Institutional Wood Collections

A formal collection of carefully documented wood samples is called a **xylarium** (plural **xylaria**). Note that the important feature that distinguishes a xylarium from a group of wood samples is that xylarium samples include herbarium materials. Such collections are found in universities, botanical gardens, government laboratories and other institutions. The xylarium at the U.S. Forest Products Laboratory at Madison, Wisconsin, has nearly 100,000 samples. Collections with approximately 40,000 specimens are housed at the Smithsonian Institution in Washington, D.C., and at the State University of New York College of Environmental Science and Forestry at Syracuse. Major collections are also located at Harvard University in Cambridge, Massachusetts, and at North Carolina State University in Raleigh.

In England, principal xylaria are found at Oxford University, at the Royal Botanical Gardens at Kew in Richmond, Surrey, and at the Princes Risborough Laboratory in Princes Risborough, Aylesbury, Buckinghamshire.

William Stern's *Index Xylariorum, Institutional Wood Collections of the World, 3* (1988), lists over 125 xylaria (see the Bibliography on pp. 212-215). Xylaria are maintained primarily for research purposes; however, they may accommodate any serious user with a demonstrated need for reference material. Xylaria sometimes include files of prepared slides of sections of selected species that are available for examination by visitors or can be taken out on loan.

As previously discussed, some woods of very closely related species cannot be separated on the basis of wood characteristics alone. To make this separation, more must be known about the leaves, twigs, flowers, fruit and bark of the trees from which the wood came. Herbarium samples contain specimens of these materials in carefully pressed and dried form. The term **herbarium** refers to a large collection of plant samples or to the place where such a collection is housed. Each sample in the herbarium has a voucher or file that includes data about the size, age, geographical origin, altitude and site characteristics of the tree, as well as information as to whether the tree was forest-grown or plantation-grown and what part of the tree — base, stem, crown or limb — was collected.

Photographs

Although there is no substitute for actual samples of wood or prepared slides of tissue, photographs of wood at various magnifications are of great value in wood identification. Wood figure, for example, can never be explained as well verbally as it can be shown in a photograph. A few books, such as B. J. Rendle's *World Timbers* and William A. Lincoln's *World Woods in Color,* have excellent color plates. Macroscopic photographs are very useful in showing the appearance of cross sections. Published photographs usually show typical, representative samples of a species.

High-resolution micrographs of wood tissue are also abundant in the literature; they are extremely helpful for identification by comparison. Yet to the practitioner, they can involve certain unfortunate trade-offs. For example, if taken at low power, micrographs may show a large area of tissue but in so doing may fail to show the most minute critical features. If taken at high power to show detail, obviously only a very limited area can be included.

When studying photographs — as opposed to using a microscope to examine tissue sections — the viewer cannot move to out-of-view adjacent areas or change the magnification. It is unfortunate that many publications apparently strive for uniformity by presenting micrographs mostly taken at the same magnification, even though, in practice, identification of different species requires that specific features be observed at different magnifications. Nevertheless, published macrographs and micrographs probably offer the most important and most accessible reference base for wood identification. In addition to the many photographs presented in this book, the reader will find a wealth of additional photographs among the references listed in the Bibliography.

CHAPTER TEN

HARDWOOD IDENTIFICATION

This chapter is devoted to the identification of the more common North American hardwoods — with an occasional brief mention of similar or related European species. It begins with an initial screening process that allows an unidentified sample to be placed in one of three major categories. Within each category a combination of photographs and verbal descriptions completes the separation process.

The woods in this chapter and the next (softwoods) are arranged in groups primarily on the basis of similar appearance. This has two advantages. First, it helps to locate, by visual comparison between an unidentified sample and the photographs provided, all those woods that look reasonably like the unknown. Second, it brings together and compares woods that are commonly confused. Once an unknown is placed within a particular group of woods, the separation schemes provided will distinguish among the individual woods in that group. Each wood has a complete descriptive summary; therefore, a tentative identification can be verified by checking all the major characteristics listed for that wood against the unknown.

Once an unknown sample is determined to be either a hardwood or a softwood, there is a choice as to how to proceed. The initial schemes provided can be used to place the wood in one of the major groups. Or you can try to find that group by browsing through the photographs to find the closest set of look-alikes. In either case, once you find the right group, follow the prescribed directions for separating the species within that group.

I strongly recommend reading this entire chapter and the next at least once before working with your first unknown sample. This will give you a clearer sense of the relationships among groups of woods and of how the separation and identification procedures are ordered. Many of the anatomical terms defined in previous chapters are used for the first time here. Unfamiliar terms can also be checked in the Glossary on pp. 200-211.

Initial Screening

All the hardwoods discussed in this chapter are initially placed into broad categories according to their pore size and distribution. Thus, the first step in identifying hardwoods is an examination of a cleanly cut cross-sectional surface with a hand lens to assess the size and distribution of pores. The traditional classifications are ring-porous, semi-ring-porous (semi-diffuse-porous) and diffuse-porous, as illustrated in the photos on p. 100.

An important comment before proceeding, however: If the presence of very narrow growth rings indicates that the tree from which the sample was taken grew slowly, particularly in ring-porous woods, the normal width of the earlywood and important latewood characteristics may be missing. It is therefore best to make observations in the area containing the widest growth rings.

Once you have determined the pore classification, turn to the appropriate section in this chapter.

Although most woods fall clearly into one pore class or another, an occasional specimen may be borderline. In this book, I have tried to resolve at least some of these cases by applying the following additional qualifications:

In order for a wood to be considered ring-porous, the earlywood pores must be relatively large and form a distinct row. For this reason, I consider cherry diffuse-porous, not ring-porous. Although its earlywood has a distinct row of pores, they are quite small. For a wood to be semi-ring-porous, the largest earlywood pores must be distinctly larger than the latewood pores, as in black walnut or butternut. Some woods show a definite pore-size gradation from earlywood to latewood, but even their earlywood pores are small; in other words, the pores grade from small to very small, as in willow and cottonwood. I have chosen to group these with the diffuse-porous woods, with the notation that they appear semi-diffuse-porous.

Once the initial pore classification of an unknown wood has been decided, turn to the appropriate section as indicated in the photos below.

GROUP I: RING-POROUS HARDWOODS

Most ring-porous woods are easy to recognize. However, not every piece of wood offers a perfect fit every time. Some species that are usually strongly ring-porous, such as catalpa, produce occasional wood that appears semi-ring-porous due to an earlywood/latewood transition that is more gradual than normal.

If an unknown wood is ring-porous, begin by trying to place it in one of the four ring-porous groups (RP I-1, I-2, I-3, I-4). Classify on the basis of latewood features, namely, pore arrangement and/or parenchyma and ray size.

Ring-Porous Subgroup I-1: Chestnut and Oak

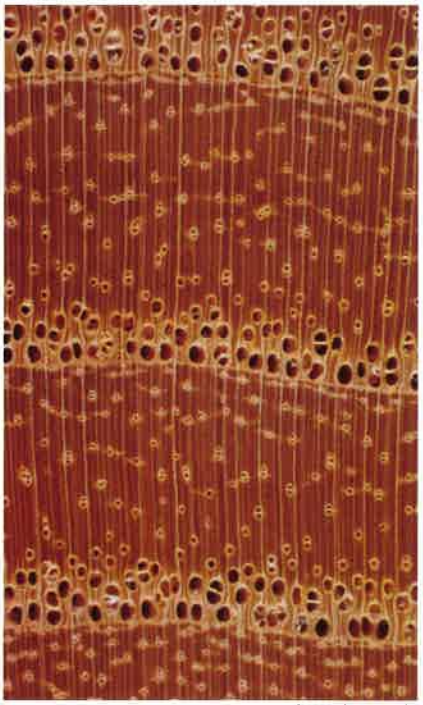
Woods in this group have radially arranged latewood pores. They can be further separated into subgroups based on ray size. The oaks have huge multiseriate rays — the largest rays of all temperate woods — that can be seen readily with the unaided eye. Oaks also have fine, mostly uniseriate rays that are barely visible with a hand lens. Other woods that have radial pore arrangement but lack the large rays of oak fall into the chestnut group.

THE CHESTNUT GROUP

This group includes two North American woods: American chestnut *(Castanea dentata)* and giant chinkapin *(Castanopsis chrysophylla),* also called golden chinkapin (see the photos on p. 102). In both, the rays are always uniseriate, although a few may be biseriate (a ray is considered biseriate if any portion of it is biseriate).

HARDWOOD CLASSIFICATION

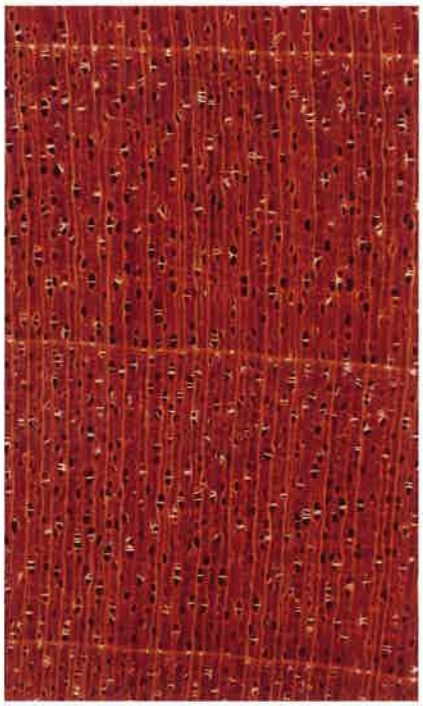
Hardwoods are classified as ring-porous, as seen in white ash (left), semi-ring-porous, as seen in black walnut (center), or diffuse-porous, as seen in yellow birch (right).



See Group I: ring-porous hardwoods above.



See Group II: semi-ring-porous or semi-diffuse-porous hardwoods, p. 114.



See Group III: diffuse-porous hardwoods, p. 117.

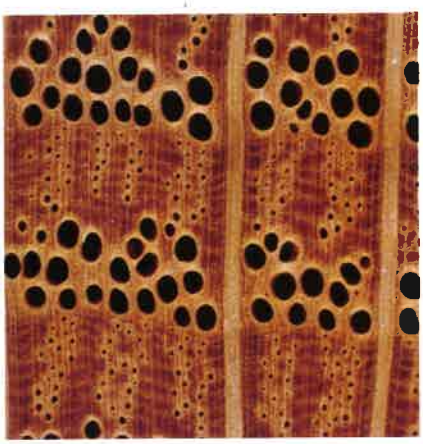
INITIAL BREAKDOWN OF RING-POROUS HARDWOODS

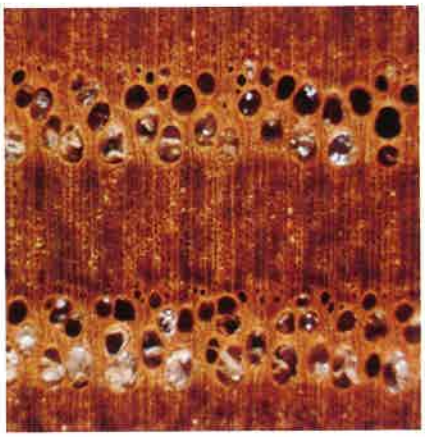
Check an unknown ring-porous hardwood by determining the latewood pore arrangement.

Ring-Porous Subgroup I-1:
Chestnut and Oak

Latewood pores in more or less radial arrangement, in obvious radial rows, or in loose dendritic or flamelike patches; rays either huge or barely visible even with hand lens.

(See p. 100.)

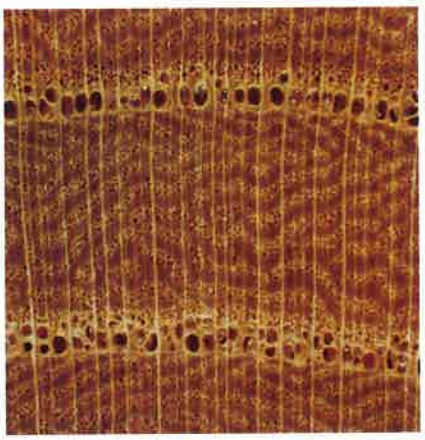


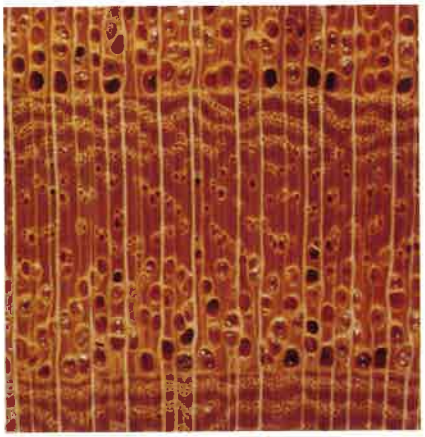


Ring-Porous Subgroup I-2:
Elm and Hackberry

Latewood pores in regular wavy tangential patterns, appearing uniformly throughout latewood.

(See p. 104.)

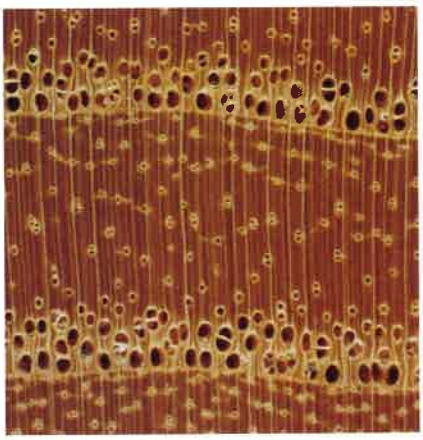


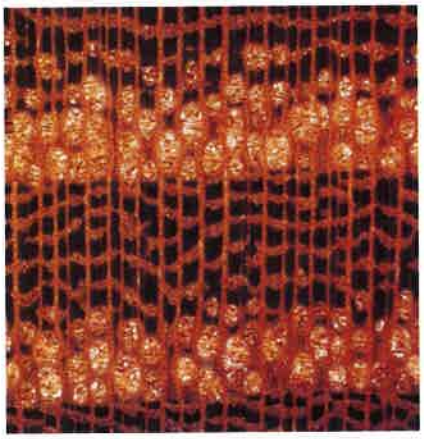


Ring-Porous Subgroup I-3:
Confusing Ring-Porous Woods

Latewood pores appear neither in strict radial nor in tangential arrangement, but rather as solitary pores, pore multiples, or pore/multiples with aliform parenchyma, or joined in outer latewood by confluent parenchyma.

(See p. 106.)



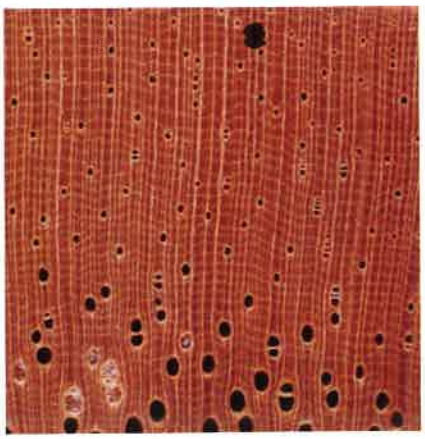


Ring-Porous Subgroup I-4:
Hickory and Pecan

Latewood pores mostly solitary or in compact radial multiples. Latewood fiber mass lined with regular banded parenchyma. (Row of earlywood pores discontinuous.)

(See p. 112.)





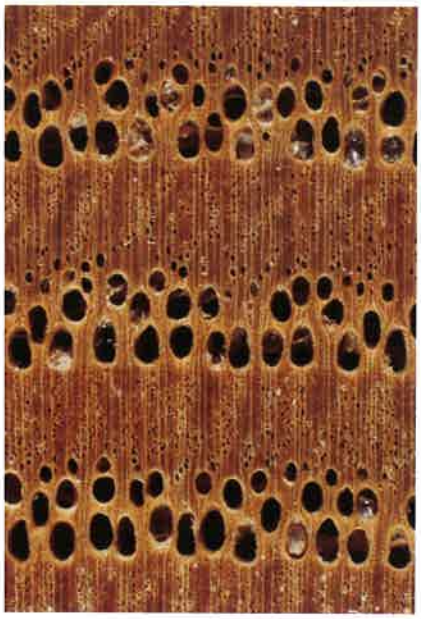
These are the only ring-porous woods with almost exclusively uniseriate rays; this separates them from other species, like sassafras and black ash, that initially resemble them. A microscopic check of a tangential section will quickly show the uniseriate rays (photo below right).

Chinkapin is usually light brown, often with a pinkish tinge, whereas American chestnut is a greyish brown or medium to dark brown. Neither has a characteristic odor. The two are separated best by pore distribution. In American chestnut, the earlywood zone consists of a continuous row of large pores up to six wide that are surrounded by lighter-colored tissue. The latewood pores are small and numerous, arranged in erratic flamelike or dendritic patches stretching radially across the latewood.

In chinkapin, the large earlywood pores are in a single, intermittent row along the growth-ring boundary. They are quite round, in contrast to the typically oval pores of chestnut. Between the earlywood pores is darker fiber mass that is continuous with the fiber mass of the latewood. The latewood pores of chinkapin are in distinct radial fanlike or dendritic patches that appear to erupt from each earlywood pore. Both chestnut and chinkapin have tyloses in medium abundance. European sweet chestnut *(Castanea sativa)* is similar to American chestnut.

CHESTNUT AND CHINKAPIN

Both chestnut and chinkapin have a flamelike, more-or-less-radial arrangement of latewood pores and imperceptible uniseriate rays. The interrupted row of round earlywood pores in chinkapin readily separates it from chestnut, which has a continuous row of multiple oval pores.



AMERICAN CHESTNUT
Castanea dentata

*Average Specific Gravity: 0.43
Heartwood Color: Greyish brown, or medium to dark brown
Pore Distribution: Ring-porous
Earlywood: Several pores wide; pores oval, surrounded by lighter tissue
Latewood: Pores very numerous, in radial, dendritic or wandering patches
Tyloses: Present
Rays: Barely visible with lens

**Rays: Amost exclusively uniseriate



GIANT CHINKAPIN
Castanopsis chrysophylla

Average Specific Gravity: 0.46
Heartwood Color: Light brown, often pinkish
Pore Distribution: Ring-porous
Earlywood: Pores large, round, in single row, intermittent with dark fiber
Latewood: Pores in distinct fanlike or dendritic patches, appearing to erupt from each earlywood pore
Tyloses: Present
Rays: Fine, barely visible with lens

Rays: Almost exclusively uniseriate

* Throughout the chapter, macroscopic features are listed in the text block immediately under the species name.
** Microscopic features are below the macroscopic and separated from them by a line.

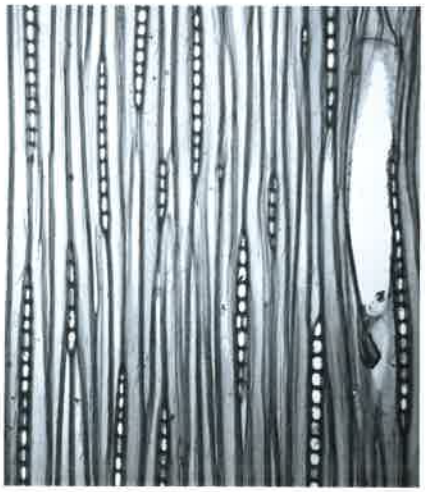
THE OAK GROUP

The oaks are widely distributed throughout the world. The wood of oaks is typically ring-porous, with the exception of live oak *(Quercus virginiana)* and tanoak *(Lithocarpus densiflorus)*. But the distinguishing feature of oak is its very large, 20+ multiseriate rays. No other North American wood has rays this big — this is a feature that can be immediately recognized on a cleanly cut surface. The oaks also have many narrow uniseriate rays.

When we examine a cross-sectional surface with a hand lens, we see that both the earlywood pores and the radial arrangements of latewood pores are surrounded by lighter-colored tissue. This tissue is a mixture of parenchyma and

UNISERIATE RAYS IN CHESTNUT

Rays in chestnut are uniseriate, or occasionally partially biseriate. (100x)



vasicentric tracheids. In the latewood between pore groupings we see darker masses of the thick-walled fibers that give oaks their characteristic high density and strength. Faint tangential lines of banded parenchyma as well as uniseriate rays are visible across the fiber mass. These features are common to all oaks.

Separating the many oak species is another matter — the best we can do is assign the wood to either the red oak or the white oak group (Table 10.1, at right).

The red oak and white oak groups can usually be separated by considering ray height, the presence or absence of tyloses, and latewood pores (see photos at right). Ray height is apparent in the initial examination. Rays among red oaks are commonly 3/8 in. to 5/8 in. high, with a maximum height of 1 in.; rays taller than 1 in. are not often seen in red oaks. Among white oaks, rays taller than 1¼ in. are usually found, and heights up to several inches sometimes occur. I came across one piece of white oak in a 17th-century Hadley chest with a single ray 9 in. high.

But ray height is probably no more than 90% to 95% reliable. Among the exceptions to the ray-height rule, the occasional red oak with rays taller than 1 in. is more common than a white oak whose rays never exceed 1¼ in.Obviously ray height cannot be used to separate oak pieces shorter than about 1½ in.

White oak heartwood usually has abundant tyloses; rarely are they completely absent. In red oaks, by contrast, tyloses are usually absent or scattered, although the occasional piece may have areas of fairly abundant tyloses.

Latewood pores are the most reliable basis for separating red and white oaks. As shown in the photo at near right, latewood pores in red oak are large, individually distinct and few enough so that they can be readily counted. By contrast, latewood pores in white oaks, shown in the photo at far right, grade downward in size to very small at the outer edge of the growth ring and are usually so numerous and indistinct that they are impossible to see and count individually.

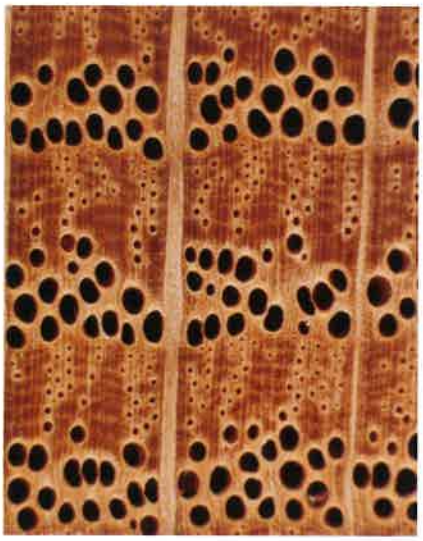
Further investigation of microscopic cross sections shows that the larger,

TABLE 10.1: SOME MAJOR SPECIES OF THE RED OAK AND WHITE OAK GROUPS *(QUERCUS)*

Red Oak Group		White Oak Group	
Q. coccinea	Scarlet oak	*Q. alba*	White oak
Q. falcata	Southern red oak	*Q. bicolor*	Swamp white oak
Q. kelloggii	California black oak	*Q. garryana*	Oregon white oak
Q. palustris	Pin oak	*Q. lyrata*	Overcup oak
Q. rubra	Northern red oak	*Q. macrocarpa*	Bur oak
Q. velutina	Black oak	*Q. petraea*	Sessile oak
		Q. prinus	Chestnut oak
		Q. robur	European oak
		Q. stellata	Post oak

RED OAK AND WHITE OAK

The oaks are recognized by their ring-porous arrangement and extremely large rays. When viewed with a hand lens, a transverse surface of red oak has fewer distinct latewood pores, as compared to the numerous, indistinct latewood pores in white oaks. Tyloses are usually abundant in white oak heartwood, sparse to absent in red oaks.



NORTHERN RED OAK
Quercus rubra

Average Specific Gravity: 0.63
Heartwood Color: Light brown, usually with flesh-colored cast
Pore Distribution: Ring-porous
Earlywood: Up to four rows of large, solitary pores
Latewood: Pores solitary in radial lines, few and distinct ("countable")
Tyloses: Absent or sparse in earlywood
Rays: Largest rays conspicuous; tallest less than 1 in.

Rays: Narrow rays uniseriate or in part biseriate
Latewood vessels: Thick-walled



WHITE OAK
Quercus alba

Average Specific Gravity: 0.68
Heartwood Color: Light to dark brown to greyish brown
Pore Distribution: Ring-porous
Earlywood: Up to four rows of large pores
Latewood: Pores small, solitary or in multiples, in spreading radial arrangement, numerous and indistinct ("uncountable"), grading to invisibly small with lens
Tyloses: Abundant
Rays: Largest rays conspicuous; tallest greater than 1¼ in.

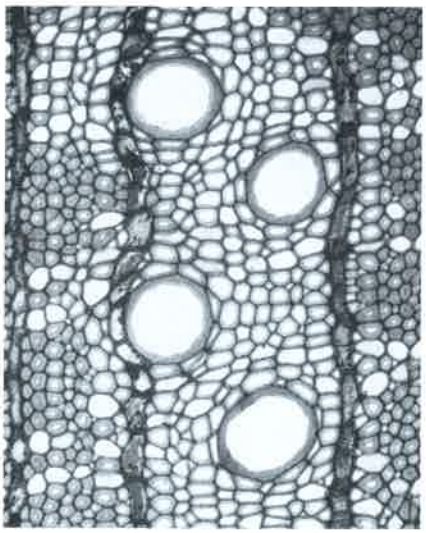
Rays: Narrow rays uniseriate or in part biseriate
Latewood Vessels: Thin-walled

more distinct red oak latewood pores are thick-walled (thicker than the earlywood pores), whereas the indistinct white oak pores are thin-walled (photos below).

This contrasting nature of latewood pores is highly reliable and should be used as the basis for separation whenever possible. It clearly has a great advantage over ray height in the identification of small specimens. And it is more reliable than the presence or absence of tyloses when it is not certain whether the specimen is sapwood or heartwood (see Table 10.2, below).

LATEWOOD PORES IN OAKS

In red oaks (left), latewood pores are solitary, with thick walls. In white oaks (right), the smaller, more numerous latewood pores have thin walls and may occur in multiples. (125x)



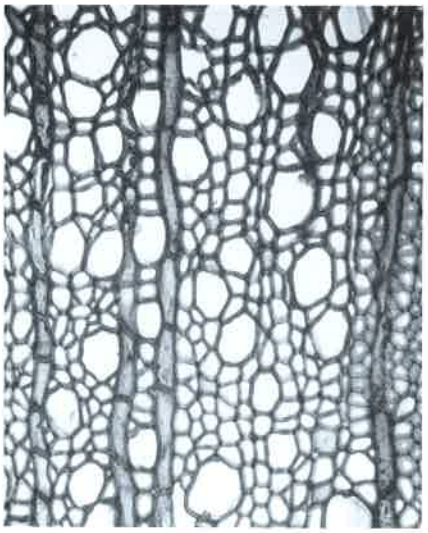


TABLE 10.2: SUMMARY OF IDENTIFICATION FEATURES FOR RED OAK AND WHITE OAK

Feature	In Red Oak	In White Oak
Rays (a)	Tallest less than 1 in. high, mostly 3/8 in. to 5/8 in. high	Tallest more than 1 1/4 in. high; can be up to several inches high
Tyloses (a)	Absent or sparse and sporadic	Abundant in heartwood
Latewood pores (b)	Distinct with lens; few enough to be counted	Grading in size to indistinctly small; too numerous and indistinct with lens to be counted
	Vessel walls thick (thicker than earlywood vessels)	Vessel walls thin (not thicker than earlywood vessels)

(a) Less reliable features.
(b) Most reliable features.

Ring-Porous Subgroup I-2: Elm and Hackberry

The important and clearly distinguishing feature of the elm/hackberry group is the arrangement of latewood pores in wavy bands. As mentioned in Chapter 4, the term ulmiform, which is used to describe this pore arrangement, is derived from the word *Ulmus* (elm) since elms display the pattern so characteristically. Typically, these wavy bands are more than one pore wide,

HACKBERRY

The multiple row of earlywood pores and wavy bands of latewood pores in hackberry imitate the appearance of slippery elm (see photos on the facing page). The cream to yellowish-grey heartwood of hackberry contrasts with the reddish brown of slippery elm. A microscopic check of the greater ray seriation (7+) in hackberry provides a more positive separation from elms, whose ray seriation is never greater than 7.



COMMON HACKBERRY
Celtis occidentalis

Average Specific Gravity: 0.53
Heartwood Color: Cream, light brown or light greyish brown, with a yellowish cast
Pore Distribution: Ring-porous
Earlywood: More than one pore wide
Latewood: Pores in wavy bands
Rays: Distinct

Rays: Heterocellular, widest up to 10-13 seriate

continuous and well established across the entire latewood.

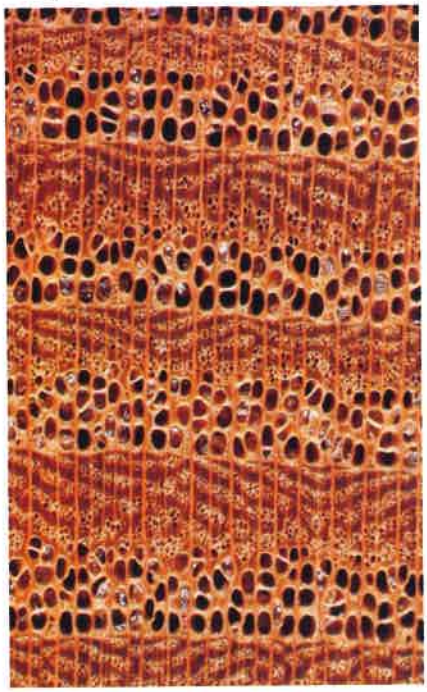
Woods in this group can be separated by considering the placement and number of earlywood pores and the character of the rays. The earlywood band of pores of slippery elm *(Ulmus rubra)* is more than one pore wide; by contrast, it is only a single pore wide in American elm and the hard elms. American elm *(U. americana)* has a fairly continuous row of large, uniformly sized, evenly spaced earlywood pores. Woods of English elm *(U. procera)* and wych elm *(U. glabra)* are similar. Earlywood pores in the hard elms are typically small, indistinct and intermittent along the growth-ring boundary. Among the hard elms, woods of rock elm *(U. thomasii)*, winged elm *(U. alata)* and cedar elm *(U. crassifolia)* are not readily separated.

Although both slippery elm and common hackberry *(Celtis occidentalis)* have earlywood bands of multiple pores, heartwood color is one basis for separating the two. In hackberry the heartwood is light brown or light greyish brown, commonly with a yellowish cast. The heartwood of slippery elm is dark brown to reddish brown.

Microscopic ray characteristics are another reliable means of separating these two woods. In slippery elm the rays are homocellular and up to 7 seriate (but commonly 4-5 seriate), whereas in hackberry they are heterocellular and up to 13 seriate (but mostly 5-8 seriate). The wood of sugarberry *(Celtis laevigata)* is very similar to hackberry.

ELM

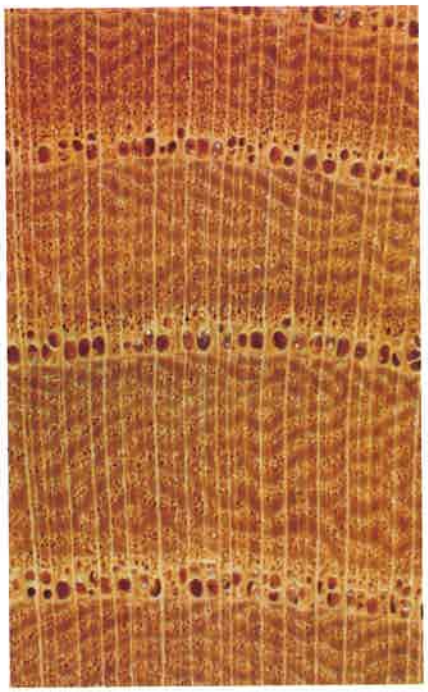
Latewood pores in elms are arranged in wavy bands (ulmiform arrangement) that are the trademark of this wood. Slippery elm has a multiple band of earlywood pores; American elm has a continuous row of earlywood pores that are easily visible to the eye. Winged elm, a hard elm, has earlywood pores in an interrupted row that are invisible without a hand lens.



SLIPPERY ELM
Ulmus rubra

Average Specific Gravity: 0.53
Heartwood Color: Red to dark brown or reddish brown
Fluorescence: Heartwood fluoresces dim yellow-green
Pore Distribution: Ring-porous
Earlywood: 2-6 pores wide
Latewood: Pores in wavy bands
Tyloses: Sparse in earlywood
Rays: Not distinct without lens

Rays: Homocellular, 1-7 (mostly 4-5) seriate



AMERICAN ELM
Ulmus americana

Average Specific Gravity: 0.50
Heartwood Color: Light brown to brown or reddish brown
Pore Distribution: Ring-porous
Earlywood: Pores large, in continuous row
Latewood: Pores in wavy bands
Tyloses: Present in earlywood, but usually sparse
Rays: Not distinct without lens

Rays: Homogeneous, 1-7 (mostly 4-6) seriate



WINGED ELM
Ulmus alata

Average Specific Gravity: 0.66
Heartwood Color: Light brown to brown or reddish brown
Pore Distribution: Ring-porous
Earlywood: Pores small and indistinct in an intermittent row
Latewood: Pores in wavy bands
Tyloses: Sparse in earlywood
Rays: Not distinct without lens

Rays: Homogeneous, 1-7 seriate

Knowing the origin of the specimen can also be very helpful in pinning down the woods of this group. American elm and slippery elm are widely distributed throughout the eastern and central United States and the southern edge of the central and eastern Canadian provinces. Rock elm is concentrated in the north-central states, winged elm in the south-central and southeastern states and at the southern tip of Ontario and hackberry in the north-central and northeastern states. Sugarberry is restricted to the southeastern part of the United States.

The chart below summarizes the separation scheme for the elm/hackberry group.

Ring-Porous Subgroup I-3: The Confusing Ring-Porous Woods

Of the many ring-porous woods, those in this group can be the most difficult to identify because they share some major characteristics. One such characteristic is the row of multiple earlywood pores. Another is the latewood pores, which are neither radially grouped as in oaks nor in strong tangential or wavy bands as in elm; rather, they range from solitary or small radial multiples to clustered. Sometimes the clusters merge into short-to-long tangential groups that are confusingly similar to ulmiform groupings.

Woods found at the extremes of this ring-porous subgroup are unlikely to be mistaken for each other. For example, it is hard to confuse white ash with Osage-orange. Yet within the group, nearly every wood is confusingly similar to one or more others. For example, white ash is confused with black ash, black ash is confused with sassafras and, toward the other end of the list, honeylocust is similar to Kentucky coffeetree. This is illustrated in the cross-sectional views in the photos on p. 108 and pp. 110-111.

KEY TO SEPARATING WOODS OF THE ELM/HACKBERRY GROUP

RING-POROUS SUBGROUP I-2

UNKNOWN WOOD

- Earlywood 2-5 pores wide, pores generally visible with lens.
- Earlywood with a single row of largest pores that may or may not be visible without lens.

As a start in narrowing the possibilities within this difficult subgroup, consider the following:

1. If the wood is bright and fresh:
A) Check for characteristic odor. Only sassafras and catalpa have noteworthy fragrances.
B) Note the heartwood color. For example, the heartwood is orange-to-red in coffeetree, grey-brown in sassafras and green in sumac.
C) Where possible, note the width of the sapwood. For example, black locust and catalpa never have sapwood more than three rings wide.

2. Evaluate density and hardness. Most of these woods are hard to extremely hard, but catalpa is soft.

3. Note the presence or absence of tyloses and whether they sparkle in iridescent colors. For example, tyloses are absent from honeylocust but extremely abundant in black locust.

4. If a black light is available, check for fluorescence. Only sumac, honeylocust, coffeetree and black locust fluoresce.

5. If you have a microscope, check for:
A) Ray seriation. For example, sumac rays are generally 1 or 2 seriate, while honeylocust rays are up to 14 seriate.
B) Latewood pores. Note whether they are solitary or occur in multiples or clusters, and whether they are thick- or thin-walled. Ashes, for example, have thick-walled latewood pores, catalpa's are thin-walled.
C) Spiral thickenings in the latewood vessels as viewed in longitudinal sections. For example, spiral thickenings are absent from sassafras but present in catalpa and sumac.

The summary of features in Table 10.5 on pp. 136-137 should also help suggest possible species.

Heartwood cream to light brown or yellowish grey. Largest rays up to 10-12-seriate, always some rays wider than 7-seriate.	HACKBERRY *(Celtis occidentalis)* SUGARBERRY *(Celtis laevigata)*	-HACKBERRY-
Heartwood brown to reddish brown. Largest rays generally 4-5-seriate, never wider than 7-seriate.	SLIPPERY ELM *(Ulmus rubra)*	SOFT ELM
Earlywood pores visible to the eye (maximum pore diameter more than 200 um), mostly in a continuous row.	AMERICAN ELM *(Ulmus americana)*	
Earlywood pores not visible without lens (maximum pore diameter less than 200 µm), mostly in a discontinuous row.	WINGED ELM *(Ulmus alata)* CEDAR ELM *(Ulmus crassifolia)* ROCK ELM *(Ulmus thomasii)*	HARD ELM

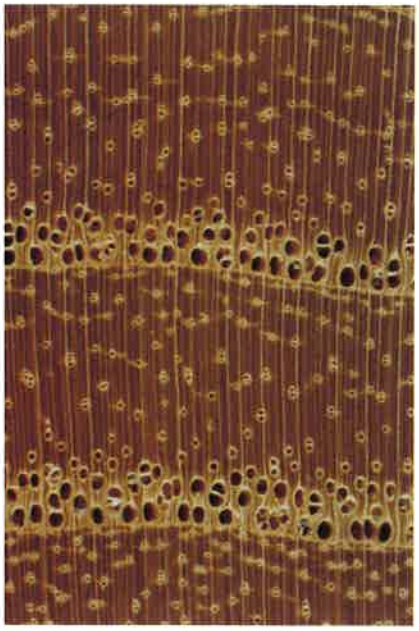
WHITE ASH

Of the woods in Subgroup I-3, ash is probably the most common. Wood known as white ash is most often *Fraxinus americana,* but it is indistinguishable from and often confused with green ash *(F. pennsylvanica).* Both species are widely distributed throughout the central and eastern United States and in southeastern Canada. In addition, the woods of Oregon ash *(F. latifolia)* and European ash *(F. excelsior)* are essentially similar.

White ash is characterized by a band of multiple earlywood pores surrounded by lighter-colored tissue. In the first-formed latewood, the pores are solitary or occur in short radial multiples, typically surrounded by a sheath of lighter-colored vasicentric parenchyma. Although the vasicentric parenchyma cells are in

ASH AND SASSAFRAS

Compared to white ash, black ash has narrow sapwood and brown heartwood color. Its growth rings are usually narrow and its latewood pores are seldom connected, as they are in white ash. Like white ash, sassafras normally has latewood pores with aliform and confluent parenchyma, but it is distinct in its grey heartwood color and spicy aroma. A good microscopic check for sassafras is its large, yellow oil cells (see the photo on the facing page).



WHITE ASH
Fraxinus americana

Average Specific Gravity: 0.60
Heartwood Color: Light brown or greyish brown
Sapwood Color: Creamy white (may be very wide)
Pore Distribution: Ring-porous
Earlywood: 2-4 pores wide; pores moderately large, surrounded by lighter tissue
Latewood: Pores solitary and in radial multiples of 2-3, surrounded by vasicentric parenchyma or connected by confluent parenchyma in outer latewood
Tyloses: Fairly abundant (some vessels open)
Rays: Not distinct to eye, but clearly visible with hand lens

Rays: 1-3 seriate
Latewood Pores: Thick-walled



BLACK ASH
Fraxinus nigra

Average Specific Gravity: 0.49
Heartwood Color: Greyish brown to medium or dark brown
Sapwood Color: Creamy white (fairly narrow)
Pore Distribution: Ring-porous
Earlywood: 2-4 pores wide; pores large, surrounded by lighter tissue
Latewood: Pores solitary and in radial multiples of 2-3, not numerous, rarely with aliform or confluent parenchyma in outer latewood
Tyloses: Fairly abundant (some vessels open)
Rays: Not distinct to eye, but clearly visible with hand lens

Rays: 1-3 seriate
Latewood Pores: Thick-walled



SASSAFRAS
Sassafras albidum

Average Specific Gravity: 0.45
Heartwood Color: Grey or greyish brown
Heartwood Odor: Spicy odor and taste
Pore Distribution: Ring-porous
Earlywood: 3-8 pores wide; pores medium to large
Latewood: Pores solitary and in radial multiples of 2-3, grading to very small with aliform parenchyma in outer latewood
Tyloses: Fairly abundant, with sparkle
Rays: Barely visible to the eye

Rays: 1-4 seriate
Oil Cells: Rays and longitudinal parenchyma contain scattered oil cells that appear very large with bright yellow contents
Latewood Pores: Thick-walled

thin layers, they are visible against the darker fiber mass. Toward the outer latewood, there is an increasing tendency for aliform parenchyma to develop and intergrade with confluent parenchyma, which connects the pores laterally. The result is variable-length interrupted tangential or wavy bands, especially in the outermost latewood. Note that these solitary pores and radial multiples connected by parenchyma are different from the continuous clusters or bands of pores seen in elm and black locust.

Radial surfaces of white ash and hackberry are easily confused at first glance, because both share a creamy white or yellowish color and are ring-porous with a multiple earlywood pore zone. However, they can be separated by careful examination of latewood pores and rays. The pores are ulmiform in hackberry and discontinuous in ash, even though they are connected by confluent parenchyma. The rays are indistinct and 1-3 seriate in ash, distinct and up to 12 seriate in hackberry. Only occasional rays in white ash exceed 2 seriate, whereas rays of European ash are commonly 3 (and occasionally 4) seriate.

BLACK ASH

Black ash *(Fraxinus nigra;* photo at center on the facing page) is sometimes confused with white ash. In white ash, the sapwood can be very wide, in some cases occupying the entire mature stem, whereas in black ash, it is narrow, rarely in excess of 1 in. Moreover, the light-colored sapwood of white ash contrasts with the medium-brown or greyish-brown heartwood of black ash. In black ash, the latewood pores are sparser, and only occasionally do confluent parenchyma connect pores in the outer latewood. The narrow rings caused by slow growth rate are common in black ash. These narrow rings have little latewood, making latewood pore distribution difficult to evaluate. White ash, a denser wood, has wider growth rings and well-represented latewood. In recent years, however, an affliction called ash dieback has caused extremely slow growth in white ash in some regions. The resulting wood can be difficult to identify.

SASSAFRAS

Black ash is more apt to be confused with sassafras *(Sassafras albidum;* photo at right on the facing page). Both woods have similar greyish-brown heartwood and a similar appearance on longitudinal surfaces. In the latewood of sassafras, however, tangential extensions of aliform parenchyma from latewood pores are the rule rather than the exception. The tyloses of sassafras are fairly abundant and tend to sparkle. Sassafras has a pleasant root-beer-like fragrance and taste. If the sample is aged and you suspect that it has lost its taste and smell, examine a radial section microscopically. The presence of oversized yellow oil cells among the rays in a radial section confirms that it is sassafras (see the photo below).

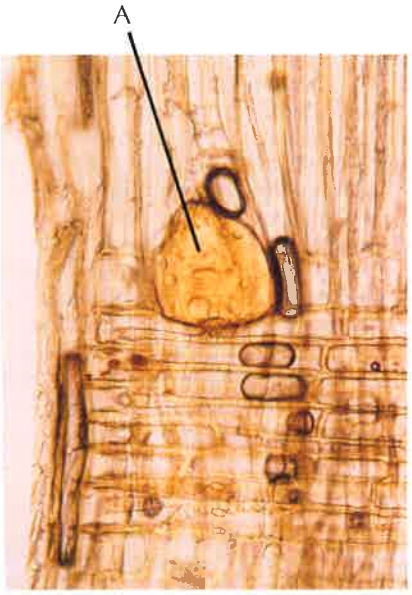
CATALPA

Of the woods in this group, catalpa (photo at left on p. 110) is the least dense and is noticeably soft. Its heartwood is medium brown to medium dark brown. It may also be greyish, and it sometimes has a faint lavender cast. Catalpa never retains more than two growth rings of sapwood; if an unknown contains sapwood with more than two rings, it is not catalpa. The tyloses of catalpa sparkle, and the wood has a faint but characteristic odor that is often described as spicy or musty. Latewood pores tend to be larger toward the earlywood; as they approach the outer latewood, they grade to very small and occur in clusters or nests. These clusters commonly merge to form either interrupted or reasonably continuous tangential bands in the outer latewood.

The earlywood is usually well defined, but occasionally it makes a gradual transition to latewood, suggesting a semi-ring-porous classification. Southern catalpa *(Catalpa bignonioides),* though essentially indistinguishable from northern catalpa *(C. speciosa),* tends to be semi-ring-porous.

OIL CELLS IN SASSAFRAS

Oil cells (A) are regularly scattered along the ray margins in sassafras. They are readily recognized by their extreme size and yellow oil contents.



RED MULBERRY

Red mulberry *(Morus rubra;* see the middle photo on page p. 110) is, at first glance, very similar to catalpa, but the heartwood is more orange or russet brown and turns deep russet brown on exposure to the atmosphere. Larger latewood pores are solitary and in multiples in first-formed latewood; they grade to small and clustered, often merging laterally in the outer latewood. Tyloses are moderately abundant and sparkle, and vessels sometimes contain white deposits. Whereas catalpa has no noticeable ray fleck, this feature is quite conspicuous in the heartwood of red mulberry, where it appears as a light fleck against darker background on radial surfaces. In cross sections, rays are not visible in catalpa but are distinct to the eye in red mulberry.

BLACK LOCUST AND OSAGE-ORANGE

The visibility of rays in cross sections also distinguishes red mulberry from black locust *(Robinia pseudoacacia)* and Osage-orange *(Maclura pomifera).* In the latter two species the rays can barely be seen with the eye, although they show up very distinctly as crisp bright lines with a hand lens. In red mulberry there is only a slight color contrast between ear-

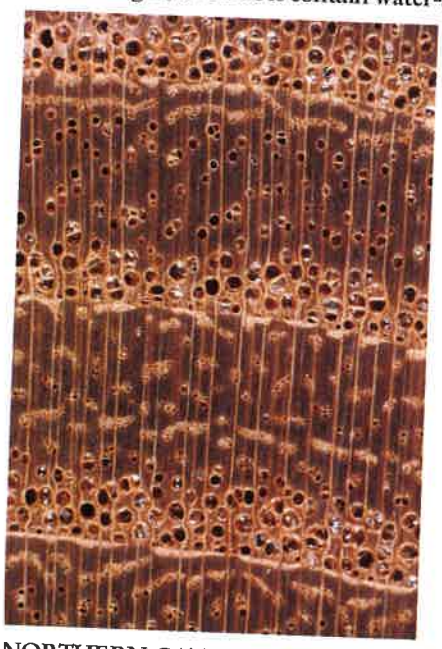
lywood and latewood; in black locust and Osage-orange the earlywood pores of the heartwood are completely packed with tyloses. Thus, individual pores are indistinct and the earlywood zone takes on a frothy yellow or creamy appearance. This contrasts with the dense, very dark brown fiber mass of the latewood, giving the wood an overall two-tone effect.

In both red mulberry and black locust the lighter-colored latewood pores and rays show up clearly against the dark fiber mass. The latewood pores of both species are small and clustered, and merge into tangential, intermittent bands and wavy lines. In both species, the high density and extreme hardness of the wood become obvious when you try to cut a cross section with a razor blade.

The similarity of principal features in

CATALPA, RED MULBERRY AND OSAGE-ORANGE

Catalpa is the least dense species in Subgroup I-3. Its softness, brown heartwood color and unique odor are characteristic. The rays of red mulberry are plainly visible on a transverse surface, and they produce conspicuous ray fleck on radial surfaces. Osage-orange, the densest of the group, has inconspicuous rays, and its pores are packed with tyloses. Osage-orange does not fluoresce under ultraviolet light, but it does contain water-soluble heartwood extractives.



NORTHERN CATALPA
Catalpa speciosa

Average Specific Gravity: 0.41
Heartwood Color: Greyish brown, sometimes with faint lavender cast
Sapwood: Never more than two growth rings wide
Odor: Faint but unique pungent, spicy odor
Pore Distribution: Ring-porous, or grading to semi-ring-porous
Earlywood: 3-8 pores wide; pores large
Latewood: Pores variable, large near earlywood, grading to very small in outer latewood, numerous in nests, which commonly merge into continuous or interrupted bands
Tyloses: Variably abundant, with sparkle
Rays: Indistinct to eye, but clearly visible with lens

Rays: 1-6 (mostly 2-3) seriate



RED MULBERRY
Morus rubra

Average Specific Gravity: 0.66
Heartwood Color: Orange-yellow to golden or russet brown, turning deep russet on exposure
Pore Distribution: Ring-porous
Earlywood: 2-8 pores wide; pores moderately large, may contain white deposits
Latewood: Pores in nestlike groups, merging laterally to form wavy or interrupted bands, especially in outer latewood
Tyloses: Variably present, with sparkle
Rays: Plainly visible to eye on transverse surface; radial surface shows conspicuous ray fleck

Rays: 1-8 (mostly 5-7) seriate



OSAGE-ORANGE
Maclura pomifera

Average Specific Gravity: 0.81
Heartwood Color: Golden yellow to orange or orange-brown, darkening on exposure; contains water-soluble dye, so shavings turn warm water yellow when soaked
Pore Distribution: Ring-porous
Earlywood: 2-3 pores wide; pores medium-large
Latewood: Pores small, in clusters, often merging or connected by confluent parenchyma into wavy or concentric bands in outer latewood
Tyloses: Extremely abundant, packing vessels
Rays: Barely visible to eye

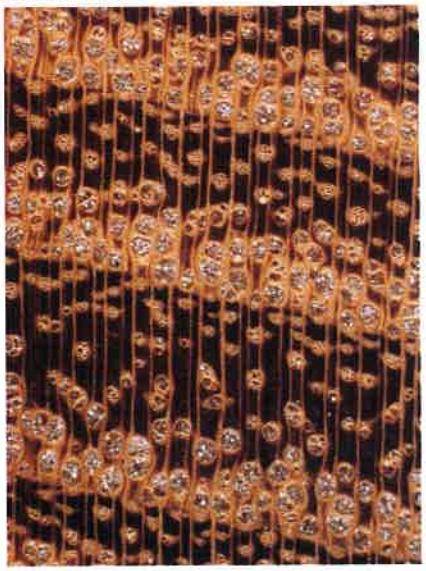
Rays: 1-6 (mostly 2-4) seriate
Crystals: Occur occasionally in longitudinal parenchyma cells

black locust and Osage-orange — high density, abundant tyloses, two-color effect, latewood pore arrangement and ray size — makes it difficult to tell these two woods apart. With a microscope, however, black locust can be confirmed by the presence of vestured intervessel pits, which do not occur in Osage-orange. Also, crystals are present in the longitudinal parenchyma of Osage-orange, whereas they are absent from black locust.

If a microscope is not available, either of two "gimmicks" can be used to separate these species. The first is a test that detects the water-soluble extractives in Osage-orange. To make the test, place a small handful of shavings in a white cup or dish, then cover with warm tap water and allow them to soak for two hours. Osage-orange will tint the water yellow

BLACK LOCUST, HONEYLOCUST AND KENTUCKY COFFEETREE

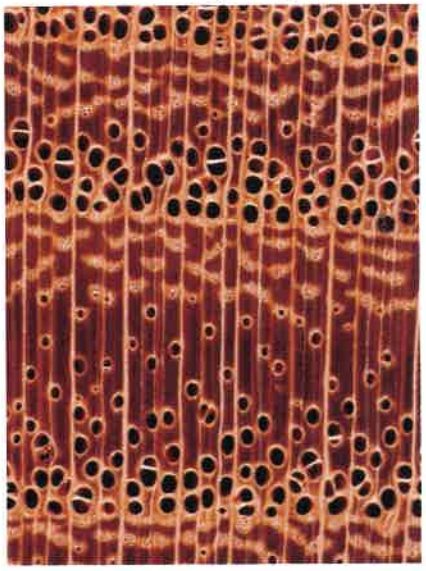
Abundant, packed tyloses give the pores of black locust a light color that contrasts with the dense, dark background fiber mass. The rays are equally light and conspicuous. Black locust has no soluble heartwood extractives, but all three woods show brilliant yellow fluorescence under ultraviolet light. Kentucky coffeetree and honeylocust have similar reddish-brown to reddish-orange-brown heartwood, but honeylocust has latewood pores that connect tangentially and more distinct rays than Kentucky coffeetree.



BLACK LOCUST
Robinia pseudoacacia

Average Specific Gravity: 0.69
Heartwood Color: Olive or yellow-brown to dark yellow-brown; dark russet brown with exposure
Fluorescence: Bright yellow
Sapwood: Never more than 3 growth rings wide
Pore Distribution: Ring-porous
Earlywood: 2-3 pores wide; pores large
Latewood: Pores in nestlike groups, which merge into interrupted or somewhat continuous bands in outer latewood; latewood fiber mass appears dense and dark in contrast to yellowish, tyloses-filled pores and rays
Tyloses: Extremely abundant, with yellow cast and sparkle, solidly packing vessels and making adjacent pores indistinct
Rays: Barely visible to eye, but distinct with lens

Rays: 1-7 (mostly 3-5) seriate



HONEYLOCUST
Gleditsia triacanthos

Average Specific Gravity: 0.66
Heartwood Color: Light red to reddish- or orange-brown
Fluorescence: Bright yellow
Pore Distribution: Ring-porous
Earlywood: 3-5+ pores wide; pores large
Latewood: Pores solitary, in radial multiples, and, especially in outer latewood, in nestlike groups and connected into bands by confluent parenchyma
Tyloses: Absent
Gum: Pores regularly contain reddish gum, especially evident on longitudinal surfaces
Rays: Variable in size, the largest conspicuous to the eye

Rays: 1-14 (mostly 6-9) seriate



KENTUCKY COFFEETREE
Gymnocladus dioicus

Average Specific Gravity: 0.60
Heartwood Color: Light red to reddish or orange brown
Fluorescence: Bright, deep yellow
Pore Distribution: Ring-porous
Earlywood: 3-6 pores wide; pores large
Latewood: Pores nested and sometimes merging into short irregular tangential bands in outer latewood
Tyloses: Absent
Gum: Reddish gum only rarely present
Rays: Uniformly fine, barely visible to eye

Rays: 1-7 (mostly 3-5) seriate

(it was used to dye military uniforms a dull khaki in World War I). Black locust shavings leave little or no color.

The second test is for fluorescent response to ultraviolet light. Osage-orange does not fluoresce under a black light, but the heartwood of black locust shows a brilliant yellow fluorescence (see Table 5.2 on p. 53).

HONEYLOCUST AND KENTUCKY COFFEETREE

Honeylocust *(Gleditsia triacanthos)* and Kentucky coffeetree *(Gymnocladus dioicus;* photos on p. 111), although detectably different from the other woods in this group, are easily confused with each other. The heartwood of both species commonly has an orange or reddish-orange hue; it also ranges from yellowish to brown. Neither wood has tyloses, as can be confirmed with a hand lens.

However, the pores of honeylocust do routinely contain red gum deposits, which are seen as deep red specks on longitudinal surfaces. These deposits are absent or very sparse in coffeetree. The two woods are more reliably separated by the size and arrangement of latewood pores, as well as by their rays. In both woods the first-formed latewood pores are large and distinct as seen with a hand lens. They are either solitary or in multiples. But they grade to very small and occur in clusters toward the outer latewood.

In coffeetree, the small latewood pores are seen with a hand lens to occur in separate nestlike clusters, with only a slight tendency to merge into short wavy bands along the outer latewood. In honeylocust, the pores in the outer latewood are fewer — either solitary or in small multiples — and are usually indistinct with a hand lens. But they are surrounded by lighter parenchyma. The parenchyma forms distinct interrupted or continuous wavy bands in the outer latewood.

In coffeetree, the rays are practically invisible to the eye, although they are distinct and appear uniformly thin with a hand lens. With a microscope, however, they are found to be 1-7 (mostly 3-5) seriate. In honeylocust, the largest rays are distinctly visible to the eye and can be seen with a hand lens to vary in size. Microscopic examination shows them to be mostly 6-9 seriate, with the widest up to 14 seriate. Both woods show yellow fluorescence under ultraviolet light. Honeylocust is the brighter of the two; in coffeetree, the earlywood shows a diminished response, making its growth rings more conspicuous.

SUMAC

The earlywood of staghorn sumac is a multiple band of very small pores. The unique heartwood shades of green, yellow-greens and russet show brilliant but variable fluorescence under ultraviolet light.



STAGHORN SUMAC
Rhus typhina

Average Specific Gravity: 0.47
Heartwood Color: Olive green to greenish yellow, often with orange or russet brown earlywood
Fluorescence: Variable yellow to bluish
Pore Distribution: Ring-porous
Earlywood: 2-6 pores wide; pores fairly small
Latewood: Pores solitary or in radial multiples, but merging into continuous bands in outer latewood
Tyloses: Variably abundant with iridescent sparkle
Rays: Not conspicuous, even with lens

Rays: 1-3 (mostly 1-2) seriate

STAGHORN SUMAC

The final wood in this group is staghorn sumac *(Rhus typhina;* photo below left). Fresh specimens are recognized quickly on the basis of color. The narrow sapwood is milky white, but the heartwood is a dusty yellowish green — or greenish yellow — reflecting the dominant latewood hue. Careful examination of the earlywood bands reveals a brownish or russet tinge. On a cross section, each growth ring appears darker along the outer latewood.

Earlywood pores are imperceptibly small to the unaided eye. They are clearly seen with a lens, but they are small compared to those of most ring-porous woods. We see the wood as ring-porous more because this 2 to 6-pore wide band is so concentrated than because the pores are large. Rays are visible but inconspicuous with a hand lens. They are the narrowest of this group; a microscopic check reveals that they are only 1-2 seriate.

Under ultraviolet light, staghorn sumac heartwood shows striking fluorescence, each ring glowing a bright greenish yellow along the outer latewood, grading through dull yellow to a very deep blue in the earlywood. The sapwood has a dim medium-blue fluorescence.

Ring-Porous Subgroup I-4: Hickory and Pecan

Woods in Subgroup I-4 belong to the genus *Carya.* All have the distinguishing feature of banded parenchyma in fairly long, straight, more or less continuous tangential lines. With a hand lens, these appear as bright as the rays. The combination of parenchyma and rays creates a netlike or weblike pattern on the dense fiber-mass background of the latewood. The earlywood pores are large and form an intermittent row along the growth-ring boundary. Between earlywood pores are masses of dense fiber, continuous with the fiber mass of the latewood, unlike the earlywood of species such as white ash, where lighter-colored tissue mass fills any earlywood areas not already occupied by pores. The latewood pores, which are thick-walled, are rela-

tively few, occurring as solitary pores or in radial multiples of two or more. They are individually distinct when viewed with a hand lens.

The above features make it possible to differentiate these woods of the *Carya* group from others. Within the genus, however, separation of the individual species is another matter. The *Carya* species at best can be divided into two subgroups, the true hickories and the pecan hickories (Table 10.3 below).

As seen in the table below, true hickories are denser — and thus stronger — than pecan hickories; the woods are used in practical applications accordingly. But these density differences alone are not great enough to be reliable for identification. A more positive separation can be made on the basis of parenchyma distribution and pore classification. In true hickories banded parenchyma does not occur in the earlywood zone (see the photo at near right), whereas in the pecan hickories the lines of banded parenchyma occur well into the earlywood pore zone.

The true hickories are typically ring-porous, the largest pores being restricted mainly to a single interrupted row along the growth-ring boundary; thus the earlywood is really only one pore wide. The transition to latewood is defined by a fairly abrupt reduction in pore size. The pecan hickories, by contrast, have less well defined earlywood and a gradual gradation in pore size across the growth ring. In this way they are more typically semi-ring-porous, which is why I have placed the *Carya* group at the end of the ring-porous woods. Pecan hickory could just as well be included in the next section on semi-ring-porous woods.

TRUE HICKORY AND PECAN HICKORY

The fine tangential lines of banded parenchyma, together with the radial lines of the rays, form a meshlike pattern against the background latewood fiber mass, which is a trademark of *Carya*. The true hickories (such as shagbark hickory) are more typically ring-porous; the pecan hickories appear more semi-ring-porous. In true hickory, the banded parenchyma is absent in the zone of earlywood pores; in pecan hickories, banded parenchyma occurs even in the earlywood.



SHAGBARK HICKORY
Carya ovata

Average Specific Gravity: 0.72
Heartwood Color: Light to medium brown or reddish brown
Pore Distribution: Ring-porous
Earlywood: Mostly an intermittent single row of thick-walled pores with fiber mass where interrupted
Latewood: Pores not numerous, solitary and in radial multiples of 2-5
Tyloses: Moderately abundant
Parenchyma: Banded parenchyma and rays form a reticulate pattern distinctly visible against the background fiber mass with a hand lens (but banded parenchyma absent from earlywood zone)

Rays: 1-4 seriate
Latewood Pores: Thick-walled



PECAN
Carya illinoensis

Average Specific Gravity: 0.66
Heartwood Color: Light to medium reddish brown
Pore Distribution: Semi-ring-porous (or ring-porous in narrow rings)
Pores: Large, interrupted along growth ring boundary by areas of fiber mass; gradual transition to smaller latewood pores, which are solitary or in radial multiples of 2-3
Tyloses: Moderately abundant
Parenchyma: Banded, distinct with hand lens, forming reticulate pattern with rays (banded parenchyma usually also in earlywood zone)

Rays: 1-4 seriate
Latewood Pores: Thick-walled

TABLE 10.3: WOODS IN THE HICKORY AND PECAN GROUP *(CARYA)*

	True Hickories	Specific Gravity		Pecan Hickories	Specific Gravity
C. glabra	Pignut hickory	0.75	*C. aquatica*	Water hickory	0.62
C. laciniosa	Shellbark hickory	0.69	*C. cordiformis*	Bitternut hickory	0.66
C. ovata	Shagbark hickory	0.72	*C. illinoensis*	Pecan	0.66
C. tomentosa	Mockernut hickory	0.72	*C. myristiciformis*	Nutmeg hickory	0.60

GROUP II: SEMI-RING-POROUS OR SEMI-DIFFUSE-POROUS HARDWOODS

As the title of this group suggests, these woods have a pore distribution that is neither ring-porous nor diffuse-porous but somewhere in between. Here we find pores that are noticeably larger in the earlywood than in the latewood but that typically show a gradual size transition from earlywood to latewood. The earlywood zone is not clearly delineated from the latewood zone.

Only a few woods consistently show the pore distribution that typifies this category. These include live oak, tanoak, persimmon and the walnuts, including butternut. It is important to emphasize that in many species, samples of the wood can intergrade from the categories of ring-porous or diffuse-porous into the "semi-" category. If they are usually ring-porous, I think of them as semi-ring-porous. If they are usually diffuse-porous, I call them semi-diffuse-porous. However, there is a wide range of opinion regarding these names.

As previously mentioned, the true hickories in the *Carya* group are typically ring-porous, whereas the pecans are semi-ring-porous. In some species, like northern catalpa, which is usually ring-porous, individual samples may appear semi-ring-porous. Among certain woods that are typically diffuse-porous, larger earlywood pore size in some samples strongly suggests semi-ring-porosity. Examples are willow and cottonwood.

Semi-Ring-Porous Subgroup II-1: Live Oak and Tanoak

Among the semi-ring-porous woods, live oak (*Quercus virginiana*) and tanoak (*Lithocarpus densiflorus*) are distinct in that they have rays that are large enough to be clearly visible to the eye on transverse surfaces, as shown in the photos at right. With a hand lens, it is apparent that

LIVE OAK AND TANOAK

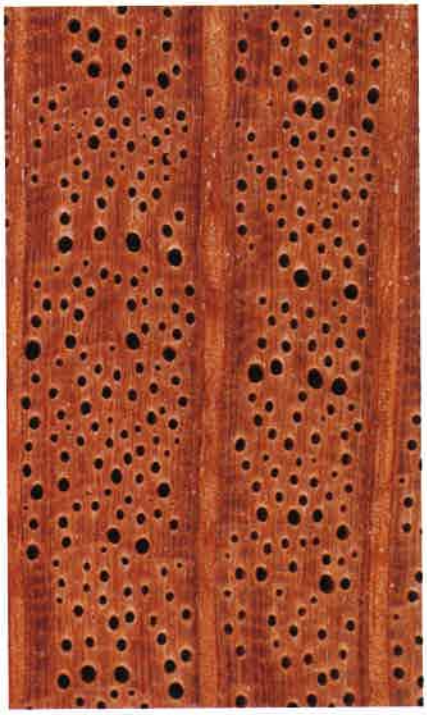
Both live oak and tanoak are semi-ring-porous (the largest pores are scarcely visible to the eye) and have occasional large conspicuous rays. In tanoak, latewood pores occur in radially arranged streamerlike patches of lighter-colored tissue; between the patches, irregular lines of banded parenchyma cross the fiber mass. In live oak, latewood pores are in a more irregular arrangement, and tangential bands of parenchyma are absent in the latewood.



LIVE OAK
Quercus virginiana

Average Specific Gravity: 0.88
Heartwood Color: Brown to grey brown
Pore Distribution: Semi-ring-porous; growth rings not always distinct
Pores: Largest pores not distinct without lens; gradual transition to smaller pores in latewood, generally in radial arrangement
Tyloses: Sparse
Parenchyma: Faintly visible in broken, irregular lines in latewood
Rays: Largest multiseriate rays conspicuous to eye

Rays: Narrow rays uniseriate



TANOAK
Lithocarpus densiflorus

Average Specific Gravity: 0.65
Heartwood Color: Light reddish brown, aging upon exposure to dark reddish brown
Pore Distribution: Semi-ring-porous; growth rings not distinct
Pores: Largest pores barely visible, distinct only with lens, arranged in streamerlike patches of lighter-colored tissue that may extend across several growth rings
Tyloses: Present
Parenchyma: Tangential lines of parenchyma visible with lens across areas of fiber mass between pore zones
Rays: Large rays present, but not always conspicuous

Rays: Narrow rays uniseriate

rays in these two woods are of two distinctly different sizes — the large, conspicuous multiseriate rays are separated by many smaller, mainly uniseriate rays.

Unlike most oaks, which are typically ring-porous woods with large, obvious earlywood pores, the largest pores in live oak are barely visible to the unaided eye. Its rings are usually indistinct, delineated more by denser marginal latewood than by pore-size variation. Although the pores are larger in the earlywood zone of the growth ring, the transition to the smallest latewood pores is gradual. Tyloses are sparse, and the pores are arranged in groups that are somewhat irregular, although they have a general radial arrangement. Broken lines of banded parenchyma are only faintly visible in the latewood.

The large rays are up to ½ in. high and show on tangential surfaces as conspicuous dark lines against the brown to grey-brown heartwood. Live oak is unusually heavy and dense, with an average specific gravity of 0.88. It is a native of coastal areas of the southern states along the Atlantic Ocean and the Gulf of Mexico. Tanoak is found in southwest Oregon and in California. Although not a true oak, it doubtless derives its common name in part from its large, oaklike rays. (Its common-name prefix alludes to the historical use of its bark as a source of tannin for the hide-tanning process.) In contrast to live oak, its wood is moderately heavy, with an average specific gravity of 0.65, and it has a light, reddish-brown heartwood that darkens with age.

In cross section, the pores of tanoak, which are barely visible to the eye, occur in streamerlike radial patches of lighter-colored tissue. These appear to be continuous across several rings, sometimes with so little pore-size variation as to suggest classification as a diffuse-porous wood. Growth rings are only faintly evident because of the denser fiber mass along the outer latewood. With a hand lens we can see that there are irregular but distinct tangential lines of banded parenchyma between the radial patches of pores; this helps distinguish tanoak from live oak. The large, multiseriate rays occur in varying numbers. The largest are up to 1 in. or more high, but, in contrast to live oak, they are often inconspicuous because of the lack of color contrast with background tissue.

Semi-Ring-Porous Subgroup II-2: Persimmon

The very wide sapwood of common persimmon *(Diospyros virginiana;* photo at right) is creamy white when freshly cut, but it typically darkens to yellow or light grey upon aging. The small core of heartwood may be dark to nearly black — persimmon is in the same genus, *Diospyros,* as ebony. Growth rings are not conspicuous to the eye, and longitudinal surfaces may be lacking in growth-ring figure. Although vessels are barely visible to the eye, vessel lines are quite evident. At first glance, they give this wood an appearance that can be confused with coarse-textured birch, cottonwood or ramin.

In cross section, the pores of persimmon are distinct with a hand lens. Vessels are very thick-walled, occurring as radially oval solitary pores or in radial multiples of two to three. The gradual gradation in pore size from larger in the earlywood to fairly small in the latewood is typical of the semi-ring-porous arrangement. Overall, the pores appear to be few in number against the uniform fiber mass. This fiber mass forms a background against which the fine 1-3 seriate rays and fine lines of banded parenchyma can be seen with a hand lens.

Persimmon is most often confused with the pecan hickories due to its similar pore distribution and ray/parenchyma network. But it can be separated by either of two important features. Persimmon has ripple marks, which are lacking in hickory. These ripple marks, which are due to storied structure, are best seen with a hand lens on tangential surfaces. Under a microscope, a tangential section shows very fine intervessel pitting — 2 to 4 micrometers in diameter — with confluent apertures connecting up to several pits. This contrasts with the larger — 6 to 8 micrometers in diameter — alternate pits of hickory.

PERSIMMON

Persimmon exemplifies the semi-ring-porous subgroup. On a transverse surface, it displays a fine-lined network of banded parenchyma and rays that is confusingly similar to that of pecan hickories. However, positive separation is provided by the ripple marks on tangential surfaces of persimmon, or microscopically by the much smaller-diameter intervessel pits of persimmon.



COMMON PERSIMMON
Diospyros virginiana

Average Specific Gravity: 0.74
Heartwood Color: Core dark, nearly black
Sapwood Color: Creamy white, darkening to yellow or light grey with age (very wide)
Pore Distribution: Semi-ring-porous; growth rings not distinct
Pores: Largest pores medium to large, thick-walled; appear to be relatively few; solitary or in radial multiples
Tyloses: Occasionally present
Parenchyma: Fine tangential lines visible with lens
Rays: Fine, visible with lens
Ripple Marks: On tangential surfaces due to storied structure

Rays: Storied, 1-3 seriate
Latewood Pores: Thick-walled
Intervessel Pitting: Alternate, minute (2-4 μm) with confluent apertures

Semi-Ring-Porous Subgroup II-3: Walnut and Butternut

The genus *Juglans* includes several species that we know as walnut, as well as butternut (photos at right). In the United States, black walnut *(Juglans nigra)* is probably the most valuable and certainly one of the most popular domestic hardwoods. Several other species of walnut with similar wood are also locally important. These include northern California walnut *(J. hindsii)* and southern California walnut *(J. californica).* Another important timber species of the genus is butternut *(J. cinerea).*

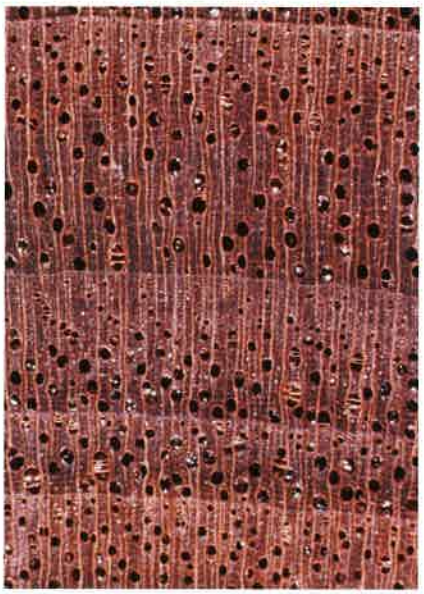
With the hand lens, the cellular features on transverse surfaces read with confusing similarity in both black walnut and butternut. Since the first earlywood pores are fairly large, vessel lines show quite prominently on longitudinal surfaces at a considerable distance. Although this feature is common to black walnut and butternut, it helps separate them from a few confusing look-alikes such as willow. The pores decrease very gradually from large in the earlywood to fairly small in the outer latewood, which is typical of the semi-ring-porous classification. This distribution is often quite striking on tangential surfaces (see the photo on the facing page).

It is especially difficult to distinguish walnut from butternut in slowly grown pieces, where the narrow rings repeat the larger earlywood pores in closely spaced succession. In both woods, the pores are sometimes solitary and sometimes in radial multiples of two to several. Other similar features, as seen with a hand lens, are the fairly abundant tyloses, fine rays (indistinct without a hand lens) and short tangential lines of banded or diffuse-in-aggregates parenchyma. These latter are visible with a hand lens, but are more distinct in some samples than in others.

Due to the similarities among features seen with the hand lens, it helps to consider several gross features when separating black walnut and butternut. The first is color. Typical black walnut heartwood is a rich, dark chocolate brown; sometimes there is a purple tinge when the wood is freshly cut. By contrast, butter-

WALNUT AND BUTTERNUT

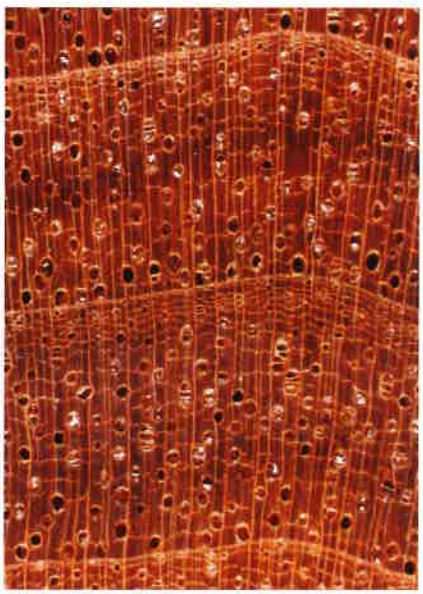
Walnut and butternut are similar in that they are both semi-ring-porous, with faint, short bands of diffuse-in-aggregates parenchyma visible with a hand lens. The chocolate-brown heartwood and higher density of black walnut distinguishes it from butternut, whose heartwood is medium brown.



BLACK WALNUT
Juglans nigra

Average Specific Gravity: 0.55
Heartwood Color: Medium brown to deep chocolate brown
Pore Distribution: Semi-ring-porous
Pores: Earlywood pores fairly large, decreasing gradually to quite small in outer latewood; pores solitary or in radial multiples of 2 to several
Tyloses: Moderately abundant
Parenchyma: Short tangential lines of banded or diffuse-in-aggregates parenchyma visible with lens
Rays: Fine, visible but not conspicuous with lens

Rays: 1-5 seriate; ray cells appear round in tangential view
Crystals: Occur sporadically in longitudinal parenchyma cells
Thickenings: Reticulate thickenings ("gashlike pits") occasionally found in latewood vessels



BUTTERNUT
Juglans cinerea

Average Specific Gravity: 0.38
Heartwood Color: Medium or cinnamon brown, often with uneven streaks of color; growth rings usually fluted
Pore Distribution: Semi-ring-porous
Pores: Earlywood pores fairly large, decreasing gradually in size to quite small in outer latewood; pores solitary or in radial multiples of 2 to several
Tyloses: Moderately abundant
Parenchyma: Short tangential lines of banded or diffuse-in-aggregates parenchyma visible with lens
Rays: Fine, visible but not conspicuous with lens

Rays: 1-4 seriate; ray cells appear oval in tangential view
Crystals: Never present in longitudinal parenchyma
Thickenings: Reticulate thickenings never present in vessels

nut is typically lighter, in shades of chestnut or cinnamon brown. It often shows considerable variegation (unevenness of pigment). When a cleanly cut end-grain surface of typical black walnut is moistened, it deepens in color to rich sepia — the color of baker's chocolate — whereas wet butternut end grain usually maintains its brown color with a distinct orange cast. Still, these color ranges overlap occasionally — darker pieces of butternut can be confused with lighter pieces of black walnut.

Density and hardness are also important distinguishing features. The softer, lighter-weight butternut is more easily dented with the thumbnail, in contrast to black walnut, which is harder. Bear in mind, however, that their specific-gravity ranges overlap. Butternut usually has fluted rings, so look for an irregular or jagged ring figure on tangential surfaces. This feature is far from conclusive, however, since black walnut occasionally has fluted rings too (see the photos on p. 64.

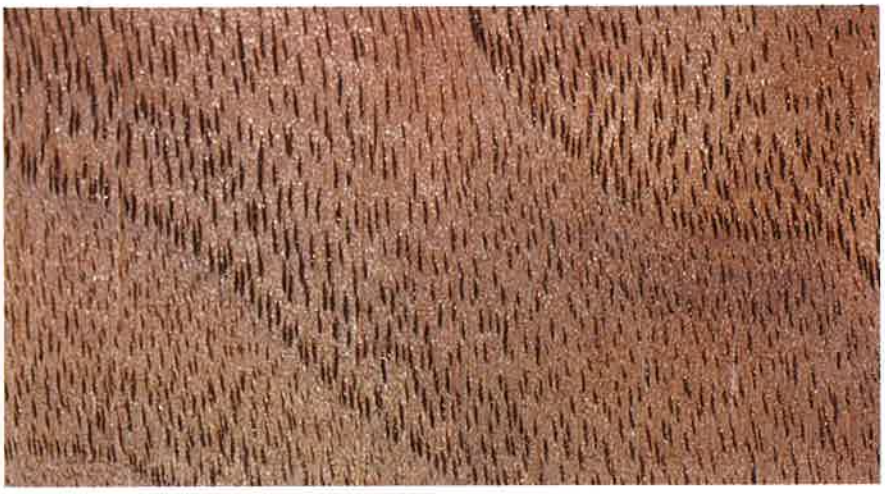
Microscopic features are especially valuable in identifying these woods. In black walnut, rays are up to 5 seriate; viewed tangentially, the cells are typically rounded. In butternut, the rays are up to 4 seriate, and the cells are vertically oval or flattened. In black walnut, reticulate thickenings occur sporadically on the walls of latewood vessel elements. These so-called gashlike pits (see the photo on p. 37), which do not occur in butternut, are best found by scanning radial sections of latewood.

In addition, some samples of black walnut may contain large, diamond-shaped crystals within longitudinal parenchyma (see the photo on p. 40). When looking for crystals, any convenient longitudinal surface can be used as a section.

Another very important species of walnut, European walnut *(Juglans regia)* — variously known as English walnut, French walnut and Circassian walnut, according to its source — is confusingly similar to black walnut *(J. nigra)*. When these two woods are placed side by side, the European walnut usually appears lighter and less uniform in color than the more evenly deep-brown black walnut. Moreover, the European walnut seems more diffuse-porous, since it lacks the pore-size contrast of black walnut. Isolated samples, however, are best separated microscopically. Since neither "gashlike pits" nor crystals in longitudinal parenchyma occur in European walnut, the presence of either confirms black walnut. It requires careful judgment to identify a sample as European walnut because neither feature is found.

PORE SIZE DISTRIBUTION IN BLACK WALNUT

The semi-ring-porous structure of black walnut is evident in the gradation of vessel lines from earlywood to latewood within each growth ring on this tangential surface.



GROUP III: DIFFUSE-POROUS HARDWOODS

As with the ring-porous hardwoods, a few diffuse-porous species have strikingly large rays that clearly distinguish them from the other species in the category. We shall begin with these since their identification is relatively easy. Among the remaining subgroups, however, there are some confusing similarities, or perhaps more accurately, a lack of differences. In some cases it is best to examine microscopic features to make a reliable separation within a group or between a pair of woods.

Diffuse-Porous Subgroup III-1: Beech and Sycamore

Among diffuse-porous woods, the two that can be identified by eye most of the time are American beech *(Fagus grandifolia)* and sycamore *(Platanus occidentalis)*. Both have large and fairly numerous rays that are easily visible on any surface (see the photos on p. 118). On smoothly cut cross sections, the rays appear as conspicuous bright lines; with a hand lens they are clearly noded. Ray fleck is striking on radial surfaces (see the photos at the top of p. 119).

Even though beech and sycamore can usually be identified by gross features, the two woods can be confused. For example, a cross section of either species will show pores that are numerous and either solitary or in multiples. The multiples are both radial and tangential, merging in some cases into small clusters. The pore size and distribution is fairly uniform through most of the ring. Toward the latewood edge, however, pores decrease abruptly in size and number, resulting in a distinct narrow-to-wide band of latewood. This band appears to be denser than the surrounding wood.

Beyond these general similarities, however, there are some important differences that enable us to separate the species readily. In a beech cross section, the latewood band has a distinctly darker shade. In sycamore, by contrast, the late-

wood appears lighter in color, which is an anomaly among most woods.

Closer study of the rays gives us further basis for separating these woods. In sycamore, the rays are much more uniform in size and more closely spaced when viewed tangentially (see the photos at the bottom of the facing page). In beech the largest rays are generally larger and are more widely and irregularly distributed. In cross section, the rays of beech look much more uneven in size.

Either wood can be checked microscopically. The rays of sycamore range in width to a maximum of about 14 seriate; beech rays are divided into two size classes: narrow 1-5 seriate, and large 15-25 seriate. Intervessel pits in sycamore are typically oval and more widely spaced. The pitting in beech is often crowded and angular and sometimes transversely elongated.

The wood of the plane tree or London plane *(Platanus acerifolia)*, which grows in Europe, is very similar to that of American sycamore *(Platanus occidentalis)*. Nor can European beech *(Fagus sylvatica)* be readily separated from American beech *(Fagus grandifolia)*, although American beech sometimes has crystals in its longitudinal and ray parenchyma cells which are not seen in European beech.

BEECH AND SYCAMORE SURFACES

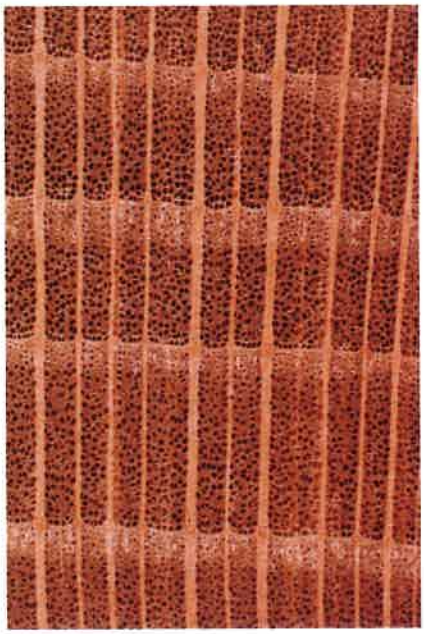
Both beech and sycamore are diffuse-porous woods with a zone of denser latewood in the outer ring; their large, conspicuous rays are noded at the growth-ring boundary. Ray size and spacing are fairly uniform in sycamore, but much more variable in beech.



AMERICAN BEECH
Fagus grandifolia

Average Specific Gravity: 0.64
Heartwood Color: Creamy white with reddish tinge to medium reddish brown
Pore Distribution: Diffuse-porous; growth rings distinct
Pores: Small, solitary and in irregular multiples and clusters, numerous and evenly distributed throughout most of the ring; narrow but distinct latewood in each ring due to fewer, smaller pores
Rays: Largest rays conspicuous on all surfaces; darker ray fleck against lighter background on radial surfaces

Rays: Largest rays 15-25 seriate; uniseriate rays common
Crystals: Occasional in longitudinal parenchyma and ray cells



SYCAMORE
Platanus occidentalis

Average Specific Gravity: 0.49
Heartwood Color: Light to dark brown, usually with a reddish cast
Pore Distribution: Diffuse-porous; growth rings distinct due to unusual lighter color of latewood
Pores: Small, solitary and in irregular multiples and clusters, numerous and evenly distributed throughout most of the growth ring; latewood zone evident by fewer, smaller pores and lighter color
Rays: Easily visible without lens on all surfaces, appearing uniform in size and evenly spaced on transverse and tangential surfaces, producing conspicuous dark ray fleck on radial surfaces

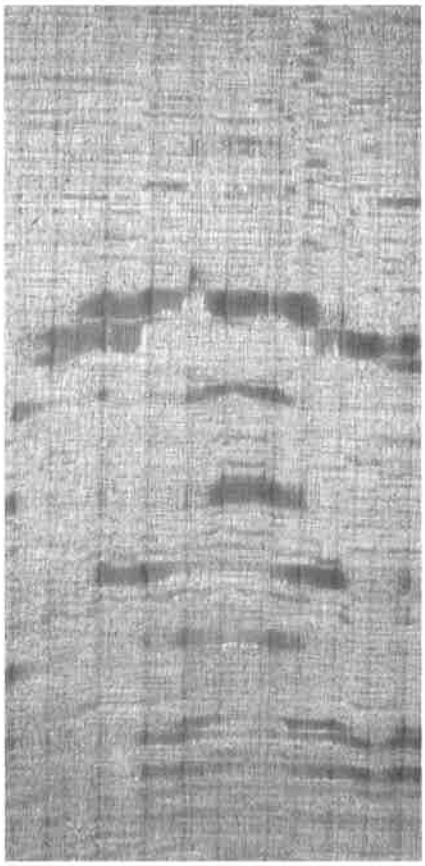
Rays: Largest up to 14 seriate; uniseriate rays not common

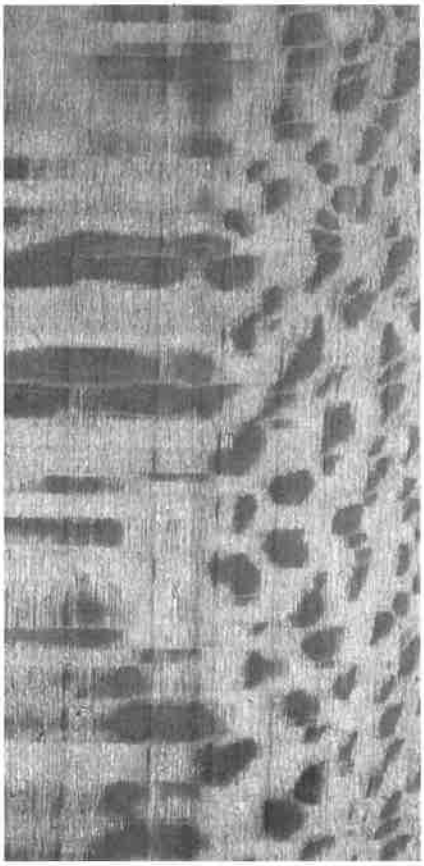
Diffuse-Porous Subgroup III-2: Hornbeam and Alder

American hornbeam *(Carpinus caroliniana)*, commonly called blue beech, and red alder *(Alnus rubra)* are the two woods in this book that have aggregate rays. Each wood has a normal distribution of invisibly narrow rays, but the aggregate rays are very conspicuous (see the photos on p. 120). This is as much a result of their erratic placement as of their large size. The placement is different from the reasonably uniform spacing of large rays in the oaks, beech and sycamore. The aggregate rays appear in cross sections as bold radial lines, less conspicuous in some samples than in others. On longitudinal surfaces they appear as darker lines or streaks against the background of fairly uniform cell structure.

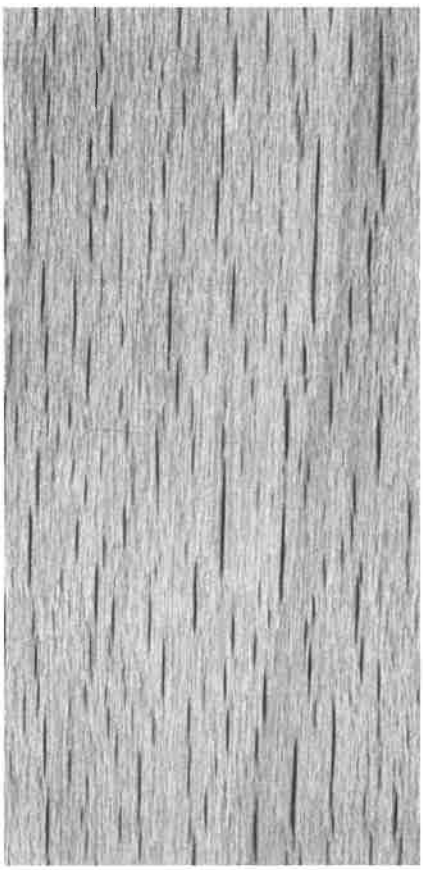
Both species are diffuse-porous and fine-textured; their pores are indistinct without a hand lens. The narrow rays are also invisibly small. The two woods can usually be separated on the basis of gross and macroscopic features and confirmed through microscopic examination.

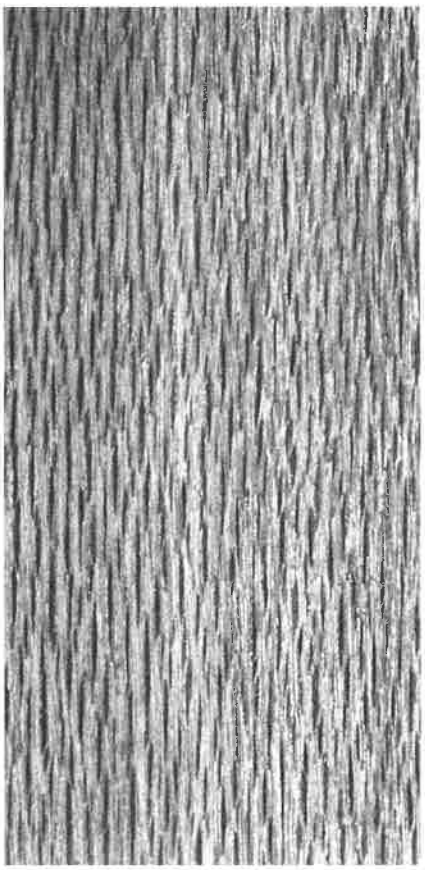
Red alder, the principal hardwood species of the coastal Pacific from central California to Alaska, is pale tan when freshly cut. It darkens gradually with age to a light reddish brown or flesh color. It is moderately soft, with an average specific gravity of 0.41. The small pores are seen with a hand lens as solitary or in multiples of a few to several — in this re-





BEECH AND SYCAMORE
RADIAL SURFACES
Although both beech (far left) and sycamore (left) display striking ray fleck, the more even size and spacing of rays in sycamore is evident.





BEECH AND SYCAMORE
TANGENTIAL SURFACES
In beech (far left), rays appear variable in size and irregular in distribution; in sycamore (left), the rays are more uniform in size and distribution, and appear to be more closely spaced. Microscopic examination reveals that the largest rays in beech are 15-25+ seriate; maximum ray width in sycamore is about 14 seriate.

AMERICAN HORNBEAM AND RED ALDER

American hornbeam and red alder are fine-textured, diffuse-porous woods that have scattered conspicuous aggregate rays. The heartwood of red alder ages to a light reddish brown or flesh color; American hornbeam heartwood is pale yellowish or brownish white, commonly with a grey cast. A microscopic check reveals that American hornbeam has vessels with spiral thickenings and perforation plates that are simple or scalariform, with very few bars. Red alder has scalariform perforation plates with 20+ bars and its vessels lack spiral thickenings.



AMERICAN HORNBEAM
Carpinus caroliniana

Average Specific Gravity: 0.70
Heartwood Color: Light with brown, gray, or yellow cast
Pore Distribution: Diffuse-porous; growth rings with irregular contours or flutes, delineated by narrow, lighter tissue in outer latewood
Pores: Small, sometimes more numerous in initial earlywood, mostly arranged in radial multiples and forming loose radial strings
Rays: Large aggregate rays few to fairly numerous and visible without lens
Rays: Narrow rays 1-4 (mostly 1-2) seriate
Spiral Thickenings: Present
Perforation Plates: Mostly simple, or scalariform with up to 5 thick bars
Intervessel Pitting: Alternate



RED ALDER
Alnus rubra

Average Specific Gravity: 0.41
Heartwood Color: Pale tan when freshly cut (not distinct from sapwood) darkening with age to light reddish brown or flesh color
Pore Distribution: Diffuse-porous
Pores: Small, solitary and in mostly radial multiples
Rays: Large aggregate rays widely scattered but easily seen without lens
Rays: Narrow rays uniseriate, occasionally biseriate
Spiral Thickenings: Absent
Perforation Plates: Scalariform with up to 20+ thin bars
Intervessel Pitting: Alternate to opposite

gard, they are confusingly similar to aspen or fine-textured birch.

Microscopically, vessels in red alder are seen to have scalariform perforation plates with up to 20 or more thin bars. The intervessel pitting is alternate to opposite, and the pits are small, oval and spaced apart from each other. The narrow rays are homocellular and uniseriate.

Grey alder *(A. incana)*, a native of Europe, and common alder *(A. glutinosa)* are anatomically similar to red alder.

American hornbeam is pale yellowish or brownish white, commonly with a greyish cast. The wood is heavy and hard, with an average specific gravity of 0.70. These relatively small trees have fluted stems, so growth rings are commonly irregular. They are distinct to the eye, with a narrow band of whitish tissue along the outer latewood. In some pieces, as seen with a hand lens, the pores along the first-formed earlywood are more numerous and form a loosely organized row; the remaining pores occur mostly in multiples of two or more and merge into longer radial multiples or irregular radial chains.

Microscopic examination of American hornbeam shows vessels with spiral thickenings and mostly simple perforations, with occasional scalariform perforations with up to five thick bars. Intervessel pitting is alternate, the large pits rounded or angular and crowded together. The narrow rays are 1-4 (mostly 1-2) seriate.

Diffuse-Porous Subgroup III-3: The Confusing Diffuse-Porous Woods

These hardwoods are the most difficult to identify because they generally lack striking figure, are fine-textured and have inconspicuous or invisible rays. Although any one wood in this group may be quite clearly different from another — for example, cherry from holly — there is also one or more species to which it is confusingly similar. There is no obvious systematic way to order these woods. I have chosen to group those that tend to be confused with each other close together, so that distinguish-

ing differences — where they exist — can be highlighted. I have also attempted to separate the overall subgroup into groupings based on the visibility of rays on transverse surfaces.

But there are two important caveats. First, the normal range of anatomical variation includes a few samples that will depart drastically from the average description. For example, although the rays in a typical piece of soft maple are moderately distinct with a hand lens, on occasion they may scarcely show; in another piece they may be unusually conspicuous. Second, the identification of diffuse-porous hardwoods is the least reliable when the wood is examined with the naked eye or hand lens. As with conifers, an identification is best confirmed with a microscope. On the plus side, very small, toothpick-sized samples of diffuse-porous woods often contain the key anatomical features for positive identification.

Table 10.6 on pp. 138-141 summarizes some of the features that are helpful in the separation process and that can be seen with the naked eye, hand lens or microscope. The table can be used for quick reference to find definitive differences between tentative possibilities. For example, it tells us that dogwood is significantly heavier than aspen, and that birch has scalariform perforation plates, whereas those in maple are simple. It can also be used as a starting point for identification within the diffuse-porous group. For example, if you examine an unknown wood and find spiral thickenings, you can immediately eliminate those woods in which spirals are not found. If that same wood is obviously soft and of low density, basswood and buckeye are likely candidates. Comparing these woods further with the chart would indicate that they differ in ray seriation. Therefore, the logical next step would be to check to see if the rays are exclusively uniseriate, as in buckeye, or multiseriate, as in basswood.

THE MAPLES

North American maples (see the photos on p. 123) are divided into hard maples and soft maples. The hard-maple group, whose specific gravity ranges from 0.57 to 0.63, consists principally of sugar maple *(Acer saccharum),* but also includes black maple *(A. nigrum).* In the soft-maple group, whose specific gravity range is 0.46 to 0.54, the most common species is red maple *(A. rubrum).* Other soft maples are silver maple *(A. saccharinum)* and boxelder *(A. negundo).* An unknown maple can usually be placed in one of these subgroups; within a group, however, species cannot be identified with certainty.

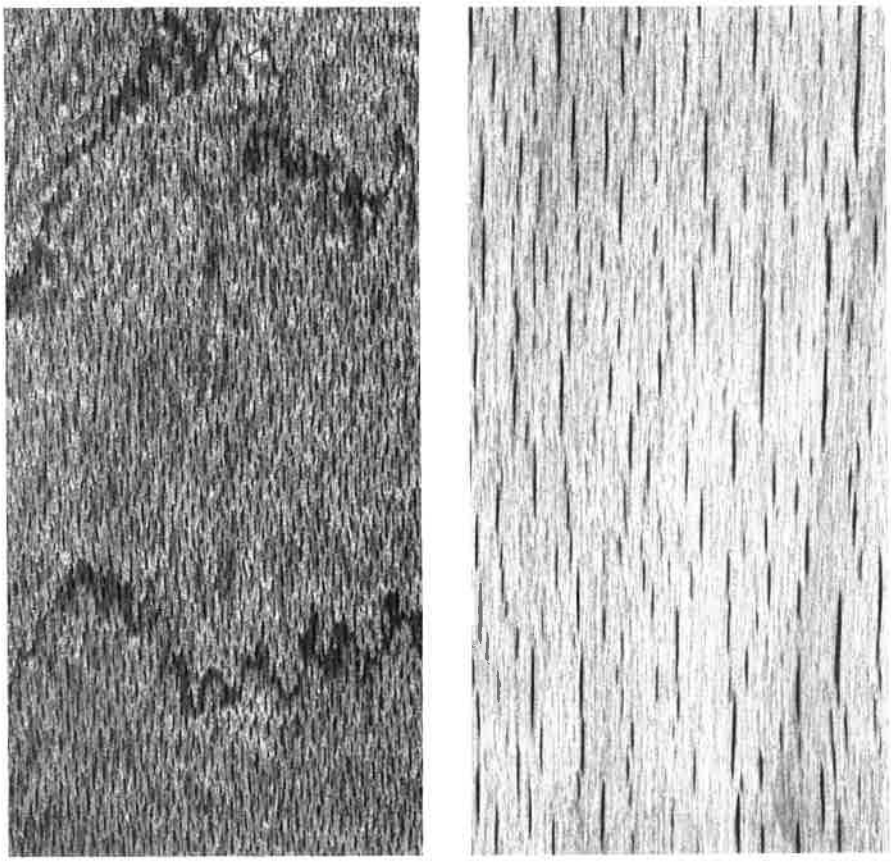
Wood of the maples ranges in color from creamy white to very light brown. Soft maples, red maple in particular, may have an overall greyish cast or streaks. Growth rings are distinct due to the narrow zone of darker brown cells at the outer margin of the growth ring. On tangential surfaces the rays are visible as tiny dark lines, reasonably uniform in size and spacing (see the photos below). They vary from quite distinct in hard maples to barely visible in some soft maples. Usually, however, they can be seen readily with a hand lens.

On radial surfaces, the rays produce a conspicuous ray fleck that appears dark against a lighter background (see the photo at bottom left on p. 122).

As seen on a cross-sectional surface with a hand lens, the pores are small and solitary or in radial multiples of two to several. They are fairly uniform in size and quite uniform in distribution. The rays are very distinct, with the largest about as wide as the diameter of the

RAY SIZE DISTRIBUTION IN MAPLE AND BEECH

Although rays in maple (left) are usually visible to the unaided eye on tangential surfaces, they appear much smaller, more numerous and more uniformly distributed than they are in beech (right).



largest pores (they are a shade wider in some sugar maples, the same width or slightly narrower in soft maples).

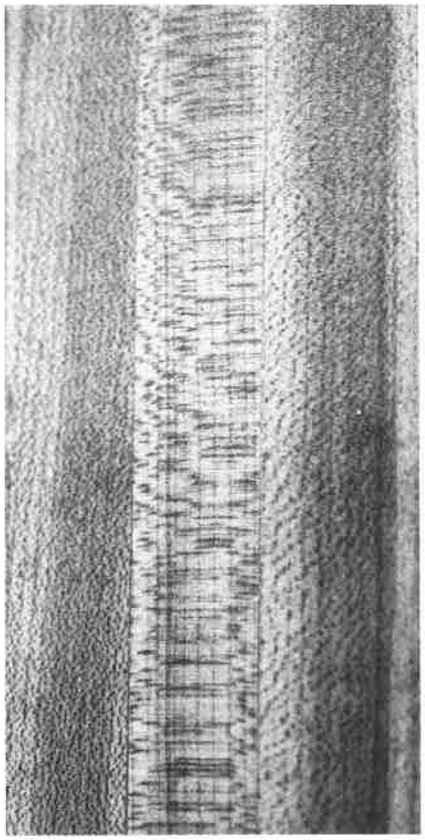
Under the microscope, vessels show simple perforations and fine, very evenly spaced spiral thickenings (see the photo below, far right). Vessels may have yellow to orange contents. Intervessel pitting is alternate. A tangential microscopic view is the best means of separating hard and soft maples because it allows ray shape and seriation to be observed. In hard maples, the rays appear to be of two distinct sizes. The smaller rays are uniseriate, and the larger are 5-8 seriate, with blunt bullet-shaped ends (see the photos on p. 45). In soft maples, the rays are variable in width up to 5 seriate, and they end in slender tapered points.

Bigleaf maple *(A. macrophyllum)* is similar to the soft maples in its ray seriation, but its heartwood usually has a pinkish cast and slightly larger pores. Field maple *(A. campestre)* and Norway maple *(A. platanoides),* both from Europe, are characteristic of the soft maples. *A. pseudoplatanus,* called "sycamore" in England, closely resembles hard maples. In England, maple wood that is artificially dyed grey is called "harewood;" it is often used in marquetry.

DOGWOOD

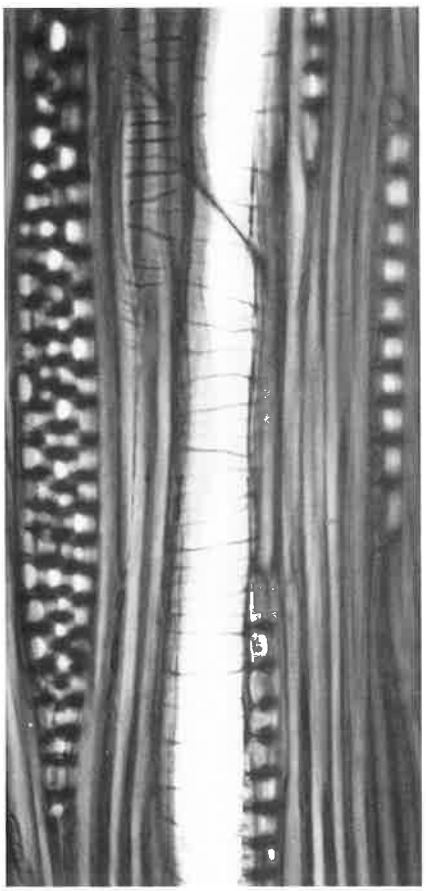
Flowering dogwood *(Cornus florida)* (see the photo on the facing page) is easily confused with maple. As with maple, the wood is fairly hard, with an average specific gravity of 0.73, and it has small, evenly distributed pores. They are mostly solitary but also occur in multiples of two or more. The broadest rays are as wide or wider than the pores. However, they are usually not as distinct to the eye or with a hand lens as they are in maple, nor are the growth rings as conspicuous. The sapwood in dogwood ranges from a creamy color with a pinkish tinge to flesh-colored. Heartwood is medium to dark brown.

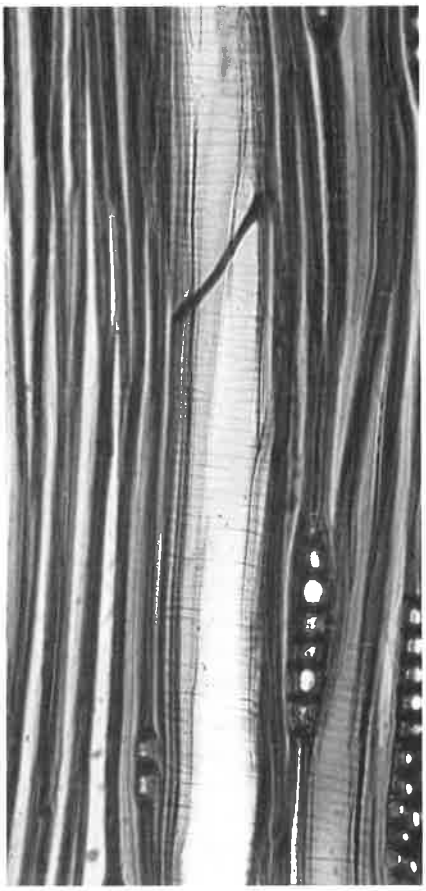
The microscopic features of dogwood positively distinguish it from other woods. The vessels have scalariform perforation plates with up to 20+ bars. Opposite-oval intervessel pitting sometimes intergrades with scalariform pitting. The heterocellular rays are up to 8 seriate. The multiseriate rays have small, rounded, procumbent cells throughout the body of the ray, but uniseriate tails of up to several upright cells. A similar species, Pacific dogwood *(Cornus nuttallii),* has rays that are much shorter and up to 5 seriate.



RAY FLECK IN MAPLE
Maple has a distinctive dark-against-light ray fleck, as shown in this photographically reproduced surface of high-pressure laminate.

SPIRAL THICKENINGS IN CHERRY AND MAPLE
Spiral thickenings in the vessels of cherry (left) are variable in thickness and irregularly spaced. In maple (right), they are uniformly fine and evenly spaced. (250x)





HARD MAPLE, SOFT MAPLE AND DOGWOOD

As seen with a hand lens, the width of rays in maple is approximately equal to the largest pore diameters. Although the greyish cast of soft maple will often distinguish it from the creamy white to light reddish brown of hard maple, a microscopic check of ray seriation — up to 5 in soft maple, up to 8 in hard maple — gives a more reliable separation. Pores in maples are commonly in multiples. In dogwood, pores are mostly solitary. Perforation plates are simple in maples, scalariform with 20+ bars in dogwood.



SUGAR MAPLE
Acer saccharum

Average Specific Gravity: 0.63
Heartwood Color: Creamy white to light reddish brown
Pore Distribution: Diffuse-porous; growth rings distinct due to darker brown narrow latewood line
Pores: Small, with largest approximately equal to maximum ray width in cross section; solitary or in radial multiples; very evenly distributed
Rays: Visible to eye on tangential surface as very fine, even-sized, evenly distributed lines; on radial surfaces, ray fleck usually conspicuous

Rays: Largest 7-8 seriate; uniseriate rays numerous
Spiral Thickenings: Fine, evenly spaced
Perforation Plates: Simple
Intervessel Pitting: Alternate, large



RED MAPLE
Acer rubrum

Average Specific Gravity: 0.54
Heartwood Color: Creamy white to light reddish brown, commonly with greyish cast or streaks
Pore Distribution: Diffuse-porous
Pores: Small, solitary and in radial multiples, very evenly distributed; largest as large or slightly larger than widest rays on cross section
Rays: May be visible on tangential surface as very fine, even-sized and evenly spaced lines; on radial surfaces, ray fleck usually conspicuous

Rays: 1-5 seriate
Spiral Thickenings: Fine, evenly spaced
Perforation Plates: Simple
Intervessel Pitting: Alternate, large



FLOWERING DOGWOOD
Cornus florida

Average Specific Gravity: 0.73
Heartwood Color: Dark brown
Sapwood Color: Creamy with flesh or pinkish cast (fairly wide sapwood)
Pore Distribution: Diffuse-porous
Pores: Very small, mostly solitary with some radial multiples
Rays: Approximately as wide or wider than largest pores

Rays: 2-8 seriate; in tangential view, multiseriate rays have uniseriate tailsof up to several upright cells
Spiral Thickenings: Absent
Perforation Plates: Scalariform with up to 20+ fine bars
Intervessel Pitting: Alternate to opposite, sometimes intergrading with scalariform

HOLLY, CHERRY AND YELLOW-POPLAR

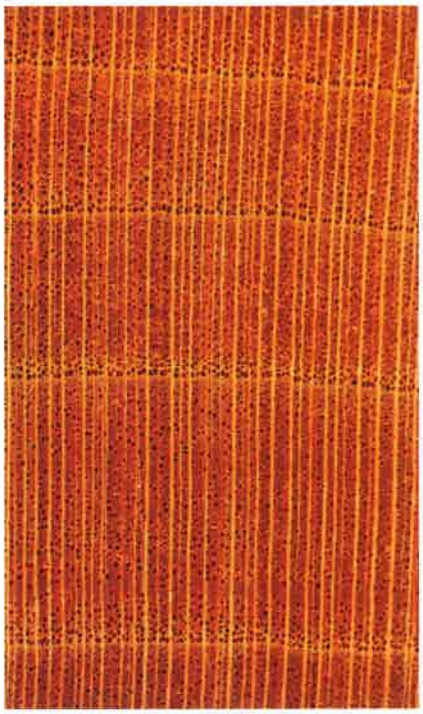
In holly, cherry and yellow-poplar, rays are visible on a transverse surface without a hand lens. The wood of holly is near white, or with a grey or bluish cast or streaks. With a hand lens, its transverse surface shows very small pores in chains that may cross the indistinct growth-ring boundaries. Cherry has heartwood color in shades of light to dark cinnamon or reddish brown; its growth rings are evident by a line of slightly larger pores along the earlywood side of the boundary. In yellow-poplar, the greenish shades of heartwood color give background contrast to the cream-colored rays, noded as they cross the bright line of terminal parenchyma at the growth-ring boundary.



AMERICAN HOLLY
Ilex opaca

Average Specific Gravity: 0.56
Heartwood Color: Near white with grey or blue-grey cast or streaks
Pore Distribution: Diffuse-porous
Pores: Extremely small, mostly arranged in chains that commonly extend across growth-ring boundaries

Rays: Widest visible without lens: with lens, widest rays exceed pore diameters
Rays: 1-5 (mostly 5) seriate, heterocellular; uniseriate rays homocellular up right
Spiral Thickenings: Present in vessels, also in fibers
Perforation Plates: Scalariform with up to 15+ bars
Intervessel Pitting: Opposite, in spiral rows following spiral thickenings



BLACK CHERRY
Prunus serotina

Average Specific Gravity: 0.50
Heartwood Color: Light to dark cinnamon or reddish brown
Pore Distribution: Diffuse-porous; growth rings sometimes distinct because of narrow zone or row of numerous slightly larger pores along initial earlywood
Pores: Pores through growth ring solitary and in radial or irregular multiples and small clusters
Gum Defects: Common
Rays: Not visible on tangential surface; conspicuous light ray fleck on radial surfaces; distinct bright lines across transverse surface, conspicuous with lens

Rays: 1-6 (mostly 3-4) seriate
Spiral Thickenings: Variable from thick to very thin, irregularly spaced
Perforation Plates: Simple
Intervessel Pitting: Alternate
Contents: Vessels with orange to ruby red contents



YELLOW-POPLAR
Liriodendron tulipifera

Average Specific Gravity: 0.42
Heartwood Color: Green, or yellow to tan with greenish cast
Sapwood Color: Creamy white (often wide)
Pore Distribution: Diffuse-porous; growth rings delineated by distinct light cream or yellowish line of marginal parenchyma
Pores: Small, solitary, but mostly in radial or irregular multiples and small clusters
Rays: Distinct on cross section with lens; produce conspicuous fine light ray fleck on radial surface

Rays: 1-5 (mostly 2-3) seriate, heterocellular
Spiral Thickenings: Absent
Perforation Plates: Scalariform with few to several thick bars
Intervessel Pitting: Opposite, oval to rectangular

HOLLY

American holly *(Ilex opaca)* is another fairly dense wood — its average specific gravity is 0.56 — that is occasionally confused with maple because its rays are visible to the naked eye. However, when viewed with a hand lens, the rays are generally not as distinct as in maple. The growth rings of holly are indistinct due to a lack of contrast; although the outer latewood has a narrow band of denser fiber, it lacks darker pigment as in maple. The wood — both sapwood and heartwood — is well known for its whiteness, described variously as ivory white or greyish white; it is valued for inlays. However, the wood often becomes discolored by blue-grey streaks of stain.

The most important feature that can be seen with a hand lens is the pores, which are uniformly quite small. Some are solitary, but most occur in multiples that are arranged in long linear series or pore chains that sometimes extend across growth-ring boundaries. Holly is commonly the textbook example used to show pore chains.

Microscopically, holly has scalariform perforation plates, with 15+ bars, along withspiral thickenings in the vessels. The fairly small intervessel pits are in opposite arrangement, the rows following the angle of the spiral thickening. Fibers also have spiral thickenings. As well as uniseriate homocellular rays, holly has heterocellular rays that are 3-5 (mostly 5) seriate.

English holly *(Ilex aquifolium)* has characteristics that are similar to American holly, and the two are difficult if not impossible to tell apart.

CHERRY

Black cherry *(Prunus serotina)* is a moderately dense hardwood whose average specific gravity is 0.50. Its distinctive heartwood ranges in color from light to dark cinnamon to reddish brown. Its rays are quite distinct on transverse surfaces, especially against the darker heartwood background. On pieces that are entirely sapwood, which is whitish to pale tan, the distinct rays are easily confused with those of maple.

With a hand lens, however, the differences are clear. In cherry, the pores form an apparent row along the earlywood, which prompts some to call the wood ring-porous. But the pores are not distinctly larger than those in the rest of the growth ring. This concentration of pores, although slight, is a major contributor to the growth-ring figure of cherry as seen on tangential surfaces. Throughout the body of the growth ring, the pores are both solitary and in variable multiples or small clusters. This contrasts to the predominantly radial multiples in maple. Insect-caused gum spots are common in cherry and result in a familiar feature on longitudinal surfaces (see the photo on p. 62).

On tangential surfaces the rays are not visible, as they are in maple. But on radial surfaces, a striking ray fleck is revealed (see the photo below). This lighter-colored fleck against a darker heartwood background is a most familiar figure in cherry, but it is sometimes confused with yellow-poplar.

With a microscope, we find that cherry has rays that are up to 6 (mostly 3-4) seriate. Vessels have simple perforations and alternate intervessel pitting, features that are confusingly similar to maples. One distinguishing feature is the spiral thickenings of the vessels, which are variable in thickness, unevenly spaced and at inconsistent angles. This contrasts with the very uniformly thin, closely and evenly spaced spiral thickenings in maple (see the photos on p. 122).

European cherry *(Prunus avium)* is similar to black cherry, as are several other woods in the genus *Prunus*, including plums, peaches and apricots. Also in the *Rosaceae* family are the genera *Malus* (apple) and *Pyrus* (pear), whose woods have narrower rays — 1-3 (mostly 2) seriate and sparse spirals. The term "fruitwood" is used as a convenient collective term for the indistinguishable species in this group.

YELLOW-POPLAR AND MAGNOLIA

Yellow-poplar *(Liriodendron tulipifera)* is probably the most common of the traditional secondary hardwoods. It is also known as tulip tree and tulip poplar because of its tuliplike yellow flowers. Yellow-poplar grows tall and straight, and old-growth trees have yielded clear (knot-free) boards up to 3 ft. wide. The sapwood, which is a flat creamy white, is fairly wide. As a result, boards consisting entirely of sapwood are frequent, and have earned for this wood the alternate common name of whitewood. By contrast, heartwood color is distinct but varies from tree to tree. The most common color is green,

RAY FLECK IN CHERRY

A drawer front displaying striking light-against-dark ray fleck in black cherry.



ranging from moss green to yellow-green to tan with a greenish cast. An occasional piece has a purple cast, or is streaked with dark brown or black. The wood is moderately soft, with an average specific gravity of 0.42.

In cross-sectional view, yellow-poplar growth rings are delineated by light-colored whitish or yellowish marginal parenchyma (see the photo below). This line is usually conspicuous to the eye, but occasionally it is so thin as to be distinct only with a hand lens.

The light-colored rays are also visible to the eye and are distinct with a hand lens. This is especially true of the darker heartwood, where they appear to be slightly wavy as they pass radially among the pores (this contrasts sharply with the arrow-straight rays of maple and cherry). They are conspicuously noded as they cross through the band of marginal parenchyma.

The pores of yellow-poplar are fairly small, although they can vary somewhat in average size from one sample to the next. They seem to occupy the majority of the exposed surface. Some are solitary but most are in irregular multiples and clusters.

On tangential surfaces, figure is subtle at best, sometimes displaying lines of marginal parenchyma. But the rays are not visible. On radial surfaces, however, a light-colored ray fleck may show strikingly, especially against the darker heartwood (photos below). This light-on-dark ray-fleck figure can be deceivingly suggestive of black cherry, especially where pieces have darkened or faded with age or have been stained artificially to imitate cherry's color. The best means of telling these two woods apart by eye or with a hand lens is by checking for the light-colored line of marginal parenchyma that is present in yellow-poplar but absent from cherry.

Microscopically, yellow-poplar is quick and easy to check. Its perforation plates are scalariform, commonly with only two to four bars, although some plates have up to a dozen or more.

Intervessel pitting is opposite, with fairly large, oval to rectangular pits that on rare occasion intergrade to scalariform. The pits have distinct borders and apertures (see the photos at the bottom of the facing page). Because the pores in yellow-poplar are so irregularly arranged in multiples and clusters, virtually any longitudinal section shows perforation plates and intervessel pitting in face view when examined microscopically. Because it is not necessary to get a perfect tangential or radial cut to check perforations or intervessel pitting, you can section directly from furniture parts along any exposed longitudinal surface to confirm yellow-poplar.

A proper radial cut (top photo on the facing page) shows the rays to be heterocellular. These horizontally elongated, thin-walled, procumbent cells are in obvious contrast to the squarish or rectangular upright cells at the margins of the rays that have extremely thick walls and large rounded



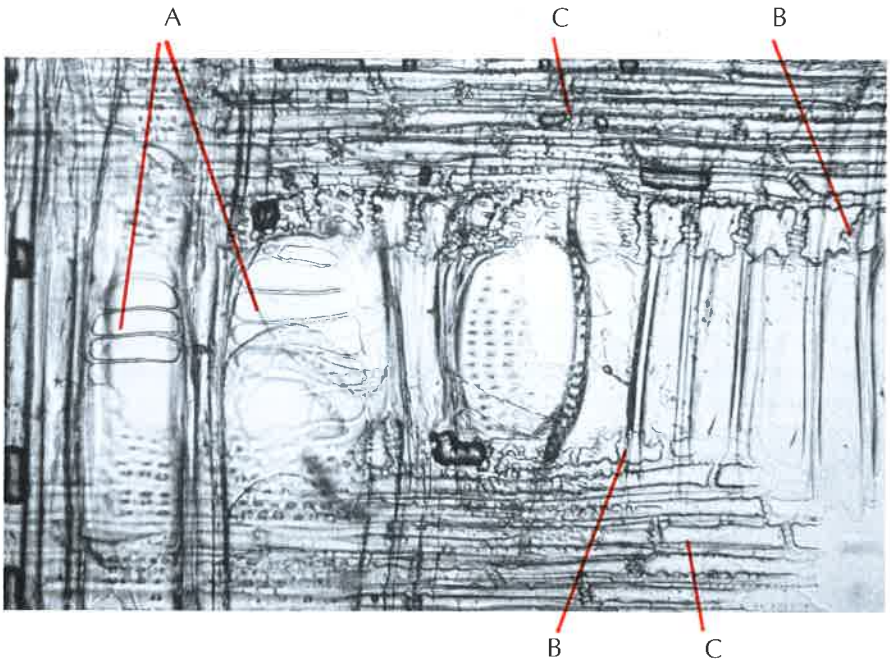
GROWTH RINGS IN YELLOW-POPLAR
The growth-ring pattern on this yellow-poplar veneer results from the very thin layers of lighter-colored terminal parenchyma cells.

RAY FLECK IN YELLOW-POPLAR
The light-against-dark ray fleck evident on this yellow-poplar board (left) could be mistaken for that of cherry (right) if the yellow-poplar were stained a cherry-brown color.

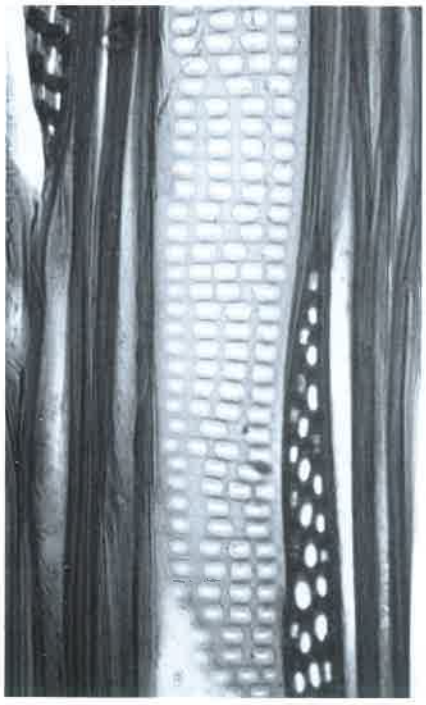




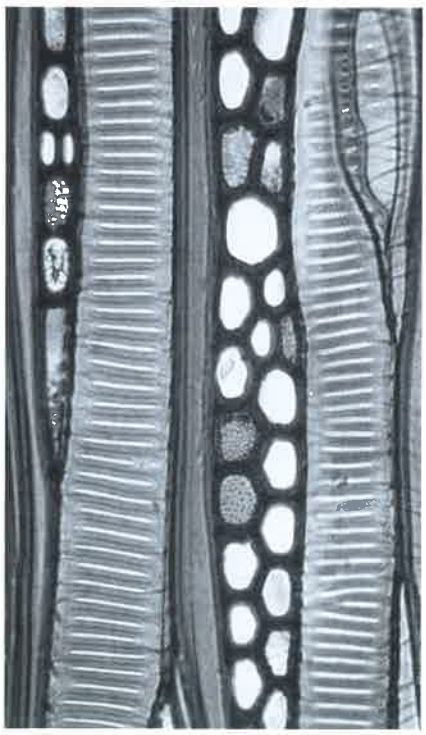
PERFORATION PLATES AND RAY CELLS IN YELLOW-POPLAR
Scalariform perforation plates with only a few or several bars (A) are important identification features of yellow-poplar. The portion of the ray visible clearly shows a row of thick-walled upright cells (B) and thinner-walled procumbent cells (C). (175x)



INTERVESSEL PITTING IN YELLOW-POPLAR
The oval to rectangular opposite intervessel pitting is a prominent feature of yellow-poplar. Note that rays are commonly 2-3 seriate. (250x)



INTERVESSEL PITTING IN MAGNOLIA
The scalariform intervessel pitting of magnolia provides positive separation from yellow-poplar. (250x)



pits. A tangential section shows rays to be in the 1-5 (mostly 2-3) seriate range.

The woods of the genus *Magnolia* are strikingly similar to yellow-poplar and cannot be reliably separated from yellow-poplar by eye. In the lumber trade, boards of cucumbertree *(M. acuminata),* which is also called simply "cucumber," are usually combined with and sold as "yellow poplar." Southern magnolia *(M. grandiflora)* is likewise confusingly similar in appearance to yellow-poplar. The only reliable separation is by microscopic examination, since magnolias have linear (scalariform) intervessel pitting, in comparison to the opposite pitting characteristic of yellow-poplar (compare the photos at left and right below).

Separation of the two *Magnolia* species is less clear-cut. Perforation plates are mainly simple in cucumbertree, but in southern magnolia they are both scalariform and simple. Southern magnolia has spiral thickenings in its vessels; it also has wider rays, 1-5 seriate, in comparison to 1-3 (mostly 2) seriate in cucumbertree.

BASSWOOD

American basswood *(Tilia americana;* center photo on p. 128) is a fairly soft, low-density hardwood with an average specific gravity of 0.37. It ranges in color from creamy white or pale tan (sapwood) to pale brown (heartwood). Basswood has a faint but characteristic musty odor.

In cross-sectional view, growth rings are delineated by marginal parenchyma that is conspicuous in some samples but quite faint in others. In some samples there are small, blurry whitish spots along the growth-ring boundary. Rays are usually faintly visible to the eye; with a hand lens they are distinct and noded where they cross through the growth-ring boundary.

Pores are small and fairly evenly distributed. Sometimes, however, they are more numerous at the beginning of the growth ring, then sparse and smaller toward the outer margin of the ring. Some pores are solitary, but most occur in irregular multiples and clusters. The combination of distinct marginal paren-

chyma and distinct noded rays may appear confusingly similar to the sapwood of yellow-poplar.

Vessels in basswood have simple perforation plates and alternate intervessel pits that usually appear crowded. Vessels also have thick spiral thickenings. Ray cells are homocellular and 1-6 seriate. In tangential view, the ray cells appear to be compressed into vertically elongated ellipses or hexagons, which I call "coffin-shaped" cells (see the bottom left photo on the facing page). These are quite distinctive in comparision to the rounded cells of soft maple or the slightly oval ray cells of yellow-poplar.

Microscopically, basswood can be distinguished from yellow-poplar sapwood by its simple perforations, alternate intervessel pitting and spiral thickenings. (Yellow-poplar sapwood has scalariform

MAGNOLIA, BASSWOOD AND BIRCH

Magnolias resemble yellow-poplar in their green or greenish yellow heartwood and the bright lines of terminal parenchyma. But with a microscope, magnolia is positively separated by its linear (scalariform) intervessel pitting (which is opposite in yellow-poplar). Although basswood is soft and has a characteristic musty odor, it lacks other definitive macroscopic features. It is best confirmed microscopically by its vessels with thick spirals and laterally compressed ray cells. Birches are moderately dense, and have pores (solitary and in radial multiples) that are clearly wider tangentially than ray widths. Some appear to have whitish contents. It is best to confirm birch microscopically by its scalariform perforation plates and extremely small intervessel pits.



SOUTHERN MAGNOLIA
Magnolia grandiflora

Average Specific Gravity: 0.50
Heartwood Color: Yellow, medium to dark greenish yellow, or dark green
Pore Distribution: Diffuse-porous; growth rings delineated by fine to distinct line of marginal parenchyma
Pores: Small, solitary or in radial multiples or clusters of 2 to several
Rays: Distinct with lens on transverse surface, producing light, fine ray fleck on radial surfaces

Rays: 1-5 seriate, heterocellular
Vessels: In *M. grandiflora*, vessels with spiral thickenings and scalariform perforation plates; in *M. acuminata*, vessels lack spiral thickenings, having mostly simple perforations
Intervessel Pitting: Scalariform



AMERICAN BASSWOOD
Tilia americana

Average Specific Gravity: 0.37
Heartwood Color: Creamy white to pale brown
Odor: Faint but characteristic musty odor
Pore Distribution: Diffuse-porous; growth rings indistinct or faintly delineated by marginal parenchyma, sometimes with blurry whitish spots along the growth-ring boundary
Pores: Small, mostly in irregular multiples and clusters
Rays: Distinct but not conspicuous on transverse surface with lens

Rays: 1-6 seriate; ray cells appear laterally compressed in tangential view; rays have bright yellow cast
Spiral Thickenings: Thick, evenly spaced
Perforation Plates: Simple
Intervessel Pitting: Alternate



YELLOW BIRCH
Betula alleghaniensis

Average Specific Gravity: 0.62
Heartwood Color: Light to dark brown or reddish brown
Pore Distribution: Diffuse-porous
Pores: Small to medium, solitary or in radial multiples of 2 to several; with lens, pore diameters clearly greater than ray width; some pores appear to be filled with whitish substance

Rays: 1-5 seriate
Spiral Thickenings: Absent
Perforation Plates: Scalariform with many fine bars
Intervessel Pitting: Alternate, very small with confluent apertures

perforations and opposite intervessel pitting, and it lacks spirals.) The multiseriate rays of basswood make it easy to separate from aspen, cottonwood and buckeye, which have only uniseriate rays.

White basswood *(Tilia heterophylla)* is indistinguishable from American basswood. European lime *(T. vulgaris)* is anatomically similar but somewhat denser (its average specific gravity is 0.48) than American basswood.

BIRCH

The birches include several species. Some of the more common are yellow birch *(Betula alleghaniensis)*, with an average specific gravity of 0.62; sweet birch *(B. lenta)*, with an average specific gravity of 0.65; and paper birch *(B. papyrifera)*, with an average specific gravity of 0.55. Birches usually have whitish or light yellow sapwood and heartwood ranging from light brown to dark brown or reddish brown. The growth rings may not be very distinct and are terminated by a narrow zone of slightly denser and darker fiber mass.

The rays are barely visible to the unaided eye, but they are distinct with a hand lens on cross-sectional surfaces. The wood is uniformly diffuse-porous, with pores either solitary or in multiples that are mainly radial. Average pore diameter may vary from sample to sample among or within species. The pores are usually distinct and well separated; some may appear to have whitish contents. The pore diameters are clearly larger than the width of the rays, which provides a quick and reliable means of separating this wood from maple, whose pore diameter and ray width are about the same (compare the photos on p. 128 of yellow birch with the photos on p. 123 of sugar maple and red maple).

Birch can always be confirmed microscopically. The intervessel pitting is alternate, but the pits are extremely small and numerous, giving the intervessel wall the appearance of a pebbly surface. These pits may be connected by confluent apertures; that is, there may be fine lines running from one pit aperture to the next. Once this very small alternate intervessel pitting is seen in one sample, it will be easily recognized in others. Intervessel pitting in birch is most easily found in tangential sections because most multiples are radial. Rays in birch are 1-5 seriate.

The second important microscopic feature is the scalariform perforation plates with up to 20 or more bars. These are best seen in a radial section, which also shows ray-vessel pitting. These pits, another easily recognized feature of birch, are very small, numerous and similar in appearance to the intervessel pits.

Although birches cannot be separated from one another with certainty on the basis of cell structure, it should be noted that pith flecks are usually numerous in paper birch, but sparse or absent from yellow birch (see the photo on p. 62).

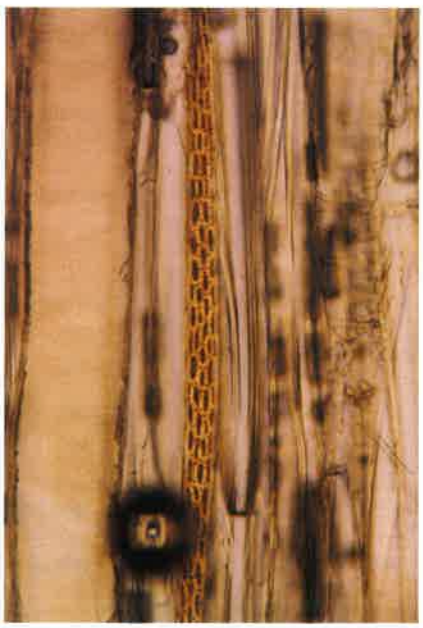
It is also important to note that European birch (principally *B. pubescens* and *B. pendula)* cannot be distinguished from North American species.

EASTERN HOPHORNBEAM

Eastern hophornbeam *(Ostrya virginiana)* is sometimes confused with birch, and the lumber of these two trees is sometimes mixed together. Eastern hophornbeam is fairly dense, with an average specific gravity of 0.70, and has light sapwood. Its heartwood ranges from very light brown to reddish brown. On cross-sectional surfaces, the growth rings are inconspicuous and rays are indistinct. With a hand lens, rays are visible and tiny whitish spots are seen in the outer latewood along the growth boundary. Pores are both solitary and in multiples of two to several, commonly aggregated in short radial or diagonal chains or in flamelike groups. Banded parenchyma are faintly visible with a hand lens.

In the vessels, perforation plates, although usually simple, are occasionally scalariform with three to six bars. Intervessel pitting is alternate with medium-sized rounded to angular pits. Spiral thickenings are also present in the vessels. These spiral thickenings and larger intervessel pits provide a positive separation from birch. The rays of eastern hophornbeam are 1-3 seriate, compared to 1-5 in birch.

RAY CELLS IN BASSWOOD
Ray cells in basswood appear to be laterally compressed.



INTERVESSEL PITTING IN BIRCH
This portion of a vessel element in birch shows its extremely small intervessel pitting. Most pits are connected by confluent apertures.



CALIFORNIA-LAUREL

California-laurel, also called Oregon-myrtle (*Umbellularia californica*), is a moderately dense diffuse-porous hardwood with an average specific gravity of 0.55. Its sapwood is near-white to light brown, and its heartwood is light brown to greyish brown, sometimes with darker streaks. The wood has a characteristic spicy odor that is quite pronounced when the wood is freshly cut but fades with time and exposure.

Growth rings are fairly distinct because of a narrow band of darker fiber at the growth-ring boundary. Rays are not easily seen with the unaided eye, but are fairly distinct with a hand lens. The small pores are solitary or in radial multiples of two to several. They are spaced well apart and are evenly distributed throughout the growth ring; some pore multiples extend

BIRCH, HOPHORNBEAM AND CALIFORNIA-LAUREL

Paper birch resembles other birches, but commonly has abundant pith flecks. Hophornbeam resembles birch at a glance, but examination with a hand lens reveals whitish specks along the outer latewood and pores that form into short radial or diagonal chains or flamelike aggregates. Its vessels have spiral thickenings and medium-large alternate intervessel pits. California-laurel is light brown to greyish brown, and is typically streaked with varying darker shades. It has a characteristic spicy odor. With a lens, the pores and pore multiples are seen to be encircled by a whitish sheath of parenchyma.



PAPER BIRCH
Betula papyrifera

Average Specific Gravity: 0.55
Heartwood Color: Light brown to dark or reddish brown (pith flecks usually conspicuous and numerous)
Pore Distribution: Diffuse-porous
Pores: Small to medium, solitary or in radial multiples of 2 to several; with lens, pore diameters clearly greater than ray width; some pores may appear to be filled with whitish substance
Rays: Distinct with lens on transverse surface

Rays: 1-5 seriate
Spiral Thickenings: Absent
Perforation Plates: Scalariform with many fine bars
Intervessel Pitting: Alternate, very small with confluent apertures



EASTERN HOPHORNBEAM
Ostrya virginiana

Average Specific Gravity: 0.70
Heartwood Color: Light brown to brown tinged with red
Pore Distribution: Diffuse-porous; growth rings usually distinct due to whitish spots along outer latewood
Pores: Small, solitary and in multiples commonly aggregated into radial, diagonal or flamelike groups; banded parenchyma faintly visible with hand lens
Rays: Distinct with lens on transverse surface

Rays: 1-3 seriate
Spiral Thickenings: Present
Perforation Plates: Mostly simple; occasionally scalariform, 3-6 bars
Intervessel Pitting: Alternate, medium to large



CALIFORNIA-LAUREL
Umbellularia californica

Average Specific Gravity: 0.55
Heartwood Color: Light brown to greyish brown with darker streaks
Odor: Characteristically spicy
Pore Distribution: Diffuse-porous
Pores: Small to medium, evenly distributed, solitary or in multiples of 2 to several, each pore or multiple surrounded by a lighter sheath of vasicentric parenchyma
Rays: Fine, clearly visible with hand lens

Rays: 1-4 (mostly 2) seriate
Oil Cells: Scattered oil cells common
Spiral Thickenings: Sporadically present
Perforation Plates: Simple
Intervessel Pitting: Alternate, medium to large

across the growth-ring boundary. As seen with a hand lens, each pore or pore multiple is surrounded by a lighter-colored layer of vasicentric parenchyma.

California laurel is confirmed microscopically by its simple perforation plates and alternate intervessel pitting with medium-sized, rounded to angular pits. Spiral thickenings are sporadic. Rays are heterocellular and 1–4 (mostly 2) seriate; they contain scattered oil cells.

Among the remaining woods in this section, none have rays that are visible to the naked eye; viewed with a hand lens they may just barely be visible, although not distinct.

WILLOW

Black willow (*Salix nigra*) is a moderately soft hardwood with an average specific gravity of 0.39. Its sapwood is very light in color, and its heartwood ranges from light brown to medium grey-brown, frequently showing streaks of variable color.

Willow commonly has interlocked grain. Although some samples appear diffuse-porous, the gradation in pore size across the growth ring in most samples suggests classification as a semi-diffuse-porous wood. The first-formed earlywood pores are barely visible to the eye, but grade to invisibly small toward the

WILLOW, COTTONWOOD AND ASPEN

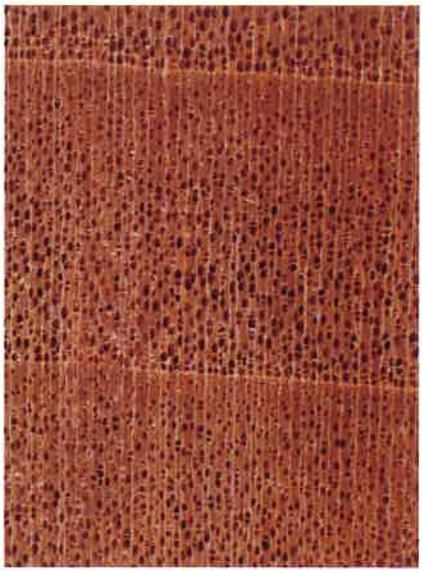
Willows and poplars are moderately soft, diffuse-porous woods without distinct characteristic features. Rays are invisibly fine. In willows and cottonwoods, large pores in the earlywood may give the wood a semi-diffuse-porous appearance. Aspens have the smallest pores; their wood is typically creamy or whitish, compared to the greyish brown of cottonwood and the reddish brown of willow. Microscopically, all three woods have simple perforations, large alternate intervessel pitting and uniseriate rays that are homocellular in poplars, heterocellular in willow.



BLACK WILLOW
Salix nigra

Average Specific Gravity: 0.39
Heartwood Color: Light brown to pale reddish or greyish brown
Pore Distribution: Diffuse-porous to semi-diffuse-porous
Pores: Medium to small, usually with apparent size gradation from earlywood to latewood, solitary and in multiples of 2 to several
Rays: Very fine, barely visible with hand lens

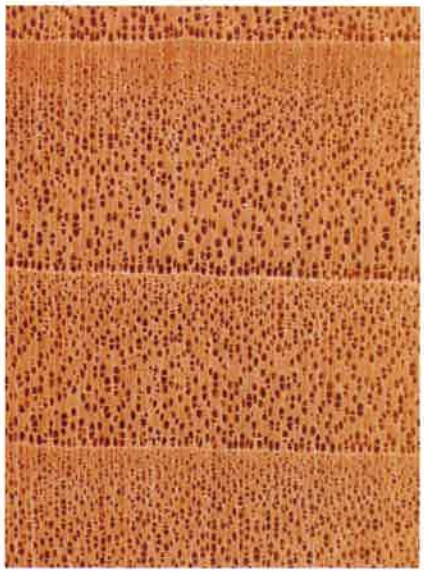
Rays: Uniseriate, heterocellular
Spiral Thickenings: Absent
Perforation Plates: Simple
Intervessel Pitting: Alternate, medium to large



EASTERN COTTONWOOD
Populus deltoides

Average Specific Gravity: 0.40
Heartwood Color: Greyish to light greyish brown, sometimes with olive cast
Odor: Moist wood with foul odor
Pore Distribution: Diffuse-porous or semi-diffuse-porous
Pores: Medium to small, usually with apparent size gradation from earlywood to latewood, solitary and in radial multiples of 2 to several
Rays: Very fine, not easily seen with lens

Rays: Uniseriate, homocellular
Spiral Thickenings: Absent
Perforation Plates: Simple
Intervessel Pitting: Alternate, large



QUAKING ASPEN
Populus tremuloides

Average Specific Gravity: 0.38
Heartwood Color: Creamy white to light greyish brown
Pore Distribution: Diffuse-porous
Pores: Small to very small, with gradation in pore size from earlywood to latewood, solitary and in multiples of 2 to several
Rays: Very fine, not easily seen with hand lens

Rays: Uniseriate, homocellular
Spiral Thickenings: Absent
Perforation Plates: Simple
Intervessel Pitting: Alternate, large

outer latewood. The pores are solitary or in multiples that are mainly radial.

The rays of willow are very fine, invisible to the eye and just barely visible with a lens. A tangential section examined microscopically reveals that the rays are exclusively uniseriate. A radial view shows that the rays are heterocellular (see the photo below); the upright cells, which occur at the margins of the rays or within the body of the ray, have large, rounded, crowded pits connecting them to the vessel elements.

Willow also has simple perforations in the vessels and alternate intervessel pitting with distinct medium-sized, rounded to angular pits.

In summary, *Salix* is a huge genus with dozens of species in North America and elsewhere, including white willow *(S. alba)*, which is common in the British Isles. Wood specimens of the various willows cannot be reliably separated.

HETEROCELLULAR RAYS IN WILLOW

In this radial view of willow, the upright cells with large pits identify a heterocellular ray, which is important in distinguishing willow from poplars. (250x)



POPLARS

The genus *Populus* includes several common species (see the photos on p. 131), many of which we know as cottonwoods, aspens or, simply, poplars (see Table 10.4 below). The woods of all species of *Populus* are very similar. They can usually be recognized as belonging to either the cottonwood group or the aspen group, principally on the basis of the slightly larger size of the pores in cottonwoods, but also on such physical properties as color and odor. Even so, this separation cannot always be made with certainty.

The poplars are moderately soft to soft, with average specific gravities ranging from 0.33 to 0.40. The light-colored sapwood zone is indistinct. It merges gradually into heartwood that is typically light greyish brown in aspen. Cottonwood heartwood is greyish to light greyish brown, sometimes with an olive cast; it is darkest in swamp cottonwood. The wood of aspen may be lustrous, while cottonwood's is usually dull. When moist, cottonwood has a foul odor, which fortunately disappears as the wood dries.

On cross-sectional surfaces, growth rings are distinct due to narrow margins of slightly darker, denser fibers, although they are not conspicuous. Within a ring, the pores are larger, more numerous and crowded in the earlywood, grading to small in the outer latewood. This suggests a semi-diffuse-porous arrangement. A few pores are solitary, but most occur in multiples. The multiples are typically radial, but frequently also form tangential multiples or merge into small clusters.

The average size of the largest pores best serves to separate cottonwood from aspen. In aspen, all pores are invisibly small. In cottonwood, the largest pores are usually barely visible to the unaided eye, which makes them confusingly similar to willow's. It is worthwhile making a direct comparison to known samples of aspen and cottonwood to assess pore-size ranges. The rays of *Populus* are extremely fine; they are invisible to the unaided eye and barely visible even with a hand lens.

Microscopic anatomy is virtually the same among all the species, except for vessel (pore) diameter, which is larger among cottonwoods. Vessels have simple perforations and no spiral thickenings. Intervessel pitting is alternate, with large, clearly defined pits that are usually rounded or slightly angular due to crowding (see the top photo on the facing page). In tangential sections, rays are seen as uniseriate, and the cells appear to be laterally compressed and flattened.

In radial sections, the rays are found to

TABLE 10.4: SELECTED SPECIES OF *POPULUS* COMMON IN NORTH AMERICA AND EUROPE

	North America:		Europe:	
Cottonwoods/Poplars	*P. balsamifera*	Balsam poplar	*P. alba*	White poplar
	P. deltoides	Eastern cottonwood	*P. canescens*	Grey poplar
	P. heterophylla	Swamp cottonwood	*P. nigra*	Black poplar
	P. trichocarpa	Black cottonwood		
Aspens	*P. grandidentata*	Bigtooth aspen	*P. tremula*	European aspen
	P. tremuloides	Quaking aspen		

be homocellular with procumbent cells. Cells along the ray margin where they come into contact with vessels have large, crowded pits that look like bunches of grapes, virtually filling the cell. Because these pits are so distinctive, they are an easily recognized feature for identifying *Populus.* The homocellular composition of the rays, as seen in radial sections (photo below right), distinguishes *Populus* from *Salix* (willow), in which the rays are heterocellular (compare the photo at bottom right on this page with the photo on p. 132).

Aspen is sometimes confused with basswood, but the two can be distinguished quickly by comparing ray width, which is uniseriate in aspen and multiseriate in basswood, or spiral thickenings, which are absent in aspen and present in basswood.

BUCKEYE AND HORSECHESTNUT

Of the several species of buckeye found in the United States, two of the more common are yellow buckeye *(Aesculus octandra;* photo at left on p. 135) and Ohio buckeye *(A. glabra).* The wood is relatively soft, with an average specific gravity of 0.36, and has near-white sapwood and creamy to yellowish white heartwood. The growth rings are imperceptible in most samples, although they are faintly visible in some due to a thin light line of marginal parenchyma.

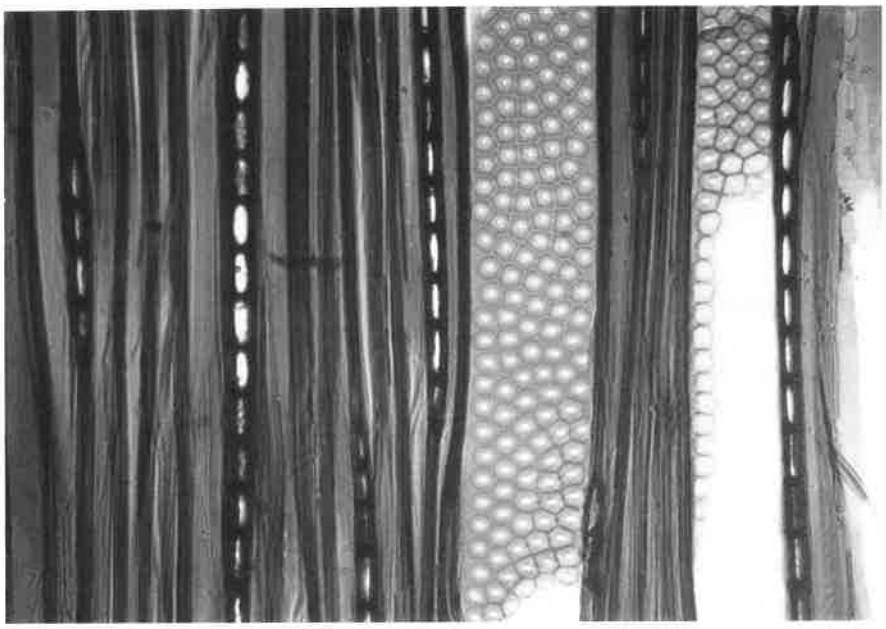
Rays in buckeye are invisibly fine to the naked eye and are barely visible even with a hand lens. The very small pores are not visible except with a hand lens. They are numerous and fairly evenly distributed, and are either solitary or in multiples of two to several. The multiples occur radially, tangentially and in small clusters. In short, there are few striking features in buckeye that can be seen with either the eye or the hand lens.

Microscopic examination reveals vessel elements that have simple perforations and alternate intervessel pitting with medium-large pits. Spiral thickenings are usually absent, but occasionally they appear in latewood vessels. The rays are either homocellular or heterocellular, but they are entirely uniseriate.

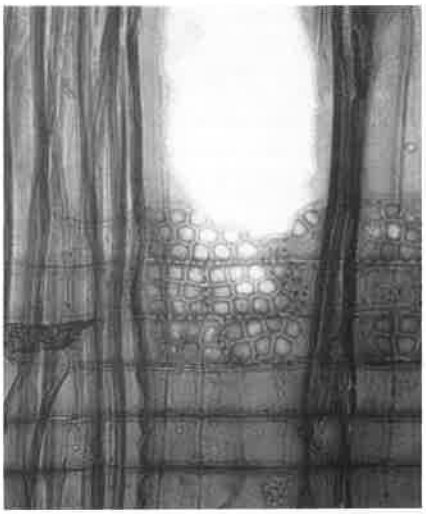
Woods of the two buckeye species are quite similar. However, yellow buckeye usually has visible ripple marks due to its storied rays and other longitudinal cells. This feature is seldom present in Ohio buckeye. The wood of horsechestnut *(A. hippocastanum),* a native of Europe but widely planted in the United States, closely resembles buckeye. But spiral thickenings in horsechestnut are regularly present in the vessel elements, and the wood is denser, with an average specific gravity of 0.45. Buckeye is probably most often confused with aspen. When present, ripple marks or spiral thickenings indicate *Aesculus.* Also, the ray-vessel pitting, as seen microscopically in a radial section, is smaller in buckeye than in aspen.

SWEETGUM

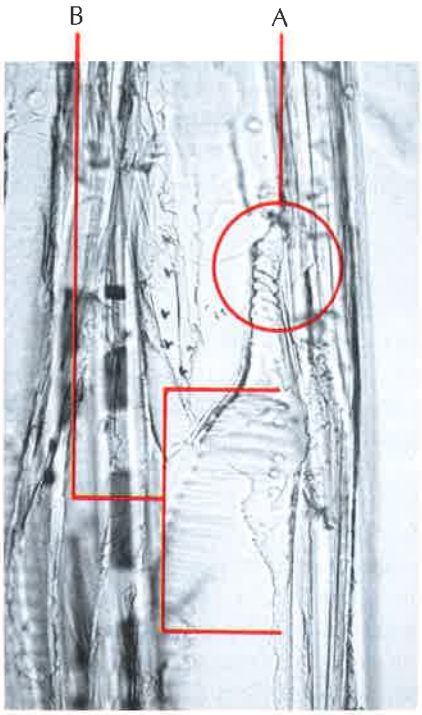
Sweetgum *(Liquidambar styraciflua;* photo at center on p. 135) is a moderately dense diffuse-porous hardwood with an average specific gravity of 0.52. Its alternate common name, redgum, derives from the heartwood, which is often reddish brown, frequently with streaks of varying shades. Wood with these streaks is marketed as "figured redgum" (see the photo on p. 63). The heartwood is also found in varying shades of grey and greyish brown. The sapwood is near-white, sometimes with a pinkish cast, and is marketed separately



INTERVESSEL PITTING IN *POPULUS*
A tangential view of poplar showing the large alternate intervessel pitting and uniseriate rays. (250x)



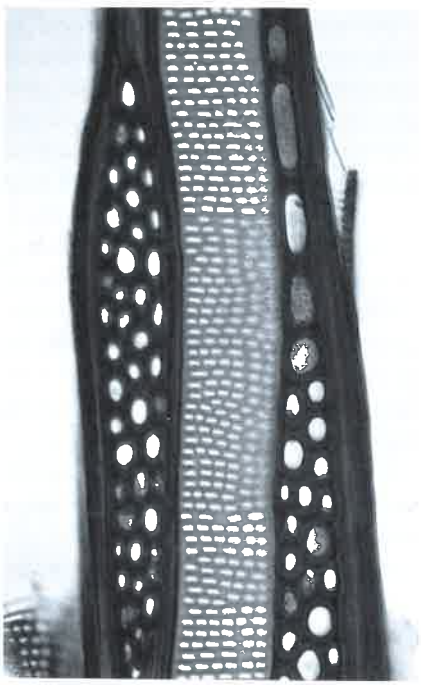
RAYS IN *POPULUS*
As seen in radial view, ray cells in poplars are exclusively procumbent; therefore, the rays are homocellular. The ray-vessel pitting is large and conspicuous, especially in marginal rows of ray cells. (250x)



LIGULES IN SWEETGUM
A ligule with spiral thickenings (A) at the end of a vessel element in sweetgum. The scalariform perforation plate (B) is also visible. (250x)



INTERVESSEL PITTING IN SWEETGUM
In sweetgum, the intervessel pitting commonly intergrades from scalariform to opposite, with up to three pits across the vessel. (250x)



INTERVESSEL PITTING IN BLACK TUPELO
In black tupelo, intervessel pitting is opposite, with up to 6 or more pits across vessels. It only occasionally intergrades to scalariform. (250x)

as "sap-gum." The wood commonly has interlocked grain.

Neither the growth rings nor the rays are distinct to the eye, and neither is always clearly visible with a hand lens. The pores, which are extremely small and numerous, are solitary, in multiples, in short chains or in small irregular clusters. Some pores give the appearance of being channeled into a radial arrangement by pairs of closely spaced rays.

Sweetgum is much easier to identify when its sections are examined microscopically. The vessels have scalariform perforations with up to 20 or more bars. Intervessel pitting is opposite, up to three pits across, and regularly intergrades with scalariform pitting (see the photo at center above).

Spiral thickenings are present only in the ligules, the tail-like extensions of the vessel elements. Although of value in identification, spiral thickenings in the ligules are often difficult to find and see clearly (see the photo at left above). The rays of sweetgum are heterocellular and 2-3 (mainly 2) seriate. In radial sections, the elongated thin-walled procumbent cells contrast clearly with the squarish, very thick-walled upright cells.

BLACK TUPELO

Black tupelo *(Nyssa sylvatica;* photo at far right on the facing page), also known as blackgum, is moderately dense, with an average specific gravity of 0.50. Its sapwood is pale grey, and its heartwood is a darker grey with a green or brown cast. The wood usually has interlocked grain.

In cross sections, neither growth rings nor rays are visible; they are indistinct even with a hand lens. Pores are very small and numerous. They are evenly distributed and are solitary, in radial multiples or in small clusters.

Microscopic examination shows scalariform perforation plates with up to 20 or more very thin bars. Intervessel pitting is opposite, with up to six pits per row (see the photo above). The opposite pitting occasionally intergrades with scalariform pitting.

Spiral thickenings are present in the ligules at the ends of vessel elements. The rays are heterocellular; they range from 1-4 (mostly 2-3) seriate.

BUCKEYE, SWEETGUM AND TUPELO

Buckeye, sweetgum and tupelo are uniformly diffuse-porous with extremely fine texture. Growth rings and rays may not be distinct even with a hand lens. Confident identification depends on microscopic analysis. Buckeye has uniseriate rays and simple perforation plates. Sweetgum and tupelo have scalariform perforation plates; both also have scalariform intervessel pitting intergrading with opposite pitting. But opposite pitting is only up to 3 across in sweetgum, and up to 6 or more across in black tupelo.



YELLOW BUCKEYE
Aesculus octandra

Average Specific Gravity: 0.36
Heartwood Color: Creamy white to pale yellowish white
Pore Distribution: Diffuse-porous
Pores: Very small, solitary in multiples and small clusters
Ripple Marks: On tangential surface due to storied ray structure

Rays: Not clearly seen even with hand lens; uniseriate, heterocellular and homocellular; storied
Spiral Thickenings: Absent or sporadic
Perforation Plates: Simple
Intervessel Pitting: Alternate, medium to large



SWEETGUM
Liquidambar styraciflua

Average Specific Gravity: 0.52
Heartwood Color: Grey or reddish brown, sometimes with variegated pigment
Pore Distribution: Diffuse-porous
Pores: Very small, numerous, solitary and in multiples and small clusters, often in intermittent radial chains
Rays: Very fine, not distinct even with hand lens

Rays: 2-3 (mostly 2) seriate, heterocellular
Spiral Thickenings: Restricted to ligules
Perforation Plates: Scalariform with up to 20+ bars
Intervessel Pitting: Opposite intergrading to scalariform; 1-3 pits across vessel



BLACK TUPELO
Nyssa sylvatica

Average Specific Gravity: 0.50
Heartwood Color: Medium grey or grey with green or brown cast (wood usually has interlocked grain)
Pore Distribution: Diffuse-porous
Pores: Very small, numerous, solitary and in multiples and small clusters
Rays: Barely visible even with hand lens

Rays: 1-4 seriate, heterocellular
Spiral Thickenings: Sometimes present in ligules
Perforation Plates: Scalariform with up to 20+ bars
Intervessel Pitting: Opposite, occasionally intergrading to scalariform; up to 6-8 pits across vessel

TABLE 10.5: SUMMARY CHECKLIST OF FEATURES FOR RING-POROUS HARDWOODS IN SUBGROUP I-3

NAME	AVG. SPEC. GRAV.	HEARTWOOD COLOR		LATEWOOD (LW) CHARACTERISTICS
WHITE ASH *(Fraxinus* spp.)	0.56-0.61	Light brown or greyish brown (sapwood creamy white; may be very wide).	LW PORES THICK-WALLED	LW pores solitary and in radial multiples of 2-3, surrounded by vasicentric parenchyma or confluent parenchyma connecting pores into tangential lines, especially in outer LW.
BLACK ASH *(Fraxinus nigra)*	0.49	Greyish brown to medium or dark brown (sapwood creamy white; fairly narrow).		LW pores solitary and in radial multiples of 2-3, not numerous, rarely with aliform or confluent parenchyma in outer LW.
SASSAFRAS *(Sassafras albidum)*	0.45	Grey, greyish brown or brown.		LW pores solitary and in radial multiples of 2-3, grading to very small with pronounced aliform parenchyma in outer LW.
CATALPA *(Catalpa* spp.)	0.41	Greyish brown, sometimes with a faint lavender cast.	SPIRAL THICKENINGS COMMONLY PRESENT IN SMALLER LW VESSELS	LW pores variable, larger near earlywood, grading down to very small in outer LW, numerous in nests.
RED MULBERRY *(Morus rubra)*	0.66	Orange-yellow to golden or russet brown (turning deep russet on exposure to atmosphere).		LW pores in nestlike groups, merging laterally to form wavy or interrupted bands, especially in outer LW.
OSAGE-ORANGE *(Maclura pomifera)*	0.81	Golden yellow to orange or orange-brown (darkening on exposure).		LW pores small, in clusters, often merging or connected by confluent parenchyma into wavy or concentric bands in the outer LW.
BLACK LOCUST *(Robinia pseudoacacia)*	0.69	Olive or yellow-brown to dark golden yellow-brown (turning dark russet brown on exposure).		LW pores in nestlike groups, which merge into interrupted or somewhat continuous bands in the outer latewood.
KENTUCKY COFFEETREE *(Gymnocladus dioicus)*	0.60	Light red to reddish or orange-brown.		LW pores nested and sometimes merging into short irregular tangential bands in the outer LW.
HONEYLOCUST *(Gleditsia triacanthos)*	0.66	Light red to reddish brown or orange-brown.		LW pores solitary in radial multiples, and, especially in outer latewood, in nestlike groups connected into bands by confluent parenchyma.
STAGHORN SUMAC *(Rhus typhina)*	0.47	Olive green to greenish yellow, often with orange or russet brown in earlywood (R, T), variable color in latewood (X).		LW pores solitary or in radial multiples, but merging into interrupted or continuous bands in the outer LW.

EARLYWOOD (EW) CHARACTERISTICS	VESSEL OCCLUSIONS	RAY CHARACTERISTICS	REMARKS AND MISCELLANEOUS
EW 2-4 pores wide, pores surrounded by lighter tissue. Pores 150-250µm.	Tyloses fairly numerous (some vessels open).	Rays not distinct, barely visible to eye, but clearly visible with lens. 1-3 (mostly 1-2) seriate.	
EW 2-4 pores wide, pores surrounded by lighter tissue. Pores 200-300µm, easily visible to eye.	Tyloses fairly numerous (some vessels open).	Rays not distinct, barely visible to eye, but clearly visible with lens. 1-3 seriate.	Trees commonly slowly grown, growth rings narrow.
EW 3-8 pores wide. Pores 150-200µm.	Tyloses fairly abundant, with sparkle.	Rays barely visible to eye. 1-4 seriate.	Perforation plates occasionally scalariform in latewood. Rays contain scattered oil cells, appearing very large with bright yellow contents. Spicy odor and taste.
EW 3-8 pores wide. Pores 200-300µm.	Tyloses variably abundant, with sparkle.	Rays indistinct to eye but clearly visible with lens. 1-6 (mostly 2-3) seriate.	Faint but unique pungent/spicy odor. May be semi-ring-porous. Sapwood never more than 2 growth rings wide.
EW 2-8 pores wide. Pores 150-250µm.	Tyloses variably present in EW pores. Pores may also contain white deposits.	Rays plainly visible to eye. 1-8 (mostly 5-7) seriate.	Radial surfaces show conspicuous ray fleck.
EW 2-3 pores wide. Pores 150-250µm.	Tyloses abundant, packing vessels and making adjacent vessels indistinct.	Rays barely visible to eye. 1-6 (mostly 2-4) seriate.	Contains water-soluble dye. Shavings when soaked turn warm water yellow.
EW 2-3 pores wide. Pores 200-300µm.	Tyloses abundant, solidly packing vessels, with overall yellow cast, and with sparkle.	Rays barely visible to eye, but distinct with lens. 1-7 (mostly 3-5) seriate.	Earlywood appears as bright yellow band, contrasting with dark amber brown latewood. Sapwood never more than 2-3 rings wide. Bright yellow fluorescence under UV light.
EW 3-6 pores wide. Pores 250-300µm.	Tyloses absent. Reddish gum deposits only rarely present.	Rays uniformly fine, barely visible to eye. 1-7 (mostly 3-5) seriate. Tallest <1200µm high.	Deep yellow, bright fluorescence under UV light.
EW3-5+ pores wide. Pores 200-300µm.	Tyloses absent. Regularly contain reddish gum, especially evident on longitudinal surfaces.	Rays variable in size, largest conspicuous to eye. 1-14 (mostly 6-9) seriate. Tallest >1200µm high.	Bright yellow fluorescence under UV light.
EW 2-6 pores wide. Pores 150-250µm.	Tyloses variably abundant, with iridescent sparkle.	Rays faintly visible to eye, not conspicuous with lens. 1-3 (mostly 1-2) seriate.	Variable yellow to bluish fluorescence under UV light.

TABLE 10.6: SUMMARY CHECKLIST OF FEATURES FOR DIFFUSE-POROUS HARDWOODS IN SUBGROUP III-3

NAME	AVG. SPEC. GRAV.	HEARTWOOD COLOR	VESSEL FEATURES		
			PORE SIZE	PORE DISTRIBUTION	PERFORATION PLATES
HARD MAPLE SOFT MAPLE *(Acer* spp.)	0.46-0.63	Creamy white to light reddish brown. (Soft maple often has greyish cast or streaks.)	Small (50-100µm).	Solitary and in radial multiples of 2 to several.	Simple.
DOGWOOD *(Cornus* spp.)	0.73	Dark brown (sapwood creamy with flesh or pinkish cast).	Very small (<100µm).	Mostly solitary and occasionally in radial multiples of 2 to several.	Scalariform (with 20+ fine bars).
HOLLY *(Ilex opaca,* et al)	0.56	White, with grey or blue-grey cast or streaks.	Very small (50-75µm).	Mostly in multiples further grouped into chains, sometimes extending across growth-ring boundaries.	Scalariform (with 15+ bars).
CHERRY *(Prunus serotina,* et al)	0.50	Light to dark cinnamon or reddish brown.	Small (50-100µm).	Solitary and in radial multiples and small clusters of 2 to several (larger in a row at earlywood edge of ring).	Simple.
YELLOW-POPLAR *(Liriodendron tulipifera)*	0.42	Green, or yellow to tan with greenish cast (sapwood creamy-white).	Small-medium small (100-150µm).	Solitary and in multiples and small clusters of 2 to several.	Scalariform (with 2-16 stout bars).
CUCUMBER-TREE, MAGNOLIA *(Magnolia* spp.)	0.49	Yellow, or medium to dark greenish yellow, or dark green.	Small (50-100µm)	Solitary and in multiples and small clusters of 2 to several.	See remarks.
BASSWOOD *(Tilia americana,* et al)	0.37	Creamy white to light brown	Small (<100µm)	Numerous, solitary and in radial multiples and small clusters.	Simple.
BIRCH *(Betula* spp.)	0.55-0.65	Light brown to dark brown or reddish brown.	Small-medium (100-200µm)	Solitary and in radial multiples of 2 to several.	Scalariform (with 5-20+ bars).
EASTERN HOPHORN-BEAM *(Ostrya virginiana)*	0.70	Light brown to brown tinged with red.	Small (50-100µm)	Solitary and multiples of 2 to several, sometimes aggregated into irregular radial flamelike groups.	Simple. Occasional scalariform (with 3-6 bars).
CALIFORNIA-LAUREL *(Umbellularia californica)*	0.55	Light brown to greyish brown with darker streaks.	Small-medium (100-200µm)	Solitary, and in multiples of 2 to several, each pore or multiple surrounded by vasicentric parenchyma.	Simple.

(continued on pp. 140-141)

		RAY FEATURES		REMARKS AND MISCELLANEOUS
INTERVESSEL PITTING	SPIRAL THICKENINGS	HOMOGENOUS OR HETEROGENEOUS	SERIATION	
Alternate, rounded to angular (5-10µm).	Present (fine, evenly and closely spaced).	Homogeneous.	Hard maple: 1-8 (mostly 5-7). Soft maple: 1-5 seriate.	Vessels may have gum deposits.
Alternate to opposite/oval, intergrading with scalariform.	Absent.	Heterogeneous and homogeneous.	2-8 seriate. Uniseriate (upright).	Uniseriate margins of multiseriate rays with up to several rows ("tails," T-view) of upright cells.
Opposite (sometimes linear), in low spiral rows (4-7µm).	Present.	Heterogeneous and homogeneous.	3-5 (mostly 5) seriate. Uniseriate (upright).	Spiral thickenings in fibers also.
Alternate (7-10µm).	Present (variable in thickness).	Heterogeneous and homogeneous.	1-6 (mostly 3-4) seriate.	Vessels with orange to ruby-red contents. Characteristic gum defects common.
Opposite (oval to rectangular).	Absent.	Heterogeneous and homogeneous.	1-5 (mostly 2-3) seriate. Noded.	Rings delineated by light line of marginal parenchyma.
Scalariform.	See remarks.	Heterogeneous and homogeneous.	1-5 seriate. Noded. See remarks.	Cucumber: Simple perforations, spirals absent, rays mostly 1-2 seriate. Magnolia: Mostly scalariform, 6-10 stout bars, usually with spirals. Line of marginal parenchyma distinct.
Alternate, usually angular/crowded (5-8µm).	Present (thick).	Homogeneous.	1-6 seriate. Noded.	Faint but characteristic musty odor. (T) Ray cells appear laterally compressed.
Alternate, usually with confluent apertures (2-4µm).	Absent.	Homogeneous.	1-5 seriate.	(X) Some pores (with lens) appear filled with whitish substance.
Alternate, round/oval to angular (6-10 µm).	Present.	Heterogeneous and homogeneous.	1-3 seriate.	(X) Often growth rings distinct by whitish spots along outer latewood. Banded parenchyma faintly visible with lens.
Alternate, round/angular (6-10µm).	Occasionally present.	Heterogeneous.	1-4 (mostly 2) seriate.	Spicy odor characteristic. (R) Oil cells present in rays. Fibers thin-walled, commonly septate.

TABLE 10.6 (CONTINUED):
SUMMARY CHECKLIST OF FEATURES FOR DIFFUSE-POROUS HARDWOODS IN SUBGROUP III-3

NAME	AVG. SPEC. GRAV.	HEARTWOOD COLOR	VESSEL FEATURES		
			PORE SIZE	PORE DISTRIBUTION	PERFORATION PLATES
WILLOW (*Salix* spp.)	0.39	Light brown to pale reddish or greyish brown.	Small-medium (50-150µm).	Numerous, solitary, and in multiples of 2 to several.	Simple.
ASPEN, POPLAR, COTTONWOOD (*Populus* spp.)	0.33-0.40	Aspen: creamy white to light greyish brown. Poplar/Cottonwood: greyish to light greyish brown.	Very small-medium. Aspen: 50-100µm Poplar/cottonwood: 50-150µm.	Solitary and in multiples (mostly radial) of 2 to several.	Simple.
BUCKEYE, HORSE-CHESTNUT (*Aesculus* spp.)	0.36-0.45	Creamy white to pale yellow white.	Very small (50-100µm).	Numerous, solitary, in multiples of 2 to several, and in small clusters.	Simple.
SWEETGUM (*Liquidambar styraciflua*)	0.52	Grey or reddish brown (sometimes with variegated pigment), sapwood light, often blue-stained.	Very small (50-100µm).	Numerous, solitary, in multiples of 2 to several (often in short intermittent chains and in small clusters.)	Scalariform (with 10-20+ thin bars).
BLACK TUPELO (*Nyssa sylvatica*)	0.50	Medium grey or grey with green or brown cast.	Very small (50-100µm).	Numerous, solitary, in radial multiples of 2 to several, and in small clusters.	Scalariform (with 20+ thin bars).

NTERVESSEL ITTING	SPIRAL THICKENING	RAY FEATURES HOMOGENOUS OR HETEROGENEOUS	SERIATION	REMARKS AND MISCELLANEOUS
lternate, ound/oval to ngular -10µm).	Absent.	Heterogeneous.	Uniseriate. Large pits in upright ray cells to vessels.	Wood often semi-diffuse-porous. Wood may have interlocked grain.
lternate, ound/oval to ngular -12µm).	Absent.	Homogeneous.	Uniseriate. Large pits in marginal ray cells to vessels.	Aspen: Creamy white, no odor. Poplar/cottonwood: Foul odor when wet, never creamy white. Sometimes appears semi-diffuse-porous.
lternate, ound/oval to ngular -10µm).	See remarks.	Heterogeneous and homogeneous.	Uniseriate.	Spiral thickenings present in vessels of horsechestnut; absent or sporadic in buckeye. Yellow buckeye has ripple marks, horsechestnut sometimes does.
pposite (up to 3 cross) intergrading ith scalariform.	See remarks.	Heterogeneous and homogeneous.	2-3 (mostly 2) seriate. Uniseriate (upright).	Spiral thickenings in ligules of vessel elements only. Wood may have interlocked grain.
pposite (up to 8 cross) occasionally ntergrading with calariform.	See remarks.	Heterogeneous.	1-4 seriate.	Spiral thickenings, when present, in ligules of vessel elements only. Wood usually has interlocked grain.