

Tephra of Salmon Springs Age from the
Southeastern Olympic Peninsula, Washington

R. U. Birdseye
R. J. Carson

North Carolina State University,
December, 1974

TABLE OF CONTENTS

	Page
Abstract	1
Introduction	2
Acknowledgments	3
Pleistocene Climate, Glaciation, and Volcanism	4
The Ashes: Their Thickness, Distribution, and Stratigraphic Position	11
Color and Texture of the Ash	19
Composition of the Ash	20
Atmospheric Conditions During Deposition of the Ash	29
Usefulness of Volcanic Ash in Stratigraphic Determination	32
Conclusion	33
References Cited	34

- 1 -

ABSTRACT

The southeast Olympic Peninsula has undergone a long sequence of glaciations and interglaciations. During a nonglacial interval of the Slamon Springs Glaciation, two or more volcanic ashes were deposited on the Peninsula. This tephra has been radiocarbon dated at greater than 41,000 years B.P. Like other ash deposits of the same age or older in Washington, the source of the tephra is unknown. Five samples of this Olympic Peninsula ash have been analyzed. They are similar stratigraphically, and differences of their petrography and chemistry may be mainly due to weathering.

INTRODUCTION

The Southeast portion of the Olympic Peninsula lies between the Olympic Mountains on the west and the Puget Lowland on the east. The entire area was glaciated at least four times during the Pleistocene. The episodes of glaciation are separated by nonglacial intervals, during which weathering, erosion, and nonglacial sedimentation occurred. One of the nonglacial deposits is a layer of volcanic ash that is the subject of this paper. Five samples of this ash, herein referred to "ashes I-V" or samples I-V" will be discussed with reference to their petrologic, stratigraphic, and chronologic aspects.

ACKNOWLEDGEMENTS

The ashes were collected while working for the Washington Division of Geology and Earth Resources under a grant from the United States Geological Survey. Thanks are extended to W. H. Spence, Department of Geosciences, North Carolina State University, for providing X-ray fluorescence data on a sample, and to Mrs. Katherine H. Tew, who analyzed the samples by atomic absorption techniques. Discussions of various aspects of the study with S. W. Buol, Department of Soil Science, and G. F. Watson, Department of Geosciences, North Carolina State University, have been extremely helpful. One radiocarbon date was supplied by the United States Geological Survey.

PLEISTOCENE CLIMATE, GLACIATION, AND VOLCANISM

The Cordilleran ice sheet originated in the mountains of British Columbia. A lobe of this enormous mass of ice was responsible for at least four major glaciations of the Puget Lowland (Crandell et al, 1958; Crandell, 1963) (Fig. 1). Alpine glaciers, originating in the Olympic Mountains, were also responsible for the landforms and deposits formed on the Peninsula. At times the two ice masses merged, obscuring the extent of glaciation on the north and east sides of the Olympic Mountains (Crandell, 1965).

The climatic and geological record of the area from which the ash sample were obtained is as follows (Easterbrook et al, 1967) (Fig. 2):

- Fraser Glaciation
 - Sumas Stade
 - Everson Interstade
 - Vashon Stade
 - Evans Creet Stade
- Olympia Interglaciation
- Salmon Springs Glaciation
- Puyallup Interglaciation
- Stuck Glaciation
- Alderton Interglaciation
- Orting Glaciation

Specific details of the Fraser Glaciation and Olympia Interglaciation will not be discussed, since this paper is primarily concerned with Salmon Springs deposits. Ashes have, however, been erupted in western Washington in post-glacial times. Of the five largest Cascade volcanoes in Washington, which include Mount Adams, Mount Baker, Mount St. Helens, Mount Rainier, and Glacier Peak, all except Mount Adams have ejected ash in post-glacial time (Rigg and Gould, 1957). The youngest ash layer is believed to have been from an eruption of Mount St. Helens in 1802. Numerous eruptions of these and other volcanoes have occurred for over 6,000 years. In addition Mount Mazama, at the present site of Crater Lake, Oregon,

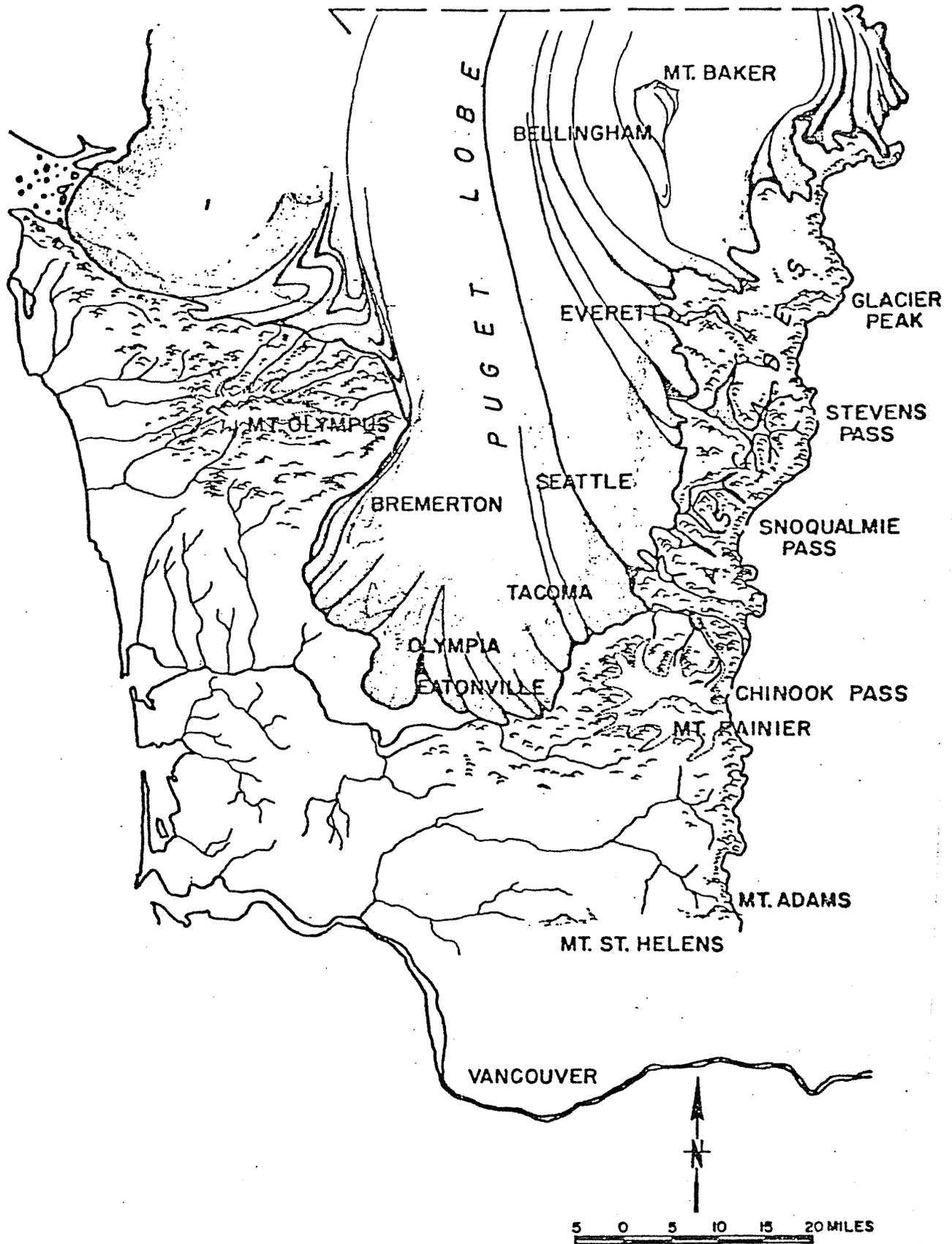
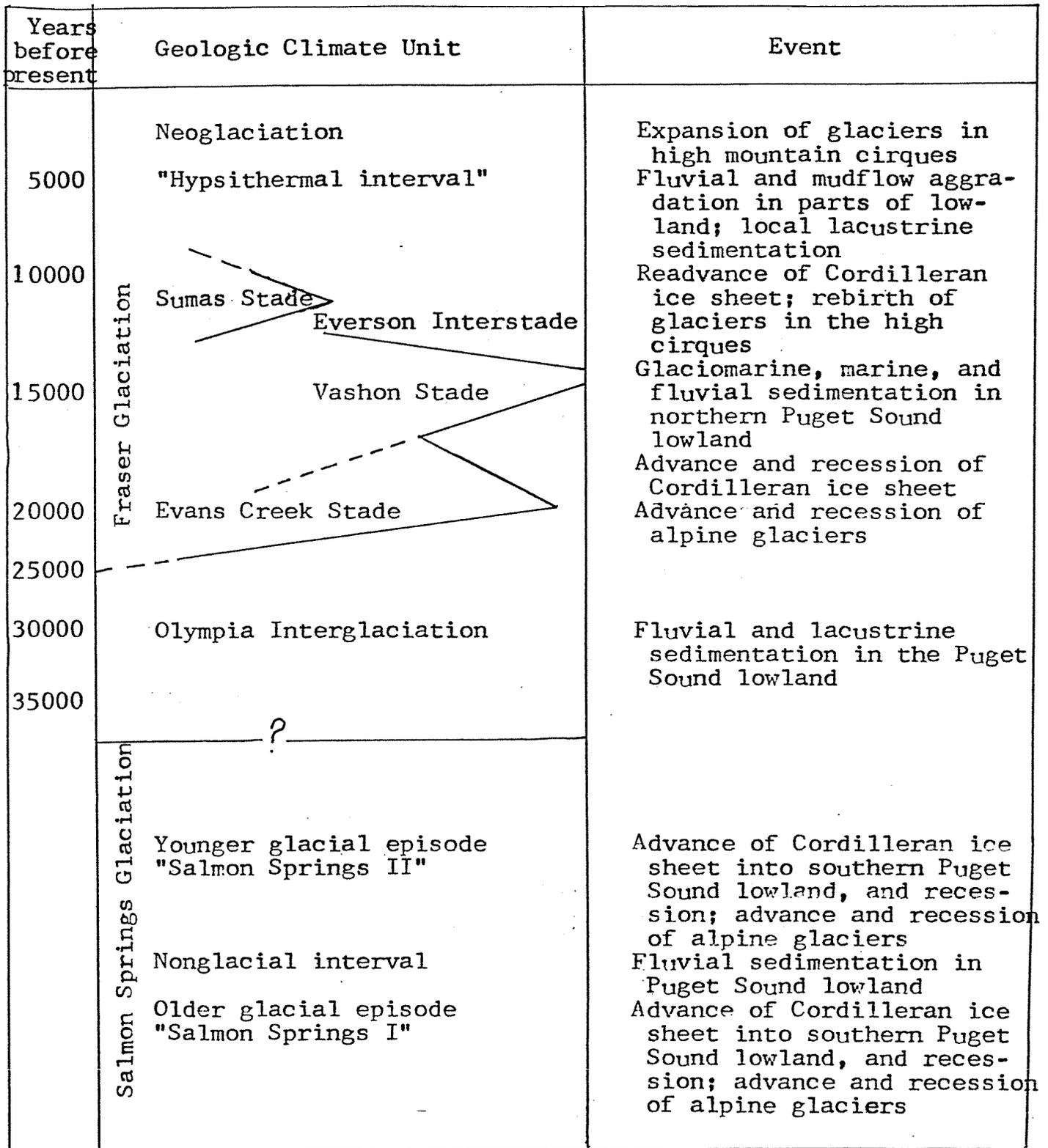


Fig. 1 -
 Maximum extent of the Cordilleran ice sheet.
 (Artim, 1973)

Fig. 2
 Summary of Late Pleistocene Events in Western Washington
 (Crandell, 1965)



erupted 6,600 years B.P., and spread ash over large areas of the Pacific Northwest (Wilcox, 1965), including the southeast Olympic Peninsula (Fryxell, 1965) (Fig. 3).

During the Everson Interstade of the Fraser Glaciation, massive ash deposits were laid down by an eruption of Glacier Peak (Fig. 3). Studies done preceding the 1960's had identified the Mazama ash layers mentioned above as deposited by Glacier Peak (Rigg and Gould, 1957). Powers and Wilcox (1964), using new chemical and petrographic data, found this to be incorrect. Glacier Peak was the source of the older ash deposit, which came from an eruption some 12,000 years B.P. (Fryxell, 1965).

Because layers of volcanic ash are common in the Pacific Northwest, they serve as extremely good stratigraphic markers when applied to geologic and archeologic problems, as long as they are correctly identified and correlated (Powers and Wilcox, 1964).

The ash samples described herein have been radiocarbon dated at greater than 41,000 years B.P. This indicates that they were deposited during the Slamon Springs Glaciation (correlated with Early Wisconsin in the mid-continent) or some older climatic unit.

The Salmon Springs Drift includes post-Puyallup, pre-Olympia glacial deposits (Crandell et al, 1958). Large glaciers formed in the Olympic Mountains twice during Salmon Springs time (Crandell, 1965). The Possession Drift of the northern Puget Lowland and San Juan Islands has been tentatively correlated with the Salmon Springs Drift present in the southern Puget Lowland and southeast Olympic Peninsula. The Possession Drift, however, is made up of a single glacial unit, while the Salmon Springs is composed of two units (Easterbrook, 1969). The Salmon Springs Drift consists of oxidized sand and gravel, and discontinuous horizons of till, silt, clay, mudflows, peat (Artim, 1973), and volcanic ash (Crandell et al, 1958; Easterbrook et al, 1967; Easterbrook, 1969).

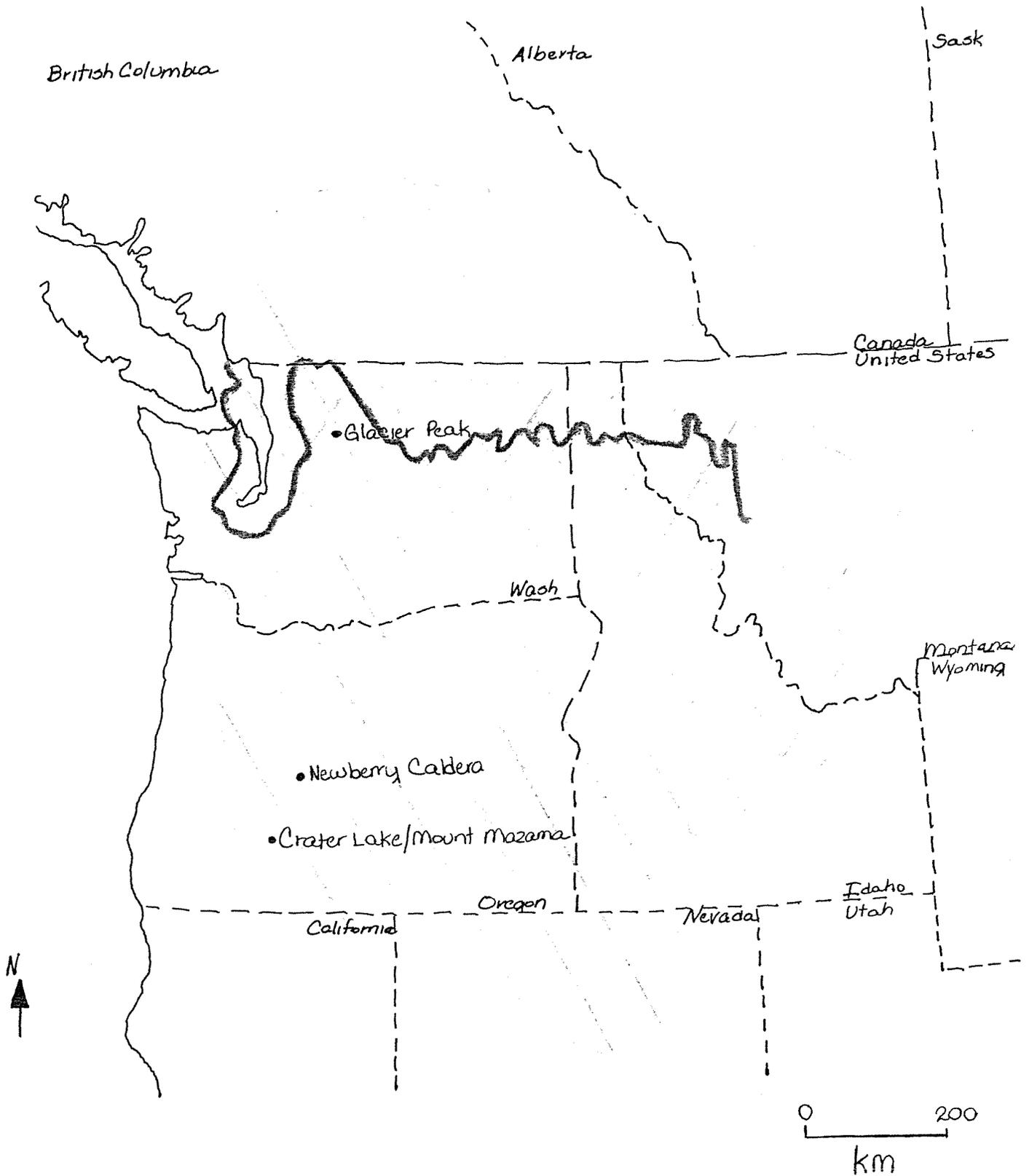


Fig. 3
 Location map, showing inferred extent of minimum areas of fallout of volcanic ash from eruptions of Mount Mazama (pink area) and Glacier Peak (green area). Maximum extent

The two drift units of the Salmon Springs Glaciation are separated in various localities by peat and volcanic ash. In a valley wall of the Stuck River in the southeastern Puget Lowland near Sumner, Washington, the upper and lower drift sheets are separated by four feet of peat and volcanic ash. The peat contains a pollen assemblage dominated by pine and fir (Abies), along with spruce, western hemlock, and mountain hemlock (Crandell et al, 1958). In order to allow this reforestation and deposition of the peat, the Puget Lobe of the Cordilleran ice sheet that had deposited the older of the two Salmon Springs units must have retreated before readvancing again to deposit the younger drift unit (Easterbrook et al, 1967).

Radiocarbon dates from the peat layers containing the ash between the two drift units near Sumner are given below (Easterbrook et al, 1967; Easterbrook, 1969):

- >38,000 years B.P.
- >51,000 years B.P. (after pretreatment)
- >49,000 years B.P. (alkali extract)
- 50,100 ± 400 years B.P. (enriched)

Dr. J. C. Vogel indicated that minute amounts of contamination can make samples in this age appear younger than they really are. He feels that the only point of which we can be certain is that the sample is at least 50,000 years old (Easterbrook et al, 1967).

This line of reasoning may be applied to the ashes studied in this paper. With a radiocarbon date in excess of 41,000 years B.P. for sample I, and a similar stratigraphic position of all samples, it appears possible that the ashes are similar in age to those near Sumner.

Although the peat and ash of the southeastern Olympic Peninsula are not as thick as those described above, they are nevertheless sometimes present between the upper and lower units of the Salmon Springs Drift.

Other volcanic ashes found in various parts of the Puget Lowland have been correlated with the Puyallup and Alderton Interglaciations (Crandell et al, 1958). These periods are older than the Salmon Springs Glaciation. Ashes of the Olympia Interglaciation have not been found, partly because nearly everywhere there is an erosional unconformity between the Salmon Springs Drift and the overlying Vashon Drift (Crandell et al, 1958).

THE ASHES: THEIR THICKNESS, DISTRIBUTION, AND STRATIGRAPHIC POSITION

The volcanic ashes under study were deposited in relatively close proximity to each other. Samples I-III were taken from beds in Mason County, sample IV was obtained on the east bank of Hood Canal near the Kitsap/Mason County line, and sample V was found on the southwestern side of the Toandos Peninsula in Jefferson County (Fig. 4).

Ash I is located in the bank of the Frigid Creek tributary at an elevation of about 380 feet above sea level. It is about 4 inches thick, with the lower 2 inches composed of white ash and tephra that fine upward. The upper 2 inches consist of white ash, tephra, and pumice which again fine upward. The tendency of ash deposits to become finer at the upper surface is a common occurrence, and has been observed in ashes that were ejected from Mount Mazama and Glacier Peak (Fryxell, 1965), (Stratigraphic column 1).

Ash II can be found on the north side of the Skokomish River at an elevation of about 80 feet above sea level. The deposit consists of lacustrine sediments with ash and peat that attain a thickness of approximately 1 foot (Stratigraphic column 2).

Ash III is located just west of the town of Hoodsport at an elevation of about 108 feet above sea level. In the roadcut there is a 2 inch thick deposit of volcanic ash and lacustrine sediments (Stratigraphic column 3).

Ash IV lies on the east shore of the Hood Canal near the Mason/Kitsap county line (Fig. 4). This ash, peat, and silt deposit is about one foot in thickness at an elevation of approximately 32 feet above the Canal (Stratigraphic column 4).

Volcanic ash V, located on the Toandos Peninsula, is at an elevation of about 9 feet above sea level. It is found mixed with peat and weathered

Mt. Jupiter .5701

The Brothers .6866

Jefferson County
Mason County

Jefferson County
Kitsap County

Kitsap County
Mason County

Mt. Washington .6255

Lake Cushman

Price
Lakes

Hood Canal

Hoodsport
3

North Fork Skokomish River

Skokomish River
2

Toandos Peninsula
5

Gravel Sand

4

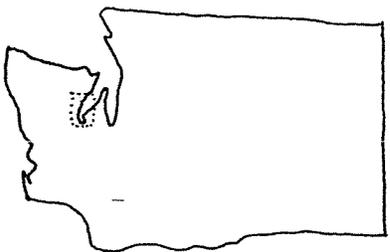
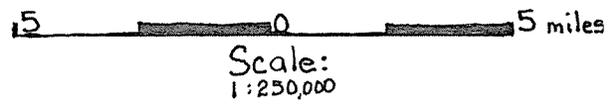


Fig. 4
Southeast Olympic
Peninsula, Washington.
Map Shows Localities From
Which Samples Were Taken.

Legend

- Sample Locations !
- County Lines - - - - -
- Streams or Rivers _____
- Elevations Shown in Feet.



Stratigraphic Column 1: The area from which ash sample I was taken near the Frigid Creek Tributary, Mason County, Washington (SW $\frac{1}{4}$, Sec. 19, T.22N., R.4W.)

Elevation (Ft. above sea level)	Lithologic Unit
600	Vashon lodgment till
590	Mostly covered (Vashon advance outwash?)
550	Weathered alpine outwash, sandy gravel
510	Covered
500	Alpine outwash (same as above)
460	Covered
450	Alpine outwash (same as above)
444	Massive gray clay with layers (up to 2 inches thick) of peat (U.S.G.S. radiocarbon date $\geq 41,000$ years B.P.)
441	Covered
425	Alpine outwash
420	Glaciolacustrine clay, silt, sand, tan, laminated. Strike N50-70°E, Dip 17-23°NW
380.4	Tephra, white pumice and ash, fining upward
380.2	Tephra, white ash fining upward
380	Glaciolacustrine silt, sand, and clay (same as above)
340	Covered
290	Glaciolacustrine silt, sand, and clay (same as above)
285	Tan alpine till, Salmon Springs
284	Tan glaciolacustrine sand
283	Alpine till (same as above)
275	Frigid Creek

Stratigraphic Column 2: The area from which ash sample II was taken on the north bank of the Skokomish River, Mason County, Washington (SE $\frac{1}{4}$, Sec. 9, T.21N., R.4W.)

Elevation (Ft. above sea level)	Lithologic Unit
490	Vashon lodgment till
485	Vashon advance outwash, sandy gravel
380	Covered
340	Vashon advance outwash (same as above)
260	Puget till, Salmon Springs II
240	Alpine till, incorporating glaciolacustrine sediments, Salmon Springs II
225	Alpine outwash, sandy gravel, weathered, Salmon Springs
215	Covered
180	Puget outwash, weathered sandy gravel, Salmon Springs
170	Covered
165	Alpine outwash, sandy gravel with glaciolacustrine sand, silt, and clay, Salmon Springs
81	Lacustrine sediments with ash and peat
80	Alpine outwash (same as above)
70	Puget outwash, sandy gravel, with glaciolacustrine sand, silt, clay, Salmon Springs I
60	Covered
50	Puget till, Salmon Springs I
40	Road north of Skokomish River

Stratigraphic Column 3: The area from which sample III was taken west of Hoodspout, Mason County, Washington (SE $\frac{1}{4}$, Sec. 11, T.22N., R.4W.)

Elevation (ft. above sea level)	Lithologic Unit
200	Vashon lodgment till, with glaciolacustrine sediments
190	Vashon advance outwash, sandy gravel
133	Glaciolacustrine sediments
130	Till (Puget?), Salmon Springs II?
120	Outwash and glaciolacustrine sediments, Puget?
115	Till (Puget?), Salmon Springs II?
110	Puget outwash, sandy gravel
108.2	Lacustrine sediments with ash
108	Puget outwash, sandy gravel
80	Alpine outwash, sandy gravel, weathered
50	Weathered alpine till, Salmon Springs I?
40	Alpine outwash (same as above)
15	Weathered alpine till, Salmon Springs I?
10	US 101, west of Hood Canal

Stratigraphic Column 4: The area from which sample IV was taken on the east shore of the Hood Canal, Mason/Kitsap Counties, Washington (SE $\frac{1}{4}$, Sec. 35, T.24N., R.3W.)

Elevation (Ft. above sea level)	Lithologic Unit
53	Weathered alpine sandy gravel. Salmon Springs?
33	Silt, peat, and ash
32	Sand
30	Weathered alpine sandy gravel. Salmon Springs?
15	Weathered silt
14	Weathered alpine sandy gravel. Salmon Springs?
9	Weathered sand
5	Beach along Hood Canal

Stratigraphic Column 5: The area from which sample V was taken on the southwest Toandos Peninsula, Jefferson County, Washington (Sec. 32, T.26N., R.1W.)

Elevation (Ft. above sea level)	Lithologic Unit
34	Weathered alpine sand and sandy gravel. Salmon Springs?
14	Weathered sand
10	Weathered lacustrine clay, silt, sand, pebbles, with ash and peat
8	Weathered sand
7	Weathered sandy alpine gravel. Salmon Springs?
5	Beach along Hood Canal

lacustrine clay, silt, sand, and pebbles, which collectively, attain a thickness of between 1 and 2 feet (Stratigraphic column 5).

Volcanic ash I occurs as a distinct unit unmixed with other deposits. Ash III is mixed with lacustrine sediments, and ashes II, IV, and V are mixed with peat. All these ashes may represent two closely-spaced eruptions from the same volcano because similar petrographically, chemically, and stratigraphically, differences among them can be attributed to varying degrees of weathering.

The post-glacial volcanic ash in many of the peat bogs in Washington occurs as a single, distinct layer, and is not mixed with the sediments above and below. Sample I is typical of this. In some bogs of eastern Washington, more than one ash layer can be found. The distribution locally of the upper layers and their compositional similarity to the lowest continuous ash layer implies that the upper layers are not from multiple eruptions, but rather from subsequent stream excavation and redeposition in the bogs of ash that formed subaerially at the time of the eruption. Only three bogs are known to contain layers that represent multiple eruptions and possibly more than one source: these are in the Mount Rainier and Mount St. Helens area. The bogs are composed of multiple layers of ash that differ in character from each other. These, however, are the only known localities of multiple ash eruptions in the State of Washington (Rigg and Gould, 1957).

Local variations in thickness of ash deposits are probably due, in part, to differences in the quantity of ash deposited from air fallout resulting from local variations in rainfall and air currents. Variable amounts of ash were likely to have been flushed into bogs and depositional areas by streams from nearby land areas. Local crosswinds and eddies also may contribute to

the irregular patterns of ash deposition (Rigg and Gould, 1957), as is the time of burial by overlying sediments (Easterbrook et al, 1967).

Kettles or other depressions in the glacial drift are many times occupied by bogs containing ash layers. Lakes filled these depressions following the retreat of the ice and became the localities of deposition of stratified sediments of meltwater origin (Rigg and Gould, 1957). In the case of the southeastern Olympic Peninsula, the retreating ice may have been the Puget lobe of the Cordilleran ice sheet during the Salmon Springs I Glaciation. Later the lakes became the sites of organic deposition, since the meltwater streams either became blocked or changed their drainage patterns. Planktonic organisms, often referred to as limnic or sedimentary peat, are the chief organic sediments in the deeper parts of the lakes. The remains of reeds and other attached plants (Rigg and Gould, 1957), including pine and fir (Easterbrook et al, 1958) and (Easterbrook et al, 1967), form what is known as fibrous peat which is found near the shallow edges of the bogs. As these deposits fill the lakes, sphagnum moss replaces the reeds and pines, and sphagnum peat is formed. Thus a typical Washington bog is distinguished by a succession of beds consisting of limnic peat, fibrous peat, and sphagnum peat overlying glacial meltwater sediments (Figure 5). Peat is found with ashes II, IV, and V.

Ashes I and III were not deposited in peat bogs. They are, the least weathered of the samples, and this is logical since organic activity proceeds at a much more rapid rate in a bog or in the presence of peat. Ash I is found covered by but not mixed with other sediments. Ash III is mixed with lacustrine sediments that were simultaneously being deposited.

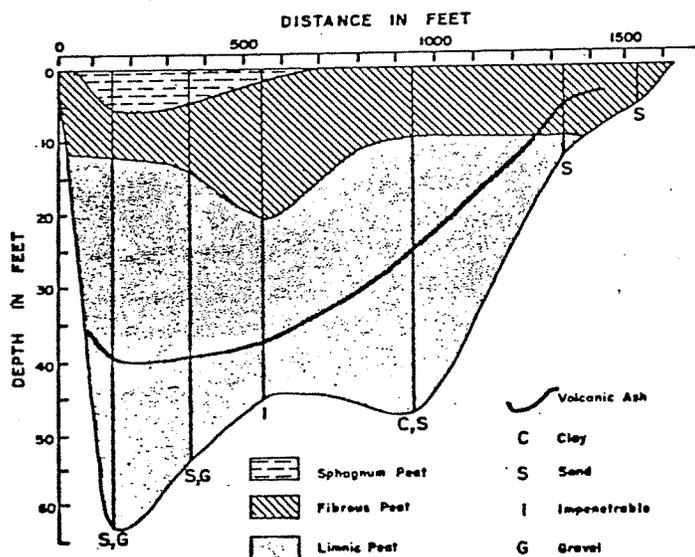


Fig. 58. Profile of Covington Bog showing the relationship of the ash layer to linnic, fibrous, and sphagnum peat. Vertical lines indicate borings on which the profile is based. Thickness of ash not to scale.
(Rigg and Gould 1957)

COLOR AND TEXTURE OF THE ASH

The ashes range in color from the light gray of samples I and III to the tan and dark gray colors of samples II, IV, and V. A tan color is usually indicative of deposition in fibric peat. It may also be the result of oxidation of mafic minerals due to subaerial exposure of the ash either during or after deposition (Rigg and Gould, 1957). In addition, organic stains from the bog environment in which the tan and gray samples came probably have much to do with the color (Czamanske and Porter, 1965).

Ash samples generally are vertically graded, fining upward. This is especially evident in ash I. Generally, tan ash in fibrous peat shows less upward fining than white or light gray ash, which may or may not be in peat. Vertical grading of ashes appears to be directly correlated with the depth of the water in which the ash is deposited. The excellent grading of sample I indicates deposition in relatively deep water (Rigg and Gould, 1957). In contrast, the poorer grading of ashes II, IV, and V suggests that they were deposited on the surface of a bog or in shallow water.

Distance from the source is another important factor in determining the texture of the ash as it is deposited. Sorting of the ash particles becomes increasingly better as distance from the source increases, and the particles deposited at greater distances are finer and more uniform in size (Rigg and Gould, 1957). Mount Rainier, the closest volcano to the Southeastern Olympic Peninsula, is 75 miles away (Fig. 1). Newberry Caldera or almost any Cascade composite cone should be considered a possible source for the tephra.

COMPOSITION OF THE ASH

The five samples analyzed all contain glass and free mineral crystals in varying amounts. Each of the ashes will be considered here separately, followed by a discussion of the correlations that exist between them.

Volcanic ash I (Fig. 6) consists primarily of angular and irregularly shaped glass shards, making it a vitric ash (Williams et al, 1954). Free mineral crystals are also present. With a refractive index of 1.508, the glass should have been derived from an acid magma with a silica content near 70% (Mathews, 1951). Atomic absorption data is presented in Table 1. X-ray fluorescence data (Table 2) further confirms this silica percentage, making the ash a rhyolite, dacite, or rhyodacite (Tables 3 and 4) (Heiken, 1974). Petrographic analysis reveals colorless glass with phenocrysts of quartz, plagioclase, hypersthene, and sanidine. The phenocrysts comprise less than 15% of the volume. The vitric fragments show a pumiceous texture with thin vesicle walls. X-ray fluorescence figures analyses for K_2O and CaO indicate that the ash is a rhyodacite. The potassium concentration of 3.5% is especially useful in determining this.

Ash II (Fig. 6) is extremely weathered. Petrographic analysis reveals very small grains that are gold in color in addition to some glass shards. Angular quartz grains lie in a matrix that appears to be montmorillonite. Montmorillonite is commonly formed by the alteration of volcanic ash (Mason and Berry, 1968). Atomic absorption data is given in Table 1; the values vary somewhat from those of a fresh ash sample due to the extreme weathering of ash II. It is difficult to determine exactly what type of ash this sample is, although a weathered rhyodacite is possible.

Fig. 6

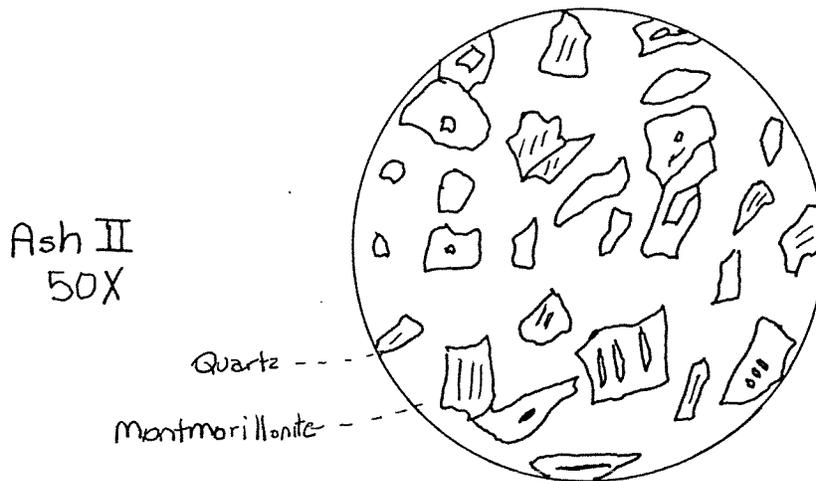
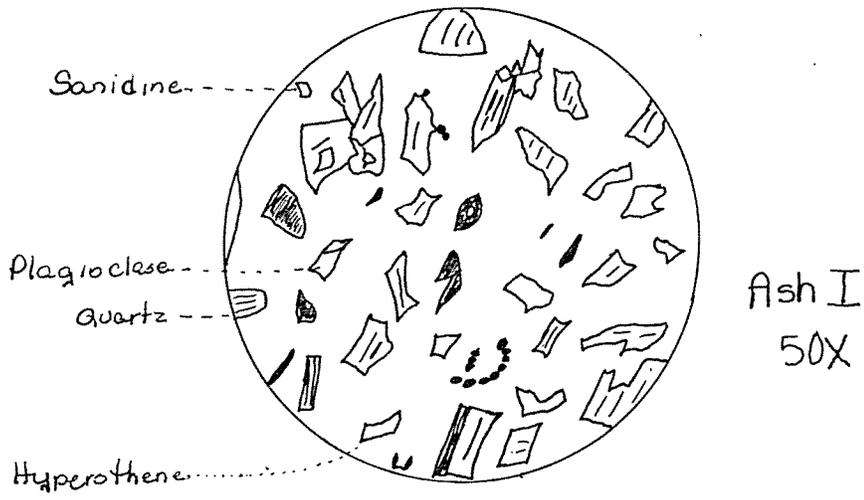
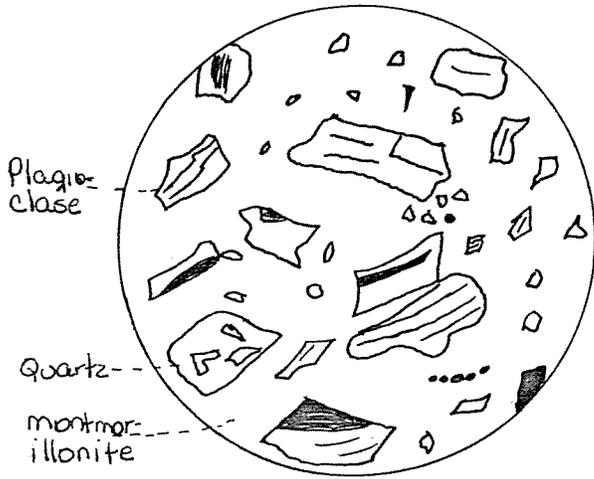
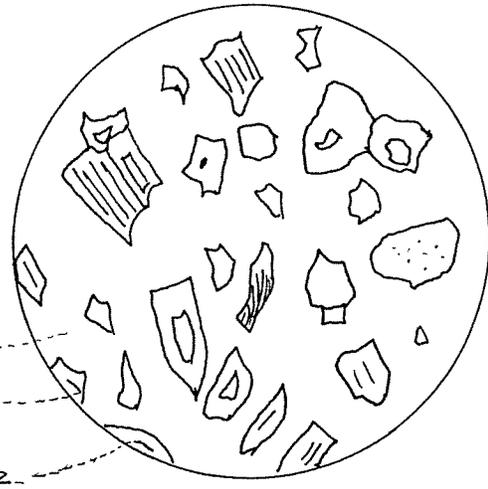


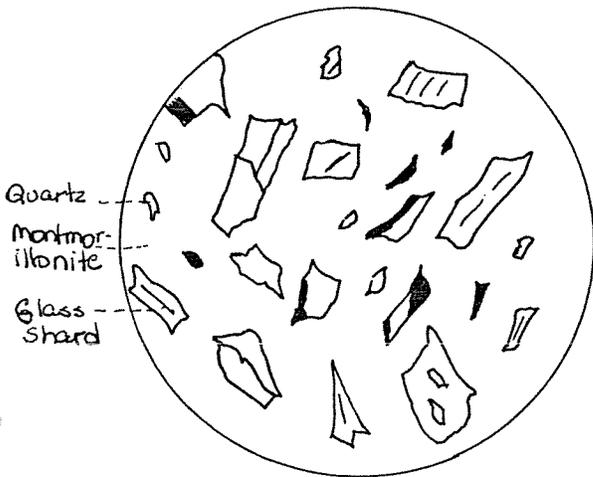
Fig. 7



Ash III
50X



Ash IV
50X



Ash V
50X

Table 1. ATOMIC ABSORPTION DATA (in percent composition)

Constituent	Ash I	II	III	IV	V
TiO ₂	0.223	0.276	0.252	0.524	0.268
Fe ₂ O ₃	0.968	1.688	1.292	2.000	1.416
MnO	0.043	0.030	0.073	0.083	0.032
MgO	0.491	0.298	0.307	0.581	0.368
K ₂ O	2.896	1.160	1.970	1.120	1.752

Table 2. X-RAY FLUORESCENCE DATA OBTAINED FOR VOLCANIC ASH I

Chemistry	Percent
SiO ₂	67.80
K ₂ O	3.50
CaO	1.83

Table 3
 Chemistry of two rhyolitic/dacitic volcanic ashes:
 (1) Katmai, Alaska and (2) Crater Lake, Oregon
 in percent by X-ray fluorescence analysis
 (After Heiken, 1973)

Chemistry	(1)	(2)
SiO ₂	73.52	71.82
TiO ₂	0.22	0.49
Al ₂ O ₃	12.15	15.07
Fe ₂ O ₃	0.49	1.33
FeO	1.28	0.89
MnO	0.07	0.06
MgO	0.52	0.44
CaO	1.29	1.91
Na ₂ O	4.10	5.02
K ₂ O	2.90	2.89
P ₂ O ₅	0.04	0.07
S	0.02	-
H ₂ O ⁺	-	-
H ₂ O ⁻	-	-
Cl	-	-
Total	96.60	99.99
Total Fe as Fe ₂ O ₃	1.91	2.22

Table 4. Average composition (oxides, wt. %) of five classes of volcanic rocks (Carmichael et al, 1974)

Constituent	Rhyolite	Dacite	Andesite	Basalt	Phonolite
SiO ₂	73.66	63.58	54.20	50.83	56.90
TiO ₂	0.22	0.64	1.31	2.03	0.59
Al ₂ O ₃	13.45	16.67	17.17	14.07	20.17
Fe ₂ O ₃	1.25	2.24	3.48	2.88	2.26
FeO	0.75	3.00	5.49	9.05	1.85
MnO	0.03	0.11	0.15	0.18	0.19
MgO	0.32	2.12	4.36	6.34	0.58
CaO	1.13	5.53	7.92	10.42	1.88
Na ₂ O	2.99	3.98	3.67	2.23	8.72
K ₂ O	5.35	1.40	1.11	0.82	5.42
P ₂ O ₅	0.07	0.17	0.28	0.23	0.17
H ₂ O	0.78	0.56	0.86	0.91	0.96
Total	100.0	100.0	100.0	100.0	100.0

Sample III (Fig. 7) also appears to contain montmorillonite, but is not as extensively weathered as sample II. Ash III contains more than any of the other samples except ash I. Plagioclase is observed, as are large amounts of quartz which is probably due to the lacustrine sand that is intermixed with the ash.

Atomic absorption data is presented in Table 1. A relatively close correlation may be drawn between sample III and sample I; differences may be due to weathering and the presence of other minerals in the sample. The ash appears to be dacitic or rhyodacitic.

Ashes IV and V are both intensely weathered. Their tan-yellow hues are suggestive of alteration and oxidation (Czamanske and Porter, 1965). When viewed with a petrographic microscope, one observes small, angular quartz grains and some weathered glass shards. Sample V has a greater amount of quartz present relative to sample IV, as indicated by X-ray diffraction techniques. This same method further demonstrates the abundance of montmorillonite (Rich and Kunze, 1964). Atomic absorption data is presented in Table 1; variations from fresh samples (Tables 3 and 4) are again attributed to weathering and to the presence of peat and foreign minerals in the ash samples. Ash type is difficult to determine as are refractive indices of the altered minerals; weathered rhyodacite is possible.

A number of correlations may be drawn from the data presented here. They are primarily concerned with the degree of weathering of the samples, although other factors are also considered.

With an increase in weathering of a volcanic ash, Czamanske and Porter (1965) found that the percentage of TiO_2 and Fe_2O_3 increases, and that the amount of K_2O decreases in the sample. The ashes with the most clay present in them should also have the highest ferric iron content (Engel et al, 1962).

All of these observations apply to the ashes under study. In Table 1, based on atomic absorption data, we can see that sample IV has the greatest amounts of Fe_2O_3 and TiO_2 , and the least amount of K_2O ; it is thus the most weathered of the ashes. Samples II and V show the next highest degree of weathering, respectively, based on their TiO_2 , Fe_2O_3 , and K_2O values. Ash I is the least weathered, as would be expected, followed by sample III (Table 1).

In addition to weathering, other factors may cause varying compositions among the ashes. Crystal content of ash may, during the period of the eruption, change, with ashes of different compositions being subjected to different wind patterns (Czamanske and Porter, 1965). An example of this occurred 6,600 years ago when Mount Mazama erupted. Huge amounts of dacite ash and pumice mixed with older andesite fragments were exploded from the cone. The explosions increased in violence, as in common for dacite eruptions. Great glowing avalanches of ash and pumice occurred, and following this the composition of the magma changed from dacite to basaltic andesite (Macdonald, 1972).

Another cause of local differences in ash composition may be caused by shifting winds during an eruption (Porter, 1965). When it is ejected, most ash is composed of glass fragments and crystals. Because the crystals are denser than the glass, they fall, along with pieces of glass containing crystals, faster than glass fragments without crystals. Thus crystals are more abundant in the ash that is deposited near the vent and become less abundant with increasing distance from the vent. Most violently explosive eruptions are caused by felsic magmas, in which the crystals contain less silica, and more iron, calcium, and magnesium, than the liquid part of the magma that forms the glass (Macdonald, 1972).

Thus we would expect to find ashes that contain fewer crystals and greater amounts of silica at greater distances away from the point of ejection. Change in the composition of an ash as it travels through the air is known as "aeolian differentiation" (Macdonald, 1972). Aeolian differentiation appears to be one of the plausible explanations for the composition of the ashes on the southeastern Olympic Peninsula. Silica is certainly abundant, and glass shards are present in all samples. With this in mind, it would appear that the samples were ejected during a violent eruption of a volcano a great distance away from the southeastern Olympics.

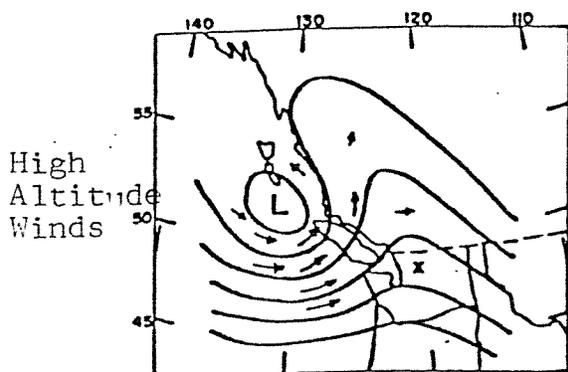
ATMOSPHERIC CONDITIONS DURING DEPOSITION OF THE ASH

A climate somewhat cooler and moister than the present one probably prevailed during the nonglacial interval of the Salmon Springs Glaciation. The prevailing winds were probably from the southwest, just as they are today. The question that comes to mind is how could a volcanic ash come from the southwest when there are no volcano to the east in the Cascades and then somehow carried westward.

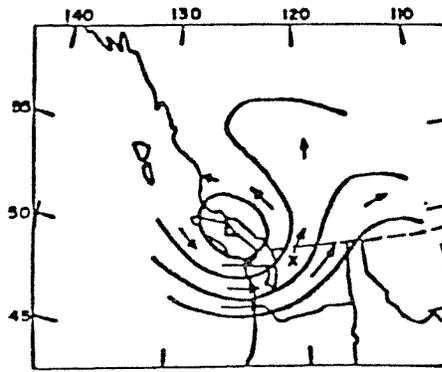
R. J. Reed of the University of Washington's Department of Meteorology and Climatology analyzed this problem in relation to ash from Glacier Peak that is presumed to have been ejected in a climate similar to the one we are speaking about here. He states that a low pressure cell moving from the Pacific eastward over the erupting volcano is the most reasonable situation that would cause ash to be distributed on both the east and west sides of the Cascades (Fig. 8). Reed assumed that it took three days for a low to travel from the Pacific across the Cascades, and that high altitude winds were more effective in distributing the ash than weak surface winds (Rigg and Gould, 1957).

The eruption of the volcano could have begun prior to the formation of the low pressure cell in the Pacific, and the ejecta would have been carried to the northeast by the prevailing winds (Fig. 8A). But in the presence of the low pressure cell off the coast, the winds around the erupting volcano would have changed to west-northwesterly, carrying the ash eastward. As the low moved in over the coast (Fig. 8B), the moving air over the erupting volcano would have shifted back again to the northeast. The low is centered over the erupting volcano in Figure 8C, and the ash would have been carried to the west

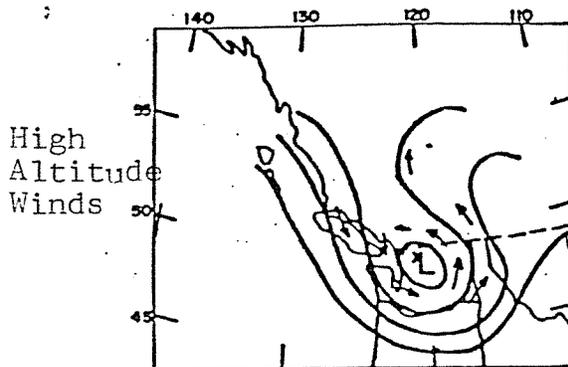
Fig. 8



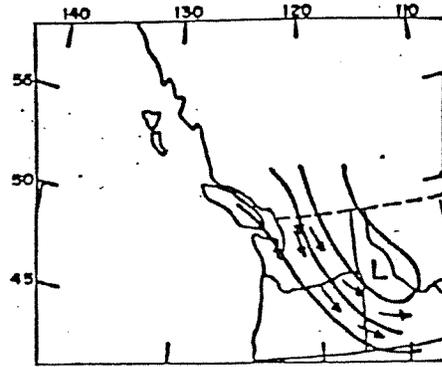
A.



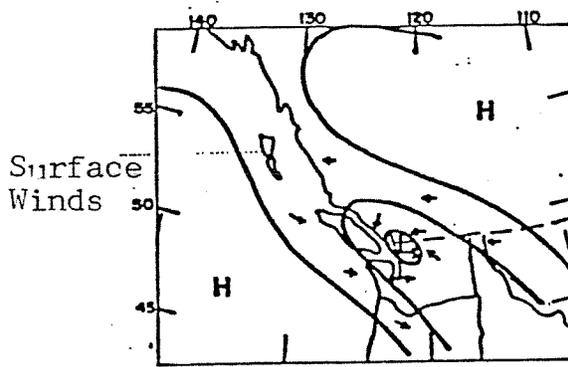
B.



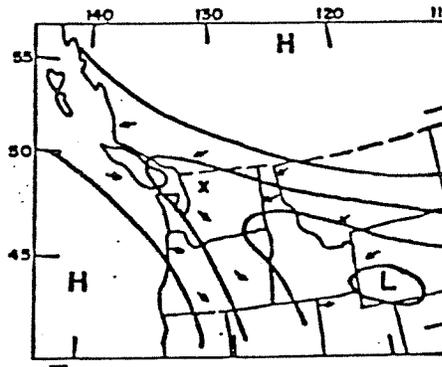
C.



D.



E.



F.

Sequence of winds accompanying movement of low pressure area eastward
(Rigg and Gould, 1957)

and northwest by easterly and southeasterly winds (Rigg and Gould, 1957). This would be the case if the ash on the Olympic Peninsula has come from a volcano in the northern Cascades. In Fig. 8D, we see that the winds would have changed to northwesterly and then back to southwesterly, completing the sequence as the low moved eastward (Rigg and Gould, 1957). Ash from an erupting volcano in the southern Cascades would have been deposited on the Olympic Peninsula in this instance. In Fig. 8, the surface winds corresponding to the high altitude patterns of Figures 8B and 8D are shown in Figures 8E and 8F, respectively. According to these patterns, volcanic ash falling into the lower strata from the higher strata in the northern Cascades would be carried by surface winds westward and southwestward into the Puget Lowland. This sequence, although occurring most frequently in late winter and spring, can occur in other seasons as well.

It has already been concluded from sedimentary and petrologic evidence that ashes I-V may have been produced by two closely-spaced eruptions of one volcano.

USEFULNESS OF VOLCANIC ASH IN STRATIGRAPHIC DETERMINATION

Many of the ash beds in the United States would be extremely useful stratigraphic markers if their petrographic, chemical, and stratigraphic relations were thoroughly studied. In many regions, including mountains and lowlands, glaciated and nonglaciated areas, volcanic ash would help to solve stratigraphic and time related problems that exist between widely separated environments of climate and deposition (Wilcox, 1965).

One of the biggest drawbacks we are faced with today is the lack of correlation between ashes. Even worse, many areas of the United States have not yet been geologically mapped in the detail necessary to discover and identify thin volcanic ash layers. The Olympic Peninsula is a case in point. Only recently has detailed geologic mapping been undertaken on the areas of Mason, Kitsap, and Jefferson counties discussed in this paper. Volcanic ashes are undoubtedly present in other areas of the Olympic Peninsula; they just need to be located and identified.

CONCLUSION

Because of petrologic, stratigraphic, and chemical similarities between these samples from the southeastern Olympic Peninsula, the ash was probably deposited by one volcano in a short period of time. An age date of greater than 41,000 years B.P. needs to be made more precise by K-Ar dating techniques. This will then make the ash increasingly useful as time and stratigraphic markers.

The source of this ash still remains a problem. Newberry Caldera or most any volcano in the Cascades could have erupted the tephra, although evidence favors one relatively distant from the southeast Olympic Peninsula. Varying winds likely brought the ash to its present location. The eruption was a violent one, as would be expected when rhyodacite ashes are produced. Although ash type is difficult to determine on the weathered sample. A slight change in the composition of the ejected material may have occurred, but most of the variation among ashes is due to weathering.

This brings us back once again to the use of ashes as stratigraphic markers. More ash layers in this vicinity need to be discovered, age dated, and correlated with other ash units elsewhere. These units must then be correlated with others, and so on, until eventually a place and time of eruption can be discerned. Larger problems, such as the age of many of the early glaciations and interglaciations, the times of eruption of volcanoes more than 12,000 years ago, and many other questions that confront stratigraphers and chronologists today, need to be solved and answered. Through ash correlation and application, these problems may someday be solved.

REFERENCES CITED

- Artim, E. R., 1973, Geology in landuse planning: State of Washington Dept. of Natural Resources Information Circular No. 47, 18 p.
- Carmichael, I. S. E., Turner, F. J., and Verhoogen, J., 1974, Igneous Petrology: McGraw Hill Book Co., New York, 739 p.
- Crandell, D. R., Millineaux, D. R., and Waldron, H. H., 1958, Pleistocene sequence in southeastern part of the Puget Sound Lowland, Washington: Am. Jour. Sci., v. 256, p. 384-397
- Crandell, D. R., 1963, Surficial geology and geomorphology of the Lake Tapps quadrangle, Washington: U. S. Geol. Survey Prof. Paper 388-A, 84 p.
- Crandell, D. R., 1965, The Glacial History of Western Washington and Oregon: in The Quaternary of the United States, Princeton University Press, New Jersey, p. 341-353
- Czamanske, G. K. and Porter, S. C., 1965, Titanium dioxide in pyroclastic layers from volcanoes in the Cascade Range: Science, v. 150, p. 1022-1025
- Easterbrook, D. J., Crandell, D. R., and Leopold, E. B., 1967, Pre-Olympia Pleistocene stratigraphy and chronology in the central Puget Lowland, Washington: Geol. Soc. America Bull., v. 78, p. 13-20
- Easterbrook, D. J., 1969, Pleistocene chronology of the Puget Lowland and San Juan Islands, Washington: Geol. Soc. America Bull., v. 80, p. 2273-2286
- Engel, A. E. J., James, H. L., and Leonard, B. F., 1962, Petrologic Studies: Geol. Soc. America Publ., 660 p.
- Fryxell, R., 1965, Mazama and Glacier Peak volcanic ash layers: relative ages: Science, v. 147, p. 1288-1290
- Heiken, G., 1974, An Atlas of Volcanic Ash: Smithsonian Institution Press, Washington D.C., 101 p.
- Macdonald, G. A., 1972, Volcanoes: Prentice-Hall Inc., Englewood Cliffs, N.J., 510 p.
- Mason, B., and Berry, L. G., 1968, Elements of Mineralogy: W. H. Freeman and Co., San Francisco, 550 p.
- Mathews, W. H., 1951, A useful method of determining approximate composition of fine grained igneous rocks: Am. Mineralogist, v. 36, p. 92-101

- Powers, H. A. and Wilcox, R. E., 1964, Volcanic ash from Mount Mazama (Crater Lake) and from Glacier Peak: Science, v. 144, p. 1334-1336
- Rich, C. I. and Kunze, C. W., 1964, Soil Clay Mineralogy: The Univ. of North Carolina Press, Chapel Hill, 330 p.
- Rigg, C. B. and Gould, H. R., 1957, Age of Glacier Peak eruption and chronology of post-glacial peat deposits in Washington and surrounding areas: Am. Jour. Sci., v. 255, p. 341-363
- Wilcox, R. E., 1965, Volcanic Ash Chronology: in The Quaternary of the United States, Princeton University Press, New Jersey, p. 807-816
- Williams, H., Turner, F. J., and Gilbert, C. M., 1954, Petrography: W. H. Freeman and Co., San Francisco, 406 p.