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SPODOSOL DEVELOPMENT AS AFFECTED BY GEOMORPHIC ASPECT,
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SPODOSOL DEVELOPMENT
AS AFFECTED BY GEOMORPHIC ASPECT,
BARAGA COUNTY, MICHIGAN

By

Robert Vincent Hunckler

A THESIS

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ABSTRACT

SPODOSOL DEVELOPMENT AS AFFECTED BY GEOMORPHIC ASPECT, BARAGA COUNTY, MICHIGAN

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The influence of geomorphic aspect on Spodosol development was studied in Baraga County, Michigan as a means of explaining within-landform variability. Soils with spodic morphology, located on steep slopes (45 to 73%) of contrasting aspect (N-NE vs. S-SW), were examined on a dissected outwash plain. Variation in slope gradient (45 to 73%) was not a determining factor in the differential soil development found here.

Soils are better developed (i.e., more podzolized) on north-to-northeast-facing slopes than on south-to-southwest slopes. Several soil characteristics indicative of strong podzolization had significantly higher values on north-to-northeast slopes, including solum thickness, POD Index and extractable Fe and Al in the B horizon. Soils were cooler on north-to-northeast slopes. In April, November (1995) and January (1996), snow depths were greater on north-to-northeast slopes.

Of the 10 pedons on north-to-northeast slopes, nine classified as Spodosols (Entic or Typic Haplorthods); the other was an Entisol. Of the 10 pedons on south-to-southwest slopes, seven classified as Entisols (Udipsamments or Udorthents); the remaining three were Spodosols.

For Kicker and Buzz and Andrea

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INTRODUCTION

Like all soils, Spodosols exist in various stages of development at different locations, even on the same landform. The study of these spatial differences in soil development is the essence of soil geography. Soil geographers often attempt to examine the causes for spatial variation in soil development by utilizing one of several theoretical models. One such examination can be accomplished by investigating individual soil-forming factors of the functional-factorial model of soil development (Jenny 1941). In this model, differneces in the five soil-forming factors (climate, organisms, relief, parent material and time) are thought to account for most of the spatial variation in soil development. The current research utilizes Jenny's model and attempts to examine differences in soil development that may have formed due to spatial variations of climate (microclimate).

Surface slope and aspect are critical factors affecting Spodosol development on landforms, due (ultimately) to variable solar radiation input at the ground and vegetational (grass or forest canopy) surfaces. Spatial patterns of Spodosol development that correlate closely with surface slope and aspect would be useful to understanding the geography of Spodosols and the relationships to the landscapes in which they exist. Such spatial patterns would aid in the classification of soils and the suggested land use of an area, and thus perhaps, increase land productivity.

In hilly terrain, the incidence angle of the sun varies from one location to another due to differences in local topography and the subsequent partial shading of the landscape. Equatorial regions of the world (i.e., less than 20° N and S latitude) are virtually unaffected by this shading phenomenon because solar radiation is received from angles both north and south of (and always very close to) celestial zenith during the entire year. Polar regions (i.e., greater than 70° N and S latitude) are also essentially unaffected by this phenomenon due to the fact that solar radiation is received from many directions throughout the summer daylight periods, and during the winter months is either not received at all or is at a very low level of intensity due to the low inclination of the sun. Thus, a hilly landscape in a polar region receives small, but nonetheless equal, amounts of solar radiation on all surfaces over the year. However, a hilly area located between 30° and 60° latitude may be dramatically affected by this shading phenomenon. It is in these latitudes that the directional orientation of a hillslope (its aspect) becomes a major factor in the amount of solar radiation received by that particular parcel of land, and hence, its microclimate.

Researchers have found that north-to-northeast-facing slopes differ from adjoining south-to-southwest-facing slopes in several climate-related categories. Soil temperature (Franzmeier et al. 1969, Macyk et al. 1978), atmospheric temperature (Cantlon 1953, Whittaker et al. 1969), soil moisture (Finney et al. 1962, Carter & Ciolkosz 1991), atmospheric moisture (Cantlon 1953, Finney et al. 1962) and wind velocity (Cantlon 1953, Lieffers and Larkin-Lieffers 1987) have been shown to vary from one location to another within a small geographic area, often due to aspect. These microenvironmental differences could play a vital role in the development of soils over time.

The purpose of this research was to determine if Spodosols (mapped as sandy and sandy over loamy, mixed, frigid Entic Haplorthods (Berndt 1988)) within the study area are more or less developed (i.e., greater translocation of mobile materials, thicker genetic horizons, etc.) due to geomorphic aspect. To attain this information, pedons were described and sampled on steep slopes (45 to 73%) of contrasting aspect (0° to 45° azimuth vs. 180° to 225° azimuth). Morphological and chemical characteristics of paired pedons were analyzed for differences and tested for statistical significance utilizing a paired-comparison approach (Wilcoxon 1949).

Numerous studies of soil development as affected by geomorphic aspect have been performed (see Literature Review, page 6). However, none of these studies has examined Spodosols and the effect of geomorphic aspect on their development. Since the present study is the first attempt at examining Spodosol development with regard to geomorphic aspect, complicating factors such as topographic position on the slope, parent material and microrelief were held as close to constant as possible.

Results of this study can be used in forestry, soil mapping and land-use planning applications in an attempt to better utilize the soil resources of the area. Foresters could plan on better tree production in the area if appropriate tree species were planted on different soil types, thus, taking advantage of the natural state of the soil. If soil types are highly correlated with slope aspect, the process of soil identification for the forester becomes a much simpler task.

The Podzolization Process

"Podzolization" or those processes leading to the development of Spodosols occurs mostly in sandy to coarse loamy parent material of Pleistocene or Holocene age. Podzolization is most commonly found to have taken place in cool humid climates

(McKeague, et al. 1983). The podzolization process involves the following steps, which often take place simultaneously (Mokma and Buurman 1982):

1. **Accumulation of organic matter on the ground surface.**

After the deposition of the (mineral) parent material(s), organic matter accumulates on the surface as a result of the litter from flora and the incorporation of its decay products by fauna. Organic matter also accumulates below the ground surface due to the decomposition of plant roots and the subsequent incorporation of its decay products by fauna (Mokma and Buurman 1982).

2. **Leaching and acidification of the parent material.**

Before humus, Fe and Al can be translocated, most exchangeable bases (especially calcium) must be removed from the upper horizons. Bases will form insoluble compounds with the water-soluble organic materials (Mokma and Buurman 1982), thus preventing any weathering/translocation of sesquioxides. In the present study, pH's of the C horizon, as well as the absence of carbonate bedrock near and north of the study area indicate that a relatively acid environment may have existed at the inception of these soils (see Soil Reaction, p.59). Thus, perhaps only a short period of time had to pass before weathering and translocation could take place.

3. **Weathering of Fe and Al; decomposition of organic matter.**

The decomposition of organic matter allows fulvic acids to chelate with Fe and Al (also Ca and Mg) to form organo-metallic complexes. The chelation of fulvic acids with Fe and Al then propogates the movement of these metals down through the soil (Petersen 1975).

4. **Translocation and subsequent immobilization of organic matter, Fe and Al (as organo-metallic complexes).**

As the organo-metallic complexes migrate downward, they chelate (adsorb) additional Fe and Al cations. Immobilization of these organo-metallic complexes can occur when sufficient amounts of Fe and Al are adsorbed to form large immobile organo-metallic compounds. Immobilization can also occur through dessication or when a horizon of different (usually higher) pH is encountered (Mokma and Buurman 1982). Immobilized organo-metallic complexes can become cemented over time. However, in the present study, very little cementation was observed.

LITERATURE REVIEW

Studies of aspect have, in general, been conducted to determine the effect of solar intensity on the physical and biological characteristics of a given location. The microclimates that result from differential solar input can change the physical response of an area. Aspect studies have analyzed, among others, the spatial variations in: 1) soil development; 2) vegetation; 3) air temperature; and 4) snow cover, all based upon slope orientation and resulting microclimatic phenomena. The literature on these individual topics will be covered in the following sections.

Soil Development

Studies that have analyzed soils with regard to slope orientation and microclimate have not been limited to any geographical area; however, the Appalchian Mountains are well represented. Franzmeier et al (1969) studied north- and south-facing slopes (36-62%) in eastern Kentucky and Tennessee. In silt loam parent materials over bedrock, they found darker profiles located on north-facing slopes. They also found greater amounts of organic matter in all horizons on north-facing slopes. Most of the profiles located on south-facing slopes had argillic horizons while most on the north-facing slopes had only cambic horizons. Finney et al. (1962) studied northeast- and southwest-facing, dissected slopes (40-60%) developed in residuum in southeastern Ohio. In silt loam to sandy loam soils, they found thinner A1 horizons on southwest-facing slopes as well as more strongly developed A2 (E) and B horizons on the same slopes. They also found lower pH values in the upper solum of soils found on southwest-facing sites. Hicks and Franks (1984) studied northeast- and southwest-facing slopes in West Virginia. In this dissected residuum, they found that the A horizons of northeast-facing slopes contained larger amounts of manganese and potassium than did those on southwest-facing slopes. They attributed this difference to more complete litter decomposition and, hence, more rapid nutrient cycling on northeast-facing slopes. Losche et al. (1970) studied north- and south-facing slopes (25-40%) in Virginia, as well as north- and south-facing slopes (50%) in North Carolina. Although the soils in Virginia exhibited very little difference from north to south slopes, the soils at the North Carolina sites did exhibit inter-slope differences. In North Carolina the soils located on south-facing slopes were redder, had a higher free iron content, contained more clay in the B horizon, exhibited more evidence of clay illuviation, had thicker sola and showed greater evidence of profile differentiation than did the soils located on north-facing slopes. Cooper (1960) studied north- and south-facing slopes of 31-60% in southeastern Michigan. On a sandy disintegration moraine, he found shallow, intensely developed sola on south-facing slopes contrasted by deeper, less intensely developed sola on north-facing slopes. Macyk et al. (1978) studied north- and south-facing slopes of 15% just west of Edmonton, Alberta. On loamy till knobs, they found that aspect and microclimate had a greater effect on soil morphology and related physical properties (chroma, structure, etc.) than on the soil chemical properties (pH, CEC, Fe, Al, etc.). Only minor differences in chemical characteristics were noted between soils on north- and south-facing slopes. They also found that profiles with a wider flucuation in water content (wet-dry cycles) over time appeared to be the most strongly developed morphologically. Marron and Popenoe (1986) studied north- and south-facing slopes (15-75%) in northwestern California. In gravelly loam residuum, they found that a greater degree of soil development existed on north-facing slopes indicated by the redder B horizons and greater clay accumulation in the B horizon of those slopes. They also found soil development to be inversely related to slope gradient due to more episodic and destructive mass movements on the steeper slopes. Alexander (1995) studied north- and south-facing slopes (14-82%) that were also in northwestern California. In residuum and colluvium over bedrock he found a larger proportion of shallow soils on south-facing slopes. Stepanov (1967) studied north- and south-facing slopes in the alpine region of Western Tien-Shan (central Asia). In limestone residuum, he found thicker layers of organic material and deeper carbonate leaching on north-facing slopes when compared to that of opposing slopes. He also found lower soil temperatures (at 40cm) and higher nitrogen content in the soils of north-facing slopes when compared to that of south-facing slopes.

The above studies ultimately mentioned microclimate and its associated vegetational and/or erosional differences as the major factors contributing to markedly different soil morphologies at their study sites.

Vegetation

Cantlon (1953) studied north- and south-facing slopes (40-50%) in central New Jersey. On opposing slopes he found the vegetation to be quite different. No species was found to be completely exclusive to either slope, yet the magnitude of the differences tended to increase toward the ground. In other words, the smallest inter-slope differences were found in the main tree layer while the greatest differences were found in the understory of ground plants. Lieffers and Larkin-Lieffers (1987) studied grassland communities in the coulees of the Oldman River, Alberta. They found that aspect, in conjunction with slope position, slope shape and slope gradient, indirectly affected the vegetational diversity of the coulees through their impact on the soil moisture regime. Species that were adapted to moist conditions or hot and dry sites were found in relatively close proximity. Cater (1961) studied sugar maple distribution in northwestern New Brunswick-- the northern limit of its range. He found that sugar maple extended further downslope on east- and northeast-facing slopes than on west- and southwest-facing slopes. No explanation was put forth for this apparent anomaly. Hicks and Franks (1984) studied forests on northeast- and southwest-facing slopes in north-central West Virginia. On ridges and southwest-facing slopes, they found white oak, black oak, northern red oak and chestnut oak. Valleys and northeast-facing slopes were generally dominated by yellow-poplar, with red maple being a substantial component of all sites. Harrington and Neithercut (1985) studied northeast- and southwest-facing slopes in northwestern Lower Michigan where they found sugar maple to be the dominant species on both aspects. However, significant differences were found in the distribution of secondary species. Beech, basswood, black cherry, slippery elm and hemlock were found more commonly on northeast-facing slopes while white ash, ironwood and bigtooth aspen were more abundant on southwest-facing slopes. Hutchins et al. (1976) studied northeast- and southwest-facing slopes in Kentucky. Vegetation of northeast-facing slopes was more diverse, sustaining such species as yellow poplar, basswood and cucumber magnolia. Southwest-facing slopes supported a less diverse plant community and less dense tree stands, with oak and hickory species dominating.

Soil and Air Temperature

Gieger (1969) states that many factors contribute to microclimate, including latitude, slope, aspect, wind, microtopography, macrotopography, precipitation, cloud cover, diffuse sky radiation, radiation reflected from the ground, outgoing longwave radiation and elevation. However, in most of the studies presented here, it seems that degree of slope and aspect are put forth as the two main factors that create differences in soil and air temperatures on opposing slopes.

Cantlon (1953) studied north- and south-facing slopes in New Jersey. He found soil and air temperatures on opposing slopes to be quite different. During the summer, on south-facing slopes, the air temperature profile was characterized by three different types: 1) under heavy shade, the air temperature was cooler near the ground when compared to two m above ground, 2) under medium shade, the daytime temperature profile was generally isothermal with no great difference in air temperature with height and, 3) in small openings in the canopy, air temperature was much more variable with height, exhibiting warmer daytime temperatures near the ground. On north-facing slopes, however, air temperatures were cooler near the ground throughout much of the year, regardless of canopy coverage. Cooper (1960) studied north- and south-facing slopes in southeastern Michigan. He found warmer average soil temperatures on south-facing slopes which he identified as the main factor contributing to increased chemical weathering on these south-facing slopes. He found that the soils on south-facing slopes were more intensely weathered than those of north-facing slopes. Cooper (1960) also observed the greatest difference in air temperature maxima (between north- and south-facing slopes) during the mid-summer. Differences in air temperature minima during the growing season were not more than one degree C between opposing slopes. Macyk et al. (1978) studied north- and south-facing slopes near Edmonton, Alberta. They found that soil temperatures decreased with depth in summer, yet during the spring and fall, variations of the soil temperature profile were observed. For example, in the spring, a cool layer was "sandwiched" between warmer upper and lower soil layers. The temperature of the soil at 100 cm was warmer than the temperature at 30 cm during most of May, September and October. Related to this phenomenon, Russell (1961) stated that heat moves downward through the surface in the summer and upward through the surface in the winter. In the spring, heat moves downward from the surface and upward from below, thus creating a "sandwiched" cooler layer within the soil. Franzmeier et al. (1969) studied soils on north- and south-facing slopes in Kentucky and Tennessee. They found greater differences in soil temperature between opposing slopes during the winter. They also found that sites located at lower topographic positions on the slope had cooler soil temperatures than those above. Although the overall air temperatures dropped dramatically in December and January, the soil temperatures did not exhibit such a dramatic drop during the same two months due to the insulating capacity of the snowpack. Solar radiation reached a maximum in June, yet soil and air temperatures changed very little between June and August. Hutchins et al. (1976) studied northeast- and southwest-facing slopes in Kentucky. They found that southwest slopes received greater intensities of solar radiation and therefore had warmer temperatures and greater evaporative demand. The results of this scenario were less dense tree stands and less developed vegetation on the southwest-facing slopes.

STUDY AREA

Location

The study area is located in northwestern Baraga County, Michigan at approximately 46° 45'N, 88° 30'W (USPLS Township and Range: T50N, R34W) (Figure 1). The study area covers nearly 30 km^2 (approximately 3 x 10 km, with the long axis oriented northeast-southwest). This area was chosen based on the following attributes: 1) abundant unplowed Spodosols; 2) deep, consistent sandy parent material that remains nearly constant throughout the area; 3) sufficiently steep slopes (45 to 73% documented in this study); 4) virtually every possible slope aspect; and 5) no indications of shallow bedrock in the area (which could influence pedogenesis). The boundary of the study area is delineated by a single soil mapping polygon (Rousseau-Ocqueoc fine sands, dissected, 15 to 70% slopes) as was mapped in the Baraga County Soil Survey (Berndt 1988).

Geomorphology

The Wisconsin Glacier retreated from Baraga County for the final time around 9900 years BP (Farrand and Drexler 1985). As the glacier retreated rapidly to the northeast from the study area (Farrand and Drexler 1985) into what is now L'Anse Bay, an outwash plain (Farrand and Bell 1982) of mostly sand, with some silt and some gravel (Berndt 1988), was deposited in the area. Today, this outwash plain (known as the Baraga Plains), lies perched above and to the south of the study area, and covers approximately 120 km^2. The northern edge, or escarpment, of this outwash plain was subsequently dissected as the glacier retreated. The study area lies within this

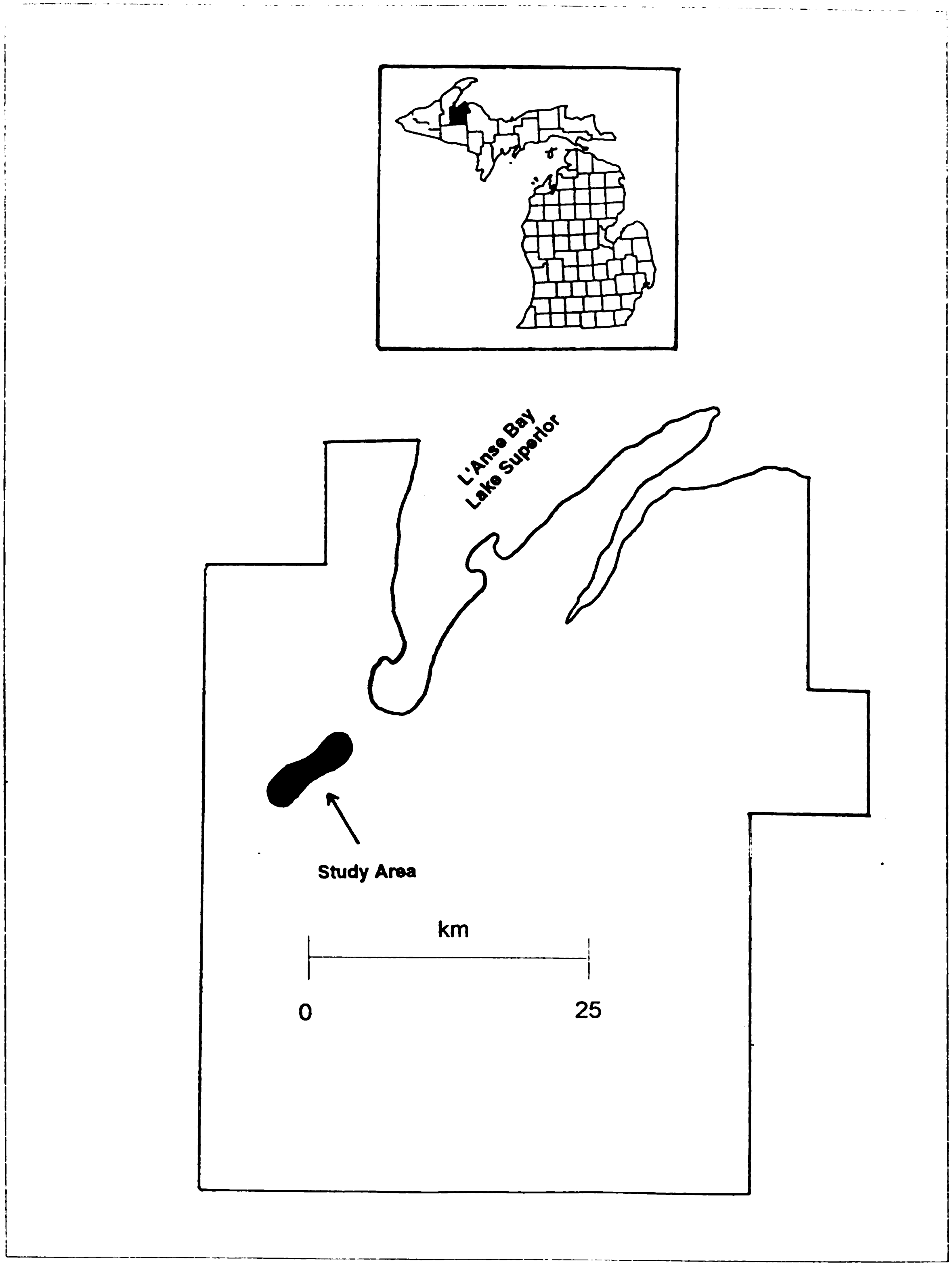

Figure 1. Location of study area within Michigan and within Baraga County.

dissected escarpment.

This dissected escarpment has a pattern of dendritic ravines, each of which varies from 15 to 500 m in width and 5 to 60 m in depth. Ridgetops range from 5 to 30 m in width and ravine bottoms from 5 to 300 m in width. The ravines often exhibit very steep sideslopes that range from 15 to 70% (Berndt 1988). The decrease in elevation from the Baraga Plains (average elevation = 400 m) to Lake Superior (elevation = 183 m) over the relatively short distance of 9 to 10 km probably led to the rapid dissection that characterizes the steep nature of the topographic features in this area. Elevations within the study area vary from 225 to 375 m.

A drainage divide exists across the center of the study area. The southwest portion of the study area is in the Clear Creek (and ultimately the Sturgeon River) drainage basin. The northeast portion of the study area is in the Menge Creek drainage basin. Half of the study sites were selected from each side of this divide. The entire study area lies within the Lake Superior drainage basin.

General Land Office Survey

In the middle 1800's, the General Land Office, a federal agency, surveyed unclaimed U.S. land in order to determine its potential resource productivity and overall usefulness. Surveyors recorded the precise location and species of many thousands of trees as they walked and plotted square-mile section lines. Brief descriptions were also recorded regarding the general nature of the land. Baraga County was surveyed by the General Land Office between the years of 1846-1854 (Barrett et al. 1995).

The study area proper was described in 1849-50 as broken and very hilly with many ravines and high sharp ridges. The soil was described as sandy and "second-rate." The forest was generally timbered with hemlock, yellow birch, sugar maple, red maple, pine, cedar, balsam fir, tamarack, spruce and aspen. No bedrock exposures were noted in and around the study area, suggesting the presence of thick glacial deposits. No mention was made of differential or alternating vegetative cover on slopes of opposing aspect as was documented in the present study (see below).

Soils and Vegetation

The soils of the study area are mapped as a complex of Rousseau and Ocqueoc fine sands, dissected, with slopes of 15 to 70% (Berndt, 1988). Rousseau soils are classified as sandy, mixed, frigid Entic Haplorthods, and Ocqueoc soils are classified as sandy over loamy, mixed, frigid Entic Haplorthods (Soil Survey Staff 1994). These two series are similar, except that Ocqueoc soils have a lithologic discontinuity and contain silty material in a 2C horizon which seems to indicate intermittent ponding of water subsequent and/or contemporaneous to the glacial retreat. Rousseau soils have fine sand textures throughout, and lack a lithologic discontinuity (Berndt, 1988). The Rousseau-Ocqueoc association is composed of approximately 62% Rousseau soils, 20% Ocqueoc soils and 18% soils of minor extent (Berndt 1988). Eleven research sites contained pedons that ultimately classified as either Rousseau or Ocqueoc fine sand. The soil at one other site was clearly more developed (with a Bhs horizon) than the others, and was identified as Liminga fine sand (sandy, mixed, frigid Typic Haplorthods). The Liminga soil series is not mapped in Baraga County due to its small areal extent. The remaining eight sites contained pedons that ultimately classified as Udorthents and Udipsamments (see

Classification section in the Results). Typical soil profiles are shown in Figure 2

Much of northern Michigan, including the study area, was logged in the late 1800's and early 1900's (Whitney 1987, Williams 1989). The present vegetative cover of the study area seems rather typical of second-growth northern hardwood forests. Vegetation observed at individual sites is listed in Appendix A. A summary of dominant vegetation at each site is listed in Table 1. Common tree species (in the study area) include aspen (*Populus* spp.), white birch (*Betula papyrifera* Marsh.), hemlock (*Tsuga canadensis* (L.) Carr.), red maple (*Acer rubrun* L.), white pine (*Pinus strobus* L.), red pine (*Pinus resinosa* Ait.) and balsam fir (*Abies balsamea* (L.) Mill.). All of the pedon sites in the study area were forested at the time of sampling and during subsequent soil temperature fieldwork. Understory vegetation ranged from only a few mosses at some sites to thick covers of bracken fern and wintergreen at other sites. In the summer of 1995, bracken fern existed at only 6 of 10 north-to-northeast-facing sites, persisting in limited size (height < 0.5 m) and number at each site. The remaining 4 sites on north-to-northeast-facing slopes exhibited sparse understory vegetation with intermittently dispersed mosses and small wildflowers. Simultaneously, the bracken fern on 8 of 10 south-to-southwest-facing sites were numerous and sometimes reached heights of 1.5 m. The remaining two sites on south-to-southwest-facing slopes exhibited only small wintergreen or else no understory vegetation whatsoever.

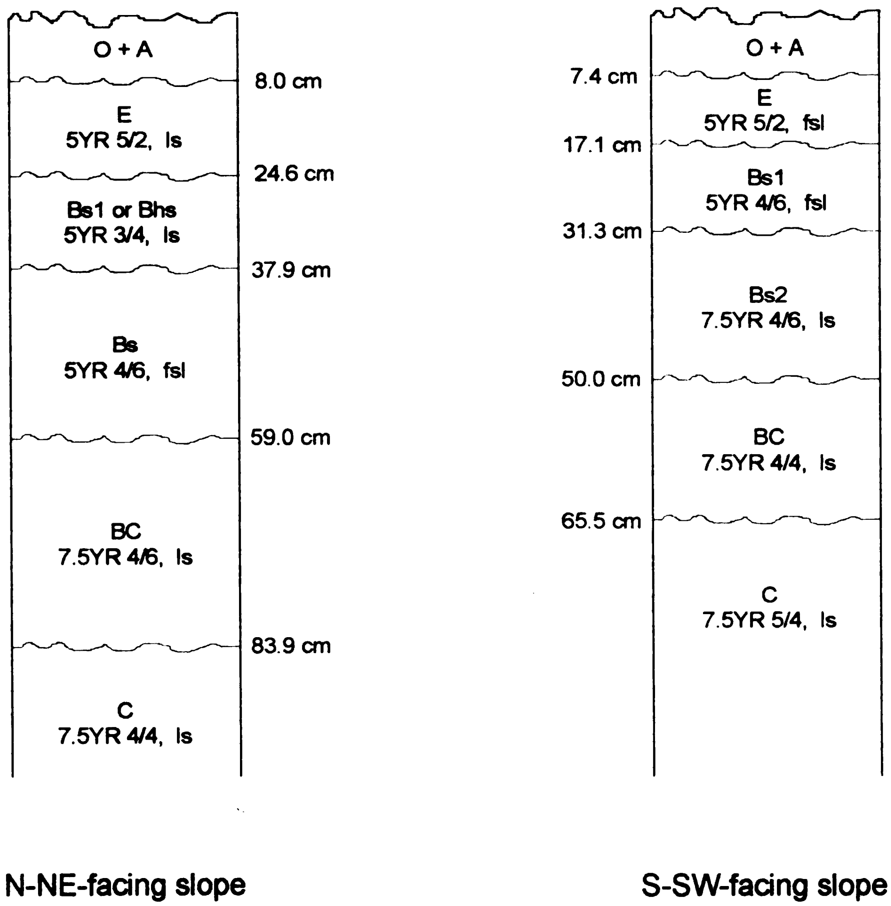

Figure 2. Typical soil profiles on opposing slopes.

Table 1. Typical tree species found on opposing slope aspects (in order of estimated dominance) documented in this study.

North-to-northeast-facing slopes	South-to-southwest-facing slopes
1. **hemlock,** *Tsuga canadensis* (L.) Carr.	1. **white birch,** *Betula papyrifera* Marsh.
2. **white birch,** *Betula papyrifera* Marsh.	2. **aspen,** *Populus* spp.
3. **red maple,** *Acer rubrum* L.	3. **red maple,** *Acer rubrum* L.
4. **aspen,** *Populus* spp.	4. **white pine,** *Pinus strobus* L.
5. **yellow birch,** *Betula alleghaniensis* Britton.	5. **hemlock,** *Tsuga canadensis* (L.) Carr.
6. **red oak,** *Quercus rubra* L.	6. **balsam fir,** *Abies balsamea* (L.) Mill.
7. **sugar maple,** *Acer saccharum* Marsh.	7. **red pine,** *Pinus resinosa* Ait.
	8. **sugar maple,** *Acer saccharum* Marsh.

Particle Size Analysis

Particle size data for genetic horizons in the 20 sampled pedons are listed in Appendix B. Coarse fragment content (> 2 mm) did not exceed 10% by volume for any horizon and most had < 5% coarse fragments. Surface textures ranged from sand to fine sandy loam and materials below lithologic discontinuities ranged from loamy coarse sand to loam in texture. Typical pedons contained between 70 and 90% total sand with fine sand and medium sand comprising most of that total. Lithologic discontinuities exist in eight of the 20 pedons, however, only one of these discontinuities occurs within the solum (site S3). Statistical analysis (Wilcoxon, at $\alpha = 0.05$) on the percentage of individual size fractions (vcs, cs, ms, fs, vfs, total sand, and silt+clay) on a horizon-basis for paired pedons shows that significant differences do not exist in the amounts of these separates in corresponding horizons on opposing slope aspects (Table 2).

Amounts of individual particle size fractions within each pedon were also then weighted by solum thickness; these data are shown in Table 3. Solum-weighted calculations included the E horizon(s) and the B horizons of each pedon. Horizons of this type that occurred below a lithologic discontinuity were eliminated from the calculation (this occurred only for site S3). The resulting horizon-weighted values were then summed and divided by their cumulative thickness to arrive at solum-weighted particle size data (Table 3). Statistical analyses (Wilcoxon, at $\alpha = 0.05$) on the weighted percentages of each size fraction (vcs, cs, ms, fs, vfs, total sand and silt+clay) show that no significant differences exist in the solum-weighted particle size data for paired pedons on opposing slope aspects (Table 4). This confirms that the textures in the solum of sampled pedons are uniform and probably of the same origin.

Table 2. Wilcoxon matched-pairs signed-ranks test for differences in particle size separates, per horizon (unweighted).

Horizon and particle size fraction	**Mean** (standard deviation) N-NE-facing slope	**Mean** (standard deviation) S-SW-facing slope	Higher value	Significance (two-tail) p
E horizon total sand	76.7 (7.1)	80.4 (6.3)	S-SW	0.20
E horizon vcs	1.2 (1.2)	1.1 (1.0)	N-NE	0.80
E horizon cs	5.8 (5.9)	4.9 (3.1)	N-NE	0.96
E horizon ms	23.8 (8.3)	20.9 (5.2)	N-NE	0.39
E horizon fs	36.7 (9.5)	34.9 (9.3)	N-NE	0.45
E horizon vfs	12.8 (5.0)	15.0 (4.2)	S-SW	0.45
Uppermost B horizon total sand	79.6 (9.9)	77.1 (6.2)	N-NE	0.36
Uppermost B horizon vcs	1.9 (2.1)	1.7 (2.3)	N-NE	0.86
Uppermost B horizon cs	6.0 (5.5)	5.0 (3.7)	N-NE	0.88
Uppermost B horizon ms	22.8 (10.2)	20.9 (6.9)	N-NE	0.65
Uppermost B horizon fs	35.3 (9.6)	33.98 (8.6)	N-NE	0.80
Uppermost B horizon vfs	13.6 (6.1)	15.5 (5.5)	S-SW	0.51
2nd uppermost B horizon tot. sand	76.7 (11.6)	81.7 (5.9)	S-SW	0.52
2nd uppermost B horizon vcs	1.1 (0.9)	1.4 (1.0)	S-SW	0.37
2nd uppermost B horizon cs	3.8 (3.3)	5.3 (3.0)	S-SW	0.09
2nd uppermost B horizon ms	18.0 (9.6)	24.4 (10.2)	S-SW	0.07
2nd uppermost B horizon fs	36.8 (9.5)	37.2 (5.3)	S-SW	0.52
2nd uppermost B horizon vfs	16.0 (6.1)	13.4 (6.0)	N-NE	0.09

Table 2. (cont'd.)

Horizon and particle size fraction	**Mean** (standard deviation) N-NE-facing slope	**Mean** (standard deviation) S-SW-facing slope	Higher value	Significance (two-tail) p
BC or 2BC horizon total sand	80.5 (12.7)	84.1 (6.3)	S-SW	0.78
BC or 2BC horizon vcs	1.1 (1.1)	1.2 (0.7)	S-SW	0.58
BC or 2BC horizon cs	4.1 (4.5)	5.4 (3.1)	S-SW	0.26
BC or 2BC horizon ms	22.2 (10.9)	28.6 (12.4)	S-SW	0.26
BC or 2BC horizon fs	39.1 (9.3)	37.7 (7.8)	N-NE	0.09
BC or 2BC horizon vfs	14.0 (5.4)	11.2 (5.7)	N-NE	0.26
C, 2C or 3C horizon total sand	80.9 (15.7)	82.8 (12.0)	S-SW	0.26
C, 2C or 3C horizon vcs	0.4 (0.5)	1.5 (2.6)	S-SW	0.33
C, 2C or 3C horizon cs	8.1 (15.1)	6.1 (8.9)	N-NE	0.67
C, 2C or 3C horizon ms	24.9 (17.8)	26.7 (20.6)	S-SW	0.48
C, 2C or 3C horizon fs	35.0 (17.9)	34.8 (12.7)	N-NE	0.89
C, 2C or 3C horizon vfs	12.4 (9.2)	13.6 (12.9)	S-SW	0.67

Table 3. Solum-weighted particle size data for sampled pedons.[1]

Pedon	Sand 2.0-0.05	Silt + Clay <0.05	VCS 2.0-1.0	CS 1.0-0.5	MS 0.5-0.25	FS 0.25-0.1	VFS 0.1-0.05
	-- mm		--				
	% of fine earth		--------% of sand fraction--------				
S1	64.4	34.9	0.3	1.9	13.9	28.5	19.7
S2	74.1	25.3	1.3	4.6	15.9	29.5	22.8
S3	69.4	29.8	1.6	6.6	19.1	24.0	18.1
S4	80.6	18.6	0.9	3.2	23.9	39.6	13.0
S5	81.9	16.6	0.6	3.1	21.8	42.0	14.5
S6	85.9	12.8	0.8	3.4	21.8	47.7	12.2
S7	77.8	21.2	0.7	2.4	14.4	41.5	18.8
S8	74.1	24.8	1.2	3.9	15.2	35.4	18.3
S9	83.5	8.8	0.9	8.1	35.1	31.0	8.5
S10	81.1	7.6	4.6	11.7	29.2	26.9	8.7
Mean	77.3	20.0	1.3	4.9	21.0	34.6	15.5
N1	70.1	29.1	2.6	11.4	28.2	19.2	8.7
N2	60.1	39.7	0.2	0.9	9.6	32.3	17.2
N3	89.2	4.6	3.6	13.0	35.2	31.1	6.4
N4	85.5	14.1	0.8	2.9	22.3	41.4	18.2
N5	89.3	9.3	2.4	7.2	29.2	40.0	10.5
N6	83.2	15.3	0.9	5.0	25.5	48.6	13.3
N7	85.0	13.9	0.7	1.7	19.0	48.7	15.0
N8	79.0	20.1	0.3	1.5	14.9	42.2	20.2
N9	71.0	27.3	1.0	4.3	24.0	30.9	10.9
N10	75.8	23.5	0.5	1.4	10.4	40.2	23.2
Mean	78.8	19.7	1.3	4.9	21.8	37.5	14.4

[1] Includes the E horizon(s) and B horizons of each pedon. Horizons below a lithologic discontinuity were eliminated from the calculation (site S3 only). Corresponding percentages on opposing slopes are not significantly different (Wilcoxon, at $\alpha = 0.05$) in any pedon.

Table 4. Wilcoxon matched-pairs signed-ranks test for differences in weighted particle size separates, per solum.

Particle size fraction	Mean % (standard deviation) N-NE-facing slope	S-SW-facing slope	Higher value	Significance (two-tail) p
TOTAL SAND	78.7 (10.3)	77.8 (6.8)	N-NE	0.58
Very coarse sand	1.2 (1.0)	1.2 (0.9)	(neither)	0.72
Coarse sand	4.6 (3.8)	4.8 (2.7)	S-SW	0.96
Medium sand	21.6 (7.3)	21.5 (7.3)	N-NE	0.80
Fine sand	37.0 (8.6)	35.0 (8.0)	N-NE	0.17
Very fine sand	14.3 (4.7)	15.3 (4.9)	S-SW	0.58
TOTAL SILT + CLAY	20.0 (10.8)	20.1 (7.9)	S-SW	0.80

METHODS

Field Methods

The USDA Soil Survey of Baraga County (Berndt 1988) was utilized to identify a broad dissected escarpment at the northern edge of the outwash plain described previously (Study Area section, page 12). The Rousseau-Ocqueoc soil complex mapped in the Soil Survey defines the study area. A USGS topographic quadrangle (7.5 minute, Baraga Plains) was used to locate potential sites with the proper geomorphic aspect and backslope gradient. Numerous hillsides were then field-checked; hillsides were selected for study based on the following criteria:

1) Each hillside exhibited an aspect between 0° and 45° azimuth (north-to-northeast-facing slopes, 10 in all) or an opposite aspect between 180° and 225° azimuth (south-to-southwest-facing slopes, 10 in all)[1]. (Figure 3).

2) Each hillside had a backslope gradient ≥ 45%, with a length > 25 m from top to bottom.

3) Slope curvature (horizontal) could not be eliminated entirely on selected hillsides. However, in order to minimize its effect, backslopes exhibited < 20° in aspect curvature across a 20 m horizontal distance.

Many hillsides within the study area exhibited characteristics and criteria suitable for this study, as listed above. However, the 20 selected hillsides were purposely distributed

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1 The range of aspects selected for this research accomodates the location of diurnal ground temperature maxima and minima in hilly areas (Geiger 1969). In general, much early morning solar heat energy is used in the evaporation of atmospheric moisture that often precipitates at night (i.e., dew). Afternoon solar heat energy tends to dry the soil and vegetation since atmospheric moisture is lower than it had been in the morning. Therefore, the location of diurnal ground temperature minima and maxima in hilly areas are displaced toward northeast- and southwest-facing slopes respectively (Geiger 1969).

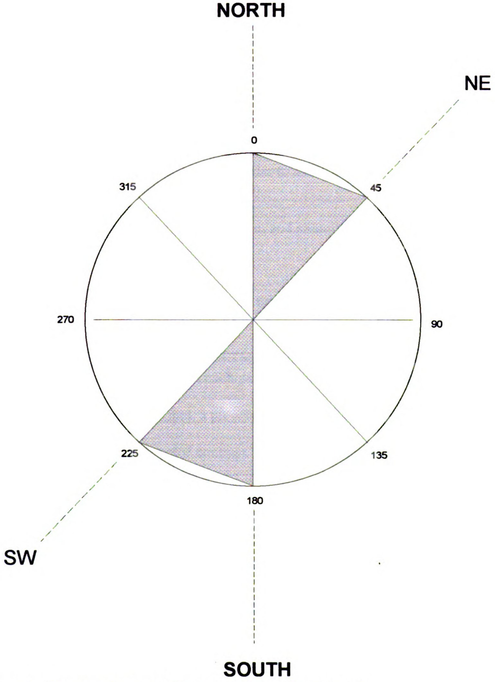

Figure 3. Ranges of geomorphic aspect chosen for this study.

across a 10 km span of the dissected escarpment in order to obtain a more comprehensive sample of the soils in this area.

One pedon from each hillside was chosen for further examination. It had to meet the following criteria:

4) The pedon was located on a backslope no closer than 10 m to the shoulder or footslope.

5) The pedon was at least 1 m away from any pits and mounds on the ground surface in order to avoid the pedoturbative effects of treefall (Schaetzl et al. 1990).

These sites were then sampled by hand auger and examined so as to meet the following criteria:

6) Pedons exhibited no lithologic discontinuities within the solum as detected in the field.[1]

7) Pedons contained less than 10% coarse fragments (> 2 mm diameter) in each genetic horizon of the solum.

Once the above criteria were met, a pit was excavated at the site. The best developed soil profile (i.e., greatest E to B color contrast, thickest horizons and deepest solum) exposed in the soil pit and/or the one exhibiting the least evidence of pedoturbation was described utilizing traditional Soil Survey techniques (Soil Survey Staff, 1994). The thickness, depth and dominant color of each genetic horizon were recorded. Soil textures were estimated in the field to be certain that parent materials remained nearly constant from

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1 Laboratory particle size data later revealed that site S3 probably contains a lithologic discontinuity within the solum.

site to site. Sufficient weight of sample (300-400 g) was taken from each genetic horizon for laboratory analysis.

Each pedon site was paired with another site of nearly opposite aspect, yet with similar slope, parent material and elevation. The paired sites were always within 1 km of one another and often within 400 m of one another. The method of pairing the sampled pedons was adopted for the purpose of paired-comparison statistics (Wilcoxon 1949) (see Statistical Methods section, page 20).

The POD Index, a numerical index designed to assess the degree of Spodosol development based on soil color and number of subhorizons (Schaetzl and Mokma 1988), was calculated in the field at each excavated soil pit. The Wilcoxon test for paired samples (Wilcoxon 1949) was then applied to the POD Index data to determine if a significant difference existed in the amount of soil development between the 10 pairs of sampled pedons. The statistical results of this field-based analysis showed the POD Index values of the soils on north-to-northeast-facing slopes to be significantly different ($\alpha = 0.01$) than the POD Index values of the soils on south-to-southwest-facing slopes (see Results, p.54). Therefore, the sample size was deemed sufficient (20 pedons in all) and the process of collecting soil samples was ended.

The locations of the sampled pedons were recorded on a map and identified in the field with flagging. Soil temperature readings were taken within 5 m of each sampled pedon, at approximately two month intervals (May 17, July 25, September 17, November 5, 1995 and January 20, 1996), at a depth of 50 cm below the surface, using copper-constantan thermocouples. The 50 cm depth was selected in an attempt to avoid diurnal variations in soil temperature (Smith, et al. 1964).

Laboratory Methods

Soil samples were air dried and coarse fragments (> 2 mm) removed by sieving. The silt+clay percentage was determined by wet sieving after dispersing 20-25 g of soil in 10ml of Na hexametaphosphate (Na_2CO_3+$[NaPO_3]_6$) solution (37.4 g in one liter distilled H_2O). The remaining sand was oven dried and seived to obtain percentages of five sand fractions (vcs = 2.0 to 1.0mm; cs = 1.0 to 0.5mm; ms = 0.5 to 0.25mm; fs = 0.25 to 0.1mm; vfs = 0.1 to 0.05mm). Extractions of Fe and Al were taken with Na pyrophosphate (McKeague, 1978) and acid ammonium oxalate (McKeague, 1978). Fe and Al contents of the extracts (Fe_p, Fe_o, Al_p, and Al_o, respectively) were determined on a DCP spectrometer (McKeague, 1978). Optical density of the oxalate extract (ODOE) at 430 nm was determined on a Perkin-Elmer 320 spectrophotometer (Daly 1982). Reaction was measured in both a 1:1 soil:water ratio and a 1:1 soil:KCl ratio using an Orion 720A combination electrode pH/ISE meter.

Statistical Methods

The Wilcoxon matched-pairs signed-ranks test (Wilcoxon 1949) was utilized to test for significant differences in soil development indicators between paired pedons on north-to-northeast- and south-to-southwest-facing slopes. Values of T were calculated for the following variables: pH of all horizons, Fe_o, Al_o, Fe_p, Al_p, Fe_o-Fe_p, and Al_o-Al_p of all E and B horizons, ODOE of the uppermost E horizon, ODOE of all B horizons, ODOE of each B horizon ÷ ODOE of the uppermost E horizon, total E horizon thickness, total B horizon thickness, uppermost E horizon hue, value and chroma, uppermost B horizon hue, value and chroma, depth to E horizon, depth to B horizon, solum thickness, soil temperature (bi-monthly values), snowpack thickness and the POD index. The calculated values of T were then compared against critical values of T in a two-tailed test for significance at $\alpha = 0.05$ (Siegal, 1956) utilizing SYSTAT 5.03 statistical software.

RESULTS AND DISCUSSION

Effects of Slope Gradient on Soil Development

Jenny (1941) suggested that slope gradient inversely affects soil development. He stated that the greatest soil development most often occurs on level terrain while lesser amounts of development occur on increasingly steeper terrain (with all other soil-forming factors remaining constant). Numerous other studies have found similar trends (Carter and Ciolkosz 1991, Losche et al. 1970, Lag 1951, Norton and Smith 1930).

Given the rather large range of slope angles in the present study (45 to 73%), it was deemed necessary to determine what, if any, effect these slope gradient variations may have had on pedogenesis, regardless of slope aspect. In order to show that slope gradient was not significantly related to soil development (neither inversely nor directly), regression analyses were performed for each variable in the data as plotted against slope gradient (variables defined previously in Methods section, page 28). Scatter plots were inspected to insure that the linear regression equations were not being forced onto obviously curvilinear distributions. Coefficients (r values) for each regression are listed in Table 5. None of the coefficient values were significantly different from 0 (zero) at $\alpha = 0.05$ and only two variables were significant at $\alpha = 0.10$. These two variables were chroma of the uppermost E horizon ($p = 0.058$) and POD Index ($p = 0.052$) (Table 5).

Upon further investigation, the regression results for the POD Index (Figure 4) seem to be unduly influenced (i.e., leveraged) by a single value (POD Index = 12 at site N6). If this high value is removed from the data, the r value changes from -0.44 to +0.07 and the p value increases from 0.052 to 0.792 which indicates that the overall

Table 5. Results of regression analyses on slope gradient vs. individual soil characteristics.

Soil characteristic	Correlation coefficient (r value)	Significance (two-tail) p
Uppermost E horizon chroma	0.43	0.058
POD Index	-0.44	0.052
------------------------------------		$\alpha = 0.10$
pH (KCl), uppermost E horizon	0.33	0.15
Snowpack thickness, 11/5/95	-0.34	0.17
Al_p, uppermost B horizon	-0.31	0.19
Fe_o, uppermost E horizon	0.31	0.19
ODOE, uppermost E horizon	0.31	0.19
pH (H_2O), uppermost E horizon	0.31	0.19
July soil temperature	0.29	0.21
Fe_p, uppermost E horizon	0.28	0.24
ODOE, upper. B ÷ upper. E horizon	-0.27	0.24
E horizon thickness	-0.27	0.25
Uppermost B horizon value	0.27	0.25
pH (H_2O), BC or 2BC horizon	0.27	0.25
Al_p, uppermost E horizon	0.25	0.29
Depth to top of the B horizon	-0.24	0.31
Uppermost E horizon value	0.24	0.31
Al_p, 2nd uppermost B horizon	-0.22	0.35
Al_o, uppermost E horizon	0.21	0.37
pH (KCl), C or 2C horizon	-0.20	0.42
Uppermost E horizon hue	-0.19	0.42
pH (H_2O), C or 2C horizon	0.20	0.44
November soil temperature	0.18	0.47

Table 5. (cont'd.)

Soil characteristic	Correlation coefficient (r value)	Significance (two-tail) p
Al_o, 2nd uppermost B horizon	-0.15	0.52
Uppermost B horizon chroma	0.15	0.52
ODOE, uppermost B horizon	-0.15	0.53
Fe_p, uppermost B horizon	-0.15	0.54
ODOE, 2nd upper. B ÷ upper. E horizon	-0.13	0.58
September soil temperature	0.13	0.58
pH (H_2O), 2nd uppermost B horizon	0.11	0.66
Fe_o, uppermost B horizon	0.11	0.66
Fe_o, 2nd uppermost B horizon	0.11	0.67
ODOE, 2nd uppermost B horizon	-0.10	0.68
pH (KCl), 2nd uppermost B horizon	0.09	0.71
Fe_p, 2nd uppermost B horizon	-0.09	0.72
B horizon thickness	0.08	0.75
Uppermost B horizon hue	0.05	0.82
Solum thickness	-0.03	0.90
pH (KCl), uppermost B horizon	0.02	0.92
Al_o, uppermost B horizon	0.02	0.93
Depth to top of the E horizon	-0.02	0.94
pH (H_2O), uppermost B horizon	0.02	0.95
pH (KCl), BC or 2BC horizon	-0.01	0.97
May soil temperature	-0.004	0.99

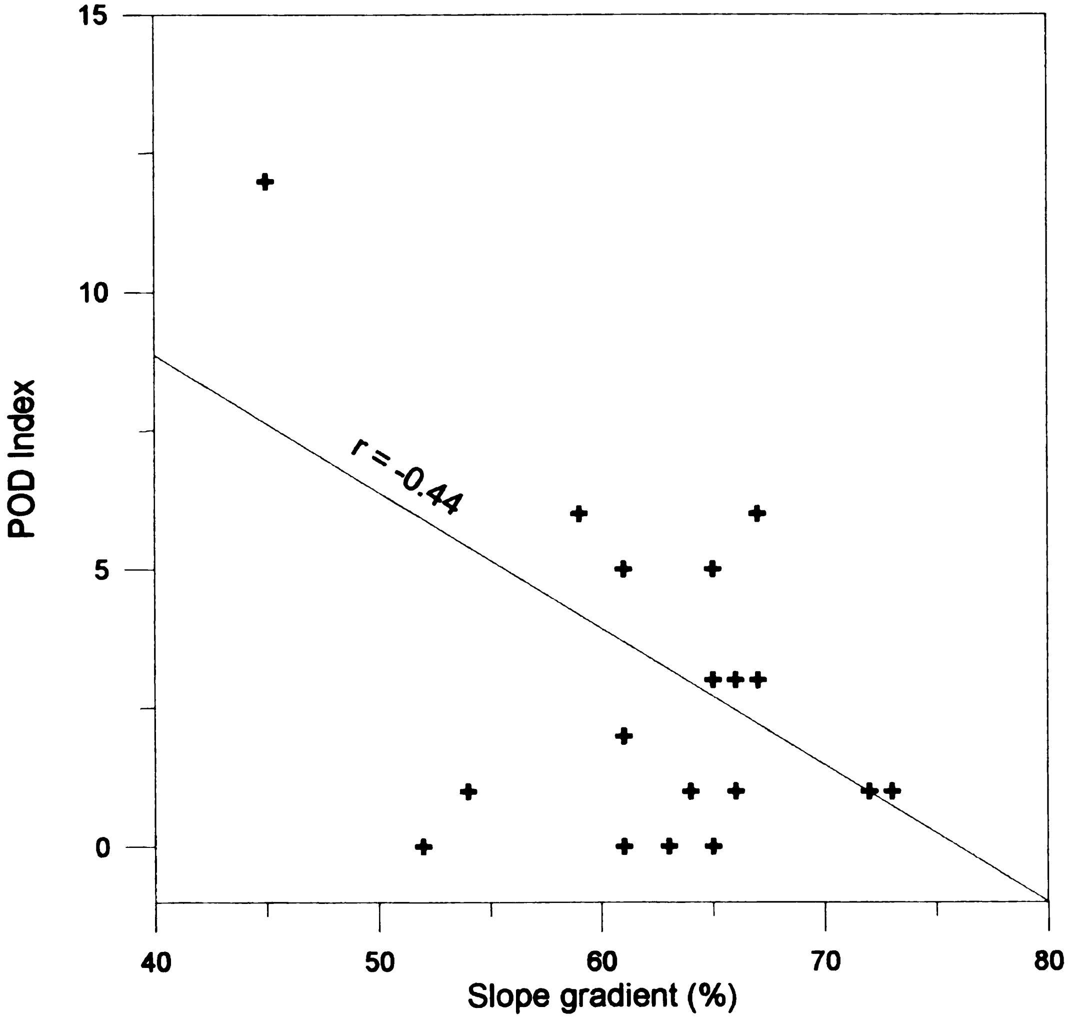

Figure 4. Slope gradient vs. POD Index regression scatter plot.

strength of this regression seems to rest on a single data point.

In general, the results of the regression analyses show that the variations in slope gradient for steep slopes such as these (45 to 73%) probably had very little influence on the differential pedogenesis observed in the area. It is likely that, had the range of slope gradients extended from zero to 73%, many significant relationships may have been revealed.

Effects of Slope Aspect on Soil Development

Soil Temperature

Soil temperature can affect spodic development within a Spodosol. The cooler the soil, the more Fe, Al and C can be translocated within the soil (Stanley and Ciolkosz 1981). Soil temperatures for individual sites are listed in Appendix A. Figures 5 to 7 show soil temperatures in May, July and September (1995) for paired pedons on opposing aspects. Soil temperatures (at 50 cm) exhibited statistically significant differences (Wilcoxon, at $\alpha = 0.01$) between north-to-northeast-facing slopes and south-to-southwest-facing slopes in May, July and September, 1995 (Table 6). At each of the three sampling periods, all soils on the south-to-southwest-facing slopes exhibited significantly warmer soil temperatures than the paired pedons on the north-to-northeast-facing slopes. The greatest mean difference in soil temperature during these months was recorded in May when south-to-southwest-facing slopes exhibited a mean soil temperature of 8.1 ±0.7° and the north-to-northeast-facing slopes exhibited a mean soil temperature of 4.9 ±0.9° (a mean difference of 3.2°).

South-to-southwest-facing slopes receive more direct-beam solar radiation

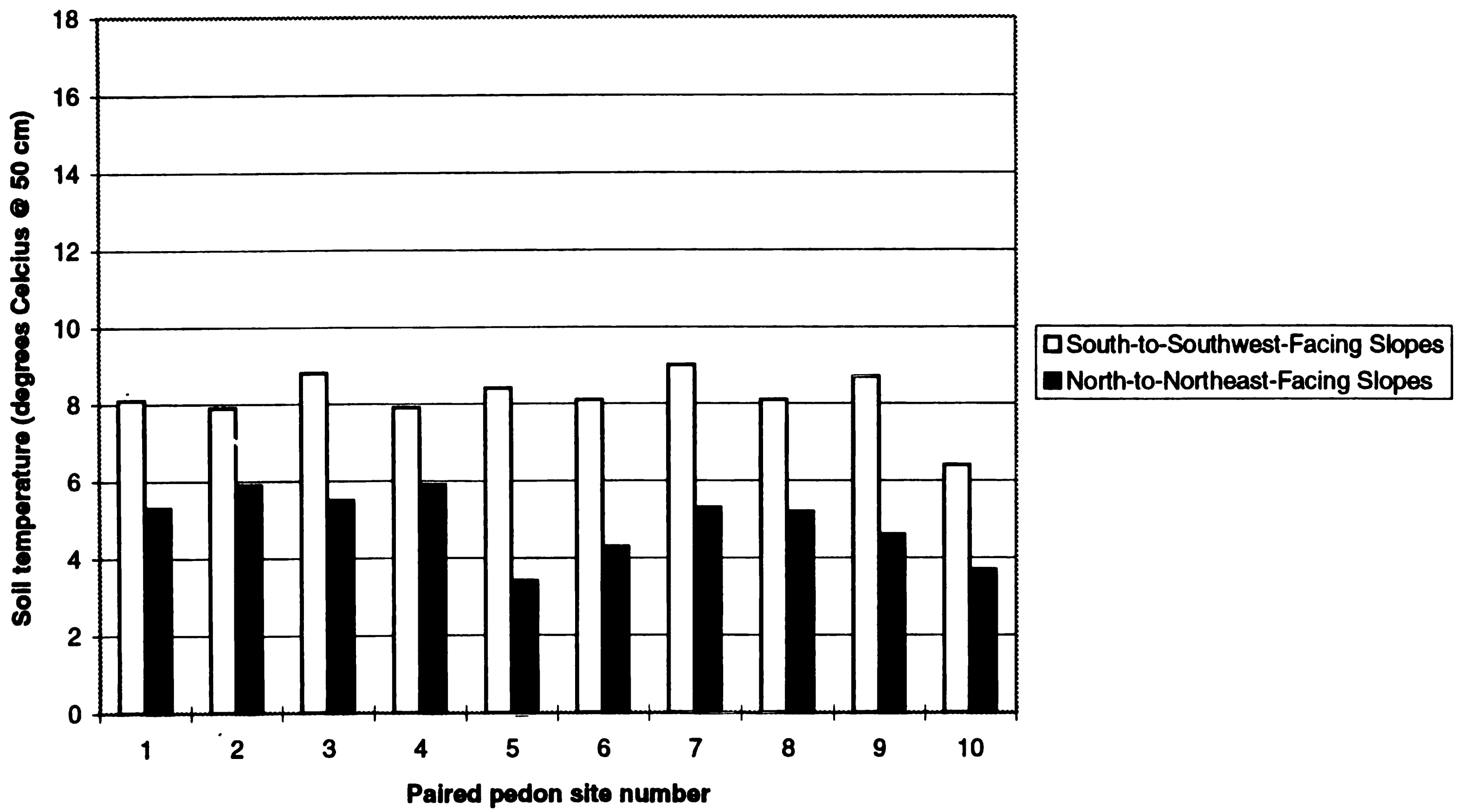

Figure 5. May soil temperatures on opposing aspects (May 17, 1995).

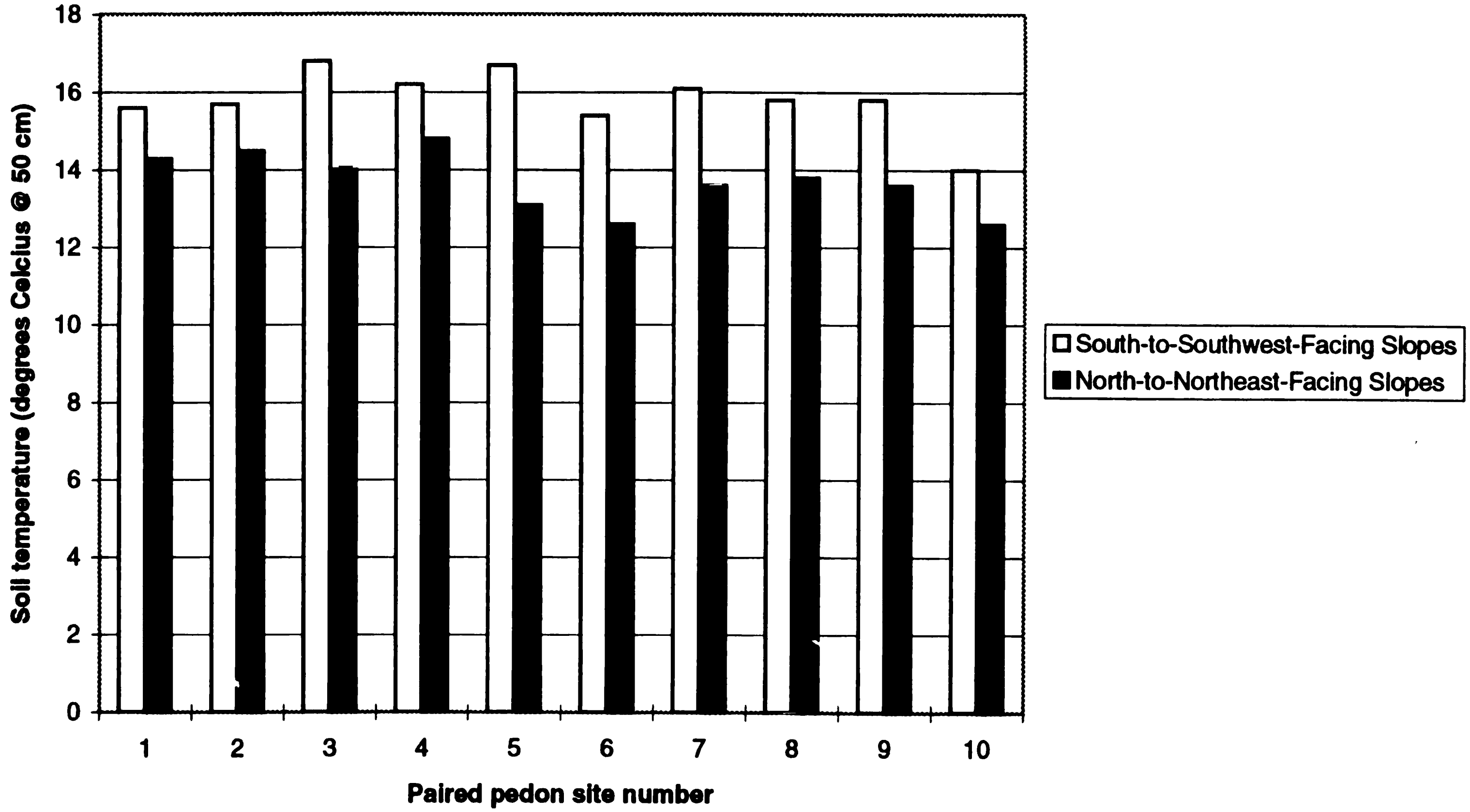

Figure 6. July soil temperatures on opposing aspects (July 25, 1995).

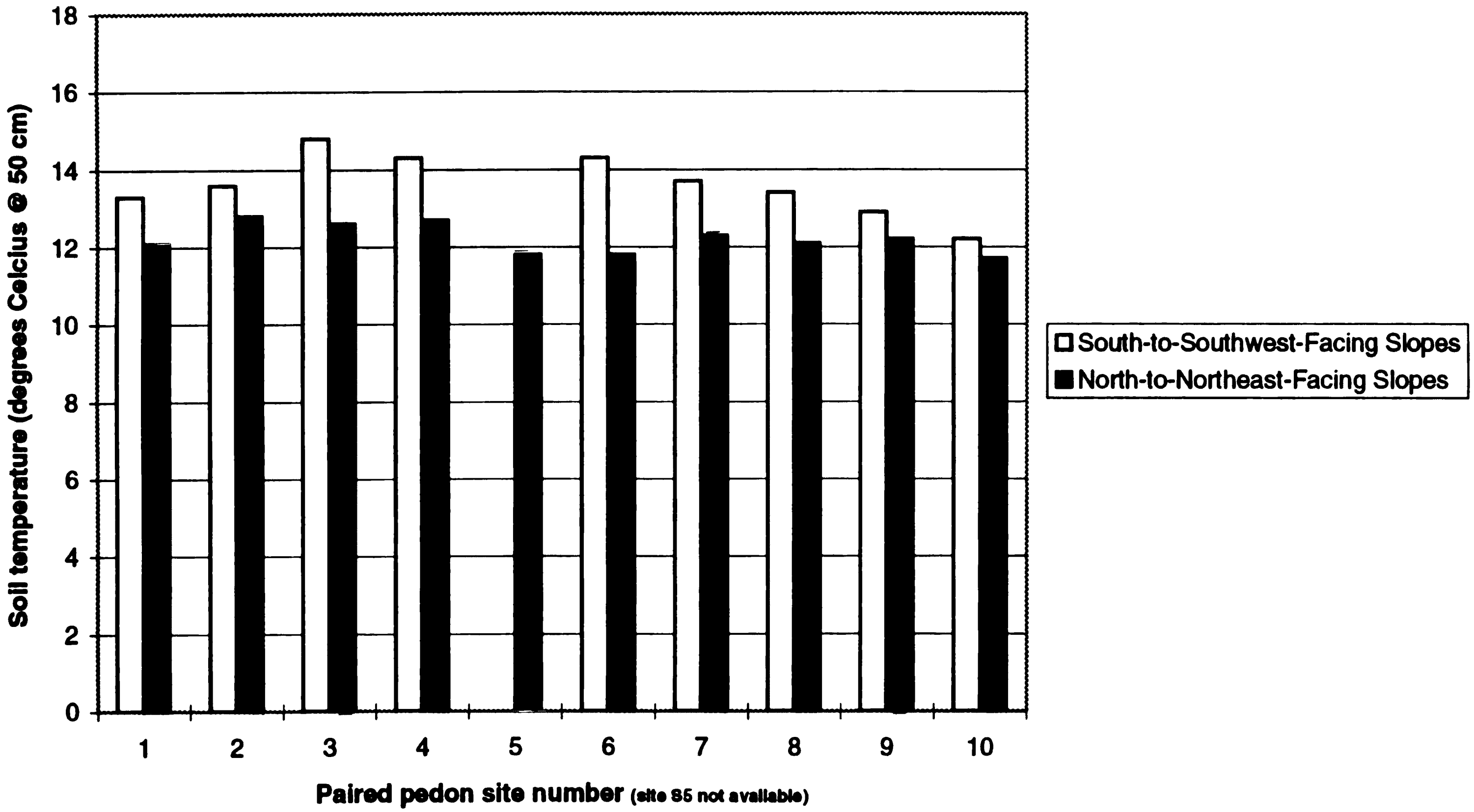

Figure 7. September soil temperatures on opposing aspects (September 17, 1995).

Table 6. Mean soil temperature data and statistics (Wilcoxon 1949).

Soil temperature date:	**Mean value on:** (st. dev.) N-NE slope	S-SE slope	**Number of greater values on:** N-NE slope	S-SE slope	**Equal values**	**Significance** (two-tail)	**Indicates or promotes stronger podzolization on:**
	---------- °C	------------					
May 17, 1995	4.9 (0.9)	8.1 (0.7)	0	10	0	0.003 **	N-NE-facing slopes
July 25, 1995	13.7 (0.8)	15.8 (0.8)	0	10	0	0.003 **	N-NE-facing slopes
September 17, 1995	11.0 (3.9)	12.3 (4.4)	0	9	0	0.004 **	N-NE-facing slopes
November 5, 1995	5.3 (0.7)	4.9 (0.6)	6	3	0	0.069	(not significantly different)
January 20, 1996	2.0 (1.1)	1.6 (0.9)	2	2	1	NA ***	(not significantly different)

** Significant at α=0.01 (Wilcoxon). *** NA = not applicable; Wilcoxon analysis does not accomodate a population size < 7.

over the course of a year than do north-to-northeast-facing slopes (Figure 8) and the incidence angle of the radiation on these south-to-southwest-facing slopes is nearly vertical throughout the summer months (Figure 9); these are probably the two primary reasons that significantly warmer temperatures were measured on south-to-southwest-facing slopes during May, July and September (Geiger 1969). Soil temperature results similar to those described above have been documented by Hutchins et al. (1976) in eastern Kentucky, Franzmeier et al. (1969) in eastern Tennessee and Kentucky and Losche et al. (1970) in North Carolina.

In contrast to the soil temperature results of May, July and September, soil temperatures measured in November (1995) (Figure 10) and January (1996) on opposing slopes were not significantly different (Wilcoxon, at $\alpha = 0.05$, Table 6). Interestingly, the mean November soil temperature on north-to-northeast-facing slopes was 5.3 ±0.7° which was slightly warmer than the mean for south-to-southwest-facing slopes at 4.9 ±0.6°. November soil temperatures on south-to-southwest-facing slopes had decreased more (down 7.4°) from September readings than had soil temperatures on north-to-northeast-facing slopes (down 5.7°) during the same time interval (Figure 11). The decrease in soil temperature on south-to-southwest-facing slopes contrasted to that of north-to-northeast-facing slopes (from summer to fall, 1995) can be explained by the relatively rapid change in solar radiation incidence angles during this time period. Unfortunately, January (1996) soil temperature readings were not completed due to inaccessibility to the sites. Adequate statistical analysis cannot be employed since the Wilcoxon method does not accomodate populations smaller than 7 samples.

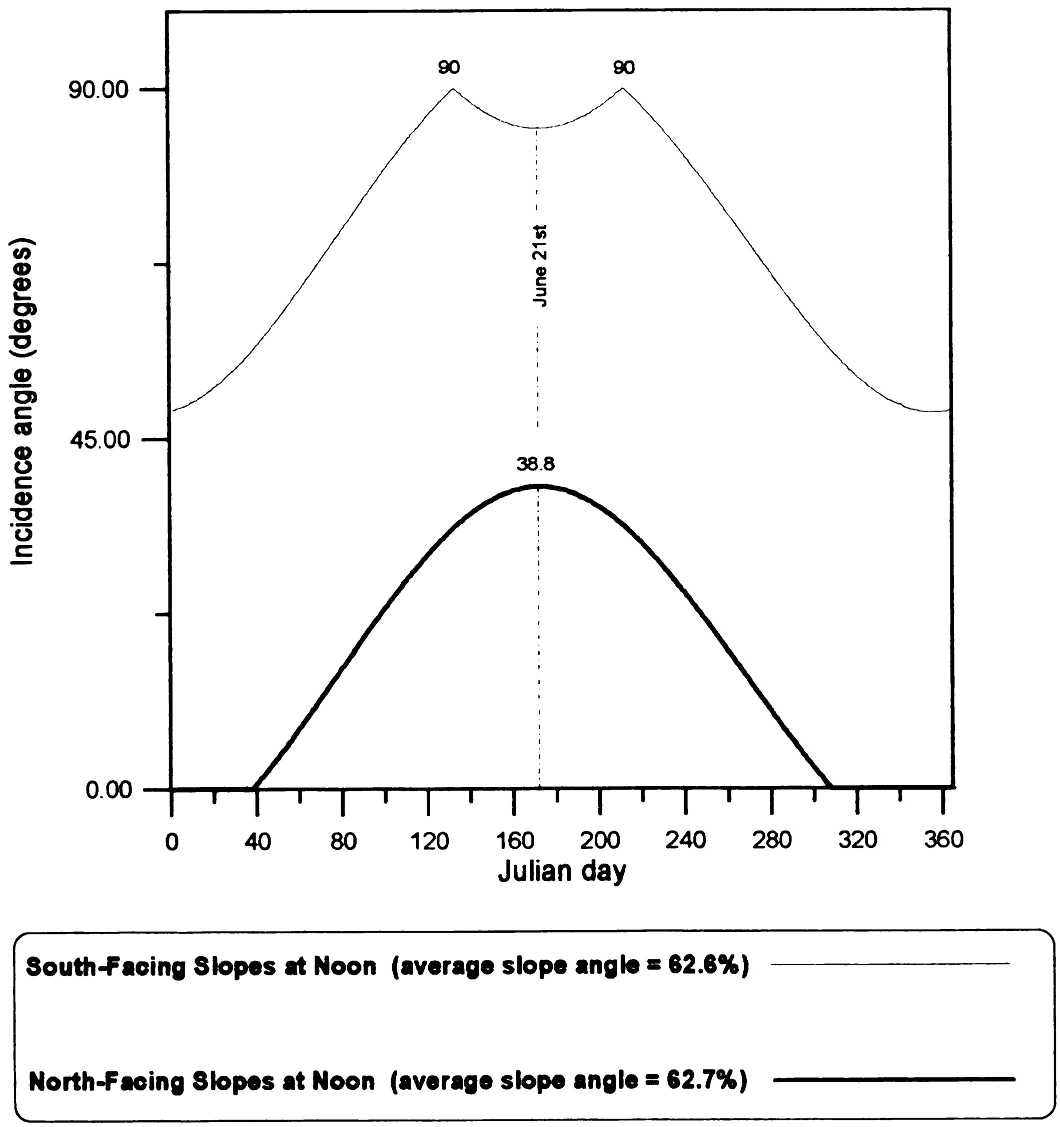

Figure 8. Incidence angle of solar radiation per Julian day on north- vs. south-facing slopes.[1]

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1 Calculated from Bonan (1989).

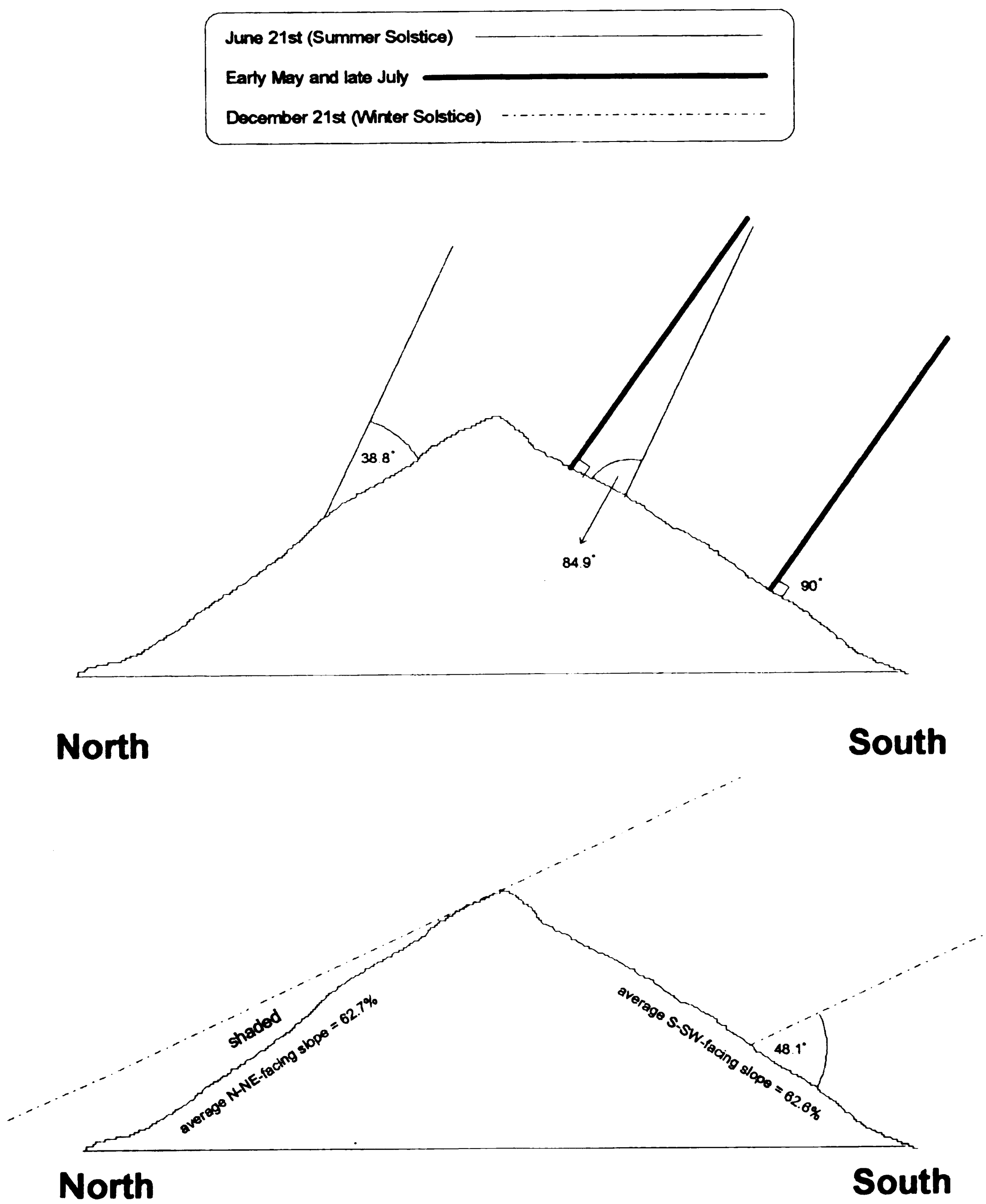

Figure 9. Incidence angle profile on average north- and south-facing slopes for June 21st, December 21st, early may and late fall.

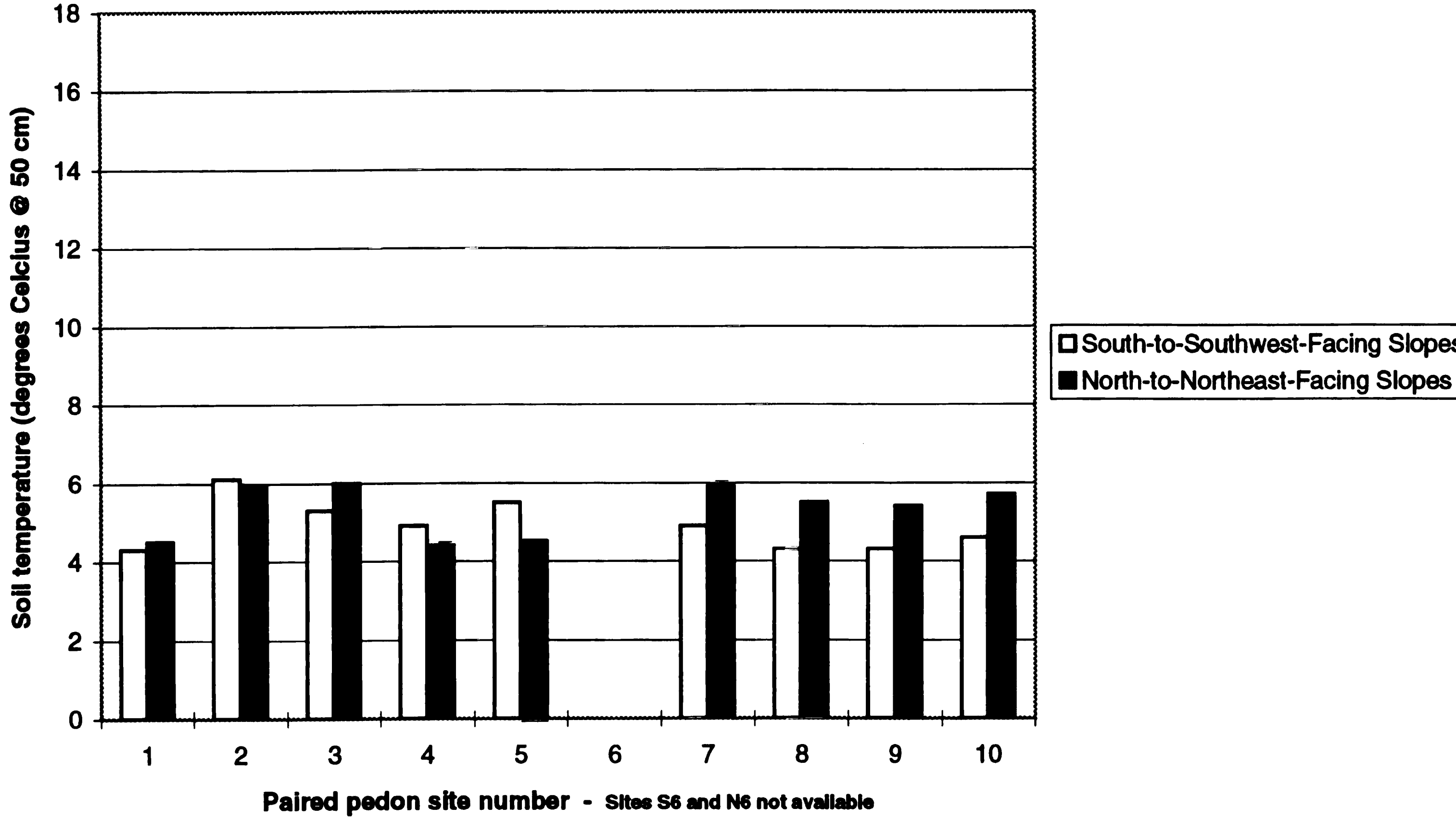

Figure 10. November soil temperatures on opposing aspects (November 5, 1995).

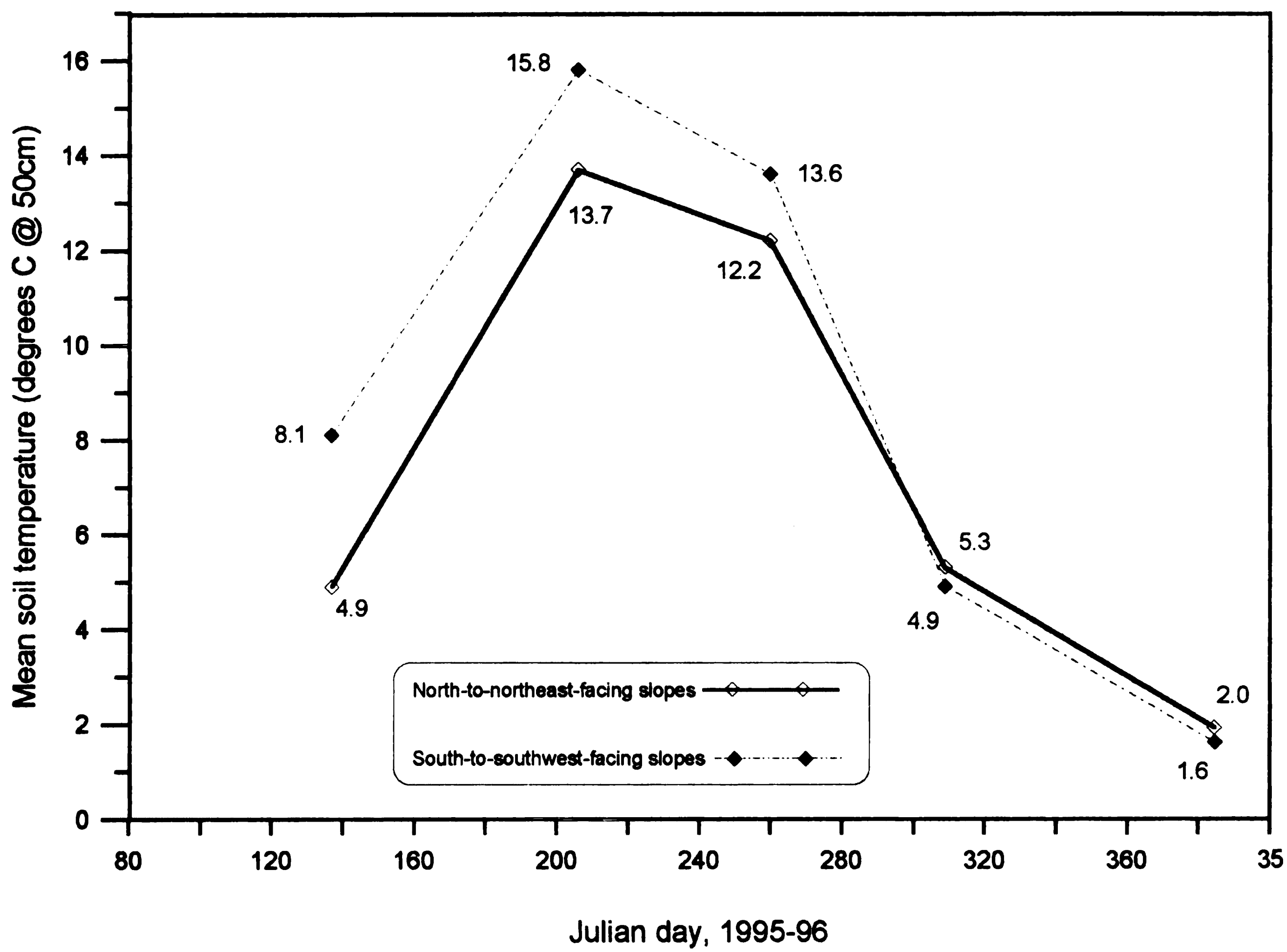

Figure 11. Mean soil temperature per Julian day on opposing aspects.

Due to slope gradient in the study area, maximum incidence angle of solar radiation (90°) on an average south-to-southwest-facing slope (62.6%) occurs twice a year; once in early May and once in late July (Figures 9 and 10). On an average north-to-northeast-facing slope (62.7%), maximum incidence angle of solar radiation occurs only once on June 21st, and even then it is only at 38.8° (Figures 9 and 10). On south-to-southwest-facing slopes, incidence angles > 80° exist (at noon) from early April to late August. The duration of this relatively intense, direct-beam solar radiation (> 80°) on south-to-southwest-facing slopes, in conjunction with relatively short summer nights, probably lends to the sustained warm summer soil temperatures documented on these slopes (at 50 cm).

On the day of the September soil temperature readings (September 17, 1995), the incidence angle of solar radiation (at noon) on an average south-to-southwest-facing slope angle was 73.4° and at that time of year, daylight still outlasts the night. However, on the day of the November soil temperature readings (November 5, 1995), the incidence angle of solar radiation on an average south-to-southwest-facing slope angle was 55.5° and nighttime was now four hours longer than daytime. This is a relatively rapid decrease in the incidence angle of solar radiation compared to the sustained high incidence angles of summer. Once solar radiation input has diminished, the soils on both aspects cool (especially now, when the cooling period of nighttime is longer than the warming period of daytime). Based on laws of thermodynamics, the warmer soils of the south-to-southwest-facing slopes cool more rapidly than those of north-to-northeast-facing slopes since they had more heat to lose.

There is another possible explanation for the rapid decrease in soil temperature on south-to-southwest-facing slopes from September to November, 1995 when contrasted to that of north-to-northeast-facing slopes. A higher moisture content in the north-to-northeast-facing pedons may have influenced the results. Since water has a relatively high thermal capacity and is therefore able to retain heat longer than other natural substances, perhaps the north-to-northeast-facing slopes retained the summer heat more efficiently than south-to-southwest-facing slopes due to greater soil moisture content. However, soil moisture data were not precisely documented in this study.

Further fieldwork is planned in order to obtain soil temperature readings for January and March (1996). This will provide a complete year of soil temperature data at two-month intervals as well as more complete snowpack depth data (p.98).

Horizon Depths and Thicknesses

E Horizon Depths and Thicknesses

Depths to the top of the E horizon, which actually reflect O + A horizon thicknesses, were not found to be significantly different (Wilcoxon, at $\alpha = 0.05$) for soils on opposing slopes (Table 7, Figure 2). Mean depth to the top of the E horizon on south-to-southwest-facing slopes was 7.4 ±3.5cm, vs. 8.0 ±3.1cm on north-to-northeast-facing slopes. Although the depth to the E horizon is not significantly different on opposing slopes, the mean values show that the soils on south-to-southwest-facing slopes have shallower E horizons which are a reflection of thinner O + A horizons. These relatively thin O + A horizons on south-to-southwest-facing slopes probably exist due to the relatively dry conditions on these slopes caused by warmer summer soil temperatures, thus, hastening the decomposition of organic

Table 7. Mean horizon and solum thickness data and statistics (Wilcoxon 1949).

Soil characteristic	Mean value on: (st. dev.) N-NE slope	Mean value on: (st. dev.) S-SE slope	Number of greater values on: N-NE slope	Number of greater values on: S-SE slope	Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
Depth to top of E horizon (cm)	8.0 (3.1)	7.4 (3.6)	4	5	1	0.500	(not significantly different)
E horizon thickness (cm)	16.6 (6.1)	9.7 (4.0)	8	2	0	0.016 *	N-NE-facing slopes
Depth to top of B horizon (cm)	24.6 (7.2)	17.1 (5.2)	8	2	0	0.018 *	N-NE-facing slopes
B horizon thickness (cm)	34.4 (10.0)	30.6 (4.1)	6	4	0	0.179	(not significantly different)
Solum thickness (cm)	59.0 (9.9)	50.0 (10.5)	7	2	1	0.017 *	N-NE-facing slopes

* Significant at α=0.05 (Wilcoxon).

materials. E horizon thicknesses on north-to-northeast-facing slopes were found to be significantly greater (Wilcoxon, at $\alpha = 0.05$) than those on south-to-southwest-facing slopes (Table 7, Figure 12). In eight out of the ten paired pedons in this study, the E horizon was thicker on north-to-northeast-facing slopes vs. south-to-southwest-facing slopes. Mean E horizon thickness on south-to-southwest-facing slopes was 9.7 ±4.0cm whereas the mean E horizon thickness on north-to-northeast-facing slopes was 16.6 ±6.1cm.

E horizon thickness is a partial measure of the amount of eluviation that has taken place in the solum. Since E horizon thickness is greater on north-to-northeast-facing slopes, one can assume that greater eluviation has occured on these slopes when compared to that of south-to-southwest-facing slopes. Furthermore, since eluviation is a product of low pH and infiltrating water, and assuming equal precipitation on corresponding pedon sites, one can assume that the E horizons on north-to-northeast-facing slopes have sustained more cumulative infiltration when compared to that of south-to-southwest-facing slopes. This conclusion seems logical since greater evapo-transpiration probably takes place on the warmer south-to-southwest-facing slopes (in the growing season), thus, decreasing the amount of water available for infiltration.

B Horizon Depths and Thicknesses

Depths to the top of the B horizon were found to be significantly greater (Wilcoxon, at $\alpha = 0.05$) on north-to-northeast-facing slopes when compared to those of south-to-southwest-facing slopes (Table 7, Figure 13). In eight out of the ten paired pedons in this study, the depth to the top of the B horizon was greater on

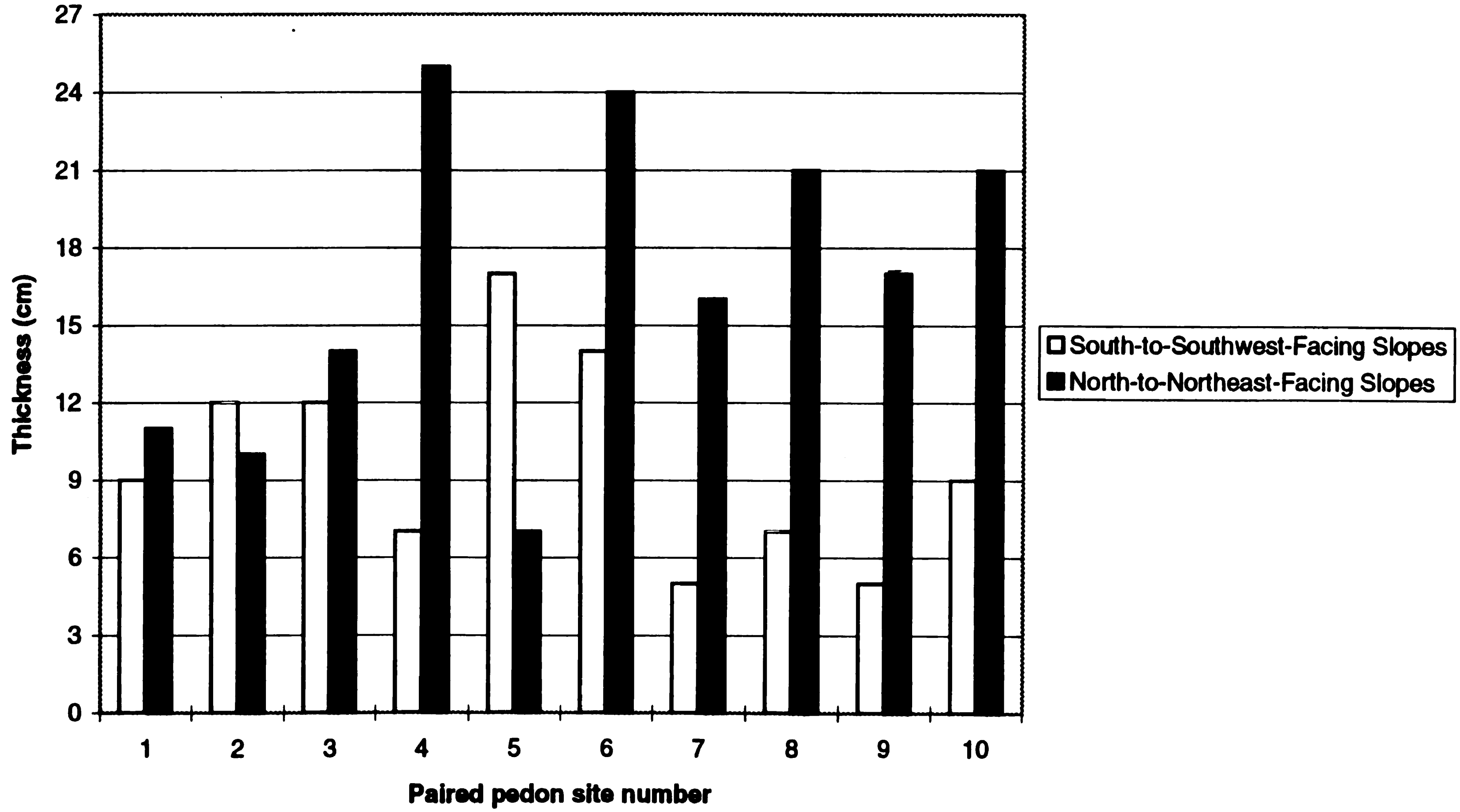

Figure 12. E horizon thickness on opposing aspects.

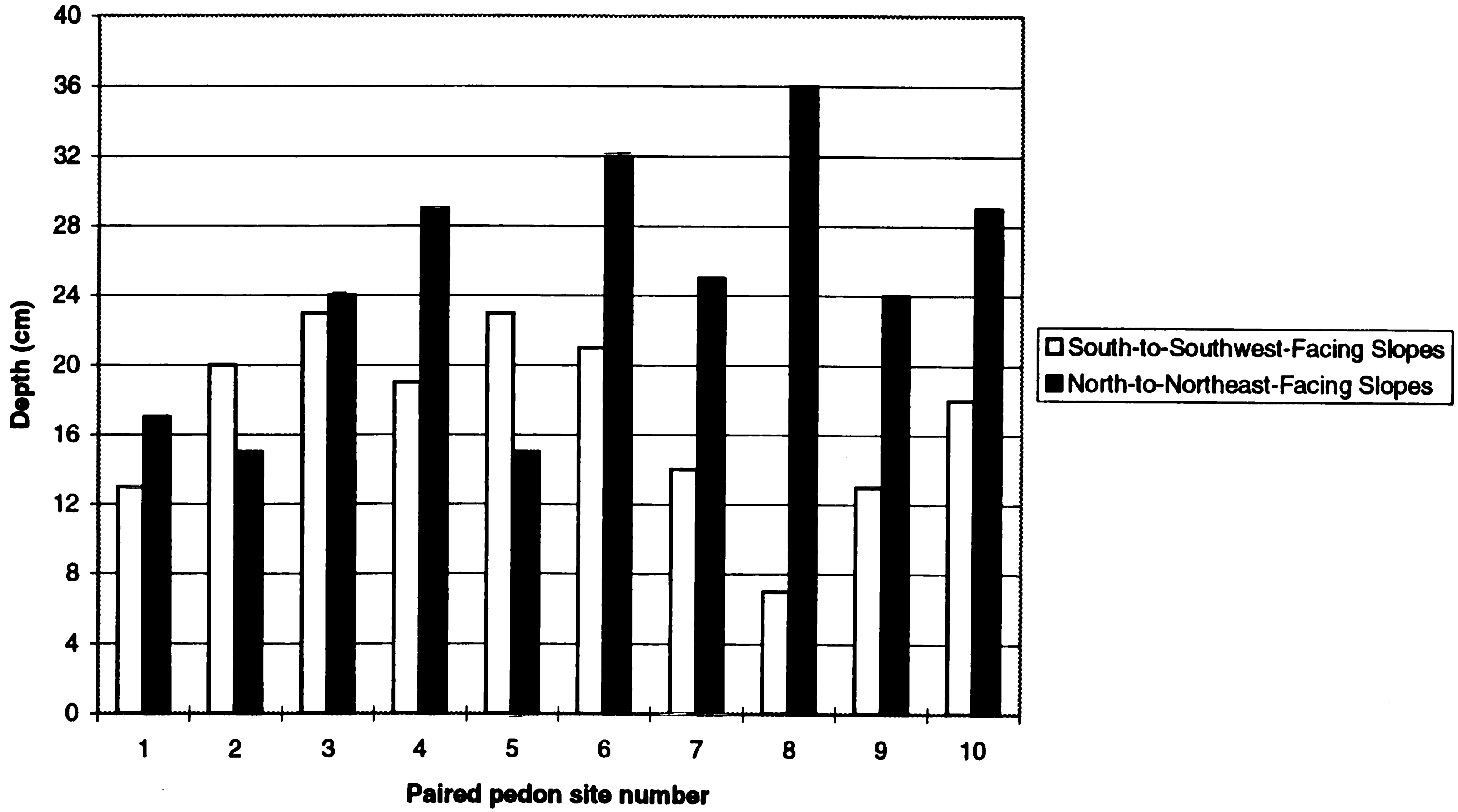

Figure 13. Depth to the top of the B horizon on opposing aspects.

north-to-northeast-facing slopes vs. that of south-to-southwest-facing slopes. Mean depth to the top of the B horizon on south-to-southwest-facing slopes was 17.1 ±5.2 cm whereas mean depth to the top of the B horizon on north-to-northeast-facing slopes was 24.6 ±7.2 cm. Greater depths to the top of the B horizon on north-to-northeast-facing slopes vs. south-to-southwest-facing slopes can be primarily attributed to the thicker E horizons also found on the north-to-northeast-facing slopes. Increased eluviation on north-to-northeast-facing slopes has caused the B horizon to be located deeper than in soils of south-to-southwest-facing slopes.

B horizon thicknesses were not found to be significantly different (Wilcoxon, at $\alpha = 0.05$) on opposing slopes (Table 7, Figure 14). Mean B horizon thickness on south-to-southwest-facing slopes was 30.6 ±4.1 cm vs. 34.4 ±10.0 cm on north-to-northeast-facing slopes. Although the mean thickness was greater on north-to-northeast-facing slopes, these values were not statistically significant since only six of the ten paired pedons had a thicker B horizon on north-to-northeast-facing slopes.

Solum Thickness

Since E horizon thickness was found to be significantly different on opposing slopes while the depth to the E horizon and thickness of the B horizon were not found to be significantly different, any disparity in overall solum thickness on opposing slopes can be primarily attributed to the relatively thick E horizons on north-to-northeast-facing slopes. In light of these circumstances, it is interesting to note that seven out of the ten paired pedons in this study exhibited a thicker solum on north-to-northeast-facing slopes when compared to that of south-to-southwest-facing slopes (Table 7, Figure 15, Figure

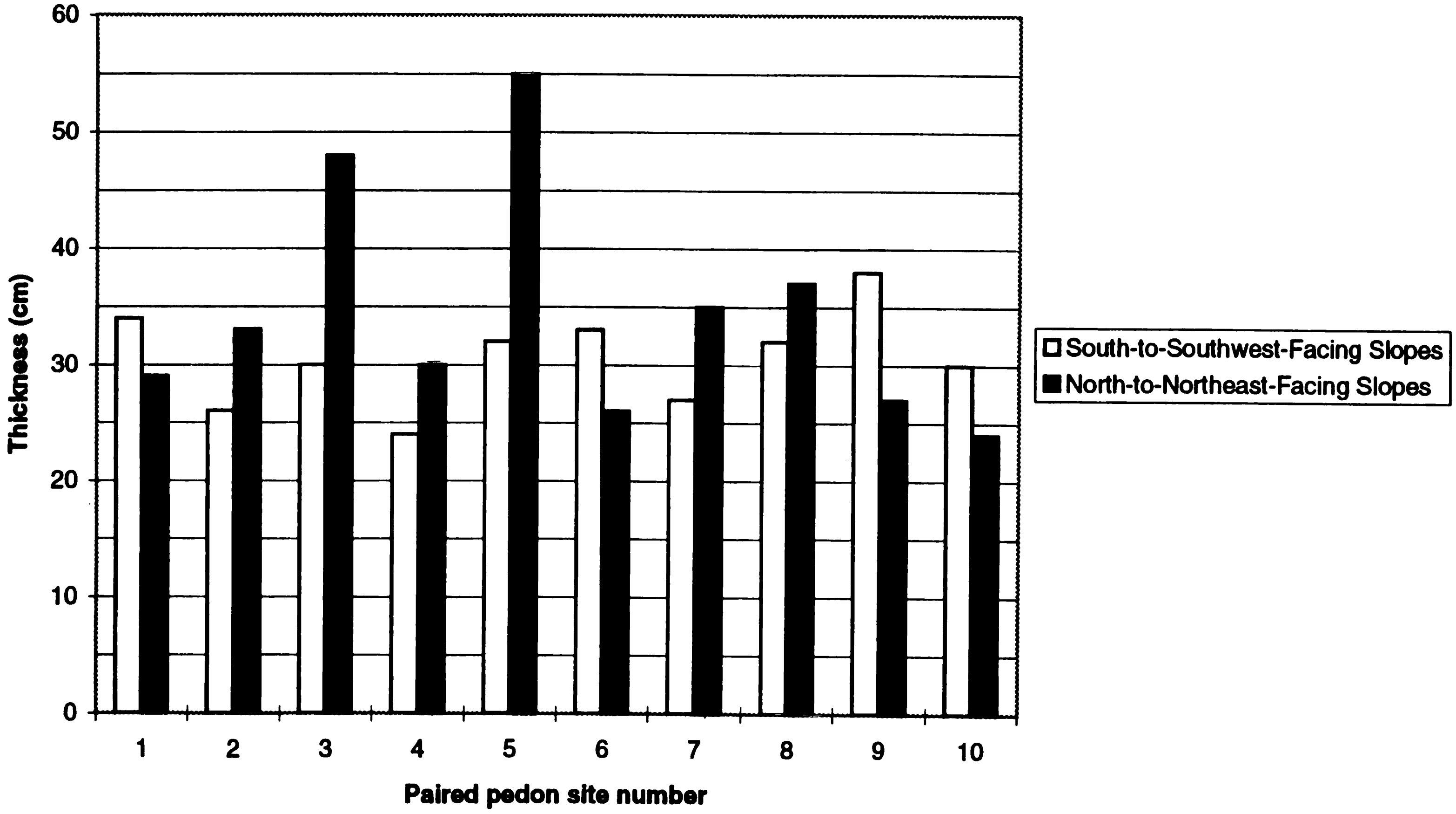

Figure 14. B horizon thickness on opposing aspects.

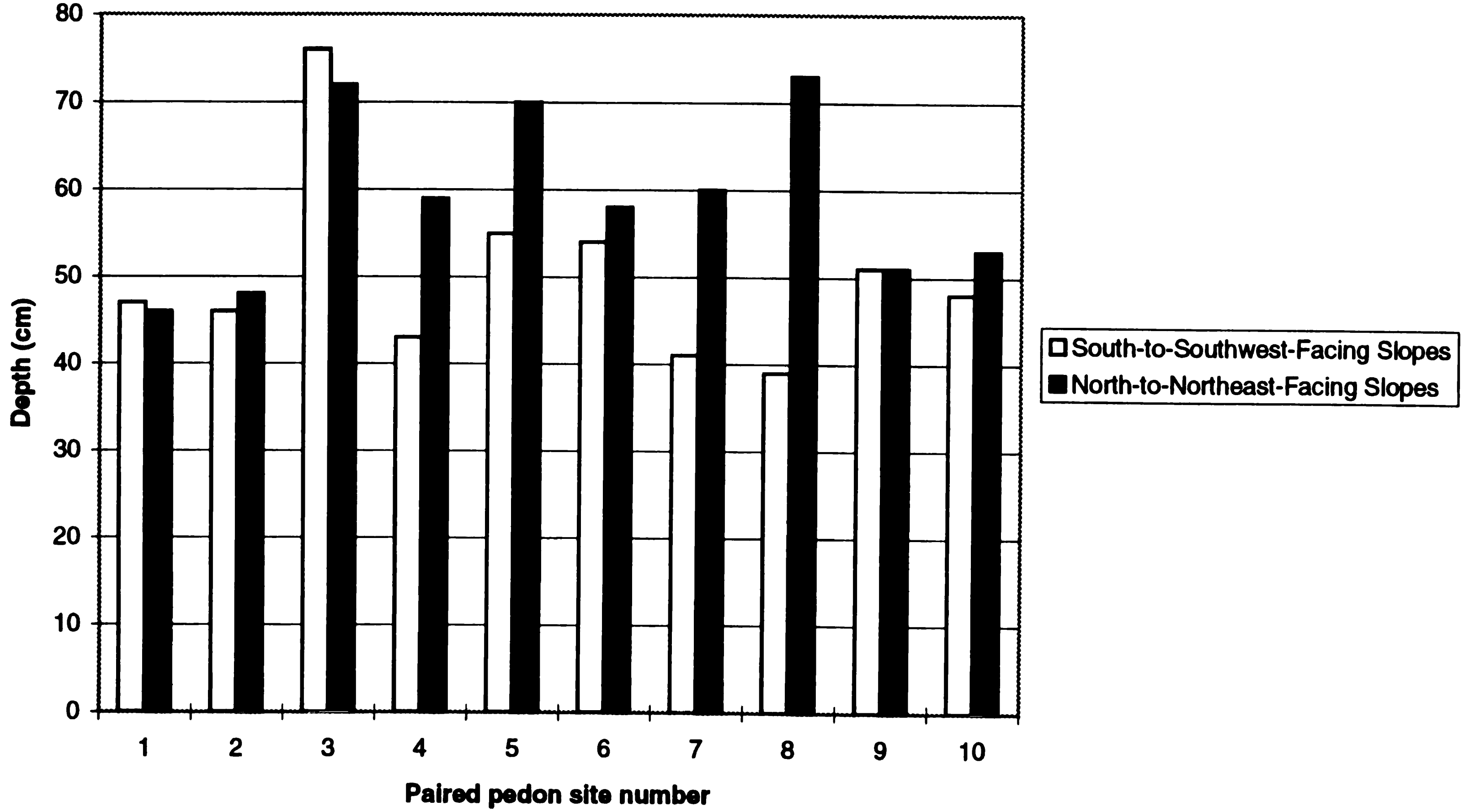

Figure 15. Solum thickness on opposing aspects.

2). Solum thickness was significantly greater (Wilcoxon, at $\alpha = 0.05$) on north-to-northeast-facing slopes when compared to that of south-to-southwest-facing slopes. North-to-northeast-facing slopes had a mean solum thickness of 59.0 ±9.9 cm whereas south-to-southwest-facing slopes had a mean solum thickness of 50.0 ±10.5 cm.

Other studies that document thicker sola on north- and/or northeast-facing slopes include Alexander (1995) in northern California, Marron and Popenoe (1986) in northwest California, and Cooper (1960) in southeast Michigan. In these studies, the findings were attributed to the presence of greater soil moisture and greater infiltration on north-facing slopes (when compared to south-facing slopes), thus translocating more material to greater depths, and forming thicker sola. Opposite findings, however, were documented by Losche et al. (1970) in North Carolina and Small (1972) in southwest Wisconsin where thicker sola were located on south- rather than north-facing slopes. They attributed these findings to higher soil temperatures that exist on south-facing slopes throughout the year, thus promoting increased chemical activity and accelerating weathering and pedogenesis.

In the current study, the presence of thicker sola on north-to-northeast-facing slopes can probably be attributed to the greater amounts of water available for leaching and translocation of materials. Since the sun does not dry the soil nor, perhaps, induce as much evapo-transpiration on the north-to-northeast-facing slopes when compared to that of south-to-southwest-facing slopes, the demand for water is less and therefore, more water is available to weather primary minerals, chelate and transport them and other materials to lower positions within the profile. The significantly thicker E horizons found in the soils of north-to-northeast-facing slopes (discussed earlier) provides plausible evidence that, indeed, greater translocation of materials has taken place on north-to-northeast-facing slopes when compared to that of south-to-southwest-facing slopes.

POD Index

The POD Index, which is a numerical index that assesses the degree of Spodosol development based on soil color and number of subhorizons (Schaetzl and Mokma 1988), was found to be significantly greater (Wilcoxon, at $\alpha = 0.01$) on north-to-northeast-facing slopes, indicating greater soil development on these slopes (Table 8, Figure 16). Mean POD index on north-to-northeast-facing slopes was 4.2 ±3.4 whereas mean POD Index on south-to-southwest-facing slopes was 1.1 ±1.2.

POD Index data provide convincing evidence that greater podzolization has taken place in the soils of north-to-northeast-facing slopes when contrasted to those of south-to-southwest-facing slopes.

Soil Color

<u>Uppermost E Horizon</u>

The hues, values and chromas of the uppermost E horizons[1] of soils on north-to-northeast-facing slopes were not significantly different (Wilcoxon, at $\alpha = 0.05$) from corresponding soils on south-to-southwest-facing slopes (Table 8, Figure 2). The mean hue of uppermost E horizons on north-to-northeast-facing slopes was 5.8 ±1.2 compared to 6.0 ±1.3 on south-to-southwest-facing slopes. The mean value of uppermost E horizons on north-to-northeast-facing slopes was 4.6 ±0.5 compared to 4.8 ±0.4 on

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[1] The "uppermost E horizon" refers to the E or E1 horizon in each profile. Likewise, the "uppermost B horizon" refers to the B horizon closest to the surface (either a Bs or Bhs horizon).

Table 8. Mean soil color and POD Index data and statistics (Wilcoxon 1949).

Soil characteristic	Mean value on: (st. dev.)		Number of greater values on:		Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
	N-NE slope	S-SE slope	N-NE slope	S-SE slope			
Hue, uppermost E horizon	5.8 (1.2)	6.0 (1.3)	1	2	7	0.282	(not significantly different)
Value, uppermost E horizon	4.6 (0.5)	4.8 (0.4)	1	3	6	0.159	(not significantly different)
Chroma, uppermost E horizon	2.2 (0.4)	2.4 (0.5)	0	2	8	0.079	(not significantly different)
Hue, uppermost B horizon	4.5 (1.1)	6.0 (1.3)	0	5	5	0.017 *	N-NE-facing slopes
Value, uppermost B horizon	3.1 (0.4)	3.9 (0.3)	0	8	2	0.004 **	N-NE-facing slopes
Chroma, uppermost B horizon	4.3 (1.0)	5.6 (0.8)	1	7	2	0.018 *	N-NE-facing slopes
POD Index	4.2 (3.4)	1.1 (1.2)	7	0	3	0.005 **	N-NE-facing slopes

* Significant at α=0.05 (Wilcoxon). ** Significant at α=0.01 (Wilcoxon).

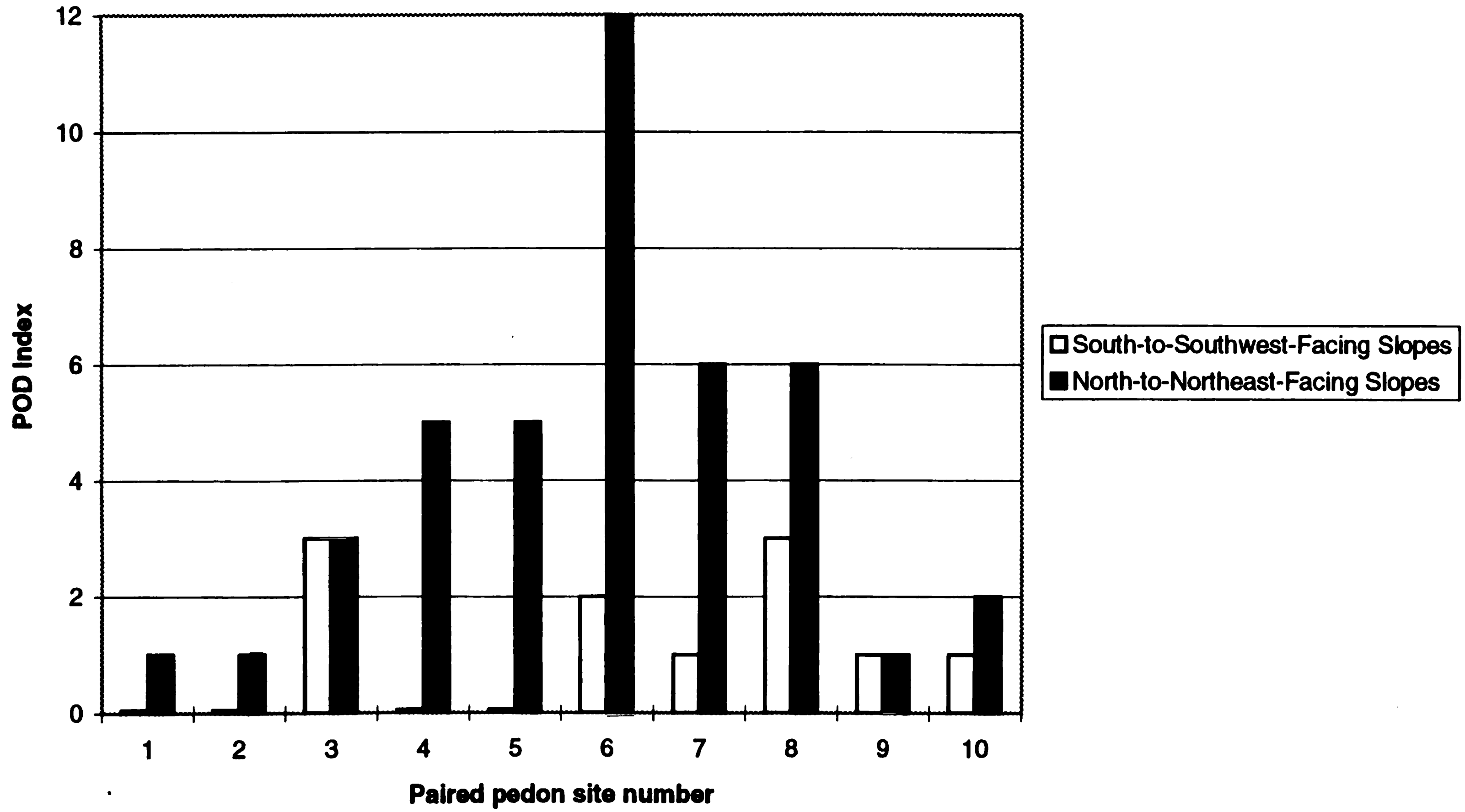

Figure 16. POD Index on opposing aspects.

south-to-southwest-facing slopes. The mean chroma of uppermost E horizons on north-to-northeast-facing slopes was 2.2 ±0.4 compared to 2.4 ±0.5 on south-to-southwest-facing slopes.

Since the ultimate existence of the E horizon is due to the depletion of humus and metal oxides from the upper horizons, one should expect to find no significant difference in E horizon color on opposing aspects. Once most of the humus and Fe oxides are depleted from the upper horizons, the translucence of the sand grains imparts the primary color to the soil horizon. The translucence of the sand appears as a grayish color (e.g. 5YR 5/2) which should be similar even on opposing aspects since it originated from the same parent material.

Uppermost B Horizon

The hues of the uppermost B horizons on north-to-northeast-facing slopes were found to be significantly redder (= lower hue; Wilcoxon, at $\alpha = 0.05$) than corresponding soils on south-to-southwest-facing slopes (Table 8). The mean hue of uppermost B horizons on north-to-northeast-facing slopes was 4.5 ±1.1 whereas the mean hue of uppermost B horizons on south-to-southwest-facing slopes was 6.0 ±1.3. The redder hues for soils on north-to-northeast-facing slopes might be attributed to greater concentrations of iron oxides in the uppermost B horizon. Similar color differences for B horizons have been documented by Franzmeier et al. (1969) in eastern Kentucky and Tennessee, and Marron and Popenoe (1986) in northwest California. They attributed this occurrence to higher concentrations of translocated clay in the B horizon, due to greater moisture content and greater throughflow on those slopes. Opposite findings, however, have been documented by Losche et al. (1970) in North Carolina and Cooper (1960) in southeastern Michigan. Cooper (1960) and Losche et al. (1970) found redder hues on south-facing slopes (when compared to north-facing slopes). Interestingly, they also attributed this occurrence to higher concentrations of translocated clay in the B horizon on those slopes. Cooper (1960) cites warmer soil temperatures as the main catalyst for this phenomenon. Warmer soil temperatures may promote increased chemical activity on south-facing slopes and therefore produce greater amounts of clay (due to increased chemical weathering) in the B horizons of those soils.

Both color values and chromas of the uppermost B horizons on north-to-northeast-facing slopes were found to be significantly less (Wilcoxon, at $\alpha = 0.05$ for chroma; at $\alpha = 0.01$ for value) than corresponding soils on south-to-southwest-facing slopes (Table 8, Figure 2). The mean color value of uppermost B horizons on north-to-northeast-facing slopes was 3.1 $\pm$0.4 whereas the mean color value of uppermost B horizons on south-to-southwest-facing slopes was 3.9 $\pm$0.3. The mean chroma of uppermost B horizons on north-to-northeast-facing slopes was 4.3 $\pm$1.0 whereas the mean chroma of uppermost B horizons on south-to-southwest-facing slopes was 5.6 $\pm$0.8.

The darker and grayer colors (i.e., lower values and chromas) for soils on north-to-northeast-facing slopes can be attributed to greater concentrations of humus in the uppermost B horizon. No other aspect study specifically reported soil color values and chromas. However, a few studies reported organic matter (or organic carbon) content for the B horizon. Daniels et al. (1987) reported greater amounts of organic matter in the B horizon (and throughout the solum) on north-facing slopes when compared to that of south-facing slopes. Franzmeier et al. (1969) also reported greater amounts of organic matter in sola on north-facing slopes. Carter and Ciolkosz (1991) reported greater organic carbon in the B horizon on steep (25 to 60%) northwest-facing slopes when compared to steep (25 to 60%) southwest-facing slopes, but discovered the reverse for less steep slopes (<20%). There they found less organic carbon on the northwest-facing slope when compared to that of the southwest-facing slope, but they considered this an anamoly.

Soil Reaction

<u>Soil:KCl Reaction</u>

Table 9 shows the mean, standard deviation and level of significance for soil:KCl reactions. Figure 17 plots mean horizon depth against mean KCl pH for opposing slope aspects. E horizons were the most acid of all horizons regardless of aspect, however they were more acid on north-to-northeast-facing slopes (see below). pH generally increased with depth down to the BC horizon. Mean C horizon pH actually decreased somewhat from the overlying BC horizon on both aspects; C horizon pH on opposing slopes are not significantly different and, in fact, have equivalent means = 4.3 (Table 9).

Statistical analysis (Wilcoxon 1949) of soil:KCl reactions show significant differences ($\alpha = 0.05$) in only two horizons (Table 9). The uppermost E horizon exhibited significantly higher (Wilcoxon, at $\alpha = 0.01$) pH values on south-to-southwest-facing slopes when compared to those of north-to-northeast-facing slopes, as did the uppermost B horizon (Wilcoxon, at $\alpha = 0.05$, Table 9).

Uppermost E horizons on south-to-southwest-facing slopes exhibited a mean

Table 9. Mean pH (KCl) data and statistics (Wilcoxon 1949).

Soil characteristic	Mean value on: (st. dev.) N-NE slope	S-SE slope	Number of greater values on: N-NE slope	S-SE slope	Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
pH in KCl							
uppermost E horizon	3.2 (0.1)	3.4 (0.2)	2	8	0	0.006 **	N-NE-facing slopes
uppermost B horizon	4.2 (0.2)	4.3 (0.2)	2	6	2	0.025 *	N-NE-facing slopes
2nd uppermost B horizon	4.5 (0.1)	4.4 (0.2)	5	5	0	0.177	(not significantly different)
BC or 2BC horizon	4.5 (0.2)	4.4 (0.2)	5	3	0	0.091	(not significantly different)
C, 2C or 3C horizon	4.3 (0.4)	4.3 (0.1)	5	2	1	0.277	(not significantly different)

* Significant at $\alpha=0.05$ (Wilcoxon). ** Significant at $\alpha=0.01$ (Wilcoxon).

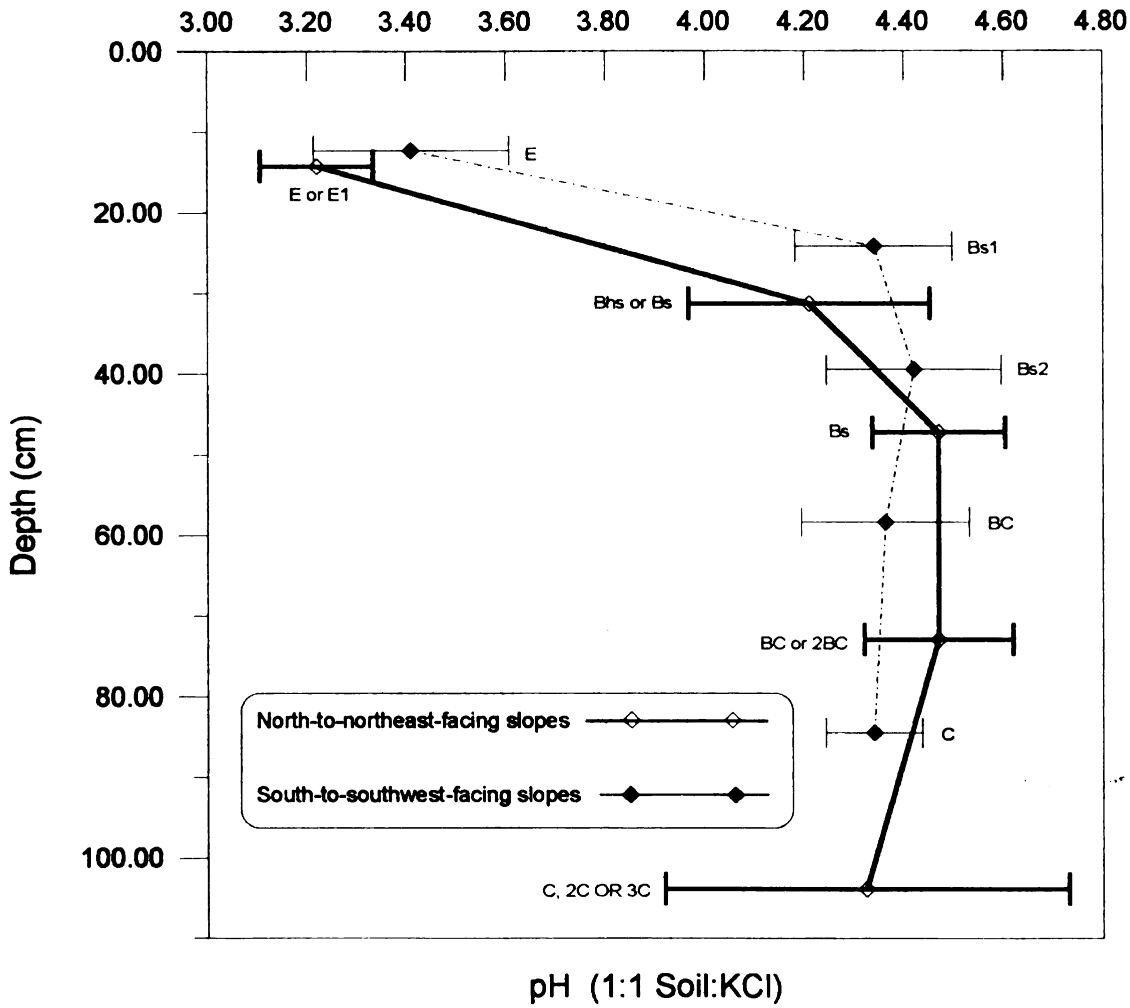

Figure 17. Mean pH (KCl) by mean horizon depth on opposing aspects.

pH of 3.4 ±0.2 whereas north-to-northeast-facing slopes exhibited a mean pH of 3.2 ±0.1. Uppermost B horizons on south-to-southwest-facing slopes exhibited a mean pH of 4.3 ±0.2 whereas north-to-northeast-facing slopes exhibited a mean pH of 4.2 ±0.2.

Soil:H_2O Reaction

Table 10 shows the mean, standard deviation and level of significance for soil:H_2O reactions. Figure 18 plots mean horizon depth against mean pH for opposing slope aspects. E horizons were the most acid of all horizons regardless of aspect, however they are somewhat less acid on north-to-northeast-facing slopes (Table 10). Values of pH generally increase with depth down to the C horizon where values on opposing slopes are not significantly different and, in fact, have equivalent means = 5.8 (Table 10).

Soil:H_2O reactions were not found to be significantly different (Wilcoxon, at $\alpha>0.05$) on opposing slopes for any horizon pair (Table 10). The pHs of the BC or 2BC horizons were the most different on opposing slopes (Wilcoxon, at $p = 0.081$) and had a higher mean on south-to-southwest-facing slopes (5.8 vs. 5.6). The 2nd most different pH on opposing slopes was in the uppermost E horizon (Wilcoxon, at $p = 0.085$, Table 10) where a higher mean was found on north-to-northeast-facing slopes (4.7 vs. 4.5).

Soil development seems to have been strongly related to pH in the upper half of the solum. Where pH values were lowest (E horizon), eluviation of materials was most prevalent. The comparatively higher pH values of the uppermost B horizon seem to have prompted the immobilization of Fe and Al (among other materials), thus, creating the greatest illuvial concentration of Fe and Al within the solum there. Similarly, the higher

Table 10. Mean pH (H_2O) data and statistics (Wilcoxon 1949).

Soil characteristic	Mean value on: (st. dev.) N-NE slope	Mean value on: (st. dev.) S-SE slope	Number of greater values on: N-NE slope	Number of greater values on: S-SE slope	Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
pH in H_2O							
uppermost E horizon	4.7 (0.4)	4.5 (0.3)	4	6	0	0.085	(not significantly different)
uppermost B horizon	5.4 (0.2)	5.5 (0.2)	5	3	1	0.220	(not significantly different)
2nd uppermost B horizon	5.6 (0.3)	5.7 (0.2)	6	4	0	0.193	(not significantly different)
BC or 2BC horizon	5.6 (0.3)	5.8 (0.2)	6	1	1	0.081	(not significantly different)
C, 2C or 3C horizon	5.8 (0.3)	5.8 (0.3)	5	2	0	0.132	(not significantly different)

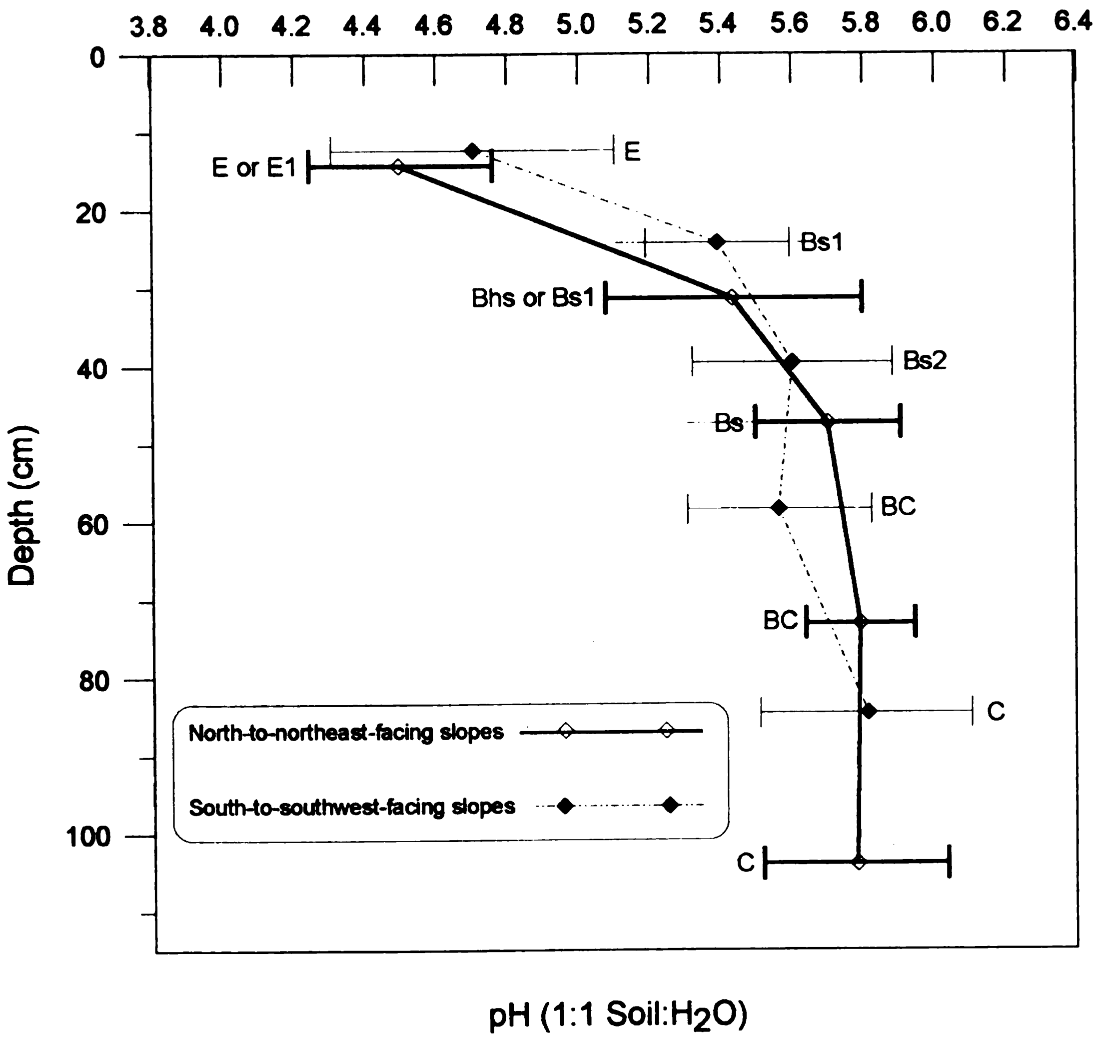

Figure 18. Mean pH (H_2O) by mean horizon depth on opposing aspects.

greater depth probably precluded any further mobilization of Fe and Al.

Acid Ammonium Oxalate Extraction Data

Ammonium oxalate extracts Fe and Al from both organic and inorganic amorphous materials but does not extract crystalline oxides well (McKeague and Day 1966). In the present study, relative depletion of oxalate-extractable Fe and Al (Fe_o and Al_o) has occurred in the E horizon for all pedons when compared to the B horizons of the same pedon. This is typical of sandy soils found throughout northern Michigan. Mean depth plots (Figures 19 and 20) exhibit the relative concentration of Fe_o and Al_o in the uppermost B horizon within soils on both aspects. The translocation of Fe_o and Al_o as affected by aspect are discussed in the following paragraphs.

Uppermost E Horizon

The E horizons on north-to-northeast-facing slopes contained significantly less (Wilcoxon, at $\alpha = 0.05$) Fe_o than those on south-to-southwest-facing slopes (Table 11, Table 12, Figure 21). The mean weight of Fe_o in the E horizon on north-to-northeast-facing slopes was 0.20 ±0.2 g/kg soil whereas the mean weight in the same horizon on south-to-southeast-facing slopes was more than double that amount: 0.44 ±0.2 g/kg.

The E horizons on north-to-northeast-facing slopes contained significantly less (Wilcoxon, at $\alpha = 0.01$) Al_o than those on south-to-southwest-facing slopes (Table 11, Table 12, Figure 22). The mean weight of Al_o in the E horizon on north-to-northeast-facing slopes was 0.15 ±0.1 g/kg soil whereas the mean weight in the same horizon on south-to-southeast-facing slopes was 0.31 ±0.1 g/kg.

The greater depletion of Fe_o and Al_o in the uppermost E horizon on north-to-

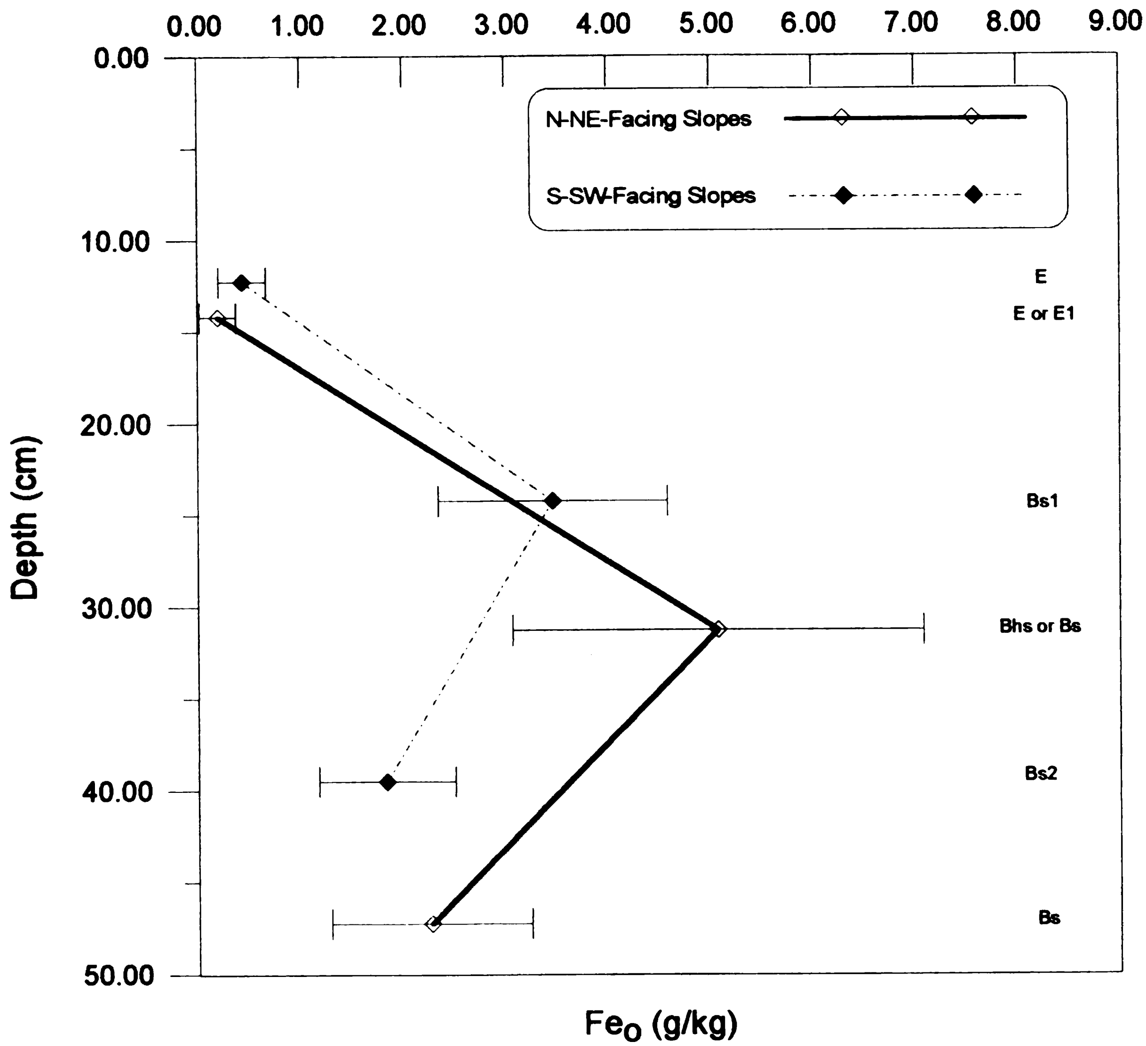

Figure 19. Mean Fe_o depth plot for opposing aspects.

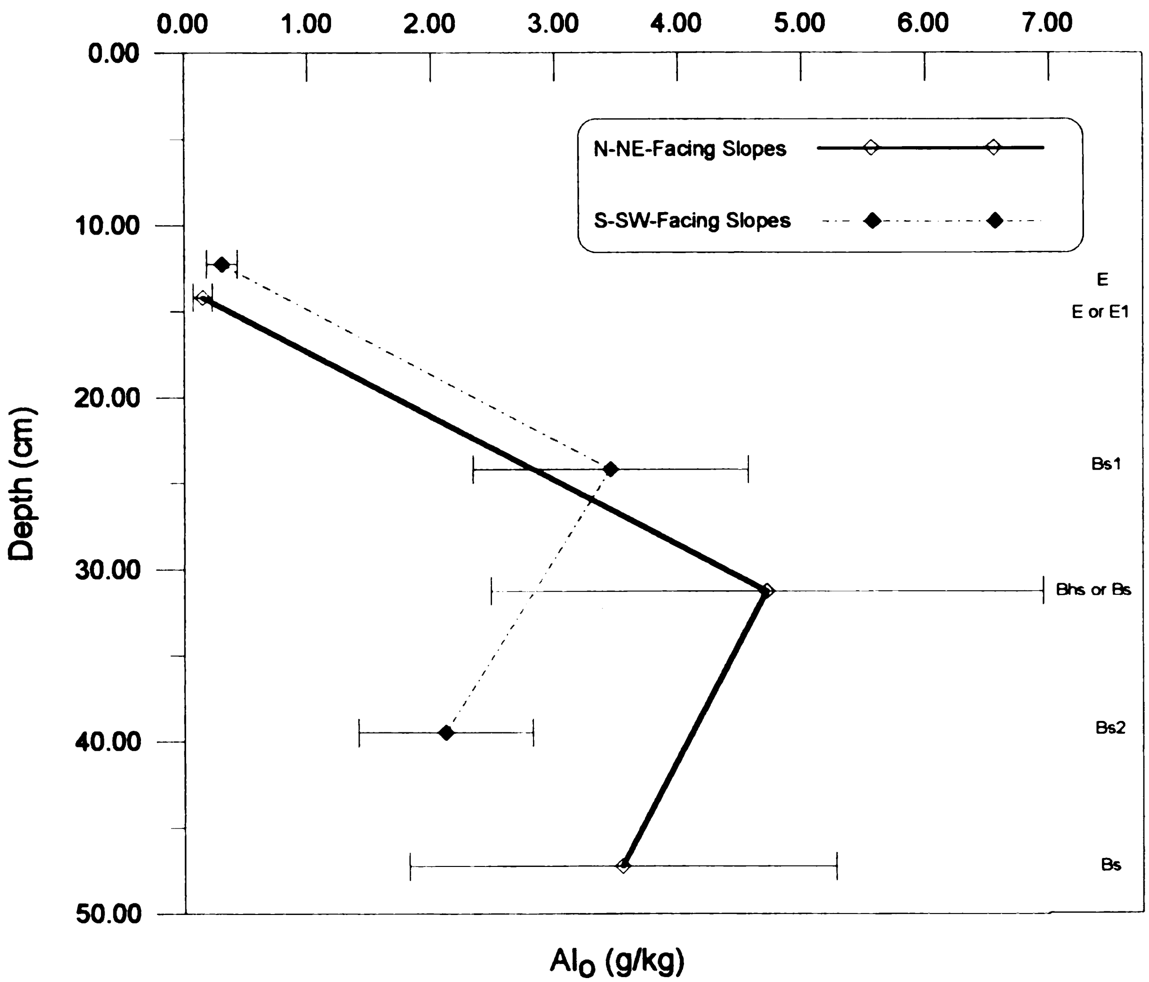

Figure 20. Mean Al_o depth plot for opposing aspects.

Table 11. Mean Fe_o and Al_o data and statistics (Wilcoxon 1949).

Soil characteristic	Mean value on: (st. dev.) N-NE slope	S-SE slope	Number of greater values on: N-NE slope	S-SE slope	Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
Fe_o, uppermost E horizon (g/kg)	0.2 (0.2)	0.4 (0.2)	2	8	0	0.047 *	N-NE-facing slopes
Fe_o, uppermost B horizon (g/kg)	5.1 (2.0)	3.5 (1.1)	8	2	0	0.037 *	N-NE-facing slopes
Fe_o, 2nd uppermost B horizon (g/kg)	2.3 (1.0)	1.8 (0.7)	7	3	0	0.169	(not significantly different)
Al_o, uppermost E horizon (g/kg)	0.2 (0.1)	0.3 (0.1)	1	9	0	0.007 **	N-NE-facing slopes
Al_o, uppermost B horizon (g/kg)	4.7 (2.2)	3.5 (1.1)	6	4	0	0.169	(not significantly different)
Al_o, 2nd uppermost B horizon (g/kg)	3.5 (1.7)	2.1 (0.7)	9	1	0	0.013 *	N-NE-facing slopes

* Significant at α=0.05 (Wilcoxon). ** Significant at α=0.01 (Wilcoxon).

Table 12. Acid ammonium oxalate extraction data.

Sample	Fe	Al	Sample	Fe	Al
	----g/kg---			----g/kg---	
S1 E	0.26	0.46	N1 E	0.44	0.33
S1 Bs1	3.66	4.02	N1 Bs1	4.45	8.70
S1 Bs2	1.02	1.95	N1 Bs2	1.52	3.13
S2 E	0.31	0.34	N2 E	0.14	0.12
S2 Bs1	3.37	3.52	N2 Bs1	2.83	2.31
S2 Bs2	1.61	1.77	N2 Bs2	0.91	1.13
S3 E	0.22	0.18	N3 E	0.53	0.15
S3 Bs1	3.66	3.60	N3 Bs1	3.75	3.16
S3 Bs2	1.01	0.92	N3 Bs2	2.42	2.10
S4 E	0.51	0.33	N4 E	0.12	0.14
S4 Bs1	3.07	4.61	N4 Bs1	4.84	6.77
S4 Bs2	1.15	1.67	N4 Bs2	1.21	2.30
S5 E	0.36	0.25	N5 E	0.17	0.14
S5 Bs1	1.84	1.30	N5 Bhs	5.93	4.16
S5 Bs2	1.56	1.79	N5 Bs1	2.54	2.94
			N5 Bs2	1.66	1.87

Table12. (cont'd.)

Sample	Fe	Al	Sample	Fe	Al
	----g/kg---			----g/kg---	
S6 E	0.13	0.18	N6 E1	0.05	0.09
S6 Bs1	2.48	2.74	N6 E2	0.09	0.13
S6 Bs2	2.69	3.21	N6 Bhs	5.99	7.17
			N6 Bs	2.09	4.68
S7 E	0.42	0.37	N7 E1	0.04	0.08
S7 Bs1	2.89	3.93	N7 E2	0.22	0.12
S7 Bs2	2.00	2.39	N7 Bs1	3.05	2.99
			N7 Bs2	2.15	2.80
S8 E	0.89	0.49	N8 E	0.08	0.09
S8 Bs1	3.79	3.34	N8 Bs1	3.38	2.15
S8 Bs2	2.60	3.23	N8 Bs2	3.88	6.63
S9 E	0.68	0.35	N9 E	0.34	0.25
S9 Bs1	6.09	5.12	N9 Bs1	8.40	5.47
S9 Bs2	2.10	1.86	N9 Bs2	3.79	5.88
S10 E	0.58	0.12	N10 E1	0.08	0.13
S10 Bs1	3.77	2.30	N10 E2	0.10	0.14
S10 Bs2	2.63	2.32	N10 Bs1	8.13	4.27
			N10 Bs2	2.21	3.85

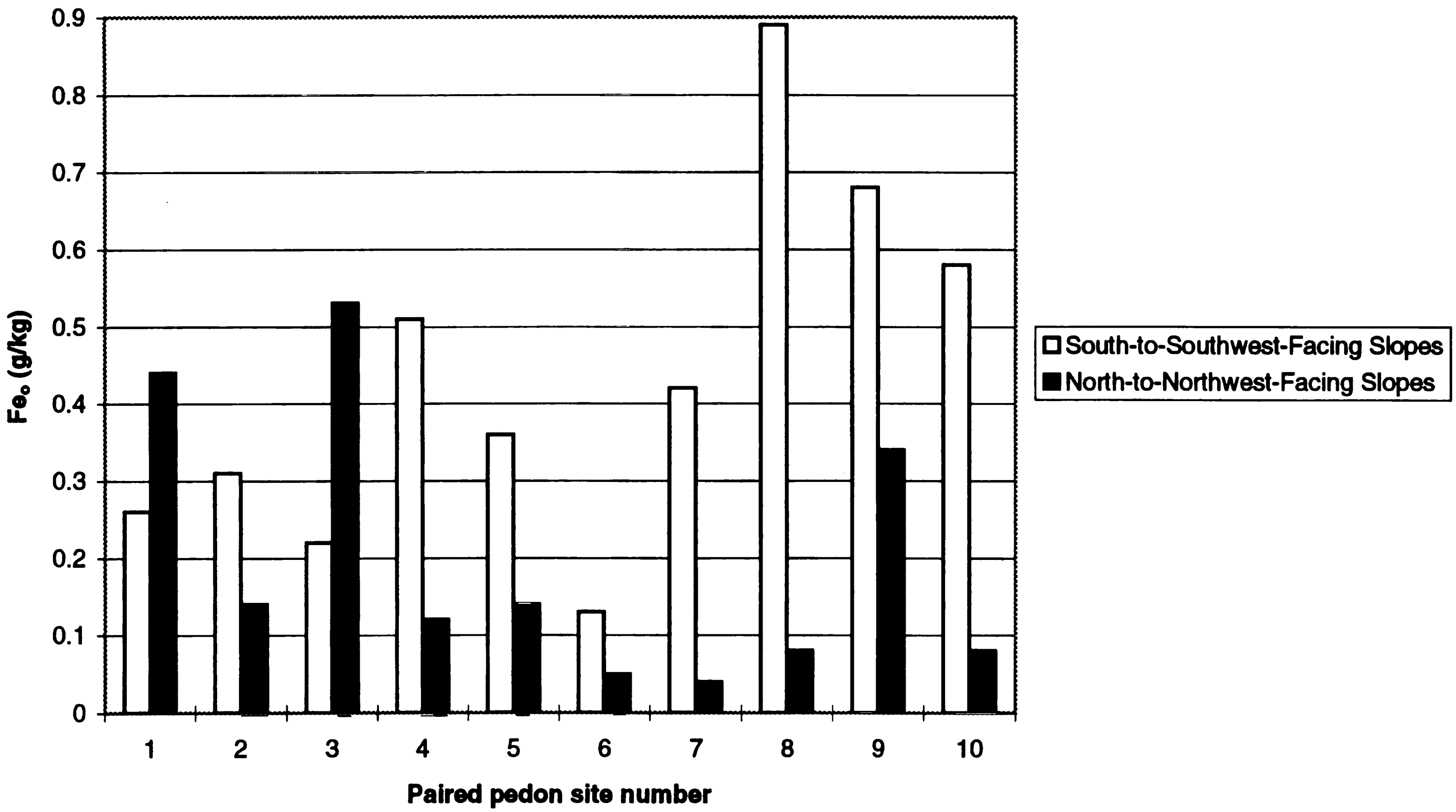

Figure 21. Fe_o of the uppermost E horizon on opposing aspects.

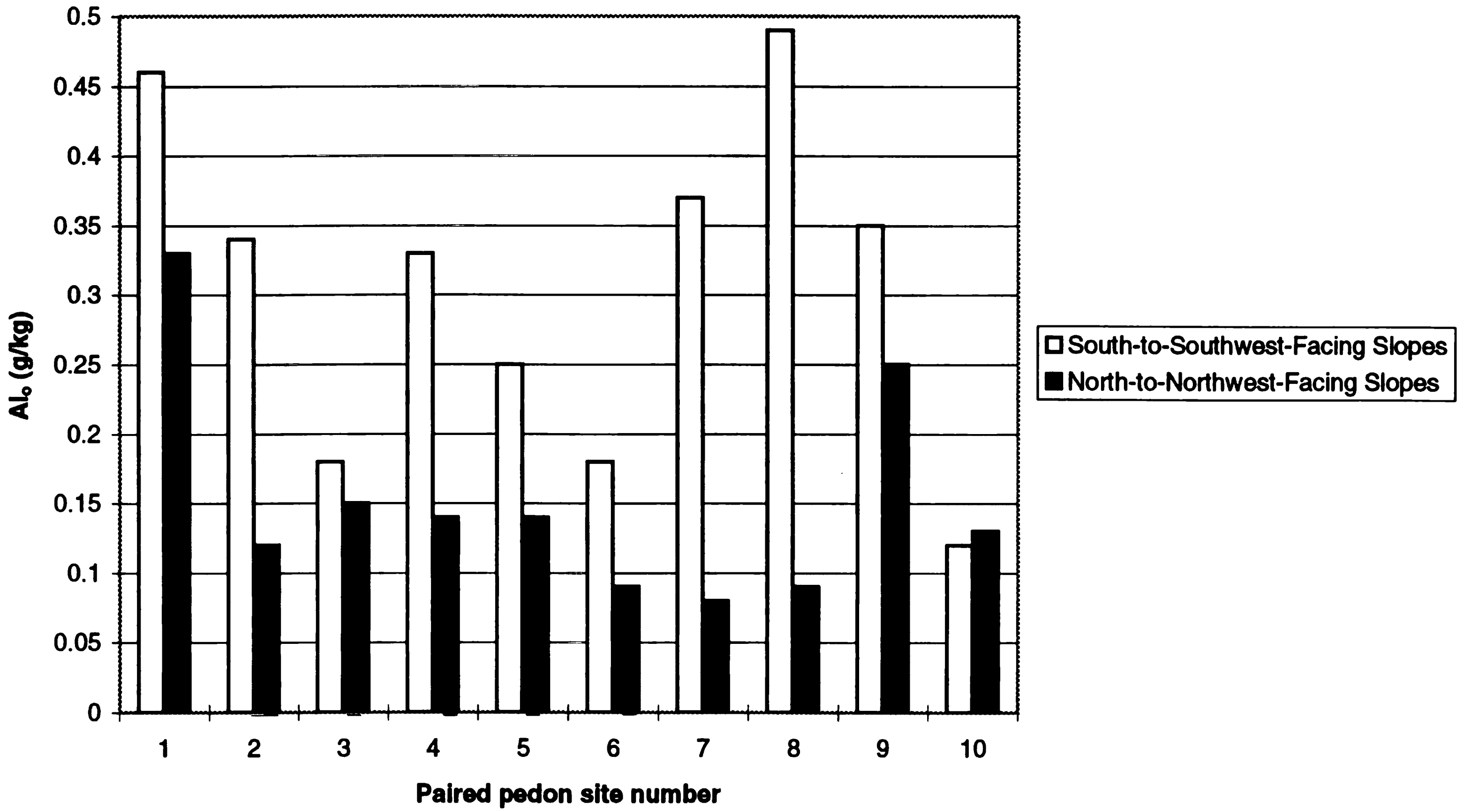

Figure 22. Al_o of the uppermost E horizon on opposing aspects.

northeast-facing slopes when compared to that of south-to-southwest-facing slopes suggests that greater leaching has occurred on the north-to-northeast-facing slopes. Increased eluviation has decreased the amounts of Fe_o and Al_o more in the E horizon on north-to-northeast-facing slopes compared to that of south-to-southwest-facing slopes. Greater infiltration of water (in part, due to the comparatively low evaporative demand) on north-to-northeast-facing slopes is probably a major factor contributing to the greater translocation of Fe_o and Al_o on these slopes. However, soil moisture data were not collected during the current study.

Uppermost B Horizon

The uppermost B horizons on north-to-northeast-facing slopes contained significantly more (Wilcoxon, at $\alpha = 0.05$) Fe_o than those on south-to-southwest-facing slopes (Table 11, Table 12, Figure 23). The mean weight of Fe_o in the uppermost B horizons on north-to-northeast-facing slopes was 5.08 ±2.0 g/kg soil whereas the mean weight of Fe_o in the same horizons on south-to-southwest-facing slopes was 3.46 ±1.1 g/kg. There was not a statistically significant difference (Wilcoxon, at $\alpha = 0.05$) in the weight of Al_o within the uppermost B horizons on opposing slopes. However, the mean weight of Al_o in the uppermost B horizons on north-to-northeast-facing slope was greater than the mean weight of Al_o in the same horizons on south-to-southwest-facing slopes. Mean weight of Al_o in the uppermost B horizons on north-to-northeast-facing slopes was 4.72 ±2.2 g/kg soil whereas the mean weight of Al_o in that of the south-to-southwest-facing slopes was 3.45 ±1.1 g/kg.

Since the E horizons on north-to-northeast-facing slopes contained significantly

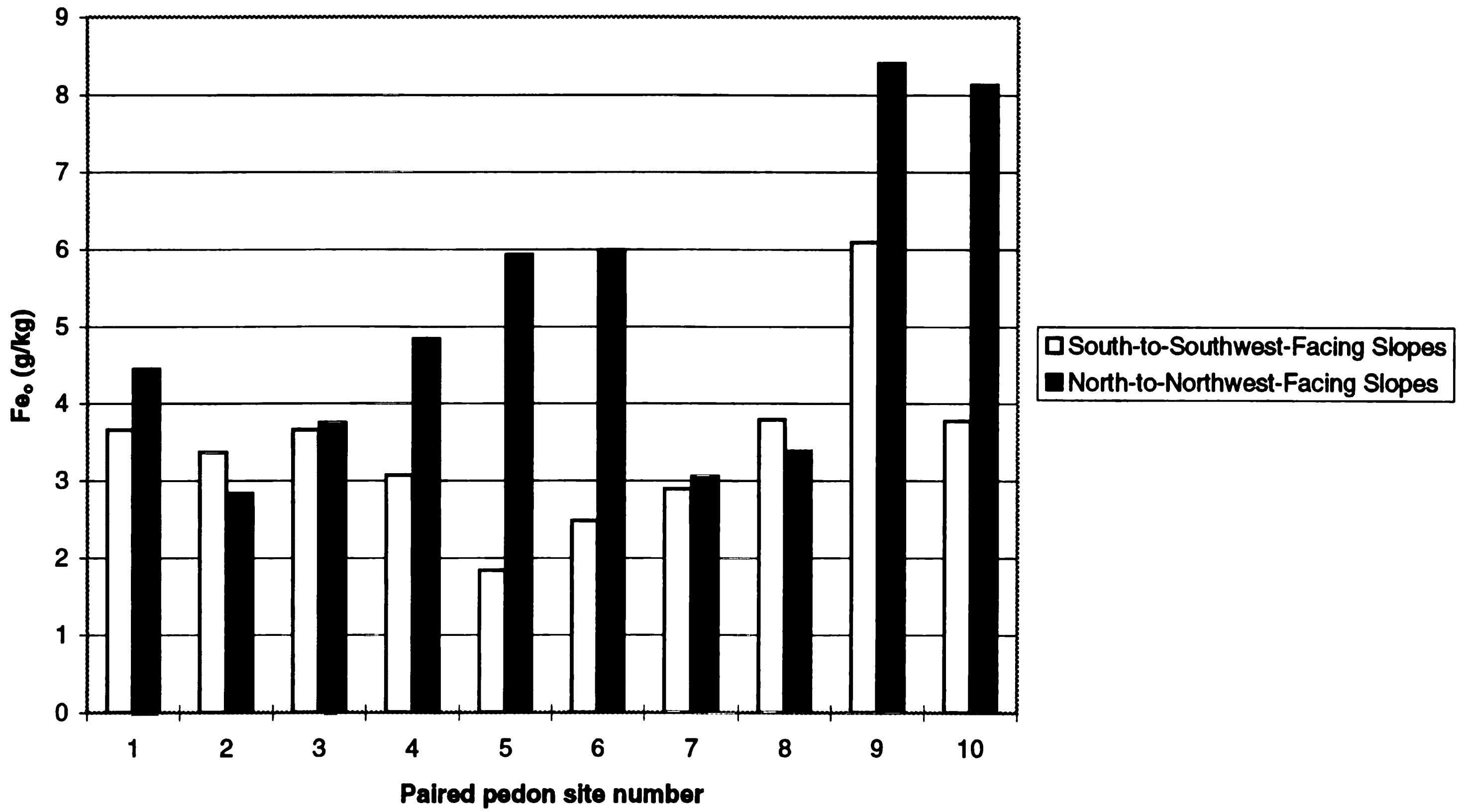

Figure 23. Fe_o of the uppermost B horizon on opposing aspects.

less Fe_o and Al_o than that of south-to-southwest-facing slopes, it seems logical that these materials have been eluviated from the E horizon and illuviated, mostly, in the uppermost B horizon. It should also be noted that even though Al_o weights were not significantly different ($\alpha = 0.05$) in the uppermost B horizons of opposing slopes, the mean weight of Al_o on north-to-northeast-facing slopes was nonetheless greater than that of the 2nd uppermost B horizon in the same pedons, which indicates, in general, that the majority of Al_o illuviated into the B horizons of these soils was deposited in the uppermost B horizon.

2nd Uppermost B Horizon

There was not a statistically significant difference (Wilcoxon, at $\alpha = 0.05$) in the weight of Fe_o within the 2nd uppermost B horizons on opposing slopes (Table 11). However, the mean weight of Fe_o in the 2nd uppermost B horizons on north-to-northeast-facing slope was still higher than the mean weight of Fe_o in similar horizons on south-to-southwest-facing slopes. Mean weight of Fe_o in the 2nd uppermost B horizons on north-to-northeast-facing slopes was 2.27 ±1.0 g/kg soil whereas the mean weight of Fe_o in that of comparable horizons on south-to-southwest-facing slopes was 1.84 ±0.7 g/kg.

The 2nd uppermost B horizons on north-to-northeast-facing slopes contained significantly more (Wilcoxon, at $\alpha = 0.05$) Al_o than those on south-to-southwest-facing slopes (Table 11). The mean weight of Al_o in the 2nd uppermost B horizon on north-to-northeast-facing slopes was 3.54 ±1.7 g/kg soil whereas the mean weight of Al_o in the same horizon on south-to-southwest-facing slopes was 2.11 ±0.7 g/kg.

Since Al_o generally is translocated deeper in the solum than Fe_o (Mizota 1982) and since more leaching seems to take place on north-to-northeast-facing slopes, it is understandable that Al_o amounts are significantly greater in the 2nd uppermost B horizon on north-to-northeast-facing slopes when compared to that of south-to-southwest-facing slopes. Mean Al_o in the uppermost B horizon are still greater than the 2nd uppermost B horizon regardless of slope, but a large portion of Al_o in the uppermost B horizon continues downward toward the 2nd uppermost B horizon (a larger portion than that of Fe_o), thus, forming a secondary concentration of Al_o in that horizon.

Optical Density of the Oxalate Extract (ODOE)

The optical density of the oxalate extract serves as a measure of podzolization based on the amount of extracted fulvic acids from each horizon (Daly 1982). Fulvic acids chelate Fe and Al cations and may render them mobile in the soil solution. These chelate complexes can then be eluviated from the upper horizons and deposited in the B horizon. The Keys to Soil Taxonomy (Soil Survey Staff 1994) states that spodic materials normally have an ODOE > 0.25 and this value is at least two times the value of an overlying eluvial horizon. In the current study, the uppermost B horizons from eight pedons exhibit ODOE values that qualify as spodic materials (Table 13). All of these sites occur on north-to-northeast-facing slopes, which seems to indicate that stronger podzolization has taken place on these slopes when compared to that of south-to-southwest-facing slopes. A depth plot of mean ODOE is shown in Figure 24.

E Horizon ODOE

ODOE values for the uppermost E horizons on south-to-southwest-facing slopes were significantly greater (Wilcoxon, at $\alpha = 0.05$) than those of north-to-northeast-facing slopes (Table 14). Mean ODOE for the uppermost E horizons on north-to-northeast-

Table 13. Data on optical density of oxalate extracts.

Sample	ODOE	B ÷ E ratio	Sample	ODOE	B ÷ E ratio
S1 E	0.107		N1 E	0.027	
S1 Bs1	0.099	0.93	N1 Bs1	0.289	10.70
S1 Bs2	0.130	1.22	N1 Bs2	0.034	1.26
S2 E	0.020		N2 E	0.001	
S2 Bs1	0.029	1.45	N2 Bs1	0.127	127.0
S2 Bs2	0.013	0.65	N2 Bs2	0.047	47.0
S3 E	0.170		N3 E	0.020	
S3 Bs1	0.074	0.44	N3 Bs1	0.057	2.85
S3 2Bs2	0.017	0.10	N3 Bs2	0.050	2.50
S4 E	0.023		N4 E	0.064	
S4 Bs1	0.057	2.48	N4 Bs1	0.449	7.02
S4 Bs2	0.026	1.13	N4 Bs2	0.045	0.70
S5 E	0.029		N5 E	0.021	
S5 Bs1	0.177	6.10	N5 Bhs	0.496	23.62
S5 Bs2	0.057	1.97	N5 Bs1	0.124	5.90
			N5 Bs2	0.038	1.81

Table 13. (cont'd.)

Sample	ODOE	B ÷ E ratio	Sample	ODOE	B ÷ E ratio
			N6 E1	0.004	
S6 E	0.016		N6 E2	0.026	
S6 Bs1	0.005	5.31	N6 Bhs	0.489	122.3
S6 Bs2	0.026	1.63	N6 Bs	0.104	26.0
			N7 E1	0.004	
S7 E	0.040		N7 E2	0.015	
S7 Bs1	0.216	5.40	N7 Bs1	0.280	70.0
S7 Bs2	0.046	1.15	N7 Bs2	0.065	16.25
S8 E	0.046		N8 E	0.001	
S8 Bs1	0.20	4.35	N8 Bs1	0.395	395.0
S8 Bs2	0.043	0.94	N8 Bs2	0.154	154.0
S9 E	0.12		N9 E	0.098	
S9 Bs1	0.217	1.81	N9 Bs1	0.411	4.19
S9 Bs2	0.164	1.37	N9 Bs2	0.269	2.74
			N10 E1	0.021	
S10 E	0.045		N10 E2	0.021	
S10 Bs1	0.175	3.89	N10 Bs1	0.448	21.33
S10 Bs2	0.236	5.24	N10 Bs2	0.236	11.24

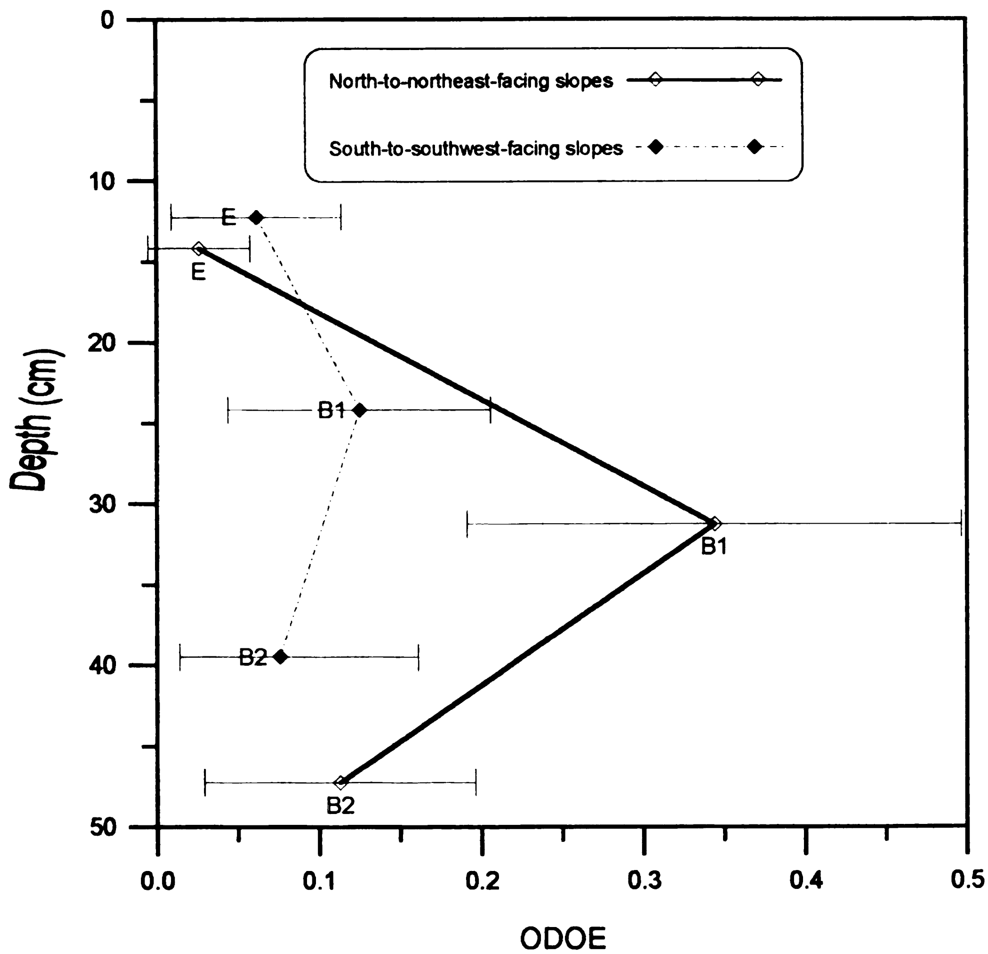

Figure 24. Mean ODOE depth plot for opposing aspects.

Table 14. Mean ODOE data and statistics (Wilcoxon 1949).

Soil characteristic	Mean value on: (st. dev.) N-NE slope	S-SE slope	Number of greater values on: N-NE slope	S-SE slope	Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
ODOE							
uppermost E horizon	0.0 (0.0)	0.1 (0.1)	1	9	0	0.019 *	N-NE-facing slopes
uppermost B horizon	0.3 (0.2)	0.1 (0.1)	9	1	0	0.004 **	N-NE-facing slopes
2nd uppermost B horizon	0.1 (0.1)	0.1 (0.1)	7	2	1	0.062	(not significantly different)
upper. B horizon ÷ upper. E horizon	78.4 (121.0)	3.2 (2.1)	10	0	0	0.003 **	N-NE-facing slopes
2nd uppermost B horizon ÷ upper. E horizon	23.3 (48.0)	1.5 (1.4)	8	2	0	0.011 *	N-NE-facing slopes

* Significant at $\alpha=0.05$ (Wilcoxon). ** Significant at $\alpha=0.01$ (Wilcoxon).

facing slopes was 0.03 ±0.0 whereas mean ODOE for the uppermost E horizons on south-to-southwest-facing slopes was 0.06 ±1.0. This is an indication that fulvic acids on north-to-northeast-facing slopes have been eluviated more completely from the E horizon than on south-to-southwest-facing slopes. These data are corroborated by other data such as significantly thicker E horizons on north-to-northeast-facing slopes (when compared to that of opposing slopes) and significantly less Fe_o, Fe_p, Al_o and Al_p in the E horizons of north-to-northeast-facing slopes (when compared to that of opposing slopes) indicating greater overall eluviation of material (including fulvic acids) from the E horizon on north-to-northeast-facing slopes.

B Horizon ODOE

The ODOE values for the uppermost B horizon of soils on north-to-northeast-facing slopes were significantly greater (Wilcoxon, at $\alpha = 0.01$) than for similar horizons on south-to-southwest-facing slopes (Table 14). The mean ODOE for uppermost B horizons on north-to-northeast-facing slopes was 0.34 ±0.2 whereas the mean ODOE for uppermost B horizons on south-to-southwest-facing slopes was 0.13 ±0.1. If significantly more fulvic acids have been eluviated from the E horizons on north-to-northeast-facing slopes, it is logical that they would tend to concentrate in the uppermost B horizons of the same slopes. The ODOE values for the 2nd uppermost B horizons on north-to-northeast-facing slopes were greater, but not significantly greater (Wilcoxon, at $\alpha = 0.05$) than those of the south-to-southwest-facing slopes (0.10 ±0.1 vs. 0.08 ±0.1, Table 14).

B Horizon ODOE ÷ E Horizon ODOE

The ratio of B horizon ODOE ÷ E horizon ODOE provides an index used to assess intensity of spodic development (Daly 1982). Higher values of this ratio indicate greater translocation (eluviation/illuviation) of fulvic acids and associated chelate complexes, thus, indicating stronger podzolization. Daly (1982) found that ratio values < 1.0 did not meet spodic horizon criteria in Soil Taxonomy (Soil Survey Staff 1975). Only two soils in the current study had ratios values < 1.0 and they both occured on south-to-southwest-facing slopes.

The ODOE of the uppermost B horizon ÷ ODOE of the uppermost E horizon was significantly greater (Wilcoxon, at $\alpha = 0.01$) on north-to-northeast-facing slopes when compared to that of south-to-southwest-facing slopes (Table 14, Figure 25). The mean value of this ratio on north-to-northeast-facing slopes was 78.4 ±121.6 whereas the mean value for south-to-southwest-facing slopes was almost 25 times lower (3.2 ±2.1). The ODOE of the 2nd uppermost B horizon ÷ ODOE of the uppermost E horizon was also significantly greater (Wilcoxon, at $\alpha = 0.05$) on north-to-northeast-facing slopes when compared to that of south-to-southwest-facing slopes (23.3 ±47.9 vs. 1.5 ±1.4, Table 14).

The results of the ODOE analyses provide convincing evidence that a greater amount of podzolization, as exemplified by eluvial/illuvial ratios of ODOE, has taken place in the soils of north-to-northeast-facing slopes when contrasted to those of south-to-southwest-facing slopes.

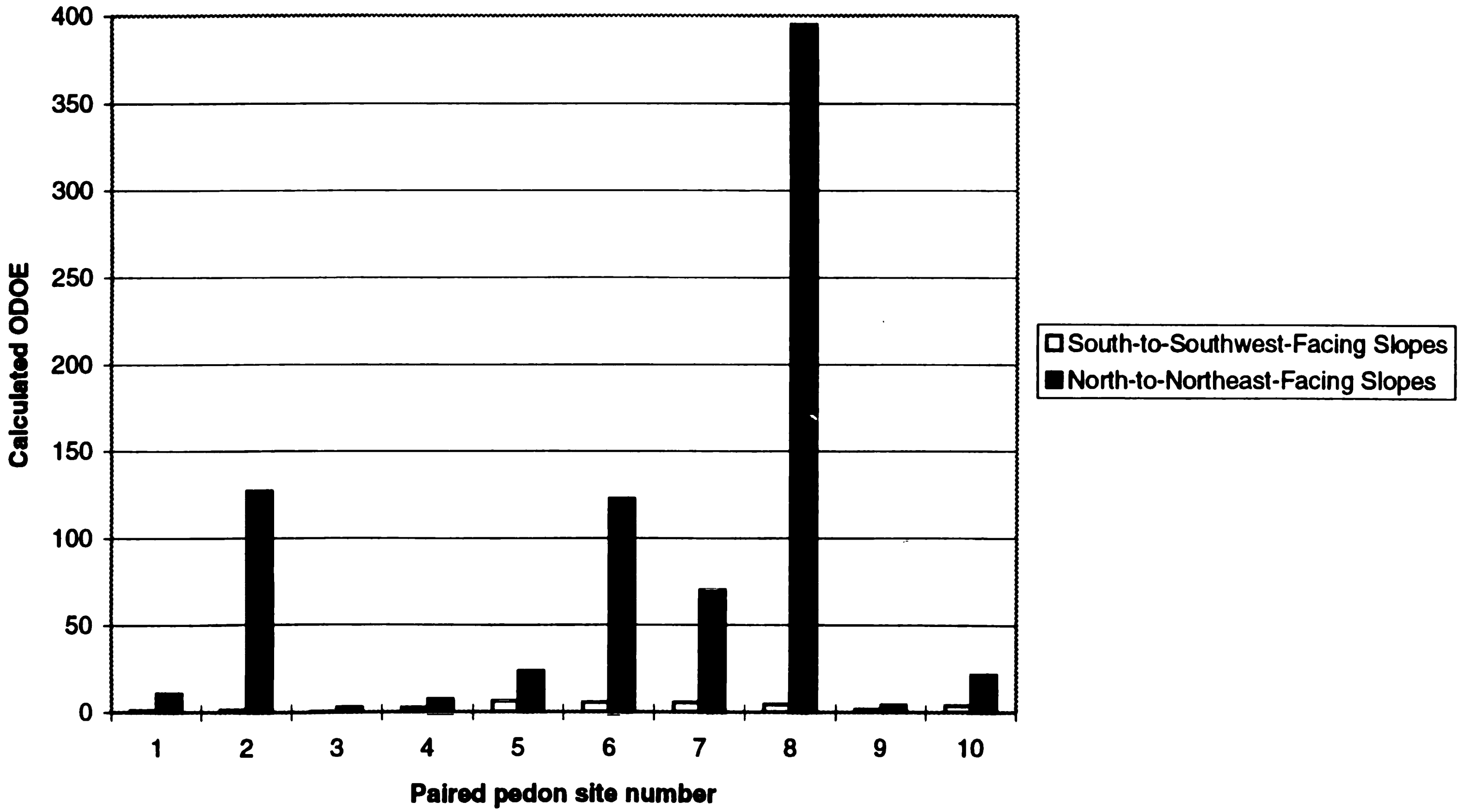

Figure 25. Calculated ODOE: uppermost B horizon / uppermost E horizon on opposing aspects.

Sodium Pyrophosphate Extraction Data

Fe_p and Al_p indicate the presence of organically-bound amorphous materials (Aleksandrova 1960). In the present study, relative depletion of these materials has occurred in the E horizon for all pedons when compared to the B horizons of the same pedon (Figures 26 and 27). Translocation of Fe_p and Al_p as affected by aspect are discussed in the following paragraphs.

Uppermost E Horizon

The E horizons on north-to-northeast-facing slopes contained significantly less (Wilcoxon, at $\alpha = 0.05$) Fe_p than those on south-to-southwest-facing slopes (Table 15, Table 16, Figure 28). The mean weight of Fe_p in E horizons on north-to-northeast-facing slopes was 0.07 ±0.0 g/kg soil whereas the mean weight in the same horizons on south-to-southeast-facing slopes was 0.15 ±0.1 g/kg.

The E horizons on north-to-northeast-facing slopes also contained significantly less (Wilcoxon, at $\alpha = 0.01$) Al_p than those on south-to-southwest-facing slopes (Table 15). The mean weight of Al_p in E horizons on north-to-northeast-facing slopes was 0.08 ±0.0 g/kg soil whereas the mean weight in the same horizons on south-to-southeast-facing slopes was 0.15 ±0.1 g/kg.

The greater depletion of Fe_p and Al_p in the uppermost E horizons on north-to-northeast-facing slopes suggests that more eluviation has occurred on the north-to-northeast-facing slopes. Eluviation has diminished the amounts of Fe_p and Al_p more in the E horizon on north-to-northeast-facing slopes compared to that of south-to-southwest-facing slopes. Relatively low pH values coincide with the depletion of Fe_p and Al_p.

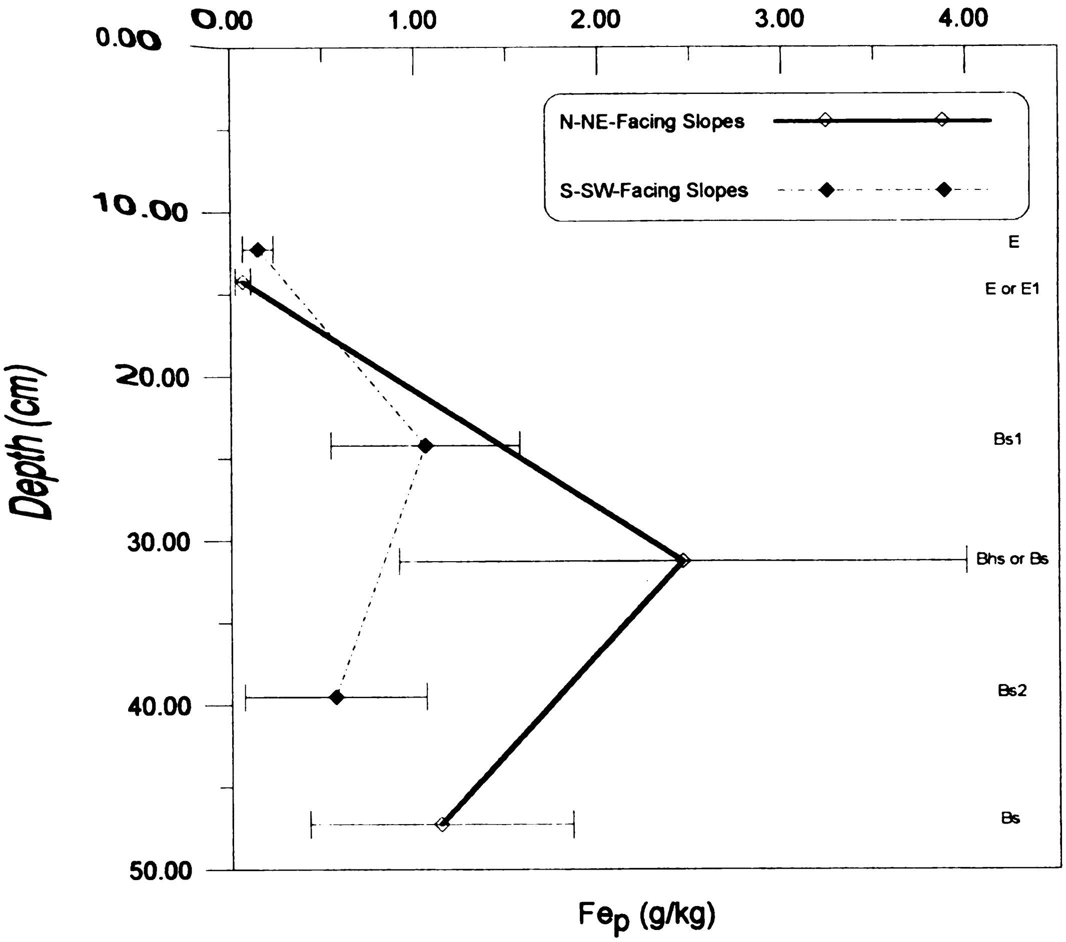

Figure 26. Mean Fe_p depth plot for opposing aspects.

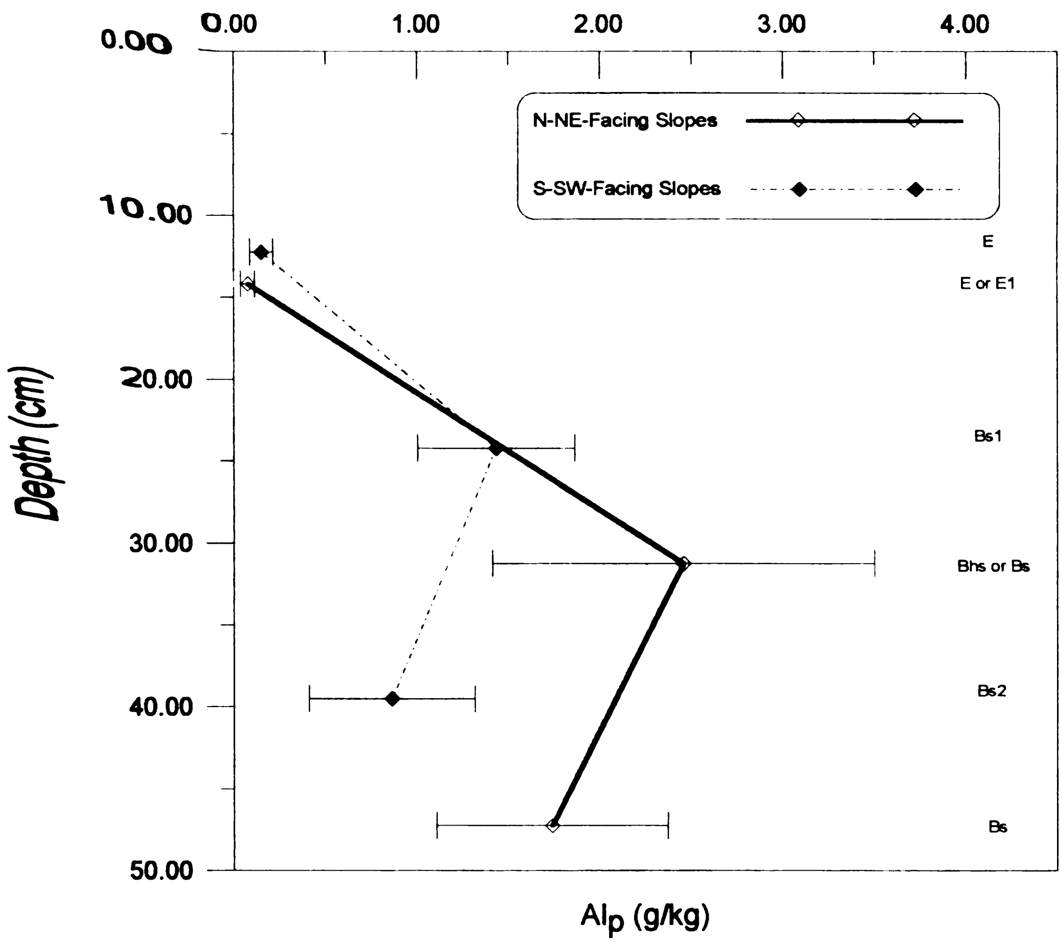

Figure 27. Mean Al_p depth plot for opposing aspects.

Table 15. Mean Fe_p and Al_p data and statistics (Wilcoxon 1949).

Soil characteristic	Mean value on: (st. dev.) N-NE slope	S-SE slope	Number of greater values on: N-NE slope	S-SE slope	Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
Fe_p, uppermost E horizon (g/kg)	0.1 (0.0)	0.2 (0.1)	2	8	0	0.014*	N-NE-facing slopes
Fe_p, uppermost B horizon (g/kg)	2.5 (1.5)	1.1 (0.5)	9	1	0	0.007**	N-NE-facing slopes
Fe_p, 2nd uppermost B horizon (g/kg)	1.1 (0.7)	0.6 (0.5)	6	4	0	0.030*	N-NE-facing slopes
Al_p, uppermost E horizon (g/kg)	0.1 (0.0)	0.2 (0.1)	0	10	0	0.003**	N-NE-facing slopes
Al_p, uppermost B horizon (g/kg)	2.5 (1.0)	1.4 (0.4)	8	2	0	0.014*	N-NE-facing slopes
Al_p, 2nd uppermost B horizon (g/kg)	1.7 (0.6)	0.9 (0.5)	9	1	0	0.003**	N-NE-facing slopes

* Significant at α=0.05 (Wilcoxon).   ** Significant at α=0.01 (Wilcoxon).

Table 16. Na pyrophosphate extraction data.

Sample	Fe	Al	Sample	Fe	Al
	----g/kg---			----g/kg---	
S1 E	0.14	0.21	N1 E	0.16	0.14
S1 Bs1	1.37	1.62	N1 Bs1	0.93	2.20
S1 Bs2	0.42	0.78	N1 Bs2	0.27	1.06
S2 E	0.12	0.15	N2 E	0.07	0.07
S2 Bs1	0.41	0.87	N2 Bs1	2.64	2.39
S2 Bs2	0.22	0.59	N2 Bs2	0.60	0.82
S3 E	0.06	0.11	N3 E	0.09	0.10
S3 Bs1	0.56	1.36	N3 Bs1	0.93	0.82
S3 Bs2	0.19	0.43	N3 Bs2	1.29	1.25
S4 E	0.17	0.12	N4 E	0.05	0.08
S4 Bs1	0.49	1.19	N4 Bs1	1.23	2.73
S4 Bs2	0.24	0.58	N4 Bs2	0.21	0.79
S5 E	0.09	0.13	N5 E	0.08	0.07
S5 Bs1	1.25	1.07	N5 Bhs	3.77	2.87
S5 Bs2	0.87	1.02	N5 Bs1	1.27	1.74
			N5 Bs2	0.70	0.79

Table 16. (cont'd.)

Sample	Fe	Al	Sample	Fe	Al
	----g/kg---			----g/kg---	
S6 E	0.05	0.08	N6 E1	0.03	0.03
S6 Bs1	0.83	1.22	N6 E2	0.03	0.05
S6 Bs2	0.23	0.46	N6 Bhs	2.48	4.25
			N6 Bs	0.53	1.68
S7 E	0.23	0.29	N7 E1	0.02	0.03
S7 Bs1	1.67	2.45	N7 E2	0.11	0.09
S7 Bs2	0.89	1.30	N7 Bs1	2.28	2.39
			N7 Bs2	1.07	1.43
S8 E	0.32	0.18	N8 E	0.03	0.04
S8 Bs1	1.04	1.43	N8 Bs1	3.25	2.28
S8 Bs2	0.53	1.03	N8 Bs2	1.67	2.50
S9 E	0.20	0.14	N9 E	0.09	0.13
S9 Bs1	0.97	1.52	N9 Bs1	3.95	2.93
S9 Bs2	0.29	0.57	N9 Bs2	1.13	1.86
S10 E	0.10	0.08	N10 E1	0.05	0.06
S10 Bs1	1.96	1.60	N10 E2	0.05	0.06
S10 Bs2	1.76	1.87	N10 Bs1	5.14	3.27
			N10 Bs2	1.29	2.68

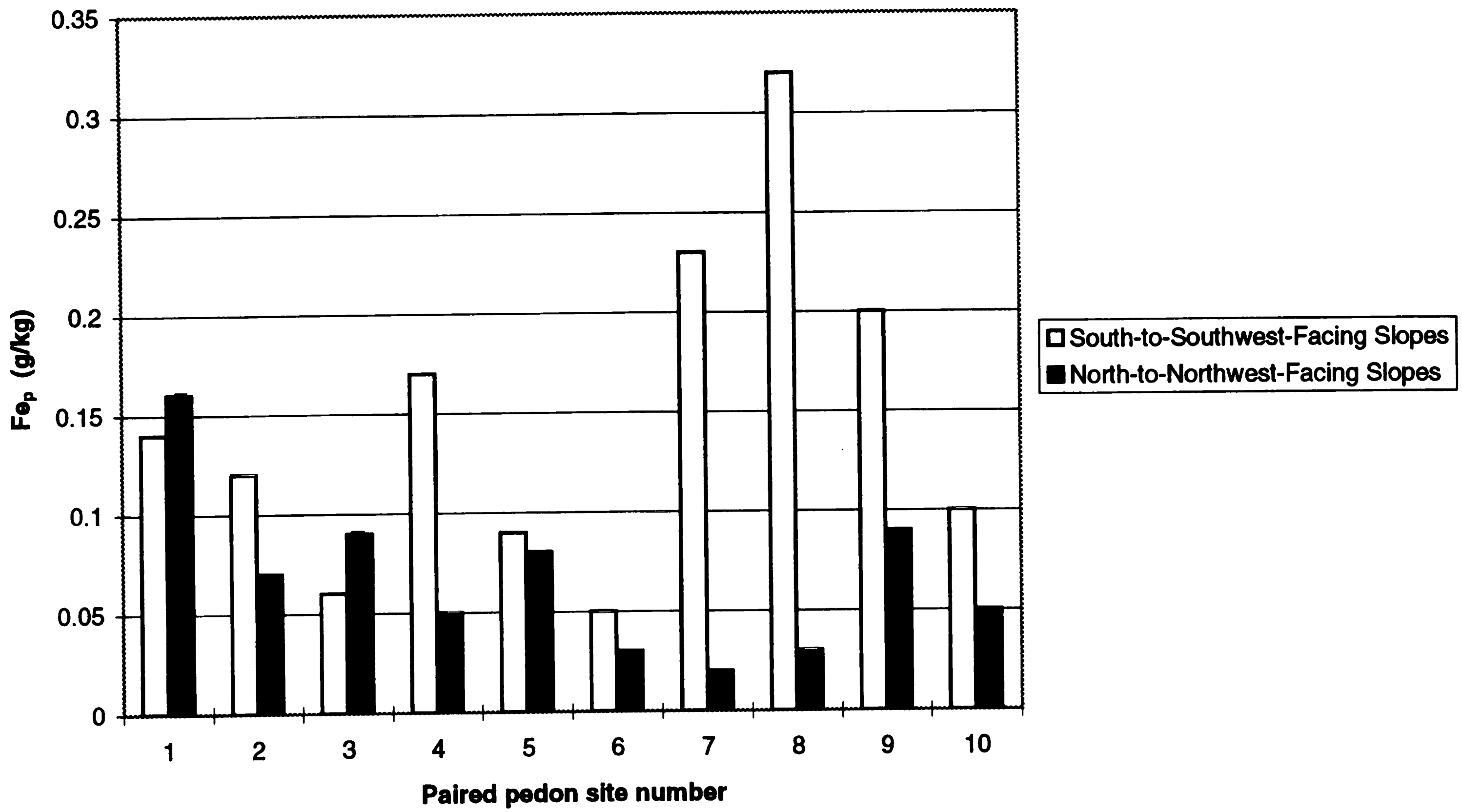

Figure 28. Fe_p of the uppermost E horizon on opposing aspects.

Higher amounts of moisture (in part, due to comparatively lower evaporative demand) on north-to-northeast-facing slopes would increase the infiltration of water and hence, also lead to greater translocation of Fe_p and Al_p (among other materials).

Uppermost B Horizon

The uppermost B horizons on north-to-northeast-facing slopes contained significantly more (Wilcoxon, at $\alpha = 0.01$) Fe_p than did those on south-to-southwest-facing slopes (Table 15, Figure 29). The mean amount of Fe_p in the uppermost B horizon on north-to-northeast-facing slopes was 2.46 ±1.5 g/kg soil whereas the mean Fe_p in the same horizon on south-to-southwest-facing slopes was less than half that (1.06 ±0.5 g/kg).

The uppermost B horizons on north-to-northeast-facing slopes contained significantly more (Wilcoxon, at $\alpha = 0.05$) Al_p than those on south-to-southwest-facing slopes (Table 15, Figure 30). The mean amount of Al_p in the uppermost B horizon on north-to-northeast-facing slopes was 2.46 ±1.0 g/kg soil whereas the Al_p in the same horizons on south-to-southwest-facing slopes was 1.43 ±0.4 g/kg.

Since greater amounts of Fe_p and Al_p were presumably eluviated from the E horizons of north-to-northeast-facing slopes (when compared to that of opposing slopes), then it is understandable that more Fe_p and Al_p would be illuviated on north-to-northeast-facing slopes most of which occurs in the uppermost B horizon. Concentrations of Fe and Al in the uppermost B horizons have been documented in several studies (Wang, et al. 1986, among others).

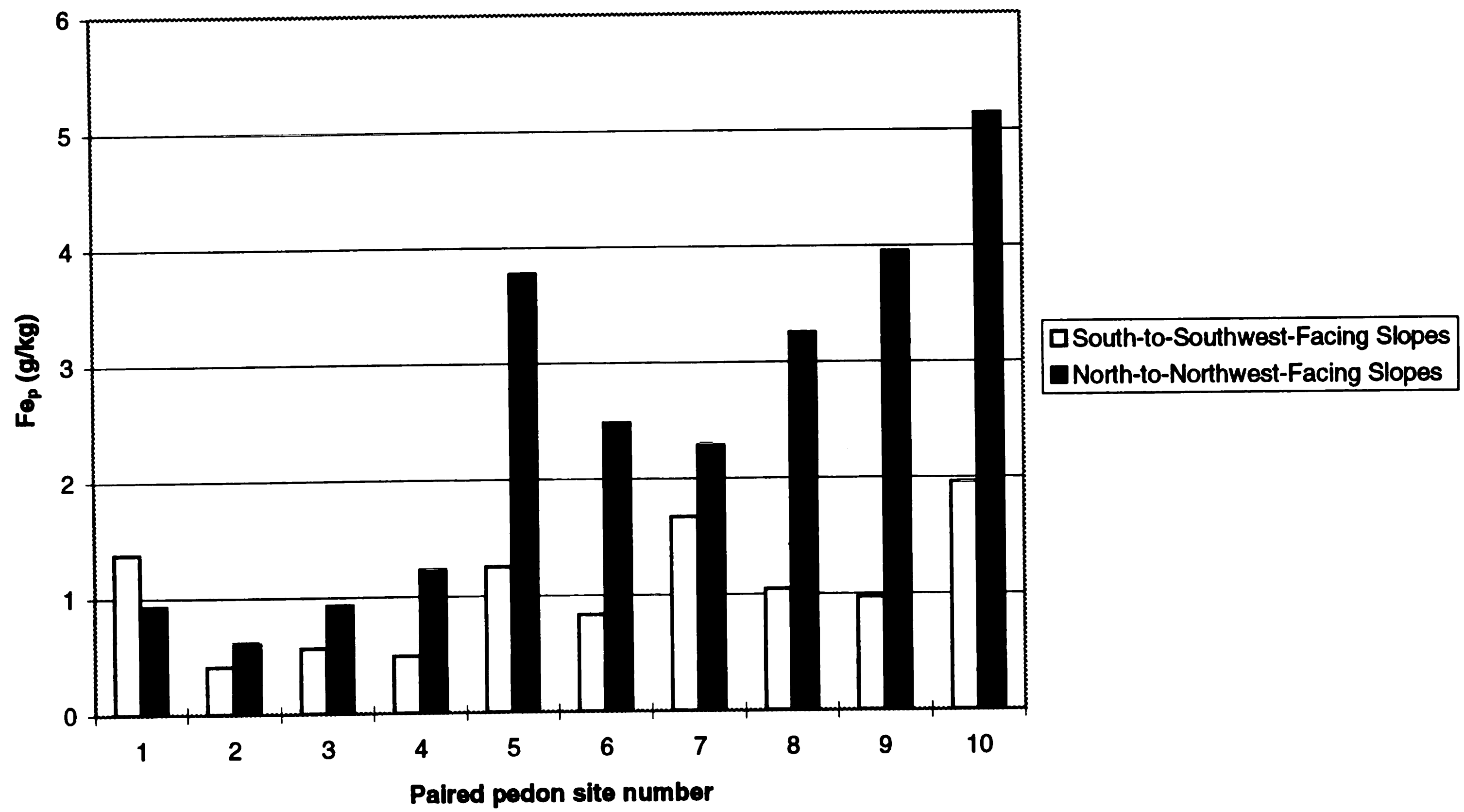

Figure 29. Fe_p of the uppermost B horizon on opposing aspects.

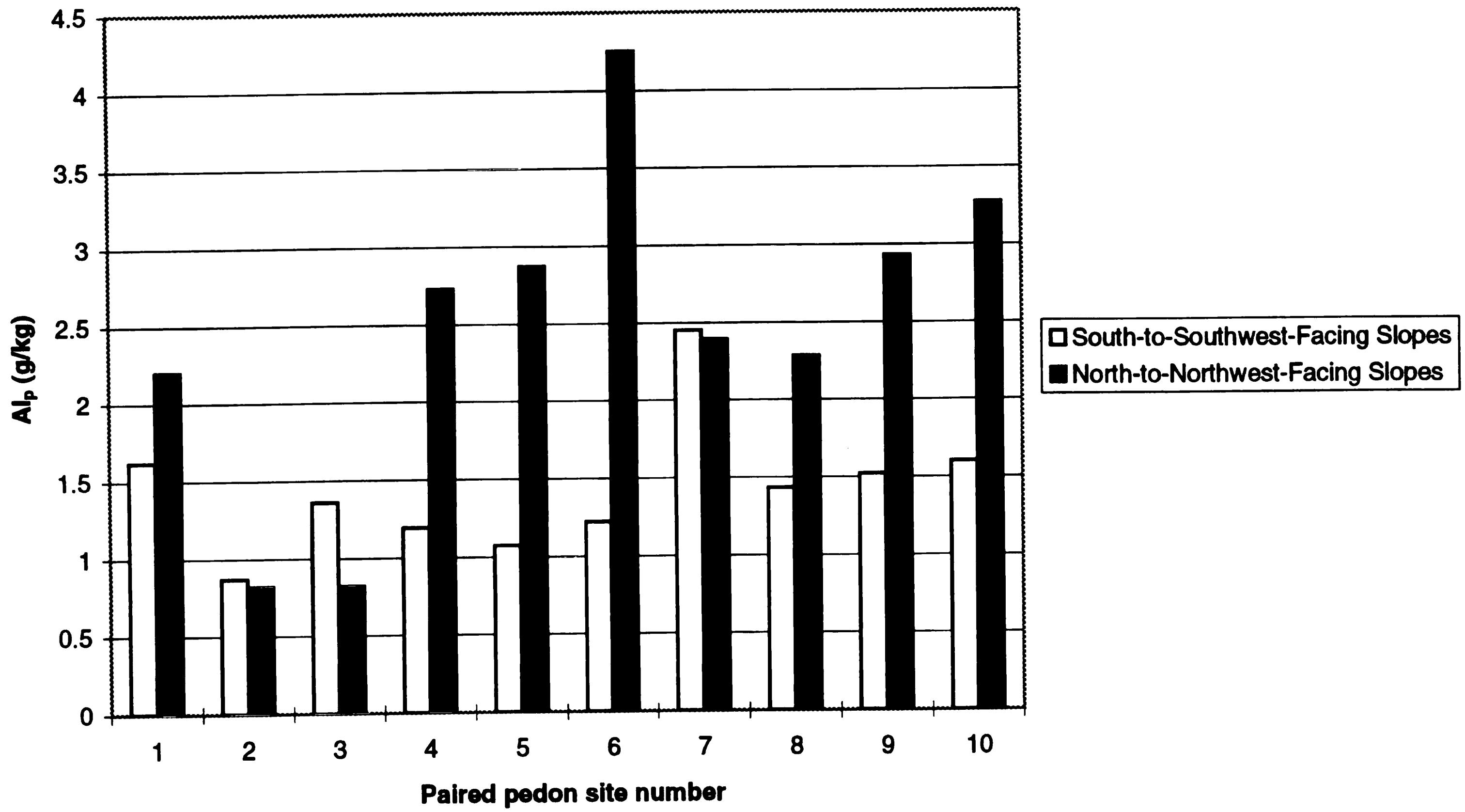

Figure 30. Al$_p$ of the uppermost B horizon on opposing aspects.

2nd Uppermost B Horizon

The 2nd uppermost B horizons on north-to-northeast-facing slopes contained significantly more (Wilcoxon, at $\alpha = 0.05$) Fe_p than did those on south-to-southwest-facing slopes (Table 15). The mean amount of Fe_p in the 2nd uppermost B horizons on north-to-northeast-facing slopes was 1.14 ±0.7 g/kg whereas the mean weight of Fe_p in the same horizons on south-to-southwest-facing slopes was 0.56 ±0.5 g/kg.

The 2nd uppermost B horizons on north-to-northeast-facing slopes also contained significantly more (Wilcoxon, at $\alpha = 0.05$) Al_p than those on south-to-southwest-facing slopes (Table 15). The mean weight of Al_p in the uppermost B horizons on north-to-northeast-facing slopes was 1.74 ±0.6 g/kg soil compared to 0.86 ±0.5 g/kg on south-to-southwest-facing slopes.

Ammonium Oxalate - Na Pyrophosphate
(Fe_o - Fe_p and Al_o - Al_p)

Since Fe_o and Al_o signify the presence of both organic- and inorganically-bound amorphous material and Fe_p and Al_p signify only organically-bound amorphous material, the difference between these corresponding values provides the weight of inorganically-bound amorphous Fe and Al (Fe_o - Fe_p and Al_o - Al_p respectively) (McKeague 1967, McKeague and Day 1966). By analyzing this difference, an estimation of the imogolite content of a soil can be obtained since imogolite is an amorphous inorganic compound. This gives us a look into the process of podzolization taking place within a soil.

Uppermost E Horizon

The E horizons of south-to-southwest-facing slopes contained more, but not significantly more (Wilcoxon, $p = 0.057$), Fe_o - Fe_p when compared to that of north-to-northeast-facing slopes (Table 17). Mean Fe_o - Fe_p in the E horizons of north-to-northeast-facing slopes was 0.1 ±0.1 g/kg soil whereas mean Fe_o - Fe_p on south-to-southwest-facing slopes was 0.3 ±0.2 g/kg.

The E horizons of south-to-southwest-facing slopes contained significantly more Al_o - Al_p (Wilcoxon at $\alpha = 0.01$) when compared to that of north-to-northeast-facing slopes (Table 18, Figure 31). Mean Al_o - Al_p in the E horizon of north-to-northeast-facing slopes was 0.1 ±0.1 g/kg soil whereas mean Al_o - Al_p on south-to-southwest-facing slopes was 0.3 ±0.2 g/kg.

Uppermost B Horizon

The uppermost B horizons did not exhibit any difference in Fe_o - Fe_p (Wilcoxon, at $\alpha = 0.05$) on opposing slopes (Table 17). Mean Fe_o - Fe_p in the uppermost B horizons of north-to-northeast-facing slopes was 2.4 ±1.5 g/kg soil whereas the mean Fe_o - Fe_p on south-to-southwest-facing slopes was 2.4 ±1.24 g/kg soil. Similarly, the uppermost B horizons did not exhibit any significant difference in Al_o - Al_p (Wilcoxon, at $\alpha = 0.05$) on opposing slopes (Table 18). Mean Al_o - Al_p in the uppermost B horizons of north-to-northeast-facing slopes was 2.1 ±2.1 g/kg soil whereas the mean Al_o - Al_p on south-to-southwest-facing slopes was 2.0 ±1.1 g/kg. This is an indication that similar amounts of imogolite have formed within the uppermost B horizons on opposing slopes.

Table 17. Mean Fe_o - Fe_p data and statistics (Wilcoxon 1949).

Soil characteristic	Mean value on: (st. dev.) N-NE slope	Mean value on: (st. dev.) S-SE slope	Number of greater values on: N-NE slope	Number of greater values on: S-SE slope	Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
Fe_o - Fe_p							
Uppermost E horizon (g/kg)	0.1 (0.1)	0.3 (0.2)	2	8	0	0.057	(not significantly different)
Uppermost B horizon (g/kg)	2.4 (1.5)	2.4 (1.2)	5	5	0	0.400	(not significantly different)
2nd uppermost B horizon (g/kg)	1.3 (0.7)	1.3 (0.6)	7	3	0	0.230	(not significantly different)

Table 18. Mean Al_o - Al_p data and statistics (Wilcoxon 1949).

Soil characteristic	Mean value on: (st. dev.) N-NE slope	Mean value on: (st. dev.) S-SE slope	Number of greater values on: N-NE slope	Number of greater values on: S-SE slope	Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
Al_o - Al_p							
Uppermost E horizon (g/kg)	0.1 (0.1)	0.2 (0.1)	1	9	0	0.005 **	N-NE-facing slopes
Uppermost B horizon (g/kg)	2.1 (2.1)	2.0 (1.1)	6	4	0	0.480	(not significantly different)
2nd uppermost B horizon (g/kg)	2.0 (1.3)	1.3 (0.7)	9	1	0	0.019 *	N-NE-facing slopes

* Significant at α=0.05 (Wilcoxon). ** Significant at α=0.01 (Wilcoxon).

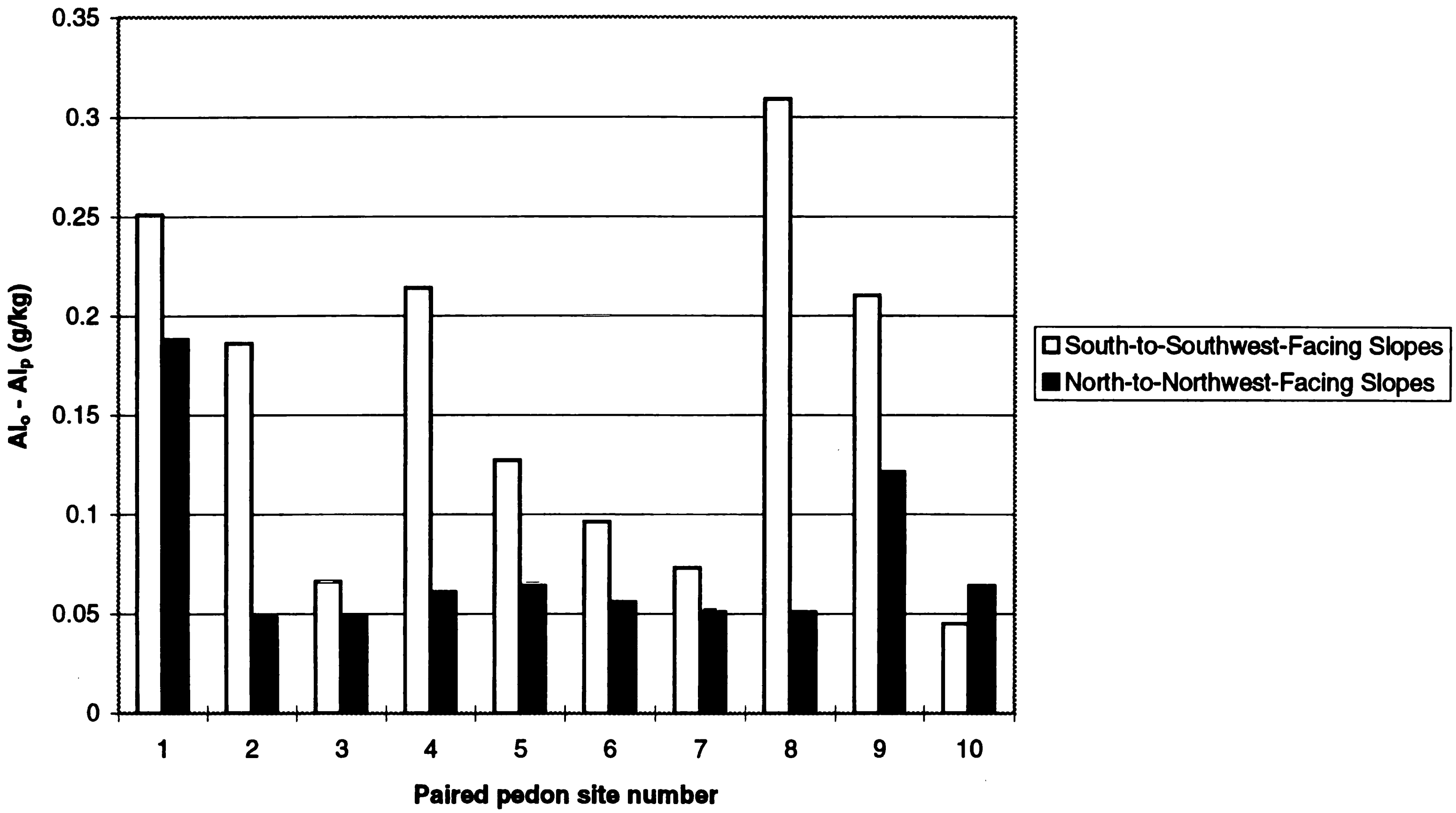

Figure 31. Al_o - Al_p of the uppermost E horizon on opposing aspects.

<u>2nd Uppermost B Horizon</u>

The 2nd uppermost B horizons did not exhibit any difference in Fe_o - Fe_p (Wilcoxon, at $\alpha = 0.05$) on opposing slopes (Table 17). Mean Fe_o - Fe_p in the 2nd uppermost B horizons of north-to-northeast-facing slopes was 1.3 ±0.7 g/kg soil whereas the mean Fe_o - Fe_p on south-to-southwest-facing slopes was 1.3 ±0.6 g/kg.

The 2nd uppermost B horizons of north-to-northeast-facing slopes did contain significantly more Al_o - Al_p (Wilcoxon at $\alpha = 0.05$) when compared to that of south-to-southwest-facing slopes (Table 18). Mean Al_o - Al_p in the 2nd uppermost B horizons of north-to-northeast-facing slopes was 2.0 ±1.3 g/kg soil whereas mean Al_o - Al_p on south-to-southwest-facing slopes was 1.3 ±0.7 g/kg.

Snowpack Thickness

Variable depths of snowpack were observed on opposing slopes on April 26 and November 5, 1995. Photographic documentation of differential snowpack thicknesses on opposing slopes on April 26, 1995 is shown in Figure 32. On November 4, 1995, up to 20 cm of snow had fallen in the early morning on portions of the study area. Lesser amounts of snow had fallen in the northeast part of the study area. Sunny weather late in the afternoon on the 4th and throughout the morning of the 5th produced differential snowmelt on opposing slopes (Figure 33). Statistical analysis of snowpack depths indicates significantly deeper (Wilcoxon, at $\alpha = 0.01$) snowpacks on north-to-northeast-facing slopes when compared to that of opposing slopes (Table 19). Average snowpack depth on north-to-northeast-facing slopes was 14.4 ±5.8 cm whereas average snowpack

North **South**

Figure 32. Variable depths of snowpack on opposing aspects (April 26, 1995).

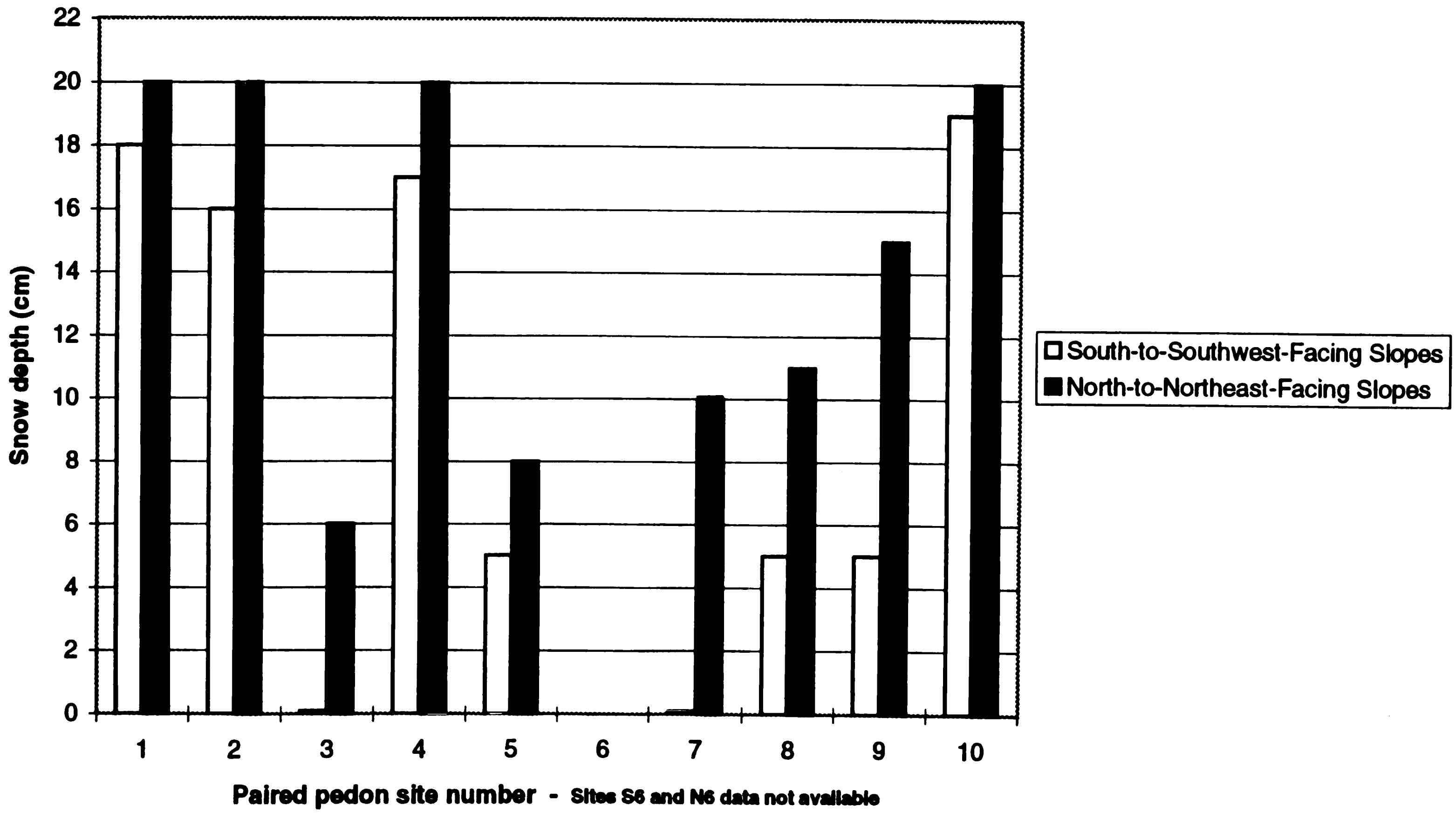

Figure 33. Snowpack depth data on opposing aspects (November 5, 1995).

Table 19. Mean snowpack depth data and statistics (Wilcoxon 1949).

Snowpack depth	Mean value on: (st. dev.)		Number of greater values on:		Equal values	Significance (two-tail)	Indicates or promotes stronger podzolization on:
	N-NE slope	S-SE slope	N-NE slope	S-SE slope			
	--------- cm ---------						
April 26, 1995	*	*	*	*	*	*	N-NE-facing slopes
November 5, 1995	14.4 (5.8)	9.4 (7.9)	9	0	0	0.004 **	N-NE-facing slopes
January 20, 1996	20.9 (4.6)	22.9 (1.5)	2	3	0	NA ***	(not significantly different)

* Significant at α=0.05 (Wilcoxon).

** Significant at α=0.01 (Wilcoxon).

*** NA = not applicable; Wilcoxon analysis does not accomodate a population size < 7.

depth on south-to-southwest-facing slopes was 9.4 ±7.9 cm.

Snowpacks can affect pedogenesis and podzolization in at least two ways:

1) thicker snow covers help to insulate the soil and can inhibit freezing of the soil (Hart and Lull 1963, Isard and Schaetzl 1993, 1995). On unfrozen soil, percolation of water is less impeded, thus, allowing pedogenic processes to occur uninterrupted. In the current study, soils on north-to-northeast-facing slopes may, indeed, remain above freezing throughout the year due to sufficient snow cover in winter. However, winter soil temperature data are not yet available.

2) snow melts more gradually on north-to-northeast-facing slopes which may allow meltwater to better infiltrate the soil. Snowmelt infiltration has been implicated as an important vector in the podzolization process (Schaetzl and Isard 1990, 1991). Comparatively rapid snowmelt may occur on south-to-southwest-facing slopes, possibly producing runoff which may erode the soil surface. Water running over the surface may also mean that, in general, less water is available for infiltration and this would result in less material moving through the solum on these slopes when compared to that of north-to-northeast-facing slopes.

Soil Classification

Classification of the pedons in this study was performed according to the Keys to Soil Taxonomy (Soil Survey Staff 1994). These data help to further demonstrate the disproportional development of soils on opposing slopes within the study area (Table 20). Based on color, morphology and/or chemical criteria (ODOE or Fe_o and Al_o), nine out of ten pedons located on north-to-northeast-facing slopes classified as Spodosols (eight Entic

Table 20. Soil classification[1] and the presence or absence of Albic and Spodic horizons.

Pedon	Albic horizon? (Y/N)	Spodic horizon? (Y/N)	Subgroup Classification
N1	Yes	Yes	Entic Haplorthod
N2	Yes	No	Typic Udorthent
N3	Yes	Yes	Entic Haplorthod
N4	Yes	Yes	Entic Haplorthod
N5	Yes	Yes	Typic Haplorthod
N6	Yes	Yes	Entic Haplorthod
N7	Yes	Yes	Entic Haplorthod
N8	Yes	Yes	Entic Haplorthod
N9	Yes	Yes	Entic Haplorthod
N10	Yes	Yes	Entic Haplorthod
S1	Yes	No	Typic Udorthent
S2	Yes	Yes	Entic Haplorthod
S3	Yes	No	Typic Udorthent
S4	Yes	No	Spodic Udipsamment
S5	Yes	No	Typic Udorthent
S6	Yes	No	Typic Udipsamment
S7	Yes	No	Typic Udorthent
S8	Yes	No	Typic Udorthent
S9	Yes	Yes	Entic Haplorthod
S10	Yes	Yes	Entic Haplorthod

1 According to Soil Survey Staff 1994.

Haplorthods; one Typic Haplorthod) and the remaining pedon (site N2) classified as Typic Udorthent. Only three out of 10 pedons located on south-to-southwest-facing slopes classified as Spodosols; all were Entic Haplorthods. The remaining seven pedons classified as Entisols (five Typic Udorthents; one Spodic Udipsamment; one Typic Udipsamment). The greater number of Spodosols existing on north-to-northeast-facing slopes when compared to that of south-to-southwest-facing slopes seems to imply (once again) that greater Spodic development, in general, has taken place on north-to-northeast-facing slopes.

Podzolization in the Study Area

Since the soils of north-to-northeast-facing slopes appear to have undergone more podzolization than those of south-to-southwest-facing slopes, it seems appropriate to examine the factors most responsible for the mobilization of Fe and Al and the subsequent immobilization of the resultant chelated organo-metallic complexes. Earlier (p.3), the podzolization process was described in four steps. The following is a re-examination of each step in this podzolization process with regard to the results of the current study:

1. **Accumulation of organic matter on the ground surface**.

The O horizons in the study area appear to have been disturbed in some areas (perhaps by fire shortly after logging) since their areal coverage is often thin and sometimes intermittent. Podzolization could not have taken place without an O horizon, suggesting that the current status of this layer is not reminiscent of the past and, therefore, must have been disturbed. In order to assess the quality of organic matter that existed before logging, the vegetation must also be examined. However, it is difficult to know exactly what types of vegetation persisted for the longest period of time on each of the opposing slopes. Present-day vegetation gives clues to the past, but cannot be utilized with much reliability. As has been stated, the General Land Office survey notes from the 19th century do not provide enough detail to determine vegetation patterns from slope to slope. Therefore, assumptions about the organic matter (O horizon) prior to logging must be made using clues from the present.

Higher soil temperatures persist on south-to-southwest-facing slopes. Thus, it seems probable that drying of the O horizon was able to take place more often (between warm season precipitation events) on these slopes than on north-to-northeast-facing slopes. With a higher frequency of wet-dry cycles and with greater soil temperatures, the organic matter could decompose more rapidly than if it simply remained moist. Thus, the quality of the organic matter and its ability to chelate with Fe and Al would be reduced on south-to-southwest-facing slopes, therefore producing thinner sola with less Fe and Al present in the B horizon when compared to that of north-to-northeast-facing slopes.

With fewer wet-dry cycles on north-to-northeast-facing slopes, the O horizon acts as a moist sponge that protects the soil from fire. This "sponge" could inhibit (or even prevent) the destruction of the O horizon by fire. Such destruction would, thus, be more likely on south-to-southwest-facing slopes where its destruction would interrupt the podzolization process due to a lack of available chelating organic material. Therefore, the total amount of podzolization having taken place over time would be less on south-to-southwest-facing slopes. Soils in the present study indicate that less podzolization has taken place on south-to-southwest-facing slopes, and thus are in agreement with the assumptions listed above.

Fire has adversely affected soil development on the Baraga Plains (Schaetzl 1990). The soils currently present on the Baraga Plains (the dissected edge of the Baraga Plains delimits the study area) are even less developed than soils found in the study area. This seems counterintuitive since the Baraga Plains were deposited in the same glacial event as that of the study area and the topography is also relatively flat compared to the steep slopes of the study area. Jenny (1941) suggested that slope gradient inversely affects soil development. In most cases this is true. However, on the Baraga Plains, fire has probably retarded the podzolization process since the O horizon has been frequently burned, thus limiting the chelation of humus with Fe and Al (Mokma and Vance 1989). Soils in the study area probably have better protection against fire than those of the Baraga Plains due to greater topographic relief. But even within the study area, soils on north-to-northeast-facing slopes have probably had better protection against fire than those on opposing slopes due to greater moisture contained in the O horizon of north-to-northeast-facing slopes.

2. **Leaching and acidification of the parent material.**

The results of the present study do not seem to indicate any major differences in soil reaction (either KCl or H_2O) between corresponding horizons on opposing slopes. The pH of the C horizons are nearly identical on opposing slopes. However, solum depths and corresponding horizon thicknesses may, in fact, be a result of variable depths of leaching (see #4 below).

More acidic organic litter could accelerate chelation and translocation processes, thus lowering pH at greater depth and allowing further podzolization to take place (Figure 34). For instance, if hemlock (*Tsuga canadensis* (L.) Carr.) had persisted more (in the past) on north-to-northeast-facing slopes than on opposing slopes, its acidic leaf litter could have accelerated the podzolization process.

Available water within the soil could also affect soil reaction over time (Figure 34). Since south-to-southwest-facing slopes exhibited greater summer soil temperatures (at 50cm) than that of opposing slopes, more water is probably evaporated through the surface of the soil or is transpired through the vegetation on south-to-southwest-facing slopes. This means that less water is available for infiltration and hence, for leaching (Figure 34). Therefore, the intensity of leaching that has occurred at depth on south-to-southwest-facing slopes may be diminished when compared to that of opposing slopes.

3. **Weathering of Fe and Al; decomposition of organic material.**

Since water is a necessary component of chemical weathering, and since more water (and organic material) probably has been available in the soil of north-to-northeast-facing slopes, then it is likely that more Fe and Al would have been weathered in the soils of north-to-northeast-facing slopes. Thus, more of the basic ingredients of organo-metallic complexes would have been provided.

Higher soil temperatures persist on south-to-southwest-facing slopes. Thus, it seems probable that drying of the O horizon was able to take place more often (between warm season precipitation events) on these slopes than on north-to-northeast-facing slopes. With a higher frequency of wet-dry cycles and with greater soil temperatures, the organic matter could decompose more rapidly than if it simply remained moist. Thus, the

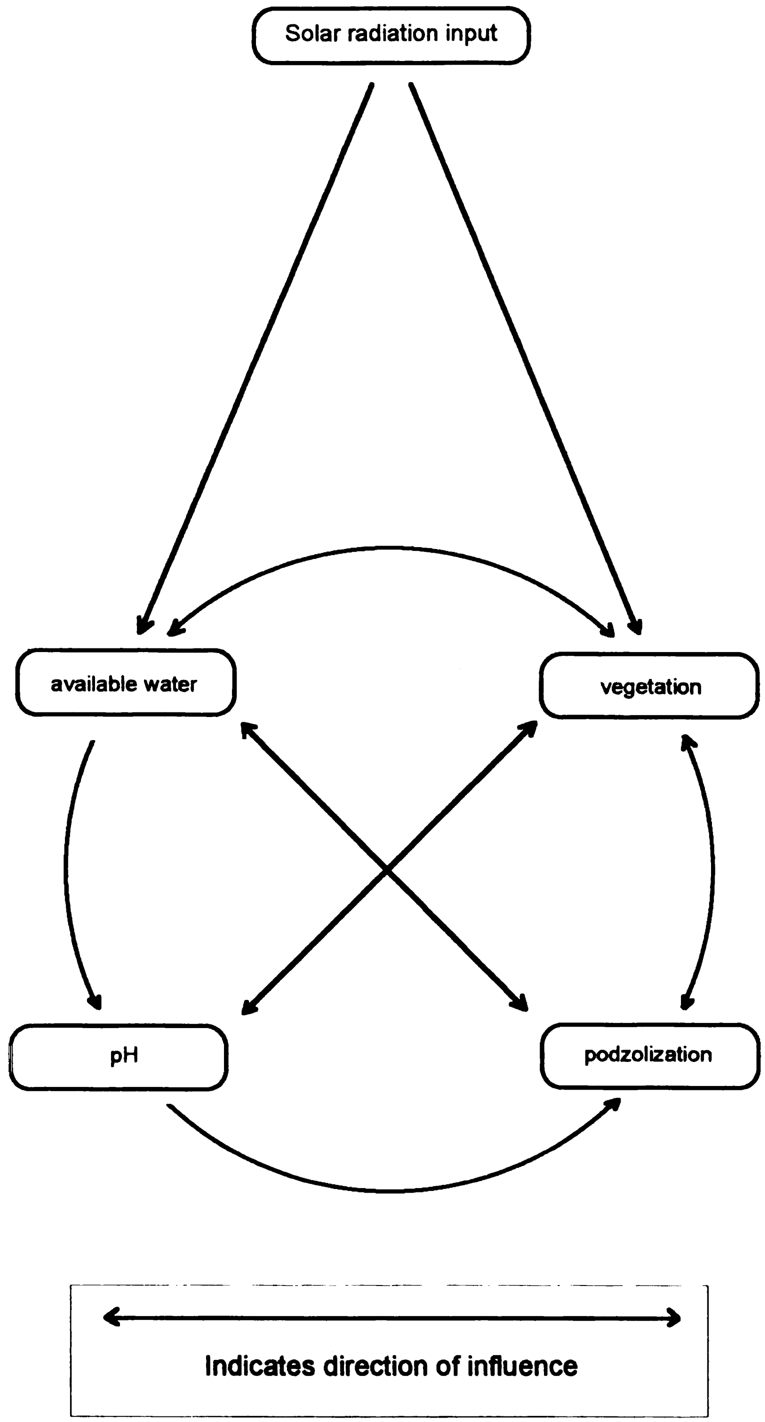

Figure 34. Podzolization feedback flow chart.

quality of the organic matter and its ability to chelate with Fe and Al would be reduced on south-to-southwest-facing slopes, therefore producing thinner sola with less Fe and Al present in the B horizon when compared to that of north-to-northeast-facing slopes.

4. **Translocation and subsequent immobilization of organic matter, Fe and Al (as organo-metallic complexes).**

As organo-metallic complexes migrate downward, they may adsorb additional Fe and Al. Organo-metallic chelates can be immobilized in one of three ways: adsorption of sufficient Fe and Al, forming a large immobile organo-metallic compound; dessication of the chelate compound; and/or an encounter of the chelate compound with a horizon of different (usually higher) pH (Mokma and Buurman 1982). There is no reason to think that immobilization processes are different on opposing slopes. The saturation of chelate complexes probably occurs in all soils sampled in this study. Therefore, reasons for immobilization of the chelate compound within the study area probably involve either available water for translocation (thus affecting dessication rates) and/or high pH (a function of vegetation and available water for infiltration as dictated by solar radiation input (Figure 34)).

Summary and Conclusions

1. Soil temperatures at 50cm in May, July and September were significantly warmer on south-to-southwest-facing slopes ($\alpha = 0.01$), however, soil temperatures in November were not significantly different on opposing slopes ($\alpha = 0.05$).

2. Whereas depths to the top of the E horizons were not significantly different on opposing slopes ($\alpha = 0.05$), E horizon thicknesses were significantly greater on north-to-northeast-facing slopes ($\alpha = 0.05$).

3. Depths to the top of the B horizons were significantly greater on north-to-northeast-facing slopes ($\alpha = 0.05$), but B horizon thicknesses were not significantly different on

opposing slopes (at $\alpha = 0.05$).

4. Solum thicknesses were significantly greater on north-to-northeast-facing slopes ($\alpha = 0.05$).

5. POD Indices were significantly greater on north-to-northeast-facing slopes ($\alpha = 0.01$).

6. Soil color:

   a. The hues, values and chromas of the uppermost E horizons were not significantly different on opposing slopes ($\alpha = 0.05$).

   b. Hues of the uppermost B horizons were significantly redder on north-to-northeast-facing slopes ($\alpha = 0.05$).

   c. Both soil color values and chromas of the uppermost B horizons were significantly less on north-to-northeast-facing slopes ($\alpha = 0.01$).

7. Reaction:

   a. Soil:KCl reactions (1:1) were significantly different in only two horizons; the uppermost E horizons exhibited significantly greater acidity on north-to-northeast-facing slopes ($\alpha = 0.01$) as did the uppermost B horizons ($\alpha = 0.05$).

   b. Soil:H_2O reactions (1:1) were not significantly different on opposing slopes in any horizon ($\alpha = 0.05$).

8. Optical density of the oxalate extract:

   a. The ODOE values for the uppermost E horizons were significantly greater on south-to-southwest-facing slopes ($\alpha = 0.01$).

   b. The ODOE values for the uppermost B horizons were significantly greater on north-to-northeast-facing slopes ($\alpha = 0.01$). The ODOE values for the 2nd uppermost B horizons were not significantly different on opposing slopes ($\alpha = 0.01$).

   c. The B horizon ODOE ÷ E horizon ODOE ratio was significantly greater for horizons on north-to-northeast-facing slopes ($\alpha = 0.01$).

9. Snowpack thicknesses (November 5, 1995) were significantly greater on north-to-

northeast-facing slopes ($\alpha = 0.01$).

10. Acid Ammonium Oxalate Extractions:

    a. The uppermost E horizons on north-to-northeast-facing slopes contained significantly less Fe_o ($\alpha = 0.05$) and Al_o ($\alpha = 0.01$).

    b. The uppermost B horizon on north-to-northeast-facing slopes contained significantly more Fe_o ($\alpha = 0.05$).

    c. The 2nd uppermost B horizons on north-to-northeast-facing slopes contained significantly more Al_o ($\alpha = 0.05$).

Within the study area, nearly uniform parent material, slope gradient and macroclimate has ultimately led to the formation of vastly different soils. Soils on north-to-northeast-facing slopes were more strongly developed (i.e., had greater podzolization) than soils on south-to-southwest-facing slopes. Morphological characteristics such as soil color, horizon thickness, solum thickness and POD Index suggest, unequivocally, that maximal pedogenic activity has taken place on north-to-northeast-facing slopes when compared to that of opposing slopes. Chemical characteristics such as Fe and Al data and ODOE provide further evidence that soils on north-to-northeast-facing slopes are more intensely developed than those of south-to-southwest-facing slopes.

Suggestions for Further Research

Supplementary investigative studies on the topic of Spodosol development as affected by geomorphic aspect could be approached in the following ways:

1) Further sampling of the study area could be performed utilizing the same site selection criteria outlined in this study, thus, simply enlarging the sample size.

2) A similar study could be performed in an area outside of Michigan where Spodosols exist on steep slopes.

3) Within the same study area, more extensive sampling of individual hillslopes could be accomplished by systematically sampling transects from the ridge crest to the valley floor in order to observe any topographic influences on Spodosol development.

4) Detailed studies of microclimatological data could be executed on these or other steeply sloping sites where Spodosols exist.

5) A similar study of Spodosols could be performed on slopes that are less steep.

6) The same study could easily be performed on various aspect ranges within the same study area.

7) A more complete inventory of the vegetation in the study area could be documented.

8) Statistical analyses could be altered so that samples in the current study were paired differently or not at all.

9) Soil moisture data could be collected at or near sampled pedons.

APPENDIX A

APPENDIX A

Site name: S1 Location: T50N, R34W, sec. 31, SE 1/4, SE 1/4, NE 1/4

Slope gradient = 52 %. Aspect = S 30 W

Slope length = 20 m. Erosion: Slight

Site position on slope = 60 % of distance from base.

Evidence for tree uprooting at site: Moderate treethrow.

Overstory vegetation at site:

white birch	*Betula papyrifera* Marsh.
white pine	*Pinus strobus* L.
balsam fir	*Abies balsamea* (L.) Mill.
red pine	*Pinus resinosa* Ait.
hemlock	*Tsuga canadensis* (L.) Carr.

<u>**Soil Temperatures**</u> (°C at 50cm)

May 17, 1995	=	8.1
July 25, 1995	=	15.6
September 17, 1995	=	13.3
November 5, 1995	=	4.3
January 20, 1996	=	nd[1].

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1 Not determined.

Site name: N1 Location: T50N, R34W, sec. 31, SE 1/4, SE 1/4, NE 1/4

Slope gradient = 66 %. Aspect = N 15 E

Slope length = 45 m. Erosion: No

Site position on slope = 50 % of distance from base.

Evidence for tree uprooting at site: No.

Overstory vegetation at site:

hemlock	*Tsuga canadensis* (L.) Carr.
white birch	*Betula papyrifera* Marsh.
red maple	*Acer rubrum* L.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	5.3
July 25, 1995	=	14.3
September 17, 1995	=	12.1
November 5, 1995	=	4.5
January 20, 1996	=	nd.

Site name: S2 Location: T50N, R34W, sec. 31, NE 1/4, SW 1/4, NW 1/4

Slope gradient = 65 %. Aspect = S 40 W

Slope length = 100 m. Erosion: Moderate

Site position on slope = 30 % of distance from base: shoulder = 50 % of total slope.

Evidence for tree uprooting at site: Some treethrow.

Notes: No A horizon sample.

Overstory vegetation at site:

white birch	*Betula papyrifera* Marsh.
aspen	*Populus* spp.
white pine	*Pinus strobus* L.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	7.9
July 25, 1995	=	15.7
September 17, 1995	=	13.6
November 5, 1995	=	6.1
January 20, 1996	=	nd.

Site name: N2 Location: T50N, R34W, sec. 31, NW 1/4, SE 1/4, NW 1/4

Slope gradient = 64 %. Aspect = N 45 E

Slope length = 20 m. Erosion: No

Site position on slope = 50 % of distance from base.

Evidence for tree uprooting at site: A few large-size treethrow.

Notes: BC has a few very thin lamellae (< 2mm each). No lamellae in 2C.

Overstory vegetation at site:

yellow birch	*Betula alleghaniensis* Britton.
white birch	*Betula papyrifera* Marsh.
red maple	*Acer rubrum* L.
hemlock[1]	*Tsuga canadensis* (L.) Carr.
white pine[2]	*Pinus strobus* L.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	5.9
July 25, 1995	=	14.5
September 17, 1995	=	12.8
November 5, 1995	=	5.9
January 20, 1996	=	nd.

1. All specimens ≤ 2 m tall.
2. Located on shoulder slope only.

Site name: S3 Location: T50N, R34W, sec. 14, SE 1/4, NE 1/4, SW 1/4

Slope gradient = 67 %. Aspect = S 13 W

Slope length = 110 m. Erosion: Slight

Site position on slope = 70 % of distance from base.

Evidence for tree uprooting at site: A few large-size treethrow.

Overstory vegetation at site:

aspen	*Populus* spp.
white birch	*Betula papyrifera* Marsh.
red maple	*Acer rubrum* L.
spruce[1]	*Picea* spp.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	8.8
July 25, 1995	=	16.8
September 17, 1995	=	14.8
November 5, 1995	=	5.3
January 20, 1996	=	2.3

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1. All specimens ≤ 2 m tall.

Site name: N3 Location: T50N, R34W, sec. 14, SW 1/4, SE 1/4, SE 1/4

Slope gradient = 66 %. Aspect = N 0 E

Slope length = 60 m. Erosion: No

Site position on slope = 65 % of distance from base.

Evidence for tree uprooting at site: Common treethrow.

Overstory vegetation at site:

red oak	*Quercus rubra* L.
red maple	*Acer rubrum* L.
white birch	*Betula papyrifera* Marsh.
aspen	*Populus* spp

<u>Soil Temperatures</u> (°C at 50cm)

May 17, 1995	=	5.5
July 25, 1995	=	14.0
September 17, 1995	=	12.6
November 5, 1995	=	6.0
January 20, 1996	=	1.2

Site name: S4 Location: T50N, R34W, sec. 31, NE 1/4, SW 1/4, NE 1/4

Slope gradient = 63 %. Aspect = S 30 W

Slope length = 80 m. Erosion: No

Site position on slope = 65 % of distance from base.

Evidence for tree uprooting at site: Slight treethrow.

Overstory vegetation at site:

aspen	*Populus* spp.
white birch	*Betula papyrifera* Marsh.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	7.9
July 25, 1995	=	16.2
September 17, 1995	=	14.3
November 5, 1995	=	4.9
January 20, 1996	=	nd

Site name: N4 Location: T50N, R34W, sec. 31, NE 1/4, SW 1/4, NE 1/4

Slope gradient = 65 %. Aspect = N 15 E

Slope length = 60 m. Erosion: No

Site position on slope = 65 % of distance from base.

Evidence for tree uprooting at site: Slight treethrow.

Notes: No lamellae. Site = cut over; open & sunny.

Overstory vegetation at site:

aspen	*Populus* spp.
white birch	*Betula papyrifera* Marsh.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	5.9
July 25, 1995	=	14.8
September 17, 1995	=	12.7
November 5, 1995	=	4.4
January 20, 1996	=	nd

Site name: S5 Location: T50N, R34W, sec. 22, SW 1/4, SE 1/4, SW 1/4

Slope gradient = 61 %. Aspect = S 14 W

Slope length = 80 m. Erosion: Slight

Site position on slope = 50 % of distance from base.

Evidence for tree uprooting at site: Some treethrow.

Notes: No A horizon sample.

Overstory vegetation at site:

aspen	*Populus* spp.
white birch	*Betula papyrifera* Marsh.
white pine	*Pinus strobus* L.
hemlock[1]	*Tsuga canadensis* (L.) Carr

Soil Temperatures (°C at 50cm)

May 17, 1995	=	8.4
July 25, 1995	=	16.7
September 17, 1995	=	nd
November 5, 1995	=	5.5
January 20, 1996	=	2.5

---

1. All specimens ≤ 2 m tall.

Site name: N5 Location: T50N, R34W, sec. 22, SW 1/4, SE 1/4, SW 1/4

Slope gradient = 61 %. Aspect = N 14 E

Slope length = 80 m. Erosion: No

Site position on slope = 50 % of distance from base.

Evidence for tree uprooting at site: Moderate treethrow.

Notes: BC has some Bsm material (20%). Profile described by RJS only.

Overstory vegetation at site:

hemlock	*Tsuga canadensis* (L.) Carr.
yellow birch	*Betula alleghaniensis* Britton.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	3.4
July 25, 1995	=	13.1
September 17, 1995	=	11.8
November 5, 1995	=	4.5
January 20, 1996	=	1.4

Site name: S6 Location: T50N, R34W, sec. 28, NW 1/4, SE 1/4, NW 1/4

Slope gradient = 61 %. Aspect = S 17 W

Slope length = 60 m. Erosion: Slight

Site position on slope = 45 % of distance from base.

Evidence for tree uprooting at site: Some treethrow, but not evident near site.

Overstory vegetation at site:

white birch	*Betula papyrifera* Marsh.
aspen	*Populus* spp.
white pine	*Pinus strobus* L.
red maple	*Acer rubrum* L.
red oak	*Quercus* rubra *L.*

Soil Temperatures (°C at 50cm)

May 17, 1995	=	8.1
July 25, 1995	=	15.4
September 17, 1995	=	14.3
November 5, 1995	=	nd
January 20, 1996	=	nd

Site name: N6 Location: T50N, R34W, sec. 28, NW 1/4, SE 1/4, SE 1/4

Slope gradient = 45 %. Aspect = N 8 E

Slope length = 85 m. Erosion: No

Site position on slope = 30 % of distance from base.

Evidence for tree uprooting at site: Common, medium-size treethrow.

Overstory vegetation at site:

hemlock	*Tsuga canadensis* (L.) Carr.
white birch	*Betula papyrifera* Marsh.

Soil Temperatures (°C at 50cm)

May 17, 1995 = 4.3

July 25, 1995 = 12.6

September 17, 1995 = 11.8

November 5, 1995 = nd

January 20, 1996 = nd

Site name: S7 Location: T50N, R34W, sec. 23, NW 1/4, NE 1/4, SW 1/4

Slope gradient = 66 %. Aspect = S 18 W

Slope length = 120 m. Erosion: Intermittent O horizon (see notes below).

Site position on slope = 30 % of distance from base: shoulder = 50% of slope.

Evidence for tree uprooting at site: Common treethrow.

Notes: Intermittent O horizon-- one third of surface is bare with A horizon exposed.

Overstory vegetation at site:

white birch	*Betula papyrifera* Marsh.
aspen	*Populus* spp.
red maple	*Acer rubrum* L.
balsam fir[1]	*Abies balsamea* (L.) Mill.

<u>**Soil Temperatures**</u> (°C at 50cm)

May 17, 1995	=	9.0
July 25, 1995	=	16.1
September 17, 1995	=	13.7
November 5, 1995	=	4.9
January 20, 1996	=	1.5

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1. All specimens ≤ 5 m tall.

Site name: N7 Location: T50N, R34W, sec. 23, NE 1/4, SW 1/4, NW 1/4

Slope gradient = 67 %. Aspect = N 35 E

Slope length = 100 m. Erosion: No

Site position on slope = 60 % of distance from base.

Evidence for tree uprooting at site: Some treethrow.

Overstory vegetation at site:

white birch	*Betula papyrifera* Marsh.
red maple	*Acer rubrum* L.
aspen	*Populus* spp.
sugar maple	*Acer saccharum* Marsh.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	5.3
July 25, 1995	=	13.6
September 17, 1995	=	12.3
November 5, 1995	=	5.9
January 20, 1996	=	3.9

Site name: S8 Location: T50N, R34W, sec. 22, SE 1/4, NW 1/4, SE 1/4

Slope gradient = 65 %. Aspect = S 30 W

Slope length = 80 m. Erosion: Slight

Site position on slope = 40 % of distance from base.

Evidence for tree uprooting at site: Very little treethrow.

Overstory vegetation at site:

white birch	*Betula papyrifera* Marsh.
red maple	*Acer rubrum* L.
aspen	*Populus* spp.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	8.1
July 25, 1995	=	15.8
September 17, 1995	=	13.4
November 5, 1995	=	4.3
January 20, 1996	=	nd

Site name: N8 Location: T50N, R34W, sec. 23, SW 1/4, NW 1/4, SW 1/4

Slope gradient = 59 %. Aspect = N 31 E

Slope length = 70 m. Erosion: No

Site position on slope = 45 % of distance from base.

Evidence for tree uprooting at site: Slight treethrow.

Overstory vegetation at site:

hemlock	*Tsuga canadensis* (L.) Carr.
white birch	*Betula papyrifera* Marsh.
red maple	*Acer rubrum* L.
aspen	*Populus* spp.
yellow birch	*Betula alleghaniensis* Britton.

<u>Soil Temperatures</u> (°C at 50cm)

May 17, 1995	=	5.2
July 25, 1995	=	13.8
September 17, 1995	=	12.1
November 5, 1995	=	5.5
January 20, 1996	=	nd

Site name: S9 Location: T50N, R34W, sec. 22, SE 1/4, NW 1/4, NE 1/4

Slope gradient = 72 %. Aspect = S 27 W

Slope length = 80 m. Erosion: Slight

Site position on slope = 50 % of distance from base.

Evidence for tree uprooting at site: Some large-size treethrow along with common medium-size treethrow.

Overstory vegetation at site:

aspen	*Populus* spp.
red pine	*Pinus resinosa* Ait
sugar maple	*Acer saccharum* Marsh.
red oak	*Quercus* rubra *L*
hemlock[1]	*Tsuga canadensis* (L.) Carr.
white birch[2]	*Betula papyrifera* Marsh

Soil Temperatures (°C at 50cm)

May 17, 1995	=	8.7
July 25, 1995	=	15.8
September 17, 1995	=	12.9
November 5, 1995	=	4.3
January 20, 1996	=	0.1

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1. All specimens ≤ 50 cm tall.
2. Located on shoulder and footslopes only.

Site name: N9 Location: T50N, R34W, sec. 22, SE 1/4, SE 1/4, NW 1/4

Slope gradient = 73 %. Aspect = N 28 E

Slope length = 90 m. Erosion: Little

Site position on slope = 40 % of distance from base.

Evidence for tree uprooting at site: Some treethrow.

Overstory vegetation at site:

white birch	*Betula papyrifera* Marsh.
sugar maple	*Acer saccharum* Marsh.
red oak	*Quercus rubra* L.
aspen	*Populus* spp.
red maple	*Acer rubrum* L.
yellow birch	*Betula alleghaniensis* Britton
hemlock[1]	*Tsuga canadensis* (L.) Carr.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	4.6
July 25, 1995	=	13.6
September 17, 1995	=	12.2
November 5, 1995	=	5.4
January 20, 1996	=	1.7

---

1. All specimens ≤ 5 m tall.

Site name: S10 Location: T50N, R34W, sec.32, NW 1/4, NE 1/4, NW 1/4

Slope gradient = 54 %. Aspect = S 30 W

Slope length = 55 m. Erosion: No

Site position on slope = 35 % of distance from base.

Evidence for tree uprooting at site: Moderate treethrow.

Notes: Profile described by RVH only.

Overstory vegetation at site:

hemlock	*Tsuga canadensis* (L.) Carr.
red maple	*Acer rubrum* L.
aspen	*Populus* spp.

<u>Soil Temperatures</u> (°C at 50cm)

May 17, 1995	=	6.4
July 25, 1995	=	14.0
September 17, 1995	=	12.2
November 5, 1995	=	4.6
January 20, 1996	=	nd

Site name: N10 Location: T50N, R34W, sec. 32, NW 1/4, NE 1/4, NW 1/4

Slope gradient = 61 %. Aspect = N 33 E

Slope length = 65 m. Erosion: Slight

Site position on slope = 40 % of distance from base.

Evidence for tree uprooting at site: Several large-size treethrow on upper slope.

Notes: Profile described by RVH only.

Overstory vegetation at site:

yellow birch	*Betula alleghaniensis* Britton.
hemlock	*Tsuga canadensis* (L.) Carr.
white birch	*Betula papyrifera* Marsh.
aspen	*Populus* spp.

Soil Temperatures (°C at 50cm)

May 17, 1995	=	3.7
July 25, 1995	=	12.6
September 17, 1995	=	11.7
November 5, 1995	=	5.7
January 20, 1996	=	nd

APPENDIX B

APPENDIX B

Table 21. Morphological characteristics and pH of site S1.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oe	0-4				
E	4-13	5YR 5/2	4.3	3.2	fine sandy loam
Bs1	13-28	7.5YR 4/6	5.4	4.5	fine sandy loam
Bs2	28-47	7.5YR 4/4	5.6	4.3	nd[1]
C	47-82+	7.5YR 4/4	5.7	4.5	sand

Table 22. Morphological characteristics and pH of site N1.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-2				
A	2-6	N 2/0			
E	6-17	5YR 4/2	4.5	3.3	sandy loam
Bs1	17-31	5YR 3/4	5.7	4.5	sandy loam
Bs2	31-46	5YR 4/4	5.9	4.6	sandy loam
2BC	46-81	7.5YR 4/6	6.0	4.7	sand
3C	81-97+	7.5YR 4/4	5.9	4.5	sand

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1 Not determined.

Table 23. Morphological characteristics and pH of site S2.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-4				
A	4-8	N 2/0	nd	nd	nd
E	8-20	5YR 5/3	4.9	3.5	fine sandy loam
Bs1	20-36	7.5YR 4/4	nd	4.5	fine sandy loam
Bs2	36-46	7.5YR 5/6	5.6	4.6	fine sandy loam
C	46-84+	7.5YR 5/4	5.7	4.3	fine sandy loam

Table 24. Morphological characteristics and pH of site N2.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-3				
Oa	3-5	N 2/0			
E	5-15	5YR 5/3	4.5	3.3	fine sandy loam
Bs1	15-29	5YR 4/6	6.0	4.3	fine sandy loam
Bs2	29-48	7.5YR 4/4	5.9	4.4	fine sandy loam
BC	48-70	7.5YR 4/3	5.9	4.2	fine sandy loam
2C	70-97+	5YR 5/4	5.9	4.2	loamy coarse sand

Table 25. Morphological characteristics and pH of site S3.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-7				
A	7-11	10YR 3/2	nd	nd	nd
E	11-23	7.5YR 5/2	4.7	3.4	fine sandy loam
Bs1	23-39	5YR 4/6	5.2	4.3	fine sandy loam
2Bs2	39-53	7.5YR 4/6	5.3	4.3	sand
2BC	53-64	7.5YR 4/6	5.2	4.3	sand
2Bs'	64-76	2.5YR 4/6	5.4	4.2	sand
2C	76-114+	5YR 4/6	5.6	4.2	sand

Table 26. Morphological characteristics and pH of site N3.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-3				
Oa	3-10	N 2/0			
E	10-24	5YR 5/2	4.3	3.2	sand
Bs1	24-50	5YR 3/4	5.4	4.3	sand
Bs2	50-72	5YR 4/6	5.9	4.6	loamy sand
BC	72-95	7.5YR 4/6	5.7	4.4	fine sandy loam
C	95-126+	7.5YR 4/4	5.6	4.3	loamy fine sand

Table 27. Morphological characteristics and pH of site S4.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-6				
Oa	6-12	N 2/0			
E	12-19	7.5YR 4/2	4.3	3.2	loamy fine sand
Bs1	19-33	5YR 4/6	5.2	4.4	loamy sand
Bs2	33-43	7.5YR 4/6	5.1	4.3	loamy sand
BC	43-60	7.5YR 4/4	5.1	4.3	sand
C	60-102+	7.5YR 5/4	5.2	4.4	sand

Table 28. Morphological characteristics and pH of site N4.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oe	0-4				
E	4-29	5YR 5/2	4.4	3.3	loamy fine sand
Bs1	29-44	2.5YR 3/6	5.3	4.3	loamy fine sand
Bs2	44-59	5YR 4/6	5.5	4.5	sand
BC	59-79	7.5YR 4/6	5.7	4.6	sand
C	79-102+	7.5YR 4/4	5.8	4.5	sand

Table 29. Morphological characteristics and pH of site S5.

Horizon	Depth (cm)	Moist color	pH $_{(H_2O)}$	pH $_{(KCl)}$	Texture
Oi	0-3				
A	3-6	10YR 3/2	nd	nd	nd
E	6-23	5YR 5/3	4.2	3.2	loamy sand
Bs1	23-40	7.5YR 4/6	5.5	4.2	loamy fine sand
Bs2	40-55	7.5YR 4/4	5.7	4.4	loamy sand
BC	55-79	10YR 5/6	6.0	4.5	loamy sand
C	79-101+	5YR 4/4	6.1	4.5	fine sandy loam

Table 30. Morphological characteristics and pH of site N5.

Horizon	Depth (cm)	Moist color	pH $_{(H_2O)}$	pH $_{(KCl)}$	Texture
Oi	0-4				
Oa	4-8	N 2/0			
E	8-15	5YR 5/2	4.3	3.1	loamy sand
Bhs	15-21	5YR 3/3 & 2.5YR 3/6	4.6	3.7	sand
Bs1	21-46	5YR 4/6	5.2	4.3	sand
Bs2	46-70	7.5YR 4/6	5.3	4.4	sand
BC	70-110+	10YR 4/6	5.4	4.4	sand

Table 31. Morphological characteristics and pH of site S6.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-2				
Oa	2-7	N 2/0			
E	7-21	7.5YR 5/2	4.3	3.2	fine sand
Bs1	21-37	7.5YR 4/6	5.1	4.3	loamy sand
Bs2	37-54	7.5YR 4/4	5.4	4.4	loamy sand
BC	54-67	7.5YR 5/4	5.6	4.4	loamy fine sand
C	67-102+	7.5YR 5/4	6.0	4.3	loamy fine sand

Table 32. Morphological characteristics and pH of site N6.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-4				
Oa	4-8				
E1	8-13	7.5YR 4/2	4.2	3.1	loamy sand
E2	13-32	7.5YR 5/2	4.6	3.4	loamy sand
Bhs	32-42	2.5YR 2.5/4	5.6	4.4	loamy sand
Bs	42-58	5YR 4/6	5.8	4.7	loamy sand
BC	58-88+	7.5YR 4/6	5.7	4.6	sand

Table 33. Morphological characteristics and pH of site S7.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
O	Intermittent				
A	0-9	10YR 2/2	nd	nd	nd
E	9-14	5YR 5/3	5.2	3.7	loamy fine sand
Bs1	14-26	5YR 4/6	5.7	4.5	loamy fine sand
Bs2	26-41	7.5YR 4/6	6.0	4.6	loamy fine sand
BC	41-77	7.5YR 4/4	5.7	4.6	loamy fine sand
2C	77-119+	5YR 4/3	6.2	4.3	very fine sandy loam

Table 34. Morphological characteristics and pH of site N7.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-5				
Oa	5-9	N 2/0			
E1	9-18	7.5YR 5/2	4.7	3.3	loamy fine sand
E2	18-25	5YR 5/3	5.0	3.5	loamy fine sand
Bs1	25-39	5YR 3/4	5.5	4.2	loamy fine sand
Bs2	39-60	5YR 4/6	5.7	4.4	loamy fine sand
BC	60-95	7.5YR 4/6	5.9	4.4	fine sand
2C	95-104+	5YR 5/3	5.3	3.4	loam

Table 35. Morphological characteristics and pH of site S8.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
O	Intermittent				
E	0-7	7.5YR 5/2	5.1	3.6	fine sandy loam
Bs1	7-20	5YR 4/6	5.6	4.4	fine sandy loam
Bs2	20-39	7.5YR 4/6	5.9	4.6	fine sandy loam
BC	39-58	7.5YR 5/4	5.6	4.2	loamy sand
C	58-89+	7.5YR 5/4	5.8	4.3	loamy sand

Table 36. Morphological characteristics and pH of site N8.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-12				
Oa	12-15	N 2/0			
E	15-36	7.5YR 5/2	4.9	3.3	loamy sand
Bs1	36-51	5YR 3/4	5.6	4.2	loamy fine sand
Bs2	51-73	5YR 4/6	5.8	4.5	fine sandy loam
BC	73-83	7.5YR 4/6	5.7	4.6	loamy fine sand
C1	83-96	7.5YR 4/4	6.0	4.7	fine sand
C2	96-112+	5YR 4/4	5.5	4.4	fine sandy loam

Table 37. Morphological characteristics and pH of site S9.

Horizon	Depth (cm)	Moist color	pH $_{(H_2O)}$	pH $_{(KCl)}$	Texture
Oi	0-3				
Oa	3-8	N 2/0			
E	8-13	5YR 5/3	4.8	3.5	loamy sand
Bs1	13-26	5YR 4/6	5.5	4.3	loamy sand
Bs2	26-51	7.5YR 4/6	5.9	4.6	loamy sand
BC	51-70	7.5YR 4/4	6.0	4.5	loamy sand
2C	70-93+	5YR 5/3	6.0	4.3	fine sandy loam

Table 38. Morphological characteristics and pH of site N9.

Horizon	Depth (cm)	Moist color	pH $_{(H_2O)}$	pH $_{(KCl)}$	Texture
Oi	0-3				
Oa	3-7				
E	7-24	5YR 4/3	4.9	3.3	fine sandy loam
Bs1	24-34	5YR 3/4	5.3	4.1	sandy loam
Bs2	34-51	7.5YR 4/4	5.5	4.3	fine sandy loam
BC	51-89	5YR 4/4	6.0	4.4	fine sandy loam
2C	89-110+	7.5YR 5/4	6.1	4.6	sand

Table 39. Morphological characteristics and pH of site S10.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-4				
Oa	4-9	N 2/0			
E	9-18	5YR 4/2	5.2	3.6	loamy sand
Bs1	18-28	5YR 3/4	5.3	4.0	loamy sand
Bs2	28-48	5YR 4/6	5.4	4.1	loamy sand
BC	48-75	7.5YR 4/4	5.3	4.1	sandy loam
2C1	75-85	7.5YR 4/4	5.7	4.3	sand
2C2	85-107+	7.5YR 4/6	6.0	4.6	nd

Table 40. Morphological characteristics and pH of site N10.

Horizon	Depth (cm)	Moist color	pH (H_2O)	pH (KCl)	Texture
Oi	0-5				
Oa	N 2/0				
E1	8-13	5YR 4/2	4.2	3.0	fine sandy loam
E2	13-29	5YR 5/3	4.6	3.3	fine sandy loam
Bs1	29-38	5YR 3/4	5.4	4.0	fine sandy loam
Bs2	38-53	7.5YR 4/6	5.7	4.4	fine sandy loam
BC	53-79	7.5YR 4/4	5.9	4.4	fine sandy loam
C	79-116+	7.5YR 4/4	5.6	4.4	fine sandy loam

APPENDIX C

APPENDIX C

Table 41. Particle size analysis for sites S1 and N1.

SAMPLE	vcs %	cs %	ms %	fs %	vfs %	sand %	silt+clay %	TEXTURE[1]
	2.0 to 1.0 mm	1.0 to 0.5 mm	0.5 to 0.25 mm	0.25 to 0.1 mm	0.1 to 0.05 mm	2.0 to 0.05 mm	< 0.05 mm	
S1								
Oe								
E	0.3	2.0	13.4	26.9	19.5	62.0	36.9	fsl
Bs1	0.4	1.8	14.2	29.5	19.9	65.8	33.7	fsl
Bs2								NA
C	0.6	9.3	62.5	22.9	1.8	97.2	2.2	s
N1								
Oi								
A								NA
E	2.0	12.3	27.7	20.3	9.6	71.9	26.2	sl
Bs1	3.4	10.6	26.2	19.6	9.8	69.6	30.2	sl
Bs2	2.4	11.6	30.6	17.9	6.8	69.2	30.3	sl
2BC	2.8	15.1	44.2	23.4	5.7	91.1	7.8	s
3C	1.1	5.4	21.1	44.1	15.5	87.2	12.4	s

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[1] Texture class abbreviations:
s = sand;
sl = sandy loam;
fs = fine sand;
fsl = fine sandy loam;
vfsl = very fine sandy loam;
ls = loamy sand;
lfs = loamy fine sand;
lcs = loamy coarse sand;
l = loam.

[2] Not determined

Table 42. Particle size analysis for sites S2 and N2.

SAMPLE	vcs %	cs %	ms %	fs %	vfs %	sand %	silt+clay %	TEXTURE
	2.0 to 1.0 mm	1.0 to 0.5 mm	0.5 to 0.25 mm	0.25 to 0.1 mm	0.1 to 0.05 mm	2.0 to 0.05 mm	< 0.05 mm	
S2								
Oi								
A								NA
E	1.0	5.4	19.1	26.4	21.1	73.0	26.3	fsl
Bs1	1.4	4.7	15.3	28.1	24.9	74.3	25.6	fsl
Bs2	1.7	3.6	13.0	35.5	21.4	75.1	23.5	fsl
C	1.0	3.5	12.0	31.4	27.0	74.9	24.7	fsl
N2								
Oi								
Oa								
E	0.1	1.3	18.9	43.8	11.0	75.1	24.5	fsl
Bs1	0.5	1.2	8.4	32.8	17.2	60.0	40.2	fsl
Bs2	0.04	0.4	5.5	25.8	20.4	52.2	47.5	fsl
BC	0.1	0.4	9.7	27.5	15.6	53.2	46.1	fsl
2C	0.2	44.8	30.8	8.1	1.0	84.9	14.0	lcs

Table 43. Particle size analysis for sites S3 and N3.

SAMPLE	vcs %	cs %	ms %	fs %	vfs %	sand %	silt+clay %	TEXTURE
	2.0 to 1.0 mm	1.0 to 0.5 mm	0.5 to 0.25 mm	0.25 to 0.1 mm	0.1 to 0.05 mm	2.0 to 0.05 mm	< 0.05 mm	
S3								
Oi								
A								NA
E	1.7	637	18.7	24.4	18.6	69.7	29.6	fsl
Bs1	1.6	6.8	19.4	23.7	17.6	69.2	30.0	fsl
2Bs2	2.7	8.5	41.5	34.6	5.1	92.4	7.0	s
2BC	2.3	10.8	51.3	29.4	2.4	96.1	3.7	s
2Bs'	6.2	17.4	51.2	19.5	1.2	95.4	3.2	s
2C	7.7	28.4	50.4	9.9	0.9	97.2	1.9	s
N3								
Oi								
Oa								
E	3.7	19.3	43.2	19.9	3.8	89.9	8.9	s
Bs1	5.5	17.3	42.0	26.3	2.5	93.5	6.2	s
Bs2	1.1	4.0	22.1	43.9	12.6	83.6	NA	ls
BC	0.3	1.7	12.1	42.0	19.1	75.2	23.8	fsl
C	0	0.5	16.5	60.2	6.8	84.0	15.1	lfs

Table 44. Particle size analysis for sites S4 and N4.

SAMPLE	vcs %	cs %	ms %	fs %	vfs %	sand %	silt+clay %	TEXTURE
	2.0 to 1.0 mm	1.0 to 0.5 mm	0.5 to 0.25 mm	0.25 to 0.1 mm	0.1 to 0.05 mm	2.0 to 0.05 mm	< 0.05 mm	
S4								
Oi								
Oa								
E	0.6	3.2	20.2	38.6	16.4	79.0	19.6	lfs
Bs1	1.1	3.4	24.6	38.1	12.6	79.6	20.2	ls
Bs2	0.9	3.1	25.5	42.4	11.3	83.2	15.6	ls
BC	0.5	2.8	33.3	47.5	6.8	90.8	9.1	s
C	0	0.4	44.1	49.2	3.1	96.9	2.3	s
N4								
Oe								
E	0.5	2.9	20.9	39.2	20.0	83.4	16.8	lfs
Bs1	0.7	2.4	19.4	45.2	18.4	86.1	13.0	lfs
Bs2	1.2	3.4	27.8	41.1	14.8	88.3	10.6	s
BC	1.6	3.7	26.0	45.8	12.3	89.3	9.5	s
C	0.1	2.3	53.3	31.6	3.5	90.8	8.1	s

Table 45. Particle size analysis for sites S5 and N5.

SAMPLE	vcs %	cs %	ms %	fs %	vfs %	sand %	silt+clay %	TEXTURE
	2.0 to 1.0 mm	1.0 to 0.5 mm	0.5 to 0.25 mm	0.25 to 0.1 mm	0.1 to 0.05 mm	2.0 to 0.05 mm	< 0.05 mm	
S5								
Oi								
A								NA
E	1.0	3.8	23.1	38.7	14.8	81.3	17.4	ls
Bs1	0.3	2.3	19.9	45.1	14.9	82.4	15.9	lfs
Bs2	0.4	3.2	22.7	42.1	13.7	82.0	16.4	ls
BC	0.4	2.9	22.3	43.7	13.6	82.8	15.8	ls
C	0.4	1.5	17.6	43.0	4.7	67.2	32.1	fsl
N5								
Oi								
Oa								
E	2.3	8.9	25.5	39.6	10.0	86.3	11.9	ls
Bhs	5.5	11.8	32.7	30.7	7.7	88.3	10.0	s
Bs1	2.8	5.7	22.3	42.2	14.6	87.5	11.4	s
Bs2	1.3	7.2	36.6	40.2	7.0	92.3	6.3	s
BC	1.5	5.6	30.5	43.6	9.4	90.5	8.1	s

Table 46. Particle size analysis for sites S6 and N6.

SAMPLE	vcs %	cs %	ms %	fs %	vfs %	sand %	silt+clay %	TEXTURE
	2.0 to 1.0 mm	1.0 to 0.5 mm	0.5 to 0.25 mm	0.25 to 0.1 mm	0.1 to 0.05 mm	2.0 to 0.05 mm	< 0.05 mm	
S6								
Oi								
Oa								
E	0.5	3.0	18.7	52.9	12.4	87.4	10.8	fs
Bs1	1.1	3.3	21.7	46.5	12.6	85.2	13.9	ls
Bs2	0.9	4.0	24.3	44.4	11.6	85.2	13.5	ls
BC	0.5	3.1	19.2	42.9	14.4	80.0	18.8	lfs
C	0.2	0.5	2.2	39.2	35.6	77.6	21.9	lfs
N6								
Oi								
Oa								
E1	0.4	4.0	26.8	39.5	11.9	82.7	15.4	ls
E2	0.4	4.0	27.9	37.9	12.8	83.0	15.4	ls
Bhs	1.1	6.0	24.8	36.2	13.5	81.6	17.0	ls
Bs	1.4	5.7	22.5	40.6	14.3	84.5	14.0	ls
BC	3.1	7.5	29.5	42.3	8.8	91.2	7.1	s

Table 47. Particle size analysis for sites S7 and N7.

SAMPLE	vcs %	cs %	ms %	fs %	vfs %	sand %	silt+clay %	TEXTURE
	2.0 to 1.0 mm	1.0 to 0.5 mm	0.5 to 0.25 mm	0.25 to 0.1 mm	0.1 to 0.05 mm	2.0 to 0.05 mm	< 0.05 mm	
S7								
Oe								
A								NA
E	0.6	2.2	19.8	45.5	9.8	77.9	21.1	lfs
Bs1	0.9	2.3	14.3	41.4	19.1	78.0	21.2	lfs
Bs2	0.6	2.4	12.7	40.3	21.6	77.6	21.2	lfs
BC	1.5	3.2	11.3	43.0	21.3	80.3	18.5	lfs
2C	0.2	0.7	5.2	29.8	30.7	66.6	32.8	vfsl
N7								
Oi								
Oa								
E1	0.4	1.4	17.9	49.1	16.0	84.9	13.8	lfs
E2	0.3	1.6	21.9	48.8	14.0	86.6	12.3	lfs
Bs1	0.6	1.6	20.6	49.7	13.8	86.3	12.5	lfs
Bs2	1.0	1.8	17.5	47.8	15.7	83.8	15.4	lfs
BC	0.04	.9	25.2	52.0	12.1	90.2	9.0	fs
2C	0	0.6	4.9	18.1	22.6	46.2	53.3	l

Table 48. Particle size analysis for sites S8 and N8.

SAMPLE	vcs %	cs %	ms %	fs %	vfs %	sand %	silt+clay %	TEXTURE
	2.0 to 1.0 mm	1.0 to 0.5 mm	0.5 to 0.25 mm	0.25 to 0.1 mm	0.1 to 0.05 mm	2.0 to 0.05 mm	< 0.05 mm	
S8								
E	1.1	4.0	16.7	36.2	17.3	75.4	23.6	fsl
Bs1	1.2	4.1	15.3	35.3	18.3	74.2	24.7	fsl
Bs2	1.2	3.8	14.7	35.3	18.6	73.6	25.3	fsl
BC	1.2	4.3	25.6	38.3	12.4	81.8	17.0	ls
C	0.4	2.5	25.7	46.5	10.4	85.6	12.6	ls
N8								
Oi								
Oa								
E	0.3	2.4	22.4	42.8	14.2	82.0	16.8	ls
Bs1	0.4	1.5	13.9	44.3	19.1	79.2	19.8	lfs
Bs2	0.2	0.7	8.4	40.1	26.6	76.0	23.4	fsl
BC	0.1	0.7	11.7	48.2	21.2	81.9	17.3	lfs
C1	0.04	0.4	8.9	56.5	23.3	89.1	9.8	fs
C2	0.04	0.1	3.3	39.1	26.6	69.1	30.3	fsl

Table 49. Particle size analysis for sites S9 and N9.

SAMPLE	vcs % 2.0 to 1.0 mm	cs % 1.0 to 0.5 mm	ms % 0.5 to 0.25 mm	fs % 0.25 to 0.1 mm	vfs % 0.1 to 0.05 mm	sand % 2.0 to 0.05 mm	silt+clay % < 0.05 mm	TEXTURE
S9								
Oi								
Oa								
E	0.4	6.4	30.2	31.5	11.0	79.4	19.1	ls
Bs1	0.8	6.9	32.7	30.1	9.1	79.5	NA	ls
Bs2	1.0	9.0	37.3	31.5	7.7	86.5	11.4	ls
BC	0.9	7.9	38.8	28.1	8.7	84.4	13.8	ls
2C	0.1	1.1	12.2	47.9	14.7	76.1	23.1	fsl
N9								
Oi								
Oa								
E	1.4	4.1	23.5	35.3	11.3	75.6	22.3	fsl
Bs1	1.2	5.7	28.6	27.9	11.1	74.5	23.9	sl
Bs2	0.6	3.7	21.6	28.2	10.4	64.4	34.3	fsl
BC	1.1	3.6	18.5	32.9	14.5	70.6	28.6	fsl
2C	1.4	8.2	48.2	30.5	5.9	94.2	4.3	s

Table 50. Particle size analysis for sites S10 and N10.

SAMPLE	vcs %	cs %	ms %	fs %	vfs %	sand %	silt+clay %	TEXTURE
	2.0 to 1.0 mm	1.0 to 0.5 mm	0.5 to 0.25 mm	0.25 to 0.1 mm	0.1 to 0.05 mm	2.0 to 0.05 mm	< 0.05 mm	
S10								
Oi								
Oa								
E	3.5	12.6	28.9	27.7	9.1	81.8	16.1	ls
Bs1	8.0	14.3	31.7	22.0	6.5	82.6	15.3	ls
Bs2	3.5	9.9	28.0	28.9	9.6	79.9	NA	ls
BC	2.2	8.4	27.0	29.0	10.2	76.8	21.9	sl
2C1	4.9	13.4	35.6	28.0	6.7	88.6	9.9	s
2C2								NA
N10								
Oi								
Oa								
E1	0.7	1.9	11.6	37.6	20.0	71.8	27.5	fsl
E2	0.6	1.2	9.0	40.4	23.5	74.7	24.6	fsl
Bs1	0.6	1.8	11.6	40.4	22.9	77.3	22.0	fsl
Bs2	0.3	1.4	10.8	40.8	24.0	77.3	21.9	fsl
BC	0.3	1.8	14.3	33.3	21.8	71.5	27.9	fsl
C	0.3	2.9	15.3	31.0	21.0	70.4	28.7	fsl

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