EVALUATING THE EFFECT OF SOIL EROSION ON SOIL FORMATION USING RADIOCARBON DATING ON A HILLSLOPE

By

KARI LIN SEVER

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Thesis Approved:

Brian J. Carter
Thesis Adviser

James H. Stiegler

John D. Vitek

Jewell Crabtree

Norman N. Durham
Dean of Graduate College

1228201

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CHAPTER I

INTRODUCTION

Accurate methods of evaluating soil erosion are of growing need in the study of landscape development. Radiocarbon dating of soil organic matter with increasing depth is a relatively new and direct method to estimate soil erosion on a hillslope.

Radiocarbon dating is primarily used in age assessments of various buried artifacts, such as pollen, bones, charcoal, and marine fossils (Bright and Davis, 1982). These radiocarbon dates reveal information about climatic eras, human habitation, and ecological changes (Ash, 1983; Holiday, 1983; Sissons, 1979; Williams and Wigley, 1983). Radiocarbon dating has also been used to date buried paleosols containing organic carbon from pre-existing organisms (Geyh, 1971; Scharpenseel, 1971).

Radiocarbon dating of soil organic carbon at several depths within a soil profile provides information on the time sequence of soil formation (Young, 1969; Campbell et al., 1967). Radiocarbon measurements of organic matter within soils across a hillslope can indicate the influence of erosion on soil formation over time. Less eroded soils at the summit of a hill tend to be older than more eroded soils on lower parts of the hillslope (Ruhe, 1969; Herrera and Tamers, 1971).

Landscape formation is dependent upon events that are both continuous and catastrophic (Tricart, 1962). Although infrequent events of immense magnitude are effective in the erosion of a landscape, the frequent events of moderate magnitude are the most effective and expend the greatest amount of work in the formation of a landscape (Wolman and Miller, 1960; Pickup and Warner, 1976; Andrews, 1980).

Several variables influencing water erosion on a landscape include slope gradient, length, curvature, and aspect. Soil erosion caused by water runoff increases with increasing slope gradient and slope length (Zachar, 1982; Gray and Leiser, 1982). Slope curvature combines the vertical and horizontal components of slope gradient and slope length (Meyer and Kramer, 1969). Slope aspect influences the intensity of soil erosion (Birkeland, 1984; Beaty, 1956). Slopes in the Northern Hemisphere with a north-facing aspect receive less direct solar radiation than their south-facing counterparts, and consequently, they tend to be cooler, wetter, and more densely vegetated (Reid, 1979). North-facing slopes retain higher and less variable moisture levels over longer periods of time, resulting in a greater susceptibility to mass movement (Churchill, 1982).

The pedologic development of soil varies with hillslope position. The principle of ascendency states that the soil midway on the hillslope is genetically less developed and younger than the soil on the higher surface to which it ascends (Ruhe, 1969).

The objectives of this study were to i) measure the effects of natural soil erosion on soil formation using the radiocarbon age of soil organic matter and ii) determine soil properties that reflect the effect of natural soil erosion across an increasing slope gradient in the south-central Great Plains.

CHAPTER II

REVIEW OF LITERATURE

Introduction

The process of soil formation is a series of complex and simple events operating simultaneously or in sequence to change parent material into soil. The formation of a soil profile (horizon differentiation) depends on the general processes of addition, removal, translocation, and transformation. Because these processes operate at different intensities, many types and sequences of horizons occur. For each soil, the relative importance of the processes acting upon varying parent material will create a unique soil pedon found within a landscape segment (Simonson, 1959).

A soil profile consists of different horizons that reflect the combined effect of the soil forming processes (Hallsworth, 1965). These processes produce soil properties that change with depth of the soil, and therefore, permit the distinction between horizons within the soil profile. Several characteristic soil properties are used to differentiate soil profiles and soil formation in western OKlahoma. These soil properties include organic matter content, clay content, bulk density, and soil structure, and emphasize the importance of additions, removal, translocations, and transformations in soil formation.

Organic Matter

Organic matter consists of decayed plant and animal residue that is eventually mixed with the inorganic mineral fraction of the soil. Organic matter is added to the soil surface and incorporated dominately in the A and B horizons of the profile by the decomposition of plants and animals. Early in the formation of a soil the gains exceed the losses and organic matter accumulates. Over time, a steady state condition is reached, where the gains equal the losses, and the amount of organic matter in the soil and its distribution with depth remain essentially constant (Birkeland, 1984). The length of time required to reach this steady state in the content of organic matter will vary with the type of parent material, climate, topography, and organisms involved in the formation of the soil.

Climate is the most important factor controlling organic matter content and other soil properties. Moisture and temperature differences determine the climate and the resulting amount and rate of physical, chemical, and biochemical weathering processes (Birkeland, 1984). Organic matter contents and rates of decomposition are influenced by the amount of plant growth. Therefore, arid regions with limited moisture and plant growth are expected to have low organic matter contents and rates of decomposition, while humid regions with extensive moisture and plant growth are expected to have high organic matter contents and rates of decomposition (Jenny et al., 1949; Jenny, 1950).

The process, in which gains and losses of organic matter proceed simultaneously, is described as turnover and may be defined as the flow of organic carbon through a given volume of soil (Jenkinson and Rayner, 1977). Normally, the organic matter of the surface horizon has a higher turnover rate than that of the subsurface horizon where the effects of climate and animal mixing are greatly reduced (Martel and Paul, 1974). The processes of organic matter turnover are largely controlled by soil micro-organisms, and therefore, are influenced by temperature, water content, pH, and soil aeration (Newbould, 1980).

Melanization is the process of darkening of soil by the addition and mixture of organic matter (Simonson, 1959; Hallsworth, 1965). Roots extending into the soil profile will eventually decay and produce relatively dark, stable compounds of protein melanins (Crompton, 1962). Grasses produce masses of roots of relatively short life and as these die and decay large quantities of organic matter are added to the soil to a considerable depth. Organic material in the form of undecomposed plants and animals accumulate at the soil surface and may remain in that form until they are mechanically incorporated by soil animals and decomposed by soil microbes (Martel and Paul, 1974).

Because carbon and nitrogen are components of soil organic matter, their ratio (C/N) is useful in identifying the degree of decomposition of organic matter. Generally, the C/N ratio will narrow with increasing modification by decomposition processes (Buol et al., 1980). Within a virgin soil, relatively high C/N ratios indicate organic matter stability, while relatively low C/N ratios may indicate erosion (Joffe, 1949). Decreasing C/N ratios with increasing depth suggest that relatively more nitrogen is stored in the resistant, nonproteinaceous forms deeper in the soil profile (Martel and Paul, 1974). The relatively higher amounts of nitrogen, resulting in lower C/N ratios enhances the activity of the nitrogen-dependent soil microbes. An increase in C/N ratios may indicate the abundance of resistant forms of organic carbon such as lignins that are found in cellulose (Kononova, 1966). A stable C/N ratio of 10-12:1 is expected for a surface soil of western Oklahoma.

Clay

In Argiustolls, a soil that commonly occurs in western Oklahoma, the distribution of clay-sized particles is at a maximum in the B horizon of the soil profile; this is called the argillic horizon. Several processes may account for this distribution. One process suggests that the clay is derived from the weathering of materials in the A horizon and is precipitated in the B horizon by percolating water;

this process combines transformation and translocation (Buol and Hole, 1961). A second process is that the clays are formed in place from minerals weathering in the B horizon; this processes is called transformation (Birkeland, 1984). A third process suggests that clay accumulates by translocation into the B horizon because of flocculation in small pores through which water percolates, while the base of the B horizon marks the lower limit of most water movement (McKeague and St. Arnaud, 1969; Birkeland, 1984). The eluviation of clay can occur only if the clay is dispersed, so that it remains in suspension in the soil water. Clay dispersion occurs under low electrolyte conditions in the soil solution and in the presence of negatively charged colloids (Soil Survey Staff, 1975). Also, the wetting and drying of soil favors disruption of soil structure and dispersion of clay (Bohn et al., 1979). Clays may appear in the B horizon by all three processes, but the importance of each process may vary from soil to soil. Because there is little or no clay movement in soils of relatively young landscapes, the formation of an argillic horizon may require a few thousand years (Bilzi and Ciolkosz, 1977).

Argillic horizons in which illuvial clay has accumulated have several diagnostic features. These features include a finer texture than the overlying eluvial horizon, the presence of clay coatings (cutans) on the ped surfaces and fine clay (< 0.0002 mm), and the lack of significant original rock structure (Soil Survey Staff, 1975).

Bulk Density

Bulk density measurements may be used to detect the presence of argillic horizons and to quantify their degree of development (Buol et al., 1980), and also to locate the lower boundary of the solum (Dawud and Gray, 1979). Because bulk density varies with the structural condition of the soil, it is often used as an indirect measure of soil structure (Blake, 1965). Relatively low bulk density measurements are found in surface soils as a result of the relatively high organic matter contents and granular-type structure found in these soils. Bulk density increases with depth because of a decrease in organic matter content, and the subsequent reduced aggregation and a reduced percentage of pore spaces (Dawud and Gray, 1979). Subsoil pore spaces are reduced as a result of clay movement and the formation of pore filling precipitates (Hausenbuiller, 1972). Generally, bulk density values beneath the solum drop from near 2.65 g/cc to less than 2.00 g/cc with physical and chemical weathering and the subsequent development of pore spaces (Buol et al., 1980).

Soil Structure

Soil structure involves the aggregation of individual soil particles into compound particles or peds. Soil structure is used to distinguish the B horizon from the C horizon, and therefore, is an indicator of soil development; the B to C depth is dependent on the depth of wetting and drying and time. Clay and organic matter accumulate by transformation and translocation processes, and are responsible for binding soil separates together and developing structure. Organic matter not only binds, but also expands the soil, and therefore, increases porosity and forms granular-type aggregates (Brady, 1974). Plant roots, extending to considerable depths within the soil profile, also promote granulation by the addition of organic matter with their decay and by the disruptive action of their roots as they move through the soil.

Clay accumulation, is important in the formation of blocky, columnar, and prismatic structure, results from the strong adsorptive surface of silicate clay particles. The adsorption of calcium on a clay colloid may promote flocculation, and therefore, a granular structure. (Brady, 1974; Smith et al., 1978).

Landscape Formation and Erosion

Landscape formation is dependent upon events that are both uniform or continuous in operation (i.e. removal of matter in solution by groundwater flow) and catastrophic (i.e. a flood caused by extreme hydrologic and meteorlogic conditions) (Tricart, 1962). Infrequent events of immense magnitude are effective in the erosion of a landscape

(Wolman and Miller, 1960). In terms of frequency and magnitude, however, the frequent events of moderate magnitude are the most effective and expend the greatest amount of work in the formation of a landscape (Pickup and Warner, 1976; Andrews, 1980).

In environments where the weathering rate is high, mass movement processes dominate erosional processes on hillslopes. The mass movement processes may be classified into three types: slide, flow, and heave (Carson and Kirkby, 1972). Landslides and slips are relatively rapid failures that may be shallow and planar, debris, or deep-seated rotational movements. Rapid slipping on a relatively shallow plane, parallel to the ground surface, is the most common form of failure on weathered slope materials and soils (Gerrard, 1981). Failure conditions in soils are at a maximum when the water table is near the surface and water flow is parallel to the slope (DacKombe and Gardiner, 1983). Many shallow slides are the result of deterioration of structure in the soil material, and as a result, the material suddenly moves downslope. These slides are often closely associated with heavy rainfall and special groundwater conditions, where high pore pressures or water seepage are likely to occur (Gerrard, 1981; Hoek and Bray 1977). While slides tend to be relatively dry, flows are moist and occur at relatively low velocities. Soil heave occurs when the soil expands perpendicular to the surface and subsequently contracts. Because the energy expended in heave movements is of small amplitude, the resulting downslope movement of soil is very slow (Carson and Kirkby, 1972).

Soil creep is another method of movement down-slope. Creep in soils is defined as any movement which is imperceptible, except by measurements over long periods of time (Sharpe, 1938). It may be caused by systematic reworking of the soil surface layers, by fluctuations in soil moisture and temperature, by random movements by soil organisms, and by the steady application of downhill shear stress (Carson and Kirkby, 1972).

Steady soil movement under low shear stress conditions is called continuous creep. This behavior of soils is directly related to the flow properties of clays and is absent in coarse-grained soils (Terzaghi, 1953). In a soil with uniform properties, the shear strength follows a downslope direction, parallel to the surface, and increases linearly with depth. The shear stress increases with depth because of variation in bulk density and moisture conditions within the soil profile (Carson and Kirkby, 1972). Several variables influencing water erosion include slope gradient, slope length, slope curvature, and slope aspect. Generally, soil erosion caused by water runoff will increase with increasing steepness of the slope. As the slope gradient increases, the water runoff increases, resulting in greater energy and carrying capacity of the water. As a result, soil stability and slope stability decrease and the possibility of soil displacement in a downslope direction is increased (Zachar, 1982).

Soil erosion increases with increasing slope length. As the slope length increases, the quantity, the velocity, and the transporting capacity of the runoff increase proportionally (Gray and Leiser, 1982).

Erosional losses and patterns are also determined by the combined variations in slope gradient and slope length, known as slope curvature (Meyer and Kramer, 1969). Slope curvature consists of two compontents: vertical and horizontal. Vertical curvature results from changing slope gradient. Slope profiles may be straight, convex, concave, a combination of convex and concave, or undulating (Meyer and Kramer, 1969). Concave slopes are produced by the concentrated flow of water, while convex slopes are a result of soil movement by creep (Gilbert, 1909; Armstrong, 1980). Frequently, a change in soil type occurs where the vertical curvature changes. Horizontal curvature exists where the direction of exposure is changing. A cove (concave horizontal curvature) occurs where the slope directons converge toward the lower part of the slope. A spur (convex curvature) occurs when the opposite is true. Where there is no horizontal curvature, the hillslope is straight (Aandall, 1948).

The intensity of soil erosion on a hillslope is influenced by slope aspect (Birkeland, 1984). As a result, slope aspect is an important factor in hillslope form and landscape development (Beaty, 1956; Tinker, 1971). Topoclimatic variation refers to the differences in climate caused by the different directional exposures of a slope. Because they receive much less direct solar radiation, the north-facing slopes tend to be cooler, wetter, and more densely vegetated than their south-facing counterparts in the northern hemisphere (Reid, 1973). Because north-facing slopes retain higher and less variable moisture levels over longer periods of time, they are more susceptible to mass movements, such as slumps and mudflows, and therefore, operate toward potential slope stability (Churchill, 1982). As a result, north-facing slopes have a flatter inclination, while south-facing slopes have a steeper inclination (Churchill, 1981).

Radiocarbon Dating

The use of quantitative studies of geomorphological processes in the evaluation of soil erosion has become frequent in the past 30 years. Four methods are available for estimating loss of material from a landscape (Young, 1969). The first method is based on estimates of the suspended and dissolved material transported by rivers, obtained by sampling the load and comparing it with river discharge (Holeman, 1968; Judson and Ritter, 1964). The second method involves measurement of the sediment accumulated in reservoirs. The third method involves measurements of surface processes on slopes, including rates of soil creep, surface wash, and landslides. The fourth method involves the comparison of radiocarbon dates with their subsequent geomorphological landforms (Young, 1969). The first two methods include the erosion effects of rivers, while the third and fourth methods refer only to surface processes on hillslopes.

Radiocarbon dating has been used extensively in the past to make age assessments on various buried artifacts, such as pollen, bones, charcoal, and marine fossils (Bright and Davis, 1982). These radiocarbon dates reveal information about climatic eras, human habitation, and ecological changes (Ash, 1983; Holiday et al., 1983; Sissons, 1979; Williams and Wigley, 1983). Radiocarbon dating has also been used to date buried paleosols containing organic carbon from pre-existing organisms, plants, and animals (Geyh et al., 1971; Scharpenseel, 1971).

Radiocarbon dating at various depths within a soil profile not only permits the evaluation of soil erosion, but also provides information on the time sequence of soil formation (Campbell et al., 1967). The radiocarbon date from the soil surface includes a mixture of organic matter that is added daily and organic matter that was incorporated over several thousand years (Birkeland , 1984). Because most organic matter decomposition occurs in the upper layers of a soil profile, and a decreasing turnover rate occurs with increasing depth, the radiocarbon ages of soil within a profile increase with depth (Scharpenseel et al., 1968;

Scharpenseel, 1971; Martel and Paul, 1974).

Absolute age measurements that indicate the inception of pedogenesis are only approximate. As a result, the term "mean residence time" has been introduced, which refers to the average age of soil organic matter that is subject to rejuvenation by root penetration, and by translocation by organisms and water (Scharpenseel, 1971; Paul et al., 1964).

Radiocarbon age measurements on a hillslope indicate the effects of erosion over time. The principle of ascendency states that the soil midway on the hillslope profile is younger that the soil on the higher surface to which it ascends (Ruhe, 1969). Therefore, the increase in radiocarbon age with depth is slower on the lower sites of a slope profile than at the upper sites. This indicates the effects of erosion and deposition of soil material on a hillslope profile (Herrera and Tamers, 1971).

CHAPTER III

MATERIALS AND METHODS

Field sampling

In selecting a sampling site, several variables needed to be minimized before hillslope erosion could be studied. The variables characteristic of northwest Oklahoma include parent material, vegetation, disturbances caused by human influence, and topoclimatic variations caused by slope aspect. A suitable hillslope was located in Woods County, Oklahoma, to minimize these variables. This hillslope was located entirely within the Ogallala geologic formation, was uniformly vegetated with native prairie grasses and a variety of weeds, and was located on the north aspect of a virgin landscape. The samples were collected from four sampling pits located across the slope profile; Pit 1 was sampled from the summit, while Pits 2, 3, and 4, followed successively across the convex shoulder to the backslope segment of the hillslope profile. Samples were taken from all horizons, including the parent material. These samples were screened to pass a 2 cm seive. In addition, 16 bulk samples were collected at equal intervals within each soil profile for radiocarbon dating analyses. The samples were obtained from depths of 0-20 cm, 40-60 cm, 80-100 cm, and 120-140 cm within each soil profile from each of the 4 pits. Natural clods were collected, weighed, and coated with Dow Saran S310 resin for laboratory bulk density determination. The slope profile dimensions, percent slope gradient, vegetation, and profile descriptions were reported.

Laboratory Analyses

Bulk Sample Preparation

The bulk samples collected from each horizon were air dried under laboratory conditions, ground by hand, and screened to pass a 2.0 mm seive. The gravel fraction (> 2.0 mm to < 7.6 mm diameter) was cleaned and weighed. Subsamples were taken form the samples bulk samples for analyses. All analyses made on samples were run in duplicate and average values are reported.

Physical Analysis

Particle size analysis was conducted on the samples following removal for carbonates and soluble salts (Grossman and Millet, 1961) and removal of organic matter (Kunze and Rich, 1959). Particle size analysis was determined by the pipette method described by Kilmer and Alexander (1949).

Bulk density of soil was determined by the clod method using saran resin to coat the natural soil clods (Brasher et al., 1966; Blake, 1965).

Chemical Analysis

The pH of the soil horizons was determined from saturated paste of 1:1 soil-water and 1:1 soil-KCl using a Beckman electronic pH meter (Fields and Parrot, 1966). Organic C was determined by using the $K_2Cr_2O_7$ Digestion with $FeSO_4$ titration (Peech et al., 1947; Walkley, 1935). The percentage of organic matter was calculated by multiplying the organic carbon by a factor of 1.724. Total N was determined by the Regular Macro-Kjeldal Method described by Bremner (1960). Total extractable acidity was determined by using an automatic mechanical extracter (Peech, 1947).

Uniformity of parent material was determined by the ratio of the amount of Zr to the amount of Ti in the sample. Standards of Zr and Ti were prepared using known amounts of Zr and Ti from U.S.G.S. rock standards of granodiorite, andesite, granite, and basalt. Concentrations of Zr and Ti were expressed on an elemental weight basis. Soil samples were finely ground to pass a 0.05 mm seive and pressed into a pillet at 4 tons per square inch (Beaver, 1960). Determinations of Zr and Ti were made on a General Electric XRD-6 X-ray spectrograph using a tungsten tube operated at 50 kvp and 45 ma. Net counts were compared to a standard curve. Zr K-alpha radiation was counted over 3 replications for 10 seconds at 22.1 for the peak and 18.0 for the background. Likewise, Ti K-alpha radiation was counted over 3 replications for 10 seconds at 85.6 for the peak and 89.0 for the background. The 10 seconds counting time was sufficient to accumulate more than 10,000 counts at the peak position.

Radiocarbon measurements on the 16 bulk samples were performed by two analytical isotope laboratories: Beta Analytic, Inc., Coral Gables, Florida, and Dicarb Radioisotope Co., Norman, Oklahoma. The individual soil samples were required to contain at least 1 gm or 0.1 % organic carbon so that a relatively accurate radiocarbon age could by measured. The samples were pretreated by hand to remove visible rootlets, dispersed in hot acid to eliminate carbonates, repeatedly rinsed to neutrality, brought to dryness, and given multiple combustions in an enclosed system. Measurements of C-14 activity were counted using the benzene synthesis method (Polach and Stipp, 1967; Polach, 1969). The ages obtained are calculated using the standard radiocarbon half-life of 5568 years and using 95% of the activity of the National Bureau of Standards Oxalic Acid, which is accepted as the modern radiocarbon reference standard. The counting errors are expressed at the 68% confidence level, based on the random nature of the radioactive disintegration process. The dates obtained are reported as radiocarbon years before 1950 A.D.

CHAPTER IV

RESULTS AND DISCUSSION

Uniformity of Parent Material

Zr/Ti ratios and clay-free silt and sand percentages determined on total soil samples (< 2.0 mm) of all horizons support the contention that the 4 soils studied on the hillslope were derived from a common parent material. Table I shows that the deviations from the mean of Zr/Ti ratios are considerable less than 81%, which is a value that has been reported for uniform soils with common parent material (Chapman and Horn, 1968). Clay-free silt percentages, presented in Table II, support the results of the Zr/Ti ratios. The clay-free silt percentages for Pit 1 decrease with depth in the soil profile because of the sorting of grain sizes that occurs during the deposition of alluvial materials (Blatt et al., 1980). Pit 2 also shows this trend, but to a lesser extent than Pit 1 because of the resulting effects of erosion. The silt contents for Pits 3 and 4 are relatively constant with depth, with slight variations between the horizons of each profile. Pits 3 and 4 do not show the same trend of Pits 1 and 2 because of the effects of increased erosion as the slope gradient

TABLE I

AVERAGE ZR/TI RATIOS AND PERCENT DEVIATION

Pit	Mean	% Deviation
1	10.38	25.38
2	7.07	11.91
3	6.10	14.01
4	6.89	11.78
Across All Pits:	7.61	24.90

TABLE II

CLAY-FREE SAND AND SILT PERCENTAGES

Horizon	Depth (cm)	% Sand	% Silt
	Pit 1		
A	0-17	18.85	81.15
AB	17-29	13.16	86.84
Bt1	29-53	10.26	89.74
Bt2	53-91	11.41	88.60
Bw1	91-124	28.45	71.55
Bw2	124-150	36.85	63.14
BC	150-214	58.71	41.29
CK	214-244	92.04	7.96
	Pit 2		
A	0-8	65.65	34.35
Bw	8-44	77.95	22.05
BC	44-75	85.16	14.84
C	75-134	94.97	5.03
CK	134-150	79.42	20.58
	Pit 3		
A	0-26	55.63	44.37
BK	26-41	45.65	54.35
Cr1	41-118	31.61	68.39
Cr2	118-155	46.30	53.70
	Pit 4		
A	0-34	56.07	43.93
Bw	34-83	47.83	52.17
BCk	83-120	33.68	66.32
Cr	120-163	43.28	56.72

increases. The higher silt content of Pit 1 may also be a reflection of its relative stability and therefore a site of deposition of eolian materials.

Radiocarbon Dating

The hypothetical development of a hillslope would begin with the uplift of a depositional surface and the subsequent attack by erosion (Figure 1). At the time of deposition and time zero of soil formation (a minimum of approximately 20,000 years ago as determined by the oldest radiocarbon date) it is assumed that the landscape was flat, and organic carbon was incorporated into the soil by plant roots and organisms. The turnover rate of organic matter decreases with depth, consequently, the radiocarbon age increases with depth within the soil profile over time (Martel and Paul, 1974; Scharpenseel, 1971). Erosion of the slope over time has exposed some of the original organic carbon to the higher turnover rates that occur in the upper layers of the soil profile. Therefore, the presence and absence of this original organic material results in older radiocarbon measurements at the summit of the hill and younger measurements at lower levels on the hillslope segment, respectively. The hypothetical radiocarbon measurements are shown as a linear regression with depth in Figure 2.

Actual radiocarbon measurements are shown as a linear regression with depth in Figure 3, and the corresponding data and regression equations are presented in Appendixes A

Figure 1. Slope Profile Development and Organic Carbon Additions Over Time

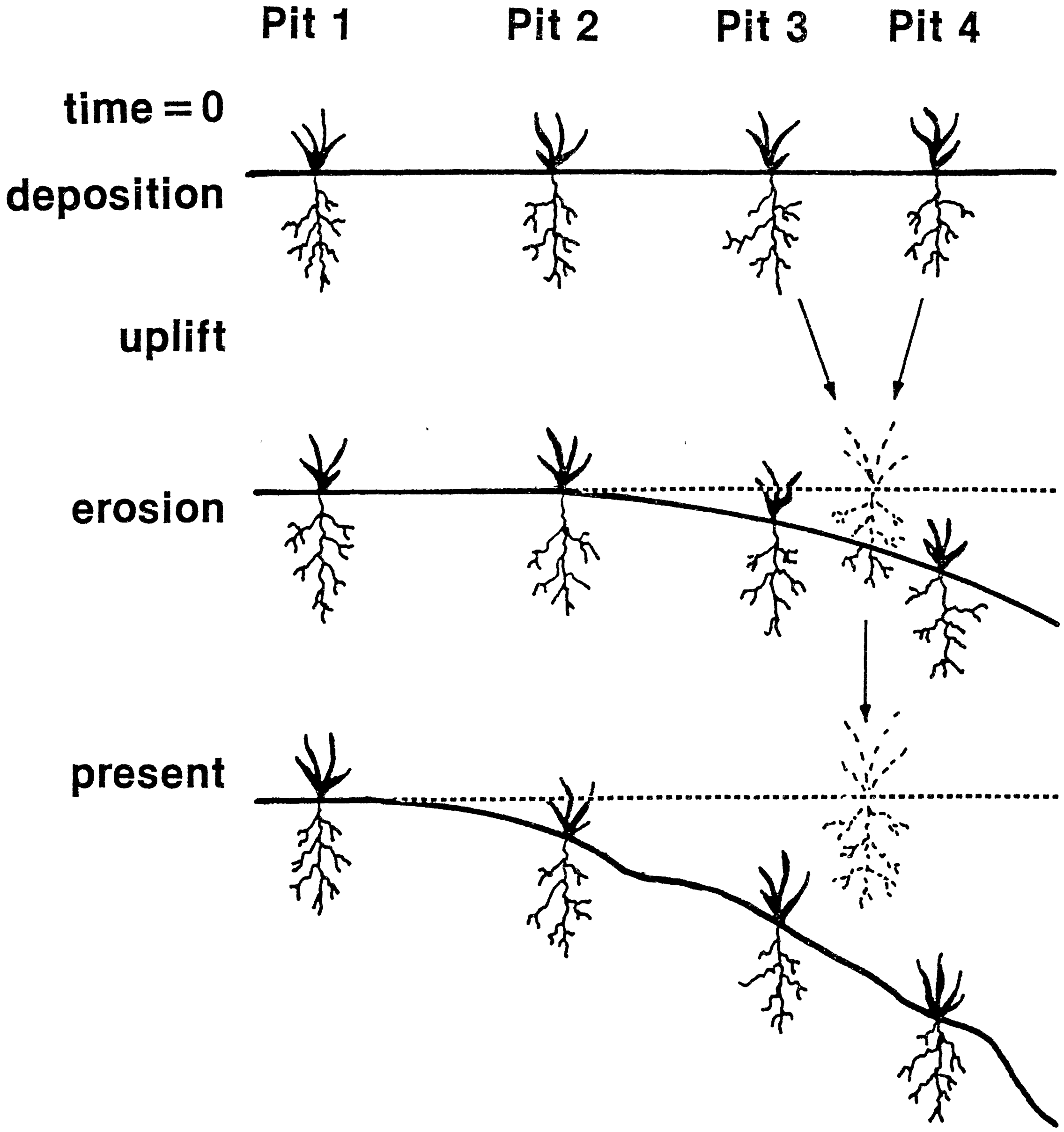

Pit 1
Pit 2
Pit 3
Pit 4
time = 0
deposition
uplift
erosion
present

Figure 2. Hypothetical Radiocarbon Measurements With Increasing Soil Depth for Hillslope Development

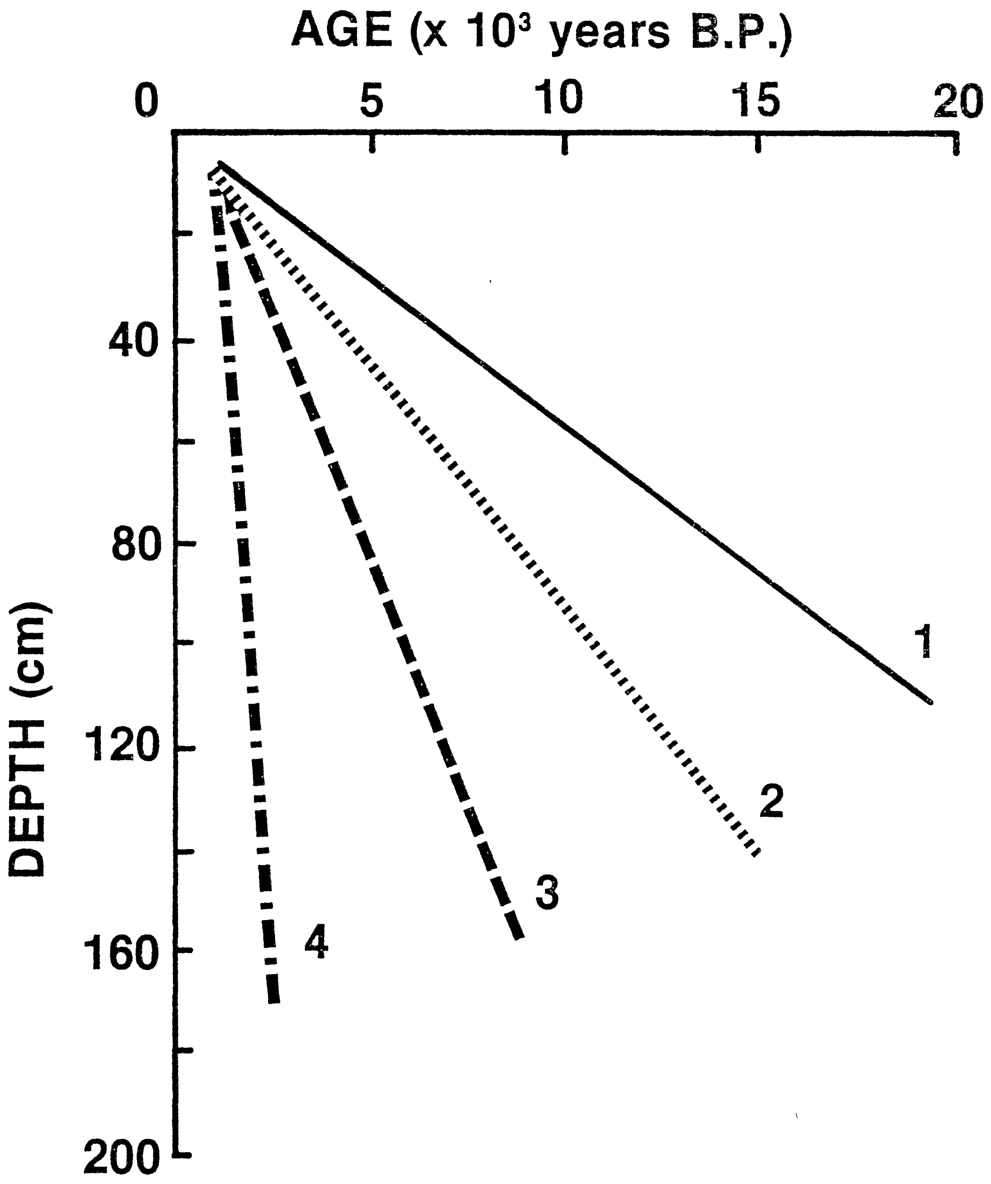
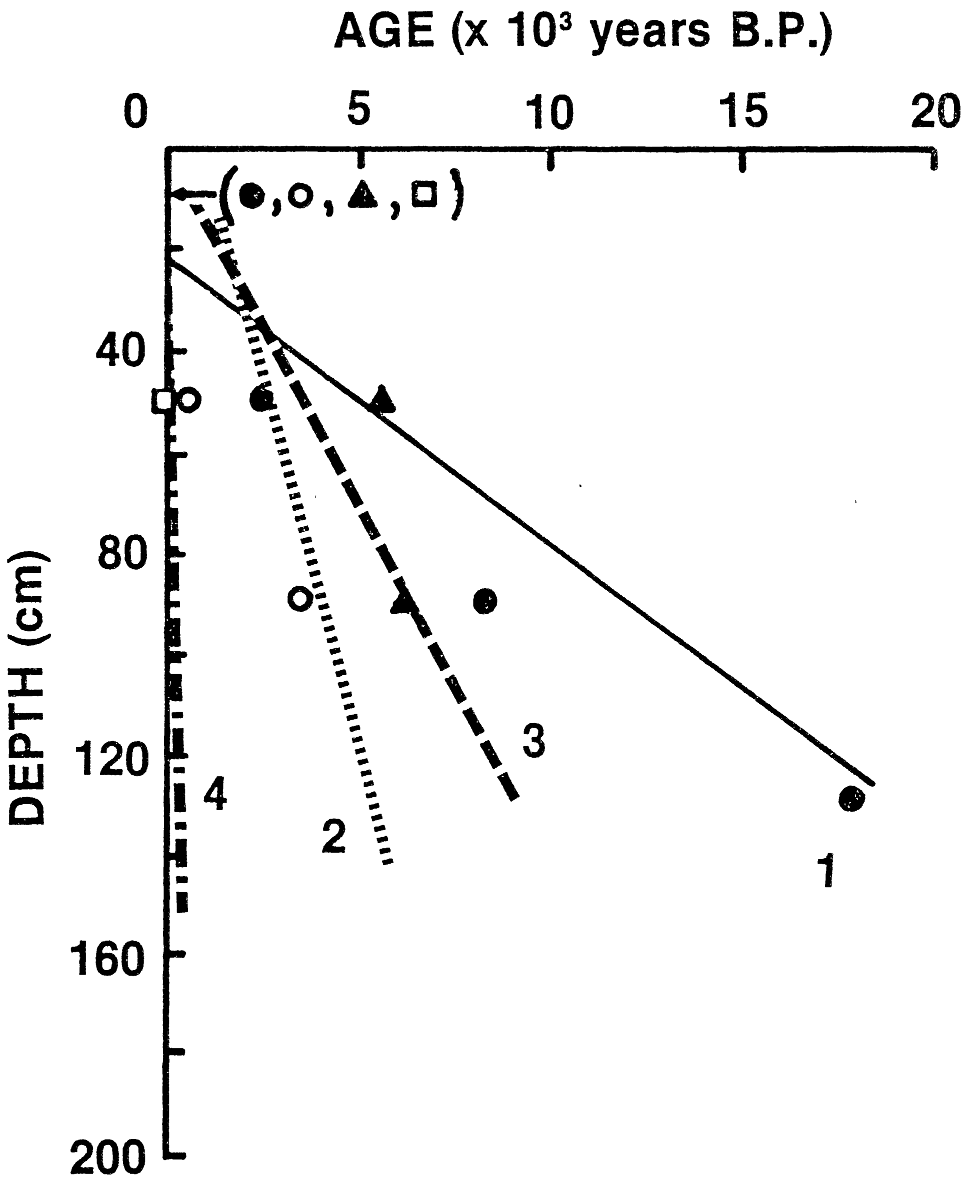

AGE (x 10³ years B.P.)
0
5
10
15
20
DEPTH (cm)
40
80
120
160
200
1
2
3
4

Figure 3. Actual Radiocarbon Measurements With Increasing Soil Depth for Hillslope Development (Pit 1= ●; Pit 2= ○; Pit 3= ▲; Pit 4= □)


AGE (x 10³ years B.P.)
0
5
10
15
20
DEPTH (cm)
40
80
120
160
200
(●, ○, ▲, □)
1
2
3
4

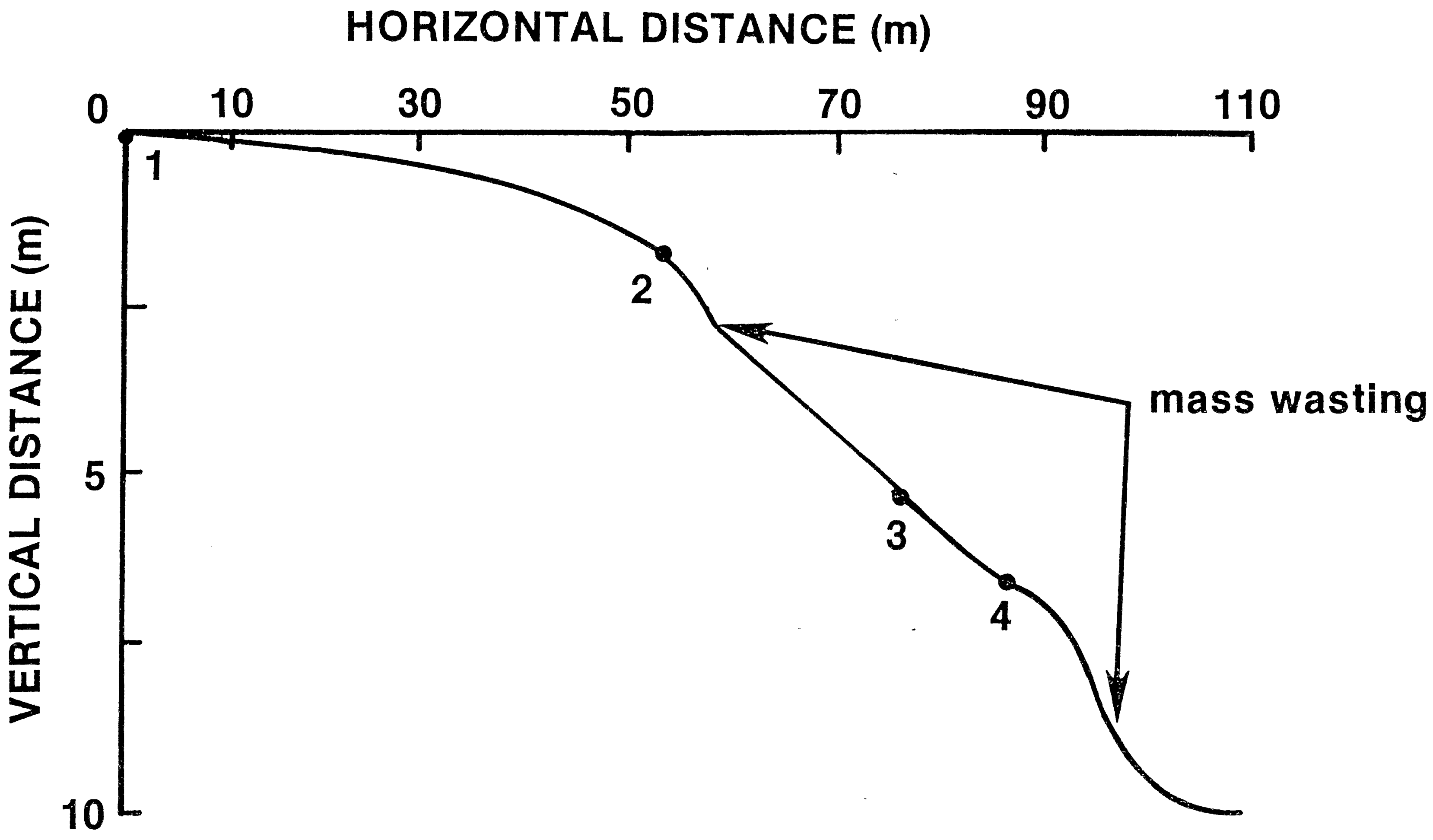
and B, respectively. The correlation coefficients are 0.88, 0.94, and 0.87 for the profiles of Pits 1, 2, and 3, respectively. The radiocarbon dates for the samples from Pit 4 were all modern, suggesting a newly formed soil. The oldest radiocarbon age, averaged from 2 measurements, was dated 17,920 + 305 years B.P., and was found in the soil profile at the summit as expected. Several samples contained insufficient amounts of carbon for analyses; these include Pits 2, 3, and 4 at 120-140 cm, and Pit 4 at 80-100 cm.

The actual radiocarbon measurements (Figure 2) follow the hypothetical relationship (Figure 3) except for the relatively younger ages found in Pit 2 compared to Pit 3. The comparison of hypothetical and actual radiocarbon ages support the contention that erosion has been occurring at a higher rate on steeper slope gradients. The radiocarbon dates of the soil from Pit 3 were older than that of Pit 2, probably because of the small scale catastrophic effects of mass wasting. Visual observation of variations in vegetation and micro-topography along the hillslope profile were evidence that mass wasting, in the form of slips and slumps, was affecting the landscape. Differences in major and minor vegetation were observed between pit locations, shown in Appendix C. The area surrounding Pit 1 contained more grasses (climax species) than the area surrounding any other pit, while an abundance of weeds (serial species) were found with increasing slope gradient. Sparcely vegetated areas exposing bare soil below Pit 4, suggest that soil movement is so recent that even dense pioneer vegetation has not had enough time to become established. Two major but less conspicuous areas of mass wasting were observed on the hillslope; a 12 x 5 x 1 meter area near Pit 2, and an 18 x 6 x 1.5 meter area just below Pit 4, shown in Figure 4. The more conspicuous nature of soil movement as found below Pit 4 was minimized near Pit 2 by few vegetational differences and small topographical variations, which suggests that this erosional process may have occurred so long ago or so infrequently that its field identification was almost impossible. Pit 2 was affected by the more recent and rapid mass wasting, exposing relatively younger parent material as compared to Pit 3. Pit 3 may also have received older soil material from slump areas upslope. With increasing slope gradient, rapid mass wasting becomes an improtant process in these hillslope areas.

Soil Properties

All chemical and physical soil analyses are given in Appendix D. Several soil properties reflect the effect of soil erosion across an increasing slope gradient. These properties include organic matter content, clay content, C/N ratios, bulk density, and pH. The amount of organic matter measured within the soil profile was influenced by its position on the hillslope (Martel and Paul, 1974). The soils sampled from Pit 1 at the summit of the hill contained

Figure 4. Hillslope Dimensions and Locations of Soil Pits
and Sites of Mass Wasting


HORIZONTAL DISTANCE (m)
0
10
30
50
70
90
110
VERTICAL DISTANCE (m)
5
10
1
2
3
4
mass wasting

significantly higher amounts of organic matter at greater depths in comparison to the soils of Pits 2, 3, and 4, as shown in Figure 5. This is explained by the additions of organic matter to a stable soil surface over time. Erosion has shaped the hillslope over a long period of time, and consequently, organic matter has not accumlulated in large quantities on the sideslopes where the erosion of the soil has had its greatest impact, compared to the more stable summit. With increasing slope gradient the rate of erosion increases, limiting the build-up of soil organic matter.

Particle size analysis of the samples reveal the presence of an argillic horizon that is unique to Pit 1, as shown in Figure 6. The translocation and accumulation of clay is a soil forming process that requires a relatively long period of time (2,000 to 5,000 years) (Bilzi and Ciolkosz, 1977). Adequate time is necessary for eluviation and illuviation zones of clay to develop. Therefore, it seems the erosion at Pits 2, 3, and 4, has occured or is occuring at a faster rate than that of the formation of the argillic horizons.

C/N ratios are shown as a linear regression in Figure 7 and the corresponding regression equations and correlation coefficients are presented in Appendix B. C/N ratios show no trend with depth for the relatively young soils of Pits 2 and 4, which may be the result of an abundance of the resistant, nonproteinaceous forms of nitrogen that are found deeper in the soil profile (Martel and Paul, 1974). C/N

Figure 5. Percent Total Soil Organic Matter With Increasing Depth for Each Soil Pit (Pit 1= ●; Pit 2= ○; Pit 3= ▲; Pit 4= □)

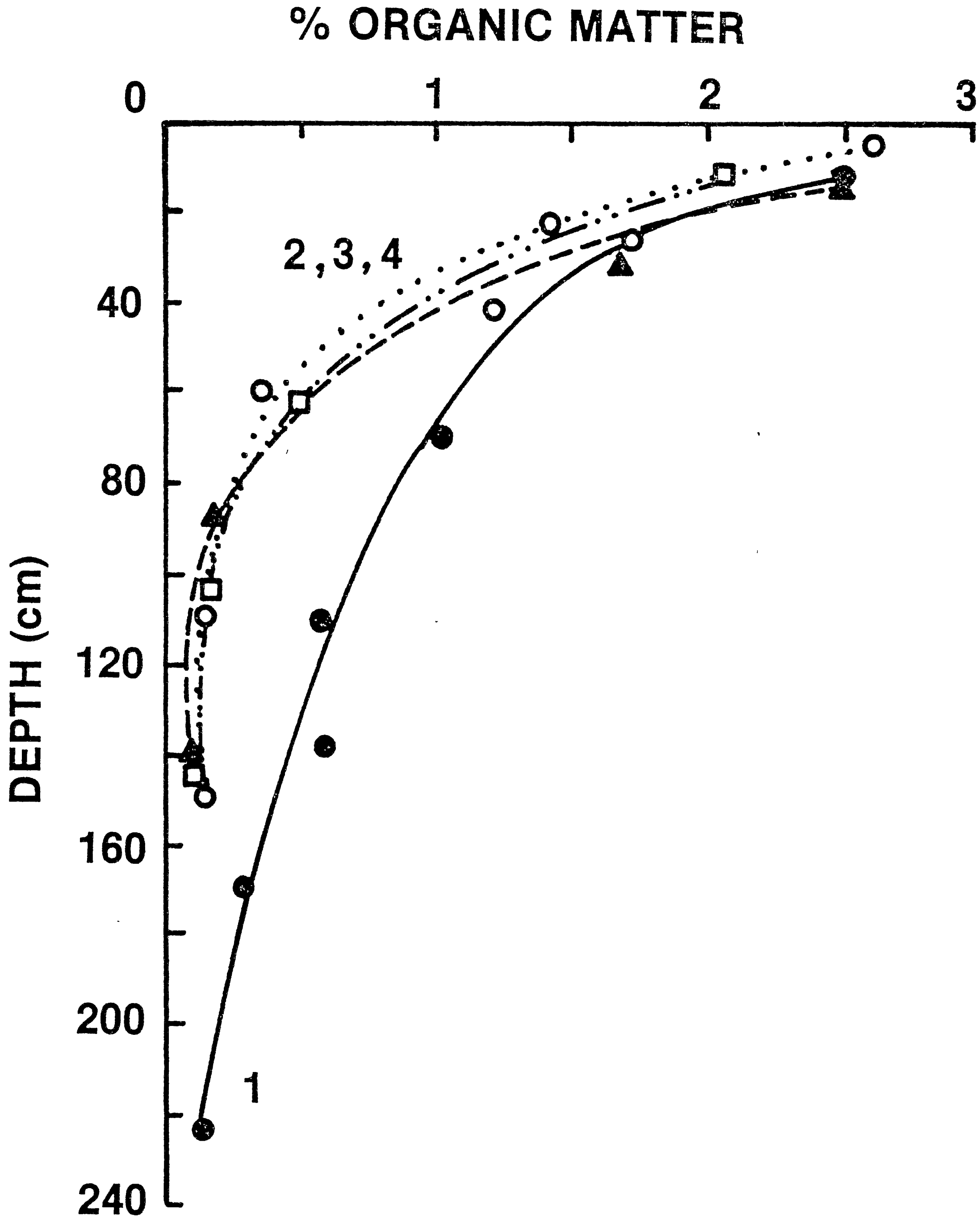

% ORGANIC MATTER
0
1
2
3
DEPTH (cm)
40
80
120
160
200
240
2,3,4
1

Figure 6. Percent Clay (<0.002 mm) With Increasing Depth for Each Soil Pit (Pit 1= ●; Pit 2= ○; Pit 3= ▲; Pit 4= □)

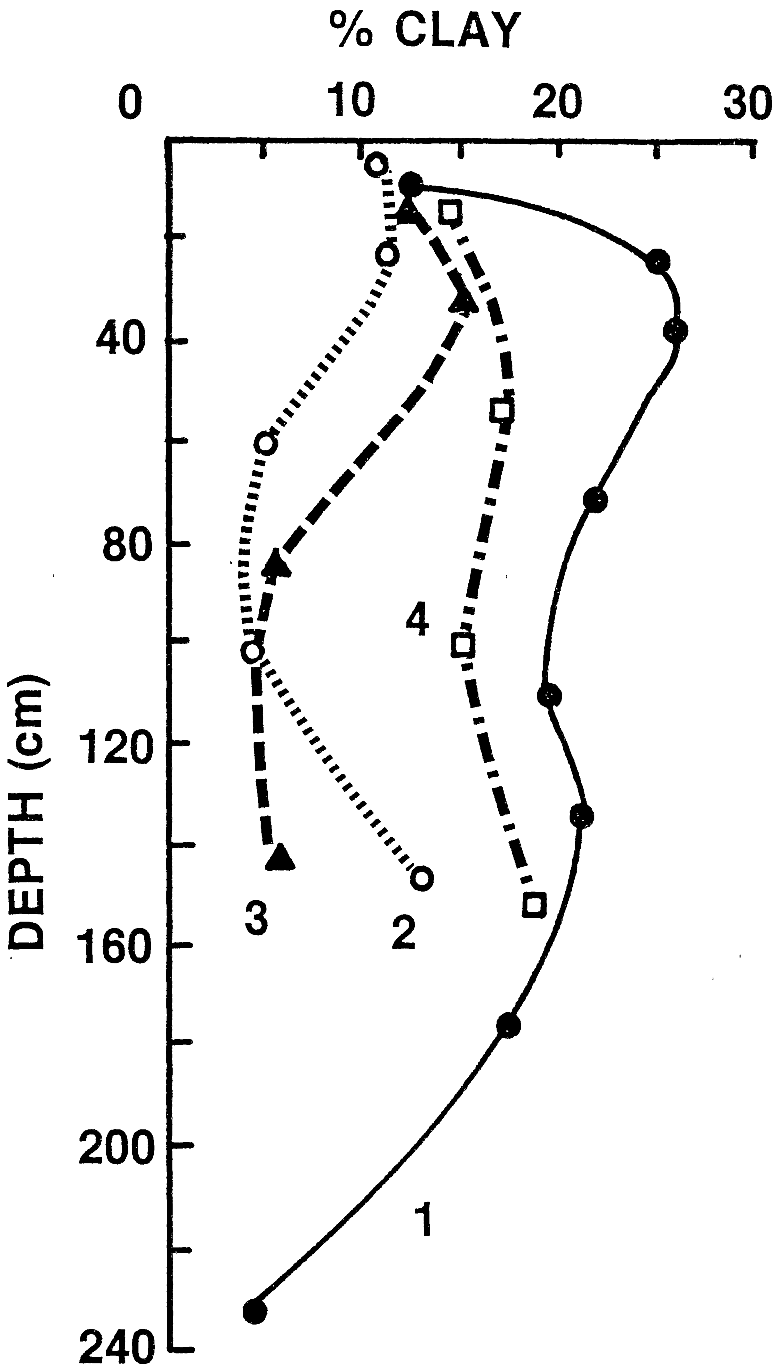
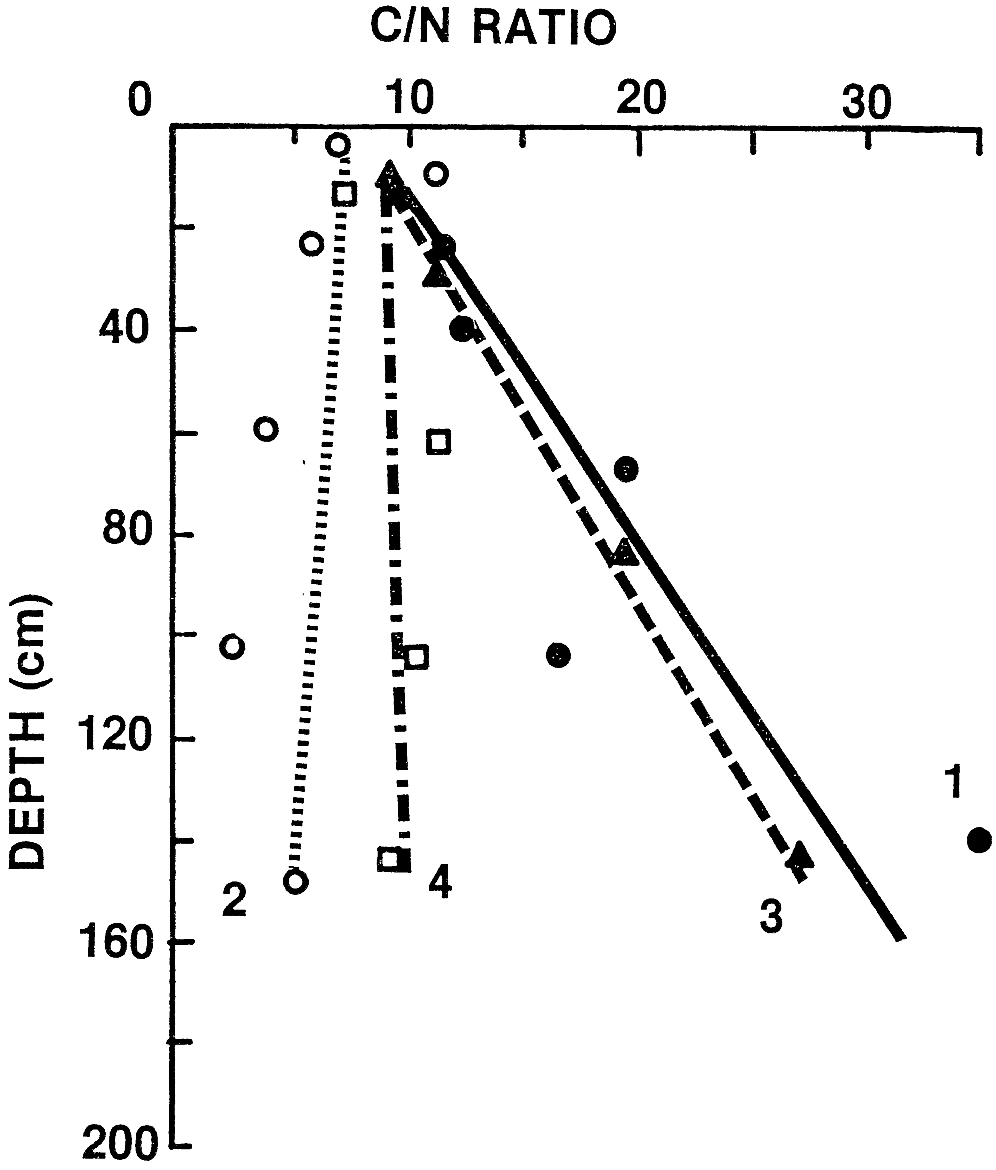

% CLAY
0
10
20
30
DEPTH (cm)
40
80
120
160
200
240
1
2
3
4

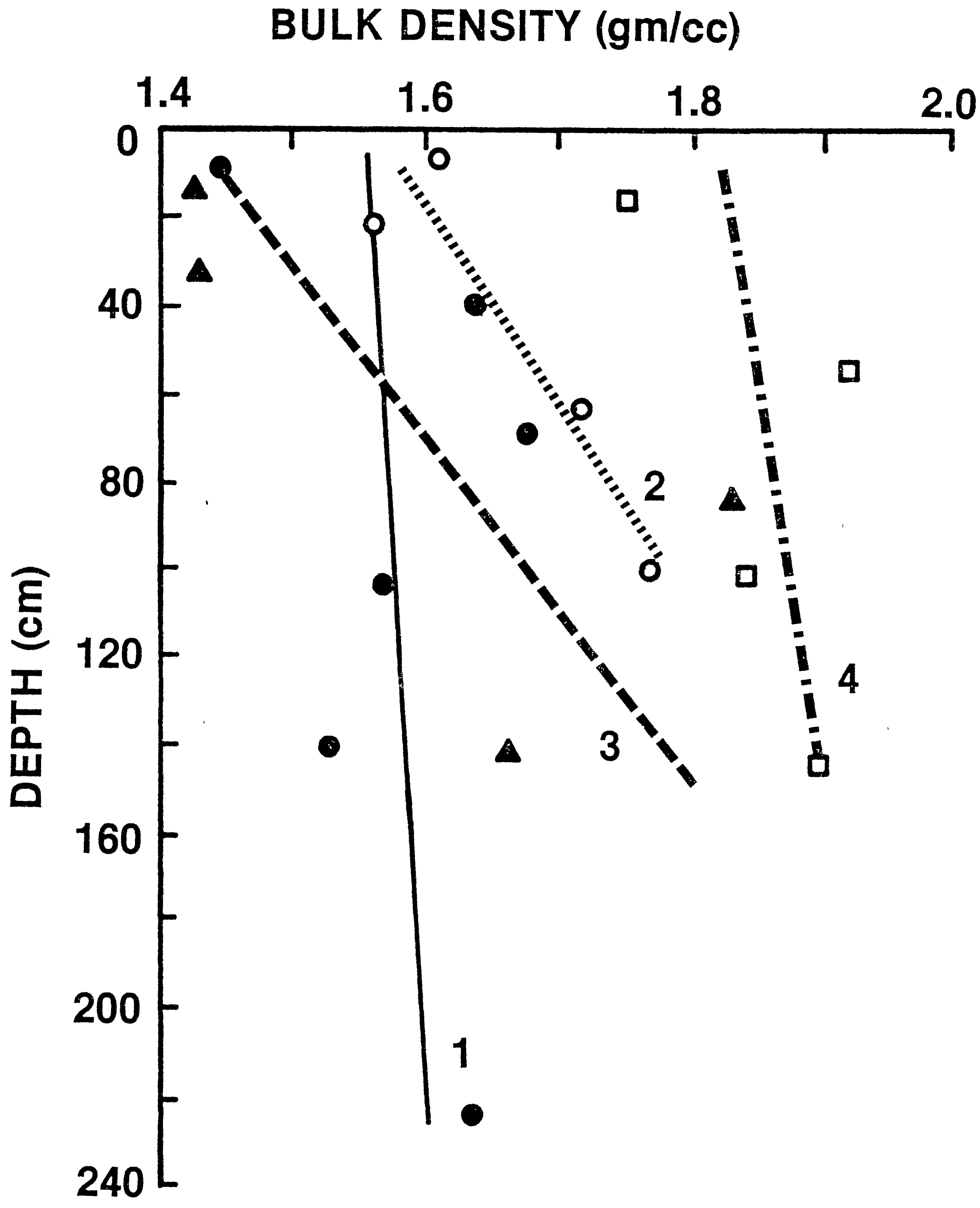
Figure 7. C/N Ratios With Increasing Depth for Each Soil Pit (Pit 1=●; Pit 2=○; Pit 3=▲; Pit 4=□)


C/N RATIO
0
10
20
30
40
80
120
160
200
DEPTH (cm)
1
2
3
4

ratios increase to a depth of 160 cm for the relatively old soils of Pit 3, and especially Pit 1, possibly because of the abundance of the resistant forms of organic carbon such as lignins (Kononova, 1966). These ratios are expected to eventually decrease at greater depths than measurable because of the current extremely low levels of organic matter (Speir and Ross, 1982).

Bulk density results are shown as a linear regression in Figure 8 and the corresponding regression equations and correlation coefficients are presented in Appendix B. The bulk density values for the four soil profiles increase with depth. This is the typical trend for bulk density values (Dawud and Gray, 1979). Figure 8 shows that the soil from Pit 1 had relatively low bulk density values throughout the entire soil profile. This results from the formation of granular type structure produced by an abundance of organic matter, deep root penetration, and animal influence (Jenny, 1949). Pit 2 consists of relatively high bulk density values due to the relatively young age of the soil caused by the effects of mass wasting and erosion. The surface bulk density of Pit 3 is low, while relatively high in the subsurface. This results from the massive structure introduced at 41 cm in the Cr1 and Cr2 horizons. The bulk density of Pit 4 is relatively high throughout the entire profile. The result of relatively low surface and subsurface levels of organic matter may express the effects of minimum time or the rate of erosion on the development of

Figure 8. Bulk Density With Increasing Depth for Each Soil Pit (Pit 1= ●; Pit 2= ○; Pit 3= ▲;Pit 4= □)

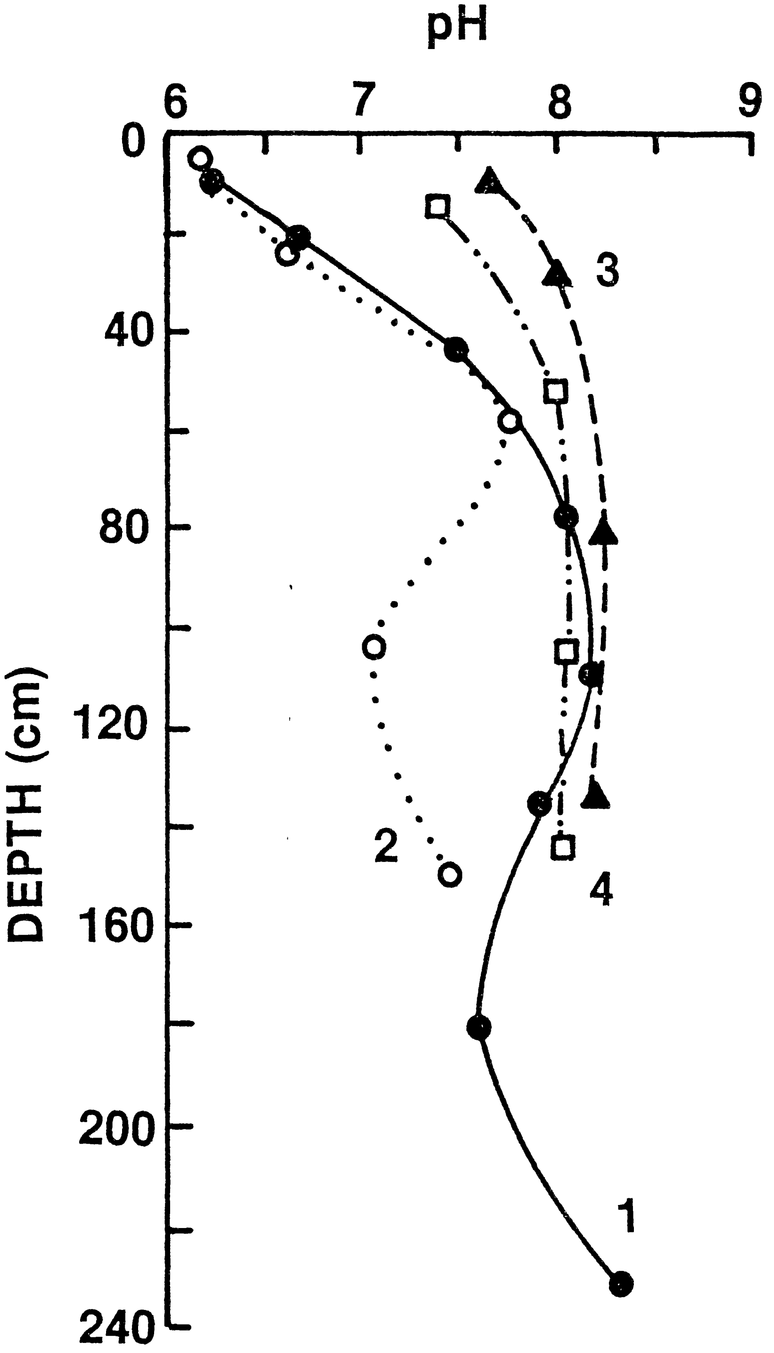

BULK DENSITY (gm/cc)
1.4
1.6
1.8
2.0
0
40
80
120
160
200
240
DEPTH (cm)
1
2
3
4

a soil profile. Bulk density results support its use as an indicator of soil depth and soil formation, and therefore, indirectly indicate the influence of erosion on the landscape.

The reaction (pH) of the soil may be affected indirectly by its position on the hillslope because of the amount of leaching. Figure 9 shows that the soils of Pits 3 and 4 have basic reactions throughout the entire profiles, while Pits 1 and 2 change from acidic to basic reactions with increasing depth. This may reflect the result of both vertical leaching in Pits 1 and 2, and horizontal leaching and accumulation into Pits 3 and 4. The leaching and accumulation of salts is dependent on not only the time involved in soil formation, but also the time invloved in the erosional processes that control the formation of the hillslope. The horizontal leaching and accumulation is a function of the physical characteristics of the hillslope, such as gradient and length.

The data from electrolytic conductivity, extractable acidity, and cation exchange capacity are found in Appendix D. The electrolytic conductivity values for the 4 pits do not show a trend with respect to soil genesis or erosional processes on a hillslope. The relative amount of rainfall in this region could be too great to show a trend with respect to soil development. Likewise, extractable acidity data supports the trends of pH and cation exchange capacity reflecting the organic matter and clay content.

Figure 9. Reaction (pH) With Increasing Depth for Each Soil Pit (Pit 1=●; Pit 2=○; Pit 3=▲; Pit 4=□)

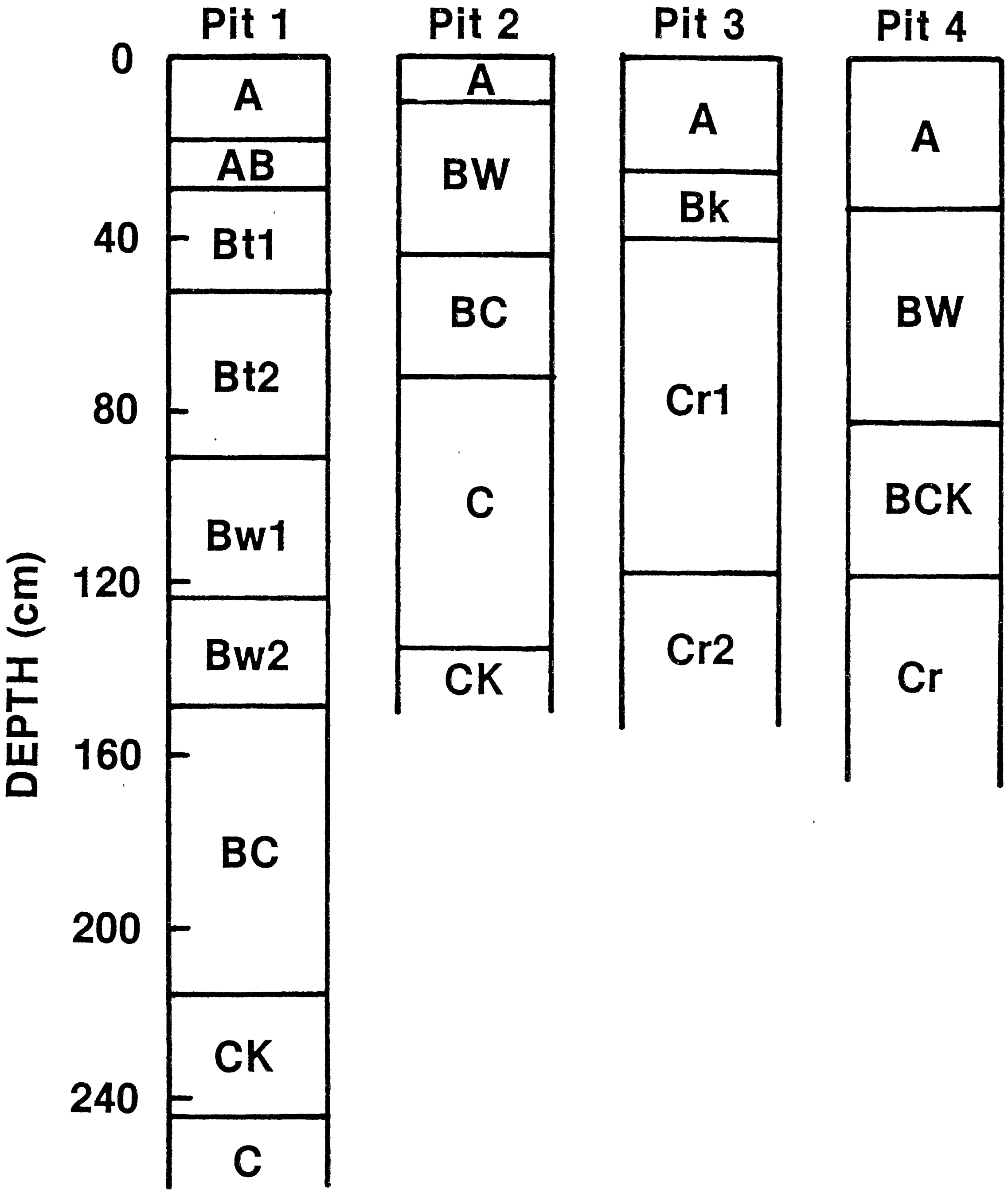

pH
6
7
8
9
0
40
80
120
160
200
240
DEPTH (cm)
1
2
3
4

Base saturation could not be calculated because of excessive amounts of "free" CaCO3 in some horizons.

Soil Classification

The soil profile and the horizon depths are shown in Figure 10, and the detailed profile descriptions may be found in Appendix C. The soil of Pit 1 was classified as a Udic Argiustoll. Mollisols are characteristic of the grassland regions and contain a thick, dark-colored surface horizon (Soil Survey Staff, 1975). The accumulation of organic matter and clay over time in Pit 1 has contributed to the development of the mollic epipedon and the argillic horizon. The calcic horizon was found too deep within the profile to classify the soil into the Typic subgroup. Pits 2, 3, and 4 are shallower soils than Pit 1 because of the effects of erosion, and are consequently classified as Inceptisols. Inceptisols are pedologically much younger soils that are just beginning to show genetic horizon development. The shallow depth of the calcic horizon allowed Pit 3 to be classified as a Typic Ustochrept, while Pits 2 and 4 were classified as Udic Ustochrepts because of the much greater depth of the calcic horizon.

Figure 10. Soil Horizon Designations and Horizon Depths for Each Soil Pit


Pit 1
Pit 2
Pit 3
Pit 4
DEPTH (cm)
0
40
80
120
160
200
240
A
AB
Bt1
Bt2
Bw1
Bw2
BC
CK
C
A
BW
BC
C
CK
A
Bk
Cr1
Cr2
A
BW
BCK
Cr

CHAPTER V

SUMMARY AND CONCLUSIONS

Four soils sampled across an increasing slope gradient were analyzed for differences in origin, soil properties, and age. Zr/Ti ratios and clay-free silt contents supported field observations that all 4 soils were derived from the same alluvial material.

The following soil properties reflect the effect of soil erosion across an increasing slope gradient: organic matter content, clay content, C/N ratios, bulk density, and pH. The organic matter was higher for all soil depths at the summit of the hill than at any other hillslope location, while clay accumulation in the B horizon was unique only to the soils at the summit of the hill. C/N ratios increased with depth for the soils sampled from the summit and midslope segment of the hill, and showed no change with depth for the soils sampled from the convex shoulder and straight backslope segments of the hillslope. Likewise, low bulk density values were found for the soil sampled from the summit and midslope segment of the hill, while relatively high values were found in the soils sampled from the convex shoulder and toe of the hillslope. Soil pH was lower for the soils sampled from the summit and shoulder of the slope, than for those soils sampled from the mid- and toe-slope segments.

Radiocarbon measurements revealed that the soil sampled from the summit of the hill was older than any other soil sampled on the hillslope. The soil sampled on the convex shoulder of the hill was found to be younger than the soil sampled on the midslope segment due to the effects of mass wasting. The soil sampled from the toeslope revealed modern radiocarbon ages, and therefore, reflected the lowest degree of genetic horizon development.

Radiocarbon dating is a useful and direct method to determine the effects of soil erosion on a hillslope. In this type of study, several variables should be examined and minimized to produce the most accurate and positive results. These variables include parent material, vegetation, slope aspect, solum thickness, and disturbances caused by human influence and by mass wasting processes. Future applications for radiocarbon dating of soils include the determination and prediction of natural soil erosion rates on a landscape.

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APPENDIXES

APPENDIX A

RADIOCARBON AGE DETERMINATIONS

Depth	Pit 1	Pit 2	Pit 3	Pit 4
cm	years B. P.			
0 - 20	modern	modern	modern	modern
40 - 60	2330 + 60	700 + 60	5480 + 90	---
80 - 100	8100 + 100	3620 + 90	5530 + 90	---
120 - 140	17920 + 305	---	---	---

APPENDIX B

REGRESSION EQUATIONS AND CORRELATION COEFFICIENTS FOR RADIOCARBON DATES, C/N RATIOS, AND BULK DENSITY

Pit	Regression Equation	Correlation Coefficient
	for Radiocarbon Dates (Table 3)	
1	$Y = 170.57\ X - 3572.9$	0.8787
2	$Y = 45.25\ X - 822.5$	0.9427
3	$Y = 69.13\ X + 213.75$	0.8699
	for C/N Ratios (Table 7)	
1	$Y = 0.1530\ X + 7.65$	0.8514
2	$Y = -0.0127\ X + 6.65$	-0.3898
3	$Y = 0.1336\ X + 7.22$	0.9975
4	$Y = 0.0050\ X + 8.78$	0.2199
	for Bulk Density (Table 8)	
1	$Y = 0.0002\ X + 1.55$	0.2283
2	$Y = 0.0020\ X + 1.57$	0.8891
3	$Y = 0.0024\ X + 1.43$	0.6940
4	$Y = 0.0006\ X + 1.80$	0.5189

APPENDIX C

SOIL PROFILE DESCRIPTIONS

Pit 1

Soil Classification: Fine-silty, mixed, thermic Udic Argiustoll

Slope Position: Summit

Slope: 0 to 2 %

Major Vegetation: Japanese brome, buffalo grass, six-weeks fescue, silver bluestem

Minor Vegetation: Blue gramma, little barley, milk vetch, western ragweed, sand sage brush

Soil Profile:

Horizon	Depth (cm)	Description
A	0 to 17	Dark brown (7.5YR 3/2) silt loam, brown to dark brown (10YR 4/3) dry; moderate fine subangular blocky structure parting to moderate medium granular; friable; many fine roots; slightly acid, clear smooth boundary.
AB	17 to 29	Dark brown (7.5YR 3/2) silt loam; moderate medium prismatic structure parting to moderate medium subangular blocky; very friable; common very fine roots; slightly acid; gradual smooth boundary.
Bt1	29 to 53	Dark brown (7.5YR 3/2) silt loam; moderate coarse prismatic structure parting to moderate medium angular blocky; very friable; common very fine roots; common distinct clay films; mildly alkaline; clear smooth boundary.
Bt2	53 to 91	Dark brown (10YR 3/3) silt loam, brown to dark brown (10YR 3/3) dry; moderate coarse prismatic structure parting to moderate medium angular blocky;; very friable; few fine roots; common distinct clay films; strong effervescence; mildly alkaline; gradual smooth boundary.

Bw1	91 to 124	Dark yellowish brown (10YR 3/4), dark yellowish brown (10YR 4/4) dry; moderate medium subangular blocky structure parting to weak coarse prismatic; friable; few very fine roots; common faint clay films; moderate effervescence only on films; mildly alkaline; gradual smooth boundary.
Bw2	124 to 150	Brown to dark brown (7.5YR 4/4) silt loam; weak coarse prismatic structure parting to moderate medium subangular blocky; friable; few very fine roots; common faint clay films; moderate effervescence only on films; mildly alkaline; clear smooth boundary.
BC	150 to 214	Yellowish red (5YR 4/6) loam; weak coarse prismatic structure; friable; few very fine roots; few faint clay films along roots and pores; moderate effervescence only on films; mildly alkaline; abrupt wavy boundary.
Ck	214 to 244	Yellowish red (5YR 5/6) loamy sand/sand; common fine prominent pink (7.5YR 7/4) mottles; massive; loose; violent effervescence; mildly alkaline.

Pit 2

Soil Classification: Sandy, mixed, thermic Udic Ustochrept

Slope Position: Shoulder

Slope: 9 %

Major Vegetation: Louisiana sage wort, Lambert crazy weed, sand sage brush

Minor Vegetation: Yucca, serrateleaf evening primrose, thistle, silver bluestem

Soil Profile:

Horizon	Depth (cm)	Description
A	0 to 8	Very dark grayish brown (10YR 3/2) sandy loam, brown to dark brown (10YR 4/3) dry; moderate medium granular structure; friable; common fine roots; slightly acid; clear smooth boundary.
Bw	8 to 44	Very dark grayish brown (10YR 3/2) sandy loam, brown to dark brown (10YR 4/3) dry; weak medium prismatic structure; friable; common fine roots; common faint clay bridges on sand grains; slightly acid; clear wavy boundary.
BC	44 to 75	Dark brown (7.5YR 3/4) loamy sand, strong brown (7.5YR 4/6) dry; weak coarse prismatic; very friable; few fine roots; mildly alkaline; clear wavy boundary.
C	75 to 134	Dark yellowish brown (10YR 4/6) sand, yellowish brown (10YR 5/6) dry; massive; loose; few fine roots; mildly alkaline; abrupt wavy boundary.
Ck	134 to 150	Yellowish brown (10YR 5/6) sandy loam, few medium prominant light brownish gray (2.5Y 6/2) mottles; weak medium angular blocky structure; friable; few fine roots; mildly alkaline.

Pit 3

Soil Classification: Coarse-loamy, mixed, thermic Typic Ustochrept

Slope Position: Midslope

Slope: 16 %

Major Vegetation: Sand sage brush, black sampson, leadplant

Minor Vegetation: Silver bluestem, sand plum

Soil Profile

Horizon	Depth (cm)	Description
A	0 to 26	Very dark grayish brown (10YR 3/3) loam, dark brown (10YR 3/2) dry; moderate fine crumb structure; friable; many fine roots; few faint clay bridges between sand grains; violent effervescence; mildly alkaline; clear wavy boundary.
BK	26 to 41	Brown to dark brown (10YR 4/3) loam, brown (10YR 5/3) dry; strong medium subangular blocky structure; friable; many fine roots; violent effervescence; mildly alkaline; abrupt wavy boundary.
Cr1	41 to 118	Yellowish brown (10YR 5/4) silt loam; light yellowish brown (10YR 6/4) dry; strong medium prismatic structure parting to massive; extremely firm; few fine roots; violent effervescence; mildly alkaline; abrupt wavy boundary.
Cr2	118 to 155	Yellowish brown (10YR 5/6) silt loam; weak medium angular blocky; friable; violent effervescence; mildly alkaline.

Pit 4

Soil Classification: Coarse-loamy, mixed, thermic Udic Ustochrept

Slope Position: Toe-slope

Slope: 23 %

Major Vegetation: Sand plum, sand sage brush, black sampson

Minor Vegetation: Silver bluestem, leadplant

Soil Profile:

Horizon	Depth (cm)	Description
A	0 to 34	Very dark grayish brown (10YR 3/2) loam; moderate medium subangular blocky structure; friable; many fine and medium roots; violent effervescence; mildly alkaline; clear wavy boundary.
Bw	34 to 83	Strong brown (7.5YR 4/6) loam; strong brown (7.5YR 5/6) dry; strong coarse prismataic structure parting to moderate medium subangular blocky; firm; common fine roots; strong effervescence; mildly alkaline; clear wavy boundary.
BCk	83 to 120	Yellowish brown (10YR 5/6) silt loam; massive; friable; few fine roots; violent effervescence; mildly alkaline; abrupt wavy boundary.
Cr	120 to 163	Yellowish brown (10YR 5/6) loam; massive; friable; strong effervescence; mildly alkaline.

APPENDIX D

PHYSICAL AND CHEMICAL SOIL ANALYSES

Horizon	Depth	Very Coarse Sand	Coarse Sand	Medium Sand	Fine Sand	Very Fine Sand	Particle Size			Bulk Density
							Sand	Silt	Clay	
	cm	2-1 mm	1-.5 mm	.5-.25 mm	.25-.1 mm	.1-.05 mm	-----------%-----------			g/cc
					Pit 1					
A	0-17	0.7	1.3	2.9	3.8	7.8	16.4	70.6	13.0	1.44
AB	17-29	1.0	1.4	1.6	1.9	3.8	9.7	65.3	25.0	----
Bt1	29-53	1.3	1.0	1.4	1.6	2.2	7.5	66.5	26.0	1.62
Bt2	53-91	0.7	1.1	2.3	2.2	2.6	8.9	69.1	22.0	1.68
Bw1	91-124	1.3	3.4	6.4	6.8	5.0	22.9	57.6	19.5	1.58
Bw2	124-150	2.1	4.7	8.8	8.1	5.6	29.3	50.2	20.5	1.51
BC	150-214	8.6	9.6	12.1	10.0	7.8	48.1	33.9	18.0	----
Ck	214-244	42.2	21.2	12.0	9.3	3.2	87.9	7.6	4.5	1.60
					Pit 2					
A	0-8	15.5	11.6	15.8	9.1	6.1	58.1	30.4	11.5	1.61
Bt	8-44	29.7	16.7	11.8	5.9	4.5	68.6	19.4	12.0	1.56
BC	44-75	34.0	23.4	13.8	8.2	1.5	80.9	14.1	5.0	1.72
C	75-134	32.5	27.7	15.7	9.0	5.7	90.6	4.9	4.5	1.77
Ck	134-150	3.3	5.2	23.1	24.3	12.4	68.3	17.7	14.0	----
					Pit 3					
A	0-26	12.5	8.3	6.6	11.6	9.4	48.4	38.6	13.0	1.43
Bk	26-41	1.2	2.3	5.1	15.8	14.4	38.8	46.2	15.0	1.43
Cr1	41-118	----	----	1.5	17.0	11.5	29.8	64.7	5.5	1.82
Cr2	118-155	----	----	4.1	29.8	9.8	43.7	50.8	5.5	1.66
					Pit 4					
A	0-34	8.4	7.6	13.1	13.7	5.7	48.5	38.0	13.5	1.77
Bw	34-83	1.2	3.8	11.0	12.1	11.6	39.7	43.3	17.0	1.92
BCk	83-120	1.3	3.9	9.6	10.3	4.2	29.3	57.7	13.0	1.83
Cr	120-163	2.0	4.9	10.8	10.9	6.5	35.1	45.9	19.0	1.89

Horizon	Depth	pH 1:1 H_2O	pH 1:1 KCL	Organic Carbon	Total Nitrogen	C/N Ratios	Electrolytic Conductivity	C.E.C.	Extractable Acidity	Zr/Ti ratios (Total soil)
	cm			%	%		mhos	------meq/100g------		
						Pit 1				
A	0-17	6.3	5.5	1.46	0.13	11.37	318	19.52	4.23	8.00
AB	17-29	6.7	5.9	1.03	0.09	11.71	349	27.70	4.46	12.29
Bt1	29-53	7.5	6.6	0.74	0.06	12.46	460	30.44	3.25	13.09
Bt2	53-91	8.1	7.1	0.62	0.03	18.64	518	27.43	0.56	12.79
Bw1	91-124	8.2	7.2	0.34	0.02	16.19	927	21.77	1.14	10.11
Bw2	124-150	7.9	7.2	0.35	0.01	35.00	4210	25.88	1.51	11.19
BC	150-214	7.7	7.1	0.20	0.02	13.00	7190	22.08	1.41	10.20
Ck	214-244	8.4	7.5	0.07	0.01	7.78	4210	9.41	0.04	5.35
						Pit 2				
A	0-8	6.2	5.5	1.54	0.20	7.71	321	12.68	4.20	6.40
Bw	8-44	6.6	5.7	0.81	0.12	6.88	244	11.76	2.65	8.28
BC	44-75	7.8	5.9	0.21	0.05	4.04	155	6.71	2.24	6.44
C	75-134	7.1	6.2	0.13	0.04	3.61	190	6.66	1.73	6.92
Ck	134-150	7.5	6.5	0.13	0.02	6.75	272	14.66	1.69	7.31
						Pit 3				
A	0-26	7.7	7.1	1.45	0.17	8.63	447	16.48	0.53	6.52
Bk	26-41	8.0	7.1	1.01	0.09	11.69	477	17.27	0	7.07
Cr1	41-118	8.3	7.5	0.13	0.01	18.57	258	9.64	0	5.20
Cr2	118-155	8.2	7.5	0.08	0.01	25.00	240	9.55	0	5.60
						Pit 4				
A	0-34	7.4	6.9	1.19	0.15	7.78	383	15.95	1.64	6.88
Bw	34-83	8.0	7.2	0.29	0.03	10.36	353	16.77	0	7.42
BCk	83-120	8.1	7.3	0.08	0.01	10.00	242	14.26	0	5.75
Cr	120-163	8.1	7.2	0.06	0.01	8.57	247	17.43	0	7.49

VITA

Kari Lin Sever

Candidate for the Degree of

MASTER OF SCIENCE

Thesis: USING RADIOCARBON DATING TO DETERMINE THE EFFECT OF SOIL EROSION ACROSS AN INCREASING SLOPE GRADIENT

Major Field: Agronomy

Biographical:

Personal Data: Born in Paola, Kansas, September 10, 1961, the youngest daughter of Mr. and Mrs. H. Lee Jacobson. Married J. Michael Sever on August 4, 1984.

Education: Graduated from Douglas MacArthur High School, Decatur, Illinois, in 1979; received Bachelor of Science degree in Agriculture from the University of Illinois, Urbana, Illinois, in May, 1983; completed requirements for the Master of Science degree in Agronomy at Oklahoma State University, Stillwater, Oklahoma, in July, 1985.

Professional Experience: Graduate Research Assistant, Agronomy Department, Oklahoma State University, 1983 to 1985.