

## Late-Quaternary Sediments at Battle Ground Lake, Southern Puget Trough, Washington

### Abstract

The mineral suites indicate that a major part of the inorganic sediment was introduced to Battle Ground Lake by the wind from sources outside the crater. Basalt derived from the crater itself was reduced to silt and clay by weathering, mixed with eolian sediment, and redeposited in the lake as slope wash. In postglacial time, when soil and forest developed on the crater slopes, the deposition of inorganic sediment, especially the wind-derived component, decreased. Five ash layers are attributed to layers of Sets P, Y, and J of Mount St. Helens and Layer O of Mount Mazama by the proportions of their major minerals:

Layer P, erupted by Mount St. Helens between 2580 and 2930 yr B.P.

Layer Y, erupted by Mount St. Helens between 3350 and 3510 yr B.P.

Layer O, erupted by Mount Mazama between 6700 and 7000 yr B.P.

Layer Ju, erupted by Mount St. Helens at about 10,490 yr B.P.

Layer JI, erupted by Mount St. Helens at about 11,280 yr B.P.

### Introduction

Battle Ground Lake lies in a volcanic crater in the southern Puget Trough of southwestern Washington (Figure 1A). The crater is a closed basin with no inflowing or outflowing streams and a catchment 1.6 times the size of the lake (Figure 1B). Six cores were obtained at different water depths in the lake (Figure 1C) with a 5-cm diameter piston sampler for paleoecologic and stratigraphic studies (Barnosky 1985). Analysis of the pollen and plant macrofossils from the longest cores (Core 80B and 81C) provides a 20,000-year record of vegetation in the unglaciated part of the Puget Trough. During much of the Fraser Glaciation (25,000-10,000 yr B.P.; Waitt and Thorson 1983), the climate was apparently cold and relatively dry (Barnosky 1985). The sudden increase in organic sediments and decrease in magnetic susceptibility (Barnosky 1983, Oldfield *et al.* 1983) suggest that the crater slopes became stabilized as soil developed and temperate trees grew near the lake at the Glacial/Holocene transition.

This paper focuses on the mineralogy and sedimentology of the inorganic sediments at Battle Ground Lake in order to document their distribution. Particular attention is given to identifying the volcanic ash layers which appear in Battle Ground Lake sediments.

#### *Sediment description*

A sedimentologic investigation was undertaken

on Core 81G in 8.6 m of water at the northeast side of the lake (Figure 1C). This core is similar to cores 80A, 80B and 80C previously described by Barnosky (1985). Two main lithologic units were identified in the core (Figure 2). An upper unit (900-1540 cm below the water surface) consisting of dark gray highly organic gyttja (40 to 80 percent organic matter); the lowest part of this unit (1370-1540 cm) is laminated. A lower unit (1540-1910 cm) consisting of blue-gray clayey silt with little organic matter (ca. 8 percent; Barnosky 1985). Eight thin sand layers, 5 to 40 mm thick, were also present in the core at depths of 1035, 1070, 1355, 1580, 1665, 1745, 1860, and 1870 cm. The crater itself formed through boring lava of early Pleistocene age (Mundorf 1964) and consists of essentially basaltic material (i.e., lava lenses and scoria).

#### *Principal transparent heavy minerals*

Seventy-eight samples were taken from core 81G (Figure 2). In addition, two samples of basalt were collected from the crater rim. After crushing, they were given the same treatment as the core samples. Mineralogic analysis was limited to the 63-500 microns fraction due to the difficulty in identifying smaller grains under the microscope. Samples were first washed through screens of 500 and 63 microns. This fraction was dried in the oven at 105°C. One g of each sample was mixed with bromoform in 10 ml centrifuge tubes. The mixture was centrifuged for 1 minute at 4000

rpm. After centrifuging, the bottom of the centrifuge tube was frozen in liquid nitrogen and the supernatant liquid was discarded. After thawing the congealed bromoform, heavy minerals were washed through paper filter with acetone, and mounted on slides in Canada balsam. Two hundred transparent heavy minerals were counted for each sample using the ribbon method (Van Harten 1965).

The relative percentages of the most abundant heavy minerals are shown in Figure 2. Together these minerals constitute about 85 percent of all transparent heavy minerals separated. The other 15 percent predominantly consist of unknown minerals, as well as low percentages of

epidote, tourmaline, garnet, zircon, kyanite, titanite, and apatite. The amphiboles (Plate 1A and B) are divided into 5 groups on the basis of their pleochroism: red hornblende (brown to red), basaltic hornblende (yellow or light brown to dark brown), brown hornblende (green to brown), green hornblende (light green to dark green), and cummingtonite (colorless to very pale green). Olivine is colorless, and weathering features were noted along cleavage planes of most of the olivine in the core samples (Plate 1C and D) but not on the olivine from basalt samples collected from the rampart of the crater (Plate 1E and F). A few clinopyroxenes are present. They are light green, generally saw-edged (Plate 1G and H) and are

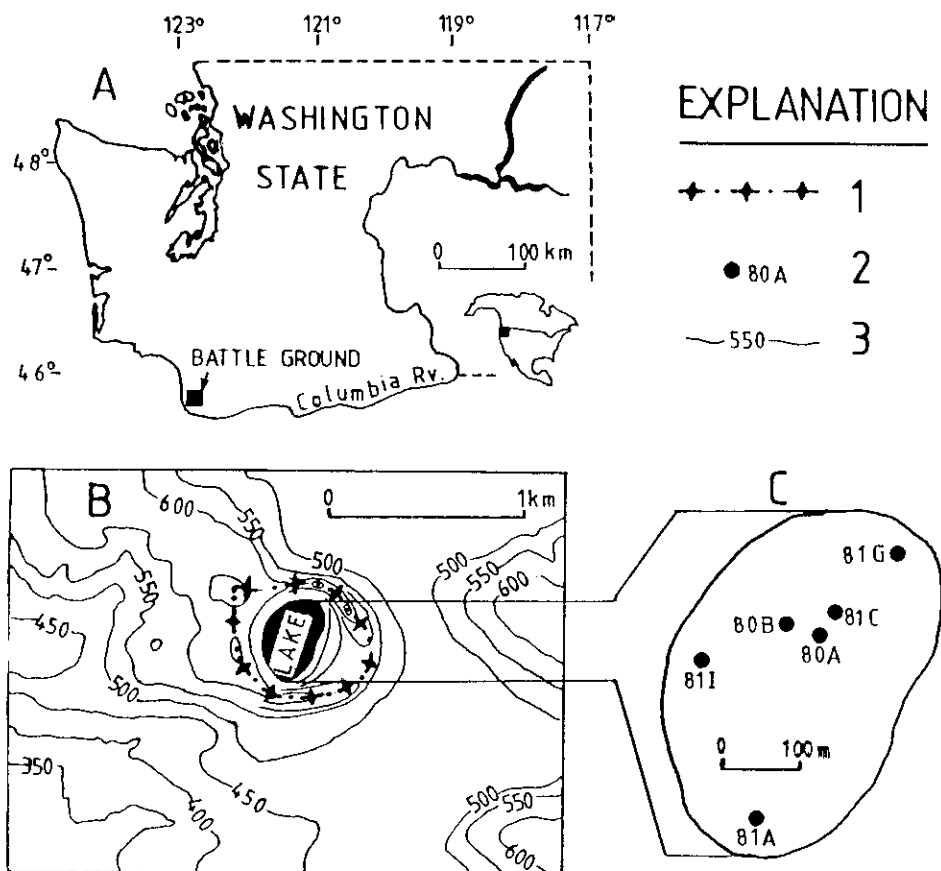


Figure 1.  
 1.A. Location of Battle Ground Lake, Washington. Lat. 45°45'N., Long. 122°48'W., altitude 155 m.  
 1.B. Location and shape of Battle Ground volcano.  
 1.C. Location of the cores (Barnosky 1983).  
 Abbreviations: 1. Watershed on the volcano. 2. Location of cores. 3. Altitude in feet.

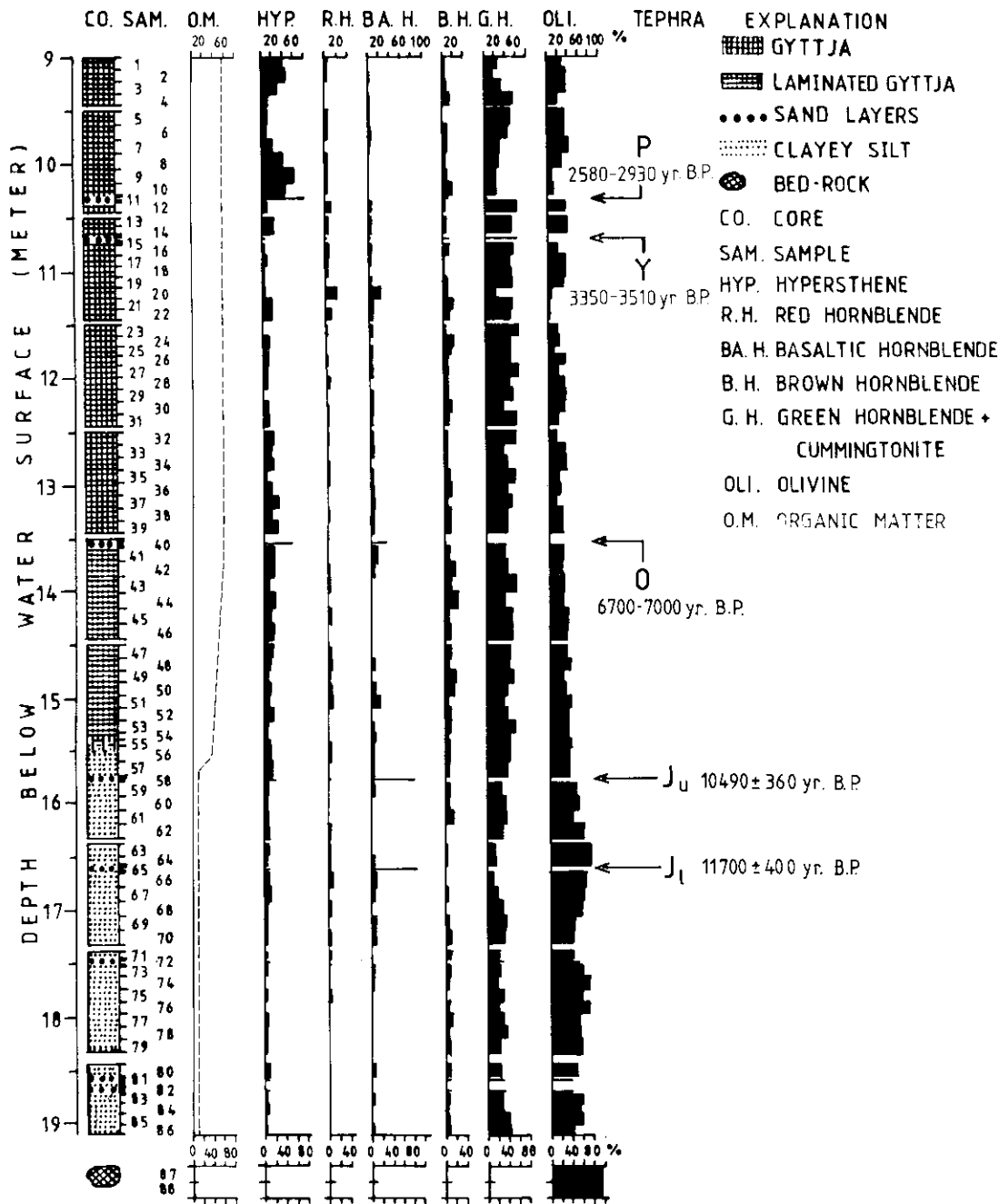


Figure 2. Main lithologic units of Core 81G; location of samples and the most frequent transparent heavy minerals.

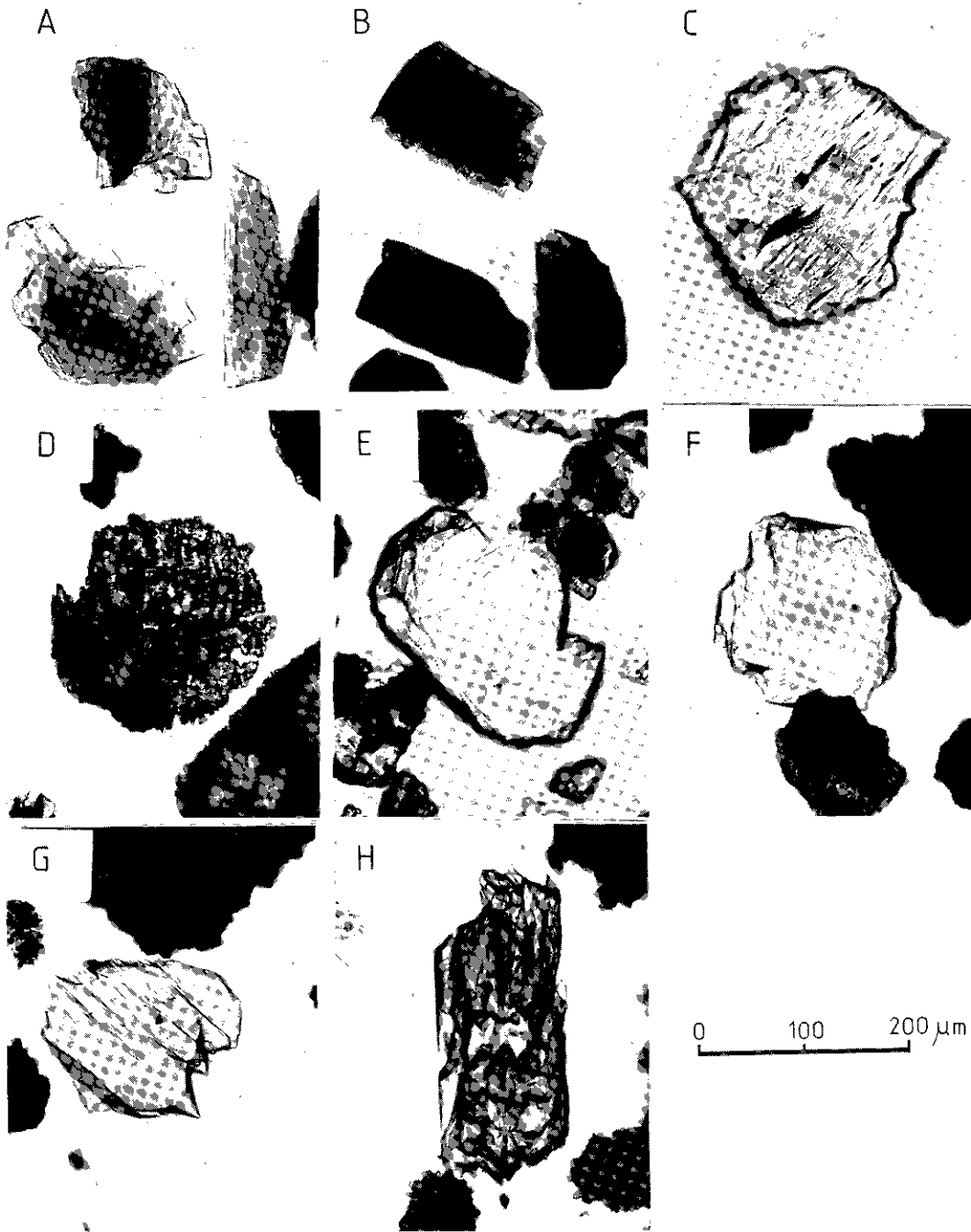


Plate 1  
 Some minerals from infilling of the lake and from basalt of the rampart:  
 A, B: amphiboles  
 C, D: olivine from the infilling  
 E, F: olivine from samples of basalt of the rampart  
 G, H: clinopyroxene (augite)

thought to be augite. Aggregates of rutile were found concentrated in samples 59 through 80. They were counted separately from other heavy minerals because they probably formed after sediment deposition. They are up to 15 times more abundant than any other heavy minerals, except in the sand layers 65, 72, 81, and 82.

#### Provenance of the minerals

The only transparent heavy mineral found in both the basalt and the core samples is olivine. The provenance of all other transparent heavy minerals (including some of the olivine) must be from outside of the crater. Because the crater is a closed depression surrounded by a continuous rampart, wind is considered as the only agent transporting sediment to the lake. This kind of sedimentation was most important in late Pleistocene time, when the vegetation was more open (Barnosky 1985). In Core 81G, this corresponds to the interval from 1540 to 1910 cm.

Barnosky (1984) notes the presence of diatoms indigenous to Tertiary deposits in eastern Washington and in Pleistocene sediments at Battle Ground and suggests that easterly winds may have transported sediments great distances across the periglacial landscape. Wind direction cannot be identified from mineralogical data.

During late Glacial and Holocene time, several ash-falls occurred in the Cascade Range that provided an additional supply of hypersthene and amphibole to the inner slopes of the crater. This explains the overall increase of amphibole and hypersthene, as well as the relative decrease in olivine in the upper unit of Core 81G (Figure 2).

#### Grain-size of the sediment

Four samples were collected at depths of 1590-1610 cm, 1690-1710 cm, 1790-1810 cm, and 1870-1890 cm. Sand fractions were washed through screens at 1 Phi intervals while silt and clay were treated using the hydrometer-method. The grain-size curves for these samples are very similar as shown in Figure 3A by the shaded area where they overlap. These curves show a modal size at about Phi 6 and a high percentage of silt (about 60 percent falls within the size fraction Phi 4-9) and clay (30 to 37 percent is smaller than Phi 8). The sand fraction, which is very fine-grained, accounts for less than 3 percent of the

samples. This grain-size is very different from that of the rampart where boulders, cobbles, and pebbles dominate over a very thin (ca. 10 cm) humic soil. The high content of fine silt and clay can be explained by a mixture of allochthonous eolian sediment and volcanic material from the rampart reduced to silt and clay by weathering before redeposition in the lake through slope wash, wave action, and water currents.

#### Ash layers

Eight sand layers were analyzed as follows: Color was determined after wet sieving as described above. Heavy mineral content was established by weighing the light and heavy fractions after the separation described earlier. Percentages of transparent heavy mineral suites were calculated on a denominator of 200 grains. Magnetite was identified in each sample but this mineral was not taken into account in heavy mineral suites in order to simplify comparisons with results of previous authors who only referred to transparent mineral suites.

The mineralogy of sand layers 72, 81, and 82 suggests they are not volcanic ash because their minerals are similar to those in samples 66 to 86. On the other hand, sand layers 11, 15, 40, 58, and 65 are allochthonous volcanic ashes. Thickness and grain-size are provided for each volcanic ash layer (Figure 3).

##### Layer 11: Mount St. Helens Set P

Thickness: 5 to 10 mm.

Color: light gray.

Grain-size: bimodal with 60 percent silt and clay and 40 percent fine and very fine sand at modal size of about Phi 2.3 (Figure 3B).

Composition: most grains of the light fraction are feldspars (approximately 80 percent), the rest are glass and pumice.

Heavy mineral content: 12 percent.

Heavy mineral suite contains: hypersthene, 79 percent; red hornblende, 0.5 percent; basaltic hornblende, 1 percent; brown hornblende 11 percent; green hornblende, 3 percent; unknown, 5.5 percent.

From both stratigraphic position and mineral suite this ash layer is attributed to Mount St. Helens Set P which was previously described by Mullineaux (1974) and dated between 2930 and 2580 yr B.P. (Mullineaux *et al.* 1975).

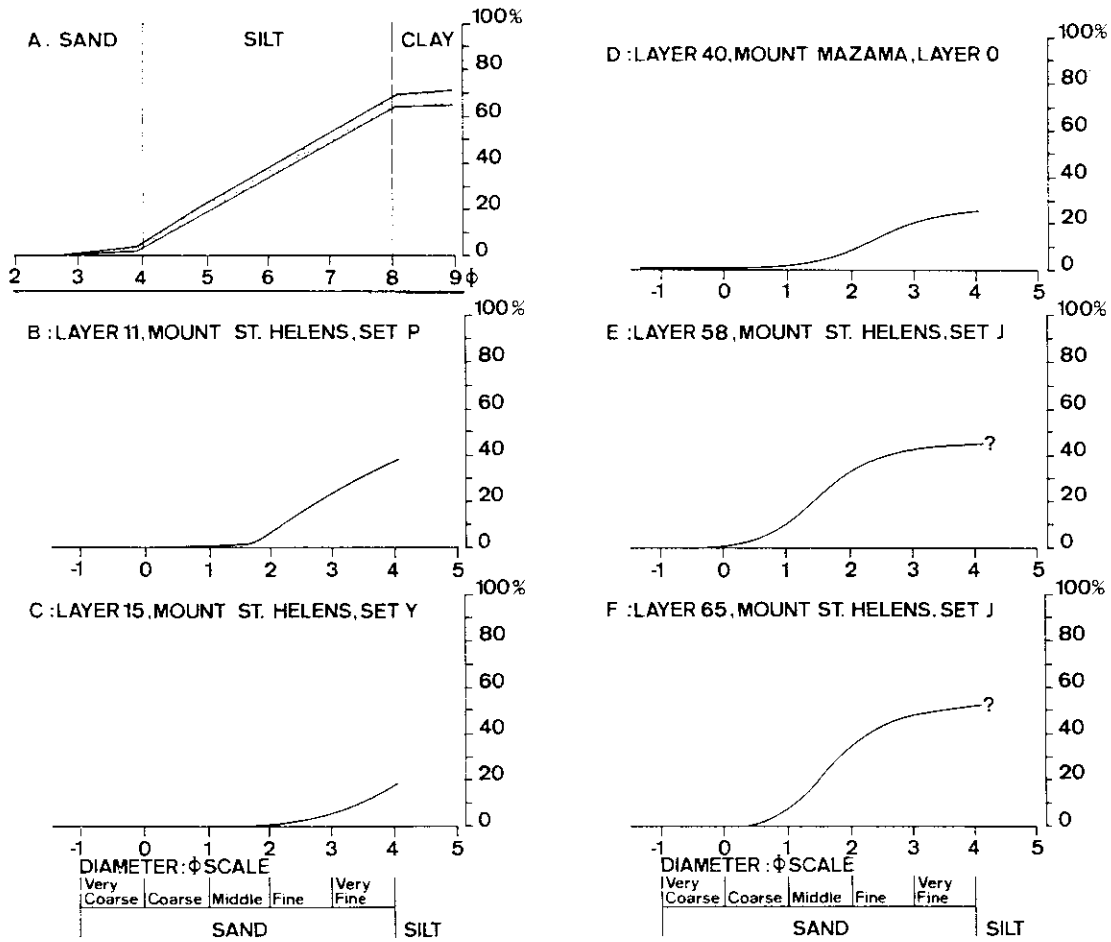


Figure 3

A. Grain-size of four samples collected at depths 15.90-16.10, 16.90-17.10, 17.90-18.10, and 18.70-18.90 m. All curves are included in the shaded area where they overlap. Due to high amount of clay, most of statistical parameters cannot be calculated.

B,C,D,E,F. Grain-size curves of the five volcanic layers of Core 81G. Due to an insufficient amount of fine ash (silt and clay), grain-size analyses were not possible using the hydrometer-method. Hence curves were not drawn beyond Phi 4. Question marks in figures E and F indicate that it was impossible to avoid collecting adjacent gyttja, and an undetermined part of silt and clay is not volcanic material. These curves should be useful in the future to delineate the lobes of each ash-fall as similar data will be provided from other peat-bogs or sections.

Layer 15: Mount St. Helens Set Y

Thickness: 3 to 5 mm

Color: light gray

Grain-size: clay and silt dominate (80 percent) over fine and very fine sand (20 percent) as shown in Figure 3C.

Composition: most grains of the light fraction (80 percent) are feldspars; the rest are glass and pumice.

Heavy mineral content: 8 percent.

Heavy mineral suite contains: hypersthene, 5 percent; red hornblende, 3.5 percent; basaltic hornblende, 2.5 percent; brown hornblende, 11 percent; green hornblende, 43 percent; cummingtonite, 20 percent; unknown, 15 percent.

From both stratigraphic position and mineral suite this ash layer is attributed to an undetermined layer of Mount St. Helens Set Y dated between 3510 and 3350 yr B.P. (Mullineaux *et al.* 1975).

Layer 40: Mount Mazama Layer O

Thickness: 40 mm of graded sediment; the lower 20 mm consists of fine sand and the upper 20 mm consists of silt and clay.

Color: very light gray.

Grain-size: bimodal distribution (Figure 3D) with silt and clay (75 percent) and fine sand (25 percent) at modal size of about Phi 2.3; the coarsest grain is 2.5 mm in diameter.

Composition: most grains of the light fraction are glass and pumice (90 percent); the rest are feldspars.

Heavy mineral suite: hypersthene, 53 percent; red hornblende, 0.5 percent; basaltic hornblende, 30.5 percent; brown hornblende, 4.5 percent; green hornblende, 1 percent; clinopyroxene (augite), 9.5 percent; unknown, 1 percent.

From both its stratigraphic position and mineral suite this layer corresponds to the Mount Mazama Layer O which erupted between 7000 and 6700 yr B.P. (Sarna-Wojcicki *et al.* 1983). The heavy mineral suite can be correlated with those described by Randle *et al.* (1971), Mullineaux (1974) and Juvigné and Porter (1985).

Layer 58: Mount St. Helens Set J

Thickness: less than 3 mm.

Color: light gray.

Grain-size: because the layer is very thin, it was impossible to avoid collecting adjacent gyt-

ja, and an undetermined part of the 55 percent silt and clay is not volcanic material. At least 45 percent consists of middle volcanic sand (Figure 3E) at modal size of about Phi 1.5. The largest grain is 1.5 mm in diameter.

Composition: glass and pumice represent about half of the light fraction and feldspars the other half part.

Heavy mineral content: 13.7 percent.

Heavy mineral suite contains: hypersthene, 17 percent; basaltic hornblende, 81.5 percent; unknown, 1.5 percent.

C<sup>14</sup> age: a sample of gytja collected 25 mm above and below the ash layer was dated at 10,490  $\pm$  360 yr B.P. (Lv-1443D).

Layer 65: Mount St. Helens Set J

Thickness: 2 to 4 mm.

Color: light gray.

Grain-size: because the layer is very thin, it was impossible to avoid collecting adjacent gytja and an undetermined part of the 50 percent silt and clay is not volcanic material. At least 50 percent consists of middle and fine volcanic sand (Figure 3F) at a modal size of about Phi 1.5.

Composition: feldspars (60 percent) dominate over pumice and glass in the light fraction.

Heavy mineral content: 10.4 percent.

Heavy mineral suite: hypersthene, 8.5 percent; red hornblende, 0.5 percent; basaltic hornblende, 88 percent; brown hornblende, 1.5 percent; unknown, 1.5 percent.

C<sup>14</sup> age: a sample of gytja collected 25 mm above and below the ash layer was dated at 11,280  $\pm$  590 yr B.P. (Lv-1444D).

Identification of layers 58 and 65

Both layers 58 and 65 are characterized by a high percentage of basaltic hornblende, and a lack of green hornblende and cummingtonite. Mullineaux and Crandell (1981) provide qualitative results for layers J, S, K, and M from Mount St. Helens. Set J is the only one which contains a similar heavy mineral suite as layers 58 and 65. Sets S, K, and M contains about 80 percent amphiboles, most are green hornblende and cummingtonite.

Bracket ages of Mount St. Helens Set J are 8,300  $\pm$  300 and 11,700  $\pm$  400 yr B.P. (Mullineaux *et al.* 1975). From both mineralogical

suite and radiocarbon ages, layers 58 and 65 should correspond to Mount St. Helens Set J. Because no precise correlation can be proposed with individual layers of Set J, designations Ju (upper J) for layer 58 and Jl (lower J) for layer 65 are used in Figure 2.

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