To the Graduate Council:

I am submitting herewith a thesis written by Gerard A. McGuire entitled "The Classification and Genesis of Soils with Spodic Morphology in the Southern Appalachians." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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THE CLASSIFICATION AND GENESIS OF SOILS WITH SPODIC MORPHOLOGY IN THE SOUTHERN APPALACHIANS

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Gerard A. McGuire

June 1983

ACKNOWLEDGMENTS

The author wishes to express his sincere gratitude and appreciation to:

Dr. D. A. Lietzke for serving as the graduate committee chairman, for initiating this research, and for his personal guidance and encouragement throughout the graduate program;

Dr. R. J. Lewis and Dr. R. J. Miles who served on his graduate committee and for the constructive criticisms and suggestions on the earlier draft;

Malaysian Government for granting a scholarship;

His wife, Jenny, for her love, patience, sacrifices and inspiration;

His two sons, Andrew and Brian, for their love and understanding;

His parents and his brother and sister for their encouragement.

ABSTRACT

Soils with Bs/Bhs horizonation have been known to occur in the Southern Appalachians. Limited soil data, particularly chemical data, have made it difficult to classify these soils in the present classification system using the spodic horizon chemical criteria of Soil Taxonomy (105). This study attempts, in part, to correct this deficiency.

Eleven pedons were selected from sites in Tennessee and North Carolina. Laboratory analyses were carried out to determine pH, particle-size distribution, extractable bases, acidity, aluminum, and iron. Two field techniques for spodic horizon identification were also evaluated.

The presence of coarse fragments causes tongueing of organic matter in the E horizon and varying expressions of spodic horizon development across the pedon face in the B horizon. The Bs/Bhs horizon in most pedons is characterized by aluminum, iron, organic carbon, and clay accumulation.

The present fraser-fir, red spruce and rhododendron vegetation which promotes conditions favorable to the formation of Bs/Bhs horizons interacts with the more potent influence of parent material as a source of clay and cations in producing varying degrees of spodic horizon development in the soils studied.

Of the 11 pedons used in this study, two pedons met all the present chemical criteria for Bs/Bhs horizon identification. The most

critical spodic horizon criterion is the pyrophosphate aluminum and iron to clay ratio of ≥ 0.2. The high clay content in the Bs/Bhs of most pedons is responsible for reducing the measured value to less than 0.2.

Two pedons were classified as Haplorthods while the remaining nine pedons were classified as either Dystrochrepts or Haplumbrepts.

Proposals were made to overcome some of the problems that were encountered with the use of the present classification system to classify soils which showed evidences of spodic horizon expression. These proposals include lowering the pyrophosphate aluminum and iron to clay ratio from ≥ 0.2 to ≥ 0.1 for soils with cambic horizons that have a loamy particle-size class in the Bs/Bhs horizons, creating spodic subgroups in Inceptisols and eliminating the depth requirement for frigid soils. These proposals need further study before any consideration is given to their inclusion in Soil Taxonomy (105).

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CHAPTER I

INTRODUCTION

Spodosols are one of the ten soil orders in Soil Taxonomy (105). The concept of Spodosols and spodic horizons is derived from the Greek 'spodos' for ashes and is comparable to the Russian name "Podzol' in which the 'zola' is Russian for ashes (100).

Spodosols in the Appalachian Region have been investigated by a number of workers. De Kimpe and Martel (42) and Stanley and Ciolkosz (107) have classified soils with Bs/Bhs morphology in the Northern and Central Appalachian Region, respectively, using the present chemical and field criteria in Soil Taxonomy (105). In the Southern Appalachian Highlands of Tennessee, North Carolina, and Virginia the existence of soils with spodic morphology has been noted by a number of researchers and their findings have been well documented (31, 57, 76, 106, 116). However, with the rigid spodic horizon criteria in Soil Taxonomy (105), many soils originally classified as Spodosols in the Southern Appalachian Highlands may not meet all the morphological physical, and chemical criteria of Spodosols.

The objectives of this study are:

1. to evaluate soils with Bs/Bhs morphology using the spodic horizon criteria in Soil Taxonomy (105),
2. to classify soils based on the present Soil Taxonomy (105) criteria,

3. to determine the problems (if any) faced in trying to classify soils with Bs/Bhs morphology as Spodosols, and

4. to evaluate the Bartlett (9) and Holmgren[1] spodic horizon field tests for their ability to differentiate spodic horizons from non-spodic horizons utilizing the spodic criteria of Soil Taxonomy (105).

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[1]G. Holmgren. 1980. A field procedure for assessing spodic characteristics. USDA. Lincoln, Nebr. (unpublished).

CHAPTER II

LITERATURE REVIEW

Introduction

Spodosols have been intensively studied within the United States. In the east, Spodosols have been known to occur from Maine and eastern Canada, along the mountains of the Appalachians, to low, wet coastal plains along the Atlantic coast (105) while in the west, Spodosols occur from northern California to Alaska (90). One of the reasons that Spodosols are intensively studied is that the process of soil formation as characterized by the transportation and deposition of material, both organic and inorganic, is morphologically but not always chemically apparent. This distinct morphology is best illustrated by the striking color spectra--from the ash-gray E horizon to the dark reddish brown Bs/Bhs, (Bir/Bhir) horizon. Although the process of spodic horizon formation plays an important role in the formation of Spodosols, it may also be a driving force in the formation of other soils such as Gray Wooded (Boralfs), other Gray-Brown Podzols (Alfisols), and Red-Yellow Podzolic (Ultisols) (108) and certain Entisols and Inceptisols.

Spodosol Morphology

A typical Spodosol profile displays distinct color differences between eluvial and illuvial horizons. Freshly fallen plant litter forms the uppermost layer. Below this layer is a dark brown partially decomposed organic horizon that is typical of most soils with spodic morphology. The underlying eluvial E horizon has very little organic matter, clay, iron, and aluminum. The spodic horizon (Bs/Bhs) which underlies the eluvial horizon is an illuvial horizon of organic carbon, aluminum and/or iron accumulation (45, 73, 92, 108, 117). The distribution of aluminum, iron, and organic carbon with depth shows a minimum in the E horizon, a maximum in the upper B horizon and a decrease with depth (87, 114). Aluminum tends to accumulate slightly deeper in the Spodosol sequum than iron (3, 26, 47, 89, 114). The spodic horizon may be very friable to loose with many roots, to very cemented with few roots (40, 41). The dark spodic horizon grades gradually into the relatively unaltered parent rock. Soil structures range from none to crumb and granular at the surface Oa and A horizons to weak subangular blocky in the spodic and underlying horizons (105).

The order of translocation of ions from the A to the B horizon is usually aluminum > iron > organic matter (91). Several authors (26, 47, 92, 114) have noted that the spodic horizon showed an increase in clay content when compared to the overlying E or the underlying parent material. In this connection, Wang and Rees (113) showed that in most of the 40 soils with spodic morphology, clay increase in the B horizon relative to the A met the requirements of a Bt horizon. Similar findings have also been reported by Franzmeier and Whiteside (47) and by Wang and McKeague (114). However, Brydon (26) is of the opinion that even though there was clay illuviation to the underlying spodic horizon there were no orientated clay skins, generally associated with the Bt horizon. He suggested that the illuviated organic matter and sesquioxides may have prevented the formation of clay skins or masked them.

Mechanism of Spodic Horizon Formation

The establishment of a spodic horizon in which organic matter, aluminum, and/or iron have accumulated (4, 7, 20, 29, 42, 48, 49, 50, 67, 71, 108, 114, 117) has stimulated many studies designed to elucidate the mechanisms for the translocation of sesquioxides.

The four mechanisms (theories) which have been hypothesized to account for the movement of iron and aluminum from the A horizons and subsequent reprecipitation in the B horizons are:

1. mutual flocculation of positively charged colloidal sesquioxides and negatively charged organic matter,
2. flocculation of sesquioxides by changes in redox potential or in pH,
3. organo-metallic complexes,
4. proto-imogolite.

The movement of positively charged sesquioxides with the decomposition products of organic materials has been recognized by numerous authors (1, 20, 29, 39, 67, 83, 111, 117) as one of the mechanisms for the formation of a spodic horizon. The strong acidity created by the decomposition products of organic matter would bring into solution sesquioxides which would move lower in the profile where higher reaction would cause their precipitation. De Coninck (40) noted that the amount of iron and aluminum at the surface horizon would determine the mobility of organic matter. A sufficient amount of the two ions would lead to immobilization of organic matter while the lack of iron and aluminum would contribute to the migration of organic matter deeper in the profile. Anderson et al. (3) have theorized that during the formation of an Iron Humus Podzol (Spodosol) the colloidal humus moves through the unreactive E horizon and subsequently precipitates on positively charged aluminum, silicon, and iron particles in the underlying spodic horizon.

The second theory of spodic horizon formation is the flocculation of sesquioxides at depth due to changes in pH. Byers et al. (30) suggested that the high sesquioxides and organic matter contents in the upper B horizon is due to the less acidic as well as the oxidizing nature of the B horizon which renders iron less soluble. However, data given by Deb (39) suggest that the adsorption of iron by sols from various complex salts of iron and organic acids is not influenced by pH. Results almost similar to Byers et al. (30) have been reported by other investigators (47, 114).

The third mechanism of spodic horizon formation is the formation of organo-metallic complexes between iron, aluminum, and organic matter. Evidences of such complexes in spodic horizon formation have been very well documented (4, 7, 20, 22, 23, 24, 38, 40, 42, 49, 52, 56, 60, 63, 65, 71, 85, 99, 108, 110, 115, 117). The role of organic acids from the decomposition of organic matter cannot be overlooked.

Gallagher (51) and Gallagher and Walsh (52) found that metallic oxalates, notably those of aluminum, iron, and even silica were formed when extracts of podzol B horizons were mixed with oxalic acid. This high extracting power of oxalic acid is due to the close proximity of the two carboxyl groups (99). However, significant deviation from the preceding results has been published by early Russian pedologists, as read in Glinka (54), and by Messenger (85). Messenger (85) found that the solvating and chelating properties of extractable aluminum and crenic acid are important in the formation of the spodic horizon. Both humic and fulvic acid have also been reported to form complexes with sesquioxides. Schnitzer and Skinner (98) demonstrated the formation of stable complex compounds of iron and aluminum with humic acid extracts from Spodosols. Levashkevich (72) showed that the amount of humic acid adsorbed by the precipitates of iron and aluminum is more than that of fulvic acid. Humic acid tends to accumulate in the upper part of the spodic horizon (Bhs) (3, 78). It has been shown to accumulate in unhumified organic matter in surface horizons of neutral to acid soils (99). Fulvic acid, on the other hand, has the larger capacity to transfer iron and aluminum and it forms more stable bonds with aluminum hydroxide gels than with iron hydroxide gels (72). In addition, fulvic acid forms stable water soluble complexes with di- and trivalent metals (13).

A new hypothesis of spodic horizon formation has been proposed by Farmer et al. (45) who pointed out that aluminum is translocated from the eluvial to the illuvial horizon as a proto-imogolite which is a soluble hydroxy-aluminum orthosilicate. Proto-imogolite has been found in spodic horizons of Canadian (28) and Scottish (45, 109) Spodosols.

Factors of Spodosol Formation

The Vegetation Factor in Spodosol Formation

Latimer (70) noted that conifers usually provide favorable conditions for Spodosol development because conifer leaves have relatively high acidity and a low basic buffer content when compared to other types of vegetation (75). This is in agreement with the conclusions of Messenger et al. (86) and Sneddon et al. (103). Wilde (115), in a similar way, pointed out that Spodosols support the "taiga" forest, composed chiefly of conifers--spruce, fir, hemlock, pine, and larch. Buol et al. (29) were able to show that in the Northern Lake states Spodosols are usually found in a hemlock forest while a Spodosol over an Alfisol is usually found in a hemlock-northern hardwood forest. However, in the case of spruce--fir vegetation and the occurrence of Spodosols, the simple vegetation--soil morphology relationship may be an exception rather than a rule because Inceptisols are associated with spruce-fir (37, 116). Spodosols also occur under deciduous forest (105, 115) and under savanna and palm as well (105). The occurrence of Spodosols in deciduous forests is limited to aspen, birch, alder, mountain ash, and willows in frigid or colder environments.

The most important aspects of vegetation in Spodosol formation are the specific decomposition products associated with different kinds of forest litter. Litter from conifers are less vulnerable to decay (115), lower in bases, but higher in iron and aluminum, as compared to deciduous litter. This would promote a condition whereby the decomposition products of coniferous forest litter would cause the translocation and, eventually, the deposition of sesquioxides in the B horizon (37, 42, 85). Bloomfield in his series of publications (14, 15, 16, 17, 18, 19), working with acqueous extracts from pine (*Pinus sp.*), New Zealand Kauri (*Agathis australis*), rimu (*Dacrydium cupressinum*), larch, ash leaves or needles (Fraxinus excelsior) was able to demonstrate that the extracts were capable of causing the non-biological solution of ferric and aluminum oxides. The ferric iron is reduced to the ferrous state and, with the dissolved aluminum, is able to form organo-metallic complexes. Similar results with leachates from deciduous leaves as well have been reported by Lutwick et al. (74) and Schnitzer and DeLong (97). DeLong and Schnitzer (43) demonstrated that poplar (*Populus grandidentata*) leaf extract is capable of complexing a greater amount of aluminum than iron.

The Climate Factor in Spodosol Formation

Spodosols are known to occur in all types of climates (105). Each pedon has a characteristic temperature regime measured in terms of the mean annual soil temperature (MAST) (102, 105) taken at a depth of 50 cm (105). In frigid or warmer soil temperature regimes, the spodic horizon must be recognized by field and chemical criteria below a depth of 12.5 cm. This depth requirement is, however, waived for a cryic or colder soil temperature regime (105). Data given by Stanley[2] and by Stanley and Ciolkosz (107) suggest that aluminum, iron, and carbon tend to accumulate in frigid temperature regime areas resulting in a more strongly expressed Spodosol as compared to mesic areas on upland landforms. The assumption being that in frigid areas there would be less decomposition of illuvial humus, hence, more organo-metallic complexes could be formed. This is in agreement with the results of Holzhey and Witty (59) who found higher sodium pyro-phosphate extractable iron and aluminum and a higher index of accumu-lation in frigid soils than in mesic soils. However, the process of spodic horizon formation in thermic and hyperthermic soils is probably different due to different vegetation, to moisture regime (most are Aquods), and to the lack of iron and very little aluminum in the spodic horizon.

The Time Factor in Spodosol Formation

Spodosols do not take long to form. Under optimum conditions, a spodic horizon can form in a few hundred (105) to several thousand years according to Franzmeier and Whiteside, as mentioned by Buol et al. (29). Tamm, as cited by Jenny (64), estimated that a normal pod-zol with 4 inches of raw humus, 4 inches of E (A2) horizon, and from 10 to 20 inches of B horizon requires from 1000 to 1500 years to

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[2]S. R. Stanley. 1979. Classification and genesis of Spodosols in Pennsylvania. M. Sc. Thesis, Penn. State Univ. (unpublished).

develop. The converse is also true. A spodic horizon can be destroyed by plowing, by erosion, and by the addition of lime and fertilizer (105).

The Parent Material Factor in Spodosol Formation

Soils which have a parent material rich in calcium will resist the formation of a spodic horizon until weathering and leaching have reduced the calcium content (37, 66). Strong morphological development of the spodic horizon has been noted in parent materials that are coarse-textured (105), acid (31, 105) and have a low clay (105) and iron content (44, 91). Spodosols developed from reddish-brown, high iron content parent materials present problems in recognition and classification because of their reddish natural color. Such natural colors would mask the expression of spodic morphological characteristics (91).

The Relief Factor in Spodosol Formation

Spodosols occur in nearly level to undulating sand plains along the Atlantic (105) and Pacific coasts (90), in steep mountainous areas (31, 37, 42, 57, 76, 95, 107), and in glaciated boreal forest regions of North America. The relationship between microtopography and soils has been used successfully in field mapping of Spodosols. Brandon et al. (21) attributed the difference in the brittleness of some Haplaquods to the occurrence of tree-throw microtopography. Wolfe (116) was able to isolate Spodosols in the Great Smoky Mountains as occurring on upland mountain summit land forms underlain by sandstone and where the soil surface shows no evidence of windthrow. Nettleton et al. (90), in their work along the Southwest Oregon coast, were able to distinguish between Inceptisols and Spodosols just by their locations on the sand dune; Inceptisols occurred on active sand dunes while Spodosols were found on stable land forms.

Chemical Identification of Spodic Horizons

The content and differentiation of amorphous and crystalline iron and aluminum oxides in soils with spodic morphology has received wide attention as a criterion for the classification of Spodosols. Several methods have been widely utilized.

Among the more widely used extraction methods is acid ammonium oxalate. Acid ammonium oxalate procedure has been reported by Lietzke[3] as the easiest to use as compared to that of citrate-dithionite and pyrophosphate-dithionite in differentiating amorphous from crystalline forms of iron in spodic horizon. McKeague and Day (81) felt that oxalate extractable aluminum of 0.6 percent or greater gave an excellent separation of podzol B horizons (spodic-like B horizons) from other soil horizons. The acid ammonium oxalate is capable of extracting amorphous forms of aluminum and iron and not crystalline iron oxides that may occur in all horizons (69, 77, 80). Oxalate extractable aluminum has also been shown to be highly correlated with the pH-dependent C.E.C. values characteristic of spodic horizons (34). However, the data obtained by Rhoton et al. (96) and by Pawluk (93)

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[3]D. A. Lietzke. 1968. Evaluation of spodic horizon criteria, and classification of some Michigan soils. M. Sc. Thesis, Michigan State Univ. (unpublished).

suggest that acid ammonium oxalate removes amorphous and crystalline forms of iron oxide from the spodic horizon.

The use of sodium pyrophosphate and sodium dithionite-citrate have gained recognition as extractants in differentiating amorphous from crystalline compounds respectively. Mehra and Jackson (84) and Higashi et al. (55) found that dithionite-citrate buffered with sodium bicarbonate was most effective in the removal of more free iron oxides in addition to being the least destructive to silicate clays. A somewhat different view was furnished by McKeague and Day (80) who were of the opinion that the dithionite-citrate extraction values approximated the combined content of amorphous and crystalline iron oxides. Findings similar to those of McKeague and Day (80) have also been reported by Titova (110), Franzmeier et al. (49), and Lietzke.[4] However, Pawluk (93) advanced the opinion that the different forms of iron and aluminum cannot be assigned to specific extractions, but rather the extraction is affected by such things as particle size, speed of shaking, and the degree of crystallinity. This is in agreement with the findings of Basil and Fran (12) who concluded that no single test was reliable enough to act as a single criterion in differentiating the spodic horizon.

The view that sodium pyrophosphate extracts amorphous iron and aluminum and not crystalline iron oxides finds many supporters (2, 77, 78, 79). It should also be pointed out that opposing views have been

[4] Ibid.

reported. Several studies (49, 110) have indicated that sodium pyrophosphate failed to differentiate between the two forms of iron.

Preliminary results, so far, for the sodium fluoride test of Fieldes and Perrott (46), originally devised for allophane, are very encouraging when used in a field procedure to distinguish between spodic and cambic horizons (9). This field procedure is based on the assumption that reactive organic aluminum complexes are the distinguishing feature of Spodosols. In this reaction, the fluoride ions appear to bring aluminum hydroxide into solution, releasing hydroxyl ions and eventually causing a rise in pH (9, 27, 46, 62). More recently, Holmgren[5] has proposed a field procedure for distinguishing the spodic horizon based on his assumption that translocated organic matter--humic and fulvic acid, and aluminum--are the distinguishing features of Spodosols. Results obtained with the use of this procedure have agreed with field morphology in identifying spodic horizons except that in certain cases the maximum accumulation of aluminum may not be in the upper spodic horizon where carbon and iron tend to accumulate but in the lower part of the B horizon (89). The use of other methods/extractants like pH-dependent C.E.C. (10, 12, 35), pH in 1 mol NaF (12), potassium pyrophosphate (6, 11), oxalic acid (6), and sodium hydroxide-tetraborate (25, 55, 82) have been proposed to separate amorphous from crystalline iron and aluminum, but have so far not been accepted by others.

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[5]Holmgren. A field procedure for assessing spodic characteristics.

Criteria for Spodic Horizon Identification

Values and ratios used in Soil Taxonomy (105) to define the spodic horizon are summarized below:

1. field criteria
   a. some part of the spodic horizon must meet one or more of the spodic horizon requirements below a depth of $\geq$ 12.5 cm for frigid or warmer soil temperature. There is no depth requirement for cryic or pergelic soil temperature regime or
   b. an ortstein that is continuously cemented and > 2.5 cm thick or the particle-size class is sandy or coarse-loamy or
   c. cracked coatings on sand grains that are clearly recognizable.
2. laboratory criteria
   a. sesquioxide to clay ratio

$$\frac{\text{whole soil sodium pyrophosphate (pH 10) Fe + Al}}{\text{clay}} \geq 0.2$$

or

$$\frac{\text{sodium pyrophosphate Al + C}}{\text{clay}} \geq 0.2$$

   b. sesquioxide ratio

$$\frac{\text{sodium pyrophosphate Fe + Al}}{\text{dithionite-citrate Fe + Al}} \geq 0.5$$

c. combined index of accumulation of amorphous material $\geq$ 65.

It has been explicitly stated (105) that a strongly developed spodic horizon can be identified by using the field criteria alone. However, the practice of using laboratory criteria has become the standard identification practice in situations of less strongly developed Spodosols.

The $\geq$ 2.5 cm subhorizon thickness that is continuously cemented by some combination of organic matter with iron or aluminum or both was introduced in Soil Taxonomy (105) to distinguish the spodic horizon from the placic horizon. Although the placic horizon has very similar chemical properties to the spodic horizon, the former is much thinner, on the order of one to a few millimeters. The placic horizon has less than the 2.5 cm minimum thickness required for the field identification of a spodic horizon (100). Wang and Rees (113) pointed out that the rationale for imposing the sesquioxide to clay ratio has been to ensure that the amorphous aluminum and iron rather than high clay content played an important role in spodic horizon soil forming process.

Problems have arisen when applying the present criteria in classifying Spodosols. De Kimpe and Martel (42) sampled 10 profiles of soils with spodic morphology in the Appalachian Highlands of S.E. Quebec and adjacent Maine and found only five of the 10 soils with apparent spodic morphology met the Bs/Bhs horizon criteria of Soil

Taxonomy (105). They pointed out that the high clay content lowered the sesquioxide to clay ratio. Almost similar results have been provided by Joslin[6] who found that none of the seven pedons with Bs/Bhs morphology met the chemical criteria for a spodic horizon. The problems noted in the study were: low pyrophosphate extractable iron, high dithionite-citrate extractable iron and aluminum, depth requirement too restrictive, clay content too high, or the spodic horizon process is minimally expressed. Stanley[7] was only able to classify four of the 17 well-drained soils with Bs/Bhs morphology as Spodosols while Bartelli et al. (8) reported that 19 of the 43 soils sampled failed the chemical criteria of the spodic horizon; the Fe plus $Al_{(pyro)}$ to clay ratio was too low. More recently, Nettleton et al. (90) working along the southwest coast of Oregon found that four of the seven soils studied met the chemical criteria of Spodosols. In Great Britain, Ragg and Clayden, as cited by Avery et al. (5), were able to identify 12 of 78 representative British soils with Bs/Bhs morphology as Spodosols. Avery et al. (5), working on some soils with spodic morphology in Upland Britain, found that only one of the 10 pedons sampled met the chemical criteria for Spodosols. The most significant conclusions from Avery's data were that the color requirements--the lowest value, the reddest hue, and the highest chroma in the upper part of the

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[6]R. V. Joslin. 1978. Selected pedons in Maine as they relate to spodic horizon criteria in Soil Taxonomy. M. Sc. Thesis, Univ. Vermont (unpublished).

[7]Stanley. Classification and genesis of Spodosols in Pennsylvania.

spodic horizon--exclude some soils otherwise identifiable as Spodosols and that the chemical criteria for the spodic horizon seem unduly restrictive. Evidence that problems exist with the application of the spodic horizon criteria in Canada is given by Wang and Rees (113). None of the 49 soils with Bs/Bhs morphology that the authors studied could be classified as a Spodosol because of the low sesquioxide to clay ratio. Similar problems have been noted in other countries (21, 36).

The review of the above problems indicates that there may be a real need for modifications to the present Soil Taxonomy (105) criteria in an effort to classify soils with spodic morphology that would have otherwise been classified with other soils lacking spodic horizons, like those of Dystrochrepts or Psamments. Some of the modifications to the present criteria are summarized below:

1. elimination of depth requirement for frigid and warmer soil temperature (Joslin),[8]
2. revision of pyrophosphate (pH 10) $\frac{Fe + Al}{C}$ from ≥ 0.2 to ≥ 0.05 (Joslin)[9] or from ≥ 0.2 to ≥ 0.1 (42,53),
3. elimination of $\frac{Fe_p + Al_p}{Fe_d + Al_d}$ and replace with ratio of accumulation of pyrophosphate Al and/or Fe of 8 $g \cdot kg^{-1}$ between the spodic and the C horizon (Joslin),[10]

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[8]Joslin. Selected pedons in Maine as they relate to spodic horizon criteria in Soil Taxonomy.

[9]Ibid.

[10]Ibid.

4. lowering of index of accumulation from ≥ 65 to ≥ 58 (88),

5. more $C_{pyro} + Al_{pyro} + Fe_{pyro}$ than the overlying E horizon or A horizon if E is absent (88),

6. $C_{pyro} + Al_{pyro} + Fe_{pyro} \geq 5 g \cdot kg^{-1}$ (88),

7. $\frac{C_{pyro}}{Al_{pyro} + Fe_{pyro}} = 5.8$ to 25.0 (88),

8. $\frac{(C + Fe + Al)_{pyro-dithio}}{clay} > 0.15$ (49),

9. $\frac{CEC_{moist} - CEC_{240°C}}{CEC_{moist}} \times 100 = > 30$ (49),

10. carbon content (by sodium pyrophosphate) of spodic horizon of $\geq 10 g \cdot kg^{-1}$ (8).

CHAPTER III

MATERIALS AND METHODS

Location and Sampling of Pedons

A total of 11 pedons were selected for this study. Ten pedons were sampled from Unaka Mountain and Clingmans Dome in Tennessee, while the eleventh pedon was located in Swain County, North Carolina. In addition, only the morphological and physical properties of five corollary pedons--three from Unaka Mountain, Tennessee, and two from Poor Mountain, Virginia--were used. The chemical data for these five corollary pedons were not used due to possible alteration and contamination by road dust. The location of the study sites is shown in Figure 1.

The primary sampling plan was to select soils with Bs/Bhs morphology for characterization. No soil without Bs/Bhs morphology was sampled. Based on transect information gathered by the author's major professor, some pedons were specifically sampled to represent the observed minimal to maximal expression of Bs/Bhs morphology at each sampling area. Other pedons were randomly selected to add or verify the range in Bs/Bhs morphology at each site as revealed by transect information. Seven of the pedons were completely sampled while only the Bs or Bhs (Bir or Bhir) horizons were sampled in the remaining four pedons. All the five corollary pedons were completely sampled. With the exception of two transects which the author participated, Dr. D. A.

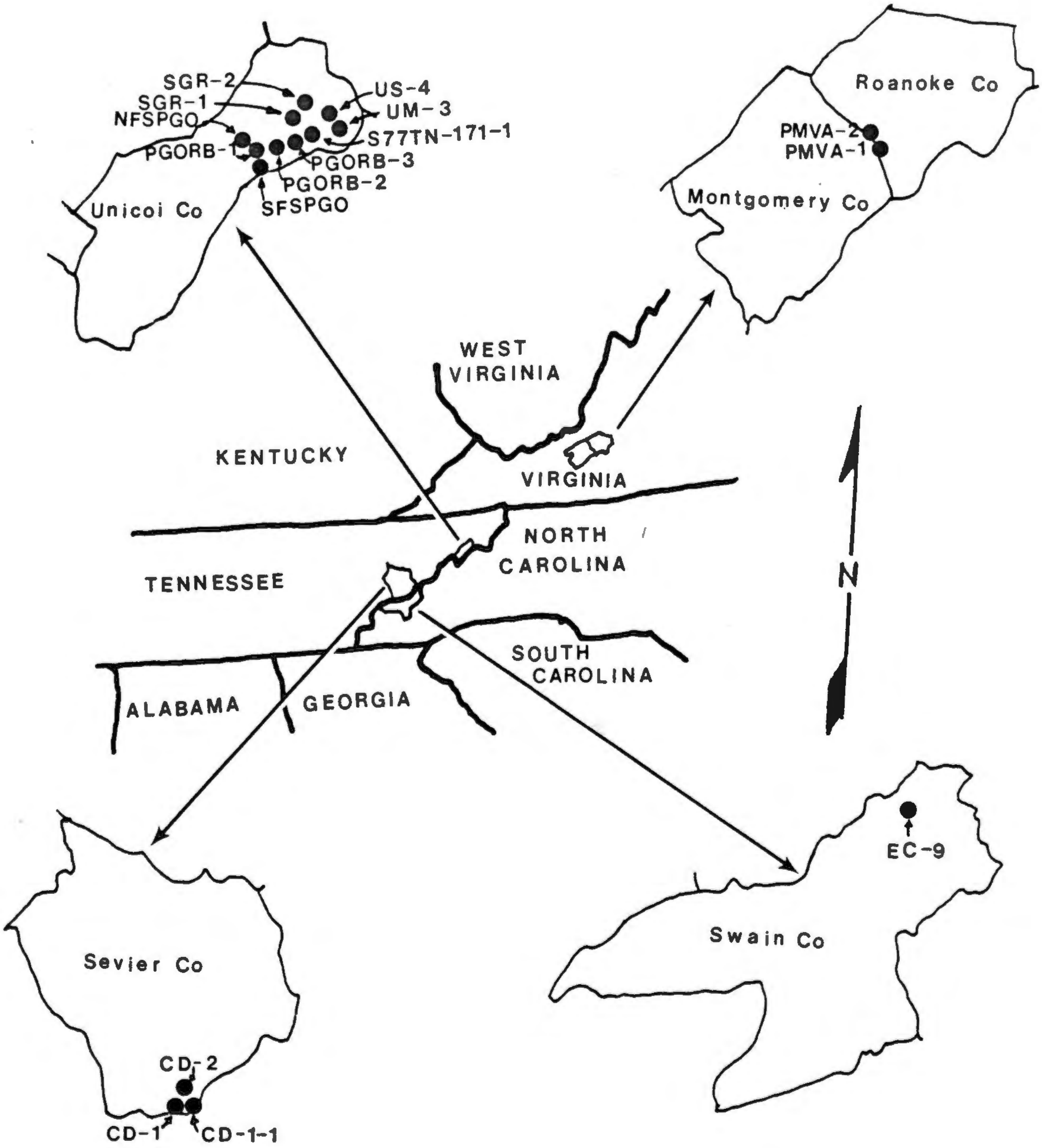

Figure 1. Location of pedons used in this study.

Lietzke (the author's major professor) ran all the remaining transects. At the Unaka Mountain site, two transects were run at the Pleasant Garden Overlook. Three corollary pedons were systematically selected to express the range in observed spodic morphology. After these profiles were characterized, additional sites on the north and south facing slopes at Pleasant Garden Overlook were selected close to temperature-moisture sites which had been previously randomly located with respect to aspect. Two additional pedons on Unaka Mountain and approximately 100 m higher in elevation than the pedons at Pleasant Garden Overlook were selected. These two pedons were sited on a ridge top and on the north facing slope. In the Clingmans Dome area, one pedon was selected for characterization because it had been used to show a soil with Bs/Bhs morphology on field trips. The pit was sampled at two locations because of visual morphological differences. Another pedon, also sited in the Clingmans Dome area, was sampled on the basis of transect observations as representing maximal Bs/Bhs character in comparison to the minimal spodic expression of the other pedon. The Enloe-Creek pedon was selected on the basis of transect information. The Poor Mountain corollary pedons, PMVA-1 and PMVA-2, were selected to show the range in Bs/Bhs morphology observed by two transects, one along the road bank and the other at right angles to the road bank.

The current vegetation under which the pedons were located is listed in detail under pedon descriptions of Appendix A.

Soil bulk samples were taken from all horizons. The pits were dug into a C horizon as far as possible or to a paralithic contact.

Laboratory Methods

The laboratory methods were in accordance with those in Soil Survey Investigation Report No. 1 (104), except where noted. The soil samples were air-dried in the laboratory. If hard clods and fragments were present, a large rubber stopper was used to mechanically break them down. Materials remaining on the U.S. standard number 10 sieve after crushing and sieving were considered as coarse fragments. The amount of coarse fragments for each sampled horizon is shown in Tables B-1 to B-11, Appendix B. The fine-earth material was then passed through a sample splitter to get representative subsamples for each analytical procedure.

All procedures were run in duplicate on each horizon and the results presented represent the average of those determinations. Samples that gave wide variation in results were rerun.

Particle size analysis was determined by the pipette method of Kilmer and Alexander (68). Five grams of soil from the Enloe Creek (EC-9) samples were used instead of the usual 10 grams. This is because of the limited amount of sample available. Particle sizes were reported according to the following classes: very coarse sand (2.0-1.0 mm), coarse sand (1.0-0.5 mm), medium sand (0.5-0.25 mm), fine sand (0.25-0.10 mm), very fine sand (0.10-0.05 mm), coarse silt (0.05-0.02 mm), fine silt (0.02-0.002 mm), and clay (< .002 mm). The fine-earth texture for each horizon was thus determined using these values.

Soil reaction was determined using a pH meter and a glass electrode with a soil to solution weight ratio of 1:2. The solutions used were distilled water and 0.01 mol (1/2 $CaCl_2^{2+}$).

Organic carbon was determined using the modified procedure of Walkley and Black (112). Values were reported as grams of organic carbon per kilogram of soil ($g \cdot kg^{-1}$).

Cation exchange capacity (CEC) was determined by the sum of the cations method. Calcium, sodium, magnesium, and potassium were extracted with pH 7.0 NH_4OAC method of Peech et al. (94) with the following modifications. Extraction was carried out using a Soil Test vacuum extractor set for two hours. Five grams of soil and 10 milliliters NH_4OAC were placed in the middle extraction tube and allowed to stand overnight. Another 40 ml NH_4OAC were added to the upper extraction tube before switching on the extractor. Calcium and magnesium were determined by atomic absorption spectrophotometry while sodium and potassium were determined by flame emission spectrophotometry. Both determinations were done on a Perkin-Elmer Model No. 5000 Atomic Adsorption Spectrophotometer. The extractable bases were expressed in millimole of single positive charge per kilogram of soil ($mmol(+)kg^{-1}$).[11] Exchangeable acidity was determined by the pH 8.2 barium chloride-triethanolamine extraction method of Peech et al. (94) with the following modifications. Two grams soil, 20 ml buffer, and 40 ml replacement were used with the vacuum extractor. One drop of brom cresol

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[11]SI unit from reprint of Journal of Agronomic Education, Vol. 10, Nov.-Dec. 1981, pp. 62-70.

green and five drops mixed indicator were utilized to obtain the end point. The results were expressed as mmol(+)kg^{-1}. Cation exchange capacity (C.E.C.) by summation method, also expressed in mmol(+)kg^{-1}, was calculated by adding the value for extractable bases to that for exchangeable acidity.

Iron and aluminum were extracted using two different extracting solutions--sodium pyrophosphate (pH 10) used in the procedure developed by Bascomb (11) and sodium dithionite-citrate used in the procedure developed by Holmgren (58). The only exception was that in the Holmgren (58) procedure the supernatant was centrifuged at 2000 rpm for 15 minutes after superfloc was added and the suspension was allowed to settle. Iron and aluminum were determined by a Perkin-Elmer Model No. 5000 Atomic Adsorption Spectrophotometer. Values of iron and aluminum were reported as gram per kilogram ($g \cdot kg^{-1}$).

The differentiation of spodic from non-spodic horizons was done using the field techniques developed by Bartlett (9) and Holmgren.[12] The results of the Bartlett (9) technique were reported as either darker (D) or lighter (L) than the blue color of the blank. The results of the Holmgren[13] procedure (Appendix C) were reported as liter-color units/gram (1 cu/g) and as grams of potassium hydroxide extractable aluminum per kilogram of soil ($g \cdot kg^{-1}$).

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[12]Holmgren. A field procedure for assessing spodic characteristics.

[13]*Ibid*.

CHAPTER IV

RESULTS AND DISCUSSION

Site Characteristics

Site characteristics of the pedons are in Appendix A, while those for the corollary pedons are in Appendix D. All the pedons are located between elevations of 1151 to 1891 m.

Annual rainfall of more than 2000 mm (106) is not uncommon, and snow cover, except in the highest elevations, rarely lasts for more than a few days. The soils freeze only to shallow depths.

The pedons studied occupy varying landform units. Two pedons, US-4 and UM-3, are on broad upland summits. Pedons S77TN-171-1, PGORB-1, PGORB-2, PGORB-3 are sited on narrow ridge tops while pedon SGR-2 is located in a ridge-saddle position. The remaining pedons are located on upper or mid-side slopes. There are aspect differences between pedons as well. Three pedons, SGR-2, US-4, and NFSPGO, are on the north-facing slopes while 11 pedons, S77TN-171-1, UM-3, SFSPGO, CD-1, CD-1-1, CD-2, PGORB-1, PGORB-2, PGORB-3, PMVA-1, and PMVA-2, are south-facing. Two pedons, EC-9 and SGR-1, are situated on west aspects.

The pedons evaluated in this study also had different types of vegetation. Pedons from the Unaka Mountain region comprising NSFPGO SGR-1, UM-3, US-4, and S77TN-171-1 are under red spruce (*Picea rubens*) with a thick understory consisting of rhododendron (*Rhododendron sp.*), spruce seedlings, and mountain ash (*Sorbus americana*) while pedons

SFSPGO, SGR-2, PGORB-1, PGORB-2, and PGORB-3 are under dwarf heath composed of rhododendron, blueberries (Vaccinium sp.), laurel (Kalmia latifolia), and blackberries (Rubus sp.) (Figures E-3 and E-4, Appendix E). At the site for pedon EC-9, vegetation is composed of a dense, mature, red spruce stand without any understory. The three pedons at Clingmans Dome have a nearly pure stand of fraser-fir (Albies fraseri) with minor intrusions of mountain ash and red spruce. There is no understory in the Clingmans Dome pedon sites (Figure E-1, Appendix E). At Poor Mountain, Virginia, vegetation is composed of Virginia pine (Pinus sp.), rhododendron, mountain laurel, and blueberries with no species dominant (Figure E-10, Appendix E). There is probably no red spruce-fraser fir at Poor Mountain. The nearest seed source for red spruce-fraser fir is the Mt. Rogers-Grayson Highlands area.

The presence of treeless shrub communities of rhododendron, blueberries, laurel, and blackberries on parts of Unaka Mountain may be due to forest fires which destroyed the original climax vegetation of red spruce. The author suspects that the seed source was probably depleted following burning or that the growth of post-fire vegetation was so thick that the spruce-fir could not become established.

The parent material for broad upland and ridge-top soils may be derived from products of past frost action which disturbed and moved soil materials. For the remaining pedons located on side slopes and in saddle positions, parent material is colluvium. The most important source rocks are metamorphosed feldspathic quartzite and graywacke.

Most of the pedons are suspected to have a perudic soil moisture regime based on rainfall and soil moisture cell resistance readings taken at monthly intervals, at two locations for about one year. Monthly soil temperatures, taken at 50 cm soil depth from Unaka Mountain and Roan Mountain are presented in Figures 2 and 3. Roan Mountain is very similar to Clingmans Dome in elevation and vegetation and is readily accessible during the winter. At Unaka Mountain, soil temperature, over a 12-month period, ranged from 2.1°C to 14.4°C while at Roan Mountain at an elevation of 1891 m soil temperatures, over 10 months, ranged from 0°C to 11.1°C. Pedon SFSPGO, which was located near to the temperature-moisture sensors on the south-facing side of Unaka Mountain, has a mean annual soil temperature of 9.3°C (Table 1). The 1.3°C difference from 8°C for frigid soils may be partly due to vegetational and aspect differences. However, the morphology of pedon SFSPGO is no different from pedon NFSPGO, sited on the north-facing side which had an average temperature of 7.4°C (Table 1). Only the present vegetation differs.

The only pedons with mesic soil temperature regime are pedons PMVA-1 and PMVA-2 which were sampled in a road cut on Poor Mountain at an elevation of 1151 m (Figure 4).

Morphological Properties

Detailed morphological descriptions of the pedons studied are in Appendices A and D. The O horizons are common in all pedons, but their thickness varies from one centimeter in pedons SGR-1 and SGR-2

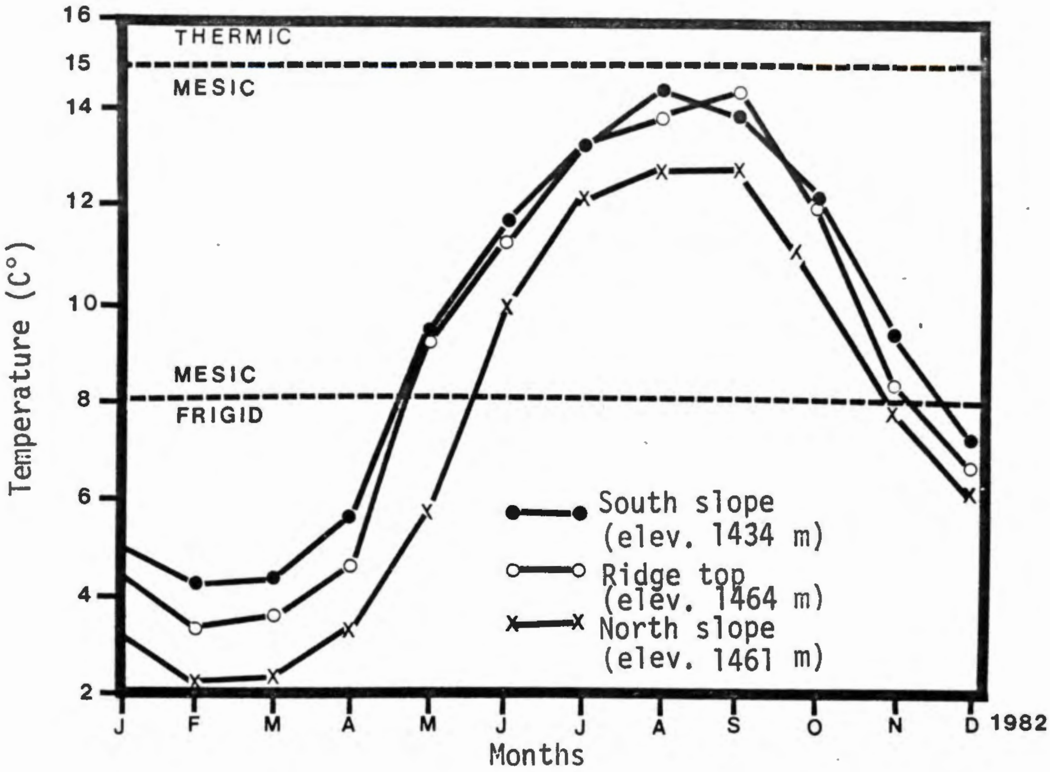

Figure 2. Monthly soil temperature for Unaka Mt., Tenn.

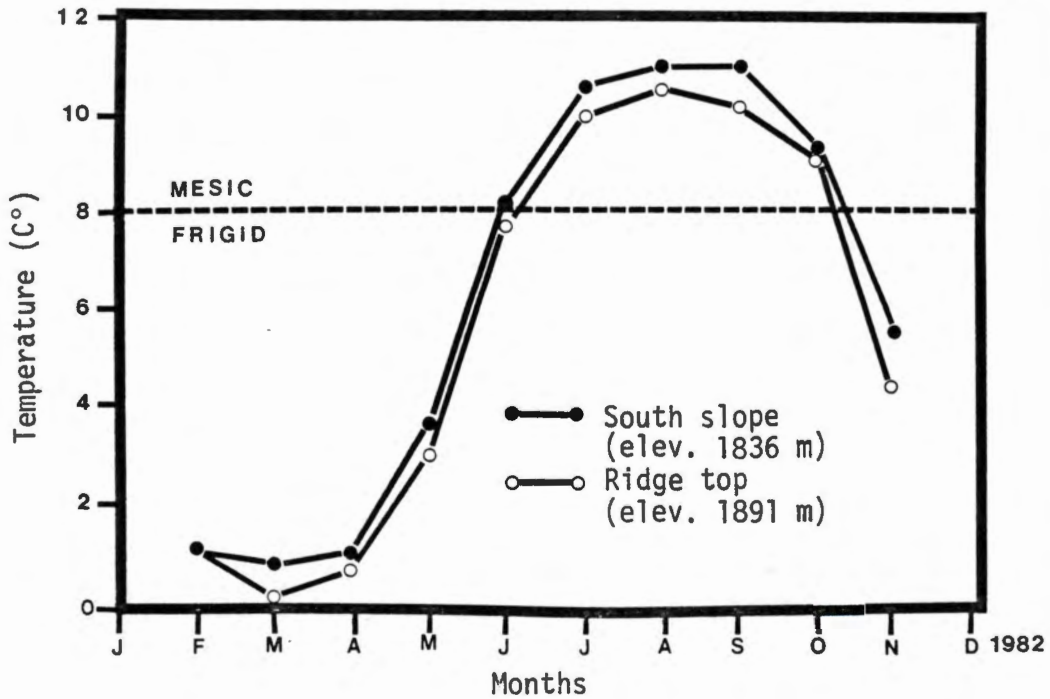

Figure 3. Monthly soil temperature for Roan Mt., Tenn. and N.C.

TABLE 1

Mean Annual Soil Temperature (MAST) for
Some of the Sampling Areas

Area	State	Site	Elevation	MAST	Soil Temperature Regime
			m	°C	
Unaka Mt.†	Tenn. and N.C.	North aspect	1461	7.4§	Frigid
		Ridgetop	1464	9.2§	Mesic
		South aspect	1434	9.3§	Mesic
Roan Mt.‡	Tenn. and N.C.	Ridgetop	1891	4.0¶	Frigid
		South aspect	1836	5.9¶	Frigid

†Temperature/moisture sensors in mineral horizons.

‡Temperature/moisture sensors in organic horizons.

§Average over 12 months.

¶Average over 10 months.

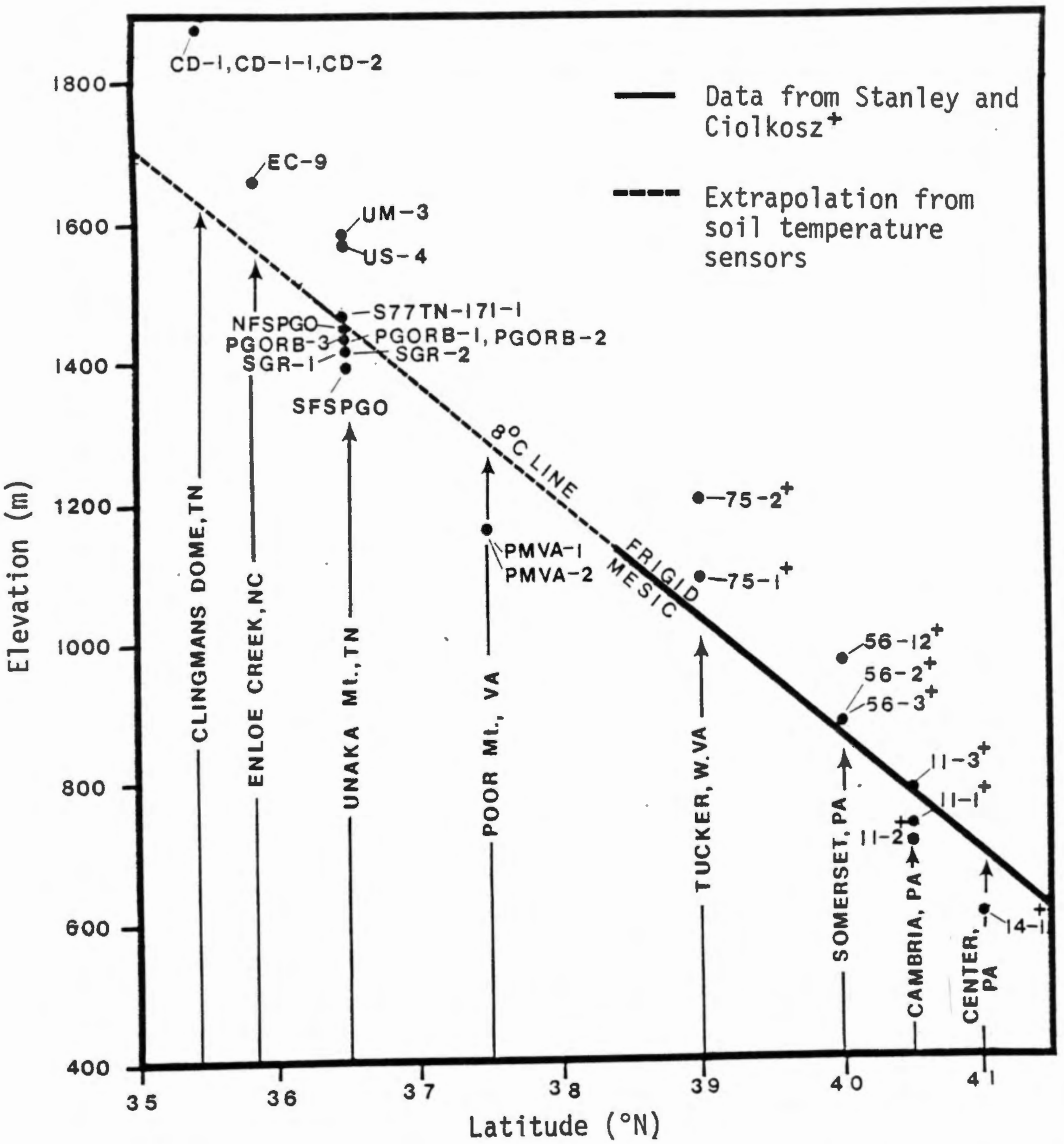

Figure 4. Mesic-frigid soil temperature boundary with respect to the location of some pedons.

+Source: Scott R. Stanley and Edward J. Ciolkosz (1981). Classification and genesis of Spodosols in the Central Appalachians. Soil Sci. Soc. Am. J. 45, 915.

to 16 centimeters in pedon CD-2. These horizons represent accumulations of leaves, needles, twigs, mosses, and lichens. Most of the roots are in O horizons (Figure E-9, Appendix E). The O horizon is separated from the underlying A horizon by an abrupt boundary. The color of most A horizons is usually black (10YR2/1 or 5YR2/1) due to decomposition products from the overlying O horizon. The color of the A horizon of pedons SGR-2 is grayish brown to dark brown (10YR5/2 to 7.5YR3/2). This may be due to a very intense burn that destroyed the organic matter at pedon SGR-2. The one centimeter thick O horizon may have been formed since the fire. Textures of the A horizon range from sandy loam to very gravelly sandy clay loam. Structures of the A horizon are granular to weak, fine subangular blocky. Thickness of the A horizon varies from one centimeter in pedon CD-1-1 to 28 cm in pedon SFSPGO.

In most pedons the high content of organic carbon, after the top 18 cm is mixed, would probably result in an umbric epipedon. Pedon EC-9 probably has a histic epipedon.

Some of the E horizons, darkened by tongueing of organic matter, do not qualify as albic horizons.

The presence of coarse fragments in parts of the E horizon alters flow pathways of organic matter into and through the E horizon. The migrating organic matter flows over and to the side of coarse fragments giving an appearance of dark plasma tongues. This tongueing of organic matter into the E horizon is evident in pedons SFSPGO, CD-2, NFSPGO, and UM-3. Figures E-5 to E-8, Appendix E, show this phenomenon. Tongueing of organic matter into the E horizon is most pronounced in soils from the Unaka Mountain sites where the organic matter and the coarse fragments are the highest. These soils are also the least well drained. Tongueing is least pronounced in the soils at Poor Mountain, Virginia. Uneven moistening and the presence of tap roots which have been reported to cause this phenomenon (105) is not as potent a force as the coarse fragments in the area of study. This is because in the area of study most of the current vegetation is suspected to be rooted in the O and A horizons where most of the bases are concentrated. In addition, most of these upland areas would be expected to receive a high amount of evenly distributed precipitation.

Table 2 gives some of the morphological properties of the B horizons illustrating the range in properties. Also shown is the present taxonomic classification of each pedon. All the pedons have a Bs or Bhs horizon that is at least the necessary 2.5 cm in thickness for classification of Spodosols under the present soil classification system. Thickness of the Bs or Bhs horizon varies from 4 cm in pedon SGR-2 to 48 cm in pedon EC-9.

The hue of the upper part of the Bs or Bhs horizon is redder than 10YR. In fact, all pedons have hues redder than 7.5YR in the upper part of the Bs or Bhs horizons. The value and chroma of the Bs or Bhs horizons are generally 5/6, 4/4, or 3/2 but may have higher chromas. The reddest hue, the lowest value or the highest chroma

TABLE 2

Characteristics of the B Subhorizons

Subhorizon	Depth cm	Color (moist) Hue	Color (moist) Value/Chroma	Sand	Silt	Clay	Texture	Soil pH (water)	Organic carbon
					$g \cdot kg^{-1}$				$g \cdot kg^{-1}$
Pedon EC-9 Humic Haplorthod, loamy-skeletal, mixed, frigid									
Bhs1	25-35	2.5YR	2/2	320	429	251	CNVL	4.3	92.0
Bhs2	35-73	5YR	3/4	309	462	229	CNVL	4.5	125.5
Pedon CD-2 Typic Haplorthod, coarse-loamy, mixed, frigid									
Bhs	33-41	5YR	2/2	615	219	166	SL	3.9	53.6
Bs1	41-49	5YR	3/3	518	290	192	GRSL	4.0	37.8
Bs2	49-61	10YR	5/6	462	400	138	GRL	4.2	16.6
Pedon SGR-2 Umbric† Dystrochrept, loamy-skeletal, mixed, mesic									
Bhs	18-22	5YR	3/4	307	341	352	GRCL	4.0	75.4
Pedon S77TN-171-1 Umbric† Dystrochrept, loamy-skeletal, mixed, mesic									
Bs	20-30	5YR	4/4	642	219	139	CBVSL	4.1	17.9
Pedon US-4 Typic Haplumbrept, fine-loamy, mixed, frigid									
Bs	26-42	5YR	3/4	572	163	265	SCL	4.0	23.2

TABLE 2 (Continued)

Subhorizon	Depth cm	Color (moist) Hue	Color (moist) Value/Chroma	Sand	Silt	Clay	Texture	Soil pH (water)	Organic carbon
				g·kg^{-1}					g·kg^{-1}
Pedon NFSPGO Typic Haplumbrept, fine-loamy, mixed, frigid									
Bs1	30-40	5YR	3/2	543	174	283	GRSCL	4.0	22.0
Bs2	40-50	10YR	5/6	594	195	211	GRSCL	4.7	33.0
Pedon CD-1-1 Lithic Haplumbrept, coarse-loamy, mixed, frigid									
Bs1	4-10	5YR	2/2	585	261	154	SL	3.8	37.0
Bs2	10-14	5YR	3/3	627	223	150	SL	3.8	33.6
Pedon UM-3 Umbric[†] Dystrochrept, coarse-loamy, mixed, frigid									
Bs	20-40	5YR	3/4-3/3	744	96	160	SL	4.3	20.3
Bw1	40-50	5YR	3/4-4/4	618	281	101	SL	4.4	7.0
Bw2	50-62	10YR	5/4	672	191	137	SL	4.1	7.9
Pedon SGR-1 Umbric[†] Dystrochrept, coarse-loamy, mixed, mesic									
Bs1	22-28	5YR	4/6	666	180	214	SCL	4.2	13.6
Bs2	28-34	7.5YR	5/6	593	209	198	GRSCL	3.9	6.8
Pedon CD-1 Typic Haplumbrept, coarse-loamy, mixed, frigid									
Bs	17-27	5YR	3/4	593	276	131	SL	3.8	31.6
Bw	27-64	10YR	5/6	705	176	119	SL	4.2	10.7

TABLE 2 (Continued)

Subhorizon	Depth cm	Color (moist) Hue	Color (moist) Value/Chroma	Sand	Silt	Clay	Texture	Soil pH (water)	Organic carbon
				——— $g \cdot kg^{-1}$	———	———			$g \cdot kg^{-1}$
Pedon SFSPGO Typic Haplumbrept, fine-loamy, mixed, frigid									
Bs1	36-41	5YR	4/6	558	203	239	SCL	3.8	27.1
Bs2	41-61	10YR	5/6	589	210	201	SCL	4.0	17.8

†The subgroup was determined after the top 18 cm of the surface horizon was mixed.

necessary for the morphological recognition of Bs/Bhs horizons in the field, is present in the upper part of the Bs or Bhs horizon of most pedons studied. Soil color is an important morphological feature in Soil Taxonomy (105) in recognizing the presence of a spodic horizon, and in this connection, it is worthwhile to note that all the pedons have at least one subhorizon that meets this color criterion.

Most of the Bs or Bhs horizons have a weak fine subangular blocky structure. Textures range from loam to very gravelly clay loam. Most of the Bs or Bhs horizons have either a coarse-loamy, fine-loamy, or loamy-skeletal particle-size class.

The presence of coarse fragments also causes variable expression of spodic horizon development across the Bs or Bhs horizons. The part of the Bs or Bhs horizon that has a higher amount of coarse fragments seems to have better spodic morphology than the part that has lower amounts of coarse fragments. The author suspects that the migrating sesquioxides and organic matter are restricted to a smaller surface area by the presence of coarse fragments. This results in a higher amount of sesquioxides and organic matter per unit of surface area. This concentration of sesquioxides and organic matter to a smaller surface area due to the presence of coarse fragments results in variability of Bs/Bhs expression across the pedon face. This variability in Bs/Bhs development due to the presence of coarse fragments is observed in pedon SGR-2 (Figure E-5), PGORB-3 (Figure E-6), CD-2 (Figure E-2), and PMVA-2 (Figure E-12), Appendix E.

Physical Properties

Physical properties of the pedons in this study are in Tables B-1 to B-11, Appendix B, and D-1 to D-15, Appendix D. Sand is the most abundant soil separate in most of the pedons. This is attributable to the high sand content of the graywacke and feldspathic quartzite parent materials. There is usually more medium (0.5 to 0.25 mm), fine (0.25 to 0.1 mm), and very fine (0.1 to 0.05 mm) sand in the A and E horizons than in the underlying horizons. There is a general trend of increasing coarse (1.0 to 0.5 mm) and very coarse (2.0 to 1.0 mm) sand content with depth in most of the pedons. This generally reflects the reduction in intensity of physical and chemical weathering with increasing depth.

There is no pattern for silt distribution with depth. It is probable that frost action which may be responsible for the reduction of feldspars and quartz to silt sizes in the area of study may have been active in varying soil depths. The highest content of fine silt (0.02 to 0.002 mm) is in the same horizon as the maximum content of silt (0.05 to 0.002 mm) as is evident in pedons SFSPGO, EC-9, NFSPGO, CD-1, and CD-2. This may be related to the intensity of frost action occurring at varying depths or to the downward translocation of silt particles.

In few of the pedons studied, there is a clay distribution with depth which follows a pedogenic pattern of maximum accumulation in the Bs/Bhs horizon. Pedons CD-2 and S77TN-171-1 have less than 15 percent clay in the E horizon. In these two pedons, there is at least three percent total clay increase in the Bs/Bhs horizon as compared to the overlying horizon. Pedons EC-9, SGR-1, and NFSPGO, on the other hand, have more than 15 percent clay in the E horizon. The Bs/Bhs horizons of these three pedons have at least 1.2 times more clay than the E horizon. Although no argillans were observed on ped faces, hand lens examination of sand grains from the Bs/Bhs horizons of pedons CD-1-1 and SFSPGO revealed that there were few faint plasma bridges between sand grains. This may suggest the presence of an argillic horizon in pedons CD-1-1 and SFSPGO. Thin sections would be needed to determine if any argillic horizon has been developed.

There are several reasons to account for the high clay content in the Bs or Bhs horizon. One such reason is that there has been a change in climatic conditions since the Pleistocene cold phases in the area of study (32, 33). Thus, the greater contents of clay-size minerals in the Bs/Bhs horizon may be quantitatively related to weathering associated with increases in precipitation and temperature. In addition, due to changes in climatic conditions, there may be a possibility of degradation of the Bs/Bhs horizons associated with increases in physical and chemical weathering rates. The degradation products from the Bs/Bhs horizons may fall into clay size, causing a high clay content in the Bs/Bhs horizons. A third reason may be that clays may have moved as particles in suspension. The presence of plasma bridging between sand grains in pedons CD-1-1 and SFSPGO may be taken as evidence for plasma translocation. However, the major reason for the high content of clay in the Bs or Bhs horizon may be that the major portion of clay that is measured is that of organo-metallic complexes that are dispersed during particle-size analysis. The high contents of organic carbon and extractable aluminum and iron of the Bs or Bhs horizon which are coincident with the horizon of high clay content provide evidence that the organo-metallic complexes were reduced to clay sizes. Thin section analysis could assist in settling this particular problem.

Chemical Properties

Chemical data of pedons are in Tables B-1 to B-11, Appendix B. Soil pH (in 1:2 soil:water) ranges from 3.2 in the Oe horizon to 5.6 in the C3 horizon. The acid reaction of the soils is a reflection of the original rock composition, the precipitation regime, the leaching contitions, as well as the nature of the forest litter on the soils. Rainfall of more than 2000 mm (106) is not uncommon in most of the high elevations where the pedons are located. Vegetation at the sites is mainly coniferous or ericaceous and one can assume the low surface soil pH's are due to the forest litter which is high in organic acids and possible extractable aluminum. Several studies (61, 85, 86) have demonstrated this forest litter-soil pH relationship.

Depth relationships of extractable bases, extractable acidity, and organic carbon content for the pedons studied are shown in Figures 5 to 11. Most of the extractable bases are in the Oa and A horizons. There is a decrease in the amounts of extractable bases in the underlying E horizon due to leaching of bases into the underlying horizons. In the Bs/Bhs horizons, a slight increase in extractable bases is evident while in the underlying Bw or C horizon, the amount of extractable bases either decreases or remains approximately constant. The higher amount of bases in the Oa and A horizons is related to the cycling of bases by the vegetation. The slight increase of extractable bases in most of the Bs/Bhs horizons is attributable to higher clay and organic matter content of this horizon which acts as a greater retentive mechanism.

The extractable bases are concentrated in the Oa and A horizons. Calcium content is higher than that of the other bases in the O and A horizons. According to Hoyle (61), the reason for the higher calcium content in forest litter is that calcium not only accumulates in the foliage but is not translocated out of the foliage just before leaf fall as are large portions of some other elements. This area receives a high amount of rainfall (106). So, the lower amounts of bases particularly magnesium, potassium, and sodium in the underlying E horizon reflect the severity of leaching by rainwater. The Bs/Bhs horizons which are illuvial horizons usually show a slight increase in bases as compared to the overlying or underlying horizon.

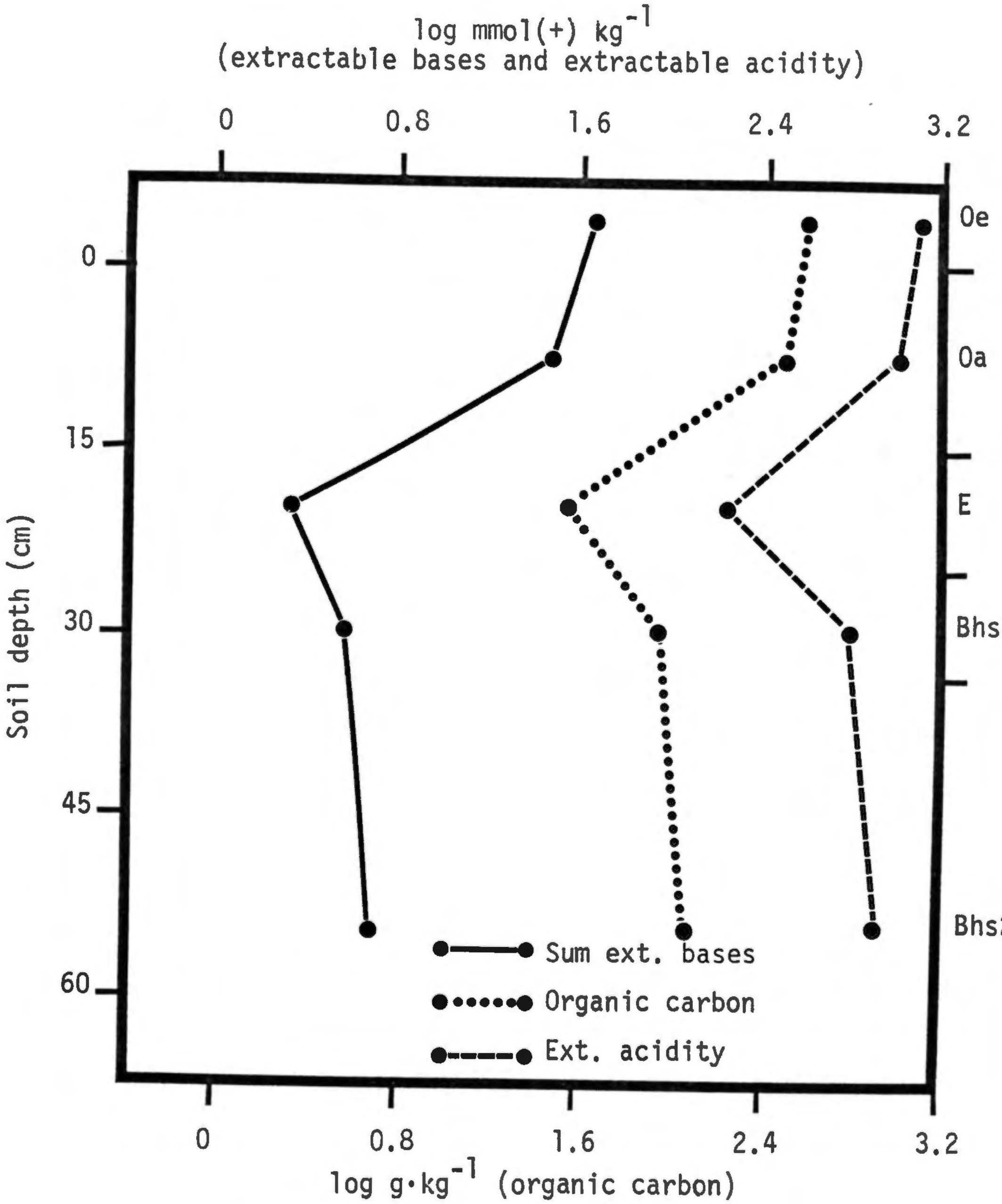

Figure 5. Depth relationship of extractable bases, extractable acidity, and organic carbon in Pedon EC-9.

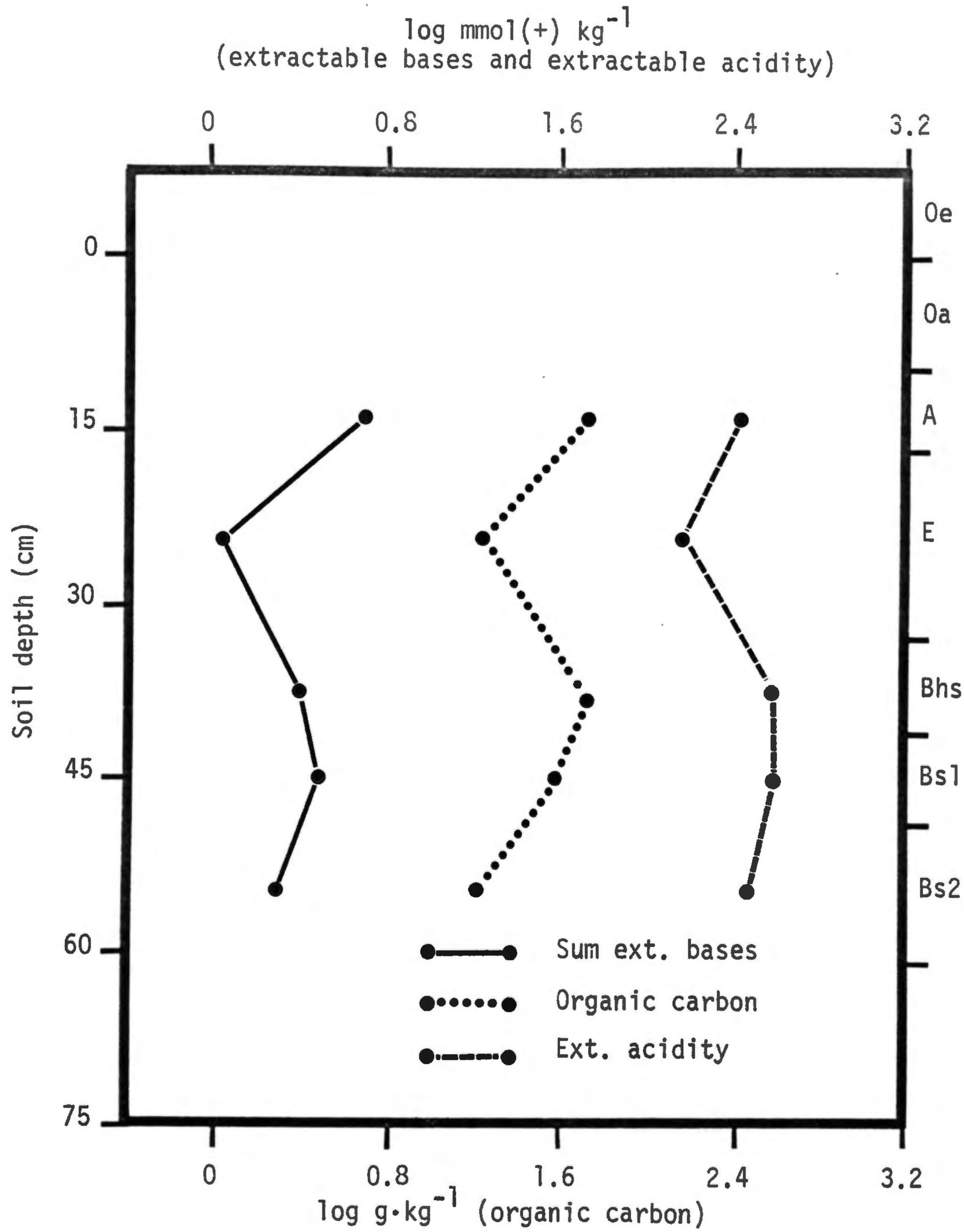

Figure 6. Depth relationship of extractable bases, extractable acidity, and organic carbon in Pedon CD-2.

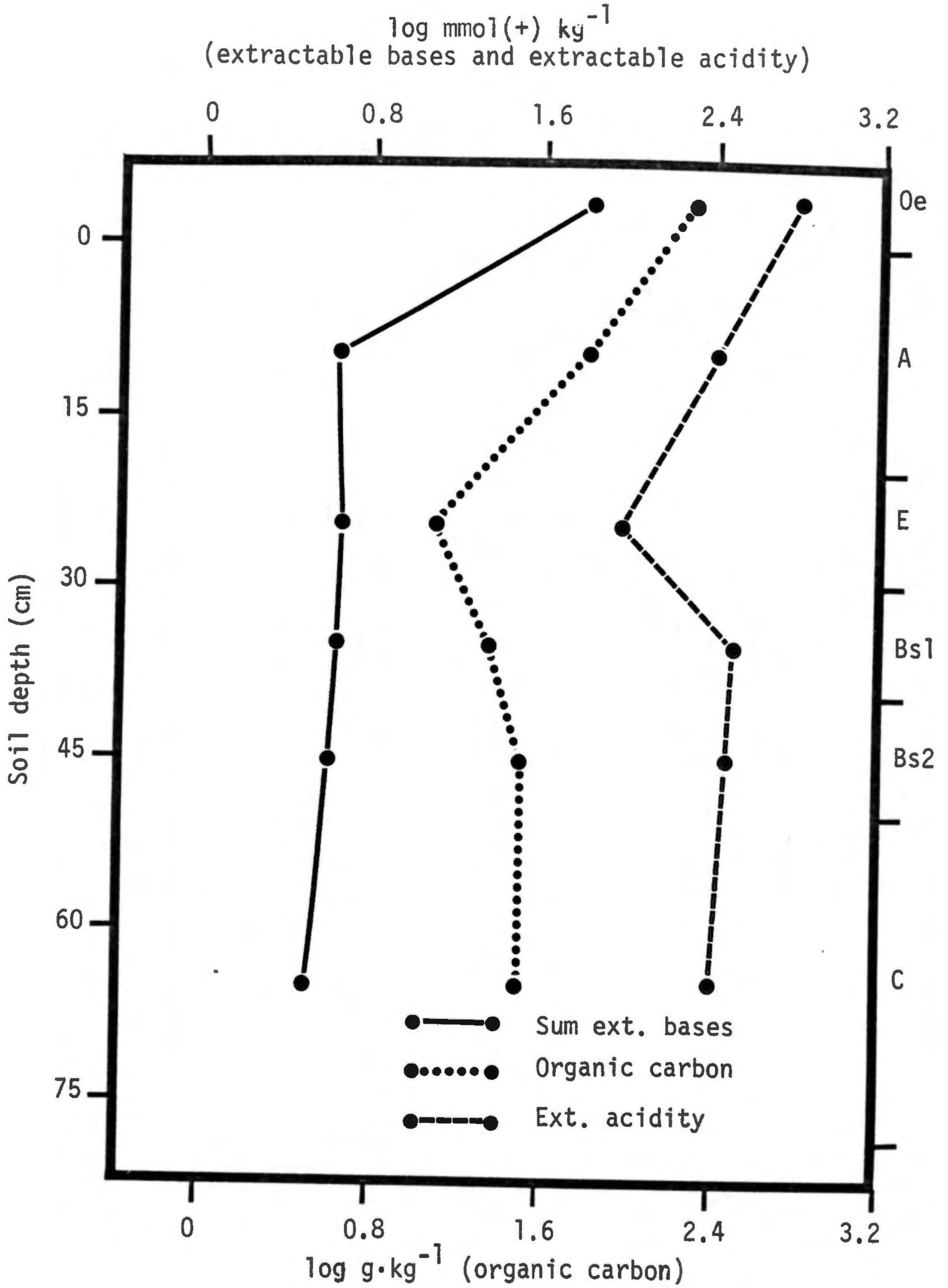

Figure 7. Depth relationship of extractable bases, extractable acidity, and organic carbon in Pedon NFSPGO.

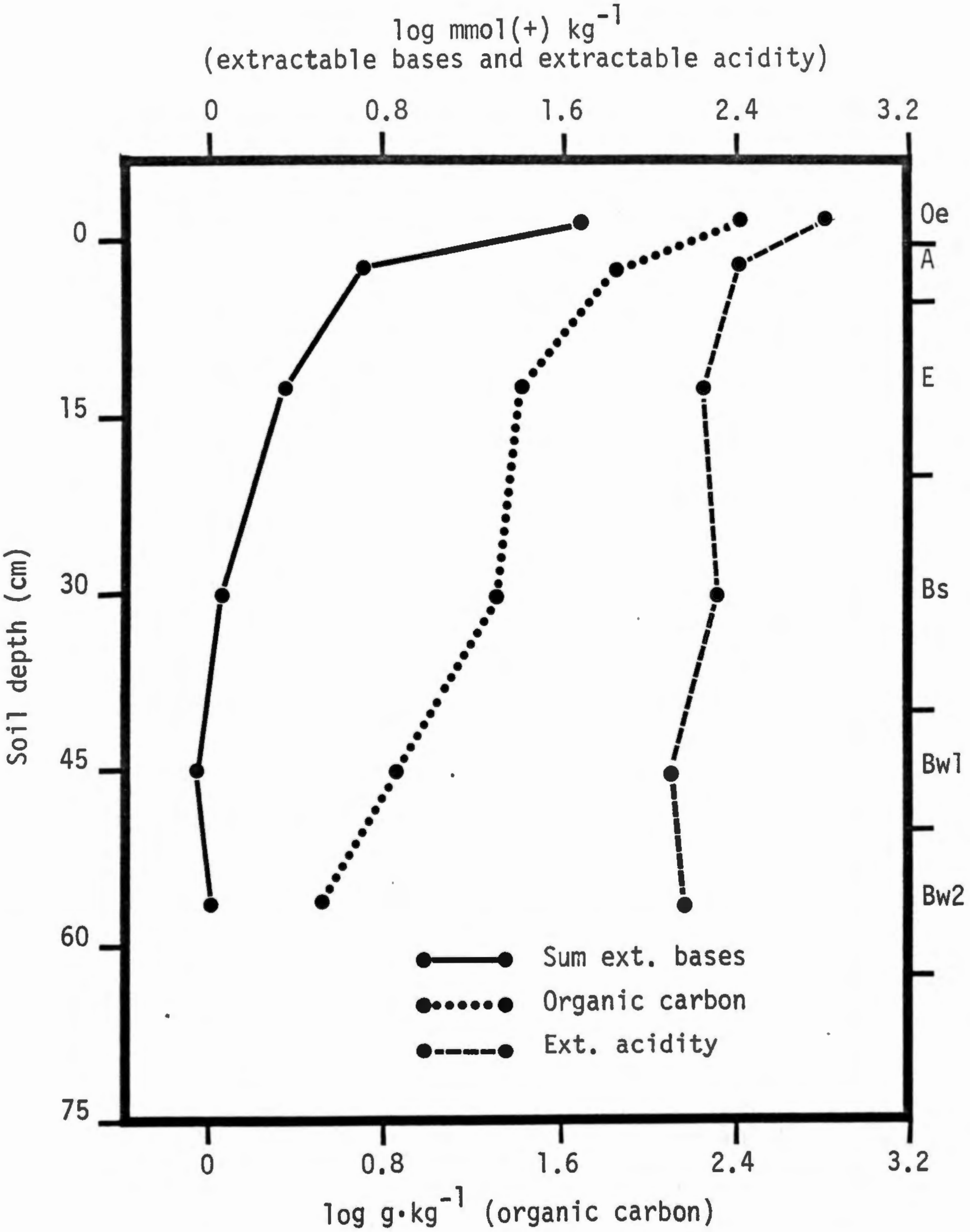

Figure 8. Depth relationship of extractable bases, extractable acidity, and organic carbon in Pedon UM-3.

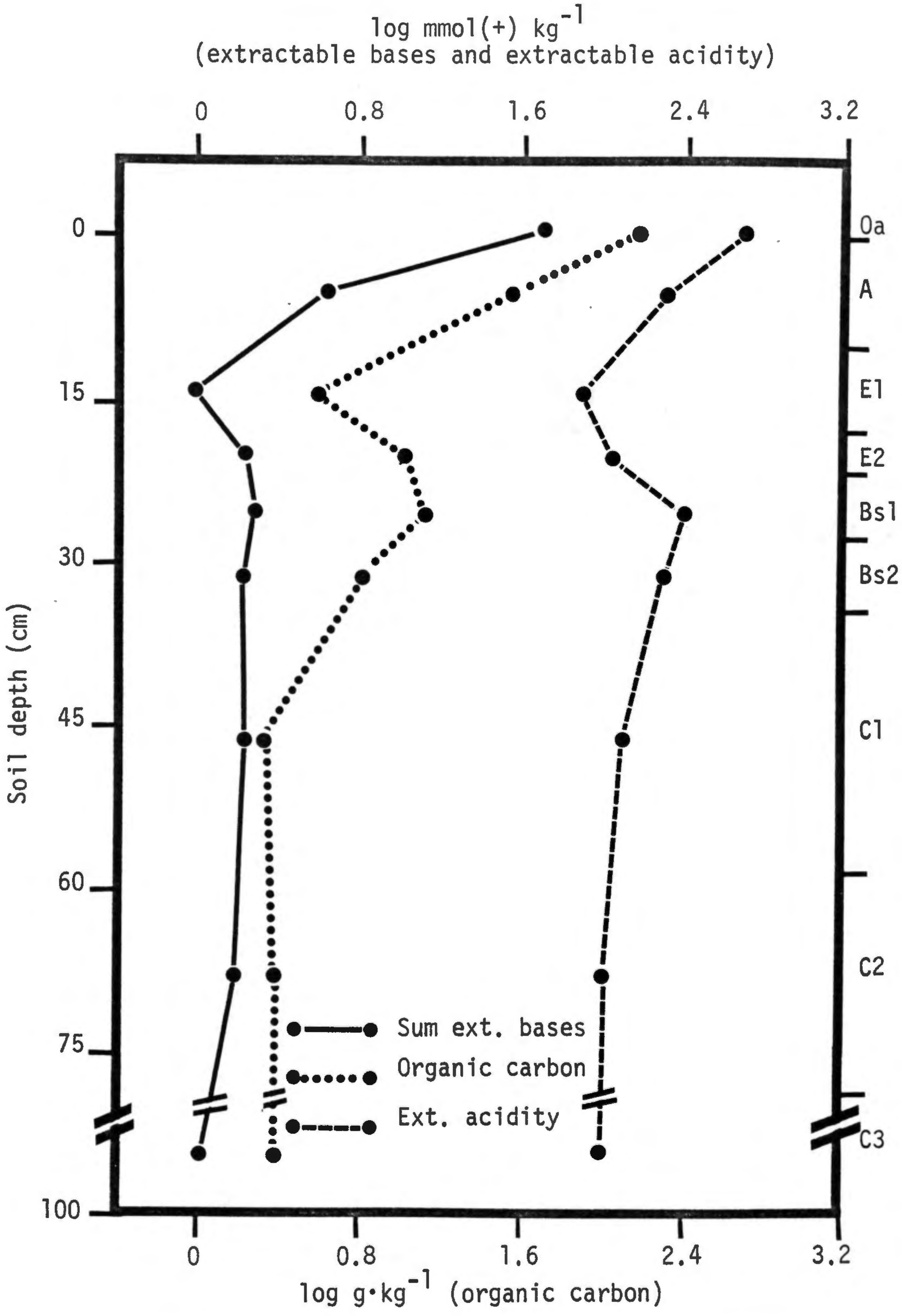

Figure 9. Depth relationship of extractable bases, extractable acidity, and organic carbon in Pedon SGR-1.

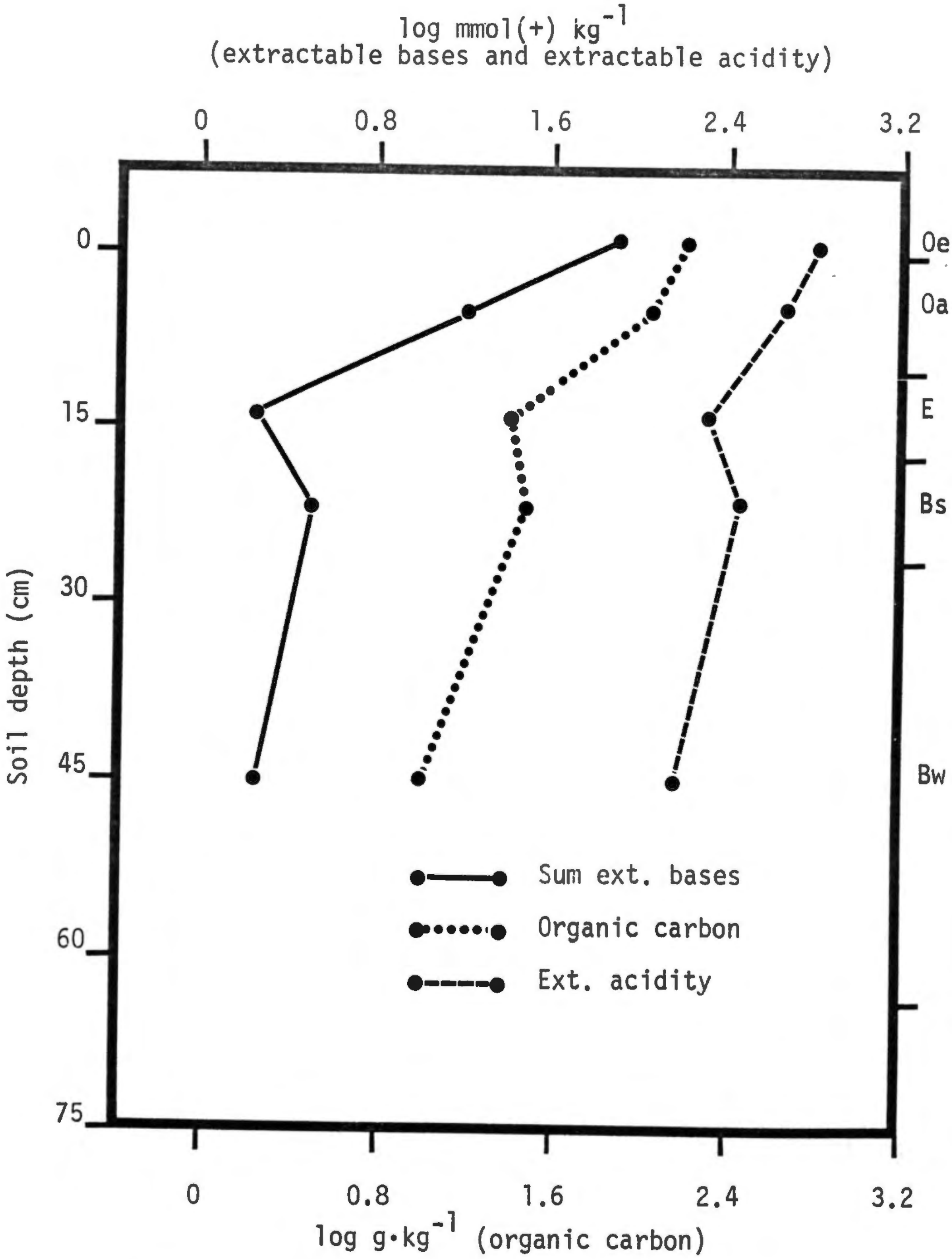

Figure 10. Depth relationship of extractable bases, extractable acidity, and organic carbon in Pedon CD-1.

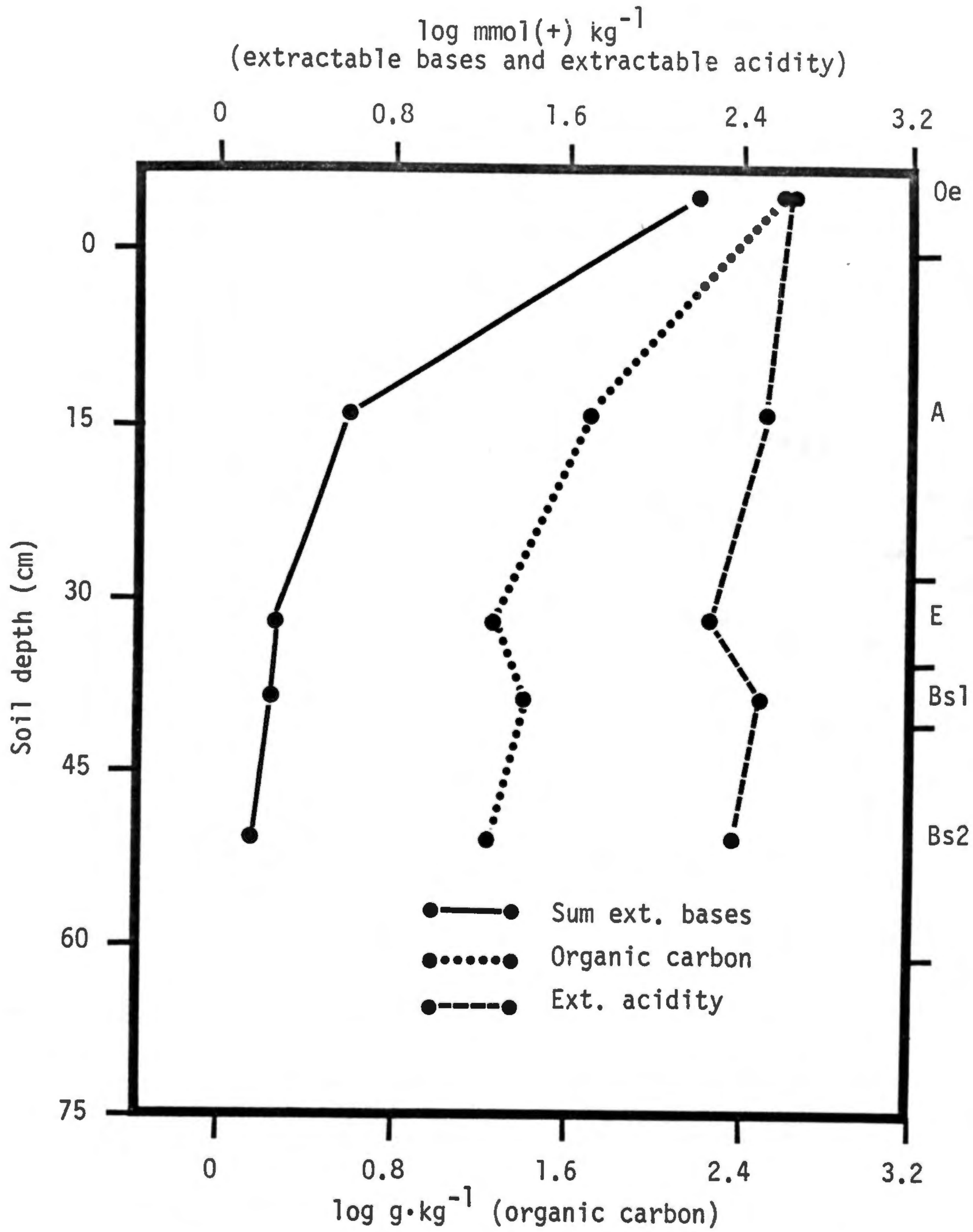

Figure 11. Depth relationship of extractable bases, extractable acidity, and organic carbon in Pedon SFSPGO.

Depth distribution of extractable acidity is shown in Figures 5 to 11. In most of the pedons, highest extractable acidity values are recorded in the O and A horizons. These values correspond to the horizon of highest organic carbon. The E horizon which is the horizon of maximum eluviation usually has the least amount of extractable acidity. There is a secondary extractable acidity maximum in most of the Bs/Bhs horizons. This bulge is noticeable in pedons EC-9, CD-2, SGR-1, CD-1, and SFSPGO and may be attributed to organic carbon rather than to the clay content as is evident in the relationships between extractable acidity and organic carbon for the three horizons (Tables F-1 and F-2, Appendix F).

Organic carbon content follows almost the same pattern with depth as extractable acidity (Figures 5 to 11). Eluviation/illuviation processes are the reasons for the E horizon having a pronounced minima and the Bs/Bhs horizons having a secondary maximum in organic carbon content. The complexing of organic matter by iron and aluminum and the subsequent precipitation of these organo-metallic complexes in the spodic horizons contribute to this secondary maximum of organic carbon, similar to the findings of De Coninck (40) and Anderson et al. (3).

Figures 12 to 18 show depth relationships of sodium pyrophosphate and dithionite-citrate extractable aluminum and iron. The maximum content of pyrophosphate extractable aluminum usually occurred lower in the soil profile than did that of iron. The maximum content of iron extracted by dithionite-citrate occurred either at the same depth as aluminum maxima (pedons EC-9, CD-2, UM-3, CD-1, SFSPGO) or higher in

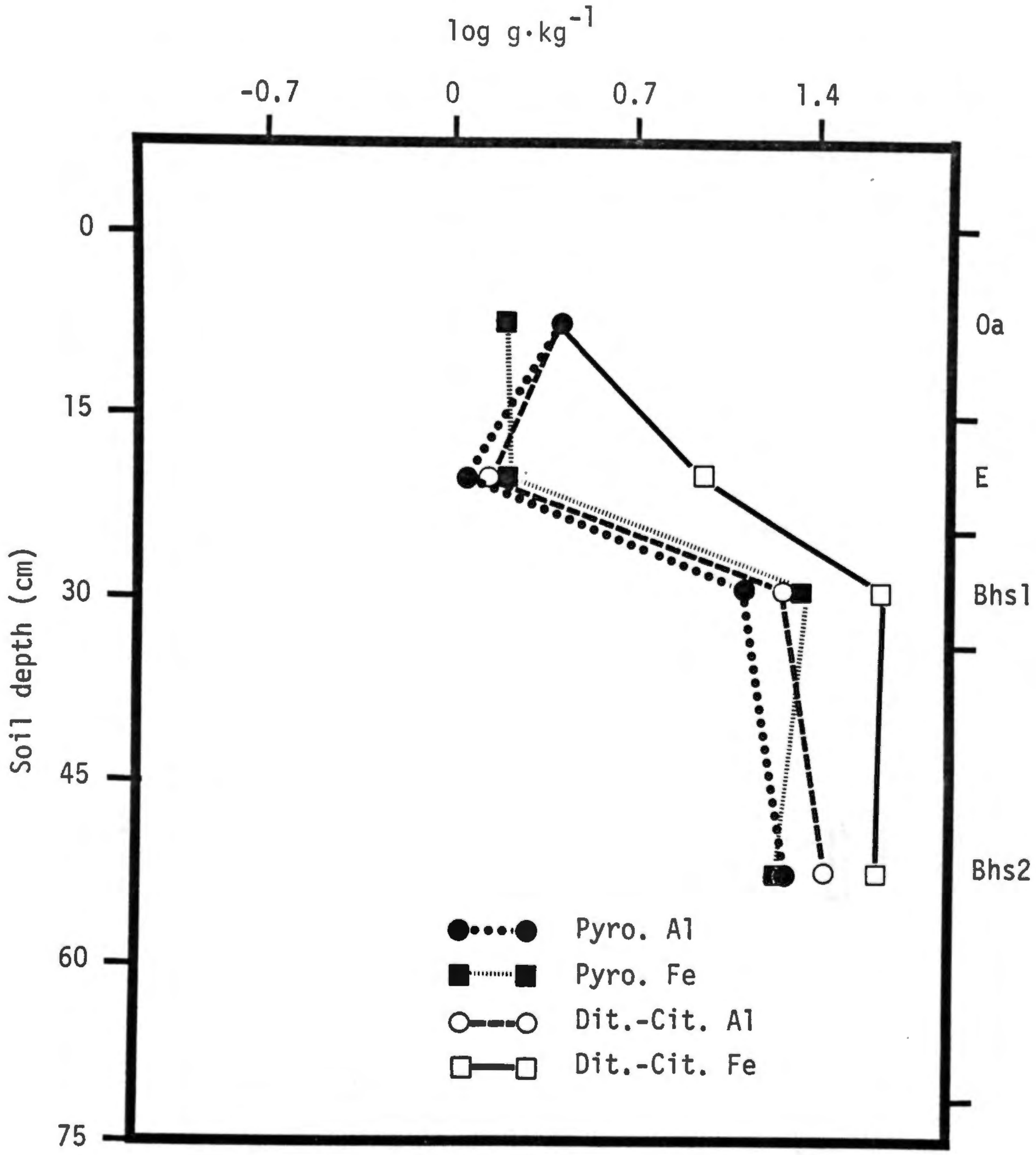

Figure 12. Depth relationship of pyrophosphate and dithionite-citrate extractable aluminum and iron in Pedon EC-9.

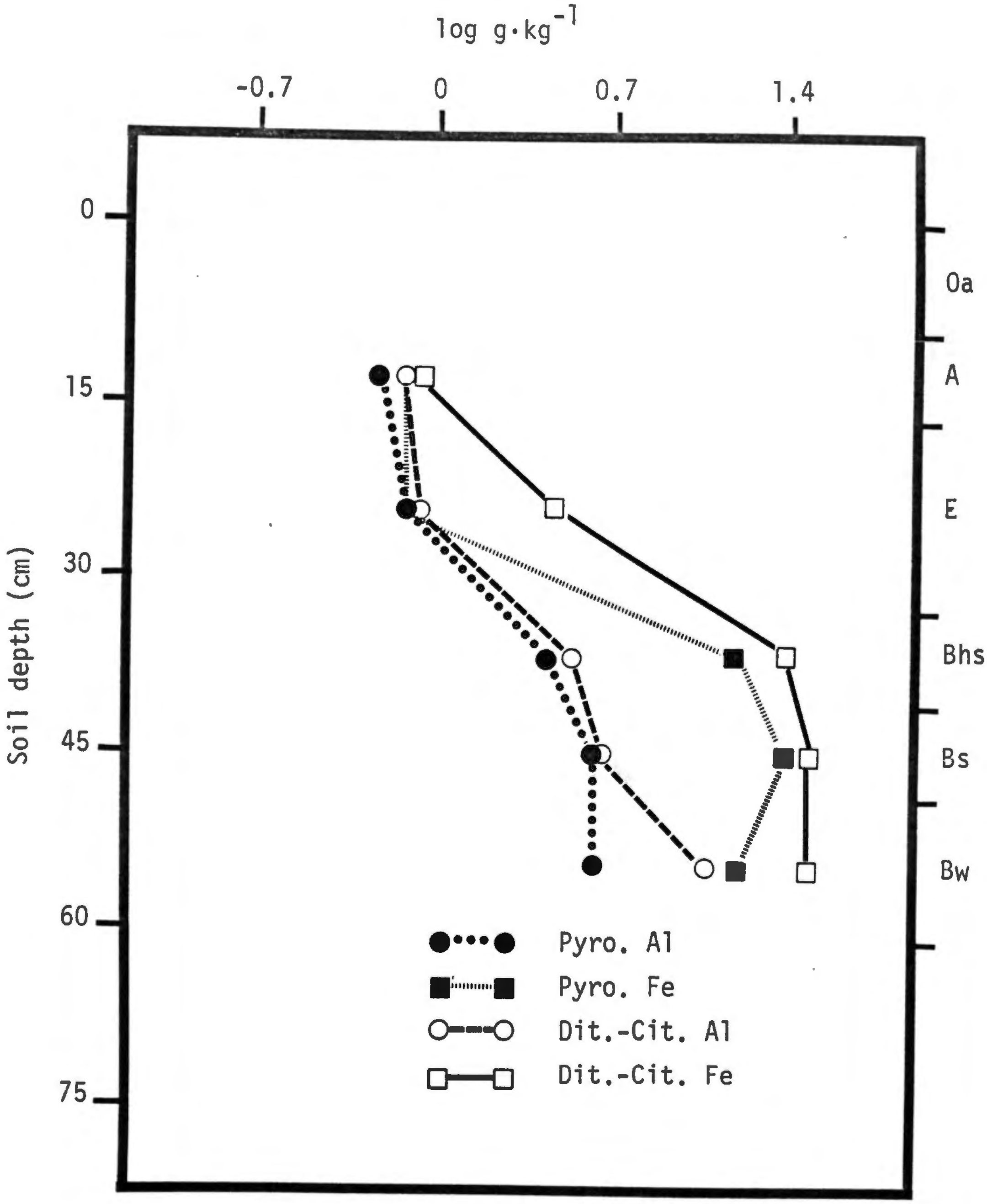

Figure 13. Depth relationship of pyrophosphate and dithionite-citrate extractable aluminum and iron in Pedon CD-2.

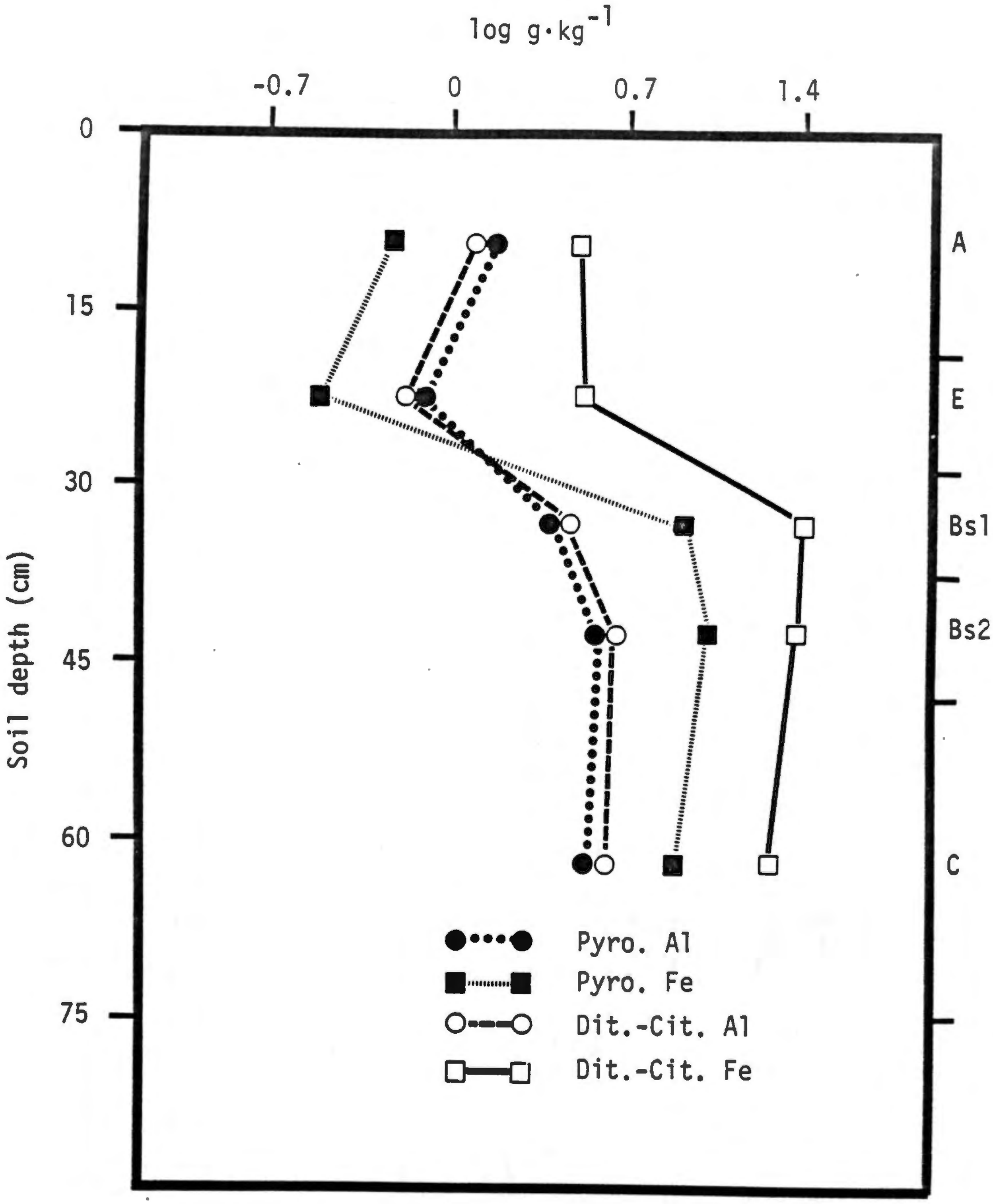

Figure 14. Depth relationship of pyrophosphate and dithionite-citrate extractable aluminum and iron in Pedon NFSPGO.

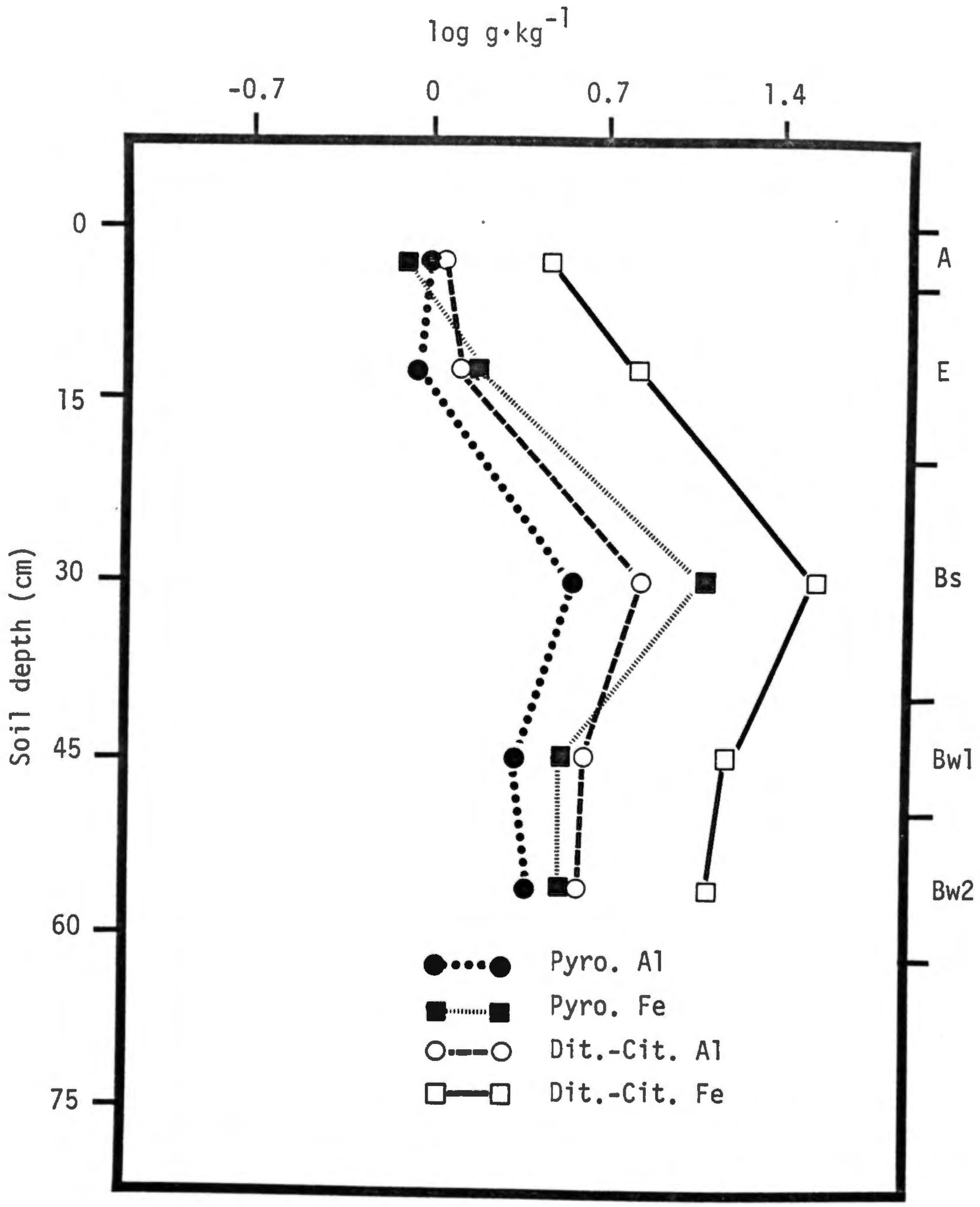

Figure 15. Depth relationship of pyrophosphate and dithionite-citrate extractable aluminum and iron in Pedon UM-3.

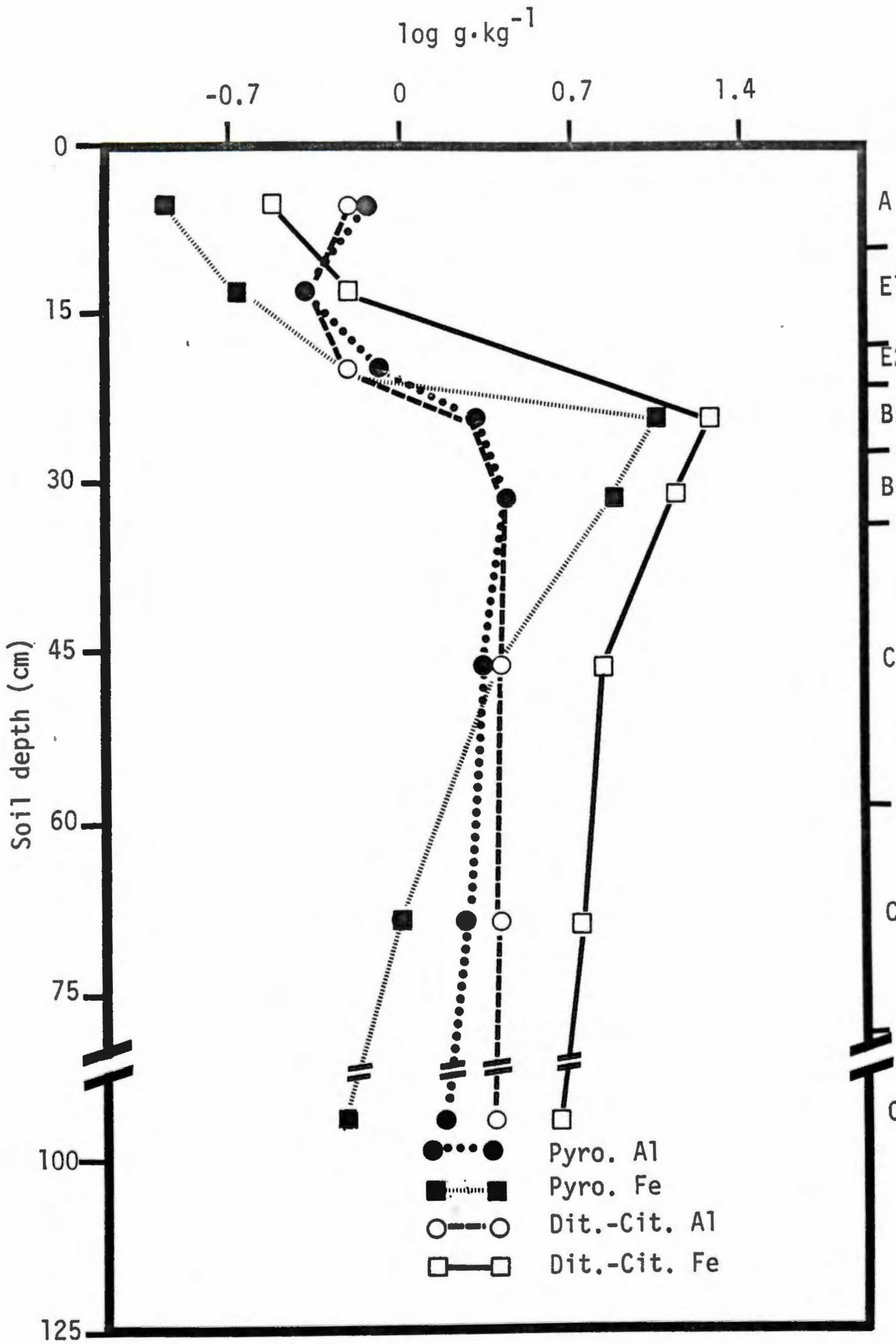

Figure 16. Depth relationship of pyrophosphate and dithionite-citrate extractable aluminum and iron in Pedon SGR-1.

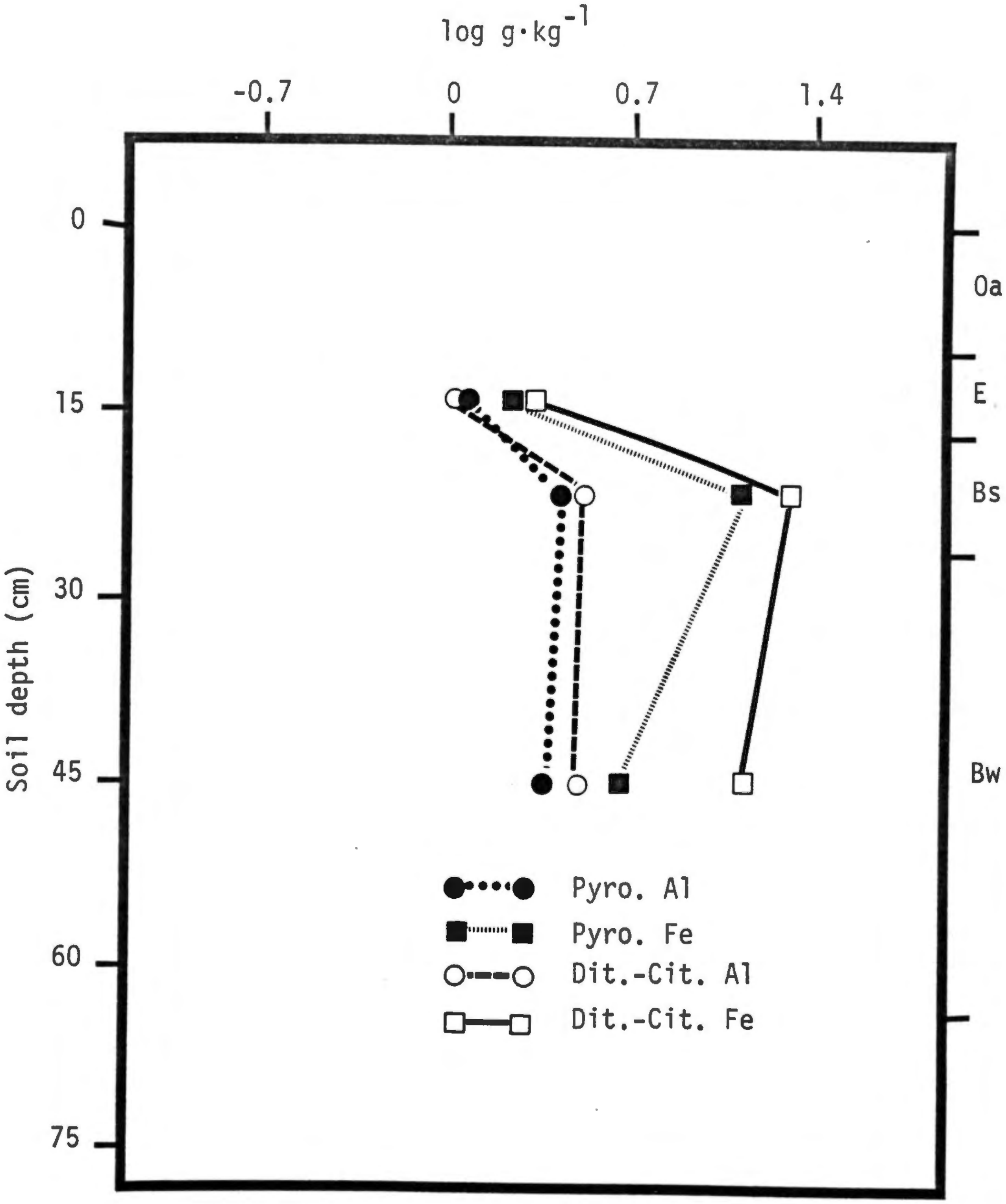

Figure 17. Depth relationship of pyrophosphate and dithionite-citrate extractable aluminum and iron in Pedon CD-1.

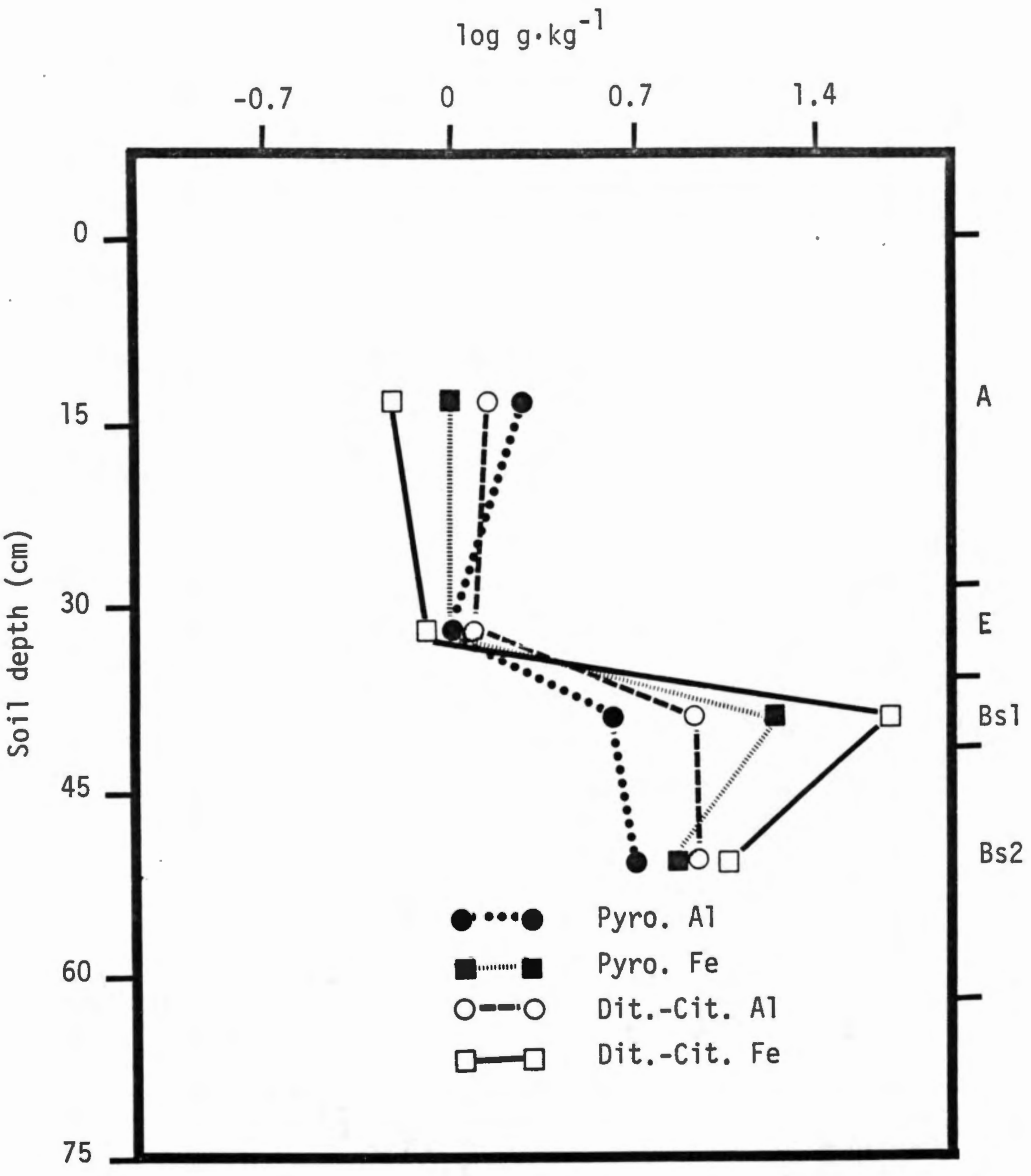

Figure 18. Depth relationship of pyrophosphate and dithionite-citrate extractable aluminum and iron in Pedon SFSPGO.

the profile (pedons NFSPGO, SGR-1). The sequence of aluminum accumulation with respect to iron or vice versa is in accordance to the sequence of accumulation of these two elements as stated in Soil Taxonomy (105). Similar findings of aluminum accumulating in the lower B or upper C horizon have been reported by Mount et al, (89).

In most Bs/Bhs horizons, sodium pyrophosphate extracted lesser amounts of aluminum and iron than the citrate-dithionite technique. This agrees with the findings of Higashi et al. (55). It is suggested that the organic aluminum and iron compounds have degraded into inorganic forms and are thus not extracted by sodium pyrophosphate. Sodium pyrophosphate at pH 10 has been reported (2, 77, 78, 79) to dissolve only amorphous aluminum and iron while citrate-dithionite dissolves both crystalline and amorphous forms (49, 80).

Sodium pyrophosphate aluminum and iron-organic carbon relationships for different horizons are presented in Table F-3, Appendix F. In all three horizons there exists a strong (118), significant relationship between sodium pyrophosphate aluminum and iron and organic carbon.

Chemical Identification of the Spodic Horizon by Field Techniques

Table 3 lists the results of applying two field techniques--the phosphorous adsorption test of Bartlett (9) and the potassium hydroxide

TABLE 3

Comparison of Field Techniques for Recognition of Spodic Horizon with the Present Chemical Criteria

		Bartlett (9) P adsorption test			Holmgren test				
					Color				
Subhorizon No.	Horizon	NaF pretest	Blue color compared to standard	Results of test	Fulvic†	Humic‡	KOH Al^{3+}§	Results of test	Soil Taxonomy Classification
EC-9-53	Bhs1	+	L-114¶	Yes	17	96	18.1	Yes	No
EC-9-54	Bhs2	+	D-92#	No	36	83	28.8	Yes	Yes
CD-2-38	Bhs	+	L-108	Yes	11	86	2.1	No	No
CD-2-39	Bs1	+	L-106	Yes	9	94	4.1	No	Yes
CD-2-40	Bs2	+	L-125	Yes	3	44	6.9	Yes	Yes
CD-1-1-34	Bs1	+	D-96	No	12	44	1.8	No	No
CD-1-1-35	Bs2	+	D-98	No	10	67	2.2	No	No
UM-3-58	Bs1	+	D-76	No	5	28	4.9	No	No
UM-3-59	Bw1	+	D-86	No	NA††	NA	3.8	No	No
UM-3-60	Bw2	+	D-74	No	NA	NA	4.0	No	No
SGR-1-45	Bs1	+	D-90	No	9	54	2.3	No	No
SGR-1-46	Bs2	+	D-99	No	NA	NA	4.1	No	No
SGR-2-22	Bhs	+	L-136	Yes	NA	164	8.0	Yes	No
NFSPGO-4	Bs1	+	D-98	No	17	58	3.1	No	No
NFSPGO-5	Bs2	+	L-108	Yes	6	59	4.4	No	No
SFSPGO-26	Bs1	+	L-120	Yes	9	54	5.6	No	No
SFSPGO-27	Bs2	+	D-74	No	NA	NA	6.4	No	No
CD-1-31	Bs	+	L-110	Yes	9	54	3.6	No	No
CD-1-33	Bw	+	D-98	No	7	6	3.0	No	No
US-4-61	Bs	+	D-98	No	7	59	2.9	No	No

†Values in liter color units per gram (cu/g/l).

‡Values in liter color units per gram (cu/g/l); critical value 10 cu/g/l.

§Critical value 7 $g \cdot kg^{-1}$.

¶Lighter than standard.

#Darker than standard.

††Not analyzed.

aluminum test of Holmgren[14] to the B horizons of pedons that had earlier been classified as Spodosols or Inceptisols (Table 2, p. 34).

Out of a total of 20 B horizons that were tested by the Bartlett (9) technique, eight had sufficient organic aluminum and were identified as spodic. The Holmgren[15] technique identified four B horizons as spodic. Three B horizons met all three chemical criteria for spodic horizon determination and were also identified as spodic according to Soil Taxonomy (105).

When the results of each field technique were compared to that of Soil Taxonomy (105), the following were found:

1. Thirteen of the 20 B horizons tested by the Bartlett (9) technique resulted in the same classification as did Soil Taxonomy (105). Two of the 13 horizons qualified as spodic by both the Bartlett (9) test and Soil Taxonomy (105).
2. The Holmgren[16] test agreed with the results of Soil Taxonomy (105) in 17 of 20 B horizons. Two of the 17 horizons were identified as spodic by both the Holmgren[17] test and Soil Taxonomy (105).

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[14] Holmgren. A field procedure for assessing spodic characteristics.

[15] Ibid.

[16] Ibid.

[17] Ibid.

The results from all three approaches--Bartlett (9), Holmgren,[18] and Soil Taxonomy (105)--agree on 12 of 20 B horizons. The remaining eight B horizons are divided into four classes:

1. EC-9-53, SGR-2-22--these two horizons were identified as spodic by both the Bartlett (9) and Holmgren[19] tests. However, these horizons do not meet the sesquioxide to clay ratio of $\geq$ 0.2.
2. CD-2-39--the Bartlett (9) test and Soil Taxonomy (105) identify this horizon as spodic. The Holmgren[20] test was unable to identify this horizon as spodic because of insufficient potassium hydroxide extractable aluminum.
3. EC-9-54--this horizon was identified as spodic by both the Holmgren[21] test and Soil Taxonomy (105). However, the Bartlett (9) test on this horizon indicated insufficient phosphorous fixation and was, thus, identified as non spodic.
4. CD-2-38, NFSPGO-5, SFSPGO-26, CD-1-31--the Bartlett (9) test indicated enough organo-aluminum accumulation for spodic. The Holmgren[22] test and Soil Taxonomy (105) did not identify these horizons as spodic.

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[18] Ibid.

[19] Ibid.

[20] Ibid.

[21] Ibid.

[22] Ibid.

The results obtained with the use of the field tests, particularly the Holmgren[23] test, have shown that in some pedons (EC-9, CD-2, CD-1-1, SGR-1, UM-3, NFSPGO, and SFSPGO) the spodic horizon was identified in the lower part of the B horizons. However, the lower B horizons of only two pedons (EC-9 and CD-2) were spodic by Soil Taxonomy (105). In addition, most of the 20 lower B horizons tested could be recognized morphologically in the field as having spodic characteristics by their color and structure. The Bartlett (9) and Holmgren[24] tests indicated only eight and four horizons as spodic respectively while two B horizons were spodic by Soil Taxonomy (105). Because of these discrepancies in the results of the field tests with that of the morphological and chemical criteria of Soil Taxonomy (105), further evaluation of the field tests should be done before recommendation is made to modify Soil Taxonomy (105) by making either of the field tests the fourth field criterion for spodic horizon determination (53).

Genesis

Generally, Spodosols that developed in cool mesic and colder soil temperature regimes would be expected to exhibit the best chemical and morphological expression of the spodic horizon. That such a relationship does exist has been shown by Holzhey and Witty (59) and

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[23] Ibid.

[24] Ibid.

by Stanley.[25] In the study area two pedons, EC-9 and CD-2 which qualified chemically as Spodosols, tentatively have a frigid soil temperature regime. However, pedon CD-1 which was sited in the same soil temperature zone as CD-2 but was about 50 m apart from CD-2 did not qualify as a Spodosol. The most limiting criterion for pedon CD-1 is the sesquioxide to clay ratio. Thus, there seems to be little relationship between pedons qualifying chemically as Spodosols and their location in the frigid or mesic soil temperature regime.

Parent material, as a source of clay and cations, exerts a potent force on the formation of Bs/Bhs horizons. In the Clingmans Dome area, for example, soils adjacent to pedons CD-2, CD-1, and CD-1-1, which are formed in phyllite and slate parent materials, show no visible evidence of Bs/Bhs morphology but are Typic Haplumbrepts or Umbric Dystrochrepts with brownish cambic horizons. At the Unaka Mountain area, although most pedons have Bs/Bhs morphology, the high clay content, especially in the Bs or Bhs horizons, reduces the sesquioxide to clay ratio to less than 0.2.

Classification of Soils and Problems with the Current Soil Classification System

Spodic horizons may be recognized either morphologically or chemically using the field and laboratory criteria of Soil Taxonomy (105).

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[25]Stanley. Classification and genesis of Spodosols in Pennsylvania.

All the 11 pedons have most of the morphological characteristics of Spodosols and these include the expression of the Bs/Bhs horizon, the horizon sequence in the profile, and particle-size class. However, none of the pedons were observed to have cracked coatings of amorphous material on sand grains. The presence of an ortstein was also lacking in all the soils. Only one pedon, CD-1-1, failed the depth requirement for frigid or warmer soil temperature regime. The spodic horizon for this pedon is from four to 14 cm below the mineral surface. Soil Taxonomy (105) requires that portion of the profile from 12.5 to 14 cm to be considered for spodic horizon determination, then the index of accumulation is less than the required 65. Secondly, pedon CD-1-1 does not qualify as a Spodosol because it does not satisfy the pyrophosphate aluminum and iron to clay ratio. What is more important is whether a depth requirement is really needed for frigid soils. Pilgrim and Harter (95) have also questioned the usefulness of the depth requirement when four pedons they sampled failed the depth requirement under a frigid soil temperature regime.

As field identification was not suitable to positively identify spodic horizons, laboratory analysis has to be utilized to positively verify if spodic characteristics exist. The three chemical requirements (105) for positive identification are:

1. sodium pyrophosphate aluminum and iron or carbon to clay ratio of ≥ 0.2,
2. sodium pyrophosphate aluminum and iron or carbon to sodium citrate-sodium dithionite aluminum and iron ratio of ≥ 0.5, and

3. index of accumulation of ≥ 65.

The results of applying the chemical requirements to the 11 pedons are found in Tables 4 to 14. Two pedons--EC-9, CD-2--have at least one B horizon meeting all the three chemical requirements (chemical requirement one is met by rounding) and are thus classified as Spodosols. The remaining nine pedons are divided as follows:

1. Seven pedons--SGR-2, US-4, NFSPGO, CD-1, CD-1-1, SGR-1, SFSPGO--failed the pyrophosphate aluminum and iron to clay ratio.
2. Two pedons--UM-3 and S77TN-171-1--failed the pyrophosphate aluminum and iron to citrate-dithionite aluminum and iron ratio.

Nine pedons failed to meet the chemical criteria due to one or more of the following reasons:

1. low pyrophosphate extractable aluminum and iron,
2. high clay content, and
3. high dithionite-citrate extractable aluminum and iron.

Obviously the most limiting chemical criterion is the pyrophosphate aluminum and iron to clay ratio of ≥ 0.2. This criterion has also been cited by De Kimpe and Martel (42), Joslin,[26] Stanley,[27] Bartelli et al. (8), and Wang and Rees (113) as the main reason for

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[26]Joslin. Selected pedons in Maine as they relate to spodic horizon criteria in Soil Taxonomy.

[27]Stanley. Classification and genesis of Spodosols in Pennsylvania.

TABLE 4

Selected Field and Laboratory Values for Spodic Horizon Determination of Pedon EC-9

Horizon	Thickness cm	Depth of upper boundary from surface† cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
E	10	23	120	0.01	0.24	No
Bhs1	10	33	570	0.14	0.53	No
Bhs2	38	43	2786	0.16‡	0.51	Yes

†Organic surface.

‡Rounded to 0.2 (101).

TABLE 5

Selected Field and Laboratory Values for Spodic Horizon Determination of Pedon CD-2

Horizon	Thickness cm	Depth of upper boundary from surface† cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
A	7	16	132	0.01	0.82	No
E	16	23	144	0.01	0.41	No
Bhs	8	39	228	0.11	0.65	No
Bs1	8	47	232	0.16‡	0.82	Yes
Bs2	12	55	266	0.16‡	0.50	Yes

†Organic surface.

‡Rounded to 0.2 (101).

TABLE 6

Selected Field and Laboratory Values for Spodic Horizon Determination of Pedon SGR-2

Horizon	Thickness cm	Depth of upper boundary from surface† cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
Bhs	4	19	186	0.10	0.60	No

†Organic surface.

TABLE 7

Selected Field and Laboratory Values for Spodic Horizon Determination of Pedon S77TN-171-1

Horizon	Thickness cm	Depth of upper boundary from surface[†] cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	(% pyrophosphate Fe+Al) / (% citrate-dithionite Fe+Al)	Meets present chemical criteria
E	20	13	134	0.02	0.33	No
Bs	11	33	180	0.05	0.33	No

[†]Organic surface.

TABLE 8

Selected Field and Laboratory Values for Spodic Horizon
Determination of Pedon US-4

Horizon	Thickness cm	Depth of upper boundary from surface[†] cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
Bs	16	32	302	0.06	0.49	No

[†]Organic surface.

TABLE 9

Selected Field and Laboratory Values for Spodic Horizon
Determination of Pedon NFSPGO

Horizon	Thickness cm	Depth of upper boundary from surface[†] cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
A	20	8	287	0.01	0.47	No
E[‡]	10	28	28	--	0.27	No
Bs1	10	38	174	0.04	0.40	No
Bs2	10	48	198	0.07	0.52	No
C	30	58	446	0.05	0.49[§]	No

[†]Organic surface.

[‡]< 0.1% iron by pyrophosphate.

[§]Rounded to 0.5 (101).

TABLE 10

Selected Field and Laboratory Values for Spodic Horizon
Determination of Pedon CD-1-1

Horizon	Thickness cm	Depth of upper boundary from surface† cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
Bs1	6	4	106	0.04	0.60	No
Bs2	4	14	94	0.09	0.62	No

†Organic surface.

TABLE 11

Selected Field and Laboratory Values for Spodic Horizon Determination of Pedon UM-3

Horizon	Thickness cm	Depth of upper boundary from surface† cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
A	5	5	95	0.01	0.44	No
E	15	10	138	0.01	0.28	No
Bs	20	25	247	0.09	0.38	No
Bw1	10	45	78	0.05	0.30	No
Bw2	12	55	98	0.04	0.35	No

†Organic surface.

TABLE 12

Selected Field and Laboratory Values for Spodic Horizon
Determination of Pedon SGR-1

Horizon	Thickness cm	Depth of upper boundary from surface[†] cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
A[‡]	9	1	104	--[§]	0.89	No
E1[‡]	8	10	22	--[§]	0.60	No
E2	4	18	12	0.01	1.00	No
Bs1	6	22	95	0.06	0.65	No
Bs2	6	28	60	0.05	0.62	No
C1	24	34	113	0.03	0.48[¶]	No
C2	22	58	122	0.03	0.34	No
C3	22	80	106	0.02	0.29	No

[†]Organic surface.

[‡]< 0.1 percent iron by pyrophosphate.

[§]Assume that the sesquioxide to clay ratio does not meet/exceed the critical value of 0.2.

[¶]Rounded to 0.5 (101).

TABLE 13

Selected Field and Laboratory Values for Spodic Horizon Determination of Pedon CD-1

Horizon	Thickness cm	Depth of upper boundary from surface† cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
E	7	13	87	0.02	0.97	No
Bs	10	20	224	0.12	0.67	No
Bw	17	30	332	0.05	0.42	No

†Organic surface.

TABLE 14

Selected Field and Laboratory Values for Spodic Horizon Determination of Pedon SFSPGO

Horizon	Thickness cm	Depth of upper boundary from surface† cm	Index of accumulation	% pyrophosphate Fe+Al / % clay	% pyrophosphate Fe+Al / % citrate-dithionite Fe+Al	Meets present chemical criteria
A	28	10	561	0.01	1.40	No
E	8	38	63	0.01	1.00	No
Bs1	5	46	107	0.09	0.40	No
Bs2	18	51	288	0.06	0.63	No

†Organic surface.

their soils not being able to be classified as Spodosols. The high clay content in many soils reduces the critical pyrophosphate aluminum and iron ratio to less than 0.2.

There is a strong geographic and climatic bias for soils with higher clay content yet exhibiting Bs/Bhs morphology. Evidence from this and other similar studies in the Appalachian Mountain region (42, 107) seems to indicate such soils are restricted to highland areas in the frigid or marginal to frigid soil temperature zone. Soil Taxonomy (105), hitherto, has not had any provisions in its chemical criteria to accommodate soils of higher clay content and at the same time have Bs/Bhs morphology. Thus, it is proposed that the present ≥ 0.2 value for pyrophosphate aluminum and iron to clay ratio remain the same but be restricted to soils that have a sandy family particle-size class and have a sand or loamy sand texture in the Bs/Bhs horizons. For soils with cambic horizons that have a loamy particle-size class in the Bs/ Bhs horizon, the critical value for pyrophosphate aluminum and iron to clay ratio should be reduced from the present ≥ 0.2 to ≥ 0.1 (52). The critical values for sodium pyrophosphate aluminum and iron to dithionite-citrate aluminum ratio and iron and index of accumulation remain the same.

Table 15 shows all the relevant data that were used for placement of soils that satisfied the proposed criteria into the various subgroups of Haplorthods. In pedon SGR-2, properties of two subgroups of Haplorthods are expressed in the same soil. The particle-size class (fine-loamy), the color value and chroma (3/4), and the thickness of

TABLE 15

Classification of Pedons Which Satisfied the Proposed Revised Chemical Criteria for Spodic Horizon Determination

	Bs/Bhs Horizon							
Pedon	Thickness cm	Texture	Organic carbon	Dithionite-citrate Fe	Dit.-cit. Fe / Org. carbon	Particle-size class	Value/chroma in upper 7.5 cm	Proposed classification
			$g \cdot kg^{-1}$					
EC-9	48	CNVL	92.0	44.0	0.5	loamy-skeletal	2/2	Humic Haplorthod
CD-2	28	GRSL	53.6	29.5†	1.2†	coarse-loamy	2/2	Typic Haplorthod
SGR-2	4	GRCL	75.4	52.0	0.7	fine-loamy	3/4	Entic/Humic Haplorthod
US-4	16	SCL	23.2	31.6	1.4	fine-loamy	3/4	Typic Haplorthod
NFSPGO	20	GRSCL	22.0	25.4	1.2	fine-loamy	3/2	Typic Haplorthod
CD-1-1	10	SL	35.3†	15.3†	0.4	coarse-loamy	2/2	Lithic Haplorthod
SGR-1	12	SCL	10.2†	16.4†	1.6	fine-loamy	4/6	Typic Haplorthod
CD-1	10	SL	31.6	20.7	0.7	coarse-loamy	3/4	Typic Haplorthod
SFSPGO	25	SCL	22.4†	31.3†	1.4	fine-loamy	4/6	Typic Haplorthod

†Average from 2 or more Bs/Bhs horizons.

the spodic horizon (4 cm) would exclude this pedon from being classified as a Typic Haplorthod. It has the properties of an Entic Haplorthod except that it has more than 60 $g \cdot kg^{-1}$ (75.4 $g \cdot kg^{-1}$) organic carbon in the upper 10 cm of the Bhs horizon. In the present classification system, there is no subgroup in the Haplorthods that includes soils that have intermediate properties between the Entic and Humic subgroups. Due to the lack of a Haplorthod subgroup in the present classification system that has properties of two other subgroups, this pedon was classified as an Entic/Humic Haplorthod. It is assumed that the thick sapric horizons as well as an accumulation of sesquioxides characteristic of soils with spodic morphology in the Southern Appalachians may have given rise to high organic carbon levels in the Bs/Bhs horizons.

Another problem deals with a change in emphasis in surface epipedons when classifying soils that are now Inceptisols but would be Spodosols with the proposed changes in criteria for spodic horizon. In the Inceptisols, emphasis has been given to surface epipedons in classifying soils not only at the suborder level, but at the subgroup level as well. When an Umbric Dystrochrept (SGR-2, CD-1-1, or SGR-1), for example, is classified as a Spodosol, the importance of the surface epipedon is reduced to the point where it is not mentioned at all at the subgroup level of Spodosols. Most of the soils in this region of study have a thick humus-rich umbric or histic epipedon coincident with the zone of nutrient accumulation. The significant role of these humus-rich O horizons and umbric epipedons as a reservoir for nutrient cycling of shallow rooted vegetation suggests that such surface horizons should be given more emphasis in Spodosol classification, at least, in the subgroup level.

Proposal for Spodic Subgroup in Dystrochrepts and Haplumbrepts

Nine of the 11 pedons used in this study did not meet the present chemical criteria for classification into Spodosols. It is important that the nine pedons not be classified identically with pedons that do not exhibit any Bs/Bhs horizons. The following are some of the reasons for justifying the creation of this new subgroup:

1. The striking contrast between soils with Bs/Bhs horizons and those soils lacking them in other Dystrochrept and Haplumbrept subgroups. The presence of an albic and a Bs/Bhs horizon occurring within the same profile makes it one of the easiest soils to recognize in the field.
2. The striking contrast between the chemistry of Bs/Bhs horizons and those lacking it in other Dystrochrept and Haplumbrept subgroups. Bs/Bhs horizons have low amounts of basic cations, high extractable acidity, high pH-dependent C.E.C., phosphorous fixation, in addition to illuvial accumulation of organic carbon, aluminum, and iron. Organic carbon content, in particular, decreases irregularly with depth. Such properties are absent in other Dystrochrept and Haplumbrept subgroups.

3. Management techniques are different with soils having Bs/Bhs horizons because the chemistry of such soils, in particular, is different from soils in other Dystrochrept and Haplumbrept subgroups. The acid reaction and the high amount of aluminum in soils with spodic morphology make phosphorous unavailable to the plant. Therefore, phosphorous fertilizer application may have to be split or applied in a band to reduce fixation losses.

With the inclusion of the proposed new subgroup of Dystrochrepts and Haplumbrepts into the present classification system, the definition of a Typic subgroup in terms of its selected properties should be amended. For example, property (e) of Typic Dystrochrept on page 249 in Soil Taxonomy (105) should now read as "Do not have an argillic or spodic horizon in any part of the pedon; and . . . ." Likewise, "Spodic Dystrochrepts would then be defined as follows: These soils have a cambic horizon that has characteristics of a spodic horizon but does not qualify as a spodic horizon because it is too shallow in the soil or does not meet the pyrophosphate iron and aluminum to clay ratio. The cambic horizon has a translocated bulge of iron, carbon, and aluminum. A Spodic Dystrochrept may have an albic horizon above the cambic horizon. If the soil has not been burned or plowed, an O horizon is common; many will have an epipedon with umbric colors. All spodic Haplumbrepts will have an umbric epipedon and some will have a histic epipedon, either as a natural entity, or by mixing."

The reclassification of the pedons into Spodic Dystrochrepts, for example, is shown in Table 16. Two pedons, S77TN-171-1 and UM-3, would be reclassified as Spodic Dystrochrepts. The remaining pedons would be classified as Spodosols after the lower limit of sodium pyrophosphate extractable iron and aluminum to clay ratio, required for spodic horizon determination, is lowered from ≥ 0.2 to ≥ 0.1.

The creation of an intergrade such as Spodic Dystrochrepts or Spodic Haplumbrepts in Soil Taxonomy (105) for soils as being marginal to Spodosols, Ochrepts, and Umbrepts should be done only after more research data are available.

TABLE 16

Current and Proposed Taxonomic Classification for Pedons Used in this Study

Pedon	Current Classification	Proposed Classification†
EC-9	Humic Haplorthod	Humic Haplorthod
CD-2	Typic Haplorthod	Typic Haplorthod
SGR-2	Umbric Dystrochrept	Entic/Humic Haplorthod
S77TN-171-1	Umbric Dystrochrept	Spodic Dystrochrept
US-4	Typic Haplumbrept	Typic Haplorthod
NFSPGO	Typic Haplumbrept	Typic Haplorthod
CD-1-1	Lithic Haplumbrept	Lithic Haplorthod
UM-3	Umbric Dystrochrept	Spodic Dystrochrept
SGR-1	Umbric Dystrochrept	Typic Haplorthod
CD-1	Typic Haplumbrept	Typic Haplorthod
SFSPGO	Typic Haplumbrept	Typic Haplorthod

†Particle-size class, mineralogy, and soil temperature remain the same like those for the current classification.

CHAPTER V

SUMMARY AND CONCLUSIONS

The main prerequisites for the formation of Spodosols are as follows: a cool climate with a predominance of precipitation over evaporation; some degree of wetting of the soil system; and a low content of bases in the soil. In many areas of the Southern Appalachians these conditions are present. Thus, a study was initiated on 11 pedons from Tennessee and North Carolina (1) to evaluate soils exhibiting Bs/Bhs morphology using the present spodic horizon chemical criteria, (2) to classify the soils into the present classification system, (3) to identify problems (if any) with regard to the use of the present classification system in classifying soils with Bs/Bhs morphology, and (4) to evaluate two field techniques for spodic horizon determination.

Ten pedons were located in the Unaka Mountain and Clingmans Dome areas of Tennessee while the remaining pedon was located in the Raven-Enloe Creek watershed of Swain County, North Carolina.

Sand forms the most abundant soil separate in most of the pedons, attributable to the high sand content of the parent materials. The greater intensity of physical and chemical weathering at the surface horizons than in the underlying horizons results in a greater amount of 0.5 to 0.05 mm over 2.0 to 0.5 mm size sands in most of the A and E horizons. No depth relationship pattern for silt was noticeable. Clay increase in the spodic horizon, as compared to the overlying horizon, meets the requirements for an argillic horizon. Although no clay skins were observed, plasma bridging between sand grains was observed in pedons CD-1-1 and SFSPGO. The major reason for the clay content in the spodic horizon may be the result of organo-metallic complexes that were dispersed during particle size analysis. Other reasons include:

1. an increase in physical and chemical weathering rates due to a gradual increase in temperature and precipitation since the Pleistocene cold phases,
2. translocation of clay size minerals from the overlying horizons, or
3. degradation of the Bs/Bhs horizon that resulted from changes in climatic patterns.

The presence of coarse fragments in parts of the E horizon causes tongueing of organic matter in that horizon by restricting the movement of organic matter in parts of the horizon that have coarse fragments. In the Bs/Bhs horizons, the presence of coarse fragments restricts sesquioxides and organic matter to a smaller surface area. This results in maximal expression of spodic horizon development in the section of the Bs/Bhs horizon that has coarse fragments.

Surface soil pH values range from 3.2 to 5.6. This low pH reflects the precipitation regime, leaching conditions, and the acid nature of the forest litter. Organic carbon depth pattern shows a maximum in the Oa and A horizon, a minimum in the E and C horizons and a secondary maximum in the Bhs horizons. This depth pattern is the result of eluviation and illuviation processes. Extractable acidity depth pattern is attributable more to organic carbon than to clay because of the apparent strong significant correlation between extractable acidity and organic carbon in all horizons.

Extractable bases have maximum accumulation in the Oa and A horizons and a secondary accumulation in the spodic horizon, attributable to the organic matter and clay content respectively.

Maximum accumulation of aluminum extracted by sodium pyrophosphate and dithionite-citrate either occurred at the same depth as iron or was precipitated lower in the profile than was iron. This may suggest that aluminum rather than iron could be a somewhat better indicator of the process of spodic horizon development. In most B horizons, larger amounts of aluminum and iron were extracted by dithionite-citrate than by sodium pyrophosphate. The difference in the amounts of sesquioxides extracted by the two methods may be attributable to the selectivity of the extractants.

Although the pedons were taken from the same physiographic region, vegetation and slight parent material differences have given rise to soils with varying expressions of Bs/Bhs horizon development.

Two of the 11 pedons satisfied all the present chemical criteria for spodic horizon development. For the remaining nine pedons, the most limiting criterion was the pyrophosphate extractable aluminum and iron to clay ratio. High clay contents, low pyrophosphate extractable aluminum and iron contents resulted in the failure of the nine pedons to satisfy the present chemical criteria.

The following problems arose from this study:

1. Soils that appeared to have resulted from the process of spodic horizon development could not be chemically identified by laboratory methods outlined as having a spodic horizon. The high clay content, in most cases, reduces the ratio of the sodium pyrophosphate aluminum and iron to clay to ≤ 0.2.
2. Some horizons which could not be classified as spodic using the taxonomic chemical criteria gave a positive reaction to the Bartlett (9) and/or the Holmgren[28] test.
3. There is (are) no subgroup (or subgroups) in Soil Taxonomy (105) that would include soils that are marginal to Spodosols and Ochrepts and Umbrepts.
4. There is no subgroup in the present Haplorthods that would handle soils that fall between Entic and Humic subgroups.
5. The 12.5 cm depth requirement for spodic identification would exclude pedon CD-1-1 otherwise identifiable as Spodosols.

The following are some proposals that need further investigations:

1. investigating the lower limit of the sodium pyrophosphate extractable iron and aluminum to clay ratio for soils with a cambic horizon that have a loamy particle-size class in the Bs/Bhs horizons,

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[28] Holmgren. A field procedure for assessing spodic characteristics.

2. investigating the possibility of spodic subgroups in Inceptisols that show evidences of Bs/Bhs horizonation,
3. eliminating the depth requirement for frigid soils while still retaining the 12.5 cm depth requirement for mesic or warmer temperature regimes,
4. withholding the creation of a new subgroup that includes soils exhibiting intermediate properties of Entic and Humic subgroups of Haplorthods until more laboratory data on such soils are available, and
5. withholding the inclusion of either the two spodic field test kits as the fourth spodic horizon field criterion until more research data on the use of these field test kits on soils in other areas are available.

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APPENDICES

APPENDIX A

PEDON DESCRIPTIONS

Soil Classification: Humic Haplorthod, loamy-skeletal, mixed, frigid.

Series: Not designated

Pedon No.: EC-9 (50-54)

Area: Smoky Mountain National Park area of Swain Co. North Carolina--Raven Fork--Enloe Creek Watershed.

Location: Mount Guyot Quadrangle, 165-NE, 1 km, 1.7 rad. (100°) from Eagle Rocks benchmark.

MLRA: 130

Climate: Frigid

Vegetation: Dense red spruce stand 90% canopy closure. Understory of viburnum sp., with hemlock and red spruce seedlings. Forest floor of mosses.

Parent Material: Graywacke and feldspathic quartzite colluvium

Physiography: Midpart of convex slope.

Topography, Slope, Aspect and Elevation: Steep to very steep, 0.29-0.38 rad. (15 to 20°), west aspect, 1671 m.

Drainage: Well drained

Ground Water: > 81 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: NA

pH Method: Extremely acid (pH 3.2 to 4.2 in water).

Sampled by: D. A. Lietzke and P. A. Mays

Described by: D. A. Lietzke and P. A. Mays

Sample No.	Description
EC-9-50	Oe-8 to 0 cm; black (10YR2/1); hemic material; massive; many medium roots; extremely acid (pH 3.1); abrupt smooth boundary.
EC-9-51	Oa-0 to 15 cm; black (10YR2/1); sapric material; weak fine granular and weak fine subangular blocky structure; very friable; many fine roots; many flags and channers; extremely acid (pH 3.5); abrupt wavy boundary.
EC-9-52	E-15 to 25 cm; dark gray (10YR4/1); very gravelly, channery and flaggy sandy loam; weak fine subangular blocky structure; very friable; few 1/2 to 1 cm roots; extremely acid (pH 3.8); abrupt wavy boundary.
EC-9-53	Bhs1-25 to 35 cm; very dusky red (2.5YR2/2); very channery loam; weak to moderate fine subangular blocky structure; friable; common fine roots; extremely acid (pH 4.3); clear smooth boundary.
EC-9-54	Bhs2-35 to 73 cm; dark reddish brown (5YR3/4); very channery loam; moderate fine to medium subangular blocky structure; friable; few 1/2 to 1 cm roots; very strongly acid (pH 4.5).

Remarks: All colors refer to moist conditions unless otherwise stated. A large rock slab was encountered at 73 cm. Soil pH values in 1:2 soil:water. Coarse fragment modifiers do not reflect what is in the laboratory analysis as coarse fragments were not sampled and brought to the laboratory.

Soil Classification: Typic Haplorthod, coarse-loamy, mixed, frigid.

Series: Not designated

Pedon No.: CD-2 (36 to 40)

Area: Clingmans Dome, Great Smoky Mountain National Park, Tennessee.

Location: Clingmans Dome Quadrangle, 165-SW, 0.6 km, 2.6 rad. (150°) from the Lookout tower.

MLRA: 130

Climate: Frigid

Vegetation: Fraser fir and mountain ash

Parent Material: Loamy deposits from feldspathic quartzite

Physiography: Mid part of a convex slope

Topography, Slope, Aspect and Elevation: Rolling, 0.1 rad. (6°), south aspect, 1891 m.

Drainage: Well drained

Ground Water: > 61 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: Less than 1% of surface covered by gravels

pH Method: Extremely acid (pH 3.2 to 4.0 in water).

Sampled by: D. A. Lietzke and G. McGuire, 6/16/82.

Described by: D. A. Lietzke and G. McGuire

Sample No.	Description
No sample taken	Oe-6 to 0 cm; black (10YR2/1); hemic material; about 50% fiber; massive; many medium to coarse roots; abrupt smooth boundary.
No sample taken	Oa-0 to 10 cm; black (10YR2/1); sapric material; 20-30% fiber; moderate fine granular structure; very friable; many medium roots; abrupt smooth boundary.
CD-2-36	A-10 to 17 cm; black (10YR2/1); sandy loam; moderate fine granular to weak fine subgranular blocky structure; very friable; many fine to medium roots; 5% coarse fragments; extremely acid (pH 3.2); abrupt smooth boundary.
CD-2-37	E-17 to 33 cm; yellowish brown (10YR5/4); and dark gray (10YR4/1) organic tongues; sandy loam; weak fine subangular blocky structure; very friable; many fine roots; 5% coarse fragments; extremely acid (pH 3.8); abrupt smooth boundary.
CD-2-38	Bhs-33 to 41 cm; dark reddish brown (5YR2/2); sandy loam; weak fine subangular blocky structure; very friable; few fine roots; 10% coarse fragments; extremely acid (pH 3.9); clear smooth boundary.
CD-2-39	Bs1-41 to 49 cm; dark reddish brown (5YR3/3); gravelly sandy loam; fine subangular blocky structure; very friable; fine roots; 15% coarse fragments comprising conglomerate; extremely acid (pH 4.0); clear smooth boundary.
CD-2-40	Bs2-49 to 61 cm; yellowish brown (10YR5/6); gravelly loam; weak fine subangular blocky structure; friable; few very fine roots; 20% coarse fragments; extremely acid (pH 4.2).
No sample taken	Cr-61 cm; meta conglomerate highly fractured.

Remarks: All colors refer to moist conditions unless otherwise stated. Soil pH values in 1:2 soil:water.

Soil Classification: Umbric Dystrochrept, loamy-skeletal, mixed, frigid.

Series: Not designated.

Pedon No.: SGR-2 (22)

Area: Unaka Mountain, Unicoi County, Tennessee.

Location: Unicoi Quadrangle, 199-NE, 1 km, 6.1 rad. (355°) from Unaka Mountain benchmark.

MLRA: 130

Climate: Frigid

Vegetation: Dwarf heath consisting of rhododendron, mountain ash and some blackberries.

Parent Material: Loamy deposit of feldspathic quartzite

Physiography: Narrow saddle

Topography, Slope, Aspect and Elevation: Nearly level to undulating, 0.02-0.06 rad. (2 to 4°), north aspect, 1418 m.

Drainage: Well drained

Ground Water: > 30 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: 15 to 50% of surface covered

pH Method: Extremely acid (pH 4.0 in water).

Sampled by: D. A. Lietzke and G. McGuire, 6/15/82

Described by: D. A. Lietzke and G. McGuire

Sample No.	Description
No sample taken	Oe-1 to 0 cm; grayish brown (10YR5/2); hemic material; 45% fiber; massive; many medium roots; abrupt wavy boundary.
No sample taken	A1-0 to 7 cm; grayish brown (10YR5/2); gravelly loam; weak fine granular structure; very friable; many fine and medium roots; 20% coarse fragments; clear wavy boundary.
No sample taken	A2-7 to 18 cm; dark brown (7.5YR3/2); gravelly loam; weak fine granular structure; very friable; few fine roots; 20% coarse fragments; abrupt irregular boundary.
SGR-2-22	Bhs-18 to 22 cm; dark reddish brown (5YR3/4); and dark reddish brown (5YR3/3); gravelly clay loam; weak fine subangular blocky structure; very friable; few fine roots; 30% coarse fragments; extremely acid (pH 4.0); abrupt irregular boundary.
No sample taken	Bw-22 to 29 cm; strong brown (7.5YR5/6); very gravelly loam; weak fine subangular blocky structure; very friable; no roots; 40% coarse fragments; clear wavy boundary.
No sample taken	C-29 to 40 cm; yellowish brown (10YR5/6); very gravelly loam; weak fine subangular to massive structure; very friable; no roots; 45% coarse fragments.
No sample taken	Cr-40 cm; rubble of feldspathic quartzite highly fractured.

Remarks: All colors refer to moist conditions. Soil pH values in 1:2 soil:water.

Soil Classification: Umbric Dystrochrept, loamy-skeletal, mixed, mesic.

Series: Not designated.

Pedon No.: S77TN-171-1 (1-3)

Area: Unaka Mountain, Unicoi County, Tennessee.

Location: Unicoi Quadrangle, 199-NE, 1.75 km, 4.6 rad. (265°) from Unaka Mountain benchmark.

MLRA: 130

Climate: Mesic

Vegetation: Laurel, rhododendron, blueberry, red spruce.

Parent Material: feldspathic quartzite colluvium

Physiography: Mountain ridgetop

Topography, Slope, Aspect and Elevation: Rolling, 0.12 rad. (7°) south aspect, 1470 m.

Drainage: Well drained

Ground Water: > 31 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: NA

pH Method: Extremely acid (pH 3.7 to 4.1 in water).

Sampled by: C. McCowan, 11-77, USDA Soil Conservation Service.

Described by: C. McCowan

Sample No.	Description
S77TN-171-1-1	Oe-13 to 0 cm; black (N2/), organic material; many fine and medium roots; abrupt smooth boundary.
S77TN-171-1-2	E-0 to 20 cm; mottled white (10YR8/1) and very dark gray (10YR3/1); organic tongueing, very cobbly sandy loam; massive to weak coarse blocky structure; friable; common fine roots mostly in cracks between peds; 35% fragments of quartzite up to 203 mm in size; common black (N2/) organic coatings on faces of some peds and in root channels up to 3 mm thick in places; very strongly acid (pH 4.5); gradual wavy boundary.
S77TN-171-1-3	Bs-20 to 30 cm; mottled reddish brown (5YR4/4); reddish yellow (7.5YR6/8) and black (N2/); very cobbly sandy loam; few medium distinct reddish yellow (5YR6/8) mottles; weak medium subangular blocky and weak medium granular structure; friable; few fine roots mostly in cracks between peds; 45% fragments of quartzite up to 203 mm in size; very strongly acid (pH 4.5); gradual wavy boundary.
No sample taken	Cr-30 cm; feldspathic quartzite, highly fractured.

Soil Classification: Typic Haplumbrepts, fine-loamy, mixed, frigid.

Series: Not designated.

Pedon No.: US-4 (61)

Area: Along the Unicoi and Mitchell Counties of Tennessee and North Carolina.

Location: Unicoi Quadrangle, 199-NE, 0.75 km, 4.5 rad. (261°) from Unaka Mountain benchmark. Site is 15 to 20 m north and below the highest summit.

MLRA: 130

Climate: Frigid

Vegetation: Red spruce

Parent Material: Loamy deposit of feldspathic quartzite

Physiography: Upland summit

Topography, Slope, Aspect and Elevation: 0-.1 rad. (6°), north aspect, 1571 m.

Drainage: Well drained

Ground Water: > 65 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: None

pH Method: Extremely acid (pH 4.0 1:2 soil:water).

Sampled by: D. A. Lietzke and G. McGuire, 7/16/82.

Described by: D. A. Lietzke

Sample No.	Description
No sample taken	Oi-6 to 0 cm; very dark grayish brown (10YR3/2); fibric and hemic material; massive, non sticky; many live roots; abrupt smooth boundary.
No sample taken	A1-0 to 7 cm; black (10YR2/1); mucky loam; moderate fine granular structure; very friable; many fine roots; 10% coarse fragments; clear smooth boundary.
No sample taken	A2-7 to 26 cm; very dark gray (10YR3/1) to dark grayish brown (10YR3/2); sandy loam; moderate fine granular structure; very friable; many fine roots; about 10% coarse fragments; abrupt smooth boundary.
US-4-61	Bs1-26 to 28 cm; dark reddish brown (5YR3/4) sandy clay loam; weak medium subangular blocky structure; very friable; many fine roots; 10% coarse fragments; extremely acid (pH 4.0); clear smooth boundary.
US-4-61	Bs2-28 to 42 cm; strong brown (7.5YR5/6); sandy clay loam; weak medium subangular blocky structure; very friable; many fine roots; 10% coarse fragments; extremely acid (pH 4.0); abrupt smooth boundary.
No sample taken	Bw1-42 to 52 cm; yellowish brown (10YR5/4 to 10YR5/6); loam; weak to moderate medium subangular blocky structure; friable; common fine roots; 10% coarse fragments; clear smooth boundary.
No sample taken	Bw2-52 to 65 cm; dark yellowish brown (10YR4/4); gravelly loam; moderate medium subangular blocky structure; friable; few fine roots; 20% coarse fragments.
No sample taken	Cr-65 cm; feldspathic quartzite highly fractured.

Remarks: All soil colors refer to moist conditions unless otherwise noted. Umbric epipedon. The A2 has some E character to it, but not very evident. Soil pH value is 1:2 soil:water.

Soil Classification: Typic Haplumbrept, fine-loamy, mixed, frigid.

Series: Not designated.

Pedon No.: NFSPGO (1-5, 14)

Area: Pleasant Garden Overlook on Unaka Mountain, Unicoi County, Tennessee

Location: Unicoi Quadrangle, 199-NE, 1.9 km, 4.6 rad. (268°) from Unaka Mountain benchmark

MLRA: 130

Climate: Frigid

Vegetation: Rhododendron, Red Spruce

Parent Material: Loamy feldspathic quartzite colluvium

Physiography: High side of convex slope

Topography, Slope, Aspect and Elevation: Rolling, 0-.12 rad. (7°), north aspect, 1461 m.

Drainage: Well drained

Ground Water: > 80 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: Less than 1% of surface covered by gravels

pH Method: Extremely acid to very strongly acid (pH 4.0-4.7 in water).

Sampled by: D. A. Lietzke and G. McGuire, 6/15/82

Described by: G. A. McGuire

Sample No.	Description
NFSPGO-1	Oe/Oa-8 to 0 cm; dark reddish brown (5YR2/2); hemic and sapric material; about 30 to 35% fiber; massive; non-sticky; many fine to medium roots; extremely acid; abrupt smooth boundary.
NFSPGO-2	A-0 to 20 cm; dark reddish brown (5YR2/2); gravelly sandy clay loam; weak fine granular structure; very friable; many fine roots; 15% coarse fragments; extremely acid (pH 4.0); abrupt smooth boundary.
NFSPGO-3	E-20 to 30 cm; brown (10YR5/3) with dark reddish brown (5YR2/2) organic tongueing; gravelly sandy loam; weak fine granular and weak fine subangular blocky structure; very friable; common fine roots; 15% coarse fragments; extremely acid (pH 4.1); clear wavy boundary.
NFSPGO-4	Bs1-30 to 40 cm; dark reddish brown (5YR3/2); represents tongues of organic material while yellowish brown (10YR5/6) represents the rest of the color; gravelly sandy clay loam; weak fine subangular blocky structure; friable; common fine roots; about 15% coarse fragments; extremely acid (pH 4.0); abrupt wavy boundary.
NFSPGO-5	Bs2-40 to 50 cm; yellowish brown (10YR5/6); gravelly sandy clay loam; weak fine subangular blocky structure; friable; few fine roots; 15 to 20% coarse fragments; very strongly acid (pH 4.7); gradual wavy boundary.
NFSPGO-14	C-50 to 80 cm; yellowish brown (10YR5/8); gravelly sandy clay loam; weak fine subangular blocky structure to massive; friable; 30% coarse fragments; extremely acid (pH 4.0).
No sample taken	Cr-80 cm; feldspathic quartzite, highly fractured.

Remarks: All colors refer to moist conditions unless otherwise stated.
Soil pH values in 1:2 soil:water.

Soil Classification: Lithic Haplumbrept, coarse-loamy, mixed, frigid.

Series: Not designated

Pedon No.: CD-1-1 (34 to 35)

Area: Clingmans Dome, Great Smoky Mountain National Park, Tennessee.

Location: Clingmans Dome Quadrangle, 165-SW, 0.7 km, 2.7 rad. (158°) from the Lookout Tower

MLRA: 130

Climate: Frigid

Vegetation: Fir

Parent Material: Feldspathic quartzite

Physiography: High side slope

Topography, Slope, Aspect and Elevation: Undulating, 0.06 rad. (3°), south aspect, 1891 m.

Drainage: Moderately well drained

Ground Water: Sometimes may be ponded due to the lithic/paralithic contact; otherwise, ground water > 64 cm.

Erosion: Slight. Disturbed by foot traffic from past field trips.

Permeability: Moderate

Moisture: Perudic

Stoniness: Less than 1% covered by gravels

pH Method: Extremely acid (pH 3.8 in water).

Sampled by: D. A. Lietzke and G. McGuire, 6/16/82

Described by: D. A. Lietzke and G. McGuire

Sample No.	Description
No sample taken	Oe-3 to 0 cm; black (5YR2/1); hemic material; about 50% fiber comprising mainly of fir needles; massive; abrupt smooth boundary.
No sample taken	A-0 to 1 cm; black (5YR2/1); loam to sandy loam; weak fine granular structure; very friable; many medium roots; 5% coarse fragments; abrupt irregular boundary.
No sample taken	E-1 to 4 cm; dark gray (10YR4/1); sandy loam; weak fine granular structure; very friable; few to many fine to medium roots; 5% coarse fragments; abrupt irregular boundary.
CD-1-1-34	Bs1-4 to 10 cm; dark reddish brown (5YR2/2); sandy loam; weak fine subangular blocky structure; very friable; few fine roots; 5% coarse fragments; extremely acid (pH 3.8); abrupt irregular boundary.
CD-1-1-35	Bs2-10 to 14 cm; dark reddish brown (5YR3/3); sandy loam; weak fine subangular blocky structure; very friable; few fine roots; 5% coarse fragments; extremely acid (pH 3.8); abrupt irregular boundary.
No sample taken	Bw-14 to 30 cm; yellowish red (5YR4/6); sandy loam to loam; weak fine subangular blocky structure; friable; 5% coarse fragments; abrupt wavy boundary.
No sample taken	R-30 cm; feldspathic quartzite.
Remarks:	From the same pit as CD-1 except that the samples were taken on the opposite side of the soil pit. Soil pH values in 1:2 soil:water.

Soil Classification: Umbric Dystrochrept, coarse-loamy, mixed, frigid.

Series: Not designated.

Pedon No.: UM-3 (55 to 60)

Area: Along the Unicoi and Mitchell Counties of Tennessee and North Carolina respectively.

Location: Unicoi Quadrangle, 199-NE, 0.75 km, 4.4 rad. (254°) from Unaka Mountain benchmark.

MLRA: 130

Climate: Frigid

Vegetation: Red spruce and mountain ash

Parent Material: Loamy feldspathic quartzite deposit.

Physiography: Broad mountain summit.

Topography, Slope, Aspect and Elevation: Nearly level to undulating, 0.04 rad. (2°), south aspect, 1580 m.

Drainage: Well drained

Ground Water: > 62 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: Less than 1% of surface covered by gravels

pH Method: Extremely acid (pH 3.2 to 4.4 in water).

Sampled by: D. A. Lietzke, R. J. Miles, and G. McGuire, 7/16/82

Described by: R. J. Miles and G. McGuire

Sample No.	Description
UM-3-55	Oe-5 to 0 cm; black (10YR2/1); hemic material; about 45% fiber derived mainly from needles and mosses; massive; many medium to coarse roots; extremely acid (pH 3.2); abrupt smooth boundary.
UM-3-56	A-0 to 5 cm; black (10YR2/1); sandy loam; weak fine and moderate medium subangular blocky structure; very friable; many fine roots; 10% coarse fragments; extremely acid (pH 3.4); abrupt irregular boundary.
UM-3-57	E-5 to 20 cm; gray (10YR5/1); with very dark gray (10 YR3/1) organic matter tongues; gravelly sandy loam; weak to moderate medium subangular blocky structure; very friable; few to common fine roots; 20% coarse fragments; extremely acid (pH 3.4); clear wavy boundary.
UM-3-58	Bs1-20 to 40 cm; dark reddish brown (5YR3/4); and dark reddish brown (5YR3/3) plasma on ped faces; sandy loam; weak medium subangular blocky structure; very friable; many fine roots; 10 to 15% coarse fragments; extremely acid (pH 4.3); clear smooth boundary.
UM-3-59	Bw1-40 to 50 cm; reddish brown (5YR4/4) to dark reddish brown (5YR3/4); sandy loam; weak fine to medium subangular blocky structure; very friable; common fine roots; 10 to 15% coarse fragments; extremely acid (pH 4.4); clear smooth boundary.
UM-3-60	Bw2-50 to 62 cm; yellowish brown (10YR5/4); sandy loam; weak fine to medium subangular blocky structure; very friable; few fine roots; 10 to 15% coarse fragments; extremely acid (pH 4.1); abrupt wavy boundary.
No sample taken	Cr-62 cm; weathered feldspathic quartzite highly fractured.

Remarks: All colors refer to moist conditions unless otherwise stated. Soil pH values in 1:2 soil:water.

Soil Classification: Umbric Dystrochrept, coarse-loamy, mixed, mesic.

Series: Not designated.

Pedon No.: SGR-1 (41 to 49)

Area: Unaka Mountain, Unicoi County, Tennessee.

Location: Unicoi Quadrangle, 199-NE, 125 km, 0.3 rad. (19°) from Unaka Mountain benchmark.

MLRA: 130

Climate: Frigid

Vegetation: Red spruce, rhododendron, yellow birch, red maple, hemlock

Parent Material: Loamy deposit from feldspathic quartzite

Physiography: Low side slope

Topography, Slope, Aspect and Elevation: Undulating, 0.08 rad. (4°), west aspect, 1397 m.

Drainage: Moderately well drained

Ground Water: > 102 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: Less than 1% of surface covered by gravels

pH Method: Extremely acid to moderately acid (pH 3.3 to 5.6 in water).

Sampled by: D. A. Lietzke and G. McGuire, 6/15/82

Described by: D. A. Lietzke and G. McGuire

Sample No.	Description
SGR-1-41	Oa-0 to 1 cm; black (5YR2/1); sapric material; massive; many medium and coarse roots; extremely acid (pH 3.3); abrupt smooth boundary.
SGR-1-42	A-1 to 10 cm; black (5YR2/1); sandy loam; weak fine granular structure; very friable; many medium roots; 5% coarse fragments; extremely acid (pH 3.3); abrupt irregular boundary.
SGR-1-43	E1-10 to 18 cm; pale brown (10YR6/3); sandy loam; weak fine granular structure; very friable; few very fine roots; 5% coarse fragments; extremely acid (pH 3.7); abrupt wavy boundary.
SGR-1-44	E2-18 to 22 cm; brown (10YR5/3); sandy loam; weak fine granular structure; very friable; few to common very fine roots; 5% coarse fragments; extremely acid (pH 3.5); abrupt irregular boundary.
SGR-1-45	Bs1-22 to 28 cm; yellowish red (5YR4/6); with dark reddish brown (5YR3/2) organic tongues; sandy clay loam; weak fine subangular blocky structure; very friable; few very fine to fine roots; 10% coarse fragments; extremely acid (pH 4.2); clear wavy boundary.
SGR-1-46	Bs2-28 to 34 cm; strong brown (7.5YR5/6); gravelly sandy loam; weak fine subangular blocky structure; very friable; no roots; 15% coarse fragments; extremely acid (pH 3.9); clear wavy boundary.
SGR-1-47	C1-34 to 58 cm; yellowish brown (10YR5/6); gravelly sandy loam; weak fine subangular blocky structure; firm; no roots; 20% coarse fragments; slightly brittle; very strongly acid (pH 4.9); gradual wavy boundary.
SGR-1-48	C2-58 to 80 cm; yellowish brown (10YR5/8); gravelly sandy loam; massive; firm; no roots; 20% coarse fragments; brittle; extremely acid (pH 4.3); gradual wavy boundary.
SGR-1-49	C3-80 to 102 cm; yellowish brown (10YR5/6); gravelly sandy loam; massive; firm; no roots; 20% coarse fragments; moderately acid (pH 5.6).
No sample taken	Cr-102 cm; weathered feldspathic quartzite highly fractured.

Remarks: Colors refer to moist conditions unless otherwise stated.
Soil pH values in 1:2 soil:water.

Soil Classification: Typic Haplumbrept, coarse-loamy, mixed, frigid.

Series: Not designated.

Pedon No.: CD-1 (28-33)

Area: Clingmans Dome, Great Smoky Mountain National Park, Tennessee.

Location: Clingmans Dome Quadrangle, 165-SW, 0.7 km, 2.7 rad. (158°) from the Lookout Tower.

MLRA: 130

Climate: Frigid

Vegetation: Fraser fir

Parent Material: Feldspathic quartzite

Physiography: High side slope

Topography, Slope, Aspect and Elevation: Undulating, 0.06 rad. (3°), south aspect, 1891 m.

Drainage: Moderately well drained

Ground Water: Sometimes may be ponded; otherwise, ground water > 64 cm.

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: Less than 1% of surface covered by gravels

pH Method: Extremely acid (pH 3.3 to 4.2 in water).

Sampled by: D. A. Lietzke and G. McGuire, 6/16/82

Described by: D. A. Lietzke and G. McGuire

Sample No.	Description
CD-1-28	Oe-3 to 0 cm; black (10YR2/1); hemic material; about 50% fiber; massive; many medium to coarse roots; extremely acid (pH 3.3); abrupt smooth boundary.
CD-1-29	Oa-0 to 10 cm; black (10YR2/1); mucky sapric material; about 20% fiber; massive; many medium roots; extremely acid (pH 3.0); abrupt smooth boundary.
CD-1-30	A-10 to 17 cm; very dark grayish brown (10YR3/2); sandy loam; weak fine subangular blocky structure; very friable; few to common fine roots; 5% coarse fragments; extremely acid (pH 4.0); abrupt wavy boundary.
CD-1-31	Bs-17 to 27 cm; dark reddish brown (5YR3/4); sandy loam; weak fine subangular blocky structure; friable; few fine roots; 5% coarse fragments; extremely acid (pH 3.8); abrupt wavy boundary.
CD-1-33	Bw-27 to 64 cm; yellowish brown (10YR5/6); sandy loam; weak fine subangular blocky structure; friable; few fine roots; 5% coarse fragments; extremely acid (pH 4.2); clear smooth boundary.
No sample taken	R-64 cm; feldspathic quartzite.

Remarks: Colors refer to moist conditions unless otherwise stated. Soil pH values in 1:2 soil:water.

Soil Classification: Typic Haplumbrept, fine-loamy, mixed, frigid.

Series: Not designated.

Pedon No.: SFSPGO (10-13)

Area: Pleasant Garden Overlook, Unaka Mountain, Unicoi County, Tennessee.

Location: Unicoi Quadrangle, 199-NE, 2 km, 4.5 rad. (261°) from Unaka Mountain benchmark.

MLRA: 130

Climate: Mesic

Vegetation: Heath comprising rhododendron, blueberries, blackberries, and laurel.

Parent Material: Loamy feldspathic quartzite deposit.

Physiography: High side slope

Topography, Slope, Aspect and Elevation: Steep, 0.42 rad. (24°), south aspect, 1452 m.

Drainage: Well drained

Ground Water: > 61 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: 1 to 3% of surface covered

pH Method: Extremely acid (pH 3.4 to 4.0 in water).

Sampled by: G. McGuire and B. J. Morgan, 6/24/82

Described by: G. McGuire

Sample No.	Description
SFSPGO-23	Oe/Oi-10 to 0 cm; black (5YR2/1); hemic and fibric material; 50 to 70% fiber; massive; many coarse and medium roots; extremely acid (pH 3.4); abrupt smooth boundary.
SFSPGO-24	A-0 to 28 cm; black (5YR2/1); sandy clay loam; moderate fine and medium subangular blocky structure; very friable; many fine and medium roots; 10% coarse fragments; extremely acid (pH 3.5); abrupt smooth boundary.
SFSPGO-25	E-28 to 36 cm; brown (10YR5/3); and dark grayish brown (10YR4/2) organic tongueing; gravelly sandy loam; weak fine subangular blocky structure; very friable; few fine roots; 15% coarse fragments; extremely acid (pH 3.8); abrupt wavy boundary.
SFSPGO-26	Bs1-36 to 71 cm; yellowish red (5YR4/6); sandy clay loam; weak fine subangular blocky structure; very friable; few fine roots; about 10% coarse fragments; extremely acid (pH 3.8); abrupt smooth boundary.
SFSPGO-27	Bs2-41 to 61 cm; yellowish brown (10YR5/6); gravelly sandy clay loam; weak fine subangular blocky structure; friable; no roots; 20% coarse fragments; extremely acid (pH 4.0).
No sample taken	Cr-61 cm; weathered feldspathic quartzite highly fractured.

Remarks: Colors refer to moist conditions. Soil pH values in 1:2 soil:water.

APPENDIX B

SELECTED PHYSICAL AND CHEMICAL PROPERTIES OF PEDONS

TABLE B-1

Selected Physical and Chemical Properties of Pedon EC-9

Sample No.	Depth cm	Horizon	Coarse Fragments	Total: Sand 2-.05	Total: Silt .05-.02	Total: Clay < .002	Sand: V. Cos. 2-1	Sand: Cos. 1-.5	Sand: Med. .5-.25	Sand: Fine .25-.1	Sand: V. Fine .1-.05	Silt: Cos. .05-.02	Silt: Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			—— % ——	—————— $g \cdot kg^{-1}$ of < 2 mm ——————											
EC-9-50	8-0	Oe	NA	-	-	-	-	-	-	-	-	-	-	3.1	2.8
EC-9-51	0-15	Oa	NA	-	-	-	-	-	-	-	-	-	-	3.5	3.1
EC-9-52	15-25	E	NA	559	290	151	182	164	87	71	55	102	188	3.8	3.1
EC-9-53	25-35	Bhs1	NA	320	429	251	90	100	54	42	34	211	218	4.3	3.7
EC-9-54	35-73	Bhs2	NA	309	462	229	130	90	43	23	23	204	258	4.5	4.2

Depth cm	Extractable Bases: Ca^{2+}	Extractable Bases: Mg^{2+}	Extractable Bases: Na^{+}	Extractable Bases: K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate: Al	Pyrophosphate: Fe	Dithionite-citrate: Al	Dithionite-citrate: Fe
	—————— $mmol(+)kg^{-1}$ ——————							—————— $g \cdot kg^{-1}$ ——————				
8-0	13.5	21.9	2.0	8.1	45.5	1167.0	1212.5	393.0	-	-	-	-
0-15	11.2	11.6	1.8	6.2	30.8	1046.5	1077.3	349.5	2.7	1.6	2.7	2.7
15-25	0.6	0.7	0.3	0.6	2.2	193.5	195.7	37.8	1.1	1.6	1.4	10.0
25-35	0.8	1.3	0.4	1.4	3.7	692.0	695.7	92.0	12.8	21.2	20.2	44.0
35-73	1.2	2.5	0.3	2.2	6.2	841.5	847.7	125.5	18.4	17.9	27.6	44.0

TABLE B-2

Selected Physical and Chemical Properties of Pedon CD-2

Sample No.	Depth cm	Horizon	Coarse Fragments	Class Size and Particle Diameter (mm): Total: Sand 2-.05	Total: Silt .05-.02	Total: Clay < .002	Sand: V. Cos. 2-1	Sand: Cos. 1-.5	Sand: Med. .5-.25	Sand: Fine .25-.1	Sand: V. Fine .1-.05	Silt: Cos. .05-.02	Silt: Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			%	g·kg^{-1} of < 2 mm											
	6-0	Oe	0	-	-	-	-	-	-	-	-	-	-	-	-
	0-10	Oa	0	-	-	-	-	-	-	-	-	-	-	-	-
CD-2-36	10-17	A	5	540	282	178	155	120	100	92	93	123	159	3.2	2.9
CD-2-37	17-33	E	5	655	221	124	156	142	132	130	95	119	102	3.8	3.3
CD-2-38	33-41	Bhs	10	615	219	166	130	128	122	134	101	129	90	3.9	3.4
CD-2-39	41-49	Bs1	15	518	290	192	68	92	98	131	129	162	128	4.0	3.5
CD-2-40	49-61	Bs2	20	462	400	138	76	94	90	96	106	212	188	4.2	3.8
	61	Cr	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth cm	Extractable Bases: Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate: Al	Pyrophosphate: Fe	Dithionite-citrate: Al	Dithionite-citrate: Fe
	mmol(+)kg^{-1}							g·kg^{-1}				
8-0	-	-	-	-	-	-	-	-	-	-	-	-
0-10	-	-	-	-	-	-	-	-	-	-	-	-
10-17	1.2	2.0	0.4	1.6	5.2	272.0	277.2	54.8	0.6	0.8	0.8	0.9
17-33	0.4	0.4	0.3	0.3	1.4	150.5	151.9	18.9	0.8	0.8	0.9	3.0
33-41	0.8	1.0	0.4	0.5	2.7	365.0	367.7	53.6	2.8	16.4	3.6	25.8
41-49	0.8	1.1	0.6	0.6	3.1	383.0	386.1	37.8	4.6	25.2	4.7	31.4
49-61	0.5	0.7	0.3	0.6	2.1	295.5	297.6	16.6	4.7	17.1	12.0	31.4
61	-	-	-	-	-	-	-	-	-	-	-	-

TABLE B-3

Selected Physical and Chemical Properties of Pedon SGR-2

Sample No.	Depth cm	Horizon	Coarse Fragments	Total: Sand 2-.05	Total: Silt .05-.02	Total: Clay < .002	Sand: V. Cos. 2-1	Sand: Cos. 1-.5	Sand: Med. .5-.25	Sand: Fine .25-.1	Sand: V. Fine .1-.05	Silt: Cos. .05-.02	Silt: Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			— % —	Class Size and Particle Diameter (mm), $g \cdot kg^{-1}$ of < 2 mm											
	1-0	Oe	0	-	-	-	-	-	-	-	-	-	-	-	-
	0-7	A1	20	-	-	-	-	-	-	-	-	-	-	-	-
	7-18	A2	20	-	-	-	-	-	-	-	-	-	-	-	-
SGR-2-22	18-22	Bhs	30	307	341	352	20	53	65	97	72	177	164	4.0	3.5
	22-29	Bw	40	-	-	-	-	-	-	-	-	-	-	-	-
	29-40	C	45	-	-	-	-	-	-	-	-	-	-	-	-
	40	Cr	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth cm	Extractable Bases: Ca^{2+}	Extractable Bases: Mg^{2+}	Extractable Bases: Na^{+}	Extractable Bases: K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate: Al	Pyrophosphate: Fe	Dithionite-citrate: Al	Dithionite-citrate: Fe
	$mmol(+)kg^{-1}$							$g \cdot kg^{-1}$				
1-0	-	-	-	-	-	-	-	-	-	-	-	-
0-7	-	-	-	-	-	-	-	-	-	-	-	-
7-18	-	-	-	-	-	-	-	-	-	-	-	-
18-22	1.2	1.3	0.8	1.0	4.3	635.5	639.8	75.4	8.2	29.5	10.6	52.0
22-29	-	-	-	-	-	-	-	-	-	-	-	-
29-40	-	-	-	-	-	-	-	-	-	-	-	-
40	-	-	-	-	-	-	-	-	-	-	-	-

TABLE B-4

Selected Physical and Chemical Properties of Pedon S77TN-171-1

Sample No.	Depth cm	Horizon	Coarse Fragments	Class Size and Particle Diameter (mm): Total: Sand 2-.05	Total: Silt .05-.02	Total: Clay < .002	Sand: V. Cos. 2-1	Sand: Cos. 1-.5	Sand: Med. .5-.25	Sand: Fine .25-.1	Sand: V. Fine .1-.05	Silt: Cos. .05-.02	Silt: Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			— % —	g·kg^{-1} of < 2 mm											
S77TN-171-1-1	13-0	Oe	0	-	-	-	-	-	-	-	-	-	-	-	-
S77TN-171-1-2	0-20	E	35	679	213	108	53	182	160	209	75	60	153	3.7	3.3
S77TN-171-1-3	20-30	Bs	45	642	219	139	36	107	127	263	109	97	122	4.1	3.6
	30	Cr	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth cm	Extractable Bases: Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate: Al	Pyrophosphate: Fe	Dithionite-citrate: Al	Dithionite-citrate: Fe
	mmol(+)kg^{-1}							g·kg^{-1}				
13-0	-	-	-	-	-	-	-	128.0	-	-	-	-
0-20	1.0	1.0	0	0	2.0	119.0	121.0	13.3	1.0	1.0	1.0	5.0
20-30	1.0	tr	0	tr	1.0	232.0	233.0	17.9	2.0	5.0	3.0	18.0
30	-	-	-	-	-	-	-	-	-	-	-	-

TABLE B-5

Selected Physical and Chemical Properties of Pedon US-4

Sample No.	Depth cm	Horizon	Coarse Fragments	Total: Sand 2-.05	Total: Silt .05-.02	Total: Clay < .002	Sand: V. Cos. 2-1	Sand: Cos. 1-.5	Sand: Med. .5-.25	Sand: Fine .25-.1	Sand: V. Fine .1-.05	Silt: Cos. .05-.02	Silt: Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			%	g·kg^{-1} of < 2 mm											
	6-0	Oi	0	-	-	-	-	-	-	-	-	-	-	-	-
	0-7	A1	10	-	-	-	-	-	-	-	-	-	-	-	-
	7-26	A2	10	-	-	-	-	-	-	-	-	-	-	-	-
US-4-61	26-42	Bs1/Bs2	10	572	163	265	72	164	157	135	44	140	125	4.0	3.4
	42-52	Bw1	10	-	-	-	-	-	-	-	-	-	-	-	-
	52-65	Bw2	20	-	-	-	-	-	-	-	-	-	-	-	-
	65	Cr	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth cm	Extractable Bases: Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate Al	Pyrophosphate Fe	Dithionite-citrate Al	Dithionite-citrate Fe
	mmol(+)kg^{-1}							g·kg^{-1}				
6-0	-	-	-	-	-	-	-	-	-	-	-	-
0-7	-	-	-	-	-	-	-	-	-	-	-	-
7-26	-	-	-	-	-	-	-	-	-	-	-	-
26-42	1.0	0.7	0.2	0.8	2.7	318.5	321.2	23.2	3.6	14.0	4.3	31.6
42-52	-	-	-	-	-	-	-	-	-	-	-	-
52-65	-	-	-	-	-	-	-	-	-	-	-	-
65	-	-	-	-	-	-	-	-	-	-	-	-

TABLE B-6

Selected Physical and Chemical Properties of Pedon NFSPGO

Sample No.	Depth cm	Horizon	Coarse Fragments	Total: Sand 2-.05	Total: Silt .05-.02	Total: Clay < .002	Sand: V. Cos. 2-1	Sand: Cos. 1-.5	Sand: Med. .5-.25	Sand: Fine .25-.1	Sand: V. Fine .1-.05	Silt: Cos. .05-.02	Silt: Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			%	g·kg^{-1} of < 2 mm											
NSFPGO-1	8-0	Oe	0	-	-	-	-	-	-	-	-	-	-	-	-
NFSPGO-2	0-20	A	15	560	207	233	13	60	133	272	82	71	136	4.0	3.0
NFSPGO-3	20-30	E	15	666	156	178	11	66	158	328	103	19	137	4.1	3.1
NFSPGO-4	30-40	Bs1	15	543	174	283	146	89	118	206	84	73	101	4.0	3.2
NFSPGO-5	40-50	Bs2	20	594	195	211	84	112	134	188	76	75	120	4.7	3.6
NFSPGO-14	50-80	C	30	620	164	216	60	104	154	222	80	55	109	4.0	3.6
	80	Cr	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth cm	Extractable Bases: Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate: Al	Pyrophosphate: Fe	Dithionite-citrate: Al	Dithionite-citrate: Fe
	mmol(+)kg^{-1}							g·kg^{-1}				
8-0	34.8	17.2	4.1	8.0	64.1	684.5	748.6	217.7	-	-	-	-
0-20	1.2	1.1	1.0	1.1	4.4	255.5	259.9	68.5	1.5	0.6	1.3	3.2
20-30	0.5	0.3	3.0	0.7	4.5	92.5	97.0	13.0	0.8	0.3	0.7	3.4
30-40	1.0	0.7	1.5	1.2	4.4	311.5	315.9	22.0	2.6	8.7	2.8	25.4
40-50	0.6	0.4	1.8	1.3	4.1	304.5	308.6	33.0	4.0	10.5	4.2	23.7
50-80	0.8	0.7	0.6	1.0	3.1	253.5	256.6	32.5	3.5	7.8	4.2	19.0
80	-	-	-	-	-	-	-	-	-	-	-	-

TABLE B-7

Selected Physical and Chemical Properties of Pedon CD-1-1

Sample No.	Depth cm	Horizon	Coarse Fragments	Total: Sand 2-.05	Total: Silt .05-.02	Total: Clay < .002	Sand: V. Cos. 2-1	Sand: Cos. 1-.5	Sand: Med. .5-.25	Sand: Fine .25-.1	Sand: V. Fine .1-.05	Silt: Cos. .05-.02	Silt: Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			%	g·kg⁻¹ of < 2 mm											
	3-0	Oe	0	-	-	-	-	-	-	-	-	-	-	-	-
	0-1	A	5	-	-	-	-	-	-	-	-	-	-	-	-
	1-4	E	5	-	-	-	-	-	-	-	-	-	-	-	-
CD-1-1-34	4-10	Bs1	5	585	261	154	62	104	138	175	106	181	80	3.8	3.4
CD-1-1-35	10-14	Bs2	5	627	223	150	52	124	165	184	102	125	98	3.8	3.5
	14-30	Bw	5	-	-	-	-	-	-	-	-	-	-	-	-
	30	R	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth cm	Extractable Bases: Ca^{2+}	Mg^{2+}	Na^+	K^+	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate: Al	Pyrophosphate: Fe	Dithionite-citrate: Al	Dithionite-citrate: Fe
	mmol(+)kg⁻¹							g·kg⁻¹				
3-0	-	-	-	-	-	-	-	-	-	-	-	-
0-1	-	-	-	-	-	-	-	-	-	-	-	-
1-4	-	-	-	-	-	-	-	-	-	-	-	-
4-10	1.3	0.7	0.4	0.4	2.8	251.5	254.3	37.0	1.4	5.4	1.7	9.6
10-14	1.2	0.6	0.3	0.3	2.4	306.5	308.9	33.6	2.0	12.6	2.4	21.0
14-30	-	-	-	-	-	-	-	-	-	-	-	-
30	-	-	-	-	-	-	-	-	-	-	-	-

TABLE B-8

Selected Physical and Chemical Properties of Pedon UM-3

Sample No.	Depth cm	Horizon	Coarse Fragments	Class Size and Particle Diameter (mm): Total: Sand 2-.05	Total: Silt .05-.02	Total: Clay < .002	Sand: V. Cos. 2-1	Sand: Cos. 1-.5	Sand: Med. .5-.25	Sand: Fine .25-.1	Sand: V. Fine .1-.05	Silt: Cos. .05-.02	Silt: Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			%	$g \cdot kg^{-1}$ of < 2 mm											
UM-3-55	5-0	Oe	0	-	-	-	-	-	-	-	-	-	-	3.2	2.7
UM-3-56	0-5	A	10	650	184	166	94	88	210	128	130	20	164	3.4	2.8
UM-3-57	5-20	E	20	681	129	190	51	147	209	206	68	13	116	3.4	3.0
UM-3-58	20-40	Bs	10-15	744	96	160	72	167	216	219	70	22	74	4.3	3.6
UM-3-59	40-50	Bw1	10-15	618	281	101	57	127	172	182	80	146	145	4.4	3.9
UM-3-60	50-62	Bw2	10-15	672	191	137	73	138	184	197	80	49	142	4.1	3.8
	62	Cr	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth cm	Extractable Bases: Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate: Al	Pyrophosphate: Fe	Dithionite-citrate: Al	Dithionite-citrate: Fe
	$mmol(+)kg^{-1}$							$g \cdot kg^{-1}$				
5-0	28.7	9.2	1.8	9.9	49.6	638.5	688.1	271.2	-	-	-	-
0-5	0.8	2.2	0.6	1.9	5.5	267.5	273.0	71.1	1.0	0.8	1.1	3.0
5-20	0.6	0.8	0.2	0.7	2.3	185.0	187.3	26.2	0.9	1.5	1.4	7.0
20-40	0.2	0.3	0.3	0.4	1.2	202.5	203.7	20.3	3.6	12.2	7.4	34.5
40-50	0.2	0.2	0.2	0.3	0.9	128.0	128.9	7.0	2.2	3.4	4.1	14.8
50-62	0.2	0.2	0.2	0.4	1.0	149.0	150.0	7.9	2.4	3.4	3.8	12.8

TABLE B-9

Selected Physical and Chemical Properties of Pedon SGR-1

Sample No.	Depth cm	Horizon	Coarse Fragments	Class Size and Particle Diameter (mm): Total Sand 2-.05	Total Silt .05-.02	Total Clay < .002	Sand V. Cos. 2-1	Sand Cos. 1-.5	Sand Med. .5-.25	Sand Fine .25-.1	Sand V. Fine .1-.05	Silt Cos. .05-.02	Silt Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			— % —	— $g \cdot kg^{-1}$ of < 2 mm —											
SGR-1-41	0-1	Oa	0	-	-	-	-	-	-	-	-	-	-	3.3	2.7
SGR-1-42	1-10	A	5	624	197	179	19	36	145	342	82	46	151	3.3	2.8
SGR-1-43	10-18	E1	5	660	196	144	21	36	130	373	100	52	144	3.7	3.2
SGR-1-44	18-22	E2	5	685	151	164	14	30	141	400	100	16	135	3.5	3.3
SGR-1-45	22-28	Bs1	10	666	180	214	17	33	141	339	136	86	94	4.2	3.5
SGR-1-46	28-34	Bs2	15	593	209	198	29	46	138	286	94	40	169	3.9	3.8
SGR-1-47	34-58	C1	20	644	212	144	20	45	161	312	106	100	112	4.9	4.0
SGR-1-48	58-80	C2	20	770	120	110	56	82	237	332	63	28	92	4.3	4.1
SGR-1-49	80-102	C3	20	765	128	107	71	101	227	302	64	16	112	5.6	4.6
	102	Cr	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth cm	Extractable Bases: Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate Al	Pyrophosphate Fe	Dithionite-citrate Al	Dithionite-citrate Fe
	— mmol(+)kg^{-1} —							— $g \cdot kg^{-1}$ —				
0-1	24.8	13.6	1.2	11.0	50.6	513.5	564.1	150.0	-	-	-	-
1-10	0.5	2.2	0.2	1.8	4.7	201.0	205.7	36.4	0.7	0.1	0.6	0.3
10-18	0.2	0.3	0.1	0.4	1.0	99.0	100.0	4.0	0.4	0.2	0.4	0.6
18-22	0.5	0.4	0.3	0.5	1.7	111.5	113.2	7.0	0.8	0.6	0.6	018
22-28	0.6	0.5	0.3	0.6	2.0	263.5	265.5	13.6	2.0	11.5	2.0	18.8
28-34	0.6	0.3	0.3	0.6	1.8	197.0	198.0	6.8	2.7	7.6	2.6	13.9
34-58	0.7	0.4	0.3	0.3	1.7	117.5	119.2	2.2	1.6	2.4	1.7	6.6
58-80	0.7	0.2	0.4	0.3	1.6	109.0	110.6	2.5	1.8	1.0	2.6	5.6
80-102	0.4	0.2	0.4	0.3	1.3	100.5	101.8	2.5	1.5	0.6	2.4	4.8
102	-	-	-	-	-	-	-	-	-	-	-	-

TABLE B-10

Selected Physical and Chemical Properties of Pedon CD-1

Sample No.	Depth cm	Horizon	Coarse Fragments	Class Size and Particle Diameter (mm): Total Sand 2-.05	Total Silt .05-.02	Total Clay < .002	Sand V. Cos. 2-1	Sand Cos. 1-.5	Sand Med. .5-.25	Sand Fine .25-.1	Sand V. Fine .1-.05	Silt Cos. .05-.02	Silt Fine .02-.002	pH 1:2 H_2O	pH 1:2 .01M $CaCl_2$
			— % —	$g \cdot kg^{-1}$ of < 2 mm											
CD-1-28	3-0	Oe	0	-	-	-	-	-	-	-	-	-	-	3.3	3.0
CD-1-29	0-10	Oa	0	293	437	270	33	44	60	90	66	259	178	3.0	3.0
CD-1-30	10-17	A	5	569	283	148	86	46	139	180	118	155	128	4.0	3.5
CD-1-31	17-27	Bs	5	593	276	131	37	94	150	185	127	184	92	3.8	3.6
CD-1-32	17-27	Max. exp. of Bs	5	566	315	119	34	181	163	165	123	232	83	-	-
CD-1-33	27-64	Bw	5	705	176	119	105	132	177	180	111	80	96	4.2	3.9
	64	R	-	-	-	-	-	-	-	-	-	-	-	-	-

Depth cm	Extractable Bases: Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Pyrophosphate Al	Pyrophosphate Fe	Dithionite-citrate Al	Dithionite-citrate Fe
	$mmol(+)kg^{-1}$							$g \cdot kg^{-1}$				
3-0	47.3	20.8	2.2	10.6	80.9	634.0	714.9	169.7	-	-	-	-
0-10	6.2	6.6	1.0	3.8	17.6	474.5	492.1	113.2	-	-	-	-
10-17	0.8	0.4	0.2	0.4	1.8	196.0	197.8	26.2	1.2	1.8	1.1	2.0
17-27	1.4	0.9	0.3	0.6	3.2	286.5	289.7	31.6	2.8	13.4	3.4	20.7
17-27	1.6	1.8	0.5	0.6	4.5	355.5	360.0	37.3	2.9	12.6	3.6	25.4
27-64	0.6	0.5	0.3	0.4	1.8	147.5	149.3	10.7	2.4	4.7	3.2	13.9
64	-	-	-	-	-	-	-	-	-	-	-	-

TABLE B-11

Selected Physical and Chemical Properties of Pedon SFSPGO

				Class Size and Particle Diameter (mm)										pH	
				Total			Sand					Silt			
Sample No.	Depth cm	Horizon	Coarse Fragments	Sand 2-.05	Silt .05-.02	Clay < .002	V. Cos. 2-1	Cos. 1-.5	Med. .5-.25	Fine .25-.1	V. Fine .1-.05	Cos. .05-.02	Fine .02-.002	1:2 H_2O	1:2 .01M $CaCl_2$
			%	$g \cdot kg^{-1}$ of < 2 mm											
SFSPGO-23	10-0	Oe/Oi	-	-	-	-	-	-	-	-	-	-	-	3.4	2.9
SFSPGO-24	0-28	A	10	580	201	219	14	96	151	245	74	98	103	3.5	3.0
SFSPGO-25	28-36	E	15	523	165	212	60	133	156	204	70	39	126	3.8	3.3
SFSPGO-26	36-41	Bs1	10	558	203	239	49	96	138	203	72	55	148	3.8	3.7
SFSPGO-27	41-61	Bs2	20	589	210	201	60	108	148	205	68	48	162	4.0	3.9
	61	Cr	-	-	-	-	-	-	-	-	-	-	-	-	-

	Extractable Bases								Pyrophosphate		Dithionite-citrate	
Depth cm	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	Sum	Ext. Acidity	C.E.C. Sum Cations	Organic Carbon	Al	Fe	Al	Fe
	$mmol(+)kg^{-1}$							$g \cdot kg^{-1}$				
10-0	83.0	63.2	0.8	15.6	162.6	389.5	552.1	389.0	-	-	-	-
0-28	0.3	2.6	0.3	1.8	5.0	305.0	310.0	53.9	1.8	1.0	1.4	0.6
28-36	0.2	0.7	0.2	0.7	1.8	182.5	184.3	18.4	1.0	1.0	1.2	0.8
36-41	0.2	0.6	0.2	0.7	1.7	332.5	334.2	27.1	4.3	19.4	8.6	51.0
41-61	0.1	0.3	0.3	0.7	1.4	243.0	244.8	17.8	5.0	7.7	8.6	11.6
61	-	-	-	-	-	-	-	-	-	-	-	-

APPENDIX C

A FIELD PROCEDURE FOR ASSESSING SPODIC CHARACTERISTICS

I. Humic - Fulvic (hf) Color Determination

Reagents:

AMP buffer (2-amino 2 methyl pentanol)
Disc color comparator
Filtration aid
4 mol HCl

Apparatus:[1]

1-ml calibrated dropper

Procedure:

Place 200 mg soil in a 125-ml Erlenmeyer flask. Add approximately 1 ml water and an equal volume of AMP buffer. Swirl occasionally for 2 minutes. Make to 50-ml volume with distilled water. Add 1 drop of filtration aid and swirl to mix. If necessary, allow a few minutes for the floc to settle.

Transfer supernatant to a disc color comparator and measure color units. Dilute if necessary to bring color within range of the comparator.

Calculations:

$$\text{Humic-fulvic (hf) liter-color units/gram} = \frac{\text{color units}}{\text{wt soil (g)}} \times \frac{50}{1000} \times \text{dilution}$$

II. Fulvic (f) Color Determination

Slowly add 2 ml 4 mol HCl to the contents in the flask of procedure I. Swirl vigorously for 30 seconds and then add 1 more drop of filtration aid. Take an aliquot for color measurement as before, but add 2 drops buffer for each 1 ml solution to bring pH back to 10.2.

Calculations:

Fulvic color (f) liter-color units/gram = $\frac{\text{color units}}{\text{wt. soil (g)}} \times \frac{50}{1000} \times$ dilution.

The humic color is the difference between humic-fulvic and fulvic color value.

III. Potassium hydroxide extractable aluminum determination

Reagents:[1]

4 mol KOH
4 mol HCl
0.75 mol HCl
0.1 mol HCl
4 mol KF
1.25 $g.kg^{-1}$ phenolphthalein

Procedure:

Place about 200 mg soil in a 125-ml Erlenmeyer flask. Add approximately 2 ml 4 mol KOH. Swirl gently for one minute. Add about 20 ml water and 8 to 10 drops of 0.125% phenolphthalein. Add 4 mol HCl until the color turns from pink to clear. Add 1 drop 4 mol KOH. Add 0.75 NHCl until pink color just begins to fade. Complete the drop count titration with 0.1 mol NHCl until the last trace of pink disappears. If end point is accidentally passed, add a drop of 4 mol KOH and retitrate.

Add 2 ml 4 mol KF. The color will again turn pink. Add 0.1 mol HCl dropwise, counting drops, until the pink color again disappears and remains clear for 30 seconds.

Calculations:

KOH Al% = number of drops $\times \frac{\text{mol}}{n} \times \frac{9}{10w}$ where mol = molar of HCl (0.1)

n = number of drops per liter delivered by dropper (normally 10)

w = weight of soil in grams

References:

Holmgren, G. 1980. A Field Procedure for Assessing Spodic Characteristic (unpublished).

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[1]All reagents and apparatus were purchased from Hach Chemical Co.

APPENDIX D

DATA FOR COROLLARY PEDONS

TABLE D-1

Selected Physical and Chemical Properties of Pedon PMVA-2

Sample No.	Depth cm	Horizon	Coarse Fragments	Total: Sand 2-.05	Total: Silt .05-.02	Total: Clay < .002	Sand: V. Cos. 2-1	Sand: Cos. 1-.5	Sand: Med. .5-.25	Sand: Fine .25-.1	Sand: V. Fine .1-.05	Silt: Cos. .05-.02	Silt: Fine .02-.002
			— % —	g·kg^{-1} of < 2 mm									
PMVA-2-70	2-0	Oe/Oi	0	-	-	-	-	-	-	-	-	-	-
PMVA-2-71	0-3	Oa	0	-	-	-	-	-	-	-	-	-	-
PMVA-2-72	3-8	A	5	843	108	49	149	294	204	144	52	26	82
PMVA-2-73	8-26	E	5	884	34	82	183	323	215	122	41	10	24
PMVA-2-74	26-34	Bhs	5	532	274	194	105	208	116	68	35	133	141
PMVA-2-75	34-53	Bw	10	676	200	124	110	239	158	113	56	22	178
PMVA-2-76	53-71	C	20	677	192	131	122	237	156	106	56	36	156
	71	Cr	-	-	-	-	-	-	-	-	-	-	-

TABLE D-2

Selected Physical and Chemical Properties of Pedon PMVA-1

				Class Size and Particle Diameter (mm)									
				Total			Sand					Silt	
Sample No.	Depth cm	Horizon	Coarse Fragments	Sand 2-.05	Silt .05-.02	Clay < .002	V. Cos. 2-1	Cos. 1-.5	Med. .5-.25	Fine .25-.1	V. Fine .1-.05	Cos. .05-.02	Fine .02-.002
			— % —	g·kg^{-1} of < 2 mm									
PMVA-1-62	3-0	Oi	0	-	-	-	-	-	-	-	-	-	-
PMVA-1-63	0-7	A	5	852	76	72	186	342	195	95	34	13	59
PMVA-1-64	7-18	E	5	872	42	86	164	336	210	116	46	6	36
PMVA-1-65	18-20	Bhs1	10	649	131	220	174	245	128	72	30	13	118
PMVA-1-66	20-22	Bhs2	10	572	156	272	146	230	110	60	26	32	124
PMVA-1-67	22-47	Bw1	15	698	92	210	155	265	148	92	38	6	86
PMVA-1-68	47-71	Bw2	30	847	23	130	166	322	212	115	32	4	19
PMVA-1-69	71-83	C	30	624	210	166	88	208	176	106	46	46	164
	83	Cr	-	-	-	-	-	-	-	-	-	-	-

TABLE D-3

Selected Physical and Chemical Properties of Pedon PGORB-1

				Class Size and Particle Diameter (mm)										
				Total			Sand					Silt	
Sample No.	Depth cm	Horizon	Coarse Fragments	Sand 2-.05	Silt .05-.02	Clay < .002	V. Cos. 2-1	Cos. 1-.5	Med. .5-.25	Fine .25-.1	V. Fine .1-.05	Cos. .05-.02	Fine .02-.002
			— % —	g·kg^{-1} of < 2 mm									
PGORB-1-15	11-0	Oe	0	-	-	-	-	-	-	-	-	-	-
PGORB-1-16	0-12	A	10	649	183	168	6	72	152	332	87	53	130
PGORB-1-6	12-16	E	10-15	612	188	200	17	56	128	324	87	68	120
PGORB-1-7	16-19	Bs	15-20	604	155	241	16	58	134	313	83	45	110
PGORB-1-17	19-30	Bw	35	605	136	259	12	63	144	300	86	32	104
PGORB-1-18	30-52	C	35-40	648	124	228	24	83	147	306	88	17	107
	52	Cr	-	-	-	-	-	-	-	-	-	-	-

TABLE D-4

Selected Physical and Chemical Properties of Pedon PGORB-3

Sample No.	Depth cm	Horizon	Coarse Fragments	Class Size and Particle Diameter (mm)									
				Total			Sand					Silt	
				Sand 2-.05	Silt .05-.02	Clay < .002	V. Cos. 2-1	Cos. 1-.5	Med. .5-.25	Fine .25-.1	V. Fine .1-.05	Cos. .05-.02	Fine .02-.002
			—— % ——	———— $g \cdot kg^{-1}$ of < 2 mm ————									
	3-0	Oi	0	-	-	-	-	-	-	-	-	-	-
PGORB-3-10	0-15	A	5-10	625	172	203	10	72	167	274	102	40	132
PGORB-3-11	15-22	E	15	634	90	276	24	68	161	307	74	31	59
PGORB-3-12	22-26	Bs	15-20	641	97	262	34	105	192	247	63	41	56
PGORB-3-13	26-45	Bw	20	594	314	92	46	82	127	219	120	107	207

TABLE D-5

Selected Physical and Chemical Properties of Pedon PGORB-2

				Class Size and Particle Diameter (mm)									
				Total			Sand					Silt	
Sample No.	Depth cm	Horizon	Coarse Fragments	Sand 2-.05	Silt .05-.02	Clay < .002	V. Cos. 2-1	Cos. 1-.5	Med. .5-.25	Fine .25-.1	V. Fine .1-.05	Cos. .05-.02	Fine .02-.002
			— % —	$g \cdot kg^{-1}$ of < 2 mm									
PGORB-2-19	0-4	Oa	0	-	-	-	-	-	-	-	-	-	-
PGORB-2-20	4-15	A	5-10	748	92	160	10	107	225	320	86	19	73
PGORB-2-8	15-23	E	20	677	183	140	33	104	184	274	82	63	120
PGORB-2-9	23-30	Bs	35	615	185	200	24	76	158	269	88	85	100
PGORB-2-21	30-54	Bw	45	651	197	152	24	76	170	292	89	51	146

TABLE D-6

Characteristics of the Corollary B Subhorizons

Subhorizon	Depth cm	Color (moist) Hue	Color (moist) Value/Chroma	Sand	Silt	Clay	Texture
				$g \cdot kg^{-1}$			
Pedon PMVA-2 Entic Haplorthod, coarse-loamy, mixed, frigid							
Bhs	26-34	5YR	3/4	532	274	194	SCL
Bw	34-53	10YR	5/6	676	200	124	SL
Pedon PMVA-1 Umbric[†] Dystrochrept, fine-loamy, mixed, frigid							
Bhs1	18-20	10YR	3/3	649	131	220	SCL
Bhs2	20-22	7.5YR	4/4	572	156	272	SCL
Bw1	22-47	10YR	5/6	698	92	210	GRSCL
Bw2	47-71	10YR	5/6-5/8	847	23	130	GRLS
Pedon PGORB-1 Umbric[†] Dystrochrept, loamy-skeletal, mixed, mesic							
Bs	16-19	5YR	3/3	604	155	241	GRSCL
Bw	19-30	7.5YR	5/8	605	136	259	GRVSCL
Pedon PGORB-3 Typic Haplumbrept, fine-loamy, mixed, frigid							
Bs	22-26	5YR	3/4	641	97	262	GRSCL
Bw	26-45	10YR	5/6	594	314	92	GRSL

TABLE D-6 (Continued)

Subhorizon	Depth cm	Color (moist) Hue	Color (moist) Value/Chroma	Sand	Silt	Clay	Texture
				g·kg^{-1}			
Pedon PGORB-2 Typic Haplumbrept, loamy-skeletal, mixed, mesic							
Bs	23-30	7.5YR	5/6	615	185	200	GRVSL
Bw	30-54	10YR	5/6	651	197	152	GRVSL

†The subgroup was determined after the top 18 cm of the surface horizon was mixed.

Soil Classification: Entic Haplorthod, coarse-loamy, mixed, frigid.

Series: Not designated.

Pedon No.: PMVA-2 (70 to 76)

Area: Poor Mountain, Virginia

Location: Along the Roanoke County and Montgomery County line. Site is by the side of the gravel road that goes to the TV and radio towers on the mountain summit.

MLRA: 130

Climate: Mesic

Vegetation: Virginia pine, table mountain pine, rhododendron, mountain laurel, blueberries.

Parent Material: Feldspathic quartzite

Physiography: Mid side slope

Topography, Slope, Aspect and Elevation: Hilly, 0.2 rad. (11°), south aspect, 1151 m.

Drainage: Well drained

Ground Water: > 71 cm

Erosion: None

Permeability: Moderate

Moisture: Udic

Stoniness: 3 to 15% of surface covered

pH Method: Extremely acid to very strongly acid (pH 3.8 to 5.0 in water).

Sampled by: D. A. Lietzke and G. McGuire, 9/9/82

Described by: G. A. McGuire

Sample No.	Description
PMVA-2-70	Oe-2 to 0 cm; fibric and hemic material consisting of leaves, twigs, mosses; many medium roots; abrupt smooth boundary.
PMVA-2-71	Oe-0 to 3 cm; black (10YR2/1) sapric material; weak fine granular structure; very friable; many medium and fine roots; abrupt smooth boundary.
PMVA-2-72	A-3 to 8 cm; very dark gray (10YR3/1); loamy sand; weak fine granular structure; very friable; many fine and medium roots; 5% coarse fragments; extremely acid (pH 3.8); abrupt smooth boundary.
PMVA-2-73	E-8 to 26 cm; light brownish gray (10YR6/2) and grayish brown (10YR5/2); loamy sand; weak fine granular structure; very friable; many fine roots; 5% coarse fragments; extremely acid (pH 4.1); abrupt smooth boundary.
PMVA-2-74	Bhs-26 to 34 cm; dark reddish brown (5YR3/4); sandy clay loam; granular to weak fine subangular blocky structure; very friable; many fine roots; 5% coarse fragments; very strongly acid (pH 4.8); abrupt smooth boundary.
PMVA-2-75	Bw-34 to 53 cm; yellowish brown (10YR5/6); sandy loam; weak, fine, subangular blocky structure; very friable; common fine roots; 10% coarse fragments; very strongly acid (pH 5.0); gradual smooth boundary.
PMVA-2-76	C-53 to 71 cm; brownish yellow (10YR6/6); gravelly sandy loam; weak fine subangular blocky structure; friable; few fine roots; 20% coarse fragments; very strongly acid (pH 4.9).
No sample taken	Cr-71 cm; weathered feldspathic quartzite highly fractured.
Remarks:	All colors refer to moist conditions unless otherwise stated. Soil pH values in 1:2 soil:water.

Soil Classification: Umbric Dystrochrept, fine-loamy, mixed, frigid.

Series: Not designated

Pedon No.: PMVA-1 (62 to 69)

Area: Poor Mountain, Virginia

Location: Along the Roanoke County and Montgomery County line. Site is by the side of the gravel road that leads to the TV and radio towers on the mountain summit.

MLRA: 130

Climate: Mesic

Vegetation: Virginia pine, rhododendron, mountain laurel, blueberries

Parent Material: Feldspathic quartzite

Physiography: Upper part of side slope of summit

Topography, Slope, Aspect and Elevation: Hilly, 0.2 rad. (11°), south aspect, 1151 m.

Drainage: Well drained

Ground Water: > 83 cm

Erosion: Moderate

Permeability: Moderate

Moisture: Udic

Stoniness: 3 to 15% of surface covered

pH Method: Extremely acid to very strongly acid (pH 4.3 to 5.0 in water).

Sampled by: D. A. Lietzke and G. A. McGuire, 9/9/82

Described by: G. McGuire

Sample No.	Description
PMVA-1-62	Oi-3 to 0 cm; black (10YR2/1); mainly fibric material; about 70% fiber; massive; many medium live roots; abrupt smooth boundary.
PMVA-1-63	A-0 to 7 cm; very dark gray (10YR3/1); loamy sand; weak fine granular structure; very friable; many medium and fine roots; 5% coarse fragments; extremely acid (pH 4.3); abrupt smooth boundary.
PMVA-1-64	E-7 to 18 cm; light brownish gray (10YR6/2); loamy sand; weak fine granular structure; very friable; many fine roots; 5% coarse fragments; extremely acid (pH 4.4); abrupt smooth boundary.
PMVA-1-65	Bhs1-18 to 20 cm; dark brown (10YR3/3); sandy clay loam; weak fine granular and weak fine subangular blocky structure; very friable; many to common fine roots; 10% coarse fragments; very strongly acid (pH 4.6); abrupt smooth boundary.
PMVA-1-66	Bhs2-20 to 22 cm; brown to dark brown (7.5YR4/4); sandy clay loam; weak fine granular and weak fine subangular blocky structure; very friable; many to common fine roots; 10% coarse fragments; very strongly acid (pH 4.8); abrupt smooth boundary.
PMVA-1-67	Bw1-22 to 47 cm; yellowish brown (10YR5/6); gravelly sandy clay loam; weak fine subangular blocky structure; very friable; few fine roots; about 15% coarse fragments; very strongly acid (pH 5.0); clear smooth boundary.
PMVA-1-68	Bw2-47 to 71 cm; yellowish brown (10YR5/6 to 5/8); gravelly loamy sand; weak fine subangular blocky structure; friable; few very fine roots; about 30% coarse fragments 8 to 10 cm in diameter; very strongly acid (pH 4.9); abrupt smooth boundary.
PMVA-1-69	C-71 to 83 cm; brownish yellow (10YR6/6); gravelly sandy loam; weak fine subangular blocky structure; few roots; 30% coarse fragments 3 to 6 cm diameter; very strongly acid (pH 5.0).
No sample taken	Cr-71 cm; weathered feldspathic quartzite, highly fractured.
Remarks:	All colors refer to moist conditions unless otherwise stated. Soil pH values in 1:2 soil:water.

Soil Classification: Typic Haplumbrept, fine-loamy, mixed, frigid.

Series: Not designated.

Pedon No.: PGORB-3 (10-13)

Area: Pleasant Garden Overlook, Unaka Mountain, Unicoi County, Tennessee

Location: Unicoi Quadrangle, 199-NE, 1.7 km, 4.6 rad. (262°) from Unaka Mountain benchmark.

MLRA: 130

Climate: Frigid

Vegetation: Red spruce and dwarf heath comprising rhododendron

Parent Material: Loamy deposit from feldspathic quartzite.

Physiography: Ridge top

Topography, Slope, Aspect and Elevation: Hilly, 0.2 rad. (11°), south aspect, 1476 m.

Drainage: Moderately well-drained

Ground Water: > 45 cm

Erosion: Moderate

Permeability: Moderate

Moisture: Perudic

Stoniness: 3 to 15% of surface covered

pH Method: Extremely acid to very strongly acid (pH 4.1 to 4.9 in water)

Sampled by: G. McGuire and B. J. Morgan, 6/24/82

Described by: G. McGuire

Sample No.	Description
No sample taken	Oi-3 to 0 cm; black (10YR2/1); fibric material; about 70% fiber; massive; many medium to coarse roots; abrupt smooth boundary.
PGORB-3-10	A-0 to 15 cm; black (5YR2/1); sandy loam; moderate fine and medium granular structure; very friable; many fine roots; 5 to 10% coarse fragments; extremely acid (pH 4.1); abrupt smooth boundary.
PGORB-3-11	E-15 to 22 cm; brown to dark brown (10YR4/3); sandy clay loam; few fine distinct brownish yellow (10YR6/8) mottles; weak fine granular structure; very friable; few fine roots; about 5% coarse fragments; extremely acid (pH 4.2); abrupt wavy boundary.
PGORB-3-12	Bs-22 to 26 cm; dark reddish brown (5YR3/4); gravelly sandy clay loam; weak fine granular and weak fine subangular blocky structure; friable; few fine roots; about 15 to 20% coarse fragments; very strongly acid (pH 4.5); clear wavy boundary.
PGORB-3-13	Bw-26 to 45 cm; yellowish brown (10YR5/6); gravelly sandy loam; weak fine subangular blocky structure; friable; no roots; about 20% coarse fragments; very strongly acid (pH 4.9); clear smooth boundary.
No sample taken	Cr-45 cm; weathered feldspathic quartzite, highly fractured.
Remarks:	Soil colors refer to moist conditions. Soil pH values in 1:2 soil:water.

Soil Classification: Umbric Dystrochrept, loamy-skeletal, mixed, mesic.

Series: Not designated.

Pedon No.: PGORB-1 (6 to 7, 15 to 18)

Area: Pleasant Garden Overlook, Unaka Mountain, Unicoi County, Tennessee

Location: Unicoi Quadrangle, 199-NE, 1.9 km, 4.6 rad. (265°) from Unaka Mountain benchmark.

MLRA: 130

Climate: Mesic

Vegetation: Rhododendron, laurel, blueberries

Parent Material: Loamy deposit of felspathic quartzite

Physiography: Ridge

Topography, Slope, Aspect and Elevation: Hilly, 0.2 rad. (11°), south aspect, 1476 m.

Drainage: Well-drained

Ground Water: < 52 cm

Erosion: Moderate

Permeability: Moderate

Moisture: Perudic

Stoniness: 3 to 15% of surface covered

pH Method: Extremely acid (pH 3.4 to 4.4 in water)

Sampled by: G. McGuire and B. J. Morgan, 6/24/82

Described by: G. McGuire

Sample No.	Description
PGORB-1-15	Oe-11 to 0 cm; black (5YR2/1); hemic material; about 40% fiber; massive; many medium roots; extremely acid (pH 3.8); abrupt smooth boundary.
PGORB-1-16	A-0 to 12 cm; black (5YR2/1); sandy loam; weak fine granular structure; very friable; many fine and medium roots; 10% coarse fragments; extremely acid (pH 3.4); abrupt wavy boundary.
PGORB-1-6	E-12 to 16 cm; brown to dark brown (10YR4/3); sandy loam; weak fine granular structure; very friable; few fine roots; 10 to 15% coarse fragments; extremely acid (pH 4.2); clear smooth boundary.
PGORB-1-7	Bs-16 to 19 cm; dark reddish brown (5YR3/3); gravelly sandy clay loam; weak fine subangular blocky structure; friable; few fine roots; 15-20% coarse fragments; extremely acid (pH 4.4); clear smooth boundary.
PGORB-1-17	Bw-19 to 30 cm; strong brown (7.5YR5/8); very gravelly sandy clay loam; weak fine subangular blocky structure; friable; few roots; 35% coarse fragments; extremely acid (pH 3.8); abrupt wavy boundary.
PGORB-1-18	C-30 to 52 cm; brown (10YR5/3); very gravelly sandy clay loam; massive; firm; no roots; 35-40% coarse fragments; extremely acid (pH 3.9).
No sample taken	Cr-52 cm; feldspathic quartzite, highly fractured.
Remarks:	Soil colors refer to moist conditions. Soil pH values in 1:2 soil:water.

Soil Classification: Typic Haplumbrept, loamy-skeletal, mixed, mesic.

Series: Not designated.

Pedon No.: PGORB-2 (8 to 9, 19 to 21).

Area: Pleasant Garden Overlook, Unaka Mountain, Unicoi County, Tennessee

Location: Unicoi Quadrangle, 199-NE, 1.8 km, 4.6 rad. (265°) from Unaka Mountain benchmark.

MLRA: 130

Climate: Mesic

Vegetation: Rhododendron, laurel, blueberries

Parent Material: Loamy skeletal deposit from feldspathic quartzite

Physiography: Ridge

Topography, Slope, Aspect and Elevation: Hilly, 0.2 rad. (11°), south aspect, 1476 m.

Drainage: Well-drained

Ground Water: > 54 cm

Erosion: None

Permeability: Moderate

Moisture: Perudic

Stoniness: 3 to 15% of surface covered

pH Method: Extremely acid to very strongly acid (pH 3.4 to 4.7 in water).

Sampled by: G. McGuire and B. J. Morgan, 6/24/82

Described by: G. McGuire

Sample No.	Description
PGORB-2-19	Oa-0 to 4 cm; black (5YR2/1); sapric material; 20% fiber; moderate fine granular structure; many medium roots; very friable; extremely acid (pH 3.4); clear smooth boundary.
PGORB-2-20	A-4 to 15 cm; dark reddish brown (5YR2/2); sandy loam; weak fine granular structure; very friable; many medium and fine roots; 5 to 10% coarse fragments; extremely acid (pH 3.8); abrupt smooth boundary.
PGORB-2-8	E-15 to 23 cm; brown (10YR5/3); gravelly sandy loam; weak fine granular and weak fine subangular blocky structure; very friable; few fine roots; 20% coarse fragments; extremely acid (pH 4.0); abrupt smooth boundary.
PGORB-2-9	Bs-23 to 30 cm; strong brown (7.5YR5/6); very gravelly sandy loam; weak fine subangular blocky structure; friable; few fine roots; 35% coarse fragments; very strongly acid (pH 4.7); clear smooth boundary.
PGORB-2-21	Bw-30 to 50 cm; yellowish brown (10YR5/6); very gravelly sandy loam; weak fine subangular blocky structure; friable; no roots; 45% coarse fragments; very strongly acid (pH 4.5); clear wavy boundary.
No sample taken	Cr-50 cm+; weathered feldspathic quartzite, highly fractured.
Remarks:	All colors refer to moist conditions. Soil pH values in 1:2 in soil:water.

APPENDIX E

SITE AND PROFILE CHARACTERISTICS OF SOME PEDONS USED IN THIS STUDY

Figure E-1. Summit vegetation on Clingmans Dome at Pedon CD-2 site. Elevation is 1891 m. The extremely rock covered surface is not evident due to the mantling of rocks by organic materials. The most common associated soils are Folists and Haplumbrepts.

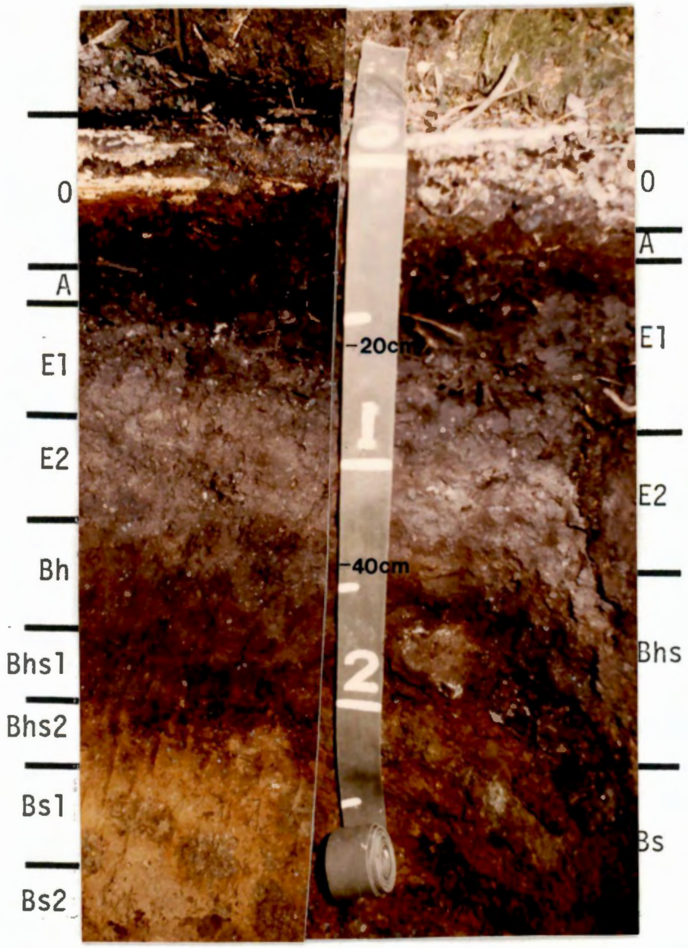

Figure E-2. Pedon CD-2 showing the variable expression of spodic horizon development across the pedon face, and the effects that coarse fragments have on spodic morphology on the right side of the pit. Scale is in feet and centimeters.

Figure E-3. Nature of the land form and vegetation at the site for Pedons US-4 and UM-3. Elevation is 1464-1586 m. View is to the east.

Figure E-4. Location of some of the pedons with respect to the landscape at the Pleasant Garden sites. Elevation is 1464 m. The view is to the west.

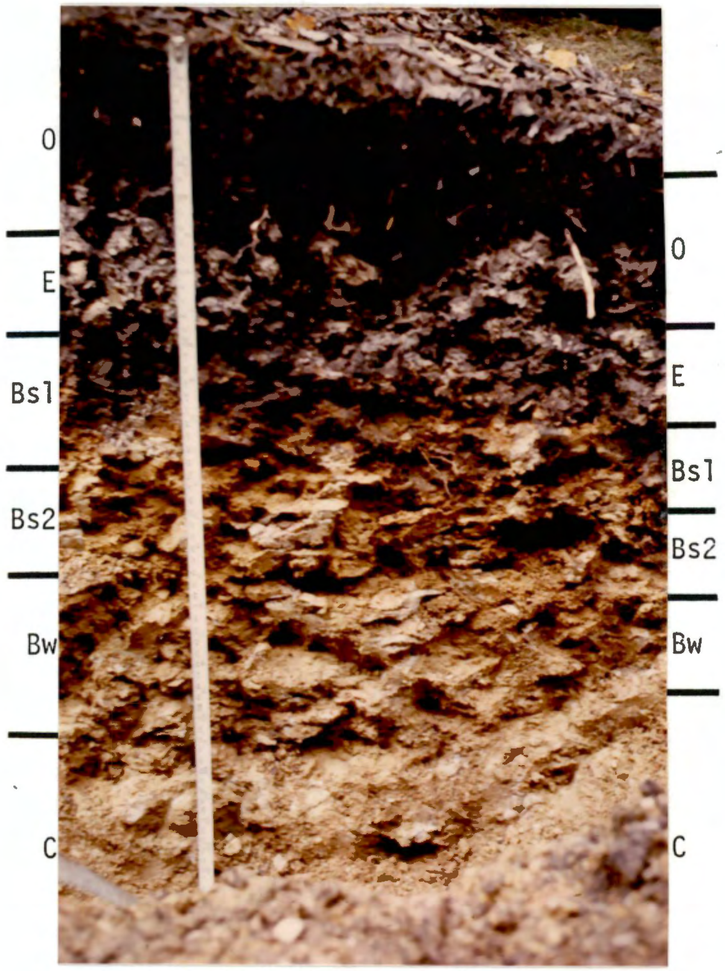

Figure E-5. Pedon SGR-2. Note the dark plasma tongues.

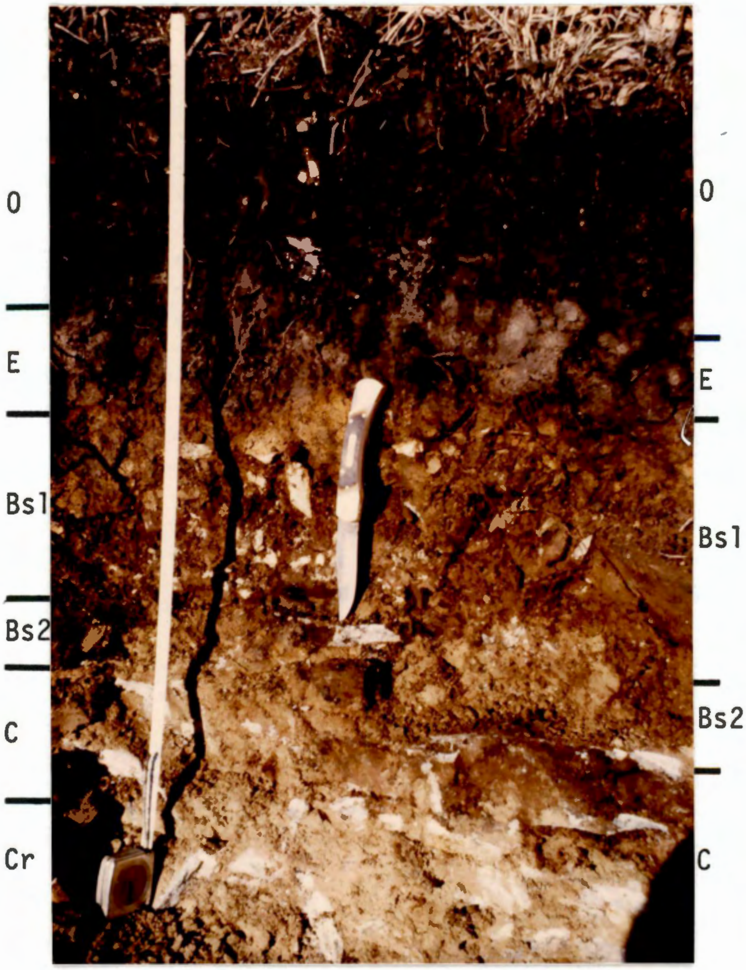

Figure E-6. Pedon PGORB-3 showing poorly sorted angular rocks fragments. Note the dark plasma tongues in the E horizon. Dark plasma also coats fragment surfaces at the top of the Cr horizon on which the tape is resting.

Figure E-7. Pedon PGORB-1 showing minimal Bs/Bhs horizon development. Note tongueing of organic materials and dark plasma on ped faces.

Figure E-8. Pedon PGORB-2 showing minimal Bs/Bhs horizon development. Note the tongueing of dark plasma into and through the E horizon.

Figure E-9. Nature of the O horizons and the underlying A horizon at an undisturbed Poor Mt. site.

Figure E-10. Summit vegetation on Poor Mt., Virginia.

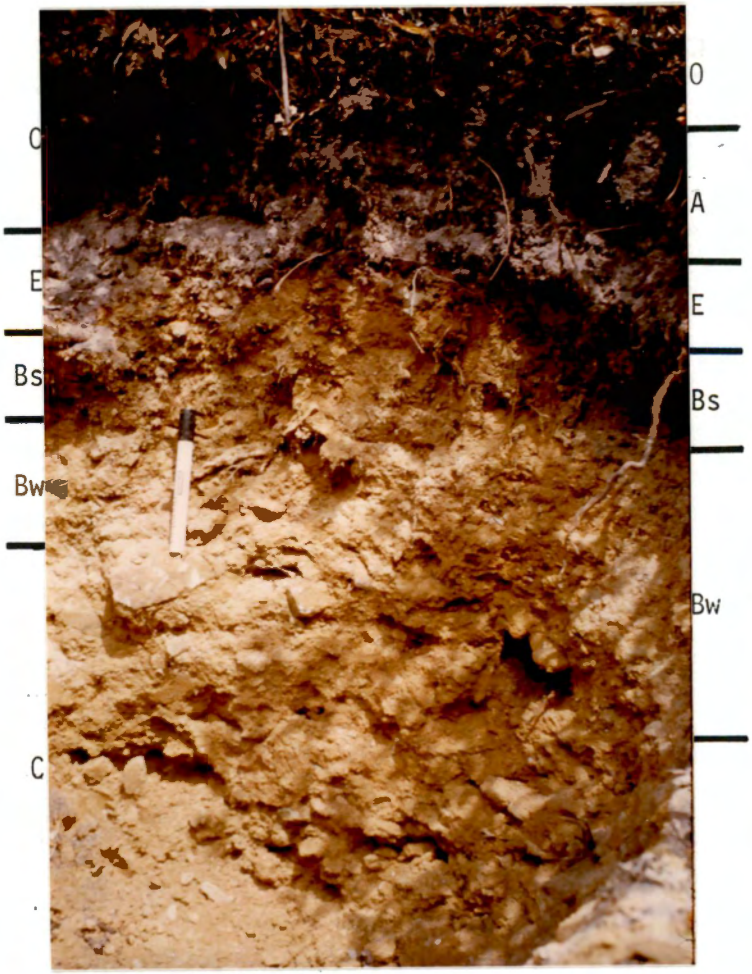

Figure E-11. Pedon PMVA-1.

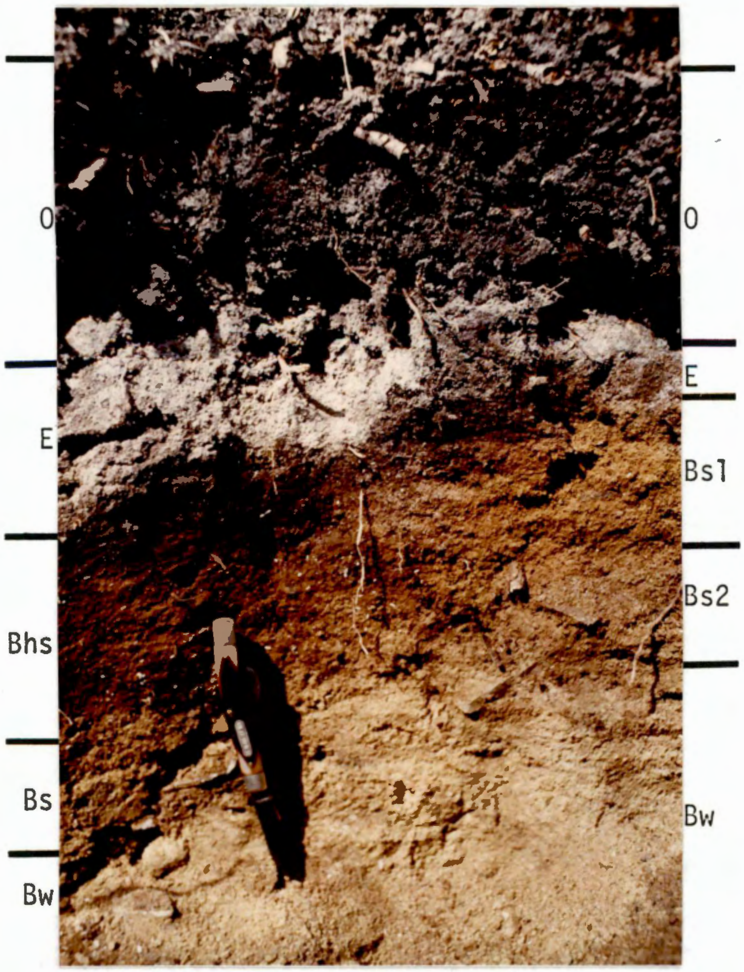

Figure E-12. Pedon PMVA-2 showing maximum expression of Bs/Bhs horizon development in part of the pedon and minimal expression in the other part.

APPENDIX F

REGRESSION EQUATIONS

TABLE F-1

Regression Equation ($\hat{Y}$) Showing Relationships Between Extractable Acidity (Y) and Organic Carbon (X) in Different Horizons

Horizon	Number of Pedons	$\hat{Y}$	r
E or A[†]	8	82.53 + 3.54X	0.84**
Bs/Bhs[†]	8	135.2 + 5.76X	0.99**
Bw or C[†]	4	102.92 + 4.65X	0.99**

**Significant at $p = 0.01$.

[†]Average value used when two or more subhorizons are present in a pedon.

Extractable acidity-----mmol(+)kg^{-1}

Organic carbon----------g·kg^{-1}

TABLE F-2

Regression Equation ($\hat{Y}$) Showing Relationships Between Extractable Acidity (Y) and Clay (X) in Different Horizons

Horizon	Number of Pedons	$\hat{Y}$	r
E or A[†]	8	101.28 + 0.33X	0.26
Bs/Bhs[†]	8	-25.15 + 1.89X	0.48
Bw or C[†]	4	-10.46 + 1.22X	0.95[*]

[*]Significant at $p = 0.05$.

[†]Average value used when two or more subhorizons are present in a pedon.

Extractable acidity-----mmol(+)kg^{-1}

Clay--------------------g·kg^{-1}

TABLE F-3

Regression Equation ($\hat{Y}$) Showing Relationships Between Sodium Pyrophosphate Extractable Aluminum and Iron (Y) and Organic Carbon (X) in Different Horizons

Horizon	Number of Pedons	$\hat{Y}$	r
E or A†	8	0.77 + 0.06X	0.84**
Bs/Bhs†	8	9.10 + 0.25X	0.90**
Bw or C†	4	3.42 + 0.25X	0.97*

*Significant at $p = 0.05$.

**Significant at $p = 0.01$.

†Average value used when two or more subhorizons are present in a pedon.

Aluminum, iron, and organic carbon-----$g \cdot kg^{-1}$

VITA

Gerard A. McGuire was born on May 1, 1948, in Penang, Malaysia. After completing his primary and secondary school education at St. Xaviers' Institution, Penang, he entered the University of Agriculture, Malaysia. After graduating with a diploma in agriculture in 1969, he worked with the Department of Agriculture, first, as an Agricultural Assistant in the Soils Division and later, as an Assistant Agricultural Officer in the Agricultural Education Division. In 1979, he accepted a Malaysian Government scholarship financed by the Malaysian Agricultural Research and Extension Project under the World Bank Loan No. 1115-MA.

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The author is a member of Phi Kappa Phi and Gamma Sigma Delta. He is married to the former Jenny Boey Ngan Fong of Johore.