in the field, a few alterations were necessary in the designation and identification of the soil horizons based on the outcome of the laboratory data. After the soil horizons were described, a soil sample was taken for each horizon. All soil samples were placed in heavy plastic bags, labeled, dried in an oven at 75 degrees C. until steady weight was obtained and stored until ready for analysis.

Laboratory Methods

The soil samples used for physical and chemical analysis were ground and sieved through a 2 mm mesh stainless steel screen

Soil moisture content was determined gravimetrically, according to the method described by Gardner (1965).

Particle size analysis was conducted using the hydrometer Bouyucous method with minor modifications as described by Day (1965), and Danielson (1978).

For all surface horizons an air-dried sand sieving was carried out using 14, 18, 25, 35, 45, 60, 80, 120, 170, 230, and 325 mesh size sieves. This corresponds to 2 mm to .45 mm diameter range of soil particles.

OC was determined by wet oxidation/diffusion developed and used by the Natural Resource Ecological Laboratory of Colorado State University. The method was developed by J.D. Snyder and J.A. Trofymow. It is a fast method and has compared well with the method of Dumas. (This is an unpublished method).

With this method there were the advantages of having less interference of Cl^- and no interference at all of Fe^2 and MnO_2. This procedure utilizes a NaOH, CO_2 trap, and is titrated with $BaCl_2$.

Nitrogen was determined by the Kjeldahl method (Keeney and Bremner, 1967).

Organic and total phosphorus was determined on ignition according to (Saunders and Williams, 1955) as modified by Walter and Adams (1958).

Statistical Analysis

Two way analysis of variance tests were applied for each of the morphological characteristics in the soils occurring on each transect to estimate the significance of relief on a given soil property. Also evaluated was the existence of patterns by which the characteristics result, as influenced by factors of soil formation.

The contribution by components of analysis of variance (catenary influence, component, interactions of the catena-component affect, and within the site) to the total variability in each morphological characteristic was evaluated.

To detect extreme values of the morphological characteristics tested, the Bonferoni test for outliers was employed.

Cluster analysis wsa applied to group pedons with similar characteristics using BMDP (Engelman and Fu, 1975).

Multiple regression analyses were then carried out to establish models which would predict the existing groups (clusters, catenary components) based on the soil morphological characteristics observed along the catenary sequence.

The distribution of the various sand fractions was evaluated with the use of statistical methods developed by Folk (1974) to estimate the degree of sorting and the frequency of occurrence of the sand fractions. These analyses were carried out using the Sedimentary Petrology Computer Program SEDPET (Werner, 1970).

RESULTS AND DISCUSSION

The three transects studied on the native landscape were selected on a hillslope at the Central Plane Experimental Range, which is located about 30 miles northeast of Fort Collins, Colorado.

To meet the objectives of this study a hillslope was selected on which the effects of the different soil forming factors could be studied. The three transects were selected on the same hillslope with the same topography, parent material and aspect. There was a slight difference in vegetative cover.

More specifically, the vegetative cover consisted of species of blue grama grass (Bouteloua gracilis) on transect 1-21, in the higher components SU and SH of the 1-22 and 1-23 and their lower components ie, LBS, FS and TS. The UBS and the MBS of the transect 1-23 is covered by needlethread grasses (Stipa comata), while the same area of the 1-22 transect is covered with a mixture of both the above grasses.

The results and discussion will be presented in four parts. The first part will describe the morphological characteristics within a landscape segment and across the catena sequence. The second part will describe the particle size distribution of soils within a landscape segment and across all transects along the catenary sequence. The third part will describe the chemical properties of carbon, nitrogen, organic phosphorus, inorganic phosphorus and total phosphorus levels within and among the three transects. The fourth part deals with the relationship among factors controlling soil characteristics within and across the catenary sequence.

MORPHOLOGICAL CHARACTERISTICS

The selected morphological properties to be evaluated are:

A horizon

B horizon

depth of the Solum

ratio of the solum over the A horizon and

depth to lime.

A horizons

The data that describe the A horizon of the soils studied are given in (Table 1) and graphically are represented in (figure 5). The expected relationship , relative to the thickness of the A horizon at the SU, was a decrease in thickness at the SH and then an increase progressing downslope. increasing along the lower components of the catenary sequence. However the general relationship as shown in (figure 5) does not follow this pattern. There is a decrease of the A horizon thickness at the SH as expected but then a relative increase at the UBS. The MBS does not show a similar change. On transect 1-21, the thickness increases but on transects 1-22 and 1-23 it decreases. At the LBS there is a dramatic decrease rather than an increase, with a continued decrease at the FS. There is no change from the FS to the TS.

A detailed analysis of the A horizon thickness indicates that: (1) on transect 1-21, the average SU A horizon thickness is 8.33 cm; There is an increase of 16%, 17%, 32%, a decrease of 60%, 40%, and an

TABLE 1: Thickness of the A horizon,means and standard deviations for the three transects.

COMPO- NENTS	OBSERV. IN CM. 1	2	3	MEAN	S-D
Transect 1-21					
SU	8	8	9	8.33	.58
SH	11	9	9	9.67	1.16
UBS	12	11	11	11.33	.58
MBS	14	20	16	16.67	3.06
LBS	6	8	6	6.67	1.16
FS	6	3	3	4.00	1.73
TS	7	7	6	6.67	0.58
Transect 1-22					
SU	10	13	6	9.67	3.51
SH	10	9	11	10.00	1.00
UBS	10	13	11	11.33	1.53
MBS	5	5	9	6.33	2.31
LBS	5	4	4	4.33	.57
FS	3	2	4	3.00	1.00
TS	3	3	5	3.67	1.16
Transect 1-23					
SU	15	9	10	11.33	3.22
SH	2	5	5	4.00	1.74
UBS	6	12	7	8.33	3.22
MBS	6	6	6	6.00	.00
LBS	6	6	6	6.00	.00
FS	5	5	6	5.33	.58
TS	3	5	6	4.67	1.53

COMPONENT	MEAN	S-D
	9.77	2.73
	7.88	3.14
	10.33	2.34
	9.67	5.59
	5.67	1.22
	4.11	1.45
	5.00	1.65

TRANSECT	MEAN	S-D
1-21	9.05	4.09
1-22	6.90	3.58
1-23	6.50	2.89

TOTAL	MEAN	S-D
	7.49	3.67

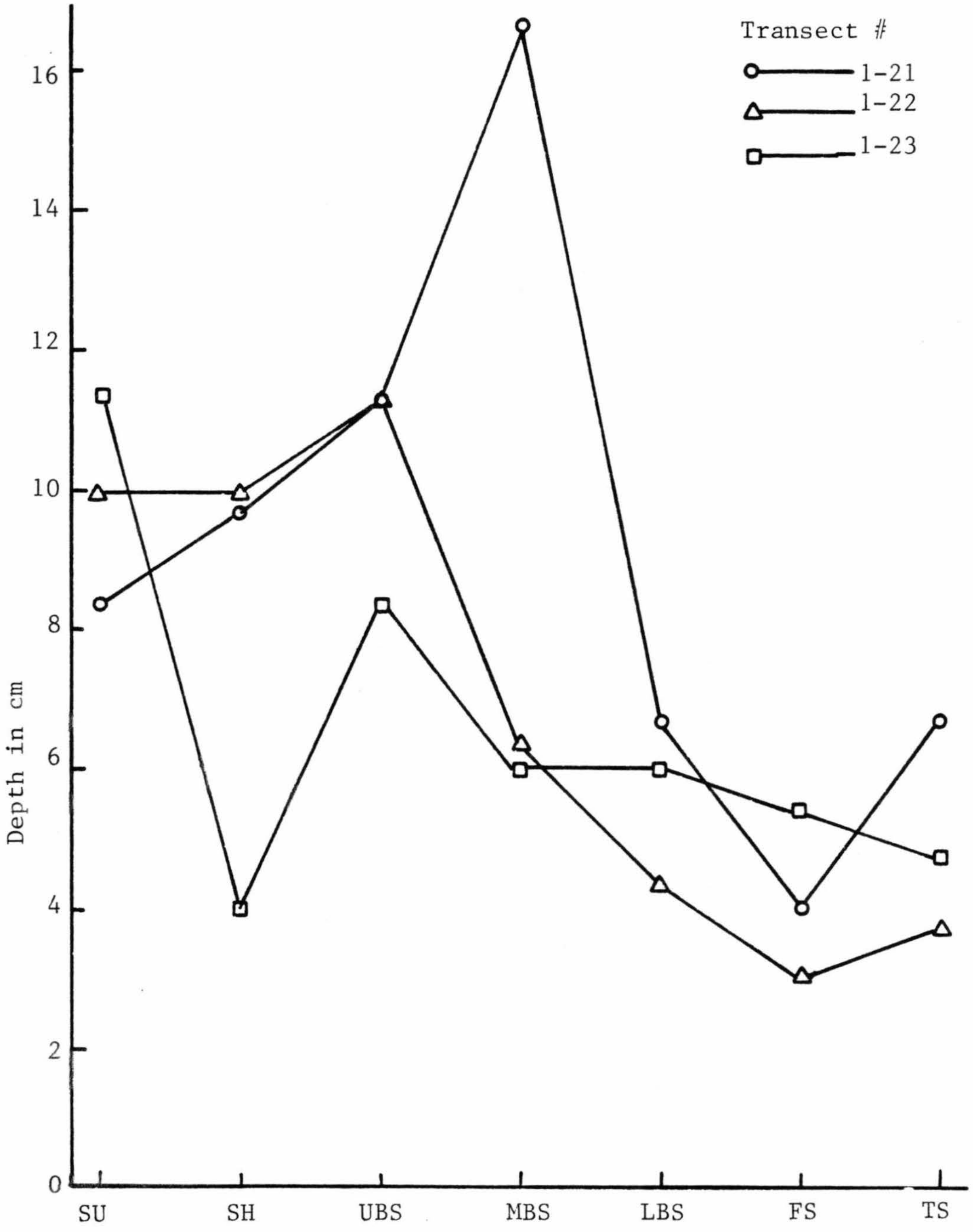

Figure 5: Thickness of the A horizons along the three transects of the catenary sequence.

increase of 67% respectively at the SU, UBS, MBS, LBS, FS and TS. The A horizon thickness ranges from 3 to 20 cm at the FS and the MBS respectively.

A similar pattern occurs along transect 1-22. There is an increase of 3%, 13%, a decrease of 44%, 32%, 31%, and then an increase of 22%, at the SH, UBS, MBS, LBS, FS, and TS respectively. The A horizon thickness on this transect ranges from 2 to 13 cm at the FS and UBS respectively.

On transect 1-23 the pattern changes even more. The average A horizon thickness at the SU is greater as compared to the SU of the other (17% increase vs. transect 1-22 and a 36% increase vs. transect 1-21). However there is a large decrease in thickness (65%) at the SH vs. the SU and then an increase by (108%) in the UBS vs. the SH. The rest of the components of this transect show a relatively uniform A horizon thickness from 5 to 6 cm. The A horizon thickness on this transect ranges between 2 and 15 cm at the SH and the SU respectively.

There appear to be two main factors affecting the thickness of the A horizon: 1) the parent material by its resistance or its susceptibility to erosion and 2) wind or water erosion processes as controlled by the parent material.

The parent material is sandier textured on the higher components of the catenary sequence and more fine textured at the lower components. This appears to have reduced runoff from and the effects of water erosion on the upper portions of the landscape. This could explain the shallower A horizon on the lower slopes. However, the very thin A horizon at the lower components of the catenary sequence also could be explained by probable greater water erosion on the finer textured parent material and may not be locally influenced.

Wind action on the catena also explains the pattern found. The relatively thick A horizon at the SU and the SH could be explained by wind deposition. Wind activity effects from the lower components by the wind must be considered. Saltation by swirling currents may pick up fine soil particles (very fine sand and silt) from the lower components and deposit them at the higher slopes. It appears that wind activity may be the dominant factor controlling the thickness of A horizons on this landscape.

A two way analysis of variance was performed and the variability of the means of the three transects, the seven components, the interactions of the transects and the component influence as well as the variability of the sites was estimated.

The results, as shown on Table 2, indicate the interaction of the transect and component effect to be significant. The significance of the interactions indicate a very low probability for a consistent kind of pattern. Irregularities exist, not only due to topographic influence on the landscape components, but similar components of the catenary sequence will differ significantly as well. Since the interactions are significant, it is not appropriate to go any further in the analysis. The non significance of the other components may be due to the fact that large differences in values may cancel each other and the true transect or component effect may not be shown.

The variability σ^2 (x=transect,component,interactions,sites) was found to be .053 due to the transect influence, .276 due to the

TABLE 2: Analysis of variance for the A horizon thickness for the three transects.

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARE	F	PROB	F(table) D.F. LEVEL	
MEAN	1	3536.254	3536.2540				
CATENA	2	77.746	38.8730	1.71	.2230	(2-12 .05)	3.89
COMPONENT	6	352.413	58.7354	2.58	.0769	(6-12 .05)	3.00
INTERACT	12	273.587	22.7989	7.25	.0000	(12-42 .05)	1.99
SITES	42	132.000	3.1429				

ESTIMATES OF VARIANCE COMPONENTS		
(1)	54.94356	
(2)	.76543	.053
(3)	3.99295	.276
(4)	6.55203	.454
(5)	3.14286	.217

component influence, .454 due to the interactions of the transect-component influence, and .217 due to the site effect.

In testing for extreme values within the population using the Bonferoni outlier test a critical value T(42-.0025)=3.165 was obtained. The results show that there were no extreme values of the A horizon thickness since all 63 cases were <t=3.165.

Thickness of the B Horizon.

The depth of the B horizon is considered to be the point to which soil development has taken place. The thickness along with the degree of development is related to the pedogenic age of the soil. A thicker B horizon was expected to be found at the SU than at the SH. Then, a gradual increase in the thickness would be expected progressing downslope with a relatively large increase in thickness at the FS and the TS.

The thickness of the B horizons is shown in Table 3 and graphically is represented in Figure 6. In general, the data show that expected changes exist with some exceptions. More specifically, on transect 1-21, the changes on each landscape segment compared to the previous higher segment are: increases of 35%, 79%, 37%, a decrease of 13%, and then an increase 152% and 6% at the SH, UBS, MBS, LBS, FS, and TS respectively. The B horizon thickness on this transect ranges from 12 to 133 cm at the summit and toeslope respectively.

On transect 1-22 there is a decrease of 9%, an increase of 27%, decrease of 4%, increase of 65%, increase of 2%, and increase of 66% at the SH, UBS, MBS, LBS, FS, and TS respectively vs. the higher component of each one on the thickness of the B horizon. For this

TABLE 3: Thickness of B horizons, means, and standard deviations on the three transects.

COMPONENTS	OBSERVATIONS IN CM.				
	1	2	3	MEAN	S-D
Transect 1-21					
SU	12	22	18	17.33	5.03
SH	17	18	35	23.33	10.12
UBS	27	35	63	41.67	18.90
MBS	41	60	70	57.00	14.73
LBS	50	44	54	49.33	5.03
FS	114	127	132	124.33	9.29
TS	132	132	133	132.33	0.577
Transect 1-22					
SU	28	60	57	48.33	17.67
SH	53	27	52	44.	14.73
UBS	63	63	42	56.	12.12
MBS	50	48	63	53.62	18.14
LBS	90	79	96	88.33	8.62
FS	93	118	67	90.33	27.50
TS	147	162	142	150.33	10.41
Transect 1-23					
SU	8	35	28	23.67	14.01
SH	30	34	35	33.00	2.65
UBS	38	40	39	45.67	10.69
MBS	54	78	53	61.67	14.15
LBS	61	54	66	60.33	6.02
FS	58	60	68	62.	5.29
TS	127	187	124	146.	35.53

COMPONENT	MEAN	S-D
	29.78	18.29
	33.44	12.72
	47.78	13.99
	57.44	11.53
	66.00	18.36
	92.22	30.79
	142.89	20.22

TRANSECT	MEAN	S-D
1-21	63.62	44.9
1-22	75.86	38.13
1-23	61.76	40.37

TOTAL MEAN	S-D
66.37	41.82

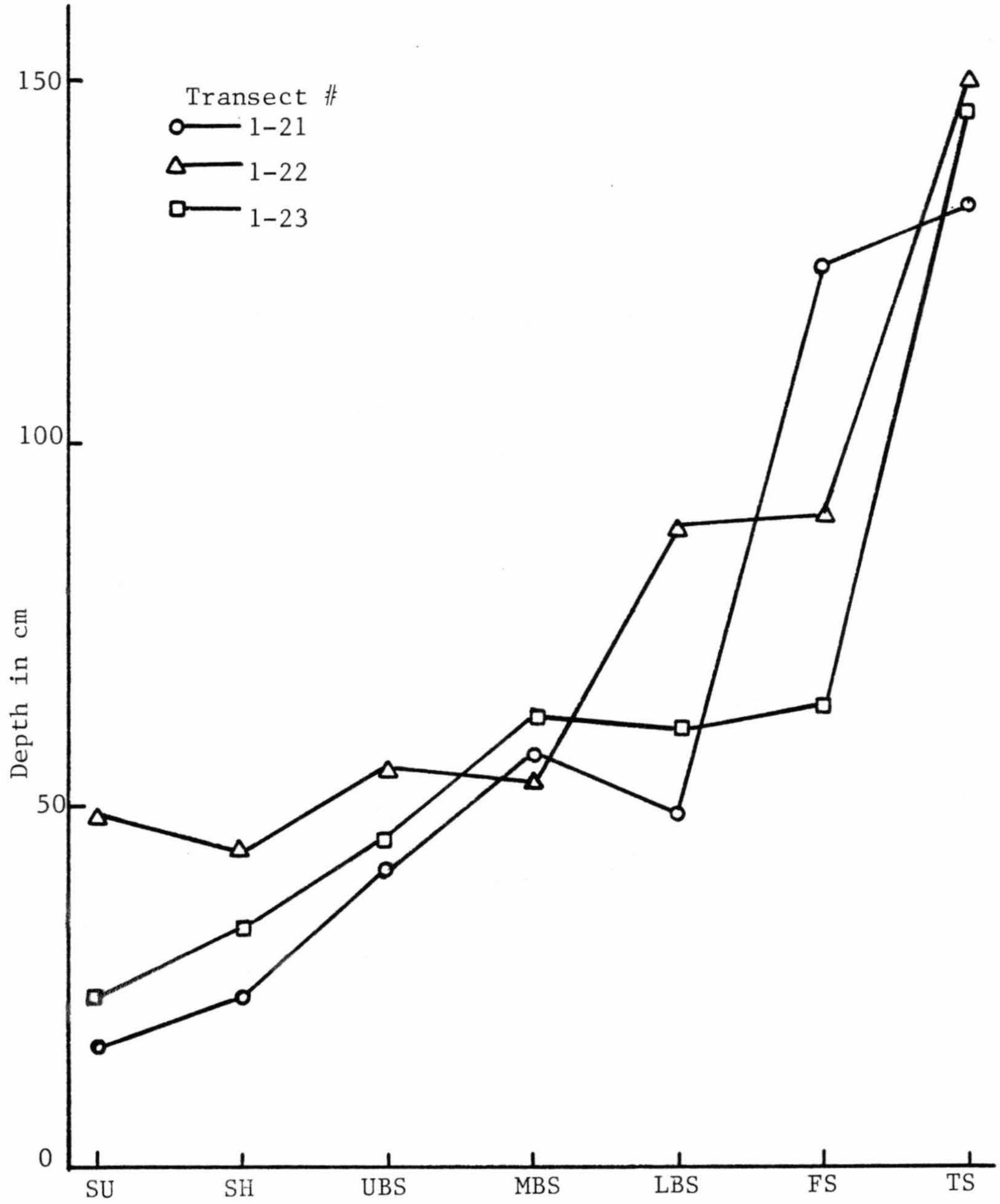

Figure 6: Thickness of the B horizon along the three transects of the catenary sequence.

transect the B horizon thickness ranges from 28 to 162 at the SU and the TS respectively.

On transect 1-23 there is a continual increase of 39%, 38%, 35%, (slight decrease) 2%, and again increases of 3%, and 135% at the SH, UBS, MBS, LBS, FS, TS respectively vs. the higher catenary component of each one. Except for the SH and the LBS, this would be the expected normal situation if erosional processes + runoff + runon relationships fit the classical model. The B horizon thickness for this transect ranges between 8 cm at the SU to 187 cm at the TS.

As shown the pattern of the B horizon thickness varies both from transect to transect for the relative landscape components as well as between the components within the catena sequence. Irregularities are found at the MBS of transect 1-22. Similar decrease in thickness is shown at the LBS of transects 1-21 , 1-23. However, considering the existence of the buried horizons at the LBS we can visualize the expected pattern of increased thickness at the lower landscape components to have occurred.

The formation of the buried B horizons and the very deep B horizon at the LBS, FS, and TS are explained by water erosional activities associated with previous geologic erosion events. Intensive erosion appears to have occurred during earlier geologic periods and indicate climatic changes through time. It appears that at one time either rains (most possible) and/or winds must have intensively disturbed the landscape by eroding the higher components and carrying and depositing coarser sandy material on the LBS and FS, while finer clayey material was carried further downslope to the FS and TS where the sloping gradient is smoother. The existing A horizon at that time might have been washed away or has been buried and transformed into a B horizon. In situ weathering and clay illuviation may have enriched the clay percentage contributing to the development of the B horizons.

The differences found are not the same across the three transects as shown with statistical analysis. Using a two way analysis of variance, the response of the transects, the component effect, and the interactions of the transects by the component was tested. The results (Table 4) show the interactions to be significant, indicating influence for the differences between the sites are not only due to the component topographic effect but also there are significant differences between the transects interacting with the component effect. The component effect is also significant showing that topography has a large effect on the depth of the B horizon. The transect effect is not significant imposing some kind of similarities between the three transects. This is not true as witnessed by the interactions. We may suspect though that there are not great differences among them.

The variability is explained by statistical analysis as follows: .0112 is explained by the transect influence, .7835 by the component effect, .0987 by the interactions and .1067 by the variability within the sites. The fact that the interactions and the site effect contribute equally to variability indicates a high degree of variability within the sites as well as between the transects. Applying the Bonferoni test for outliers the middle observation of the B horizon at the toeslope of transect 1-23 was found to be extremely large.

TABLE 4: Analysis of variance for the B horizon thickness for the three transects.

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARE	F	PROB.	F(table) D.F.	LEVEL	
MEAN	1	284820.6	284820.57					
CATENA	2	2397.2	1198.62	1.58	.2456	(2-12	.05)	3.89
COMPONENT	6	84133.4	14022.24	18.51	.0000	(6-12	.05)	3.00
INTERACT	12	9092.1	757.67	3.78	.0007	(12-42	.05)	1.99
SITES	42	8428.7	200.68					

ESTIMATES OF VARIANCE COMPONENTS

(1)	4291.38713	
(2)	20.99735	.0112
(3)	1473.84039	.7835
(4)	185.66402	.0987
(5)	200.68254	.1067

The Depth of the Solum.

The solum includes the A and B horizons and represents the developed soil. The changes that may occur in each of these horizons will affect as well the solum depth. As discussed earlier, the characteristics of the A and B horizons reflect the current environment (erosion, deposition), and the B horizons represent development of permanent and past climatic and geologic conditions, the solum thickness becomes the indicator over all of the pedological processes which have influenced soil development on the landscapes.

The data for solum depth are given in Table 5. Figure 7 represents graphically the solum depth relationship on the three transects. Generally the solum depth should be greater at the SU and on the lower components of the catenary sequence. The found trend is not much different than that of the B horizon. This indicates that the modern climatic environment has not alone influenced soil development on this landscape. Transect 1-21 shows a mean increase in solum thickness in all upper landscape components (29%, 61%, 45% at the SH, UBS and MBS respectively) and the lower slopes (129% and 8%, FS, TS respectively) vs. the higher catenary component of each site.

On transect 1-22 there is a decrease of the mean by 6.99% at the SH although one observation had equal and one had a larger value vs. the SU. There is an increase of 25%, a decrease of 11%, decrease of 54%, increase of 1%, increase of 65% at the UBS, MBS, and LBS, FS and TS respectively vs. the higher catenary component of each site.

On transect 1-23 a continual increase in solum depth occurs from the SU to the MBS, a slight decrease occurs at the LBS while an increase occurs at the FS and the TS. Relative percentages of 5.41% at

TABLE 5: Solum depth, means and standard deviations for the three transect

COMPO-NENTS	OBSERV. IN CM 1	2	3	MEAN	S-D
Transect 1-22					
SU	20	30	27	25.67	5.131
SH	28	27	44	33.00	9.54
UBS	39	46	74	53.00	18.52
MBS	65	80	86	77.00	10.82
LBS	56	52	60	56.00	4.00
FS	120	130	135	128.33	7.64
TS	139	139	139	139.00	.00
Transect 1-22					
SU	38	73	63	58.00	18.03
SH	63	36	63	54.00	15.59
UBS	73	76	53	67.33	12.50
MBS	55	53	72	60.00	10.44
LBS	95	83	100	92.66	8.74
ES	93	120	67	93.33	26.50
TS	150	165	147	154.00	9.64
Transect 1-23					
SU	23	44	38	35.00	10.82
SH	32	39	40	37.00	4.36
UBS	64	52	46	54.00	9.17
MBS	60	83	59	67.33	13.60
LBS	67	60	72	66.33	6.03
ES	63	65	74	67.33	5.86
TS	130	192	130	150.67	35.80

COMPONENT	MEAN	S-D
	39.55	18.02
	41.33	13.47
	58.11	13.92
	67.33	13.6
	71.67	17.32
	96.33	30.02
	147.89	19.80

TRANSECT	MEAN	S-D
1-21	73.14	43.12
1-22	82.76	36.00
1-23	68.29	39.23

TOTAL	MEAN	S-D
	74.714	39.4

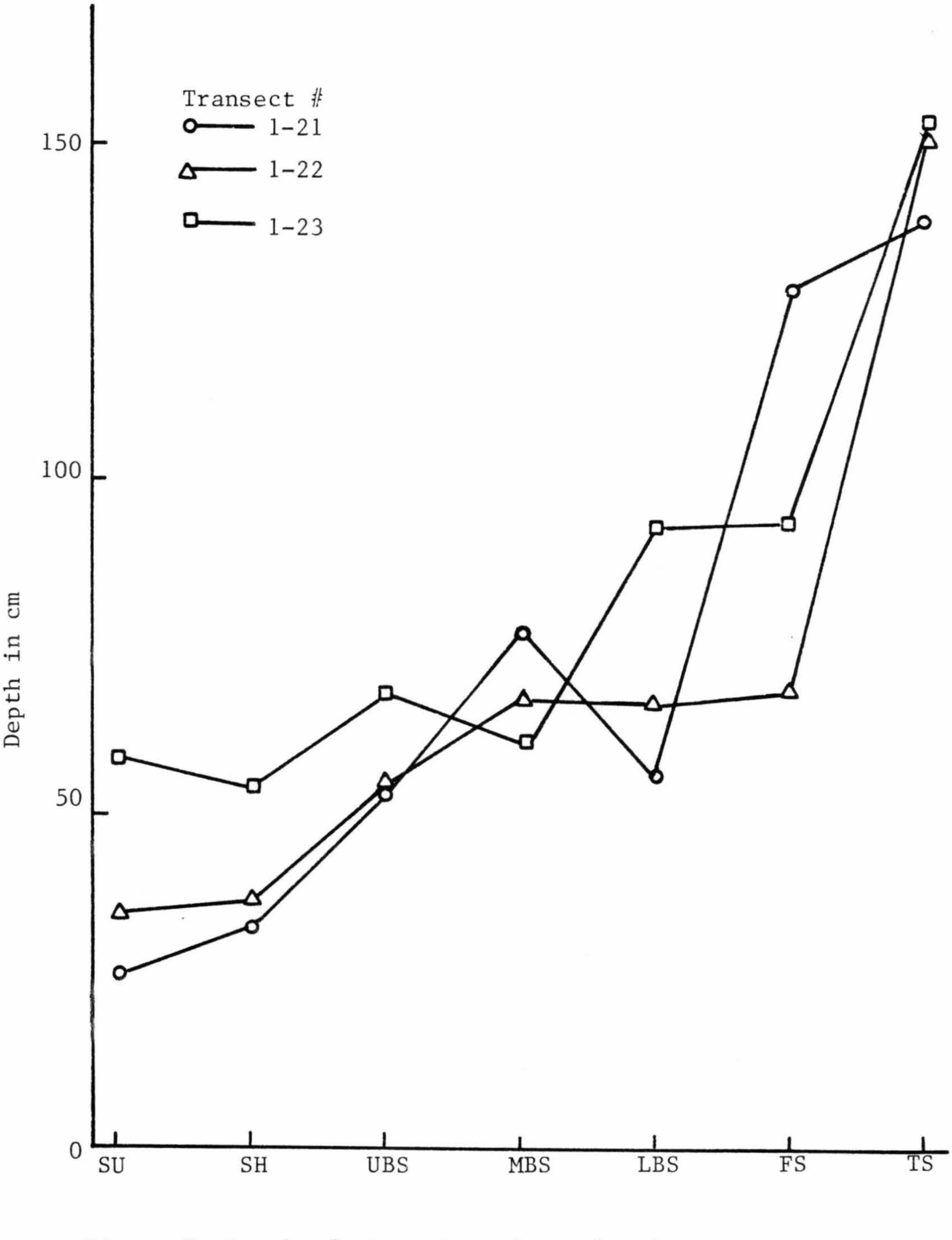

Figure 7: Depth of the solum along the three transects of the catenary sequence.

the SH, 31.48% at the UBS; 24.69% at the MBS, 1.49% decrease at the LBS, 1.51% increase at the FS and 123.78% increase at the TS when each component is compared to the higher catenary component.

The two way analysis of variance (Table 6) showed significant interactions of the catena by component effect which again show that there is not a consistent pattern of soil development because of many differences not only between components but also between transects. The contribution of each variable to the variability of the solum depth was as follows: .0105 for transect effect, .7684 for the component effect; the interactions of transect-component effect .1077, and .1134 the site effect. The Bonferoni test for outliers shows that the only extreme value is the middle toeslope of the 1-23 transect. In summary, when comparing the results with the B horizon, we see no differences which suggests that processes involved in the morphogenessis (soil development rather than erosional-depositional) are involved in the development of B horizons of the soils which in turn indicates a previous period of stable, relatively mild climatic influence on soil development.

The ratio of the solum depth to thickness of A horizon

This ratio is an indication of the degree of weathering and soil development as a function of landscape component. The ratio becomes larger as the solum thickens or the A horizon becomes thinner or both. The A horizon becomes thinner as clay increases with depth due to decreased permeability of water or erosion reduces its depth. The solum thickens as degree of soil development occurs.

This ratio also changes based on the rate of changes of both the above characteristics as a function of the direction to which climatic

TABLE 6: Analysis of variance for solum depth along the three transects.

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARE	F	PROB.	F(table) D.F.	LEVEL	
MEAN	1	351829.6	351829.59					
CATENA	2	2279.7	1139.87	1.51	.2610	(2-12	.05)	3.89
COMPONENT	6	76494.9	12749.14	16.84	.0000	(6-12	.05)	3.00
INTERACT	12	9085.8	757.15	3.85	.0006	(12-42	.05)	1.99
SITES	42	8258.0	196.62					

ESTIMATES OF VARIANCE COMPONENTS

(1)	5376.15432	
(2)	18.22487	.0105
(3)	1332.44356	.7684
(4)	186.84392	.1077
(5)	196.61905	.1134

conditions control geological or developmental changes through time. The solum depth to A horizon ratios of the three transects are shown in Table 7. Figure 8 represents graphically these ratios. The general trend is that there is a uniformity of the ratio on transects 1-21 and 1-22 on the upper landscape components. The ratio is higher and has a high variability within each site on transect 1-23 for all the components except for the TS. The TS of transect 1-23 and the MBS of transect 1-22 as well as the LBS, FS and TS of transects 1-21 and 1-22 increase tremendously. More specifically, mean changes on transect 1-21 show an increase of 13%, increase of 36%, decrease of 1%, increase of 84%, increase of 319%, decrease of 42% at the SH, UBS, MBS, LBS, FS and TS respectively vs. the previous higher catenary component.

On transect 1-22, there is a 14% decrease, 14.54% increase, 65% increase, 119% increase, 63% increase and 27% increase at the SH, UBS, MBS, LBS, FS and TS respectively compared to the previous higher catenary component.

On transect 1-23 there is a (very large) 210.8% increase at the SH vs. the SU, an increase of 32%, increase of 56%, decrease of 2%, increase of 14%, increase of 17.3% at the UBS, MBS, LBS, FS, and TS respectively compared to the previous higher catenary component.

The two way analysis of variance for the ratio on the three transects (Table 8) showed the transect by component interactions to be significant, showing that as with the other characteristics studied there is no consistent pattern of component because of differences between the transects. The transect effect is not significant but strong similarities do not exist since the interactions prove the

TABLE 7: Ratio solum depth/A-horizon thickenss means and standard deviations for the three transects.

COMPONENTS	RATIOS			MEAN	S-D
	1	2	3		
Transect 1-21					
SU	2.50	3.75	3.00	3.08	.629
SH	2.55	3.00	4.89	3.48	1.24
UBS	3.25	4.18	6.72	4.72	1.80
MBS	4.64	4.00	5.38	4.67	.69
LBS	9.33	6.5	10.00	8.61	1.86
FS	20.00	43.33	45.00	36.11	14.00
TS	19.86	19.86	23.17	20.96	1.91
Transect 1-22					
SU	3.8	5.61	10.50	6.64	3.47
SH	6.30	4.00	5.73	5.34	1.20
UBS	7.3	5.84	4.81	5.99	1.25
MBS	11.00	10.60	8.00	9.87	1.63
LBS	19.00	20.75	25.00	21.58	3.09
FS	31.00	60.00	16.75	35.92	22.00
TS	50.00	55.00	29.40	44.80	13.60
Transect 1-23					
SU	1.53	4.89	3.80	3.41	1.71
SH	16.00	7.8	8.0	10.6	4.68
UBS	10.67	4.33	6.57	7.19	3.21
MBS	10.00	13.83	9.83	11.22	2.26
LBS	11.17	10.00	12.00	11.06	1.00
FS	12.60	13.00	12.33	12.64	.34
TS	43.33	38.40	21.67	34.47	11.4

COMPONENT	MEAN	S-D
	4.38	2.59
	6.47	4.06
	5.97	2.22
	8.59	3.32
	13.75	6.26
	28.22	17.5
	33.403	13.7

TRANSECT	MEAN	S-D
1-21	11.66	12.7
1-22	18.59	10.3
1-23	12.94	10.3

TOTAL	MEAN	S-D
	14.398	13.9

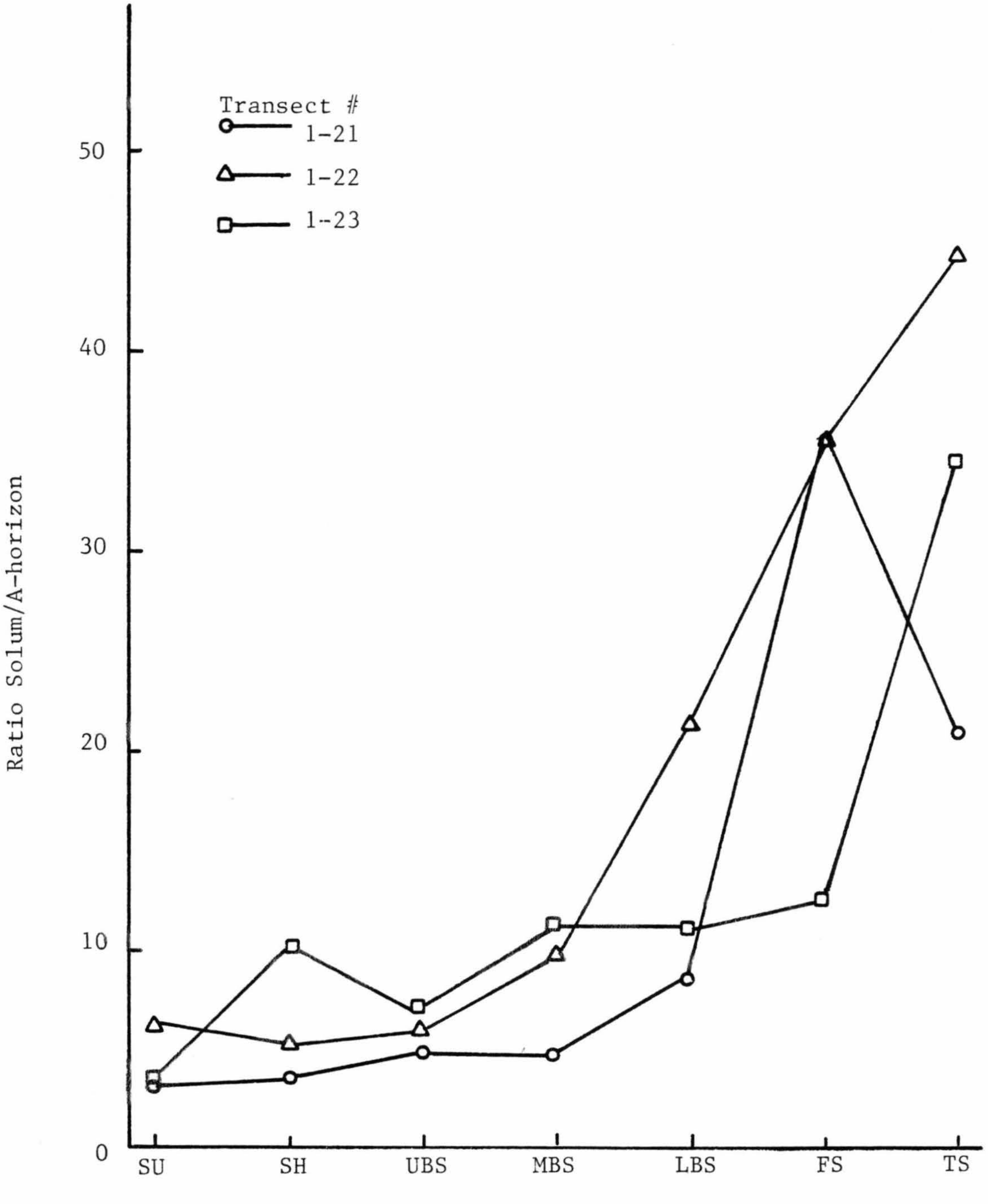

Figure 8: Ratio of the solum depth over A horizon thickness along three transects on a catenary sequence.

TABLE 8: Analysis of variance for the ratio of the solum depth/A horizon thickness for the three transects.

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARE	F	PROB.	F(table) D.F	LEVEL	
MEAN	1	13064.92	13064.915					
CATENA	2	570.43	285.216	1.85	.1996	(2-12	.05)	3.89
COMPONENT	6	7387.88	1231.314	7.98	.0012	(6-12	.05)	3.00
INTERACT	12	1851.29	154.274	3.01	.0040	(12-92	.05)	1.99
SITES	42	2151.93	51.236					

OESTIMATES OF VARIANCE COMPONENTS

(1)	185.75650	.0000
(2)	6.23533	.0295
(3)	119.67114	.5659
(4)	34.34573	.1624
(5)	51.23649	.2423

opposite while the component effect is significant. The existing variability is explained as follows: 3% by the transect effect, 57% by the component effect, 16% by the interactions and 24% by the site effect (variability within the site which is found to be very large).

Values found to be extreme by the Bonferoni outlier test were two observations at the FS of transect 1-22 due to the very thin A horizons and the relatively thick solum. Small ratio values exist at the higher landscape components of the catenary sequence where there are younger soils. Large ratio values exist at the lower components where the older soils have developed a very thick B horizon with high clay content and very strong structure.

The Depth to Lime

The depth to lime is related to the parent material characteristics and to secondary depositions by leaching activity through time. What we would expect to find if the source for the carbonates had been the parent material would be removal out of the A- and B-horizons into a C-horizon. The illuviation of clay follows the leaching of the carbonates. While the summit has limited runoff, the depth of the carbonates should be deeper there than that on the shoulder. One would expect to find carbonate much deeper in the soil profile on lower components of the catena sequence, i.e., LBS, FS and TS than on the upper landscape positions.

Table 9 shows the depth to lime and Figure 9 is a graphical representation along the three transects. Transect 1-21 shows a higher degree of variability within each site at the higher components of SU, SH, UBS, while at the lower components the variability decreases. The differences from the SU to the TS for this transect are

TABLE 9: Depth to lime, means and standard deviations on the three transects.

COMPONENTS	OBSERV. IN CM. 1	2	3	MEAN	S-D
Transect 1-21					
SU	28	33	43	34.67	7.64
SH	30	23	50	34.33	14.01
UBS	55	23	51	43.00	17.44
MBS	65	71	60	65.33	5.51
LBS	24	18	17	19.67	3.79
FS	42	34	46	40.67	6.11
TS	33	30	32	31.67	1.53
Transect 1-22					
SU	32	30	24	28.67	4.16
SH	22	29	63	38.00	21.93
UBS	62	70	73	68.33	5.69
MBS	81	80	93	84.67	7.23
LBS	30	31	28	29.67	1.53
FS	18	24	38	26.67	10.26
TS	23	24	24	23.67	.58
Transect 1-23					
SU	23	23	34	26.67	6.35
SH	45	60	34	46.33	13.05
UBS	74	72	66	70.67	4.16
MBS	70	62	59	63.67	5.69
LBS	33	28	34	31.67	3.22
FS	11	10	10	10.33	.58
TS	25	27	30	27.00	2.00

COMPONENT	MEAN	S-D
	30.00	6.48
	39.56	15.50
	60.67	16.28
	71.22	11.44
	27.00	6.14
	25.89	14.44
	27.44	3.71

TRANSECT	MEAN	S-D
	38.48	15.53
	42.81	24.15
	39.47	21.27

TOTAL MEAN	S-D
40.254	20.4

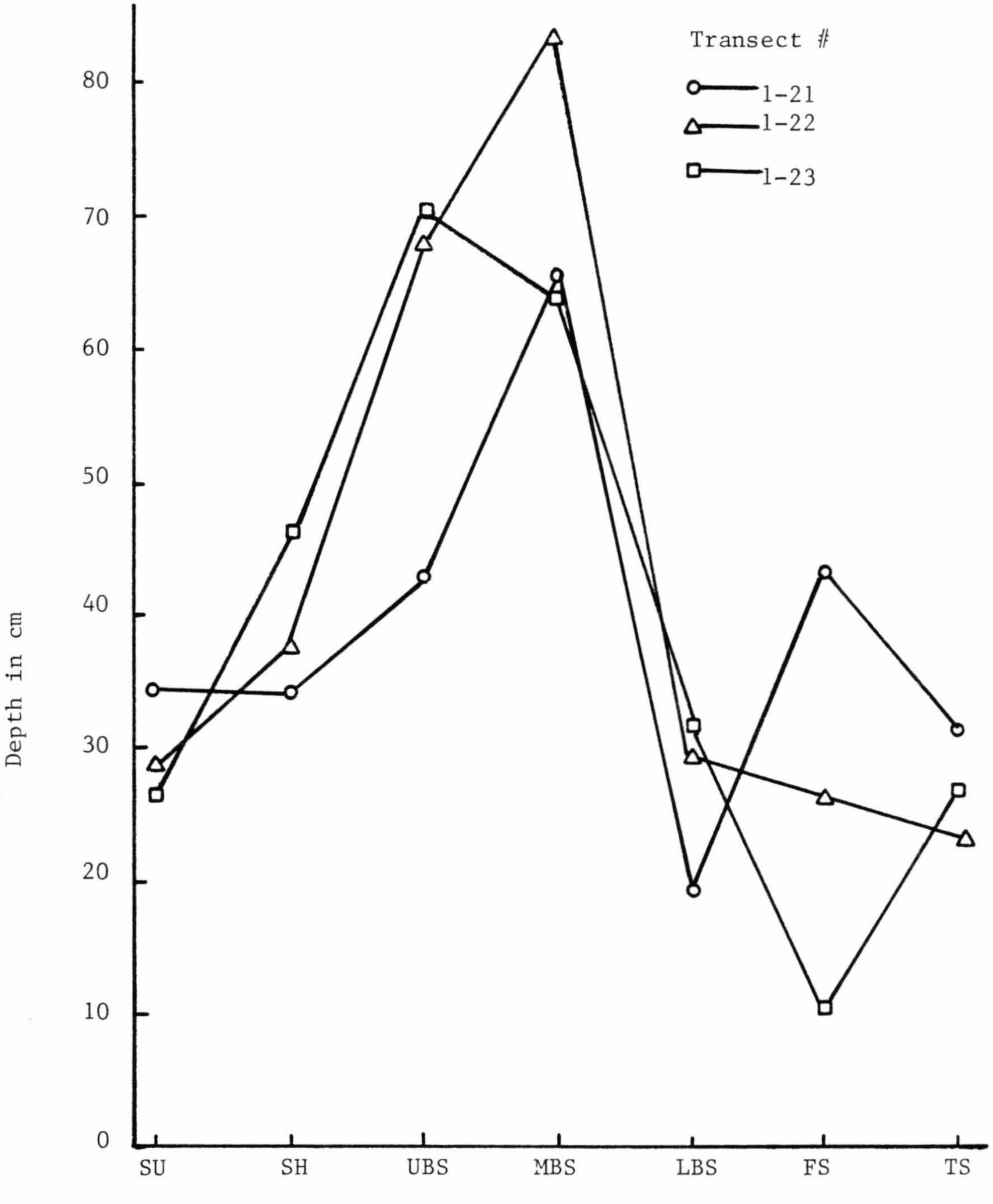

Figure 9: Depth to lime along the three transects on a catenary sequence.

as follows: a 9% decrease, 25% increase, 51% increase, 70% decrease, 106% increase, 22% decrease at the SH, UBS, MBS, LBS, FS and TS respectively vs. the previous higher catenary component.

On transect I-22 the changes are a 33% increase, 80% increase, 24% increase, 65% decrease, 10% decrease, 11% decrease at the SH, UBS, MBS, LBS, FS and TS respectively vs. the previous higher catenary component.

On transect I-23 there is a 74% increase, 53% increase, 10% decrease, 51% decrease, 67% decrease, 161% increase at the SH, UBS, MBS, LBS, FS and TS respectively vs. the previous higher catenary component.

The results are opposite of expectations. Greater depth to lime at the higher components indicates that higher infiltration and permeability of the coarser parent material has promoted the leaching of carbonates, while finer parent material which dominates the lower landscape components has prevented leaching because of lower permeability and higher water holding capacity.

Testing the influences on the variability of the depth to lime by the transects, the components and their interactions, again a two way analysis of variance, was conducted by the BMDP method. The results (Table 10) indicate significant interactions which means that differences exist not only between the components but also between the transects for the relative components. The variability is explained as follows: .023 by the influence of the transect, .631 by the component influence, .184 by the interactions and .161 by the differences within sites. The fact that the transect effect is small is an indication that there are not strong differences between the three transects and

TABLE 10: Analysis of variance for depth to lime for the three transects.

SOURCE	D.F.	SUM OF SQUARES	MEAN SQUARE	F	PROB	F(table) D.F. LEVEL
MEAN	1	102084.06	102084.06			
CATENA	2	216.22	108.11	.32	,7332	(2-12 .05) 3.89
COMPONENT	6	18247.05	3041.17	8.96	.0007	(6-12 .05) 3.00
INTERACT	12	4072.67	339.39	4.43	.0002	(12-42 .05) 1.99
SITES	42	3218.00	76.62			

ESTIMATES OF VARIANCE COMPONENTS

(1)	1575.78042	
(2)	11.01323	.0232
(3)	300.19841	.6314
(4)	87.58995	.1842
(5)	76.61905	.1612

the existing differences do not follow a uniform pattern that would have made the interactions insignificant.

Testing for extreme values with the Bonferoni test, one observation at the SH of the catena I-22 was very high. What also is of great interest is the position of the depth to lime compared to the lower depth of the B horizon. The natural sequence is to find the carbonates leached out of the soil where structure starts to form. Exception to this may be at the lower components where water percolating down the catena sequence may carry carbonates that would recharge the B horizon at these sites. This last factor appears to be a very common phenomenon for the LBS, FS and TS for all three transects.

Irregularities of the depth to lime compared with the depth of the solum are found on the three transects. On transect 1-21 one observation at the SH,two observations at the UBS and two at the MBS are showing shallower depth to lime than the solum depth. On transect 1-22, the SU, two observations at the SH and two observations at the UBS show a shallower depth to lime than the solum. The same holds for transect 1-23, where lime depth is less on the SH and MBS than the solum.

This situation raises the question as to the possible source of the carbonates. It appears that either secondary wind depositions containing carbonates and which have been deposited over a long period of time and leaching of these carbonates into the profile, or carbonate movement in a fluctuating water table are the two likely explanations. Another possible explanation is the movement of material into the cracks of soils developed in shale due to the extensive cracking of these soils as they undergo wetting and drying.

Cluster Analysis

As has been shown up to this point, there are many differences in morphological properties of the soils on the three transects. There is great variability for all characteristics, so that it is difficult to characterize the soils based on a landscape component. In an effort to find what similarities between sites do occur, the data were evaluated using cluster analysis (BMDP). The formation of the groups was studied at different stages of increasing relative distance of similarities. The distance of the first step was 0.5 and 13 different groups are formed as shown in Figure 10. By this analysis, 38% of the sites were not included in any of these 13 groups. At a distance of 1.0 (Figure 11) 9 groups are formed with 15.87% of the sites still not classified. At the distance 1.5 seven groups included 95%of the sites (Figure 12). At a distance of 2.0 (Figure 13), 5 groups are formed and all pedons are included. When five groups are formed the first group includes all the SU, six pedons at the SH, one at the UBS, six at the LBS, and four at the FS. The second group includes three pedons at the SH, eight pedons at the UBS and seven at the MBS. The third group includes three pedons at the MBS. The fourth group includes three pedons at the LBS, two at the FS and five at the TS. The fifth group includes three pedons at the FS and four pedons at the TS.

Further grouping unites the fourth and the fifth group and we have three major groups. The first matching SU, SH, LBS and FS, the second matching SH, UBS and MBS, and the third matching LBS, FS and TS, while two pedons at the MBS appear completely different from the

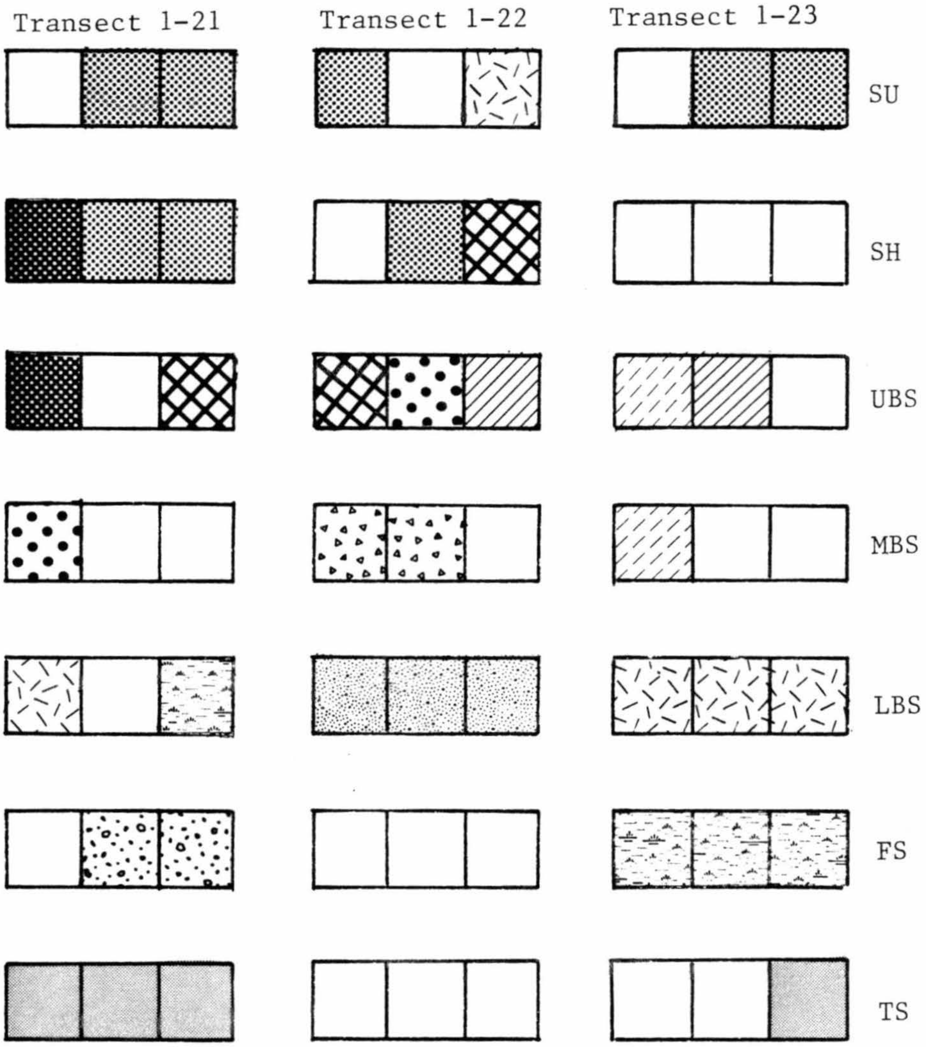

Figure 10: Cluster analysis for the three transects weight = 1, distance = .5.

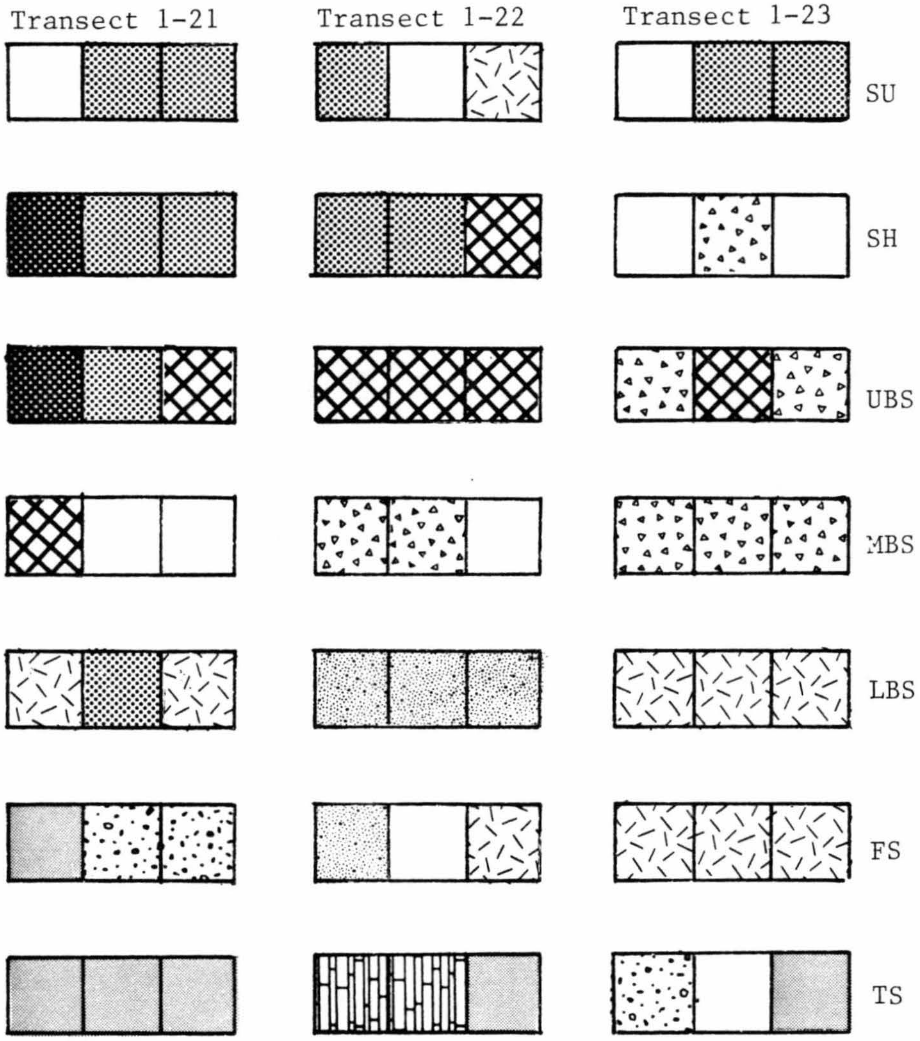

Figure 11: Cluster analysis for the three transects weight = 1, distance = 1.0.

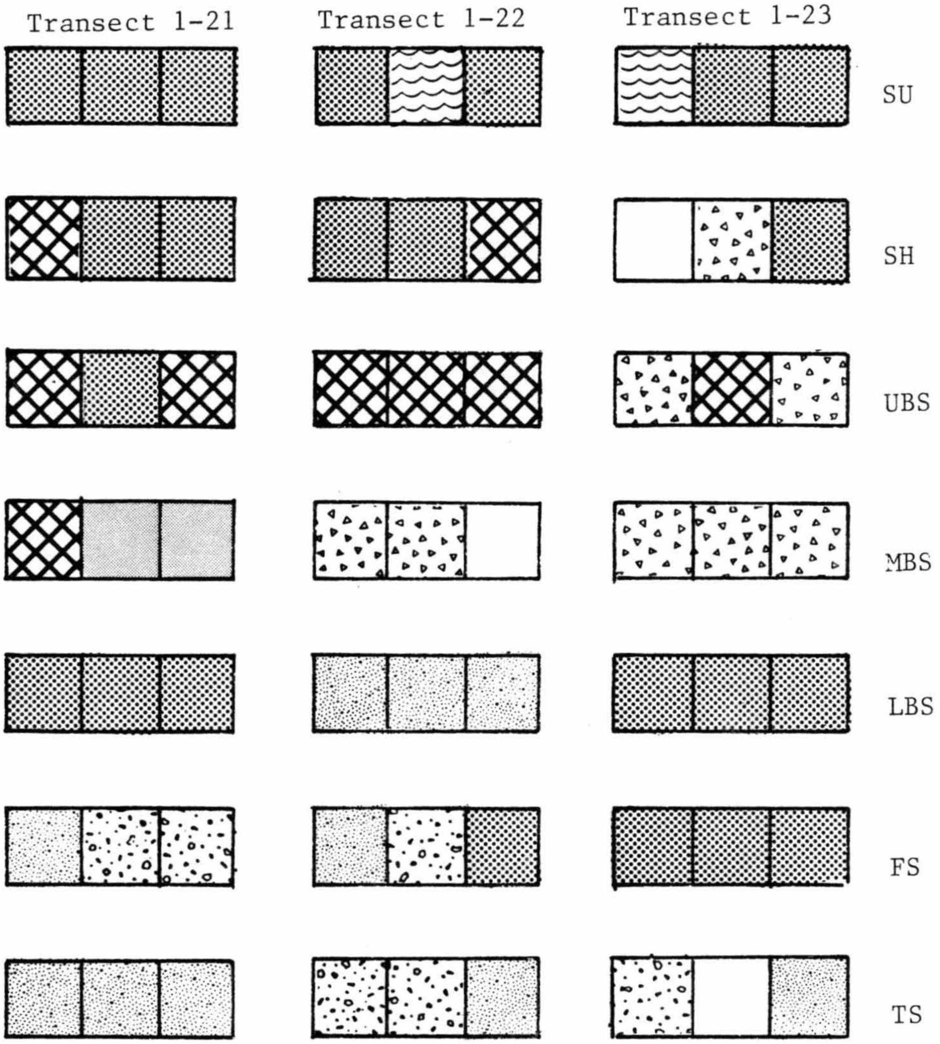

Figure 12: Cluster analysis for the three transects weight=1,distance=1.5.

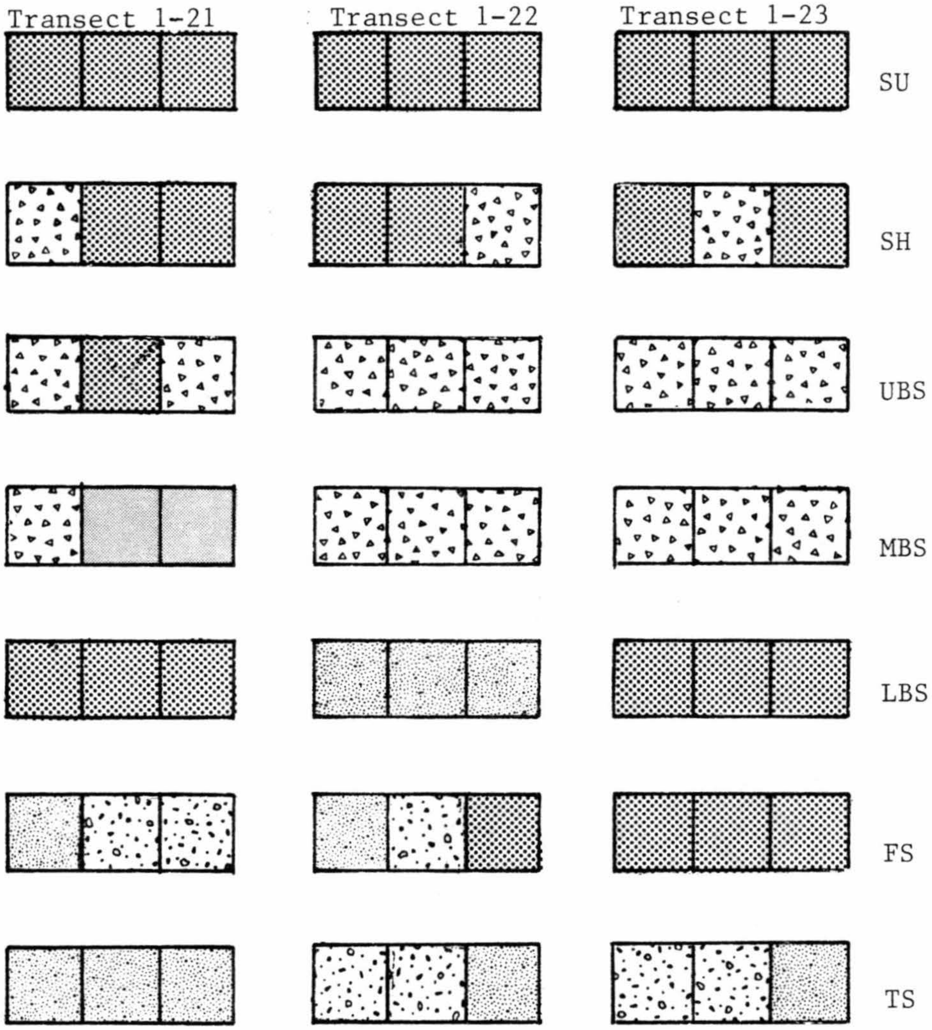

Figure 13: Cluster analysis for the three transects weight=1,distance=2.0.

rest although matching between themselves. Further clustering shows similarities between the first and second group.

Using the cluster analysis by weighting each morphological property, a different pattern appears every time.

Using a heavier weighting factor on A horizon depth four major groups were formed (Figure 14). The first includes all SU, seven SH, two UBS, six LBS and four FS. The second includes two pedons at the SH, seven at the UBS and all MBS. The third includes three pedons at the LBS two at the FS and five at the TS, and the fourth includes three pedons at the FS and three at the TS. There was one pedon at the TS of transect I-23 that was not included in any cluster.

Using a heavier weighting factor on the solum depth five groups were formed. The first includes eight pedons at the SU, four pedons at the SH, one at the UBS, and one at the LBS. The second includes two pedons at the SH, six at the UBS, and two at the MBS. The third group includes one pedon at the SH, two at the UBS and five at the MBS. The fourth group includes one pedon at the SU, two at the SH, eight at the LBS, five at the FS and four at the TS. The fifth group includes four pedons at the FS and five at the TS. There were two pedons at the MBS that were not included at all in the clusters (Figure 15).

Using a heavier weighting factor on the ratio of the solum depth to the A horizon thickness five groups were formed. The first includes seven pedons at the SU, four at the SH, one at the UBS and one at the LBS. The second group includes two pedons at the SH, six at the UBS and one at the MBS. The third includes one pedon at the SH, two at the UBS and six at the MBS. The fourth group includes two

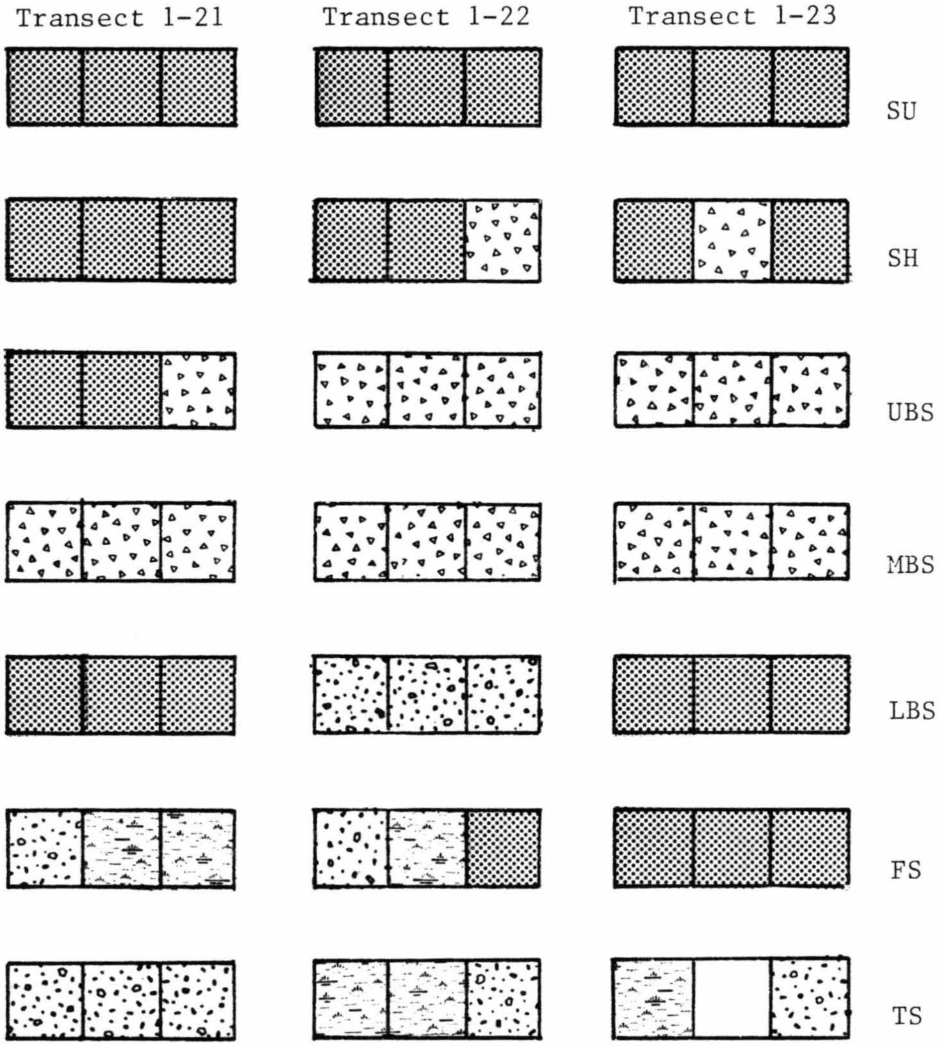

Figure 14: Cluster analysis for the three transects weight=A horizon,distance=1.5.

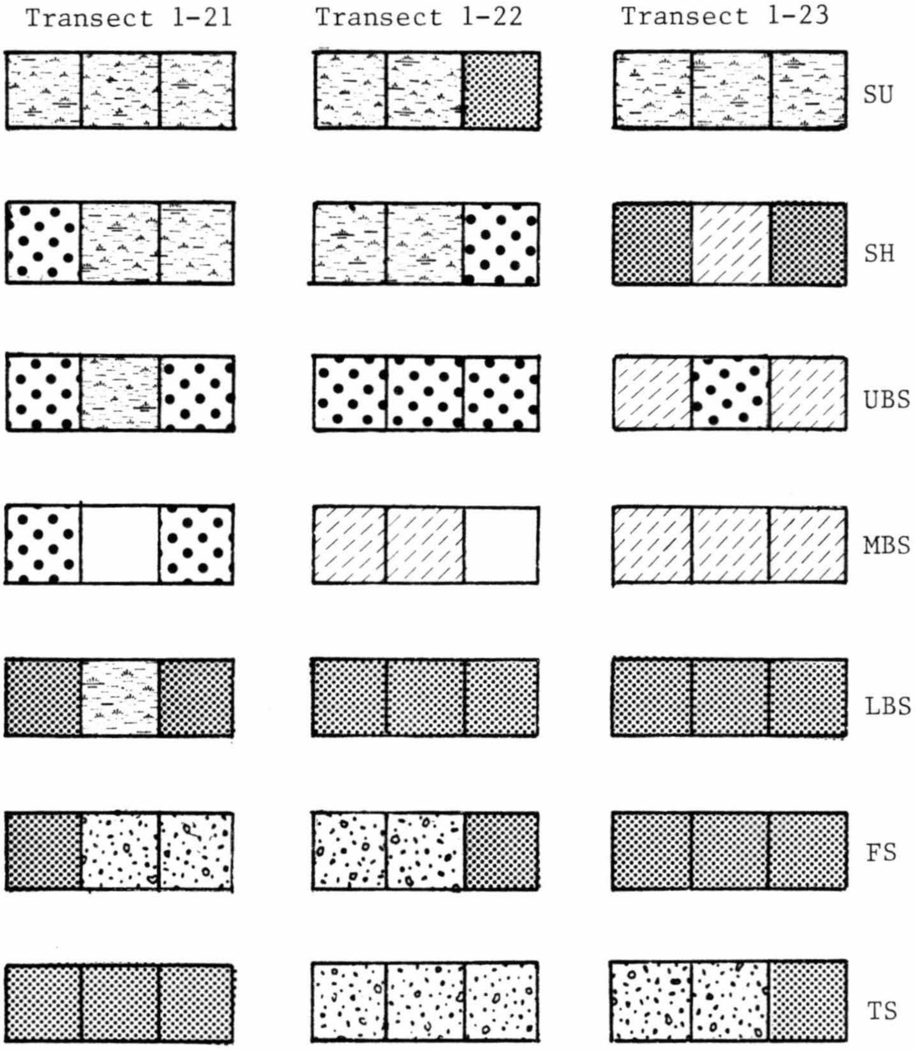

Figure 15: Cluster analysis forthe three transects weight = solum, distance = 1.5.

pedons at the MBS. The fifth group includes two pedons at the SU, two at the SH, eight at the LBS and all FS and TS (Figure 16).

Using a heavier weighting factor on depth to lime four groups are formed. The first group includes eight pedons at the SU, all SH, all UBS, seven MBS, six LBS and four FS. The second group includes one pedon at the SU and two at the MBS, the third three pedons at the LBS two at the FS and five at the TS, and the fourth includes three pedons at the FS and four at the TS (Figure 17).

Comparing the patterns that each one morphological property is creating by carrying the heaviest impact on the clustering procedure, there were not similarities found as they develop along the landscape, and a strong variability between the pedons of the same components has been indicated . As clustering goes further to the three major groups, the A horizon thickness and the depth to lime develop exactly the same pattern grouping all SU, SH, UBS, MBS all LBS of the transects 1-21 and 1-23, all pedons of the FS of the catena 1I-23 and the north pedon of the FS of the transect 1-22. The two other groups show the same pedons at the LBS, FS and TS as shown in Figure 18. The solum depth is grouping together the UBS and the MBS in one group. Another group includes the SU, the SH, the LBS and many of the pedons of the FS and TS. The third group includes four pedons of the FS and five of the TS (Figure 18).

The pattern that is created by the ratio groups the SU with the SH in one group, some of the SU and SH with the LBS, FS and TS in another group and the UBS with the MBS in a third group (figure 19).

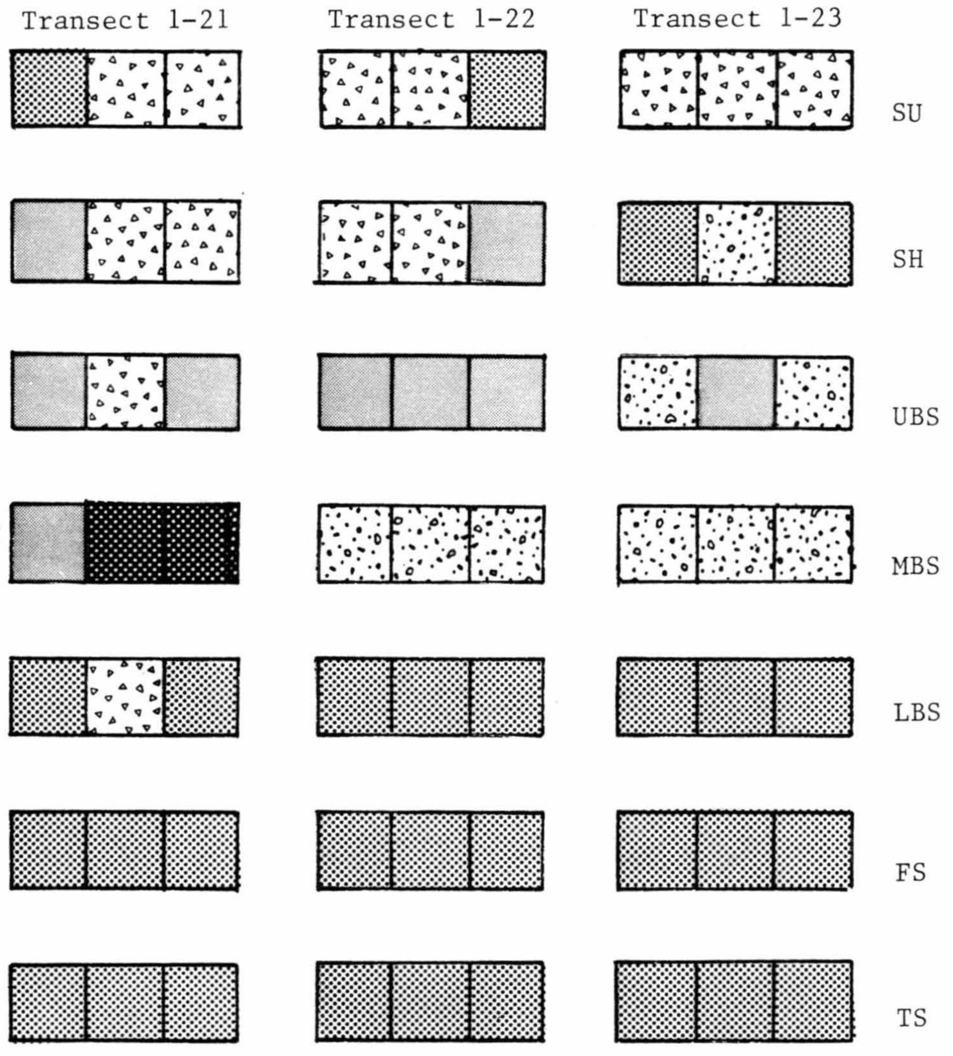

Figure 16: Cluater analysis for the three transects weight=ratio,distance=2.0.

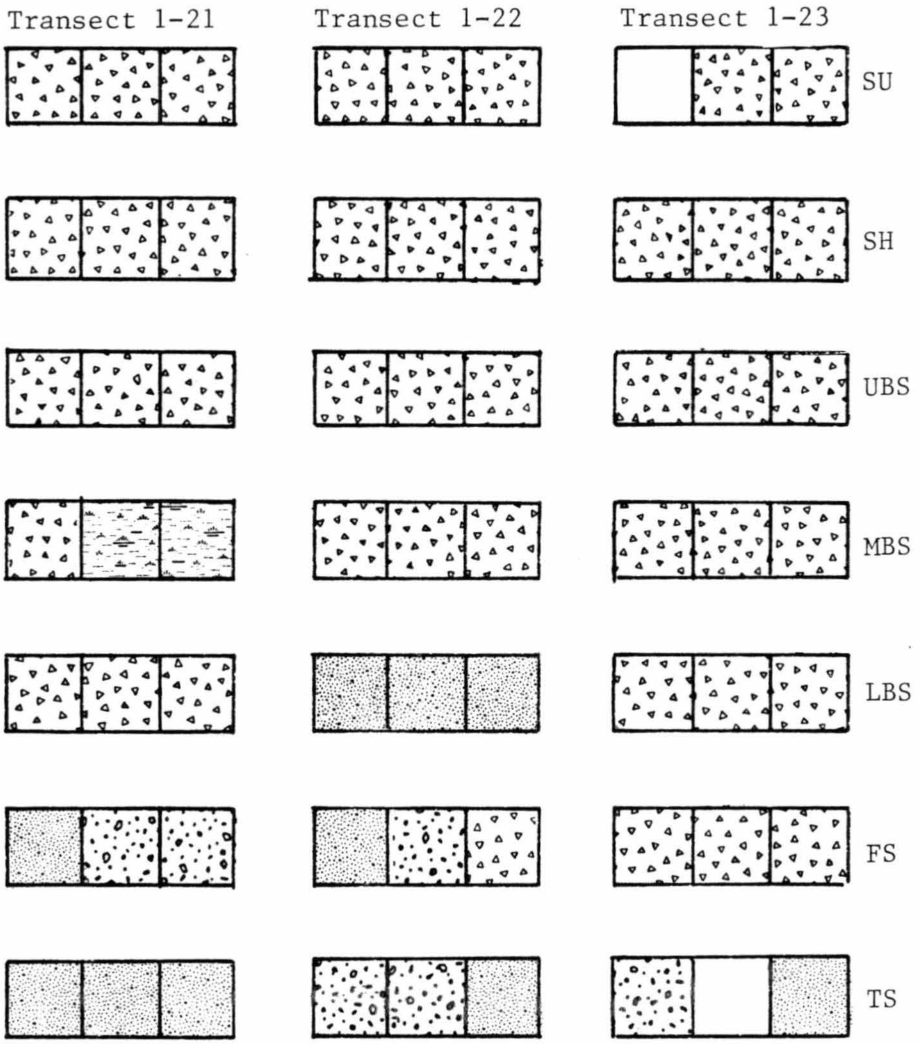

Figure 17: Cluster analysis for the three transects weight = depth to lime, distance = 1.5.

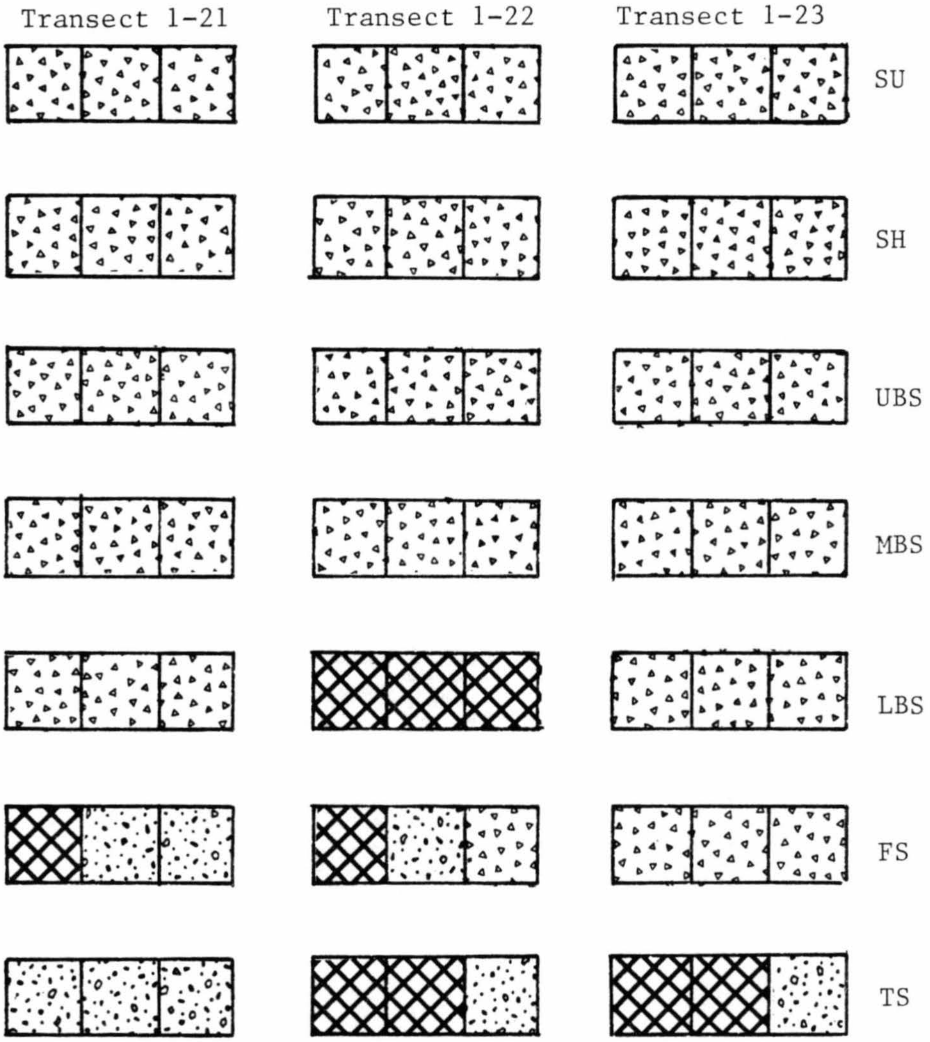

Figure 18: Cluster analysis, further grouping for the three transects weight-A horizon or depth to lime.

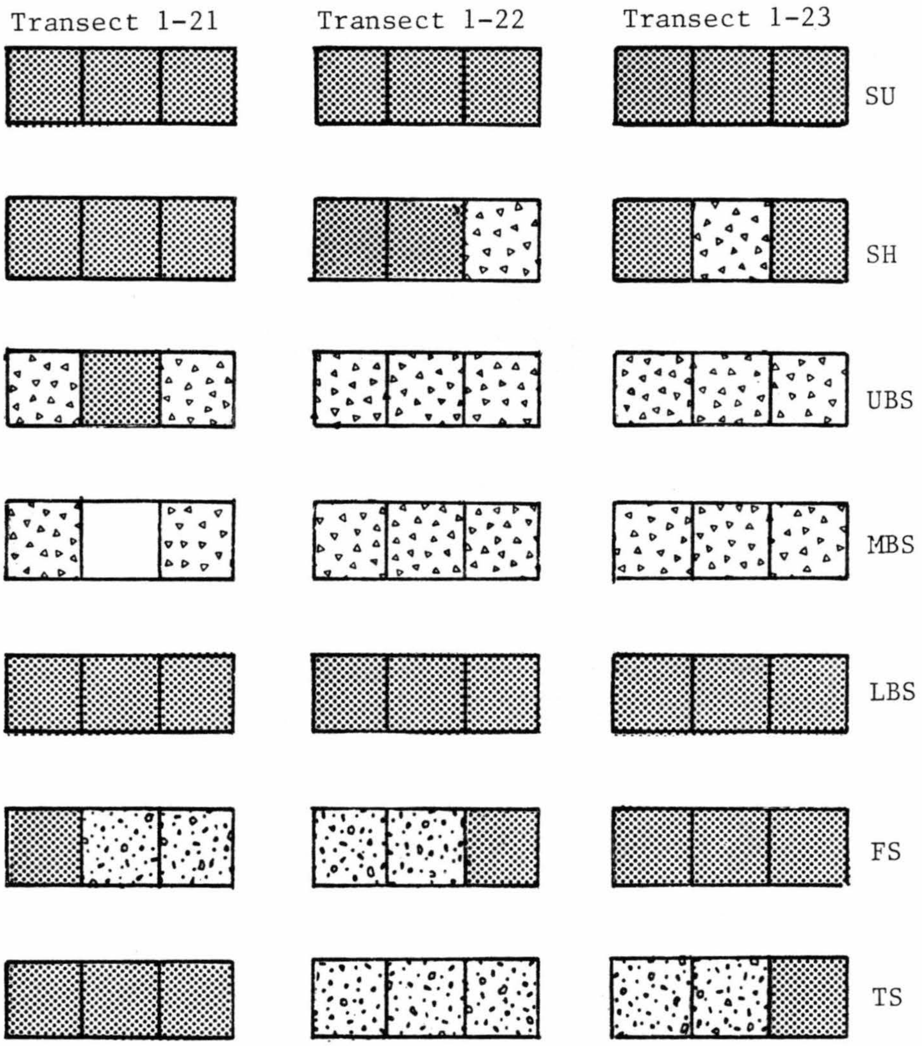

Figure 19: Cluster analysis, further grouping for the three transects weight=solum.

Using the BMDP for k-means to form seven groups, a high degree of variability is found and strong similarities are directed along the slope but not between relative components (Figure 20).

For five groups, a strong similarity developed between the components but still there are pedons from the SU and SH matching with the LBS and the FS, while two groups coexist at the UBS and MBS (Figure 21).

For three groups there are two main separate groups, one formed at the UBS and MBS and the other at the FS and the TS while the third group is separated topographically because it is matching pedons of the SU and SH with pedons at the LBS and the TS (Figure 22).

Regression Analysis

Regression analysis was carried out to see whether a group prediction could be obtained from the depth to lime, A horizon thickness, solum depth and the ratio of the solum depth to the A horizon thickness. The groups were given increasing values (dummy variables) proceeding downslope from the summit.

The regression analysis for the three groups (taken by the k-means) gave the equation $Y = 2.22 - .0209X_1 - .0183 X_2 + .0068X_3 + 0.00092 X_4$ with an R^2 of 0.82, where X_1 = depth to lime, X_2 = A horizon thickness, X_3 = solum depth, X_4 = ratio. The equation accounts for a high degree of variability and although the model is appropriate, the plot of the residuals proves that deformations for each variable should be carried out.

Testing separately each morphological characteristic to achieve homoscedasticity and applying the regression analysis the appropriate equation obtained was $Y = 2.89 - .0295 X_1 - .0300 X_2 + .0115 X_3 -$

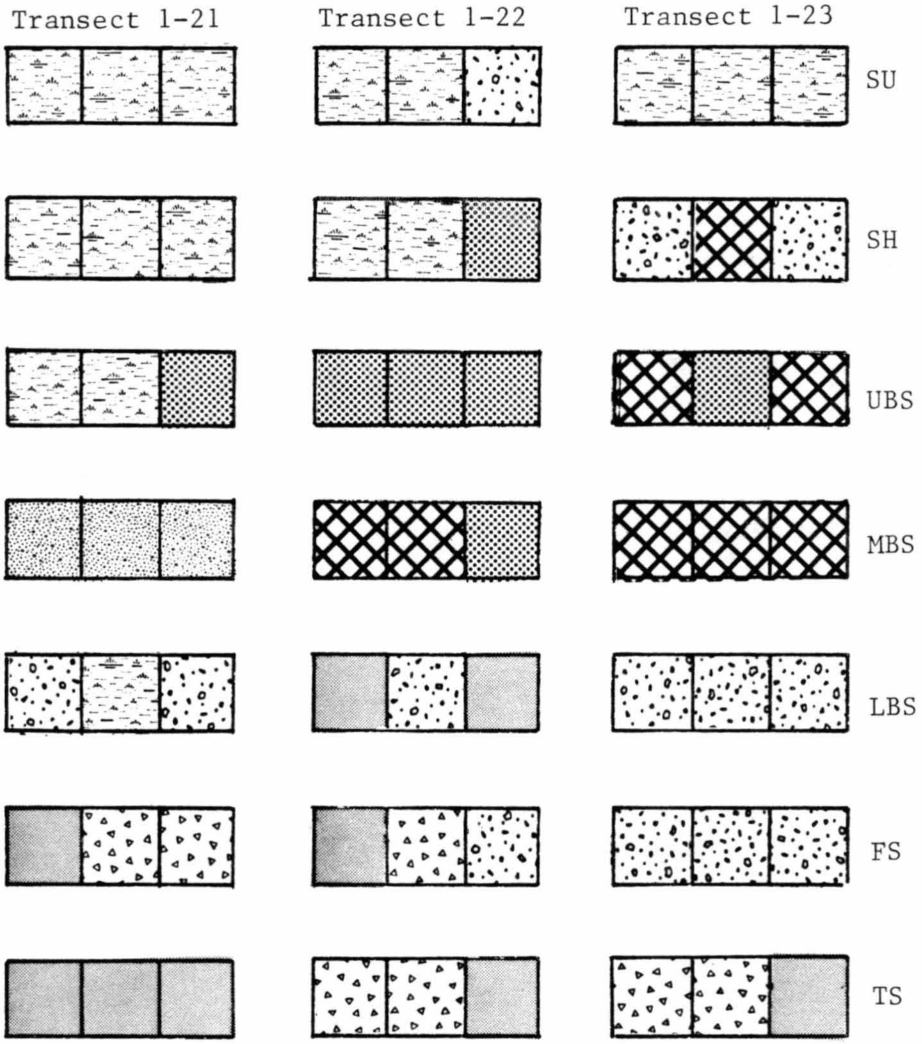

Figure 20: Cluster analysis by k-means for seven groups.

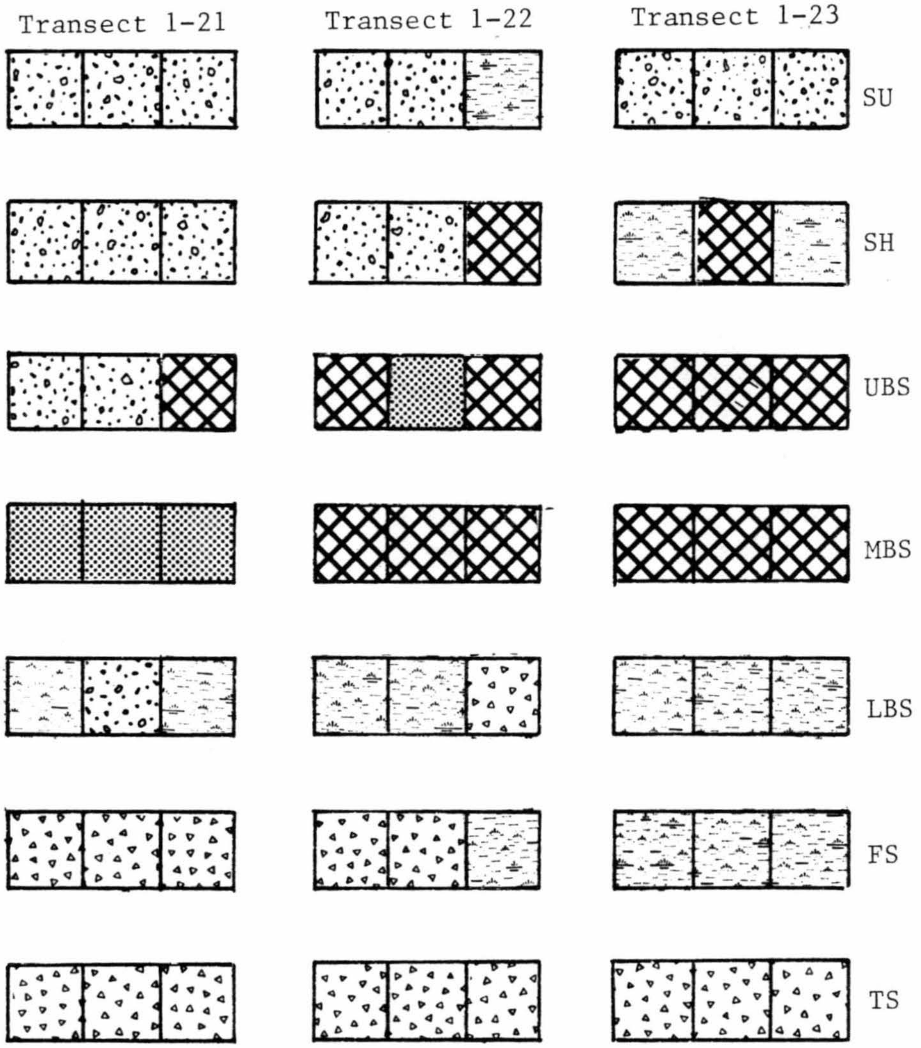

Figure 21: Cluster analysis by k-means for five groups.

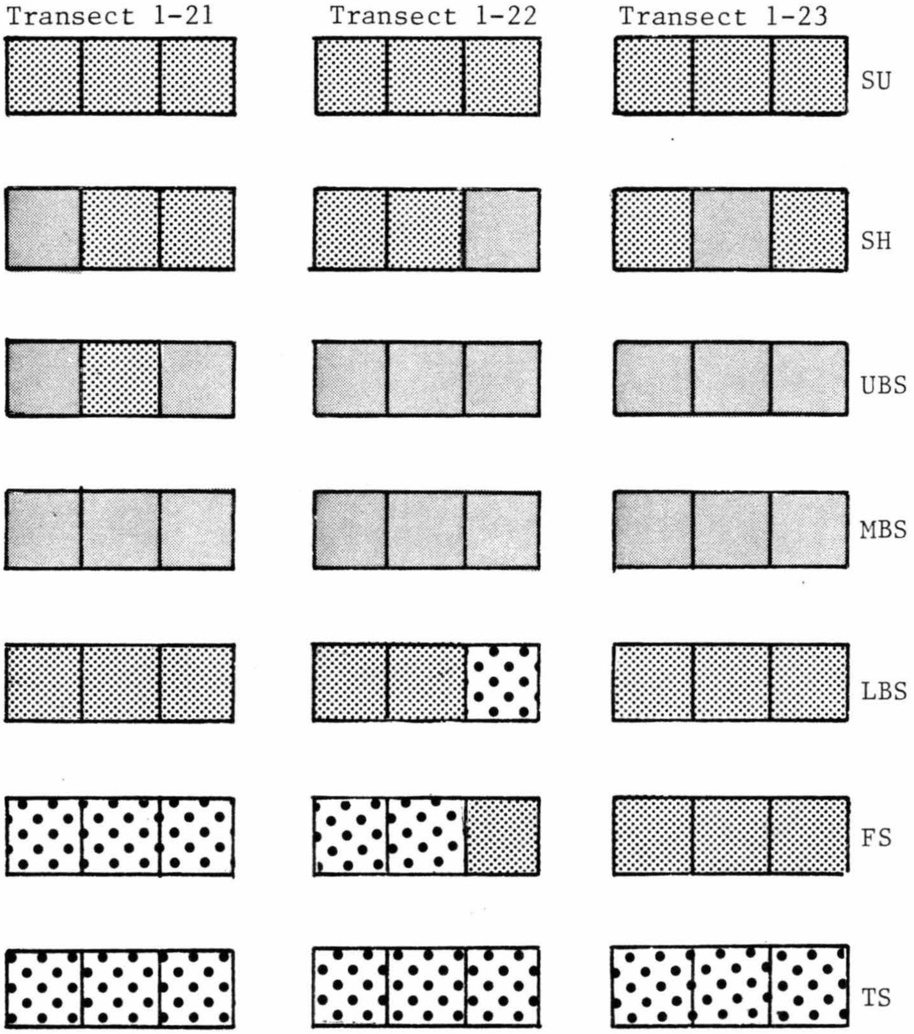

Figure 22: Cluster analysis by k-means for three groups.

$0.0006X_4 - .00001X_5 + 1.55\ X_6 + 1.96X_7 - 12.8X_8 - 2.88X_9$ where X_1=depth to lime, X_2=A horizon thickness, X_3=solum depth, X_4=A horizon^2, X_5=solum^2, X_6=1/A horizon^2 , X_7=1/ratio, X_8=1/depth to lime and X_9=1/A horizon^4.

The R^2= 87.3% better explains the variability of the area and meets the assumptions of fitness. The same procedure was followed for seven groups determined by the k-means. The equation for the straight line was $Y = 2.85 - .0034X_1 - .204X_2 + .0309X_3 + .0152X_4$ with X_1, X_2, X_3, X_4 the same as for the original straight line equation with. R^2 was 76.0%, but the assumption of homoscedasticity is not met. Improving the model as before the equation obtained was $Y = 9.13 - 0.0097X_1 - 1.51X_2 +.0608X_3 + .0573X_4 - .0002X_5 - 36.5X_6 + 1.41\ X_7 - 1.23X_5 + 92.4X_9$, where X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8 and X_9 are the same as before after deformations and the R^2= 88.2%.

The same procedure was followed by giving values to the relative geomorphic components from 1 to 7 as we descend from the summit downslope. The regression equation for a straight line was $Y = 2.55 - 0.0049X_1 - .163X_2 + .0.0441\ X_3 - .0294X_4$ where X_1, X_2, X_3, X_4 as before with an R^2= 72.8% model proved be appropriate by the F-ratio test but the plot of the residuals shows a strong trend.

The same deformations applied gave the equation $Y = 1.88 + 0.0223X_1 - .708X_2 + .0759X_3 - .0234X_4 + .0002X_5 - 23.9X_6 + 2.65X_7 + 39.0X_8 + 50.3X_9$, where X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8 and X_9 as before after deformations. The R^2= 83.4% is very high, explaining a high degree of variability and the assumptions are met.

In summary, relationships of the A horizon depth to the thickness of B horizon, solum depth and landscape position appears quite different at the study area from the classical relationships described in the literature. Starting at the summit, A horizon thickness increases downslope to the UBS or MBS, indicating that deposition does occur on the landscape. This increase is variable between transects. The lower catenary components are characterized by a thinner A horizon having smaller variability than the A horizon at the higher components. This appears to be related to deposition by wind as opposed to water.

The B horizon increases in thickness following, in general, the pattern of the classical model. There are two exceptions: (1) an increase in the SH on two transects instead of the expected decrease and (2) a decrease in two LBS instead of an increase.

The solum depth exhibits the same pattern of the thickness of the B horizon. This indicates that soil development processes are more dominant than the geomorphic changes that are occurring in the area or that the soil properties reflected today represent a previous climatic condition which was stable over a long period of time.

The ratio of the solum depth to the A horizon thickness differs between the upper and lower components. The ratios are small at the upper components and larger at the lower components. This indicates either a more stable environment or soil development is progressing much faster at the lower components. On the higher components, it is not as stable and /or geomorphic changes are stronger the increase progressing from the SU.

The depth of the carbonates increases to the middle backslope, and decreases on the lower components. The controlling factor appears to be the parent material. The parent material is very sandy at the higher components and exhibits higher permeability. It is more clayey at the lower components with higher water holding capacity, lower permeability and the leaching of carbonates is very slow. Comparison of carbonate levels in the lower B horizon indicates a secondary deposition of the carbonates has occurred.

Statistical analysis of the morphological characteristics showed that topography contributes the most to soil properties. Significant interactions, indicate strong differences between comparable components. This suggests that the influence of soil forming factors differs for the same components along the landscape. It appears that microrelief is playing a very important role.

Cluster analysis indicated a strong similarity between soils at the summit, shoulder and lower backslope positions. Relating morphological properties to the clusters, an R^2 of 87.3% was obtained for a non-linear equation. Regression analysis of the morphological data related to geomorphic components gave an R^2 of 72.8% which supports the atypical pattern of the study area.

PHYSICAL PROPERTIES

Lithological Discontinuities

The first evaluation of particle size data was to determine the extent of lithologic discontinuities, a common occurrence in soils of the study site. Discontinuities are numerous due to the (1) stratified nature of the Laramie formation, which serves as the parent material for some soils, (2) presence of characteristically different alluvial deposits and (3) variable effects of wind and water erosion on landscape components. Knowledge of the presence or absence of lithologic discontinuities is essential for understanding soil development and erosion relationships on the site. Evidence of lithologic discontinuities is shown by the data presented in Figure 23.

Clay-free index, the ratio of sand:(sand + silt), was an approach used for detecting discontinuities. This approach assumes that weathering and soil formation result in increased clay formation. This approach is limited in terms of its reliability for indicating lithologic similarities or dissimilarities or on soils derived from clayey parent material in particular. It served the purpose of this study, however, in that it was used to identify where strong texural changes occur and not as a measure of lithologic dissimilarity. In addition to the clay-free index, hue changes were utilized as a guide for determining lithologic discontinuity occurrence.

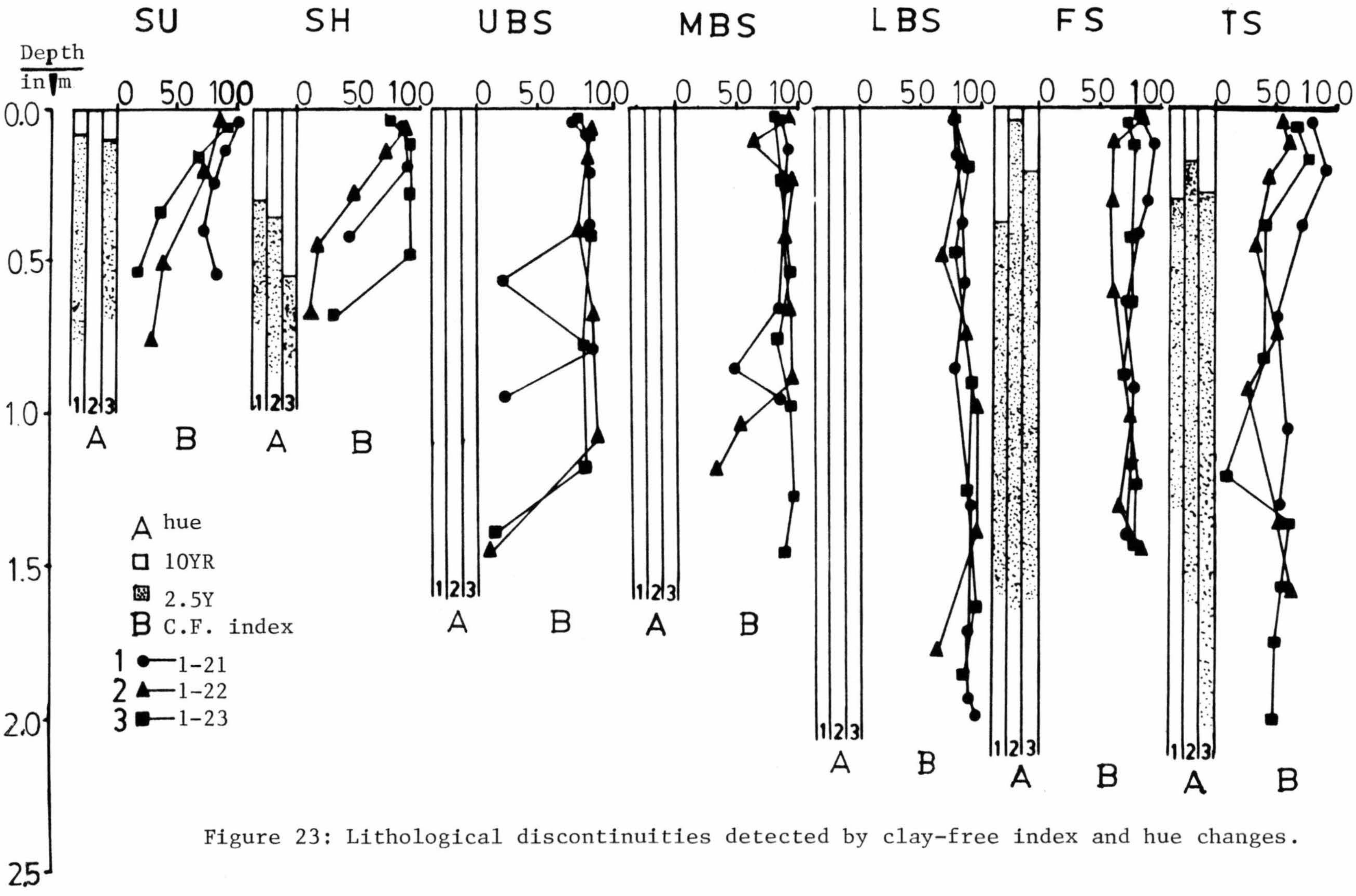

Figure 23: Lithological discontinuities detected by clay-free index and hue changes.

Soils on the SU of all 3 transects are covered with a veneer of sandy material as shown on Figure 23. There appears to be a gradual discontinuity from the surface downward in soils of all three SU positions. There appears to be a sharper discontinuity in the soils of the SU positions of transects 1-22 and 1-23 as compared to 1-21. There is a large change in hew (10YR to 2.5Y) at the 10 cm depth and only a slight decrease in sand on transect 1-21. There is a large change in sand at the 13 cm depth and no change in hue with depth on transect 1-22. There is a change on both clay-free index and color at the 9 cm depth on transect 1-23. The hew change from 10YR to 2.5Y suggests a change from sandy material to shale derived parent material. The change in clay-free index suggests the same. The data indicate that lithologic discontinuities do occur in the soils of the SU position but that the discontinuities are not uniform across transects. This suggests that the landscape unit studied, even though it has similar slope components, the same aspect and a similar general appearance, in fact is not the same situation.

Lithologic discontinuities also occur in soils of all three transects on the SH position. The upper part of the solum appears to be either eolian or loosely cemented sandstone with a hue of 10YR changing to 2.5Y in the subsoil. Changes in hue and particle size indicate changes to shale on transects 1-21 and 1-23, and to siltstone on transect 1-23. The sandy surface is much deeper in transect 1-23, a function of eolian deposition on this landscape segment which will be discussed later.

A pattern similar to that of the SH occurs at the UBS position. The difference is that the sandy surface material is much deeper on all three transects and is shallowest on transect 1-21. The MBS position is again similar to the others, in that sandy material occurs on the surface of all soils on all three transects. However, there is a wide range of variability in the subsoils.

The soils of the LBS position are characterized by very deep sandy profiles with only slight changes in clay-free index throughout. However, hue changes from 10YR to 2.5Y at 23, 4 and 60 cm in soils on transects 1-21, 1-22, 1-23 respectively,indicate lithologic discontinuities. Buried soils occur at different depths in soils of all three transects suggesting water and /or wind deposition over a previously developed soil. Stratification of materials is present in all soils, and there appears to be a high degree of variability among soils on the same landscape position in depth and thickness of the varying layers.

Hue changes from 10YR to 2.5Y at depths of 37, 2 and 20 cm for soils on the FS of transects 1-21, 1-22, and 1-23 respectively, indicating possible discontinuities. These may not reflect actual lithologic discontinuities, but do indicate (as for other landscape segments) a high degree of variability among soils within the same landscape position with respect to depth and thickness of varying layers.

Soils on the TS position are similar to soils of other landscape positions in that they are characterized by a sand layer overlying a clay layer at depths of 30, 17, and 27 cm for transects 1-21, 1-22, and 1-23 respectively. Hue changes from 10YR to 2.5Y also occur at these depths.

In summary, the clay-free index and hue changes indicate lithologic discontinuities indeed occur, and that they vary within as well as among landscape positions. This makes it very difficult to interpret the effect of topography on soil development and erosional processes. It appears from this analysis that the complex interactions of parent material x erosional processes and erosional episodes x time are important in controlling soil property-landscape relationships.

The ensuing discussion is an attempt to develop a partial understanding of these complex interactions. An effort is made to evaluate the particle size distribution relationships of the soils as a function of changes in landscape position.

Particle Size Relationships of A and B Horizons

The results of the particle size analysis are shown in Tables 11, 12, 13. Table 11 shows the percentages and distribution of the sand, silt and clay fractions in A and B horizons of soils along transect 1-21. The A horizon texture is sandy loam from the SU to the LBS and sandy clay loam for the FS and TS. Percent clay is similar from the SU to the TS with the lowest at the LBS (16.3%), and the highest (20.5%) at the FS and the TS respectively. The difference in clay content in the surface layer across all landscape segments is very small, which suggests there is very little water movement from the upper slopes to the lower slopes in this transect.

Silt is 0% for the surface horizon at the SU of transect 1-21 and increases downslope. Three landscape positions show marked increases in silt content: the UBS (13.7%), LBS (17.4%), and TS (14.8%). The increase on the upper and LBS appears to be wind related while water appears to be the agent involved in increased silt content of the TS.

All B horizons are argillic with sandy clay loam texture and prismatic or blocky structure. Structure grade is weak on higher landscape components and becomes strong to very strong downslope. This coincides with an increase in clay (Table 11). Clay content of the B horizon is higher downslope as evidenced by sandy clay and clay textures at the FS and TS respectively.

The distribution of silt in the B horizon of soils in this transect indicates:

(1) A relatively high percentage at the SU and SH reflecting a strong parent material influence (sandstone, 19-25% silt).

(2) A peak of 13.5% at the LBS.

(3) Low silt content of 3.4% at the FS.

The latter relationships may be attributed to the local wind pattern. Winds out of the west would be expected to lose their strength on the leeward, east facing backslope, resulting in the deposition of those materials carried in suspension. The increased amount of silt from the FS to the LBS may have resulted from the movement of material to these positions by saltation. The increased amount of silt and clay at the TS modified by the presence of buried horizons on this transect may have been the result of water activity of the higher components runoff and/or the effect of stream.

For soils of transect 1-22 (Table 12) the texture of the A horizon varies from sandy loam to sandy clay loam, and clay loam proceeding from the upper to the lower landscape components. At the SU the clay (16-17%), increases to 20% at the UBS and FS and to 29% at the TS. This increase may be the result of more recent water activity.

TABLE 11:Particle Size Analysis and Clay-free Index for Transect 1-21.

COMP.	HORIZ.	SAND%	SILT%	CLAY%	INDEX
SU	A	80.2	0.0	19.8	1.000
	B	68.6	7.7	23.6	.899
	IIBCt	51.8	12.0	36.3	.812
	IICr	52.4	20.0	27.7	.724
	IIICr	64.6	13.9	21.6	.823
SH	A	72.9	7.7	19.4	.904
	Bt	60.5	9.8	29.7	.861
	Cr	17.3	24.8	58.0	.411
UBS	A1	68.9	13.7	17.4	.834
	A2	72.9	7.7	19.4	.904
	Bt1	70.7	5.7	23.6	.925
	Bt2	70.7	5.7	23.6	.925
	C	6.8	24.8	68.5	.215
	IIBCt	75.0	5.7	19.4	.929
	IICr	6.8	24.8	68.5	.215
MBS	A1	70.9	9.7	19.4	.880
	A2	79.0	5.7	15.4	.933
	Bt1	66.6	8.0	25.5	.893
	IIBt2	55.9	12.0	32.1	.823
	IICr	20.1	22.6	57.3	.471
	IIICr	72.1	11.5	16.4	.862
LBS	A	66.3	17.4	16.3	.792
	Bt1	55.8	13.5	30.7	.805
	IIBt2k	56.5	10.8	32.7	.840
	IIIC1	56.5	10.8	32.7	.840
	IIIBtb	48.4	14.8	36.8	.766
	IIIBC	64.0	7.4	28.6	.896
	IIIC2	68.8	8.7	22.5	.888
	IIIAb	68.8	8.7	22.5	.888
	IVC3	72.8	6.7	20.5	.916
FS	A	66.7	12.8	20.5	.839
	Bt1	74.1	3.3	22.5	.957
	Bt2	71.4	8.2	20.5	.897
	Bt3	58.7	12.7	28.6	.822
	IIBt4k	43.7	16.6	39.7	.725
	IIBt5	49.4	13.1	37.6	.790
	IIBC	45.2	13.1	41.7	.775
	IIC	48.4	16.5	35.1	.746
TS	A	64.7	14.8	20.5	.814
	Bt1	72.1	5.4	22.5	.930
	IIBt2k	43.1	15.2	41.7	.739
	IIBt3k	29.2	22.8	48.0	.562
	IIBt4	32.7	17.2	50.1	.655
	IIBC	26.5	23.5	50.1	.530

TABLE 12:Particle Size Analysis and Clay-free Index for Transect 1-22

COMPON.	HORIZ.	SAND%	SILT%	CLAY%	INDEX
SU	A1	72.1	11.5	16.4	.862
	A2	68.8	6.7	24.6	.911
	Bt1	58.6	25.0	16.4	.701
	IIBt2	11.7	19.4	69.0	.376
	IICr	6.0	14.3	79.7	.296
SH	A	73.1	10.3	16.6	.876
	Bt1	50.9	16.4	32.7	.756
	IIBt2	18.7	19.7	61.6	.487
	IICB	5.2	26.8	68.0	.162
	IICr	3.5	26.8	69.7	.116
UBS	A	75.1	4.6	20.3	.942
	AB	71.4	6.1	22.5	.921
	Bt	61.5	7.5	31.0	.891
	BC	76.9	4.1	19.0	.949
	C	81.0	2.8	16.3	.967
	IICr	11.1	31.5	57.4	.261
MBS	A	75.1	8.1	16.9	.903
	AB	53.6	29.6	16.9	.644
	ABb	75.8	4.4	19.8	.945
	Bt	65.0	8.2	26.7	.888
	CB	74.9	4.1	21.1	.948
	C	81.1	2.8	16.1	.967
	IIBtb	27.2	25.0	47.8	.521
	IICr	17.4	33.9	48.7	.339
LBS	A	62.7	18.3	19.0	.774
	Bt	61.3	8.0	30.7	.885
	IIBtb1	37.5	19.3	43.2	.660
	IIBtb2	69.5	10.2	20.3	.872
	IIICB	71.5	3.9	24.6	.948
	IIIAb	77.6	3.9	18.5	.952
	IVBtb	48.0	22.1	29.8	.685
FT	A	64.7	15.0	20.3	.812
	Bt1	38.4	21.8	39.9	.638
	Bt2	38.3	22.7	39.1	.628
	Bt3	42.4	20.6	37.0	.673
	BC	44.4	13.7	41.9	.764
	CB	43.1	21.6	35.3	.666
	C	65.4	12.2	22.4	.843
TS	A	40.3	30.9	28.8	.566
	Bt1	39.0	23.6	37.4	.623
	Bt2	22.3	27.3	50.4	.450
	Bt3	17.4	32.3	50.4	.350
	Bt4	26.5	25.2	48.3	.513
	Bt5	11.0	29.7	59.3	.270
	Bt6	24.4	21.0	54.6	.537
	Bt7	30.7	18.9	50.4	.619

Higher clay content at the UBS can be explained by the presence of the underlying clayey parent material on the SU and SH positions.

Percent silt (16.5%) at the SU and SH decreases at the BS and then gradually increases to the TS. This gradual increase suggests a dominating water activity while the higher silt content (18%) at the LBS indicates wind influence through saltation from the FS where the silt content is lower (15%). The B horizon of soils on the SU and SH are much more clayey then the corresponding relative components of the 1-21 transect, due to the underlying shale. This material must have influenced the whole transect and may have been the cause of the more clayey surface horizons on the higher landscape components and clay loam and clay textures at the lower landscape components.

The deep solum on transect 1-21, with the very high clay content, has been formed in a high clay environment (field observations indicate a mixing of shale parent material below 10 cm depth). The clay content increases downslope and by depth for each profile. The B horizons at the TS, with a clay content >50%, and including buried ones, indicate soils developed under a climate wetter than the present.

Percent silt is high in the B horizons of soils found on the SU and SH positions and remains high at the lower components. (The lesser amount of silt at the UBS and MBS may be an indication of translocation of silt and clay by percolation).

Surface soil textures along transect 1-23 (Table 13) are sandy loam with a clay content of 12-14% increasing to 20% at the lower components. Percent silt also shows a continual increase from the UBS to the TS. A silt content of 18% at the SH is some indication of wind

TABLE 13: Particle Size Analysis and Clay-Free Index for Transect 1-23

COMPON.	HORIZ.	SAND%	SILT%	CLAY%	INDEX
SU	A	79.8	6.1	14.1	.929
	Bt1	41.8	18.7	39.5	.691
	IIBt2	21.0	37.5	41.6	.359
	IICr	11.8	48.3	39.9	.196
SH	A	68.2	18.3	13.5	.788
	AB	76.3	8.2	15.5	.903
	Bt	70.6	5.4	23.9	.929
	C	76.3	8.2	15.5	.903
	IICr	19.7	43.7	36.6	.311
UBS	A1	73.9	14.8	11.7	.833
	A2	81.3	6.1	12.7	.930
	Bt1	77.6	6.1	16.3	.927
	Bt2	74.3	6.1	19.6	.924
	CBk	75.3	9.2	15.5	.891
	C1	72.3	10.2	17.6	.876
	IICr	4.9	34.1	61.0	.126
MBS	A	70.5	16.9	12.7	.707
	Bt1	74.3	10.2	15.5	.879
	Bt2	71.9	6.2	21.9	.921
	BCk	63.7	12.4	23.9	.837
	C1	76.3	4.1	19.6	.949
	C2	80.4	2.0	17.6	.976
	C3	73.6	8.9	17.6	.892
LBS	A	66.2	20.4	13.5	.764
	Bt1	68.2	10.2	21.6	.870
	Bt2k	56.8	18.5	24.7	.754
	C1	72.3	8.2	19.6	.898
	C2	64.4	12.1	23.5	.842
	C3	71.5	6.8	21.6	.913
	Ab	80.6	6.1	13.4	.930
	C4	72.3	14.3	13.5	.835
FS	A	58.0	22.4	19.6	.721
	Bt1	53.4	16.5	30.1	.764
	Bt2	50.9	16.7	32.5	.753
	C1	46.7	18.7	34.6	.714
	C2	56.2	14.4	29.4	.796
	C3	61.6	14.4	23.9	.811
TS	A	53.4	26.8	19.8	.666
	Bt1	53.4	16.5	30.1	.764
	Bt2	20.1	28.8	51.1	.411
	Bt3	18.0	28.3	53.7	.389
	Bt4	2.8	33.3	64.0	.078
	Bt5	31.2	20.2	48.6	.607
	Bt6	22.2	17.7	60.1	.556
	Btb1	19.3	20.6	60.1	.484
	C	27.1	36.6	36.3	.425

activity while along the BS the gradual increase of silt and clay indicate the dominating factor to be water.

The B horizons of soils along transect 1-23 range from sandy clay loam to clay, have prismatic to subangular blocky structure ,and show a high clay content at the SU. This is mostly due to the underlying clayey parent material. Clay content decreases towards the MBS but increases again from the LBS to the TS. Structure is weak in all soils of the landscape components except at the TS where it becomes very strong.

Silt content is higher (19-37%) at the SU as influenced by the silty clay loam texture of the subsoil. At the SH the silt is (5.5%) and shows a gradual increase on the lower landscape components. B horizons of soils along this transect have a lower clay content than the soils on similar landscape components on the other two transects. There is very high accumulation of clay and silt on the TS which reinforces the idea of water activity being dominant factor in soil redistribution. Deposition at the TS is a combined function of its relationship to higher components on the catena as well as its relationship to the floodplain.

Sand Sieving for the A Horizon

To further evaluate the particle size relationships the method of sand sieving was used. The A horizon in particular was examined by comparing soil fractions represented by the following sieve sizes (14,18,25,35,45,60,80,120,170,230,and 325 mesh). Based on the method of Folk (1974a), the graphic mean grain size (Mz), the inclusive graphic standard deviation (Si), the skewness $Sk= \sum_{i=1}^{n}(Xi-m)3/n$ and the mode were estimated for each site.

Although this sorting estimation technique has been questioned by several workers,(Sedimentation Seminar 1981) it was felt this method might aid in evaluating factors responsible for the particle size relationships found (M.R.Leeder, 1982). Plotting the Mz against the Si for all the surfaces (Figure 24) we find :

On transect 1-21 ,the surface horizons of soils on the SU, SH and UBS consist of fine sands and are better sorted in comparison to those on other landscape components. Coarse sand is found downslope and the sorting is poor.

On transect 1-22,the (ϕ) values are similar and are associated with a shorter sorting range. This is not true for the FS and TS which have poorer sorting, especially the TS which has finer sand classes.

On transect 1-23 the surface soils of the SU and the TS are the coarsest although the sorting is intermediate and poor respectively. The rest of the sites on this transect have small differences in the means and standard deviation.

On this same figure we see a discrimination between FS, TS (sorting and wide range of sand classes) and the other components which show a smaller range of sand classes and finer textured, better sorted parent material.

This supports the hypothesis that wind activity may be an important factor at the higher landscape components while water influences the lower landscape components. The SU of the 1-23 transect must have been subjected to stronger wind sorting influence as it has coarse sands. Fine sands found at the SH and the UBS of the same transect as well as the upper components of the other transects.

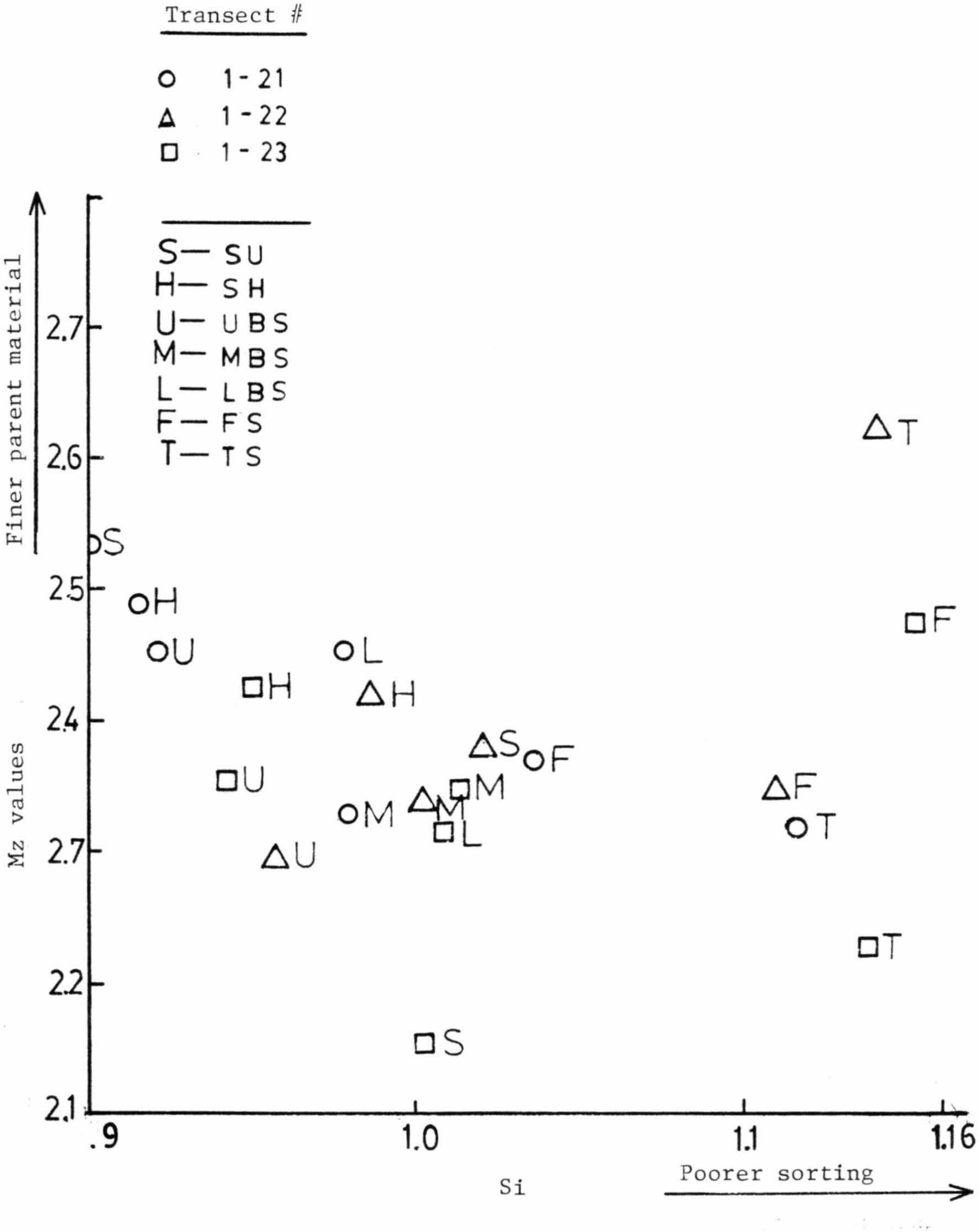

Figure 24: Plotting Mz vs. Si of sieved sands of the surface horizon along the three transects of the catenary sequence.

Plotting the skewness vs. the standard deviation we are able to relate the finer or coarser material to the intensity of sorting activity of the climatic factors. On Figure 25, samples positively skewed on the finer material would be expected to be influenced by the wind activity showing the higher frequencies on the coarser classes while the samples negatively skewed to finer material show higher frequencies on the coarser classes. Sorting also is better at smaller standard deviations.

Results indicate a strong discrimination between the upper landscape components, with the BS showing a positive skewness and small standard deviation, which leads to the conclusion that their higher frequencies are in the coarser classes and better sorting occurs, the FS and the TS including the SU and SH of the 1-22 transect have the higher frequencies in finer classes (negative skewness) and show worse sorting. Again by looking at the skewness we are led to support the possibility that wind is very influencial on the SU, SH and BS, and water activity is influencing particle size relationships on the FS and TS which show negative skewness.

The SU and the SH positions of the 1-22 transect are included in the group of lower landscape positions with negative skewness though their sorting is in average of the area. This suggests conditions of both erosional-depositional activities. Probably the wind is striking this area in a different way then the other two SU. Lower elevation (37 cm less than the 1-23 SU) may be a critical influential factor on both becoming a depositional area as influenced by the north wind direction and receiving an amount of the runoff from the same area.

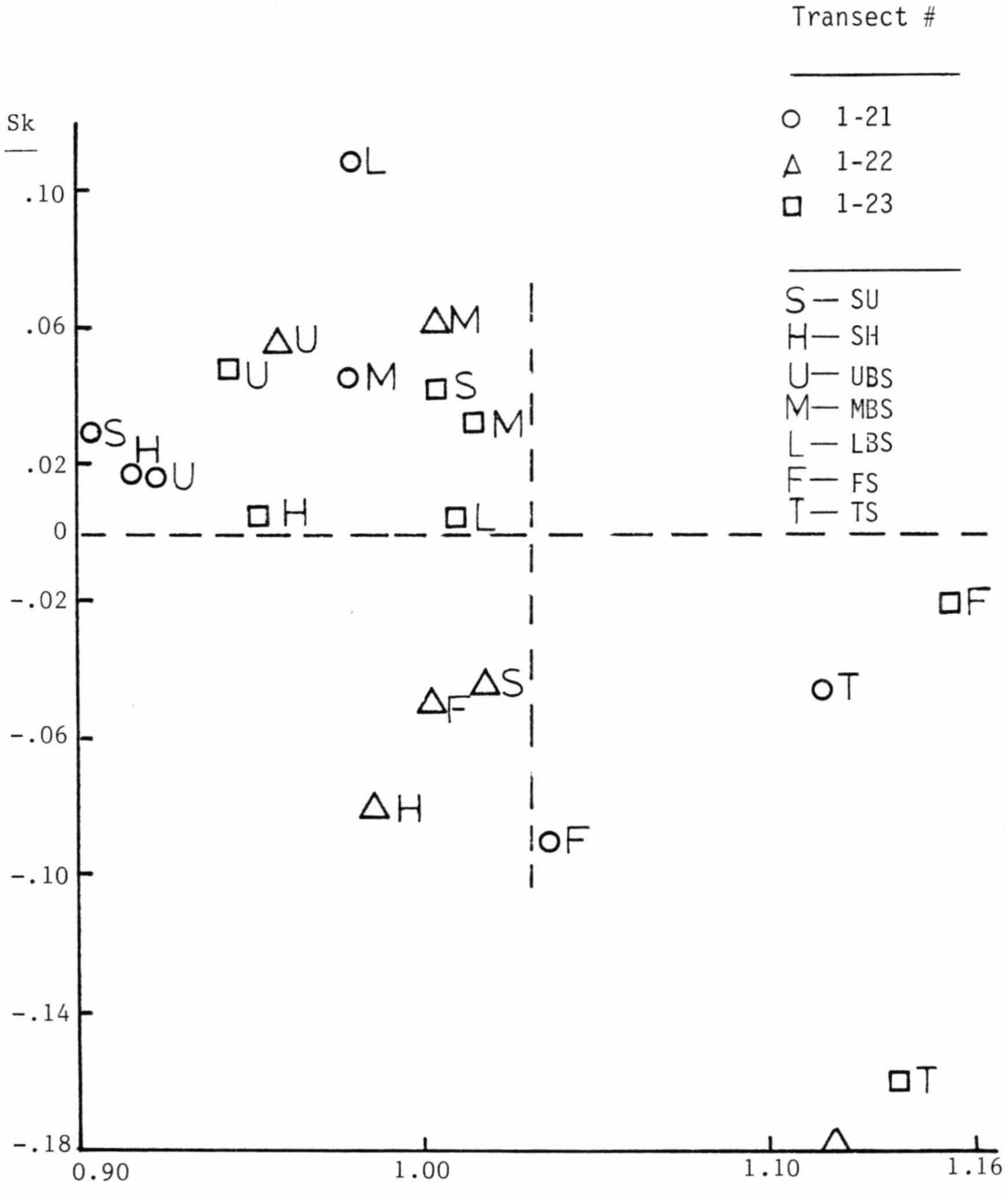

Figure 25: Plotting Sk vs. Si of sieved sands of the surface horizon along the three transects of the catenary sequence.

Plotting the mode vs. the standard deviation (Figure 26) relates the most frequent class of sands with the sorting activity of each site. A trend of poorer sorting where sand classes have a higher frequency at higher (ϕ) units (finer material) occurs.

When along with the sand the silt and clay fraction parent material is included, the general trend of each transect is not mainly changed but there is no discrimination between the higher and the lower components (Figure 27).

The skewness of each sample plotted vs. the standard deviation shows negative or small positive values for the lower components while at the higher components all values are positive with some differences between them (Figure 28).

The highest frequency (mode) is shown for the clay fraction on all the sites on the transects 1-21, 1-22. On transect 1-23 the highest frequencies of 2.0, 2.5, and 2.0 occur for the SU, UBS and MBS respectively and represent the sand fractions. The SU and the LBS show the highest frequency 5.0 (ϕ) units in the silt fraction. The FS and the TS show the highest frequency 5.5(ϕ) units in the clay fraction.

This high frequency of the sand and silt fraction may be creating specific conditions under which vegetation cover may differ from that on the other transects.

In summary the distribution of silt and clay along the landscape indicate more water activity for transects 1-22 and 1-23. There is less evidence of water activity on transect 1-21. All three transects show the influence of west winds. The increase of the fine textured material at the LBS appears to be the result of saltation. Its

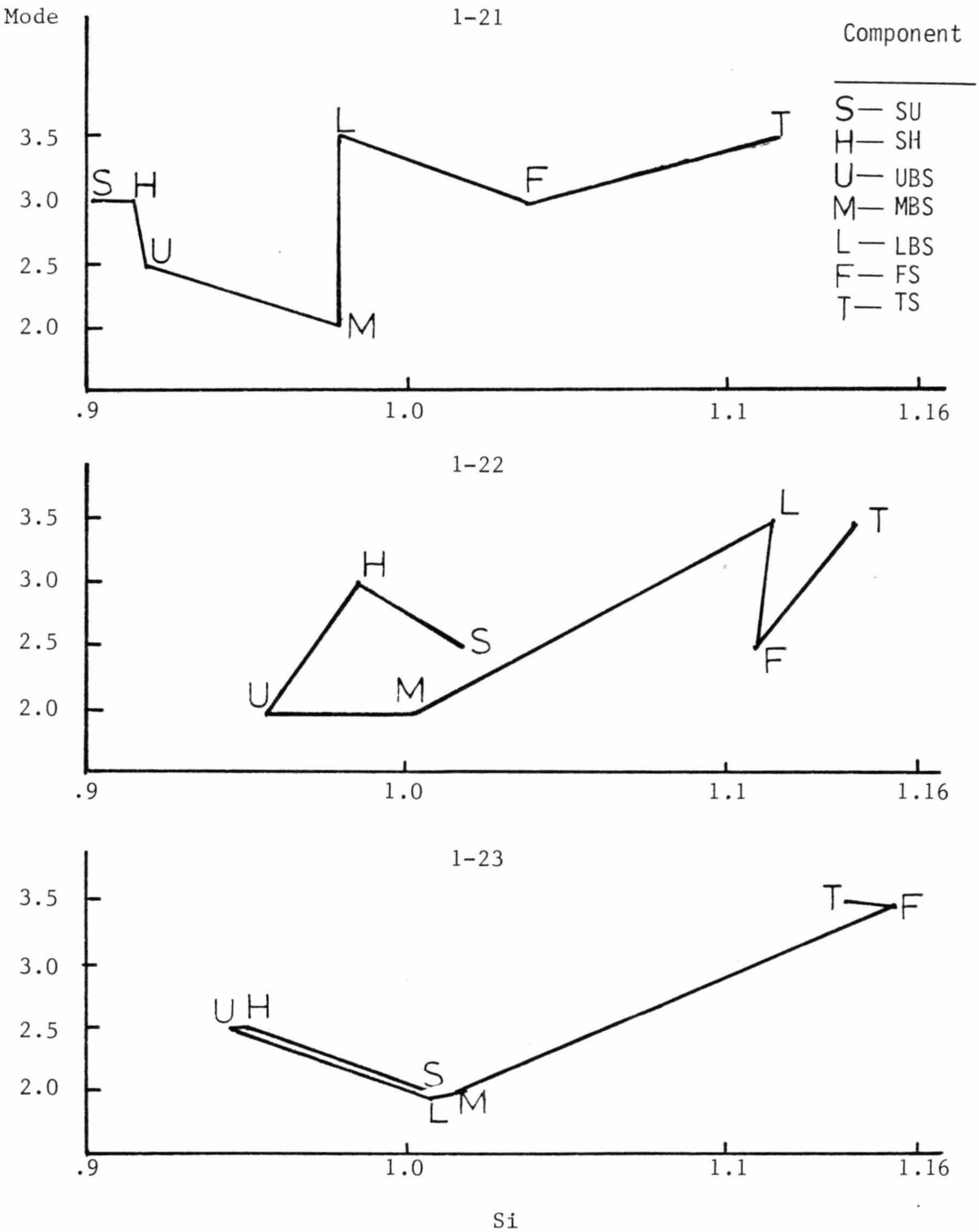

Figure 26: Plotting Mode vs. Si of sieved sands of the surface horizon along the three transects of the catenery sequence.

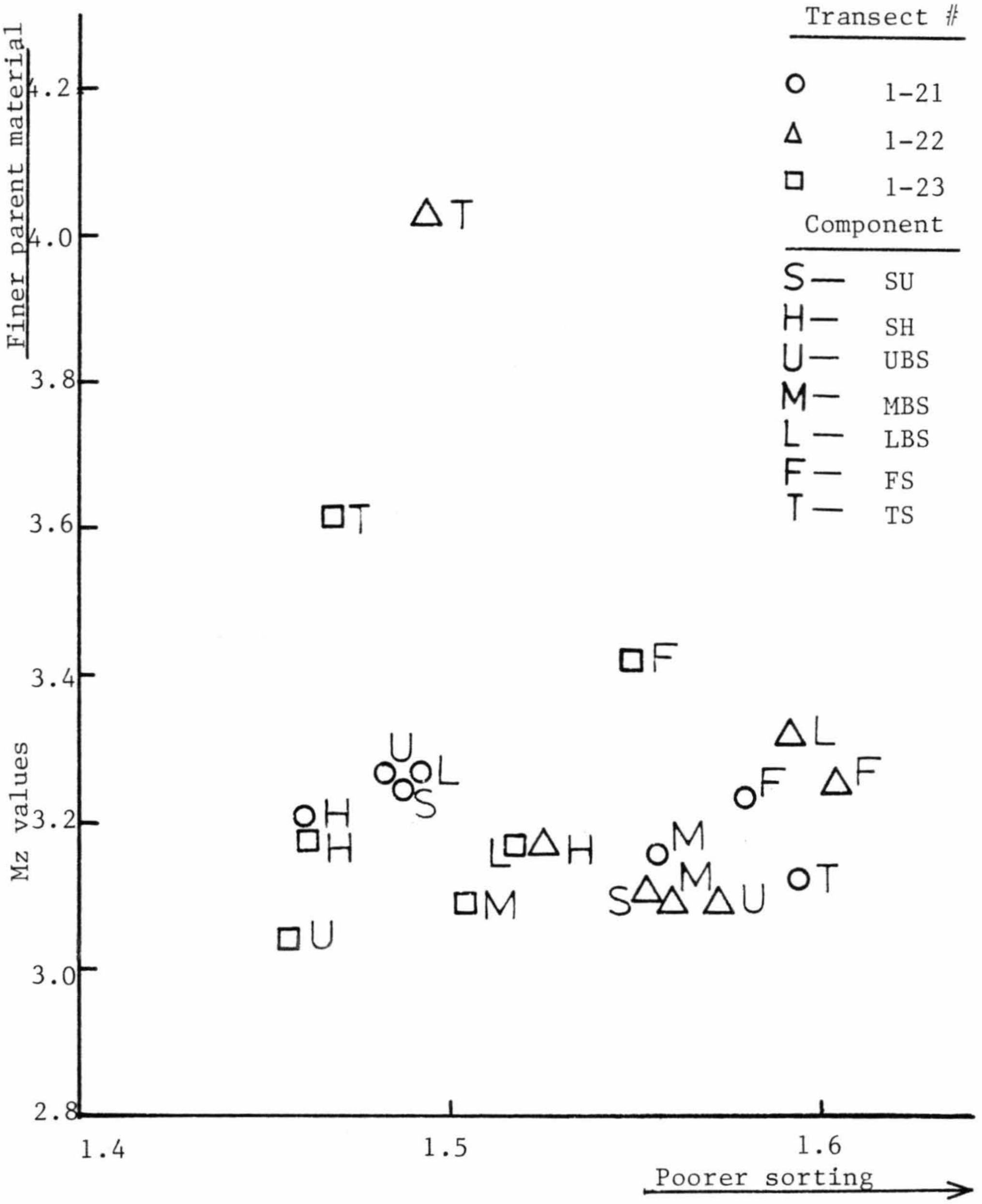

Figure 27: Plotting Mz vs. Si of sand classes,silt, and clay of the surface layer on the three transects.

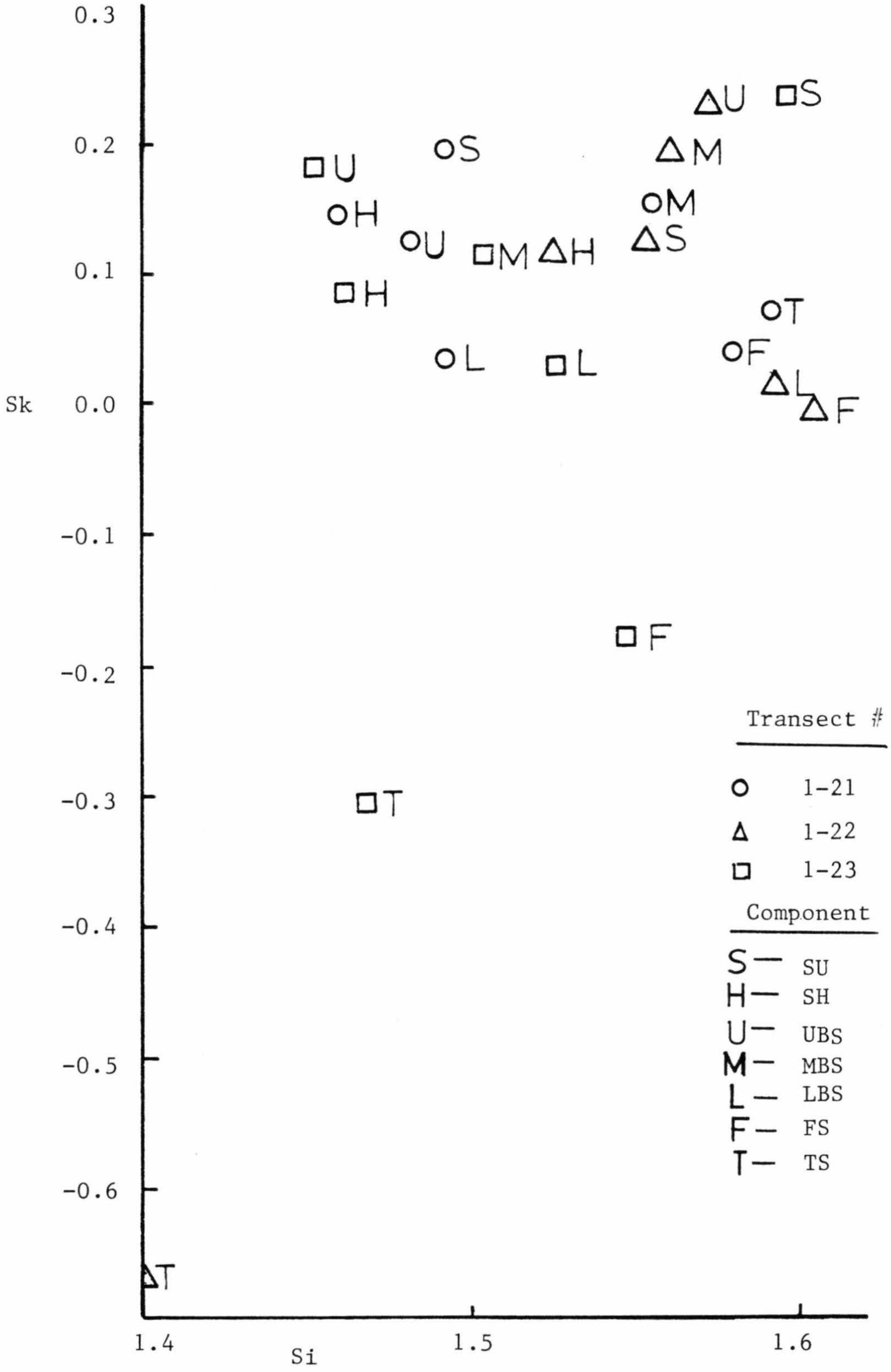

Figure 28: Plotting Sk vs. Si of sand classes,silt,and clay of the surface of the three transects.

distribution in the B horizons shows an influence of the parent material below the sandy veneer (shale,siltstone) at the SU and SH while water activity obviously has influenced the lower components, especially the influence of a previous wetter climate. Sand sieve analysis has also indicated stronger wind effect at the higher catenary components (finer better sorted sand classes). Coarser sands and poorer sorting at the lower components indicate once again stronger evidence of water activity.

CHEMICAL PROPERTIES

The chemical properties of the soil are influenced by all five factors of the soil formation. Topography affects soil development by movement of materials and modification of the climate. Parent material affects soil development due to its chemical and physical characteristics. Interaction of vegetation, parent material and topography through time are the controlling factors on the chemical, physical and biological properties of the soil.

In this study, we were interested in how organic carbon, nitrogen and phosphorus change within soils and among soils across landscapes as a function of change in parent material, relief, and vegetation. Typically, organic carbon, Nitrogen and organic P vary systematically along catenary sequence. The lower slope positions are expected to have higher OC, N and organic P than the ridgetops, although this pattern may be reversed on sand hills (Barnes and Harrison 1983).

Organic Carbon and Nitrogen.

The distribution of organic carbon along the catenary sequence of our site ranges between .5% to 1% for all the surface horizons showing a continual increase from the SU down to the TS The only exception is the FS and the TS of transect 1-22 which show a decrease at the FS and a more than double increase at the TS surface (see Table 14).

The profile distribution of organic carbon in soils on the backslopes and lower slope positions show a gradual decrease with depth and an increase where buried horizons occur.

TABLE 14: Organic C and Nitrogen for the three transects.

	TRANSECT 1-21			TRANSECT 1-22			TRANSECT 1-23		
COMP.	HORIZ.	N.PPM	OC.PPM	HORIZ.	N.PPM	OC.PPM	HORIZ.	N.PPM	OC.PPM
SU	A	933	5500	A1	802	6700	A	565	4400
	B	757	5500	A2	828	5500	Bt1	1103	6000
	IIBCt	895	6100	Bt1	649	4800	IIBt2	739	8200
	IICr	741	4300	IIBt2	737	5700	IICr	556	4200
	IIICr	259	500	IICr	688	8200			
SH	A	801	4900	A	615	4300	A	882	6900
	Bt	799	6600	Bt1	1055	8000	AB	638	5000
	Cr	924	6400	IIBt2	1033	9600	Bt	611	4500
				IICB	834	8400	C	375	1900
				IICr	737	7100	IICr	1110	7600
UBS	A1	1227	8600	A	822	6900	A1	654	5600
	A2	783	4800	AB	771	5700	A2	532	3800
	Bt1	764	6200	Bt1	599	3800	Bt1	585	4800
	Bt2	550	4100	BC	370	2000	Bt2	526	4100
	C	446	4900	C	183	1100	CBk	313	2300
	IIBCt	699	2700	IICr	399	3000	C1	307	1700
	IICr	566	4900				IICr	495	3100
MBS	A1	1188	8900	A	935	8200	A	755	5500
	A2	592	5100	AB	569	4400	Bt1	522	4200
	Bt1	608	4400	ABb	561	4000	Bt2	440	3000
	IIBt2	521	2900	Bt	685	4500	BCk	444	3300
	IICr	699	4400	CB	403	2200	C1	232	1600
	IIICr	243	1300	C	266	1500	C2	183	1000
				IIBtb	527	4000	C3	182	900
				IICr	490	3900			
LBS	A	930	7500	A	1192	8900	A	1069	7700
	Bt1	740	5600	Bt	661	4500	Bt1	619	4700
	IIBt2k	437	3100	IIBtb1	515	3700	Bt2k	424	2500
	IIIC1	365	2400	IIBtb2	291	1400	C1	323	2000
	IIIBtb	353	2300	IIICB	328	1600	C2	265	1400
	IIIBC	317	2400	IIIAb	270	1800	C3	237	1500
	IIIC2	278	1300	IVBtb	424	2300	Ab	265	2200
	IIIAb	322	1900				C4	275	1800
	IVC3	263	1200						
FS	A	912	6600	A	569	4000	A	1031	9500
	Bt1	503	3500	Bt1	1005	7200	Bt1	732	5700
	Bt2	456	2700	Bt2	561	4000	Bt2	434	3200
	Bt3	478	3300	Bt3	372	2300	C1	309	1800
	IIBt4K	454	3500	BC	283	1900	C2	216	1100
	IIBt5	328	2000	CB	310	1900	C3	372	1300
	IIBC	300	2400	C	213	1300			
	IIC	316	1900						

Table 14 continued

Table 14 continued

COMP.	HORIZ.	N.PPM	OC.PPM	HORIZ.	N.PPM	OC.PPM	HORIZ.	N.PPM	OC.PPM
TS	A	1235	10300	A	2468	23300	A	1296	10200
	Bt1	717	4900	Bt1	1196	9300	Bt1	1054	7700
	IIBt2k	648	4600	Bt2	1114	8900	Bt2	837	6000
	IIBt3k	506	3600	Bt3	635	4500	Bt3	490	3200
	IIBt4	365	2700	Bt4	433	2600	Bt4	538	4400
	IIBC	466	3800	Bt5	558	4800	Bt5	436	2900
				Bt6	515	2700	Bt6	643	5200
				Bt7	554	4600	Btb1	736	6600
							C	426	2400

In soils of the FS on transect 1-22, the organic carbon levels are lower at the surface than below 10 cm. This decreased amount of OC at the surface can be explained by water activity that might have removed an amount of the OC. by runoff and may have leached another amount deeper in the profile, since both the subsurface of the same profile and the surface of the lower component show an increased amount of OC Although evidences of runoff is not shown in the area there is some evidence of transport of OC to the TS since field observations indicate the existence of an alluvial fan landscape formation at the toeslope of this transect.

A similar increase in the B horizon of the OC at an increased depth of 50cm occurs on transect 1-21. At this site parent material appears more sandy and more permeable than that at transect 1-22 explaining the higher OC accumulation at that particular depth.

The SU and the SH of the catena shows an individual pattern for each transect. On transect 1-21, both the SU and the SH show a similar pattern and similar percentages of organic carbon at the surface, similar increase at the B horizon level and a sudden drop at the SU in the sandstone parent material. This increase of the organic carbon may be the result of several events. First, organic accumulations may have been resulted by leaching through the sandy parent material of the surface or through the cracks. Cracking is a very strong characteristic of these sites due to shrinking and swelling of the underlying shale parent material and organic accumulations were discovered on the ped faces in the B horizon. The second possible source may be the shale parent material which accumulated OC at the time of its genesis.

The SU of transect 1-22 has a deep sandy parent material in which the organic carbon gradually decreases with depth and then increases in the underlying shale. On the SH of the same transect the sandy surface is very shallow and the increase of the organic carbon is higher right under the surface.

The organic carbon relationships along transect 1-23 are completely opposite of transect 1-22. Organic carbon increases in the subsoil on the SU while at the SH there is a decrease just below the surface and increases again in the lower siltstone material.

In general there is a general decrease in organic carbon for soils on all the BS and FS and an abrupt increase at the TS. There is an increase of organic carbon at the SH vs. the SU on the transects 1-21 and 1-22 , while on transect 1-23 there is a high concentration on the SU as compared to the SH (Figure 29).

The distribution of nitrogen follows the pattern of OC as shown in Figure 30. Correlating the data of N to those of the OC an r=.961 for the whole catena is found. Transect 1-21 has a correlation=.944, transect 1-22 has a correlation =.978 and transect 1-23 has a correlation = .954. This high degree of correlation shows that conclusions derived from the distribution of the OC also hold for total N.

In summary the distribution pattern of the OC and N is almost classical along the three transects (increasing slightly downslope and decreasing with depth). Water activity is obviously the controlling factor which is stronger at the TS of transect 1-22 creating an irregular decrease at the surface. The SU and SH of the catenary sequence are more highly charged with OC than the lower components

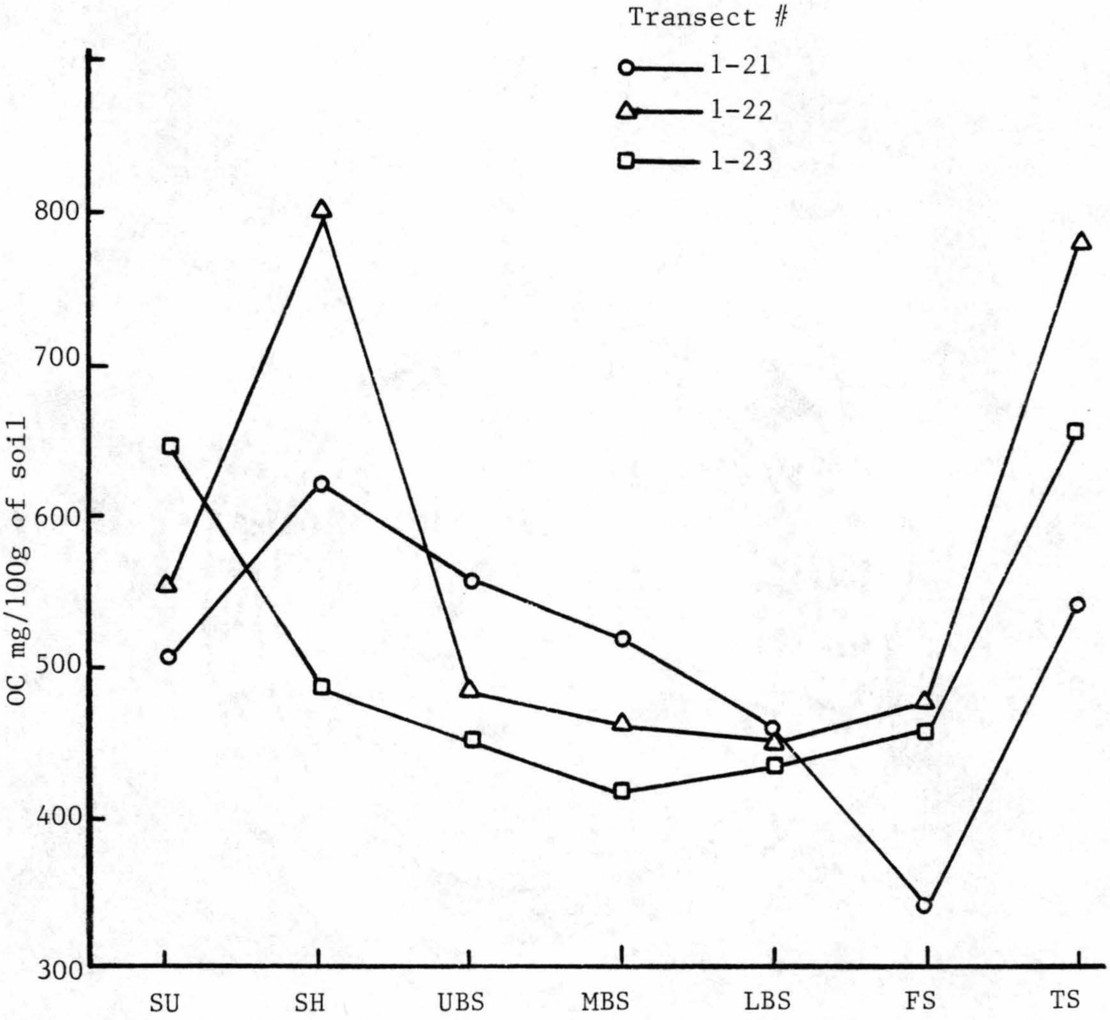

Figure 29: Average concetration of OC for a depth of 50 cm along three transects of the catenary sequence.

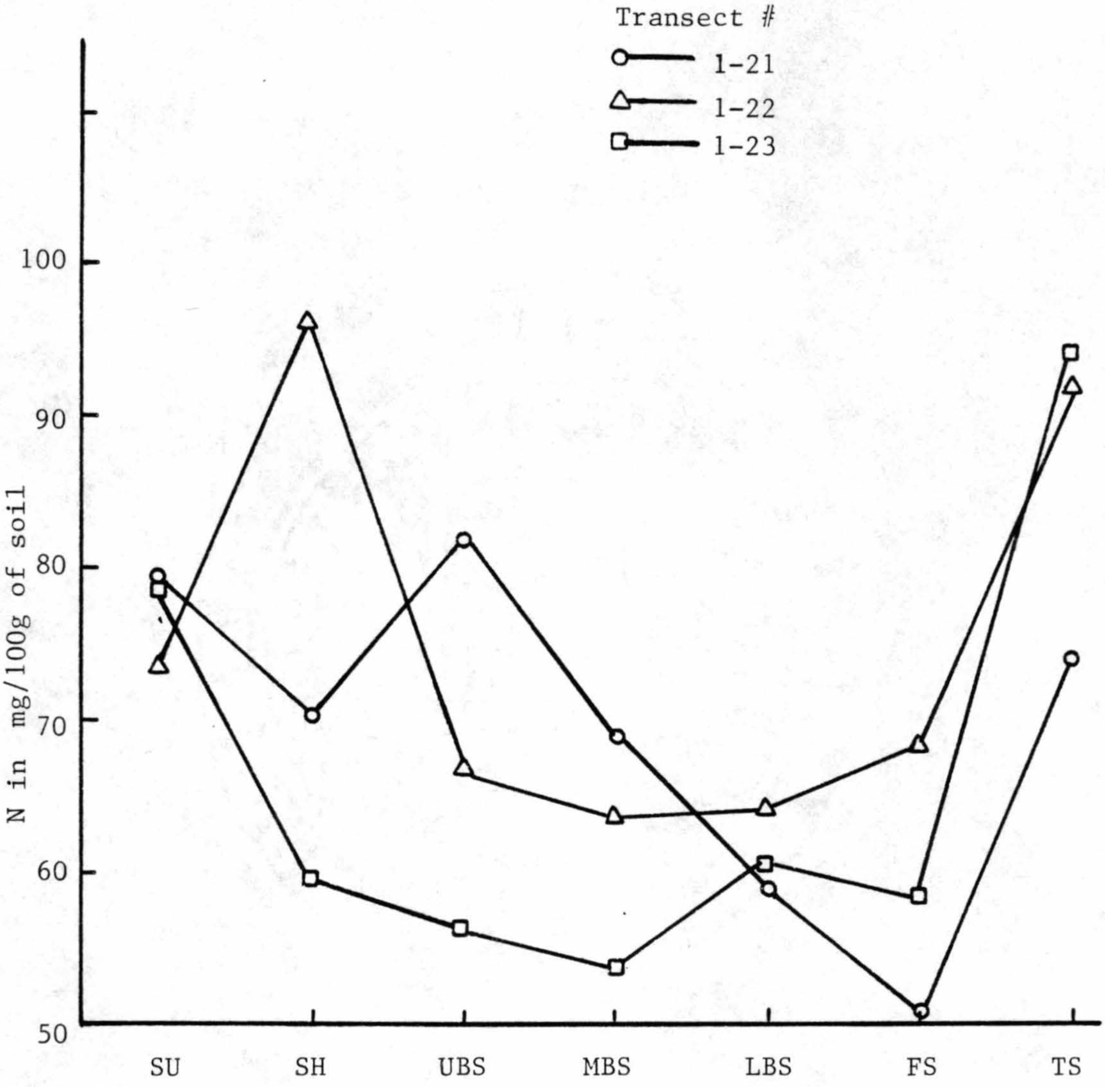

Figure 30: Average concentration of Nitrogen for a depth of 50 cm along three transects of the catenary sequence.

from the amount present in the parent material (shale). The average concentration of those two chemical properties in mg/100g of soil for a depth of 50 cm showed the pattern described by Barnes and Harrison (1983) decreasing downslope except for the TS that showed a sudden increase.

2) Organic and Total Phosphorus.

Phosphorus (P) is present in the soil in both organic and inorganic forms. Soluble P may move downslope (Smeck and Runge 1973) as well as organic P or P-enriched sediment (Sharply 1980). The distribution of P along hillslopes was used by Smeck (1973) as an indicator of processes for the movement within a profile and also the movement between the soils.

The distribution of the organic P (Table 15) shows similarities between the three transects but differences between the components of each transect. The distribution of the organic P within the soil profile of the SU, SH and UBS positions show an increase at the subsoil and a decrease at the C horizon. At the MBS after a slight decrease there is an increase in the deeper horizons. The LBS show a decrease with depth except for the transect 1-21 which shows a slight increase and then variable increases and decreases with depth.

At the FS the organic P distribution pattern differs on each transect. On the transect 1-21 there is a decrease in the subsoil then an increase followed by a continual decrease to the deepest horizon. In transect 1-22 there is an increase below the surface then it decreases (questionably) and after an increase it follows a continual decrease. In transect 1-23, it decreases with depth except for the last horizon where it increases. On the TS position there is a

TABLE 15: Organic phosphorus and total phosphorus for the three transects.

	TRANSECT 1-21			TRANSECT 1-22			TRANSECT 1-23		
COMP.	HORIZ.	TOT.P PPM	ORG.P PPM	HORIZ.	TOT.P PPM	ORG.P PPM	HORIZ.	TOT.P PPM	ORG.P PPM
SU	A	320	46	A1	342	85	A	178	79
	B	296	94	A2	237	94	Bt1	242	131
	IIBCt	342	107	Bt1	236	78	IIBt2	253	138
	IICr	315	112	IIBt2	587	99	IICr	263	57
	IIICr	249	18	IICr	341	58			
SH	A	328	66	A	256	36	A	327	60
	Bt	613	127	Bt1	224	118	AB	289	81
	Cr	3874	144	IIBt2	243	142	Bt	273	120
				IICB	195	87	C	235	51
				IICr	247	69	IICr	481	188
UBS	A1	395	92	A	254	75	A1	266	70
	A2	352	103	AB	259	117	A2	233	54
	Bt1	293	131	Bt1	258	100	Bt1	235	119
	Bt2	302	104	BC	286	49	Bt2	251	112
	C	272	70	C	236	21	CBk	236	52
	IIBCt	335	34	IICr	172	39	C1	263	41
	IICr	315	42				IICr	897	42
MBS	A1	307	73	A	291	78	A	288	73
	A2	245	52	AB	237	47	Bt1	228	82
	Bt1	238	111	ABb	241	78	Bt2	304	63
	IIBt2	295	85	Bt	238	103	BCk	382	67
	IICr	269	126	CB	312	84	C1	303	32
	IIICr	172	31	C	312	48	C2	259	13
				IIBtb	332	84	C3	312	12
				IICr	220	27			
LBS	A	320	83	A	342	99	A	289	79
	Bt1	345	102	Bt	280	97	Bt1	257	78
	IIBt2k	336	84	IIBtb1	397	69	Bt2k	295	64
	IIIC1	330	28	IIBtb2	256	25	C1	301	42
	IIIBtb	385	53	IIICB	267	30	C2	222	1
	IIIBC	344	35	IIIAb	217	44	C3	237	16
	IIIC2	320	16	IVBtb	357	72	Ab	214	33
	IIIAb	323	24				C4	272	35
	IVC3	305	36						

Table 15 continued

Table 15 continued

	TRANSECT 1-21			TRANSECT 1-22			TRANSECT 1-23		
COMP.	HORIZ.	TOT.P PPM	ORG.P PPM	HORIZ.	TOT.P PPM	ORG.P PPM	HORIZ.	TOT.P PPM	ORG.P PPM
FS	A	333	64	A	275	68	A	350	85
	Bt1	240	59	Bt1	336	120	Bt1	302	71
	Bt2	358	118	Bt2	406	6	Bt2	353	76
	Bt3	287	81	Bt3	377	40	C1	356	41
	IIBt4K	372	70	BC	397	31	C2	253	25
	IIBt5	413	54	CB	404	29	C3	253	37
	IIBC	388	22	C	305	10			
	IIC	319	49						
TS	A	366	143	A	499	205	A	416	120
	Bt1	330	120	Bt1	410	162	Bt1	286	124
	IIBt2k	320	101	Bt2	508	166	Bt2	449	121
	IIBt3k	395	71	Bt3	492	98	Bt3	438	73
	IIBt4	426	38	Bt4	451	62	Bt4	538	69
	IIBC	495	60	Bt5	571	63	Bt5	275	55
				Bt6	431	63	Bt6	437	80
				Bt7	493	81	Btb1	433	79
							C	533	67

continual decrease with depth. The quantities of the organic P seem to range similarly along the catenary sequence showing a small decrease at the MBS and a considerable increase at the TS.

Total P shows many differences between the transects and the components of the same transect as well as alternating increases and decreases with depth in the soil profile. There does not appear to be any particular pattern by which it varies. In general there is a tendency to increase with depth and downslope. It is also important to note that in most of these soils as total P increases the organic P decreases, which is an indication of advanced pedogenesis. The last is very characteristic of the TS.

To compare the organic P and the total P the average concentration in mg/100g of soil for a depth of 50 cm was estimated. The data were plot in (Figure 31). Organic P shows a characteristic uniformity on all the sites with a tendency to decrease at the MBS, LBS and FS. All transects showed an increase at the TS. Total P (Figure 31) shows a higher range of concentration at the SU between the three transects and an exceptional increase at the SH of transect 1-21. The remaining sites show smaller differences between each site and a continual increase downslope from the LBS to the TS.

The inorganic P (Figure 32) shows the same pattern as the total P. Characteristic differences among the three transects are similar to those of the organic P for the SU of three transects and the SH of the 1-21 transect. The increase down to the TS also exhibits the same pattern.

The ratio of the organic : inorganic P was plotted (Figure 33) to estimate the degree of weathering for each site. In the cases the

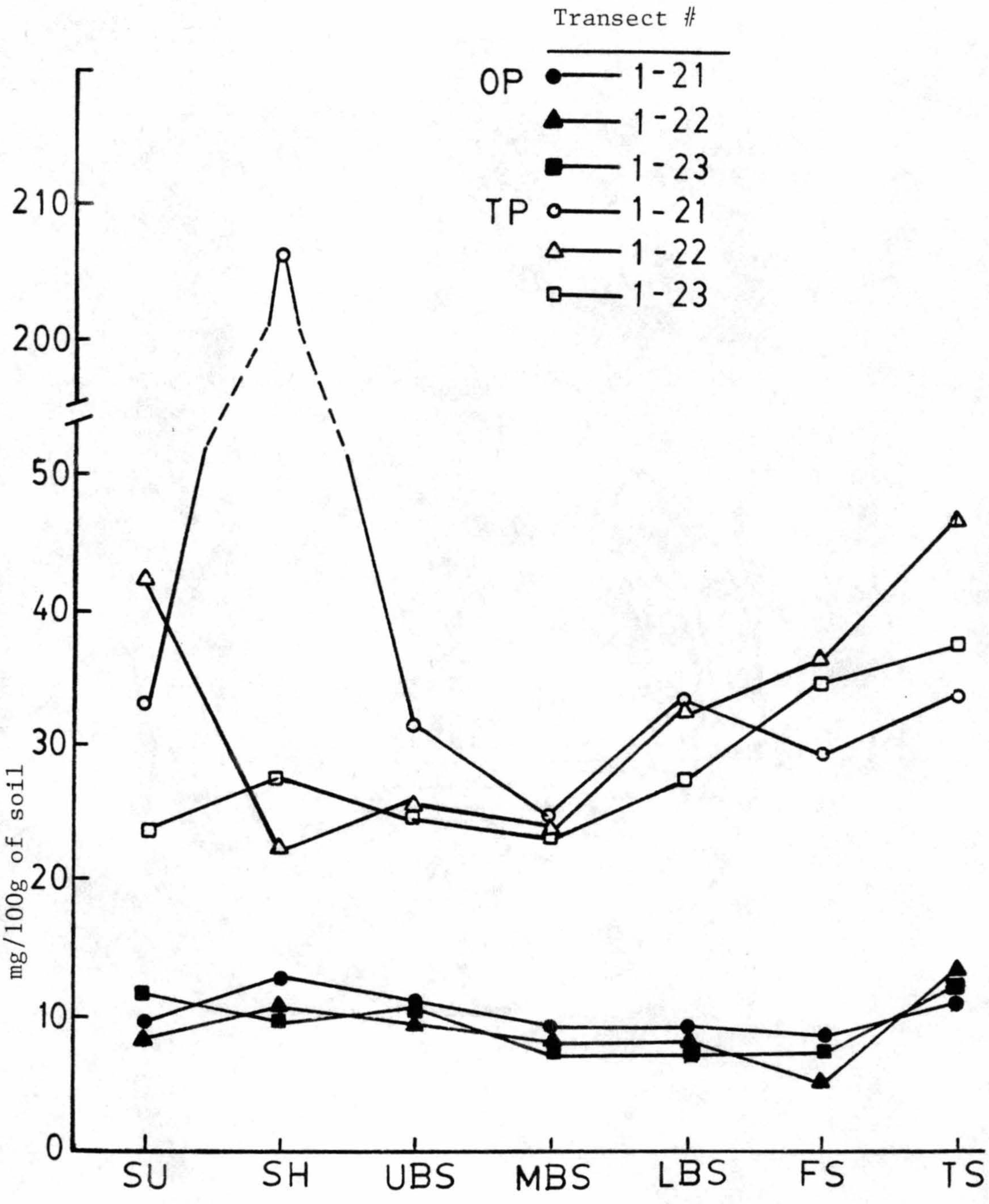

Figure 31: Average consentration of organic P and toral P for a depth of 50 cm along three transects of the catenary sequence.

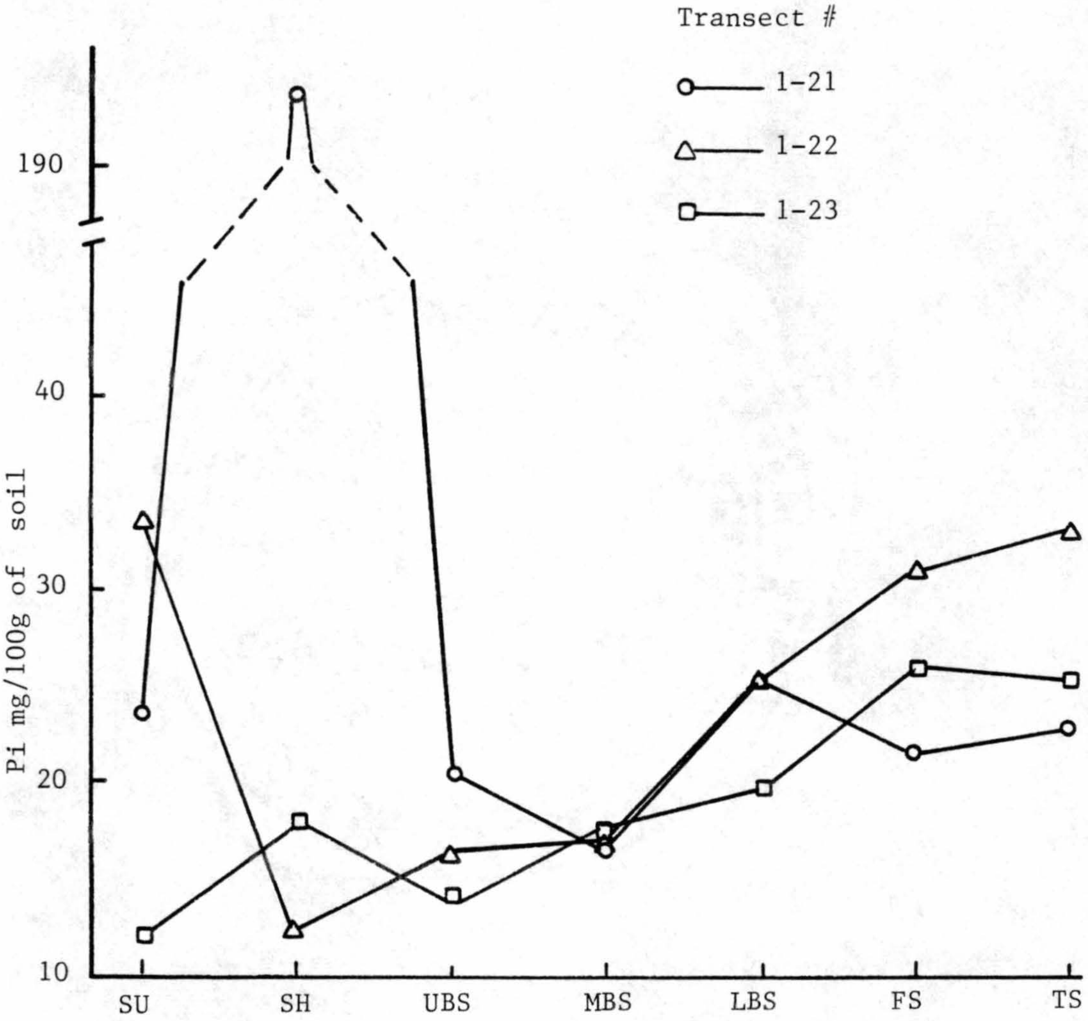

Figure 32: Average concentration of inorganic P along three transects on the catenary sequence.

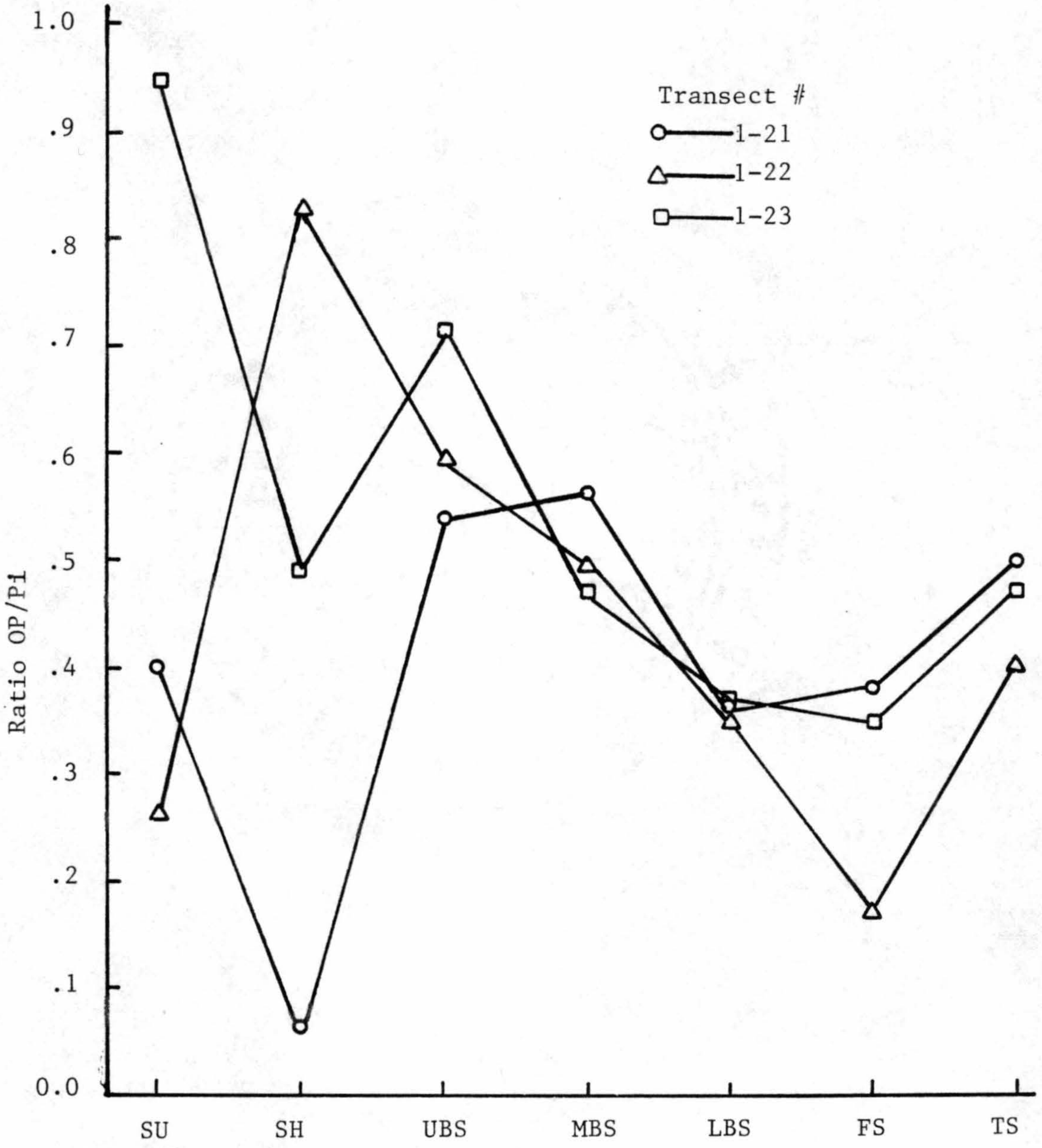

Figure 33: Ratio of organic P:inorganic P for the three transects of the catenary sequence.

ratio never exceeded 1 which indicates that the amount of the organic P was always less then the inorganic P. This is an indication that small amount of organic matter is added annually. This ratio on transect 1-21 decreases from the SU to the SH, increases at the UBS and MBS, decreases again at the LBS and FS and finally increases at the TS. On transect 1-22 there is an increase of this ratio from the SU to the LBS, a continual decrease downslope to the FS and an increase again at the TS. On transect 1-23 the ratio decreases at the SH, increases at the UBS, continually decreases downslope to the FS and increases at the TS.

Using this ratio as an index of weathering related to the erosional activity it is shown that soils on the SU of the transects 1-21, 1-22, the SH of all three transects, the MBS of the transects 1-22, 1-23, and the LBS, FS and TS of all three transects are more highly weathered and probably have experienced lower erosional activity since the balance of phosphoro-organo-compounts : inorganic compounts for the above cases shows that less is added from the first while more is contained of the second. The source of the inorganic P can be the mineralization of the organic compounts and the P-bearing minerals. Since inorganic P is the source for the production of the organic phosphorus by the plants, the balance of organic:inorganic phosphorus will depend upon the vegetation and the losses by the erosional processes at each site. In any case as fewer organic is added to the soil due to the erosional processes, the lower the organic P and the smaller the ratio of the organic to inorganic P. That indicates a slow rate of soil development and a minor influence of weathering factors at a depth of 50 cm that create differences between the components of the catenary sequence.

In summary the distribution of the organic and total P show many differences between the three transects for the relative components and many changes within each profile. Total P is influenced by the parent material (shoulder of transect 1-21). Organic P is influenced by the vegetation and shows a uniformity along the hillslope when compared as an average concentration in mg/100g of soil for a depth of 50 cm. That could be expected since vegetation is almost uniforme on the whole landscape. This uniformity also indicates stability on landscape changes. Organisms as a factor shown by the ratio OP/Pi do not appear to intensively influence soil formation.

SUMMARY AND CONCLUSIONS

This study was conducted for two reasons. First, to evaluate which factor or combination of factors (i.e., parent material, topography, biota) is/are the most important controls on soil development, soil organic matter accumulation and soil textural attributes in this environment. Second, to evaluate the spatial variability of selected soil properties and relate this variability to geomorphic form and process.

As shown, the relationship of the A horizon thickness, B horizon thickness, solum depth and landscape position appears to be quite different from the classical catenary relationship described in the literature. Changes in thickness of the A horizon indicate that erosional-depositional processes do occur in the area and further, there is evidence of both water and wind activity. Wind and water interact with topography to create a variability in A horizon thickness. The B horizon thickness exhibits the classical pattern, demonstrating the interaction of water activity and topography.

Solum depth follows the pattern of the B horizon, which indicates soil development processes are more dominant than geomorphic processes with regard to soil formation. This also indicates that soil properties reflect a previous climatic condition, apparently stable for a long period of time.

The ratio of the solum to the A horizon indicates a more stable microenvironment at the lower catenary components allowing soil development to proceed without interruption by erosion, while the higher exhibit a less stable environment for soil development and for the influence of geomorphic processes on soil development. The depth of carbonates shows a high degree of variability, and is directly influenced by the parent material, climate and topography. Secondary depositions of carbonates are evidenced by the carbonate level in comparison to the lower B horizon level.

Microrelief is very critical as demonstrated by the variability of soils on comparable components of the landscape. The variability is better explained when soils are grouped by cluster analysis than when soils are related to geomorphic concepts. This demonstrates the existence of an atypical pattern for this area.

Clay free-index and hue changes indicate the occurrence of lithologic discontinuities within and among landscape positions. This made it difficult to interpret the effect of topography on soil development and erosional processes. It appears from this analysis that the complex interactions of parent material x erosional processes x erosional episodes x time are important in controlling soil property-landscape relationships.

The distribution of silt and clay indicate the dominance of water as opposed to wind activity on two of the three transects. All surface horizons of all transects show evidence of wind reworking. Better sorting and finer sandy material on the higher components indicate wind activity to be stronger. Coarser sands and poorer sorting at the lower components indicate water activity.

The parent material below the sandy veneer has influenced the distribution of silt and clay, as modified by soil development during a previous wetter climate.

The chemical properties indicate an almost classical distribution of organic carbon and nitrogen. This distribution is controlled by wind and water activity, as modified by topography. Parent material also influences chemical characteristics of the summit and shoulder due to the influence of residual C and N levels.

Organic P and total P show many differences between the transects for the relative components and within each transect. Total P is influenced by parent material and redistribution along the landscape. Organic P is uniformly distributed along the catenary sequence, possibly a function of the uniformity in vegetation along the landscape.

Morphological properties particularly of the subsoils do not appear to represent the modern day environment. The morphological, physical, and chemical properties of the surface soil appear to represent the modern day environment. Thus, what we see is evidence of soil morphological, physical, and chemical properties changing through time as a function of a change in the influence of soil forming factors through time.

In addition this study indicated there is a high degree of variability in the soils along the landscape. The climate (water and wind activity) in interaction with parent material and topography are the main factors of soil development and the cause of variability in the soil properties observed.

LITERATURE CITED

Aandahl, A. R. 1948. The characterization of slope positions and their influence on total nitrogen content of a few Virgine soils of Western Iowa. Soil Sci. Soc. of America Proceedings 13:449-454.

American Society for Testing and Materials. 1961. Tentative method for grain-size analysis of soils. In The 1961 Book of ASTM Standards. Part 4, pp. 1272-1283. Am. Soc. Testing Mater., Philadelphia.

Bagnold, R.A. 1941. The Physics of blown sand and desert dunes, London: Methacen and Co.

Barnes, P. and A. T. Harrison. 1982. Species, distribution and community organization in a Nebraska sandhills mixed prairie as inluenced by plant-soil-water relations. Ecologia 52:192-202.

Beasley, R.P. 1972. Erosion and sediment pollution control. Iowa State Univ. Press, Ames, Iowa.

Bennett, H.H. 1939. Soil conservation. McGraw-Hill Book Company, Inc. New York and London. pp. 125-169.

Bennett, H.H. 1955. Elements of soil conservation. McGraw-Hill Book Company, Inc. New York and London.

Bertolin, G. and J. Rasmussen. 1969. Preliminary report on the study of the precipitation on the Pawnee National Grassland. U.S. IBP Grassland Biome Tech. Rept. No. 17, Colorado State Univ., Fort Collins, Colorado. 34pp.

Bockheim, J. g. 1979. Ice core and ice cement effects on soil development, eastern Wright Valley, Antarctica N. Z. Journal of Geology and Geophysics Vol 22 No 4:487-493.

Bonferoni,:G. W. Snedesor, and W. G. Cochran,(1980) Statistical Methods seventh edition pp. 166.

Buol, S.W., Hole, F.D. and McCracken, R.J. 1973. Mollisols: grassland soils of steppes and prairies. In Soil Genesis and Classification, p. 240-246.

Carson, M. A. and Kikby, M. 1972. Hillslope form and process. London: Cambridge Univ. Press.

Chepil, W.S. 1954. Dynamics of wind erosion, the initiation of soil movement. Soil Sci. 60:397-411.

Chepil. W. S. and Woodruft, N.P. 1963. The physics of wind erosion and its control. Advances in Agron. 15:221-302.

Chittleborough, D. J. and Oades, J. M. 1980. The development of a red-browm earth. III. The degree of weathring and translocation of clay. Australian journal of soil Research 18(4) 383-393.

Cole. C. V., and R. D. Heil. 1981. Phosphorus effects on terrestrial nitrogen cycling: In F.E. Clark and T. Rosswall (eds.) Terrestrial Nitrogen Cycles: Ecological Bulletin (Stockholm) 33:363-374.

Cunningham, R.L. and Drew, J.V. 1962. Characterization and genesis of a Moody-Nora-Crofton soil sequence in northeastern Nebraska. Soil Sci. Soc. Amer. Proc. 26:191-196.

Dan, J. and D.H. Yallon. 1964. The application of the catena concept in studies of pedogenesis in Mediterranean and desert fringe regions. Int. Congr. Soil Sci. Trans. 8th (Bucharest, Romania) Paper 83. pp. 751-758.

Danielson, R.E. 1978. Soil physics laboratory manual (reviewed). Department of Agronomy, Colorado State Univ., Fort Collins, CO.

Day, P.R. 1965. Particle fraction and particle-size analysis. In C.A. Black (ed). Methods of Soil Analysis. Part I. Physical and mineralogical properties, including statistics of measurement and sampling pp. 546-567. Am. Soc. of Agron. Madison, Wis.

Dong, A., G. V. Simsiman and G. Chesters 1983. Particle size distribution and phosphorus levels in soil, sediment, and urban dust and dirt samples from the Menomonec River watershed, Wisconcin, U.S.A. Water Research 17 (5):569-577.

Eggler, D. H>, Larson, E. E. and Bradley, W. C. 1969. Granites, grusses, and the Sherman erosion surface, Southern Laramie Range, Colorado-Wyoming. Am. Jour. Sci. 267:510-22.

Engelman, L. and S. Fu. 1975. Cluster analysis on cases (BMDP2M) p. 323-337. In W.J. Dixon (ed). Biomedical computer programs (BMDP) Univ. California Press, Los Angeles.

Fenneman, N.M. and D.W. Johnson. 1946. A map of the physical divisions of the United States. U.S. Dept. of Interior, Physiographic Committee of the Geological Survey, Wash., D.C.

Folk, R.L. 1974. Petrology of sedimentary rocks. (2d ed.) Austin, Tex. Hemphill Pub. Co. 159.

Franklin, W.T. 1969. Mineralogy of representative soils at the Pawnee site. U.S. IBP Grassland Biome Tech. Rept. No. 30. Colorado State Univ., Fort Collins, Col. 10pp.

Gamble, E. E., Daniels, R.B., and McCracken, R.J. 1970. A2 Horizons of coastal plain soils: Pedogenic of geologic origin. Souteastern Geol. 11:37-52.

Gamble, E.E., Daniels, R.B., and Nettleton, W.D. 1970. Geomorphic surfaces and soils in the black Creek Valley, Johnston County, North Carolina, Soil Sci. Soc. Amer. Proc. 34:276-281.

Gardner, W.H. 1965. Water content. In C.A. Black (ed). Methods of Soil analysis. Part I Physical and Mineralogical Properties, including statistics of measurement and sampling. pp. 82-127. Amer. Soc. Agron., Masison, Wis.

Guidilin, I.S. 1973. Interpretation of landscape as an indicator of geologic structure. In A.G. Chicishev (ed). Landscape indicators. Consultants Bureau, New York. pp. 92-105.

Haidouti,C. and N. T. Yassoglou. 1982. Soil genesis of certain profiles on an Archaeological site in Sauthern Greece, Soil Science of Amer. J. 46, p.1047-1051

Happ, S. C., Rittenhouse, G.g and Dobson, G. C.1940. Some principles of accelerated stream and valley Sedimentation. U.S.Dept. Agri. Tech. Bull. 695.

Howard, A. D.,Fairbridge, R. W. and Quinn J. H. 1968. Terraces, Fluvial-Introduction. In Encyclopedia of geomorphology, edited by R. Fairbridge, pp.1117-23, New York; Reinhold book Corp.

Hudson, N. 1971. Soil Conservation. Cornell Univ. Press, Ithaca, New York.

Jameson, D.A. (coordinator). 1969. General description of the Pawnee Site, U.S. IBP Grassland Biome Tech. Rept. No. 1, Colorado State Univ., fort Collins, Col. 32 pp.

Jenny, H. 1941. Factors of soil formation. Mc Graw-Hill, New York.

Jenny, H. 1980. The soil Resource: Origin and behavior. Ecological Studies, Vol. 37. Springer-Verlag, New York. p. 201-206.

Keeney, D. R. and J. M. Bremner. 1967. A simple steam distillation method of estimating b-hydroxy-a-amino acids. Anal. Biochem 18:274-285.

Kleiss, H.J. 1970. Hillslope sedimentation and soil formation in Northeastern Iowa. Soil Sci. Soc. Amer. Proc. 34:287-290.

Klipple, G.E. and D.F. Costello. 1960. Vegetation and cattle responses to different intensities of grazing on short grass ranges of the central Great Plains. U.S. Dept. Agr. Tech. Bull. 1216. 82 pp.

Kramer, L.A., and Meyer, L.D. 1969. Small amounts of surface mulch reduce soil erosion and runoff velocity. Transaction ASAE. 12:638-641.

Kuenen, Ph H. 1960. Experiment abration for eolian action. Jour. Geology 68:427-49.

Lattman, L. H. 1960. Cross section of a flood plain in a moist region of medarate relief: Jour. Sed. Petrology. 30:275-82.

Malo, D.D. Worcester, B.K., Cassel, D.K., and Matzdorf, K.D. 1974. Soil-landscape relationships in a closed drainage system. Soil Sci. Soc. Amer. Proc. 38:813-818.

Meyer, L.D. and L.A. Kramer. 1969. Relationship between land-slope shape and soil erosion. Agric. Eng. 50(1):522-523.

Meyer, L.D. and W.H. Wischmeier. 1969. Mathematical simulation of the process of soil erosion by water. Trans. of the ASAE 12(6):754-758, 762.

Minitab, Ryan, Thomas, Arthur, 1940. Minitab student handbook. Thomas A. Ryan, Brian L. Joiner, Barbara F. Ryan. North Scituate, Mass. Duxbury Press; c1976.

Neal, J.H. 1938. The effect of the degree of slope and rainfall characteristics on runoff and soil erosion. Missouri Agricultural Exp. Station Bull. 280, 47 pp.

Norton, E.A., and Smith, R.S. 1930. The influence of topography on soil profile character. J. Amer. Soc. Agron. 22:251-260.

Rabenhorst, M. C., Foss. J. E. and Fanning D. S. 1982. Genesis of Maryland Soils Formed from Serpentine. Soil Sci. Soc. Am. J. Vol 46.

Rasmussen, J.L., G. Bertolin, and G.F. Almeyda. 1971. Grassland climatology of the Pawnee Grassland. U.S. IBP Grassland Biome Tech. Rept. No. 127. Colorado State Univ., Fort Collins, Col. 79pp.

Reuss, J.O. 1971. Soils of the grassland biome sites. pp. 35-39. In N.R. French (ed). Preliminary Analysis of Structure and Function in Grasslands. Range Science Department Series No. 10, Colorado State Univ., Fort Collins, Col.

Rose, C. W. 1961. Rainfall and soil structure. Soil Sci. 91:49-51.

Ruhe, R. V. 1956. Geomorphic surfaces and the nature of soils. Soil Sci. 82:441-455.

Ruhe, R. V. 1960. Elements of the soil landscape. Trans. 7th International Congr. Soil Sci., (Madison, Wisconsin). 4:165-169.

Ruhe, R. V. 1969a. Quaternary landscapes in Iowa. Iowa State Univ. Press, Ames,Iowa.

Ruhe, R. V. 1969b. Principles of dating pedogenic events in the quaternary. Soil Sci. 107:398-402.

Ruhe, R. V., and Scholtes. W. H. 1955. Ages and development of soil landscape in relation to climatic and vegetation changes in Iowa. Soil Sci. Soc. Amer. Proc. 20:264-273.

Ruhe, R. V., and P. H. Walker. 1968. Hillslope models and soil formation. I. Open system. International Congr. of Soil Sci. Trans. 9th (Adeliade, Australia). IV:551-560.

Russel, R. 1943. Freeze thaw frequencies in the United States. Amer. geophys. Union Trans. 24:125-33.

Saunders, W. M. H. and E. G. Williams.1955. Observations on the determination of total organic phosphorus in grassland soils. Soil Sci. 85:307-318.

Smeck, Neil E. 1973. Phosphorus . An indicator of pedogenic weathering processes. Soil Science 115 (3): 199-206.

Sharp, R. P. 1963. Wind ripples. journ. Geology 71:617-36. 1964. Wind driven sand in Coachella Valley, California. Geol. Soc. America Bull. 75:785-804.

Sharpley,A. N. 1980. The enrichment of soil phosphorus in runoff Sediments. Journal of Environmental Quality 9(3):521-526.

Smith, F. M. and W. D. Striffler. 1969. Pawnee Site microwatershieds: Selection, description, and installation. U. S. IBP Grassland Biome Tech. Rept. No. 5, Colorado State Univ., Fort collins, Co. 29pp.

Soil Servey Staff. 1975. Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys. Soil Conser. Service. U. S. Dept. of Agric. Handbook No. 436. 754pp.

Striffler, W. D. 1971. Hydrologic data, 1970, Pawnee Grasslands. U.S. IBM Grassland Biome Tech. Rept. No. 75. Colorado State Univ., Fort Collings, Co. 23pp.

Striffler, W. D. 1972. Hydrologic data at Pawnee Site, 1971. U. S. IBM Grasslands Biome Tech. Rept. No. 196, Colorado State Univ., Fort Collins, Co. 67pp.

Thompson, M. L., Smeek, N. E. and Bighorn 1981. Parent Materials and paleosols in the Teays River Valley, Ohio.

Twidale, C. R. 1968b. Weathering. In encyclopedia of geomorphology, edited by R. W. Fairbridge pp.1228-32. New York: Reinhold Book Corp.

U.S.D.A. 1982. Soil Servey of Weld County, Colorado Northern Part pp. 77-82.

Wahrhaftig, C. 1965. Stepped topography of the southern sierra Nevada. Geol.Soc. America Bull. 76:1165-90.

Walker, T. W. and A. F. R. Adams. 1958. Studies on soil organic matter: I. Influence of organic phosphorus in grassland soils. Soil Sci. 85:307-318.

Williams G. 1964. Some aspects of the eolian saltation load. Sedimentology 3:257-87.

Wischmeier, W. H. 1966. Relation of field-plot runoff to management and physical factors. Soil Sci. Soc. Amer. Proc. 30:272-277.

Wischmeier, W. H. and D. D. Smith. 1961. A universal soil-loss estimating equation to guide conservation farm planning. Trans. 7th Congr. Inter. Soil Sci. Soc. 1:418-159.

Wischmeier, W. H. and D. D. Smith. 1962. Soil-loss estimtion as a tool in soil and water managment planning. Publ. NO. 59. Inter. Assoc. Sci. Hydrol. pp. 148-159.

Wischmeier, W. H. and D. D. Smith 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains -Guide for selection of practices for soil and water conservation. Agr. Handbook No. 282, U. S. Gov't. Printing Off., Wash., D. C. 47pp.

Wood, A. 1942. The development of hillside slopes. Geol. Assoc. Proc. 53:128-138.

Young, R. A. and C. K. Mutchler. 1969. Soil movement of irregular slopes. Water Resources Res. 5(5):1084-1089.

Zavdelman, F. R., Busrgina, Ve. A., Narocova, R. p. and Shtina E. A. 1981. Moscow University, Department of soil Science, and Kirov Agricultural institute.

Zingg, A. W. 1940. Degree and length of land slope as it affects soil loss in runoff. Agr. Eng. 21:59-64.

APPENDIX

This appendix contains soil profile data for the 21 sites which constitute three transects along the investigated landscape.

Component	Horizon	Depth		-	Color	-	Structure			Coarse
	Name	Range (cm)		Dry	Moist	Crushed	Primary	Secondary	Roots	Frag %
SU	A	0	8	10YR4.5/3	10YR3/2	10YR3/3	X X GR		Many	1
	B	8	18	2.5Y4/4	10YR4/6	2.5Y4/4	1 C BK	1 C SBK	Many	1
	IIBCt	18	30	2.5Y4.5/4	10YR5/6	2.5Y4/4	1 C BK	1 F SBK	Common	1
	IICr	30	49	2.5Y6/6	2.5YR6/6	2.5Y5/6			Many	
	IIICr	49	58	10YR6/6	10YR5/6	10YR5/6			Few	
SH	A	0	9	10YR4.5/3	10YR3/3	10YR3/2	X X GR		Many	1
	Bt	9	27	10YR4.5/3	10YR3/3	10YR3.5/3	2 C BK	1 M BK	Many	1
	Cr	27	56	2.5Y6/3	10YR4/6	2.5Y5/3			Few	
UBS	A1	0	6	10YR4/2	10YR3/3	10YR3/3	X X GR		Many	
	A2	6	11	10YR4.5/3	10YR3/4	10YR3/3	1 M BK	1 F GR	Many	
	Bt1	11	30	10YR4.5/3	10YR3/4	10YR3.5/3	1 C PR	1 M SBK	Many	
	Bt2	30	46	10YR5/3	10YR4.5/3	10YR4.5/3	1 C PR	1 M SBK	Common	
	C	46	66	10YR5/3	10YR5/3	10YR4.5/3	0 X M		Common	1
	IIBCt	66	91	10YR7/1	10YR5/1	10YR5.5/1	1 C PR		Common	
	IICr	91	97	10YR6/1	5Y3/1	2.5Y5/2			Common	
MBS	A1	0	7	10YR4.5/3	10YR3/2	10YR3/3	1 X GR		Many	1
	A2	7	20	10YR4.5/3	10YR3/3	10YR3/3	1 C BK	1 F GR	Many	1
	Bt1	20	50	10YR4.5/3	2.5Y4/4	10YR3/3	2 C PR	2 F SBK	Common	1
	IIBt2	50	80	10YR5.5/3	2.5Y4/2	2.5Y4.5/3	2 C PR	2 F SBK	Common	1
	IICr	80	91	2.5Y6/6	2.5Y5/6	10YR4.5/2	0 X M		Few	
	IIICr	91	99	10YR6/8	10YR4/6	2.5Y5/6			V Few	
LBS	A	0	8	10YR5/3	10YR3/2	10YR4.5/3	X X GR		Many	1
	Bt1	8	23	10YR5/3	2.5Y4/4	10YR4.5/3	2 M SBK	2 F SBK	Many	1
	IIBt2k	23	52	10YR5/3	5Y4/3	2.5Y5/3	1 C PR	1 M SBK	Many	1
	IIIC1	52	63	2.5Y5.5/2	5Y4/3	2.5Y5/3	0 X M		Common	1
	IIIBtb	63	107	2.5Y5.5/2	5Y4/2	2.5Y4/3	1 C PR	1 F SBK	Common	1
	IIIBC	107	153	10YR5/3	5Y4/3	2.5Y4.5/2	1 C PR	X X GR	Common	1
	IIIC2	153	190	10YR5/3	2.5Y4/2	2.5Y4/2	0 X M		Few	1
	IIIAb	190	196	10YR5.5/3	5Y3/2	2.5Y4/2	X X GR		Few	1
	IVC3	196	203	10YR6/4	10YR5/3	10YR4.5/3	0 X M		Few	1
FS	A	0	3	10YR4/2	10YR3/2	10YR3/3	X X GR		Many	1
	Bt1	3	22	10YR5.5/4	10YR3/6	10YR4.5/3	1 C BK	1 M SBK	Many	
	Bt2	22	37	10YR5.5/4	10YR4/3	10YR4.5/3	1 C PR	1 M SBK	Common	
	Bt3	37	47	10YR5.5/3	2.5Y3/4	2.5Y4/4	1 C BK	2 M SBK	Common	1
	IIBt4k	47	79	10YR5.5/3	2.5Y5/4	2.5Y4.5/3	2 C PR	2 F SBK	Common	1
	IIBt5	79	105	10YR5/3	5Y5/3	2.5Y4.5/3	1 C PR	1 F SBK	Common	1
	IIBC	105	130	2.5Y5/2	5Y4/2	2.5Y4.5/2	1 C BK	X X GR	Few	1
	IIC	130	150	2.5Y5.5/3	5Y4/2	2.5Y4.5/3	0 X M		Few	1
TS	A	0	7	10YR4.5/3	10YR3/3	10YR3/3	X X GR		Many	1
	Bt1	7	30	10YR4.5/4	10YR3/4	10YR4/3	1 C BK	1 M SBK	Many	1
	IIBt2k	30	45	2.5Y5/3	2.5Y5/4	2.5Y4/4	3 C PR	3 M SBK	Common	1
	IIBt3k	45	88	2.5Y7.5/2	2.5Y5/4	2.5Y5/3	3 C PR	3 M SBK	Common	1
	IIBt4	88	120	2.5Y6/2	5Y5/3	5Y5/3	1 C PR	1 M SBK	Few	1
	IIBC	120	139	2.5Y6/2	5Y4.5/3	5Y4.5/2	1 C BK	0 X M	Few	2

Profile description of transect 1-21.

Compo-	Horizon	Depth		-	Color	-	Structure			Coarse
nent	Name	Range (cm)		Dry	Moist	Crushed	Primary	Secondary	Roots	Frag %
SU	A1	0	6	10YR4.5/3	10YR3/3	10YR3/3	X X GR		Many	1
	A2	6	13	10YR4.5/3	10YR4.5/3	10YR3.5/4	X X GR		Many	1
	Bt1	13	25	10YR4.5/3	10YR4/3	10YR4.5/3	2 C PR	2 F SBK	Many	1
	IIBt2	25	73	10YR5/1	2.5Y3/2	10YR4.5/1	1 C PR	X X GR	Common	
	IICr	73	79	10YR5/1	5Y4/1	10YR4.5/1				
SH	A	0	9	10YR5/3	10YR3/2	10YR3/3	X X GR		Many	1
	Bt1	9	18	10YR4.5/3	10YR2/2	10YR3/3	1 C PR	1 F SBK	Many	1
	IIBt2	18	36	10YR4/2	2.5Y4/2	10YR4.5/3	1 C PR	2 F SBK	Many	
	IICB	36	53	10YR5.5/1	2.5Y4/2	2.5Y3/2	1 C PR	0 X M	Common	
	IICr	53	79	10YR5/2	10YR5/8	10YR4/6			Few	
UBS	A	0	13	10YR4.5/3	10YR3/2	10YR3/3	X X GR		Many	1
	AB	13	19	10YR4.5/3	10YR2/2	10YR3/2	1 C BK	X X GR	Many	
	Bt1	19	58	2.5Y5/6	10YR3/4	2.5Y5/6	2 C PR	2 M SBK	Common	
	BC	58	76	2.5Y4/4	2.5Y4/4	2.5Y4/4	1 C BK	1 F SBK	Common	
	C	76	140	10YR6/4	10YR5/3	10YR5/3	0 X M		Few	
	IICr	140	158	10YR5/1	5Y4/1	2.5Y3/2		1 M GR	Few	
MBS	A	0	5	10YR4.5/3	10YR3/1	10YR3/3	X X GR		Many	1
	AB	5	14	10YR4.5/2	10YR3/3	10YR3/2	1 C PR	X X GR	Many	1
	ABb	14	34	10YR3.5/3	10YR2/2	10YR3/3	1 C PR	X X GR	Common	1
	Bt	34	53	2.5Y4.5/4	10YR3/4	10YR3.5/3	1 C PR	1 M SBK	Common	1
	CB	53	80	2.5Y5.5/4	2.5Y4/3	2.5Y4/4	1 C PR	X X GR	Common	1
	C	80	96	10YR5/3	5Y5/3	10YR4.5/3	0 X M		Common	1
	IIBtb	96	111	2.5Y6/2	10YR4/2	2.5Y4.5/2	1 C PR	X X GR	Few	
	IICr	111	127	2.5Y6/2	5Y4/1	2.5Y5/2			Few	
LBS	A	0	4	10YR5/3	10YR3/2	10YR3/2	X X GR		Many	5
	Bt	4	30	10YR5.5/3	10YR3/3	2.5Y4/3	2 C PR	2 M SBK	Many	1
	IIBtb1	30	63	2.5Y6/3	2.5Y4/3	2.5Y5/3	1 C PR	1 F SBK	Common	1
	IIBtb2	63	83	10YR5.5/3	5Y5/3	2.5Y4.5/3	1 C PR	1 F SBK	Common	1
	IIICB	83	113	10YR5/3	5Y5/3	2.5Y5/3	1 C BK	X X GR	Few	1
	IIIAb	113	165	10YR4.5/2	10YR3/2	10YR4/2	X X GR		Few	
	IVBtb	165	188	10YR5.5/4	10YR4.5/3	10YR4.5/4	2 C PR	1 M SBK	Few	
FS	A	0	2	10YR5/3	10YR5/3	10YR4/2	X X GR		Many	10
	Bt1	2	20	10YR4.5/3	10YR4.5/3	2.5Y4/4	1 C PR	2 M SBK	Many	2
	Bt2	20	40	2.5Y6/2	2.5Y4/2	2.5Y4/3	2 C PR	2 M SBK	Many	2
	Bt3	40	80	2.5Y5.5/2	2.5Y4/2	2.5Y4.5/2	1 C PR	1 F SBK	Many	1
	BC	80	120	2.5Y5.5/2	2.5Y4/2	2.5Y4.5/3	1 C PR	1 M SBK	Common	1
	CB	120	141	2.5Y5.5/2	5Y4/2	2.5Y4.5/2	1 C PR	X X GR	Common	1
	C	141	145	2.5Y5/3	5Y5/3	2.5Y4.5/3	0 X M		Few	1
TS	A	0	3	10YR5/3	10YR3/2	10YR3/3	X X GR		Many	1
	Bt1	3	17	10YR4.5/3	10YR3/2	10YR3/3	2 M SBK	2 F SBK	Many	1
	Bt2	17	27	2.5Y5/2	10YR3/3	2.5Y4.5/2	1 C PR	3 M SBK	Many	1
	Bt3	27	62	2.5Y6/2	10YR3/2	2.5Y4.5/2	3 C PR	3 M BK	Many	1
	Bt4	62	85	2.5Y6/2	2.5Y4/2	2.5Y4.5/3	3 C PR	3 F SBK	Common	1
	Bt5	85	120	2.5Y5.5/2	5Y4/2	2.5Y4.5/2	3 C ABK	2 F SBK	Common	1
	Bt6	120	148	2.5Y6/2	5Y4/2	2.5Y4/2	3 M SBK	2 F SBK	Common	1
	Bt7	148	165	2.5Y4/2	5Y3/2	2.5Y3/2	2 C PR	1 F SBK	Few	1

Profile description of transect 1-22

Component	Horizon Name	Depth Range (cm)		Color			Structure		Roots	Coarse Frag %
				Dry	Moist	Crushed	Primary	Secondary		
SU	A	0	9	10YR4.5/3	10YR3/3	10YR3/3	X X GR		Many	1
	Bt1	9	22	2.5Y6/2	10YR3/2	2.5Y4/4	1 C PR	1 F SBK	Many	1
	IIBt2	22	44	2.5Y6/3	10YR3/3	2.5Y4.5/4	1 M CR	1 F CR	Common	
	IICr	44	64	2.5Y7/2	5Y4/2	2.5Y5/2			Common	
SH	A	0	5	10YR5/2	10YR3/2	10YR3/3	X X GR		Many	1
	AB	5	16	10YR4.5/4	10YR3/3	10YR3/3	1 M BK	X X GR	Many	
	Bt	16	39	10YR4.5/3	10YR3/4	10YR4/3	1 C PR	1 M SBK	Common	
	C	39	55	10YR5.5/3	10YR4.5/3	10YR4.5/3	1 M BK	0 X M	Common	
	IICr	55	78	2.5Y6/6	10YR6/4	2.5Y5/6			Common	
UBS	A1	0	6	10YR4/2	10YR3/3	10YR3/2	X X PL	X X GR	Many	
	A2	6	12	10YR4.5/3	10YR3/3	10YR3/3	X X GR		Many	
	Bt1	12	30	10YR4/3	10YR3/2	10YR3/3	1 C PR	1 F SBK	Common	
	Bt2	30	52	10YR4.5/4	10YR3/4	10YR4/3	1 C PR	1 F SBK	Common	
	CBk	52	100	10YR6/4	10YR3/4	10YR5/3	1 C BK	X X GR	Common	1
	C1	100	134	10YR5.5/3	10YR5/3	10YR5/3	0 X M		Few	1
	IICr	134	144	5Y6/1	2.5Y4/2	5Y5.5/2			Few	
MBS	A	0	6	10YR5/3	10YR3/3	10YR3/3	X X GR		Many	
	Bt1	6	43	10YR4.5/3	10YR3/3	10YR3/3	2 VC PR	1 M SBK	Many	
	Bt2	43	65	10YR5.5/3	10YR3/3	10YR4/3	1 C PR	1 F SBK	Many	
	BCk	65	84	10YR6.5/3	10YR6/3	10YR5/3	1 C BK	1 F SBK	Common	1
	C1	84	110	10YR6/4	10YR5/3	10YR5.5/3	1 C BK	0 X M	Common	1
	C2	110	144	10YR6/4	10YR6/4	10YR5/3	1 C BK	0 X M	Few	
	C3	144	182	10YR6/4	10YR5/3	10YR5.5/3	1 C BK	0 X M	Few	
LBS	A	0	6	10YR5/3	10YR3/2	10YR3/2	X X GR		Many	1
	Bt1	6	34	10YR5.5/4	10YR3/4	10YR4.5/3	1 C PR	1 M SBK	Many	1
	Bt2k	34	60	2.5Y6.5/2	2.5Y4/2	10YR5/3	2 C PR	1 M SBK	Common	1
	C1	60	120	2.5Y6/3	5Y5/2	2.5Y4.5/3	1 C BK	0 X M	Few	1
	C2	120	130	2.5Y6/2	5Y4.5/3	2.5Y4.5/2	1 C BK	0 X M	Few	
	C3	130	146	2.5Y5.5/2	5Y5/3	2.5Y4.5/2	1 C BK	0 X M	Few	
	Ab	146	180	10YR4/2	10YR3/2	10YR3/2	X X GR		Few	
	C4	180	190	10YR5/2	10YR4/2	10YR3/3	0 X M			
FS	A	0	5	10YR4.5/2	10YR2/2	10YR3/2	X X GR		Many	4
	Bt1	5	20	10YR5/3	5Y5/3	10YR4.5/3	1 C PR	1 M SBK	Many	4
	Bt2	20	65	2.5Y6/2	5Y5/3	2.5Y5/3	1 C PR	1 M SBK	Many	1
	C1	65	110	2.5Y5.5/2	5Y4/2	2.5Y5/3	1 C BK	0 X M	Common	1
	C2	110	135	2.5Y5/2	5Y5/2.5	2.5Y4.5/2	1 C BK	0 X M	Few	1
	C3	135	152	2.5Y5/2	5Y5/3	2.5Y4/3	1 C PR	0 X M	Few	1
TS	A	0	5	10YR4.5/3	10YR3/2	10YR3/3	X X GR		Many	1
	Bt1	5	27	10YR5/3	10YR3/2	10YR3/3	2 C PR	2 M SBK	Many	1
	Bt2	27	48	2.5Y5.5/2	2.5Y4/2	2.5Y4.5/2	2 C PR	3 M SBK	Many	1
	Bt3	48	113	2.5Y6/2	2.5Y4/2	2.5Y5/2	2 C PR	3 M ABK	Common	1
	Bt4	113	127	2.5Y5.5/2	5Y5/3	2.5Y4.5/2	3 C ABK	3 M BK	Common	1
	Bt5	127	145	2.5Y5.5/2	5Y4/3	2.5Y4/2	1 C PR	2 F SBK	Common	1
	Bt6	145	164	2.5Y5/2	5Y4/2	2.5Y4/2	2 C PR	2 F SBK	Few	1
	Btb1	164	192	2.5Y4.5/2	5Y2.5/1	2.5Y3/2	2 C PR	2 F SBK	Few	1
	C	192	222	10YR6/4	10YR5/3	10YR6/4	1 C PR	1 F SBK	V Few	1

Profile description of transect 1-23.

	Sieve	Geomorphic Component						
	Number	SU	SH	UBS	MBS	LBS	FS	TS
Transect 21	-0.5	.209	.078	.028	.068	.174	.087	.151
	0	.153	.141	.117	.154	.269	.404	.370
	0.5	.257	.355	.315	.426	.574	.882	1.08
	1.0	.876	1.210	1.251	1.870	1.578	2.109	2.403
	1.5	3.172	3.591	3.802	4.777	3.301	3.863	3.800
	2.0	6.017	6.326	6.413	6.725	5.206	5.365	4.836
	2.5	7.278	7.031	6.669	6.337	5.797	5.815	5.0
	3.0	7.324	7.185	6.575	5.617	6.527	6.262	5.146
	3.5	7.0	6.858	6.321	5.489	6.644	6.251	5.231
	4.0	3.561	3.206	2.833	2.690	2.890	2.992	2.516
	4.5	1.733	1.707	1.700	1.459	1.346	1.445	2.065
	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	37.58	37.688	36.024	35.612	34.306	35.475	32.598

	Sieve	Geomorphic Component						
	Number	SU	SH	UBS	MBS	LBS	FS	TS
Transect 22	-0.5	.734	.395	.051	.007	.044	.485	.089
	0	.46	.334	.135	.142	.274	.549	.259
	0.5	.575	.587	.545	.599	.85	.843	.552
	1.0	1.346	1.584	1.951	1.963	1.91	1.796	1.093
	1.5	3.65	3.67	5.212	4.637	3.599	3.733	1.89
	2.0	6.47	6.033	7.426	6.98	5.362	5.445	2.628
	2.5	6.892	6.815	7.388	6.525	5.645	5.575	2.752
	3.0	6.611	7.218	6.263	5.798	5.327	5.296	2.811
	3.5	5.904	6.982	5.23	4.839	5.924	5.175	4.327
	4.0	2.854	3.147	3.068	3.137	3.201	3.065	3.09
	4.5	1.659	1.675	1.061	1.705	2.363	1.867	1.881
	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	37.155	38.44	38.33	36.332	37.577	33.829	21.372

	Sieve	Geomorphic Component						
	Number	SU	SH	UBS	MBS	LBS	FS	TS
Transect 23	-0.5	.242	.01	.028	.072	.02	.264	.154
	0	.54	.114	.108	.309	.25	.364	.307
	0.5	1.184	.459	.522	.644	.697	.711	.688
	1.0	2.605	1.53	1.671	1.896	1.989	1.631	1.423
	1.5	5.908	4.05	4.607	4.541	4.38	3.345	2.44
	2.0	7.912	6.447	7.207	6.839	6.06	4.615	3.414
	2.5	7.364	6.542	7.514	6.533	5.79	4.489	3.671
	3.0	6.294	6.286	6.446	5.932	5.49	4.187	4.332
	3.5	5.119	6.351	5.799	5.411	5.174	4.68	5.682
	4.0	2.192	2.961	2.714	2.934	2.921	3.412	3.526
	4.5	1.076	1.639	1.466	1.84	1.095	2.65	2.762
	5.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	TOTAL	40.436	36.389	38.082	36.951	33.866	30.348	28.399

Sand classes of the surface layer of the three transects.