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Neoglaciation of Avalanche Gorge and the Middle Fork Nooksack River Valley Mt. Baker, Washington

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NEOGLACIATION OF AVALANCHE GORGE
AND THE MIDDLE FORK NOOKSACK RIVER VALLEY
MT. BAKER, WASHINGTON

A Thesis

Presented to

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Master of Science

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MASTER'S THESIS

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by

Steven R. Fuller

Accepted in Partial Completion
of the Requirements for the Degree
Master of Science

Dean of Graduate School

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ABSTRACT

The Neoglacial fluctuations of two of Mt. Baker's alpine glaciers were studied by tephrochronologic, dendrochronologic, and relative dating methods coupled with detailed geologic mapping. The earliest recognizable advance of the Deming Glacier occurred prior to deposition of Mazama tephra and after the Vashon Stade of Fraser Glaciation. The oldest recognizable Holocene advance of the Deming Glacier occurred >800 years B.P. and <6000 years B.P. Younger moraines of the Deming Glacier date to the 16th, 17th, 18th(?), early 19th, late 19th, and 20th centuries. The Neoglacial record for the Rainbow Glacier is poorly preserved due to modification by two historic rock-debris avalanches, but the 20th century moraines of the Rainbow and Deming Glaciers disclose a close synchronism in their fluctuations. Glacier fluctuations on Mt. Baker during the past 500 years are broadly synchronous with those of glacier fluctuations elsewhere in the Pacific Northwest.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

INTRODUCTION

The Deming and Rainbow Glaciers on Mt. Baker, Washington (Fig. 1), have experienced numerous expansions and recessions during the past few thousand years. Similar advances and retreats of alpine glaciers during the Holocene are recognized throughout western North America.

Early work by Matthes (1935, 1939, 1941, 1942, 1945) established the existence of a post-Wisconsin "Climatic Optimum" during the time which alpine glaciers were greatly reduced in size or disappeared altogether. Matthes hypothesized that several alpine readvances occurred in the 4000 years following the "Climatic Optimum" and referred to the renewed glacier activity as the "Little Ice Age". Moss (1951) suggested the term Neoglaciation as an equivalent to the "Little Ice Age".

Neoglaciation was reviewed by Porter and Denton (1967) and they consider the boundary between the Hypsithermal interval and Neoglaciation as time-transgressive. Alpine glacier expansion in the Pacific Northwest during Neoglaciation, as suggested by Porter and Denton (1967), occurred during two intervals: (1) an early expansion between 2800-2600 years B.P., and (2) the most recent episode of glacier expansion which began approximately 800 years B.P. and ended in the mid-20th century. In many areas the earlier advance is not as extensive as the more recent advance.

Evidence for at least two pre-Neoglaciation periods of alpine glacier expansion during the Holocene is present in the Pacific Northwest. The earlier period of advance occurred after the Fraser Glaciation, but prior to deposition of Mazama tephra (Beget, 1980; Waitt

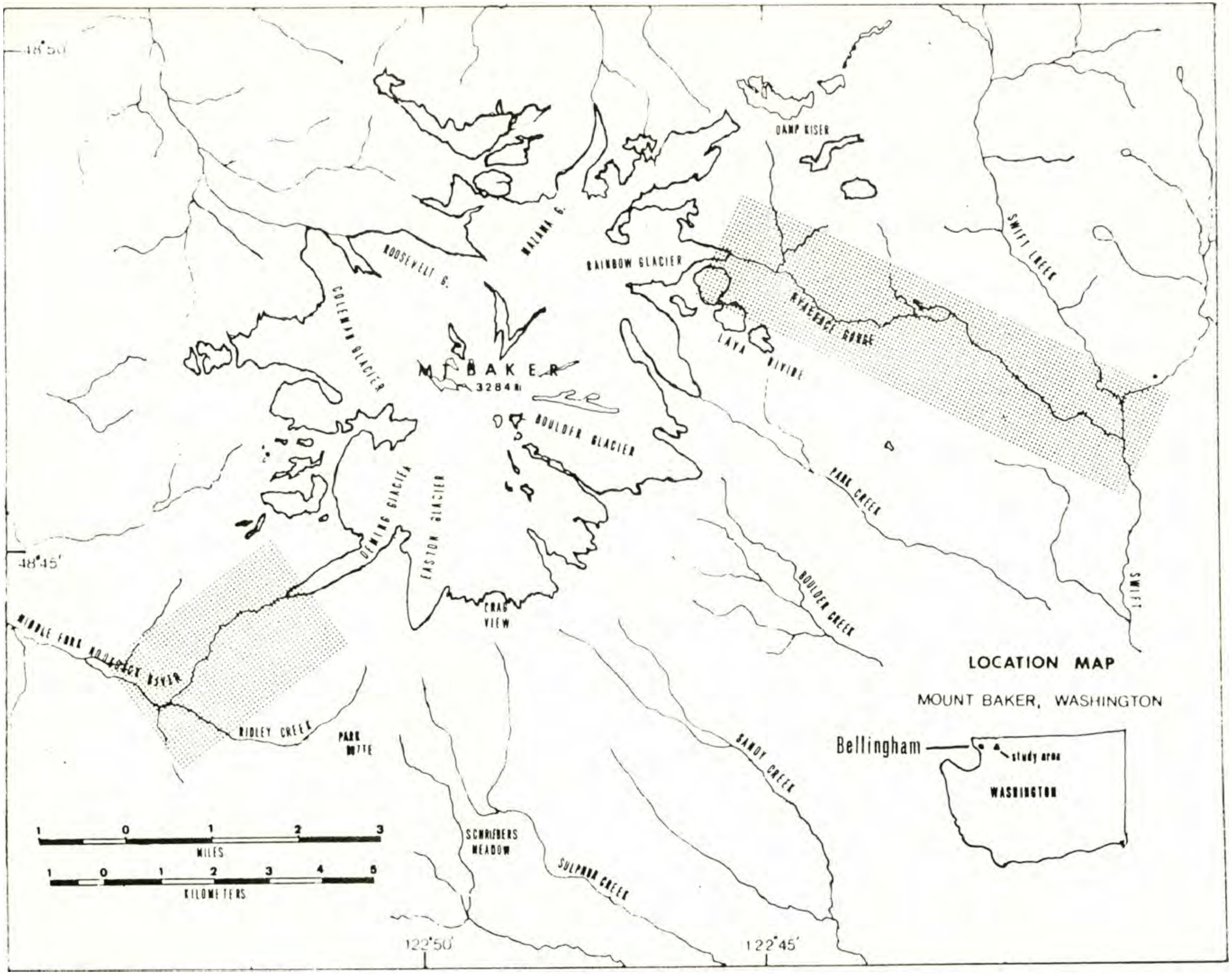

Figure 1. Location map Mt. Baker, Washington. Shaded areas indicate study sites.

et al., 1980). A younger expansion occurred about 5000 years B.P. (Mathews, 1951; Meier, 1964).

This investigation produced further information on the Holocene fluctuations of two glaciers on Mt. Baker, and thus provides a more complete understanding of Neoglaciation in the Cascade Range.

Geologic Setting

Mt. Baker (3284 m) is located in the North Cascade Range 24 km south of the Canadian border and 53 km east of Bellingham, Washington (Fig. 1). The eruptive history of Mt. Baker was first described by Smith and Calkins (1904) and later by Coombs (1939), Misch (1952, 1966), and others. Mt. Baker is constructed on Jurassic and Cretaceous rocks of the Nooksack Group which are exposed in a window of the overthrust Shuksan Metamorphic Suite (Misch, 1966).

Mt. Baker is a Quaternary calc-alkaline stratovolcano characterized by pyroxene andesite flows. The present cone overlaps older volcanic rocks of an earlier eruptive center called the Black Buttes (Coombs, 1939; Easterbrook and Rahm, 1971; Easterbrook, 1975a; McKeever, 1977). Two identical potassium-argon dates of 400,000 ± 100,000 years B.P. were obtained from Black Butte flows (Easterbrook and Rahm, 1971).

Postglacial eruptive deposits, numerous postglacial mudflows and debris flows (Hyde and Crandell, 1978), and Holocene moraines (Burke, 1972; Easterbrook and Burke, 1971, 1972; Long, 1953, 1955) are exposed in the valleys and on the flanks of Mt. Baker. Mt. Baker shows ongoing thermal activity (Easterbrook, 1972a, 1980; Malone and Frank, 1975; Frank et al., 1978) and historic glacier fluctuations (Harrison, 1961a, 1961b, 1970; Bengston, 1951, 1956).

The volcano is almost entirely ice covered above 1880 m and the flanks have been highly dissected by alpine glaciers (Plate 1). Below timberline (1820 m) the densely forested flanks support Douglas Fir (Pseudotsuga), Western Hemlock (Tsuga Heterophylla), and Western Red Cedar (Thuja Plicata). Forest soils are typically incipient Spodsols

PLATE 1. Aerial view of Mt. Baker, Washington.
(Photo by D. J. Easterbrook)

(Inceptisols) (Birkeland, 1964; Bockhiem, 1972) developed beneath thick humic mats.

The present study includes the Deming Glacier in the Middle Fork Nooksack Valley and the Rainbow Glacier in Avalanche Gorge (Fig. 1). The Deming Glacier is 4.5 km^2 in area and 5.5 km in length with the present terminus at 1180 m. The Rainbow Glacier is considerably smaller, 1.9 km^2 in area, 1.2 km in length, and terminates at 1200 m (Post et al., 1971). Both glaciers are essentially ice aprons with valley tongues. The upper limit of accumulation for the Rainbow Glacier is at 2290 m and 3260 m for the Deming Glacier.

Previous Work

Late Pleistocene continental ice of the Vashon Stade of Fraser Glaciation inundated the North Cascade Range between 18,000 and 13,500 years B.P. (Easterbrook, 1969, 1975b) and deposited erratics at elevations of 1700 m. Till deposited during the Vashon Stade blankets the flanks of Mt. Baker to 1550 m. The final event of the Fraser Glaciation, the Sumas Stade, was characterized by an advance of continental ice which terminated just south of the international border (Easterbrook, 1963, 1966). The Sumas readvance has been dated between 11,400-10,000 radiocarbon years B.P. (Armstrong, 1965, 1977; Easterbrook, 1966).

Late Pleistocene and Holocene deposition on Mt. Baker includes many debris and rock avalanches, and mudflows, which are confined to the valleys flanking the mountain. Two or more major mudflows have been described in the following valleys: Sulphur Creek Valley, Middle Fork Nooksack Valley, Park Creek Valley, and Avalanche Gorge (Hyde and Crandell, 1978). Several mudflows, rock avalanches, a pyroclastic flow, and a lava flow are reported in the Boulder Valley (Burke, 1972, Hyde and Crandell, 1978).

Six Holocene tephra layers are exposed in Mt. Baker stratigraphy, but their age, distribution, and provenance are imprecisely known (Easterbrook, 1975a; Hyde and Crandell, 1978). The oldest tephra consists of grey-brown, fine sand (.25 mm) particles. Wood found in the tephra is dated at 10,350 ± 300 years B.P. (W-2972). A scoria layer directly overlies the older tephra. It is as much as 100 cm thick and contains some bombs 25 cm in diameter. The scoria is in turn overlain by a black, sand-size tephra. The scoria and black sand tephra are older than Mazama tephra and are thought to have their source from a cinder cone in Schriebers Meadow. Mazama tephra on Mt. Baker is bracketed between 6,630 ± 130 years B.P. (I-2917) and 5,965 ± 120 years B.P. (I-2916) which is slightly younger than the 6,600 year date obtained by Powers and Wilcox (1964) (Easterbrook, 1975a). A post-Mazama black tephra is exposed in several localities on Mt. Baker and is bracketed in age between 6,000-500 years B.P. The most recent tephra consists of hydrothermally altered rock fragments and is interpreted as ejecta erupted from Mt. Baker in the past 200 years (Easterbrook, 1975a; Hyde and Crandell, 1978). Burke (1972) reported three tephra layers in the Boulder Valley. Two of the tephra units predate Mazama tephra but their age and provenance are unknown.

Neoglacial moraines are exposed beyond the termini of all glaciers flanking Mt. Baker. The first investigation of Neoglacial activity on Mt. Baker was conducted by Long (1955) in Boulder Valley. Tree-ring counts by Long (1955) established dates of stable glacier regimes from forested moraines in the late 1700's A.D., 1850 A.D., and 1880 A.D.

Burke (1972) and Easterbrook and Burke (1972) refined Long's earlier work and dated four moraines in the Boulder Valley to the 16th century or older, mid-19th, late 19th, and early 20th centuries. Neoglacial moraines preserved from advances of the Deming, Easton, and Coleman Glaciers were dated by Easterbrook and Burke (1971). Each glacier constructed a moraine prior to the 16th century. The Coleman Glacier has moraines dating to 1859 and 1903; the Easton Glacier has a moraine dating to 1920. All dates are from tree-ring counts.

Investigations of historic glacier fluctuations have been undertaken on the Deming and Easton Glaciers (Long, 1953), Boulder Glacier (Long, 1955), and the Coleman Glacier (Bengston, 1951, 1956; Harrison, 1961a, 1961b, 1970).

Recent studies on Mt. Baker have focused on the increased thermal activity (Easterbrook, 1975a, 1980; Frank et al., 1978, Frank and Krimmel, 1980; Malone and Frank, 1975) and Holocene debris flow and eruptive activity (Easterbrook, 1975a; Hyde and Crandell, 1978).

Alpine glaciers in the Cascade Range and elsewhere in the Pacific Northwest have responded to climatic influences during the Neoglaciation in a broadly synchronous manner. Investigations dealing with fluctuations of these glaciers are used for correlation with glaciers of this study.

Neoglacial moraines of Price Glacier on neighboring Mt. Shuksan, date to the pre-17th, early and late 19th, and 20th centuries (Leonard, 1974). Three moraines in the Nooksack cirque on Mt. Shuksan date to the late 18th, early 19th, and early 20th centuries (R. Zasoski, personal communication). In the Dome Peak area of the North Cascade Range, the South Cascade, Le Conte, and Dana Glaciers reached Neoglacial maxima in the 16th century and subsequently constructed moraines in the 19th and 20th centuries (Miller, 1969). The Chickaman Glacier reached a maximum downvalley position in the 13th century and deposited several moraines between the 16th and early 20th centuries (Miller, 1969). An early advance of the South Cascade Glacier about 4,900 years B.P. was reported by Meier (1964).

Maximum downvalley extent of alpine glaciers in the Mount Garibaldi area, British Columbia, occurred in the 16th century with subsequent moraines constructed in the 19th and 20th centuries (Mathews, 1951). An early Holocene moraine is also present and is dated at approximately 5,300 years B.P. (Mathews, 1951; Barendsen et al., 1957).

Alpine glacier fluctuations during Neoglaciation at Mt. Rainier were more diverse. Crandell and Miller (1964) subdivided Neoglacial deposits into two stades: the Burrows Mountain Stade, 3,500-2,000 years B.P., and the Garda Stade, between the 13th and mid-20th centuries. Neoglacial maximum positions for different glaciers on Mt. Rainier vary considerably relative to Mt. Baker glaciers. The Nisqually Glacier reached its maximum stand in 1845 whereas the Winthrop Glacier reached its maximum position 3,500-2,000 years B.P.

Variations of the Blue, Hoh, and White Glaciers in the Olympic Mountains of Washington reveal an early expansion in the 13th century with less extensive moraines deposited in the 19th and 20th centuries (Heusser, 1957).

Purpose of Investigation

This study of the Deming and Rainbow Glaciers was designed to aid in the development of a Neoglacial chronology of Mt. Baker. The purposes of this investigation are: (1) to unravel the chronology of glacier fluctuations in Avalanche Gorge and the Middle Fork Nooksack Valley; (2) to evaluate a variety of relative dating methods for use in interpreting the alpine glacial deposits on Mt. Baker; and (3) to correlate alpine glaciation on Mt. Baker with glaciation elsewhere in the Cascade Range.

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DATING METHODS

A variety of absolute and relative dating methods were used in this study. Absolute methods used were dendrochronology and tephrochronology. Relative dating methods included lichenometry, soil development, rock weathering parameters, relative topographic position of moraines, moraine morphology, and degree of post-depositional modification.

Absolute Dating

Absolute minimum ages for many of the glacial sediments were determined by dendrochronologic methods. Annual tree ring growth counts obtained from forested moraines or trees growing in front of glaciers provide minimum ages for these deposits (Bray and Struck, 1963; Fritts, 1965; Lawrence, 1950; Sigafoos and Hendrix, 1961, 1969, 1972; Strok, 1963). Field techniques used in this study are those described by Sigafoos and Hendrix (1972). Cores from trees less than 150 years of age were counted in the field; those from older trees were counted in the laboratory with the use of a binocular microscope. Radial sections were taken from trees less than five cm in diameter and counted in the field. A partial radial section was removed from an avalanche damaged tree and returned to the laboratory for analysis.

Only actual tree ages are presented in this report. Several factors restrict the dates to minimum ages for the deposits upon which they grow. These factors are discussed thoroughly by Sigafoos and

Hendrix (1969). Despite limitations, dendrochronology has proved to be a reliable dating technique for moraines constructed in the past 500 years.

Mazama tephra exposed in the Middle Fork Nooksack Valley and elsewhere on Mt. Baker (Burke, 1972; Easterbrook, 1975; Hyde and Crandell, 1978) provides an excellent time-stratigraphic marker for post-Hypsithermal deposition (Wilcox, 1965; Rigg and Gould, 1957). Mazama tephra has been radiocarbon dated as approximately 6600 years B.P. (Powers and Wilcox, 1964) at Crater Lake, Oregon.

Relative Dating

Relative dating (RD) has produced excellent results in differentiating glacial deposits of varying ages (Blackwelder, 1931; Birkeland et al., 1976, 1979; Birman, 1964; Sharp and Birman, 1963).

The application of lichenometry (Beschel, 1961, 1973; Benedict, 1967, 1968; Denton and Karlen, 1973; Burbank, 1979) as a RD technique was restricted to use on moraines in Avalanche Gorge. Sampling techniques were modified from Burbank (1979). Measurement of lichens was restricted to Rhizocarpon genera, a green crustose lichen. For a thorough discussion of the factors which limit the use of lichenometry to a relative dating method see Webber and Andrews (1973). Individual lichen thalli were measured across the shortest diameter to the nearest millimeter. A minimum of 100 lichens were measured at each sampling site. The minimum number of sampling sites, for a single moraine, was three.

Soil weathering profiles proved useful in the downvalley correlation of buried moraines and as an indicator of relative age. The thicknesses of B_2 weathering horizons were measured in excavated soil pits, stream bank exposures and exposures provided by blowdowns. Soil colors were named by comparison with a Munsell soil color chart.

Time-dependent rock weathering properties (Porter, 1976; Scott, 1977; Crandell and Miller, 1975) are extremely useful for determining relative ages. Weathering rinds to the nearest tenth of a millimeter were measured on andesite clasts. Birkeland et al. (1979) report this technique to be applicable to deposits ranging in age from 10,000 to 100,000 years B.P.

Field observations of the relative topographic position, morphology and degree of post-depositional modification of moraines were made in both valleys. The position of these moraines were mapped on aerial photographs at a scale of 1:15,000.

STRATIGRAPHY

Middle Fork Nooksack Valley

A nearly complete record of Neoglacial activity is preserved in the Middle Fork Nooksack Valley (Fig. 2). Pre-Neoglacial Holocene deposits are exposed beyond the Neoglacial maxima of the Deming Glacier. Pre-Neoglacial stratigraphic units, from oldest to youngest, include: (1) a till grading upward into a cross-laminated silt, (2) a diamicton exhibiting debris-flow characteristics, (3) Mazama tephra, and (4) a clayey mudflow containing wood fragments about 6000 years old (Fig. 3).

Neoglacial moraines dated as the pre-13th, 16th, 17th, 18th(?), mid- and late 19th, and 20th centuries rib the valley walls between Ridley Creek and the present glacier terminus (Fig. 3). Two buried moraines are exposed on both valley walls. The younger buried moraine probably dates to the 18th century. The age of the older ice marginal deposit is problematic.

Lower-Valley Stratigraphy

The lower-valley sequence is exposed in a southwest cutbank of the Middle Fork Nooksack River 30 m upriver from the confluence of Ridley Creek (Fig. 4). The basal unit is a massive dark grey till, nine meters thick, grading upward into a cross-laminated silt bed. The till is well compacted and forms vertical exposures. Prolate, subangular andesite clasts show a lineation fabric. The long axes of the prolate clasts are inclined at approximately 25^{o} plunging in the upstream direction. The clasts are surrounded by a grey sandy silt matrix. The fabric appears to be the result of shear generated by overriding ice. Gradation from till to silt occurs in 50 cm of vertical exposure. The thinly (5 mm)

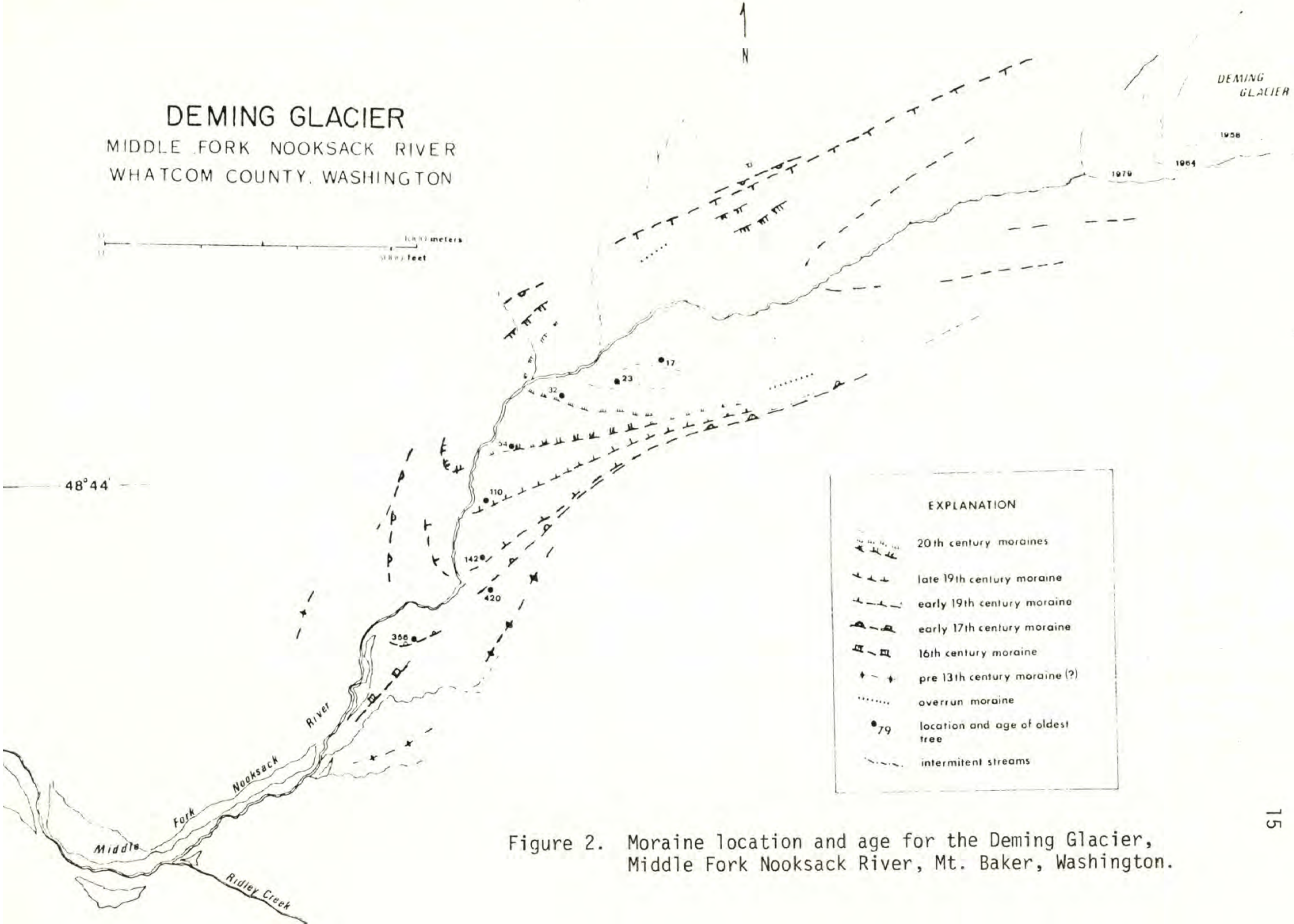


Figure 2. Moraine location and age for the Deming Glacier, Middle Fork Nooksack River, Mt. Baker, Washington.

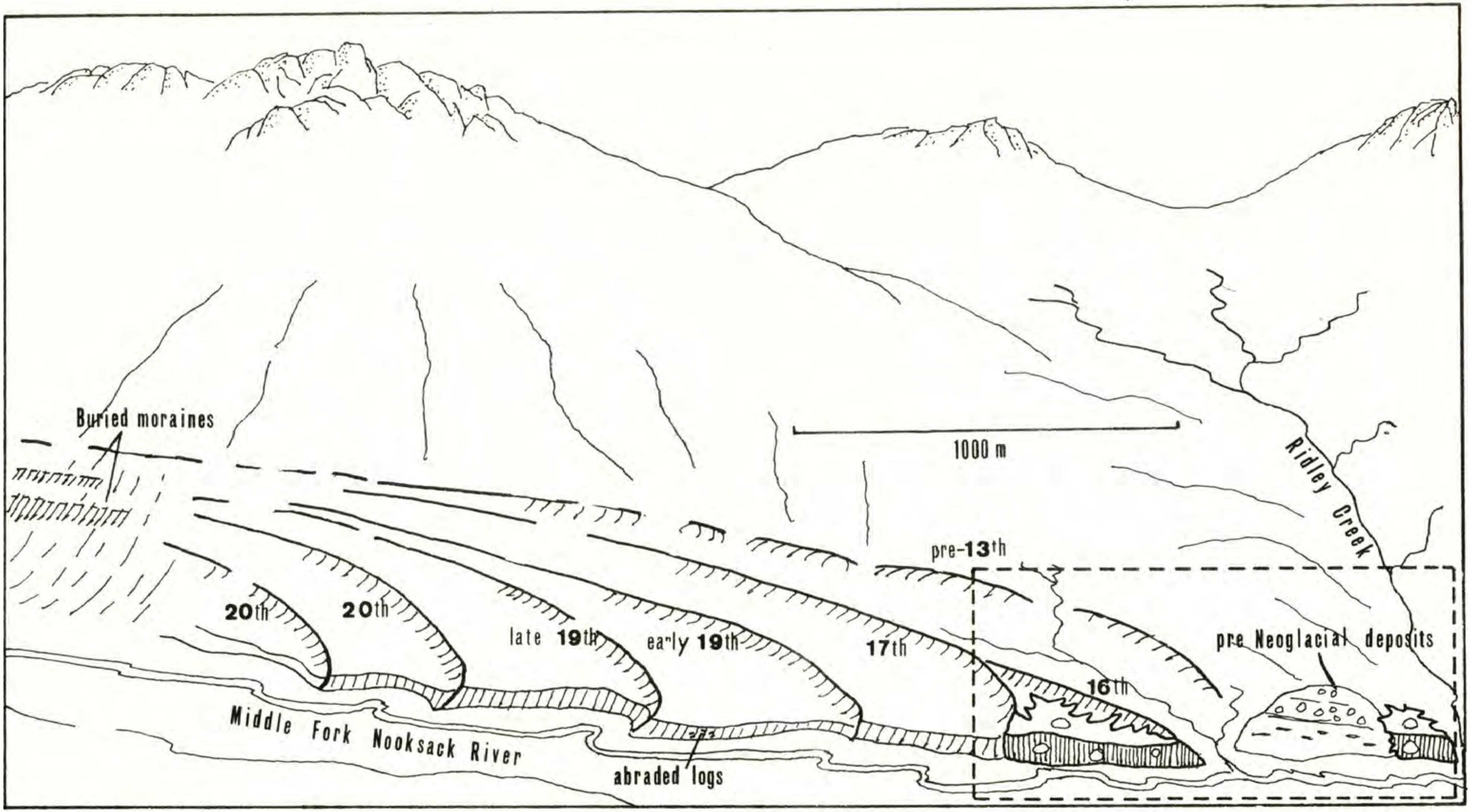


Figure 3. View of the Middle Fork Nooksack River Valley looking to the southeast. The terminus of the Deming Glacier is just off the sketch to the left. Moraine ages are in centuries. Note that pre-Neoglacial deposits are exposed beyond the pre-13th century moraine. Dashed border portion of the figure is expanded in Figure 4.

cross-laminated silt bed is light grey in color on fresh surfaces and locally contains isolated subrounded to rounded stones which do not exceed three cm in diameter. The silt bed thins laterally upriver and becomes interstratified with till. Downvalley the silt bed is 70 cm thick. The base of the till is covered with colluvium derived from an overlying diamicton (Plate 2).

The till is older than Mazama tephra and tentatively considered late Pleistocene or early Holocene in age. Till from a similar alpine advance is also exposed in the Boulder Valley (Burke, 1972; Easterbrook and Burke, 1972) and on the northeast flank of Park Butte (Easterbrook, 1979, personal communication). Alpine till older than Mazama tephra on Mt. Baker may have been deposited during the final pulses of Fraser Glaciation, possibly an alpine equivalent to the Sumas Stade about 10,000 years B.P. (Armstrong et al., 1965; Easterbrook, 1963). Porter (1978) provided evidence for an alpine ice advance during the Sumas Stade in the Southern Cascade Range. Till on Mt. Baker may be younger than late Fraser. Beget (1980) and Waitt et al. (1980) recently provided evidence for an alpine ice advance in the North Cascades about 8000 years B.P. Correlation of the pre-Neoglacial till on Mt. Baker to an advance of either 8,000 or 10,000 years B.P. is not possible at this time.

The silt bed probably was deposited in a pro-glacial lake formed by localized damming of the Middle Fork Nooksack River by a landslide as suggested by landslide deposits exposed 9 km downriver from the silt bed exposure.

The till unit is overlain by a two-meter thick boulder diamicton which consists predominantly of angular andesite cobbles and boulders;

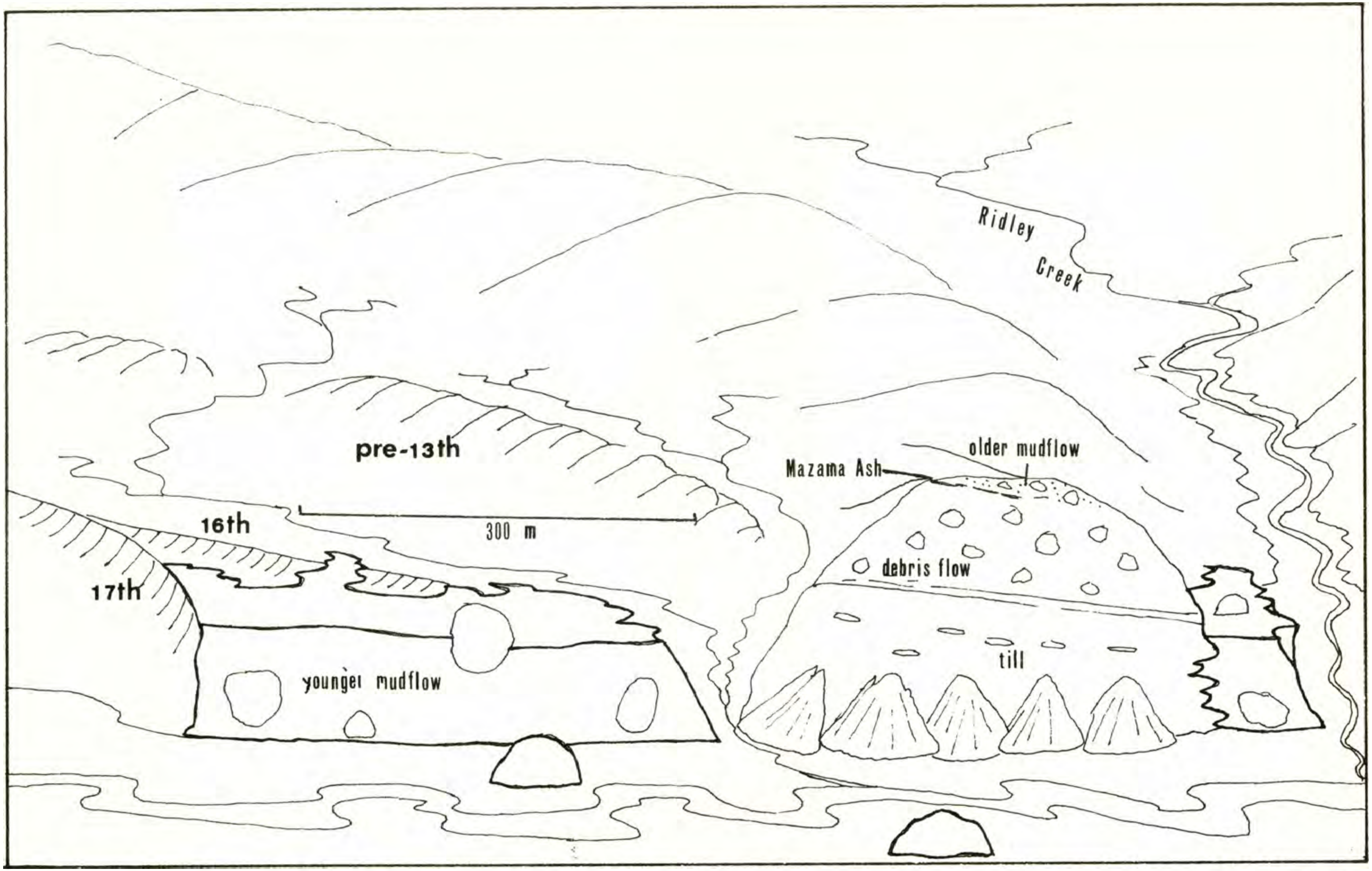


Figure 4. Relationship of the younger mudflow to the 16th and 17th century moraines. Location of Mazama ash between mudflow and and debris flow deposits.

PLATE 2. Holocene stratigraphy in the Middle Fork Nooksack Valley. The exposure is approximately 18 m high.

PLATE 3. Youngest mudflow deposit in the Nooksack drainage. The small tree is 1.5 m in height.

clasts more than 40 cm in diameter are common. Sparse well-rounded granitic cobbles within this deposit indicate fluvial reworking of older Fraser deposits. The grey-brown sandy matrix exhibits one cm-thick iron oxidation halos surrounding many of the clasts. Andesite clasts exhibit weathering rinds less than .5 mm in thickness. This diamicton is interpreted as a debris flow because of the large (>40 cm) clasts, occurrence of stream rounded cobbles (granitic) and it looks like debris flows elsewhere on Mt. Baker.

Four cm of bioturbated Mazama tephra underlain by a two cm peaty horizon overlies the diamicton (Hyde and Crandell, 1978). Exposure of the tephra is discontinuous. The color of the moist tephra is yellow-brown (10YR 5/6) and dry color is brownish yellow (10YR 6/6).

Glass shards in the tephra are equidimensional, less than 150 microns in size and stained by iron oxides. The glass is clear and contains abundant microlites of undetermined material and elongate vesicles with circular cross-sections. Refractive index of the glass is 1.501 ± .001. Sparce phenocrysts enclosed in glass include euhedral, lath-shaped, plagioclase less than 100 microns in length, and brown-green colored, anhedral, amphibole less than 50 microns in length. These data are consistent with that obtained for Mazama tephra by Powers and Wilcox (1964). The relatively high refractive index of this tephra distinguishes it from other tephras with lower refractive indices on Mt. Baker.

Other minerals recognized, in order of decreasing abundance, are quartz, plagioclase, hypersthene, opaques, and microcline. Due to contamination by bioturbation, minerals from the tephra and from the soil are intermixed. The tephra is in turn overlain by one m of clayey mudflow deposits. Wood obtained from this deposit, about 6.5 km downvalley, yielded a radiocarbon age of 5980 ± 250 years B.P. (W-2944, Hyde and Crandell, 1978). There are two mudflow deposits in the Middle Fork Nooksack drainage. The one just described is referred to as the older mudflow. The other mudflow deposit is referred to as the younger mudflow.

The younger mudflow forms a distinct terrace four m above the river channel. It overlaps the previously described units and contains blocks of andesite flow breccia, some of them five m in diameter, in a reddish sand matrix. The mudflow extends approximately six km downvalley from the present terminus of the Deming Glacier (Plate 3). The deposit overlies a 16th century moraine, but has been eroded by an advance in the 17th century (Fig. 4).

Upper-Valley Stratigraphy

An early Neoglacial moraine is found between two intermittent streams which drain the south wall of the valley 300 m upstream from the confluence of Ridley Creek (Fig. 4). The morainal morphology is subdued and indistinct. The great antiquity of the deposit is shown by the maturity of the forest growing on the moraine. Trees in excess of 450 years are rooted in completely decayed, downed trees of similar diameter. Living trees greater than 1.5 m in diameter are perched upon boulders three m in diameter. The boulders are imprisoned by the root systems of these trees which suggests that the original relief of the moraine has been greatly reduced (Fig. 5). Weathering profiles exposed by blowdowns exceed 1.3 m in thickness and are yellow in color (10YR 7/6). Subangular andesite clasts are oxidized but no measurable weathering rinds were found. Exposed boulders are completely covered by lichens

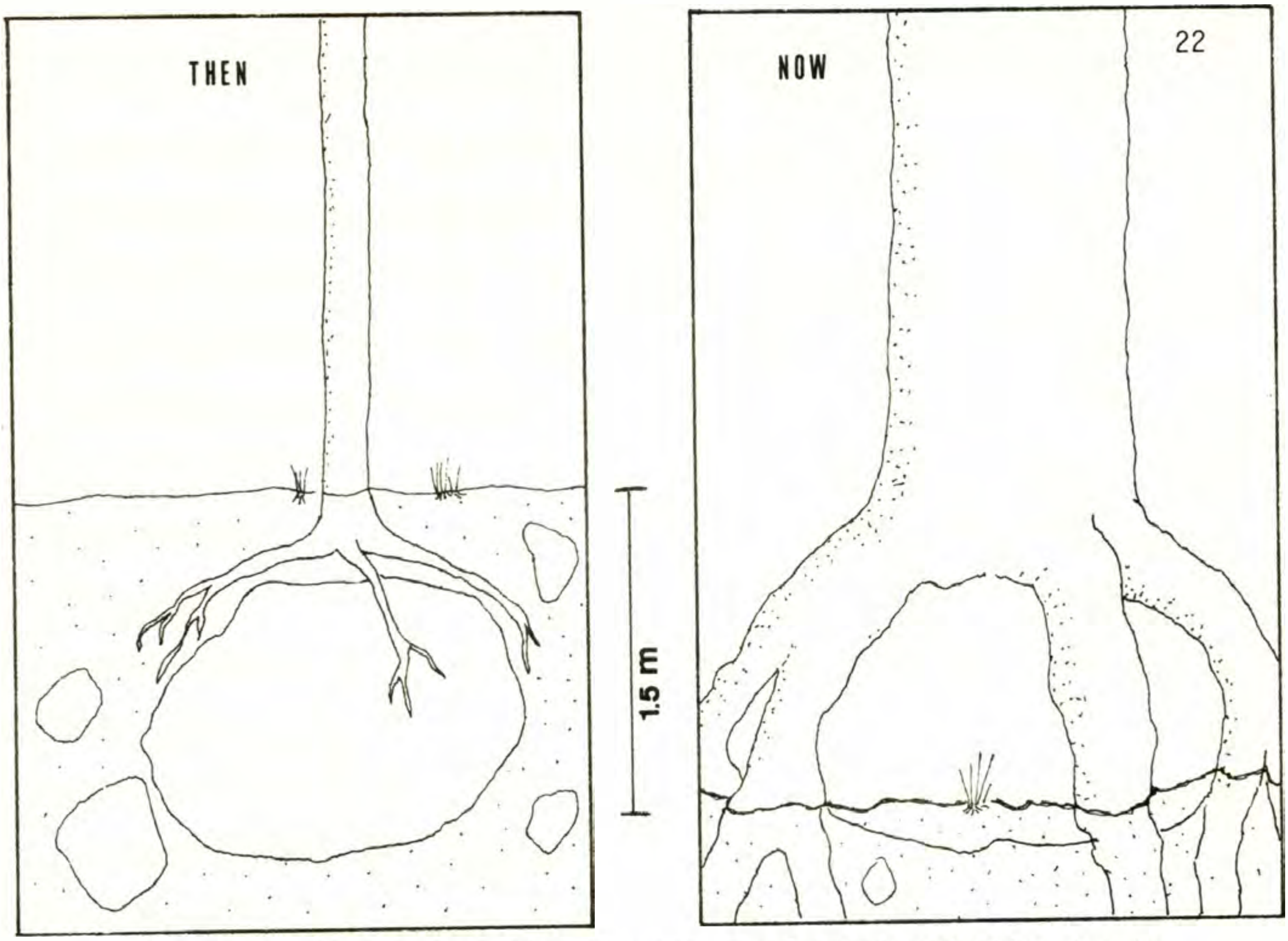


Figure 5. Sketch depicting the amount of crest reduction due to erosion on the pre-13th century moraine, Middle Fork Nooksack Valley.

and mosses. No ash was found on this moraine.

This moraine, referred to as the pre-13th century moraine, is at least 800 years old, based on the relationship between the living and downed trees, and may be much older, possibly constructed by the Deming Glacier 2000 or more years ago. Evidence for this estimate is discussed in the section on results of dating methods.

Erosional remnants of a much younger Neoglacial moraine are exposed in two places: (1) on the southeast valley wall, upriver from the two intermittent streams mentioned above, and (2) on the northwest valley wall above the present glacier terminus. The moraine is truncated downriver by an intermittent stream which parallels the moraine before joining the river. The confluence of the intermittent stream with the river is near the maximum downvalley extent of the moraine (Fig. 3). The moraine merges upriver with a 17th century moraine.

This moraine is 200 m long and 70 cm high, supporting a first-generation forest approximately 450 years old. The crest is segmented on the northwest wall by landslides. Downed trees less than 1.5 m in diameter, in the early stage of decomposition, rest in approximately 20 cm of forest duff in obvious contrast to the older forest beyond this moraine. A reddish brown (2.5YR 4/4) B_2 horizon is developed to 60 cm depth on the crest of the moraine. No exposures of the moraine are found in river cutbanks due to debris from the younger mudflow. The oldest tree cored on this moraine is 420 years old, suggesting that the moraine was constructed in the early 16th century.

The first well-preserved Neoglacial advance is marked by a lateral moraine with a slightly rounded crest. It can be traced along the south valley wall from above the glacier terminus to its intersection with the river and discontinuously along the north valley wall. The oldest tree cored began growing in the 1600's (17th century). Morainal deposits from this advance are exposed in river cutbanks 2.5 km down-river from the present glacier terminus. The younger mudflow has been eroded by this advance (Fig. 4).

A deeply weathered paleosol approximately 1.5 m thick is exposed in a few places at the base of the 17th century moraine. Based on topographic relationships, thickness, and color (10YR 6/6) this weathering profile may be correlative with the weathered surface exposed in the valley walls near the terminus of the Deming Glacier. The age of the weathered surface is uncertain and is discussed in the section on results of relative dating.

Several well-defined, sharp-crested moraines and associated trimlines are present upvalley from the 17th century moraine. Two of the moraines date to the early and late 19th century and six record standstills during this century.

Buried logs are present in a six m cutbank exposure of the early 19th century moraine (Fig. 3). The age of the logs prior to burial is estimated to be approximately 100 years based on the diameter of the largest log (60 cm). Lichen suitable for measurement were not found on this moraine. The oldest tree cored on this moraine is 142 years (1837). This moraine is one m high, 1.5 m wide, and the crest is only slightly rounded; the crest is weathered to a depth of 40 cm. This early 19th century moraine merges upvalley with the late 19th century moraine (1889). Together they form a double crested lateral moraine on the southeast valley wall above the present glacier terminus and are one m higher in elevation than the 17th century lateral moraine. Since the downvalley extent of the 17th century advance is greater than that of the 19th century, the difference in crest height (1 m) may reflect a minimum amount of crest reduction on the 17th century lateral moraine.

Distinctive trimlines accent the early 20th century moraines which are covered by dense thickets of alder and willow (Plate 4). The oldest trees cored on these moraines are 54, 32, 23, and 17 years respectively. Two recently constructed lateral moraines exposed on the southeast valley wall, 12 m below the 19th century lateral moraines, are devoid of vegetation. Thirty-five cm of silty clay is exposed in a creek cutbank between the moraines dated by tree rings at 54 and 32 years respectively.

PLATE 4. Twentieth century moraines and associated trimlines of the Deming Glacier.

The sediment exhibits alternating beds of dark grey silt grading upwards into light grey clay which are about 1.5 cm thick. The deposit appears to be varved. Fifteen varve couplets were counted. The deposit is overlain by outwash sands and gravels. Deposition of the silty clay probably was in a small lake ponded behind a morainal dam (54 years) or ponded behind one of three landslides. Three unforested landslide scarps are present just downriver from the varved sediment exposure.

Lichen diameters were not measured on the 20th century moraines. In June of 1927 a large ice and boulder avalanche was reported (Easton, 1911) to have transported debris 9.5 km down the valley. Blocks from this event are strewn about these moraines, severely complicating lichenometric measurements.

Hydrothermally altered sand and rock fragments rest on the oldest 20th century moraine. Several rock fragments are 15 cm across and emit a strong sulphurous odor. Similar ejecta have been described elsewhere in the Mt. Baker area by Easterbrook (1975) and Hyde and Crandell (1978). The mode of deposition of this ejecta in the Middle Fork Nooksack Valley is duscussed in the section on dating methods.

In September of 1979 a small moraine, 45 cm high and 60 cm wide, was exposed 1.7 m beyond the terminus of the glacier. The moraine is composed of angular andesite boulders and minor sand matrix. This boulder-rich moraine was probably constructed during the 1979 ablation season by accumulation of supraglacial material derived from the Black Buttes. Evidence from aerial photographs and historical records (Long, 1953) suggest that the Deming Glacier has been advancing since about 1950.

Evidence for two buried moraines is exposed in both valley walls beneath the 19th century lateral moraines (Fig. 3, Plate 5). The older buried moraine exhibits a yellow oxidized (10YR 7/6) weathering profile about 1.5 m thick and is exposed 3.5 m below the 19th century lateral moraines. A similar exposure is seen in the northwest wall of the Coleman-Roosevelt Glacier valley (Plate 6). The older buried moraine is apparently the result of a stillstand following construction of the pre-13th century moraine, and a lengthy period of recession, prior to readvance and deposition of the 16th century moraine. Evidence presented in the section on results of relative dating suggests that the pre-13th century moraine is correlative with the Burrows Mountain Stade of the Winthrop Glaciation at Mt. Rainier, 2000-3500 years B.P. Therefore, the older buried moraine reflects a less advanced stand of the glacier between approximately 1000-2000 years ago.

Buried in situ tree stumps are exposed at the surface of a younger buried moraine which occurs one m above the older buried moraine. The bases of these trees were apparently buried in till and then sheared off by advancing ice. Abraded logs exposed in the early 19th century moraine, 1.5 km downvalley from the in situ stumps, suggests that the overrun moraine containing the stumps dates to the 18th century (Plate 7). Wood from both exposures was collected for future radiocarbon dating. Sample collection localities are found in Appendix A.

Avalanche Gorge

The Neoglacial deposits of the Rainbow Glacier are modified by two historic rock-debris avalanches which date to the early 1860's and to 1888. A remnant of a lateral moraine predates the 1860's avalanche deposits and may date to the 16th century. A prominent, sharp crested,

PLATE 5. Buried moraines in the Middle Fork Nooksack stratigraphic sequence.

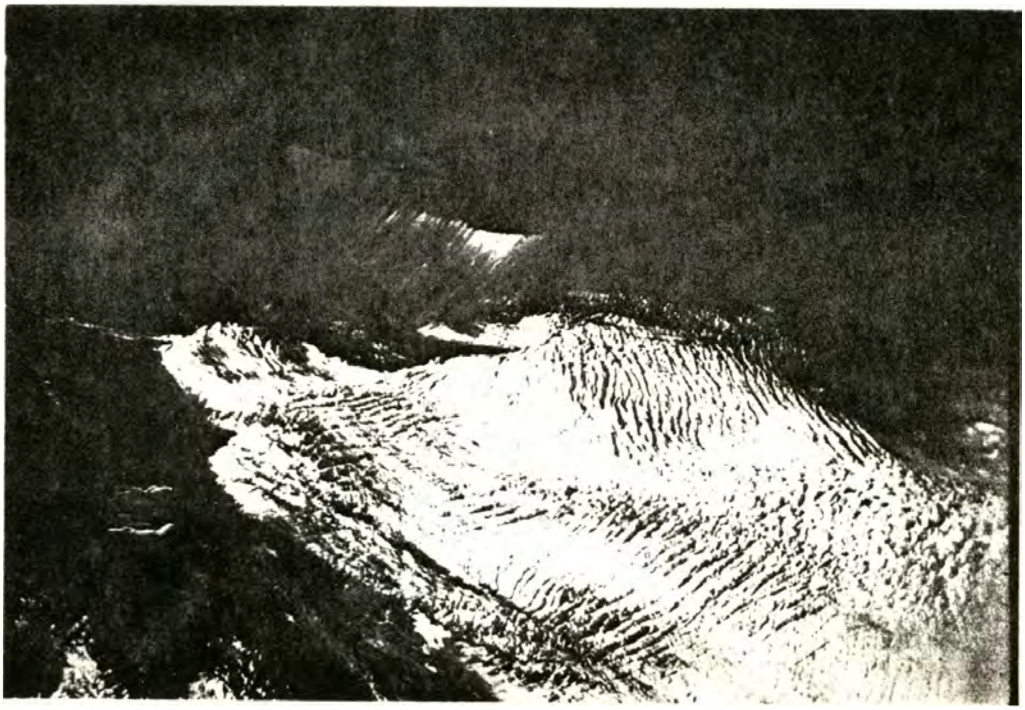


PLATE 6. Buried moraine in the valley of the Coleman-Roosevelt Glacier (photo by D. J. Easterbrook).

PLATE 7. Buried logs exposed at the base of the early-19th century moraine approximately 1.5 km downvalley from the 1979 glacier terminus.

early 20th century moraine postdates 1888 avalanche deposits and encloses several 20th century recessional moraines (Fig. 6), the youngest of which in turn encloses 2000 m^2 of ablation morainal deposits.

Lower-Valley Stratigraphy

The lower-valley stratigraphic sequence is exposed three km downvalley from the 1979 glacier terminus. A 15 m section is exposed on the north cutbank of Rainbow Creek. Mt. Baker andesite, exhibiting glacial striations, is overlain by a grey diamicton which resembles till. Deposits of two historic rock-debris avalanches overlie the diamicton (Plate 8).

The rock-debris avalanche deposits were formed when a large mass of rock avalanched from Lava Divide (Fig. 1) onto the glacier. Depending upon the season, ice and snow may be incorporated in the mass movement. The rock debris travels rapidly down the glacier and may cause some melting. When the mass reaches the glacier terminus, outwash and morainal sediments accompanied by meltwater are mobilized and incorporated in the moving mass. This chaotic assemblage of sediments continues downvalley, removing the forest in its path, and blankets the valley floor with debris to form hummocky topography. The resulting deposit varies considerably along its downvalley extent in thickness, composition, and texture.

The underlying diamicton which is thought to be a till consists of unweathered clasts of Mt. Baker andesite. The clasts are subangular and less than 30 cm in diameter. The grey clayey silt matrix has no oxidation halos surrounding the clasts. The deposit is massive and well compacted in sharp contrast to the overlying rock-debris avalanche sediments which

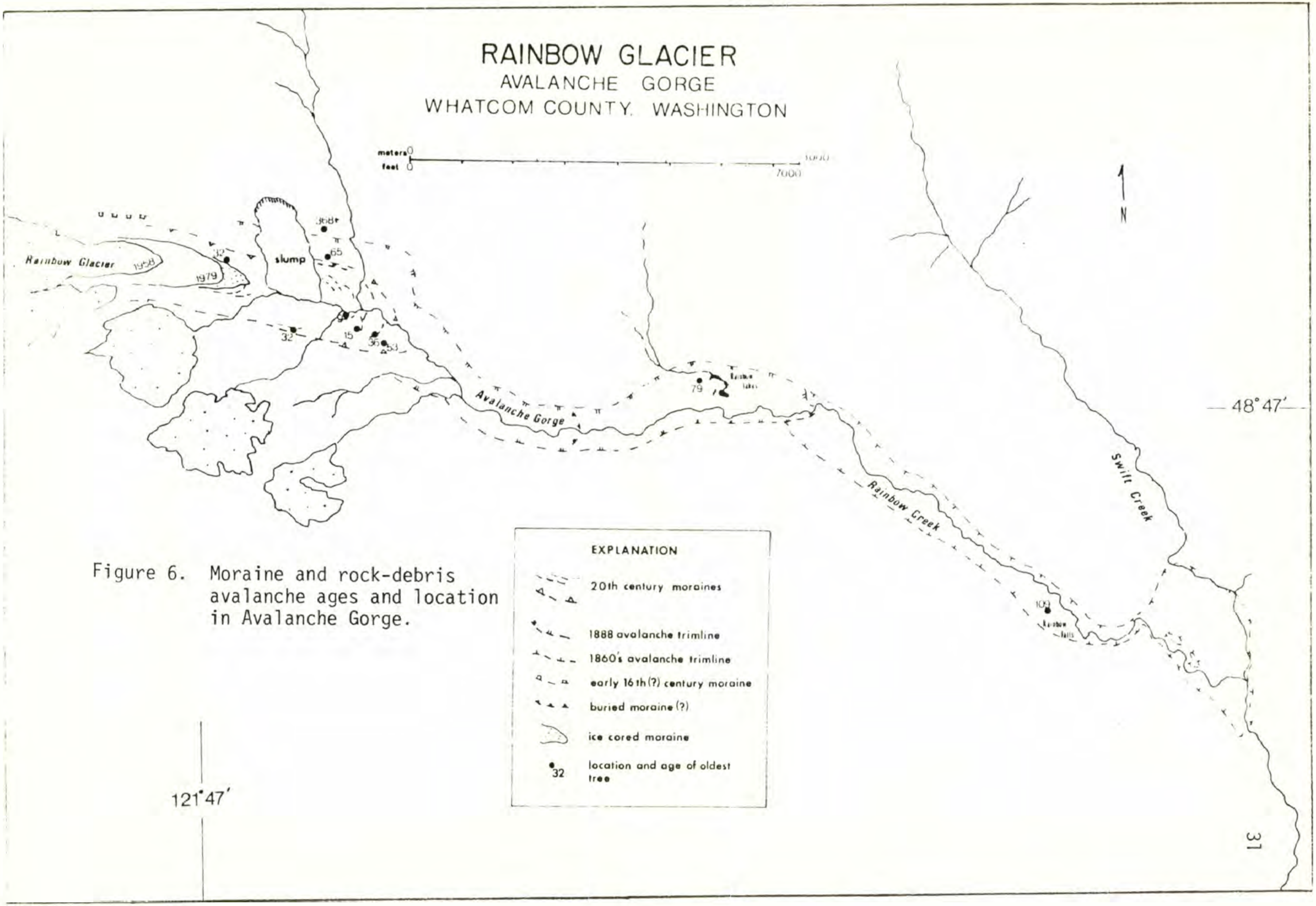


Figure 6. Moraine and rock-debris avalanche ages and location in Avalanche Gorge.

PLATE 8. Diamicton (till) exposed beneath rock-debris avalanche deposits in Avalanche Gorge. The exposure is approximately 15 m high.

PLATE 9. View upvalley of the same exposure in Plate 8. The morphology is suggestive of a terminal moraine.

show little compaction. Based upon the morphology of a six m high, subdued arcuate ridge on the valley floor, this till may be a buried end moraine (Plate 9). Extrapolating an approximate ice gradient upvalley to the present terminus locates the ice margin in the vicinity of the oldest preserved lateral moraine and supports this interpretation.

Two rock-debris avalanches, which overlie the till, have been briefly described by Hyde and Crandell (1978). Trimlines from both mass movements can be readily identified on aerial photographs. The older rock-debris avalanche occurred in the mid-1860's (Easton, 1911) and is best exposed in creek cutbanks between Rainbow Lakes and the confluence of Rainbow and Swift Creeks. The oldest tree cored in the first generation forest growing on the deposit is 109 years. The five to seven year difference between the date of the avalanche and the oldest tree suggests that reforestation was rapid. Lichen thalli diameters were not measured on this deposit (see results of dating methods).

The younger rock-debris avalanche occurred in 1888. This date is based on a tree-ring count obtained from a partial radial section removed from an avalanche damaged tree. Deposits from this event are best exposed 4.5 km downvalley from the 1979 glacier terminus and extend past Rainbow Falls. The deposit is poorly sorted and contains some blocks greater than three m in diameter set in a sandy cobble matrix. The deposit occurs as a hummocky surfaced veneer, generally two m thick, mantling the valley floor. Between the glacier terminus and Rainbow Lakes this deposit looks like a debris flow. The oldest tree cored on the 1888 debris avalanche deposits is 79 years (1900). The slightly longer reforestation time of 12 years may be due to seed-source removal by the earlier rock-debris avalanche.

Although the longer reforestation time can be used as an argument favoring two separate events (first the 1888 rock-debris avalanche followed possibly 10 years later by a debris flow (1900)), the author favors the single event hypothesis. A rock-debris avalanche with a magnitude great enough to sweep past Rainbow Falls probably generated the less extensive debris flow-like deposit. The 1888 rock-debris avalanche appears to be a continuum of textures, composition, and thickness. At the proximal end of the deposit it exhibits debris flow characteristics, at the distal end it is predominantly a boulder avalanche.

Upper-Valley Stratigraphy

A 400 m long remnant of a lateral moraine is located on the north valley wall 110 m above the 1979 glacier terminus (Fig. 6). Elsewhere, the moraine is covered by avalanche debris or has been eroded. The crest is severely eroded and is essentially a flat, one meter-wide mountain goat thoroughfare, with gently sloping sides. The moraine is composed of Mt. Baker andesite and lacks the large blocks of andesite flow breccia which are common in younger moraines. The morainal surface is devoid of vegetation and is deeply weathered to a yellow-grey (10YR 4/6) color. Exposures in a small creek show that the weathering profile is 45 cm thick on the crest. The color of the fresh till is grey and the matrix lacks oxidation halos around the clasts. Lichen growing on andesite clasts on the moraine measure 36 mm in diameter. The rounded crest morphology, thick weathering profile, and topographic position attest to the moraine's relative antiquity. No trees are growing on this moraine. By extrapolating an approximate ice gradient from the remnant lateral moraine downvalley, the estimated location of the terminus of the glacier during construction of the lateral moraine is very near the till located three km downvalley from the present terminus. Positive correlation of the lateral moraine with the till is not possible, but highly suggestive. This moraine may date to the 16th or 17th century.

A prominent sharp-crested moraine occurs three m below the moraine just described. It can be traced discontinuously along both valley walls and across the valley floor. At its maximum downvalley extent, the moraine is three m high and is composed of large blocks of andesite flow-breccia (>1 m in diameter) reworked from earlier avalanche deposits, or transported as supraglacial debris to the terminus.

Cross-sections, exposed in two locations where the moraine is breached by streams, reveal a 15 cm light brown (10YR 5/3) weathering profile. The oldest tree on the moraine began growing 53 years ago. Maximum thalli diameters of lichen measure 38 mm. This moraine was probably constructed about 1900 A.D.

Nested within the 1900 moraine is a rather complete record of the glacier's activity since that time. Several short-lived standstill in a rapid recession are preserved in three sinuous moraines which enclose a 2000 m^2 exposure of ablation moraine (Fig. 6). The three most prominent recessional moraines do not exceed two m in height and are very fresh in appearance (Plate 10). Tree-ring counts and maximum lichen-thalli diameters for the three moraines are 36 years and 35 mm, 15 years and 24 mm, and 9 years and 15 mm, respectively.

A 2400 m^2 rotational slump on the north side of the valley, active prior to 1947, overlies ablation moraine on the valley floor and cuts the

PLATE 10. Twentieth century moraines of the Rainbow Glacier.

20th century moraines. Evidence from 1947 and 1972 aerial photographs indicate that the glacier has not advanced downvalley past the slump. No trees are found growing on the slump-covered moraine. This indicates that reforestation of ablation moraine in Avalanche Gorge may take as long as 32 years.

Ablation moraine near the present terminus is ice cored. In August of 1979, clean ice of Rainbow Glacier was observed shearing over the stagnant, ice-cored morainal deposits and deposition of flow till was observed. A 32-year-old tree, growing on the north side of the valley, was being buried by till of this advance.

RESULTS OF DATING METHODS

Absolute Methods

Tephrochronology

Mazama tephra provides a time-stratigraphic marker for post-Hypsithermal deposition. In the Middle Fork Nooksack Valley Mazama tephra is overlain by a mudflow containing wood fragments which have yielded a radiocarbon age of 5,980 ± 250 years B.P. (W-2944) (Hyde and Crandell, 1978). No other tephra layers were found in the Nooksack drainage, and none were found in Avalanche Gorge. Mazama tephra in the Nooksack drainage was used to assign a maximum age to the first recognizable Neoglacial advance. This tephra was also used to assign a minimum age to a post-Fraser till in the Nooksack River Valley.

Recent ejecta from Mt. Baker is restricted to the surface of the earliest 20th century moraine in the Middle Fork Nooksack Valley. This suggests that the altered rock was erupted from Sherman Crater onto the surface of the Deming Glacier prior to, or during construction of the early 20th century moraine and transported as supraglacial debris to the moraine. Particle size of the ejecta ranges from 15 cm to 2 mm, is hydrothermally altered and emits a strong sulfurous ordor. Similar material was not found in Avalanche Gorge. Hyde and Crandell (1978) report similar deposits elsewhere in the Mt. Baker area and consider them to represent ejecta from several eruptive events during the past 200 years.

Dendrochronology

Absolute minimum ages for Neoglacial deposits were determined by dendrochronologic methods. Tree-core data for the different deposits are compiled in Appendix B. No attempt was made to develop a tree ring chronology.

Although evidence of Neoglacial fluctuations of Rainbow Glacier is not well preserved in morainal deposits, three separate reforestation times were determined for Avalanche Gorge. Historical accounts of a large mass movement, which removed the forest from the terminus of Rainbow Glacier to the confluence of Rainbow and Swift Creeks, indicate that the event occurred about 1863 (Easton, 1911). The oldest tree cored on deposits of this avalanche is 109 years (1870). The seven-year difference in time between the age of the oldest tree and the age of the deposit suggest that reforestation was rapid.

A slightly longer reforestation time was determined for deposits from the younger rock-debris avalanche. The date of the event was determined by analyzing a partial radial section removed from a tree damaged by the avalanche. The bark had been scraped off on the canyon-facing side and an angular clast was embedded in the bark-free surface 3 m above the ground. By counting the annual tree rings, a date of 1888 (91 years) was obtained for the time of bark removal. The oldest tree cored growing on the deposit was 79 years (1900).

A third minimum reforestation time was determined in the area of the rotational slump near the terminus of Rainbow Glacier. In this area the slump overlies ablation moraine on the valley floor. No trees are growing on the ablation moraine. The slump is present on a 1947 aerial photograph. Therefore, reforestation of ablation moraine during this century exceeds 32 years. The longer reforestation time is primarily controlled by the time necessary for the stablization of the morainal surface. Due to the ice-cored nature of these deposits, stabilization of the moraine may take several decades.

In the area of the Middle Fork drainage, no control dates were found that could be used to establish reforestation times. Reforestation time for moraines deposited by the East Nooksack Glacier, Mt. Shuksan, is 25 years (Robert Zasoski, personal communication). Reforestation in the Middle Fork drainage is thought to be rapid, probably less than 10 years, based on the available seed source from the surrounding forest.

Relative Dating

Lichenometry

The use of lichenometry as a relative dating (RD) technique was of limited use in the two glaciated valleys of this study. Several restricting factors became apparent during the course of the fieldwork. As both glaciers terminate below timberline, reforestation is nearly synchronous with ice recession and deposit exposure. In this environment, lichens are rapidly crowded out by mosses or buried in forest litter.

On several of the moraines, only the largest boulders have exposed surfaces available to lichen colonization. Many of these large boulders are younger than the deposit, having been deposited later by one of the many rock, snow, or debris avalanches. In other instances, the boulders have been progressively weathered out of the moraine to their present exposure. These large boulders (>1 m in diameter) are composed of andesite flow-breccia which is extremely susceptible to weathering. In deposits less than 100 years of age, many of these boulders have disintegrated to a rubble mound. Thus, the exposed surfaces on these boulders are not conducive to lichen colonization. This observation was reached independently by Porter and Burbank (1979) on Mt. Rainier.

The use of lichenometric methods as a RD technique was restricted to moraines in Avalanche Gorge. All lateral and recessional moraines, with one exception, were forested. The author's intent was to calibrate a lichen growth curve and attempt to date an unforested remnant of a lateral moraine. Results indicate that the obviously older remnant lateral moraine was younger than the earliest 20th century moraine (Appendix C). The younger lichen population on the older moraine is apparently renewed colonization following a lichen kill. Burbank (1979) reports a lichen kill on Mt. Rainier approximately 150 years B.P. Lichen kill by burial in a permanent snow bank for one or more years is probably responsible for the anomalously young lichen colony.

Rock Weathering

In the Mt. Baker area, the only rocks old enough to show measurable rock weathering parameters, other than the flow breccia blocks, are andesite clasts which predate Mazama tephra. The most obvious weathering feature in pre-Mazama exposures consists of oxidation halos in the matrix surrounding clasts. In a diamicton immediately underlying Mazama tephra these halos measure about one cm in thickness. The halos are apparently the result of oxidation of iron originating from the clasts.

Andesite clasts within pre-Mazama deposits reveal the first occurrence of measurable weathering rinds. Many of the clasts have rind thicknesses less than .5 mm. All of these clasts have coatings of iron oxides and clay about one mm thick.

Deposits which postdate Mazama tephra lack measurable weathering characteristics which could be used for dating. Clasts within moraines do not exhibit weathering rinds and their surfaces are only slightly oxidized. However, some of the clasts have oxidized surfaces, which suggest reworking of older deposits.

Soil Development

Soil weathering profiles were measured on moraine crests to determine relative age. Colors were based on comparison with a Munsell soil color chart. Measurements of B_2 weathering horizon thickness were made on all moraines and on buried soils in the Nooksack drainage. These measurements could not be used for intervalley correlation because the soil profiles of forested moraines of the Deming Glacier are different from those of the sparcely forested moraines in Avalanche Gorge. Soil weathering profiles on forested and unforested moraines in the Nooksack Cirque, Mt. Shuksan, show drastic differences in degree of development (Robert Zasoski, personal communication).

The measurement of B_2 weathering horizon thickness to indicate relative age proved useful in the correlation and chronology of buried moraines in the Middle Fork Nooksack Valley. Exposed in the southeast valley wall, above alder thickets growing on the 20th century moraines, the following stratigraphic sequence is observed: a 1.5 m weathering profile (paleosol) occurs approximately 10 m above the valley floor. A weakly developed 10-20 cm paleosol containing in situ tree stumps occurs one to three meters above the older, lower paleosol. An early 19th century moraine overlies both paleosols (Plate 5). The lower paleosol is also overlain by a 16th century moraine.

The paleosol containing in situ tree stumps is interpreted as the weathered surface of an 18th century moraine which was overrun by a more extensive ice advance in the early 19th century. Abraded logs exposed at the base of the early 19th century moraine, 1.5 km farther downvalley, supports this interpretation (Plate 7).

Evidence for an 18th century moraine is preserved in Nooksack Cirque on Mt. Shuksan (Robert Zasoski, personal communication). No 18th century moraine is found in the moraines of Price Glacier on Mt. Shuksan but Leonard (1974) suggests it may have been overrun.

The lower paleosol is deeply weathered, yellowish brown (10YR 5/6) and 1.5 m thick. Clasts in the paleosol do not exhibit weathering rinds. This paleosol is also capped by the 16th century moraine. Exposures of the paleosol are not found downstream past the 17th century recessional moraine. Based on the linear outcrop exposure and the preservation of the weathering surface on bedrock, the paleosol is interpreted as the weathered surface of a buried moraine. On the basis of similar color, thickness, and topographic relationships, the paleosol in the Middle Fork Nooksack Valley may be correlated to an analogous outcrop in the valley of the Coleman-Roosevelt Glacier (Plate 6). The buried moraines in the Coleman-Roosevelt and Nooksack Valleys are overlain by moraines dating to the last five centuries. They do not appear to have been overrun by the pre-13th century moraine (>800 years old); thus, the pre-13th century moraine is thought to be older than the lower paleosol. The glacier advance responsible for deposition of the large pre-13th century moraine probably would have removed the paleosol if it has existed prior to that advance (Plate 11). The possibility that the paleosol weathered through the Hypsithermal interval is unlikely because of its stratigraphic position and the lack of weathering rinds developed on the clasts.

An approximate age can be assigned to the pre-13th century advance

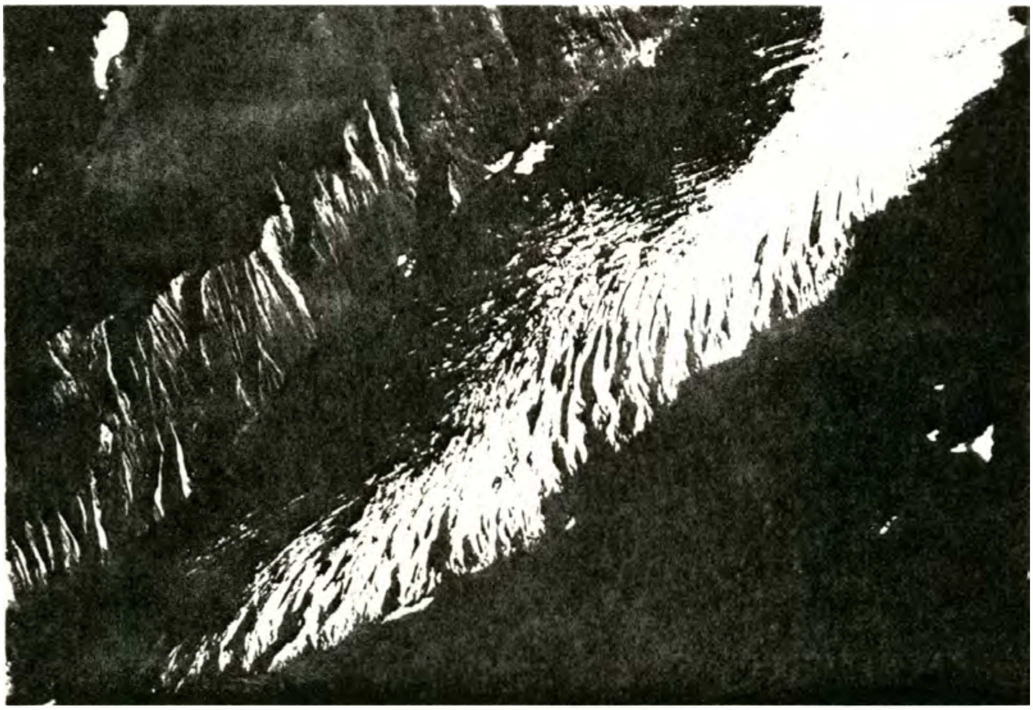


PLATE 11. Relationship between the extensive pre-13th century advance of the Deming Glacier and less extensive advances during the past five centuries. View to the northwest, Middle Fork Nooksack Valley. Pre-13th century moraine in lower right hand corner (photo by D. J. Easterbrook).

based on these relationships. The length of time required to weather a morainal crest to 1.5 m depth is problematic. Weathering profiles developed to 60 cm thick are present on moraines dating to the 16th century. Therefore, the time necessary to weather the buried moraine was at least 450 years. When these observations are summed, a conservative estimate of 1000 years is necessary to span the time from moraine deposition, weathering, and burial of the moraine to the present. This indicates that the pre-13th century moraine is considerably older than 1000 years in age. The ancient forest growing on the deeply weathered and eroded surface of the pre-13th century moraine reinforces this estimate.

The relationships discussed above suggest that the pre-13th century moraines of the Coleman-Roosevelt and Deming Glaciers may have been constructed during the phase of Neoglacial expansion about 2600-2800 years B.P. These moraines may be correlative to moraines on Mt. Rainier of the Burrows Mountain Stade (Crandell and Miller, 1964) which date between 3500-2000 years B.P. The chronology of these moraines is discussed in the following section.

An unforested lateral moraine which occurs as a remnant in Avalanche Gorge is of unknown age except that it predates a rock-debris avalanche of the mid-1860's. A dark yellowish brown (10YR 4/6) weathering profile is developed to a 45 cm depth. Based upon weathering profiles in the Middle Fork Nooksack Valley, the weathering on this moraine has taken place for at least 200 years. Weathering is accelerated on forested deposits (Birkeland, 1974). Whether this lateral moraine was forested in the past is uncertain. This moraine is at least as old as the 18th century. The moraine is undoubtedly older, perhaps dating to the 16th century.

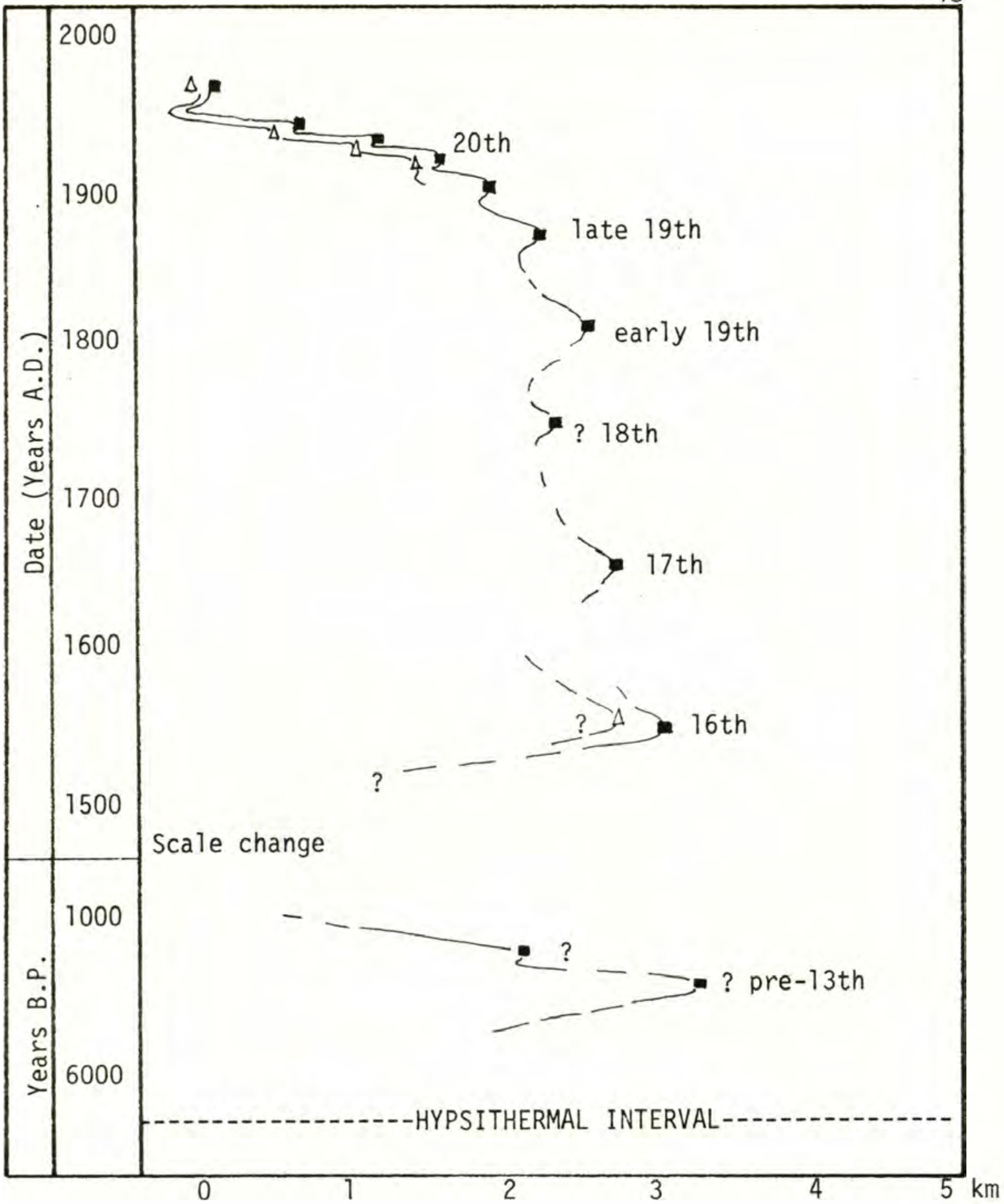
The relative topographic and downvalley position of moraines, coupled with the degree of postdepositional modification, is invaluable in the interpretation of past glacier fluctuations. The best example of this is seen by contrasting the pre-13th century moraine with moraines constructed in the past five centuries.

In summary, dendrochronology, tephrochronology, moraine morphology, degree of postdepositional modification of moraines, and soil development proved to be the most valuable field techniques for dating Neoglacial deposits on Mt. Baker. Linchenometry and rock weathering proved less useful.

CHRONOLOGY

Neoglacial fluctuations of the Deming and Rainbow Glaciers are presented in Figure 7. Although the record for the Rainbow Glacier is short, its response appears to have been similar to that of the Deming Glacier during this century. The record for the Deming Glacier begins early in Neoglaciation with the construction of the pre-13th century moraine, followed by retreat and construction of a moraine which is extensively weathered. Moraines from the most recent Neoglacial expansion were constructed within the confines of the pre-13th century moraine and buried the extensively weathered moraine. Moraines from this expansion date to the 16th, 17th, 18th, 19th and 20th centuries. Each moraine was built during a less extensive stillstand with the exception of the early 19th century advance which overrode the 18th century moraine. Maximum recession of alpine glaciers on Mt. Baker, during the past 500 years, occurred about 1950; since then, glaciers have advanced to their present positions.

This study of the Deming and Rainbow Glaciers coupled with information on the Boulder Glacier (Easterbrook and Burke, 1971; Burke, 1972) and the Easton, Deming and Coleman Glaciers (Easterbrook and Burke, 1971; Easterbrook, personal communciation) provide the data base for developing a Neoglacial chronology for Mt. Baker (Table 1). A generalized curve for the Neoglacial fluctuations of glaciers on Mt. Baker is presented in Figure 8. The first recognizable advance predates the 13th century and is followed by a lengthy period of glacier retreat. Subsequent readvance in the past five centuries built moraines nested within the pre-13th century moraine.



Distance of moraine beyond the present glacier terminus in kilometers

■ = Deming Glacier   Δ = Rainbow Glacier

FIGURE 7. Neoglacial fluctuations of the Deming and Rainbow Glaciers, Mt. Baker, Washington.

TABLE 1. Moraine ages for five glaciers on Mt. Baker, Washington. Dates determined by tree ring counts. Moraines older than oldest tree (*).

MT. BAKER, WASHINGTON						
		Deming (A)	Rainbow	Boulder (B)	Easton (C)	Coleman (D)
Years A.D.		1947	1944			
	1900	1925	1926	1920	1920	1903
		1869		1878		1859
	1800	1835				
	1700	?	*?			
	1600	1627			*?	
		1559				
	1500			1538		
Scale Change						
Years B.P.	800	*? *?			*?	*?
	6000					
Hipisthermal Interval						

(A) Easterbrook and Burke, 1971; Long, 1953; (B) Burke, 1972; Easterbrook and Burke, 1972; Long, 1955; (C) Easterbrook and Burke, 1971; Long, 1953; (D) Easterbrook, 1972, personal communication.

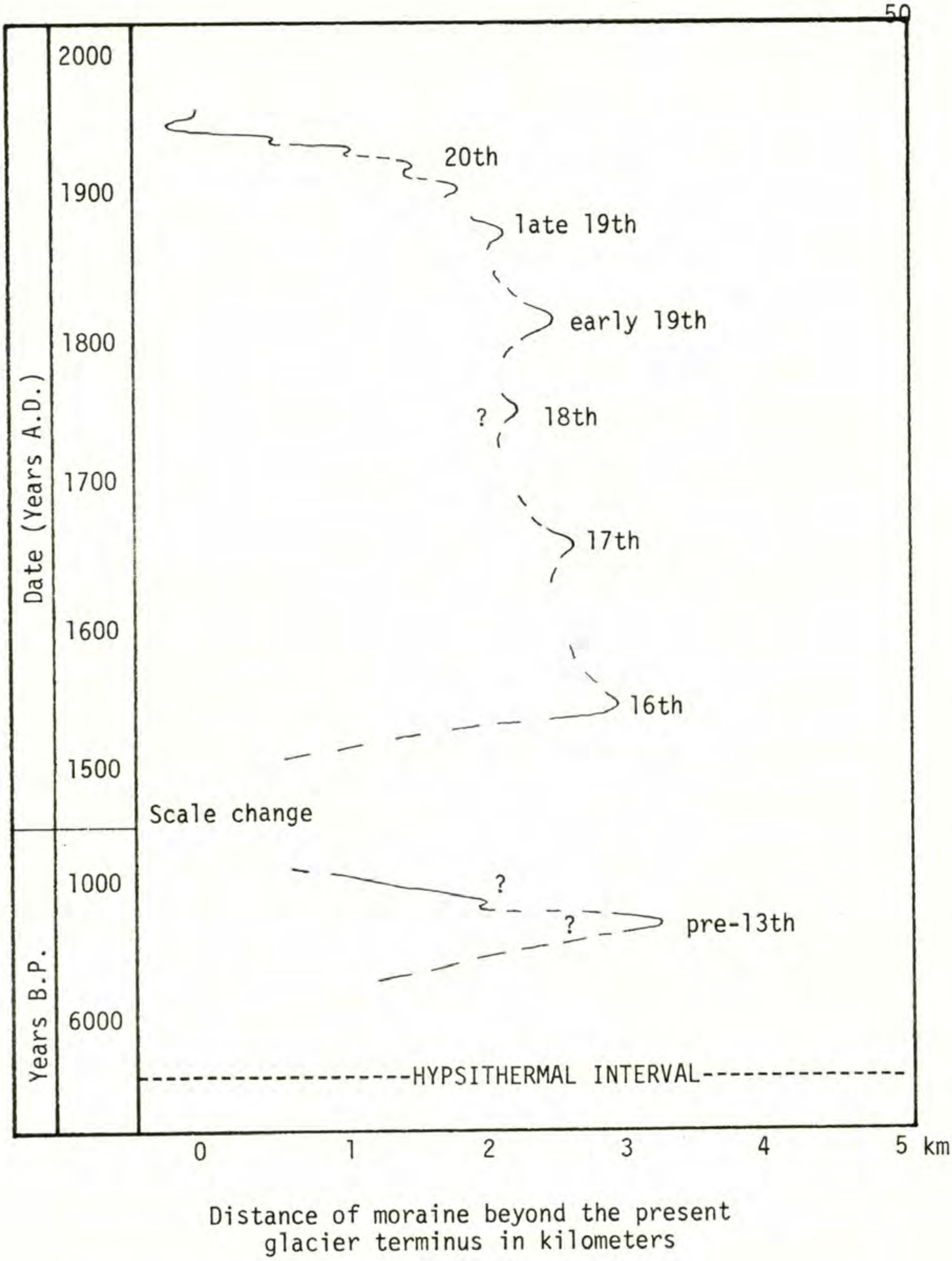


FIGURE 8. Generalized curve for Neoglacial alpine glacier fluctuations on Mt. Baker, Washington. Data from Table 1.

CORRELATION

Examination of Table 2 reveals a broadly synchronous pattern for the Neoglacial fluctuations of glaciers in the Pacific Northwest. Dated moraines from different localities distinguish two periods of expansion during Neoglaciation; an early period between about 5000-2500 years B.P. and a more recent period of expansion within the past eight centuries. The two periods were described by Porter and Denton (1967) who developed a generalized Neoglacial fluctuation curve (Fig. 9). Glaciers on Mt. Baker, Washington, appear to have responded in a similar manner (Fig. 8).

Neoglacial moraines on Mount Rainier are assigned to two stades of the Winthrop Glaciation (Crandell and Miller, 1964; Crandell, 1965). Moraines of the Burrows Mountain Stade were constructed between 3500-2000 years B.P. while moraines of the Garda Stade were built between the 13th and mid-20th centuries. Maximum Neoglacial expansions for different glaciers on Mount Rainier vary considerably but most glaciers reached their maximum position between the 14th and 19th century (Crandell and Miller, 1975).

Neoglacial moraines of the East Nooksack (Robert Zasoski, personal communication) and Price Glaciers (Leonard, 1974) on Mt. Shuksan were constructed in the last five centuries. No evidence for an early Neoglacial expansion is preserved. Moraines of the East Nooksack Glacier date to the late 18th, mid-19th and 20th centuries. Evidence presented by Leonard (1974) suggests Price Lake moraines date to the 16th, 17th, 19th and 20th centuries.

Moraines in the Dome Peak area, North Cascades, contain an excellent

TABLE 2. Compilation of dated moraines from six locations in the Pacific Northwest. Fluctuations of any particular glacier should not be inferred.

	NORTH CASCADES			SOUTH CASCADES	BRITISH COLUMBIA	OLYMPIC MOUNTAINS
YEARS B.P.	(A) Mt. Baker	(B) Mt. Olympus	(C) Dome Peak	(D) Mt. Rainier	(E) Mt. Garibaldi	(F) Mt. Olympus
100	*****	***	****	***	****	***
200	* *?	*	*	*		
300	*		*	*		
400			**	*		*
500	*			*	*	
600				*		
700			*			*
800				*		
Scale Change						
2000	*?					
3500	*?		*	*		
5300					*	

(A) Burke, 1972; Easterbrook and Burke, 1971, 1972; Long, 1955; this study; (B) Bardo, 1980; Leonard, 1974; (C) Miller, 1969; (D) Barendsen et al., 1957; Mathews, 1951; (E) Crandell and Miller, 1974; Sigafoos and Hendrix, 1961, 1972; (F) Heusser, 1957.

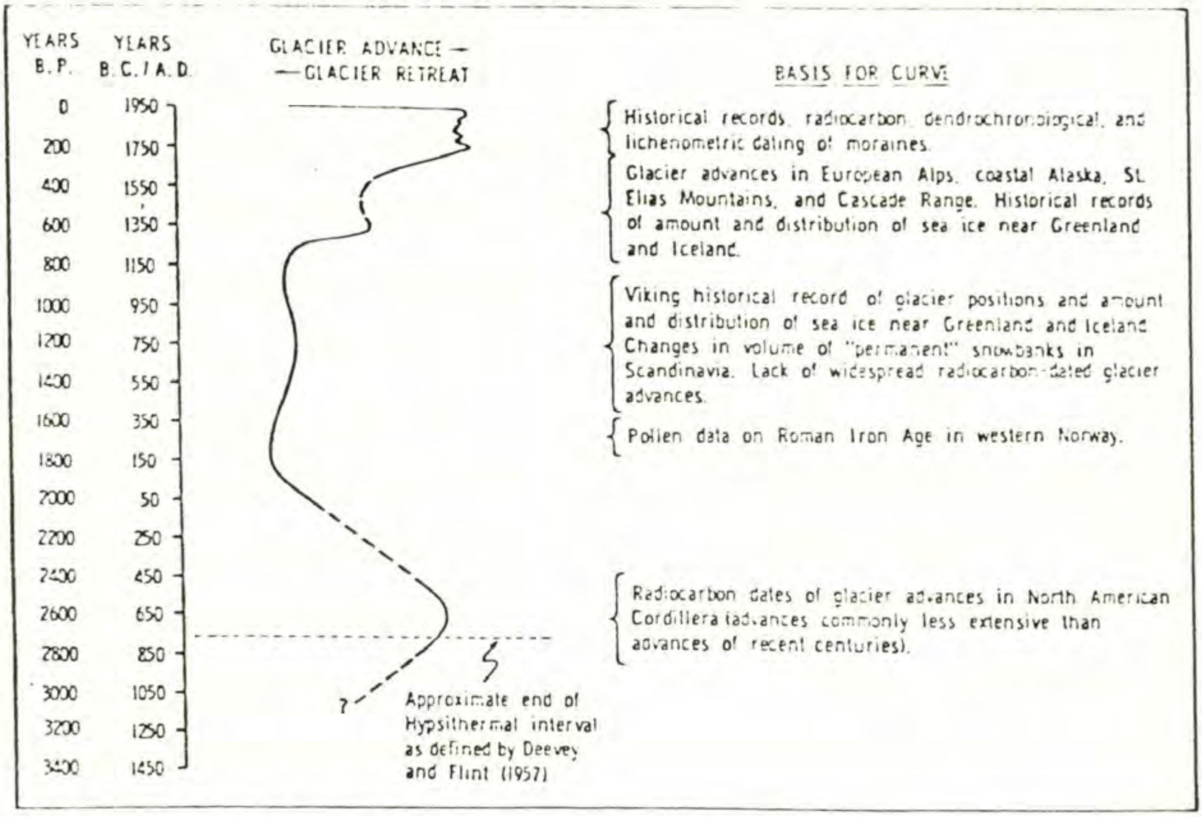


Figure 9. Generalized curve of glacier fluctuations during Neoglaciation (from Porter and Denton, 1967).

record of Neoglaciation. An early advance of the South Cascade Glacier about 4900 years B.P. (Meier, 1964) was followed by more extensive advances in the 16th, 19th and 20th century. Le Conte and Dana Glaciers reached Neoglacial maxima in the late 16th century and built subsequent moraines in the 19th and 20th centuries (Miller, 1969). The Chickamin Glacier behaved somewhat differently by reaching a maximum advance in the 13th century followed by construction of moraines in the 16th, 17th, 18th, 19th and 20th centuries. Evidence for an early Neoglacial expansion of the Le Conte, Chickamin, and Dana Glaciers is not present (Miller, 1969).

Glaciers in the Mount Garibaldi map area, British Columbia, underwent initial expansion about 5300 years B.P. (Mathews, 1951) during the pre-Neoglacial time. Recently constructed moraines date to the

16th, 18th and 19th centuries (Mathews, 1951; Barendsen et al., 1957).

The Neoglacial record of glacial activity on Mt. Olympus, Washington, spans the last seven centuries. Studies by Heusser (1957) indicate that the Blue Glacier constructed two moraines more than 700 years ago and subsequently built moraines in the mid-17th, 19th and 20th centuries. In contrast, the maximum advance of the Hoh Glacier was in 1810.

Although evidence is not overwhelming, the pre-13th moraine on Mt. Baker may be related to a Neoglacial expansion between 2600-2800 years B.P. This would be in general agreement with Neoglacial moraines on Mount Rainier. The period of glacier recession between the two periods of Neoglacial expansion, presented by Porter and Denton (1967), is recognized in the post pre-13th century buried weathered moraine exposed on Mt. Baker. Moraines on Mt. Baker which date to the past five centuries are in good agreement with the youngest portion of the generalized curve for glacier fluctuations during Neoglaciation and moraines elsewhere in the Cascade Range.

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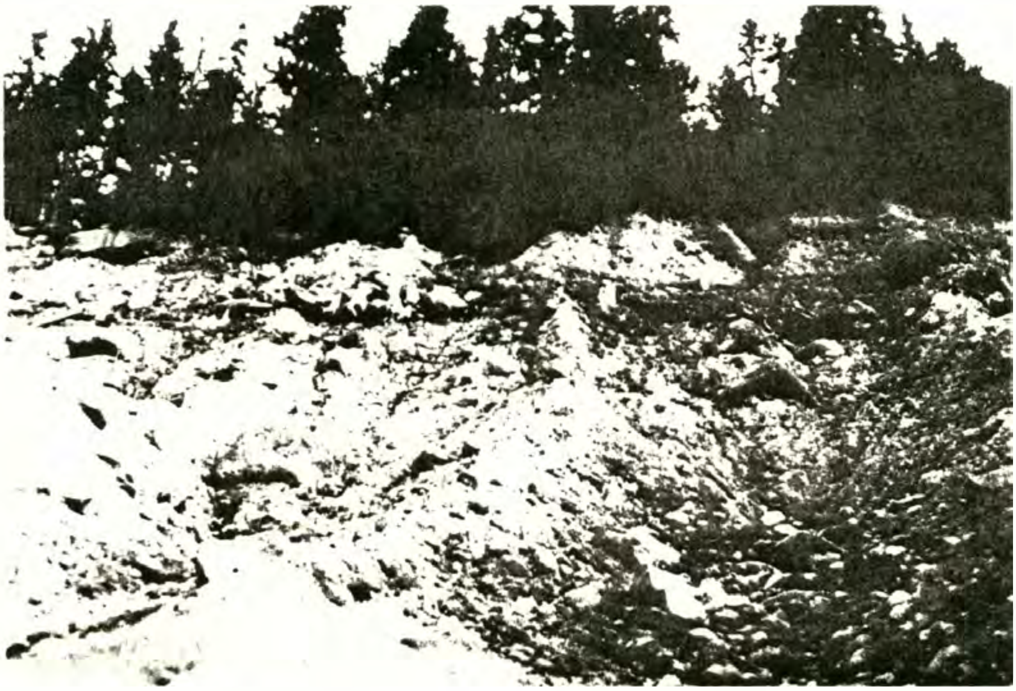
APPENDIX A

Sample DG01 (Radiocarbon sample) Wood collected from south valley wall. Approximately 400 m downvalley from the 1979 terminus, Deming Glacier, Middle Fork Nooksack Valley. Collection site recorded in Plate 5.



Sample DG02 (Radiocarbon sample) Wood collected from southwest river cutbank approximately 1.5 km downvalley from the 1979 glacier terminus, Deming Glacier, Middle Fork Nooksack Valley. Collection site recorded in Plate 7.

APPENDIX B.

TREE CORE DATA: AVALANCHE GORGE

1860's Rock-Debris Avalanche Deposits

Sample #	Diameter (cm)	# of Rings
RBF 01	28.0	101
RBF 02	37.0	106
RBF 03	39.5	98
RBF 04	40.5	91
RBF 05	39.0	108
RBF 06	32.0	107
RBF 07	39.5	96
RBF 08	35.0	101
RBF 09	45.0	109
RBF 10	37.0	105
SCD 01	26.0	89
SCD 02	41.0	105
SCD 03	32.5	102
SCD 04	42.5	104
SCD 05	43.0	99
SCD 06	45.5	97

1888 Rock-Debris Avalance Deposits

RBL 01	27.5	59
RBL 02	30.0	62
RBL 03	30.0	71
RBL 04	29.5	68
RBL 05	29.0	64
RBL 06	26.1	67
RBL 07	22.2	63
UVV 04	25.5	65
UVV 05	30.5	78
UVV 06	25.0	65
OWR 05	24.0	62
OWR 06	22.5	58
OWR 07	31.0	53
UVT 08	20.0	43
UVT 09	13.5	42
UVT 10	18.5	45
UVT 11	21.5	68
UVT 12	30.0	71
UVT 13	27.5	75
UVT 14	28.0	76
UVT 15	25.5	70
UVT 16	26.0	77
UVT 17	23.0	79
UVT 18	29.0	72

APPENDIX B. Continued

1888 Rock-Debris Avalance Deposits (continued)

Sample #	Diameter (cm)	# of Rings	Estimated Age
UVT 20	30.0	77	
UVT 21	29.5	69	
UVT 25	31.0	78	
UW 01	16.5	67	
UW 02	28.0	76	

Early 20th Century Moraine

UVW 01	7.5	52	
UVW 02	7.0	53	
UVW 03	4.5	32	
UVW 04	6.5	41	

20th Century Moraine

UVX 01	4.0	21	
UVX 02	4.5	36	
UVX 03	3.5	26	
UVX 04	4.0	39	

20th Century Moraine

UVC	2.0	11	
UVC	2.0	15	
UTC	1.5	9	

20th Century Moraine

UVZ 01	1.5	9	
UVZ 02	1.0	7	

TREE CORE DATA: MIDDLE FORK NOOKSACK VALLEY

Pre-13th Century Moraine

DGV 050	196.0	207	>650

16th Century Moraine

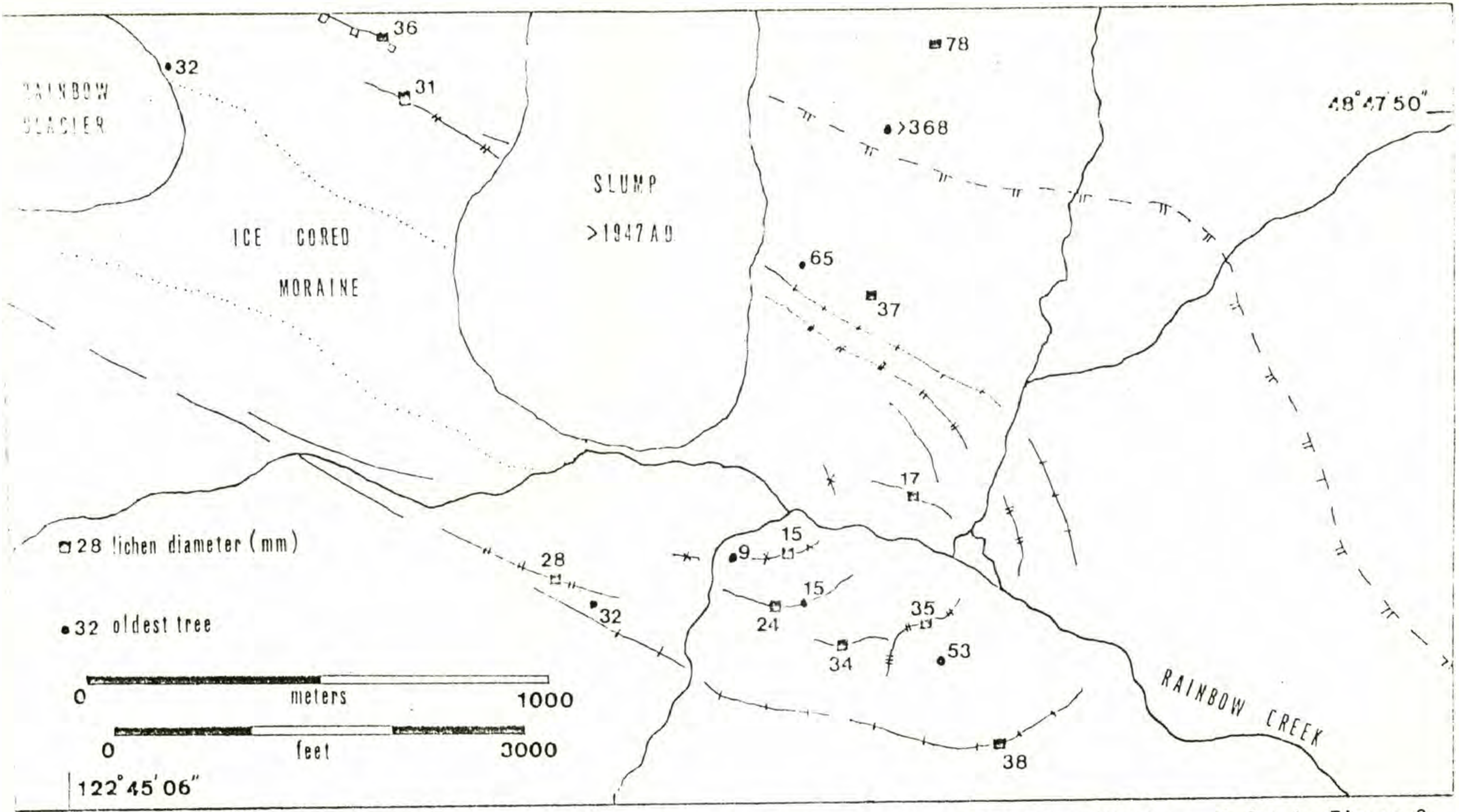
DGV 048	142.0	224	420
DGV 049	138.5	198	401

APPENDIX B. Continued

Sample #	Diameter (cm)	# of Rings	Estimated Age
17th Century Moraine			
DGV 031	76.5	321	356
DGV 032	70.5	289	340
DGV 033	72.0	307	349
DGV 034	68.0	275	304
Early 19th Century Moraine			
DGV 011	85.5	138	
DGV 012	81.0	135	
DGV 013	82.0	121	
DGV 014	80.0	132	
DGV 015	82.5	134	
DGV 016	84.5	137	
DGV 017	83.0	140	
DGV 018	85.0	141	
DGV 019	83.5	136	
DGV 020	86.5	127	
DGV 021	87.0	142	
DGV 022	81.5	140	
DGV 023	80.5	129	
DGV 024	78.0	132	
DGV 025	77.5	139	
DGV 026	70.2	122	
DGV 027	78.5	129	
DGV 028	82.0	135	
DGV 029	85.0	140	
Late 19th Century Moraine			
DGVE 01	65.0	103	
DGVE 02	63.0	98	
DGVE 03	68.0	110	
DGVE 04	67.5	96	
DGVE 05	58.0	98	
DGVE 06	60.5	105	
DGVE 07	64.0	109	
DGVE 08	59.0	105	
DGVE 09	62.5	101	
DGVE 10	60.5	97	
DGVE 11	62.0	105	
DGVE 12	66.0	109	
DGVE 13	61.0	100	
DGVE 14	57.0	92	
DGVE 15	63.5	110	

APPENDIX B. Continued

Sample #	Diameter (cm)	# of Rings	Estimated Age
Late 19th Century Moraine (continued)			
DGVE 16	65.0	103	
DGVE 17	62.5	97	
DGVE 18	66.0	109	
Early 20th Century Moraine			
DGVD 01	23.5	48	
DGVD 02	20.5	42	
DGVD 03	26.0	51	
DGVD 04	27.0	53	
DGVD 05	22.0	46	
DGVD 06	24.5	53	
DGVD 07	27.0	50	
DGVD 08	26.0	49	
DGVD 09	25.0	52	
DGVD 10	27.5	54	
DGVD 11	24.0	51	
DGVD 12	19.5	47	
20th Century Moraine			
DGVC 01	10.0	30	
DGVC 02	8.5	28	
DGVC 03	10.0	30	
DGVC 04	10.0	31	
DGVC 05	11.0	32	
DGVC 06	9.5	27	
20th Century Moraine			
DGVB 01	5.0	22	
DGVB 02	5.0	23	
DGVB 03	4.0	22	
DGVB 04	3.5	19	
DGVB 05	4.0	21	
20th Century Moraine			
DGVA 01	4.0	16	
DGVA 02	3.5	14	
DGVA 03	3.0	11	
DGVA 04	4.0	15	
DGVA 05	4.0	17	
DGVA 06	3.5	12	



APPENDIX C. Maximum lichen thalli diameters and tree ages for moraines of Rainbow Glacier. Refer to Figure 3 for geographic location. Note that the 1900 A.D. moraine supports a lichen population in which the largest thalli measured is 38 mm. The partial remanent of a lateral moraine (16th century?) is colonized by lichens which do not exceed 36 mm in diameter. Limited data restrict construction of lichen-growth curve.