1983

Genesis of Mollisols under Douglas-fir

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The University of Montana

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THE GENESIS OF MOLLISOLS

UNDER DOUGLAS-FIR

by

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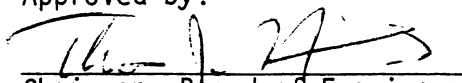
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        Soils were sampled along transects that crossed adjacent forested
and grassland Mollisols in southwestern Montana. Grasslands had
three times as many grass opal phytoliths as forests; Douglas-fir
opal was found in small quantities only on forested plots. Grassland
and forested soil populations did not have significant differences
in organic carbon; soils sampled beneath and beyond the crowns of
old, spreading Douglas-fir were also not significantly different in
organic carbon. This evidence supports Mollisol genesis under
Douglas-fir. A mean fire interval of 24 years (680 ha area) was
calculated for these forests; in the past, frequent, low, spreading
fires gave these forests an open appearance with lush, graminoid
undergrowth. Since the exclusion of fire from these areas, stands
are becoming closed and later successional species are becoming
prominent; it is possible that forested mollic epipedons may degrade
because of these changes.

ACKNOWLEDGEMENTS

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INTRODUCTION

Mollisols are soils that develop under prairie vegetation. They are categorized as one of the ten soil orders; the soil order is the broadest level of soil classification as defined by soil taxonomy (Soil Survey Staff 1975). (The distinguishing feature of these soils is the mollic epipedon, a dark, thick, base-rich surface horizon.)

These soils are most extensive in the mid-latitudes, developing under a wide range of moisture and temperature regimes. Vegetation and climate, respectively, are considered the most important factors in Mollisol genesis. Fire is not considered a soil forming factor, although fire is recognized as playing an important role in grassland ecology. Fire directly affects the form and rate of organic matter return to the soil and it also influences the composition of the vegetation growing on these soils.

Mollisols are also found under conifer and hardwood forest. This would appear to be anomolous when considering the previous statement that grassland vegetation is the major soil genesis factor. This could be explained if a climate change favored the invasion of grassland by forest, and the soils that formed under the previous grasslands persisted. An alternative hypothesis would be that these soils developed under forest cover.

One way to gauge the importance of vegetation as a soil forming factor is to examine soils along a transect through distinctly different vegetative types, such as grassland and forest (this is

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referred to as a soil biosequence). The boundary, or ecotone, between grasslands and forests may be stable or shifting, and the degree of this movement may affect soil development. Fire may be a major cause in ecotone shift. The objectives of this study were as follows:

1. Determine if Mollisols can develop under Douglas-fir forest.

2. Determine if grassland-forest ecotones have been stable for approximately the past few thousand years.

3. Interpret the role of fire in the above.

This study had several sections that were used to answer these objectives. The opal phytolith and wolf tree soil organic carbon distributions were used to answer objectives one and two. General soil organic carbon distribution with elevation also helped with the interpretation of these first two objectives. The determination of fire history helped answer objective three.

Each of these sections were first discussed individually, but the final conclusions of this report were developed by integrating the results of the separate sections.

LITERATURE REVIEW

Mollisol Genesis

There are five accepted soil forming factors: climate, organisms, parent material, relief and time (Buol et al. 1980). In Mollisols, these factors influence soil genesis to varying degrees, but their combination will lead to the formation of the mollic epipedon. Mollisol genesis, then, is strongly tied to mollic epipedon formation. The influence of each of the soil forming factors will be briefly discussed.

Climate:

The mollic epipedon forms when a balance is reached between the accumulation of plant and animal remains and their subsequent decomposition. The thickness of this epipedon, the organic carbon and nitrogen contents, and the dark color are the result of this balance. Climate influences both accumulation and decomposition (Jenny 1950).

Thorp (1931) describes soil profiles that were sampled along transects from deserts to mountainous areas in northern Wyoming. Desert surface horizons were lighter and shallower than at higher elevation where vegetation was similar.

Temperature and moisture are related to soil organic carbon and total nitrogen; temperature is probably the more influential factor. In the United States, for every 10° C decrease in mean annual temperature, soil nitrogen increases two or three times (Jenny 1929, 1930). Soil moisture affects the type and amount of vegetation, microbial decomposition rates (Fogel and Cromack, Jr. 1977), and fire frequency and intensity. Leaching of cations, clay (amount) and organic colloids is also affected. Temperature also affects these processes, but seems especially important in controlling rates of decomposition (Edwards 1975, Daubenmire and Prusso 1963).

Mollisols are found in any of the temperature and moisture regimes (Soil Survey Staff 1975). Mean annual temperatures can vary from 0° C to 22° C and moisture regimes can be very wet to desert-like. The majority of Mollisols are found at mid-latitudes; the following climatic features are associated with many of the Mollisols of the United States:

1. Cold, severe winters with little snow.

2. Moist, springtime conditions.

3. Summers with periods of water deficiency. (Buol et al. 1980)

Organisms:

Plants and animals living upon and within soil are the source of dark organic stains that coat the mineral fraction of the mollic epipedon. The amount and stability of these stains is determined by the type and quantity of above- and below-ground plant litter and by the nature and activity of decomposing organisms.

Mollisols usually support grasses; forest cover is the exception. Some soil scientists would hypothesize that the presence of grasses is necessary for the formation of the mollic epipedon (Soil Survey Staff 1975). Grasslands must have special properties that are conducive to mollic epipedon formation.

In general, forests have greater net primary production than do grasslands (Spurr and Barnes 1980), although individual values may vary considerably (Bray 1963). Although large differences in primary production occur, it is probably the nature of the biomass, rather than the amount, that is important to soil genesis. Grasses usually have higher below-ground/above-ground biomass ratios than forests (Bray 1963). Weaver (1958) found that up to 85% of the root system of little bluestem (*Andropogon scoparius*) lies within 15 cm of the soil surface. Similar values have been reported for other common prairie grasses, although grass roots may extend quite deeply into the profile (up to 3 m),

especially on more xeric sites. There is probably a linear relation
between the amount of grass roots and soil organic carbon below 15 cm
in a profile (Weaver 1935). The relation is more tentative above 15 cm
because of the abundance of grass rhizomes, which are more resistant
to decomposition than are the roots. Grass roots decompose rather
rapidly, usually within three to four years after root death (Dahlman
and Kucera 1965, Weaver 1958). Roots not only decompose rapidly and
contribute to organic matter, but they physically bind soil peds
together and stabilize the surface horizon against erosion.

Grasslands rarely have litter or 0-horizons because the above-
ground biomass decomposes readily and is incorporated into the soil.
Frequent prairie fires also remove litter buildups (Vogl 1974).

Calcium (Ca^{+2}) and magnesium (Mg^{+2}) ions dominate the cation
exchange sites of Mollisols. These bases are returned to the soil
through decomposition and through release by fire. Calcium is thought
to play a role in stabilizing soil organic matter. Calcium humates
were found to be the most stable organic fraction of a Mollisol; calcium
ions may act as bridges between clay micelles and organic molecules
(Campbell 1967). Calcium is usually more soluble in forest soils, so
its role as a stabilizing agent is less apparent. The granular and
crumb structures, typically found in the mollic epipedon, that are so
important to horizon stability, are due in part to the influence of
calcium.

Grasses not only recycle needed nutrients, but they also absorb
and deposit silicon, an element that seems to have no physiological

function in the plant. Soluble silica is absorbed by plant roots and is deposited in vascular tissue as a hard, quartz-like particle known as an opal phytolith. As the plant dies, the resistant phytoliths are returned to the soil; surface horizons contain phytoliths that are thousands of years old. Tree phytoliths are also produced, but they are not as abundant or as variable in shape as graminoid phytoliths.

The distribution of both above- and below-ground portions of forest biomass is not well known, mainly because of the sampling difficulties involved. Tree root systems, especially the fine roots, are particularly difficult to sample. Root turnover rates, which could be relatively rapid, are even more obscure than root biomass distribution (Hermann 1974). There appears to be a strong, positive relationship between tree diameter and root biomass for many tree species (Santantonio 1977).

Conifer litter accumulates on the forest floor as an O-horizon. Not only is decomposition slower than rates found in grasslands, but the breakdown products are more susceptible to leaching and are less stable; mollic epipedons are usually not formed. Probably the major reason for the slow rates of decomposition is the high lignin content of the litter, which makes it much more difficult to break down (Fogel and Cromack, Jr. 1977).

Conifer foliage and soils often have low amounts of calcium and magnesium; both the vegetation and soils are more acidic than their grassland counterparts. Neutral soils can occur under some conifer

species, notably Douglas-fir, even over acid parent materials.
Daubenmire and Prusso (1963) studied the chemical composition of foliage
from eleven northwest conifer species; they found that the calcium
content of Douglas-fir litter was exceeded by only two other conifer
species, *Abies grandis* and *Thuja plicata*, and the calcium content of
Douglas-fir litter was two to three times greater than the litter of
Pinus, *Picea*, *Larix* and *Tsuga*.

Forest fires are a strong influence on stand composition in the
northern Rocky Mountains; fire frequency and intensity are quite
variable. Some Douglas-fir habitat types (Pfister et al. 1977) in
western and southwestern Montana had mean fire intervals of 15-30
years (Arno 1980).

Soil scientists have long recognized that ecotones are especially
suitable study sites for assessing the effects of vegetation on soil
development. If soils are examined in adjacent grassland and forest
communities, major differences in both chemical and physical properties
are often observed. Soils under forest cover have 0-horizons. They
also have lower organic carbon, lower base saturation and pH values in
surface horizons, and greater clay accumulations and strength of struc-
ture in subsurface horizons than nearby grassland soils (Severson and
Arneman 1973, Geis et al. 1970 and Bailey et al. 1964). Profile differ-
ences can be dramatic, occurring within 9 m of the ecotone (Thorp 1931);
or the changes can be more gradual, within 100 to 400 m of the ecotone
(Bailey et al. 1964). In the latter case transitional soils are

observed with properties intermediate between those of grassland and forest soils; these soils have an E horizon that underlies the A.

Although climate and organisms can clearly act as independent soil forming factors, it is also clear that there are probably many interactions between the two.

Parent Materials:

Parent materials impart important physical and chemical properties to soils; this influence is more pronounced on younger soils. Mollic epipedons have formed on a wide range of parent materials; parent materials seem to have no consistent influence on epipedon formation. Therefore, parent materials are not considered a major factor in Mollisol development. However, a few exceptions are found in the literature.

Parsons and Herriman (1975) found that Mollisols would develop on schist and pyroclastic parent materials, but not on granite. The granite soils were highly leached and erodible; relatively young Inceptisols and Entisols were the only soils that had formed on these unstable parent materials.

Borolls were found on limestone and Boralfs on nearby sandstone parent materials in the Sacramento Mountains of New Mexico (Anderson et al. 1975). Since the Borolls had twice the organic carbon content of the Boralfs, with all genetic factors appearing equal other than parent material, it appears that calcium carbonate was involved in organic matter accumulation. Calcium carbonate is also known to retard clay illuviation.

Relief:

ı Relief is not a major factor in Mollisol development, but in some cases it can affect the formation or degradation of the mollic epipedon. ı

Steep slopes that are actively eroded often have no mollic eipiedon, yet Mollisols will develop on the surrounding gentle slopes. Geis et al. (1970) noticed that recently forested Mollisols resisted the change to Alfisols that is normally expected, especially if the soils were in poorly drained positions. Apparently high soil moisture retards oxidation of organic matter and the mollic epipedon is preserved.

Time:

Compared to many of the other soil orders, Mollisols are relatively young. Based on productivity data, Dahlman and Kucera (1965) estimated that it would take 99 years for the organic carbon content of a tall-grass prairie A-horizon to reach an equilibrium where decomposition equals accumulation. Epipedon development would take longer because the epipedon must become thicker and the initial vegetation must stabilize. Nonetheless, this could probably happen in a few hundred years.

The mollic epipedon is both fragile and stable. The A horizon of the Iowa plains lost one third of its thickness after 100 years of cultivation (Weaver 1958). The vegetation and the soils of the Great Plains (primarily Mollisols) have probably been stable for a few thousand years. The interactions between a moister climate and forest

vegetation can slowly degrade a prairie Mollisol; Illinois soils that
have been forested for 400-600 years still have characteristics
distinctive of Mollisols (Bailey et al. 1964). An organic fraction of
a prairie soil was carbon dated at over a thousand years, and the soil
may have been stable for much longer. The same author concluded that
only 7% of the soil organic carbon was "active"; the major portion is
inert (Campbell et al. 1967).

Mollisols Under Forest

Mollisols occur under deciduous and conifer forest. In the former
case, these soils have been reported under sugar maple (*Acer saccharum*)
in Illinois (Geis et al. 1970), and oak (*Quercus spp.*) in Nebraska
(Al-Barrack and Lewis 1978). In both cases, forest vegetation had
probably not occupied the site for longer than 500 years; it is thought
that forest had invaded tall grass prairie and the prairie soils persisted.
Forested Mollisols cover small areas in the Midwest today because many
of these forested areas were harvested, burned or cleared for farming.

Mollisols have been reported under conifer forest in the western
United States. Nimlos and Tomer (1982) report that Montana may have
300,000 ha of Mollisols under Douglas-fir. Similar soils exist in the
Wasatch Mountains of Utah, according to Professor R. Fisher, Soil
Scientist at Utah State University, Logan, Utah (personal communication).
The western Cascades in Oregon have Mollisols under Douglas-fir and
grand fir (*Abies grandis*) (Parsons and Herriman 1975). The southern-most
extension of sub-alpine fir (*Abies lasiocarpa*) forest in the United

States is in the Sacramento Mountains of New Mexico, and this forest
has Haploborolls and Pachic Cryoborolls, both Mollisols (Anderson
et al. 1975 and Dye and Moir 1977). Any soil name ending in *oll* is in
the Mollisol order. Haploborolls and Argiustolls have been described
under ponderosa pine (*Pinus ponderosa*) in the Black Hills of South
Dakota (White et al. 1969). In most of these cases the forest
understory is often dominated by graminoid species. There are probably
other areas of the mountainous West that also have forested Mollisols,
but they have yet to be described in the scientific literature; these
soils are probably more extensive than scientists realized.

Floral and Climatic History in Southwestern Montana

Since past vegetation types and climates can influence the soil
that we see today, it is important to document changes in these factors.
These changes in southwestern Montana have been inferred from studies
that were done in two areas; the first area is Lost Trail Pass, located
115 km northwest of Dillon, Montana and 200 km northwest of the Centennials;
the second area is the Gallatin National Forest-Yellowstone National
Park area, located from 115-165 km southeast of Dillon and 80-100 km
east of the Centennials.

The last major glacial advance (Pinedale glaciation) in southwestern
Montana ended about 13,000 years b.p. (before present); small glaciers
are found on the highest peaks of the Absaroka Range (Morrison-Maierle
staff writers 1981). Vegetative history since 12-13,000 years b.p. has
been constructed by comparing the pollen counts of ancient bog and lake

sediments to modern pollen counts. Following Pleistocene glaciation, *Pinus-Artemesia* (sagebrush) vegetation probably dominated the areas at both Lost Trail Pass and Yellowstone National Park (Baker 1976, Mehringer et al. 1977 and Waddington and Wright 1974). A warming trend, referred to as the Altithermal Period (9000-4500 years b.p.) followed; sagebrush declined, pine dominated, and Douglas-fir and possibly larch (*Larix*) later mixed with pine. Although the vegetative histories just mentioned are general and differ somewhat depending on the area sampled, there is agreement that vegetation has changed little in the past 3000-4000 years (Mehringer et al. 1977 and Baker 1976). This period of time is sufficient for Mollisol development. The same data indicate no marked climatic changes since the Altithermal Period. Studies in northern Idaho and western Montana also indicate that fire frequency or intensity has been greater in the past 1000 years than in the previous 9500 years (Mehringer et al. 1977, Smith 1983, Hemphill 1983).

The interested reader is further referred to tree-ring chronologies that have been recorded at Dell and Gardner in southwestern Montana; these chronologies cover the past 500 to 600 years but analysis of this data is beyond the scope of this paper (edited by Stokes et al. 1973). Apparently these data have provided only limited interpretation of past climates.

STUDY AREAS

The majority of the sampling took place on the south flank of the Centennial Valley in Beaverhead County; this is a high-elevation (2000 m), east-west trending valley in southwestern Montana, about 90 km southeast of Dillon, Montana (Figure 1). Much of this land is administered by the USDI Bureau of Land Management (BLM) and some of it is owned by private landowners. The valley and its bordering mountains are extensively grazed by cattle; an occasional timber harvest for poles or firewood has taken place in the mountains; past harvests were probably for timber. Five out of the six transects that were sampled in this study were located in the Centennial Valley.

A sixth transect was sampled in the Snowcrest Range in Madison County, about 60 km southeast of Dillon (Figure 2) and 50 km north of the Centennials. The Snowcrest Mountains lie on the west side of the Ruby River Valley; much of this land is part of the Beaverhead National Forest. This land is also grazed by cattle, but there has been little if any timber harvest from this area.

Since these sites are very similar, the subsequent discussion will treat them as one area, except where specific distinctions must be made.

Organisms

Vegetation:

Several vegetative habitat types (Pfister et al. 1977) were encountered in the study area (Figure 3). The dry, lower slopes of the valley (below 1975 m) are occupied by mountain-big sagebrush (*Artemesia*
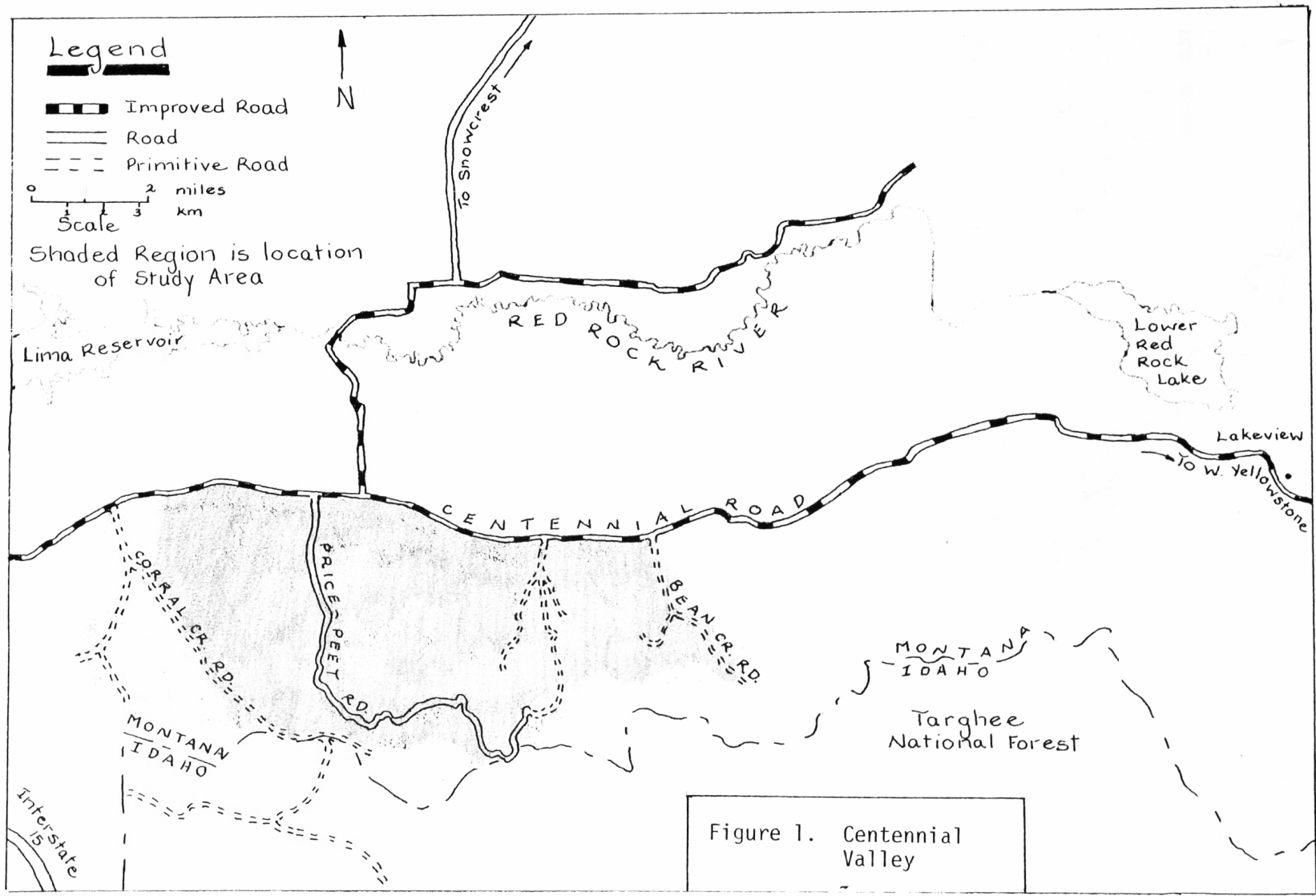
Figure 1. Centennial Valley
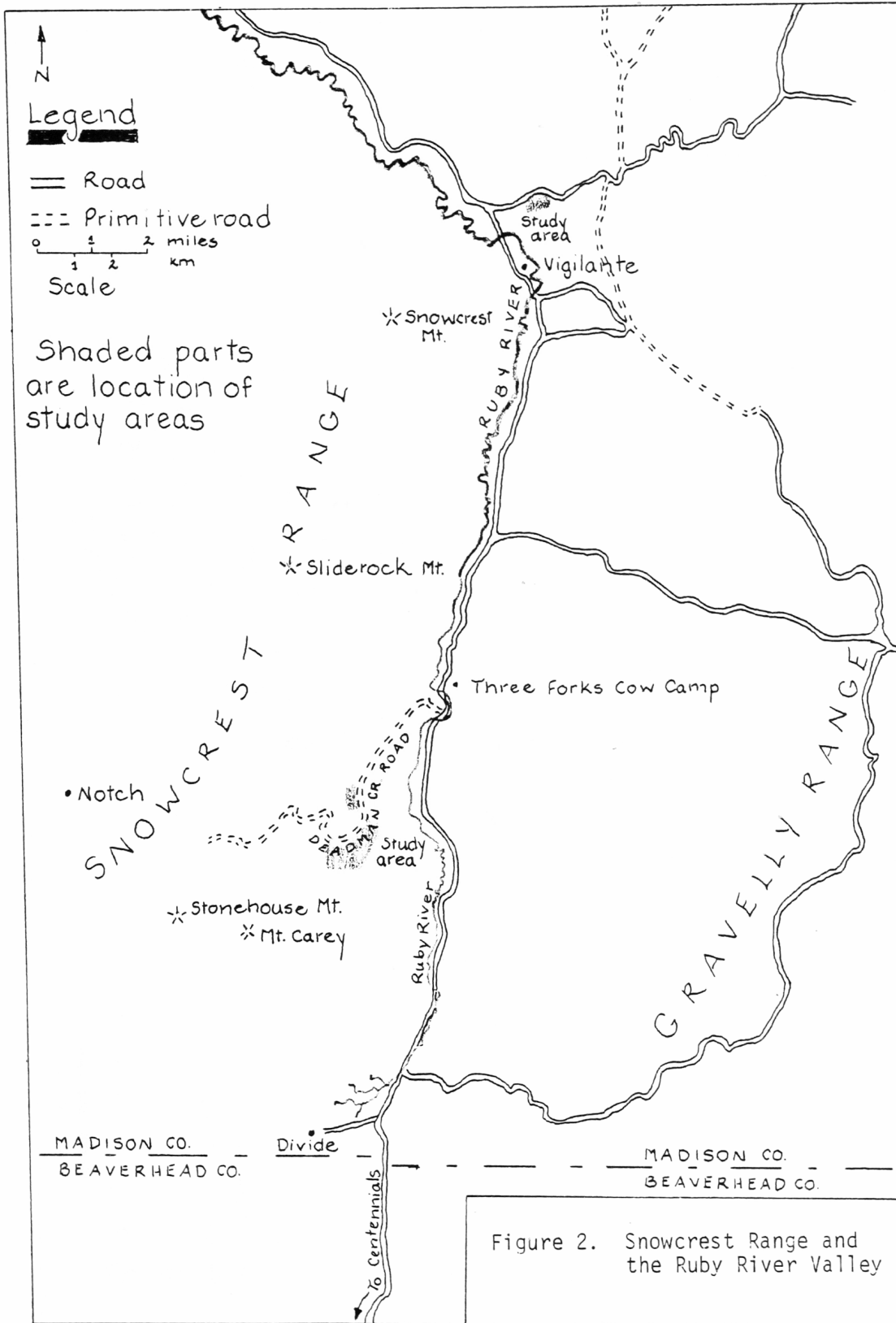
Figure 2.   Snowcrest Range and the Ruby River Valley

Figure 3.   Vegetation and ecotones in the Centennial Range.

Legend

Douglas-fir

Subalpine fir

Mountain big sagebrush

Idaho fescue

Plot location

N

PARK

TRANSECT A

TRANSECT B
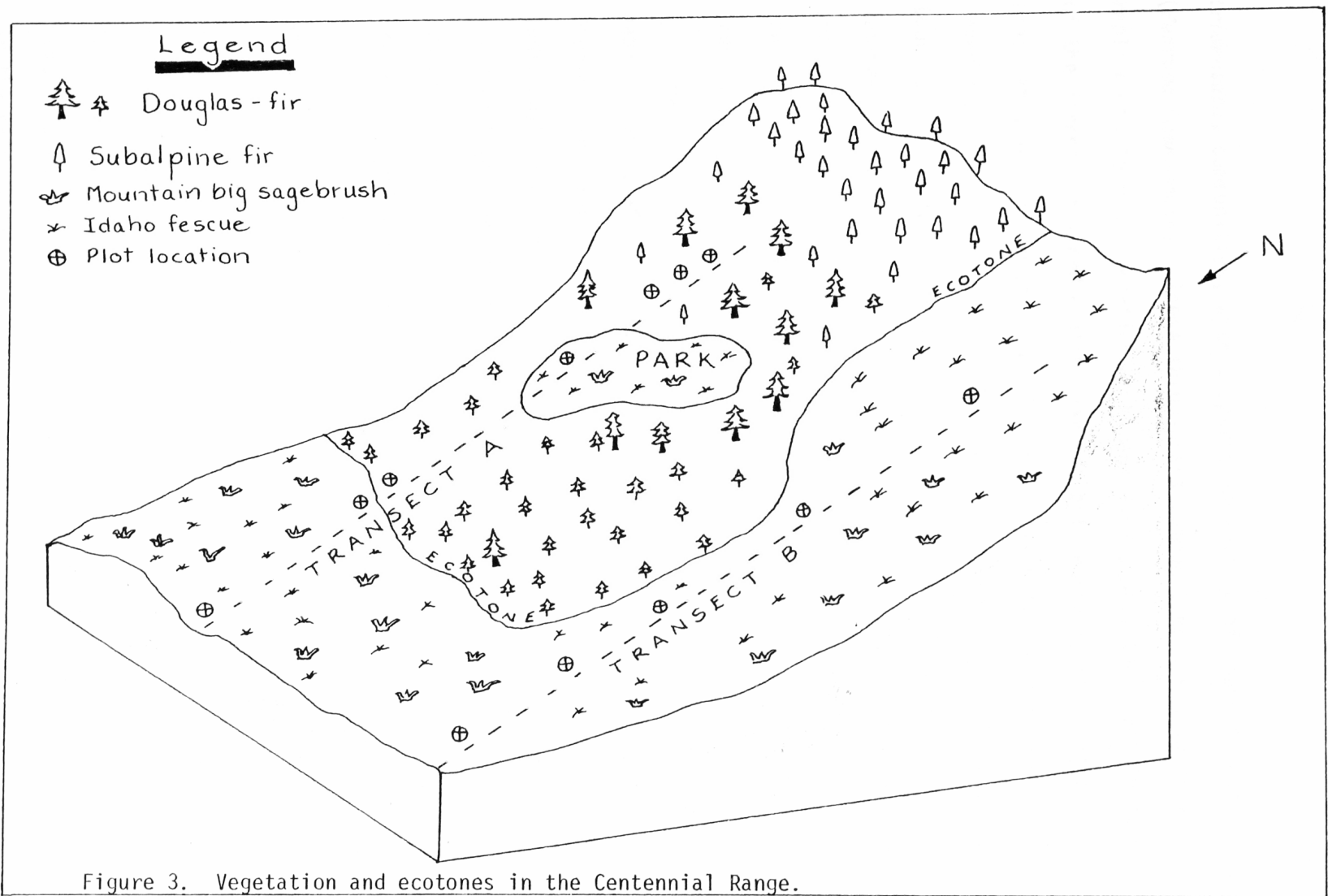
ECOTONE

ECOTONE

tridentata) communities, with a sparse understory of Idaho fescue (*Festuca idahoensis*). These shrub-grass communities are gradually replaced by forest vegetation at higher elevations; the exact location of the forest-grassland ecotone varied, but generally the change took place at an elevation of about 2000 m. This is not a sharp ecotone; the *Artemesia-Festuca* communities often break the continuity of the forest. Douglas-fir habitat types are found at elevations of 2000-2200 m, but *Artemesia-Festuca* habitat types are also common. The Douglas-fir stands are dominated by juvenile trees, especially at the lower timberline; there are also scattered mature individuals and small patches of aspen trees (*Populus tremuloides*).

Upper elevation areas, above 2200 m, are usually subalpine fir habitat types, although these stands are dominated by old-growth, seral, Douglas-fir. Subalpine fir is usually present in the understory; mature individuals are scarce. There are also scattered large and small areas of Engelmann spruce (*Picea engelmannii*) and lodgepole pine (*Pinus contorta*) at these elevations. Occasional park-like openings of sage-brush and grass are found within the forest.

At elevations above 2350 m, on cool exposures, the forest is blanketed with subalpine fir.

The Centennial Valley also has an unusual east-west grassland-forest ecotone. In the vicinity of Corral Creek Road (Figure 1), the forest gives way to the west; trees are found only in stream drainages. Sagebrush-grass communities are found from valley floor to mountaintop west of this road. It is possible that this nearly treeless area lies in the rain shadow of mountains further to the west.

This east-west ecotone was only one of three ecotones encountered in this study. Another ecotone has been previously mentioned; this will be referred to as the lower-timberline ecotone, where the dry grassland meets the dry forest. The last ecotone will be called the park ecotone; these areas are found as grassy openings within the forest (see Figure 3).

The mountains of both the Centennial and Ruby River Valleys have had limited logging in the past. In both instances the logging has been "patchy", and old-growth Douglas-fir stands are often undisturbed; their excessive branchiness and large size probably made commercial harvest unfeasible.

For thousands of years fire influenced the distribution of these vegetative communities, but this influence has been negated since the advent of fire suppression, which took place gradually after the turn of the century. Since both sagebrush and subalpine-fir are less tolerant of fire than are their current associates (grass and Douglas-fir, respectively), these species were probably not as extensive in past plant communities (Arno and Gruell 1983).

There are no areas from either study site that have escaped domestic grazing. Sheep grazing was common in the Centennial Valley, beginning in the late 1800's, and continued there until about 1945. Currently all of the private lands are grazed by cattle, and much of the public land is leased for this purpose. Cattle grazing is more significant at the lower elevations.

The principal wild herbivores of these areas include elk, moose, and mule deer.

Climate

Weather data for the study area are available from Lakeview, Monida and Lima; see Figure 4 for location. The average annual temperature and precipitation are summarized in Table 1. Monthly rainfall distribution is given for Lakeview, and monthly temperature is plotted for Lima (Figure 5).

Table 1. Average annual temperature and precipitation at Lakeview, Lima and Monida, Montana.

	Average Annual Precipitation (mm)	Average Annual Temperature (°C)	Elevation (meters)
Lakeview	521	1.8 (estimated)	2038
Monida	354 (estimated)	unavailable	2061
Lima	275	3.8	1905

In general, the study areas are cool and relatively dry. Mean annual temperatures are between 2 and 4° C (Climatological Data 1982), and mean annual precipitation varies from 275 mm in the drier valleys to 760 mm on the higher peaks (Ross and Hunter 1976).

Freezing temperatures may occur at any season, and extreme summer temperatures rarely exceed 38° C.
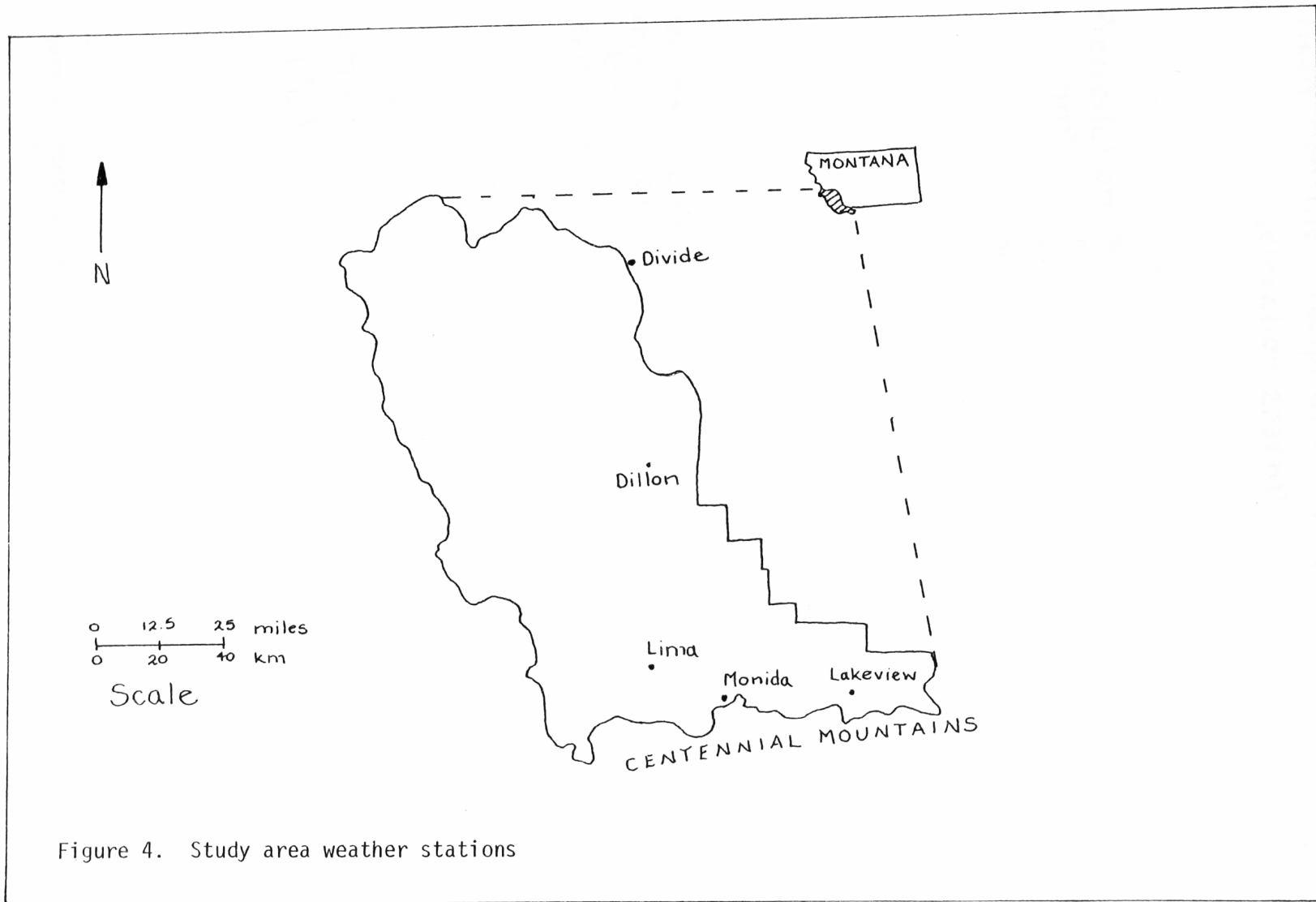
Figure 4.   Study area weather stations

Mean Monthly Precipitation At Lakeview (elevation 2038m)

Precipitation (mm)

90
80
70
60
50
40
30
20
10

J F M A M J J A S O N D

Month

Mean Monthly Air Temperature at Lima (elevation 1905m)

Air Temperature (°C)

18
16
14
12
10
8
6
4
2
0
-2
-4
-6
-8

J F M A M J J A S O N D

Month

Figure 5.   Monthly precipitation and temperature in the Centennial
Area.
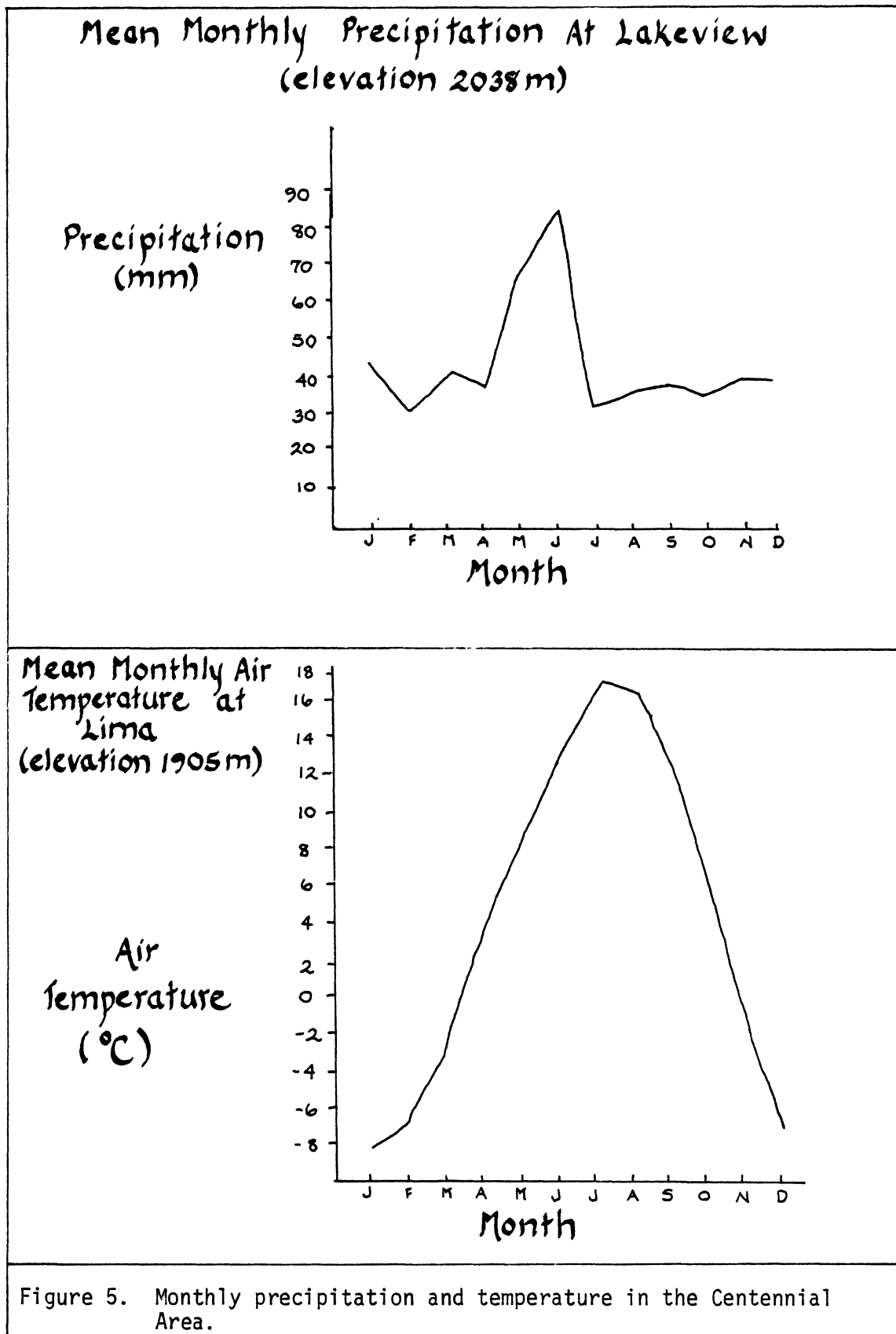
Much of the precipitation falls between April and June, and summer water deficits may occur from early June until late September, depending on elevation.

Nimlos and Tippy (1981) found that most of the soils that were encountered in this study have cryic temperature regimes, and possibly pergelic temperature regimes at high elevations (Table 2). Soil moisture regimes vary from udic to aridic (Table 3). Most of these soils are classified as Cryoborolls.

Landform

Landforms,which are variable in the study area,are a major influence on soil development only in steeply eroded areas and areas of sediment accumulation. Since both of these types of areas were avoided in the sampling design, landform variation was not an important factor in this study. Plots that were located at lower elevations had more gentle slopes (5-15%) than did the upper elevation sites (15-30%).

Parent Materials

The Centennial Valley has both volcanic and sedimentary parent materials. The first uplifting of the Rocky Mountains in Tertiary times was followed by a long period of erosion; these sediments filled many intermontane valleys in southwestern Montana (Veseth et al. 1980). These sediments may be covered by more recent alluvial deposits on the valley flood plain; a few scattered gravel pits along the Centennial Road are evidence of this. In later Tertiary times, much of the soft valley fill was covered with lava flows or volcanic ejecta; ryolite

Name of Regime	Mean Annual Soil Temperature °C	Summer Temperature °C
Pergelic	< 0	
Cryic	0-8	< 15
Frigid	0- 8	
Mesic	8- 15	
Thermic	15 < 22	
Hyperthermic	> 22	

TABLE 2. SOIL TEMPERATURE REGIMES (Soil Taxonomy 1975).

Aquic   Saturated long enough so that reducing conditions exist.

Aridic   Dry more than half the time when not frozen; not moist more than 90 consecutive days when soil temperature is > 8°C at 50 cm depth.

Perudic Precipitation > Evapotranspiration every month of the year.

Udic   Not dry as long as 90 cumulative days.

Ustic   Dry more than 90 days but less than 180 days.

Xeric   Dry summers and moist winters. Soil is dry > 45 consecutive summer days and moist > 45 consecutive winter days.

TABLE 3. SOIL MOISTURE REGIMES (Soil Taxonomy 1975)

outcrops occur sporadically throughout the valley. Soil profiles that were sampled showed evidence of all of the aforementioned parent materials.

The Snowcrest Mountains have an older sedimentary geology than the Centennial Mountains; these deposits were laid down between 180-600 million years ago when the area was covered by shallow inland seas; these rocks were later deformed by the Rocky Mountain uplift (Montana Forest and Conservation Experiment Station Staff 1978).

Time

These areas have both young and mature soils. The younger soils occupy landscape positions that are unstable, either actively eroding or accumulating sediment. The plots that were sampled at the lower elevations in the valley are younger than the upper elevation plots, yet they show no signs of recent geologic events. All surfaces have probably been stable for 5000 to 10,000 years. It is worth repeating that climate and vegetation are the predominant soil forming factors for these study areas.

METHODS

Thirty-nine plots, laid out along six transects, were sampled in this study. Data taken from these transects were used to test the three hypotheses stated in the introduction. Samples were also taken from wolf tree (large, spreading old-growth trees) sites and from fire scarred trees.

All of the plots had some similarities and some differences; the specific differences will be described first, followed by a general plot and transect description.

Soil Organic Carbon

The soils of the study area have high levels of organic carbon (Nimlos and Tomer 1982). It is possible that high organic carbon has been maintained in these soils due to the cool, dry environment, which would retard organic carbon oxidation. Soil temperature and moisture are both correlated with elevation. Hockensmith and Tucker (1933) found that total soil nitrogen content of grassland soils increased with elevation, but forest soils were probably not as well correlated with elevation (equations were not presented). It can be assumed that organic carbon would show trends similar to total soil nitrogen.

Soil organic carbon was measured on all 39 plots. A multiple regression analysis was used to determine the relationship between organic carbon (dependent variable), elevation, and thickness of A and O-horizons (independent variables).

Although soil organic carbon relationships could not be expected to prove or disprove any of the stated hypotheses, it was thought that these data could aid in the interpretation of soil genesis. For instance, if the forested soils were previously vegetated by grasses and had been recently invaded by forest, the present day organic carbon relationships between the contrasting types of vegetation might be similar.

Through preliminary sampling of the area soils, we determined that six samples were sufficient to estimate mean soil organic matter to +/- 10% with 90% confidence. Six soil samples were taken from each plot at the 0-10 cm depth and sealed in a labeled plastic bag.

Soil organic carbon was determined using the Walkley-Black method of wet-oxidation (Black 1965). Samples were sieved through a number 30 sieve (0.590 mm) and weighed to the nearest 0.00 g; all weights were corrected for moisture. These soils had such high carbon levels that 0.5 g samples were used, and in some cases 0.25 g samples were necessary; duplicates were run on the latter samples. The precision of the method was tested by running multiple sub-samples of the same soil; the sub-sample values were within 3% of the sample mean. An 0.16% barium indicator was used for the titration. Organic carbon values were not corrected for carbonate carbon; this did not influence the results. Results are presented on a percent weight basis.

Soil Opal

To test the hypothesis that Mollisols can develop under conifer forest, opal phytoliths were examined from forest and grassland soils of the study area. Opal phytoliths, if carefully analyzed, have proven to be an important tool in analyzing past vegetative history (Witty and Knox 1964).

Opal particles often have distinct shapes (morphologies) because silica absorbed by plants takes on the shape of the cell in which it was deposited; the resulting hardened phytolith is returned to the soil.

By ashing fresh plant material and examining the opal phytoliths in the residue, phytoliths can often be identified at the genus and sometimes at the species level. The plants that deposited the soil phytoliths can then be identified.

There are problems with interpretation of opal phytolith data. One question of primary importance to the investigator is the number of years that is required for a given amount of opal to accumulate in the soil. This has been estimated at approximately a few thousand years (Jones and Beavers 1964) to 7000 years (Witty and Knox 1964), although individual opal phytoliths may be much older (Gill 1967 and Wildling 1967). Soil opal content also varies with soil depth and internal drainage because both of these factors affect erosion, deposition and biomass production (Jones and Beavers 1964).

Finally, laboratory procedures typically analyze only about 10% of the total opal present in a soil sample, and preparation of the samples can break or disfigure the phytoliths, making identification difficult (Stevens 1966).

Nonetheless, by minimizing the above sources of variation, an analysis of soil opal would be helpful in determining the genesis of the soils in the study area. Although it is difficult to determine the type of vegetation and its length of occupancy on the site from these data, broad comparisons can be made that should be helpful in interpreting soil genesis.

Soil opal was analyzed from twenty of the same samples that were collected for organic carbon analysis. Samples were analyzed using the

methods of Witty and Knox (1964); a summary of these methods and minor modifications that were used are given in Appendix A.

The following opal phytoliths have been identified and photographed in other studies; the photos served as the basis for identifying the phytoliths found in this study:

1. Idaho fescue (Witty and Knox 1964).

2. Douglas-fir (Klein and Geis 1978 and Brydon et al. 1963).

3. Subalpine fir does not produce phytoliths (Garber 1966).

4. Bluebunch wheatgrass (*Agropyron spicatum*) (Jakoy 1983).

5. Pinegrass (*Calamagrostis rubescens*) (Jakoy 1983).

A general group of high-elevation plots were subjectively chosen for opal analysis because at these elevations two ecotones were present: the east-west and park ecotones. If Mollisols had formed under conifer forest, we would expect to find significant differences in opal quantities as ecotones were crossed.

There were three general types of vegetation that were found at high elevation: forest, sagebrush-grass park openings, and extensive sagebrush grassland areas of the western Centennial Valley. The soils of these three areas were treated as separate populations, and the number of samples analyzed within each population depended on the variation found and the cost and time constraints of the analysis. Group T-tests were used to compare mean soil opal contents of each population (Snedecor and Cochran 1980).

"Wolf" Tree Analysis

As stated previously, degrading mollic epipedons usually have lower organic carbon values than nearby stable Mollisols. If forests had invaded previous grasslands in the study area, mollic epipedon degradation would be expected. To test this hypothesis, soils were sampled underneath and beyond the crowns of Douglas-fir "wolf" trees. "Wolf" trees are large, spreading, old-growth trees that were either isolated or at least 35 m away from similar individuals.

Twenty-four soil samples were collected from each of three wolf trees; one of these trees was located in the Centennial Range and the remaining two were from the Snowcrest Range. Trees were aged with a 76 cm increment bore. Soil samples were collected along the cardinal directions; twelve samples were from under the crown and twelve from beyond the crown. Organic carbon was determined as previously described.

Organic carbon content (dependent variable) was regressed on distance from tree bole (independent variable) to see if there was a continuous increase in organic carbon from the bole outward. A T-test was used to compare mean organic carbon under the crown to organic carbon beyond the crown.

Root Analysis

During the course of the field sampling, I observed that grassland soils seemed to have more roots than nearby forest soils; the former soils had so many roots that intact soil volumes could easily be removed from the soil surface by cutting with a knife. This led to the

sampling of two forest plots and one grassland plot; five samples were randomly selected from each plot for a total of fifteen samples. Soil samples were cut out of the ground in rectangular blocks; depth was held constant at 9 cm, and soil blocks were trimmed and volumes measured carefully in the lab (Figure 6).
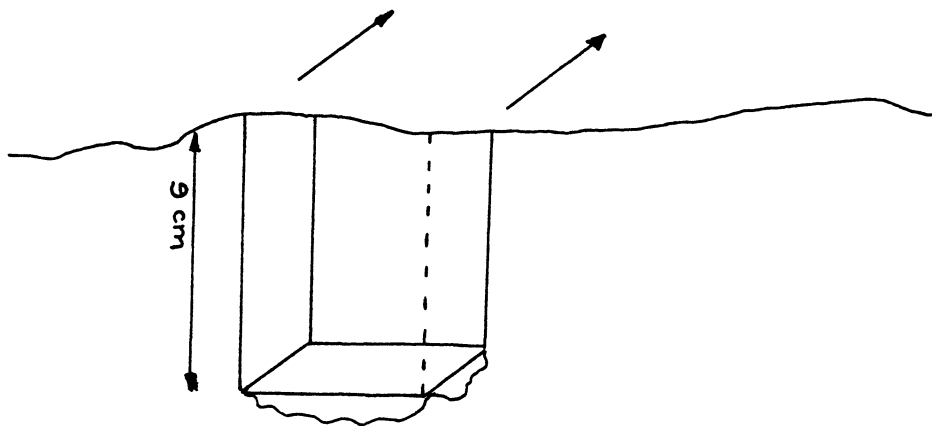
Figure 6. Field sampling for root biomass.

Soil samples were first dispersed in a 5% calgon solution, and then wet sieved into the following size classes:

1. > 2.00 mm

2. 2.00 - 1.00 mm

3. < 1.00 mm

Roots were removed from the sieves, oven dried, and weighed to the nearest 0.00 g. All results are reported on a mass/volume (g/cc) basis. These data are exploratory and the results were not subjected to statistical tests; conclusions from these data are tentative.

Fire History

Little information exists that documents the influence of fire on soil genesis. Since Mollisols are found in ecosystems where fire is a natural phenomenon, it is logical to hypothesize that fire may play a role, in both the formation and maintenance of these soils.

Knowledge of fire history is necessary to understanding the role of fire in these systems. Fire history of the forested portions of the study area was determined by sampling fire scars on old-growth trees (Arno and Sneck 1977). Approximately two fire scar trees were sampled per transect (excluding treeless transects in the Centennials). Tree cross-sections containing fire scars were dried, sanded and examined using a binocular microscope.

In addition, habitat types were identified on most plots. Unidentified plant species were placed in a plant press and identified (a list of habitat types appears in Appendix B).

Stand tables were constructed for all forested plots; these tables recorded all trees by species and diameter. Increment cores were taken from three or four trees that represented the age classes found on each plot; cores were sealed in plastic straws and aged with the aid of a binocular microscope; rates and patterns of radial growth also were noted. These stand tables provided a picture of tree community structure and forest succession, which aids in the interpretation of fire history. All ages that are reported are at d.b.h.

Transect and Plot Description

Samples were taken along six transects; five were located in the

Centennial Range and one in the Snowcrest Range. There were two types
of transects: 1) grassland-park-forest; and 2) grassland.

The grassland-park-forest transects began in the low elevation
grasslands (1980 m) and proceeded upward into the forest zone (2376 m).
Each transect had seven sampling locations (plots), except the two Corral
Creek Road transects, which had five and six plots, respectively.
Transect plots are defined as follows:

a. Upper-elevation, mature Douglas-fir (PSME) stand with pine-
   grass (CARU) understory.

b. Upper-elevation PSME stand with arnica (*Arnica cordifolia*)
   understory. Reconnaissance had shown that these mature stands
   were about 300 years old or older and rather small; 0.2 ha/0.5
   acre was the average. Often the undergrowth is mixed
   pinegrass-arnica; since pinegrass is more predominant, a plot
   that has only small amounts of pinegrass, yet has enough arnica
   to have a canopy coverage of 5-25% will be defined as a mature
   PSME/arnica plot. Some of the mature trees should be at
   least 100 cm d.b.h.

c. Upper-elevation juvenile PSME. Trees were less than 100
   years old and there was variable undergrowth.

d. Upper-elevation sites, previously referred to as parks.
   These areas did not have a predominance of sylvan grasses
   (pinegrass).

e. Mid-elevation PSME stands; whatever was available was
   sampled.

f. Mid-elevation sagebrush-grassland.

g. Low-elevation sagebrush-grassland.

High, mid and low elevations were not rigidly defined for these transects. This was due to the difficulty in finding the desired vegetation at the proper elevation. Transects were not ordinated as a straight line up a single slope. Rather, they comprised a group of replicates that covered the range of elevations. Figure 3 shows representative transects.

Three of these transects were in the Centennial Range and the remaining transect was in the Snowcrest Range.

The last two transects were located west of Corral Creek Road in the Centennials; these grassland transects had no forested plots. They differed from the grassland-park-forest transects in that there were five or six plots per transect, rather than seven. These five or six plots were placed at approximate equal elevational spacings from valley to mountaintop. Pertinent features of the six transects are summarized in Table 4.

Each plot was 375 m^2/0.09 acre in size, and circular in shape, after the reconnaissance methods of Pfister and Arno (1980). After plot center was established, four radii were flagged along the cardinal directions. A soil pit was dug at plot center; the pit was an average of 50 cm in depth; a soil probe was used to describe horizons at lower depths. Six surface soil samples (0-10 cm) were collected, one from plot center, and the other five systematically as follows:

1. Two samples were taken along the uphill direction at 2 and 8 m.

TRANSECTS 1-4	(Transects 1-3 are in the Centennials, Transect 4 in the Snowcrest.)			
Plot	1	2	3	4
High Elevation	Mature Douglas-fir PSME/CARU	Mature Douglas-fir PSME/ARCO	Juvenile Douglas-fir No Defined undergrowth	Park ARTR/FEID
Plot	5		6	
Mid Elevation	Juvenile Douglas-fir		ARTR/FEID	
Plot	7			
Low Elevation	ARTR/FEID			

Transects 1-4 were each comprised of the 7 plots displayed above.

Grassland transects 5 and 6 were west of the forest-grassland ecotone in the vicinity of Corral Creek Road in the Centennials. Each transect had 5 plots with shrub-grass vegetation that were found from low to high elevations. See Appendix B for habitat type terminology.

TABLE 4. TRANSECT DESCRIPTIONS

2. Moving clockwise, one sample was taken along the next
    direction at 4 m.

3. Moving clockwise to the next direction at 6 m.

4. Moving clockwise to the next direction at 8 m.

This sampling scheme was devised to ensure maximum and non-biased
coverage of the plot. Figure 7 details the sampling. Appendix C
lists representative soil profiles, and more detailed profiles are
available in the Dillon Resource Area Resources Inventory: Soil
Survey (1978).
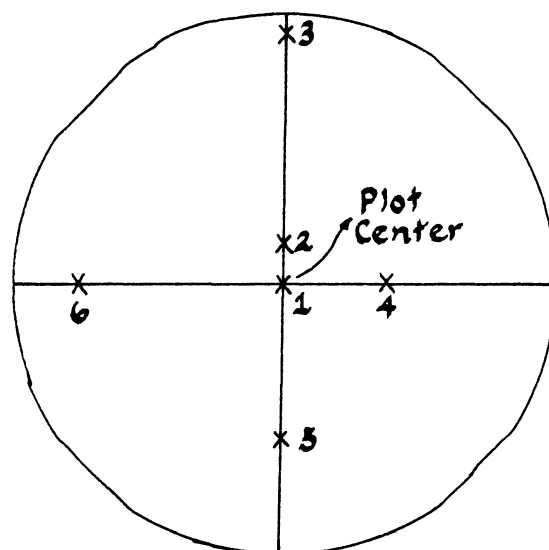
Figure 7. Detailed plot sampling for soil organic carbon.

All six soil samples per plot were analyzed for organic carbon;
in most cases only the center sample of the high elevation plots was
analyzed for soil opal. In some cases additional samples were needed
for opal analysis from the same plot, and these were randomly chosen.

Plot elevation was determined by an altimeter (the altimeter was calibrated twice per day and positions were checked on a topographic map) and slope angle and aspect were determined by a clinometer and compass, respectively.

Since soil properties can be affected by slope angle and aspect, type of vegetation, etc., the following criteria applied for all plots:

a. Plots were on N to E slopes.

b. Slopes were convex, as viewed along the contour.

c. Slope angle did not exceed 30°.

d. Plots were located at least 30 m away from a forest-grassland ecotone.

e. Plots were rejected if there was evidence of substantial logging or grazing.

f. Plots were rejected if they contained wet site species such as Engelmann spruce.

The plot center was located so that it was representative of the surrounding vegetation. In other words, large openings or dense thickets, bare spots, rock outcrops, etc., were not allowed within plot boundaries unless they were typical or characteristic of the stand. Condition e above was violated at mid and low elevations because it was impossible to find areas that were not considerably affected by domestic grazing.

RESULTS

Organic Carbon

The relationships between organic carbon, elevation, A-horizon thickness and litter thickness were examined. Summary statistics are given for these variables in Table 5 (elevation has been omitted). The data are arranged by the broad vegetation classes of forest, park and grasslands. A new variable, organic carbon mean, was created; this is the mean of the six organic carbon values for each plot. Since the variance and the ranges of the organic carbon plot means were lower than the individual carbon values, plot means were used in the subsequent analysis. As an illustration, the range in organic carbon values for plot 8 was 1.94% to 11.44%; a plot mean conveys more information than does one of these individual values. As a warning to the reader, subsequent statistics will refer to means of plot mean organic carbon.

T-tests for both individual and mean plot organic carbon values found no significant differences in means between forest, park and grassland plots at the .01 and .05 levels (Table 6). However, the variance of the individual forest plots was significantly greater than the park and grassland plots at the .01 level.

Regressions were conducted for all plots, forest plots, and park and grassland plots. The latter two vegetal classes were treated as one because their habitat types were similar and the three park plots did not constitute enough data points for a separate analysis.

TABLE 5. SUMMARY STATISTICS FOR ORGANIC CARBON

		FOREST	PARK	GRASSLAND
Litter Thickness (cm)	Range	9.00	----	----
	S.E.	0.66	----	----
	S.D. (s)	2.63	----	----
	Mean	6.44	----	----
A-Horizon Thickness (cm)	Range	24.00	11.00	60.00
	S.E.	1.92	3.67	4.81
	S.E. (s)	7.2	6.35	18.63
	Mean	19.1	32.33	28.6
Organic Carbon Mean %	Range	5.9	2.94	5.41
	S.E.	0.43	0.678	0.42
	S.E. (s)	1.71	1.18	1.85
	Mean	5.54	6.08	5.02
Organic Carbon %	Range	14.7	5.13	8.87
	S.E.	0.29	0.33	0.20
	S.D. (s)	2.86	1.35	2.01
	Mean	5.54	6.01	5.07

S.E. = $(s/\sqrt{n})$

S.D. (s) = standard deviation

TABLE 6. T-TEST FOR ORGANIC CARBON & ORGANIC CARBON PLOT MEANS

1) Organic Carbon

		mean %	df	s	observed t	2-tailed p-value	α	
a)	Forest	5.54	45.39	2.8	-1.30	.411	.01 NS	.05 NS
	Park	6.01		1.3				
b)	Forest	5.54	165.9	2.8	1.06	0.291	.01 NS	.05 NS
	Grass	5.07		2.0				
c)	Park	6.01	120	1.3	1.85	0.67	.01 NS	.05 NS
	Grass	5.07		2.0				

2) Organic Carbon Means

		mean %	df	s	observed t	2-tailed p-value	α	
a)	Forest	5.55	17	1.72	-0.51	.614	.01 NS	.05 NS
	Park	6.08		1.18				
b)	Forest	5.55	31	1.77	0.61	.924	.01 NS	.05 NS
	Grass	5.02		1.83				
c)	Park	6.08	19	0.68	0.86	.402	.01 NS	.05 NS
	Grass	5.02		0.43				

The hypothesis tested is: H_o: $U_1 = U_2$; H_A: $U_1 \neq U_2$.

The variance of the forest organic carbon was significantly greater than the variances of the park and the grassland at the .01 level.

None of the group means were significantly different at the given α.

The following model was used for the bivariate regressions:

$Y = \alpha + \beta x + \epsilon$ where $\epsilon \sim N(0, \sigma^2_{y \cdot x})$;   where y is the dependent variable, x the independent.

If a multiple regression was used, then the model would become:

$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 \ldots + \beta_i X_i + \epsilon$; $\epsilon \sim N(0, \sigma^2)$.

In general, the regression equations (Table 7) were not very helpful in explaining the variation in organic carbon means. Elevation had better correlations with organic carbon mean than did thickness of the A-horizon and thickness of the litter horizons, if present. In most cases, the latter two variables added no significant improvement to the equations; the exception was equation 4, where there was a significant improvement with the addition of A-horizon thickness at the .01 level. Equation four was the regression of organic carbon mean on elevation and A-horizon thickness for park and grassland plots only; this was the only equation to have an r^2 value (0.73) that explained a substantial portion of the variation in organic carbon.

Opal Phytoliths

The results of the opal data are given in Table 8. Grass opal dominated almost all of the samples; Douglas-fir opal was found only on forested plots, and then only sporadically. Since the tree opal was scarce, all the opal was counted as one class of opal that included tree opal, grass opal, and an occasional unidentified opal fragment.

.061. Accept H_o at α = .05
and .01.

B) Test H_o: β_2 = 0 provided β_1 is in the equation. $F_{(2,11)}$ = 1.95. The $p(F \geqslant 1.95$ if H_o true)= .967. Accept H_o at α= .05 and .01. The thickness of the A-horizon does not add a significant improvement to the equation.

C) Test H_o: β_3 = 0 provided that β_1 and β_2 are in the equation. $F_{(3,10)}$ = 1.20. The $p(F \geqslant 1.20$ if H_o true) = .851. Accept H_o at α = .05 and .01. Litter adds no significant improvement to the equation.

Equation 3 (cont'd)	r^2
C) orgcm(%) = 32.64 - 0.012 elevation (m) - 0.008 AHOR (cm) - 0.045 litter (cm).	.26

4) Orgcm regressed on elevation and A-horizon for <u>Park and Grassland plots only</u>.

A) Test H_o: β_1 = 0. $F_{(1,16)}$ = 19.02. The $p(F \geqslant 19.02$ if H_o true) = .000. Reject H_o at α = .05 and .01.

B) Test H_o: β_2 = 0 if β_1 is in the equation. $F_{(2,15)}$ = 20.21. The $p(F \geqslant 20.21$ if H_o true) = .000. Reject H_o at α = .05 and α = .01.

Equation 4	r^2
A) orgcm(%) = -1.13 + 0.003 elevation (m).	.54
B) orgcm(%) = -0.82 + 0.002 elevation (m) + 0.064 AHOR (cm).	.73

TABLE 8. T-TESTS FOR OPAL DATA (*Significant at given ∝.)

		mean %	df	n	s	observed t	2-tailed p-value	∝	
1)	Forest	2.82	12	8	2.70	-2.30	0.040	.01	*.05
	Park	5.70		6	1.62				
2)	Forest	2.82	11	8	2.70	-3.51	0.005	*.01	*.05
	Grassland	8.56		5	3.13				
3)	Park	5.70	9	6	1.62	-1.96	.082	.01	.05
	Grassland	8.56		5	3.13				
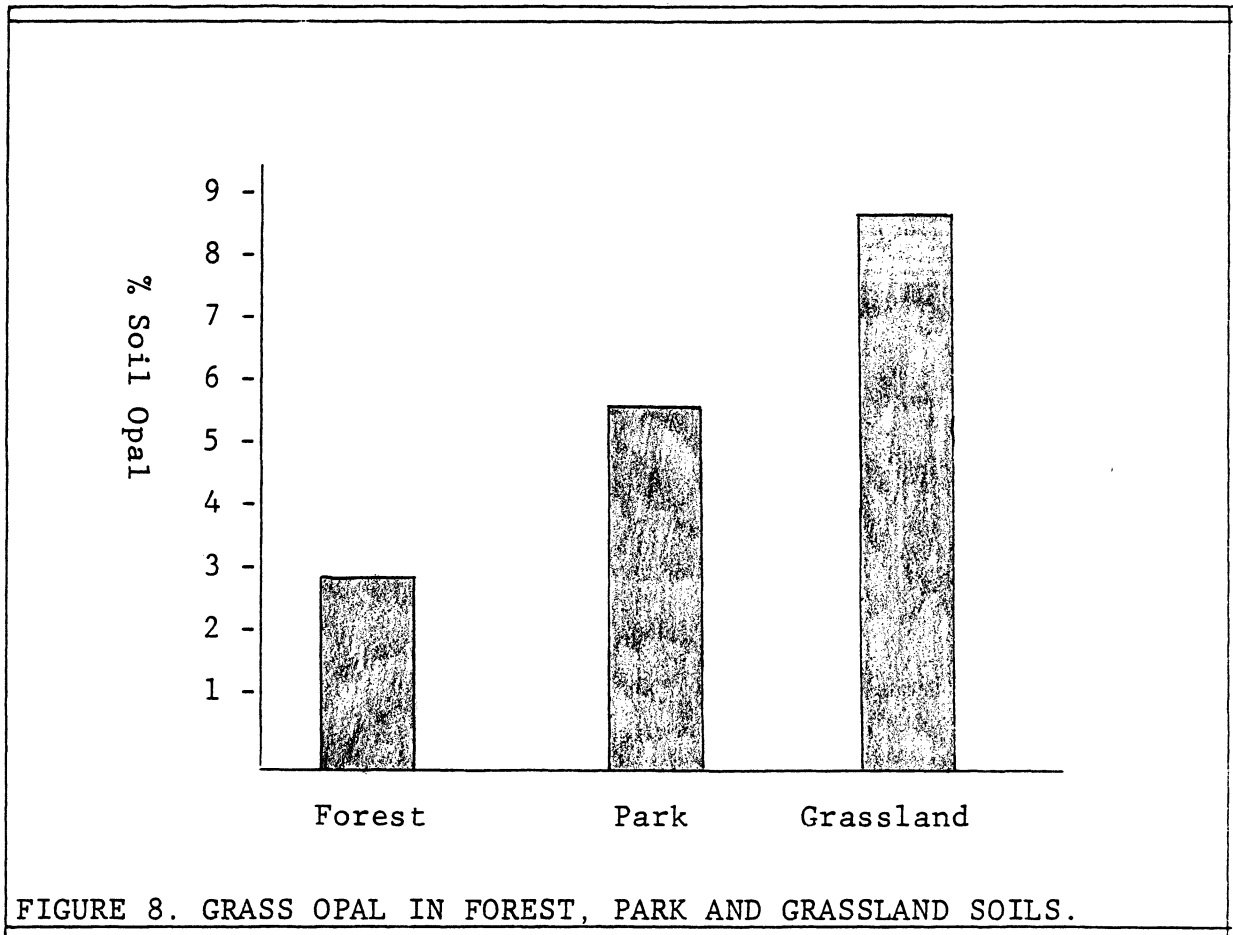
FIGURE 8. GRASS OPAL IN FOREST, PARK AND GRASSLAND SOILS.

This would make the forested counts slightly high, so the mean differences between forest, park and grassland grass opal counts are actually slightly greater than reported here.

Since six soil samples were collected from each plot, there were six possible samples to analyze for opal. Within-plot variation was very low for each habitat type, so it was decided that one sample was sufficient to represent each plot; this was systematically chosen as the center sample. Park plots were an exception because the three plots were too small to designate as an appropriate sample size, so multiple soil samples from one plot were analyzed for opal. Although this is acceptable statistically, the reader should keep in mind that the park plots represent a much smaller land area than do the forest and grassland data. However, the park soil opal had the lowest variance of the three vegetal types, so fewer plots are needed than the forest and grassland sites. The grassland plots had a greater variance than either the forest or park plots, although none of the variances was significantly different. Other studies have found that forest opal variance is usually greater than nearby grasslands (Jones and Beavers 1964).

There was an increasing progression of soil opal by weight from forest to park to grassland; the park areas had twice as much opal as the forest (significant at α = .05) and the grassland areas had three times as much opal as the forest (significant at α = .01 (Figure 8). Park and grassland opal were not significant.

Wolf Trees

Data for the wolf trees are given in Table 9. There were no significant differences in organic matter under the tree crown and beyond the tree crown; these means were respectively 5.91% and 5.80%. Regressions were run with organic carbon as the dependent variable and distance from tree bole as the independent variable. Since the hypothesis that $\beta = 0$ was accepted for all of the equations, the equations are not presented.

Fire History

Seven fire-scarred Douglas-fir were sampled in the Centennial Range and one tree in the Snowcrest Range. The locations of the Centennial trees are given in Figure 9; the tree in the Snowcrest Range was within the boundaries of plot 23 of Sec. 24, T11S, R4W. The mean fire interval in the Centennials was 24 years; the fire interval range was 14 to 85 years. These intervals represent the period of 1710-1898 and the trees sampled cover an approximately 680-ha (1500-acre) area (there were eight fire intervals for this time period). The mean fire interval of 24 years represents the entire area sampled and is the average period of time between spreading fires in that area.

The one sample from the Snowcrest Range had three intervals and the mean fire interval was 50 years, with a range of 15 to 82 years. This history covers the years 1740-1890 and represents a "point on the ground". All fire terminology is from Romme (1980).

Arno and Petersen (1983) show that mean fire intervals vary inversely with size of sample area; this is clearly seen when comparing

	mean	df	n	s	observed t	2-tailed p-value	α
organic carbon under crown (%)	5.91		36	2.05			.01
		70			0.23	0.815	
organic carbon beyond crown (%)	5.80		36	2.05			.05

*Significant at given α.

mean organic carbon = 5.80%

mean organic carbon = 5.91%

Tree center

N
W   E
S
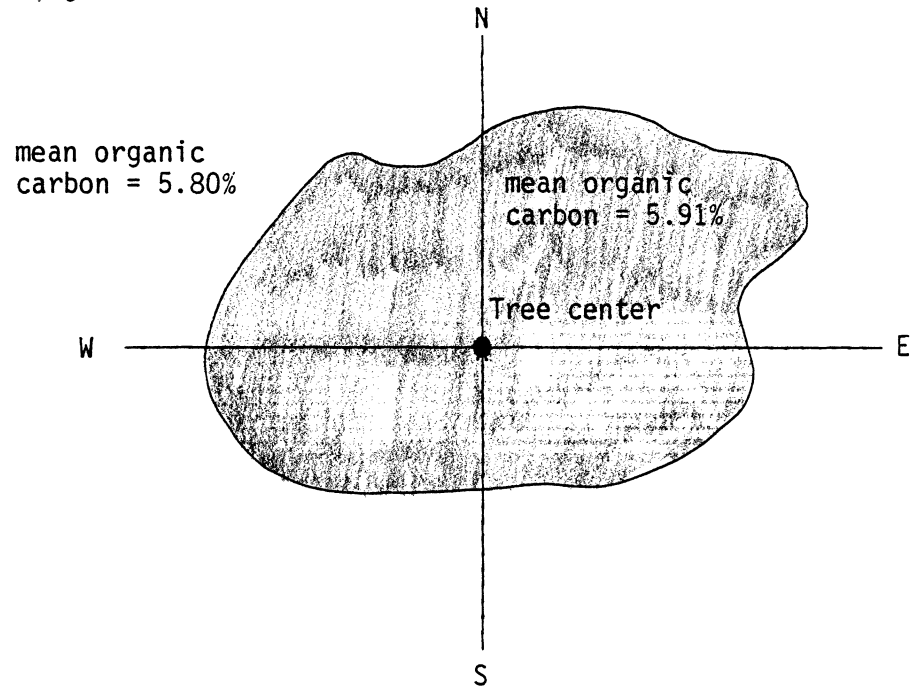
Shaded area is underneath tree crown. There is no significant difference between organic carbon under and beyond the crown.

TABLE 9. WOLF TREE T-TESTS.

R 4 W

T 14 S

T 15 S

N

Legend

☐ Section number
═ Road
═ ═ ═ Primative Road
○ Plot number
X Fire scar tree
   with years of fires
── Stream
·····─ Intermittant stream

0 5

Scale in miles

⑬ X 1888
      1871 ±1

⑥

⑤

X
1897±3
1821

3

X
1870
1794
1744
1730±2

⑧

5

X
1898
1873
1794

2

East Fork Peet Creek

③

Peet Creek

X 1871
  1800 ±1

Price-Peet Road

Price-
Peet
Divide

⑩

⑩

Price-Peet Road

11

8

9

X 1875
  1798
  1744

⑨ X -76
① -127
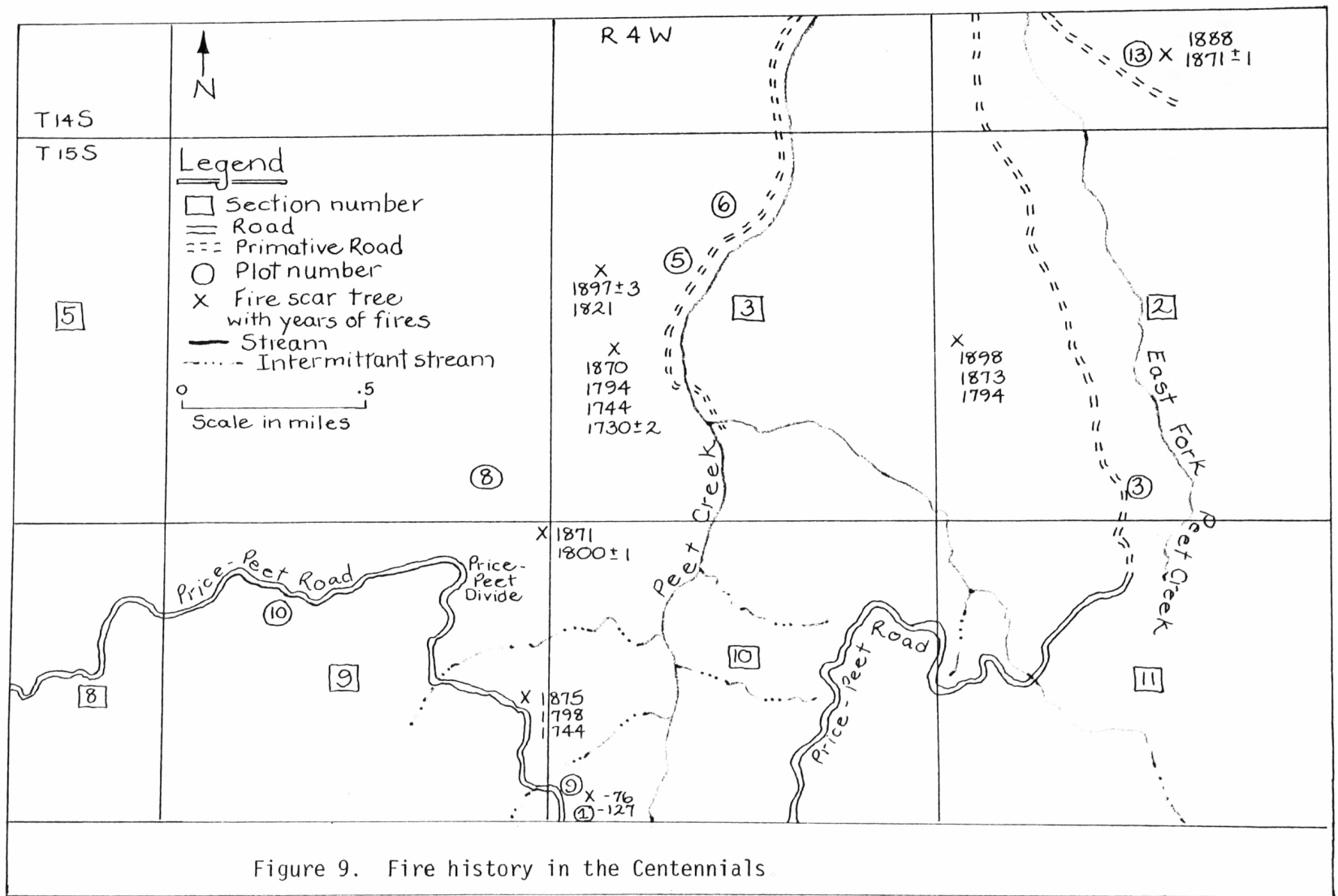
Figure 9. Fire history in the Centennials

the large Centennial area to the much smaller Snowcrest area. Although the mean fire interval for the Snowcrest tree was 50 years, the larger Centennial area fire interval of 24 years was shorter because it includes all fires that occurred anywhere within the larger area. The date at which tree 3 died was not known because the tree was dead when sampled. However, the fire intervals were very close to the intervals of tree 2; based on this information, the date of death was established as 1870. Most of the scars were clear and the fire dates are probably accurate; fires were recorded within +/- two years from more obscure scars. The complete fire chronologies are given in Figure 10.

To test the hypothesis that these fires were intense, stand-replacing fires that were followed by conifer regeneration, conifer age classes were determined for all forested plots. If the fires were intense, conifer regeneration might be expected within 1-12 years of the fire. These results are given in Appendix D.

Although age classes were recorded for all plots, not all plots were close enough to the fire-scarred trees to be helpful in the interpretation. The plots that were close enough are displayed in Figure 11 and are compared to the fires that were recorded. There are only a few instances where conifer regeneration occurred soon after a fire; the fire of 1898, the fire of 1888, and the fires of the early-to-mid 1870's. Even in these cases, the regeneration probably grew beneath a scattered overstory, since all pith rings are moderately spaced rather than the wide spacings expected of young, open-grown trees.

Fire Year	Tree Number							
	1	2	3	4	5	6	7	8

1982

1900

1890 ← 2/6

1880 ← 1/6

1870 ← 2/6 ← 3/6

1860

1850

1840

1830

1820 ← 1/6

1810

1800 ← 2/5

1790 ← 3/4

1780

1770

1760

1750

1740 ← 3/3

1730 ← 1/1

1720

1710

1700
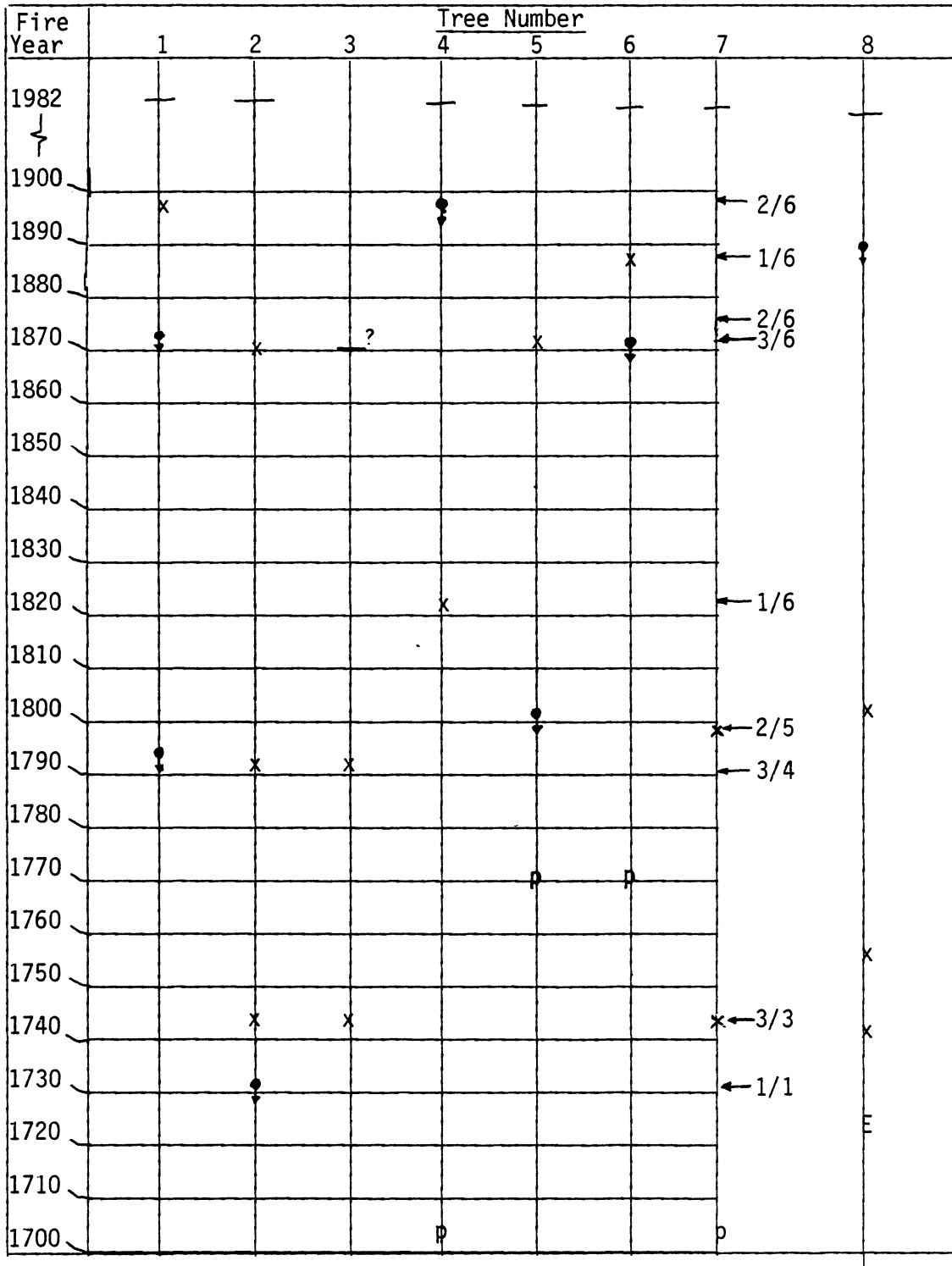
Continued

Fire Year	Tree Number							
	1	2	3	4	5	6	7	8
1690								
1680								
1670								
1660			p					
1650	E							
1640		p						
1630								

Trees 1 through 7 are in the Centennial. Mountains. Tree 8 is in the Snowcrest Range.

x	clear date
♀	date ± 2 yrs. maximum
E	Earliest ring on Cross Section
p	Pith
__	Year of Cambium

The fractions are:

$$\frac{\text{No. of Trees Scarred That Year}}{\text{No. of Fire Susceptible Trees}}$$

FIGURE 10. FIRE CHRONOLOGIES IN THE CENTENNIAL AND SNOWCREST RANGES.

- Single tree

R Possible regeneration due to fire based on tree age and fire year and proximity of plot to fire scar tree(s).

All trees are Douglas-fir unless otherwise noted.
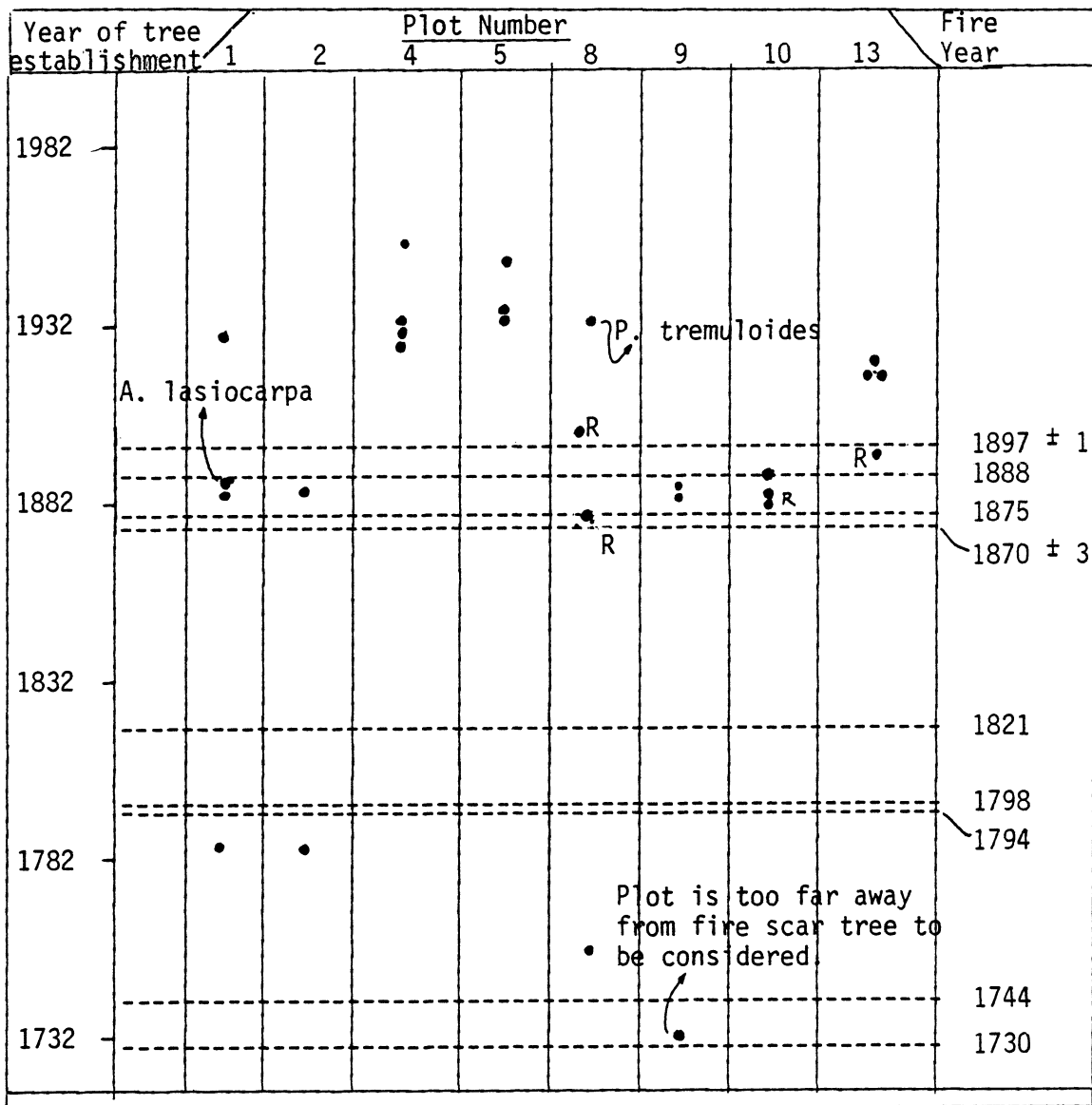
FIGURE 11. TREE AGE CLASS DESIGNATIONS COMPARED TO FIRE YEARS.

Even in some of the more extensive fires, such as those in 1794 and 1744, no fire-caused regeneration is found.

Root Analyses

Results are presented in Table 10.

DISCUSSION

Organic Carbon

The organic carbon means (means of plot means) were all very high for forest, grassland and park plots, ranging from 5.02% to 5.68%. Grassland organic carbon would have been greater if the low-elevation plots had not been included in the calculation. It is unusual that forests and nearby grasslands have such similar soil carbon values.

In each of the three types of plots, the variation of the mean of the plot mean organic carbon was lower than the individual carbon values; the former variable represents the plots more clearly. There were no significant differences in meaned plot variances from the three plot types.

The average A-horizon thickness of the forested plots is 19.1 cm, which is just thick enough for the majority of the plots to meet the 18-cm-thickness requirement for Mollisols. This would include PSME and ABLA habitat types. Grassland A-horizons averaged 28.6 cm, and park plots 32.33 cm; both of these soils seem to have more well-developed mollic epipedons than the forest soils, although these differences were not significant. The grassland variance of the

TABLE 10.   ROOT BIOMASS IN FOREST AND GRASSLAND HABITAT TYPES

Habitat Type	2.00mm (g/cc)	1.00mm- 2.00mm (g/cc)	1.00mm (g/cc)	Total (g/cc)
Abies lasiocarpa/ Arnica cordifolia	1.39×10^{-3}	1.34×10^{-2}	1.69×10^{-2}	$3.17 \times 10-^{2}$
Abies lasiocarpa/ Calamagrostis rubescens	6.59×10^{-4}	1.57×10^{-2}	1.69×10^{-2}	3.33×10^{-2}
Average of the two forest plots above	1.02×10^{-3}	1.46×10^{-2}	1.69×10^{-2}	3.25×10^{-2}
Artemesia tridentata/ Festuca idahoensis	3.33×10^{-4}	4.34×10^{-2}	2.29×10^{-2}	6.66×10^{-2}

A-horizon thickness was 2.5-3 times greater than the park and forest variances; this is probably a reflection of the greater range of elevations covered by the grassland soils. A few of the forested plots did not have A-horizons. Some of the low-elevation grassland plots had A-horizons that were too thin to qualify as mollic and these soils would probably be classified as Aridisols, even though they met the organic carbon requirement of Mollisols.

When all the plots were grouped together, covering a wide range of elevations and types of vegetation, and organic carbon mean was regressed on elevation and thickness of A-horizon, weak relationships were found. Elevation explained 22% of the variation in organic carbon, and if A-horizon thickness was added to the equation it was rejected as a significant variable.

If the same regressions were conducted on forest plots only with the addition of a third independent variable, litter horizon thickness, very similar relationships were found. Elevation was the independent variable most closely correlated with organic carbon, and the hypothesis that the elevation beta coefficient equalled zero was accepted ($\beta_1 = 0$). The other two independent variables, A-horizon and litter-thickness, did not significantly improve the prediction of organic carbon. If any relation exists between forest soil organic carbon and these variables, it is very weak.

In contrast, shrub-grass habitat types show a much stronger relationship between organic carbon, elevation and A-horizon thickness.

Elevation explained 65% of the variability in organic carbon; if A-horizon thickness was added to the equation, 74% of this variation was explained.

One explanation for the weak relationships in the forest and the stronger relationships in the grasslands is the wider elevational range found in the grasslands and the greater number of data points. Still, the r^2 values are so different in the forest and grassland soils that it can be concluded that grassland organic carbon correlates more strongly with elevation and thickness of A-horizon than the forest soils.

These data appear confusing; mean organic carbon contents for forest and grassland soils are not significantly different, yet the regressions show wide differences in the correlations to the independent variables. One possible explanation of these data indicate that forest and grassland soils have achieved similar levels of organic carbon, not by the persistence of organic carbon from previous grass- lands, but rather by distinct pathways that have been and are controlled by different sets of variables. For example, forest soil decomposition rate is probably highly correlated with substrate lignin content (Fogel and Cromack, Jr. 1977), and grassland decomposition is correlated better with elevation, indicating that moisture and temperature play an important role in organic matter accumulation in these soils.

It is surprising that organic carbon is not more highly correlated to A-horizon thickness (for forest and grassland habitat types). It

is not safe to say that a thicker A-horizon has more organic carbon than a thinner A-horizon. Apparently, these two variables reach an equilibrium with their environments along pathways that are distinct from one another.

Wolf Tree Analysis

Results of this aspect of the study are quite clear; decreases in soil organic carbon cannot be attributed to the presence of old Douglas-fir. These trees were located within and on the perimeter of forest stands; they had understories of sylvan and prairie grasses, and many herbs and shrubs. All of these soils had litter horizons that were greater than average forest plot litter thickness, and heavy accumulations of branchwood were found beneath the three sample trees; tree age ranged from 184-325 years. If mollic epipedons are indeed degrading under the influence of forest cover, these changes are not discernable within the 250-300 year life span of a single mature tree. It may be argued that changes would not be expected if these forests support graminoid understories. Still, this type of forest community does not appear to degrade the mollic epipedon within a few hundred years of forest occupancy.

Root Analysis

The preliminary data here suggest that the grassland soils have an average of twice as many total roots in a given soil volume than do the forest soils. This difference is three times if the finer roots, less than 2 mm in diameter, are considered. The forest soil had three times as many large roots, greater than 2 mm, than the grassland.

Opal Phytoliths

The first two objectives of this study were:

1. Determine if ecotones are stable in southwestern Montana.

2. Determine if Mollisols can develop under Douglas-fir.

These objectives are intimately related; if Mollisols have developed under forest, it must be assumed that the present-day ecotones have been stable.

The opal phytolith data are critical to answering the above questions. These data are all from high-elevation plots, and the two ecotones represented are the park-forest ecotone and the forest-grassland ecotone near Corral Creek Road. There was a nearly linear increase in grass opal phytoliths from forest to park to grassland. Time and money did not allow analysis of the ecotone where the dry grassland contacted lower-elevation Douglas-fir habitat types. Grasslands had three times more grass phytoliths than did the forest, and twice that of the park areas. A closer look at the analysis is necessary before interpretations can be made.

It was assumed that phytoliths could be identified from the following species: Idaho fescue, blue-bunch wheatgrass, pinegrass and Douglas-fir; phytoliths were identified from photographs in the literature. Blue-bunch wheatgrass opal, although distinctive, was not observed in any of the samples; it can be concluded that none of these areas were drier grasslands in the past since this particular grass is generally associated with drier sites. Opal from the remaining two grasses, Idaho fescue and pinegrass, could not be distinguished from one another

under the microscope because both had rod shapes that were very similar. It would have been especially helpful to the interpretation if the prairie grass (Idaho fescue) could have been separated from the sylvan grass (pinegrass), but this was not possible.

Most of the Douglas-fir opal morphologies reported by Klein and Geis (1978) are more block-like than grass opal, so separation of these classes is not difficult. Douglas-fir opal, derived from transfusion tracheids or asterosclerid cells were observed under forested plots only. This indicates that the grassland and park areas were probably not forested in the past. Typically, tree opal was only one-tenth the amount of grass opal on the same plot; this might suggest a short period of forest occupancy. The paucity of tree opal under forests has also been reported by other investigators (Verma and Rust 1969, Wilding and Drees, 1971). The latter authors found that much tree opal is in smaller size fractions (< 2µ) than grass opal, and may be overlooked in the counts, because of the small size. Also, since most grasses produce more opal in their tissue than trees, it is not surprising to find more grass soil opal than tree opal.

I am left to explain why the three sites had differing amounts of grass opal, and what these differences mean. One possibility is that all of these areas were grasslands in the past, but different rates of biomass production have led to the differences in modern soil opal. However, nothing was observed in the field to indicate there were dramatic grass biomass differences; certainly the uniformity of the organic carbon contents would not support this. A more likely explanation is that some

of the forested plots were forested in the past and grass production on these areas was reduced because of shading. This would not eliminate the shade-tolerant pinegrass, but both total understory production and graminoid understory production would decrease as canopy coverage increased, and it would certainly be lower than surrounding grasslands (Dutton 1983, Kinnet, Missoula Co. SCS, personal communication).

Are the differences in soil opal between the forest and grasslands large or small? Unfortunately, direct comparisons cannot be made to the literature because there are no standards on the depth at which soil samples are taken and the size class of the opal analyzed. Comparisons are also confounded by differences in grass biomass production from one area to another. Forests with limited graminoid understory production would be expected to have greater differences in soil grass opal between their adjacent grasslands than the differences found here; the forests in this study had significant graminoid understories.

Grasslands had three times more opal content than the forested areas; these differences are not overwhelming, yet seem sizeable and real. Some of the opal levels of the forest and grasslands actually overlapped indicating that opal levels were not so different. Plots with overlapping values were from the Snowcrest Range, possibly suggesting a shorter period of forest occupancy than the Centennial Range. Yet in general, the forest-grassland ecotone has been stable in the recent past. The former statement does not apply to the lower timberline ecotone.

The intermediate amounts of opal found in the park plots suggest a mixed history of forest and grassland. The lack of tree phytoliths in these plots does not support this; it is possible that mistakes were made in opal identification or that tree opal was simply overlooked, since these particles were much fewer in number than grass opal. The mollic epipedon was better developed in parks than adjacent forest, indicating that park grasslands have probably been stable for at least a few hundred years.

I have used the two terms "stable ecotone" and "recent past" in this paper; can they be further defined? Very few researchers have tried to do this; Witty and Knox (1964) estimated phytolith age at four to seven thousand years, based on biomass and opal production rates; Wilding (1967) used radioactive carbon dating of carbon impurities found in the opal of a Mollisol to age it at 13,000 years b.p. I think that 13,000 years is too old for these data; it is likely that during the warmer period of the Altithermal (about 5000 years b.p.) blue-bunch wheatgrass was more prevalent, yet there is no evidence of this. It would seem that this opal is less than 5000 years old, and older than, say, 2000 years. The younger date is an estimate based on the resistant nature of phytoliths to weathering, and the mild (cold and dry) weathering environment of the study area.

This estimated minimum opal age of 2000 years is very important to the hypothesis concerning soil genesis. Two possible scenarios can develop that must be examined:

1. Forests have been stable for at least 2000 years and

Mollisols have developed under this vegetation.

2. Previous grassland soils have persisted at least 2000 years under forest cover.

In my opinion, the first scenario is much more plausible. In most of the reported cases, soils that have vegetation changes from grassland to forest undergo significant morphological and chemical changes. Although thinner A-horizons and subangular, blocky structure were more prevalent in the forest, E-horizons (leached surface horizons expected under forest) were rare, and organic carbon levels were very similar to nearby grasslands. The organic carbon and "wolf-tree" analyses of this study support the contention that the forested and grassland soils may have very different aspects of organic carbon accumulation and that forested mollic epipedons are not being degraded. The evidence seems to support Mollisol genesis under Douglas-fir.

If this is indeed the case, it is interesting to consider the role of sylvan grasses, notably pinegrass, in the genesis process. Grasses play the dominant role in the genesis of a prairie Mollisol, but do sylvan grasses play the same part? Present day forest stands have less above- and below-ground grass production than do adjacent prairies. This may not have been the case in the more open, fire-maintained stands of 100 years ago (Gruell 1983).

Therefore, it is hard to determine the extent of grass influence on these forest soils. It is probably a safe assumption that historically, sylvan grass production has been somewhat less than nearby prairie.

Fire History and Soil Implications

Fire history data are sparse for dry, cool Douglas-fir and subalpine fir habitat types. Arno and Gruell (1983) reported MFI's of 35-40 years at grassland-forest ecotones in southwestern Montana; these areas included dry Douglas-fir habitat types (the MFI's reported are usually for single tree areas). These intervals are slightly shorter than the MFI of 50 years reported here for the Snowcrest Range Douglas-fir/ pinegrass habitat types (also single tree area). The single tree with the most complete history in the subalpine fir habitat types in the Centennials had a comparable MFI of 46 years. Lightning is a major source of ignition at these ecotones (Higgins, in press).

The slightly cooler and wetter subalpine fir habitat types in the Centennials had a MFI of 24 years (680 ha area); fire history has not been previously reported for these habitat types.

It is probably safe to say that cool, dry Douglas-fir and sub-alpine fir habitat types have similar fire histories, with MFI's of 25 to 50 years, when calculated for small to medium size stands.

The fire histories of many western forests have been influenced by Native Americans (Arno 1983, Barrett and Arno 1982), and these areas are probably not an exception.

Data from the Centennials indicate that many of these fires were light surface fires; in most of the reported fires (Figure 10), less than half of the fire-susceptible trees were scarred. As fuel loads built up, combined with drier and warmer fuel and weather conditions, more severe, stand-replacing fires occurred, probably at least once a century.

The effects of fire on soil development are not well known.
Besides the effects of eastern hemlock (*Tsuga canadensis*) on Spodosol
development, and successional changes due to fire (Milfred et al. 1967),
very little has been recorded. Water repellent soils caused by fire
have been reported in California and Arizona chapparral (Savage 1974
and Scholl 1975), but these conditions apparently are rare or absent in
interior western forests.

Fire can directly and indirectly affect soils; severe fires
causing erosion would be a direct impact; maintenance of different
vegetation because of recurring fires would be an indirect impact.
This study found no evidence of direct fire impacts on soils, although
it was not designed to do so. Charcoal was observed in some of the
surface horizons of the forested plots; since it was not prevalent in
all plots, it may be that significant amounts of charcoal are added to
the soil only after severe fires.

Successional changes in vegetation were evident in Douglas-fir
and subalpine fir habitat types in the Centennials.

Mid-elevation Douglas-fir habitat types are dominated by juvenile
Douglas-fir less than 86 years old; ring spacing at tree pith would
indicate that these trees regenerated under tree canopies and in the
open (Appendix D). Most of these stands had many dead or diseased
aspen in them with an occasional isolated "wolf" tree. Fruiting bodies
on some of these trees were identified as *Fromes pini* by Clint Carlson,
Forest Science Lab, Missoula, MT. It appears that aspen was much more
prevalent at these elevations in the past, being periodically rejuvenated

by fire (Loope and Gruell 1973). Occasionally a Douglas-fir seedling would grow up in these aspen stands, but even these trees were rare. As man excluded fire from these areas, the aspen died out and the isolated Douglas-fir "wolf" trees seeded in nearby areas. It is possible that some of these juvenile trees are growing in areas that were grassland 100 years ago; however, even if there has been an ecotone shift because of fire suppression or grazing disturbance (Sindelar 1971 and Arno and Gruell 1983), this is probably not affecting the degeneration of the mollic epipedon, because Mollisols are found in grass, Douglas-fir and aspen communities.

The subalpine fir habitat types, sampled at their lower elevational limit, were similar to the mid-elevation Douglas-fir habitat types in that dead aspen trees were prevalent. Subalpine fir seedlings were found on the majority of the plots; they appeared to be reproducing by layering. Mature individuals were rare. It is interesting to note that all of the juvenile Douglas-fir stands in these subalpine fir habitat types had remnants of *Artemesia* in their understories. It can be argued that these were former park areas, but their A-horizons are more like the mature forest plots in thickness than the park plots. It is possible that these areas were former Douglas-fir stands (some did have old stumps) that were destroyed by intense fires; they have gone through an unstable sagebrush-grass phase and are now being replaced by Douglas-fir.

This evidence indicates that successional changes are taking place in Douglas-fir and subalpine fir habitat types. Fire plays an

important part in these successional changes; will these successional changes influence soil development?

In the case of Douglas-fir habitat types soil development is very similar in seral and climax successional stages; major soil changes are not anticipated. Successional changes in subalpine fir habitat types could possibly have profound effects on forested mollic epipedons. Davis et al. (1980) and Fischer and Clayton (1983) report that subalpine fir habitat types rarely reach a climax stage because subalpine fir is killed and succession repeatedly set back by fire.

If fire suppression activities allow these forests to reach a climax stage, what will be the effect on these forested Mollisols? This may be stated as the hypothesis:

H_o: Mollic epipedons degrade under subalpine fir.

H_A: Mollic epipedons will persist under subalpine fir.

If seral and climax subalpine fir habitat types are compared, the following points are observed:

a. Seral Douglas-fir and subalpine fir have similar foliage chemical composition (Daubenmire and Prusso 1963).

b. Climax stands will be more closed, with less undergrowth production, than seral stands.

If graminoid production is important to forested Mollisol genesis, then point b above indicates that mollic epipedons under climax forest degrade.

The Centennials did have forested areas that did not meet the Mollisol requirements. It is not known if this was due to variation in

parent materials (or other soil forming factors) or successional differences. It is difficult to determine if these areas are actively degrading Mollisols or if they ever were Mollisols. It is clear that subalpine fir will become more prevalent in seral Douglas-fir stands if fire is removed from these ecosystems, but the effect on the mollic epipedon would have to be determined by further research.

The effect of fire on soil development is probably most pronounced in these forests through its influence on forest succession. There are probably other important fire effects, but these are difficult to measure because they probably occur slowly over a long time period; changes in soil properties lag behind vegetational changes. Fire history data are helpful in interpreting forest succession, but more specific questions, such as the relationship between fire and soil organic carbon, will remain obscure until the proper control sites are located and the methods are devised. We may be able to measure the effect of one fire on certain soil properties, but the long-range implications of repeated fires over many centuries are open to broader interpretation. The continuous monitoring of selected soil properties on areas where fire is allowed to function as a natural part of the ecosystem (and is not suppressed) might help to answer such long-range questions.

Management Implications

Timber harvesting operations in the study areas will create openings within and on the edges of these forests. Tree regeneration on these sites may be hindered by sylvan or prairie grasses. Forest

areas that are cut near the forest-prairie ecotone will eventually regenerate, but they may go through a grass stage that will lengthen the period that seedlings will need to capture the site. This may be a more serious problem on cuts within the forest itself (park-like areas), because these areas may support grasslands for hundreds of years before trees can gain a firm foothold. In both instances, grasses,and possibly gophers,may have to be controlled if proper tree stocking is desired.

The open nature of these forest stands is partially due to the fires that once swept through them. If fire is continually excluded from these areas, the forest canopy coverage will gradually increase and graminoid production will decrease. Since forage is a major resource of these areas, the land manager might consider the use of low-intensity fires to maintain open stands with plentiful understories of graminoids and herbs. Fire would also rejuvenate aspen stands and create a more variable vegetation mosaic, both of which would benefit wildlife.

SUMMARY

Soil samples were taken along transects that crossed forest-grassland ecotones in the Centennial and Snowcrest Ranges in southwestern Montana in order to determine the genesis of the forest soils and to determine the effect of fire on these soils. Grassland habitat types were generally *Artemesia tridentata/Festuca idahoensis;* lower elevation forests were *Pseudotsuga menziesii/Calamagrostis rubescens*

or *Pseudotsuga menziesii/Arnica cordifolia*; and upper elevation forests
were *Abies lasiocarpa* with the same undergrowth types as lower elevation
forests. Soil samples were analyzed for organic carbon, as were
samples taken beneath and beyond the canopies of old-growth Douglas-
fir wolf trees. Selected upper elevation soil samples were analyzed
for soil opal phytoliths to aid in the determination of ecotone
stability and forest soil genesis. Both grassland and forested soils
had been previously classified as Cryoborolls. Cross sections were
also removed from fire scarred trees to determine fire histories of the
forested areas.

Organic carbon in the A-horizon was not significantly different
for forest, grassland, and grassy openings called parks within the
forests. Regression equations were developed where organic carbon was
regressed on elevation, A-horizon thickness, and litter thickness
(the last variable was used for forested plots only). The regression
equations had low r^2 values for forested transects (0.26) and much
higher r^2 values for grassland transects (0.73). The correlations
between organic carbon and A-horizon thickness were weak. These data
indicate that organic carbon accumulates through different pathways
in adjacent forest and grassland soils, even though their classification
is nearly identical.

Organic carbon was not significantly different under and beyond
the crowns of the isolated "wolf" trees; these trees do not cause
reduction of soil organic carbon levels within their 250-300 year
life spans.

Grass opal phytoliths were three times more prevalent in grass-
lands than adjacent forests, and grasslands had twice the amount of
the park areas. Bluebunch wheatgrass phytoliths were not observed in
any samples, and sylvan pinegrass was indistinguishable from the
prairie fescue under the microscope. Douglas-fir opal was found only
on forested plots, and then in small quantities. It was concluded
from these data that forest-grassland ecotones have been relatively
stable for an estimated 2000 years, and that park-forest ecotones
are more fluctuating. These forested Mollisols have probably formed
under their present forest vegetation, although their genesis may
differ from their prairie counterparts.

The mean fire interval of these forested areas was between 25
and 50 years for small to medium size stands (680 ha); most fires
were low intensity surface fires but there were occasional intense
stand replacing fires. It is expected that subalpine fir will
increasingly dominate upper elevation forested stands because of
fire exclusion; it was hypothesized that the increasing amounts of
subalpine fir may degrade these forested mollic epipedons.

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APPENDIX A.   OPAL PREPARATION PROCEDURES

1) Using weights, crush entire sample.

2) Pass entire sample through 2mm sieve.

3) Quarter sample, weight and label container, weigh out 3 g of sample.

4) Add 5 ml 35% H_2O_2.

   Agitate.

   Repeat in 2 hours.

   Repeat after 4 hours.

   Add small amount H_2O_2; if no reaction, go to step 5.

5) Add 20 ml distilled water, wait 2 hours, decant.

6) Add 50 ml calgon solution, let sit overnight.

7) Decant, add 20 ml distilled H_2O, let settle 2 hours, decant.

8) Oven-dry at 60°C.

9) Weigh, record.

10) Sieve through 100u sieve by crushing gently with a rubber-ended mortar in a pestle.

11) Weigh the < 100u fraction passing through the sieve.

Appendix B

HABITAT TYPES IN THE CENTENNIAL AND SNOWCREST RANGES

Plot #	Habitat Type Abbreviation[1]	Location	Relative Elevation
1	ABLA/CARU	Centennials	High
2	ABLA/CARU	Centennials	High
3	ARTR/FEID-GRVS	Centennials	High
4	PSME/ARCO	Centennials	High
5	PSME/CARU	Centennials	Mid
6	ARTR/FEID	Centennials	Mid
7	ARTR/FEID-GRVS	Centennials	Low
8	ABLA/ARCO	Centennials	High
9	ABLA/CARU	Centennials	High
10	ABLA/CARU	Centennials	High
12	ARTR/FEID	Centennials	Mid
13	PSME/CARU	Centennials	Mid
14	ARTR/FEID	Centennials	Low
15	ABLA/ARCO	Centennials	High
16	ABLA/ARCO	Centennials	High
17	ABLA/CARU	Centennials	High
18	ARTR/FEID-GRVS	Centennials	High
19	ARTR/FEID-GRVS	Centennials	Mid
20	PSME/CARU	Centennials	Mid
21	ARTR/FEID	Centennials	Low
22	FEID/CAFI	Centennials	High
23	PSME/CARU	Snowcrest	High
24	PSME/ARCO	Snowcrest	High
25	PSME/CARU	Snowcrest	High
26	ARTR/FEID	Snowcrest	High
27	FEID/CAFI	Centennials	High
29	ARTR/FEID	Centennials	High
31	ARTR/FEID	Centennials	Low
32	ARTR/FEID	Centennials	High
34	ARTR/FEID	Centennials	Mid
36	ARTR/FEID	Centennials	Low
37	ARTR/FEID	Centennials	Mid
38	PSME/ARCO	Snowcrest	Mid
39	ARTR/AGSP	Snowcrest	Low

Plot 11 was not used. Plots 28, 30, 33 and 35 are probably ARTR/FEID.

[1]Explanation of abbreviations:
a) ABLA/CARU -- Abies lasiocarpa/Calamagrostis rubescens. (Subalpine fir/pinegrass)
b) ARTR/FEID -- Artemesia tridentata/Festuca idahoensis. (Mountain big sagebrush/Idaho fescue)
c) ARTR/FEID-GRVS -- Same as above but Geranium viscosissimum phase. (Geranium)
d) PSME/ARCO -- Pseudotsuga menziesii/Arnica cordifolia. (Douglas-fir/heartleaf arnica)
e) PSME/CARU -- Pseudotsuga menziesii/Calamagrostis rubescens. (Douglas-fir/pinegrass)
f) ABLA/ARCO -- Abies lasiocarpa/Arnica cordifolia. (Subalpine fir/heartleaf arnica)

Appendix B (Continued)

g) FEID/CAFI -- Festuca idahoensis/Carex filifolia.
   (Idaho fescue/sedge)

h) ARTR/AGSP -- Artemesia tridentata/Agropyron spicatum.
   (Mountain big sagebrush/blue-bunch wheatgrass)

Forest habitat types from Pfister et al. (1977).
Grassland habitat types from Mueggler and Stewart (1980).

APPENDIX C. REPRESENTATIVE SOIL PROFILES

1. High and Mid-Elevation Plots

O_i 8-5 cm.

O_e 5-0 cm.

A   0-25 cm   Dark brown (10YR 3/3) moist, silt clay loam; weak, medium, subangular blocky structure; friable (moist), slightly sticky and slightly plastic (wet); slightly acid (pH 6.5), non-calcareous, gradual boundary.

B_w 19-70+   Dark yellowish brown (10YR 4/4) moist, clay loam; moderate, medium subangular blocky structure; firm (moist), slightly sticky and slightly plastic (wet); neutral (pH 7.0), non-calcareous.

C   Pits were rarely excavated to the depth needed to expose the C-horizon.

Park and grassland plots did not have O-horizons.

A-horizons also had loam or clay loam textures and weak, fine, granular structure (these structures were prevalent in the grassland and park plots). Park and high-elevation grasslands had thicker A-horizons (> 32 cm). pH values were occasionally one unit higher.

B-horizons also had silty clay loam, sandy clay or clay textures and moderate, medium angular blocky structure.

In general, the mid-elevation plots had thinner O-, A- and B-horizons and some of the profiles were calcareous (excluding any Douglas-fir plots).

2. Low-Elevation Grassland

A   0-7 cm Brown (10YR 5/3) silt loam, dark grayish brown (10YR 4/2) moist; weak fine granular structure; loose (dry), friable (moist), non-sticky and non-plastic (wet); medium acid (pH 6.0), non-calcareous, clear boundary.

BC   7-33 cm Yellowish brown (10YR 5/4) silty clay loam, dark brown to brown (10YR 4/3) moist; moderate fine subangular blocky structure; hard (dry), friable (moist), slightly sticky and slightly plastic (wet); neutral (pH 7.0), non-calcareous, clear boundary.

B_w 33-41+ cm Light yellowish brown (10YR 6/4) silty clay loam, yellowish brown (10YR 5/4) moist; moderate fine subangular blocky structure; friable (moist), slightly sticky and slightly plastic (wet); neutral (pH 7.0), violently calcareous.

A-horizons were also thicker, coarser-textured (a few plots had alluvial deposits) and more acid (pH 6.5).

B-horizons also had finer textures (possibly making them argillic) and were also deeper and non-calcareous.

APPENDIX D. TREE AGE, DIAMETER AND RING SPACING FOR FORESTED PLOTS

Transect 1

Plot No./ Habitat Type	Total Age (Years)	Species	d.b.h. (inches)	Spacing At Pith
1. ABLA/CARU				
	52	PSME	7.5	moderate
	192	PSME	36.2	wide
	93	ABLA	11.7	tight
	97	PSME	13.5	moderate
2. ABLA/ARCO				
	(230)	PSME	44.2	no pith
	98	PSME	6.1	moderate
	194	PSME	31.1	wide
4. PSME/ARCO				
	32	PSME	3.3	moderate
	48	PSME	7.4	wide
	52	PSME	10.7	wide
	55	PSME	9.8	wide
5. PSME/CARU				
	44	PSME	10.0	moderate.
	45	PSME	14.3	wide
	37	PSME	11.1	wide.

High Elevation (applies to plots 1, 2, 4)

Mid-Elevation (applies to plot 5)

APPENDIX D. (Continued)

Transect 2

	Plot No./ Habitat Type	Total Age (Years)	Species	d.b.h. (inches)	Spacing At Pith
	9. PSME/CARU				
		94	PSME	11.2	wide
		95	PSME	9.1	moderate
		243	PSME	29.4	wide
	8. ABLA/ARCO				
Elevation		51	Aspen	6.4	moderate
		75	PSME	6.5	moderate
		222	PSME	37.2	wide
High		114	PSME	25.1	wide
	10. ABLA/CARU				
		110	PSME	15.9	moderate
		86	PSME	4.6	moderate
		107	PSME	10.4	moderate
	13. PSME/CARU				
Mid-Elevation		64	PSME	10.1	moderate
		65	PSME	11.0	wide
		86	PSME	17.3	moderate
		65	PSME	6.7	moderate

APPENDIX D. (Continued)

Transect 3

	Plot No./ Habitat Type	Total Age (Years)	Species	d.b.h. (inches)	Spacing At Pith
High Elevation	17. ABLA/CARU				
		74	PSME	6.0	moderate
		194	PSME	24.6	moderate
		82	ABLA	6.9	moderate
		195	PSME	33.3	wide
	15. ABLA/ARCO				
		210	PSME	10.2	moderate
		201	PSME	12.2	tight
		199	PSME	31.2	wide·
		243	PSME	29.1	wide
	16. ABLA/ARCO				
		55	PSME	8.3	moderate
		75	PSME	14.1	wide
		68	PSME	15.5	wide
		74	PIAl	7.1	moderate
Mid-Elevation	20. PSME/CARU				
		59	PSME	12.7	moderate
		52	PICO	14.4	wide
		35	PSME	8.4	wide
		39	PSME	8.2	wide¨

Transect 4

	Plot No./ Habitat Type	Total Age (Years)	Species	d.b.h. (inches)	Spacing At Pith
High Elevation	23. PSME/CARU				
		60	PSME	10.3	wide
		90	PICO	12.8	wide
		(255)	PSME	35.2	no pith
	24. PSME/ARCO				
		34	PSME	4.1	moderate
		(331 + 20)	PSME	35.3	no pith
		(331)	PSME	51.5	no pith
		139	PSME	17.5	moderate
		70	Aspen	5.3	moderate
	25. PSME/CARU				
		67	PSME	10.2	moderate
		66	PSME	15.5	wide
		65	PSME	7.8	wide
		58	PSME	7.1	wide
Mid-Elevation	38. PSME/ARCO				
		93	PSME	8.3	moderate
		98	PSME	7.5	moderate
		99	PSME	16.0	wide
		110	PSME	13.9	moderate