ABSTRACT

Title of Thesis: Soils with Spodic Characteristics on the Eastern Shore of Maryland

Name of degree candidate: Margaret Anne Condron

Degree and Year: Master of Science, 1990

Thesis directed by: Dr. Martin C. Rabenhorst, Associate Professor, Department of Agronomy

A seasonally fluctuating water table may be an important factor in the formation of spodic horizons in sandy, quartzose sediments on the Lower Eastern Shore of Maryland. This study was conducted to examine spodic horizon formation and expression along two topo-hydrosequences. After a reconnaissance study, two research sites were chosen in the Pocomoke State Forest in Worcester County, Maryland.

The soils were classified according to Soil Taxonomy as siliceous, mesic, Typic Quartzipsamments, Aquic Haplorthods, and Aeric and Typic Haplaquods. The spodic horizons were thickest (26-204cm) in the wettest positions. Total organic carbon, pyrophosphate-extractable carbon, and extractable aluminum were greatest in the spodic horizons, and there was little extractable iron in the Haplaquods. There was less structural aluminum and potassium in the surface horizons than in the lower horizons. This suggests that feldspar weathering in the surface horizons provides a source of aluminum for the spodic horizon formation. Quantitative estimates of

pedogenesis showed net gains of extractable aluminum, total (organic) carbon, and pyrophosphate carbon in the lower landscape positions. The seasonally fluctuating water table appears to influence the movement of soluble organic aluminum complexes through the soil downslope, as well as within the pedon from the surface to subjacent horizons.

Soils with Spodic Characteristics on the
Eastern Shore of Maryland

by

Margaret Anne Condron

Thesis submitted to the Faculty of the Graduate School
of the University of Maryland in partial fulfillment
of the requirements for the degree of
Master of Science
1990

Advisory Committee:
Associate Professor Martin C. Rabenhorst, Chairman/
Advisor
Professor Delvin S. Fanning
Associate Professor Robert L. Hill
Assistant Professor Bruce R. James

DEDICATION

For Gaylord A. Hart

"And you...my sudden bouquet."

ACKNOWLEDGEMENTS

As with any research project, this work is the culmination of guidance and assistance from many people. I am extremely thankful to Dr. Martin Rabenhorst, who has been an inspirational example of excellence in his roles as advisor, researcher, and friend. Without the hard work and good humor of Mark Elless, Dick Hall, and Marty Rabenhorst during difficult field conditions, this project would not have been completed. Members of my committee, Drs. D.S. Fanning, B.R. James, and R.L. Hill, and their graduate students provided helpful suggestions and conversations during our research meetings.

Others to whom I am thankful are: Drs. M. Junkov, K.M. McSweeney, and J.G. Tokuhisa for their direction and encouragement prior to graduate studies; the graces, L.A. Frank, A.J. Koziski-Hart, C.A. Olle, and M.E. Schey for their steadfast confidence; and, most importantly, Gaylord, for his wonderful wit, kindness, and conversation. And, of course, my thanks to dear Edward and Marilyn, for emphasizing the value of both words and deeds....

TABLE OF CONTENTS

PREFACE i

LIST OF TABLES vi

LIST OF FIGURES vii

INTRODUCTION 1

REVIEW OF THE LITERATURE 3
GENERAL CHARACTERISTICS AND CLASSIFICATION . . 3
OCCURRENCE IN MARYLAND 8
MORPHOLOGY 9
CHEMICAL PROPERTIES 11
GENETIC PROCESSES 14

MORPHOLOGY AND GEOMORPHOLOGY OF HAPLAQUODS ON THE LOWER EASTERN SHORE OF MARYLAND 17
MATERIALS AND METHODS 18
Site Description and Methodology 18
RESULTS 23
Morphology and Relation to Landscape Position 25
CONCLUSIONS 31

CHARACTERIZATION AND CLASSIFICATION OF SOILS WITH SPODIC EXPRESSION ON THE EASTERN SHORE OF MARYLAND 33
MATERIALS AND METHODS 34
Site Description 34
RESULTS AND DISCUSSION 39
Physical Characteristics 43
Chemical Characteristics 44
Carbon 45
Iron 49
Aluminum 52
Classification 55
CONCLUSION 59

ESTIMATES OF PEDOGENESIS IN SOILS WITH SPODIC CHARACTERISTICS IN MARYLAND 60
MATERIALS AND METHODS 61
Site Description 61
Soil Analyses 64
RESULTS AND DISCUSSION 66
Operational Definitions of Aluminum Phases 66
Distribution of Aluminum Phases 67
Carbon 74
CONCLUSIONS 78

THESIS CONCLUSIONS 80

REFERENCES 82

APPENDIX A. SOIL MORPHOLOGICAL DESCRIPTIONS OF THE PEDONS SAMPLED 87

APPENDIX B. WATER TABLE AND TOPOGRAPHIC TRANSECT DATA FROM THE TWO SITES 104

APPENDIX C. CHEMICAL AND PHYSICAL DATA FROM THE NINE PEDONS SAMPLED 106

LIST OF TABLES

Table 1. Abbreviated morphological descriptions of four pedons selected to represent different degrees of spodic horizon expression in the two transects. 26
Table 2. Characterization data from four pedons selected to represent different degrees of spodic horizon expression in the two transects. 40
Table 3. Classification of the nine pedons sampled during this study. 56
Table 4. Calculated net gains or losses of constituents from six pedons. Values were based on an areal basis ($g/100cm^2$) and summed for all horizons within each pedon. Positive values represent net gains and negative values represent net losses. 73
Table 5. Calculated net gains or losses of total carbon and pyrophosphate carbon from six pedons. Values were based on an areal basis ($g/100cm^2$) for the thickness of each given horizon. Values were then summed for all horizons within each pedon. Positive values represent net gains and negative values represent net losses. 76

LIST OF FIGURES

Figure 1. Locations of reconnaissance and sampling sites on the lower Delmarva Peninsula of Maryland. 19
Figure 2. Soil morphology, topography and water table levels along the transect of site 1. Water table levels shown represent the average of the five highest and five lowest levels observed during the 16 months of examination. 21
Figure 3. Soil morphology, topography and water table levels along the transect of site 2. Water table levels shown represent the average of the five highest and five lowest levels observed during the 16 months of examination. 22
Figure 4. Locations of reconnaissance and sampling sites on the lower Delmarva Peninsula of Maryland. 35
Figure 5. Locations and classification of pedons sampled along the transect at site 1. 37
Figure 6. Locations and classification of pedons sampled along the transect at site 2. 38
Figure 7. Distribution of total organic C and pyrophosphate extractable C in four pedons selected to represent degrees of spodic horizon expression 46
Figure 8. Distribution of extractable Fe in four pedons selected to represent degrees of spodic horizon expression in the two transects. . . . 50
Figure 9. Distribution of extractable Al in four pedons selected to represent degrees of spodic horizon expression in the two transects. . . . 53
Figure 10. Locations and classification of pedons sampled along the transect at site 1. 62
Figure 11. Locations and classification of pedons sampled along the transect at site 2. 63
Figure 12. Distribution of various Al phases in four pedons selected to represent degrees of spodic horizon expression in the two transects. . . . 68
Figure 13. Micrographs of a weathered feldspar grain from the E horizon of pedon 1:5 suggesting loss of structural Al from these aluminosilicates during pedogenesis; A - plane polarized light; B - circularly polarized light; frame length is 1.2mm. 71
Figure 14. Micrographs of free grain argillans around quartz grains in the Bhsm horizon of pedon 1:5; circularly polarized light; frame length is 1.2mm. 79

INTRODUCTION

The delineation of wetlands has become increasingly important in recent years as Federal and State governments pass laws to protect and regulate their use. Wetlands form part of a continuous gradient between terrestrial and aquatic ecosystems, and because of this, there are many types of tidal and non-tidal wetlands. Though the variety of wetlands makes it difficult to develop a precise definition of a wetland, there are several general characteristics that wetlands have in common: shallow depth to seasonally high water tables, hydrophytic vegetation, and unique soils that differ from soils in upland positions.

Aquods, a suborder of soils with spodic horizons and aquic moisture regimes, are one group of soils associated with wetlands. In Maryland, approximately 6,000 ha of Aquods were mapped on the Lower Eastern Shore as Leon (Aeric Haplaquod) and St. Johns (Typic Haplaquod) (Hall, 1970) soil series. They develop in sandy quartzose sediments in areas where there is a high, but seasonally fluctuating, water table. When Soil Conservation Service (USDA) workers originally mapped these areas, they used broad delineations because there was limited access to wet areas and no demand for intensive mapping. To meet the current need for wetland delineation and more intensive soil maps, the Soil Conservation Service has been updating maps in Maryland, and it appears that a portion of the 60,000 ha of soils previously mapped as Pocomoke, Rutledge, and Plummer (very poorly drained, and loamy or sandy soils - Aquepts and Aquults) may, in fact, be wet Spodosols.

To understand more about spodic horizon formation in the Coastal Plain sediments of the Lower Delmarva Peninsula, this project (1) examines the spodic characteristics of soils along a topo-hydrosequence and (2) develops a pedogenetic model relating these characteristics to landscape position. The results should be useful to Soil Conservation Service mappers and others interested in the process of podzolization.

The research portions of this thesis are presented as three separate chapters (2, 3, and 4), and are written to be read independently. Those chapters follow the standard format of a research paper. Each paper contains sections on the methods, results, and conclusions of the research on each particular topic.

REVIEW OF THE LITERATURE

GENERAL CHARACTERISTICS AND CLASSIFICATION

Spodosols represent a major group of soils found throughout the world. What distinguishes them from other major soil groups is the formation of a distinct, dark subhorizon composed of organic matter and sesquioxides: a spodic horizon (Soil Survey Staff, 1987). Spodosols commonly develop in sandy to loamy sediments, and though they occur most extensively in cool humid areas in the Northern Hemisphere, they also can be found in humid tropical, Arctic, and temperate or mountainous regions.

The origin of the soil order Spodosol, as used by Soil Taxonomy, can be found in the Russian concept of the podzol soil. Generally, the horizons in Spodosols are very easy to distinguish because of their distinct appearance: a dark, organic surface horizon overlies a bleached, ashy, eluvial horizon underlain by a dark, illuvial spodic horizon. From the Russian words "pod", meaning under, and "zola" meaning ashy, the term podzol came into use in 19th century Russia to name these soils. In Soil Taxonomy, podzol soils are generally classified as Spodosols. Though the word Spodosol, which is derived from the Greek word "spodos" for wood ashes, emphasizes the ashy colored eluvial horizon, it is actually the presence of a dark illuvial spodic horizon that is required for classification as a Spodosol in Soil Taxonomy (McKeague, et al., 1980).

To distinguish Spodosols from other soils with illuvial horizons, Soil Taxonomy uses morphological and chemical criteria to emphasize the central concept of the Spodosol: the spodic horizon is a zone of accumulated organic matter and aluminum, with or without iron. To be classified as a Spodosol, the soil must have uniform color with depth, or the reddest hue and brightest chroma must be in the upper portion of the spodic horizon. In addition to this color requirement, the spodic horizon must meet other morphological or chemical criteria. Cracked coatings on sand grains or dark pellets composed of paracrystalline material are morphological features that may indicate the presence of translocated organic matter, aluminum and iron. Similarly, the presence of ortstein, a cemented horizon. is an indication of spodic horizon formation.

Not all Spodosols have cracked coatings or ortstein, therefore chemical extractions are used to confirm the presence of paracrystalline organic sesquioxide materials in the illuvial horizon. If the chemical criteria are met, the soil is considered a Spodosol. Pyrophosphate is a fairly selective extractant for organic complexes of aluminum and iron (Farmer, et al., 1983), and dithionite citrate buffer (DCB) removes free aluminum and iron oxides (McKeague, et al., 1971) although Farmer et al. (1983) found that DCB only partially extracts allophane and imogolite. To be considered a spodic horizon the amount of pyrophosphate extractable Al and Fe must be high compared to the amount extracted by DCB (ratio >0.5). To prevent inclusion of horizons high in silicate clays, the amount of pyrophosphate extractable Al and Fe, or Al and C, must be high relative to the %clay (>0.2). Finally, the cation exchange capacity (CEC) of the spodic horizon must be relatively high as a result of contributions from illuvial paracrystalline organic sesquioxide material rather than from silicate clay sources (McKeague, et. al., 1980; Soil Taxonomy, 1987).

Soil Taxonomy divides the Spodosol order into four suborders based on the degree of wetness and the nature of the material accumulated in the spodic horizon. Humods, Ferrods, and Orthods are freely drained Spodosols, and Aquods are more poorly drained Spodosols with an aquic moisture regime. Ferrods have an iron rich spodic horizon with a ratio of DCB extractable iron (free iron)-to-carbon of six or more. Intended for Spodosols formed in iron rich parent materials, this suborder has not been found in the U.S. Humods are more or less freely drained Spodosols with a greater accumulation of organic carbon than free iron (Fe DCB/organic C <0.2). They occur extensively in

Western Europe in iron deficient sands under heathland, but they are not common in the U.S. (Bullock and Clayden, 1980). Another more or less freely drained spodosol is the Orthod. The spodic horizon in Orthods contains carbon, iron, and aluminum, but none of these elements dominates the horizon as in the other suborders. Orthods are the most common spodosols in North America, Scandinavia, and the Soviet Union (Bullock and Clayden, 1980). Finally, Aquods are the Spodosols that are not freely drained; they have an aquic moisture regime or are artificially drained. Aquods have been reported mainly in sandy materials in Florida, South Borneo, northwest Soviet Union, and the British Isles (Bullock and Clayden, 1980).

In the United States, there are approximately 67,000 km^2 of Aquods (Soil Survey Staff, 1975) representing approximately 1% of the land in the U.S. They occur in the Atlantic and Gulf Coastal Plains from New Jersey to southern Florida (Marbut, 1935). They have also been reported in Oregon (Nettleton, et.al. 1982) and Northern California (Jenny, et. al., 1969).

Though the morphological features of Aquods that are considered indicators of wetness are rather detailed, Soil Taxonomy (Soil Survey Staff, 1975) describes the general morphology as "a nearly white (thick) albic horizon... or, in the wettest Aquods, a black surface horizon resting on a dark reddish brown spodic horizon...." The diagnostic features of an aquic moisture regime in a Spodosol include one or more of the following: a histic epipedon, mottles in the albic or in the upper part of the spodic horizon, the position of albic or placic horizon or duripan in relation to a spodic horizon or fragipan. There are also color requirements that are considered diagnostic features for Aquods. If free iron and manganese are absent in the spodic horizon, a moist color value of four or more in or immediately below the spodic horizon, or the presence of mottles immediately below the spodic horizon are considered to be indicators of an aquic moisture regime (Soil Survey Staff, 1990).

Wetness in Aquods can be attributed to various causes such as a shallow fluctuating water table, impermeable layers in the soil (as in Duraquods, Placaquods, and Fragiaquods), or excessive surface wetness. These possible causes and soil temperature regimes are the basis for classification of Aquods at the great groups level (Soil Survey Staff, 1990). The cause of wetness in Maryland Aquods is a shallow fluctuating water table. Their classification at the great group level as Haplaquods implies that an absence of free iron in the spodic horizon distinguishes them from other Aquods (Soil Survey Staff, 1990).

OCCURRENCE IN MARYLAND

On the Lower Eastern Shore of Maryland, the two soil series which were mapped as Haplaquods are St. Johns, a Typic Haplaquod, and the presumably slightly better drained, Leon, an Aeric Haplaquod. These were originally classified under the 1938 classification system (Baldwin, 1938) when Haplaquods were known as Ground Water Podzols at the great soil group level and the names Leon and St. Johns were used at the series level. Since the adoption of Soil Taxonomy in 1970, however, Leon and St. Johns are the series names for Aeric and Typic Haplaquods in thermic temperature regimes and new series were developed for mesic temperature regimes. In New Jersey, the series mapped as Aeric and Typic Haplaquods are Atsion and Berryland, respectively. Since the temperature regime in Maryland is also mesic, the names Atsion and Berryland will be used in updated soil survey reports.

Haplaquods comprise approximately 6,000 ha of soils in Wicomico, Worcester, and Somerset Counties on the Lower Delmarva Peninsula. The Peninsula is an eroded plain with little variation in relief; the average elevation is approximately 11 m above sea level. Rivers and their tributaries move sluggishly and 75% of the soils require drainage for agricultural use (Hall,R., 1970). Aquods on the Lower Delmarva Peninsula are reported to form in Coastal Plain sediments (Hall,R., 1970).

Though the literature on Aeric and Typic Haplaquods is scant, some generalizations about their morphology, chemistry, and mineralogy can be made.

MORPHOLOGY

In a statistical comparison of spodic characteristics in U.S. soils, Rourke, et. al. (1988) found differences between Aquods in "cold" (0-8° C) and "warm" (>15° C) temperature regimes. All warm Aquods had A or Ap horizons compared to only 50% of the cold Aquods. Also, E and Bh horizons were thicker in warm Aquods than in cold Aquods.

A and E horizons are present in Aeric and Typic Haplaquods in hyperthermic, thermic and mesic temperature regimes (Collins, 1990; Lee, et al., 1988; N.J. SCS; Daniels, et al., 1975; Hall, 1970). The depth to Bh horizons is generally deeper in Florida soils (50-70 cm) (Collins, 1990) than in North Carolina (38 cm) (Holzhey, et. al.,1975) and New Jersey (38-43 cm) (NJ SCS).

The thickness of the Bh horizon varies greatly. In Florida the Bh horizons range from 10-76 cm thick (Zelazny and Carlisle, 1971; Lee, 1988a) and in some instances a second spodic horizon forms lower in the profile (Collins, 1990). SCS mappers report Bh horizons 15-20 cm thick in New Jersey and 55-60 cm in Maryland. Most impressive are Bh horizons 5-9 m thick in North Carolina. Daniels, et al. (1975) examined the thickness of Bh horizons along a transect in North Carolina. They found that thinner, discontinuous spodic horizons formed in soil textures of sandy loam or finer, whereas the thicker spodic horizons occurred in coarser textured materials. The thickest Bh horizons were in pedons where groundwater movement was unrestricted.

Haplaquods generally form in very sandy sediments. Throughout the soil profile the sand content ranges from 88-95%, and the amount of clay varies from 4-7% (Brandon, et al., 1971; Zelazny and Carlisle, 1971; Holzhey, et al., 1975; Lee, et al., 1988b). Zelazny and Carlisle (1971) and others (Lee, 1988b; Holzhey et al., 1975) note that the clay content increases with depth in the profile and is greatest in the spodic horizon.

Soil Taxonomy recognizes the presence of ortstein, an indurated horizon cemented by organic matter with iron and/or aluminum, as an indicator of a spodic horizon. Reports of ortstein in spodic horizons come from many parts of the world including the U.S., Australia, Netherlands, Canada, and Great Britain. There is great interest in the nature of the cementing agents because it provides a clue to the processes involved in spodic horizon genesis. DeConinck (1980) and McKeague and Wang (1980) found monomorphic cutans composed of Fe or Al organic complexes to be the cementing agents. Farmer (1984) found the paracrystalline cementing material in

Australian spodosols to be proto-imogolite, and Wang (1986) found evidence of imogolite in Canadian ortstein.

Studies of ortstein in Aeric Haplaquods provide information about the formation of spodic horizons under aquic moisture regimes. Brandon, et al.(1971) analyzed Aeric Haplaquods in North Carolina and found textural differences between spodic horizons with and without ortstein. Micromorphological examination of the indurated horizons revealed pores filled with organic material embedded by silt particles, and particle size analysis showed ortstein to be finer textured and more poorly sorted than non-ortstein horizons. In a study of ortstein in Florida Haplaquods, Lee et. al.(1988a) found an aluminum gel substance and fine particles to be the components of the cementing agent. In other studies, Lee et. al. (1987, 1988b) determined the predominant form of aluminum to be organic matter complexes rather than proto-imogolite allophane.

CHEMICAL PROPERTIES

The pH of Haplaquods is generally acidic (Soil Survey Staff, 1975). Reports show the surface pH to be 3.3 - 3.8 in North Carolina (Brandon, et al., 1971; Holzhey et al., 1975) and 4.4 - 4.9 in Florida (Collins, 1990; Lee et al., 1988b). Data from those studies also show that pH tends to increase with depth in the profile.

Aluminum is the dominant cation in the spodic horizon of Haplaquods. Quantities of aluminum extracted by pyrophosphate, dithionIte, and oxalate are greatest in the spodic horizon and the amounts range from 0.08 to 0.70 % (Brandon, et al., 1971; Holzhey, et al., 1975; Lee, et al., 1988a, Nettleton, et al., 1982). These studies show the greatest amounts of aluminum to be in the form of organic matter complexes.

There is essentially no extractable iron in these soils. The amount of iron removed by the three extractants was generally less than 0.1% (Brandon, et al., 1971; Holzhey, et al., 1975; Lee, et al., 1988a). Some workers report that what little iron there is in the profile, tends to be highest in the spodic horizon (Brandon, et al. 1971; Lee et al., 1988a).

Organic carbon content is high in the spodic horizon, and in some instances it is higher than in the surface horizon. Reports from North Carolina show a range of 1.0 to 5.4% organic carbon in the A horizon which drops abruptly to 0.1-0.6% in the E horizon and increases to 1.0 to 2.5 to in the spodic horizon (Brandon, et al., 1971; Holzhey, et al., 1975). Lee, et al. (1987) reported a soil with organic carbon content of 0.8% in the surface horizon increasing to 2.7% in the spodic horizon.

The ratio of pyrophosphate extractable carbon to total organic carbon is higher in the spodic horizon than the surface horizon, indicating the movement and accumulation of carbon (Holzhey, et al., 1975; Lee, et al., 1987). Lee et al.(1987) reported fulvates were the main form of carbon accumulated in spodic horizons in Florida. In an interesting study of 5-9m thick spodic horizons in North Carolina, Holzhey, et al. (1975) found mainly fulvic acids in the water percolating through the soil profile, but the organics in the Bh horizon were predominantly humic acids. They estimated from 3 to 40 g of carbon/m^2 per year was available to move into solution through the profile, and this quantity was estimated to be sufficient to develop a Bh horizon of the age and thickness observed in those soils.

The CEC tends to be higher in spodic horizons than in other horizons in the profile because of substantial amounts of organic matter and noncrystalline materials (Yuan,1968). Holzhey, et al (1975) determined the CEC in a North Carolina Haplaquod (5 - 17 cmol/kg) to be dominated by aluminum and organic carbon, and as a consequence the CEC is very pH dependent. They also report 0.2 cmol (1/2 Ca^{2+})/kg and 0.1 cmol(1/2 Mg^{2+})/kg of Mg in two horizons and small, but measurable, quantities of K throughout the profile. Extractable acidity in the profile is highest in the Bh horizon (Holzhey, et al., 1975; Collins, 1990; Nettleton, et al., 1982).

Haplaquods form in sandy sediments. In North Carolina Haplaquods the sand is mainly quartz with <3% weatherable minerals in the fine sand of most subhorizons. Feldspar and biotite are present in the very fine sand fraction of the C horizon.

Zelazny and Carlisle (1971) analyzed the crystalline clay fraction of Florida Aeric Haplaquods. The soils contained quartz and kaolinite in all horizons, hydroxy Al interlayered vermiculite in the spodic horizon, and gibbsite in the C horizon. Holzhey, et al. (1975) found similar clay minerals, mica and interstratified mica-vermiculite, in a Typic Haplaquod. In a comparison of ortstein and non-ortstein spodic horizons, quartz was the dominant mineral with hydroxy Al interlayered vermiculite and kaolinite also present (Lee,et al.,1988b).

GENETIC PROCESSES

Various theories have been proposed to explain the mechanism which causes spodic horizon development. Though the theories differ in their explanations about the specific processes that cause the spodic horizon to form, they are in agreement about the illuvial nature of the horizon. The E horizon is depleted of metal cations, and there is a Bhs horizon enriched with an organo-metal cation and/or a Bs horizon enriched with metal cations.

Theories of spodic horizon genesis generally fall into two categories. One theory depicts Al and Fe movement through the soil as soluble metal-organic complexes. Water soluble organic acids (fulvates) form from decomposing plant litter. Iron and aluminum from minerals or plant material then complex with the fulvates forming soluble chelates. The chelates are able to move through the soil in percolating water and stop in a lower horizon where they become insoluble and accumulate (DeConinck, et al., 1980; McKeague, et al., 1983). Precipitation in the spodic horizon may due to an increase in the ratio of metal ions to fulvic acid (Fanning and Fanning, 1989; Reeves, 1961).

The other main theory was developed by Farmer, et al. (1980) to explain the presence of allophane, imogolite, and organic matter in freely drained spodosols. They suggest that Fe and Al move through the soil profile as inorganic sols, rather than organic complexes. The inorganic sols, called protoimogolite, are soluble Si-Al and Fe(III)Al oxide hydroxide complexes which precipitate and form a spodic horizon. Soluble organic complexes move independently of metals and are stopped by previously translocated inorganic sols.

Aquods differ from other Spodosols because they are not freely drained, and studies of Aquods have pointed to the importance of a fluctuating water table as a possible mechanism for spodic horizon formation. Daniels, et al. (1975) examined the thickness of spodic horizons along a landscape in North Carolina and found thicker Bh horizon formation in areas of the landscape with sandy textures, high water tables, and a downward flow of groundwater. Garman, et al. (1981) measured redox potentials of ground water in Aquods and found more negative potentials in soils with thicker Bh horizons.

Other studies have focused on the composition of indurated horizons in Aquods as a means to provide insight into the processes involved in spodic horizons formation. Brandon, et al. (1977) suggested that brittleness in spodic horizons of Aquods may be caused by infilling of macropores with organic matter and silt particles. In a study of Florida Aquods, Lee, et al. (1988a) used electron microprobe techniques and determined the cementing agent in ortstein horizons to be a mixture of aluminum and fine particles. In a separate study (Lee, et al., 1988b), they determined that the cementing agent was composed predominantly of Al organic complexes rather than hydrous oxides and noncrystalline Al silicates.

MORPHOLOGY AND GEOMORPHOLOGY OF HAPLAQUODS ON THE LOWER EASTERN SHORE OF MARYLAND

Topography is one of several factors that strongly influence soil formation (Jenny, 1941). One of the aspects of topography is its effect on the depth to the water table at different positions on the landscape. These become translated into drainage differences which often influence the development of soil properties. If differences in other major soil forming factors (parent material, time, organisms, and climate) can be minimized, it is possible to examine the causal effect of landscape position on particular soil properties.

Studies of spodic horizon development in Haplaquods have pointed to the importance of a fluctuating water table as a mechanism for spodic horizon formation in wet spodosols. Daniels, et al., (1971) found the thickest spodic horizons along a transect formed in sand or loamy sand materials in areas where the water table was above the spodic horizon for part of the year. They attributed the accumulation of organic materials in the spodic horizon to the downward movement of the water table. Garman, et al. (1981) noted more negative redox potentials favored the formation of thicker spodic horizons in Florida Haplaquods. Workers in New Jersey found Haplaquods formed in coastal sands in landscape positions where the water table level was closer to the surface (Tedrow, 1986)

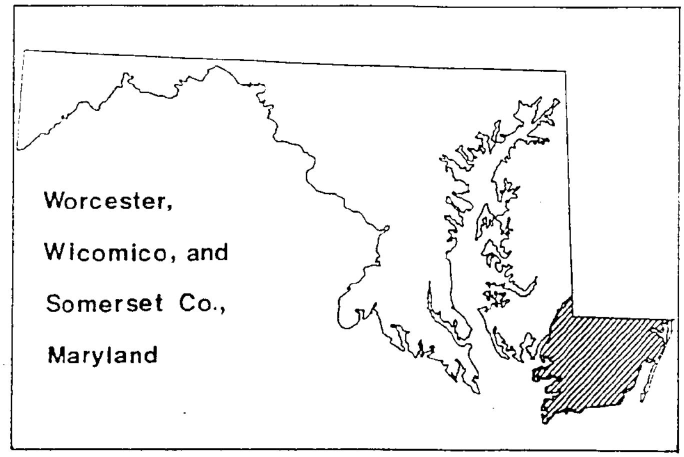
In Maryland, soils with spodic horizon characteristics form in Coastal Plain sediments on the Lower Eastern Shore in areas with seasonally high water tables. Since water table levels appear to be a possible influence on the formation of Haplaquods, we attempted in this study to examine the development and expression of spodic horizon morphology in sandy soils along two topo-hydrosequences on the Lower Delmarva Peninsula.

MATERIALS AND METHODS

Site Description and Methodology

Two research sites were chosen after a reconnaissance study of 35 sites in Worcester, Wicomico, and Somerset Counties, Maryland (Fig. 1). The research sites were located in the Pocomoke State Forest, Worcester County, where there appeared to be minimal effects from drainage ditches, and the land was relatively undisturbed. Managed by the State since the earlier part of the century the forests are almost pure stands of loblolly pine (Pinus taeda) with greenbrier (Similax rotundifolia) underbrush. The average annual temperature is 13.7° C and precipitation averages 1249 mm per year (Hall, 1970).

Surficial geology maps of the Delmarva Peninsula show the sandy parent material in the research sites to be of



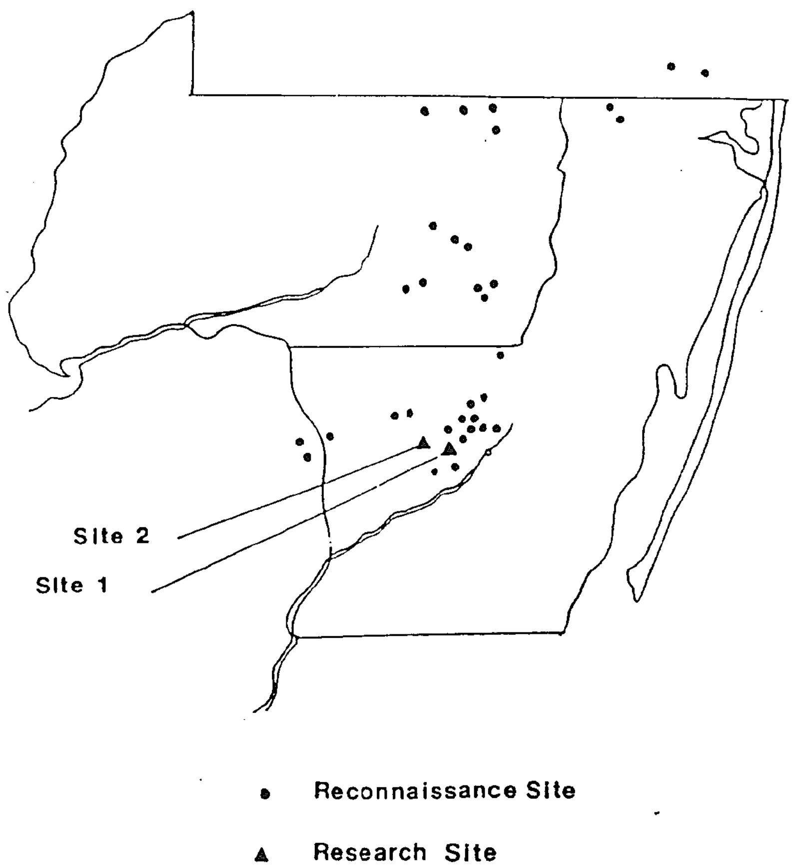


Figure 1. Locations of reconnaissance and sampling sites on the lower Delmarva Peninsula of Maryland.

marine origin: however, it is more likely the sands are eolian deposits formed during the late Pleistocene or early Holocene. Approximately 10,000-30,000 YBP, wind blown sands were deposited on the Peninsula creating a dunal topography known as the Parsonsburg Sand Formation (Denny, 1979). Surficial geology maps show the Parsonsburg Formation only in areas where the deposits are thickest, on the lee side (SE) of major tributaries of the Chesapeake Bay. Field observations indicate that eolian deposits may be more extensive than shown on the maps, although some deposits may be relatively thin, <50 cm, and some eolian activity may have occurred more recently during the Holocene.

A topographic transect representing a sequence of drainage classes was identified at each of Sites 1 & 2. Along each transect, relief was determined by using a level and rod. Wells made of perforated PVC pipes (7.6 cm diameter) were installed along the transects, and the depth of the ground water from the soil surface was measured using a weighted wire connected to an electronic multitest meter, approximately every two weeks from March, 1989 to June, 1990. Nine wells were installed along a 200 m transect at Site 1, and six wells were installed along a 100 m transect at Site 2 (Figs. 2 & 3). Pits were opened adjacent to five wells at Site 1 and four wells at Site 2. The pedons were described using standard SCS

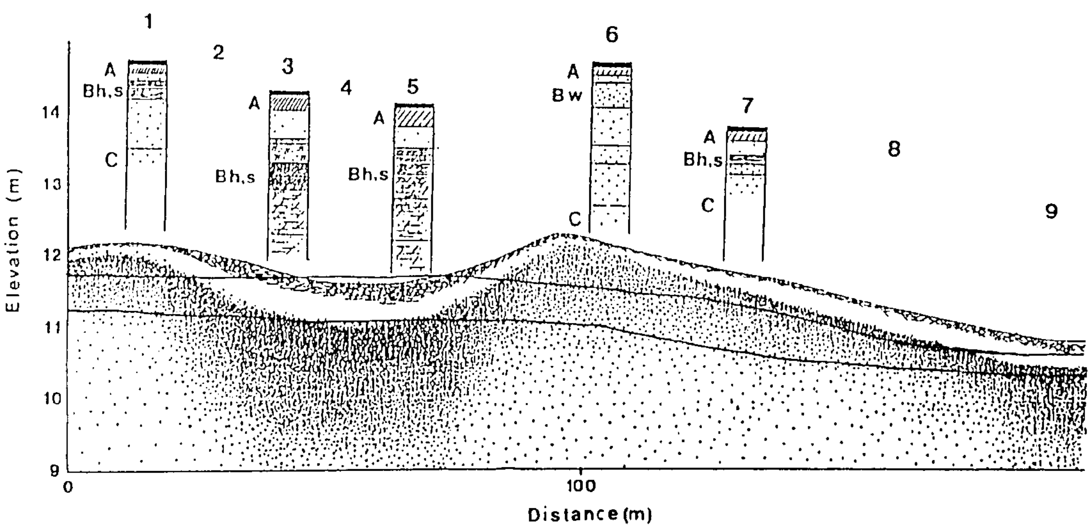


Figure 2. Soil morphology, topography and water table levels along the transect of site 1. Water table levels shown represent the average of the five highest and five lowest levels observed during the 16 months of examination.

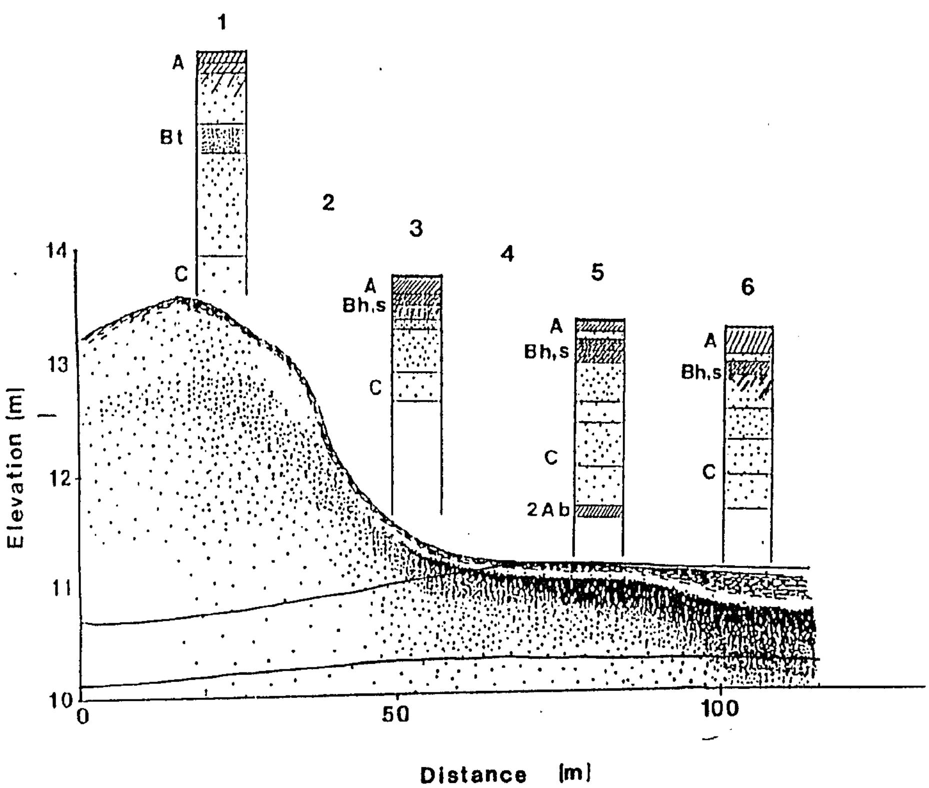


Figure 3. Soil morphology, topography and water table levels along the transect of site 2. Water table levels shown represent the average of the five highest and five lowest levels observed during the 16 months of examination.

procedures (Soil Survey Staff, 1981). Before and during soil sampling and description, water was pumped from the pits. A sample from a buried horizon at Site 2 was analyzed for radiocarbon dating ^{14}C (Beta Analytic, Coral Gables, Florida).

The water table measurements were made from March 1989 through June 1990, a period during which rainfall was much greater than average. The average annual precipitation in Worcester County is 1249 mm, however in 1989, the total precipitation was 1596 mm due to higher than average rainfall in July and August. Though this data is rather limited, it does provide evidence of the upper limits of the water level during a wetter than normal year.

RESULTS

During the topographic analysis and sampling, an organic rich (1.64%C) layer was observed at a depth of 1.8 m at pit 5 along the transect at Site 2. This layer was interpreted to represent a buried surface. The age of this surface was determined to be 10,200 +/- 270 years old based on radiocarbon dating. These results suggest that the sandy sediments at this Site are approximately 10,000 years old, and they are part of the Parsonsburg Formation. In New Jersey, workers found evidence of Haplaquods forming in Quaternary dunal deposits (Tedrow, 1986).

Dunal topography is also evident at our sites and is especially pronounced at Site 2 where there is greater than 2 meters of local relief.

Morphology and Relation to Landscape Position

Descriptions of four pedons are in Table 1. They were chosen because each pedon best represents a different degree of spodic horizon development, ranging from no expression to strongly expressed spodic horizon morphology.

At Site 2 (Fig. 3), all of the soils have sand or loamy sand textures. Near the summit, pedon 1 (2:1) has a thin 1 cm thick organic mat overlying a gray (10YR 5/1) A horizon. The B horizon is dark yellowish brown (10YR 4/6) and lacks mottling, which indicates that it is well aerated. There is no evidence of spodic horizon development in the profile, but there are indications of clay illuviation. Although this soil did not have an argillic horizon, the clay content was higher in the B horizon than the surface horizons, and clay enriched lamellae are present between 1 and 1.5 meters. Micromorphological observation confirmed this clay to be illuvial in origin. In this profile the water table did not rise to within 3 m of the surface during the year. Downslope, in pedon 2 (2:2), there is no spodic horizon morphology in the yellowish brown (10YR 5/6) B horizon, but there are dark yellowish brown (10YR 4/6) pockets in the upper part of the horizon. The water level was higher in this pedon, ranging between 137 cm and 214 cm from the surface during the year.

Table 1. Abbreviated morphological descriptions of four pedons selected to represent different degrees of spodic horizon expression in the two transects.*

Horizon	Depth (cm)	Color	Texture	Structure	Consistence	Boundary
			Pedon 2:1			
Oe	1-0					
A1	0-10	10YR 5/1	s	sgr	l	cw
A2	10-20	2.5Y 5/4	ls	wmsbk	vfr	cs
BA	20-69	10YR 5/4	ls	wmsbk	vfr	cs
Bt	69-98	10YR 4/6	ls	wmsbk	vfr	cs
CB	98-194	10YR 6/4	s	sgr	l	cs
C1	194-249	2.5Y 6/4	s			
C2	249-284	2.5Y 6/4	s			
C3	284-313	10YR 5/6	s			
C4	313-359	2.5Y 6/4	s			
			Pedon 1:6			
Oe	2-0					
A	0-7	10YR 3/1	ls	wmg	vfr	cs
E	7-15	7.5YR 5/2	ls	wmsbk	vfr	ci
Bw	15-46	10YR 4/6	ls	wmsbk	fr	gs
BC1	46-91	10YR 5/4	ls	wcosbk	vfr	
BC2	91-116	5Y 6/2	ls			
BC3	116-166	2.5Y 6/4	s			
C	166-176	2.5Y 7/2	s			
			Pedon 2:5			
Oe	5-0					as
A	0-10	10YR 2/1	ls	wmsbk	vfr	cs
E	10-17	10YR 4/2	s	sgr	l	cs
Bh	17-30	5YR 2/1	ls	wmsbk	fr	cs
Bhs	30-43	5YR 3/3	ls	ma	fi	cs
BC	43-80	10YR 5/4	ls	msbk	fr	
C1	80-100	5Y 6/3	s	sgr	l	
C2	100-145	2.5Y 6/4	s	sgr	l	
C3	145-185	2.5Y 4/2	s	sgr	l	
2Ab	185-195	10YR 3/3	ls			
2AC	195-223	10YR 3/2	s			
			Pedon 1:5			
Oe	6-0					as
A	0-22	N 2/0	ls	wmsbk	vfr	cs
E	22-50	10YR 5/2	s	sgr	l	cs
Bh1	50-58	10YR 2/1	ls	wcosbk	fr	cw
Bhsm	58-81	5YR 3/2	ls	ma	fi	cd
Bh2	81-114	10YR 2/1	ls	ma	fr	
Bh3	114-164	10YR 2/1	ls			
Bhs	164-209	7.5YR 3/2	ls			
Bs	209-254	7.5YR 3/4	ls			
BC	254-294	10YR 5/6				

*Abbreviations used in this appendix are the standard ones reported in the Soil Survey Manual (Soil Survey Staff, 1981).

Downslope on the landscape in pedon 3 (2:3), there is evidence of incipient spodic horizon formation. The A horizon is very dark grayish brown (10YR 3/2). This is underlain by a thin, 11cm thick dark brown (7.5YR 3/3) Bh horizon and 13cm thick strong brown (7.5YR 4/6) Bs horizon. Within the spodic horizon, there are some reddish brittle zones, perhaps indicators of iron oxides. Strong brown mottles are present immediately below the spodic horizon in the lower BC1 horizon as well as in the underlying horizons. During the wettest periods of the year the water table was within 19 cm of the surface (approximately the upper part of the Bh horizon). The lowest level was observed in the summer at 115 cm below the surface in the C horizon.

In the lower portions of the landscape, which tend to be wetter, there are well developed spodic horizons and E horizons are evident. occur in the soil. In pedon 5 (2:5), the grayish brown (10YR 4/2) color of the E horizon is a distinctly contrasting horizon between the black A and Bh horizons. The spodic horizon in pedon 5 (2:5) is darker and would appear to have more organic material than that of pedon 3 (2:3); the black (5YR 2.5/1) Bh horizon is underlain by a dark reddish brown (5YR 3/3) Bhs horizon. The water table ranged from within 6 cm of the surface, the upper A horizon, to 94 cm depth in the gleyed, pale olive (5Y 6/3) upper C horizon. The sands in the lower C horizons are also gleyed colors (2.5Y 4/2), and at 185 cm depth, we observed the silty, dark brown (10YR 3/3) surface horizon, presumably buried by drifting sand.

Pedon 6 (2:6) is similar to pedon 5 (2:5) and has a grayish brown (10YR 4/2) E horizon between black A and Bh horizons. One fundamental difference, however, is that the A horizon in Pedon 6 is 23 cm thick, twice the thickness observed in Pedon 5. The A horizon appears to be rich in organic carbon and to meet the color and thickness criteria for an umbric epipedon. The thickness of the A horizon in this pedon most likely is due to the water table being ponded (+5 cm) during wet periods. The soil environment is probably more anaerobic than during wet periods, and organic material would decompose less rapidly than in the slightly better aerated conditions in pedon 5 (2:5). The lowest water table level in pedon 6 (2:6) was 83 cm below the surface in the upper BC2 horizon

At Site 2 a trend in the occurrence of spodic morphology emerges. The soil properties of the better drained soils (summit, shoulder, and upper backslope) clearly differ from the wetter soils in the lower landscape positions. Along the slope, from the upper to lower positions, the spodic morphology becomes more pronounced. There is no evidence of spodic morphology in the best (excessively) drained soil at the summit and upper backslope, but farther downslope where the water table extends closer to the soil surface (pedon 2:3), is where spodic morphology initially becomes evident. Landscape position is the variable factor, but more important is the depth to the seasonally high water table which is related to landscape position. Where the water table comes closer to the surface, spodic morphology is more evident, and it is strongest in the areas of the landscape where the water is ponded or near the surface for part of the year.

This relationship between landscape position (and therefore depth to water table) and spodic expression is also apparent at Site 1 (Fig. 2). The dunal topography is more subtle, but as at Site 2, spodic morphology is more strongly expressed in the wetter, lower landscape positions. The difference, however, is that the spodic horizons at Site 1 are much thicker, and in some instances, have zones that are strongly cemented.

At Site 1, pedon 6 (1:6) occupies the summit position, however the water table level is closer to the surface than in the summit soil at Site 2. Unlike the summit soil at Site 2, pedon 6 (1:6) has some indications of spodic horizon formation, and the morphology is more similar to pedon 3 (2:3) in the lower backslope position at Site 2. In pedon 6 (1:6), the Bw is dark yellowish brown (10YR 4/6), the same color as the Bt in pedon 1 (2:1) at Site 2; however, the Bw horizon contains 5-10%

dark (10 YR 3/4) zones. The shallowest water table level at this location was 48 cm. Although there seemed to be zones of incipient spodic horizon development, those zones were not as continuously nor as strongly expressed as in pedon 3 (2:3) at Site 2 where the water table extended to 19 cm from the surface. The BC and C horizons have olive colors with strong brown mottles (7.5YR 5/8, 7.5YR 5/6) which indicates the occurrence of iron transformation and segregation.

Pedons 1 (1:1) and 7 (1:7) have shallower water tables than pedon 6 (1:6). In both soils the water table extends into the E horizon: 26 cm at pedon 1 (1:1) and 21 cm at pedon 7 (1:7). Consequently they have thicker A and E horizons than Pedon 6, and the spodic horizons are more strongly expressed.

The wettest position was at well 4 (1:4) where the water table was ponded 12 - 21 cm above the surface most of the year. Since it was not possible to open a pit at this position pedons were described near wells 3 (1:3) and 5 (1:5). At these positions the water table was at or 10 cm above the surface during wet periods, but dropped to 61-66 cm below the surface during dry periods. These pedons were the most spectacular of those described at the two sites. The A horizons are black (N2) and 20-22 cm thick, followed by grayish brown (10YR 5/2) E horizons. Both pedons had black (10YR 2/1) Bh horizons underlain by dark reddish brown (5YR 3/2) cemented horizons. In Pedon 3 the spodic horizon spans 162 cm, and the cemented horizon was 45 cm thick. Underneath the spodic horizons was a sandy pale olive (5Y6/3) C horizon. The spodic horizon at Pedon 5 was even thicker, 204 cm, though the cemented horizon was thinner, 23 cm.

CONCLUSIONS

The location of the soil on the landscape in relation to the water table seems to influence the formation of spodic horizons at these sites. The parent material, vegetation, and regional climate are the same for all the soils. The age of the soils is presumably the same and is thought to be approximately 10,000 years old, as indicated by the age of the buried horizon at Site 2. The variable factor in these soils is the depth to seasonally high water tables. Erosion and deposition of soil materials on landscapes are processes related to slope position, however in these sandy soils with high surface hydraulic conductivity, the effects of runoff and transport are probably minimal. What is important on these landscapes seems to be the relation between landscape position and water table depth. In the highest landscape positions, where the water table was not within 159 cm of the surface, there was no evidence of spodic morphology. The positions where the water table came closer to the surface

(19-48 cm) were the positions where spodic horizon morphology first began to appear. At both sites, the thickest, most strongly expressed spodic horizons were in the lowest landscape positions where the water table was ponded 5 - 10 cm above the soil surface for part of the year. The results suggest that on these landscapes, spodic horizon morphology only develops in positions where the water table is close to the surface, and therefore, the water table may be a mechanism for the development of the spodic characteristics.

CHARACTERIZATION AND CLASSIFICATION OF SOILS WITH SPODIC EXPRESSION ON THE EASTERN SHORE OF MARYLAND

In the Eastern U.S., Aeric and Typic Haplaquods formed in sediments of the Atlantic and Gulf coastal plains from New Jersey to Florida (Soil Survey Staff, 1975). Extractable Al and organic C dominate the spodic horizons, and only trace amounts of extractable iron are present. In some instances ortstein forms in the spodic horizons (Brandon, et al., 1971; Holzhey, et al., 1975; Lee, et al., 1988a). Daniels, et al.,(1971) found the thickest spodic horizons to occur in sand or loamy sand materials where the ground water movement was unrestricted and the water table extended above the spodic horizon during wet periods of the year.

In Maryland, soils with spodic morphology form on the Lower Delmarva Peninsula in late Pleistocene or early Holocene dune deposits in areas which have seasonally high water tables. In a study of spodic horizon expression along topographic transects in those areas, the soils were found to demonstrate varying degrees of, what is typically thought of as, spodic horizon morphology: dark brown B horizons overlain by E horizons. In general, the lower a soil was positioned along the toposequence, with accompanying shallower depths to the water table, the more strongly the spodic horizon morphology was expressed in the soil. The strongest spodic horizon morphology was in the lowest areas of the landscape where the seasonally fluctuating water table was at or within a few cm of the soil surface during wet periods of the year (Condron, 1990). The purpose of this study was to examine the physical and chemical properties of these soils showing varying degrees in the expression of spodic horizons and to discuss these properties in their relation to landscape position, classification, and morphology.

MATERIALS AND METHODS

Site Description

A reconnaissance study was made of 35 potential research sites in Worcester, Wicomico, and Somerset Counties, Maryland (Fig. 4). Two research sites were chosen in the Pocomoke State Forest in Worcester Co. because the soils were relatively undisturbed and the effects of drainage ditches were minimal. Lobolly pine (Pinus taeda) is the predominant vegetation, and the soil temperature is mesic (marginal to thermic). Transects representing drainage conditions from excessively to very poorly drained were identified at two sites along dune deposits dated to be approximately 10,000 years old. Along each transect, relief was determined by using a level and rod. Wells made of perforated PVC pipes (7.6 cm diameter)

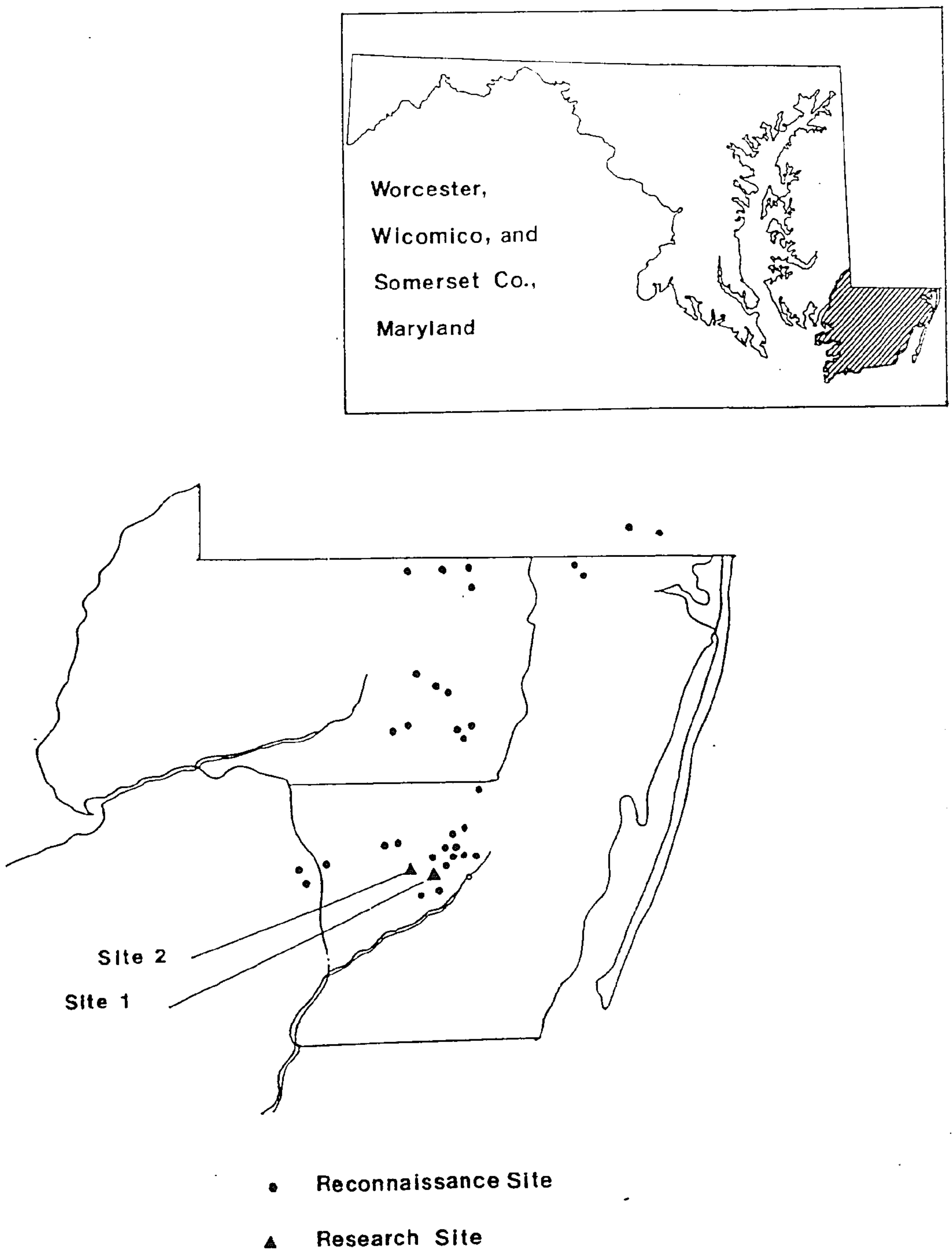


Figure 4. Locations of reconnaissance and sampling sites on the lower Delmarva Peninsula of Maryland.

were installed along the transects, and the depth of the ground water from the soil surface was measured using a weighted wire connected to an electronic multitest meter, approximately every two weeks from March, 1989 to June, 1990. Nine wells were installed along a 200 m transect at Site 1, and six wells were installed along a 100 m transect at Site 2 (Figs. 5 & 6). Water table levels were determined with an ohm meter approximately every two weeks from March, 1989 through June, 1990. Pits were described adjacent to five wells at Site 1 and four pits at Site 2 and samples were taken for bulk density, chemical, and micromorphological analyses. Because of the high levels of the water tables, water had to be pumped from the pits throughout the sampling process.

Sample Preparation and Analysis

Samples for chemical and particle size analysis were air dried, crushed, and passed through a 2mm sieve. Bulk density was measured on field moist samples using the saran clod method (Brasher & Franzmeier, 1966). After oxidation of organic matter using H_2O_2 and dialysis to remove salts, particle size distribution was determined by the pipette method (Gee and Bauder, 1986). Organic C was measured by dry combustion using a LECO model CHN600 Carbon Analyzer. Fe and Al were extracted using sodium pyrophosphate (Method 6C8, Soil Survey Staff, 1984),

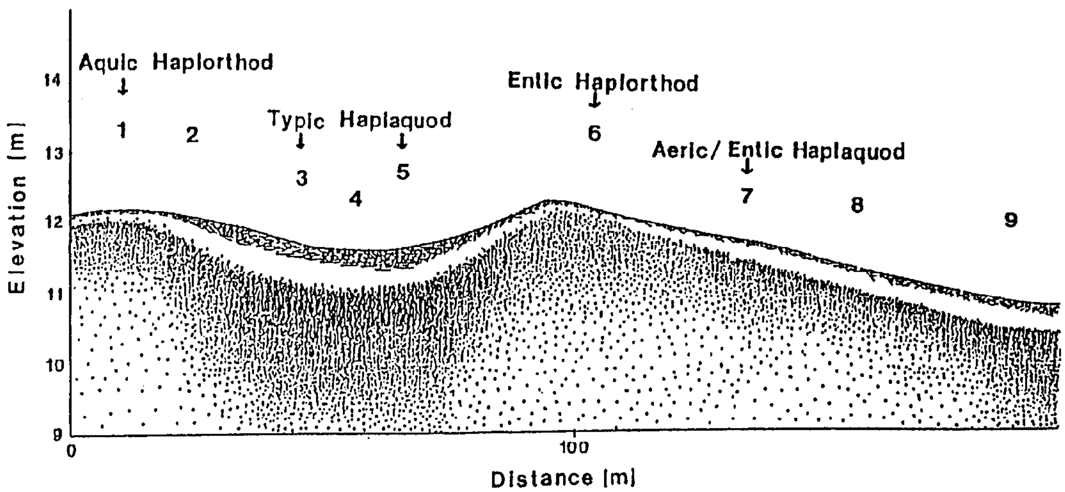


Figure 5. Locations and classification of pedons sampled along the transect at site 1.

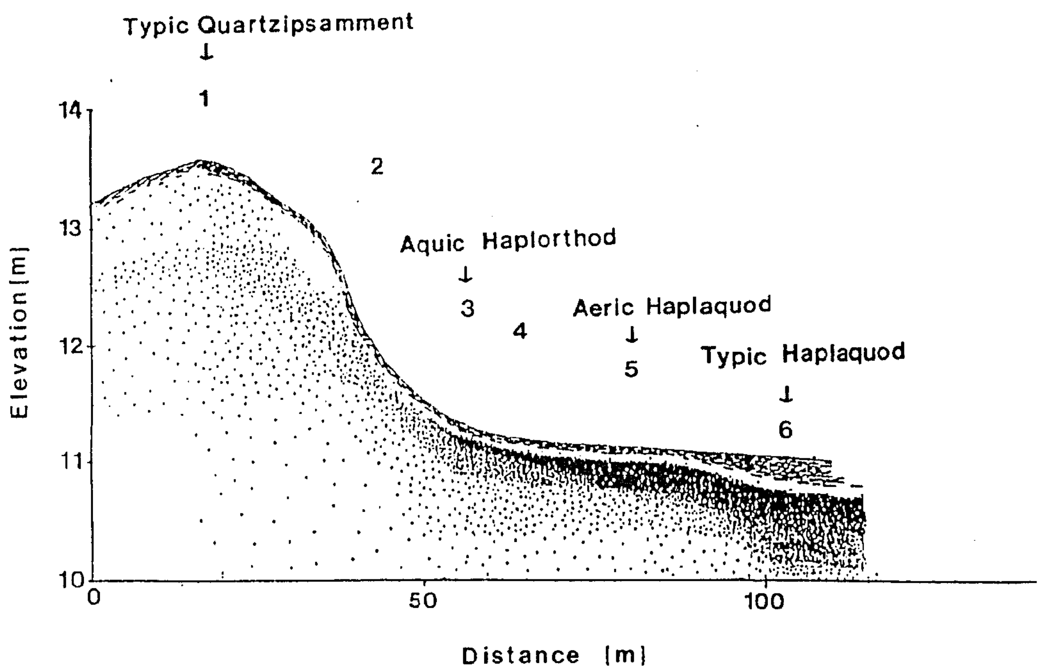


Figure 6. Locations and classification of pedons sampled along the transect at site 2.

dithionite citrate bicarbonate (Fanning, et al. 1970), and ammonium oxalate (McKeague and Day, 1966), and measured by atomic absorption spectroscopy. Pyrophosphate C was determined on the extracts with a Dohrmann DC 80 Carbon Analyzer. Duplicate extractions of each sample were made and reported as averages. Soil pH was measured using 1:1 soil/water ratio by weight. Whole soils were treated with NaF to estimate the reactivity of the soil (Method 8C1d, Soil Survey Staff, 1984). Extractable bases, Na, Ca, Mg, and K were removed with 1N NH_4OAC (pH 7.0) and measured by atomic absorption spectroscopy (Thomas, 1982). Extractable acidity was determined using $BaCl_2$-TEA at pH 8.2 (Thomas, 1982). CEC was reported as the sum of extractable bases and extractable acidity.

RESULTS AND DISCUSSION

Table 2 presents characterization data from four pedons sampled at Sites 1 and 2. These pedons were chosen because each one represents a different degree of spodic horizon development, ranging from no expression of spodic morphology to strongly expressed spodic morphology. They also represent a range of drainage classes from excessively to very poorly drained. Site 2, pedon 1 (2:1) showed no spodic horizon morphology and was excessively drained. Pedon 6 from Site 1 (1:6) should be considered a transitional soil both with respect to drainage and in

Table 2. Characterization data from four pedons selected to represent different degrees of spodic horizon expression in the two transects.

Pedon	Horizo	Depth (cm)	Fed	Fep	Feo	Ald	Alp	Alo	Ct	Cp	Fep+Alp/ %Clay	Cp+Alp/ %Clay	Fep+Alp/ Fed+Ald	CEC pH 8.2	ODOE	NaF pH	%Sand	%Silt	%Clay	BD
			g/kg																	g/cm3
1:1	Oe	6-0																		
	A	0-12	2.0	0.1	0.1	0.1	0.2	0.2	27.8	5.5	0.02	0.40	1.00	17.2	0.012	6.95	95.1	3.5	1.4	0.86
	E	12-21	0.2	0.1	0.0	0.0	0.0	0.0	4.4	2.2	0.02	0.19	1.00	9.5	0.010	7.45	93.6	5.2	1.2	1.57
	Bh	21-25	2.2	1.8	2.4	0.9	0.9	1.0	11.8	8.4	0.08	0.26	0.87	15.8	0.460	8.10	89.5	7.0	3.5	1.20
	Bhs	25-31	4.4	3.0	1.6	4.7	4.0	2.8	19.4	16.8	0.16	0.46	0.77	30.3	0.436	10.70	86.4	9.1	4.5	
	Bs	31-44	3.2	1.4	3.5	1.9	1.4	5.8	3.4	2.6	0.09	0.13	0.55	10.4	0.020	10.10	88.6	8.2	3.1	1.40
	BC	44-104	2.3	1.4	1.0	0.7	0.6	0.6	1.0	1.2	0.06	0.05	0.67	7.5	0.006	8.95	94.6	2.1	3.3	1.62
	C	104-12	0.3	0.1	0.0	0.1	0.2	0.7	0.1	0.1	0.02	0.02	0.75	2.0	0.001	8.40	98.0	0.4	1.6	1.62
1:3	Oe	5-0																		
	A	0-19	0.1	0.1	0.1	0.2	0.3	0.2	32.7	8.2	0.02	0.41	1.33	21.7	0.004	6.75	93.9	4.0	2.1	1.13
	E	19-53	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.8	0.00	0.01	0.00	0.0	0.001	7.80	95.6	3.6	0.8	1.58
	BE	53-58	0.0	0.1	0.0	0.5	0.8	0.6	8.2	6.0	0.02	0.12	1.80	7.6	0.148	7.63	81.8	12.6	5.6	1.82
	Bh	58-72	0.0	0.1	0.0	1.8	2.2	2.2	16.6	16.6	0.04	0.36	1.28	23.5	0.680	9.25	92.7	2.1	5.2	1.49
	Bhsm1	72-99	0.0	0.0	0.0	2.1	2.2	2.4	10.4	9.6	0.10	0.58	1.05	22.4	0.455	10.53	93.7	4.1	2.2	1.72
	Bhsm2	99-117	0.0	0.0	0.0	1.7	1.5	2.1	8.7	9.0	0.06	0.39	0.88	17.2	0.814	9.70	96.5	0.9	2.7	1.68
	Bhs	117-17	0.0	0.0	0.0	0.8	0.7	0.8	6.4	7.0	0.05	0.54	0.88	9.2	0.354	9.25	98.0	0.6	1.4	
	Bs	170-22	0.0	0.0	0.0	0.4	1.2	0.6	3.4	3.6	0.08	0.33	3.00	6.3	0.170	8.95	98.1	0.5	1.5	
	BC	220-25	0.0	0.0	0.0	0.3	1.6	0.5	1.9	2.4	0.17	0.43	5.33	2.6	0.068	9.23	98.0	1.1	0.9	
	C	255-28	0.0	0.0	0.0	0.4	1.4	0.8	1.8	2.1	0.05	0.12	3.50	0.0	0.028	9.62	95.2	1.9	2.9	
	2C2	285-29	0.1	0.2	0.0	1.2	3.2	1.8	4.1	3.4	0.03	0.07	2.62	4.6	0.044	10.02	74.3	15.6	10.1	
1:5	Oe	6-0																		
	A	0-22	0.3	0.2	0.2	0.3	0.6	0.4	21.1	7.2	0.04	0.34	1.33	15.3	0.014	6.95	92.8	5.0	2.3	1.24
	E	22-50	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.0	0.00	0.07	0.00	4.9	0.008	7.70	93.5	5.1	1.4	1.57
	Bh1	50-58	0.1	0.1	0.1	2.7	4.4	3.2	35.4	25.7	0.04	0.24	1.61	35.9	0.801	7.82	80.8	6.6	12.6	1.30
	Bhsm	58-81	0.1	0.2	0.2	4.8	7.5	5.5	28.0	25.0	0.11	0.47	1.57	28.4	0.748	11.14	84.9	8.2	6.9	1.48
	Bh2	81-114	0.1	0.0	0.0	0.7	3.7	0.8	9.5	7.7	0.09	0.29	4.63	9.0	0.221	7.65	95.3	0.7	4.0	1.58
	Bh3	114-16	0.0	0.0	0.0	0.4	0.8	0.5	6.2	5.5	0.04	0.32	2.00	4.4	0.110	7.95	97.5	0.6	1.9	
	Bhs	164-20	0.0	0.0	0.0	0.4	0.7	0.5	4.2	4.2	0.04	0.25	1.75	2.8	0.101	8.45	97.8	0.2	2.0	
	Bs	209-25	0.0	0.0	0.0	0.6	0.8	0.7	4.2	4.4	0.04	0.25	1.33	5.4	0.132	9.33	97.8	0.1	2.1	
	BC	254-29	0.0	0.0	0.0	0.2	0.6	0.4	1.8	2.2	0.04	0.14	3.50	0.7	0.040	9.05	97.9	0.1	2.0	

Table 2 (continued). Characterization data from four pedons selected to represent different degrees of spodic horizon expression in the two transects.

Pedon	Horizo	Depth (cm)	Fed	Fep	Feo	Ald	Alp	Alo	Ct	Cp	Fep+Alp/ %Clay	Cp+Alp/ %Clay	Fep+Alp/ Fed+Ald	CEC pH 8.2	ODOE	NaF pH	%Sand	%Silt	%Clay	BD
			g/kg																	g/cm3
1:6	Oe	4-0																		
	A	0-6	0.2	0.1	0.1	0.0	0.2	0.0	15.0	3.5	0.02	0.30	1.50	5.0	0.011	7.15	96.2	2.6	1.2	
	E	6-14	0.3	0.2	0.1	0.0	0.2	0.0	6.4	2.0	0.03	0.18	1.33	0.5	0.017	7.60	95.6	3.2	1.2	1.49
	Bw	14-46	2.9	2.5	1.2	2.4	4.2	2.8	6.8	5.0	0.19	0.26	1.26	8.8	0.052	10.45	91.5	4.9	3.6	1.32
	BC1	46-91	1.4	1.0	0.3	0.6	1.1	0.6	1.3	1.0	0.06	0.06	1.05	0.5	0.008	9.05	91.9	4.4	3.7	1.52
	BC2	91-116	1.2	1.2	0.6	0.3	1.1	0.4	0.7	0.6	0.10	0.07	1.53	0.9	0.008	9.00	96.8	0.8	2.4	
	BC3	116-16	0.5	0.3	0.2	0.6	0.4	0.2	0.0	0.4	0.04	0.05	0.64	0.0	0.004	8.53	97.7	0.6	1.7	
	C	166-17	0.3	0.1	0.1	0.0	0.4	0.3	0.0	0.4	0.03	0.04	1.67	0.0	0.004	8.48	98.1	0.0	1.9	
1:7	Oe	0-4																		
	A	0-11	0.1	0.1	0.1	0.0	0.2	0.1	27.8	3.6	0.05	0.62	3.00	8.0	0.006	7.30	95.8	3.6	0.6	
	E	11-28	0.1	0.1	0.0	0.0	0.1	0.0	2.2	1.2	0.02	0.13	2.00	0.0	0.007	7.80	97.3	1.7	1.0	1.47
	Bh	28-34	3.8	3.6	3.7	2.4	2.4	2.6	18.3	13.7	0.14	0.37	0.97	19.3	0.456	9.68	90.0	5.7	4.3	1.24
	Bs	34-40	2.0	1.4	1.4	3.0	3.1	4.3	8.2	7.5	0.15	0.37	0.90	12.2	0.134	11.05	92.5	4.6	2.9	1.25
	BC1	40-59	1.8	1.2	0.4	1.0	1.6	1.2	1.3	1.5	0.07	0.07	1.00	2.6	0.008	9.45	92.3	3.4	4.3	1.54
	BC2	59-63	0.4	1.6	0.9	0.4	1.3	0.5	1.3	1.4	0.12	0.11	3.63	1.5	0.008	8.90	97.4	0.3	2.4	1.66
2:1	Oe	1-0																		
	A1	0-9	0.4	0.2	0.2	0.1	0.2	0.1	7.3	1.1	0.01	0.02	0.80	3.27	0.010	7.70	91.8	1.5	6.7	
	A2	9-20	1.6	0.6	0.5	0.3	0.5	0.4	4.2	1.4	0.01	0.03	0.58	3.31	0.008	8.12	90.9	1.5	7.6	1.42
	BA1	20-44	2.2	0.7	0.4	0.8	0.8	0.9	2.2	0.8	0.02	0.02	0.50	2.61	0.013	9.70	90.0	1.3	8.7	1.44
	BA2	44-69	3.0	0.7	0.3	0.6	0.6	0.5	2.2	0.8	0.02	0.02	0.36	2.19	0.017	6.90	90.6	0.8	8.6	
	Bt	69-98	4.5	1.1	0.5	0.8	2.6	0.8	1.0	0.6	0.04	0.03	0.70	4.72	0.020	9.12	88.2	2.3	9.5	1.57
	CB1	98-149	1.0	0.2	0.1	0.1	0.4	0.2	0.3	0.2	0.05	0.05	0.55	1.12	0.011	7.95	97.7	1.0	1.3	1.66
	CB2	149-19	1.2	0.3	0.1	0.1	0.5	0.3	0.3	0.3	0.06	0.06	0.62	0.00	0.008	8.05	97.5	1.2	1.3	1.66
	C1	194-24	1.2	0.3	0.1	0.1	0.3	0.2	0.3	0.3	0.04	0.04	0.46	0.45	0.008	8.00	97.6	1.2	1.2	
	C2	249-28	1.0	0.2	0.1	0.1	0.3	0.2	0.0	0.3	0.04	0.04	0.45	0.00	0.007	8.10	97.7	0.9	1.4	
	C3	284-31	1.3	0.4	0.4	0.1	0.3	0.2	0.4	0.3	0.05	0.04	0.50	0.00	0.009	8.20	97.5	1.0	1.5	
	C4	313-35	1.1	0.4	0.3	0.1	0.3	0.2	0.2	0.3	0.04	0.04	0.58	0.00	0.008	8.20	97.9	0.5	1.6	

Table 2 (continued). Characterization data from four pedons selected to represent different degrees of spodic horizon expression in the two transects.

Pedon	Horizo	Depth (cm)	Fed	Fep	Feo	Ald	Alp	Alo	Ct	Cp	Fep+Alp/ %Clay	Cp+Alp/ %Clay	Fep+Alp/ Fed+Ald	CEC pH 8.2	ODOE	NaF pH	%Sand	%Silt	%Clay	BD
			g/kg																	g/cm3
2:3	Oe	4-0																		
	A	0-7	1.3	0.8	1.2	0.3	0.4	0.3	11.9	2.6	0.04	0.11	0.92	7.29	0.047	7.75	92.9	4.4	2.7	
	Ap	7-15	1.8	1.2	1.8	0.7	1.1	0.7	11.8	4.9	0.08	0.22	0.92	9.07	0.083	8.10	92.5	4.8	2.8	
	Bh	15-26	3.3	2.4	2.8	3.2	4.8	4.5	13.4	7.7	0.20	0.35	1.11	12.79	0.136	11.05	89.0	7.4	3.6	1.08
	Bs	26-39	4.2	2.4	2.9	2.1	3.0	3.6	4.8	2.8	0.16	0.17	0.86	6.25	0.032	10.65	89.0	7.6	3.4	1.29
	BC1	39-53	3.2	1.7	1.9	1.3	1.8	1.8	1.6	0.8	0.04	0.03	0.78	4.39	0.012	9.70	86.2	4.7	9.1	1.48
	BC2	53-91	6.6	2.9	1.1	1.9	5.5	1.0	1.2	0.4	0.08	0.06	0.99	5.80	0.011	9.55	85.1	4.5	10.4	1.53
	C1	91-105	0.4	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.05	0.02	0.75	0.00	0.007	8.05	99.0	0.3	0.7	
2:5	Oe	5-0																		
	A	0-10	0.1	0.1	0.1	0.0	0.1	0.1	13.3	2.9	0.02	0.24	2.00	8.07	0.010	7.15	93.8	5.0	1.2	1.55
	E	10-17	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.9	0.00	0.06	0.00	1.82	0.008	7.53	92.9	5.7	1.5	1.70
	Bh	17-30	0.3	0.4	0.2	5.6	8.1	5.9	34.2	30.8	0.11	0.49	1.44	37.80	1.132	11.25	85.7	6.4	7.9	1.20
	Bhs	30-43	0.5	0.3	0.2	2.6	3.6	3.0	9.0	8.3	0.10	0.29	1.26	12.96	0.186	11.37	89.6	6.3	4.1	1.53
	BC	43-80	0.9	0.6	0.2	0.8	2.6	1.1	2.0	1.9	0.07	0.10	1.88	3.45	0.024	10.58	91.6	4.0	4.4	1.64
	C1	80-100	0.1	0.2	0.0	0.4	1.8	0.8	1.0	0.8	0.07	0.09	4.00	2.98	0.013	10.35	96.5	0.7	2.8	
	C2	100-14	0.0	0.0	0.0	0.1	0.8	0.4	0.7	0.7	0.04	0.08	8.00	1.12	0.010	9.95	96.7	1.3	2.0	
	C3	145-18	0.0	0.0	0.0	0.1	0.5	0.4	0.6	0.7	0.02	0.05	5.00	1.49	0.010	9.55	97.1	0.4	2.5	
	2Ab	185-19	0.0	0.2	0.0	1.8	3.1	1.8	16.4	7.7	0.05	0.15	1.83	10.46	0.065	10.75	78.8	14.0	7.3	
	2AC	195-22	0.1	0.1	0.0	0.2	0.9	0.8	1.4	1.6	0.04	0.09	3.33	4.93	0.018	9.80	96.5	0.7	2.9	
2:6	Oe	5-0																		
	A	0-23	0.2	0.2	0.2	0.4	0.8	2.7	43.0	6.9	0.02	0.16	1.67	35.85	0.020	6.80	88.6	6.8	4.7	1.15
	E	23-31	0.0	0.0	0.0	0.0	0.0	0.1	4.0	2.6	0.00	0.16	0.00	9.69	0.008	7.55	92.4	5.9	1.7	
	Bh	31-45	0.1	0.1	0.1	6.1	6.4	8.8	36.2	19.7	0.09	0.37	1.05	41.89	0.770	11.50	84.0	8.9	7.1	1.24
	BC/Bh	45-75	0.2	0.1	0.1	3.8	4.2	6.3	13.4	12.2	0.10	0.38	1.08	20.95	0.184	10.95	86.2	9.5	4.3	1.61
	BC2	75-105	0.0	0.1	0.0	0.4	1.4	1.0	1.9	1.6	0.06	0.13	3.75	4.39	0.035	10.25	97.3	0.4	2.3	
	BC3	105-14	0.0	0.0	0.0	0.0	0.9	0.4	0.6	0.6	0.07	0.11	0.00	3.48	0.010	9.45	97.9	0.8	1.3	
	C1	140-17	0.0	0.2	0.0	0.1	2.5	0.1	0.8	0.7	0.26	0.33	27.00	2.16	0.010	9.52	98.4	0.6	1.0	
	C2	175-20	0.0	0.0	0.0	0.0	1.4	0.1	0.3	0.5	0.11	0.15	0.00	0.00	0.010	8.45	95.5	3.3	1.2	

the expression of spodic horizon morphology. There were zones of slight spodic horizon morphology in the Bw, and the soil would be considered moderately well drained (water table ranging from 48 to 114 cm below the surface). Pedons 2:5 and 1:5 had strong spodic horizon morphology, however pedon 2:5 was slightly better drained than pedon 1:5.

Physical Characteristics

All of the soils had sand or loamy sand particle size distribution. Particle size data suggested that there may be clay translocation in all of the soils, but the greatest clay accumulation was in the Bh horizons of the wetter soils, pedons 2:5 and 1:5. In pedon 1:5, the wettest soil, the clay content increased sharply to 126 g/kg in the Bh horizon and decreased in the lower horizons to 21 g/kg. Other studies of Haplaquods have reported clay accumulations in the spodic horizon, although not as great as in these soils (Lee, et al., 1988b; Zelazny and Carlisle, 1971). In the field, an argillic horizon was described in excessively drained pedon 2:1; however, laboratory analysis revealed that the clay increase in the B horizon was not sufficient to meet the criteria of an argillic horizon. Clay illuviation was, nevertheless, apparent.

The soils with spodic morphology showed a different pattern of bulk density values than pedon 2:1 which has no spodic expression. The bulk density in pedon 2:1 increases gradually from 1.42 Mg/m^3 in the A horizon to 1.66 Mg/m^3 in the C horizon. In pedons 2:5 and 1:5, the bulk density values increased slightly in the E horizons and dropped in the Bh horizons to between 1.20 Mg/m^3 and 1.30 Mg/m^3. The Bh horizons have greater amounts of organic carbon than the other horizons, which may account for the lower bulk densities of these horizons.

Chemical Characteristics

The pH values were acidic to extremely acidic. They were lowest in the surface horizons (3.8) and increased with depth to approximately 4.6. The acidic conditions at the surface may be caused by decomposition of organic matter and subsequent release of organic acids.

The soil pH in NaF was measured in order to estimate the presence of paracrystalline and noncrystalline materials in the soil which have structural hydroxyls capable of being replaced by fluoride. At the surface fluoride ions displace hydroxyls, and these liberated hydroxyls increases the solution pH. More reactive materials release greater amounts of hydroxyls (Perrott, et al., 1976). This is common for in spodic horizons and in andic materials (Kimble, et al., 1990). For example, Alvarado and Buol (1985) reported that soils with NaF pH >10.6 have the greatest potential for P fixation. The highest pHs were observed in the spodic horizons where values of 10.5 to 11 were measured. Though these results indicate the presence of paracrystalline or noncrystalline materials, it is believed that there is probably no proto-imogolite nor imogolite in these soils as other data indicated that there was virtually no extractable Si in the soils. The high values observed here are thought to be related to the presence of Al compounds abundant in the spodic horizons of these soils.

Cation exchange capacity was greatest in horizons with high organic carbon contents. Spodic horizons had the highest CEC, 30-35 cmol(+)/kg. Substantial amounts of organic matter and noncrystalline materials have been found to contribute to high CEC in spodic horizons (Yuan, 1968). The pH dependent nature of negative charges in spodic horizons in Haplaquods dominated by organic C and Al has been demonstrated by Holzhey, et al. (1975)

Carbon

One of the most obvious differences among the soils in this topo-hydrosequence is the distribution of organic carbon in the profiles (Fig. 7). The wetter soils (pedons 2:5, 1:5) had more organic carbon in the surface horizons than the better drained soils (pedons 2:1, 1:6). The

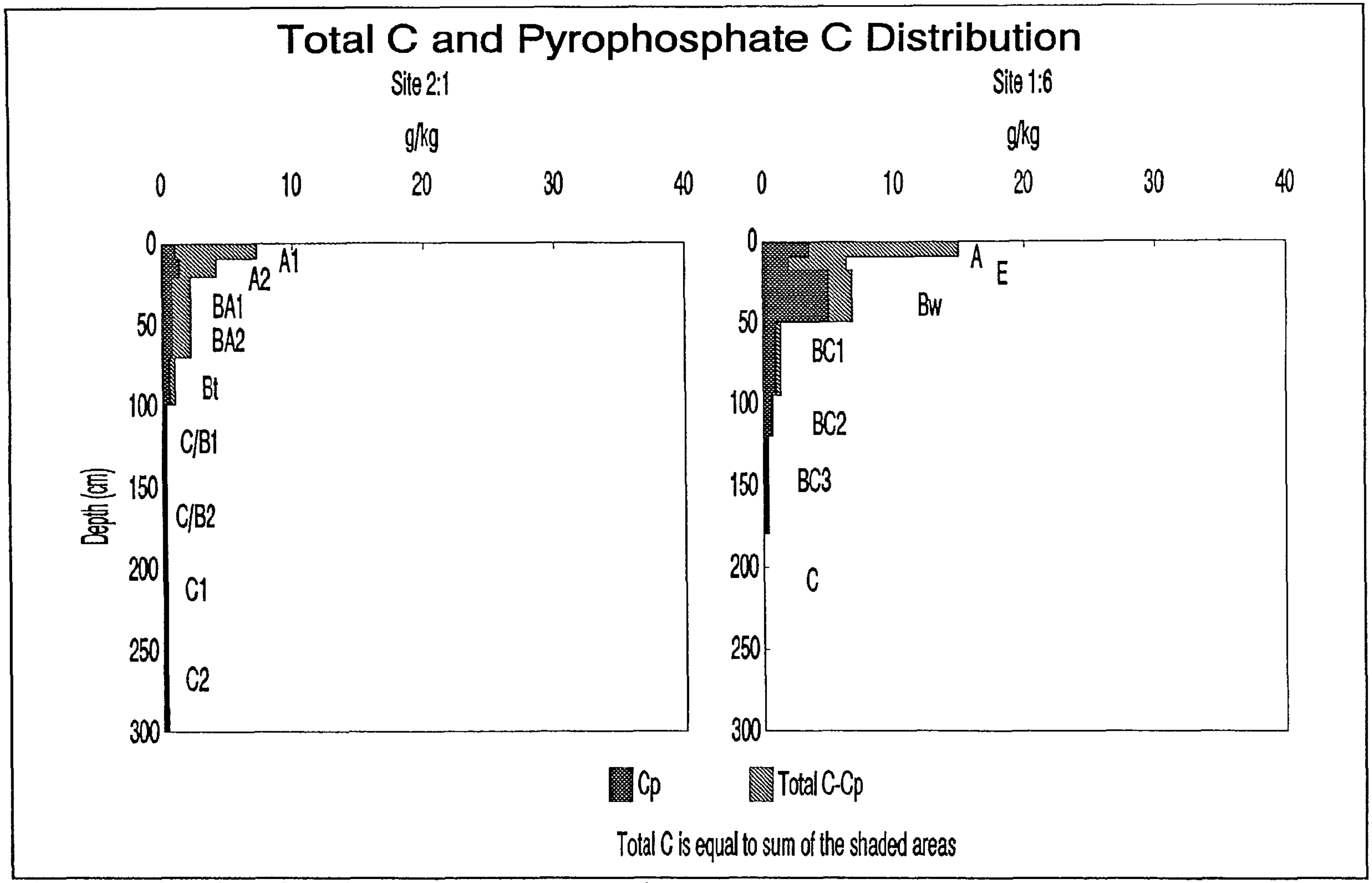


Figure 7a. Distribution of total organic C and pyrophosphate extractable C in four pedons selected to represent degrees of spodic horizon expression in the two transects.

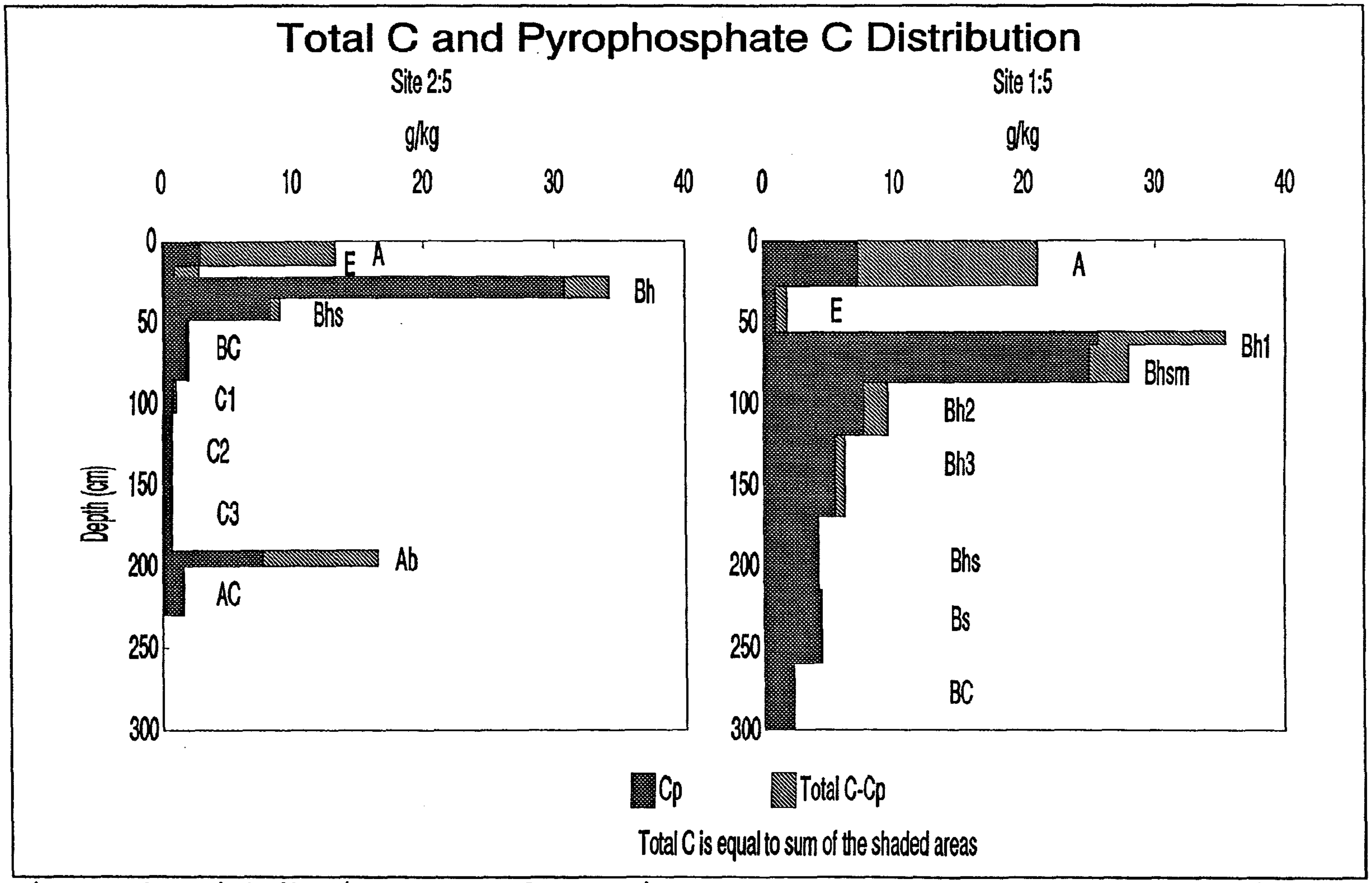


Figure 7b. Distribution of total organic C and pyrophosphate extractable C in four pedons selected to represent degrees of spodic horizon expression in the two transects.

amount of organic C (21.1 g/kg) in the A horizon of the very poorly drained pedon 1:5 was almost triple the amount found in the A horizon of excessively drained pedon 2:1 (7.7 g/kg), and the A horizon was twice as thick (22 cm) as the A horizon in pedon 2:1 (9 cm). The surface horizons of better drained soils are better aerated than the soils in low landscape positions where the water table is within several cm of the soil surface or higher during wet seasons of the year. Because of the capillary fringe, which in sandy soils is estimated to be 10-15 cm (Soil Survey Staff, 1990), the surface horizons may remain wet for even longer periods than water table levels indicate. The aerobic conditions of the surface horizons in pedons 2:1 and 1:6 probably favor more rapid decomposition of organic matter than the more anaerobic conditions of pedons 2:5 and 1:5. Also, there may be greater biomass production in the wetter soils in comparison to the dryer or better drained areas which commonly become droughty during the dry summer months.

A pattern of carbon illuviation is evident in the soils with spodic horizon morphology. Pedons 2:5 and 1:5 had 10-20 g/kg more organic C in the spodic horizons than in the surface horizons. The portion of organic C that was pyrophosphate extractable was greater in spodic horizons than surface horizons. Pedon 1:6, which had slight spodic horizon morphology, had 5.0 g/kg extractable C, whereas the better developed spodic horizons in pedons 2:6 and 1:5 had five to six times that amount (25.8-30.8 g/kg). Similar trends in carbon accumulation in the spodic horizon of Haplaquods have been reported by Holzhey, et al., (1975) and Lee, et al., (1987). Sodium pyrophosphate is thought to extract the fraction of organic carbon which associated with metal organic complexes, and therefore mobile in the soil water (Buurman, 1985). These results suggest that organic C was illuviated from the surface horizons and accumulated in the spodic horizons, and that this process is most evident in the lowest landscape positions where the water table is closer to the soil surface.

Iron

Extractable iron was present in the better drained soils, but in the wetter soils there were only trace amounts (Fig.8). In pedon 2:1, the excessively drained soil, there was almost 5.0 g/kg DCB extractable Fe in the B horizon. In pedon 1:6, a slightly wetter soil with slight spodic horizon morphology, there was less Fe and most of it was pyrophosphate extractable. Pyrophosphate is a fairly selective extractant for organic metal complexes of iron and aluminum (Farmer, et al., 1983), and a large portion of the iron in pedon 1:6 appears to be bound in organic-metal complexes. The wetter soils (2:5,

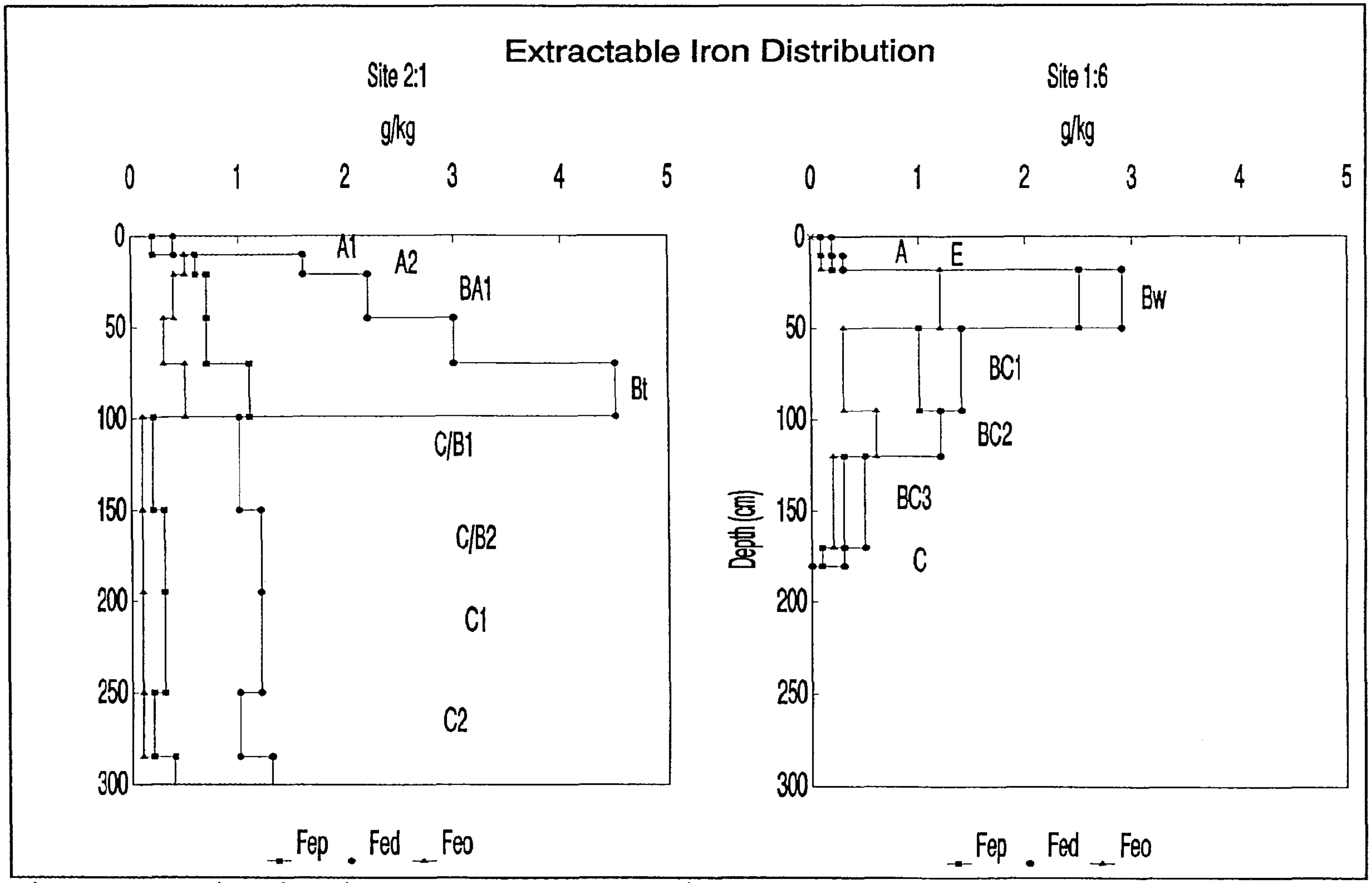


Figure 8a. Distribution of extractable Fe in four pedons selected to represent degrees of spodic horizon expression in the two transects.

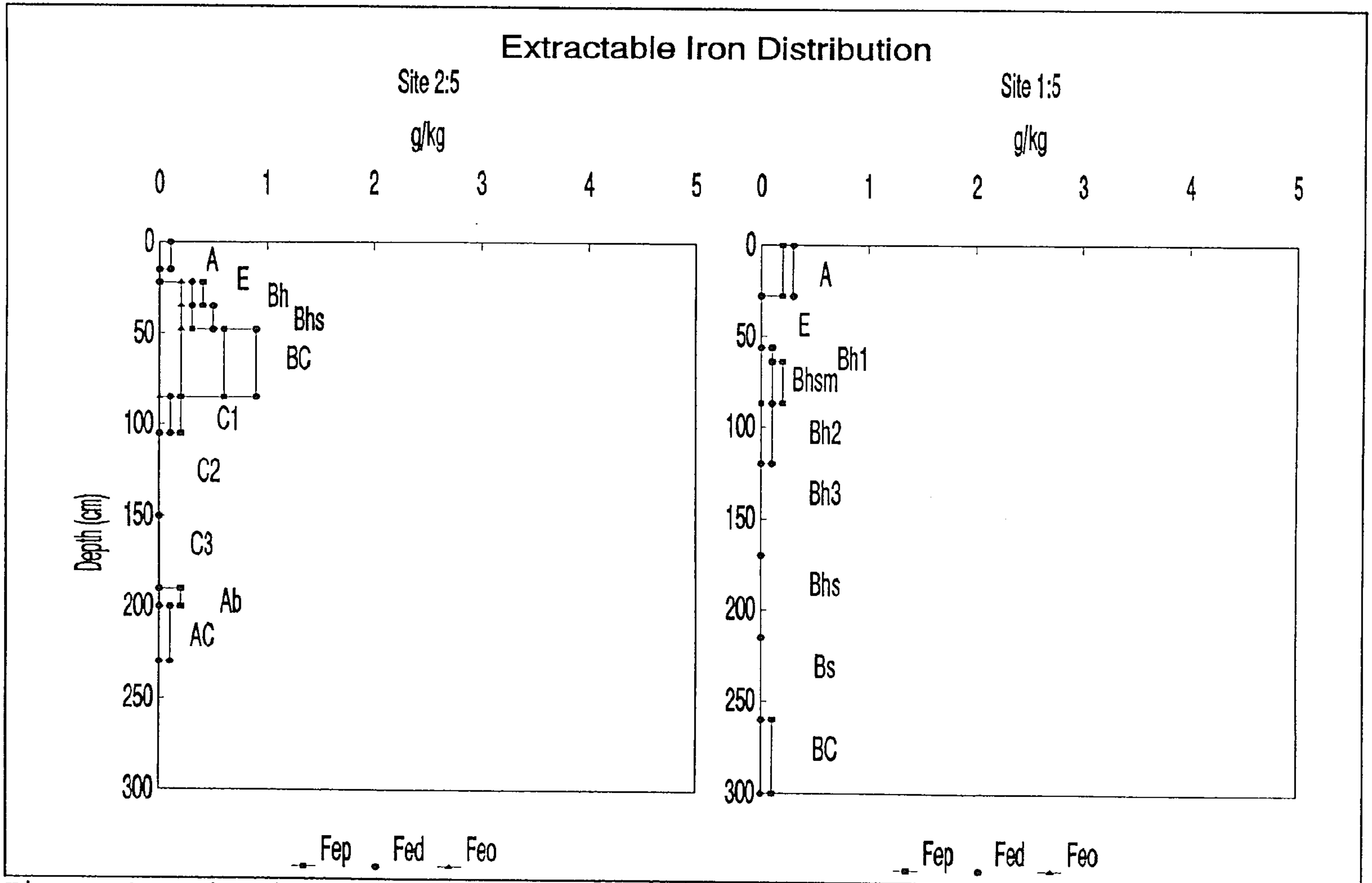


Figure 8b. Distribution of extractable Fe in four pedons selected to represent degrees of spodic horizon expression in the two transects.

1:5) had only traces of extractable iron. The brown or reddish brown colors commonly associated with the Bhs and Bs horizons must, therefore, be due to organic materials or complexes or organic matter and Al, and not to the presence of extractable iron. The low levels of extractable iron are similar to those reported in other studies of Haplaquods (Brandon, et al., 1971; Holzhey, et al., 1975; Lee, et al.,1988).

The small amounts of extractable Fe in the wetter soils may be attributed to the extended anaerobic conditions in these soils and to the highly permeable sandy sediments. Because these soils are at or near saturation for extended periods, it is expected that ferric iron is reduced to ferrous iron and removed with the percolating ground water. These soils seem to fit the Ground-Water Gley Model in a recharge wetland situation as described by Fanning and Fanning (1989).

Aluminum

In general, pyrophosphate extracted more Al than the other extractants (Fig.9). All of the soils had evidence of accumulation of extractable Al in the subhorizons, and the greatest amount was in the spodic horizons of the wetter soils. The Bt horizon of pedon 2:1 had 2.6 g/kg pyrophosphate extractable Al; the amount in the Bh of 2:5 was triple that amount (8.1 g/kg). Because the level of

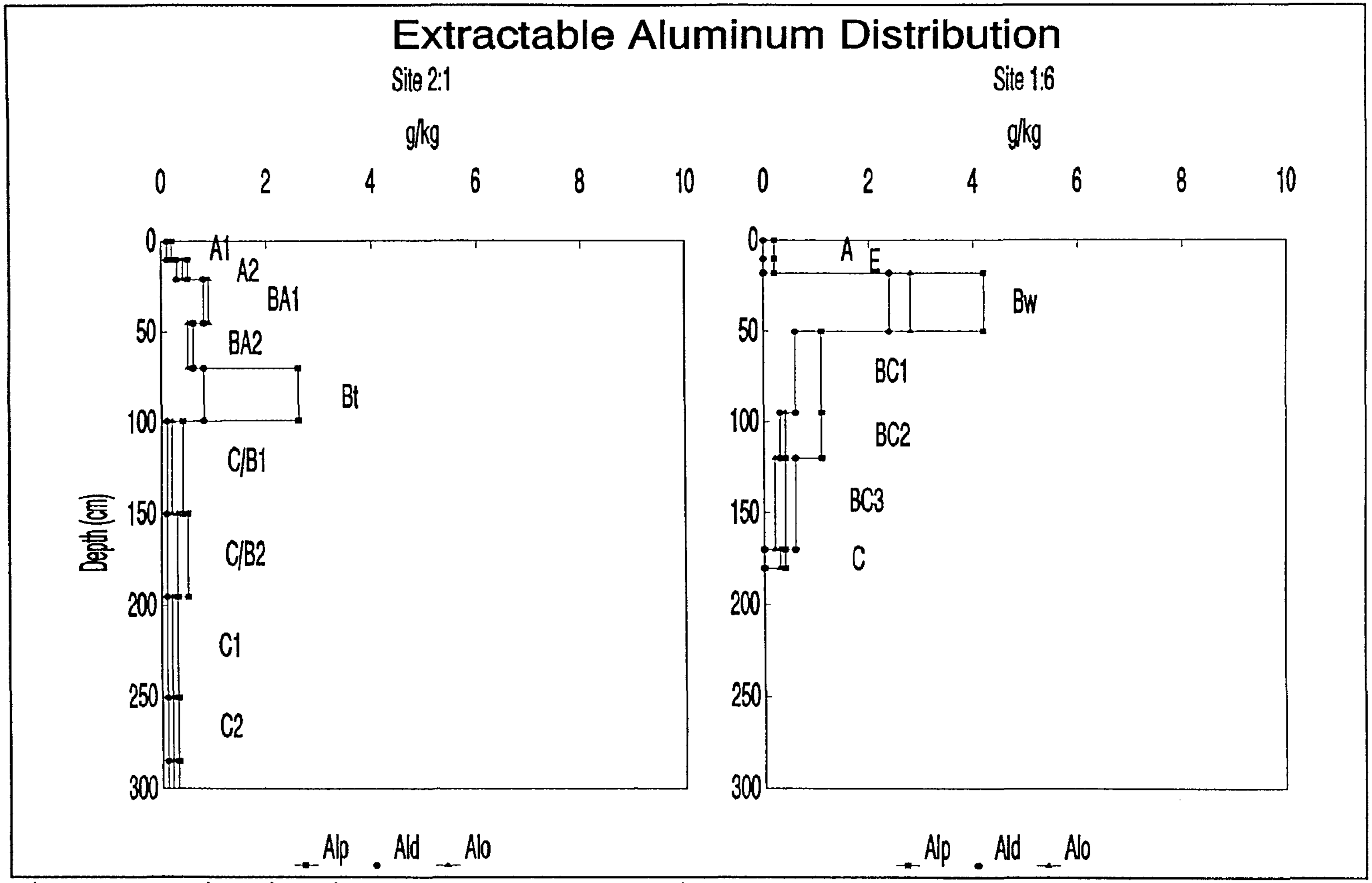


Figure 9a. Distribution of extractable Al in four pedons selected to represent degrees of spodic horizon expression in the two transects.

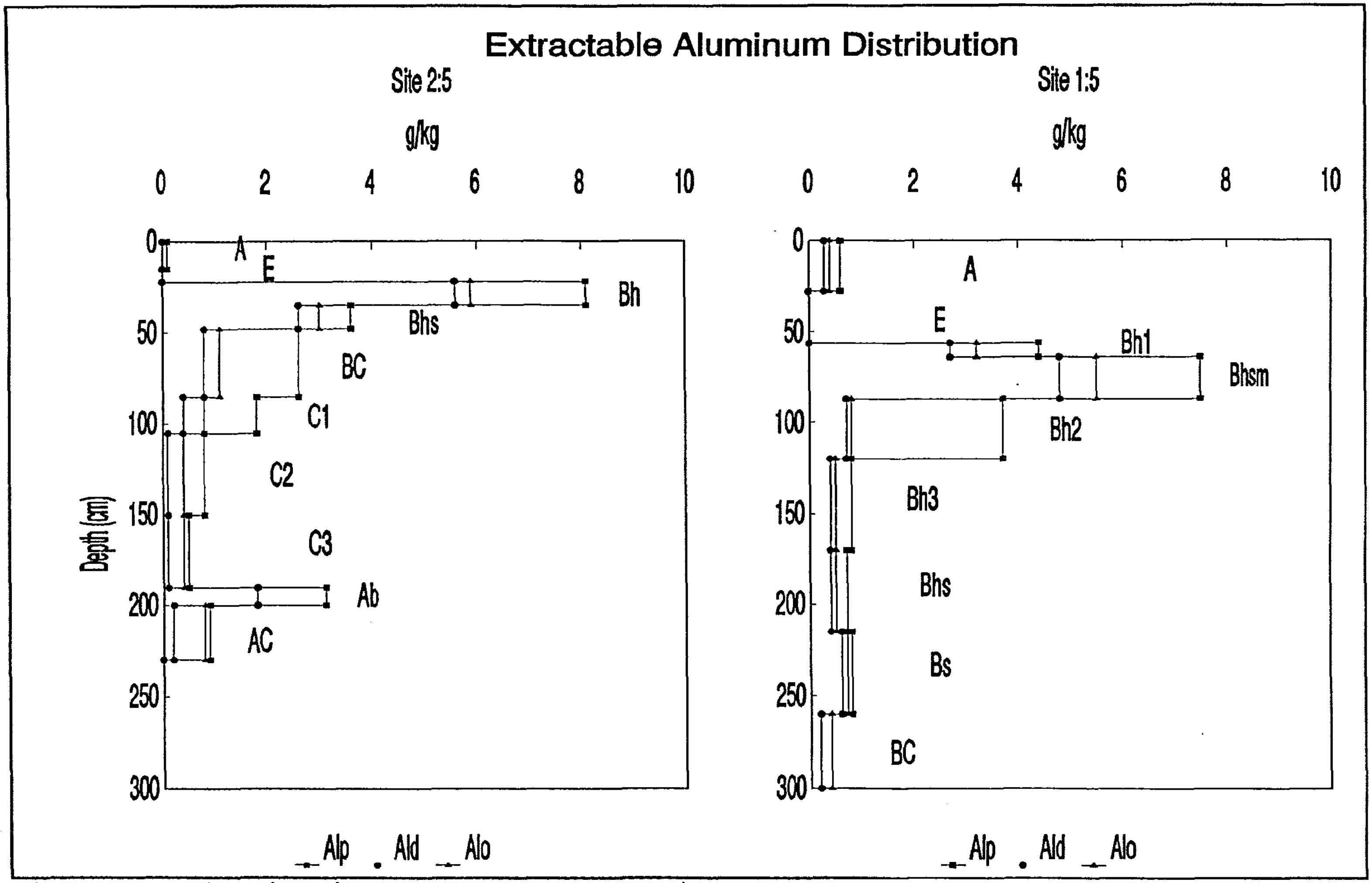


Figure 9b. Distribution of extractable Al in four pedons selected to represent degrees of spodic horizon expression in the two transects.

pyrophosphate extractable Al is greater than the other extractants, it can be inferred that Al is predominantly in an organically bound form. Formation of imogolite and proto-imogolite allophane in spodic horizons has been suggested by Farmer, et al., (1980) as a process in podzolization. There does not seem to be evidence of these phases in these soils. The predominance of pyrophosphate extractable aluminum suggests that extractable aluminum is in an organic rather than inorganic form, and the virtual absence of extractable Si further suggests that these phases have not formed in these Aquods.

Classification

Figures 5 & 6 show the location of the soils along the transects at Sites 1 and 2 and the subgroup classification of each pedon. The classification of the nine pedons sampled is also presented in Table 3. All of the soils were in sandy, siliceous, mesic families. With the exception of the excessively drained soil at the summit of Site 2 (2:1, and also 2:3), all of the soils met the criteria for spodosols. The main difference among the soils was depth to the water table and the resultant drainage conditions. The difference in the degree of wetness is reflected in the classification of the soils.

Table 3. Classification of the nine pedons sampled during this study.

Pedon #	Classification
1:1	Aquic Haplorthod
1:3	Typic Haplaquod
1:5	Typic Haplaquod
1:6	Entic Haplorthod
1:7	Aeric (Entic) Haplaquod
2:1	Typic Quartizipsamment
2:3	Aquic Haplorthod
2:5	Aeric Haplaquod
2:6	Typic Haplaquod

Pedon 1, in the summit position at Site 2, appeared to have a Bt horizon in the field, but particle size analysis revealed that clay increase in the horizon was insufficient to be an argillic horizon, and the soil was classified as Typic Quartzipsamment. Pedon 6 at Site 1 (1:6) and Pedon 3 at Site 2 (2:3) are examples of transitional soils which have weak spodic morphology. Pedon 1:6 had 5-10% dark zones in the Bw, and pedon 2:3 had a continuous, though very weakly expressed, thin spodic horizon. Their surface horizons are freely drained, but the subhorizons (below 48 cm in pedon 1:6 and 19 cm in pedon 2:3) are saturated by a fluctuating water table for part of the year. Surprisingly, both met the spodic horizon criteria, however they met the chemical criteria only because values were rounded to one significant figure, as suggested by Soil Survey staff (personal communication). Though the spodic horizons are weakly expressed, morphologically and chemically, they have measurable amounts of Fe and Al which qualify them as Orthods. One of the spodic horizon criteria is that the Fep+Alp/%Clay must be 0.2% or greater. In the Bs horizon of Pedon 2:3, that value is 0.16%. If the value is rounded to one decimal place, the soil meets the spodic horizon criteria, and it is classified as an Aquic Haplorthod, whereas if the value were not rounded, the soil would be a Spodic Quartzipsamment. Similarly, the Bw in Pedon 1:6 meets spodic horizon criteria if the Fep+Alp/%Clay value (0.19%) is rounded to one decimal place, and it is classified as an Entic Haplorthod.

In the lowest landscape positions (Pedons 2:5, 2:6, 1:3, and 1:5), the soils are saturated throughout their sola by the seasonally high water table for part of the year. There has been some discussion concerning the differentiation of andic and spodic properties. Most of the problem appears to be associated with Orthods. Though the bulk density values were low in the Bh horizons, they were not low enough to meet bulk densities ($\leq$90 g/cm^3) criterion for andic materials. Thus the higer bulk densities of spodic horizons in soils of this study would seem to preclude a problem with Aquods.

The presence of an umbric epipedon distinguishes Typic Haplaquods from Aeric Haplaquods. An umbric epipedon develops in the soils in the lowest landscape positions (Pedons 2:6, 1:3, and 1:5) where wetter, less aerobic conditions favor slower organic matter decomposition than in slightly better drained positions (Pedon 2:5). Pedon 2:5, which has an ochric epipedon, is an Aeric Haplaquod, and Pedons 1:3, 1:5 and 2:6, which have umbric epipedons, are Typic Haplaquods. Interestingly, the thickest spodic horizons were at Site 1. We were not able to sample between pedons 3 and 5 at Site 1 because the water table level was too close to the surface (within 19 cm at the lowest point during the year). The spodic horizon in the Typic Haplaquod at Site 2 was 44 cm thick as compared to 162 and 204 cm thick at Site 1.

Proposals to amend the criteria for spodic horizon definition have suggested the use of the optical density of oxalate extracts (ODOE) to define Spodosols (Rourke and Kimble, 1989). The procedure assumes that the optical density of the oxalate extract at 320 nm is due to extracted fulvic acid (Daly, 1982); the ODOE value must be greater than 0.25 to meet the spodic horizon criterion. Interestingly, the transitional soils, Pedons 1:6 and 2:3, which barely met the current chemical criteria, do not meet the proposed ODOE value. The soils which were classified as Aeric and Typic Haplaquods did meet the proposed criteria. The ODOE method, used in addition to classical methods, could be very helpful for separating intergrades.

CONCLUSION

In the sandy, late Pleistocene and early Holocene sediments of the Delmarva Peninsula, spodic horizons form in soils in the wetter areas of the landscape. The thickest spodic horizons are in Aeric and Typic Haplaquods which form in areas where the water table is ponded or close to the surface during the year. The spodic horizons contain large amounts of total organic C, pyrophosphate extractable C, and pyrophosphate extractable Al, but only trace amounts of extractable Fe. The slightly better drained soils (Entic Haplorthods and Aquic Haplorthods) were freely drained in the surface horizons and had spodic horizons which contained both extractable Fe and Al. The Typic Quartzipsamment was the best drained (excessively) soil and had no evidence of spodic horizon development. Spodic horizons develop in landscape positions where the seasonally fluctuating ground water table is closer to the soil surface, and it appears that the seasonally fluctuating ground water may be a mechanism for spodic horizon formation in these sandy sediments.

ESTIMATES OF PEDOGENESIS IN SOILS WITH SPODIC CHARACTERISTICS IN MARYLAND

Aeric and Typic Haplaquods form in the U.S. in sandy sediments in areas with shallow fluctuating ground water. Studies of Aeric and Typic Haplaquods report that aluminum dominates the spodic horizon, and unlike better drained Spodosols, there is very little extractable iron (Brandon, et al., 1970; Holzhey, et al, 1975; Lee, et al., 1988). Organic carbon and pyrophosphate extractable carbon also accumulate in the spodic horizon, and in some instances, the amounts are greater than in the surface horizon (Lee, et al., 1987; Condron,1990). Based on a study of spodic horizon thickness along a transect, Daniels, et al. (1975) suggested that seasonal fluctuations of shallow ground water tables play an important role in the development of spodic horizons in Haplaquods.

On the Lower Delmarva Peninsula, siliceous, mesic, Aeric Haplaquods (Atsion) and Typic Haplaquods (Berryland), form in lower, more poorly drained landscape positions of late Pleistocene and early Holocene eolian deposits. In a study of two topo-hydrosequences in the Pocomoke State Forest, spodic horizons in Aeric and Typic Haplaquods were found to be 26-204 cm thick and to contain more extractable aluminum, organic carbon, and pyrophosphate extractable carbon than better drained soils on the landscape (Condron, 1990). Depletion of feldspars has been found in surface horizons of some Spodosols (McKeague and Brydon, 1970). We hypothesize that a source of aluminum accumulated in the spodic horizons at the two research sites was primary alumino-silicate minerals in the surface horizons which had been weathered, resulting in the release of Al. The objective of this study was to examine the distribution of aluminum phases in soils along the two topo-hydrosequences and reconstruct the net losses or gains of various soil constituents during pedogenesis.

MATERIALS AND METHODS

Site Description

Soils were studied along two topographic transects in the Pocomoke State Forest on the Lower Eastern Shore of Maryland. Numerous observations were made and five pedons were sampled along a transect approximately 200 m in length at Site 1. Four pedons were sampled along a transect approximately 100 m long at Site 2 (Figs 10 & 11). The parent materials are sandy eolian sediments which were deposited approximately 10,000 years ago (Condron, 1990). The drainage conditions along the dunal topography ranged from excessively drained in the summit position to very poorly drained in the toeslope position where the water table is at or near the surface for extended periods in the year. The predominant vegetation is loblolly pine

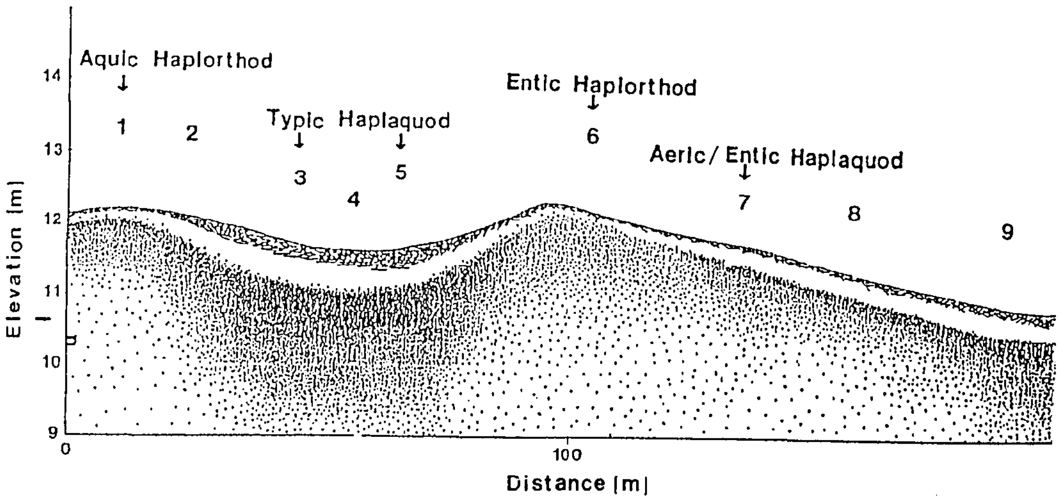


Figure 10. Locations and classification of pedons sampled along the transect at site 1.

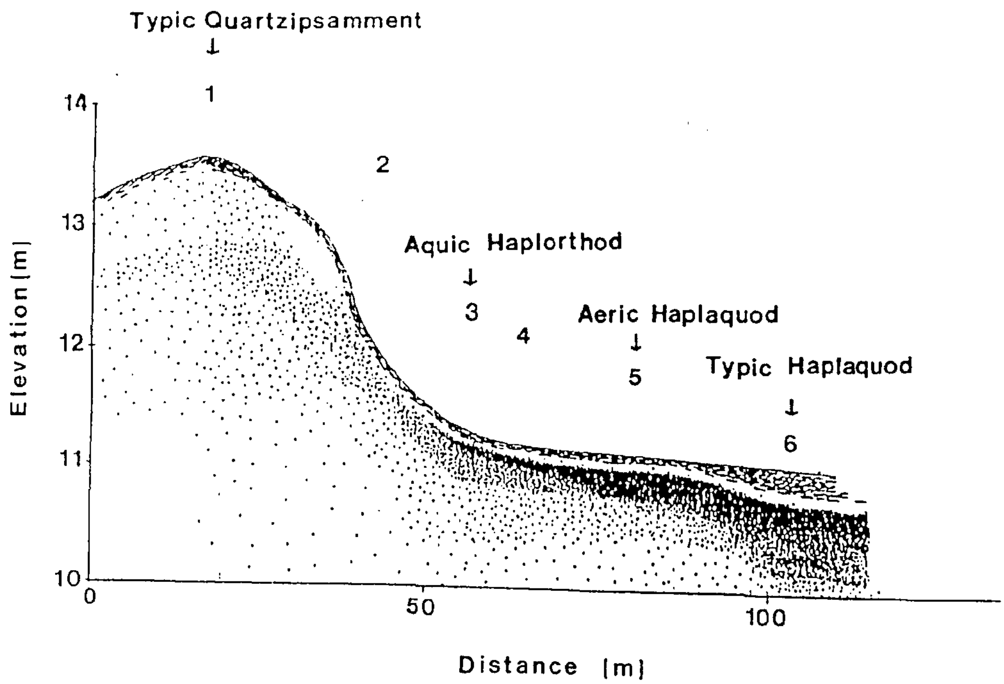


Figure 11. Locations and classification of pedons sampled along the transect at site 2.

(Pinus taeda) with an understory of greenbrier (Similax rotundifolia), and the soils are acidic to extremely acidic.

Classified according to Soil Taxonomy, all the soils were in siliceous, mesic, families. Depending upon landscape position and drainage, the soils exhibited varying degrees of spodic horizon formation. In the excessively drained positions near the summit, the soils lacked any indications of spodic horizons development and were Typic Quartzipsamments. Entic Haplorthods or Aquic Haplorthods were in transitional positions, and Aeric and Typic Haplaquods were in the more poorly drained footslope and toeslope positions. (Condron, 1990)

Soil Analyses

Sand and silt fractions from several horizons in the pedons were powdered and analyzed by X ray diffraction to determine their mineralogy. Total digestions of the whole soil were performed based on a modification of the method outlined by Bowman (1989). Samples were ground to pass a 60 mesh sieve and digested in teflon beakers. Initially, the samples were treated with H_2O_2 and HNO_3 to digest organic material. HF and HCl were added to the beakers, and the contents were heated to 200 C on a hotplate. Total Al, Fe, K, Na, and Ca in the samples were measured by atomic absorption spectroscopy. The same procedure was used for total digestion and analysis of the clay fraction from several horizons in each pedon. Total K and Na in the digests were measured by atomic absorption spectroscopy. Al and Fe were extracted from the whole soil with sodium pyrophosphate (Method 6C8,Soil Survey Staff, 1984), dithionite citrate bicarbonate (Fanning, et al., 1970), and acid ammonium oxalate (McKeague and Day, 1966) and measured by atomic absorption spectroscopy. All chemical procedures were performed in duplicate and reported as means.

To estimate the net losses and gains of various constituents from soil profiles during pedogenesis, several calculations were made following the principles of Brewer (1976). In each pedon, a base horizon which best represented the soil material least affected by pedogenesis was chosen. The other horizons in the pedon were compared with the base horizon to calculate changes during pedogenesis. Since the soils in this study are predominantly quartz (< 5% feldspars) and only 10,000 years old, relatively little mineral weathering would be anticipated. Zirconium or another stable constituent would, therefore, not be appropriate to use in determining the volume factor (for estimating volume change during pedogenesis) as greater variability in the stable constituent would be expected from stratigraphic variation than from mineral weathering. Therefore, the volume factor was based solely on bulk density (BD).

RESULTS AND DISCUSSION

Operational Definitions of Aluminum Phases

A preliminary investigation was conducted to determine which primary aluminosilicate minerals were present in the sand and silt fractions of the soil, and therefore, potential sources of aluminum during weathering. X-ray diffraction revealed the dominant mineral to be quartz. Potassium feldspars, orthoclase and microcline ($KAlSi_3O_8$), and albite ($NaAlSi_3O_8$) were also present, although only in much lower quantities. The absence of a peak at 10 angstrom indicated that mica was not present. The x-ray diffraction work did not indicate the presence of Ca-plagioclase. This was confirmed by total digestion of the samples which showed no measurable amounts of Ca. It was concluded that K-feldspar and Na-plagioclase were the principal primary aluminosilicate minerals in the sand and silt fractions.

To estimate the gains and losses of Al in soil horizons due to soil formation, Al phases in the soil were operationally defined. Primary structural Al was determined by measuring Na and K in the HF digests and using the stoichiometry of potassium and sodium feldspars to calculate the quantity of Al in the feldspars. Total

K and Na in the clay fractions of various soil horizons were measured in order to account for the small contributions of these elements from clay minerals. Exchangeable K and Na were not present in measurable amounts. Extractable Al presented was equal to the maximum amount of aluminum extracted by one of the three extractants: pyrophosphate, oxalate, or DCB. Secondary structural Al, the amount of Al thought to be associated with clay minerals, was defined as the difference between total Al and the sum of primary structural Al and maximum extractable Al.

$$Al_{Total} - (Al_{max\ extr} + Al_{primary}) = Al_{secondary}$$

Distribution of Aluminum Phases

Fig. 12 shows the distribution of aluminum phases in several pedons representing varying degrees of spodic horizon development and drainage conditions. If mineral weathering of primary aluminosilicates were a source of extractable Al in spodic horizons, one would expect the amount of primary structural Al to be less in the upper (A and E) horizons than in the underlying horizons. This trend was evident in the better drained Entic Haplorthod (pedon 1:6) (Fig. 12) where 2.6 g/kg structural Al in the A and E increased to 5.0 g/kg in the lower horizons.

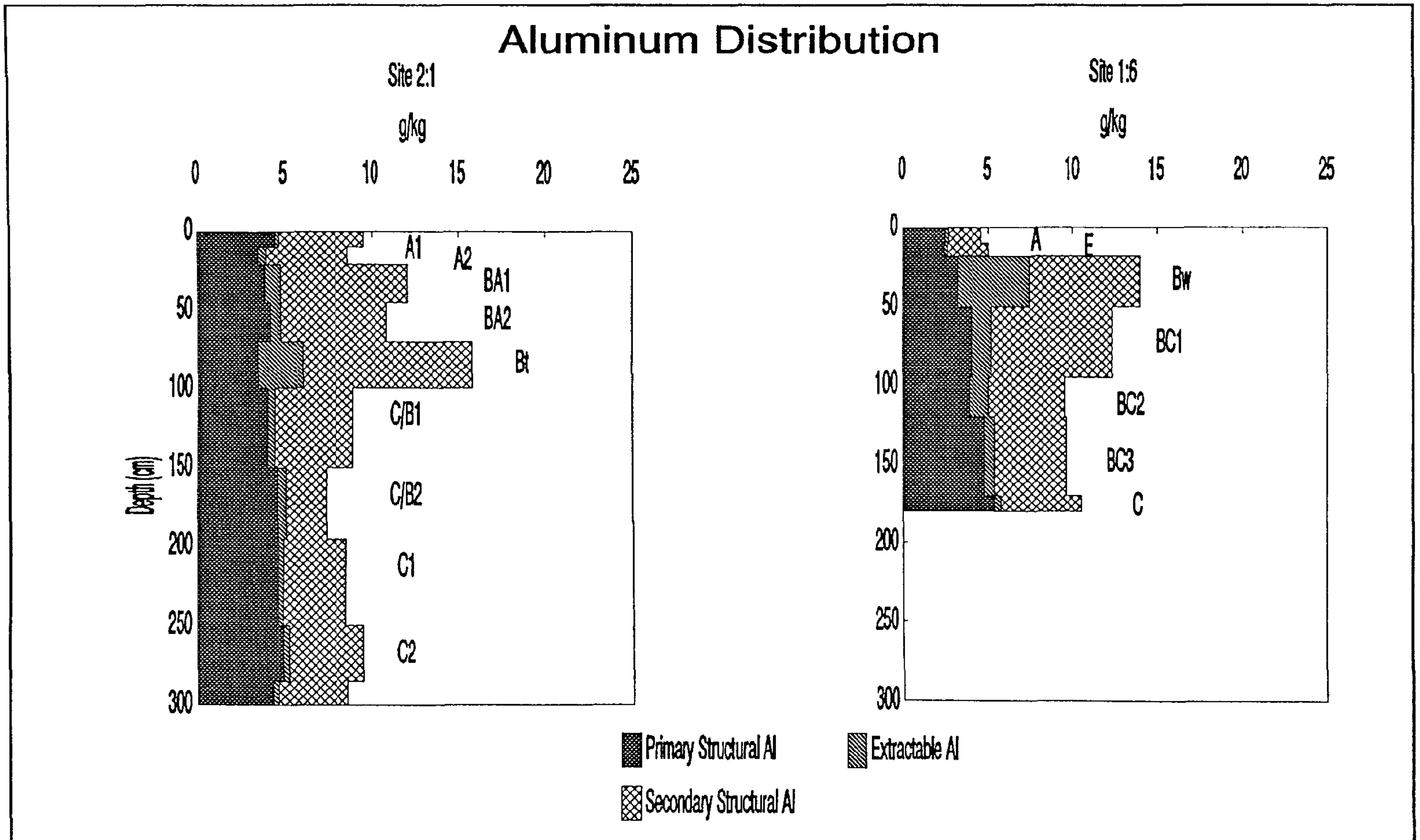


Figure 12a. Distribution of various Al phases in four pedons selected to represent degrees of spodic horizon expression in the two transects.

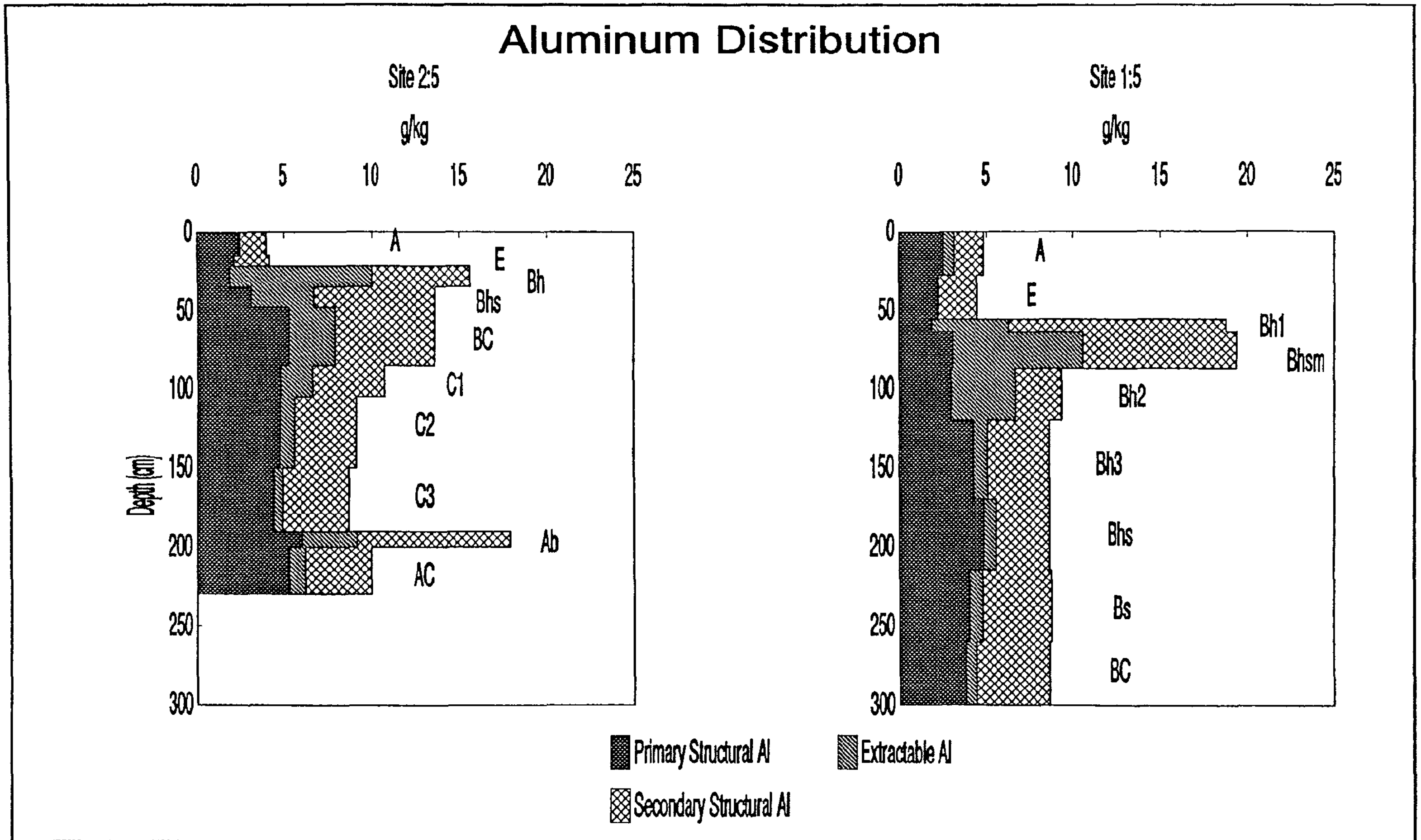


Figure 12b. Distribution of various Al phases in four pedons selected to represent degrees of spodic horizon expression in the two transects.

Extractable Al was greatest in the spodic horizon (4.0 g/kg). In the Typic Haplaquod (pedon 1:5), the wettest soil, the amount of structural Al in the upper horizons increased from 2.8 g/kg in the A horizon to 5.1 g/kg in the Bhs horizon. There was, however, more extractable Al in the lower horizon (0.77g/kg) than in the better drained soil. In general, the primary structural Al content in the lower horizons ranged from 4.5 - 5.5 g/kg. Acid attack of the feldspars could release Al which subsequently could be translocated to lower horizons. The accumulation of Al was most evident in the wetter Haplaquods where thick spodic horizons were strongly enriched with Al. Fig. 13 is a micrograph which shows weathering of a feldspar grain illustrating the loss of structural Al.

All of the soils had accumulations of secondary structural Al in the lower horizons and appear to follow typical clay translocation patterns. Particle size distribution patterns show accumulations of clay in the B horizons, with the greatest amount (126g/kg) in the Bh horizon of pedon 1:5 (Typic Haplaquod). Preliminary XRD analysis shows the presence of kaolinite and smectite in the clay fraction. In addition to Al from clay minerals, the fraction defined as secondary structural aluminum may contain Al in paracrystalline phases not extractable by pyrophosphate or oxalate.

Figure 13. Micrographs of a weathered feldspar grain from the E horizon of pedon 1:5 suggesting loss of structural Al from these aluminosilicates during pedogenesis; A - plane polarized light; B - circularly polarized light; frame length is 1.2mm.

Table 4 shows the gains or losses of several constituents from the pedons at Sites 1 and 2. At Site 1, regardless of landscape position or drainage, all of the pedons had a net loss of primary structural aluminum (from feldspar). There was a corresponding net gain of pyrophosphate extractable aluminum in all of the pedons. The greatest accumulation of pyrophosphate extractable aluminum was in the very poorly drained Typic Haplaquod. Comparison between net loss of primary structural aluminum and net gain of extractable aluminum reveals an overall net gain of aluminum in the Typic Haplaquods, whereas the soils in better drained positions had an overall net loss of aluminum (Table 4). At Site 1 it is possible that the accumulation of aluminum in the lower, wetter landscape positions is due to movement of soluble organic-aluminum complexes through the soil downslope, as well as Al movement within the pedon from the surface to the subhorizons.

Site 2 also had net losses of primary structural aluminum and net gains of extractable aluminum in all of the pedons. The overall net gain of aluminum, however, differs from Site 1. In both Site 1 and Site 2, the soil in the better drained position had a net loss of aluminum, and the wetter soils (Aquic Haplorthods and Aeric Haplaquods) had net gains of aluminum. However, unlike Site 1, the data for the wettest soil (Typic Haplaquod)

Table 4. Calculated net gains or losses of constituents from six pedons. Values were based on an areal basis (g/100cm^2) and summed for all horizons within each pedon. Positive values represent net gains and negative values represent net losses.

Pedons	1° Struc Al	Alp	1°Al-Alp	Ct	Cp	Sand	Silt	Clay
	g/100cm^2							
Site 1								
1:6 (Entic Haplorthod)	-32	23	-9	56	28	-828	642	186
1:1 (Aquic Haplorthod)	-18	9	-9	70	40	-721	512	209
1:5 (Typic Haplaquod)	-15	39	24	242	165	-1135	772	326
Site 2								
2:1 (Typic Quartzipsamment)	-20	16	-4	43	7	-1047	141	906
2:5 (Aeric Haplaquod)	-6	29	23	100	73	-719	433	287
2:6 (Typic Haplaquod)	-28	5	-23	247	113	-904	670	235

at Site 2 shows a net loss of aluminum. It is possible that there may be some sort of a lithological (sedimentary) discontinuity within that pedon. Such a discontinuity could affect the calculations of net gains and losses because comparisons are made using the assumption that all the horizons, including the base horizons, have formed from a uniform parent material.

Carbon

At both sites 1 and 2, the greatest accumulation of total carbon and pyrophosphate carbon occurred in the wetter soils (Table 4). All of the pedons have a net gain of total carbon and pyrophosphate extractable carbon, but the amount differs with landscape position and wetness. At Site 1, the better drained Entic Haplorthod (1:6) had an overall gain of 56 g/100cm^2 total organic carbon through the depth of the soil. This amount increased in pedons at lower landscape positions and was greatest in the Typic Haplaquod (1:5) which had 242 g/100cm^2 total organic carbon. The results at Site 2 were similar, with less total organic carbon in the better drained soil,Typic Quartzipsamment (43 g/100cm^2), than in the Typic Haplaquod (247 g/100cm^2).

Like total organic carbon, gains in pyrophosphate carbon (Cp) increased with lower landscape position. At Site 1, the overall Cp gain in the Entic Haplorthod (1:6) was 28 g/100cm^2, and in the Typic Haplaquod (1:5) it was 165 g/100cm^2. An illuvial pattern of Cp distribution was evident in all the pedons at Site 1; there was a gain in Cp in the spodic horizons than in the surface horizons (Table 5). This pattern was most evident in the Typic Haplaquod (1:5) where there was a calculated loss of 5 g/100cm^2 in the E followed by an increase to 24 and 77 g/100cm^2 in the Bhs and Bhsm horizons. In actuality this loss of C in the E horizons is probably an artifact related to a small amount of illuvial C present in the base horizons which are used for comparison. The soils at Site 2 had similar patterns of illuviation with the strongest expression in the Typic Haplaquod (2:6). The wetter anaerobic conditions of soils in lower landscape positions are probably less conducive to oxidation and decomposition of carbon resulting in greater carbon content than in better drained soils. The moist conditions of lower landscape positions may favor greater biomass production over the drier, better drained positions. Also, some of the overall gain of pyrophosphate extractable carbon may be due to movement through the soil from higher to lower landscape positions.

At both sites, the particle size data show net losses from the sand fraction in all of the pedons,

Table 5. Calculated net gains or losses of total carbon and pyrophosphate carbon from six pedons. Values were based on an areal basis (g/100cm^2) for the thickness of each given horizon. Values were then summed for all horizons within each pedon. Positive values represent net gains and negative values represent net losses.

Pedon	Horizon	Ct	Cp
		---(g/100cm^2)--	
2:1	A1	9	1
(Typic Quartzipsamment)	A2	6	2
	BA1	8	2
	BA2	8	1
	Bt	4	1
	CB1	2	1
	CB2	2	0
	C1	3	0
	Total	42	8
2:5	A	20	3
(Aeric Haplaquod)	E	2	0
	Bh	52	47
	Bhs	16	15
	BC	8	7
	C	1	0
	Total	99	72
2:6	A	112	17
(Typic Haplaquod)	E	4	2
	Bh	62	33
	BC/Bh	62	56
	BC2	7	5
	BC3	0	0
	Total	247	113
1:6	A	11	2
(Entic Haplorthod)	E	8	2
	Bw	28	19
	BC1	8	4
	BC2	2	1
	BC3	0	0
	Total	57	28

Table 5 (continued). Calculated net gains or losses of total carbon and pyrophosphate carbon from six pedons. Values were based on an areal basis ($g/100cm^2$) for the thickness of each given horizon. Values were then summed for all horizons within each pedon. Positive values represent net gains and negative values represent net losses.

Pedon	Horizon	Ct	Cp
		---($g/100cm^2$)--	
1:1	A	29	6
(Aquic Haplorthod)	E	6	3
	Bh	6	4
	Bhs	15	12
	Bs	6	4
	BC	9	11
	Total	71	40
1:5	A	52	14
(Typic Haplaquod)	E	-2	-5
	Bh1	34	24
	Bhsm	88	78
	Bh2	38	29
	Bh3	32	26
	Total	242	165

whereas the silt and clay fractions have net gains (Table 4). It appears that weathering of the sand fraction has taken place resulting in accumulations of silt and clay. Within pedons, there is greater clay content in the B horizons than in the surface horizons which suggests clay illuviation has occurred. In the wetter soils, Aeric and Typic Haplaquods (2:5 & 1:5), the greatest clay accumulation was in the spodic horizons (Fig. 12). Fig. 14 shows the presence of free grain argillans in the Bhsm horizon of Pedon 1:5 (Typic Haplaquod). Although only moderately oriented and striated, the oriented clay around the grains supports the interpretation that clay illuviation has occurred.

CONCLUSIONS

There was less primary structural aluminum in the surface horizons than in the lower horizons. This suggests that feldspar weathering is a source of aluminum accumulated in the spodic horizons. In general, there is a net gain of aluminum in the lower, wetter landscape positions. Total carbon and pyrophosphate carbon gains were also greatest in the lower landscape positions. Movement of soluble organo-aluminum complexes through the soil downslope as well as within the pedons may be a cause of aluminum and pyrophosphate carbon accumulations in the lower landscape positions.

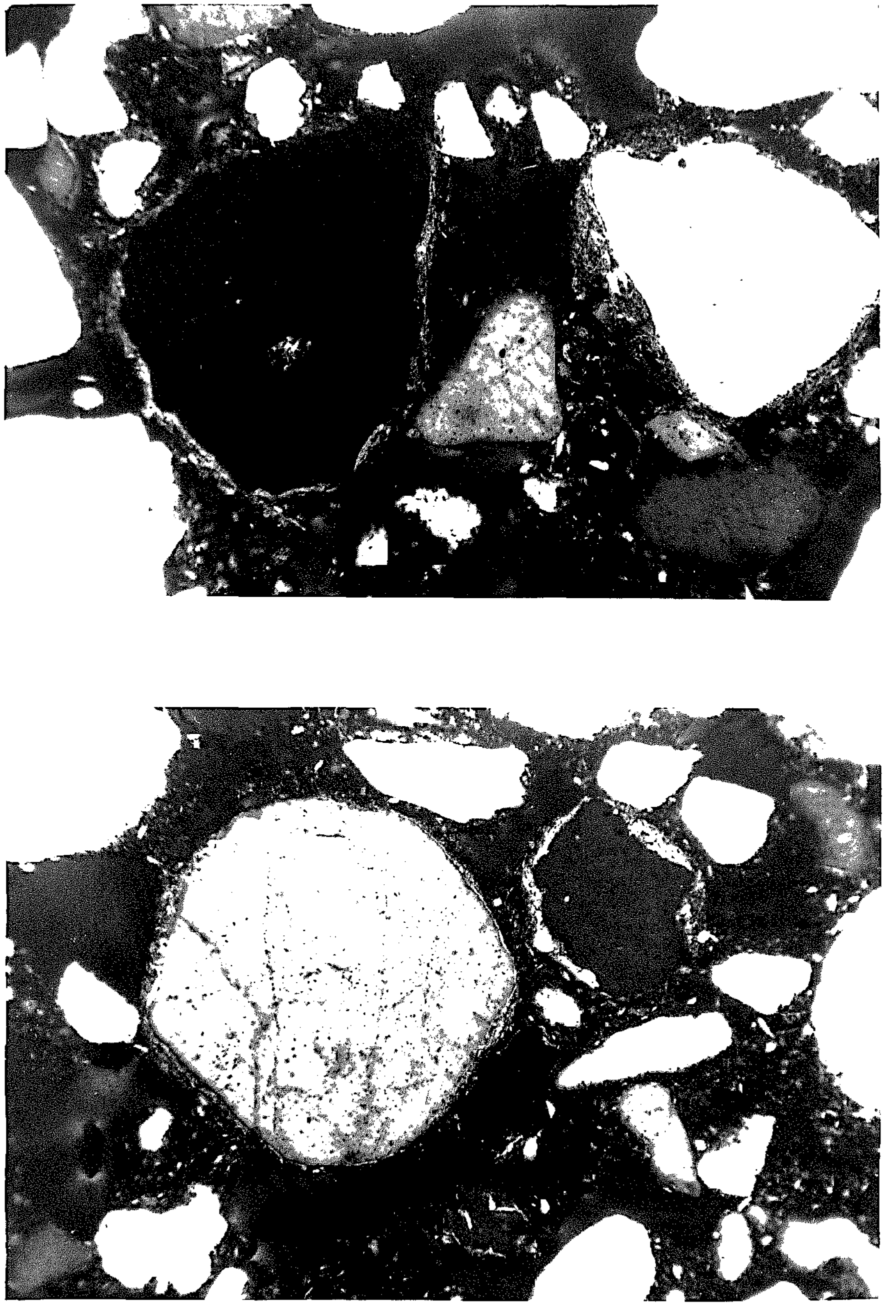


Figure 14. Micrographs of free grain argillans around quartz grains in the Bhsm horizon of pedon 1:5; circularly polarized light; frame length is 1.2mm.

THESIS CONCLUSIONS

Seasonally fluctuating groundwater tables influence the formation of spodic horizons in sandy, quartzose sediments on the Lower Eastern Shore of Maryland. Iron translocation to the B horizons is evident in better drained soils. The spodic horizons of somewhat freely drained transitional soils (Entic Haplorthods and Aquic Haplorthods) had accumulations of Fe organic complexes, but in the wettest soils (Aeric Haplaquods and Typic Haplaquods), where the water table was near or above the soil surface for part of the year, there was no extractable Fe. Iron reduction and removal from the soil system via the fluctuating groundwater may cause the absence of iron in the spodic horizons in the Haplaquods. Though the spodic horizons in the Haplaquods had a dark reddish appearance, the coloring must be due to organic material and complexes of aluminum rather than iron.

Translocation of aluminum as soluble organic complexes also appears to have taken place. Analyses of primary aluminosilicate minerals showed weathering of feldspar minerals in the surface horizons. Aluminum released from the weathered mineral surface is then available for translocation to the subhorizons. Analyses of carbon and extractable aluminum revealed that aluminum in the spodic horizons occurred predominantly as soluble organic complexes. There were accumulations of clay in the spodic horizons, and there did appear to be highly reactive paracrystalline and noncrystalline materials in the Bh horizons; however, chemical analyses did not show evidence of proto-imogolite or imogolite formation. The greatest accumulations of aluminum and soluble carbon were in the wetter, low landscape positions. These data, along with the evidence that extractable aluminum is predominantly in the soluble organic complex form, suggest that aluminum accumulations in the spodic horizons of the Haplaquods may be due to movement via percolating water through the soil downslope as well as within the pedon from the surface to subjacent horizons.

REFERENCES

Alvarado, A., and S. W. Buol. 1985. Field estimation of phosphorous retention by Andepts. Soil Sci. Soc. Am J. 49:911-14.

Baldwin, M., C.E. Kellogg, and J. Thorp. 1938. Soil Classification. In Soils and Men. U.S. Gov Print Office. Washington, D.C.

Bowman, R.A. 1988. A rapid method to determine total phosphorous in soils. Soil Sci Soc Am J. 52:1301-1304.

Brandon, E.E., W.W. Buol, E.E. Gamble, and R.Z. Pope. 1977. Spodic horizon brittleness in Leon soils. Soil Sci Soc Am J. 41:951-954.

Brasher, B.R., D.P. Franzmeier, V.T. Valassis, and S.E. Davidson. 1966. Use of saran resin to coat natural soil clods for bulk density and water retention measurements. Soil Sci. 101:108.

Brewer, R. !976. Fabric and mineral analysis of soils. Wiley, New York.

Bullock, P. and B. Clayden. 1980. Morphological properties of Spodosols. p.45-65. In B.K.G. Theng (ed.) Soils with variable charge. N.Z. Soc Soil Sci, Soil Bureau, DSIR, Lower Hutt, New Zealand.

Buol, S.W., F.D. Hole, R.J. McCracken. 1989. Soil Genesis and Classification. 1989. Iowa State Univ. Press, Ames, IA.

Collins, M.E. Aquods. 1990. Aquods. In J.M. Kimble & R.D. Yeck (eds) Proceedings from the fifth international soil correlation meeting (ISCOM IV) Characterization, Classification, and Utilization of Spodosols. USDA, SCS, Lincoln, NE.

Condron, M.A. 1990. Soils with Spodic Characteristics on the Eastern Shore of Maryland. Thesis.

Daniels, R.B., E.E. Gamble, and J.G. Cady. 1971. The relation between geomorphology and soil morphology and genesis. p. 51-88. In Advances in agronomy. Academic Press, Inc., New York.

Daniels, R.B., E.E. Gamble, and C.S. Hozhey. 1975. Thick Bh horizons in the N. Carolina coastal plains: Morphology and relations to texture and soil ground water. Soil Sci Soc Am Proc. 39:1177-1181.

Daly, B.K. 1982. Identification of podzols and podzolised soils in New Zealand by relative absorbance of oxalate extracts of A and B horizons. Geoderma. 28:29-38.

De Coninck, F. 1980. Major mechanisms in formation of spodic horizons. Geoderma. 24:101-128.

De Coninck, F. and D. Righi. 1983. Podzolisation and the spodic horizon. p. 389-417. In P. Bullock and C.P. Murphy (eds.) Soil mircromorphology, vol. 2 : Soil genesis. AB Academic Publ., Berkhamsted, England.

Denny, C.S. and J.P. Owens. 1979. Sand dunes on the central Delmarva Peninsula Maryland and Delaware. U.S. Geol Survey Prof Paper 1067-A.

Fanning, D.S., R.F. Korcak, and C.B. Coffman. 1970. Free iron oxides: Rapid determination using x-ray spectroscopy to determine iron in solution. Soil Sci. Soc. Am. Proc. 34:941-946.

Fanning, D.S. and M.C.B. Fanning. 1989. Soil: morphology, genesis, and classification. John Wiley and Sons, New York.

Farmer, V.C., J.D. Russell, and M.S. Berrow. 1980. Imogolite and Proto-imogolite allophane in spodic horizons: evidence for a mobile aluminum silicate complex in podzol formation. J. Soil Sci. 31:673-684.

Farmer, V.C., J.D. Russell, and B.F.L. Smith. 1983. Extractions of Al, Fe, and Si from a podzol Bs horizon. J. Soil Sci.34:571-576.

Farmer, V.C., A.R. Fraser, L.Robertson, and J.R. Sleeman. 1984. Proto-imogolite allophane in podzol concretions in Australia: possible relationships to aluminous ferrallitic (lateritic) cementation. J. Soil Sci. 35:333-340.

Garman, C.R., V.W. Carlisle, L.W. Zelazny, and B.C. Beville. 1981. Aquiclude related spodic horizon development. Crop Sci. Soc. Fla. 40:105-109.

Gee, G.W. and J.W. Bauder. 1986. Particle size analysis. pp. 377-382. In A. Klute (ed.) Methods of Soil Analsis, Part 1. Physical and Mineralogical Methods (2nd Ed.) Agronomy Monograph No. 9. ASA,SSA, Madison, WI.

Hall, R.L. 1970. Soil Survey of Wicomico County, Maryland. USDA, SCS. U.S. Govt. Print. Office. Washington, D.C.

Hall, R.L. 1970. Soil Survey of Worcester County, Maryland. USDA, SCS. U.S. Govt. Print. Office. Washington, D.C.

Harris, W.G., and V.W. Carlisle. 1987. Clay mineralogical relationships in Florida Haplaquods. Soil Sci. Soc. Am. J. 51:481-484.

Harris, W.G., V.W. Carlisle, and K.C.J. Van Rees. 1987. Pedon zonation of hydroxy-interlayered minerals in Ultic Haplaquods. Soil Sci. Soc. Am. J. 51:1367-1372.

Holzhey, C.S., R.B. Daniels, and E.E. Gamble. 1975. Thick Bh horizons in the N. Carolina coastal plain: Physical and chemical properties and rates of organic additions from surface sources. Soil Sci. Soc. Am. Proc. 39:1182-1187.

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

Jenny, H., R.J. Arkley, and A.M. Schultz. 1969. The pygmy forest-Podzol ecosytem and its dune associates in the Mendocina Coast. Madrono. 20:60-74.

Kimble, J., H. Eswaran, and T. Cook. 1990. Spodosols transitions with other soils. pp171-180 In J. M. Kimble and R. D. Yeck (eds). Proceedings of the fifth international soil correlation meeting (ISCOM) Characterization, classification and utilization of spodosols. USDA, Soil Conservation Service, Lincoln, NE.

Lee, F.Y., T.L. Yuan, and V.W. Carlisle. 1987. Characterization of organic matter in ortstein and non-ortstein horizons of selected Florida Spodosols. Soil and Crop Sci. Soc. Fla. Proc. 47:72-78.

Lee, F.Y., T.L. Yuan, and V.W. Carlisle. 1988a. Nature of cementing materials in ortstein horizons of selected Florida Spodosols: I. Constituents of cementing materials. Soil Sci. Soc. Am. J. 52:1411-1418.

Lee, F.Y., T.L. Yuan, and V.W. Carlisle. 1988b. Nature of cementing materials in ortstein horizons of selected Florida Spodosols: II. Soil properties and chemical form(s) of aluminum. Soil Sci. Soc. Am. J. 52:1796-1801.

McKeague, J.A. and J.H. Day. 1966. Dithionite and oxalate extractable Fe and Al as acids in differentiating various classes of soils. Can. J. Soil Sci. 46:13-22.

McKeague, J.A. and J.E. Brydon. 1970. Mineralogical properties of the reddish brown soils from the Atlantic

Provinces in relation to parent materials and pedogenesis. Cna. J. Soil Sci. 50:47-55.

McKeague, J.A., J.E. Brydon, and N.M. Miles. 1971. Differentiation of forms of extractable iron and aluminum in soils. Soil Sci. Soc. Am. Proc. 35:33-38.

McKeague, J.A., F. De Coninck, and D.P. Franzmeier. 1983. Spodosols. p.217-252. In L.P. Wilding, N.E. Smeck, and G.F. Hall (ed.) Pedogenesis and Soil Taxonomy, II: The soil orders. Elsevier, Amsterdam.

McSweeney, K. and E.A. FitzPatrick. 1990. Microscopic characterization of the spodic horizon. In Proceedings from the Fifth International Soil Correlation Meeting (ISCOM IV) Characterization, Classification, and Utilization of Spodosols. USDA, SCS, Lincoln, NE..

Marbut, C.F. 1935. Atlas of American Agriculture, Part III: Soils of the United States. U.S. Gov. Print. Office. Washington, D.C.

Nettleton, D.A., R.B Parsons, A.O. Ness, and F.W. Gerderman. 1982. Spodosols along the southwest Oregon coast. Soil Sci. Soc. Am. J. 46:593-598.

Perrott,K.W., B.F.L. Smith and B.D. Mitlchell. 1976. Effect of pH on the reacton of sodium fluoride with hydrous oxides of silicon, aluminum, and iron, and with poorly ordered aluminosilicates. J. Soil Sci. 27:348-356.

Rhoades, J.D. 1982. Cation exchange capacity. pp 149-158. In A.L. Page (ed.) Methods of Soil Analysis Part 2. Chemical and Microbiological Properties (2nd ed.). ASA, SSSA. Madison, WI.

Rourke, R.V., B.R. Brasher, R.D. Yeck, and F.T. Miller. 1988. Characeristic morphology of U.S. Spodosols. Soil Sci. Soc. Am. J. 52:445-449.

Rourke, R.V. and J.A. Kimble. 1989. Proposed Changes in Spodosols. Soil Survey Horizons. 30:61-65.

Soil Survey Staff. 1975. Soil taxonomy: A basic system of soil classification for making and interpreting soil survey. USDA-SCS Agric Handb 436. U.S. Gov. Print. Office, Washington, D.C.

Soil Survey Staff. 1981. Soil survey manual. USDA-SCS Agri handb. 430-V-SSM. U.S. Gov. Print. Office. Washington, D.C.

Soil Survey Staff. 1984. Procedures for collecting soil samples and methods of analysis for soil survey. Soil Survey Investigations Report No.1. USDA, Gov. Print. Office, Washington, D.C.

Soil Survey Staff. 1987. Keys to soil taxonomy (3rd ed.) SMSS Technical Monogr. 6. Ithaca, NY.

Soil Survey Staff. 1990. Keys to soil taxonomy (4th ed.) SMSS Technical Monogr. 19. Blacksburg, VA.

Taylor, R.M. 1988. Proposed mechanism for the formation of soluble Si-Al and Fe(3+)-Al hydroxy complexes in soils. Geoderma. 42:65-77.

Tedrow, J.C.F. 1986. Soils of New Jersey. Kreiger Pub. Co. Malabar, Fla.

Thomas, G.W. 1982. Exchangeable cations. pp 159-165. In A.L. Page (ed.) Methods of Soil Analysis Part 2. Chemical and microbiological properties (2nd ed.). ASA,SSSA. Madison, WI.

Wang, C., J.A. McKeague, and H. Kodama. 1986. Pedogenic imogolite and soil environments: Case study of Spodosols in Quebec, Canada. Soil Sci. Soc. Am. J. 50:711-718.

Yuan, T.L. 1966. Characteristics of surface and spodic horizons of some spodosols. Proc. Soil Crop. Sci. Soc. Fla. 26:163-174.

Yuan, T.L. 1968. Composition of the amorphous materials in the clay fraction of some Entisols, Inceptisols, and Spodosols. Soil Sci. 107:242-248.

Zelazny, L.W. and V.W. Carlisle. 1971. Mineralogy of Florida Aeric Haplaquods. Proc. Soil Crop. Sci. Soc. Fla. 31:160-165.

APPENDIX A. SOIL MORPHOLOGICAL DESCRIPTIONS OF THE PEDONS SAMPLED

PEDON 1:1
Soils Series: Klej
Soil Survey # S90-MD-047-001
Description Type: full pedon description
Geographically Associated Soils: Evesboro, Atsion, Berryland
Location: Pocomoke State Forest; on Old Furnace Rd., 2.5 miles W of Rt. 12, on N side of road.
Latitude: 38-12-10-N
Longitude: 075-29-35-W
Classification: sandy, siliceous, mesic Aquic Haplorthod
Physiography: Dune in Coastal Plain
Geomorphic Position: on upper third, summit of an interfluve
Elevation: 12 m MSL
Precipitation: 124 cm udic moisture regime
MLRA: 153
Hydraulic Conductivity: very high
Air Temperature: Ann 13 C Sum 22 C Win 1 C
Drainage Class: excessively drained
Land Use: forest land not grazed
Particle Size Control Section: 25 to 101 cm
Parent Material: eolian-sand material
Diagnostic Horizons: 25 to 30 cm spodic
Described By: Margaret Condron, Martin Rabenhorst, Mark Elless, Dick Hall
Date: 12/90

Oe--5 to 0 cm.

A--0 to 12 cm; black (5Y 2/1) loamy sand; weak medium granular structure; very friable; clear smooth boundary.

E--12 to 20 cm; brown to dark brown (7.5YR 4/2) loamy sand; weak medium subangular blocky structure; very friable; clear wavy boundary.

Bh--20 to 25 cm; black (5YR 2/1) loamy sand; weak medium subangular blocky structure; friable; clear smooth boundary.

Bhs--25 to 30 cm; dark reddish brown (5YR 3/3) loamy sand; massive; friable; the soil consistence is slightly brittle.

Bs--30 to 43 cm; yellowish brown (10YR 5/6) loamy sand; weak medium subangular blocky structure; very friable; gradual smooth boundary.

BC--43 to 104 cm; yellowish brown (10YR 5/4) loamy sand; common coarse distinct strong brown (7.5YR 5/6) mottles; weak coarse subangular blocky structure; very friable; the mottles were firm and slightly brittle.

C--104 to 119 cm; yellowish brown (10YR 5/4).

PEDON 1:3
Soils Series: Berryland
Soil Survey # S90-MD-047-002
Description Type: full pedon description
Geographically Associated Soils: Evesboro, Klej, Atsion
Location: Pocomoke State Forest; on Old Furnace Rd., 2.5 miles W of Rt. 12, on N side of road.
Latitude: 38-12-10-N
Longitude: 075-29-35-W
Classification: sandy, siliceous, mesic Typic Haplaquod
Physiography: Dune in Coastal Plain
Geomorphic Position: on a slope & in a depression, foot slope
Elevation: 12 m MSL
Precipitation: 124 cm udic moisture regime
MLRA: 153
Hydraulic Conductivity: very high
Air Temperature: Ann 13 C Sum 22 C Win 1 C
Drainage Class: very poorly drained
Land Use: forest land not grazed
Particle Size Control Section: 25 to 101 cm
Parent Material: eolian-sand material
Diagnostic Horizons: 0 to 17 cm umbric, 58 to 254 cm spodic
Described By: Margaret Condron, Martin Rabenhorst, Mark Elless
Date: 12/90

Oe--5 to 0 cm; abrupt smooth boundary.

A--0 to 17 cm; black (N 2/0) loamy sand; weak medium subangular blocky structure; very friable; clear smooth boundary.

E--17 to 53 cm; grayish brown (10YR 5/2) sand; single grain; loose; clear smooth boundary.

BE--53 to 53 cm; very dark grayish brown (10YR 3/2) loamy sand; massive; firm; clear smooth boundary.

Bh--58 to 71 cm; black (10YR 2/1) loamy sand; massive; friable; the horizon thickness ranged from 16-28 cm.; clear wavy boundary.

Bhsm1--71 to 99 cm; dark reddish brown (5YR 3/2) loamy sand; massive; very firm, brittle by humus; the horizon thickness ranges from 15-28 cm; clear wavy boundary.

Bhsm2--99 to 116 cm; black (5YR 2/1) loamy sand; massive; very firm, brittle by humus; the consistence is firm at the bottom of the horizon.

Bhs--116 to 170 cm; black (10YR 2/1) loamy sand.

Bs--170 to 220 cm; dark brown (7.5YR 3/4) sand.

BC--220 to 254 cm; yellowish brown (10YR 5/6) sand.

C1--254 to 284 cm; pale olive (5Y 6/3) sand.

2C2--284 to 294 cm; olive gray (5Y 5/2) fine sandy loam.

PEDON 1:5
Soils Series: Berryland
Soil Survey # S90-MD-047-003
Description Type: full pedon description
Geographically Associated Soils: Evesboro, Klej, Atsion
Location: Pocomoke State Forest; on Old Furnace Rd., 2.5 miles W of Rt. 12, on the N side of the road.
Latitude: 38-12-10-N
Longitude: 075-29-35-W
Classification: sandy, siliceous, acid Typic Haplaquod
Physiography: Dune in Coastal Plain
Geomorphic Position: on a slope & in a depression, foot slope of an interfluve
Elevation: 12 m MSL
Precipitation: 124 cm udic moisture regime
MLRA: 153
Hydraulic Conductivity: very high
Air Temperature: Ann 13 C Sum 22 C Win 1 C
Drainage Class: very poorly drained
Land Use: forest land not grazed
Particle Size Control Section: 25 to 101 cm
Parent Material: eolian-sand material
Diagnostic Horizons: 0 to 22 cm umbric, 50 to 254 cm spodic
Described By: Margaret Condron, Martin Rabenhorst, Mark Elless
Date: 12/90

Oe--5 to 0 cm; abrupt smooth boundary.

A--0 to 22 cm; black (N 2/0) loamy sand; weak medium subangular blocky structure; very friable; clear smooth boundary.

E--22 to 50 cm; grayish brown (10YR 5/2) sand; single grain; loose; the horizon thickness ranges from 10-30 cm.; clear smooth boundary.

Bh1--50 to 58 cm; black (10YR 2/1) loamy sand; weak coarse subangular blocky structure; friable; The horizon thickness ranges from 7-30 cm; the average thickness is 11cm; clear wavy boundary.

Bhsm--58 to 81 cm; dark reddish brown (5YR 3/2) loamy sand; massive; firm by humus; the horizon thickness ranges from 0-3 cm; there are pockets of Bh1 material, like krotovinas, that comprise 60-70% of the material; clear broken boundary.

Bh2--81 to 140 cm ; black (10YR 2/1) loamy sand; massive.

Bh3--114 to 162 cm; black (10YR 2/1) loamy sand.

Bhs--162 to 208 cm; dark brown (7.5YR 3/2) sand.

Bs--208 to 254; dark brown (7.5YR 3/4) sand.

BC--254 to 294 cm; yellowish brown (10YR 5/6) sand.

PEDON 1:6
Soils Series: Evesboro
Soil Survey # S90-MD-047-004
Description Type: full pedon description
Pedon Type: Within range of series
Correlated Name: Evesboro
Geographically Associated Soils: Klej, Atsion, Berryland
Location: Pocomoke State Forest; on Old Furnace Rd., 2.5 miles W of Rt. 12, on the N side of the road
Latitude: 38-12-10-N
Longitude: 075-29-35-W
Classification: sandy, siliceous, mesic Entic Haplorthod
Physiography: Dune in Coastal Plain
Geomorphic Position: on upper third, summit of an interfluve
Elevation: 12 m MSL
Precipitation: 124 cm udic moisture regime
MLRA: 153
Hydraulic Conductivity: very high
Air Temperature: Ann 13 C Sum 22 C Win 1 C
Drainage Class: well drained
Land Use: forest land not grazed
Particle Size Control Section: 25 to 101 cm
Parent Material: eolian-sand material
Diagnostic Horizons: 15 to 45 cm spodic
Described By: Margaret Condron, Martin Rabenhorst, Mark Elless
Date: 12/90

Oe--2 to 0 cm; clear smooth boundary.

A--0 to 7 cm; very dark gray (10YR 3/1) loamy sand; weak medium granular structure; very friable; clear smooth boundary.

E--7 to 15 cm; brown (7.5YR 5/2) loamy sand; weak medium subangular blocky structure; very friable; clear irregular boundary.

Bw--15 to 45 cm; dark yellowish brown (10YR 4/6) loamy sand; weak medium subangular blocky structure parting to weak coarse subangular blocky; friable; approximately 5-10% of the horizon had dark zones (10YR 3/4); gradual smooth boundary.

BC1--45 to 91 cm; yellowish brown (10YR 5/4) loamy sand; weak coarse subangular blocky structure; very friable.

BC2--91 to 116 cm; light olive gray (5Y 6/2) loamy sand; strong brown (7.5YR 5/8), and mottles; this horizon was sampled with a bucket auger.

BC3--116 to 170; light yellowish brown (2.5Y 6/4) sand; brown (7.5YR 5/4), and brown (7.5YR 5/4) mottles.

C--165 to 175 cm; light gray (2.5Y 7/2) sand; strong brown (7.5YR 5/8) mottles; this horizon was sampled with a bucket auger.

PEDON 1:7
Soils Series: Atsion
Soil Survey # S90-MD-047-005
Description Type: full pedon description
Geographically Associated Soils: Evesboro, Klej, Berryland
Location: Pocomoke State Forest; on Old Furnace Rd., 2.5 miles W of Rt. 12, on the N side of the road.
Latitude: 38-12-10-N
Longitude: 075-29-35-W
Classification: siliceous, mesic Aeric/Entic Haplaquod
Physiography: Dune in Coastal Plain
Geomorphic Position: on lower third, back slope
Elevation: 12 m MSL
Precipitation: 124 cm udic moisture regime
MLRA: 153
Hydraulic Conductivity: very high
Air Temperature: Ann -10 C Sum -17 C Win -17 C
Drainage Class: somewhat poorly drained
Land Use: forest land not grazed
Particle Size Control Section: 25 to 101 cm
Parent Material: eolian-sand material
Described By: Margaret Condron, Martin Rabenhorst, Mark Elless
Date: 12/90

Oe--2 to 0 cm; clear smooth boundary.

A--0 to 10 cm; very dark gray (10YR 3/1) loamy sand; weak medium granular structure; very friable; clear smooth boundary.

E--10 to 27 cm; light brownish gray (10YR 6/2) sand; single grain; loose; clear wavy boundary.

Bh--27 to 33 cm; black (10YR 2/1) loamy sand; massive; friable; clear wavy boundary.

Bs--33 to 40 cm; dark brown (7.5YR 3/4) loamy sand; massive; friable; there are a few firm, brittle zones that are redder than the matrix; clear wavy boundary.

BC1--40 to 58 cm; light olive brown (2.5Y 5/4) loamy sand; few medium distinct strong brown (7.5YR 5/6) mottles; weak medium subangular blocky structure; very friable; clear smooth boundary.

BC2--58 to 63 cm; brownish yellow (10YR 6/6) loamy sand; common coarse distinct strong brown (7.5YR 5/6), and few fine yellowish red (5YR 4/6) mottles; weak medium subangular blocky structure; very friable; the consistence was slightly stronger around the mottles.

PEDON 2:1
Soils Series: Evesboro
Soil Survey # S90-MD-047-006
Description Type: full pedon description
Geographically Associated Soils: Klej, Atsion, Berryland
Location: Pocomoke State Forest; on Old Furnace Rd, 4.75 W of Rt. 12, on N side of the road
Latitude: 38-12-54-N
Longitude: 075-31-30-W
Classification: siliceous, mesic Typic Quartzipsamment
Physiography: Dune in Coastal Plain
Geomorphic Position: on upper third, summit of an interfluve
Elevation: 12 m MSL
Precipitation: 124 cm udic moisture regime
MLRA: 153
Hydraulic Conductivity: very high
Air Temperature: Ann 13 C Sum 22 C Win 1 C
Drainage Class: excessively drained
Land Use: forest land not grazed
Particle Size Control Section: 25 to 101 cm
Parent Material: eolian-sand material
Diagnostic Horizons: 0 to 20 cm ochric
Described By: Margaret Condron, Martin Rabenhorst, Mark Elless
Date: 12/90
Notes: Sampled 1 June 1989

Oe--0 to 0 cm; abrupt smooth boundary.

A1--0 to 7 cm; gray (10YR 5/1) sand; single grain; loose; an E horizon appears to be forming in the lower 2 cm. It may be from an old plow layer; clear wavy boundary.

A2--7 to 20 cm; olive brown (2.5Y 4/4) loamy sand; weak medium subangular blocky structure; very friable; this horizon may be the lower part of a plow layer; clear smooth boundary.

BA--20 to 68 cm; yellowish brown (10YR 5/4) loamy sand; weak coarse subangular blocky structure; very friable; clear smooth boundary.

Bt--68 to 96 cm; dark yellowish brown (10YR 4/6) loamy sand; weak coarse subangular blocky structure; very friable; clay bridging; clear smooth boundary.

CB--96 to 193 cm; light yellowish brown (10YR 6/4) sand; single grain; loose; there were approximately 10% lamellae (7.5YR 4/4) in the sand; clear smooth boundary.

C1--193 to 248 cm; light yellowish brown (2.5Y 6/4) sand; single grain; loose; there were approximately 2% lamellae; clear smooth boundary.

C2--248 to 284 cm; light yellowish brown (2.5Y 6/4) sand; single grain; loose; clear smooth boundary.

C3--284 to 312 cm; yellowish brown (10YR 5/6) sand; common fine distinct yellowish red (5YR 5/8) mottles; single grain; loose; clear smooth boundary.

C4--312 to 358 cm; light yellowish brown (2.5Y 6/4) sand; few fine distinct light brownish gray (2.5Y 6/2), and strong brown (7.5YR 5/8) mottles; single grain; loose.

PEDON 2:3
Soils Series: Klej
Soil Survey # S90-MD-047-007
Description Type: full pedon description
Geographically Associated Soils: Evesboro, Atsion, Berryland,
Location: Pocomoke State Forest; on Old Furnace Rd., 4.75 miles west of Rt. 12, on the N side of the Rd.
Latitude: 38-12-54-N
Longitude: 075-31-30-W
Classification: sandy, siliceous, mesic Aquic Haplorthod
Physiography: Dune in Coastal Plain
Geomorphic Position: on middle third, back slope of a side slope
Slope Characteristics: northeast facing convex horizontal, convex vertical
Elevation: 12 m MSL
Precipitation: 124 cm udic moisture regime
MLRA: 153
Hydraulic Conductivity: very high
Air Temperature: Ann 13 C Sum 22 C Win 1 C
Drainage Class: somewhat poorly drained
Land Use: forest land not grazed
Particle Size Control Section: 25 to 101 cm
Parent Material: eolian-sand material
Diagnostic Horizons: 38 to 66 cm spodic
Described By: Margaret Condron, Martin Rabenhorst, Mark Elless
Date: 12/90
Notes: Sampled on 8/17/89.

Oe--2 to 0 cm; abrupt smooth boundary.

A--0 - 7 cm; dark gray (10YR 4/1) loamy sand; single grain; loose; clear smooth boundary.

Ap--7 to 15 cm; very dark grayish brown (10YR 3/2) loamy sand; weak medium subangular blocky structure; very friable; clear smooth boundary.

Bh--15 to 25 cm; dark brown (7.5YR 3/2) loamy sand; weak medium subangular blocky structure; very friable; There were a few reddish, firm, brittle zones; clear smooth boundary.

Bs--25 to 38 cm; strong brown (7.5YR 4/6) loamy sand; weak medium subangular blocky structure; very friable; clear smooth boundary.

BC1--38 to 53 cm; yellowish brown (10YR 5/4) loamy sand; few fine distinct strong brown (7.5YR 5/8) mottles;

weak medium subangular blocky structure; very friable; clear smooth boundary.

BC2--53 to 91 cm; yellowish brown (10YR 5/6) loamy sand; common medium distinct strong brown (7.5YR 5/8) mottles; weak medium subangular blocky structure; very friable; there were many mottles in the lower part of the horizon; clear smooth boundary.

C1--91 to 104 cm; pale yellow (5Y 7/3) sand; common fine distinct strong brown (7.5YR 5/6) mottles; single grain; loose.

PEDON 2:5
Soils Series: Atsion
Soil Survey # S90-MD-047-008
Description Type: full pedon description
Geographically Associated Soils: Evesboro, K l e j , Berryland
Location: Pocomoke State Forest; on Old Furnace Rd., 4.75 miles W of Rt. 12, on the N side of the road.
Latitude: 38-12-54-N
Longitude: 075-31-30-W
Classification: sandy, siliceous, mesic Aeric Haplaquod
Physiography: Dune in Coastal Plain
Geomorphic Position: on lower third, foot slope
Slope Characteristics: northeast facing convex horizontal, plane vertical
Elevation: 12 m MSL
Precipitation: 124 cm udic moisture regime
MLRA: 153
Hydraulic Conductivity: very high
Air Temperature: Ann 13 C Sum 22 C Win 1 C
Drainage Class: poorly drained
Land Use: forest land not grazed
Particle Size Control Section: 25 to 101 cm
Parent Material: eolian-sand material
Diagnostic Horizons: 30 to 43 cm spodic
Described By: Margaret Condron, Martin Rabenhorst, Mark Elless
Date: 12/90

Oe--5 to 0 cm; abrupt smooth boundary.

A--0 to 10 cm; black (10YR 2/1) loamy sand; weak medium subangular blocky structure; very friable; clear wavy boundary.

E--10 to 17 cm; dark grayish brown (10YR 4/2) sand; single grain; loose; the horizon thickness ranged from 1-8 cm; clear smooth boundary.

Bh--17 to 30 cm; black (5YR 2/1) loamy sand; weak medium subangular blocky structure; friable; Deep lenses of the Bh material made up 20% of the pedon and extended to 85cm; clear wavy boundary.

Bhs--30 to 43 cm; dark reddish brown (5YR 3/3) loamy sand; massive; firm; this horizon was discontinuous and ranged from 0-18cm in thickness; clear wavy boundary.

BC--43 to 78 cm; yellowish brown (10YR 5/4) loamy sand; common fine and medium distinct dark yellowish brown (10YR 4/6) mottles; weak medium subangular blocky structure; friable; approximately 50-60% of the pedon had mottles, although there were zones 20-30 cm thick without mottles.

C1--78 to 99 cm; pale olive (5Y 6/3) sand; single grain; loose; this horizon was sampled with a bucket auger.

C2--99 to 144 cm; light yellowish brown (2.5Y 6/4) sand; single grain; loose; this horizon was sampled with a bucket auger.

C3--144 to 185 cm; dark grayish brown (2.5Y 4/2) sand; single grain; loose; this horizon was sampled with a bucket auger.

2Ab--185 to 195 cm; dark brown (10YR 3/3) loamy sand; This horizon was sampled with a bucket auger.

2AC--195 to 223 cm; very dark grayish brown (10YR 3/2) sand; single grain; loose; this horizon was sampled with a bucket auger.

PEDON 2:6
Soils Series: Berryland
Soil Survey # S90-MD-047-009
Description Type: full pedon description
Geographically Associated Soils: Evesboro, Klej, Atsion
Location: Pocomoke State Forest; on Old Furnace Rd., 4.75 miles W of Rt. 12, on the N side of the road.
Latitude: 38-12-54-N
Longitude: 075-31-30-W
Classification: sandy, siliceous, mesic Typic Haplaquod
Physiography: Dune in Coastal Plain
Geomorphic Position: on a slope & in a depression, toe slope of a nose slope
Slope Characteristics: northeast facing convex horizontal, plane vertical
Elevation: 12 m MSL
Precipitation: 124 cm udic moisture regime
MLRA: 153
Hydraulic Conductivity: very high
Air Temperature: Ann 13 C Sum 22 C Win 1 C
Drainage Class: very poorly drained
Particle Size Control Section: 25 to 101 cm
Parent Material: eolian-sand material
Diagnostic Horizons: 0 to 22 cm umbric, 45 to 104 cm spodic
Described By: Margaret Condron, Martin Rabenhorst, Mark Elless
Date: 12/90

Oe--5 to 0 cm; clear smooth boundary.

A--0 to 22 cm; black (7.5YR 2/0) loamy sand; weak medium granular structure; friable; clear smooth boundary.

E--22 to 30 cm; dark grayish brown (10YR 4/2) sand; single grain; loose; clear wavy boundary.

Bh--30 to 45 cm; black (5YR 2/1) loamy sand; weak medium subangular blocky structure; friable; in 20-30% of the pedon there are 5-50cm tongues of Bh material that extend to 80-90cm depth; clear irregular boundary.

BC/Bh--45 to 76 cm; yellowish brown (10YR 5/4) loamy sand; weak medium subangular blocky structure; friable; A fairly continuous 3cm thick band of Bh material extends around the pedon. There are also vertical and diagonal rods of Bh material that may be along old root channels.

BC2--76 to 104 cm; brown to dark brown (10YR 4/3) sand; this horizon was sampled with a bucket auger..

BC3--104 to 139 cm; pale olive (5Y 6/3) sand; This horizon was sampled with a bucket auger.

C1--139 to 175 cm; light olive gray (5Y 6/2) sand; this horizon was sampled with a bucket auger.

C2--175 to 205 cm; light olive gray (5Y 6/2) sand; this horizon was sampled with a bucket auger.

APPENDIX B. WATER TABLE AND TOPOGRAPHIC TRANSECT DATA FROM THE TWO SITES

Site 1

Date	1	2	3	4	5	6	7	8	9
	depth below ground surface (meters)								
3/28/89	0.53	0.36	0.10	-0.14	0.09	0.66	0.41	0.14	0.03
4/6/89	0.31	0.24	0.05	-0.10	0.03	0.48	0.21	0.09	0.01
4/11/89	0.34	0.36	0.11	-0.10	0.08	0.56	0.41	0.14	0.03
4/16/89	0.36	0.28	0.09	-0.10	0.06	0.33	0.28	0.10	0.01
4/27/89	0.51	0.41	0.08	-0.06	0.15	0.74	0.56	0.20	0.05
5/2/89	0.42	0.36	0.16	-0.08	0.16	1.40	0.48	0.15	0.05
5/9/89	0.57	0.48	0.21	-0.04	0.22	0.89	0.65	0.33	0.09
5/25/89	0.65	0.59	0.31	0.01	0.36	1.00	0.70	0.25	0.10
6/1/89	0.81	0.71	0.51	0.30	0.55	1.12	0.80	0.32	0.14
6/12/89	0.88	0.83	0.65	0.49	0.64	1.23	0.88	0.37	0.21
6/21/89	0.72	0.66	0.48	0.21	0.53	1.08	0.71	0.28	0.11
7/25/89	0.86	0.73	0.61	0.37	0.66	1.14	0.82	0.32	0.13
8/15/89	0.39	0.31	0.05	-0.06	0.02	0.52	0.32	0.11	-0.02
9/10/89	0.79	0.71	0.42	0.26	0.54	1.25	0.84	0.27	0.15
10/2/89	0.26	0.20	0.03	-0.20	0.10	0.65	0.03	0.02	-0.03
11/2/89	0.54	0.49	0.21	-0.05	0.31	0.90	0.60	0.07	0.04
12/17/89	0.54	0.42	0.19	-0.08	0.25	0.89	0.57	0.01	0.00
1/8/90	0.48	0.36	0.10	0.20	0.79	0.55	0.17	0.01	-0.02
2/5/90	0.39	0.30	0.00	-0.21	0.10	0.60	0.38	0.05	-0.03
2/19/90	0.35	0.25	0.00	-0.21	0.10	0.65	0.41	0.07	-0.03
3/12/90	0.52	0.42	0.11	-0.13	0.21	0.86	0.63	0.16	0.00
4/20/90	0.46	0.41	0.13	-0.06	0.21	0.86	0.59	0.05	0.00
5/30/90	0.36	0.31	0.06	-0.15	0.08	0.56	0.32	0.11	-0.03
6/22/90	0.69	0.69	0.47	0.18	0.53	1.07	0.78	0.26	0.08

Elevation and lateral distance between wells(meters)

	1	2	3	4	5	6	7	8	9
Surface	12.19	12.11	11.88	11.68	11.88	12.31	11.75	11.22	10.98
Lateral	11.90	31.10	43.60	65.50	75.70	105.60	136.10	165.60	195.80

Site 2

Date	1	2	3	4	5	6
	depth below ground surface (meters)					
4/16/89	2.82	1.29	0.24	0.15	0.05	-0.05
3/28/89	3.00	1.44	0.44	0.35	0.21	0.08
4/11/89	NA	NA	0.30	0.22	0.11	0.00
4/16/89	2.82	1.29	0.24	0.15	0.05	-0.05
4/27/89	NA	NA	0.47	0.38	0.28	0.16
5/2/89	NA	NA	0.46	0.31	0.21	0.11
5/9/89	3.01	1.64	0.57	0.53	0.37	0.28
5/25/89	NA	NA	0.72	0.64	0.54	0.42
6/1/89	3.21	1.88	0.84	0.76	0.67	0.55
6/12/89	3.41	2.02	0.99	0.89	0.79	0.66
6/21/89	3.36	1.99	0.90	0.81	0.68	0.56
7/25/89	3.49	2.14	1.16	0.98	0.94	0.83
8/15/89	2.67	1.31	0.29	0.17	0.06	0.04
9/10/89	3.10	1.71	0.67	0.62	0.59	0.43
10/2/89	2.98	1.58	0.32	0.20	0.07	-0.04
11/2/89	3.15	1.79	0.62	0.52	0.36	0.23
12/17/89	3.13	1.74	0.61	0.50	0.36	0.22
1/8/90	2.94	1.54	0.47	0.41	0.24	0.12
2/5/90	3.08	1.52	0.32	0.26	0.07	-0.02
2/19/90	3.06	1.48	0.33	0.19	0.10	-0.02
3/12/90	3.11	1.69	0.54	0.47	0.32	0.21
4/20/90	3.01	1.60	0.53	0.46	0.31	0.16
5/30/90	3.00	1.39	0.28	0.21	0.08	-0.03
5/30/90	3.11	1.75	0.80	0.75	0.66	0.55

Elevation and lateral distance between wells(meters)

Surface	13.53	12.28	11.29	11.22	11.10	11.01
Lateral	20.00	39.30	55.40	68.30	83.10	102.40

APPENDIX C. CHEMICAL AND PHYSICAL DATA FROM THE NINE PEDONS SAMPLED

Pedon	Horizo	Depth (cm)	Fed	Fep	Feo	Ald	Alp	Alo	Ct	Cp	Fep+Alp/ %Clay	Cp+Alp/ %Clay	Fep+Alp/ Fed+Ald	CEC pH 8.2	ODOE	NaF pH	%Sand	%Silt	%Clay	BD
			g/kg																	g/cm3
1:1	Oe	6-0																		
	A	0-12	2.0	0.1	0.1	0.1	0.2	0.2	27.8	5.5	0.02	0.40	1.00	17.2	0.012	6.95	95.1	3.5	1.4	0.86
	E	12-21	0.2	0.1	0.0	0.0	0.0	0.0	4.4	2.2	0.02	0.19	1.00	9.5	0.010	7.45	93.6	5.2	1.2	1.57
	Bh	21-25	2.2	1.8	2.4	0.9	0.9	1.0	11.8	8.4	0.08	0.26	0.87	15.8	0.460	8.10	89.5	7.0	3.5	1.20
	Bhs	25-31	4.4	3.0	1.6	4.7	4.0	2.8	19.4	16.8	0.16	0.46	0.77	30.3	0.436	10.70	86.4	9.1	4.5	
	Bs	31-44	3.2	1.4	3.5	1.9	1.4	5.8	3.4	2.6	0.09	0.13	0.55	10.4	0.020	10.10	88.6	8.2	3.1	1.40
	BC	44-104	2.3	1.4	1.0	0.7	0.6	0.6	1.0	1.2	0.06	0.05	0.67	7.5	0.006	8.95	94.6	2.1	3.3	1.62
	C	104-12	0.3	0.1	0.0	0.1	0.2	0.7	0.1	0.1	0.02	0.02	0.75	2.0	0.001	8.40	98.0	0.4	1.6	1.62
1:3	Oe	5-0																		
	A	0-19	0.1	0.1	0.1	0.2	0.3	0.2	32.7	8.2	0.02	0.41	1.33	21.7	0.004	6.75	93.9	4.0	2.1	1.13
	E	19-53	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.8	0.00	0.01	0.00	0.0	0.001	7.80	95.6	3.6	0.8	1.58
	BE	53-58	0.0	0.1	0.0	0.5	0.8	0.6	8.2	6.0	0.02	0.12	1.80	7.6	0.148	7.63	81.8	12.6	5.6	1.82
	Bh	58-72	0.0	0.1	0.0	1.8	2.2	2.2	16.6	16.6	0.04	0.36	1.28	23.5	0.680	9.25	92.7	2.1	5.2	1.49
	Bhsm1	72-99	0.0	0.0	0.0	2.1	2.2	2.4	10.4	9.6	0.10	0.58	1.05	22.4	0.455	10.53	93.7	4.1	2.2	1.72
	Bhsm2	99-117	0.0	0.0	0.0	1.7	1.5	2.1	8.7	9.0	0.06	0.39	0.88	17.2	0.814	9.70	96.5	0.9	2.7	1.68
	Bhs	117-17	0.0	0.0	0.0	0.8	0.7	0.8	6.4	7.0	0.05	0.54	0.88	9.2	0.354	9.25	98.0	0.6	1.4	
	Bs	170-22	0.0	0.0	0.0	0.4	1.2	0.6	3.4	3.6	0.08	0.33	3.00	6.3	0.170	8.95	98.1	0.5	1.5	
	BC	220-25	0.0	0.0	0.0	0.3	1.6	0.5	1.9	2.4	0.17	0.43	5.33	2.6	0.068	9.23	98.0	1.1	0.9	
	C	255-28	0.0	0.0	0.0	0.4	1.4	0.8	1.8	2.1	0.05	0.12	3.50	0.0	0.028	9.62	95.2	1.9	2.9	
	2C2	285-29	0.1	0.2	0.0	1.2	3.2	1.8	4.1	3.4	0.03	0.07	2.62	4.6	0.044	10.02	74.3	15.6	10.1	
1:5	Oe	6-0																		
	A	0-22	0.3	0.2	0.2	0.3	0.6	0.4	21.1	7.2	0.04	0.34	1.33	15.3	0.014	6.95	92.8	5.0	2.3	1.24
	E	22-50	0.0	0.0	0.0	0.0	0.0	0.0	1.8	1.0	0.00	0.07	0.00	4.9	0.008	7.70	93.5	5.1	1.4	1.57
	Bh1	50-58	0.1	0.1	0.1	2.7	4.4	3.2	35.4	25.7	0.04	0.24	1.61	35.9	0.801	7.82	80.8	6.6	12.6	1.30
	Bhsm	58-81	0.1	0.2	0.2	4.8	7.5	5.5	28.0	25.0	0.11	0.47	1.57	28.4	0.748	11.14	84.9	8.2	6.9	1.48
	Bh2	81-114	0.1	0.0	0.0	0.7	3.7	0.8	9.5	7.7	0.09	0.29	4.63	9.0	0.221	7.65	95.3	0.7	4.0	1.58
	Bh3	114-16	0.0	0.0	0.0	0.4	0.8	0.5	6.2	5.5	0.04	0.32	2.00	4.4	0.110	7.95	97.5	0.6	1.9	
	Bhs	164-20	0.0	0.0	0.0	0.4	0.7	0.5	4.2	4.2	0.04	0.25	1.75	2.8	0.101	8.45	97.8	0.2	2.0	
	Bs	209-25	0.0	0.0	0.0	0.6	0.8	0.7	4.2	4.4	0.04	0.25	1.33	5.4	0.132	9.33	97.8	0.1	2.1	
	BC	254-29	0.0	0.0	0.0	0.2	0.6	0.4	1.8	2.2	0.04	0.14	3.50	0.7	0.040	9.05	97.9	0.1	2.0	

Pedon	Horizo	Depth (cm)	Fed	Fep	Feo	Ald	Alp	Alo	Ct	Cp	Fep+Alp/ %Clay	Cp+Alp/ %Clay	Fep+Alp/ Fed+Ald	CEC pH 8.2	ODOE	NaF pH	%Sand	%Silt	%Clay	BD
			---------- g/kg ----------																	g/cm3
1:6	Oe	4-0																		
	A	0-6	0.2	0.1	0.1	0.0	0.2	0.0	15.0	3.5	0.02	0.30	1.50	5.0	0.011	7.15	96.2	2.6	1.2	
	E	6-14	0.3	0.2	0.1	0.0	0.2	0.0	6.4	2.0	0.03	0.18	1.33	0.5	0.017	7.60	95.6	3.2	1.2	1.49
	Bw	14-46	2.9	2.5	1.2	2.4	4.2	2.8	6.8	5.0	0.19	0.26	1.26	8.8	0.052	10.45	91.5	4.9	3.6	1.32
	BC1	46-91	1.4	1.0	0.3	0.6	1.1	0.6	1.3	1.0	0.06	0.06	1.05	0.5	0.008	9.05	91.9	4.4	3.7	1.52
	BC2	91-116	1.2	1.2	0.6	0.3	1.1	0.4	0.7	0.6	0.10	0.07	1.53	0.9	0.008	9.00	96.8	0.8	2.4	
	BC3	116-16	0.5	0.3	0.2	0.6	0.4	0.2	0.0	0.4	0.04	0.05	0.64	0.0	0.004	8.53	97.7	0.6	1.7	
	C	166-17	0.3	0.1	0.1	0.0	0.4	0.3	0.0	0.4	0.03	0.04	1.67	0.0	0.004	8.48	98.1	0.0	1.9	
1:7	Oe	0-4																		
	A	0-11	0.1	0.1	0.1	0.0	0.2	0.1	27.8	3.6	0.05	0.62	3.00	8.0	0.006	7.30	95.8	3.6	0.6	
	E	11-28	0.1	0.1	0.0	0.0	0.1	0.0	2.2	1.2	0.02	0.13	2.00	0.0	0.007	7.80	97.3	1.7	1.0	1.47
	Bh	28-34	3.8	3.6	3.7	2.4	2.4	2.6	18.3	13.7	0.14	0.37	0.97	19.3	0.456	9.68	90.0	5.7	4.3	1.24
	Bs	34-40	2.0	1.4	1.4	3.0	3.1	4.3	8.2	7.5	0.15	0.37	0.90	12.2	0.134	11.05	92.5	4.6	2.9	1.25
	BC1	40-59	1.8	1.2	0.4	1.0	1.6	1.2	1.3	1.5	0.07	0.07	1.00	2.6	0.008	9.45	92.3	3.4	4.3	1.54
	BC2	59-63	0.4	1.6	0.9	0.4	1.3	0.5	1.3	1.4	0.12	0.11	3.63	1.5	0.008	8.90	97.4	0.3	2.4	1.66
2:1	Oe	1-0																		
	A1	0-9	0.4	0.2	0.2	0.1	0.2	0.1	7.3	1.1	0.01	0.02	0.80	3.27	0.010	7.70	91.8	1.5	6.7	
	A2	9-20	1.6	0.6	0.5	0.3	0.5	0.4	4.2	1.4	0.01	0.03	0.58	3.31	0.008	8.12	90.9	1.5	7.6	1.42
	BA1	20-44	2.2	0.7	0.4	0.8	0.8	0.9	2.2	0.8	0.02	0.02	0.50	2.61	0.013	9.70	90.0	1.3	8.7	1.44
	BA2	44-69	3.0	0.7	0.3	0.6	0.6	0.5	2.2	0.8	0.02	0.02	0.36	2.19	0.017	6.90	90.6	0.8	8.6	
	Bt	69-98	4.5	1.1	0.5	0.8	2.6	0.8	1.0	0.6	0.04	0.03	0.70	4.72	0.020	9.12	88.2	2.3	9.5	1.57
	CB1	98-149	1.0	0.2	0.1	0.1	0.4	0.2	0.3	0.2	0.05	0.05	0.55	1.12	0.011	7.95	97.7	1.0	1.3	1.66
	CB2	149-19	1.2	0.3	0.1	0.1	0.5	0.3	0.3	0.3	0.06	0.06	0.62	0.00	0.008	8.05	97.5	1.2	1.3	1.66
	C1	194-24	1.2	0.3	0.1	0.1	0.3	0.2	0.3	0.3	0.04	0.04	0.46	0.45	0.008	8.00	97.6	1.2	1.2	
	C2	249-28	1.0	0.2	0.1	0.1	0.3	0.2	0.0	0.3	0.04	0.04	0.45	0.00	0.007	8.10	97.7	0.9	1.4	
	C3	284-31	1.3	0.4	0.4	0.1	0.3	0.2	0.4	0.3	0.05	0.04	0.50	0.00	0.009	8.20	97.5	1.0	1.5	
	C4	313-35	1.1	0.4	0.3	0.1	0.3	0.2	0.2	0.3	0.04	0.04	0.58	0.00	0.008	8.20	97.9	0.5	1.6	

Pedon	Horizon	Depth (cm)	Fed	Fep	Feo	Ald	Alp	Alo	Ct	Cp	Fep+Alp/ %Clay	Cp+Alp/ %Clay	Fep+Alp/ Fed+Ald	CEC pH 8.2	ODOE	NaF pH	%Sand	%Silt	%Clay	BD
			g/kg																	g/cm3
2:3	Oe	4-0																		
	A	0-7	1.3	0.8	1.2	0.3	0.4	0.3	11.9	2.6	0.04	0.11	0.92	7.29	0.047	7.75	92.9	4.4	2.7	
	Ap	7-15	1.8	1.2	1.8	0.7	1.1	0.7	11.8	4.9	0.08	0.22	0.92	9.07	0.083	8.10	92.5	4.8	2.8	
	Bh	15-26	3.3	2.4	2.8	3.2	4.8	4.5	13.4	7.7	0.20	0.35	1.11	12.79	0.136	11.05	89.0	7.4	3.6	1.08
	Bs	26-39	4.2	2.4	2.9	2.1	3.0	3.6	4.8	2.8	0.16	0.17	0.86	6.25	0.032	10.65	89.0	7.6	3.4	1.29
	BC1	39-53	3.2	1.7	1.9	1.3	1.8	1.8	1.6	0.8	0.04	0.03	0.78	4.39	0.012	9.70	86.2	4.7	9.1	1.48
	BC2	53-91	6.6	2.9	1.1	1.9	5.5	1.0	1.2	0.4	0.08	0.06	0.99	5.80	0.011	9.55	85.1	4.5	10.4	1.53
	C1	91-105	0.4	0.2	0.1	0.0	0.1	0.0	0.0	0.0	0.05	0.02	0.75	0.00	0.007	8.05	99.0	0.3	0.7	
2:5	Oe	5-0																		
	A	0-10	0.1	0.1	0.1	0.0	0.1	0.1	13.3	2.9	0.02	0.24	2.00	8.07	0.010	7.15	93.8	5.0	1.2	1.55
	E	10-17	0.0	0.0	0.0	0.0	0.0	0.0	2.8	0.9	0.00	0.06	0.00	1.82	0.008	7.53	92.9	5.7	1.5	1.70
	Bh	17-30	0.3	0.4	0.2	5.6	8.1	5.9	34.2	30.8	0.11	0.49	1.44	37.80	1.132	11.25	85.7	6.4	7.9	1.20
	Bhs	30-43	0.5	0.3	0.2	2.6	3.6	3.0	9.0	8.3	0.10	0.29	1.26	12.96	0.186	11.37	89.6	6.3	4.1	1.53
	BC	43-80	0.9	0.6	0.2	0.8	2.6	1.1	2.0	1.9	0.07	0.10	1.88	3.45	0.024	10.58	91.6	4.0	4.4	1.64
	C1	80-100	0.1	0.2	0.0	0.4	1.8	0.8	1.0	0.8	0.07	0.09	4.00	2.98	0.013	10.35	96.5	0.7	2.8	
	C2	100-14	0.0	0.0	0.0	0.1	0.8	0.4	0.7	0.7	0.04	0.08	8.00	1.12	0.010	9.95	96.7	1.3	2.0	
	C3	145-18	0.0	0.0	0.0	0.1	0.5	0.4	0.6	0.7	0.02	0.05	5.00	1.49	0.010	9.55	97.1	0.4	2.5	
	2Ab	185-19	0.0	0.2	0.0	1.8	3.1	1.8	16.4	7.7	0.05	0.15	1.83	10.46	0.065	10.75	78.8	14.0	7.3	
	2AC	195-22	0.1	0.1	0.0	0.2	0.9	0.8	1.4	1.6	0.04	0.09	3.33	4.93	0.018	9.80	96.5	0.7	2.9	
2:6	Oe	5-0																		
	A	0-23	0.2	0.2	0.2	0.4	0.8	2.7	43.0	6.9	0.02	0.16	1.67	35.85	0.020	6.80	88.6	6.8	4.7	1.15
	E	23-31	0.0	0.0	0.0	0.0	0.0	0.1	4.0	2.6	0.00	0.16	0.00	9.69	0.008	7.55	92.4	5.9	1.7	
	Bh	31-45	0.1	0.1	0.1	6.1	6.4	8.8	36.2	19.7	0.09	0.37	1.05	41.89	0.770	11.50	84.0	8.9	7.1	1.24
	BC/Bh	45-75	0.2	0.1	0.1	3.8	4.2	6.3	13.4	12.2	0.10	0.38	1.08	20.95	0.184	10.95	86.2	9.5	4.3	1.61
	BC2	75-105	0.0	0.1	0.0	0.4	1.4	1.0	1.9	1.6	0.06	0.13	3.75	4.39	0.035	10.25	97.3	0.4	2.3	
	BC3	105-14	0.0	0.0	0.0	0.0	0.9	0.4	0.6	0.6	0.07	0.11	0.00	3.48	0.010	9.45	97.9	0.8	1.3	
	C1	140-17	0.0	0.2	0.0	0.1	2.5	0.1	0.8	0.7	0.26	0.33	27.00	2.16	0.010	9.52	98.4	0.6	1.0	
	C2	175-20	0.0	0.0	0.0	0.0	1.4	0.1	0.3	0.5	0.11	0.15	0.00	0.00	0.010	8.45	95.5	3.3	1.2	