2

Macroscopic Character of Wood

A number of features of wood can be detected by casual observation and are termed *macroscopic* because a microscope is not needed for detection. Macroscopic characteristics of wood are of interest because they often give clues to conditions under which wood was grown, provide an indication of physical properties, and serve as an aid in wood identification.

Three Distinct Surfaces of Wood

Illustrated in Figure 2.1 is a wedge-shaped piece of wood as it would appear if cut from a round cross section. Notice that the macro features of the cross-sectional, radial, and tangential surfaces appear quite different (see also Fig. 1.3).

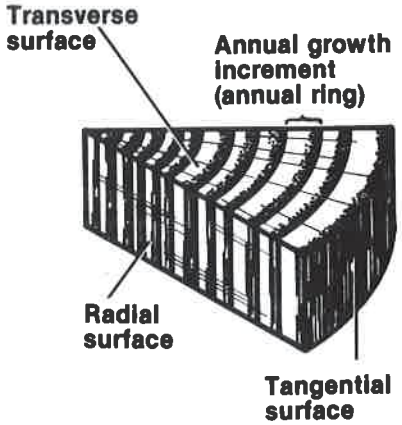
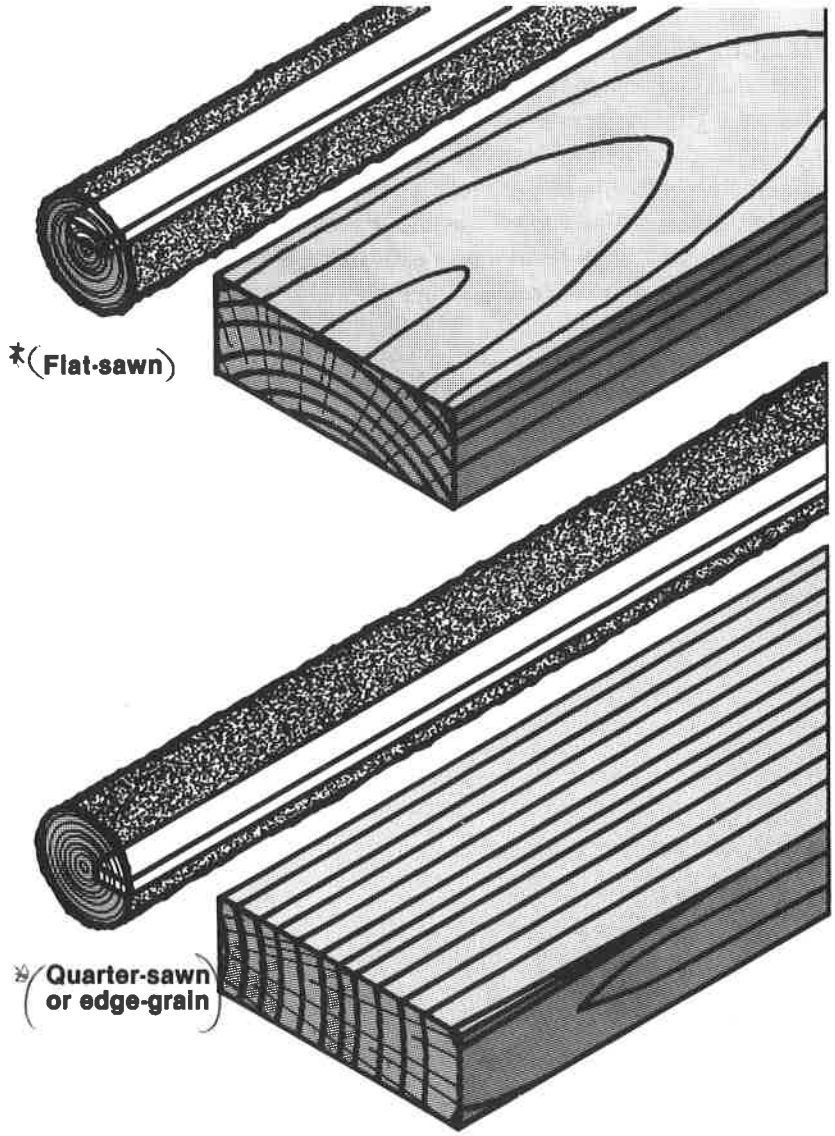


Figure 2.1. The three primary surfaces of wood (gross appearance).

Wood differs not only in appearance, depending upon the direction from which it is viewed, but (as will be explained a bit later) in physical properties as well. Thus in a solid wood product such as lumber, boards are classified by the surface of wood that corresponds to the widest face (Fig. 2.2).

Figure 2.2. Classification of lumber by the manner of cutting.

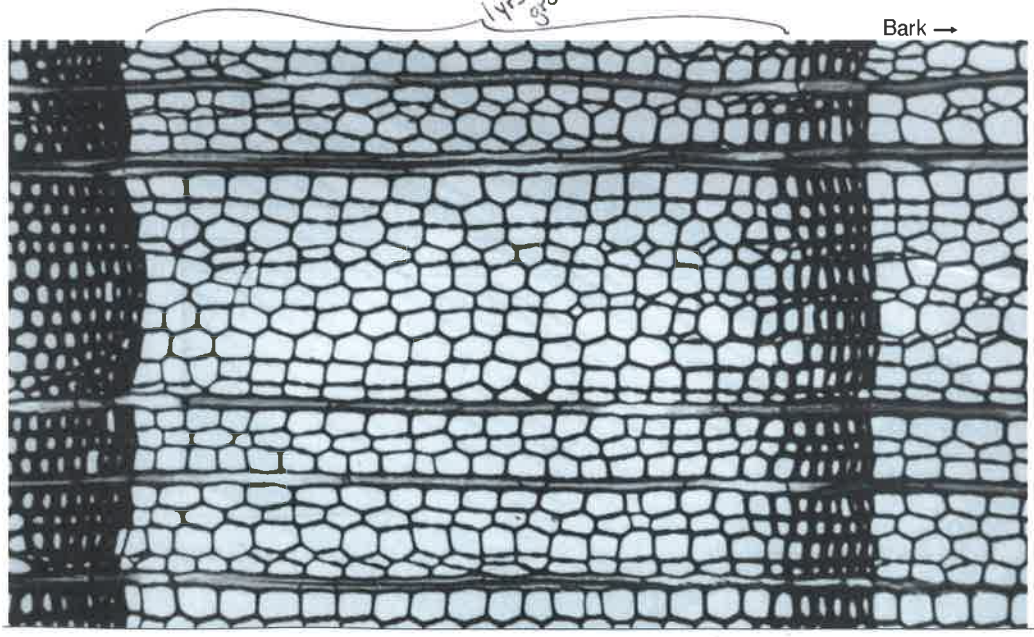


Growth Rings

The seasonal nature of growth was indicated in Chapter 1. Growth in temperate zones was characterized as proceeding rapidly in early spring and slowing in late summer before ceasing in the fall. For reasons explained in succeeding paragraphs, this kind of growth pattern usually results in the formation of one growth ring annually and more or less distinct layers of early- and late-formed wood within each ring.

APPEARANCE. Figure 2.3 is a photograph of a magnified thin cross section of redwood. At this magnification it is easy to see why wood formed in the latter part of a growing season appears distinctly different to the unaided eye than that formed early in the year. The latewood tissue is of greater density, being composed of cells of relatively small radial diameter, with thick walls and small lumens. Latewood forms the darker-colored portion of the growth ring. Illustrations of end portions of earlywood and latewood longitudinal trachieds of softwoods are presented in Figure 2.4.

Figure 2.3. Latewood cells appear as distinct bands. Transverse view of redwood (*Sequoia sempervirens*). ×85.



(Courtesy Ripon Microslides Laboratory)

Growth rings do not always appear as distinct alternating bands of earlywood and latewood. Some temperate hardwoods, for example, form large-diameter pores early in a growing season and much smaller pores later in the

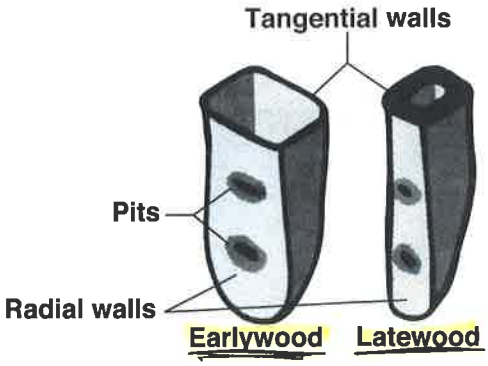
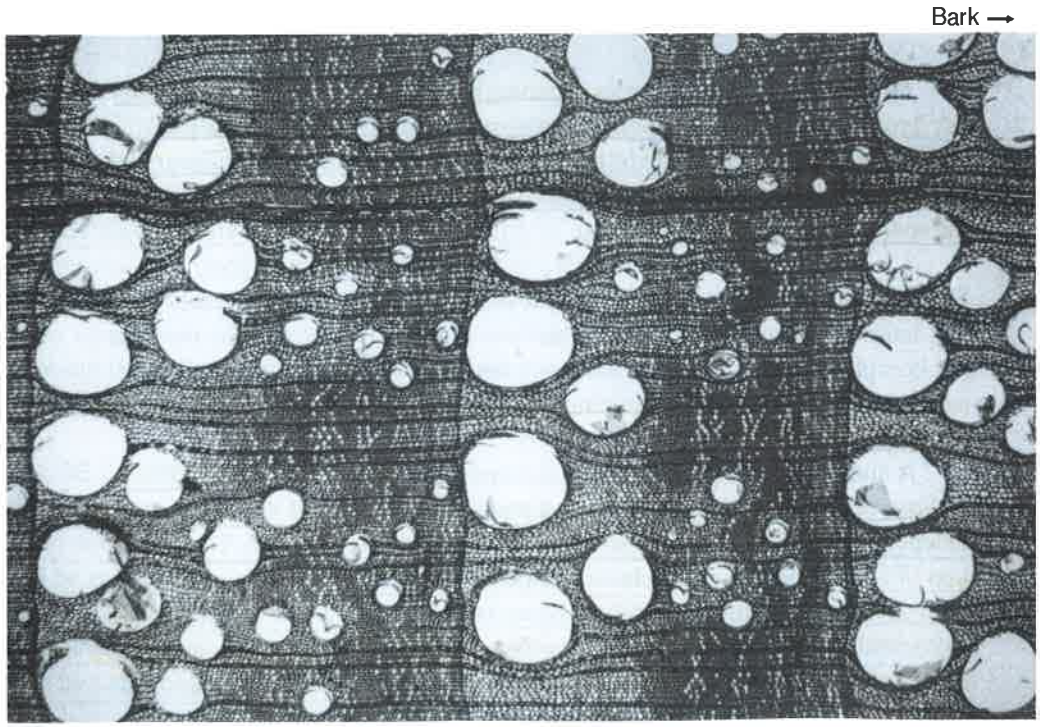


Figure 2.4. Tapered ends of earlywood and latewood longitudinal tracheids of a softwood.

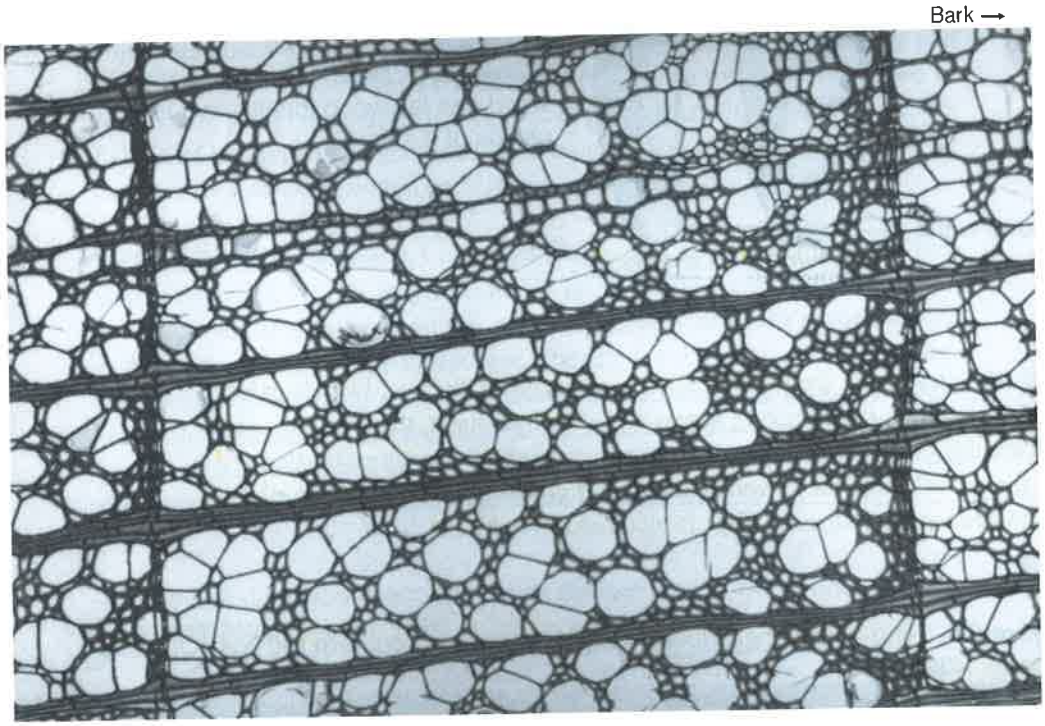
year (Fig. 2.5); such woods are called *ring-porous*. Other hardwoods exhibit little variation in cell structure across a growth increment, thus forming rings that are difficult to detect. Because the pores are about the same size throughout the growth ring, these woods are termed *diffuse-porous*. A diffuse-porous hardwood having indistinct rings is pictured in Figure 2.6.

Figure 2.5. Ring-porous hardwood. Transverse view of southern red oak (*Quercus falcata*). ×30



(Reproduced with permission from North Carolina Agric. Res. Serv. Bull. 474, 1986)

Figure 2.6. Diffuse-porous hardwood. Transverse view of yellow poplar (*Liriodendron tulipifera*). ×80



(Courtesy Department of Wood and Paper Science, North Carolina State Univ.)

As noted in Chapter 1, trees growing in the tropics sometimes produce one growth ring annually, but more commonly will form more than one ring each year. Often there is little or no difference in the structure and appearance of early- and late-formed wood within such rings or in wood formed within the span of one year.

FORMATION. Scientists have sought to explain the causes of earlywood and latewood formation for more than one hundred years, and the riddle is not completely solved. Strong evidence does exist, however, indicating that earlywood and latewood formation is related to photosynthate availability and presence of auxins.

A number of investigators have concluded that two major characteristics of *latewood*—relatively small radial diameter and thick cell walls—develop independently of each other (Zimmermann and Brown 1971, 96). The formation of large-diameter cells, characteristic of *earlywood*, is apparently dependent upon an abundance of soil moisture (Kozlowski et al. 1991). Conversely, water deficits can induce early formation of latewood, and continued moisture deficits are reported to shorten the period of latewood forma-

tion. Development of thick cell walls, on the other hand, is generally related to a plentiful supply of photosynthate (Kozlowski and Pallardy 1997a, 93).

Using the deciduous softwood larch as an example, spring finds the tree with swollen buds but no leaves. Sugars used in the growth process come from storage sites in the roots and elsewhere. As new needles emerge and begin to produce photosynthate, they also begin to increase in size. At the same time, a flush of shoot growth at the apical meristems is typically underway and the rate of new cell formation in the cambium is rapid. Thus most available sugars at this time of the growing season are consumed in building new shoots; photosynthate reaching cambial regions supplies large numbers of new and developing cells. Later in the growing season, factors such as drought, low temperature, and shortened daylight hours provide less favorable growing conditions, resulting in a reduced rate of new cell production in the cambium and development of cells of lesser radial diameter. By this time, the growth of shoots and development of new needles have largely ceased. Thus much of the photosynthate produced by the now full-grown needles is available for cell wall synthesis. Small-diameter and thick-walled cells are the result.

The effect of late-season abundance of photosynthate is less obvious in hardwoods than in softwoods. In ring-porous hardwoods, formation of large-diameter vessels early in the season is commonly followed by production of wood having smaller diameter vessels and a greater volume of fibers. Diffuse-porous hardwoods likewise often produce a higher proportion of fibers late in a growing season, and these are sometimes radially flattened as well (Zimmermann and Brown 1971, 91–93).

DISCONTINUOUS RINGS. *Growth rings* sometimes fail to form around the complete cross section. This is a result of the cambium remaining dormant in one or more places around the stem. *Discontinuous rings* are occasionally found in trees having one-sided crowns and in heavily defoliated, suppressed, and overmature trees (Kramer and Kozlowski 1979). The fact that the discontinuous rings do occur indicates that caution should be used when using increment borings to determine tree age; borings from several locations around a stem should be used where presence of discontinuous rings is suspected.

FALSE RINGS. Occasionally, normal seasonal growth is interrupted by an event such as drought, late frost, or defoliation by insects or hail. If such an event results in slowing or cessation of terminal growth, auxin production will be reduced and may cause latewood-type cells to be produced. If events that cause slow growth are followed in the same growing season by conditions favorable to growth, normal growth patterns may be resumed, accompanied by production of large and thin-walled earlywood cells (Kozlowski and

Pallardy 1997b, 48). Casual observation of an annual ring formed under such circumstances will show two rings to have formed in a single year. The ring thus created is called a *false ring* (Fig. 2.7). It is possible for several of these to form in a given year (Esau 1965). Such rings may form throughout the length of a stem, but more commonly they are restricted to upper regions of the crown.

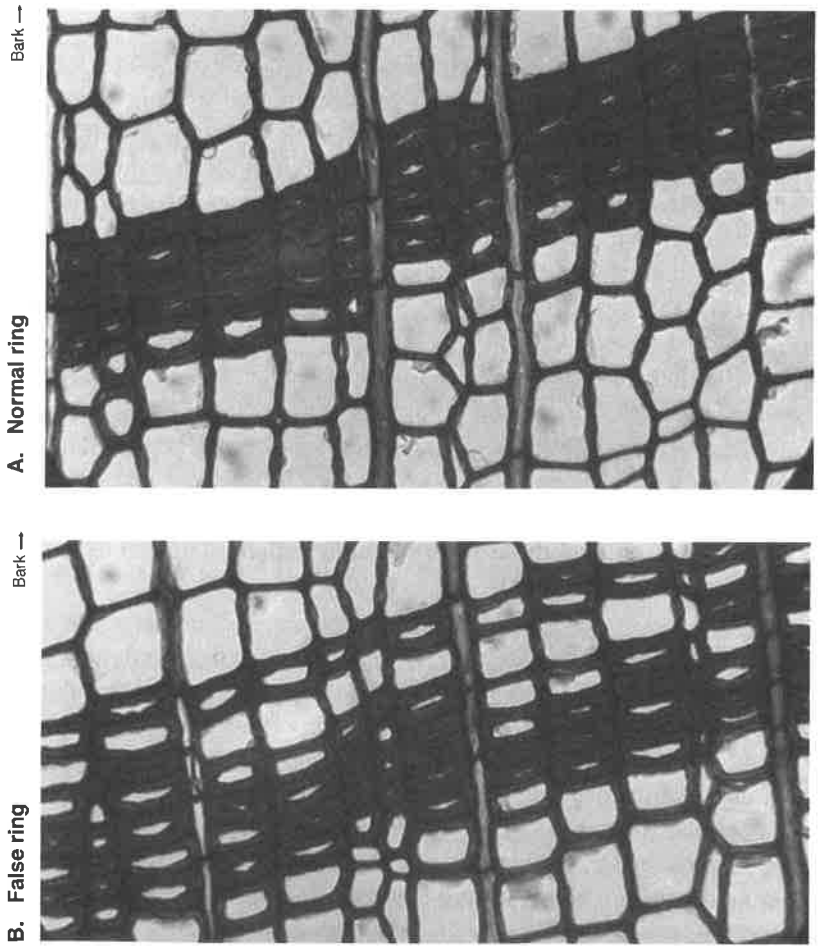


Figure 2.7. Normal vs. false growth rings. Transverse view of cypress (*Taxodium distichum*).

False rings of conifers can usually be distinguished from normal growth rings by examining latewood to earlywood transition (Panshin and de Zeeuw 1980). Normal growth rings are characterized by an abrupt change in cell size and wall thickness from the last-formed latewood of one seasonal ring to the earlywood of the next (Fig. 2.7A). False rings exhibit a gradual change in cell

character on both sides of the false latewood, resulting in a double gradation (Fig. 2.7B).

Heartwood and Sapwood

Trees were defined in Chapter 1 as being one of nature's largest living organisms. Some are described as nature's oldest living creations as well. Indeed, one bristlecone pine growing in the White Mountains of California is estimated to be Earth's oldest living resident at a ripe old age of about forty-six hundred years.

An estimate that a living organism is almost five thousand years old is impressive, but it can also be misleading. Plant tissue seldom remains alive longer than several years, even when part of an old bristlecone pine. This apparent contradiction is explained by the fact that new cells are continually being produced while others cease functioning. Even cambial initials are periodically replaced. It has been estimated that living cells of a coniferous tree may comprise as little as 1 percent of its total bulk (Mirov and Hasbrouck 1976). The longevity of trees such as the bristlecones provides evidence that wood will last indefinitely if conditions are favorable.

Examination of a stem cross section often reveals a dark-colored center portion surrounded by a lighter-colored outer zone (Fig. 2.8). The dark center area is known as *heartwood*, the lighter tissue as *sapwood*. It is important to note that heartwood is occasionally the same color as sapwood. It is in the sapwood that the living cells are found. The inner region of the sapwood, in which most of the cells are dead, also serves to conduct water upward in a living tree. Heartwood no longer functions physiologically because all the cells in this region of the tree are dead.

FORMATION OF HEARTWOOD. Perhaps no term relating to wood has more mystery associated with it than the word *heartwood*. A typical belief is that because heartwood is older than sapwood, it is better. Heartwood is reputed to be heavier, stronger, more highly figured, and more resistant to decay than sapwood. Some of these notions are true but others are not. Before an understanding can be gained of what properties heartwood does and does not have, and why, it is first necessary to know what heartwood is.

When a tree or tree part is very young and growing vigorously, it contains no heartwood. After a number of years, however, heartwood typically begins to form near the center of a stem. The most common age at which transformation from heartwood to sapwood occurs is reported to be fourteen to eighteen years (Hillis 1987). However, as reported by Dadswell and Hillis (1962), some species, such as eucalyptus, may begin to form heartwood at five years of age. Other studies confirm heartwood formation at relatively young tree ages. Gominho and Perieira (2000), for instance, reported that

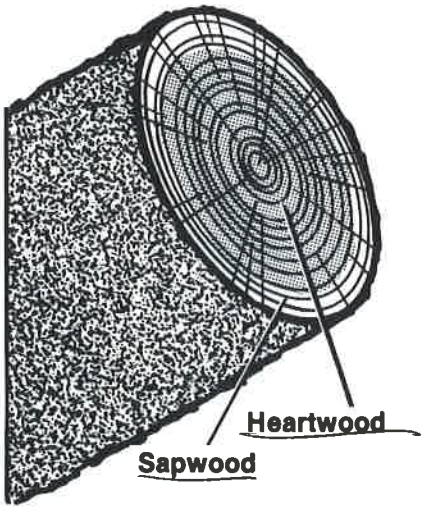


Figure 2.8. Heartwood in a round cross section.

heartwood formation in nine-year-old plantation *Eucalyptus globulus* had been found in all trees; heartwood was noted to extend to 60 to 75 percent of tree height, and to account for one-third of tree volume. In contrast, Dadswell and Hillis reported that some species, such as beech or European ash, may not begin to form heartwood until reaching sixty to one hundred years of age, and that a few species apparently never form heartwood. Once initiated, the transformation of sapwood into heartwood occurs continuously. In general, the number of rings of sapwood is directly related to the size of the crown of the tree (Hazenburg and Yang 1991; Yang and Hazenburg 1991). The boundary between heartwood and sapwood does not necessarily follow the growth rings.

Chapter 1 discusses formation of new cells by the cambium. Recall that for a time these cells retain the ability to further subdivide, and then they lose this capacity as thickened and lignified cell walls form. Death of most cells follows cell wall thickening and is marked by the disappearance of nuclei and protoplasm (Esau 1965). However, some cells (from 5 to 40 percent of those that comprise sapwood) retain their protoplast; these are storage cells known as *parenchyma cells* that occur both as longitudinal and ray cells (Kollmann and Côté 1968). The living cells of the sapwood carry on metabolic processes. As the living parenchyma cells get older and progressively farther from the cambium, metabolic rates and enzymatic activity decline and the remaining living cells begin to fail. The cytoplasm begins to change chemically, with a reduction in starches, sugars, and nitrogenous materials. Cell nuclei become rounded, begin to deteriorate, and then disappear completely (Frey-Wyssling 1963), marking the death of these cells. In heartwood all cells have died.

The precise cause of heartwood formation continues to be debated, but death of cells is known to be related to at least two events: reduction of water

content of cells (especially in softwoods) and species-dependent biosynthesis of compounds termed secondary metabolites. Secondary metabolites are defined as substances that do not participate directly in tree growth and development. These metabolites accumulate in cell walls and lumens and are usually polyphenolic in nature.

Polyphenols commonly associated with heartwood include oils, resins, gums, tannins, and aromatic and coloring materials (Koch 1972, 202). Other compounds include fats and waxes. Many heartwood secondary metabolites can be removed or extracted from heartwood by soaking or boiling in water or alcohol or by other extraction processes. Because of this capacity to be extracted as well as the fact that the number of individual components is great, these various compounds are commonly and collectively referred to as *extractives*.

Whether the death of remaining storage cells is caused by development of secondary metabolites and other substances within these cells, or whether death is caused by water deficits, with the production of polyphenols being a secondary result of cell failure, is not clear. Regardless of what causes the death of parenchyma cells at the stem center, it appears likely that photosynthates that are not consumed in growth processes in the cambial zone play a direct role in polyphenol development. Hillis (1968) found, for example, that rapid growth and efficient utilization of carbohydrate is associated with low amounts of heartwood polyphenols. More recently, it has been noted that "although starch has been detected in the [heartwood/sapwood] transition zone of some species, the translocation of a considerable amount of primary metabolites from the sapwood to the sapwood/heartwood transition zone is required to form the high levels of extractives found in some heartwoods" (Hillis 1987, 187). Ten years later, Kozlowski and Pallardy (1997b, 51), after a review of sometimes conflicting scientific evidence, supported the findings of Hillis and others, concluding that the weight of the evidence indicates that extractives are formed from transported metabolites (products of physical and chemical processes associated with the maintenance of life) by living parenchyma cells at the heartwood boundary.

As indicated previously, heartwood formation is often marked by a reduction in water content of cells. Moisture content of heartwood versus that of sapwood is listed in Table 2.1 for a number of species. Huber observed in 1956: "We are virtually certain that the water columns in the xylem are under tension and that these tensions play a role in the movement of water. It is equally certain that, sooner or later, water columns under tension must break and the vessels embolize, probably irreversibly." An *embolism* is an obstruction, caused in this case by formation of air bubbles as liquid pressure is reduced; embolism is more likely to occur as height from the ground increases. The reduction of water content of cells is thought to be the first step in heartwood formation (Zimmermann 1983). This is said to be the reason for the existence of higher proportions of heartwood with increasing height in a tree; it also may explain why the wood of roots contains very little

heartwood. This explanation is muddled a bit by the recent findings of Zwienecki et al. (2001) that resistance to liquid transport through dead hardwood vessels can be substantially increased by increasing the ion concentration of the solute. This finding raises the possibility that the mechanism controlling reduced rates of flow and water content of cells that precede the onset of heartwood formation is more complex than earlier thought.

Table 2.1. Moisture content of heartwood and sapwood when in green condition.

Hardwoods			Softwoods		
	Moisture Content			Moisture Content	
Species	Heartwood	Sapwood	Species	Heartwood	Sapwood
	(%)			(%)	
Red Alder	...	97	Baldcypress	121	171
Apple	81	74	Cedar		
Ash			Alaska	32	166
Black	95	...	Eastern red	33	...
Green	...	58	Incense	40	213
White	46	44	Port Orford	50	98
Aspen	95	113	Western red	58	249
American basswood	81	133	Douglas-fir, coast type	37	115
American beech	55	72	Fir		
Birch			Grand	91	136
Paper	89	72	Noble	34	115
Sweet	75	70	Pacific Silver	55	164
Yellow	74	72	White	98	160
Black cherry	58	...	Hemlock		
American chestnut	120	...	Eastern	97	119
Black cottonwood	162	146	Western	85	170
Elm			Western larch	54	119
American	95	92	Pine		
Cedar	66	61	Loblolly	33	110
Rock	44	57	Lodgepole	41	120
Hackberry	61	65	Longleaf	31	106
Pecan Hickory			Ponderosa	40	148
Bitternut	80	54	Red	32	134
Water	97	62	Shortleaf	32	122
Hickory (true)			Sugar	98	219
Mockernut	70	52	Western white	62	148
Pignut	71	49	Redwood (old-growth)	86	210
Red	69	52	Spruce		
Sand	68	50	Eastern	34	128
Magnolia	80	104	Engelmann	51	173
Maple			Sitka	41	142
Silver	58	97	Tamarack	49	...
Sugar	65	72			
Oak					
California black	76	75			
Northern red	80	69			
Southern red	83	75			
Water	81	81			
White	64	78			
Willow	82	74			
Sweetgum	79	137			
American Sycamore	114	130			
Tupelo					
Black	87	115			
Swamp	101	108			
Water	150	116			
Black walnut	90	73			
Yellow-poplar	83	106			

From the preceding discussion, it is evident that the basic cell structure is unchanged in the transformation to heartwood and that the primary change is the presence of extractable chemicals. Recognition of this fact is important in understanding differences in properties of heartwood and sapwood. One structural change sometimes associated with heartwood formation in softwoods is aspiration of many of the bordered pits in tracheids. Pit structure and aspiration is covered in Chapter 3.

PROPERTIES OF HEARTWOOD. Because the differences between heartwood and sapwood are mostly chemical, the presence of these chemicals is primarily responsible for giving heartwood its unique properties, a number of which are as follows:

1. *Heartwood may be darker in color than sapwood.* Most polyphenols found in temperate zone trees are colorless in regular light. However, they are also unstable and degrade with time. The death of parenchyma cells allows secondary metabolites to diffuse in the wood, and these subsequently darken as a result of random oxidation reactions. In some woods, heartwood and sapwood show no color difference; this lack does not necessarily mean an absence of heartwood but may simply indicate that no dark-colored extractives have formed. Hardwoods exhibit a wider range of heartwood coloration than softwoods.

2. *Heartwood may be highly decay- or insect-resistant, or both.* When woods are naturally resistant to decay and insects, such as the heartwood of cypress, redwood, and most cedars, it is because some of the extractives provide protection from decay, fungi, and insects. Recent research (Goodell et al. 1999, Schultz and Nicholas 2000) suggests that the initial stages of brown-rot decay, the most serious form of decay affecting the softwood lumber used in residential construction, involves reactions of hydrogen peroxide, which is produced by fungi, with ferrous ions. It is believed that to impart decay resistance, extractives must have both antioxidant and antifungal properties. The heartwood of many woods does not contain extractives exhibiting these dual properties, or has lower levels than do the naturally decay-resistant woods; such heartwood has either no or only slight decay resistance. Because decay resistance is imparted by extractives that occur only in heartwood, sapwood of all species is readily susceptible to decay.

3. *Heartwood may be difficult to penetrate with liquids* (such as chemicals used to help preserve it). Resistance to penetration is the result of (a) the presence of extractable oils, waxes, and gums that may serve to plug tiny passages in cell walls; (b) closure of cell-to-cell passageways in softwoods through slight rearrangement of tiny membranes in the passageways (called *pit aspiration*); (c) blocking of bordered pit membranes of hardwoods and softwoods through progressive deposition of encrusting materials (such as phenolic compounds) over a period of time (Sano and Nakada 1998); or (d)

blocking of pores in hardwoods by ballooning of parenchyma cell sacs into vessel lumens (called *tyloses*) (see Chapter 5). When a wood is both susceptible to decay and difficult to penetrate, its usefulness for certain applications is limited. Douglas-fir is an example of a wood not highly resistant to decay; furthermore, its heartwood is difficult to treat for improved durability.

4. *Heartwood may be difficult to dry.* Drying difficulties are generally traceable to the same factors that inhibit penetration and permeability.

5. *Heartwood may have a distinct odor.* When it does, the odor is usually due to the presence of aromatic extractive compounds. Most cedars contain pungent-smelling compounds.

6. *Heartwood may have a slightly higher weight-per-unit volume than sapwood.* When this occurs, it is from the presence of significant quantities of extractives.

Several other properties, such as low hygroscopicity and a reduced fiber saturation point (see Chapter 8), might be listed. Note that strength does not appear on the preceding list. There is no difference in the strength of heartwood and sapwood, with one relatively rare exception. In some instances, as in redwood, western redcedar, and black locust, considerable amounts of infiltrated material may somewhat increase the weight of wood and its resistance to crushing.

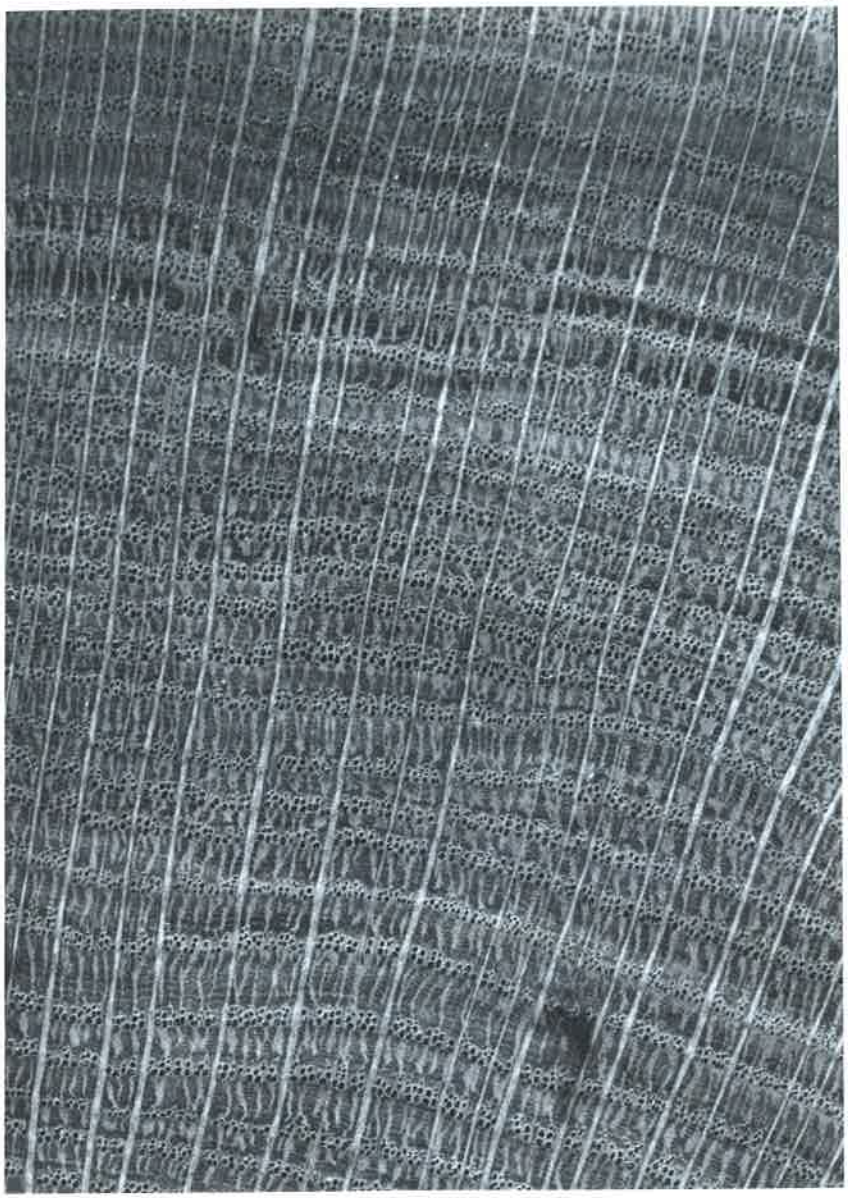
Rays

Rays provide an avenue by which sap can travel horizontally either to or from the phloem layer. Virtually all woods contain rays. In some hardwoods such as oak, rays are quite large and readily visible in a cross section (Fig. 2.9). In softwoods and a number of hardwoods, rays are very narrow and in some cases difficult to see even with a magnifying glass (Fig. 2.10). Many highly valued hardwoods used for paneling and furniture and other decorative purposes are characterized by distinct ray patterns on radial and tangential surfaces (Fig. 2.11). These patterns are often helpful when identifying wood species.

Rays also have an effect upon wood properties. For example, rays restrain dimensional change in the radial direction, and their presence is partially responsible for the fact that upon drying, wood shrinks less radially than it does tangentially. Rays also influence strength properties because they constitute radially oriented planes of weakness. Because of this effect upon strength, splitting may occur along rays in veneer-slicing operations if the veneer knife is improperly oriented. Splitting can also develop along rays when wood is dried.

A close look at a ray layout on a cross section (refer to Fig. 2.9) reveals that rays extend from the cambium and bark inward. Few rays can be traced to the stem center. Further observation shows that the distance between rays remains relatively constant in growth rings near the pith and outward.

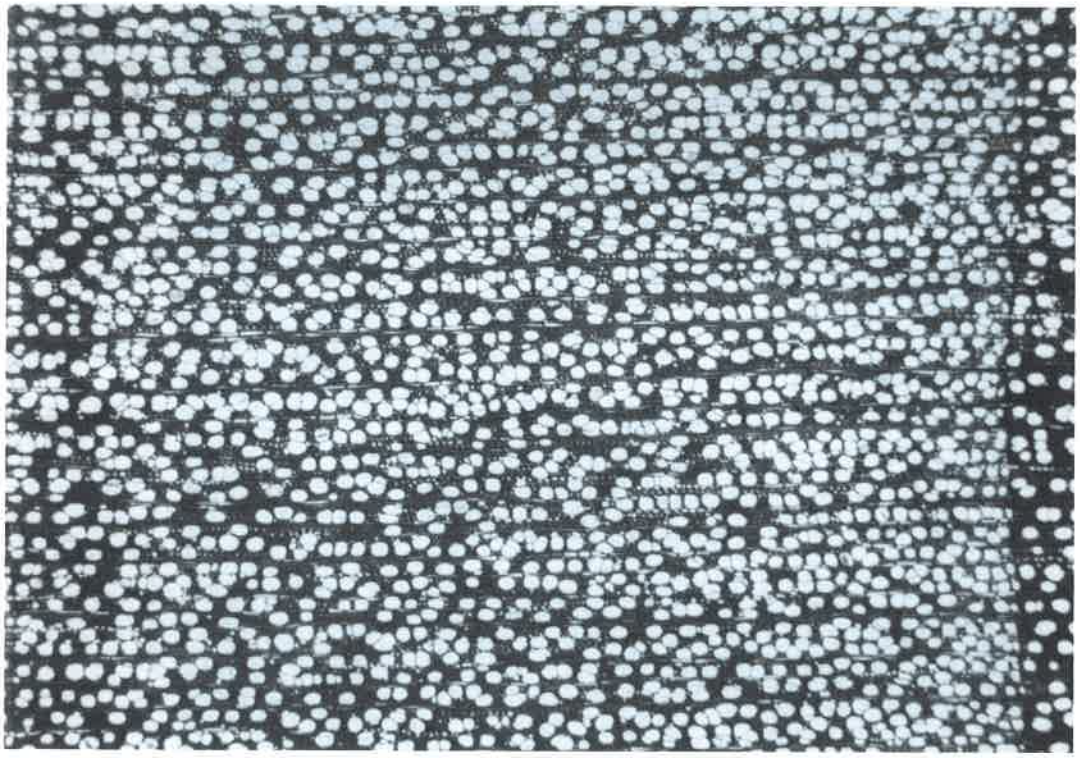
Figure 2.9. Large rays of oak are readily visible even without magnification.



(Reproduced with permission from North Carolina Agric. Res. Serv. Bull. 474, 1986)

Review of the way in which rays form helps to explain why rays are arranged as they are. Ray cells of the xylem and phloem are produced by division of ray initials in the cambium. Ray initials, in turn, arise either from division of other ray initials or from an unequal division of a fusiform initial. An undernourished or unusually small product of cell division will invariably fail to redivide; such a cell is likely to fail or may convert to a ray initial (Larson 1994). Because the cause for inadequate nourishment is lack of proximity

Figure 2.10. Rays in some hardwoods are hard to see even under magnification. Transverse view of red gum (*Liquidambar styraciflua*). ×30

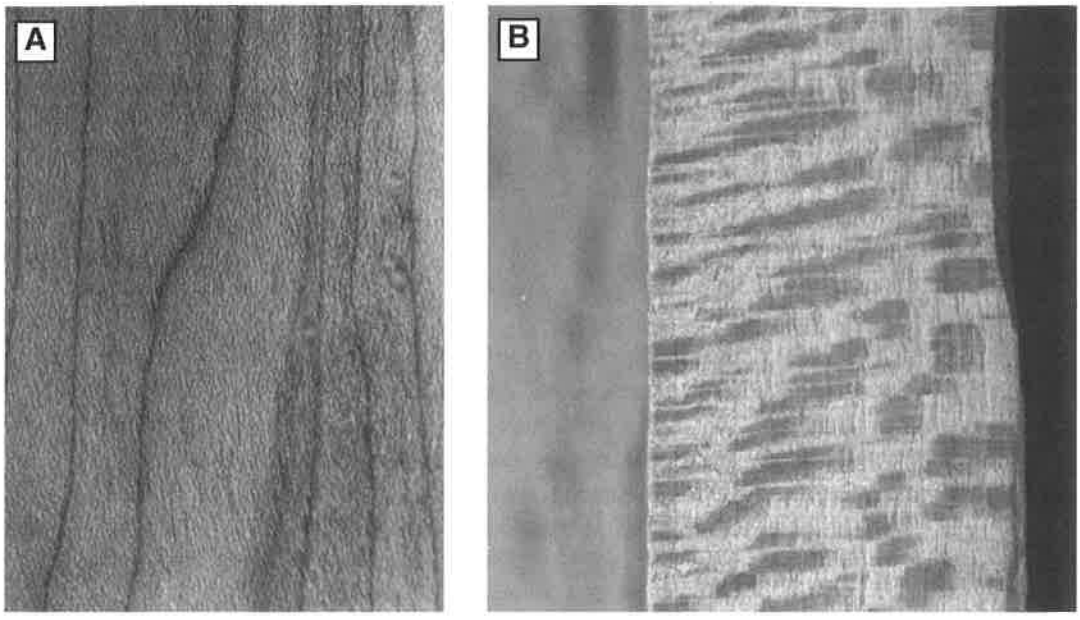


to rays, uniform spacing of rays is methodically assured. As soon as the distance between rays begins to increase, chances decrease that a cell midway between them will obtain sufficient nutrients and thus develop normally, and the chances increase that a new ray initial will be formed.

Yet other ways exist for additional rays to appear. At any given point along the length of a stem cross section, a "new" ray may appear as a result of an increase in the height of an existing ray through cell division that results in new cells located above or below the parent cells. In some hardwood species, rays can increase in width through division of cells tangentially; such division can lead to rays that are many cells in width when viewed tangentially.

Growing evidence indicates that conversion of fusiform initials to ray initials and expansion of existing rays are regulated by hormones and influenced specifically by the presence of ethylene that originates in the xylem (Kozlowski and Pallardy 1997b, 145). The finding that availability of specific chemical compounds, and not simply inadequate nourishment, controls or

Figure 2.11. Distinct ray patterns in hardwoods. A. Tangential view of sugar maple (*Acer saccharum*). ×3. B. Radial view of sycamore (*Planatus occidentalis*). ×3



influences conversion of fusiform initials to ray initials suggests that mechanisms involved in ray initiation and development are more complex than previously thought.

The fact that most rays can be traced from the xylem to the cambium and into the phloem is traceable to permanence of the cambium. Initials, once formed, continue to divide while the cambium of which they are a part moves outward. A ray will be terminated (and thus not connect with the cambium) only if the ray initials that formed it fail and are not replaced by new ones.

Grain Orientation

The direction parallel to the long axis of most of the long tapered fibers of wood is called the *grain direction*. Fibers are normally oriented as illustrated in Figure 2.12, with their length essentially parallel to the long axis of the stem. Not uncommon, however, is fiber arrangement at a slight angle to the stem axis rather than precisely parallel to it. In fact, angled grain orientation may be the rule rather than the exception (Beals and Davis 1977). Occasionally, the deviation from parallel is large, resulting in an obvious spiraling grain pattern. This kind of grain orientation can significantly affect wood properties.

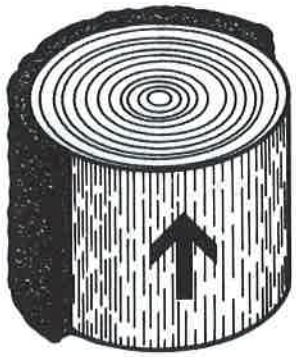


Figure 2.12. Straight-grain orientation.

SPIRAL GRAIN. Trees in which fibers are spirally arranged about the stem axis (Fig. 2.13) are said to have *spiral grain.* This condition is apparently caused by anticlinal division in which new cambial cell formation occurs in one direction only, that is, walls formed during fusiform initial division consistently slant the same way (Bannan 1966). In at least one instance, spiral grain was shown to be the result of entwinement of stemwood with a woody vine or liana (Lim 1996).



Figure 2.13. Spiral-grain orientation.

When logs exhibiting spiral grain are sawn, the lumber formed has a grain direction that is not parallel to the board length. Such lumber is said to have slope of grain (see Fig. 10.15); it is typically low in strength and stiffness and may tend to twist as it dries. Planing of such lumber to a high-quality surface may also be difficult.

INTERLOCKED GRAIN. In some trees, grain may spiral in one direction for several years and then reverse direction to spiral oppositely (Fig. 2.14). Wood produced in this way is said to have *interlocked grain.*

Reversing spiral grain is evidently genetically controlled, occurring very frequently in some species and seldom if at all in others. Woods with inter-



Figure 2.14. Reversing spiral grain (interlocked grain).

locked grain, such as elm, are difficult to split and thus are recognized as woods for the do-it-yourself firewood splitter to avoid. Wood with this characteristic may also shrink longitudinally upon drying, warp unpredictably, or both. Occurrence of interlocked grain is occasionally considered desirable from an appearance standpoint. Grain directions that alternate cause light to reflect in varying patterns across radially cut wood, giving what is known as a ribbon stripe figure. When well developed, this feature can add considerably to the value of appearance-grade veneer.

Knots

The seasonal addition of new wood results in progressive layering over previously produced wood. As new growth increases the diameter of the main stem, branch bases become more and more deeply embedded in the trunk.

Examination of Figure 2.15 shows the living branch extending to the pith, the point at which most branches originate. The base of the branch is cone shaped, appearing as a tapered wedge when sectioned. The cone-shaped appearance arises from the fact that the cambium, which sheaths branches and the main stem, moves ever farther from the embedded branch base as the main stem grows larger, preventing further diameter increase at this location. Because main stem and branch growth are simultaneous, incorporation of living branches into the main stem results in knots that are an integral part of the surrounding wood. Such knots do not become loose or fall out upon drying and are called *intergrown* or *tight knots*.

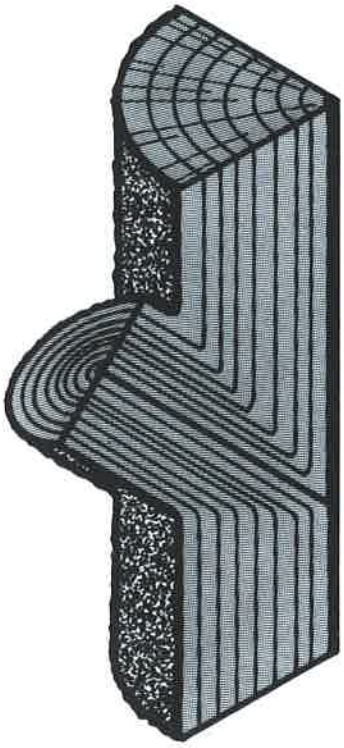


Figure 2.15. Branch configuration in main stem.

When a branch dies, its cambial layer also dies, stopping diameter growth throughout its length. The cambial layer of the main stem or bole continues to grow, however, slowly encasing the dead branch in the process. Knots formed in this way are not an integral part of the surrounding wood and, if included in lumber, may fall out as drying takes place. These are called *loose* or *encased knots*.

Embedded branch stubs are usually free of surrounding bark. This was explained by Eames and MacDaniels (1947), who wrote: "As the base of a [living] branch is buried by the formation of new xylem on the main axis, the phloem tissues about its insertion are forced outward . . . so that the base of the branch is stripped of its phloem. In small branches in which the increase in diameter is relatively small as compared with that of the main axis . . . this stripping is most marked. In this process the phloem tissues are thrown up into folds which often appear as concentric rings about the base of the partly buried branch." A similar process takes place in larger branches.

When branches are lost from a stem, the surrounding cambium layer gradually overgrows the area (similar to the growth depicted in Fig. 2.16) and within a few years begins to produce clear, knot-free wood. In some species, dead branches are persistent, so clear wood is not produced for many years after the lower branches on the tree die. Artificial pruning is sometimes used on valuable trees. The results of pruning are illustrated in Figure 2.16.

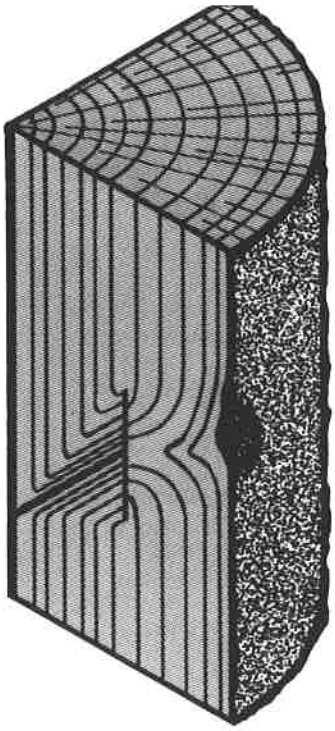


Figure 2.16. Progressive covering of branch stub by seasonal growth following pruning.

REVIEW

A. Terms to define or explain:

1. Discontinuous ring
2. Heartwood
3. Straight grain
4. Intergrown knot
5. Loose knot

B. Questions or concepts to explain:

1. Distinguish among transverse (cross-sectional), radial, and tangential surfaces.
2. Explain the difference between earlywood and latewood.
3. Discuss the difference between the terms growth ring and annual ring (refer back to Chapter 1).
4. List properties that are unique to heartwood, including reasons for variation in heartwood and sapwood properties.
5. Illustrate the appearance of rays on the three surfaces of wood and explain why rays are arranged as they are.
6. Discuss deviations from straight grain orientation that can occur and point out differences in wood properties resulting from this variation.

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