

MIOCENE FOSSIL WOODS FROM THE COLUMBIA BASALTS OF CENTRAL WASHINGTON

U. PRAKASH AND ELSO S. BARGHOORN

OVER EXTENSIVE AREAS of the northwestern United States, especially in Central Washington, there occur thick accumulations of basalt and related pyroclastic sediments. These are known as the Columbia Lava Series and contain within them numerous fossil woods, in places preserved virtually as fossil forests *in situ*. One of the areas most extensively investigated has been designated locally as the Russell Forests, the term proposed by Beck (1945a). The area included under this designation comprises several hundred square miles in an area centered around Vantage, in the Columbia Valley. Beck (1955–1956) noted that in botanical composition and age, the fossil forests are quite comparable in botanical identity, on the generic level, with the well-known leaf impressions from the Latah beds in and around the city of Spokane, Washington. In Beck's extensive studies, he listed (1945a) thirteen localities in which fossil woods had been found in varying abundance.

In a series of informal notes and publications, Beck presented an impressive list of identified fossil dicotyledonous and coniferous woods (Beck 1941a–e; 1942a–c; 1942–43; 1944a–c; 1945a–c; 1948; 1955a–c; 1955–56; 1956). Unfortunately, however, the identifications are, with few exceptions, not associated with illustration, anatomical description and formal binomial designation. Hence, they do not constitute permanent accessible additions to palaeobotanical and palaeogeographic literature. The authors are in full agreement with the validity and accuracy of Beck's investigations on the fossil woods of central Washington and wish to dedicate this study, in part, to commemoration and formalization of his many years of painstaking work in this difficult aspect of palaeobotanical research. The genera and species described in this paper comprise only a fraction of those which have been determined from the Columbia Basalt fossil forests, and it is proposed to expand our taxonomic treatment of this flora as additional material is examined.

The locality of particular interest is near the town of Vantage, Kittitas County, Washington, on the west bank of the Columbia River about 28 miles east of Ellensburg. From Beck's study (1945a) and our own observations, it is evident that the Vantage locality is rich in quantity and diversity of fossil woods. It is of much interest also to note that this region, once covered by a rich deciduous forest, is now featured by a semiarid sagebrush vegetation (*Artemisia*). The various causes for extinction of the forest, the pronounced changes in climate and topography of the region and other related problems will be dealt with in a subsequent paper when the flora and its ecological significance are more fully known.

This paper deals with the systematic description of woods belonging to the families Aceraceae, Ebenaceae, Fagaceae, Hamamelidaceae, Juglandaceae, Leguminosae, Platanaceae, and Ulmaceae. The field collection was made in 1954 by Mr. Jay O'Leary while he was a student in Harvard College. Our determinations are based on his specimens and preparations supplemented by additional thin-sections.

In general, the preservation of structural details of the wood is quite good, although not consistently so. The siliceous matrix fluctuates from hyaline to microcrystalline but is not accompanied, to any serious degree, by opaque minerals. Some specimens are varicolored by iron mineral stain, but even in these cases the woody structure is well preserved.

The age of the fossil woods described in this study is Upper Miocene. This determination is consistent with the presently accepted stratigraphic position of the Columbia basalts in this area of Washington.

ACERACEAE

1. *Acer puratanum* Prakash & Barghoorn, sp. nov. (Figs. 25–28, 30)

Growth rings: Fairly distinct (FIG. 27), delimited by 2 or 3 rows of thick-walled fibers.

Vessels: Small, 30–72 μ in tangential diameter (mean 53 μ); chiefly solitary (FIG. 27), often in multiples of 2–several cells, quite uniform in size and evenly distributed, thin-walled, the solitary vessels round to oval in cross-section. Vessel elements 130–350 μ long, with spiral thickenings (FIG. 26). Perforation plates exclusively simple, oblique, often tailed. Intervascular pit-pairs bordered (FIG. 30), alternate, orbicular or angular where crowded, 5–7 μ in diameter, with linear apertures. Tyloses absent; vessels often plugged with yellow or brown gummy deposits.

Parenchyma: Sparse, restricted to occasional cells; terminal and paratracheal. Terminal parenchyma occurring as scattered cells associated with the narrow terminal bands of thick-walled fibers. Paratracheal parenchyma (FIG. 25) scanty, occurring as a few cells in association with the vessels. Parenchyma cells sometimes crystalliferous.

Xylem rays: Homogeneous (Kribs Homogeneous Type 1), composed chiefly of procumbent cells (FIG. 28), nonstoried, 1–5 cells wide; uniseriate rays quite common, 1–15 (often 3–8) cells high; multiseriate rays mostly 3–4 cells broad and 0.56 mm. high; up to 8–12 rays per mm. Ray cells square, rectangular or oval in tangential section, thin- to moderately thick-walled and 10–20 μ in diameter.

Imperforate tracheary elements: Fiber tracheids (FIG. 25) thin- to moderately thick-walled, especially through the late-wood zone near the growth ring, usually polygonal in cross-section with a small to large lumen, 8–20 μ in diameter, nonseptate; pits bordered.

MATERIAL. A single specimen of silicified, mature, secondary xylem measuring 4 × 4 × 3 cm.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55200. The name is derived from Sanskrit, *puratan*, meaning *ancient*.

There is close agreement in almost all details of structure of this wood with that of *Acer*. The fossil wood shows also a superficial resemblance to the mature secondary xylem of *Betula* as seen in transverse and tangential sections. However, in *Betula*, the perforation plates are scalariform, in contrast with the simple plates in *Acer*. Also, spiral thickenings are present in the vessels of *Acer* but absent in *Betula*. A survey of available woods of *Acer* indicates that the nearest affinity of the fossil within this genus is with *A. circinatum* Pursh and *A. mandschuricum* Maxim., especially with the former. Our survey included the study of thin-sections of the woods of 29 species of the genus and published descriptions of 14 other species. The latter are *A. oblongum* Wall., *A. caesium* Wall., *A. thomsonii* Miq. (Pearson and Brown, 1932, pp. 299–308, figs. 107–111), *A. pseudoplatanus* L. (Kribs, 1959, fig. 61), *A. cissifolium* C. Koch., *A. rufinerve* Sieb. & Zucc. (Kanehira, 1921a, pp. 17, 18), *A. rubescens* Hay., *A. kawakamii* Koidz., *A. duplicato-serratum* Hay., *A. oliverianum* Pax var. *nakaharai* Hay., *A. taiton-montanum* Hay., *A. morrisonense* Hay. (Kanehira, 1921b, pp. 74–76, pl. 14, figs. 79–81), *Acer circinatum* Pursh, and *A. leucoderme* Small (Stark, 1954, pp. 8, 10).

The size and distribution of the vessels in *Acer puratanum* agree with the distributional pattern in *A. circinatum*. Tangential diameter of vessels in *A. puratanum* (30–72 μ) is quite comparable to the measurements secured from comparable secondary xylem of *A. circinatum* (25–72 μ). Both in *A. circinatum* and in the fossil species the perforations are simple and the intervascular pit-pairs are alternate, bordered, orbicular, or angular where crowded, with linear apertures. However, the vessels are more closely placed in the fossil wood than in the modern wood of *A. circinatum*.

The distribution of parenchyma appears to be almost identical in both, as is the fiber and ray structure. However, conspicuous differences between the two species are in the crystalliferous parenchyma and the distribution of thick-walled fibers. The crystalliferous parenchyma is occasionally present in the fossil wood but absent in *Acer circinatum*, although it is known to occur in a number of other species of *Acer*. Also, *A. circinatum* shows alternate areas of thin- and thick-walled fibers (Stark, 1954, p. 8), whereas in *A. puratanum* thick-walled fibers are found only in the late wood.

Fossil woods related to *Acer* are known from the Cretaceous onward under the names *Acerinum* Unger (1842), *Aceroxylon* Loubière (1939), and *Acer* L. These woods are *Acerinum danubiale* Unger (1842), from the Tertiary of Upper Austria; *A. borussicum* Caspary (1888) and *A. terraecoeruleae* Caspary (1888), from the Tertiary (?) of East Prussia; *A. aegypticum* Schenk (1888, 1890), from the Tertiary of Egypt; *A. astianum* Pampaloni (1904), from the Tertiary of the Piedmont; *Aceroxylon madagascariense*, from the Cretaceous of Madagascar (Loubière, 1939); *Aceroxylon* cf. *paleosaccharinum* Greguss (1943), from Hungary; *Aceroxylon* sp., from the Oligocene of Prambachkirchen, Austria (Hofmann, 1944, 1952); *Acer* sp. (Szafer, 1914; Fietz, 1926b), from the Pleistocene of Poland, and from the prehistoric deposits of Czechoslovakia; *Acer iwatense*

Watari (1941, 1952) and *Acer* cf. *amoenum* Carr. (Watari, 1952), from the Tertiary of Japan. However, our present fossil wood differs distinctly from all the known species. Thus, *Acer* cf. *amoenum* (Watari, 1952) differs from *A. puratanum* in having broad xylem rays 1–9 cells wide and in the presence of diffuse parenchyma in addition to paratracheal and terminal types. Diffuse parenchyma is absent from *A. puratanum*. Similarly, *A. iwatense* (Watari, 1941, 1952) also differs from *A. puratanum* in having broad, homogeneous to heterogeneous xylem rays, 1–7 cells wide, and in the presence of only diffuse parenchyma.

The family Aceraceae is composed of two genera and about 150 species. One genus, *Dipteronia*, comprises two species of small trees indigenous to China. The other, *Acer*, composed of numerous species of small to large deciduous trees, is widely distributed over the Northern Hemisphere, one form extending south of the equator to the mountains of Java. It attains its greatest development in eastern Asia and eastern North America (Record and Hess, 1943; Stark, 1954). There are only thirteen species of *Acer* indigenous to the United States. *Acer saccharum* Marsh. and *A. nigrum* Michx. occur in most of the eastern hardwood region of the United States and Canada and also locally in northeastern South Dakota, with the best stands near the Great Lakes and in northern New England and the St. Lawrence Valley (Munns, 1938, *maps 148, 149*; Record and Hess, 1943). *Acer saccharum* Marsh. also grows in southwestern Manitoba, eastern Oklahoma and northeastern Texas. The two principal soft maples, *A. rubrum* L. and *A. saccharinum* L., have much the same range, but extend farther south and attain their best development in the lowlands of the Ohio Valley (Munns, 1938, *maps 150, 151*). *Acer macrophyllum* Pursh grows along the Pacific Coast, from British Columbia to southern California, with the greatest development in Washington and Oregon (Munns, 1938, *map 147*). *Acer pennsylvanicum* L. (Munns, 1938, *map 146*) and *A. spicatum* Lam. grow in the undergrowth of the northeastern hardwood forests and also south in the mountains to northern Georgia (Record and Hess, 1943). *Acer circinatum* Pursh grows naturally along streams and lakes, often forming impenetrable thickets, from British Columbia to northern California, mainly near the coast (Britton, 1908, p. 642). *Acer negundo* L. ranges naturally from western Vermont to western New Jersey and central Florida, westward to Ontario, Manitoba, central Saskatchewan, southern Alberta, central Montana, Wyoming, Utah, California, and Mexico (Munns, 1938, *map 152*; Little, 1953). *Acer leucoderme* Small inhabits rocky river-banks and ravines from North Carolina and Georgia, westward to southeastern Oklahoma and Louisiana. *Acer grandidentatum* Nutt. is a species of the Rocky Mountain region and ranges from northern Montana to eastern Utah, Wyoming, western Texas, and New Mexico, extending southward into Mexico. *Acer barbatum* Michx. (*A. floridanum* (Chapm.) Pax) grows naturally from southeastern Virginia to central Florida and is reported to exist farther west in Texas, northern Mexico, and north in the Mississippi Valley to southeastern Missouri. *Acer glabrum* Torrey grows from Montana, southwestern Oregon, and Idaho to Wyoming,

western Nebraska, and throughout Colorado to New Mexico and Arizona, and also the Sierra Nevada of California (Britton, 1908, pp. 640–56; Little, 1953).

2. *Acer beckianum* Prakash & Barghoorn, sp. nov. (FIGS. 59–63)

Growth rings: Distinct, delimited by 1 or 2 layers of flattened thick-walled fibers.

Vessels: Small, 30.6–81.5 μ in tangential diameter (mean diameter 60 μ), chiefly solitary (FIG. 62), sometimes in multiples of 2 or 3 or rarely 4 or 5 cells, uniform in size and evenly distributed, slightly thick-walled, the solitary vessels round to oval in cross-section (FIGS 61, 62). Vessel segments 102–408 μ long with spiral thickenings (FIG. 59); end walls usually oblique, sometimes horizontal and often tailed. Perforation plates exclusively simple. Intervascular pit-pairs (FIG. 60) bordered, alternate, 7–8 μ in diameter, orbicular (or angular where crowded) with linear apertures. Tyloses absent; vessels sometimes plugged with brown or black gummy deposits.

Parenchyma: Sparse, terminal and paratracheal. Terminal parenchyma scanty, associated with the growth ring. Paratracheal parenchyma found as 1–few cells in association with some vessels.

Xylem rays: Homogeneous (Kribs Homogeneous Type 1) composed chiefly of procumbent cells, nonstoried; 1–3 cells wide; uniseriate rays quite frequent, 3–16 cells high; multiseriate rays mostly 3 cells broad and 0.7 mm high; up to 12–16 rays per mm. Ray cells round to oval, sometimes vertically elongate in tangential section, thick-walled and 7–14 μ in diameter.

Imperforate tracheary elements: Fiber tracheids polygonal in cross-section, 10–18 μ in diameter, the walls thin to thick, with a small to large lumen, non-septate; pits bordered.

MATERIAL. A single specimen of silicified, mature, secondary xylem measuring 4 \times 2.5 \times 3 cm.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55226. The species is named in honor of George F. Beck, of Yakima, Washington, who pioneered the work on the fossil woods of Vantage and its neighboring areas.

A survey of all available woods of the genus *Acer* indicates that the nearest affinity of the fossil is with *Acer negundo* L. The size and distribution of the vessels of *A. beckianum* agree with the distributional pattern in *A. negundo* var. *violaceum* Jaeg. & Beissn. The tangential diameter of the vessels in the fossil wood (30.6–81.5 μ) is somewhat similar to the measurements secured from comparable secondary xylem of *A. negundo* (25–80 μ). The only obvious difference between the two species is in the shape of the vessels which are mostly oval and slightly angular in *A. negundo* but almost always round in *A. beckianum*.

The distribution of parenchyma appears to be almost identical in both,

as is the fiber and ray structure. However, a minor difference between the two species is in lower and rarely 4-seriate rays in *A. negundo*; the rays are slightly higher and up to 3-seriate in *A. beckianum*.

As previously noted, a number of fossil woods related to *Acer* are known and all of them differ from *Acer beckianum* in certain features. The fossil wood of *A. puratanum* Prakash & Barghoorn, described in the preceding pages and from the same locality, also differs distinctly from *A. beckianum*.

3. *Acer olearyi* Prakash & Barghoorn, sp. nov. (FIGS. 55–58)

Growth rings: Slightly distinct, delineated by flattened, thick-walled fibers.

Vessels: Small, 30–80 μ in tangential diameter (FIG. 55), (mean diameter 58.5 μ); commonly in multiples of 2–8 cells, often solitary, almost uniform in size and evenly distributed, thin-walled, the solitary vessels round to oval or slightly angular in cross-section, radially compressed when in multiples. Vessel elements with spiral thickenings, the end walls probably oblique. Perforation plates exclusively simple. Intervascular pit-pairs bordered, alternate, slightly loosely arranged, 5–7 μ in diameter, orbicular (or angular when crowded), with linear to lenticular apertures. Tyloses absent, but vessels commonly plugged with brown or black gummy deposits (FIG. 55).

Parenchyma: Scanty, terminal, paratracheal and diffuse. Terminal parenchyma occurs as occasional cells associated with the rows of thick-walled fibers at the growth ring. Paratracheal parenchyma very sparse, 1–few cells associated with the vessels, sometimes forming incomplete sheaths.

Xylem rays: Homogeneous (Kribs Homogeneous Type 1), composed of procumbent cells (FIG. 58), nonstoried, 1–7 cells wide; uniseriate rays common, 3–16 cells high; multiseriate rays mostly 5 or 6 cells broad and 1.05 mm. high; up to 8–10 rays per mm. Ray cells square, rectangular, or polygonal in tangential section and 8–15 μ in diameter.

Imperforate tracheary elements: Fiber tracheids oval to angular in cross-section, 12–25 μ in diameter, the wall thin to thick with a small to large lumen, non-septate; pits bordered.

MATERIAL. A single specimen of silicified, mature, secondary xylem measuring 3.5 \times 4 \times 2.5 cm.

HOLOTYPE. Palaeobotanical Collections, Harvard University No. 55311. This species is named for Mr. Jay O'Leary, who collected this material.

A survey of all available woods of the genus *Acer* indicates that the nearest affinity of the fossil is with *Acer grandidentatum* Nutt. Both in *Acer olearyi* and the modern wood of *A. grandidentatum* the vessel size and their distribution, the nature of the perforation plates, the intervacular pit-pairs, the parenchyma distribution, and the ray and fiber structure are similar. However, the only obvious difference between the two species is that the vessels are more crowded and with a slightly greater frequency of the vessel multiples in *A. grandidentatum* than in *A. olearyi*.

Acer grandidentatum Nutt. occurs in the western United States and ranges from northern Montana to eastern Utah, Wyoming, western Texas, and New Mexico, extending southward into Mexico (Britton, 1908, p. 652). The present fossil wood differs from all extant species examined as well as from the other fossil species described so far.

EBENACEAE

4. *Diospyros washingtoniana* Prakash & Barghoorn, sp. nov.

(FIGS. 46–50)

Growth rings: Distinct; wood semi-ring-porous (FIG. 47).

Vessels: Large vessels in the early wood, gradually decreasing in size towards the outer margin of the ring (FIG. 47), 40–240 μ in tangential diameter (mean diameter 146 μ); sometimes solitary, usually in radial rows of 2–4 cells, evenly distributed and somewhat widely placed, thick-walled; solitary vessels round to oval or elliptical in cross-section (FIGS. 47, 49), sometimes irregular in shape. Vessel elements 190–310 μ long with horizontal to oblique end walls. Perforation plates exclusively simple. Intervascular pit-pairs bordered, minute, 3–5 μ in diameter, orbicular to oval, with linear apertures, sometimes confluent. Vessels often plugged with black or brownish gummy deposits and tyloses (FIG. 50).

Parenchyma: Paratracheal, metatracheal, and terminal. Paratracheal parenchyma confined to immediate vicinity of the vessels, the sheath being narrow, 1- or 2-seriate but incomplete. Metatracheal parenchyma distinguishable with difficulty in cross-section because of bad preservation, but apparently quite abundant and arranged in broken, irregular tangential bands 1–3 cells thick, sometimes ending blindly. Terminal parenchyma forming a 1- or 2-seriate tangential band at the growth ring. Parenchyma cells usually larger than the fibers, variously shaped, those occurring in close association with the vessels flattened to conform to the vessel wall, those found elsewhere oval to rectangular in shape.

Xylem rays: Homogeneous to heterogeneous, storied (FIG. 48) but slightly irregular in some places, 1–2 (mostly 2)-seriate and 0.45 mm. high; uniseriate rays 2–13 cells high; biseriate rays up to 18 cells high. Ray cells thick-walled, broadly oval to vertically elongate in tangential section, 10–20 μ in diameter.

Imperforate tracheary elements: Slightly thick-walled fiber tracheids variously shaped, more or less angled in cross-section, 20–35 μ in diameter, non-septate; pits bordered, with slit-like vertical apertures.

MATERIAL. A single specimen of mature secondary xylem, measuring 9 × 6 × 5 cm. Structural preservation of the fossil wood is poor.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55305.

The affinity of the fossil wood is clearly with the genus *Diospyros*, although it shows a superficial resemblance to the mature secondary xylem of *Carya*. The broad rays of *Carya*, however, are nonstoried, whereas the fossil possesses conspicuously storied, narrow rays.

A survey of all of the available woods of the genus *Diospyros* indicates that the nearest affinity of the fossil is with *D. virginiana* L. Our survey included the study of thin sections of woods of 19 species of the genus and published descriptions of 15 other species (Kanehira, 1921a, pp. 38, 39, fig. 26; 1921b, pp. 141–144, pl. 27, fig. 160; 1924, pp. 41, 42; Pearson and Brown, 1932, pp. 698, 699, 706–708, figs. 226, 229; Reyes, 1938, pp. 408–412, 414–415, pl. 79, fig. 3, pl. 80, figs. 1–3; Kribs, 1959, pp. 38, 39, figs. 129, 358, 359).

The size and distribution of the vessels of *Diospyros washingtoniana* agree with the distribution pattern in *D. virginiana*. The tangential diameter of the vessels in the fossil wood (40–240 μ) is quite close to the measurements secured from comparable secondary xylem of *D. virginiana* (35–220 μ). The only obvious difference between the two species is in slightly more thickened vessel walls in *D. virginiana* which also shows vessel groups up to 7 cells. However, both in *D. virginiana* and in the fossil species, the perforations are simple and the intervascular pit-pairs are bordered, alternate, orbicular to oval with linear aperture.

The distribution of parenchyma appears to be almost identical in both as is also the fiber structure.

The xylem rays of the fossil wood and of *Diospyros virginiana* are basically similar, although there are slight differences. In both they are homogeneous to heterogeneous and storied, although the storied structure is slightly irregular in certain areas of the fossil. The rays of *D. virginiana* are 1–3 (mostly 1 or 2) cells broad, often with long, uniseriate wings, whereas in *D. washingtoniana* they are 1 or 2 (mostly 2) cells broad with short uniseriate wings.

Only two other fossil woods of *Diospyros* are known. These are *Diospyros* sp. (Schonfeld, 1925), from the Tertiary of Germany, and *Diospyros* sp. (Slijper, 1932), from the Pliocene of Holland. It is interesting to note that a fossil wood, *Ebenoxylon speciosum*, showing resemblance to *Diospyros* is also known from the Tertiary of California (Platen, 1908).

The genus *Diospyros* is composed of 160 or more species, mostly trees, more abundant in tropical Asia than elsewhere. *Diospyros virginiana* L. is the only representative in temperate North America. It grows in forests, primarily on dry soil, from Rhode Island to southern New York, Iowa, Kansas, Florida, and Texas (Britton, 1908; Munns, 1938, map 162).

FAGACEAE

5. *Quercus leuca* Prakash & Barghoorn, sp. nov. (Figs. 39–45)

Growth rings: Distinct; wood ring-porous. Transition between early and late wood abrupt.

Vessels: Large vessels in the early wood, 130–390 μ in tangential diameter (mean 252 μ) (Figs. 43, 45), solitary, forming a conspicuous band 1–2 pores in width, thin-walled, vessels round to oval in cross-section. Vessel elements up to 400 μ long. Perforation plates exclusively simple, usually horizontal. Intersvascular pit-pairs alternate, bordered, and round to oval

in shape. Tyloses common. Late-wood vessels small (FIG. 45), 25–75 μ in tangential diameter (mean 47 μ), scattered in radially aligned, flame-shaped tracts (FIGS. 43, 45) of light-colored tissue, usually solitary, sometimes in pairs, rarely in threes, open, angular in cross-section. Perforation plates and intervascular pit-pairs similar to early-wood vessels.

Parenchyma: Abundant, paratracheal and metatracheal. Paratracheal parenchyma intermingled with the tracheids, (1) forming part of the conjunctive tissue between the early wood vessels and the rays, (2) comprising most of the tissue in the flame-shaped tracts (FIG. 41) in which late-wood vessels are inserted. Metatracheal parenchyma scanty (FIG. 42), restricted to fibrous tracts, mostly in the outer half of the growth ring where it occurs as diffuse, isolated cells or in broken, wavering lines 1 or 2 cells (mostly 1) thick. Parenchyma cells thin walled (FIG. 42), slightly larger than the fiber, very often containing brownish, gummy deposits. Crystalliferous parenchyma abundant, cells slightly swollen (FIG. 39) with rectangular to polygonal crystals.

Xylem rays: Homogeneous (Kribs Homogeneous Type 1), composed of procumbent cells; both narrow and aggregate (FIG. 44); narrow rays mostly uniseriate, rarely partly biseriate, 2–29 cells high; aggregate rays 18–35 cells broad and 14.5 mm. high. Ray cells thin-walled, variously shaped in tangential section and 7–25 μ in diameter, sometimes with crystals in swollen elements.

Imperforate tracheary elements: Libriform fibers and vasicentric tracheids. Thick-walled fibers well developed between the spaces among the flame-shaped tracts, polygonal in cross-section, 12–20 μ in diameter, non-septate; pits simple. Vasicentric tracheids intermingled with parenchyma, (1) forming most of the conjunctive tissue between the early-wood vessels and the rays and, (2) comprising part of the flame-shaped tracts in which the late-wood vessels are distributed; pits bordered, round and in 1 or 2 rows, aperture round to elliptic (FIG. 40).

MATERIAL. A single specimen of silicified mature secondary xylem measuring 7.5 \times 2.5 \times 13 cm.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 54916.

The woods of the various species of oaks exhibit considerable variation but possess many features in common. Anatomically, two groups of species can be readily distinguished, the white oak group and the red-black oak group (Record and Hess, 1943, p. 168). These divisions correspond to important botanical differences. The woods can also be grouped into ring-porous, from deciduous trees, and diffuse-porous, from the evergreen or so-called live oaks, but these distinctions are not taxonomic. The red oaks can be distinguished from the white oaks by the following anatomical characters (Brown, Panshin, and Forsaith, 1949, p. 544):

WHITE OAKS

Transition from early to late wood generally abrupt.

RED OAKS

Transition from early to late wood gradual to more or less abrupt.

WHITE OAKS

RED OAKS

Early-wood pores in the heart-wood usually occluded with tyloses.	Early-wood pores in the heart-wood usually open.
Late-wood pores thin-walled, more or less angular, not sharply defined with a hand lens.	Late-wood pores plainly visible with a hand lens, thick-walled, rounded.
Large rays averaging $\frac{1}{2}$ - $1\frac{1}{4}$ " in height, frequently taller than $1\frac{1}{2}$ ".	Large rays averaging $\frac{1}{4}$ - $\frac{1}{2}$ " in height, rarely taller than $1\frac{1}{2}$ ".

According to these characters, the fossil wood under consideration belongs to the white oak group. A survey of the available woods of the genus *Quercus* indicates that the nearest affinity of the fossil is with *Quercus alba* L. Our survey included the study of thin-sections of the woods of 86 species of the genus and published descriptions of 15 other species (Sudworth and Mell, 1911, pp. 22-56, *figs. 11-48*; Kanehira, 1921a, pp. 67-71, *pl. 8, figs. 44, 45*; Kanehira, 1924, p. 52; Kanehira, 1940; Pearson and Brown, 1932, pp. 981-996, *figs. 299-304*; Reyes, 1938, pp. 60-62, *pl. 4, figs. 1, 2*; Metcalfe and Chalk, 1950, pp. 1311-1314, *figs. 313G, L*; Greguss, 1947, pp. 41-46, *figs. 18-27*).

The size and distribution pattern of the vessels in early and late wood of *Quercus leuca* and *Q. alba* are almost identical, there being 1 or 2 rows of large vessels in the early wood and small, thin-walled, angular vessels arranged in a flame-like pattern in the late wood. In addition, both in the living and fossil species the perforation plates are exclusively simple and the intervacular pit-pairs are bordered, alternate, and round to oval.

The distribution of parenchyma appears to be almost identical in both, as is the fiber structure. However, a conspicuous difference between the two species is in the crystalliferous parenchyma, which is present in the fossil wood but absent in *Quercus alba*.

The xylem rays of the fossil wood and of *Quercus alba* are basically similar, although there are slight differences in the height of the rays and in the presence of crystals in the ray cells of the fossil. In both they are narrow (mostly uniseriate) and aggregate and composed solely of procumbent cells. However, the rays are 14.5 mm. high and possess large crystalliferous cells in *Q. leuca*, whereas in *Q. alba* they are much higher and do not have crystalliferous cells.

Fossil woods and leaves assigned to *Quercus* are known from the Cretaceous onward from many areas of the earth. Fossil woods have been described under the names *Quercinium* Unger (1842, emend. Brett, 1960), *Quercoxylon* Krausel (1939) and *Quercus* L. These have been listed by Edwards (1931) and Boeshore and Jump (1938). Others not listed and subsequently described are by Ogura (1932), Shimakura (1934), Krausel (1939), Watari (1941, 1952), Hofmann (1944, 1952), Andreanszky (1951), Beyer (1954), Müller-Stöll & Mädler (1957), Boureau (1958), and Brett (1960). All of them differ distinctly from the fossil wood under consideration. Those known from this country are *Quercinium knowltonii* Felix (1896), *Q. lamarensis* Knowlton (1899), *Quercus rubida* Beyer

(1954), from the Miocene of Yellowstone National Park; *Quercinium album* Boeshore & Jump (1938), from the Miocene of Idaho; *Quercinium solerederi* Platen, *Q. wardii* Platen, *Q. anomalum* Platen, *Q. lesquereuxii* Platen, *Q. abromeitii* Platen (Platen, 1908), and *Quercus ricardensis* Webber (1933), from the Miocene and Pliocene, and *Q. agrifolia* Nee (Frost, 1927), from the Pleistocene of California; and *Quercus marcapana* Penhallow (1891), from the post-glacial deposits of Illinois.

Quercus, one of the most important woody genera in the world, is widely distributed in the North Temperate Zone and extends at high altitudes into the tropics as far south as the East Indies in the Old World and the mountains of Colombia and Ecuador in the New World. More than 500 species and varieties of oaks, from low shrubs to stately forest trees, have been described (Record and Hess, 1943).

There are about fifty species of *Quercus* native to the United States. *Quercus alba* L., with which our fossil compares well, grows throughout the entire eastern half of the United States (Munns, 1938, *map 110*). The only oak growing in the state of Washington is *Q. garryana* Douglas (Record and Hess, 1943; Munns, 1938, *map 112*) which also belongs to the white oak group.

HAMAMELIDACEAE

6. *Liquidambar* cf. *styraciflua* L. (FIGS. 20-24)

Growth rings: Not very conspicuous, delimited by 1 or 2 rows of thick-walled, flattened fibers; wood diffuse-porous (FIG. 20).

Vessels: Small, 30-81 μ in tangential diameter (mean 48 μ), solitary, in multiples of 2 or 3 (mostly 2), or paired laterally, quite uniform in size and crowded (FIG. 20), thin-walled, oval to slightly angular in cross-section. Vessel elements up to 1070 μ long, with tapering, often tailed ends; spiral thickening present, restricted to tapering ends. Perforation plates exclusively scalariform with about 15-30 bars (FIG. 22). Intervascular pit-pairs (FIG. 23) bordered, in transverse rows of 1-3, orbicular to oval or linear through fusion, 7-35 μ in diameter. Tyloses absent.

Parenchyma: Scanty, paratracheal and diffuse, either associated with the vessels or found as solitary cells among the fibers; parenchyma cells thin-walled, oval to oblong in cross-section.

Xylem rays: Heterogeneous, nonstoried, 1-3 cells wide; uniseriate rays 5-18 cells high, composed of both upright and procumbent cells; multi-seriate rays 2 or 3 (mostly 3) cells broad through the central portion of procumbent cells, with uniseriate extensions above and/or below composed wholly or mainly of upright cells; sometimes with end to end ray fusion; up to 12-20 rays per mm.

Imperforate tracheary elements: Fiber tracheids quadrangular to polygonal in cross-section, 15-35 μ in diameter, the walls fairly thick (FIG. 24), non-septate; pits bordered, with vertical or oblique, linear apertures.

MATERIAL. A single specimen of silicified mature secondary xylem

measuring $2 \times 2.5 \times 8$ cm. Structural preservation of the fossil wood poor.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55240.

The fossil wood shows a superficial resemblance to the mature, secondary xylem of *Cercidiphyllum*. However, *Cercidiphyllum* differs from the present fossil wood in having 1- or 2-seriate heterogeneous rays with very frequent end-to-end ray fusion and in having numerous (20–50) bars in the perforation plates.

A survey of all available woods of the *Liquidambar* indicates that the nearest affinity of the fossil is with *Liquidambar styraciflua* L. Our survey included the study of thin-sections of the woods of *L. styraciflua* L., and *L. formosana* Hance.

The size and distribution of the vessels of the fossil wood under consideration agree with the distribution pattern in *Liquidambar styraciflua*. The tangential diameter of the vessels (30–81 μ) in the fossil wood is more or less similar to the measurements secured from comparable secondary xylem of *L. styraciflua*. In both, the perforation plates are scalariform, and the intervacular pit-pairs are in transverse rows of 1–3, orbicular to oval or linear through fusion. The distribution of parenchyma appears to be almost identical in both as is the fiber and ray structure. However, a minor difference between the two is in higher and sometimes 4-seriate rays in *L. styraciflua*.

Only three fossil woods showing resemblance to *Liquidambar* are known. These are *Liquidambaroxylon speciosum* Felix (1884), from the Tertiary of Hungary, *L. lecointreae* Houlbert (1910), from the Middle Miocene of Touraine (Edwards, 1931), and *Liquidambar formosana* Hance (Watari, 1952), from the Pliocene of Yokohama City and the Miocene of Honsyu [Honshu], Japan. These species differ from the present fossil. The fossil wood of *Liquidambar formosana* differs in having mostly scalariform intervessel pits, rays 1–4 (mostly 2–3) cells broad with 2 or 3 rays fused frequently, and in possessing a large number of bars (7–39) in the perforation plates.

Liquidambar is represented by about four extant species, three in eastern Asia and one, *Liquidambar styraciflua* L., in America, where it is commonly known as red or sweet gum. This important timber tree is widely distributed throughout the southeastern part of the United States, its northern and western boundaries being from Connecticut, westward through the Ohio Valley to Kansas, and southward through Oklahoma into Texas. It reappears on the mountains of eastern Mexico and the highlands of southern British Honduras and eastern Guatemala and Honduras. It is most abundant and of largest size in wet, rich soil bordering streams or swamps (Record and Hess, 1943; Britton, 1908; Munns, 1938, *map 131*).

JUGLANDACEAE

7. *Carya tertiara* Prakash & Barghoorn, sp. nov. (FIGS. 14–19)

Growth rings: Distinct, delineated by narrow bands 2 or 3 cells thick,

of flattened, thick-walled fibers; wood semi-ring-porous to diffuse porous. Transition between early and late wood gradual (FIGS. 15, 19).

Vessels: Usually large vessels (FIG. 15) in the early wood, 150–320 μ in tangential diameter (mean 214 μ), solitary (FIGS. 15, 19) and in radial rows of 2–4 or rarely 5 or 6 cells, thin- to slightly thick-walled, the solitary vessels round to oval in cross-section (FIG. 19). Vessel elements 255–485 μ in length with the end walls usually inclined, sometimes truncate, rarely tailed. Perforation plates exclusively simple. Intervascular pit-pairs (FIG. 18) bordered, alternate, orbicular to oval or angular when crowded, 7–12 μ in diameter with linear or lenticular apertures. Thin-walled tyloses abundant (FIGS. 15, 17). Late-wood vessels small to medium-sized, 60–150 μ in tangential diameter (mean 112.5 μ); solitary (FIG. 19) and in radial multiples of 2 or 3 or rarely more; walls thin to conspicuously thickened. Intervascular pit-pairs and perforation plates similar to early wood vessels.

Parenchyma: Paratracheal, metatracheal, metatracheal-diffuse, and terminal. Paratracheal parenchyma varying from isolated cells to uniseriate sheaths partially encircling the vessels. Metatracheal parenchyma (FIGS. 15, 19) in tangential, slightly undulating, usually continuous, sometimes broken, narrow lines 1–3 (usually 1 or 2) cells thick which are arranged irrespective of pores. Diffuse parenchyma scattered among the fibers as groups of two or isolated cells. Terminal parenchyma uniseriate, associated with the flattened fibers at the growth rings. Parenchyma cells thin-walled, oval or tangentially elongate in cross-section, often quite large and crystaliferous (FIGS. 14, 15), 15–40 μ in diameter.

Xylem rays: Homogeneous to slightly heterogeneous (FIG. 16), mostly composed of procumbent cells; 1–4 cells wide; uniseriate rays frequent, 2–21 (usually 6–10) cells high; multiseriate rays often fusiform, mostly 3, rarely 4, cells broad and 0.87 mm high with uniseriate wings (up to 11 cells) at one or both ends; broad rays composed either entirely of procumbent cells or rarely with a marginal row of upright cells at one of the ends; up to 9–12 rays per mm. Ray cells 15–30 μ in diameter, round to oblong in tangential section, sometimes angular where crowded.

Imperforate tracheary elements: Thick-walled fiber tracheids (FIGS. 15, 19), oval to slightly angular in cross-section, 10–25.5 μ in diameter; walls moderately thick with fairly large lumen; non-septate; pits bordered.

MATERIAL. A single specimen of silicified mature secondary xylem measuring approximately 9 × 7 × 3 cm.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55210.

There is close agreement in all structural details with the genus *Carya*, except as noted below. A survey of the available woods of the genus *Carya* indicates that the nearest affinity of the fossil is with *C. leioderms* Sarg. Our survey included the study of thin sections of the woods of 18 species and published descriptions of two additional species. The latter are *C. tonkiensis* Lecomte (Heimsch and Wetmore, 1939, pp. 655–7, figs. 21, 22) and *C. texana* var. *arkansana* (Sarg.) Little (Stark, 1953, p. 31).

The fossil wood of *Carya tertiara* resembles the modern wood of *C. leiodermis* in the distribution pattern of the vessels, in the type of perforation plates, in the nature of the intervacular pit-pairs, in parenchyma distribution, and in the nature of the xylem rays. However, *C. leiodermis* differs from the fossil wood under consideration in having slightly narrower (1–3 cells) and higher (1042μ) xylem rays, in possessing fewer tyloses in the vessels, and in having much less crystalliferous parenchyma which is not swollen like that of the fossil wood. On the other hand, swollen crystalliferous parenchyma is seen in the modern woods of *C. pallida* Engl. & Graebn., *C. cordiformis* K. Koch, *C. aquatica* Nutt., *C. tonkiensis* Lecomte, *C. tomentosa* Nutt., *C. illinoensis* (Wang.) K. Koch, *C. glabra* Sweet, and *C. floridana* Sarg. Since the present fossil wood differs slightly from the modern wood of *Carya leiodermis*, it is assigned to a new species, *C. tertiara* Prakash & Barghoorn.

Only two fossil woods of *Carya* are known. These are *Carya* sp. (Beck, 1942a), from the Upper Miocene of Washington, and *C. protojaponica* (Watari, 1952), from the Miocene of Honsyu [Honshu], Japan. Both these species differ quite distinctly from the present fossil wood. Thus *C. protojaponica* differs from *C. tertiara* in having mostly uniseriate, partly biseriate bands of metatracheal parenchyma and in having homogeneous to decidedly heterogeneous xylem rays 1 or 2, rarely 3 or 4, cells broad. However, in *C. tertiara* the metatracheal parenchyma bands are 1–3-seriate and the xylem rays are 1–4 (mostly 1 and 3) cells broad, homogeneous to weakly heterogeneous.

Similarly, the *Carya* species known from Vantage looks different (Beck, 1942a, pls. 1731e,b,c,k) from *C. tertiara*. Unfortunately, a detailed comparison between the two is impossible since Beck's material was not illustrated.

Carya includes about 22 species: one is native to China (*C. cathayensis* Sarg.), a second to Indochina (*C. tonkinensis* Lecomte), a third is restricted to the highlands of Mexico (*C. mexicana* Engelm.), and the remaining nineteen are widely distributed in eastern North America. There are also a number of varieties and hybrids (Stark, 1953). *Carya leiodermis* Sarg. grows in northern Florida, western Alabama, Mississippi, southern Arkansas, Louisiana, and eastern Texas (Little, 1953, p. 87). For a detailed distribution of other species, see Munns (1938), Record and Hess (1943), Fernald (1950), and Little (1953).

LEGUMINOSAE

8. *Albizzia vantagiensis* Prakash & Barghoorn, sp. nov. (Figs. 51–54)

Growth rings: Distinct; wood diffuse-porous (FIG. 52).

Vessels: Large to medium-sized, sometimes small, 76 – 245μ in tangential diameter (mean diameter 152μ), encircled by a conspicuous halo of parenchyma (FIG. 52), chiefly solitary, sometimes paired, rarely in rows of 3–4 or even 6 cells, thin-walled, the solitary vessels circular to oval in

cross-section. Vessel elements 178–484 μ long, with truncate or slightly tailed ends. Perforation plates exclusively simple. Intervascular pit-pairs (FIG. 51) alternate, sometimes slightly opposite, oval to orbicular, and vested. Tyloses absent, vessels sometimes plugged with gummy deposits.

Parenchyma: Abundant, paratracheal, paratracheal-zonate, terminal, and metatracheal-diffuse. Paratracheal parenchyma (FIG. 54) forms a narrow or wide halo (up to 5 cells thick) about the vessels or vessel groups, frequently extending laterally beyond proximate rays and usually ending blindly or sometimes uniting with those of other vessels forming paratracheal-zonate parenchyma. Terminal parenchyma sparse, forming a 1- or 2 (mostly 1)-seriate line at the growth ring. Diffuse parenchyma scanty, cells scattered among the fibers. Parenchyma cells 15–30 μ in diameter, occasionally crystalliferous.

Xylem rays: Homogeneous (Kribs Homogeneous Type 2), composed chiefly of procumbent cells (FIG. 53), nonstoried, 1–4 cells wide; uniseriate and biseriate rays rare, the uniseriate rays 5–14 cells high; multiseriate rays mostly 3 cells broad and 0.97 mm. high; up to 6–10 rays per mm. Ray cells thin-walled, circular to oval in tangential section, 10–20 μ in diameter.

Imperforate tracheary elements: Libriform to semilibriform fibers polygonal in cross-section, 10–20 μ in diameter, walls fairly thick (FIG. 54), with a small to fairly large lumen, nonseptate; pits simple.

MATERIAL. Two specimens of silicified secondary xylem. The type specimen measured 5 \times 4 \times 5 cm.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55237.

The fossil wood most closely resembles the structural features of the leguminous genus *Albizzia*, although it shows a superficial resemblance to the mature secondary xylem of *Artocarpus* (*A. indica*, *A. chaplasha*), particularly as seen in transverse section. The rays in *Artocarpus*, however, are broad and heterogeneous, whereas the fossil possesses homogeneous, narrow rays. A survey of all available woods of the genus *Albizzia* indicates that the nearest affinity of the fossil is with *A. stipulata* Boivin. Our survey included the study of thin-sections of the woods of 14 species of the genus and published descriptions of 8 other species. The latter are *A. montana* Benth., *A. tomentella* Miq. (Moll & Janssonius, 1914, pp. 193–195), *A. lucida* Benth. (Pearson and Brown, 1932, pp. 465–467, fig. 158), *A. acle* (Blanco) Merr. (Kanehira, 1924, p. 25; Kribs, 1959, pp. 63, 64, fig. 163), *A. gummiifera* C. A. Sm., *A. ferruginea* Benth. (Kribs, 1959, pp. 64, 65, figs. 397–398), *A. chinensis* (Osb.) Merr. (Reyes, 1938, pp. 117, 118, pl. 16, fig. 1) and *A. retusa* Benth. (Schneider, 1916, pp. 116–118, pl. 2, fig. 15).

The fossil wood of *Albizzia vantagiensis* resembles the modern wood of *A. stipulata* in the size and distribution pattern of the vessels, in the perforation plates and intervacular pit-pairs, in parenchyma distribution, and the fiber and ray structure. However, *A. stipulata* differs from the fossil in

having partly septate fibers and slightly wider and very low xylem rays. The rays are 1–5 (mostly 2 or 3) cells broad and 0.23 mm. high in *A. stipulata*, whereas they are 1–4 (mostly 3) cells broad and 0.97 mm. high in *A. vantagiensis*.

Albizzia is a rather large genus of small to large trees widely distributed in tropical Asia, Africa, and America. Of the species the best known is probably *A. lebbek* Benth., native to Asia but planted for shade and ornament throughout tropical regions. *Albizzia julibrissin* Boiv., another Asiatic tree, is widely planted for shade and ornament in the southern United States and has become naturalized in woods and thickets from Virginia to Florida and Louisiana (Britton, 1908, p. 519). Its hardy forma *rosea* (Carr.) Rehd. makes favorable growth under climatic conditions as far north as Boston, Massachusetts.

A large number of fossil woods belonging to the family Leguminosae are known. However, woods related to *Albizzia* are limited to two references in the literature. These are *Leguminoxylon albizziae* Krausel (1939), from the Tertiary of Egypt, and *Albizzioxylon sahnii* Ramunjam (1960), from the Cuddalore series (Mio-Pliocene) of the South Arcot district in South India. *Albizzioxylon sahnii* differs from *Albizzia vantagiensis* in its slightly thickened aliform sheaths of parenchyma around the vessels, its septate fibers, and its short xylem rays (5–15 cells high) locally showing a storied tendency. However, in *A. vantagiensis* the fibers are nonseptate and the rays are quite high (5–55 cells) without any storied arrangement.

9. *Gleditsia columbiana* Prakash & Barghoorn, sp. nov.

(Figs. 29, 31–34)

Growth rings: Distinct; wood ring-porous. Transition between the early and late wood quite marked (Figs. 29, 34).

Vessels: Large vessels in the early wood, 100–214 μ in tangential diameter (mean diameter 138 μ), chiefly solitary (Fig. 34), occasionally paired, forming a band 4–6 vessels in width, thin-walled, the solitary vessels oval to elliptic in cross-section. Vessel elements 130–265 μ long. Perforation plates exclusively simple, usually horizontal, sometimes slightly oblique. Intervascular pit-pairs (Fig. 31) vestured, alternate, orbicular to oval or angular (where crowded), 7–10 μ in diameter, apertures linear, often coalescent. Vessels frequently plugged with gum deposits. Late-wood vessels small (Figs. 29, 34), barely visible with a hand lens, 15–25 μ in tangential diameter (mean 21 μ), usually in short radial rows or in small groups embedded in short tangential bands of parenchyma; vessels variously shaped, polygonal, irregular, or occasionally oval. Vessel elements with spiral thickenings (Fig. 32). Perforation plates and intervascular pit-pairs similar to early-wood vessels except slightly smaller.

Parenchyma: Quite abundant (Fig. 34), paratracheal, paratracheal-confluent and terminal. Paratracheal parenchyma (1) composing an appreciable portion of the conjunctive tissue between the vessels and the rays in the early-wood zone, (2) forming fairly extensive tracts about vessels

farther out in the ring, and (3) in the late summer-wood extending from the flanks of the vessels and frequently uniting with parenchyma from proximate vessels and forming short, slightly irregular, 4–10-seriate tangential bands of paratracheal-confluent parenchyma in which the vessels or vessel groups are included (FIG. 29). Terminal parenchyma forming a distinct line passing over into the paratracheal parenchyma of the next ring.

Xylem rays: Homogeneous (Kribs Homogeneous Type II) composed of procumbent cells (FIG. 33), 1–5 cells wide; uniseriate and biseriate rays few, the uniseriate rays usually 6–8 cells high; multiseriate rays fusiform, mostly 3–4 cells broad and 0.86 mm. high; up to 6–8 rays per mm. Ray cells slightly thick-walled, orbicular to oval or sometimes angular in tangential section, 8.5–15 μ in diameter.

Imperforate tracheary elements: Libriform fibers oval to angular in cross-section, 10–20 μ in diameter, the walls moderately thick, with a fairly large lumen, nonseptate; pits simple.

MATERIAL. A single specimen of silicified mature secondary xylem measuring 7 \times 5 \times 8 cm.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55204.

The fossil wood may be assigned to the genus *Gleditsia*, although it also shows resemblance to the mature secondary xylem of *Gymnocladus*. It is rather difficult to distinguish *Gleditsia* from *Gymnocladus* anatomically, but it is proposed to assign the present fossil to *Gleditsia*. However, the possibility remains that it may be the wood of a *Gymnocladus*. Unfortunately, the range of structural variation in the secondary xylem of the fossil is not possible to determine.

Gymnocladus comprises two species, *G. dioicus* (L.) Koch, confined to east-central North America, and *G. chinensis* Baill., known from central China. *Gymnocladus dioicus* differs from the present fossil in having fairly abundant parenchyma forming 1–several (mostly 1)-seriate, occasionally interrupted sheaths about the vessels or vessel groups in the early wood, whereas in the fossil the parenchyma consists of an appreciable portion (usually most) of the conjunctive tissue between the vessels and the rays. Similarly, *G. chinensis* differs from the fossil species in the size and distribution pattern of the vessels in the late-wood zone; in *G. chinensis* they are quite large and usually solitary.

A survey of all available woods of the genus *Gleditsia* indicates that the nearest affinity of the fossil is with *G. triacanthos* L. Our survey included the study of thin-sections of the woods of six species of the genus and published descriptions of two other species. The latter are *G. japonica* Miq. (Kanehira, 1921a, p. 23, pl. 3, fig. 15) and *G. formosana* Hay. (Kanehira, 1921b, pp. 93, 94, pl. 19, fig. 114).

The size and distribution pattern of the vessels in *Gleditsia columbiana* and *G. triacanthos* (Aw 17464) are almost identical, there being (3)4–6 rows of large vessels (tangential diameter 100–225 μ in *G. columbiana*, 125–255 μ in *G. triacanthos*) in the early wood and small groups or radial rows

of small vessels ($15\text{--}25\mu$ in *G. columbiana*, $15\text{--}35\mu$ in *G. triacanthos*) embedded in tangential bands of parenchyma in the late wood. In addition, both in *G. triacanthos* and *G. columbiana*, the perforation plates are exclusively simple and the intervacular pit-pairs are alternate, vested, and orbicular to oval with linear apertures which are often coalescent.

The distribution of parenchyma appears to be almost identical in both, as is the structure of the fibers.

The xylem rays of the fossil wood and of *Gleditsia triacanthos* are basically similar, although there are some differences in the height and breadth of the rays. In both they are homogeneous, composed of procumbent cells of similar size and shape. However, the rays are 1–5 (mostly 3 or 4) cells broad and up to 0.86 mm. high in *G. columbiana*, whereas in *G. triacanthos* they are 1–14 (mostly 6–9) cells broad and the tallest are more than 1.2 mm. high (Brown, Panshin & Forsaith, 1949, *fig. 274*, pp. 576–77). However, in specimen Aw 9454 (Arnold Arboretum wood collections) of *G. triacanthos* examined by us, the rays are only 1–5 (mostly 4 or 5) cells broad but are slightly higher than the present fossil wood.

Only one occurrence of fossil wood of *Gleditsia* (cf. *G. japonica* Miq.), from the Miocene of Japan, is known (Watari, 1952). It differs from the present fossil wood in possessing rays 1–12 cells broad flanked by incomplete sheath cells and in the presence of chambered parenchyma containing solitary crystals.

Gleditsia consists of about eleven species of trees, chiefly Asiatic, usually with the stem and branches heavily armed. It is represented in the Western Hemisphere by only three species, two in eastern North America, the third in southern South America (Record and Hess, 1943). *Gleditsia triacanthos* L. is a large forest tree of scattered occurrence throughout most of the eastern half of the United States, achieving optimum development along small streams in southern Indiana and Illinois (Munns, 1938, *map 142*). *Gleditsia aquatica* Marsh. is a smaller tree of river-swamps, from Florida to Texas, northward to North Carolina, southern Indiana and Illinois, and southeastern Missouri. The single species of the Southern Hemisphere, *G. amorphoides* (Griseb.) Taub., grows in northern Argentina, Bolivia, and southern Brazil.

PLATANACEAE

10. *Platanus americana* Prakash & Barghoorn, sp. nov. (FIGS. 8–13)

Growth rings: Distinct (FIG. 10), marked by a few rows of tangentially flattened fibers.

Vessels: Small (FIG. 10), $30\text{--}77\mu$ in tangential diameter (mean diameter 54μ), somewhat smaller in the late summer wood. Vessels solitary and in irregular groups of 2–5 cells, numerous and crowded, and more or less evenly distributed through most of the annual ring (FIG. 10), about 140 per sq. mm. in the early wood, somewhat less abundant and widely spaced in the late summer wood; vessels variously shaped in cross-section (FIG.

10), oval, elliptical, nearly round with sides in contact much flattened, and angular where crowded, those first formed usually compressed tangentially. Vessel elements $305-765\mu$ in length usually with oblique often tailed ends. Perforation plates both simple and scalariform (FIGS 12, 13); simple perforation large, oval to elliptic in shape and more numerous than the scalariform; scalariform perforations uncommon, bars 2-11 in number, fine, widely spaced and occasionally bifurcate (FIG. 12). Intervascular pit-pairs bordered (FIG. 8), opposite to subopposite on the vessel wall, often loosely arranged, oval to orbicular or elongated in shape, $9-12\mu$ in diameter, with slit-like apertures. Tyloses absent. Vessel distribution graded porous (FIG. 10).

Parenchyma: Scanty, paratracheal and metatracheal-diffuse; paratracheal parenchyma restricted to occasional cells never forming a sheath around the vessels; diffuse parenchyma sporadically distributed as isolated cells among the fibers; parenchyma cells oval to elliptic in cross-section.

Xylem rays: Homogeneous (Kribs Homogeneous Type 2), composed of procumbent cells (FIG. 11), 2-15 cells wide; multiseriate rays fusiform (FIG. 11), mostly 6-15 cells broad and 3.84 mm. in height with pointed or blunt ends, often arranged closely and vertically upon each other so as to appear as parts of the same ray dissected into smaller units; up to 3-4 rays per mm. Ray cells thin-walled, oval to oblong (sometimes polygonal) in tangential section.

Imperforate tracheary elements: Thick-walled fiber tracheids with a small lumen, polygonal in cross-section (FIG. 9), $15-25\mu$ in diameter; nonseptate, about 1020μ in length; pits bordered with vertical slit-like aperture.

MATERIAL. A single specimen of silicified mature secondary xylem broken into a number of fragments.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55218.

This fossil wood shows a superficial resemblance to the mature secondary xylem of *Euptelea* and *Fagus*, particularly as seen in transverse section. However, the broad rays of *Euptelea* are conspicuously heterogeneous, whereas the fossil possesses homogeneous multiseriate rays. Similarly, *Fagus* differs from the present fossil wood in having oak-type rays, i.e., large, broad rays accompanied with numerous, small, uniseriate rays.

A survey of all available woods of the genus *Platanus* indicates that the nearest affinity of the fossil within this genus is with *P. wrightii* S. Wats. Our survey included the study of thin sections of the woods of *P. wrightii*, *P. occidentalis* L. and *P. racemosa* Nutt., and published descriptions of three others. The latter are *P. orientalis* L. (Metcalfe and Chalk, 1950, p. 1281, figs. 300a,b; Greguss, 1947, pp. 74, 75, fig. 68), *P. acerifolia* Willd. (Henderson, 1953, p. 6, fig. 308) and *Platanus* sp. (Dadswell and Record, 1936, p. 23, pl. 2, fig. 3). The secondary xylem of *P. wrightii* is characterized by small, solitary or irregular groups of 2-5 vessels. There is a conspicuous difference in diameter between the vessels of the early wood and those of the late wood (Brush, 1917, pp. 493, 494, pl. 33). The

size and distribution of the vessels in *P. americana* agree with the distribution pattern in the modern *P. wrightii*. Mean tangential diameter of vessels in *P. americana* (54μ) is quite comparable to the measurements secured from comparable secondary xylem of *P. wrightii* (61μ). In both *P. wrightii* and the fossil species the intervacular pit-pairs are bordered, oval to elongate, usually opposite, sometimes alternate, and often loosely arranged in vertical rows. Similarly, simple as well as scalariform perforations are present in both *P. wrightii* and the fossil species. However, in *P. wrightii* the scalariform perforations are more numerous than the simple type and are characterized by 1–20 (most frequently 6–15) closely spaced, fine bars which are sometimes bifurcate. Contrary to this, in *P. americana* simple perforations are more numerous than the scalariform type which are characterized by 2–11 widely spaced bars. It is evident that in this respect the fossil species is more highly specialized than the living species *P. wrightii*. However, in *P. occidentalis*, the perforation plates are simple, for the most part, or occasionally scalariform with a few bars (Brown, Panshin & Forsaith, 1949, p. 570), a condition quite comparable to the fossil wood under consideration.

Very little wood parenchyma is present in the fossil *Platanus* and sometimes it becomes quite difficult, in cross-section, to distinguish parenchyma from the tracheary elements because of the absence of the secondary walls of the latter, which thus resemble parenchyma cells. However, in longitudinal sections it is possible to distinguish between them. The distribution of parenchyma appears to be similar in both, as is the fiber structure; but a conspicuous difference is in the quantity of diffuse parenchyma which is quite abundant in *Platanus wrightii* but much less so in the fossil wood. In *P. wrightii*, parenchyma occurs both as isolated cells and as uniseriate lines of 2–4 or rarely more cells, whereas in *P. americana* it occurs only as diffuse solitary cells.

The xylem rays of the fossil wood and of *Platanus wrightii* are basically similar, although there are slight differences in frequency of broad, multi-seriate rays. In both they are very high, usually broad, and homogeneous, composed of round to oval procumbent cells. However, the rays are 2–15 (mostly 6–15) cells broad in *P. americana*, whereas in *P. wrightii* they are 1–14 (rarely uniseriate, mostly 10–14) cells broad.

A number of fossil woods belonging to the family Platanaceae are known from various localities in the world. The woods have been included under the names *Plataninium* Unger (emend. Vater, 1884), *Platanoxylon*, and *Platanus* (Windisch, 1886; Kaiser, 1890; Felix, 1894; Platen, 1908; Schonfeld, 1930; Slijper, 1932; Stockmans, 1936; Hofmann, 1952; Andreánszky, 1951; Beyer, 1954). Those known from this country are *Plataninium crystallophilum* Platen (1908), from the Tertiary of Arizona, *P. pacifica* Platen (1908), from the Miocene of California (Nevada County), *P. knowltonii* Platen (1908), and *Platanus haydenii* (Felix) Beyer (1954), the last two from the Miocene of Amethyst Mountain in the Yellowstone National Park. The general agreement between these and the Vantage fossil wood is close.

The only two fossil woods described under *Platanus* are *Platanus* sp. (Slijper, 1932) and *Platanus haydenii* (Beyer, 1954). Slijper's *Platanus*, from the Pliocene of Reuver, Limburg, Holland, differs from *P. americana* in having spiral thickenings in the vessels and xylem rays 8–10 cells wide (Slijper, 1932, pp. 27, 28, fig. 3). Spiral thickenings are not found in the vessels of *P. americana* and the rays are 2–15 (mostly 6–15) cells broad. Similarly, *P. haydenii* (Felix) Beyer, (1954) also differs from *P. americana* in having exclusively simple perforation plates and narrower (3–10-seriate) rays. However, in *P. americana* both simple and scalariform perforation plates are present and the rays are mostly 6–15 cells broad.

Platanus, the only genus of the Platanaceae, includes about eleven species of large trees, three in southern Europe and Asia, eight in temperate North America (Record and Hess, 1943). The largest and the best known species in the United States is *P. occidentalis* L., which is common along streams and lakes and throughout most of the eastern half of North America, growing at optimum in the lower Ohio and Mississippi Valleys (Record and Hess, 1943; Britton, 1908). *Platanus wrightii* S. Wats. and *P. racemosa* Nutt. occur in the southwestern United States and northern Mexico (Record and Hess, 1943; Munns, 1938, map 132). Five other species are found only in Mexico.

ULMACEAE

11. *Ulmus miocenica* Prakash & Barghoorn, sp. nov. (Figs. 1–7)

Growth rings: Very distinct; wood ring-porous. Transition between early and late wood quite marked (Figs. 1, 4).

Vessels: Large vessels in the early wood, 81–179 μ in tangential diameter (mean 118 μ), chiefly solitary, usually arranged in one, sometimes in two rows (FIG. 1), occasionally associated with or interspersed by clusters or radial rows of small vessels (FIG. 4), thick-walled, the solitary vessels circular to oval in cross-section. Vessel elements 153–367 μ long. Perforation plates exclusively simple, usually horizontal, sometimes slightly oblique. Intervascular pit-pairs (FIG. 5) bordered, alternate to subopposite on the vessel wall, orbicular or angular where crowded, 8–10 μ in diameter with circular or elongate aperture, occasionally confluent. Late-wood vessels small (Figs. 1, 4), 30–70 μ in tangential diameter (mean 51 μ), grouped in more or less continuous wing-like or festoon-like tangential or oblique bands, usually polygonal due to clustering, occasionally round to oval in form. Vessel elements 112–163 μ in length, with spiral thickenings (FIG. 6). Perforation plates and intervascular pit-pairs similar to early wood vessels except slightly smaller. Thin-walled tyloses quite common.

Parenchyma: Paratracheal and metatracheal-diffuse. Paratracheal parenchyma (FIG. 4) quite abundant, contiguous to (but never forming a continuous sheath around) the large vessels of the early wood, marginal to and included in the clusters of smaller early-wood vessels and vascular tracheids (FIG. 4), and marginal to and included in the clusters of wavy bands of late-wood vessels and vascular tracheids. Diffuse parenchyma

sparse, scattered among the fibers, often in contact with the rays. Chambered parenchyma quite abundant (FIG. 7) usually consisting of eight or more elements per strand bearing crystals in a vertical series. Crystalliferous parenchyma usually associated with the xylem rays. (FIG. 3, 7).

Xylem rays: Homogeneous (Kribs Homogeneous Type 1) composed of procumbent cells (FIGS. 3, 7), 1–4 cells wide; uniseriate rays rather scanty, 2–10(14) cells high; multiseriate rays fusiform, mostly 3 or 4 cells broad and 0.76 mm. high; up to 6–10 rays per mm. Ray cells (FIG. 7) slightly thick-walled, circular to oval in tangential section and 10–15 μ in diameter.

Imperforate tracheary elements: Libriform fibers and vascular tracheids. Libriform fibers circular to polygonal with rounded corners (FIG. 4) in cross-section, 10–15 μ in diameter, the walls fairly thick, with a small lumen, nonseptate; interfiber pits simple. Vascular tracheids present both in the early-wood porous zone and in the wavy bands of late-wood vessels.

MATERIAL. A single specimen of silicified mature secondary xylem measuring 6 \times 4 \times 4 cm.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55213.

Structural features of the fossil wood indicate, after extensive comparison, that its closest affinities are with the modern genus *Ulmus*. There is close agreement in all structural details except as noted below. A survey of all available woods of the genus *Ulmus* indicates that the nearest affinity of the fossil is with *U. americana* L. Our survey included the study of thin sections of the woods of 14 species of the genus supplemented by published descriptions of five other species. The latter are *U. sieboldii* Daveau (Kanehira, 1921a, p. 55, *pl.* 6, *figs.* 34, 35), *U. uyematsui* Hay. and *U. parvifolia* Jacq. (?) (Kanehira, 1921b, p. 211, *pl.* 40, *fig.* 237), *U. Wallichiana* Planch., and *U. lancifolia* Roxb. (Pearson and Brown, 1932, pp. 897–902, *figs.* 279, 280).

The size and distribution pattern of the vessels in the early wood of *Ulmus miocenica* and *U. americana* are almost identical, there being one or two rows of large vessels. However, the pattern of vessel arrangement in the late wood differs slightly in the fossil species. In *U. americana* there are usually almost parallel patches of small vessels separated from each other, whereas these patches are larger, closer, and slightly oblique in the fossil wood. Both in *U. americana* and in the fossil species the perforations are simple and the intervacular pit-pairs are bordered, usually alternate, orbicular or angular through crowding, and with circular to extended apertures.

The distribution of parenchyma appears to be almost identical in both, as is the fiber structure. However, a conspicuous difference between the two species is in the quantity of crystalliferous parenchyma which is quite frequent in the fossil wood but much less so in *Ulmus americana*.

The xylem rays of the fossil wood and of *Ulmus americana* are basically similar although there are slight differences in the height and breadth of the rays. In both they are closely spaced and homogeneous, composed of

procumbent cells of similar size and shape. However, the rays are 1–4 cells broad and up to 40 cells high in *U. miocenica*, whereas in *U. americana* they are up to 7 (mostly 4–6) cells broad and lower (up to 28 cells high: Brown, Panshin & Forsaith, 1949).

Determination of the degree of affinity to modern species of the genus leads to only a few observable differences between the Upper Miocene wood and that of the modern *Ulmus americana*. These differences are mainly limited to the distribution pattern of the late-wood vessels and the height and breadth of the xylem rays.

Sixteen species of fossil woods assigned to the family Ulmaceae have been reported hitherto. These have been described under the names *Ulminium* Unger (1842), *Ulmoxylon* Kaiser (1879), *Ulmus* L., *Zelkova* Spach, *Celtis* L., and *Celtoxylon*. Of these sixteen, five are recorded as species of extant genera, two each of *Zelkova* and *Ulmus*, viz., *Z. wakimizui* (Watari) Watari (1952), *Z. zelkoviformis* (Watari) Watari (1952), *Ulmus* sp. (Fietz, 1926a,b), *U. crystallophora* Watari (1952), and one of *Celtis* (Shimakura, 1936). The remaining eleven are designated as species of *Ulminium*, *Ulmoxylon*, and *Celtoxylon* (Pampaloni, 1904; Penhallow, 1907; Platen, 1908; Nagelhard, 1922; Greguss, 1943; Hofmann, 1944; Boureau, 1957).

Our fossil wood under consideration differs from all the species of *Ulminium* and *Ulmoxylon* and from both the fossil species of *Ulmus* recorded. Thus *Ulmus crystallophora* Watari, from the Miocene of Honsyu [Honshu], Japan, differs from *U. miocenica* in having 2–4-seriate large vessels in the early wood and in possessing rays 1–6 cells wide and up to 1020 μ in height. However, in *U. miocenica* the large early-wood vessels are mostly in one row and the xylem rays are only 1–4 cells wide and up to 620 μ in height.

It is interesting to note that a fossil wood, *Ulmoxylon simrothii*, showing resemblance to modern elms is also known from the Pliocene of California (Platen, 1908, pp. 26, 27, *pl. 1, figs. 5, 6*). This fossil wood differs from *Ulmus miocenica* in a number of features, especially in having small, radially elongated vessels (97.5 μ in tangential diameter) mostly isolated in the early wood and forming a ring-like zone and in having numerous xylem rays five or six cells broad which are often weakly heterogeneous.

Ulmus, with about twenty species of small to very large trees, is widely distributed throughout the North Temperate Zone, except in the western half of North America. Of the six species native to the United States, three are of commercial importance. *Ulmus rubra* Mühl. (*U. fulva* Michx.) is of scattered occurrence over the entire eastern half of the country and southeastern Canada. *Ulmus thomasi* Sarg. occurs in western Vermont to extreme southern Quebec, New York, Ohio, Indiana, Kentucky, Illinois, Iowa, Missouri, and parts of adjoining states, being at its best in the Ohio Valley. *Ulmus alata* Michx. grows in the south-central states. *Ulmus americana* L. has a natural range including the eastern half of the United States, extending from the Great Plains to the Atlantic and from Canada to the Gulf of Mexico (Munns, 1938, *map 120*; Record and Hess, 1943).

Ulmus serotina Sarg. is known to inhabit banks and bluffs from southern Illinois and southern Kentucky to Arkansas, Georgia, and Alabama, and is thus one of the most restricted in geographic distribution. *Ulmus crassifolia* Nutt. prefers moist soil and is most abundant in river valleys from southwestern Tennessee, Arkansas to Mississippi, Louisiana, southern Oklahoma, Texas, and northern Mexico (Britton, 1908). The only species in tropical America is Mexican elm, *U. mexicana* (Liebm.) Planch. growing in lower mountain regions from Veracruz and Oaxaca, Mexico, southward to Panama and northwestern Colombia (Record, 1924).

12. *Ulmus pacifica* Prakash & Barghoorn, sp. nov. (FIGS. 35–38)

Growth rings: Distinct (FIG. 37); wood semi-ring porous. Transition between early and late wood not very marked.

Vessels: Large vessels (FIG. 37) in the early wood, 70–160 μ in tangential diameter (mean 114 μ), chiefly solitary, arranged in one row, very rarely associated with small vessels, thin-walled, the solitary vessels usually circular to oval in cross-section. Perforation plates exclusively simple, horizontal to slightly oblique. Intervascular pit-pairs bordered, alternate to subopposite on the vessel wall (FIG. 36) oval to orbicular, 5–8 μ in diameter and often somewhat loosely arranged, the aperture circular. Late-wood vessels (FIG. 37) slightly smaller, 40–120 μ in tangential diameter (mean 76.5 μ), almost always clustered in irregular groups, often forming radial rows, very rarely in wing- or festoon-like oblique bands, usually round to oval, sometimes variously shaped due to clustering. Vessel elements with spiral thickenings. Perforation plates and intervascular pit-pairs similar to early-wood vessels. Thin-walled tyloses quite common.

Parenchyma: Paratracheal and metatracheal-diffuse. Paratracheal parenchyma not abundant, occurring in association with the large early-wood vessels but never forming a continuous sheath, marginal to and sometimes included in the groups of late-wood vessels and vascular tracheids. Diffuse parenchyma very scanty, occurring as scattered cells among the fibers.

Xylem rays: Homogeneous (Kribs Homogeneous Type 2), composed of procumbent cells (FIG. 38), 1–8 cells wide, uniseriate and biseriate rays rare; uniseriate rays 2–9 cells high; multiseriate rays fusiform (FIG. 38), mostly 5–7 cells broad and 1.07 mm. high; up to 6–10 rays per mm. Ray cells thin-walled, circular to oval, sometimes vertically elongate in tangential section and 7–12 μ in diameter.

Imperforate tracheary elements: Libriform fibers and vascular tracheids. Libriform fibers round to polygonal in cross-section (FIG. 35), 10–15 μ in diameter, thick-walled, with a small lumen, non-septate; pits simple. Vascular tracheids often associated with the groups of late-wood vessels.

MATERIAL. A single specimen of silicified mature secondary xylem measuring 11 × 8 × 4 cm. Structural preservation of the fossil is poor.

HOLOTYPE. Palaeobotanical Collections, Harvard University, No. 55229.

There is close agreement with *Ulmus* in all structural details except as noted below. The fossil wood shows a superficial resemblance to the mature secondary xylem of *Ptelea*. However, the xylem rays of *Ptelea* are heterogeneous and the vessels are devoid of tyloses, whereas the fossil possesses homogeneous rays and the vessels are tylosed.

The fossil wood does not compare in all details with any extant species of *Ulmus*, but it shows some structural resemblance with *Ulmus mexicana* (Liebm.) Planch. Although both in the fossil and *Ulmus mexicana* the vessel distribution is semi-ring-porous and there is little difference in vessel size in the early- and late-wood zones, the frequency of the vessels in the fossil wood is greater than in *U. mexicana* in which the vessel groups or rows are smaller and more widely separated than the fossil under consideration. However, the vessel perforations and intervacular pit-pairs are similar in both.

The distribution and amount of parenchyma is different in the fossil and extant *Ulmus mexicana*. The paratracheal parenchyma is more abundant in *U. mexicana* than in *U. pacifica* and the metatracheal parenchyma often forms broken tangential bands one to three cells wide in *U. mexicana*. Such parenchyma bands are not known in the fossil under consideration. Furthermore, in *U. mexicana* there are usually several layers of parenchyma cells associated with the growth rings, a type of parenchyma not found in *U. pacifica*; and crystalliferous parenchyma is quite common in *U. mexicana* but lacking in the fossil wood.

The xylem rays of the fossil wood and of *Ulmus mexicana* are basically similar, although there are some differences in height and breadth. In both they are closely spaced and homogeneous, composed of procumbent cells. However, the rays are 1-8 cells broad and 1.07 mm. high in *U. pacifica*, whereas in *U. mexicana* they are only 1-6 cells broad and lower, including uniseriate and biseriate rays quite frequently. Uniseriate and biseriate rays are very rare in the present fossil wood.

Lastly, the fiber structure appears to be almost identical in both. The fibers are nonseptate, thick walled, and usually polygonal in cross-section, with simple pits.

The general agreement in, as well as the numerous microscopic details of, anatomical structure provides sufficient evidence to identify the Vantage fossil wood as *Ulmus*. However, there are no extant species of *Ulmus* with which the fossil wood can be compared very closely. Therefore, it is quite possible that the fossil wood belongs to an extinct species somewhat differing from modern *Ulmus* species but exhibiting the general anatomical organization of the genus.

DISCUSSION

The present study of the petrified woods from the Columbia Basalts at Vantage has given valuable information regarding the changes in the forest vegetation of the western United States since Miocene times. In the present paper, the authors describe fossil woods of *Acer*, *Diospyros*,

Quercus, *Liquidambar*, *Carya*, *Albizzia*, *Gleditsia*, *Platanus*, and *Ulmus*. A study of the present-day distribution of these genera reveals important clues to the migration of these forms since the Upper Miocene. At present, the genera *Diospyros*, *Liquidambar*, *Carya*, *Gleditsia*, and *Ulmus* are largely limited to the eastern United States. On the other hand, the genus *Platanus* grows in both the eastern and the southwestern United States, while *Acer* and *Quercus* occur almost throughout. The genus *Acer* attains its greatest development in eastern Asia and the eastern United States and only a few species are now found in the western part of the country. Among the species of *Quercus*, *Q. alba* L., with which the fossil wood of *Q. leuca* Prakash & Barghoorn compares well, grows throughout the entire eastern half of the United States. *Albizzia*, at present, is widely distributed in tropical Asia, Africa, and America. However, *A. julibrissin* Boiv., an Asiatic tree, long planted for ornament and shade in the southern United States, has become naturalized from Virginia to Florida and Louisiana. From this, it is evident that the Vantage forest is composed of the eastern, the western, and the exotic elements, particularly those of Asia. It, therefore, seems quite likely that during the Miocene the present forest vegetation of this country was more widely distributed than at the present time. It appears to have become restricted after the Miocene as a result of climatic and orographic change. The complete extinction of the deciduous forest at Vantage and neighboring areas seems to have been accelerated with the late Tertiary rise of the Cascade Mountains and their concomitant effect on depleting the moisture from the Pacific air masses. The effect of increasing cold resulting from the oncoming Pleistocene and the failure of remigration in post-glacial times also helped to accelerate this process. A further study of this flora, which will throw more light on the past vegetation of the northwest United States, its trend of migration, and a number of other related problems, is in progress.

The authors are indebted to Dr. Edmund L. Lind and Mr. Klucking, of the Central Washington College of Education, Ellensburg, for numerous courtesies. To Mr. John R. Vanderzicht, Director, State Parks and Recreation Commission, Olympia, Washington, our thanks are due for providing facilities for collecting in the field. We wish to acknowledge the assistance of Mrs. A. W. Peeler, of Vantage, and especially that of Mr. Roald Fryxell, for providing facilities to the first author and for guidance in the field. We are indebted to Mr. Frank Hankins, of Collegeville, Pennsylvania, for making numerous contacts to facilitate the field collections.

This investigation was carried out while the first author was a participant in the Visiting Research Scientists Program of the National Academy of Sciences, Washington, D. C., to which he is indebted for financial assistance.

DEPARTMENT OF BIOLOGY
AND
BOTANICAL MUSEUM,
HARVARD UNIVERSITY

LITERATURE CITED

- ANDREÁNZKY, G. 1951. Der versteinerte Baumstämme aus Ungarn. *Ann. Biol. Univ. Hungariae* 1: 15-24.
- BECK, G. F. 1941a-d. Fossil woods of the Far West, 1(1-4). (Mimeographed.) Central Washington College.
- . 1941e. *Ibid.* 1(8). (Mimeographed.)
- . 1942a. Tertiary juglandaceous woods. 1. Hickory (*Carya*). *Geol. News Lett. Portland, Ore.* 8: 103-106.
- . 1942b. Tertiary juglandaceous woods. 2. *Pterocarya*. *Ibid.* 8: 143-145.
- . 1942c. Fossil woods of the Far West, 1(10). (Mimeographed.) Central Washington College.
- . 1942-43. *Ibid.* 2(7-12).
- . 1944a. Two newly discovered genera among the coniferous woods of the western Tertiary. *Northw. Sci.* 18: 9.
- . 1944b. Status of Tertiary woods of the western States representing the Juglandaceae. *Ibid.* 10.
- . 1944c. Ancient maples of the central Washington region. *Ibid.* 18: 87-89.
- . 1945a. Ancient forest trees of the sagebrush area in Central Washington. *Jour. Forestry* 43: 334-338.
- . 1945b. *Nyssa* woods of the Pacific Northwest Mid-Tertiary. *Northw. Sci.* 19: 11-13.
- . 1945c. Tertiary coniferous woods of western North America. *Ibid.* 67-69, 89-102.
- . 1948. Pine and pine-like woods of the West American Tertiary. *Geol. News Lett. Portland, Ore.* 14(9): 78-79.
- . 1955a. Fossil woods of the Far West. Conifers of the Russell Flora. *Northw. Mineral News* 9: 12-15.
- . 1955b. Fossil woods of the Far West. Gum and gum-like hard woods of the Russell Forests. *Ibid.* 10: 10-22.
- . 1955c. Fossil woods of the Far West. Walnut and oak-like woods of the Russell Forests. *Ibid.* 11: 16-19.
- . 1955-56. Fossil woods of the Far West. Maple and maple-like woods of the Russell Forests. *Ibid.* 12: 12-14.
- . 1956. Fossil woods of the Far West. Miscellaneous hardwoods of the Russell Forests. *Ibid.* 14: 19-20.
- BEYER, A. F. 1954. Some petrified woods from the specimen ridge area of Yellowstone National Park. *Am. Midl. Nat.* 51: 553-567.
- BOESHORE, I., AND J. A. JUMP. 1938. A new fossil oak wood from Idaho. *Am. Jour. Bot.* 25: 307-311.
- BOUREAU, E. 1957. *Anatomie Végétale*. Vol. 3. Paris.
- . 1958. Contribution a l'étude Paleoxylogique de l'Indochine (VI). Sur le *Quercoxylon ogurai* n. sp., bois fossile de l'Ile de Bach Long VI (Golfe du Tonkin). *Bull. Mus. Hist. Nat. Paris* 30: 526-531.
- BRETT, D. W. 1960. Fossil oak wood from the British Eocene. *Palaeontology* 3: 86-92.
- BRITTON, N. L. 1908. *North American Trees*. New York.
- BROWN, H. P., A. J. PANSKIN, & C. C. FORSAITH. 1949. *Textbook of Wood Technology*. Vol. I. New York.
- BRUSH, W. D. 1917. Distinguishing characters of North American sycamore woods. *Bot. Gaz.* 64: 480-496.

- CASPARY, R. 1888. Einige fossile Hölzer Preussens. *Schriften Phys-Oekonom. Ges. Königsberg* 28: 27-45.
- DADSWELL, H. E. AND S. J. RECORD. 1936. Identification of woods with conspicuous rays. *Trop. Woods* 48: 1-30.
- EDWARDS, W. N. 1931. *Fossilium Catalogus II: Plantae Dicotyledones (Ligna)*. Pars 17: 3-96.
- FELIX, J. 1884. Die Holzopale Ungarns in palaeophytologischer Hinsicht. *Mitt. Jahrb. Ungar. Geol. Anstalt* 7: 1-43.
- . 1896. Untersuchungen über fossile Hölzer. 5. *Zeitschr. deutsch. Geol. Ges.* 48: 249-260.
- FERNALD, M. L. 1950. *Gray's Manual of Botany*. ed. 8. New York.
- FIETZ, A. 1926a. Fossile Hölzer aus Schlesien. *Jahrb. Geol. Bundesanst.* 76: 217-244.
- . 1926b. Prähistorische Holzkohlen aus der Umgegend Brünns. *Planta* 2: 414-423.
- FROST, F. H. 1927. The Pleistocene flora of Rancho La Brea. *Univ. Calif. Publ. Bot.* 14: 73-98.
- GREGUSS, P. 1947. The identification of Central-European dicotyledonous trees and shrubs based on xylotomy. Budapest.
- HEIMSCH, C., AND R. H. WETMORE. 1939. The significance of wood anatomy in the taxonomy of the Juglandaceae. *Am. Jour. Bot.* 46: 651-660.
- HENDERSON, F. Y. 1953. An atlas of end-grain photomicrographs for the identification of hardwoods. *Forest. Bull.* 26: 1-87. Forest Prod. Res. Lab., Princes Risborough, London.
- HOFMANN, E. 1929. Verkieselte Hölzer von der Vashegy(Eisenberg)-Gruppe. *Ann. Sebarienses* 3: 81-87.
- . 1944. Pflanzenreste aus dem Phosphoritvorkommen von Prambachkirchen in Oberdonau. *Palaeontographica* 88: 1-86.
- . 1952. Pflanzenreste aus dem Phosphoritvorkommen von Prambachkirchen in Oberösterreich. *Ibid.* 92: 122-183.
- KAISER, P. 1879. Ulmoxyton. Ein Beitrag zur Kenntnis fossiler Laubhölzer. *Zeitschr. Gesamt. Naturwiss.* 3(4): 88-100.
- . 1890. Die fossilen Laubhölzer. *Wiss. Beilage Jahresber. Realprogymn Schonbeck a. E.*
- KANEHIRA, R. 1921a. Identification of the important Japanese woods by anatomical characters. Taihoku, Formosa.
- . 1921b. Anatomical characters and identification of Formosan woods with critical remarks from the climatic point of view. Taihoku, Formosa.
- . 1924. Identification of Philippine woods by anatomical characters. Taihoku, Formosa.
- . 1940. Atlas of Formosan woods. *Bull. For. Exp. Station. Taiwan.*
- KNOWLTON, F. H. 1899. Fossil flora of the Yellowstone National Park. *Monogr. U. S. Geol. Surv.* 32: 651-882.
- KRAUSEL, R. 1939. Ergebnisse der Forschungsreisen Prof. E. Stromers in dem Wüsten Ägyptens. 4. Die fossilen Floren Ägyptens. *Abh. Bayer Akad. Wiss. Math-Naturwiss.* 47: 1-140.
- KRIBS, D. A. 1959. Commercial foreign woods on the American market. Pennsylvania.
- LITTLE, E. L. 1953. Check list of native and naturalized trees of the United States (including Alaska). *U. S. Dep. Agr. Handb.* 41.
- LOUBIÈRE, A. 1939. Anatomie comparée d'un bois de dicotylédone crétacique de Madagascar. *Bull. Mus. Hist. Nat. Paris* 11: 484-486.

- METCALFE, C. R., AND L. CHALK. 1950. Anatomy of the dicotyledons. 2 vols. Oxford.
- MOLL, J. W., AND H. H. JANSSONIUS. 1914. Mikrographie des Holzes der auf Java vorkommenden Baumarten. vol. 3. Leiden.
- MÜLLER-STÖLL, W. R., AND ERIKA MÄDEL. 1957. Über tertiäre Eichenhölzer aus dem pannonischen Becken. *Senckenbergiana Lethaea* 38(3/4): 121-168.
- MUNNS, E. 1938. The distribution of important forest trees of the United States. Misc. Pub. No. 287, United States Dep. Agr. Washington.
- NAGELHARD, K. 1922. Ulmaceae. *Foss. Cat. Plantae, pars* 10, pp. 84.
- OGURA, Y. 1932. On the structure of 'Hobashira-ishi,' a famous silicified trunk at Najima near Fukuoka City. *Jap. Jour. Bot.* 6: 173-181.
- PAMPALONI, L. 1904. Sopra alcuni Legni Silicizzati del Piemonte. *Boll. Soc. Geol. Ital.* 22: 535-548.
- PEARSON, R. S., AND H. P. BROWN. 1932. Commercial timbers of India, 2 vols. Calcutta.
- PENHALLOW, D. P. 1891. Two species of trees from the post-glacial of Illinois. *Proc. Trans. Roy. Soc. Canada* 9(4): 29-32.
- . 1907. A report on fossil plants from the international boundary survey for 1903-1905. *Trans. Roy. Soc. Canada III.* 1(4): 287-334.
- PLATEN, P. 1908. Untersuchungen fossiler Hölzer aus dem Westen der Vereinigten Staaten von Nordamerika. Leipzig.
- RAMANUJAM, C. G. K. 1960. Silicified woods from the Tertiary rocks of South India. *Palaeontographica* 106: 99-140.
- RECORD, S. J. 1924. Timbers of tropical America. New Haven.
- RECORD, S. J., AND R. W. HESS. 1943. Timbers of the New World. New Haven.
- REYES, L. J. 1938. Philippine woods. *Philippine Dep. Agr. Tech. Bull.* 7: 27-449.
- SCHENK, A. 1888. Fossile Hölzer aus Ostasien u. Ägypten. *Bihang Sv. Vet. Akad. Hand.* 14, Afd. 3, No. 2, 24 pp.
- . 1890. Dicotyle Hölzer. *Palaeophytologie* 2(9): 890-904.
- SCHNEIDER, E. E. 1916. Commercial woods of the Philippines: Their preparation and uses. *Philippine Bur. Forestry Bull.* 14.
- SCHÖNFELD, E. 1930. Sächsische Braunkohlenhölzer. Untersucht und bestimmt von G. Schönfeld. *Sitzber. Nat. Ges. Isis. Dresden.* 1929: 68-70.
- SCHÖNFELD, G. 1925. Ueber unsere Braunkohlenwälder und die Entstehung der Braunkohlenflöze. *Ber. Freiberg. Geol. Ges.* 10: 18-24.
- SHIMAKURA, M. 1934. Notes on fossil woods 3. *Jour. Geol. Soc. Tokyo* 41: 13-15.
- . 1936. Studies on fossil woods from Japan and adjacent lands. Contribution 1. *Sci. Rep. Tôhoku Imp. Univer. Sendai. Ser. 2 (Geol.)* 18: 267-310.
- SLIJPER, E. J. 1932. Über Pliozäne Hölzer aus dem ton von Reuver (Limburg, Holland). *Rec. Trav. Bot. Néerl.* 29: 18-35.
- STARK, E. W. 1953. Wood anatomy of Juglandaceae indigenous to the United States. *Agr. Exp. Sta. Purdue Univ. Bull.* 595: 4-42.
- . 1954. Wood anatomy of the Aceraceae indigenous to the United States. *Ibid.* 606: 3-26.
- STOCKMANS, F. 1936. Vegetaux Eocenes des environs de Bruxelles. *Mém. Mus. Hist. Nat. Belg.* 76: 1-56.
- SUDWORTH, G. B. 1927. Check list of the forest trees of the United States: their names and ranges. U. S. Dep. Agr. Misc. Circ. 92.
- and C. D. MELL. 1911. Identification of important American oak woods. U. S. Forest Serv. Bull. 152.

- SZAFER, W. 1914. Anatomische Bestimmung der diluvialen Holzreste von Ludwinow. Bull. Int. Acad. Sci. Cracovie **2B**: 345-350.
- UNGER, F. 1842. Synopsis lignorum fossilum plantarum acramphibryarum. In: Endlicher, Genera plantarum Suppl. 2(append.): 100-102.
- VATER, H. 1884. Die fossilen Hölzer der Phosphoritlager des Herzogthums Braunschweig. Zeitschr. Deutsch. Geol. Ges. **36**: 783-853.
- WATARI, S. 1941. Studies on the fossil woods from the Tertiary of Japan, I: Fossil woods from the River Mabeti, Anatai Village, Ninohe District, Iwate Prefecture. Jap. Jour. Bot. **11**: 385-416.
- . 1952. Dicotyledonous woods from the Miocene along the Japan-Sea side of Honsyu [sic]. Jour. Fac. Sci. Univ. Tokyo. Bot. **6**:(1-3): 97-134.
- WEBBER, I. E. 1933. Woods from Ricardo Pliocene of Last Chance Gulch, California. Carnegie Inst. Publ. **412**: 113-134.
- WINDISCH, P. 1886. Beiträge zur Kenntnis der Tertiärflora von Island. Inaugural Dissertation, Halle.

EXPLANATION OF PLATES

PLATE 1

FIGS. 1-7. Wood of *Ulmus miocenica*: 1, transverse section, $\times 26$ — note the ulmiform bands of late-wood vessels; 2, tangential section, $\times 75$; 3, tangential section showing shape, size, and distribution of xylem rays, $\times 26$ — also note chambered parenchyma associated with rays; 4, transverse sections showing the cellular structure of various tissues, $\times 100$; 5, intervascular pitting, $\times 320$; 6, spiral thickening of late-wood vessels, $\times 130$; 7, tangential section showing a xylem ray and chambered parenchyma, $\times 100$. FIGS. 8-9. Wood of *Platanus americana*: 8, intervascular pitting, $\times 320$; 9, transverse section showing the details of the structure, $\times 75$.

PLATE 2

FIGS. 10-13. Wood of *Platanus americana*: 10, transverse section, $\times 26$ — note vessel distribution and growth rings forming a notch where they meet the rays; 11, tangential section showing shape and size of xylem rays, $\times 26$; 12, scalariform perforation plate, $\times 90$; 13, simple perforation plate, $\times 90$. FIGS. 14-18. Wood of *Carya tertiara*: 14, swollen chambered parenchyma with crystals, $\times 110$; 15, transverse section, $\times 40$ — note the distribution of metatracheal parenchyma cells often with crystals; 16, tangential section showing form and distribution of the rays, $\times 35$; 17, tyloses in the vessels, $\times 90$; 18, intervascular pitting, $\times 90$.

PLATE 3

FIG. 19. Wood of *Carya tertiara*: 19, transverse section, $\times 26$ — note the vessel and parenchyma distribution. FIGS. 20-24. Fossil wood of *Liquidambar styraciflua*: 20, transverse section, $\times 26$ — note vessel distribution; 21, tangential section, $\times 90$; 22, scalariform perforation plate, $\times 150$; 23, intervascular pitting, $\times 250$; 24, transverse section, $\times 150$. FIGS. 25-27. Wood of *Acer puratanum*: 25, transverse section, $\times 90$; 26, spiral thickenings, $\times 90$; 27, transverse section, $\times 26$ — note vessel distribution.

PLATE 4

FIG. 28. Wood of *Acer puratanum*: 28, tangential section showing shape and size of the xylem rays, $\times 90$. FIG. 29. Wood of *Gleditsia columbiana*: 29, transverse section, $\times 65$ — note vessel distribution in the late wood. FIG. 30. Wood of *Acer puratanum*: 30, intervascular pitting, $\times 190$. FIGS. 31–34. Wood of *Gleditsia columbiana*: 31, intervascular pitting, $\times 280$; 32, spiral thickening, $\times 310$; 33, tangential section, $\times 65$ — note ray distribution; 34, transverse section, $\times 26$ — note vessel distribution in early and late wood. FIGS. 35–36. Wood of *Ulmus pacifica*: 35, transverse section, $\times 125$; 36, intervascular pitting, $\times 220$.

PLATE 5

FIGS. 37, 38. Wood of *Ulmus pacifica*: 37, transverse section, $\times 40$ — note vessel distribution; 38, tangential section, $\times 50$ — note xylem rays, tyloses in vessels. FIGS. 39–43. Wood of *Quercus leuca*: 39, transverse section showing parenchyma and fiber cells, $\times 140$ — note slightly enlarged cells of parenchyma often with crystals; 40, tracheid pitting, $\times 310$; 41, transverse section showing late-wood vessels, $\times 65$ — note thin-walled, angular pores; 42, transverse section showing the distribution of metatracheal parenchyma, $\times 65$; 43, transverse section, $\times 26$ — note large vessels in early wood and smaller vessels in late wood arranged in flame-shaped tracts.

PLATE 6

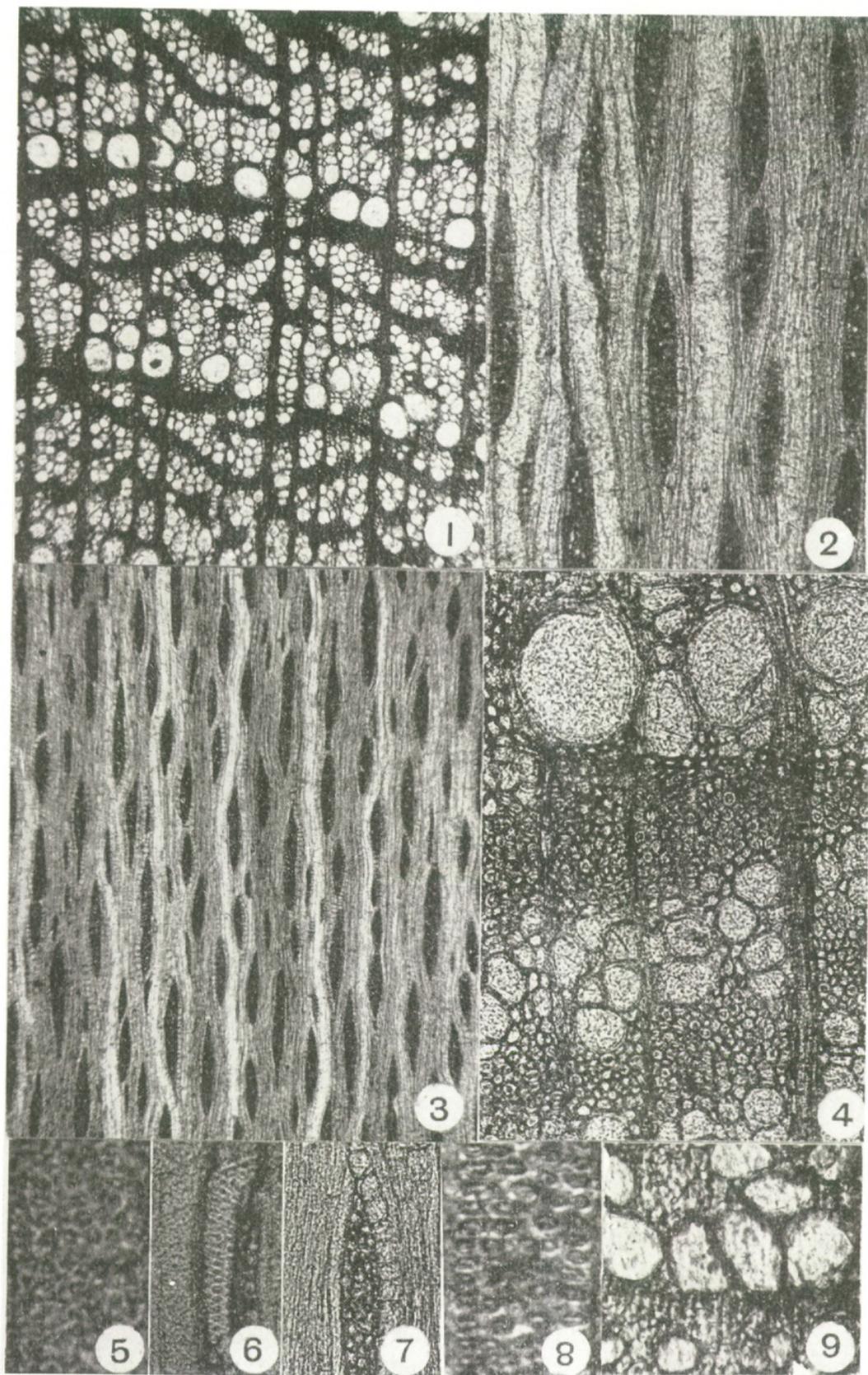
FIGS. 44, 45. Wood of *Quercus leuca*: 44, tangential section, $\times 75$ — note part of an aggregate ray and numerous uniseriate rays; 45, another transverse section showing three growth-zones, $\times 18$ — note the distribution of vessels in early and late wood. FIGS. 46–50. Wood of *Diospyros washingtoniana*: 46, part of tangential section showing the ray structure, $\times 105$; 47, transverse section showing vessel distribution, $\times 35$; 48, tangential section, $\times 40$ — note the storied arrangement of the xylem rays; 49, part of transverse section highly magnified, $\times 70$ — note thick vessel wall; 50, tyloses, $\times 90$. FIG. 51. Wood of *Albizzia vantagensis*: 51, intervascular pitting, $\times 280$.

PLATE 7

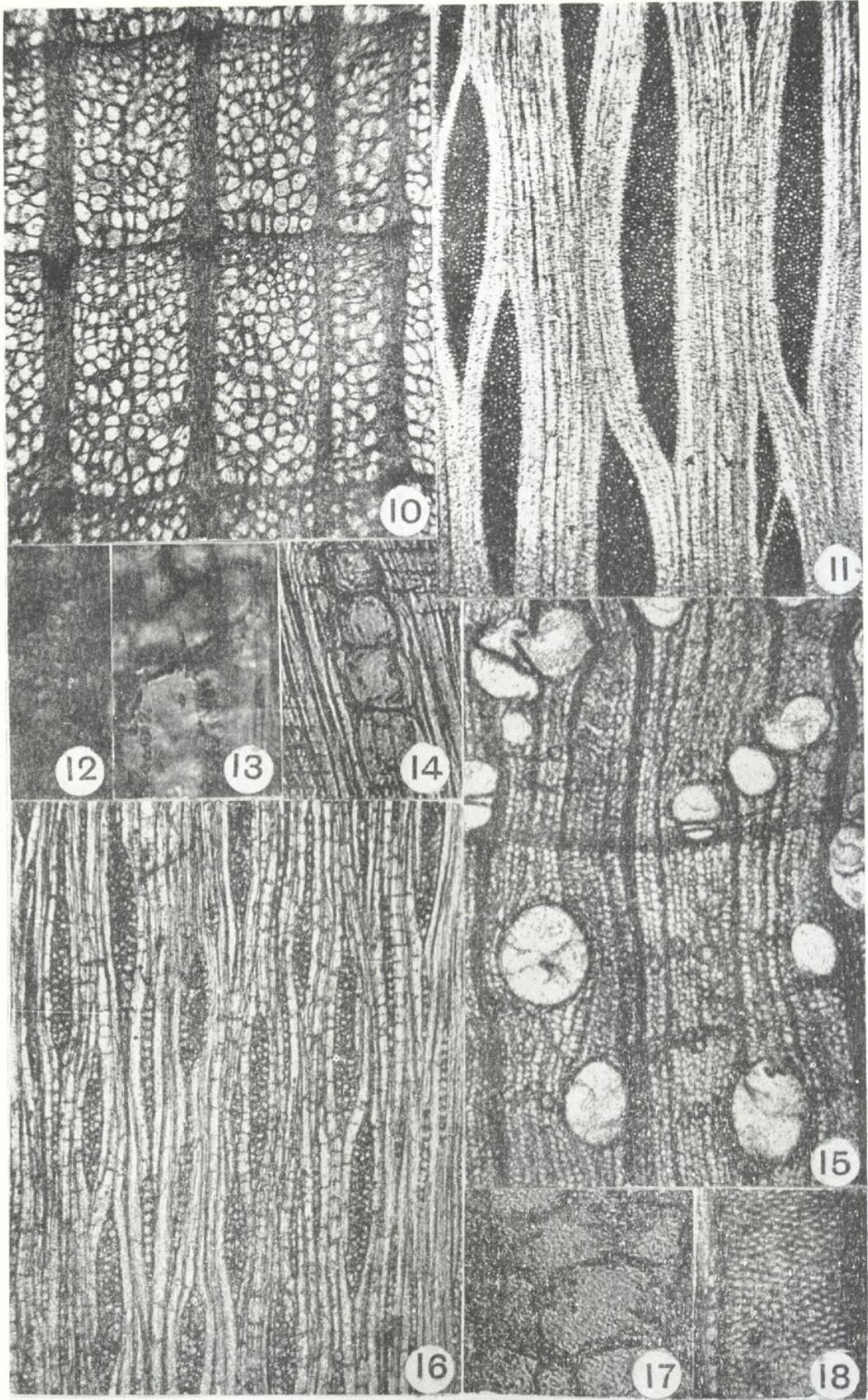
FIGS. 52–54. Wood of *Albizzia vantagensis*: 52, transverse section, $\times 26$ — note vessel and parenchyma distribution forming eyelets around vessels; 53, tangential section, $\times 65$ — note shape, size, and distribution of xylem rays; 54, transverse section magnified to show parenchyma distribution, $\times 65$. FIGS. 55–57. Wood of *Acer beckianum*: 55, transverse section, $\times 50$ — note vessel distribution and broad xylem rays; 56, part of Fig. 55 magnified to show structural details, $\times 80$; 57, intervascular pitting, $\times 220$.

PLATE 8

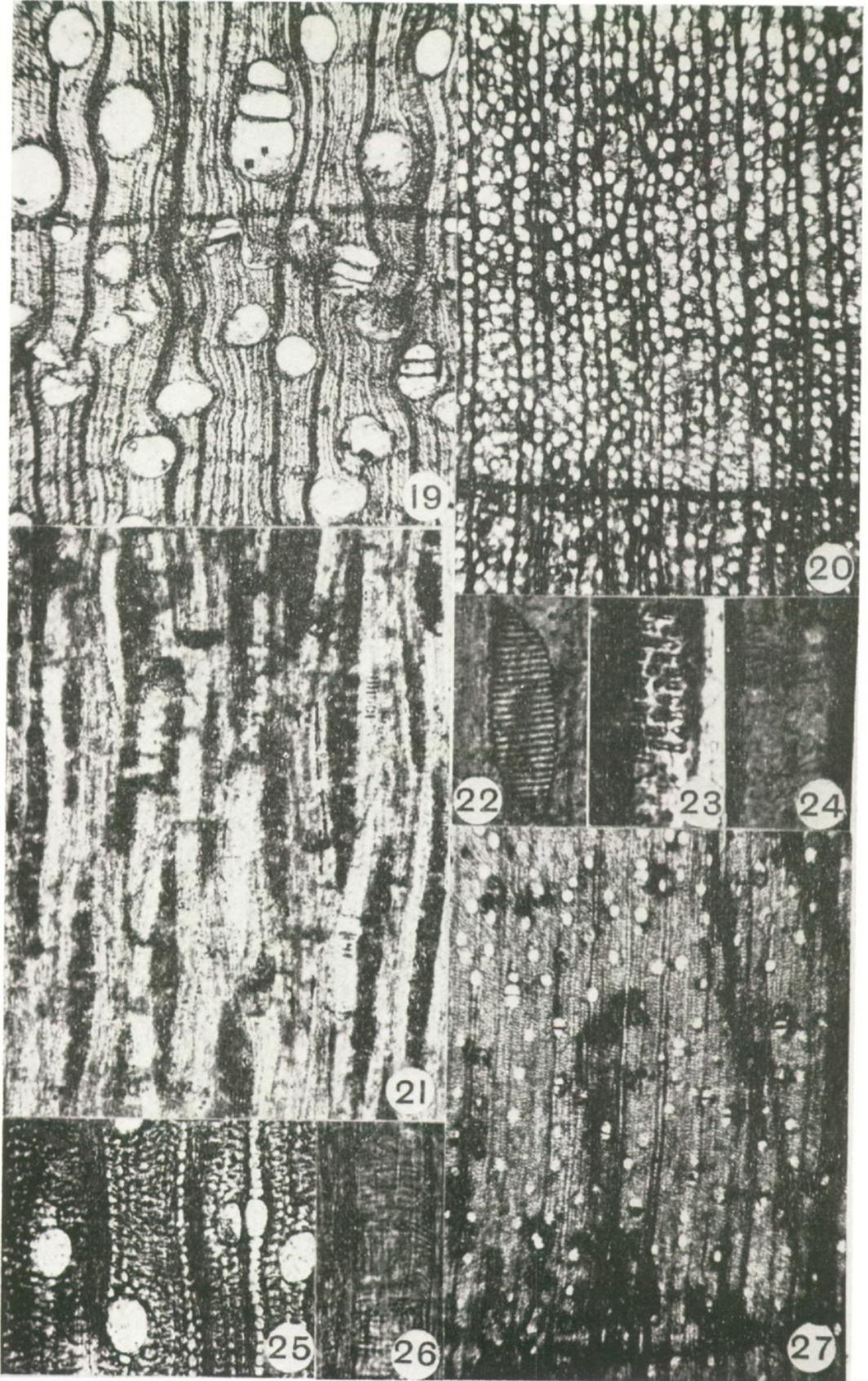
FIG. 58. Wood of *Acer beckianum*: 58, tangential section, $\times 65$. FIGS. 59–63. Wood of *Acer olearyi*: 59, simple perforation and spiral thickening, $\times 225$; 60, intervascular pitting, $\times 225$; 61, transverse section, $\times 105$; 62, transverse section, $\times 38$ — note solitary vessels and narrow rays; 63, tangential section showing xylem rays, $\times 105$.



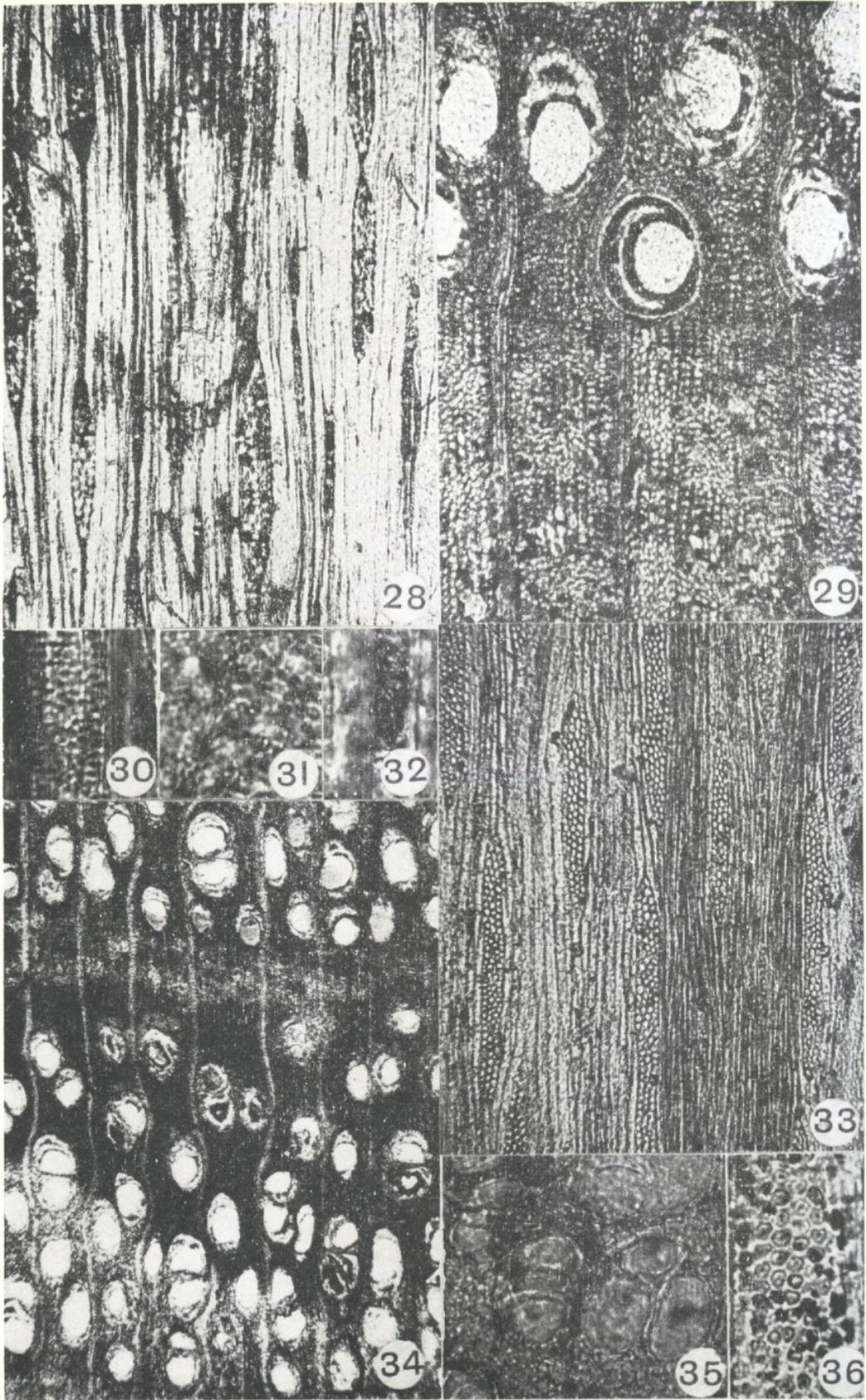
PRAKASH & BARGHOORN, MIOCENE WOODS



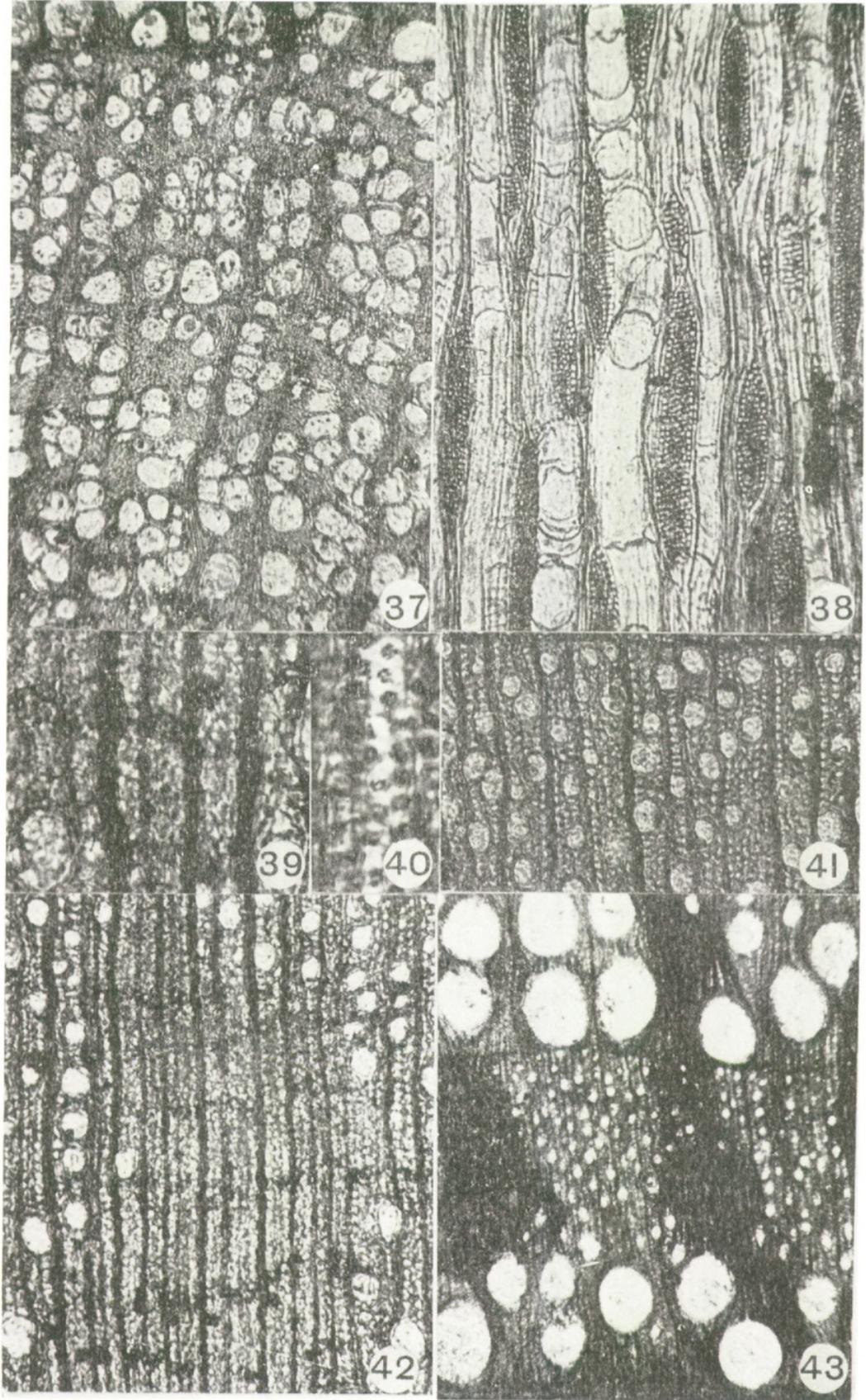
PRAKASH & BARGHOORN, MIOCENE WOODS



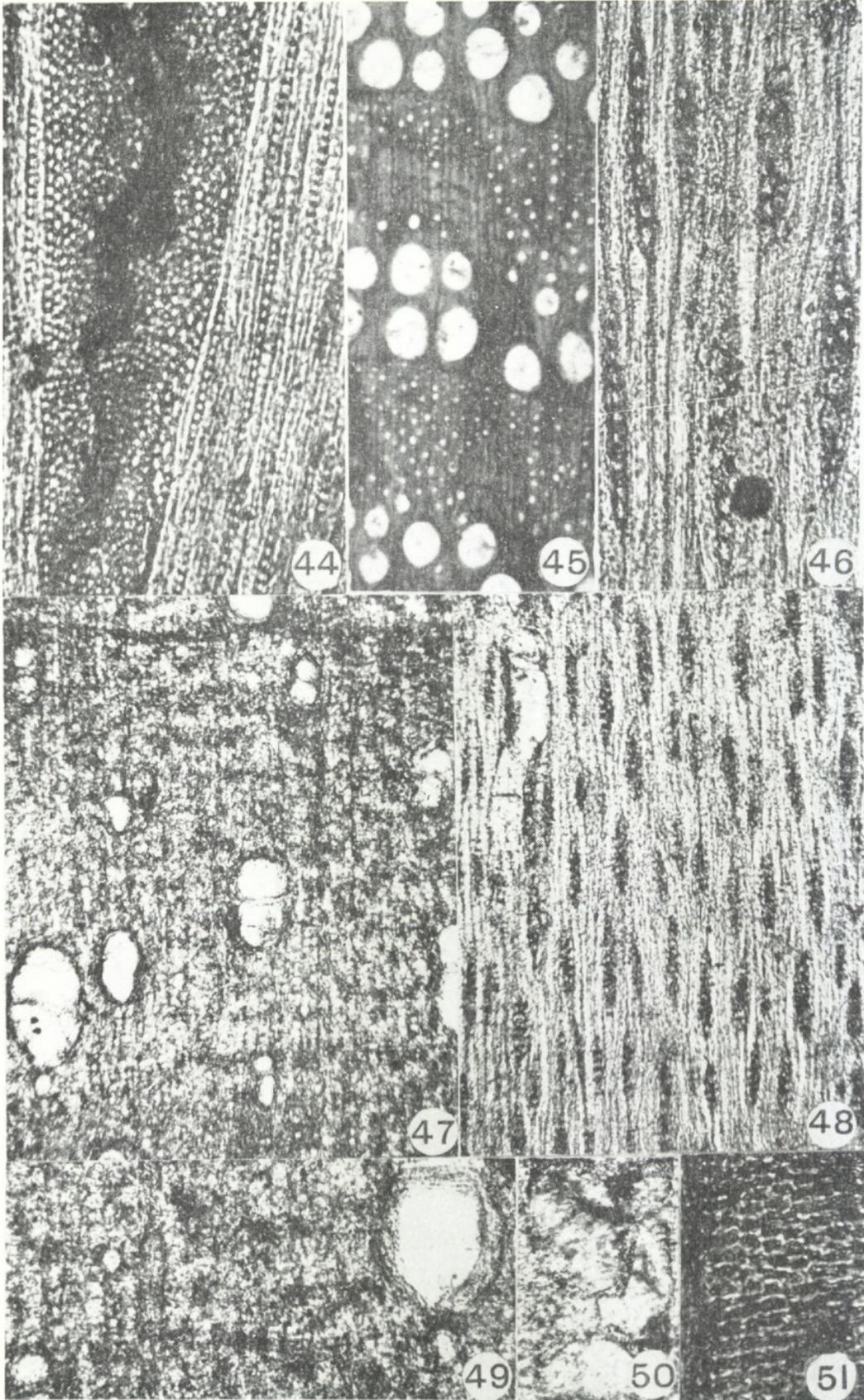
PRAKASH & BARGHOORN, MIOCENE WOODS



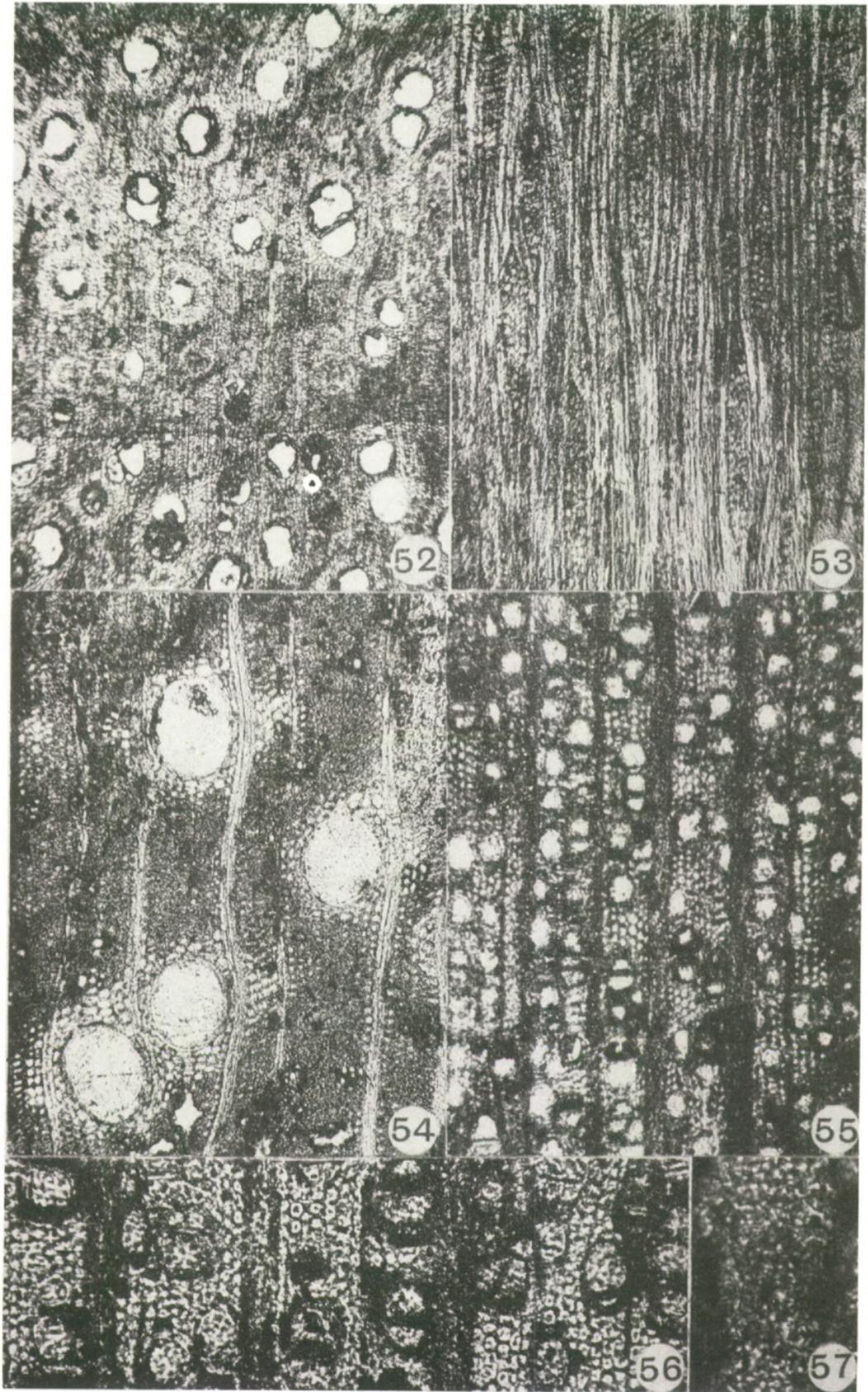
PRAKASH & BARGHOORN, MIOCENE WOODS



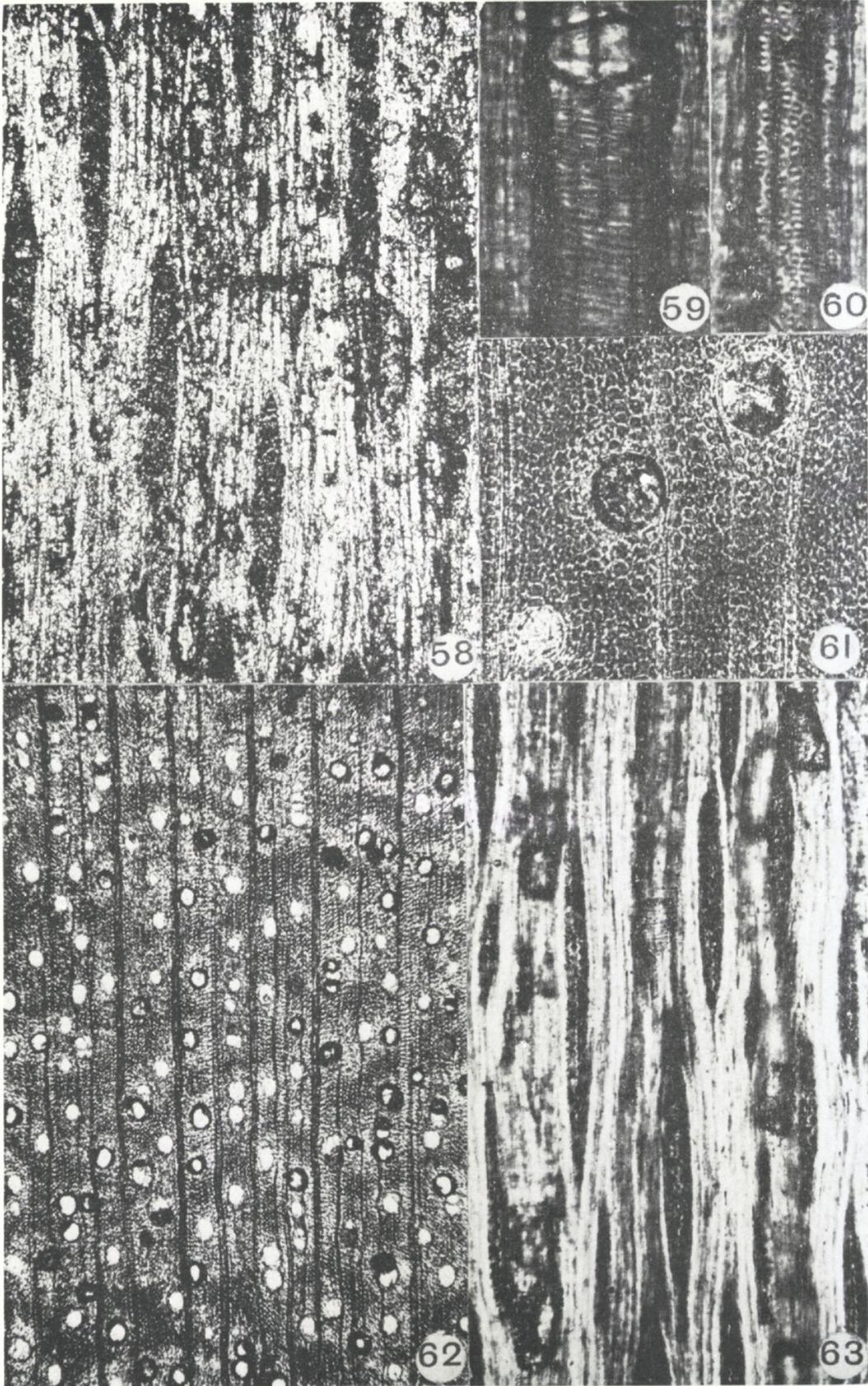
PRAKASH & BARGHOORN, MIOCENE WOODS



PRAKASH & BARGHOORN, MIOCENE WOODS



PRAKASH & BAUGHORN, MIOCENE WOODS



PRAKASH & BARGHOORN, MIOCENE WOODS



Prakash, U and Barghoorn, Elso S. 1961. "Miocene fossil woods from the Columbia basalts of central Washington." *Journal of the Arnold Arboretum* 42(2), 165–203. <https://doi.org/10.5962/bhl.part.19013>.

View This Item Online: <https://www.biodiversitylibrary.org/item/33618>

DOI: <https://doi.org/10.5962/bhl.part.19013>

Permalink: <https://www.biodiversitylibrary.org/partpdf/185622>

Holding Institution

Missouri Botanical Garden, Peter H. Raven Library

Sponsored by

Missouri Botanical Garden

Copyright & Reuse

Copyright Status: In copyright. Digitized with the permission of the rights holder.

Rights Holder: Arnold Arboretum of Harvard University

License: <http://creativecommons.org/licenses/by-nc-sa/3.0/>

Rights: <https://biodiversitylibrary.org/permissions>

This document was created from content at the **Biodiversity Heritage Library**, the world's largest open access digital library for biodiversity literature and archives. Visit BHL at <https://www.biodiversitylibrary.org>.