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
Montana State University

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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by

WILLIAM DICKSON KLEIN

A thesis submitted in partial fulfillment
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Approved:

Cliff Montagne
Chairperson, Graduate Committee

Dwane G. Miller
Head, Major Department

Michael Malone
Graduate Dean

MONTANA STATE UNIVERSITY
Bozeman, Montana

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ABSTRACT

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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.