Pollen and Lignin Records of Late Quaternary Vegetation, Lake Washington

Abstract. *Analyses of lignin oxidation products and pollen for an 11-meter core from Lake Washington provide independent but similar reconstructions of the late Quaternary vegetation in the Puget Lowland. An exception is in sediments of the late Pleistocene where pollen percentages and influx values suggest conifer forest whereas lignin compositions suggest a treeless source region. This dissimilarity appears to result from different major provenances: eolian transport of pollen to the lake from adjacent or downstream drainage basins as opposed to fluvial transport of lignified plant debris only from the Lake Washington drainage basin.*

The study of pollen and spores preserved in lake sediments has become a standard means of investigating local paleovegetation and paleoclimate. Because pollen is produced in varying amounts by different vascular plants and is subject to differential transport and preservation (*1*), the pollen analyst has difficulty in separating local from regional source plants and in determining the size of local plant populations. Thus pollen assemblages are best interpreted with the aid of supplementary information provided by paleontologic (*2*), isotopic, and geochemical data (*3*).

Lignin compounds are phenolic polymers found in all vascular plants and like pollen are unique to this source (*4*). Lignins are resistant to microbial degradation, compositionally characteristic of different plant tissues (*5, 6*), and can be detected in small amounts by chemical oxidative analyses (*4*). Although these characteristics suggest that lignin oxidation products might be useful paleovegetation indicators, most applications as chemical tracers have involved modern sediments or individual macrofossils (*7*). We report a systematic comparison of pollen and lignin paleovegetation records as applied to a sequence of postglacial and late Pleistocene sediments from Lake Washington, near Seattle, Washington.

A sediment core, 11 m by 6.4 cm in diameter, was obtained at a water depth of 55 m near the center of northern Lake Washington (*8*). Sediment samples were collected for pollen analysis at 10- to 12-cm intervals and for lignin analysis at intervals of about 75 cm. We prepared pollen from 0.5-cm^3 samples by standard methods (*1, 9*). Whole sediment samples (0.5 to 2.0 g dry weight) were oxidized with alkaline cupric oxide to produce lignin-derived phenols (Table 1) that were quantified by gas chromatography (*10*).

We used the total yield of phenols in Table 1 as an indicator of lignin abundance and the weight percentages of total vanillyl, syringyl, and cinnamyl phenols to indicate the relative abundances of gymnosperm woods (softwoods), angiosperm woods (hardwoods), and nonwoody plant tissues (herbs, grasses, tree leaves, and needles) in sedimentary mixtures (*6, 11, 12*). This method is based on the observation that gymnosperm woods produce only vanillyl oxidation products, whereas syringyl phenols are characteristic of angiosperm tissues and cinnamyl phenols are produced by nonwoody tissues of both gymnosperms and angiosperms (Table 1) (*6*). Chemical evidence (*12*) indicates that well-preserved vascular plant tissues are the major source of lignin-derived phenols throughout the Lake Washington core.

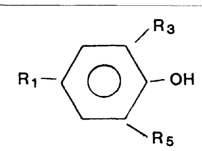
The basal 1.5 m of the Lake Washington core (zone W-0, Fig. 1) consists of a blue silty clay that was deposited before 13,400 years ago. The clay consists of rock flour (*13*) and contains remains of marine diatoms (*14*), silicoflagellates (*15*) and dinoflagellates. Total organic matter, lignin, and pollen concentrations are extremely low (*16*), apparently because of dilution by glacial flour. The pollen assemblage is dominated by pine (*Pinus*) with lesser amounts of spruce (*Picea*), mountain hemlock (*Tsuga mertensiana*), and grass (*Poaceae*). We also found moderate abundances of apparently reworked pollen grains of Tertiary (*Carya* and *Pterocarya*) and Pleistocene (western hemlock, *T. heterophylla*, and alder, *Alnus*) ages (Fig. 1).

The lignin oxidation products from zone W-0 are rich in vanillyl phenols and relatively poor in syringyl and cinnamyl compounds. This composition indicates a high proportion of gymnosperm wood debris in the lake sediments, a result that is consistent with the prominence of conifer pollen in the zone. The early marine phase of Lake Washington occurred when seawater invaded an isostatically depressed Puget Lowland after the northward retreat of the Cordilleran Ice Sheet approximately 13,400 years ago (*17*). Much of the organic material in the blue clay apparently comes from glacial outwash as indicated by the prevalence of reworked pollen (*18*) and an anomalously old ^{14}C age of 20,700 ± 700 years (*19*).

Younger Pleistocene sediments (zone W-1, Fig. 1) from 9.5- to 7.5-m depths (~ 13,400 to 11,000 years old) are partially laminated silts that contain a progressively greater content of organic matter (8 to 10 percent), lignin, and pollen. Annual pollen influx (6000 to 12,000 grains per square centimeter per year) is comparable to that of modern boreal forest sites (*20*). The pollen assemblage consists predominantly of pine with spruce, alder, and bracken fern spores (*Pteridium*). Only freshwater plankton are present, indicating the absence of seawater in the basin (*14*).

Taken at face value the pollen evidence suggests a local pine forest with some spruce and understory shrubs and herbs. However, pine produces large

Table 1. Common CuO oxidation products of lignin. Plant source abbreviations: *G*, gymnosperm woods; *g*, nonwoody gymnosperm tissues; *A*, angiosperm woods; *a*, nonwoody angiosperm tissues. An asterisk indicates typical production at greater than one weight percent of the total phenolic yield (*11*).



	A = CHO B = $COCH_3$ C = CO_2H Structure			D = *trans*-$CH=CHCO_2H$ E = H F = OCH_3 Plant sources			
	R_1	R_3	R_5	*G*	*g*	*A*	*a*
Vanillyl phenols							
Vanillin	A	E	F	*	*	*	*
Acetovanillon	B	E	F	*	*	*	*
Vanillic acid	C	E	F	*	*	*	*
Syringyl phenols							
Syringaldehyde	A	F	F			*	*
Acetosyringone	B	F	F			*	*
Syringic acid	C	F	F			*	*
Cinnamyl phenols							
p-Coumaric acid	D	E	E		*		*
Ferulic acid	D	E	F		*		*

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amounts of highly mobile pollen and tends to be overrepresented in pollen rain. Furthermore, the strong maximum in cinnamyl phenols accompanied by an increase in the syringyl component in the same interval indicates a sedimentary mixture of vascular plant remains consisting almost exclusively of nonwoody angiosperm tissues (*12*). The scarcity of woody debris in these sediments suggests an essentially treeless source region since the presence of trees within the drainage basin should be sensitively indicated by a much lower ratio of cinnamyl to vanillyl phenols (*21*). Thus the dominance of coniferous trees suggested by the moderately high pollen influx data is not at all indicated by the lignin analysis.

A brief transition period (zone W-2) at about 7.5 m is marked by an initial increase in Douglas fir (*Pseudotsuga*) and a temporary presence of fir (*Abies*) pollen. Above this interval percentages of alder and bracken fern increase sharply and grass pollen increases gradually. The predominance of alder, Douglas fir, and grass pollen along with bracken fern spores in zone W-3a (~ 10,000 to 7000 years ago) suggests an open forest of Douglas fir and alder or a forest mosaic and a climate both warmer and drier than that at present (*22*). The prominence of Douglas fir pollen in the early Holocene exceeds that of more recent periods according to both percentage and influx values (Fig. 1). The abundant pollen and spores of successional plants (alder, bracken fern, and the fire-adapted Douglas fir) as well as charcoal (*23*) indicate frequent perturbations of the vegetation by fire (*24*). Pollen influx rates (10,000 to 12,000 grains per square centimeter per year) are consistently high as in the previous zone.

Total lignin phenol yields are uniformly high in zone W-2 and above, supporting other evidence (*12*) for minimal in situ degradation of sedimentary lignin. The high concentrations of syringyl oxidation products in zone W-3a accompanied by low cinnamyl phenol values indicate a major angiosperm wood component and lesser amounts of gymnosperm wood and herbaceous tissues. This interpretation corresponds well with pollen evidence for abundant alder during the W-3a period.

The most recent pollen interval records a sharp increase in western red cedar (*Thuja plicata* type), which is not fire-adapted, at the expense of alder and to some extent Douglas fir. This change begins about 7000 years ago immediately above the Mazama ash horizon and reaches full expression at the top of zone W-4, signifying a cooler, more moist climate (*22*). Pollen influx reaches maximum values (30,000 to 60,000 grains per square centimeter per year) in the middle of zone W-4, perhaps because sedimentation rates are lower here than the average for this zone as a whole. A trend in lignin oxidation products consisting of a regular increase in vanillyl phenols with an equivalent drop in syringyl compounds also begins during W-3b. This pattern indicates a relatively wood-rich mixture of vascular plant detritus with an increased softwood component and corroborates the pollen evidence for a local expansion of western red cedar and a decline of alder.

The chronologies of change and predominant vegetation types indicated by pollen are generally consistent with the lignin record for the Lake Washington sediment core and correspond well with pollen results from other sites in the southern Puget Lowland (*25*). The outstanding instance of apparent inconsistency is for zone W-1, in which pine pollen strongly predominates whereas the lignified debris is essentially all nonwoody angiosperm tissues and includes little or no wood indicative of trees.

These data are not necessarily conflicting. Both pollen and lignified plant remains are introduced to large lakes primarily by streams and slope wash (*21*, *26*). However, pollen grains, because of their relatively small size, can be transported by winds between drainage basins before deposition and stream erosion. Pine pollen is particularly susceptible to long-range eolian transport (*27*). In contrast, the generally larger lignified plant debris are much less susceptible to eolian transport and, like other macrofossils, are derived almost exclusively from vascular plants that grow around the lake

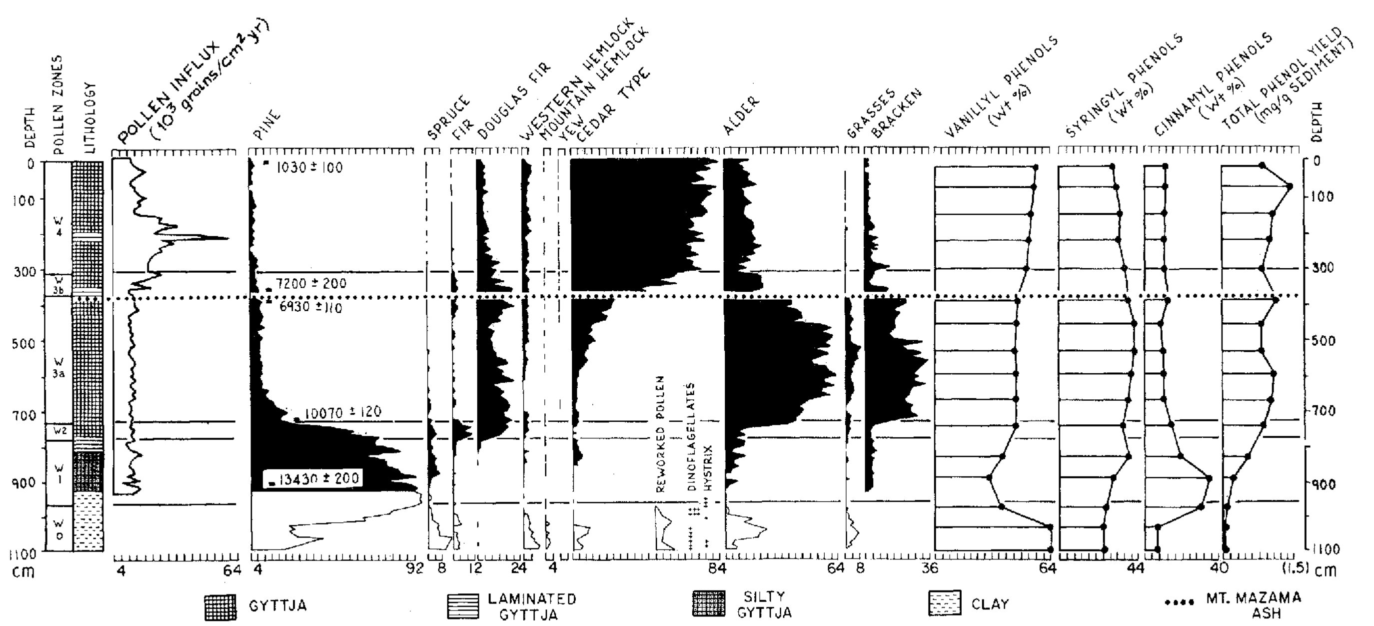

Fig. 1. Profiles of pollen and lignin oxidation products for the Lake Washington sediment core. Pollen data are percentages of total pollen less aquatics; lignin compositions are expressed as weight percentages. Weight percentages of vanillyl, syringyl, and cinnamyl phenols are reproducible within an average of ±1 percent, which corresponds approximately to the dimensions of individual data points. Some disturbed sediment at the top of the piston core was discarded. Annual pollen influx values are not given for zone W-0 because a reliable ^{14}C age is not available for the base of this interval.

or at higher elevations within its drainage basin.

In the specific example of zone W-1 the moderately high influx of pine pollen to Lake Washington sediments suggests a pine forest nearby (*28*). The contemporaneous lignin record, however, indicates that this woodland probably did not extend upstream of the lake, where herbaceous flowering plants apparently predominated. This suggested vegetation pattern for zone W-1 may have been transitional to those of later periods when regional vegetation and vegetation within the upstream drainage basin were similar, resulting in more consistent sedimentary lignin and pollen records.

In conclusion, it is clear that lignin does not reflect genus-level changes in vegetation that can be characteristic of paleoenvironmental conditions. However, as indicated by our results for zone W-1, the lignin chemical analyses may under some circumstances detect classes and distributions of local vegetation that are not evident from pollen remains. Determinations of lignin compositions in lake sediments, in association with pollen analyses, may provide complementary indicators of paleovegetation.

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8. Lake Washington (elevation 6.4 m) is 29 by 3 km and up to 65 m deep; it drains an area of about 300 km^2 directly east of the lake. The core was collected at 47°40.4'N and 122°13.4'W with the cooperation of the captain and crew of the R.V. *Thompson*, D. Morrison and A. van Geen.
9. Pollen percentages were calculated from tallies of 500 to 600 grains mounted in silicone oil. Influx values were determined by counting the proportion of exotic grains added and applying ^{14}C ages to calculate sedimentation rates [L. J. Maher, *Rev. Paleobot. Palynol.* **32**, 153 (1981)].
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29. We thank M. Stuiver for all radiocarbon dates cited and M. L. Peterson for helpful comments. Supported in part by NSF grants DEB79-12241 and OCE80-23970. Acknowledgment is made to the donors of the Petroleum Research Fund administered by the ACS for partial support of this research. This is contribution 1291 from the School of Oceanography, University of Washington.
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Eruption of El Chichón Volcano, Chiapas, Mexico, 28 March to 7 April 1982

Abstract. *El Chichón volcano erupted at 2322 hours on 28 March 1982 after being dormant during historic times. Three major eruptions of tephra occurred between that date and 7 April, discharging approximately 0.3 cubic kilometer of andesitic pyroclastic material. The initial eruption produced crystal-rich tephra of higher silica and alkali content than the lithic pyroclastic materials of the second and third eruptions. The initial tephra consists of primarily juvenile materials, whereas the later eruptions produced both lithic and juvenile fractions.*

The volcano El Chichón, located in the southeastern state of Chiapas, Mexico, initiated a series of major tephra eruptions at 2322 hours on 28 March 1982. The late Pliocene or early Pleistocene stratovolcano, which lies on the east end of the Mexican neovolcanic zone in the modern Chiapacean Volcanic Arc (*1*), historically had been inactive, displaying only solfataric activity (*2*).

Chiapas marks the juncture of the American, Cocos, and Caribbean plates. Current volcanic activity in the area is attributed to continued subduction of the Cocos plate beneath southeastern Mexico (Fig. 1) (*1*).

During the first 10 days of activity approximately 0.3 km^3 of tephra was ejected in three major eruptions, causing 187 confirmed deaths and leaving 60,000 people homeless (*3*). No lava flow was reported, but pyroclastic flows and

Table 1. Chemical analysis of tephra and dome material, El Chichón. The data for tephra ejected between 28 March and 2 April represent 12 samples; the 3 to 7 April data represent 22 samples. Values are percentages by weight. N.D., not determined.

Compound	28 March to 2 April		3 to 7 April		Andesite dome	Standard deviation	Mean standard error
	Mean	Range	Mean	Range			
SiO_2	59.3	54.9 to 62.2	56.4	53.8 to 60.2	58.2	±0.6	±0.13
TiO_2	0.7	0.6 to 0.8	0.8	0.7 to 0.9	0.8	±0.2	±0.01
Al_2O_3	17.3	16.8 to 17.8	17.3	16.6 to 18.5	16.8	±0.7	±0.10
FeO*	5.4	4.8 to 5.6	6.3	5.2 to 10.3	6.5	±0.1	±0.01
MnO	0.1	0.1 to 0.2	0.1	0.1 to 0.2	0.2	±0.1	±0.00
MgO	1.8	1.2 to 2.8	2.2	1.8 to 3.3	2.1	±0.8	±0.16
CaO	6.2	6.0 to 8.0	6.9	5.8 to 8.8	7.5	±0.4	±0.01
Na_2O	4.5	3.5 to 6.0	4.2	3.6 to 5.2	4.2	±0.7	±0.19
K_2O	3.1	2.0 to 3.6	2.9	1.8 to 3.5	2.4	±0.2	±0.01
P_2O_5	0.1	0.0 to 0.1	0.1	0.0 to 0.1	0.1	±0.1	±0.01
LOI†	1.4	1.1 to 1.4	1.3	0.3 to 1.5	N.D.		
Total	99.9		98.6		98.8		

*Includes total Fe. †Loss on ignition.

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