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Aspect induced differences in vegetation and soil on north- and south-facing slopes in western Massachusetts /

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ASPECT INDUCED DIFFERENCES IN VEGETATION AND SOIL ON NORTH- AND SOUTH-FACING SLOPES IN WESTERN MASSACHUSETTS

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by

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ABSTRACT

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Slopes of contrasting aspects receive considerably different amounts of solar radiation. The spatial variation of radiative energy distribution causes differences in microclimatic site conditions which affect the distribution of plants species and soil formation. On the study site, the cooler and wetter north slope supported a relatively species poor forest-community with *Tsuga canadensis* and *Betula lenta* among the dominant tree species. *Carya* sp. and *Acer saccharum* occurred preferentially on the warmer and drier south slope. Differences in soil properties were generally restricted to the upper horizons. Increasing amounts of organically bound Al with depth for soils on the north slope are interpreted as indication of incipient podzolization. A more intense chemical weathering regime on the north slope is also demonstrated by the presence of hydroxy interlayered vermiculite, which probably originated by partial dissolution of Al in the interlayer sheet. C/N ratios varied within a small range and did not show a considerable change in litter quality. Thus, vegetation and soils seem to respond to some degree independently to changes in site conditions. However, possible effects of historical land-use limit the conclusions about vegetation-soil relationships.

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CHAPTER 1

INTRODUCTION

Soils, natural assemblies of organic and inorganic solids, liquids, and gases, are complex, open systems at the surface of the earth undergoing pedogenetic processes (Simonson 1968, Sparks 1995, Jenny 1980). They represent an important component of all terrestrial ecosystems. Through their position at the interface among geo-, bio-, hydro-, and atmosphere, the development and properties of soils are affected by a variety of external factors. These factors control directly or indirectly the processes of soil formation, e.g., the addition, loss, transfer, and transformation of energy and matter (Jenny 1980).

On a global scale, the distribution of soil types is determined predominantly by latitudinal climate changes (zonal soils) (e.g., Duchaufour 1982). Within a particular climatic zone, differences in soil properties may be associated with varying parent material or disturbance history (intrazonal and azonal soils). On even smaller scales, opposing slopes often show distinct differences in soils and vegetation due to aspect induced variations in environmental conditions. Aspect, defined as the orientation of a land surface relative to the compass direction, affects the microclimate of a site by determining the amount of solar energy input (Oke 1978). Slopes receive different amounts of solar radiation per unit area due to their orientation, tilt angle, and subsequent shading effects. A detailed knowledge of the response of vegetation and soil formation to these microclimatic characteristics may support the classification of soils, and allow more accurate predictions of soil attributes. It also can contribute to the development of an ecological site classification system. This concept integrates different components of ecosystems for the purpose of environmental management and sustainable resource use.

The spatial variation in soil development was first recognized by Russian soil scientists in the late-nineteenth century. Dokuchaev recognized climate, biota, parent material, relief and landscape age as soil-forming factors, and Sibertsev produced a system of soil classification based on bioclimatic zones (Ellis and Mellor 1995). Jenny (1941) extended the approach of Dokuchaev in a systematic manner and explained the spatial variability and distribution of soils as a result of five soil-forming factors. In this pedological model, the relationship between soil formation and environmental conditions is described by the equation $s = f(cl,o,r,p,t)$. Climate (cl), organisms (o), relief/topography (r), parent material (p), and time (t) are variables (factors) that affect soil development and the state of the soil system.

In order to assess the dependency of soil properties on a single factor, the concept of sequences or functions has been applied. Here, only one factor is allowed to vary while all others are held constant. This is also known as the univariant functional approach (Hugget 1982). In this study, the influence of aspect (as part of topography) on soil development is examined in a toposequence consisting of several transects across a ridge. Ideally, all other factors of soil formation remain unchanged for every site along the transect. The basic assumption of this approach is that all state factors operate as continuous, independent variables. In reality, these factors are often discrete and interdependent. One factor does not vary without causing some variation in others (Ellis and Mellor 1995). This can be illustrated by the various interactions in the climate – vegetation – soil system. Vegetation may have a profound influence on the climatic conditions at ground level and below which ultimately affect soil formation. However, vegetation itself is strongly affected by climate. The distribution of vegetation is generally a function of the same set of factors as for soil formation (Scott 1974, Birkeland 1984). Soil properties like pH or nutrient availability can determine the occurrence of plant species as well. In turn, vegetation may influence soil morphology and chemistry (e.g., Binkley and Giardina 1998). Since vegetation acts upon soil and soils act upon vegetation, it is difficult, if not impossible, to assess cause and effect and to separate biotic and climatic factors of soil development from each other (Ellis and Mellor 1995, Birkeland 1984).

The interdependency of soil forming factors limits the use of Jenny's concept of soil development. Nevertheless, the significance of a single environmental factor can still be determined if this factor is considered to be the dominant variable controlling soil formation and if the variations of the remaining factors are negligible (Ellis and Mellor 1995). This is shown in numerous articles that deal with soil forming factor analysis to understand the spatial variability of soils (Wilding 1994). Jenny's model that the spatial variability of soils is a result of processes caused by interactions between the factors of soil formation is still the basis of modern pedology (Odeh et al. 1991).

This study investigates whether the observed association of soils, vegetation, and climatic zones on a global scale holds also on a considerably smaller scale. This is accomplished by the examination of aspect-induced differences of soils and vegetation on opposite slopes of Ox Hill, an east-west running ridge in the Mt. Toby area in western Massachusetts. Variations in microclimate caused by local differences in topography represent 'natural controlled experiments to study the processes and factors of soil genesis' (Cooper 1960).

The study site is located in the transitional forest zone of the southern oak-hickory forests (former oak-chestnut association) and the northern hemlock-hardwood (maple, beech, birch) forests (Flaccus 1972, Westveld 1956, Livingston and Lund, unpublished). Thus, relatively small differences in microclimatic site conditions may cause a distinct change in forest composition. The generally cooler and wetter (mesic) environment on the north-facing slope should favor northern hemlock-hardwood forest species, whereas on the dry and warm (xeric) south-facing slope a deciduous oak-hickory forest type might be predominant. It was hypothesized that these possible differences in forest composition cause significant differences in soil development on both slopes. Higher abundances of hemlock *(Tsuga canadensis*) and other evergreen species such as mountain laurel (*Kalmia latifolia*) growing on the cooler and wetter north-facing slope strongly acidify the soil through acidic, 'poor' quality litter, which does not decompose easily. These conditions generally enhance podzolization through increased weathering and chelation processes (Johnson and Siccama 1979, DeKimpe and Martel 1976, Schaetzl and Isard 1996). For example, April and Newton (1983) found that forest composition had an effect on the development of spodosols. They reported thin or discontinuous organic and albic horizons for spodosols developed under deciduous trees in three watersheds of the Adirondack Mountains, New York. Under coniferous stands, these horizons were better developed and the spodic B-horizons were more indurated with ortstein. Hence, soil characteristics indicative of podzolization (for example the pedogenic accumulation of Fe and Al in a spodic B-horizon) were expected under a more coniferous forest type on the north-facing sites.

Spodosols (podzols) are acidic forest soils characterized by the pedogenic accumulation of Fe and Al in the B horizon (spodic horizon). This soil type is characteristic of moist, temperate and boreal climate zones (Courchesne and Hendershot 1997).

On the south-facing slopes, conditions are unfavorable for spodosol formation. Under primarily deciduous trees, litter decomposition and thus nutrient cycling are likely to be much faster. These soils are expected to have higher pH values and higher base saturation compared to the north-facing slope. Drier conditions could have reduced the soil development and soils are expected to classify as weakly developed Inceptisols.

The specific objectives of this study were

- to predict the potential direct solar radiation for both sides of the ridge and evaluate the differences in solar energy input due to aspect and slope angle,
- to describe the vegetation on both sides of the ridge and identify species occurring preferentially on a specific topographic position,
- to characterize the soil on north- and south-facing slopes by their physical, chemical, and mineralogical properties and identify soil properties that best discriminate between pedons on opposite slopes,
- to analyze the data to assess the relationship between soils, vegetation and aspect.

There are only few east-west running ridges in New England. Ox Hill was chosen as study site because of its steep slopes of contrasting aspects within a short distance, relatively easy accessibility, and presumably limited human impact during the last 300 years compared to most other sites in the area. An intensive study of soils and vegetation on a single site was preferred over a comparison of several widespread sites. It is likely that other factors of soil formation (e.g., parent material) vary considerably between distant sites, thus making comparisons among sites difficult. Furthermore, New England has experienced significant changes in land use over the last 350 years. Consequently, differences in land use history may have induced various successional vegetation dynamics that are still active today (Foster et al. 1998). Different stages of succession are likely to be more dominant compared to differences in vegetation caused by microclimate and may lead to invalid conclusions about the relationship between soil and vegetation.

CHAPTER 2

LITERATURE REVIEW

2.1 Aspect Effects on Microclimate

Relief generally does not affect soils and vegetation directly but through modification of other environmental components (Scott 1974). Similar to the factor climate, which includes several distinct variables such as precipitation and temperature, the factor relief combines different elements. These include variables such as elevation, aspect, slope angle, slope position, and configuration, all of which have an effect on other environmental factors like for example climatic site conditions and geomorphological processes (e.g., erosion or deposition). The topographic effects on microclimate is controlled mainly by variations in the input of solar radiation, although other effects like the modification or generation of airflow (topographically generated winds) might be also important (Oke 1978).

Next to effects of latitude and cloud cover, topographic variability exerts a major control over the distribution of radiative energy (Dubayah 1994). Incoming solar radiation is a key component of the climate system of the earth. Local gradients in solar radiation may affect ecosystems through changes in temperature and moisture within in the soil and the boundary layer of the atmosphere. In the northern temperate latitudes, slopes with southern aspect experience significantly higher net solar radiation and light intensities (e.g., Cooper 1960, Hutchins et al. 1976). Consequently, air and soil temperatures tend to be higher on south-facing slopes (Hunckler 1996, Macyk et al. 1978, Hutchins et al. 1976). They also experience greater annual temperature fluctuations

(Cooper 1960, Finney et al. 1962). In Colorado, Branson and Shown (1989) observed 57 freeze-thaw cycles within one year on south-facing slopes, compared to only 24 on slopes with northern aspect. Macyk et al. (1978) assume that the growing season is at least one week longer on south facing slopes in Alberta. Franzmeier et al. (1969) report approximately 2°C lower mean annual soil temperatures on north facing slopes. On opposite slopes in Virginia, Stephenson (1982) found differences in mean soil temperatures at 2 cm soil depth of 4.6 °C. These reported contrasting soil temperatures are partially due to the water content of the soil (Hunckler 1996, Macyk et al. 1978). The moisture status of a soil affects its temperature regime because the heat capacity of a soil increases with water content. Hence, permanently moist soils tend to be cooler than soil with lower water contents. Differences in soil moisture between aspects are reported for example by Cooper (1960), Stoeckler and Curtis (1960), Finney et al. (1962), Macyk et al. (1978), Hairston and Grigal (1991), and Cremeans (1993). All studies show that north facing slopes have generally higher water contents. However, Reid (1973) found only small differences in the cumulative annual water loss by evaporation on pastures of opposite slopes in Great Britain. He further notes, that these small differences might become significant over an extended period of time.

On the Holyoke Range, an east-west oriented ridge in western central Massachusetts, Lund (1969) and Livingston and Lund (unpublished data) found markedly different microclimates on opposite slopes. North-facing slopes received only 20-30% of the solar radiation compared to a south-facing slope with more open forest communities. In early spring, the higher insolation on the southern slope resulted in temperatures well above the freezing point, while soils on the north slope remained frozen. During the period from April through September, average temperatures were higher on the south than on the north slope. The mean maximum and minimum temperatures were higher both at 10 cm and 120 cm above the ground surface (25.0°C / 13.2 °C compared to 17.5°C / 9.7 °C). Evaporation on the north-facing slope was only 69% as large as that on the south-facing slope. A flat area on the ridgetop showed intermediate values for radiant energy, temperature, and evaporation.

2.2 Aspect Effects on Forest Vegetation

Relative levels of solar radiation, temperature, and potential evaporation are aspect related climatic influences on vegetation affecting the species composition, distribution, and growth characteristics (Cremeans 1992, Dubayah 1994). Thus, aspect is an important factor in many land classification systems (e.g., Hix and Pearcy 1997).

Holland and Steyn (1975) discussed the vegetation-topography-radiation relationship in a theoretical manner based on a simple model of solar energy input. They predicted that for any slope angle the greatest differences in vegetation of north- and south-facing slopes are observable in mid-latitudes and least in equatorial and polar regions. Their literature survey generally supported this hypothesis.

Hicks and Frank (1984) found correlations between importance values of several tree species and aspect in West Virginia. In New Jersey, Cantlon (1953) reported that no plant species was completely exclusive on opposing slopes. However, the composition of the vegetation was markedly different with greatest differences in the understory vegetation. Similarly, Harrington and Neithercut (1985, cited in Hunckler 1996) found sugar maple (*Acer saccharum*) to be the dominant tree species on northeast- and southwest-facing slopes in northwestern Michigan, but also noted significant differences in the distribution of secondary species. Beech (*Fagus grandiflora*), black cherry (*Prunus serotina*), hemlock (*Tsuga canadensis*), elm (*Ulmus rubra*), and basswood (*Tilia americana*) were commonly found in higher abundances on northeast-facing slopes, while ash (*Fraxinus americana*), aspen (*Populus grandidentata*), and ironwood (*Carpinus caroliniana*) were more abundant on south-west-facing slopes. Similarly, Hutchins et al. 1975 reported that in eastern Kentucky some plant species were restricted to only one slope, the northeast-facing slope being more diverse than the south-facing. The latter supported a less productive and less dense forest type with oak and hickory species dominating. Finney et al. (1962) studied the effect of aspect in northwest-southeast oriented valleys within the Allegheny Plateau, Ohio. The southwest-facing slopes were dominated by a mixed oak association, whereas on the northeast facing slopes a mixed mesophytic forest type occurred with no particularly dominant canopy species. In Wisconsin, Stoeckler and Curtis (1960) found mixed hardwood stands on slopes with northern aspects and stands of scrub oak (*Quercus ilicifolia*) on south-facing slopes. The influence of aspect on tree productivity was investigated by Hairston and Grigal (1991). They found that the twenty-year radius of site-index trees was significantly different among slope positions and aspect, although total wood volume and basal area did not differ significantly. However, the slopes of their study site in Minnesota were gentle (less than 15%) and the relief differences small (about 5 m). In general, productivity correlates with aspect with highest values for northeast sites and lowest for southwest sites (Hicks and Frank 1984).

No aspect-related differences of vegetation were found by Strahler (1978) who studied the relationship of woody species and site factors in Maryland. The most important factor in his large study area was rock type. However, Strahler emphasizes the interrelationship between lithology and other landscape parameters and argues that the observed patterns were not produced by rock type itself but by a complex of geomorphic, microclimatic and edaphic processes interacting with lithology. It is therefore likely that aspect could have had an effect in a smaller sampling area with uniform bedrock.

Similarly, Whitney (1991) related some of the variation observed in species composition on different landscape positions in Harvard Forest (Massachusetts) to microclimatic differences between low-lying areas (valley bottoms) and exposed ridges. Cold air drainage in enclosed basins may reduce the frost-free season from 161 days on ridge top to 77 days. The dominant factor determining species occurrences was substrate, which was related to landscape position. The great variation of parent material may thus override any effect of slope aspect.

2.3 Aspect Effects on Soils

Since aspect causes variations in microclimate and vegetation – both factors of soil formation – the properties of soils on opposing slopes may also differ notably. However, aspect can also influence soil formation directly. Higher temperatures on sunny slopes may favor soil formation through higher chemical weathering rates. Conversely, the associated higher evapotranspiration rates and thus generally drier environments may enhance soil formation on opposite, shaded slopes particularly where water availability is a limiting factor.

Cooper (1960) found that north- and south-facing slopes on glacial outwash in Michigan differ significantly in their development stage. On slopes with southern aspect, A-horizons were generally thinner. However, B-horizons on south slopes showed stronger structure development, were redder in hue, and contained significantly more silt and clay than on north slopes. Cooper attributed these observations to more intense soil-forming processes caused by higher soil temperatures and the higher number of freezing-thawing and wetting-drying cycles found on the south slopes.

On soils on north- and south-facing slopes of a kame overlain by loess deposits in Wisconsin, Kochis and Lasca (1994) found A-E-Bt-C profiles on the north slope and A-Bt-C profiles on sites with southern aspect. They attributed the stronger soil development on the north slope to lower temperatures and higher soil moisture which favor carbonate dissolution and clay translocation.

Finney et al. (1962) reported that soils on northeast-facing slopes in Ohio had thicker A-horizons, higher base saturation, and higher pH values than on south-west facing slopes. Similarly, Stephenson (1982) observed significantly higher organic matter, pH values, and Ca, Mg and K concentrations on south-facing slopes in Virginia. However, Hutchins et al. (1976) and Hicks and Frank (1984), found soils on north-facing slopes with higher pH and base saturation compared to soils on south-facing slopes. Thicker soil horizons and higher amounts of organic matter on north facing slopes are reported by Cooper (1960), Franzmeier et al. (1969), Cremeans (1992), and Hunckler (1996). Similarly, Carter (1983), and Carter and Ciolkosz (1991) found slightly thicker E horizons on a northwest slope compared to a southwest-oriented slope on a sandstone ridge in Pennsylvania. They also found that differences in soil properties (solum depth, free iron oxide, extractable acidity) were apparent only for slope gradients greater than 15 to 20%.

Soils on north slopes were found to have sandier surface textures, higher clay contents in B-horizons, and redder subsurface horizons than soils on south slopes (Cooper 1960, Franzmeier et al. 1969). In contrast, Hutchins et al. (1976) reported that soils of a southwest slope in Kentucky had about twice as much sand as soils on the opposite slope. Higher amounts of sand in the surface horizons have been considered as evidence for accelerated clay eluviation. These results are not confirmed by Stephenson (1982) and Cremeans (1992) who found no significant differences in soil texture on opposite slopes.

Hunckler (1996) reports stronger indications (e.g., extractable Fe and Al in the B-horizons) of podzolization on soils of north- to northeast-facing slopes in Michigan. In contrast to this finding, Macyk et al. (1978) conclude that relief and microclimate appears to have a greater effect on soil morphology and related physical properties than on soil chemistry. They found only minor differences in chemical characteristics between soils on north- and south-facing slopes in Alberta. Hicks and Frank (1984) studied the relationship to forest composition and soil nutrients in West Virginia. Interestingly, they found much more statistically significant correlations for the A- than for the B-horizons. They concluded that aspect directly or indirectly affected only the chemical soil properties of the upper horizons.

CHAPTER 3

STUDY SITE

3.1 Location and History

The study site of Ox Hill (ca. 280 m above sea level) is one of three steep ridges on the east side of Mount Toby located in the Connecticut River valley in central western Massachusetts (42°30' N, 72°31'W). The site is part of the Mount Toby Demonstration Forest (306 ha), owned by the University of Massachusetts since 1916 (O'Keefe 1987). Indications of agricultural activities such as stone walls are mainly limited to the flatter parts of the forests. A landuse map of 1830 shows that the Mt. Toby area was forested at that time (Foster et al. 1998). In the second half of the nineteenth century, the Mt. Toby area was extensively used for recreation. This fact and the inaccessibility due to steep slopes probably restricted the extent of clear cutting (O'Keefe 1987). During the 1920's "chestnut replacement plots" were established on Ox Hill. This indicates that relatively old chestnut trees were growing at that time and the site has been forested for at least 60 years (Matthew Kelty, Dept. of Forestry and Wildlife Management, University of Massachusetts, personal communication). It is likely that forest fires creeping uphill from the nearby railway track could have affected especially the southern side of Ox Hill (William Patterson, Dept. of Forestry and Wildlife Management, University of Massachusetts, personal communication). The forest in this area was extremely damaged by a hurricane in 1938 (O'Keefe 1987) and by a gypsy mouth outbreak in the early 1980s.

3.2 Geology

The bedrock of the Mount Toby area consists of lower Jurassic alluvial-fan deposits, commonly called Mt. Toby conglomerate. This formation comprises two grain-size types, fluvial sandstones and alluvial-fan pebble conglomerates. The sandstones are generally arkoses whereas the conglomerate mainly consists of quartz with rock-fragments of gneiss, schist, amphibolite, and phyllite. Along the eastern side of the Mt. Toby area including the study site, the sedimentary rocks are cemented by hematite and calcite. Common minerals are quartz, plagioclase, muscovite, biotite, chlorite, and hematite (Taylor 1991).

New England was covered by the Laurentide ice sheet during the last glaciation. Deglaciation of central Massachusetts occurred very rapidly over a period of less than 1,000 years between 14 and 15 cal. ka BP (Brigham-Grette 1988). Through glacial erosion and widespread deposition of till and glacio-fluvial sediments, the time of soil development was reset. These unconsolidated deposits provided also the source areas for windblown sediments during and shortly after deglaciation (Fletcher 1976). Along the Connecticut Valley, lake sediments of glacial Lake Hitchcock are considered to be the primary source of the frequently observed, distinct eolian mantle overlying till deposits. The eolian material is generally comprised of fine and very fine sand (Fletcher 1976). Thus, the effect of the underlying bedrock as parent material for soil development is diminished for most soils in New England. In addition, soil mineralogy may be influenced by the presence of relict products (e.g., kaolinite) of earlier weathering phases during interglacial periods (Bodine 1986).

3.3 Climate

Central western Massachusetts is situated in the north temperate climate zone. The climate is primarily continental (Massachusetts Agricultural Experiment Station Bulletin 511, 1959, cited in Bradley 1987). Proximity to the Atlantic Ocean (ca. 120 km to the west) is only a modifying factor, since maritime influences are minimized by prevailing westerly winds. The nearest climate station is located in the town of Amherst, approximately 20 km south of the study area. The mean annual temperature is 8.4°C (1836-1985), with summer temperatures (June-August) of 19.8°C and winter temperatures (December-February) of -4.0°C. The average temperature in the growing season equals 18.2°C. The mean annual precipitation of 1107 mm (1836-1984) shows a slight maximum during the summer months (Bradley 1987).

3.4 Vegetation

O'Keefe (1987) reported hemlock-hardwood (36%) and oak-hardwood (25%) as the dominant overstory cover types in the Mount Toby Demonstration Forest. Other common types are northern hardwood (17%), and white-pine hardwood (9%). Dominant tree species were hemlock (*Tsuga canadensis*), red oak (*Quercus rubra*) and sugar maple (*Acer saccharum*) which together comprise ca. 55% of the basal area. White pine (*Pinus strobus*), white ash (*Fraxinus americana*), red maple (*Acer rubrum*), black birch (*Betula lenta*), and paper birch (*Betula papyrifera*) are other important species. Minor components of the overstory include hop-hornbeam (*Ostrya virginiana*), chestnut oak (*Quercus prinus*), yellow birch (*Betula alleghaniensis*), white oak (*Quercus alba*), and various hickory species (*Carya* sp.) With 32 tree species, the forest shows a great diversity. The oldest tree found by O'Keefe (1987) was 215 years old.

3.5 Soils

The soils in the study area are mapped as Hollis series (loamy, mixed, mesic Lithic Dystrudepts, [former Dystrochrepts]) with slopes of 25 to 60% (Mott and Fuller 1967). No differentiation has been made between soils on slopes with different aspects. Hollis soils are shallow, somewhat excessively drained soils formed in a thin mantle of glacial till with fine sandy loam textures and pH values ranging from very strongly acidic through moderately acidic. They occur on nearly level areas to very steep upland sites on bedrock-controlled hills and ridges with few to many rock outcrops. Depth to bedrock ranges from 25 to 50 cm. The series is of large extent in Connecticut, Massachusetts, New Hampshire, and eastern New York (Mott and Fuller 1967).

CHAPTER 4

METHODS

4.1 Modeling

Since no measurements were taken to quantify the microclimatic conditions on the study site, a simple model was developed to qualitatively describe differences in potential solar radiation. The annual shortwave radiation received by a slope surface is a function of latitude, aspect, and slope angle. Although integrated equations exist to calculate total daily radiation (e.g., Swift 1976), a stepwise summation of instantaneous radiation data was used in order to include a simple absorption model (Garnier and Ohmura 1968). No attempt was made to account for other atmospheric and topographic effects, for example shading of surrounding terrain (e.g., Flint and Childs 1987).

The instantaneous solar radiation on a tilted surface can be calculated using the following formula (Linacre 1992, Sharrat et al. 1992):

$I_i = I_n \cos\theta$ where

I_i : instantaneous direct radiation on tilted surface
I_n : direct normal radiation
$\cos\theta$: zenith angle: Angle between the solar beam and the normal of the surface.

The zenith angle θ, which expresses the position of the sun in relation to the slope surface, can be determined according to

$\cos\theta = \cos\gamma \sin\phi + \sin\gamma \cos\phi \cos(\alpha-\beta)$ where

γ : slope angle
ϕ : solar elevation angle (zenith angle)
α : azimuth angle of the sun
β : slope aspect

Solar elevation and azimuth are calculated with the following astronomical equations (Linacre 1992):

$$\sin \phi = \sin \lambda \sin \delta + \cos \lambda \cos \delta \cos (0.25\,(t-720)) \qquad \text{and}$$

$$\cos \alpha = \frac{\sin \lambda \sin \phi - \sin \delta}{\cos \lambda \cos \theta} \qquad \text{where}$$

λ : latitude
δ : solar declination, in first approximation:
$\delta = 23.45° \sin (2\pi/365\,(d-80))$, d : day of year
t : time of the day in minutes (solar time)

The direct normal radiation I_n depends on the solar constant S_0, an absorption factor b, and a correction term for the eccentricity of the earth's orbit (McCullough and Porter 1971):

$$I_n = b\, S_0\, (a/r)^2 \quad \text{where}$$

S_0 : solar constant (1364 Wm-2)
b : absorption factor
$(a/r)^2$: eccentricity correction, can be written as
$(a/r)^2 \approx 1 + 2\,\varepsilon \cos(2\,\pi\, d\, /\, 365)$
ε : eccentricity of the earth's orbit (= 0.01675)
d : day of the year

For the purpose of this study, $(a/r)^2$ was set to 1 (assuming a circular orbit of the earth), since the value never differs more than 3.5% from unity (Gates 1980, cited in Bristow et al. 1985).

A simple expression described in Garnier and Ohmura (1968) and Campbell (1977) was used to account for atmospheric absorption. The absorption factor is a function of the atmospheric transmission coefficient and the optical air mass number, which is the path length of the solar beam in relation to zenith path length.

$b = a^m$ where

a	:	mean-zenith-path atmospheric transmission coefficient, typical value for clear days around 0.84
m	:	optical airmass number, $m = (p/p_0) / \sin \phi$
		ϕ : solar elevation
		p/p_0 : atmospheric pressure at observation site / pressure at sea level

This expression is valid for solar elevation angles greater than 10° (Campbell 1977). For smaller angles, a value of m = 0.2 was assumed.

The algorithm for computing the instantaneous solar radiation was then used to calculate the daily and yearly amount of potential solar irradiance by stepwise summation over time. To obtain daily values, the time of sunrise and sunset was calculated as described in McCullough and Porter (1972). Starting at sunrise, the instantaneous solar radiation was calculated for every 5 minutes. These values were multiplied by the step size (i.e. 5 minutes) and added up until the position of the sun was below the horizon (=sunset). The yearly calculation was calculated similarly starting at day one (i.e. January 1th) with a step size of 5 days. The source code of the Pascal program to calculate yearly potential solar radiation for a certain latitude, aspect and slope angle is listed in Appendix A.

Since aspect cannot be described meaningful in terms of compass direction, the calculated potential solar radiation values relative to a flat surface were used in the statistical analysis as a substitute for aspect (Fribourg 1972).

4.2 Field Methods

4.2.1 Plot Selection

Field work was conducted in the months of July and August 1998. Seven transects were randomly located perpendicular to a baseline of approximately 350 m length on top of the ridge (Fig. 4.1.). Each transect consisted of two plots on the northern and southern side and one plot on top, resulting in a total of 35 plots. The distance between plots along a transect was fixed at 45 m. No attempt was made to place the plots in representative forest stands, thus some plots included gaps in the canopy due to disturbance. Based on species-area curves of a preliminary study, the plot size was set to 14×14 m according to the concept of minimum area described by Mueller-Dombois and Ellenberg (1974) or Kent and Coker (1992).

4.2.2 Vegetation

The vegetation of each plot was described using combined frequency and cover estimates for every vascular plant species using a relevé method (Mueller-Dombois and Ellenberg 1974). Areal cover is defined as the area of ground, which is occupied by all above-ground parts of each species when viewed from above. Frequency describes the proportion of plots in which each species occurs.

For each stratum (first and second tree-layer, shrub-, and herbaceous layer), species were assigned scores according to a modified Braun-Blanquet scale (Tab. 4.1). The corresponding scores were used to calculate importance values for each species by summation of all values for all strata. The number of strata in which the species occurred was then subtracted and the value 1 added to the total (Motzkin et al. 1993).

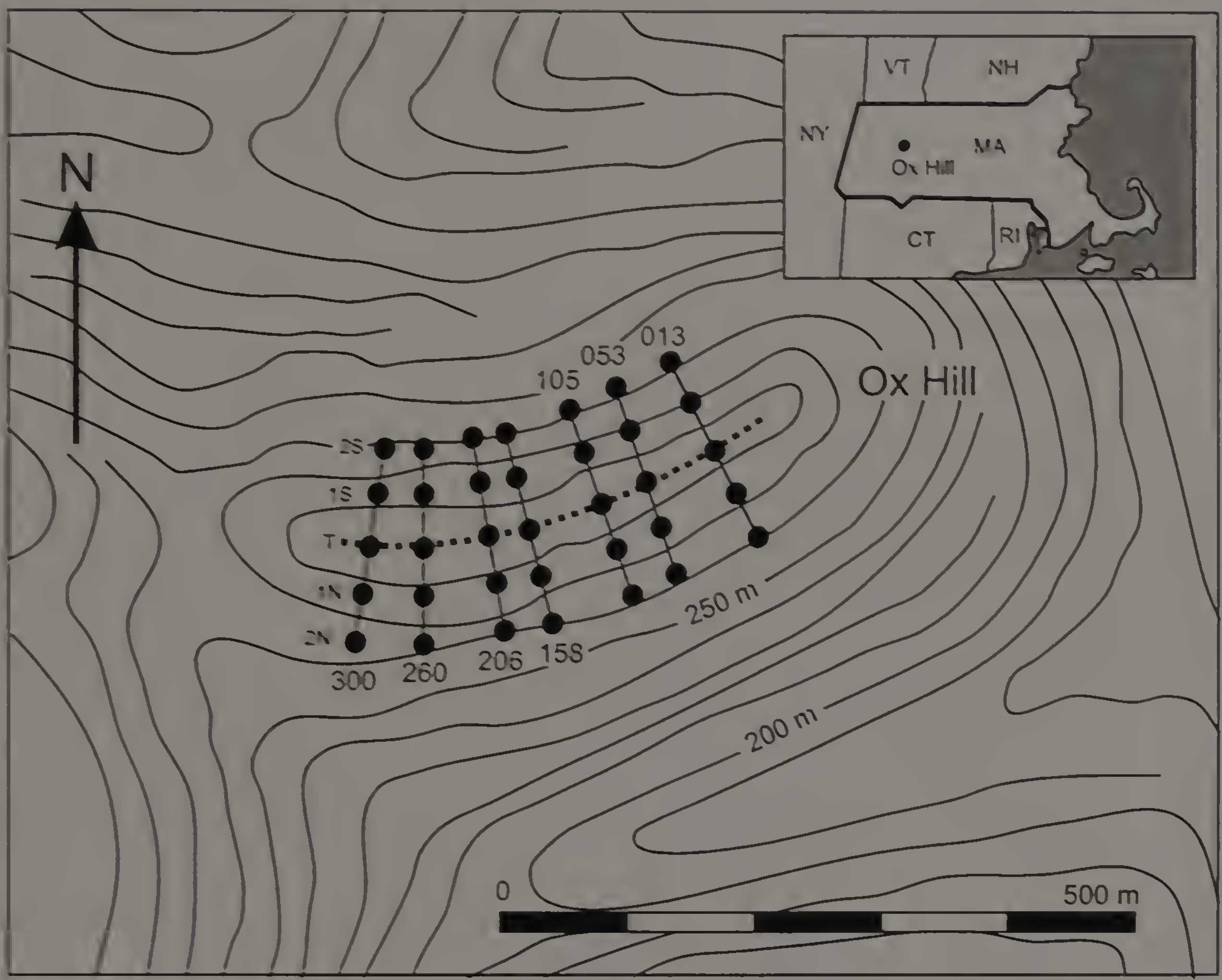


Figure 4.1. Location of study site and sampling scheme; Ox Hill, Franklin County, Massachusetts. Contour lines are 10 m elevation intervals. Modified from US Geological Survey 1985.

Table 4.1. Modified cover classes after Braun-Blanquet (Dierschke 1994).

Symbol (Braun-Blanquet)	Score	Cover (%)	Frequency		Average (%)
r	1	<1	1	(herbaceous species)	0.1
+	2	<1	1-5	(herbaceous species)	0.5
1	3	1-5	6-50	(herbaceous species) or 1-5 (trees)	2.5
2a	4	5-15	any number		10.0
2b	5	15-25	any number		20.0
3	6	25-50	any number		37.5
4	7	50-75	any number		62.5
5	8	75-100	any number		87.5

This procedure increases the importance of species which occur in more than one stratum and emphasizes the occurrence of species over their cover. In addition, the diameter at breast height (DBH) was recorded for all living trees with a DBH greater than 5 cm. The data were then converted to basal area (in m^2/ha).

Samples of unknown species were identified at the herbarium of the University of Massachusetts Amherst. No effort was made to distinguish hickory species (*Carya* sp.). Red oak (*Quercus rubra*) and black oak (*Quercus velutina*) were combined to *Quercus rubra*. The nomenclature of the plant species follows Gleason and Cronquist (1991).

4.2.3 Soils

Soil pits were excavated to bedrock in the center of each plot. Standard soil profile descriptions were made using the methods and terminology of Soil Survey Division Staff (1993). Descriptions for each pedon are listed in Appendix B. Pedons were classified using guidelines of the Soil Survey Staff (1998). Soil samples (ca. 400 g) were taken from every identified horizon.

4.3 Laboratory Methods

4.3.1 Sample Preparation

All soil samples were air-dried and passed through a 2-mm sieve prior to further analysis. For extractions of iron and aluminum approximately 25g soil were ground mechanically for 1.5 minutes using a shatter box (Model #8510 Spex Pulverizer) and tungsten carbide grinding containers. Soil data are reported on an air-dry basis of the fine earth fraction. Results of the laboratory analysis can be found in Appendix C.

4.3.2 Soil Reaction and Loss on Ignition

Due to the high water-holding capacity of the organic rich A-horizons, soil pH was determined in 1:2 (weight) ratio of soil with water and 0.01 M $CaCl_2$ solution. A suspension of 10 g of soil and 20 ml of deionized distilled water was stirred and left for 30 minutes before pH (H_2O) measurements were taken with a standard glass electrode (Fisher Accumet # 805 pH meter) in the supernatant (Soil Survey Laboratory Staff 1996). Then 200 μl of 1 N $CaCl_2$ were added, the suspensions were stirred again and left for 30 minutes before pH ($CaCl_2$) was measured.

Loss of ignition was taken as a measure of mineral and organic matter content (Soil Survey Laboratory Staff 1996). Five to six grams of oven-dry soil were weighed in porcelain crucibles and heated overnight in a muffle furnace at 500 °C. The crucibles were then allowed to cool and re-weighed to the nearest 0.01 g.

4.3.3. Particle Size Analysis

Particle size distribution was determined on a 25-g sample of soil by a combination of dry sieving for the sand fractions and the pipet method for silt and clay fractions as described by Gee and Bauder (1986). Samples from A-horizons were pretreated with 30% hydrogen peroxide to oxidize binding organic matter. After the reaction stopped, the clear supernatant was discarded. No removal of iron oxides with sodium dithionite-citrate/bicarbonate was performed since a preliminary study showed no statistical difference between treated and untreated samples. Following pretreatment, 10 ml of 5% Calgon solution (sodium hexametaphosphate) was added together with 150 ml of distilled water and the samples were shaken overnight. The suspension was then sieved through a 53-μm sieve into a sedimentation cylinder. The retained sand fractions were oven-dried and passed through nested sieves to determine the individual weight percentages for very coarse, coarse, medium, fine, and very fine sand. The silt and clay fractions in the sedimentation cylinder were re-suspended and 25-ml aliquots were taken at a prescribed time and depth according to Stokes Law. After the last aliquot was taken approximately 40 ml of the suspension was centrifuged, and another aliquot was taken from the supernatant to correct for the calgon and any dissolved substances. The aliquots were oven-dried and weighed to the nearest milligram. Textural classification followed USDA specifications (Soil Survey Divison Staff 1993).

4.3.4 Clay-mineralogical Analysis

The clay-mineralogical analysis concentrated on the A-horizons, since a preliminary analysis of B-horizons showed no differences in clay mineral composition. The suspended clay and silt in the sedimentation cylinders was flocculated with $Al_2(SO_4)_3$ and centrifuged. The material was washed several times with distilled water and redispersed with calgon solution. No attempt was made to remove coating Fe-oxides by sodium citrate/dithionite, since this treatment may also alter the clay minerals (e.g., Su and Harsh 1996).

The silt fraction was separated by centrifugation (9 min 37 s at 500 rpm) and saved for SEM and XRD analysis. The clay fraction remaining in suspension was separated in the 0.5 – 2 μm and <0.5 μm fraction by centrifugation at 2000 rpm for 9 min and 37 s with a high speed centrifuge (Sorvall RC-2B) using polycarbonate bottles. In some cases, especially in samples from the ridgetop, not enough material was present in the <0.5 μm fraction to prepare a sample for XRD. Each fraction was split in half and saturated with about 70 ml of 1 M $MgCl_2$ and 1 M KCl solution respectively. The samples were shaken overnight, centrifuged, and redispersed and centrifuged twice with distilled water. After a final centrifugation step at 10,000 rpm for 20 minutes, oriented slides were prepared by smearing the saturated clay paste on petrographic glass slides following a procedure by Moore and Reynolds (1989). Oriented slides were also made from a Mg-saturated portion of the silt fractions.

X-ray diffractograms were obtained using a Phillips X'pert X-ray diffractometer with Cu radiation (45 kV, 40 mA, 0.25° divergence and anti-scatter slit width, beam mask 15 mm, 0.2 mm receiving slit). The slides were X-rayed from 2° to 30° 2θ, with a step size of 0.05° and a count time of 1 second. The following treatments were applied to characterize the clay mineral composition:

- Mg-saturated, airdry
- Mg-saturated, ethylene glycol
- Mg-saturated, glycerol
- Mg-saturated, 100 °C
- K-saturated, airdry
- K-saturated, 300 °C
- K-saturated, 500 °C

Glycolated samples were placed in an ethylene-glycol containing desiccator for at least 24 hours at 60°C and were analyzed immediately after taking them out of the desiccator. For the glycerol treatment a few drops of glycerol were added onto the slide and the slide was placed in a glycerol-containing desiccator for several days.

4.3.5 Exchangeable Cations

Exchangable cations were measured by the $BaCl_2$ method (Hendershot et al. 1993). Approximately 8 grams of soil (weight recorded to the nearest mg) were put into large 250 ml polycarbonate centrifuge tubes and 100 ml of 0.1 M $BaCl_2$ solution was added. The samples – including blanks and duplicates – were shaken overnight, centrifuged at high speed and filtered through Whatman No. 41 filter paper to remove any floating organic material. An aliquot was stored in 20 ml glass vials until the extract was analyzed for base cations (Ca, Mg, K) and Fe, Al, and Mn by ICP-AES and flame AES (atomic emisson spectrometer). Cation exchange capacity (CEC) was calculated as the sum of these exchangeable cations. Base saturation was obtained by dividing the sum of the exchangeable base cations by the total CEC (Soil Survey Divison Staff 1993).

Since cations were extracted with a neutral, unbufferd $BaCl_2$ solution of relatively weak ionic strength, the effective cation exchange capacity was measured at the pH of the soil. Especially organic rich, acid soils with large amounts of pH-dependent charges will have a higher CEC in systems buffered at a higher pH. Thus, the CEC and base saturation are of greater significance when measured with an unbuffered salt (Singh 1978).

4.3.6 Extractions of Fe, Al, and Mn

Dithionite citrate, ammonium oxalate, and sodium pyrophosphate as extractants were used to describe the forms of Fe, Mn, and Al present in the soil. Dithionite citrate removes finely divided crystalline and non-crystalline Fe oxides (e.g., goethite) as well as organically bound Fe and Al. It is less effective in dissolving noncrystalline inorganic forms of Al (Ross and Wang 1993). Sodium dithionite extracts almost no Fe and Al from crystalline silicate minerals and is therefore used as an estimate of 'free' (nonsilicate) Fe in soils. Acid ammonium oxalate dissolves amorphous inorganic forms of Al and Fe and organic-complexed Fe and Al from soils (Wang 1978). It hardly dissolves most silicate minerals (with the exception of finely divided, easily weathered silicates like olivine) and well crystalline oxides. Sodium pyrophosphate extracts mainly organic-complexed forms of Al and Fe and does not significantly dissolve silicate minerals or crystalline Fe and Al oxides and hydroxides (Ross and Wang 1993).

Extraction procedures were slightly modified as described by Ross and Wang (1993). For dithionite citrate extraction, 0.5 g of pulverized soil was weighed to the nearest milligram and filled in large centrifuge bottle. Several duplicates to check precision and a blank were included. 0.8 g of sodium dithionite was put in with a calibrated scoop and 50 ml of 0.68 M sodium citrate solution (200g/L) was added using a volumetric flask. The bottles were shaken overnight, centrifuged at high speed and filtered through a Whatman No. 41 filter. An aliquot was stored in 20 ml glass vials until concentrations of Fe, Al, and Mn were measured. Procedures for oxalate and pyrophosphate extractions followed the same basic scheme, except that about 1 g of material (weighed to the nearest mg) was used. A 0.2 M ammonium oxalate (adjusted to pH 3 with oxalic acid) and a 0.1 M sodium pyrophosphate solution, respectively, were used as extraction solutions.

The amount of finely divided, crystalline forms of Fe was estimated by the difference between citrate/dithionite- and oxalate-extraction (Ross and Wang 1993). The difference between citrate/dithionite- and oxalate-extraction was assumed to represent crystalline and amorphous forms of Mn. Noncrystalline inorganic (amorphous) forms of

Fe and Al were calculated as the difference between oxalate- and pyrophosphate-extraction. Pyrophosphate extractable fractions were assumed to represent the organic complexed forms of Fe, Al, and Mn, respectively.

4.3.7 Determination of Element Concentrations

Concentrations of Ca, Mg, Al, Fe, and Mn in the undiluted extraction solutions were analyzed simultaneously using an ICP-AES (Thermal Jarrel-Ash ICAP61 Inductive coupled plasma atomic emission spectrometer). K was measured with by AES (Varion SpectrAA-10 Atomic emission spectrometer). Standard solutions in the appropriate concentration range were prepared in a matrix of the extracting solution.

4.3.8 C/N Analysis

Carbon and nitrogen analyses were performed at the Microanalysis Laboratory at the University of Massachusetts Amherst using a 240XA Elemental Analyzer (Exeter Analytical). The instrument operates on modified Pregl-Dumas techniques which combusts a weighed sample in an atmosphere of O_2 at ~1000°C. The reaction products are swept through a reduction tube of Cu metal at 650°C in a He stream. The gases of interest (CO_2 and N_2) are quantified using thermal conductivity detectors, which have been blanked and standardized. Based on the carbon percentages, depth of horizon, and gravel content (A-horizon), the total amount of stored organic carbon per m^2 was estimated for each horizon assuming a dry bulk density of 0.9 g/cm^3 for O-horizons and 1.1 g/cm^3 for A-horizons.

4.4 Statistical Analysis

4.4.1 Vegetation

For each dominant tree species, the aspect-related differences in basal area were analyzed with Kruskal-Wallis tests, a non-parametric analog of a one-way analysis of variance. The use of this non-parametric test was applicable, since the data generally followed a non-normal distribution due to many zero values within groups (i.e. topographic position). Total basal area, total number of species, and maximum observed DBH per plot were compared by one-way analysis of variance (ANOVA) with aspect as class variable.

The overall effect of aspect on the distribution of tree species was assessed by a multiple response permutation procedure (MRPP, McCune and Mefford 1997). MRPP is a multivariate, non-parametric procedure for testing the null hypothesis of no difference between two or more groups. In contrast to Discriminant Analysis (DA), this randomization test does not require e.g. multivariate normality and homogeneity of variances (McCune and Mefford 1997). The test statistic is based on the within-group average of pairwise euclidian distance measurements, which is compared to the null distribution derived from random assignments of objects into groups of the same size (Zimmermann et al. 1985).

A TWINSPAN (Two Way Indicator Species Analysis) analysis was performed on the complete vegetation data (combined strata) in order to determine if the three topographic positions can be differentiated based on vegetation. TWINSPAN is a polythetic, divisive classification technique, which utilizes presence/absence data of species in several abundance classes (concept of 'pseudospecies', McCune and Mefford 1995). It is based on reciprocal averaging which ordinates sample sites based on their similarity and simultaneously classifies species and sites into groups (Smith 1995). Contrary to discriminant analysis techniques like DA or MRPP, TWINSPAN does not require pre-defined groups.

The value of each species as indicator of north- and south-facing slope and ridgetop was assessed using Indicator Species Analysis (Dufrêne and Legendre 1997, cited in McCune and Mefford 1997). For each species, an indicator value (IV) is calculated by multiplying the relative abundance of a species in a group with the proportional frequency. The indicator values range from 0 to 100% (perfect indication). Perfect indication means, that based on the dataset, the presence of a species indicated group membership without error (McCune and Mefford 1997). The highest indicator value for each species is then evaluated with a randomization test under the null-hypothesis that the species has no indicator value (IV not larger as expected by chance). During this Monte-Carlo procedure, indicator values are calculated multiple times from randomly re-assigned groups. The obtained p-value describes the proportion of runs where the calculated IV exceeded the actual IV.

4.4.2 Soils

To evaluate potential differences in soil development resulting from slope aspect, a variety of statistical tests was performed on the data. The results of the texture analysis were examined by MRPP for the A- and B-horizons. For this test, the multiple sand and silt fractions were combined to one sand and silt fraction, respectively.

A set of MANOVA models (Multiple Analysis of Variance) was used to test for effects of aspect (independent variable) on subsets of the soil data. These subsets consisted of soil properties of the A- and B-horizons, and forms of Al, Mn, and Fe. Pillai's trace was chosen as test statistic because of its robustness to violations of assumptions (Scheiner 1993). In addition, Wilk's lambda was used to evaluate the association between aspect and soil variables with small values indicating a strong relationship.

A multivariate analysis is preferable over multiple univariate analysis since differences among groups may result from interactions between several dependent variables rather than from a single variable alone (Scheiner 1993). Furthermore, a series of univariate test may inflate the probability of a type I error (the declaration of the null hypothesis to be false when it is actually true). Contrasts were used to reveal which topographic position differs. Total canonical structure coefficients were used to evaluate which variable was responsible for the differences among groups. In addition, univariate ANOVA models were applied in cases where a significant MANOVA result was obtained. This procedure is also called 'protected framework'. (Scheiner 1993). The critical p-values was adjusted using a Bonferoni correction, that is the conventional probability level of α=0.05 was divided by the number of tests.

A set of variables was chosen for Discriminant Analysis (DA) based on their ecological importance and potential discriminating power (F-value, total structure coefficients) as judged from the MANOVA results. The purpose of Discriminant Analysis is to construct a set of classification functions that maximize differences between groups ('optimal' separation). The analysis follows procedures described in

McGarigal and Stafford (unpublished manuscript). Potential variables were checked for high pairwise correlations and, if necessary, excluded to avoid multi-collinearity problems. The classification accuracy and stability of DA were assessed by resubstitution and resampling procedures. In the resampling procedure (cross-validation), one sample is omitted and the classification is built from the remaining samples. The omitted sample is then classified and this procedure is repeated for the next sample. The correct classification rate is used to evaluate the robustness of the canonical functions. Prior probabilities of group membership were set equal to 0.33.

4.4.3 Vegetation-Soil Relationship

In order to assess the relationship between vegetation, soils and aspect, the vegetation data and a set of selected environmental parameters were subjected to canonical correspondence analysis (CCA, Ter Braak 1986). As a direct ordination technique, CCA provides information about species distribution in relation to environmental variables. The ordination based on reciprocal averaging of sample sites and species is constrained by their relationship to environmental parameters (McCune and Mefford 1997). Thus, the ordination shows only those available patterns in the vegetation data that can be explained by environmental variables. The complete vegetation data set was used for CCA and rare species were down-weighed. The set of environmental variables was chosen based on their ecological meaning. The parameter 'aspect' was included in the form of potential solar radiation. The overall performance of CCA was assessed by comparing the outcome with the results of a ordination by reciprocal averaging (CA) without environmental variables (indirect gradient analysis).

4.4.4 Limitations

In general, the acquired data fail to meet a variety of statistical assumptions and requirements. Although the locations of the transects were chosen at random, plots were located systematically since a) the distance between plots in a transect was fixed, and b) all plots were located on a single ridge. This sampling scheme has therefore a priori a strong underlying spatial auto-correlation, which violates the assumption of independent samples for the majority of statistical analysis. The relatively small sample size (35 plots in total, with 14 plots on north and south slope, and 7 on ridgetop) decreases the validity of statistical tests, especially in the case of Discriminant Analysis.

The homoscedasticity of the soil variables was evaluated using Levine's test of homogeneity of variance. The distribution of the residuals was assessed by their skewness, kurtosis, and by normal probability plots. If necessary, variables were transformed (log- or square root transformations) to improve homogeneity of variance and normal distribution of residuals (Sokal and Rohlf 1981). Almost all floristic variables were inherently non-normal, since cover data were measured in classes (categorical variables). Furthermore, many species were restricted to only one side of the ridge. Variables were also used in more than one statistical test.

Since basic assumptions and sample size requirements are not met, all statistics can only be considered as exploratory.

The statistical software packages used in the statistical analysis included SAS 6.12 (SAS Institute Inc. 1993), SYSTAT 7.0 (Wilkinson 1997), PCORD 3.0 (McCune and Mefford 1997), and CANOCO 4 (Ter Braak and Smilauer 1998).

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Modeling of Solar Radiation

The modeling results show significant differences in potential direct solar radiation for slopes with different aspect. On north-facing slopes, the yearly energy input is steadily decreasing with slope angle at low and mid-latitudes (Fig. 5.1 A). Only north of the polar circle, the potential solar radiation is independent from slope angles greater than approximately 28°. The yearly short-wave energy input for the north facing slope of the study site (42°N, 30° slope) is approximately equivalent to the energy input on a flat surface at 70° northern latitude. On slopes with southern aspect, the energy income increases with slope angle, reaches a maximum, and declines thereafter (Fig. 5.1 B). The energy-equivalent flat surface for the south-facing slope of the study site is approximately at 25° northern latitude. These results are generally comparable to those of Holland and Steyn (1975). The difference in latitudes converts to a distance of over 4,600 km. While this comparison demonstrates the importance of aspect and slope angle for energy receipts of tilted surfaces, it does not translate directly into microclimatic site conditions. The local topographic effect is moderated by the meso- and macro-scale exchange of sensible and latent heat.

The difference in potential solar radiation between a north- and south-facing slope is greatest at mid-latitudes (40°-55°) and slope angles between 50° and 70° (Fig. 5.2). Here, a north-facing slope receives less than 40 percent of solar radiation of a south-

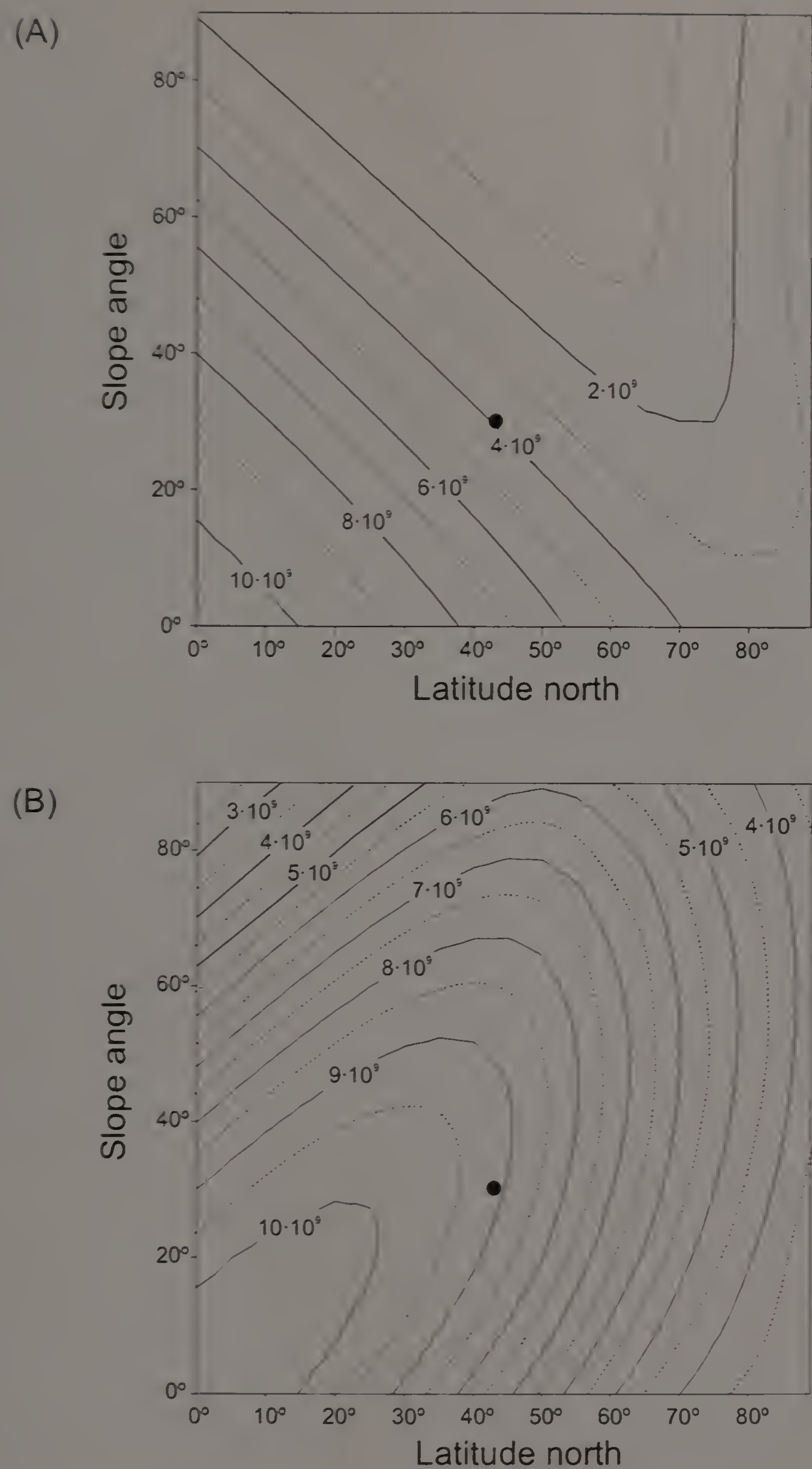


Figure 5.1. Contour plot of changes in potential solar radiation in relation to latitude and slope angle. (A) North-facing slope. (B) South-facing slope. The approximate location of the study site is marked with a black circle. Units of contour lines are in J/m^2/yr.

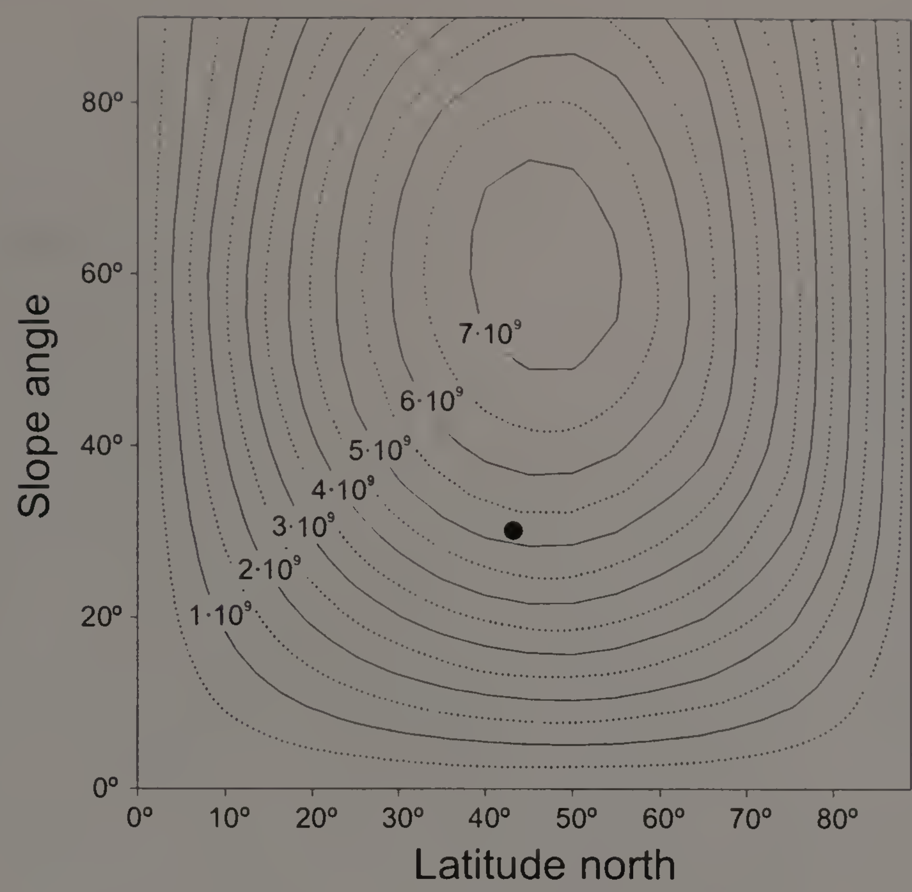


Figure 5.2. Contour plot of differences in potential solar radiation between a north- and south-facing slope in relation to latitude and slope angle. The approximate location of the study site is marked with a black circle. Units for contour lines in $J/m^2/yr$.

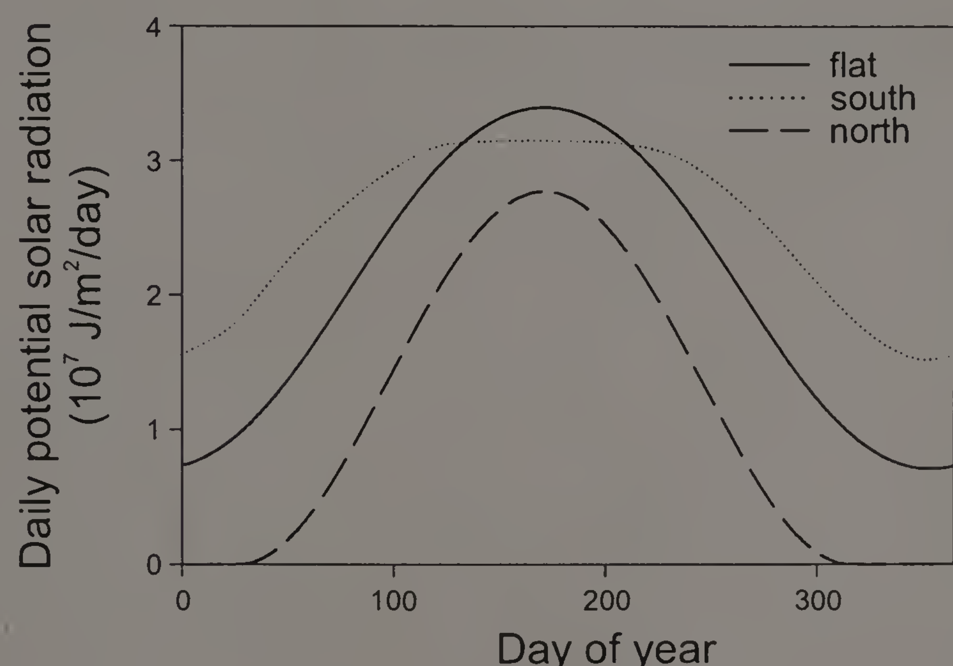


Figure 5.3. Daily variations in potential solar radiation for the study site (42°N, 30° slope).

facing slope. Opposing slope in equatorial and polar regions experience only minor differences in solar radiation, which are almost independent from slope angle.

The study site at 42° northern latitude shows a difference in potential solar radiation of $5.8 \cdot 10^9$ J/m^2/yr (southern slope: $9.3 \cdot 10^9$ J/m^2/yr, northern slope: $3.5 \cdot 10^9$ J/m^2/yr, flat area: $7.5 \cdot 10^9$ J/m^2/yr) assuming 30° slopes. The southern slope receives 23.6 % more direct solar radiation, whereas the northern slope only 53.2 % less compared to a flat area. This demonstrates that the flat area is in fact more similar to the southern slope in terms of radiative energy input.

The annual distribution of the daily shortwave energy input for the study site is shown in Fig. 5.3. During the winter months, the north-facing slope is completely shaded for about 85 days and does not receive any direct solar radiation. The south-facing slope receives the highest amount of energy in winter compared to the north facing slope and a flat area. However, the potential solar radiation in summer is highest for a flat area. Furthermore, the relative differences in potential solar radiation between these three surfaces are smallest in summer and greatest during the winter months.

5.2 Vegetation

Altogether, 113 vascular plant species were recorded in the 35 vegetation plots. Nine species (8 %) occurred exclusively on the north-facing slope, 25 species (22 %) were found only on the southern slope. Nine plant species were restricted to the top of the ridge, and 39 species (35 %) occurred on both sides of the ridge as well as on top. A large number of species (33, ≈29 %) were found in less than four of the 35 plots.

Overall, there was a significant difference in number of species per plot. Species richness was lowest on the north-facing slope and highest on the south-facing slope (Fig. 5.4 A). This was mainly caused by the rich understory and ground vegetation on the ridgetop and the southern slope. On the north-facing slope, the herbaceous layer was often very sparse and consisted only of few individuals. *Tsuga canadensis* and *Kalmia latifolia* might suppress ground vegetation through shading.

No dominant tree species except white oak (*Quercus alba*) occurred exclusive on one slope (Tab. 5.1). On the north-facing slope, the dominant trees species included black birch (*Betula lenta*), red maple (*Acer rubrum*), chestnut oak (*Quercus prinus*), and hemlock (*Tsuga canadensis*). The south-facing slope was dominated by hickory species (*Carya* sp.) and sugar maple (*Acer saccharum*). Red oak (*Quercus rubra*) occurred at high abundance on both slopes as well as on top of the ridge and had the highest basal area on all positions (Tab. 5.1.). Its ubiquitous distribution is consistent with the description of forest vegetation zones in New England by Westveld (1956), in which *Quercus rubra* occurs in several vegetation zones. The co-occurrence of *Acer saccharum,* a tree species more associated with cooler and moister conditions of the northern hardwood zone, and *Carya* species, dominant in central hardwood forests, demonstrates the transitional character of the forest vegetation on the south slope. As expected, *Tsuga canadensis* occurred in higher abundances on the north slope and had the second highest basal area after *Quercus rubra*. However, the basal area of *Tsuga canadensis* reached only 18% of the total basal area on the north-facing slope. The acidic litter produced by this coniferous species is therefore only a relatively small fraction of total litter production.

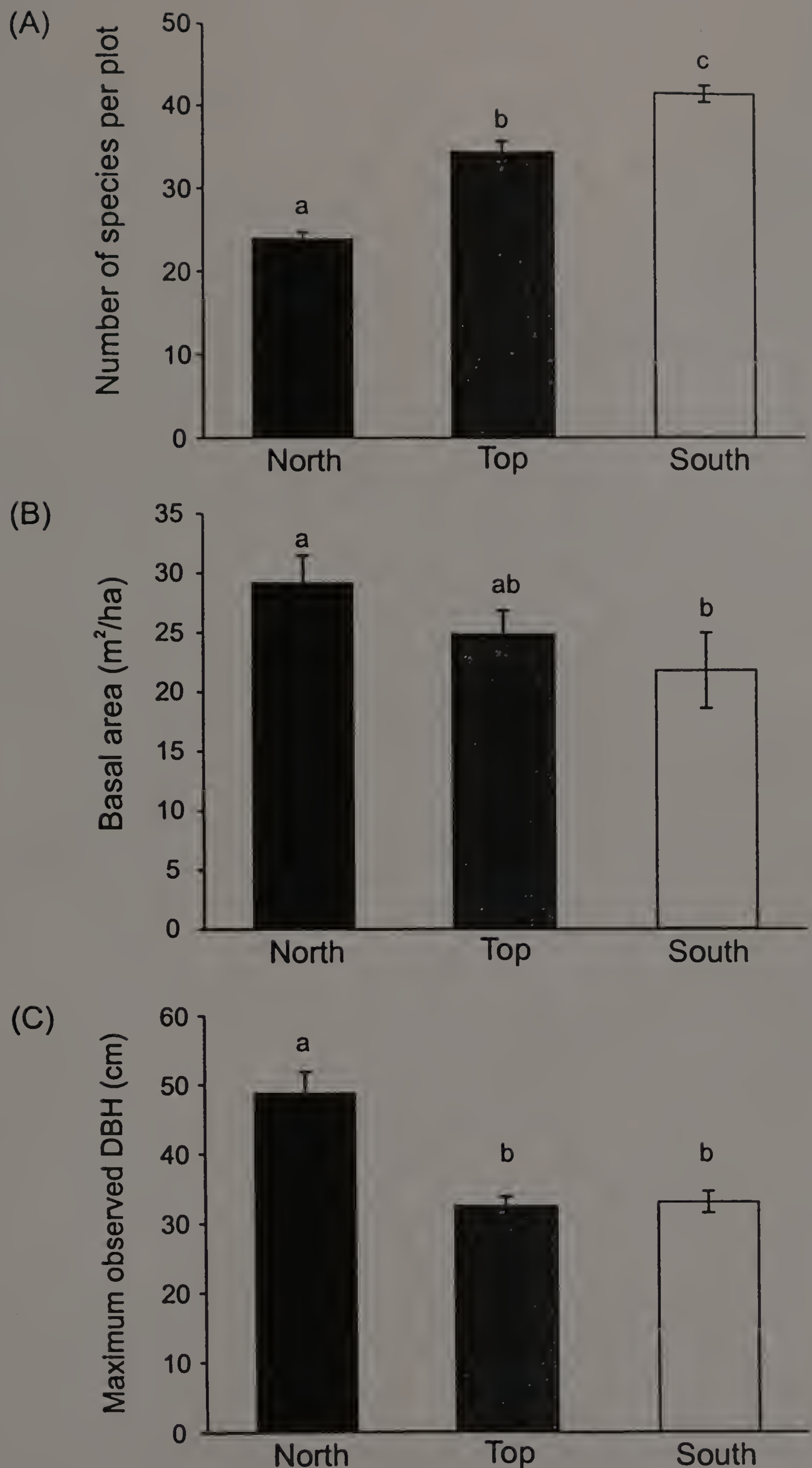


Figure 5.4. Total number of species per plot, total basal area, and maximum observed diameter at breast height (DBH). (A) Number of species, ANOVA: $F_{2,32}=27.58$, $p<0.001$. (B) Basal area, ANOVA: $F_{2,32}=4.71$, $p<0.017$. (C) Max. observed dbh: ANOVA: $F_{2,32}=18.26$, $p<0.001$. Means with the same letter did not differ ($p>0.05$, Tukeys HSD). All values are means ± 1 SE.

Table 5.1. Frequency and basal area of tree species > 5 cm dbh for north- and south-facing slope and top of the ridge. Species were included in the table if they occurred in more than three plots on at least one slope. Values for basal area are means (1 SE). P-values are based on a Kruskal-Wallis test. The overall effect of aspect was assessed by a Monte-Carlo test (MRPP).

Species	Frequency (%)			Basal area (m^2/ha)			
	N	T	S	N	T	S	P
Acer rubrum	92.9	57.1	57.1	2.870 (0.591)	1.588 (0.790)	0.346 (0.107)	0.001 **
Acer saccharum	50.0	100.0	92.9	0.701 (0.292)	5.519 (1.084)	2.944 (0.552)	<0.001 **
Betula lenta	92.9	14.3	7.1	4.827 (1.253)	0.062 (0.062)	0.019 (0.019)	<0.001 **
Betula papyrifera	28.6	0.0	14.3	1.083 (0.561)	0	0.096 (0.082)	0.202
Carya sp.	14.3	100.0	100.0	0.118 (0.098)	7.207 (2.365)	6.561 (0.780)	<0.001 **
Ostrya virginiana	50.0	100.0	71.4	0.262 (0.095)	1.168 (0.349)	0.541 (0.210)	0.024 *
Quercus alba	0.0	0.0	35.7	0	0	0.309 (0.180)	0.015 *
Quercus prinus	42.9	28.6	57.1	3.872 (1.578)	0.215 (0.177)	0.355 (0.121)	0.465
Quercus rubra	85.7	100.0	100.0	9.992 (2.571)	8.318 (2.900)	8.736 (0.983)	0.821
Tsuga canadensis	100.0	14.3	35.7	5.260 (1.937)	0.241 (0.241)	1.565 (0.739)	0.001 *

MRPP: R=0.098 (R=0 when heterogeneity within groups equals expectation by chance)

p = 0.00000133

Species groups that occurred preferentially on one part of the ridge were identified in a manually ordered vegetation table (Table 5.2). In the herbaceous layer, species like *Antennaria plataginifolia*, *Aureola flava*, *Hieracium paniculatum*, and *H. venosum* seemed to be restricted to the southern slope. Twenty-one species with frequencies higher than 10% occurred preferentially on the south-facing slope and on the top of the ridge. This group includes *Solidago* species, *Panicum dichotonum*, *Galium circaezans*, and *Carex laxiflora*. *Aster divariactus*, *Carex pennsylvanica*, and *Deschampsia flexuosa* followed the same pattern, but were also found occasionally on the north slope. A few species, including *Festuca subverticillata*, *Elymus hystix*, and *Arabis canadensis* were restricted to the top of the ridge. Only *Maianthemum canadense* occurred on both, ridgetop and northern slope. Eight species (e.g., *Aralia nudicaulis* and *Trientalis borealis*) were almost exclusively found on the north-facing slope. Twelve herbaceous species (e.g., *Dryopteris marginalis*, *Polygonatum pubescens*) with overall frequencies over 10 % did not show any pattern and occurred on both sides on the ridge. Similar species groups were also obtained by indicator species analysis (Table 5.3), although this method generally failed to reveal species groups indicative of more than one topographic position.

A TWINSPAN analysis of the calculated importance values for plants that occurred at least in four plots (80 species) showed a clear distinction between north-facing slope, ridgetop, and south-facing slope (Fig. 5.5). The first level of division separated the plots of the northern slope from the southern slope and the ridge-top based on the distribution of *Carya* sp. In the next division, plots on the north slope were further separated based on the species *Quercus prinus* and *Dryopteris intermedia*. The second

Table 5.2. Manually ordered vegetation table for the complete vegetation dataset (Braun-Blanquet cover estimates). Each stratum was ordered separately. Tree seedlings were excluded in the herabecous layer, if the species occurred in a higher stratum. Plots are grouped according to their location (south-facing slope, ridgetop, north-facing slope). Rectangles mark subjectively identified species groups.

	013 1S	013 2S	053 1S	053 2S	105 1S	105 2S	158 1S	158 2S	206 1S	206 2S	260 1S	260 2S	300 1S	300 2S	013 Top	053 Top	105 Top	158 Top	206 Top	260 Top	300 Top	013 1N	013 2N	053 1N	053 2N	105 1N	105 2N	158 1N	158 2N	206 1N	206 2N	260 1N	260 2N	300 1N	300 2N	Frequency (%)
1. Tree-layer:																																				
Carya sp.	3	2b	3		3	3	2b	3	3	3	2a	4	3	3	3	4	2b		2a	2b	2b															54.3
Quercus alba		2a	1	1	1		1					1					1																			20.0
Acer saccharum	2b	2b	1	2a	1	2b	1	2b	1	3	2a			2b	3	2b		2b	3	2b							1				2b		2b			57.1
Quercus rubra/velutina	3	2b	3	4	3	3	4	3	3	2b	4	2b	4	3	3	2a	2b	4	2b	3	5	3	2b	3	2b	2a	3	3	2b	2b	2a	3	2b	2b	1	100.0
Quercus prinus				1			2a				1							2a				4	3	4	3	2b	2b									28.6
Tsuga canadensis		2b			2b			2a					2a									1	2a		2a	3	2a	2a	2b	1				2b	1	40.0
Acer rubrum				1					1			1	1			+	3		2b	2b			2a	1	1	2a	2b		2b	4	2a	2b	2a	2a	2b	57.1
Betula papyrifera				1																								2b			3	1		1	3	17.1
Betula lenta																							1		2a	2a			3	2b	1	3	3	4	3	28.6
Prunus serotina				1																2a																5.7
Fraxinus americana			1												2a																					5.7
Fagus grandifolia																																1		1		5.7
2-Tree-layer:																																				
Ostrya virginiana	2b	+	1	3	1	3	2a		2a			2a		2a	2b	1	2a	2a	1	2b	2a	1				+	2a	1	2b	2a	2a	2a	2b			74.3
Acerccharum	2b	1	2a	3	2b	2a	2a	2a	4	2a	2b	2a	1	2a	3	2a		3	2b	2b							2a	1	2b			1			2a	68.6
Acer rubrum							2a				2a		2a	2a			2b	1		2a	2b	+	2a	2a	1	2a	2b	2b	2a	2b			+		2a	54.3
Carya sp.	2a	1	2a	1	2a	1	2a				1	1	2a		2a	1	1	2a	1	2a							2b							1		51.4
Quercus prinus			+		1	+		1		2a												+	+	2b												22.9
Fagus grandifolia												1	1																			2a			2a	11.4
Betula lenta														2a							1		1		2a	2a	2a	2a			2a			1	1	28.6
Tsuga canadensis																					2a		3	2b	4	+	3		1	2a	2a				2a	28.6
Acer pennsylvanicum																						1	+	1	+			3			2a	1	2a			22.9
Quercus rubra/velutina			1																				1	1	+			+								14.3
Betula papyrifera													1												1									2a	1	11.4
Quercus alba							1			1		1																								8.6
Pinus strobus	1																				2a															5.7
Castanea dentata																																	+			2.9

Continued, next page

Table 5.2 continued.

	013 1S	013 2S	053 1S	053 2S	105 1S	105 2S	158 1S	158 2S	206 1S	206 2S	260 1S	260 2S	300 1S	300 2S	013 Top	053 Top	105 Top	158 Top	206 Top	260 Top	300 Top	013 1N	013 2N	053 1N	053 2N	105 1N	105 2N	158 1N	158 2N	206 1N	206 2N	260 1N	260 2N	300 1N	300 2N	Frequency (%)
Shrub-layer:																																				
Ostrya virginiana	2a	1	1		1	1	1	2a	2a	2a	2a	+	1	+	2a	1	3	2a	+	1	1	+		r	r		+	1	+		+		1			80.0
Acer pennsylvanicum		r			r		r		r	1	+									+	1	+	1	1	+	1	1	+	1	2a	1	2b	1	1	2a	62.9
Acer saccharum	1	+	+		2a	1	2a	1	2a	1		2a		+	+	1		+	1	1							+		1							51.4
Viburnum acerifolium		r				r		1	+	1	+	1	1					+		+	+	2a		+		+	+	+							+	48.6
Corylus americana	r	r								+					r							+	+				+				+			+		25.7
Betula lenta					r		r	+												1	+			2a								+				20.0
Fagus grandifolia					r			+					2a								+											1		+		17.1
Amelanchier cf. arborea		1			r				+														+							1						14.3
Carya sp.			1	2a	1	+	2a	1	1	1		1	1		+			1			+															37.1
Quercus alba	+	r	+		+		+				1										1															20.0
Prunus serotina		r							r									+			r															11.4
Kalmia latifolia							r	r			+		1				r				1	3	3	2a	2a			+	1			2a	1	3	2b	45.7
Hamamaelis virginiana														1									+		+	+	+	1	1	2a		2a	2a	1	2a	34.3
Rhododendron sp.					r						+										1	1		1		+						r		+	+	25.7
Tsuga canadensis																							1	+	1					2a		1		+		17.1
Acer rubrum																								1			+			1	+					11.4
Castanea dentata																															1		1		1	8.6
Quercus rubra/velutina															+			+				+														8.6
Fraxinus americana				r	r																															5.7
Prunus virginiana																	r																			2.9
Herbacous layer:																																				
Antennaria plataginifolia	1	1	2a	1	1	1	+	1	+	1	1	+		1																						37.1
Aureola flava	+	+				+		1	1	1	1	+	+																							25.7
Hieracium paniculatum		1				+	1	1	1	1		1	+	1																						25.7
Hieracium venosum			+		1	+	+			+		1	+																							20.0
Senescio obovatus	1	+	+			+		1		1				1																						20.0
Desmodium nudiflorum	+			+		+		+	+	+	1	+		1																						25.7
Conocephalum americanum		+	r			r			r					r																						14.3
Aster undulatus		+	+			1		+		1																										14.3
Asplenium platyneuron	r	+			r			r																												11.4
Aster patens		r				+					+			+																						11.4
Parthenocissus quinquefolia				r	r							r																								8.6
Aureola virginica			r				r			+																										8.6
Vitis sp.				r				r						r																						8.6
Cornus rugosa							+							r																						5.7
Crataegus sp.			+									+																								5.7
Adiantum pedatum	r							+																												5.7
Specularia perfoliata				+				+																												5.7
Hypericum sp.					r			r																												5.7
Mitchella repens	r								+																											5.7
Luzula multiflora	r												+																							5.7

Table 5.2 continued.

	013 1S	013 2S	053 1S	053 2S	105 1S	105 2S	158 1S	158 2S	206 1S	206 2S	260 1S	260 2S	300 1S	300 2S	013 Top	053 Top	105 Top	158 Top	206 Top	260 Top	300 Top	013 1N	013 2N	053 1N	053 2N	105 1N	105 2N	158 1N	158 2N	206 1N	206 2N	260 1N	260 2N	300 1N	300 2N	Frequency (%)
Solidago ulmifolia																																				54.3
Solidago sp.																																				54.3
Solidago caesia																																				48.6
Galium circaezans																																				48.6
Panicum dichotomum																																				45.7
Hepatitis americana																																				45.7
Carex laxiflora																																				40.0
Potentilla sp.																																				37.1
Viola palmata																																				31.4
Aster sp.																																				28.6
Carex rosea																																				20.0
Panicum commutatum																																				22.9
Geranium maculatum																																				20.0
Uvularia sessilifolia																																				20.0
Danthonia spicata																																				17.1
Carex sp.																																				17.1
Muhlenbergia sp.																																				17.1
Solidago flexicaulis																																				14.3
Uvularia perfoliata																																				11.4
Lysimachia quadrifolia																																				11.4
Aster divaricatus																																				71.4
Carex pennsylvanica																																				68.6
Deschampsia flexuosa																																				62.9
Festuca subverticillata																																				20.0
Elymus hystix																																				14.3
Veronica officinalis																																				11.4
Poaceae																																				11.4
Arabis canadensis																																				8.6
Campanula rotundifolia																																				8.6
Bromus latiglomis																																				5.7
Poa compressa																																				5.7
Maianthemum canadense																																				40.0
Aralia nudicaulis																																				51.4
Trientalis borealis																																				40.0
Dryopteris intermedia																																				25.7
Lonicera sp.																																				22.9
Polypodium vulgare																																				20.0
Gaylussacia baccata																																				17.1
Huperzia lucidula																																				17.1
Gaultheria procumbens																																				11.4

Table 5.2 continued.

	013 1S	013 2S	053 1S	053 2S	105 1S	105 2S	158 1S	158 2S	206 1S	206 2S	260 1S	260 2S	300 1S	300 2S	013 Top	053 Top	105 Top	158 Top	206 Top	260 Top	300 Top	013 1N	013 2N	053 1N	053 2N	105 1N	105 2N	158 1N	158 2N	206 1N	206 2N	260 1N	260 2N	300 1N	300 2N	Frequency (%)
Dryopteris marginalis	1	+		+	+	+	+	1		+				+	1	+	+		r	+		+	1	1		+	1	1	1	1	1	1	2a	1	1	77.1
Polygonatum pubescens	+		+	+	+	+	+	+	+				+	+	1	1	1	1	1	+	r	+		+			+	+	+	r	+	1				71.4
Monotropa uniflora	1	+	1	+	+	+	+	+	+	+	+	+	+	r	1	r			+	+	1						+		r		+		+			65.7
Vaccinium angustifolium	+		+		1	+	1	1	+	+	1	3	1	+	1		+	+		1	1	2b	r	2a	+	1								1	r	68.6
Smilancia racemosa			+	+				+	+	+	+			+		+	1	1	+	+				+				r		r		+			+	48.6
Polypodium acrostichoides	+	+		+		[illegible]	+	1		1	r			+					1								1		1	1	2a	+	1		+	48.6
Vaccinium pallidum	2a		2a		1	1			+	+	+	+						+				+	1		+		+									37.1
Amelanchier cf. arborea				+		+	+		+			+	+	r					+	+	+			+							r			+		37.1
Viola sp.								+	+	+	+							+						+			1		+	r	+		1		1	34.3
Vaccinium stamineum		+	+	1							+	+	1											+	+			r								25.7
Carex platyphylla					[illegible]					1					+							+											r			14.3
Rosa sp.		+	r	r																r								r								14.3
Dennstaedia punctilobata				r							1																				+					8.6
Melampyrum cf. lineare																						+		1		+										8.6
Lycopodium obscurum																											r						r			5.7
Viburnum sp.																		r											r							5.7
Chimaphila maculata											+									+																5.7
Rubus sp.														+																						2.9
Lespedeza sp.					+																															2.9
Convolvulus sp.																	r																			2.9
Symphoricarpus albus																					+															2.9
Scirpus verecundus																		+																		2.9
Comptonia peregrina												r																								2.9
Diervilla lonicera																								r												2.9
Osmunda cf. claytoniana																															+					2.9

Table 5.3. Importance values (IV) of plant species based on abundance and frequency. The significance (p-value) of the largest IV value is inferred from randomization test (n=1000). Topographic position with highest IV are shaded. Only species with significant ($p<0.05$) importance values > 50 are included.

Species	North	Top	South	p
Trientalis borealis	88	0	0	0.001
Aralia nudicaulis	81	1	2	0.001
Betula lenta (tree)	77	6	2	0.001
Hamamaelis virginiana	76	0	2	0.001
Tsuga canadensis	73	4	7	0.001
Acer pennsylvanica	62	22	16	0.001
Lonicera sp.	57	0	0	0.001
Kalmia latifolia	53	4	3	0.009
Festuca subverticillata	0	83	0	0.001
Elymus hystix	0	71	0	0.001
Polygonatum pubescens	13	50	20	0.004
Maianthemum canadense	16	55	0	0.007
Carex pennsylvanica	1	53	41	0.001
Carya sp. (tree)	0	43	54	0.001
Betula lenta (shrub layer)	0	43	54	0.001
Antennaria plantaginifolia	0	0	93	0.001
Panicum dichotomum	0	6	80	0.001
Potentilla sp.	0	1	80	0.001
Desmodium nudiflorum	0	0	64	0.001
Hieracium paniculatum	0	0	64	0.001
Deschampsia flexuosa	5	12	58	0.001
Aureolaria flava	0	0	64	0.002
Quercus albus	0	18	58	0.002
Senecio obovatus	0	0	50	0.002
Hieracium venosum	0	0	50	0.003
Monotropa uniflora	3	27	50	0.006

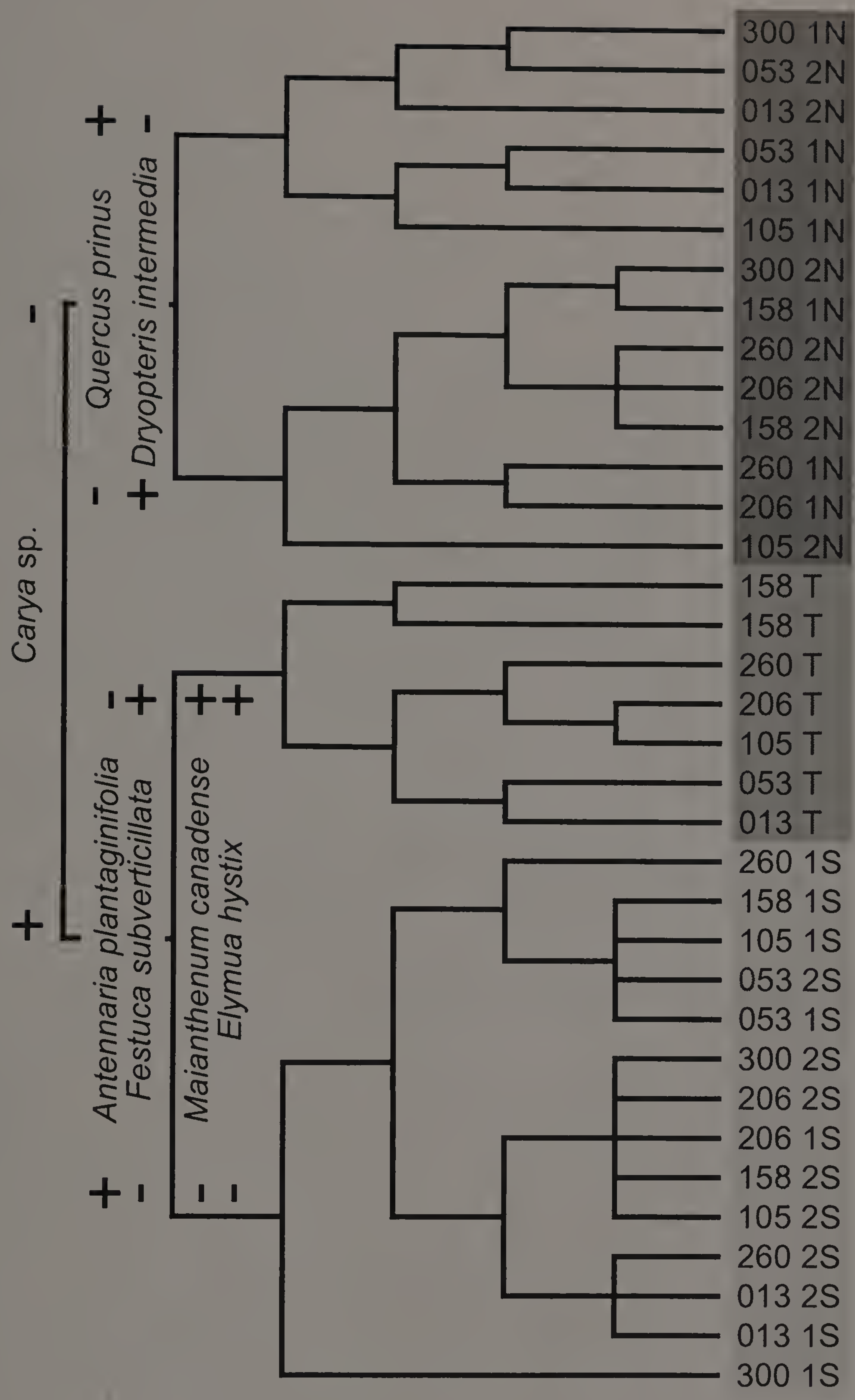


Figure 5.5. Dendrogram of site hierarchy resulting from TWINSPAN analysis. For the first two levels, indicator species (the most preferential species) responsible for the division are shown. Cutlevels for pseudospecies are 0, 1, 2, 3, 6, 9, 12, and 15; maximum level of division = 5, minimum group size = 3. Only species abundant in at least 4 plots are included. Shading indicates topographic position.

divison also differentiated plots on the southern from those of the ridgetop. The indicator species for this step were all herbaceous plants, namely *Antennaria plataginifolia*, which occurred preferably on the south-facing slope, and *Festuca subverticillata*, *Elymus hystix*, and *Maianthemum canadense*, which were more abundant on the ridgetop. Closely associated with the ridgetop was also *Carex pennsylvanica*, which was often found in dense patches of several square meters. More light penetration at the more exposed ridgetop and higher windspeeds resulting in drier conditions may explain the preferential occurrence of grasses and sedges on the ridgetop.

The observed scheme of divisions in TWINSPAN was consistent for several different cut levels in TWINSPAN. However, other species (*Trientalis borealis*, *Betula lenta*, and *Aralia nudicaulis*; all preferential to the northern aspect) were in some cases added to the indicator species for the first division. The grouping of species agreed well with the manually ordered vegetation table (Table 5.2).

There was a significant difference in the total basal area of tree species (DBH > 5 cm) between the three topographic positions (Fig. 5.4 B). Sites on the north slope had a significantly higher total basal area than plots on the south slope. Similarly, the maximum observed diameter at breast height (DBH) was significantly greater on the north-facing slope (Fig. 5.4 C). No differences were observed in mean DBH (north: 15.9 (0.7); south: 14.8 (0.6) cm; top: 15.1 (0.4) cm; values are means (SE); ANOVA: $F_{2,32}$=0.429, p=0.429). The difference in total basal area raises questions about the influence of disturbance on the vegetation of Ox Hill. The higher basal area of the north-facing slope seems to be an effect of a few tall trees rather than an effect of increased productivity. It is likely that top and south slope experienced some kind of disturbance, probably fire, cutting, or both. In New England, human impact caused significant disturbances and shifts in biotic communities, so that modern vegetation is compositionally distinct from pre-colonial vegetation and could bear little resemblance to historical forest composition (Foster et al. 1998, Foster and Zebryk 1993). Human impact over the last 200 years may have weakened of the tight vegetation-climate relationship and increased the similarity of vegetation across sites. Although direct human impact was most likely restricted to cutting (no agricultural activity), it may have changed forest composition from that of 200 years ago. Depending on the response time of the soil system to the 'recovering' vegetation, the observed differences in the soil properties of Ox Hill might be the result of former vegetation types with little relationship to the actual vegetation. Furthermore, a complete clearcut could have had pronounced impact on soils through increased surface runoff and soil erosion. The importance of human impact on forest composition is shown by Aude and Lawesson (1998) in Denmark, where management-related parameters explained more floristic variation within beech forests than soil or microclimatic variables.

5.3 Soils

5.3.1 Site Characteristics and Soil Morphology

Measured slope angles on both sides of the ridge were in most cases above 25° (= 46%). The north-facing slope was slightly steeper than the south-facing slope (31.4° (1.1) vs. 26.1° (0.7); values are means (SE)). Signs of soil creep as curved bases of tree stems and oriented rock fragments were visible on both sides on the ridge. At some pedons on the north-facing slope, a surface layer of rock debris originating from rock outcrops was intermixed with the O-horizon. Mound-and-pit microtopography caused by tree uprooting was commonly observed. The occurrence of worm casts on top of the A-horizons seemed to be restricted to the south slope.

The most common observed sequence of soil horizons was Oi-A-Bw-R. In general, the pedons were very shallow and skeletal. Estimated rock fragments reached from 20 to 80 % on the slopes, only soils on top of the ridge showed a noticeably lower content of coarse fragments. Cobbles and stones consisted of flat, angular pieces of conglomerate and rounded to sub-rounded pieces of igneous and metamorphic rocks, indicating the presence of till.

Only a few morphological differences were observed between north and south slope. On average, the A-horizons were deeper on the south-facing slope than on the north-facing slop, while O-horizons were thicker on the north-facing slope. However, there was no significant difference in total depth (ANOVA, $F_{2,32}=2.60$, $p=0.089$). Mean depth was for soils on the north slope 35.5 cm (3.1); top: 32.8 (5.3) cm; and south slope 47.6 cm (5.7); values are means (SE). One notable exception was found on the south slope, where one pedon had a total depth of 93 cm. The lowermost horizon of this pedon had a olive brown color (2.5 Y 4/4 Munsell color notation) and was designated as a Cr horizon.

No striking differences were found in soil colors. Moist colors for A-horizons varied between very dark gray (10 YR 3/1), which was preferentially found on the north side, and predominantly (very) dark brown (10 YR 2/2, 10 YR 3/2) on top and the south slope. Colors of B-horizons were generally dark yellowish brown and did not differ with respect to aspect. In some cases dark brown colors (7.5 YR 3/4 and 10 YR 3/3) were recorded.

5.3.2 Classification

Twenty-four of the 35 described pedons had a lithic contact within 50 cm. Eighteen of them fulfilled the requirements of a cambic horizon (i.e. cambic properties in a horizon over 15 cm thick) and were classified as Lithic Dystrudepts (Soil Survey Staff 1998). The other six pedons did not have a cambic horizon and were classified as Lithic Udorthents. Ignoring the lithic contact, six of these 24 pedons (all on the north-facing slope) would also meet the requirements for a Spodic Dystrudept (Al + ½ Fe [oxalate] > 0.25% and half or less in an overlying horizon). The remaining 11 pedons (8 from the south slope, 2 from the north slope, and one from the top) had a lithic contact below 50 cm and were classified as Typic Dystrudepts.

5.3.3 MANOVA

A summary of the MANOVA results and the univariate ANOVA models including posthoc test (Tukeys HSD) are listed in Tables 5.4 to 5.6. The MANOVA analysis of soil variables of the O- and A-horizons showed a highly significant overall difference between the three topographic positions ($F_{[\text{Pillai's trace}]} = 3.853$, $p<0.0001$, Table 5.4). The contrast statements revealed that this difference is greatest between north slope and top of the ridge ($F_{[\text{Pillai's trace}]} = 5.232$, $p=0.0001$), and lowest between south slope and top of the ridge. ($F_{[\text{Pillai's trace}]} = 3.482$, $p=0.022$). This resembles the results of the vegetation analysis, which showed a marked contrast between north and south slope, and

Table 5.4. MANOVA results for variables of A- and O-horizons. Variables found to be significant under the adjusted critical p-value are dark shaded, variables significant at p=0.05 are light shaded.

	F	p
overall	3.853	0.000
N-S	3.449	0.010
N-T	5.232	0.001
S-T	3.482	0.022

Wilk's lambda: 0.032

	CAN1	CAN2
squared can. correlation	0.864	0.761
relative percent variance	0.667	0.333

	total canonical structure		univariate ANOVA		Tukeys HSD		
Variable	**CAN 1**	**CAN 2**	$F_{(2,32)}$	p	**N-S**	**N-T**	**S-T**
depth O-horizon	0.130	0.519	4.49	0.019	+		
C/N O-horizon	0.789	0.162	20.15	0.000	+	+	
total carbon O-horizon	0.238	0.602	7.83	0.002	+		
pH ($CaCl_2$) O-Horizon	-0.455	-0.486	8.93	0.001	+	+	
depth A-horizon	-0.326	-0.339	3.49	0.042	+		
C/N A-horizon	0.699	0.142	12.43	0.000	+	+	
total carbon A-horizon	-0.508	-0.170	5.19	0.011	+	+	
pH ($CaCl_2$) A-Horizon	-0.138	-0.551	5.26	0.011	+		
% clay	0.617	-0.017	7.85	0.002		+	
exchangeable K	0.157	-0.060	0.40	0.677			
exchangeable Mg	0.027	0.144	0.27	0.768			
exchangeable Ca	0.058	-0.151	0.33	0.720			
exchangeable Al	0.272	0.634	9.38	0.001	+		
exchangeable Fe	0.573	0.617	21.59	0.000	+	+	
exchangeable Mn	-0.622	-0.082	8.23	0.001	+	+	
CEC	0.227	0.491	4.72	0.016	+		
base saturation	-0.096	0.460	3.25	0.052			
total carbon	0.062	0.575	5.59	0.008	+		+

Bonferroni corrected p-value: 0.0028

Table 5.5. MANOVA results for variables of the B-horizon. Variables found to be significant under the adjusted critical p-value are dark shaded, variables significant at p=0.05 are light shaded.

	F	p
overall	3.364	0.002
N-S	3.116	0.018
N-T	2.626	0.027
S-T	2.139	0.064

Wilk's lambda: 0.216

	CAN1	CAN2
squared can. correlation	0.584	0.602
relative percent variance	0.653	0.398

	total canonical structure		univariate ANOVA		Tukeys HSD		
Variable	**CAN 1**	**CAN 2**	$F_{(2,32)}$	p	N-S	N-T	S-T
% clay	-0.144	0.778	6.97	0.003		+	+
pH ($CaCl_2$)	-0.396	-0.047	1.64	0.211			
exchangeable K	0.181	0.129	0.45	0.643			
exchangeable Mg	0.246	-0.118	0.70	0.504			
exchangeable Ca	0.387	-0.074	1.59	0.220			
exchangeable Al	0.194	-0.175	0.61	0.550			
exchangeable Fe	0.460	-0.231	2.81	0.075			
exchangeable Mn	-0.512	-0.263	3.66	0.037		+	
CEC	0.334	-0.162	1.35	0.273			
base saturation	0.275	0.061	0.77	0.472			

Bonferroni corrected p-value: 0.005

Table 5.6. MANOVA results for extraction data. Variables found to be significant under the adjusted critical p-value are dark shaded, variables significant at p=0.05 are light shaded.

	F	p
overall	8.094	0.000
N-S	6.012	0.000
N-T	8.881	0.000
S-T	9.511	0.001

Wilk's lambda: 0.005

	CAN1	CAN2
squared can. correlation	0.972	0.955
relative percent variance	0.625	0.375

	total canonical structure		univariate ANOVA		Tukeys HSD		
Variable	**CAN 1**	**CAN 2**	$F_{(2,32)}$	p	**N-S**	**N-T**	**S-T**
crys. Fe A-horizon	-0.125	0.648	10.57	0.000	+		
cyrs. Fe B-horizon	-0.443	0.167	4.27	0.023			+
amorphous Fe A-horizon	0.225	0.267	2.03	0.148			
amorphous Fe B-horizon	0.268	-0.135	1.48	0.243			
org. bound Fe A-horizon	0.543	-0.141	6.75	0.004		+	+
org. bound Fe B-horizon	0.237	-0.522	6.90	0.003	+		+
amorphous Al A-horizon	-0.080	0.557	6.52	0.004	+		
amorphous Al B-horizon	0.353	0.016	2.14	0.134			
org. bound Al A-horizon	0.473	0.689	29.03	0.000	+	+	
org. bound Al B-horizon	0.515	-0.489	14.13	0.000	+		+
crys. Fe ratio	0.401	0.328	5.34	0.010		+	
amorphous Fe ratio	0.005	0.245	0.92	0.408			
org. bound Fe ratio	0.304	0.383	4.54	0.018		+	
amorphous Al ratio	-0.163	0.547	6.78	0.004	+		
org. bound Al ratio	-0.041	0.794	21.83	0.000	+	+	
crys. Mn A-horizon	0.247	0.304	2.65	0.086			
crys. Mn B-horizon	0.382	0.102	2.76	0.079			
org. bound Mn A-horizon	0.530	0.416	11.73	0.000	+	+	+
org. bound Mn B-horizon	0.454	0.111	4.14	0.025		+	+
crys. Mn ratio	0.073	0.411	3.03	0.062			
org. bound Mn ratio	0.316	0.598	11.63	0.000	+	+	

Bonferroni corrected p-value: 0.002

some similarity of ridgetop and south slope. The squared canonical correlation, which expresses how much of the total variation is due to group differences equals 0.86 for the first canonical variate, and indicates a strong relationship between groups and canonical function. This first canonical variate accounts for over 67% of all explainable variation by the MANOVA model. The following variables are correlated with the first canonical function (total canonical structure coefficients > 0.5): C/N-ratio of O- and A-horizon, pH ($CaCl_2$) of the O-horizon, and exchangeable Fe and Mn.

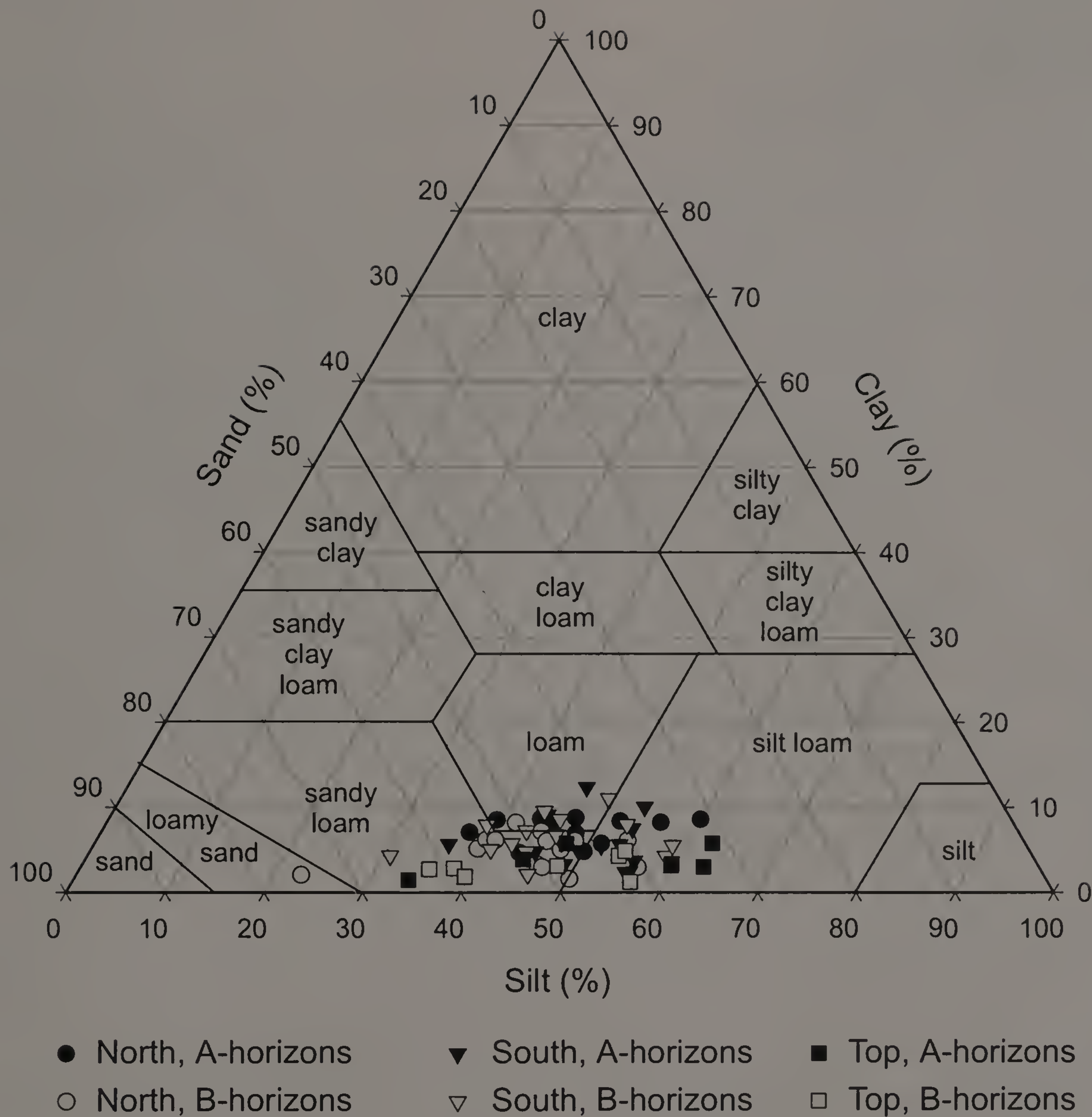
MANOVA also revealed a significant multivariate effect of aspect for properties of the B-horizon ($F_{[Pillai's\ trace]} = 3.364$, p=0.0023, Table 5.5), although no variable except clay content was significant under univariate ANOVA models with the Bonferroni-corrected critical p-value. However, the low squared canonical correlation of 0.58 is indicating that there is considerable variation within groups. The weak relationship between aspect and properties of B-horizons is also demonstrated by a relatively high Wilk's lambda statistic of 0.216. The contrast statements showed that there is no difference between the south slope and ridge-top for the tested variables.

On the Fe, Al, and Mn extraction subset, the Pillai's trace test statistic was 8.09, resulting in a highly significant p-value of 0.0001 (Table 5.6). Subsequent contrast procedures showed that all three topographic positions were highly significantly different. The squared canonical correlation coefficient of 0.97 for the first canonical variate showed that much of the total variation is caused by group differences. Especially the organically bound forms of Fe, Al, and Mn along with crystalline Fe and amorphous Al were highly correlated with the canonical functions.

The large number of variables caused a very small critical p-value in the univariate ANOVA models. This conservative approach drastically reduced the number of soil variables that vary significantly across the ridge. Nevertheless, meaningful trends were also found in variables, which failed to be significant under the strict conditions but would show significance when tested alone.

5.3.4 Texture

Almost all soil textures fell within the sandy loam, loam and silt loam classes (Fig. 5.6). Only one sample classified as loamy sand. The clay content was usually less than 10 percent. Variations in sand and silt content were much higher and ranged generally from 35 to 60 % for the silt fraction and 30 to 65 % for the sand fraction. The high silt content indicates the presence of a windblown component deposited after deglaciation. An aeolian mantle is a typical feature for most upland soils in Massachusetts (Fletcher 1979). The MRPP randomization test revealed no difference in texture in A-horizons among top, north- and south slope (p=0.107). However, MRPP indicated a difference in texture for B-horizons (p=0.035). This might be caused by differences in clay content. An analysis of the clay percentages with ANOVA showed that soils on top of the ridge had significantly lower clay contents in all horizons (Fig. 5.7). Furthermore, the mean clay content of soils on the north slope decreased with depth, whereas on the south slope clay percentages tended to increase slightly with depth.



MRPP results:	A-horizons:	p = 0.107	R = 0.035
	B-horizons:	p = 0.035	R = -0.004

Figure 5.6. Textural triangle with USDA fine earth textural classes and MRPP results for differences in topographic position. Open symbols mark samples from B-horizons, filled symbols from A-horizons. MRPP: R=chance corrected within-group agreement, R=0 when heterogeneity within groups equals expectation by chance. p=probability of a smaller test statistic.

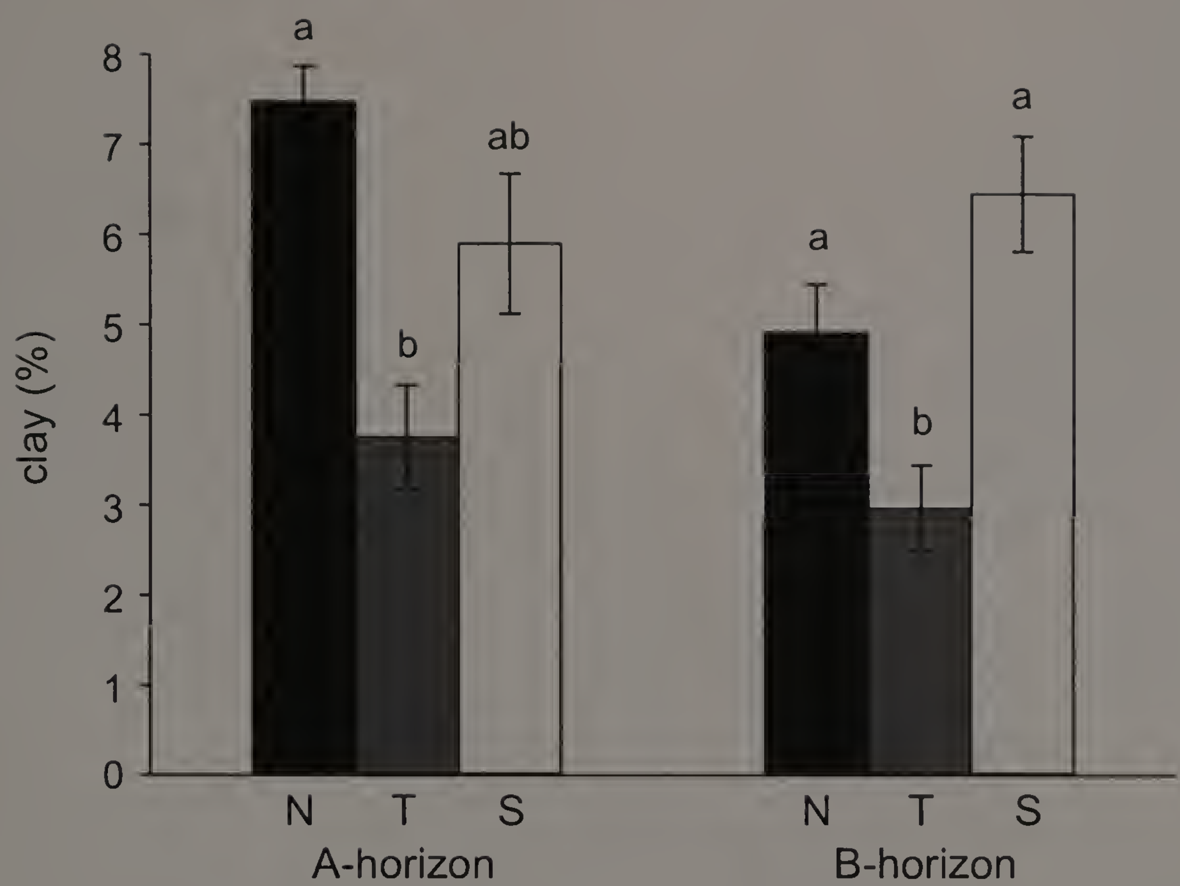


Figure 5.7. Clay content of A- and B-horizons. Values are means ± 1 SE. Means with the same letter did not differ (p>0.05 Tukey; ANOVA model with adjusted p-value).

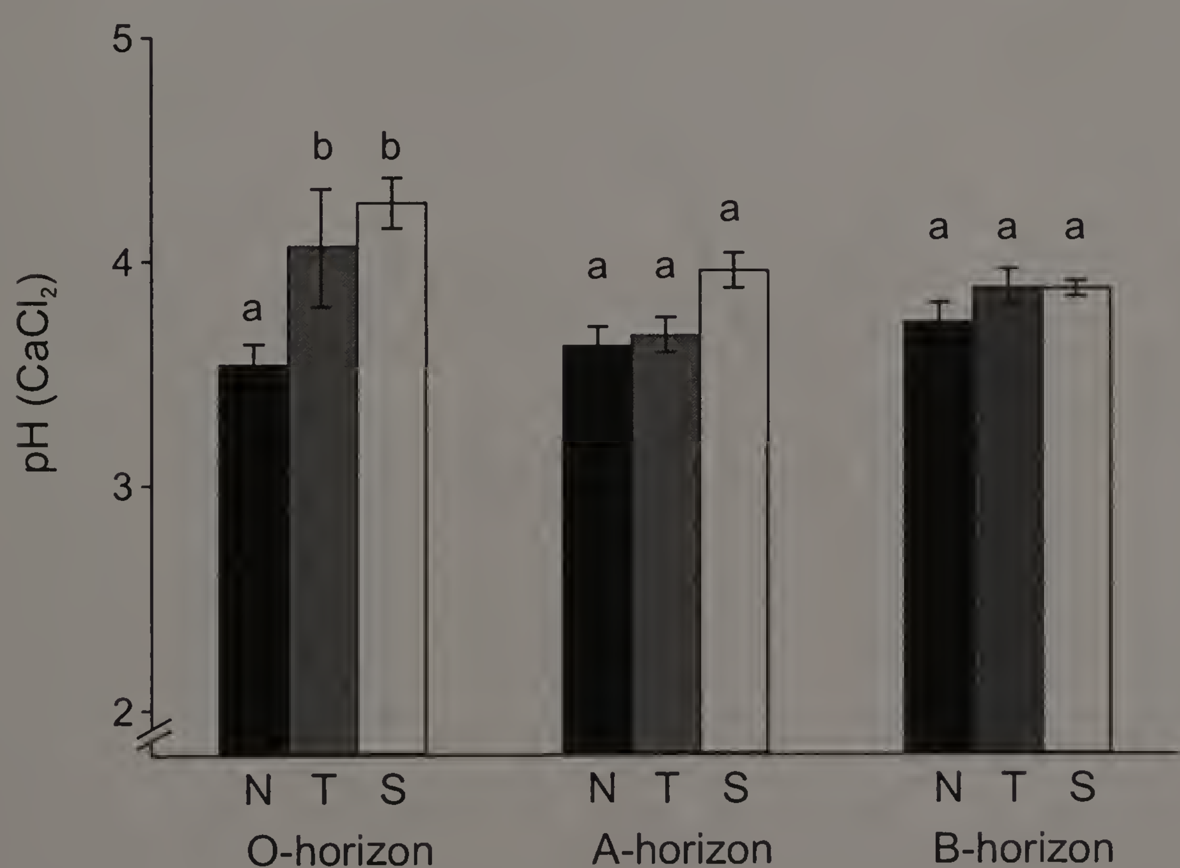


Figure 5.8. pH ($CaCl_2$) of O-, A-, and B-horizons. Values are means ± 1 SE. Means with the same letter did not differ (p>0.05 Tukey; ANOVA model with adjusted p-value).

5.3.5 Soil Reaction and Extractable Acidity

Soil pH (H_2O) of all soil horizons were in most cases very strongly to extremely acidic (pH 3.8-5.2). The pH ($CaCl_2$) of O- and A-horizons differed significantly between topographic position, but no significant difference was found for soil reactions of the B-horizons (Fig. 5.8). On the north-facing slope, the mean pH was more than 0.7 units lower in the O-horizons, and 0.4 units less in A-horizons than the respective pH values on the southern slope.

The amounts of exchangeable Al and Fe (the two most important cations determining extractable acidity), were significantly higher in the A-horizons of the north slope (Fig. 5.9.) than on the south-facing slope (Al: 4.5 vs. 2.9 cmol(+)/kg; Fe: 0.5 vs. 0.1 cmol(+)/kg). Interestingly, the mean amount of exchangeable Mn in A-horizons of the ridgetop (0.30 cmol(+)/kg) was more than ten times higher than in soils on either slope. No significant differences in exchangeable amounts of Al, Fe and Mn were found for B-horizons.

5.3.6 CEC, Base Saturation, and Exchangeable Base Cations

The cation exchange capacity of the A-horizons was highest on the north-facing slope (7.4 cmol(+)/kg, Fig. 5.10) and lowest on the south-facing slope (5.3 cmol(+)/kg). However, under the adjusted p-value in the protected MANOVA framework, there was no significant difference in CEC between topographic positions (ANOVA, $F_{2,32}=4.72$, $p=0.016$). In the B-horizons, CEC_{eff} was similar among top, north and south slope with a value of around 2.6 cmol(+)/kg. The values for effective CEC were considerably lower than values for CEC obtained in a buffered system (see e.g. Bodine 1986). This indicates

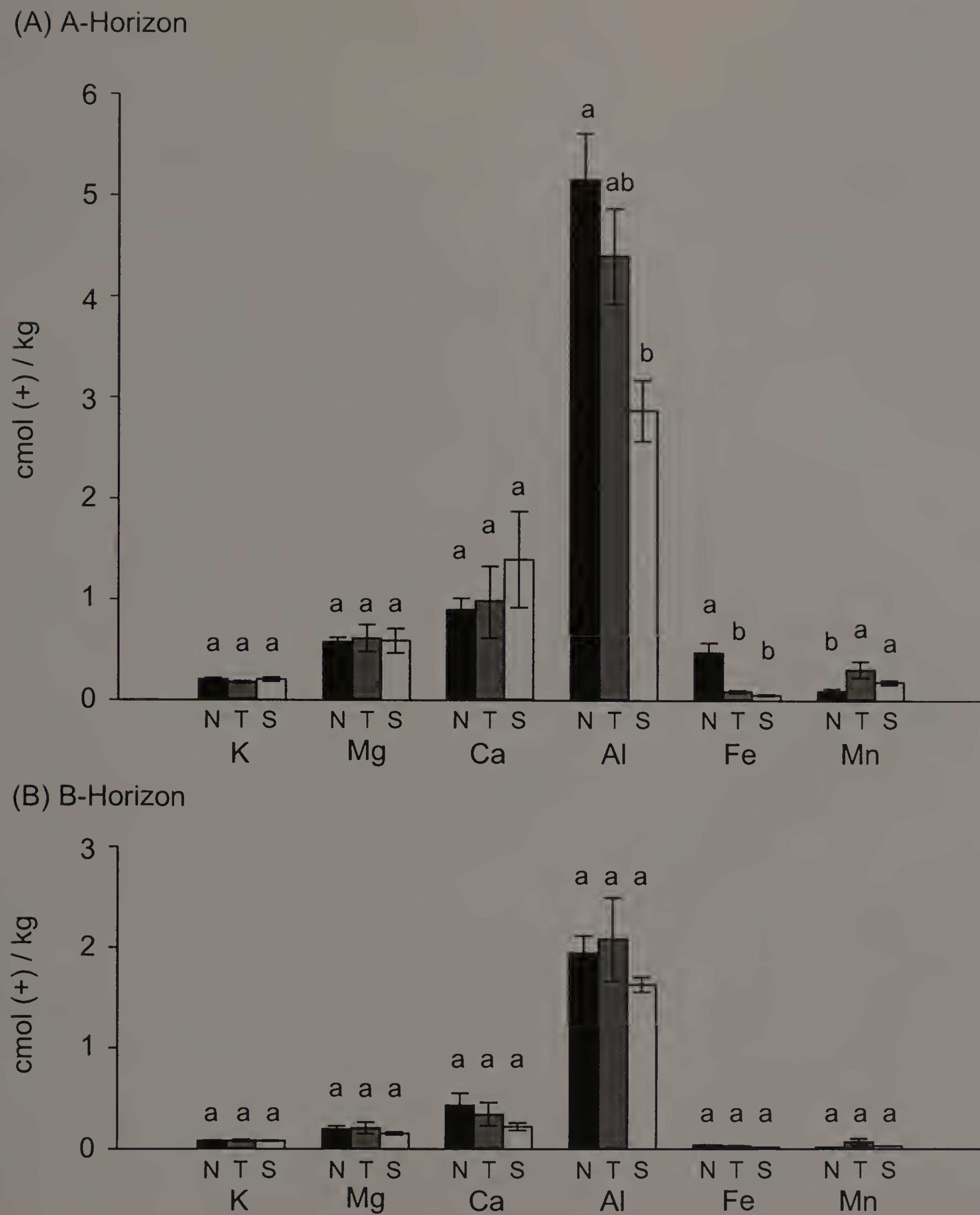


Figure 5.9. Exchangeable cations ($BaCl_2$-method). (A) A-horizons. (B) B-horizons. Values are means ± 1 SE. Means with the same letter did not differ (p>0.05 Tukey; ANOVA model with adjusted p-value).

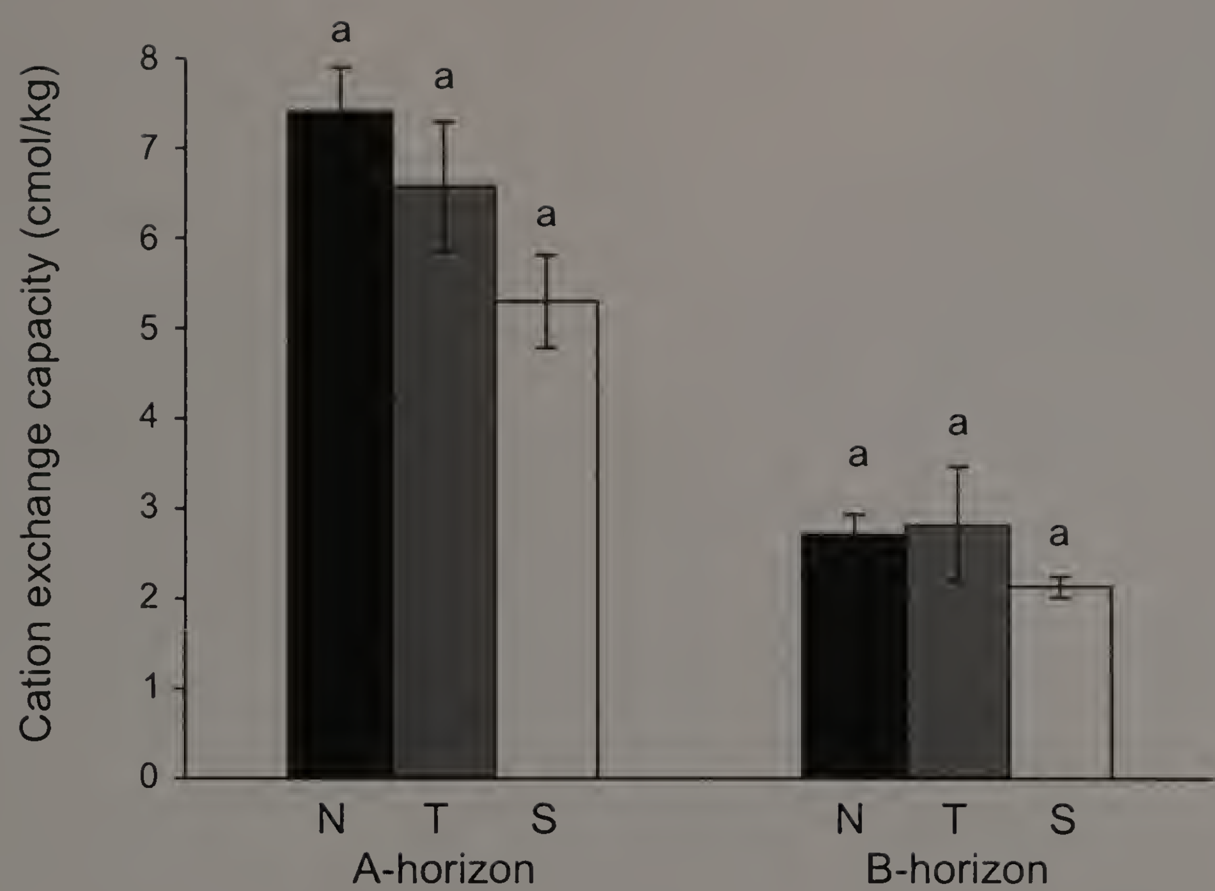


Figure 5.10. Cation exchange capacity. Values are means ± 1 SE. Means with the same letter did not differ (p>0.05 Tukey; ANOVA model with adjusted p-value).

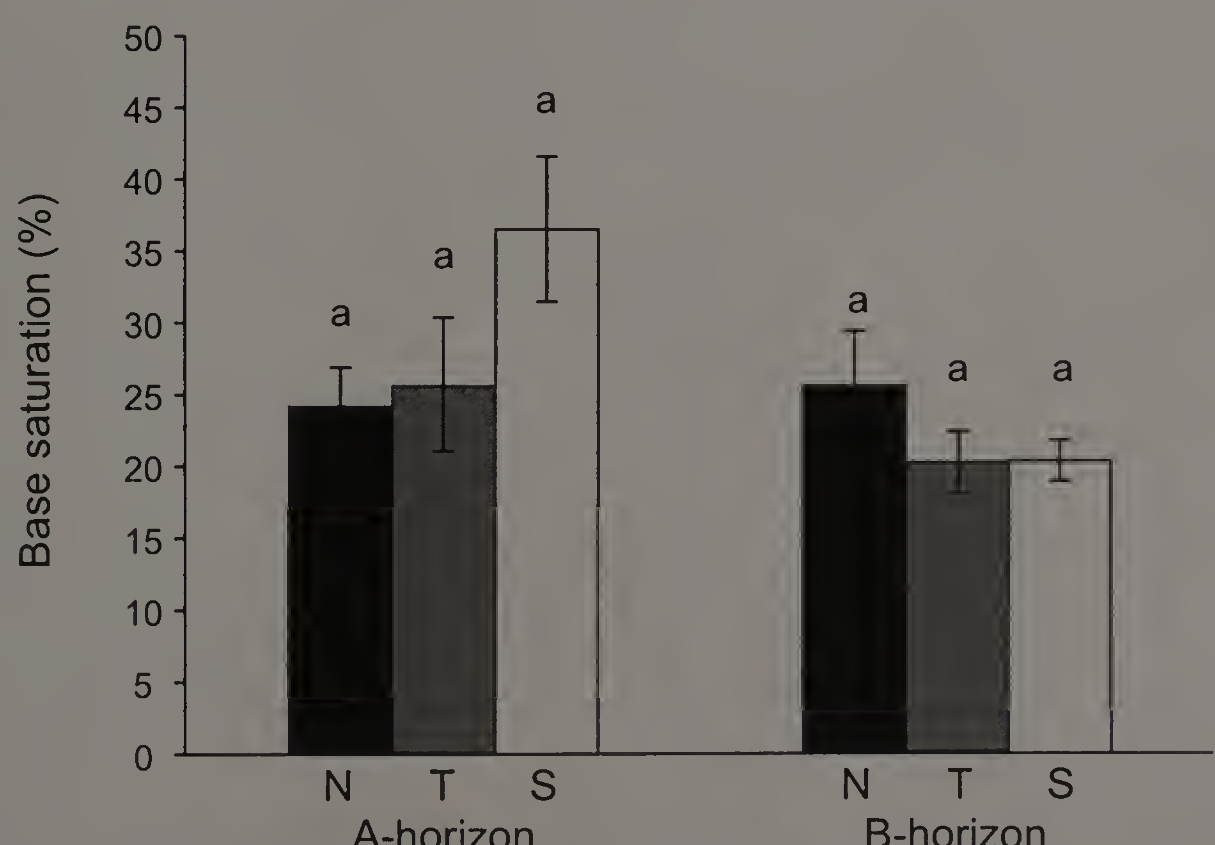


Figure 5.11. Base saturation. Values are means ± 1 SE. Means with the same letter did not differ (p>0.05 Tukey; ANOVA model with adjusted p-value).

that large portion of the CEC originates from pH-dependent exchange sites like soil organic matter.

Base saturation within the A-horizons was with 36.6% highest on the south slope, compared to 24.2% on the north slope (Fig. 5.11), but this difference was not found to be statistically significant (ANOVA, $F_{2,32}$=3.25, p=0.052). A notable exception was found on the south slope, where one A-horizon had a base saturation of 68%. No difference in base saturation was observed for B-horizons.

The exchangeable amounts of K, Mg, and Ca did not differ among topographic position for both A- and B-horizons (Fig. 5.9). However, there might be a difference in the total amount of exchangeable base cations, since A-horizons horizons were generally thicker on the south-slope.

5.3.7 Extractable Forms of Fe, Al, and Mn

A-horizons of the north-facing slope contained significantly less crystalline iron oxides (0.50 (0.04) g/100g; ANOVA, $F_{2,32}$=10.57, p=0.0003; values are means (SE)) than A-horizons on top (0.60 (0.03) g/100g) and the south slope (0.75 (0.04), Fig. 5.12 A). With a adjusted critical p-value (p<0.0023), ANOVA failed to reveal significant effects of aspect on amorphous and organically bound forms of Fe in both, A- and B-horizons (Fig. 5.12 A, B). The lower content of crystalline Fe in B-horizons on the top might be an effect of less soil development or slightly different parent material with less oxidizable Fe(II). Comparable amounts in B-horizons of north and south slope indicate a similar degree of soil development. On average, the ratios of all forms of Fe between A- and B-horizons were lower on the north than on the south slope (Fig. 5.12 C).

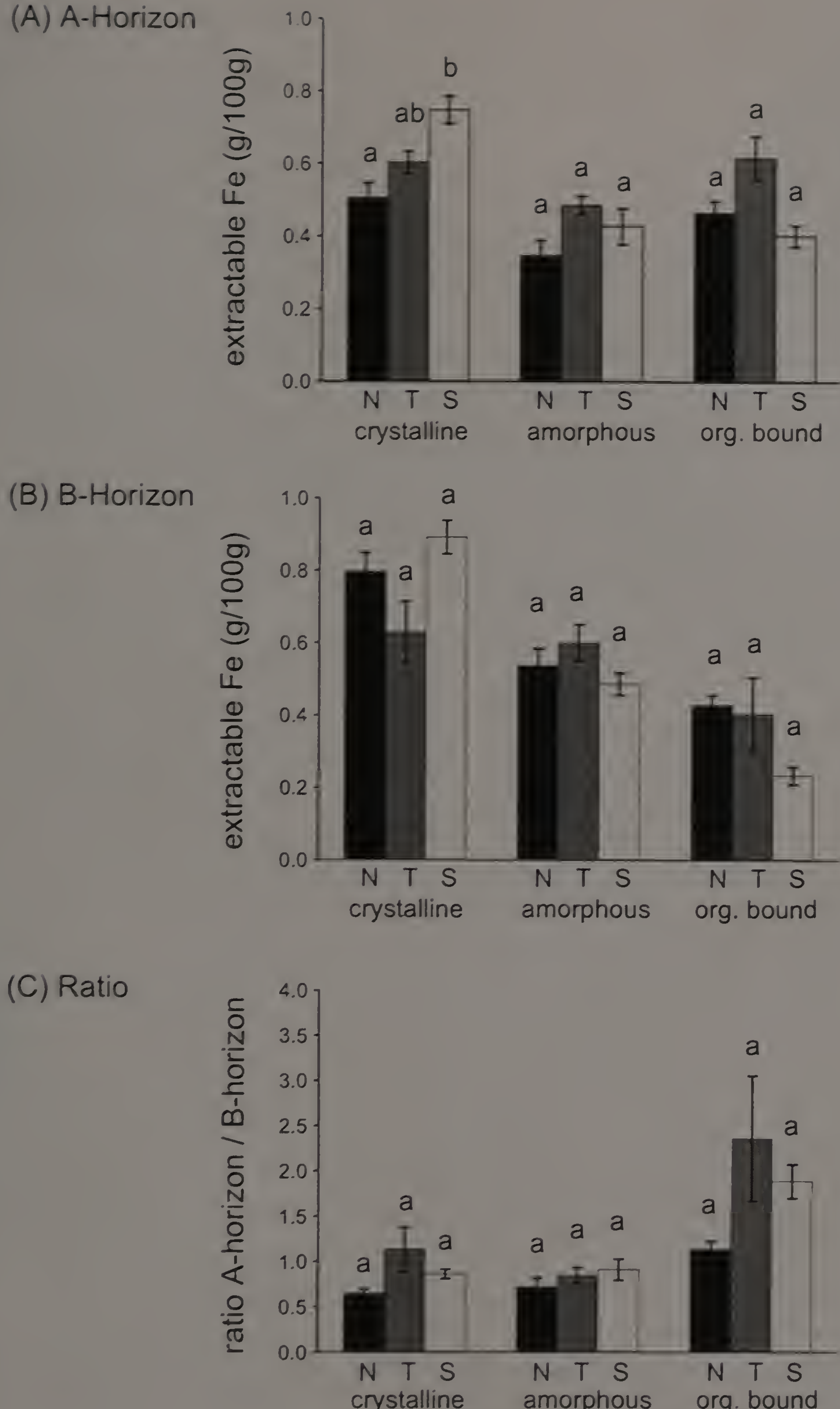


Figure 5.12. Distribution of crystalline, amorphous, and organically bound forms of Fe. (A) A-horizons. (B) B-horizons. (C) Ratio A-horizon / B-horizon. Crystalline Fe was calculated as the difference between citrate/dithionite- and oxalate-extractable Fe; amorphous Fe as the difference between oxalate- and pyrophosphate extractable Fe. Values are means ± 1 SE. Means with the same letter did not differ (p>0.05 Tukey; ANOVA model with adjusted p-value).

The mean amounts of amorphous and organically bound forms of Al were lowest in the A-horizons of the north slope (Fig. 5.13 A). However, only the distribution of organically bound forms were found to be highly significant different under the adjusted p-value (ANOVA, $F_{2,32}$=29.03, p=0.0001). Aspect had also an important effect on the amount of organically bound Al in the B-horizons.

The distribution of Al and Fe indicates some podzolization processes occurring on the north slope. A-horizons seem to be depleted of amorphous and organically bound forms of Al as well as crystalline Fe, whereas B-horizons are relatively enriched in organically bound Al and Fe. This is evidence for translocation of these elements into lower soil horizons by complexation through organic acids and subsequent precipitation in the B-horizons. On the south slope, the ratios between A- and B-horizons are above one for both forms of Al indicating no or only minimal migration of Al.

Although there is some soil chemical indication for podzolization processes on the north slope, the morphological evidence was sparse and in most cases limited to uncoated quartz grains commonly observed in upper soil horizons (salt and pepper appearance). The lack of well developed albic or spodic horizons could have several reasons:

- Frequent uprooting of trees and slow downslope movement of soil material (soil creep) might mix material and thus prevent the formation of well-developed soil horizons (Schaetzl et al. 1990, Veneman et al. 1984). Evidence of both processes like tip-and-mound microtopography was found to be common at the study site.

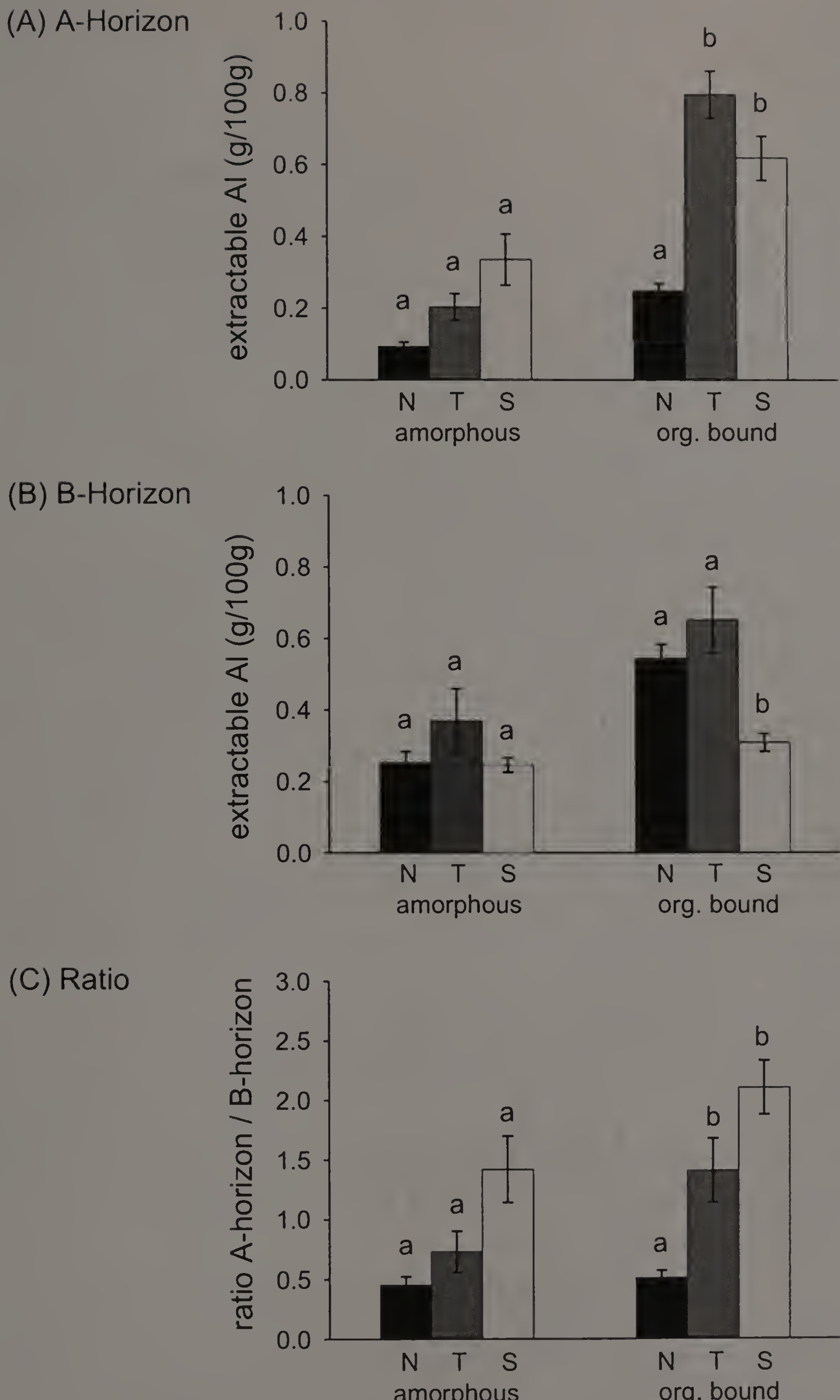


Figure 5.13. Distribution of amorphous and organically bound forms of Al. (A) A-horizons. (B) B-horizons. (C) Ratio A-horizon / B-horizon. Amorphous Al was calculated as the difference between oxalate- and pyrophosphate extractable Al. Values are means ± 1 SE. Means with the same letter did not differ ($p>0.05$ Tukey; ANOVA model with adjusted p-value).

- The relatively low abundance of *Tsuga canadensis* may not significantly change litter quality as seen by the relatively low C/N ratios and thus not considerably enhance the complexation and mobilization of Fe and Al by organic acids.
- Clear cutting may have caused extensive soil erosion. The rate of soil formation may have been too slow to cause development of characteristic horizons since the last disturbance.
- Soil textures might be too fine to allow enough percolation of water through the soil profile. Spodosols are best developed in sandy soils and less in loams and finer textured soils (Courchesne and Hendershot 1997). In addition, the parent material might still provide enough base cations (e.g. through chemical weathering of feldspars) to prevent podzolization processes. In a preliminary SEM study of the silt and sand fractions, highly weathered feldspars were found in an A-horizon of the north slope.

The distribution of organically bound Mn in the A-horizons together with the ratio between A- and B-horizons showed significant differences between topographic positions (Fig. 5.14 A-C). Again, the lowest ratios were found for soil of the north-facing slope. Soils on top of the ridge had the highest amount of Mn in all horizons. The origin of this relatively large quantity of Mn is unclear. It is possibly related to higher amounts of windblown material. However, this hypothesis does not explain why the crystalline / amorphous forms Mn were not significantly different between sites for both A- and B-horizons.

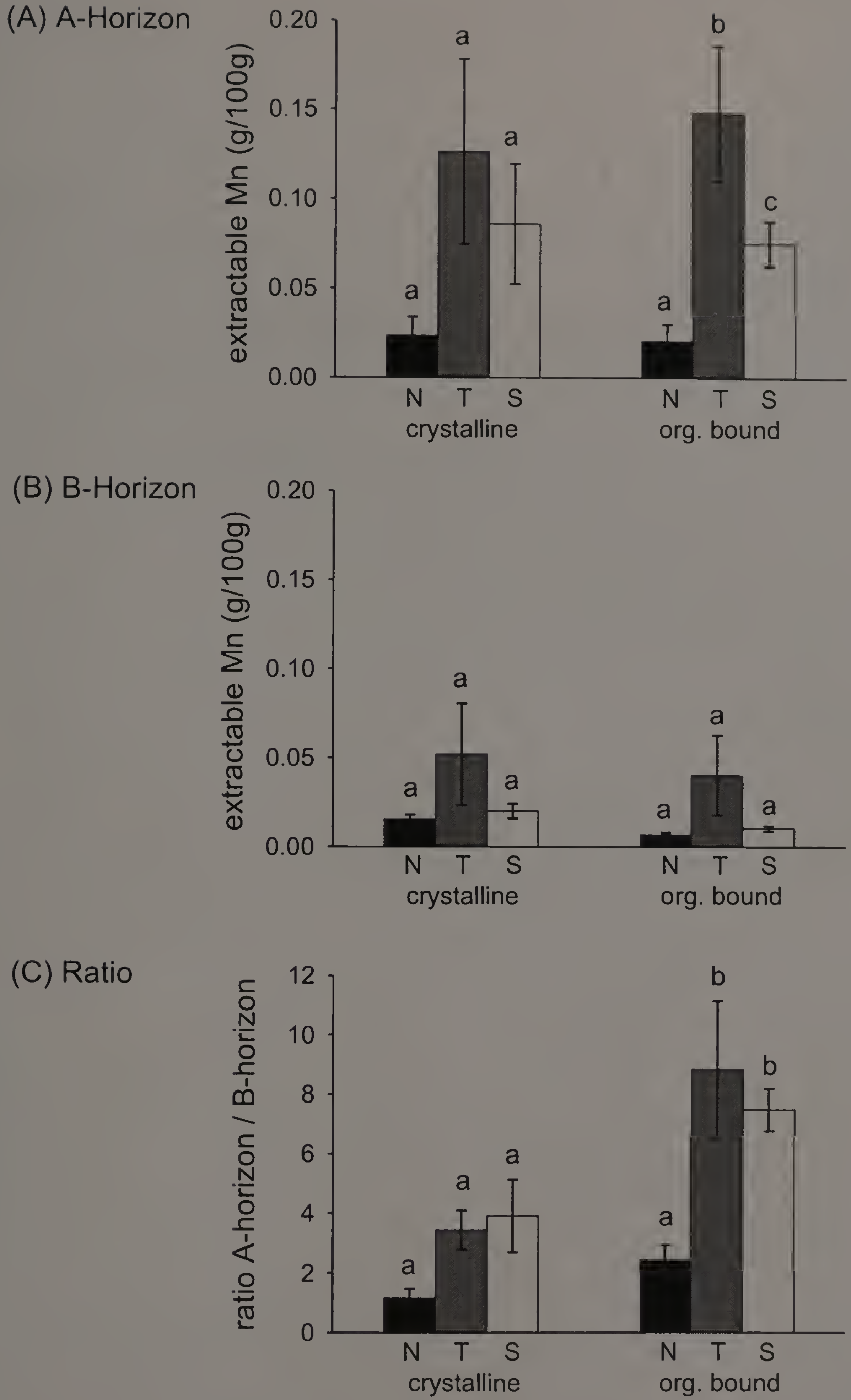


Figure 5.14. Distribution of crystalline and organically bound forms of Mn. (A) A-horizons. (B) B-horizons. (C) Ratio A-horizon / B-horizon (C). Crystalline Mn was estimated as the difference between citrate/dithionite- and pyrophosphate extractable Mn. Values are means ± 1 SE. Means with the same letter did not differ ($p>0.05$ Tukey; ANOVA model with adjusted p-value).

5.3.8 C/N Ratio and Organic Carbon

C/N ratios were significantly higher on the north-facing slope for both O- and A-horizons (Fig. 5.15). The C/N ratios did not differ between ridgetop and south slope. Generally, there was only a minimal decrease from O- to A-horizon. Mean values (SE) for the A-horizon were 22.7 (0.9) on the north slope, 17.2 (0.9) on top, and 19.2 (0.5) on the south-facing slope. No C/N ratio greater than 30 were found. The amount of total carbon stored in the O-horizon as estimated by horizon thickness, carbon content, and bulk density showed significantly lower amounts on plots on the south slope (Fig. 5.16). The opposite trend was observed for the A-horizons, although the differences were not found significant.

The high proportion of deciduous litter may explain the relatively low C/N ratios on the north slope, which might still be quite favorable for microbial degradation on all topographic positions. In spodosols, C/N ratios may reach values of 50 and higher in the upper horizons (e.g., Takahashi et al. 1990). Although highly statistically significant, the mean C/N ratios of O- and A-horizons are varying only over a relatively short range between topographic positions. It seems unlikely that the slightly higher C/N ratio is a significant factor for the observed initial signs of podzolization. The translocation of Fe and Al on the north slope is rather a result of microclimatic factors like wetter conditions, which increase the rate of leaching. Visual inspections of plots of C/N ratios versus forms of Fe and Al revealed no obvious correlation between these variables. This explanation is supported by the results of Schaetzl and Isard (1996) who related the degree of podzolization primarily to a gradient in snowpack thickness. In their meso-scale study in

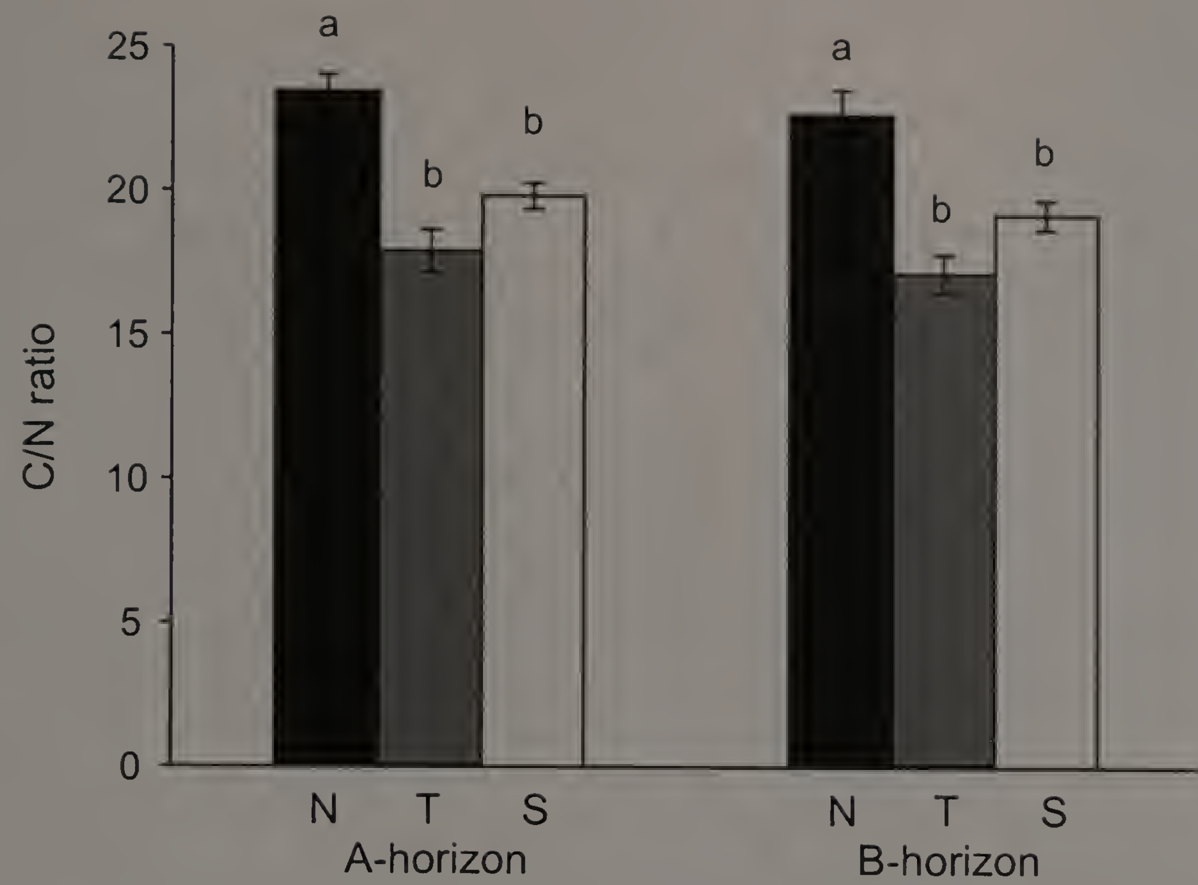


Figure 5.15. C/N ratios for O- and A-horizons. Values are means ± 1 SE. Means with the same letter did not differ (p>0.05 Tukey; ANOVA model with adjusted p-value).

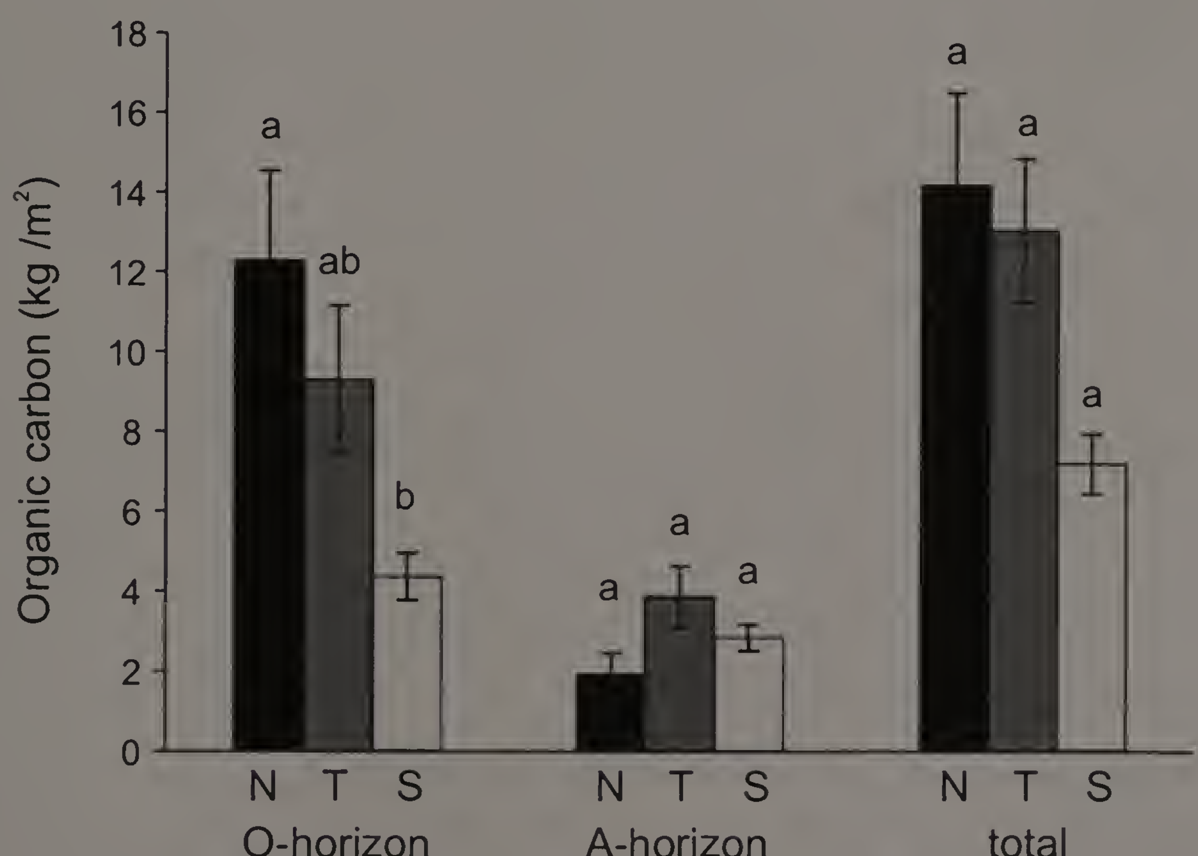


Figure 5.16. Amount of organic carbon stored in A- and O-horizons and total amount of organic carbon. Values are means ± 1 SE. Means with the same letter did not differ (p>0.05 Tukey; ANOVA model with adjusted p-value).

Wisconsin, they considered changes in the coniferous component of only minor importance.

The low C/N ratios on the ridgetop seem to be contradictory to the high amounts of organic carbon stored in the O- and A-horizons since low ratios should enhance the mineralization of organic matter. It is likely that the thick O-horizons on the ridgetop are rather a result of reduced biomineralization caused by dry conditions than of 'poor' litter quality. The high levels of Mn, observed in exchangeable as well as in organically bound forms, may reach toxic levels and further inhibit the degradation of organic material. Less leaching through drier conditions may also explain why, despite the availability of organic substances, no morphological evidence of podzolization was found on top of Ox Hill. Likewise, the high ratios of organically bound forms of Fe, Al, and Mn between A- and B-horizons indicate little or no translocation of these elements. In addition, the lowest amount of crystalline Fe and clay content was found in B-horizons of the ridgetop, which suggests a reduced rate of soil formation. However, the validity of these observations is limited by the small sample size of soils on the ridgetop.

5.3.9 Discriminant Analysis

Six soil variables were used for Discriminant Analysis: pH ($CaCl_2$), C/N ratio, and total carbon (all of the O-horizon), and crystalline Fe, exchangeable and amorphous Al of the A-horizon. Normal probability plots of the canonical scores indicated that the assumption of multivariate normality was probably not grossly violated. The first derived canonical function (CAN 1) had a squared canonical correlation coefficient of 0.852 and described over 85% of all explainable variation among groups (relative percent variance:

0.858). Based on the total canonical structure coefficients, C/N ratio and exchangeable Al were highly correlated with CAN 1 and thus were the most important variables in discriminating the three topographic positions. The second canonical function had consequently much less discriminatory power (relative percent variance: 0.142; squared canonical correlation coefficient: 0.49). No variable was preferentially associated with CAN 2. The evaluation of classification accuracy by resubstitution revealed, that all samples were correctly classified (Cohen's Kappa statistic = 1.00). However, this result is highly biased upward since the assessment was made on the same samples from which the discriminant functions (i.e. the classification) were derived. The validation of the canonical function by cross-validation indicated that one sample from each slope was incorrectly classified to the opposite slope. However, all seven samples from the top were incorrectly classified to the south slope. Cohen's Kappa equaled 0.57, meaning that the classification was only 57% better than random assignment. Thus DA seemed able to discriminate well between north- and south-facing slope, but failed to distinguish between sites of ridgetop and south slope. A scatterplot of the canonical scores showed, that CAN 1 clearly separates between samples from the north slope from the rest, whereas the weaker CAN 2 discriminated south slope from ridge top (Fig. 5.17).

5.3.10 Clay Mineralogy

Based on the results of the X-ray diffraction analysis on 18 A-horizons, a typical suite of minerals was identified in the coarse and fine clay fraction of A-horizons. X-ray diffractograms can be found in Appendix D. A dominant feature in most samples was a strong peak at 14.2-14.4 Å. This peak was found to be unstable on several samples from

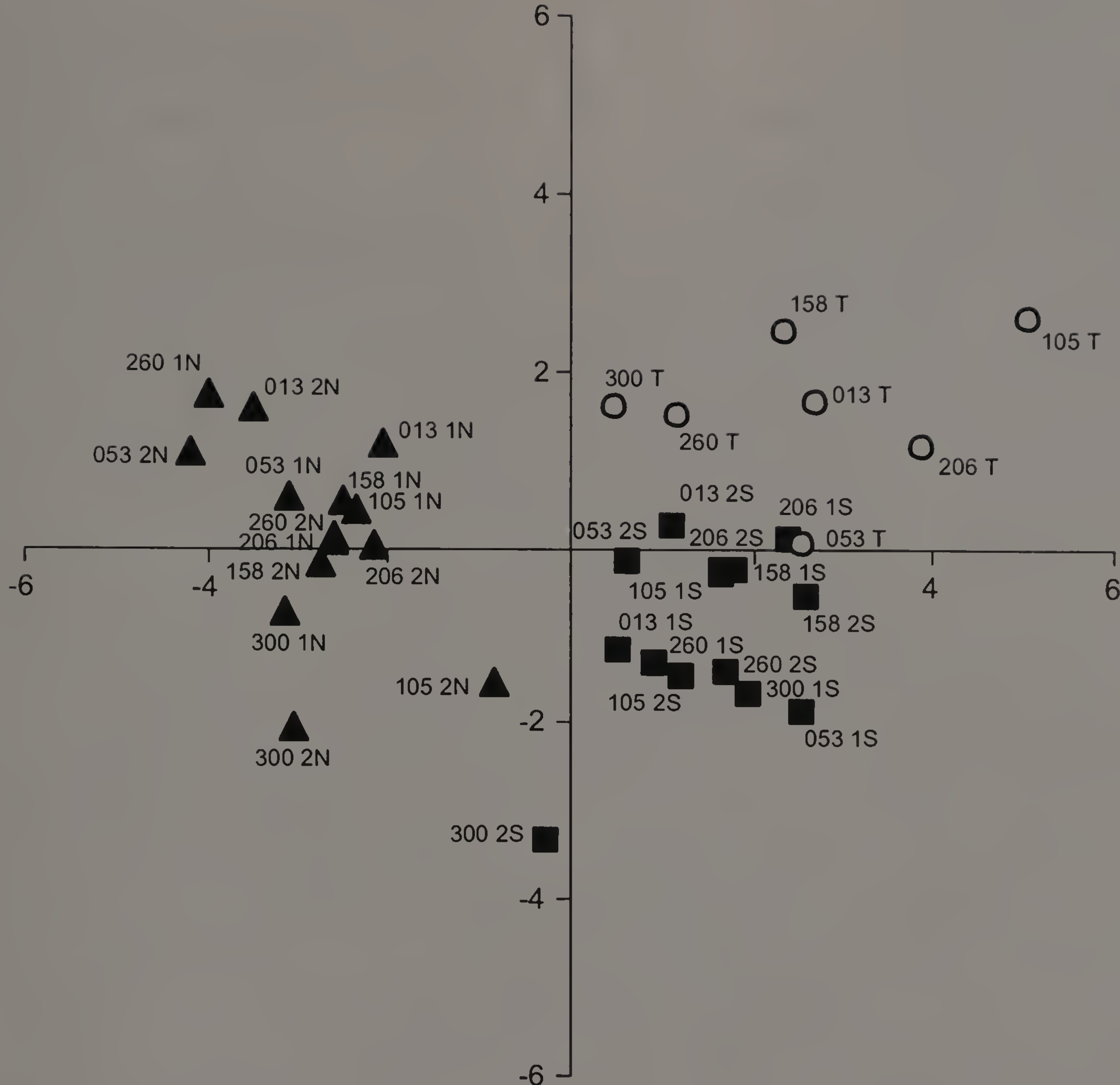


Figure 5.17. Plot of canonical scores from Discriminant Analysis of selected soil variables. Filled triangles: sites on the north-facing slope, filled squares: sites on the south-facing slope, open circles: sites on top of the ridge. Variables used in this analysis were: pH ($CaCl_2$), C/N, total C (all O-horizon); crystalline Fe, exchangeable and amorphous Al (A-horizon).

the north slope. An expansion to higher d-spacings was observed when treated with ethylene glycol, and the peaks often collapsed partially upon K-saturation. No expansion was observed when solvated with glycerol. These properties are characteristic for hydroxy interlayered vermiculites (HIV) as intermediate forms between the endmembers vermiculite and chlorite (Barnhisel 1977). Vermiculite is a 2:1 layer phyllosilicate (either dioctahedral and trioctahedral) with two discrete water sheets associated with the cations in the interlayer positions (Weaver 1989). The layer charge of vermiculite ranges from 0.6 to 0.9 (Moore and Reynolds 1989). It is higher than that of smectite (0.2-0.6) which reduces the amount of expansion with ethylene glycol. Hydroxy interlayered vermiculites are characterized by variable amounts of dominantly Al hydroxide components in the interlayer position, which reduce CEC and cause delayed collapse upon heat treatments (Weaver 1989). These minerals may originate from either chlorite degradation or precipitation of hydroxy Al in interlayer positions of 2:1 clay minerals. The polymeric hydroxy-Al species may occur as uniformly distributed 'islands' in the interlayer space or can form complete sheets. Thus, HIV can also be described as chlorite-like mineral with an incomplete interlayer hydroxide sheet. However, organic matter in the interlayer space of vermiculites can simulate the properties of a HIV (Weaver 1989).

The observed HIV ranged from varieties that had more properties of vermiculite (sample 13 1N) to more chlorite-like clay minerals (158 1N), depending on the degree of 'filling' with interlayer Al. The latter showed only minimal expansion visible in a slight shoulder of the 14 Å peak and collapsed incompletely when K saturated or heated with a wide range of d-spacings between 10 Å and 14 Å. The presence of some chlorite was generally indicated by a remaining 14 Å peak. A replicate of sample 13 1N did not show any expansion or collapse as observed the first time. The reason of this phenomenon is unclear, but it demonstrates the rather sensitive characteristics of the clay minerals in the sample.

The 14 Å peak was much more stable on samples from the south-facing slope, indicating a more 'chloritic' type of clay mineral. No expansion of glycolated samples was observed, and K saturation generally caused - if at all - only a slight shoulder of the 14 Å peak (e.g., sample 13 2S A coarse). However, the peak partially collapsed under heat treatment at 300°C, which indicates some degradation of the chlorite structure.

The proportions of peak heights calculated as 10Å / (10Å+7Å) on the Mg-airdry count data of the coarse clay fraction were not significantly different between north and south slopes ($p_{[Kruskal\text{-}Wallis]}=0.29$). This indicates that the relative amounts of illite (10Å) and '14Å' clays (chlorite and hydroxy interlayered vermiculite) are the same. XRD analysis of the silt fraction of some samples indicated that mica/illite was present in about the same abundance as chlorite. However, the illite/mica peak is greatly reduced in most samples of the coarse clay fraction and was generally absent in the fine clay fraction (<0.5 µm). This decrease of the relative abundance of mica/illite with finer particle size may be attributed to a greater 'mechanical' stability of micas compared to chlorite.

Occasionally, superlattice peaks of interstratified clay minerals between 24-25 Å were found on the north slope (e.g., 53 2N, 260 1N). The clay fractions of seven B-horizons were also analyzed, but no differences between north and south slope were found. Besides noticable amounts of quartz and feldspar, the clay mineral assemblages consisted of chlorite and illite. No evidence of HIV was found in these lower horizons. This is contrary to the results of Bodine (1986) who commonly observed hydroxy interlayered vermiculite in subsoil horizons throughout Massachusetts. However, his strong pre-treatments may have altered the properties of the original clay minerals.

The occurrence of hydroxy interlayered vermiculite seemed to be restricted to the north facing slope. It is likely that HIV originated from chlorite minerals by mobilization of interlayer Al through organic complexation. The wetter and more acidic conditions on the north-facing slope could enhance the dissolution and leaching processes. The experimental transformation of chlorite into an interstratified chlorite/vermiculite was reported by Ross and Kodoma 1976). Likewise, April et al. (1986) observed low Al-fixation in interlayer position of vermiculites in E-horizons of spodosols. They attributed that to the presence of organic acids which inhibit precipitation of hydroxy-Al, or to a different weathering regime which mobilizes Al in interlayer positions of chlorites.

5.4 Correlation of Vegetation and Environmental Factors

The variables chosen for CCA included base saturation, pH, exchangeable Fe and Mn, and potential solar radiation (the only 'non-soil' parameter). These variables were thought to be primarily influencing the distribution of plant species. Depth of O- and A-horizons, C/N ratio, and crystalline Fe and amorphous Al ratio (both an index of podzolisation) are probably more an effect of vegetation. However, it must be pointed out that all these variables are closely interrelated and the distinction between 'cause' and 'effect' variables is somewhat arbitrary.

The results of CCA showed a highly significant relationship between vegetation and environmental variables. The randomization test for significance of all canonical axes revealed a p-value of 0.005. The first three axes accounted for over 73% of the species-environment relation and were highly related with the environmental variables (multiple correlation > 0.9). However, they could only account for about 42% of the total variation within the vegetation data. This percentage was similar to the percentage obtained by a indirect ordination of the vegetation data (47%). The relatively low value indicates that there is there was not much redundancy of the vegetation data, i.e. the individual distribution patterns of the plant species were not strongly related. Thus, the environmental variables are apparently not sufficient to explain more than 50% of the main variation of species composition, but they can predict a large part of the remaining variation.

The first axis explained 29 % of the variation within the vegetation and over 50% of all variation of the species-environment relation. Potential solar radiation was highly correlated with axis 1 (r=-0.95) and is by far the most dominant parameter (Fig. 5.18). Further negatively correlated variables were crystalline Fe and Mn (r=-0.51 and r=-0.44, respectively), pH (r=-0.40), depth of A-horizon (r=-0.35), and base saturation (r=-0.33). Axis 1 was positively correlated with C/N ratio (r=0.61) exchangeable Fe (r=0.66), depth of the O-horizon (r=0.46), and total carbon (r=0.45). Relatively high correlations of all variables with axis 1 are not surprising, since changes in all of the variables are related to aspect. Thus, the first axis describes mainly the differences between north- and south-facing slope also seen in the previous statistical analysis. A clear separation between south slope and top only by this axis is not possible, when plots are projected onto this axis alone (Fig. 5.18 and Fig. 5.19).

The second and third axes are more difficult to interpret since no environmental variable was highly correlated (r>0.5). Axis 2 explained 13 % of species-environment

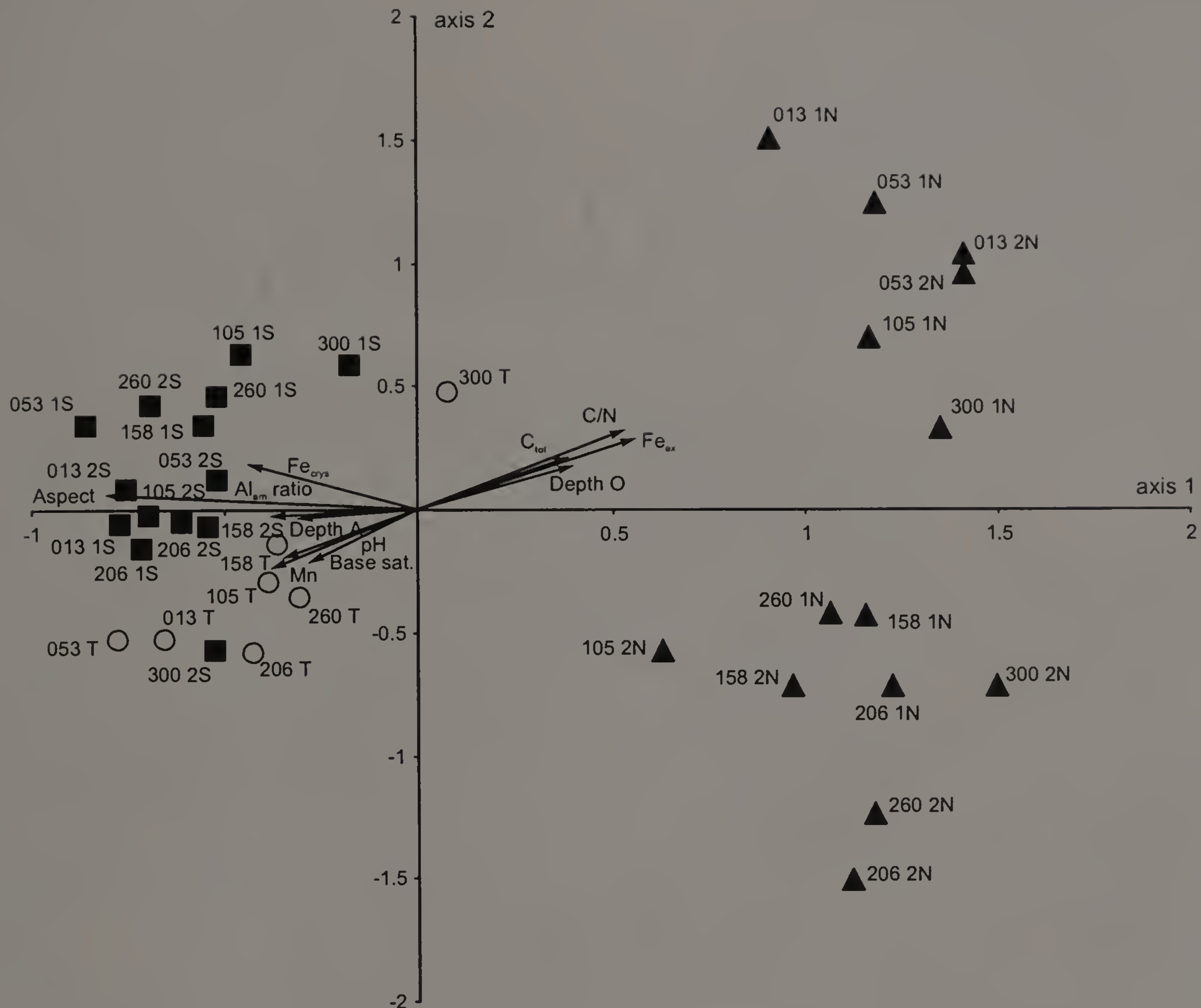


Figure 5.18. Ordination diagram of axis 1 vs. axis 2 based on canonical correspondence analysis (CCA) of vegetation and environmental data. The plots shows location of sample sites. Environmental variables are indicated as arrows. Arrows point in the direction of maximum change. The length of an arrow is proportional to its rate of change. Variables are labeled: Aspect, potential solar radiation; Depth A, depth of A-horzion; Depth B, depth of O-horizon; Base sat., percent base saturation; Mn, exchangeable Mn, C/N, C/N ratio of A-horizon; Fe_{ex}, exchangeable Fe, Fe_{cry} , crystalline Fe; C_{tot} total organic carbon.

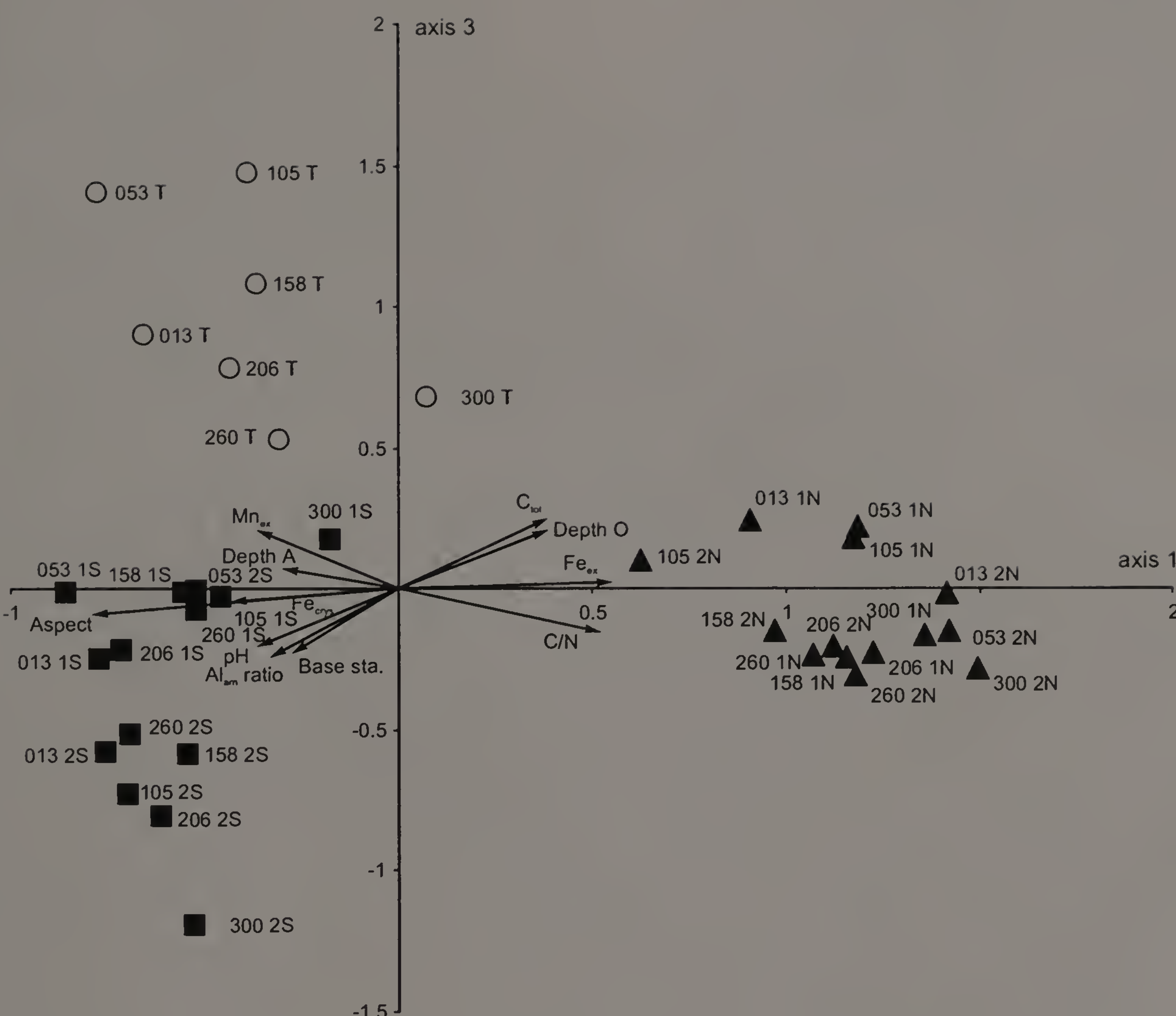


Figure 5.19. Ordination diagram of axis 1 vs. axis 3 based on canonical correspondence analysis (CCA) of vegetation and environmental data. The plots shows location of sample sites. Environmental variables are indicated as arrows. Arrows point in the direction of maximum change. The length of an arrow is proportional to its rate of change.

relation and represented a gradient within plots of the north slope (Fig. 5. 18). The apparent grouping of sites (positive and negative scores on axis 2) resembles the results of the TWINSPAN analysis, where in the second level of division the same separation of sites on the north slope was obtained. Based on the interpretation of the ordination plot, the group of six sites with positive scores on axis scores are characterized through high C/N ratios, high amounts of exchangeable Fe, thick O-horizons, and low pH and base saturation. Five of these plots are located on the most eastern transects on the more exposed part of Ox Hill. Dead snags of *Quercus* sp. possibly resulting from a gypsy moth infestation were common on these sites. Axis 2 may thus represent a weak east-west or disturbance gradient

The third axis accounted for 10% of species-environment relationship and separated plots of the south slope from those of the ridge top, whereas plots of the north slope are grouped closely together (Fig. 5.19). None of the included environmental parameters seems able to be particularly associated with the floristic differences between south and top. However, the ordination plots shows that sites on the top have intermediate values in pH, depth of the O-horizon, total carbon, and the ratio of amorphous Al when projected onto the respective axes.

The ordination plot of species scores showed the relationship of each plant to the tested environmental variables (Fig. 5.20 and 5.21). Species to the left side of the diagram are preferentially found on the southern aspect, those to the right are associated with northern aspects and low potential solar radiation. Plants like *Gaylussacia baccata*, *Rhododendron* sp., *Polypodium vulgare*, *Hamamaelis virginiana*, *Trientalis borealis*, *Huperzia lucidula* and to a certain extent also *Tsuga candensis* are occur dominantly in plots with higher C/N ratios, thick O-horizons and higher amounts of exchangeable Fe. *Festuca subverticillata*, *Dryopteris intermedia*, *Huperzia lucidula*, and *Gaylussacia baccata* occupy extreme positions and are possibly outliers.

Although CCA reveals correlations between environmental variables and floristic data, it does not necessarily evaluate the ecological importance of the measured variables. In other words, no definite conclusion can be made if a highly associated environmental variable is actually related to vegetation. Both can be responding to one, possibly undetected, dominating gradient without taking part in any feedback processes. Likewise, no inference can made about cause and effect between vegetation and soil properties.

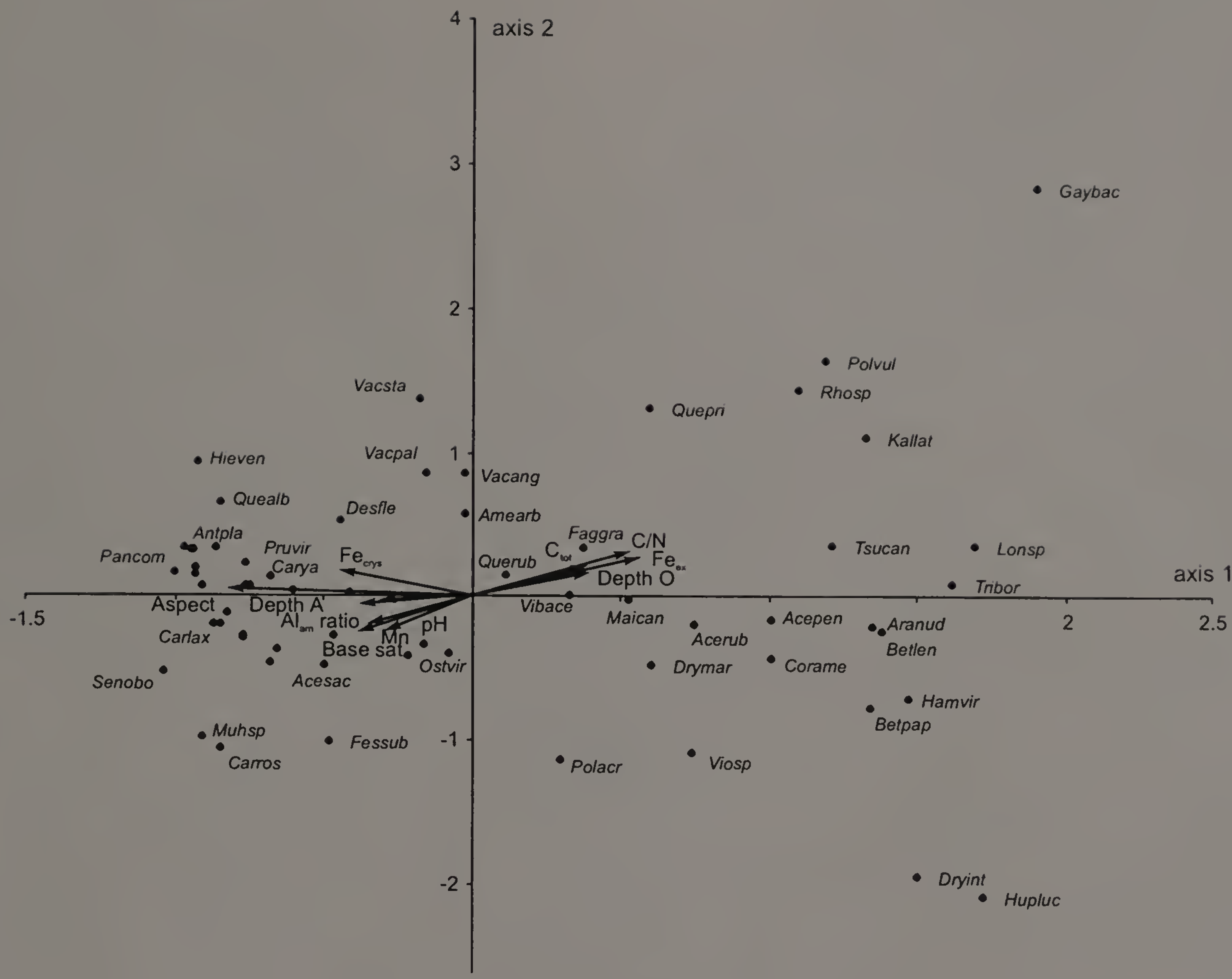


Figure 5.20. Ordination diagram of axis 1 vs. axis 2 based on canonical correspondence analysis (CCA). The plots shows location of plant species. Plants are labeled: Acesac, *Acer saccharum*; Acepen, *Acer pennsylvanica*; Acerub, *Acer rubrum*; Antpla, *Antennaria plantaginifolia*; Amearb, *Amelanchier arborea*; Aranud, *Aralia nudicaulis*; Betlen, *Betula lenta*; Betpap, *Betula papyrifera*; Carros, *Carex rosea;* Carlax, *Carex laxiflora*; Carya, *Carya* sp.; Corame, *Corylus americana*, Desfle, *Deschampsia flexuosa*; Dryint, *Dryopteris intermedia*; Drymar, *Dryopteris marginalis*; Faggra, *Fagus grandiflora*; Fessub, *Festuca subverticillata*; Gaybac, *Gaylussacia baccata*; Hamvir, *Hamamaelis virginiana*; Hieven, *Hieracium venosum*; Hupluc, *Hupertia lucidula;* Kallat, *Kalmia latifolia*; Lonsp, *Lonicera* sp., Maican, *Maianthenum candense*; Muhsp, *Muhlenbergia* sp.; Ostvir, *Ostrya virginiana*; Pancom, *Panicum commutatum*; Polacr, *Polystichum acrostichoides*; Polvul, *Polypodium vulgare*; Pruvir, *Prunus virginiana*; Quealb, *Quercus albus*; Quepri, *Quercus prinus*; Querub, *Quercus rubra*; Rhosp, *Rhododendron* sp., Senobo, *Senecio obovatus*; Tribor, *Trientalis borealis*; Tsucan, *Tsuga candensis*; Vacang, *Vaccinium angustifolium*; Vacpal, *Vaccinium pallidum*; Vacsta, *Vaccinium stamineum;* Vibace, *Viburnum acerifolium*; Viosp, *Viola* sp.. Some plant labels were omitted.

Figure 5.21. Ordination diagram of axis 1 vs. axis 3 based on canonical correspondence analysis (CCA). The plots shows location of plant species. Plants are labeled: Acesac, *Acer saccharum*; Acepen, *Acer pennsylvanica*; Acerub, *Acer rubrum*; Amearb, *Amelanchier arborea*; Aranud, *Aralia nudicaulis*; Astsp, *Aster* sp.; Aurfla, *Aureola flava*; Betlen, *Betula lenta*; Betpap, *Betula papyrifera*; Carpen, *Carex pennsylvanica;* Carya, *Carya* sp.; Corame, *Corylus americana*; Desnud, *Desmodium nudiflorum*; Dryint, *Dryopteris intermedia*; Faggra, *Fagus grandiflora*; Fessub, *Festuca subverticillata*; Gaybac, *Gaylussacia baccata*; Hamvir, *Hamamaelis virginiana*; Hepame, *Hepatica americana*; Hieven, *Hieracium venosum*; Hupluc, *Hupertia lucidula;* Kallat, *Kalmia latifolia*; Maican, *Maianthenum candense*; Ostvir, *Ostrya virginiana*; Pancom, *Panicum commutatum*; Pandic, *Panicum dichotomum*; Polacr, *Polystichum acrostichoides*; Polpub, *Polypodium pubescens*; Polvul, *Polypodium vulgare*; Pruvir, *Prunus virginiana*; Pruser, *Prunus serotina*; Quealb, *Quercus albus*; Quepri, *Quercus prinus*; Querub, *Quercus rubra*; Rhosp, *Rhododendron* sp., Senobo, *Senecio obovatus*; Smirac, *Smilancia racemosa*; Tribor, *Trientalis borealis*; Tsucan, *Tsuga candensis*; Vacsta, *Vaccinium stamineum;* Vibace, *Viburnum acerifolium*; Viopal, *Viola palmata*. Some plant labels were omitted.

CHAPTER 6

SUMMARY AND CONCLUSIONS

6.1 Solar Radiation

Significant differences exist in potential direct solar radiation for slopes with different aspect. At 42° northern latitude, the south slope receives 23% more, the north slope 54% less of the solar radiation received by a level area. Although this strongly simplified approach does not reflect actual conditions, it demonstrates the relation between yearly solar energy input and aspect and slope angle. The predicted differences in insolation have pronounced effects on microclimatic parameters. The north-facing slope is expected to have lower air and soil temperatures, lower annual and daily temperature fluctuations, less effective evapotranspiration and thus higher soil moisture contents, and a greater thickness and longer duration of snow cover compared to the south-facing slope. Thus, the opposing slopes of Ox Hill have different site conditions, which can influence the distribution of plant species as well as the formation of soils.

6.2 Vegetation

The vegetation on both sides of the ridge was significantly different in species composition and richness. Several plant species were restricted to only one aspect or occurred preferentially on one slope. The north slope supported a relatively species-poor forest community with *Tsuga canadensis* and *Betula lenta* among the dominant tree species and an often sparse ground vegetation. *Carya* sp. and *Acer saccharum* occurred preferentially on the south slope and on top of the ridge. The vegetation of these plots was more diverse than on the north slope. *Quercus rubra* had the highest basal area on all topographic positions. Differences between ridgetop and south-slope were less pronounced and were primarily found in the ground vegetation.

The significant difference in the maximum DBH observed in each plot indicates that sites on the south slope and ridgetop may have experienced human induced disturbance through cutting or fire. The actual vegetation may therefore not reflect the potential vegetation.

6.3 Soils

Soils on Ox Hill generated on a thin mantle of till with a significant component of aeolian material, indicated by a very high content of very fine sand and silt. Soil textures ranged between sandy loams, loams, and silt loams. Clay content was generally less than 10%. Although considerable differences were found in the sand and silt fractions, soils can be assumed to have developed in similar parent material.

The differences in soil properties between slopes were mainly restricted to parameters of A- and O-horizons. Soils of the ridgetop are more similar to soils of the south-facing slope and both differ significantly from soils on the north slope. C/N ratios, pH, and exchangeable Al and Fe differed most between topographic positions. Soil reaction at the north-facing slope was more than 0.7 pH units lower in O-horizons and 0.4 pH units lower in A-horizons than the respective pH values on the south slope. Exchangeable Al and Fe were significantly higher in A-horizons of the north slope. However, no differences were found in the amount of exchangeable base cations. Mean effective CEC values of the A-horizons were highest on the north slope (7.4 cmol(+)/kg) and lowest on the south-facing slope (5.3 cmol(+)/kg). Most of the CEC originates from pH-dependent exchange sites. Base saturation within A-horizons was highest on south-facing slopes (37%) compared to the north-facing slope (24%). Significantly more organic carbon was stored in soil of the north slope. Differences were also found in organically bound forms of Fe, Al, and Mn along with crystalline Fe and amorphous Al. Although an overall (multivariate) significant difference was found between B-horizons, most variables did not differ when analyzed alone. The similarity in chemical parameters indicates a similar degree of soil formation for B-horizons.

The increase of organically bound forms of Al with depth and significantly lower amount of crystalline Fe in A-horizons of soils on the north slope is an indication for incipient podzolization. Al and Fe released from chemical weathering in the upper soil horizons is mobilized as and translocated downward as organic complexes. No evidence for the migration of Al and Fe into lower soil horizons was found on the south slope and ridgetop. Increased leaching processes and a more intense chemical weathering regime explain also the occurrence of hydroxy interlayered vermiculites on the north slope, which may have originated by partial dissolution Al from the interlayer sheets of chlorites.

Several factors like pedoturbation may have prevented the formation of characteristic albic or spodic horizons on the north slope. It is possible that soil erosion following clear cutting may have reset the time for soil formation.

6.4 Vegetation-Soil Relationship

Both soils and vegetation were affected by aspect-determined changes in site conditions. However, there is some evidence for soil-forming processes to occur unrelated to changes in vegetation. The influence of vegetation on soils is primarily caused by the quality of litter (e.g., elemental composition, type of organic compounds). Despite significantly higher abundances of *Tsuga candensis* on the north slope, the forest composition does not change to a dominantly coniferous forest type. Thus, the litter quality is probably not considerably different across the ridge as seen by the very narrow range of C/N ratios. The observed incipient podzolization may therefore rather be a result of microclimatic effects or reflect differences in the original vegetation prior to European settlement. Cooler temperatures cause a slower breakdown of organic matter, and wetter conditions enhance leaching processes. Thus, vegetation and soils seem to respond to some degree independently to aspect induced changes in microclimate and are not involved in strong feedback mechanisms.

A more detailed analysis of the humus fraction is necessary to evaluate whether indeed vegetation and not microclimatic site conditions alone are responsible for the observed differences in soil development. Of special interest here are differences in elemental composition, the amount of functional groups and the ability to form complexes with Fe and Al. Further research should also concentrate on the rate of nutrient cycling and decomposition of organic material.

6.5 Applications

Results of this investigation will be useful for land-use planning and forest management. A better understanding of the relationship between topography and site characteristics can support the management of natural resources. Geographic information systems, which include the parameter aspect, can be used to evaluate forest productivity in relation topographic position. More information about importance of each factor of soil formation is of considerable interest for the understanding, modeling and management of forested ecosystems and for the forecasting of their response to environmental changes. In addition, a better understanding of the spatial variability of soils in relation to topography will help in soil classification and mapping.

APPENDIX A

SOURCE CODE

Pascal program to calculate yearly potential solar radiation for a given latitude, aspect, and slope angle.

```
program solar_radiation;

uses wincrt;


const    S       = 1364;   {solar constant}
         pi      = 3.14159;
         min_dec = 5;
         day_dec = 5;
         p_ratio = 0.95;   {pressure ratio observation site/sea level}
         a       = 0.85;   {atmospheric transmission coefficient}

var      sindec, cosdec, sinlat, coslat,
         latitude, aspect, slope, result  : real;

{----------------------------------------------------------------------}

{trigonometric functions}

function arcsin(x:real):real;
begin
  if x=1  then arcsin:= pi/2;
  if x=-1 then arcsin:=-pi/2;
  if abs(x)<1 then
  arcSin:=ArcTan(x/sqrt(1-sqr(x)));
end;

function arccos(x:real):real;
begin
  if x=1  then arccos:= 0;
  if x=-1 then arccos:= pi;
  if abs(x)<1 then
  Arccos:=ArcTan(-x/sqrt(1-sqr(x)))+pi/2;
end;

{----------------------------------------------------------------------}

{calculation of sunrise}

Function sunrise(sinlat, coslat, sindec, cosdec: real):real;

var tanlat, tandec : real;

begin

  tandec:=sindec/cosdec;
  tanlat:=sinlat/coslat;
```

```
  {test for long day & night, and calculation of sunrise in min}

  If Abs(tandec * tanlat) > 1 Then
    begin
      If -tandec * tanlat > 1 Then
        begin
          sunrise := 1440; {longnight}
        end
      Else
        begin
          sunrise := 0;    {longday}
        end;
    end
  Else
    begin
      sunrise := 720 - (arccos(-tandec * tanlat) * 720 / pi);
    end;
end;      {end function sunrise}


{-----------------------------------------------------------------------}


function inst_rad(sinlat, coslat, sindec, cosdec, aspect, slope: real;
                  minute: real):real;

{calculates the instantaneous solar radiation for given parameters,
 sinlat, coslat: sin and cos of latitude
 sindec, cosdec: sin and cos of declination
 aspect, slope in radiants}

var b, m, h, sa, az, sinaz, cosaz, alpha, cosi, sinsa : real;

{sinaz, cosaz: sin and cos of azimuth
 sa : solar altitude angle}

begin

  h     :=0.25 * (minute-720) * pi/180;
  sa    :=arcsin(sindec*sinlat + cosdec*coslat*cos(h));
  sinsa :=sindec*sinlat + cosdec*coslat*cos(h);
  sinaz :=cosdec*sin(h)/cos(sa);

  if sinlat>=0 then
    cosaz:=(sinlat*sinsa - sindec)/(coslat*cos(sa))
  else
    cosaz:=-(sinlat*sinsa - sindec)/(coslat*cos(sa));

  if sa>=10*pi/180 then
  begin
    m:=p_ratio/sinsa;
    b:=exp(m*ln(a));
  end
  else
    b:=0.2;    {sets the optical airmass number to 0.2 if solar
                elevation is less than 10 deg}
```

```
  if sinaz<0 then
    az:=-arccos(cosaz)
  else
    az:=arccos(cosaz);

  alpha:=az-aspect;
  if alpha>pi then
    alpha:=alpha - 2*pi
  else
    alpha:=alpha + 2*pi;

  cosi:=cos(slope)*sin(sa) + sin(slope)*cos(sa)*cos(alpha);

  if cosi>0 then
    inst_rad:=b*s*cosi
  else
    inst_rad:=0;

end;     {end function inst_rad}


{----------------------------------------------------------------------}


function rad_day(sinlat, coslat, sindec, cosdec, aspect, slope: real;
                 incr: integer):real;

{calculates total radiative energy received per m2 per day}

var Q, dq, minute, sun_rise, sun_set : real;

begin

  sun_rise:=sunrise(sinlat, coslat, sindec, cosdec);
  sun_set :=1440-sun_rise-1;
  minute  :=sun_rise+1;

  dq:=0;
  Q :=0;

  while minute<sun_set do
  begin
    dq:=inst_rad(sinlat, coslat, sindec, cosdec, aspect, slope,
                 minute)*incr*60;
    Q :=Q + dq;
    minute:= minute + incr;
  end;

  rad_day:=Q;

end; {end of function rad_day}


{----------------------------------------------------------------------}
```

```
function rad_year(latitude, aspect, slope:real;
                  incr_min, incr_day: integer):real;

{calculates total radiative energy received per m2 per year}

var R, dr           : real;
    day, day_mod    : integer;

begin

  day  :=1;
  sinlat:=sin(latitude * pi/180);
  coslat:=cos(latitude * pi/180);
  dr:=0;
  R :=0;

  while day<=365 do
  begin
    if day>=80 then            {adjusts day to equinox = March 21st}
      begin
        day_mod:=day-80;
      end
    else
      begin
        day_mod:=day-80+365;
      end;

    sindec:=sin(23.45 * sin(2 * pi/365 * day_mod) * pi/180);
    cosdec:=cos(23.45 * sin(2 * pi/365 * day_mod) * pi/180);

    dr:=rad_day(sinlat, coslat, sindec, cosdec, aspect, slope,
                incr_min) * incr_day;
    R :=R+dr;
    day:= day+incr_day;
  end;

  rad_year:=R;

end; {end of function rad_year}

{----------------------------------------------------------------------}


begin      { main program }

 write('Latitude      : ');readln(latitude);
 write('Aspect (S=0)  : ');readln(aspect);
 write('Slope         : ');readln(slope);
 writeln;

 result:=rad_year(latitude,aspect*pi/180,slope*pi/180,min_dec,day_dec);

 writeln('Potential yearly solar radiation in MJ/m2: ',result/1000000);

end.       { main program }
```

APPENDIX B

PEDON DESCRIPTIONS

Site: 13 2S

Date: July 1998
Slope: 28°
Classification: Lithic Dystrudept

Remarks: 50% surface stones; thin (< 1cm) and patchy Oi and Oe horizons; soil creep visible at base of young tree stems; tree mounds.

Horizon	Depth (cm)	
Oa	2-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; forms crust; some worm castings; abrupt wavy boundary.
A	0-10	Very dark grayish brown (10 YR 3/2); fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 15%; clear wavy boundary.
Bw1	10-25	Dark yellowish brown (10 YR 3/4); gravelly fine sandy loam; weak-moderate medium to coarse granular structure; friable; many fine and medium roots; estimated rock fragments 30%; gradual smooth boundary.
Bw2	25-31	Dark yellowish brown (10 YR 3/4); very gravelly fine sandy loam; weak coarse granular structure; friable; few roots all sizes; estimated rock fragments 40%; abrupt wavy boundary.
R	31+	Mt. Toby conglomerate.

Site: **13 1S**

Date: July 1998
Slope: 26°
Classification: Lithic Dystrudept

Remarks: 30% surface stones, thin (< 1cm) and patchy Oi and Oe horizons, significant amount of windblown material; some soil creep visible at base of young tree stems; tree mounds.

Horizon	Depth (cm)	
Oa	3.5-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; forms crust; some worm casts; abrupt wavy boundary.
A	0-12.5	Very dark grayish brown (10 YR 3/2); gravelly fine sandy loam; estimated rock fragments 20%; moderate medium granular structure; friable; many fine roots; clear wavy boundary.
Bw	12.5-31	Dark yellowish brown (10 YR 3/4); gravelly fine sandy loam; friable; weak-moderate medium to coarse granular to blocky structure; common fine and medium roots estimated rock fragments 30%; abrupt smooth boundary.
R	31+	Mt. Toby conglomerate.

Site: **13 Top**

Date: July 1998
Slope: /
Classification: Lithic Dystrudept

Remarks: No surface stones, soil assumed to have developed from windblown material. Some tree mounds.

Horizon	Depth (cm)	
Oi + Oe	8-5	Litter and fibric material
Oa	5-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; abrupt smooth boundary.
A	0-4	Very dark brown (10 YR 2/2); fine sandy loam; estimated rock fragments <5%; moderate medium granular structure; friable; many fine roots; clear wavy boundary.
Bw1	4-20	Dark yellowish brown (10 YR 3/4); fine sandy loam; weak-moderate medium to coarse granular structure; friable; many fine and medium roots; estimated rock fragments 10%; gradual smooth boundary.
Bw2	20-36	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; estimated rock fragments 40% (angular); friable; weak coarse granular to blocky structure; common medium and coarse roots; abrupt wavy boundary.
R	36+	Mt. Toby conglomerate.

Site: **13 1N**

Date: July 1998
Slope: 32°
Classification: Lithic Dystrudept

Remarks: 40% surface stones, rocks concentrated near surface; significant soil creep.

Horizon	Depth (cm)	
Oi + Oe	14-8	Litter and fibric material
Oa	8-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; high content of angular rocks and boulders (50%); clear wavy boundary.
A/E	0-2.5	Very dark gray (10 YR 3/1); material significantly lighter when dry (Grayish brown, 10YR 5/2); uncoated quartz grains (salt and pepper); very cobbly fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 50%; clear wavy boundary.
Bw1/B(h)s	2.5-7.5	Dark brown (7.5 YR 3/3); cobbly fine sandy loam;; moderate medium granular structure; friable; many fine and medium roots; clear broken boundary; estimated rock fragments 30% broken, wavy boundary.
Bw2	7.5-39	Dark yellowish brown (10 YR 3/4); stony fine sandy loam; estimated rock fragments 40%; friable; weak coarse granular to blocky structure; common medium and coarse roots: abrupt, wavy boundary.
2R	39+	Mt. Toby conglomerate.

Site: **13 2N**

Date: July 1998
Slope: 38°
Classification: Lithic Dystrudept

Remarks: 70% surface stones; rocks concentrated at surface; significant soil creep.

Horizon	Depth (cm)	
Oi + Oe	20-12	Litter and fibric material
Oa	12-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; many fungal hyphae; extremely high content of rocks and boulders (80%), forming many cavities; clear wavy boundary.
A/E	0-2.5	Very dark gray (10 YR 3/1); extremely stony, fine sandy loam; estimated rock fragments 60% (angular-subangular); moderate medium granular structure; friable; many fine roots; clear wavy boundary.
Bw	2.5-25	Dark yellowish brown (10 YR 3/4); cobbly, stony, bouldery fine sandy loam; moderate medium granular to blocky structure; friable; common fine and medium roots; estimated rock fragments 40%; abrupt wavy boundary.
2R	25+	Mt. Toby conglomerate.

Site: **53 2S**

Date: August 1998
Slope: 32°
Classification: Lithic Dystrudept

Remarks: 40% surface stones; thin (< 1.5 cm) and patchy Oi and Oe horizons; soil creep visible at base of young tree stems; tree mounds.

Horizon	Depth (cm)	
Oa	2.5-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; forms crust; some worm casts; estimated gravel content 10%; abrupt wavy boundary.
A	0-6	Very dark brown (10 YR 2/2); fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 10%; clear wavy boundary.
Bw1	6-22	Dark yellowish brown (10 YR 3/4); gravelly fine sandy loam; moderate medium to coarse granular structure; friable; many fine and medium roots; estimated rock fragments 20%; gradual wavy boundary.
Bw2	22-38	Dark yellowish brown (10 YR 3/4); very cobbly fine sandy loam; weak coarse granular structure; friable; few roots all sizes; estimated rock fragments 50%; abrupt wavy boundary.
R	38+	Mt. Toby conglomerate.

Site: **53 1S**

Date: August 1998
Slope: 26°
Classification: Typic Dystrudept

Remarks: 40% surface stones; thin (< 0.5 cm) and patchy Oi and Oe horizons.

Horizon	Depth (cm)	
Oa	3-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; forms crust; some worm castings; estimated gravel content 10%; abrupt wavy boundary.
A	0-8.5	Very dark brown (10 YR 2/2); fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 10%; clear wavy boundary.
Bw1	8.5-33.5	Dark yellowish brown (10 YR 3/4); gravelly fine sandy loam; moderate medium to coarse granular structure; friable; many fine and medium roots; estimated rock fragments 20%; gradual wavy boundary.
Bw2	33.5-59	Dark yellowish brown (10 YR 3/6); very cobbly fine sandy loam; weak coarse granular to blocky structure; friable; few roots all sizes; estimated rock fragments 40%; abrupt wavy boundary.
R	59+	Mt. Toby conglomerate.

Site:	**53 Top**	
Date:	August 1998	
Slope:	/	
Classification:	Lithic Udorthent	
Remarks:	10% surface stones; tree mounds.	
Horizon	Depth (cm)	
Oi+Oe	4-2	Litter, fibric and hemic material
Oa	2-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; forms crust; estimated gravel content 10%; abrupt smooth boundary.
A	0-5.5	Very dark brown (10 YR 2/2); fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 10%; abrupt wavy boundary.
Bw	5.5-12	Dark brown (10 YR 3/4); gravelly fine sandy loam; weak to moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 25%; gradual wavy boundary.
R	12+	Mt. Toby conglomerate.

Site: **53 1N**

Date: August 1998
Slope: 28°
Classification: Lithic Udorthent

Remarks: 50% surface stones; significant soil creep.

Horizon	Depth (cm)	
Oi+Oe	8-5	Litter, fibric and hemic material; common fine roots.
Oa	5-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; common fungal hyphae; estimated gravel content 10%; abrupt wavy boundary.
A/E	0-7.5	Very dark grayish brown (10 YR 3/2); some soil material grayish brown (10 YR 5/2); very cobbly fine sandy loam; structureless to weak medium granular structure; friable; few fine roots; estimated rock fragments 60%; clear wavy boundary.
Bw	7.5-18	Dark brown (10 YR 3/3); gravelly fine sandy loam; moderate medium to coarse granular structure; friable; common fine and medium roots; estimated rock fragments 30%; gradual wavy boundary.
R	18+	Mt. Toby conglomerate.

Site: **53 2N**

Date: August 1998
Slope: 36°
Classification: Lithic Dystrudept

Remarks: 10% surface stones; soil creep; some tree mounds.

Horizon	Depth (cm)	
Oi+Oe	9-7	Litter, fibric and hemic material; some fine roots
Oa	7-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; many fungal hyphae; estimated gravel content 30%; abrupt wavy boundary.
A	0-3.5	Very dark gray (10 YR 2/2); fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 10%; clear wavy boundary.
Bw1	3.5-26	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; moderate medium to coarse granular structure; friable; common fine and medium roots; estimated rock fragments 20%; gradual smooth boundary.
Bw2	26-48	Dark yellowish brown (10 YR 3/4); extremely stony fine sandy loam; weak coarse granular to blocky structure; friable; few roots all sizes; estimated rock fragments 70%; abrupt wavy boundary.
R	48+	Mt. Toby conglomerate.

Site: **105 2S**

Date: August 1998
Slope: 26°
Classification: Typic Dystrudept

Remarks: 80% surface stones; thin (< 1cm) and patchy L-layer; soil creep; some tree mounds.

Horizon	Depth (cm)	
Oa	3-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; estimated gravel content 30%; abrupt wavy boundary.
A	0-2.5	Very dark grayish brown (10 YR 3/2); cobbly fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 30%; clear wavy boundary.
Bw1	2.5-27.5	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; moderate medium granular structure; friable; common fine and medium roots; estimated rock fragments 30%; gradual smooth boundary.
Bw2	27.5-56	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; structureless to weak coarse granular to blocky structure; friable; few roots all sizes; estimated rock fragments 30%; abrupt wavy boundary.
R	59+	Mt. Toby conglomerate.

Site: 105 1S

Date: August 1998
Slope: 26°
Classification: Lithic Dystrudept

Remarks: 60% surface stones; thin (< 1cm) and patchy L-layer; soil creep; some tree mounds.

Horizon	Depth (cm)	
Oa	4.5-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; forms crust; some worm castings; estimated gravel content 10%; abrupt wavy boundary.
A	0-7.5	Very dark brown (10 YR 2/2); cobbly fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 15%; clear wavy boundary.
Bw1	7.5-25	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 20%; clear smooth boundary.
Bw2	25-37.5	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; weak coarse granular to blocky structure; friable; few roots all sizes; estimated rock fragments 20%; abrupt wavy boundary.
R	37.5	Mt. Toby conglomerate.

Site:	**105 Top**	
Date:	August 1998	
Slope:	/	
Classification:	Lithic Udorthent	
Remarks:	<5% surface stones; some tree mounds.	
Horizon	Depth (cm)	
Oi+Oe	9-6	Litter, fibric and hemic material, common fine roots.
Oa	6-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; many worm castings; abrupt wavy boundary.
A	0-8	Very dark brown (10 YR 2/2); cobbly fine sandy loam; weak medium granular structure; friable; many fine and medium roots; estimated rock fragments 15%; abrupt smooth boundary.
AB	8-13	Very dark grayish brown (10 YR 3/2); cobbly fine sandy loam; weak medium blocky structure; friable; common fine and many medium rootws; estimated rock fragments 15%; abrupt smooth boundary.
R	13+	Mt. Toby conglomerate.

Site: 105 1N

Date: August 1998
Slope: 26°
Classification: Lithic Dystrudept

Remarks: 15% surface stones; soil creep; some tree mounds.

Horizon	Depth (cm)	
Oi+Oe	4-2.5	Litter and hemic material.
Oa	2.5-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; forms crust; estimated gravel content <5%; abrupt wavy boundary.
A	0-2.5	Very dark gray (10 YR 3/1); cobbly fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 20%; abrupt wavy boundary.
Bw	2.5-21	Dark brown (7.5 YR 3/3); cobbly fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 20%; abrupt smooth boundary.
R	37.5+	Mt. Toby conglomerate.

Site: **105 2N**

Date: August 1998
Slope: 34°
Classification: Lithic Udorthent

Remarks: 15% surface stones; soil creep; tree mounds.

Horizon	Depth (cm)	
Oi+Oe	3.5-2.5	Litter and hemic material.
Oa	2.5-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; estimated gravel content <5%; abrupt wavy boundary.
A	0-2.5	Very dark gray (10 YR 3/1); fine sandy loam; structureless to weak medium granular structure; friable; many fine and medium roots; estimated rock fragments 10%; abrupt wavy boundary.
Bw	2.5-16	Dark brown (10 YR 3/3); fine sandy loam; structureless to weak medium granular structure; friable; common roots all sizes; estimated rock fragments 10%; abrupt wavy boundary.
R	16+	Mt. Toby conglomerate.

Site: **158 2S**

Date: August 1998
Slope: 24°
Classification: Lithic Udorthent

Remarks: 40% surface stones; thin (< 1 cm) and patchy litter–layer; soil creep; tree mounds.

Horizon	Depth (cm)	
Oa	2.5-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; forms crust; common worm castings; estimated gravel content 20%; abrupt smooth boundary.
A	0-7.5	Very dark brown (10 YR 2/2); cobbly fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 30%; clear wavy boundary.
Bw	7.5-16	Dark brown (10 YR 3/3); stony fine sandy loam; moderate medium granular structure; friable; many roots all sizes; estimated rock fragments 30%; abrupt wavy boundary.
R	16+	Mt. Toby conglomerate.

Site: **158 1S**

Date: August 1998
Slope: 28°
Classification: Typic Dystrudept

Remarks: <5 % surface stones; soil creep; tree mounds.

Horizon	Depth (cm)	
Oi+Oe	5-3	Litter and hemic material
Oa	3-0	Very dark brown (10 YR 2/2); sapric matter; friable; common fine roots; some worm castings; estimated gravel content 20%; abrupt smooth boundary.
A	0-5	Very dark brown (10 YR 2/2); gravelly fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 20%; clear wavy boundary.
Bw1	5-32	Dark brown (7.5 YR 3/4); gravelly fine sandy loam; moderate medium granular structure; friable; common roots all sizes; estimated rock fragments 30%; clear smooth boundary.
Bw2	32-60	Dark brown (7.5 YR 3/4); cobbly fine sandy loam; weak medium granular structure; friable; many roots all sizes; estimated rock fragments 30%; abrupt wavy boundary.
R	60+	Mt. Toby conglomerate.

Site:	**158 Top**	
Date:	August 1998	
Slope:	/	
Classification:	Lithic Udorthent	
Remarks:	0 % surface stones; soil creep; tree mounds common.	
Horizon	Depth (cm)	
Oi+Oe	8-5.5	Litter and hemic material
Oa	5.5-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; some worm castings; estimated gravel content <5%; clear smooth boundary.
A	0-7.5	Very dark brown (10 YR 2/2); fine sandy loam; moderate medium granular structure; friable; common fine and medium roots; estimated rock fragments 10%; clear smooth boundary.
Bw	7.5-19	Dark brown (7.5 YR 3/4); gravelly fine sandy loam; weak medium granular structure; friable; common roots all sizes; estimated rock fragments 20%; abrupt smooth boundary.
R	19+	Mt. Toby conglomerate.

Site: **158 1N**

Date: August 1998
Slope: 28°
Classification: Lithic Dystrudept

Remarks: 25 % surface stones; soil creep; tree mounds.

Horizon	Depth (cm)	
Oi+Oe	5-3.5	Litter and hemic material
Oa	3.5-0	Black (10 YR 2/1); sapric matter; friable; common fine roots; estimated gravel content 10%; clear wavy boundary.
A	0-2.5	Very dark grayish brown (10 YR 3/2); cobbly fine sandy loam; moderate medium granular structure; friable; common fine and medium roots; estimated rock fragments 20%; clear wavy boundary.
Bw1	2.5-22	Dark yellowish brown (10YR 3/4); fine sandy loam; moderate medium granular structure; friable; common roots all sizes; estimated rock fragments 10%; gradual smooth boundary.
Bw2	22-42	Dark yellowish brown (10 YR 3/4); fine sandy loam; weak medium granular structure; friable; common roots all sizes; estimated rock fragments 10%; abrupt wavy boundary.
R	42+	Mt. Toby conglomerate.

Site: **158 2N**

Date: August 1998
Slope: 32°
Classification: Lithic Dystrudept

Remarks: 20 % surface stones; significant soil creep; many tree mounds.

Horizon	Depth (cm)	
Oi+Oe	5-3	Litter and hemic material
Oa	3-0	Black (10 YR 2/1); sapric matter; friable; few fine roots; estimated gravel content 10%; abrupt irregular boundary.
A	0-3	Very dark grayish brown (10 YR 3/2); cobbly fine sandy loam; moderate medium granular structure; friable; common fine and medium roots; estimated rock fragments 30%; clear wavy boundary.
Bw1	3-20	Dark yellowish brown (10YR 3/4); fine sandy loam; moderate medium granular structure; friable; many roots all sizes; estimated rock fragments 10%; gradual smooth boundary.
Bw2	20-37	Dark yellowish brown (10 YR 3/4); fine sandy loam; weak medium granular structure; friable; common roots medium roots; estimated rock fragments 10%; abrupt wavy boundary.
R	37+	Mt. Toby conglomerate.

Site: **206 2S**

Date: August 1998
Slope: 26°
Classification: Lithic Dystrudept

Remarks: 20 % surface stones; very thin (< 1cm) and patchy litter layer; soil creep; many tree mounds.

Horizon	Depth (cm)	
Oa	3-0	Very dark brown (10 YR 2/2); sapric matter; foms crust; friable; many fine roots; some worm castings; estimated gravel content <5%; abrupt wavy boundary.
A	0-3	Very dark brown (10 YR 2/2); cobbly fine sandy loam; moderate fine to medium granular structure; friable; common fine and medium roots; estimated rock fragments 10%; clear wavy boundary.
Bw1	3-20	Dark yellowish brown (10YR 3/4); cobbly fine sandy loam; moderate medium granular structure; friable; many roots all sizes; estimated rock fragments 25%; gradual smooth boundary.
Bw2	20-37	Dark yellowish brown (10 YR 3/4); extremely bouldery fine sandy loam; weak medium granular structure; friable; few medium and coarse roots; estimated rock fragments 80%; abrupt wavy boundary.
R	37+	Mt. Toby conglomerate.

Site: **206 1S**

Date: August 1998
Slope: 24°
Classification: Typic Dystrudept

Remarks: 5 % surface stones; slight; soil creep; many tree mounds.

Horizon	Depth (cm)	
Oi+Oe	7-5	Litter and hemic material, many fine roots.
Oa	5-0	Very dark brown (10 YR 2/2); sapric matter; foms crust; friable; many fine roots; estimated gravel content <5%; abrupt smooth boundary.
A	0-6	Very dark brown (10 YR 2/2); fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 10%; clear wavy boundary.
Bw1	6-45	Dark yellowish brown (10YR 3/4); cobbly fine sandy loam; weak to moderate medium granular structure; friable; many roots all sizes; estimated rock fragments 30%; gradual smooth boundary.
Bw2	45-93	Olive brown (2.5 Y 4/4); gravelly fine sandy loam; massive; friable; few medium roots; krotovinas filled with material from overlying horizons (10 YR 2/2); estimated rock fragments 20%; abrupt wavy boundary.
R	93+	Mt. Toby conglomerate.

Site:	**206 Top**	
Date:	August 1998	
Slope:	/	
Classification:	Typic Dystrudept	
Remarks:	5 % surface stones; many tree mounds.	
Horizon	Depth (cm)	
Oi+Oe	5-2	Litter and hemic material, many fine roots.
Oa	2-0	Black (10 YR 2/1); sapric matter; foms crust; friable; many fine roots; abrupt smooth boundary.
A	0-5.5	Very dark brown (10 YR 2/2); fine sandy loam; moderate fine granular structure; some worm castings; friable; many fine and medium roots; estimated rock fragments 5%; clear wavy boundary.
Bw1	5.5-32	Dark yellowish brown (10YR 3/4); cobbly fine sandy loam; moderate medium granular structure; friable; many roots all sizes; estimated rock fragments 15%; gradual smooth boundary.
Bw2	32-59	Dark yellowish brown (10 YR 3/4); stony fine sandy loam; structureless to weak medium granular structure; friable; few medium and coarse roots; estimated rock fragments 25%; abrupt wavy boundary.
R	59+	Mt. Toby conglomerate.

Site: **206 1N**

Date: August 1998
Slope: 28°
Classification: Lithic Dystrudept

Remarks: 5 % surface stones; thin (ca. 1 cm) and patchy litter layer; slight soil creep; many tree mounds.

Horizon	Depth (cm)	
Oa	1-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; estimated rock fragments <5%; abrupt wavy boundary.
A	0-3	Very dark grayish brown (10 YR 3/2); fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 10%; clear wavy boundary.
Bw1	3-25	Dark yellowish brown (10YR 3/4); darker material (7.5 YR 3/3) occurs preferred drainage paths; very stony fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 50%; clear smooth boundary.
Bw2	25-47.5	Dark yellowish brown (10 YR 3/4); extremely bouldery fine sandy loam; structureless to weak medium granular structure; friable; few medium and coarse roots; estimated rock fragments 70%; abrupt irregular boundary.
R	47.5+	Mt. Toby conglomerate.

Site: **206 2N**

Date: August 1998
Slope: 36°
Classification: Lithic Dystrudept

Remarks: 15 % surface stones; slight soil creep; many tree mounds.

Horizon	Depth (cm)	
Oi+Oe	7-5	Litter and hemic material.
Oa	5-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; estimated rock fragments 30%; abrupt wavy boundary.
A	0-7	Very dark brown (10 YR 2/2); cobbly fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 20%; clear wavy boundary.
Bw	7-32	Dark brown (7.5 YR 3/3); stony fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 30%; abrupt smooth boundary.
R	32+	Mt. Toby conglomerate.

Site: **260 2S**

Date: August 1998
Slope: 30°
Classification: Typic Dystrudept

Remarks: 10 % surface stones; thin (ca. 1 cm) and patchy litter layer; slight soil creep; many tree mounds.

Horizon	Depth (cm)	
Oa	1.5-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; many worm castings; estimated rock fragments <5%; clear wavy boundary.
A	0-5.5	Dark brown (10 YR 3/3); cobbly fine sandy loam; moderate to strong fine to medium granular structure; friable; many fine roots; estimated rock fragments 15%; clear wavy boundary.
Bw1	5.5-35	Dark brown (7.5 YR 3/4); very cobbly fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 40%; gradual smooth boundary.
Bw2	35-60	Dark yellowish brown (10 YR 3/4); very stony fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 40%; abrupt smooth boundary.
R	60+	Mt. Toby conglomerate.

Site: **260 1S**

Date: August 1998
Slope: 22°
Classification: Typic Dystrudept

Remarks: <5 % surface stones; thin (ca. 2 cm) and patchy litter layer; slight soil creep; many tree mounds; some A-material mixed in Bw1 horizon probably due to old tree mound.

Horizon	Depth (cm)	
Oi	5.5-3.5	Litter.
Oa	3.5-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; many worm castings; estimated rock fragments <5%; clear wavy boundary.
A	0-9	Dark brown (10 YR 3/2); cobbly fine sandy loam; moderate to strong fine to medium granular structure; friable; many fine roots; estimated rock fragments 10%; clear irregular boundary.
Bw1	9-30	Dark brown (10 YR 3/3); cobbly fine sandy loam; moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 30%; gradual smooth boundary.
Bw2	30-55	Brown (10 YR 4/3); very cobbly fine sandy loam; weak medium granular structure; friable; many fine and medium roots; estimated rock fragments 40%; abrupt wavy boundary.
R	55+	Mt. Toby conglomerate.

Site:	**260 Top (VI Top)**	
Date:	August 1998	
Slope:	/	
Classification:	Lithic Dystrudept	
Remarks:	Tree mounds.	
Horizon	Depth (cm)	
Oi+Oe	7-5	Litter and hemic material; many fine roots.
Oa	5-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; many worm castings; estimated rock fragments <5%; clear wavy boundary.
A	0-3	Very dark brown (10 YR 2/2); fine sandy loam; moderate to strong fine to medium granular structure; friable; many fine roots; estimated rock fragments 10%; clear wavy boundary.
Bw1	3-19	Dark yellowish brown (10 YR 3/6); fine sandy loam; moderate medium granular structure; friable; common fine and medium roots; estimated rock fragments 10%; gradual smooth boundary.
Bw2	19-35	Dark yellowish brown (10 YR 3/6); fine sandy loam; moderate coarse granular structure; friable; many fine and medium roots; estimated rock fragments 10%; abrupt wavy boundary.
R	35+	Mt. Toby conglomerate.

Site:	**260 1N**	
Date:	August 1998	
Slope:	26°	
Classification:	Lithic Dystrudept	
Remarks:	<5% surface stones; slight soil creep; tree mounds.	
Horizon	Depth (cm)	
Oi+Oe	7-4.5	Litter and hemic material; many fine roots.
Oa	4.5-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; many worm castings; estimated rock fragments <5%; clear wavy boundary.
A/E	0-7.5	Very dark grayish brown (10 YR 3/2); cobbly fine sandy loam; moderate to strong fine to medium granular structure; friable; many fine roots; estimated rock fragments 20%; clear wavy boundary.
B(h)s	7.5-10	Dark brown (7.5 YR 3/3); cobbly fine sandy loam; moderate medium granular structure; friable; common fine and medium roots; estimated rock fragments 20%; abrupt broken boundary.
Bw2	10-30	Dark yellowish brown (10 YR 3/4); fine sandy loam; weak to moderate coarse granular structure; friable; many fine and medium roots; estimated rock fragments 15%; abrupt wavy boundary.
R	30+	Mt. Toby conglomerate.

Site:	**260 2N**	
Date:	August 1998	
Slope:	34°	
Classification:	Lithic Dystrudept	
Remarks:	<5% surface stones; slight soil creep; tree mounds.	
Horizon	Depth (cm)	
Oi+Oe	9-5	Litter and hemic material; many fine roots.
Oa	5-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; many worm castings; estimated rock fragments 40%; clear wavy boundary.
A/E	0-7.5	Dark brown (7.5 YR 3/3); cobbly fine sandy loam; moderate medium granular structure; friable; many fine roots; estimated rock fragments 20%; clear wavy boundary.
Bw	7.5-25	Dark yellowish brown (10 YR 3/4); fine sandy loam; weak to moderate coarse granular structure; friable; many fine and medium roots; estimated rock fragments 20%; abrupt wavy boundary.
R	25+	Mt. Toby conglomerate.

Site: **300 2S**

Date: August 1998
Slope: 24°
Classification: Typic Dystrudept

Remarks: 25% surface stones; thin (<1 cm) and patchy litter layer; soil creep; tree mounds, probably disturbed site.

Horizon	Depth (cm)	
Oe	1-0	Litter and hemic material.
A	0-5	Very dark grayish brown (10 YR 3/2); fine sandy loam; moderate fine to medium granular structure; friable; many fine roots; estimated rock fragments <5%; clear wavy boundary.
Bw1	5-30	Dark yellowish brown (10 YR 3/4); fine sandy loam; weak to moderate medium granular structure; friable; common fine and medium roots; estimated rock fragments 10%; gradual smooth boundary.
Bw2	30-54	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; weak to moderate coarse granular structure; friable; many fine and medium roots; estimated rock fragments 20%; abrupt wavy boundary.
R	54+	Mt. Toby conglomerate.

Site: **300 1S**

Date: August 1998
Slope: 24°
Classification: Typic Dystrudept

Remarks: 5% surface stones; thin (<1 cm) and patchy litter layer; soil creep; tree mound right above soil pit.

Horizon	Depth (cm)	
Oa	2-0	Very dark brown (10 YR 2/2); sapric matter; friable; many fine roots; abrupt smooth boundary.
A	0-6	Dark brown (10 YR 3/3); fine sandy loam; moderate fine to medium granular structure; friable; many fine roots; estimated rock fragments <5%; clear wavy boundary.
Bw1	6-32	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; weak to moderate medium granular structure; friable; common fine and medium roots; estimated rock fragments 15%; gradual smooth boundary.
Bw2	32-60	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; weak coarse granular structure; friable; common roots all sizes; estimated rock fragments 20%; abrupt wavy boundary.
R	60+	Mt. Toby conglomerate.

Site:	**300 Top**	
Date:	August 1998	
Slope:	/	
Classification:	Lithic Dystrudept	
Remarks:	5% surface stones.	
Horizon	Depth (cm)	
Oi+Oe	10.5-7.5	Litter and hemic material; many fine roots.
Oa	7.5-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; some worm castings; abrupt wavy boundary.
A	0-5	Very dark brown (10 YR 2/2); fine sandy loam; moderate fine to medium granular structure; friable; many fine roots; estimated rock fragments 10%; clear wavy boundary.
Bw	5-25	Dark yellowish brown (10YR 3/4); cobbly fine sandy loam; weak to moderate medium granular structure; friable; common fine and medium roots; estimated rock fragments 20%; abrupt smooth boundary.
R	25+	Mt. Toby conglomerate.

Site: **300 1N**

Date: August 1998
Slope: 28°
Classification: Typic Dystrudept

Remarks: 10% surface stones; soil creep; tree mounds.

Horizon	Depth (cm)	
Oi+Oe	8-6	Litter and hemic material; many fine roots.
Oa	6-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; some worm castings; estimted gravel content 40% (stones and boulders); abrupt irregular boundary.
A	0-5	Dark brown (10 YR 3/3); cobbly fine sandy loam; moderate fine to medium granular structure; friable; many fine and medium roots; estimated rock fragments 25%; clear wavy boundary.
Bw1	5-29	Dark yellowish brown (10 YR 3/4); very cobbly fine sandy loam; weak to moderate medium granular structure; friable; many fine and medium roots; estimated rock fragments 40%; gradual smooth boundary.
Bw2	29-51	Dark brown (7.5 YR 3/4); very stony fine sandy loam; weak coarse granular structure; friable; common medium and coarse roots; estimated rock fragments 40%; abrupt wavy boundary.
R	51+	Mt. Toby conglomerate.

Site: **300 2N**

Date: August 1998
Slope: 34°
Classification: Typic Dystrudept

Remarks: 15% surface stones; soil creep; tree mounds.

Horizon	Depth (cm)	
Oi+Oe	8-5	Litter and hemic material; many fine roots.
Oa	5-0	Black (10 YR 2/1); sapric matter; friable; many fine roots; some worm castings; estimted rock fragments 10%; abrupt wavy boundary.
A	0-6	Dark brown (10 YR 3/3); fine sandy loam; moderate fine to medium granular structure; friable; many fine and medium roots; estimated rock fragments 10%; clear wavy boundary.
Bw1	6-27	Dark yellowish brown (10 YR 3/4); cobbly fine sandy loam; moderate medium granular structure; friable; few fine and medium roots; estimated rock fragments 20%; gradual smooth boundary.
Bw2	27-50	Dark brown (7.5 YR 3/4); stony fine sandy loam; moderate coarse granular structure; friable; many medium and coarse roots; estimated rock fragments 20%; abrupt wavy boundary.
R	50+	Mt. Toby conglomerate.

APPENDIX C

LABORATORY DATA

Laboratory data for soil samples collected during August 1998 on Ox Hill, Franklin County, Massachusetts. Values of B-horizons represent weighed averages (by thickness) if two B-horizons were specified.

O-horizons

Sample	pH (H_2O)	pH ($CaCl_2$)	L.I. (%)	C (%)	N (%)	C/N
013 1N	3.9	3.2	42.5	23.6	0.9	26.0
013 1S	5.4	4.8	34.8	21.0	1.0	20.8
013 2N	3.9	3.0	56.3	32.4	1.3	24.7
013 2S	4.7	3.9	41.5	20.2	1.1	18.4
013 T	5.0	4.5	32.3	16.1	1.0	15.8
053 1N	4.1	3.5	50.3	29.1	1.2	23.8
053 1S	5.3	4.8	37.0	19.1	0.8	22.7
053 2N	4.0	3.4	59.0	34.4	1.3	26.5
053 2S	4.6	3.8	19.2	10.4	0.5	19.6
053 T	5.4	5.1	42.7	22.7	1.3	17.8
105 1N	4.0	3.4	45.9	25.2	1.2	21.9
105 1S	4.8	3.9	25.4	14.1	0.7	19.0
105 2N	4.4	3.6	38.1	23.3	1.0	22.9
105 2S	5.1	4.8	26.4	13.9	0.7	19.3
105 T	5.0	4.4	45.6	22.8	1.5	15.1
158 1N	4.4	3.8	33.5	20.2	0.9	21.5
158 1S	4.0	3.4	50.3	27.2	1.2	22.6
158 2N	4.0	3.5	53.4	30.5	1.3	23.8
158 2S	4.9	4.3	25.1	12.6	0.7	18.5
158 T	4.6	4.1	53.5	28.7	1.7	16.9
206 1N	4.4	3.8	43.5	25.6	1.2	22.3
206 1S	4.9	4.2	24.9	13.1	0.7	17.9
206 2N	4.3	3.6	27.3	16.5	0.8	21.6
206 2S	5.1	4.6	34.4	17.1	0.9	19.2
206 T	4.5	3.8	31.8	17.2	1.0	17.1
260 1N	4.2	3.7	45.6	24.6	1.2	20.3
260 1S	4.7	4.3	44.8	25.2	1.1	22.3
260 2N	4.8	4.4	46.8	27.2	1.3	21.1
260 2S	5.1	4.5	27.8	13.9	0.8	18.3
260 T	4.1	3.5	34.9	18.4	1.0	19.1
300 1N	3.8	3.1	36.2	21.4	0.8	26.7
300 1S	4.8	4.3	34.1	18.7	1.0	19.0
300 2N	4.3	3.6	37.7	22.7	0.9	25.5
300 2S	4.9	4.3	32.7	17.4	0.9	19.8
300 T	3.7	3.1	44.8	23.5	1.0	23.5

A-horizons

Sample	pH (H_2O)	pH ($CaCl_2$)	L.I. (%)	C (%)	N (%)	C/N
013 1N	3.2	3.8	14.0	7.6	0.3	22.5
013 1S	4.0	4.8	16.8	7.8	0.5	17.0
013 2N	3.4	4.0	10.5	6.5	0.3	26.0
013 2S	3.6	4.4	14.8	7.2	0.4	19.4
013 T	3.6	4.3	15.0	7.6	0.5	16.1
053 1N	3.4	4.0	17.1	11.0	0.4	27.6
053 1S	3.5	4.2	15.7	8.0	0.4	18.1
053 2N	3.9	4.3	11.7	6.6	0.2	28.5
053 2S	4.1	4.4	18.4	10.3	0.5	21.4
053 T	3.7	4.5	22.9	12.6	0.9	14.2
105 1N	3.6	4.3	15.8	9.1	0.4	21.7
105 1S	3.9	4.4	11.7	5.4	0.3	20.6
105 2N	4.0	4.5	11.2	6.0	0.3	18.7
105 2S	3.9	4.4	13.1	5.7	0.3	20.4
105 T	3.7	4.4	18.7	9.3	0.6	14.6
158 1N	3.7	4.2	16.6	7.3	0.3	22.8
158 1S	4.1	4.5	18.6	8.4	0.4	20.9
158 2N	4.0	4.5	11.0	5.5	0.3	19.6
158 2S	4.4	5.2	17.2	7.5	0.5	16.4
158 T	3.9	4.4	13.8	6.5	0.4	17.7
206 1N	4.1	4.6	14.2	7.3	0.3	24.4
206 1S	3.8	4.5	15.1	6.2	0.4	17.6
206 2N	3.6	4.4	13.1	6.5	0.3	19.0
206 2S	4.0	4.5	17.5	9.1	0.4	20.8
206 T	3.9	4.4	16.0	8.0	0.5	17.7
260 1N	3.1	3.8	13.2	6.6	0.3	23.7
260 1S	3.9	4.5	13.9	7.1	0.3	22.0
260 2N	3.8	4.5	9.5	4.7	0.2	21.2
260 2S	3.9	4.4	10.0	4.3	0.2	20.3
260 T	3.5	4.1	13.7	6.2	0.3	18.8
300 1N	3.4	3.9	14.3	6.4	0.3	23.6
300 1S	3.8	4.5	12.6	5.5	0.3	17.3
300 2N	3.7	4.4	6.1	2.8	0.2	18.5
300 2S	4.6	5.2	13.4	5.7	0.3	17.2
300 T	3.3	4.0	16.1	7.9	0.4	21.3

B-horizons

Sample	pH (H_2O)	pH ($CaCl_2$)	L.I. (%)
013 1N	4.4	4.1	8.0
013 1S	4.4	3.7	6.3
013 2N	4.4	4.0	5.8
013 2S	4.4	3.7	6.8
013 T	4.5	4.0	6.8
053 1N	4.4	3.8	13.1
053 1S	4.5	3.9	7.2
053 2N	4.1	3.6	8.1
053 2S	4.3	3.7	5.1
053 T	4.4	3.6	13.0
105 1N	3.7	3.1	8.8
105 1S	4.4	3.8	4.5
105 2N	4.2	3.5	5.2
105 2S	4.6	3.9	3.3
105 T	4.3	3.7	16.2
158 1N	4.3	3.6	6.9
158 1S	4.4	3.9	6.1
158 2N	4.1	3.5	5.3
158 2S	4.6	4.0	6.6
158 T	4.4	3.8	9.1
206 1N	3.9	3.2	10.5
206 1S	4.5	4.1	4.0
206 2N	4.9	4.1	5.2
206 2S	4.4	4.0	5.0
206 T	4.4	4.2	5.3
260 1N	4.6	4.0	10.0
260 1S	4.6	3.9	4.9
260 2N	4.7	4.0	5.5
260 2S	4.4	3.9	4.1
260 T	4.3	4.0	6.2
300 1N	4.4	3.8	6.6
300 1S	4.3	4.0	5.3
300 2N	4.6	3.9	4.4
300 2S	4.5	3.8	3.4
300 T	4.2	3.9	9.0

Texture Analysis of A-horizons. Values are percentages.

Sample	clay	f. silt	m. silt	c. silt	vf. sand	f. sand	m. sand	c. sand	vc. Sand
013 1N	5.8	5.6	26.1	19.5	8.8	9.7	9.5	8.7	6.3
013 1S	5.6	5.8	14.9	15.3	10.1	11.3	9.9	12.4	14.8
013 2N	8.5	6.7	16.7	15.9	8.0	10.3	11.1	12.5	10.3
013 2S	5.8	5.4	22.1	19.7	9.4	8.1	7.3	9.5	12.6
013 T	3.2	4.4	25.2	30.0	12.8	9.6	6.4	4.8	3.6
053 1N	7.1	8.1	17.4	11.8	6.6	10.0	13.5	17.0	8.6
053 1S	4.9	5.1	19.3	24.9	14.0	10.6	7.0	7.6	6.5
053 2N	8.2	6.5	24.6	24.8	9.9	8.6	7.5	5.7	4.0
053 2S	12.3	5.5	19.0	22.0	9.5	8.1	7.2	8.1	8.2
053 T	5.7	8.1	25.3	14.4	7.7	9.9	9.2	11.0	8.7
105 1N	9.1	5.9	19.3	18.6	8.9	10.6	8.8	8.3	10.5
105 1S	4.8	6.2	18.9	19.9	10.7	11.4	9.7	10.9	7.4
105 2N	8.7	7.9	15.9	20.0	8.0	10.2	10.0	10.7	8.7
105 2S	3.7	3.5	26.0	26.2	10.6	8.1	6.4	7.2	8.3
105 T	1.5	2.1	13.8	18.1	13.2	16.5	12.1	11.0	11.8
158 1N	6.9	7.1	16.0	24.9	8.0	9.0	9.2	9.6	9.2
158 1S	2.3	4.8	22.8	27.8	12.5	9.2	6.7	7.0	6.8
158 2N	8.2	5.5	18.3	21.4	9.1	9.3	9.0	10.0	9.3
158 2S	2.4	3.2	25.1	27.5	11.9	9.8	7.8	7.4	5.0
158 T	3.3	4.3	27.9	27.3	8.2	9.7	6.3	6.8	6.1
206 1N	8.6	9.4	22.8	27.7	9.1	6.9	5.8	5.3	4.4
206 1S	3.3	4.9	18.7	25.1	16.3	10.1	7.4	7.7	6.5
206 2N	8.8	7.7	17.8	21.6	9.7	8.8	8.1	9.3	8.2
206 2S	5.6	6.5	22.4	24.2	11.2	7.9	6.9	7.7	7.5
206 T	3.0	7.1	22.0	33.9	13.0	7.7	4.8	4.9	3.6
260 1N	8.4	9.0	19.1	23.8	9.0	8.3	7.5	8.1	6.8
260 1S	5.5	7.2	20.1	24.1	8.8	8.4	7.5	8.2	10.2
260 2N	4.7	7.7	19.2	16.6	9.1	10.5	10.3	12.1	9.8
260 2S	10.0	6.0	20.9	26.7	11.8	8.3	5.9	5.6	4.8
260 T	5.8	7.2	24.7	30.6	10.4	7.6	7.2	4.6	1.9
300 1N	4.8	10.6	21.4	18.0	8.4	9.4	9.3	9.9	8.2
300 1S	7.4	6.8	20.5	26.2	12.4	9.2	6.4	5.7	5.3
300 2N	7.0	7.6	18.6	18.8	9.7	8.8	8.3	10.5	10.6
300 2S	9.1	6.7	24.0	13.4	10.7	9.3	8.0	9.2	9.6
300 T	3.9	4.8	25.1	14.5	8.6	9.6	8.7	10.4	14.5

Texture Analysis of B-horizons. Values are percentages.

Sample	clay	f. silt	m. silt	c. silt	vf. sand	f. sand	m. sand	c. sand	vc. Sand
013 1N	7.1	4.9	19.2	20.5	10.6	10.1	8.7	9.6	9.4
013 1S	4.3	5.4	12.3	13.0	10.4	13.0	12.9	15.9	12.8
013 2N	6.0	8.7	18.8	20.9	10.9	11.1	8.9	8.1	6.5
013 2S	4.7	7.8	16.6	19.8	11.6	10.7	9.6	10.4	8.7
013 T	4.3	4.6	18.5	30.7	14.2	11.0	7.2	5.5	4.0
053 1N	2.1	2.7	13.2	6.8	9.4	14.7	18.4	19.9	12.9
053 1S	5.1	6.1	14.3	20.1	11.8	11.8	9.9	11.5	9.5
053 2N	6.1	5.9	22.2	25.6	10.4	9.3	8.1	7.1	5.2
053 2S	9.5	6.1	15.6	22.0	10.6	9.9	8.4	9.5	8.4
053 T	2.8	4.2	18.3	15.4	8.5	12.6	12.7	13.8	11.7
105 1N	5.1	5.5	16.2	17.3	8.6	11.8	9.8	12.0	13.6
105 1S	7.9	4.4	14.8	19.5	11.5	12.4	10.1	10.5	9.0
105 2N	8.2	5.2	17.9	18.3	10.9	11.4	9.5	10.2	8.4
105 2S	11.0	5.3	14.9	29.2	11.9	7.9	6.8	7.3	5.7
105 T	1.9	3.0	17.6	18.8	14.3	14.4	10.8	10.3	9.0
158 1N	3.3	3.9	18.6	23.4	11.2	9.7	9.8	10.8	9.2
158 1S	6.8	6.2	18.4	21.6	10.9	9.6	8.5	9.9	8.1
158 2N	6.0	5.3	17.3	23.0	10.4	9.8	8.7	10.8	8.7
158 2S	2.1	6.9	15.8	22.9	13.3	11.3	10.1	11.0	6.6
158 T	1.2	5.7	25.4	25.3	12.7	9.8	6.5	7.0	6.4
206 1N	1.6	4.1	21.7	24.2	12.7	10.1	10.2	8.9	6.4
206 1S	4.2	5.7	19.9	33.0	13.1	6.3	5.1	6.1	6.6
206 2N	3.0	6.6	22.4	27.3	12.8	7.8	6.4	7.0	6.8
206 2S	5.5	6.9	20.0	31.8	13.2	6.8	5.2	6.0	4.7
206 T	3.1	3.9	19.2	25.0	17.9	12.3	7.4	5.9	5.3
260 1N	3.0	4.1	20.2	22.3	10.7	9.2	10.0	11.1	9.4
260 1S	7.2	5.6	15.2	22.1	12.3	10.4	8.9	9.4	8.7
260 2N	5.0	6.7	18.1	22.7	10.3	8.3	7.7	10.3	10.9
260 2S	8.6	4.9	17.7	23.0	12.6	9.5	7.6	8.3	7.6
260 T	4.9	5.8	20.5	27.7	14.1	10.9	7.8	5.4	2.9
300 1N	6.2	5.0	16.5	17.9	9.8	10.2	11.0	12.8	10.5
300 1S	8.0	6.4	19.2	27.2	12.4	8.5	6.4	6.2	5.8
300 2N	6.2	3.9	16.6	19.8	11.1	9.7	9.0	12.4	11.2
300 2S	5.7	5.6	14.2	22.5	11.5	11.6	10.2	10.3	8.3
300 T	2.7	3.1	17.4	14.9	10.3	11.6	10.9	13.9	15.1

Exchangeable cations in A-horizons. Values are cmol(+)/kg

Sample	Al	Ca	Fe	K	Mg	Mn	CEC
013 1N	8.51	0.47	1.36	0.20	0.49	0.01	11.04
013 1S	2.52	1.31	0.05	0.27	0.70	0.29	5.14
013 2N	5.03	0.78	0.83	0.23	0.53	0.03	7.43
013 2S	3.73	1.26	0.09	0.27	0.71	0.19	6.25
013 T	3.15	0.79	0.06	0.16	0.55	0.36	5.07
053 1N	5.55	0.41	0.48	0.31	0.59	0.07	7.40
053 1S	3.06	2.87	0.04	0.14	0.36	0.20	6.68
053 2N	7.10	0.59	0.58	0.17	0.41	0.01	8.85
053 2S	4.73	1.48	0.16	0.28	0.80	0.14	7.58
053 T	4.52	2.93	0.12	0.24	1.38	0.68	9.86
105 1N	5.84	1.28	0.51	0.30	0.92	0.16	9.01
105 1S	3.17	0.43	0.03	0.13	0.25	0.06	4.06
105 2N	3.77	1.32	0.06	0.20	0.66	0.13	6.15
105 2S	2.12	0.87	0.02	0.15	0.40	0.07	3.63
105 T	3.60	1.47	0.08	0.19	0.68	0.46	6.47
158 1N	5.59	0.58	0.30	0.20	0.58	0.06	7.31
158 1S	4.58	0.34	0.04	0.16	0.35	0.10	5.56
158 2N	4.97	1.09	0.69	0.18	0.68	0.10	7.70
158 2S	2.63	0.46	0.04	0.23	0.52	0.23	4.10
158 T	4.18	0.25	0.04	0.18	0.42	0.12	5.19
206 1N	6.77	1.10	0.42	0.17	0.46	0.05	8.97
206 1S	1.97	0.40	0.03	0.11	0.31	0.17	2.99
206 2N	3.67	1.07	0.08	0.21	0.77	0.36	6.15
206 2S	3.19	1.02	0.04	0.18	0.46	0.23	5.12
206 T	3.51	0.65	0.04	0.16	0.41	0.17	4.93
260 1N	5.48	0.94	0.40	0.24	0.69	0.12	7.86
260 1S	3.56	0.61	0.04	0.17	0.42	0.19	4.98
260 2N	2.53	1.91	0.07	0.11	0.53	0.12	5.27
260 2S	2.51	0.47	0.03	0.14	0.34	0.08	3.58
260 T	5.09	0.29	0.10	0.11	0.34	0.08	6.01
300 1N	5.11	0.52	0.80	0.21	0.51	0.03	7.19
300 1S	2.27	0.89	0.07	0.26	0.55	0.25	4.29
300 2N	2.33	0.50	0.06	0.12	0.29	0.08	3.38
300 2S	1.25	2.16	0.06	0.36	1.07	0.35	10.27
300 T	6.82	0.53	0.18	0.20	0.55	0.29	8.57

Exchangeable cations in B-horizons. Values are cmol(+)/kg

Sample	ALB	CAB	FEB	KB	MGB	MNB	CECB
013 1N	1.48	0.10	0.05	0.06	0.11	0.00	1.81
013 1S	1.96	0.22	0.02	0.10	0.21	0.04	2.55
013 2N	1.56	0.20	0.06	0.07	0.15	0.00	2.05
013 2S	2.13	0.18	0.05	0.10	0.21	0.03	2.71
013 T	1.07	0.12	0.01	0.05	0.11	0.03	1.39
053 1N	3.45	0.41	0.09	0.14	0.30	0.02	4.40
053 1S	1.88	0.20	0.03	0.09	0.17	0.05	2.43
053 2N	1.87	0.08	0.08	0.07	0.11	0.00	2.21
053 2S	1.70	0.16	0.05	0.15	0.15	0.02	2.22
053 T	3.34	0.76	0.03	0.11	0.35	0.15	4.74
105 1N	2.69	0.42	0.04	0.09	0.20	0.01	3.45
105 1S	1.53	0.15	0.02	0.05	0.09	0.01	1.85
105 2N	2.01	0.48	0.01	0.08	0.17	0.02	2.78
105 2S	1.37	0.30	0.01	0.04	0.13	0.01	1.86
105 T	3.67	0.77	0.04	0.18	0.47	0.23	5.36
158 1N	1.59	0.21	0.03	0.08	0.15	0.01	2.07
158 1S	1.41	0.17	0.01	0.05	0.14	0.03	1.82
158 2N	1.50	1.88	0.05	0.12	0.56	0.07	4.17
158 2S	1.85	0.29	0.02	0.12	0.20	0.03	2.52
158 T	1.90	0.33	0.02	0.06	0.17	0.02	2.49
206 1N	2.34	0.27	0.05	0.07	0.13	0.01	2.88
206 1S	1.27	0.10	0.01	0.04	0.08	0.02	1.52
206 2N	0.91	0.70	0.01	0.05	0.16	0.02	1.85
206 2S	1.55	0.09	0.01	0.04	0.11	0.05	1.86
206 T	0.75	0.08	0.01	0.03	0.06	0.01	0.94
260 1N	2.43	0.29	0.02	0.06	0.15	0.01	2.96
260 1S	1.85	0.52	0.01	0.08	0.17	0.04	2.67
260 2N	1.71	0.53	0.02	0.08	0.18	0.02	2.54
260 2S	1.35	0.12	0.01	0.07	0.08	0.01	1.64
260 T	1.63	0.06	0.02	0.03	0.08	0.01	1.84
300 1N	2.31	0.22	0.05	0.08	0.20	0.02	2.87
300 1S	1.32	0.09	0.02	0.07	0.12	0.02	1.64
300 2N	1.36	0.30	0.02	0.09	0.19	0.03	2.00
300 2S	1.73	0.52	0.02	0.08	0.27	0.05	2.67
300 T	2.27	0.28	0.09	0.12	0.21	0.03	3.00

Extractable forms of Fe, Al, and Mn in A-horizons. Values are g/100g.

Sample	crys. Fe	am. Fe	org. Fe	am. Al	org. Al	crys. Mn	org. Mn
013 1N	0.70	0.20	0.43	0.09	0.26	0.00	0.00
013 1S	0.59	0.39	0.42	0.21	0.69	0.05	0.13
013 2N	0.52	0.23	0.41	0.10	0.26	0.00	0.00
013 2S	0.66	0.40	0.40	0.26	0.50	0.01	0.03
013 T	0.53	0.51	0.39	0.37	0.75	0.06	0.16
053 1N	0.43	0.41	0.52	0.14	0.28	0.01	0.01
053 1S	0.73	0.36	0.62	0.00	1.06	0.14	0.09
053 2N	0.43	0.14	0.44	0.04	0.20	0.00	0.00
053 2S	0.71	0.22	0.44	0.09	0.40	0.01	0.01
053 T	0.74	0.45	0.72	0.10	0.62	0.10	0.29
105 1N	0.54	0.43	0.40	0.10	0.15	0.03	0.02
105 1S	0.85	0.37	0.39	0.25	0.50	0.02	0.02
105 2N	0.85	0.37	0.50	0.12	0.26	0.02	0.02
105 2S	0.74	0.33	0.34	0.37	0.57	0.03	0.04
105 T	0.66	0.51	0.46	0.29	1.01	0.43	0.27
158 1N	0.42	0.26	0.39	0.05	0.21	0.00	0.01
158 1S	0.77	0.50	0.51	0.50	0.84	0.04	0.14
158 2N	0.48	0.31	0.53	0.08	0.30	0.01	0.02
158 2S	0.69	0.36	0.55	0.30	0.80	0.07	0.13
158 T	0.54	0.58	0.73	0.12	0.77	0.04	0.06
206 1N	0.42	0.04	0.35	0.00	0.19	0.01	0.01
206 1S	0.59	1.00	0.27	1.10	0.85	0.46	0.11
206 2N	0.39	0.48	0.68	0.07	0.40	0.16	0.14
206 2S	0.52	0.58	0.44	0.62	0.84	0.24	0.13
206 T	0.53	0.36	0.59	0.18	1.05	0.13	0.14
260 1N	0.18	0.32	0.22	0.14	0.10	0.01	0.01
260 1S	0.86	0.34	0.40	0.22	0.58	0.05	0.08
260 2N	0.44	0.55	0.58	0.11	0.31	0.03	0.02
260 2S	0.90	0.47	0.38	0.33	0.40	0.02	0.02
260 T	0.60	0.51	0.60	0.23	0.62	0.03	0.04
300 1N	0.60	0.52	0.67	0.09	0.29	0.03	0.01
300 1S	1.05	0.36	0.28	0.24	0.37	0.03	0.04
300 2N	0.66	0.55	0.38	0.16	0.26	0.02	0.01
300 2S	0.80	0.31	0.20	0.21	0.28	0.03	0.07
300 T	0.61	0.46	0.84	0.14	0.75	0.10	0.08

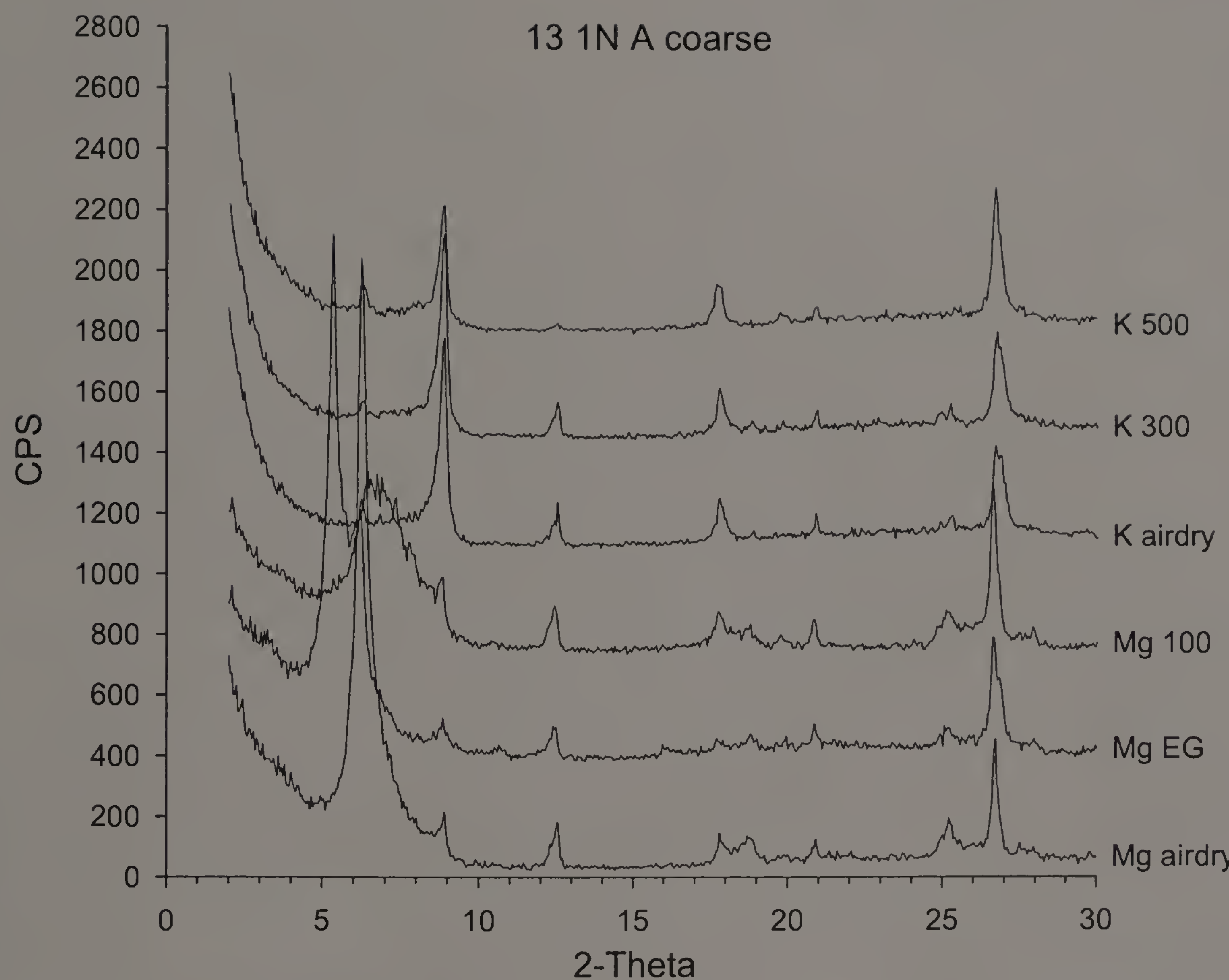
Extractable forms of Fe, Al, and Mn in B-horizons. Values are g/100g.

Sample	crys. Fe	am. Fe	org. Fe	am. Al	org. Al	crys. Mn	org. Mn
013 1N	0.94	0.53	0.38	0.37	0.56	0.01	0.00
013 1S	0.77	0.56	0.34	0.19	0.28	0.02	0.01
013 2N	1.04	0.17	0.32	0.11	0.39	0.00	0.00
013 2S	0.66	0.52	0.32	0.26	0.35	0.01	0.01
013 T	0.49	0.71	0.18	0.64	0.49	0.01	0.01
053 1N	0.62	0.51	0.68	0.16	0.77	0.02	0.01
053 1S	0.88	0.47	0.38	0.25	0.51	0.02	0.02
053 2N	1.15	0.46	0.41	0.32	0.59	0.00	0.00
053 2S	1.01	0.48	0.26	0.21	0.32	0.01	0.00
053 T	0.90	0.52	0.82	0.11	0.80	0.05	0.08
105 1N	0.73	0.56	0.38	0.30	0.57	0.03	0.00
105 1S	0.74	0.48	0.17	0.28	0.24	0.01	0.00
105 2N	0.90	0.51	0.38	0.24	0.37	0.01	0.01
105 2S	0.85	0.46	0.10	0.23	0.15	0.01	0.00
105 T	0.75	0.43	0.54	0.18	0.86	0.12	0.06
158 1N	0.71	0.50	0.49	0.17	0.60	0.01	0.00
158 1S	1.05	0.68	0.26	0.34	0.39	0.04	0.02
158 2N	0.53	0.40	0.33	0.15	0.32	0.01	0.02
158 2S	1.11	0.35	0.38	0.19	0.43	0.01	0.01
158 T	0.69	0.73	0.43	0.30	0.70	0.02	0.01
206 1N	0.72	0.84	0.51	0.47	0.77	0.01	0.00
206 1S	0.65	0.44	0.16	0.26	0.27	0.03	0.01
206 2N	0.59	0.62	0.52	0.14	0.61	0.03	0.02
206 2S	1.09	0.69	0.14	0.35	0.24	0.06	0.02
206 T	0.21	0.69	0.10	0.65	0.37	0.03	0.01
260 1N	0.65	0.88	0.50	0.47	0.74	0.02	0.01
260 1S	0.75	0.45	0.19	0.24	0.29	0.02	0.01
260 2N	0.60	0.58	0.41	0.19	0.43	0.01	0.01
260 2S	1.12	0.36	0.16	0.19	0.24	0.02	0.01
260 T	0.61	0.67	0.16	0.55	0.37	0.01	0.00
300 1N	0.93	0.53	0.43	0.23	0.48	0.02	0.00
300 1S	1.04	0.58	0.23	0.37	0.36	0.02	0.00
300 2N	1.04	0.43	0.27	0.23	0.39	0.02	0.01
300 2S	0.78	0.31	0.20	0.08	0.25	0.01	0.01
300 T	0.76	0.43	0.59	0.14	0.96	0.02	0.01

APPENDIX D

X-RAY DIFFRACTOGRAMS

Representative X-ray diffractograms of the coarse and fine clay fraction of A-horizons.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2-Theta
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K 300
K airdry
Mg 100
Mg EG
Mg airdry
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5
10
15
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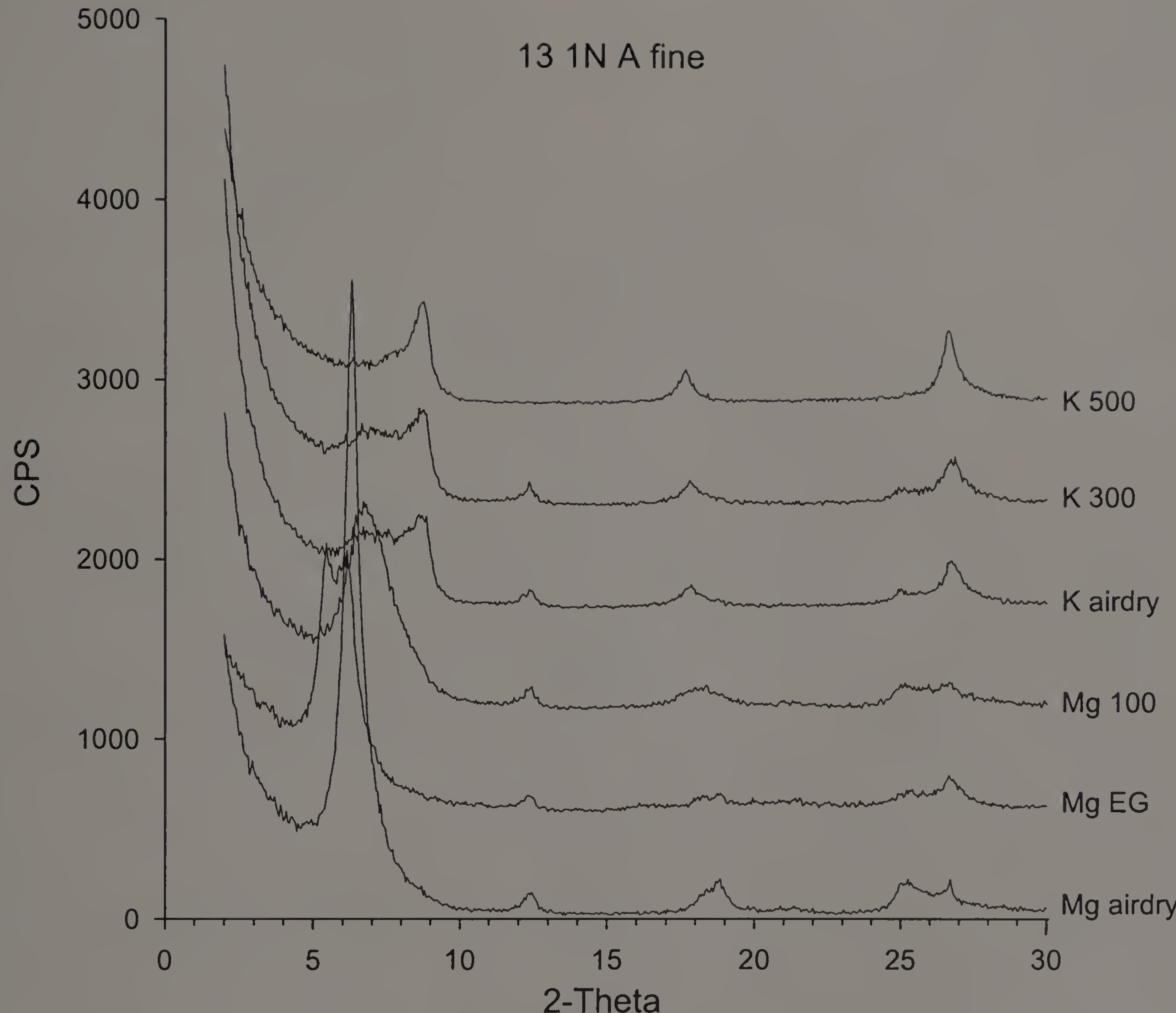
800
600
400
200
0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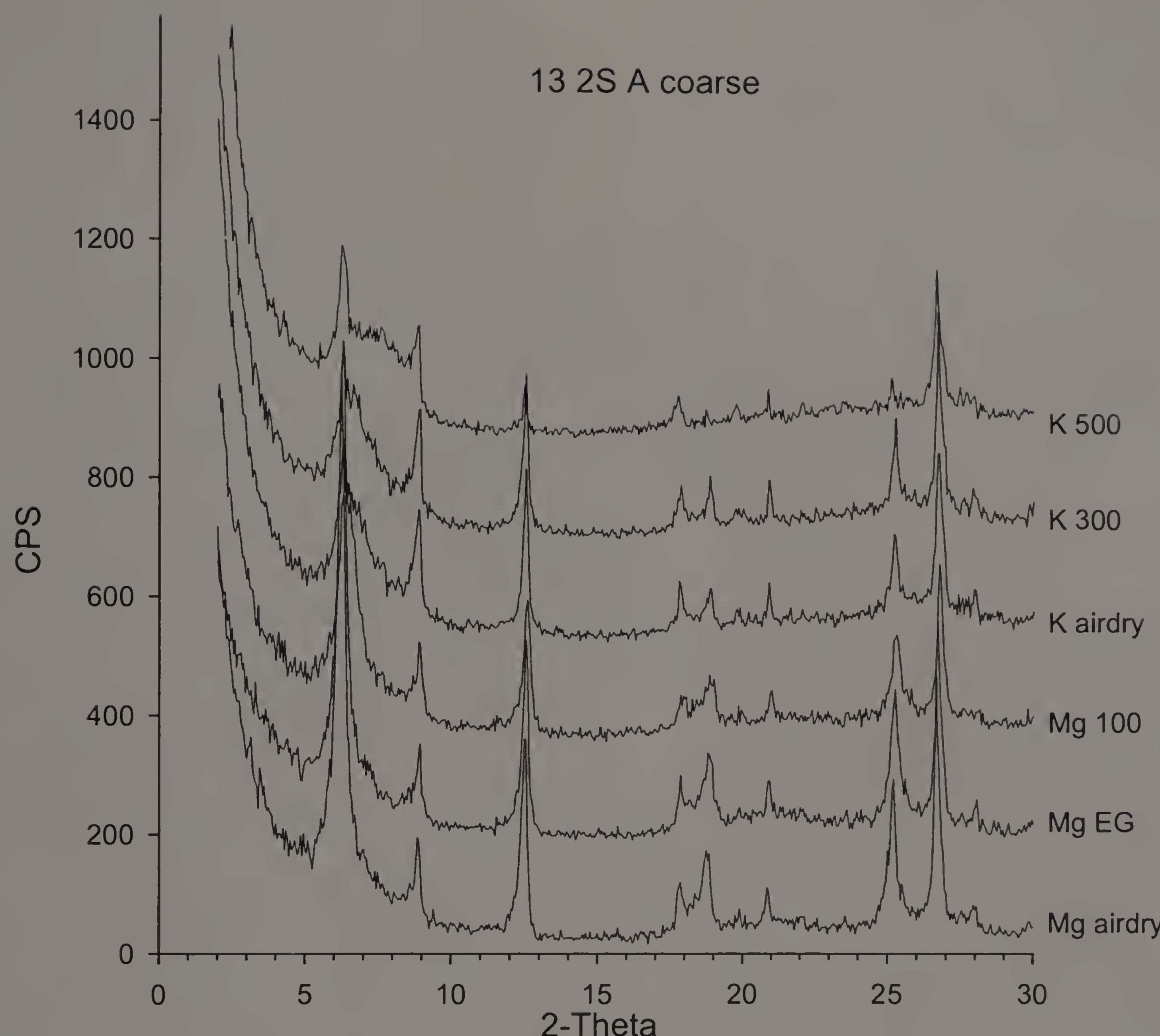
CPS
2-Theta
5000
4000
3000
2000
1000
0
0
5
10
15
20
25
30
K 500
K 300
K airdry
Mg 100
Mg EG
Mg airdry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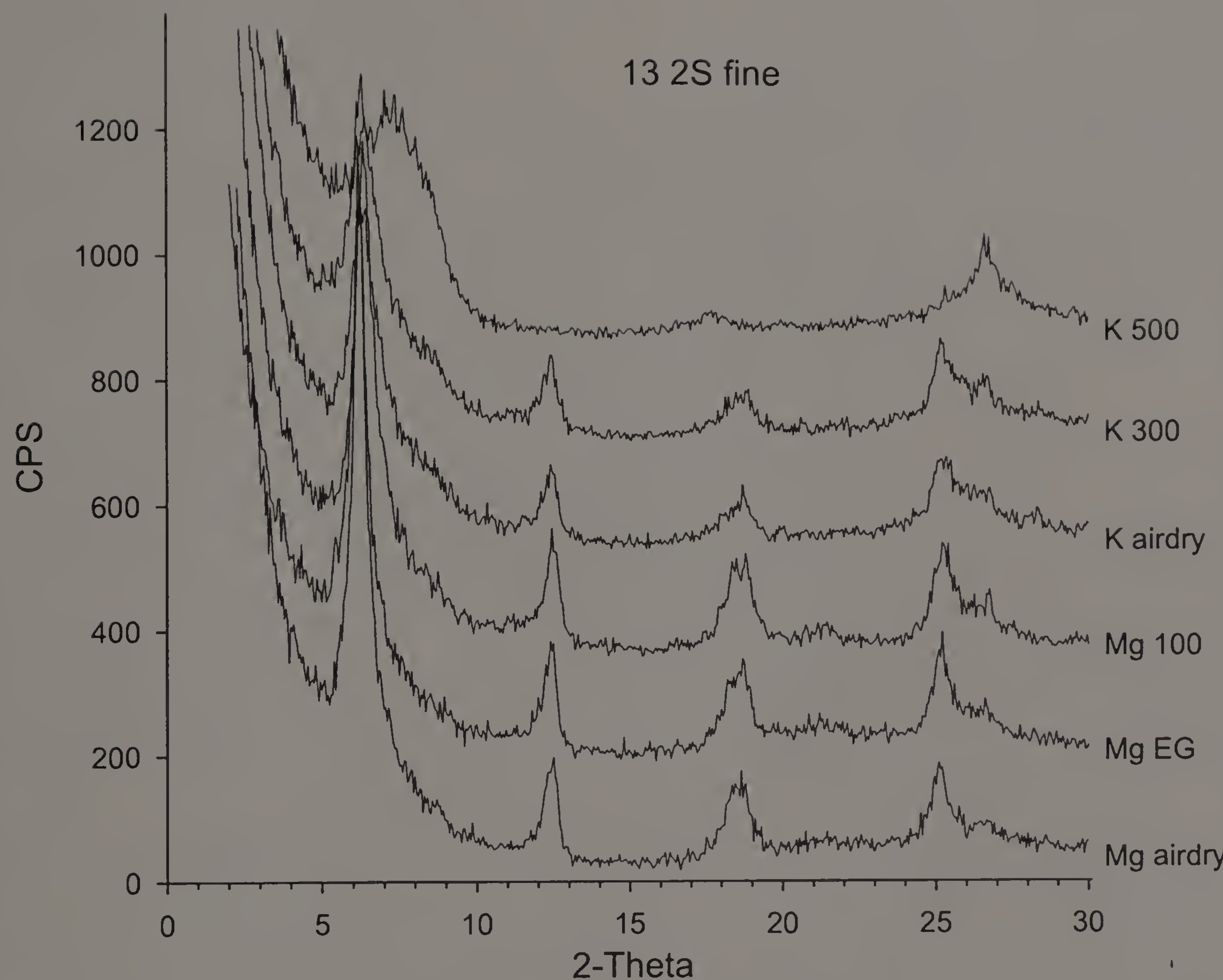
CPS
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
2-Theta
K 500
K 300
K airdry
Mg 100
Mg EG
Mg airdry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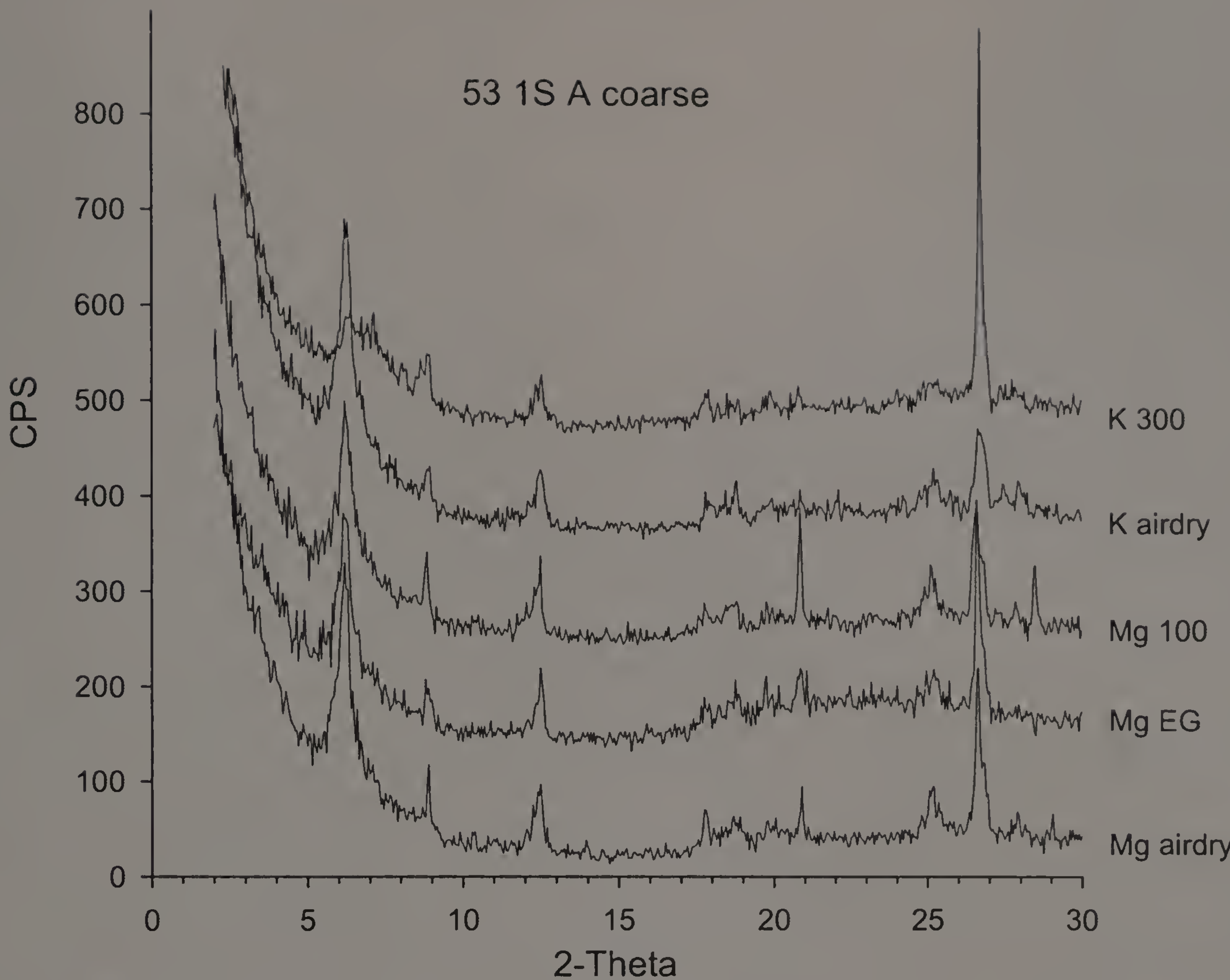
CPS
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
2-Theta
K 500
K 300
K airdry
Mg 100
Mg EG
Mg airdry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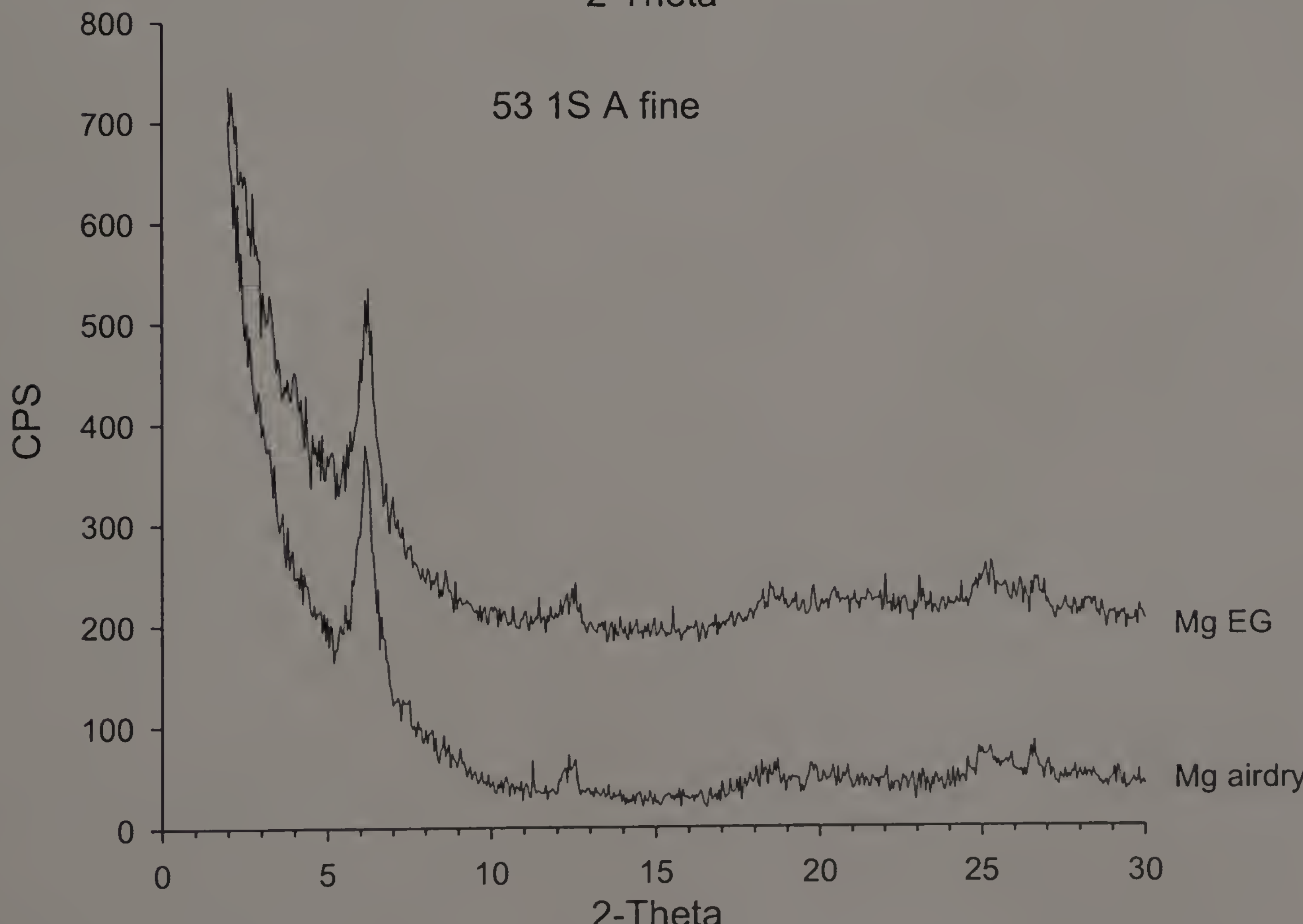
CPS
2-Theta
K 300
K airdry
Mg 100
Mg EG
Mg airdry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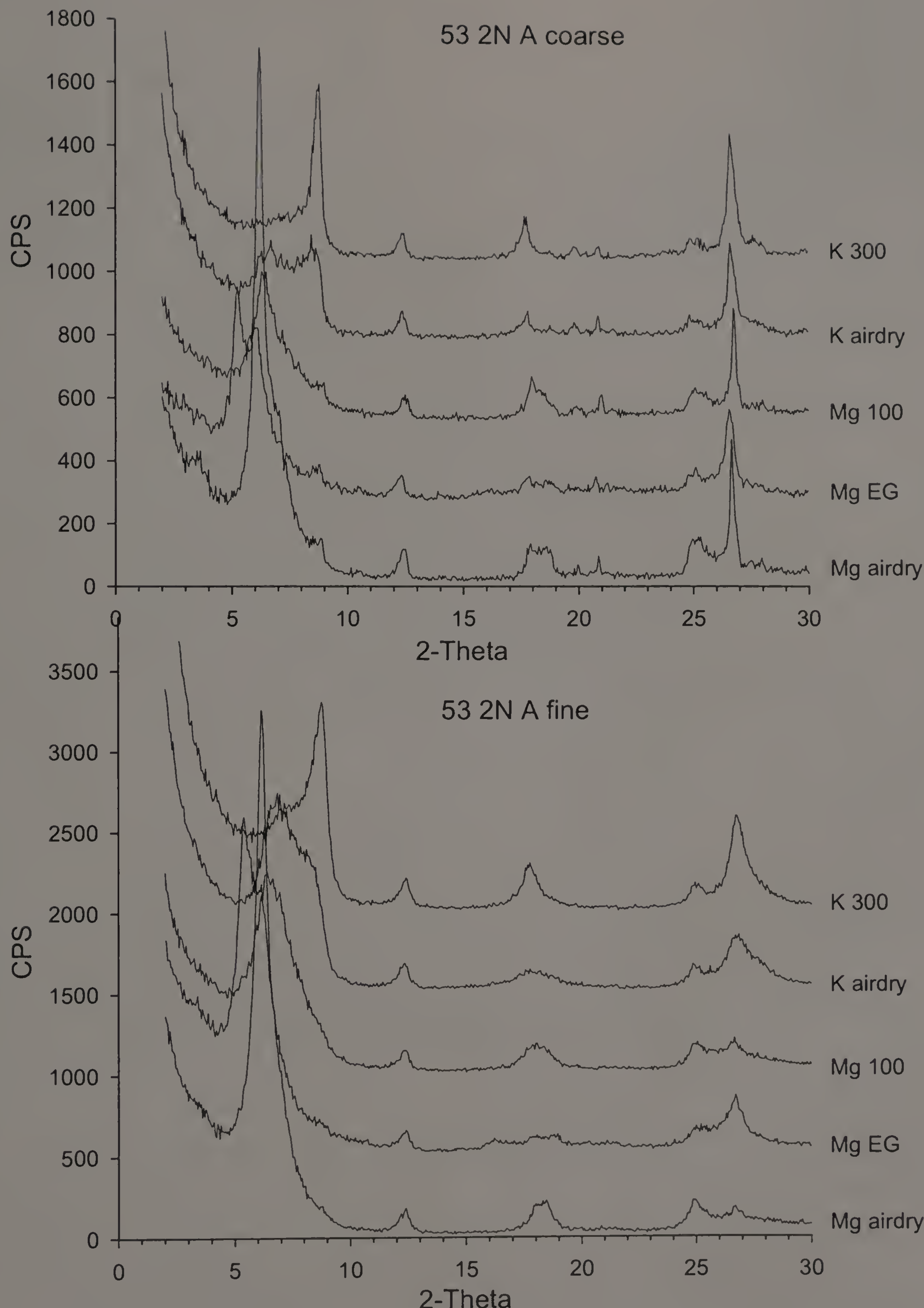
CPS
2-Theta
Mg EG
Mg airdry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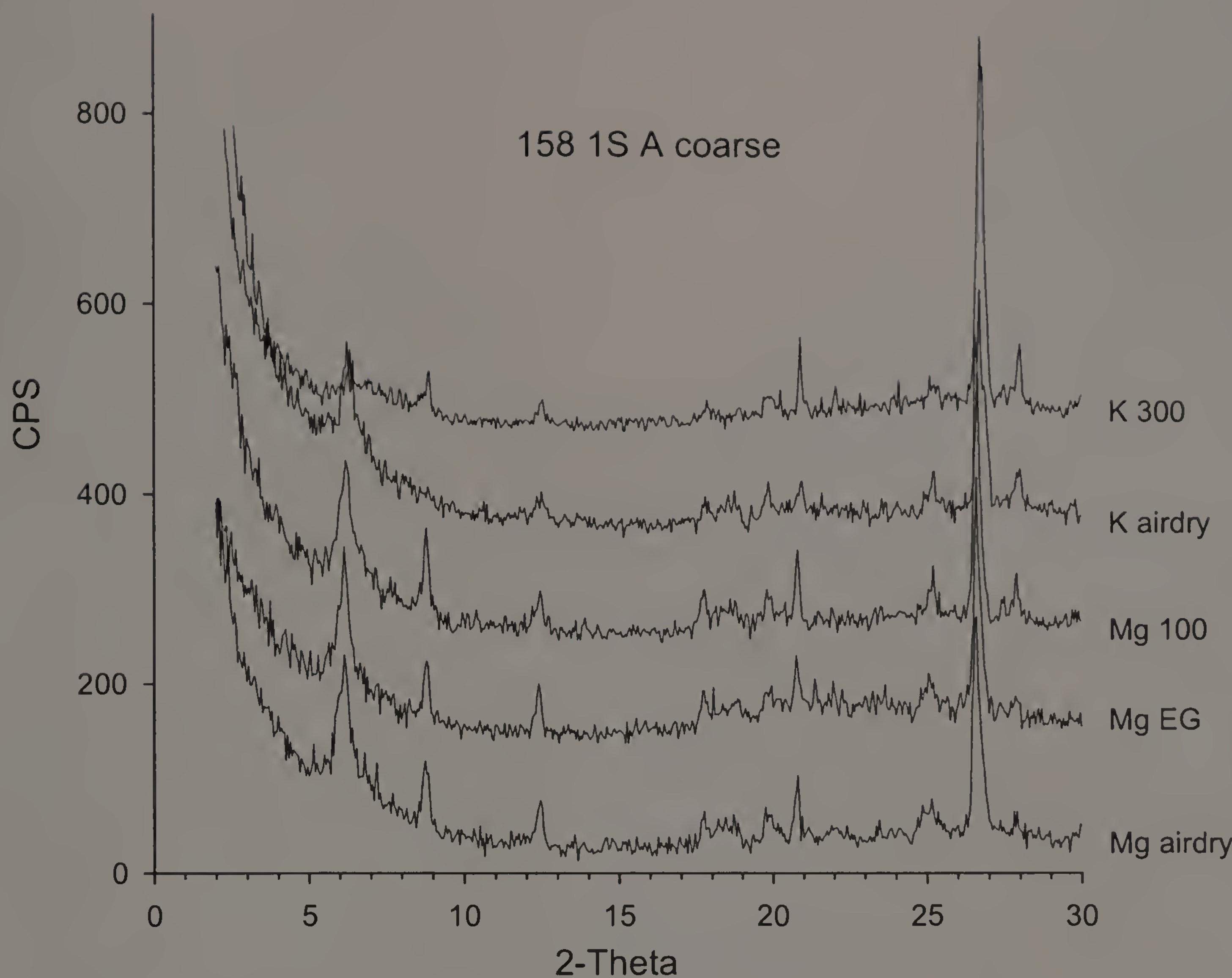
CPS
2-Theta
K 300
K airdry
Mg 100
Mg EG
Mg airdry
1800
1600
1400
1200
1000
800
600
400
200
0
0
5
10
15
20
25
30
53 2N A fine
CPS
2-Theta
K 300
K airdry
Mg 100
Mg EG
Mg airdry
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30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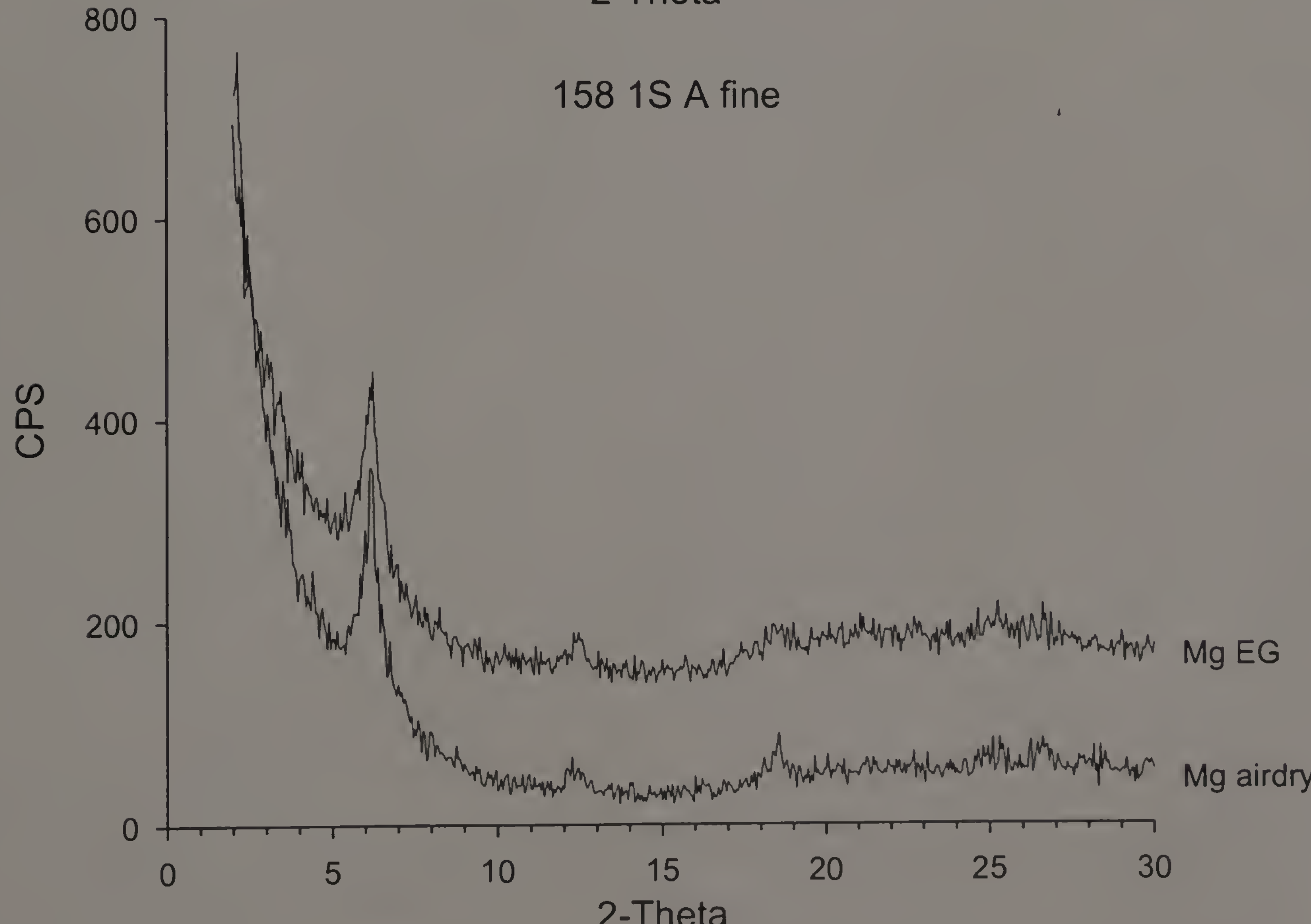
CPS
2-Theta
K 300
K airdry
Mg 100
Mg EG
Mg airdry
0
200
400
600
800
0
5
10
15
20
25
30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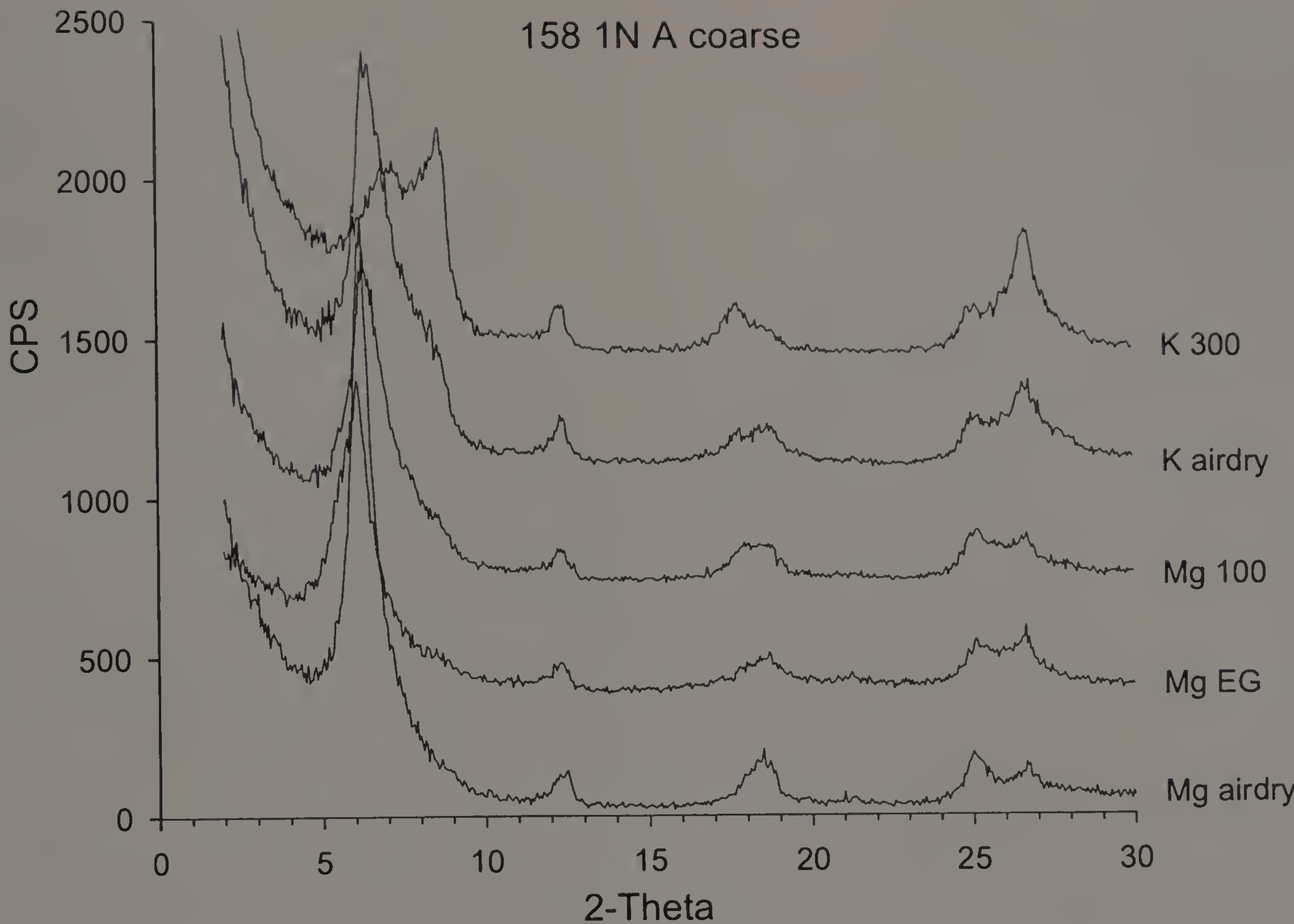
CPS
2-Theta
Mg EG
Mg airdry
0
200
400
600
800
0
5
10
15
20
25
30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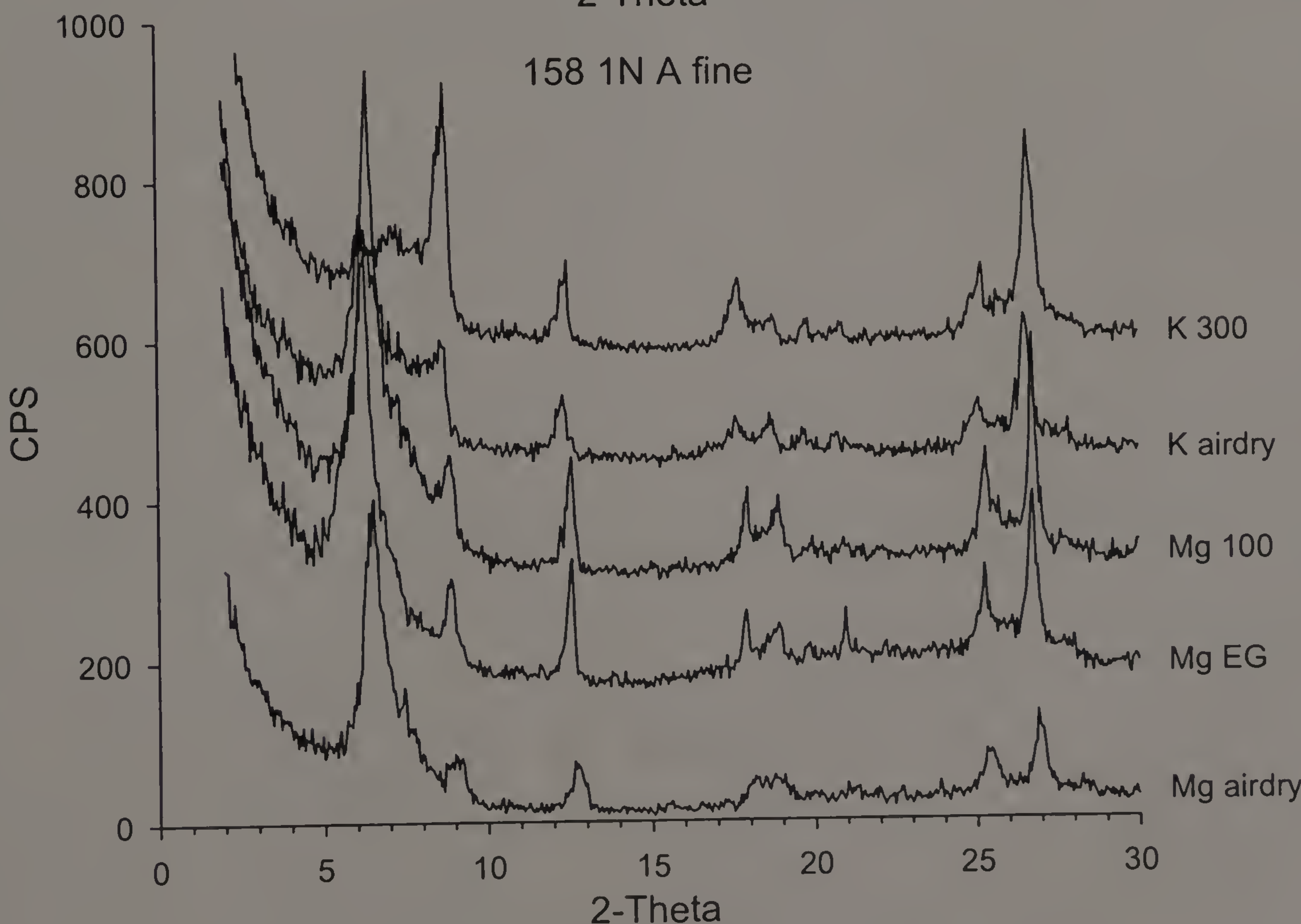
CPS
2-Theta
K 300
K airdry
Mg 100
Mg EG
Mg airdry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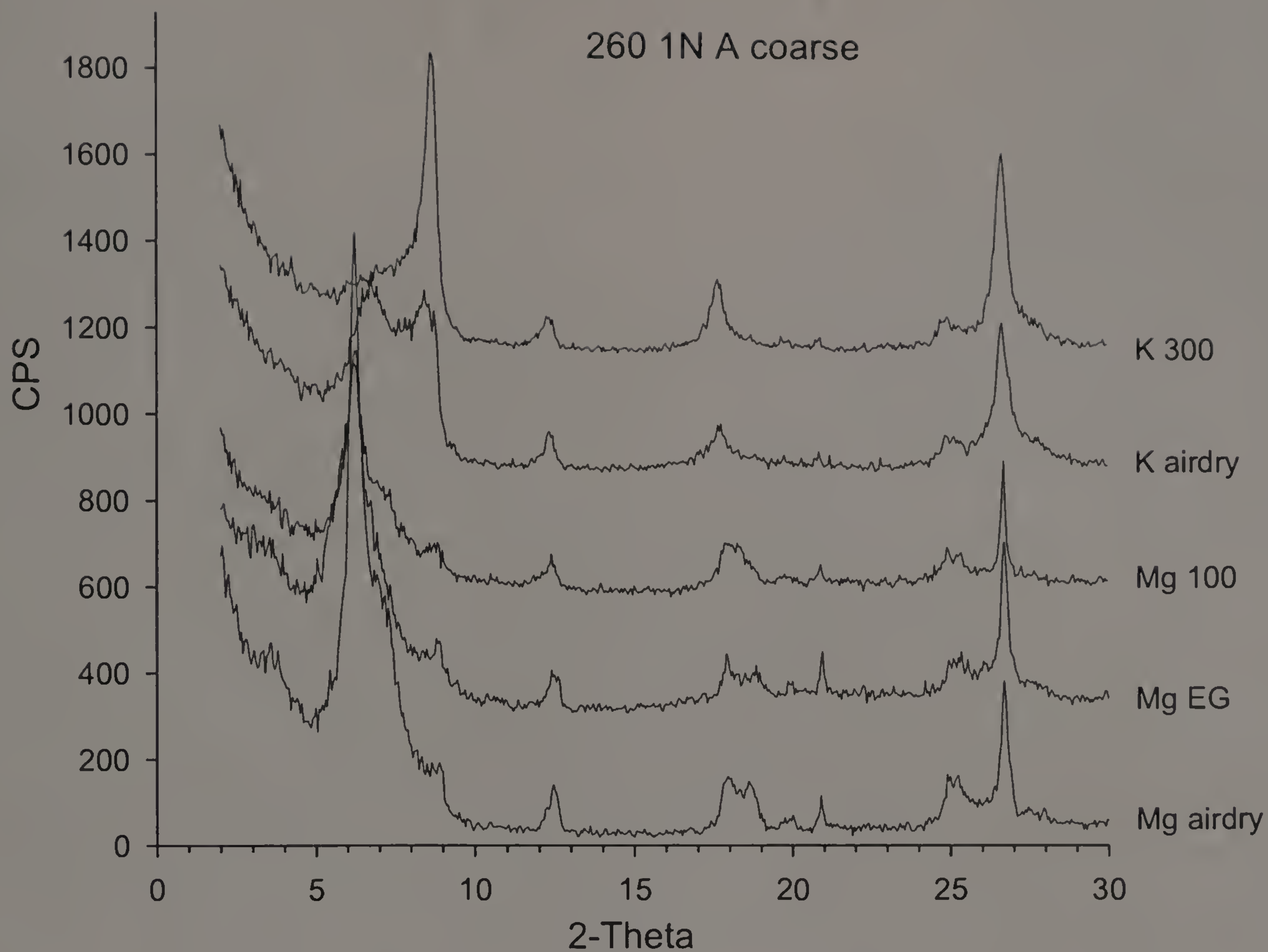
CPS
2-Theta
K 300
K airdry
Mg 100
Mg EG
Mg airdry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CPS
1800
1600
1400
1200
1000
800
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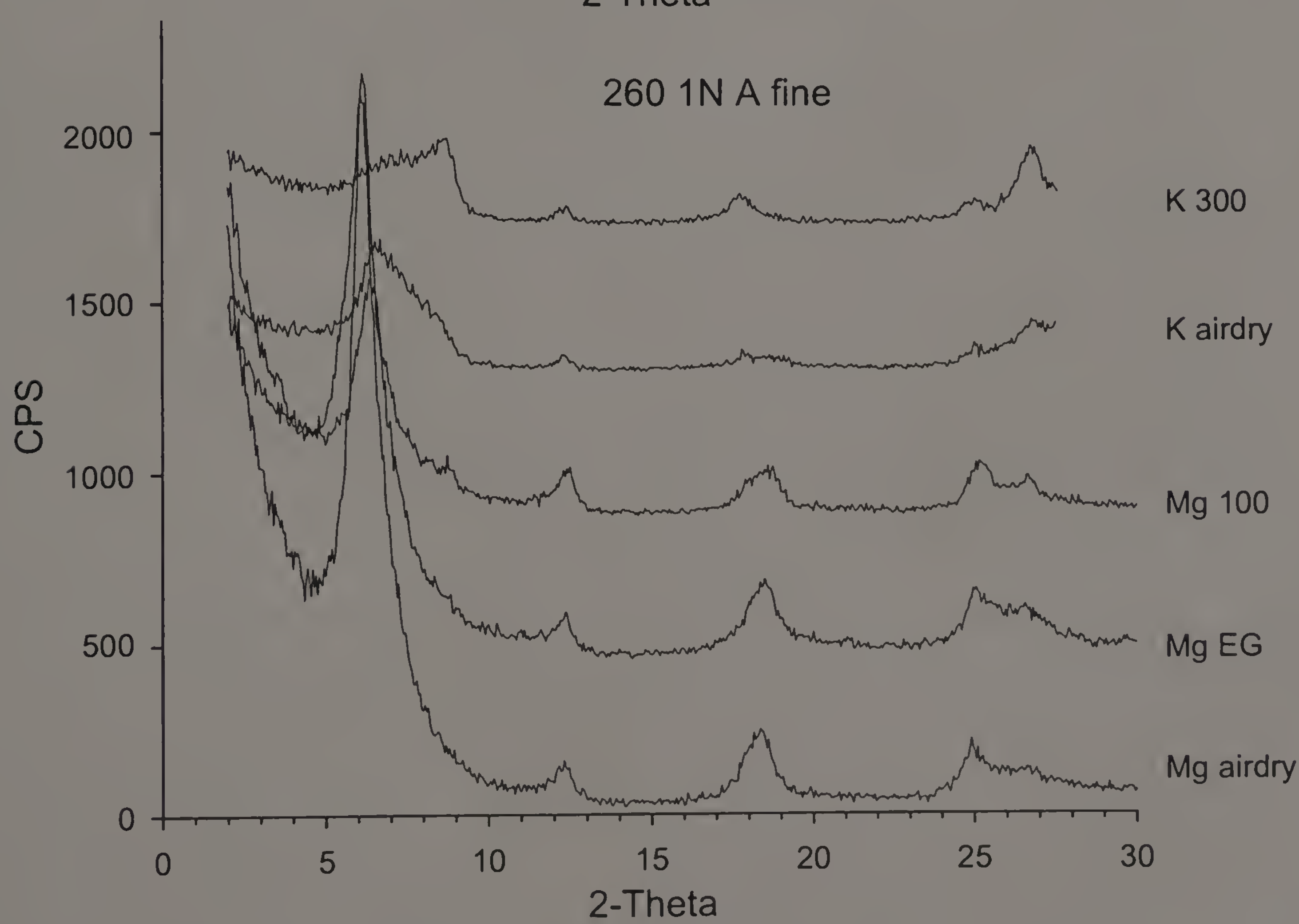
400
200
0
0
5
10
15
20
25
30
2-Theta
K 300
K airdry
Mg 100
Mg EG
Mg airdry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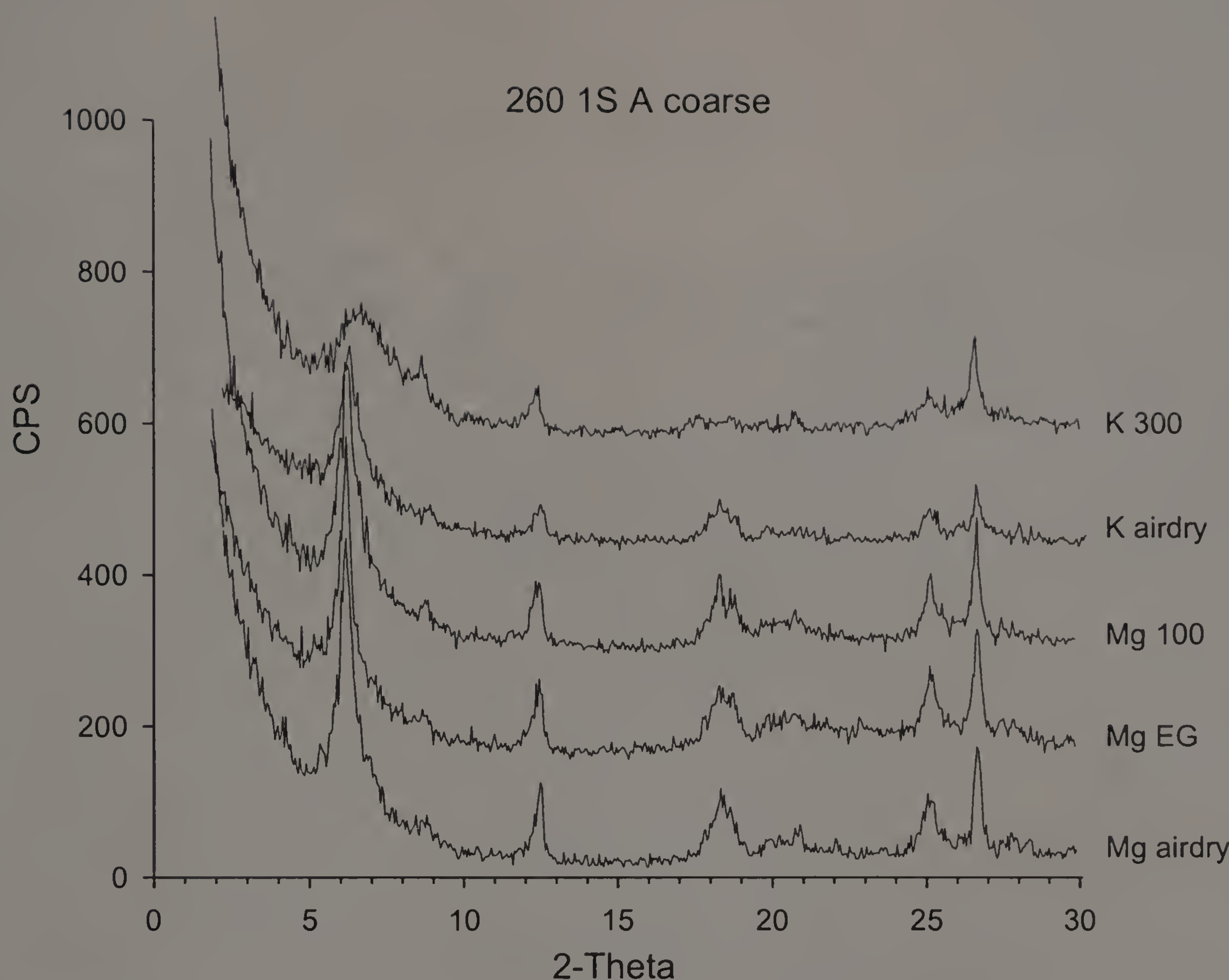
CPS
2000
1500
1000
500
0
0
5
10
15
20
25
30
2-Theta
K 300
K airdry
Mg 100
Mg EG
Mg airdry



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CPS
2-Theta
K 300
K airdry
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Mg EG
Mg airdry
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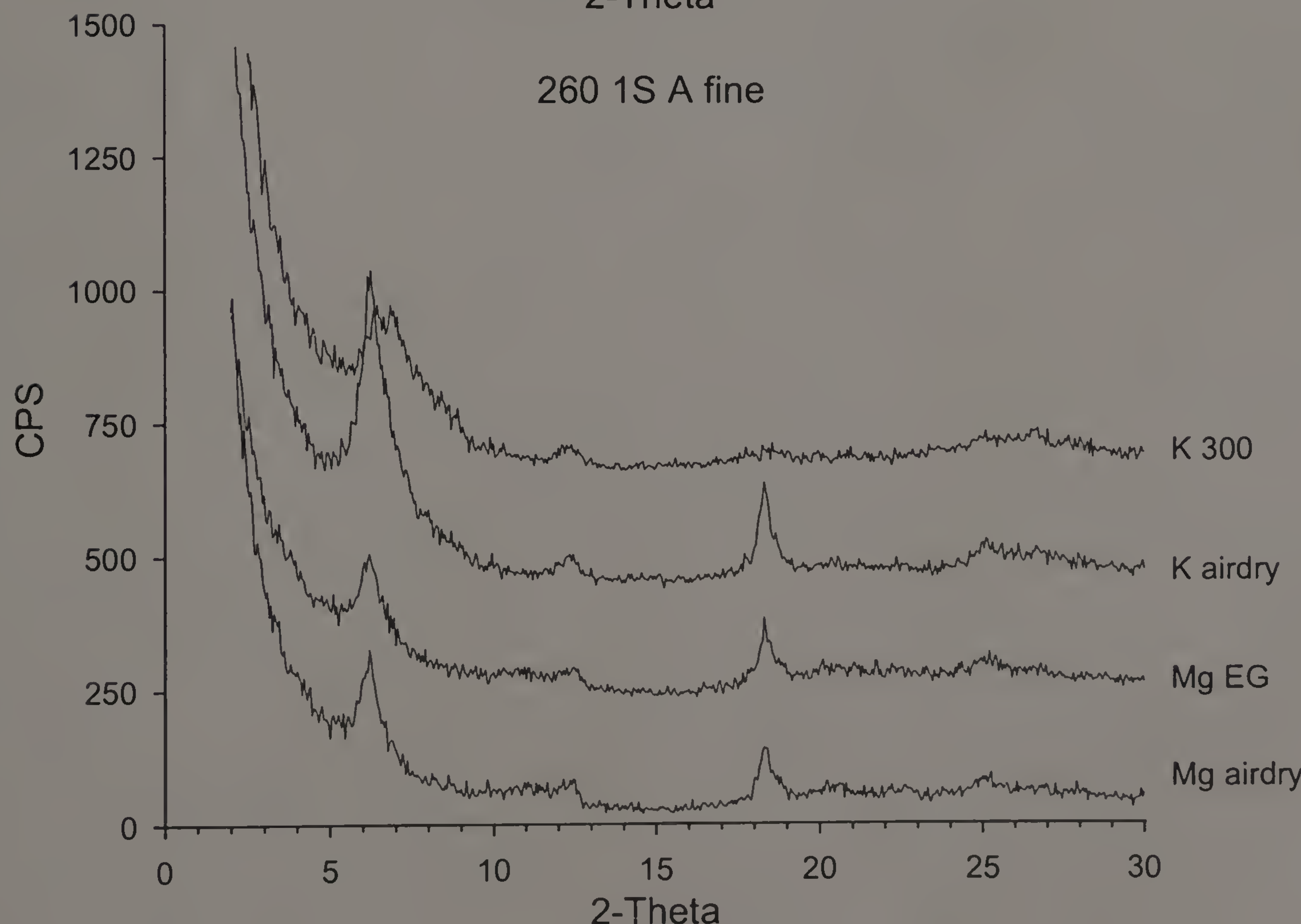
400
600
800
1000
0
5
10
15
20
25
30



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2-Theta
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K airdry
Mg EG
Mg airdry
0
250
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750
1000
1250
1500
0
5
10
15
20
25
30

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