THE VASA PARK FLORA, KING COUNTY, WASHINGTON, U.S.A.: A WINDOW INTO THE LATE MIOCENE OF THE PACIFIC NORTHWEST

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ABSTRACT

A Late Miocene flora (11.4 ± 0.61 Ma) from Bellevue, Washington, is described using macro- and microfossils to summarize the flora and estimate climate and vegetation coverage. Genera recognized from macrofossils include pteridophytes (*Equisetum* L., *Woodwardia* Sm., and *Allantodiopsis* Knowlt. & Maxon, an apparent relict from the Eocene Puget Group flora), a rare cupressaceous conifer, and common angiosperms (*Platanus* L., *Cercidiphyllum* Siebold & Zucc., *Ulmus* L., *Fagus* L., *Hydrangea* L., *Alnus* Mill., *Acer* L., and *Persea* Mill.). Including unidentified morphotypes, the macroflora records one bryophyte, six pteridophytes, one gymnosperm, and 24 angiosperms. Well-preserved fossil pollen from the same sediments reveals a much richer regional flora. Although cupressaceous pollen is the most common element, a diverse record of Pinaceae is revealed by the palynoflora, including *Abies* Mill., *Picea* A. Dietr., *Pinus* L., *Pseudotsuga* Carrière/ *Larix* Mill., and *Tsuga* Carrière. In contrast, the Pinaceae are totally absent from the macrofossil record. Additional angiosperm genera identified from pollen include *Liquidambar* L., *Ilex* L., cf. *Sarcobatus* Nees, *Carya* Nutt., *Juglans* L., *Nyssa* L., *Fraxinus* L., and *Salix* L. Significant rare elements in the pollen flora include representatives of the Poaceae and Asteraceae. In total the palynomorph assemblage documents more than twice the diversity found in the macroflora. Coexistence analysis based on the pollen assemblage estimates mean annual temperature (MAT) of 11.6°C–16.6°C. Together, the macroflora and palynofloras suggest that Pacific Northwest plant communities—and climates—had not changed substantially since the Middle Miocene. Phytoliths recovered from the sediments suggest a closed-canopy forest with warm-adapted grasses of the PACMAD (Panicoideae, Arundinoideae, Chloridoideae, Micrairoideae, Aristidoideae, and Danthonioideae) clade in the understory or in forest gaps. Geological and botanical evidence indicate that the fossils are preserved in flood overbank deposits associated with widespread Late Miocene conglomerates found throughout western Washington.

Key words: geology, Miocene, paleobotany, palynology, phytoliths.

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We are pleased to participate in the Festschrift honoring Alan Graham on his 80th birthday. Alan's early fieldwork included the Middle Miocene sites at Trout and Sucker creeks in eastern Oregon. Alan used both macrofossils and palynomorphs to describe the local and regional flora of southeastern Oregon in the Middle Miocene. We will follow in his footsteps, using macrofossils, the palynoflora, and phytoliths, in addition to sedimentology, to describe the flora, paleoclimate, and paleoenvironment of the Vasa Park locality in the Late Miocene and compare Vasa with other Northwest Miocene occurrences (Fig. 1).

The site is located in a narrow ravine on land owned by a private park on the southern shore of Lake Sammamish in Bellevue, Washington. The majority of sedimentary exposures in the immediate vicinity of Vasa Park are the nearshore marine Oligocene sediments of the Blakely Formation and extensive Quaternary glacial deposits (Fig. 2). Tectonic activity along the Seattle fault created small isolated exposures of Miocene continental sediments, including the Vasa Park locality (Fig. 3). The Middle Miocene paleobotany of eastern Washington, eastern Oregon, and adjacent Idaho has been extensively documented by studies beginning over 100 years ago (Merriam, 1901; Knowlton, 1902, 1926; Chaney & Axelrod, 1959; Graham, 1963, 1965; Smiley, 1963; Smiley & Rember, 1985). These floras have documented floral evolution and vegetation change in the Pacific Northwest during this important time, characterized by substantial global warming associated with the Mid-Miocene Climatic Optimum (MMCO; Zachos et al., 2001). However, there is comparatively little data from the Late Miocene, especially in a coastal plain setting. As a result, our knowledge of the composition and structure of plant communities during the regional transition to a cooler and more seasonal climate has been extremely limited. Vasa Park provides an important new window into the Late Miocene environment of the Pacific Northwest.

Our data show that the Vasa Park flora is preserved in flood overbank deposits of a fluvial system. Large cobble conglomerates bracketing the fossil-bearing sediments record a high-energy environment, and the fossil-bearing sediments point
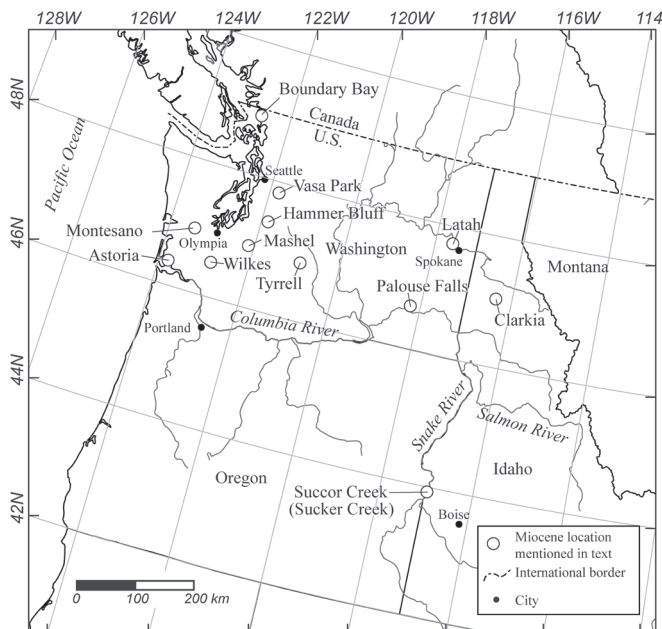

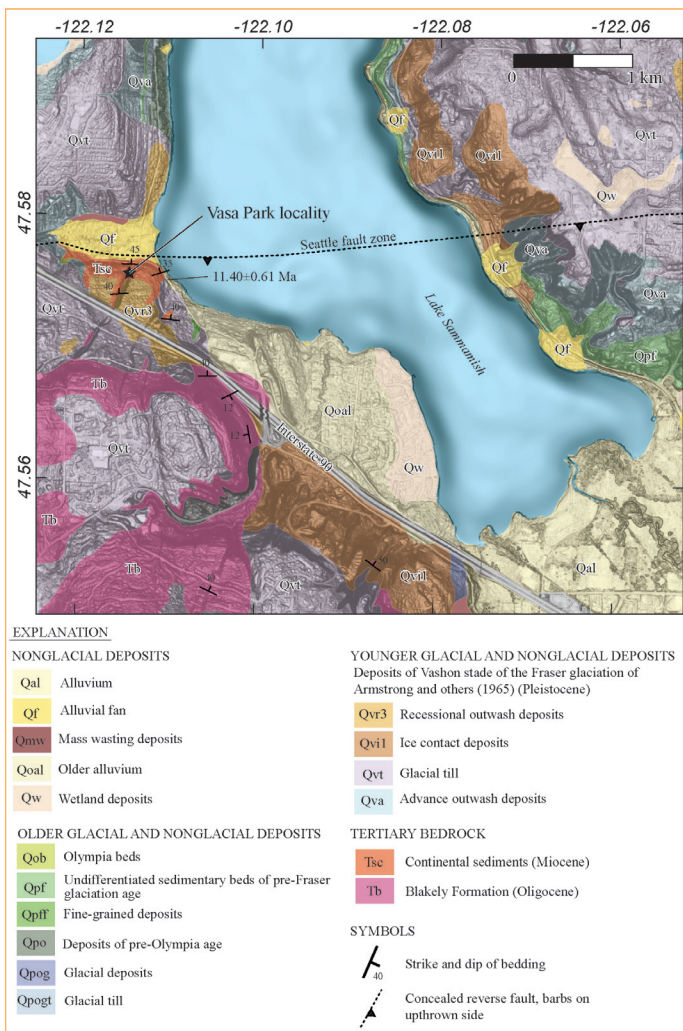FIGURE 1. Pacific Northwest Miocene localities mentioned in the text.

FIGURE 2. Geologic map of Vasa Park locality and surrounding area (Booth et al., 2012).

to a highly disturbed local environment subject to periodic inundation. The macroflora contains many species that grow in regularly disturbed fluvial environments and the most diverse assemblage of ferns known from a Northwest Miocene locality. The palynoflora records a diverse regional flora containing many elements that are not found in the macroflora. The climate estimate based on the palynoflora is of a warm temperate environment with ample precipitation during the growing season, similar to other Northwest Middle and Late Miocene deposits. Phytolith analysis shows the environment to have been primarily closed forest with only one horizon indicating a substantial presence of open habitat grasses.

GEOLOGIC SETTING

REGIONAL GEOLOGY

The Puget Lowland, a broad, low-lying region between the Cascade Mountains to the east and the Olympic Mountains to the west, is part of a
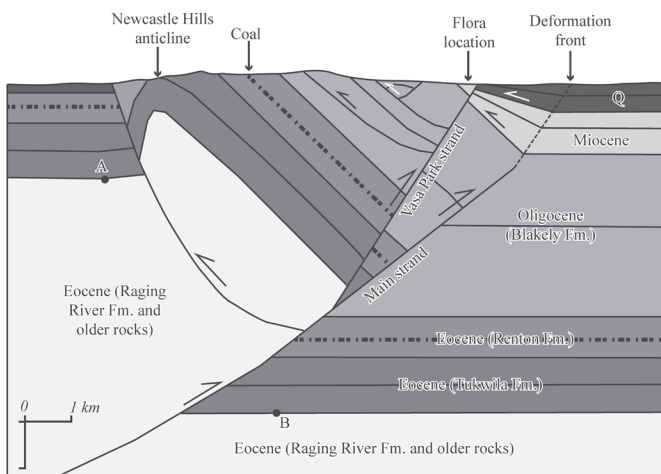
FIGURE 3. Stratigraphy of the Newport Hills anticline in the vicinity of Vasa Park. Redrawn from Liberty and Pratt (2008).

forearc basin formed in the Early Cenozoic that preserved Paleocene oceanic volcanic rocks and Eocene through Quaternary marine and terrestrial volcanic rocks and sedimentary deposits. Climate changes in the Quaternary resulted in a thick blanket of glacial deposits mantling bedrock. Eocene to Quaternary volcanic and sedimentary rocks lie beneath the glacial deposits in the central Puget Lowland, and north to south shortening warps these rocks into a series of east-west-trending folds (Wells et al., 1998; Brocher et al., 2001; Booth et al., 2004). The most prominent of these folds in the Seattle region are the Newcastle Hills and Gold Mountain anticlines; together these anticlines form a linear, northwest-trending bedrock extending almost 90 km across the central Puget Lowland (Mullineaux, 1970; Booth et al., 2012).

Outcrops of Miocene rocks at Vasa Park owe their exposure to profound tectonism along the north limb of the Newport Hills anticline, localized along a thrust fault—the Seattle fault— lying beneath the north limb of the anticline. Blakely et al. (2002), Johnson et al. (1994, 1999), and Liberty and Pratt (2008) identify several subparallel fault strands within an east-trending zone along the north side of the Newport Hills anticline using high-resolution aeromagnetic, geologic mapping, and seismic reflection methods. Rocks within the Newport Hills anticline consist of Eocene nonmarine arkosic sandstones with abundant plant fossils, Oligocene marine sandstones and siltstones with nearshore marine and plant fossil horizons, and minor amounts of conglomerate. These are overlain by Miocene nonmarine conglomerate, volcanic sandstone and siltstone, and mudstone, with local peat and tephra layers (Fig. 3). Booth et al. (2012) describe the Miocene deposits as outcrops of sandstone, conglomerate, tuff, and volcaniclastic sandstone above the southwest and southeast shores of Lake Sammamish. Interbeds of lignite contain nearly coherent logs. Bedding is concordant with underlying Oligocene marine deposits.

VASA PARK STRATIGRAPHIC SECTION

A 17-m-thick section at Vasa Park consists of three main units: a lower conglomeratic unit, a middle fine-grained unit, and an upper conglomeratic unit (the upper two parts are shown in a measured section on Fig. 4). Conglomerates are generally reddish brown (oxidized), matrix-supported pebble/cobble conglomerates with clast lithologies predominately of dark-colored, fine-
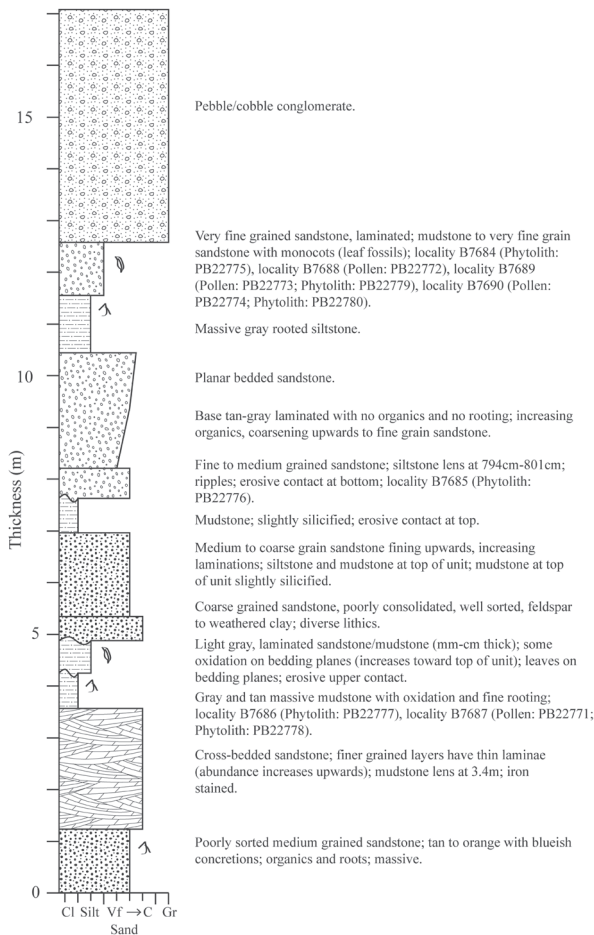
FIGURE 4. Stratigraphic section of Vasa Park sedimentary rocks. Burke Museum of Natural History and Culture, University of Washington (UWBM) locality numbers begin with "B"; UWBM sample numbers begin with "PB."

grained crystalline rocks and fine-grained andesitic and felsic volcanic rocks. The middle fine-grained part contains brownish gray tuffaceous siltstone, sandy siltstone, and silty sandstones. Volcanic fragments and tuffaceous material in finer-grained deposits commonly weather to clay. Lamination in finer-grained strata is common. A thick stratum of cross-bedded tuffaceous sandstone lies near the base of the section.

The stratigraphic position and low degree of lithification of the strata exposed in the creek section led some previous workers to assign a Quaternary age to these deposits (for example, Liesch et al., 1963). However, potassium-argon (K-Ar) ages from one nearby locality range from 9.3 to 14.7 Ma (Yount & Gower, 1991), and subsequent argon-argon (Ar/Ar) laser fusion dating from this same unit yielded an age of 11.40 ± 0.61 Ma (Booth et al., 2012).

Lithologies, sedimentary structures, and plant fossils suggest deposition in an alluvial system issuing from and between Miocene stratovolcanos located to the east. Conglomerates and interbedded sandstones are indicative of deposition in high-energy, nonglacial braided stream channels, and finer-grained sandstone and siltstone were deposited on the stream's floodplain. However, strata of fossiliferous silt, clay, and log-bearing lignite indicate that other parts of the deposit are fluvio-lacustrine in origin. The presence of poorly sorted,

thin, and interbedded fluvial and lacustrine sediments at Vasa Park suggests deposition in a low-relief piedmont environment characterized by floodplains and small lakes (possibly oxbow lakes).

CORRELATIVE UNITS

Exposures of Middle Miocene conglomerate and sandstone deposits throughout the Puget Lowland attest to widespread alluvial deposition in the Middle Miocene: the Hammer Bluff Formation near Enumclaw, Washington; the Mashel Formation near Orting, Washington; the Wilkes Formation near Toledo, Washington; and the Boundary Bay Formation (found in subsurface only) near Bellingham, Washington (Fig. 1). These deposits, like those at Vasa Park, suggest prevalent low-relief piedmont environments characterized by floodplains and small lakes in western Washington, with low hills to the east and west at the present locations of the Cascade and Olympic mountains (e.g., see Mullineaux, 1970). Leopold and Denton (1987) showed that the Columbia Plateau in eastern Washington did not take on its modern character until Pliocene or even Pleistocene time, suggesting that a significant moisture barrier at the present-day location of the Cascade Mountains did not exist in the Middle Miocene.

Middle to Late Miocene siltstones, sandstones, and conglomerates of the Astoria and Montesano formations outcrop west of Olympia, Washington, and fossils within each formation demonstrate deposition in shallow-water marine environments (Rau, 1967). The location of these marine deposits of similar age as nonmarine deposits found in the Puget Lowland suggest that the Middle to Late Miocene shoreline probably lay west of present-day Olympia.

MATERIALS AND METHODS

The Vasa Park locality occurs in a steep canyon that starts at the I-90 freeway and ends near the southwestern shore of Lake Sammamish in King County, Washington, located in T24N R5E. The exposure consists of approximately 17 m of mudstone, siltstones, and sandstone bracketed by massive beds of coarse, well-rounded basaltic conglomerate that has been documented across the Puget Sound region in association with the Seattle fault (see above; Blakely et al., 2002). Conglomerate layers often contain woody debris up to 50 cm in length, whereas leaves are preserved in fine-grained sandstones. Plant fossils (Figs. 5–7) typically occur along bedding planes separated by 1- to 5-cm sections of barren rock. The macroflora locality is designated as Burke Museum of Natural History and Culture, University of Washington locality UWBM 6816 (see Figs. 8 and 9 for microflora locality numbers within the section). Macrofossils were morphotyped using methods from the *Manual of Leaf Architecture* (Ellis et al., 2009).

Sediment samples (Figs. 8, 9) for pollen and phytolith analysis were collected from two main horizons. We did not attempt to collect incremental samples from the entire section, which consists largely of non-fossiliferous (based on preliminary sampling) sandstone; rather, in an attempt to provide an overview of the microfloral assemblages of the deposit, samples were collected from fine-grained exposures that are more likely to contain palynomorphs and phytoliths. Incremental stratigraphic sampling would be further complicated at this site because it is heavily vegetated, thus there is not a continuous exposure of the sediments. Two sediment samples (resulting in pollen or phytolith sample/specimen UWBM nos. PB22777 and PB22771/PB22778; see Fig. 9) were collected from a layer 0–75 cm below the leaf-bearing layer in gray and tan massive mudstone with oxidation and fine rooting sediment. Another four samples (resulting in pollen or phytolith sample/specimen UWBM nos. PB22772, PB22773/PB22779, and PB22774/PB22780; Figs. 8, 9) were collected from a single, fine-grained siltstone leaf-bearing exposure between 11.5 and 12 m from the base of the section.
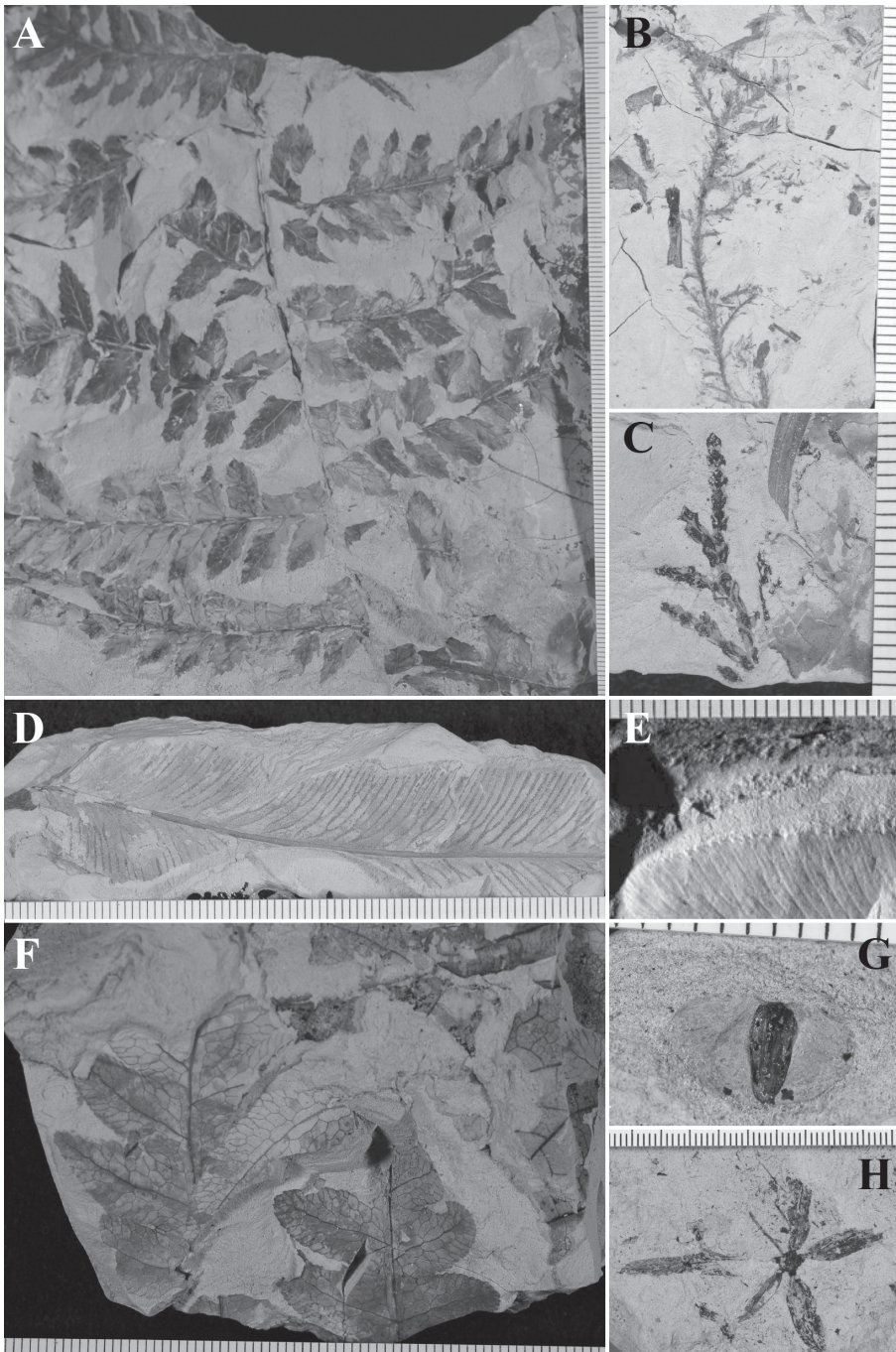
FIGURE 5. Pteridophytes and allies, bryophytes, and gymnosperms. —A. Dryopteridaceae (UWBM PB9440). —B. Gametophyte of unknown bryophyte (UWBM PB9474). —C. Foliage of *Chamaecyparis linguaefolia* (Lesquereux) MacGinitie (UWBM PB9698). —D. Pinnule of *Allantodiopsis* sp. (UWBM PB9613). —E. Serrate margin of *Allantodiopsis* sp. (UWBM PB9611). —F. Pinnules of *Woodwardia* sp. (UWBM PB9616). —G. Winged seed of *C. linguaefolia* (UWBM PB9766). —H. *Equisetum* sp. bulbils (UWBM PB9449).
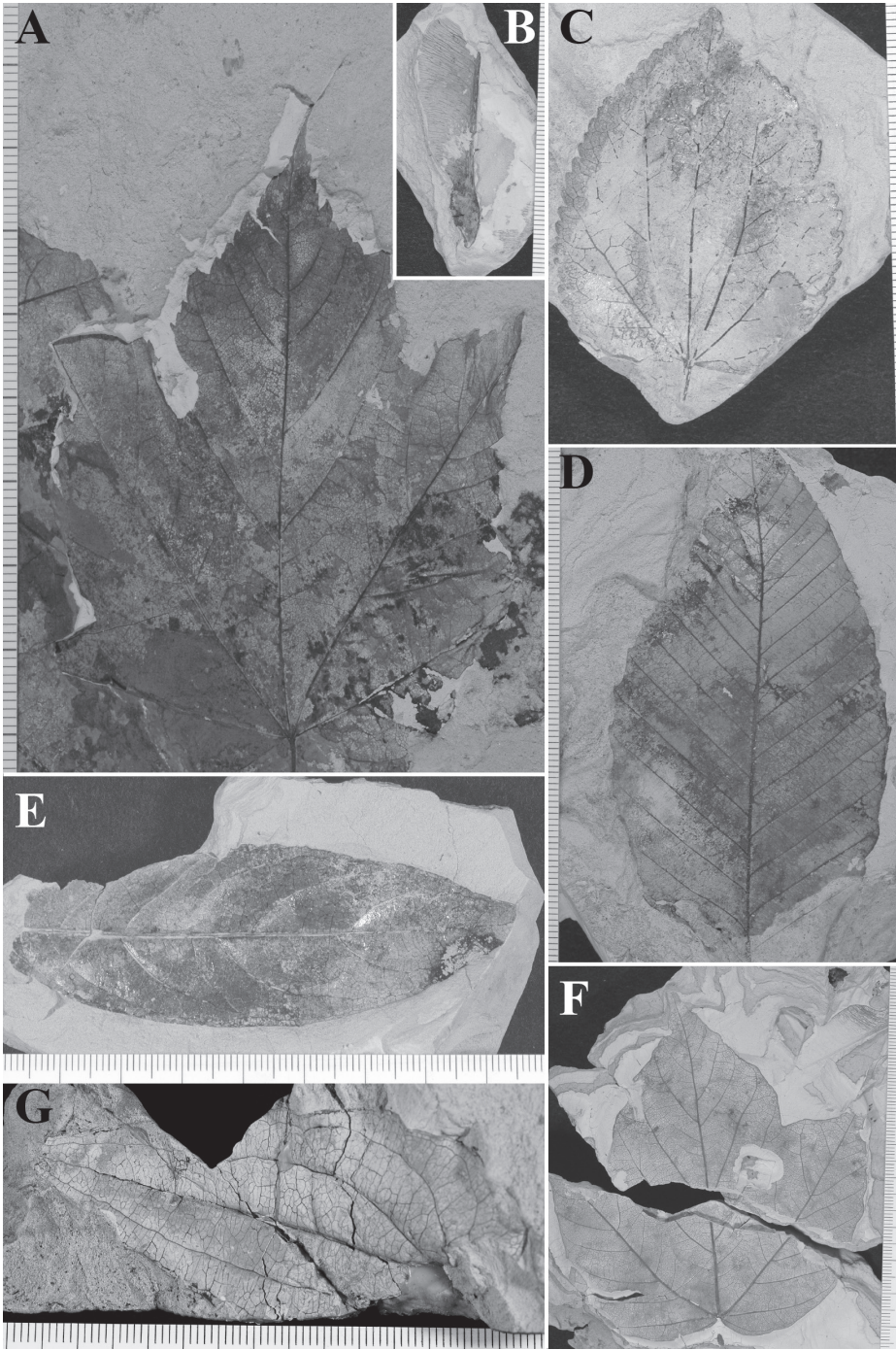
FIGURE 6. Vasa Park angiosperms. —A. Leaf of *Acer* sp. (UWBM PB89436). —B. Samara of *Acer* sp. (UWBM PB9961). —C. Leaf of *Cercidiphyllum crenatum* (Unger) Brown (UWBM PB9964). —D. Leaf of *Fagus washoensis* LaMotte (UWBM PB9538). —E. Leaf of *Persea pseudocarolinensis* Lesquereux (UWBM PB9960). —F. Leaf of cf. *Gossypium* sp. (UWBM PB9961). —G. Leaf of *Smilax magna* Chaney (UWBM PB9732).

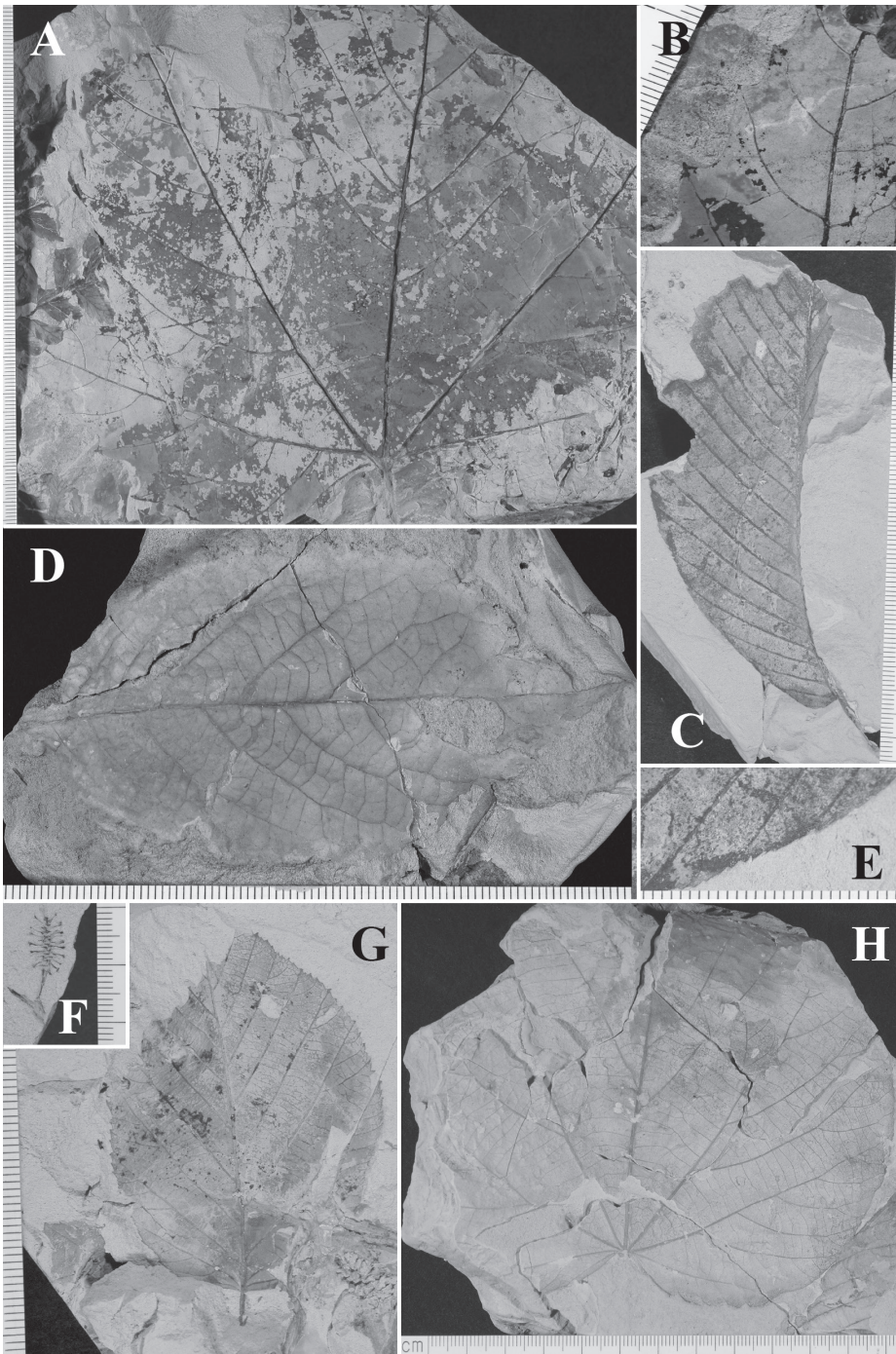FIGURE 7. Vasa Park angiosperms continued. —A. Leaf of *Platanus dissecta* Lesquereux (UWBM PB9440). —B. Detail of A showing teeth. —C. Leaf of *Aesculus* sp. (UWBM PB9448). —D. *Hydrangea bendirei* (Ward) Knowlton (UWBM PB9944). —E. Detail of C showing teeth. —F. Infructescence of *Alnus* sp. (UWBM PB9605). —G. Leaf of *Alnus* sp. (UWBM PB9955). —H. Leaf of *Pauwlonia columbiana* Smiley (UWBM PB9588).
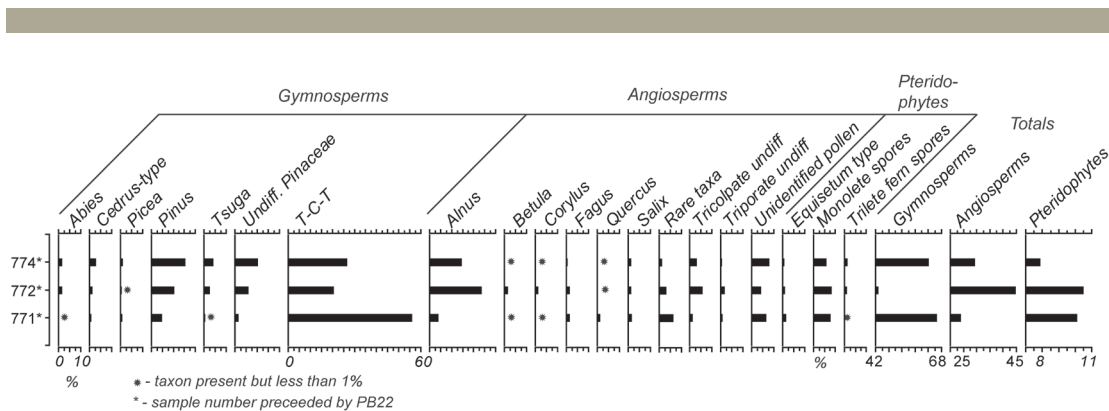
FIGURE 8. Vasa Park pollen diagram. TCT indicates pollen from the families Taxodiaceae, Cupressaceae, and Taxaceae.

Sample UWBM no. PB22774/PB22780 is closer to the modern creek bed, with approximately 2 m separating it from UWBM nos. PB22772 and PB22773/PB22779 (Fig. 8).

The sediment samples were processed for pollen using a modified version of the Faegri-Iversen method (Faegri & Iversen, 1964). Samples of the sediment matrix were washed and dried, then
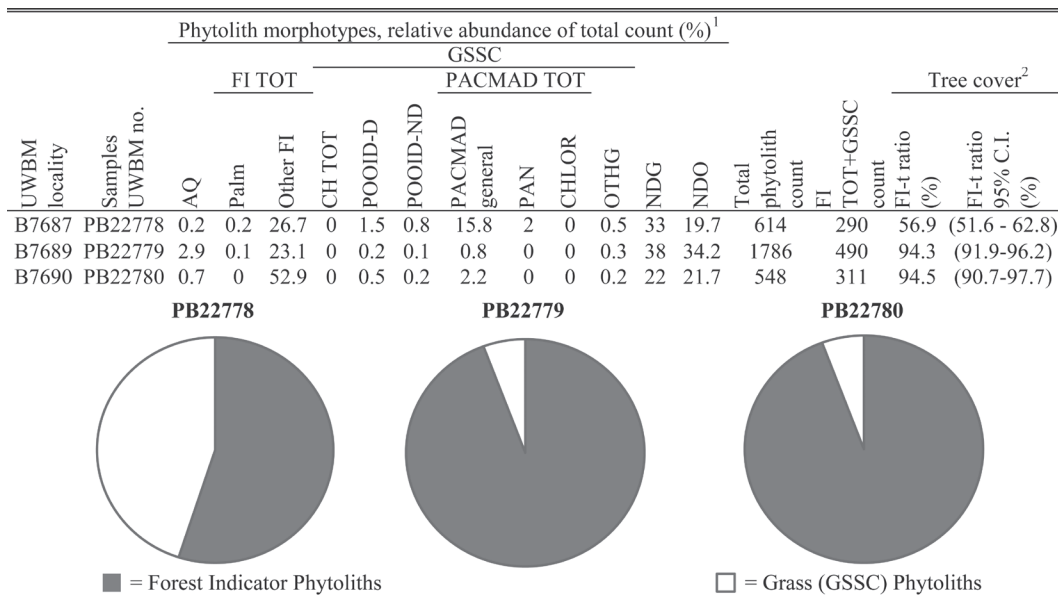
UWBM locality	Samples UWBM no.	AQ	Palm	Other FI	CH TOT	POOID-D	POOID-ND	PACMAD general	PAN	CHLOR	OTHG	NDG	NDO	Total phytolith count	FI TOT+GSSC count	FI-t ratio (%)	FI-t ratio 95% C.I. (%)
B7687	PB22778	0.2	0.2	26.7	0	1.5	0.8	15.8	2	0	0.5	33	19.7	614	290	56.9	(51.6 - 62.8)
B7689	PB22779	2.9	0.1	23.1	0	0.2	0.1	0.8	0	0	0.3	38	34.2	1786	490	94.3	(91.9-96.2)
B7690	PB22780	0.7	0	52.9	0	0.5	0.2	2.2	0	0	0.2	22	21.7	548	311	94.5	(90.7-97.7)

FIGURE 9. Relative abundance of phytolith morphotypes at Vasa Park. [1]AQ = phytoliths from wetland plants (e.g., *Equisetum*, sedges); Other FI = morphotypes typical of forest indicators (woody and herbaceous dicotyledons, ferns, conifers); GSSC = grass silica short cell; POOID-D = GSSC diagnostic of Pooideae; POOID-ND = GSSC produced in abundance by Pooideae but also present in other grasses; CH-TOT = GSSC of closed habitat grasses such as bamboos and basal grasses; PAN = GSSC typical of Panicoideae (many of which are C_4); CHLOR = phytoliths typical of Chloridoideae (C_4); PACMAD general = GSSC typical of PACMAD grasses (C_3/C_4); OTHG = nondiagnostic or unidentified GSSC; NDG = nondiagnostic (potential) grass phytoliths (e.g., cuneiform bulliforms, elongate sinuous, echinate, and dendritic, acicular hair base); NDO = nondiagnostic and unidentified non-GSSC phytoliths. [2]Tree cover is estimated using a rough proxy: FI-t = 100 × (Palm + Other FI)/(Palm + Other FI + GSSC). Confidence intervals are estimated using bootstrapping.

ca. 3 g of shale were crushed with a mortar and pestle and treated with 1 M hydrochloric acid (HCl) to remove carbonates. The samples were then rinsed with deionized water followed by an overnight soak in cold 48% hydrofluoric acid to remove silicates. The remaining material was rinsed twice in 1N HCl followed by two additional rinses with deinoized water to remove the acid residuals. After rinsing, the samples were washed through a 185-μm mesh Nitex filter to remove large particles, then through a 10-μm mesh Nitex filter to remove fine particles. The sample fraction remaining on the 10-μm mesh filter was treated by acetolysis to remove excess organics. Slides were prepared from the processed sample by mounting in glycerin jelly treated with 2% safranin dye. Of the four samples prepared for pollen analysis, one (UWBM PB22773) preserved only an insignificant amount of pollen and spores. The other three samples contained sufficient pollen and spores to allow detailed counting and analysis (Figs. 10–12).

Pollen slides were viewed at ×400 magnification under an optical light microscope to identify and photograph the different palynomorphs, and then counts of at least 500 grains were made for each sample to obtain relative abundances for the palynoflora. Pollen and spores were identified based on available literature (e.g., Wodehouse, 1935; Erdtman, 1952, 1957) and by comparison with modern pollen slides from the Jane Gray collection at the Burke Museum of Natural History and Culture, University of Washington.

Paleoclimate was estimated from the pollen assemblage using the coexistence approach developed by Mosbrugger and Utescher (1997). This method provides quantitative climate data based on the assumption that fossil taxa will have similar climatic requirements as their modern nearest living relative. After fossil pollen from the Vasa Park site was identified to the genus or family level as appropriate, quantitative climatic data for the modern representatives of these taxa were obtained from the Palaeoflora database (<http://www .palaeoflora.de>) and analyzed using the ClimStat program (Heinemann, 1998–1999). This program determines the zone where the climate requirements for the nearest living relatives of identified taxa overlap and provides a quantitative range for the analyzed parameters, including mean annual temperature, cold month mean temperature, warm month mean temperature, mean annual precipitation, wet month precipitation, dry month precipitation, and warm month precipitation.

In addition to the samples collected for both pollen and phytolith extraction, three sediment samples from other fine-grained paleosols (entisol; Soil Survey Staff, 2006) levels, as marked by root traces, were also collected, because fossil soils have been shown to contain the highest concentrations of phytoliths (Strömberg, 2004). Phytolith extraction was carried out following methods modified from Strömberg (2003, 2005). Approximately 1.2 g of sediment was treated with concentrated (12 M) HCl to remove carbonates, sieved through a 250-μm sieve to remove coarse particles, and treated with heated Schultze's solution to remove organic compounds. Clay particles were removed after deflocculation by sieving through a 53-μm sieve and repeated centrifuging. Finally, biogenic silica was isolated using heavy liquid (ZnBr+HCl+H$_2$O). From the extracted silica, multiple fixed microscope slides were prepared for counting and analysis using an optical light microscope under ×1000 magnification with immersion oil.

In samples considered sufficiently productive (UWBM nos. PB22778, PB22779, PB22780), at least 250 (290–490) diagnostic phytoliths (see definition below) were classified along with nondiagnostic phytoliths, to provide statistically robust counts for vegetation analysis (Strömberg, 2009), resulting in total counts of 548 to 1786 (Fig. 5). Rare phytolith morphotypes were noted to establish the presence of certain taxa, but not factored into the counts. Other biogenic silica, including diatoms, sponge spicules, and chrysophyte cysts, were noted for presence but not quantified.
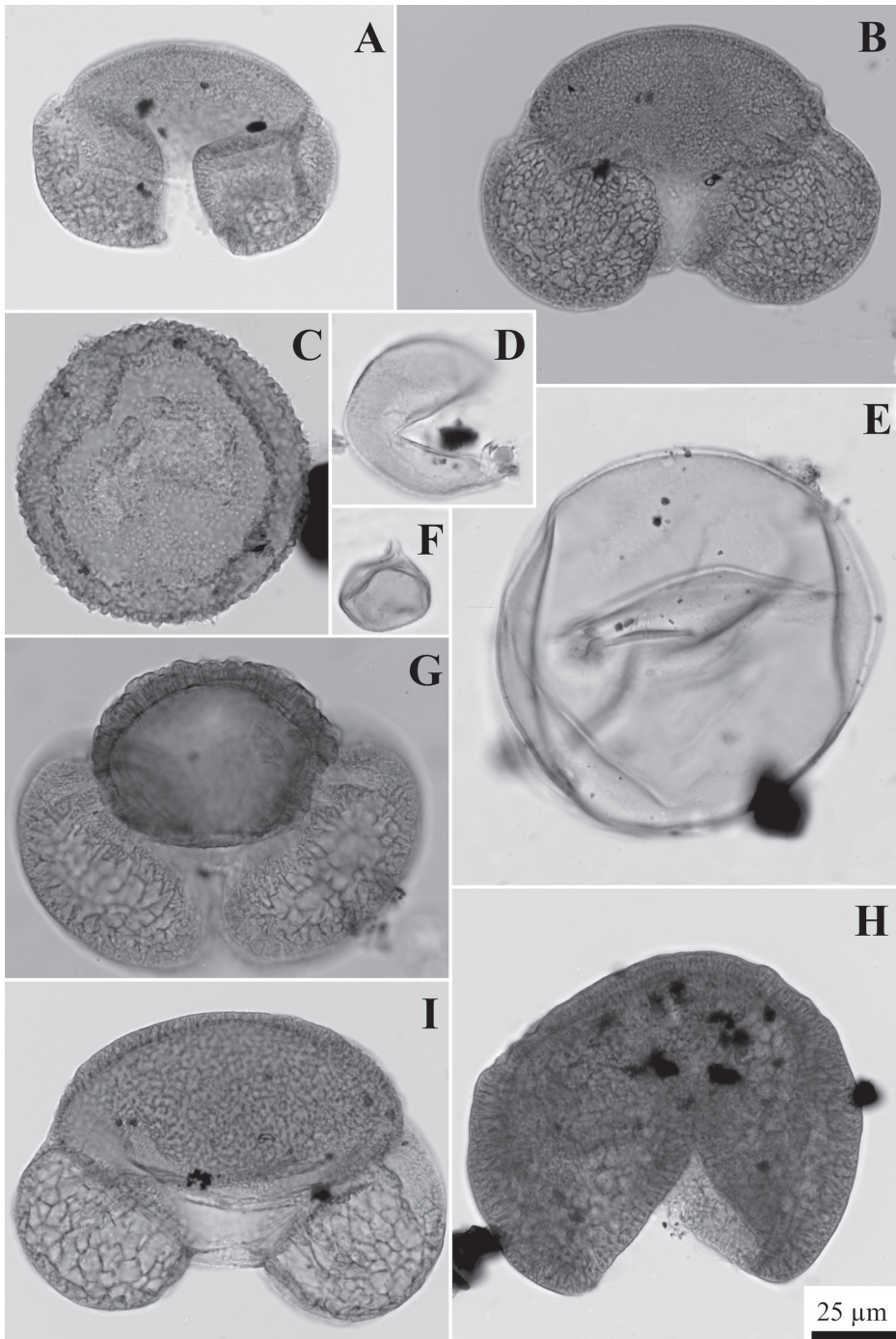
FIGURE 10. Vasa Park gymnosperm pollen. —A. *Picea* (slide no. UWBM PB22771A). —B. *Pinus* (UWBM PB22771C). —C. *Tsuga* (UWBM PB22771C). —D. TCT (UWBM PB22771A). —E. *Pseudotsuga/Larix* (UWBM PB22772A). —F. *Metasequoia/Sequoia* type (UWBM PB22771B). —G. Podocarpaceae/*Cathaya* type (UWBM PB22772D). —H. *Cedrus* (UWBM PB22771A). —I. *Abies* (UWBM PB22771C).
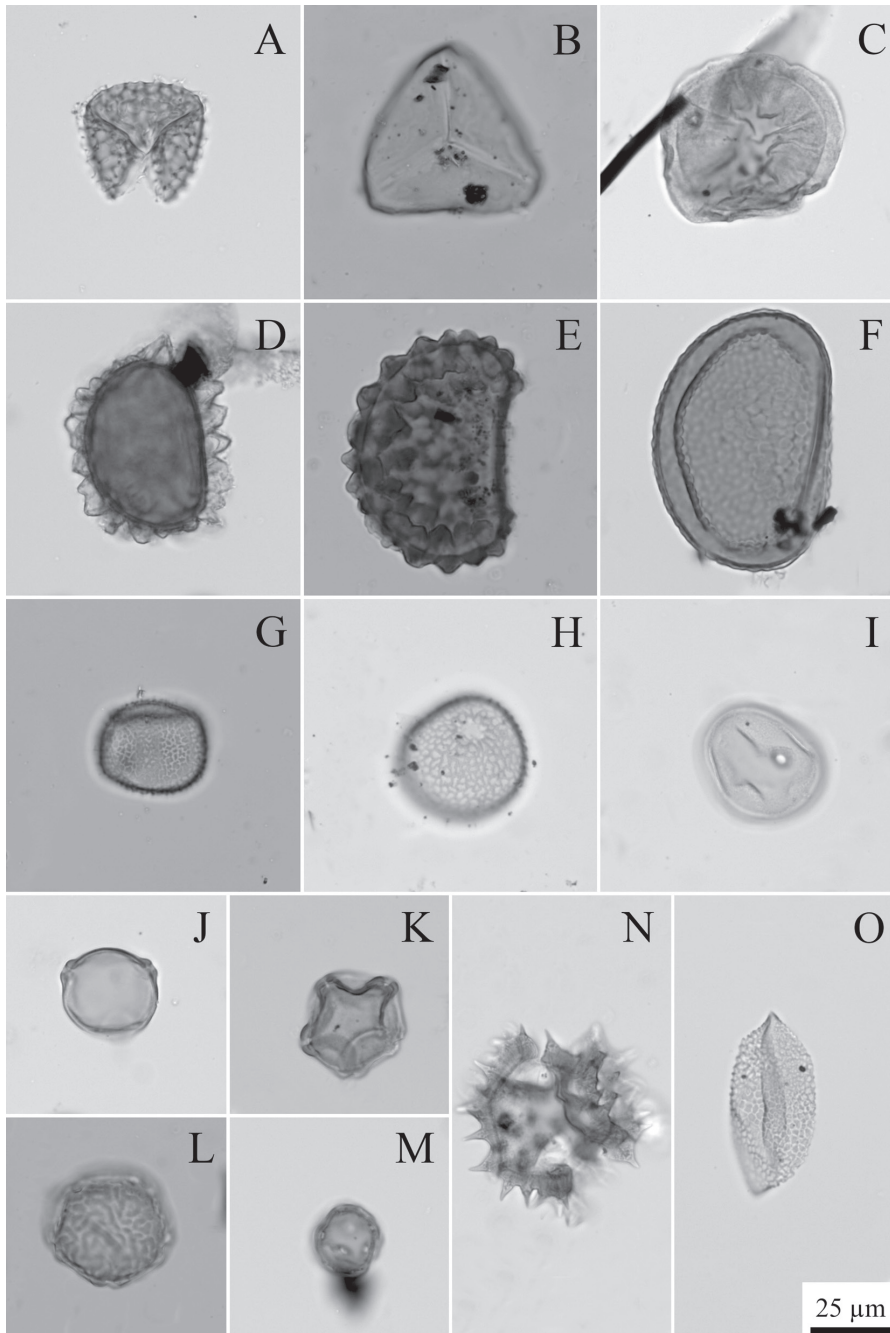
FIGURE 11. Vasa Park pteridophyte spores and angiosperm pollen. —A. *Lycopodium* (slide no. UWBM PB22771A). —B. Unidentified trilete spore (UWBM PB22774A). —C. *Selaginella* (UWBM PB22771D). —D. Dryopteridaceae (UWBM PB22771B). —E. Monolete spore (UWBM PB22771A). —F. Polypodiaceae (UWBM PB22771C). —G. *Potamogeton* (UWBM PB22772B). —H. Typhaceae (UWBM PB22772A). —I. Poaceae (UWBM PB22772A). —J. *Betula* (UWBM PB22772A). —K. *Alnus* (UWBM PB22771A). —L. *Ulmus* (UWBM PB22772B). —M. Cf. Chenopodiaceae (UWBM PB22771C). —N. Asteraceae (UWBM PB22772A). —O. Liliaceae (UWBM PB22771C).

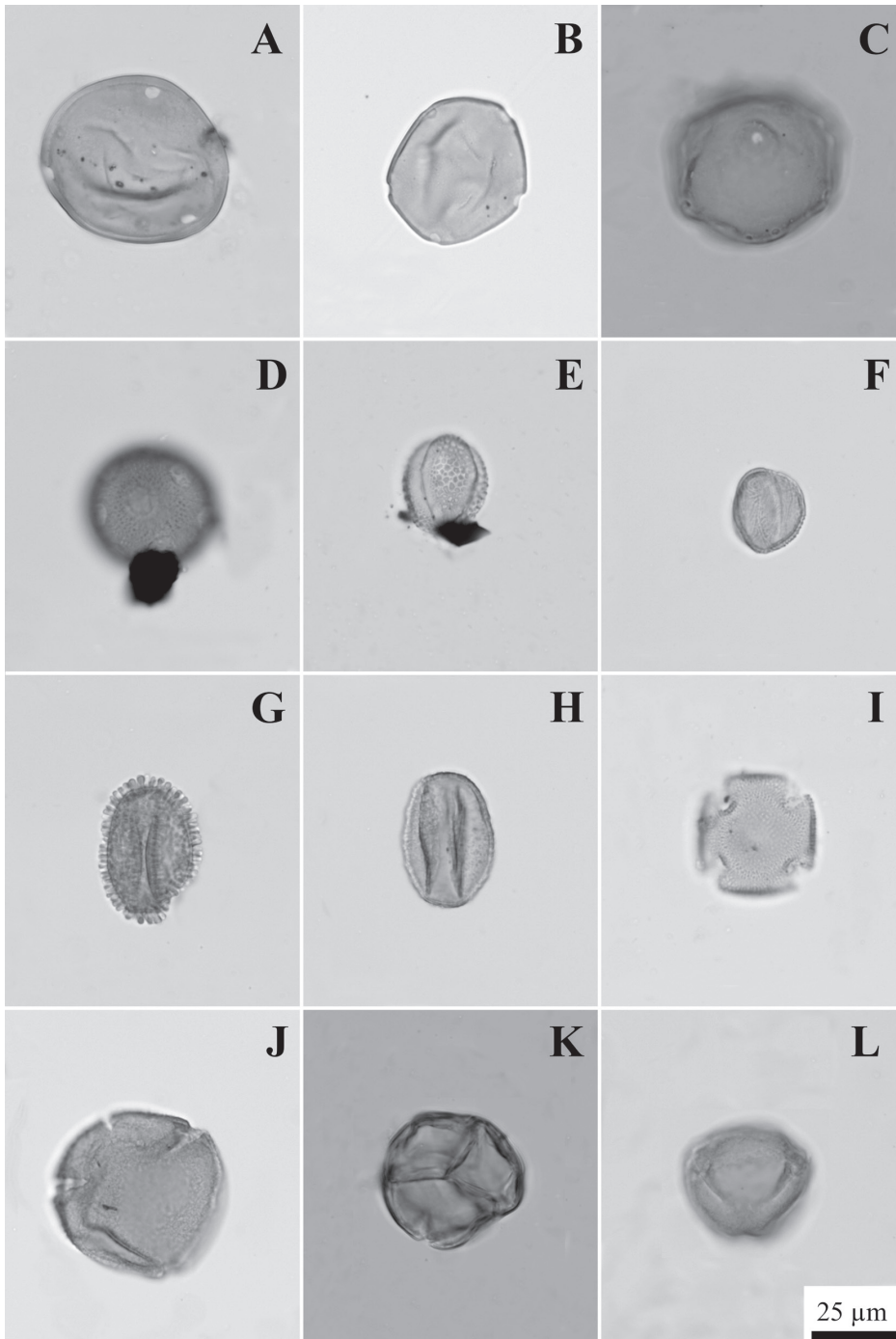FIGURE 12. Vasa Park angiosperm pollen continued. —A. *Carya* (slide no. UWBM PB22772A). —B. *Pterocarya* (UWBM PB22771D). —C. *Juglans* (UWBM PB22772B). —D. *Liquidambar* (UWBM PB22771A). —E. *Salix* (UWBM PB22772A). —F. *Acer* (UWBM PB22771A). —G. *Ilex* (UWBM PB22771C). —H. *Quercus* (UWBM PB22771C). —I. *Fraxinus* (UWBM PB22772A). —J. *Fagus* (UWBM PB22771A). —K. Ericaceae (UWBM PB22772D). —L. *Nyssa* (UWBM PB22771D).

The fossil phytoliths were classified according to a scheme outlined in Strömberg (2004, 2005) and Strömberg et al. (2007a, 2007b) based on the literature (e.g., Piperno, 1988, 2006) and on description and analysis of a modern reference collection (Strömberg, 2003, unpublished data). Morphotypes were grouped into the following major categories: (1) forest indicator phytoliths (FI TOT), forming primarily in palms, woody or herbaceous dicotyledons, conifers, and ferns (Fig. 13G–J, L); (2) grass silica short cells (GSSC), found only in grasses, including forms indicative of closed-habitat grasses, such as bambusoid and basal grasses, and open-habitat grasses, such as pooid and PACMAD (Panicoideae, Arundinoideae, Chloridoideae, Micrairoideae, Aristidoideae, and Danthonioideae) grasses (Duvall et al., 2007; Aliscioni et al., 2012) (Fig. 13A–F); (3) phytoliths indicative of taxa typically growing in wetlands (AQ), including *Equisetum* L. and sedges (Fig. 13K); and (4) various nondiagnostic and unclassified forms.

Diagnostic phytoliths (FI TOT and GSSC) were used for reconstruction of vegetation type (e.g., forest, grassland) following Strömberg (2005) and Strömberg et al. (2007a, 2007b, 2013); specifically, types and abundances of forest indicator forms relative to grass silica short cells, as well as the composition of the GSSC assemblages, were examined. The so-called FI-t ratio (FI TOT/(FI TOT + GSSC)%) provided a rough estimate of tree cover; bootstrap 95% confidence intervals (unconditional case, using the total count as the sample size) for this metric was estimated using the software Resampling Stats (Simon, 1997). FI-t does not directly translate to percent tree cover, but a comparison of FI-t through time or space can allow inference of trends in openness through time (Strömberg, 2004, 2005, 2009).

Grass community composition was inferred by analyzing relative abundances of different grass types within the GSSC assemblages. Using bootstrapping methods (Resampling Stats), the fossil samples were statistically compared to grasses in a modern reference collection to account for overlap in morphotype production among major grass groups (see Strömberg, 2005, for detailed methods). Specifically, because the samples contained high relative abundance of PACMAD grasses they were tested to determine if pooid grasses may also have contributed to the GSSC assemblages (Strömberg 2005, 2009). In addition, the presence of particularly diagnostic morphotypes (certain crenate GSSC) was documented. Proximity to water is indicated by relative frequency of sedge phytoliths, as well as semiquantitative estimates of relative abundance of diatoms, chrysophyte cysts, and sponge spicules (Strömberg, 2005).

RESULTS

FLORISTIC STUDY

Taxa identified from macrofossil (Figs. 5–7) and palynomorph remains (Figs. 10–12) are summarized in Table 1.

Pteridophytes and allies (Figs. 5, 11).

Bryophyta. The vegetative gametophyte of an unknown bryophyte (Fig. 5B) is preserved at Vasa Park.

Lycopodiaceae. *Lycopodium* L. spores (Fig. 11A) are uncommon but present in all samples.

Selaginellaceae. *Selaginella* P. Beauv. spores with intact endospore (Fig. 11C) occur rarely in the pollen and spore assemblage.

Equisetaceae. *Equisetum* L. sp. (Fig. 5H). Compressions of small woody underground bulbils arranged radially in groups of five are relatively common at Vasa Park. A few specimens representing nodal sheaths from fertile shoots have also been recognized (not figured). This represents the first confirmed occurrence of *Equisetum* macrofossils in the Miocene of Washington. The specimen figured as an underground stem of *Equisetum* from the Middle Miocene Latah Formation by Knowlton (1926: plate IX, fig. 1) is a stem with attached *Nordenskioldia* Heer fruits. An *Equisetum* rhizome and stem were found at the
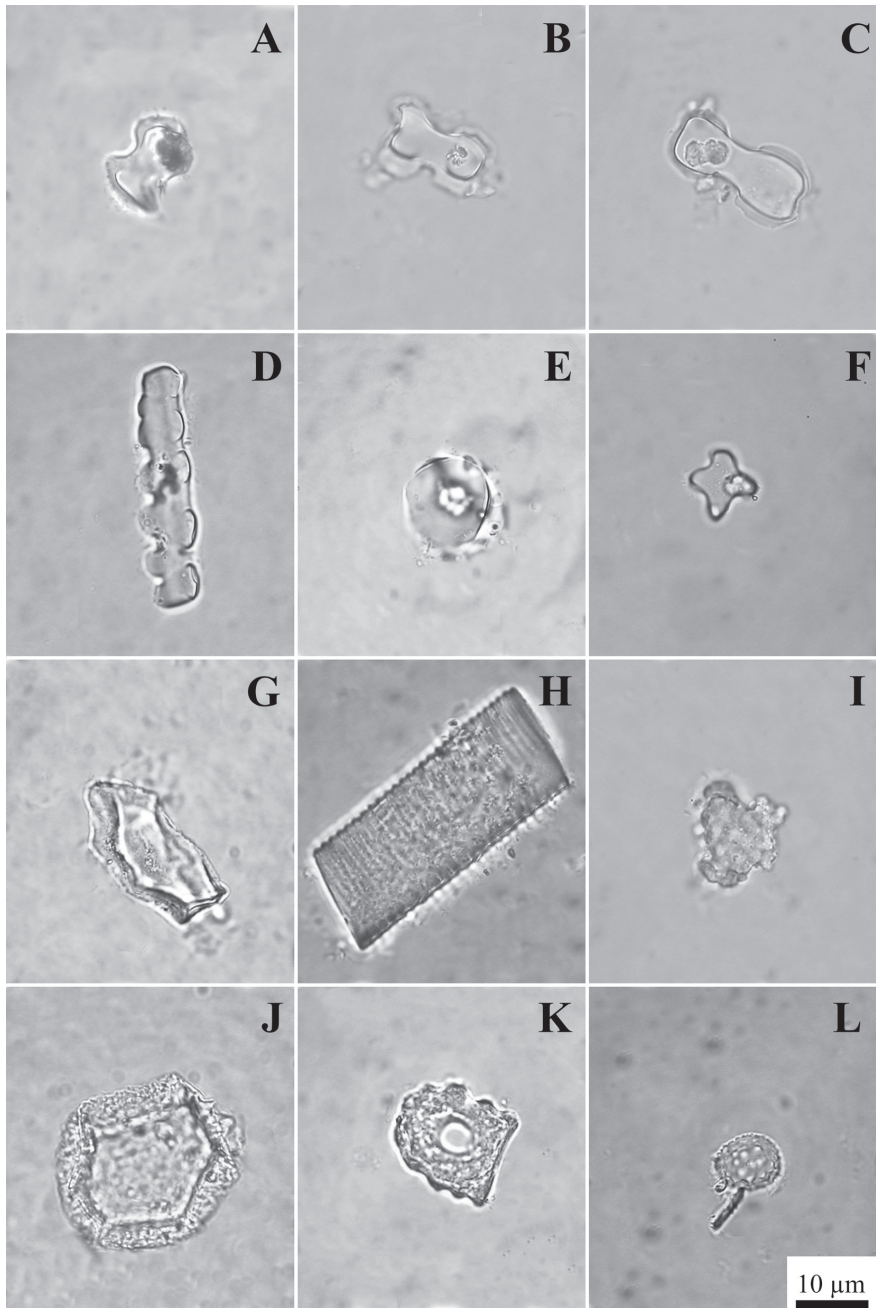
FIGURE 13. Phytoliths from Vasa Park. A–F. Grass silica short cells (Poaceae). A–C. Bilobates (PACMAD grasses). —A. Simple lobate (UWBM PB22778G). —B. Inverted bilobate (UWBM PB22778M). —C. Almost panicoid bilobate (UWBM PB22778B). —D. Crenate (Pooideae) (UWBM PB22779C). —E. Keeled rondel (Pooideae?) (UWBM PB22778I). —F. Cross (Panicoideae/PACMAD) (UWBM PB22778B). G–J. Forest indicator phytoliths. —G. Sclereid element (typical of woody dicotyledons) (UWBM PB22778C). —H. Tracheary element (dicotyledons and other forest indicator taxa) (UWBM PB22779B). —I. Large nodular body (woody dicotyledons) (UWBM PB22778B). —J. Polyhedral epidermis (dicotyledons) (UWBM PB22778E). —K. Epidermal sedge plate (Cyperaceae) (UWBM PB22780E). —L. Echinate (spiky) sphere (Palmae?) (UWBM PB22779D).

TABLE 1. Vasa Park combined flora from macrofossils and palynomorphs.

Group/Family	Taxon	Macrofossils	Pollen/Spores	Figure
Bryophytes	undetermined genus	G		Fig. 5B
Lycophytes				
Lycopodiaceae	*Lycopodium* sp.		Sp	Fig. 11A
Selaginellaceae	*Selaginella* sp.		Sp	Fig. 11C
Pteridophytes				
Equisetaceae	*Equisetum* sp.	B, Ns	Sp?	B = Fig. 5H; Ns not figured
Blechnaceae	*Woodwardia* sp.	L		Fig. 5F
Dryopteridaceae	*Allantodiopsis* sp.	L		Fig. 5D, E
	undetermined genus	L	Sp	Fig. 5A; Fig. 11D
Polypodiaceae	undetermined genus		Sp	Fig 11F
Monolete spores	undetermined genus		Sp	Fig. 11E
Trilete spores	undetermined genus		Sp	Fig. 11B
Gymnosperms				
Cupressaceae	*Chamaecyparis linguaefolia* (Lesquereux) MacGinitie	Lt, S		Fig. 5C, G
	Sequoia/Metasequoia sp.		P	Fig. 10F
TCT	undetermined genus		P	Fig. 10D
Pinaceae	*Abies* sp.		P	Fig. 10I
	Cedrus sp.		P	Fig. 10H
	Picea sp.		P	Fig. 10A
	Pinus sp.		P	Fig. 10B
	Pseudotsuga/Larix sp.		P	Fig. 10E
	Tsuga sp.		P	Fig. 10C
Incertae sedis	*Podocarpidites/Cathaya* sp.		P	Fig. 10G
Angiosperms				
Monocotyledons				
Liliaceae	undetermined genus		P	Fig. 11O
Poaceae	undetermined genus		P	Fig. 11I
Potamogetonaceae	*Potamogeton* sp.		P	Fig. 11G
Smilacaceae	*Smilax magna* Chaney	L		Fig. 6G
Typhaceae	*Typha/Sparganium* sp. (monad)		P	Fig. 11H
Dicotyledons				
Altingiaceae	*Liquidambar* sp.		P	Fig. 12D
Aquifoliaceae	*Ilex* sp.		P	Fig. 12G
Asteraceae	undetermined genus		P	Fig. 11N
Betulaceae	*Alnus* sp.	I, L	P	Fig. 7G, F; Fig. 11K
	Betula sp.		P	Fig. 11J
	Carpinus/Ostrya sp.		P	not figured
	Corylus sp.		P	not figured
Cercidiphyllaceae	*Cercidiphyllum crenatum* (Unger) Brown	L		Fig. 6C
	cf. *Cercidiphyllum* sp.		P	not figured
Chenopodiaceae	undetermined genus		P	Fig. 11M
Ericaceae	undetermined genus		P	Fig. 12K

TABLE 1. (*continued*)

Group/Family	Taxon	Macrofossils	Pollen/Spores	Figure
Fagaceae	cf. *Castanea* sp.		P	not figured
	Fagus washoensis LaMotte	L		Fig. 6D
	Fagus sp.		P	Fig. 12J
	Quercus sp.		P	Fig. 12H
Juglandaceae	*Carya* sp.		P	Fig. 12A
	Pterocarya sp.		P	Fig. 12B
	Juglans sp.		P	Fig. 12C
Hydrangeaceae	*Hydrangea bendirei* (Ward) Knowlton	L		Fig. 7D
Lauraceae	*Persea pseudocarolinensis* Lesquereux	L		Fig. 6E
Magnoliaceae	undetermined genus		P	not figured
Malvaceae	cf. *Gossypium* sp.	L		Fig. 6F
Nyssaceae	*Nyssa* sp.		P	Fig. 12L
Oleaceae	*Fraxinus* sp.		P	Fig. 12I
Onagraceae	undetermined genus		P	not figured
Platanaceae	*Platanus dissecta* (Lesquereux)	L		Fig. 7A, B
	Platanus sp.		P	not figured
Salicaceae	*Salix* sp.		P	Fig. 12E
	cf. *Populus* sp.		P	not figured
Sapindaceae	*Acer* sp.	L, S	P	Fig. 6A, B; Fig. 12F
	Aesculus sp.	L		Fig. 7C, E
Ulmaceae	*Ulmus speciosa* Newberry	L		not figured
	Ulmus sp.		P	Fig. 11L

Abbreviations: B = bulbil; G = gametophyte; I = infructescence; L = leaves; Lt = leafy twigs; Ns = nodal sheath; S = seeds; P = pollen; Sp = spore; TCT = Taxodiaceae–Cupressaceae–Taxaceae pollen.

Sucker and Trout creeks Middle Miocene localities in southeastern Oregon (Graham, 1963, 1965). Stems and similarly preserved bulbils of *Equisetum* occur in the nearby Paleocene/Eocene Chuckanut Formation (Pabst, 1968). *Equisetum*-type spores (not figured) are common in all spore-pollen samples. There is some question as to whether these actually represent *Equisetum* or *Larix* Mill., since these two types are similar. The relatively small size of this palynomorph (32–40 µm), the inferred floodplain environment, and the presence of *Equisetum* macrofossils make it likely that this taxon is represented in the palynoflora.

Blechnaceae. *Woodwardia* Sm. sp. (Fig. 5F). Small pinnules of *Woodwardia* are a relatively common component of the pteridophyte flora at Vasa. The Vasa Park species most closely resembles modern *Woodwardia fimbriata* Sm., still found in western Washington (Pigg et al., 2006). *Woodwardia* has also been described from the Middle Miocene Sucker Creek, Idaho, and Yakima Canyon, Washington localities (Graham, 1965; Pigg & Rothwell, 2001).

Dryopteridaceae. *Allantodiopsis* Knowlt. & Maxon sp. (Fig. 5D, E). Pinnules with the characters of the extinct genus *Allantodiopsis* are not uncommon at Vasa. *Allantodiopsis* was widespread in the Paleocene and Eocene of the Rocky Mountain area (Brown, 1962; Wing, 1987) and also recognized from the Paleocene-Eocene Chuckanut and Puget Group formations of western

Washington (Pabst, 1968; Wolfe, 1968). Wolfe (1968) differentiated *A. pugetensis* Wolfe based primarily on unbranched secondary veins. The Vasa species typically has branched secondaries, or occasionally twice branched, as seen in *A. erosa* (Lesquereux) Pabst.

The phylogenetic position of *Allantodiopsis* among the ferns is uncertain (Collinson, 2001). The association of the single specimen of fertile material associated with the common sterile foliage that is the basis for the genus name has been questioned (McIver & Basinger, 1993). Similar foliage originally assigned to *Allantodiopsis* from the Eocene of Oregon was determined based on the cuticle to be an extinct cycad with fernlike foliage, *Eostangeria barthel* (Kvaček & Manchester, 1999). In that genus secondaries sometimes reunite at the margin, forming loops, but secondaries in the Vasa specimens do not. The Vasa Park occurrence dramatically extends the known stratigraphic occurrence of *Allantodiopsis*.

In addition to *Allantodiopsis*, foliage of a second member of the family, morphotype VP003 (Fig. 5A), is recognized as a member of the Dryopteridaceae. In the absence of fertile material it is not possible to assign this material to a genus; it could represent a bipinnate *Polystichum* Roth or *Dryopteris* Adans. The pinnule morphology of the fossil resembles modern *P. dudleyi* Maxon found in coastal California. Spores of the Dryopteridaceae type (Fig. 11D) are also present in the palynoflora.

Pteridophyte spores are diverse and constitute a significant percentage of all palynological samples. Monolete spores without preserved perine of the *Laevigatosporites* Ibrahim type (not figured) are common throughout the deposit. In addition, there are four distinct types with well-preserved perine; three of these are figured (Fig. 11D–F). Trilete spores are less common but still diverse, with at least two types without preserved perine (Fig. 11B), and three distinct types with preserved perine.

Gymnosperms (Figs. 5, 10).

Cupressaceae s.l. *Chamaecyparis linguaefolia* (Lesquereux) MacGinitie (Fig. 5C, G). *Chamaecyparis* Spach macrofossils have been identified from foliage, seeds, and a possible ovulate cone. The genus has also been identified from the Middle Miocene at Clarkia, Idaho (Smiley & Rember, 1985) and Trout Creek in southeastern Oregon (Graham, 1963). MacGinitie (1933) identified this taxon at Trout Creek and later identified it as *C. linguaefolia* (MacGinitie, 1953). The Vasa Park species is consistent with the Trout Creek occurrence. *Chamaecyparis* was also identified in coeval sediments from the nearby Late Miocene Hammer Bluff Formation (Mullineaux, 1970).

Metasequoia Hu & W. C. Cheng/*Sequoia* Endl. type (Fig. 10F). Rare cupressaceous pollen grains with papillae are found in all samples. The overall morphology is most similar to *Metasequoia/ Sequoia*, but other cupressaceous genera are known to have papillae, including *Taxodium* Rich. and *Glyptostrobus* Endl. All four of these genera have been reported as macrofossils from the Miocene of the Pacific Northwest (Chaney & Axelrod, 1959; Graham, 1965; Smiley & Rember, 1985). In the absence of co-occurring macrofossils from Vasa Park, it is difficult to assign this pollen type to a particular genus.

The palynoflora also contains a large proportion of cupressaceous Taxodiaceae–Cupressaceae–Taxaceae (TCT) pollen (Fig. 10D).

Pinaceae. *Abies* Mill. (Fig. 10I). Two distinct types of *Abies* pollen have been noted in the palynoflora. *Abies* pollen is rare, but present in all pollen-bearing samples. The first type is quite large (155–187 μm) and is the one most often encountered. The figured type is smaller and is similar to modern *A. amabilis* Douglas ex J. Forbes, which is extant in the Pacific Northwest.

Cedrus Trew sp. (Fig. 10H). *Cedrus* pollen is a minor element in all samples from Vasa Park. This type is widespread in the Miocene of the Pacific Northwest, although to our knowledge

there have been no reports of confirmed *Cedrus* macrofossils.

Picea A. Dietr. (Fig. 10A). There are two types of *Picea* pollen found in the Vasa Park palynoflora: one is particularly large at up to 170 μm, while the other is smaller (90–97 μm). *Picea* is well represented throughout the Cenozoic of the Pacific Northwest and is widely reported in the Miocene.

Pinus L. sp. (Fig. 10B). *Pinus* is a common element of the Vasa Park palynoflora, contributing between 5% and 15% of the total pollen count.

Pseudotsuga Carrière/*Larix* Mill. type (Fig. 10E). Pollen of *Pseudotsuga* and *Larix* is very similar, thus they are reported as a single palynomorph. The large size of the grains (101–109 μm) indicates that they most likely represent *Pseudotsuga*. *Pseudotsuga* macrofossils are not common in the fossil record of the region, but foliage and cones have been reported from the Miocene of Oregon (Chaney & Axelrod, 1959; Graham, 1965). Recently, *Pseudotsuga* has been confirmed from the Middle Miocene of Washington based on well-preserved wood from the Ginkgo Petrified Forest (Wheeler & Dillhoff, 2009). To our knowledge, there have been no confirmed reports of *Larix* macrofossils from the Miocene of the Pacific Northwest.

Tsuga Carrière (Fig. 10C). *Tsuga* pollen is represented by two distinct types. One type is similar to modern *T. heterophylla* (Raf.) Sarg., which is extant in the Pacific Northwest. Similar pollen has been figured from the Clarkia deposit of Idaho (Gray, 1985). The second type is superficially similar to *T. canadensis* (L.) Carrière, but under high magnification it has visible spines, which are lacking in *T. canadensis*. This type may be more closely related to some of the modern Asiatic species of *Tsuga,* which are similar in morphology and have small spines.

Incertae sedis. There are two bisaccate pollen types (Fig. 10G) similar to those reported as *Podocarpus* Persoon or *Podocarpidites* Cookson ex Couper from other Cenozoic floras of the Pacific Northwest (Barnett & Fisk, 1980; Reininck-Smith & Leopold, 2005). Zetter et al. (2011) state that pollen of this type may also represent *Cathaya* Chun & Kuang, and that the pollen can only be reliably distinguished using features visible under SEM. Because of this uncertainty, these types are reported as Podocarpaceae/*Cathaya.* There have been no confirmed macrofossils of *Podocarpus* reported from the Cenozoic of the Pacific Northwest, while cones and foliage with preserved cuticle of *Cathaya* were described from the Middle Miocene Clarkia deposit of western Idaho (Kvaček & Rember, 2000).

Angiosperms, Monocotyledons.

Liliaceae. Several pollen grains attributed to the Liliaceae (Fig. 11O) were found at Vasa Park. These are rare, but present in both the upper and lower sampling horizons. Similar pollen was reported from the Miocene Palouse Falls locality of Washington, but not figured (Barnett & Fisk, 1980).

Poaceae. Several well-preserved grains of grass pollen (Fig. 11I) have been identified from all sample horizons at Vasa Park. This type is rare, but the presence of grasses at Vasa Park is corroborated by the phytolith analysis.

Potamogetonaceae. Rare pollen of *Potamogeton* L. (Fig. 11G) is present at Vasa Park.

Smilacaceae. *Smilax magna* Chaney (Fig. 6G). *Smilax magna* is preserved as rare examples at Vasa and was also present in the Middle Miocene Clarkia (Smiley & Rember, 1985), Mascall (Chaney and Axelrod, 1959), and Trout Creek (Graham, 1963) localities. It was also present in the Late Miocene Ellensburg Formation (Smiley, 1963). Chaney and Axelrod (1959) argued for designating all Northwest Miocene occurrences of *Smilax* L. by the epithet *magna* because species could not be reliably separated on leaf characters alone. The nearby Middle Eocene Puget Group deposits record the first known occurrence of *Smilax* in western Washington (Wolfe, 1968).

Typhaceae. Pollen monads of the *Typha* L./ *Sparganium* L. type (Fig. 11H) are found from the upper sampling horizon at Vasa Park. No macrofossils have been found.

Angiosperms, Dicotyledons.

Altingiaceae. *Liquidambar* L. sp. (Fig. 12D). Pollen grains of *Liquidambar* occur rarely at the site. No macrofossils have been found. *Liquidambar* is a common element in the Middle Miocene floras of the Pacific Northwest, and today has disjunct distribution in Asia and eastern North America and Central America.

Aquifoliaceae. *Ilex* L. sp. (Fig. 12G). *Ilex* is uncommon, but found in all pollen samples. No macrofossils have been found.

Asteraceae. Uncommon but distinctive grains of pollen from the Asteraceae (Fig. 11N) are present in samples from the upper horizon.

Betulaceae. *Alnus* Mill. sp. (Fig. 7G, F). Common leaves and rare infructescences document the presence of *Alnus* at Vasa Park. Overlapping leaf morphologies preclude the separation of *Alnus* from *Betula* L. based on leaf characters alone. At Vasa Park the presence of *Alnus* reproductive structures and the overwhelming preponderance of *Alnus* over *Betula* pollen support an identification of *Alnus* for the leaves. The species *A. relata* (= *A. relatus* (Knowlton) Brown) is recorded from the nearby coeval Mashel Formation (Walters, 1964) and *Alnus* pollen was also recovered from the Hammer Bluff Formation in Renton (Mullineaux, 1970). *Alnus* is common in most Northwest deposits from the Early Eocene onwards, and five species occur today in Washington and Oregon (Franklin & Dyrness, 1988). The leaf characters of the Vasa Park *Alnus* correspond closely to modern *A. sinuata* (Regel) Rydb., which occurs in western Washington.

Several genera of Betulaceae are represented in the palynoflora, including *Alnus* (Fig. 11K), *Betula* (Fig. 11J), *Corylus* L. (not figured), and *Ostrya* Scop./*Carpinus* L. (not figured) type. *Alnus* is particularly abundant, represented by 4-, 5-, 6-, and 7-pore forms (the 4- and 5-pore forms are predominant). It comprises 4% of the pollen count in the lower sampling horizon, and up to 24% of the counts in the upper horizons, where it is a dominant type. The other genera of the Betulaceae are minor contributors to the overall palynoflora.

Cercidiphyllaceae. *Cercidiphyllum crenatum* (Unger) Brown (Fig. 6C). *Cercidiphyllum crenatum* is a common macrofossil species recovered at Vasa Park, as well as from the Middle Miocene in the Mascall Formation and at Clarkia (Chaney & Axelrod, 1959; Smiley & Rember, 1985). It is recorded from the Late Miocene Ellensburg Formation (Smiley, 1963) as well. Wolfe (1968) identified *C. piperoides* (Lesquereux) LaMotte from Middle Eocene Puget Group sediments in King County.

Rare grains of *Cercidiphyllum* Siebold & Zucc. type pollen (not figured) are found in the lower sampling horizon. These are consistent with modern pollen of *Cercidiphyllum*, and are similar to fossil pollen from the Miocene of Oregon identified as *Cercidiphyllum* by Gray (1958); however, the grains are folded and thus their identification is not certain.

Chenopodiaceae. Three pollen grains similar to that of the Chenopodiaceae (Fig. 11M) were identified from the Vasa Park palynoflora. Similar pollen has been reported from other Miocene sites in the Pacific Northwest (Chaney & Axelrod, 1959; Graham, 1965; Barnett & Fisk, 1980; Smiley & Rember, 1985). Graham (1965) notes that pollen of the Chenopodiaceae is morphologically similar to the Amaranthaceae and thus difficult to separate. Barnett and Fisk (1980) recorded their specimens as Chenopodiaceae, cf. *Sarcobatus* Nees. The Vasa Park specimens are small in size (20–25 µm), have relatively few pores, and bear a strong resemblance to modern *S. vermiculatus* (Hook.) Torr. It should be noted that *Sarcobatus* was removed from the Chenopodiaceae/ Amaranthaceae clade and assigned to the monogeneric family Sarcobataceae by Behnke (1997). We refer to the Vasa Park pollen type as cf. Che-

nopodiaceae to allow comparison with the previously described palynofloras in Table 2.

Ericaceae. Rare tetrads of ericaceous pollen (Fig. 12K) were found in sample UWBM PB22772. These were not detected in any other samples.

Fagaceae. *Fagus washoensis* LaMotte (Fig. 6D). Common leaves at Vasa Park match the characters of *F. washoensis*. This species was recorded in the Middle Miocene Mascall Formation (Chaney & Axelrod, 1959), at Trout and Sucker creeks (Graham, 1963), and *Fagus* L. also occurs at Clarkia (Smiley & Rember, 1985). The species is also recorded in Late Miocene deposits of the Ellensburg Formation (Smiley, 1963) and the nearby coeval Hammer Bluff Formation (Mullineaux, 1970).

The Fagaceae is also represented in the pollen assemblage by cf. *Castanea* Mill., *Fagus* sp., and two types of *Quercus* L. The *Castanea* type (not figured) is only represented by a few pollen grains. *Fagus* (Fig. 12J) and *Quercus* (Fig. 12H) are more common, especially from the lowest sampling horizon.

Hydrangeaceae. *Hydrangea bendirei* (Ward) Knowlton (Fig. 7D). Several well-preserved leaves of *Hydrangea* L. have been found at Vasa Park. The species was widespread in the Middle Miocene, occurring in the Latah (Knowlton, 1926; Brown, 1936), Mascall (Knowlton, 1902; Chaney & Axelrod, 1959), and Trout Creek and Sucker Creek (Graham, 1963) deposits.

Juglandaceae. The Juglandaceae is represented by pollen of *Carya* Nutt. (Fig. 12A), *Juglans* L. (Fig. 12C), and *Pterocarya* Kunth (Fig. 12B). *Juglans* is quite rare, with only two pollen grains found in the 16 slides examined for this study. *Carya* and *Pterocarya* are more common, but still compose less than 1% of the pollen in all of the samples that were counted. All three of these taxa are commonly reported in the palynofloras of the Pacific Northwest.

Lauraceae. *Persea pseudocarolinensis* Lesquereux (Fig. 6E). *Persea pseudocarolinensis* was a widespread species first recorded in King County from

the Middle Eocene Puget Group (Wolfe, 1968). This species is also found at all of the well-known Northwest Middle Miocene localities and the Late Miocene Ellensburg flora (Smiley, 1963). *Persea lanceolata* (Berry) Brown was identified by Wolfe (Walters, 1964) from the nearby coeval Mashel Formation, but no description or figure was provided. That species was separated from *P. pseudocarolinensis* based on a narrow-leaved morphotype of *Persea* found in the Latah flora.

Magnoliaceae. Only two pollen grains of the Magnoliaceae (not figured) have been identified from Vasa Park. No macrofossils have been identified.

Malvaceae. Cf. *Gossypium* L. sp. (Fig. 6F). Common leaves at Vasa Park have morphology similar to modern *G. barbadense* L. In both cases, leaves are palmate, 3- to 5-lobed, entire, lobes with acuminate tips, actinodromous with an obtuse to reflex cordate base, brochidodromous secondaries, percurrent tertiaries, and an irregular reticulate fabric. Gossypol glands observable on modern leaves are possibly present in the fossil but equivocal. The stellate hairs present on modern *Gossypium* leaves are not observed in the fossil. Graham (1963) described *G. arnoldii* Graham from Trout Creek based on leaf morphology, but no other *Gossypium* fossils have been described prior to the Pleistocene. The genus *Gossypium* has been estimated to have originated approximately 12.5 Ma (Wendel et al., 2010).

Nyssaceae. *Nyssa* L. pollen (Fig. 12L) is present but rare at Vasa Park. This genus was widespread in the Pacific Northwest during the Miocene.

Oleaceae. Rare examples of *Fraxinus* L. pollen (Fig. 12I) are present in the Vasa Park assemblage. No macrofossils have been found.

Onagraceae. Only two grains of distinctive pollen (not figured) from the Onagraceae were noted at Vasa Park; both were from the upper sample horizon.

Platanaceae. *Platanus dissecta* Lesquereux (Fig. 7A, B). This widespread species has been found in the Northwest Middle Miocene at Clarkia

TABLE 2. Vasa Park palynoflora compared to selected Middle Miocene localities.

Family	Genus	Vasa Park 11.4 Ma	Palouse Falls[1] 15.5 Ma	Clarkia[2,3] 15–15.5 Ma	Sucker Creek[4,5] 14.8–16 Ma[6]
Lycopodiaceae	*Lycopodium*	×	×	×	×
Selaginellaceae	*Selaginella*	×	×		
Equisetaceae	*Equisetum*	x?	×		×
Azollaceae	*Azolla*		×		
Blechnaceae	*Woodwardia*				×
Davalliaceae	*Davallia*				×
Dryopteridaceae	undetermined	×			
Osmundaceae	*Osmunda*				×
Polypodiaceae	undetermined	×	×	×	×
Cupressaceae	*Sequoia/Metasequoia*	×			x?
Gnetaceae	*Ephedra*				×
Pinaceae	*Abies*	×	×	×	×
	Cedrus type	×	×	×	×
	cf. *Keteleeria*			×	×
	Picea	×	×	×	×
	Pinus	×	×	×	×
	Pseudotsuga/Larix	×	×	x?	x?
	Tsuga	×	×	×	×
Taxodiaceae-Cupressaceae-Taxaceae	TCT	×	×	×	×
Incertae sedis	Podocarpaceae/*Cathaya*	×	×		×
Liliaceae	undetermined	×	×		
Poaceae	undetermined	×	×		×
Potamogetonaceae	*Potamogeton*	×	×		×
Typhaceae	*Typha/Sparganium* (monad)	×	×	x?	×
Altingiaceae	*Liquidambar*	×	×	×	×
Anacardiaceae	*Rhus*			×	
Apiaceae	undetermined				×
Aquifoliaceae	*Ilex*	×	×	×	×
Asteraceae	undetermined	×			×
Berberidaceae	*Mahonia*				×
Betulaceae	*Alnus*	×	×	×	×
	Betula	×	×	×	×
	Corylus	×	×	×	×
	Ostrya/Carpinus	×	×	x?	×
Buxaceae	*Pachysandra*				×
Caprifoliaceae	undetermined				×
Cercidiphyllaceae	cf. *Cercidiphyllum*	×			
cf. Chenopodiaceae	undetermined	×	×	×	×
Coriariaceae	undetermined		×		
Cornaceae	*Alangium*				×
	Cornus				×

TABLE 2. (*continued*)

Family	Genus	Vasa Park 11.4 Ma	Palouse Falls[1] 15.5 Ma	Clarkia[2,3] 15–15.5 Ma	Sucker Creek[4,5] 14.8–16 Ma[6]
Elaeagnaceae	*Shepherdia/Elaeagnus*			×	×
Ericaceae	undetermined	×	×	×	×
Fabaceae	undetermined				×
Fagaceae	cf. *Castanea*	×		x?	×
	Fagus	×	×	×	×
	Lithocarpus				×
	Quercus	×	×	×	×
Hippocastanaceae	*Aesculus*			×	
Juglandaceae	*Carya*	×	×	×	×
	Engelhardtia type			x?	
	Juglans	×	×	×	×
	Pterocarya	×	×	×	×
Lamiaceae	undetermined		×		
Magnoliaceae	undetermined	×			
	Liriodendron			×	
	Magnolia			×	
Malvaceae	undetermined		×		×
	Tilia		×	×	×
Moraceae	*Morus*		×		
Myricaceae	*Myrica*			×	
Nymphaceae	*Nymphaea polymorpha*		×		×
Nyssaceae	*Nyssa*	×	×	×	×
Oleaceae	*Fraxinus*	×	×		×
Onagraceae	undetermined	×	×		×
Platanaceae	*Platanus*	×	×	×	×
Polygonaceae	cf. *Polygonum*		×		
Rhamnaceae	undetermined			×	
Rosaceae	undetermined			×	×
Salicaceae	*Populus*	x?	×		×
	Salix	×	×		×
Sapindaceae	*Acer*	×	×	×	×
Theaceae	undetermined		×		
Ulmaceae	*Celtis*		×	×	×
	Ulmus/Zelkova	×	×	x?	×
Vitaceae	cf. *Parthenocissus*			×	

[1] Barnett & Fisk (1980).
[2] Smiley & Rember (1985).
[3] Gray (1985).
[4] Graham (1965).
[5] Fields (1996).
[6] Graham (1965) reports a date of 16.7 Ma for the Sucker Creek Formation. Fields (1996) suggests a younger date of 14.8–16 Ma based on newer Ar/Ar dates and geologic evidence. We accept Fields' date for the purpose of this comparison.

(Smiley & Rember, 1985), Mascall (Chaney & Axelrod, 1959), Sucker and Trout creeks (Graham, 1965), and in the Late Miocene Ellensburg Formation (Smiley, 1963). The species was also recorded in the nearby coeval Mashel Formation (Walters, 1964), and Wolfe (1968) included *Platanus* L. in the flora of the Middle Eocene Puget Group in King County. *Platanus* pollen is a rare constituent of the Vasa Park palynoflora.

Salicaceae. This family is represented by pollen of *Salix* L. (Fig. 12E) and possibly *Populus* L. (not figured). *Salix* pollen is relatively common, making up slightly over 1% of the assemblage in each sample that was counted. The cf. *Populus* pollen is rare, with only two grains identified. Gray (1985) notes that *Populus* pollen has low preservation potential, and thus its presence in the fossil record is sporadic.

Sapindaceae. *Acer* L. (Fig. 6A, B). Well-preserved leaves and samaras of *Acer* are common at Vasa Park. The leaves range widely in size from a laminar length of 5–20 cm. They are shallowly lobate, 3- or 5-lobed, with a finely serrate margin. The leaves most closely resemble *A. glabroides* Brown, although *A. glabroides* is usually 3-lobed. The samaras found at Vasa Park do not match those associated with *A. glabroides* by previous authors (Brown, 1936; Wolfe & Tanai, 1987). The samaras found at Vasa closely resemble samaras of *A. medianum* Knowlton. Wolfe and Tanai (1987) argued for an association between samaras of *A. medianum* and leaves of *A. columbianum* Chaney & Axelrod based on the co-occurence of leaves of *A. columbianum* with samaras of *A. medianum* at eight of the 14 known localities where *A. medianum* samaras occur. But *A. glabroides* is also found at many of the same localities.

Multiple species of *Acer* are present at each of the Middle Miocene localities of the Pacific Northwest (Knowlton, 1902, 1926; Brown, 1936; Chaney & Axelrod, 1959; Graham, 1963; Smiley & Rember, 1985). In many cases the actual number of species is overstated because isolated leaves

and samaras cannot be reliably associated with each other. *Acer* was also found at both of the coeval western Washington Late Miocene localities of the Mashel and Hammer Bluff formations (Walters, 1964; Mullineaux, 1970).

Two types of *Acer* pollen (Fig. 12F) are also found at Vasa Park, although they are both rare.

Aesculus L. sp. (Fig. 7C, E). A few leaflets of *Aesculus* have been found at Vasa Park. *Aesculus* has also been identified at Clarkia (Smiley & Rember, 1985) but has not been recognized at other Pacific Northwest Miocene localities.

Scrophulariaceae. *Paulownia columbiana* Smiley (Fig. 7H). Distinctive palmate leaves with prominent tertiaries and a round to obtuse apex were described as *P. columbiana* by Smiley (1961) from the Late Miocene Ellensburg Formation and compared to extant *P. tomentosa* (Thunb.) Steud. *Paulownia tomentosa* has a wider range of leaf morphologies, including lobed leaves, while *P. columbiana* leaves are not lobed. Unlobed leaves of *P. tomentosa* and *P. columbiana* are entire, except for a few small teeth found near the leaf base. Excellent examples have been collected at Vasa Park. *Paulownia* Siebold & Zucc. is also found in the Middle Miocene at Clarkia (Smiley & Rember, 1985), and Knowlton (1926) figured a Latah specimen as *Acer* (plate XXVIII, fig. 1) that likely represents this taxon. He also illustrates a *Paulownia* capsule (plate XXIX, fig. 12) that he described as *Carpites paulownia* Knowlton. *Paulownia columbiana* was also identified by Wolfe in the coeval Mashel Formation (Walters, 1964). Wolfe figures a leaf with the same characteristics from the Puget Group (Wolfe, 1968: plate 5, fig. 1) which he described as *Macaranga pugetensis*.

Ulmaceae. *Ulmus speciosa* Newberry (not figured). *Ulmus* L. is another widespread genus found at most of the Middle and Late Miocene localities in the Pacific Northwest. Knowlton (1926) included *U. speciosa* in the Latah flora, and Chaney and Axelrod (1959) also identified it in the Mascall flora, but described a second species, *U. paucidentata*, based on smaller leaf size

and slender shape. That species was included in the Ellensburg Formation flora (Smiley, 1963), but the specimens at Vasa correspond best with the description of *U. speciosa*. This species was reported by Wolfe in the coeval Mashel Formation (Walters, 1964). *Ulmus* was also reported from the nearby Late Miocene Hammer Bluff Formation (Mullineaux, 1970). *Ulmus oregoniana* Knowlton was recognized in the Middle Eocene Puget Group flora (Wolfe, 1968). Ulmaceous pollen (Fig. 11L) has been found in 4-, 5-, and 6-pored forms, although it is rare.

POLLEN RESULTS

The pollen in the three counted samples was generally abundant and well preserved. In the interest of showing the most significant aspects of the palynoflora, the pollen diagram (Fig. 8) presents only those taxa that contributed at least 1% of the total counts. Conifer pollen is dominant in all samples, with TCT being the major contributor. *Pinus* also makes a strong showing, and *Tsuga* is important from the layers near the top of the exposure. Among angiosperms, *Alnus* is by far the major contributor, and is the single most common palynomorph in sample UWBM no. PB22772. Pteridophytes are an important constituent of all samples, making up approximately 8%–10% of the total counts. One aspect of the flora that is not clear from the pollen diagram is the high species richness in all three samples. We were able to distinguish over 100 distinct palynomorphs, with high species richness in all groups: pteridophytes, conifers, and angiosperms. Those types that were identifiable to the family or genus level are presented in Table 2.

Because the macroflora assemblage was not sufficiently well preserved or diverse to allow a climate estimate based on techniques using nearest living relatives or leaf morphology, we used the coexistence approach (Mosbruger & Utescher, 1997) based on the fossil pollen assemblage. Pollen is adequate but not ideal for this purpose, since the coexistence approach works best with

fossils identified to the genus or species level. This allows for a better determination of possible nearest living relatives for a given fossil taxon and thus tighter constraints on the paleoclimate estimates. Since pollen is typically only identified at the family or genus level, the climatic resolution provided by the analysis is lower. The results of the coexistence analysis are as follows:

Mean annual temperature: 11.6°C–16.6°C

Cold month mean temperature: –0.3°C–2.9°C

Warm month mean temperature: 23.0°C–25.7°C

Mean annual precipitation: 641–1577 mm

Wet month precipitation: 116–245 mm

Dry month precipitation: 8–41 mm

Warmest month precipitation: 89–175 mm

PHYTOLITH RESULTS

The extracted phytolith assemblages were deemed well preserved, due to the presence of fine ornamentation on the grass silica short cells and the generally unaltered texture of the phytoliths, despite some etching of larger bodies, and thus considered appropriate for quantitative phytolith analysis (Strömberg, 2003; Strömberg et al. 2007b). Although sample UWBM no. PB22779 had relatively low phytolith productivity, UWBM nos. PB22778 and PB22780 had extremely low productivity (13 slides had to be examined to achieve a sufficient count).

UWBM no. PB22778 has a relatively high abundance of FI-t phytoliths at 57% (95% CI: 52%–63%), including anticlinal epidermal cells, helical tracheary elements, and nodular bodies. A single palm phytolith was also noted, as well as rare sedge forms. UWBM no. PB22779 has a very high FI-t ratio (94%; 95% CI: 92%–96%), and contained forms such as nodular bodies and polyhedral epidermis, as well as a single palm phytolith. Similarly, UWBM no. PB22780 has a high FI-t ratio (94%; 95% CI: 91%–98%), with FI-TOT forms made up primarily by nodular bodies.

In all three samples, GSSC assemblages are dominated by PACMAD forms (60%–86% of GSSC), represented by, for example, simple lobates, inverted bilobates, and near panicoid bilobates, with a smaller component of pooid morphotypes (11%–24% of GSSC). Closed habitat GSSC forms were not observed in any of the samples. Bootstrapping tests indicate that the relative abundance distribution of different GSSC morphotypes could be explained by PACMAD grasses alone; however, the occurrence of highly diagnostic pooid forms (e.g., crenates) in all three samples suggests that pooids were present in low abundances as well.

Sedge phytoliths were found in abundance in UWBM no. PB22778 and are rare in nos. PB22779 and PB22780. Other biosilica types potentially indicative of wetlands (diatoms, etc.) were relatively rare.

DISCUSSION

The macroflora and palynoflora provide detailed floristic information compared to phytoliths (except within Poaceae) and will be considered together for reconstructing the plant community composition at Vasa Park. They complement each other because of the localized nature of the macrofossil assemblage versus the more regional sampling provided by windborne pollen. Among the pteridophytes and allies, a rich macroflora consisting of a bryophyte, *Equisetum*, and five fern morphotypes is reinforced by a diverse spore record. In the case of gymnosperms, macrofossils are extremely rare, but pollen documents a rich flora of at least a dozen taxa, consistent with other regional Miocene palynofloras (see Table 2). The angiosperm macroflora is not very diverse compared to Northwest Middle Miocene localities (see Table 3), but this likely represents taphonomic bias. Flood overbank deposits, such as those found at Vasa Park, typically preserve mostly autochthonous plant macrofossils while many lacustrine deposits record allochthonous material, some-

times on a regional scale (Behrensmeyer & Hook, 1992). Most of the described Middle Miocene sites represent lacustrine deposition and are much more diverse than the Vasa Park flora. The Late Miocene record from the Tyrrell site in the Ellensburg flora (Table 3) is the only one directly comparable to Vasa Park, representing collections from a single site of fluvial deposition.

The identified macroflora at Vasa Park consists of elements common to all of the well-studied Middle Miocene sites from the interior of northwest North America (see Table 3). At the genus and often the species level, *Acer*, *Alnus*, *Fagus*, *Hydrangea*, *Persea*, *Platanus*, *Smilax*, and *Ulmus* are common to virtually all localities. Only a few of the genera recognized at Vasa Park are rare at other localities, namely *Equisetum* (likely because of taphonomic bias), *Aesculus*, and *Allantodiopsis* sp. Five distinctive fern morphotypes have been found at Vasa Park, which is a much more diverse fern component than other Northwest Miocene occurrences. We hypothesize that this difference is also likely due to taphonomic bias linked to facies type.

Comparison of Vasa Park to other Northwest Middle and Late Miocene sites shows a striking stasis in the floras. Ninety-five percent of the identified macrofossils from Vasa occur in at least one of the Middle Miocene sites, and all of the morphotypes that can be resolved to the species level were first described from Middle Miocene localities. The Middle Eocene Puget flora, which occurs within a few miles of Vasa Park, includes 50% of the macroflora found at Vasa Park at the genus level.

Vasa Park gymnosperms are primarily known from the palynoflora. The Pinaceae are represented by *Abies* (two types)*, Cedrus, Picea* (two types), *Pinus*, *Pseudotsuga/Larix*, and *Tsuga* (two types). In addition, there are several bisaccate palynomorphs, which we were unable to identify at the genus level. *Pinus* is the most common type, constituting approximately 5%–15% of the pollen in the counted samples. The *Pseudotsuga/Larix* type

TABLE 3. Vasa Park macroflora compared to selected Northwest Miocene localities and the Middle Eocene Puget Group floras.

Vasa Park	Tyrrell PA 19[1]	Latah[2]	Mascall[3]	Sucker/Trout Creek[4]	Clarkia[5]	Puget[6]
Equisetae						
Equisetum sp.	*		*	Equisetum miocenicum		
Pteridophytae						
Allantodiopsis sp.						Allantodiopsis pugetensis
Woodwardia sp.				Woodwardia deflexipinna		
Gymnospermae						
Chamaecyparis linguaefolia				Chamaecyparis linguaefolia	Chamaecyparis sp.	
Angiospermae						
Acer sp.	Acer tyrrellii	Acer (4 spp.)	Acer (6 spp.)	Acer (7 spp.)	Acer sp.	
cf. Gossypium sp.				Gossypium arnoldii		
Platanus dissecta	Platanus dissecta		Platanus dissecta	Platanus dissecta	Platanus sp.	Platanus sp.
Paulownia sp.	Paulownia columbiana	Carpites paulownia, "Acer" L ?			Paulownia sp.	Macaranga pugetensis
Hydrangea bendirei		Hydrangea bendirei	Hydrangea bendirei	Hydrangea bendirei	Hydrangea sp.	
Fagus washoensis	**		Fagus washoensis/idahoensis	Fagus washoensis	Fagus/Pseudofagus	
Cercidiphyllum crenatum	**		Cercidiphyllum crenatum		Cercidiphyllum sp.	Cercidiphyllum piperoides
Smilax magna	**		Smilax magna/wardii	Smilax magna	Smilax sp.	Smilax sp.
Alnus sp.	Alnus relatus	Alnus, Betula (8 spp.)	Alnus, Betula (4 spp.)	Alnus, Betula (6 spp.)	Alnus, Betula	Alnus (3 spp.)
Persea pseudocarolinensis	Persea pseudocarolinensis	Persea lanceolata	Persea pseudocarolinensis	Persea pseudocarolinensis	Persea sp.	Persea pseudocarolinensis
Aesculus sp.					Aesculus sp.	
Ulmus speciosa	Ulmus paucidentata	Ulmus speciosa	Ulmus speciosa/paucidentata	Ulmus speciosa/paucidentata	Ulmus	Ulmus oregoniana

Abbreviations: L = Leaf.
* Reported but discredited.
** Occur at other Ellensburg Formation localities.
[1] Ellensburg flora (Smiley, 1963).
[2] Flora of the Latah Formation (Knowlton, 1925; Brown, 1936).
[3] Miocene floras of the Columbia Plateau (Chaney & Axelrod, 1959).
[4] Sucker Creek and Trout Creek Miocene floras of southeastern Oregon (Graham, 1963).
[5] Miocene Clarkia flora (Smiley & Rember, 1985).
[6] Paleogene biostratigraphy of nonmarine rocks in King County, Washington (Wolfe, 1968).

is relatively rare, whereas the remainder contribute a small but significant percentage of the pollen in each sample. Coniferous pollen is often interpreted as a slope or montane element (e.g., Chaney & Axelrod, 1959; Smiley & Rember, 1985), but it should be noted that *Abies, Picea, Pinus, Pseudotsuga*, *Thuja* L., and *Tsuga* are all present in the extant coastal lowland forests of the Pacific Northwest, as well as at higher elevations.

The abundance of *Alnus* pollen suggests a local source. Modern *Alnus* is a common riparian tree type and a pioneer species in disturbed habitats. The relative abundance of fern spores can also be associated with disturbance (Walker & Sharpe, 2010), and *Salix* is a common riparian shrub, while *Nyssa* is associated with swamps and wetlands. The macrofossil records of abundant ferns and pioneer angiosperms such *Alnus* and *Acer*, coupled with evidence provided by the palynoflora, are consistent with a disturbance or early successional flora that formed in a fluvial, floodplain environment. The presence of fine siltstone sediments and aquatic taxa such as *Typha*/*Sparganium* and *Potamogeton* in the pollen record indicate that there were also some quiet water areas in the vicinity.

Table 2 shows a comparison of the Vasa Park palynoflora with several other Miocene sites from the Pacific Northwest. Even though these sites span a distance of hundreds of kilometers and a time period of several million years, the similarities are striking. Of the 64 total taxa listed in the table, 36% are common to all of the floras and 51% are found in at least three out of four floras, indicating that there was a widespread and stable regional forest assemblage during the Miocene. Vasa Park occurred during the global cooldown that followed the Mid-Miocene Climatic Optimum (Zachos et al., 2001), but it is clear that no significant floral turnover had yet occurred in the Pacific Northwest by this time.

Fifty percent of the genera found at Vasa Park are no longer extant in northwest North America. They are found in eastern North American and Eurasian forests with a temperate climate and year-round rainfall. The coexistence approach analysis suggests a similar climate at Vasa Park during the Miocene, with the mean annual temperature in a range of 11.6°C–16.6°C, limited frost in the winter (cold month mean temperature, –0.3°C to 2.9°C), moderate to high precipitation (mean annual precipitation, 641–1577 mm), and adequate rainfall during the growing season (warm month precipitation, 89–175 mm). This is consistent with climate interpretations for other Miocene floras from the Northwest, and the Vasa Park climate analysis, coupled with the high degree of taxonomic overlap between the Miocene palynofloras, supports the hypothesis that the regional climate did not change significantly during the 4- to 5-million-year time frame represented by these floras. Graham (1999) uses evidence from a number of fossil sites in the western United States to show that a cooling climate and dry summer conditions started to set in after the Mid-Miocene Climatic Optimum, beginning in southwestern North America and the continental interior. The dry summer conditions would have resulted in the loss of many deciduous hardwoods that require adequate summer rainfall. According to this analysis and consistent with our data, the Pacific Northwest did not experience these effects until later, and Graham (1999) states that the warm temperature and wet summer climate conditions persisted in the region into the Early Pliocene.

Because the phytolith assemblages were generally well preserved in Vasa Park deposits, we assume that they reflect deposition from plants growing on the floodplain, rather than phytoliths transported by water or wind from surrounding highlands (Osterrieth et al., 2009). The overall low abundances of sedge phytoliths and other biosilica (e.g., diatoms, sponge spicules) commonly associated with lakes and rivers further indicate that the assemblages represent deposition in a soil, rather than in water, such as in an oxbow lake. All extracted samples from Vasa Park had very low

concentrations of phytoliths compared to typical Cenozoic sediments (Strömberg, unpublished data). This suggests that the horizons collected, even those that had clear root traces, did not remain stable soil surfaces for very long. Of the three samples that were quantitatively analyzed for phytoliths, UWBM nos. PB22779 and PB22780 both point to closed habitats (forest) with a low abundance of PACMAD grasses and rare pooids. Since these samples were collected from the same horizon, their similarity indicates little spatial heterogeneity in vegetation, at least over the small distance sampled at Vasa Park. The higher abundance of sedges in UWBM no. PB22779 suggests that this sample reflects a microhabitat closer to water. Assemblage UWBM no. PB22778 appears to represent a somewhat more open microhabitat, with a mix of trees and forbs, mainly PACMAD grasses and infrequent pooids. The presence of palm phytoliths in two assemblages opens up the intriguing possibility that palms persisted in the Pacific Northwest until the early Late Miocene; the youngest previously described palms from the region are pollen from the Middle Miocene Succor Creek flora of the Oregon-Idaho border (Taggart & Cross, 1990), and phytoliths from the late Middle and early Late Miocene of southwestern Montana (Strömberg, 2005; Smith et al., 2012; Strömberg et al., 2012). In addition, palm phytoliths have been recovered from the Middle Miocene Mascall Formation of Oregon (R. Dunn & C. Strömberg, unpublished data). However, because of the very low abundance of palm phytoliths at Vasa Park, the fact that other monocotyledons produce phytoliths that can look similar to palm phytoliths (e.g., orchids; Piperno, 1988), and the lack of co-occurring pollen attributable to Arecaceae, the identification of palms at Vasa Park has to remain tentative.

In all, phytolith assemblages point to a mostly forested floodplain at Vasa Park. The abundance of PACMADs in grass communities could be consistent with warmer climates, and could also point to mesophytic PACMAD grasses growing close to water (e.g., *Arundo* L.; see Strömberg et al., 2007a). The specific PACMAD morphotypes that dominate GSSC assemblages (e.g., so-called almost panicoid bilobates) are similar to those produced by *Arundo*. However, as noted above, other lines of evidence (diatoms, etc.; Fig. 9) are not congruent with an interpretation of these assemblages as mirroring wetland vegetation. Palms, if present, would also support the pollen-based inference that climate was warmer than today in Washington during the early Late Miocene. This reconstructed vegetation differs from roughly coeval phytolith assemblages from sites further inland, in western Montana. Here, assemblages appear to reflect open habitats dominated by cool-temperate pooids (Strömberg et al., 2012). Similarly, faunal and paleosols data have been interpreted as pointing to savanna or woodland habitats for the early Late Miocene of eastern Oregon (Shotwell, 1970; Retallack, 2004). These differences may be a result of a difference in regional climate (e.g., rainfall) between western Washington and areas further east, but it cannot be ruled out that it is a consequence of sampling different, local edaphic conditions.

CONCLUSIONS

Applying a range of geological and paleobotanical approaches, we are able to more completely describe the flora recorded at Vasa Park than by using single lines of evidence. Geological study not only provides a "big picture" view of the sedimentary system that created the deposit but also informs us about taphonomic filtering and the age of fossil-bearing sediments. The macroflora mostly records localized plant communities adapted to regular disturbance close to fluvial channels and is not diverse enough to estimate climate. The palynoflora adds a regional perspective of likely conifer-dominated upland floras and the much more species-rich surrounding hardwood forests. It also provides us with a regional climate estimate. The phytolith assemblage informs us about

forest coverage and grass ecology in the flora recorded at Vasa Park. In all, these lines of evidence indicate that plant communities in western Washington differed little from Middle to Late Miocene floras from around the Pacific Northwest, and that the regional climate had remained mild and humid since the Middle Miocene. Unlike coeval sites from the northern Rocky Mountains and Great Plains, open habitats dominated by cool- and dry-adapted pooid grasses appear not to have been important in the Pacific Northwest during this time. These patterns suggest that the Pacific Northwest may have served as a climatic refugium amidst dropping global temperatures and increasing seasonality during the Late Miocene (Zachos et al., 2001).

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