CHAPTER FOUR

THE STRUCTURE OF WOODY PLANTS: HARDWOODS

Among coniferous woods, similarity in structure and appearance makes identification of most species uncertain without the use of a microscope. In the case of most hardwoods, however, the extreme variability in cell type and arrangement usually produces unique combinations of features that can be easily recognized with a 10x ("ten-power") hand lens. The secret to success in hand-lens identification of hardwoods does not come through memorization of visual designs and patterns, but through an understanding of these visual features in terms of the cells or cell masses that produce them.

In the discussion of each of the major cell types that follows, the features that are visible to the eye or with a hand lens are explored first in some detail, since macroscopic features alone suffice to identify many woods. Within each wood group, the discussion then moves on to cover microscopic features. These features are most reliable in the identification of the more difficult woods, and they also provide a positive check as well as an alternative approach in the identification of pieces that cannot be routinely examined on a cross section.

The Four Basic Cell Types

In the initial examination of a cross-sectional surface of a hardwood with the unaided eye and hand lens, the features that are visible are usually associated with the following:

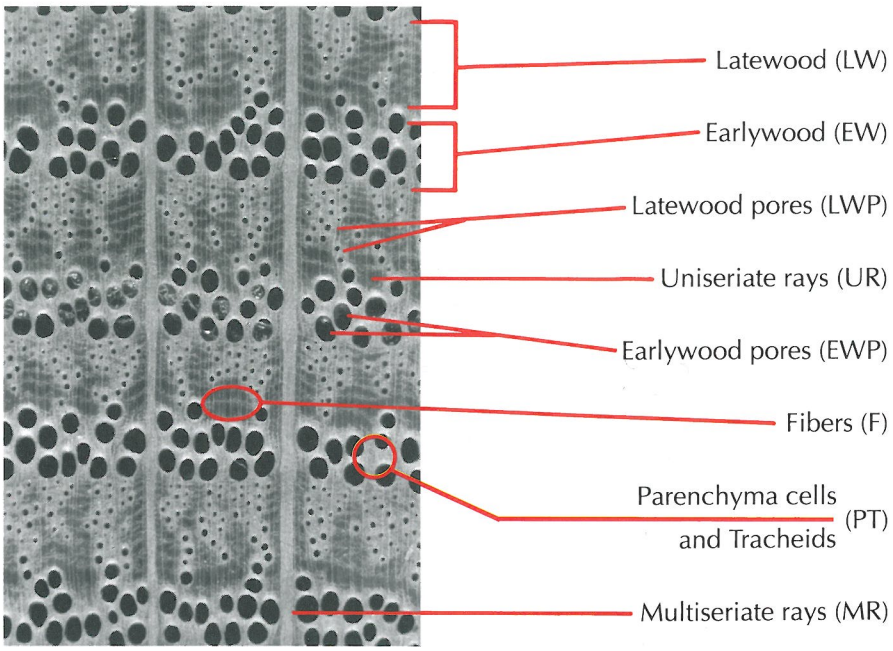
Vessels (or "pores");
Fibers;
Ray cells;
Longitudinal parenchyma and tracheids.

Pores are the transverse openings of vessel elements. In hardwoods, these are the largest-diameter openings you see on a transverse plane. The smallest pores are barely visible with a 10x hand lens, but the prominent pores in some species are obvious to the unaided eye. Pores usually appear as dark holes in the wood. Sometimes they are filled with various kinds of material, but they nonetheless remain recognizable as individual cells.

In the other three cell types, cells are too small to be seen individually with a hand lens. However, we can observe them en masse, and the differences among these cell groups usually enable us to tell them apart.

Fibers are among the smallest-diameter cells and have the thickest walls. On a transverse surface, masses of fibers take on a dense appearance, often forming a dark background or ground mass against which pores and lighter-colored masses of parenchyma and ray cells contrast.

Ray cells form rays, one to many cells wide. Some rays are



INTRODUCTORY VIEW OF HARDWOOD ANATOMY: RED OAK
This is a cross-sectional surface of northern red oak as seen with a hand lens. Within each growth ring, the first-formed earlywood is clearly defined by a zone of large pores, followed by latewood with its smaller pores. Other visible features include large multiseriate rays, narrow uniseriate rays, lighter-colored masses of mixed parenchyma cells and tracheids and darker masses of fibers.

barely visible with a hand lens, others are clear to the unaided eye. They appear as fairly straight radial lines across a transverse surface and are usually of a lighter shade than the ground mass. In woods that lack obvious growth rings, locating rays can be an important aid in establishing a radial surface and the tangential surface perpendicular to it.

Longitudinal parenchyma cells are found in varying numbers among hardwoods. In species like black cherry, they are absent entirely; in sweetgum, they are present but so sparse that they cannot be seen. In many woods, however, they are visible en masse in transverse section as lighter-colored lines or areas. **Tracheids** are less frequent among hardwoods. In cross section they are virtually indistinguishable from parenchyma because both are thin-walled and about the same diameter. Moreover, the two are usually intermixed in the vicinity of pores. As seen with the hand lens, such combined masses of tracheids and parenchyma are described as "lighter-colored tissue," or, less accurately, simply as parenchyma.

An Introduction to the Hardwoods: Red Oak

Eastern white pine was used to introduce softwood anatomy in Chapter 3. Here we will examine northern red oak *(Quercus rubra)* to provide an overview of hardwood features (see the photo above).

Within each growth ring, the earlywood is evident as a distinct band of larger pores that are surrounded by lighter-colored tissue. This lighter-colored tissue is actually a mixture of parenchyma and tracheids. In the latewood, smaller pores occur in more or less radial lines, surrounded by lighter-colored parenchyma and tracheids. The rays are of two distinct sizes. There are conspicuously larger rays, many cells wide, that are obvious at a glance. There are also numerous fine, uniseriate rays that are barely visible with a hand lens. In the latewood, tangential bands of parenchyma appear as continuous or broken lighter lines across the darker masses of fiber.

The combination of features just described is unique to the red oak group (which is discussed more fully in the hardwood-identification section, Chapter 10) and would be sufficient to identify an actual red oak sample. Other hardwood species show variations of the same basic features.

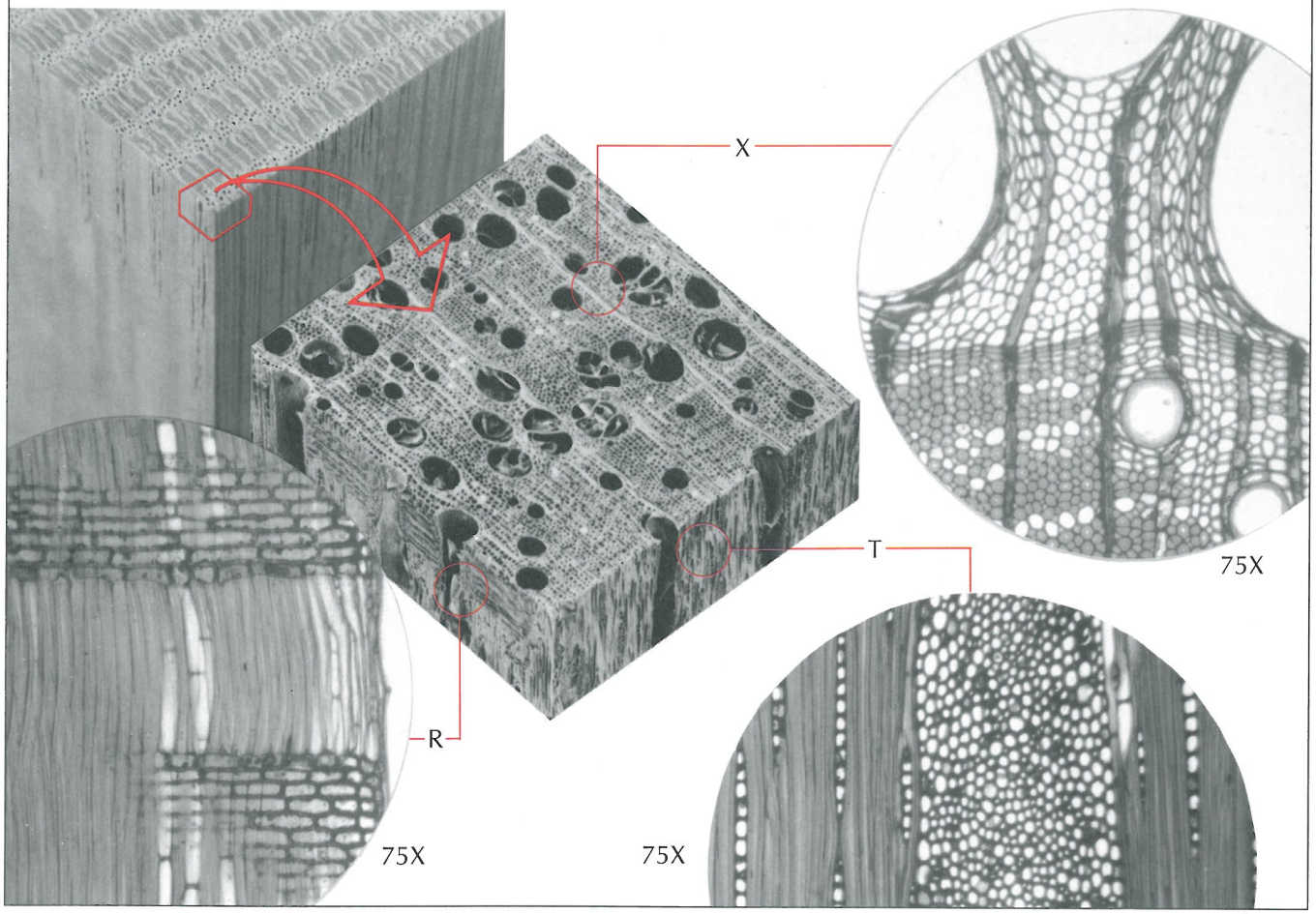
Choice of Viewing Surface and Instrument

When a generously sized cross section is available for examination, enough of the pore, parenchyma and ray characteristics are usually visible with a hand lens to permit identification. But sometimes, as when examining thin veneers, an adequate cross section is not available. In such cases we turn to the longitudinal surfaces. Fortunately, many additional features are apparent here. For example, ray height — the dimension of the ray along the grain — can be measured on a tangential surface. And ray fleck — the exposed ray surfaces — can be seen in radial view. Consequently, this chapter also reviews gross and macroscopic (nonmicroscopic) features on longitudinal surfaces.

Although hardwoods can frequently be identified based on macroscopic features alone, there are instances in which a microscope is mandatory. Fragments are sometimes so thin or tiny that they preclude macroscopic identification. In other cases, the macroscopic features are similar between two species, and only a microscopic examination will separate them accurately. Hence, some of the more important microscopic features are reviewed on the following pages. To give you an idea of how much more you can see with a microscope, compare the hand-

TRANSVERSE, RADIAL AND TANGENTIAL SURFACES OF RED OAK

The circled insets show, from left to right, typical handcut thin sections from the cross-sectional (X), radial (R) and tangential (T) surfaces as viewed for identification under a standard microscope.



Center photo by Wilfred Côté

lens view with the microscopic view of the same red oak sample (above). Although red oak can be identified readily with the hand lens, here we see that it is anything but simple in structure.

Growth Rings

As mentioned in Chapter 2, hardwoods that grow in the temperate zone undergo annual growth/dormant cycles that produce wood in annual growth rings. In some species these growth rings may be clearly evident due to a concentration of large earlywood pores; in others the rings may be very faint because of insignificant variation in cell characteristics. The trained eye can usually recognize even the more indistinct growth rings on a cleanly cut cross-sectional surface.

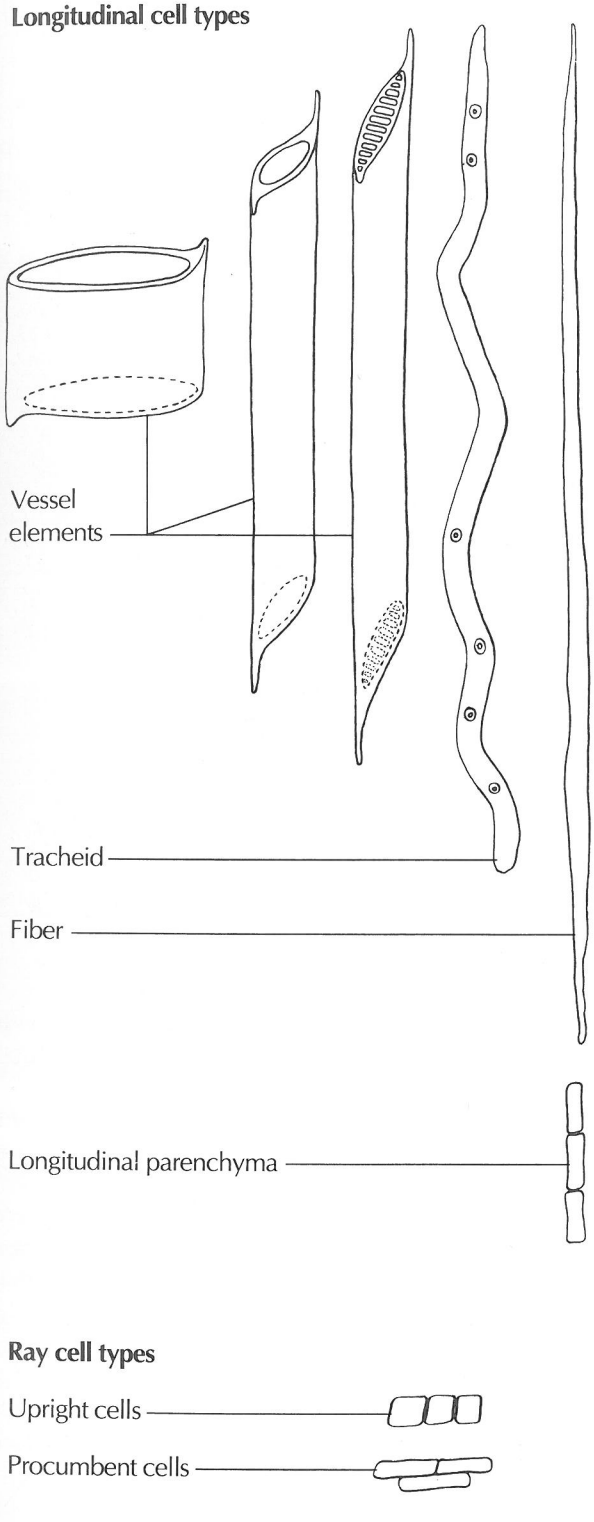
It should also be noted, however, that in tropical regions growth may be continuous, so it is possible for wood to form without typical rings. However, growth may be interrupted at intervals, although not necessarily on an annual or other cycle. These interruptions can result from variation in rainfall or from other causes, and the consequent growth rings can be either periodic or sporadic. For example, in Central American mahogany — the traditional and familiar furniture wood — visible growth rings are formed periodically due to a distinct fine line of parenchyma called marginal parenchyma.

In some other woods, visible growth rings may result from cyclic variation in pigmentation. However, these zones of pigmentation may not coincide with the concentric anatomical arrangement of the wood.

At this point it is appropriate to examine the various cell types found in hardwoods. Each cell type is discussed separately in terms of shape, size, arrangement within the wood and features. As you will see, each cell type contains a number of features that are useful in identification. The drawing at left on the facing page characterizes and compares these basic cell types.

HARDWOOD CELL TYPES

This diagram shows the relative sizes and shapes of typical cell types found among hardwoods.



Vessel Elements

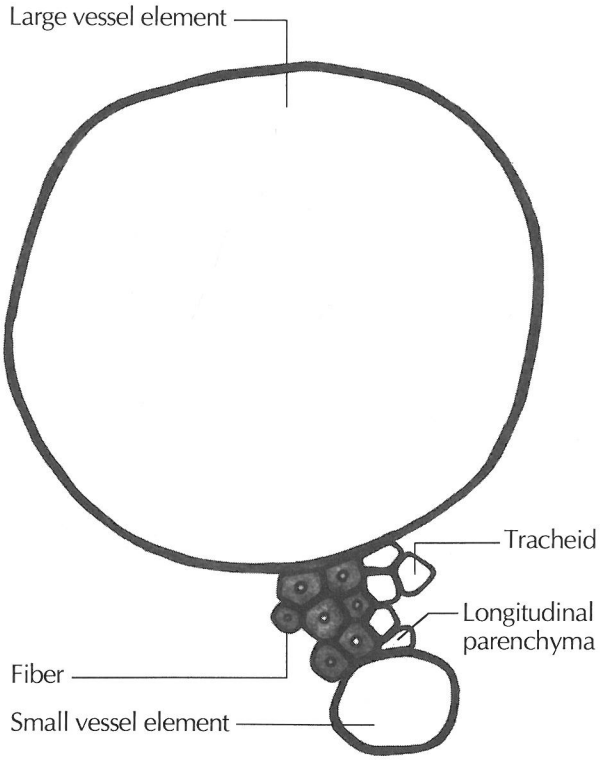
Vessel elements are the largest cells in hardwoods (drawing below). With their thin walls and spacious cell cavities, they are well adapted to sap conduction. They always occur end to end in vertical series, and they are unique in that each end wall has an opening called a perforation. This perforation is matched to a similar perforation in the adjacent vessel element, so the vertical series of elements forms a continuous conductive passageway called a **vessel.**

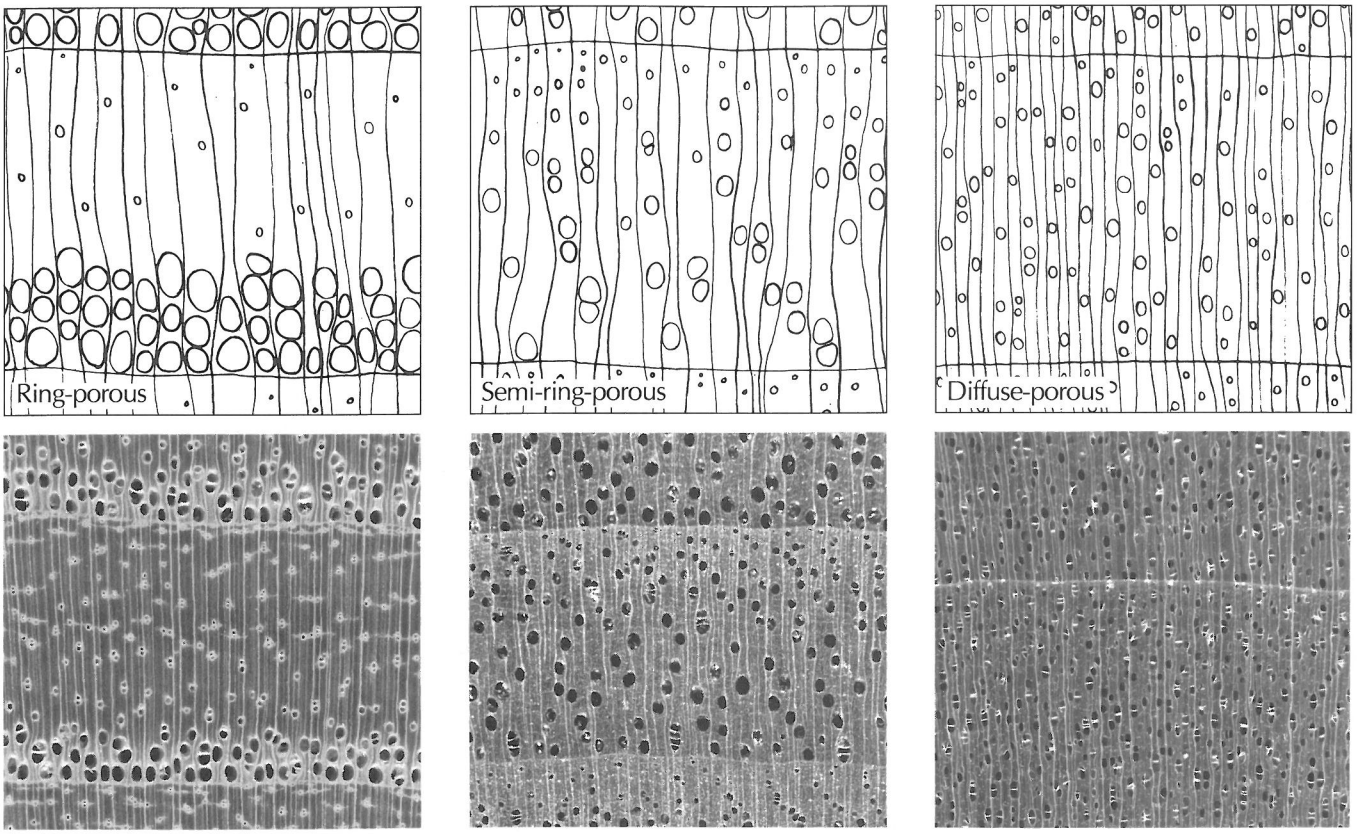
When a vessel is split lengthwise, as often happens when you section a longitudinal surface, it appears as a minute groove called a **vessel line.** Depending on vessel diameter and the presence or absence of contents, vessel lines may have a conspicuous and unique appearance. This makes them important identification features.

When cut transversely, the opening of a vessel on a cross-sectional surface is called a pore. Pores vary in size according to vessel diameter from a minimum of 50 to 60 micrometers, as in red gum, to over 300 micrometers, as in oaks. Among hard-

RELATIVE HARDWOOD CELL DIAMETER AND WALL THICKNESS

This diagrammatic transverse view of hardwood longitudinal cell types gives an approximate comparison of cell diameter and cell-wall thickness.





CLASSIFICATION OF RING POROSITY
Hardwoods are classified as ring-porous, semi-ring-porous (or semi-diffuse-porous) or diffuse-porous, based on pore size and distribution within a growth ring as viewed with a hand lens in cross section.

woods, texture designations are based on pore size and range from fine-textured for the smallest pores to coarse-textured for the largest.

One of the first steps in identifying a hardwood sample is to classify it according to pore size and distribution within a growth ring (photos and drawings above). If the pores are uniform in size and evenly distributed, the wood is **diffuse-porous**. Maples *(Acer* spp.) are diffuse-porous woods with fine texture; American mahoganies *(Swietenia* spp.) are diffuse-porous but coarse-textured.

A **ring-porous** wood is one that has a distinct concentration of larger pores in the earlywood. The earlywood may consist of a single row of these pores, as in American elm, or may be two to several pores wide, as in white ash or sassafras.

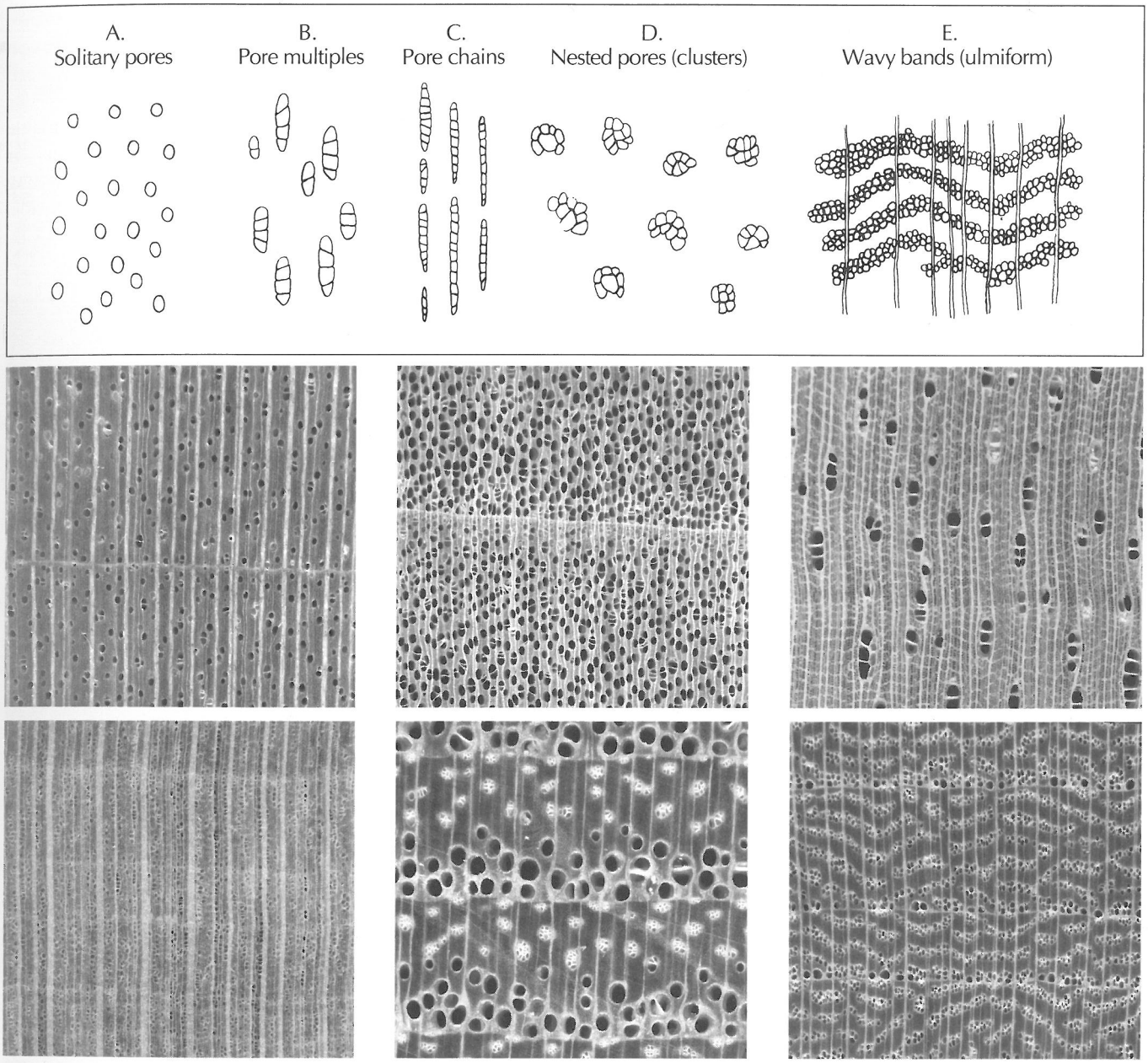
In ring-porous species, the zone of large pores identifies the earlywood portion of the ring. The transition from earlywood to latewood may be sharply defined by an abrupt change in pore size, or it may be poorly defined due to gradually decreasing pore diameter.

If a wood has a concentration of earlywood pores at the growth-ring boundary but the pores are about the same size as others throughout the growth ring, the wood is considered diffuse-porous, not ring-porous. A good example is black cherry, where a distinct line of pores is usually conspicuous at the very first portion of the growth ring, tempting us to classify it as ring-porous.

Woods whose pore diameters vary gradually from large at the earlywood edge to much smaller at the latewood edge, with no clear separation of earlywood and latewood zones, are described as **semi-ring-porous** or **semi-diffuse-porous**. Black walnut, butternut and persimmon are semi-ring-porous woods.

Although woods of a given species usually fall into one of the above categories, some species range from one classification to the next. True hickories, for example, are typically ring-porous, but pecan hickories vary from ring-porous to semi-ring-porous. Cottonwood and willow are typically diffuse-porous, but some species show enough variation in pore size to be considered semi-diffuse. It should also be noted that tropical woods are typically diffuse-porous. An exception is teak, which can be either, although it is most often ring-porous.

Pores are further described according to their position relative to one another in cross section. This configuration is known as pore arrangement.



PORE ARRANGEMENTS IN HARDWOODS

The drawing above illustrates various pore arrangements, which are described according to the relationship of pores to one another within a growth ring as they appear on a cross section. Examples of each type are shown in the corresponding photographs. Top row: (A) maple, (B) cottonwood and jelutong; bottom row: (C) holly, (D) Kentucky coffeetree, (E) American elm. (15x)

In hardwoods, pores are arranged in various ways (see the drawing above). A **solitary pore** is a single pore that does not touch any others (e.g., as in maple, top row, left). A **pore multiple** occurs where two or more pores come in contact with one another (cottonwood, top row, center). Multiples are most commonly arranged in radial groups, which are more precisely called **radial multiples**, as are seen, for example, in jelutong (top row, right). When tightly crowded, the multiple may appear as a single large oval pore, elongated in a radial direction with one or more divisions. In multiples where larger numbers of pores contact one another both radially and tangentially, as in Kentucky coffeetree (bottom row, center), the term **nested pores** or **pore cluster** is used. Radially arranged series of multiples or closely arranged solitary pores are called **pore chains**, as seen in holly (bottom row, left). Pores arranged in irregular concentric bands that are more or less tangential are called **wavy bands** (bottom row, right), also referred to as **ulmiform** because this arangement is a distinctive feature of all elms (*Ulmus* spp.).

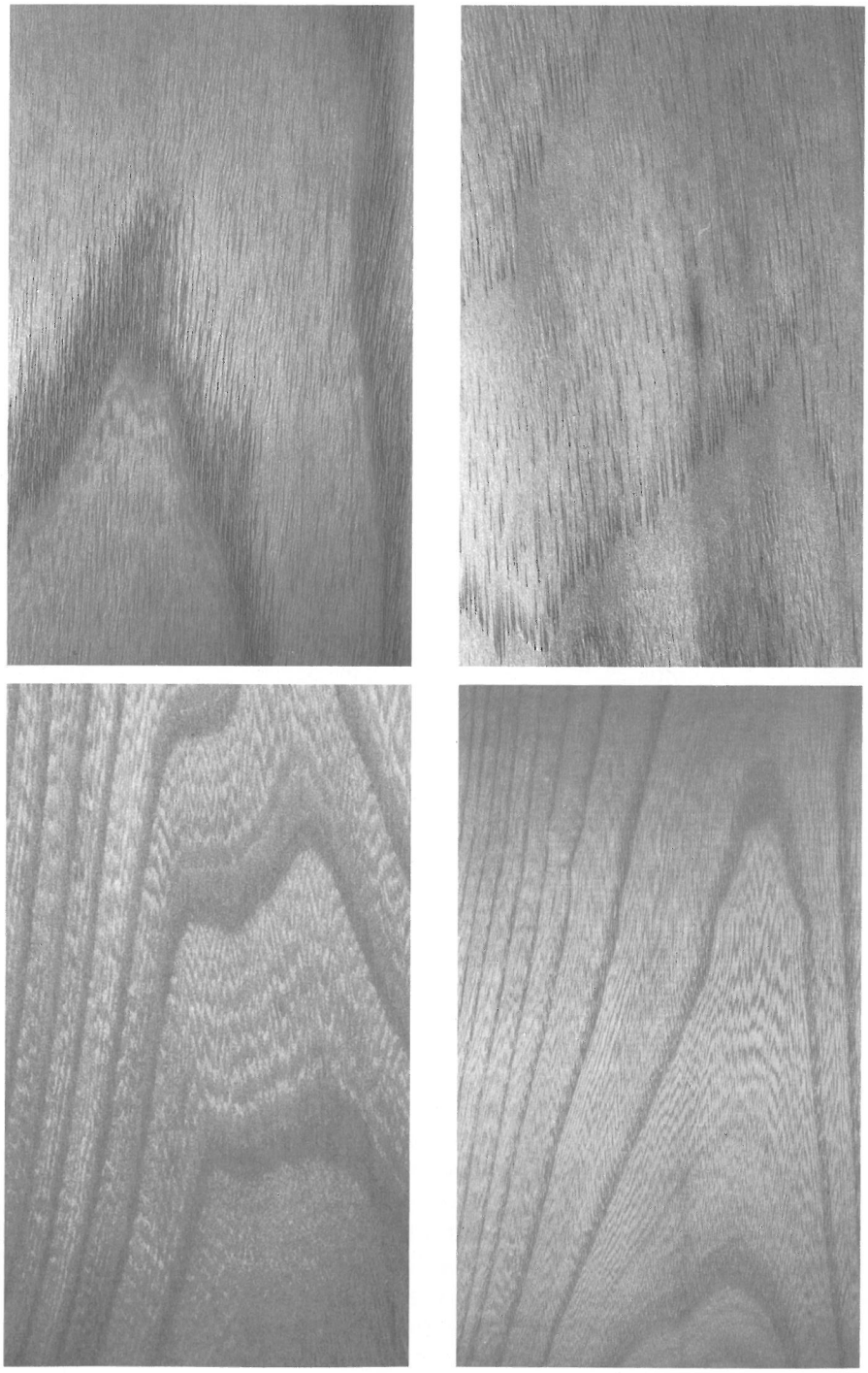
On longitudinal surfaces, vessel lines may hint at pore arrangement, as shown in the photos below. For example, on the tangential surface of ash, the earlywood vessel lines are crowded and in multiple layers, as opposed to the predominantly single rows of more widely spaced pores in hickory. In woods such as elm and hackberry, the wavy bands of latewood pores are revealed as distinctive zigzag patterns of vessel lines in the latewood portions of tangential board surfaces.

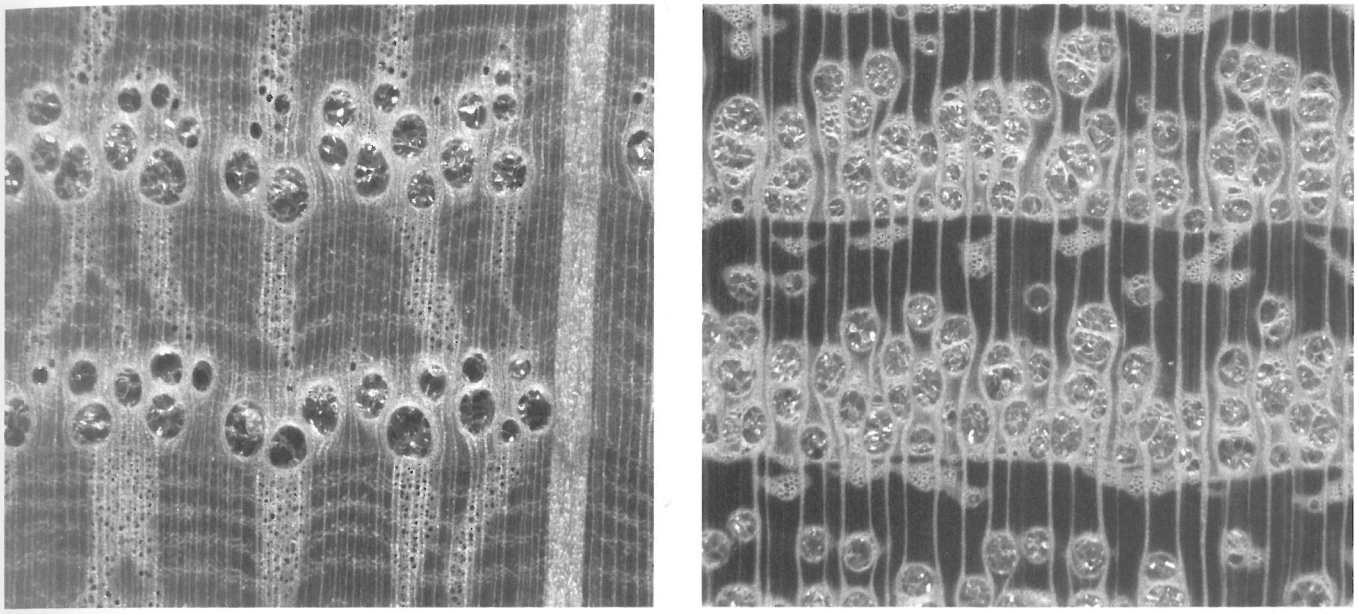
Not all vessels have contents, but where contents are present, they can be valuable in identification. **Tyloses** (see the photos on the facing page) are bubblelike structures that form in the cell cavities of vessels of some species.

Tyloses may be absent or sparse (as in most red oaks), variable (as in chestnut and ash), abundant (as in most white oaks) or densely packed (as in black locust). In some species, including black locust, tyloses have a characteristic iridescence or sparkle.

VESSEL LINES ON LONGITUDINAL SURFACES

Vessel lines on longitudinal surfaces can be diagnostic. In ash (top left), the earlywood is comprised of a multiple layer of large pores, whereas in hickory (top right), earlywood is clearly a single row of the largest pores. In elm (bottom left) and hackberry (bottom right), the ulmiform latewood pores show as jagged patterns of short vessel lines in the latewood areas.





TYLOSES IN VESSEL ELEMENTS
Abundant tyloses can be seen in the vessel elements in these cross-sectional views of white oak (left) and black locust (right). (20x)

Other significant vessel contents include whitish or chalky mineral deposits and reddish or brown gummy deposits.

MICROSCOPIC DETAIL

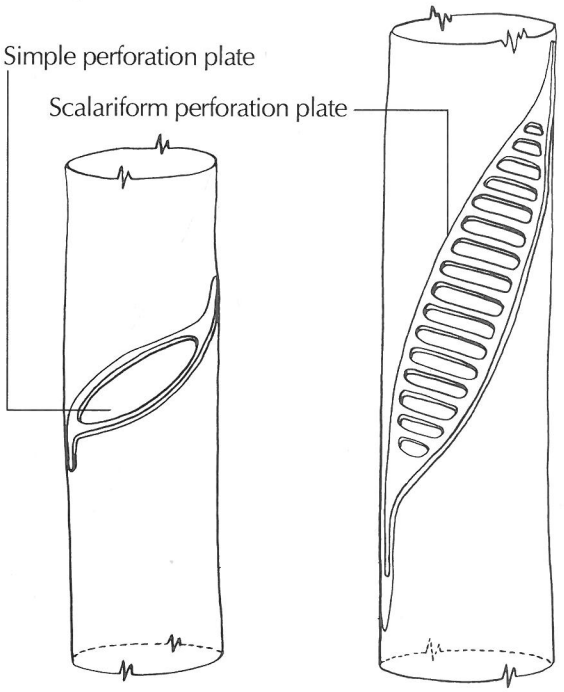
The double end wall joining two consecutive vessel elements is called a perforation plate because it has a perforation through it.

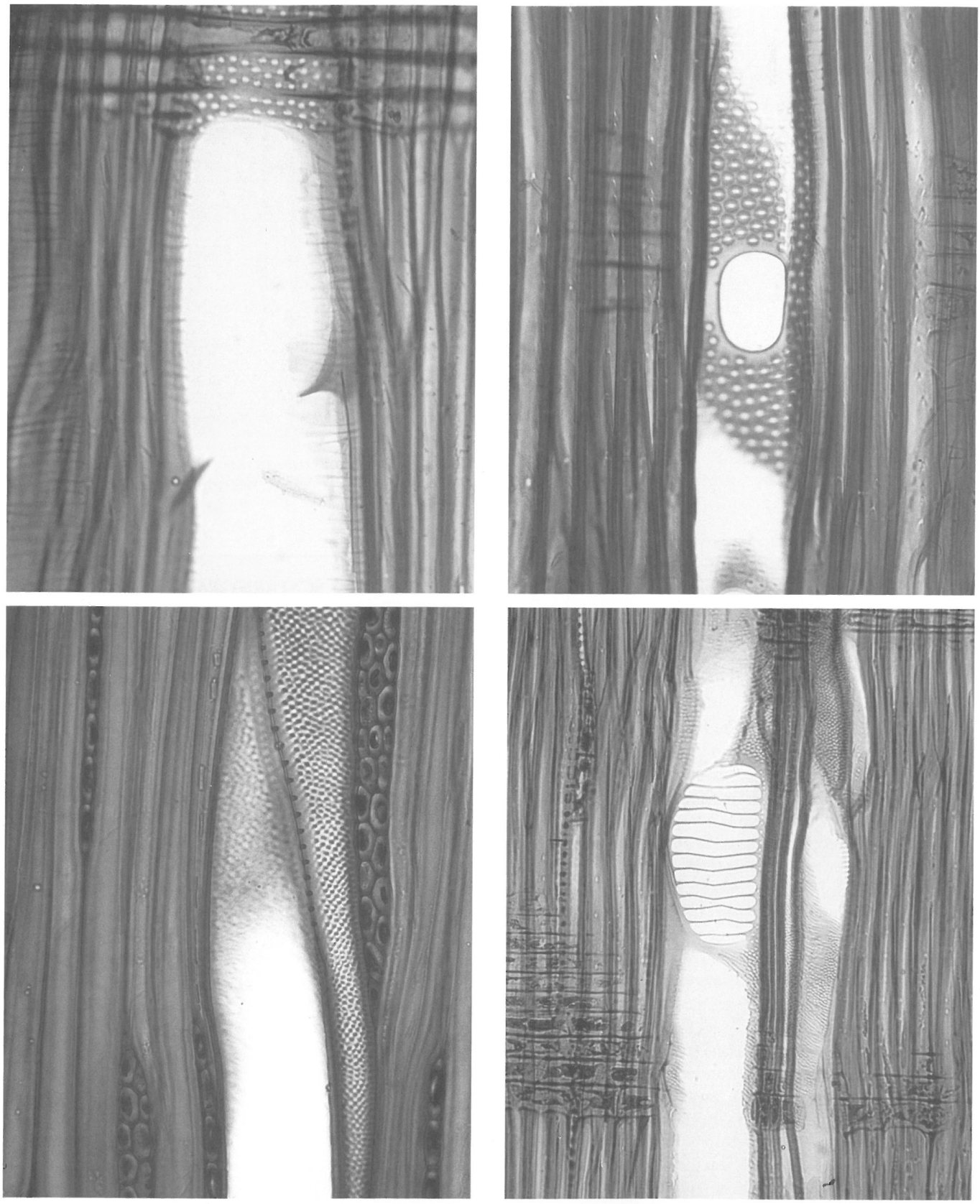
There are two basic types of perforation plates, simple and scalariform. A **simple perforation** denotes a single opening, usually occupying almost the entire plate. The remaining wall at the edge of the plate is called the **perforation rim.** Simple perforations are found in many species, including oaks, ashes, maples and basswood. A **scalariform perforation** consists of parallel openings, the remaining **bars** lending a ladderlike or gratelike appearance to the plate. Bars range in number from few, as in yellow-poplar, to many, as in sweetgum. In some species, such as sassafras, both types of perforation plates occur. Beech has a transitional type of perforation plate with a simple opening in the center and scalariform areas above and below. Irregular or distorted bars in scalariform plates are called **reticulate** or **foraminate perforations.**

Of the two types of perforations (as seen in the drawing at right), scalariform is easier to detect because it has a distinctive appearance. Even where the scalariform plate is damaged or partially cut away, the barlike pattern is still recognizable. Simple perforations are more difficult to confirm. It helps to remember that in large vessels where the plates are simple, they are nearly perpendicular to the vessel. In smaller vessels, the plate is usually at an angle, sometimes forming a very long sloping end wall. Often the orientation of the plate approaches the radial plane. Therefore, a radial section is more apt to show a

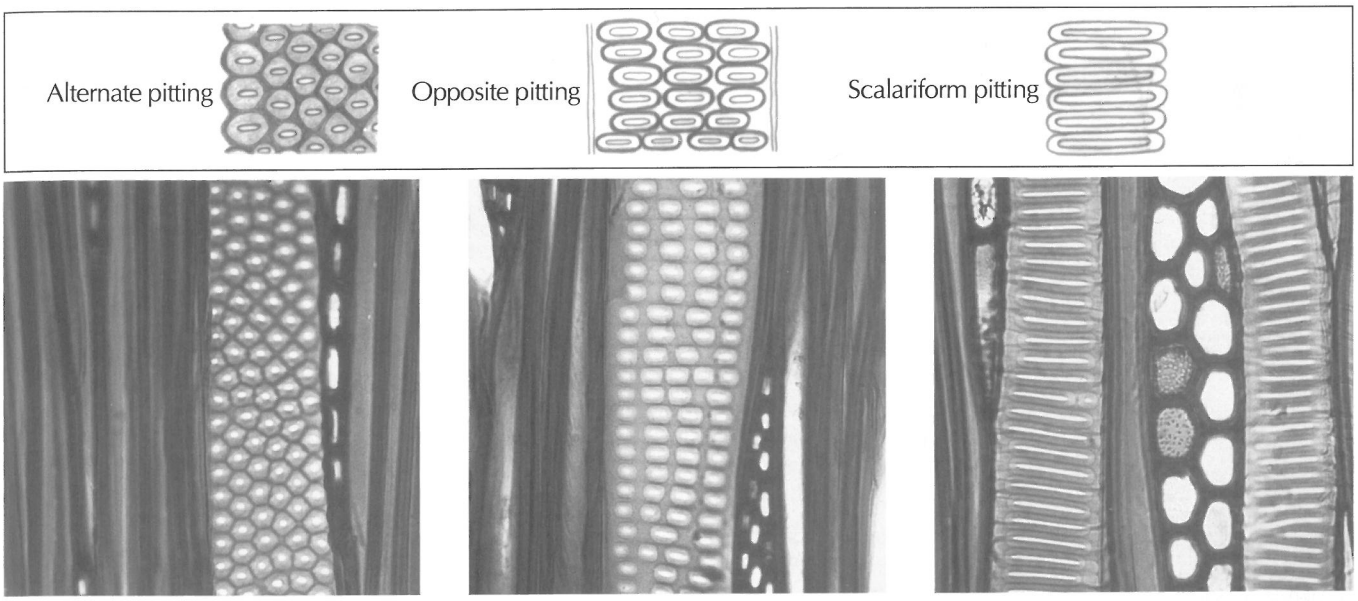
SIMPLE AND SCALARIFORM PERFORATION PLATES

The composite end wall formed where adjoining end walls of two vessel elements have matching openings, or perforations, is called a perforation plate. A perforation plate is simple if it has a single large opening, scalariform if it has multiple, slotlike openings.





PERFORATION PLATES IN RADIAL AND TANGENTIAL VIEW
These micrographs show simple perforation plates in maple (viewed tangentially at top left and radially at top right) and scalariform perforation plates in yellow birch (viewed tangentially at bottom left and radially at bottom right). (350x)



INTERVESSEL PITTING TYPES
Intervessel pitting occurs along the common lateral walls joining two vessels. Pitting is classified according to shape and arrangement into three broad types, as indicated in the micrographs of aspen (alternate pitting), left, yellow-poplar (opposite pitting), center, and magnolia (scalariform pitting), right. (275x)

perforation plate in face view (see the photos on the facing page). You should consider this when cutting sections to observe perforation plates.

Where two vessels are in lateral contact, the fairly wide common wall joining them is usually heavily pitted. The characteristic appearance of this **intervessel pitting** can also be very helpful in identification.

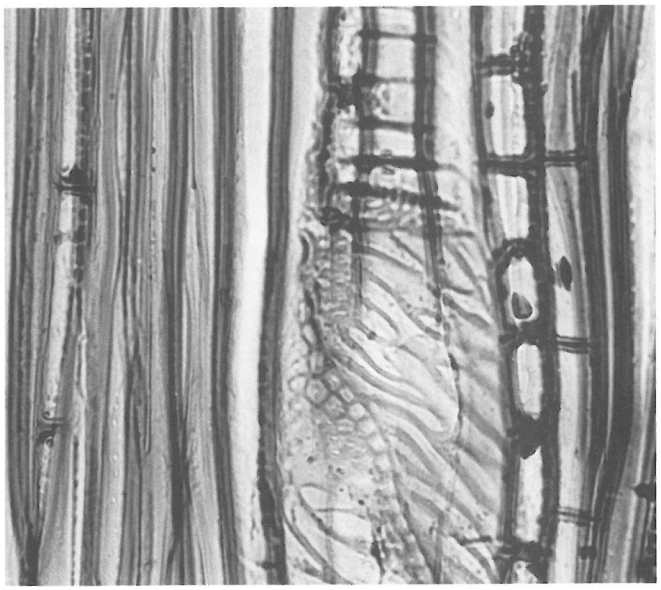
Alternate pitting designates pits that are crowded together, resulting in an irregular or diagonal arrangement. **Opposite pitting** refers to short rectangular or slightly rounded pits in a distinct horizontal arrangement. Elongated barlike pits in parallel, ladderlike arrangement are **scalariform,** as in magnolia.

The various types of pitting may intergrade. In sweetgum, for example, pitting intergrades between scalariform and opposite, and the pits range in shape from short and rectangular or oval to linear.

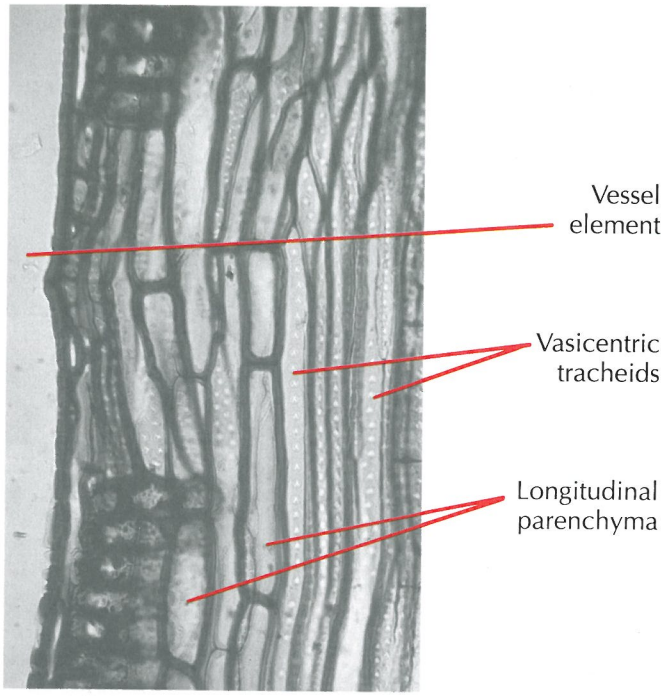
When inspecting a sample for intervessel pitting, first carefully study the cross-sectional view to determine the general orientation of pore multiples. This helps you decide which longitudinal plane is best for sectioning. If the pores are predominantly in radial multiples, a tangential section is more apt to include an intervessel wall.

Characteristic pitting sometimes occurs between vessel elements and other cell types, especially between ray cells and vessel elements, as in willow and aspen.

Because spiral thickenings are present in the vessel elements of only some species, they are also useful in identification. For example, hophornbeam has thickenings, but birch does not. In sweetgum and black tupelo, spiral thickenings are restricted to the ligules (elongated tips) of the vessel elements. The reticulate (netlike) thickenings that occur sporadically in the latewood vessels of black walnut *(Juglans nigra)* are referred to as **gash pits** or **gashlike pitting** (see the photo below). This feature, when present, provides a positive means of separating black walnut from butternut *(J. cinerea)* and English walnut *(J. regia),* which lack gash pits.



GASH-PIT THICKENINGS IN BLACK WALNUT
Reticulate thickenings, often referred to as 'gash pits,' on a latewood vessel wall in black walnut. (300x)



VASICENTRIC TRACHEIDS AMONG LONGITUDINAL PARENCHYMA
Vasicentric tracheids with abundant bordered pits are easily distinguished from the strands of longitudinal parenchyma cells as seen in this radial view of northern red oak. (200x)

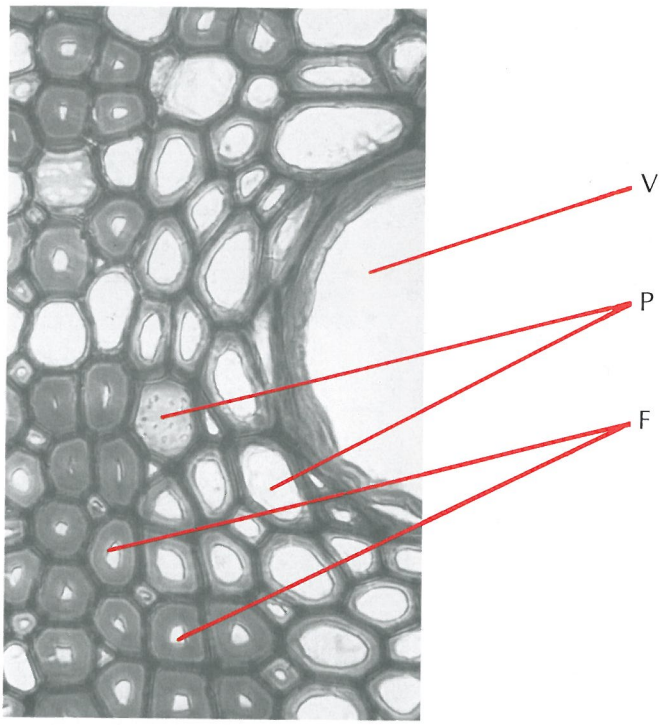
Vasicentric Tracheids

Tracheids are functionally intermediate between vessel elements and fibers. They are imperforate — closed at the ends — but fairly thin-walled and usually have numerous pits on the side walls. As the term vasicentric implies, they occur near vessel elements. Vasicentric tracheids are usually intermixed with longitudinal parenchyma (photo at left). The two form areas of "lighter-colored tissue" as viewed on cross sections with a hand lens.

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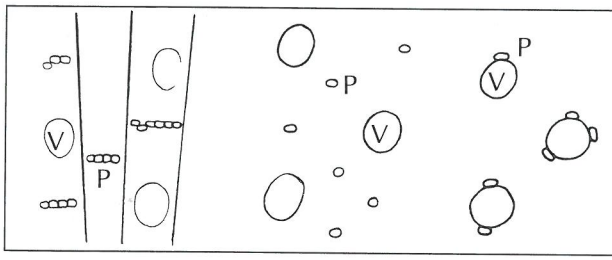
Vasicentric tracheids only appear separate and distinct microscopically. In longitudinal section they show up as small-diameter, thin-walled, abundantly pitted cells. In this view they are readily distinguishable from longitudinal parenchyma. Parenchyma cells are short, as indicated by the frequent cross walls.

Tracheids are present in oaks and chestnut in the vicinity of the large earlywood pores. In ash, cells resembling vasicentric tracheids also occur among the earlywood vessels. Since ash, oak and chestnut can be identified readily on the basis of macroscopic features, these microscopic clues are useful primarily when only small slivers or fragments are available for identification. Tracheids intergrade somewhat with fibers, which are discussed in the next section.

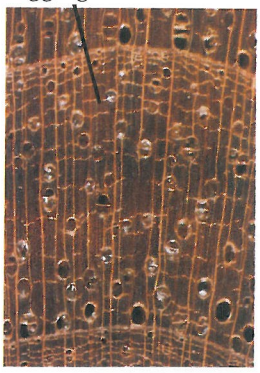


FIBERS IN OAK
In this cross-sectional view of latewood in red oak, the small-diameter fibers (F) are easily distinguished from the thinner-walled parenchyma cells (P). Note the thick wall of the vessel (V) in the pore at right. (200x)

PARENCHYMA ARRANGEMENTS



Apotracheal diffuse-in-aggregates | Apotracheal diffuse | Paratracheal scanty



(Apotracheal diffuse and paratracheal scanty parenchyma are not visible with hand-lens magnification.)

Butternut (10x)

Fibers

Fibers are typically long, slender, straight cells whose ends taper to a point. They are among the smallest-diameter cells. Because of their small size and thick walls, they appear as darker areas when seen en masse in cross section. Without higher magnification they simply form a background for pores, rays and parenchyma. A microscope must be used to observe greater detail.

MICROSCOPIC DETAIL

With a microscope, there is a clear contrast between the thick-walled fibers and the thinner-walled parenchyma and tracheids (see the photo at bottom left on the facing page).

Note, however, that in lower-density woods such as aspen and balsa, the fibers can be fairly thin-walled. In cross section they are usually somewhat rounded in outline. But in a few species, sweetgum for example, the fibers are distinctly angular, which can be helpful in identification.

Fibers can be separated into two intergrading types, **libriform fibers** and **fiber tracheids**. Fiber tracheids have bordered pits; libriform fibers have simple pits. However, these differences are difficult to distinguish with an elementary microscope. Therefore, this book will refer to fibers collectively; it will not distinguish between the two types.

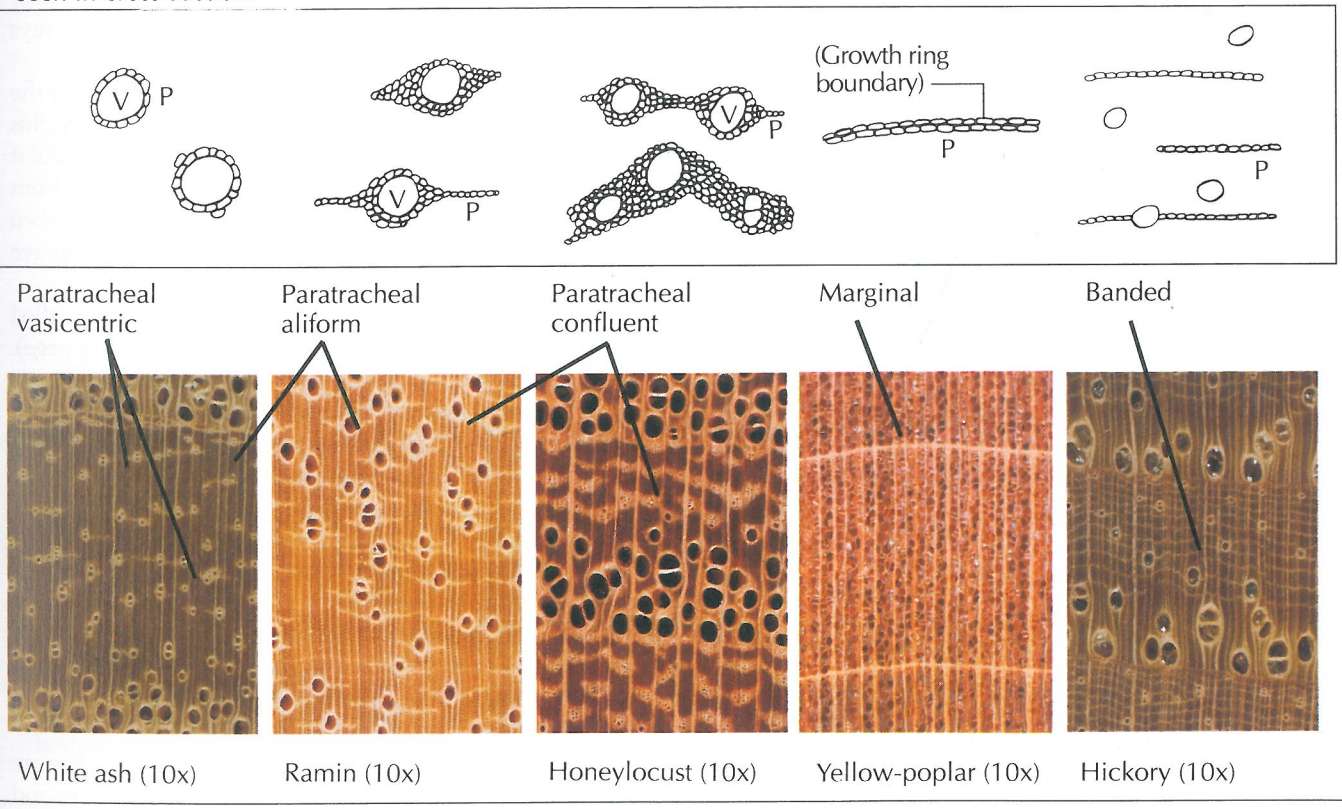
Parenchyma

Parenchyma arrangement is described according to the relationship between parenchyma cells and pores as viewed in cross section (see the photos below). If the parenchyma cells make direct contact with the pores, they are **paratracheal parenchyma**. If they are separated from the pores by rays or fibers, they are **apotracheal parenchyma**.

Single, isolated cells of apotracheal parenchyma are called **diffuse parenchyma**; they cannot be seen without a microscope. Apotracheal parenchyma occurring in short tangential lines is described as **diffuse-in-aggregates parenchyma**. In woods like basswood and birch, this parenchyma is visible only with a microscope, but in other woods like black walnut and butternut, diffuse-in-aggregates parenchyma can be seen with a hand lens.

Single cells of paratracheal parenchyma are called **scanty paratracheal parenchyma**, or simply, **scanty parenchyma**. If parenchyma cells are numerous enough to form a complete or partially complete sheath around a pore, they are called **vasicentric parenchyma**. As with scanty parenchyma, a broken layer of vasicentric parenchyma might not be visible with a hand lens. But a complete layer of parenchyma will usually be apparent at that level, particularly where the layer is several cells thick, as in the latewood of white ash.

Arrangement of longitudinal parenchyma (P) is classified on the basis of relationship to pores (V) as seen in cross section.



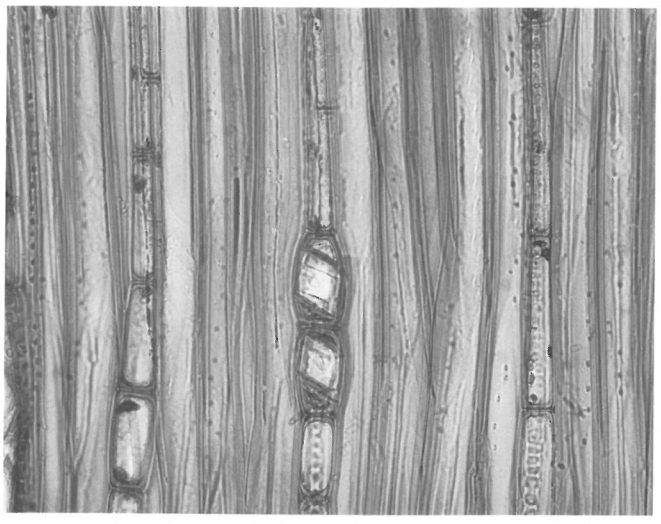
Vasicentric parenchyma that occurs in a well-developed layer with additional cells forming tangential winglike extensions on either side is called **aliform parenchyma**. The aliform parenchyma of ramin, a tropical wood, is a good example. When parenchyma forms a continuous tangential or diagonal zone connecting two or more pores, it is called **confluent parenchyma**. The term **zonate parenchyma** is often used when cells form well-developed continuous bands.

Banded parenchyma describes the distinct tangential lines of cells that usually occur with fairly regular spacing, as in hickory. The lines may intergrade with shorter lines of diffuse-in-aggregates parenchyma, as in black walnut. In species with banded parenchyma, some of the lines appear to make contact with the pores while others do not; consequently no attempt is made to classify banded parenchyma as either apotracheal or paratracheal. When lines of banded parenchyma join with ray lines of approximately the same width to form a meshlike or netlike pattern—as in hickory and persimmon—the term **reticulate parenchyma** is used.

Parenchyma occurring at the growth-ring boundary is called **marginal parenchyma**. The terms **initial** and **terminal** parenchyma are also used. Single cells are not discernible with a hand lens, but in species such as yellow-poplar and American mahogany the growth ring is clearly delineated by a line of marginal parenchyma several cells thick.

MICROSCOPIC DETAIL

Microscopically, longitudinal parenchyma cells are seen to occur in strands of several to many cells — hence, the term **strand parenchyma**. In some species, crystals or gummy deposits are found in parenchyma cells, and this is important in identification. For example, crystals occur in black walnut (see the photo below), but not in butternut or English walnut.



CRYSTALS IN BLACK WALNUT
This micrograph shows crystals in the longitudinal parenchyma cells of black walnut. (250x)

Rays

Ray size in hardwoods varies widely among species or even within a single species. Thus, the relative size and appearance of rays on all three principal surfaces are important identification characteristics. Measurements of particular significance are height along the grain and tangential width. Ray length, however, is of no value, since rays are continuous along a radial plane once they have formed.

The narrowest rays are only one cell, or 10 to 15 microns (about 0.01mm or 1/2000 in.) wide. They are invisible to the unaided eye. The widest rays may be 40 or more cells or 300 microns (about 1/64 in.) wide; they are distinctly visible. It should be noted, however, that it is not only size that determines visibility, but also contrast with adjacent tissue. In oak, even one-cell-wide rays can be seen on a cross-sectional surface with a hand lens against the contrasting background mass of dense fibers.

Actual ray size is difficult to judge. It is often useful to compare ray width to pore diameter (see the photos at the top of the facing page). In maples, for example, the widest rays are approximately the same width as the largest pores; in birch, maximum pore diameter is much larger than the widest rays. Comparing ray width to parenchyma band width can also be informative.

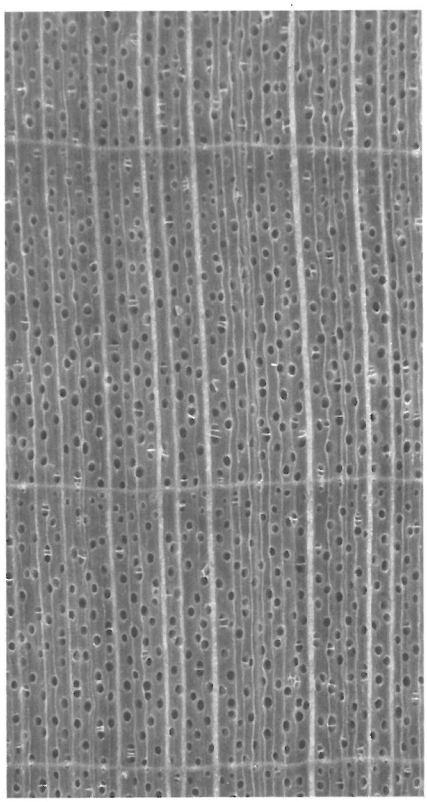
The number or frequency of rays over a given area and their relative spacing are also important. One method of counting is to measure the number of rays that cross the growth-ring boundary over a fixed distance along the boundary — over a distance of one millimeter, for example. Another method is to estimate how many pore diameters would fit into the space between two rays an average distance apart.

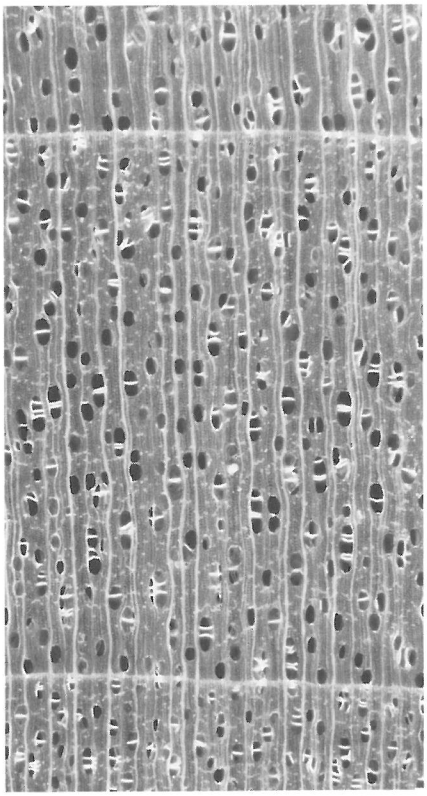
You can also attempt to estimate what percentage of the cross-sectional surface is occupied by ray tissue. Obviously, this is a less precise, more subjective estimate, but it can be useful if you are reasonably consistent in your criteria for judging from sample to sample. Another subjective observation I make when examining rays is whether they are straight or appear to weave as they pass the pores.

When rays swell at the growth-ring boundary they are called **noded rays** (see the photos at the bottom of the facing page). These are seen in yellow-poplar, beech and sycamore.

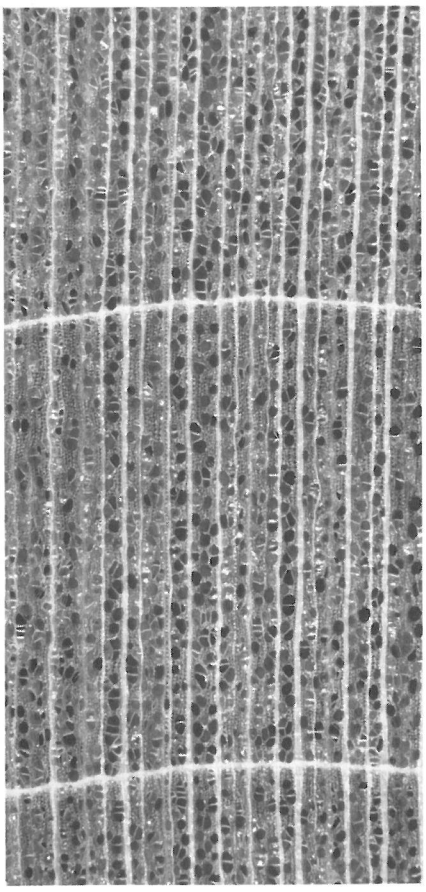
A tangential surface cuts through the rays and shows them in cross section. They may appear as fine vertical lines, sharply pointed at the top and bottom. On this surface, they range from invisible to clearly distinct, depending on size, shape and contrast with background longitudinal tissue. The tiny rays of chestnut cannot be seen in this view at all, even with a hand lens. In black cherry rays are perceptible with a hand lens but not with the unaided eye. In maple they are visible with the naked eye and distinct with the lens. And in beech, sycamore and oak (see the photos on p. 42) they are easily seen without any magnification.

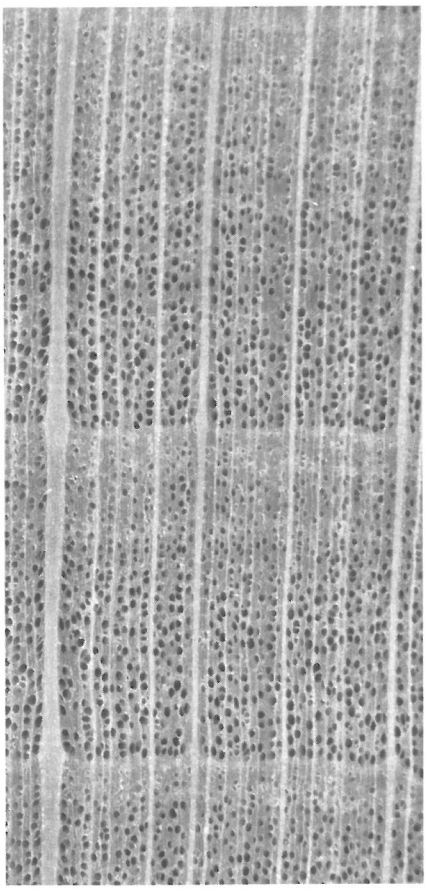
In a ring-porous wood like oak, the rays show up much more distinctly when the wood is sectioned through the latewood



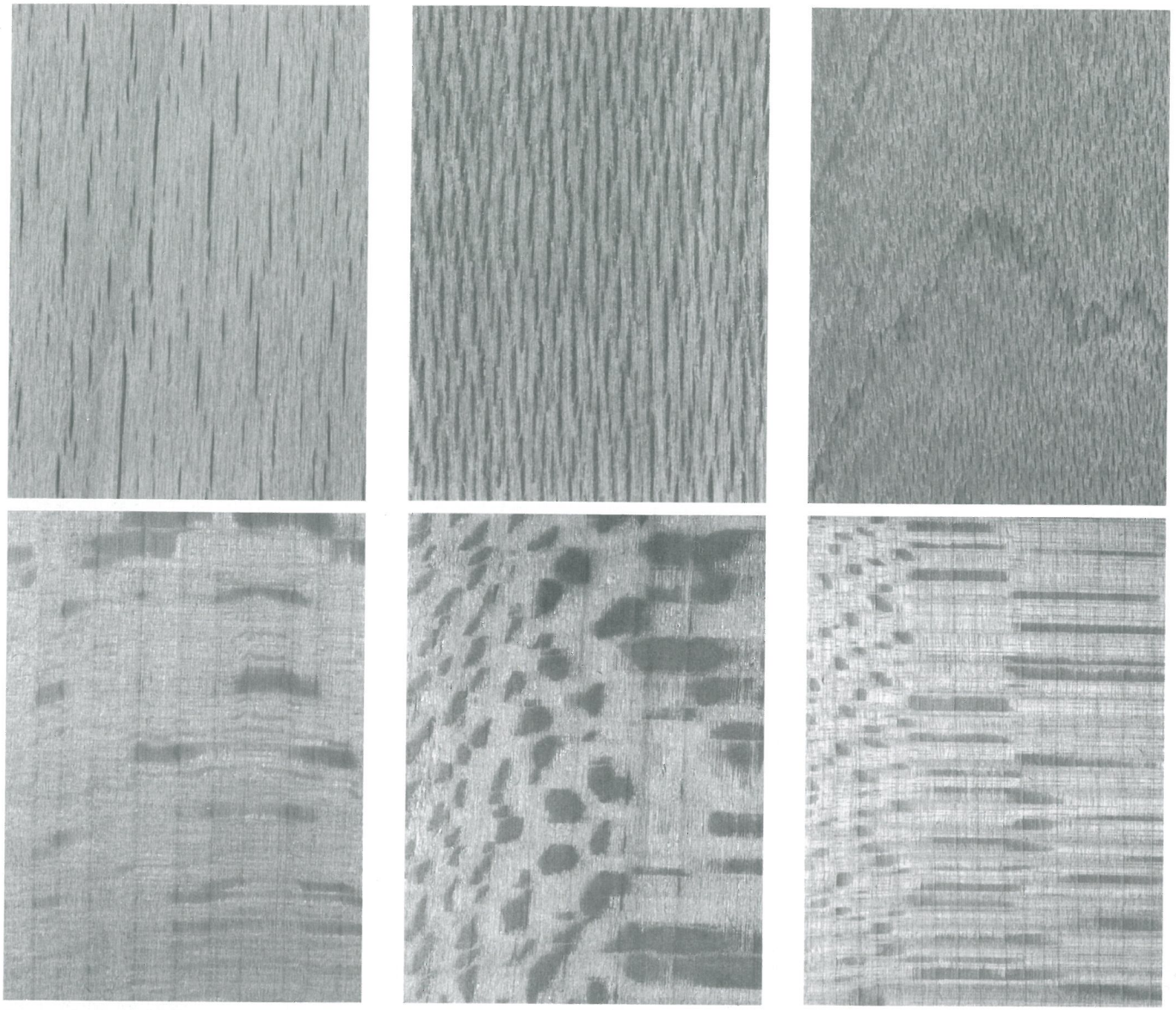


RAY WIDTH/PORE DIAMETER COMPARISON
Comparing ray width to pore diameter quickly distinguishes maple (near right) in which the largest rays (R) are about the same width as the largest pores (P), from birch (far right) in which the largest rays are much narrower than the largest pores. (20x)





NODED RAYS
Noded rays appear to flare or become swollen as they cross the growth-ring boundary, as shown in the cross-sectional views of yellow-poplar (near right) and beech (far right). (20x)



RAY HEIGHT AND RAY FLECK IN THREE HARDWOODS
These pairs of macrographs compare ray heights as seen tangentially (top row) and ray fleck as seen radially (bottom row) in American beech (left), sycamore (center) and maple (right).

rather than through the earlywood. The dense fibers make a uniform background against which the outline of the rays is distinctly seen.

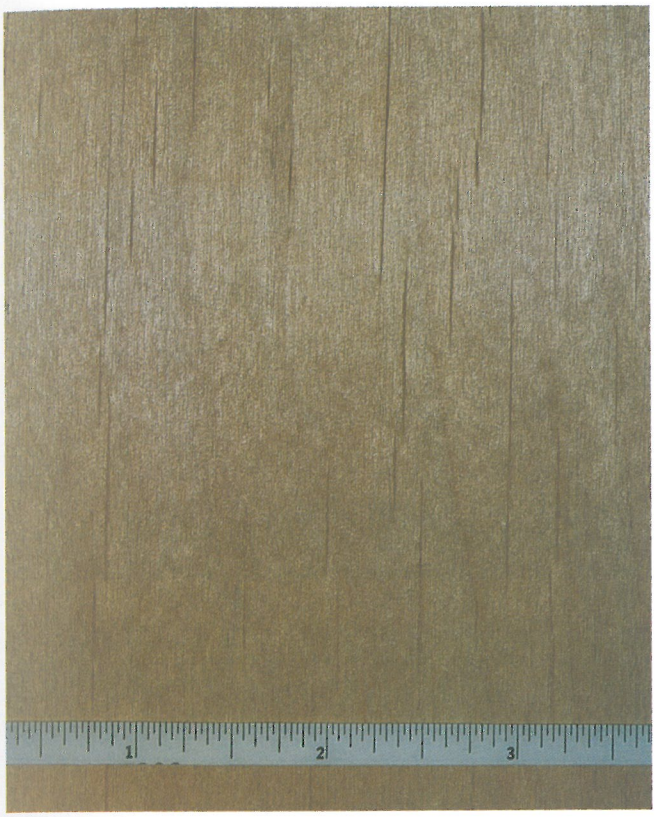
Ray height (see the photo at right) is best evaluated in tangential view. It varies from imperceptibly small to several inches high, as in white oaks.

Aggregate rays are large rays that have longitudinal cells running irregularly through them. When the sample is viewed in tangential section, it appears as though there are multiple rays that are closely arranged but separated by longitudinal cells. These rays are usually found in addition to smaller rays in the same species; the aggregate rays are relatively few in number and may be sporadic in distribution. Red alder and American



Richard Starr

RAY HEIGHT IN WHITE OAKS
Ray height in white oaks usually exceeds 1¼ in.



AGGREGATE RAYS IN ALDER
The large, scattered aggregate rays in red alder are conspicuous on the tangential surface.

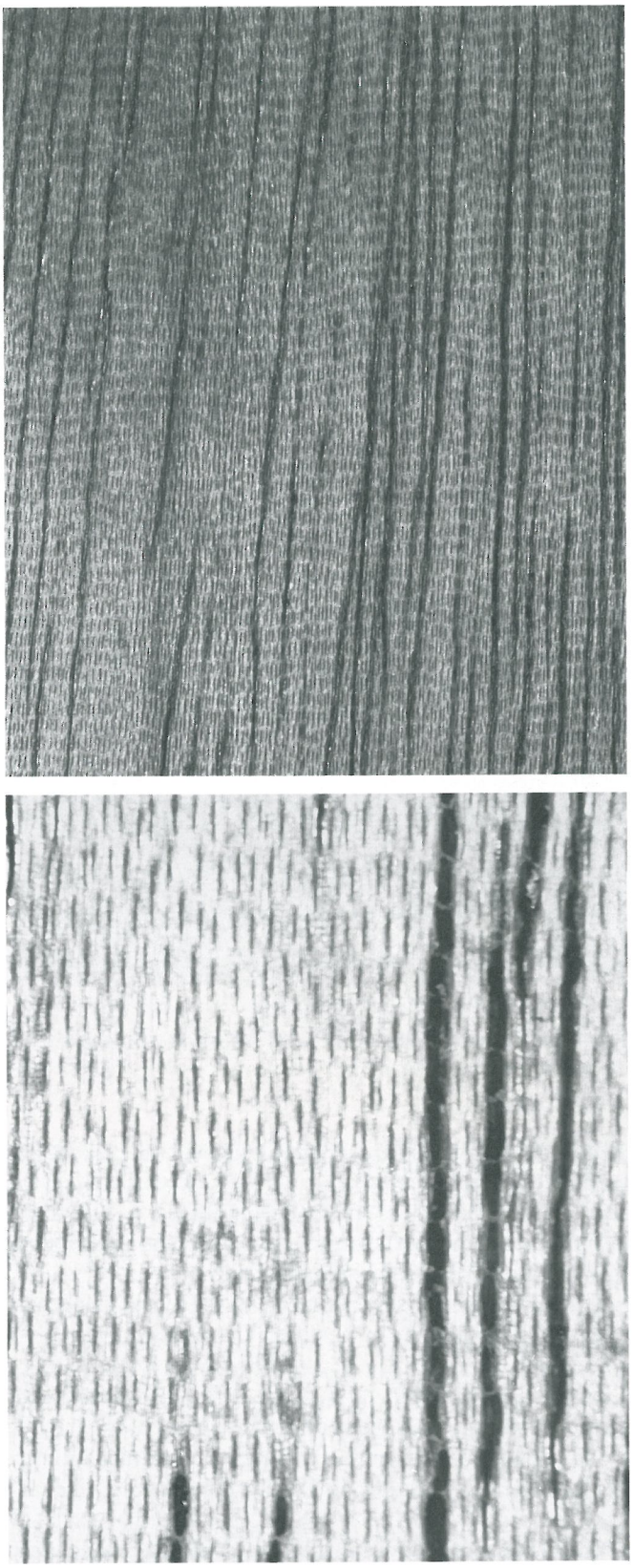
hornbeam are two species that show aggregate rays (see the photo above).

In some species the rays are of fairly even height and are spaced at even horizontal levels throughout the tree. As a result, they form even horizontal rows when the wood is sectioned tangentially. These are called **storied rays** and produce **ripple marks** (see the photos at right).

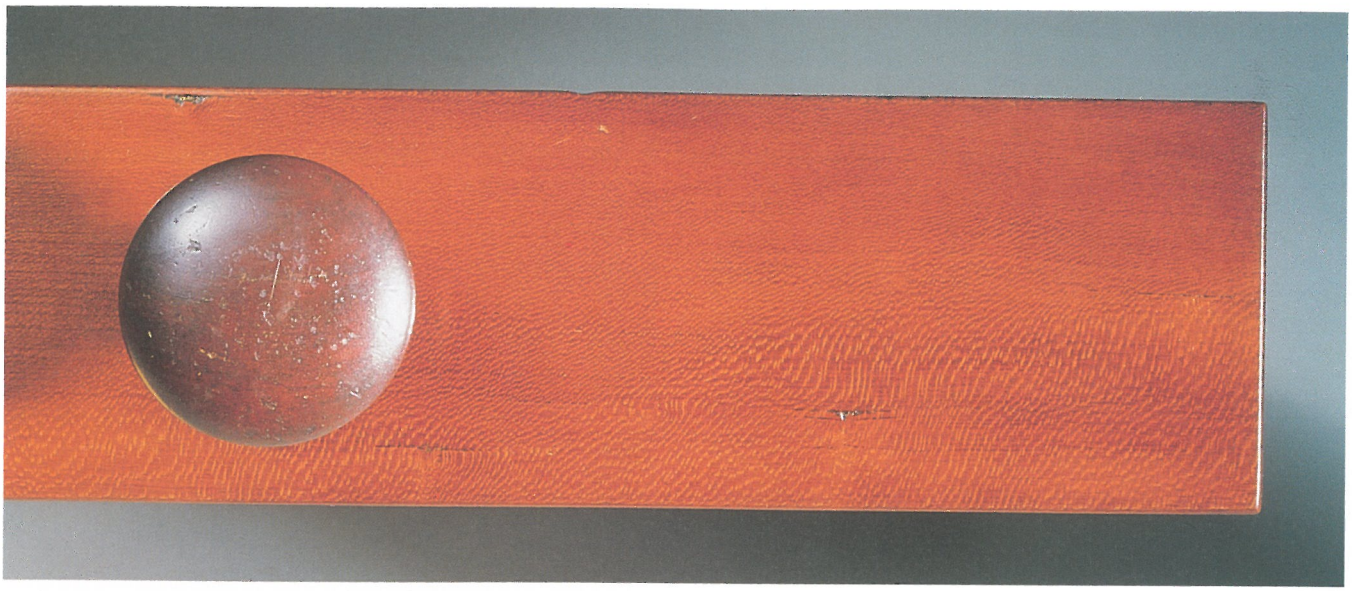
Ripple marks appear to the unaided eye as horizontal striations of lighter and darker wood 1/64 to 1/32 in. apart. They are rare in domestic species — persimmon is one of the few that has ripple marks — but fairly common in tropical woods, notably in Central American mahogany (although not as a constant feature), rosewood and ebony. It should be noted that longitudinal cells can also be storied. Ripple marks can result from these alone, or they can result from a combination of longitudinal cells and storied rays.

When wood is sectioned radially, many rays are split and exposed at the surface. The resulting patches of ray tissue — to the extent that they contrast with the background longitudinal tissue — are called **ray fleck** (see the photos on p. 44).

The prominence of ray fleck (see the photos on the facing page) depends on the size of the rays and how closely the cut approximates a true radial plane. In yellow-poplar, ray fleck appears lighter against a darker background; in maple and



RIPPLE MARKS AND STORIED RAYS
The ripple marks commonly seen on tangential surfaces of American mahogany (top) result from storied rays, which can be seen more clearly at higher magnification (bottom). (20x)





RAY FLECK
Ray fleck on radial surfaces of cherry (top) and oak (above).

sycamore, the rays are darker against a lighter background. The contrast can also vary between sapwood and heartwood in the same species. In black cherry, for example, the ray fleck appears darker than the background in the sapwood, but lighter than the background in the heartwood.

The term **silver grain** is sometimes used to describe the glossy ray fleck in oak. In veneer and lumber manufacturing, white oak is often riftcut (cut at an angle to the rays) to produce a uniform, narrow and vertical ray fleck called **needlepoint grain** or **comb grain.** Lacewood, a well-known tropical hardwood, is also cut at an angle to the radial plane; its uniformly sized and spaced rays form its familiar repetitive, lacelike surface appearance.

With a little experience, you will recognize the characteristic ray fleck, where present, of various species. Remember that ray fleck is particularly dependent on the plane of the cut and may not appear on a particular sample. But on a spindle or turning, look for the radial sides where ray fleck will likely appear.

MICROSCOPIC DETAIL

Viewed microscopically, rays have several important identification characteristics.

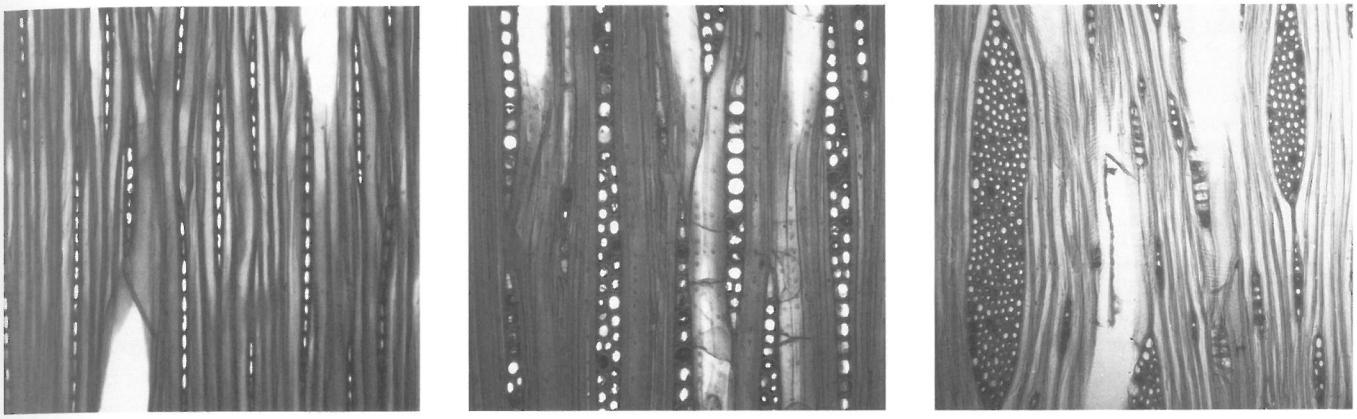
On a tangential surface, we first note the ray width. A ray that consists of a single vertical series of cells — that is, a ray that is only one cell wide — is a **uniseriate ray.** If it is two cells wide, it is a **biseriate ray,** and if it is three or more cells wide it is **multiseriate.** To be more precise, you can attach specific numbers to the designation: 5-seriate, 8-seriate, etc.

Ray "seriation" can be extremely valuable. For example, willows *(Salix* spp.), aspens and cottonwood (both of which are *Populus* spp.) and buckeyes *(Aesculus* spp.) have uniseriate rays. But sweetgum, basswood, yellow-poplar and magnolia have multiseriate rays. In soft maples the rays are generally no more than 5-seriate, but in hard maples they can be up to 8-seriate.

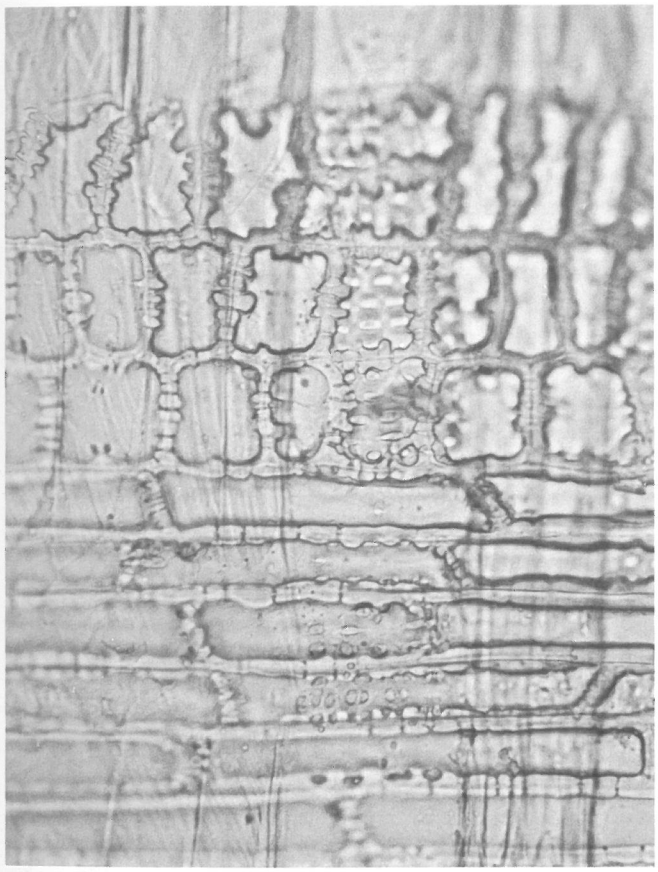
Ray height is not as broadly useful for identification due to its variability within species, but occasionally it is definitive. Pacific dogwood, for example, has rays up to about 40 cells high, whereas the rays of flowering dogwood may reach 80 cells in height.

Although rays in coniferous woods may contain ray tracheids as well as ray parenchyma, hardwood rays consist entirely of ray parenchyma cells. However, there are two types of ray parenchyma cells, classified on the basis of overall shape. In radial view, **procumbent ray cells** are elongated horizontally; **upright ray cells** are either squarish or vertically oriented (photo at bottom on the facing page).

A hardwood ray that contains both upright and procumbent ray cells is called a **heterocellular** or **heterogeneous** ray (note that these terms have a different meaning when used in reference to conifers). The upright cells are usually located in one or more rows along the margins of the rays; the main body of the ray, especially if multiseriate, is usually composed of procumbent cells. If only one type of cell is present



RAY SERIATION
Ray seriation, easily determined from tangential sections at relatively low microscopic power, is an extremely useful identification feature. Shown here are uniseriate rays in aspen (left), biseriate rays in sweetgum (center) and multiseriate rays in sugar maple (right). (100x)



HETEROCELLULAR RAYS WITH UPRIGHT AND PROCUMBENT CELLS
A heterocellular ray, shown here in yellow-poplar, has both upright and procumbent cells. (400x)

in the ray, the ray is **homocellular** or **homogeneous**. Most homogeneous rays have procumbent cells; homogeneous rays with upright cells are less common.

Ray composition is sometimes helpful in separating woods. In cottonwoods and aspens, for example, the rays are homocellular; in willows they are heterocellular.

As in the case of longitudinal parenchyma, ray parenchyma cells of some species contain crystals that help in identification.