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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by

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

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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

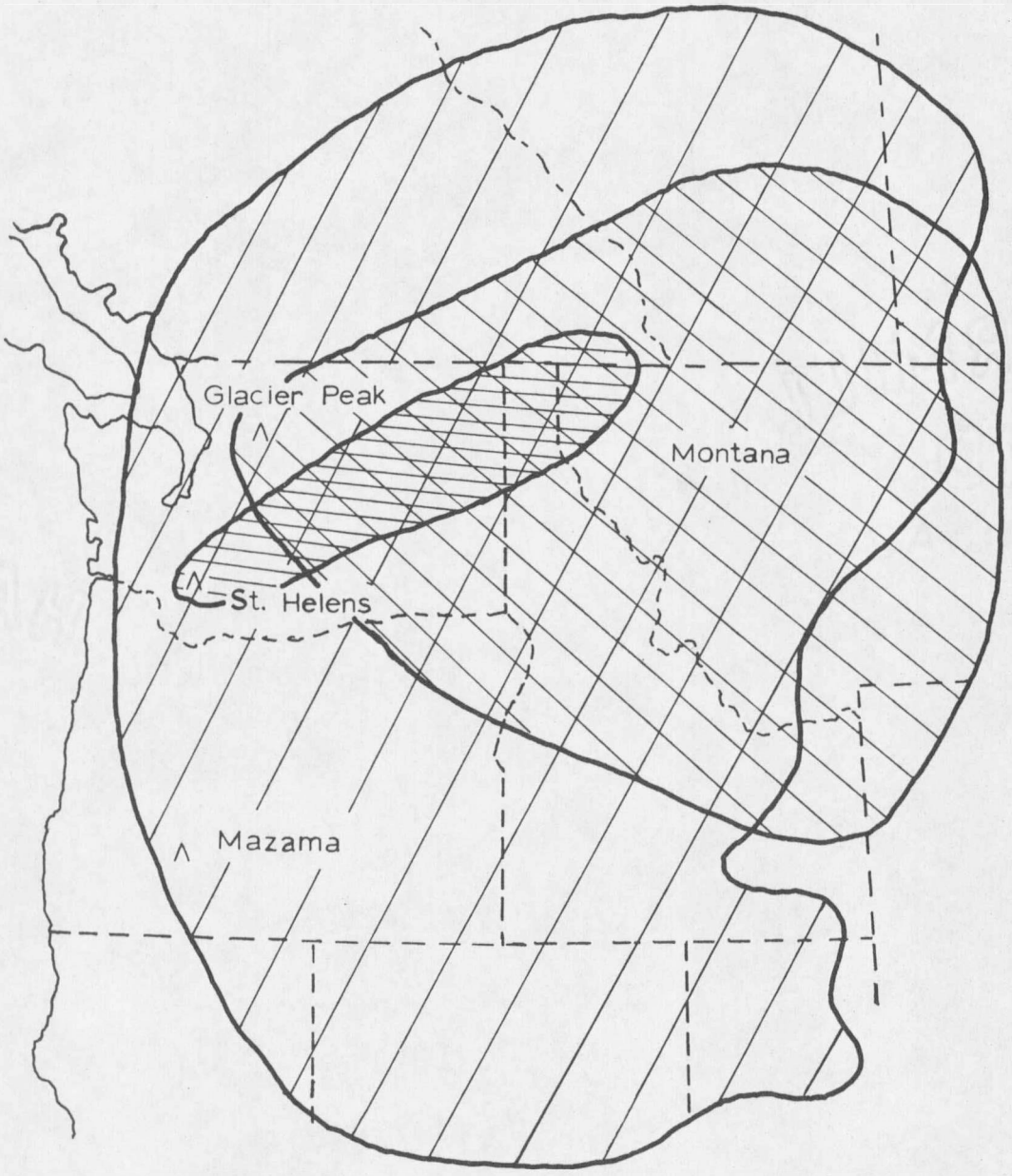


Figure 1. Recent volcanic ash which was deposited in Montana.*

*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.

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 2θ for Mg-saturated samples and between 2 and 15 degrees 2θ 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 Ca++, Mg++, Na+, and 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 amonium 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 CaH_2PO_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 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 Andeptics
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

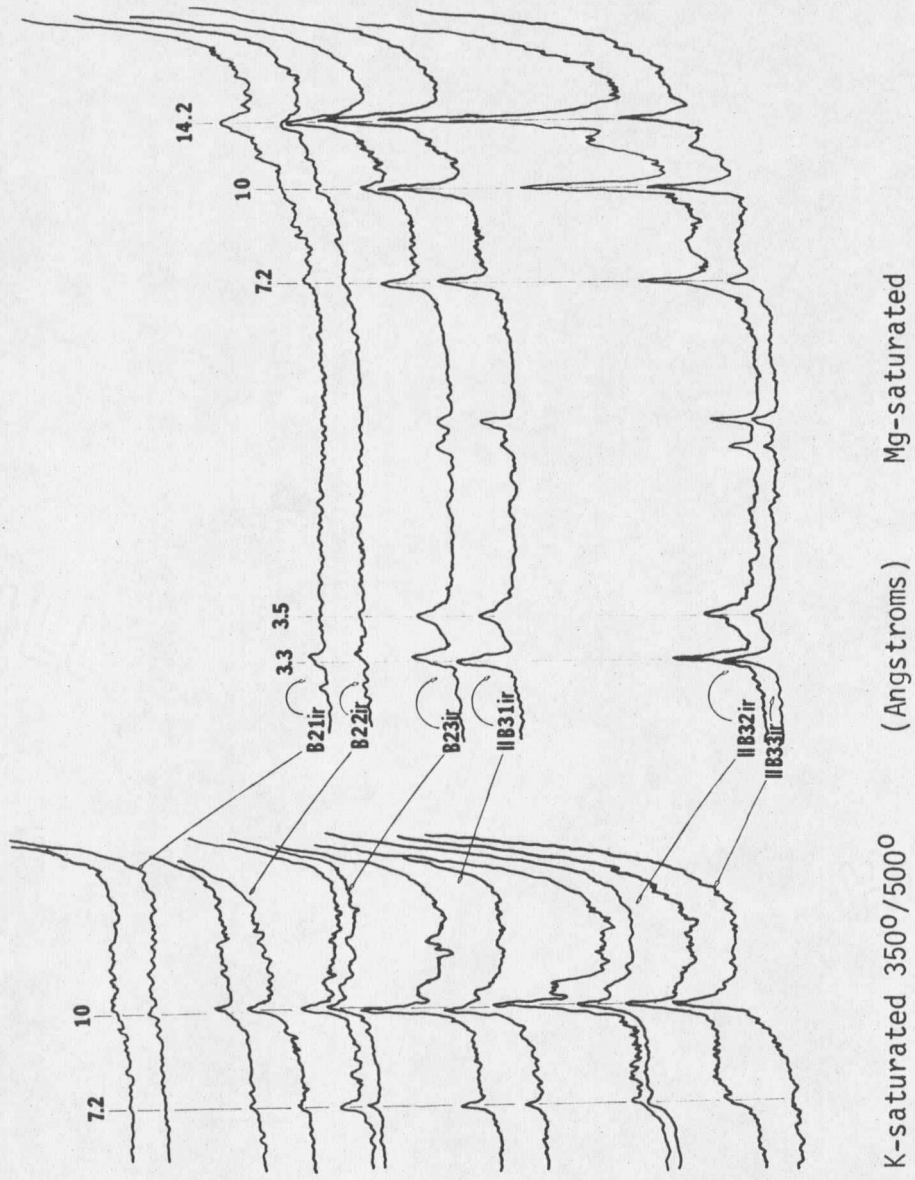


Figure 3. X-ray diffraction patterns of Truefissure.

(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)

Table 10 Continued

Soil	Horizon	Clay Mineral* Abundance†
Truefissure	B21ir	Vr(2), Am(5)
	B22ir	Vr(2), Am(5)
	B23ir	Cl(1), Vr(1), In(2), Il(2), Ka(1), Am(2-3)
	IIB31ir	Vr(2 to 3), In(2), Il(2 to 3)
	IIB32ir	Cl(1), Vr(3), In(2 to 3), Il(3), Ka(2)
	IIB33ir	Vr(2), In(2), Il(2) Hl or Ka(1)
Cabinet	B2	Cl(1 to 2), Vr(1 to 2), In(2), Il(2), Ka or Hl(1 to 2), Am(5)
	IIA2	Cl(2), Vr(3), In(2 to 3), Il(3 to 4), Ka(2)
	IIB2t	Cl(2 to 3), Vr(4), In(3), Il(4), Ka(1)
Krause	B21	Vr(1), In(2), Il(1), Am(4-5)
	IIA+B	Cl(2), Vr(2), In(2), Ka(2)
Sugarloaf 1	B2	Vr(1), Am(5)
	IIB3	Cl(3), Vr(2), In(2), Il(2) Ka(6)
Spring Emery	B22ir	Vr(1), Am(5)
	IIA2	Vr(1 to 2), In(1), Hl(1), Il(2), Ka(1), Am(2)
Hilgard	B2	Vr(2 to 3), In(2 to 3), Ka(6), Am(1)
Sugarloaf 2	B21	Cl(2), Vr(2), In(2), Il(1), Am(1 to 2)
	B3	Cl(2 to 3), Vr(2), In(2), Il(1)
Elkner	A1	Vr(2), In(1 to 2), Il(1), Ka(1), Am(4)
	B2	Vr(2 to 3), In(2), Il(2), Hl(2), Ka(2), Am(1)
	B31	Vr(2), In(2 to 3), Il(2 to 3), Ka or Hl (2 to 3), Am(1)
	B32	Mt(1), Vr(1), Il(2 to 3), Hl(1),
	C1	Mt(3), Il(2 to 3)
Holloway#	B2	Am(6), Cl(1), Mi(1)
	IIA21	--
	IIA22	--
	IIC1	Cl(4) Mi(4)

Table 10 Continued

Soil	Horizon	Clay Mineral* Abundance†
Felan#	A2	Mi(4) Cl(2)
	B2	Vr(3), Mi(3), Ka(2), Mt(1)
	IIA21	--
	IIA22	Am(6)

*Mi = mica, Cl = chlorite, Vr = vermiculite, Ka = Kaolinite, Mt = montmorillonite, Am = amorphous, Hl = halloysite, In = Interstratified, Il = Illite.

#SCS Lab determination

†1 = trace, 2 = small, 3 = moderate, 4 = abundant, 5 = dominant, 6 = indetermined

Morphological Indices of Amorphous Clays

Strong amorphous character was associated with the following morphological characteristics:

1) high silt content, usually 60% or more but as low as 40%;

2) bright chroma, usually four or more for Andept suborder and three or more for Andic and Andeptic subgroups;

3) weak consistence, usually soft, friable, non-sticky, non-plastic;

4) weak aggregation, indicated by weak structural grade.

Forest soils in Western Montana with these four morphological characteristics are probably dominated by amorphous clay. Accuracy of these indices decreases as thickness of the andic layer decreases.

Soils with thin andic layers may need lab data to determine medial designation. In Montana, few soils had enough glass to make classification based on glass content likely. Lab data is still necessary to determine if enough glass is present for Andept suborder or ashy family designations.

Exceptions to the morphological indices of strong amorphous character were found in the Buckhouse and Wishard series. These soils had few of the morphological characteristics common to other andic soils with strong amorphous character. A difference in soil forming factors may explain these exceptions. Grass-like vegetation of Buckhouse and Wishard may result in stronger structure due to root penetration and the stabilizing effect of humus. Both of these soils have higher Ca++ contents than any other andic layer so flocculation should be greater.

Individual morphological characteristics were not useful for indicating strength of amorphous character. Bright chromas were found in the Holloway variant of Group 3, which had weak amorphous character (Table 13, page 37). Silt content in the andic layers of Hilgard and Unnamed 1 was 58% and 56% respectively (Table 13). Both were moderately high silt contents but these soils had weak amorphous character. The andic layer of Cabinet had only 38% silt but strong amorphous character. High sand contents were not from contamination

by the lacustrine silts from below but were iron and manganese nodules which formed in place (Nimlos, Unpublished Data).

The effects of contamination of the andic layer with non-eolian material could be seen in some morphological indices of amorphous character listed in Tables 11, 12 and 13. General contamination of the whole andic layer was more evident in the thinner eolian deposits of Group 2 and 3. Tree throw may be an important factor in mixing surface horizons of forest soils (22). Sugarloaf 2 was from a similar site as Sugarloaf 1 but nearer the ridge crest where chances of erosion and tree throw may have been greater. Sugarloaf 1 had more silt and brighter chromas than Sugarloaf 2 and also stronger amorphous character (Tables 12 and 13). Elkner v1 and v2 were also found very close together in the landscape but micro relief at the Elkner v2 site created a wetter site with a thicker vegetative cover. Erosion was probably not as great where vegetation was thicker. Elkner v2 had larger silt content showing less contamination and resulted in stronger amorphous character (Table 12).

The morphological characteristics associated with amorphous character are not necessarily caused by amorphous clays or volcanic ash. Other pedogenic processes can cause these same features. Fungal hyphae in New England Brown Podzolics created soils with little structure, a friable consistence and a low bulk density (23).

Bright chromas are found in soils where the podzolization process is occurring and are many times confused with andic layers (43). It is probably more important to a soil mapper to be able to recognize dominance of amorphous clays using morphological indices than to know the pedogenetic origin of those indices.

Table 11. Morphological Data Associated with Amorphous Character, Group 1.

Soil Name	Rank	Horizon	Thickness (cm)	Consistence Index	Structural Grade	Silt (%)	Chroma Moist	Chroma Dry
Buckhouse	1	A11	10	4	6	49	2	2
		A12	13	4	6	48	2	2
		A13	18	4	6	51	2	2
		A14	18	4	6	52	2	2
		B21ir	20	4	2	54	4	4
		B22ir	18	4	2	50	4	4
		C1	30	3	-	59	3	3
Unnamed 3	2	B21	20	3	2	62	4	5
		B22	35	3	2	75	6	5
Unnamed 4	3	B21	23	3	3	69	4	6
		B22	33	3	3	77	4	6
Truefissure	4	B21ir	13	3	2	70	4	4
		B22ir	13	3	2	67	4	4
		B23ir	15	5	2	55	4	4
		IIB31ir	20	4	2	47	6	6

Table 12. Morphological Data Associated with Amorphous Character, Group 2.

Soil Name	Rank	Horizon	Thick-ness (cm)	Consis-tence Index	Struc-tural Grade	Silt (%)	Chroma Moist	Chroma Dry
Wishard	5	A11	5	3	2	66	2	-
		A12	13	5	6	64	2	4
		A13	13	5	4	67	4	3
		B2ir	20	7	4	65	4	-
Felan	6	B2	13	3	-	64	6	5
		IIA21b	18	7	-	58	3	2
Holloway	7	B2	20	3	1	63	3	4
		IIA21	55	8	-	39	3	2
Spring Emery	8	B21	10	3	-	55	3	4
		B22	13	5	2	51	4	3
		IIA2	15	3	-	23	3	3
Sugarloaf 1	9	B21	18	5	2	54	3	3
		IIB22	20	9	-	25	3	2
Elkner v-2	10	B2ir	18	4	1	62	3	4
		IIB3	25	9	-	36	3	2
Cabinet	11	B2ir	25	2	2	38	5	4
		IIA2	13	8	6	53	3	2
Krause	12	B2	23	4	2	29	4	4
		IIA&B	35	6	2	35	4	4
Elkner v-1	13	B2ir	18	3	2	32	4	4
		IIB3	10	3	-	13	3	3
Unnamed 5	14	A1	5	-	4	61	4	2
		B21	8	-	2	65	4	3
		B31	10	-	2	69	3	3

Table 13. Morphological Data Associated with Amorphous Character, Group 3.

Soil Name	Rank	Horizon	Thick-ness (cm)	Consis-tence Index	Struc-tural Grade	Silt (%)	Chroma Moist	Chroma Dry
Sugarloaf 2	15	B2	20	5	2	30	2	2
		B3	15	9	-	54	2	2
Hilgard	16	B2ir	20	7	-	58	3	3
Holloway v	17	B2ir	20	5	2	33	5	5
		IIB31	28	3	-	23	4	2
Elkner	18	B2	13	4	5	23	3	2
		B31	15	3	-	12	3	2
Unnamed 2	19	B2	15	5	2	48	2	2
		IIC1	58	5	2	39	2	3
Unnamed 1	20	B21	15	7	4	56	3	3
		IIB22	58	7	4	39	4	3

Amorphous Character and Chemical Properties

Mean chemical data was tabulated by taxonomic group for andic horizons and subjacent horizons within 25 cm (Table 14). Chemical data was recorded by horizon in Appendix 3, Table 19.

Andic layers from Group 1 and 2 had on the average larger cation exchange capacities (CEC), more available phosphorus, total nitrogen, exchangeable potassium, and extractable copper than andic layers of Group 3 (Table 14). Group 1 and 2 soils with strong amorphous character also have lower bulk densities than non-andic

Table 14. Mean Chemical Properties of Andic (a) and Subjacent (b) horizons within 25 cm.

Degree of Amorphous Character		Extractable Minor Elements				Extractable Cations				Available	Total			
		Fe	Mn	Cu	Zn	Ca	Mg	Na	K	P	N	pH	CEC (7)	CEC (8.2)
		ppm				me/100g				ppm	%		me/100g	
High														
1	a	28	38	2.8	1.0	3.0	.6	.14	.62	171	.225	5.8	16.2	19.2
	b	23	16	4.1	1.7	1.0	.4	.09	.24	22	.024	5.5	7.2	6.7
Med														
2	a	90	75	1.7	.7	8.5	1.0	.34	.59	320	.105	5.7	27.4	27.1
	b	38	11	1.1	.4	5.7	1.2	.28	.20	30	.038	5.3	11.6	11.4
Low														
3	a	79	149	.9	.9	6.6	1.2	.36	.51	140	.063	5.7	--	15.5
	b	36	77	1.0	.2	11.6	1.3	.03	.26	49	.038	6.1	--	11.6

soil material (Table 17, page 47). Because of this, values expressed on a volume basis are not as large for andic layers as it appears when expressed on a weight basis. The CEC of the Truefissure 0 to 25 cm andic layer is not significantly larger than non andic material in the 25 to 37 cm zone, when expressed on a weight basis (Fig. 4).

Texture of Truefissures andic and buried layers are similar when compared to the contrast between andic and buried layers of Elkner v-2 (Table 15). Expression of CEC for Elkner v-2 on a volume basis shows a much stronger contrast between CEC of andic and buried layers than does the Truefissure data (Table 15).

Table 15. Effects of Texture on Contrast Between Andic and Buried Soil.

	Sand (%)	Silt (%)	Clay (%)	CEC by wt. (me/100 g)	CEC by volume (me/100 cc)
Truefissure					
andic	26	68	6	20.3	14.4
buried	42	51	7	9.7	12.6
difference	16	17	1	10.6	1.8
Elkner v-2					
andic	21	62	17	41.7	35.0
buried	58	36	7	5.7	7.5
difference	37	26	10	36.0	27.5

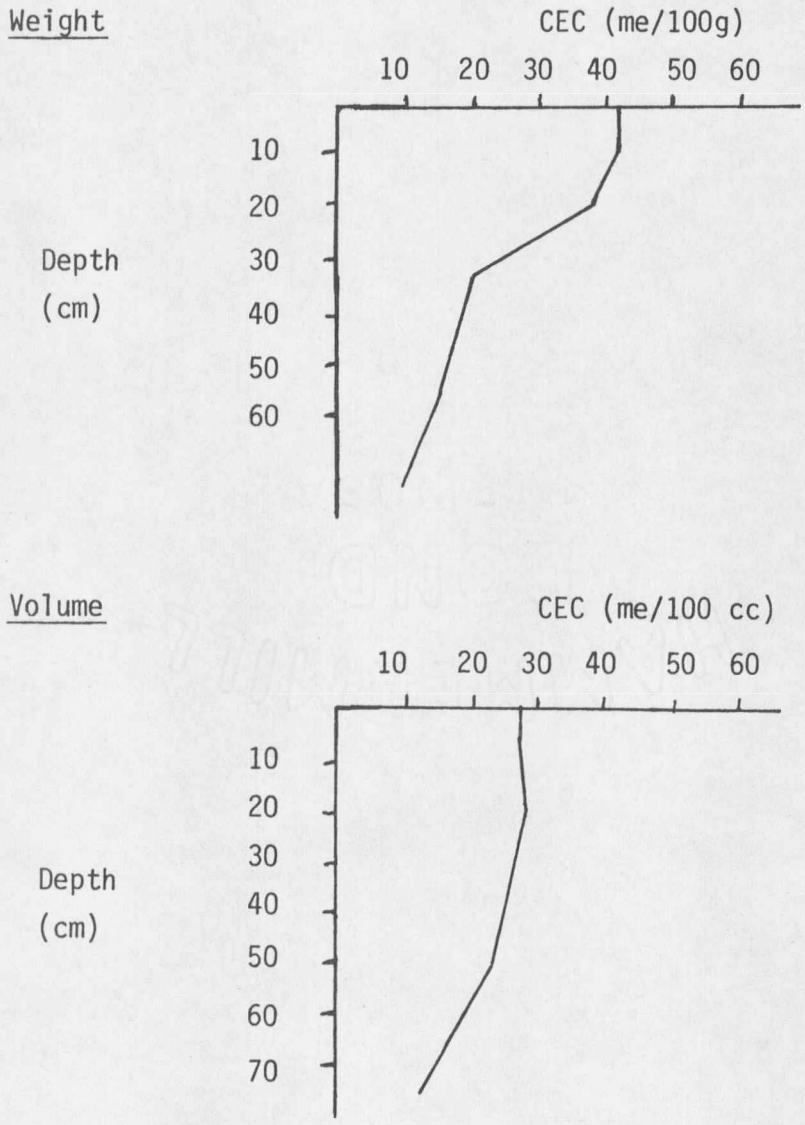


Figure 4. Comparison of CEC on a weight and volume basis for Truefissure.

Mean cation exchange capacity for Group 1 andic layers was 3 me/100g larger when measured at pH 8.2 than when measured at pH 7.0 (Table 14). Only the Andic layer of Wishard showed any sign of pH dependent charge for the other groups (Appendix 3). The average pH for andic layers is 5.8; therefore, CEC is expected to be lower under field pH than at the pH 7.0 or 8.2 that CEC was measured at in the lab. Because of the probable pH dependent charge, liming to raise the pH may be an important management tool in the future for increasing CEC.

Group 2 andic layers had the greatest mean available phosphorus (Bray P) content (Table 14). Variability was high among horizons in this group ranging from 26 to 1200 ppm (Appendix 3). Mean Bray P for andic layers of Group 1 and 3 were nearly the same (Table 14). On a volume basis Group 1 andic layers would have less Bray P than Group 3. All buried layers had less Bray P than andics.

Phosphorus sorption was generally higher in surface horizons but not just in horizons with strong amorphous character. The Elkner B21 has low amorphous character but high P-sorption (Fig. 5 and Table 16). Burning of this soil may have decreased its amorphous character. Although P-sorption may be >95% in most andic layers, it (Bray P) appears to be highly available at least in the Group 2 andic layers (Table 14). Plants on Group 1 andic layers may show a response to added P.

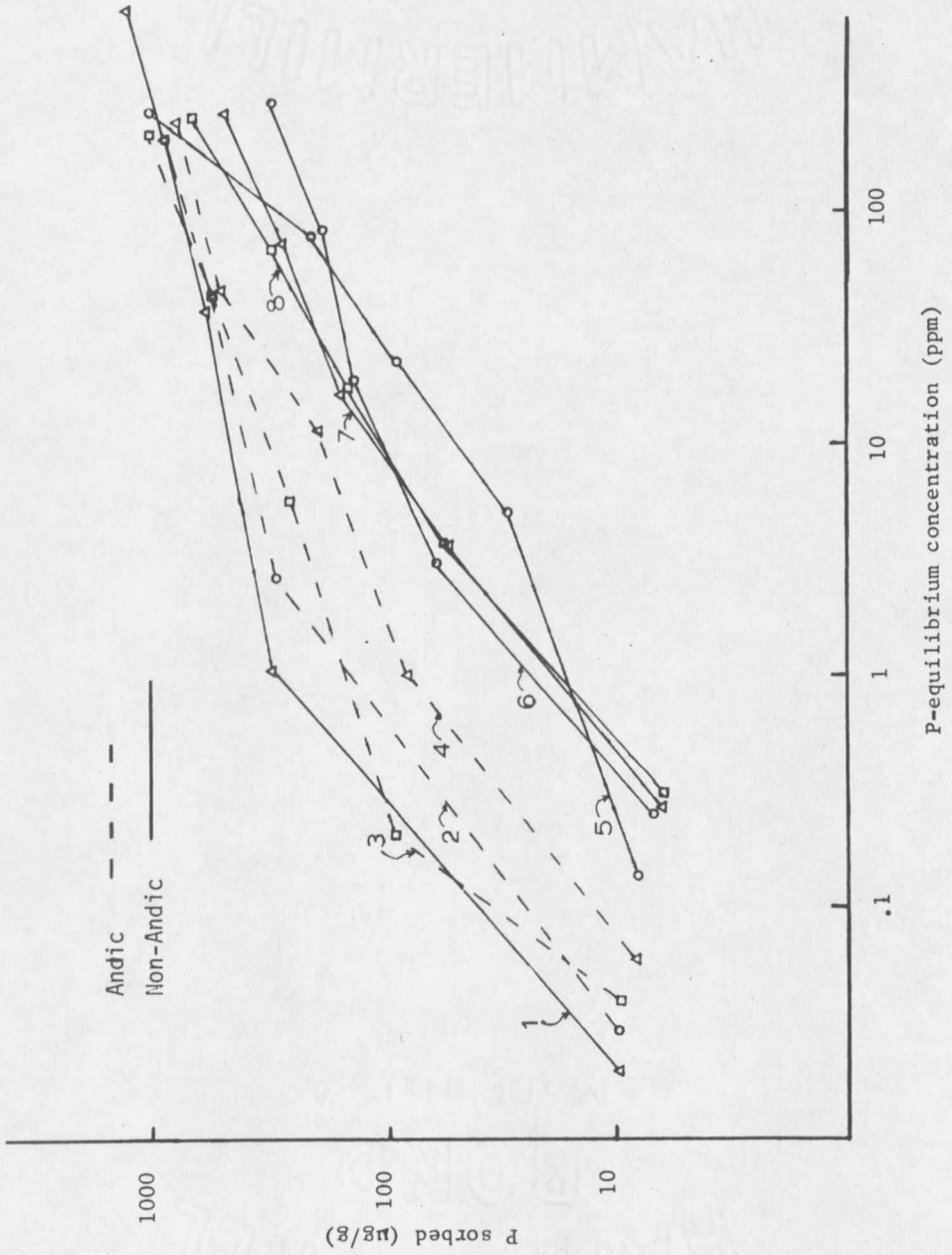


Figure 5. Phosphorus Sorption "Isotherms"

Table 16. Soil Samples used for Phosphorus Sorption "Isotherms."

Number	Soil Name	Horizon	Depth
1	Elkner	B21	0- 7
2	Wishard*	A12	2- 7
3	Buckhouse*	B21ir	23-31
4	Wishard*	B21ir	12-20
5	Wishard	IIC1	46-62
6	Elkner	IIB3	7-11
7	Cabinet	IIA2	11-16
8	Sugarloaf 2	B3	8-15

*Andic horizons

Total nitrogen was greatest in andic layers of Group 1; and Group 2 had more than Group 3 (Table 14). Mean total nitrogen is apparently high because of the high organic matter contents in A1 horizons of Buckhouse and Wishard (Appendix 3). Brown andic layers of Group 1 had a mean total nitrogen of .065 ppm; not much different from .059 ppm for brown andic layers of Group 2. Group 3 was not much lower at .063 ppm.

Exchangeable bases (Ca^{++}, Mg^{++}, Na^{+}, and K^{+}) tended to be more abundant in upper horizons of soils with strong amorphous character (Table 14). Group 1 and 2 soils had more bases and higher pHs than the horizons immediately below (Table 14). The slight decrease in pH below the andic layer instead of the usual increasing pH with

depth may indicate the effects of nutrient cycling in this layer. The lowered pH below the andic layers of Group 1 and 2 is a remnant of a highly leached horizon of buried forest soils. Since the buried A2 horizons still have low pH values, this indicated they are still within the zone of eluviation.

DTPA extractable iron and manganese were least abundant in andic layers with strongest amorphous character (Table 14). In general, these elements were more abundant near the surface. No trend was seen for copper or zinc.

Amorphous Character and Physical Properties

Water holding capacity expressed on a volume basis was less than when expressed on a weight basis for soils with strong amorphous character for the same reasons there is a difference for chemical data. The difference between andic and buried layers was still significant when a large textural difference existed between andic and buried. In Truefissure, sand content of the andic layer is 12% different from the buried (Table 15). The difference between andic and buried sand content of Elkner v-2 is 37%. Water holding capacity of the andic layer of Elkner v-2 is significantly larger than the coarse textured buried layer (Fig. 6). Truefissure did not show as great a change in water holding capacity (Fig. 7). Andic layers over granitic buried material should be more important to

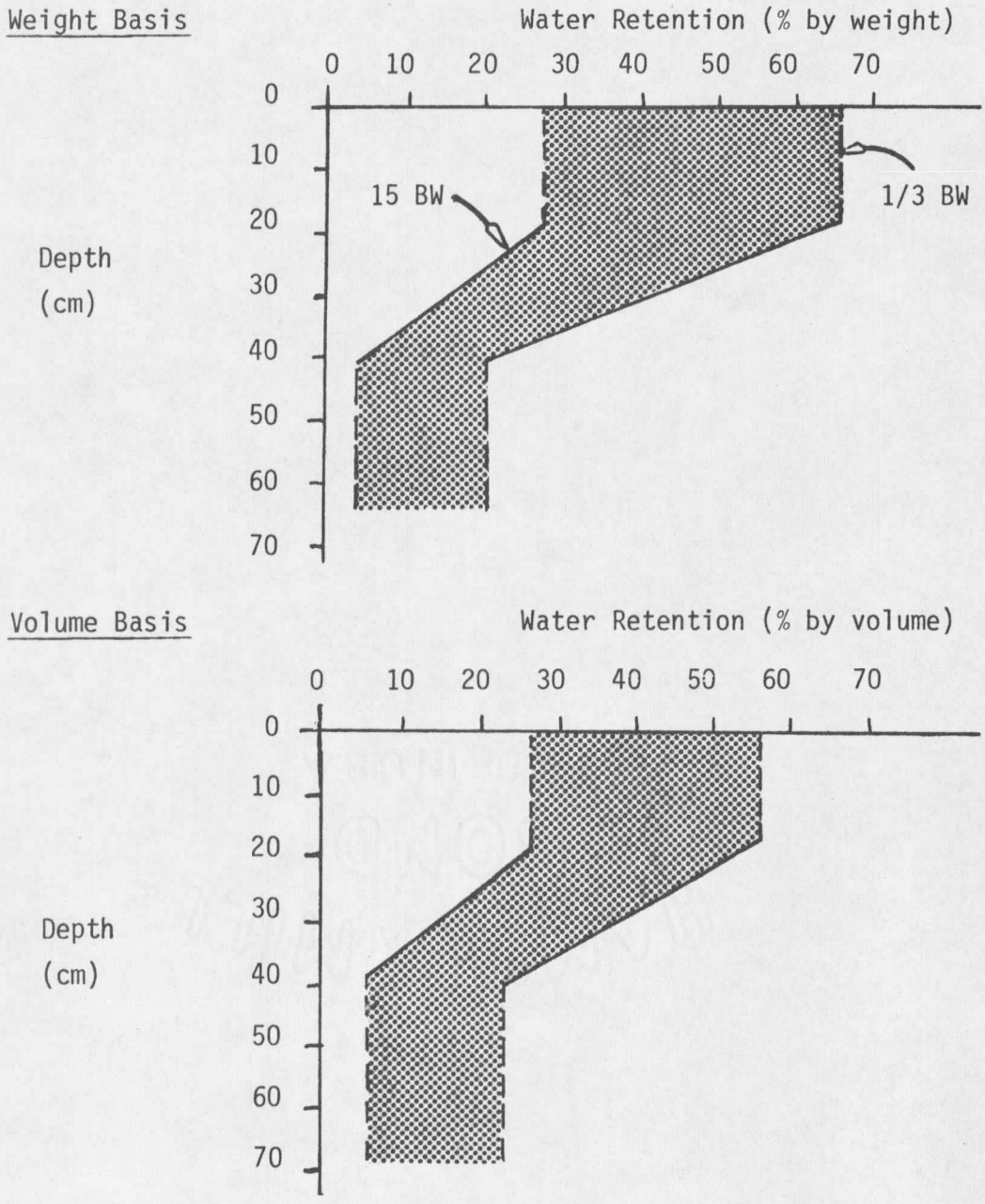


Figure 6. Comparison of water holding capacities on a weight and volume basis for Elkner v-2.

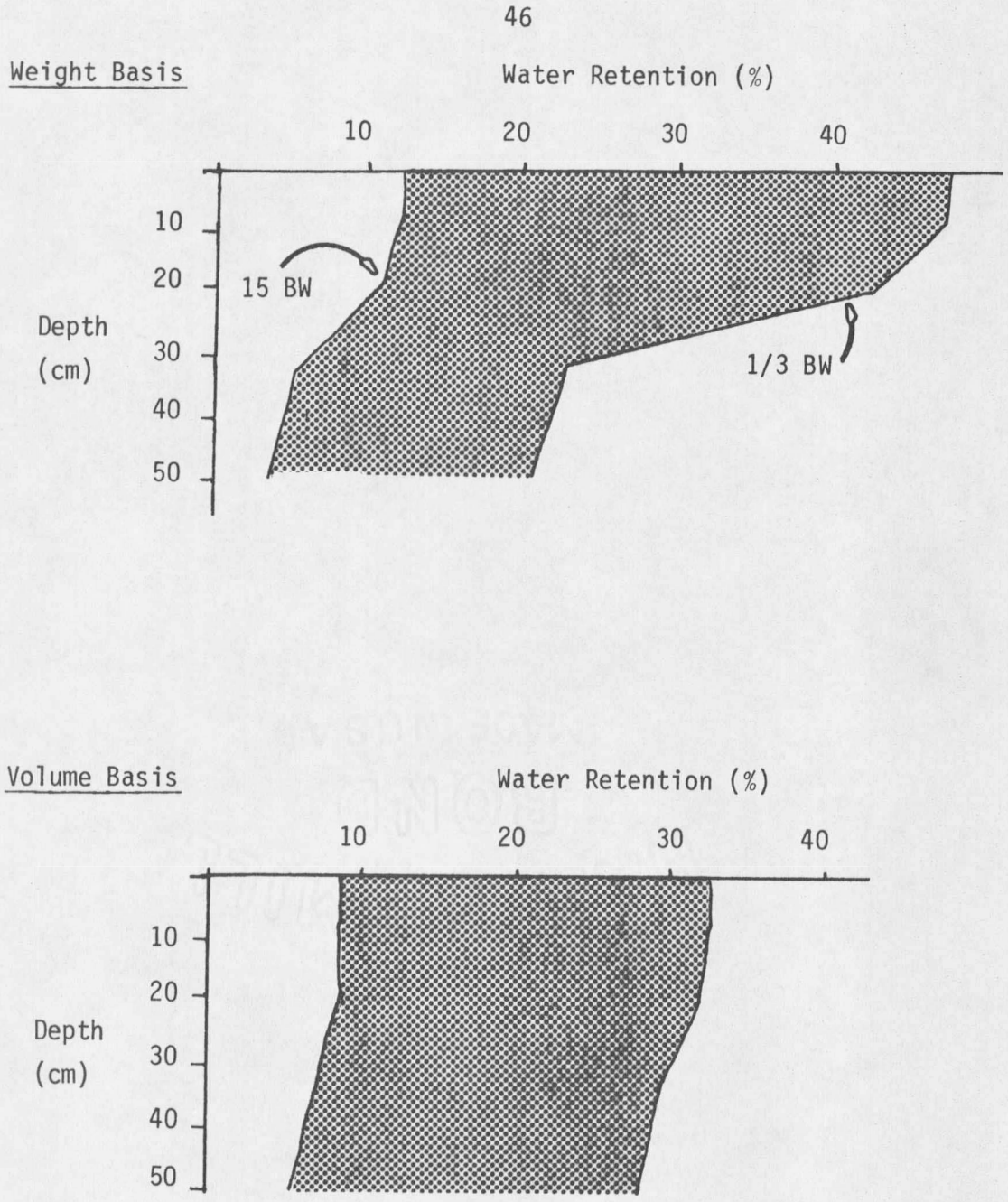


Figure 7. Comparison of water holding capacity on a weight and volume basis for Truefissure.

plant growth than andic layers over finer textured rocks such as the argillites of Truefissure.

Andic layers with strong amorphous character generally had less clay and more silt than others (Table 17). Layers with the strongest amorphous character were usually thicker so would have less contamination due to mixing than thinner layers. They would retain their eolian character.

Bulk density in Group 1 was less than Group 2 and Group 3 mostly by definition of Andepts. Thinner andic layers of Group 2 would be susceptible to mixing and contamination by high bulk density material from below which could have a higher bulk density than eolian materials.

Table 17. Mean Physical Properties of Andic (a) and Subjacent (b) Horizons Within 25 cm.

Degree of Amorphous Character		Mechanical Analysis Sand (%)	Silt (%)	Clay (%)	Bulk Density (g/cc)	Water Holding Capacity 1/3 Bar (% by wt.)	15 Bar (% by wt.)
High (Gr.1)	a	28	61	8	0.73*	38.3	10.9
	b	46	48	5	1.32	20.5	2.4
Medium (Gr.2)	a	33	56	12	0.81	55.6	17.0
	b	44	43	12	1.18	27.5	6.4
Low (Gr.3)	a	46	39	15	1.20	28.2	11.4
	b	58	30	12	--	23.5	4.3

*Not including Truefissure B23ir

Distribution of Amorphous Character in Montana

Andepts of this study were found in three counties of Montana which border Idaho; Lincoln, Sanders and Mineral (Fig. 2). This corresponded to areas mentioned in the survey where the thickest deposits were found (Appendix 1). It also corresponded to the northern portion of the area in Montana where the National Soils Atlas recognized Andepts (38). Within this area are three soils from Group 2 which had some unique properties. Wishard had the strongest amorphous character of Group 2 and came close to qualifying as an Andept. Cabinet has one of the lowest elevations of any site with strong amorphous character. Most soils of Group 2 were restricted to higher elevations (>1097 meters) (Table 3). Unnamed 5 appeared to have formed in alluvium rather than eolian parent materials. It still had fairly strong amorphous character. A regional distribution of amorphous character appears related to climate. The Andepts are found where precipitation is high.

All other soils from Group 2 were found in counties which border Missoula County (Fig. 2). Aerial distribution in this region was limited to northeast aspects and higher elevations according to the survey and site locations of Group 2 soils. Elkner v-1 and v-2 and Sugarloaf 1 and 2 were close together but showed the localized strengths of amorphous character in their region.

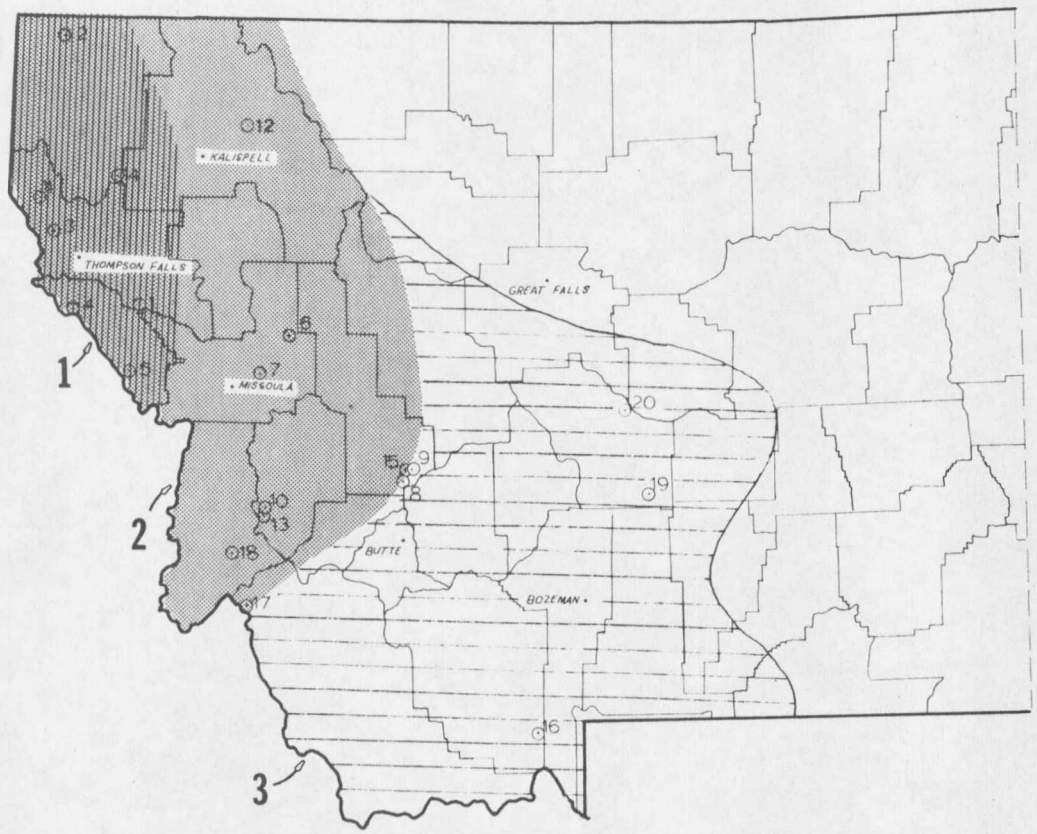
Soils from Group 3 were found in the mountains to the south and east of the counties in which Groups 1 and 2 were found.

Three zones were delineated from the locations of sites within each group, to represent regions where the three degrees of amorphous character may be expected (Fig. 8).

The distribution of eolian deposits with strong amorphous character had a strong association with an orographic effect on the prevailing winds which carried ash, loess and precipitation. This orographic effect is exaggerated by the protection from erosion coming from thicker vegetation where precipitation is greater. The Idaho Batholith appears to be an effective funneling device which concentrated Cascade Range volcanic ash, Palouse loess and wet maritime air into the northwestern part of Montana.

Another climatic factor in the genesis of ash enriched loess is the moderating effect of deep snow. One respondent in the survey suggested that andic layers were found where the snow was deep enough in most years to prevent the soil from freezing (Appendix 1). Freezing and thawing cycles would be greater above and below this zone and may tend to increase physical weathering and decrease chemical weathering.

Climate may be as important in the genesis of andic layers as are parent materials such as volcanic ash.



Zone	Amorphous Character	Thickness cm.	Distribution
1	strong	30-45	general
2	moderate	15-20	high elevation
3	weak	10-20	spotty

Figure 8. Estimated distribution of soils with amorphous character in Montana.

SUMMARY

A survey of soil scientists in Montana and parts of Idaho regarding their knowledge of volcanic ash influenced soils indicated there was disagreement as to the genesis and properties of a layer of soil associated with volcanic ash influence. Twenty soils were collected from Western Montana having apparent eolian influence and probable volcanic ash influence.

Chemical and physical analysis were completed and used to rate the soils in order of amorphous character. Three groups were formed representing soils with strong, moderate and weak volcanic ash influence as indicated by the strength of amorphous character. Group 1 were classified as Andept suborders; Group 2 as Andic and Andeptic subgroups, and Group 3 were not recognized at either of these two levels of Soil Taxonomy.

Soils with strong amorphous character tended to have the following morphological characteristics:

1) low bulk density
2) high silt content, usually >60%,
3) weak consistence, usually soft, friable, non sticky, non plastic,
4) high chroma, usually four or more for Andept suborders and three or more for Andic and Andeptic subgroups,
5) weak aggregation, a weak structural grade.

Andic layers appear to be fertile when CEC, fertilizer elements and water holding capacity are expressed on a weight basis. Because of low bulk density in soils with strong amorphous character, expression of these data on a volume basis shows little difference between andic and non andic soils of similar texture.

In general amorphous character appears strongest in Lincoln, Sanders, and Mineral counties and weakens to the south and east.

CONCLUSION

Soils with strong amorphous character are generally found northwest of Missoula, where the climate is wet and the loess apparently rich in volcanic ash. East and south of Missoula misclassification of soils with eolian surface layers could be prevented if the morphological indices of amorphous character presented in this paper are used. Very few andic layers in Montana appear to have enough volcanic glass to make petrographic examination necessary for classification.

Andic layers have characteristics which make them relatively fertile compared with layers that are coarse textured, fine textured or compacted. The andic layer is expected to be the major source of nutrients and water when it occurs over coarse textured granitic materials. Poor root penetration in clayey or compacted subsoils could make andic layers the main source of air, nutrients and water. On a volume basis, nutrient and water holding capacity may be no greater in andic layers than comparably textured soils. The pH dependent cation exchange capacity is potentially valuable. Liming to raise the pH could significantly increase cation exchange capacity.

APPENDICES

APPENDIX 1

Responses to the Survey on Volcanic Ash Influenced Soils in Montana and Parts of Idaho

October 1975

#1 HAVE YOU SEEN VOLCANIC ASH INFLUENCED SOILS? IF SO, WHERE?

(1) Near Condon, Missoula County and Rye Creek, Ravalli County.

(3) The volcanic ash recognized on the Bitterroot National Forest is Eolian. In addition, there are areas of residual soils developing from weathered volcanic rock types.

(4) I have seen loess influenced soils that may contain (volcanic) ash. These areas of deposition are the high elevation (2580 m +) ridges, cirque basins and northern exposures of windswept ridges. The loess influence on the northern exposures varies from 2100 m to 2,700 m. Locations include: Madison Range, Gallatin Range, Absaroka Range.

(5) A volcanic ash mantle exists from Lewiston, Idaho thickening towards the Canadian border in the mountains, including ash over loess east of Moscow in the Palouse. Thins to east and south.

(6) In surface soils in Glacier County and as buried ash in Glacier, Toole, Lewis & Clark, Jefferson, Broadwater, Cascade and Madison counties and in western Alberta, Canada. In Glacier County the ash layer can be found in wet areas such as pot holes or wet terraces like along the Milk River and Cut Bank Creek.

(7) Ash caps are common in the mountains east of the Continental Divide from Glacier Park south to Roger's Pass. They are particularly extensive at higher elevations in the Bob Marshall and Scapegoat Wilderness portions of this area. Remnants of formerly more extensive caps are found in the Little Belt, Crazy, and Big Snowy Mountains.

(8) Western Montana.

(9) Deepest influence on the Kootenai National Forest and less in the St. Regis Area of the Lolo National Forest.

(10) Yes, in Northern Idaho.

(11) Early work done in the field and laboratory study of volcanic-ash influenced soils was of the Holloway and Buckhouse (Horsehead) series in Missoula County and of the Truefissure, Craddock and Wishard series in Mineral County. Those are where I first studied the volcanic ash influenced soils, in correlation of soil surveys. The Sheburne series in Glacier County is similarly influenced. But also in Glacier County, out on the grass-covered pitted ground moraine, near the Glacier Mountains, layers of volcanic ash measured in thickness of inches or feet occur buried several feet deep in beds of ponds. This condition has been found in low places in inter-mountain valleys. Volcanic ash influenced soils like in Missoula and Mineral Counties can be expected to occur in comparable high mountain landscapes in Lincoln, Glacier, Flathead, Sanders, Ravalli, and Beaverhead Counties.

(12) Northwest part of the state: from Noxon to East Glacier, reaching lowest elevations in the West.

(13) Flathead County, in parts of the Bob Marshall Wilderness, and other parts of the Flathead National Forest not in Flathead County.

(14) From Canadian border south to Hamilton where it begins to fade out. The distribution extends into Idaho as far south as McCall. Ash is found in the Lubrecht Experimental Forest but fades east of there.

(15) They are extensive over the Lolo National Forest and adjacent forests.

(16) Beaverhead National Forest, mainly on the Continental Divide. The ash thins or is greatly mixed when going east and south. The Bitterroot Range shows the least mixing in the Beaverhead while the Gravelly and Madison Ranges have the most mixing. Can find some ash influence by Red Lodge.

(17) Volcanic influence in soil is prevalent throughout Idaho (north of the Salmon River) and in Western Montana.

(18) Has seen on the Deer Lodge National Forest as far east as Boulder, Montana and considers the Forest as being in the periphery of ash deposits. Thickness increases toward west.

(19) I have seen the brown surface layer on soils in all counties in Western Montana and have been told the brown surface was an indication of the presence of ash.

(20) Yes or so they are called. Near Coloma and at other high elevation in Montana, Jewel Basin. I am working on my own theory of Bir formation.

(21) North of Couer d'Alene, most of the mountain soils have a "loess cap" which contains varying amounts of volcanic ash. Some, but not all, high energy aspects will have lost this "loess cap" through erosion.

(22) Ash caps in north central Idaho that thin out to the south at the Salmon River. Up to 90 cm thick east of Moscow with thickening when going into the Palouse.

#2 HOW IS VOLCANIC ASH INFLUENCE RECOGNIZED IN THE FIELD?

(1) Low bulk density.

(2) The ash layers we recognize in the Salmon River Mountains east of Cascade, Idaho, appear morphologically as A (albic) horizons. They range in thickness to approximately 15 cm. Colors are gray and white, they run about 64% silt, less than 5% clay, and the rest is fs and vfs. The ash itself is chiefly tubular shards and glass encased phenocrysts. Index of refraction of the glass ranges from 1.497 to 1.499.

(3) Thin 0 to 15 or 20 cm thick, low bulk density, loam to fine sandy loam to silt loam texture, reddish brown color, generally no coarse fragments, very contrasting boundary, weak fine granular structure and on moister landscape positions are all used to recognize volcanic ash influence.

(4) I use bulk density, silt loam textures, abrupt horizon changes to help recognize loess in the field. Many times these loess deposits sound hollow where they occur as a thin deposit over bedrock.

(5) Smeary feel resulting from high water holding capacity; Bir horizon indicates volcanic ash influence. Thickness is 60 cm east of Moscow, Idaho and 60 cm at Sandpoint, Idaho.

(6) Bir is not a good indicator by itself. It is pale brown to nearly white with a sharp feel. Very fine sand (vfs) is most common. In Glacier County it is possible to see elongate particles with sharp points using a hand lens.

(7) Recognize by reddish color (7.5 YR 4/3-4/4) and a silty clay loam texture. Occurs as an ashy loess mantle <1 ft. thick. The ash cap is mixed with other materials.

(8) Bir not always an indicator of volcanic glass.

(9) Recognition is by color, texture, bulk density. Under most conditions the color is 10 YR 5/4 to 5/6 with moist areas having 10 YR 3/2 to 3/1 and South aspects having a grayer color. The St. Regis area has silt loam textures while the Kootenai National Forest has sandy loam textures. Thickness may be 10

to 15 cm on south aspects or up to 55-60 cm but has an average of 30 to 45 cm thick. A thin discontinuous surface A2 horizon is possibly the result of recent ash fall.

(10) Low bulk density, floury when dry, silt loam, generally non sticky and non plastic.

(11) The unique and striking property of volcanic ash mantle on the forested soil is the strong brown color of the low density, massive silt loam, loam, or gravelly or stony silt loam or loam that rests upon variable substratum or upon the light gray or white buried A of the covered Cryoboralf. Even in the development of the A2-Bir zonation as in the Evaro and Sherburne series, the material has the same low density massive character.

Mineral identification of volcanic glass shards, abundant in these soils attest to deposition from atmospheric suspension as in loess deposits.

(12) A combination of brown color (as in Bir), low bulk density (0.8-1.1), and fluffy, weak structure. Brown color alone is not a good indicator.

(13) The ashy mantle is loess textured and is a 10-20 cm thick layer when pure. It is commonly brown but may be darker and almost black as when found in an avalanche chute (due to the grass vegetation in these chutes).

(14) Found as a brown B2 ashy mantle, chromas 4 or greater (sometimes as high as 8), abrupt lower boundary and low bulk density.

(15) Generally by color (reddish brown) and texture (silt loams and very fine sandy loams).

(16) Silt texture and reddish brown color as a 10-20 cm surface mantle. Also high organic matter with a fine root mat.

(17) The surface soil characteristics are readily recognized. A sharp discontinuity between the texture of the surface and underlying horizons is visible and easily determined.

(18) Low bulk density; bright yellow brown color (10 YR 4/4-3/4), possibly 7.5 YR; few coarse fragments and a silt loam or loam texture are all used. Thickest deposits are 35 cm and may have

a thin A2 on the surface. Average of 15 to 20 cm thick. Has seen as an A1 horizon a few times.

(19) Brown Bir ashy mantle may indicate influence, but uncertain that the color is from volcanic ash.

(20) As conventionally described - a reddish brown light weight horizon at the surface or beneath a shallow A1, with (often but not always) recognizable iron concretions, or other concretions.

(21) The volcanic ash presence is inferred wherever the "loess cap" is found. Laboratory analysis on some scattered soils provides the basis for this inference.

(22) A reddish tea colored Bir that may contain a thin A on top, soapy feel resulting from thixotropic character, silt loam texture, weak fine medium granular structure, low bulk density from .88-.95, and a non-plastic and very slightly sticky consistency are all used.

#3 HOW IS VEGETATION RELATED TO VOLCANIC ASH INFLUENCE?

(1) The areas with the so-called brown surface usually do not have ponderosa pine.

(2) Lodgepole pine, Engelmann spruce and subalpine fir forests all grow on the ash deposits.

(3) Generally thickest under subalpine fir types, much thinner or absent under open canopy ponderosa pine or Douglas fir. I believe this is due to erosive forces being more active on the warm southerly exposures that are sparsely vegetated. Have seen thick layer under grass on the Clearwater National Forest.

(4) In the higher elevations it appears that the loess deposits may be supporting grasses and forbs while the rocky knobs or glacial till deposits support a mixed stand of subalpine fir, white bark pine or Engelmann spruce trees. I do not know why vegetative patterns occur. The Yellowmule area south of the West Fork of the Gallatin River is a very good example of this pattern of vegetation. I have thought that aeration, temperature, or moisture conditions may explain the influence of loess on vegetative patterns.

(5) An intact layer of ash is found under grand fir, western red cedar, and western red cedar-western hemlock zones. Under grassland vegetation it is mixed with other soil - probably washed from slopes lacking a protective forest cover at the time of ashfall.

(6) I have no knowledge.

(7) In this area ash caps are strongly associated with forest soils (forest vegetation including ponderosa pine and wetter sites). There are very few recognizable caps found in soils developed under grassland in this area.

(8) Associated with subalpine fir-climax vegetation type or Douglas fir going to subalpine fir.

(9) Association with lodgepole pine and other forest types but not ponderosa pine.

(10) Since most of my areas are derived from coarse grained batholith assorted rocks, habitat types tend to be moister ones than normal.

(11) I do not know if there is a true vegetation-soil correlary associated with the volcanic ash influence; for at the high elevations of the Andeptic Cryoboralfs, the Cryandepts, Andic Cryochrepts and Cryorthods, they are under subalpine fir, Engelmann spruce and lodgepole pine and on south and west exposures under grass as in the Buckhouse series. In Idaho and in Montana valleys adjacent to Idaho the Krause and Waits soils on sloping to level stream terraces are under Douglas fir and possibly also under ponderosa pine.

(12) Relations are very broad.

(13) SW aspects with residual soils seldom have an ash mantle, but may have an ash influenced solum.

(14) Related to wet forest zones like Western Larch, subalpine, fir, cedar hemlock, spruce but not under ponderosa pine or Douglas fir.

(15) Vegetation communities are related quite predictably to the ash mantled soils, but both the vegetation and the ash seems to be controlled by the local climate rather than by each other. Direct correlation.

(17) Subalpine turf at 2550 m + elevation.

(18) Thickness increases with vegetation associated with higher elevations. Thickest soils are under subalpine fir where an A2 may be found.

(19) Associated with most all forest types.

(20) Nearly always find spruce-fir on Bir or occasionally lodgepole.

(21) I don't know how vegetation is related to volcanic ash influence. Several habitat types occur on these materials. A general feeling is that the loess cap is the basis for vegetative productivity on glaciated areas.

(22) The depth of the loess cap has an influence in the regeneration capability of a soil. This is especially true if the soil would be droughty without the loess cap.

#4 IS ELEVATION OR TOPOGRAPHIC POSITION RELATED TO VOLCANIC ASH INFLUENCE?

(1) The so-called brown surface is mainly at high elevations on south sides of mountains, but continues to lower elevations at north slopes.

(2) Bottomlands favor the preservation of the ash.

(3) North aspects and higher elevations have thicker ash influence because of the thicker vegetative cover on these sites. Southwest aspects are more erosive due to the prevailing winds and more frost action especially in late spring when ice pedestalling begins.

(4) Yes. I feel that certain factors affect the deposition of loess and/or more apt to retard the subsequent loss of loess by erosional processes. I have observed most of the loess deposits above 2580 m elevation along alpine ridges and cirque basins. Very little erosion is occurring in many of these alpine cirque basins. I have also observed more loess on the lee side of wind swept ridges on the northern exposures. I suspect that vegetation may have retarded erosion on some of these north exposures, while the loess may have been stripped from the wind swept southern exposures.

(5) North aspects have deeper and more continuous loess caps. On south slopes loess caps are not common. Precipitation distribution is correlated with the ash layer more than is aspect, especially where annual precipitation is 100 to 125 cm.

(6) Found in areas not prone to erosion by wind or water. Generally on north slopes with depth increasing at higher altitudes.

(7) No leeward thickening.

(8) On the Kootenai National Forest the loess cap is relatively uniform in thickness on all aspects and at all elevations. In the St. Regis area the thickness increases with elevation. Older stream terraces may have thicker deposits (45-48 cm) due to redeposition after erosion from south aspects.

(9) The east most extent of volcanic ash influence on soils in Montana is on high mountain slopes where on forested east and north facing slopes the volcanic ash mantle extends down slope several hundred feet lower elevation than on south and west facing exposures. The volcanic ash mantle occurs at lower elevations and on old stream terraces adjacent to Idaho.

(10) Volcanic ash influence generally occurs or is deeper on northeast slopes; often absent on steep south facing breaks, possibly due to sparse vegetation.

(11) North and east aspects and high elevations have greatest degree of influence as shown by thicker layers.

(12) Ash cap not on south aspects at elevations as low as (high basins, etc.) on north slopes.

(13) Most common at high elevations because precipitation correlates positively with elevation. An exception is Thompson Falls and west.

(15) Better preserved on stable landforms at higher elevations.

(16) High energy south aspects usually lack an ash mantle.

(17) Mostly on ridge tops, north east cirque - like basins or well-protected nivation areas.

(18) Found on all aspects. In Lake County it occurs down to elevations of 990 m which are the toe slopes of the Mission Mountains. In Lake County elevation is a poor indicator of thickness even on the same slope; however, in Granite County there seemed to be a little more correlation between thickness and elevation on the same slope (thicker at the higher elevations).

(19) "Ash" influenced soils are usually at higher elevations, always in forest, and often on north slopes - there are exceptions here but not many. Ash influenced soils rarely occur in low places, draws, depressions.

(20) Depth is varied. Topographic influence is sporadic; we have "loess shadows" occurring over the forest. The cap becomes more mixed with underlaying material as elevation increases.

This probably related to cryic land forming processes such as cryoplanation.

(21) This is answered in part for the first question. High elevation areas that have soil mixing due to freeze-thaw processes do not have the "loess cap" characteristics that are associated with volcanic ash. In some of these areas I think ash influence will be found when lab work is done.

#5 ARE THERE ANY RELATIONSHIPS BETWEEN VOLCANIC ASH INFLUENCE AND UNDERLYING BEDROCK?

(1) Not necessarily, however, some think it is less likely to have brown surface over limestone. I cannot prove this.

(3) None observed.

(4) Thus far I have not seen this to be a factor. I have observed loess deposits on Tertiary volcanics, Precambrian gneiss, Cretaceous groups; hence, the full range of rock types. I have observed more widespread occurrence of loess in the volcanics on the Gallatin (N.F.).

(5) No. Found on Palouse loess and other formations of Northern Idaho.

(6) Not to my knowledge.

(7) More common on more permeable Mississippian limestone because of less surface erosion. Loess caps on all types of glacial deposits including heavy till.

(8) Calcareous parent materials have less.

(10) No.

(11) The volcanic ash mantle soils derived from quartzites, sandstones, granites and limestone. There is no relationship with underlying rock except as these rocks occur at predicted high or low mountain elevations in the eastern most extent of the Rocky Mountain system.

(12) No. Usually contrasting. Occurs over granite, argillite, volcanic rocks, terrace and stream alluvium (often buried). This makes it a unique deposit.

(13) Mixing may add material from below by frost action and churning. In fine-textured weathering products the ash cap may appear to be deep but the % glass is small due to mixing. If the cap is over compacted till, loss by erosion may have occurred due to lower permeability in the till.

(14) Rarely is ash found on limestone. Ralph Dunmire says this is not so. Ash is on limestone at Lubrecht.

(15) Not observed to be of any significance - we have ash mantles on residual, glacial and alluvial parent materials.

(16) Ash soils over limestone or "hard" bedrock are much more critical in terms of erosion (creates a stone pavement). Ash over shale is less critical because eroded areas have some capacity to revegetate.

(19) The brown layer is present on soils formed from materials containing calcareous rock fragments; however, the brown layer is not as thick or it takes longer to form on such soils than on comparable positions with soils from materials containing non-calcareous rocks. Possibly this could be a result of the soil fraction being smaller (higher silt content) and consequently having a much larger surface area of particles in which the coloring agent would have to coat. The brown ash is not low enough in Lake County to be associated with Glacial Lake Missoula materials.

(20) No - have found Bir on limestone and on granite soils.

(21) Most of the land between Canada and Coeur d'Alene has been glaciated to varying degrees; therefore, most soils are not from residual materials. The amount of transporting and mixing by glaciation varies from area to area.

(22) Loess caps tend to be eroded and thinner over impermeable bedrock (weakly fractured granitics).

#6 WHAT IS THE IMPORTANCE OF VOLCANIC ASH INFLUENCE FOR PURPOSES OF LAND MANAGEMENT?

(1) Does not feel the ashy mantle is as erodible or as productive as the Forest Service maintains.

(3) The thin volcanic ash layer is important for vegetative production because of its more favorable chemical and physical properties. Excessive disturbance such as that which is sometimes caused by terracing and slash piling with heavy equipment will remove the ash layer and expose the much less fertile subsurface material that is more difficult to revegetate. This is especially true in the sandy granitic soils which have low inherent fertility. The silt size ash particles can become a dust problem on unsurfaced roads. Slash burning especially if wind rowed or piled decreases permeability for 1 to 1½ years. Erosion a problem after a fire for only a short time.

(4) One management concern in the high elevation is that of the low bulk density and the influence of wind erosion, drying, and frost heaving on the alpine turfs. Thus, once these alpine turf mats are broken up and soil is exposed, these areas are difficult to regenerate due to the factors previously listed.

(5) Fertility may be reduced due to phosphorus fixing capacity of these soils, evidence is not complete yet. (Presented to ASA, SSSA Annual Summer Meeting, 1975.) Very erosive and with high water holding capacity.

(6) This is probably the area where we need information now. We know we have these soils and have made provision in the soil classification to separate them at the family particle class level. There is likely more information available on use and management than I am aware of.

(7) Has higher site index than if removed. More manageable because of lower stone content. Easier to plant trees, etc.

(8) The Bir is not any more important than any other forest soil. It is not as erosive nor as fertile as is regarded by some especially since the % base saturation is less than 50% in many of these soils.

(9) The loess mantle contains most of the nutrient value of the soil and is high in N and P.
The erosion hazard is high if soil is bare for any length of time.
Drying by fire or dry spells only temporarily decreases permeability. Rewetting by winter snow or rain returns the loess cap to its normally high permeability.

(10) Increased fertility from ash influence. CEC for pure loess with 45% ash is in the range of 26 to 30 meg/100g. Water holding capacity is greater.

(11) The volcanic ash mantle, because of its low volume weight and massive-flour like character, erodes badly by rainfall or wind where unprotected by vegetative cover. Forest management in clean up after timber cutting precludes the tractor drawn windrowing of harvest residue for burning. The high affinity of the ash for water, organic humus and bases increase the productivity of the volcanic ash influenced soil over comparable textured soils on like topography under similar temperature and rainfall. But this comparison of production is difficult to make, locally, because the volcanic ash influence is continuous and comparably textured ash and non-ash influenced soils will differ appreciably in temperature at the higher and lower elevations of several thousand feet.

(12) Fertility depends on how well the soil suits the plant growing on it, so I can't say if it is fertile or not. Fire may have effect on these soils if hot enough. Weak structure makes it erosive on slopes.

(13) The ash cap is fertile and has high water holding, high infiltration, and high cation exchange capacities so it should be protected.

(14) Burning may effect microflora (not only ash problem). Slash piling with heavy equipment may cause the B2 to be concentrated in some areas, reduced in others. Most of the nutrient and water retaining capacity is in the Bir horizon.

(15) Very important - has a direct and significant effect on erosion regeneration, planting techniques, harvest methods, etc.

(16) Dust is a problem in the fall when the area dries, especially on the west side of the Bitterroot divide. Also the soil has:

a) High susceptibility to frost heaving especially on road cuts
b) Very high moisture holding capacity, especially in sub-alpine turf
c) Easily eroded under grazing at higher elevations, therefore erosion is critical to watershed stability.

(17) High exchange capacity in the surface and lower in the Belt sub-surface.

(18) Shallow road cuts may produce dust problem. Ash mantle is very productive, so I recommend leaving slash so as not to disturb a mantle. Granite soils need the cap for fertility.

(19) The brown layer is strongly acid, low in base saturation, low in available water holding capacity, and probably due to its dark color would absorb more solar heat if exposed and thus create higher soil temperatures and evapotranspiration; all of which would result in a poorer media for revegetation. Theoretically it should be very highly erosive material if exposed (fine particle and ped size and low bulk density); however I have not been able to locate any real evidence of severely eroded areas even in clear-cuts.

(20) We are studying this as a sideline. The data have not been processed at this time.

(21) The loess cap has a low bulk density. It seems to be subject to compaction under critical moisture regimes, with a definite effect on plant growth.

(22) The ash is important for fertility when over granite and is essential for revegetation. It has excellent cation retention capacity, is very dusty, and is not thick enough to slump.

#7 DO VOLCANIC ASH INFLUENCED SOILS HAVE ANY OTHER PECULIAR CHARACTERISTICS?

(1) High 15 bar water content (6.6) may indicate that either allophane or organic matter is important. I think that the so-called brown surface is a pedogenic development. It is likely that some of the other surfaces have as much ash but it hasn't weathered into a brown surface. Appear to be found where snow is normally deep enough to prevent freezing during most winters.

(2) The Forest Service has experienced poor survival of spruce seedlings in many of these sites. We do not feel it is related to the properties of the tephra deposits. Rather, the topographic features which favor preservation of the ash (bottomlands) influence microclimates on these sites, and they act as cold air drainages and cold air pockets.

(3) Bulk density, cation exchange capactiy, organic carbon content, and percent of pyroclastic material in the silt and sand fractions. Also of concern are the effects of hot fires on these soils. Do they become hydrophobic, and if so, how long does this condition last?

(4) I am not completely assured that what I have seen on the Gallatin National Forest is volcanic loess or localized loess deposits. I suspect that what I have observed is localized loess. However, there appears to be many points of similarity where volcanic ash or localized loess should respond comparably because their particle sizes are or can be fairly similar. Those questions which respond comparably are #2, 4, 5 and only partial similarity on #6.

(5) Phosphorous absorption may be related to Mn + Fe from common concretions or to allophane. Thickness of volcanic ash varies from 60 cm east of Moscow to 50 cm at Sandpoint, with thinning to the east and south. In the Selkirk Mountains the ash is unweathered at high elevations.

(6) When not buried volcanic ash may be mixed by roots or animals, leaving a low percentage of ash in surface soil.

(7) Has finer texture than western loess caps. Loess caps with sil texture show a more pronounced thixotropy than the more

highly weathered sicl loess cap. In regards to needs for additional information about volcanic ash influenced soils:

a) We need more local data on ash content of the cap to adequately classify these soils at the family level of the soil taxonomy.
b) Soil moisture relationships within and fertility status of the caps should be quantitatively determined. It is widely assumed that ash caps are superior in these respects to other parent materials, but there is little documentation to support this assumption.
c) If ash caps are a superior plant growth medium, how much greater is productivity on them than on similar soils without caps? Is productivity related to the thickness of the cap?
d) What effect do logging practices which disturb or rearrange the caps have on site quality, particularly dozer piling of logging slash?

I think the basic physical characteristics of the loess caps found in various parts of the State would be the most important information needed.

(8) The brown (Bir) surface associated with volcanic ash may be the result of pedogenesis and not from volcanic ash alone. It may be a result of the environment associated with subalpine fir.
The degree of Bir formation is associated with parent materials. Dolomitic and calcareous Belt rocks don't have a brown surface at elevations as low as the noncalcareous Belt rocks.
The silica that is associated with amorphous character of the Bir may have come partly from plant opal phytoliths and not volcanic ash alone.

(9) The particle size discontinuity between the loess cap and buried soil is striking.

(10) Often presents what appear to be a spodic horizon but in reality is due to iron rich weathering products.

(11) Special studies of the character of the glass shards in the volcanic ash mantle show a weak to moderate degree of change or weathering of the glass shards, but still recognizeable as glass shards. Yet in Montana the weathering is sufficient

that iron has been released or retained from the solution of organic matter in solution or suspension from the forest litter as it passes through the ash mantle. Other development of the Bir horizon as in Orthods is weak - having started with a massive material having any amorphous clay increasing in quantity with increased weathering.

(12) May be phosphate deficiency in the volcanic ash influenced soils. Probably contain allophane. Under microscope exhibits shards and much related material very difficult to identify because of weathering regimes. Ash (glass content) varies from 5 to 60%. Needs study in the area of fertility.

(13) The ashy mantle may not contain volcanic ash in some Entic spodosols found in cold wet areas. Soils never freeze under the ash cap - probably from the insulation. Base exchange capacity would be good to know.

(14) High phosphate fixing capacity (at least in Chile), high cation exchange capacity if measured as cation exchange capacity for the clay fraction, high water holding capacity, low bulk density, and allophane. Sample throughout the ashfall distribution for chemical and mineralogical analysis and compare with the underlying soil.

(16) Lab analysis is needed to determine how much of the silty surfaces are influenced by volcanic ash, especially in the eastern part of its distribution.

(17) Popcorn pumice found near the Phillipsburg-Drummond area indicates that volcanic ash did not necessarily come from as far as the Cascade Range.

(18) Burning does not necessarily cause erosion but may give a hydrophobic character to the mantle. Information on water relationships, i.e., plant available water; infiltration rates, etc. Also chemcial information, i.e., Cation Exchange Capacity, base status, etc. Also it would be interesting to document the effect of fire on these soils.

(19) An oddity occurring in Lake County is a poorly drained alluvial soil having a thin layer near the surface looks to me to be similar to the brown surface layer on timbered mountain slopes. This thin layer, even though saturated with water during much of the growing season, still has the bright chroma's (/4, /5)

of a well drained soil. After removing the native Englemann spruce forest from this soil and providing drainage, grasses do very poorly on it.

a) Why is the Cation Exchange Capacity variable in the Bir from soil to soil, especially in the Felan 1970 Missoula County 32-2 and Wishard 64-31-3.
b) Why is the 15 bar water: clay ratio in Felan the way it is.
c) Why is there such a wide variety of clays (chlorite, vermiculite) in the Bir of Felan and others.
d) Why in Lake County is the Bir found as low as 1080 m on southwest aspects.

(20) I would like to have time and funds to pursue my theories on these soils. I believe that we need to know much more about them before we prescribe management of spruce-fir and other high elevation forests with this type of soil.

(21) I can't think of any, but this may be due to my association with the materials.

(22) We need to know relative moisture retention and nutrient values of loess caps vs. subsoils formed from igneous parent materials. Also, do loess caps contain enough volcanic ash to be classified as Andic at the subgroup level?

Table 18. Code to Respondents' Position and Location.

Name	Position	Location
1. Shelby Brownfield	State Correlator	SCS,Montana
2. James Clayton	Research Soil Scientist	USFS,Region 1
3. Norman Davis	Soil Scientist	USFS,Bitterroot NF
4. Carl Davis	Soil Scientist	USFS,Gallatin NF
5. Maynard Fosberg	Prof of Soils	Univ Idaho,Moscow
6. June Haigh	Soil Scientist	SCS,Madison County
7. Herb Holdorf	Soil Scientist	USFS,Lewis & Clark NF
8. Harold Hunter*	Soil Scientist	SCS,Missoula County
9. Lew Keunnen	Soil Scientist	USFS,Kootenai NF
10. Dick Kline	Soil Scientist	USFS,Nez Perce N.F.
11. Clint Mogen+	State Correlator	SCS,Montana
12. Ron McConnell+	Soil Scientist	USFS
13. Al Martinson	Soil Scientist	USFS,Flathead N1F
14. Thomas Nimlos	Prof of Soils	Univ Mont Missoula
15. Stan Peterson	Soil Scientist	USFS,Lolo NF
16. Roger Poff	Soil Scientist	USFS,Beaverhead NF
17. E. M. Richlen	Soil Scientist	USFS, Region 1
18. Dave Ruppert	Soil Scientist	USFS, Deer Lodge NF
19. J. S. Seago*	Soil Scientist	SCS,Lake County
20. Nellie Stark	Prof of Soils	Univ Mont Missoula
21. Gordon Warrington	Soil Scientist	USFS,Idaho Panhandle NF
22. Dale Wilson	Soil Scientist	USFS,Clearwater NF

*previously soil scientist

+retired soil scientists

APPENDIX 2

Pedon Descriptions

Buckhouse Typic Cryandepts; Medial over loamy skeletal, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
A11	0-10 cm (0-4 in) Black (7.5 YR 2/2); stony loam; dark grayish brown (10 YR 4/2) interior dry; strong fine granular structure; soft, very friable, slightly sticky, nonplastic; common roots; 10% fragments strongly acid pH 5.5; gradual wavy boundary.
A12	10-23 cm (4-9 in) very dark brown (7.5 YR 2/2) stony loam; dark grayish brown (10 YR 4/2) dry; strong very fine granular structure; soft, very friable, slightly sticky, nonplastic; common roots; 20% fragments; slightly acid pH-6.5; gradual boundary.
A13	23-41 cm (9-16 in) very dark brown (7.5 YR 2/2) stony loam; dark grayish brown (10 YR 4/2) dry; strong very fine granular structure; soft, very friable, slightly sticky, nonplastic; common roots; 20% fragments; medium acid pH-6.0 gradual boundary.
A14	41-58 cm (16-23 in) very dark brown (7.5 YR 2/2) stony loam; dark grayish brown (10 YR 4/2) exterior dry; strong very fine granular structure; soft, very friable, slightly sticky, nonplastic; common roots; 30% fragments; medium acid pH-6.0; gradual wavy boundary.
B21ir	58-79 cm (23-31 in) dk. yellowish brown (10 YR 3/4) very stony loam; lt. yellowish brown (10 YR 6/4) dry; weak very fine granular structure; soft, very friable, slightly sticky, nonplastic; many fine roots; many fine pores; 70% fragments; neutral pH-7.0; gradual wavy boundary.
B22ir	79-97 cm (31-38 in) dk. yellowish brown 10 YR 3/4) very stony loam; dk. yellowish brown (10 YR 3/4) dry; weak very fine granular structure; soft, very friable, slightly sticky, nonplastic; common fine roots; many fine pores; 70% fragments; neutral pH-7.0; clear wavy boundary.

C1 97-127 cm (38-50 in) olive brown (2.5 Y 4/3) very stony loam; pale brown (10 YR 6/3) dry; weak fine granular structure; soft, very friable, nonsticky, nonplastic; few roots; 85% fragments; strongly acid pH-5.5; gradual irregular boundary.

C2 127-182 cm (50-72 in) olive brown (2.5 Y 4/3) very stony loam; pale brown (10 YR 6/3) dry; soft, very friable, nonsticky, nonplastic; few fine roots; 85% fragments; strongly acid pH-5.5

Vegetation: Abla, Psme, Pial, Pico parkland with Xete, Agsu, Cage, Powh, Acmi and lupine.

Location: 3/16 mi. E., 1/16 mi. N. of SW corner of Sec. 32, T18N, R24W, Missoula Co., MT., approximately 1/2 mi. east of microwave tower.

Remarks: Old Horsehead stony loam. Collected Aug. 3, 1964, McConnell, Grossman, Lynn, Cawlfield, Richlen, Mogen, and Southard. Described by McConnell. S64Mt. 32-1.

Unnamed 3 Entic Cryandepts; Medial over loamy skeletal, mixed

Colors are for moist soil unless otherwise indicated

Horizon Profile Description

B21 1-20 cm (0-8 in) dk. yellowish brown (10 YR 4/4) silt loam; reddish yellow (7.5 YR 6/5) crushed dry; yellowish red (5 YR 5/5) crushed; weak, very fine, granular structure; soft, very friable, nonsticky, nonplastic; many fine and medium roots; common pores, 10% fragments; >2 mm; clear smooth boundary.

B22 20-56 cm (8-22 in) yellowish brown (10 YR 5/6) silt loam; reddish yellow (7.5 YR 6/5) crushed dry; weak, very fine, granular structure; soft, very friable, nonsticky, nonplastic; common coarse roots; common tubular continuous pores; 15% fragments; abrupt irregular boundary.

IIA2 56-74 cm (22-29 in) olive brown (2.5 Y 4/4) gravelly sandy loam; lt. yellowish brown (2.5 Y 6/3) crushed dry; light

olive brown (2.5 Y 5/3) crushed; weak fine and medium; subangular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; few fine and medium roots; few pores, common vesicular pores; 35% fragments; not reached wavy boundary.

IIAB 74-94 cm (29-37 in) olive yellow (2.5 Y 6/6) gravelly sandy loam; lt. yellowish brown (2.5 Y 6/4) crushed dry; light olive brown (2.5 Y 5/3) crushed; weak fine subangular blocky; slightly hard, friable, slightly sticky, slightly plastic; few coarse roots; few pores; 45% fragments; gradual wavy boundary.

IIB2 94-135 cm (37-53 in) yellowish brown (10 YR 5/4) gravelly loam; yellowish brown (10 YR 5/4) crushed dry; light olive brown (2.5 Y 5/3) crushed; moderate to strong subangular blocky structure; hard, firm, sticky, plastic; few coarse roots; few pores; dk. yellowish brown (10 YR 4/4) clay skins on ped faces; 45% fragments; clear wavy boundary.

IIC 135- cm (53- in) lt. yellowish brown (2.5 Y 6/4) sandy loam; lt. yellowish brown (2.5 Y 6/4) crushed dry; light olive brown (2.5 Y 5/3) crushed; moderate to strong subangular blocky structure; hard, firm, slightly sticky, slightly plastic; few roots; 50% fragments.

Vegetation: Juoc/clun

Location: Sec 33, T36N, R33W, Lincoln Co., Near Spread Cr., Kooteni NF.

Remarks: Sample collected by Lew Keunnen.

Unnamed 4 Entic Cryandepts; medial, mixed

Colors are for moist soil unless otherwise indicated

Horizon Profile Description

B21 0-23 cm (0-9 in) brown (7.5 YR 4/4) crushed; silt loam; brownish yellow (10 YR 6/6) crushed dry; brownish yellow (10 YR 6/6) dry; weak very fine granular structure; soft,

very friable, nonsticky, nonplastic; many fine roots; many pores; 10% fragments; clear smooth boundary.

B22 23-56 cm (9-22 in) dk. yellowish brown (10 YR 4/4) crushed; silt loam; brownish yellow (10 YR 6/6) crushed dry; weak very fine granular structure; soft, very friable, nonsticky, nonplastic; common fine & medium roots; common tubular pores, many pores; abrupt irregular boundary.

Vegetation: Abgr/clun.

Location: Sec 20, T23N, R31W, Sanders Co., Near White Pine Cr.

Remarks: Sample collected by Lew Keunnen.

Truefissure Entic Cryandepts; medial over loamy-skeletal, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
B21ir	3-13 cm (1.2-5 in) reddish brown (5 YR 4/4) silt loam; light brown (7.5 YR 6/4) dry; weak fine granular structure; soft, very friable, nonsticky, nonplastic; common roots in cracks; common vesicular pores; few fragments >2 cm; clear wavy boundary.
B22ir	13-25 cm (5-10 in) brown (7.5 YR 4/4) silt loam; lt. yellowish brown (10 YR 6/4) dry; weak fine subangular blocky parting to weak fine granular structure; soft, very friable, nonsticky, nonplastic; common fine roots; 5% fragments >2 cm; abrupt broken boundary.
B23ir	25-41 cm (10-16 in) dark brown (7.5 YR 3/4) very gravelly fine sandy loam; yellowish brown (10 YR 5/4) dry; weak fine granular structure; slightly hard, very friable, nonsticky, slightly plastic; common roots; few medium pores; abrupt boundary.
IIB31ir	41-61 cm (16-24 in) strong brown (7.5 YR 5/6) very gravelly very fine sandy loam; yellow (10 YR 7/6) dry; weak medium subangular blocky structure; slightly hard brittle (51) very friable, nonsticky, nonplastic; many fine pores;

clear wavy boundary, common vesicles, few med. pores, abundant skeletans, common roots between co. frag. 30% channers >3/4".

IIB32ir 61-91 cm (24-36 in) brown (10 YR 5/3) very gravelly fine sandy loam; very pale brown (10 YR 7/4) dry; very weak very fine granular structure; very friable, slightly sticky, slightly plastic; clear wavy boundary; 50% channer >3/4" clear and stained skeletans.

IIB33ir 91-112 cm (36-44 in) yellowish brown (10 yr 5/6) sandy loam; yellowish brown (10 YR 5/6) dry; single grain, soft, very friable, nonsticky, nonplastic; clear irregular boundary, 80% gravel channers >3/4" few roots.

Vegetation: Pien, Abla, Pimo, Laoc, Pico, Psme, Xete, Vagl, Mefe.

Location: Wishard Cr. area, 8.9 mi from US #10, at Haugen on Middle Fork Big Creek Rd. Turn right and cross Wishard Cr and proceed 3.3 mi. Pit is to right of road when traveling west. Mineral County.

Remarks: Sample collected by Mueller, Thomas, Grossman, Lyman, Richlen, Mogan and Southard.

Wishard Silt Loam Aquic Cryoborolls; loamy-skeletal, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
A11	0-5 cm (0-2 in) very dark brown (7.5 YR 1/2) silt loam; v dk grayish brown (10 YR 3/2) dry; weak fine & medium granular structure; soft, very friable, nonsticky, nonplastic; common roots; common pores; few fragments; clear boundary.
A12	5-18 cm (2-7 in) very dark brown (7.5 YR 1/2) silt loam; brown (10 YR 4/3) dry; strong fine subangular blocky and moderate fine granular structure; slightly hard, friable, nonsticky, nonplastic; common roots; few fine pores; skeletans; slightly acid pH-6.2.

A13 18-30 cm (7-12 in) very dark brown (7.5 YR 2/4) silt loam; brown (7.5 yr 5/3) dry; weak fine granular structure; slightly hard, friable, nonsticky, nonplastic; common roots; skeletans; 10% fragments >2 cm; gradual boundary.

B21ir 30-51 cm (12-20 in) dark brown (7.5 YR 3/4) silt loam; lt. yellowish brown (10 YR 6/4) dry; moderate fine & medium granular structure; slightly hard, friable, slightly sticky, slightly plastic; common roots; common medium pores, many fine pores; many skeletans; clear irregular boundary.

B22ir 51-79 cm (20-31 in) yellowish brown (10 YR 5/6) gravelly loam; very pale brown (10 yr 7/4) dry; massive structure; slightly hard, very friable, slightly sticky, slightly plastic; few roots; many skeletans; 25% fragments, 10% fragments >25 cm; gradual boundary.

IIC1 117-157 cm (46-62 in) yellowish brown (10 YR 5/6) very gravelly loam; pale yellow (2.5 Y 7/4) dry; massive structure; hard, friable, slightly sticky, slightly plastic; few roots; 40% fragments >2 cm; clear boundary.

IIC2 157-193 cm (62-76 in) lt. yellowish brown (2.5 Y 6/3) very gravelly sandy loam; light gray (2.5 Y 7/2) dry; massive structure; skeletans on upper surfaces of peds; clear boundary.

Vegetation: Juoc, Pien, Acar, Rupa, Veca, Alsi, Caro and Acgl.

Location: On Moore Cr. Rd. 9.5 miles from U.S. Highway 10, 2.2 miles past junction with South Fork Little Joe Cr. Rd., Mineral County.

Felan Andic Cryochrepts; loamy-skeletal, mixed

Colors are for moist soil unless otherwise indicated

Horizon Profile Description

01 8-5 cm (3-2 in) forest litter undecomposed.

02 5-0 cm (2-0 in) black highly decomposed forest litter.

A2 0-8 cm (0-3 in) grayish brown (10 YR 5/2); silt loam; light gray (10 YR 7/2) dry; strong fine granular; soft, very friable, slightly sticky, slightly plastic; many very fine to coarse roots; many very fine and fine interstitial pores; pH-5.6; clear undulating boundary.

B2 8-20 cm (3-8 in) strong brown (7.5 YR 5/6) very fine sandy loam; reddish yellow (7.5 YR 7/5) dry; soft, very friable, nonsticky, nonplastic; many fine roots; many fine void interstitial pores; medium acid pH-5.6; clear wavy boundary.

IIA21b 20-38 cm (8-15 in) lt. yellowish brown (2.5 Y 6/3) gravelly loam; white (2.5 Y 8/2) dry; massive structure; slightly hard, friable, slightly sticky, slightly plastic; many fine roots; many fine pores, many void interstitial pores; 45% fragments; medium acid pH-5.8; clear smooth boundary.

IIA22b 38-58 cm (15-23 in) lt. yellowish brown (2.5 Y 6/4) gravelly loam; pale yellow (2.5 Y 7/3) dry; massive structure; slightly hard, friable, slightly sticky, slightly plastic; many fine roots; many fine pores, many void interstitial pores; 45% fragments; medium acid pH-5.8; diffuse boundary.

IIA23b 58-84 cm (23-33 in) lt. yellowish brown (2.5 Y 6/4) gravelly loam; pale yellow (2.5 Y 7/4) dry; massive structure; slightly hard, friable, slightly sticky, slightly plastic; many fine roots; many fine pores, may void interstitial pores; 40% fragments; neutral pH-7.0.

IIB21t 84-124 cm (33-49 in) light olive brown (2.5 Y 5/4) gravelly clay loam; olive yellow (2.5 Y 6/5) dry; massive structure; slightly hard, friable, sticky, plastic; common fine roots; many fine pores, many void interstitial pores; 40% fragments; mildly alkaline pH-7.6; gradual smooth boundary.

IIB22t 124-152 cm (49-60 in) light olive brown (2.5 Y 5/4) gravelly clay loam; pale yellow (2.5 Y 7/4) dry; massive structure; slightly hard, friable, sticky, plastic; few fine roots; many fine pores, many void interstitial pores; 40% fragments; moderately alkaline pH-8.2; clear wavy boundary.

Vegetation: Pien, Psme, Vagl, Pamy, and Chum.

Location: 1500 ft N, 1500 ft W of SE corner Sect 18 T15N, R16W, Missoula County.

Remarks: Described by: J. Purcell, H. Hunter, C. Mogen, K. Flack, July 22, 1970. S70Mt 32-2

Holloway Andic Cryochrepts; loamy-skeletal, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
O1	7-5 cm (3-2 in)
O2	5-0 cm (2-0 in)
A2	0-5 cm (0-2 in) dark grayish brown (10 YR 4/2); silt loam; light brownish gray (10 YR 6/2) dry; moderate fine and very fine granular; soft, very friable, slightly sticky, slightly plastic; many fine to coarse roots, many fine to very fine pores; 10% coarse fragments; pH-5.4; abrupt wavy boundary.
B2	5-25 cm (2-10 in) dark brown (10 YR 3/3) gravelly silt loam; yellowish brown (10 YR 5/4) dry; very weak very fine crumb structure; soft, very friable, nonsticky, nonplastic; fine roots; many fine pores, many pores; 25% fragments; medium acid pH-5.6; abrupt wavy boundary.
IIA21	25-81 cm (10-32 in) light brown (7.5 YR 6/3) very gravelly fine sandy loam; pinkish gray (7.5 YR 7/2) dry; massive structure; hard, friable, nonsticky, nonplastic; many fine roots; many fine pores; 60% fragments; strongly acid pH-5.4; gradual smooth boundary.
IIA22	81-140 cm (32-55 in) light brown (7.5 YR 6/4) very gravelly loam; pink (7.5 YR 7/3) dry; massive structure; hard, friable, nonsticky, nonplastic; many fine roots; many fine pores; 65% fragments; medium acid pH-5.6; gradual smooth boundary.
IIC1	140-157 cm (55-62 in) brown (7.5 YR 5/3) very gravelly fine sandy loam; pinkish white (7.5 YR 8/2) dry; massive structure; hard, friable, nonsticky, nonplastic; few fine roots; many fine pores; 70% fragments; medium acid pH-5.8.

Vegetation: Laoc, Psme, Pico, Xete, Vagl, Chum and Cage.

Location: 2400 ft W, 800 ft S of NE corner Sec 11, T14N, R17W, Missoula County.

Remarks: Described by: J. Purcell, H. Hunter, C. Mogen, K. Flack, July 28, 1970. S70Mt 32-6.

Spring Emery — Andic Cryochrepts; coarseloamy over sandy skeletal, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
B21	0-15 cm (0-6 in) brown (10 YR 4/3) gravelly silt loam; dark grayish brown (10 YR 4/2) dry; weak medium to coarse crumb; soft, very friable, nonsticky, nonplastic; common fine & medium roots; 30% fragments; gradual wavy boundary.
B22ir	15-23 cm (6-9) light olive brown (2.5 Y 5/4) crushed; very gravelly silt loam; pale yellow (2.5 Y 7/3) crushed dry; weak medium subangular blocky structure; slightly hard, friable, nonsticky, nonplastic; common fine & medium roots; 60 to 70% fragments; abrupt irregular boundary.
IIA2	23-58 cm (9-23 in) light olive brown (2.5 Y 5/3) crushed; very gravelly sandy loam; pale yellow (2.5 Y 7/3) crushed dry; massive structure; loose, friable, nonsticky, nonplastic; 65% fragments; not reached boundary.

Vegetation: Abla/Mefe.

Location: SW 1/4, NE 1/4, Sec 27, T7N, R8W, Powell County. Spring Creek-Emery Road.

Sugarloaf 1 Andic Cryochrepts; coarse loamy, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
O1	3-0 cm (1-0 in) decomposed forest litter.
O2	3-0 cm (1-0 in) decomposed forest litter.
B21	0-18 cm (0-7 in) brown (10 YR 4/3) crushed; gravelly silt loam; pale brown (10 YR 6/3) crushed dry; weak medium subangular blocky structure; soft, very friable, slightly sticky, slightly plastic; many fine & medium roots; 30% fragments, 5% fragments >25 cm; gradual smooth boundary.
IIB22	18-38 cm (7-15 in) brown (10 YR 5/3) crushed; very gravelly loam; light gray (10 YR 7/2) crushed dry; hard, firm, slightly sticky, slightly plastic; few roots; not reached boundary.

Vegetation: Abla, Alsi, Vasc.

Location: SW 1/4, NW 1/4, Sec 6, T7N, R7W, Powell County.

Remarks: Sample collected on Sugarloaf Mountain, October 29, 1975.

Elkner Variant 2 Andic Cryochrepts; coarse-loamy, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
B2ir	10-28 cm (4-11 in) brown (10 YR 4/3) crushed; silt loam; lt. yellowish brown (10 YR 6/4) crushed dry; very weak medium angular blocky structure; soft, very friable, slightly sticky, nonplastic; common roots; 5% fragments; abrupt boundary.
IIB3	28-53 cm (11-21 in) pale brown (10 YR 6/3) crushed; fine gravelly sandy loam; white (10 YR 8/2) crushed dry; massive structure; hard, friable, slightly sticky, slightly plastic; 40% fragments; not reached boundary.

Vegetation: Abla, Pien, Alsi, and Caca.

Location: Photo Point 1273-45-2, about 6.5 miles south of Skalkaho Pass, Granite County.

Remarks: Sample collected with Dave Ruppert.

Cabinet Andeptic Cryoboralfs; medial over clayey, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
B2ir	2-28 cm (1-11 in) strong brown (7.5 YR 4/5) crushed; silt loam; very pale brown (10 YR 7/4) crushed dry; weak fine subangular blocky structure; loose, very friable, nonsticky, nonplastic; many fine roots; firm fine iron-manganese concretions; abrupt smooth boundary.
IIA2	28-41 cm (11-16 in) pale brown (10 YR 6/3) silt loam; white (10 YR 8/2) dry; massive parting to moderate medium angular blocky structure; slightly hard, friable, slightly sticky, plastic; few fine roots; few fine tubular pores; 2% fragments; gradual wavy boundary.
IIB2+	41-79 cm (16-31 in) pink (7.5 YR 7/4) crushed; silty clay; few fine & medium mottles; strong medium & coarse angular blocky structure; very hard, firm, sticky, plastic; distinct light reddish brown (5 YR 6/3) clay skins; 1% fragments; gradual irregular boundary.

Vegetation: Juoc, Abgr, Laoc, Pimo, Potr, Syal, Rose Sp. Libo.

Location: 100 ft N and 100 ft W of intersection Highway 200 and Noxon Rapids Dam Road.

Remarks: Nimlos 1964 study site Sanders County.

Krause Andic Ustochrept; loamy skeletal, mixed, frigid

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
B21	3-25 cm (1-10 in) brown (7.5 YR 4/4) very gravelly sandy loam; light brown (7.5 YR 6/4) dry; weak fine crumb structure; soft, friable, nonsticky nonplastic; common, fine & medium roots; 70% fragments.
IIA&B	25-61 cm (10-24 in) pink (7.5 YR 7/4) very gravelly sandy loam; very pale brown (10 YR 8/4) dry; weak fine subangular blocky structure; slightly hard, friable, slightly sticky, nonplastic; >60% coarse fragments.

Vegetation: Thoc, Laoc, Pien, Abla, Psme, Acgl, Mare, Syal, Rupa, Vagl, Pamy and Libo

Location: NW 1/4, SW 1/4 Sec 1, T30N, R19W, Flathead County.

Remarks: Coram #12(19).

Elkner Variant 1 Andic Cryochrepts; coarse-loamy, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
B2ir	0-18 cm (0-7 in) dk. yellowish brown (10 YR 3/4) crushed; fine gravelly sandy loam; yellowish brown (10 YR 5/4) crushed dry; weak medium subangular blocky structure; soft, very friable, nonsticky, nonplastic; common roots; 20% fragments >2 mm; gradual boundary.
IIB3	17-28 cm (7-11 in) brown (10 YR 5/3) crushed; gravelly loamy sand; very pale brown (10 YR 7/3) crushed dry; massive structure; soft, loose, slightly sticky, nonplastic; few roots; 45% fragments; not reached boundary.

Vegetation: Abla/Vasc.

Location: Photo Point 1273-45-1, about 6 miles S of Skalkaho Pass, Granite County.

Remarks: Sample collected with Dave Ruppert.

Unnamed 5 Fluventic Eutrochrepts; coarse loamy, mixed acid

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
A1	0-5 cm (0-2 in) brown (7.5 YR 4/4) silt loam; moderate fine crumb structure; many roots; medium acid pH-5.8; abrupt smooth boundary.
B21	5-13 cm (2-5 in) dk. yellowish brown (10 YR 4/4) silt loam; brown (7.5 YR 4/4); weak medium granular structure; many roots; many fine pores; common faint cutans of unknown type in root channels and/or pores; slightly acid pH-6.2; abrupt smooth boundary.
B31	13-23 cm (5-9 in) brown (10 YR 5/3) crushed; sandy loam; brown (10 YR 5/3) crushed dry; weak subangular blocky structure; common roots; common fine pores; many black (10 YR 2/1) organic cutans, brown (7.5 YR 4/4) organic cutans; slightly acid pH-6.4; clear smooth boundary.
B32	23-51 cm (9-20 in) yellowish brown (10 YR 5/4) sandy loam; massive structure; common fine pores; common dark brown (7.5 YR 3/2) organic cutans; slightly acid pH-6.4 clear smooth boundary.
B33	51-64 cm (20-25 in) brown (10 YR 5/3) sandy loam; massive structure; few roots; few tubular pores; few dark brown (7.5 YR 3/2) organic cutans in root channels and/or pores; neutral pH-7.0; abrupt wavy boundary.
IIA21b	64-71 cm (25-28 in) pale brown (10 YR 6/3) sandy loam; weak medium platy structure; few roots; common coarse tubular pores, common vesicular pores; yellowish brown (10 YR 5/4) cutans of unknown type in root channels and/or pores lt. yellowish brown (10 YR 6/4) cutans of unknown type on horizontal ped faces; neutral pH-7.0; abrupt smooth boundary.

IIB22b 76-84 cm (30-33 in) brown (10 YR 5/3) silt loam; weak coarse subangular blocky structure; soft, friable, sticky, slightly plastic; few fine tubular pores, few fine vesicular pores; few faint white (10 YR 8/2) calcium carbonate cutans, grayish brown (10 YR 5/2) cutans of unknown type on vertical ped faces, grayish brown (10 YR 5/2) cutans of unknown type in root channels and/or pores; mildly effervescent; moderately alkaline pH-8.2; clear smooth boundary.

IIB31b 84-112 cm (33-44 in) grayish brown (2.5 Y 5/2) silt loam; massive structure; soft, friable, sticky, slightly plastic; few fine vesicular pores, few fine tubular pores; few dk. yellowish brown (10 YR 4/4) cutans of unknown type in root channels and/or pores; few fine iron-manganese concretions; mildly effervescent; moderately alkaline pH-8.2.

Vegetation: Laoc, Vasc, Aruv, Caru.

Location: 415 ft E, 480 ft S of NW corner of Sec 8, T29N, R26W Lincoln County.

Sugarloaf 2 Andic Cryochrepts; coarse loamy, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
Ó1	2-0 cm (2-0 in) decomposed forest litter.
02	2-0 cm (1-0 in) decomposed forest litter.
B2	0-20 cm (0-8 in) dark grayish brown (10 YR 4/2) crushed; gravelly sandy loam; light brownish gray (10 YR 6/2) crushed dry; weak medium subangular blocky structure; slightly hard, friable; slightly sticky, slightly plastic; common fine roots; gradual smooth boundary.
B3	20- cm (8-15 in) grayish brown (10 YR 5/2) crushed; very gravelly loam; light brownish gray (10 YR 6/2) crushed dry; hard, firm, slightly sticky, slightly plastic; few roots; 45% fragments; gradual smooth boundary.

Vegetation: Abla, Psme, Aruv.

Location: SW 1/4, NE 1/4, Sec 1, T7N, R8W, Powell County.

Remarks: Sample collected on Sugarloaf Mountain east of Deer Lodge on October 29, 1976.

Hilgard Lithic Cryorthent, fine loamy, mixed, shallow

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
B2ir	0-20 cm (0-8 in) brown (10 YR 4/3) crushed; silt loam; brown (10 YR 5/3) crushed dry; slightly hard, friable, slightly sticky, slightly plastic; few fragments; abrupt boundary.

Vegetation: Alpine turf.

Location: N 1/2 Sec 11, T10S, R2E, Gallatin County.

Remarks: Sample collected by Carl Davis.

Holloway Variant Typic Cryochrepts; loamy-skeletal, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
A2	2-13 cm (1-5 in) brown (7.5 YR 4/2) loam; pinkish gray (7.5 YR 6/2) dry; loose, friable, slightly sticky, slightly plastic; 5% fragments.
B2ir	13-33 cm (5-13 in) strong brown (7.5 YR 4/5) crushed; sandy loam; reddish yellow (7.5 YR 6/5) crushed dry; weak fine subangular blocky structure; loose, friable, slightly sticky, slightly plastic; gradual boundary.

IIB31 13-61 cm (5-24 in) brown (7.5 YR 5/4) crushed; gravelly sandy loam; very pale brown (10 YR 7/4) crushed dry; massive structure; soft, very friable, nonsticky, nonplastic; gradual boundary.

IIB32 61-97 cm (24-38 in) brownish yellow (10 YR 6/5) crushed; gravelly sandy loam; very pale brown (10 YR 7/4) crushed dry; massive structure; loose, friable, nonsticky, nonplastic.

Vegetation: Abla/Xete.

Location: NW1/4, NW1/4, NW1/4, Sec. 36, T2S, R19W, Beaverhead County.

Remarks: Sample collected with Roger Poff.

Elkner Sandy Loam Typic Cryochrepts; coarse-loamy, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
A1	0-3 cm (0-1 in) black (10 YR 2/1) sandy loam; dark grayish brown (10 YR 4/2) dry; moderate medium granular structure; many roots; abrupt wavy boundary.
B2	3-15 cm (1-6 in) brown (10 YR 5/3) sandy loam; light gray (10 YR 7/2) dry; moderate to strong medium granular structure; soft, friable, nonsticky, nonplastic; many fine roots; faint skeletans on sand and gravel; clear wavy boundary.
B31	15-30 cm (6-12 in) pale brown (10 YR 6/3) sandy loam; light gray (10 YR 7/2) dry; weak coarse subangular blocky structure; soft, very friable, nonsticky, nonplastic; common roots; few fine pores; yellowish brown (10 YR 5/4) skeletans on sand and gravel; 5% fragments >2 cm; gradual wavy boundary.
B32	30-46 cm (12-18 in) pale brown (10 YR 6/3) sandy loam; light gray (10 YR 7/2) dry; massive structure; few fine roots; yellowish brown (10 YR 5/4) skeletans on sand and gravel; abrupt wavy boundary.

C1 46-107 cm (18-42 in) light gray (10 YR 6/1) loamy sand; light gray (10 YR 7/1) dry; weak, fine crumb structure; loose, very friable, nonsticky, nonplastic; few roots; clear irregular boundary.

Vegetation: Abla, Psme, Pico originally; now Pipo Plantation.

Location: Near Sec 25, T3N, R19W, Ravalli County, Near Rye Cr.

Remarks: Rye Creek No. 1 -- Ponderosa Pine Improvement Study S74Mt 81-1. From the Sleeping Child Burn.

Unnamed 2 Typic Cryorthents; mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
B2	0-15 cm (0-6 in) brown (7.5 YR 4/2) silt loam; light brownish gray (10 YR 6/2) dry; weak medium angular blocky parting to moderate medium granular structure; slightly hard, friable, nonsticky, nonplastic; 5% fragments; abrupt wavy boundary.
IIC1	15-73 cm (6-29 in) grayish brown (2.5 Y 5/2) loam; lt. yellowish brown (2.5 Y 6/3) dry; weak medium angular blocky parting to weak medium granular structure; slightly hard, friable, nonsticky, nonplastic; 40% fragments; clear smooth boundary.
IIIC2	73-101 cm (29-40 in) light olive brown (2.5 Y 5/3) silty clay loam; light brownish gray (2.5 Y 6/2) dry; weak medium angular blocky structure; hard, friable, sticky, plastic; 20% fragments; moderately effervescent (HCL); clear wavy boundary.

Vegetation: Abla and Pien.

Location: SW 1/4, SE 1/4, Sec 10, T6N, R10E, Meagher County, near West Fork Cottonwood Creek.

Remarks: Sample collected by Herb Holdorf.

Unnamed 1 Typic Cryochrepts; fine silty, mixed

Colors are for moist soil unless otherwise indicated

Horizon	Profile Description
B2	0-15 cm (0-6 in) brown (7.5 YR 4/4) silty clay loam; light brown (7.5 YR 6/3) dry; weak medium angular blocky parting to moderate fine granular structure; slightly hard, friable, slightly sticky, slightly plastic; 15% limestone fragments; noncalcareous (HCL); abrupt wavy boundary.
IIB2	15-100 CM (6-39 in) brown (7.5 YR 5/4) clay loam; light brown (7.5 YR 6/3) dry; moderate medium angular blocky parting to moderate fine angular blocky structure; slightly hard, friable, slightly sticky, slightly plastic; 60% limestone fragments; moderately effervescent; clear smooth boundary.
IICca	100-150 cm (39-59 in) light brown (7.5 YR 6/4) clay loam; pale brown (10 YR 6/3) dry; weak fine angular blocky structure; slightly hard, friable, nonsticky, nonplastic; prominent calcium carbonate cutans on lower surfaces of fragments, prominent calcium carbonate cutans throughout the soil.

Vegetation: Pico.

Location: SW 1/4, SW 1/4, Sec 23, T12N, R8E, Meagher County, Near junction Deadman and Sheep Creek.

Remarks: Sample collected by Herb Holdorf.

Table 19. Chemical Properties by Horizon.

		Horizon	Depth (cm)		Fe*	Mn*	Cu*	Zn*	Ca	Mg	Na	K	P*	N	pH	CEC (pH7)	CEC (pH8.2)
					ppm				me/100g				ppm	%		me/100g	
GROUP 1	Buckhouse#	A11	0	10	41	128	6	-	6.2	1.0	tr	1.2	120	.634	4.8	23.0	31.8
		A12	10	23	28	90	4	2.3	4.6	.7	tr	1.2	124	.432	5.1	19.9	26.8
		A13	23	41	28	52	3	1.9	2.7	.6	tr	.8	156	.361	5.3	17.6	21.6
		A14	41	58	28	52	3	1.3	2.6	.6	tr	.7	212	.342	5.3	15.2	19.4
		B21ir	58	79	21	34	2	.7	.9	.4	tr	.5	220	.218	5.4	11.7	14.6
		B22	97	127	19	52	4	1.7	.6	.4	tr	.4	46	.056	5.3	5.7	7.1
		C	127	182	20	16	9	4.0	.5	.2	tr	.5	37	.010	5.3	5.3	6.7
	Unnamed 3*	B21	1	20	28	8	1	.4	1.5	.3	.4	.4	96	.050	6.7	-	14.2
		B22	20	56	31	6	1	.3	.4	.1	.3	.3	99	.020	6.3	-	16.0
		IIA2	56	74	23	1	1	.2	.6	.2	.3	.1	6	.020	6.1	-	3.1
		IIAB	74	94	-	-	1	-	.7	.3	.3	.1	4	.010	6.1	-	-
	Unnamed 4*	B21	0	23	31	5	-	.6	5.4	.7	.3	.4	430	.040	6.4	-	13.1
		B22	23	56	34	4	-	1.6	6.4	.6	.3	.4	220	.060	6.2	-	12.6**
	Truefissure#	B21ir	3	13	28	34	2	.8	1.5	.8	.1	.5	107	.131	5.8	14.7	21.3
		B22ir	13	25	15	8	tr	.2	1.1	.6	.1	.4	99	.092	6.0	11.5	19.4
		B23ir	25	41	30	17	2	.6	2.1	.8	tr	.3	16	.010	5.3	9.5	10.5
		IIB31ir	41	61	23	5	7	2.0	1.4	.6	tr	.2	19	.010	5.3	8.0	8.9
		IIB32ir	61	91	22	6	5	1.5	1.0	.5	tr	.1	24	.030	5.3	7.3	4.1
GROUP 2	Wishard #	A11	0	5	129	128	3	-	33.9	1.9	tr	.5	78	.390*	5.4	41.4	43.5**
		A12	5	18	61	52	3	1.2	20.9	1.2	tr	.4	44	.240*	5.5	30.2	36.7**
		A13	18	30	24	19	1	.6	11.3	.7	tr	.3	26	.130*	5.9	19.8	24.5**
		B21ir	30	51	23	6	3	.8	8.7	.4	tr	.1	10	.083	6.0	13.6	17.2**
		B22ir	51	79	19	5	2	.7	9.3	.5	tr	tr	9	.049	6.1	12.2	14.9**
	Felan+	B2	8	20	55	71	1	1.1	3.4	.6	.1	.8	275	.101*	5.3	27.7	24.7
		IIA21	20	38	-	-	tr	.4	4.5	1.1	.1	.3	21	.087*	3.2	13.3	13.8
		IIA22	38	58	23	12	tr	.2	10.8	1.1	.1	.2	2	.010*	6.0	14.7	13.3
	Holloway+	B2	5	25	68	90	tr	1.2	3.3	1.2	.1	.8	201	.096	5.5	18.0	17.3
		IIA2b	25	81	49	5	tr	.2	1.7	.8	.1	.1	35	.016	5.6	4.4	4.6
	Spring Emery*	B21ir	0	15	96	260	8	-	4.2	.5	.5	.9	1200	.050	5.4	-	34.9
		B22ir	15	33	56	34	2	.4	3.8	.4	.5	.6	1200	.020	6.2	-	33.5
		IIA2	33	58	25	9	2	.3	-	1.6	.4	.3	58	.050	6.5	-	14.6

Table 19 Continued

		Horizon	Depth (cm)		Fe*	Mn*	Cu*	Zn*	Ca	Mg	Na	K	P*	N	pH	CEC (pH7)	CEC (pH8.2)
					ppm				me/100g				ppm	%		me/100g	
GROUP 2 continued	Sugarloaf 1*	B2	0	18	67	12	1	.5	3.8	.5	.4	.3	536	.010	5.8	-	17.2
		IIB	18	38	74	12	1	.5	8.1	1.9	.4	.2	115	.040	6.4	-	16.9
	Elkner V2*	Bir	10	28	109	71	.3	.4	3.0	.4	.6	.2	194	.060	5.5	-	41.7
		IIB	28	53	56	1	.4	.3	2.3	.4	.4	tr	19	.010	5.6	-	5.7
	Cabinet*	Bir	2	28	85	34	.6	.5	3.8	.5	.6	.6	275	.090	5.7	-	24.7
		IIA2	28	41	49	8	1.2	.4	4.6	1.5	.4	.3	11	.020	5.4	-	10.1
		IIB2+	41	79	45	8	1.5	.4	7.3	4.6	.4	.4	24	.020	5.2	-	16.7‡
	Krause*	B21	3	25	112	52	.8	1.5	8.4	1.1	.3	.9	28	.082	6.3	-	24.4
		IIA+B	25	61	55	60	1.4	.5	4.2	.8	.3	.2	2	.040	6.6	-	8.5
	Elkner V1*	B21	0	18	68	90	.5	.6	.7	.1	.5	.19	137	.030	5.2	-	13.6
		IIB3	18	28	20	2	0	.3	.7	tr	.5	tr	46	.020	6.1	-	2.3
	Unnamed 5	A1	0	5	252	165	1.5	-	16.7	3.0	.5	.8	78	.140	5.7	-	36.6
		B21	5	13	93	34	.8	.7	8.1	1.5	.5	.8	339	-	6.1	-	17.3
		B31	13	23	68	19	1.4	.4	6.5	1.3	.5	.8	194	.030	6.0	-	16.0
		B32	23	51	17	4	1.2	.2	6.5	1.1	.5	.5	35	.050	6.7	-	9.2
GROUP 3	Sugarloaf 2*	B2	0	20	151	90	1.3	.9	7.3	1.5	.4	.5	372	-	5.6	-	20.8
		B3	20	45	67	16	1.2	.3	10.0	2.0	.4	.4	124	.080	6.1	-	17.0
	Hilgard*	B2	0	20	63	6	1.2	.4	4.6	1.3	.4	.2	11	.050	5.6	-	22.4
	Holloway V*	A2	0	25	96	203	1.0	2.0	1.9	.3	.5	.2	88	.060	4.9	-	10.2
		B21ir	5	13	75	6	.3	.3	.7	.1	.5	.1	124	.040	5.1	-	9.3
		IIB31	13	61	26	1	.3	.2	1.1	.1	.4	tr	24	.020	5.4	0	5.2
	Elkner*	A1	0	3	14	203	.7	-	11.2	1.7	.3	.8	96	.120	6.0	-	21.4
		B2	3	15	14	627	.4	.5	2.7	.5	.2	.7	177	.110	5.8	-	10.1
		B31	15	30	-	356	.1	.2	2.6	.7	.3	.2	43	.060	6.0	-	6.1
	Unnamed 2	A2	0	15	151	52	1.2	1.5	9.1	2.0	.3	1.2	219	.050	5.8	-	15.5
		IIC	15	73	34	5	1.6	.2	10.2	2.5	.3	.5	43	.010	6.1	-	16.7
	Unnamed 1*	A2	0	15	68	5	1.2	.6	15.0	1.8	.3	.4	32	.010	6.2	-	14.5**
		IIB2	15	100	15	5	2.0	.3	34.0	1.2	.3	.2	11	.020	7.1	-	13.1**

Analysis by *Montana State University Soil Testing Lab, ‡Author, **Murray Klage's Lab, +Soil Conservation Service-Riverside, #Soil Conservation Service-Lincoln

Table 20. Physical Properties by Horizon.

	Horizon	Sand	Silt (%)	Clay	Bulk Density (g/cc)	1/3BW	15BW	PAW
Buckhouse#	A11	40	49	11	-	-	10.9	-
	A12	43	48	9	.78	22.6	11.2	11.4
	A13	40	51	9	.79	22.2	10.4	11.8
	A14	40	52	8	.70	-	9.0	-
	B21ir	39	54	7	.70	-	6.5	-
	B22	46	50	4	.90	-	3.2	-
	C	36	59	5	1.60	-	3.1	-
Unnamed 3*	B21	24	62	14	-	48.9**	10.8**	38.1
	B22	21	75	4	-	62.6**	22.8**	39.8
	IIA2	43	49	8	-	19.6**	3.0**	16.6
	IIA+B	-	-	-	-	21.7**	5.2**	16.5
Unnamed 4**	B21	18	69	13		55.7**	10.7**	45.0
	B22	17	77	6		53.4**	13.4**	40.0
Truefissure#	B21ir	24	70	6	.68	47.2	11.8	35.4
	B22ir	28	67	5	.75	42.0	10.8	31.2
	B23ir	36	55	9	1.29	22.5	5.4	17.1
	IIB31ir	48	47	5	1.38	20.1	3.6	16.5
	IIB32ir	59	37	4	1.40	-	3.0	-
Wishard+	A11	17	66	18	.60	64.3**	40.7	23.6
	A12	20	64	17	.86	49.7	14.6	35.1
	A13	21	67	12	.80	51.5	9.9	41.6
	B21ir	25	65	10	1.25	24.4	5.8	18.6
	B22ir	37	60	3	1.34	20.4	4.0	16.4
Felan+	B2	33	64	3	.71	30.8	12.1	18.7
	IIA21	23	58	19	.88	29.9	5.9	24.0
	IIA22	29	60	11	1.25	24.0	6.8	17.2
Holloway	B2	27	63	10	.87	13.1	9.5	3.6
	IIA2b	56	39	5	-	15.1	2.8	12.3

Table 20 Continued

	Horizon	Sand	Silt (%)	Clay	Bulk Density (g/cc)	1/3BW	15BW	PAW
Spring Emery**	B21ir	34	55	11	.90	59.2	20.5	38.7
	B22ir	36	51	13	.90	62.0	18.5	43.5
	IIA2	70	23	7	-	20.4	6.4	14.0
Sugarloaf 1**	B2	36	54	10	.93	36.9	12.2	24.7
	IIB	67	25	8	-	24.1	8.7	13.4
Elkner V2**	Bir	21	62	17	-	65.9	28.0	37.9
	IIB	57	36	7	-	17.9	2.0	15.9
Cabinet**	Bir	53	38	9	-	46.4	13.9	32.5
	IIA2	32	53	15	-	28.5	7.5	21.0
	IIB2+	7	43	50	-	35.6	16.2	19.4
Krause**	B21	58	29	13	-	26.2	8.8	17.4
	IIA+B	55	35	10	-	8.4	4.1	4.3
Elkner V1**	B21	57	32	11	-	23.7	8.8	14.9
	IIB3	84	13	3	-	10.8	1.5	9.3
Unnamed 5**	A1	26	61	13	-	64.5	23.9	40.6
	B21	24	65	11	-	43.6	13.1	30.5
	B31	20	69	11	-	44.7	12.6	32.1
	B32	-	-	-		33.6	7.7	25.9
Sugarloaf 2**	B2	58	30	12	1.14	26.0	10.7	15.3
	B3	41	44	15		19.2	8.5	10.7
Hilgard**	B2	17	58	25	-	35.4	13.9	21.5
Holloway*	A2	47	45	8	-	30.2	8.3	21.9
	B21ir	57	33	10	1.25	17.8	6.7	11.1
	IIB31	71	23	6	-	9.0	2.5	6.5
Elkner**	A1	65	27	8	-	-	-	-
	B2	68	23	9	-	-	-	-
	B3	82	12	6	-	-	-	-

Table 20 Continued

	Horizon	Sand	Silt (%)	Clay	Bulk Density (g/cc)	1/3BW	15BW	PAW
Unnamed 2**	A2	29	48	24	-	33.2‡	8.6‡	24.6
	IIC	31	39	30	-	22.0‡	7.7‡	14.3
Unnamed 1**	A2	13	56	31	-	31.7‡	17.4*	14.3
	IIB2	39	39	22	-	32.1‡	12.3*	19.8

Analysis by: *Montana State University Soil Testing Lab, ‡ Author, **Murray Klage's Lab, +Soil Conservation Service-Riverside, #Soil Conservation Service-Lincoln.

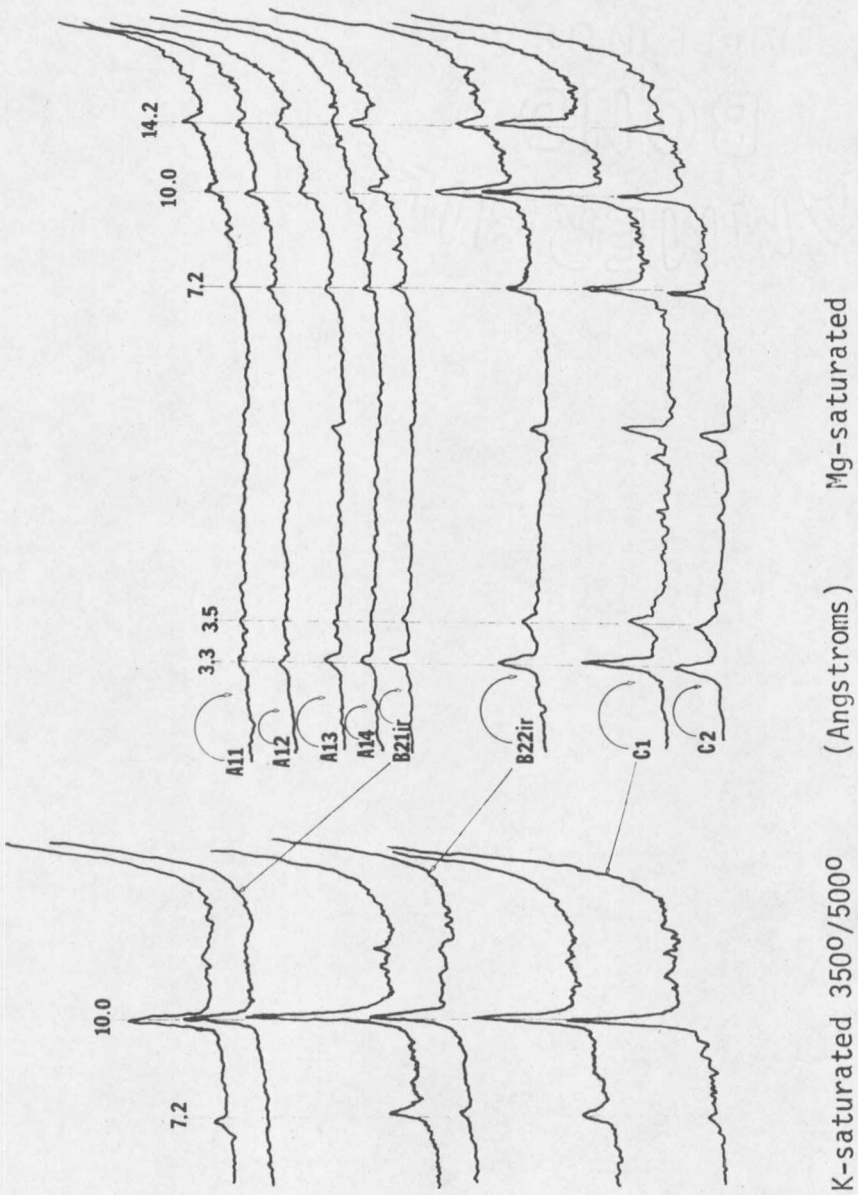


Figure 9. X-ray diffraction patterns, Buckhouse

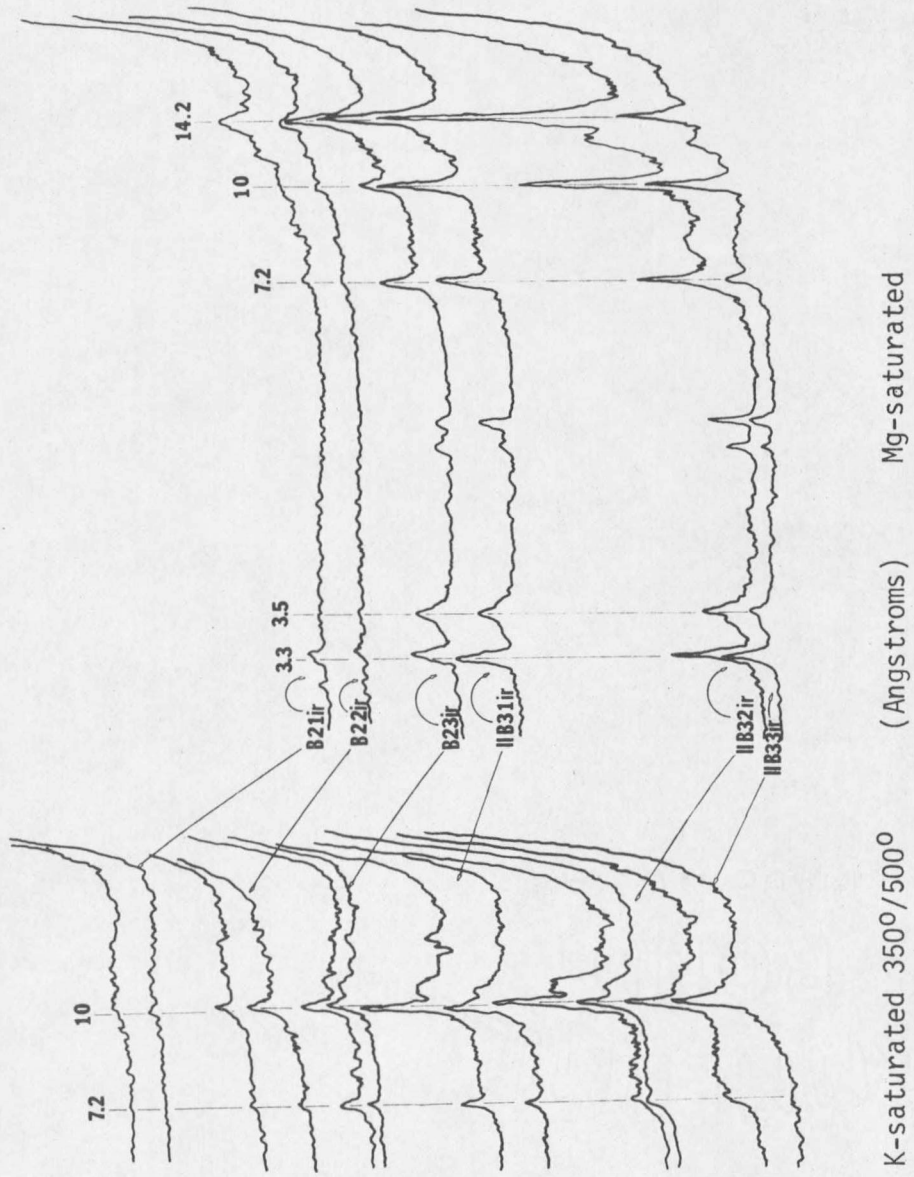


Figure 10. X-ray diffraction patterns, Truefissure

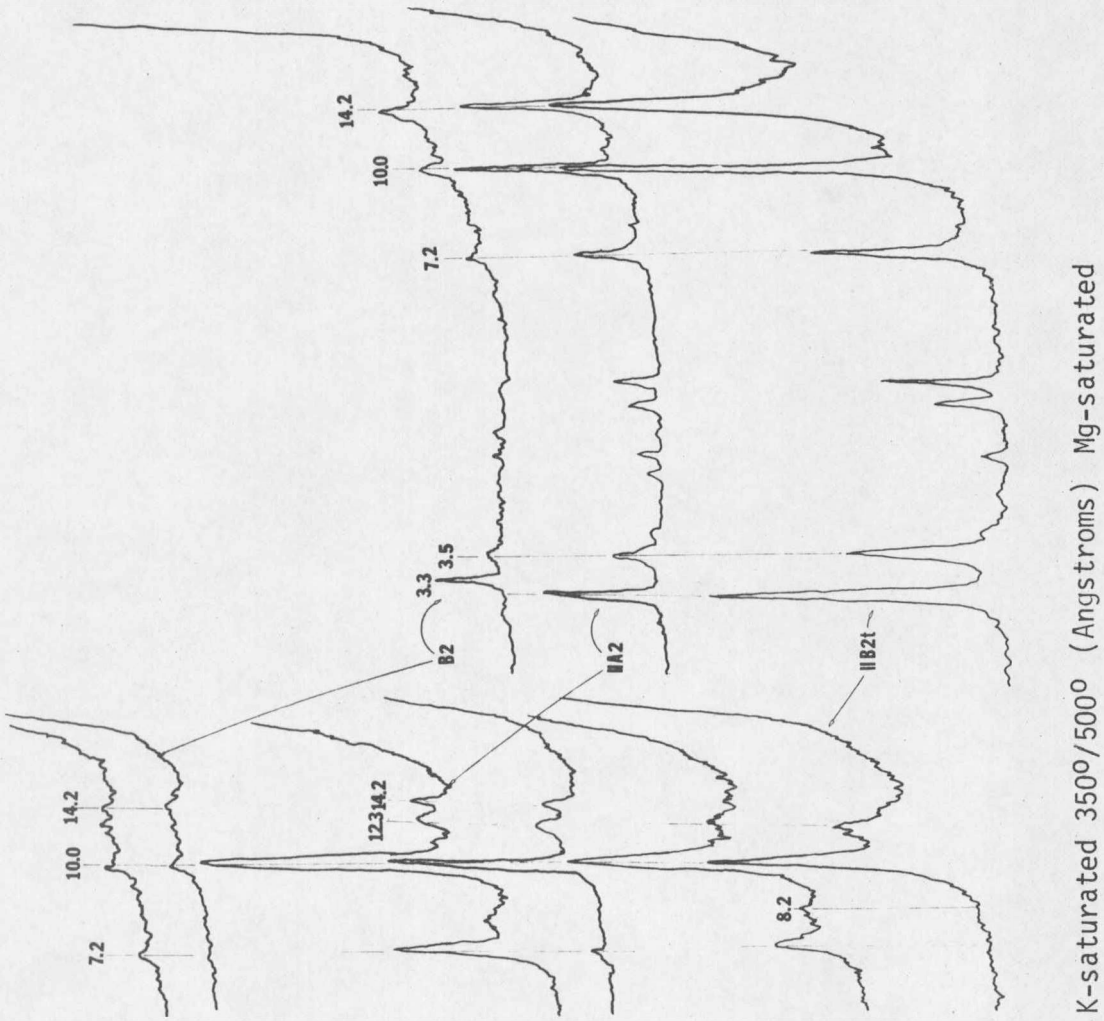


Figure 11. X-ray diffraction patterns, Cabinet

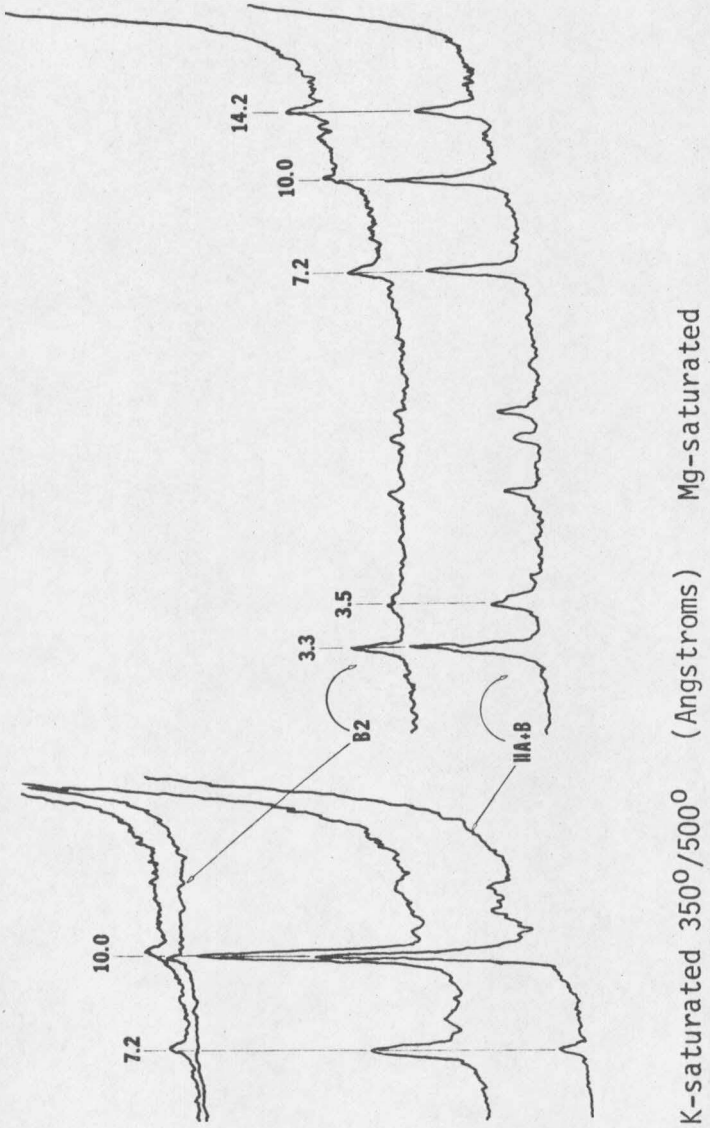


Figure 12. X-ray diffraction patterns, Krause

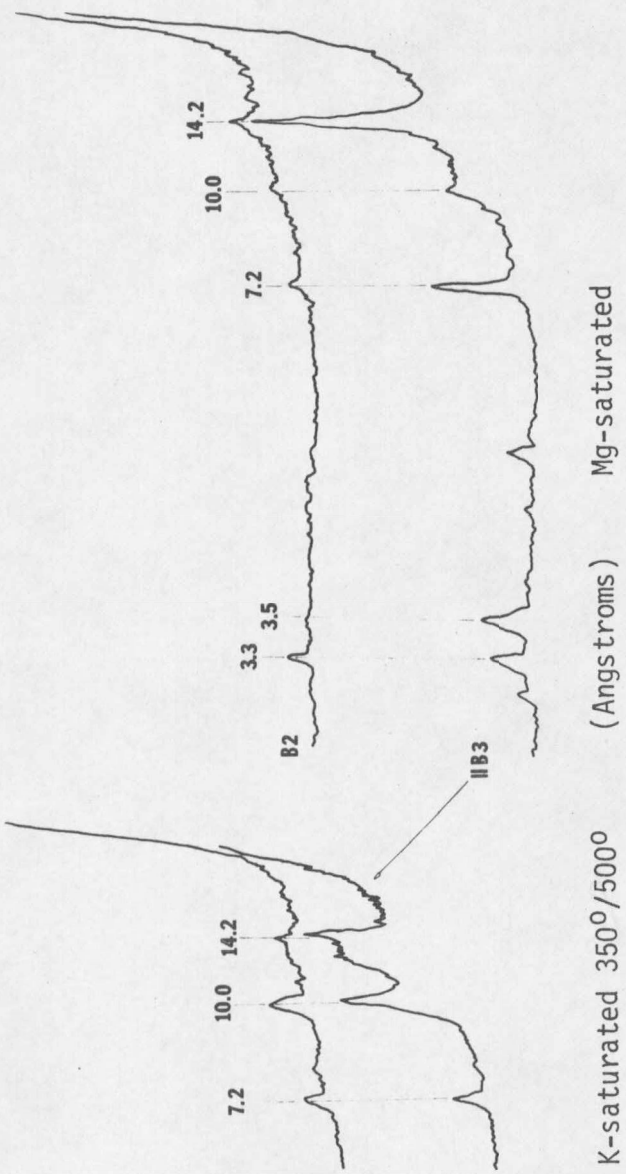


Figure 13. X-ray diffraction patterns, Sugarloaf 1

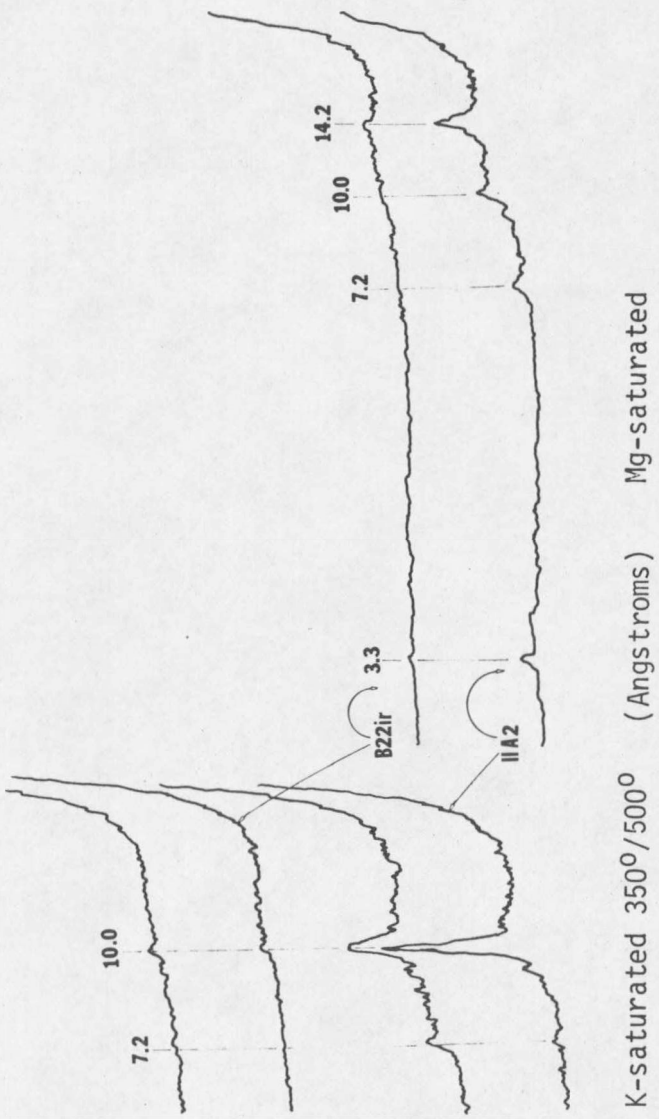


Figure 14. X-ray diffraction patterns, Spring Emery

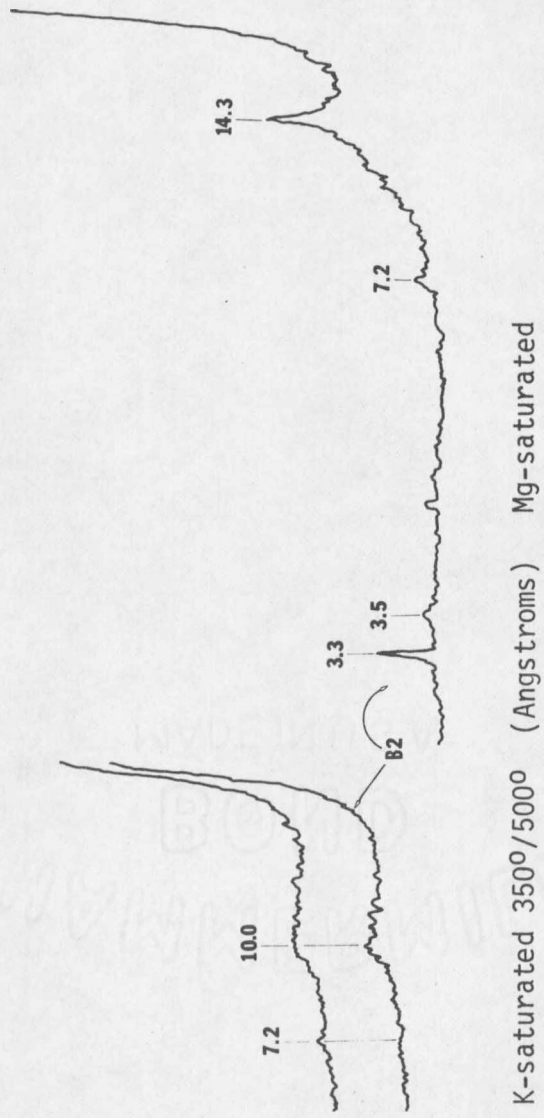


Figure 15. X-ray diffraction patterns, Hilgard

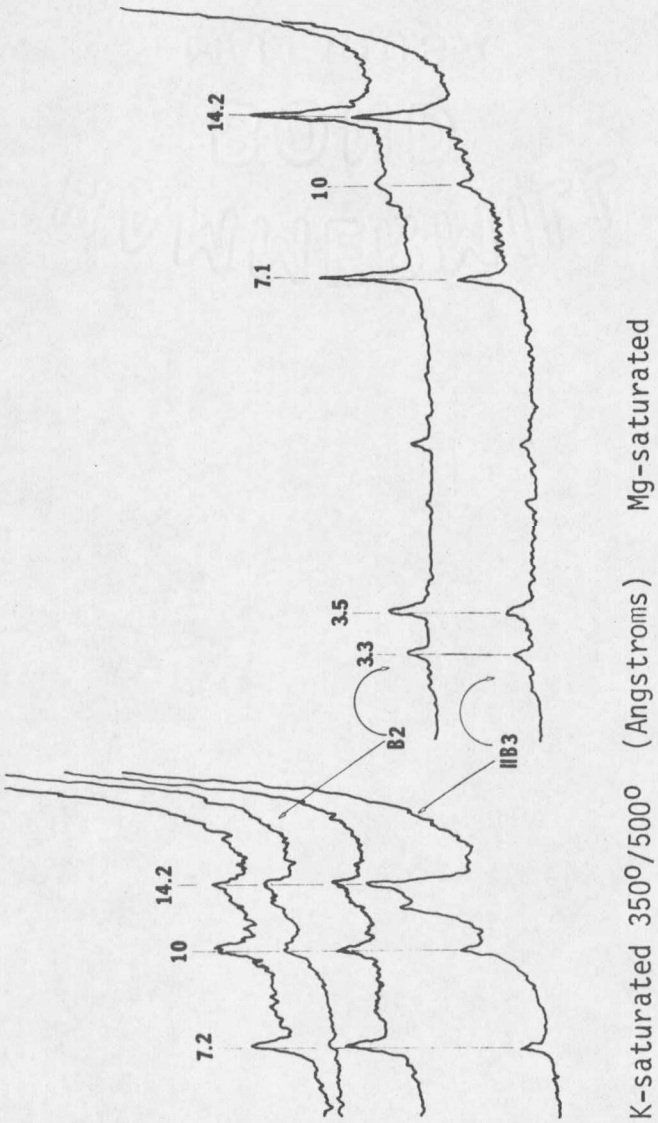


Figure 16. X-ray diffraction patterns, Sugarloaf 2

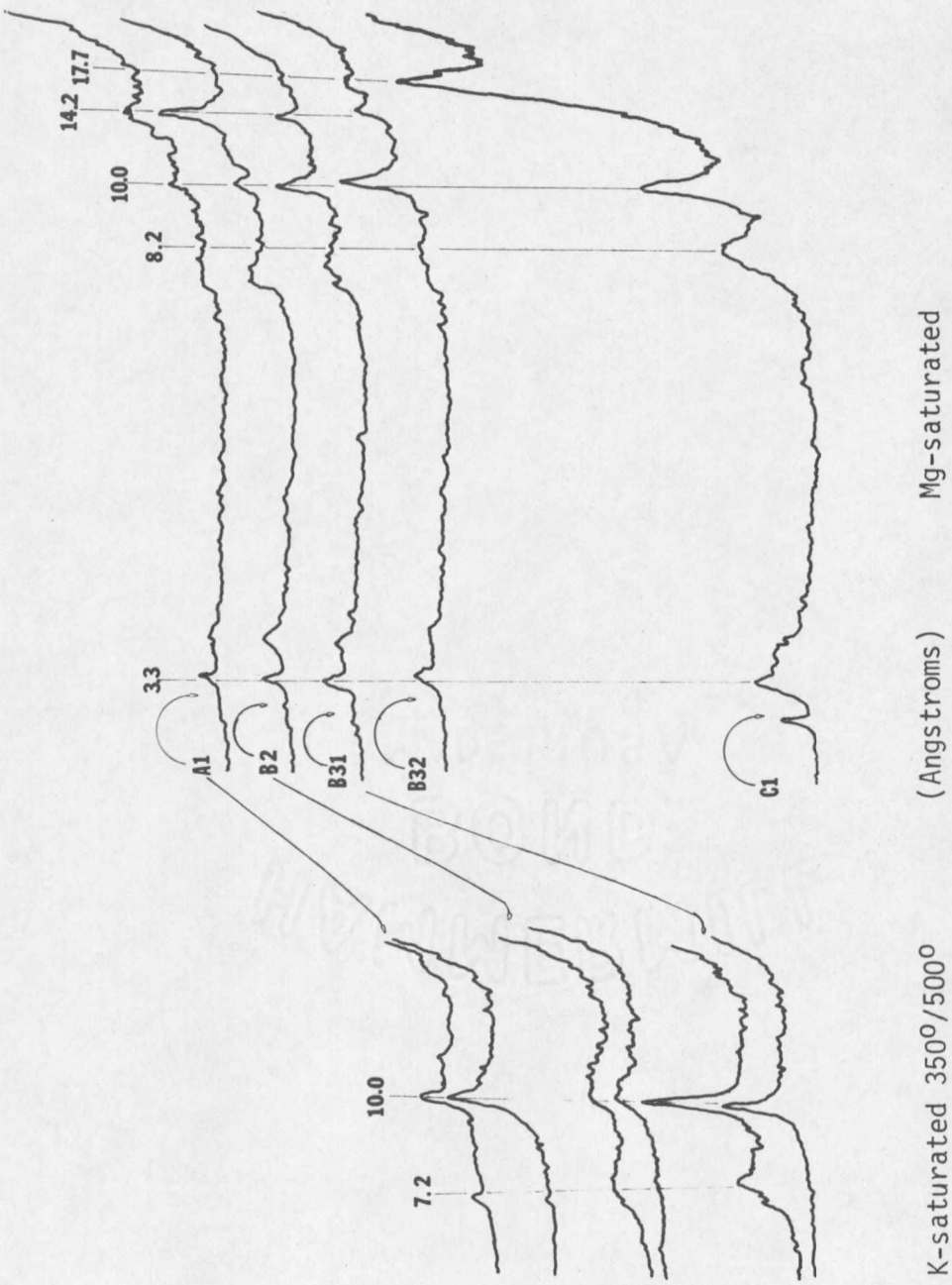


Figure 17. X-ray diffraction patterns, Elkner

APPENDIX 4

Unpublished Preliminary Data from the
Soil Conservation Service

Table 21. Volcanic Ash Influenced Soil Series in Montana Recognized by SCS.

	Previous Classification	Present Classification
At suborder level:		
Buckhouse	Chernozem	Typic Cryandept
Truefissure	Brown Podzolic	Entic Cryandept
Hebgen	Grey Wooded	Entic Cryandept
Coerock	Lithosols	Lithic Cryandept
At subgroup level:		
Blackburn	Brown Podzolic	Andic Cryochrept
Craddock	Brown Podzolic	Andic Cryochrept
Felan	Brown Podzolic inter-Gray Wooded	Andic Cryochrept
Holloway	Brown Podzolic	Andic Cryochrept
Upsata	Brown Podzolic	Andic Cryochrept
Wessell	Brown Podzolic	Andic Cryochrept
Elkner	Brown Podzolic	Andic Cryochrept
Bata	Brown Podzolic inter-Gray Wooded	Andeptic Cryoboralf
Savenac	Brown Podzolic	Andeptic Cryoboralf
Sherlock	Brown Podzolic	Andeptic Cryoboralf
Tenibac	----------	Andeptic Cryoboralf
Tamely	Brown Podzolic	Andeptic Cryorthent
Waits	Podzols	Andic Xerochrept
Nevine	Brown Podzolic	Andic Xerochrept
Totelake	Brown Podzolic	Andic Ustochrept
Krause	Brown Podzolic	Andic Ustochrept

UNITED STATES GOVERNMENT MEMORANDUM

To: Herschell D. Hurd, State Conservationist
SCS, P. O. Box 855, Bozeman, Montana
ATTN: Dave R. Cawlfield, State Soil Scientist

Date: March 25, 1963

From: Robert B. Grossman, Head, Soil Survey Laboratory, SCS,
4th Floor, 1325 "N" Street, Lincoln 8, Nebraska

Subject: Granite and Missoula Counties, Montana--Sand Mineralogy

I have examined the sands from the particle-size analysis for the soils sampled in Granite and MIssoula Counties in 1961. Unless indicated otherwise, the observations pertain to the very fine sand fraction. We hope to do a little clay mineralogical work in cooperation with John Cady, the results of which will be sent later.

Quartz commonly runs about 50 percent in most horizons examined. From 10 to 30 percent of the grains are identified feldspar*. Ferromagnesian minerals (amphibole, pyroxene) and the epidote-zoisite group are very scarce. Mica is rare except in the lower part of Loberg 20-4. Grains of what will be referred to as highly altered feldspar are abundant. These grains appear to be composed largely of clay-size minerals, and in most instances they cannot be identified as altered feldspar except by inference. In many instances, the grains consist of an intergrowth of altered feldspar and quartz. These grains of highly altered feldspar (or grains with parts of highly altered feldspar) account for from 15 to over 50 percent of the very fine sand. Fairly fresh feldspar occurs in association with all gradations to the highly altered feldspar.

The alteration of the feldspar shows little change with depth. Apparently the alteration pattern as observed today is largely inherited from the parent material, and pedogenic weathering may actually be slight even though the sola show evidence of strong mineral alteration. I suspect that the alteration of the feldspar is due in part to very low-grade metamorphism of the sedimentary rock. Probably the extent of feldspar alteration for a particular profile depends on the extent to which low-grade metamorphism has affected the parent material. In general the soils that contain fragments of reddish sandstone, as opposed to gray siltstone(?), have more quartz and a lower proportion of highly altered feldspar. In passing, it should be noted that these highly altered grains may have some cation exchange capacity. This could lead to higher apparent clay exchange capacity (calculated by dividing the measured cation exchange capacity by the clay percentage) than the true value. The difference between the apparent and true values would be larger for horizons low in clay.

By identified feldspar I mean grains that are fresh enough to be identified as feldspar from crystal form, index of refraction, twinning, or a combination.

Of particular interest is the abundance of glass shards in the upper two mineral horizons (Bir) of Holloway and the essential absence below. (The other soils all contain some glass shards in the upper surface and second horizons but not in excess of 10 percent.) As seen under the stereoscopic microscope, the sands of the Bir contain an abundance of brownish porous aggregates. These aggregates may have considerable exchange capacity and contribute substantially to the high apparent exchange capacity of the clay of these horizons.

The following are observations on the individual soils:

Greenough - Quartz subordinate to highly altered feldspar. Several percent glass shards in surface horizon. Ferromagnesian minerals and epidote-zoisite are very scarce. A few grains of tourmaline occur. Some of the identified feldspar is probably albite. As seen under the stereoscopic microscope, 15345 and 15348 of 32-1 contain numerous brownish, porous aggregates.

Holloway - Estimate 60 percent glass shards in surface and 50 percent in subsurface mineral horizons of 32-5, and 80 and 60 percent in comparable horizons of 32-6. Only an occasional shard in the third horizon and essentially none below that. Many of the shards are cracked and furrowed (look like tree bark), and most have solution embayments. Quartz, highly altered feldspar and identified feldspar are the three major constituents below the second horizon. Many grains appear to consist of an intergrowth of quartz and highly altered feldspar. Very few ferromagnesian minerals. A few muscovite(?) grains in 32-6.

Loberg - Several observations made with the stereoscopic microscope may be pertinent. The coarser sand fractions are largely reddish brown sandstone instead of grayish siltstone as in Greenough and Holloway. A higher proportion of well rounded grains occur than in Greenough and Holloway. A golden-colored micaceous mineral occurs in the lower part of 20-4.

Estimate about 50 percent quartz, 20 percent highly altered feldspar and 20 percent identified feldspar. Quartz occurs more commonly as discrete grains rather than as an intergrowth with highly altered feldspar. Probably a smaller percentage of highly altered feldspar than in Greenough and Holloway. A few amphibole in upper two horizons; very scarce below. Surface horizon contains 5 to 10 percent glass shards and the subsurface 2 to 5 percent in 20-3; comparable horizons of 20-4 contain somewhat less. Very little glass occurs below the second horizon. In profile 20-4, micaceous grains appear in 15423, reach 20 to 30 percent by 15426, and then drop sharply back in 15427. 15427 is high in grains of highly altered feldspar. The mineralogy suggests two lithological discontinuities; across 15423, and between 15426 and 15427. An increase in the apparent exchange capacity of the clay in the lower part of 20-4 coincides with the increase in micaceous grains.

3 - Herschell D. Hurd, March 25, 1963

Philipsburg - Stereoscopic microscope: The coarser sand is dominated by fragments of reddish sandstone. Many of the coarser grains are quite well rounded.

Quartz, identified feldspar, and highly altered feldspar in that order predominate. Perhaps a somewhat lower proportion of highly altered feldspar than in Greenough, Holloway, or Loberg. All accessory minerals very minor. About 5 percent glass shards in surface horizon of 20-5 and somewhat less in 20-6; very little below the surface horizon. A few grains of primary carbonate occur in the lower horizons.

Pintlar - Stereoscopic microscope: Profile 20-1 contains more reddish brown sandstone than does 20-2.

About 40 to 50 percent quartz, 30 to 40 percent highly altered feldspar and 20 percent identified feldspar. 5 percent glass shards in surface of 20-1 and 5 to 10 percent in 20-2; the respective subsurface horizons contain less than half that in the surface. Accessory minerals are very scarce. A substantial part of the identified feldspars are probably albite. The surface horizon of 20-2 contains more epidote than horizons below. Both profiles contain a trace of mica.

Tarkio - There is so little sand and coarse silt that microscopic observations are of doubtful value. The very fine sand has a mineralogy essentially similar to the other soils. One difference is somewhat more glass shards in the surface horizon than for the other profiles with the exception of Holloway. The surface horizons are relatively rich in plant opal, particularly in the coarse silt fraction. Elongate grains predominate in the fine silt.

Yourame - Stereoscopic microscope: The coarser sand dominantly gray siltstone or sandstone that shows schistosity.

About 50 percent quartz, decreasing below 15394 and reaching a low of 20 percent in the bottom horizon. Most of the non-quartz grains are highly altered feldspar intergrowths with quartz or discrete grains of highly altered feldspar. The surface horizon contains 10 percent glass shards and the subsurface 5 percent, with little glass below. Essentially no ferromagnesian minerals are present. Some of the identified feldspar is relatively fresh. The bottom horizon contains mainly highly altered feldspar. The high proportion of highly altered feldspar and the apparent schistasity of the coarser sands may be related. The high apparent exchange capacity, particularly for the bottom horizon, may be the result of an exchange capacity contribution from grains of highly altered feldspar in the non-clay fraction.

cc: C. A. Mogen
F. J. Carlisle
A. R. Aandahl
J. G. Cady
L. T. Alexander
G. D. Smith
R. W. Simonson
W. M. Johnson
A. H. Post

UNITED STATES GOVERNMENT MEMORANDUM

To: Herschel D. Hurd, State Conservationist, SCS, P. O. Box 855, Bozeman, Montana 59715
ATTN: Dave R. Caulfield, State Soil Scientist

Date: July 7, 1965

From: Robert B. Grossman, Head, Soil Survey Laboratory, SCS, 4th Floor, 1325 "N" Street, Lincoln, Nebraska 68508

Subject: SOILS - Mineral and Missoula Counties, 1964 - Occurrence of Glass

We have made a cursory examination of the sands from selected horizons of Craddock, Drexel, and Horsehead to determine the abundance of volcanic glass. The observations are given below. Earlier, preliminary observations were distributed on the glass content of Truefissure and Wishard. With the exception of Wishard, all the soils examined contain appreciable volcanic glass. Roman numeral horizon notation would seem necessary. I suggest that another profile of Wishard should be grab sampled to examine for glass. If it turns out that glass is absent in Wishard, it would suggest the parent material was emplaced after the ash fall.

All the samples contain a high proportion of altered feldspar aggregates that presumedly are the result of low-grade metamorphism, not soil weathering. They are similar in this respect to the 1961 samples from Granite and Missoula Counties. These sand- and silt-size aggregates should have some cation exchange capacity. One would expect that such grains would be more easily broken down than an assemblage of discrete quartz and feldspar, where the feldspar is relatively fresh. Our concern with glass may lead us to overlook this characteristic of the mineralogy of these soils developed on weakly metamorphosed sedimentary rocks.

Craddock S64Mont-31-5

LSL No. 19687 Appreciable volcanic glass in the very fine sand with perhaps more in the coarse silt.

LSL No. 19691 No glass in the very fine sand; largely aggregates of altered feldspar or mosaics of quartz and altered feldspar, with some discrete quartz; a few pyroxene.

Drexel S64Mont-31-4

LSL No. 19665 Significant volcanic glass in very fine sand, perhaps less than in 19687; grains consisting of mosaics of altered feldspar and quartz are very common; some pyroxene, a portion glass-enclosed.

LSL No. 19700 No glass in very fine sand. Most of the very fine sand consists of abundant silt-size and coarse clay-size crystals of mica or mica-like minerals arranged in sub-parallel orientation and held in an extremely fine grain matrix having grayish interference color; grains have ragged edges and are somewhat elongate.

Horsehead S64Mont-32-1

LSL No. 19729 Appreciable glass in the very fine sand--more than in Craddock 19687 or Drexel 19665. Aggregates of altered feldspar are common; more like those in Craddock than those in Drexel. A few ferromagnesian minerals present.

LSL No. 19732 Some glass (10-15 percent) in the very fine sand; less than in 19729.

Truefissure S64Mont-31-1

LSL No. 19710 No glass; largely altered feldspar aggregates and mosaics of altered feldspar and quartz.

cc: C. A. Mogen
E. M. Richland
A. R. Southard
L. T. Alexander
G. D. Smith
J. L. Retzer

UNITED STATES GOVERNMENT MEMORANDUM

To: Horschell D. Hurd, State Conservationist, SCS, P. O. Box 855, Bozeman, Montana 59715
ATTN: Dave R. Cawlfield, State Soil Scientist

Date: August 13, 1965

From: Robert B. Grossman, Head, Soil Survey Laboratory, SCS, 4th Floor, 1325 "N" Street, Lincoln, Nebraska 68508

Subject: SOILS - Cascade, Mineral, and Missoula Counties - Clay Mineralogy

Warren Lynn has determined the clay mineralogy on selected soils of Craddock, Drexel, Horsehead, Truefissure, and Tarkio. With the exception of the last named, the determinations were made on the same samples for which the soil mineralogical observations were distributed July 7, 1965. Warren's comments follow:

Horsehead, Craddock, and Truefissure are andic in their upper parts. Drexel and Wishard likely contain crystalline clays throughout. Upper horizons of Drexel may contain sufficient glass for andic, but probably would not qualify on the basis of clay mineralogy. Wishard apparently would not qualify for andic either on clay mineralogy or abundance of glass in the silt and sand. The exchange capacity for clay ratios may suggest a more extensive influence of amorphous material than the mineralogical observations to date indicate. For example, the 7 to 12 inch horizon of Wishard has wide ratios of exchange capacity and of 15-bar water retention to clay, but yet has little glass in the sand. This may be a reflection of organic matter or it may not. The story is not all in yet.

Two of the samples, 19687 and 19732, dispersed in a mild acid, but would not disperse in water or a mild base.

Craddock S64Mont-31-5

ISL No. 19687 Dominated by amorphous material. Crystalline clays barely detectable. Acid-dispersed sample yielded small 14Å peak, probably vermiculite.

ISL No. 19691 Contains well-crystallized montmorillonite and mica, probably also some halloysite and vermiculite. Interlayer chlorite-montmorillonite (or possibly vermiculite) is present. Montmorillonite remains at 14Å after sodium dispersion which indicates a high-charge montmorillonite or an influence of the chlorite interlayers.

Drexel S64Mont-31-4

ISL No. 19695 Well-crystallized kaolinite, mica, and vermiculite present along with trace amounts of chlorite and montmorillonite.

ISL No. 19700 Well-crystallized mica, kaolinite, and vermiculite are abundant. Smaller amounts of montmorillonite and what appears to be gibbsite are also present.

Horsehead S64Mont-32-1

LSL No. 19729 Amorphous materials dominate. Trace amounts of kaolinite, mica, and montmorillonite are detectable.

LSL No. 19732 Amorphous materials dominate. No crystalline clays detected. The sample dispersed in a mild acid but not in water or a mild base.

Truefissure S64Mont-31-2

LSL No. 19710 Moderate amounts of well-crystallized mica and vermiculite, with less kaolinite and a small amount of montmorillonite are present.

Monad S64Mont-7-2

LSL No. 19632 JIB23t 40-49 inches
The clay is high in montmorillonite with a moderate amount of kaolinite and a little mica also present. The montmorillonite retains a 14-Å spacing after sodium dispersion. This indicates that divalent cations remain on the exchange and suggests a high-charge montmorillonite. The mineralogy is mixed. Tiger and Highwood may have similar clay mineralogies.

Tarkio S61Mont-32-3

LSL No. 15356 A_2 0-5 inches
LSL No. 15359 B_{22} 12-20 inches
Both horizons contain abundant mica, moderate kaolinite and a trace of chlorite. The A_2 contains a moderate amount of montmorillonite which increases considerably in the B_{22}. The mineralogy is mixed.

cc: C. A Mogen
E. M. Richland
A. R. Southard
L. T. Alexander
G. D. Smith
J. L. Retzer
J. G. Cady

L. T. Alexander, Chief, Soil Survey Laboratories, December 8, 1966
SCS, Plant Industry Station, Beltsville, Maryland 20705

June G. Haigh, Soil Scientist, SCS, Cut Bank,
Montana 59427

SOILS - Volcanic Glass - Field and Laboratory Study in Glacier County, Montana, Soils

Thanks to you and Dr. Tee for the report of July 15, 1966, of the above study. Since the snow and cold came to my area I have taken the time to consider the report thoroughly.

I believe we have answered the primary study question: What is the distribution and influence of volcanic ash in the soils of Glacier County? The samples were taken in diverse areas of the county from soils on varying kinds of transported parent material and from contrasting kinds of soils. Considering the sampling and the data, we can say:

1. Volcanic glass occurs in at least very small amounts in all soils of the area.
2. There is a greater amount of glass in the surface horizons of most soils.
3. The amount of glass even in the surface horizons (1 to 3% of the coarse silt 20-50 microns) is probably not significant in the genesis, morphology, or classification of these soils.

I note that the soils with the higher glass content in the surface occur in the higher precipitation portion of the County. This might be expected from either rain carrying the ash or more abundant vegetation preserving the ash where it fell. I also note that 4 of the 5 soils, with only a trace of ash in the surface horizon, could have developed in lacustrian or alluvial deposits deposited after the ash fall. In the fifth (A-64-Mont-18-12) the site is presently exposed to the prevailing wind and ash may never have accumulated.

As there has been no study of clay in this area it was interesting to confirm the dominance of montmorillonite in nearly all soils. Do you attach any significance to the dominance of vermiculite in the one Sherburne profile (A-64 Mont-18-8)? The landscape here was considered by W. C. Alden as pre-Wisconsin and this profile was sampled within one half mile of profile No. 16 as reported in Soil Survey Laboratory Memo No. 1, 1952.

In the last paragraph of your report you point out that the glass in the samples of ash layers was dominantly fibers or thin rods. Is this also true of the glass in the surface horizons of the soils sampled? I am wondering: Does the glass in the surface soils represent the same ash fall as the glass in the easily recognized layers in wet areas? By now I have found ash layers in sub-horizons in many places; not only in wet areas, but in well drained uplands.

I believe now that my attention should be focused on the second part of my original study plan; that is an attempt to use these ash layers, physiographic features, and soil development to establish some age relationships (pre-Wisconsin to recent) for better prediction and correlation of soils. You are, no doubt, familiar with the work of Roy E. Wilcox and Howard A. Powers of the Geologic Survey and Roald Fryxell of Washington State University in correlation and dating of ash deposits. In correspondence with Wilcox last year he indicated hopes of doing some additional work with ash in Western Montana. It is possible that he would try to correlate some of my ash finds with the Mazama and Glacier Peak Ash. Is there any possibility of new Soil-Geomorphic study areas for our own field investigation staff?

Once again thank you for your part in this study. It has been stimulating for me in the sometimes routine operation of field mapping.

cc: C. A. Mogen ✓
A. R. Southard

APPENDIX 5

Plant Abbreviation Code

	Abbreviation	Name
Overstory	Abla	Abies lasiocarpa
	Abgr	Abies grandis
	Laoc	Larix occidentalis
	Juoc	Juniperus occidentalis
	Pial	Pinus albicaulis
	Pico	Pinus contorta
	Pien	Picca englemanii
	Pimo	Pinus monticola
	Pipo	Pinus ponderosa
	Potr	Populus tremuloides
	Psme	Pseudotsuga menusii
	Thoc	Thuja occidentalis
Understory	Acar	Actea arguta
	Acgl	Acer glabrum
	Acmi	Archillea millefolium
	Agsu	Agropyron subsecundum
	Alsi	Alnus sinuata
	Aruv	Arctostaphylos uva-ursi
	Caca	Calamagrostis canadensis
	Cage	Carex gerii
	Caro	Calamagrostis robusta
	Cara	Calamagrostis rubescens
	Chum	Chimaphila umbellata
	Clun	Clintonia uniflora
	Libo	Linnea borealis
	Mare	Mahonia (Berberis) repens
	Mefe	Menzesia ferruginea
	Pamy	Pachistima myrsinites
	Powh	Poa wheeleri
	Rupa	Rubus parriflora
	Syal	Symphoracarpus albus
	Vagl	Vaccinium globulare
	Vasc	Vaccinium scoparium
	Veca	Veratrum californicum
	Xete	Xerophyllum texax

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