7. The terms *fusiform initial* and *fusiform ray* sound similar but refer to quite different things. What is a fusiform ray? A fusiform initial?
8. Do all softwoods have crossfields? Of what significance are crossfields?

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CHAPTER

5

Hardwood Structure

The wood formed by hardwoods is much different than that produced by softwoods. Softwoods are composed of only a few cell types, have a relatively simple structure, and frequently lack a distinctive appearance. Hardwoods, on the other hand, are composed of widely varying proportions of markedly different kinds of cells and are thus often uniquely and even spectacularly figured. Because of the unique figure possessed by many hardwood species, their woods are widely used for furniture, paneling, and other decorative purposes.

Differences between Hardwood and Softwood Xylem

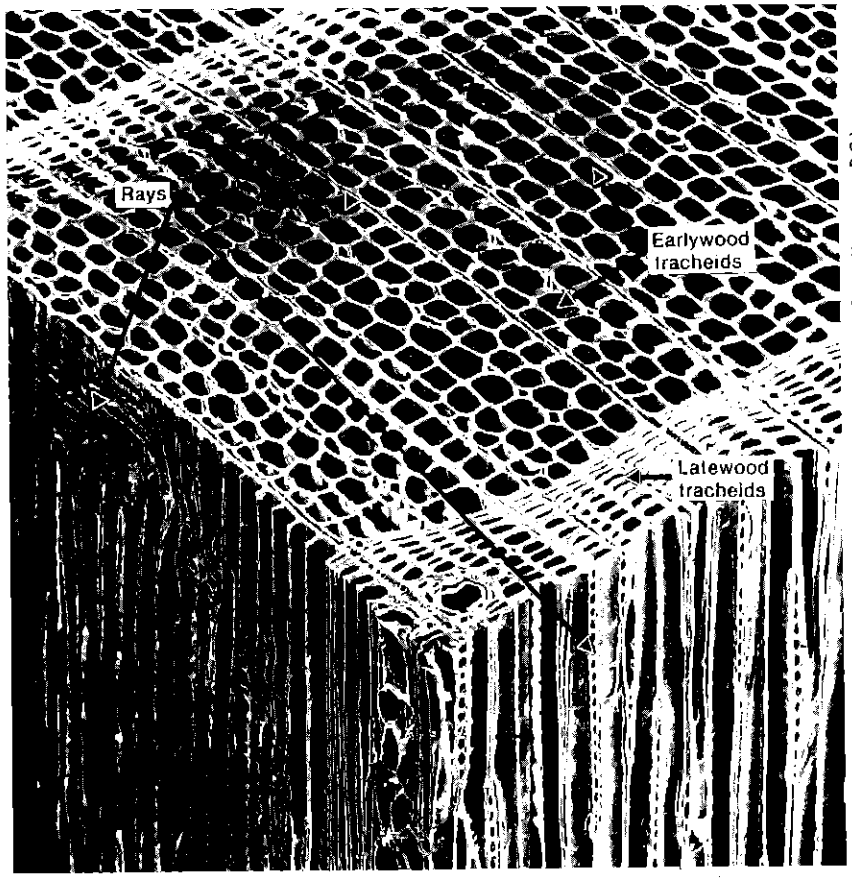
It was mentioned in the introduction that softwoods are uniform in structure whereas hardwood structure is complex. This and other differences are summarized in the following:

1. Softwoods are composed of only a few significant cell types—hardwoods of many (Fig. 5.1). Long cells known as *longitudinal tracheids* comprise 90–95 percent of the volume of softwoods. *Ray cells* (either ray tracheids or ray parenchyma) constitute the remainder of softwood xylem. Although a few other types of cells may occur, they make up an insignificant part of the volume of softwoods. Hardwoods are composed of at least four major kinds of cells (Table 5.1); each of these may constitute a significant portion of hardwood volume.

2. Only hardwoods contain vessels, a structure composed of *vessel elements*. The nature of vessel elements is discussed in the next section.

3. Hardwood ray widths vary within and between species. They are often wider than the (mostly) uniseriate rays found in softwoods (Fig. 5.2). Except for fusiform rays, softwood rays are one cell (or occasionally two) in width when viewed tangentially. Collectively, ray cells comprise about 5–7 percent of total softwood volume. Hardwood rays range in width from one cell to thirty or more in some species. These rays can constitute more than 30 percent of the volume of hardwood xylem, the average being around 17 percent.

4. Straight radial rows of cells characterize softwoods, but generally not hardwoods (Fig. 5.3). Softwood cells are aligned in straight radial rows in parallel form, with straight spokelike rays; each row of cells is formed by a single fusiform initial in the cam-



(Scanning electron micrograph by Josefina Gonzalez, Forintek Canada Corp., Vancouver, B.C.)

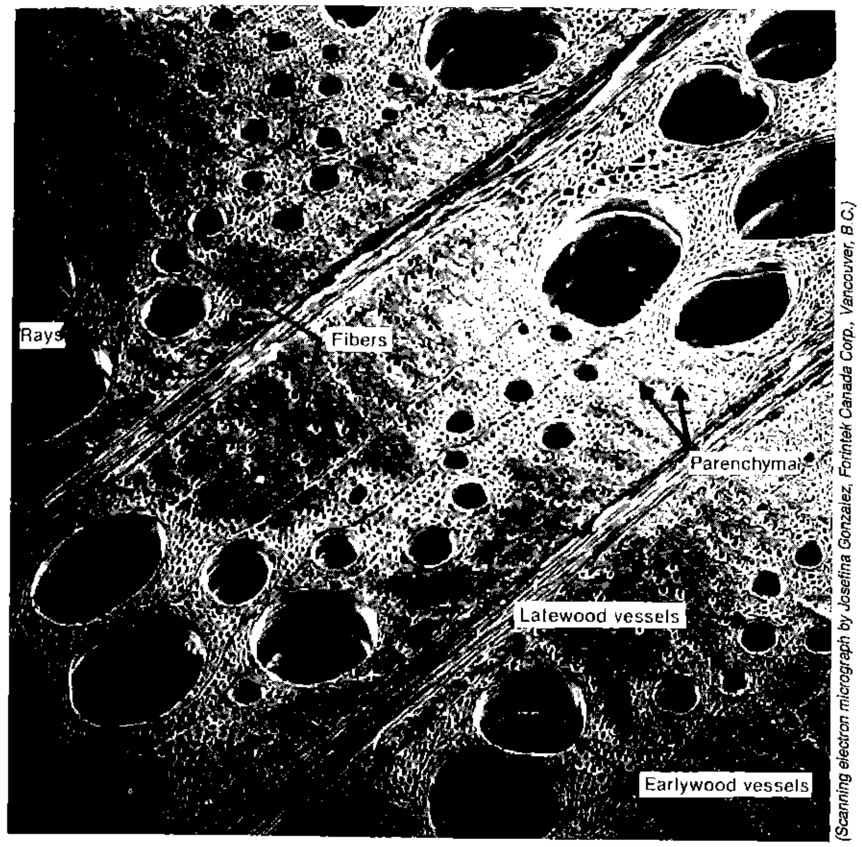
FIGURE 5.1. Principal cell types of hardwoods and softwoods.
A. Softwood: Sitka spruce (*Picea sitchensis*). ×75.

TABLE 5.1. Major hardwood cell types.

Cell type	Proportion of xylem volume accounted for by cell type*
	(%)
Fiber tracheid†	15–60
Vessel element	20–60
Longitudinal parenchyma	0–24
Ray parenchyma	5–30

*Within a species, the relative proportion of various cell type is quite consistent. Between species and species groups (genera), the proportions of various cells can vary widely.

†Included in this category are several kinds of cells: variations of true fiber tracheids and transition elements between fibers and vessel elements or between fibers and longitudinal parenchyma.



(Scanning electron micrograph by Josefina Gonzalez, Forintek Canada Corp., Vancouver, B.C.)

FIGURE 5.1. (*continued*)
B. Hardwood: Red oak (*Quercus* spp.). ×55.

bium. Hardwood rays are seldom aligned in straight radial rows, nor are other hardwood elements. Distortion from a purely radial orientation occurs in the vicinity of large vessel elements.

5. Hardwood fibers are considerably shorter than softwood tracheids (Fig. 5.4). The softwood tracheids average 3–4 mm in length; hardwood fibers, in contrast, have an average length of less than 1 mm. This fact explains why softwood tracheids are often preferred as raw material for paper manufacture. Fiber length is an important determinant of paper strength; thus, long fibers are a necessary ingredient of kraft paper used for unbleached paper products such as corrugated cartons and grocery bags.

It is important to note that the terms *hardwood* and *softwood* have no relevance to the actual hardness or strength of the wood produced. Many softwoods produce wood that is harder and denser than wood produced by some hardwoods.

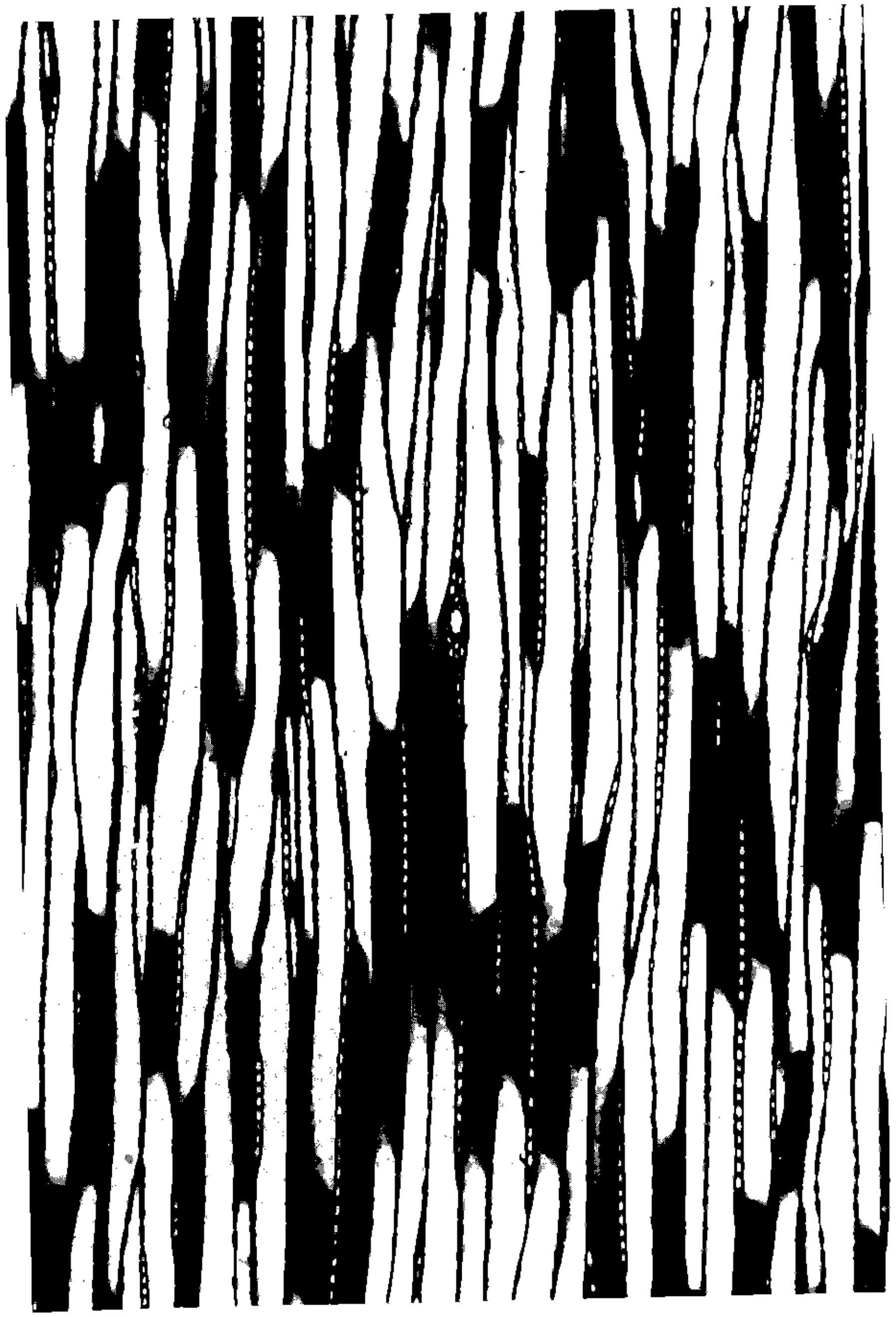


FIGURE 5.2. Narrow rays of softwood (A) vs. narrow to broad rays of hardwoods (B,C). Tangential view. (Courtesy of Ripon Microslides Laboratory)
A. Western larch (*Larix occidentalis*). ×85.

FIGURE 5.2. (*continued*)
B. Quaking aspen (*Populus tremuloides*). ×80.

FIGURE 5.2. *(continued)*
C. Sugar maple (*Acer saccharum*). ×100.

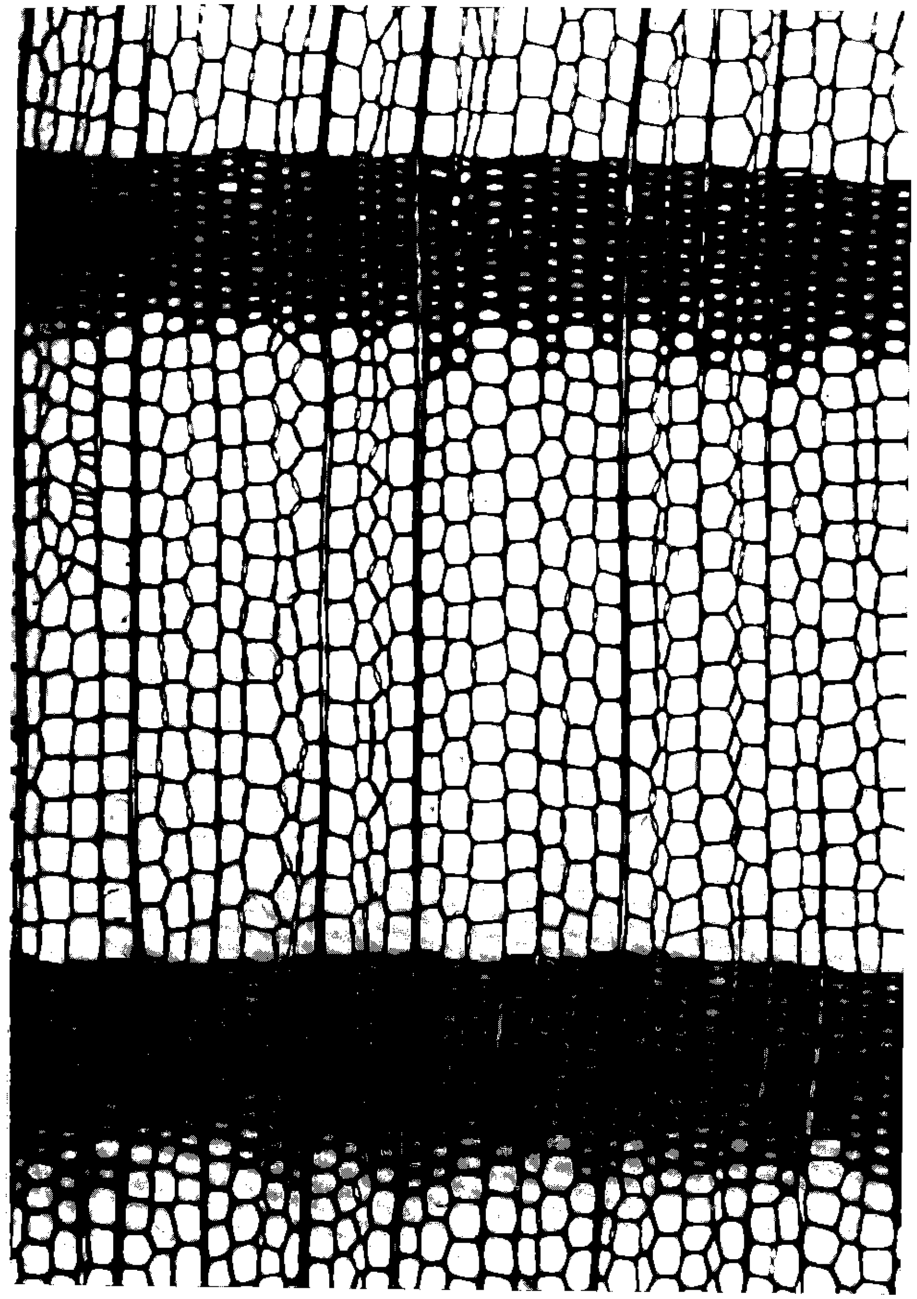


FIGURE 5.3. Straight rays of softwood (A) and meandering rays of hardwood (B). Transverse view.
A. Western larch (*Larix occidentalis*). ×85.

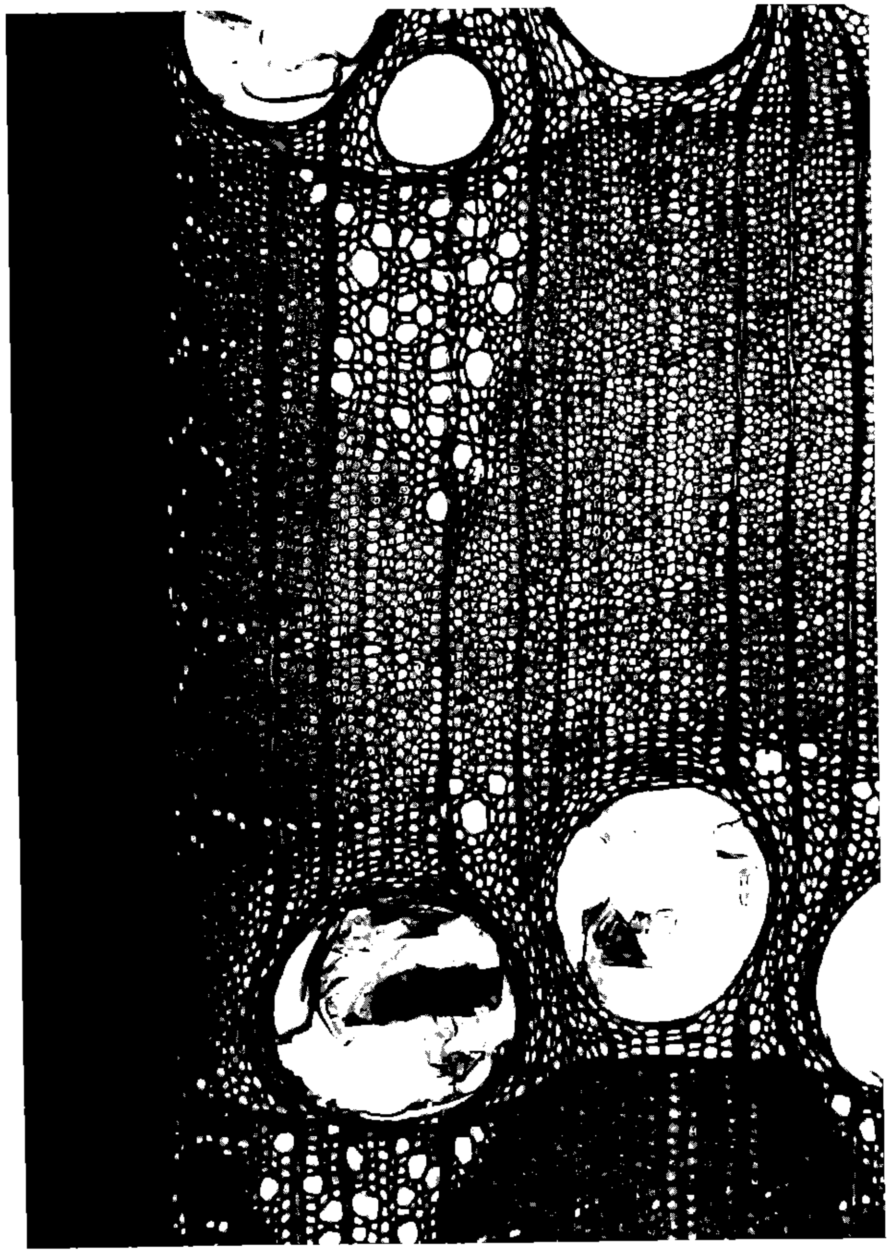


FIGURE 5.3. (*continued*)
B. White oak (*Quercus alba*). ×55.

Longitudinal Cells

Although longitudinal cells of hardwoods vary considerably in size and general configuration, all these different cell types can be produced by a single fusiform initial in the cambium. Newly produced cells appear quite similar. The differences between types develop during the process of cell maturation.

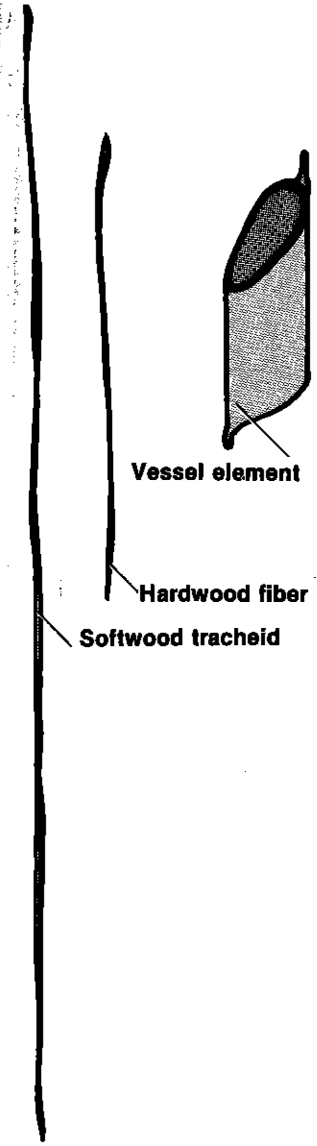


FIGURE 5.4. Relative sizes of woody cells.

Vessel Elements—Unique Cells of Hardwoods

Several differences exist between hardwood and softwood xylem, but the fundamental anatomical difference is that hardwoods contain specialized conducting cells called *vessel elements*. This cell type is found in virtually all hardwoods but rarely in softwoods. The wood of a few dicotyledons does not contain vessels; however, the number and economic importance of species exhibiting this feature are small. Vessel elements are generally much larger in diameter than other types of longitudinal cells. Figure 5.4 compares the size and shape of a softwood tracheid, a typical hardwood fiber, and a hardwood vessel element. Note that vessel elements are shorter than both hardwood and softwood fibers but larger in diameter. The short length of vessel elements is traceable to the fact

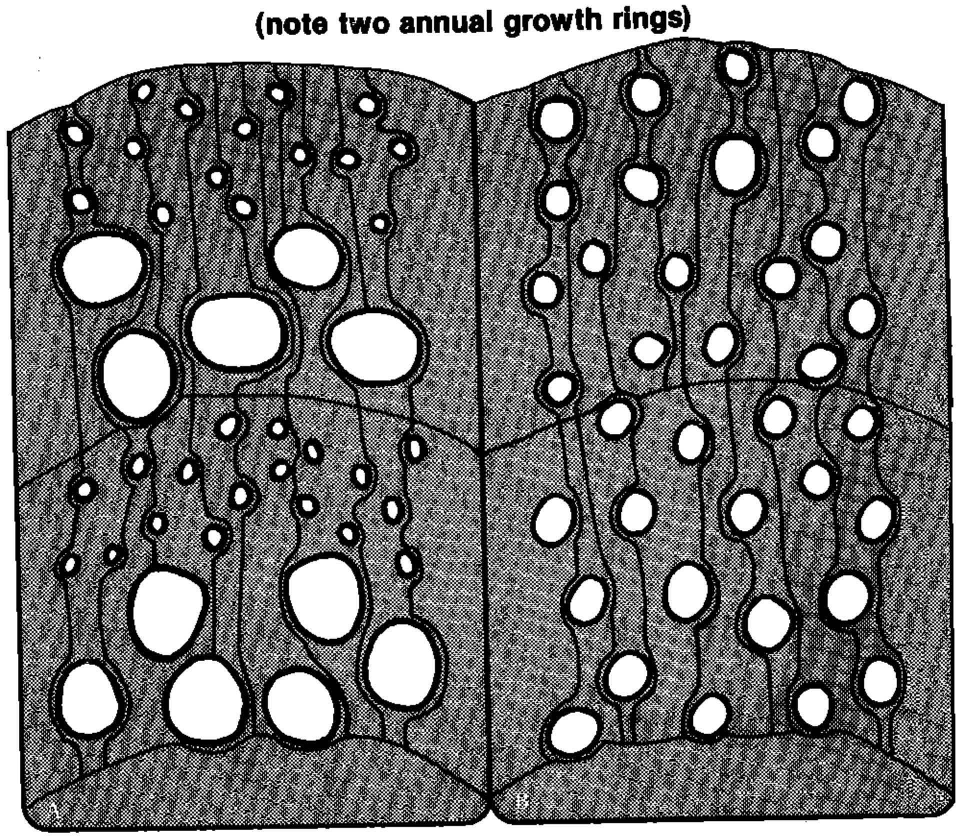


FIGURE 5.5.
A. Ring-porous hardwood.
B. Diffuse-porous hardwood.

that they often do not grow in length during the maturation process and may become even shorter than the cambial initials from which they were produced (Jane et al. 1970). Normally, a number of vessel elements link end to end along the grain to form long tube-like structures known as *vessels*. Such vessels are seldom arranged in a precise parallel and vertical alignment; instead, within a growth ring, vessels form a network with considerable tangential variation from a straight vertical orientation. This arrangement ensures that each branch of the crown receives water from many different roots, providing a safety feature against crown damage from the loss of one or more roots (Zimmermann 1983).

Vessel Arrangement. Because of their large diameter, vessels often appear as holes when viewed in cross section; in this view they are often referred to as *pores*. Both size and arrangement of pores are used to classify hardwoods for purposes of identification. Figure 5.5A is a drawing of a magnified cross section of a hardwood. Only the vessels and rays are illustrated. Vessels of large diameter are concentrated in the earlywood, with vessels of much smaller diameter in the latewood. This type of wood is called *ring-*

porous because the earlywood vessels form a visible ring in a tree cross section. Figure 5.5B shows a hardwood that has pores of uniform size distributed fairly evenly across the growth ring. This wood is classified as *diffuse-porous*. The majority of hardwoods are diffuse-porous, but in northern temperate regions some of the most valuable woods, such as oak (*Quercus* spp.), ash (*Fraxinus* spp.), and pecan (*Carya illinoensis*), are ring-porous. When hardwoods are sawn into lumber, the lengthwise sectioning of vessels results in a distinctive scratchlike pattern on radial and tangential surfaces. Sectioning of large earlywood vessels in ring-porous woods forms a very deep and sometimes spectacular pattern of vessel scratches (*vessel lines*) that is interrupted by latewood regions that have little texture. Photographs of ring- and diffuse-porous woods are shown in Chapter 2 (see Figs. 2.5, 2.6). Look ahead to Figure 5.19 for an artist's conception of a three-dimensional diffuse-porous hardwood.

The lack of radial alignment of cells in hardwoods has been mentioned. Recall that all types of longitudinal cells arise from the same fusiform initial in the cambium and that all longitudinal cells are quite similar in size and shape immediately after formation. Because nothing occurs to disrupt alignment, newly formed hardwood xylem cells tend to be arranged in neat radial files corresponding to the initials that produced them. During the maturation process, however, cells begin to change, and eventually assume the characteristics of the mature units. In the case of vessel elements, one of these characteristics is a large diameter. Thus cells that will mature to become vessels begin marked diameter growth, expanding from two to fifty times their original diameter. Other cells expand little in cross section. This diameter growth of vessel elements pushes cells out of radial alignment. Follow the path of rays around the large earlywood vessels pictured in Figure 5.3; it is evident that the meandering ray pattern is caused by vessel growth.

End-to-End Connection of Vessel Elements. Vessels are uniquely suited to serve as avenues of fluid conduction. Relatively small and membrane-divided pit pairs connect other cells, such as fiber tracheids, end to end. Common end walls of longitudinally linked vessel elements are, however, perforated by unrestricted holes. To facilitate discussion about this feature, names are given to the common vessel element end walls (*perforation plates*) and the holes in them (*perforations*).

Perforations develop near the end of the cell maturation process. Certain enzymes contained in the protoplast of developing vessel elements (such as cellulase) are apparently responsible for this dissolving of portions of the perforation plates (Roelofsen 1959). Some rearrangement of cell wall material may also be involved in formation of perforations (Frey-Wyssling 1959). It is interesting to note that perforations do not develop in a random fashion; instead, they form in one of several definite patterns, as depicted in Figure 5.6. A photograph of scalariform perforations is shown in Figure 5.7.

Within a given species, the pattern of perforations is commonly the same in all perforation plates. Because of this, the nature of vessel perforations is often useful as an aid in the identification of hardwood timbers. Perforation plates invariably slope at an angle toward the radial plane. This surface should be examined microscopically to determine the type of perforation.

Side-to-Side Connection of Vessels. Lateral communication from vessel to vessel is provided by numerous pairs of bordered pits. Closely packed bordered pits are depicted in Figure 5.8. As is the case with perforation plates, the shape and arrangement of vessel-to-vessel pitting is often consistent within a given species and can be of assistance in

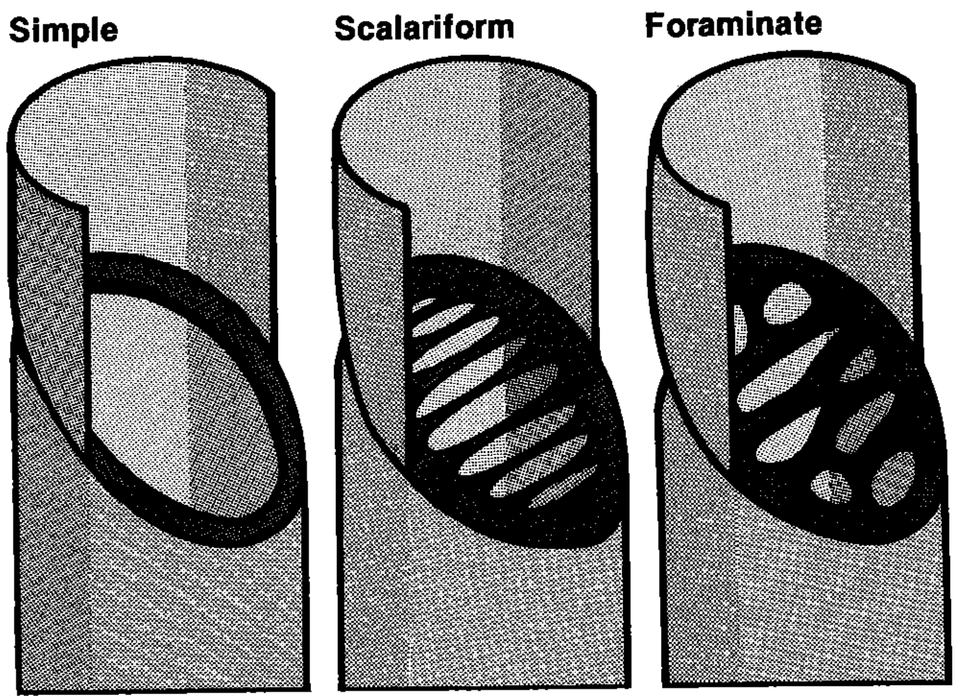


FIGURE 5.6. Types of vessel perforation plates.

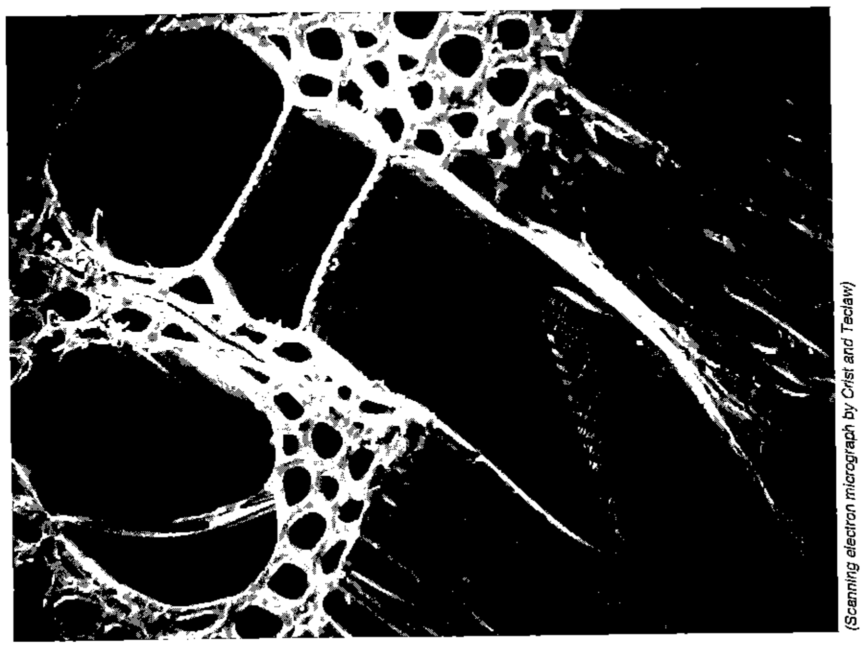


FIGURE 5.7. Scalariform perforation between vessel elements of white birch (*Betula papyrifera*). ×400.

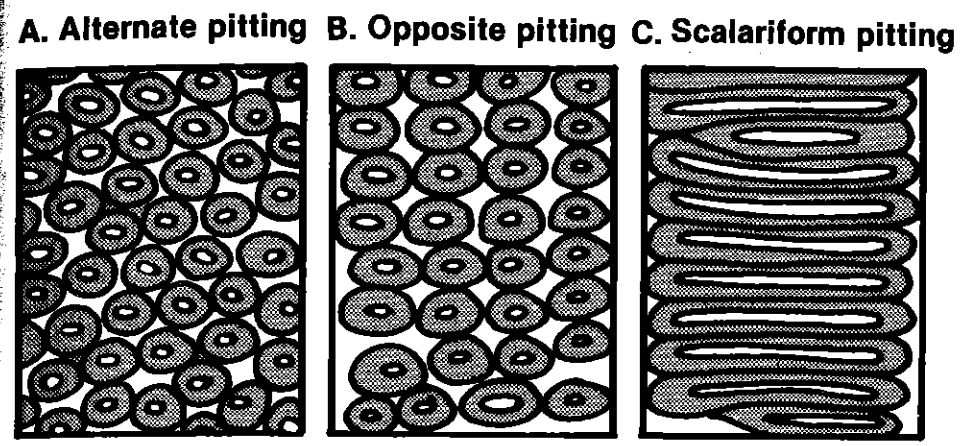


FIGURE 5.8. Vessel-to-vessel pitting arrangements.

wood identification. Photographs of adjacent vessels are presented in Figures 5.9 and 5.10, in which intervessel pitting is clearly visible.

Connections between Vessels and Other Cells. Vessels often occur adjacent to fiber tracheids, longitudinal and ray parenchyma, or other kinds of cells. Although fiber tracheids and vessels are sometimes not linked by pitting, other kinds of cells typically form pits where they contact vessel elements.

Tyloses—Their Significance. *Tyloses* are outgrowths of parenchyma cells into the hollow lumens of vessels. They commonly form in many hardwoods as a result of wounding and effectively act to prevent water loss from the area around damaged tissue (Zimmermann 1983). Tyloses also form in a number of species during the transition from sapwood to heartwood and may also develop as a result of infection from fungi or bacteria (Kozlowski and Pallardy 1997).

Just prior to tylosis formation, enzymatic action partially destroys membranes in vessel-to-parenchyma pit pairs. At about the same time, the cytoplasm of the parenchyma cells begins to expand with protrusion of the parenchyma cell membrane through pit pairs into the vessel lumen; this protrusion is called a *tylosis*. Several studies have indicated that a special membrane-like meristematic layer forms in parenchyma cells, completely encasing the cytoplasm, prior to tylosis formation. This layer, known as the *protective layer*, is believed to actually form tyloses (Schmidt 1965; Meyer and Côté 1968). The membrane forming the tylosis may remain quite thin, or the walls may thicken in much the same way that they do in developing cells. Pits may even form where one tylosis contacts another (Foster 1967).

Tyloses are significant in that they partially or often completely block the vessels in which they occur, a situation that can be either detrimental or beneficial depending upon the use to which the wood is put. The existence of tyloses in the heartwood vessels of white oak, and the relative lack of them in red oak (Fig. 5.11), is the reason white oak is preferred in the manufacture of barrels, casks, and tanks for the storage of liquids. White oak heartwood, with its tightly plugged vessels, is almost universally used in the manu-

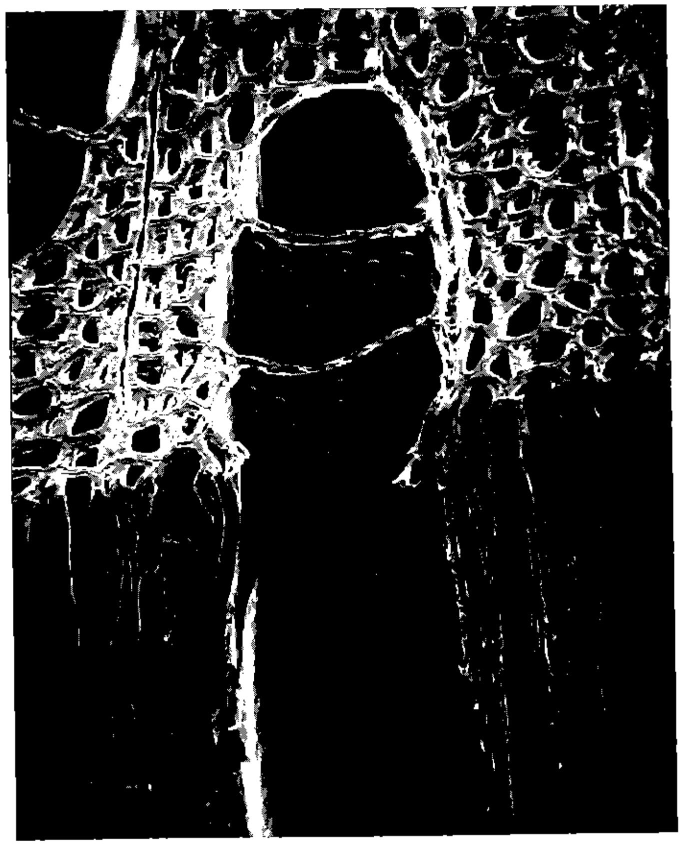


FIGURE 5.9. Abundant vessel-to-vessel pits in alternate arrangement. Tangential view of *Populus* spp. ×450.

facture of whiskey barrels, for example, whereas the open-vesseled red oak is avoided for this use. In contrast to this beneficial feature of tyloses, wood in which they are well developed may be difficult to dry or to impregnate with decay-preventive or stabilizing chemicals. A radial view of thick-walled tyloses in hickory is shown in Figure 5.12.

An interesting discovery (Dute et al. 1999) is that tyloses form in softwood tracheids in the vicinity of abscission scars following separation of needles from loblolly pine stems. As in hardwoods, tyloses arise from parenchyma cells adjacent to longitudinal tracheids.

Fibers

The term *fiber* is often used in a general way to refer to all wood cells isolated in pulping processes. However, in the context of wood morphology, the term *fiber* refers to a specific cell type. Thus fibers, or *fiber tracheids* as they are more properly called, are long, tapered, and usually thick-walled cells of hardwood xylem. A casual look suggests a great similarity to the longitudinal tracheids of softwoods, but closer examination reveals several significant differences.

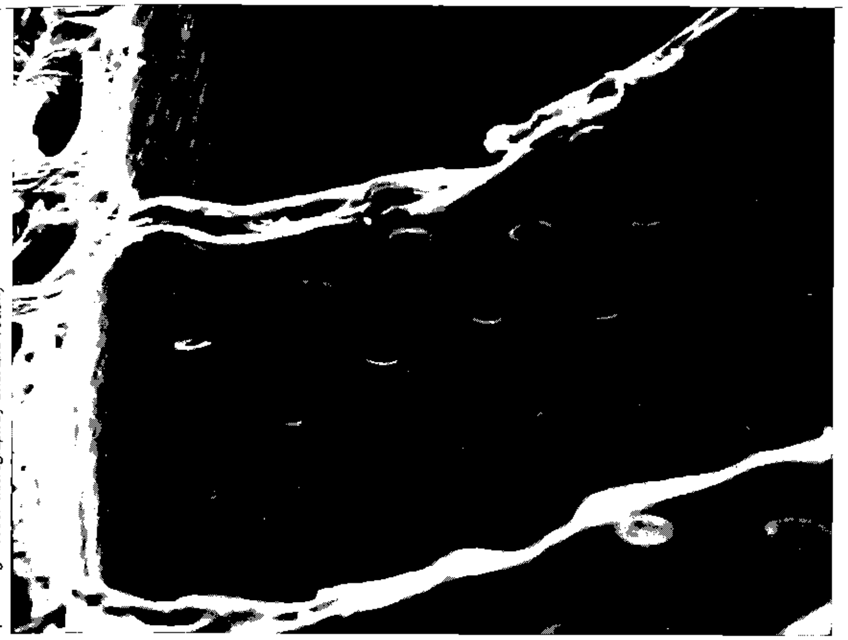


FIGURE 5.10. Highly magnified bordered pits in adjacent vessels in alternate arrangement. *Populus* spp. ×1750.

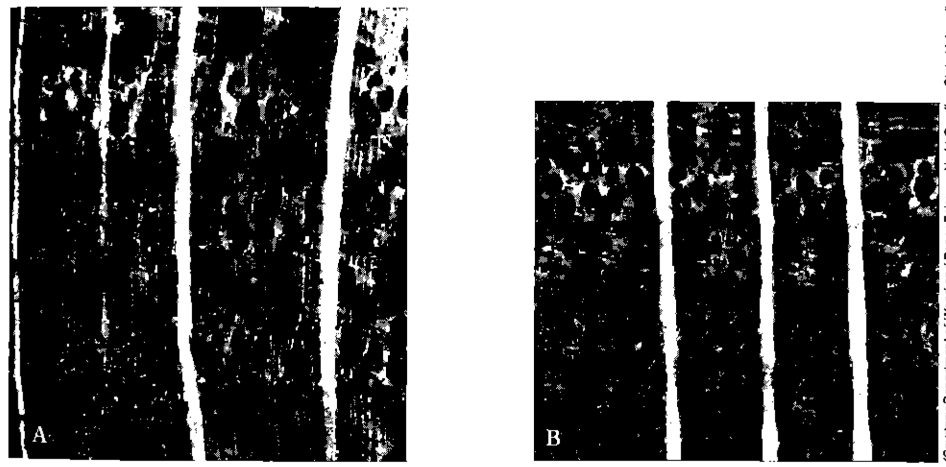
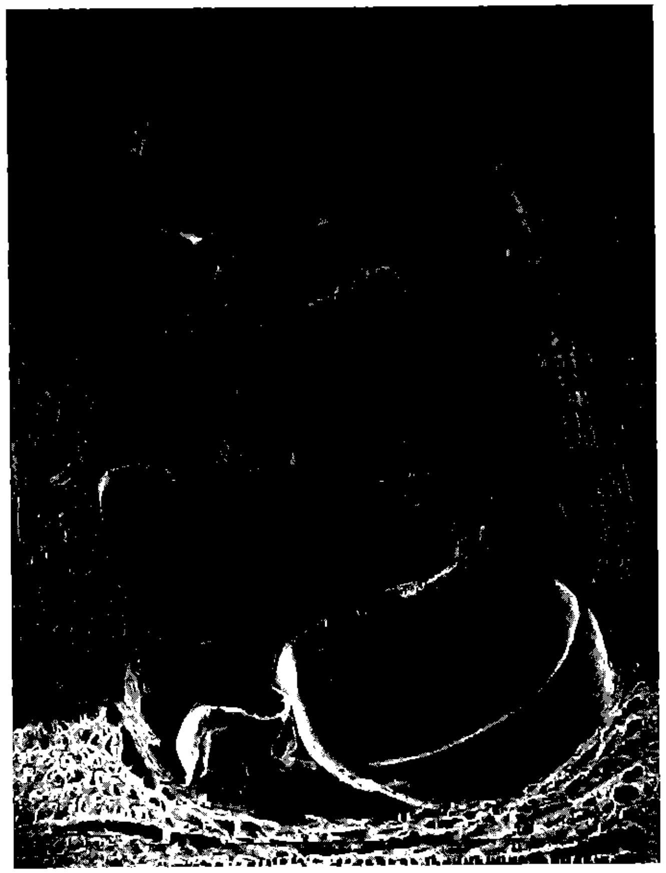


FIGURE 5.11. Tyloses fill earlywood vessels of white oak (A), not red oak (B).
A. White oak. ×16.
B. Red oak. ×16.

As noted earlier, hardwood fibers are considerably shorter than softwood tracheids. Hardwood fibers also tend to be rounded in cross section as compared to the nearly rectangular shape of softwood tracheids (Fig. 5.13). However, fibers are sometimes flattened radially in last-formed latewood in much the same way that latewood tracheids



(Scanning electron micrograph by Crist and Teclaw)

FIGURE 5.12. Tyloses in vessel. Hickory (*Carya* spp.). ×170.

are in softwoods. Fibers are also characteristically very thick walled and have bordered pits with less-developed borders than softwood tracheids (Esau 1965, 239).

Although hardwood fibers and softwood tracheids are similar, the function of the fiber is more specialized. Longitudinal tracheids of softwoods serve as primary avenues of conduction while also being almost totally responsible for the strength of the wood of which they are a part. A high proportion of thin-walled earlywood tracheids is invariably related to low wood strength. The situation is somewhat different in hardwoods, where two kinds of longitudinal cells—fibers and vessel elements—are common. Most conduction occurs through the specialized vessels, leaving the thick-walled fibers the primary function of mechanical support. Fibers are most highly specialized as supporting elements in those woods that have the most specialized vessel members (Esau 1965, 239). Density, and thus strength, of hardwoods is therefore generally related to the portion of wood volume occupied by fibers relative to that accounted for by vessels. As a general rule, the higher the proportion of thick-walled fibers, the higher the strength.

The walls of fiber tracheids are marked by pits of the bordered type. Fiber-to-fiber pit pairs are normally bordered, whereas fiber-to-parenchyma pitting is typically half-

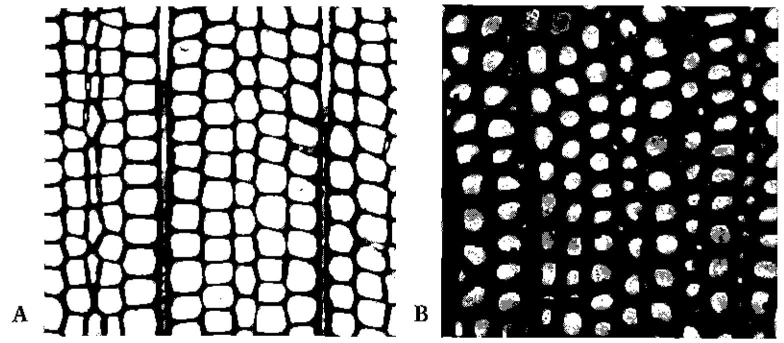


FIGURE 5.13. Softwood tracheids (A) and hardwood fibers (B) in transverse view.

bordered. A variation of the fiber, known as a *libriform fiber*, is marked by simple, rather than bordered, pits. Libriform fibers occur in considerable numbers in some species. Fibers and vessels are seldom connected by pit pairs.

Longitudinal Parenchyma

Parenchyma cells are thin-walled storage units. In hardwoods, such cells occur in the form of long, tapered longitudinal cells; short, brick-shaped epithelium around gum canals (in only a few species); and ray cells. The longitudinal form of parenchyma is often divided into a number of smaller cells through the formation of crosswalls during the process of cell maturation (Fig. 5.14).

Parenchyma cells on occasion are thin walled to the point that no secondary wall forms. Because a *pit* is defined as a gap in the secondary wall, a cell with an unthickened

(Courtesy Ripon Microslides Laboratory)

FIGURE 5.14. Longitudinal strand parenchyma. Radial view of Honduras mahogany (*Swietenia macrophylla*). ×85. (Strand parenchyma indicated by arrows.)

wall is therefore unpitted. Pits do form in parenchyma cells that form thickened walls, and in accordance with rules set forth in Chapter 3, simple pit pairs connect cells of the parenchyma type. Pitting "rules" are often broken where thickened parenchyma contact vessels or fibers; in this case, the pit pairs formed are usually half-bordered but may be of the simple or bordered type (Esau 1965, 239).

Whereas *longitudinal parenchyma* is relatively rare in softwood species (no more than 1–2 percent of the volume of those woods in which it does occur), the longitudinal form of parenchyma is often quite significant in hardwoods. Certain species of hardwoods contain no longitudinal parenchyma. Some domestic hardwoods may, however, have up to 24 percent of their volume made up of longitudinal parenchyma cells; this figure may even exceed 50 percent for a few tropical hardwoods (Panshin and de Zeeuw 1980). In these woods, the longitudinal parenchyma is commonly arranged into definite and unique patterns that are readily visible in a transverse section (Fig. 5.15). Because both the proportion and arrangement of longitudinal parenchyma are genetically reproduced, this kind of cell is often of value in the identification of hardwood timbers.

Gum canals occur in a few hardwoods and are similar to resin canals of softwoods. The hardwood canals are sometimes lined with parenchyma-type epithelial cells.

Other Kinds of Longitudinal Cells

In addition to vessels, fibers, and longitudinal parenchyma, other kinds of longitudinal cells occur in a few hardwoods, contributing to the variable nature of this group of woods. These other cells are mostly transition elements between major cell types and as such have features typical of each kind of cell to which they are related.

An example of a transition element is a *vascular tracheid;* this cell has a shape like a vessel element, but it lacks perforations in the end walls, having instead bordered pits in this location similar to those found in fibers. Another kind of cell known as a *vasicentric tracheid* looks much like parenchyma in cross section, yet it is covered with numerous bordered pits.

Rays

As listed in the summary of hardwood-softwood differences, hardwood rays range in width tangentially from one to thirty or more cells. Softwood rays in comparison are generally one or, rarely, two cells in width. Also, unlike softwoods, the cells of hardwood rays are all of the parenchyma type (although two distinct types of ray parenchyma are formed).

Ray Size

Hardwoods characterized by very large rays, such as oak, exhibit distinctive ray patterns on both tangential and radial faces (Fig. 5.16); such rays often add to a wood's aesthetic appeal. Note that a highly magnified tangential view of this wood (Fig. 5.16D) reveals numerous narrow rays in addition to the wide ones; the rays seen without magnification in 5.16A and C represent only the largest of these.

Not all hardwoods exhibit wide rays. Woods such as aspen (*Populus tremuloides*) and cottonwood (*Populus deltoides*) have rays that are of the uniseriate type only (see Fig. 5.2B). These woods lack a visible ray pattern unless viewed under high magnification.

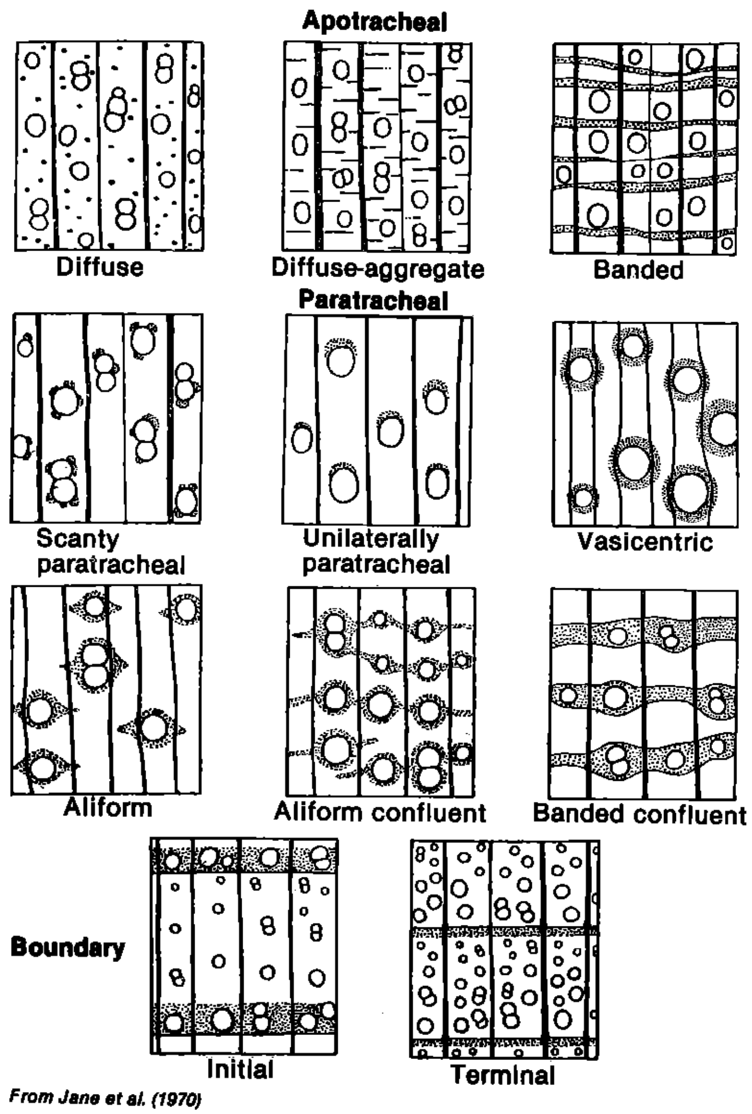


FIGURE 5.15. Parenchyma configurations occurring in hardwoods as seen in transverse view.

Types of Ray Cells

Although all ray cells are of the parenchyma type, there are, nonetheless, different types of hardwood ray cells. The difference is in cell shape or configuration.

The ray parenchyma cells of hardwoods are sometimes almost square when viewed radially, but more commonly such cells have a rectangular shape. In most woods these rectangular ray cells are arranged such that the long dimension is perpendicular to the axes of longitudinal cells (Fig. 5.16B). Because ray cells arranged in this way appear to be lying down, they are said to be *procumbent.* In some hardwood species, part of the

FIGURE 5.16. Ray patterns in white oak (*Quercus alba*)
A. Radial surface (unmagnified)

rectangularly shaped ray cells appear to stand on end with their long axes parallel to the grain direction (Fig. 5.17); these cells are logically called *upright ray cells*. Upright or *square ray cells* usually occur along the upper and lower margins of rays.

The significance of ray cell configuration is that this feature can be used in wood identification because upright and square ray cells occur as a constant feature in only some species. An example is provided by cottonwood and willow—two easily confused species. Positive identification is based upon the fact that rays of willow consistently have upright cells along the margins, whereas cottonwood rays do not.

In some hardwood species, the rays tend to be arranged into definite tiers as viewed on a tangential surface. In these woods, rays in each layer are roughly the same height, and all begin and end at about the same levels along the grain (Fig. 5.18A). Such woods are said to have *storied rays*, and they often exhibit a readily visible banded pattern on tangential surfaces (Fig. 5.18B). A storied cell arrangement is not restricted to ray cells. Almost any type of hardwood cell can occur in storied arrangement, and the resulting pattern is often similar to that produced by storied rays. This pattern will show on both tangential and radial surfaces, whereas that from storied rays will be seen only on the tangential. Storying of elements is primarily of interest for wood identification.

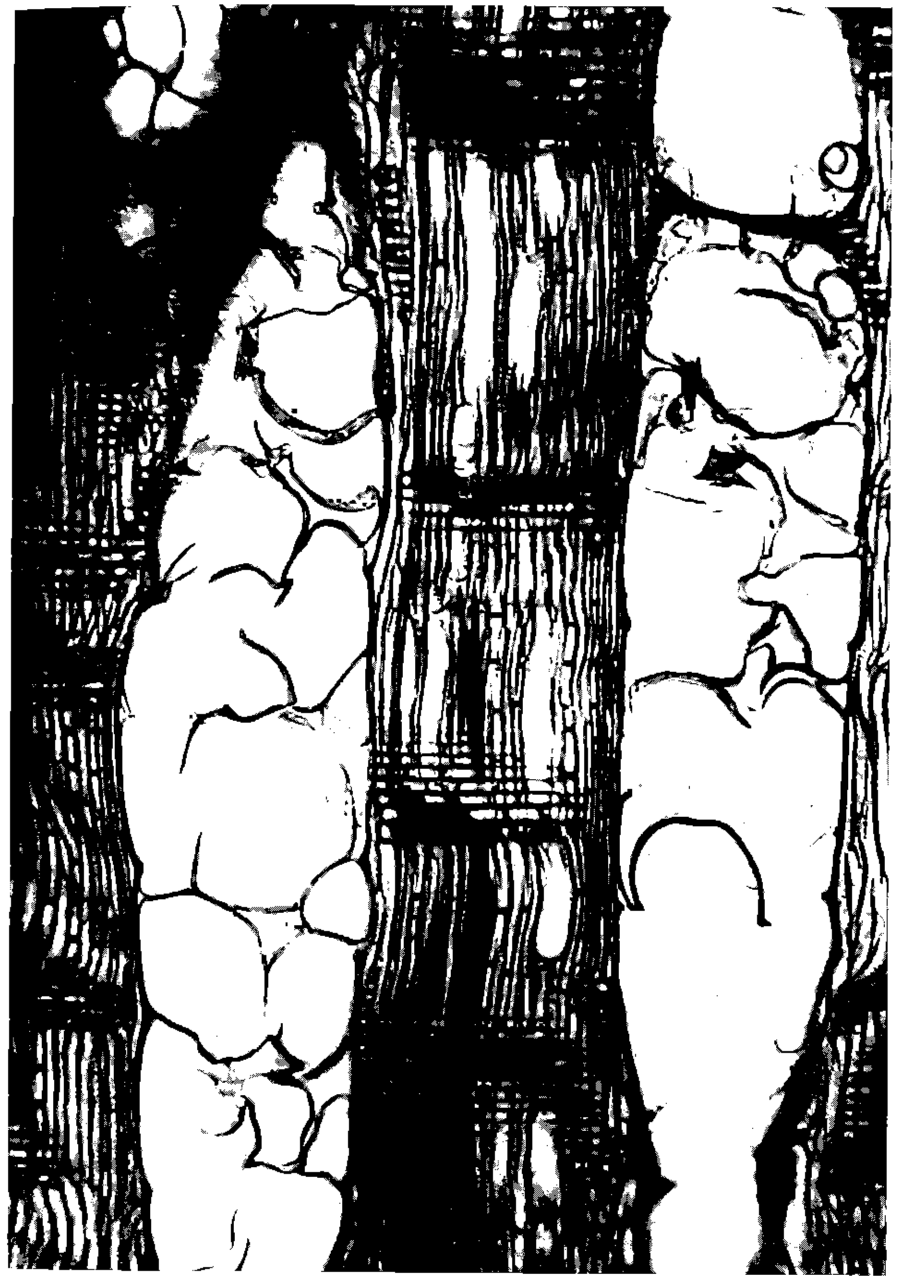


FIGURE 5.16. (*continued*)
B. Radial surface (×85)

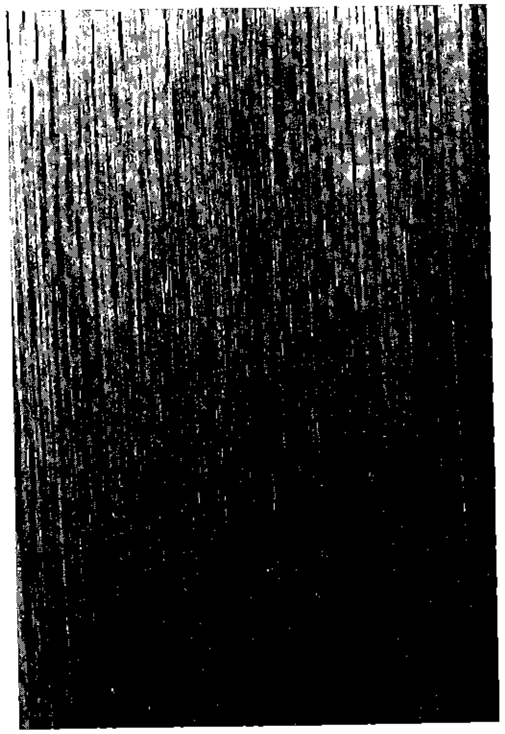


FIGURE 5.16. (*continued*)
C. Tangential surface (unmagnified)

Wood Identification

As with softwoods, no discussion of hardwood identification is included in this text. For a listing of books that deal with this subject, the reader is referred to Chapter 4.

Summary

A three-dimensional drawing of a diffuse-porous hardwood is presented in Figure 5.19 and is used as a means of reviewing structural features of hardwoods. The figure is drawn to the same scale as the softwood block depicted in Figure 4.12.

Transverse Surface (I)

Portions of two annual growth rings appear on the transverse surface (Fig. 5.19). The latewood of one growth ring can be seen at the left (1–1a) followed at the right by a portion of the earlywood of the succeeding growth layer (1a–1b). Growth rings in this case are delineated by a difference in wall thickness and radial diameter between earlywood fibers (c) and latewood fibers (d); latewood fibers have thicker walls, and in the outermost part of the growth ring these cells are flattened radially.

(Courtesy Ripon Microslides Laboratory)

FIGURE 5.16. (*continued*)
D. Tangential surface (×85)

Thin-walled longitudinal parenchyma can be seen in cross section (e). Ray parenchyma is much in evidence, with three rays visible in cross section (2a–2b, 2c–2d, 2e–2f). Vessel-to-vessel pitting can be seen (f), as can vessel-to-ray parenchyma pits (g) and pitting between vessels and fibers (h).

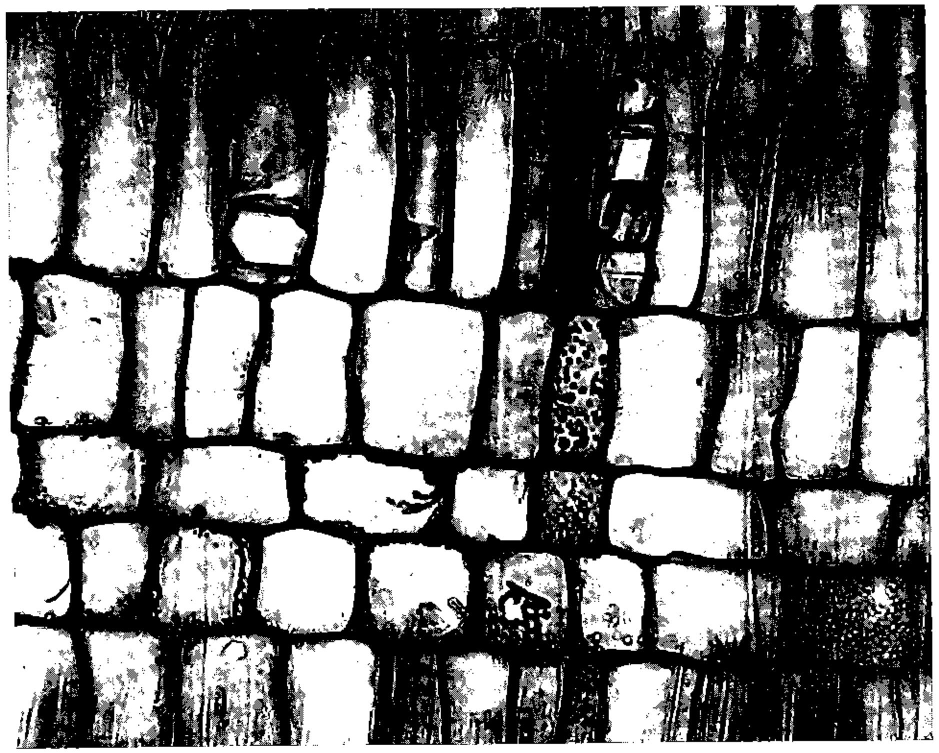


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FIGURE 5.17. Upright ray cells on ray margins. Radial view of Andiroba (*Carapa guianensis*). ×200.

Radial Surface (II)

Several radially sectioned vessels are visible on this surface, revealing the scalariform perforation plates between vessel elements (i). Also visible are earlywood and latewood fibers (c, d).

A ray (j) is seen to be made entirely of procumbent ray parenchyma. Pitting of ray cells can be seen as small dots on sidewalls and as gaps in common end walls.

Tangential Surface (III)

Rays appear in the end view on the tangential surface (k), providing an opportunity to judge ray size. The rays in this wood are not in a storied arrangement and thus begin and end at different levels along the grain. Rays vary from two to five cells in width.

A long, hollow vessel appears on the tangential surface, interrupted by a perforated remnant of the plates marking the ends of individual vessel elements (i); the perforation is of the scalariform type. Between vessels and rays are thick-walled fibers (c). Note the small bordered pits connecting adjacent fibers (m). Because the cut forming the tangential face was made through a transition area between earlywood and latewood, no fibers of the type found in 1–1a are seen on this surface.

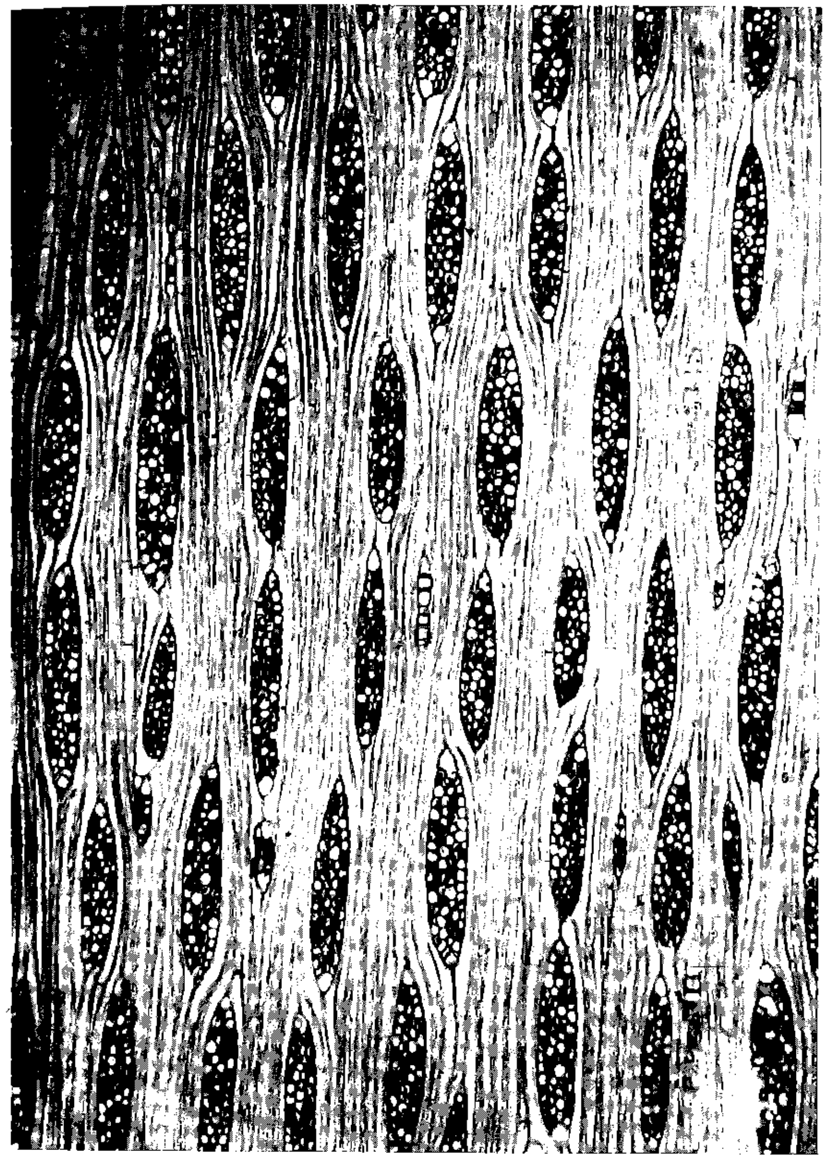

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FIGURE 5.18. Storied rays on tangential surface of Sapele (*Entandrophragma cylindricum*). A. Tangential view. ×50. Rays occur in a definite tier arrangement.

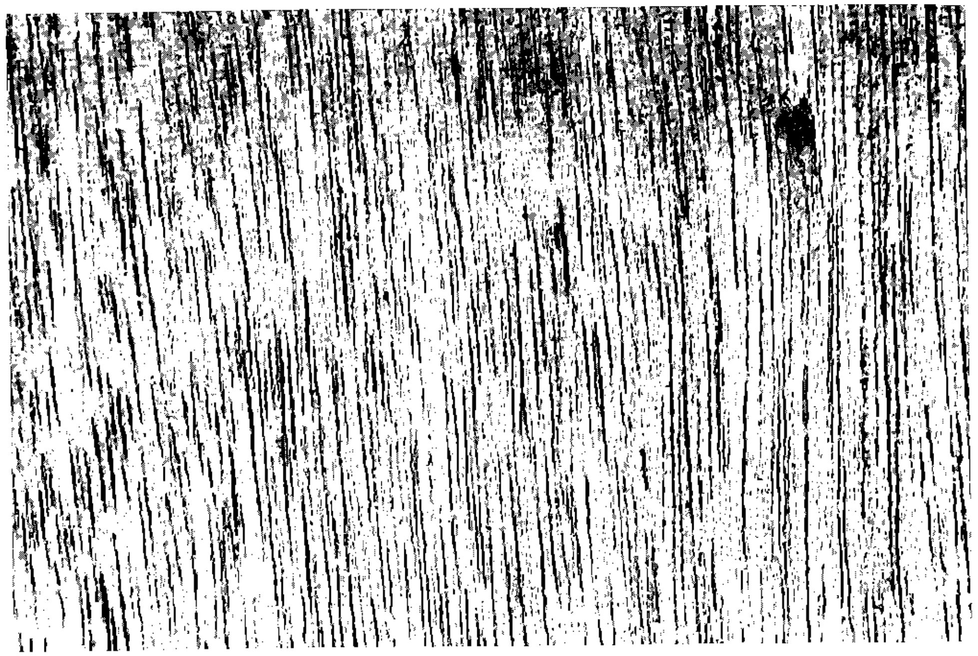


FIGURE 5.18. *(continued)*
B. Rays show up as ripple marks on unmagnified tangential surface.

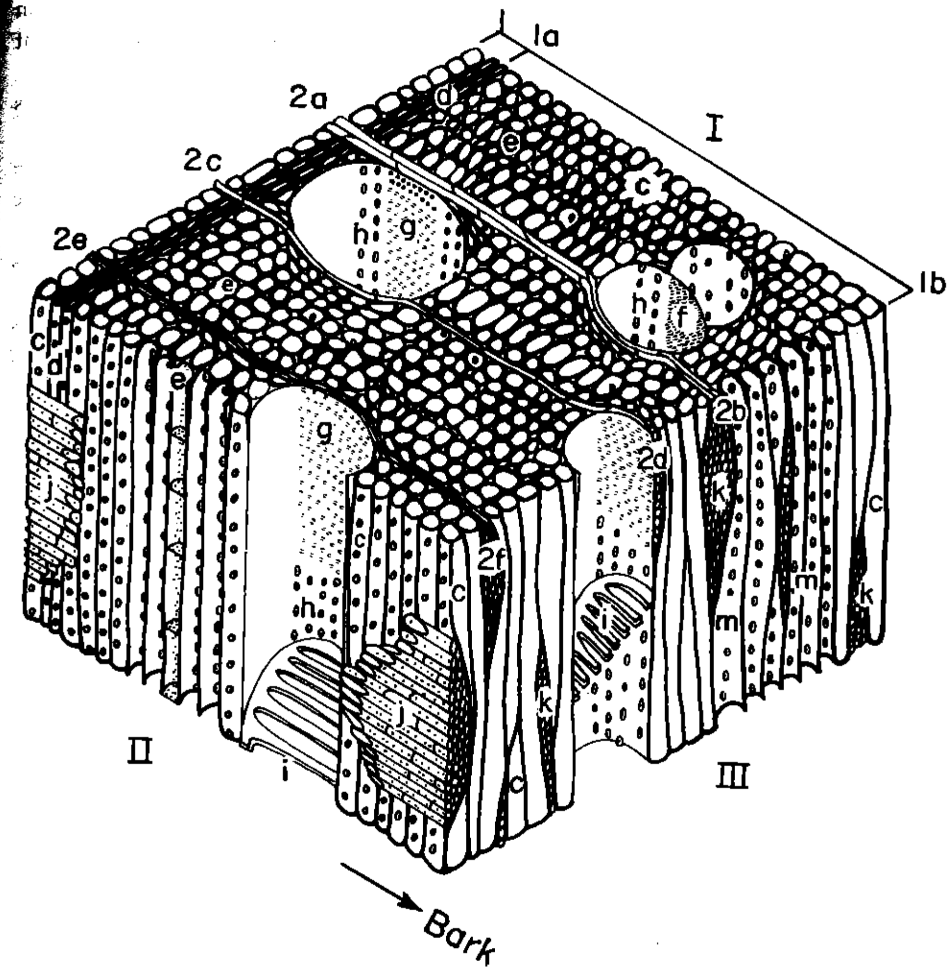
Review

A. Terms to define or explain:

1. Hardwood
2. Vessel
3. Vessel element
4. Perforation
5. Perforation plate
6. Intervessel pitting
7. Tyloses
8. Ring-porous
9. Diffuse-porous
10. Fiber tracheid
11. Libriform fiber
12. Upright ray cell
13. Procumbent ray cell
14. Storied rays
15. Gum canal
16. Longitudinal strand parenchyma

B. Questions or concepts to explain:

1. A furniture salesperson points out a desk made totally of northern hardwoods, implying that because of this it is superior to a competitor's desk constructed with comparable workmanship but made of a softwood species. Assuming that the desk is, in fact, made of hardwoods, does this mean that it is a superior product to the softwood desk?
2. Furniture is often advertised as being constructed of fine hardwoods. What is meant by this? Why are fine hardwoods widely preferred for use in furniture?
3. The xylem of hardwood species is quite different from that of softwoods. In what ways do hardwood and softwood xylem differ?



Transverse view. I. *I-Ia*, latewood; *Ia-Ib*, earlywood of succeeding growth ring; *c*, earlywood fiber; *d*, latewood fiber; *e*, longitudinal parenchyma; *f*, vessel-to-vessel pitting; *g*, vessel-to-ray parenchyma pitting; *h*, vessel-to-fiber pitting; *2a-2b, 2c-2d, 2e-2f*, rays.

Radial view. II. *c*, earlywood fiber; *d*, latewood fiber; *e*, longitudinal parenchyma; *g*, vessel-to-ray parenchyma pitting; *h*, vessel-to-fiber pitting; *i*, perforation plate between vessel elements; *j*, ray composed of procumbent ray parenchyma.

Tangential view. III. *c*, fibers; *i*, perforation plate between vessel elements; *k*, rays in end view; *m*, fiber-to-fiber pitting (bordered).

Birch (*Betula* spp.)

FIGURE 5.19. Three-dimensional representation of diffuse-porous hardwood.

4. End-to-end connection of fibers is quite different from the type of communication between elements making up a given vessel. What is the difference, and of what significance is this difference?
5. The presence or absence of tyloses in a wood has an effect on the types of products for which it may be used. What are tyloses, and how do they affect utilization?
6. Although hardwood fibers and softwood tracheids appear somewhat similar, there are major differences. What are they, and which is the most important from the standpoint of utilization?
7. What types of parenchyma cells occur in hardwoods? Of what significance is hardwood parenchyma?
8. Ray flecks characterize radial surfaces of many hardwoods, even when care is taken to ensure that a precise radial face is formed. Why do rays appear as flecks instead of radially aligned stripes on such surfaces?

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CHAPTER

6

Juvenile Wood, Reaction Wood, and Wood of Branches and Roots

The first five chapters deal only with the formation, composition, structure, and gross features of wood formed in the main stem of mature, upright trees. The character of wood in the centers of young trees, in trees that are leaning rather than vertical, and in branches and roots is considerably different from the normal wood of the mature *bole*. Such wood commonly has properties that affect the ways it may be processed and utilized.

Wood formed in the early (or juvenile) stages of growth of a tree stem is called *juvenile wood*. Juvenile wood is formed as part of the developmental process of tree growth and is found in the center portions of stem cross sections. It is present in every tree, and virtually every living tree, regardless of age, continues to form juvenile wood during each growing season.

A different kind of wood—*reaction wood*—is produced in response to tipping of a tree. This kind of wood, although abnormal, is nonetheless rather common.

Branchwood and *rootwood* properties are increasingly important as more emphasis is being placed on maximizing use of all material in a tree. Thus a working knowledge of wood must include an awareness of these variations in wood form.

Juvenile Wood

In Chapter 1 it was noted that an undefined mass of tissue known as the pith marks the stem center, and this region is surrounded by a thin layer of primary xylem. Both the pith and primary xylem are wholly formed in the first year of the life of a stem, and both types of tissue differ from secondary xylem produced later by the cambium. An important point is that secondary xylem produced for the first 5 to 15 years is different from secondary xylem produced after this juvenile period.

Juvenile wood is the secondary xylem at the center of a tree formed throughout the life of the tree. The width of the juvenile wood zone decreases upward to the tree crown. The width is species specific, can be affected by environmental conditions, and is the re-