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A 6000-YEAR RECORD OF FOREST HISTORY ON MOUNT RAINIER, WASHINGTON[1]

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Abstract. Sediments in three ponds between 1300—1500 m on the south side of Mt. Rainier were examined for plant macrofossils and pollen. Macrofossils of seral species such as *Abies lasiocarpa, Pseudotsuga menziesii, Pinus monticola, Abies procera,* and *Pinus contorta* are conspicuous from 6000 to 3400 BP. These species suggest a climate that was warmer/drier than today and favored frequent fires. Neoglacial cooling may have begun 3700–3400 BP, as species typical of higher elevations became prominent; a decline in seral species after 3400 BP suggests less frequent fires. In the last 100 yr, *Tsuga heterophylla* became abundant and then declined at the highest elevation site. General trends in pollen percentages are similar to the macrofossil curves. Tephra deposition from Mt. Rainier and Mt. St. Helens did not produce conspicuous changes in forest composition. Few major fires are evident from charcoal and macrofossils at these sites.

Key words: climate change; conifer forest; fire; forest history; Mount Rainier; plant macrofossils; pollen; succession; tephra.

INTRODUCTION

Direct study of forest succession is difficult because of the longevity of trees. Few reconstructions are available of succession for more than several hundred years (e.g., Henry and Swan 1974). Fossil pollen may be used to reconstruct long-term changes in forest communities, including succession (Iversen 1969, Brubaker 1975), but most palynological studies emphasize regional vegetation, and may lack the spatial or taxonomic resolution to study community dynamics.

Plant macrofossils can provide valuable additional information about local vegetation, since they are less widely dispersed than pollen, and often can be identified to species (Watts 1967, Birks 1973). The conifer-dominated forests in the Pacific Northwest are particularly well suited for reconstructing past composition based on foliage macrofossils. Needles are well preserved in pond sediments, identifiable to species, and occur in percentages that approximate the basal areas of the species in the surrounding forest (Dunwiddie 1983, 1985).

In this study quantitative plant macrofossil data are supplemented with information on fossil pollen and charcoal to reconstruct forest history over the last 6000 yr at three sites in Washington. I asked the following questions: (1) Did elevational shifts of tree species occur on Mt. Rainier during the Holocene? If so, (2) were these movements caused by climatic changes that are not apparent in records from lower elevations? and (3) What do macrofossils reveal about forest disturbance and long-term succession?

Until now no radiocarbon-dated studies have been published documenting forest change during the Holocene in the North Cascade Mountains of Washington. But late Quaternary vegetational and climatic fluctuations have been described in the Puget Lowland by Hansen (1947), Heusser (1977), Barnosky (1981), Tsukada et al. (1981), and Leopold et al. (1982). These sections record a parkland of *Picea engelmannii, Tsuga mertensiana,* and *Pinus contorta* after ice retreat. *Pseudotsuga, Alnus,* and *Abies* were common during a warm, dry interval which began ≈10 000 BP and continued until ≈7000–5000 BP, when *Tsuga heterophylla* and *Thuja plicata* increased during apparently cooler/moister conditions. After culmination of the Hypsithermal Interval, little change is evident in these pollen diagrams until postsettlement disturbance. Records from the Olympic Peninsula (Heusser 1973, 1974, 1978) depict a similar climatic sequence, although the warmest interval (8000–3000 BP) was longer than that identified in the Puget Lowland.

East of the Cascade crest, a more complex Holocene sequence has been reported. Palynological studies by Mathewes and Rouse (1975) and Alley (1976) in British Columbia, and Mack et al. (1978*a, b, c,* 1979, 1983) in eastern Washington, Idaho, and Montana, report a warmer/drier interval beginning around 10 000–8000 BP, and ending variously at ≈6600 BP in British Columbia, 4800 BP in the Okanogan Valley of Washington, and 3300–3000 BP further east. A cooler/moister period was reported in some areas in the late Holocene: 3300–2400 BP (Mack et al. 1978*a*), 3000–1500 BP (Mack et al. 1978*b*), 4000–2700 BP (Mack et al. 1978*c*). This period was followed by the development of modern vegetation.

In the Cascade Range, climatic change is interpreted from moraines (Crandell and Miller 1974, Porter 1976) and dendrochronological studies (Graumlich and Brubaker 1986). The last Pleistocene glacial advance in the North Cascades (Hyak Drift) occurred ≈11 000 BP and may be correlated with the McNeeley Drfit on Mt.

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Rainier (Porter 1976). Two late-Holocene Neoglacial advances have been reported by Crandell and Miller (1974) on Mt. Rainier at ≈2600–2800 BP (Burroughs Mountain Stade), and during the last 600–800 yr (Garda Stade).

Regional Setting

Physical features

Mt. Rainier is the largest Quaternary volcano in the Cascade Range. Since the last major advance of Pleistocene ice, it has been altered by a series of avalanches, lahars (mudflows and debris flows from a volcano), at least two smaller ice advances, and tephra (volcanic ash and coarser airfall debris) deposits (Crandell 1969). Lahars have formed frequently and may extend as much as 110 km from the volcano (Crandell 1971). Most glaciers were near their Holocene maximum in the late 18th and early 19th centuries; extensive ice recession occurred after 1860 (Crandell and Miller 1974, Burbank 1981).

The tephra deposits on Mt. Rainier have been well documented (Mullineaux 1974). Due to prevailing winds, most Mt. Rainier pyroclastic layers are found east of the summit. Three tephra units from Mt. St. Helens are widespread, including layer W, set P, and set Y. Layer Yn (hereafter referred to as the Y tephra layer) is the thickest of the set Y tephra, with deposits of 15 cm common on the south side of the mountain.

The temperate maritime climate is characteristically cool and moist, with a precipitation minimum in summer. The moisture gradient on the south side of Mt. Rainier is steep; mean annual precipitation at Paradise (elevation 1692 m) and Longmire (elevation 842 m) are 2795 mm and 2098 mm, respectively. Mean temperatures at these stations are from −5° to 0°C in January, and 10°–15° in July.

Vegetation

Nearly all dominant trees on Mt. Rainier are conifers and include 15 species in seven genera. Successional relationships among these species in three forest zones: the *Tsuga heterophylla, Abies amabilis,* and *Tsuga mertensiana* zones, are described by Franklin and Dyrness (1973).

In the *Tsuga heterophylla* zone (up to ≈900 m on Mt. Rainier), *Pseudotsuga menziesii* is the most important seral tree (J. F. Franklin, *personal communication*). It reaches ages up to 1000 yr, and may persist in forests with late successional dominants *Tsuga heterophylla* and *Thuja plicata. Alnus rubra* occurs as a short-lived pioneer.

Forest composition in the *Abies amabilis* zone (900–1350 m) is more variable. *Pseudotsuga menziesii* and *Abies procera* are common early in succession along with *Pinus monticola,* and occasionally *Pinus contorta,* but they usually do not reproduce (Franklin and Dyrness 1973). If moisture is sufficient, *T. heterophylla*

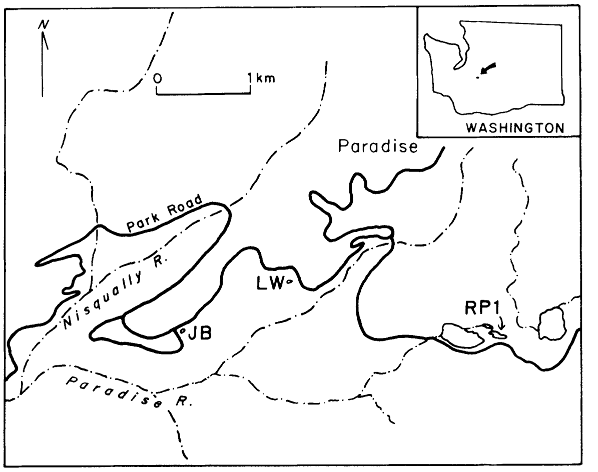

FIG. 1. Location of Jay Bath (JB), Log Wallow (LW), and Reflection Pond 1 (RP1) on Mt. Rainier, Pierce County, Washington.

and *A. amabilis* may be present in seral communities, and generally are dominant in late successional forests (Schmidt 1957, Franklin and Dyrness 1973). At higher elevations in this zone, *Abies lasiocarpa* may be an important seral component, with *Chamaecyparis nootkatensis* and *T. mertensiana* prominent late in succession (J. F. Franklin, *personal communication*).

The *Tsuga mertensiana* zone occurs from 1250–1850 m on Mt. Rainier. *Abies lasiocarpa* is a drought-tolerant species common in early successional forests in this area, although *A. amabilis* and *T. mertensiana* are also frequent pioneers (Lowery 1972, J. F. Franklin, *personal communication*). *Abies amabilis* is the dominant late successional species, with *T. mertensiana* and *C. nootkatensis* also important (Franklin and Dyrness 1973).

Study sites

Sediment cores were taken from three sites: Jay Bath, Log Wallow, and Reflection Pond 1. The sites are along a 3.5-km east–west transect that spans 170 m in elevation within the Nisqually River drainage (Fig. 1). All occupy irregular depressions on the 6000-yr-old Paradise lahar (Crandell 1971).

Jay Bath (latitude 46°46′ N, longitude 121°46′ W) is a small (0.14-ha), shallow (120 cm depth), nearly flat-bottomed pond. There is no inflowing stream, but snowmelt in spring overflows a retaining berm of lahar debris. *Carex lenticularis* and *C. muricata* are common shoreline herbs. The only rooted aquatic species is *Nuphar polysepalum.*

At 1311 m elevation, Jay Bath is near the boundary between the *Abies amabilis* and *Tsuga mertensiana* zones. The adjacent forest is dominated by *A. amabilis, C. nootkatensis,* and both *Tsuga* species. Understory shrubs include *Vaccinium alaskaense, Vaccinium ovalifolium, Menziesia ferruginea, Rhododendron al-*

TABLE 1. Radiocarbon dates from Jay Bath and Log Wallow.

Depth (cm)	Laboratory no.	Date BP
Jay Bath		
38–41	QL-1729	1320 ± 30
68–72	QL-1730	2920 ± 60
123–126	Beta-6332	3740 ± 80
149.5–155	QL-1704	6050 ± 110
Log Wallow		
28–30	QL-1726	1650 ± 80
116–118	QL-1727	4900 ± 80
138–142	QL-1728	5980 ± 60

biflorum, and *Alnus sinuata*. *Abies lasiocarpa*, *A. procera*, *P. monticola*, and *P. menziesii* are present in the forest but are not common. A fire reported to have burned up the Paradise River Valley in 1894 (Hemstrom and Franklin 1982) was confirmed by increment cores from fire-scarred trees at Jay Bath. *Abies amabilis*, *C. nootkatensis*, and both *Tsuga* species were protected from the fire on the north and east sides of the pond, and form a 30–40 m tall closed canopy.

Log Wallow (latitude 46°46′ N, longitude 121°45′ W), 1.2 km northeast and 50 m higher than Jay Bath, is smaller (≈0.07 ha) and shallower (90 cm depth). The pond is located on a bench on southwest-facing slopes above the Paradise River. Much of the level terrain near the pond is saturated with moisture and covered with abundant *Carex* spp., *Juncus ensifolius*, and *Eriophorum polystachion*. *Sparganium minimum* and *Isoetes echinospora* grow in the shallow water.

This site is also close to the boundary between the *Abies amabilis* and *Tsuga mertensiana* zones. The forest is dominated by *Abies amabilis*, *C. nootkatensis*, and *T. mertensiana*, along with scattered *T. heterophylla* and *A. lasiocarpa*. Understory shrubs include *V. ovalifolium*, *M. ferruginea*, and *A. sinuata*. Based on dated fire scars, this area was also incompletely burned in the 1894 fire.

Reflection Pond 1 (latitude 46°46′ N, longitude 121°43′ W) is the easternmost of several ponds collectively referred to as the Reflection Lakes, 2.4 km east of Log Wallow. The pond has an area of ≈0.6 ha, and lies at 1482 m; maximum water depth is ≈3 m. A very small outflow at the northwest end drains into the Paradise and Nisqually rivers. *Carex lenticularis*, *C. scopulorum*, and *C. nigricans* are prevalent in meadows on the south side of the pond along with *Vaccinium deliciosum* and *Spiraea densiflora*. *Sparganium minimum* and *Isoetes echinospora* are common aquatics.

A very open forest of *A. lasiocarpa*, with fewer *A. amabilis* and *T. mertensiana*, surrounds Reflection Pond 1. This forest resembles the *Abies lasiocarpa/Valeriana sitchensis* community, an early successional stage on the *Abies amabilis/Rubus lasiococcus* habitat type (J. F. Franklin, *personal communication*). A single stunted *T. heterophylla* grows near the pond. *Chamaecyparis nootkatensis* is present but not adjacent to the pond. Shrubs are prominent, including *V. deliciosum*, *V. membranaceum*, *Sorbus sitchensis*, and *Spiraea densiflora*.

The absence of large trees and the presence of burned snags suggest that the present forest originated after a fire. An extensive burn occurred in this area in 1885; the site also may have burned in 1856 and 1841 (Hemstrom and Franklin 1982). Tree recruitment is commonly slow at this elevation, especially after repeated burns deplete potential seed sources, and accounts for the open forest today (Hemstrom and Franklin 1982).

METHODS

Cores were collected with a modified 5 cm diameter Livingstone piston corer from a floating platform near the center of each pond. Sediment was extruded, wrapped in the field, and stored at 5°C. In the laboratory, cores were cut into 2 cm (Log Wallow and Reflection Pond 1) or 3 cm (Jay Bath) long segments, yielding volumes of ≈35 mL and 50 mL, respectively. Samples were gently sieved (710, 300, and 106 μm) under tap water. Many 1–2 cm inorganic layers had occasional macrofossils in them and thus were sieved along with adjacent sediments. Sodium pyrophosphate was added when necessary to help disaggregate clay-rich sediment. Macroscopic plant remains were sorted under a dissecting microscope, and stored in glycerine. Fruits, seeds, leaves, twigs, other reproductive parts, and bud scales were identified to the lowest possible taxon (Dunwiddie 1983). All conifer leaves were identified to species (Dunwiddie 1985).

Conifer "needle equivalents" were counted for all species except for *Pinus* and Cupressaceae species. "Needle equivalents" are defined here as whole needles, or combinations of base, midsection, and tip, that roughly equal a whole needle in length. Two categories of *Pinus* remains were counted for each species. The woody short shoots that form the base of needle fascicles were counted as needle equivalents. Since *Pinus* needles are more fragile than those of other taxa, they are often highly fragmented in sediments, and difficult to reconstruct. Consequently, all *Pinus* needle fragments were tabulated separately, but no attempts were made to reconstruct needle equivalents from them. *Chamaecyparis nootkatensis* foliage was counted in two categories: individual leaves, and fragments with more than one attached leaf. The multiple-leaved fragments were treated as needle equivalents in computations. Replicate samples from parallel cores provided additional material for levels in which macrofossil concentrations were low. Typical samples included 20–50 needles.

Percentage diagrams of needles are based on sums of all needle equivalents at each level. I used this approach rather than concentration or influx diagrams, because frequent tephra deposits in the sediments cause large fluctuations in macrofossil concentrations. Male and female cone fragments, conifer seeds and wing

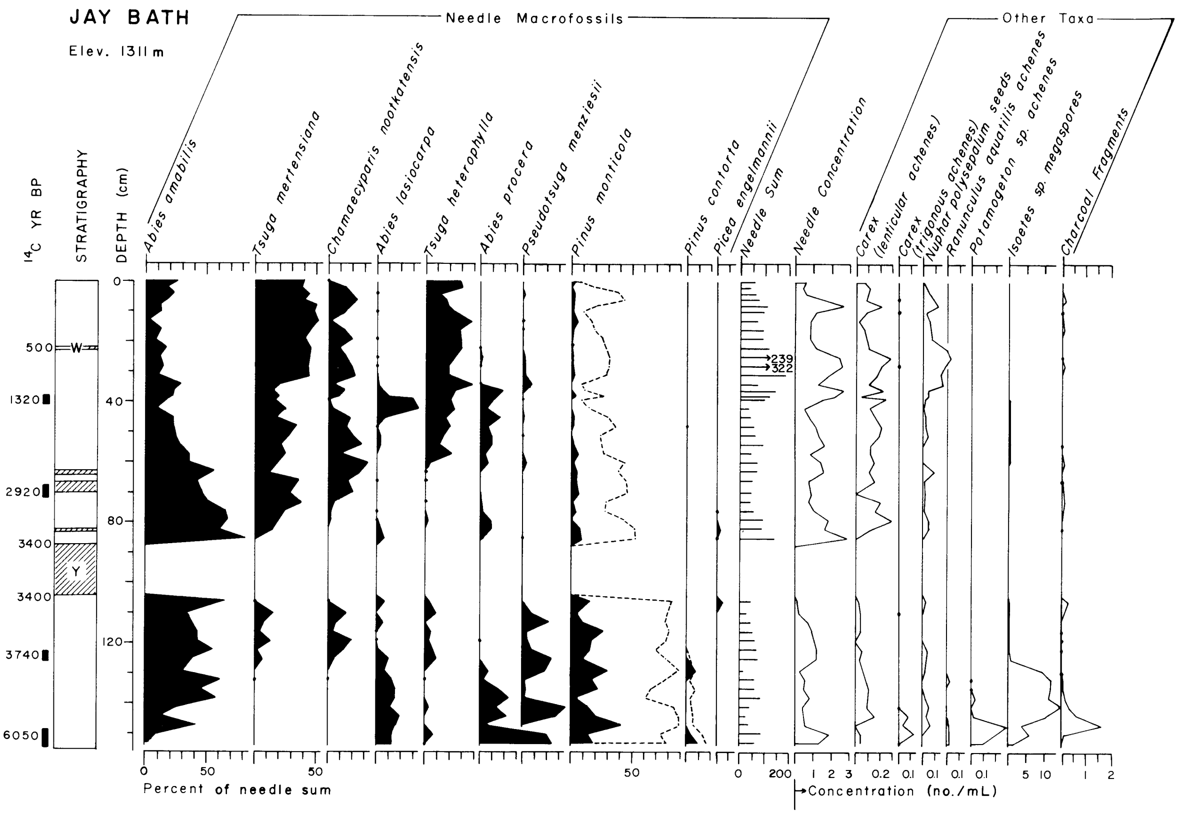

FIG. 2. Macrofossil diagram for sediment in Jay Bath. Late successional trees are generally to the left side of each diagram, with seral species to the right. *Pinus* fragments (dashed lines) are excluded from the needle sum. Note changing scales for concentrations. Single macrofossils are indicated by dots. Only tephra layers >1 cm thick are depicted by hatching. Organic lake sediments are unshaded.

fragments, bud scales, and twigs were identified, but omitted from the diagrams. Charcoal fragments were counted in the 710-μm fraction.

One-half millilitre samples were taken from Jay Bath and Reflection Pond 1 cores prior to macrofossil sieving, or from parallel cores, and processed for pollen according to standard methods (Faegri and Iversen 1975). A minimum of 275 grains was counted at each level. Identifications were made using reference collections at the University of Washington.

Radiocarbon dates were obtained from unsieved portions of replicate cores, or from sieved organics that were saved following identification (Table 1). Published dates for W and Y tephra layers provided additional stratigraphic control (Mullineaux 1974, Yamaguchi 1983). These tephra were identified based on the criteria of Mullineaux (1974).

RESULTS

Figs. 2–6 show sediment lithology, macrofossils, and pollen from Jay Bath, Log Wallow, and Reflection Pond 1. Sedimentation curves at the three sites (Fig. 7) were fitted by eye using seven radiocarbon dates from Log Wallow and Jay Bath (Table 1), published dates for tephra layers (Mullineaux 1974, Yamaguchi 1983), and identification of this stratigraphy at Reflection Pond. Interpolations of age–sediment depth relationships indicate that samples generally represent time intervals of 80–200 yr. Low sedimentation rates prior to 4900 BP at Jay Bath and Reflection Pond 1 result in sample durations from 300 to 370 yr.

Jay Bath

At Jay Bath (Fig. 2), the uppermost lahar sediments are overlain by 4 cm of finely layered silt (159–155 cm). Organic sediments begin abruptly at 155 cm and continue to the surface with interbedded tephra layers.

Abies amabilis is conspicuous throughout the macrofossil record, reaching its greatest prominence at ≈3400 BP. Other taxa, including *A. lasiocarpa, A. procera, P. menziesii, P. monticola, P. contorta,* and most aquatic species are most abundant below the Y tephra, and decline above this level. *Tsuga mertensiana, C. nootkatensis,* and *T. heterophylla* needles increased at ≈3700 BP and became abundant after 3400 BP. *Carex* is the only common terrestrial herb macrofossil. Charcoal fragments are conspicuous near the base of the section but occur infrequently elsewhere.

Alnus rubra and *A. sinuata* are represented at Jay Bath by pollen but not macrofossils. Herbaceous pollen

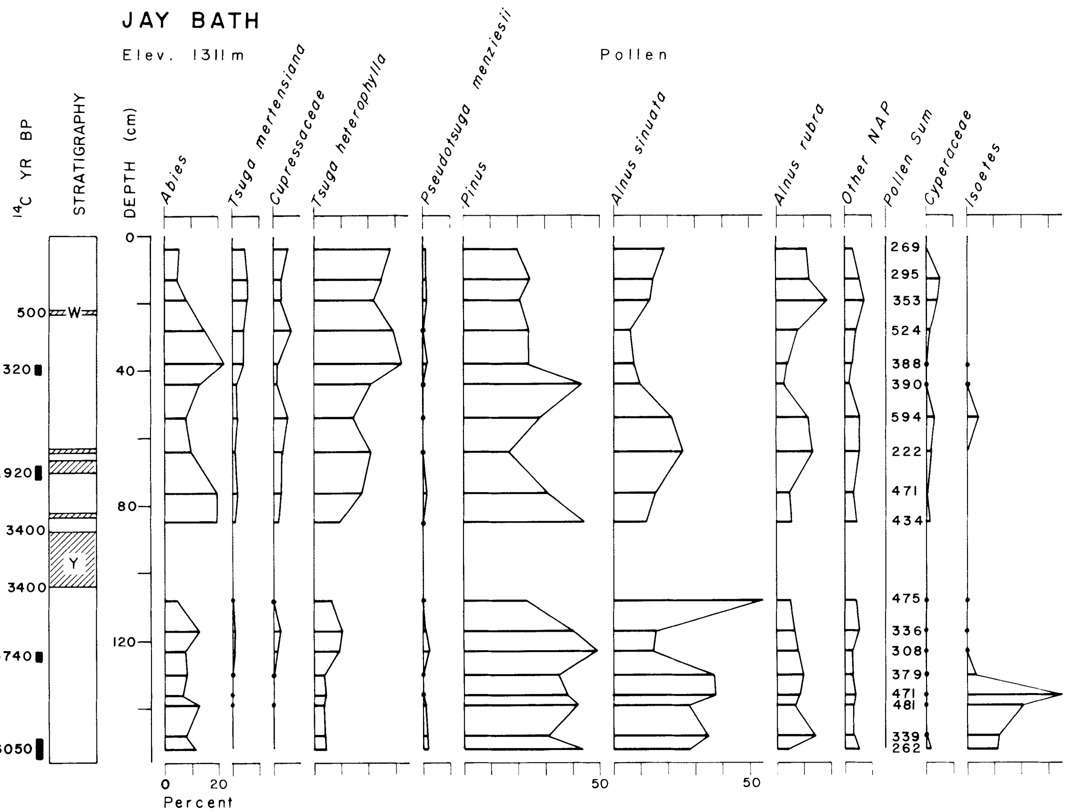

FIG. 3. Percentage pollen diagram from Jay Bath. Pollen from all terrestrial species included in sum. Percentages <1 indicated by dots.

ranges from 2 to 6% of the total. Pollen percentages of both *Tsuga* species and Cupressaceae increase between the lowest and uppermost levels. Pollen of *Alnus sinuata* and *Pinus* generally decrease over this same interval (Fig. 3).

Log Wallow

Few tephra layers are distinct in Log Wallow sediments, and fine laminae are absent (Fig. 4). Lahar sediments are overlain by 8 cm of coarse and fine organic detritus. *Drepanocladus exannulatus* peat is prominent through much of the section. The Y tephra is overlain by 43 cm of redeposited Y tephra (not shown in Fig. 4). The top 35 cm of sediment is mixed silt, sand, and organics.

Needles of *Abies amabilis* and *A. lasiocarpa* are common in the basal sediments at Log Wallow. These taxa, as well as *A. procera, P. menziesii, P. monticola, P. contorta, Carex, Juncus, Nuphar polysepalum,* and *Potamogeton* are most conspicuous below the Y tephra. *Tsuga mertensiana* and *C. nootkatensis* needles became abundant after ≈5000 BP, and remained so to the present. Charcoal fragments are conspicuous throughout the sediments. No pollen was examined from this site.

Reflection Pond 1

At Reflection Pond 1, abundant inorganic laminae are interspersed with organic sediments, producing a complex stratigraphy (Fig. 5). For example, between 30 and 50 cm, at least 19 inorganic bands are visible.

Macrofossils of *Abies amabilis* and *T. mertensiana* are predominant throughout the record. *Abies lasiocarpa* needles are common below the Y tephra, and at intervals above this level. *Chamaecyparis nootkatensis* needles are present in small numbers after ≈1500 BP, and *T. heterophylla* is abundant only in the last 100 yr. *Carex* and *Juncus* seeds, and *Isoetes* megaspores, are most common below the Y tephra, but reach small peaks again in the uppermost sediments. Three charcoal peaks are conspicuous.

The pollen spectra at Reflection Pond 1 (Fig. 6) are similar to that at Jay Bath but contain more pollen of *Abies* and *T. mertensiana* and no pollen of Cupressaceae or *P. menziesii*. Herbaceous pollen ranges from 2 to 7% of the total.

DISCUSSION

Plant succession on the Paradise lahar

Conifer needles were found in the basal organic sediments at all sites, suggesting that trees rapidly became

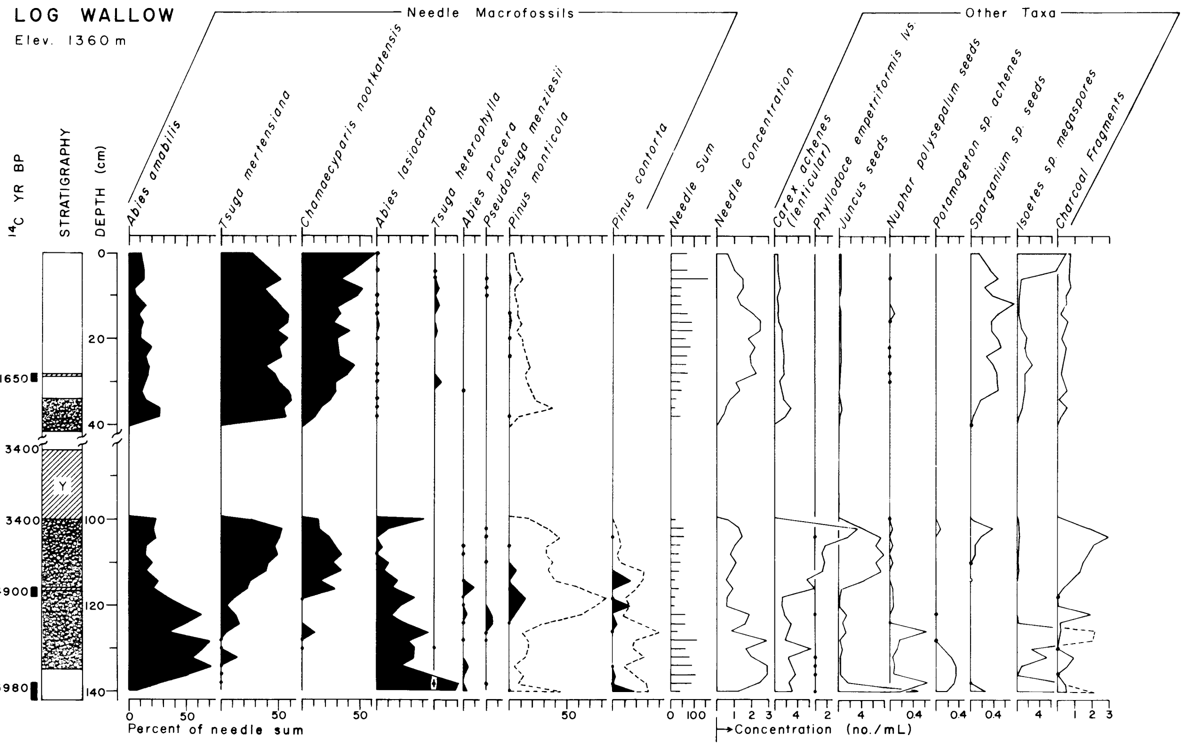

FIG. 4. Macrofossil diagram from Log Wallow. Lithology symbols are as in Fig. 2, with an additional textured pattern designating *Drepanocladus exannulatus* peat. Redeposited Y tephra (86–43 cm) is omitted.

established on the Paradise lahar. However the higher sites have more *Juncus* seeds and lower needle concentrations, suggesting that reforestation may have been slower than at Jay Bath. Recent mudflows on nearby Mt. St. Helens may provide an analog; *Juncus parryi* is common in dry, open meadows with scattered *Abies lasiocarpa* and *Pinus contorta* (P. W. Dunwiddie, *personal observation*).

Needles of seral species are conspicuous in the lowest levels: *A. procera, A. lasiocarpa, P. monticola,* and *P. contorta* at Jay Bath, and *A. lasiocarpa* and both *Pinus* species at Log Wallow. The presence of *P. contorta* is noteworthy because it is today uncommon on Mt. Rainier. Generally, it may persist for several hundred years as a dominant, or may be replaced sooner (Franklin and Dyrness 1973). Its occurrence at Jay Bath and Log Wallow reflects its seral role on newly formed landscapes.

The diversity of rooted aquatics was highest soon after formation of these sites. Four species were present at each of the two lower elevation sites, but *Potamogeton* and *Ranunculus* disappeared after several centuries.

Pre-Y tephra macrofossils, pollen, and climate (6000–3400 BP)

At all three sites, needles of seral species are prominent for nearly 2500 yr before the deposition of the Y tephra. *Alnus sinuata* pollen is also more abundant during this period. While the hot, dry surface of the lahar may have initially arrested succession, I believe another explanation for the persistence of these species is more plausible. Heusser (1977) and Mack et al. (1978*a, b*) reported a climate warmer and/or drier than today during this period. Such conditions may have reduced moisture availability and encouraged frequent fires.

Evidence of fire frequencies is ambiguous. At Jay Bath, conspicuous deposits of the needles of *A. procera, P. monticola,* and *P. menziesii* may reflect forest succession following fires, but there is only one corresponding charcoal peak. Charcoal is frequently abundant at Log Wallow, but disruption of stratigraphy by the inflowing stream probably obscures the detection of individual fires. A coarse sampling interval (370 yr/sample) at Reflection Pond 1 and the relatively short life-span of the seral *A. lasiocarpa* limits resolution on shorter term events at this site.

Tsuga mertensiana and *C. nootkatensis* appeared in the forest of largely seral species at Log Wallow at ≈5000 BP, and probably represent immigration onto the lahar surface from surrounding areas. Macrofossils of these species later appeared at Jay Bath, at ≈3700 BP, and may mark the beginning of the shift to cooler/moister conditions discussed below. The increase in both species is also reflected in the Jay Bath pollen

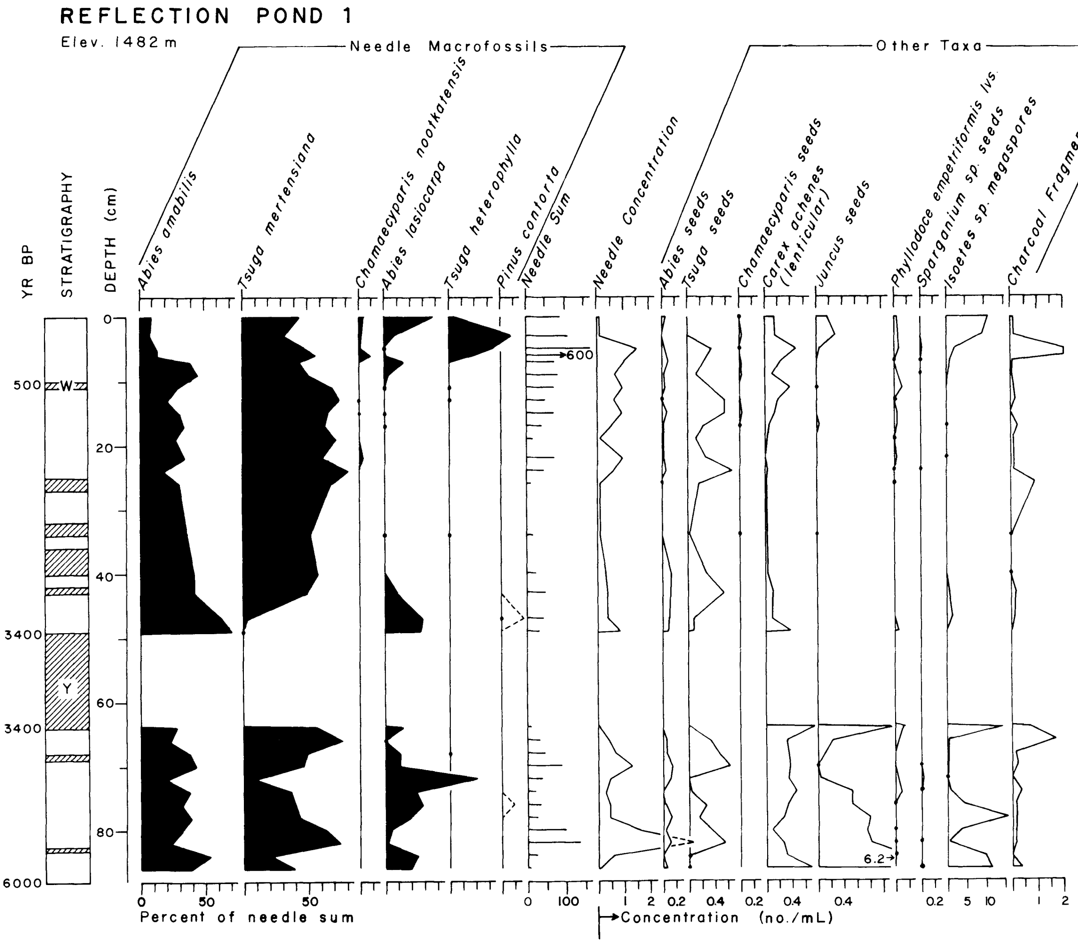

FIG. 5. Macrofossil diagram from Reflection Pond 1. See Fig. 2 for explanation of symbols.

diagram. At Reflection Pond 1, no new species appeared in the macrofossil record below the Y tephra.

The pre-Y tephra fire(s) (≈3600 BP)

At all three sites charcoal peaks are evident 4–6 cm below the Y tephra. These probably represent one or more fires which occurred roughly 200 yr before the Y tephra eruption and significantly altered the forest composition. Low needle concentrations and abundant *Juncus* seeds at Log Wallow and Reflection Pond 1 suggest that local tree density may have been drastically reduced. *Alnus sinuata* pollen reached its highest levels in both diagrams during this time, a further indication of succession after fire.

The seral species that followed this fire or fires suggest that conditions became cooler and moister. Species of lower elevations, *A. procera, P. menziesii,* and *P. contorta,* are rare or absent as macrofossils at Log Wallow and Jay Bath. Even *P. monticola* gained only brief, moderate prominence before declining. Instead, taxa of higher elevation seral sequences are conspicuous. *Abies lasiocarpa* and *A. amabilis* occupied all the sites. The brief appearance of *Picea engelmannii* at Jay Bath is unexplained; it is presently found primarily on the east side of the mountain.

This fire or fires coincided with a shift to cooler and/or wetter conditions reported elsewhere in the Pacific Northwest. Mack et al. (1978*a, b, c,* 1983) document a climatic change in northeastern Washington at the end of the Hypsithermal Interval beginning 4000–3000 BP. Alley (1976) similarly reports cooler, moister conditons beginning ≈3400 BP in southern British Columbia. Neoglacial moraines on Mt. Rainier date from 2800–2600 BP (Crandell and Miller 1974) and also reflect a change to cooler, moister conditons that probably began several hundred years earlier. These climatic changes may have produced shorter growing seasons and a reduced fire frequency that would tend to favor *T. mertensiana* and *C. nootkatensis* at the expense of seral *Pinus* and *P. menziesii.*

Post-Y tephra macrofossils, pollen, and climate (3400–0 BP)

The Mt. St. Helens Y tephra fell on a landscape still recovering from extensive fire(s). Peaks in needle concentration immediately above the tephra at Reflection

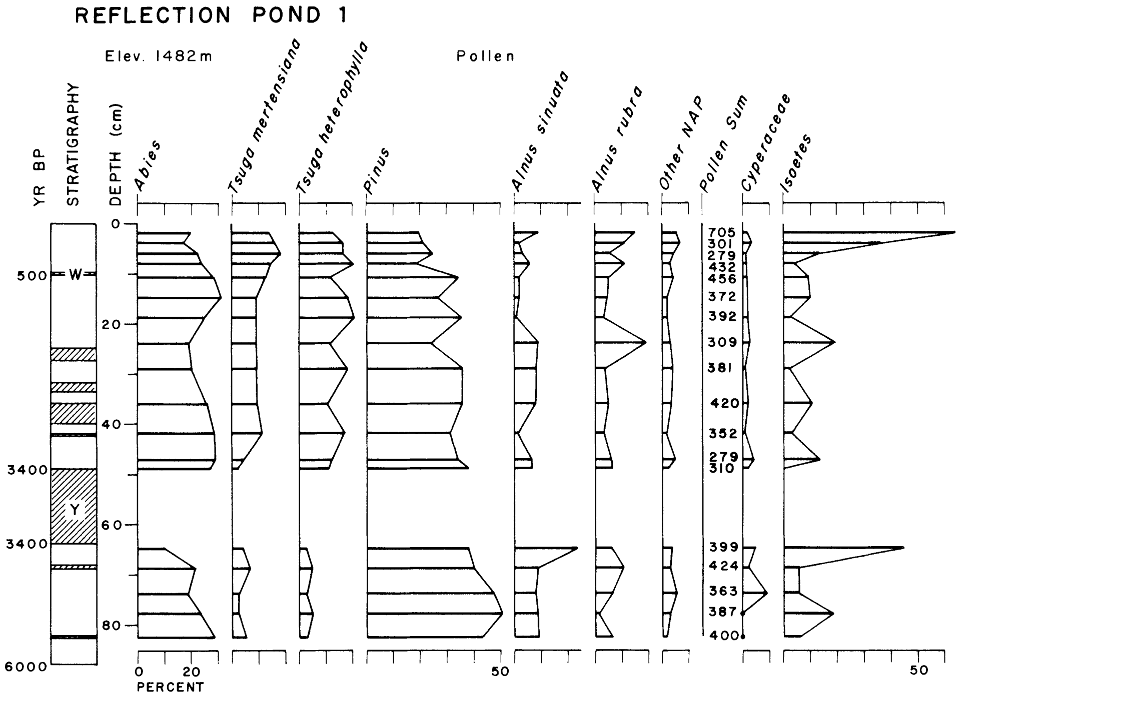

FIG. 6. Percentage pollen diagram from Reflection Pond 1. Pollen from all terrestrial species included in sum.

Pond 1 and Jay Bath may indicate some mortality. Increased needle drop has been reported in some areas blanketed by 10–20 cm of ash from the 1980 Mt. St. Helens eruption, due to the elevation of foliage temperatures by the ash covering (Seymour et al. 1983). The macrofossil curves show no changes in forest composition that can be clearly attributed to effects from the Y tephra. Most taxa remained within 10% of their pre-eruption levels. Where larger declines occurred (e.g., *T. mertensiana* and *A. amabilis* at Reflection Pond 1, *A. lasiocarpa* at Log Wallow), opposite trends are evident with the same taxa at the other sites. Declines in the seed concentration of all herbaceous and aquatic species after deposition of the Y tephra may reflect the burying of these species by ash, although changes in sedimentation cannot be ruled out.

At Jay Bath, the shift to a cooler/moister climate is reflected by increases in *T. mertensiana* and *C. nootkatensis*, taxa characteristic of high elevations. Another climatic shift may have occurred at ≈2000 BP, when the once sparse *Tsuga heterophylla* became continuously prominent. Mack et al. (1978*a*, *b*, 1983) also document the emergence of a modern forest dominated by *T. heterophylla* around this time (≈2700 BP at Tepee Lake, 2400 BP at Big Meadow, and 1500 BP at Hager Pond). The longer growing season and warmer summer temperature implied by these trends (R. N. Mack, *personal communication*, 1983) may have facilitated *T. heterophylla* expansion at Jay Bath during the same period on Mt. Rainier. It is not clear, however, why species characteristic of higher elevations, such as *T. mertensiana* and *C. nootkatensis*, did not concurrently decline at Jay Bath.

A peak in *A. lasiocarpa* needles at Jay Bath at ≈1500 BP is followed by peaks in *A. procera*, *P. menziesii*, *T. heterophylla*, and *A. amabilis*, and may represent forest

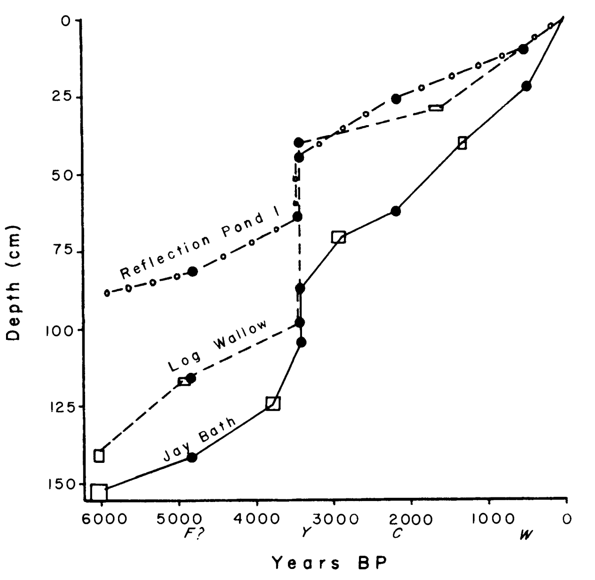

FIG. 7. Age-depth relationships at Jay Bath (—), Log Wallow (— — —), and Reflection Pond 1 (o—o—o). Radiocarbon dates determined in this study (Table 1) are indicated by open rectangles. Dates for tephra layers F, Y, C, and W (●) are from Mullineaux (1974) and Yamaguchi (1983). Identifications of F and C are tentative.

succession after a disturbance. By ≈1100 BP, *T. mertensiana* and *C. nootkatensis* regained dominance. The prominence of *T. mertensiana* and the lack of seral species since then implies a cool, moist climate with few if any fires. This period roughly coincides with the "Little Ice Age" glacier advance that began on Mt. Rainier sometime before 1200 AD (Crandell and Miller 1974).

The two higher sites suggest little change in the cooler/moister climatic conditions until the last century. At Log Wallow, scarce needles of seral species and a decline in charcoal concentrations from pre-Y tephra levels are similar to Jay Bath, and suggest that large fires were infrequent. At Reflection Pond 1, *A. lasiocarpa* was briefly prominent following the 3600 BP fire(s), but *T. mertensiana* and *A. amabilis* became codominant during most of the last 3000 yr. The only major changes in pollen at this site are long-term increases in both *Tsuga* species and declines in *Pinus*; similar trends are evident at Jay Bath. Because regionally derived pollen, including *Pinus, A. rubra,* and *T. heterophylla,* exceeds 50% at Reflection Pond 1, these trends probably reflect regional vegetation changes.

19th century changes

The last major change in macrofossils at Reflection Pond 1 occurs in the top 7 cm, following an increase in deposited charcoal. This charcoal probably represents the 19th-century fires in the Cowlitz drainage that did not reach the two lower sites in the Nisqually River Valley. The closed, stable forest of *A. amabilis* and *T. mertensiana* that had persisted for centuries was destroyed. *Tsuga heterophylla* became abundant briefly, but was replaced by *A. lasiocarpa*. This fir presently dominates the landscape and its macrofossils are conspicuous in the surface sediments.

The brief prominence of *T. heterophylla* at Reflection Pond 1 may have been caused by several factors. Summer temperature reconstructions from tree rings at Longmire show a distinct warming beginning in the late 19th century (Graumlich and Brubaker 1986). Glaciers on Mt. Rainier reached their Neoglacial maxima in the early 19th century, were receding by the 1860's (Burbank 1981) and receded rapidly during the early 20th century. The site is currently near the range limit of *T. heterophylla,* which is strongly inhibited by heavy snowpacks and short growing seasons at this elevation (Thornburgh 1969). The one surviving individual near the pond today exhibits repeated breakage by snow. The fires in the mid-1800's occurred when warming temperatures and perhaps reduced winter precipitation caused earlier seasonal snowmelt and longer growing seasons. Therefore, the environmental balance may have been tipped briefly to favor *T. heterophylla* in the open habitat following fire. Because western hemlock is close to its range limit, high mortality has since eliminated most individuals near Reflection Pond 1.

A small *T. heterophylla* macrofossil peak in the highest two levels at Jay Bath may also reflect this brief climatic reversal, although there is no evidence of this event at Log Wallow. *Tsuga heterophylla* may not have increased as much at these lower sites because mature trees of other species occupied the habitat when climates were most favorable for *T. heterophylla* establishment. Many trees pre-date the 1894 fire, suggesting that this burn was not as severe as the one in the Cowlitz drainage, and probably did not create large openings in the forest. Alternatively, the lower sites may be too far below the upper range boundary of *T. heterophylla* for the climatic changes to have caused significant increases in its numbers.

Implications for forest ecology and climatic reconstructions

Deposition of tephra is frequent in this volcanically active area. Evidence of at least five eruptions in the last 3400 yr are preserved in sediments at Jay Bath, but forest composition does not appear to have been greatly altered. Most layers do not coincide with changes in needle macrofossil trends. This suggests that changes in forest composition: (1) were too short-term to detect using these methods; (2) were of a magnitude insufficient to separate them from other perturbations; or (3) did not alter the proportions of tree species. There is some evidence for a suppressive effect of the large Y tephra deposit on herbaceous terrestrial and aquatic vegetation.

Historical fires at Jay Bath and Reflection Pond 1 are represented by peaks in charcoal concentrations accompanied by low needle concentrations. However, only two or three similar events appear in the entire record, suggesting a very low frequency of severe fires. Other estimates of fire regimes are needed to reconcile these data with the fire frequency of <465 yr on Mt. Rainier reported by Hemstrom and Franklin (1982).

Short-term climatic fluctuations may produce little change in composition in many Pacific Northwest forests because long-lived, mature trees may survive conditions lethal to seedlings. Species that are best adapted to the climate may only be able to enter the forest in open habitats following severe fires. Thus forest compositon may respond to climatic changes primarily after disturbance. Furthermore, the frequency and intensity of disturbances may be altered by climatic changes. For example, dry climates might increase fire frequency, resulting in vegetation changes with shorter lag times.

The climatic sequence presented here is more similar to those described from east of the Cascade Range (Mack et al. 1978*a, b, c,* 1983) than to nearby sites west of Mt. Rainier (Barnosky 1981, Tsukada et al. 1981), which show little vegetational change during the last 5000 yr. Forests in the climatically equitable Puget Lowland may be less sensitive to climatic changes than vegetation in eastern Washington or at higher elevations in the mountains. The variations in the timing of Holocene climatic changes between sites (Mack et al. 1978*c*) may be due to a combination of different sensitivities among the species, lags in vegetation response, physical characteristics of the sites, dating of the sediments, migration rates of species, and climatic circulation patterns producing differential effects.

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