Characterization and productivity of soils on Tertiary valley fill in northwestern Montana

by William Dickson Klein

A thesis submitted in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Soils
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Abstract:
This study characterizes three soil groups (Teepee, Ridge, White) formed from Tertiary sediment-derived glacial till in or adjacent to the Flathead National Forest. Three pedons of each soil group were characterized. Characterization data included organic matter content, total nitrogen content, Bray P content, particle size distribution, desorption, Proctor, Atterburg limits, soluble cations, extractable cations, cation exchange capacity, pH, bulk density, and clay mineralogy. Soil groups means calculated from these analyses were compared by major horizon to identify differences among soil groups.

Volcanic ash surface horizons (B2ir horizons) of the Teepee and Ridge soil groups had' the highest weight basis water holding capacity, organic matter content, total nitrogen content, Bray P content and cation exchange capacity of the four major horizons evaluated. Excluding the B2ir ash cap horizon the three soil groups increase in value from Teepee (loams) to Ridge (silt loams) to White (silt loams) in organic matter content, total nitrogen content, Bray P content, water holding capacity at .33 and 15 atmospheres tension, and Atterburg limits.

The influence of climate, topography and solum soil properties on site productivity was evaluated by comparing means derived from eleven study sites: five from this study and six from Cullen (1981). Sites located on the Flathead National Forest have high yield capabilities (92 ft^3/a/yr). Cullen's six sites, which have moderate yield capabilities (66 ft3/a/yr or 72 ft^3/a/yr) are developed on Tertiary Volcanic-derived sediments and limestone or quartzite-derived glacial till in the Bitterroot and Kootenai National Forests, respectively.

The most dramatic difference between sites in the high and moderate yield capability classes involved precipitation. Sites on the high yield capability class received twice as much mean annual precipitation as well as mean annual precipitation between April 1 and July 31 as the moderate yield capability classes. Pedons supporting high yield capability stands have lower available water holding capacities than pedons associated with the moderate yield capability class. Apparently, relatively high summer precipitation compensates for the low water holding capacity soils associated with high productivity.

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ABSTRACT

This study characterizes three soil groups (Teepee, Ridge, White) formed from Tertiary sediment-derived glacial till in or adjacent to the Flathead National Forest. Three pedons of each soil group were characterized. Characterization data included organic matter content, total nitrogen content, Bray P content, particle size distribution, desorption, Proctor, Atterburg limits, soluble cations, extractable cations, cation exchange capacity, pH, bulk density, and clay mineralogy. Soil groups means calculated from these analyses were compared by major horizon to identify differences among soil groups.

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The influence of climate, topography and solum soil properties on site productivity was evaluated by comparing means derived from eleven study sites: five from this study and six from Cullen (1981). Sites located on the Flathead National Forest have high yield capabilities (92 ft^3/a/yr). Cullen's six sites, which have moderate yield capabilities (66 ft^3/a/yr or 72 ft^3/a/yr) are developed on Tertiary Volcanic-derived sediments and limestone or quartzite-derived glacial till in the Bitterroot and Kootenai National Forests, respectively.

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INTRODUCTION

The Flathead National Forest, located in northwestern Montana, encompasses 2.3 million acres of timberland in the Whitefish, Salish and Swan Ranges of the Northern Rocky Mountains (United States Forest Service, 1981). This land is managed for timber, water, wildlife and range.

Forest lands are currently being classified and mapped at the landtype level of the United States Forest Service Land System Inventory method of land mapping. The landtype is characterized by properties of soils, landforms and climax plant communities (United States Forest Service, 1976). Soil characterization is a supplemental component of the Flathead National Forest landtype inventory.

Most glacial till soils in the Forest are dominated by the quartzites, argillites and limestones of the Belt Supergroup and some have been characterized by Forest Service soil scientists. Many of the large valleys, such as the North Fork of the Flathead River, are partially filled with Tertiary age sediments consisting of highly varied conglomerates, sandstones, siltstones and claystones. There is no characterization information for soils of tills influenced by the Tertiary sediments. They comprise the three soil groups described in the following paragraph.

Tertiary sediment-derived glacial till soils of the North Fork of the Flathead River are divided into loams and silt loams. These two groups occupy 10 to 20 sections of land in the North Fork drainage and may be extensive in other valleys. In the Upper Flathead valley, the third group (mostly Whitefish series) includes silt loams developed on calcareous Tertiary sediment influenced glacial till, occupies 30 to 40 sections of land.

Climax plant communities in landtype mapping units are defined by the habitat classification of Pfister, et al. (1977), which also estimates yield capability class in ft^3/a/yr for timbered habitat types. Some of the Tertiary sediment-derived glacial till soils of the North Fork have high yield capability class ABLA/CLUN/CLUN (Abies lasiocarpa/ Clintonia uniflora/Clintonia uniflora) habitat types. Others have moderate yield capability class PSME/LIBO (Pseudotsuga menziesii/ Linnaea borealis) and ABLA/LIBO (Abies lasiocarpa/Linnaea borealis) habitat types. Cullen (1980) characterized soils of similar moderate yield capability PSME/LIBO and ABLA/LIBO habitat types on Tertiary Volcanic-derived sediments, and limestone or quartzite derived glacial till on the Bitterroot and Kootenai National Forests of western Montana.

The objective of this study is twofold. The first is to characterize the three soil groups developed from Tertiary sediment-derived glacial till and the second to identify soil, climatic and topographic factors attributable to the contrasting timber productivity of sites supporting moderate and high yield capability classes.

LITERATURE REVIEW

Forest Site Evaluation

The forest site is composed of the physical environment which surrounds the tree both above and below the ground surface (Spurr and Barnes, 1972). Lemmon (1955) states that this physical environment is influenced by climatic, physiographic, biotic and edaphic factors. Forest site quality is directly related to how well these factors converge into an environment conducive to tree growth. Tarrant (1949) reported that interrelationships between these four site factors are complex.

Generally, site index is a measure of forest site quality. Site index is determined from the age of the stand and the average height of several dominant and often codominant trees (Spurr and Barnes, 1973). In a review of site evaluation methods, Jones (1969) reported that site index curves used with proper regard for their limitations are a somewhat rough index to the productivity of sites. But it is the most direct method, and for most species in suitable stands, good site index curves probably are the best tool for evaluating productivity. Effective use of site index is limited to well-developed stands of mature, even-aged timber where tree height and age can be directly measured. Unfortunately, many forests in the northwestern United States have been logged or burned and do not support stands of suitable age or stocking for direct measurement of site index (Copeland, 1958; Cox, et al., 1960; Hill, et al., 1948). Several researchers in this region have identified soil-site index correlations to estimate site quality on areas not conducive to determining site index (Brown and Loewenstein, 1978; Carmean, 1954; Gessel and Lloyd, 1950; Lemon, 1955). Periodic annual increment, tree height and tree volume have also been used to correlate site quality with soil characteristics (Brown and Loewenstein, 1978; Dumanski, et al., 1973). Topographic and climatic factors are also often correlated with site quality.

Climatic Factors

Climate has long been recognized as a factor in soil-site quality studies (Lemmon, 1955). A few studies have involved study sites with nearly equal amounts of annual precipitation (Dumanski, et al., 1973; Hill, et al., 1948). Carmean (1954) and more recently Steinbrenner (1965), conducted studies in Washington over areas of widely varying annual precipitation. Site quality for Douglas-fir in southwestern Washington increased as total annual precipitation increased (Carmean, 1954).

In northwestern Washington, Gessel and Lloyd (1950) found Douglas-fir site index on the same soil profile and textural groups was related to mean annual precipitation. Site index on one soil type increased as the precipitation increased from 25 to 40 inches. A decrease in site index as precipitation exceeds 40 inches may be associated with lower temperatures and shorter growing season of high precipitation sites.

Stephens (1963) concluded that Douglas-fir site index is correlated positively with temperature and length of growing season and negatively with annual precipitation and winter snowpack in the northwestern Cascades of Oregon. He also states that these climatic factors (temperature, length of growing season, precipitation and snowpack) are only vaguely correlated with aspect, elevation and latitude.

Physiographic Factors

Physiographic factors are correlated with site quality in several studies (Carmean, 1954; Dumanski, et al., 1973; Hill, et al., 1948; Steinbrenner, 1965). Carmean (1954) suggested that poor high elevation Douglas-fir site quality resulted from soil moisture shortage caused by a delay of the growing season to the period of lowest summer rainfall. Steinbrenner (1963) and Brown and Loewenstein (1978) also found a negative correlation between site index and elevation in Douglas-fir stands in western Washington and northern Idaho, respectively. They attributed this relationship to severe climates associated with high elevations.

In southwestern Alberta, Dumanski, et al. (1973) observed that aspect had minimal effect on lodgepole pine productivity on all except sandy or gravelly soils. This may be due to the droughty nature of coarse-textured soils.

Steinbrenner (1965) stratified slope, aspect and topographic position by elevation classes. He found site index generally did not change with aspect except on northwest and southwest exposures. The effect of position was more significant at higher elevations (over 1,000 ft) than at low elevations. At high elevations, footslopes had higher site indexes than ridge tops. Slopes of 30 percent and steeper had reduced site indexes. Dumanski (1973) also found a decrease in productivity on slopes greater than 30 percent.

Soil Survey Information

Soil-mapping units established by the Soil Conservation Service have been correlated with site quality by Hill, et al. (1948) and Gessel and Lloyd (1950). In northwestern United States, Hill, et al., (1948) conducted the first study of this type. He found soil series and types to be unnecessarily refined and land capability classes too general for correlation with Douglas-fir site index. Soil mapping units were developed by grouping all soils of similar profile, texture and depth. Soil moisture relationships were indicative of site index. Gessel and Lloyd tested the validity of this method on soils of glacial origin and found similar results.

Contrary to Hill, et al. (1948), Stephens (1963) concluded that the soil taxonomic unit, at the series level, provides an accurate prediction of Douglas-fir site index.

Dumanski, et al. (1973) used a soil map compiled on the basis of soil associations, soil complexes and soil mapping units to evaluate land productivity. There were strong interrelationships among soil parent materials (soil associations and complexes), soil drainage, and regional and local climates with pine productivity.

Soil Chemical and Physical Properties

Several studies have examined the influence of soil chemical properties on site quality (Brown and Loewenstein, 1978; Forristall and Gessel, 1955; Jameson, 1965; Tarrant, 1949; Zinke, 1960). Few chemical properties consistently influence site quality.

Brown and Loewenstein (1978) and Forristall and Gessel (1955) each found cation exchange capacity and total nitrogen to be positively related to site productivity. In Saskatchewan, Jameson (1965) observed the same relationship with cation exchange capacity. Zinke (1960) found a positive relationship between total nitrogen and site productivity in California.

Tarrant (1949) studied the relationship between Douglas-fir site quality and soil fertility in five localities in Washington and Oregon. No statistically significant relation was found between site class and values obtained from chemical properties; including cation exchange capacity and total nitrogen. He concluded that the nutrient content of the Douglas-fir region is too high to constitute a limiting factor for tree growth.

Several scientists have demonstrated a positive correlation between site productivity and soil physical properties (Brown and Loewenstein, 1978; Carmean, 1954; Copeland, 1958; Cox, et al., 1960; Holtby, 1947; Jameson, 1965; Lemmon, 1955; Stevens, 1965). Most of these properties affect the quantity of moisture available for plant growth.

Several researchers have found a positive correlation between effective soil depth and site quality (Copeland, 1958; Cox, et al., 1960; Jameson, 1965; Lemmon, 1955). Effective soil depth is total soil depth corrected for coarse fragment content. High bulk density-induced low permeability may also limit effective soil depth.

Copeland (1958) working in the northern Rocky Mountain region found effective soil depth, depth to zone of reduced permeability and the available water holding capacity of the effective depth in the top three feet of soil, to be useful in estimating western white pine site index. Field measurements of effective soil depth were more valid than laboratory measurements. Lemmon (1955) reported that total effective soil depth was the most important factor in determining the productive capacity of a Douglas-fir site in the Willamette Basin of Oregon.

In western Montana, Cox, et al. (1960) found the influence of soil depth to be minimal on areas receiving supplementary moisture from seepage or high water tables. Similar conclusions were drawn by Jameson (1965).

A few authors have pointed out an inverse relationship between gravel content and site quality (Carmean, 1954; Stevens, 1965). Carmean (1954) reported that gravel contains little available moisture for tree growth during the dry summer growing season. Gravel, therefore, may be viewed as relatively inert material occupying space that might otherwise be occupied by more adsorptive soil.

Brown and Loewenstein (1978) used several soil characteristics which effect water retention in prediction equations for site index, height and total volume of mixed conifer stands. Soil to rock ratio in the buried horizons was positively correlated to both site index and total volume. Organic matter content in the ash and buried horizons was positively correlated to height and site index, respectively. Soil to rock ratio and organic matter content are instrumental in the retention of soil water in the soil; an increase in these two properties would probably lengthen the time in summer that water is available for plant growth in an area where most precipitation occurs in the winter.

Holtby (1947) concluded that soil texture six inches below the soil surface is a fairly reliable indicator of site quality in the ponderosa pine region near Glenwood, Washington. He found a positive relationship between mean percentages of fine soil material (clay and silt) and total tree height in the three site quality classes evaluated.

General Observations

Currently, researchers have not identified a simple solution to the problem of predicting site quality in the absence of a suitable timber stand for direct measurement (Lemmon, 1955). Various studies show different factors to be significant, depending on the species, the factors examined, their range of values, the manner in which they were measured and expressed, and the statistical and biological relations between the "independent" factors (Jones, 1969).

Coile (1951) stated that the productivity of soil for forest growth is conditioned by the quantity and quality of growing space for tree roots, soil properties that may be classed under these two categories may have direct effects on growth, both direct and indirect effects (interaction), or only indirect effects.

HISTORICAL GEOLOGY OF THE FLATHEAD AREA

Precambrian

The Pony and Cherry Creek Series constitute the "basal complex," oldest of Montana rocks (Perry, 1962). Composed largely of gneiss and schist, this complex formed during Early or Middle Precambrian time. Overlying the basal complex is the Belt Supergroup.

Four groups of rock comprise the Belt Supergroup, which originated during the Late Precambrian. Following are the group names in ascending order, pre-Ravalli or Lower Belt, Ravalli, Piegan or Middle Belt Carbonate and Missoula (Ross, 1959 and Johns, 1970). The Whitefish Range forms the western margin of the North Fork Valley and the northwestern border of the Upper Flathead Valley, while the Swan and Salish Ranges border the Upper Flathead Valley. These three mountain ranges are to a large extent formed from the Ravalli, Piegan and Missoula Groups.

Belt Supergroup sediments were deposited in a broad, shallow basin during a semi-arid climate (Jones, 1970). They have undergone low grade metamorphism resulting in argillite, siltite, quartzite, dolomite and limestone lithologies.

Tertiary

The Rocky Mountains were formed during the Laramide Orogeny. Two successive periods of mountain building occurred between Late Cretaceous and Middle or Late Tertiary time.

Compressional forces caused folding and faulting producing the first Rocky Mountains. During this first period of the Laramide Orogeny, a large slab of Precambrium rock in northwestern Montana slid eastward, forming the Lewis Overthrust Belt which extends through Glacier National Park (Peterson, et al., 1973). Stream action eroded these mountains to a peneplain by Early or Middle Tertiary time. No remnants of these first Rocky Mountains have been uncovered in western Montana (Alden, 1953).

Tensional forces released by block or normal faulting uplifted mountain ranges and downdropped valleys forming the Rocky Mountains as we see them today. This type of faulting began during the Miocene Epoch of the Tertiary and has been intermitently active to the present (Peterson, et al., 1973).

Alt and Hyndman (1973) have developed an additional theory concerning the formation of the North Fork and Flathead Valleys. As the mass of Precambrian rock slowly slid eastward, large gaps opened behind it forming the North Fork and Flathead Valleys. The Whitefish Range, situated between the two valleys, may have also slid eastward. Rocks in the southern end of the North Fork Valley suggest that the valley floor has also dropped vertically.

Uplifting blocked major drainage ways, forming lakes and marshes in many valleys. Erosion from the surrounding mountains then filled the valleys with Tertiary valley-fill sediments.

Johns (1970) reviewed descriptions by Daly (1912) and Barnes (1963) of Tertiary beds in the North Fork Valley. Daly described these beds as the Kishenehn Formation. Barnes reported that the Kishenehn Formation was predominantly deposited on a broad flood-plain, in river channels, and in flood-plain lakes and swamps. He further stated that the coarse, poorly sorted conglomerate facies, which is found at places along the edge of the present valley of the North Fork may have been deposited by mud flows from adjacent uplands. Lithologies within this calcareous unit are sandstone, siltstone, lignite, comglomerate and claystone.

The thickness of the Kishenehn Formation is unknown. Barnes estimated it to be several thousand feet, while Daly reported that an exploratory oil well near Yakinikak Creek intercepted 700 feet of Kishenehn strata (Johns, 1970).

There are very few known outcrops of Tertiary rock in the Flathead Valley. Unlike the study area in the North Fork Valley, the area adjacent to the Flathead Valley study sites has no outcrops of Tertiary sediments.

Konizeski (1968) states that the lack of outcrops is probably due to three circumstances: (1) during the Quarternary, glaciation may have removed or reworked the upper part of the Tertiary fill; (2) during the Quarternary valley floor subsidence and resultant alluvial deposition may have covered the Tertiary rocks; and (3) Tertiary outcrops in this region are difficult to identify. He further reports that most of the valley fill (as much as 4,800 ft) in the Kalispell Valley is Tertiary.

Annual precipitation began to increase near the close of the Tertiary Period. Stream rejuvenation induced the excavation of a substantial portion of the Tertiary valley fill in western Montana (MSU Statigraphy Classes, 1978). Alt and Hyndman (1973) reported that 1,000 feet of sediment was removed from the North Fork Valley during this time.

Quarternary

This wetter climate initiated the formation of glaciers during the Quarternary Period. Different types of glaciers existed in the North Fork and Flathead Valleys.

The Cordilleran ice sheet, which originated in British Columbia, flowed 96-112 km (60-70 mi) into the northwestern corner of Montana (Veseth and Montagne, 1980). Flanked on the western margin, by the Whitefish Range, this ice sheet moved south to Polson. The thickness of ice at Kalispell was 610 m (2,000 ft) (Johns, 1970). While the Cordilleran ice sheet was forming in British Columbia, alpine and piedmont glaciers were developing in the North Fork Valley. A piedmont glacier originates from several coalescing alpine glaciers. The piedmont glacier of the North Fork joined similar glaciers from the Middle and South Forks of the Flathead River. This mass of ice was

3,000 ft thick as it passed through Bad Rock Canyon (Alden, 1953). Near Columbia Falls this coalescent piedmont glacier met the Cordilleran ice sheet and they flowed south down the Flathead Valley. This was the last major glacial activity in the Flathead and North Fork Valleys. Earlier glaciation did occur but its affects have been masked by this latter glacial activity.

The surficial geology of the North Fork and Flathead Valleys is largely a function of depositional landforms produced by glacial activity. A mantle of glacial till overlies Tertiary material in both the North Fork and Flathead Valleys. This Tertiary sediment-derived glacial till was a fresh parent material from which soil developed. Soil which develops from glacial till possesses properties characteristic of the most prevalent lithology present in the till.

The last major geologic event in northwestern Montana was the deposition of volcanic ash which forms the surface layer of many soils in this area. Most of this volcanic ash came from three Cascade Range volcanos in Washington and Oregon (Veseth and Montagne, 1980). The most entensive deposits of ash in western Montana are from the eruptions of Mt. Mazama (Crater Lake) about 7,000 years ago (Nimlos, 1980). In the present study all of the Tertiary sediment-derived glacial till sites in the North Fork Valley have a surface layer of volcanic ash.

MATERIALS AND METHODS

Characterization

This study utilized nine study sites in or adjacent to the Flathead National Forest (Figure 1) to characterize three groups of Tertiary sediment-derived glacial till soils. The three soil groups studied were 1) the Whitefish series, a calcareous silt loam with three study sites located near Ashley and Blanchard Lakes (T28N, T30N, R22W, and R23W MPM); 2) silt loams; and 3) loams located in the Glacier View Ranger District on the North Fork of the Flathead River between Ketchekan Ridge and Whale Buttes (T36N, T37N, R22W, and R23W MPM). Figure 2 shows the location of these nine study sites.

Sites were selected to compare silt loams and loams from siltstone and sandstone parent materials. Forest Service soil scientists helped identify the study sites. The Upper Flathead Valley Area soil survey (Soil Conservation Service, 1960) was used to identify the Whitefish study sites. Soil pedons sampled are typical of the three different Tertiary sediment-derived glacial tills common in the area. Prior to selecting study sites, exploratory soil pits were hand dug to assess the variability. Two study sites within each soil group were located in the same section (sq. mi.). The third site ranged in distance from 2 to 16 miles from this section.

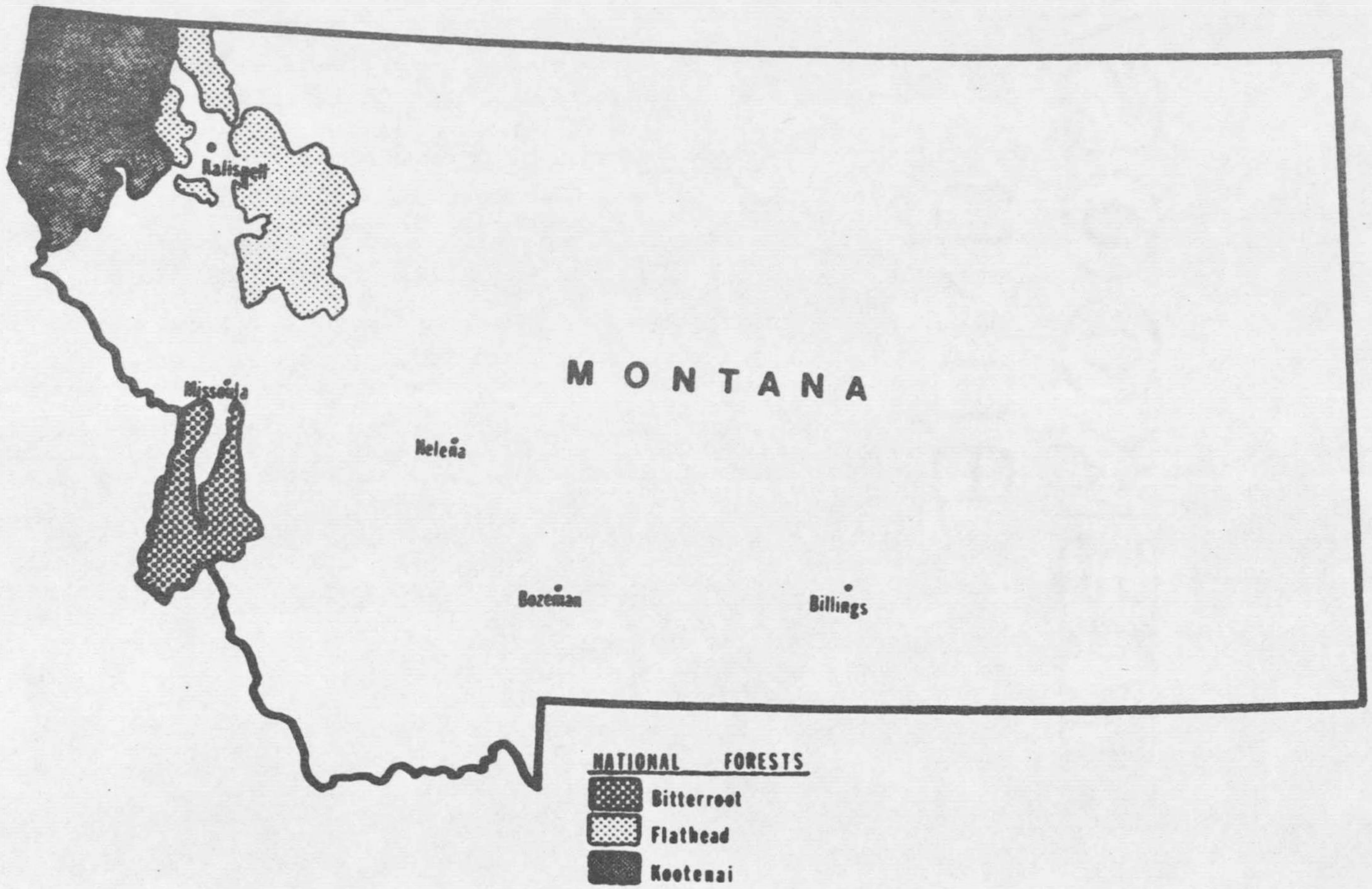

Figure 1. Location of National Forests.

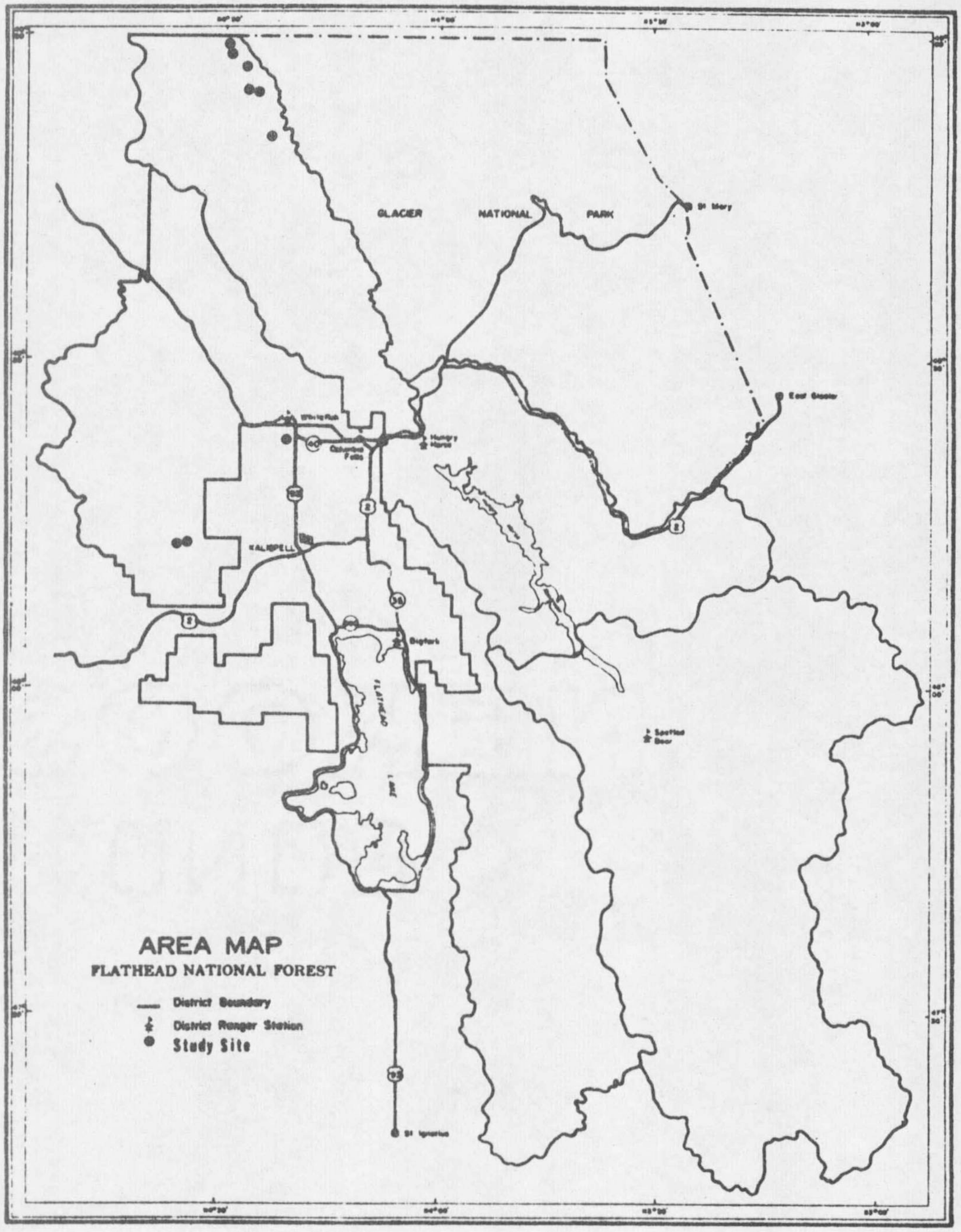

Figure 2. Location of characterization study sites.

The study soils will be referred to as follows: Ridge soils consist of the silt loams near Ketchekan Ridge in the Glacier View Ranger District. Teepee refers to the loam soils in the Glacier View Ranger District. These names do not represent soil series. The White soil group represents the soils sampled from the Whitefish soil series in the upper Flathead Valley.

Sampled soil pedons in the Glacier View Ranger District and Tally Lake Ranger District were dug with a backhoe and by hand, respectively. Each soil pedon was described following the Soil Survey Manual (Soil Survey Staff, 1951) guidelines. The vegetation and pedon at each study site was classified in accordance with Forest Habitat Types of Montana (Pfister, et al., 1977) and Soil Taxonomy (Soil Survey Staff, 1975), respectively. Bulk samples passing a 6.35 mm sieve were collected from continuous horizons at each study site. Three undisturbed clods of soil were removed from continuous horizons excluding the B_2ir horizons. Clods were coated with a 1:5 saran:acetone solution for laboratory determination of bulk density by a modification of Brasher, et al. (1966) developed by Bates (1981). Two soil correlation trays were collected from every site. Bulk samples of Tertiary sandstone and siltstone were collected in the Glacier View Ranger District from outcrops in the Teepee Lake area and adjacent to Whale Creek, respectively. Photographs of each soil profile and associated landscape and vegetation were taken prior to sampling. Bulk samples were oven dried at 55^{o}C and crushed in a flail type soil grinder before sieving to remove the greater than 4.75 mm fraction. A subsample was taken for Proctor analysis. The remaining portion of the bulk sample was sieved to remove the greater than 2 mm fraction. Subsamples of the fine earth fraction were taken for laboratory characterization. To insure representative subsamples were obtained, a quartering technique was employed (ASTM, 1979a).

The following analyses were conducted on each horizon sampled: soluble cation content and pH with a 1:5 dilution (U. S. Salinity Laboratory Staff, 1954); particle size analysis (Tanner and Jackson, 1947); organic matter (Sims and Haby, 1971); cation exchange capacity and extractable Ca, Mg, Na and K (Chapman, 1965a, 1965b). Modified Bray P (Smith, et al., 1957) and total nitrogen (Bremer, 1965) analyses were conducted on the solum horizons of each site. Phosphorus analysis was conducted by the Soil Testing Laboratory at Montana State University. A Proctor analysis was conducted on samples of each horizon excluding the B_2ir (ASTM, 1979b). The liquid limit (ASTM, 1979c), plastic limit and plasticity index (ASTM, 1979d) were determined for the B and C horizons present at each site.

A pressure chamber apparatus and porous ceramic plates similar to those described by Richards (1972) were used to develop desorption curves for the solum horizons. Moisture contents were gravimetrically determined at 1/10, 1/7, 1/3, 1/2, and 15 atmospheres tension.

The fine textured samples and coarse textured samples were analyzed separately.

Crystalline clays present in the Tertiary siltstone and most clay-rich B horizon of each soil pedon were identified by x-ray diffraction. Clay samples were mounted on glass slides by the paste method developed by Theisen and Harward (1962). Samples were analyzed and x-ray diffraction patterns interpreted according to methods set forth by Whittig (1965). A semi-quantitative method employing area weighting factors for various clay mineral types was used to estimate relative abundance of clay minerals (Klages and Hopper, 1980).

Site Productivity

Site productivity, as indicated by yield capability, was compared on eleven study sites. Five of these sites were among the six study sites selected for soil characterization in the Glacier View Ranger District of the Flathead National Forest. The remaining sites are situated in the Bitterroot and Kootenai National Forests of western Montana (Figure 1). Soil profile descriptions and characterization data for these six sites were obtained from Cullen (1981).

Several edaphic soil properties were calculated for the solum of each pedon from characterization data. Properties calculated include available water holding capacity, average bulk density (excluding the surface horizon), effective soil depth, and the weight per volume of exchangeable cations and organic matter. The equations used to calculate these properties are shown in the following section. When data for a particular horizon were not determined in Cullen's thesis, data from a similar horizon within the same pedon were used.

Cullen determined exchangeable cation and organic matter content by the same laboratory methods referenced in the previous section. Bulk density determinations were the same except that Cullen wet-sieved clods to remove coarse-fragments and in this study we removed coarse fragments by dry sieving. Since B_2ir horizon bulk densities were not determined in this study, a value of .72 g/cm^3, an average value of the surface horizon determined by Cullen (1981), was used.

Mean annual soil temperature and mean summer soil temperature were predicted for each pedon using Soil Temperature Predictions in Mountains and Foothills of Montana (Munn and Nielsen, 1979). Mean annual precipitation and precipitation between April 1 and July 31 was obtained from maps from the Soil Conservation Service (1977) and Caprio (1980), respectively.

The following information was part of the description of each pedon; slope, aspect, elevation, and habitat type. Yield capabilities (ft^3/a/yr) of these habitat types as estimated by Pfister, et al. (1977) were used.

Calculations

Calculations used in this study are:

1. Percent by weight of fines (in horizons of pedons located on the Flathead National Forest:)

   a) TVCF = %CF x TVH, where

      TVCF = total volume of coarse fragments in horizon,

      %CF = percent by volume of coarse fragments in horizon as estimated in soil profile description,

      TVH = total volume of horizon.

   b) TVF = TVH - TVCF, where

      TVF = total volume of fines in the horizon.

   c) TWF - TVF x BDF, where

      TWF = total weight of fines in the horizon,

      BDF = bulk density of fines as determined by the clod method.

   d) TWCF = TVCF x BDCF, where

      TWCF = total weight of coarse fragments in the horizon,

      BDCF = estimated bulk density of coarse fragments (2.65 g/cm^3).

   e) %WF = (TWF ÷ TWH) x 100, where

      %WF = percent by weight of fines in the horizon,

      TWH = total weight of horizon.

2. Exchangeable cations or organic matter expressed as grams per square meter for a given horizon depth.

(EC or OM, $g/_m 2$) = (%EC or OM)(100 - % >2 mm)(BD)(Horizon Depth)x254,

where

EC or OM, $g/_m 2$ = exchangeable cation or organic matter expressed as grams per square meter for a given horizon depth,

%EC or OM = percent by weight of exchangeable cation or organic matter in the fine fraction of the soil,

100 - % >2 mm = percent by weight of the fine fraction,

BD = bulk density of the horizon expressed in grams per cubic centimeter,

Horizon Depth = horizon depth measured in inches (Zinke, 1960).

3. Percent by volume of fines in a 100 gram sample from horizons of pedons located on the Bitterroot National Forest.

a) VF = WF ÷ BDF, where

VF = volume of fines in a 100 g sample,

WF = weight of fines in a 100 g sample,

BDF = bulk density of fines as determined by the clod method.

b) VCF = WCF ÷ BDCF, where

VCF = volume of coarse fragments in a 100 g sample,

WCF = weight of coarse fragments in a 100 g sample,

BDCF = estimated bulk density of coarse fragments (2.65 g/cm^3).

c) %VF = (UF ÷ TV) x 100, where

%VF = percent by volume of fines in a 100 g sample,

TV = total volume of 100 g sample.

4. Available water holding capacity of a horizon in centimeters.

$$AWC\ (cm) = \frac{(0.3\ atm\ \% - 15\ atm\ \%)(BD)(\%F)(HD)}{100}, \text{ where}$$

.3 atm % = moisture percentage of a soil subjected to 0.3 atmosphere suction.

15 atm % = moisture percentage of a soil subjected to 15 atmosphere suction,

BD = bulk density of horizon,

%F = percent by volume of fines,

HD = horizon depth in centimeters (Hagan, et al., 1967).

5. Weighted average bulk density of solum excluding surface horizon

$$WABD = \frac{BD \times HD}{TSD} \text{ summation of all pertinent horizons, where}$$

BD = bulk density of horizon,

TSD = total solum depth in centimeters.

6. Effective soil depth of a horizon in centimeters

ESD (cm) - % VF x HD, where

ESD (cm) = effective soil depth of horizon in centimeters,

%VF = percent of fines by volume in the horizon,

7. Porosity

$e = (1 - \frac{BD}{PD}) \times 100$, where

e = percent pore space

BD = bulk density of horizon

PD = particle density (Soil Conservation Service, 1967)

8. Exchange acidity

$H^{+}(exch) = CED - (Ca^{++} + Mg^{++} + Na^{+} + K^{+})(exch)$, where

CEC = cation exchange capacity.

H^{+} = exchange hydrogen,

Ca^{++} = exchange calcium,

Mg^{++} = exchange magnesium,

Na^{+} = exchange sodium

K^{+} = exchange potassium (Peech, 1965)

9. Percent base saturation

$\%BS = (Ca^{++} + Mg^{++} + Na^{+} + K^{+}) \div CEC$, where

%BS = percent base saturation.

Statistical Comparisons

Comparisons of means determined differences between major horizons in the three soil groups characterized. Table 1 shows specific horizons in each pedon from which laboratory data was taken to calculate means for major horizons. Means from the following analyses were compared, particle size, Proctor, bulk density, Atterburg limits, pH, total nitrogen.

Table 1. Horizons in each pedon which constitute soil group major horizons.

Soil Group	Pedons 1	2	3	Major Horizon+
	B_2ir	B_2ir	B_2ir	B_2ir
Teepee	IIA_2	IIA_2	IIA_2	IIA_2
	$IIB_{21}t$	IIB_2t	IIB_2t	IIB_2t
	IICca	IIC	IICca	IIC
	B_2ir	B_2ir	B_2ir	B_2ir
Ridge	IIA_2	IIA_2	IIA_2	IIA_2
	$IIB_{22}t$	IIB_2t	IIB_2t	IIB_2t
	IIC	IIB_3	IICca	IIC
White	A_2	A_2	IIA_2	A_2
	B_2t	B_2t	IIB_2t	B_2t
	Cca	Cca	IICca	C

+Data from horizons across rows were used to calculate means for the major horizon in the last column. Means from similar major horizons were statistically compared.

Bray P, organic matter, base saturation, cation exchange capacity, 1/3 bar moisture content and 15 bar moisture content.

Desorption data from each horizon were analyzed using a curve fitting equation which indicates the linearity of the relationship between matric potential and moisture content by assigning a correlation coefficient (Hillel, 1972).

Mean climate, topography and soil properties were compared between all combinations of the high yield capability class and two moderate yield capability classes. Means were calculated from study sites within each yield capability class. Properties compared include mean annual soil temperature, mean summer soil temperature, aspect, slope, elevation, effective soil depth, available water holding capacity, bulk density, porosity, extractable cations, and organic matter content. Aspect was coded from one to eight beginning with N45E and continuing in a clockwise direction using 45^{o} increments to North (Brown and Loewenstein, 1978).

Mean comparisons in both the characterization and site productivity sections of this study were conducted using the T Grouped computer program developed by Lund (1978). This program utilizes the Students t-test (Snedecor and Cochran, 1973) to compare mean values. Significance levels of .05 and .01 were measured. The assumption that group variances were equal was generally correct. Normal distributions were assumed.

RESULTS AND DISCUSSION OF CHARACTERIZATION STUDY

Appendices II and IV show profile descriptions and characterization data for the nine soil pedons characterized in this study. Appendix I is a key to the pedon coding scheme.

Organic Matter, Bray Phosphorus and Total Nitrogen

Table 2 lists mean organic matter content by horizon for the three groups of Tertiary sediment-derived glacial till soils. In the same table are mean comparison results.

The soil groups can be ranked according to organic matter content in the three lowest major horizons. Organic matter increases from Teepee to Ridge to White soils. Organic matter content in the Teepee and White soil groups is significantly different ($p = .05$) only in the $(II)A_2$ and $(II)B_2t$ horizons.

Higher organic matter content of the White A_2 horizon may be related to the occurrence of pine grass (Calamagrostis rubescens) as a dominant understory species at two study sites. Forbs, shrubs, and subshrubs dominate the understory of the remaining seven study sites. Root residues of grass species are very effective in adding organic matter to the soil. In addition, the White soils have much shallower solum depths than the other two soil groups.

Table 2. Mean organic matter content data+ for the major horizons of the three Tertiary sediment-derived glacial till soil groups.

Major Horizon	Soil Groups: Teepee		Ridge		Major Horizon	White	
	--------------------		% by wt		--------------------		
B_2ir	2.3a	(.76)	3.9a	(.70)			
IIA_2*	0.5a	(.10)	0.9ab	(.21)	A_2	1.7b	(.53)
IIB_2t*	0.5a	(.10)	0.6a	(.12)	B_2t	1.0b	(.10)
IIC	0.5a	(0)	0.7a	(.15)	C	1.0a	(.35)

+Numbers in parentheses are standard deviations.

*Numbers across rows not followed by the same letter are significantly different at the p = .05 level.

Pedons in the White soil group lack the consistent presence of the B_2ir horizon located above the IIA_2 horizon in the Teepee and Ridge pedons. Organic matter content of each B_2ir horizon is considerably higher than any other major horizon.

Nitrogen and phosphorus are common constituents of organic matter. Table 3 displays and compares mean total nitrogen and Bray P contents by major horizon.

Total nitrogen and Bray P levels mirror changes in organic matter amounts. Tarrant (1949) found soil nitrogen to be closely correlated with the amount of organic matter present in the soil. Significant differences in total nitrogen and Bray P occur only in the $(II)B_2$t horizons of the Teepee and White soil groups. The level of significance in both cases is $p = .01$.

Particle Size Distribution and Soil Texture

Table 4 shows and compares means of sand, silt and clay contents by major horizon of the Teepee, Ridge and White soil groups. Variability as indicated by the standard deviation is similar in each of the soil groups.

The Teepee and Ridge soil groups have significantly different silt and sand content in all horizons. An exception is the sand contents of the B_2ir horizons which are not significantly different. The $(II)A_2$ and $(II)B_2$t horizons of the Teepee and White soil groups contain

Table 3. Mean total nitrogen and Bray phosphorus data[+] for the major horizons present in the solum of the three Tertiary sediment-derived glacial till soil groups.

		Soil Groups						
Analysis	Major Horizon	Teepee		Ridge		Major Horizon	White	
		---% by wt---						
Total Nitrogen	B_2ir	.072a	(.02)	.125a	(.03)			
	IIA_2	.013a	(.01)	.030a	(.03)	A_2	.044a	(.01)
	IIB_2t**	.010a	(0)	.016ab	(.01)	B_2t	.034b	(.01)
		---ppm---						
Bray Phosphorus	B_2ir	355.0a	(109.7)	541.7a	(240.4)			
	IIA_2	29.3a	(17.9)	37.7a	(15.5)	A_2	159.0a	(90.1)
	IIB_2t**	24.0a	(4.4)	21.7a	(13.3)	B_2t	75.3b	(14.6)

+Numbers in parentheses are standard deviations.

**Numbers across rows not followed by the same letter are significantly different at the p = .01 level.

Table 4. Mean particle size fraction data+ and associated textural classes for the major horizons of the three Tertiary sediment-derived glacial till soil groups

Particle Size Fraction	Major Horizon	Soil Groups: Teepee		Ridge		White	
		--------------------%		--------------------			
Sand 2mm - .05 mm	B_2ir	31.0a	(7.2)	35.3a	(.6)	-	
	IIA_2**	53.3a	(5.0)	28.7b	(4.5)	27.3b	(4.2)
	IIB_2t*	47.3a	(3.1)	24.3b	(2.5)	32.3c	(2.3)
	IIC**	48.7a	(5.5)	23.7b	(3.5)	41.7c	(3.8)
Silt .05 mm-.002 mm	B_2ir*	49.0a	(3.5)	59.0b	(2.6)	--	
	IIA_2**	38.7a	(4.0)	60.3b	(1.5)	60.7b	(4.0)
	IIB_2t *	39.4a	(2.1)	55.3b	(2.1)	51.4c	(1.5)
	IIC*	40.6a	(1.5)	57.0b	(1.0)	47.6ab	(7.5)
Clay <.002 mm	B_2ir*	20.0a	(5.3)	5.7b	(2.1)	-	
	IIA_2*	8.0a	(3.6)	11.0ab	(4.4)	12.0b	(1.7)
	IIB_2t	13.3a	(3.8)	20.4a	(4.6)	16.3a	(2.5)
	IIC*	10.7a	(4.2)	19.3b	(3.2)	10.7a	(3.8)
Textural Class	B_2ir	loam		silt loam		--	
	IIA_2	sandy loam		silt loam		silt loam	
	IIB_2t	loam		silt loam		silt loam	
	IIC	loam		silt loam		loam	

+Numbers in parentheses are standard deviations.

*,**Numbers across rows not followed by the same letter are significantly different at the p = .05 or p = .01 level, respectively.

significantly different silt and sand contents. Excluding the B_2ir horizons, silt and sand contents within the Teepee and Ridge soil groups vary little. In the White soil group silt and sand contents decrease and increase, respectively, with depth. A reduction in weathering with depth may explain these trends.

Clay content is highest in the (II)B_2t horizon of each soil group. An exception is the clay content of the B_2ir horizon in the Teepee soil group. The highest (II)B_2t horizon clay content is in the Ridge soil group, but the difference is not significant. Clay content in the IIC horizon of the Ridge soil group is significantly different ($p = .05$) from the other two soil groups which had equal clay contents in the (II)C horizon.

Means from the particle size analysis of the siltstone and sandstone parent materials are shown in Table 5. Relatively high silt and sand contents found in the Ridge and Teepee soil groups, respectively, were inherited from their associated parent material. Horizons within both soil groups have higher clay contents than their respective parent materials. These clay content variations between soil and parent material plus others involving silt and sand may be due to several factors such as weathering, glacial till influence and particle size variability within the parent material.

Table 5. Mean sand, silt and clay contents for the siltstone and sandstone parent materials of the Ridge and Teepee soil groups, respectively.

Parent Material	Sand 2 mm - .05 mm	Silt .05 mm - .002 mm	Clay <.002 mm
		%	
Sandstone	68	25	7
Siltstone	5	82	13

Table 4 shows the textural class of each major horizon of each soil group. Textural classes within each soil group were generally consistent. All major horizons in the Ridge and White soil groups are silt loams. An exception is the C horizon of the White soil group, which due to a higher sand content has a loam texture. The Teepee soil group has loam textures in every horizon except the IIA_2. Clay eluviation in this horizon has resulted in a sandy loam textural class.

Water Holding Capacity

Appendix VII shows desorption and curve fitting results for the horizons present in the solum of each pedon studied. Table 6 exhibits and compares mean water holding capacities at .33 and 15 atmospheres tension.

The B_2ir horizons possess the highest 1/3 and 15 atmosphere water holding capacities. Cullen (1981) reported similar results. Excluding the B_2ir horizons, the White soil group has the highest water holding capacity and the Teepee soil group has the lowest.

Significant differences at the .01 level occur between all combinations of 1/3 atmosphere water holding capacities in the IIA_2 horizon. Water holding capacities for the Teepee and White soil groups are significantly different in the $(II)A_2$ and $(II)B_2t$ horizons at both 1/3 and 15 atmospheres tension. Differences between the water holding capacities in the $(II)A_2$ horizon of the three soil groups are graphically shown in

Table 6. Mean fine earth water holding capacities+ of the major horizons present in the solum of the three Tertiary sediment-derived glacial till soil groups.

ATM Tension	Major Horizon	Teepee		Ridge		Major Horizon	White	
		Soil Groups						
		---% by wt---						
	B_2ir	34.6a	(5.6)	35.2a	(3.5)			
.33 ATM	IIA_2*	16.5a	(1.1)	19.0b	(.5)	A_2	30.9c	(2.0)
	IIB_2t**	17.8a	(1.3)	20.6a	(1.3)	B_2t	26.7b	(1.7)
	B_2ir	13.1a	(3.8)	12.6a	(.6)			
15 ATM	IIA_2*	5.5a	(.9)	8.6b	(1.0)	A_2	12.7b	(4.0)
	IIB_2t*	6.9a	(1.5)	11.5b	(1.6)	B_2t	10.7b	(.9)
	B_2ir	21.5		22.6				
AWHC‡ <2 mm	IIA_2	11.0		10.4		A_2	18.2	
fraction	IIB_2t	10.9		9.1		B_2t	16.0	

+Numbers in parentheses are standard deviations.

‡AWHC = available water holding capacity (these values were not statistically analyzed).

*,**Numbers across rows not followed by the same letter are significantly different at the p = .05 and p = .01 level, respectively.

Figure 3. Desorption results from one representative pedon in each soil group were used to produce these curves.

Matric potential dictates water holding capacity under conditions present in a pressure plate apparatus. Generally, finer soil textures have greater matrix potentials and associated water holding capacities. Soil texture explains the water holding capacity differences between the Teepee and other two soil groups.

Differences between the White and Ridge soil group cannot be explained on a textural basis. Higher organic matter content in the White soil group is one possible explanation.

Plant available water holding capacities (AWHC) were calculated as the difference between 1/3 and 15 atmosphere water holding capacities (Table 6). Excluding the B_2ir horizons, the White soil group has the highest AWHC. The Teepee and Ridge soil groups have similar available water holding capacities in each horizon.

Bulk Density

Appendix VIII contains bulk density raw data from three replications used in calculating bulk densities for each pertinent horizon in the nine soil pedons. Table 7 lists and compares mean bulk densities for the major horizons present in each soil group.

Significant differences ($p = .05$) between the bulk densities of the Ridge and White soil groups occur in the (II)B_2t and (II)C

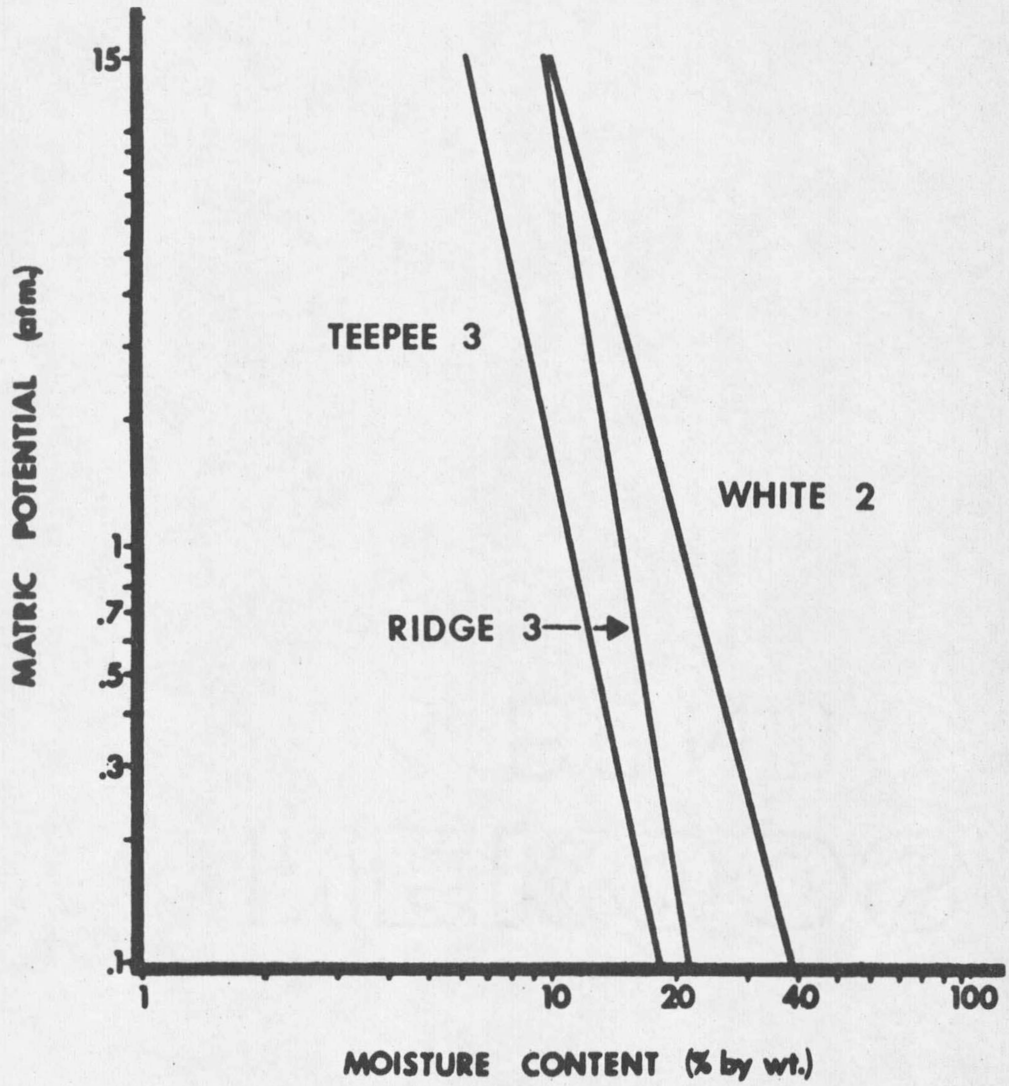

Figure 3. Water desorption curves for the A_2 horizon of one pedon in each Tertiary sediment-derived glacial till soil group.

Table 7. Mean bulk densities[+] for the major horizons of the three Tertiary sediment-derived glacial till soil groups

Major Horizon	Soil Groups: Teepee		Ridge		Major Horizon	White	
	g/cm^3						
B_2ir	ND		ND				
IIA_2	1.50a	(.15)	1.50a	(.20)	A_2	1.13a	(.19)
IIB_2t*	1.48a	(.09)	1.51a	(.09)	B_2t	1.15b	(.18)
IIC*	1.51ab	(.19)	1.45a	(.03)	C	1.19b	(.15)

[+]Numbers in parentheses are standard deviations.

*Numbers across rows not followed by the same letter are significantly different at the p = .05 level.

ND = not determined.

horizons. Bulk densities in the $(II)A_2$ horizons of the Teepee and Ridge soil groups are larger than that of the White soil group but the difference is not significant at the $p = .01$ level.

The highest bulk density within each soil group is associated with the $(II)B_2t$ or (II)C horizon. Likewise, the lowest organic matter contents are present in these two lowest horizons. Organic matter content and bulk density are generally inversely proportional. The low bulk densities in the White soil group can be explained by relatively high organic matter contents.

Standard Proctor Test

This test determines the relationship between water content and dry density in a soil compacted by a standard method. Optimum moisture content is the soil moisture content when maximum density is achieved through compactive efforts. Proctor test results are often expressed by a moisture density curve. Hand-drawn moisture density curves are shown in Appendix VI for all horizons tested. Mean maximum density achieved (MDA) and mean optimum moisture content (OMC) for the major horizons in each soil group are shown and compared in Table 8.

No statistical differences at the $p = .05$ level are present in the (II)C horizon. The Ridge and White soil groups have significantly different MDA and OMC means in the $(II)A_2$ horizon. MDA and OMC means in the $(II)A_2$ and $(II)B_2t$ horizons of the Teepee and the White soil

Table 8. Mean maximum density achieved and mean optimum moisture content data+ for the major horizons of the three Tertiary sediment-derived glacial till soil groups.

Analysis	Major Horizon	Teepee		Ridge		Major Horizon	White	
		Soil Groups						
		g/cm^3						
Maximum Density Achieved	B_2ir	ND		ND				
	IIA_2**	2.00a	(.09)	1.90a	(.04)	A_2	1.58b	(.09)
	IIB_2t**	2.02a	(.03)	1.88b	(.02)	B_2t	1.78c	(.25)
	IIC	1.99a	(.10)	1.90a	(.02)	C	1.78a	(.15)
		% by wt						
Optimum Moisture Content	B_2ir	ND		ND				
	IIA_2*	10.7a	(0.9)	12.7a	(1.4)	A_2	19.7b	(3.4)
	IIB_2t**	10.4a	(0.5)	13.0ab	(1.8)	B_2t	15.8b	(0.7)
	IIC	11.0a	(1.1)	12.4a	(.9)	C	15.8a	(3.8)

+Numbers in parentheses are standard deviations.

*,**Numbers across rows not followed by the same letter are significantly different at the p = .05 or p = .01 level, respectively.

ND = not determined.

groups are significantly different. The only significant difference ($p = .01$) between the Teepee and Ridge soil groups is the MDA means in the IIB_2t horizon. Low clay content and high sand content explain the MDA and OMC means obtained for the Teepee soil group. Felt (1965) states that there is a decrease in maximum density achieved and an increase in optimum water content for compaction as the soil texture becomes finer. Means for the Ridge and White soil groups do not support Felt's statement. The Ridge soil group generally has higher clay contents but lower optimum moisture contents and higher maximum densities than the White soil group. This may be due to more organic matter in the White soil group. Organic matter has a high adsorptive capacity for water and a low bulk density.

Atterburg Limits

This test measures the effect of soil moisture content on soil consistency. The moisture content at which soil changes from a friable to a plastic consistency is known as the plastic limit. The liquid limit is that moisture content at which a soil changes from a plastic to a viscous (semi-fluid) consistency. These two limits and the numerical difference between them, termed the plastic index, constitute Atterburg's limits. Table 9 shows and compares mean plastic limits, liquid limits and plastic indices for the $(II)B_2t$ and (II)C horizons of the soil groups.

Table 9. Mean plastic limit, liquid limit and plastic index data[+] for the two lowest major horizons of the three Tertiary sediment-derived glacial till soil groups

		Soil Groups						
Analysis	Major Horizon	Teepee		Ridge		Major Horizon	White	
		---------------------%---------------------						
Plastic Limit	IIB_2t*	16.0a	(1.4)	19a	(1.0)	B_2t	25.3b	(0.6)
	IIC	16.0a	(1.4)	18.3a	(0.6)	C	30.5a	(7.8)
Liquid Limit	IIB_2t*	18.0a	(1.4)	22.7a	(2.1)	B_2t	30.7b	(0.6)
	IIC*	17.5a	(0.7)	22.7b	(1.5)	C	34.5c	(4.9)
Plastic Index	IIB_2t*	2.0a	(0)	3.7ab	(2.9)	B_2t	5.3b	(0.6)
	IIC	1.5a	(0.7)	4.3a	(1.2)	C	4.0a	(2.8)

[+]Numbers in parentheses are standard deviations.

*Numbers across rows not followed by the same letter are significantly different at the p = .05 level.

Plasticity increases from the Teepee to the Ridge and to the White soil groups. There is a significant difference at the $p = .05$ level between both limits of the White soil group and the other two soil groups in the (II)B_2t horizon. Clay content in the (II)B_2t horizon of these soil groups does not explain this plasticity difference. Accordingly, the Ridge soil group should have the highest limits.

Organic matter affects soil consistency. Baver (1956) showed that organic matter increased plastic and liquid limits. The White soil group has the highest organic matter content in the (II)B_2t horizons which may explain the relatively high plastic and liquid limits associated with these soils.

In Baver's study, different organic matter contents failed to materially change the plastic index. His research implies that the plastic index may best reflect soil clay content. Mean clay contents and plastic indices of the three soil groups show no consistent relationship. Highest clay contents and plastic indices are associated with the Ridge and White soil groups, respectively.

Soil Chemistry

Table 10 exhibits mean exchangeable cation contents for the major horizons present in each soil group. This table also contains mean comparison results. High standard deviations reflect the variability of these chemical data.

Table 10. Mean exchangeable cation data[+] for the major horizons of the three Tertiary sediment-derived glacial till soil groups.

Exchange-able Cation	Major Horizon	Soil Groups: Teepee		Ridge		Major Horizon	White	
		-----------------	-----------------	me /100 g	-----------------	-----------------	-----------------	-----------------
	B_2ir	4.97a	(3.29)	1.76a	(0.35)			
	IIA_2*	2.50ab	(2.45)	1.23a	(1.06)	A_2	6.07b	(1.68)
Ca	IIB_2t**	6.70ab	(6.04)	4.36a	(1.66)	B_2t	12.77b	(2.21)
	IIC*	20.83ab	(17.16)	10.73a	(11.04)	C	33.70b	(4.24)
	B_2ir	1.90a	(1.35)	.40a	(0.20)			
	IIA_2*	.60a	(0.70)	.63a	(0.43)	A_2	1.93b	(0.40)
Mg	IIB_2t**	.80a	(0.56)	1.86ab	(1.36)	B_2t	2.40b	(0.17)
	IIC_2*	.83a	(0.32)	1.50ab	(0.82)	C	1.93b	(0.32)
	B_2ir	.07a	(0.06)	.10a	(0)			
	IIA_2*	.03a	(0.06)	.07ab	(0.06)	A_2	.17b	(0.06)
Na	IIB_2t	.03a	(0.06)	.07a	(0.06)	B_2t	.13a	(0.06)
	IIC	.07a	(0.06)	1.0a	(0)	C	1.0a	(0)
	B_2ir	.50a	(0.10)	.50a	(0.17)			
	IIA_2**	.47a	(0.06)	.30ab	(0.10)	A_2	.83b	(0.15)
K	IIB_2t*	.43a	(0.12)	.37a	(0.06)	B_2t	.73b	(0.06)
	IIC	.30a	(0.10)	.30a	(0.10)	C	.40a	(0.10)

[+] Numbers in parentheses are standard deviations.

*,** Numbers across rows not followed by the same letter are significantly different at the p = .05 or p =.01 level, respectively.

Exchangeable cations are the numerical differences between extractable and soluble cations. The exchangeable cations in each soil group are present in the same relative quantities. In ascending order of quantity present the cations are sodium, potassium, magnesium and calcium. Bohn (1979) reports that this ranking is commonly found in most productive agricultural soils. Excluding the B_2ir horizon, the calcium cation increased with depth in each soil group, reflecting the influence of leaching. No other relationships between cation quantity and depth are present.

No significant differences occur between the exchangeable cations of the Teepee and Ridge soil groups. Generally, calcium and potassium quantities are higher in the Teepee soil group, while sodium and magnesium quantities are higher in the Ridge soil group.

The White soil group has the highest quantity of exchangeable cations in each of the major horizons. Exchangeable calcium contents of the White and Ridge soil groups are significantly different in each major horizon. Exchangeable magnesium contents of the White and Teepee soil groups are significantly different in each major horizon.

Mean pH, base saturation and cation exchange capacity results for the major horizons in each soil group are shown in Table 11. Mean comparison results are summarized in this table, also.

Base saturation and pH results are generally directly proportional. In each soil group base saturation and usually pH increase with depth,

Table 11. Mean pH, base saturation and cation exchange capacity data+ for major horizons in the three Tertiary sediment-derived glacial till soil groups

Analysis	Major Horizon	Teepee	Ridge	Major Horizon	White
		Soil Groups			
pH	B_{2ir}	5.6a (0.12)	5.5a (0.26)		
	IIA_2*	6.0a (0.36)	5.4b (0.15)	A_2	6.1ab (0.74)
	IIB_2t	6.8a (0.90)	6.5a (0.50)	B_2t	7.0a (0.36)
	IIC	7.2a (1.40)	6.9a (0.83)	C	7.6a (0.21)
		---%	---	---	---
Base Saturation	B_2ir	32.3a (15.4)	13.7a (6.0)		
	IIA_2**	41.0ab (25.5)	29.5a (18.3)	A_2	52.8b (6.7)
	IIB_2t**	68.3a (36.2)	54.4a (8.8)	B_2t	84.1b (5.4)
	IIC	80.2a (34.2)	72.4a (26.0)	C	100.0a (0)
		---me /100 g	---	---	---
Cation Exchange Capacity	B_2ir	21.23a (3.72)	21.13a(5.99)		
	IIA_2*	7.53a (2.57)	7.37a(1.19)	A_2	17.00b (2.49)
	IIB_2t*	8.20a (2.25)	12.00a (2.66)	B_2t	18.67b (1.78)
	IIC	6.50a (1.74)	10.40a (0.56)	C	12.93a (6.23)

+Numbers in parentheses are standard deviations.

*,**Numbers across rows not followed by the same letter are significantly different at the p = .05 and p = .01 level, respectively.

reflecting the effect of leaching. The highest base saturation and pH values are associated with the White soil group. This result reflects the influence of precipitation and nutrient cycling. The White soil group receives less than half the mean annual precipitation of the two soil groups located in the North Fork Valley (Soil Conservation Service, 1977). This precipitation difference effectively reduces the quantity of cations leached out of the soil profile. Pinegrass, which is common in the understory of the White soil group is very proficient at cycling nutrients.

Few significant base saturation and pH differences occur between the three soil groups. Base saturation in the (II)A_2 and (II)B_2t horizons of the Ridge and White soil groups is significantly different at the p = .01 level. Mean pH is significantly different in the (II)A_2 horizon of the Teepee and Ridge soil groups. No other significant differences are present.

Sandstone and siltstone parent materials have pH values of 6.0 and 6.7, respectively. However, the Teepee soil group has higher pH values than the Ridge soil group in each horizon. This contrast may be explained by a difference in glacial till composition or precipitation. The Ridge study sites are located at higher elevations, and may receive more precipitation increasing the leaching potential.

Cation exchange capacity results are highest in the White soil group and generally lowest in the Teepee soil group. This same ranking is present in the organic matter results. The relatively high CEC of the White soil group is attributable to organic matter. CEC in the $(II)A_2$ and $(II)B_2t$ horizons of the White soil group and other two soil groups differ significantly at the $p = .05$ level.

Clay Mineralogy

Table 12 summarizes x-ray diffraction means by soil group. These means were not analyzed statistically.

Similar clay minerals were identified within the $(II)B_2t$ horizons of each soil group. The only striking difference in the clay mineralogy results is the relative abundance of the minerals and the presence of chlorite in the Ridge soil group. Illite and kaolinite are the dominant clay minerals with illite constituting about 50 percent of the clay in each soil group. Together chlorite, smectite and interstratified vermiculite-chlorite account for less than 30 percent of the clay identified in each soil group. The x-ray diffraction patterns shown in Figure 4 are from a pedon within the Ridge soil group. Chlorite is identified by the $7^{o}A$ peak in the x-ray diffraction of the K-saturated slide which was heated to $500^{o}C$. Except for the chlorite peak, these x-ray diffraction patterns are very similar to the diffraction patterns of the Teepee and White soil groups.

Table 12. Mean clay mineralogy data+ for the (II)B_2t horizon of the three Tertiary sediment-derived glacial till soil groups and siltstone parent material.

Mineralogy‡	Teepee		Ridge		White		Siltstone
Illite	H 55	(7.8)	M 48	(12.3)	M 49	(6.4)	H 57
Kaolinite	L 19	(4.6)	L 24	(20.2)	M 26	(14.6)	L 16
Smectite	L 13	(12.3)	L 13	(7.9)	L 7	(9.5)	L 9
Interstratified Vermiculite-Chlorite	L 13	(3.5)	Tr 3	(5.2)	L 18	(7.8)	L 18
Chlorite		--	L 12	(10.4)		--	

+Numbers in parentheses are standard deviations.
‡VH = Very high (75-100 percent); H = high (50-75 percent); M = medium (25-50 percent); L = low (5-25 percent); Tr = trace (<5 percent).

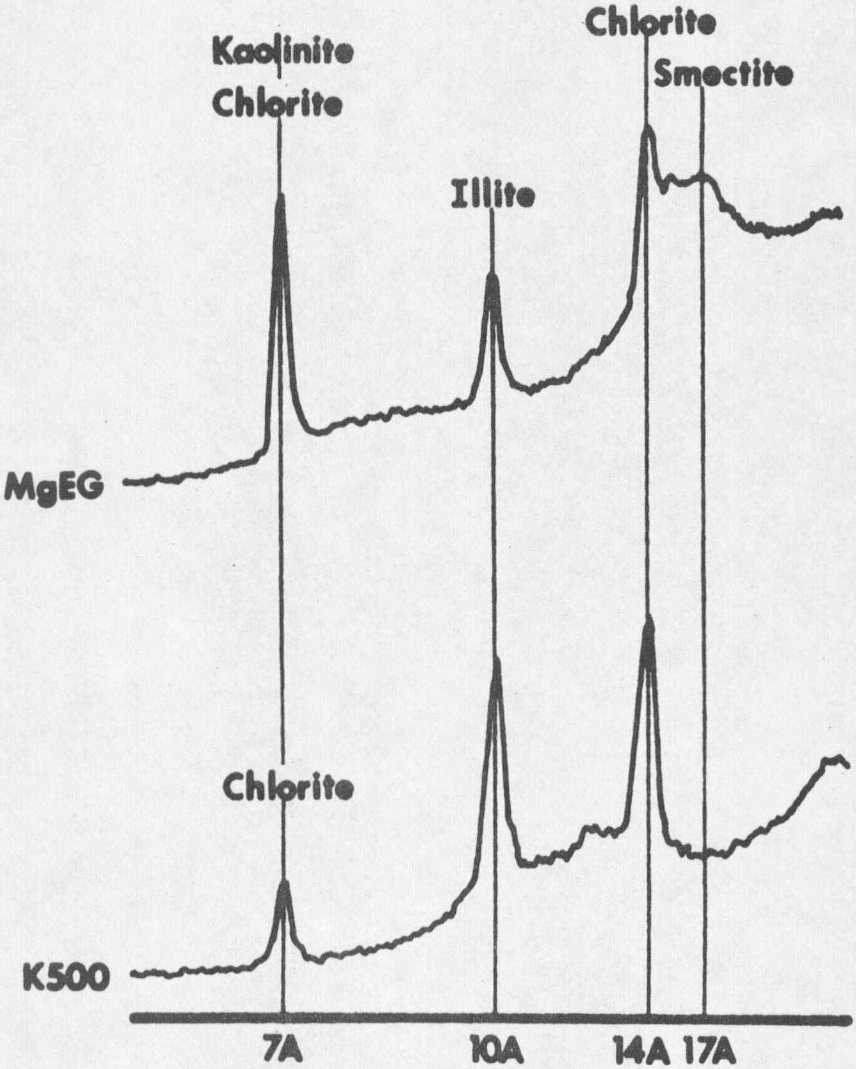

Figure 4. X-ray diffraction patterns from a pedon (R2) in the Ridge soil group.

The homogeneity of the clay mineralogy results reflect the influence of similar parent materials. Results from the qualitative analysis of the clay minerals identified in the siltstone parent material of the Ridge soil group are shown in Table 12. These results show a striking similarity to the soil clay mineralogy results, especially those of the Ridge soil group. This agrees with Veseth's (1981) statement that soil texture and clay mineralogy are closely associated with parent material. Tertiary sediment dominated glacial till in both the North Fork and Flathead valleys is largely composed of Belt Supergroup sediments.

The dominance of illite can be attributed to the presence of micaceous minerals within the Belt Supergroup. All the clay minerals identified in this study can be formed through the weathering of mica. Jenny (1980) states that modifications in the state factors of a site, such as a change in the climate to raise the pH or initiate a leaching regime, may lead to the formation of these clay minerals from mica.

RESULTS AND DISCUSSION OF SITE PRODUCTIVITY STUDY

Appendices II to V show profile descriptions and characterization data for the eleven soil pedons included in this study. The topographic, climatic, physical and chemical data used in this study are summarized by site in Appendices IX to XI. Table 13 displays the following information for each site: parent material, habitat type and associated yield capability.

Habitat types are generally consistent within the three groups of parent materials. The ABLA/CLUN/CLUN (Abies lasiocarpa/Clintonia uniflora/Clintonia uniflora) habitat type represents the high yield capacity class for which productivity ranges from 85 to 102 $ft^3/a/yr$. Pfister, et al. (1977) state that this habitat type is extensive in northwestern Montana. The other two habitat types represent the moderate yield capability class which has a productivity range from 50 to 85 $ft^3/a/yr$. The PSME/LIBO/SYAL (Pseudotsuga menziesii/Linnaea borealis/Symphoricarpos albus) habitat type is a major habitat type in northwestern, west-central and central Montana while the ABLA/LIBO/XETE (Abies laciocarpa/Linnea borealis/Xerophyllum tenax) habitat type is found only in the vicinities of the Flathead, Lolo and Bitterroot National Forests.

The Tertiary Volcanic-derived sediments and limestone or quartzite-derived glacial tills of Cullen (1981), both support moderate yield