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Holocene Fluctuations of the Coe Glacier, Mount Hood, Oregon

Karl Douglas Lillquist
Portland State University

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AN ABSTRACT OF THE THESIS OF Karl Douglas Lillquist for the
Master of Science in Geography presented July 15, 1988.

Title: Holocene Fluctuations of the Coe Glacier, Mount
Hood, Oregon.

APPROVED BY MEMBERS OF THE THESIS COMMITTEE:

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Numerous moraines front the Coe Glacier on the north
side of Mount Hood, Oregon. These moraines were identified
and dated using a multiple methodology approach in order to
establish a chronology for the advances and stillstands of
the Coe Glacier. This chronology was compared to
chronologies established for other glaciers on Mount Hood,
North Sister, Mount Rainier and Mount Baker as well as

glaciers in Scandinavia. The chronology was also compared to a long term temperature record from Longmire, Washington.

The maximum identified extent of the pre-Little Ice Age Coe Glacier was indicated by moraines located at an elevation of about 1530 m and about 2 km downvalley of the present terminus. A general period of shrinkage of the pre-Little Ice Age Coe Glacier followed resulting in the deposition of moraines upvalley of the older pre-Little Ice Age moraines.

The Little Ice Age Coe Glacier reached its maximum downvalley extent of about 1650 m elevation prior to 1731 AD. An earlier advance (1607 AD) was more extensive laterally than the 1731 AD advance. The Coe Glacier has been in a general state of recession since the mid to late 1700's. The prominent lateral moraines formed prior to 1882 AD. Four low moraines located within the Coe Glacier trough formed before 1901. Historical records indicate that the Coe Glacier has generally continued to recede since then.

A comparison of the moraine ages and the historical activity of the Coe Glacier to other glaciers on Mount Hood as well as others in the Pacific Northwest and Scandinavia reveals that fluctuations of the glacier termini are generally synchronous. This similarity, combined with the similarity of the ages of Coe Glacier moraines to cool periods in a long term temperature record, indicates that hemispheric climatic patterns have played a major role in the past fluctuations of the Coe Glacier.

HOLOCENE FLUCTUATIONS OF THE COE GLACIER, MOUNT HOOD, OREGON

by

KARL DOUGLAS LILLQUIST

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

MASTER OF SCIENCE
in
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Portland State University

1988

TO THE OFFICE OF GRADUATE STUDIES:

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CHAPTER I

INTRODUCTION

Numerous moraines exist downvalley of the present terminus of the Coe Glacier on the north side of Mount Hood, Oregon (Figure 1). However, they lie far upvalley from the maximum extent of the Late Pleistocene ice masses that flowed from the mountain (Figure 2). Moraines occupying similar positions in relation to present glaciers are found

Figure 1. Aerial view of the Coe Glacier, north side Mount Hood, Oregon.

Figure 2. Inferred extent of Fraser age glaciers at Mount Hood. Adapted from Crandell, 1980, p. 5.

in mountainous areas throughout the world. Various techniques have established that these moraines resulted from glacier advances since the Pleistocene. While the moraines of the Eliot Glacier and the Ladd Glacier on the north side of Mount Hood have received some attention, the moraines of the Coe Glacier have not been mapped or dated.

The concept of an expansion of glaciers since the melting of the Pleistocene ice masses was first proposed by Matthes (1933; 1935; 1939; 1942; 1948). Prior to this time, it was thought that existing glaciers were remnants of the more extensive Pleistocene ice masses. While the original theory may apply to some of the larger "trunk glaciers" of Alaska and Canada and major "ice streams" of the high mountains of the Pacific Northwest, it is doubtful that the cirque glaciers and the small alpine glaciers of the Western Cordillera survived the warm, dry period (Climatic Optimum or Hypsithermal) following the Pleistocene. Thus, Matthes hypothesized that the small glaciers of the western Cordillera formed following the Climatic Optimum, likely during the past 4000 years. Matthes (1939, p. 520) termed this period the "little ice age". Porter and Denton (1967, p. 181) suggested replacement of the term "little ice age" by a more permanent and accepted term "Neoglaciation" to refer to "the period of glacier expansion subsequent to maximum Hypsithermal shrinkage". Porter and Denton (1967, p. 202) identified two general northern hemisphere episodes

of glacial advance during the Neoglacial period - 2800-2600 yr BP (years before present) and more recently, during the past few centuries. Less widespread advances occurred between 5500-4000 and 1800-500 yr BP.

Subsequent compilation by Denton and Karlen (1973) refined the chronology of Holocene (post-Pleistocene) glaciation. Early advances occurred between 5800-4900 and 3300-2400 yr BP, and the most recent advances have taken place between A.D. 1500-1920. This recent period of renewed alpine glacial activity has been termed the Little Ice Age (Denton and Karlen, 1973, p. 159; Lowe and Walker, 1984, p. 26; Porter, 1986, p. 27) thereby adding confusion to the post-Pleistocene glacial terminology. Glacial advances have been reported from each century during the Little Ice Age (see Denton and Karlen, 1973, p. 171).

Burke and Birkeland (1983) compiled evidence of early, middle and late Neoglacial advances in the mountains of the western United States. In addition, evidence was presented for pre-Neoglacial (but post-Pleistocene) glacial advances.

PURPOSE

The moraines immediately downvalley of the Coe Glacier were investigated during July-September 1987. The primary purpose of the study was to identify and date glacial features and moraines immediately downvalley of the Coe Glacier and to determine the timing, extent and frequency of

Neoglacial activity in the area. Dating was accomplished through a variety of techniques.

A secondary purpose was to fit the Coe Glacier chronology into a regional and hemispheric context to determine how climatic patterns have played a role in the past activity of the glacier. This was accomplished by comparing moraine ages and documentary evidence of the Coe Glacier to other glaciers in the Pacific Northwest and in Scandinavia. The past activity of the Coe Glacier was also compared to a tree ring - derived temperature record from Longmire, Washington. This temperature record spans most of the Little Ice Age.

CHAPTER II

AREAL SETTING

PHYSIOGRAPHY

Mount Hood is located about 80 km (50 mi.) east of Portland in the northern Cascade Range, Oregon. It is part of the High Cascades Physiographic Province; the Western Cascades are located to the west while the Deschutes-Umatilla Plateau lies to the east (Baldwin, 1959) and the Columbia River is to the north. The High Cascades are a narrow summit plateau above 1800 m (5900 ft.) capped by Quaternary age composite volcanoes. The Western Cascades are deeply dissected uplands with summit elevations ranging from 600-1800 m (1970-5900 ft.) (Crandell, 1965, p. 348). Regionally, Mount Hood is part of the chain of Quaternary composite volcanoes that extend from California's Lassen Peak northward to Mount Garibaldi in British Columbia (Figure 3). At 3420 m (11,235 ft.), Mount Hood is the highest mountain in Oregon and is a visible landmark for much of northern Oregon and southern Washington.

As a result of glaciation and recent volcanism, Mount Hood is asymmetrical when viewed from the west or east. The north slopes are steep and highly dissected while the south slope is smooth and more gently sloping (Figure 4).

Figure 3. Regional setting of Mount Hood in relation to other Cascade volcanoes.

Three major rivers have their origins on the snow clad slopes of Mount Hood (Figure 2). The White River drains the south side, the Sandy River drains the south and the west slopes and the three forks of the Hood River drain the north and the east sides. All are tributaries to the Columbia River with the White River entering the Columbia via the Deschutes River.

Figure 4. West side of Mount Hood. Note the contrasting steepness of the northern and southern slopes.

The study area covers an area of approximately 4 km² (1.5 mi.²) in the vicinity of the Coe Glacier and Elk Cove on the north side of Mount Hood (Figure 5). The study area

Figure 5. Mount Hood, Oregon. Coe Glacier study area within rectangle.

lies within the Mount Hood North, Oregon 1:24,000 United States Geological Survey (USGS) Quadrangle (Township 2 South, Range 9 East - Hood River County). The elevation of the study area ranges from 1520 m (5000 ft.) north of Elk Cove to nearly 2130 m (7000 ft.) on Barrett Spur. Three streams dissect the study area in a southerly to northerly direction - the Coe Branch of the Middle Fork of Hood River and the unnamed tributaries to the east and west (Figure 5). Topography is rugged reflecting the volcanic, glacial and fluvial events that have shaped the terrain in the recent past. Steep-sided stream valleys, moraines, mudflow levees and bedrock ridges are encountered as one passes through the area.

Access to the Coe Glacier area is limited to foot travel due to the inclusion of the area within the boundaries of the Mount Hood Wilderness. Access is best along the 8 km (5 mi.) section of the Timberline Trail - United States Forest Service (USFS) #600 - which connects the Cloud Cap trailhead with Elk Cove (Figure 5).

GEOLOGY

Mount Hood is a late Pleistocene composite volcano composed of andesite and dacite lava flows, and interbedded pyroclastic deposits. Large volume olivine andesite flows and pyroxene andesite intracanyon flows form the base of the volcano. The waterfalls on Compass Creek and likely the

waterfalls on the Coe and Eliot Branches are a result of the early olivine andesite flows. Subsequent outpourings of pyroxene andesite lavas and interbedded pyroclastic deposits constructed the upper 1830 m (6000 ft.) of Mount Hood (including Barrett Spur). More recently, a post-Pleistocene hornblende dacite plug dome (Crater Rock) was extruded near the summit on the south side of the mountain (Wise, 1964; 1966; 1968; 1969, p. 993-94). In addition, several pre-Fraser age (10,000-29,000 yr BP - Armstrong et al, 1965) olivine andesite lava flows were erupted from satellite vents near Cloud Cap and The Pinnacle (Crandell, 1980, p. 8) (Figure 5).

Volcanic activity at Mount Hood has produced extensive mudflows, pyroclastic flows and ash cloud deposits ranging from pre-Fraser age to 180 years ago. Pre-Fraser age mudflows originated on the upper slopes of Mount Hood and moved down the Sandy River and the Hood River numerous times (Crandell, 1980, p. 8). Some of the Sandy River mudflows extended as far as the Portland metropolitan area (Trimble, 1963). In addition, the deposits of four synglacial and postglacial eruptive periods have been identified on the slopes and in the valleys radiating from Mount Hood (Crandell and Rubin, 1977; Crandell, 1980; Cameron and Pringle, 1986; Cameron and Pringle, 1987). The 12,000-15,000 yr BP Polallie eruptive period (Crandell, 1980, p. 10) is the oldest of the group and is followed in age by the

1,400-1,800 yr BP Timberline (Crandell, 1980, p. 26; Cameron and Pringle, 1986, p. 225), the 400-600 yr BP Zig Zag (Cameron and Pringle, 1986, p. 225) and the 180-270 yr BP Old Maid (Crandell, 1980, p. 35; Cameron and Pringle, 1986, p. 225) eruptive periods. All, except the Zig Zag eruptive period, consist of mudflows, pyroclastic flows and associated ash cloud deposits. The limited Zig Zag deposits are composed of mudflows and a thin tephra layer. Polallie deposits are found on all sides of Mount Hood indicating that the eruptive center was at or near the summit. In contrast, the Timberline, Zig Zag and Old Maid deposits are concentrated in the valleys to the south and west of Mount Hood. Crater Rock, due to its location at the apex of the Timberline-age debris fan, combined with the distribution of these deposits, was the likely eruptive center for these periods (Cameron and Pringle, 1986, p. 237). It is this Timberline-age debris fan which gives Mount Hood its characteristic non-symmetrical shape. Timberline and Old Maid-age mudflows travelled as far as 80 km (50 mi.) downvalley to the Sandy River delta near Troutdale (Cameron and Pringle, 1986, p. 228; Cameron and Pringle, 1987, p. 847).

Recent eruptive activity at Mount Hood was reported between 1846-1869 and again in 1908 (see Harris, 1980, p. 146-50). The presence of active fumaroles around Crater Rock combined with recent eruptive evidence suggests that

Mount Hood is still an active volcano.

GLACIERS

Eleven glaciers originate on the slopes of Mount Hood. Beginning on the northwest slope and moving counter-clockwise, these are the Ladd, Sandy, Reid, Zig Zag, Palmer, Coalman, White River, Newton Clark, Eliot, Langille and Coe (Figure 5) (Driedger and Kennard, 1986, p. 18). In addition, the Glisan Glacier and a number of perennial snowfields are shown on USGS topographic maps. Most of the glaciers on Mount Hood terminate between 1830-2440 m (6000-8000 ft.). The largest glaciers, both in surface area and volume, are located on the north side of Mount Hood. The Eliot Glacier has the largest ice volume at 91 million m³ (3.2 billion ft³) of any of the glaciers on the mountain. The Coe-Ladd Glacier system has the largest surface area - 2.2 million m² (23.1 million ft²) (Driedger and Kennard, 1986, p. 12). That the glaciers of Mount Hood have been much larger in the past is evidenced by moraines, drift, U-shaped valleys and glacially scoured terrain downvalley from the termini of the present glaciers.

The Coe Glacier is a large valley glacier that heads near the summit on the north side of Mount Hood. The ice mass extends downslope to just below an icefall where a lobe branches to the northwest and forms the Ladd Glacier. The main lobe of the Coe Glacier continues northward to about

1800 m (5900 ft) (Driedger and Kennard, 1986, Plate 3). The portion of the Coe Glacier below approximately 2070 m (6800 ft.) is mantled by a thick accumulation of debris (ablation moraine) derived from the steep slopes of Barrett Spur.

This debris cover is sufficiently thick and stable to support a variety of low growing vegetation. The portions of the Coe Glacier above 2070 m (6800 ft.) are mostly free of debris and have abundant crevasses dissecting the surface (Figure 1). The Coe Glacier occupies a trough delineated by two prominent lateral moraines. One major stream, the Coe Branch, emits from the terminus of the Coe Glacier. This stream is heavily charged with sediment as evidenced by its braided nature and "milky" appearance.

CLIMATE

The climate of Mount Hood is influenced by latitude, proximity to the Pacific Ocean, the positions of high and low pressure cells over the eastern Pacific Ocean, the pressure conditions east of the Cascade Range, the predominant westerlies and the transverse position of the Cascade Range to eastward moving air masses. Elevation and topography play major roles in the local climate. The regional climate of Mount Hood and the surrounding environs is characterized by warm, dry summers and cool, wet winters. The dry summers result from high pressure conditions off the Oregon Coast. Most precipitation falls between October and

April when the subtropical high pressure cell has moved southward allowing low pressure systems to move down from the north. Much of the precipitation that falls in the Cascades is orographic (due to topography), hence the western slopes of the range receive much more precipitation than the eastern slopes. The influence of orographic precipitation and the resulting rain shadow effect is demonstrated by the mean annual precipitation of two Soil Conservation Service (SCS) SNOTEL sites. The Mount Hood Test Site lies just west of the crest of the Cascades and receives 285 cm (112 in.) of precipitation annually. Clear Lake is located immediately east of the crest of the Cascades and about 10 miles south of the Mount Hood Test Site, and receives only 117 cm (46 in.) of precipitation annually (Soil Conservation Service, 1986, p. 25-26).

The Red Hill SNOTEL and Snow Course Site, located about 6.5 km (4 mi.) north of the study area (Township 1 South, Range 9 East, Section 20 - 1340 m elevation) (Figure 2), is the closest and most representative climate station to the Coe Glacier. Snow depths and snow water equivalents have been measured there since 1948. Precipitation measurements began only in 1979 (Diana McLaughlin - SCS, personal communication, 8 June 1988) and temperature measurements began in October 1981. Unfortunately, the temperature measurements are unreliable due to equipment malfunctions at the site and the fact that temperature

readings are taken once a day rather than as maximum and minimum readings.

The annual temperature cycle of the Coe Glacier area was estimated by using the 1961-1985 Parkdale National Oceanic and Atmospheric Administration (NOAA) station mean monthly temperature data (Figure 6). These data were adjusted for the difference in altitude between the two sites (1700 m to 520 m) by using the standard adiabatic lapse rate of $6.5^{\circ}\text{C}/1000\text{ m}$ (Barry and Chorley, 1982, p. 50). The highest temperatures occur in July while the lowest are in January. Temperatures average below freezing for five months of the year.

A correlated 1961-1985 precipitation record has been constructed by the U.S.D.A. - S.C.S. for Red Hill (Figure 7). Mean annual precipitation is 282 cm (111 in.) with a summer (July) minimum and a winter (December) maximum. Over 85% of the total (240 cm) precipitation falls between October and April with much of this falling as snow. Average snow depths at Red Hill during the 1961-1985 period are shown in Table 1.

TABLE I

RED HILL SNOW DEPTHS - 1961-1985

	February	March	April
Mean	158 cm	210 cm	239 cm
Maximum	340 cm (1972)	457 cm (1974)	493 cm (1974)
Minimum	25 cm (1977)	3 cm (1963)	25 cm (1963)

MEAN MONTHLY TEMPERATURE 1961-1985

PARKDALE and ELK COVE*

Figure 6. Temperature patterns (1961-1985) for Parkdale (record) and Coe Glacier (estimated).

RED HILL MEAN MONTHLY PRECIPITATION 1961-85

Mean Annual Precipitation = 282 cm

Figure 7. Red Hill precipitation 1961-1985

While these totals do not represent the total amount of snowfall received during a year, they do show the amount that persists through the late winter and early spring months. The increase in snow depth from February through April indicates that spring comes late at this elevation hence the area has a long snow accumulation season.

VEGETATION

As a result of the north-south trending Cascade Range and the predominantly westerly flow of air, vegetation to the east and west of the Cascade Range contrasts greatly. Dense forests of Douglas Fir (Psuedotsuga menziessii), Western hemlock (Tsuga heterophylla), Western red cedar (Thuja plicata) and Pacific Silver Fir (Abies amabilis) mantle the wet western slopes of the Cascades while east of the Cascade crest, forest communities dominated by Subalpine Fir (Abies lasiocarpa), Grand fir (Abies grandis), Douglas fir, lodgepole pine (Pinus contorta), ponderosa pine (Pinus ponderosa) and western juniper (Juniperus occidentalis) give way to shrub-steppe vegetation in the semi-arid environment (Franklin and Dyrness, 1973, p. 49).

The study area lies within the mountain hemlock (Tsuga mertensiana) zone, the highest forested zone of the western slopes and crest of the Cascade Range (Franklin and Dyrness, 1973, p. 101). Mountain hemlock and Pacific silver fir are the dominant overstory species in the lower portions of the

study area, forming a nearly closed canopy. Common beargrass (Xerophyllum tenax) and huckleberry (Vaccinium spp.) are common understory species. In the upper reaches of the study area, forest gradually gives way to parkland. Mountain hemlock and whitebark pine are common overstory associates. Subalpine fir is occasionally found in association with whitebark pine at the extreme upper elevations. Krummholz (the bent, stunted and often prostrate form of trees near timberline) is common on the windswept upper moraines and ridges. Timberline occurs between 1680 m (5500 ft.) and 1980 m (6500 ft.) (Franklin and Dyrness, 1973, p. 250). Common understory species include huckleberry and red mountain heather (Phyllodoce empetrifomis) while Sitka alder (Alnus sinuata) is common on rocky exposed slopes. Broadleaf lupine (Lupinus latifolia) and subalpine lupine (Lupinus latifolia var. subalpinus) are common herbaceous genera throughout the middle and upper elevation portions of the study area. Abundant wildflowers bloom in the upper parkland during the summer months and include Indian paintbrush (Castilleja spp.), alpine aster (Aster alpigenus), anemone (Anemone spp.), Sitka valerian (Valeriana sitchensis), saxifrage (Saxifraga spp.), penstamen (Penstamen spp.) and several compositae. Luetkea (Luetkea pectinata), stonecrop (Sedum spp.), broadleaf lupine, subalpine lupine and Sitka alder are common colonizers of freshly exposed surfaces including

the debris-covered surface of the Coe Glacier.

SOILS

The soils of the slopes of Mount Hood are poorly developed due to immaturity, coarse volcanic and glacial parent material, steep slopes and harsh climatic conditions. In the study area, soils are best developed at lower elevation forested sites. These soils have been classified as Typic Cryorthods on the basis of the spodic diagnostic horizon (Howes, 1979, p. 143-46; Steve Howes - USFS, 20 June 1988, personal communication). The soils consist of a thin layer of partially decomposed forest litter overlying a fine sandy, light gray to pinkish gray horizon. This gray horizon may be interpreted as an albic (E) horizon or as a tephra layer. No chemical analysis has yet been done to determine the exact origin. This horizon overlies a stony fine sandy yellowish brown B horizon. Soils at the upper elevations show little or no evidence of horizonation.

LAND USE

Mount Hood and much of the surrounding area is managed by the U.S. Forest Service - Mount Hood National Forest. The Mount Hood Wilderness encompasses all but the south side of the mountain. Mount Hood is a popular winter and summer recreation area, serving the metropolitan Portland and Vancouver areas. Logging is also an important activity in

the forests surrounding the mountain.

The study area lies within the Mount Hood Wilderness; therefore access is limited to foot traffic. Five trailheads lie within 10 km (6.5 mi.) of Elk Cove and the Coe Glacier (Figure 3). The proximity to trailheads combined with the local aesthetics and the intersection of the area by the popular Timberline Trail, make Elk Cove a popular destination area for day hikers as well as campers during the summer months (July-September).

CHAPTER III

LITERATURE REVIEW

Very little definitive research has been carried out on the number and extent of different Pleistocene or Holocene advances of the Coe Glacier. Previous investigations have been primarily concerned with historical changes of the Coe Glacier. An approximate limit for the Fraser-age glaciers of Mount Hood has been mapped and the Neoglacial histories of the Eliot and Ladd Glaciers have briefly been explored. Measurements of the termini of the Eliot, Ladd, Coe, White River and Newton Clark Glaciers have been recorded in historical times. In addition, aerial observations have been made on the other glaciers of Mount Hood. This chapter explores the past research concerning glaciation and the glaciers of Mount Hood.

PLEISTOCENE GLACIATION

Hague (1871, p. 167) remarked on the formerly more extensive glaciers on Mount Hood. He believed that the larger U-shaped valleys resulted from three main glaciers - the Sandy River and White River Glaciers on the south and the Hood River Glacier to the north. Hodge (1940, p. 45-46), used the morphometry of valleys to identify five

glacial periods at Mount Hood. The first glacial advances were the most extensive with glaciers reaching the Columbia River by way of the Hood and Sandy River Valleys. However, it is unlikely that Mount Hood glaciers extended 30 km (18 mi.) down the Hood River or 80 km (50 mi.) down the Sandy River to reach the Columbia River. There has been no recent evidence to substantiate Hodge's claim.

Crandell (1965, p. 348-49) was the first to map the extent of Pleistocene ice masses in the entire Oregon Cascade Range. Crandell (1980, p. 4-7) found evidence for at least one pre-Fraser age drift in the valleys to the southeast, south and west of Mount Hood. He differentiated this drift from other deposits on the basis of soil oxidation, stone weathering rind development and the presence of the 35,000-40,000 year old pumice of Mount St. Helens (D.R. Mullineaux, personal communication in Crandell, 1980, p. 7) atop the drift. The characteristics of this drift are similar to the >35,000 yr BP Hayden Creek drift of Mount Rainier (Crandell and Miller, 1974, p. 8).

Wise (1968, p. 85) recognized drift likely correlative to Fraser drift in all of the valleys surrounding Mount Hood. He used depth of soil weathering as a prime criteria in recognizing this drift. Crandell (1980, 4-5) also outlined the inferred extent of Fraser age drift (Figure 2). He suggested that the distribution of Polallie-age mudflow deposits indicates that the north slopes of Mount Hood were

covered by Fraser-age ice down to about 1370 m (4500 ft) while the south side was covered by ice to 1525-1677 m (5000-5500 ft). In contrast, most glaciers on the north flanks of Mount Hood presently terminate around 1830-1980 m (6000-6500 ft) while those on the south facing slopes terminate at approximately 2150 m (7000 ft) (Crandell, 1980, p. 6). Assuming that the glaciers of Mount Hood were synchronous with the alpine glaciers of Washington and British Columbia, they probably reached maximum downvalley extents at about 18,000 yr BP. A general retreat occurred following 18,000 yr BP signalling the end of the Fraser Glaciation at Mount Hood about 11,000 yr BP (Crandell, 1980, p. 4).

Evidence of Pleistocene glaciation is found in cirques in the mountains surrounding Mount Hood. The average altitude of Fraser-age cirques to the north and northwest of Mount Hood is approximately 1030 m (3400 ft), while cirque elevations to the south and east are 1250 m (4100 ft) and 1370 m (4500 ft) respectively (Crandell, 1980, p. 5-6).

HOLOCENE GLACIATION

H.F. Reid (1905) and A.H. Sylvester (1908a; 1908b) were the first to recognize evidence for a recent period of glaciation. Reid (1905, p. 195-97) recognized ground moraine about 3 km (2 mi.) downvalley of the present terminus (1901) of the White River Glacier indicating that

the glacier had once extended at least that far downvalley. The presence of fresh wood buried in the drift and the relatively unvegetated moraine surface indicated that the White River Glacier had receded from the downvalley position within the past 100 years. Sylvester (1908a, p. 585; 1908b, p. 520) recognized evidence of both an earlier more extensive glaciation and a more recent but less extensive glaciation.

Reid (1905, p. 196-98) noted the downvalley positions of Mount Hood's glaciers in relation to the ends of their lateral moraines as an indication that the glaciers (with the exception of the White River Glacier) were as long at present (1901) as they had been in "a long time". However, the position of the lateral moraines often 15-30 m (50-100 ft.) above the ice masses indicated that the ice masses were once much higher and that considerable downwasting had taken place. Double crested moraines associated with the Ladd, Eliot and Coe were also used as evidence that the ice masses were once much larger. Reid described the termini of each the Coe, Ladd and Eliot Glaciers as being located where the lateral moraines "suddenly pitch down into a canyon". He also marked the terminal positions of the Coe, Eliot and White River Glaciers on the lateral moraines with red paint and photographed the termini of these glaciers thus providing subsequent investigators with valuable datum points by which to compare changes during this century.

D.B. Lawrence used dendrochronology, tephrochronology and documentary evidence to date moraines adjacent to the Ladd and Eliot Glaciers on the north side of Mount Hood (Table II) (Matthes, 1946; Lawrence, 1948). He identified six different moraines near the Ladd Glacier varying in age from 1749 (A.D.) to 1936. Around the Eliot Glacier, eight moraines were identified ranging in age from pre-1500 to 1900. Both the Eliot and the Ladd reached their maximum downvalley extents (of the past 500 years) between 1740-1749. In fact, the ages of trees downvalley of the 1740 moraine indicated that the Eliot had not extended beyond that moraine since before 1300. The lateral moraines of the Ladd and the Eliot Glaciers were also similar in age, forming between 1850-1852.

Lawrence and Lawrence (1959, p. 13) found logs buried in glacial drift along the Zig Zag River on the west side and along the White River on the south side of Mount Hood. The radiocarbon dates of these logs were 950 plus or minus 150 years before present (yr BP) (Zig Zag) and 250 plus or minus 150 yr BP (White River) suggesting that Neoglacial advances resulted in the burial of the logs.

HISTORICAL GLACIATION

The glaciers of Mount Hood have been in a general state of recession since the late 1800's and likely since the mid-1700's as indicated by the age of the Ladd and Eliot

TABLE II
MORaine AGES OF THE ELIOT AND LADD GLACIERS

<u>MOUNT HOOD</u>		
	ELIOT	LADD
<hr/>		
		1935-36
1900	1900	
	<1850	1852
		1818
1800		1806
	1740	1749
1700	<1700 <1690	
1600		

Sources: Matthes, 1946;
Lawrence, 1948

Glacier moraines. Lyman (1886, p. 284) mentioned that the Eliot Glacier was wasting away "at the rate of 20 feet per year and has become less steep with the wearing process". Langille et al (1903, p. 28) recognized that the glaciers of Mount Hood were "slowly diminishing and receding" in the early 1900's and had been doing so for several years.

The Research Committee of the Mazamas began annual and semi-annual measurements of the terminus of the Eliot Glacier in 1925 and subsequently initiated similar measurements on the Ladd Glacier in 1927 and the Coe Glacier in 1928. A nearly continuous record of the changes in the termini of these glaciers was collected until 1946 (Table III). These measurements and observations indicate that all of the glaciers were receding (Phillips, 1935; 1938; 1939; 1946; Matthes and Phillips, 1943; Mason, 1946a; 1946b; Matthes, 1946). In addition, ground and aerial observations were made on the White River and Newton Clark Glaciers by the Mazama Research Committee (Phillips, 1935; 1938) and compared to the observations made by Hague (1871) and Reid (1905). During the period 1901-1937, the Newton Clark Glacier receded about 150 m (500 ft.) and downwasted 30 m (100 ft.) (Phillips, 1938, p. 26). In comparison, the White River Glacier receded about 560 m (1840 ft.) between 1901-1936 and 660 m (2160 ft.) between 1871-1901 (Phillips, 1938, p. 26). Handewith (1959) noted an increase in the upper profiles of both the Coe and Eliot Glaciers on the north

TABLE III
HISTORICAL ACTIVITY OF THE COE, ELIOT AND LADD GLACIERS, MOUNT HOOD, OREGON

COE				ELIOT				LADD			
Date	Slope Distance Above Base Line (m)	Advance(+) or Recession(-) (m)	Date	Slope Distance Above Base Line (m)	Advance(+) or Recession(-) (m)	Date	Slope Distance Above Base Line (m)	Advance(+) or Recession(-) (m)	Date	Slope Distance Above Base Line (m)	Advance(+) or Recession(-) (m)
26 August 1928	-3	---	23 July 1901	-73	---	28 August 1927	0	---	20 October 1935	+4	+4
11 August 1929	-3	0	13 September 1925	+15	-88	11 August 1929	+9	-9	2 August 1936	+2	+2
27 September 1931	+10	-13	31 October 1926	---	-1	27 September 1931	+4	+5			
24 September 1932	+16	-6	26 August 1928	---	-11	25 September 1932	+8	-4			
22 September 1934	+23	-7	27 September 1931	+3	-3						
20 September 1935	+19	+5	24 September 1932	+29	+1						
			23 September 1933	+22	+7						
			14 October 1934	+34	+12						
			19 October 1935	+41	-4						
			20 September 1936	+44	-2						
11 September 1937	+27	-9	11 September 1937	+50	-6						
14 August 1938	+34	-6	18 September 1938	+57	-7						
24 September 1939	+52	-18	24 September 1939	+76	-20						
			21 September 1940	+82	-6						
28 September 1941	+73	-22	28 September 1941	+88	-6						
20 September 1942	+86	-13	20 September 1942	+95	-8						
19 September 1943	+91	-6	24 September 1944	+102	-7	20 September 1942	+29	-26			
24 September 1944	+125	+34	21 September 1946	+102	-6	19 September 1943	+32	-4			
24 August 1946	+131	-6				24 August 1946	+43	-9			
TOTAL GLACIER RECESSION											
1901-1926											
1928-1946		135 m			97 m						41 m
1946-1954		106 m			85 m						

Sources: Phillips, 1935; Phillips, 1938; Phillips, 1939; Phillips, 1946; Mason, 1954.

side and in the White River Glacier on the south side of Mount Hood beginning in 1958. However, the lower portions of these glaciers were still retreating. Dodge (1964) also measured an increase in the upper profile of the Eliot Glacier but this increase, like those measured in 1959, was not reflected in the terminus. From 1960-1983, the glacier mass balance fluctuated but was positive during most of the period. Equilibrium Line Altitude (ELA) measurements ranged from 2430 m (7400 ft.) in 1974 and 1983 to >2930 m (9600 ft.) in 1977. No definite trend was seen in the data; however, 1.3 m of water equivalent was added to the surface of the Eliot Glacier during this 24 year period (Dodge, 1971; Dodge, 1987).

CHAPTER IV

METHODOLOGY

Several techniques were used in the identification and dating of moraines adjacent to the Coe Glacier including relative moraine positions, moraine morphology, relative vegetation cover, dendrochronology, lichenometry, tephrochronology, soil weathering and radiocarbon dating. Use of several techniques is warranted by the limitations of each method and various local effects which may alter the effectiveness of one technique but are unlikely to adversely impact all methods (Birkeland, 1982, p. 436). Indeed, Birkeland et al (1979, p. 534) states "the chances of arriving at a valid subdivision [of deposits] and correct correlations are greatly enhanced if a variety of surface and subsurface RD [relative dating] parameters are measured." This chapter describes the methodology used in this study.

MORAINES - RELATIVE POSITIONS AND MORPHOLOGY

The relative positions of terminal and lateral moraines, and their morphology are very useful indicators of the extent and relative age of glacial events. The outermost (or most distant from the source area) of a series

of moraines represents the oldest deposit while the moraines located inward are successively younger unless these moraines show evidence of being overridden or truncated by a more recent advance. Fluted (parallel grooved) moraine surfaces or discordant (non-continuous or abrupt) moraine trends are evidence of more extensive recent advances or surges (Miller, 1969, p. 51; Kiver, 1974, p. 176; Waitt et al, 1982, p. 194-95). In addition, the position of a lateral or terminal moraine indicates the extent of a particular advance or stillstand (Lowe and Walker, 1984, p. 21-31).

Angle of proximal (inner) and distal (outer) moraine slopes and the width of moraine crests are also indicators of the relative age of moraines. Young moraines commonly have steep slopes and sharp narrow crests. With increased time, weathering, erosion and mass wasting will act to decrease the angle of the moraine slopes and broaden the crests (Miller, 1969, p. 51; Porter, 1969, p. 10; Carver, 1973, p. 18; Scott, 1977, p. 114).

In this study, the positions of lateral and terminal moraines were mapped at a scale of 1:10,032 on topographic maps and at a scale of 1:15,840 on aerial photograph overlays. Moraines were identified by their ridge-like relief, broad to narrow crests, linear extent and diamicton (mixture of clay, sand, pebbles, cobbles and boulders) composition. Large boulders were common on the surface of

moraines as were large conical debris mounds. Striated boulders were only found on the moraines closest to the Coe Glacier, therefore were not diagnostic of all glaciated surfaces. Proximal and distal slope angles were measured with an Abney hand level and the widths of moraine crests were estimated.

RELATIVE VEGETATION COVER

When a glacier advances, it destroys all vegetation in its path, including the largest trees. With the recession of the ice, moraines are exposed and a distinct vegetation line forms delineating the glaciated (and now unvegetated) surface from the non-glaciated (thus retaining its vegetation cover) area. This feature has been termed the "trimline" (Lawrence, 1948, p. 26). As the ice downwastes and recedes, vegetation successively colonizes the areas upglacier. Hence, vegetation cover is less well developed on those surfaces most recently exposed and increases outward. Vegetation differences also occur between distal and proximal slopes, with distal slopes having higher vegetation cover than proximal slopes. This is due to the more recent presence of ice on the proximal slopes than on distal slopes.

The technique of using relative vegetation cover to date moraines is based on the premise that vegetation cover is a function of time - i.e. the longer the time elapsed

since deglaciation/stabilization, the more vegetation covering a surface (Kiver, 1974; Waitt et al, 1982, p. 196). Vegetation cover is also dependent upon soil development which in turn is related to time (Kiver, 1974, p. 180). Vegetation cover may be affected by secondary disturbances such as fire, burrowing animals, mass wasting, avalanche and meltwater erosion.

In this study, total vegetation cover on the crest, and the distal and proximal slopes of moraines was estimated from field investigations and aerial photographs. Vegetation cover was then classified quantitatively by approximating percentage cover.

DENDROCHRONOLOGY

Trees add new layers of outer wood each year in the form of an annual ring. Annual rings are easily identified because of the difference between the dark "summer" wood and the light "spring" wood (Lawrence, 1950, p. 247). The total number of annual rings represents the age of the tree.

The age of the oldest tree on a moraine indicates the minimum number of years elapsed since the moraine surface was created (Lawrence, 1946, p. 57-58). In addition, the age of trees beyond the extent of glaciation provides a minimum estimate of the time elapsed since the area was free of ice. The dates derived from dendrochronology are minimum because of various factors, i.e. variable substrate

stabilization periods (Sigafoos and Hendricks, 1961, p. A13; 1972, Burbank, 1981, p. 370), difficulties in determining whether the oldest tree on a moraine has been sampled (Sigafoos and Hendricks, 1961, p. A7), various secondary disturbances (Sigafoos and Hendricks, 1972, p. B3) and the relatively short lifespans of conifers in the Pacific Northwest (Burbank, 1981, p. 371; Franklin and Dyrness, 1973, p. 48).

The use of tree rings to date moraines adjacent to the Coe Glacier follows the methodology of other investigators (Lawrence, 1946; 1948; 1950; Sigafoos and Hendricks, 1961; 1972; Miller, 1969; Heikkinen, 1984). In this study, a 400 mm (16 in.) Swedish increment borer was used to core the largest trees of each species at several different sites on the crest of each moraine. Tree rings were counted in the field if time permitted. Tree species, number of rings (if counted), circumference, sampling height and sampling location were noted. In the laboratory, samples were glued into slotted boards and sanded. Rings were then counted with a 20x binocular microscope. In addition to core samples, several cut sections were taken from trees less than 5 cm (2 in.) diameter because size limited the feasibility of coring the small trees. The cut sections were analyzed in the laboratory in the same manner as the core samples. The effectiveness of dendrochronology was limited by heart rot (on some of the larger and older

mountain hemlock and whitebark pine) and by an increment bore that was not long enough to reach the core of several of the largest trees. However, these limitations did not seriously affect the results of the study.

LICHENOMETRY

Lichen growth is largely a function of time with lichen diameters larger and lichen percentage covers higher on older surfaces than on younger surfaces. Consequently, lichen measurements have been used to establish specific ages (through the establishment of lichen growth curves) and as a measure of the relative ages for surfaces (when compared to lichen on other surfaces) (Benedict, 1967; Denton and Karlen, 1973; Porter, 1981b; Burbank, 1981; Miller, 1969). Rhizocarpon geographicum, a green black lichen, is the species most commonly used in lichenometry in alpine areas because of its widespread distribution (enabling comparisons between different areas), swift colonization of fresh surfaces, a lifespan of at least 3000 years (Benedict, 1967, p. 831) and a relatively slow growth rate (Locke et al, 1980, p. 4; Porter, 1981, p. 13; Benedict, 1967, p. 819). Due to abundant R. Geographicum subspecies and resulting difficulties in field identification, the lichen will hereafter be referred to as R. Geographicum s.l. (sensu lato, which is Latin for "in a broad sense") (Locke et al, 1980, p. 5; Waitt et al, 1982,

p.199).

In this study, the largest R. geographicum s.l. growing on surface boulders along the crests of moraines were measured to the nearest 1 mm with a metric rule. Measurements were not limited to circular or nearly circular thalli; instead, the diameter of the largest inscribed circle of all continuous patches of lichen was measured following the methodology of Locke et al (1980, p. 7). The mean of the five largest lichen on a surface was used to eliminate the effects of lichen that were transported onto the surface by rockfall or avalanche, or those that were growing on the previous substrate and survived the development of the present surface (Locke et al, 1980, p. 9-10). In the few cases where less than five lichen measurements were made, the mean of the total measurements taken was used. The maximum percentage cover of R. geographicum s.l. on boulders found along moraine crests was estimated using Data Sheet 6 of Geotimes (American Geological Institute). However, lichen diameters are more commonly used in dating surfaces than lichen percentage cover (Locke et al, 1980, p. 7)) hence lichen diameters will be relied upon more heavily in this study.

TEPHROCHRONOLOGY

Tephrochronology is the use of tephra layers to date events over time. It is based on the premise that tephra

layers are younger than the surfaces they overlie. If the age of a tephra unit is known, a minimum specific age for the surface may be determined. Improved age control is possible if two or more tephra units of known ages are present in an area thus providing bracketing ages for the dates of formation (Porter, 1981a, p. 94). Limitations in the use of tephrochronology include the effects of snow cover and bioturbation on the accumulation and longevity of tephra layers (Burbank, 1979, p. 18). Tephrochronology is a commonly used tool in the dating of Quaternary glacial deposits, especially in the Pacific Northwest where there has been abundant volcanic activity (Miller, 1969; Crandell and Miller, 1974; Kiver, 1974; Scott, 1977; Burbank, 1979; Fuller, 1980; Waite et al, 1982).

In the study area, soil pits were excavated on many of the moraines and in a bog beyond the outermost identified moraine. The purpose of the excavations was to determine the presence of and identify the tephra layers overlying the moraines. Tephra units were described in the field on the basis of Munsell color, texture, position in the soil profile and distribution. Eleven tephra samples were subsequently analyzed following the methodology of Kittleman (1973, p. 2959-62) to determine their composition. Samples were washed and cleaned ultrasonically. Grains between 60 and 500 micrometers in size were then examined at 125x and counted to determine the percentage of lithic

clasts, glass shards and mineral assemblages.

Subsequently, a scatter diagram of mineral abundance ratios was constructed plotting lithic clasts (LTX) / free crystal (FX) ratios on the y-axis and plagioclase (PL) / ferromagnesian (FM) ratio on the x-axis.

SOIL DEVELOPMENT

The degree and depth of soil redness is a function of time. Iron-bearing minerals are weathered and leached downward into the B horizon. Oxidation occurs where the minerals come in contact with oxygen-rich waters. Over time, the B horizon becomes more yellow brown to red due to oxidation (Birkeland, 1984, p. 72-74). Soil redness is also a function of the other soil forming factors, especially climate and parent materials. However, some soils are red and oxidized before weathering occurs; hence soil color should not be the sole methodology in making inferences about the age of land surfaces (Birkeland, 1984, p. 211).

Many past investigators have used soil weathering as an aid in differentiating Quaternary glacial deposits (Burke and Birkeland, 1979, p. 25; Scott, 1977, p. 114; Fuller, 1980, p. 12-13; Waitt et al, 1982, p. 200). In this study, a soil pit was dug about 1 m (3 ft.) deep on the crest of several of the moraines. A Munsell soil color chart was used to identify the color of each different horizon. The depth and texture of each horizon was also

noted. Soil horizons were described following the nomenclature of Birkeland (1984, p. 7-9). The Munsell color of the B horizon of each profile was quantitatively compared using the Buntley-Westin color index (Buntley and Westin, 1965) to determine relative ages of the moraines. The Buntley-Westin color index was derived by recalculating the hue into a number ($7.5YR=4$; $10YR=3$; $2.5YR=2$; $5Y=1$) and multiplying this number by the chroma. Higher Bentley-Westin indices are interpreted to represent more highly weathered soils.

RADIOCARBON DATING

Living organisms are constantly replacing decayed ^{14}C in their bodies. Once they die, ^{14}C decay continues but replenishment ceases. Since the decay rate of ^{14}C is known, the time elapsed since the death of the organism can be calculated by comparing the present amount of ^{14}C in the atmosphere to the amount of ^{14}C in an organic sample. Samples may be obtained from organic matter buried in glacial till and outwash as well as soils, alluvium, tephra, lava flows, lahars and pyroclastic debris. The dates obtained may be limiting, bracketing or contemporaneous depending upon the position of the organic matter in relation to the deposit, and the number of samples present (Porter, 1981a, p. 93). However, the reliability of radiocarbon dating, especially in dating materials

deposited in the past 450 years, is questionable because of assumptions about the quantity (through production and decay) of atmospheric ^{14}C over time (Stuiver, 1978, p. 271). Porter (1981a, p. 92) cautions against the establishment of Little Ice Age chronologies based solely on radiocarbon dates.

Radiocarbon dating is used in this study, despite its limitations, because of a need for increased accuracy in dating those deposits formed more than 450 yr BP. Several organic samples were taken from a sequence of organic layers and tephra units in a soil pit in a bog at the north end of the study area. This sequence overlies possible glacial outwash or till. One sample was subsequently dated at the Quaternary Research Center Radiocarbon Laboratory, University of Washington.

CHAPTER V

RESULTS OF FIELD INVESTIGATIONS

Numerous moraines were identified and dated in the Coe glacier study area. The moraines identified are described from south to north (or closest to farthest from the present glacier), beginning with those located west of the Coe Glacier and concluding with those east of the Coe Glacier (Figure 8). Moraines located west of the Coe Glacier and south of the Timberline Trail (USFS #600) are designated with the prefix SEC (South Elk Cove) while those located west of the Coe Glacier and north of the Timberline Trail are identified by the prefix NEC (North Elk Cove). All moraines identified east of the Coe Glacier are designated by the prefix ECG (East Coe Glacier). A letter or numeral suffix is attached to each designation to differentiate between individual moraines. Informal letter and numeral designations have been used to differentiate the moraines because they can be abandoned more easily than names if revision of the glacial chronology is warranted (Birkeland et al, 1979, p. 533). Use of the terms South Elk Cove, North Elk Cove and East Coe Glacier is meant merely as a way to group the moraines by geographical area to aid in the description of the moraines. These terms are not meant to

Figure 8. Moraines adjacent to the Coe Glacier.

be permanent. The results of the moraine identification and dating are presented below.

MORAINE POSITION AND MORPHOLOGY

Coe Glacier moraines extend from the east face of Barrett Spur (2000 m) downvalley to an elevation of 1520 m (5000 ft.) or lower. The downvalley moraines are generally lower in height with lower slope angles, and broader crests than the upvalley moraines (Table IV). The subdued nature of these downvalley moraines, combined with their downvalley positions and lack of truncation and overriding, suggests that they are older than the upvalley moraines.

South Elk Cove

The relative position of SEC-N downvalley of SEC-M and SEC-L (Figure 8) indicates that SEC-N is older than SEC-M and SEC-L, and that SEC-M is older than SEC-L. The view upvalley to the immediate west of these moraines reveals oversteepened slopes and a "U-shaped" appearance which suggests that a lobe of the Coe Glacier overtopped the left lateral moraine, SEC-LL, and descended as far as SEC-N (Figure 9). SEC-L, SEC-M and SEC-N all have narrow crests and relatively high angle slopes (Table IV) indicating that they are similarly young in age.

Moraine SEC-C is the largest and outermost (although upvalley) moraine of a group of nested moraines (Figure 8).

TABLE IV
MORAINE MORPHOLOGY

Location	Slope Angle (degrees)		Height (m)		Crest Width (m)
	Distal/Proximal		Distal/Proximal		
<hr/>					
SOUTH ELK COVE					
SEC-L	26	27	10	20	1-3
SEC-M	30	26	20	15	1-3
SEC-N	30	29	25	15	1-3
SEC-C	30	32	45	35	1-3
SEC-B	29	--	25	--	1-3
SEC-A	27	24	10	10	1-3
SEC-D	--	--	--	--	1-3
SEC-E	32	27	30	15	1-3
SEC-LL (up)	30	35	40	30	1
" " (down)	30	25	20	30	3
SEC-LT4	--	20	--	5	1-3
SEC-LT3	--	20	--	5	1-3
SEC-LT2	--	22	--	10	1-3
SEC-LT1	--	23	--	10	1-3
SEC-H	28	34	20	20	3
SEC-I	--	--	--	--	3
SEC-J	--	33	--	20	3
SEC-J1	--	--	--	--	1-3
SEC-K	--	--	--	--	1-3
SEC-U	27	--	10	--	5
SEC-V	23	30	10	10	5
NORTH ELK COVE					
NEC-F	28	--	15	--	3-5
NEC-G	<10	13	10	<5	>5
NEC-S	<10	25	25	<5	>5
NEC-T	--	--	--	--	3
NEC-Y	15	<10	10	<5	3-5
NEC-W	20	--	15	--	>5
NEC-X	19	<10	20	<5	>5
EAST COE GLACIER					
ECG-RL (up)	23	35	10	35	1
" " (down)	25	30	20	30	1-3
ECG-RT1	25	--	5	--	1
ECG-RT2	25	--	5	--	1
ECG-O (up)	>30	34	30	5	1-3
" " (down)	26	30	30	20	3
ECG-O1	--	--	--	--	3
ECG-P	11	--	10	5	>5
ECG-Q	21	25	20	20	>5

Located successively northward, are SEC-B, SEC-A, SEC-D and SEC-E (Figure 10). All have similar slope angles and crest widths (Table IV). The trend of these moraines suggests that they are left lateral moraines and this, combined with their relative positions, indicates that SEC-C is the oldest, while the innermost in the sequence, SEC-E, is the youngest. The height of SEC-C (30-40 m) suggests that the ice occupied one position for an extensive period of time. Moraines SEC-C, SEC-B, SEC-A and SEC-D all have abrupt termini suggesting that they were truncated by meltwater. The position of these moraines illustrates the point made by Sigafoos and Hendricks (1961, p. A7-A8) that glaciers do not follow the same paths during each advance; rather, the areas covered by each advance may vary greatly.

The southern portion of the left lateral moraine (SEC-LL) has a distinctly different character from the northern section. South of a large conical debris mound located at 1820 m (5960 ft.) (Figure 11), the moraine has a relatively level, narrow crest and oversteepened proximal slopes (Figure 12) while the section to the north (downslope) has a wider and more inclined crest, and a proximal slope that is more gentle (Figure 13; Table IV). These data suggest that the northern portion of the moraine stabilized prior to the southern portion. The northern portion of SEC-LL ends at a large painted boulder located at about 1770 m (5800 ft.) (Figure 14). This boulder was

Figure 9. Moraines SEC-N, SEC-M and SEC-L. View upvalley.

Figure 10. Aerial view of the lower Coe Glacier and surrounding moraines. View to the south.

Figure 11. Debris mound on SEC-LL. View to north.

Figure 12. Upvalley section of SEC-LL. Coe Glacier to left. View to south.

Figure 13. Downvalley section of SEC-LL. View to south.

painted by Mazamas Research Committee members in August, 1928 and again in 1946 to aid in the aerial survey of the Coe Glacier (Phillips, 1935, p. 50; Mason, 1946a). It also may have been painted by Reid (1905, p. 197) when he visited the Coe Glacier in 1901. North of the painted boulder, the moraine splits into several less distinct moraines, SEC-H, SEC-I, SEC-J and SEC-K (Figure 8), all of which trend generally northward. Moraine SEC-H is the outermost (hence the oldest), and located successively inward (and progressively younger) are SEC-I, SEC-J and SEC-K. All have similar slope angles and crest widths (Table IV) indicating that they are relatively similar in age. Moraine SEC-J1

branches off the lower, proximal slope of SEC-J suggesting that it is younger than J. Branching off SEC-LL and SEC-J into in the Coe Glacier trough, are moraines SEC-LT1, SEC-LT2, SEC-LT3 and SEC-LT4 (Figure 15). All are similar in appearance and have similar slopes, heights and crest widths (Table IV). The outermost position of SEC-LT4 indicates that it is the oldest and SEC-LT3, SEC-LT2 and SEC-LT1 are progressively younger. The present left lateral moraine lies inside of SEC-LL and upvalley of SEC-LT1, and abuts the Coe Glacier (Figure 10).

SEC-V lies downvalley and outside of SEC-U. Both have similar slope angles, heights and crest widths (Table IV). The relative position of the moraines implies that SEC-V is older than SEC-U.

North Elk Cove

The North Elk Cove moraines are generally lower, have broader crests, lower slope angles and lie downvalley from the South Elk Cove moraines (Table IV) suggesting that they are older. The outermost position of NEC-F in relation to the other North Elk Cove moraines indicates that it is the oldest identified moraine (Figure 8). Located inward or upvalley (hence successively younger) are NEC-G, NEC-S, NEC-T and NEC-Y. The transverse nature of the termini of NEC-S and NEC-T implies that they represent terminal moraines, and both may have once joined NEC-F but were probably truncated

Figure 14. Painted boulder on SEC-LL (1770 m). Indicates the position of the Coe Glacier terminus when painted in 1928 by the Mazamas.

Figure 15. Moraines SEC-LT4 and SEC-LT3. View to northeast.

by meltwater. The westward bend of NEC-S and NEC-T suggests that they are remnants of right lateral moraines that originated from an ice mass other than the main portion of the Coe Glacier. This ice may have originated from a lobe of the upper Coe Glacier which spread out into Elk Cove upon leaving the confines of the upper bedrock trough; or it may have originated from a cirque glacier that formed in Elk Cove; or perhaps it was a combination of the two. The similarity of crest widths and slope angles lends little help in the relative dating of these moraines (Table IV).

At least three level areas are present on the east side of Barrett Spur (Figure 16). These levels decrease in elevation downvalley (1760 m, 1730 m and 1680 m) and may represent kame terraces which were formed when the Coe Glacier occupied Elk Cove. In this hypothesis, runoff carried sediments into the void between the ice and the flank of Barrett Spur. With the recession of the ice, the terraces were exposed representing different heights of the ice over time, or the decreasing elevation of the ice downvalley. The terraces also may correspond to the subdued ridge trending northeast off the northern end of Barrett Spur (Figure 8). This ridge lies downvalley of NEC-F but upvalley of the bog sampling site (Soil Pit #6) and may be a moraine; if so, it is older than NEC-F. However, the poorly defined crest, and the lack of surface boulders and debris mounds casts doubt on this interpretation.

Located to the east of the previously mentioned North Elk Cove moraines, NEC-X lies downvalley of NEC-W (Figure 8) suggesting that NEC-X is older than NEC-W. Both moraines have similar slope angles, heights and crest widths (Table IV) thus these characteristics are of little assistance in the relative dating of the moraines. The eastward curve of the moraines suggests that both are left lateral moraines which originated from the main branch of the Coe Glacier rather than the lobe that created the other North Elk Cove moraines. Both also have several conical debris mounds associated with them (Figure 17). These mounds are similar to mounds found on other moraines in north Elk Cove as well as the prominent knob located on the crest of SEC-LL. The mounds are from four to five m (12 to 15 ft.) high and are from 40 to 50 m (130 to 160 ft.) in circumference. Composition is a mixture of boulders and fine debris and they are vegetation covered. These mounds likely resulted from the dumping of superglacial debris at selected sites on the lateral moraines.

East Coe Glacier

Fewer moraines were identified and dated to the east of the Coe Glacier than to the west (Figure 8). The southern portion of the prominent right lateral moraine, ECG-RL, like SEC-LL, differs from the northern portion. South of about 1770 m (5800 ft.), the crest is narrow and

Figure 16. Elk Cove and kame terraces on the east side of Barrett Spur. View downvalley.

Figure 17. Debris mound on NEC-W.

inclined slightly, and has steep slopes (with the proximal slope being more highly inclined than the distal slope) (Figure 18; Table IV). North of about 1770 m (5800 ft.) altitude, the crest bends to the northwest, and is more broad and steeply inclined than the southern portion (Figure 19; Table IV). These differences in the crest and slope angle data indicate that the southern portion of ECG-RL stabilized more recently than the northern portion of ECG-RL. Moraine ECG-RL is also ice cored (Figure 20). In the Coe Glacier trough and branching off ECG-RL, lie ECG-RT1 and ECG-RT2 (Figure 8). Moraine ECG-RT1 lies upvalley from ECG-RT2 hence is younger than ECG-RT2. Both are low and have poorly distinguished crests (Table IV).

Above 1770 m (5800 ft.) elevation, moraines ECG-RL and ECG-0 are separated by a narrow ablation valley that is about 10 m lower than ECG-RL and 6 m lower than ECG-0 (Figure 21). An overhead view of two closely parallel moraines gives the impression that they are one moraine with two crests, hence the term "double crested moraine" (Lawrence, 1948, p. 27) (Figure 10). Below 1770 m (5800 ft.), the intervening valley widens, and the crest of ECG-0 becomes more broad and inclined. These data indicate that the northern portion of ECG-0 is older than the southern portion of ECG-0, and that ECG-0 is older than ECG-RL. In addition, the position of ECG-01 (Figure 8) branching off the proximal slope of ECG-0 suggests that it is younger than

Figure 18. Upvalley portion of ECG-RL. View to the south.

Figure 19. Downvalley portion of ECG-RL. View to north.

ECG-0. The relative positions of ECG-Q and ECG-P (Figure 8, Figure 22) suggest that ECG-Q is older than ECG-P, and that both of these moraines are older than the other East Coe Glacier moraines lying to the west. The moraine morphology data is inconclusive. Moraine ECG-P has gentle to moderate slopes, a broad crest and a low profile while ECG-Q has generally steep slopes and a broad crest throughout much of its length (Table IV). Moraine ECG-Q is underlain by bedrock which is evident at 1960 m (6448 ft.), 1800 m (5915 ft.) and at about 1650 m (5400 ft.) suggesting that the ridge is not entirely a glacial constructional landform.

Figure 20. Ice cored nature of ECG-RL.

Figure 21. Ablation valley between ECG-RL and ECG-0. View to south.

Figure 22. Moraines ECG-P and ECG-Q. View to southeast from the east side of ECG-0.

At least five low ridges trend off the distal slope of ECG-0 into the valley to the east of the Coe Branch (Figure 10). These may be ridges may be moraines, mudflow levees or erosional features. No data were collected from these features. A proposed glacial origin of these ridges, combined with the presence of the unnamed moraine upvalley of ECG-P (Figure 10; Figure 23), suggests that a lobe of the Coe Glacier occupied this valley down to an elevation of about 1650 m (5400 ft.).

RELATIVE VEGETATION COVER

In the study area, the vegetation cover on the moraines is highly variable ranging from scant vegetation on

Figure 23. Unnamed moraine upvalley of ECG-P.
View to southwest.

several of the more southerly (upvalley) moraines to a nearly closed forest canopy on some of the northern (downvalley) moraines (Table V). In general, vegetation cover increases with distance away from the Coe Glacier. Relative vegetation cover methodology worked best on the moraines upvalley and closest to the Coe Glacier.

South Elk Cove

A strong gradient in vegetation cover exists between SEC-L, SEC-M and SEC-N (Table V) suggesting that SEC-N is the oldest moraine of the group and that SEC-M is older than SEC-L. SEC-N has well developed vegetation cover on the distal (north) slope and the crest (Table V). However, little vegetation is found on the proximal (south) slope (Figure 9) suggesting that a lobe of ice once abutted this slope. The lack of vegetation may also be a function of late lying snow, avalanches, mudflows or katabatic winds.

There is little difference between the abundant vegetation cover of SEC-C, SEC-B, SEC-A, SEC-D or SEC-E (Table V) thus making a determination of the relative ages of the moraines difficult. Moraines SEC-B, SEC-A and SEC-D have bald areas on their upper crests (Figure 10) which are likely due to strong katabatic winds and the exposed nature of the moraine crests. Mature trees are noticeably absent on the proximal slope of SEC-C reflecting the past presence of ice and more recently, the existence of late lying snow.

TABLE V
RELATIVE VEGETATION COVER
Percent Vegetation Cover

Location	Distal %	Crest %	Proximal %
<u>SOUTH ELK COVE</u>			
SEC-L	<1	<1	<1
SEC-M	<10	<5	<10
SEC-N	<10	<50	<75
SEC-C	<90	<90	<75
SEC-B	<75	<75	<75
SEC-A	<75	<75	<75
SEC-D	<75	<75	<75
SEC-E	<75	<75	<75
SEC-LL (upvalley)	<50	<10	<1
" " (downvalley)	<50	<25	<10
SEC-LT4	<50	<50	<50
SEC-LT3	<50	<50	<50
SEC-LT2	<25	<25	<25
SEC-LT1	<10	<10	<1
SEC-H	<90	<90	<90
SEC-I	<90	<90	<75
SEC-J	<90	<90	<50
SEC-K	<90	<90	<50
SEC-U	<90	<90	<75
SEC-V	<90	<90	<90
<u>NORTH ELK COVE</u>			
NEC-F	<90	<90	<90
NEC-G	<90	<90	<90
NEC-S	<90	<90	<90
NEC-T	<90	<90	<90
NEC-Y	<90	<90	<90
NEC-W	<90	<90	<90
NEC-X	<90	<90	<90
<u>EAST COE GLACIER</u>			
ECG-RL (upvalley)	<75	<10	<1
" " (downvalley)	<75	<75	<10
ECG-RT1	<1	<1	<1
ECG-RT2	<5	<5	<5
ECG-O (upvalley)	<75	<75	<75
" " (downvalley)	<90	<90	<90
ECG-O	<90	<90	<90
ECG-P	<90	<90	<90
ECG-Q	<90	<90	<90

Vegetation cover, especially tree cover, is relatively light on SEC-LL, SEC-LT4, SEC-LT3, SEC-LT2 and SEC-LT1 reflecting the youth of these moraines. There is little vegetation cover on the southern portion of SEC-LL but it increases northward (downvalley), especially on the proximal slope and the crest (Figure 12, Figure 13; Table V); thus the northern portion of SEC-LL stabilized before the southern portion making it older. The Coe Glacier has also undercut and oversteepened the proximal slopes of SEC-LL thus preventing the slopes from being stabilized by vegetation. A prominent trimline exists between SEC-LT2 and SEC-LT3 with vegetation cover decreasing downvalley and increasing upvalley (Figure 15). This indicates that SEC-LT4 and SEC-LT3 are older than SEC-LT2 and SEC-LT1. In addition, SEC-LT1 has distinctly less vegetation growing on its proximal slopes than on its distal slopes (Table V). This is likely due to the relatively recent withdrawal of the Coe Glacier from that position, or possibly due to stream erosion or mass wasting.

Moraines SEC-K, SEC-J, SEC-I, SEC-H, SEC-U and SEC-V have similar, abundant vegetation cover (Table V) indicating that all are older than SEC-LL and SEC-LT1, SEC-LT2, SEC-LT3 and SEC-LT4. The similarities in the vegetation cover prevented the determination of age differences within this group of moraines.

North Elk Cove

The North Elk Cove moraines have similar vegetation cover (Table V) with abundant trees, shrubs, grasses and herbs making age differentiation among the moraines difficult (Figure 17). The data do suggest that these moraines are similar in age to the heavily vegetated South Elk Cove moraines, and older than the lightly vegetated South Elk Cove moraines. However, the impact of avalanches is seen on the trees of the southern portion of NEC-Y (Figure 16), and fire has been a factor on NEC-X.

East Coe Glacier

Vegetation cover is highly variable on the moraines to the east of the Coe Glacier. Vegetation is better developed on the crest and proximal slope of the northern (downvalley) portion of ECG-RL than on the southern (upvalley) portion (Table V) (Figure 18, Figure 19) suggesting that the downvalley end of ECG-RL stabilized prior to the upvalley end. In the Coe Glacier trough, the outermost moraine - ECG-RT2 - has more vegetation cover than does the innermost moraine - ECG-RT1 (Table V) indicating that ECG-RT2 is older than ECG-RT1. Moraines ECG-RT1 and ECG-RT2 have less vegetation cover than ECG-RL indicating that these moraines are younger than ECG-RL. A prominent trimline is present just downvalley of ECG-RT2 with noticeably more vegetation north of the line than to the south. The position of this

trimline corresponds with the trimline between SEC-LT2 and SEC-LT3 (Figure 10, Figure 15) suggesting that ECG-RT2 and ECG-RT1 are similar in age to SEC-LT2 and SEC-LT1.

Vegetation is more abundant on ECG-0 than on the aforementioned East Coe Glacier moraines and it increases from the upvalley to the downvalley portions (Table V). In addition, ECG-01 and ECG-0 have similar vegetation cover. Like SEC-LL and ECG-RL, the upvalley portion of ECG-0 apparently stabilized first thus is older than the southern portion. The southern distal slope of ECG-0 is conspicuous for its lack of tree cover (Figure 24). This is probably due to the droughty substrate or it may be a result of a lobe of the Coe Glacier that occupied the area east of ECG-0 at some time in the past.

Figure 24. Moraines ECG-0, ECG-P and ECG-Q. View to northwest.

Moraine ECG-P and ECG-Q are similarly well vegetated (Table V) suggesting that they are similar in age to ECG-0 and ECG-01, and older than ECG-RL.

DENDROCHRONOLOGY

Over 180 trees were cored to collect tree ring data. Only the data from the oldest sampled trees growing on each moraine are presented in Table VI. The dendrochronology derived ages of moraines are plotted in Figure 25. In general the trees growing on moraines farthest downvalley, or on the outermost moraines of nested moraine sequences were the oldest while those growing upvalley were younger.

South Elk Cove

Of the moraines farthest upvalley (SEC-N, SEC-M and SEC-L), the oldest tree sampled was located on the outermost moraine, SEC-N, and had 189 annual rings. Farther upvalley, SEC-M had only 19 annual rings while there were no trees growing on SEC-L (Table VI). Hence, tree rings indicate that SEC-N is older than SEC-M, and SEC-M is older than SEC-L. A similar pattern of relative age is provided by the positions of moraines and the vegetation cover.

Trees growing on moraines SEC-C and SEC-E had more annual rings than any tree sampled on SEC-A, SEC-B or SEC-D (Table VI). The oldest sampled tree growing on SEC-C had 380 annual rings while the oldest on SEC-E had 373 annual

TABLE VI
DENDROCHRONOLOGY

Location	Elevation m (ft.)	Number	Species	Height	Circ.	Rings
<hr/> SOUTH ELK COVE						
SEC-L	-----	---	----	---	---	---
SEC-M	1860 (6090)	121	Pial	6	14	19
SEC-N	1810 (5940)	75	Tsme	146	113	189
SEC-C	1790 (5880)	13	Pial	134	216	380
SEC-B	1740 (5720)	50	Pial	116	140	198
SEC-A	1720 (5660)	61	Tsme	116	159	231
SEC-D	1800 (5910)	84	Pial	119	61	61
SEC-E	1710 (5620)	91	Tsme	128	207	373
SEC-LL	1830 (6000)	8	Pial	137	61	94
" "	1170 (5800)	65	Tsme	101	88	65
SEC-LT4	1710 (5620)	101	Tsme	110	73	92
SEC-LT3	1740 (5700)	98	Tsme	73	27	31
SEC-LT2	1740 (5700)	94	Tsme	64	34	32
SEC-LT1	1750 (5750)	105	Tsme	--	--	26
SEC-K	1610 (5300)	141	Pial	116	265	168
SEC-J	1610 (5300)	112	Tsme	91	192	275
SEC-I	1690 (5560)	109	Tsme	122	168	242
SEC-H	1670 (5480)	124	Abam	152	156	161
SEC-U	1580 (5200)	145	Abam	116	393	224
SEC-V	1640 (5380)	152	Abam	122	229	292
SEC-J1	1610 (5280)	111	Abam	70	43	35
<hr/> NORTH ELK COVE						
NEC-F	1580 (5200)	128	Tsme	125	265	312
NEC-G	1540 (5060)	136	Abam	122	223	295
NEC-S	1570 (5140)	139	Tsme	122	216	425
NEC-T	-----	---	----	---	---	---
NEC-Y	1610 (5280)	114	Tsme	3.3	9.9	168
NEC-W	1590 (5220)	132	Abam	122	247	355
NEC-X	1540 (5040)	134	Abam	119	299	379
<hr/> EAST COE GLACIER						
ECG-RL	1820 (5960)	25	Tsme	91	79	105
" "	1650 (5420)	172	Abam	116	149	240
ECG-RT1	1760 (5760)	167	Pial	---	9	20
ECG-RT2	1760 (5760)	168	Tsme	6	20	25
ECG-O	1760 (5760)	164	Tsme	107	162	169
-----	1790 (5860)	157	Abam	107	344	427
ECG-O1	1570 (5140)	156	Tsme	107	165	196
ECG-P	1850 (6060)	31	Pial	113	149	298
ECG-Q	1800 (5920)	42	Tsme	133	130	240

KEY

Pial - *Pinus albicaulis*

rings. In addition, there were several trees with diameters larger than the tree yielding 380 annual rings on SEC-C. However, these had rotten cores preventing the counting of their annual rings. The similar ages of trees on SEC-C and SEC-E, and the much younger ages of trees on SEC-B, SEC-A and SEC-D suggests that SEC-C is a left lateral moraine and SEC-E is a right lateral moraine, with both representing the same one advance or stillstand. This hypothesis would then suggest that SEC-B, SEC-A and SEC-D are nested lateral moraines. However, the lack of corresponding ages among SEC-A, SEC-B and SEC-D (Table VI) combined with the absence of terminal sections of these moraines, and the moraine position data casts doubt on this hypothesis.

The age of sampled trees located on SEC-LL, SEC-LT4, SEC-LT3, SEC-LT2 and SEC-LT1 generally decreased upglacier (Table VI). The oldest tree sampled on SEC-LL was located upslope of the large debris mound at 1820 m (5960 ft.) and had 94 annual rings (Table VI). In the Coe Glacier trough, the outermost of the moraines, SEC-LT4 included a tree with 92 annual rings, while a tree sampled on the innermost moraine, SEC-R, had 29 annual rings (Table VI) indicating a general trend of decreasing moraine ages upglacier.

There was not a neat progression of tree ages extending outward from SEC-K, SEC-J, SEC-I, SEC-J, SEC-U and SEC-V (Table VI). The oldest tree sampled was located on SEC-V and had 292 rings. However, the next oldest tree had

275 annual rings and was located on the innermost of these moraines, SEC-J. The dendrochronology data do not suggest a nested moraine sequence with the ages of the moraines decreasing toward the glacier.

North Elk Cove

The oldest North Elk Cove tree sampled had 425 annual rings and was growing on NEC-S, which is located upvalley and toward the Coe Glacier from two other sampled moraines, NEC-G and NEC-F. Hence, the tree rings and the lack of overriding or truncation of NEC-G and NEC-F suggest that it has been more than 425 years since the Coe Glacier has extended beyond 1570 m (5140 ft.) (NEC-S) in the North Elk Cove area, and that NEC-G and NEC-F, despite the results of dendrochronology (Table VI), should be older than NEC-S.

The easternmost North Elk Cove moraines, NEC-W and NEC-X, had 355 and 379 annual rings, respectively. This evidence suggests that the moraines decrease in age upvalley. It also suggests that it has been at least 379 years since the Coe Glacier extended beyond 1540 m (5040 ft.) in the vicinity of these moraines.

East Coe Glacier

The oldest tree sampled on the downvalley portion of ECG-RL had 240 annual rings, which was far more than any tree growing on the upvalley portion of ECG-RL (Table VI). Of the moraines in the Coe Glacier trough, the oldest tree

was found on the outermost moraine, ECG-RT2, and had 25 annual rings (Table VI). The dendrochronologic data indicates that, like the left lateral moraine (SEC-LL) and included low moraines in the Coe Glacier trough (SEC-LT1, SEC-LT2, SEC-LT3 and SEC-LT4) the downvalley portion of ECG-RL stabilized first and was followed by the upvalley portion, the outermost trough moraine (ECG-RT2) and the innermost trough moraine (ECG-RT1).

Tree ages on ECG-0 also decreased downvalley with a Pacific silver fir (Abies amabilis) having 427 annual rings (Table VI). This was the oldest tree cored in the entire study area. The 196 annual rings of ECG-01 suggests that it formed more recently than ECG-0.

The dendrochronological data for ECG-P and ECG-Q provide mixed results (Table VI). The oldest tree sampled on ECG-P had 298 annual rings while the oldest sampled tree on moraine ECG-Q had 240 annual rings. The dendrochronology data, like the relative moraine positions, indicates that ECG-P is older than ECG-0. However, unlike the relative moraine positions, tree rings also suggest that ECG-P is older than ECG-Q.

LICHENOMETRY

Lichens were generally larger and covered greater percentages of rock surfaces on outermost or downvalley moraines in the study area (Table VII). However, lichen

TABLE VII
LICHENOMETRY

Location	Largest Diameter (cm)	Mean Diameter (cm)	% Cover (%)	Mean % Cover (%)
<u>SOUTH ELK COVE</u>				
SEC-L	---	---	---	---
SEC-M	2.2	1.6	1	1
SEC-N	4.0	2.7	10	3
SEC-C	9.5	7.3	50	21
SEC-B	4.5	4.2	19	11
SEC-A	4.5	4.1	25	11
SEC-D	4.0	2.8	2	1
SEC-E	7.0	4.2	40	13
SEC-LL (up)	2.3	2.0	2	2
" " (down)	9.0	6.2	49	33
SEC-LT4	5.5	3.2	3	3
SEC-LT3	2.7	2.3	3	2
SEC-LT2	neg	neg	neg	neg
SEC-LT1	neg	neg	neg	neg
SEC-H	5.5	3.5	30	19
SEC-I	7.0	6.0	20	16
SEC-J	6.5	5.9	30	27
SEC-J1	---	---	---	---
SEC-K	---	---	---	---
SEC-U	5.0	4.0*	15	6*
SEC-V	6.0	4.7	15	7
<u>NORTH ELK COVE</u>				
NEC-F	7.0	4.3	10	5
NEC-G	---	---	---	---
NEC-S	---	---	---	---
NEC-T	---	---	---	---
NEC-Y	5.0	5.0*	---	---
NEC-W	5.0	4.3*	5.0	5*
NEC-X	3.4	3.0*	2.0	2*
<u>EAST COE GLACIER</u>				
ECG-RL (up)	7.0	5.2	40	17
" " (down)	---	---	---	---
ECG-RT1	neg	neg	neg	neg
ECG-RT2	neg	neg	neg	neg
ECG-O (up)	7.0	6.2	15	8
" " (down)	7.0	5.8	15	10
ECG-O1	5.4	4.6	10	5*
ECG-P	12.5	7.6	10	5*
ECG-Q	7.0	4.8	60	16

* indicates that less than five samples were used in determining the means.

diameters and percentage covers decreased in heavily forested downvalley areas contrasting with the results of dendrochronology, moraine position and moraine morphology data which suggest that moraines are older downvalley. Hence, the usefulness of this technique was confined to moraines where there was limited vegetation cover.

South Elk Cove

The largest mean lichen diameter and the highest mean percentage cover of the upvalley South Elk Cove moraines was found on SEC-N, which had totals of 2.7 cm and 3% respectively SEC-L (Table VII). These totals, like the dendrochronology data, indicate that SEC-N is older than SEC-M, and that SEC-M is older than SEC-L.

Of moraines SEC-A, SEC-B, SEC-C, SEC-D and SEC-E, SEC-C had the largest mean lichen diameter (7.3 cm) and the highest mean percentage cover (21%) (Table VII). Moraine SEC-E had the next highest totals. The lichen data are similar to the dendrochronology data in that they indicate that SEC-C is the oldest moraine of this group, followed by SEC-E, SEC-B, SEC-A and SEC-D.

Mean lichen diameter and mean percentage cover decreased upvalley on SEC-LL and on the associated moraines located in the Coe Glacier trough (Table VII). Moraine SEC-LL had the largest mean lichen diameter at 6.2 cm and a largest mean percentage cover of 33%. Moraine SEC-LT4 had

the next largest mean lichen diameter and the next highest mean percentage cover, and was followed by SEC-LT3 (Table VII). No measurable lichen were found on SEC-LT2 or SEC-LT1. The lichen data indicate that the northern portion of SEC-LL stabilized prior to the southern portion, and of the moraines in the Coe Glacier trough, the farthest downvalley, SEC-LT4, stabilized before those moraines upvalley.

Unlike lichen measurements on the previous groups of moraines, the ranking of the largest mean lichen diameters on SEC-J, SEC-I, SEC-H, SEC-U and SEC-V did not correspond with the highest percentage cover (Table VII). Moraine SEC-I had the largest mean lichen diameter and was followed by SEC-V, SEC-H and SEC-U. However, SEC-J had the highest mean percentage cover. These results are inconsistent with the dendrochronology data (Table VI) and the moraine position data (Figure 8).

North Elk Cove

R. geographicum s.l. was scarce on the North Elk Cove moraines, especially in the heavily forested areas. Lichens were measured on moraines NEC-F, NEC-W and NEC-X (Table VII). The westernmost moraine, NEC-F, had the largest mean lichen diameter and mean percentage cover while NEC-X (located downvalley of NEC-W) had the lowest totals in both categories. Lichen data, which are in agreement with

relative moraine positions, imply that NEC-F is the oldest moraine in North Elk Cove. However, lichen growth, contrary to the findings of relative moraine position and dendrochronology, suggests that NEC-X is younger than NEC-W. The lichenometry results for these moraines, like the results for the latter group of South Elk Cove moraines, do not provide conclusive evidence of the relative age of the moraines.

East Coe Glacier

Similar to the South Elk Cove moraines, lichen diameters and percentage cover generally decreased with closer to the Coe Glacier (Table VII). Measurable lichen were scarce on ECG-RT1 and ECG-RT2 but on ECG-RL, the largest mean lichen diameter was 5.2 cm and the highest mean percentage cover was 17%. Moraine ECG-0 had higher mean lichen diameters and percentage cover than ECG-RL. These data suggests that ECG-RL is older than ECG-RT1 and ECG-RT2 and that ECG-0 is older than ECG-RL.

Lichen measurements taken on ECG-P and ECG-Q were somewhat contradictory (Table VII). ECG-P had the largest mean lichen diameter of the East Coe Glaciers as well as in the entire study area but had a lower mean percentage cover than ECG-Q, ECG-0 and ECG-RL. The lichen diameter measurements suggest that ECG-P is older than both ECG-0 and ECG-Q.

TEPHROCHRONOLOGY

At least six tephra layers of different ages have been identified at various sites on and around Mount Hood. Four of the tephra layers originated from Mount Hood while at least one is from Mount St. Helens and one is from Mount Mazama.

The Polallie (12,000-15,000 yr BP), Timberline (1,400-1,800 yr BP), Zig Zag (400-600 yr BP) and the Old Maid (180-270 yr BP) are Mount Hood eruptive periods represented by ash cloud deposits resulting from pyroclastic flows (Crandell and Mullineaux, 1973, p. A6), mudflows and pyroclastic flows (Crandell and Rubin, 1977; Crandell, 1980; Cameron and Pringle, 1986). While little quantitative petrographic characterization has been done on these ash cloud deposits, one can see from Table VIII that all have generally similar compositions making identification of the different layers difficult (Ken Cameron - USGS, personal communication, 9 June 1988). The layers have been differentiated by the degree of weathering, positions in profiles, dendrochronology and radiocarbon dating.

A layer of Mount St. Helens tephra dated at 35,000-40,000 yr BP is present in the Sandy River Valley on the west side of Mount Hood (D.R. Mullineaux, personal communication in Crandell, 1980, p. 7). Crandell (1980, p. 33) also mentions the presence of 6,900 yr BP Mount Mazama

TABLE VIII
MOUNT HOOD TEPHRA DEPOSITS

	Polallie	Timberline	Zig Zag	Old Maid
Source	Crandell, 1980	Crandell, 1980 Cameron and Pringle, 1986	Cameron and Pringle, 1986; 1987	Lawrence, 1948 Crandell, 1980 Cameron and Pringle, 1986
Description	fine yellowish brown lithic ash	fine reddish to yellowish gray ash	white ash	light gray lithic ash
Composition	feldspars, particles of volcanic rock, products of weathering, pyroxenes, hornblende, glass(rare), pumice(rare),	fine rock particles, feldspars, g l a s s , hypersthene, hornblende, augite(rare), some pumice	?	fine rock particles, feldspar, hypersthene, hornblende, a u g i t e , glass(rare?), no pumice,
Texture				
Fine	sand & silt	silt	sand	silt to sand
Course	lapilli	lapilli		scattered <5mm gravels
Thickness	<.5 m	15-60 cm	1 cm	1-20 cm
Stratigraphic Relations	atop Polallie- age mudflows & pyroclastic flows	atop Mazama tephra, below O l d M a i d tephra	atop drift, below Old Maid lahar	directly atop glacial drift and just below forest litter
Origin	Pyroclastic flows leading to ash cloud deposits	Pyroclastic flows leading to ash cloud deposits	Pyroclastic flows leading to ash cloud deposits	rockfalls and avalanches from Crater Rock leading to ash cloud deposits
Age	12,000-15,000 yr BP	1,400-1,800 yr BP	400-600 yr BP	180-270 yr BP

tephra in the area to the east and northeast of Government Camp. Lawrence (1948, p. 23) reported an "old yellowish brown volcanic ash" underlying the recent [Old Maid] ash layer at Hood River Meadows on the southwest flanks of Mount Hood. This layer may be a Polallie or Timberline ash cloud deposit, or possibly Mount Mazama or Mount St. Helens tephra. Neither Mount Mazama or Mount St. Helens tephras were identified in the study area.

Besides the lack of quantitative analysis on Mount Hood tephras and the lack of easily identifiable and well dated tephras from other Pacific Northwest volcanoes, a third problem was encountered involving the differentiation of tephra layers from albic (E) soil horizons. The soils of the study area have been mapped as Typic Cryorthods (Howes, 1979, p. 143-46) suggesting that the gray layer beneath the forest litter is an albic horizon. However, Lawrence (1948) and Crandell (1980, p. 45-47) designate the 1 to 17 cm thick light gray layer located beneath the duff and often directly atop glacial till as a tephra, based primarily on the decreasing thickness of the layer with distance from Mount Hood. Other arguments for a volcanic origin of the layer include the lack of weathered ferromagnesian minerals in the tephra samples (L.R. Kittleman, personal communication, 9 June 1988) and the amount of time required for the development of albic horizons in an alpine environment. This study will follow the designation of Lawrence (1948)

and Crandell (1980) in calling this widespread layer a tephra (Old Maid) rather than an albic horizon. Indeed, it may be a combination of the two (Jerry Latshaw - SCS, personal communication, 9 June 1988).

One or more tephra layers were identified on all moraines sampled. Eleven samples were subsequently analyzed and characterized as lithic-crystal volcanoclastic sediments with a small range of composition containing no significant pumice or volcanic glass (L.R. Kittleman, personal communication, 26 May 1988). This analysis does not prove that these layers are unequivocally airfall tephras but it does show that they are of volcanic origin. They are likely ash cloud deposits associated with pyroclastic flows resulting from the construction of Mount Hood lava domes as suggested by Crandell (1980, p. 45-47), and indicated by the composition and grain size of the samples.

South Elk Cove

One tephra layer was identified in most excavations on the South Elk Cove moraines (Table IX; Figure 26). In addition, a possible second tephra layer was located lower in a profile on one of the northern moraines. This tephra was found in all soil pits dug on South Elk Cove moraines (SEC-N, SEC-C, SEC-H, SEC-U and SEC-V) except SEC-B. The upper tephra had similar Munsell soil colors that ranged from 5YR 6/1 to 7.5YR 6/2. The average thickness was

TABLE IX
TEPHROCHRONOLOGY

Location	Soil Pit #	Elevation m(ft)	Munsell (%)	Depth (cm)	Texture
<u>SOUTH ELK COVE</u>					
SEC-L	---				
SEC-M	---				
SEC-N	10	1790(5860)	5YR 7/2	24 to 32	silt
SEC-C	7	1730(5690)	5YR 6/1	3 to 11	silt
SEC-A	---				
SEC-B	5	1790(5890)	10R 5/1	64 to 91	lap+sand
SEC-D	---				
SEC-E	---				
SEC-LL	---				
SEC-LT4	---				
SEC-LT3	---				
SEC-LT2	---				
SEC-LT1	---				
SEC-H	8	1650(5420)	5YR 7/1	6 to 12	silt
SEC-I	---				
SEC-J	---				
SEC-U	A	1590(5220)	7.5YR 6/2	6 to 12	silt
SEC-V	17	1650(5400)	7.5YR 6/2	6 to 12	silt
" "			10YR 6/2	17 to 21	sand
<u>NORTH ELK COVE</u>					
NEC-F	12	1600(5250)	10YR 6/2	9 to 31	silt
" "			10YR 6/3	55 to 61	sand
NEC-G	13	1580(5200)	7.5YR 6/2	0 to 3	silt
NEC-S	16	1570(5140)	7.5YR 6/2	3 to 6	silt
" "			7.5YR 6/2	14 to 20	silt
NEC-T	19	1580(5200)	7.5YR 6/2	6 to 9	silt
NEC-Y	9	1670(5480)	10YR 6/2	6 to 12	silt
NEC-W	14	1600(5240)	5YR 7/1	6 to 9	silt
" "			10YR 4/1	16 to 20	sand
NEC-X	15	1520(4980)	5YR 7/1	6 to 12	lap+silt
" "			10YR 6/6	49 to 76	cob+silt
Meadow	6	1530(5020)	7.5YR 5/2	3 to 6	silt
" "			10YR 6/2	8 to 11	silt
" "			7.5 YR 4/4	20 to 34	silt
" "			7.5 YR 4/2	35 to 40	silt
<u>EAST COE GLACIER</u>					
ECG-RL	---				
ECG-RT1	---				
ECG-RT2	---				
ECG-O	B	1650(5400)	7.5YR 6/2	6 to 12	silt
ECG-O1	C	1570(5140)	7.5YR 6/2	6 to 12	silt
ECG-P	3	1790(5860)	5Y 6/3	56 to 64	silt
ECG-10	4	1830(6000)	10YR 6/2	18 to 27	silt

approximately 6 cm and texture was of fine silt. This layer was commonly within 6 cm of the surface but ranged to 24 cm below the surface. Tephra samples 4 (SEC-C), 5 (SEC-N) and 6 (SEC-V) (Table X) represent this layer. All fall within Group II (Figure 26) hence are petrographically similar having like lithic clasts (LTX)/Free Crystal (FX) ratios and plagioclase (PL)/ferromagnesian (FM) ratios. The location (in the profile), thickness, color, texture, petrographic analysis and similarity of the upper layer to the descriptions of Lawrence (1948) and Crandell (1980) suggests that is the 180-270 yr old Old Maid (Crandell, 1980, p. 10; Cameron and Pringle, 1986, p. 225). Its presence atop SEC-N, SEC-C, SEC-H, SEC-U and SEC-V suggests that these moraines were free of ice more than 180 yr BP. These data correlate well with the tree ring data.

A second possible tephra was located between 17 and 21 cm on SEC-V (Table IX). This layer was very similar to the overlying tephra in Munsell color, thickness and texture, and similar to the tephra on SEC-N in depth below the surface. The similarity in these characteristics suggests that this layer is the same as the overlying layer. However, the separation of the two layers by 5 cm of oxidized soil suggests that they do not represent one airfall tephra. The petrographic characteristics of this tephra also differ from the aforementioned layers in that it falls in group III (Figure 26) due to a significantly lower

LTX/FX ratio than group II, and a conspicuous "bubble wall texture of the free crystals" (Fisher, 1963; Fisher, 1984, p. 96). This grouping and the location of the layer below the oxidized zone suggests that this layer may represent a

Figure 26. Scatter diagram of mineral abundance ratios for volcaniclastic layers, Coe Glacier moraines. LTH/FX is the ratio of lithic clasts to free crystals, and PL/FM is the ratio of plagioclase to ferromagnesian silicates. Error bars for the abscissa are plus or minus one standard deviation. Analyzed and plotted by L.R. Kittleman.

TABLE X
VOLCANICLASTIC LAYERS OF COE GLACIER AREA

PERCENT¹

CONSTITUENT	SAMPLE NUMBER and LOCATION										
	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11
	Meadow S.P. 62 8-11 cm	Meadow S.P. 6 20-31 cm	Meadow S.P. 6 35-40 cm	SEC-C S.P. 7 3-11 cm	SEC-N S.P. 10 24-32 cm	SEC-V S.P. 17 6-12 cm	SEC-V S.P. 17 14-21 cm	SEC-S S.P. 16 3-6 cm	SEC-S S.P. 16 14-20 cm	ECG-10 S.P. 4 18-27 cm	ECG-10 S.P. 4 8-9 cm
Lithic clasts	60.0	65.5	49.8	62.0	61.8	69.3	58.5	67.0	65.7	67.1	65.0
Microphyric lithic clasts	10.7	9.2	1.6	5.8	6.2	2.4	1.2	3.6	3.0	3.9	2.8
Plagioclase	23.2	17.5	38.0	26.0	23.8	22.1	31.2	23.5	21.4	23.0	24.8
Hypersthene	1.4	1.2	3.4	1.7	2.1	1.1	3.3	1.6	1.8	1.4	2.6
Hornblende	0.8	0.8	1.1	0.7	0.6	1.1	0.6	0.4	0.6	0.4	0.5
Lamprobolite	1.1	3.1	0.4	0.6	1.8	1.1	0.6	1.7	1.8	1.8	1.1
Opaque grains ³	2.4	2.6	3.6	3.2	3.5	2.8	3.5	2.3	5.3	2.3	3.3
Glass shards	trace	trace	1.4	trace	nil	nil	trace	nil	trace	nil	nil
Clinopyroxene	trace	trace	0.5	nil	trace	trace	0.6	nil	trace	nil	nil
Zircon	trace	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
Sideromelane	trace	nil	nil	nil	nil	nil	nil	nil	nil	nil	nil
SUM	99.6	99.9	99.8	100.2	99.8	99.9	99.5	100.1	99.2	99.9	100.1

1. Percent by number, determined by counting at least 1000 grains in the size range of 62 to 500 micrometers. Analytical error ranges from plus or minus 1.5 for lithic clasts to plus or minus 0.5 for hypersthene.

2. S.P. means soil pit.

3. Opaque iron-titanium oxides (mostly magnetite).

different lens of the Old Maid eruptive period or may be ash cloud deposits from the Zig Zag eruptive period thus dating the moraine as forming between 400-600 yr BP. The moraine morphology and dendrochronology data suggest that SEC-V is not considerably older than the 180-270 yr BP Old Maid tephra.

A layer resembling tephra was located on SEC-B but the Munsell color, thickness, depth below the surface and texture all differ from the previously described tephra (Table IX). The characteristics of the layer combined with the rocky texture and Munsell color of the overlying, surficial horizon (5YR 4/3 reddish brown) suggest that this layer is not a tephra but rather a result of glacial or glaciofluvial deposition.

North Elk Cove

At least one tephra was identified on all of the moraines sampled in North Elk Cove including NEC-F, NEC-G, NEC-S, NEC-T, NEC-Y, NEC-W and NEC-X (Table IX). All moraines had a 3 to 6 cm thick accumulation of tephra which varied between 10YR 6/2 and 5YR 7/1 and all were encountered less than 10 cm below the soil surface. In addition, a second tephra layer was found on NEC-F, NEC-S, NEC-W and NEC-X. This tephra layer had a variable Munsell color, a sandy texture and changeable depths of occurrence. Tephra samples 8 and 9 represent these upper and lower tephra

layers present on NEC-S (Table IX). Both fall in Group II because they have similar LTX/FX ratios and PL/FM ratios (Figure 26). The similarities and the association with the other tephras of Group II implies that both are from the Old Maid eruptive period hence the NEC-S was formed more than 180-270 yr BP. These data correlate well with the tree ring data except in the case of NEC-Y which has 168 annual rings. However, snow avalanches and mudflows may have affected the ecesis period on this moraine in the past, as there is abundant evidence of these activities at present.

Four tephra layers were identified in a soil profile excavated in a meadow west of the junction of the Elk Cove Trail and stream, and beyond the limit of identified moraines in the northern part of the study area (Table IX; (Figure 8, Figure 27). The layers had Munsell colors ranging from 10YR 6/2 to 7.5YR 4/2 and varied from 3 to 14 cm in thickness. All had a texture of fine silt. Laboratory analysis of the three lower tephra layers (tephra samples 1, 2 and 3) (Table X) placed them into different groups based on LTH/FX and PL/FM ratios (Figure 26). Sample 1 has similar characteristics to samples 5,6,8,9 and 11, hence falls in Group II (Figure 26). This grouping, plus the position of the tephra in the profile suggests sample 1 is Old Maid tephra. Sample 2 is the sole constituent of Group I. The sufficiently different LTX/FX and PL/FM ratios of sample 1 (Figure 26), combined with its

Figure 27. Bog soil profile showing upper tephra and organic layers. Soil Pit #6.

position in the meadow soil pit, imply that it represents an older lens of Old Maid tephra or more likely, is 400-600 yr BP Zig Zag tephra. Sample 3 coincides with sample 7 (SEC-V) to form Group III (Figure 26). The significantly different LTX:FX ratio of sample 3 plus the position of sample 3 in the meadow soil pit suggests that it represents an older eruptive period. The petrology of the sample is unlike tephra from Mount Mazama or Mount St. Helens (L.R. Kittleman, personal communication, 26 May 1988). It is likely that the sample represents the 1,400 to 1,800 yr BP Timberline eruptive period (Crandell, 1980, p. 10; Cameron and Pringle, 1986, p. 225). However, this interpretation

does not agree with that of sample 7 because the results of the other data (moraine position and dendrochronology) suggest that SEC-V is not as old as the Timberline eruptive period. The sample should logically fit in Group II. The importance of the meadow profile is that four tephras are lying atop possible glacial till or outwash hence the underlying surface is older than the lower tephra. These data suggest that glaciers have not advanced as far as the meadow in more than 425 years (dendrochronology) and possibly more than 1400 yr BP (tephrochronology).

East Coe Glacier

A tephra layer was identified in excavations on ECG-0), ECG-01 and ECG-Q (Table IX). Munsell soil colors were very similar ranging from 10YR 6/2 to 7.5YR 7/2 and the layer had a fine sand texture. The thickness of the layer varied from 1 to 9 cm and the depth of tephra occurrence was shallow for all but ECG-Q (soil pit #4)¹. Tephra samples 10 (ECG-Q) and 11 (ECG-Q) have very similar petrographic characteristics (Table IX) with similar PL/FM and LTX/FX ratios (Figure 26). Both lie within Group II. The similarity of these layers and the placement of samples 10 and 11 in Group II suggests that both are from the Old Maid

¹. The difference in depth of occurrence for the tephra in soil pit #4 and soil pit #21 on ECG-10 may be due to the increased accumulation of fine wind blown sediments on the upvalley portions of ECG-10.

eruptive period hence ECG-Q formed more than 180 yr BP. In addition, the similar positions, Munsell colors and textures of the analyzed samples and the tephra on ECG-0 and ECG-01 moraines suggest that these tephras are all from the Old Maid eruptive period.

A layer located deep in the soil horizon with a contrasting Munsell color was identified on ECG-P (Table IX). These characteristics are so different that it is not likely that this is the same layer as that found near the surface on the other East Coe Glacier moraines. It may be equivalent to the lower possible tephra of several of the previously mentioned South Elk Cove and North Elk Cove moraines but the Munsell color is not similar to colors of those layers. The tree ring and lichen data indicate that ECG-P should be overlain by Old Maid tephra but the abundance of loose, sandy soil in the area east of the Coe Glacier is evidence of the katabatic winds and westerly flow of air that may have blown the Old Maid tephra away or mixed it into soil. It is possible that this layer is not a tephra.

SOIL DEVELOPMENT

The downvalley and outermost soils were more strongly oxidized as reflected by higher Buntley-Westin (B-W) indices than the upvalley soils (Table XI) indicating that the downvalley moraines are older. The depths of oxidation were

TABLE XI
SOIL DEVELOPMENT

Location	Soil Pit #	Elevation m(ft)	Munsell	Depth (cm)	B-W Index
<u>SOUTH ELK COVE</u>					
SEC-L	---				
SEC-M	---				
SEC-N	10	1790 (5860)	10YR 5/3	32 to 67	9
SEC-C	7	1730 (5690)	10YR 5/6	11 to 67	18
SEC-B	5	1790 (5890)	10R 4/4	52 to 64	28
SEC-A	---				
SEC-D	---				
SEC-E	---				
SEC-LL	---				
SEC-LT4	---				
SEC-LT3	---				
SEC-LT2	---				
SEC-LT1	---				
SEC-H	8	1650 (5420)	10YR 6/6	13 to 34	18
SEC-I	---				
SEC-J	---				
SEC-U	---				
SEC-V	17	1650 (5400)	10YR 6/4	12 to 14	12
" "			10YR 5/6	21 to 46	18
<u>NORTH ELK COVE</u>					
NEC-F	12	1600 (5250)	10YR 5/6	30 to 55	18
" "			10YR 5/8	61 to 91	24
NEC-G	13	1580 (5200)	10YR 6/4	3 to 34	12
" "			10YR 5/6	34 to 101	18
NEC-S	16	1570 (5140)	10YR 6/4	6 to 11	12
" "			10YR 6/4	20 to 41	12
" "			5YR 6/4	41 to 70	20
NEC-T	19	1580 (5200)	10YR 6/4	11 to 30	12
NEC-Y	9	1670 (5480)	10YR 5/4	12 to 91	12
" "			5YR 5/3	91 to 110	15
NEC-W	14	1600 (5240)	10YR 6/4	9 to 17	12
" "			10YR 6/4	20 to 35	12
" "			10YR 5/6	35 to 70	18
NEC-X	15	1520 (4980)	10YR 5/6	12 to 49	18
" "			10YR 5/4	76 to ?	12
<u>EAST COE GLACIER</u>					
ECG-RL	---				
ECG-RT1	---				
ECG-RT2	---				
ECG-O	---				
ECG-O1	---				
ECG-P	3	1820 (5960)	10YR 5/4	26 to 56	12
" "			10YR 5/4	64 to 101	12
ECG-Q	4	1830 (6000)	10YR 4/4	64 to 110	12

not as useful as the degree of oxidation in this study.

South Elk Cove

The oxidized (B) horizons in soil pits on moraines in South Elk Cove ranged from Munsell colors of 10YR 4/4 to 10YR 6/6 (Figure 28; Table XI). Thicknesses of oxidized horizons varied from 12 to 56 cm. The B-W indices of SEC-V (lower oxidized zone), SEC-H and SEC-C were identical and were twice as high as the B-W index calculated for SEC-N, and SEC-C had the deepest oxidized zone (Table XI). This suggests that SEC-N is the youngest of the group of moraines analyzed. These data correlate well with the age implied by dendrochronological and lichenometric data. Similar to the results of the tephra data, SEC-B had an anomalous Munsell color which translated into an abnormally high B-W index number. This number is not thought to be a reliable indicator of the relative age so this investigation will rely on moraine position, dendrochronologic and lichenometric data in dating SEC-B.

North Elk Cove

Several oxidized horizons were recognized in soil pits on North Elk Cove moraines. These horizons ranged from 5YR 5/6 to 10YR 6/4 in Munsell color and had horizon thicknesses varying from 5 to 69 cm (Table XI). B-W indices were highest for NEC-F (24) and NEC-S (20) while NEC-T had the lowest indices (12). These data suggest that NEC-F is the

Figure 28. Soil profiles.

oldest of the North Elk Cove moraines. This contradicts with the moraine position and dendrochronology data which indicate that NEC-S is older. The similarity in the B-W indices for NEC-G, NEC-W and NEC-X suggests that they are of similar ages (Table XI). The position of NEC-G downvalley of NEC-S casts doubt on the soil weathering-derived relative age. The youngest moraines indicated by the B-W indices are NEC-Y and NEC-T. This interpretation is in agreement with the dendrochronological data and the relative moraine positions but does not correlate well with the soil of NEC-W, which is located to the east at about the same elevation as NEC-T yet has a higher B-W index.

East Coe Glacier

Soil pits were excavated on SEC-P and SEC-Q of the moraines east of the Coe Glacier (Table XI). Munsell colors for the oxidized horizons ranged from 10YR 4/4 to 10YR 5/8. The thicknesses of the oxidized horizons ranged from 21 to 46 cm. The oxidized horizon on the northern portion of ECG-Q (soil pit #21) had the highest B-W index (24) for this group and the upvalley portion of ECG-Q (soil pit #4) had the next highest B-W index (15) (Table XI). The B-W indices indicate that ECG-Q is the oldest of the East Coe Glacier moraines. These data correspond well with the relative moraine position but contradict the dendrochronological and lichenometric data.

RADIOCARBON DATING

A sample taken from a buried organic layer (Figure 27, Figure 28) in the bog located west of the junction of the Elk Cove Trail and stream, and north of the NEC-F (Figure 8) was analyzed at the Quaternary Research Center Radiocarbon Laboratory, University of Washington. The sample, QL 4229, had a date of 6,480 plus or minus 40 yr BP. Fine grained tephra layers and organic horizons overlie the sampled layer. The underlying layer consists of stones, cobbles and gravels scattered throughout a sandy matrix. This coarse textured layer suggests that different environmental conditions prevailed prior to the deposition of the overlying organic matter. The underlying diamicton is likely glacial outwash or till, hence the radiocarbon date, combined with the absence of overlying rocky layers, suggests that it has been more than 6,480 plus or minus 40 years since the surface was glaciated.

CHAPTER VI

COE GLACIER CHRONOLOGY

The Coe Glacier has been much larger in both the distant and recent past, than at present. While the present Coe Glacier terminates at about 1800 m (5900 ft.) and occupies the trough between two prominent lateral moraines, it has in the past extended far downvalley of 1800 m and has spread laterally beyond the prominent lateral moraines. The past fluctuations of the Coe Glacier are discussed in this chapter.

PRE-LITTLE ICE AGE

The outermost moraines identified indicate that the Coe Glacier extended about 2 km (1.2 mi.) downvalley of the present terminus to an elevation of 1460-1520 m (4800-5000 ft.) (Figure 29). This ice mass extended 1.4 km (.9 mi.) laterally from Barrett Spur to the bedrock ridge east of the Coe Glacier. The uppermost of three level areas (1760 m) on Barrett Spur indicate that ice was nearly 90 m (300 ft.) thick over Elk Cove in the vicinity of the Timberline Trail. This ice likely extended to a similar elevation on the bedrock and drift mantled ridge to the east of the Coe Glacier (ECG-Q). The ice mass originated as the Coe

Figure 29. Inferred extent of the pre-Little Ice Age Coe Glacier (earlier).

glacier broadened upon leaving the bedrock confines upvalley. It was also due to a lower firn line which resulted in the formation of a cirque glacier in amphitheater-shaped Elk Cove. The age of the moraines located north of 1560 m (5120 ft.) (NEC-S) is uncertain; the results of tree ring dating indicate that the moraines formed more than 425 years ago. The downvalley positions of the moraines, the subdued morphology and the degree of soil development suggest that they may be much older than 425 years. The downvalley positions and degree of soil weathering are similar to the late Pleistocene or early Holocene advances or stillstands in the southern Oregon Cascades (Waban and Zephyr Lake drifts) (Carver, 1973), north central Oregon Cascades (Suttle Lake or Canyon Creek tills) (Scott, 1977) and the central portion of the Washington Cascades (Evans Creek and McNeeley Drifts) (Crandell and Miller, 1974). The downvalley Coe Glacier moraines may have formed as the late Pleistocene Coe Glacier receded upvalley from the Fraser-age maximum position of about 1370 m (4500 ft.) (Crandell, 1980, p. 6) or they may represent Holocene advances or stillstands. The radiocarbon date from the bog downvalley of the outermost identified moraine indicates that the Coe Glacier has not extended beyond the bog in the past 6500 years.

The downvalley positions, subdued morphology and degree of weathering of the remaining North Elk Cove

moraines suggests that these moraines probably also formed prior to the Little Ice Age and perhaps as early as the late Pleistocene. They are likely recessional to the moraines located farther downvalley. The morphology of these moraines suggests that the Coe Glacier split into two lobes with recession of the ice upvalley (Figure 30). The main lobe occupied the Coe Branch Valley and the valley to the east to an elevation of about 1520 m (5000 ft.) (NEC-X) while a lobe to the west occupied Elk Cove and the area to the north as far as 1560 m (5120 ft.) (NEC-S). The lobes likely joined above the point where the Timberline Trail crosses NEC-T and NEC-W (1630 m) (Figure 8). Recession and subsequent advances or prolonged stillstands of these ice masses formed prominent moraines at 1580 m (5200 ft.) (NEC-T and NEC-W).

The absence of a sequence of several overlying tephras (including Mazama or St. Helens) is problematic to a late Pleistocene or early Holocene age interpretation of the moraines. Perhaps this absence can be explained by the deposition of tephra onto snow covered ground (a common phenomena during nine months of the year) thus preventing a continuous layer from accumulating, or perhaps burrowing rodents disturbed the layers (bioturbation).

The distinct compositional similarities between tephra sample #3 (the lowest tephra identified in the bog soil pit) and tephra sample #7 (located on SEC-V) (Table X)(Figure 26)

Figure 30. Inferred extent of the pre-Little Ice Age Coe Glacier (later).

strongly suggests that they represent the same eruptive period. Furthermore, the position of sample #3 immediately overlying the organic material dated at 6480 plus or minus 40 yr BP and underlying two tephra layers suggests that samples #3 and #7 represent an eruptive period older than Old Maid or Zig Zag. Since neither Mount Mazama or Mount St. Helens tephras were petrographically identified in the study area, I will tentatively assign these samples as Timberline age tephras (1400-1800 yr BP) indicating that moraine SEC-V (and likely SEC-U) formed prior to 1400-1800 yr BP. The position of SEC-V upvalley and toward the glacier from the North Elk Cove moraines suggests that it is younger than the downvalley moraines. It may represent a late Neoglacial advance or possibly continued recession of the Holocene Coe Glacier.

LITTLE ICE AGE

The Little Ice Age moraines of the Coe Glacier are located upvalley of the pre-Little Ice Age moraines. The oldest Little Ice Age moraines were formed more than 380 years ago when the Coe Glacier spread to the area immediately west of its left lateral moraine, forming SEC-C. This advance extended to about 1710 m (5600 ft.) (Figure 31). The size of SEC-C indicates that the glacier occupied the area adjacent to SEC-C for a significant period of time before receding and forming SEC-B, SEC-A, SEC-D and SEC-E.

Figure 31. Inferred extent of the Little Ice Age Coe Glacier (earlier).

Because there are three moraines between SEC-C and SEC-E, it is unlikely that there is only a seven years difference in age between the two moraines hence SEC-C likely formed >380 years ago.

This period of lateral ice expansion subsequently moved downvalley reaching beyond 1650 m (5400 ft.) (SEC-I and SEC-H) to ECG-01. A minor readvance apparently overrode the two earlier moraines and formed SEC-J >256 years ago. Moraine ECG-P may represent a possibly correlating period of glacier advance. If ECG-P does correlate to this period, it suggests that the Coe Glacier extended to the east beyond the present right lateral moraine (ECG-RL) or that a separate lobe of ice occupied the valley to the east of ECG-RL and ECG-0 (Figure 31).

The Coe Glacier was in an expanded position >189 years ago as indicated by the age of the moraine (SEC-N) outside of the upper left lateral moraine (SEC-LL), and the outermost double crested right lateral moraine (ECG-0). Moraine SEC-N is significant because it represents the presence of a lobe of the Coe Glacier beyond the left lateral moraines beginning >189 years ago and possibly continuing until the late 1800's. Moraine ECG-0 (169 years old) may also represent the expanded condition of the Coe Glacier during this period. Subsequent recession resulted in the deposition of the prominent left lateral moraines (SEC-LL and ECG-RL) at least 105 years ago (Figure 32).

Since that time, four low moraines (SEC-LT4, SEC-LT3, SEC-LT2, SEC-LT1 and SEC-J1) have formed in the Coe Branch Valley. Moraine SEC-LT4, which has a tree ring derived age of 92 years, lies upvalley of the outermost of these moraines, SEC-J1. The downvalley position and the lack of truncation or overriding evidence suggests that SEC-J1 is older than 92 years. These moraines formed as the Coe Glacier receded upvalley. There are no East Coe Glacier equivalents to SEC-J1 and SEC-LT4. This absence is probably due to stream erosion which has undercut the right lateral moraine.

HISTORICAL TIMES

Continued recession of the Coe Glacier has occurred into the 1900's. Stillstands or slight readvances in this general period of recession are represented by three low moraines upvalley of SEC-LT4. Tree ring dating indicates that moraines SEC-LT3 and SEC-LT2 formed >32 years ago and SEC-LT1 formed >26 years ago. The relative positions, vegetation cover and tree ring evidence suggest that ECG-LT2 and ECG-LT1 are equivalent to SEC-LT2 and SEC-LT1. In addition, relative vegetation cover and dendrochronology indicate that the low moraines at the south end of Elk Cove, SEC-M and SEC-L, are probably equivalent to these moraines. Moraines SEC-L and SEC-M represent the last time that the Coe Glacier has overtopped the left lateral

moraines. No East Coe Glacier equivalents to SEC-LT3 were located; this is likely due to undercutting of the slopes by the Coe Branch thus removing the moraines. Documentary evidence indicates that the moraines are much older than suggested by the tree ring evidence. The large boulders painted by the Mazama Research Committee in August 1928 were located "just below the terminus of the glacier" (on the left and right lateral moraines) (Phillips, 1938, p. 28). The painted boulder on the left lateral moraine is located just upvalley of SEC-LT1, and the painted boulder on the right lateral moraine is immediately upvalley of ECG-RT1. Because of the initial establishment of the painted rocks in relation to the terminus of the glacier, combined with the fact that the Coe Glacier has receded and thinned since the first measurements were taken in 1928 (Table III), SEC-LT1, SEC-LT2, SEC-LT3, SEC-LT4, ECG-RT1 and ECG-RT2 must have formed before 1928. A photograph taken by H.F. Reid in 1901 show the terminus of the Coe Glacier and SEC-LT1 (Figure 33) indicating that the all of the moraines were formed before 1901. Another photograph taken by Reid shows the left lateral moraine and the Coe Glacier as it was in 1901 (Figure 34). As a comparison, Figure 15 illustrates the same scene 86 years later.

The Coe Glacier has been in a general state of recession since 1901 (Figure 35). Measurements taken by the Mazama Research Committee between 1928-1946 show that the

Figure 33. Terminus of the Coe Glacier in 1901.
View to the west. H.F. Reid photograph.

Figure 34. Moraine SEC-LL and the Coe Glacier
in 1901. View upvalley. H.F. Reid photograph.

Figure 35. Historical changes in the terminus of the Coe Glacier.

Coe Glacier receded nearly 135 m (450 ft.). A measurement made in 1954 by the Mazama Research Committee showed that the Coe Glacier terminus had receded approximately 107 m (350 ft.) since 1947 (Mason, 1954, p. 37). Analysis of USFS aerial photographs shows that the Coe Glacier terminus receded from 1946 through at least 1959 (Figure 35). Subsequent aerial photographs taken in 1972 indicate that the glacier terminus had advanced slightly since 1959. Perhaps this slight advance was a reflection of the buildup of ice in the upper part of the Coe Glacier seen by Handewith (1959). Between 1972 and 1984, the terminus remained relatively stationary. The present low, left and right lateral moraines, which are immediately adjacent to the Coe Glacier, have formed since 1959. The 1984 Coe Glacier terminus was upvalley of the 1946 terminus (Table III) indicating that the minor advance which occurred between 1959-1972 did not affect the overall trend toward recession.

CHAPTER VII

HEMISPHERIC COMPARISON AND CLIMATIC IMPLICATIONS

The termini of glaciers are sensitive to changes in glacier mass balance which in turn is largely a function of temperature during the ablation season and precipitation during the accumulation season (Burbank, 1982, p. 141). Small, mid-latitude alpine glaciers such as the Coe Glacier reflect mass balance changes relatively rapidly so they are good indicators of the frequency and magnitude of climate changes (Porter, 1981, p. 83; Porter, 1986, p. 27). While local environmental conditions can be expected to affect the timing and extent of glacial activity (Meier, 1965, p. 802; Andrews, 1975, p. 28), the general climate trends should be reflected in the changes of glaciers over time.

In this chapter, a comparison of the moraine ages of the Coe Glacier to those of the Eliot and Ladd Glaciers of Mount Hood is made to determine whether the local scale glaciers have behaved in a relatively synchronous manner over the past 500 years. As a regional comparison, the past activity of the Coe Glacier is related to the well dated moraines of Mount Rainier and Mount Baker, Washington, and to the historical record of the Collier Glacier on the North Sister, Oregon. A hemispheric comparison is made

between the Coe Glacier and the general moraine ages of glaciers in western Scandinavia. Scandinavia was chosen for the hemispheric comparison because of similar climatic conditions to the Pacific Northwest. Finally, the activity of the Coe Glacier is related to a 1590-1979 proxy temperature record for Longmire, Washington to determine how closely the timing of short term temperature changes corresponds with glacier activity.

MOUNT HOOD GLACIERS

A comparison of the ages of the Coe Glacier moraines to moraine ages of the Eliot (Lawrence, 1948) and Ladd Glaciers (Matthes, 1946) of Mount Hood reveals that the glaciers have been fairly synchronous over time (Table XII). While there are no corresponding Eliot and Ladd moraines to the early 1600's moraine of the Coe Glacier, there is a close correspondence between Coe and Eliot moraine ages in the late 1600's. There is no Ladd Glacier equivalent to these moraines. Moraines of the Coe, Eliot and Ladd from the mid-1700's roughly correspond. A Coe Glacier moraine dating from 1798 (SEC-N) corresponds to the 1806 Ladd Glacier moraines, and both the Coe and the Ladd have 1818 moraines. There are no corresponding Eliot Glacier moraines dating from this period. A marked difference occurs between the age of the prominent lateral moraines of the Coe compared to those of the Eliot and Ladd Glaciers. The large

TABLE XII
THE AGES OF THE COE GLACIER MORAINES IN RELATION TO OTHER MORAINES
IN THE PACIFIC NORTHWEST AND SCANDINAVIA*

COE	<u>MOUNT HOOD</u>			<u>MOUNT RAINIER</u>	<u>MOUNT BAKER</u>	<u>SCANDINAVIA</u>
	ELIOT	LADD				
					1978-79	
				1955		
		1935-36			1944-47	1930-34
				1923-24	1920-26	
				1912-1915	1908-1912	1910-20
1900-10	1900	<1901	1900		1901-1903	1903
	<1893-95					1890-99
	<1882			1880-85	1886-87	1880
				1876-78	1878	1873-75
				1860-64	1869	1860
	<1850	1852		1854-57	1850-59	
						1840
				1830	1835-37	
				1823-26	1823	
1800	<1818	1818				1810-20
	<1798	1806				1800
						1780
				1777		
				1760-68		
		1740	1749	1741-50	1740	1742-50
	<1731			1731		1735
				1720		1700-20
1700		<1700				
	<1689	<1690		1690-95		1691-1702
						1680-84
				1661-66		
				1650-55		1650
				1640		
				1623	1627	1590-1620
1600	<1614			1613		
	<1607					
				1576-80		
				1552	1559	
					1538	
				1528		
1500				1519	early 1500's	early 1500's

* Sources for each area are listed in the text.

lateral moraines of the Coe (SEC-LL and ECG-RL) formed between 1893-1895 while the conspicuous lateral moraines of the Ladd and Eliot Glaciers stabilized between 1850-1852. The 1895 (SEC-LT4) Coe Glacier moraine corresponds with the 1900 Eliot Glacier moraine both in age and relative position.

During historical times, the glaciers of Mount Hood have continued to behave in a relatively synchronous manner. The Coe, Eliot and Ladd generally receded during the 19-year period (1928-1946) that the Mazama Research Committee measured the termini of these glaciers (Table III). During the period of measurement, the Coe receded the farthest, 135 m (442 ft.), while the Eliot and the Ladd receded 85 (279 ft.) and 41 m (135 ft.) respectively. The greatest amount of recession occurred during the last eight years of the record (1939-1946) with the Coe having the highest losses during this period. In addition, all three of the glaciers advanced during one or more years during the period. The Ladd Glacier advanced in 1931, 1935 and again in 1936. The Eliot advanced slightly in 1932 and again in 1933. The Coe advanced only in 1935. Annual glacier termini measurements were discontinued following 1946.

Measurements on U.S. Forest Service aerial photographs show that the 1984 termini of the Coe, Ladd and Eliot Glaciers were all upvalley of the 1946 termini. However, the Coe and the Ladd advanced slightly between 1959

and 1972, then remained at about the same position between 1972 and 1984 while the Eliot apparently receded during the entire period.

In addition to a general recession of the terminus, the Coe, Eliot and Ladd have thinned considerably during this century (see photos and diagrams in Phillips, 1935; Phillips, 1938; Matthes and Phillips, 1943; Matthes, 1946; Lawrence, 1948; Mason, 1954; Mason, 1956; Handewith, 1959; Dodge, 1964). The lower portion of the Coe downwasted more rapidly than the lower portion of the Eliot Glacier during the period 1947 to 1959. While the lower portions of the Coe and Eliot downwasted and receded, transects taken across the upper portions of the glaciers actually showed an increased volume beginning in 1957 continuing through at least 1959 when studies were discontinued on the Coe Glacier (Handewith, 1959). It is possible that the increased volume in the upper portion of the Coe Glacier resulted in the slight advance seen between 1959-1972. Measurements on the Eliot in 1964 similarly showed a trend toward increasing ice mass in the upper glacier while the terminus continued to waste away (Dodge, 1964, p. 49). Net mass balance measurements taken on the Eliot between 1960-1983 indicate that the glacier has added nearly 1.3 m of water equivalent to its entire surface over this period (Dodge, 1987, p. 53).

PACIFIC NORTHWEST GLACIERS

The ages of Coe Glacier moraines compare favorably with the ages of other moraines in the Pacific Northwest (Table XII). The North Mowich, Carbon, Winthrop, Emmons, Ohanapecosh, Cowlitz, Nisqually, South Tahoma and Tahoma Glaciers of Mount Rainier, like the Coe Glacier, formed moraines in the early, middle and late 1600's, mid-1700's and late 1800's (Sigafoos and Hendricks, 1961; Sigafoos and Hendricks, 1972; Crandell and Miller, 1964; Burbank, 1981). Present on Mount Rainier, but absent around the Coe Glacier, are moraines dated between 1520-1580, 1640-1666, 1741-1768, 1840-1864, early 1900's and more recently, 1955. Conspicuously lacking adjacent to the Mount Rainier glaciers are the early 1800's moraines of the Coe Glacier. Some of the glaciers of Mount Rainier reached their Neoglacial maximums in the 1800's while others reached maximum positions as early as 1217 AD (Sigafoos and Hendricks, 1972, p. B22). In comparison, the Coe Glacier reached its maximum Little Ice Age extent prior to 1731 AD, and the advances of the 1800's did not approach this maximum.

Mount Baker moraines formed by the Boulder, Coleman, Deming, Easton and Rainbow Glaciers are also similar in age to the Coe Glacier moraines (Table XII) (see Long, 1953; Long, 1955; Easterbrook and Burke, 1972; Burke, 1972; Fuller, 1980; Heikkinen, 1984). Corresponding moraines were identified in the early 1600's, mid-1700's and early and

late 1800's. Notable differences in the chronology are the early 1500's, mid-1800's, early 1900's and the 1978-1979 moraines on Mount Baker. The Mount Baker glaciers reached their maximum Neoglacial extent in the 1500's; however, the 1823 Coleman Glacier moraine suggests that the glacier of this period was nearly as extensive as that during the 1500's (Heikkinen, 1984, p. 62).

A photographic record of the Collier Glacier on the North Sister in the central Oregon Cascades exists for the period 1934-1981 (Hopson, 1960; Hopson, 1961; Hopson, 1962; Hopson, 1963; Hopson, 1965; Keen, 1969; Keen, 1978; Keen, 1981). The photographs show that recession of the terminus of the Collier Glacier has resulted in a loss of about one half of its length during the 1934-1981 period. Similar to the Coe and Eliot Glaciers of Mount Hood, a buildup of ice in the upper portion of the Collier Glacier was first detected in 1960 and continued through 1963. Since 1963, the earlier volume gain of the upper portion of the Collier Glacier has been lost and the terminus has continued to recede.

SCANDINAVIA GLACIERS

The ages of Neoglacial moraines in Scandinavia, especially Norway and Sweden, are very similar to those of the Coe Glacier (Table XII). Generally corresponding moraine ages occur in the early, middle and late 1600's,

middle and late 1700's and early and late 1800's (Andersen and Sollid, 1971; Karlen, 1973; Ostrem et al, 1976; Karlen and Denton, 1976; Matthews, 1977; Karlen, 1979; Erikstad and Sollid, 1986). Scandinavian moraines, similar to Mount Rainier and Mount Baker glaciers but conspicuously lacking adjacent to the Coe Glacier, formed in the early 1700's, mid-1800's and early 1900's. The most extensive late Neoglacial advances occurred between 1600-1750; however, the maximum extent of some Scandinavian glaciers occurred as early as 1500 (Karlen and Denton, 1976, p. 185) and as late as 1820 (Erikstad and Sollid, 1986, p. 85).

CLIMATIC IMPLICATIONS

The similarity of moraine ages and glacial activity of the glaciers of Mount Hood, North Sister, Mount Rainier and Mount Baker in the Pacific Northwest, and in Scandinavia, suggests similar northern hemisphere climate patterns. Indeed, strong similarities are seen between the Coe Glacier moraine ages and short term periods of lower temperatures on a tree ring-derived temperature record for Longmire, Washington (1590-1979) (Figure 36) (Graumlich and Brubaker, 1986, p. 230-31). Longmire is located on the south side of Mount Rainier. This record shows a cool period from about 1600-1650 followed by a warmer period extending from 1650-1690. A generally cool period occurred from 1700 to about 1900 with well developed cool intervals taking place

Figure 36. Dendrochronology-derived temperature record at Longmire, Washington 1590-1979.

between 1700-1790 and 1860-1900. A warming trend occurred between 1900-1940 with higher temperatures occurring in this period than during any earlier time. Although temperatures have been high since 1940, the trend during this period has been toward cooling. Coe Glacier moraine ages coincide with the general climatic patterns seen in Figure 36. At least six moraines formed during the cold period of 1600-1650 and another 12 formed during the general cool period of 1700-1900. The pre-1928 moraines likely formed during the short cold period between 1905-1915. The general recession of the Coe Glacier following the early 1900's has followed the temperature trend. The exceptions to the direct relationship between temperature and the Coe Glacier are the 1695 and 1689 moraines which apparently stabilized during a warmer period.

CHAPTER VIII

SUMMARY AND CONCLUSIONS

Field investigations in the glaciated area around the Coe Glacier combined with subsequent data analysis support the following summary and conclusions.

1. A multiple methodology approach was used to date the moraines adjacent to the Coe Glacier.

2. Pre-Little Ice Age (<1500 AD) and Little Ice Age (1500-1920 AD) moraines were identified in the study area.

3. Pre-Little Ice Age advances or stillstands were more extensive (laterally and downvalley) than the Little Ice Age events.

4. At least nine Pre-Little Ice Age moraines were identified with the outermost extending downvalley to about 1530 m (5020 ft.). Radiocarbon dating indicates that the Coe Glacier has not extended downvalley of this elevation in the past 6500 years.

5. At least eighteen Little Ice Age moraines were identified with the most extensive moraine reaching beyond about 1650 m (5400 ft.) prior to 1731 AD.

6. The oldest Little Ice Age advance occurred prior to 1607 AD when the Coe Glacier extended laterally beyond the present left lateral moraine.

7. The Little Ice Age Coe Glacier has generally been receding since before 1798 AD and possibly as early as pre-1731.

8. The prominent left and right lateral moraines formed prior to 1882. Their size indicates that a much thicker Coe Glacier occupied the trough for a considerable period of time.

9. The outermost of the four low moraines located in the Coe Glacier trough formed prior to 1895 AD (perhaps much more so) while the innermost formed prior to 1901 AD.

10. Documentary evidence indicates that the Coe Glacier has been in a general state of recession since about 1901.

11. The past fluctuations of the Coe Glacier generally correspond with the activity of the Eliot and Ladd Glaciers on Mount Hood and other glaciers in the Pacific Northwest and Scandinavia.

12. Coe Glacier moraine ages and periods of low temperatures generally coincide; this similarity combined with comparable moraine ages on local, regional and hemispheric scales suggests that hemispheric climate patterns have played a major role in the past activity of the Coe Glacier.

FURTHER RESEARCH

As often is the case at the "completion" of a research

problem, there are as many questions now as when the study was initiated in April 1987. Foremost of the problems to be solved in the future is better age control on the Little Ice Age moraines. This can be accomplished by taking sections from trees on recent moraines, and through use of a longer increment bore on trees located on older moraines. The identification of ice scars in cut sections would be a big help in determining more precise dates for glacial advances. The construction of a lichen growth curve would also be helpful in the better dating of those moraines above timberline.

A second problem to be encountered is more precise dating of the probable pre-Little Ice age moraines located downvalley of the Little Ice Age moraines. This may be accomplished through the analysis of additional soils and tephra data, and by obtaining radiocarbon dates from organic matter buried in the downvalley moraines.

A final problem to be examined is the further study of the Little Ice Age moraines adjacent to the other glaciers on the north side of Mount Hood. It may be possible to further refine the chronology of the Eliot and the Ladd Glaciers, and to establish a chronology for the Langille Glacier.

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