



Amorphous character in twenty western Montana forest soils with apparent eolian influence  
by Robert Joseph Ottersberg

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE  
in Soils

Montana State University

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Abstract:

Volcanic ash is a significant component of eolian deposits of Recent age in Western Montana. A survey of soil scientists in this region indicated brown color, low bulk density and high silt content are used by many respondents to recognize volcanic ash influence. Twenty forest soils were sampled and characterized.

The soils represent Andept suborders, Andic and Andeptic subgroups and soils with apparent eolian influence indicated by their morphology. Strong amorphous character was associated with a combination of the following morphological properties: 1) high silt content, usually 60% or more; 2) high chroma, usually four or more for Andept suborders, and three or more for Andic and Andeptic subgroups; 3) weak consistence, usually soft, friable, nonsticky, nonplastic; 4) weak structural grade. Nutrient content, cation exchange capacity and water holding capacity appear to be much larger in andic soil with strong amorphous character than non-andic soil material when expressed on a weight basis. On a volume basis, analysis of andic layers was not very different from other soil material with similar textures.

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Date May 26, 1977

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FOREST SOILS WITH APPARENT EOLIAN INFLUENCE

by

ROBERT JOSEPH ÖTTERSBERG

A thesis submitted in partial fulfillment  
of the requirements for the degree

of

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Soils

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## ABSTRACT

Volcanic ash is a significant component of eolian deposits of Recent age in Western Montana. A survey of soil scientists in this region indicated brown color, low bulk density and high silt content are used by many respondents to recognize volcanic ash influence. Twenty forest soils were sampled and characterized. The soils represent Andept suborders, Andic and Andeptic subgroups and soils with apparent eolian influence indicated by their morphology. Strong amorphous character was associated with a combination of the following morphological properties: 1) high silt content, usually 60% or more; 2) high chroma, usually four or more for Andept suborders, and three or more for Andic and Andeptic subgroups; 3) weak consistence, usually soft, friable, nonsticky, nonplastic; 4) weak structural grade. Nutrient content, cation exchange capacity and water holding capacity appear to be much larger in andic soil with strong amorphous character than non-andic soil material when expressed on a weight basis. On a volume basis, analysis of andic layers was not very different from other soil material with similar textures.

## INTRODUCTION

Silt rich horizons cover many forest soils of Western Montana. Eolian deposits contributing to this layer include loess and volcanic ash. Volcanic ash influenced soils are considered important for plant growth by some whereas others say they are no more important than any other forest soil.

In a well drained site with a cool humid climate, volcanic ash can be expected to weather to form the amorphous clay mineral allophane. Distinctive properties of this clay mineral are used to determine its presence for classification purposes in Soil Taxonomy. Properties such as high water holding capacity, large pH dependent charge and the ability to complex organic matter may significantly affect fertility of soils containing amorphous clays.

The object of this study is to analyze Western Montana forest soils with apparent eolian deposits and probable amorphous character and to clarify the following questions:

- 1) Is amorphous character found in all forest soils with apparent eolian mantles? If so, is it strong enough for taxonomic recognition?
- 2) Can amorphous character be determined in the field by using morphological characteristics?
- 3) Does amorphous character relate to any physical or chemical properties of the soil?

## LITERATURE REVIEW

### Sources of Eolian Deposits in Western Montana

Two types of wind blown deposits were important in Western Montana in recent times; loess and volcanic ash. Loess is usually associated with glacial silt (11). Glacier-fed rivers like the Gallatin, Madison, and Bitterroot provided much of the silt deposited in areas they flowed through (4). Loess deposits were not limited to the valleys, but extended into nearby mountains such as the Sapphire Mountains east of the Bitterroot Valley (39). Silt rich surface mantles resulting from Bitterroot loess were found in soil series like Holloway and Trapper, both previously classified as Brown Podzolics. Mineralogy of the Holloway series from the Ninemile Canyon area north of Missoula showed that silt of the surface horizons was of a different origin than residual quartzite and argillite of lower horizons (44). Though early studies of Brown Podzolic soils in the Northern Rockies did not recognize the influence of loess, its presence is suggested by the large amounts of silt and very fine sand in upper horizons of some pedons (Table 1).

Other sources of loess are desert and aerosolic dust (16). Desert dust deposition was expected to have been high from 4,000 to 8,000 years ago during the altithermal or hypsithermal interval (15, 29). Volcanic ash deposited during this warm, dry period has been found sandwiched between layers of loess in Saskatchewan (9). Upper horizons of Palouse loess contain significant quantities of volcanic

Table 1. Three Brown Podzolic Soils with Apparent Eolian Deposition.\*

Pend Orielle loam Bonner County, ID		Waits gravelly loam Flathead County, MT		Unnamed Glacier County, MT	
depth (cm)	si+vfs (%)	depth (cm)	si+vfs (%)	depth (cm)	si+vfs (%)
0 - 0.6	76	0 - 0.6	66	0 - 1.3	63
0.6- 1.9	80	0.6- 3.1	64	1.3- 8	58
1.9- 10	75	3.1- 13	66	8 - 23	56
10 - 25	76	13 - 28	65	23 - 43	55
25 - 38	70	28 - 75	58	43 - 68	46
38 - 50	57	75 -110	28	68 - 88	26
50 - 78	54			88 -118	47
78 -128	39			118 -150	53

\*from Soil Survey Lab Memorandum #1 (38).

ash (30). During the altithermal, ash could have been deposited in the Rocky Mountains with desert dust, after initial deposition on the Palouse prairies.

Primary deposits of volcanic ash from at least three Cascade Range volcanoes are found in Western Montana (Fig. 1). Glacier Peak, Washington erupted near the end of the Wisconsin glacial period about 12,000 years ago (13). Mount Mazama (Crater Lake), Oregon ejected an

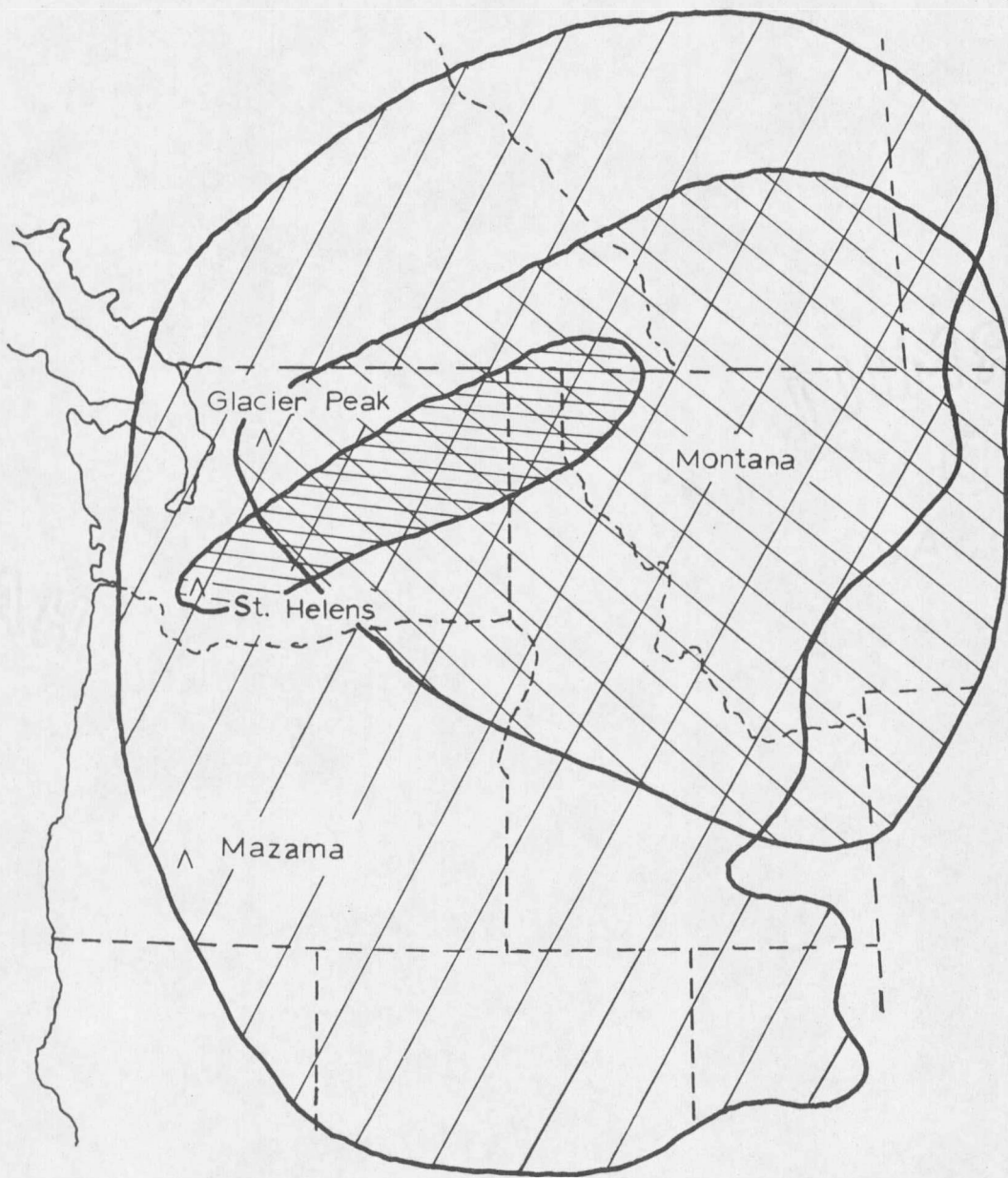


Figure 1. Recent volcanic ash which was deposited in Montana.\*

\*Adapted from Lemke et al '75, Okazaki et al '72, Smith et al '68

estimated 30 cubic kilometers of tephra over several states in the Pacific Northwest about 6,500 years ago (47, 28). Mount St. Helens, Washington deposited ash near the northwestern corner of Montana at least three times in the last 4,000 years. These ashfalls include the Mount St. Helens Y (3,400 years old), W (400 to 500 years old) and T (about 180 years old) eruptions (26, 35). Ashfall W is only anticipated in Montana now (36).

#### Volcanic Ash Recognition in Forest Soils of the Northern Rockies

In 1960, volcanic ash was reported in upper horizons of mountain soils of Northern Idaho (33). Since then volcanic ash has been recognized in many forested soils of Western Montana. Soil Conservation Service (SCS) studies in 1963 reported from 60 to 80% volcanic glass in the sands of surface horizons of the Holloway series from a site in Missoula County (Appendix 4). That much glass in surface horizons has been reported in only one other place in Western Montana forest soils. Northwest of Missoula in the Savenac Nursery, 60% glass was found in the surface horizon of one site (25). Most soils studied had only 5 to 10% glass, usually concentrated in upper horizons of soil (Appendix 4). Most Montana soils with significant glass content were once classified as Brown Podzolics. Soil series also containing significant glass included the Tarkio,

Greenough, Loberg and Phillipsburg series in Missoula County (Appendix 4). Volcanic ash contents are higher in the western portion of the Northern Rocky Mountains. In Northern Idaho, Brown Podzolics had ash contents as high as 72 to 80% (14). To the east of Missoula County, in Glacier County, only 1 to 3% volcanic ash was found in the upper horizons of any soil studied (Appendix 4).

#### Genesis of Ash-Rich Loess Mantles

Volcanic ash will readily weather to form the amorphous clay mineral allophane when the site is well drained (2). Montmorillonite clays form when drainage is poor as in closed basins (2, 8). In Nova Scotia, small amounts of allophane have formed in loess without the presence of volcanic ash (7). The disordered arrangement of loess particles and a cool humid environment associated with podzolization were thought to be the reason for allophane formation there (7). In New Zealand, loess rich in volcanic ash has resulted in the formation of allophane in a cool humid environment (31).

In Montana and parts of adjacent Idaho and Alberta, allophane has formed in the cool humid environment of conifer forests. As much as 60% allophane was found in ash influenced soil of the Coram Experimental Forest (19). Amorphous clays were predicted for mountainous areas north and west of Missoula County which had ash influenced soils (18). Eleven soil series in the St. Regis-Ninemile

area of Mineral County were thought to have allophane present (45). Three soils from Mineral and Missoula Counties analyzed at the SCS Lincoln lab were dominated by amorphous material (Appendix 4). Two of those three were used in this study; the Buckhouse and Wishard. Amorphous clays dominate a loess rich forest soil in Alberta which contained 50% volcanic glass (27). In well drained sites of the Idaho Batholith, amorphous clays dominated "loess" mantled soils (8).

#### Taxonomic Recognition of Volcanic Ash Influence

In Montana, volcanic ash influence is recognized at three levels of Soil Taxonomic classification; suborder, subgroup and family (43). At the suborder level, where volcanic ash is the dominant soil forming factor, classification is based on the dominance of volcanic glass or the amorphous clays which form as glass weathers (43). These soils are called Andepts. Classification of ash influence at the subgroup level is based on the presence of properties associated with amorphous clays. Soils with secondary but important ash influence have Andic or Andeptic name modifiers. At the family level of classification significant quantities of glass are recognized by the name "ashy." The weathering products are recognized by the names medial or thixotropic. Medial soils are dominated by amorphous clays and thixotropic soils have distinctive physical properties not restricted to weathering products of volcanic glass.

In Montana, three Andept soil series and 20 Andic or Andeptic soil series have been recognized by the SCS (Appendix 4). Many of these soils were previously classified as Brown Podzolics (Appendix 4). All but the Hebgen series appear to be related to loess rich in volcanic ash. The Hebgen series formed in alluvial deposits dominated by obsidian glass sand and gravels (18).

Volcanic ash influenced soils are thought to occur in several parts of Northwestern Montana. Andepts are predicted in Lincoln, Sanders, Mineral, and Ravalli Counties in the National Soils Atlas (38). Recognition of ash rich loess mantles on the Spotted Bear District was as Andic or Andeptic subgroups (24). Similar influence occurs on the Lower Blackfoot area of Missoula County (42). Allophane was recognized as probably being present in several soil series in the St. Regis-Ninemile area of Mineral County (45).

According to ash fall distributions (Fig. 1), a much larger area has the potential for volcanic ash influenced soils.

## MATERIALS AND METHODS

### Survey of Soil Scientists

Forest and soil researchers do not completely agree upon the origin, distribution, properties, and importance of volcanic ash in Western Montana soils. Therefore, in August, 1974, a telephone survey was initiated and questionnaires were distributed to supplement a review of literature on volcanic ash influenced soils in the region. Because a potentially large area of the Northern Rockies is affected, a primary objective was determining how soil scientists recognize volcanic ash influenced soil and what they understand about its nature.

Soil Conservation Service and Forest Service Soil scientists represent many years of experience with Western Montana and Northern Idaho soils where ash influence is recognized. These and other scientists were contacted by phone and later by letter for confirmation of the oral discussion. Responses to the seven topics covered in the survey are listed in Appendix 1 along with respondents' names. A summary is found on page 20.

### Sample Selection

Sampling sites include seven collected for SCS laboratory characterization, four sent to Murray Klages for characterization, and nine collected for this study with the help of soil scientists familiar with the area of collection (Table 2). Of these, five were Andepts

Table 2. Classification and Source of Soil Samples.

Site Name	Classification	Source
Buckhouse	Typic Cryandept	SCS S 64 Mt
Truefissure	Entic Cryandept	SCS S 64 Mt
Unnamed 3	Entic Cryandept*	M. Klages-L. Keunnen
Unnamed 4	Entic Cryandept*	M. Klages-L. Keunnen
Elkner	Andic Cryochrept	SCS S 74 Mt
Felan	Andic Cryochrept	SCS S 70 Mt
Holloway	Andic Cryochrept	SCS S 70 Mt
Krause	Andic Ustochrept	RJO Coram Study Area
Cabinet	Andeptic Cryoboralf	RJO Nimlos Study Area
Elkner v	Andic Cryochrept*	D. Ruppert-RJO
Elkner v-2	Andic Cryochrept*	D. Ruppert-RJO
Hilgard	Andic Cryochrept*	C. Davis
Holloway v	Andic Cryochrept*	R. Poff-RJO
Spring Emery	Andic Cryochrept*	D. Shay-RJO
Sugarloaf 1	Andic Cryochrept*	D. Shay-RJO
Sugarloaf 2	Andic Cryochrept*	D. Shay-RJO
Unnamed 1	Andic Cryochrept	M. Klages-H. Holdorf
Unnamed 2	Andeptic Cryorthent	M. Klages-H. Holdorf
Unnamed 5	Fluventic Eutrocrept	SCS S 74 Mt
Wishard	Aquic Cryoboroll	SCS S 64 Mt

\*Tentative classification

or Andic Cryochrepts based on laboratory determined criteria. Other samples had apparent volcanic ash influence indicated by morphological characteristics such as high silt content, distinct lower boundary, brown color, low bulk density, and distinctive feel (see Survey of Soil Scientists, P. 20, 58).

Though a wide range of soil forming factors are represented, most soils are from conifer forest sites (Table 3). The Buckhouse is from an alpine parkland. Residual parent materials below the eolian mantles varied from quartzite and argillite from the Belt Supergroup to granites, basalts and glacial lake sediments. Only Cabinet, Krause and Unnamed 5 were not from mountain slope positions but from fans or terraces. The aerial distribution represented two major climatic types. Northern locations felt a strong maritime influence with 75 to 200 cm (30 to 80 in) annual precipitation. The east and southern locations are more continental with precipitations from 50 to 100 cm (20 to 40 in) (46) (Fig. 2).

#### Preparation of Samples

Samples collected by the SCS for characterization were prepared according to standard procedures (36). Morphological characteristics of all other samples were recorded in the field (Appendix 2). All samples were air dried at 100° F, then crushed, ground and passed through square 2 mm sieve holes.

Table 3. Site Characterization.

Site Name	Parent Material*	Slope (%)	Aspect	Elevation (m)	Vegetation**
Buckhouse	quartzite, argillite	50	S	2134	Abla/(parkland)
Cabinet	glacial lacustrine, mixed	3	W	720	Juoc, Abgr/
Elkner	granite	5	N	1585	Abla/
Elkner v-1	granite	20	NE	-	Abla/vasc
Elkner v-2	granite	27	N	-	Abla/Alsi
Felan	calcareous argillite	47	E	1749	Pien/vagl
Hilgard	granite	15	E	-	(Alpine turf)
Holloway	quartzite, argillite	18	NE	1371	Laoc, Psme/
Holloway v	quartzite	35	NE	2362	Abla/Xete
Krause	quartzite, argillite	30	N	1097	Thoc, Abla, Pien/
Spring Emery	andesite	40	NE	2073	Abla/Mefe
Sugarloaf 1	basalt	25	NE	2097	Abla/Alsi-vasc
Sugarloaf 2	basalt	20	NE	2100	Abla, Psme/Aruv
Truefissure	argillite	30	SW	1508	Abla, Pien/
Unnamed 1	limestone, shale	-	NW	1798	Pico/
Unnamed 2	shale, siltstone	40	N	1737	Abla, Pien/
Unnamed 3	argillite, igneous	-	-	1341	Juoc/Clun
Unnamed 4	argillite	-	-	1280	Abgr/Clun
Unnamed 5	lacustrine, mixed	1	N	963	--
Wishard	argillite	40	N	1524	Juoc, Pien/

\*underlying parent material

\*\*dominant overstory/dominant understory; see Appendix 5.



Figure 2. Distribution of sampling sites.

Table 4. Sample Location Code for Figure 2.

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Number	Name
1	Buckhouse
2	Unnamed 3
3	Unnamed 4
4	Truefissure
5	Wishard
6	Felan
7	Holloway
8	Spring Emery
9	Sugarloaf 1
10	Elkner v-2
11	Cabinet
12	Krause
13	Elkner v-1
14	Unnamed 5
15	Sugarloaf 2
16	Hilgard
17	Holloway v
18	Elkner
19	Unnamed 2
20	Unnamed 1

---

## Chemical and Physical Analysis

Characterization was completed in four separate laboratories by several different people. Procedural variation is explained below and recorded in the data tables (Appendix 3).

Mechanical analysis was done with 20 gram samples and Anderson's 1963 method of organic matter removal and dispersion (1). The pipette method was used to determine fine earth fractions (10, 41). Samples done in SCS labs used hydrogen peroxide for organic matter removal and sodium hexametaphosphate for dispersion (41). Samples from nine soil sites chosen for X-ray diffraction analysis were collected from soil cylinders used in mechanical analysis. This was done by taking a 50 to 75 ml sample from the top 15 cm of the suspension in the cylinder when only clay remained in that portion. One half of this sample was saturated with salts of magnesium (Mg) and one half with those of potassium (K). To saturate the clays, three washings of 1N magnesium chloride ( $MgCl_2$ ) and 1N potassium chloride (KCl) were followed by centrifugation and decantation. Excess salts were removed with a water wash for Mg-saturated clays and a 60% methanol solution for K-saturated clays. Clays were mounted on glass slides after making a thick clay suspension in water and dripping this in a relatively uniform thickness over the slide. Air dry Mg-saturated clays were solvated with ethylene glycol by heating for

four hours in the presence of ethylene glycol. Potassium-saturated samples were first heated to 350 degrees Celsius. X-ray diffraction patterns were obtained and the slides were then heated to 500 degrees Celsius. Diffraction patterns were obtained between 2 and 30 degrees  $2\theta$  for Mg-saturated samples and between 2 and 15 degrees  $2\theta$  for both K-saturated clay treatments. Interpretation of X-ray diffraction patterns used Jackson's (17) guide to the basal spacings of dominant clay minerals of soils. Areas under diffraction curves were estimated so a rating of relative abundance could be given to each major clay mineral. The procedure of the SCS Riverside laboratory for sample preparation was the same, but ceramic tiles were used instead of glass slides for mounting samples.

Determination of 15 atmosphere water holding capacity was done with a pressure membrane apparatus. A pressure cooker and porous plate were used to determine 1/3 atmosphere water holding capacity. Both determinations used soil samples which had passed an 18 mesh screen. Analyses done in SCS labs were similar.

Two dilutions of soil samples with water were used in measuring pH; a 1:1 soil to water ratio for SCS samples and a 1:2 soil to water ratio for all others.

Organic carbon was determined in the SCS laboratories with the Acid Dichromate digestion method (41). Other samples, analyzed in the Montana State University Soil Testing Laboratory, used

a modified version of the same procedure using a colorimetric instead of titration methods to measure organic carbon (34).

Total nitrogen determination used the Kjeldahl digestion method for SCS samples and the Micro Kjeldahl method modified from Bremner (6) for other samples.

Available phosphorus was done with the Bray #1 method modified by Smith (37).

Exchangeable bases were estimated with an ammonium acetate extraction. Soluble salt content was corrected for on SCS samples but not on any others. Electrical conductivity of a 1:2 soil to water ratio was determined to indicate possible need to correct for salts. Flame photometry or atomic absorption spectrophotometry were used to measure  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$ ,  $\text{Na}^+$ , and  $\text{K}^+$ .

The minor elements copper, iron, manganese and zinc were determined by the DTPA-TEA extraction of Lindsay and Norvel (21) as modified by the MSU Soil Testing Lab. The Perkin-Elmer 290-B atomic absorption spectrophotometer, with lamps for Fe, Mn, Ca, and Zn, was used for measurement.

Cation exchange capacity determined by SCS Labs was done with the ammonium acetate (pH 7.0) method (41). All other cation exchange capacity measurements were done with the sodium acetate (pH 8.2) method of Bower (5).

Bulk Density was done with Saran coated peds at 1/3 atmosphere tension for SCS samples. Other samples were air dried, coated with liquid Saran, and weighed in and out of water. The >2 mm fraction was separated after weighing to make measurements based on fine earth.

Phosphorus sorption "isotherms" were done according to procedures of Fox and Kamprath (12). Fifteen samples representing eolian and buried horizons with a variety of colors and textures were chosen for this analysis. Phosphorus as  $\text{CaH}_2\text{PO}_4$  with the following concentrations: 0.9, 9.0, 32.0, 100.0, and 320.0 ppm was added to each of the 15 samples. Values for P sorbed by 8 representative samples are plotted against equilibrium concentrations on log-log graph paper (Fig. 5, page 42). Fox and Kamprath plotted theirs on semi-log with P-sorbed on the linear scale (12).

These "isotherms" indicated that 32.0 ppm P gave a wide range of P sorption values. A 1:10 soil to solution ratio was made with each sample and 32 ppm P in a .01 M  $\text{CaCl}$  solution to determine a phosphorus sorption index similar to that of Bache and Williams (3). The ratio of P sorbed to P added over an equilibration period of one week is converted to a percentage. This value will be called the phosphorus sorption index.

### Analysis of Data

An index of consistence was created for rating morphological data. Adhesive and cohesive forces give the soil a characteristic feel varying with moisture content of the soil. Four determinations are made representing wet (w), moist (m), and dry (d) conditions. The minimum consistence is defined here as a soil that is loose when moist and dry and is non-sticky and non-plastic when wet. This is the lowest value for the consistence index or 1. The highest consistence index of 20 represents the maximum consistence when a soil is extremely firm (m), extremely hard (d), very sticky (w) and very plastic (w). For every change in any of the four characteristics of consistence or level of consistence within that characteristic, the consistence index will change by 1 unit.

Structural grade was quantified as follows: 1 - very weak, 2 - weak, 3 - weak to moderate, 4 - moderate, 5 - moderate to strong, 6 - strong, and 7 - very strong.

Interpretation of X-ray diffraction patterns includes an estimate of the relative abundance of crystalline clay minerals. This estimate was based on areas under the primary X-ray diffraction peaks and is useful only for comparisons within this thesis. Relative abundance of amorphous clays was based on indices of amorphous character (Table 10) and lack of peaks in the diffraction pattern.

## RESULTS AND DISCUSSION

### Survey of Soil Scientists

This survey suggests that many soils in Western Montana have surface horizons that have properties commonly associated with volcanic ash influence. Not all the respondents feel this layer is a result of volcanic ash alone. The many names given to this layer reflect the questionable origin including: "loess cap," "brown surface," "Bir," and "ashy mantle." It will be called the "andic" layer in this thesis because this term refers to properties associated with Andosols or volcanic ash soils, and does not attribute these properties to volcanic ash alone.

Andic layers are recognized in the field by their color, texture, and bulk density. Sixteen of the 22 respondents used brown to reddish brown color as an indicator of ash influence. Of these 16, three said brown color alone was not a good indicator of volcanic ash influence. One said brown color was not necessarily from volcanic ash. Three respondents said white to gray colors were associated with volcanic ash. Two felt that darker values and chromas as low as 3/1 or 3/2 were possible for andic layers. Even though brown color may come from several pedogenic processes, it was the color most often associated with volcanic ash influence.

Fourteen respondents say texture is used in andic layer recognition. Ten of these said the layer has a silt loam texture indicating high silt content. Three said loam was the texture of ash influenced

soil. One mentioned fine sandy loam and another silty clay loam. Two referred to loess-like character.

All nine who used bulk density to recognize ash influence say it is low. Values of 0.8 to 1.1 grams/cubic centimeter were given.

Other properties used to recognize ash influence were related to the way the andic layer felt to the touch. Respondents said the andic layer had a smeary, soapy feel in the western zone of the survey. Soils in the western areas of influence may be thixotropic. One respondent from the Glacier Park area said the layer had a sharp feel. Unweathered buried ash has been found near Glacier Park (20). Fluffy and floury when dry, nonsticky and nonplastic when wet were terms associated with andic layers.

An abrupt lower textural boundary below the andic layer and hollow sound were two other characteristics mentioned.

Thickness of the andic layer varied with geographic location. A 55 to 60 cm maximum thickness is found in Northern Idaho and adjacent parts of Mineral, Sanders, and Lincoln Counties in Montana. The depth averages 30 to 45 cm in the mountains to the east of the Northern Idaho-Montana border and may average <50 cm to the south of Sandpoint, Idaho. The majority of the mountains from Glacier National Park south to near Dillon have a layer that is 10 to 20 cm thick (Fig. 8, page 50).

Physiographic position appears related to depth and distribution in areas where the layer is relatively thin. Ten respondents associated the layer with north or northeast aspects while one said it could be found on south aspects. Seven said high elevations are associated with the andic layer; one disagreed. Two felt that greater thickness of the andic layers at higher elevations followed a direct relationship with precipitation which also increased at higher elevations.

Forest vegetation is found with andic soils by 11 respondents. Four said it could be found under grassy vegetation without trees. One said it was more mixed under grass. The andic layers found under grass were generally in the western end of the survey distribution or at high elevations. Three said they saw only broad or no relationship with vegetation. One respondent suggests that the andic layer is found where snow is deep enough in the winter to prevent the soil from freezing in most years.

Nine respondents saw no relationship between the andic surface and parent material found below. Three said limestone affected thickness of the andic layer and raised in elevation the lower limit of its distribution. Permeability of the buried material was related by four to thickness of the andic layer. Coarse permeable substrata

had thicker andic layers than less permeable material such as compacted till.

The fertility value of the andic layer was questioned. Six said the andic layer added to the fertility. Six others said the layer had properties associated with good fertility, but did not mention high fertility directly. These properties included: High cation exchange capacity, high water holding capacity, high nitrogen and phosphorus, and high organic matter. Three said the andic layer is no more fertile than other soils and may even have a low fertility value. One reason mentioned was that at low pH values, the base saturation is very low in andic layers. Available water was thought to be low too.

Other properties included: Weak aggregation, high erosion hazard and susceptibility to severe fire damage. One thought low bulk density made the andic layer susceptible to compaction.

#### Taxonomic Grouping of Amorphous Character

Soils in this study were ranked (Table 6) according to criteria in Table 5. Three groups were then formed representing dominant, important and insignificant amorphous character (Table 6). Group 1 included Andept suborders; Group 2 included Andic and Andeptic subgroups; and Group 3 were soils lacking characteristics of amorphous clays used in Soil Taxonomy.

Table 5. Criteria for Ranking and Grouping Strength of Amorphous Character.

Index	Group 1	Group 2
Bulk density of the fine earth (g/cc)	< 0.85	< 0.95
Exchange capacity of the clay at pH 8.2 (me/100g)	>150	not used
15-bar water retention: measured clay	> 1.0	> 0.8
Organic Carbon (%)	> 0.6	not used
Cation exchange capacity: 15-bar water retention	not used	> 1.5
Phosphorus sorption index* (%)	> 85	>75

\*An arbitrary rating and the only index not used in Soil Taxonomy.

Table 6. Order of Amorphous Character and Taxonomic Recognition.

Soil Name	Group #	Rank	Taxonomic Recognition
Buckhouse	1	1	Andepts
Unnamed 3		2	
Unnamed 4		3	
Truefissure		4	
Wishard	2	5	Andic and Andepts
Felan		6	
Holloway		7	
Spring Emery		8	
Sugarloaf 1		9	
Elkner v-2		10	
Cabinet		11	
Krause		12	
Elkner v-1		13	
Unnamed 5		14	
Sugarloaf 2	3	15	Non-Andic
Hilgard		16	
Holloway v		17	
Elkner		18	
Unnamed 2		19	
Unnamed 1		20	

Three soils in Group 1 qualified for Andept classification only if data were averaged for the required 35 cm layer. Individual horizons in Unnamed 3 and 4 and Truefissure did not meet criteria indicating dominance by amorphous clays (Table 7). The 15-bar water:% clay ratios of all three and most criteria in the Truefissure B23ir horizon were not met. The 78 cm andic layer of Buckhouse easily qualified as an Andept.

Table 7. Physical and Chemical Indices of Amorphous Character, Group 1.

Soil Name	Horizon	Depth (cm)	Bulk Density (g/cc)	CEC (me./100gclay)	15 Bar Water/% clay	Organic Carbon (%)	P Sorption (%)
Buckhouse	A11	0- 10	--	292	1.0	9.6	95
	A12	10- 23	0.78	298	1.2	6.4	98
	A13	23- 40	0.79	235	1.1	5.4	95
	A14	40- 58	0.70	249	1.2	4.7	95
	B21ir	58- 78	0.70	221	1.0	2.3	94
	B22ir	78- 95	0.90	178	0.8	0.7	50
	C1	95-125	1.60	149	0.7	0.3	50
Unnamed 3	B21	0- 20	--	101	0.8	1.3	98
	B22	20- 55	--	410	3.0	1.4	98
	IIA2	55- 73	--	37	0.4	1.0	38
Unnamed 4	B21	0- 23	--	104	0.8	1.9	98
	B22	23- 55	--	197	2.1	1.8	98
Truefissure	B21ir	0- 13	0.68	349	1.9	2.8	98
	B22ir	13- 25	0.75	404	2.3	1.9	100
	B23ir	25- 40	1.29	112	0.6	0.3	52
	IIB31ir	40- 60	1.38	178	0.7	0.2	41

Amorphous character in most soils of Group 2 was strong enough for Andept classification. Only Wishard comes close to meeting the

35 cm thickness required of the Andic layer of Andepts (Table 8). Because of an aquic moisture regime Wishard could not be an Andept. If this soil lacked a cryic temperature regime it would probably be an Andaquept (42). Most other soils in Group 2 would be Andic Cryochrepts. The Cabinet series would be an Andeptic Cryoboralf.

The main difference between the amorphous character of Group 1 and 2 was the larger bulk densities in the Andic layer of Group 2 (Table 8). This is most likely an effect of contamination by material from buried horizons associated with thinner eolian deposits in Group 2. Mixing of eolian and non-eolian materials increases as thickness of the eolian deposit decreases (32).

Eolian mantles of Group 3 soils had amorphous character that was too weak for recognition. At least one andic criteria for each soil was not met (Table 9). In most cases bulk density was too high. The Elkner series has a CEC of only 105 me/100g clay and a low P-sorption index of 56, neither index being characteristic of significant amorphous character.

Table 8. Physical and Chemical Indices of Amorphous Character, Group 2.

Soil Name	Horizon	Bulk Density (g/cc)	15 BW/ % clay	CEC/ 15 BW	P-Sorption Index (%)	CEC of clay (me/100g)	Organic Carbon (%)
Wishard	A11	0.60	1.2	2.1	84	249	13.7
	A12	0.86	0.9	2.5	97	222	7.0
	A13	0.80	0.8	2.7	94	209	3.2
	B21ir	1.25	0.6	2.9	63	177	1.0
Felan	B2	0.71	3.6	2.0	98	726	3.0
	IIA2b	0.88	0.6	2.3	53	150	0.8
Holloway	B2	0.87	1.0	1.8	88	180	2.4
	IIA21	--	0.5	1.6	25	82	0.4
Spring Emery	B21	0.90	1.9	1.7	98	329	6.0
	B22	0.90	1.5	1.8	98	266	2.8
	IIA2	--	0.9	2.3	45	212	0.4
Sugarloaf 1	B21	0.93	1.2	1.4	98	167	1.9
	IIB22	--	0.9	1.9	56	172	0.7
Elkner v-2	B2ir	0.97	1.6	1.5	100	240	5.8
	IIB3	--	0.3	2.8	33	86	0.1
Cabinet	B2ir	--	1.5	1.7	100	274	2.2
	IIA2	--	0.5	1.3	47	66	1.3
Krause	B2	0.87	0.7	2.8	97	194	2.5
	IIA+B	--	0.4	2.0	36	77	0.8
Elkner v-1	B2ir	0.91	0.8	1.5	97	126	1.9
	IIB3	--	0.5	1.5	45	72	0.1
Unnamed 5	A1	--	1.9	1.5	56	290	7.0
	B21	--	1.1	1.3	69	152	1.9
	B3	--	1.1	1.3	53	140	1.3

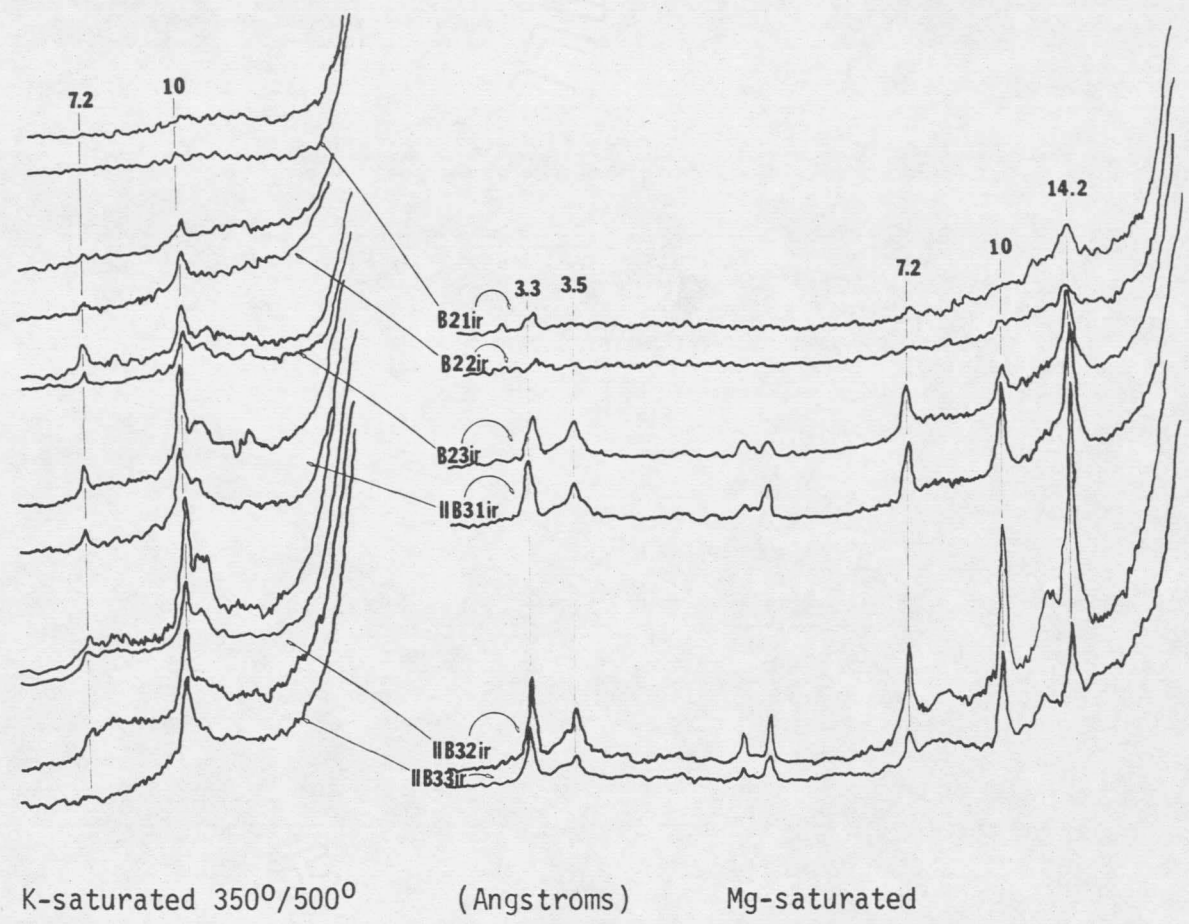
Table 9. Physical and Chemical Indices of Amorphous Character, Group 3.

Soil Name	Horizon	Bulk Density (g/cc)	15 BW/ % clay	CEC/ 15 BW	P-Sorption Index (%)	CEC of clay (me/100g)	Organic Carbon (%)
Sugarloaf 2	B2	1.14	0.9	1.9	75	168	1.4
	B3	--	0.6	2.1	53	113	0.5
Hilgard	B2ir	--	0.5	1.6	97	88	3.7
Holloway var	B2ir	1.25	0.7	1.4	97	95	2.6
	IIB3	--	0.4	2.1	52	84	0.3
Elkner	B2	--	---	---	56	109	5.8
	B3	--	---	---	30	102	0.9
Unnamed 2	B21	--	0.5	0.8	69	45	1.6
	IIB22	--	0.4	1.5	--	59	1.0
Unnamed 1	B2	--	0.4	1.8	67	65	2.0
	IIC	--	0.3	2.2	--	56	0.7

#### Amorphous Character Indicated by Clay Mineralogy

In general the nine soils with X-ray diffraction patterns indicated very small quantities of crystalline clays in horizons with strong amorphous character (Appendix 3). Both non-andic eolian mantles and buried horizons had more crystalline clays (Table 10). Weakened amorphous character in the B23ir of Truefissure was partially explained by the presence of more crystalline clays than any overlaying eolian horizon with strong amorphous character (Fig. 3). The largest variety of clay types in andic layers was seen in the Cabinet series

Figure 3. X-ray diffraction patterns of Truefissure.



(Table 10). Chlorite, vermiculite, interstratified clays, illite, partially hydrated halloysite and/or kaolinite were all present. Much larger quantities of all those clays were found in the buried argillic horizons below Cabinet's andic layer. Most other andic layers with strong amorphous character had only vermiculite if crystalline clays were present.

Soil Conservation Service data indicated that the andic layer of the Holloway series was dominated by amorphous clays (Table 10). Felan was shown to have a large amount of amorphous clay, but in the IIA22 horizon (Table 10).

Group 3 soils had larger quantities and greater variety of crystalline clays in eolian mantles than did soils with strong amorphous character (Table 10).

Table 10. Interpretations of X-ray Diffraction Patterns of Crystalline Clays of Eleven Study Sites.

Soil	Horizon	Clay Mineral* Abundance†
Buckhouse	A11	Vr or Cl(1), Il(1), Am(5)
	A12	Vr(1), Il(1), Am(5)
	A13	Vr(1), Il(1), Am(5)
	A14	--
	B21ir	Vr(2), Il(1), Ka(1), Am(5)
	B22ir	Vr(2), Il(2-3), Am(4)
	C1	Vr(2 to 3), In(2), Il(3), Cl(1)
	C2	Vr(2), In(1), Il(2 to 3), Ka(1)































































































































































































