1983

Characterization study of ash-influenced soils in western Montana

O. Lee Gorby

The University of Montana

Let us know how access to this document benefits you.

Follow this and additional works at: https://scholarworks.umt.edu/etd

Recommended Citation

https://scholarworks.umt.edu/etd/1783

This Thesis is brought to you for free and open access by the Graduate School at ScholarWorks at University of Montana. It has been accepted for inclusion in Graduate Student Theses, Dissertations, & Professional Papers by an authorized administrator of ScholarWorks at University of Montana. For more information, please contact scholarworks@mso.umt.edu.
COPYRIGHT ACT OF 1976

This is an unpublished manuscript in which copyright subsists. Any further reprinting of its contents must be approved by the author.

Mansfield Library
University of Montana
Date: 1983
CHARACTERIZATION STUDY OF ASH-INFLUENCED SOILS
IN WESTERN MONTANA

By
O. Lee Gorby
B.A., North Dakota State University, 1976

Presented in partial fulfillment
of the requirements for the degree of
Master of Science
UNIVERSITY OF MONTANA
1983

Approved by:

[Signature]
Chairman, Board of Examiners

[Signature]
Dean, Graduate School

5-18-83
Date
Characterization Study of Ash-Influenced Soils in Western Montana
(62 pp.)

Director: Thomas J. Nimlos

The taxonomic classification of ash-influenced soils has been controversial since the inclusion of these soils to the classification system in the 1940's.

The purpose of this study was to determine if ash-influenced soils of western Montana meet their present taxonomic criteria. Ten ash-influenced soils, of western Montana, previously classified in the field were sampled and analyzed using present taxonomic criteria parameters. These parameters included percent volcanic glass, thickness of ash layer, cation exchange capacity, 15-bar water content, percent clay, bulk density and organic carbon content.

Although these ash-influenced soils met most of their taxonomic requirements, there were exceptions. Ash-influenced soils sampled at the suborder level failed the criteria of cation exchange capacity and percent volcanic glass. Soils of the subgroup level surpassed their taxonomic requirements except the cation exchange capacity to 15-bar water content ratio.
ACKNOWLEDGEMENTS

I would like to thank Tom Nimlos, Professor of Soils, for his support and guidance and Nellie Stark, Professor of Soils, for her ideas and use of laboratory facilities and chemical reagents. Forest Service and Soil Conservation Service soil scientists are thanked for their assistance in locating soil sites.
# TABLE OF CONTENTS

ABSTRACT ........................................... ii
ACKNOWLEDGEMENTS ................................. iii
TABLE OF CONTENTS ................................. iv
LIST OF TABLES ...................................... vi
LIST OF FIGURES ..................................... vii

Chapter

I. INTRODUCTION ................................. 1

II. REVIEW OF LITERATURE ....................... 4

   History of Classification ...................... 4
   Ash-Influenced Soils of Western Montana ..... 8

III. CLASSIFICATION .............................. 12

   Suborder ......................................... 12
   Subgroup ......................................... 13
   Family ........................................... 13

IV. METHODS ....................................... 15

   Sampling ......................................... 15
   Analyses ......................................... 18

V. RESULTS ........................................ 21

   Important and Unique Taxonomic Criteria ..... 21
   Cation Exchange Capacity ....................... 24
   Taxonomic Classes ............................... 26
LIST OF TABLES

1. Soil Site Data ............................................. 17
2. Chemical, Physical and Mineralogical Properties 
of Four Andept Soils as Compared to their 
   Taxonomic Requirements ................................. 23
3. Chemical, Physical and Mineralogical Properties 
of Six Andic Soils as Compared to their 
   Taxonomic Requirements ................................. 25
4. Chemical and Physical Properties of Andept Soils 
in Western Montana Compiled by Various Authors  .... 27
5. Chemical and Physical Properties of Andic Soils 
in Western Montana Compiled by Various Authors  .... 32
LIST OF FIGURES

1. Recent Volcanic Ash which was Deposited in Montana ............... 3
2. Distribution of Sampling Sites .................. 16
CHAPTER I

INTRODUCTION

Quaternary vulcanism has played a major role in the formation of soils in western Montana with an estimated four million acres covered by volcanic ash from Cascade Range volcanoes (Figure 1). The eruption of Mt. Mazama 6,600 years ago produced the thickest and most extensive surficial ash deposit with lesser deposits from Glacier Peak 12,000 years ago and Mt. St. Helens which had several eruptions ranging in age from 35,000 years to 200 years ago.

In the 1940's ash-influenced soils of the western United States were first recognized and characterized as Brown Podzolics. The term Brown Podzolic had its origin in northeastern United States. Although the Brown Podzolics of the Northeast were older in age, differed in parent material, weathering environment and native vegetation, the genesis was presumed to be the same.

Lab data generated during the formation of the present soil taxonomic classification system in the 1950's proved ash-influenced soils had been unsatisfactorily
placed in different levels and categories of the developing classification system.

Soil scientists in western Montana have been hindered by the lack of laboratory and field data on differentiating criteria used to identify the Andept sub-order and Andic subgroup, the taxa of most ash-influenced soils. Because of the lack of data, I characterized the chemical, physical and mineralogical properties of ten common ash-influenced soils in western Montana.
Figure 1. Recent Volcanic Ash which was Deposited in Montana (Robert Ottersberg 1977).
CHAPTER II

REVIEW OF LITERATURE

Various terms are applied to soils with a mantle of volcanic ash: andic, volcanic-ash soils, ash-capped, eolian-influenced and soils with Bir horizons. The term used throughout my thesis is ash-influenced soils. It describes soils having a surficial layer of volcanic ash 17 centimeters or more thick in which chemical, physical and mineralogical properties often contrast sharply with underlying sola.

History of Classification

Ash-influenced soils were first recognized in the Pacific Northwest in the 1940's (Lyford 1946). Soil scientists initially claimed these ash-influenced soils similar to the Brown Podzolics of the Northeast. The latter soils being characterized by a pale gray leached $A_2$ horizon over a heavier textured brown to yellowish brown $B$ horizon developing under a deciduous or mixed deciduous and conifer forest in a temperate or cool temperate humid region (USDA Agricultural Yearbook 1938).
In 1949 as the present classification system was developed, controversy arose over ash-influenced soils. According to their original definition, as Brown Podzolics, these soils were considered zonal; defined as great groups having soil characteristics that reflect the influence of the active factors of soil genesis, climate and vegetation. Others thought these soils intrazonal, having soil characteristics that reflect the dominating influence of relief or parent material.

However, in 1951, under the first approximation of the present classification system, the ash-influenced soils were still included in the great group Brown Podzolics. These soils were listed in the order (highest level of classification) Oxybods defined by the horizon sequence of A-B-C or B-C lacking pans or horizons. The suborder to which these soils belonged, Mesothermal Lixosols, were defined as possessing an A₂-B-C horizon sequence; having friable structural horizons, low bulk densities, but lacking silicate clay illuviation and high iron or aluminum content. Their subgroup, Tepegraylem, criteria were possession of a weak but distinct A₂.

The 7th approximation (1960) to the present classification system had the Brown Podzolics, including ash-influenced soils; in the order Spodosol, suborder Orthod and great group Typorthod. The central concept of the Spodosols is exhibited in the spodic horizon, where
amorphous mixtures of organic matter and aluminum, with or without iron, have accumulated. This horizon has at least 0.29 percent organic carbon and 1.0 percent sesquioxides.

Research on ash-influenced soils in the middle 60's provided the first clues that these soils may not be Spodosols. Data collected compared ash-influenced soils of the western United States versus their counterparts in the Northeast; both classified as Spodosols. The dithioniate treatment to determine free oxides had little affect on the amorphous materials and clay aggregates of the ash-influenced soils of the western United States, while spodic pellets and coatings were destroyed in the Northeastern soils. Also when heating the amorphous materials (200°C) of both soils, the exchange capacity of the Northeastern soils was affected much more than their counterparts of the west. Western soil scientists also reported these ash-influenced soils failed to show leaching or organic matter and sesquioxides needed for the formation of a spodic horizon.

Further supporting evidence in the middle 60's caused the Soil Survey Staff to place ash-influenced soils in the Order Inceptisol whose central concept were soils having one or more diagnostic horizons that form quickly while not representing significant illuviation or eluviation or extreme weathering. These soils are most often found on young geomorphic surfaces limiting soil
development. At this time a new suborder, Andepts, was introduced. Andepts were defined as Inceptisols with an epipedon, a cambic horizon or both. Bulk density is less than 1.0 g/cc and either (1) have an exchange complex dominated by amorphous materials or (2) have more than 60 percent volcanic ash, pumice or other pyroclastic material in the silt and coarser fractions (unpublished govt. memorandum 1964). The subgroup, Andic, was also introduced; defined as having (1) detectable amorphous colloids with a high exchange capacity and (2) more than 20 percent volcanic ash, pumice and other pyroclastic material in the silt and coarser fractions. Andic subgroups were included in all orders except Vertisols, Histosols and Spodosols (unpublished govt. memorandum 1964).

In a 1967 supplement to the 7th approximation Andept requirements had been amended to having a bulk density of less than 0.85 g/cc, lacking a plaggen epipedon and being at no time saturated with water. Andic criteria now required a bulk density of 0.95 g/cc or less and had either (1) a ratio of measured clay to 15-bar water of 1.25 percent or less, or (2) a ratio of CEC to 15-bar water of more than 1.5 and more exchangeable acidity than sum of bases plus KCl extractable aluminum.

Minor additions, deletions and alterations to these requirements gave us our present classification criteria published in 1975 by the Soil Survey Staff.
Today controversy still surrounds classification of ash-influenced soils. A critique of the present classification system by worldwide users indicated taxonomic problems were still identified with Andepts; the range of properties being too broad and not adequately subdivided. Lack of laboratory data was also cited as a hindrance in the study of these soils (Cline 1980).

**Ash-Influenced Soils of Western Montana**

Research of volcanic ash, while voluminous for the Pacific Rim area and the Cascade Range states of Washington and Oregon, is scant for western Montana.

Nimlos (1980) discusses the history of ash falls in western Montana, gives a summary of chemical, physical and mineralogical properties, taxonomic requirements and management implications of these soils.

Ottersberg's study (1977) presents chemical and physical data of twenty ash-influenced soils in western Montana. These soils were grouped into differing levels of amorphous character. Soils classified as Andepts had the strongest index, based on their chemical and physical properties. These soils also met Andept taxonomic requirements in most cases, exceptions being cation exchange values and 15-bar water content to clay ratio. Volcanic glass content was not analyzed. Soils classified as Andic met taxonomic limits of bulk density and cation exchange
capacity to 15-bar water content ratio. Other taxonomic criteria were not determined.

Stevens (1960) studied the ash-influenced series Holloway, reporting on changes in chemical, physical and mineralogical properties with elevation. As elevation increased, pH, calcium, potassium and manganese decreased. The physical properties of particle size distribution, 1/3 and 15-bar water content were similar at all elevations. The mineralogical analysis did not determine volcanic glass content; however ash thickness increased with increasing elevation.

Klages (1978) determined the clay minerals of Montana soils formed from volcanic parent materials. He found amorphous clays in Cascade Range ash that fell during the Quaternary. The weathering products of older ash with origin other than Cascade Range volcanoes were smectites and occurred in south central to southwestern Montana. Samples collected from counties located in the northern third of western Montana had volcanic glass contents ranging from 50 to 85 percent. Taxonomic classification of these soils was not determined (unpublished memorandum (1977)).

A characterization study involving an ash-influenced soil representative of northern Idaho and northwestern Montana was conducted by Fosberg, et al. (1979). This soil was originally classified Alfic Fragiorthod.
indicating the presence of a spodic horizon. Chemical and physical data indicated classification as an Andic Fragiochrept. Extractable Fe and Al were below the limits for a spodic horizon. This soil possessed an ochric epipedon based on chroma and n value and lacked an A₂ or albic horizon. However, there was a higher Al content in the B than IIA and IIB horizons indicating possible transition to spodic horizons. Ash thickness, CEC, 15-bar water content and bulk density values were similar to ash-influenced soils of western Montana.

Garber (1966) examined two ash-influenced soils representing northern and central Idaho respectively. These soils were originally classified as Spodosols. Through chemical and physical analysis he found these soils have properties common to both Spodosols and ash-influenced Inceptisols. Taxonomic criteria for ash-influenced soils were exceeded by these soils for thickness of ash layer, cation exchange capacity and organic carbon; they failed the criteria of volcanic glass content and bulk density. No other ash-influenced criteria were examined. Garber suggested an intergrade category for both Spodosols and Inceptisols to cover this situation.

Schurger (1979) evaluated particle density as the reason for characteristically low bulk density of ash horizons. He reported values of 2.33 to 2.62 g/cc, common to mineral soils, thus discounting his hypothesis.
Busskohl (1979) showed no glass shards in the very coarse, coarse and medium sand fractions of ash samples collected from western Montana. He concluded these larger size fractions to be contaminants; either loessial or from the underlying sola. Nimlos (1981) has reached the same conclusion after analyzing Forest Service data concerning particle size distribution of ash-influenced soils in western Montana.

Starry (1980) has shown an increasing linear relationship between the amount of glass in the silt fraction of volcanic ash and pH after mixing with 1.0N NaF. Fieldes and Perrot (1966) used a NaF procedure to develop a field test for percent allophane of ash-influenced soils in New Zealand. Since allophane is a weathering product of volcanic glass this test may be used to predict relative abundance of volcanic glass in ash-influenced soils of western Montana.

Stone (1978) reported pedogenesis of ash-influenced soils differing according to aspect. Chemical analysis of iron content in ash horizons on a northern aspect indicated a higher concentration or bulge in the second mineral horizon. Physical investigation indicated development of a weakly expressed Bhir horizon, suggesting eluviation of iron within the profile. Ash horizons located on a southern aspect indicated no iron movement or morphological development.
CHAPTER III

CLASSIFICATION

Taxonomic criteria for ash-influenced soils apply at the suborder, subgroup and family levels (Soil Survey Staff 1975).

Suborder: Andepts

1. Have to a depth of 35 cm. or more, or to a lithic or a paralithic contact if one is shallower than 35 cm., one or both of the following:
   a. A bulk density (at 1/3-bar water content) in the fine-earth fraction of the soil that is less than 0.85 g/cc and the exchange complex is dominated by amorphous material; or
   b. Sixty percent or more of the soil (by weight) is vitric volcanic ash, cinders, or other vitric pyroclastic material; and

2. Do not have an aquic moisture regime or do not have the characteristics associated with wetness that are defined for Aquepts.

Having the "exchange complex dominated by amorphous material" requires:
1. The exchange capacity of the clay at pH 8.2 is greater than 150 meq per 100 grams of measured clay.

2. If there is enough clay to have a 15-bar water content of 20 percent or more, the pH of a suspension of 1 gram of soil in 50 ml. 1.0 N NaF is greater than 9.4 after 2 minutes.

3. The ratio of 15-bar water content to measured clay is more than 1.0.

4. The amount of organic carbon exceeds 0.6 percent.

5. Differential thermal analysis shows a low temperature endotherm.

6. The bulk density of the fine-earth fraction is less than 0.85 g/cc at 1/3-bar water content.

   **Subgroup: Andic**

1. A layer in the upper 75 cm. having a texture finer than loamy fine sand and at least 18 cm. thick.

2. Bulk density of the fine-earth fraction (at 1/3-bar water content) is 0.95 g/cc or less.

3. Has either a ratio of measured clay to 15-bar water percentages of 1.25 or less or a ratio of CEC (determined at pH 8.2) to 15-bar water content of greater than 1.5 and more exchange acidity than sum of bases plus KCl-extractable aluminum.

   **Family: Ashy**

1. Sixty percent or more of the whole soil (by weight) volcanic ash, cinders and pumice.
2. Less than 35 percent (by volume) is 2 mm. in diameter or larger.

Family: Medial

1. Less than 60 percent of the whole soil (by weight) volcanic ash, cinders and pumice.

2. Less than 35 percent (by volume) is 2 mm. in diameter or larger.

3. The fine-earth fraction is not thixotrophic; the exchange complex is dominated by amorphous materials.

Ash deposits in western Montana are usually less than 60 cm. thick. The depth of the ash layer is a differentiating characteristic in classification. Andept soils possess an ash layer deeper than 35 cm., Andic between 17 - 35 cm.; ash layers less than 17 cm. are not considered in the taxonomy.

Families are a taxonomic level of classification defined to provide grouping of soils with restricted ranges: of particle size distribution in the control section, mineralogy, temperature regimes and thickness of soil penetrable by roots. The families of ash-influenced soils, ashy and medial, are modifiers of particle size and/or mineralogy.
CHAPTER IV

METHODS

Sampling

Sampling sites were selected to represent a wide geographical range within the area of the ash fall to test the limits of the present classification criteria for ash-influenced soils. Forest Service soil scientists considered the sites representative of common ash-influenced series in western Montana. Soil profiles were described and sampled by standard procedures (Soil Survey Staff 1975). Only the northern and eastern aspects of slopes less than 40 degrees were sampled to avoid deposits that are apt to be mixed (Ottersberg 1977). The geographical locations of the ten soil profiles sampled are given in Figure 2 with site characteristics in Table 1.

Variations in the soil forming factors of climate, vegetation and sola underlying the ash existed among the sites. The northernmost sites of Flathead and Lincoln counties experience more annual precipitation and warmer overall temperatures, due to a maritime influence, than those of central western Montana. Vegetation, described by habitat types, varied from the drier Douglas fir
Figure 2. Distribution of Sampling Sites.
### Table 1. Soil Site Data

<table>
<thead>
<tr>
<th>Soil Series</th>
<th>Taxonomic Classification</th>
<th>*Habitat Type</th>
<th>Location</th>
<th>Elevation (Meters)</th>
<th>Aspect</th>
<th>Slope (deg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unnamed II</td>
<td>Entic Cryandept</td>
<td>Thpl/Clun</td>
<td>Sec 14, R32W T34N Lincoln Co.</td>
<td>1429</td>
<td>N</td>
<td>35</td>
</tr>
<tr>
<td>Unnamed III</td>
<td>Entic Dystandept</td>
<td>Abgr/Clun</td>
<td>Sec 36, R33W T25N Lincoln Co.</td>
<td>1277</td>
<td>N</td>
<td>30</td>
</tr>
<tr>
<td>Unnamed IV</td>
<td>Lithic Cryandept</td>
<td>Abla/Xete</td>
<td>Sec 27, R22W T32N Flathead Co.</td>
<td>1885</td>
<td>N</td>
<td>30</td>
</tr>
<tr>
<td>Coerock</td>
<td>Lithic Cryandept</td>
<td>Abla/Mefe</td>
<td>Sec 5, R17W T13N Missoula Co.</td>
<td>1976</td>
<td>N</td>
<td>30</td>
</tr>
<tr>
<td>Unnamed I</td>
<td>Andic Cryorthent</td>
<td>Abla/Libo</td>
<td>Sec 31, R23W T31N Flathead Co.</td>
<td>1125</td>
<td>NE</td>
<td>20</td>
</tr>
<tr>
<td>Totelake</td>
<td>Andic Ustochrept</td>
<td>Psme/Caru</td>
<td>Sec 25, R16W T18N Missoula Co.</td>
<td>1378</td>
<td>E</td>
<td>5</td>
</tr>
<tr>
<td>Sherlock</td>
<td>Andic Cryoboralf</td>
<td>Abla/Xete</td>
<td>Sec 25, R16N T18N Missoula Co.</td>
<td>1353</td>
<td>NW</td>
<td>5</td>
</tr>
<tr>
<td>Holloway</td>
<td>Andic Cryochrept</td>
<td>Psme/Vaca</td>
<td>Sec 11, R17W T14N Missoula Co.</td>
<td>1824</td>
<td>NE</td>
<td>20</td>
</tr>
<tr>
<td>Felan</td>
<td>Andic Cryochrept</td>
<td>Abla/Libo</td>
<td>Sec 18, R17W T21N Missoula Co.</td>
<td>1246</td>
<td>E</td>
<td>10</td>
</tr>
<tr>
<td>Krause</td>
<td>Andic Ustochrept</td>
<td>Thpl/Clun</td>
<td>Sec 27, R26W T16N Missoula Co.</td>
<td>912</td>
<td>E</td>
<td>0</td>
</tr>
</tbody>
</table>

*see Appendix 1 for habitat type abbreviations
(Pseudotsuga menziessi) series to the wetter grand fir (Abies grandis) and the colder subalpine fir (Abies lasiocarpa) series. The underlying sola included quartzite and argillitic till at the southernmost sites to quartzite and argillitic bedrock in the northwestern sites.

Ash-influenced soils over limestone were avoided because of high bulk density values, absence of B horizons and lighter color values (Van Fossen 1979).

**Analyses**

Standard characterization procedures (Soil Conservation Service 1972) were followed except where noted. All samples were air-dried to 40° C then passed through a 2 mm sieve.

Organic carbon was determined by the acid dichromate digestion method. For cation exchange capacity and extractable aluminum I used an atomic absorption spectrophotometer with NH₄OAc at pH 8.2 as the extractant. Exchangeable acidity was determined by the BaCl₂ triethanolamine method. Particle size analysis was by the hydrometer method (Bouyoucos 1937).

Bulk density measurements of ash-influenced soils are very difficult. The clod method, using liquid saran, is time consuming and collection of samples in the field difficult. Garber (1966) reports ash, being porous, tends to take up liquid saran during coating, increasing the
weight of the clod. This method also neglects coarse fragment content which affects results.

I tried two different methods. The cylinder method involved two different sized cores: one a PVC pipe, 5 centimeters in diameter and 12 centimeters long; the other, a tin can, 13 centimeters in diameter and 10 centimeters long. The cores were manually pushed into the ash layer after the organic layer was removed. The soil inside the cylinder was retained and sealed in a plastic bag.

The second method consisted of digging a hole in the ash layer with one insertion of the spade, so as to minimize compaction of the ash. The ash from the hole was retained, sealed in a plastic bag and later weighed. The hole was lined with saran and filled with garbanzo beans to the original level. The beans were lifted from the hole and measured in a graduated cylinder representing the volume of the hole. Samples were collected, sealed in a plastic bag, air dried and weighed. The difference in bulk density results from air dried versus the taxonomic requirement of 1/3-bar water are usually .01 g/cc to .02 g/cc and were considered negligible.

Fifteen bar water content was determined with a pressure plate apparatus (Richards 1954). Volcanic glass content was determined by use of a cleaning and identification procedure developed by Dr. Okazaki of the Soil Department of Washington State University. Five gram
samples were mixed with 2-3 mls. of 30% $\text{H}_2\text{O}_2$ to oxidize any organic matter. After several decantings, 35-40 mls. of hot sodium citrate solution were added along with 1 gram of sodium dithionite to remove iron coatings. The solution is heated, decanted, allowed to dry and sieved. The various size fractions are mounted onto a slide for examination by a petrographic microscope. Five hundred grains were counted in the determination of percent volcanic glass.
CHAPTER V

RESULTS

Laboratory results from 10 ash-influenced soils of western Montana, previously classified as Andepts and Andics, are presented in Tables 2 and 3 and published chemical, physical and mineralogical data on ash-influenced soils of western Montana in Tables 4 and 5. The latter data were taken from the following publications: Soil Survey of the St. Regis-Ninemile Area (1972), Soils of the Corum Experimental Forest (1976), Stillwater State Forest Landtypes Survey Report (1978) and Robert Ottersberg's master thesis (1977).

Since bulk density and cation exchange capacity are very important and unique properties of ash-influenced soils and are suborder and subgroup taxonomic criteria, these properties will be discussed individually.

**Important and Unique Taxonomic Criteria**

**Bulk Density**

A bulk density of less than 0.85 g/cc is a differentiating criterion for Andepts. The values found in the 10 profiles were unusually low (<.90 g/cc); most soils,
formed in materials other than ash, have bulk densities of 1.0 to 1.8 g/cc.

The core method for bulk density determinations proved unsatisfactory. Inserting the cylinder compacted the ash causing low bulk densities. Bulk densities from the smaller PVC cylinder ranged from 0.35 to 0.50 g/cc and showed greater compaction within the cylinder than did the larger tin can cylinder. The tin can bulk density values ranged from 0.55 to 0.80 g/cc. Although the tin can presented more creditable results, tin proved a poor material as its edges bent easily when encountering coarse fragments. A larger size cylinder also presents problems in recovering the sample. Ash is friable and easily falls out of the cylinder as it is being lifted from the sample site.

The garbanzo bean method proved more satisfactory; however, there are several disadvantages. First, the precision is dependent on the operator's experience; I performed this test approximately 50 times before adopting it. I found my precision increased with experience. Secondly, preliminary data indicated samples taken from horizons having more than 30% coarse fragments, by volume, provided inaccurate and inconsistent results.

The four previously classified Andept series sampled all had bulk densities below the required 0.85 g/cc; the range being 0.68 to 0.78 g/cc (Table 2). The six
Table 2. Chemical, Physical and Mineralogical Properties of Four Andept Soils as Compared to Their Taxonomic Requirements.

<table>
<thead>
<tr>
<th>Taxonomic requirements</th>
<th>Coerock</th>
<th>Unnamed 1</th>
<th>Unnamed 3</th>
<th>Unnamed 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash thickness</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 35 cm</td>
<td>36</td>
<td>43</td>
<td>38</td>
<td>38</td>
</tr>
<tr>
<td>Bulk density</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 0.85 g/cc</td>
<td>0.71</td>
<td>0.68</td>
<td>0.78</td>
<td>0.72</td>
</tr>
<tr>
<td>CEC &gt; 150 meg/100 grams of clay</td>
<td>99</td>
<td>57</td>
<td>69</td>
<td>83</td>
</tr>
<tr>
<td>15-bar water content &gt; 1.0 % clay</td>
<td>1.3</td>
<td>1.0</td>
<td>1.3</td>
<td>1.4</td>
</tr>
<tr>
<td>Organic carbon &gt; 0.6</td>
<td>3.1</td>
<td>3.9</td>
<td>2.2</td>
<td>5.0</td>
</tr>
<tr>
<td>Vitric volcanic ash &gt; 60 percent</td>
<td>41</td>
<td>39</td>
<td>40</td>
<td>74</td>
</tr>
</tbody>
</table>
previously classified Andic subgroups sampled all had values less than their taxonomic requirement of 0.95 g/cc (Table 3).

Comparison of my results, using the garbanzo bean method, with published results of the same series show a difference of no more than .08 g/cc. Ash-influenced soils of western Montana appear to meet their taxonomic requirements at the suborder and subgroup level.

Cation Exchange Capacity

The cation exchange capacity (CEC) of ash-influenced soils is usually high and pH dependent. The high values are surprising because the amounts of clay are usually less than 10 percent.

Because the index cation used in the determination of CEC influences the results (Sawhney 1959) and the exchange capacity is pH dependent, the Soil Survey (1975) recommends the displacing salt be buffered at pH 8.2.

Andepts must have a CEC greater than 150 meq per 100 grams of clay. All Andept classified soils sampled did not meet this taxonomic criterion, the range of results being 57 to 99 meq/100 grams of clay (Table 2). Other authors (Stark 1978) have also recorded low values. However, published Andept CEC values (Table 4) show only 18 percent of the soils did not exceed this taxonomic criterion; no reported values were less than 100 meq per 100 grams of clay.
Table 3. Chemical, Physical and Mineralogical Properties of Six Andic Soils as Compared to Their Taxonomic Requirements.

<table>
<thead>
<tr>
<th>Taxonomic requirements</th>
<th>Felan</th>
<th>Holloway</th>
<th>Krause</th>
<th>Sherlock</th>
<th>Unnamed I</th>
<th>Totelake</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ash thickness (17 - 35 cm)</td>
<td>20</td>
<td>25</td>
<td>33</td>
<td>25</td>
<td>23</td>
<td>31</td>
</tr>
<tr>
<td>Texture</td>
<td>SiL</td>
<td>SiL</td>
<td>SL</td>
<td>SiL</td>
<td>SiL</td>
<td>L</td>
</tr>
<tr>
<td>Bulk density &lt; 0.95 g/cc</td>
<td>0.76</td>
<td>0.88</td>
<td>0.86</td>
<td>0.88</td>
<td>0.82</td>
<td>0.93</td>
</tr>
<tr>
<td>Clay content (%) 15-bar water content &lt;1.25</td>
<td>0.70</td>
<td>0.73</td>
<td>1.42</td>
<td>1.24</td>
<td>1.25</td>
<td>1.21</td>
</tr>
<tr>
<td>CEC &gt; 1.5 15-bar water content</td>
<td>0.4</td>
<td>0.3</td>
<td>0.6</td>
<td>0.4</td>
<td>0.6</td>
<td>0.6</td>
</tr>
<tr>
<td>Exchangable acidity &gt; sum of bases + extractable Al</td>
<td>14&gt;8</td>
<td>9&gt;5</td>
<td>14&gt;9</td>
<td>15&gt;6</td>
<td>12&gt;4</td>
<td>21&gt;17</td>
</tr>
</tbody>
</table>
The subgroup, Andic, requires a ratio of CEC to 15-bar water content of greater than 1.5. All soils in my study did not meet this requirement, the cause being low CEC values (Table 3); however, only 10 percent of Andic soils reporting results failed this criterion.

CEC appears to be a reliable taxonomic characteristic of ash-influenced soils of western Montana.

**Taxonomic Classes**

**Andept**

Andept soils must have a bulk density of 0.85 g/cc or less and have the exchange complex dominated by amorphous material. As previously discussed, ash soils of western Montana meet their bulk density requirements. To satisfy the amorphous domination requirement these soils must meet a series of criteria:

1. The exchange capacity of the clay at pH 8.2 is greater than 150 meq per 100 grams of measured clay. Ash-influenced soils of western Montana appear to meet this criterion.

2. If there is enough clay to have a 15-bar water content of 20 percent or more, the pH (of the suspension of 1 gram of soil in 50 ml of 1.0 N NaF) is greater than 9.4 in 2 minutes. The only publication to report a 15-bar water content greater than 20 percent was Ottersberg (1977); the sample was collected near Spread Creek in the Kooteni National Forest. Most soils classified as
Table 4. Chemical and Physical Properties of Andept Soils in Western Montana Compiled by Various Authors.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ottersberg's thesis</th>
<th>SCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC meq/100g soil</td>
<td>27  22  19  15  14  16  13  13  21  19</td>
<td>15  12</td>
</tr>
<tr>
<td>CEC meq/100g clay</td>
<td>298  240  243  209  101  400  101  210  355  323</td>
<td>238  244</td>
</tr>
<tr>
<td>Clay content (%)</td>
<td>9   9   8   7   14   4   13   6   6   6</td>
<td>6   5</td>
</tr>
<tr>
<td>15-bar water clay content</td>
<td>1.2  1.2  1.1  0.9  0.8  2.7  0.8  2.2  2.0  1.8</td>
<td>1.9  2.3</td>
</tr>
<tr>
<td>15-bar water content %</td>
<td>11.2  10.4  9.0  6.5  10.8  22.8  10.7  13.4  11.8  10.8</td>
<td>11.8  10.8</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
<td>6.4  5.4  4.7  2.3  1.3  1.4  1.9  1.8</td>
<td>2.8  1.9</td>
</tr>
</tbody>
</table>
| Bulk density g/cc             | 0.78  0.79  0.70  0.70 | (continued)
Table 4.  Continued

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Ninemile</th>
<th></th>
<th>Stillwater</th>
<th></th>
<th>Corum</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC meq/100g soil</td>
<td>14 15 12 10 20 13</td>
<td></td>
<td>18 19 7</td>
<td></td>
<td>17</td>
</tr>
<tr>
<td>CEC meq/100g clay</td>
<td>180 241 240 101 221 242</td>
<td>165 227 116</td>
<td></td>
<td>204</td>
<td></td>
</tr>
<tr>
<td>Clay content (%)</td>
<td>8 6 5 9 9 5</td>
<td></td>
<td>11 8 6</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>15-bar water clay content</td>
<td>1.1 1.9 2.3 0.6 1.2 2.0</td>
<td></td>
<td>1.0 1.5 0.9</td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>15-bar water content %</td>
<td>7.9 11.8 10.8 5.4 11.2 10.4</td>
<td></td>
<td>10.5 12.9 5.4</td>
<td></td>
<td>8.0</td>
</tr>
<tr>
<td>Organic carbon (%)</td>
<td>1.5 2.8 1.9 0.3 6.4 5.4</td>
<td></td>
<td></td>
<td></td>
<td>2.1</td>
</tr>
<tr>
<td>Bulk density g/cc</td>
<td>0.80 0.68 0.75 0.78 0.79</td>
<td></td>
<td></td>
<td></td>
<td>0.84</td>
</tr>
</tbody>
</table>
Andept in western Montana usually have 15-bar water contents of 10 to 11 percent. Ash-influenced soils of western Montana would not meet this criterion.

3. The ratio of 15-bar water content to measured clay is more than 1.0. This taxonomic criterion was satisfied by each soil in my study and over 75 percent of published values also exceeded this limit. The average value of these soils was 1.3.

4. The organic carbon content exceeds 0.6 percent. Fieldes and Claridge (1975) have suggested that organic matter complexes with amorphous clays, thereby resisting microbial breakdown which gives ash-influenced soils consistently higher amounts of organic matter when compared to other mineral soils. All soils I sampled exceeded this criterion and 94 per cent of all reported values did also. The range of values being 0.3 to 6.5 percent with 2.9 percent the average. This criterion is a useful characteristic of ash-influenced soils of western Montana.

5. Differential thermal analysis shows a low temperature endotherm. A measurement of the difference in heat absorbed by or evolved from a sample versus a thermally inert material when the two are heated at a constant rate is called differential thermal analysis (Soil Survey Staff 1972). The temperature of which an exothermic or endothermic reaction occurs identifies
the material. Amorphous clays give a broad endotherm at about 160°C giving rise to the taxonomic requirement of a low temperature endotherm at about 160°C. I did not evaluate this criterion because the instrumentation was not available. Blackmore (1978) suggests this criterion be discontinued for the lack of readily available equipment.

6. Have a bulk density of less than 0.85 g/cc.

If a soil does not meet the bulk density and amorphous domination requirement they must have 60 percent of the soil, by weight, being volcanic glass. John E. McClelland, former Director of Soil Survey Classification and Correlation Division (1977) interpreted this requirement to mean the silt size (or most abundant fraction) must have at least 60 percent of grains being volcanic glass. Volcanic glass and other mineral grains are assumed to have a 1:1 weight relationship in this case. In my study, counts of 500 were made on the silt size fraction, the most abundant size fraction of ash-influenced soils in western Montana. Most of the soils sampled averaged 40 percent glass (Table 2); the highest value, 74 percent, was from the Unnamed 4 series located in the Stillwater State Forest.

The only published results of volcanic glass content are by Green (1976) and Klages (1977). Green examined three different size fractions (medium sand, fine
sand and very fine sand) of five ash-influenced soils of western Montana to determine volcanic glass content. He found the glass content to decrease as particle size increased. In analyzing the very fine sand fraction Green reported values ranging from 40 to 95 percent.

Klages (1977) analyzed the very fine sand fraction of ten ash-influenced soils in western Montana. His results ranged from 50 to 85 percent.

Results indicate that glass content is not related to the thickness of the ash layer. Many of the Andic soils, possessing thinner depths of ash, had similar percentages of glass when compared to Andepts. Nor is volcanic glass evenly distributed within a geographical area. Two sites in my study less than 100 miles apart had glass contents varying 30 percent.

**Andic**

Andic soils possess a thinner, 17-35 cm, ash deposit than Andepts and must satisfy different taxonomic criteria. These criteria are:

1. The ash layer must have a texture finer than loamy fine sand. Soils sampled had textures ranging from sandy loam to loam with silt loam predominant. Because of western Montana's distance from the source, Cascade Range, only the finer sized fractions, mostly silt sized particles were deposited in the state. Most
Table 5. Chemical and Physical Properties of Andic soils in Western Montana Compiled by Various Authors.

<table>
<thead>
<tr>
<th>Publication</th>
<th>Bulk Density (g/cc)</th>
<th>CEC (meq/100g)</th>
<th>Clay Content (%)</th>
<th>15-BW Content (%)</th>
<th>Sum of Bases (meq/100g)</th>
<th>Exchangeable Acidity (meq/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co rum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>13</td>
<td>11.7</td>
<td>11</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>22</td>
<td>16</td>
<td>11.0</td>
<td>13</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>4</td>
<td>11.5</td>
<td>7</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>8</td>
<td>12.4</td>
<td>9</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>12</td>
<td>8.8</td>
<td>12</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>8</td>
<td>6.2</td>
<td>14</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Ninemile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>7</td>
<td>7.2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.90</td>
<td>22</td>
<td>9.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.87</td>
<td>18</td>
<td>9.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.93</td>
<td>16</td>
<td>8.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.89</td>
<td>13</td>
<td>8.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.82</td>
<td>14</td>
<td>5.2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Table 5. (continued)

<table>
<thead>
<tr>
<th>Publication</th>
<th>Clay Content 15-bar water</th>
<th>CEC 15-bar water</th>
<th>CEC 100g clay</th>
<th>15-bar water Clay content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ottersberg</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>2.0</td>
<td>823</td>
<td>4.1</td>
<td></td>
</tr>
<tr>
<td>1.05</td>
<td>1.8</td>
<td>173</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>0.54</td>
<td>1.7</td>
<td>317</td>
<td>1.9</td>
<td></td>
</tr>
<tr>
<td>0.70</td>
<td>1.8</td>
<td>258</td>
<td>1.4</td>
<td></td>
</tr>
<tr>
<td>0.82</td>
<td>1.4</td>
<td>172</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>0.61</td>
<td>1.5</td>
<td>245</td>
<td>1.7</td>
<td></td>
</tr>
<tr>
<td>1.48</td>
<td>2.8</td>
<td>188</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>1.25</td>
<td>1.6</td>
<td>124</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>SCS</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.18</td>
<td>2.4</td>
<td>208</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>1.01</td>
<td>1.9</td>
<td>188</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>0.97</td>
<td>3.4</td>
<td>355</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>1.13</td>
<td>2.4</td>
<td>211</td>
<td>0.9</td>
<td></td>
</tr>
<tr>
<td>Stillwater</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.25</td>
<td>1.7</td>
<td>663</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>0.38</td>
<td>1.0</td>
<td>250</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>0.33</td>
<td>1.2</td>
<td>354</td>
<td>3.1</td>
<td></td>
</tr>
</tbody>
</table>
### Table 5. (continued)

<table>
<thead>
<tr>
<th>Publication</th>
<th>Bulk Density (g/cc)</th>
<th>CEC (meq/100g)</th>
<th>Clay Content (%)</th>
<th>15-BW Content (%)</th>
<th>Sum of Bases (meq/100g)</th>
<th>Exchangeable Acidity (meq/100g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ottersberg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.71</td>
<td>25</td>
<td>3</td>
<td>12.1</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.87</td>
<td>17</td>
<td>10</td>
<td>9.5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.90</td>
<td>35</td>
<td>11</td>
<td>20.5</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.93</td>
<td>34</td>
<td>13</td>
<td>18.5</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>10</td>
<td>12.2</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>42</td>
<td>17</td>
<td>28.0</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>13</td>
<td>8.8</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>11</td>
<td>8.8</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.90</td>
<td>22</td>
<td>11</td>
<td>9.0</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.87</td>
<td>18</td>
<td>10</td>
<td>9.5</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.78</td>
<td>23</td>
<td>6</td>
<td>6.6</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.77</td>
<td>13</td>
<td>6</td>
<td>5.5</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stillwater</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>6</td>
<td>23.9</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>6</td>
<td>16.3</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>34</td>
<td>10</td>
<td></td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>8</td>
<td>24.2</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Publication</td>
<td>Clay Content 15-bar water</td>
<td>CEC 15-bar water</td>
<td>CEC 100g clay</td>
<td>15-bar water Clay content</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-------------</td>
<td>---------------------------</td>
<td>-----------------</td>
<td>---------------</td>
<td>--------------------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corum</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.08</td>
<td>2.1</td>
<td>192</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.45</td>
<td>2.0</td>
<td>136</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.32</td>
<td>2.4</td>
<td>743</td>
<td>3.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.66</td>
<td>2.0</td>
<td>306</td>
<td>1.5</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.35</td>
<td>1.5</td>
<td>112</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.31</td>
<td>3.0</td>
<td>103</td>
<td>0.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ninemile</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.94</td>
<td>3.7</td>
<td>400</td>
<td>1.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.18</td>
<td>2.4</td>
<td>208</td>
<td>0.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.01</td>
<td>1.9</td>
<td>187</td>
<td>1.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.86</td>
<td>1.9</td>
<td>216</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.64</td>
<td>1.7</td>
<td>268</td>
<td>1.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.46</td>
<td>1.2</td>
<td>262</td>
<td>2.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.86</td>
<td>1.7</td>
<td>195</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
ash-influenced soils of western Montana are silt loams and thus will meet this criterion.

2. Bulk density must be less than 0.95 g/cc. All soils sampled met this criterion. The range of bulk density results was 0.76 to 0.93 g/cc. All published results of bulk density also surpassed the taxonomic requirement, however data was limited to only fourteen samples (Table 5).

3. Andic soils must have a ratio of clay content to 15-bar water content of 1.25 or less or CEC to 15-bar water content ratio greater than 1.5 and more exchangeable acidity than sum of bases plus KCl-extractable aluminum. In the determination of aluminum NH₄OAc was substituted for KCl.

   a. All series sampled, except Krause, had clay to 15-bar water content of less than 1.25. Krause failed possibly due to its texture, sandy loam. Since only 14 percent of published values failed this criterion it appears ash-influenced soils of western Montana classified as Andic will meet this requirement.

   b. Due to my CEC values the ratio of CEC to 15-bar water content was not met by any of my series; however, most (85%) published values easily surpass this criterion. The exchangeable acidity criterion
was met by all series sampled; there are no published values for comparison.

**Family**

The family level of classification was not the main emphasis of my thesis, but I have some data and observations concerning this level of the taxonomy.

Families reflect a combination of particle size and mineralogy. The usual taxonomic terms to describe particle size do not apply to ash-influenced soils because they are a mixture of discrete mineral particles and a gel that cannot be dispersed (Soil Survey Staff 1975). Hence the usual particle size class names are not used in a soil consisting of glass or having the exchange complex dominated by amorphous materials.

Ashy and medial are taxonomic terms defining ash-influenced soils at the family level. Family definitions are based on the 25 to 100 cm depth of a soil profile, the control section.

Ash layers of western Montana are not thick enough, usually less than 40 cm., to dominate a control section's chemical and physical properties. The only exception is ash-influenced soils having a lithic or paralithic contact immediately below the ash layer; in this situation the control section is restricted to the material immediately above the contact point. Some ash-influenced soils of western Montana fit this situation.
An ashy family must have at least 60 percent of the whole soil, by weight, being volcanic ash with less than 35 percent, by volume, being 2 mm in diameter or larger. The Andept classified series, Coerock, is an example of an ash soil with a paralithic contact. Coerock had approximately 80 percent ash and 20 percent being greater than 2 mm in diameter. However, interpretation of these results should be tempered with the fact that the sample was not representative of the whole profile; it represented only the upper part of the ash layer which had less coarse fragments than near the paralithic contact.

Medial families must have less than 60 percent of the whole soil, by weight, volcanic ash and the exchange complex dominated by amorphous materials. I did not analyze any ash-influenced soils for medial requirements. The ash soils I researched had more than 60 percent ash yet in some cases these soils barely met the amorphous domination requirements of CEC 150 meq/100 grams clay, bulk density 0.85 g/cc, organic carbon 0.6 percent and 15-bar water to clay 1.0. I do not believe any ash-influenced soils having less than 60 percent ash would meet these requirements in order to satisfy the medial definition.
CHAPTER VI

DISCUSSION

Soils classified in the Andept suborder or Andic subgroup in western Montana seem to meet their present respective taxonomic requirements; however, exceptions can be found for each criterion.

In my study, Andept classified soils consistently failed the 60 percent volcanic glass content and CEC taxonomic requirement, while Andic classified soils most often failed the CEC to 15-bar water content ratio.

Although present taxonomic criteria are adequate, I propose raising ash-influenced soils to the order level using the properties of glass content, bulk density, CEC, organic carbon and thickness of the ash layer.

Ash-influenced soils should be raised to the order level for the following reasons:

1. Uniqueness of properties. Bulk density, volcanic glass content, CEC and organic carbon values differentiate these soils from other mineral soils.

2. Amount of land surface covered by ash. Ash-influenced soils are very widespread occurring on most continents (Blackmore 1978).
3. Range of weathering environments. Ash-influenced soils occur from the equator to the high latitudes with vegetation zones ranging from tundra through tropical rain and conifer forests to grasslands (Soil Survey Staff 1975).

4. Varying age of ash. Ages of ash fall range from the beginning of the Pleistocene to present day (Soil Survey Staff 1975).

5. Varying material underlying ash soils. Some ash soils are formed from pyroclastic rocks, sedimentary rocks or basic extrusive igneous rocks (Soil Survey Staff 1975).

**Glass Content**

Volcanic glass is a reliable physical characteristic which can be used to identify ash. However, percent glass is an inconsistent parameter and the taxonomic requirement of 60 percent excludes soils otherwise qualifying as an Andept.

My results and other published data indicate that the amount of volcanic glass is not directly related to:
(1) depth of ash, (2) geographical location, (3) physiographic position, (4) and distance from the source. In my study the Unnamed I series, having an ash layer 23 cm thick, possessed 74 percent volcanic glass while another Andept series, Unnamed II, being 43 cm thick possessed only 40 percent glass. Percent glass content also varied
30 percent between two sites located within a 100 mile geographical area. Garber (1966) has shown percent glass varies with physiographic position and inconsistently with the distance from the source.

Percent glass is not a predictor of amorphous domination. In my study ash-influenced soils, classified as Andic, possessing only 20 percent met most requirements for amorphous domination. Taxonomy suggest 60 percent glass is needed to show amorphous domination of the exchange complex.

The best taxonomic use of percent volcanic glass would be as a physical characteristic to identify ash. Having a taxonomic requirement of 20 percent would serve the purpose of ash identification.

**Bulk Density**

Low bulk density is a taxonomically reliable physical characteristic of ash-influenced soils in western Montana. However, present taxonomic criteria used to differentiate between the suborder Andept and subgroup Andic are not reliable. According to Soil Taxonomy (1975), an Andept classified soil must exhibit amorphous domination of the exchange complex; which consists of a series of requirements. One requirement is that bulk density must be less than 0.85 g/cc. The subgroup Andic requires less than 0.95 g/cc for bulk density. My study had several Andic
series which would meet the amorphous domination requirements except for bulk density. The bulk density requirement for Andept excludes ash-influenced soils otherwise qualifying for the suborder. Cline (1980) after reviewing unpublished ash-influenced data concurs with this finding.

The suborder and subgroup should not be divided on the basis of present taxonomic bulk density requirements. For ash-influenced soils of western Montana, a requirement of 1.0 g/cc is sufficient to divide these soils from other mineral soils.

Information concerning bulk density of these soils in western Montana is scant. Future studies should investigate at what point, in terms of bulk density values, will ash-influenced soils not meet amorphous domination requirements.

My data, for bulk density, was collected on northern and eastern slopes less than 40 degrees. Does changing the slope and aspect affect bulk density values for a series?

Although I did not use the core method extensively, preliminary data indicated this method to be an alternative if a suitable cylinder can be developed. My results indicate the cylinder material should be thin, yet durable possessing a low coefficient of friction against the ash.
The diameters of my cylinders were 5 and 13 cm. and proved unsuitable.

**CEC**

High CEC values are characteristic of ash-influenced soils in western Montana. Using previously published data, over 50 results of soils classified as Andept or Andic found most to exceed the present taxonomic requirement of 150 meq/100 grams of clay. The CEC criterion is applied only to Andepts, yet data suggests Andics would also surpass this limit. Because thickness of ash or clay content does not seem to influence CEC, I suggest the present taxonomic criterion be applied at both the suborder and subgroup level.

Blackmore (1978) has unpublished data providing evidence for a criterion that uses the characteristic pH-dependent charge of ash-influenced soils. Subtracting the bases plus exchangeable Al from CEC at pH 8.2 (using BaCl₂) will yield values greater than 0.7, differentiating these soils from other mineral soils. This criterion has not been applied to ash-influenced soils of western Montana and should be tested.

**Organic Carbon**

High organic carbon content characterizes ash-influenced soils of western Montana. However, the
taxonomic limit, set for Andepts, is greater than 0.6 percent. Mineral soils may exceed this limit, but raising the taxonomic criterion to 2.0 percent would differentiate ash-influenced soils from mineral soils. All soils in my study would exceed 2.0 percent.

**Thickness of Ash Layer**

Ash thickness in western Montana is usually between 17-35 cm. My and others' data show that most soils classified as Andic will meet the amorphous domination requirements of Andepts even though the ash layer is less than 35 cm.

Results indicate the thickness of the ash layer does not appreciably change bulk density values. Andics, possessing thinner ash layers, may possess bulk density approaching the 0.85 g/cc value taxonomically required for the Andepts, whose ash layer is much thicker.

Published results show soils classified as Andic will meet, in most cases, Andept taxonomic criteria. Soils in my study possessing even 20 cm of ash would meet Andept criteria of volcanic glass and amorphous domination of the exchange complex. Chemically and physically these soils do not differ appreciably from soils having over 35 cm of ash. The only Andept requirement Andic classified soils consistently failed was the amorphous domination criteria of 15-bar water content to clay content of greater than 1.0.
This evidence suggests the same taxonomic requirements could be applied to both Andept and Andic classified soils. Differentiating the suborder, Andept, from the subgroup, Andic, by ash thickness of 35 cm is not a valid criterion.

I suggest the same taxonomic requirements should apply to ash-influenced soils having an ash layer thicker than 20 cm. This criterion would differentiate ash-influenced soils exhibiting amorphous domination from other mineral soils or soils having lesser amounts of ash.
CHAPTER VII

CONCLUSION

Ash-influenced soils have always been an enigma in the soil classification system. Early attempts were made to place these soils in a taxonomic group of supposedly similar mineral soils, as in the case of Brown Podzolics and later Spodosols. However, data generated has proved these soils dissimilar to any other group of soils because of the uniqueness of volcanic ash properties, method of deposition and wide range of weathering environments in which they are found. For these reasons, I propose ash-influenced soils to be raised to the order level.

Using properties examined in my thesis I formulated general minimal requirements for entrance into this order. These criteria are heavily biased toward ash-influenced soils of western Montana.

1. Volcanic glass content, by weight, 20 percent or more.
2. Bulk density < 1.0 g/cc.
3. CEC > 150 meq/100 grams of clay.
4. Organic carbon content of greater than 2.0 percent.
5. Thickness of ash layer greater than 20 cm.
These criteria are suggested because they differentiate these soils from other mineral soils by using two parameters distinctive to these soils:

(1) volcanic glass
(2) amorphous domination of the exchange complex.

Throughout taxonomic history, ash-influenced soils have always been grouped with supposedly similar types of mineral soils; but evaluation of data now indicates ash-influenced soils are dissimilar to other types of soils. Therefore, I suggest the chemical and physical properties of ash-influenced soils are so unique as to classify these soils as a separate entity. Problems of placing ash-influenced soils in the present taxonomic system can best be solved by raising these soils to the order level.
APPENDICES
## APPENDIX 1

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Scientific Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abgr/Clun</td>
<td>Abies grandis/Clintonia uniflora</td>
</tr>
<tr>
<td>Abla/Libo</td>
<td>Abies lasiocarpa/Linnea borealis</td>
</tr>
<tr>
<td>Abla/Mefe</td>
<td>Abies lasiocarpa/Menziesia ferruginea</td>
</tr>
<tr>
<td>Abla/Xete</td>
<td>Abies lasiocarpa/Xerophullum tenax</td>
</tr>
<tr>
<td>Psme/Caru</td>
<td>Pseudotsuga menziesii/Calamagrostis rubescens</td>
</tr>
<tr>
<td>Psme/Vaca</td>
<td>Pseudotsuga menziesii/Vaccinium caespitosum</td>
</tr>
<tr>
<td>Thpl/Clun</td>
<td>Thuja plicata/Clintonia uniflora</td>
</tr>
</tbody>
</table>
APPENDIX 2

Soil Profile Descriptions

Unnamed 1  Andic Cryorthent

Colors are for moist soil unless otherwise indicated.

Horizon: Profile Description

$O_2$  2-0 cm decomposed forest litter.

$A_2$  0-2 cm dark grayish brown (10 YR 4/2); gravelly silt loam; grayish brown (10 YR 5/2) dry; weak fine platy; soft, friable, nonsticky, nonplastic, many fine and common medium roots; 40% coarse fragments; pH 7.0; clear wavy boundary.

$B_2$  2-23 cm dark yellowish brown (10 YR 4/4); gravelly loam; very pale brown (10 YR 7/4) dry, weak fine subangular blocky; soft, very friable, nonsticky; common fine and medium roots; 30% coarse fragments; pH 6.0; clear wavy boundary.

$IIc$  23-76 cm light brownish gray (10 YR 6/2); gravelly coarse sand; light gray (10 YR 7/2) dry; massive; loose, non-sticky, nonstocky, nonplastic; 80% coarse fragments; pH 6.0.

Habitat type: Abla/Libo

Location: Northeast aspect, Sec 6, T31N, R23W, Flathead Co., ele. 1125 meters.
Unnamed 2  Entic Cryandept

Colors are for moist soil unless otherwise indicated.

Horizon: Profile Description

O2  4–0 cm decomposed forest litter.

A2  0–2 cm dark grayish brown (10 YR4/2); loam; light brownish gray (10 YR 6/2) dry; weak fine subangular blocky; soft, very friable, slightly sticky, slightly plastic; many fine to coarse roots; pH 6.0; clear wavy boundary.

B2  2–43 cm dark yellowish brown (10 YR 3/4); loam; light yellowish brown (10 YR 6/4) dry; moderate medium subangular blocky; soft, very friable, slightly sticky, slightly plastic; many fine and medium, few coarse roots; 10% coarse fragments; pH 6.0; clear wavy boundary.

IIIB2  43–59 cm yellowish brown (10 YR 5/4); loam; very pale brown (10 YR 8/4) dry; moderate coarse subangular blocky; slightly hard, friable, slightly sticky slightly plastic; common fine; few medium and coarse roots; 25% coarse fragments; pH 5.5; abrupt wavy boundary.

IIIB2  59–97+ cm light olive brown (2.5 Y 5/4) gravelly coarse loamy sand; light yellowish brown (2.5 Y 6/4) dry; loose, non-sticky, nonplastic; few if any roots; 50% coarse fragments; pH 5.5.

Habitat type     Thpl/Clun

Location:  North aspect, NE1/4, Sec 14, T34N, R23W, Lincoln Co., ele. 1429 meters.
Entic Dystrandept

Colors are for moist soil unless otherwise indicated.

Profile Description

Horizon: O2
1-0 cm decomposed forest litter.

Horizon: A1
0-12 cm dark yellowish brown (10YR 3/4); silt loam; light yellowish brown (10YR 6/4) dry; moderate fine granular; soft, very friable, slightly sticky, slightly plastic; many fine, common medium roots; 15% coarse fragments; pH 6.5; gradual wavy.

Horizon: B2
12-35 cm dark yellowish brown (10YR 3/6); silt loam; yellowish brown (10 YR 5/6) dry; moderate fine granular; soft, very friable, slightly sticky, slightly plastic; many fine, few medium and coarse roots; 20% coarse fragments; pH 6.5 abrupt wavy.

Horizon: IIB2
35-75 cm olive brown (2.5 Y 4/4); gravelly sandy loam; light yellowish brown (2.5 Y 6/4); weak fine granular blocky; loose, loose, nonplastic and nonsticky; few roots; 70% coarse fragments; pH 6.5; abrupt wavy boundary.

Horizon: IIC
75-88+cm olive brown (2.5 Y 4/4); gravelly sandy loam; light yellowish brown (2.5 Y 6/4) dry; massive; loose, loose, nonstocky and nonplastic; 80% coarse fragments.

Habitat type: Abgr/Clun

Location: North aspect, Sec 36, T25N, R33W, Lincoln Co., ele. 1277 meters.
Totelake Andic Ustochrept

Colors are for moist soil unless otherwise indicated.

Horizon: Profile Description

**A_2**
0-5 cm dark grayish brown (10 YR 4/2); gravelly loam; grayish brown (10 YR 5/2) dry; weak fine granular; soft, very friable, nonstocky, nonplastic; many fine and medium roots; 50% coarse fragments; pH 7.0; clear wavy boundary.

**B_21**
5-30 cm dark yellowish brown (10 YR 3/4); gravelly loam; yellowish brown (10 YR 5/4) dry; weak fine granular; slightly hard, very friable, nonsticky, nonplastic; many fine and medium roots; 30% coarse fragments, pH 6.0; clear wavy boundary.

**B_22**
30-48 cm brown (7.5 YR 5/3); very gravelly sandy loam; pale brown (10 YR 6/3) dry; very weak fine granular; slightly hard, very friable, nonsticky, nonplastic; pH 6.0; common fine and medium roots; 75% coarse fragments; clear wavy boundary.

**C_1**
48-81 cm brown (7.5 YR 5/4); very gravelly coarse sandy loam; light brown (7.5 YR 6/4) dry; massive; soft, very friable, non-sticky, nonplastic; pH 6.0; 80% coarse fragments.

Habitat type: Psme/Caru

Location: East aspect; NE1/4, Sec 25, T18N, R16W, Missoula Co., ele. 1378 meters.
<table>
<thead>
<tr>
<th>Horizon</th>
<th>Profile Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂</td>
<td>2-0 cm decomposed forest litter.</td>
</tr>
<tr>
<td>A₂</td>
<td>0-1 cm not sampled or described.</td>
</tr>
<tr>
<td>B₂</td>
<td>2-25 cm dark yellowish brown (10 YR 4/6); gravelly loam; yellowish brown (10 YR 5/6) dry; moderate fine granular; soft, very friable, nonstocky, nonplastic; many fine roots; 10% coarse fragments; pH 6.0; abrupt wavy boundary.</td>
</tr>
<tr>
<td>IIA₂</td>
<td>25-46 cm light reddish brown (5 YR 6/3); gravelly fine sandy loam; pink (5 YR 7/3) dry; weak medium subangular blocky; slightly hard, very friable, nonsticky, nonplastic; common fine and few medium roots; 50% coarse fragments; pH 5.0; gradual wavy boundary.</td>
</tr>
<tr>
<td>IIB₂</td>
<td>46-81 cm reddish brown (5 YR 5/4); gravelly light clay loam; pink (5 YR 7/4) dry; moderate medium subangular blocky; hard, friable, slightly sticky, slightly plastic; few fine roots; 75% coarse fragments; pH 5.0.</td>
</tr>
</tbody>
</table>

Habitat type: Abla/Xete

Location: Northwest aspect; SW1/4, Sec 25, T18N, R16W, Missoula Co., ele. 1353 meters.
Holloway  Andic Cryochrept

Colors are for moist soil unless otherwise indicated.

Horizon:  Profile Description

O₂  2-0 cm decomposed forest litter.

A₂  0-2 cm dark brown (7.5 YR 4/2); silt, loam; brown (7.5 YR 5/2) dry; weak fine granular; soft, very friable, slightly sticky, slightly plastic; many fine roots; 10% coarse fragments; pH 5.0; abrupt wavy boundary.

B₂  2-25 cm yellowish brown (10 YR 5/6); silt loam; brownish yellow (10 YR 6/6) dry; weak fine granular; soft, very friable, nonsticky, nonplastic; many fine and few coarse roots; 10% coarse fragments; pH 6.0; abrupt wavy boundary.

IIA₂₁  25-86 cm yellowish red (5.0 YR 5/6); gravelly very fine sandy loam; reddish yellow (5.0 YR 6/6) dry; massive, slightly hard, friable, nonsticky, nonplastic, few fine, few coarse roots; 75% coarse fragments; pH 6.0.

Habitat type:  Psme/Vaca

Location:  Northeast aspect, NE1/4, Sec11, T14N, R17W, Mineral Co., ele. 1824 meters.
Coerock Lithic Cryandept

Colors are for moist soil unless otherwise indicated.

**Horizon:** Profile Description

<table>
<thead>
<tr>
<th>Layer</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂</td>
<td>1-0 cm decomposed forest litter.</td>
</tr>
<tr>
<td>B₂</td>
<td>0-35 cm dark yellowish brown (10 YR 3/4); gravelly loam, brownish yellow (10 YR 6/6) dry; weak fine granular structure; soft very friable, nonsticky, and nonplastic; many fine roots; 30% coarse fragments; pH 6.0; abrupt wavy boundary.</td>
</tr>
<tr>
<td>R</td>
<td>35+cm fractured argillite bedrock.</td>
</tr>
</tbody>
</table>

**Habitat type:** Abla/Mefe

**Location:** North aspect; NW1/4, Sec5, T13N, R17W, Missoula Co., ele. 1976 meters.
Unnamed 4  Lithic Cryandept

Colors are for moist soil unless otherwise indicated.

Horizon:  Profile Description

\begin{align*}
A_1 & \quad 0-5 \text{ cm very dark grayish brown (10 YR 3/2); gravelly silt loam; dark grayish brown (10 YR 4/2) dry; weak fine granular; soft, very friable, nonsticky, nonplastic; many fine and medium roots; 30\% coarse fragments; pH 7.0; clear wavy boundary.} \\
B_2 & \quad 5-38 \text{ cm brownish yellow (10 YR 6/6); gravelly silt loam; yellow (10 YR 7/6) dry; weak fine subangular blocky; soft, very friable, nonsticky, nonplastic, common fine and medium roots; 60\% coarse fragments; pH 6.0; abrupt wavy boundary.} \\
R & \quad 38 \text{ cm+ fractured argillite bedrock}
\end{align*}

Habitat type:  Abla/Xete

Location:  North aspect, Sec 27, T32N, R22W, Flathead Co., ele. 1277 meters.
Felan Andic Cryochrept

Colors are for moist soil unless otherwise indicated.

<table>
<thead>
<tr>
<th>Horizon</th>
<th>Profile Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂</td>
<td>2-0 cm decomposed forest litter.</td>
</tr>
<tr>
<td>A₂</td>
<td>0-2 cm grayish brown (10 YR 5/2); gravelly loam; light brownish gray (10 YR 6/2) dry; weak fine subangular blocky; soft, very friable, nonsticky, nonplastic; many fine roots; 20% coarse fragments; pH 6.5; clear wavy boundary.</td>
</tr>
<tr>
<td>B₂</td>
<td>2-20 cm yellowish brown (10 YR 5/6); gravelly loam; brownish yellow (10 YR 6/6) dry; weak fine granular; soft, very friable, nonsticky, nonplastic, few fine roots and many medium roots; 20% coarse fragments; pH 6.5; clear wavy boundary.</td>
</tr>
<tr>
<td>IIA₂₁</td>
<td>20-40 cm pale brown (10 YR 6/3); gravelly heavy loam; very pale brown (10 YR 7/3) dry; weak fine subangular blocky; slightly hard, friable, slightly sticky, slightly plastic; no fine and few fine medium roots; 30% coarse fragments; pH 6.5; clear wavy boundary.</td>
</tr>
<tr>
<td>IIA₂₂</td>
<td>40-53 cm pale yellow (2.5 Y 7/4); gravelly clay loam; pale yellow (2.5 Y 8/4) dry; weak medium subangular blocky structure; hard, friable, slightly sticky, slightly plastic; no fine and few medium roots; 50% coarse fragments; pH 7.0; gradual wavy boundary.</td>
</tr>
<tr>
<td>IIB₁</td>
<td>53-97 cm olive yellow (2.5 Y 6/6); gravelly clay loam; yellow (2.5 Y 8/6) dry; weak medium subangular blocky; hard, friable, sticky, slightly plastic; 15% coarse fragments; pH 7.0.</td>
</tr>
</tbody>
</table>

Habitat type: Abla/Libo

Location: East aspect, SW1/4, Sec 28, T21N, R17W, Missoula Co., ele. 1246 meters.
Krause Andic Ustochrept

Colors are for moist soil unless otherwise indicated.

Horizon: Profile Description

O<sub>2</sub> 3-0 cm decomposed forest litter.

A<sub>2</sub> 0-5 cm dark grayish brown (10 YR 4/2); loam; light brownish gray (10 YR 6/2) dry; very fine granular; slightly hard, very friable; nonsticky, nonplastic; many fine and common roots, few coarse; 10% coarse fragments; pH 7.0; clear smooth boundary.

B<sub>2</sub> 5-30 cm dark yellowish brown (10 YR 4/4); very fine sandy loam; pale brown (10 YR 6/4) dry; weak very fine subangular blocky; soft, very friable, nonsticky, nonplastic, few fine and common roots; 10% coarse fragments; pH 6.0; gradual smooth boundary.

IIC 30-102+ cm yellowish brown (10 YR 5/4); gravelly loamy sand; light yellowish brown (10 YR 6/4) dry; massive; loose, nonsticky, nonplastic; 55% coarse fragments; pH 6.0.

Habitat type: Thpl/Clun

Location: East aspect, NW1/4, Sec 27, T16N, R26W, Missoula Co., ele. 912 meters.
BIBLIOGRAPHY


______. 1967 Supplement to 7th Approximation. USDA June memo. pp 1-52.


