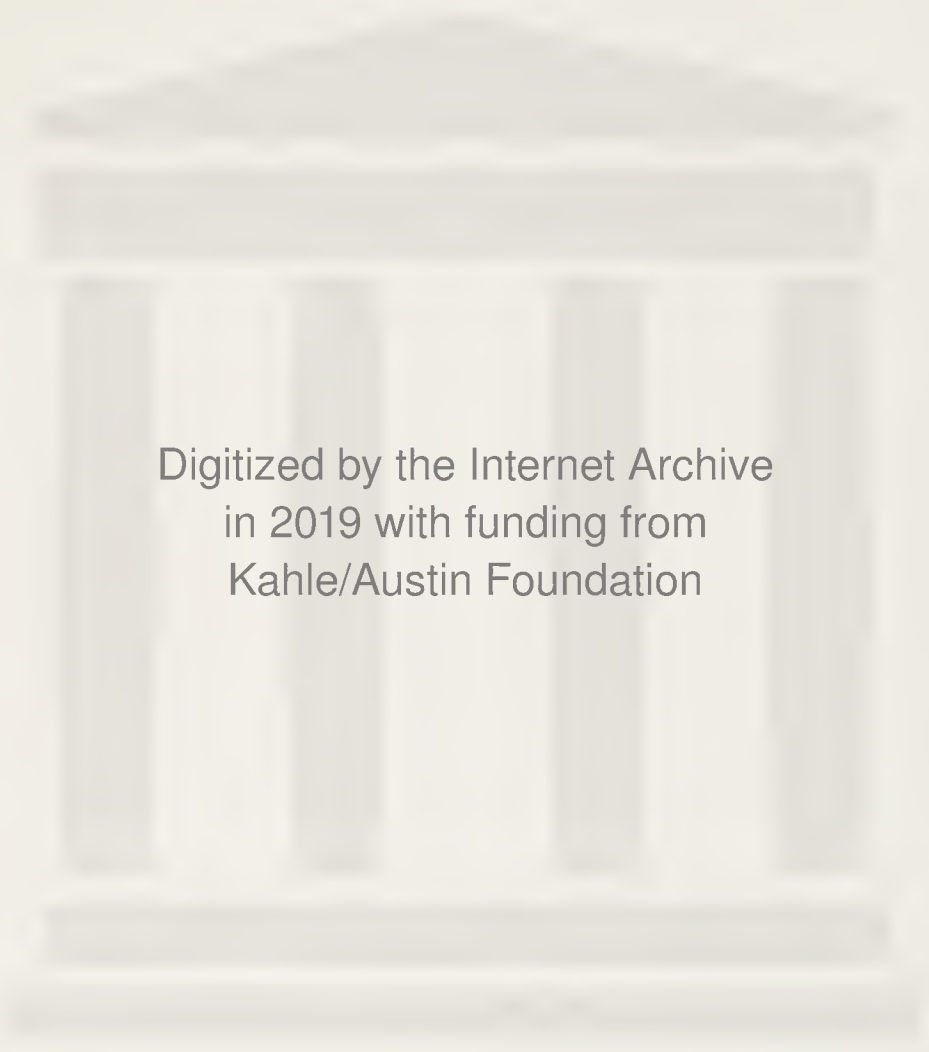


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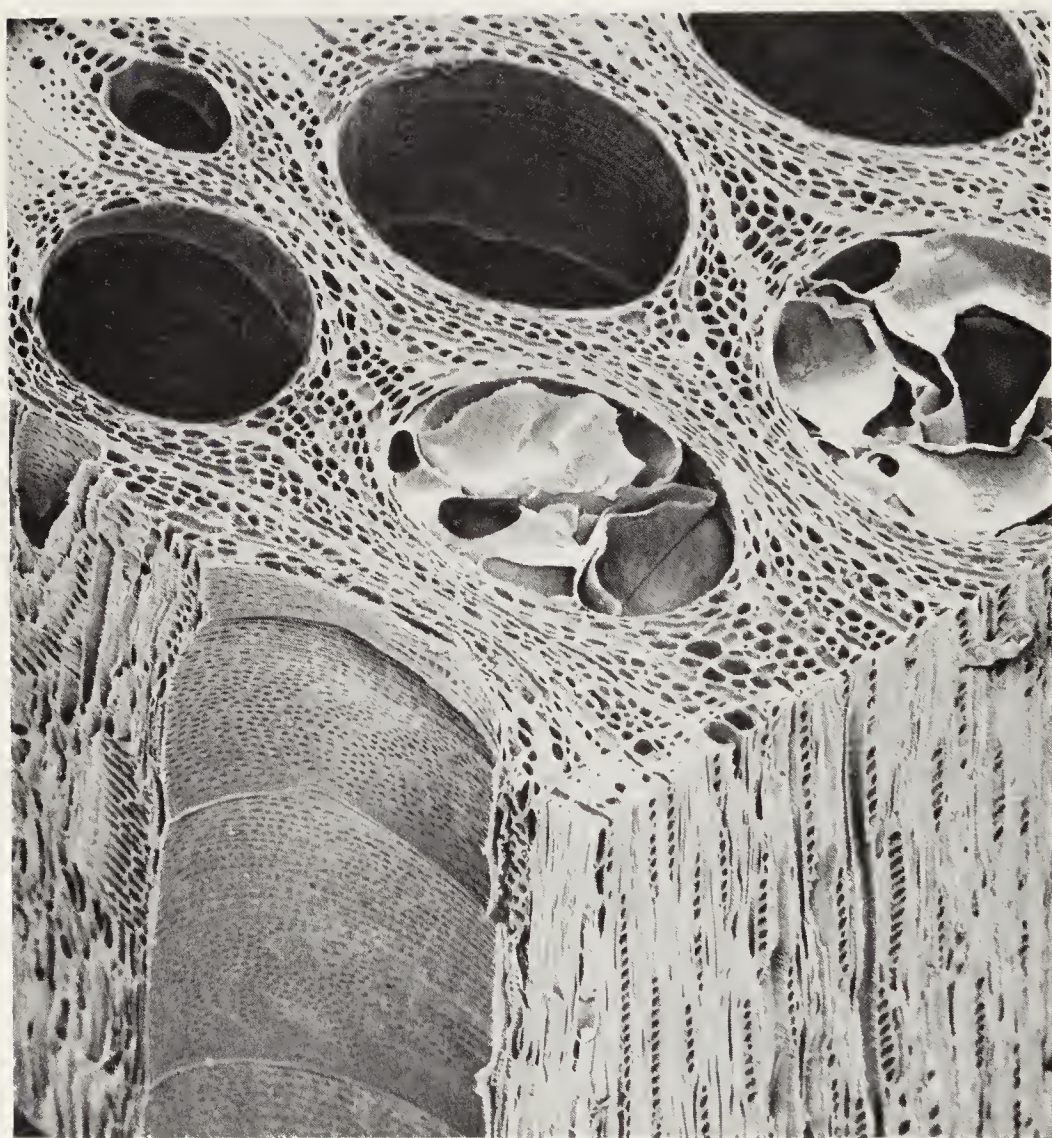
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Scanning electron micrograph of a block of white oak
(*Quercus alba* L.). (120 X)

(Courtesy of Center for Ultrastructure Studies, State University of New York, College of Environmental Science and Forestry, Syracuse, New York.)

Textbook of Wood Technology

Structure, Identification,
Properties, and Uses
of the Commercial Woods
of the United States and Canada

Fourth Edition

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McGraw-Hill Book Company

New York St. Louis San Francisco Auckland Bogotá Hamburg Johannesburg
London Madrid Mexico Montreal New Delhi Panama
Paris São Paulo Singapore Sydney Tokyo Toronto

This book was set in Optima by Black Dot, Inc. (ECU).
 The editors were Marian D. Provenzano and Stephen Wagley;
 the production supervisor was Dominick Petrellese.
 New drawings were done by J & R Services, Inc.
 R. R. Donnelley & Sons Company was printer and binder.

TEXTBOOK OF WOOD TECHNOLOGY

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234567890DODO89876543210

Library of Congress Cataloging in Publication Data

Panshin, Alexis John, date

Textbook of wood technology.

(McGraw-Hill series in forest resources)

Includes index.

1. Wood. 2. Trees—United States. I. De Zeeuw, Carl, joint author. II. Title.

TA419.P25 1980 674'.1 79-18520

ISBN 0-07-048441-4

Dedicated to the Late H. P. Brown, and to C. C. Forsaith, whose pioneering work helped to elevate wood technology to the status of a science and whose enthusiasm for a scientific approach to this subject was an inspiration to their students and associates.

34649¹⁰⁷

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The Minute Structure of Coniferous Woods (Softwoods)

This chapter deals with the comparative wood anatomy of the coniferous species. The different kinds of elements (cells) are described in detail, and their arrangement is illustrated principally by reference to the wood of North American softwoods.

The types of cells found in coniferous woods native to North America are listed in Table 4-1. Examination of this table reveals that softwoods possess only a few kinds of cells. Because of this and the uniform arrangement of the cells, softwoods give an appearance of having a very simple structure (Figs. 4-1 and 4-2).

Only two types of cells shown in Table 4-1 occur in all softwoods: longitudinal tracheids, which constitute over 90 percent of the volume of softwoods, and ray parenchyma cells. The other kinds of cells may be present or absent characteristically in the different groups of softwoods. In fact, no softwood normally possesses all the elements listed in Table 4-1. In addition it must be realized that all the elements which may be present need not appear in a given cross section of wood. Their presence or absence depends on whether cells of the type in question happen to project into the plane under examination. Every kind of cell possible for the particular kind of wood will eventually appear if a series of sections are examined.

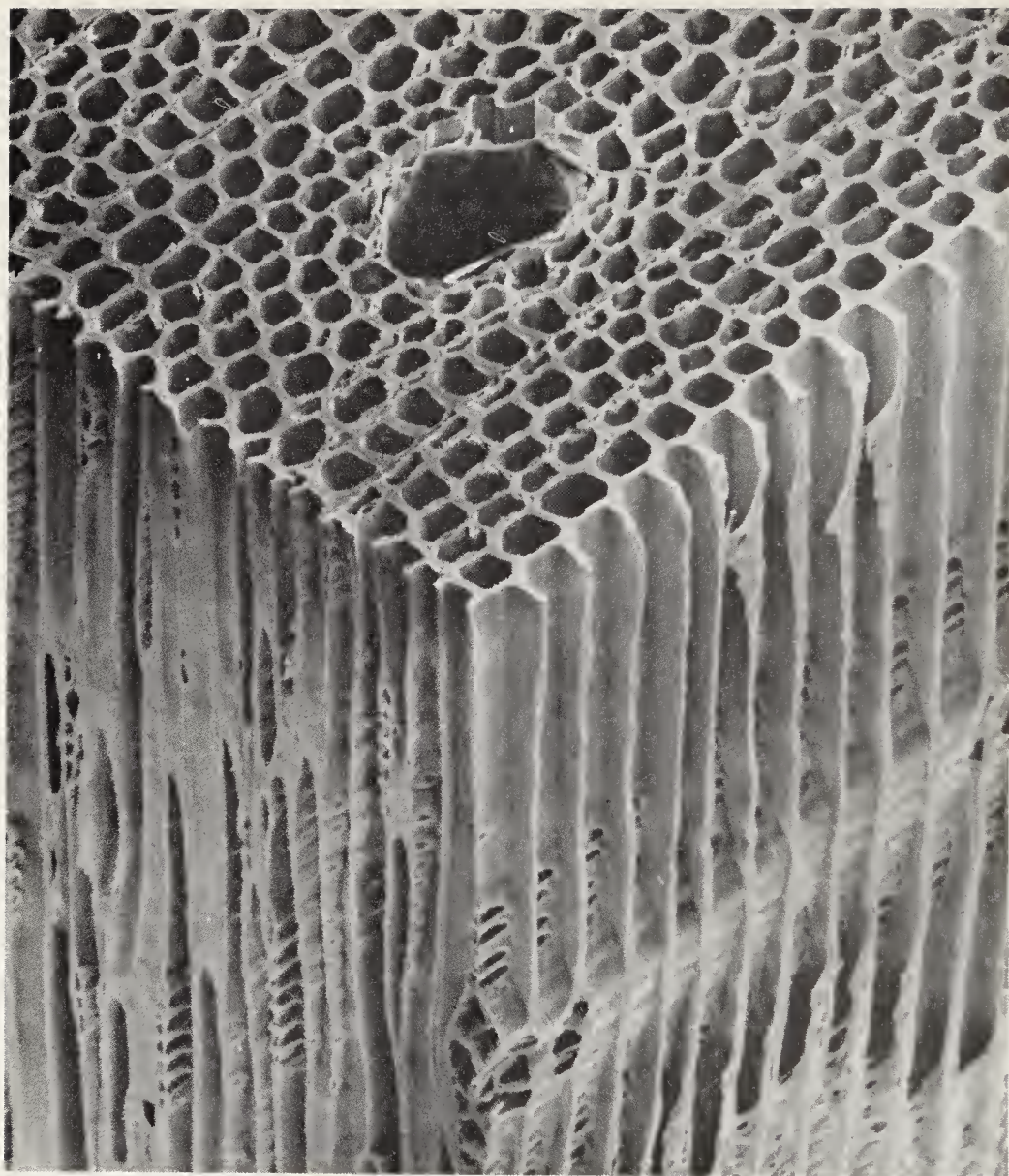


Figure 4-1 Eastern white pine (*Pinus strobus* L.) wood as viewed with the scanning electron microscope. (150×) The structures visible are noted in Fig. 4-2. (Courtesy of Center for Ultrastructure Studies, State University of New York, College of Environmental Science and Forestry, Syracuse, N.Y.)

Table 4-1 Elements (Cells) of Coniferous Woods

Longitudinal elements	Transverse elements			
1 a Longitudinal tracheids b Strand tracheids	1 Ray tracheids	Homocellular (uniseriate)* rays	Heterocellular (uniseriate)* rays	Fusiform ray
2 Parenchyma a Cells of longitudinal parenchyma b Epithelial cells:† excreting cells of longitudinal resin canals	2 Parenchyma a Cells of ray parenchyma b Epithelial cells:† excreting cells of transverse resin canals	Homocellular (uniseriate)* rays		

*Rarely biseriate and then usually only through the middle portion of the rays seen in the tangential section.

†Longitudinal and transverse resin canals are not listed, since they are intercellular spaces encircled by excreting cells (epithelium) and hence not true elements.

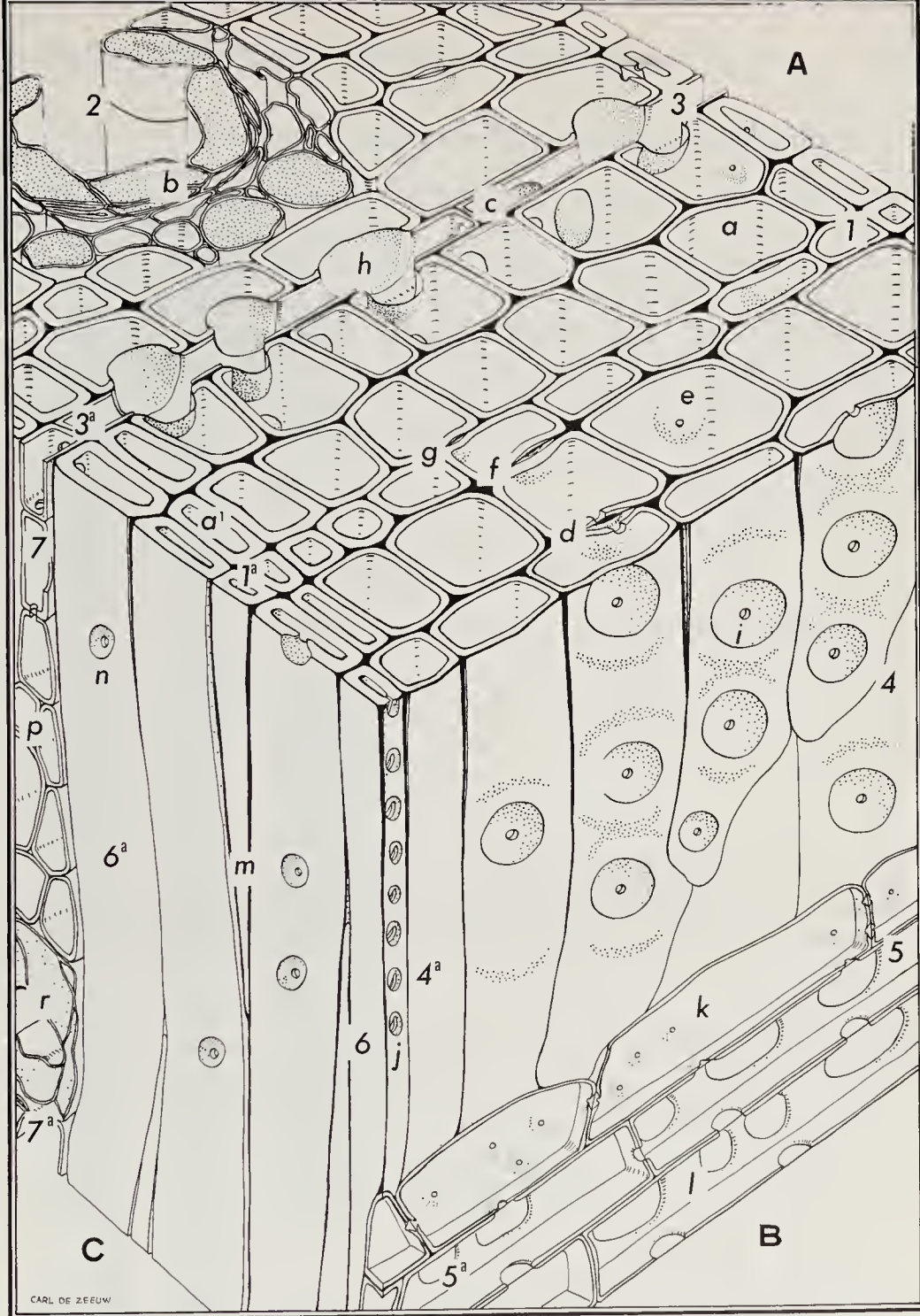


Figure 4-2 Schematic three-plane drawing of the wood of eastern white pine (*Pinus strobus* L.). (400×)

Surface A. 1-1', portion of an annual ring; 2, resin canal; 3-3', wood ray; a-a', longitudinal tracheids; b, epithelial cells; c, ray cells; d, pit pair in median sectional view; bordered pits in the back walls of longitudinal tracheids, in surface view; f, pit pair in sectional view, showing the margin of the torus but so cut that the pit apertures are not included in the plane of section; g, pit pair in which neither the pit aperture nor the torus shows; h, window-like pit pairs between longitudinal tracheids and ray parenchyma.

Surface B. 4-4', portions of longitudinal tracheids in radial aspect (the ends are blunt); 5-5', upper part of a uniseriate ray; i, bordered pits on the radial walls of longitudinal, early-wood tracheids (the base of the pit is toward the observer); j, small bordered pits on the radial walls of longitudinal late-wood tracheids, in the same view as in i, k, ray tracheids; l, cells of ray parenchyma.

Surface C. 6-6', portions of longitudinal tracheids in tangential aspect; 7-7', portion of a xylary ray; m, tapering ends of longitudinal tracheids; n, a bordered pit on the back wall of a longitudinal late-wood tracheid; p, cells of ray parenchyma; r, ray tracheids.

I LONGITUDINAL CONIFEROUS TRACHEIDS

The longitudinal coniferous tracheids are relatively long (3.0 to 5.0 millimeters), four- to six-sided, prismatic cells with closed ends (Fig. 4-3). They are the principal type of cell in the wood of all softwoods, but neither their grouping within growth increments nor the variations in their shape among the various kinds of softwoods are large enough to be of any diagnostic value. In contrast, the longitudinal tracheids manifest considerable variation in size and markings, sufficient to permit separation of softwoods into genus and occasionally into species.

A Tracheid Volume

Table 4-2 shows that the proportion of volume of wood occupied by tracheids in different softwood species varies only from 90 to 94 percent.

B Arrangement and Shape of Tracheids within Growth Rings

The regular arrangement of the relatively uniform longitudinal tracheids in radial rows, as seen in the transverse sections, is a characteristic feature of softwoods. In the early wood the longitudinal tracheids are hexagonal in cross section (Figs. 4-1 and 4-2A, a), with the larger diameter usually in the radial direction. In the late wood the cross sections of the tracheids are essentially rectangular and flattened radially to a tabular shape. The change in cross-sectional shape of tracheids is associated with seasonal growth. The largest radial diameter, with a minimal wall thickness for the species, occurs a short distance from the beginning of the increment, i.e., shortly after growth starts in the spring. Later in the growing season the radial tracheid diameters decrease, and the narrowest tracheids are formed at the outer margin of the growth increment just before the end of the growing season. At the same time the cell walls become thicker, with a maximum amount of wall material in the last part of the increment. The transition in diameter and wall thickness between early and late wood may be abrupt (Fig. 11-49), forming sharply defined tangential bands of dense late wood, as in the hard pines (Fig. 11-49), or bands with a gradual transition, as in the spruces (Fig. 11-55).

The tangential diameter of longitudinal tracheids remains quite constant within the growth ring and does not vary much with the age of the tree. The apparent differences in tangential width of some rows of tracheids, as seen in the cross section (Fig. 4-2A, 1-1^a), is related mainly to the position of the transverse cut along the tracheid length. Cross sections of the tracheids cut across their ends will be narrower tangentially than those cut through the central portions, thus giving rise to long radial files of narrow tracheids.

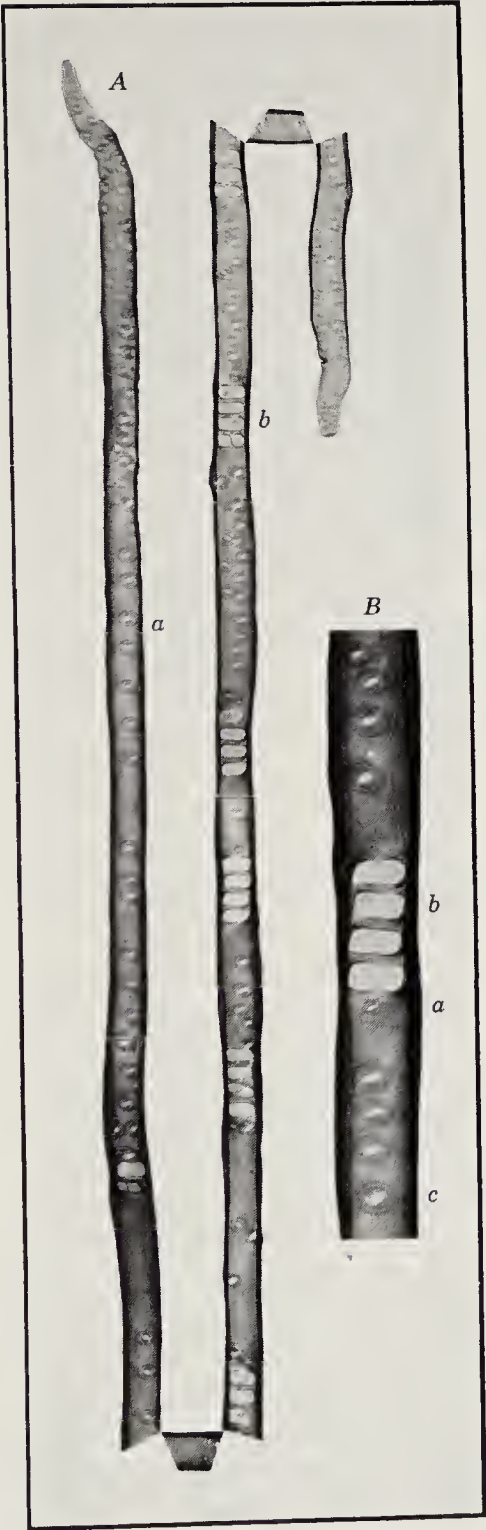


Figure 4-3
(A) A longitudinal tracheid of eastern white pine (*Pinus strobus* L.) in radial surface aspect. (65×) a, bordered pits leading laterally to a contiguous longitudinal tracheid; b, ray contact area.
(B) Portion of the same, at a higher magnification, depicting a ray contact area. (130×) The features shown are: a, a small bordered pit leading laterally to a ray tracheid; b, window-like pits leading laterally to ray parenchyma cells; c, bordered pits leading laterally to a contiguous longitudinal tracheid. (Photograph by C. H. Carpenter.)

Table 4-2 Volumetric Composition of Some Coniferous Woods

Species	Longitudinal tracheids	Total ray volume	Fusiform ray volume	Longitudinal resin canals	Longitudinal parenchyma
<i>Pinus strobus</i> (US)*	93.0	6.00	—	1.00	—
<i>Pinus strobus</i> (Y)†	93.3	5.29	0.76	0.93	—
<i>Pinus cembra</i> (Y)	89.8	9.24	1.20	0.94	—
<i>Pinus nigra</i> (Y)	94.1	5.49	0.76	0.38	—
<i>Pinus pinaster</i> (Y)	93.3	6.22	0.60	0.93	—
<i>Pinus sylvestris</i> (Y)	93.0	6.41	0.93	0.58	—
<i>Picea abies</i> (Y)	94.1	5.95	0.77	0.14	—
<i>Larix decidua</i> (Y)	93.4	6.13	0.66	0.42	—
<i>Pseudotsuga menziesii</i> (Y)	92.4	7.22	0.84	0.35	—
<i>Abies alba</i> (Y)	92.6	7.45	—	—	—
<i>Cupressus sempervirens</i> (Y)	94.2	5.58	—	—	0.20
<i>Juniperus excelsa</i> (Y)	91.5	8.26	—	—	0.26

*Data produced by the author from trees grown in the United States (US).

†Data marked (Y) adapted from B. Petrić and V. Šćukanec, Volume Percentage of Tissues in Wood of Conifers Grown in Yugoslavia, *Int. Assoc. Wood Anat. Bull.* **1973** (2):3–7 (1973).

C Size of Longitudinal Tracheids

As has been stated, the radial diameter of a tracheid varies according to its position in the growth increment; this dimensional fluctuation is not generic or specific in significance.

The tangential diameter of a longitudinal tracheid varies according to the place within its length where the measurement is taken, the position in the tree, and finally, according to the kind of wood. The relationship which exists between tracheid size and position in the tree, as affected by the age of the tree and the height in the stem, is discussed at length on pages 255 to 264. The variation in the tangential diameter of tracheids in the coniferous woods discussed in this text is indicated in Table 4-3. *Sequoia sempervirens* and *Taxodium distichum* head the list with tracheids that attain a maximum diameter of 80 and 70 micrometers, respectively. The other extreme is represented by *Taxus brevifolia*, with a maximum tracheid breadth of 25 micrometers and the average of 15 to 20 micrometers. On the basis of these figures, a medium-textured coniferous wood is defined arbitrarily in this text as one with the average tangential diameter of the tracheids somewhere between 30 to 45 micrometers. Above these figures, softwoods are considered to be coarse-textured; below these, as fine-textured.

The tracheid lengths of the conifers included in this text are given in Table 4-4. The average length ranges from 1.18 millimeters in *Juniperus osteosperma* (Torr.) Little to 7.39 millimeters in *Sequoia sempervirens* (D.

Table 4-3 Tangential Diameter (Breadth) of Longitudinal Tracheids of the Coniferous Woods of the United States
(Arranged in Order of Averages)

Scientific name	Diameter, μm	Scientific name	Diameter, μm
<i>Sequoia sempervirens</i>	80 (avg 50–65)	<i>Calocedrus decurrens</i>	50 (avg 35–40)
<i>Taxodium distichum</i>	70 (avg 45–60)	<i>Tsuga heterophylla</i>	50 (avg 30–40)
<i>Pinus lambertiana</i>	65 (avg 40–50)	<i>Abies balsamea</i>	50 (avg 30–40)
<i>Larix occidentalis</i>	60 (avg 38–50)	<i>Abies fraseri</i>	50 (avg 30–40)
<i>Pinus monticola</i>	60 (avg 35–45)	<i>Pinus resinosa</i>	45 (avg 30–40)
<i>Pinus palustris</i>	60 (avg 35–45)	<i>Thuja plicata</i>	45 (avg 30–40)
<i>Pinus echinata</i>	60 (avg 35–45)	<i>Tsuga canadensis</i>	45 (avg 28–40)
<i>Pinus taeda</i>	60 (avg 35–45)	<i>Larix laricina</i>	45 (avg 28–35)
<i>Pinus elliotii</i>	60 (avg 35–45)	<i>Torreya californica</i>	55 (avg 25–35)
<i>Pinus ponderosa</i>	60 (avg 35–45)	<i>Torreya taxifolia</i>	55 (avg 25–35)
<i>Pinus jeffreyi</i>	60 (avg 35–45)	<i>Pinus strobus</i>	45 (avg 25–35)
<i>Abies concolor</i>	60 (avg 35–45)	<i>Chamaecyparis</i>	40 (avg 25–35)
<i>Abies grandis</i>	60 (avg 35–45)	<i>nootkatensis</i>	
<i>Abies magnifica</i>	60 (avg 35–45)	<i>Chamaecyparis</i>	40 (avg 25–35)
<i>Abies procera</i>	60 (avg 35–45)	<i>thyoides</i>	
<i>Pinus contorta</i>	55 (avg 35–45)	<i>Picea glauca</i>	35 (avg 25–30)
<i>Picea sitchensis</i>	55 (avg 35–45)	<i>Picea mariana</i>	35 (avg 25–30)
<i>Pseudotsuga</i>	55 (avg 35–45)	<i>Picea rubens</i>	35 (avg 25–30)
<i>menziesii</i>		<i>Thuja occidentalis</i>	35 (avg 20–30)
<i>Chamaecyparis</i>	50 (avg 35–40)	<i>Juniperus virginiana</i>	35 (avg 20–30)
<i>lawsoniana</i>		<i>Taxus brevifolia</i>	25 (avg 15–20)

Don) Endl.* Comparison of information in Tables 4-3 and 4-4 indicates a correlation between tracheid breadth, i.e., tangential diameter, and tracheid length; those species whose tracheids are widest also are the longest. Tracheids measuring 3.0 to 5.0 millimeters may be considered as average for coniferous woods. Above or below these figures, the wood in question will be considered as unusually long- or short-fibered, respectively.

D Markings of Longitudinal Tracheids

The walls of the longitudinal tracheids are commonly marked with pits and in a few conifer species also with spiral thickenings on the inner-wall surface. Rarely, a few other structures such as trabeculae or callitrisoid thickenings (see page 138) may be present.

- 1 PITS The pits in the longitudinal tracheids fall into three categories:

*The average values shown in Table 4-4 will vary not only among trees but also with position in the same tree, as is discussed in Chap. 7.

Table 4-4 Average Length of Longitudinal Tracheids of the Coniferous Woods of the United States

(Determined from Specific Samples. Arranged in Order of Longest Average Length for the Species.)

Scientific name	Average length, mm	Standard deviation*	Scientific name	Average length, mm	Standard deviation*
<i>Sequoia sempervirens</i>	5.79	1.03	<i>Larix laricina</i>	2.86	0.39
	7.39	1.31		3.00	0.46
<i>Taxodium distichum</i>	3.14	0.58		3.68	0.65
	5.23	1.42	<i>Picea engelmannii</i>	2.49	0.48
	5.79	1.10		2.75	0.66
<i>Picea sitchensis</i>	5.22	0.85		3.63	0.55
	5.37	1.06	<i>Abies procera</i>	3.60	0.58
	5.45	0.98	<i>Calocedrus decurrens</i>	3.60	0.59
<i>Pinus lambertiana</i>	5.14	0.94	<i>Abies balsamea</i>	3.33	0.43
	5.24	0.96		3.37	0.50
	5.40	1.03		3.53	0.61
<i>Pinus palustris</i>	4.90	0.83	<i>Abies grandis</i>	3.05	0.47
<i>Pinus echinata</i>	4.46	0.91		3.35	0.43
	4.64	0.92		3.53	0.65
	4.85	0.76	<i>Chamaecyparis thyoides</i>	3.20	0.45
<i>Pinus elliotii</i>	4.58	0.87		3.34	0.42
<i>Pinus taeda</i>	4.33	0.91	<i>Abies magnifica</i>	3.27	0.52
<i>Tsuga canadensis</i>	3.37	0.57	<i>Pinus contorta</i>	3.19	0.44
	3.80	0.82		3.26	0.44
	4.24	0.99	<i>Torreya californica</i>	3.23	0.67
<i>Larix occidentalis</i>	2.82	0.48	<i>Pinus jeffreyi</i>	3.20	0.61
	2.97	0.55	<i>Chamaecyparis</i>	3.18	0.47
	4.09	0.71	<i>lawsoniana</i>		
<i>Pinus ponderosa</i>	3.53	0.75	<i>Thuja plicata</i>	3.00	0.45
	3.71	0.86		3.18	0.48
	4.08	0.98	<i>Picea rubens</i>	3.01	0.49
<i>Pinus strobus</i>	3.00	0.55		3.01	0.61
	3.70	0.66		3.17	0.60
	3.99	0.69	<i>Tsuga heterophylla</i>	2.87	0.40
	4.00	0.91		2.91	0.58
<i>Pseudotsuga menziesii</i>	3.00	0.31		3.10	0.59
	3.32	0.39	<i>Pseudotsuga menziesii</i>	2.85	0.45
	3.88	1.41	var. <i>glauca</i>		
<i>Picea mariana</i>	3.25	0.40	<i>Torreya taxifolia</i>	2.76	0.39
	3.60	0.72	<i>Pinus serotina</i>	2.73	0.36
	3.81	0.52	<i>Pinus resinosa</i>	2.51	0.54
<i>Abies concolor</i>	3.79	0.63		2.63	0.45
<i>Pinus monticola</i>	2.83	0.59		2.67	0.27
	2.97	0.58		2.70	0.89
	3.79	0.69	<i>Juniperus silicicola</i>	2.38	0.62
<i>Picea glauca</i>	2.92	0.41	<i>Taxus brevifolia</i>	2.31	0.34
	3.24	0.51		2.32	0.45
	3.76	0.79	<i>Chamaecyparis</i>	2.24	0.39
<i>Pinus rigida</i>	3.57	0.74	<i>nootkatensis</i>		
	3.75	0.83	<i>Thuja occidentalis</i>	2.16	0.43
				2.17	0.47
			<i>Juniperus virginiana</i>	2.15	0.50
			<i>Juniperus osteosperma</i>	1.18	0.29

*The standard deviation is a length in millimeters that, added to and subtracted from the tracheid average length, establishes limits of length within which approximately two-thirds of the tracheids will fall. Limits obtained as above by adding and subtracting 3 times the standard deviation will include over 99% of the tracheids.

(1) intertracheal, i.e., those belonging to pit pairs between the adjacent longitudinal tracheids, (2) those that are a part of pit pairs providing communication between the longitudinal tracheid and ray parenchyma cells in contact with it, and (3) those that belong to pit pairs that connect the longitudinal tracheids with the ray tracheids, when these are present in the ray.

The intertracheal bordered pits on the radial walls of the early wood are always numerous, conspicuous, and maximum in diameter, with rounded outlines for both the pit chamber and the pit aperture. The intertracheal pits on the radial walls of the late wood are less numerous and are smaller because of the narrowing of the radial diameter of the longitudinal tracheids toward the outer margin of the growth increments; the pit chambers may assume an oval or even an elliptical shape, while the pit apertures lose their rounded contours and become oval, elliptical, or slitlike.

The number of pits across the radial face of an early-wood tracheid is directly related to the width of the face. The larger the radial diameter of the tracheid, the greater the number of pits per row across the tracheid. Fine-textured softwoods (Table 4-3) such as spruce (*Picea* spp.) exhibit pits in a single row (uniseriate) along the tracheid length. Medium-textured woods such as pines (*Pinus* spp.) commonly have pairs of pits (biseriate) across the width of the tracheid. Coarse-textured woods such as redwood [*Sequoia sempervirens* (D. Don) Endl.] frequently show transverse rows of three to four pits (Fig. 4-9c3).

The pits on the radial walls of the tracheids are arranged oppositely, i.e., in rows aligned both along the length of the tracheid and across the width, in all softwoods except for the family Araucariaceae of the Southern Hemisphere.

With one reported exception, that of western redcedar (*Thuja plicata* Donn, ex D. Don), radial intertracheal pits of all native conifers are equipped with well-defined tori. The absence of these structures in western redcedar can therefore serve as a means of identification of this species. Eastern and western hemlocks are characterized by the torus extensions in the form of broad supporting strands and a wartlike layer, extending from the lumen into the pits. In a number of species, e.g., incense-cedar, western redcedar, and hemlocks, the intertracheal pits are heavily encrusted with extractives. Such pit encrustations are either absent or sparse in some species such as Douglas-fir (Ref. 10). But since many of these features require high magnification obtainable only with an electron microscope, their usefulness in everyday identification of wood is limited.

The bordered pits on the radial wall of tracheids are bounded above and below by zones of darker substances. These structures, formerly called *bars of Sanio*, are now known as *crassulae* (Fig. 4-4a and c). They are traceable to a concentration of intercellular substance at these points, this layer being overlaid by the primary and secondary walls of the cell.

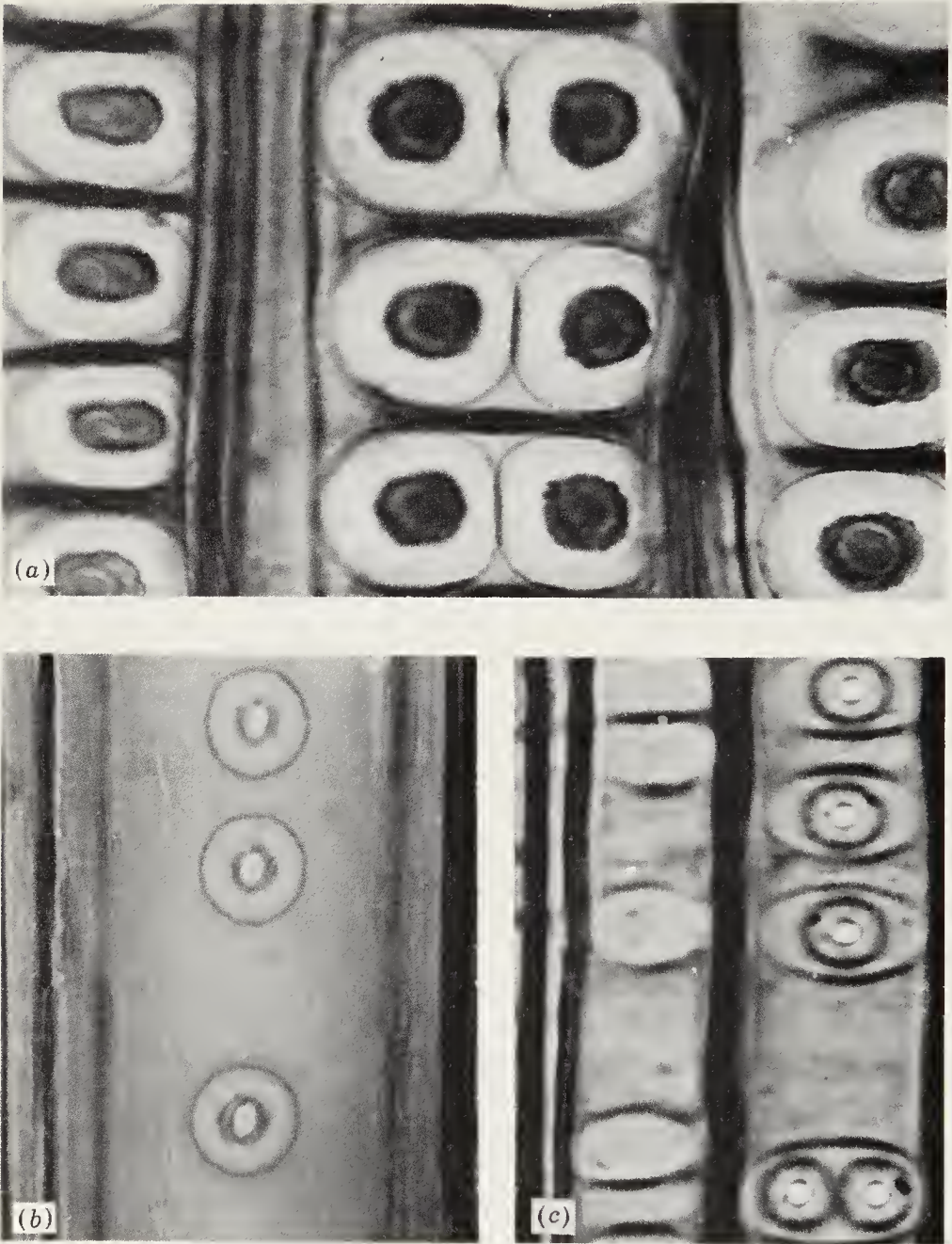


Figure 4-4 Nature of the pits on the lateral walls of coniferous tracheids.

(a) Paired bordered pits on the radial walls of the longitudinal early-wood tracheids of sugar pine (*Pinus lambertiana* Dougl.). The outer circle of the pit marks the limits of the pit chamber; the dark irregular central area is the torus; the smaller rounded spot within the boundary of the torus is the pit aperture; the dark bars above and below the pits are crassulae. (875 $\times$)

(b) Bordered pits on the tangential wall of a late-wood tracheid of sugar pine (*Pinus lambertiana* Dougl.) taken at the same magnification as (a); the pits are much smaller and crassulae are wanting.

(c) Pit fields on the radial walls of the longitudinal tracheids of baldcypress [*Taxodium distichum* (L.) Rich.], bounded above and below by crassulae. Five of the pit fields are empty, three contain one pit each, and one has two bordered pits. (230 $\times$) Three and four pits, aligned in a transverse row, frequently occur in a pit field in this species (see Fig. 4-9).

Crassulae are confined to the radial walls of tracheids. They are common throughout the coniferous woods with the exception of the Araucariaceae and hence are of no diagnostic value in wood identification. They are also visible in the vessels and tracheids of certain hardwoods.

In most coniferous woods, the bordered pits on the radial walls of the longitudinal tracheids develop in places where the true middle lamella is thinner than elsewhere. Such a thin place, bounded above and below by crassulae, is called a *primary pit field*. It may contain one or more pits. Not infrequently, however, pits fail to develop, resulting in an empty pit field (Fig. 4-4c).

The bordered pits on the tangential walls of longitudinal tracheids are always smaller than those on the radial walls; this fact is evident when (a) and (b) of Fig. 4-4, taken at the same magnification, are compared. They occur throughout coniferous woods with the exception of the hard pines, in which species the pits on the tangential walls of longitudinal tracheids are either absent or found only occasionally. Where present, tangential pitting is confined mainly to the last few rows of late-wood tracheids and the inner tangential walls of the early-wood tracheids of the succeeding growth increment. The pitting on the tangential walls in black spruce [*Picea mariana* (Mill.) B.S.P.] is reported to be different from that on the radial walls, because tori are lacking in some pits on the tangential walls, while in others the pit membrane has the primary-wall texture associated with the simple pits (Ref. 9).

2 SPIRAL THICKENINGS ON THE WALL OF LONGITUDINAL TRACHEIDS Spiral thickenings (Figs. 4-5 and 4-7) are present as a constant feature in the longitudinal and ray tracheids in Douglas-fir, Pacific yew, and *Torreya* spp. They may also occasionally occur in other woods, notably in the ray tracheids and in the longitudinal tracheids in the juvenile wood of the spruces and in the late-wood tracheids in tamarack and in some hard pines; in these woods, however, presence of the spirals is of no diagnostic value.

In Douglas-fir the spirals are most conspicuous in the early-wood tracheids as a multiple set of coils; they are less well developed and sometimes absent in the late-wood tracheids. In the tracheids of *Taxus brevifolia* and *Torreya* spp. spirals occur throughout the growth increment in a double helix; Pacific yew differs from *Torreya* in possessing steeper-angled and more compact spirals. These features are of some generic significance but difficult to use since the angle of the spirals is also contingent on the width of the cells and the thickness of the cell wall. Cells that are narrow-lumened for either of the above reasons possess steeper spirals than those with wider cell cavities. The angle of the spirals therefore varies according to the position of the tracheid in the growth increment.

Examination of the spiral thickenings in coniferous woods shows that they are specialized, discontinuous deposits of microfibrillar wall material

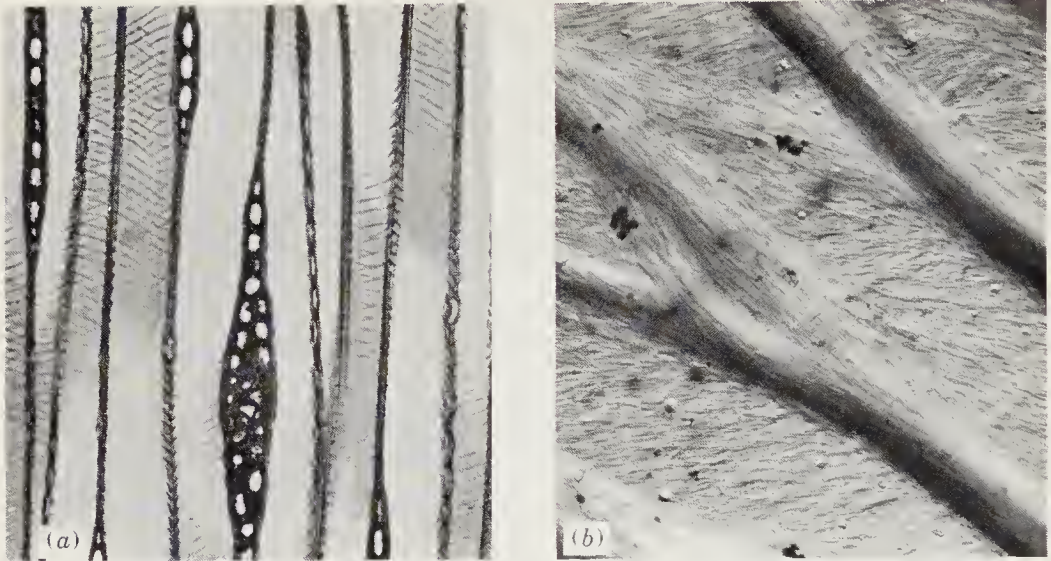


Figure 4-5 Spiral thickening in Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco].

(a) Appearance of spiral thickenings under a light microscope. (110 $\times$)

(b) Electron micrograph of the surface of a tracheid showing the microfibrillar structure of the spiral thickenings. (6800 $\times$) (Courtesy of W. A. Côté, Jr.)

on the inner face of the secondary wall, oriented with the same S or Z twist as the microfibrils of the innermost wall layer, but not necessarily at the same angle. In Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco], the spirals are closely spaced, low-angled, and branching; they have a flattened shape in cross section, are evidently microfibrillar in structure, and in places merge with the S3 layer of the wall (Fig. 4-5) (Ref. 18). In *Taxus* the spirals do not merge with the S3 layer of the cell wall but are firmly attached to the inner face of the wall. In contrast the spirals of *Torreya* are only loosely and partially attached to the S3 layer (Ref. 14).

3 CALLITRISOID THICKENINGS These structures are local thickenings of the cell wall that are typical of the genus *Callitris*, a conifer which occurs mostly in Australia. However, a recent investigation of the southern hard pines (Ref. 6) has shown that they occur also in this group, but as a fairly uncommon feature. Callitrisoid thickenings appear in surface view as a pair of slightly curved, parenthesis-shaped bars positioned above and below the pit apertures normal to the axis of the cell (Fig. 4-6). They are ridges on the inner surface of the wall and are probably elaborations of the S3 layer.

4 TRABECULAE IN LONGITUDINAL CONIFEROUS TRACHEIDS A *Trabecula* is a barlike structure extending across the lumen of a tracheid from one tangential wall to another. Recent studies by C. T. Keith et al. (Ref. 7) have shown that the trabeculae are usually cylindrical or spool-shaped, but

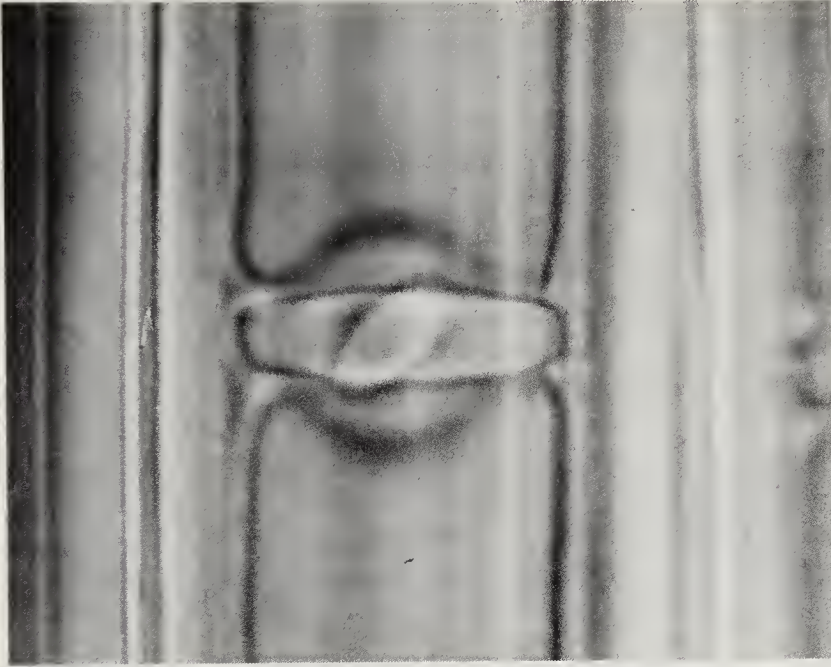


Figure 4-6 Callitrisoid-like thickenings of the radial intertracheid pitting of the transition zone between early and late wood in pond pine (*Pinus serotina* Michx.). Note the ridges that continue onto the tangential walls. (2000×) (Courtesy of E. T. Howard and F. G. Manwiller, Ref. 6.)

several may fuse laterally to form a flat plate with its wide face longitudinally oriented. Trabeculae have all the wall layers equivalent to and continuous with the lateral walls of the tracheid in which they are found. The surfaces of the trabeculae exhibit whatever sculpturing or modifications may appear in the tracheid wall, i.e., spiral thickening in Douglas-fir, which is continuous with that on the tracheid walls, warts if they appear in the tracheid, and poorly developed pitting in some cases. The core of the trabecula may be hollow or solid.

There may be one or more trabeculae at a given location in the tracheid. Each trabecula usually appears as part of a radial series extending across a number of tracheids and is best observed in the radial sections of wood (Fig. 4-7). It is evident from the radial alignment of the trabeculae that they are traceable to an individual cambial initial. McElhanney (Ref. 13) has ascribed the origin of trabeculae to the presence of a fungal hypha around which the trabecula is formed. This contention finds support in the fact that trabeculae are likely to be present in regions where the cambium has been exposed to fungal infection, notably in wood formed after wounding and in close proximity to fungal cankers.

Trabeculae may occur in any of the gymnosperms, both recent and fossil forms, and in the angiosperms as well. For this reason they are of no diagnostic significance.

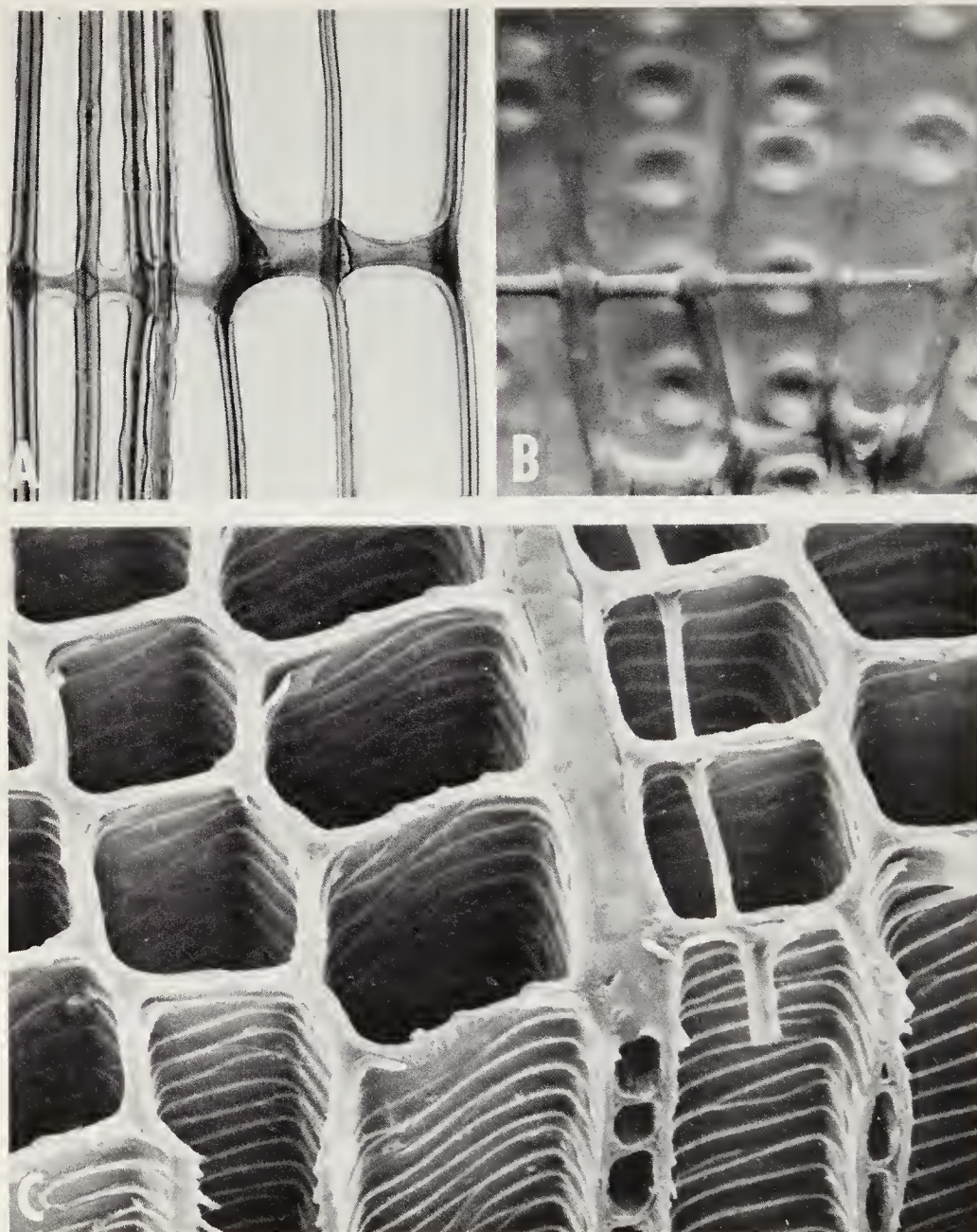


Figure 4-7 Trabeculae in softwoods.

(A) Alaska-cedar [*Chamaecyparis nootkatensis* (D. Don) Spach.]. Radial view. (360×)

(B) Western white pine (*Pinus monticola* Dougl.), radial view photographed with incident light. (430×)

(C) Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco]. Scanning electron micrograph. (700×)
 [(B) photograph by R. E. Pentoney; (C) courtesy of Center for Ultrastructure Studies, State University of New York, College of Environmental Science and Forestry, Syracuse, N.Y.]

5 LONGITUDINAL RESINOUS TRACHEIDS Occasionally resin is deposited in some longitudinal tracheids as heartwood is formed. The deposits occur at or near areas in contact with rays, and when observed along the grain, they may be in the form of either a transverse plate across the cell, simulating cross walls, or lumps on the walls on one or both sides of the

tracheid. In cross sections the resin appears to fill the cells either partly or completely. Tracheids with these sorts of reddish brown to nearly black inclusions are called *resinous tracheids*. The occurrence of these cells has been reported in *Abies fraseri* (Pursh.) Poir. and *Abies grandis* (Dougl.) Lindl. and in some of the soft pines in the United States, but is most common in the family Araucariaceae of the Southern Hemisphere.

E Longitudinal Strand Tracheids

The term *strand tracheids* is applied to the short cells arranged in longitudinal strings or strands. These cells differ from the longitudinal tracheids in being shorter and in possessing end walls, one or both of which are at right angles to the longitudinal walls. When the end walls are at right angles, the cells are narrowly rectangular along the grain. Both end walls and radial walls are provided with bordered pits of the normal type for tracheids.

Strand tracheids arise by subdivision of a cambial daughter cell which would otherwise have developed into a longitudinal tracheid. All segments produced by subdivision and formation of cross walls may lose their protoplasm, or some may retain it, becoming parenchymatous and resulting in a "mixed" strand (Fig. 4-8).

Strand tracheids may be regarded as transitional elements between longitudinal tracheids and epithelial or longitudinal parenchyma. When present, they are found in the vicinity of the longitudinal resin canals, on the outer face of the annual increment, i.e., terminally, or in or near traumatic resin canals. Terminal strand tracheids are sometimes present in *Larix* spp. and in Douglas-fir [*Pseudotsuga menziesii* (Mirb.) Franco]. In these genera they apparently replace the strands of longitudinal parenchyma that occupy the same position and are sporadic in their distribution.

II PARENCHYMA IN CONIFEROUS WOODS

There are three types of parenchyma in softwoods, viz., *longitudinal parenchyma* (also called *axial parenchyma*), *Epithelial parenchyma*, and *ray parenchyma*.

A Longitudinal (Axial) Parenchyma

Longitudinal parenchyma is never very abundant in softwoods, as is evident by examination of Table 4-2. However, it may be quite conspicuous because of the presence of dark-colored inclusions in many of the cells.

The longitudinal parenchyma in softwoods occurs in the form of strands extending along the grain (Fig. 4-9c, 1). Each strand arises by the further division of a daughter cell formed by division of a fusiform initial in the cambium. When cut transversely, such a strand appears as a cell which is



Figure 4-8 Strand tracheids in western larch (*Larix occidentalis* Nutt.). The strands become epithelial cells near the resin canal. (120×)

usually thinner-walled than the neighboring tracheids and frequently contains extraneous materials (Fig. 4-9).

The number of cells composing a strand is undoubtedly variable in different coniferous woods, in different samples of a given species, and even in the same sample. No definite figure can be cited because of the variations in length of the strands, which precludes accurate count. In some woods (*Larix* spp., *Pseudotsuga* spp.), the strands consist in part of strand tracheids.

The units composing a strand vary in shape according to their position. Those at the ends are square or rectangular at the base and taper abruptly or gradually to a point; the remainder of the strand consists of cells that approach the rectangular as viewed in the longitudinal section.

Pits in the cross walls of axial parenchyma when present are invariably simple. When viewed in the longitudinal sections (i.e., radial or tangential), simple pits give the appearance of beadlike (*nodular*) thickenings on the transverse walls of parenchyma cells (Fig. 11-43). Simple pits are absent or

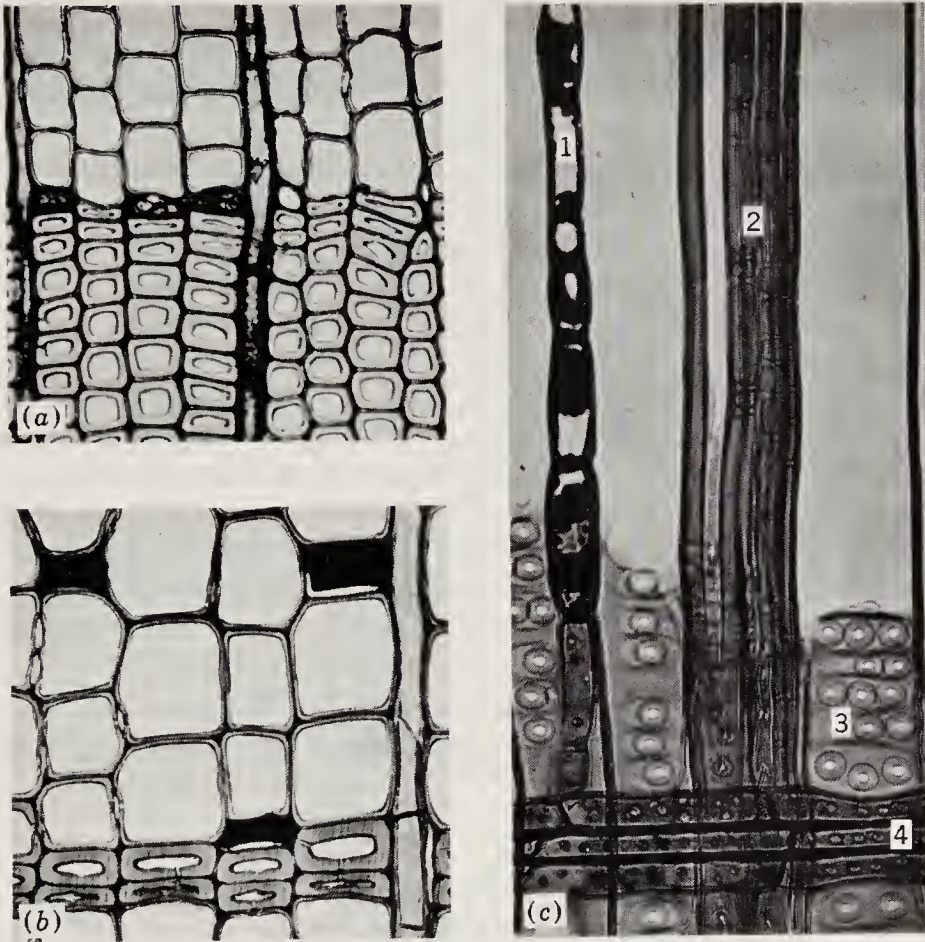


Figure 4-9 Longitudinal parenchyma in coniferous woods.

(a) Marginal parenchyma in western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] (three cells on the outer margin of an annual ring). (200×)

(b) Diffuse parenchyma in redwood [*Sequoia sempervirens* (D. Don) Endl.] (three dark cells in the first-formed early wood). (200×)

(c) Portion of a strand of longitudinal parenchyma of baldcypress [*Taxodium distichum* (L.) Rich.], radial view. (165×) (1) strand; (2) bordered pit pairs in sectional view, the pits with pit canals; (3) bordered pits in transverse rows of three on the radial walls of early-wood tracheids; (4) wood ray in radial aspect.

sparse and inconspicuous in *Chamaecyparis thyoides* and *Sequoia*. In the case of *Sequoia* the absence of simple pits (and hence nodular thickenings) in the transverse walls of the axial parenchyma serves as a ready means for separating it from *Taxodium*.

As viewed in the transverse section, the axial parenchyma cells may be widely scattered among the tracheids. In that case the parenchyma is said to be *diffuse*. If the cells are sufficiently numerous to be loosely grouped in a row or a band extending concentrically in a growth ring (i.e. tangentially), the

parenchyma is termed *banded* (formerly called *metatracheal*). These two types of arrangements intergrade. If the cells are confined to the outer margins of the growth ring, i.e., to the last-formed or first-formed rows of cells, they are called *terminal* or *marginal*.*

Axial parenchyma does not occur in the wood of *Pinus*, *Taxus*, and *Torreya*, among the genera represented in the United States, or in *Araucaria* and *Agathis* of the Southern Hemisphere. It is present in the root wood of *Picea* but not in the trunk wood. It is sporadic and sparse in *Larix*, *Pseudotsuga*, *Tsuga*, and *Abies*, and is either terminal, diffuse, or both. In the Cupressaceae (*Thuja*, *Chamaecyparis*, *Cupressus*, *Calocedrus*, and *Juniperus*) it is relatively abundant, banded or diffuse, but unevenly distributed; i.e., parenchyma cells may be found in appreciable numbers in one ring or one sample of wood, and be sparse or lacking in the others. Axial parenchyma is best developed in the Taxodiaceae (*Sequoia* and *Taxodium*), in which woods it ranges from diffuse to banded but is always abundant enough to be found in any given section of the wood under examination.

B Ray Parenchyma

Ray parenchyma cells are discussed in detail in the section on rays (page 149).

C Epithelial Parenchyma and Resin Canals

The epithelial cells are excreting, thin-walled parenchyma cells which surround longitudinal and transverse (ray) resin canals. The cavity of a canal, as depicted on surface A in Fig. 4-2, is in reality an intercellular space, i.e., a place where immature longitudinal xylary cells pulled apart, leaving a tubular cavity. The resin canal as such is therefore not a wood element but a cavity surrounded by thin-walled, parenchymatous cells (*epithelial cells*).

1 FORMATION OF RESIN CANALS Longitudinal and ray epithelial cells are traceable to daughter cells arising from fusiform initials in the cambium and cambial ray cell initials, respectively. In both of these cases there are clusters of daughter cells, as seen in the transverse section, which fail to mature into longitudinal tracheids or ray cells in the normal way. Each of the daughter cells adjacent to the cavity divides mitotically into a number of smaller cells aligned in a row parallel to the axis of the resin canal that is being formed. Subsequently, the true middle lamella between cells near the

*In the strict sense, parenchyma cells formed at the beginning of a season's growth should be called *initial*, and those formed at the close of a season, *terminal*. But because it is difficult to differentiate between the two, the term terminal or marginal is generally used to include both forms.

center of the cluster splits, and an intercellular cavity called a *resin canal* is formed presumably by the fluid pressure from the resin produced by the epithelial cells.

The entire layer of epithelial cells surrounding a resin canal is called *epithelium*. It may consist of one to several layers of cells in thickness. In *Pinus* epithelial cells are mostly thin-walled, devoid of pits, and unlignified. In the other three genera with resin canals (*Picea*, *Larix*, and *Pseudotsuga*) epithelial cells are thick-walled, pitted, and lignified.

In epithelium consisting of thin-walled cells some epithelial cells may collapse (Fig. 4-10). However, in all woods with resin canals the cells immediately adjacent to the canal retain their shape and remain functional; i.e., they remain alive as long as they are a part of the sapwood in a living tree. In the heartwood of pines the resin canals are usually plugged with tylosoides (see page 124 and Fig. 4-10*h*) and hence become nonfunctional.

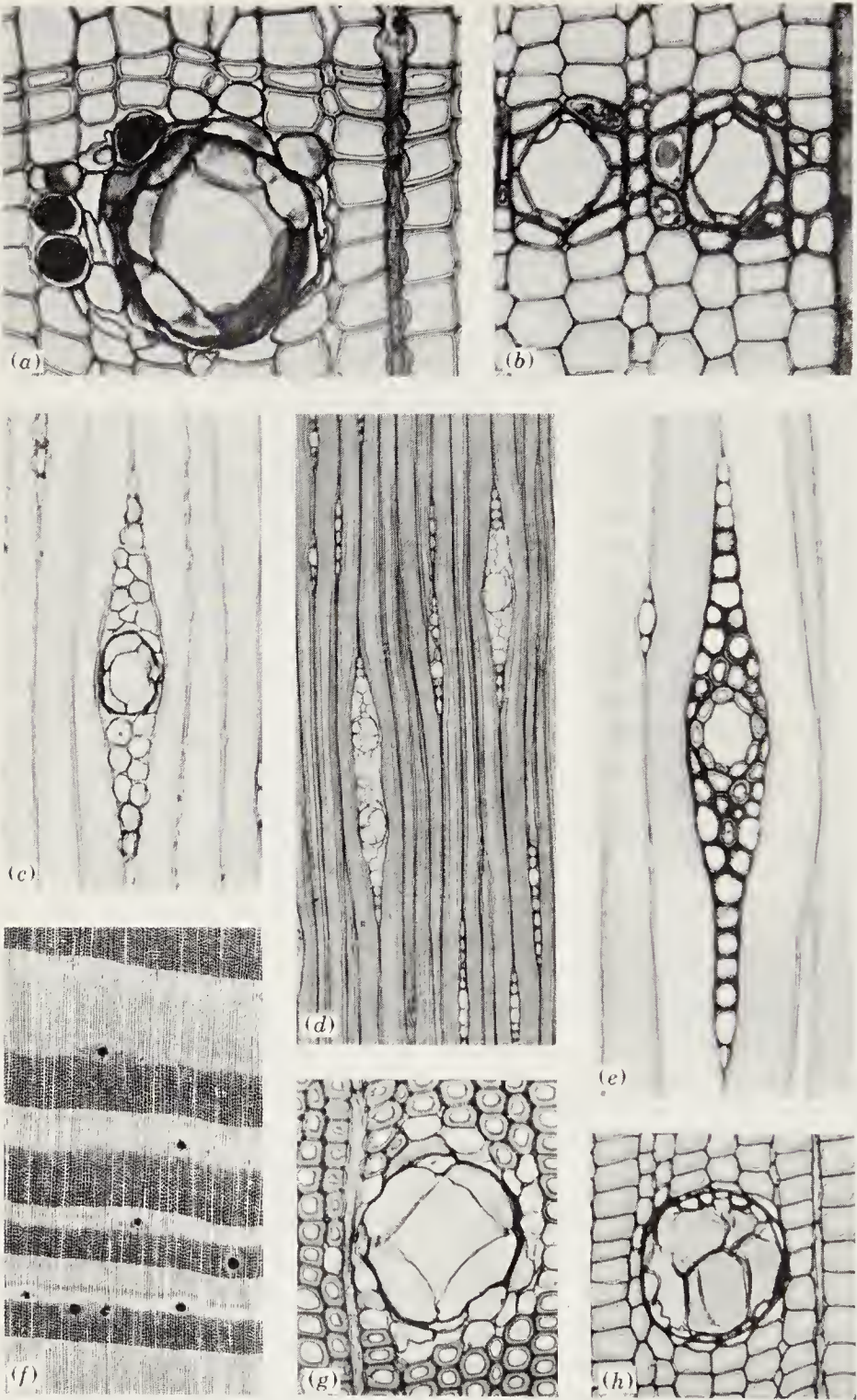
From this discussion it is evident that the longitudinal and transverse resin canals in softwoods are intercellular spaces and are of postcambial development. The continuity of the cambium is not interrupted prior to their formation, nor is there any evident change in the nature of the cambial cells.

Resin canals in softwoods are of two kinds, those that are *normal* in the wood and those that presumably arise as a result of wounding and are therefore termed *traumatic*.

2 NORMAL RESIN CANALS Normal resin canals are a constant feature in *Pinus*, *Picea*, *Larix*, and *Pseudotsuga* (Figs. 11-45 through 11-58). Normal canals occur in both longitudinal and transverse directions in wood. The canals in the transverse orientation are always found in fusiform rays (see page 157).

Since the origin of normal resin canals is identical throughout the softwoods, the differences that may be observed in these structures are traceable to variations in the relative number and grouping of resin canals, their size, and the size and nature of the epithelial cells. Some of these features are of diagnostic significance.

Normal resin canals vary in size not only according to whether they are longitudinal or transverse but also according to the genus and sometimes the species. Variation in size of canals also depends on the age of the tree and the rate of growth, insofar as it affects texture. In a given wood, the longitudinal resin canals are invariably larger than those of the transverse type, as is apparent by comparing (a) and (c) or (b) and (e) in Fig. 4-10. For example, in eastern white pine (*Pinus strobus* L.) the longitudinal canals attain a maximum of 200 micrometers measured tangentially to include the epithelial tissue, and the average diameter ranges from 135 to 150 micrometers, while the transverse canals are usually less than 80 micrometers in diameter.



Normal longitudinal and transverse resin canals are largest in *Pinus*. In some species, for instance *Pinus lambertiana* Dougl., the longitudinal canals average 175 to 225 micrometers but reach a maximum diameter of more than 300 micrometers; on the other hand, in *Pinus banksiana* Lamb. the longitudinal resin canals seldom exceed 100 micrometers in diameter and usually are much smaller.

The resin canals in *Picea*, *Larix*, and *Pseudotsuga* are considerably smaller than those in *Pinus*. The longitudinal resin canals in these woods occasionally reach a maximum diameter of 150 micrometers, averaging 50 to 90 micrometers. In the genus *Picea*, Sitka spruce [*Picea sitchensis* (Bong.) Carr.] stands out because of the somewhat greater size of its canals.

The nature of the epithelial cells offers a means of separating pines from the other three genera. As stated before, the epithelial cells in the sapwood of all pines are thin-walled, unlignified, and apparently unpitted. With a few exceptions this is true also for the epithelium in the longitudinal canals in the heartwood. Exceptions are found in the heartwood of the soft pines, as well as in *Pinus resinosa* Ait. and *Pinus sylvestris* L., in which the epithelial cells in the fusiform rays have thickened, pitted walls which are lignified (Ref. 2). In *Picea*, *Larix*, and *Pseudotsuga* the epithelial cells are mostly thick-walled, are generally provided with pits, and appear to be lignified (Fig. 4-10e and h).

Normal resin canals are more abundant and more evenly distributed in pines than in the other three genera. A trend to greater concentration of longitudinal resin canals in the late wood, particularly in hard pines, is evident.

The distribution of normal longitudinal canals is far less regular in the spruces (*Picea* spp.), larches (*Larix* spp.), and Douglas-fir (*Pseudotsuga* spp.). Spruces and Douglas-fir are peculiar in that the normal longitudinal canals in some samples are solitary and fairly evenly distributed in the outer

Figure 4-10 Normal resin canals in coniferous woods.

- (a) Longitudinal resin canal in transverse section, with thin-walled epithelial cells. Eastern white pine (*Pinus strobus* L.). (150×)
- (b) Two longitudinal resin canals in transverse section, with thick-walled epithelial cells. Sitka spruce [*Picea sitchensis* (Bong.) Carr.]. (150×)
- (c) Transverse resin canal in a fusiform ray, cut at right angles, with thin-walled epithelial cells. Eastern white pine (*Pinus strobus* L.). The magnification is the same as in (a).
- (d) Transverse resin canals in fusiform rays, cut at right angles; the canals are occluded with tylosoids; rays with two canals are relatively rare. Longleaf pine (*Pinus palustris* Mill.). (75×)
- (e) Transverse resin canal in a fusiform ray, cut at right angles, with thick-walled epithelial cells. Sitka spruce [*Picea sitchensis* (Bong.) Carr.]. The magnification is the same as in (a).
- (f) Distribution of longitudinal resin canals in longleaf pine (*Pinus palustris* Mill.). (8×)
- (g) Longitudinal resin canal of longleaf pine (*Pinus palustris* Mill.) in transverse section; the canal is bounded on the left by a ray and elsewhere by thick-walled late-wood tracheids. (125×)
- (h) Longitudinal resin canal of red spruce (*Picea rubens* Sarg.) in transverse section; the orifice of the canal is occluded with tylosoids. (150×) [(a), photograph by W. M. Harlow.]

portion of the growth ring, while in others a strong tendency is manifested toward the grouping of the canals in tangential rows of 5 to 30 or more (Figs. 11-11 and 11-22). In *Larix* they occur singly or in groups of several.

The volume of conifer woods occupied by the epithelial tissue alone has not been reported. Data are available to show the combined volumes occupied by the epithelial tissue and the resin canals which it surrounds, for a limited number of woods in which resin canals occur normally. Table 4-2 shows that the maximum volume, as found in the pines, is about 1 percent.

In spite of the limited volume occupied by the normal resin canals in coniferous woods, their presence and the wall thickness of the epithelial cells serve as an important diagnostic aid in wood identification.

3 TRAUMATIC RESIN CANALS Traumatic resin canals, i.e., canals presumably arising as a result of injury, may accompany transverse canals of the normal type, as in Sitka spruce [*Picea sitchensis* (Bong.) Carr.], or they may occur in a wood devoid of normal canals, as in deodar [*Cedrus deodara* (Roxb. ex Lamb.) G. Don], hemlocks (*Tsuga* spp.), and true firs (*Abies* spp.). They may be longitudinal or transverse; furthermore they arise from the cleavage or separation of cells in a manner entirely comparable to that occurring in the formation of normal canals.

Longitudinal and transverse traumatic canals usually do not occur in the same sample, as shown, for example, in the extensive study of *Tsuga heterophylla* (Raf.) Sarg. by Leney and Moore (Ref. 12). Exceptions do occur, as is the case with deodar [*Cedrus deodara* (Roxb. ex Lamb.) G. Don].

The longitudinal traumatic resin canals are generally arranged in a tangential row (Fig. 4-11a) that may extend for an inch or two along a ring. Usually they are restricted to the early-wood portion of the growth increments.

The traumatic transverse canals, like the normal transverse kind, are confined to the wood rays. They are much larger than the normal canals occurring in this position, and the wood rays containing traumatic canals are greatly enlarged as a result. When present in a coniferous wood, transverse traumatic canals frequently show as radial streaks extending across the grain in edge-grained stock (Ref. 4).

The epithelial cells of traumatic resin canals as a rule are thick-walled and pitted, and have every appearance of being lignified.

III TRANSVERSELY ORIENTED CELLS

A Types of Transverse Cells in Softwoods

There are three kinds of transversely oriented cells in the xylem of softwoods, all of which are included in the rays: (1) ray parenchyma cells,

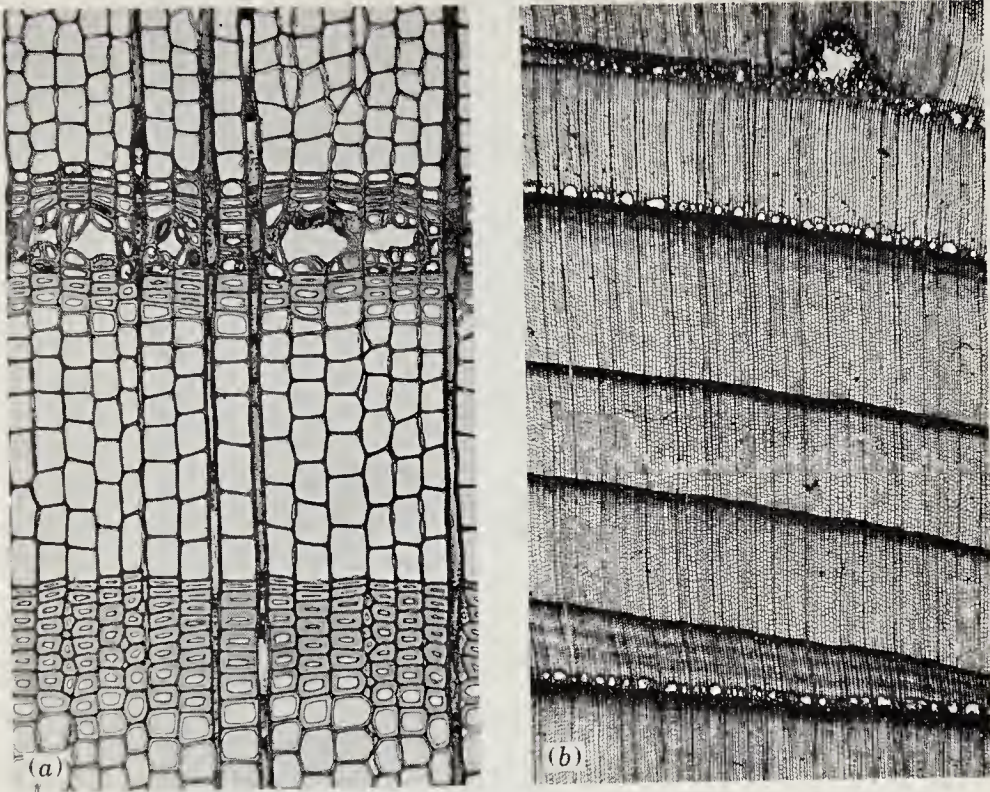


Figure 4-11 Traumatic resin canals in conifers.

(a) Traumatic schizogenous resin canals (x) in western hemlock [*Tsuga heterophylla* (Raf.) Sarg.]. Part of a longer row extending tangentially. (95×)

(b) Three rows of traumatic schizogenous resin canals in redwood [*Sequoia sempervirens* (D. Don) Endl.]. The upper row also exhibits a small resin cyst in cross section. (6×)

(2) ray tracheids, and (3) epithelial cells, which were discussed earlier (see page 144).

1 RAY PARENCHYMA The cells of ray parenchyma are thin-walled and as all parenchyma in the softwoods, they have simple pits. For identification purposes the most important type of pitting in the ray parenchyma cell walls is that found in the radial walls where they contact the longitudinal tracheids. The common-wall areas between cells of the ray parenchyma and the longitudinal tracheids are called *cross fields*. The shape, size, and arrangement of the pitting in the cross fields varies characteristically in different softwoods. The variations arise from the differing shapes of the ray parenchyma pits and the overhanging borders of the matching pits on the tracheid side of the half-bordered pit pairs.

Phillips (Ref. 15) has described the five fairly well-defined types of cross field pits in conifers as given in the following section.

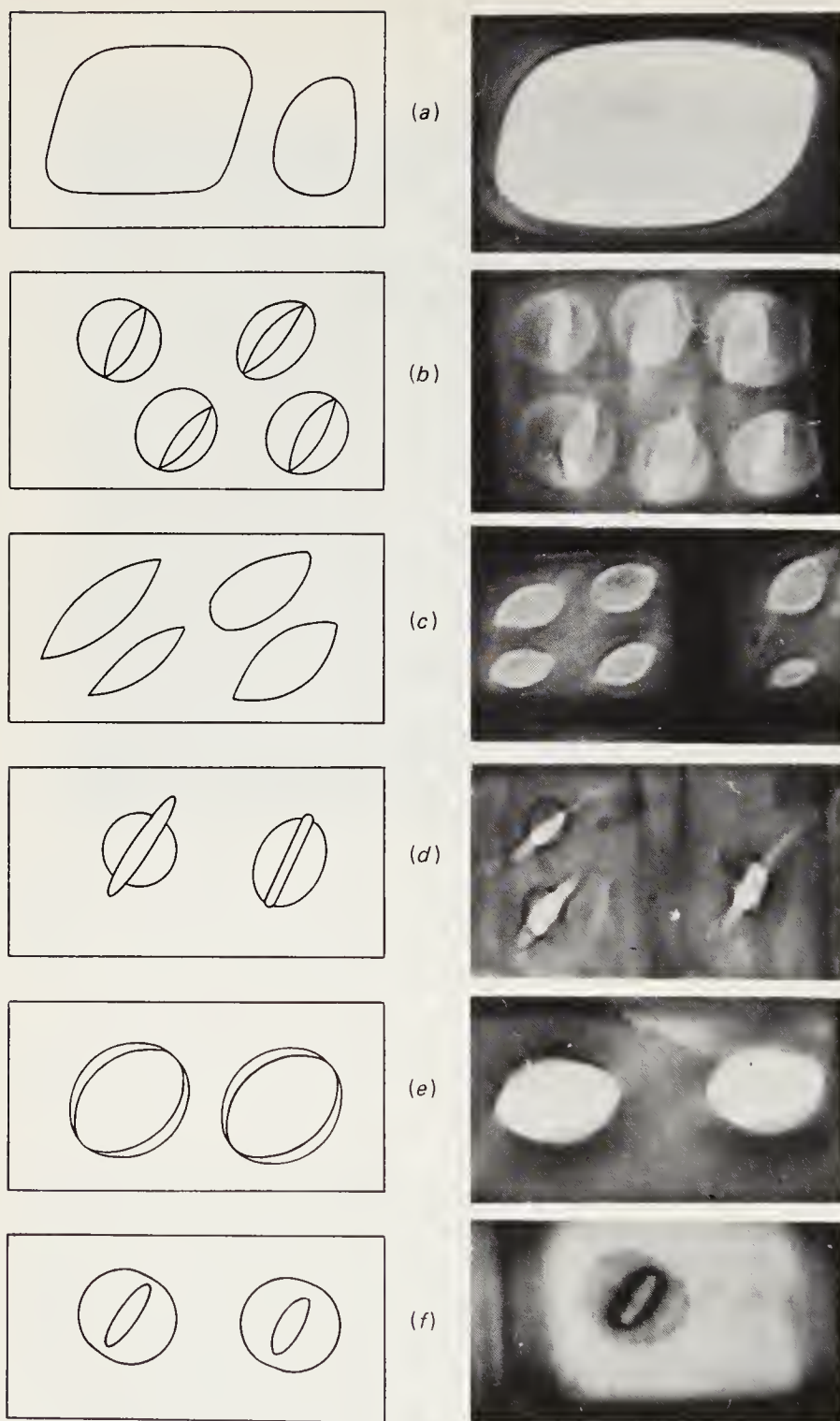


Figure 4-12 Types of pit pairs occurring in the cross fields of coniferous woods.

(a) Window-like pit pairs of the type that characterize the three commercial soft pines, and red pine (*P. resinosa* Ait.).

(b) and (c) Pinoid pit pairs of the type occurring in the hard pines other than red pine (*P. resinosa* Ait.). A border may (b) or may not (c) be present.

(d) Piceoid pit pairs of the type encountered in *Picea*, *Larix*, and *Pseudotsuga*.

(e) Taxodioid pit pairs of the type that feature *Sequoia* and *Taxodium* of the Taxodiaceae, *Abies* of the Pinaceae, and *Thuja* of the Cupressaceae.

(f) Cupressoid pit pairs of the type that occur in *Chamaecyparis*, *Calocedrus*, and *Juniperus* (but not in *Thuja*) of the Cupressaceae, and in *Tsuga* of the Pinaceae.

1 Large pits with broad apertures and an overhanging border on the tracheid side so narrow that careful focusing is required to determine its presence are termed *window-like*, or *fenestriform* (Fig. 4-12a). They are found in the three commercial soft pines and in red pine, among native woods, also in Scotch pine, and in a number of other exotic species of conifers.

2 *Pinoid* pits differ from the window-like pits by being smaller, more variable in size, and more numerous per cross field (Figs. 11-32 and 11-33). According to Thomas and Nicholas (Ref. 17), no secondary thickening has been detected in the ray parenchyma cell walls. Therefore the ray side of the pinoid pit membrane is apparently continuous with the rest of the ray walls. A distinctive border was found on the longitudinal tracheid side of the pit, and thus the pinoid pit pair can be classified as half-bordered (Fig. 4-13); with the lower magnifications (below 1000X) this border may or may not be evident (Fig. 4-12b and c). The same investigators found that the pinoid pit membranes are void of detectable openings (Fig. 4-14). In the heartwood the pit membranes are heavily encrusted with materials insoluble in acidified sodium chlorite. Pinoid pits are a feature of all native hard pines, other than red pine, which has window-like pits.

3 *Piceoid* pits, shown in Fig. 4-12d, are small bordered pits, generally elliptical in shape, with a narrow (linear) and frequently slightly extended aperture. Pits of piceoid type are found in *Picea*, *Larix*, and *Pseudotsuga*.

4 *Taxodioid* pits (Fig. 4-12e) possess apertures which range from oval to circular, are included, and are much wider than the narrow, fairly even border. Pits of this type are featured in the Taxodiaceae, i.e., *Sequoia* and *Taxodium*, although pits of the cupressoid type may also be present in the latter. Taxodioid pits also are present in *Abies* and *Thuja*.

5 *Cupressoid* pits (Fig. 4-12f) resemble piceoid pits but differ from them in that the aperture is included and elliptical, rather than linear as in the piceoid type, and the border remains wide. Cupressoid pits are found in *Chamaecyparis*, *Juniperus*, *Calocedrus*, and *Taxus*, and are occasionally present in *Tsuga*. They are also present in a number of foreign conifers.

Pits in the transverse (end) walls of ray parenchyma, when present, are simple. As viewed in the radial section, they impart a beadlike (*nodular*) appearance to the transverse walls. Their presence or absence may be of diagnostic value in the case of species which are otherwise difficult to separate. For instance, *Calocedrus*, in which the transverse (end) walls of ray parenchyma exhibit conspicuous nodules, can be readily separated from *Thuja* and *Chamaecyparis*, which do not.

Thomas and Nicholas (Ref. 17) report that in the four species of yellow pine studied by them the end walls of the ray parenchyma cells were void of simple pits, presumably because of absence of the secondary-wall thickening. On the other hand Balatinecz and Kennedy (Ref. 1) present evidence that in hard pines, unlike in all other coniferous species, the secondary-wall thickening and apparently the lignification* of ray parenchyma cells and hence development of pits is a gradual process, related to aging of the sapwood. They have found that most ray parenchyma cells in the sapwood

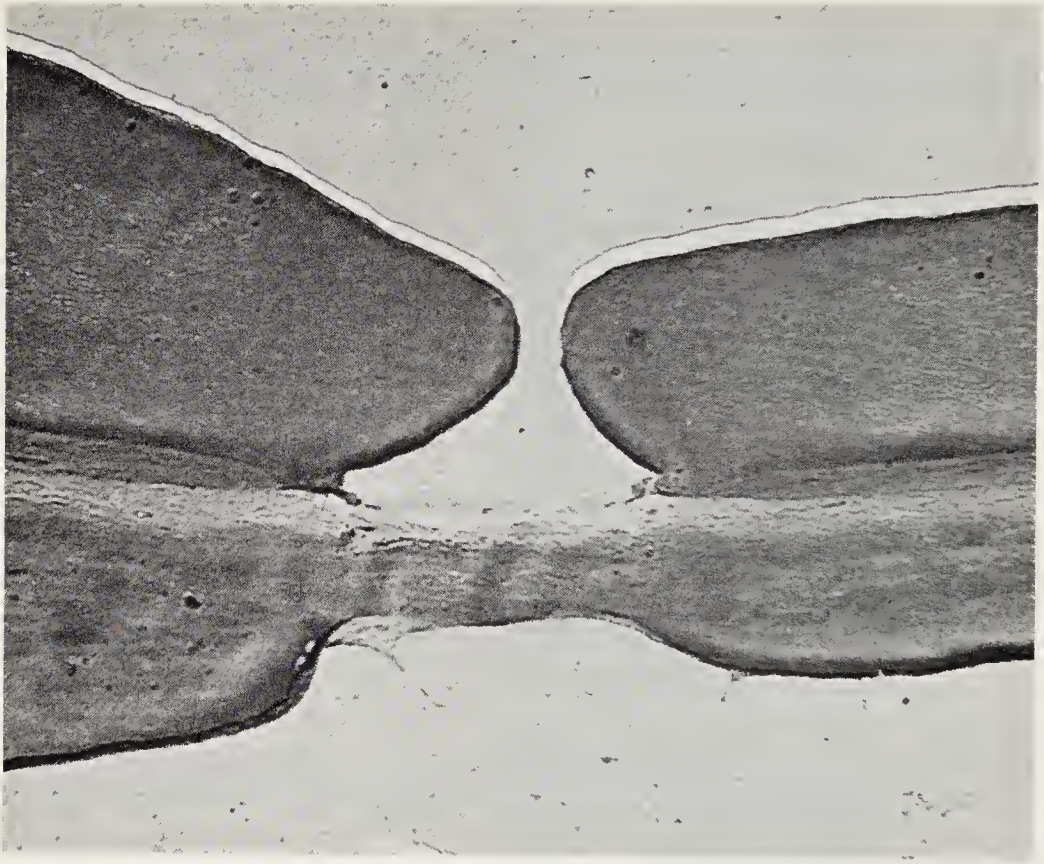


Figure 4-13 Cross section of a half-bordered pit pair between a longitudinal tracheid and a ray parenchyma cell in tamarack [*Larix laricina* (Du Roi) K. Koch]. Electron micrograph of a thin section at 6500 $\times$. (Courtesy of W. A. Côté, Jr.)

adjacent to the cambium are thin and apparently unlignified, and possess smooth walls. The number of lignified cells increases toward the heartwood, until in the heartwood itself all but about 10 percent of the ray parenchyma cells are completely lignified (Figs. 4-15 and 4-16). Some of the lignified cells possess thin and smooth walls, while others exhibit knoblike projections, with the gaps between them representing variable forms of simple pits. From this it may be concluded that absence or presence of simple pits in the ray parenchyma of hard pines depends on location of a given cell in the stem, in relation to sapwood and heartwood. No such lagging in maturation of ray parenchyma cells was observed by the authors in the soft pines and other coniferous species.

The secondary walls in ray parenchyma cells of *Chamaecyparis nootkatensis* (D. Don) Spach. are thickened on the radial walls with ridges running transversely to the ray-cell axis and in the direction of the longitudinal tracheid axis (Ref. 3). These ridges can be seen with a light microscope on the radial walls of the ray cells in contact with the tangential walls of the neighboring tracheids. They are evident also in a reduced form

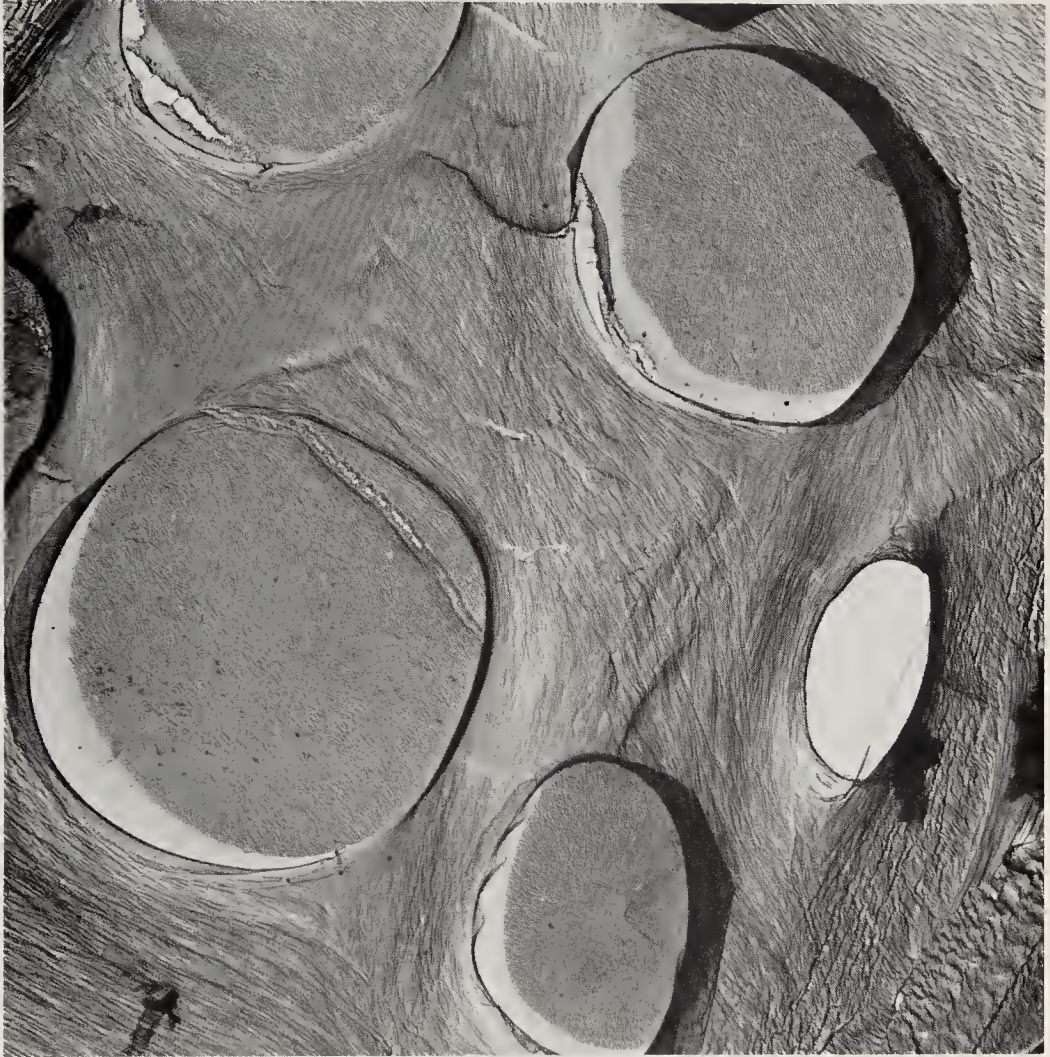


Figure 4-14 Pinoid pits in radial surface view in slash pine (*Pinus elliottii* Englem.). The microfibrillar structure of the pit membranes has been revealed by chlorite removal of the surface encrustations. Electron micrograph of a direct carbon replica at 2700 $\times$. (Courtesy of W. A. Côté, Jr.)

at some places in *Chamaecyparis lawsoniana* (A. Murr.) Parl. but not in *Chamaecyparis thyoides* (L.) B.S.P.

2 RAY TRACHEIDS Ray tracheids are transversely oriented cells found in some softwoods. They are provided with bordered pits of the same general type as those found in the longitudinal tracheids, only smaller (Figs. 11-31 to 11-36).

*The extent of lignification was determined by histological staining techniques, a method of determining the chemical composition of the cell wall that is not regarded as absolutely reliable. However, the authors point out that they employed four staining methods and fluorescence microscopy on the same material, and since the results were in agreement, the conclusions drawn from them may be considered valid.

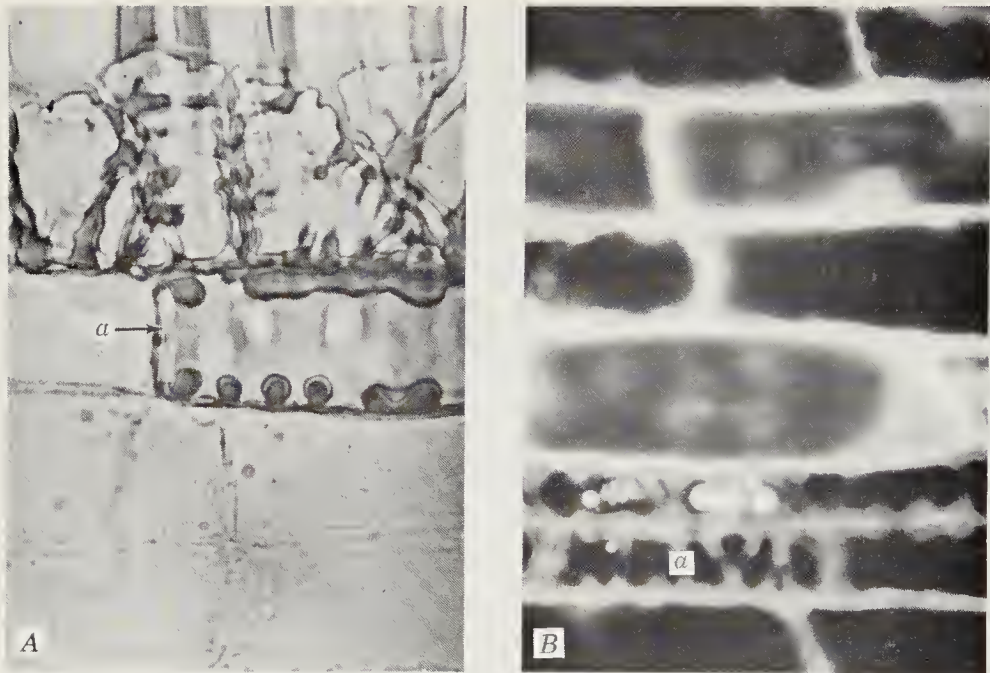


Figure 4-15 (A) A ray in sapwood of *Pinus contorta* Dougl. ex Loud., (r), stained with phloroglucinol-HCl. Only a single parenchyma cell (a) has thickened and lignified. (B) Fluorescence micrograph of *Pinus banksiana* Lamb., indicating general wall thickening and lignification of ray cells typical of heartwood of the hard pines. Note interspersed ray tracheids at a. (Photographs courtesy of J. J. Balatinecz and R. W. Kennedy, Ref. 1)

Ray tracheids occur normally in the Pinaceae and are constant features of the woods of *Pinus*, *Picea*, *Larix*, *Pseudotsuga*, and *Tsuga*. It should be noted that the first four genera also possess resin canals and hence fusiform rays. Ray tracheids also occur sporadically in certain species of *Abies* and quite erratically in the Taxodiaceae (*Taxodium*, *Sequoia*) and the Cupressaceae (*Thuja*, *Chamaecyparis*, *Calocedrus*, *Juniperus*). They are invariably present in the wood of Alaska-cedar [*Chamaecyparis nootkatensis* (D. Don) Spach.], in which species ray tracheids and ray parenchyma seldom occur in the same ray; i.e., a ray is composed wholly of either the one or the other type of cell (Compare Figs. 11-41 and 11-42).

Ray tracheids attain their best development in the genus *Pinus*, especially in the hard pines. In this genus, one or more rows of ray tracheids are present on the upper and lower margins of the ray, and not infrequently in the median portion as well. The low rays of hard pines frequently consist wholly of ray tracheids.

The inner wall of ray tracheids in hard pines possesses irregular tooth-like projections, or is reticulated (Figs. 3-16, 11-31, and 11-33). Ray tracheids with these types of wall irregularities are said to be *dentate*. They serve as an easy and positive means of identification of hard pines. A number of investigators, using the electron microscope, have found that

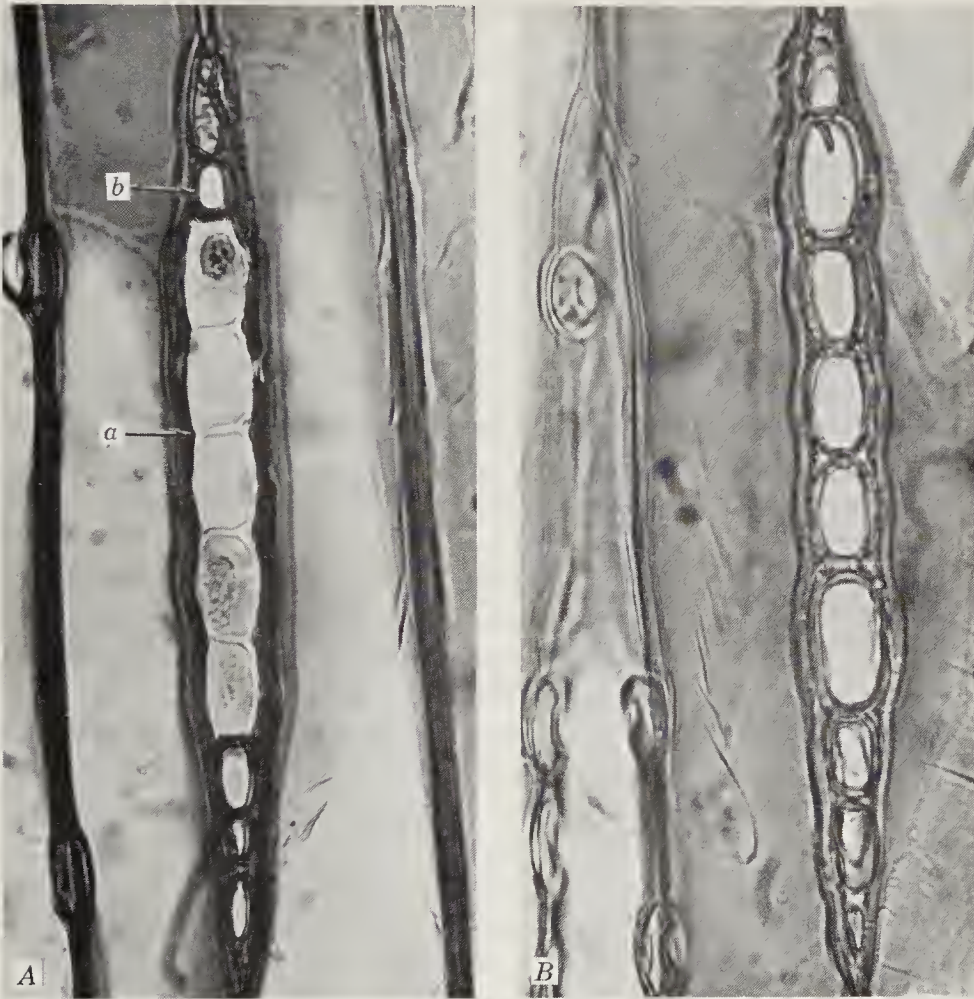


Figure 4-16 Tangential sections of *Pinus banksiana* Lamb., stained by the Coppick and Fowler technique. (A) Tangential section from sapwood. The almost transparent ray parenchyma cell wall (a), contrasted with thick, lignified walls of ray tracheid (b). (B) Tangential section from heartwood. Ray parenchyma walls are thickened and lignified and stain identically to ray tracheids. (Photographs courtesy of J. J. Balatinecz and R. W. Kennedy, Ref. 1)

pinus with dentate ray tracheids also have “warts” on the inner walls of the bordered pits of the longitudinal tracheids, and that these are absent in pines with smooth-walled ray tracheids (soft pines).

The ray tracheids of Douglas-fir possess spiral thickening comparable to that of the longitudinal tracheids.

B Rays in Softwoods

The wood- or xylary rays in softwoods consist entirely of transversely oriented cells which are arranged in ribbon-like structures extending radially in the tree stem. A wood ray is only part of a larger structure which, for lack of a better term, may be called a *complete ray*. It consists of a *xylary ray*, i.e., the portion of the ray in the wood (xylem), and a *phloem ray* which is

part of the same ray in the phloem. Both of these originate from a *cambial ray*, i.e., the cambial ray initial.

The first-formed wood rays extend completely across the secondary xylem, and they may initiate adjacent to the primary xylem. But since all wood rays originate in the cambium, such terms as *pith rays* and *medullary rays*, frequently encountered in literature on wood, should not be used, because they imply that wood rays consist of the same kind of tissue as the pith or medulla and originate from it.

Coniferous woods may have either one or two types of rays: (1) rays without resin canals (uniseriate) and (2) rays with normal transverse resin canals. The latter type is invariably accompanied by longitudinal canals in softwoods native to North America. The inclusion of resin canals in the rays results in the formation of *fusiform rays*, so-called because of their spindle shape when cut transversely (Fig. 4-10c, d, and e).

1 RAYS WITHOUT RESIN CANALS (UNISERiate RAYS) The rays of softwoods which do not contain resin canals are almost exclusively uniseriate, i.e., one cell wide in the tangential direction, and will be called *uniseriate rays throughout this discussion*. However, occasional rays with one or more pairs of cells in the central portion of the ray (*t*) may be found in about half of the species of the Pinaceae and in 40 percent of all the Gymnosperms (Ref. 11). Rays completely biseriate except for the end cells are sometimes encountered in redwood [*Sequoia sempervirens* (D. Don) Endl.] and in this species may be as wide as five seriate (Ref. 5). As a result of their sporadic occurrence biseriate rays are of no diagnostic significance.

The uniseriate rays may be composed exclusively of ray parenchyma, or only of ray tracheids as in the low rays of *Chamaecyparis nootkatensis* (D. Don) Spach., or of both these kinds of cells. When the uniseriate rays are composed of only one type of cell, whether ray parenchyma or ray tracheids, they are said to be *homocellular*; rays possessing both kinds of cells are called *heterocellular*. The determination of the types of cells present in the rays is best made on the radial section. Heterocellular rays are always present in the Pinaceae except for the genus *Abies* in which they occur occasionally in balsam fir [*Abies balsamea* (L.) Mill.]. An example of this sort of ray is shown in eastern white pine (*Pinus strobus* L.) in Fig. 4-2B, k and l. Usually the heterocellular rays are composed predominantly of ray parenchyma, with ray tracheids forming one or more marginal rows of cells and an occasional row of ray tracheids in the body of the ray. The homocellular rays may be composed exclusively of ray tracheids, as is the case in occasional rays in some species of *Chamaecyparis* and *Pinus*.

The uniseriate rays vary in height, as viewed in tangential section, both in number of cells and in linear measurements. This holds not only for different woods but also for the same wood. Some variations in the number

of cells and in the overall height of the rays are genetically or ecologically controlled, and some are due to the manner in which new ray initials are formed in the cambium. As the diameter of a tree increases, the rays diverge outward toward the cambium. Since, in a given kind of wood, the spacing of rays as they appear on the transverse surface remains approximately constant, additional rays are formed to maintain the spacing characteristic of the species (see page 76). Once a new cambial ray is formed, it increases in height and width by the process of pseudotransverse anticlinal division of the cambial ray cell initials.

In their spacing the xylary rays of softwoods exhibit no marked departures of diagnostic significance. Measured tangentially the rays range in number from six to nine per millimeter.

The upper limit in the height of coniferous wood rays varies according to the kind of wood and location of the sample in the tree (see Chap. 7). The highest figures are reached in *Taxodium distichum* (L.) Rich. and *Sequoia sempervirens* (D. Don) Endl. in which rays of 40 to 60 plus cells and 500 to 1000 micrometers in height are encountered, although the averages are much lower. *Juniperus virginiana* L. and *Chamaecyparis lawsoniana* (A. Murr.) Parl. are examples of woods in which the tallest rays are seldom over 6 cells and 300 micrometers in height. The mean maximum height of the narrow rays of softwoods, taken as a group, is somewhere in the neighborhood of 10 to 15 cells.

The range of ray heights and the maximum heights are occasionally of sufficient significance to be of some value as a secondary characteristic in differentiating between various kinds of softwoods. For instance, the true firs (*Abies* spp.) have taller rays than the hemlocks (*Tsuga* spp.), and the same holds true between *Taxodium distichum* (L.) Rich. and *Sequoia sempervirens* (D. Don) Endl.

The volume of ray tissues in softwoods is quite small, ranging from about 5 to 9 percent (Table 4-2), including fusiform rays when these are present. However, considerable difference in ray volume exists between species as indicated in Tables 4-2 and 4-5.

The average ray volume for all coniferous woods discussed in this text is 7.0 percent compared to 17.0 percent for hardwoods. The lowest figure of 3.4 percent is for northern white-cedar (*Thuja occidentalis* L.), and the highest of 11.7 percent is for slash pine (*Pinus elliottii* Engelm.), closely followed by the larches (*Larix* spp.) with volumes of 11.0 and 10.0 percent.

2 FUSIFORM RAYS The *fusiform rays*, so-called because of their spindle-like shape as seen in tangential section, consist of the same kind of elements as the uniseriate rays, i.e., of ray tracheids and ray parenchyma, but in addition they include one or rarely two resin canals surrounded by epithelial cells (Fig. 4-10). The narrow ends of the fusiform rays consist of

Table 4-5 Average Ray Volumes of the Coniferous Woods of the United States
(Arranged in Botanical Sequence, by Genera)

Scientific name	Average ray volume, %	Variation in samples examined, %	Scientific name	Average ray volume, %	Variation in samples examined, %
<i>Pinus lambertiana</i>	5.7	0.7	<i>Picea sitchensis</i>	7.3	3.1
<i>Pinus monticola</i>	6.6	2.6	<i>Pseudotsuga menziesii</i>	7.4	2.1
<i>Pinus strobus</i>	5.4	0.4	<i>Tsuga canadensis</i>	6.0	0.7
<i>Pinus contorta</i>	5.7	0.9	<i>Tsuga heterophylla</i>	8.8	4.0
<i>Pinus palustris</i>	8.3	3.7	<i>Abies balsamea</i>	5.7	2.3
<i>Pinus echinata</i>	8.1	3.3	<i>Abies concolor</i>	9.5	1.8
<i>Pinus taeda</i>	7.6	1.6	<i>Abies grandis</i>	6.7	5.2
<i>Pinus elliotii</i>	11.7	1.8	<i>Abies procera</i>	6.6	2.1
<i>Pinus rigida</i>	7.3	2.7	<i>Sequoia sempervirens</i>	7.9	2.5
<i>Pinus ponderosa</i>	6.8	2.4	<i>Taxodium distichum</i>	6.6	2.6
<i>Pinus jeffreyi</i>	8.1		<i>Calocedrus decurrens</i>	8.9	0.9
<i>Pinus resinosa</i>	7.0	1.4	<i>Thuja occidentalis</i>	3.4	0.6
<i>Larix laricina</i>	11.0	4.2	<i>Thuja plicata</i>	6.9	1.4
<i>Larix occidentalis</i>	10.0	1.1	<i>Chamaecyparis</i>	5.6	1.7
<i>Picea glauca</i>	7.1	0.4	<i>lawsoniana</i>		
<i>Picea rubens</i>	4.9	2.7	<i>Chamaecyparis thyoides</i>	5.2	2.4
<i>Picea engelmannii</i>	5.9	2.5	<i>Juniperus virginiana</i>	6.3	1.3

ray tracheids and ray parenchyma arranged in the same relative position as in the uniseriate rays. Fusiform rays occur in four genera of the Pinaceae which have normal resin canals: *Pinus*, *Picea*, *Larix*, and *Pseudotsuga*. The ratio of fusiform to uniseriate rays ranges from a minimum of 1 to 25 in *Pseudotsuga*, 1 to 40 or 45 in *Picea*, and 1 to 60 plus in *Larix*.

The volume of fusiform rays in softwoods constitutes less than 1 percent of the volume of the wood in softwoods, as is evident in Table 4-2.

**IV CRYSTALLIFEROUS WOOD ELEMENTS IN
SOFTWOODS**

Crystal-bearing cells are rarely encountered in the softwoods and occur so sporadically that they are of no diagnostic significance. They are apparently restricted to the Pinaceae. When present, crystals occur in the form of exceedingly small cubes, octahedra, or rectangular prisms, and are ordinarily associated with parenchyma cells. Crystals of rhomboidal and elongated forms, mainly in the marginal ray parenchyma cells, are regularly found in *Abies bracteata* D. Don, *Abies procera* Rehd., *Abies grandis*

(Dougl.) Lindl., *Abies magnifica* A. Murr., and *Abies concolor* (Gord. & Glend.) Lindl., but they are absent in *Abies amabilis* (Dougl.) Forbes, *Abies balsamea* (L.) Mill, and *Abies lasiocarpa* (Hook.) Nuttall (Ref. 8). Occasional crystals of calcium oxalate have also been reported in the ray parenchyma cells of *Picea sitchensis* (Bong.) Carr (Ref. 16).

Crystals have been reported only in ray parenchyma of North American softwoods, but in the Eastern Asian, monotypic genus *Pseudolarix*, crystals are also found in the longitudinal tracheids.

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The Minute Structure of Hardwoods (Porous Woods)

The anatomical features that distinguish hardwoods from coniferous woods may be summarized as follows:

1 Hardwoods differ from softwoods in possessing *vessel elements* (also called *vessel members* and *vessel segments*), which when viewed in the transverse section are called *pores*, hence the name *porous woods*. Softwoods are said to be *nonporous* in the sense that they do not contain vessels (Figs. 5-1 and 5-2 and Frontispiece).

2 The radial alignment of the longitudinal cells that characterizes softwoods, when viewed in transverse section, is wanting or more or less obscured in hardwoods. This lack of radial alignment is the result of two processes acting simultaneously. (a) The vessels (pores) of hardwoods usually enlarge appreciably in diameter following their formation from the cambial initials. The enlargement in diameter of vessel elements causes crowding of some of the other longitudinal cells out of alignment and forces the rays, especially if they are narrow, to bend around the large pores. (b) The meristematic cells on the flanks of the cambial initial that is to form a vessel element fail to divide, thus allowing the developing vessel element to expand both radially and tangentially. This latter phenomenon can be demonstrated most readily in ring-porous woods by counting the number of

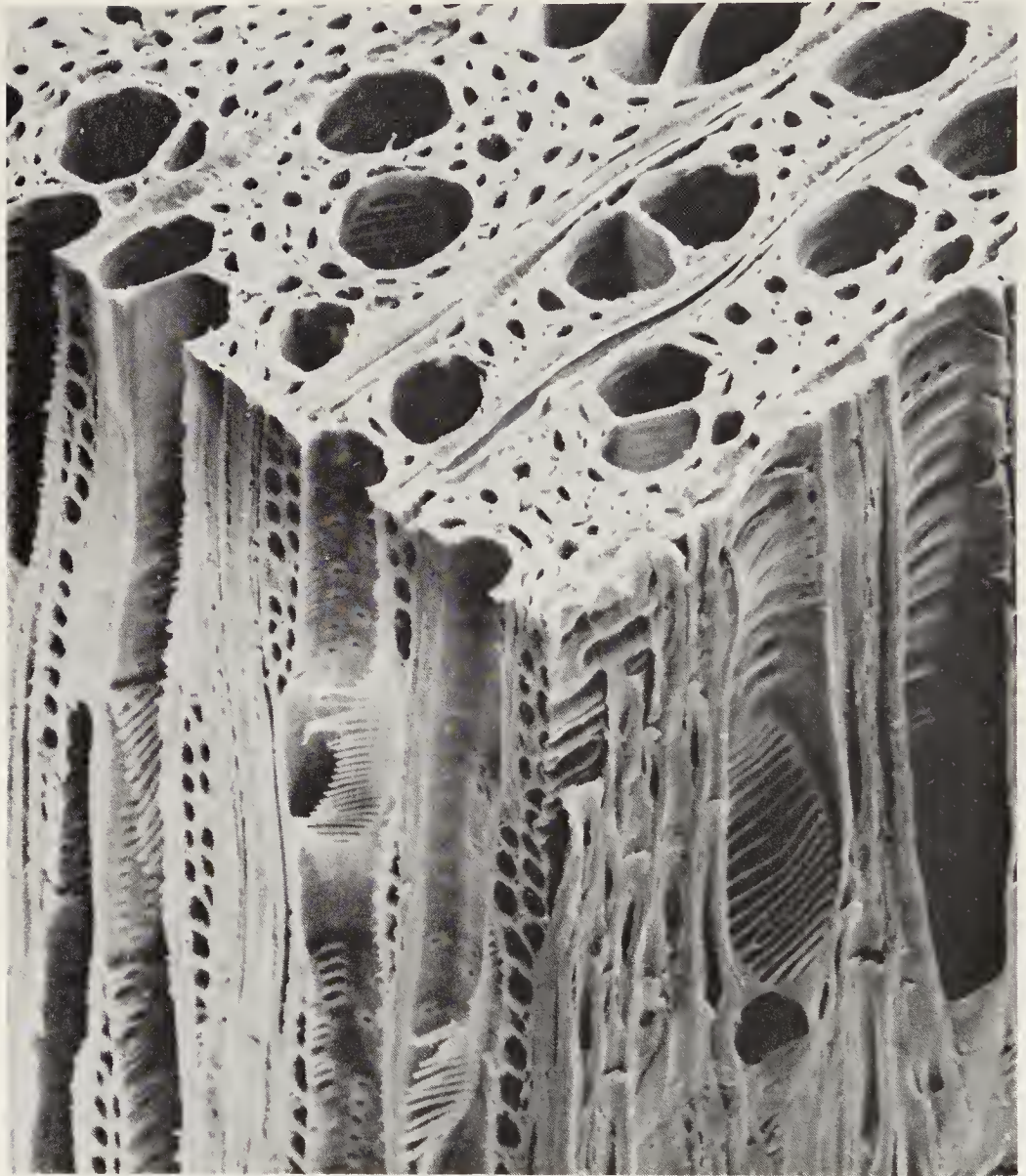
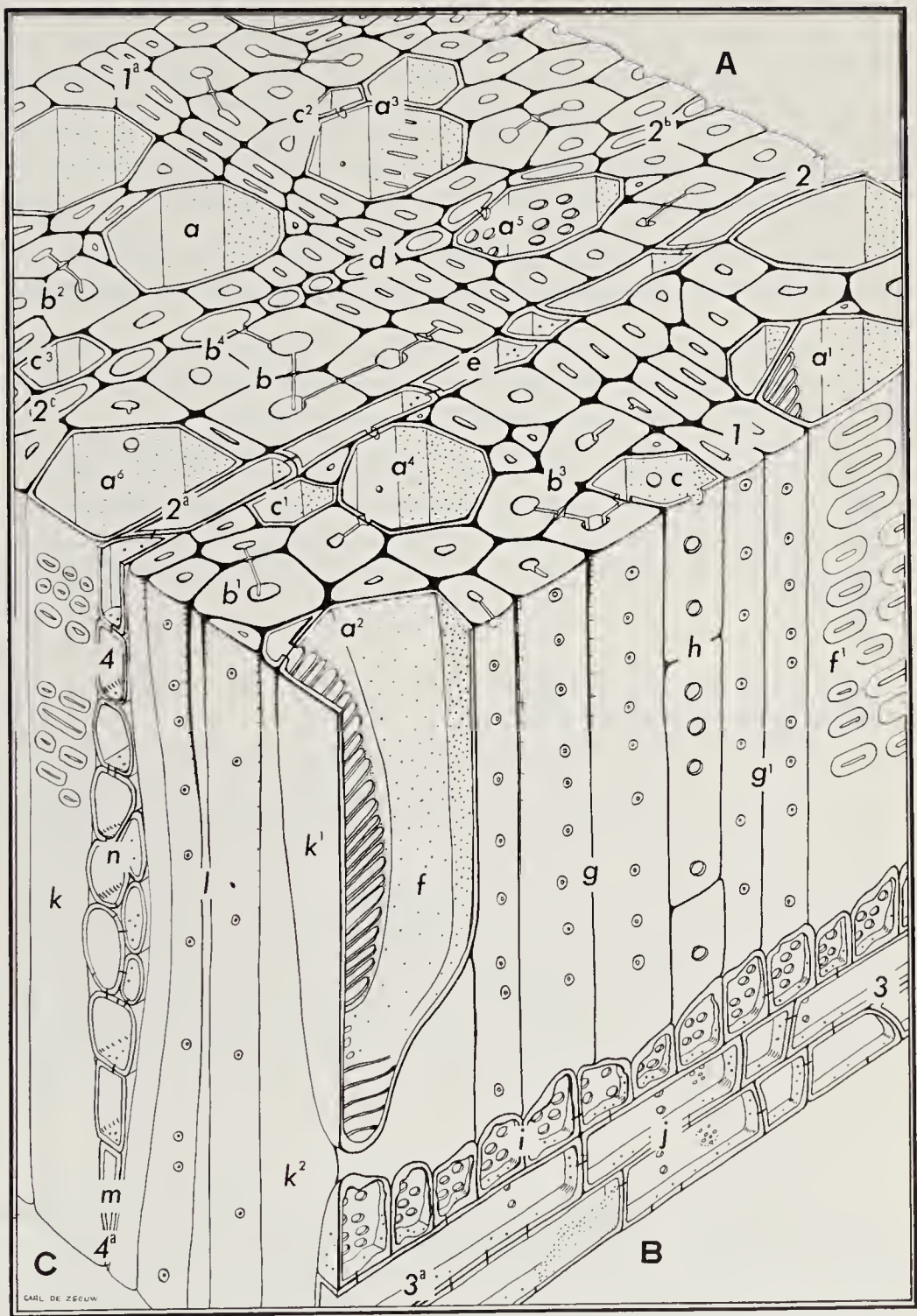


Figure 5-1 Sweetgum (*Liquidambar styraciflua* L.) wood as viewed with the scanning electron microscope. The structures visible are described in Fig. 5-2. (350×) (Courtesy of Center for Ultrastructure Studies, State University of New York, College of Environmental Science and Forestry, Syracuse, N.Y.)

Figure 5-2 Schematic three-plane drawing of the wood of sweetgum (*Liquidambar styraciflua* L.). (330×)

Surface A. 1-1^a, boundary between two annual rings (growth proceeded from right to left); 2-2^a, wood ray consisting of procumbent cells; 2^b2^c, wood ray consisting of upright cells; a-a^b, inclusive, pores (vessels in transverse section); b-b^d, inclusive, fiber tracheids; c-c^e, inclusive, cells of longitudinal parenchyma; e, procumbent ray cell.

Surface B, f, f^f, portions of vessel elements; g, g^g, portions of fiber tracheids in lateral surface aspect; h, a strand of longitudinal parenchyma in lateral surface aspect; 3-3^a, upper portion of a



heterocellular wood ray in lateral sectional aspect; *i*, a marginal row of upright cells; *j*, two rows of procumbent cells.
 Surface C. *k*, portion of a vessel element in tangential surface aspect; *k'*, *k''*, overlapping vessel elements in tangential surface aspect; *l*, fiber tracheids in tangential surface aspect; 4-4', portion of a wood ray in tangential sectional view; *m*, an upright cell in the lower margin; *n*, procumbent cells in the body of the ray.

cells in the radial direction from one growth boundary to the next. A comparison is made of the cell counts between a place where an early-wood vessel is flanked on each side by a ray and a nearby location in the same ring between two rays where no large early-wood vessels have formed. Invariably it will be found that fewer cells have been formed throughout the growing season by the cambium initials in the former than in the latter instance, thus indicating that the initials divided fewer times opposite the vessel. This can be seen, for example, in Fig. 11-186, where the central increment shows 50 cells next to the multiseriate ray and only 35 cells above the large early-wood pore at the lower right side of the figure.

3 Hardwoods are much more complex in structure than softwoods because more cells enter into their composition, and these cells show more variation in size, shape, and arrangement within a growth ring.

4 The rays of hardwoods are more variable in width than those of conifers. In the latter rays are mostly uniseriate (*t*); uniseriate rays also characterize certain hardwoods, but the great majority of them possess rays two or more cells wide. Ray width, in many instances, may be used as a diagnostic feature in the separation of hardwoods; this does not hold for softwoods.

I DEVELOPMENT OF THE ELEMENTS OF POROUS WOODS FROM CAMBIAL INITIALS

Figure 5-3 serves to emphasize the fact that the longitudinal elements of wood are all derived from the same type of cambial initial. A cambial fusiform initial is shown in the center at *a*. In a ring-porous wood, daughter cells cut off from this cell mature without or with little elongation into early-wood vessel members of the type depicted at *b*, or into late-wood vessel members of the kind shown at *c* and *d*, or into other types of cells described in the succeeding paragraphs.

A vascular tracheid is illustrated at *g* and a vasicentric tracheid at *h*. In contrast to the vessel elements, both types of these cells have imperforate ends. The vasicentric tracheid is the longer of the two, but both grew somewhat in length as they matured, for they are obviously longer than cambial cell *a*.

A fibrous cell is portrayed at *i*. Its exact nature cannot be determined because the type of pitting is not indicated. The long fibrous elements in hardwoods arise from the same type of fusiform cambial initial that produces the vessel elements and tracheids. As the fibrous cells mature they increase in length several hundred percent, and as a result become more fiber-like in nature.

The cells of type *e* are designated as *strand parenchyma*. Such a strand results through the partition of a daughter cell derived from a longitudinal fusiform initial cell (*a*) into separate cells by postcambial mitotic division.

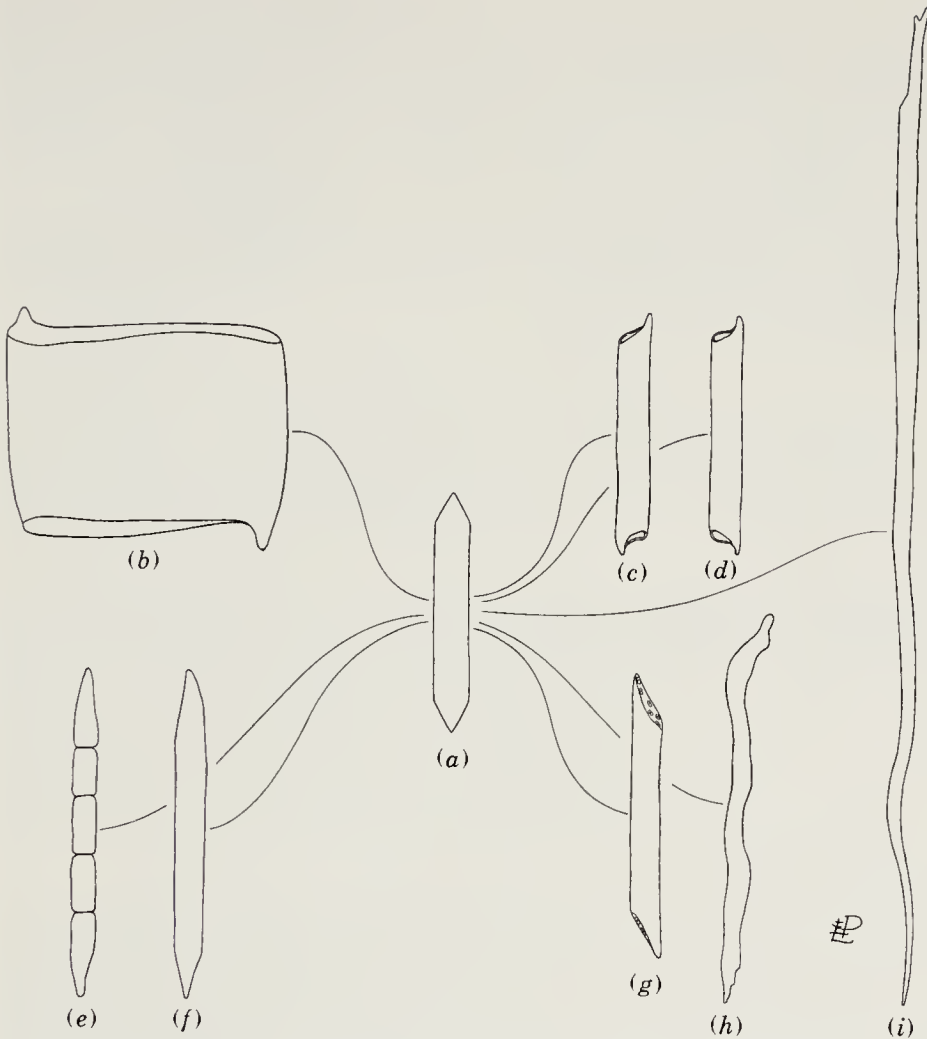


Figure 5-3 Schematic drawings indicating the manner in which the longitudinal elements of porous wood are derived from fusiform cambial initials. The cells are illustrated in lateral aspect. (a) Fusiform cambial initial. (b) Early-wood vessel element. (c) and (d) Late-wood vessel elements with tailed ends, on the opposite and on the same side, respectively. (e) A strand of longitudinal parenchyma. (f) A fusiform parenchyma cell. (g) A vascular tracheid (in shape, it is similar to a late-wood vessel element but is imperforate). (h) A vasicentric tracheid. (i) A fibrous cell.

The number of cells in a strand that may arise this way depends on the number of cross walls that are laid down. Evidence of the manner of the formation of such strands from single fusiform cambial initials is permanently recorded in the wood in that the cells at each end of it taper to a point. The strand parenchyma e is somewhat longer than the fusiform initial a. This is indicative of the fact that a certain amount of elongation occurs in the parent longitudinal cell before the cross walls are formed. The extent of this elongation, and the number of units composing such a strand, vary in different hardwoods.

Cell type *f* is comparatively rare in commercial hardwoods but abounds in the woods of certain shrubs. It is known as a *fusiform parenchyma cell*. Such an element is parenchymatous in nature in that it retains a living protoplast for some time, but it has the shape of a short fiber. It obviously arises from a longitudinal fusiform initial (a), without partition.

By way of summation it should be noted that differentiation of the various types of cells derived from the fusiform initials in the cambium proceeds along three principal lines, with considerable overlapping between them.

1 Elongation; i.e., the mature cell becomes longer than the fusiform initial. This type of differentiation is most characteristic of the fibers (libriform fibers and fiber tracheids). Some elongation, however, occurs also in the tracheids (vasicentric and vascular), in the total length of the axial parenchyma strand, and in the vessel elements of more primitive hardwoods.

2 Increase in diameter, associated with little or no elongation. This is characteristic of the vessel elements (members) and to some extent of the vascular tracheids. The mature early-wood vessel elements in some ring-porous woods may, in fact, become shorter than the cambial fusiform initials.

3 Division into a vertical row of cells by means of transverse walls. This is the manner by which strands of the axial parenchyma are formed from a single fusiform initial.

All the xylary ray cells originate from the ray cell initials in the cambium. These are not shown in Fig. 5-1, because except for elongation in the horizontal-radial direction, mature xylary ray cells are largely replicas of the cambial ray cell initials, which through division in the tangential plane give rise to them.

II CAMPARATIVE ANATOMY OF THE HARDWOODS

The elements that occur in the native species of porous woods are listed in Table 5-1. When compared with those in Table 4-1, the more complex structure of hardwoods is quite apparent.

A Longitudinal Elements (Cells) of Porous Woods

The longitudinal cells listed in Table 5-1 as vessel elements, fibers, and tracheids are elongated longitudinally, i.e., in the direction of the long axis of the tree trunk. They are equipped with a variety of pits and perform primarily conductive or mechanical functions, or both. These elements are characterized by the loss of their protoplast as soon as or shortly after they are fully developed. The parenchyma cells, in contrast, are short cells,

Table 5-1 Elements (Cells) of Porous Wood

Longitudinal elements	Transverse elements
<div>1 Vessel elements</div> <div>2 Tracheids</div> <div> a Vasicentric tracheids</div> <div> b Vascular tracheids</div> <div>3 Fibers</div> <div> a Fiber tracheids</div> <div> b Libriform fibers</div> <div>4 Longitudinal (axial) parenchyma</div> <div> a Cells of axial (strand) parenchyma</div> <div> b Fusiform parenchyma cells</div> <div> c Epithelial cells; excreting cells encircling the cavities of longitudinal gum canals*</div>	<div>1 Cells of ray parenchyma</div> <div> a Procumbent or upright } Homocellular ray cells exclusively } rays</div> <div> b Procumbent and upright ray cells } Heterocellular rays</div> <div>2 Epithelial cells; excreting cells encircling the cavities of transverse gum canals*</div>

*Longitudinal gum canals, apparently of traumatic origin, are occasionally present in sweetgum. They are not found elsewhere in the woods covered by this text. Longitudinal and transverse canals are normal features of certain tropical timbers, but the two types seldom occur in the same wood. The term gum canal in hardwoods includes canals whose contents may be gum, resin, or mucilage, depending on the genus.

equipped only with simple pits. Parenchyma cells retain their protoplasts for some time and mainly perform a storage function.

1 VESSEL ELEMENTS As has been stated, porous woods are characterized by the presence of *vessels*, composite, tubelike structures of indeterminate length composed of a number of cells called *vessel elements*, *vessel members*, or *vessel segments*. It has been found that while individual vessels follow a generally longitudinal course, they also diverge tangentially and to a lesser extent radially, thus forming a three-dimensional conduction network in the secondary xylem (wood) (Refs. 1, 2, 10, 13).

Zimmermann and Tomlinson (Ref. 14) studied the axial course followed by vessels in *Acer rubrum* L., *Populus* spp., *Quercus* spp., and *Fraxinus* spp. by cutting sequential sections from a block of wood and photographing them through a microscope with a modified motion picture camera. When the sequence of pictures is projected as a motion picture, the changes in the relative position of vessels can be observed. The film shows that in maple and poplar, individual vessels move from cluster to cluster of vessels and that they never end in isolation but begin and end within a vessel cluster. Because of this and the fact that in many cases two or more vessels may run side by side over considerable distances, the water-conducting units do not have dead ends and water can pass through pits and perforations from one vessel system into several others. Oak vessels were found to be very long and rather straight, while in ash, "Vessels do not run parallel but describe what appears to be random deviation from their path."

This tangential deviation was calculated to amount to more than 30 centimeters over an axial distance of 5 meters. Even more extensive spread was found in maple and poplar. This was demonstrated by the upward tangential spread of dye introduced at some point in the stem. The authors suggest that the physiological implication of this is that "water must spread tangentially during its ascent in the stem" (Ref. 13) and that "any one point at the base of a tree stem is in direct axial contact with a good part (or all) of the circumference of the top of the tree" (Ref. 14).

Skene (Ref. 10), in a study of *Eucalyptus maculata* Hook., has shown that a given vessel may have direct contact with as many as 10 others in an axial distance of 50 centimeters. In other hardwoods such as oaks (*Quercus* spp.) the early-wood vessels maintain lateral communication through the vasicentric tracheids. From these observations it is evident that vessels do not exist in isolation, but, in fact, numerous areas of communication exist between vessels over their surfaces.

a Formation of Component Vessel Elements Each component vessel cell (vessel element) develops from a longitudinal cell that has arisen through division of a fusiform cambial initial. In the early stages of development, a longitudinal cell destined to become a vessel member is imperforate. It enlarges rapidly transversely, but there is little or no elongation along the grain, except in some diffuse porous hardwoods, of which sweetgum (*Liquidambar styraciflua* L.) is one. After the vessel element has attained its maximum size, the secondary wall develops, leaving gaps for pits and unthickened places at the cell ends adjoining other vessel elements. These thin walls at the ends of the vessel elements are removed by enzymatic action, before the protoplast disappears, leaving openings called *perforations*. Matching perforations in adjacent vessel elements provide an open passage for the upward movement of water in the tree stem.

b Shape and Size of Vessel Elements As viewed laterally the vessel elements range from drum-shaped (Fig. 5-4F) and barrel-shaped to oblong and linear (Fig. 5-4C, D, E, and H), with or without broadly tapering or tail-like extensions at one or both ends.

The vessel extensions, i.e., the parts of the vessel extending beyond the perforations, may vary from a short or long slender tail to a straplike (ligulate) end, or the extensions may have a broad taper as in Fig. 5-4A and B. The extensions may occur on the same side of a vessel member or on opposite sides. Vessel extensions are readily visible only when the cells have been separated by maceration.

Vessel elements vary considerably in length in different woods (Table 5-2), even though little or no elongation occurs along the grain as they enlarge in diameter. This variation in length of vessel elements is due to the fact that the longitudinal cambial initials are of different length in different species of trees.

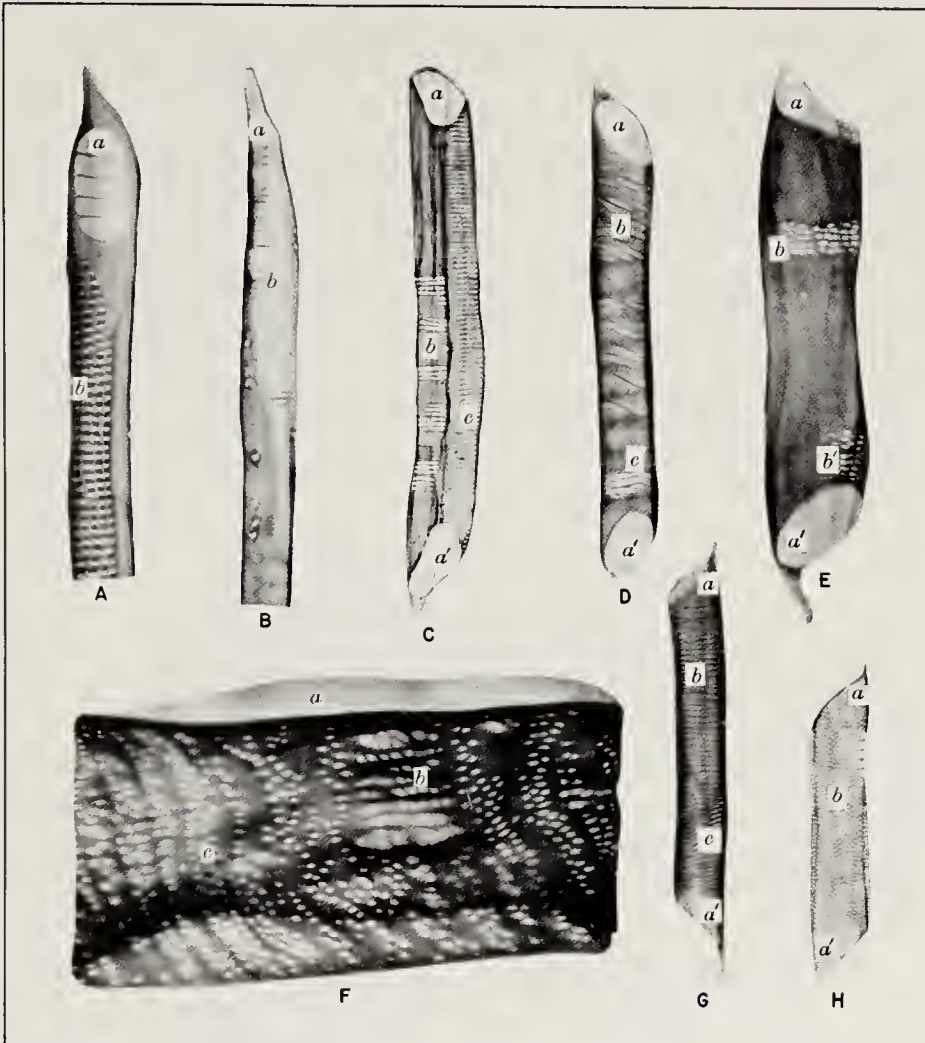


Figure 5-4 Types of vessel elements in hardwoods. (115X)

(A) Portion of a vessel element of yellow-poplar (*Liriodendron tulipifera* L.) showing a scalariform perforation plate with few bars (a), and opposite pitting (b).

(B) Portion of a vessel element of sweetgum (*Liquidambar styraciflua* L.) showing spiral thickening at tip (a), and scalariform perforation plate with many bars (b).

(C) A vessel element of cucumbertree (*Magnolia acuminata* L.) showing simple perforations at the ends (a, a'), several cross fields on the radial face (b), and scalariform pitting composed of linear pits on the tangential wall (c).

(D) A vessel element of yellow buckeye (*Aesculus octandra* Marsh.) showing simple perforations at the ends (a, a'), spiral thickening (b), and a cross field (c).

(E) A vessel element of black willow (*Salix nigra* Marsh.) showing simple perforations at the ends (a-a'), and two cross fields (b-b').

(F) Annular (ring-shaped) vessel element from the early wood of chestnut [*Castanea dentata* (Marsh.) Borkh.] showing simple perforations at the upper end (a), a cross field (b), and strips of pits leading to vasicentric tracheids (c).

(G) A vessel element of silver maple (*Acer saccharinum* L.) showing tailed ends (a-a') on the same side, spiral thickening (b), and pits leading to longitudinal parenchyma (c).

(H) A vessel element of butternut (*Juglans cinerea* L.) showing short tails (a-a') on opposite sides, and intervessel pitting on the tangential wall (b).

(Photographs (A), (B), (D), (E), (F), (G), and (H), inclusive, by C. H. Carpenter; photograph (C) by W. M. Harlow.)

Scientific name	Vessel elements		Fibers		Scientific name	Vessel elements		Fibers	
	Average length	Stand-ard devia-tion	Average length	Stand-ard devia-tion		Average length	Stand-ard devia-tion		
<i>Acer macrophyllum</i>	0.33	0.05	0.77	0.15	<i>Liriodendron tulipifera</i>	0.89	0.13	1.74	0.29
<i>Acer rubrum</i>	0.42	0.05	0.92	0.12	<i>Lithocarpus densiflorus</i>	0.57	0.11	1.10	0.15
<i>Acer saccharinum</i>	0.41	0.07	0.76	0.13	<i>Maclura pomifera</i>	0.18	0.02	1.14	0.16
<i>Acer saccharum</i>	0.41	0.09	0.92	0.13	<i>Magnolia acuminata</i>	0.72	0.15	1.39	0.28
<i>Aesculus octandra</i>	0.44	0.08	1.00	0.13	<i>Magnolia grandiflora</i>	0.99	0.14	1.81	0.29
<i>Alnus rubra</i>	0.85	0.14	1.19	0.18	<i>Morus rubra</i>	0.21	0.03	0.91	0.12
<i>Arbutus menziesii</i>	0.53	0.10	0.79	0.14	<i>Nyssa aquatica</i>	1.11	0.28	1.89	0.33
<i>Betula alleghaniensis</i>	0.84	0.16	1.38	0.17	<i>Nyssa sylvatica</i>	1.33	0.34	2.30	0.36
<i>Betula lenta</i>	0.91	0.12	1.52	0.22	<i>Ostrya virginiana</i>	0.68	0.11	1.23	0.18
<i>Betula papyrifera</i>	1.00	0.26	1.35	0.15	<i>Oxydendrum arboreum</i>	0.47	0.09	1.05	0.16
<i>Betula populifolia</i>	0.74	0.15	1.26	0.14	<i>Platanus occidentalis</i>	0.63	0.12	1.08	0.17
<i>Carpinus caroliniana</i>	0.42	0.10	1.17	0.18	<i>Populus grandidentata</i>	0.64	0.09	1.33	0.17
<i>Carya cordiformis</i>	0.44	0.11	1.38	0.22	<i>Populus tremuloides</i>	0.67	0.18	1.32	0.22
<i>Carya illinoënsis</i>	0.41	0.08	1.28	0.20	<i>Populus trichocarpa</i>	0.58	0.09	1.38	0.19
<i>Carya ovata</i>	0.47	0.09	1.34	0.28	<i>Prunus serotina</i>	0.39	0.06	1.21	0.18
<i>Carya tomentosa</i>	0.44	0.06	1.62	0.26	<i>Quercus alba</i>	0.40	0.09	1.39	0.20

Scientific name	Vessel elements		Fibers		Scientific name	Vessel elements		Fibers	
	Average length	Stand-ard deviation	Average length	Stand-ard deviation		Average length	Stand-ard deviation	Average length	Stand-ard deviation
<i>Castanea dentata</i>	0.58	0.12	1.22	0.16	<i>Quercus bicolor</i>	0.41	0.07	1.19	0.17
<i>Castanopsis chrysophylla</i>	0.67	0.11	0.87	0.11	<i>Quercus coccinea</i>	0.43	0.09	1.61	0.26
<i>Catalpa speciosa</i>	0.28	0.09	0.64	0.11	<i>Quercus lyrata</i>	0.42	0.08	1.35	0.20
<i>Celtis occidentalis</i>	0.26	0.03	1.13	0.17	<i>Quercus macrocarpa</i>	0.35	0.07	1.20	0.19
<i>Cladrastis kentukea</i>	0.23	0.03	0.61	0.14	<i>Quercus palustris</i>	0.46	0.09	1.30	0.20
<i>Cornus florida</i>	1.04	0.17	1.74	0.29	<i>Quercus phellos</i>	0.45	0.08	1.38	0.25
<i>Cornus nuttallii</i>	1.13	0.20	1.64	0.27	<i>Quercus prinus</i>	0.40	0.09	1.45	0.22
<i>Diospyros virginiana</i>	0.36	0.04	1.39	0.20	<i>Quercus rubra</i>	0.42	0.09	1.32	0.29
<i>Fagus grandifolia</i>	0.61	0.11	1.28	0.21	<i>Quercus shumardii</i>	0.45	0.08	1.44	0.20
<i>Fraxinus americana</i>	0.29	0.03	1.26	0.17	<i>Quercus stellata</i>	0.43	0.09	1.35	0.21
<i>Fraxinus latifolia</i>	0.23	0.05	1.20	0.16	<i>Quercus velutina</i>	0.43	0.08	1.44	0.29
<i>Fraxinus nigra</i>	0.27	0.04	1.27	0.17	<i>Robinia pseudoacacia</i>	0.18	0.02	1.13	0.16
<i>Fraxinus pennsylvanica</i>	0.26	0.03	1.27	0.17	<i>Salix nigra</i>	0.42	0.09	0.85	0.17
<i>Fraxinus quadrangulata</i>	0.23	0.04	1.03	0.15	<i>Sassafras albidum</i>	0.39	0.06	1.02	0.14
<i>Gleditsia triacanthos</i>	0.19	0.03	1.24	0.11	<i>Tilia americana</i>	0.43	0.09	1.21	0.17
<i>Gymnocladus dioica</i>	0.27	0.06	1.12	0.15	<i>Tilia heterophylla</i>	0.48	0.04	1.34	0.18
<i>Ilex opaca</i>	0.88	0.24	1.74	0.27	<i>Ulmus americana</i>	0.22	0.04	1.55	0.20
<i>Juglans cinerea</i>	0.36	0.14	1.13	0.17	<i>Ulmus rubra</i>	0.22	0.03	1.30	0.15
<i>Juglans nigra</i>	0.51	0.08	1.21	0.14	<i>Ulmus thomasii</i>	0.25	0.03	1.21	0.16
<i>Liquidambar styraciflua</i>	1.32	0.30	1.82	0.16	<i>Umbellularia californica</i>	0.37	0.06	0.94	0.14

Vessel elements may also vary in length to a lesser extent in the same tree, because of increase in size of the cambial initials as a tree matures. Considerable variation in length of the elements may be also found in the same ring, particularly in the ring-porous woods such as oak. This situation arises because the vessel members in the late wood remain about the same length as the cambial initials, but those in the early wood shorten appreciably as they increase in diameter and become annular or barrel-shaped.

A vessel element in transverse aspect, i.e., cut at right angles to the grain, appears as a pore. The term *pore* includes not only the actual opening but the encircling wall as well. The cross sections of vessel elements (the wood pores) vary greatly in diameter. The tangential diameter is the more conservative and hence is the dimension usually measured in determining the size of vessel elements. The smallest pores have a tangential diameter in the neighborhood of 20 micrometers; the other extreme is found in the oaks (*Quercus* spp.), where pores at the beginning of the ring are frequently 300 plus micrometers in width. Lianas, such as grape and woodbine, have even larger pores.

c Arrangement of Vessel Elements Hardwoods can be divided into three groups on the basis of the variation in pore size within growth rings. If the pores formed in the spring are much larger than those formed later in the season, the wood is *ring-porous*, as in oak (*Quercus* spp.), elm (*Ulmus* spp.), and ash (*Fraxinus* spp.). On the other hand, if the pores are fairly uniform in size and quite evenly distributed throughout the ring, the wood is said to be *diffuse-porous*, as in birch (*Betula* spp.), maple (*Acer* spp.), basswood (*Tilia* spp.), and yellow-poplar (*Liriodendron tulipifera* L.). Certain woods such as *Juglans* spp. and persimmon (*Diospyros virginiana* L.) are intermediate in this respect, and are classed as *semi-ring-porous* or *semi-diffuse-porous*.

Woods of the same genus, and even the same species, may be ring-porous in one region of the North Temperate Zone but exclusively diffuse-porous farther south. The first few rings of ring-porous wood, next to the pith, retain a certain degree of diffuse porousness because the early-wood pores do not attain maximum size in successive rings for a number of years.

Pores may be solitary or grouped in various ways. A *solitary* pore is generally rounded; the oval shape predominates, with the long axis directed radially. In woods with thick-walled fibrous elements and thin-walled vessels, as in sweetgum (*Liquidambar styraciflua* L.), the pores are angular (Figs. 5-1 and 5-2). Not infrequently several pores are contiguous in a radial direction. Such a pore cluster appears as one pore consisting of several divisions. This type of pore arrangement is known as a *pore multiple*; it is common in maple (*Acer* spp.), birch (*Betula* spp.), *Populus* spp., and many

other woods. Radial series of solitary pores are called *pore chains*; this kind of pore grouping is exemplified by holly (*Ilex* spp.). Nested late-wood pores (*pore clusters*) are an important diagnostic feature of coffeetree [*Gymnocladus dioica* (L.) K. Koch]. Tangential grouping of late-wood pores into concentric wavy *bands* is characteristic of elms (*Ulmus* spp.), hackberry (*Celtis* spp.), and a few other woods.

The spacing and number of pores per square millimeter of surface are also variable. In some woods tracts of tissue can be found that are entirely devoid of pores, whereas in neighboring tracts of the same portion of the ring, numerous pores can be counted. In boxwood (*Buxus sempervirens* L.) the pores average about 180 per square millimeter. Pore counts between 6 and 20 per square millimeter may be considered as average.

d Sculpturing of Vessel Elements The sculpturing of vessel elements is occasioned in part by the nature of the openings that form at or near their ends, in part by the nature of their pitting, and by thickenings, provided these are present, on the inner surface of the secondary wall.

1 *Nature of the opening between vessel elements* (Fig. 5-5) Communication between elements of a vessel is ensured through the formation of an aperture or a series of transversely oriented apertures through the walls common to two adjacent vessel elements. The portion of the wall involved in the coalescence of two members of a vessel is known as a *perforation plate*, and the apertures are termed *perforations*.

In reality a perforation plate consists of two *half plates* that are reversed as to direction, each half belonging to different vessel elements meeting at that point. Ordinarily a given vessel element possesses two such half perforation plates, one at each end; but occasionally more than two are present, indicating that the vessel element in question connects with as many vessel elements as there are perforation plates.

When but one aperture (perforation) is in evidence, the perforation plate is *simple* (Fig. 5-5a and f). When a number of parallel, transversely oriented apertures are present, it is called a *scalariform perforation plate* (Fig. 5-5c and e). Some of the bars in plates of this type may be branched. Another type of plate, not seen in commercial trees of the temperate zone, is the *reticulate perforation plate* with irregular perforations in a network of bars (Fig. 5-5g). In any case, that portion of the margin of the plate remaining after perforation is complete is called a *perforation rim* (Figs. 5-5a and 5-6); it may be narrow or wide. The number of bars in a multiple perforation plate may be few or many. If there are only a few bars, they are usually rather thick (Fig. 5-5c). In the elongated plates with many bars, the bars are slender, as, for instance, in sweetgum (*Liquidambar styraciflua* L.) (Fig. 5-5e).

2 *Nature and extent of pitting on the walls of vessel elements* The nature and the extent of the pitting on the walls of a vessel element vary

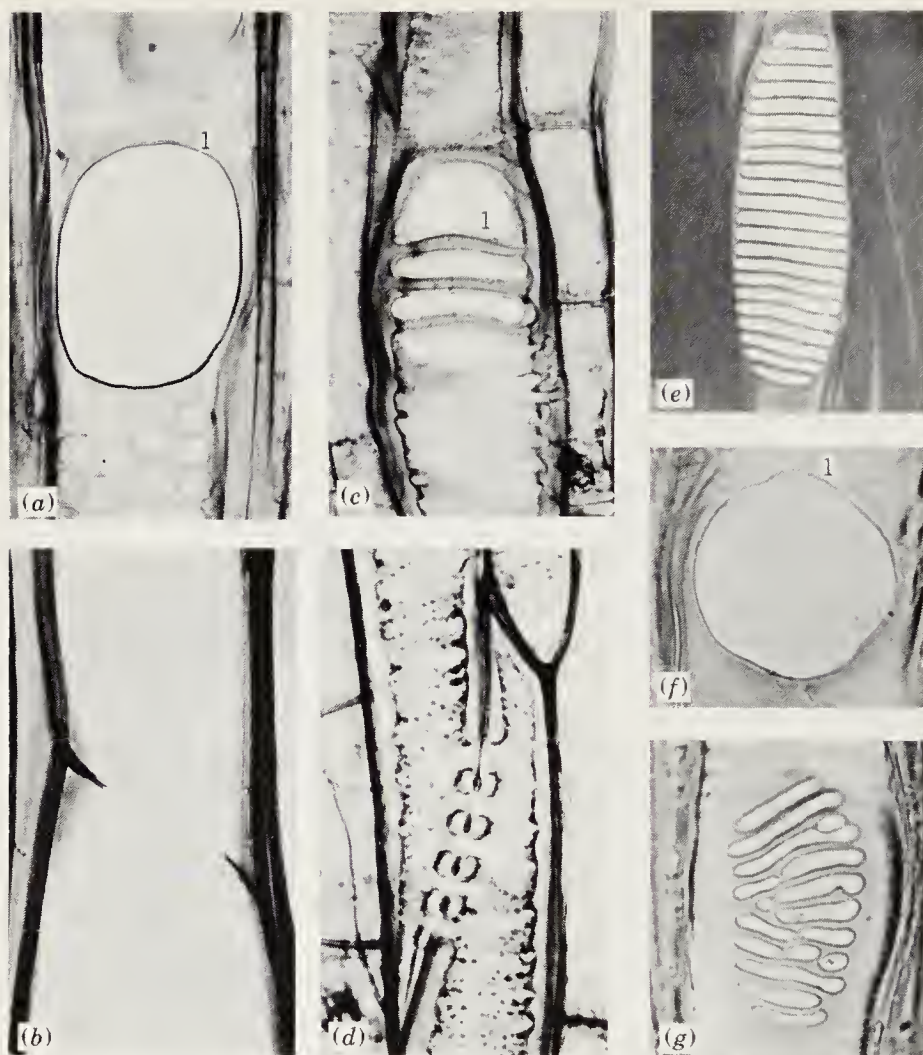


Figure 5-5 Types of perforations between vessel elements.

- (a) Simple perforation plate in cottonwood (*Populus deltoides* Bartr.) in oblique surface (radial) view; the perforation rim (1) is visible on the upper margin of the orifice. (550 $\times$)
- (b) A similar perforation plate in sectional (tangential) view, at the same magnification as (a).
- (c) Scalariform perforation plate with three thick bars (1) in a late-wood vessel in sassafras [*Sassafras albidum* (Nutt.) Nees] in oblique surface (radial) view. (550 $\times$)
- (d) A similar plate in sectional (tangential) view, at the same magnification as (c).
- (e) Scalariform perforation plate with many thin bars, in sweetgum (*Liquidambar styraciflua* L.) in oblique surface (radial) view. (170 $\times$)
- (f) Simple perforation plate in sparkleberry (*Vaccinium arboreum* Marsh.) in oblique surface (radial) view; the perforation rim (1) is visible at the upper margin of the orifice. (1240 $\times$)
- (g) Reticulate perforation plate in sparkleberry (*Vaccinium arboreum* Marsh.) in oblique surface (radial) view. (1240 $\times$) Both simple [see (f)] and foraminated perforations occur in this wood.

greatly depending upon the kinds of cells that happen to be in contact with them. Pit pairs between vessel elements and fibers or tracheids are usually bordered. Where they lead to parenchymatous elements they may be bordered, half-bordered, or simple.

Points of contact of vessel elements and rays usually stand out, because the pits are different in size, in nature, and in arrangement from those leading to longitudinal elements (Fig. 5-6). Pits leading to tracheids and fibers are usually in vertical or nearly vertical rows, conforming to the configuration of these elements (Fig. 5-6Ab). In some woods pit pairs are wanting where libriform fibers are in contact with vessel elements.

Intervessel pitting is generally the most conspicuous, and it appears to best advantage on the tangential faces of a vessel element. It is frequently of diagnostic significance. Three arrangements of intervessel pit grouping are



Figure 5-6 Pitting in vessel elements.

(A) Two vessel elements of northern red oak (*Quercus rubra* L.). The larger vessel element shows a. areas of horizontally oriented ray-vessel pitting and b. areas of pitting between the vessel element and the mixed axial parenchyma strands and vasicentric tracheids touching the element. Intervessel pitting is very scarce and is not visible in this view. The ends of three vasicentric tracheids that are attached to the vessel are visible at c.

(B) A vessel element of cucumbertree (*Magnolia acuminata* L.) showing the linear, scalariform intervessel pitting at a. The ray-vessel pitting on the top face at b clearly shows that the rays in contact with this vessel element were all homocellular as is evident from the transversely oriented pit apertures. Scanning electron micrographs of freeze-dried vessel elements. (125×) (Courtesy of Center for Ultrastructure Studies, State University of New York, College of Environmental Science and Forestry, Syracuse, N.Y.)

recognized: *alternate pitting* (Figs. 11-149 and 11-154), *opposite pitting* (Figs. 11-160 and 11-161), and *scalariform pitting* (Fig. 11-153).

The pits in the alternate pitting arrangement are in diagonal rows. They range from circular to oval, if they are uncrowded; if crowded they are polygonal and frequently hexagonal. Where the opposite arrangement prevails, i.e., when the pits in adjacent horizontal rows are oppositely arranged, the pits are often rectangular. The pitting is described as scalariform when the pits are linear, with the long axis across the vessel, and are arranged in a ladder-like series.

The variations in shape and size of intervessel pits may best be observed by reference to Figs. 11-142 to 11-161. Those in birch or persimmon, ranging from 2 to 4 micrometers in diameter, may be considered as unusually small; pits in maple, ranging from 5 to 10 micrometers in diameter, are of average size; linear pits in magnolia, varying from 12 to 50 micrometers in size, are exceptionally large.

The intervessel pits of *Cladrastis*, *Gleditsia*, *Gymnocladus*, and *Robinia* of the Leguminosae are *vestured*. These structures appear as dots in the pit apertures when viewed with the light microscope (Fig. 3-17). The presence of these structures is difficult to determine because other materials lodged in the pits may give the same appearance; for this reason, vestures are of secondary importance in identification.

3 *Spiral thickening in vessel elements* Spiral thickening in hardwoods is localized thickening in the form of ridges on the inner surface of the secondary wall and is believed to be an integral part of the wall. Spiral thickening characterizes the vessel elements of some hardwoods (Figs. 11-142, 11-152, and 11-157), but in some woods it occurs also in the fibers and the tracheids (Figs. 3-15 and 5-9).

In diffuse-porous hardwoods the vessel elements throughout the ring may have spiral thickenings; in ring-porous woods, on the other hand, the spirals, when present, are usually confined to the smaller vessel elements in the late wood. Sweetgum and tupelos are peculiar in that the spiral thickening is restricted to the tips of the vessel extensions.

Spiral thickening is an important diagnostic feature. It occurs, for example, in *Acer* spp. but is lacking in *Betula* spp. Tropical hardwoods rarely show thickenings of this sort. The small vessels and vascular tracheids of the elms (*Ulmus* spp.) and hackberry (*Celtis* spp.) are always characterized by its presence.

A special form of ridged thickening on the inner face of the vessel walls is found in *Juglans nigra* L. and three others of the less-important species of the black walnut group of the United States, i.e., *Juglans californica* S. Wats. (including *Juglans hindsii* Jepson), *Juglans major* (Torr.) Heller, and *Juglans microcarpa* Berlandier. In these species, the radial walls of the smaller late-wood vessel elements have an interlacing reticulum of thickenings

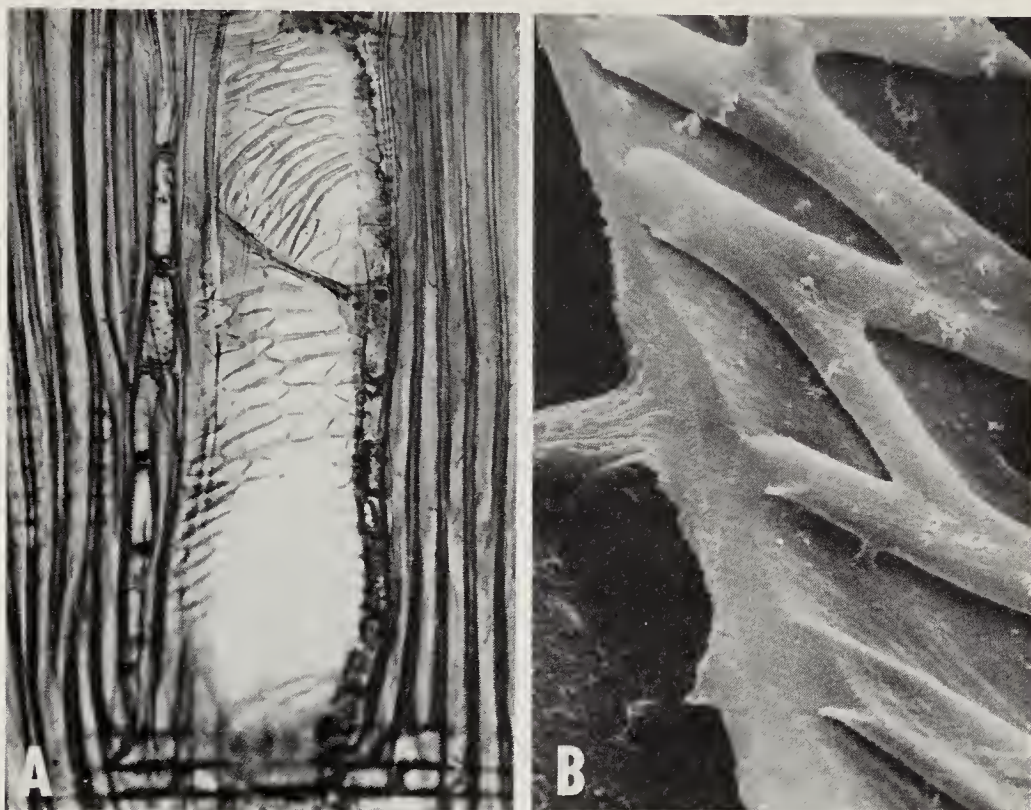


Figure 5-7 Reticulate thickenings of vessel elements in black walnut (*Juglans nigra* L.).

(A) Light micrograph of radial section. (175 $\times$)

(B) Scanning electron micrograph of the reticulate thickenings on the inner wall of the vessel element. (2500 $\times$)

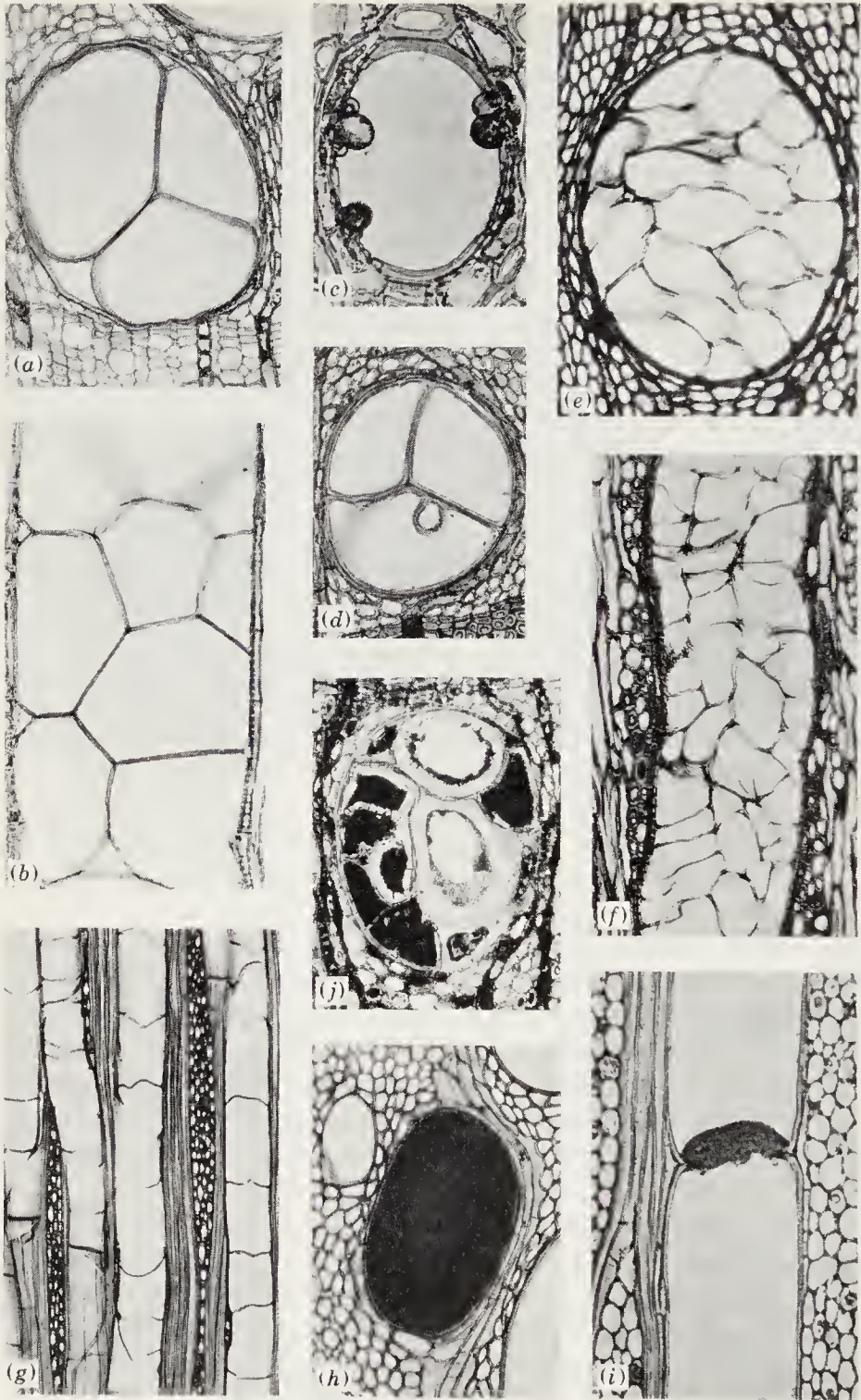
(Courtesy of Regis Miller, U. S. Forest Products Laboratory. Ref. 9.)

which give the appearance under the light microscope of irregular “gashlike” vessel pitting which does not coincide with the contact areas of the ray cells (Fig. 5-7) (Ref. 9). This feature furnishes a definite separation between black walnut (*Juglans nigra* L.) and butternut (*Juglans cinerea* L.).

e Inclusions in Vessel Elements The inclusions that are most frequent in vessel elements are tyloses and various amorphous exudations that are gummy, resinous, or chalky in nature. Rarely, starch grains and crystals are also in evidence.

A *tylosis* (pl. *tyloses*) may be defined as an outgrowth of protoplasm from an adjacent parenchyma cell through a pit cavity in the cell wall into the cavity of a vessel element, forming a saclike structure. When numerous, tyloses may fill the vessel lumen completely (Fig. 5-8*b*, *e*, and *f*). Occasionally tyloses may have thick, pitted walls, dark gum in their lumens (Fig. 5-8*j*), and crystals.

Tyloses are usually formed in the inner sapwood, just prior to its transformation into heartwood. This is a normal physiological process that occurs in many species of hardwoods. However, normal tyloses sometimes



form in the outer sapwood also, particularly in regions where, for one reason or another, the water content falls below normal. Tyloses may also form as a result of mechanical injury, fungous growth, and virus infection. Such tyloses are considered to be traumatic. Likewise, cases are known where tyloses formed in trees after they had been felled, plugging all the sapwood vessels. For further information on tylosis and its formation, see page 121.

Chattaway (Ref. 3) states that when the pit apertures in the pit pairs leading from the ray cells into the vessels are small, the activity of ray cells results in secretion of gummy substances, instead of tylosis formation. When these substances come in contact with the air in the vessels, they solidify and form gums and resins of various types and chemical compositions.

Chattaway (Ref. 3) suggests further that, since the ray cells play an important role in blocking of vessels at heartwood formation, one of the clues to the development of heartwood may be found in the length of life of the ray cells.

Profuse tylosis and gum formation inhibits the penetrability of a wood but does not necessarily increase its durability. The white oaks normally have a high tylosic content, and the wood is used for tight cooperage. The red oaks, in contrast, have so few tyloses that it is possible to blow through a piece of wood for some distance along the grain; red oaks hence are not suited for tight cooperage unless specially treated. On the other hand, woods with open pores treat more easily with preservatives.

Gummy materials in the vessel elements occur in irregular lumps on the inner walls. They may completely occlude the cell (Fig. 5-8*h*) or form false partitions (Fig. 5-8*i*) across the vessel at the juncture where two vessel members meet, thus effectively blocking the vessel at these points. In

Figure 5-8 Inclusions in the vessels of hardwoods.

- (a) Tyloses in an early-wood pore of post oak (*Quercus stellata* Wangerh.); walls somewhat thickened. (115×)
- (b) Portion of an early-wood vessel element (*t*) of post oak (*Q. stellata* Wangerh.) showing contiguous tyloses in lateral view. (115×)
- (c) Tyloses in the bud stage in a late-wood pore of live oak (*Q. virginiana* Mill.). (225×)
- (d) Secondary tylosis bud forming on the wall of a tylosis in blue oak (*Q. douglasii* Hook. & Arn.). (115×)
- (e) Thin-walled tyloses in an early-wood pore of black oak (*Q. velutina* Lam.). (115×)
- (f) Portion of an early-wood vessel (*t*) of black locust (*Robinia pseudoacacia* L.) showing thin-walled tyloses in lateral view. (115×)
- (g) Uniseriate rows of tyloses in the vessels of beech (*Fagus grandifolia* Ehrh.); the upper and lower walls (which are in contact) appear as nearly horizontal transverse partitions arranged in a ladder-like series. (115×)
- (h) A pore of honeylocust (*Gleditsia triacanthos* L.) occluded with gum. (115×)
- (i) A gum plug at the juncture of two vessel elements in large-leaved mahogany (*Swietenia macrophylla* King). (115×)
- (j) Sclerosed, pitted tyloses, with dark contents, in a pore in Emory oak (*Quercus emoryi* Torr.) (115×)

[Photographs (a) to (f), inclusive, by S. Williams.]

domestic timbers the color of the gum is usually some shade of red or brown. In pale-yellow woods, of the type included in the Rutaceae, it appears yellow by transmitted light. The jet black of ebony (*Diospyros ebenum* Koenig) is due to copious deposits of gummy infiltration of the same color, not only in the vessel members but in the lumina of the other elements of the wood as well.

The presence or absence of gummy deposits in the vessels is frequently of value in identification. Honeylocust (*Gleditsia triacanthos* L.) has abundant reddish deposits of this sort in the heartwood; they are wanting or scanty in the wood of the botanically related Kentucky coffeetree [*Gymnocladus dioica* (L.) K. Koch], and hence this feature can assist in the separation of these woods.

Chalky deposits occur in the vessels of some woods, although their distribution is too sporadic to serve as a positive aid in identification. They are usually present in mahogany (*Swietenia* spp.) and in teak (*Tectona grandis* L. f.) and occasionally in mulberry (*Morus rubra* L.). Little is known about the chemistry of these deposits; those of teak are said to consist of calcium phosphate.

f Trabeculae in Vessel Elements Trabeculae are well known in softwoods (see page 138) and were noted many years ago as being present in hardwoods but were not described or illustrated. Recent work by Meylan and Butterfield (Ref. 8) using the scanning electron microscope with several New Zealand hardwoods has shown the same types of structures as previously described for the tracheids in the softwoods. In hardwoods trabeculae appear in the vessel elements. In contrast with the softwoods, the trabeculae in hardwoods apparently do not form long, radial strands, and their bases at the vessel walls tend to be more expanded.

g Vessel Volume The average vessel volume in the hardwoods of the United States and Canada, listed in Table 5-3, is approximately 30 percent with a range from 6.5 to 55 percent.

2 HARDWOOD TRACHEIDS Two distinct types of hardwood tracheids are recognized; these are *vascular tracheids* and *vasicentric tracheids*.

a Vascular Tracheids These are cells very similar in size, shape, and position to small late-wood vessel elements, except that they are imperforate at the ends. They are arranged in vertical series, like the small vessels with which they are associated (Fig. 5-9b); a given series may consist entirely of vascular tracheids, or of a mixture of these and vessel members, without any regular sequence.

The lateral walls of vascular tracheids contain numerous bordered pits, of the same general type as intervessel pits, and frequently possess conspicuous spiral thickenings. Vascular tracheids with spirals are found in *Ulmus* and *Celtis* in the wavy bands of mixed small vessel elements and vascular tracheids that characterize their late wood. Since vascular trache-

Table 5-3 Volumetric Composition of Some Porous Woods

Species	Percentages of total volume			
	Vessels	Fibers	Rays	Axial parenchyma
<i>Acer rubrum</i>	18.0	68.0	13.3	0.1
<i>Acer saccharinum</i>	21.4	66.6	11.9	0.1
<i>Acer saccharum</i>	21.0	61.0	17.9	0.1
<i>Betula alleghaniensis</i>	21.4	63.8	10.8	2.0
<i>Betula papyrifera</i>	10.6	75.7	11.7	2.0
<i>Carya ovata</i>	6.5	65.5	20.0	8.0
<i>Carya pecan</i>	7.7	55.0	26.4	10.9
<i>Castanea dentata</i>	39.8	46.8	11.9	1.5
<i>Celtis occidentalis</i>	50.8	27.4	13.3	8.5
<i>Cornus florida</i>	9.9	57.5	27.0	5.6
<i>Fagus grandifolia</i>	21.4	56.7	20.4	—
<i>Fraxinus americana</i>	20.4	61.7	11.9	4.2
<i>Fraxinus nigra</i>	11.6	69.4	12.0	7.0
<i>Fraxinus latifolia</i>	31.4	51.3	14.5	2.8
<i>Juglans cinerea</i>	22.6	58.0	10.4	9.0
<i>Juglans nigra</i>	21.0	48.7	16.8	13.5
<i>Liquidambar styraciflua</i>	54.9	26.6	18.3	0.2
<i>Liriodendron tulipifera</i>	36.6	49.0	14.2	0.2
<i>Magnolia acuminata</i>	38.6	47.3	13.9	0.2
<i>Nyssa sylvatica</i>	38.4	45.0	17.6	—
<i>Platanus occidentalis</i>	51.9	28.9	19.2	—
<i>Populus deltoides</i>	33.0	53.1	13.7	0.2
<i>Populus grandidentata</i>	33.8	55.0	11.1	0.1
<i>Prunus serotina</i>	41.4	41.4	17.2	—
<i>Quercus alba</i>	16.1	47.8	28.0	8.0
<i>Quercus macrocarpa</i>	26.6	40.8	20.6	12.0
<i>Quercus rubra</i>	21.6	43.5	21.4	13.5
<i>Quercus rubra*</i>	19.5	41.3	15.9	23.4
<i>Quercus velutina</i>	14.1	37.3	31.4	17.2
<i>Robinia pseudoacacia</i>	14.8	57.9	20.9	6.4
<i>Salix nigra</i>	38.1	54.4	7.4	0.1
<i>Tilia americana</i>	55.6	36.1	6.1	2.2
<i>Ulmus americana</i>	48.0	34.7	11.3	6.0
<i>Ulmus rubra</i>	29.3	57.3	11.4	2.0
<i>Ulmus thomasii</i>	25.4	55.4	11.7	7.6

*Represents 240 mature, dominant, or co-dominant trees throughout range of *Quercus rubra* measured by R. R. Maeglin (Ref. 7).

Source (with one exception): G. E. French, unpublished M.S. thesis, New York State College of Forestry, Syracuse, N.Y., 1923.

ids, when cut transversely, have the same appearance as pores, they cannot be distinguished from true pores in the cross section of wood.

b Vasicentric Tracheids These are short, irregularly shaped cells, with closed ends, that abound in the proximity of the large early-wood vessels of

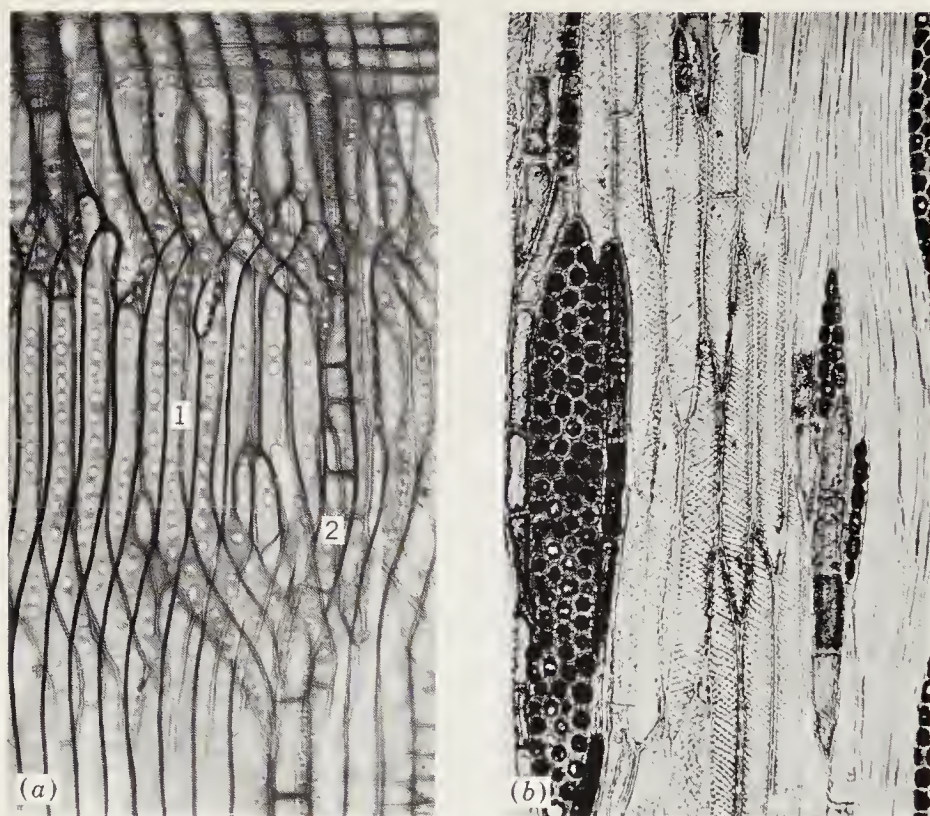


Figure 5-9 Vasicentric and vascular tracheids in hardwoods.

(a) Overlapping vasicentric tracheids with bordered pits (1) and a strand of longitudinal parenchyma (2), in chestnut [*Castanea dentata* (Marsh.) Borkh.] (r). (240×)

(b) Vascular tracheids with spiral thickening, which grade into small vessel members elsewhere in the wood. Slippery elm (*Ulmus rubra* Mühl.) (t). (160×)

such ring-porous woods as oaks and chestnut; they are also found in lesser numbers in the flame-shaped areas of porous tissue extending into the late wood in these woods. In both instances they are associated with axial parenchyma, which they resemble in cross section (Fig. 5-9a). The lateral walls of vasicentric tracheids are copiously pitted with conspicuous bordered pits.

Vasicentric tracheids differ from vascular tracheids in having tapering or rounded ends and in not being arranged in definite longitudinal rows.

The transition from large early-wood vessel elements to neighboring vasicentric tracheids is abrupt; that from the latter to wood fibers, in contrast, is more gradual, often through intermediate cell types.

3 FIBERS The term *fiber* is frequently used loosely for any kind of wood cell. Specifically this term applies to long, narrow cells with closed ends, other than tracheids. Two types of fibers are recognized: *fiber tracheids* and *libriform fibers*. Both types of fibers may have moderately to very thick walls. The difference between the two is based on the nature of the pitting.

Fiber tracheids have distinctly bordered pits, with lenticular to slitlike apertures. Obviously this terminology could be applied equally well to the late-wood tracheids in softwoods, but the term fiber tracheid is restricted to hardwoods by most authors (Fig. 3-11a and d).

Libriform fibers possess pits which are simple or have borders too narrow to be apparent.

Fiber tracheids grade into libriform fibers on the one hand, and, when septate, into strand parenchyma on the other. Fiber tracheids and libriform fibers may occur in the same wood, and the transition between them is often so gradual that it may be an arbitrary matter in assigning a given cell to one or the other type.

Both types of fibers exhibit a number of modifications, some of which are of diagnostic value. As a rule the inner surface of the secondary wall of fibers is smooth; in some woods, such as holly (*Ilex opaca* L.), spiral thickenings may be present. In other woods, for instance, California-laurel [*Umbellularia californica* (Hook. & Arn.) Nutt.], thin transverse walls (*septa*) form in the fibers, resulting in *septate* libriform fibers or fiber tracheids. Such transverse walls extend only to the inner surface of the lateral secondary walls of the fiber, dividing the fiber into two or more compartments. Not infrequently the fibers are falsely septated. This feature is rare in temperate-zone woods but common in tropical timbers. False septation results from the deposition of transverse plates of gummy or resinous materials, simulating true *septa*.

Tyloses occur in the fibers of several genera of the Magnoliaceae (Ref. 5). In the woods of the United States they may be seen in *Magnolia fraseri* Walt., *Magnolia tripetala* L., and rarely in *Magnolia virginiana* L. on the tangential sections in the vicinity of the rays.

Another modification of fibers consists of the *gelatinous fibers*, encountered mostly in tension wood of hardwoods (see page 315), but also mixed with unmodified fibers in the normal wood of oaks (*Quercus* spp.). These fibers differ from the normal kind in possessing an innermost cell wall layer which differs in physical and chemical properties from the usual secondary cell wall layer (Figs. 5-10, 8-12, and 8-13). This layer, generally described as *gelatinous*, is highly refractory to light and usually gives a cellulose reaction with various staining reagents, indicating absence or a low degree of lignification. The so-called *gelatinous layer* may be present in addition to layers S 1, S 2, and S 3, or may replace layer S 3 or layers S 2 and S 3.

Fiber tracheids and libriform fibers vary greatly in diameter, in length (Tables 5-2, 5-4, and 5-5), in the thickness of walls, and in the volume entering into the structural composition of a wood. This holds not only for different species but also in different individuals of the same species, and even at different places in a tree.

For instance, Taylor (Ref. 11), on the basis of the analysis of six



Figure 5-10 Gelatinous (dark-colored) and normal fibers in white oak (*Quercus alba* L.). (450×) (Photomicrograph by S. Williams.)

yellow-poplar trees (*Liriodendron tulipifera* L.), reports that the weighted average of fiber length in this species decreased steadily with increase in height from the base of the trees, as shown in column 1 of Table 5-5.

Taylor observes further that this decrease in fiber length cannot be attributed to increased proportion of juvenile wood alone, since this same trend was evident in the fibers from the mature wood as well. This is illustrated in column 2, Table 5-5. Discussion of the possible reasons for these observed differences can be found in Chap. 7. The variations in the amount and quality of fibrous tissue have a profound effect on wood density, strength, shrinkage characteristics, and other factors affecting utilization of wood.

a Fiber Volume in Wood The proportion of the total volume of wood in the hardwoods occupied by fiber tracheids and libriform fibers, either separately or in admixture, varies widely from a minimum of 27 percent in sweetgum (*Liquidambar styraciflua* L.) to a maximum of 76 percent in paper birch (*Betula papyrifera* Marsh.), with the average of about 50 percent for all species (Table 5-3). The distribution of the fibers may be quite uniform

Table 5-4 Mean Weighted Specific Gravity, Fiber Length in the Thirtieth Ring, and Their Ranges Sampled from Cross Sections 4.5 Ft from Tree Base

Species	Average weighted sp gr	Range	Average fiber length 30th year, mm	Range, mm
Yellow poplar	0.440	0.380-0.520	2.0	1.40-2.40
Sweetgum	0.496	0.434-0.580	1.93	1.65-2.14
Water tupelo	0.474	0.433-0.550	1.85	1.44-2.13
Sycamore	0.476	0.404-0.533	1.83	1.49-2.16
Swamp blackgum	0.479	0.381-0.587	1.78	1.46-2.21
Water oak	0.599	0.538-0.643	1.54	1.32-1.76
Willow oak	0.587	0.522-0.640	1.54	1.33-1.81
White ash	0.546	0.480-0.593	1.14	0.99-1.42
Red maple	0.496	0.429-0.540	0.97	0.89-1.06

Source: R. L. McElwee, Wood and Fiber Characteristics of Selected Southern Hardwoods, presented at the Carolinas-Chesapeake Section Meeting, Forest Products Research Society, Clemson, S.C., Oct. 20, 1967.

throughout the growth increment as in *Liquidambar*; it may be concentrated in the late wood as in the ring-porous oaks (*Quercus*); or it may be distributed in tangential bands as in the late wood of elm (*Ulmus*).

4 LONGITUDINAL (AXIAL) PARENCHYMA Wood parenchyma is a tissue composed of comparatively short, brick-shaped, or isodiametric cells equipped in most cases with simple pits only. These cells are involved primarily in storage and to a lesser extent in the conduction of carbohydrates; they remain functional for a much longer period (supposedly as long as they are a part of the sapwood) than the conductive and mechanical cells. As indicated in Table 5-1, there are three kinds of longitudinal parenchyma: (a) *strand parenchyma*, (b) *fusiform parenchyma*, and (c) *epithelial parenchyma*.

a **Strand Parenchyma** This type is formed through transverse division of the fusiform cambial daughter cell, with the entire strand approximately

Table 5-5 Average Fiber Length at Varying Heights in Six Yellow-Poplar (*Liriodendron tulipifera* L.) Trees

Height above ground, ft	Weighted average length, mm (1)	Average length in 20th ring, mm (2)
4.5	1.91	2.02
20	1.77	—
40	1.61	1.86
60	1.45	1.40

Source: F. W. Taylor, Variations in the Size and Proportion of Wood Elements in Yellow-Poplar Trees, *Wood Sci. & Technol.*, 2(3):153-165 (1968).

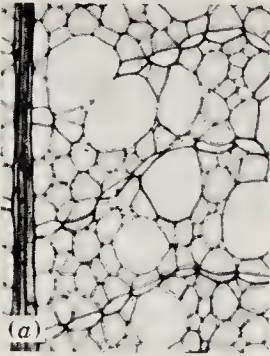
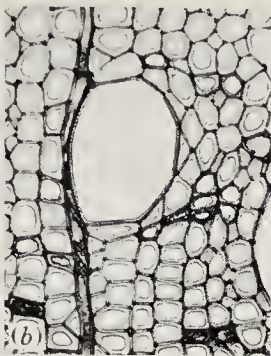
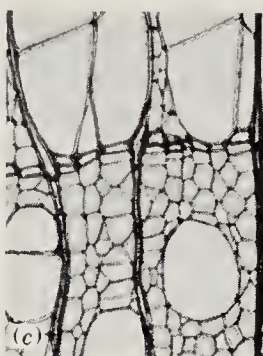
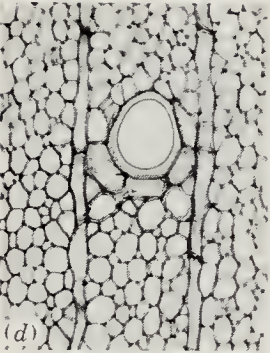
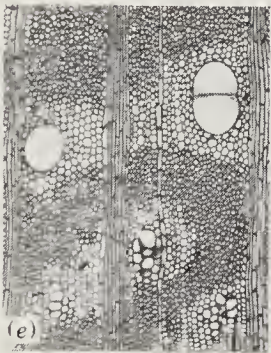
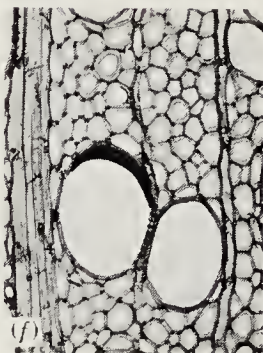
the same shape as the original cambial cell. As seen along the grain (Fig. 5-11), the parenchyma strands vary in number of cells from one to many, although in the same kind of wood the range is usually small.

Strand parenchyma is by far the most common type of longitudinal parenchyma in hardwoods. In some tropical tree species it may comprise an appreciable volume of the wood, at times more than 50 percent; in domestic woods it ranges from less than 1 to about 24 percent in volume (Table 5-3). Longitudinal strand parenchyma, when massed in various ways, is often visible on transverse surfaces at low magnification, appearing lighter or darker than the surrounding tissue. Various arrangements of parenchyma are recognized, and these are sufficiently uniform to permit their use in the identification of the various porous woods. The descriptive terms used in this text in defining different arrangements of longitudinal parenchyma, as visible in transverse sections, are as follows (Fig. 5-11):

- 1 *Apotracheal parenchyma*—longitudinal parenchyma arranged independently of the pores.
 - a *Diffuse-apotracheal*—single parenchyma cells distributed irregularly among fibers, as in sweetgum (*Liquidambar styraciflua* L.) and tupelo (*Nyssa* spp.).
 - b *Diffuse-in-aggregates*—apotracheal parenchyma cells that tend to be grouped in short tangential lines, sometimes extending from ray to ray (Fig. 5-11b), as in yellow birch (*Betula alleghaniensis* Britton).
- 2 *Paratracheal parenchyma*—longitudinal parenchyma associated with the vessels or vascular tracheids.
 - a *Scanty paratracheal*—paratracheal parenchyma confined to a few cells around the vessels, as in birch (*Betula* spp.) and maple (*Acer* spp.).
 - b *Vasicentric paratracheal* (Fig. 5-11d)—paratracheal parenchyma

Figure 5-11 Longitudinal (axial) parenchyma in hardwoods.

- (a) Longitudinal apotracheal-banded parenchyma (x) in basswood (*Tilia americana* L.). (150×)
- (b) Longitudinal diffuse-in-aggregates parenchyma (dark cells) (x) in yellow birch (*Betula alleghaniensis* Britton). (150×)
- (c) Marginal parenchyma (x) on the outer margin of an annual ring in eastern cottonwood (*Populus deltoides* Bartr.)
- (d) Vasicentric paratracheal parenchyma (x) nearly encircling a late-wood pore in white ash (*Fraxinus americana* L.). (150×)
- (e) Paratracheal confluent parenchyma (x) in honeylocust (*Gleditsia triacanthos* L.). (40×)
- (f) Xylem tissue (x) devoid of axial parenchyma in black cherry (*Prunus serotina* Ehrh.). Axial parenchyma is extremely sparse in this wood. (150×)
- (g) Strands of axial parenchyma (1), and a late-wood vessel (2), with scalariform perforation plates, in lateral, tangential view. [*Sassafras albidum* (Nutt.) Nees]. (150×)
- (h) Strands of axial parenchyma composed of two (1) and four (2) units, and fusiform longitudinal parenchyma cells (3), in lateral, tangential view. Black locust (*Robinia pseudo-acacia* L.). (150×)
- (i) Portions of a number of strands of axial parenchyma, separated by fibers, in lateral, radial view. Scarlet oak (*Quercus coccinea* Muenchh.). (150×)



- forming a more or less complete sheath, one or more cells wide, around a vessel, as in persimmon (*Diospyros virginiana* L.).
- c *Aliform paratracheal*—paratracheal parenchyma that extends from the flanks of the pore, forming winglike lateral extensions. This type of parenchyma is more common in the tropical woods; it is present occasionally in California laurel *Umbellularia californica* (Hook. & Arn.) Nutt. and in the outer late wood of some species of ash (*Fraxinus*).
 - d *Confluent-paratracheal* (Fig. 5-11e)—aliform parenchyma forming irregular tangential or diagonal bands that coalesce, as in honeylocust (*Gleditsia triacanthos* L.).
- 3 *Banded parenchyma*—parenchyma forming concentric lines or bands. It could be further differentiated into *apotracheal banded*, if mainly independent of the pores, as in basswood (*Tilia* spp.) (Fig. 5-11a), or *paratracheal-banded*, if definitely associated with the pores. Since, however, both types of banded parenchyma generally occur in the same wood, as, for example, in hickory (*Carya* spp.) and beech (*Fagus* spp.), the use of the term *banded* without further qualification is quite appropriate.
 - 4 *Marginal parenchyma*—longitudinal parenchyma occurring either as occasional cells, or forming a more or less continuous layer of one to more cells in width, at the margin of a growth ring (Fig. 5-11c). Formerly this type of parenchyma was described as *terminal*. However, Chowdhury (Ref. 4) has shown that longitudinal parenchyma can occur either at the end of the season's growth or at its beginning. He has therefore proposed the designation of *terminal* for the former and *initial* for the latter. But since in actual practice it is frequently difficult to distinguish between these two types, a single term *marginal* is preferred. *Marginal parenchyma* occurs as occasional cells in the maples (*Acer* spp.) and birches (*Betula* spp.), associated with other types of parenchyma, or in more or less continuous bands as in the genera *Salix*, *Populus*, *Liriodendron*, and *Magnolia*.

More commonly than not, several types of longitudinal-strand parenchyma are present in the same wood. For instance, in red oaks apotracheal parenchyma, ranging from diffuse to banded, occurs together with several different forms of paratracheal parenchyma. Paratracheal parenchyma ranging from scanty to confluent, together with terminal parenchyma, features *Gleditsia*, *Robinia*, and other native genera belonging to the family Leguminosae, while *Carya* is characterized by apotracheal- and paratracheal-banded and marginal forms of parenchyma.

b Fusiform Parenchyma This is longitudinal parenchyma derived from a fusiform cambial initial without subdivision (Fig. 5-11h). Fusiform parenchyma cells are characteristic of the more highly developed hardwoods, and the cells are often storied as in persimmon (*Diospyros virginiana* L.).

c Epithelial Parenchyma (Fig. 5-16) This type consists of parenchyma cells which encircle the cavities of longitudinal canals. Longitudinal gum (resin) canals are not present as normal structures in any of the hardwoods covered in this text; they occur sporadically in sweetgum (*Liquidambar styraciflua* L.), presumably as a result of injury. Consequently, longitudinal epithelial cells are wanting in domestic woods of normal structure. Certain tropical hardwoods, among others those belonging to the Dipterocarpaceae in which some species of the genus *Shorea* supply the lauans (Philippine mahogany) and merantis of commerce, possess normal resin canals. As a rule, in the hardwoods in which canals occur, the canals are either of the longitudinal or the transverse type, the two kinds rarely occurring in the same wood.

d Inclusions in Parenchyma Cells These occur frequently and may consist of gums or resins, which may or may not be dark-colored, or starch grains, and, less commonly in temperate-zone woods, amorphous lumps of silica ranging in size from small to minute.

Crystals, mostly of calcium compounds, are quite common in parenchyma cells and are usually rhomboidal in shape (Fig. 5-12).

When crystals form in strand parenchyma, a single cell unit of the strand may be transformed into a crystal-bearing loculus, or two or more may serve as crystal repositories (Fig. 5-12). A strand may be in part crystalliferous and in part devoid of crystals. Since the crystal-bearing cells are usually somewhat enlarged, they can be readily recognized. Sometimes one or more units of the strand subdivide, so that the resulting cells are just large enough to accommodate a crystal. Such crystal-bearing parenchyma is designated as *chambered* or *crystalliferous*.

B Transverse Elements (Cells) of Porous Woods (Wood Rays)

The transverse elements in hardwoods are confined to the rays, as is true for the softwoods. The rays in the porous woods differ from those in the softwoods in having a greater variety of cell shapes, more variation in cell arrangement, and more variety in the cell inclusions. Rays in hardwoods are also more variable in width and height than those of softwoods.

1 COMPOSITION OF WOOD RAYS IN POROUS WOODS The rays of hardwoods consist entirely of parenchyma cells, with the exception of the specialized type of ray called *aggregate*, which is a composite structure of closely spaced small rays, fibers, and sometimes vessels (Figs. 5-14e and f, and 11-178). The parenchymatous ray cells may, however, vary considerably in size and shape. When ray cells are all of approximately the same size and shape, the rays are termed *homocellular* (formerly called *homogeneous*); the rays are said to be *heterocellular* (formerly termed *heterogeneous*) if containing more than one type of ray parenchyma cells (see Fig. 5-13a and b).

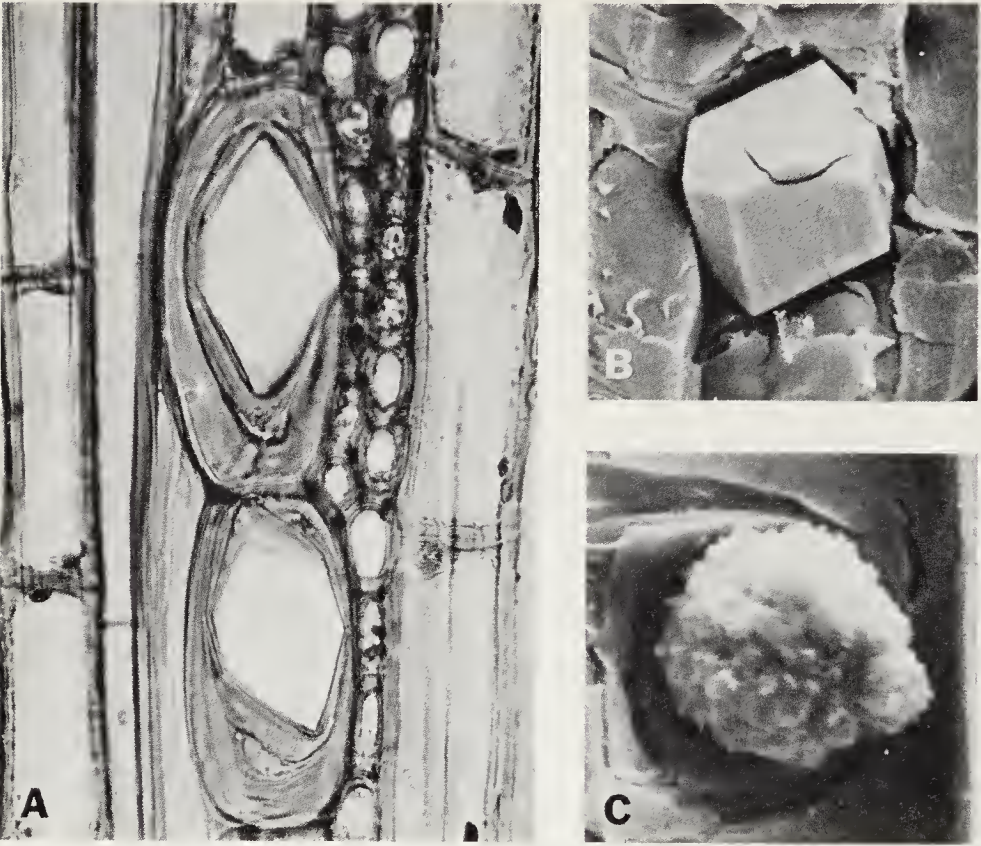


Figure 5-12 Crystals and silica in hardwoods.

(A) Crystal locules in two enlarged and sclerosed cells of an axial parenchyma strand in black walnut (*Juglans nigra* L.). The crystals in the section used for this light micrograph have been removed in the preparation of the section, leaving cavities in the shape of the crystals. (490 $\times$)

(B) Single crystal in an axial parenchyma cell in black walnut (*Juglans nigra* L.). Scanning electron micrograph at 765 $\times$.

(C) Amorphous silica body in a procumbent ray cell of *Eschweilera odora* (Poepp. ex Miers) Berg. Scanning electron micrograph at 1590 $\times$. [Scanning electron micrographs ((B) and (C) courtesy of Center for Ultrastructure Studies, State University of New York, College of Environmental Science and Forestry, Syracuse, N.Y.)]

The radially elongated ray cells, of the type pictured in Fig. 5-13a and b, are called *procumbent cells*, while those vertically oriented, as in upper marginal row of 5-13b, are called *upright cells*. Homocellular rays may be composed entirely of either type of cell. In the native species upright cells in the heterocellular rays are generally confined to one or more cells on the upper and lower margins of the ray. In some woods, for instance, in dogwood (*Cornus* spp.), there may be several rows of such marginal upright cells, forming uniseriate, tail-like projections of the rays (Fig. 11-216). In the tropical woods upright cells sometimes form a sheath around the central portion of the ray made up of the procumbent ray cells; in this case the upright cells are called *sheath cells*.

Ray composition is an important and frequently easily determinable characteristic for separation of woods that are closely related or otherwise easily confused. For instance, *Salix* spp. are characterized by the uniseriate,

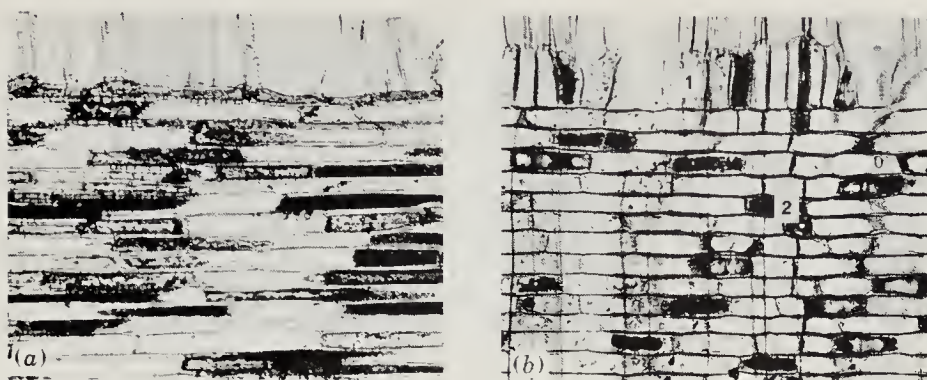


Figure 5-13 Composition of rays in hardwoods.

(a) Homocellular ray (*r*) in sycamore (*Platanus occidentalis* L.) consisting entirely of procumbent cells. (125×)

(b) Heterocellular ray (*r*) in sweetgum (*Liquidambar styraciflua* L.) consisting of marginal upright (1) and of procumbent (2) cells. (125×)

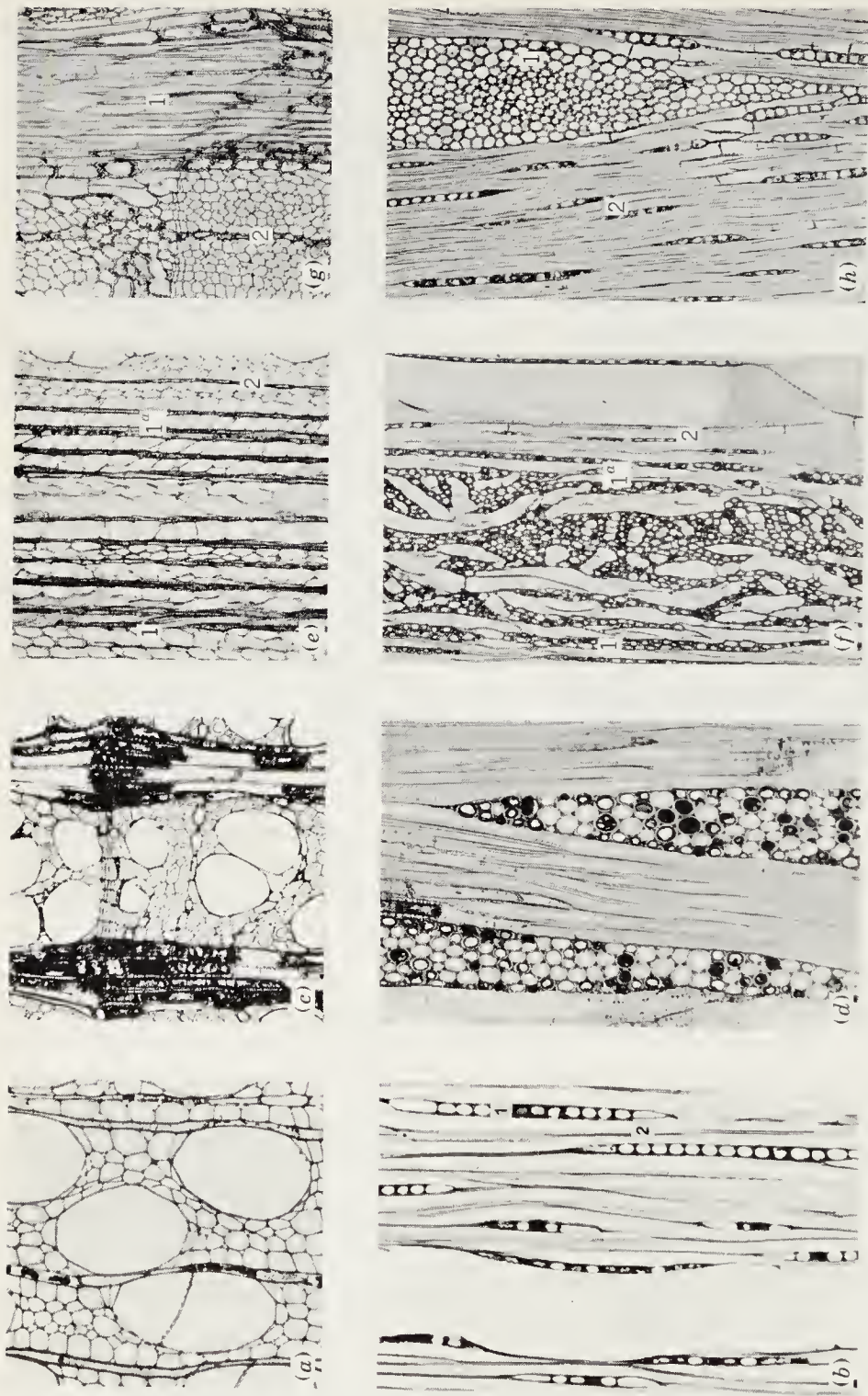
heterocellular rays, while *Populus* spp. have the uniseriate but essentially homocellular type. Likewise, hackberry (*Celtis occidentalis* L.) is easily separated from the elms (*Ulmus* spp.) by the multiseriate heterocellular rays, in contrast to the homocellular kinds found in elms. Sassafras [*Sassafras albidum* (Nutt.) Nees], frequently mistaken for black ash (*Fraxinus nigra* Marsh.), can be separated from it by rays ranging from homocellular to heterocellular containing oil cysts (see Fig. 5-15), while rays in ash are strictly homocellular.

Some woods possessing multiseriate homocellular and heterocellular rays may also have strictly uniseriate rays consisting either entirely of procumbent cells as in the oaks (*Quercus* spp.) and hard maple (*Acer saccharum* Marsh.), or entirely of upright cells as in holly (*Ilex opaca* Ait.), or of both types as in dogwood (*Cornus* spp.).*

Red alder (*Alnus rubra* Bong.), American hornbeam (*Carpinus caroliniana* Walt.), tanoak [*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.], and some *Quercus* spp. are characterized by rays of two kinds, narrow and usually uniseriate, which to all appearances are spaced normally as viewed on the transverse and tangential surfaces, and aggregations of narrow rays which are closely spaced, but between which there is tracheary tissue, i.e., fibers and vessels (Fig. 5-14e and f). These aggregate rays are relatively abundant, as in American hornbeam (*Carpinus caroliniana* Walt.) (Figs. 11-89 and 11-112), or relatively infrequent and then at wide and irregular intervals, as in red alder (*Alnus rubra* Bong.) (Fig. 11-82).†

*Kribs (Ref. 6) has proposed a classification of rays based on their appearance in radial and tangential sections. This classification is outside the scope of this text but may be found useful when dealing with a large number of woods from tropical regions.

†Noskowiak, A. F.: Distribution of Aggregate Rays in Red Alder, *Wood & Fiber*, 10(1):58-68 (1978), states that aggregate rays in alder are virtually absent in juvenile wood, but are present in varying numbers in the adult wood in the lower half of the trunk—as well as in both juvenile and adult wood in the upper half.



2 SIZE OF RAYS Rays may or may not be visible with the naked eye on the transverse and tangential surfaces. When they are in evidence, this feature can be used to separate certain woods. For example, rays are barely visible on the transverse section and indistinct on the tangential in birch (*Betula* spp.), but are distinct on both surfaces in maple (*Acer* spp.). Beech (*Fagus* spp.) can be separated from maple (*Acer* spp.), because in the former, rays are more conspicuous and varied in size, as seen in the flat-sawn lumber (Figs. 11-80 and 11-101).

Exclusively or predominantly uniseriate rays of the type that characterize the softwoods are seldom found in domestic hardwoods. Notable exceptions are *Salix* spp. (Fig. 5-14a and b), *Populus* spp., *Aesculus* spp., and *Castanea dentata* (Marsh.) Borkh. Most hardwoods, however, possess rays ranging from two to many seriate (Fig. 5-14c and d). In timbers covered by this text, maximum seriation is reached in oaks (*Quercus* spp.), where the large rays are often 30 or more cells wide (Fig. 5-14g and h) and 300 plus micrometers in width. In a number of woods the rays are of distinctly two sizes, the smaller frequently being uniseriate. Such ray combinations are found in sugar maple (*Acer saccharum* Marsh.), American beech (*Fagus grandifolia* Ehrh.), and other species but have their optimum development in oaks (*Quercus* spp., Fig. 5-14g and h). Multiseriate rays frequently flare where they cross the boundaries of growth rings (Fig. 5-14c); this condition is described as *noded*.

In height hardwood rays range from one cell and a few micrometers (about 20) to the upper limit of 2 inches or more along the grain (50,000 plus micrometers), found in the oaks.

As viewed in tangential section, the rays in hardwoods are generally quite variable in height, and usually intergrade in size, possibly indicating that those which arose last in the cambium have not yet attained their maximum height and width. Such variously sized rays are commonly staggered in the tangential plane. In persimmon (*Diospyros virginiana* L.) and in yellow buckeye (*Aesculus octandra* Marsh.), as well as in many tropical timbers, rays and sometimes other longitudinal elements are arranged in regular horizontal rows (Fig. 11-220). Such arrangement of

Figure 5-14 Ray types in porous woods. (100×) (a) Uniseriate rays (four) in black willow (*Salix nigra* Marsh.) (x). (b) Similar rays in black willow (*Salix nigra* Marsh.) (t) composed of procumbent (1) and upright (2) cells, and hence heterocellular. (c) Multiseriate rays (two) in sycamore (*Platanus occidentalis* L.) (x). (d) Portions of two similar rays in sycamore (*P. occidentalis* L.) (t) composed only of procumbent cells, and hence homocellular. (e) Portion of an aggregate ray (1-1^a), and one uniseriate ray (2) in red alder (*Alnus rubra* Bong.) (x). (f) Portions of a similar aggregate ray (1-1^a) and uniseriate rays (2) in red alder (*A. rubra* Bong.) (t). (g) Oak type of ray (1) and one uniseriate ray (2) in scarlet oak (*Quercus coccinea* Muenchh.) (x). (h) Portion of a similar oak type of ray (1), and a number of uniseriate rays (2) in scarlet oak (*Q. coccinea* Muenchh.) (t).

wood elements is called *storied* ; when viewed with the naked eye or a hand lens, woods with storied cells exhibit *ripple marks* on the tangential surface. Storied rays are quite uniform in height, provided that they are restricted to one story. However, in some woods with tiered rays some of the rays extend through several stories. In such instances ray height is variable, even though the wood exhibits ripple marks. If the rays alone are storied, then the cambial rays are likewise storied; when all the longitudinal cells are stratified, then both the fusiform initials, as well as rays in the cambium, are storied.

3 SPACING OF RAYS The rays of porous woods differ not only in size (width and height) but also in their spacing. Ray spacing in hardwoods can be studied to best advantage in transverse sections. It is computed as the number of rays per millimeter that cross the boundary of a ring; the upper and the lower figures, rather than the average, are recorded, e.g., six to nine per millimeter.

Table 5-6 indicates the range of ray spacing in the native species and gives convenient terms to record the degree of spacing. In most domestic woods the spacing is normal, i.e., the rays average six to nine per millimeter. In sweetgum (*Liquidambar styraciflua* L.), the species of *Nyssa*, and a few others, rays are so close together (21 or more per millimeter) that often half the area of a transverse surface appears to consist of ray tissue.

It should be pointed out that the figure of wood, especially that on the radial surface, may be affected by the size, and to a lesser degree by spacing, of the rays; this figure is described as *ray fleck*. In most native woods ray flecks range from inconspicuous as in species of *Salix*, *Populus*, *Aesculus*, and *Betula* to relatively conspicuous as in the genera *Liriodendron*, *Magnolia*, and *Acer*. The most noticeable ray fleck pattern occurs in the quarter-sawn stock in woods with exceptionally high rays, such as in species of *Fagus*, *Platanus*, and *Quercus*.

4 GUM CANALS IN RAYS OF POROUS WOODS Transverse gum canals in hardwoods are of the same general nature as those in softwoods with

Table 5-6 Spacing of Wood Rays in Porous Woods

Rays per mm	Spacing
5 or less	Widely spaced
6-9	Normally spaced
10-13	Fairly close
14-20	Close
21 or more	Extremely close

parenchymatous epithelial cells. The canals may be filled with gums, resins, latex, or other materials. Gum canals are found only in noncommercial hardwoods of the United States.

5 PITS IN RAYS OF POROUS WOODS The pits of ray parenchyma range from simple and minute to bordered and relatively large. The pitting may be equally abundant on all the walls, and their nature is often strongly influenced by the nature of the complementary pit on the wall of the adjacent element. Not infrequently the lateral walls of the upright cells are copiously and conspicuously pitted as in sweetgum (*Liquidambar styraciflua* L.) and willow (*Salix* spp.), whereas pits are sparse or wanting altogether on the lateral walls of the procumbent cells.

The nature of pitting between rays and vessel elements is frequently of some diagnostic value. All the native species of wood can be grouped on the basis of ray-vessel pitting under three headings:

1 Ray-vessel pitting that is simple and elongated, as in yellow buckeye (*Aesculus octandra* Marsh.) and hackberry (*Celtis* spp.).

2 Ray-vessel pitting ranging from simple to bordered and quite variable in shape and size, as in oak (*Quercus* spp.) and basswood (*Tilia* spp.).

3 Ray-vessel pitting similar to intervessel pitting, as in maple (*Acer* spp.), birch (*Betula* spp.), and ash (*Fraxinus* spp.).

6 INCLUSIONS IN RAY CELLS The ray cells frequently contain the same kind of inclusions as the longitudinal parenchyma cells. These materials may be crystals, silica, and numerous amorphous materials of complex chemical nature, including gums, resins, tannins, oils, latex, coloring matter, and nitrogenous materials, such as alkaloids. Carbohydrates, usually in the form of starch grains, are also common, particularly in the sapwood portion of the stem. Little exact information is available on the chemical nature of many of these infiltrations. Frequently the color, odor, and taste of wood are traceable to these products. For instance, the rays of sassafras are characterized by oil cysts (Fig. 5-15); the persistent aromatic odor of this wood is due in part to the contents of such cells.

Silica is very commonly found in certain families of tropical woods but much less so in woods from the temperate zones. When present it usually occurs in the procumbent cells as amorphous, rounded bodies which increase in size from the sapwood to a maximum in the heartwood. The presence of even small amounts of silica is very detrimental to machining properties of dry wood (Fig. 5-12c).

Crystals appear in ray cells in a greater variety of forms than in the axial parenchyma. They often are rhomboidal but also occur in the form of spherical clusters in enlarged cells (druses), as separate needle-like crystals

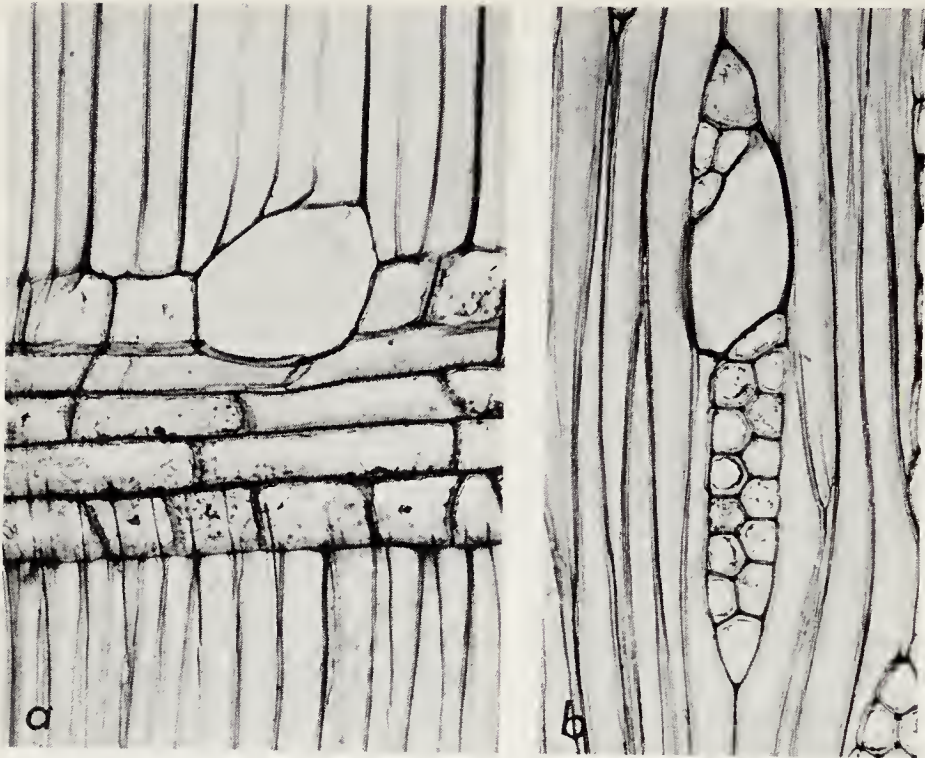


Figure 5-15 Oil cells in the wood rays of sassafras [*Sassafras albidum* (Nutt.) Nees]:
 (a) Wood ray in a radial section showing one oil cell. (240×)
 (b) Wood ray in a tangential section, showing one oil cell. (240×)

(acicular), as bundles of long, needle-shaped crystals (raphides), as rods, or as granular masses of very fine crystals (crystal sand). The crystals may form in either the upright or the procumbent cells, as single crystals in a cell, or in multiples.

7 RAY VOLUME IN POROUS WOODS The ray volume of porous woods exerts an important effect on their physical properties, especially on dimensional changes, formation of checks, and lateral permeability, and also to some extent on strength properties.

Ray volume in hardwoods is contingent upon the size attained by the rays and on their number (spacing). It varies not only in different kinds of wood but also within a species and at different places in the same tree.

Data on ray volumes of a number of the porous woods of the United States and Europe are presented in Tables 5-3 and 5-7. The smallest ray volume among the species listed occurs in the genus *Tilia*, which has an average volume of ray tissue of about 6.5 percent. This minimum value for porous woods is comparable to the average for softwoods. Most species listed in the tables have ray volumes between 10 and 20 percent, with an average close to 17 percent. The greatest volume of rays occurs in the oaks

Table 5-7 Average Ray Volume of Some Porous Woods

Scientific name	Average ray volume, %	Origin
<i>Acer campestre</i>	15.4	Y*
<i>Acer macrophyllum</i>	18.5	US†
<i>Aesculus hippocastanum</i>	13.2	Y
<i>Alnus incana</i>	13.7	Y
<i>Betula lenta</i>	16.6	US
<i>Betula nigra</i>	15.8	US
<i>Betula populifolia</i>	9.3	US
<i>Betula verrucosa</i>	10.1	Y
<i>Carpinus betulus</i>	15.7	Y
<i>Carya cordiformis</i>	16.8	US
<i>Castanea sativa</i>	12.2	Y
<i>Catalpa speciosa</i>	13.3	US
<i>Fagus sylvatica</i>	18.2	Y
<i>Fraxinus excelsior</i>	14.7	Y
<i>Gleditsia triacanthos</i>	18.5	US
<i>Juglans regia</i>	16.2	Y
<i>Morus alba</i>	18.2	Y
<i>Ostrya carpinifolia</i>	23.5	Y
<i>Platanus orientalis</i>	25.6	Y
<i>Populus nigra</i>	11.8	Y
<i>Populus tremuloides</i>	9.6	US
<i>Prunus avium</i>	16.4	Y
<i>Prunus domestica</i>	26.3	Y
<i>Quercus bicolor</i>	29.7	US
<i>Quercus ilex</i>	34.1	Y
<i>Quercus robur</i>	20.6	Y
<i>Quercus virginiana</i>	32.2	US
<i>Robinia pseudoacacia</i>	19.0	Y
<i>Salix alba</i>	9.2	Y
<i>Salix nigra</i>	10.6	US
<i>Tilia heterophylla</i>	5.3	US
<i>Tilia platyphylla</i>	7.8	Y
<i>Ulmus procera</i>	20.8	Y
<i>Ulmus rubra</i>	13.0	US
<i>Ulmus thomasii</i>	18.6	US

*Data marked Y are adapted from B. Petrić and V. Šćukanec, Ray Tissue Percentages in Wood of Yugoslavian Hardwoods, *Int. Assoc. Wood Anat. Bull.* **1975**(3):43 (1975).

†Data marked US are taken from J. E. Meyer, Ray Volumes of the Commercial Woods of the United States and Their Significance, *J. For.*, **20**:337-351 (1922).

(*Quercus* spp.), in which rays occupy more than 30 percent of the total volume of the wood.

White and Robards (Ref. 12) point out that the number of rays and their width, and hence the ray volume, are affected by the growth rate, as measured by the width of growth rings. They report that in the three species they studied—sweet chestnut (*Castanea sativa* Mill), ash (*Fraxinus excelsa* L.), and sassafras [*Sassafras albidum* (Nutt.) Nees]—there were significantly more rays in the samples with wide growth rings than in the slower-grown wood. For instance, in sassafras there was an increase from 41 ± 3 rays per square inch in the ring measuring 3.6 millimeters in width to 65 ± 3.9 rays per square inch in the growth ring 7.2 millimeters wide. In ash and sassafras the extra ray width was due to the increased size and greater number of cells; in chestnut it was due to the presence of a large number of biseriate rays, which are seldom found in chestnut wood of slower growth. No consistent relationship between the radial growth and ray height was found. These findings point out the uncertainties surrounding the use of numerical data involving sizes and frequency of anatomical features, for purposes of wood identification.

C Normal and Traumatic Gum Canals in Porous Woods

Gum canals in porous woods, when present, may be normal or of traumatic (wound) origin. They are not found as normal structures in any of the domestic woods covered by this text. The term gum canal, as used for hardwoods, includes canals whose contents may be gums, resins, or mucilage depending upon the genus concerned.

Normal gum canals occupy the same position in porous woods as the resin canals of conifers; i.e., they extend with the grain, embedded in longitudinal elements, or across the grain, included in the wood rays. The two types, however, are seldom present in the same wood; i.e., the canals in a given hardwood are usually either longitudinal or transverse. Normal longitudinal canals, for instance, feature the dipterocarp woods of the Indo-Malayan region. These include the lauans (Philippine mahogany) and merantis (*Shorea* spp.) of commerce, and this feature provides a ready separation of these woods from American mahogany (*Swietenia* spp.) and African mahogany (*Khaya* and *Entandrophragma* spp.).

Normal transverse canals are found in the woods of some genera of the Anacardiaceae and Burseraceae. When present, such canals are embedded in the fusiform rays, in the same way as in the coniferous woods.

Traumatic canals in hardwoods may form in one of two ways, or by a combination of these, and they are restricted to the longitudinal kind only. One kind of traumatic canal in hardwoods is of a *schizogenous* nature, of the same kind as in softwoods; these canals result from the separation of cells at the middle lamella. Usually they are arranged in tangential rows, as

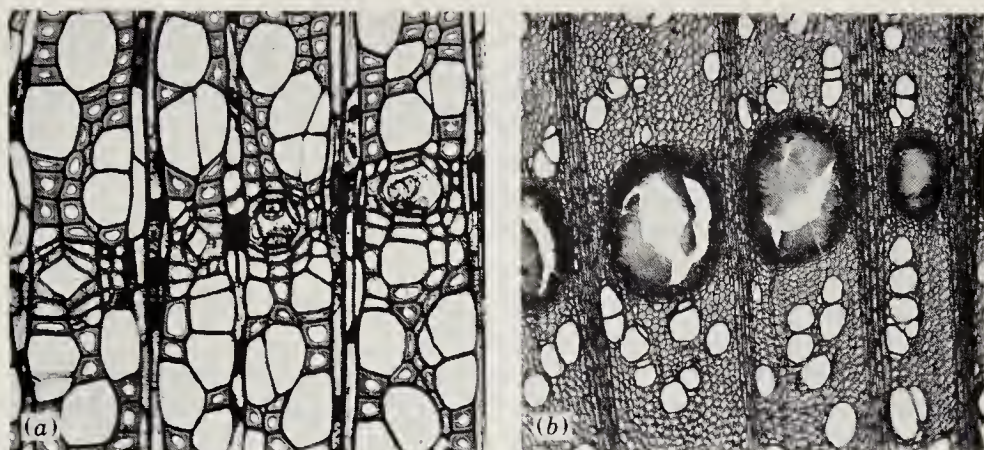


Figure 5-16 Traumatic intercellular spaces in hardwoods.

(a) Traumatic schizogenous gum canals (x) in sweetgum (*Liquidambar styraciflua* L.). A row may extend some distance in the tangential direction. (95×)

(b) Traumatic lysigenous gum cavities (x) in black cherry (*Prunus serotina* Ehrh.). (50×)

viewed in cross section (Fig. 5-16a). Others are formed through the actual disintegration (gummosis) of cell walls, in which case they are called *lysigenous* canals (Fig. 5-16b). In some cases traumatic canals are formed as a result of both these processes; i.e., the cavity first forms through cell fusion and separation of cells at the middle lamella, followed by the enlargement of the cavity through gummosis of the cells immediately surrounding it. This kind of canal formation is described as *schizolysigenous*.

The traumatic schizogenous canals of hardwoods are provided with epithelium, the same as the normal canals; those of lysigenous origin are devoid of it. Since the lysigenous and schizolysigenous canals result from cell disintegration, they are generally much larger (often $\frac{1}{8}$ inch or more in diameter) than the schizogenous canals. Lysigenous canals may be scattered singly, or more commonly they are arranged in tangential rows as seen across the grain, and are often conspicuous to the naked eye because of their size and gummy contents. Along the grain the cavity may be continuous, or appear as a series of cysts separated by wound tissue.

Traumatic schizogenous gum canals are occasionally found in sweetgum (*Liquidambar styraciflua* L.) (Fig. 5-16a). They do not occur in any other woods covered by this text. Traumatic lysigenous canals are common in cherry (*Prunus* spp.) (Fig. 5-16b), in which wood they sometimes form as a result of the work of cambial miners.

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PART 2

Wood Identification and Descriptions of Woods by Species

Keys for Identification and Descriptions of Woods by Species

Part two of this text deals with identification of the more important species of wood native to the temperate zone of North America. A few, presently less-valuable, species are also included because of their potential importance or because of special interest they present in terms of their anatomy.

This chapter contains five keys for identification, descriptions of woods by species, and comparative physical data for the more important woods native to the United States and Canada. Softwoods and hardwoods are dealt with in separate sections in order to bring the pertinent material closer together.

This material is arranged as follows:

Coniferous Woods—Keys and Descriptions by Species.

- I Key to Coniferous Woods—Gross Features, pp. 411 to 415
- II Key to Coniferous Woods—Minute Features, pp. 420 to 424
- III Key to Coniferous Woods Based on Gross and Minute Features, pp. 427 to 434
- Index to Descriptions of Coniferous Woods, p. 434
- Descriptions of Coniferous Woods by Species, pp. 435 to 495
- Anatomical Data for Coniferous Woods, Table 11-1
- Comparative Physical Data for Coniferous Woods, Table 11-2

Hardwoods—Keys and Descriptions by Species

- IV Key to Hardwoods—Gross Features, pp. 502 to 512
- V Key to Hardwoods—Minute Features, pp. 523 to 532
- Index to Descriptions of Hardwoods by Species, p. 536

Descriptions of Hardwoods by Species, pp. 537 to 628
Anatomical Data of Hardwood Species, Table 11-3
Comparative Physical Data for Hardwoods, Table 11-4
Wood Identification by Chemical Means, pp. 644 to 645

USE OF KEYS AND IDENTIFICATION OF SAMPLES

Before attempting to identify a given piece of wood the reader must familiarize himself with the general (gross) and minute features that are common to all kinds of woods regardless of their botanical origin. Only then will it be possible to recognize those characteristics that are specific to a given kind of wood and which, therefore, will identify its botanical source.

In approaching wood identification the logical procedure is from the gross features, i.e., the characteristics evident with little or no magnification, to the minute, i.e., those that are evident only at magnifications that can be obtained with a compound microscope.

The gross features of wood are in general of two kinds: those traceable to its cellular structure, and those which fall in the category of physical or chemical properties, e.g., color, odor, weight, and hardness. In some cases the gross physical characteristic of the wood, such as its color or grain appearance, will provide all the information needed for its identification. In other instances these observations must be supplemented with information on wood structure that can be obtained with the 10× hand lens. The gross physical properties of wood are often less reliable for identification purposes than are the structural, i.e., anatomical, features. This is because the former exhibit greater fluctuation than the latter. However, accurate identification can seldom be made on the basis of one feature alone; rather, a number of wood characteristics must be considered together.

When positive identification is not possible on the strength of the gross anatomical and physical characteristics of wood, resort must be made to the minute anatomical features, i.e., those features which are discernible only with a compound microscope. When this becomes necessary, knowledge of wood anatomy should suggest which structural features are most important and reliable and on what surface, i.e., transverse (x), radial (r), or tangential (t), they can be seen to the best advantage.

To assist identification of woods grown in the temperate zone of North America a number of keys are presented in the pages to follow. Keys I and IV are based on features visible with a 10× hand lens or discernible without magnification. Keys II, III, V, and VI require use of a microscope. Before attempting to use Keys I and IV it should be helpful to review information presented in Chapter 1. The keys to coniferous woods, II, and to hardwoods, V, are based on minute features requiring a microscope for their determination. Key III to conifers is based on a combination of gross and minute features. Each key has a particular value, depending on the size and nature

of the sample to be identified and the accessibility of a compound microscope. Use of Keys II, III, V, and VI (Chap. 12), based on minute anatomical features of wood, presupposes intimate knowledge of wood anatomy; therefore the anatomical information presented in Chaps. 4 and 5 must be studied first.

When confronted with a specimen of an unknown wood it is helpful to bear in mind those gross and minute structural features which may bring about positive identification in the simplest and most dependable way. In some cases the gross features, such as color of the wood, smell, and grain appearance, provide all the identification needed. In other instances these observations on the gross characteristics of wood must be supplemented with information that can be obtained with a hand lens, and in still other cases no positive identification is possible without resorting to a microscope. It is therefore advantageous to proceed in examining a piece of wood from the gross to the minute anatomical features and, when confronted with the latter, to select those which are more easily observable and most reliable.

In order to determine the presence or absence of many of the gross features with Keys I and IV it is necessary to cut a smooth surface with a *sharp* knife or a safety razor blade. Unless a clean cut is made with a sharp cutting tool, details to be observed on the surface will be obscured.

A presumed identification is made when the point is reached in the key at which the name of the particular wood or genus is given. However, this identification should not be accepted as final until additional verification is made with the low-power (5×) cross-section photographs, accompanying Keys I and IV, and the descriptions by species, following the keys.

For purposes of study of the microscopic features, permanent mounts of wood cut with a sliding microtome are desirable. However, identification of wood on the basis of minute features can be done very well with temporary sections made freehand with a safety razor blade. To make such slides, cut a clean surface in the area to be observed, moisten the surface with water or alcohol, and slice off a small piece using a sharp, new safety razor blade. The important points to bear in mind when making freehand sections are to use a sharp edge, to slice across the surface with a shearing motion, and to cut the section as thin as possible. Temporary sections of this sort mounted in water, alcohol, glycerin, or white corn syrup under a cover glass can demonstrate all the details evident in a permanent mount—however, usually not over so large an area.

As in the case of keys based on the gross features, the final identification should be verified by reference to the accompanying high-power photographs and by studying the more complete information on the minute anatomy of a given species presented in the description of woods by species section, which follows the keys.

When the available pieces of wood are too small to be sectioned, the

material can be macerated to produce fibrous material that can be identified with the fiber key, i.e., Key VI, Chap. 12.

Users of this textbook should be cautioned about placing too much reliance on the measurements of the cell dimensions and the cell wall thicknesses, or on the information on frequency of cell distribution and volume occupied by the different kinds of cells. This is so because of the great variability in size and distribution of cells that exists not only among individual trees of a species, but also in different parts of the same tree and even in the same growth ring. Considerable discrepancies may also arise depending on the method used in selecting and preparing the sample, the number of measurements made, and the technique employed in making the measurements. The average values given in this text are useful as an aid to identification only when they are proved to be reasonably constant within the limits given and when the spread in the range of the average values between the species is appreciable. For comprehensive treatment of this subject, see the article by D. M. Smith, *Microscopic Methods for Determining Cross-sectional Cell Dimensions*, *U.S. For. Serv. Res. Pap. FPL 79*, 1969.

DESCRIPTIONS OF WOODS BY SPECIES

Descriptions of Woods by Species, beginning on pp. 435 and 535, present a summary of the general characteristics and minute anatomy of the more important woods of the United States and Canada. Several less-important species are also included to illustrate the range of anatomical features found in the native woods. Where several closely related species, e.g., southern pines, cannot be separated with any degree of certainty on the basis of either gross features or minute anatomy of the wood, they are discussed under a single heading.

Each description of a wood, or a group of closely related woods, is divided into two sections: General Description and Minute Anatomy. The first deals with wood characteristics that can be recognized either without magnification or with the aid of a 10× hand lens; the section entitled Minute Anatomy presents wood features which require a compound microscope for their identification.

The reader should also note that summations of the anatomic features of the coniferous woods and hardwoods are presented in Tables 11-1 and 11-3, respectively.

These two sections are followed by a paragraph summarizing the most important uses of that wood. This information is not necessarily arranged in the order of importance of these uses but is rather grouped, when appropriate, under major categories, such as round-wood uses, lumber uses, veneer and plywood, and miscellaneous. In some instances, when information of special interest or of value in separating allied species is available, this is included under Remarks.

For convenience in comparing the various physical, mechanical, and nonmechanical properties of North American woods, data are presented in Tables 11-2 and 11-4, immediately following each section of the species descriptions.

Coniferous Woods—Keys and Descriptions by Species

I KEY TO CONIFEROUS WOODS—GROSS FEATURES*

- Woods nonporous (without vessels); cross sections consisting of distinct radial rows of tracheids; rays indistinct to the naked eye.
- 1 Resin canals present; longitudinal (x)† canals appear as small openings mostly in the outer part of the late wood; transverse canals included in some rays, which then appear larger (Figs. 11-8 to 11-22 inc.). 2
 - 1 Resin canals normally absent; longitudinal wound (traumatic) canals occasionally present in a tangential row (x); no transverse canals in rays 5
 - 2 Resin canals numerous, evenly distributed in outer portion of every ring (x̄); generally visible to the naked eye‡ as dark- or light-colored dots, easily seen with a hand lens (Figs. 11-12 to 11-19 inc.) 3
 - 2 Resin canals sparse, unevenly distributed, and sometimes absent in some rings (occasionally appear as 2 to many in a tangential row), barely visible to the naked eye as light or dark flecks, inconspicuous without a hand lens (Figs. 11-8 to 11-11, 11-20 to 11-22 inc.) 4

*This key is designed for the separation of the more important temperate North American woods based on features visible with a 10X hand lens or without magnification.
A series of photographs (Figs. 11-1 to 11-30) at low magnification (5X) accompanies this key, to illustrate the normal appearance of the various kinds of woods under a hand lens.
†(x) indicates that the feature is observed on the cross section; (r) and (t) refer to the radial and tangential surfaces, respectively.
‡Numerous but relatively inconspicuous in *Pinus resinosa* Ait., *Pinus banksiana* Lamb., *Pinus contorta* Dougl., and sometimes in *Pinus ponderosa* Dougl. ex Laws.

- 3 Transition from early to late wood gradual; wood soft, light, quite even in density (Figs. 11-12, 11-14, 11-15, 11-19).
- A Wood relatively coarse-textured; resin canals appearing as minute openings to the naked eye (x).
Sugar pine—*Pinus lambertiana* Dougl. Fig. 11-14. Desc. p. 435.
- B Wood medium- to relatively fine-textured, with resinous odor; heartwood creamy white to light brown or reddish brown, turning darker with age and exposure, split tangential surface not dimpled; resin canals appearing as light- or dark-colored dots (x).
Eastern white pine—*Pinus strobus* L. Fig. 11-19. Desc. p. 439
Western white pine—*Pinus monticola* Dougl. ex D. Don Fig. 11-15. Desc. p. 437
- C Wood medium- to relatively fine-textured, without resinous odor; heartwood light pinkish yellow to pale brown with purplish tinge, darkening to silver-brown on exposure; split tangential surface often noticeably dimpled; resin canals appearing as light- or dark-colored dots.
Sitka spruce*—*Picea sitchensis* (Bong.) Carr. Fig. 11-12. Desc. p. 460
- 3 Transition from early to late wood quite abrupt; wood medium-hard to hard; uneven in density (Figs. 11-13, 11-16 to 11-18 inc.).
- A Split tangential surface with numerous depressions which give it a dimpled effect. This feature is present in some samples of
Lodgepole pine—*Pinus contorta* Dougl. Desc. p. 441
Jack pine—*Pinus banksiana* Lamb. Fig. 11-13. Desc. p. 451
Ponderosa pine†—*Pinus ponderosa* Dougl. ex Laws. Fig. 11-17. Desc. p. 446.
- B Split tangential surface not dimpled.
Hard pines—*Pinus* spp. Figs. 11-13, 11-16 to 11-18 inc. Desc. pp. 441 to 453.
- 4 Transition from early to late wood gradual, late wood distinct but not pronounced.
- A Heartwood light pinkish yellow to pale brown with purplish tinge, darkening to silvery brown on exposure, dull to somewhat lustrous, medium-textured; split tangential surface often noticeably dimpled.
Sitka spruce—*Picea sitchensis* (Bong.) Carr. Fig. 11-12. Desc. p. 460.
- B Heartwood yellowish to pale reddish yellow to orange-red or deep red; wood with characteristic odor on freshly cut

*Occasional samples of *Picea sitchensis* (Bong.) Carr. are about as coarse-textured as many pieces of *Pinus lambertiana* Dougl.

†Typical old-growth ponderosa and lodgepole pine wood is rather soft, with the late-wood zones appearing as narrow lines, indistinct without magnification, the wood then resembling that of the soft pines.

surface, medium-textured, contours of growth rings frequently wavy.

Douglas-fir (Fast growth)—*Pseudotsuga menziesii* (Mirb.) Franco. Fig. 11-21. Desc. p. 462.

- C Heartwood not evident; wood nearly white to pale yellow or light yellow-brown, lustrous, relatively fine-textured; split tangential surface only occasionally dimpled.

Spruce—*Picea* spp. Figs. 11-10, 11-11. Desc. p. 457.

- 4 Transition from early to late wood abrupt; wood medium hard to hard, uneven in density.

- A Heartwood yellowish or pale reddish yellow to orange-red or deep red; wood with characteristic odor on freshly cut surface. not oily; contours of growth rings often wavy; resin canals (x) frequently in short tangential lines.*

Douglas-fir—*Pseudotsuga menziesii* (Mirb.) Franco. Fig. 11-20, 11-22. Desc. p. 462.

- B Heartwood with distinct brownish cast, wood lacking characteristic odor on freshly cut surface, somewhat oily; contours of growth rings usually smooth; resin canals (x) sometimes in tangential groups of 2–5, or single and sporadic, not in tangential lines.

Tamarack and western larch—*Larix* spp. Figs. 11-8, 11-9. Desc. p. 453.

- | | | |
|---|--|---|
| 5 | Heartwood with distinct odor, pleasantly fragrant or ill-scented | 6 |
| 5 | Wood without distinct odor | 9 |
| 6 | Wood with fragrant, “cedar-like” or sweetish odor | 7 |
| 6 | Wood ill-scented, or with rancid odor | 8 |
| 7 | Heartwood dull red, or rose-red to purplish, reddish brown, or dull brown. | |

- A Wood fine-textured; heartwood rose-red or purplish when first exposed, aging to dull red or reddish brown.

Eastern redcedar—*Juniperus virginiana* L. Fig. 11-7. Desc. p. 490.

- B Wood medium- to coarse-textured, firm; texture within growth rings even; wood frequently pecky; heartwood reddish brown to dull brown, sometimes with a lavender tinge, with a distinct acrid taste.†

Incense-cedar—*Calocedrus decurrens* (Torr.) Florin Fig. 11-3. Desc. p. 479.

- C Wood medium- to coarse-textured, soft; texture within growth rings uneven, with the late wood considerably harder than the early wood; wood never pecky; heartwood reddish, pinkish brown to dull brown, with faint sweetish odor.

Western redcedar—*Thuja plicata* Donn. ex D. Don. Fig. 11-27. Desc. p. 483.

*Color and characteristic odor of heartwood are usually sufficient to separate *Pseudotsuga* from *Larix*. However, the most positive separation is the presence of spiral thickenings in all early-wood tracheids in Douglas-fir, as seen with a microscope.

†This test is made by placing a thin shaving of wood on the tongue; a stinging sensation (not a bitter taste) after a short time indicates the acrid taste.

- 7 Heartwood yellowish white to clear yellow, straw-brown or light brown tinged with red or pink.
- A Heartwood clear yellow, darkening on exposure, wood with odor resembling raw potatoes on freshly cut surfaces.
Alaska-cedar—*Chamaecyparis nootkatensis* (D. Don) Spach. Fig. 11-5. Desc. p. 487.
- B Heartwood yellowish white to pale brown, with pungent gingery odor on freshly cut surfaces.
Port-Orford-cedar—*Chamaecyparis lawsoniana* (A. Murr.) Parl. Fig. 11-4. Desc. p. 485.
- C Heartwood light brown, tinged with red or pink (roseate); zonate parenchyma visible with a hand lens and sometimes with a naked eye as darker lines (x).
Atlantic white-cedar—*Chamaecyparis thyoides* (L.) B.S.P. Fig. 11-6. Desc. p. 489.
- D Heartwood uniformly straw-brown; parenchyma not visible (x).
Northern white-cedar—*Thuja occidentalis* L. Fig. 11-26. Desc. p. 481.
- 8 Heartwood clear yellow.
- A Heartwood with odor resembling raw potatoes on freshly cut surfaces.
Alaska-cedar—*Chamaecyparis nootkatensis* (D. Don) Spach. Fig. 11-5. Desc. p. 487.
- B Heartwood with strong unpleasant odor and mild characteristic bitterish taste.
California torrey—*Torreya californica* Torr. Fig. 11-28. Desc. p. 494.
- 8 Heartwood variable in color, ranging from yellowish to light or dark brown, reddish brown to almost black, with rancid odor on freshly cut surfaces; wood often greasy or oily and frequently pecky (see p. 366); strand parenchyma visible along the grain as dark lines; contours of the individual rings irregular.
Baldcypress—*Taxodium distichum* (L.) Rich. Fig. 11-24. Desc. p. 477.
- 9 Heartwood distinct, bright orange to rose-red, light cherry-red, or deep reddish brown; sapwood nearly white, grayish white, or light yellow.
- A Heartwood light cherry-red to deep reddish brown; sapwood nearly white or grayish white, wood coarse-textured, light to moderately light, soft to moderately hard.
Redwood—*Sequoia sempervirens* (D. Don) Endl. Fig. 11-23. Desc. p. 475.
- B Heartwood light orange to rose-red; sapwood light yellow; wood fine-textured, dense, fairly heavy.
Pacific yew—*Taxus brevifolia* Nutt. Fig. 11-25. Desc. p. 492.

9 Heartwood not distinct; wood creamy white to buff, yellow, or yellowish brown to brown, with or without a lavender, roseate, or reddish brown tinge.

A Wood light buff to light brown, sometimes with a reddish brown to pinkish tinge; early wood usually with a reddish tinge; transition from early to late wood semiabrupt to abrupt.

Hemlock—*Tsuga* spp. Figs. 11-29, 11-30. Desc. p. 465.

B Wood whitish to creamy white or pale brown;; early wood whitish, changing gradually to a darker lavender late wood (color contrast more pronounced in wide rings); transition from early to late wood gradual to semiabrupt.

True fir—*Abies* spp. Figs. 11-1, 11-2. Desc. p. 469.



Figure 11-1 *Abies balsamea* (L.) Mill. (x—5×)



Figure 11-2 *Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr. (x—5×)



Figure 11-3 *Calocedrus decurrens* (Torr.) Florin (x—5×)

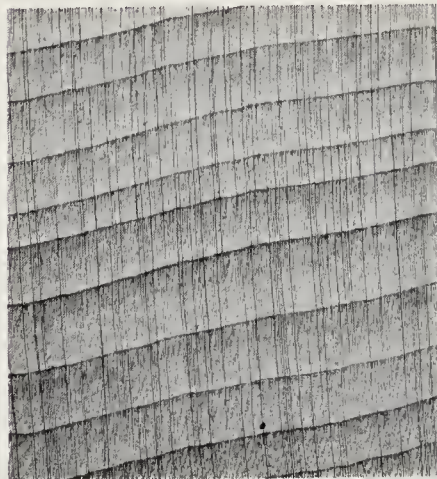


Figure 11-4 *Chamaecyparis lawsoniana* (A. Murr.) Parl. (x—5×)

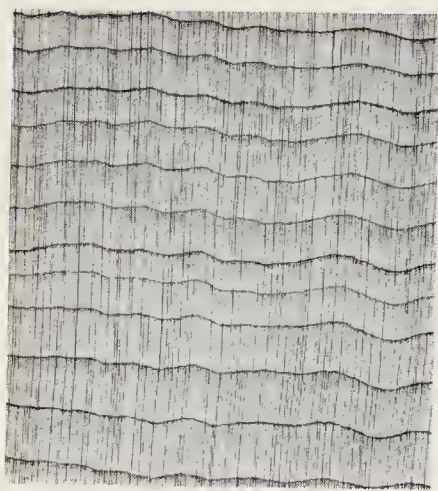


Figure 11-5 *Chamaecyparis nootkatensis* (D. Don) Spach. (x—5×)



Figure 11-6 *Chamaecyparis thyoides* (L.) B.S.P. (x—5×)



Figure 11-7 *Juniperus virginiana* L. (x—5×)

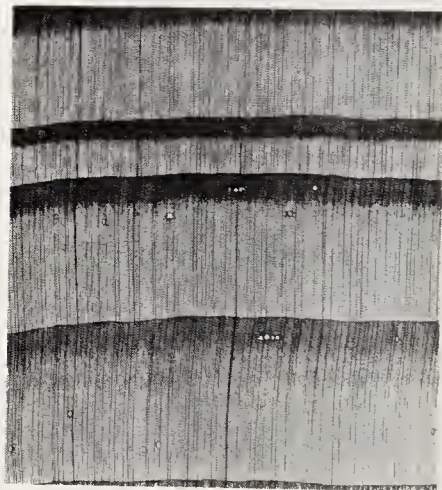


Figure 11-8 *Larix laricina* (DuRoi) K.Koch. (x—5×)

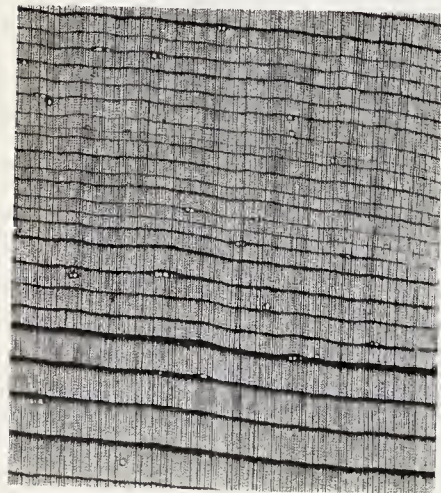


Figure 11-9 *Larix occidentalis* Nutt. (x—5×)

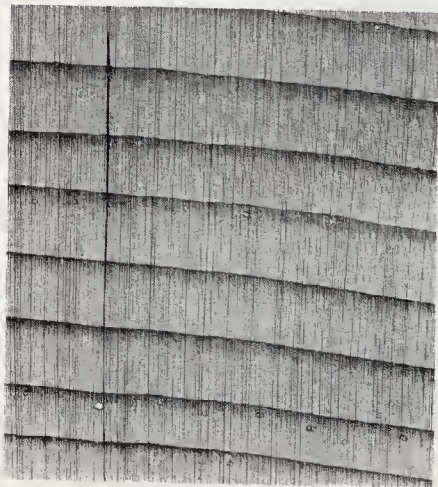


Figure 11-10 *Picea engelmannii* Parry. ex Engelm. (x—5×)

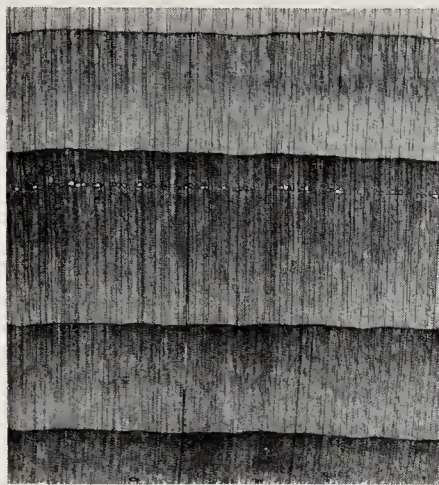


Figure 11-11 *Picea rubens* Sarg.
(x—5×)

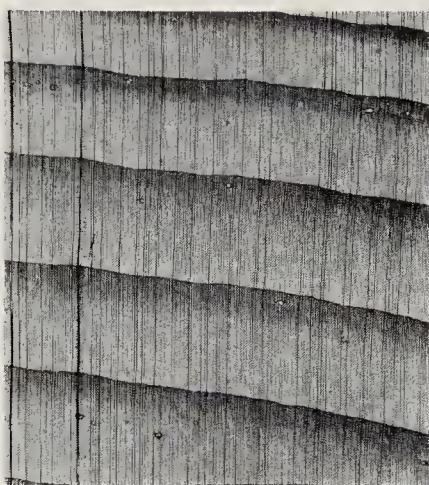


Figure 11-12 *Picea sitchensis* (Bong.)
Carr. (x—5×)

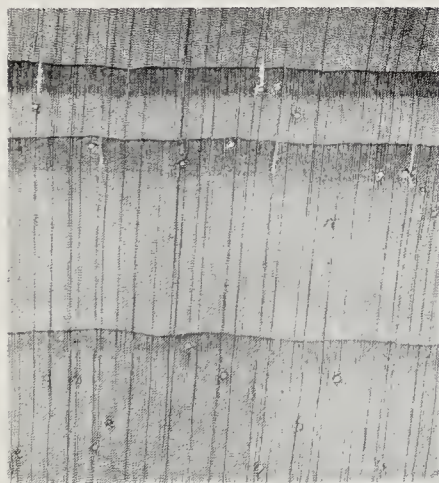


Figure 11-13 *Pinus banksiana* Lamb.
(x—5×)

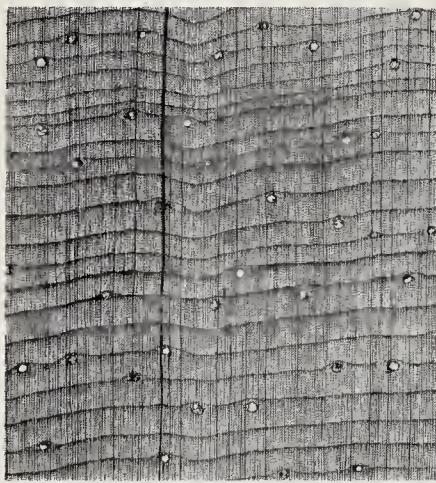


Figure 11-14 *Pinus lambertiana*
Dougl. (x—5×)

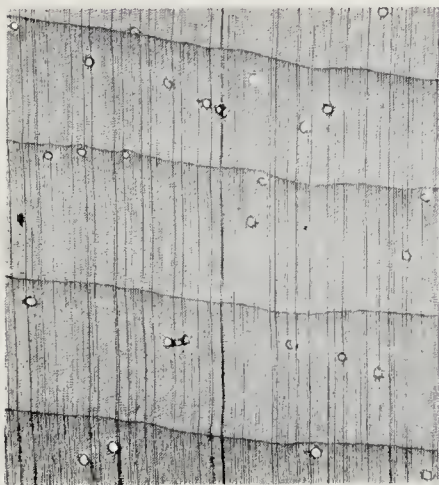


Figure 11-15 *Pinus monticola* Dougl.
ex D. Don (x—5×)

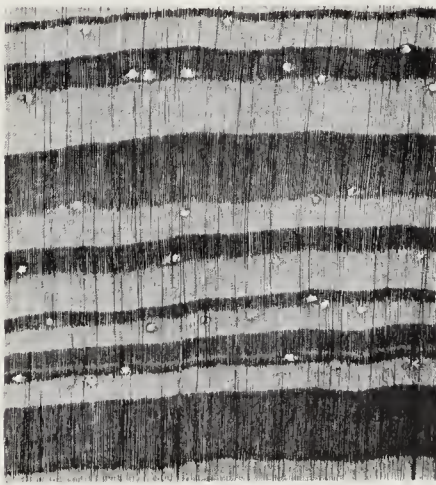


Figure 11-16 *Pinus palustris* Mill.
(x—5×)

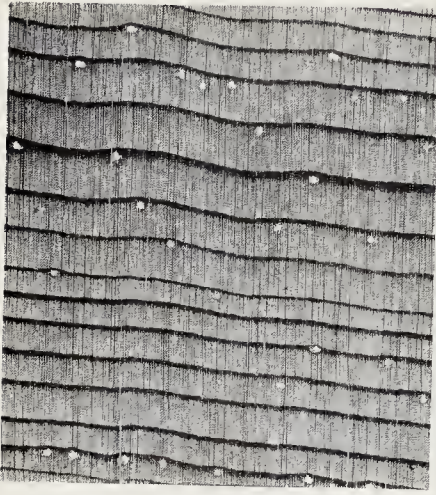


Figure 11-17 *Pinus ponderosa*
Dougl. ex Laws. (x—5×)

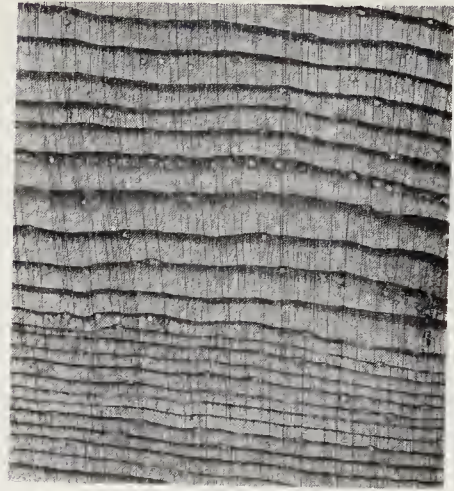


Figure 11-18 *Pinus resinosa* Ait.
(x—5×)



Figure 11-19 *Pinus strobus* L.
(x—5×)

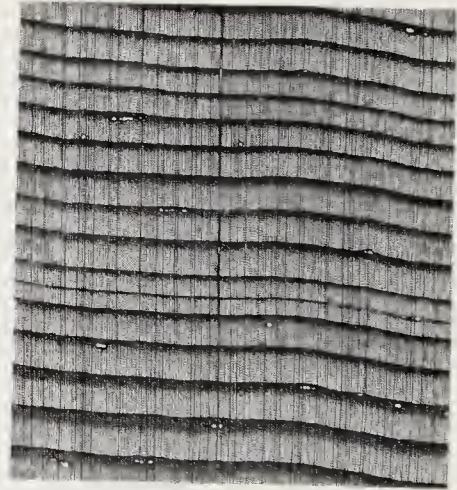


Figure 11-20 *Pseudotsuga menziesii*
(Mirb.) Franco (slow growth, x—5×).



Figure 11-21 *Pseudotsuga menziesii*
(Mirb.) Franco (Fast growth, x—5×).

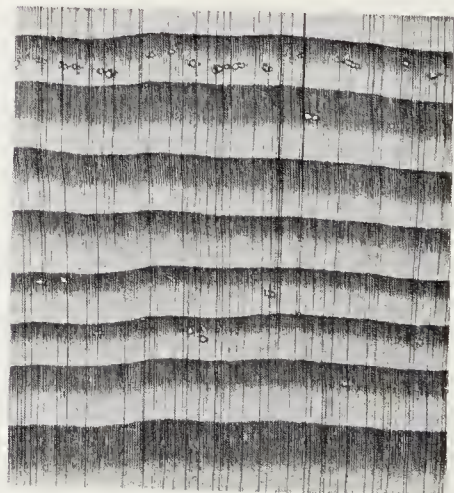


Figure 11-22 *Pseudotsuga menziesii*
(Mirb.) Franco (average growth,
x—5×).

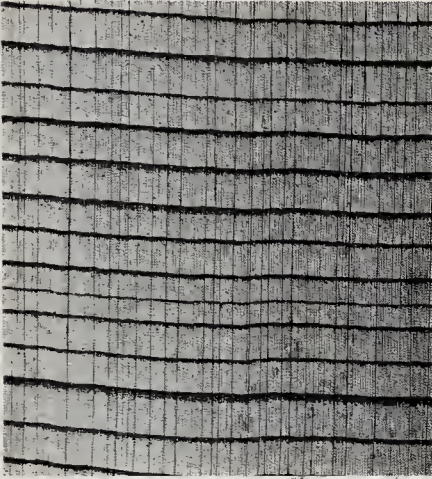


Figure 11-23 *Sequoia sempervirens*
(D. Don) Endl. (x—5×)

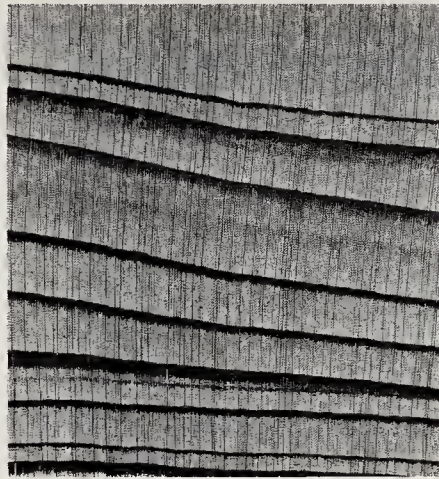


Figure 11-24 *Taxodium distichum*
(L.) Rich. (x—5×)

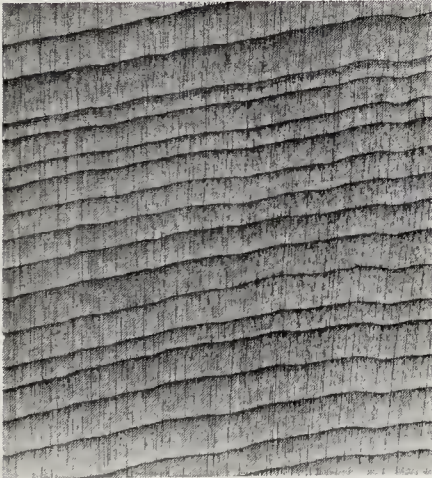


Figure 11-25 *Taxus brevifolia* Nutt.
(x—5×)

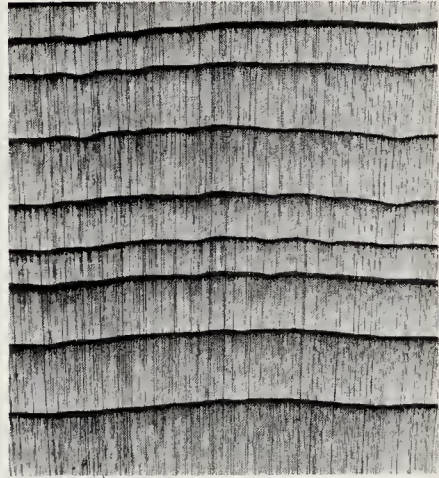


Figure 11-26 *Thuja occidentalis* L.
(x—5)

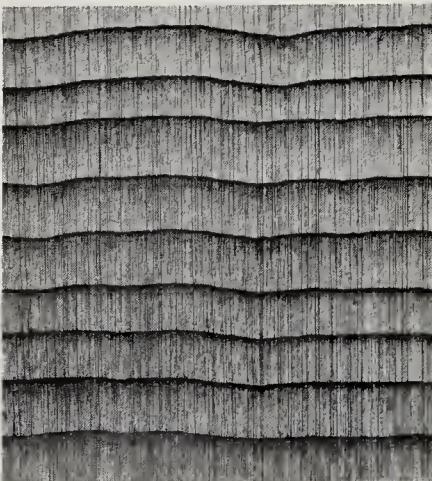


Figure 11-27 *Thuja plicata* Donn. ex
D. Don (x—5×)



Figure 11-28 *Torreya californica*
Torr. (x—5×)

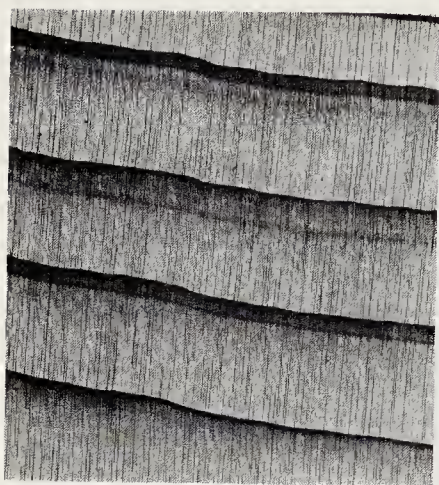


Figure 11-29 *Tsuga canadensis* (L.)
Carr. (x—5×)

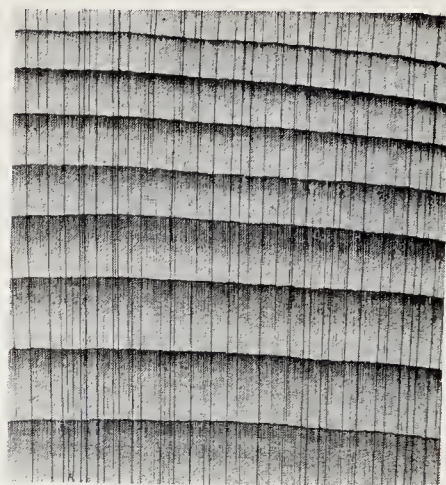


Figure 11-30 *Tsuga heterophylla*
(Raf.) Sarg. (x—5×)

II KEY TO CONIFEROUS WOODS—MINUTE FEATURES*

- | | | |
|---|---|----|
| 1 | Longitudinal and transverse resin canals both present. | 2 |
| 1 | Longitudinal and transverse canals normally absent; traumatic canals† occasionally present, aligned in a tangential row (x) . . . | 14 |
| 2 | Ray parenchyma cross-field pitting window-like, lenticular, or pinoid (see Figs. 11-31 to 11-35 inc.); epithelial cells thin-walled (Fig. 4-10a and c). | 3 |
| 2 | Ray parenchyma cross-field pitting in form of small pits resembling in appearance normal bordered pits in the ray tracheids (see Figs. 11-36 to 11-42 inc.); epithelial cells thick-walled (Fig. 4-10b and e). | 11 |
| 3 | Ray tracheids dentate (r) (Figs. 11-31 to 11-33 inc.) | 4 |
| 3 | Ray tracheids not dentate (r) (Fig. 11-34) | 9 |
| 4 | Ray parenchyma cross-field pits large, rounded window-like (fenestriform), usually 1 or 2 per cross field (Fig. 4-12).
Red pine — <i>Pinus resinosa</i> Ait. Desc. p. 449.
Scotch pine — <i>Pinus sylvestris</i> L. | |
| 4 | Ray parenchyma cross-field pits pinoid to lenticular, generally variable in shape and size, usually 1–6 per cross field (Fig. 4-12). | 5 |

*This key is designed to separate the more important North American coniferous woods on features requiring the use of a compound microscope.

The key is accompanied by a series of 14 figures (Figs. 11-31 to 11-44), at 300×, illustrating the cross-field pitting in conifers.

†Canals supposedly formed as a result of wounding; resembling normal canals when viewed on transverse section, but arranged in a row along the growth ring and often extending for some little distance.

- 5 Wall thickness (radial direction) of late-wood tracheids less than 6 μm ; late-wood band (x) usually 3–10 cells in width 6
- 5 Wall thickness (radial direction) of late-wood tracheids 6 μm or more; late-wood band (x) usually 10 or more cells in width. 8
- 6 Average number of contiguous rows of ray parenchyma cells per ray in the direction of the tracheid axis more than 3.
Ponderosa Pine—*Pinus ponderosa* Dougl. ex Laws. Desc. p. 446
- 6 Average number of contiguous rows of ray parenchyma cells per ray in the direction of the tracheid axis less than 3. 7
- 7 Ray tracheids prominently dentate; average horizontal diameter of resin canal in fusiform rays (t) 45 μm ; average number of rows of ray parenchyma cells in vertical direction per ray less than 3.
Lodgepole pine—*Pinus contorta* Dougl ex Loud. Desc. p. 441.
- 7 Ray tracheids shallowly dentate (seldom extending to the center of the cell cavity); average horizontal diameter of resin canals in fusiform rays (t) 30–35 μm ; average number of rows of ray parenchyma cells in vertical direction per ray more than 3.
Jack pine—*Pinus banksiana* Lamb. Desc. p. 451.
- 8 Radial diameter of the lumen of the last-formed late-wood tracheids (x) 1–3 times the radial thickness of the secondary wall; average number pits per ray parenchyma cross field in the early wood less than 2.8; less than 20 percent of pits in the ray parenchyma cross fields paired vertically.
Ponderosa pine—*Pinus ponderosa* Dougl. ex Laws. Desc. p. 446.
Jeffrey pine—*Pinus jeffreyi* Grev. & Balf. Desc. p. 446.
- 8 Radial diameter of the lumen of the last-formed late-wood tracheids (x) about equal to the radial thickness of the secondary wall; average number of pits per ray parenchyma cross field more than 2.8; more than 20 percent of the pits in the ray parenchyma cross fields paired vertically.
Southern hard pines—*Pinus* spp. Desc. p. 444.
- 9 Ray parenchyma cross-field pits broad-oval to fenestriform, in transverse rows of pits of 2 or commonly 3, paired pits separated laterally by a distance of 8 μm or more; longitudinal resin canals with tangential diameter* up to 300 μm (avg. between 175 and 225).
Sugar pine—*Pinus lambertiana* Dougl. Fig. 11-35. Desc. p. 435.
- 9 Ray parenchyma cross-field pits fenestriform, transverse rows of pits of 3 per cross field absent or rare, lateral separation between paired pits less than 8 μm ; longitudinal resin canals with maximum tangential diameter up to 200 μm 10

*The diameter of the canal inclusive of the epithelium.

- 10** Paired fenestriform pits in the early-wood tracheids occur less than 60 percent of the time; ray parenchyma cross-field pits rarely lenticular, occasionally superimposed (margins overlapping laterally).
Eastern white pine—*Pinus strobus*. L. Desc. p. 439.
- 10** Paired fenestriform pits in early-wood tracheids occur more than 60 percent of the time; lenticular ray parenchyma cross-field pits sometimes present, rarely superimposed.
Western white pine—*Pinus monticola* Dougl. ex D. Don Desc. p. 437.
- 11** Longitudinal tracheids with spiral thickening.
Douglas-fir—*Pseudotsuga menziesii* (Mirb.) Franco. Desc. p. 462
- 11** Longitudinal tracheids lacking spiral thickening (rarely evident in the late-wood tracheids of tamarack) **12**
- 12** Late wood pronounced, with abrupt transition; bordered pits on the longitudinal tracheids frequently biseriate (*r*); cross-sectional view of ray tracheid pits showing pit borders tapering smoothly to a rounded edge at the pit aperture.
Larch—*Larix* spp. Fig. 11–36. Desc. pp. 453 to 457.
- 12** Late wood not pronounced, transition usually gradual; bordered pits on the longitudinal tracheids uniseriate or biseriate (*r*); cross-sectional view of some of the ray tracheid pits showing pit borders distinctly thickened, ridged, or spurred on the cell lumen side and bluntly angled to the pit aperture (rare in Engelmann spruce). **13**
- 13** Ray cells (*t*) oblong to oval in shape; bordered pits on the longitudinal tracheids rarely biseriate.
White, Black, Red, and Engelmann spruce—*Picea* spp. Desc. p. 457.
- 13** Ray cells (*t*) orbicular to oval in shape; abundant yellowish brown deposits in the ray cells; bordered pitting on the longitudinal tracheids frequently biseriate; occasional crystals in ray cells.
Sitka spruce—*Picea sitchensis* (Bong.) Carr. Desc. p. 460.
- 14** Longitudinal tracheids with spiral thickening **15**
- 14** Longitudinal tracheids without spiral thickening **16**
- 15** Angle of spiral thickening about 80° from the tracheid axis; spirals unevenly spaced; ray parenchyma cross-field pitting commonly in transverse rows of 3 or more; widest early-wood tracheids 50 µm or more.
California torreyia—*Torreya californica* Torr. Desc. p. 494.
- 15** Angle of spiral thickening about 60° from the tracheid axis; spirals quite evenly spaced; ray parenchyma cross-field pitting never or rarely in transverse rows of 3 or more; widest early-wood tracheids less than 50 µm wide.
Pacific yew—*Taxus brevifolia* Nutt. Desc. p. 492.

- 16 Parenchyma (longitudinal), excepting marginal parenchyma, fairly abundant to abundant, present in every growth ring. 17
- 16 Parenchyma wanting or very sparse and sporadic (sometimes abundant in a given growth ring but wanting in adjacent rings), marginal parenchyma present or absent 25
- 17 End walls of ray parenchyma cells nodular (r). 18
- 17 End walls of ray parenchyma cells smooth (r). 20
- 18 Ray tracheids (r) abundant in low rays, often constituting the entire ray.
Alaska-cedar—*Chamaecyparis nootkatensis* (D. Don) Spach. Figs. 11-41, 11-42. Desc. p. 487.
- 18 Ray tracheids (r) absent or extremely sparse 19
- 19 Intercellular spaces at rounded corners of the longitudinal tracheids (x) frequent and conspicuous; end walls of ray parenchyma cells with indentures similar to those in *Thuja plicata* (Fig. 12-44); ray tracheids absent.
Redcedar—*Juniperus* spp. Desc. p. 490.
- 19 Intercellular spaces at corners of the longitudinal tracheids (x) lacking or rarely present; end walls of ray parenchyma cells lacking indentures; ray tracheids occasionally present.
Incense-cedar—*Calocedrus decurrens* (Torr.) Florin. Desc. p. 479.
- 20 Transverse walls of longitudinal parenchyma cells nodular (t). 21
- 20 Transverse walls of longitudinal parenchyma cells not nodular or inconspicuously nodular (t). 24
- 21 End walls of ray parenchyma cells with indentures (Fig. 11-44) 22
- 21 End walls of ray parenchyma cells lacking indentures. 23
- 22 Ray parenchyma cross-field pitting taxodioid; intertracheid pitting commonly biseriate.
Western redcedar—*Thuja plicata* Donn ex D. Don. Desc. p. 483.
- 22 Ray parenchyma cross-field pits cupressoid; intertracheid pitting rarely biseriate.
Port-Orford-cedar—*Chamaecyparis lawsoniana* (A. Murr.) Parl. Desc. p. 485.
- 23 Intertracheid pitting in 1–4 longitudinal rows (frequently in 3); angle of ray parenchyma cross-field pit apertures 80° from the tracheid axis.
Baldcypress—*Taxodium distichum* (L.) Rich. Fig. 12-40. Desc. p. 477.
- 23 Intertracheid pitting in 1 longitudinal row or occasionally in part biseriate; angle of ray parenchyma cross-field pit apertures 40° from the tracheid axis.
Port-Orford-cedar—*Chamaecyparis lawsoniana* (A. Murr.) Parl. Desc. p. 485.

- 24 Intertracheid pitting in 1–3 longitudinal rows (usually 2); ray parenchyma cross-field pitting taxodioid.
Redwood—*Sequoia sempervirens* (D. Don) Endl. Fig. 11-39. Desc. p. 475.
- 24 Intertracheid pitting in 1 longitudinal row or rarely paired; ray parenchyma cross-field pitting cupressoid.
Atlantic white-cedar—*Chamaecyparis thyoides* (L.) B.S.P. Desc. p. 489.
- 25 Ray tracheids present (*r*) 26
- 25 Ray tracheids absent (*r*) 28
- 26 Ray tracheids fairly abundant, at least in the low rays; rays generally less than 25 cells in height 27
- 26 Ray tracheids sporadic, wanting from many rays; rays frequently 25 or more cells in height.
Balsam fir—*Abies balsamea* (L.) Mill.* Fig. 11-38. Desc. p. 469.
- 27 Ray tracheids usually restricted to 1 row on the upper and lower margins of the rays, low along the grain.
Hemlock—*Tsuga* spp.† Desc. pp. 465 to 469.
- 27 Ray tracheids usually wanting in the high rays, abundant in the low rays and frequently constituting the entire ray, high along the grain.
Alaska-cedar—*Chamaecyparis nootkatensis* (D. Don) Spach. Figs. 11-41 and 11-42. Desc. p. 487.
- 28 Ray parenchyma cells with end walls nodular and horizontal walls conspicuously pitted 29
- 28 Ray parenchyma cells with end walls smooth and horizontal walls inconspicuously pitted 30
- 29 Ray cells (*t*) oblong, contents colorless.
Eastern fir—*Abies* spp. Desc. p. 469.
- 29 Ray cells (*t*) orbicular to oval, contents reddish brown.
Western fir—*Abies* spp. Desc. p. 471.
- 30 Bordered pitting in 1 longitudinal row or very rarely biseriate on the radial walls; tracheids fine, up to 35 (avg 20–30) μm in diameter.
Northern white-cedar—*Thuja occidentalis* L. Desc. p. 481.
- 30 Bordered pitting in 1–2 longitudinal rows on the radial walls; tracheids medium-coarse, up to 50 (avg 32–38) μm in diameter.
Western redcedar—*Thuja plicata* Donn. ex D. Donn Desc. p. 483.

*Ray tracheids may occur sporadically on the margins of rays in western redcedar, *Thuja plicata* Donn ex D. Don. The separation can then be made on the basis of ray heights (see descriptions of species).

†For separation of eastern and western hemlock see remarks under the description of western hemlock. p. 467.

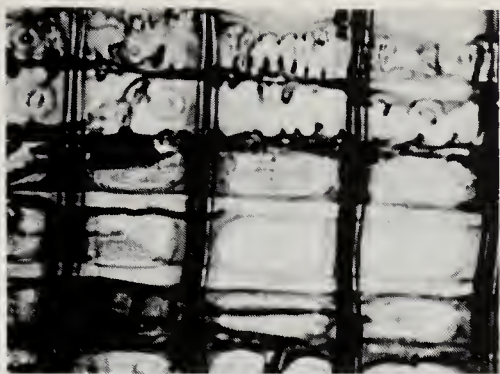


Figure 11-31 Radial section of the wood of red pine, *Pinus resinosa* Ait., showing a portion of a ray composed of two rows of dentate ray tracheids at the top, and three complete rows of ray parenchyma cells, the latter possessing angular, window-like (fenestriform) pits in the back walls of their cross fields. (300×)

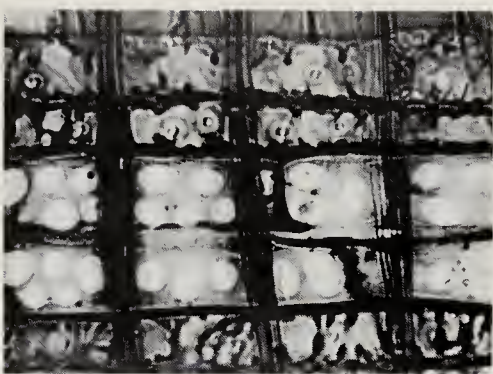


Figure 11-32 Radial section of the wood of ponderosa pine, *Pinus ponderosa* Dougl. ex Laws., showing a portion of a ray composed of three rows of dentate ray tracheids (two at top and one below), and two rows of ray parenchyma cells with rounded pinoid pits in the back walls of their cross fields. (300×)



Figure 11-33 Radial section of the wood of longleaf pine, *Pinus palustris* Mill., showing a portion of a ray composed of three rows of dentate ray tracheids at the top and one complete row of ray parenchyma cells. The latter cells possess cross fields with several pinoid pits having acute apices. (300×)

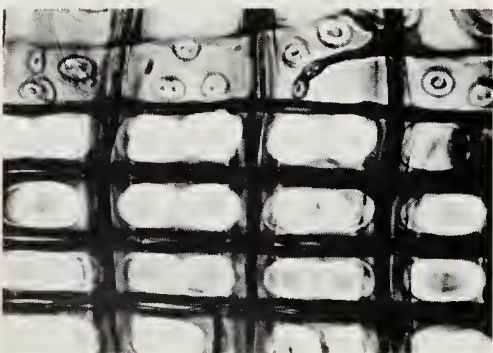


Figure 11-34 Radial section of the wood of eastern white pine, *Pinus strobus* L., showing portion of a ray composed of one row of nondentate ray tracheids at the top, and three complete rows of ray parenchyma cells, the ray parenchyma cross fields exhibiting one to two window-like (fenestriform) pits in each back wall. (300×)

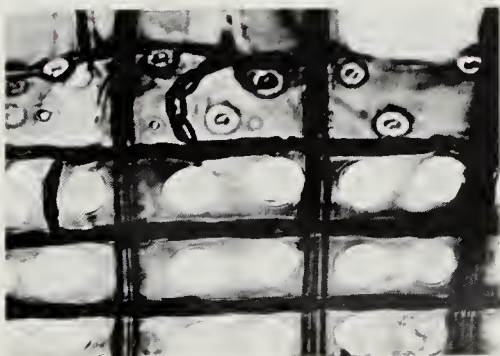


Figure 11-35 Radial section of the wood of sugar pine, *Pinus lambertiana* Dougl., showing portion of a ray composed of one row of nondentate ray tracheids at the top and two complete rows of ray parenchyma cells, the ray parenchyma cross fields having paired, rounded, window-like pits in the back walls. (300×)

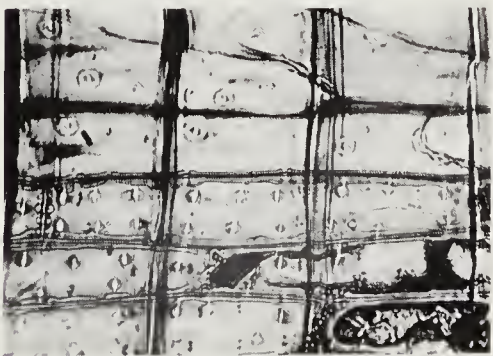


Figure 11-36 Radial section of the wood of western larch, *Larix occidentalis* Nutt., showing portion of a ray composed of two rows of nondentate ray tracheids at the top and two complete rows of ray parenchyma cells, the ray parenchyma cross fields with small, piceoid pits arranged in part in two horizontal rows. (300×)

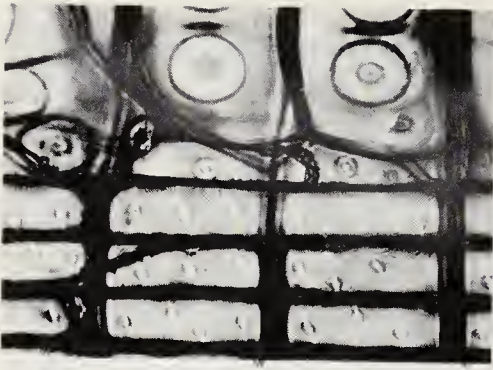


Figure 11-37 Radial section of the wood of Sitka spruce, *Picea sitchensis* (Bong.) Carr., showing portion of a ray composed of one row of nondentate ray tracheids at the top and three rows of ray parenchyma cells, the ray parenchyma cross fields exhibiting small piceoid pits in their back walls arranged in single transverse rows, for the most part. (300×)

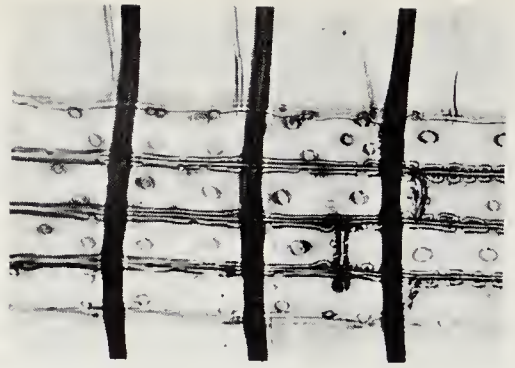


Figure 11-38 Radial section of the wood of balsam fir, *Abies balsamea* (L.) Mill., showing portion of a ray entirely composed of ray parenchyma cells whose cross-field pits are small and taxodioid. (300×)

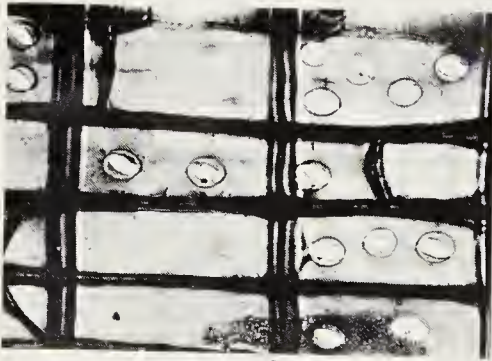


Figure 11-39 Radial section of the wood of redwood, *Sequoia sempervirens* (D. Don) Endl., showing portion of a ray composed entirely of ray parenchyma cells whose cross-field pits are large, oval, and taxodioid. (300×)

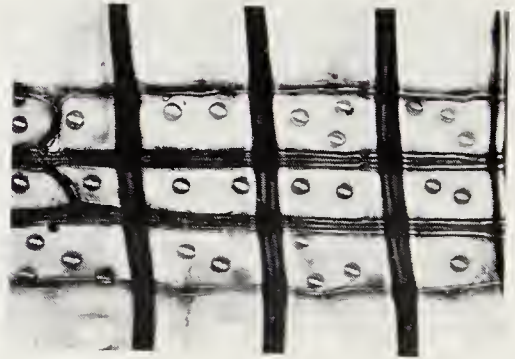


Figure 11-40. Radial section of the wood of baldcypress, *Taxodium distichum* (L.) Rich., showing portion of a ray composed entirely of ray parenchyma cells whose cross fields are equipped with small, oval-orbicular, taxodioid-cupressoid pits. (300×)

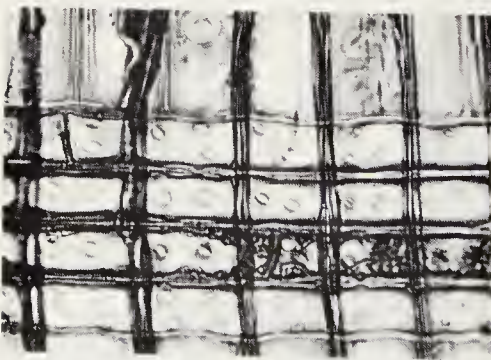


Figure 11-41 Radial section of the wood of Alaska-cedar, *Chamaecyparis nootkatensis* (D. Don) Spach, showing portion of a ray composed entirely of ray parenchyma cells whose cross-field pits are small, orbicular, and cupressoid. (300×)

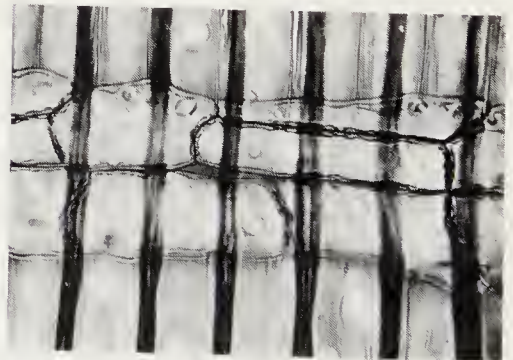


Figure 11-42 Same as in Fig. 12-41 except that the low ray shown consists entirely of ray-tracheid cells. (300×)

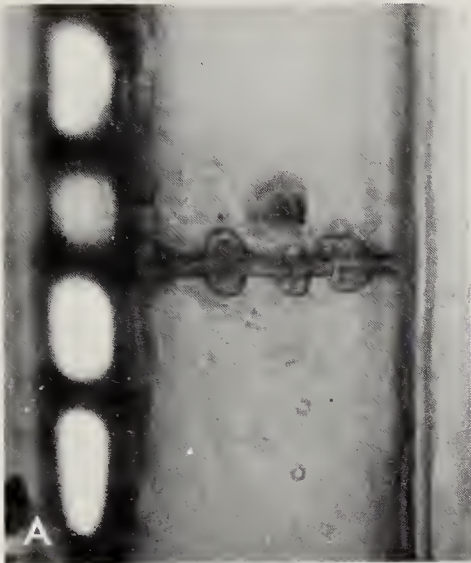


Figure 11-43 Nodular transverse (end) walls in the longitudinal parenchyma (t) of baldcypress, *Taxodium distichum* (L.) Rich. (680×)

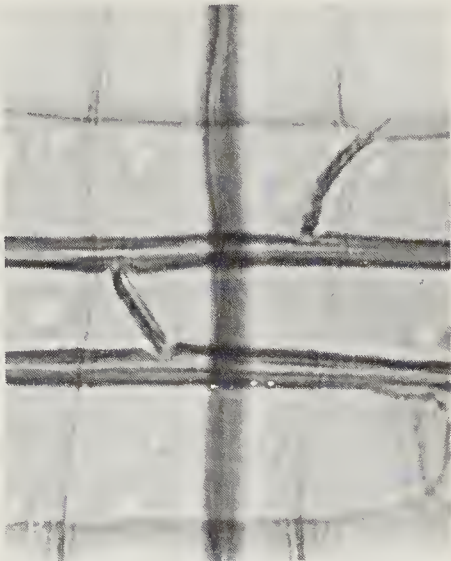


Figure 11-44 Radial view of ray parenchyma cells in a ray of western redcedar, *Thuja plicata* Donn ex D. Don, showing indentures (pitlike depressions) where the end walls of the ray parenchyma cells abut on the horizontal walls. (710×)

III KEY TO CONIFEROUS WOODS BASED ON GROSS AND MINUTE FEATURES

- 1 Longitudinal and transverse resin canals present; longitudinal canals appearing as small openings or flecks (x) confined for the most part to the outer portion of the growth rings; transverse canals present in some of the rays, forming radial streaks on the transverse surface (Figs. 11-8 to 11-22 inc.) 2
- 1 Longitudinal and transverse resin canals normally absent; longitudinal wound canals (traumatic) occasionally present, aligned in a tangential row (x) (Figs. 11-1 to 11-7 inc., 11-23 to 11-30 inc.) . 18
- 2 Longitudinal resin canals numerous, quite evenly distributed in the outer portion of every growth ring, generally visible to the naked eye* as dark- or light-colored dots or as small openings, conspicuous or relatively conspicuous with a hand lens (Figs. 11-12 to 11-19 inc.); epithelial cells thin-walled except in *Picea sitchensis* (Bong.) Carr. (Fig. 4-10e) 3
- 2 Longitudinal resin canals generally sparse, unevenly distributed, sometimes absent in portions of some growth rings (if numerous, 2 to many in a tangential row), invisible or barely

*Numerous but relatively inconspicuous in red pine (*Pinus resinosa* Ait.), jack pine (*Pinus banksiana* Lamb.), lodgepole pine (*Pinus contorta* Dougl.), and sometimes in ponderosa pine (*Pinus ponderosa* Dougl. ex Laws).

- visible as small dark or white flecks to the naked eye, not conspicuous with a hand lens (Figs. 11-8 to 11-11 inc., 11-20 to 11-22 inc.), epithelial cells thick-walled 14
- 3 Wood soft, light, quite even-grained; transition from early to late wood gradual (Figs. 11-12, 11-14, 11-15, 11-19); ray tracheids not dentate 4
- 3 Wood soft to medium-hard or hard, more or less uneven-grained; transition from early to late wood more or less abrupt (Figs. 11-16 to 11-18 inc.); ray tracheids dentate 7
- 4 Wood medium-coarse to relatively coarse-textured; longitudinal tracheids with average tangential diameter of 35–45 μm 5
- 4 Wood medium-textured; longitudinal tracheids with average tangential diameter of 25–35 μm

Eastern white pine—*Pinus strobus* L. Desc. p. 439.

- 5 Wood with a resinous odor; heartwood cream-colored to light or deep reddish brown; tangential surface (split) not noticeably dimpled; ray parenchyma cross-field pits large and window-like (fenestriform, Fig. 11-35), 1–2 per cross field. 6
- 5 Wood without resinous odor; heartwood light pinkish yellow to pale brown with a purplish cast, darkening on exposure to silvery brown with a faint tinge of red; tangential surface (split) frequently noticeably dimpled; ray parenchyma cross-field pits small, piceoid (Fig. 11-37), quite uniform in size, 1–4 (generally 2–3) per cross field.

Sitka spruce—*Picea sitchensis* (Bong.) Carr. Desc. p. 460.

- 6 Wood with unusually prominent dark streaks along the grain (resin canals), frequently exuding a sugary substance when green; seasoned heartwood a pale reddish brown; resin canals appearing to the naked eye as minute openings on the transverse surface; window-like pits in the ray parenchyma crossfields of the early-wood tracheids with rounded or lemon-shaped apertures, not occupying most of the cross field, frequently in transverse rows of 3 or 4; longitudinal resin canals with maximum tangential diameter* of 300 μm (avg between 175–225).

Sugar pine—*Pinus lambertiana* Dougl. Desc. p. 435.

- 6 Wood without unusually prominent dark streaks along the grain (resin canals), lacking sugary exudations when green; seasoned heartwood dark reddish brown; resin canals appearing to the naked eye as dark- or light-colored dots; window-like pits in the ray parenchyma crossfields of the early-wood tracheids with angular orifices, occupying most of the cross field, rarely in transverse rows of 3; longitudinal resin canals with maximum tangential diameter of 200 μm (avg between 135–150).

Western white pine—*Pinus monticola* Dougl. ex D. Don. Desc. p. 437.

*Diameter inclusive of the epithelium.

- 7

Tangential surface (split) with numerous depressions which give it a dimpled appearance (Fig. 1-14b); outer margin of the growth increment (r) with depressions or sinuses

8
- 7

Tangential surface (split) not dimpled; outer margin of the growth increment (r) not obviously distorted.

9
- 8

Longitudinal resin canals (x) small, inconspicuous or not visible with the naked eye, with maximum tangential diameter of 100 µm (avg between 80–90).
Lodgepole pine—*Pinus contorta* Dougl ex Loud. Desc. p. 441.
- 8

Longitudinal resin canals comparatively large (x), plainly visible to the naked eye, with maximum tangential diameter of 230 µm (avg between 160–185).
Ponderosa pine—*Pinus ponderosa* Dougl. ex Laws. Desc. p. 446.
Jeffrey pine—*Pinus jeffreyi* Grev. & Balf. Desc. p. 446.
- 9

Wood hard, heavy, strong, generally highly resinous; bands of late wood broad; late-wood tracheids forming a band 10 to many cells in width (x).

10
- 9

Wood approaching that of the soft pines, soft to moderately hard, light to moderately heavy; bands of late wood usually narrow; late-wood tracheids forming a band 3–10 cells in width (x)

12
- 10

Longitudinal resin canals small (x), inconspicuous or not visible to the naked eye, the majority with a tangential diameter of less than 125 µm; dentations in the ray tracheids shallow (not prominent), seldom extending across the cell (r)

11
- 10

Longitudinal resin canals comparatively large, plainly visible to the naked eye, the majority with a tangential diameter of more than 125 µm; dentations in the ray tracheids prominent, frequently extending across the cell (r) forming a reticulate pattern.
Southern hard pines—*Pinus* spp. Desc. p. 444.
Ponderosa pine—*Pinus ponderosa* Dougl. ex Laws. Desc. p. 446
Jeffrey pine—*Pinus jeffreyi* Grev. & Balf. Desc. p. 446.
- 11

Pits in the ray parenchyma cross fields in the early wood large, window-like, rounded (Fig. 11-31), 1–2 per cross field.
Red pine—*Pinus resinosa* Ait. Desc. p. 449.
Scotch pine—*Pinus sylvestris* L.
- 11

Pits in the ray parenchyma cross fields in the early wood small, pinoid, similar to those in *Pinus palustris* (Fig. 11-33), and variable in shape, 1–6 (generally 4–6), in 2 transverse rows per cross field.
Jack pine—*Pinus banksiana* Lamb. Desc. p. 451.
- 12

Heartwood light red to light brown; resin canals small (x), inconspicuous or not visible to the naked eye, the majority with a tangential diameter of less than 125 µm; dentations in the ray tracheids shallow and not prominent, seldom extending across the cell

13

- 12** Heartwood yellowish, not oily; resin canals large (x), visible to the naked eye, the majority with a tangential diameter of more than 125 μm ; dentations in the ray tracheids prominent, frequently extending across the cell (r), forming a reticulate pattern.
Ponderosa pine—*Pinus ponderosa* Dougl. ex Laws. Desc. p. 446.
Jeffrey pine—*Pinus jeffreyi* Grev. & Balf. Desc. p. 446.
- 13** Ray parenchyma cross-field pits in the early wood, large, oval, window-like (Fig. 11–31), 1–2 per cross field.
Red pine—*Pinus resinosa* Ait. Desc. p. 449.
- 13** Ray parenchyma cross-field pits in the early wood, small, pinoid, and variable in shape, 1–6 (generally 4–6 in 2 transverse rows) per cross field.
Jack pine—*Pinus banksiana* Lamb. Desc. p. 451.
- 14** Late wood not pronounced; transition from early to late wood gradual **15**
- 14** Late wood pronounced (the band of late wood frequently narrow); transition from early to late wood abrupt. **16**
- 15** Heartwood light pinkish yellow to pale brown with a purplish cast, darkening on exposure to silvery brown with a faint tinge of red, dull to somewhat lustrous, medium-textured; tangential surface (split) frequently noticeably dimpled; longitudinal tracheids with average tangential diameter between 35 and 45 μm ; ray cells (t) orbicular to oval.
Sitka spruce—*Picea sitchensis* (Bong.) Carr. Desc. p. 460.
- 15** Heartwood not distinct; wood nearly white to pale yellowish white or light yellowish brown, lustrous, relatively fine-textured; tangential surface (split) not noticeably dimpled, longitudinal tracheids with average tangential diameter between 25 and 30 μm ; ray cells (t) oblong to oval.
White, Black, Red, and Engelmann spruce—*Picea* spp. Desc. p. 457.
- 16** Wood with characteristic odor on fresh-cut surface, not oily; contour of growth rings frequently wavy; heartwood yellowish or pale reddish yellow to orange-red or deep red (without brownish cast); early-wood longitudinal tracheids with obvious spiral thickenings; longitudinal resin canals (x) in short tangential lines; transverse resin canals (t) usually with 6 epithelial cells.
Douglas-fir—*Pseudotsuga menziesii* (Mirb.) Franco. Desc. p. 462.
- 16** Wood without characteristic odor on fresh-cut surface, more or less oily; contour of growth rings seldom wavy; heartwood with brownish cast; longitudinal tracheids without spiral

- thickenings or the spirals sporadic and confined to the late wood (*Larix laricina*); longitudinal resin canals (x) not in tangential lines (sometimes in tangential groups of 2–5); transverse resin canals (t) with up to 12 or more epithelial cells 17
- 17 Wood medium-textured; heartwood yellowish brown (occasionally reddish brown); growth rings generally wide (5–20 per in), variable in width; bands of late wood usually wide; longitudinal tracheids with average diameter between 30 and 40 μm .^{*}
Eastern larch—*Larix laricina* (Du Roi) K. Koch. Desc. p. 453.
- 17 Wood coarse-textured; heartwood russet or reddish brown; growth rings generally narrow (15–30 plus per in), quite uniform in width; bands of late wood usually narrow; longitudinal tracheids with average tangential diameter between 40 and 50 μm .
Western larch—*Larix occidentalis* Nutt. Desc. p. 455.
- 18 Wood fragrant when freshly cut. 19
- 18 Wood not fragrant, sometimes ill-scented when freshly cut . . . 25
- 19 Heartwood purplish or rose-red to dull red, reddish or pinkish brown, or dull brown 20
- 19 Heartwood yellowish white to clear yellow, straw-brown, or light brown with a tinge of pink 22
- 20 Wood medium- to coarse-textured; heartwood reddish to pinkish brown or dull brown, sometimes with a lavender tinge; longitudinal tracheids with average tangential diameter between 30 and 40 μm ; intercellular spaces few or wanting at the corners of the tracheids (x), if present, inconspicuous . . . 21
- 20 Wood fine-textured; heartwood purplish or rose-red when first exposed, aging to dull brown or reddish brown; longitudinal tracheids with average tangential diameter between 20 and 30 μm ; intercellular spaces frequent at the rounded corners of the tracheids (x).
Redcedar—*Juniperus* spp. Desc. p. 490.
- 21 Wood firm when cut across the grain with a knife, with pungent, acrid taste (spicy),[†] often pecky;[‡] early and late wood of about the same hardness; ray parenchyma cross-field pits cupressoid (see Fig. 4-12f); rays occasionally in part biseriate, the ray cells in the heartwood with deposits of dark gum.
Incense-cedar—*Calocedrus decurrens* (Torr.) Florin. Desc. p. 479.

^{*}Computed by counting the number of tracheids falling under the calibrated scale of an eyepiece micrometer, using a 10 $\times$ eyepiece and a 16-mm objective, *making no allowance for the rays*. To obtain an approximate average, 5 random positions on the section are recommended. A similar procedure should be followed whenever data of this general type are required.

[†]See second footnote (†) in Key 1, p. 413.
[‡]See Chap. 10 for description of pecky condition.

21 Wood crumbly when cut across the grain with a knife, without pungent, acrid (spicy) taste; late wood considerably harder than the early wood; ray parenchyma cross-field pits taxodioid; rays strictly uniseriate, the ray cells in the heartwood with scanty, gummy infiltration.

Western redcedar—*Thuja plicata* Donn. ex D. Don. Desc. p. 483.

22 Heartwood yellowish white to bright clear yellow or yellowish brown 23

22 Heartwood light brown tinged with red or pink (roseate), or straw-brown 24

23 Wood with a pungent, ginger-like odor on fresh-cut surfaces; heartwood yellowish white to pale yellowish brown; annual rings usually averaging 6–15 per in; rays consisting entirely of ray parenchyma or very rarely with ray tracheids.

Port-Orford-cedar—*Chamaecyparis lawsoniana* (A. Murr.) Parl. Desc. p. 485.

23 Wood with an odor resembling that of raw potatoes on fresh-cut surfaces; heartwood bright clear yellow, darkening somewhat upon exposure; growth rings usually very narrow, generally averaging 30–50 plus per in; low rays frequently consisting entirely of ray tracheids, the high rays usually composed entirely of ray parenchyma.

Alaska-cedar—*Chamaecyparis nootkatensis* (D. Don) Spach. Desc. p. 487.

24 Wood somewhat oily, rubbery when cut across the grain with a knife; heartwood light brown, tinged with red or pink; parenchyma fairly abundant to abundant, present in every growth ring, visible with hand lens; ray parenchyma cross-field pits cupressoid.

Atlantic white-cedar—*Chamaecyparis thyoides* (L.) B.S.P. Desc. p. 489.

24 Wood dry, crumbly when cut across the grain with a knife; heartwood uniformly straw-brown; parenchyma lacking, or very sparse and sporadic (sometimes abundant in a growth ring but then wanting in adjacent rings); ray parenchyma cross-field pits taxodioid.

Northern white-cedar—*Thuja occidentalis* L. Desc. p. 481.

25 Wood very coarse-textured; longitudinal tracheids with average tangential diameter between 45 and 65 μm ; strands of longitudinal parenchyma readily visible along the grain with a hand lens as dark lines (dark gummy infiltration in the cells). 26

25 Wood fine- to medium-coarse-textured; longitudinal tracheids with tangential diameter between 15 and 45 μm ; strands of longitudinal parenchyma wanting or, if present, not readily visible along the grain with a hand lens 27

26 Wood more or less oily (with a greasy feel), often with a rancid odor on fresh-cut surface, frequently pecky; heart-

wood very variable in color, ranging from yellowish white to light or dark brown, reddish brown, or almost black; contour of individual rings frequently irregular; pits in the ray parenchyma cross fields in the early wood orbicular to oval-orbicular, the long axis of the aperture of the inconspicuously taxodioid pit less than 8 μm ; end walls of longitudinal parenchyma conspicuously nodular.

Baldcypress—*Taxodium distichum* (L.) Rich. Desc. p. 477.

- 26 Wood dry and brittle, not pecky; heartwood clear light red to deep reddish brown; contour of individual growth rings usually quite regular; pits in the ray parenchyma cross fields in the early wood oval for the most part, the long axis of the aperture of the conspicuously taxodioid pit more than 8 μm ; end walls of longitudinal parenchyma inconspicuously or sporadically nodular.

Redwood—*Sequoia sempervirens* (D. Don) Endl. Desc. p. 475.

- 27 Spiral thickening present in longitudinal tracheids 28

- 27 Spiral thickening absent in longitudinal tracheids 29

- 28 Heartwood bright orange to rose-red; sapwood nearly white to light yellow; wood heavy; longitudinal tracheids with average tangential diameter between 15 and 20 μm ; spiral thickenings evenly spaced.

Pacific yew—*Taxus brevifolia* Nutt. Desc. p. 492.

- 28 Heartwood clear yellow; sapwood yellowish white, not much different from heartwood; wood moderately heavy; longitudinal tracheids with average tangential diameter between 25 and 35 μm ; spiral thickenings fine, in widely spaced bands.

California torreya—*Torreya californica* Torr. Desc. p. 494.

- 29 Wood usually without characteristic odor; heartwood generally wanting, the color whitish or creamy white through shades of pale straw-buff and light brown; early and late wood generally differentiated through differences in color 30

- 29 Wood with a characteristic odor resembling that of raw potatoes on a fresh-cut surface; heartwood distinct, bright clear yellow with no conspicuous distinction between color of early and late wood; ray tracheids abundant in the low rays (frequently composing the entire ray), usually lacking in the high rays.

Alaska-cedar—*Chamaecyparis nootkatensis* (D. Don) Spach. Desc. p. 487.

- 30 Wood light buff to light brown; early wood usually with a reddish tinge; late wood darker, with a reddish brown to purplish tinge; pits in the ray parenchyma cross fields cupressoid to piceoid; ray tracheids present, usually restricted to 1 row on the upper and lower margins of the ray, lower than the cells of the ray parenchyma 31

- 30
Wood whitish to creamy white or pale brown; early wood whitish passing gradually into darker, usually lavender late wood (color contrasts of early and late wood more pronounced in wider rings); pits in the ray parenchyma cross fields taxodioid; ray tracheids absent or, if present, sporadic and wanting from many rays.

32
- 31
Wood dry, brittle, harsh under tools, uneven-grained; transition from early to late wood frequently rather abrupt; longitudinal strands of resin cells and wound canals (termed *bird peck*) rarely present.
Eastern hemlock—*Tsuga canadensis* (L.) Carr. Desc. p. 465.

31
Wood not very brittle, hard but not harsh under tools, quite even-grained; transition from early to late wood gradual; longitudinal strands of resin cells and wound canals (termed *bird peck*) frequently present.
Western hemlock*—*Tsuga heterophylla* (Raf.) Sarg. Desc. p. 467.

32
Ray cells (t) oblong, without crystals.
Eastern fir—*Abies* spp. Desc. p. 469.

32
Ray cells (t) orbicular to oval; crystals may be present in ray cells.
Western fir—*Abies* spp. Desc. p. 471.

*For separation of western hemlock (*Tsuga heterophylla*), noble fir (*Abies procera*), and California white fir (*Abies concolor*), see remarks on p. 474.

ALPHABETICAL INDEX TO DESCRIPTIONS OF CONIFEROUS WOODS

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<i>Calocedrus</i> (Libocedrus)	479	<i>Pseudotsuga</i>	462
<i>Chamaecyparis</i>	485	<i>Sequoia</i>	475
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B Index to Common Names of Species

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DESCRIPTION OF CONIFEROUS WOODS BY SPECIES

In spite of repeated warnings against placing too much reliance on the measurements of the various wood cell features, in this section the numerical values of the anatomical structures have been largely retained. This is because the tangential dimensions of the anatomical structures in the coniferous woods tend to remain fairly constant within relatively narrow limits; i.e., they are not excessively affected by the location of a cell within the growth rings or the various parts of the stem. Furthermore, the softwoods possess only a few different kinds of cells, by far the most abundant of which are the longitudinal tracheids. These cells comprise upward of 90 percent of the total volume of a softwood. Because of these factors the numerical values for wood cells in the coniferous woods are considered to be quite reliable and are given in the descriptions that follow. *Measurements of the diameter of the resin canals include the epithelium.* Further numerical information on the anatomical features of the coniferous woods is found in Tables 4-2 to 4-5 in Chap. 4.

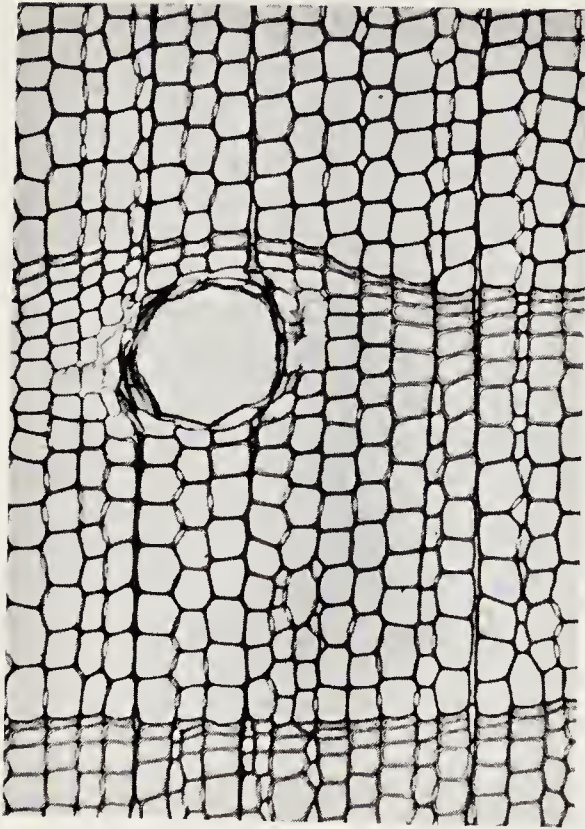
SUGAR PINE

(Pinaceae)

Pinus lambertiana Dougl.

General Characteristics

Sapwood nearly white to pale yellowish white, narrow to medium wide, frequently discolored by blue stain; *heartwood* light brown to pale reddish brown (never deep reddish brown as in the eastern and western white pines), frequently discolored with brown stain; *wood* with a faint, non-characteristic odor, often exuding a sugary substance when green but without characteristic taste when dry, straight- and even-grained, relatively coarse-textured, light (sp gr approx 0.34 green, 0.38 oven-dry), moderately soft (some samples spongy, others quite hard). *Growth rings* distinct, delineated by a rather narrow band of darker late wood at the outer margin, narrow to medium wide. Early-wood zone usually wide, appearing to occupy most of the ring; transition from early to late wood gradual; late wood as described above, not appreciably more resistant to tools than the early wood. *Parenchyma* not visible. *Rays* very fine (x), not visible to the naked eye except where they include a transverse resin canal, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals conspicuous (the orifice visible to the naked eye), numerous, confined largely to the central and outer portions of the ring, solitary or rarely 2–3 contiguous in the tangential plane, appearing as prominent dark streaks along the grain, especially in



x—75x



t—75x

Figure 11-45 Sugar pine, *Pinus lambertiana* Dougl.

heartwood, where dark streaks are caused by dust in resin canals (t); (b) transverse canals less conspicuous than the longitudinal canals, appearing as whitish, rather prominent wood rays spaced at irregular intervals on the transverse surface, visible with a hand lens as brownish specks on the tangential surface.

Minute Anatomy

Tracheids up to 65 (avg 40–50) μm in diameter; bordered pits in 1–2 rows on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma large (window-like), 1–4 (generally 2 and not infrequently 3) per cross field; those in the early wood rounded to elliptical (lemon-shaped) and more or less widely spaced (Fig. 4-12), occasionally superimposed. *Longitudinal parenchyma* wanting. Rays of 2 types, uniseriate and fusiform; (a) uniseriate rays numerous (t), 1–12 plus cells in height; (b) fusiform rays scattered, with a transverse resin canal, 2–4-seriate through the central thickened portion, tapering above and below to uniseriate margins similar to the (a) rays, up to 30 plus cells in height; end walls nodular; ray tracheids present in both types of rays,

marginal and interspersed, nondentate. *Resin canals* with thin-walled epithelium in the sapwood but thick-walled in the heartwood, frequently occluded with tylosoids in the heartwood; longitudinal canals with maximum diameter of 300 (avg 175–225) μm , the transverse canals much smaller (usually less than 80 μm).

Remarks

Sometimes confused with eastern white pine (*Pinus strobus* L.) and with western white pine (*Pinus monticola* Dougl.), but the heartwood never aging to deep reddish brown as in these species; coarser-textured, with more rounded (lemon-shaped) and widely spaced pits in the early-wood ray crossings, and with larger longitudinal resin canals resulting in more prominent streaks along the grain.

Uses

Boxes and crates (because of light weight and color, nailing properties, and freedom from odor and taste); *millwork* (door, sash, interior and exterior trim, siding, panels, etc., especially suited for such uses because of ease of working and ability to stay in place and to take and hold paint);* lower grades for *building construction* (sheathing, subflooring, roofing, etc); *foundry patterns* for which it is in increasing demand because of the scarcity of high-grade eastern white pine (considered as standard for wood patterns), its ability to meet the exacting requirements of this use, and its availability in defect-free, wide and thick pieces; *signs*; *piano keys* and *organ pipes*; *plywood*; *pulpwood*.

WESTERN WHITE PINE, IDAHO WHITE PINE (Pinaceae)

Pinus monticola Dougl. ex D. Don

General Characteristics

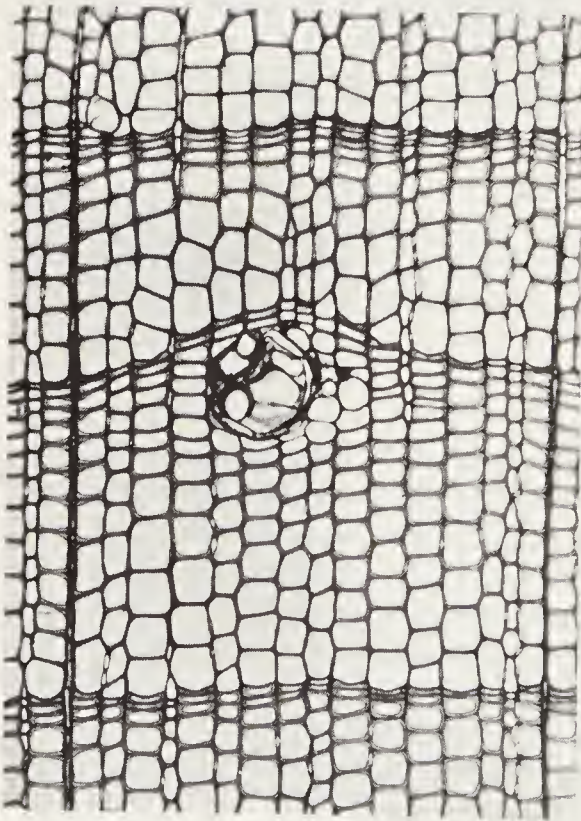
Sapwood nearly white to pale yellowish white, narrow to medium wide; *heartwood* cream colored to light brown or reddish brown, turning darker on exposure; *wood* with a slightly resinous, noncharacteristic odor, without characteristic taste, straight- and even-grained, medium-coarse to rather coarse-textured, moderately light (sp gr approx 0.35 green, 0.42 oven-dry), moderately soft. *Growth rings* distinct, delineated by a band of darker late wood, generally narrow (mature trees). Early-wood zone usually wide; transition from early to late wood gradual; late-wood zone usually narrow, not appreciably more resistant to tools than the early wood. *Parenchyma* not

* The resin in the heartwood tends to discolor paint.

visible. Rays very fine (x), not visible to the naked eye except where they include a transverse resin canal, forming a fine, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals appearing as whitish flecks to the naked eye, numerous, confined largely to the central and outer portions of the ring, solitary or rarely 2–3 contiguous on the tangential plane, forming more or less prominent streaks along the grain (t); (b) transverse canals less conspicuous than the longitudinal canals, appearing as whitish, rather prominent wood rays spaced at irregular intervals on the transverse surface, scarcely visible with a hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 60 (avg 35–45) μm in diameter; bordered pits in 1 row (occasionally in 2) on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma large (window-like), 1–4 (mostly 1–2) per cross field, occasionally superimposed, those in the early wood more or less angled and occupying most of the back wall. *Longitudinal parenchyma* wanting. *Rays* of 2 types, uniseriate and fusiform; (a) uniseriate rays numerous (t) 1–12 plus cells in height; (b)



x—75×



t—75×

Figure 11-46 Western white pine, *Pinus monticola* Dougl. ex D. Don.

fusiform rays scattered, with a transverse resin canal, 2–4-seriate through the central thickened portion, tapering above and below to uniseriate margins similar to the (a) rays, up to 20 plus cells in height; end walls nodular; ray tracheids present in both types of rays, marginal and interspersed, nondentate. *Resin canals* with thin-walled epithelium in the sapwood but thick-walled in the heartwood, frequently occluded with tylosoids in the heartwood; longitudinal canals with maximum diameter of 200 (avg 135–150) μm , the transverse canals much smaller (usually less than 80 μm).

Remarks

Very similar to eastern white pine (*Pinus strobus* L.) but usually somewhat coarser-textured, with narrower, more uniform rings and with smaller and more angular pits in the early-wood ray crossings and larger longitudinal resin canals.

These 2 species cannot be separated positively on the basis of minute wood anatomy. Acetone extractives of their heartwood, however, can be distinguished by simple paper chromatography (see page 645). When the extractive components separate in the chromatograph, eastern white pine develops yellowish orange spots because of the presence of a high percentage of cryptostrobin and strobobanksin, while western white pine shows pinkish red spots indicative of a preponderance of pinocembrin.

Uses

Matches; boxes and crates (very satisfactory because of light weight and color, ability to take nails and screws without splitting, and freedom from odor and taste); *building construction* (lower grades for sheathing, sub-flooring, roof boards; higher grades for siding, exterior and interior trim, partitions, paneling, etc.); *millwork* (such as sash, frames, doors) for which it is very well suited because of the ease of working and its ability to stay in place and hold paint; *patterns; fixtures; caskets; core stock* for plywood (especially table tops); *pulpwood*.

EASTERN WHITE PINE, NORTHERN WHITE PINE (Pinaceae)

Pinus strobus L.

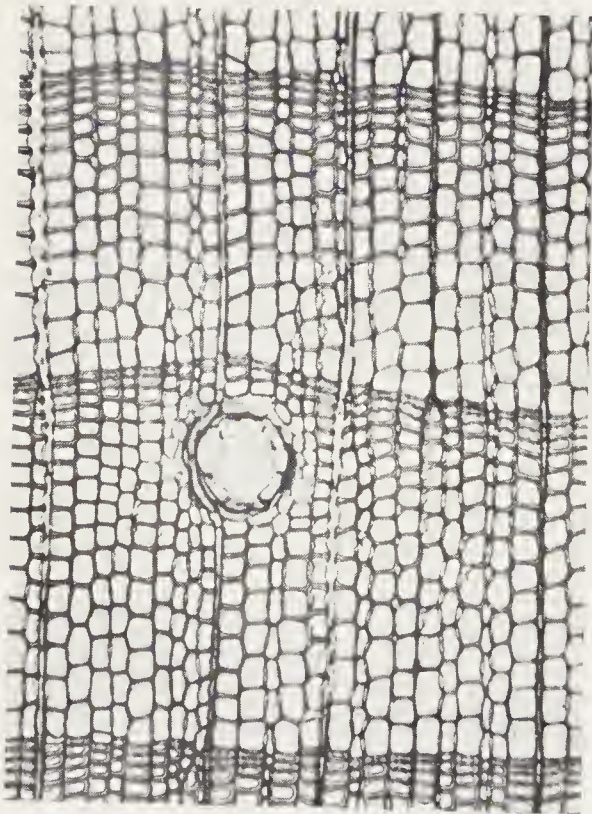
General Characteristics

Sapwood nearly white to pale yellowish white, narrow to medium wide; *heartwood* cream colored to light brown or reddish brown, turning much darker on exposure; *wood* with a slightly resinous, noncharacteristic odor, without characteristic taste, generally straight- and even-grained, medium-textured, light (sp gr approx 0.34 green, 0.37 oven-dry), moderately soft. *Growth rings* distinct, delineated by a band of darker late wood, narrow to

wide according to the age and vigor of the tree. Early-wood zone usually wide; transition from early to late wood gradual; late-wood zone narrow (wood from mature trees) to wide (second-growth stock) not appreciably more resistant to tools than the early wood. *Parenchyma* not visible. *Rays* very fine (x), not visible to the naked eye, except where they include a transverse resin canal, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals appearing as whitish flecks to the naked eye, numerous, confined largely to the central and outer portions of the ring, solitary or rarely 2–3 contiguous on the tangential plane, forming more or less prominent streaks along the grain (t); (b) transverse canals less conspicuous than the longitudinal canals, appearing as whitish, rather prominent wood rays spaced at irregular intervals, on the transverse surface, barely visible with a hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 45 (avg 25–35) μm in diameter; bordered pits in 1 row or occasionally paired on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma large



x—75x



t—75x

Figure 11-47 Eastern white pine, *Pinus strobus* L.

(window-like), 1–2 (mostly 1) per cross field, those in the early wood mostly oblong and occupying most of the back wall (Fig. 11-34). *Longitudinal parenchyma* wanting. *Rays* of 2 types, uniseriate and fusiform; (a) uniseriate rays numerous (t), 1–8 plus cells in height; (b) fusiform rays scattered, with a transverse resin canal, 2–3 seriate through the central thickened portion, tapering above and below to uniseriate margins similar to the (a) rays, up to 30 plus cells in height; end walls nodular; ray tracheids present in both types of rays, marginal and interspersed, nondentate. *Resin canals* with thin-walled epithelium in the sapwood but thick-walled in the heartwood, frequently occluded with tylosoids in the heartwood; longitudinal canals with maximum diameter of 150 (avg 90–120) μm , the transverse canals much smaller (usually less than 60 μm).

Remarks

See Remarks under western white pine (*Pinus monticola* Dougl. ex D. Don p. 439).

Uses

Boxes and crates (one of the principal species, second-growth stock being used for the most part), for which it is specially suited because of its light weight, good color for stenciling, and lack of objectionable odor and taste; *patterns* (formerly the standard pattern wood, owing to its uniform texture, ease of cutting in any direction, minimal shrinkage and swelling, ability to stay in place, ease of gluing, freedom from resin, and strength to withstand rough handling; replaced largely by sugar and western white pines, because of scarcity of high-grade stock); *millwork* (principally sash and doors); *toys*, *woodenware* and *novelties*; *signs*; *caskets*; *building construction* (formerly widely used for practically every part of a house, but now infrequently because of the scarcity of suitable stock); *matches* (formerly the leading wood, now largely replaced by western white pine and aspen); *shade* and *map rollers*; *venetian blinds*; *dairy* and *poultry supplies*; *boot* and *shoe findings*.

LODGEPOLE PINE

(Pinaceae)

Pinus contorta Dougl. ex Loud.

General Characteristics

Sapwood nearly white to pale yellow, narrow; *heartwood* light yellow to pale yellowish brown, often scarcely darker than the sapwood and not clearly distinct; wood with a distinct, noncharacteristic, resinous odor (especially when green), without characteristic taste, generally straight- but

somewhat uneven-grained, medium fine-textured, frequently prominently dimpled on the tangential surface (split), moderately light (sp gr approx 0.38 green, 0.43 oven-dry), moderately soft. *Growth rings* distinct, not as conspicuous as in many of the other hard pines, delineated by a band of darker late wood. Early-wood zone wide or narrow (outer rings of mature trees); transition from early to late wood more or less abrupt; late-wood zone narrow but distinct, not appreciably more resistant to tools than the early wood. *Parenchyma* not visible. *Rays* very fine (x), not visible to the naked eye, appearing whitish or brownish with a lens where they contain a transverse resin canal, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals relatively inconspicuous or not visible to the naked eye, numerous, confined largely to the central and outer portions of the ring, solitary for the most part, forming fairly conspicuous, brownish streaks along the grain (t); (b) transverse canals less conspicuous than the longitudinal canals, appearing as brownish radial lines spaced at irregular intervals on the transverse surface, barely visible with a hand lens on the tangential surface.

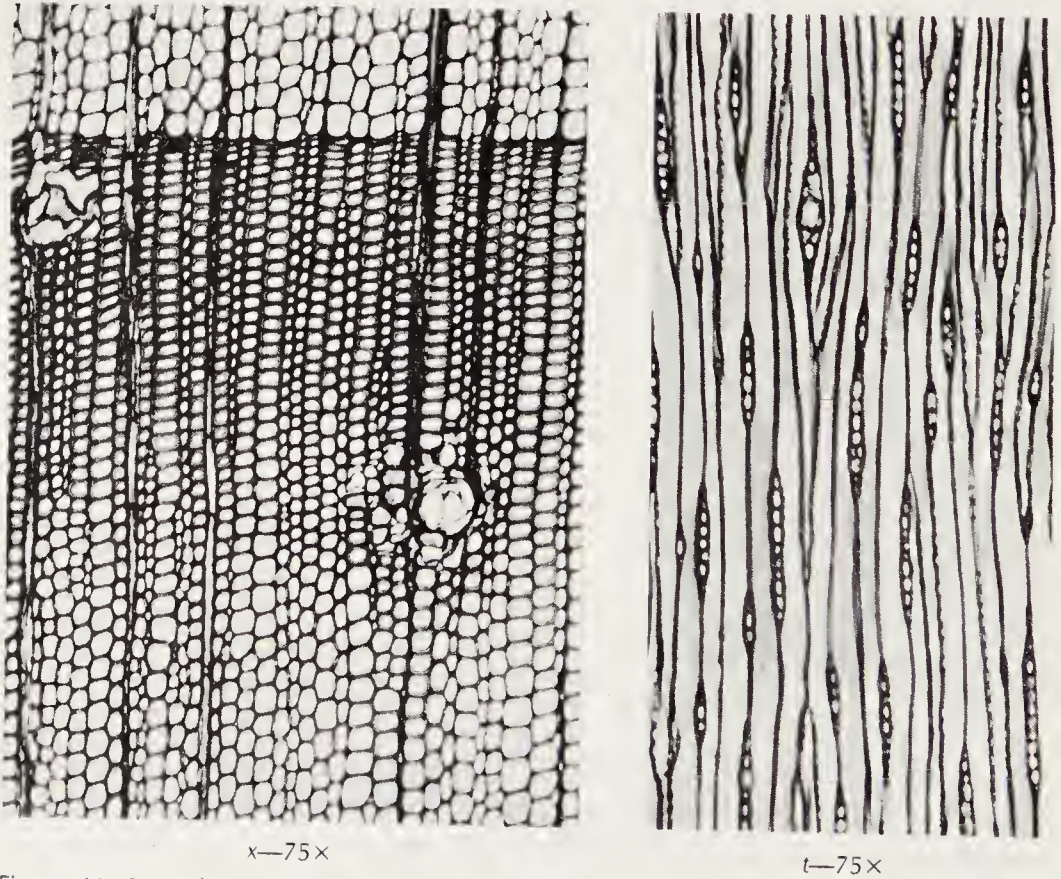


Figure 11-48 Lodgepole pine, *Pinus contorta* Dougl. ex. Loud.

Minute Anatomy

Tracheids up to 55 (avg 35–45) μm in diameter, those in the dimpled areas swirled as viewed in the tangential section; bordered pits in 1 row or occasionally paired on the radial walls; tangential pitting wanting in the last few rows of late-wood tracheids (sometimes appearing to be present owing to a twist in the tracheids); pits leading to ray parenchyma pinoid, variable in size and shape, 1–6 (generally 2–4) per cross field. *Longitudinal parenchyma* wanting. *Rays* of 2 types, uniseriate or in part biseriate, and fusiform; (a) uniseriate rays numerous (*t*) 1–15 plus cells in height; biseriate rays frequent in the areas of swirled tissue; (*b*) fusiform rays scattered or rarely 2–3 confluent along the grain in the swirled areas, with a transverse resin canal, 2–3-seriate through the central thickened portion, tapering above and below to uniseriate margins similar to the (*a*) rays, up to 15 plus cells in height; ray tracheids present in both types of rays, marginal and interspersed, prominently dentate [with teeth frequently extending across the cell forming a reticulate pattern (*r*)]; marginal tracheids often in several rows; low rays frequently consisting entirely of ray tracheids; ray parenchyma thin-walled. *Resin canals* with thin-walled epithelium, frequently occluded with tylosoids in the heartwood; longitudinal canals with maximum diameter of 110 (avg 80–90) μm , the transverse canals much smaller (usually less than 50 μm).

Remarks

Lodgepole pine can usually be separated from the other commercial pines, except ponderosa and jack pines, by the dimpling on the split tangential surface. Ponderosa pine has much larger resin canals (see Remarks, p. 448). Resin canals, especially horizontal, tend to be smaller in jack pine than in lodgepole,* this feature provides a fairly reliable means of separation. Black† reports that ray parenchyma in lodgepole pine have thin walls, lacking in localized thickenings, while those of jack pine are slightly and irregularly thickened. Positive identification of these two species is possible on the basis of the analysis of terpenes; jack pine has large amounts of α - and β -terpenes, while lodgepole pine contains β -phellandrene.

Uses

Mine timbers; poles; posts; railroad ties; pulpwood; suitable for hardboard and particle board; lumber for rough construction, frequently mixed with spruce; planing mill products, such as siding, knotty pine paneling, and

* According to E. Perem, the average diameter of the horizontal resin canals in lodgepole pine is 45 μm and in jack pine 32 μm . Personal communication, J. D. Hale, Forest Products Research Branch, Ottawa Laboratory, 1963.

† T. M. Black, Some Features of the Timber Anatomy of *Pinus contorta* Loud. and *Pinus banksiana* Lamb., *J. Inst. Wood Sci.*, **11**:57–65 (1963).

flooring; railroad car decking; veneer for decorative faces for prefinished plywood; structural plywood; locally for corral rails; orchard props; rustic furniture; and shingles.

SOUTHERN PINE

(Pinaceae)

Longleaf pine (*Pinus palustris* Mill.)

Shortleaf pine (*Pinus echinata* Mill.)

Loblolly pine (*Pinus taeda* L.)

Slash pine (*Pinus elliottii* Engelm.)

Pitch pine (*Pinus rigida* Mill.)

Pond pine (*Pinus serotina* Michx.)

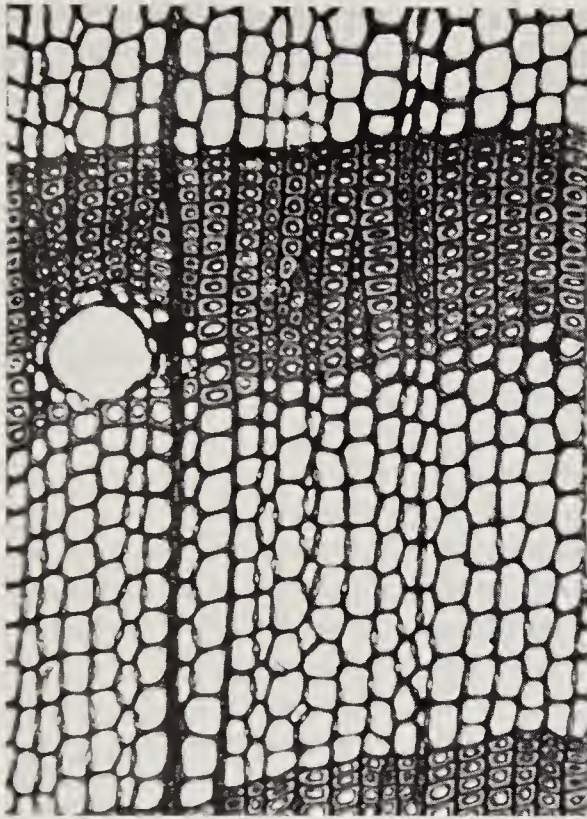
Etc.

General Characteristics

Sapwood nearly white to yellowish or orange-white or pale yellow, thin to very thick; heartwood distinct, ranging through shades of yellow and orange to reddish brown or light brown, resinous,* wood with a distinct, noncharacteristic, resinous odor, without characteristic taste, generally straight- but uneven-grained, medium-textured, moderately heavy to very heavy (avg sp gr 0.45–0.59 green, 0.52–0.66 oven-dry)† moderately hard to hard. Growth rings distinct, delineated by a pronounced band of darker late wood. Early-wood zone varying from wide or very wide (slash pine, loblolly pine) to narrow (slow-growth shortleaf pine, etc.); transition from early to late wood abrupt, the contrast frequently very striking; late-wood zone ranging from broad to narrow, varying greatly in width and density according to age of the tree, conditions of growth, and within general limits according to species. Parenchyma not visible. Rays very fine (x), not visible to the naked eye except where they include a transverse resin canal, forming a fine, close, inconspicuous fleck on the quarter surface. Resin canals present, longitudinal and transverse; (a) longitudinal canals appearing as whitish or brownish flecks which are conspicuous or relatively conspicuous to the naked eye, plainly distinct with a hand lens, numerous, confined largely to the central and outer portions of the ring, solitary or rarely 2–3 contiguous in the tangential plane, generally visible as relatively inconspic-

* In longleaf pine the sapwood contains about 2 percent resin, while the average for the heartwood is 7–10 percent. The average resin content for the heartwood in butt logs may be 15 percent and that in the stump 25 percent.

† In order to assist in selection of wood suitable for structural purposes, the grading rules for southern yellow pine contain the density rule provision. To qualify under this provision, structural timber must show on one end of the piece an average of not fewer than 6 rings per inch and 1/8 summerwood.



x—75×



t—75×

Figure 11-49 Shortleaf pine, *Pinus echinata* Mill.

uous streaks along the grain (t); (b) transverse canals less conspicuous than the longitudinal canals, appearing as whitish, relatively inconspicuous wood rays spaced at irregular intervals on the transverse surface, not visible or barely visible with a hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 60 (avg 35–45) μm in diameter; bordered pits in 1 row or not infrequently paired on the radial walls; tangential pitting wanting on the last few rows of late-wood tracheids; pits leading to ray parenchyma pinoid, variable in size and shape, 1–6 (generally 2–5) per cross field (Fig.11-33). *Longitudinal parenchyma* wanting. *Rays* of 2 types, uniseriate and fusiform; (a) uniseriate rays numerous (t), 1–10 plus cells in height; (b) fusiform rays scattered, with a transverse resin canal, 2–4-seriate through the central thickened portion, tapering above and below to uniseriate margins similar to the (a) rays, up to 12 plus cells in height; ray tracheids present in both types of rays, marginal and interspersed, prominently dentate [the teeth frequently extending across the cell, forming a reticulate pattern (r)]; marginal and interspersed tracheids often in several rows; low rays frequently consisting

entirely of ray tracheids; ray parenchyma thin-walled. *Resin canals* with thin-walled epithelium, frequently occluded with tylosoids in the heartwood; longitudinal canals with maximum diameter of 180 (avg 90–150) μm , the transverse canals much smaller (usually less than 70 μm).

Remarks

The yellow or hard pines of Southeastern and Eastern United States cannot be separated on the basis of wood structure; in the trade, southern pine is usually marketed according to density. Kukachka* reports that growth rings of longleaf and slash pines frequently exhibit multiple late-wood bands and that the pith of longleaf pine is 0.2 in in diameter as against 0.1 in or less for other southern pines.

Uses

Pulpwood (converted largely by the sulfate process for use in the manufacture of kraft paper and insulation and other types of fiberboard); *hardboard*, *particle board*; *poles*; *mine timbers*; *piling*; *railroad ties*; *slack cooperage* (shortleaf and loblolly); *veneer* and *construction plywood*; *excelsior*; *structural timbers* (such as stringers, beams, and joists in bridge, trestle, warehouse, and factory construction, for which it is highly suited because of its strength, stiffness, and hardness); *building construction* (joists, rafters, studdings, and building lumber); †*boxes*; *baskets*; *crates* (boards and veneer), and *pallets*; *planing-mill products* and *millwork* (because of hardness and good wearing qualities); *railroad-car construction*; *agricultural implements*; *ship- and boatbuilding*; *paving blocks*; *tanks and silos*; *woodenware* and *novelties*; *destructive distillation* (mostly heartwood from the stumps and tops of longleaf pine).

PONDEROSA PINE AND JEFFREY PINE (Pinaceae)

Ponderosa pine, western yellow pine (*Pinus ponderosa* Dougl. ex Laws.)
Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.)

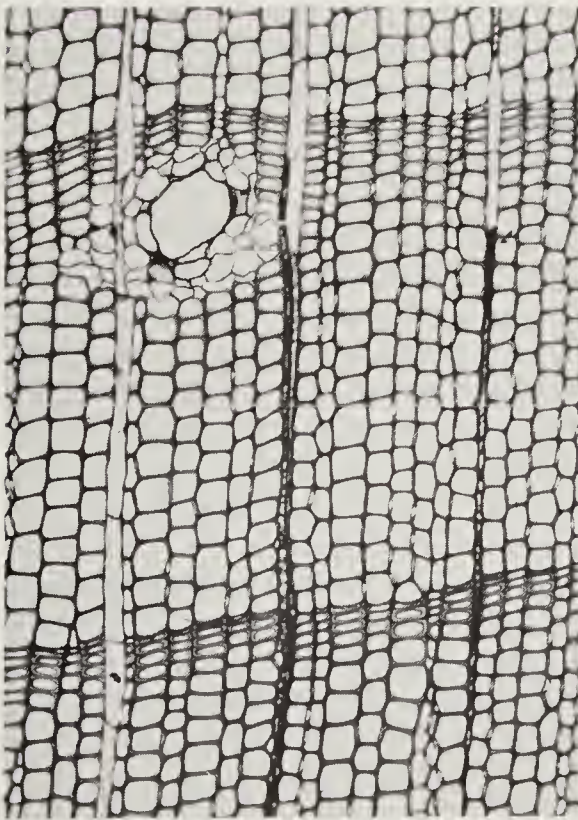
General Characteristics

Sapwood nearly white to pale yellowish, wide (often composed of 80 or more rings); *heartwood* of ponderosa pine yellowish to light reddish or orange-brown, that of Jeffrey pine sometimes with a pinkish cast; wood of

* B. F. Kukachka, Identification of Coniferous Woods, *Tappi*, **43**:887–896 (1960).

†Longleaf and slash pines are used for heavy construction such as for factories, warehouses, bridges, and docks, whereas loblolly and shortleaf pines are used principally for such building materials as interior finish, frame and sash, wainscoting, joists, and subflooring.

ponderosa pine with distinct, noncharacteristic, resinous odor, that of Jeffrey pine sweet (apple-like) when first exposed; woods of both species without characteristic taste, generally straight- and quite even- to very uneven-grained, medium coarse-textured, frequently dimpled on the tangential surface (split) but the dimples less conspicuous than in lodgepole pine, moderately light (sp gr approx 0.38 green, 0.42 oven-dry), moderately soft. *Growth rings* distinct, inconspicuous to conspicuous, delineated by a band of darker late wood. Early-wood zone narrow to wide (wide-ringed stock); transition from early to late wood abrupt; late-wood zone broad and conspicuous in wide rings, in narrow rings much reduced and often appearing as a narrow line which is not visible without magnification, the wood then resembling soft pine. *Parenchyma* not visible. *Rays* very fine (x), not visible to the naked eye except where they include a transverse resin canal, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals conspicuous (the orifice generally visible to the naked eye), numerous, confined largely to the central and outer portions of the ring, solitary or



x—75×



t—75×

Figure 11-50 Ponderosa pine, *Pinus ponderosa* Dougl. ex Laws.

rarely 2–3 contiguous in the tangential plane, appearing as relatively prominent dark streaks along the grain (*t*); (*b*) transverse canals less conspicuous than the longitudinal canals, appearing as whitish, relatively inconspicuous wood rays spaced at irregular intervals on the transverse surface, barely visible with a hand lens as brownish specks on the tangential surface.

Minute Anatomy

Tracheids up to 60 (avg 35–45) μm in diameter; bordered pits in 1 row (occasionally in 2) on the radial walls; tangential pitting wanting in the last few rows of late-wood tracheids; pits leading to ray parenchyma pinoid, variable in shape and size, 1–7 (generally 4–5) per cross field (Fig. 11-32). *Longitudinal parenchyma* wanting. *Rays* of 2 types, uniseriate and fusiform; (*a*) uniseriate rays numerous (*t*), 1–12 plus cells in height; (*b*) fusiform rays scattered, with a transverse resin canal, 3–5-seriate through the central thickened portion, tapering above and below to uniseriate margins similar to the (*a*) rays, up to 20 plus cells in height; ray tracheids present in both types of rays, marginal and occasionally interspersed, prominently dentate [the teeth frequently extending across the cell, forming a reticulate pattern (*r*)]; marginal tracheids often in several rows; low rays frequently consisting entirely of ray tracheids; ray parenchyma thin-walled. *Resin canals* with thin-walled epithelium, frequently occluded with tylosoids in the heartwood; longitudinal canals with maximum diameter of 230 (avg 160–185) μm , the transverse canals much smaller (usually less than 70 μm).

Remarks

Ponderosa and Jeffrey pines cannot be separated on the basis of wood structure. The heartwood of Jeffrey pine is generally softer than that of ponderosa pine and frequently has a pinkish cast which is lacking in ponderosa pine; the odor of fresh-cut Jeffrey pine is sweet (hence the term *apple pine*), in contrast to the resinous odor of ponderosa pine. The 2 pines can be positively separated on the basis of the composition of their essential oils; Jeffrey pine contains 90 to 95 percent heptane, while ponderosa pine oils are a mixture of α -pinene, β -pinene, and limonene.

Dimpled ponderosa pine is sometimes confused with lodgepole pine, which also contains this feature. Ponderosa pine differs from the latter by possessing darker heartwood and larger longitudinal resin canals [ponderosa pine—230 (avg 160–185) μm ; lodgepole pine—110 (avg 80–90) μm].

Uses

Boxes and crates, usually lower grades (for which it is well suited because of its light weight and color, ability to take nails and screws without splitting, strength to withstand rough handling, and freedom from objectionable

odors and taste); *millwork* (the softer grades), especially for sash, doors, and screens (because of its softness and uniformity of grain which permit accurate machining, and its moderately low shrinkage, ability to stay in place, resistance to abrasion, and attractive clear color); *planing-mill products* [interior finish, trim, siding, paneling, including knotty grade (the difference between the color of the heart- and sapwood is accentuated upon exposure, necessitating care in matching the wood for interiors)]; *building construction* (the heavier, wider-ringed, more resinous wood), as joists, rafters, studdings, sills, and sheathing; *turned work* (porch columns, posts, balusters, stair rails); caskets and coffins; *furniture*; *shade and map rollers*; *patterns* (not considered equal to the white pines); *trunks*; *toys*; *piling*; *poles*; *posts*; *mine timbers*; *plywood*; *pulpwood*.

RED PINE, NORWAY PINE (Pinaceae)

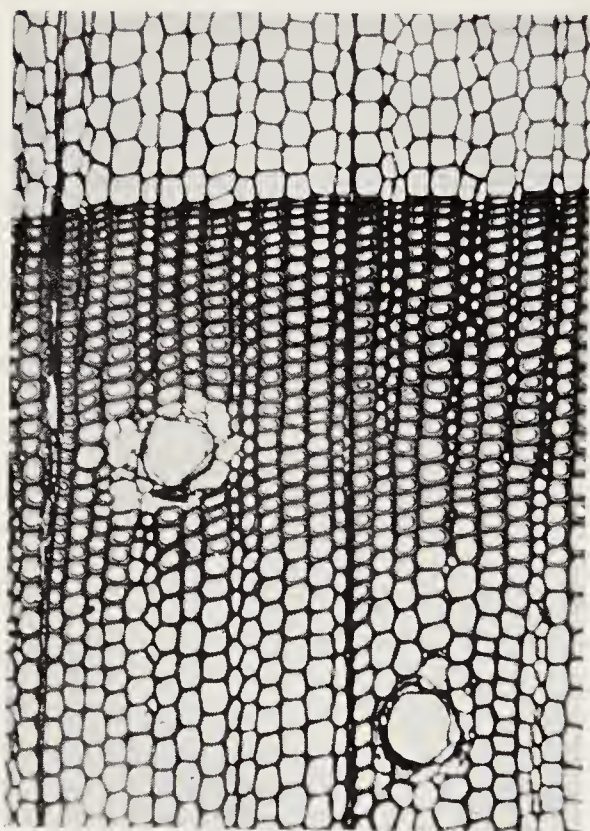
Pinus resinosa Ait.

General Characteristics

Sapwood nearly white to yellowish, narrow to medium wide; *heartwood* light red to orange-brown or reddish brown; wood somewhat oily, with a fairly strong, resinous, noncharacteristic odor, without characteristic taste, usually straight- and quite even-grained, medium-textured, moderately heavy (sp gr approx 0.41 green, 0.48 oven-dry), moderately soft. *Growth rings* distinct, delineated by a band of darker late wood, narrow to wide. Early-wood zone generally wide; transition from early to late wood more or less abrupt; late-wood zone narrow to fairly wide (in wide rings), darker and appreciably denser than the early-wood zone. *Parenchyma* not visible. *Rays* very fine (x), not visible with the naked eye, appearing whitish with a lens where they contain a transverse resin canal, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals relatively inconspicuous to the naked eye, appearing as minute, brownish flecks, relatively conspicuous with a hand lens, numerous, confined largely to the central and outer portions of the ring, solitary or rarely 2–3 contiguous in the tangential plane, not visible or forming relatively inconspicuous streaks along the grain (t); (b) transverse canals less conspicuous than longitudinal canals, appearing as whitish, radial lines spaced at irregular intervals on the transverse surface, not visible with hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 45 (avg 30–40) μm in diameter; bordered pits in 1 row or occasionally paired on the radial walls; tangential pitting wanting or very



x—75×



t—75×

Figure 11-51 Red pine, *Pinus resinosa* Ait.

sporadic in the last few rows of late-wood tracheids; pits leading to ray parenchyma large (window-like); 1–2 (mostly 1) per cross field (Fig. 11-31). *Longitudinal parenchyma* wanting. *Rays* of 2 types, uniseriate and fusiform; (a) uniseriate rays numerous (t), 1–10 plus cells in height; (b) fusiform rays scattered, with a transverse resin canal, 2–3-seriate through the central thickened portion, tapering more or less abruptly above and below to uniseriate margins, up to 10 plus cells in height; ray tracheids present in both types of rays, marginal and interspersed, shallowly dentate (the teeth seldom extending to the center of the cell cavity). *Resin canals* smaller than in most pines, with thin-walled epithelium in the sapwood but thick-walled in the heartwood, frequently occluded with tylosoids in the heartwood; longitudinal canals with maximum diameter of 120 (avg 80–110) μm , the transverse canals much smaller (usually less than 50 μm).

Remarks

Norway pine is sometimes confused with the soft pines but can readily be separated by the more or less abrupt transition between early and late wood

and the presence of dentate ray tracheids (nondentate in the soft pines). The window-like pits that feature the ray crossings are similar to those of the soft pines and serve to distinguish Norway pine from all other domestic hard pines.

Uses

Pulpwood (converted by sulfate process); *railroad ties*; *poles*; *posts*; *building construction* (locally); *boxes*; *crates*; *pallets*; *planing-mill products* (sash, doors, blinds, interior and exterior finish).

JACK PINE (Pinaceae)

Pinus banksiana Lamb.

General Characteristics

Sapwood nearly white, wide; *heartwood* formation frequently delayed until trees reach the age of 40–50 years, light orange to light brown, somewhat resinous; wood with a distinct, noncharacteristic, resinous odor, without characteristic taste, generally straight- but somewhat uneven-grained, medium-textured, moderately heavy (sp gr approx 0.40 green, 0.45 oven-dry), moderately soft; split tangential surface sometimes dimpled. *Growth rings* distinct, delineated by a band of darker late wood. Early-wood zone variable in width; transition from early to late wood abrupt; late-wood zone narrow to fairly wide, darker and appreciably denser than the early-wood zone. *Parenchyma* not visible. *Rays* very fine (x), not visible to the naked eye, appearing whitish with a lens where they contain a transverse resin canal, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals relatively inconspicuous to the naked eye, numerous, confined for the most part to the central and outer portion of the ring, mostly solitary, forming inconspicuous, brownish streaks along the grain (t); (b) transverse canals inconspicuous, appearing with a hand lens as whitish, radial lines spaced at irregular intervals on the transverse surface, barely visible with a hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 45 (avg 27–37) μm in diameter; bordered pits in 1 row or occasionally paired on the radial walls; tangential pitting wanting in the last few rows of late-wood tracheids; pits leading to ray parenchyma pinoid, variable in size and shape, 1–6 (generally 4–6 in 2 rows) per cross field.

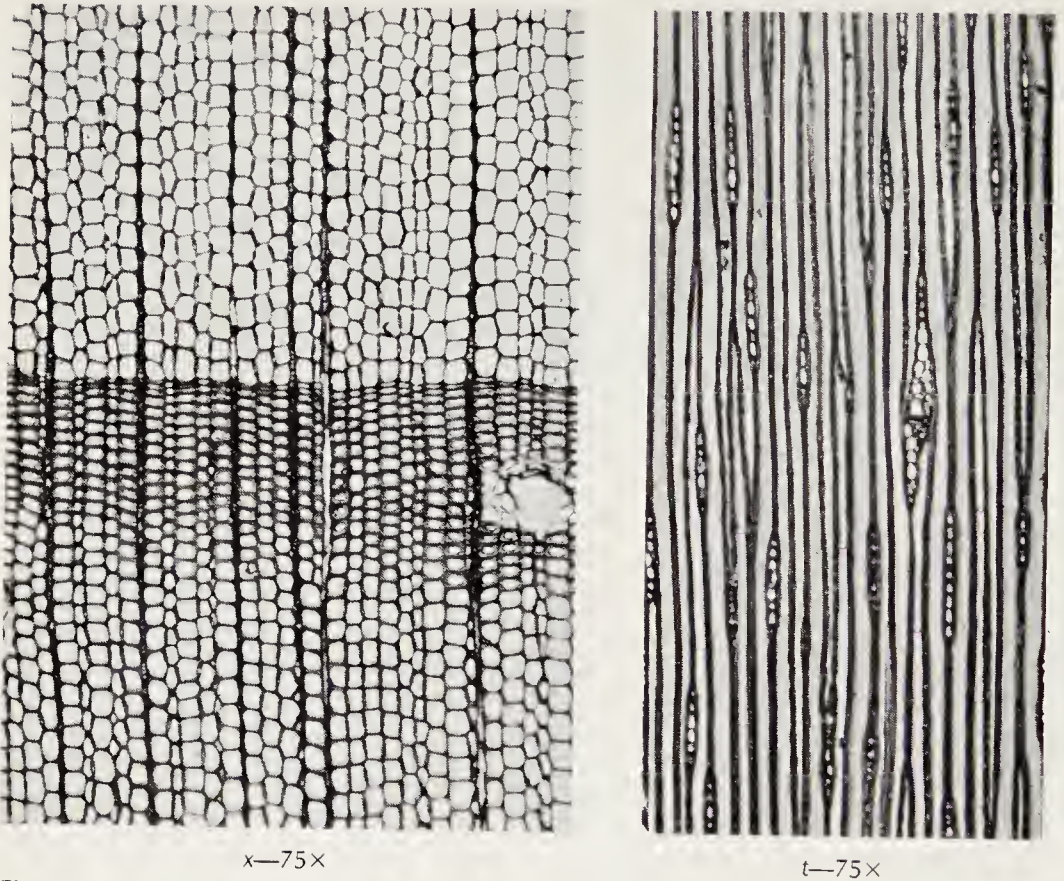


Figure 11-52 Jack pine, *Pinus banksiana* Lamb.

Longitudinal parenchyma wanting. Rays of 2 types, uniseriate and fusiform; (a) uniseriate rays numerous (t), 1–10 plus cells in height; (b) fusiform rays scattered, with a transverse resin canal, 2–3-seriate through the central thickened portion, tapering more or less abruptly to uniseriate margins similar to the (a) rays, up to 10 plus cells in height; ray tracheids present in both types of rays, shallowly dentate [the teeth seldom extending to the center of the cell cavity (r)]; marginal tracheids often in several rows; low rays frequently consisting entirely of ray tracheids; ray parenchyma thin-walled. *Resin canals* smaller than in most pines (comparable in size to those of lodgepole and red pine), with thin-walled epithelium, frequently occluded with tylosoids in the heartwood; longitudinal canals with maximum diameter of 100 (avg 75–90) μm , the transverse canals much smaller (usually less than 45 μm). See first footnote, p. 443.

Remarks

For separation of jack pine from ponderosa pine and lodgepole pine, see Remarks, p. 443.

Uses

Pulpwood (converted usually by sulfate process); *poles*; *posts*; *mine timbers*. Lumber generally knotty and considered less desirable than that of red pine, used principally for *boxes* and *crates*; *rough construction*; better grades generally marketed as red pine and used for *planing-mill products* (sash, doors, interior and exterior finish).

TAMARACK, EASTERN LARCH
 (Pinaceae)

Larix laricina (Du Roi) K. Koch

General Characteristics

Sapwood whitish, narrow; *heartwood* yellowish to russet brown or occasionally reddish brown (fast-grown stock); wood generally without characteristic odor or taste, more or less oily and with somewhat greasy feel, frequently spiral-grained, medium-fine-textured, moderately heavy (sp gr approx 0.49 green, 0.57 oven-dry), moderately hard. *Growth rings* distinct, delineated by a pronounced band of darker late wood, generally moderately wide to wide (8–20 per in) and variable in width. Early-wood zone usually occupying three-quarters or more of the ring; transition from early to late wood abrupt; late-wood zone narrow to wide, conspicuous to the naked eye. *Parenchyma* not visible. *Rays* very fine (x), not distinct to the naked eye, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals small, inconspicuous, not visible to the naked eye or appearing as whitish or dark flecks, sparse, confined largely to the central and outer portions of the ring, solitary or 2 to several contiguous in the tangential plane, occasionally in a tangential line extending for some distance along the ring; (b) transverse canals smaller than the longitudinal canals, appearing with a hand lens as somewhat broader, whitish rays spaced at irregular intervals on the transverse surface, not visible or barely visible with a hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 45 (avg 28–35) μm in diameter, those in the late wood occasionally with spiral thickening; bordered pits in 1–2 rows on the radial walls; tangential pits present in the last few rows of late-wood tracheids; pits leading to ray parenchyma piceoid, small, quite uniform in size, with distinct border, 1–12 (generally 4–6) per cross field, often in a double horizontal row. *Longitudinal parenchyma* marginal and very sparse, or wanting. *Rays* of 2 types, uniseriate or rarely in part biseriate, and fusiform; (a) uniseriate rays numerous (t), 1–20 plus cells in height; biseriate rays very

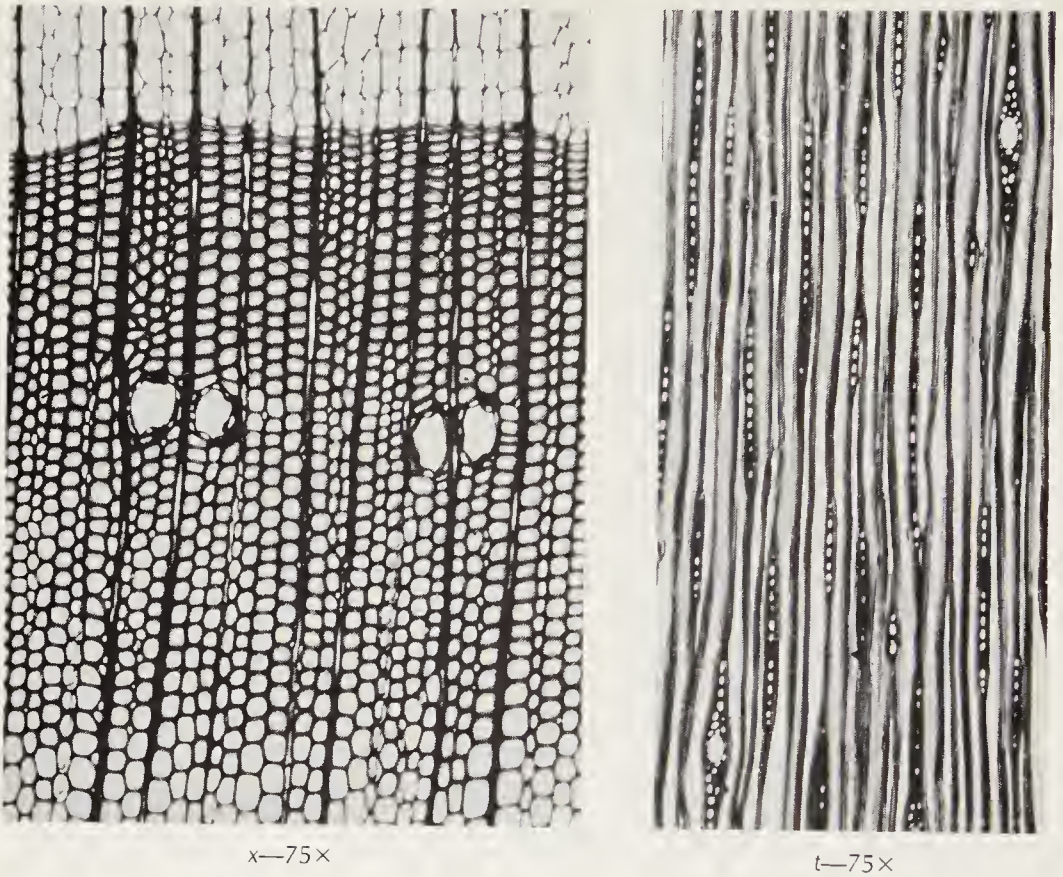


Figure 11-53 Tamarack, *Larix laricina* (Du Roi) K. Koch.

sparse and scattered, or wanting; (b) fusiform rays scattered, with a transverse resin canal, 2–3-seriate through the central thickened portion, tapering above and below to uniseriate margins similar to the (a) rays, up to 20 plus cells in height; end walls nodular, with indentures; ray tracheids in both types of rays, marginal and rarely interspersed, nondentate; marginal tracheids usually in 1 row; cross sections of ray tracheid pit borders tapering to a smoothly rounded edge at the pit aperture. *Resin canals* with thick-walled epithelium, occasionally with tylosoids in the heartwood; longitudinal canals with maximum diameter of 110 (avg 60–90) μm ; transverse canals much smaller (usually less than 25 μm).

Remarks

Tamarack or eastern larch is sometimes confused with western larch; for distinguishing characters, see Remarks under Western Larch, p. 456.

Uses

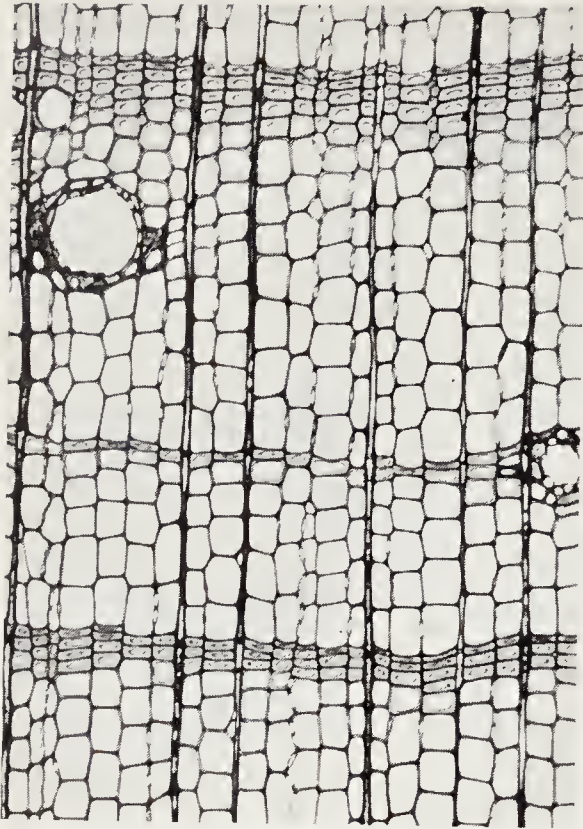
Locally for rough construction; posts; poles; ties; novelties; boxes, crates, and pallets; pulpwood.

WESTERN LARCH
(**Pinaceae**)*Larix occidentalis* Nutt.**General Characteristics**

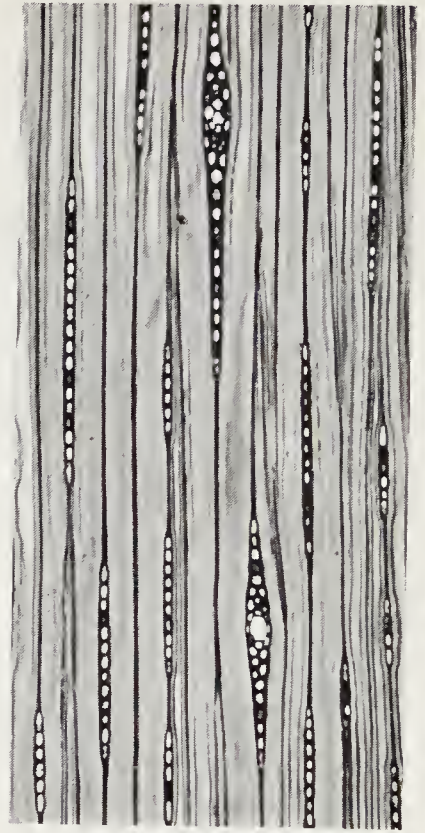
Sapwood whitish to pale straw-brown, narrow (rarely over 1 in in width); *heartwood* russet or reddish brown; wood without characteristic odor or taste; with characteristic oily appearance, straight-grained, coarse-textured, moderately heavy (sp gr approx 0.48 green, 0.55 oven-dry), moderately hard. *Growth rings* distinct, delineated by a pronounced band of darker late wood, generally very narrow (30–60 per in) and quite uniform in width. Early-wood zone usually occupying two-thirds or more of the ring, appearing porous with a hand lens (large tracheids); transition from early to late wood very abrupt; late-wood zone generally very narrow, sharply delineated and conspicuous to the naked eye. *Parenchyma* not visible. *Rays* very fine (x), not distinct to the naked eye, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals small, inconspicuous, not visible to the naked eye or appearing as whitish or dark flecks, sparse, confined for the most part to the narrow bands of late wood, solitary or 2 to several contiguous in the tangential plane, not visible or forming inconspicuous streaks along the grain; (b) transverse canals smaller than the longitudinal canals, appearing with a hand lens as somewhat broader, whitish rays spaced at irregular intervals on the transverse surface, not visible or barely visible with a hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 60 (avg 38–50) μm in diameter, those in the late wood occasionally with spiral thickening; bordered pits 1–2 rows on the radial walls; tangential pitting present on the last few rows of late-wood tracheids; pits leading to ray parenchyma piceoid, small, quite uniform in size, with distinct border, 1–10 (generally 4–6) per cross field, often in a double horizontal row (Fig. 11-36). *Longitudinal parenchyma* marginal and very sparse, or wanting. *Rays* of 2 types, uniseriate or rarely in part biseriate, and fusiform; (a) uniseriate rays numerous (t), 1–20 plus cells in height; biseriate rays very sparse and scattered, or wanting; (b) fusiform rays scattered, with 1 or very rarely 2 transverse resin canals, 2–3-seriate through the central thickened portion, tapering above and below to uniseriate margins similar to the (a) rays, up to 20 plus cells in height; end walls nodular, with indentures; ray tracheids in both types of rays, marginal and rarely interspersed, nondentate; marginal tracheids usually in 1 row; cross sections of ray tracheid pit borders tapering to a smoothly rounded edge at the pit aperture.



x—75×



t—75×

Figure 11-54 Western Larch, *Larix occidentalis* Nutt.

Resin canals with thick-walled epithelium, occasionally with tylosoids in the heartwood; longitudinal canals with maximum diameter of 135 (avg 60–90) μm , transverse canals much smaller (usually less than 25 μm).

Remarks

For differences between western larch and Douglas-fir, see Remarks under Douglas-fir, p. 465. Western larch is sometimes confused with tamarack (eastern larch) but can be separated by the following characters; the heartwood of eastern larch is generally yellowish brown in contrast to the russet- or reddish brown heartwood of western larch; the annual rings in the eastern species are usually much wider and less uniform in width than those in the old growth of western larch, the grain is not so straight, and the texture is finer [tracheids with maximum diameter of 45 (avg 30–40 μm).

Uses

Building materials (principal use) in the form of small timbers, planks, boards, rough-dimension stock; *glue-laminated beams*, esteemed for their

coloration; *planing-mill products*, especially for edge-grained flooring (for which it is very satisfactory because of hardness resulting from narrow rings with a large percentage of late wood; flat-grained flooring tends to separate along the annual increments), also for *interior finish* (because of the distinctive figure and ease with which it can be finished in the natural color); *railroad car construction*; *boxes*; *crates* (shows a tendency to split if large, pointed nails are used); *pallets*; *veneer*, rotary converted mostly into structural plywood, sliced veneer for faces in *prefinished plywood*; *ties*; *poles*; *fuel wood* (rated high in fuel value compared with other softwoods of the Inland Empire); growing use for *pulpwood* and *particle board* is indicated. Western larch, as well as tamarack, contains considerable quantities of a water-soluble gum (arabogalactan), especially in butt logs; it can be easily extracted and oxidized into mucic acid, used in making baking soda.

TRANSCONTINENTAL, RED, ENGELMANN SPRUCE (Pinaceae)

White spruce [*Picea glauca* (Moench) Voss]

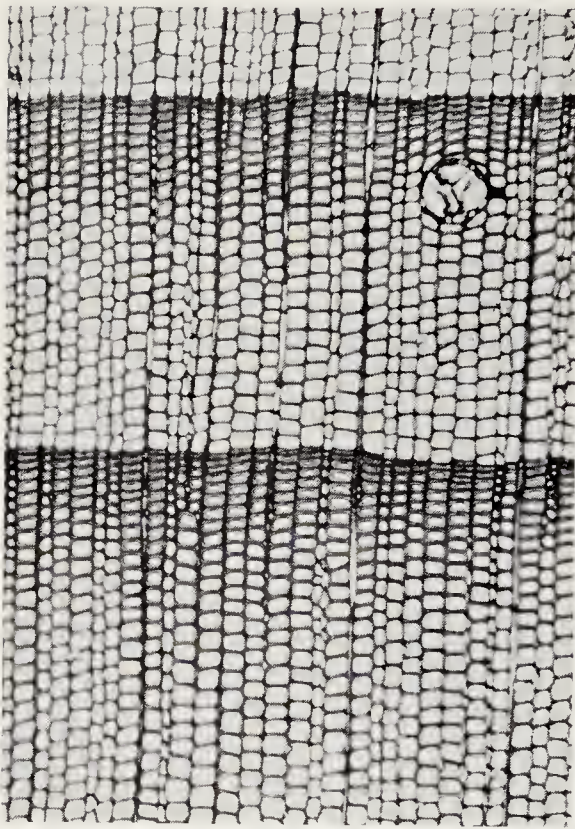
Black spruce [*Picea mariana* (Mill.) B.S.P.]

Red spruce (*Picea rubens* Sarg.)

Engelmann spruce (*Picea engelmannii* Parry ex Engelm.)

General Characteristics

Wood nearly white to pale yellowish brown (*heartwood* not distinct), lustrous, without characteristic odor or taste, even- and usually straight-grained, medium- to fine-textured, light (Engelmann spruce, avg sp gr approx 0.33 green, 0.36 ovendry) to moderately light (other spruces, avg sp gr approx 0.37 green, 0.41–0.45 ovendry), soft to moderately soft. *Growth rings* distinct, delineated by the contrast between the late wood and the early wood of the succeeding ring, narrow to wide. Early-wood zone usually a number of times wider than the late wood, grading into the late wood; late-wood zone distinct to the naked eye but usually not pronounced, somewhat darker than the early wood, generally narrow. *Parenchyma* not visible. *Rays* very fine (x), not distinct to the naked eye or barely visible where they include a transverse resin canal, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals small, generally not visible to the naked eye, appearing as white flecks with a hand lens, solitary or 2 to several contiguous in the tangential plane or not infrequently grouped in a tangential line extending for some distance along the ring, often irregularly distributed and wanting entirely from portions of some rings, not visible or barely visible along the grain; (b) transverse canals smaller than the



x—75×



t—75×

Figure 11-55 Red spruce, *Picea rubens* Sarg.

longitudinal canals, visible with a hand lens and occasionally to the naked eye as somewhat broader, whitish rays spaced at irregular intervals on the transverse surface, not visible or indistinct with a hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 35 (avg 25–30) μm in diameter; bordered pits in 1 row or very rarely paired on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma piceoid, small, quite uniform in size, with distinct border, 1–6 (generally 2–4) per cross field, generally in a single horizontal row. *Longitudinal parenchyma* wanting. *Rays* of 2 types, uniseriate or rarely in part biseriate, and fusiform; (a) uniseriate rays numerous (t), 1–20 plus cells in height, biseriate rays very sparse and scattered, or wanting; (b) fusiform rays scattered, with 1 or rarely 2 transverse resin canals, 2–3-seriate through the central thickened portion, tapering above and below to uniseriate margins like the (a) rays, up to 20 plus cells in height; end walls nodular, with indentures; ray tracheids in both types of rays, usually restricted to 1 row on the upper and lower

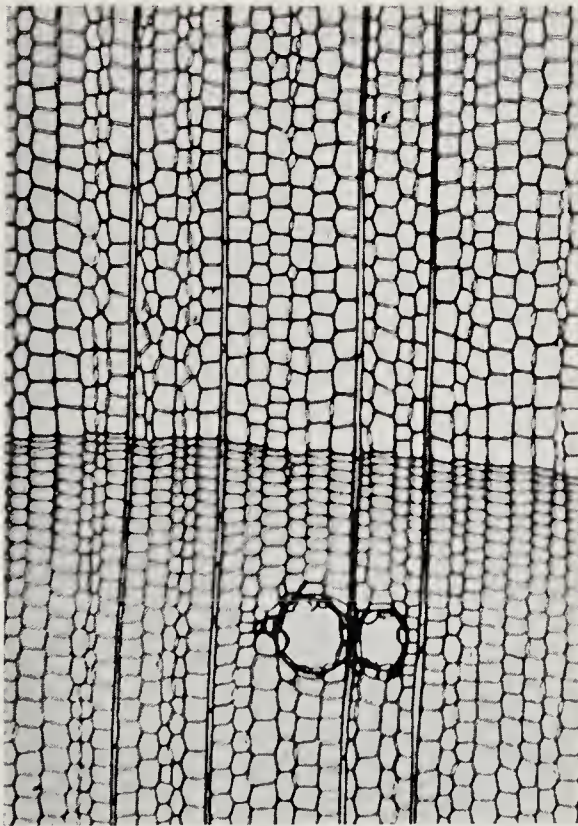
margins, nondentate; cross sections of some of the ray tracheid pit borders distinctly thickened, ridged, or spurred on the cell lumen side and bluntly angled to the pit aperture (uncommon in Engelmann spruce). *Resin canals* with thick-walled epithelium, occasionally with tylosoids in the heartwood; longitudinal canals with maximum diameter of 135 (avg 50–90) μm ; transverse canals much smaller (usually less than 30 μm).

Remarks

The woods of white, red, black, and Engelmann spruce cannot be separated with certainty by either gross characteristics or minute anatomy. Engelmann spruce is usually slightly lighter and weaker than other spruces; in some samples of Engelmann spruce the transition from early to late wood is more abrupt than in other spruces, and the late wood is then usually appreciably denser than the early wood.

Using a statistical approach, Denyer et al.* have found that on the

* W. B. G. Denyer, D. J. Gerrard, and R. W. Kennedy, A Statistical Approach to the Separation of White and Black Spruce on the Basis of Xylem Anatomy, *For. Sci.*, **12**(2):177–184 (1966).



x—75×



t—75×

Figure 11-56 Engelmann spruce, *Picea engelmannii* Parry ex Engelm.

average white spruce has tracheids and resin canals of larger diameter (28.3 μm versus 25.3 μm and 71.0 μm versus 55.0 μm respectively) than black spruce. White spruce has less late wood (10.6 percent versus 16.2 percent) than black spruce. All these differences, however, amount to only 1 standard deviation, or less.

Spruce wood is sometimes confused with that of the true firs (*Abies* spp.) but can be readily separated from it by resin canals of the normal type which do not occur in the latter.

Uses

Pulpwood (principal use), reduced mainly by the sulfite and mechanical processes, and converted into a wide range of papers (from newsprint to high-grade writing paper); *fiber molded products*; *insulating boards*; *hard-board*; *particle board*; *round timbers* (poles, mine props); *railroad ties* (especially Engelmann spruce); *cooperage* (staves and headings); *lumber* used for *boxes and crates* (very satisfactory in every way except when exceptionally high nail-holding capacity is required); *pallets*; *general building purposes* (boards, planks, joists, dimension stock); *planing-mill products* (doors, sash, casing, interior finish, roof decking, paneling); *laminated timbers*; *railroad car construction and repairs*; *boatbuilding*; *musical instruments*, especially for sounding boards (long a favorite because of its high resonant qualities); *furniture and kitchen cabinets*; *woodenware and novelties*; *ladder rails*; *paddles and oars* (because of its lightness combined with the required stiffness and strength); *veneer for containers*; *structural and prefinished interior plywood* on a limited scale (especially Engelmann spruce; because of the scarcity of peeler-grade logs it seldom is used for rotary-cut veneer, but is considered to be excellent for production of cants for sliced veneer).

SITKA SPRUCE

(Pinaceae)

Picea sitchensis (Bong.) Carr.

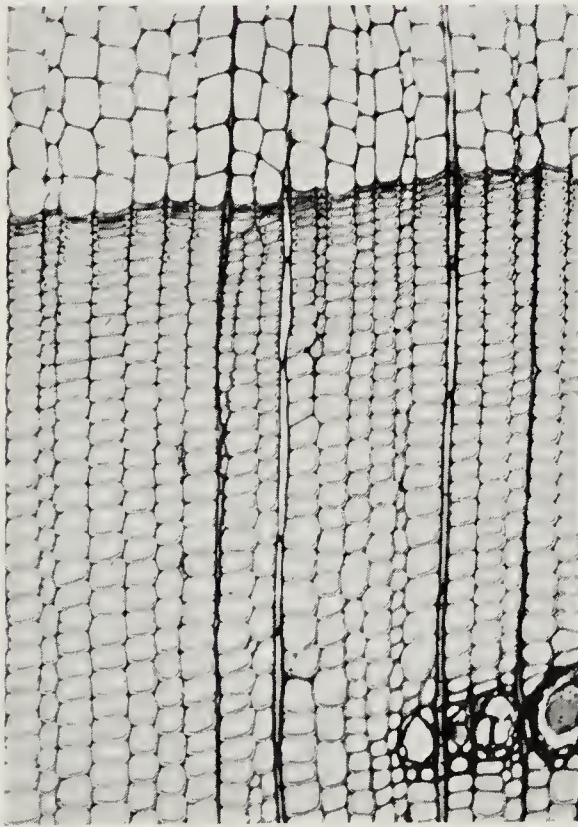
General Characteristics

Sapwood creamy white to light yellow, grading into the darker heartwood, wide; *heartwood* light pinkish yellow to pale brown with purplish cast, darkening on exposure to silvery brown with a faint tinge of red; wood more or less lustrous, without characteristic odor or taste, generally straight- and even-grained and frequently dimpled on the tangential surface, medium-textured, moderately light (sp gr approx 0.37 green, 0.42 ovendry), moderately soft. *Growth rings* distinct, delineated by a band of darker late wood, narrow to medium-wide. Early-wood zone usually occupying one-half to two thirds of the ring; transition from early to late wood gradual;

late-wood zone somewhat darker and denser than the band of early wood. *Parenchyma* not visible. *Rays* very fine (x), not visible to the naked eye except where they include a transverse resin canal, darker than the background (infiltration) and forming a fine, rather conspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals fairly large, appearing as white flecks in the dark heartwood to the naked eye, sparse to fairly numerous, solitary or 2 to several contiguous in the tangential plane or rarely in longer tangential lines, more or less regularly distributed and often wanting entirely from portions of some rings, appearing as scattered streaks along the grain; (b) transverse canals smaller than the longitudinal canals, visible against the dark background of heartwood on the transverse surface as somewhat broader, whitish rays spaced at irregular intervals, usually distinct with a hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 55 (avg 35–45) μm in diameter; bordered pits in 1 row or rarely paired on the radial walls; tangential pitting present in the last few



x—75×



t—75×

Figure 11-57 Sitka spruce, *Picea sitchensis* (Bong.) Carr.

rows of late-wood tracheids; pits leading to ray parenchyma piceoid, small, quite uniform in size, with distinct border, 1–6 (commonly with 3 or more) per cross field, generally in a single horizontal row (Fig. 11-37). *Longitudinal parenchyma* wanting. *Rays* of 2 types, uniseriate and fusiform; (a) uniseriate rays numerous (t), 1–20 plus cells in height; (b) fusiform rays scattered, with a transverse resin canal, 3–5-seriate through the central portion, tapering above and below to uniseriate margins like the a rays, up to 16 plus cells in height, end walls nodular, with indentures; ray tracheids in both types of rays, usually restricted to 1 row on the upper and lower margins, nondentate; cross sections of some of the ray tracheid pit borders ridged or spurred on the cell lumen side, ray parenchyma in the heartwood generally with gummy infiltration. *Resin canals* with thick-walled epithelium, occasionally with tylosoids in the heartwood; longitudinal canals with maximum diameter of 135 (avg 60–90) μm ; transverse canals much smaller (usually less than 35 μm).

Remarks

Distinct from white, red, black, and Engelmann spruces in color and texture (coarser-textured and more or less woolly-fibered), Sitka spruce is sometimes confused with eastern white pine (*Pinus strobus* L.) because of its dark-colored heartwood and unusually large resin canals but readily separated through the absence of resinous odor and window-like pits in the cross fields, and by its thick-walled epithelium.

Uses

Pulpwood (reduced by the sulfite and mechanical processes); *poles*; *sailing-boat masts*. *Lumber* used for *boxes and crates*; *pallets*; *general construction*; *planing-mill products* and *millwork* (siding, ceiling, paneling, sash, doors, blinds); *laminated beams*; *musical instruments*, especially sounding boards (slow-growing material preferred because of its high resonant qualities); *furniture* (mostly hidden parts); *kitchen cabinets*; *boatbuilding*; *railroad car construction and repairs*; formerly extensively used for *aircraft construction* because of its high strength properties on the basis of weight, availability in clear pieces of large size, uniform texture, and freedom from hidden defects); *portable bleachers* and *gymnasium seats*; *overhead garage and warehouse doors*; *ladder rails*; *woodenware* and *novelties*. *Veneer* for plywood core stock.

DOUGLAS-FIR (Pinaceae)

Pseudotsuga menziesii (Mirb.) Franco

General Characteristics

Sapwood whitish to pale yellowish or reddish white, narrow (Rocky Mountain type) to several inches in width (Pacific Coast type); *heartwood* ranging from yellowish or pale reddish yellow (slow-grown stock) to orange-red or deep red (fast-grown stock), the color varying greatly in different samples; *wood* with a characteristic resinous odor when fresh (different from that of pine), without characteristic taste, usually straight- and even- or uneven-grained, medium- to fairly coarse-textured, moderately light (sp gr approx 0.45 green, 0.48 oven-dry—Rocky Mountain type) to moderately heavy (sp gr approx 0.45 green, 0.51 oven-dry—Pacific Coast type), moderately hard. *Growth rings* very distinct, frequently wavy, delineated by a pronounced band of darker late wood, narrow (yellow fir) to very wide (red fir); growth increments (striae) usually less conspicuous than those in pine on the radial surface. Early-wood zone usually several times wider than the band of late wood; transition from early to late wood generally abrupt (in wide rings sometimes more or less gradual); late-wood zone pronounced, very narrow in slow-grown stock to very wide and dense in wide rings. *Parenchyma* not visible. *Rays* very fine (x), not visible to the naked eye, forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* present, longitudinal and transverse; (a) longitudinal canals small, barely visible or indistinct to the naked eye, plainly visible with a hand lens as dark spots or openings, confined largely to the outer half of the ring, sparse and scattered or numerous and exhibiting more or less a tendency (especially in certain rings) toward alignment in tangential rows of 2–30 plus, not visible or forming relatively inconspicuous streaks along the grain (t); (b) transverse canals smaller than the longitudinal canals, appearing with a hand lens as somewhat broader rays spaced at irregular intervals on the transverse surface, not visible or barely visible with a hand lens on the tangential surface.

Minute Anatomy

Tracheids up to 55 (avg 35–45) μm in diameter, characterized (especially in early wood) by fine, closely spaced spiral thickening arranged in systems consisting of 4–6 parallel spirals; bordered pits in 1 row or occasionally paired on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma piceoid, small, quite uniform in size, with distinct border, 1–6 (generally 4) per cross field. *Longitudinal parenchyma* marginal and very sparse, or wanting. *Rays* of 2 types, uniseriate or rarely in part biseriate, and fusiform; (a) uniseriate rays numerous (t), 1–25 plus cells in height; biseriate rays very sparse and scattered, or wanting; (b) fusiform rays scattered, with 1 or very rarely 2 transverse resin canals, 3–5-seriate through the central thickened portion, tapering above and below to uniseriate margins similar to the (a) rays, up to

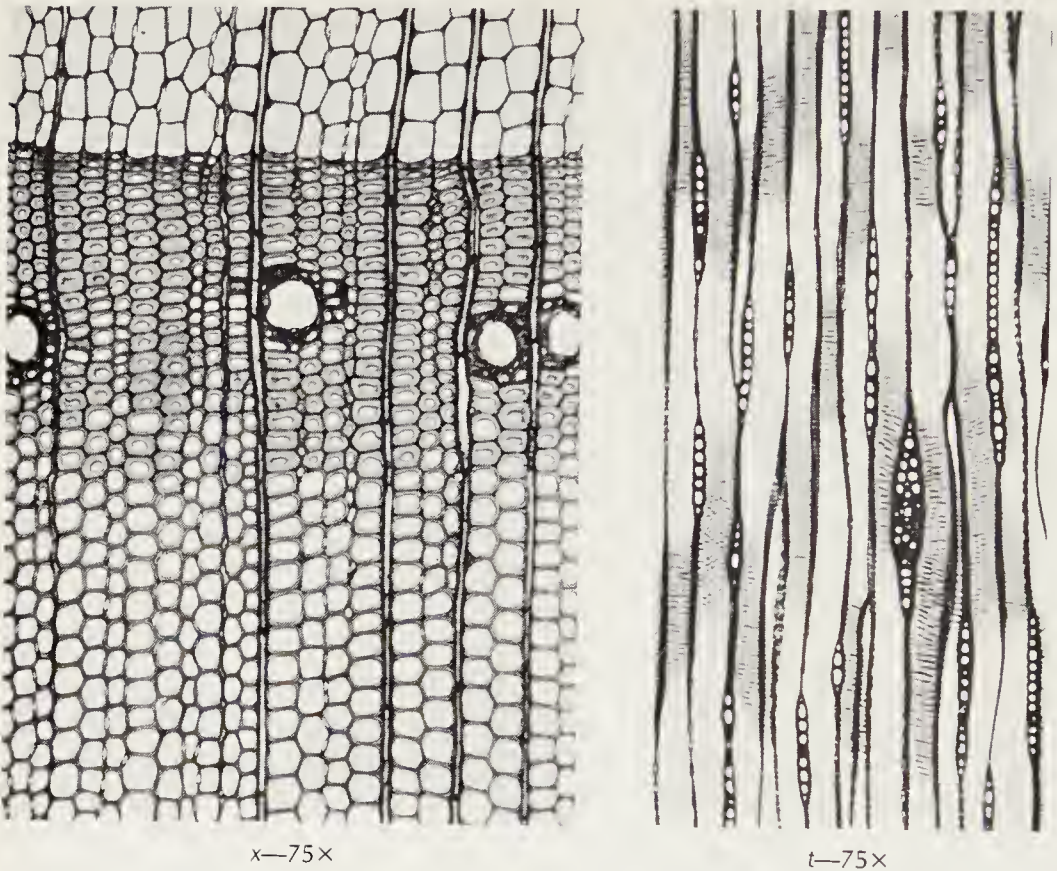


Figure 11-58 Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco.

16 plus cells in height; end walls nodular; ray tracheids present in both types of rays, marginal and very rarely interspersed, nondentate, occasionally with spiral thickening; marginal tracheids usually in 1 row. Resin canals with thick-walled epithelium, constricted at intervals and occasionally with tylosoids in the heartwood, longitudinal canals with maximum diameter of 150 (avg 60–90) μm ; transverse canals much smaller (usually less than 25 μm).

Remarks

Douglas-fir wood is very variable in color, ring width, strength, and working qualities. Narrow-ringed Douglas-fir is quite uniform-textured, moderately soft, and easily worked. It tends to be yellow or pale reddish yellow in color, and because of this it was formerly known in the trade as “yellow fir.” In contrast, Douglas-fir with wide rings is characterized by wide bands of reddish late wood, which is responsible for its overall orange-red or deep-red color; such wood is coarser-grained and more unevenly textured than the narrow-ringed stock and also stronger and more refractory under

tools. Because of its prevailing reddish cast the wide-ringed Douglas-fir is sometimes sold as “red fir.”

Douglas-fir grown in the Rocky Mountains, especially in the southern parts of the range, tends to contain smaller percentages of late wood, at any rate of growth, and to be lower in specific gravity and strength than Douglas-fir grown in the coastal areas, the Cascades, and the Sierras. Likewise, wide-ringed, second-growth Douglas-fir from the coastal areas is frequently lighter in weight and lower in strength properties than virgin-growth wood from the same regions.

Douglas-fir wood is sometimes confused with southern pine and western larch. It can usually be separated from the former on the basis of color, distinctive odor, and the smaller resin canals, which in Douglas-fir show a tendency toward alignment in tangential rows of 2–20 plus. The heartwood of western larch, in contrast to that of Douglas-fir, has a distinct brownish cast. Presence of spiral thickening in both the early- and the late-wood tracheids in Douglas-fir permits certain identification of this species; spiral thickening is found only occasionally in the late-wood tracheids in western larch, and only rarely in southern pines, in wood immediately adjacent to the pith.

Uses

Building and construction in the form of lumber, timbers, and piling; large *laminated beams* and *arches* for churches, schools, and commercial buildings; *veneer*, converted largely into *structural plywood*, extensively used in building and construction. The principal uses of *lumber*, in addition to general construction, are *planing-mill products* (sash, doors, flooring, and general millwork); *railroad car construction*; *boxes, crates and pallets*; *containers* for corrosive chemicals; *silos and tanks*; *ship and boatbuilding*; *furniture*. *Motion-picture and theatrical scenery* (mainly plywood). *Pulpwood* (leading pulpwood species in the west for sulfate pulp); *insulating and other types of fiberboard*; *particle and hardboard*. *Poles*; *piling*; *mine timbers*; *railroad ties*.

EASTERN HEMLOCK, HEMLOCK, CANADA HEMLOCK (Pinaceae)

Tsuga canadensis (L.) Carr.

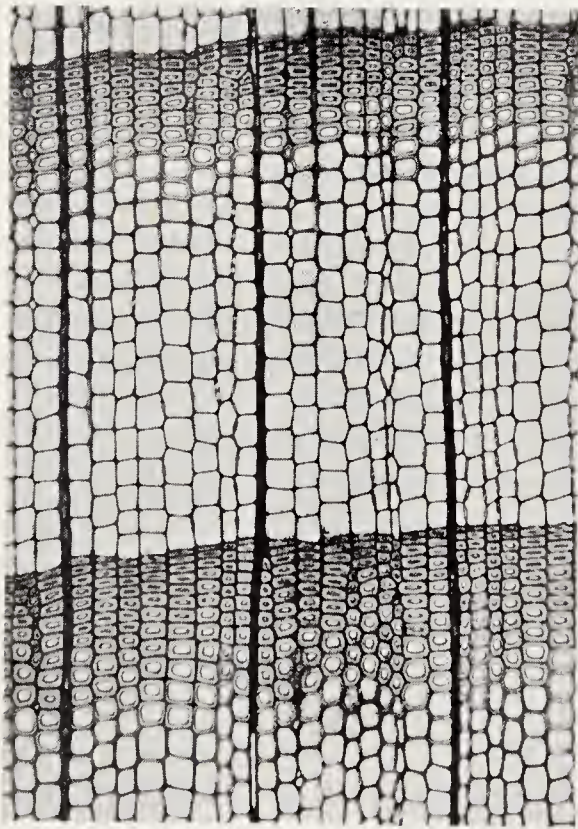
General Characteristics

Wood buff to light brown, the late-wood portion of the ring frequently with a roseate or reddish brown tinge (*heartwood* not distinct, but the last few rings near the bark usually somewhat lighter in color), odorless or with a sour

odor when fresh, without characteristic taste, uneven- and frequently spiral-grained, coarse- to medium-textured, moderately light (sp gr approx 0.38 green, 0.42 oven-dry), moderately hard. *Growth rings* distinct, delineated by a pronounced band of darker late wood, narrow to wide (proximate rings not infrequently very variable in thickness; individual rings often variable in thickness and hence more or less sinuate in contour). Early-wood zone usually occupying two-thirds or more of the ring; transition from early to late wood gradual to abrupt; late-wood zone distinct to the naked eye, decidedly darker (roseate or reddish brown) and denser than the early wood, variable in thickness in different rings and often in a given ring. *Parenchyma* not visible. *Rays* very fine (x), not distinct to the naked eye, forming a fine, close, inconspicuous fleck on the quarter surface. Normal *resin canals* wanting; traumatic canals very rare.

Minute Anatomy

Tracheids up to 45 (avg 28–40) μm in diameter; bordered pits in 1–2 (mostly 1) rows on the radial walls; tangential pitting present in the last few rows of



x—75x



t—75x

Figure 11-59 Eastern hemlock, *Tsuga canadensis* (L.) Carr.

late-wood tracheids, pits leading to ray parenchyma piceoid to cupressoid, small, quite uniform in size, with distinct border, 1–5 (generally 3–4) per cross field. *Longitudinal parenchyma* marginal and very sparse, or wanting. Rays uniseriate, 1–12 plus cells in height; ray tracheids present, usually restricted to 1 row on the upper and lower margins of the ray. End walls nodular, with indentures.

Remarks

For differences between eastern and western hemlock, see Remarks under Western Hemlock. Eastern hemlock differs from the spruces (*Picea* spp.) in the absence of normal resin canals and from the firs (*Abies* spp.) in possessing ray tracheids [ray tracheids sporadic in *A. balsamea* (L.) Mill., wanting in other North American species of *Abies*].

Uses

Pulpwood (converted largely by the sulfite process); *general construction* (framing, sheathing, roofing, subflooring); *boxes and crates* (principally for heavy shipping containers); *pallets*; *railroad car construction*. The bark contains 10–13 percent of tannin and has been an important domestic source of this product.

WESTERN HEMLOCK, WEST COAST HEMLOCK

(Pinaceae)

Western Hemlock [*Tsuga heterophylla* (Raf.) Sarg.]

Mountain hemlock [*Tsuga mertensiana* (Bong.) Carr.]

General Characteristics

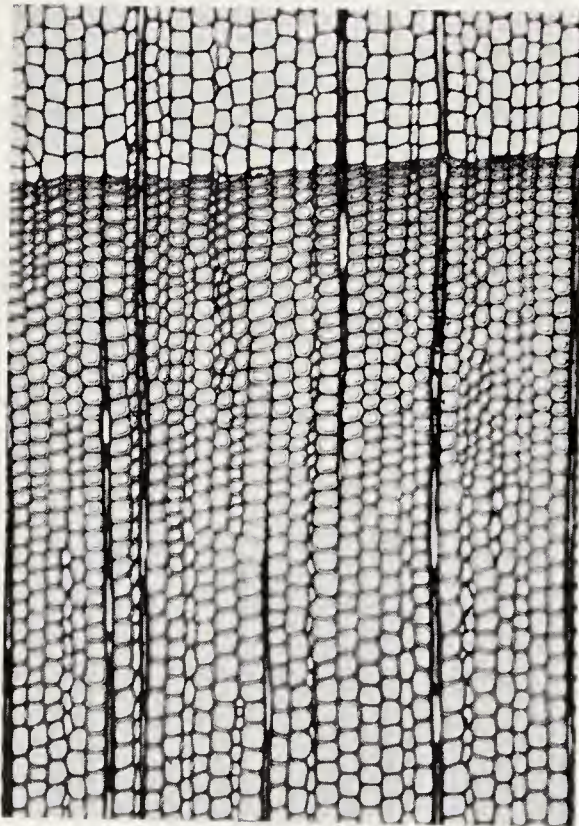
Wood whitish to light yellowish brown, the late-wood portion of the ring frequently with a roseate, purplish, or reddish brown tinge (*heartwood* not distinct, but the last few rings near the bark almost white), frequently with dark streaks (termed *bird pecks* in the trade) caused by the maggots of a small black fly (*Chilosia alaskensis* Hunter), occasionally with whitish spots (floccosoids),* odorless or with a sour odor when fresh, without characteristic taste, generally straight- and quite even-grained, medium- to fine-textured, moderately light (sp gr approx 0.42 green, 0.47 ovendry), moderately hard. *Growth rings* distinct, delineated by a band of darker late wood, narrow to wide but generally narrower and more uniform in width

*The floccosoids are produced by whitish deposits of α -conidendrin-4'-glucoside within the wood cells (see E. Gerry, U.S. Dep. Agric., For. Prod. Lab. Rept. 1392, 1943).

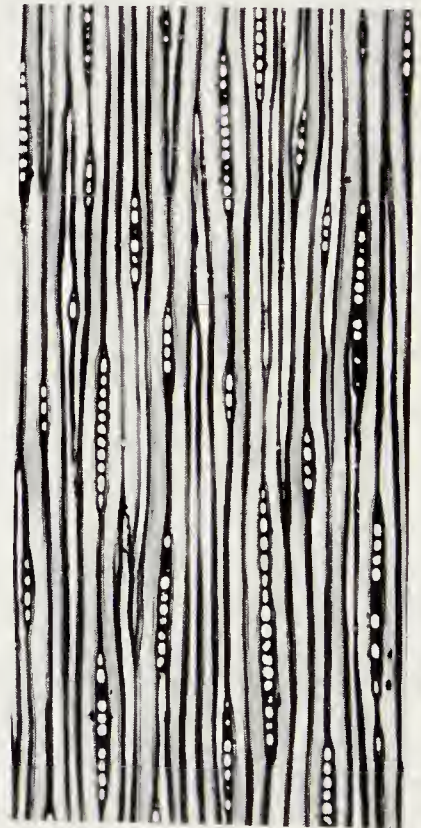
than in the eastern hemlock; individual rings frequently variable in thickness and hence more or less sinuate in contour. Early-wood zone usually occupying two-thirds or more of the ring; transition from early to late wood more or less gradual; late-wood zone distinct to the naked eye, darker and denser than the early wood (the contrast between early and late wood less accentuated than in the eastern hemlock). *Parenchyma* not visible. *Rays* very fine (x), not distinct to the naked eye, forming a fine, close, inconspicuous fleck on the quarter surface. Normal *resin canals* wanting; longitudinal strands of traumatic resinous cells or wound canals sometimes present, the latter sporadic and often in widely separated rings, arranged in a tangential row (x), appearing as dark streaks along the grain.

Minute Anatomy

Tracheids up to 50 (avg 30–40) μm in diameter; bordered pits in 1–2 (mostly 1) rows on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma piceoid to cupressoid, small, quite uniform in size, with distinct border, 1–3 (generally 1–2) per



x—75x



t—75x

Figure 11-60 Western hemlock, *Tsuga heterophylla* (Raf.) Sarg.

cross field. *Longitudinal parenchyma* very sparse and terminal, or wanting. Rays uniseriate or very rarely with paired cells, 1–16 plus cells in height; end walls nodular with indentures; ray tracheids present, usually restricted to 1 row on the upper and lower margins of the ray, rather low and about 20 percent of the time occurring on only 1 side of the ray, or absent (see page 474) in trees grown in California.

Remarks

Wood of the 2 species of western hemlock is indistinguishable and is considered to be comparable in strength properties, with the possible exception of the modulus of elasticity, which is lower on the average for mountain hemlock. Western hemlock cannot always be separated with certainty from eastern hemlock, but the following characters will serve to distinguish these woods in most instances; roseate cast less pronounced than in the eastern species; straighter-grained and less harsh under tools; early wood somewhat finer-textured; rings generally narrower and more uniform in width; transition from early to late wood more gradual and the latter less accentuated; longitudinal strands of resin cells and wound canals, termed *bird pecks* in the trade, not infrequent (rare in eastern hemlock).

Western hemlock is sometimes confused with western fir; for distinguishing characteristics, see Remarks under western fir, p. 474.

Uses

Pulpwood (important source in the Pacific Northwest; converted by the sulfite and mechanical processes); *general construction* (all but the heaviest type); *planing-mill products* (such as siding, ceiling, flooring, shiplap, and finish); *paneling, boxes and crates* (generally in the type requiring rather thick boards because of the tendency to split in nailing); *railroad car construction*; *slack cooperage*, formerly used for sugar and flour barrels (because of freedom from resinous materials and the absence of taste, and its clear color); *ladder rails*, for which purpose it competes with spruce; *plywood*. The bark contains 12–22 percent of tannin and may become an important domestic source of this product.

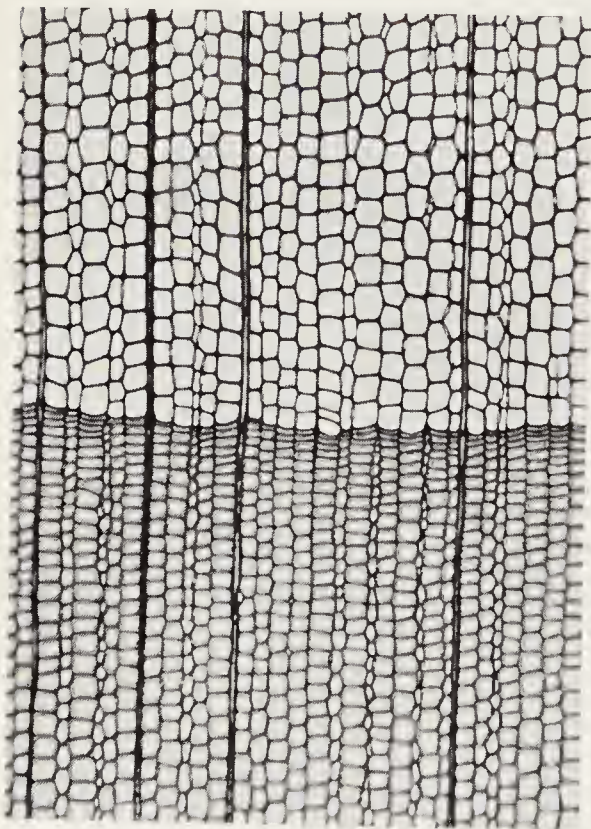
BALSAM AND FRASER FIR (Pinaceae)

Balsam fir [*Abies balsamea* (L.) Mill.]

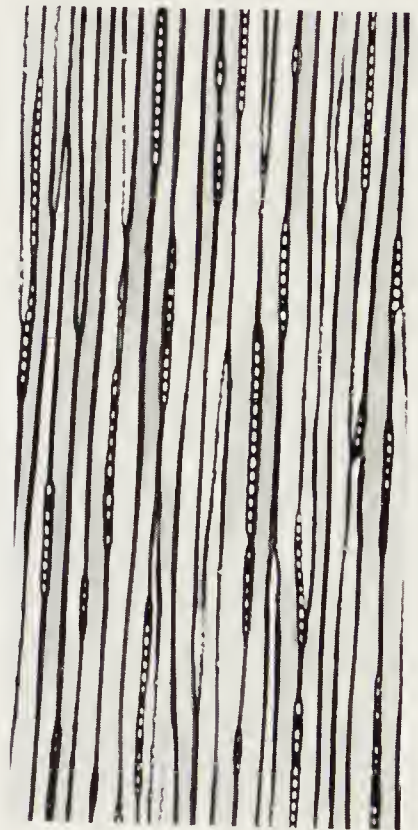
Fraser fir, southern balsam fir [*Abies fraseri* (Pursh) Poir.]

General Characteristics

Wood whitish to creamy white or pale brown (especially the early wood), the late-wood portion of the ring frequently with a lavender tinge (*heartwood* not distinct), without characteristic odor, tasteless or with a slight salty tang, straight- and even-grained, medium-textured, light (sp gr approx 0.34 green, 0.38 oven-dry), soft. *Growth rings* distinct, delineated by the contrast between the somewhat denser late wood and the early wood of the succeeding ring, medium-wide to wide or narrow in the outer portion of mature trees. Early-wood zone usually occupying two thirds or more of the ring; transition from early to late wood very gradual; late-wood zone distinct to the naked eye, somewhat darker than the early wood, generally narrow. *Parenchyma* not visible. *Rays* very fine (x), not distinct to the naked eye, forming a fine, close, inconspicuous fleck on the quarter surface. Normal *resin canals* wanting; longitudinal wound (traumatic) canals sometimes present, sporadic and often in widely separated rings, arranged in a tangential row (x) which frequently extends for some distance along the ring, appearing as dark streaks along the grain.



x—75×



t—75×

Figure 11-61 Balsam fir, *Abies balsamea* (L.) Mill.

Minute Anatomy

Tracheids up to 50 (avg 30–40) μm in diameter; bordered pits in 1 row or very rarely paired on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma taxodioid, small, quite uniform in size, with distinct border, 1–3 (generally 2–3) per cross field (Fig. 11-38); end walls nodular. *Longitudinal parenchyma* very sparse, marginal, or wanting. *Rays* uniseriate, very variable in height (1–30 plus cells), consisting wholly of ray parenchyma or rarely with a row of ray tracheids on the upper and lower margins [*Abies balsamea* (L.) Mill.]; end walls nodular.

Remarks

Lighter, softer, and weaker than spruce, balsam and Fraser fir are frequently confused with eastern spruce but readily separated in that ray tracheids [*A. balsamea* (L.) Mill. excepted] and normal resin canals do not occur in the true firs (*Abies* spp.). The longitudinal wound (traumatic) canals, which are occasionally present, sometimes resemble normal canals; in case of doubt, examine a tangential section of the wood and note the absence (true fir) or presence (spruce) of transverse resin canals in the wood rays.

Uses

Pulp (in admixture with eastern spruce); *cooperage* (formerly for sugar and butter tubs, because of the absence of objectionable taste and resinous materials that might taint). *Lumber* used for *boxes* and *crates* (especially cheeseboxes); *pallets*; *millwork* (siding, molding); *general construction*; *novelties* and *woodenware*; bark on young trees and branches contains blisters filled with an *oleoresin* (Canada balsam), formerly used in cementing lenses and mounting specimens for observation with a microscope.

WESTERN FIRS

(**Pinaceae**)

White fir [*Abies concolor* (Gord. & Glend.) Lindl ex Hildebr.]

Grand fir [*Abies grandis* (Dougl.) Lindl.]

Subalpine fir [*Abies lasiocarpa* (Hook.) Nutt.]

California red fir [*Abies magnifica* A. Murr.]

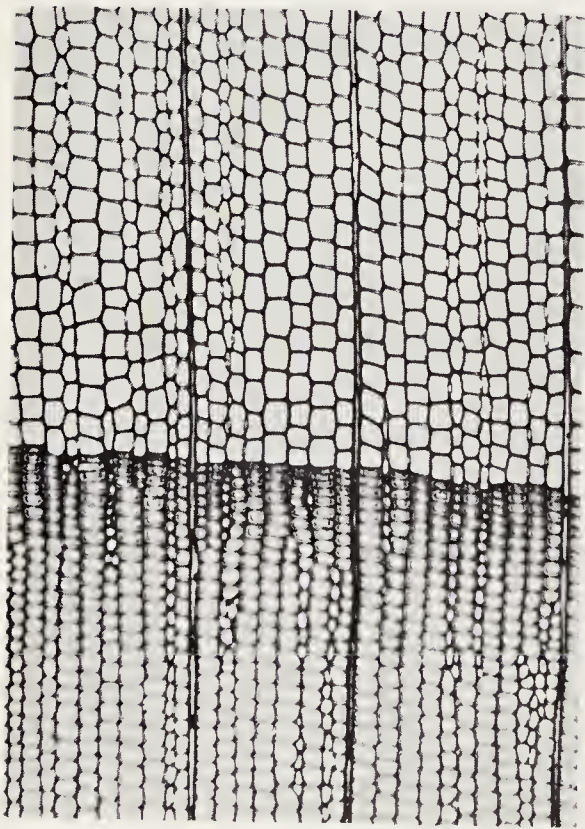
Noble fir [*Abies procera* Rehd.]

Pacific silver fir [*Abies amabilis* (Dougl.) Forbes]

General Characteristics

Wood whitish or light buff to yellowish brown or light brown, the late-wood portion of the ring frequently with a roseate, reddish brown, or lavender

tinge (*heartwood* not distinct), without characteristic odor (sometimes with a slight disagreeable odor when green), tasteless, generally straight- and quite even-grained, medium- to somewhat coarse-textured, light (sp gr approx 0.35–0.37 green, 0.30–0.45 oven-dry; occasionally as high as 0.56 in noble fir), moderately soft. *Growth rings* distinct, delineated by a band of darker late wood, medium-wide to wide (3–4 per in) or narrow in the outer portion of mature trees. Early-wood zone usually occupying one-half or more of the ring; transition from early to late wood gradual; late-wood zone distinct to the naked eye, variable in depth of color and density according to conditions of growth, ranging from broad in wide rings to very narrow. *Parenchyma* not visible. *Rays* very fine (x), not distinct to the naked eye, forming a fine, close, inconspicuous fleck on the quarter surface. Normal *resin canals* wanting; longitudinal wound (traumatic) canals sometimes present, sporadic and often in widely separated rings, arranged in a tangential row (x) which frequently extends some distance along the ring, appearing as dark streaks along the grain.



x—75x



t—75x

Figure 11-62 White fir, *Abies concolor* (Gord. & Glend.) Lindl. ex Hildebr.

Minute Anatomy

Tracheids up to 60 (avg 35–45) μm in diameter; bordered pits in 1 row or occasionally biseriate on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma taxodioid, small, quite uniform in size, with distinct border, 1–4 (generally 2–4) per cross field. *Longitudinal parenchyma* marginal and very sparse, or wanting.* *Rays* uniseriate (or occasionally in part biseriate in *Abies magnifica* A. Murr.), very variable in height (1–30 plus cells), consisting wholly of ray parenchyma; end walls nodular. Crystals are regularly found in the marginal parenchyma cells of *A. procera*, *A. grandis*, *A. magnifica*, and *A. concolor*; they are absent in *A. amabilis* and *A. lasiocarpa*, as well as in *A. balsamea*. (See reference 8, Chap. 4.)

* The strands of traumatic resinous cells, forming black streaks and termed *bird pecks*, that are sometimes found in the body of the ring as a transitional stage in the formation of longitudinal wound canals, are not interpreted here as true longitudinal parenchyma.

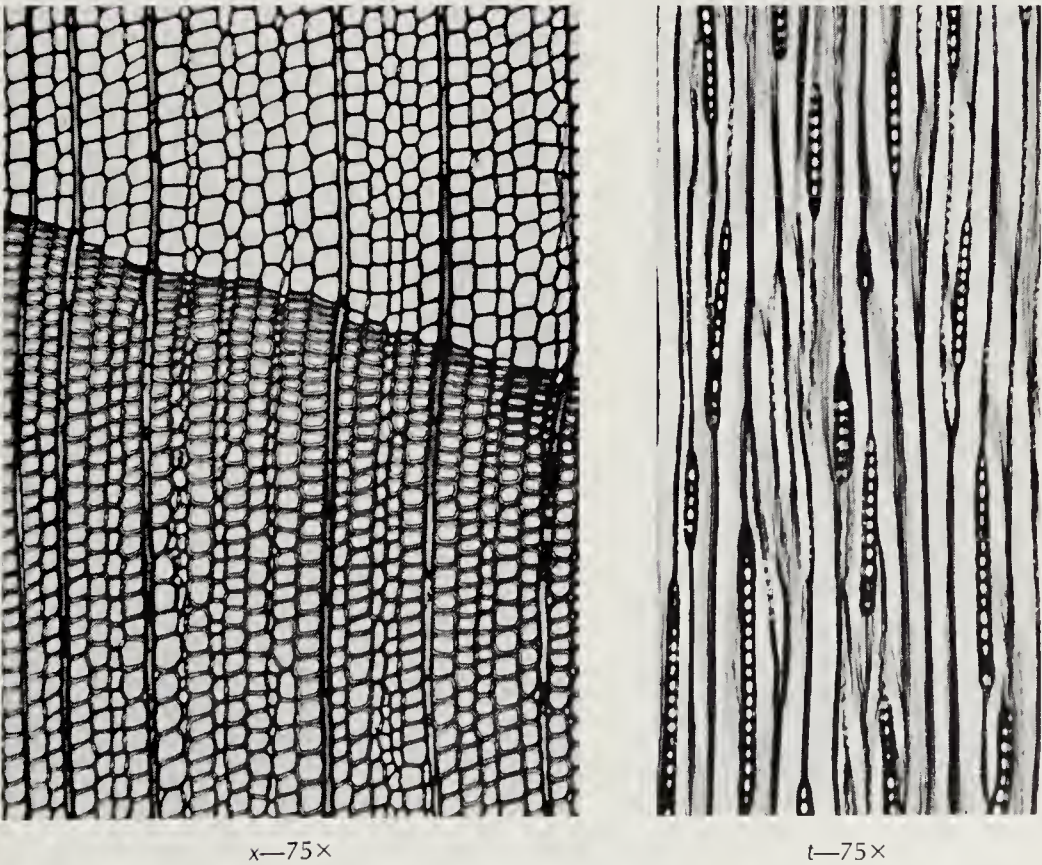


Figure 11-63 California red fir, *Abies magnifica* A. Murr.

Remarks

The timber of noble fir (*A. procera* Rehd.) resembles that of western hemlock [*Tsuga heterophylla* (Raf.) Sarg.] but can be separated as follows: the wood of western hemlock is more brittle, and harsher under tools; the rings are generally narrower (tolerant tree) and more uniform in width than those of the noble fir, and the early wood is finer and more even-textured (early wood coarse and somewhat variable in texture in noble fir); marginal-ray tracheids are invariably found in the wood rays of hemlock and are generally wanting in the western firs. *Tsuga heterophylla* from California often lacks ray tracheids and cannot be conclusively separated from the local white fir. N. C. Rem and W. W. Wilcox [*For Prod. J.* **28**(1):47–48, 1976] have shown that crystals in the inner bark remaining on logs and lumber are a ready means of separation. White fir has isodiametric, rhombic crystals, and western hemlock has crystals at least 4 times longer than wide and usually with pointed ends. The woods of the other western balsam firs resemble balsam fir [*Abies balsamea* (L.) Mill.] in color, ranging from white and creamy white to pale brown with lavender, reddish, or reddish brown bands of late wood. The true firs (*Abies* spp.) cannot be separated on the basis of wood anatomy.

For chemical and chromatographic methods of separating true firs from western hemlock see p. 645.

Uses

General construction (rough and dressed boards, studs, dimension timbers); *boxes and crates* (because of its light weight, clean appearance, freedom from odors and stains, and relatively low cost); *planing-mill products* (especially sash, doors, and trim); *pulpwood* (used in manufacture of printing paper and high-grade wrapping paper); *plywood*.

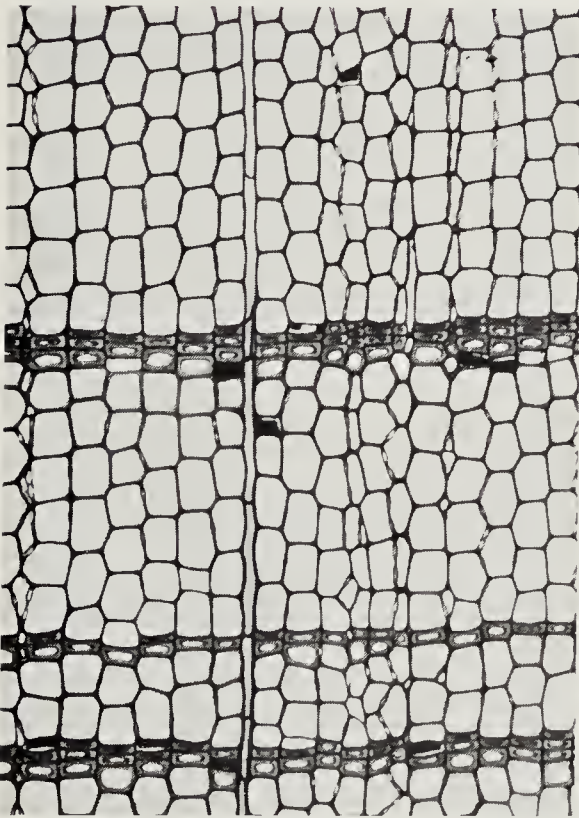
REDWOOD, COAST REDWOOD (Taxodiaceae)

Sequoia sempervirens (D. Don) Endl.

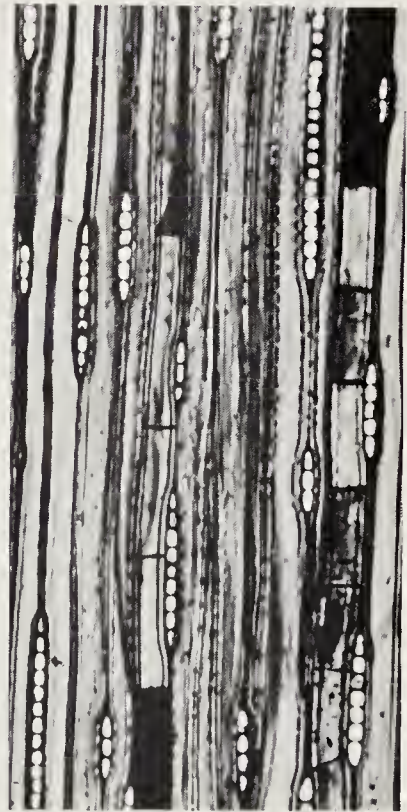
General Characteristics

Sapwood nearly white, narrow; *heartwood* clear light red to deep reddish brown; wood without characteristic odor or taste, generally straight- and even-grained (slow growth) or uneven-grained (second growth), rarely wavy-grained, coarse-textured, light to moderately light (sp gr 0.38 green, 0.41 oven-dry), soft to moderately hard. *Growth rings* distinct, delineated by a band of darker late wood, very narrow (sometimes only 2–3 tracheids in

width and not infrequently discontinuous in old trees) to very wide (coppice-grown stock). Early-wood zone porous (the openings of the tracheids readily visible with a hand lens), narrow to wide; transition from early to late wood generally abrupt; late-wood zone distinct to the naked eye, darker and denser than the early wood, narrow or wide in broad rings. *Parenchyma* abundant, present in every growth ring; cells scattered, readily visible in the sapwood with a lens and sometimes to the naked eye because of their dark resinous contents, inconspicuous in the dark-colored heartwood; strands of parenchyma visible along the grain (split) as dark lines. *Rays* coarse (x) for a coniferous wood, lighter than the background in the heartwood and hence generally visible to the naked eye, forming a fine, close, relatively conspicuous fleck on the quarter surface. Normal *resin canals* wanting; longitudinal wound (traumatic) canals sometimes present, sporadic and often in widely separated rings, arranged in a tangential row (x), appearing as dark streaks along the grain.



x—75×



t—75×

Figure 11-64 Redwood, *Sequoia sempervirens* (D. Don) Endl.

Minute Anatomy

Tracheids up to 80 (avg 50–65) μm in diameter; bordered pits in 1–3 (generally 2) rows on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma taxodioid, fairly large, quite uniform in size, oval for the most part (the long axis of the pit orifice more than 8 μm), 1–4 (generally 2–3) per cross field (Fig. 11-39). *Longitudinal parenchyma* apotracheal-diffuse to diffuse-in-aggregates (the cells solitary or occasionally 2 to several contiguous in the tangential plane, conspicuous because of their dark resinous contents); end walls smooth. Rays uniseriate, or not infrequently in part biseriate, or occasionally multiseriate,* consisting entirely of ray parenchyma or rarely with marginal or isolated ray tracheids,† the tallest up to 40 (mostly 10–15) cells in height.

Remarks

Unique among domestic coniferous woods because of its distinctive characteristics (straightness of grain, coarseness of texture, freedom from oily materials that characterize some coniferous wood, etc.), redwood resembles some of the cedars in color but is much coarser-textured, without characteristic odor, and with more conspicuous parenchyma. It is readily separated from baldcypress by its color, lack of greasiness, and the nature of the pits in the cross fields (compare Fig. 11-39 and 11-40). Some samples of redwood are peculiar in exhibiting even-width zones of compression wood composed of a number of annual increments which alternate at regular intervals with bands of normal wood.

Sierra redwood is the product of an allied tree, the bigtree or giant sequoia of the high Sierra, *Sequoia gigantea* (Lindl.) Decne. [*Sequoiadendron giganteum* (Lindl.). Buchholz]; it is occasionally used for fence posts, vineyard stakes, shakes, shingles, and for lumber, but the supply is becoming more limited as the groves of this species are incorporated into parks. Formerly employed for siding, it is generally too light and too soft for this purpose.

The wood of Sierra redwood closely resembles that of coast redwood. The following characters will usually suffice to separate these 2 timbers: Sierra redwood is generally softer and more brittle; its heartwood is darker, often with a purplish cast; its bands of late wood are generally narrower (1–4 tracheids in width); and its rays are less conspicuous and more abundant.‡

* R. L. Gray, Multiseriate Rays in Redwood [*Sequoia sempervirens* (D. Don) Endl.] *Int. Assoc. Wood Anat. Bull.*, **1973**(1):7–8 (1973), has reported multiseriate rays up to 5 cells wide in a sample of mature redwood.

† M. Gordon, Ray Tracheids in *Sequoia sempervirens*, *New Phytol.*, **11**:1–7 (1912).

‡ J. N. Mitchell, The Detailed Structure of the Stem Wood of the Two Sequoias, *J. For.*, **34**(11):988–993 (1936).

Uses

General and building construction (timbers, sills, joists, building lumber), because of its durability combined with strength and availability in large sizes; *planing-mill products* and *millwork* (especially sash, doors, and blinds, also siding, ceiling, and general millwork); *fences* and *patios*; *boxes* and *crates*; *caskets* and *coffins* (because of high natural durability); *tanks*, *vats*, and *cooling towers* (because of durability, high resistance to action of chemicals, low shrinkage, and freedom from twisting and warping); *cigar-*, *tobacco-*, and *candy boxes*; *conduits* such as pipes and flumes (because of durability, smoothness of surface, and ability to withstand extremes of temperature); *garden furniture*; *apiary supplies*; *signs*; *stadium seats*; *ship-* and *boatbuilding*; *greenhouses*; *plywood* for exterior and interior novelty application; *woodenware* and *novelties*; *shingles* and *shakes* (sawed and hand-split); wood from *burls* used for turned and carved articles and occasionally for table tops; *shredded bark* converted into wool-like insulating sorptive material; *pulpwood*; *particle board*.

BALDCYPRESS, RED CYPRESS, YELLOW CYPRESS, SOUTHERN CYPRESS (Taxodiaceae)

Taxodium distichum (L.) Rich.

General Characteristics

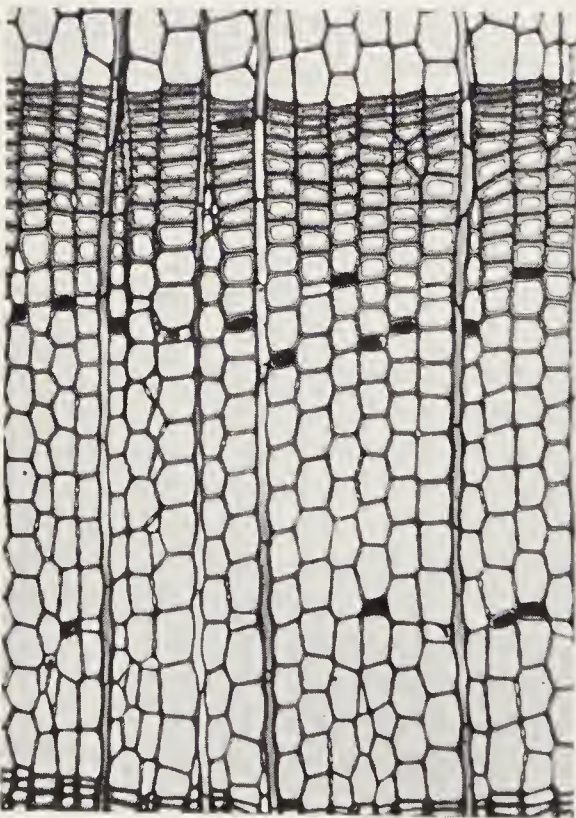
Sapwood pale yellowish white, merging more or less gradually into the *heartwood*, usually 1 in or more in width; *heartwood* very variable in color, ranging from yellowish to light or dark brown, reddish brown, or almost black (in the Gulf Coast and South Atlantic regions, the color averages darker than farther north); *wood* with greasy feel (especially along the grain), often with a rancid odor (light-colored stock, sometimes odorless),* generally straight- and even- or uneven-grained, coarse-textured, moderately heavy (sp gr approx 0.42 green, 0.47 oven-dry), moderately hard. *Growth rings* distinct, delineated by a band of darker late wood, narrow and occasionally discontinuous in old, overmature trees, or wide (proximate rings not infrequently variable in thickness; individual rings often variable in thickness and the rings then sinuate in contour). Early-wood zone narrow to wide, usually several times wider than the late-wood; transition from early to late wood more or less abrupt; late-wood zone conspicuous (in the darker

* In spite of the presence of an oil that is responsible for the greasy feel and rancid odor, cypress wood does not impart taste, odor, or color to food products that come into contact with it.

grades) or inconspicuous (light stock), narrow or broad in wide rings. *Parenchyma* abundant, present in every growth ring; cells scattered, readily visible in the lighter-colored grades with a hand lens and sometimes to the naked eye because of their dark resinous contents; strands of parenchyma visible along the grain as dark lines. *Rays* rather coarse (x) for a coniferous wood, forming a fine relatively conspicuous fleck on the quarter surface. *Resin canals* wanting. Finger-shaped pockets extending along the grain and containing a brown friable mass of decayed wood, frequently present; this defect, known as brown rot or peckiness, is caused by the fungus *Fomes geotropus* Cke.

Minute Anatomy

Tracheids up to 70 (avg 45–60) μm in diameter; bordered pits in 1–4 (frequently 3) rows on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma taxodioid or more rarely cupressoid, fairly large, quite uniform in size, orbicular for the most part (the long axis of the pit orifice less than 8 μm), 1–6 (generally



x—75×



t—75×

Figure 11-65 Baldcypress, *Taxodium distichum* (L.) Rich.

4) per cross field (Fig. 12–40). *Longitudinal parenchyma* apotracheal-diffuse to diffuse-in-aggregates (the cells solitary or occasionally 2 to several contiguous in the tangential plane, conspicuous because of their dark resinous contents); end walls nodular. *Rays* uniseriate or rarely in part biseriate, consisting entirely of ray parenchyma, the tallest more than 15 (up to 60) cells in height; end walls occasionally nodular.

Remarks

Baldcypress is one of the most variable woods in the United States in color, weight, and durability, and various grades such as red cypress, tidewater red cypress, yellow cypress, and white cypress are recognized by the trade; red cypress is usually slightly heavier and more durable than the yellow or white grades. The term *yellow cypress* is also applied to the wood of Alaska-cedar [*Chamaecyparis nootkatensis* (D. Don) Spach.]. Pondcypress, *T. distichum* var. *nutans* (Ait.) Sweet, occurs on the coastal plain in Southeastern United States, but the wood is not distinguished from that of baldcypress.

Uses

Most of the major uses of this wood depend on its reputed durability when exposed to conditions favorable to decay: *construction*, especially parts exposed to the weather (such as siding, beams, posts, timbers in docks and bridges);* *caskets and coffins*; *millwork* (especially doors, sash, and blinds, also interior trim and paneling); *kitchen cabinets*; *tanks, vats, and silos*; *containers* for corrosive chemicals; *laundry appliances*; *greenhouses*; *machine parts*; *ship- and boatbuilding*; *fixtures*; *stadium seats, boxes and crates* (considerable quantities, but mostly low-grade stock). In forms other than lumber, cypress is used extensively for *railroad ties* and in limited quantities for *poles, piling, fence posts, and cooperage*.

INCENSE-CEDAR, PENCIL CEDAR (Cupressaceae)

Calocedrus decurrens (Torr.) Florin
(Syn. *Libocedrus decurrens* Torr.)

General Characteristics

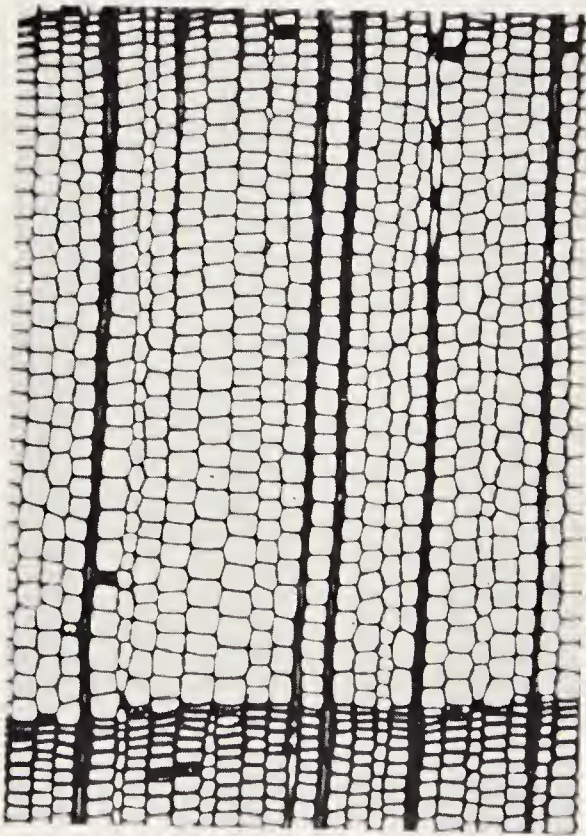
Sapwood nearly white, thin; *heartwood* reddish brown to dull brown, sometimes with a lavender tinge; *wood* with characteristic pungent odor

* Second-growth stock, regardless of its color or source, is only moderately decay resistant and should not be used in contact with the ground, unless treated. R. N. Campbell and J. W. Clark, Decay Resistance of Baldcypress Heartwood, *For. Prod. J.*, **10**(5):250–253 (1960).

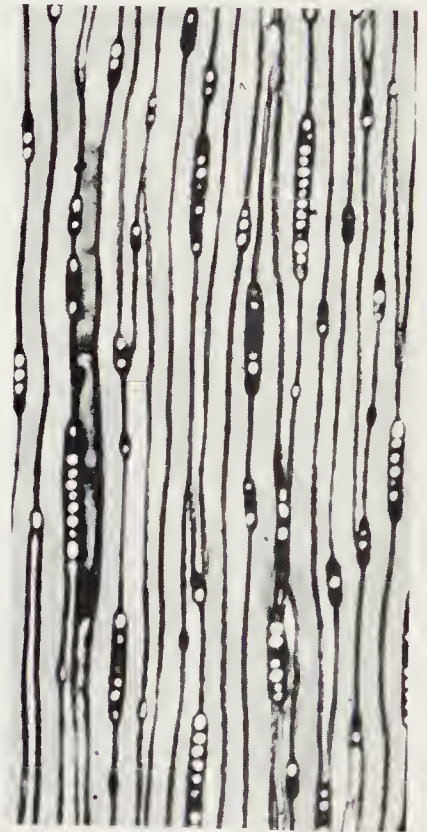
and spicy acrid taste, straight- and even-grained, medium-textured, light (sp gr approx 0.35 green, 0.38 oven-dry), moderately soft. *Growth rings* distinct, delineated by a band of darker late wood, quite uniform in width, medium-broad to broad (avg 9–12 per in). Early-wood zone usually broad, occupying most of the ring; transition from early to late wood zone fairly conspicuous, narrow. *Parenchyma* very abundant, (a) apotracheal-diffuse and not visible or barely visible with a hand lens in the early wood, (b) not infrequently banded in 1–2 dark bands in the late wood which are visible with a hand lens and often to the naked eye. *Rays* fine (x), plainly visible with a hand lens, forming a fine, close fleck on the quarter surface. *Resin canals* wanting. Finger-shaped pockets extending along the grain and containing a brown mass of decayed wood frequently present; this defect, known as *peckiness*, is caused by the fungus *Tyromyces* (*Polyporus*) *amarus* (Hedg) Lowe.

Minute Anatomy

Tracheids up to 50 (avg 35–40) μm in diameter; bordered pits in 1–2 rows on the radial walls; tangential pitting present in the last few rows of



x—75x



t—75x

Figure 11-66 Incense-cedar, *Calocedrus decurrens* (Torr.) Florin (*Libocedrus decurrens* Torr.).

late-wood tracheids; pits leading to ray parenchyma cupressoid, small, oval, quite uniform in size, with distinct border and lenticular orifice, 1–4 (generally 1–2) per cross field. Cells of *longitudinal parenchyma* solitary, 2 to several contiguous in the tangential plane, and in interrupted bands in the outer late wood, with dark gummy contents; end walls nodular. Rays uniseriate or not infrequently in part biseriate, mostly low (tallest rays 15 plus cells in height), consisting entirely of ray parenchyma or with occasional ray tracheids; broadest rays (uniseriate) 15–25 μm wide; ray cells in the heartwood with deposits of dark gum; end walls nodular with indentures.

Remarks

This cedar is sometimes confused with western redcedar (*Thuja plicata* Donn ex D. Don). For distinguishing characteristics of these 2 woods, see Remarks under Western Redcedar, p. 484.

Uses

Fence posts (because of its durability and ease of splitting); *ties* (very satisfactory as to durability but so soft that they require tie plates). *Lumber* used for *pencil slats* (principal species), for which purpose it is especially suited because of the ease with which it may be whittled owing to the evenness of the grain (early and late wood of approximately the same hardness), its uniformity of texture, and its relative firmness; *woodenware* and *novelties*; *millwork* (interior finish, outside trim, doors, and sash); *mothproof chests* and *closets*; *furniture*; *veneer*, sliced for decorative interior grades of plywood.

NORTHERN WHITE-CEDAR, EASTERN ARBORVITAE (Cupressaceae)

Thuja occidentalis L.

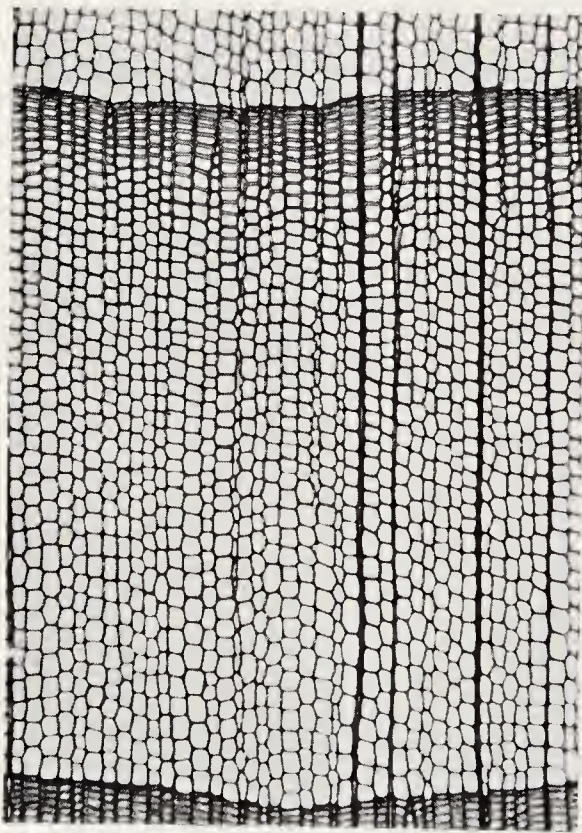
General Characteristics

Sapwood nearly white, narrow; *heartwood* uniformly straw-brown; wood with characteristic cedary odor [distinct from that of Atlantic white-cedar (*Chamaecyparis thyoides* (L.) B.S.P.)], with faint bitter taste, usually straight- and even-grained, fine-textured, very light (sp gr approx 0.29 green, 0.31 oven-dry), soft. *Growth rings* distinct, delineated by a darker band of late wood, usually narrow. Late-wood zone occupying most of the ring; transition from early to late wood more or less gradual; late-wood zone somewhat denser than the early wood, narrow. *Parenchyma* not visible.

Rays very fine (x), forming a fine, close, inconspicuous fleck on the quarter surface. Resin canals wanting.

Minute Anatomy

Tracheids fine [up to 35 (avg 20–30) μm in diameter]; bordered pits in 1 row or very rarely paired on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma taxodioid, small, orbicular or nearly so, quite uniform in size, with distinct border and lenticular orifice, 1–4 per cross field. *Longitudinal parenchyma* variable in distribution, (a) sparse (apotracheal-diffuse) and often apparently wanting, or (b) abundant and banded in a given growth ring and then often wanting in neighboring rings; end walls nodular. Rays uniseriate, 1–8 plus cells in height, consisting entirely of ray parenchyma or sometimes with an occasional ray tracheid; ray cells empty or with scanty infiltration; end walls with indentures.



x—75×



t—75×

Figure 11-67 Northern white-cedar, *Thuja occidentalis* L.

Remarks

Comparable to western redcedar (*Thuja plicata* Donn ex D. Don), but lighter in color, finer-textured, and generally with less-prominent growth rings. Northern white-cedar is sometimes confused with Atlantic white-cedar [*Chamaecyparis thyoides* (L.) B.S.P.], and most readily separated by gross features viz: heartwood drier (less oily) and more brittle; straw-brown in contrast to the roseate-tinted heartwood of Atlantic white-cedar; with a characteristic odor that is different from that of the last-named species. Structurally, these two woods are very similar, but the parenchyma is much more abundant and more evenly distributed in Atlantic white-cedar (see description of parenchyma under each species). Heartwood can be distinguished from sapwood, when there is no obvious color difference, by the use of a ferric ammonium oxalate solution [E. A. Behr, *Wood Sci.*, 6(4):394 (1974)]. A small excess of iron in the solution turns heartwood red-brown, and a large excess produces a greenish color, the sapwood color is not altered.

Uses

Principally for *poles and posts* (because of its durability when in contact with the ground); *cabins*; *ties* (so soft that it requires tie plates); *rustic furniture*; *shingles*. Lumber used for *tanks*; *boatbuilding* (especially canoe ribs); *fish-net floats* and *imitation minnows* (because of the extreme lightness of the wood); *woodenware* and *novelties*.

WESTERN REDCEDAR, GIANT ARBORVITAE (Cupressaceae)

Thuja plicata Donn ex D. Don

General Characteristics

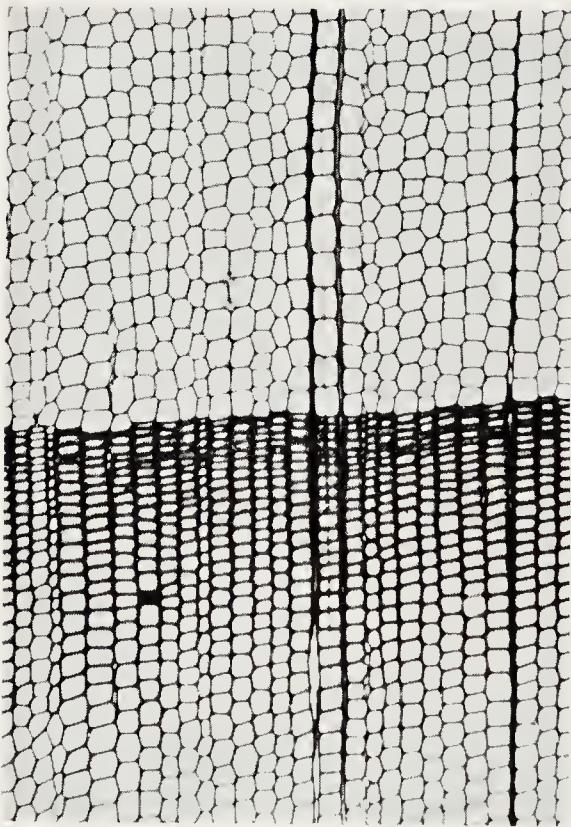
Sapwood nearly white, narrow; *heartwood* reddish or pinkish brown to dull brown; wood with a characteristic sweet, fragrant (cedary) odor and faint bitter taste, straight- and quite even-grained, medium- to somewhat coarse-textured, light (sp gr approx 0.31 green, 0.33 oven-dry), moderately soft. *Growth rings* distinct and generally quite conspicuous, delineated by a darker band of late wood, narrow to fairly wide. Early-wood zone occupying most of the ring, soft under tools; transition from early to late wood more or less abrupt; late-wood zone narrow, hard. *Parenchyma* not visible or barely distinct with a hand lens as a narrow line in the late wood. *Rays* fine (x), forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* wanting.

Minute Anatomy

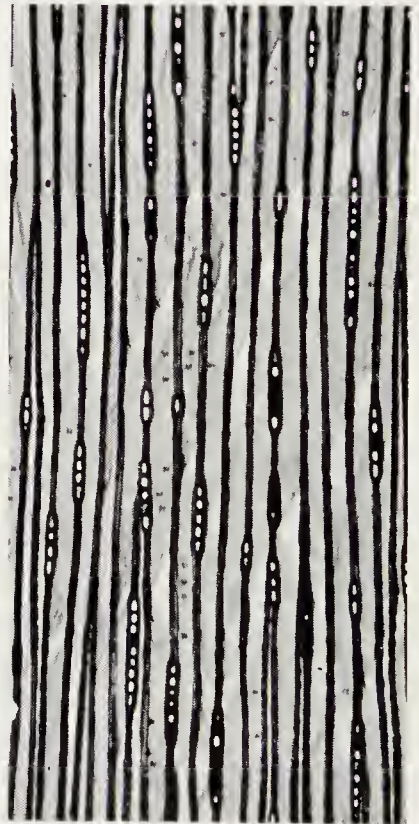
Tracheids medium coarse [up to 45 (avg 30–40) μm in diameter]; bordered pits in 1–2 rows on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma taxodioid, small, orbicular or nearly so, quite uniform in size, with distinct border and lenticular orifice, 1–4 per cross field. Lines of banded *parenchyma* very variable in distribution, (a) present in every ring in some samples, (b) in other instances sporadic in distant rings, the wood then often apparently without parenchyma; end walls nodular. Rays uniseriate, 1–12 plus cells in height, consisting entirely of ray parenchyma or rarely with a more or less continuous or interrupted row of ray tracheids on the upper and lower margins; ray cells with scanty gummy infiltration; end walls with indentures.

Remarks

Similar in color to, and hence often confused with, incense-cedar [*Calocedrus decurrens* (Torr.) Florin] and sometimes with redwood; softer,



x—75×



t—75×

Figure 11-68 Western redcedar, *Thuja plicata* Donn ex D. Don.

more brittle (drier), and less firm under tools than incense-cedar, without the relatively high infiltration content and acrid taste that are features of this wood; parenchyma generally much less abundant; rays strictly uniseriate (those of incense-cedar not infrequently in part biseriate). Can be easily separated from redwood, which lacks the cedar-like odor characteristic of western redcedar. For differences between *Thuja plicata* Donn ex D. Don and *T. occidentalis* L., see Remarks under the latter, p. 483.

Uses

Shingles (more than 95 percent of wood shingles manufactured in the United States), for which purpose its durability, ease of working, and lightness make this the premier wood; *poles* (because of the good form of the tree and its durability); *posts*; *piling* (has a tendency to crush in driving); *boxes* and *crates*. The *lumber* is used for all purposes where durability and ease of working are of first importance [especially for *caskets* and *coffins*, *siding* (most important western species for this purpose), *tank stock*, *porch columns*, *hothouse construction*, *boatbuilding* (planking of racing shells)], also for *interior finish*; *veneer*, used for faces and backs, especially in the manufacture of exterior siding, for which purpose it is more desirable than Douglas-fir.

PORT-ORFORD-CEDAR, PORT-ORFORD WHITE-CEDAR (Cupressaceae)

Chamaecyparis lawsoniana (A. Murr.) Parl.

General Characteristics

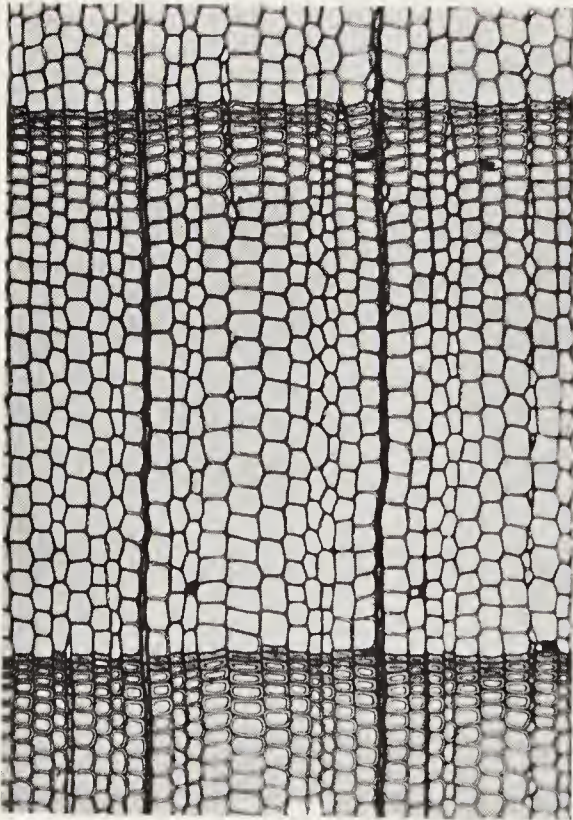
Sapwood nearly white to pale yellowish white, frequently not clearly distinguishable from the heartwood, narrow to fairly wide (1–3 in); *heartwood* yellowish white to pale yellowish brown; wood with a characteristic pungent, ginger-like odor when freshly cut,* with bitter, somewhat spicy taste, straight- and even-grained, medium- to somewhat coarse-textured, moderately light (sp gr approx 0.39 green, 0.44 oven-dry), moderately soft. *Growth rings* distinct but not conspicuous, delineated by a band of somewhat darker late wood, narrow to fairly wide (usually of medium width). Early-wood zone generally broad, occupying most of the ring; transition from early to late wood more or less gradual; late-wood zone only slightly denser than the early wood, narrow. *Parenchyma* abundant,

* This odor is due to a volatile oil, which, if inhaled continuously for a long time, may cause kidney complications. Men working at the sawmills cutting Port-Orford-cedar use masks as a protection against the oil and the fine dust resulting from sawing this wood.

not distinct or barely visible with a hand lens. Rays narrow (x), appearing fine with a hand lens, forming a close, low, inconspicuous fleck on the quarter surface. *Resin canals* wanting.

Minute Anatomy

Tracheids up to 50 (avg 35–45) μm in diameter; bordered pits in 1 row or occasionally in part biseriate on the radial walls; tangential pitting present on the last few rows of late-wood tracheids, pits leading to ray parenchyma cupressoid, small, orbicular or nearly so, quite uniform in size, with distinct border and lenticular orifice, 1–4 per cross field. *Longitudinal parenchyma* apotracheal-diffuse or occasionally exhibiting more or less a tendency toward zonation; cells usually conspicuous on account of their gummy contents, solitary or 2 to several contiguous in the tangential plane; end walls nodular. Rays uniseriate or rarely with paired cells, low (1–6 plus cells in height), narrow (7–12 μm), consisting entirely of ray parenchyma or very rarely with ray tracheids; gummy infiltration fairly abundant in the ray cells in the heartwood; indentures may be present in end walls.



x—75 $\times$



t—75 $\times$

Figure 11-69 Port-Orford-cedar, *Chamaecyparis lawsoniana* (A. Murr.) Parl.

Remarks

Distinctive among North American coniferous woods because of its pungent, ginger-like odor. This cedar is comparable to Alaska-cedar [*Chamaecyparis nootkatensis* (D. Don) Spach] but without the pronounced yellow cast that is a feature of that wood, with a different odor, broader rings, somewhat coarser texture, and seldom with ray tracheids.

Uses

Formerly the principal wood for *storage-battery separators* because of its electrical resistance and high resistance to the action of acids; *millwork* (sash, doors, interior finish); *lining* for *mothproof boxes* and *closets* (because of its reputed moth-repellent qualities; closets should be aired when new, as otherwise the volatile oil from the wood condenses on hardware, buttons, and glass); *woodenware* and *novelties*; *arrowshafts*; *boat construction*, especially *decking*; *general construction*; *tanks*; *planking*; *mine timbers* (lower grades).

ALASKA-CEDAR, YELLOW CYPRESS

(Cupressaceae)

Chamaecyparis nootkatensis (D. Don) Spach

General Characteristics

Sapwood nearly white to yellowish white, very narrow; *heartwood* bright clear yellow, darkening upon exposure; wood with a characteristic odor which in some samples resembles that of raw potatoes, with a faint bitter, somewhat spicy taste, straight- and even-grained, fine- to medium-textured, moderately heavy (sp gr approx 0.42 green, 0.46 oven-dry), moderately hard. *Growth rings* not visible or barely visible to the naked eye, generally plainly visible with a hand lens, delineated by a darker band of late wood, narrow to very narrow (50–90 per in), quite uniform in width. Early-wood zone occupies most of the ring; transition from early to late wood more or less abrupt; late-wood zone appreciably denser than the early wood, narrow, not conspicuously differentiated from the early wood through discrepancy in color. *Parenchyma* not distinct at low magnifications. *Rays* narrow (x), appearing fine with a hand lens, forming a low, inconspicuous fleck on the quarter surface. *Resin canals* wanting.

Minute Anatomy

Tracheids up to 40 (avg 25–35) μm in diameter; bordered pits in 1 row or rarely paired on the radial walls; tangential pitting present on the last few rows of late-wood tracheids; pits leading to ray parenchyma cupressoid, small, orbicular or nearly so, quite uniform in size, with distinct border and

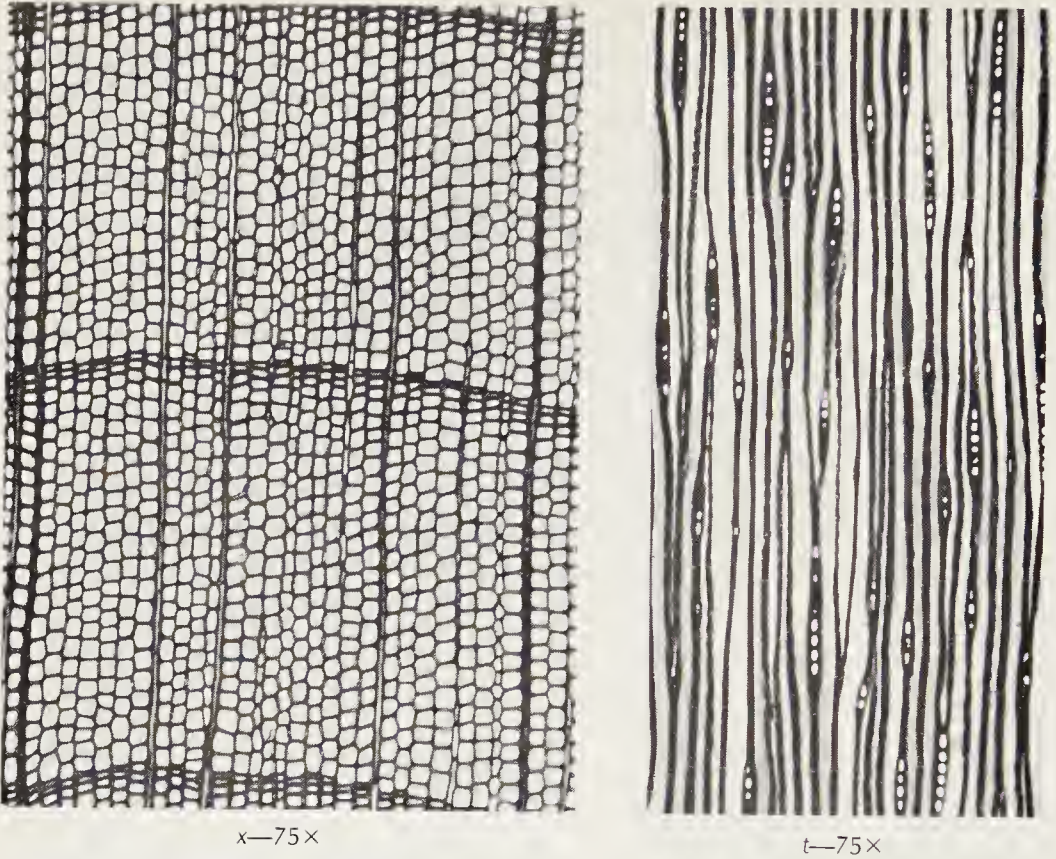


Figure 11-70 Alaska-cedar, *Chamaecyparis nootkatensis* (D. Don) Spach.

lenticular orifice, 1–3 per cross field (Fig. 11-41). *Longitudinal parenchyma* sparse, or not infrequently wanting altogether, to abundant; cells apotracheal-diffuse, usually distinguishable on account of their gummy contents, solitary or 2 to several contiguous in the tangential plane; end walls nodular. Rays uniseriate or rarely with paired cells, 1–20 plus (the majority less than 12) cells in height; end walls with indentures; low rays with ray tracheids, these frequently constituting the entire ray (Fig. 11-42); ray tracheids (*r*) short and high (along the grain); gummy infiltration fairly abundant in some of the ray cells.

Remarks

This cedar is comparable to Port-Orford-cedar [*Chamaecyparis lawsoniana* (A. Murr.) Parl.], and not to be confused with yellow cypress produced by *Taxodium distichum* (L.) Rich. For distinguishing characters, see Remarks under *Taxodium*, p. 479.

Uses

Locally for poles, interior finish, furniture, cabinetwork, novelties, caskets, and hulls of small boats; valuable for patterns (because of its good working

qualities, low shrinkage, and ability to stay in place); *canoe paddles* (long preferred by the Alaska Indians); *oars*; *piling* and *marine buoys* (because of its resistance to marine borers); *greenhouse* and *conservatory* construction (because of its resistance to decay); *acid tanks* and *chemical containers* (because of its acid resistance); *sounding boards* of musical instruments (because of its uniform density, straightness and evenness of grain, low shrinkage, and ability to stay in place). A few logs are shipped to Japan, where the wood is used in temple buildings and other important structures, because of its purported resistance to termite attack.

ATLANTIC WHITE-CEDAR, SOUTHERN WHITE-CEDAR (Cupressaceae)

Chamaecyparis thyoides (L.) B.S.P.

General Characteristics

Sapwood whitish, narrow; *heartwood* light-brown tinged with red or pink (roseate); wood somewhat oily, with a characteristic cedary odor [distinct from that of northern white-cedar (*Thuja occidentalis* (L.)) and faint bitter taste, usually straight- and even-grained, fine-textured, light (sp gr 0.31 green, 0.35 oven-dry), moderately soft. *Growth rings* distinct but not conspicuous, delineated by a darker band of late wood, usually fairly wide. Early-wood zone occupying most of the ring; transition from early to late wood more or less gradual; late-wood zone somewhat denser than the early wood, narrow. *Parenchyma* fairly abundant to abundant (present in every growth ring), banded and apotracheal-diffuse, in the former instance appearing as darker concentric lines which are visible with a hand lens and not infrequently to the naked eye. *Rays* very fine (x), forming a fine, close, inconspicuous fleck on the quarter surface. *Resin canals* wanting.

Minute Anatomy

Tracheids fine [up to 40 (avg 25–35) μm in diameter], without or with few intercellular spaces at the corners; bordered pits in 1 row or very rarely paired on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma cupressoid, small, orbicular or nearly so, quite uniform in size, with distinct border and lenticular orifice, 1–4 per cross field. Cells of *longitudinal parenchyma* solitary and often scattered, or 2 to several contiguous in the tangential plane and banded, generally distinguishable in the transverse section by their contents. *Rays* uniseriate or rarely with paired cells, 1–12 plus cells in height, consisting entirely of ray parenchyma or with an occasional ray tracheid; ray cells empty or with scanty infiltration. Ray parenchyma end walls smooth, with indentures in many cells.

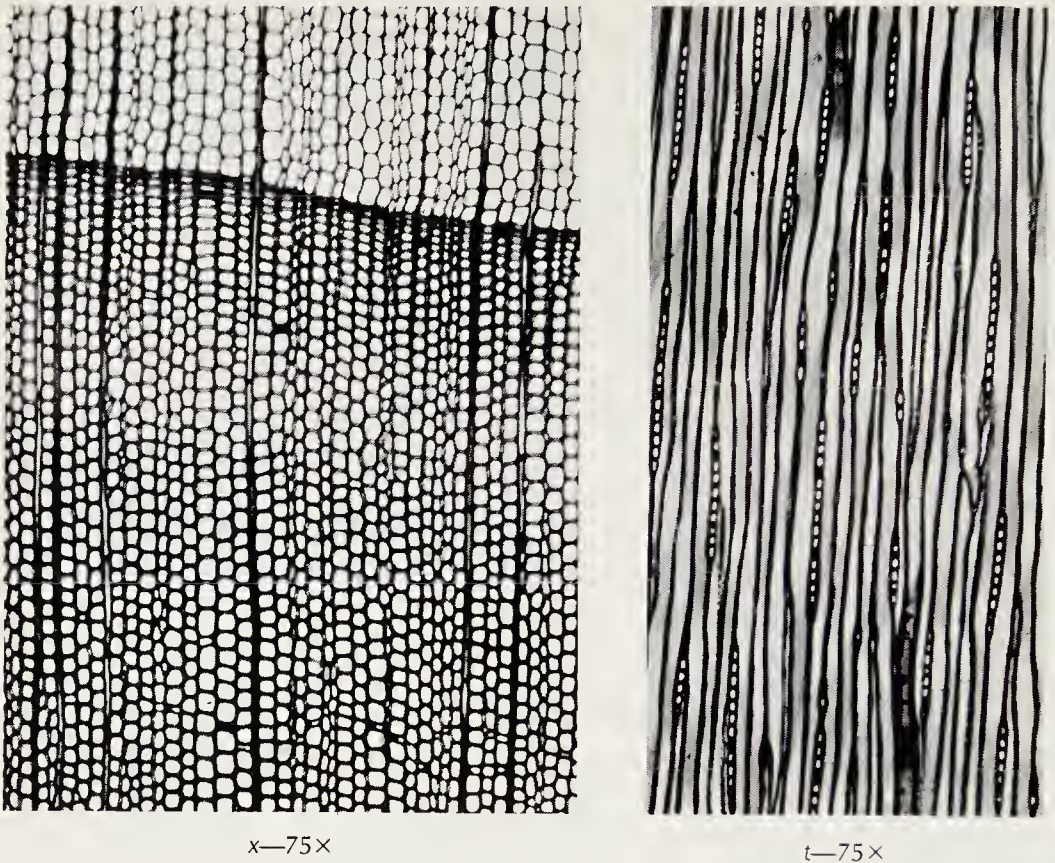


Figure 11-71 Atlantic white-cedar, *Chamaecyparis thyoides* (L.) B.S.P.

Remarks

This cedar is similar in structure to northern white-cedar (*T. occidentalis* L.). For distinguishing characters see Remarks under Northern white-cedar, p. 483.

Uses

Principally for *poles*, *posts*, *shingles*, and *lumber* (with many defects, particularly knots and wind shakes), *water tanks* (because of its lightness and durability); *boat construction*. Lumber used for *planing-mill* products (such as siding, porch lumber); *boxes* and *crates* (especially for vegetables and small fruits); *fencing*.

REDCEDAR (Cupressaceae)

Eastern redcedar, Tennessee redcedar (*Juniperus virginiana* L.)
Southern redcedar [*Juniperus silicicola* (Small) Bailey]

General Characteristics

Usually available only in small sizes and generally knotty; *sapwood* nearly white, thin; *heartwood* purplish or rose-red when first exposed, aging to dull red or reddish brown, sometimes with lighter streaks of included sapwood;* wood with mild characteristic “pencil-cedar” odor and taste, straight- (except near knots) and even-grained, fine-textured, moderately heavy (sp gr approx 0.44 green, 0.49 oven-dry), hard. *Growth rings* distinct, delineated by a band of darker late wood, narrow to wide (a given ring often variable in width and the rings hence sinuate in contour), not infrequently eccentric; false rings occasioned by 2–3 bands of late wood sometimes present. Early-wood zone usually broad, occupying most of the ring; transition from early to late wood gradual to rather abrupt; late-wood zone conspicuous, much darker than the early wood, narrow. *Parenchyma* very abundant, banded, in 1 to several (usually 1–2) dark bands which are visible with a hand lens and often to the naked eye (especially in the sapwood). *Rays* very fine (x), darker than the background and forming a fine, low fleck on the quarter surface. *Resin canals* wanting.

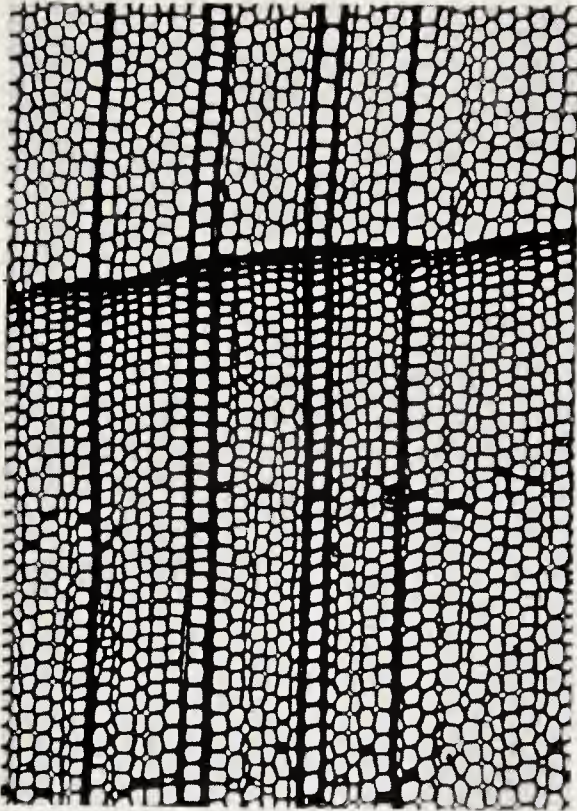
Minute Anatomy

Tracheids fine [up to 35 (avg 20–30) μm in diameter], often with intercellular spaces at the corners (x); bordered pits in 1 row or very rarely paired on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma cupressoid, small, orbicular or nearly so, quite uniform in size, with distinct border and lenticular orifice, 1–4 per cross field. Cells of *longitudinal parenchyma* solitary or 2–3 contiguous in the tangential plane, and banded, with dark gummy contents; end walls nodular. *Rays* uniseriate, low (1–6 plus cells and less than 250 μm in height), consisting entirely of ray parenchyma; ray cells in the heartwood with copious deposits of dark gum; end walls nodular with indentures.

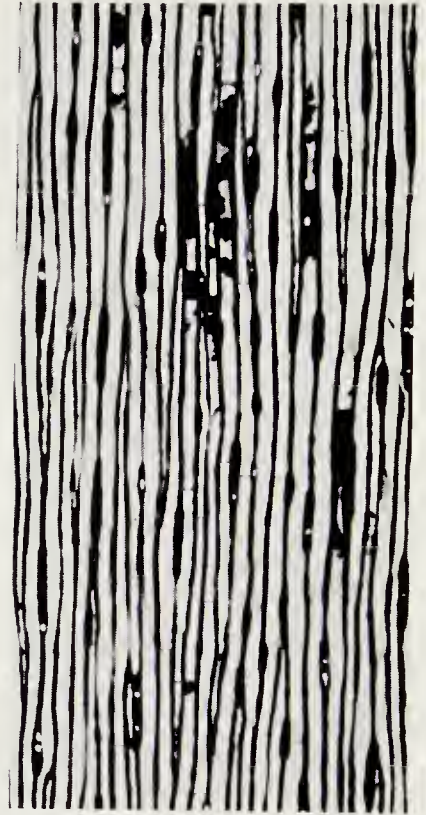
Remarks

Redcedar is distinctive among North American coniferous woods because of the color of the heartwood. The 2 species producing this timber cannot be separated on the basis of wood structure.

* McGinnes et al. have found that included sapwood zones in redcedar were more numerous at the base of trees, decreasing in frequency with the tree height. Longer patches were usually associated with some injury, e.g., frost damage and bird pecks, and were characterized by abnormal tissue formation; smaller patches of included sapwood appeared to consist of normal wood tissue. E. A. McGinnes, Jr., S. A. Kandel, and P. S. Szopa, Frequency and Selected Anatomical Features of Included Sapwood in Eastern Redcedar, *Wood Sci.*, 2(2):100–106 (1969).



x—75×



t—75×

Figure 11-72 Eastern redcedar, *Juniperus virginiana* L.

Uses

Fence posts (principal use from the standpoint of quantity). Lumber used for *chests, wardrobes, and closet linings* (because of its color, excellent working qualities, fragrance, and reputed moth-repellent properties); *mill-work* (sash, doors, interior finish); *pencil slats* (formerly the most important use; today, because of the scarcity of suitable material, composing less than 10 percent of the output); *woodenware and novelties*.

PACIFIC YEW

(Taxaceae)

Taxus brevifolia Nutt.

General Characteristics

Sapwood light yellow, thin; *heartwood* bright orange to rose-red; wood without characteristic odor or taste, even-grained, very fine-textured, heavy (sp gr approx 0.60 green, 0.67 oven-dry), very hard. *Growth rings* distinct, delineated by a band of darker late wood, narrow to medium-wide or broad.

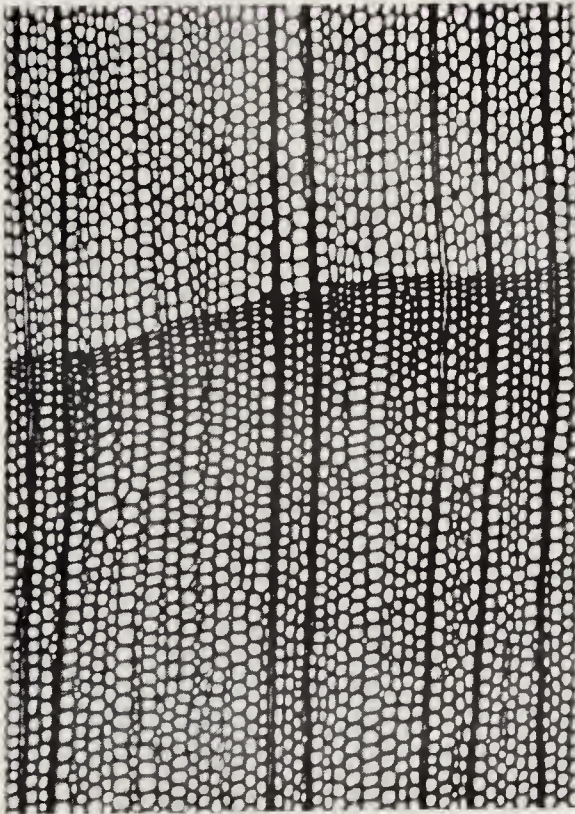
Early-wood zone usually occupying about one-half of the ring; transition from early to late wood very gradual; late wood very dense. *Parenchyma* not visible. *Rays* very fine (x), not distinct to the naked eye, forming a fine, close, inconspicuous fleck on the quarter surface. Normal and wound (traumatic) *resin canals* wanting.

Minute Anatomy

Tracheids fine [up to 25 (avg 15–20) μm in diameter], more or less rounded, featured by fine, close bands of spiral thickening in a double coil; bordered pits in 1 row on the radial walls; tangential pitting present in the last few rows of late-wood tracheids; pits leading to ray parenchyma cupressoid, small, orbicular or nearly so, quite uniform in size, with distinct border and lenticular orifice, 1–4 (generally 1–2) per cross field. *Longitudinal parenchyma* wanting. *Rays* uniseriate or very rarely with paired cells, 1–25 cells in height, consisting entirely of ray parenchyma; end walls with indentures.

Remarks

Yew is of limited commercial importance because of its scarcity and small size.



x—75×



t—75×

Figure 11-73 Pacific yew, *Taxus brevifolia* Nutt.

Uses

Poles, bows, canoe paddles, small turned articles, and carvings; locally for paneling and furniture.

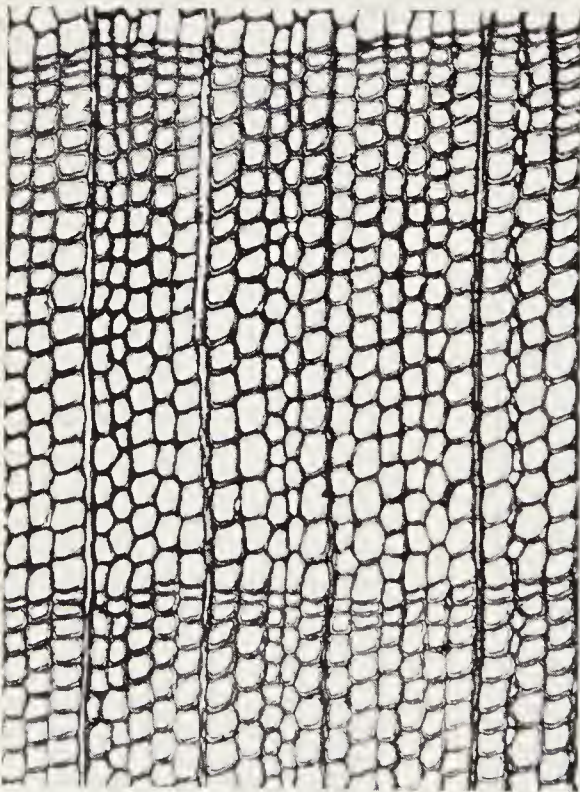
CALIFORNIA TORREYA AND FLORIDA TORREYA (Taxaceae)

California torrey (Torrey *californica* Torr.).

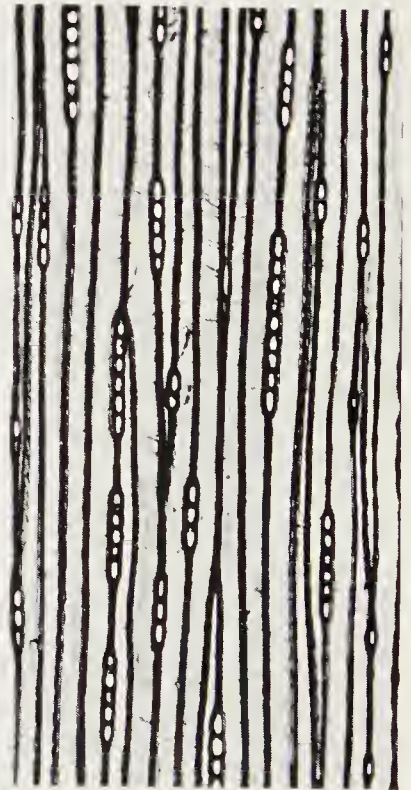
Florida torrey (Torrey *taxifolia* Arn.)

General Characteristics

Sapwood whitish to yellowish white, frequently difficult to distinguish from the heartwood; *heartwood* clear yellow; wood with a characteristic odor (strong and unpleasant in *T. taxifolia*), with a mild, characteristic, bitterish taste, even-grained, medium- to somewhat coarse-textured, moderately light to moderately heavy (avg sp gr approx 0.48 green), soft to moderately hard. *Growth rings* fairly distinct but not prominent, delineated by a band of



x—75×



t—75×

Figure 11-74 California torrey, *Torrey californica* Torr.

darker late wood. Early wood occupying most of the ring; transition from early to late wood very gradual; late wood dense. *Parenchyma* not visible. Rays very fine (x), not distinct to the naked eye, forming a fine, close, inconspicuous fleck on the quarter surface. Normal and wound (traumatic) resin canals wanting.

Minute Anatomy

Tracheids fine [up to 55 (avg 25–35) μm in diameter], featured by fine, widely spaced bands of spiral thickening in a double coil; bordered pits in 1–2 rows on the radial walls; tangential pitting sparse, usually confined to the late-wood tracheids; pits leading to ray parenchyma cupressoid, small, orbicular or nearly so, 2–7 (generally 1–4) per cross field. *Longitudinal parenchyma* wanting. Rays uniseriate, 1–12 plus cells in height, consisting entirely of ray parenchyma; end walls of cells with indentures.

Uses

Of no commercial importance; used locally for fence posts, cabinets, models, novelties, and patterns.

SUMMARY OF ANATOMICAL INFORMATION ON THE WOOD OF CONIFERS

Information on the anatomical features of the secondary wood of conifers is given in Table 11-1. The data in this table may be used directly for identification of softwood samples, or the information can be transferred to edge-punched cards for manual sorting with a needle. A sample card is shown in Fig. 11-75, following the table. When using these data in either way, it is well to bear in mind that some characteristics are more reliable and useful for purposes of identification than are others. The most important wood anatomy features are rather limited for coniferous woods as is apparent in the following list.

- 1 Transition from early to late wood gradual or abrupt
- 2 Resin canals present or absent
- 3 Epithelial cells in resin canals thin- or thick-walled
- 4 Spiral thickening present in longitudinal tracheids
- 5 Ray tracheids present or absent
- 6 Ray tracheids dentate
- 7 Cross-field pit types: fenestriform, pinoid, piceoid, cupressoid, taxodioid
- 8 Longitudinal parenchyma present
- 9 End walls of parenchyma cells nodular or smooth
- 10 Indentures at end walls of ray parenchyma cells

Table 11-1 Anatomical Data of Coniferous Woods*

Species	General							Tracheids			Canals		Rays						Cross-field pits					Parenchyma		
	Heartwood distinct†	Heartwood odor‡	Heartwood greasy	Tangential surface dimpled	Abrupt early-late wood transition	Gradual early-late wood transition	Radial pits 2-more	Pits on tangential walls	Spirals	Epithelium walls thin	Epithelium walls thick	Fusiform epithelium walls thin	Fusiform epithelium walls thick	Tracheids present	Tracheids dentate	End walls nodular	Indentures	Fenestriform	Pinoid	Piceoid	Taxodioid	Cupressoid	Present	End walls smooth	End walls nodular	
Abies spp.		s			+	+	s	+						s		+	+				+		s		+	
Calocedrus decurrens	+	+			+	+	s	+								+	+					+	+		+	
Chamaecyparis lawsoniana	+	+			+	+		+						s			+					+	+		s	
Chamaecyparis nootkatensis	+	+			+	+		+						+			+					+	+		+	
Chamaecyparis thyoides	+	+			+	+		+						s			+					+	+		+	
Juniperus virginiana	+	+			+	+		+								+	+					+	+		+	
Larix spp.	+						+	+	s		+			+		+	+						s		+	
Picea sitchensis	+			+	+	+	s	+			+	+		+		+	+				+					
Picea spp.					+	+		+			+	+		+		+	+				+					
Pinus lambertiana	+	s			+	+	+	+		+		+	+	+		+	+		+							

Table 11-2 Comparative Physical Data for Coniferous Woods Native to the United States

Common name of wood ^a (1)	Sp gr, average		Weight, lb/cu ft		Shrinkage based on green dimension, % ^b				Index classes to mechanical properties ^c											
									Bending strength (10)	Compression as a post (11)	Hardness (12)	Stiffness (13)	Shock resistance (14)	Splitting (15)	Screw holding (16)	Ability to stay in place (17) ^d	Drying defects (18) ^e	Machining qualities (19) ^f	Gluing qualities (20) ^g	Durability rating (21) ^h
	Green (2)	12% (3)	Green (4)	12% (5)	Volume (6)	T (7)	R (8)	T/R (9)												
Alaska-cedar Baldcypress Douglas-fir (coast type) Douglas-fir (inland north) Fir, balsam	0.42	0.44	36	31	9.2	6.0	2.8	2.1	4	3	4	3	4	4	3	1	1	G	3	R
	0.42	0.46	51	32	10.5	6.2	3.8	1.6	4	3	5	3	4	4	3	2	1	A	3	R,M
	0.45	0.48	38	34	12.4	7.6	4.8	1.6	3	2	4	1	4	4	3	3	2	A	2	M
	0.45	0.48	38	36	10.7	6.9	3.8	1.9	3	3	4	2	4	4	3	3	2	A	2	M
	0.34	0.36	45	25	11.2	6.9	2.9	2.4	5	4	5	4	5	5	4	3	2	P	1	S
Fir, white Hemlock, eastern Hemlock, western Incense-cedar Larch, western	0.37	0.39	47	26	9.8	7.0	3.3	2.2	5	4	5	3	5	4	4	3	2	A	1	S
	0.38	0.40	50	28	9.7	6.8	3.0	2.3	4	3	4	3	5	4	4	3	2	P	2	S
	0.42	0.45	41	31	12.4	7.8	4.2	1.8	4	3	4	2	5	4	4	3	2	A	2	S
	0.35	0.37	45	26	7.7	5.2	3.3	1.6	4	3	5	4	5	4	5	1	1	G	1	R
	0.48	0.52	50	36	14.0	9.1	4.5	1.9	3	2	4	2	4	4	2	3	2	A	1	M
Pine, eastern white Pine, jack Pine, loblolly Pine, lodgepole Pine, longleaf	0.34	0.35	36	25	8.2	6.1	2.1	2.6	5	4	5	4	5	5	5	1	2,4	G	2	M
	0.40	0.43	40	30	10.3	6.6	3.7	1.9	4	4	4	3	4	4	3	3	2	A	2	S+
	0.47	0.51	53	36	12.3	7.4	4.8	1.5	3	3	4	2	4	4	3	3	2	A	2	S+
	0.38	0.41	39	29	11.1	6.7	4.3	1.5	5	4	5	3	5	4	4	2	2	A	2	S+
	0.54	0.59	55	41	12.2	7.5	5.1	1.5	2	2	4	1	3	4	2	3	2	A	2	M
Pine, ponderosa Pine, red Pine, shortleaf Pine, slash Pine, sugar	0.38	0.40	45	28	9.7	6.2	3.9	1.6	5	4	5	3	5	4	4	2	2	A	2	S+
	0.41	0.46	49	30	11.3	7.2	3.8	1.6	5	4	5	3	4	4	3	3	2	A	2	S+
	0.47	0.51	52	36	12.3	7.7	4.6	1.8	3	3	4	2	4	4	3	3	2	A	2	S+
	0.54	0.59	58	43	12.1	7.6	5.4	1.4	2	2	3	1	3	4	2	3	2	A	2	M
	0.34	0.36	52	25	7.9	5.6	2.9	1.9	5	4	5	3	5	4	4	5	1	G	2	S+

Table 11-2 Comparative Physical Data for Coniferous Woods Native to the United States

Common name of wood ^a (1)	Sp gr, average		Weight, lb/cu ft		Shrinkage based on green dimension, % ^b					Index classes to mechanical properties ^c											
					Green (2)	12% (3)	Green (4)	12% (5)	Volume (6)	T (7)	R (8)	T/R (9)	Bending strength (10)	Compression as a post (11)	Hardness (12)	Stiffness (13)	Shock resistance (14)	Splitting (15)	Screw holding (16)	Ability to stay in place (17) ^d	Drying defects (18) ^e
Pine, western white Port-Orford-cedar Redcedar, eastern Redcedar, western Redwood old growth	0.35	0.38	35	27	11.8	7.4	4.1	1.8	5	4	5	3	5	4	4	4	2	2	G	2	S+
	0.39	0.43	36	29	10.1	6.9	4.6	1.5	4	3	5	2	5	5	4	4	2	1	G	3	R
	0.44	0.47	37	33	7.8	4.7	3.1	1.5	3	3	3	5	3	4	3	1	1	G	2	R	
	0.31	0.32	27	23	6.8	5.0	2.4	2.1	5	4	5	4	5	5	5	5	1	1,5	A	1	R
	0.38	0.40	50	28	6.8	4.4	2.6	1.7	3	2	4	3	5	5	4	4	2	1,5	A	1	R
Spruce, eastern and Engelmann Spruce, Sitka Tamarack White-cedar, Atlantic White-cedar, northern Yew, Pacific	0.36	0.38	36	27	12.9	7.4	4.0	1.8	5	4	5	3	5	5	5	4	2	2	A	1	S
	0.37	0.40	33	28	11.5	7.5	4.3	1.7	5	4	5	3	5	5	4	4	2	2	A	1	S
	0.49	0.53	47	37	13.6	7.4	3.7	2.0	3	3	5	3	4	4	2	3	2	2	P	2	M
	0.31	0.32	26	23	8.8	5.4	2.9	1.9	5	4	5	5	5	5	5	5	2	1	A	2	R
	0.29	0.31	28	22	7.2	4.9	2.2	2.2	5	5	5	5	5	5	5	5	1	1	A	2	R
	0.60	0.62	54	44	9.7	5.4	4.0	1.4	2	1	2	4	3	3	2	2	2	2	G	2	R

^aCommon names according to "Check List of Native and Naturalized Trees of the United States," U.S. Department of Agriculture Handbook 41, 1953. See text for scientific names.

^bShrinkage values are for change from green to oven-dry.

^cCoding of mechanical properties according to index classes:

Column no.	Mechanical property	Index classes				
		5	4	3	2	1
10	Modulus of rupture in bending, green wood, psi	<6000	6000 to	7000 to	8000 to	11,000 +
11	Maximum crushing strength parallel, green wood, psi	<2200	2200 to	3000 to	3600 to	4500 +
12	Side hardness, green wood, lb	< 400	400 to	600 to	900 to	1200 +
13	Modulus of elasticity in bending, psi × 1000	< 800	800 to	1000 to	1300 to	1500 +
14	Height of drop with 50-lb hammer, in	15 to	25 to	35 to	50 to	70 +
15	Load, lb/in of width to split green wood	< 150	150 to	250 to	350 to	450 +
16	Nail and screw withdrawal as function of sp gr OD	< 0.40	0.40 to	0.45 to	0.55 to	0.70 +

^dDimensional changes with moisture in normal use ranges from Class 1 with little change, to Class 5 with greatest dimensional change.

^eDrying defects classed as follows: 1. Slight warping and little dimensional change. 2. Distinct warping. 3. Pronounced warping. 4. Tendency to check and split. 5. Subject to collapse and honeycombing.

^fMachining qualities: G = good to excellent, smooth surface. A = average. P = poor, requiring care to be acceptable.

^gGluing qualities: 1. Glues very easily. 2. Glues well. 3. Requires control. 4. Difficult to glue, requires close control.

^hHeartwood durability ratings: R = resistant to decay; M = moderate resistance to decay; S = low decay resistance. + indicates high rating within the group.

Sources: "Wood Handbook," U.S. Department of Agriculture Handbook 72, 1974 and U.S. Dep. Agric. Bull. 479, 1935, except for cols. 9 and 18.

Hardwoods—Keys and Descriptions by Species

IV KEY TO HARDWOODS—GROSS FEATURES*

Woods porous (with vessels); cross section consisting of pores (vessels) embedded in a mass of fibers and parenchyma tissue; rays distinct or indistinct to the naked eye (Figs. 11-76 to 11-141 inc.).

- 1 Early-wood pores *conspicuously larger* than the late-wood pores, distinct with the naked eye (**wood ring-porous** or **semi-diffuse-porous**)† (Figs. 11-102, 11-109, 11-131) 2
- 1 Early-wood pores *not conspicuously larger* than the late-wood pores and indistinct to the naked eye (Fig. 11-88); early-wood zones not sharply defined (**wood diffuse-porous**) 33
 - 2 Transition in size of pores from early to late wood abrupt, **wood ring-porous** (Fig. 11-102) 3
 - 2 Transition in size of pores from early to late wood somewhat gradual, **wood semi-ring-porous** (Fig. 11-109) 24
- 3 Broad rays present, conspicuous without a lens (x; Figs. 11-128 to 11-131 inc.) often 1 in or more in height along the grain (t; Fig. 11-127), forming a broad ray fleck on the radial surface 4
- 3 Broad rays absent (Fig. 11-78) 5
 - 4 Late-wood pores distinct with a hand lens, not numerous, thick-walled, the orifices plainly visible, rounded; tyloses usually absent or sparse in the early-wood pores; heartwood usually pinkish or pale brown.
Red oak—*Quercus* spp. Figs. 11-129 and 11-131. Desc. pp. 565 to 568.
 - 4 Late-wood pores indistinct with a hand lens, numerous, thin-walled, the orifices scarcely visible, angular; tyloses

*This key is designed for the separation of the more important temperate North American hardwoods based on features visible with a 10× hand lens or without magnification.

A series of photographs (Figs. 11-76 to 11-141) at low magnification (5×) accompanies this key to illustrate the normal appearance of the various kinds of woods under a hand lens.

†In osage-orange and black locust (Figs. 11-113 and 11-134) early-wood pores are large but poorly defined because of occlusion with tyloses.

generally present in the early-wood pores (heartwood); heartwood rich light to dark brown, usually without flesh-colored cast.

White oak—*Quercus* spp. Figs. 11-128 and 11-130. Desc. pp. 568 to 572.

- 5 Late wood figured with wavy concentric, continuous, or interrupted (tangential) bands of pores separated by bands of mechanical tissue (x; Fig. 11-138) 6
- 5 Late wood not figured with wavy, concentric (tangential) bands of pores (Fig. 11-104) 12
- 6 Early-wood pores mostly in a single line 7
- 6 Early-wood pores in several rows (Figs. 11-139) 8
- 7 Early-wood pores plainly visible without a hand lens, approximately equal in size and quite evenly spaced in a more or less continuous row; tyloses sparse.

American elm—*Ulmus americana* L. Fig. 11-138. Desc. p. 572.

- 7 Early-wood pores scarcely visible without a hand lens, the larger spaced at intervals in an interrupted row and separated by smaller pores; tyloses abundant.

Hard elm—*Ulmus* spp. Fig. 11-140. Desc. p. 575.

- 8 Early-wood pores in the heartwood completely occluded with tyloses, pore contours poorly defined 9
- 8 Early-wood pores in the heartwood not completely occluded with tyloses, pore contours distinct 10
- 9 Heartwood golden yellow to bright orange, darkening upon exposure, often with reddish streaks along the grain; coloring matter readily soluble in water.

Osage-orange—*Maclura pomifera* (Raf.) Schneid. Fig. 11-113. Desc. p. 579.

- 9 Heartwood greenish yellow to dark yellowish or golden brown; coloring matter not readily soluble in water.

Black locust—*Robinia pseudoacacia* L. Fig. 11-134. Desc. p. 599.

- 10 Rays indistinct without a lens; wood light brown to dark reddish brown.

Slippery elm—*Ulmus rubra* Mühl. Fig. 11-139. Desc. p. 573.

- 10 Rays distinct without a lens on cross section; sapwood pale yellow to grayish or greenish yellow; heartwood light brown streaked with yellow or orange-yellow to golden brown . . . 11
- 11 Sapwood pale yellow to grayish or greenish yellow; imperfectly developed heartwood yellowish gray or light brown streaked with yellow.

Hackberry—*Celtis* spp. Fig. 11-96. Desc. p. 576.

- 11 Sapwood yellowish, narrow; heartwood orange-yellow to golden brown, turning dull dark brown on exposure; ray fleck conspicuous on the radial surface.

Red mulberry—*Morus rubra* L. Fig. 11-116. Desc. p. 578.

- 12 Late-wood parenchyma appearing under the lens as fine, numerous, continuous, or broken, light-colored, tangential lines (Fig. 12-91), or closely and evenly punctate (Fig. 11-99) 13
- 12 Late-wood parenchyma not evident, or if evident associated with pores (paratracheal) and occasionally connecting the pores in the outer late-wood zone 14
- 13 Sapwood creamy white when freshly cut, darkening on exposure to light yellow-brown (sometimes with grayish brown stain); heartwood rarely present, then only in small bands, blackish brown to black; wood with storied rays, forming ripple marks on the tangential surface; parenchyma (x) closely and evenly punctate, relatively inconspicuous.
Common persimmon—*Diospyros virginiana* L. Fig. 11-99. Desc. p. 621.
- 13 Sapwood whitish to pale brown; heartwood pale brown to brown or reddish brown (that of pecan rich brown, sometimes with streaks of a darker hue); wood without storied rays; parenchyma conspicuous, in concentric tangential lines in the late wood.
Hickory—*Carya* spp. Figs. 11-90 to 11-92 inc. Desc. p. 540.
- 14 Early-wood pores in the heartwood completely occluded with tyloses, their contours poorly defined 15
- 14 Early-wood pores in the heartwood open or partly occluded with tyloses, their contours distinct 16
- 15 Heartwood golden yellow to bright orange, darkening upon exposure, often with reddish streaks along the grain; coloring matter readily soluble in water.
Osage-orange—*Maclura pomifera* (Raf.) Schneid. Fig. 11-113. Desc. p. 579.
- 15 Heartwood greenish yellow to dark yellowish golden brown; coloring matter not readily soluble in water.
Black locust—*Robinia pseudoacacia* L. Fig. 11-134. Desc. p. 599.
- 16 Late-wood pores small, thin-walled, grouped in patches of porous tissue, which are obliquely radial (flame-shaped); rays very fine, barely visible with a hand lens. 17
- 16 Late-wood pores solitary or in radial rows of 2–3, in nestlike groups or in interrupted tangential bands; rays plainly visible with the naked eye or a hand lens (x) 18
- 17 Early-wood pores in 1 somewhat interrupted row.
Giant chinkapin—*Castanopsis chrysophylla* (Dougl.) A.DC. Fig. 11-94. Desc. p. 560.
- 17 Early-wood pores very large, in several rows.
American chestnut—*Castanea dentata* (Marsh.) Borkh. Fig. 11-93. Desc. p. 559.

- 18 Pores in the late wood solitary or in radial rows of 2–3, frequently united laterally by parenchyma toward the outer margin of the ring. 19
- 18 Pores in the outer late wood in nestlike groups, in short radial rows, and solitary; they may be embedded in interrupted, tangential parenchyma bands 21
- 19 Freshly cut surface with aromatic odor; sapwood light yellow; heartwood dull grayish brown to orange-brown or dark brown.
Sassafras—*Sassafras albidum* (Nutt.) Nees. Fig. 11-136. Desc. p. 587.
- 19 Freshly cut surfaces without aromatic odor; sapwood nearly white to light brown; heartwood light brown to pale yellow streaked with brown, lustrous, or grayish brown, dull 20
- 20 Wood lustrous, strong; sapwood nearly white, wide; heartwood light brown to pale yellow streaked with brown.
White ash—*Fraxinus* spp. Figs. 11-102 and 11-103. Desc. p. 623.
- 20 Wood dull, weak; sapwood whitish to light brown, narrow; heartwood grayish brown to brown.
Black ash—*Fraxinus nigra* Marsh. Fig. 11-104. Desc. p. 625.
- 21 Heartwood light red to reddish brown. 22
- 21 Heartwood grayish brown or orange-yellow to golden brown . . 23
- 22 Pores in the outer late wood solitary, in short radial rows or in small groups, embedded in short tangential bands of parenchyma; rays conspicuous to the naked eye (x); reddish gum deposits in the pores are frequent in the heartwood.
Honeylocust—*Gleditsia triacanthos* L. Fig. 11-105. Desc. p. 596.
- 22 Pores in the outer late wood in nestlike groups which occasionally coalesce laterally; short bands of parenchyma not evident; rays not conspicuous to the naked eye; gum deposits in the pores infrequent in the heartwood.
Kentucky coffeetree—*Gymnocladus dioica* (L.) K. Koch. Fig. 11-106. Desc. p. 594.
- 23 Heartwood grayish brown to brown, with a faint odor resembling that of kerosene; rays relatively inconspicuous to the naked eye; the ray fleck on the radial surface not pronounced.
Catalpa—*Catalpa* spp. Fig. 11-95. Desc. p. 627.
- 23 Heartwood orange-yellow to golden brown, turning dull dark brown on exposure, without characteristic odor; rays conspicuous to the naked eye (x), forming a pronounced fleck on the radial surface.
Red mulberry—*Morus rubra* L. Fig. 11-116. Desc. p. 578.
- 24 Late wood with tangential bands of parenchyma evident with or without a lens, appearing as continuous or broken lines or punctate. 25
- 24 Late-wood parenchyma not readily evident 29

- 25 Ripple marks evident on tangential surface; pores appear thick-walled with hand lens; sapwood creamy white to yellowish brown; heartwood seldom evident, narrow, black-streaked or with a gray tinge.
Common persimmon—*Diospyros virginiana* L. Fig. 11-99. Desc. p. 621.
- 25 Ripple marks not evident on tangential face; heartwood shades of brown 26
- 26 Parenchyma in fine, continuous, concentric lines in the late-wood zone and in the early wood; sapwood whitish to pale brown; heartwood brown to rich reddish brown and may be streaked.
Pecan hickory—*Carya* spp. Fig. 11-90. Desc. p. 540.
- 26 Parenchyma in late wood evident with hand lens as broken or continuous lines or closely and evenly punctate (x), or in lines at the margin of the growth ring; heartwood dull brown to gray-brown or rich chocolate to purplish brown 27
- 27 Wood hard and heavy; heartwood dull brown to gray-brown; rays of 2 widths, broad rays conspicuous and separated by several narrow rays (t).
Live oak—*Quercus virginiana* Mill. Fig. 11-132. Desc. p. 564.
- 27 Wood moderately hard to soft, easily dented; rays inconspicuous and of uniform width (t); heartwood rich chocolate or purplish brown, dull, or light chestnut brown, lustrous 28
- 28 Heartwood rich chocolate or purplish brown, dull, with characteristic odor; wood relatively hard, heavy.
Black walnut—*Juglans nigra* L. Fig. 11-109. Desc. p. 538.
- 28 Heartwood light chestnut-brown, lustrous, without characteristic odor; wood soft.
Butternut—*Juglans cinerea* L. Fig. 11-108. Desc. p. 537.
- 29 Rays plainly visible to the naked eye on the cross section and form a conspicuous, low ray fleck on the radial surface; heartwood light to dark red-brown.
Black cherry—*Prunus serotina* Ehrh. Fig. 11-126. Desc. p. 592.
- 29 Rays indistinct without a hand lens; heartwood shades of chocolate, chestnut, light grayish or pinkish brown, or pale creamy white 30
- 30 Heartwood rich chocolate or purplish brown, dull, or light chestnut-brown, lustrous; rays distinct with a hand lens . . . 31
- 30 Heartwood grayish, pale reddish brown, or pale creamy white; rays barely visible with a hand lens. 32
- 31 Heartwood rich chocolate or purplish brown, dull, with a characteristic odor; relatively hard and heavy.
Black walnut—*Juglans nigra* L. Fig. 11-109. Desc. p. 538.
- 31 Heartwood light chestnut brown, lustrous, without characteristic odor, soft, relatively light.
Butternut—*Juglans cinerea* L. Fig. 11-108. Desc. p. 537.

- 32

Heartwood grayish or pale pinkish brown; pores gradually decreasing in size from early to late wood, the largest in early wood barely visible to the naked eye.
Cottonwood—*Populus* spp. Fig. 11-123. Desc. p. 543.
Willow—*Salix* spp. Fig. 11-135. Desc. p. 547.
- 32

Heartwood pale creamy white to light grayish brown; pores small, not visible without a lens, decreasing in size from early to late wood.
Aspen—*Populus* spp. Figs. 11-124 and 11-125. Desc. p. 546.
- 33

Rays wholly or in part broad (x), the broadest fully twice as wide as the largest pores (Figs. 11-100 and 11-121) 34
- 33

Rays narrow (x), the broadest less than twice the width of the largest pores (Figs. 11-79, 11-88, 11-111) 38
- 34

Rays nearly uniform in width, close, appearing to the naked eye on the tangential surface as closely packed, broken lines (Fig. 11-122); grain generally interlocked.
Sycamore—*Platanus occidentalis* L. Fig. 11-121. Desc. p. 591.
- 34

Rays obviously of 2 widths, broad and very narrow: broad rays separated by several of the narrow type, conspicuous (x; Fig. 11-100), or broad rays relatively inconspicuous because of color, sporadic and widely spaced (Fig. 11-82) 35
- 35

Broad rays sporadic, rather inconspicuous because of color (x), up to $\frac{4}{5}$ plus in in height (t) along the grain (Fig. 11-83); pores numerous, quite evenly spaced except in the outer late wood where they may be crowded; wood light and soft.
Red alder—*Alnus rubra* Bong. Fig. 11-82. Desc. p. 555.
- 35

Broad rays common, conspicuous; wood hard and heavy 36
- 36

Pores irregularly spaced, arranged in radial fan-shaped or streamlike groups extending across the rings; broad rays frequently extending 1 in or more along the grain 37
- 36

Pores quite evenly spaced except in the outer late wood where they may be crowded, but not in radial or fan-shaped groups; rays plainly visible to the naked eye on the tangential surface as short, staggered lines (Fig. 11-101).
American beech—*Fagus grandifolia* Ehrh. Fig. 11-100. Desc. p. 557.
- 37

Sapwood reddish brown; heartwood brown tinged with red; banded parenchyma plainly visible with a hand lens, in ragged tangential lines (x).
Tanoak—*Lithocarpus densiflorus* (Hook. & Arn.) Rehd. Fig. 11-112. Desc. p. 562.

- 37 Sapwood whitish to grayish brown; heartwood dull brown to gray-brown; banded parenchyma barely visible with a hand lens, appearing closely and evenly punctate (x).
Live oak—*Quercus virginiana* Mill. Fig. 11-132. Desc. p. 564.
- 38 Wood ivory-white, creamy to grayish white, grayish brown, or shades of yellow or green. 39
- 38 Wood light to dark brown, pinkish or reddish brown. 49
- 39 Rays distinct to the naked eye (x). 40
- 39 Rays not distinct to the naked eye (x). 44
- 40 Wood shades of yellow or green or grayish green to greenish brown, or grayish brown. 41
- 40 Wood ivory-white, creamy, or creamy brown. 43
- 41 Heartwood grayish brown, frequently with darker streaks of pigment figure, aromatic on the freshly cut surface; pores encircled by a whitish sheath of parenchyma.
California laurel—*Umbellularia californica* (Hook. & Arn.) Nutt. Fig. 11-141. Desc. p. 586.
- 41 Heartwood with shades of yellow, yellow-brown, greenish brown to brownish gray; not aromatic. 42
- 42 Heartwood variable in color, ranging from clear yellow to dark yellowish green, green, or greenish brown to greenish black (in magnolia); growth rings delineated by a whitish line of marginal parenchyma; rays normally spaced, distinct with a naked eye.
Yellow-poplar—*Liriodendron tulipifera* L. Fig. 11-111. Desc. p. 584.
Magnolia—*Magnolia* spp. Figs. 11-114 and 11-115. Desc. p. 581.
- 42 Heartwood greenish or brownish gray; growth rings not delineated by marginal parenchyma (indistinct); rays very close together, seemingly occupying half the area on the cross section (x, impression gained by casual observation).
Black tupelo, blackgum—*Nyssa* spp. Figs. 11-117 and 11-118. Desc. p. 613.
- 43 Wood ivory-white, frequently with bluish cast; hard; pores small, grouped in radial strings (x); rays distinct with a naked eye.
American holly—*Ilex opaca* Ait. Fig. 11-107. Desc. p. 601.
- 43 Wood creamy white to pale creamy brown; soft, easily dented with thumbnail; appearing lacelike under a hand lens (x); rays quite uniformly spaced and forming a rectangular grid with light-colored growth rings.
Basswood—*Tilia* spp. Fig. 11-137. Desc. p. 611.
- 44 Rays plainly visible with a hand lens (x). 45
- 44 Rays barely visible or indistinct with a hand lens (x). 47
- 45 Wood creamy white to pale creamy brown, soft and light, often appearing lacelike under the lens (x).
Basswood—*Tilia* spp. Fig. 11-137. Desc. p. 611.
- 45 Heartwood greenish or brownish gray or grayish brown, moder-

- ately heavy to heavy, moderately hard, not appearing lacelike under a hand lens (x). 46
- 46 Wood aromatic on the freshly cut surface; heartwood grayish brown, frequently with darker streaks of pigment figure; pores encircled by a whitish sheath of parenchyma; rays normally spaced.
California-laurel—*Umbellularia californica* (Hook. & Arn.) Nutt. Fig. 11-141. Desc. p. 586.
- 46 Wood not aromatic; heartwood greenish or brownish gray; pores not encircled by a whitish sheath of parenchyma; rays very close together, seemingly occupying half the area on the cross section (x, impression gained by casual observation).
Black tupelo, blackgum—*Nyssa* spp. Figs. 11-117 and 11-118. Desc. p. 613.
- 47 Pores minute and mostly constant in size, evenly distributed over the growth ring; heartwood creamy white to pale yellowish white and often with grayish streaks of stain; ripple marks sometimes evident.
Buckeye—*Aesculus* spp. Fig. 11-81. Desc. p. 608.
- 47 Pores small, decreasing gradually in size across the growth ring. 48
- 48 Heartwood uniformly grayish or grayish brown; the largest pores in early wood barely visible to the naked eye.
Cottonwood—*Populus* spp. Fig. 11-123. Desc. p. 543.
Willow—*Salix* spp. Fig. 11-135. Desc. p. 547.
- 48 Heartwood pale creamy white to light grayish brown; largest pores not visible to naked eye.
Aspen—*Populus* spp. Figs. 11-124 and 11-125. Desc. p. 546.
- 49 Rays distinct to the naked eye (x) 50
- 49 Rays not distinct to the naked eye (x) 58
- 50 Rays variable in width, the broadest separated by several narrow rays which are scarcely visible with the naked eye . 51
- 50 Rays nearly uniform in width (Fig. 11-126) 52
- 51 Sapwood whitish with a reddish tinge, narrow; heartwood uniformly light brown to reddish brown; outer margin of the growth ring usually sharply marked by a narrow darker line of denser fibrous tissue; wider rings usually quite sharply delineated against the background of pores and fibrous tissue.
Hard maple—*Acer* spp. Fig. 11-79. Desc. p. 603.
- 51 Sapwood carneous to light pinkish brown, wide; heartwood, when present, dark brown, frequently variegated; outer margin of the growth ring and wider rays are not sharply delineated against the background of pores and fibrous tissue.
Dogwood—*Cornus* spp. Fig. 11-98. Desc. p. 616.
- 52 Rays very close, seemingly occupying half the area of the transverse surface (x, impression gained by casual examination); sapwood pinkish; heartwood carneous gray to varying

shades of reddish brown, frequently with darker shades of reddish brown pigment figure.

Sweetgum—*Liquidambar styraciflua* L. Fig. 11-110. Desc. p. 589.

- 52 Rays normally spaced, not seemingly occupying half the area on the transverse surface of the wood. 53

- 53 Wood aromatic on the freshly cut surface; heartwood light brown, frequently with darker streaks of pigment figure; pores encircled by a whitish sheath of parenchyma.

California-laurel—*Umbellularia californica* (Hook. & Arn.) Nutt. Fig. 11-141. Desc. p. 586.

- 53 Wood not aromatic; pores not encircled with parenchyma 54

- 54 Pores in the early wood in a distinct uniseriate row; heartwood distinctly light to dark red-brown.

Black cherry—*Prunus serotina* Ehrh. Fig. 11-126. Desc. p. 592.

- 54 Pores in the early wood not in a distinct uniseriate row . . . 55

- 55 Wood soft, easily dented with thumbnail, light brown, sometimes with a pinkish cast; rays uniformly spaced and of the same color as the background, forming a rectangular grid with the light-colored growth increments (x).

Basswood—*Tilia* spp. Fig. 11-137. Desc. p. 611.

- 55 Wood moderately hard to hard, not easily dented with thumbnail 56

- 56 Pores appearing as white dots to the naked eye; the larger pores obviously wider than the rays (x); rays inconspicuous (t).

Birch—*Betula* spp. Figs. 11-85 to 11-88 inc. Desc. p. 552.

- 56 Pores indistinct without a hand lens; largest pores about equal to the width of the broadest rays (x); rays appearing on tangential surface as short, crowded lines with the naked eye 57

- 57 Sapwood white; heartwood pale brown, sometimes with grayish or greenish cast; pith flecks fairly common.

Soft maple—*Acer* spp. Fig. 11-77. Desc. p. 607.

- 57 Sapwood reddish white; heartwood pinkish brown; pith flecks rare.

Bigleaf maple—*Acer macrophyllum* Pursh. Fig. 11-76. Desc. p. 605.

- 58 Rays barely visible with a hand lens 59

- 58 Rays plainly visible with a hand lens 61

- 59 Pores very small except for a larger uniseriate row in the first part of the early wood, elsewhere clustered or banded with the pore bands usually alternating with bands of dense fibrous tissue; heavy and hard; sapwood frequently pinkish; heartwood light reddish brown.

Pacific madrone—*Arbutus menziesii* Pursh. Fig. 11-84. Desc. p. 620.

- 59 Growth boundaries marked by a light line of parenchyma or fibers; pores or pore groups uniformly distributed 60
- 60 Wood whitish, aging to flesh-colored or light brown with a reddish tinge, frequently stained with gray oxidative stain; rays very close together, seemingly occupying half the area (x, impression gained by casual examination).
Red alder—*Alnus rubra* Bong. Fig. 11-82. Desc. p. 555.
- 60 Heartwood light brown to pale reddish brown; rays normally spaced.
Cottonwood—*Populus* spp. Fig. 11-123. Desc. p. 543.
Willow—*Salix* spp. Fig. 11-135. Desc. p. 547.
- 61 Wood aromatic on the freshly cut surface; heartwood light brown, frequently with darker streaks of pigment figure; pores encircled by a whitish sheath of parenchyma.
California-laurel—*Umbellularia californica* (Hook. & Arn.) Nutt. Fig. 11-141. Desc. p. 586.
- 61 Wood not aromatic; heartwood light brown, brown or reddish brown; pores not encircled by white sheaths of parenchyma . . . 62
- 62 Rays very close together, seemingly occupying half the area on the transverse surface (x, impression gained by casual examination); sapwood pinkish; heartwood carneous gray to varying shades of brown, frequently with darker streaks of pigment figure.
Sweetgum—*Liquidambar styraciflua* L. Fig. 11-110. Desc. p. 589.
- 62 Rays normally spaced, not seemingly occupying half the area on the transverse surface 63
- 63 Late wood figured with wavy, concentric bands of pores which are mostly continuous and separated by bands of mechanical tissue.
Hard elm—*Ulmus* spp. Fig. 11-140. Desc. p. 575.
- 63 Late wood not figured with wavy, concentric bands of pores . . . 64
- 64 Wood soft, light brown, sometimes with a pinkish cast; often appearing lacelike under a lens (x); rays uniformly spaced, of the same color as background (x); ray flecks (r) high, rather distant.
Basswood—*Tilia* spp. Fig. 11-137. Desc. p. 611.
- 64 Wood hard, light to dark brown or reddish brown, not lacelike under a lens (x). 65
- 65 Pores minute to very small, with a larger, uniseriate row in the first part of the early wood, elsewhere pores clustered or banded.
Pacific madrone—*Arbutus menziesii* Pursh. Fig. 11-84. Desc. p. 620.
- 65 Pores small to medium-sized, uniformly distributed within the ring 66
- 66 Pores appearing as white dots to the naked eye; the larger pores obviously wider than the rays (x); rays inconspicuous (t).
Birch—*Betula* spp. Figs. 11-85 to 11-88 inc. Desc. p. 552.

- 66 Pores indistinct without a hand lens; largest pores about equal to the width of the broadest rays (x); rays appearing on tangential surface as short, crowded lines with the naked eye 67
- 67 Sapwood white; heartwood pale brown, sometimes with grayish or greenish cast; pith flecks fairly common.
Soft maple—*Acer* spp. Figs. 11-77 and 11-78. Desc. p. 607.
- 67 Sapwood reddish white; heartwood pinkish brown; pith flecks rare.
Bigleaf maple—*Acer macrophyllum* Pursh. Fig. 11-76. Desc. p. 605.

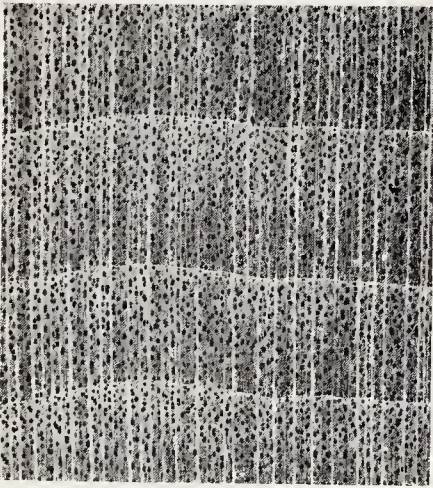


Figure 11-76 *Acer macrophyllum* Pursh. (x—5x)

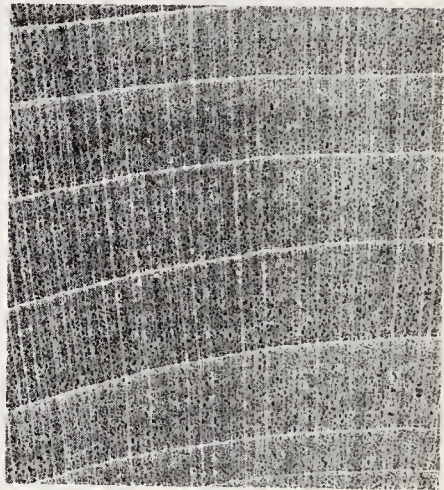


Figure 11-77 *Acer rubrum* L. (x—5x)

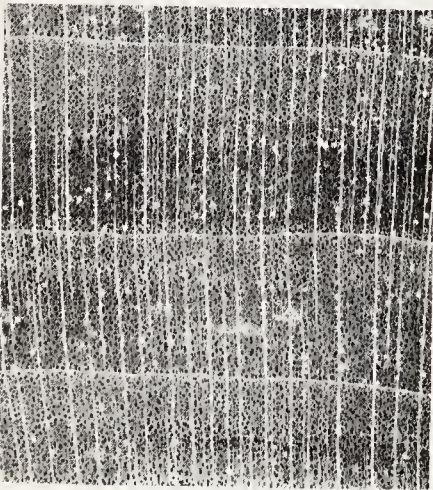


Figure 11-78 *Acer saccharinum* L. (x—5x)



Figure 11-79 *Acer saccharum* Marsh. (x—5x)

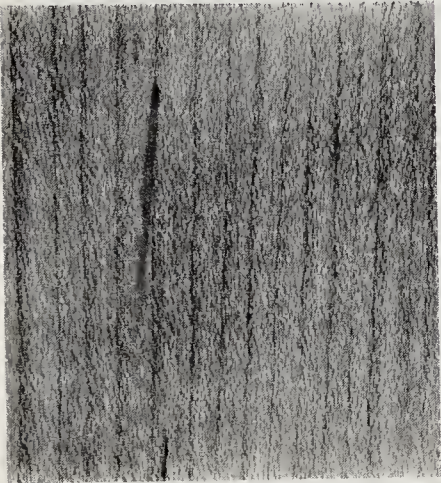


Figure 11-80 *Acer saccharum* Marsh.
(t—natural size)

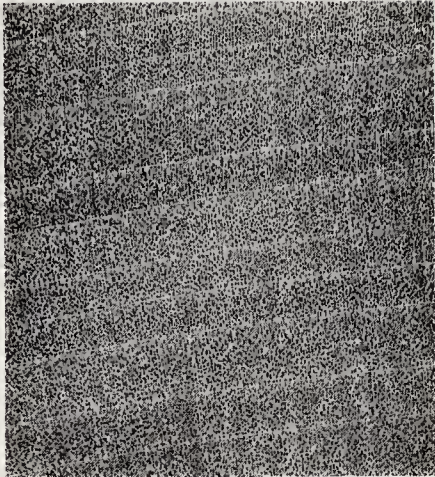


Figure 11-81 *Aesculus octandra*
Marsh. (x—5×)

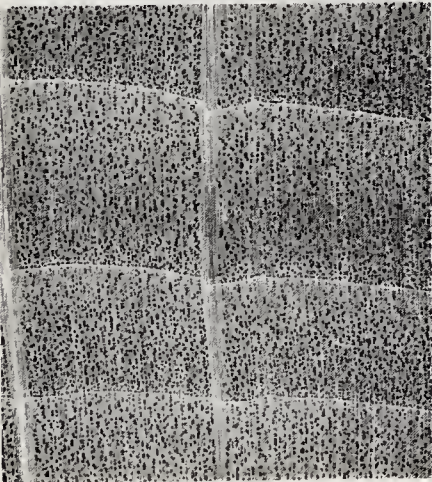


Figure 11-82 *Alnus rubra* Bong.
(x—5×)

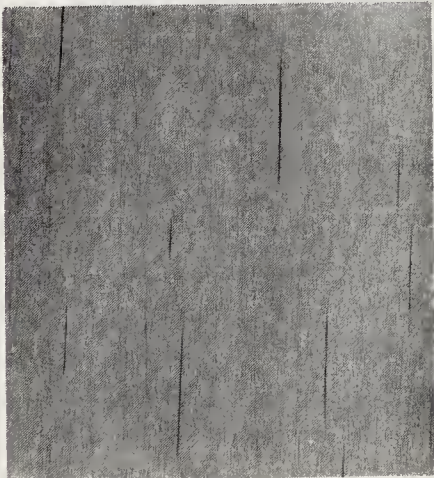


Figure 11-83 *Alnus rubra* Bong.
(t—natural size)

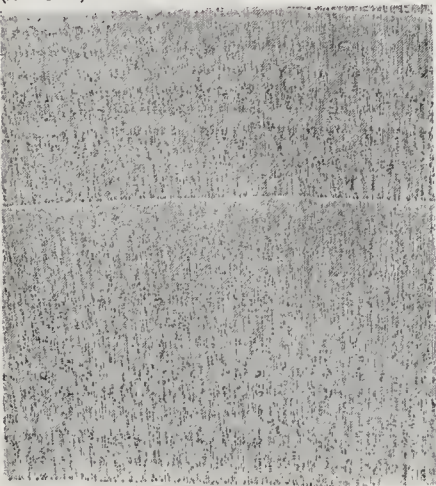


Figure 11-84 *Arbutus menziesii*
Pursh (x—5×)

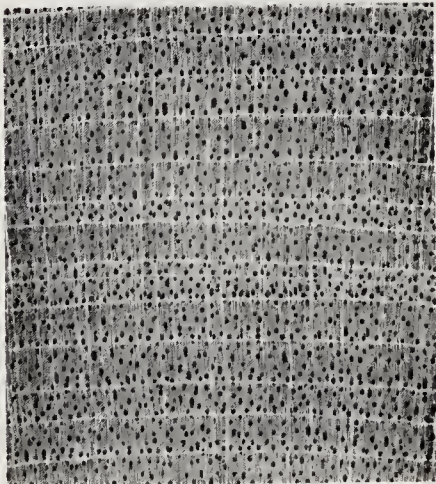


Figure 11-85 *Betula alleghaniensis*
Britton. (x—5×)

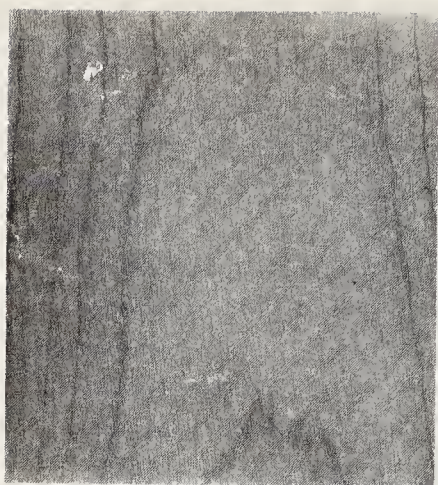


Figure 11-86 *Betula alleghaniensis* Britton. (t—natural size)

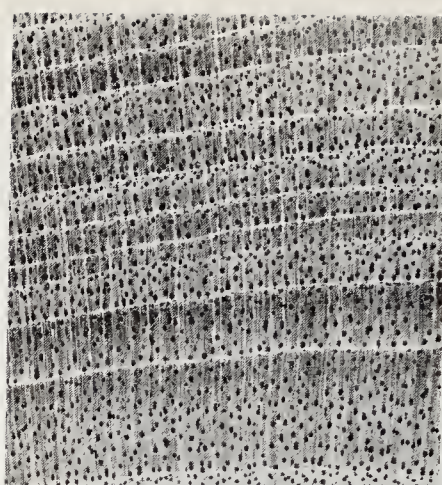


Figure 11-87 *Betula lenta* L. (x—5x)

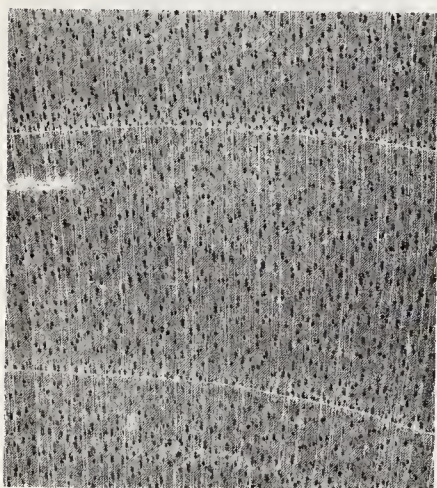


Figure 11-88 *Betula papyrifera* Marsh. (x—5x)

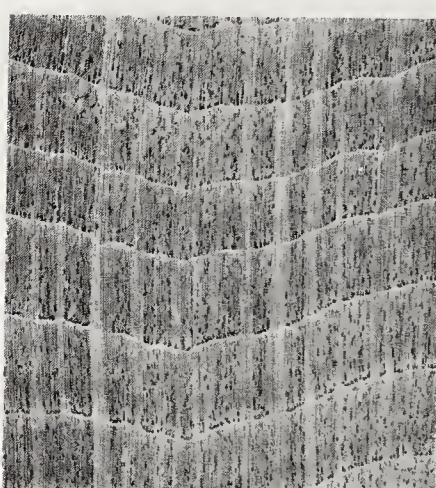


Figure 11-89 *Carpinus caroliniana* Walt. (x—5x)

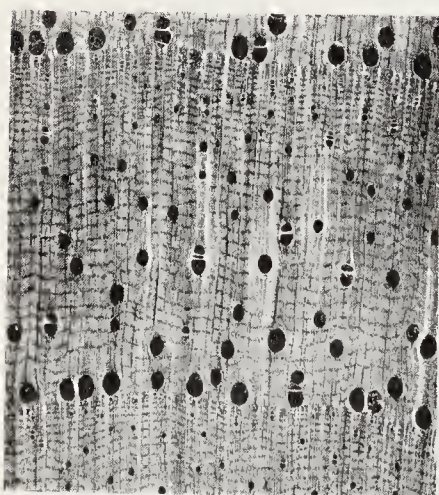


Figure 11-90 *Carya cordiformis* (Wangenh.) K. Koch. (x—5x)

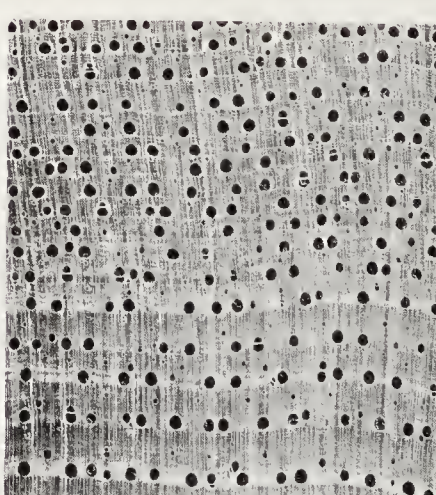


Figure 11-91 *Carya glabra* (Mill.) Sweet. (x—5x)

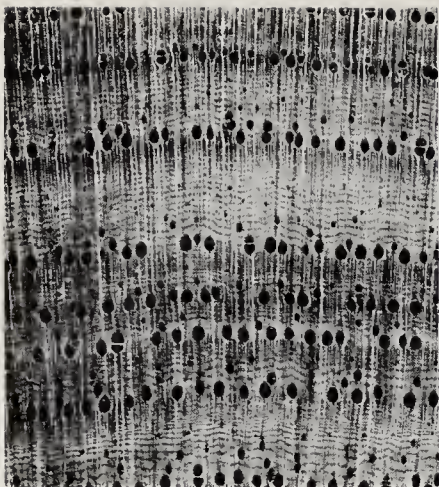


Figure 11-92 *Carya ovata* (Mill.) K. Koch. (x—5×)

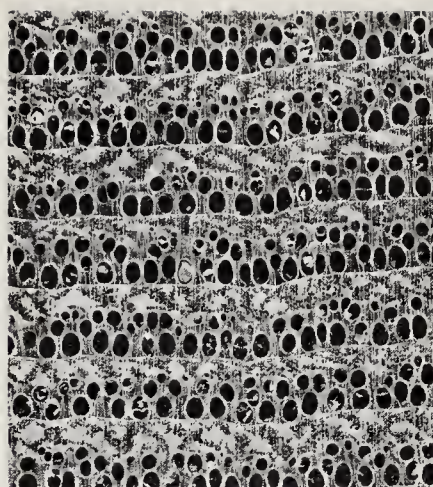


Figure 11-93 *Castanea dentata* (Marsh.) Borkh. (x—5×)

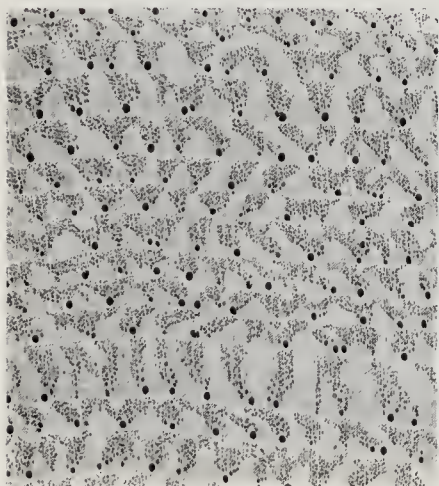


Figure 11-94 *Castanopsis chrysophylla* (Dougl.) A. DC. (x—5×)

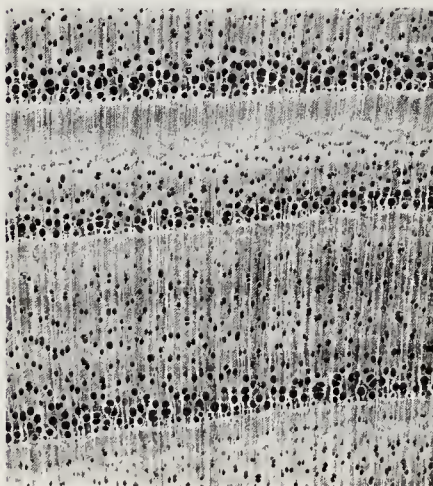


Figure 11-95 *Catalpa speciosa* Warder. ex Engelm. (x—5×)

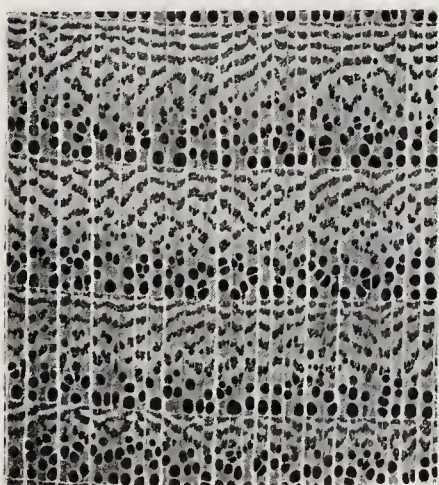


Figure 11-96 *Celtis occidentalis* L. (x—5×)

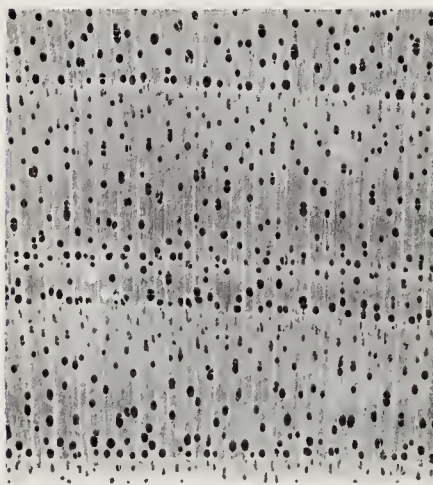


Figure 11-97 *Cladrastris kentukea* (Dum.-Cours.) Rudd. (x—5×)



Figure 11-98 *Cornus florida* L.
(x—5×)

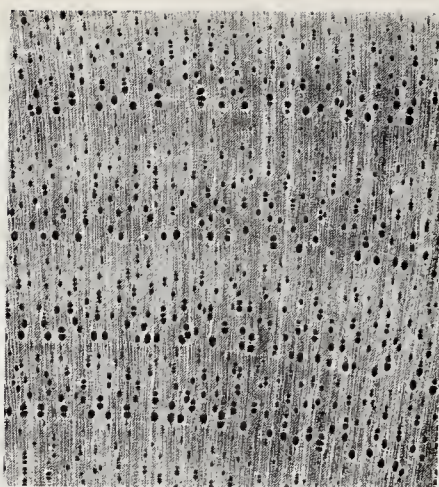


Figure 11-99 *Diospyros virginiana* L.
(x—5×)

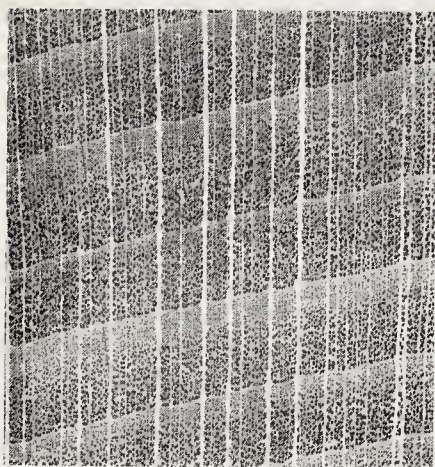


Figure 11-100 *Fagus grandifolia*
Ehrh. (x—5×)



Figure 11-101 *Fagus grandifolia*
Ehrh. (t—natural size)

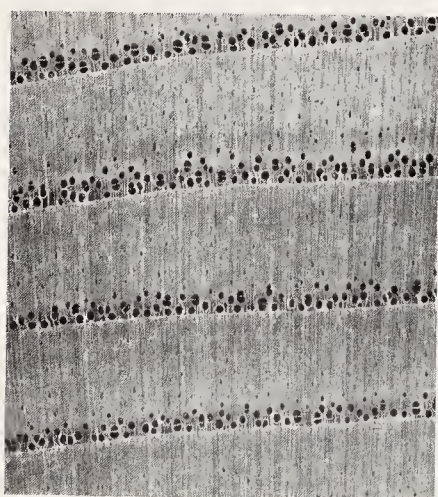


Figure 11-102 *Fraxinus americana* L.
(x—5×)

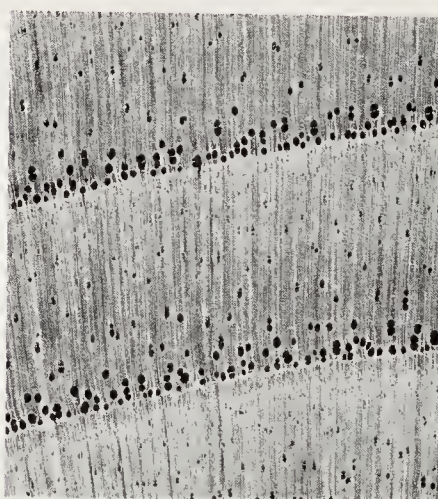


Figure 11-103 *Fraxinus latifolia*
Benth. (x—5×)

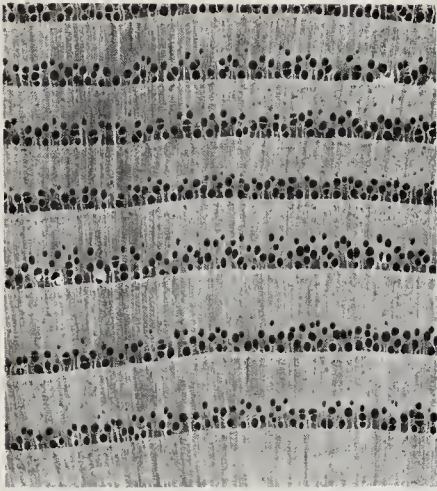


Figure 11-104 *Fraxinus nigra* Marsh.
(x—5×)

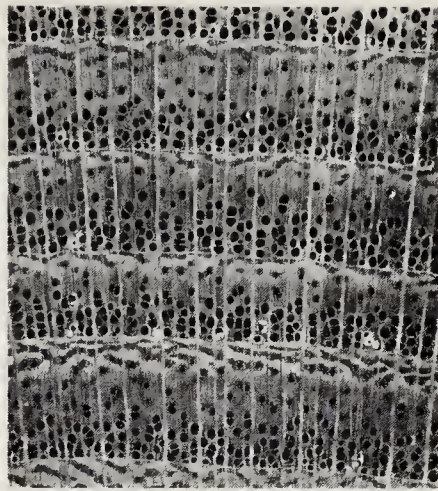


Figure 11-105 *Gleditsia triacanthos*
L. (x—5×)

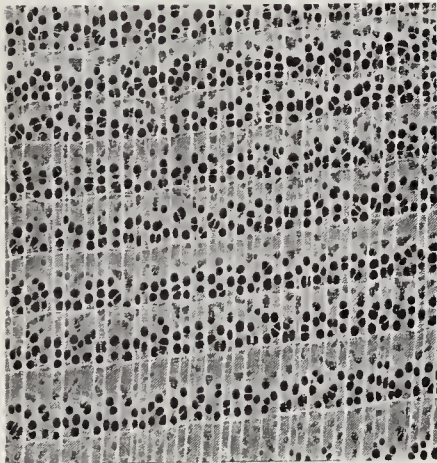


Figure 11-106 *Gymnocladus dioica*
(L.) K. Koch. (x—5×)

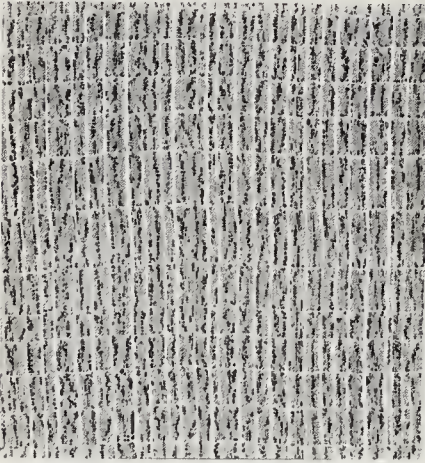


Figure 11-107 *Ilex opaca* Ait.
(x—5×)

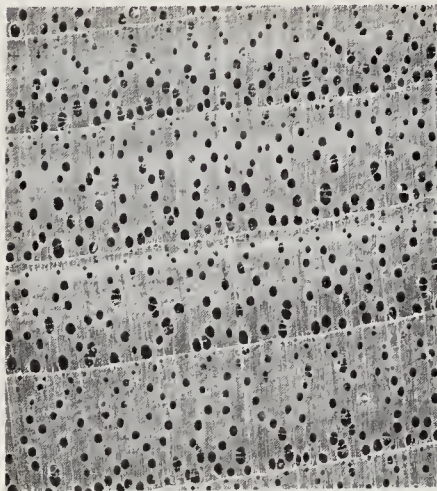


Figure 11-108 *Juglans cinerea* L.
(x—5×)

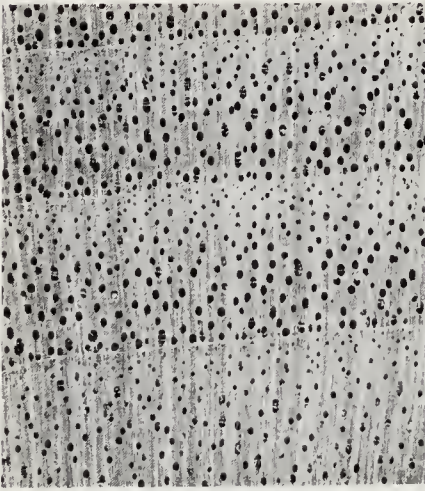


Figure 11-109 *Juglans nigra* L.
(x—5×)

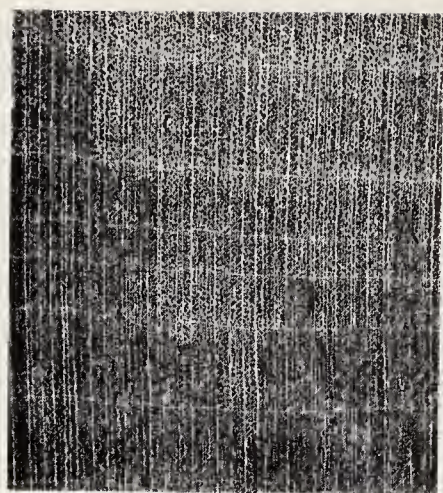


Figure 11-110 *Liquidambar styraciflua* L. (x—5×)

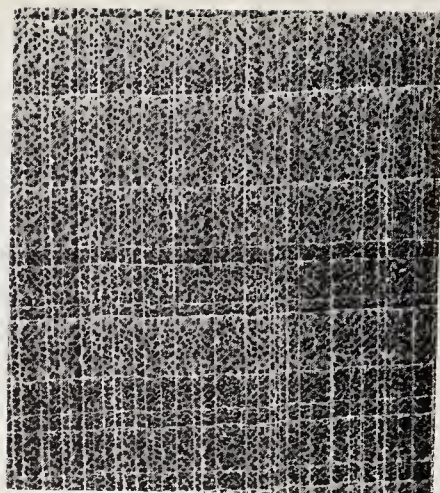


Figure 11-111 *Liriodendron tulipifera* L. (x—5×)

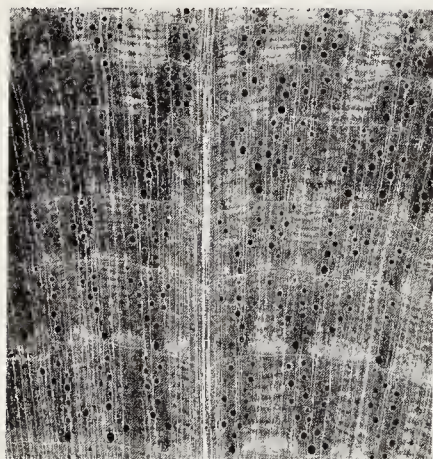


Figure 11-112 *Lithocarpus densiflorus* (Hook. & Arn.) Rehd. (x—5×)

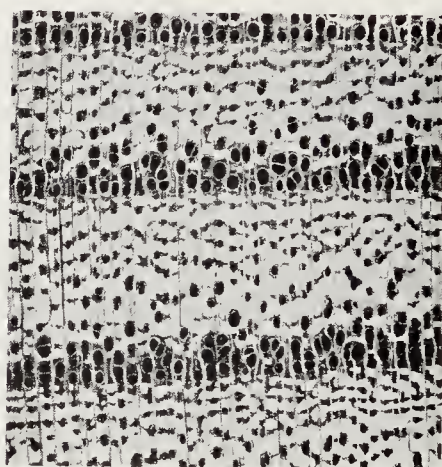


Figure 11-113 *Maclura pomifera* (Raf.) Schneid. (x—5×)

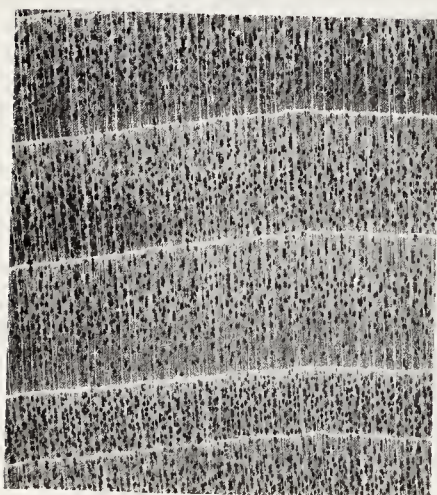


Figure 11-114 *Magnolia acuminata* L. (x—5×)

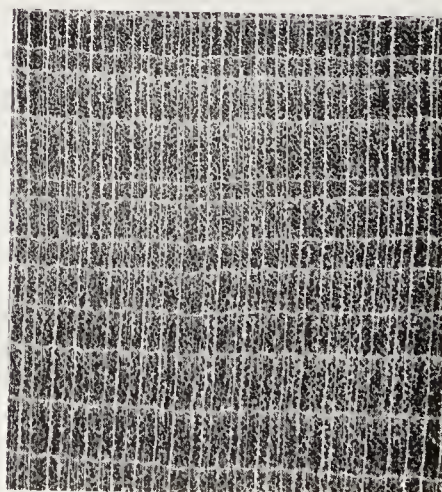


Figure 11-115 *Magnolia grandiflora* L. (x—5×)

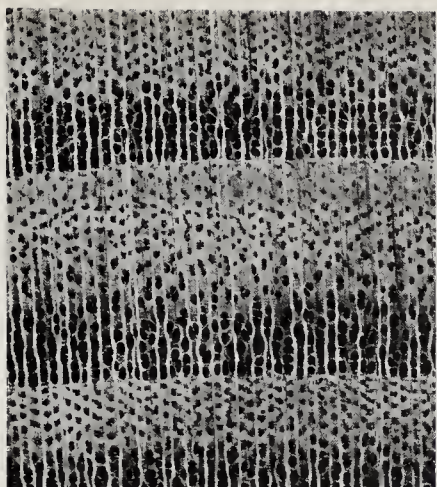


Figure 11-116 *Morus rubra* L.
(x—5×)



Figure 11-117 *Nyssa aquatica* L.
(x—5×)

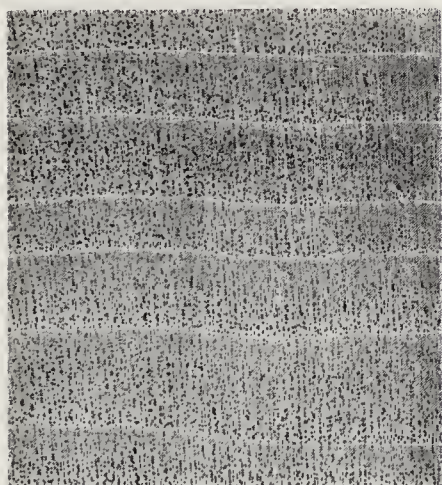


Figure 11-118 *Nyssa sylvatica*
Marsh. (x—5×)

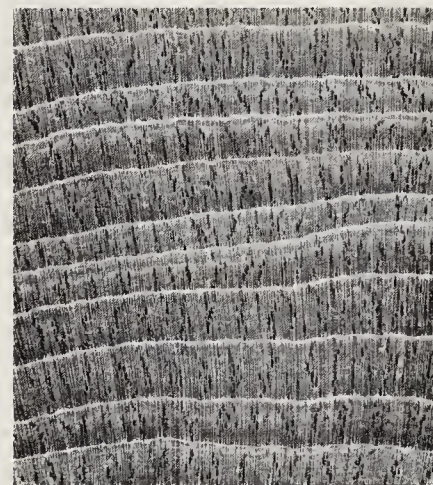


Figure 11-119 *Ostrya virginiana*
(Mill.) K. Koch. (x—5×)

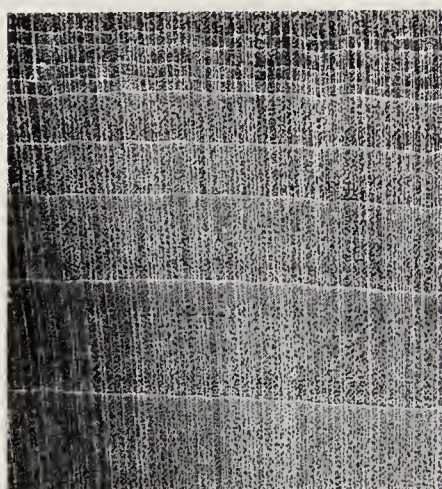


Figure 11-120 *Oxydendrum*
arboreum (L.) DC. (x—5×)

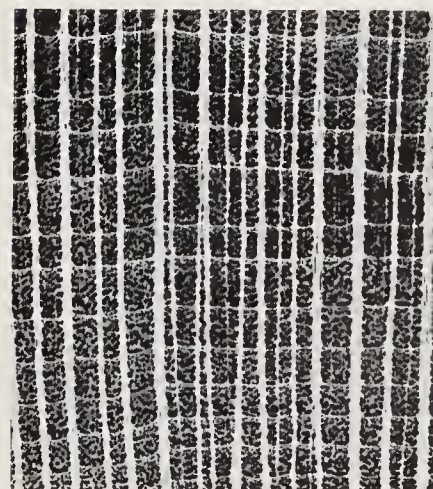


Figure 11-121 *Platanus occidentalis*
L. (x—5×)



Figure 11-122 *Platanus occidentalis* L. (t—natural size)

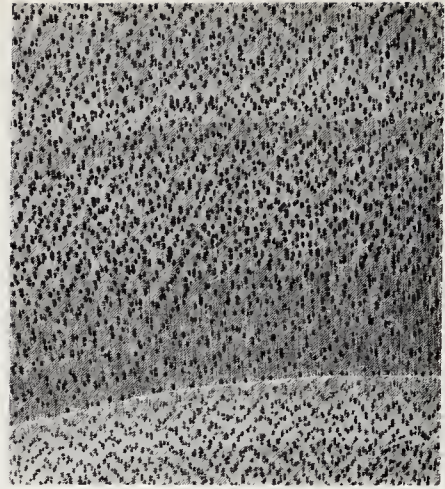


Figure 11-123 *Populus deltoides* Bartr. ex. Marsh. (x—5x)

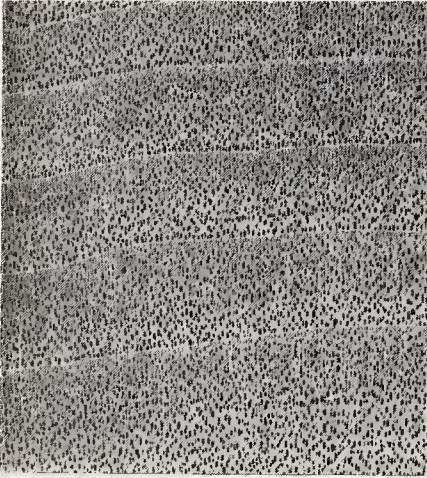


Figure 11-124 *Populus grandidentata* Michx. (x—5x)

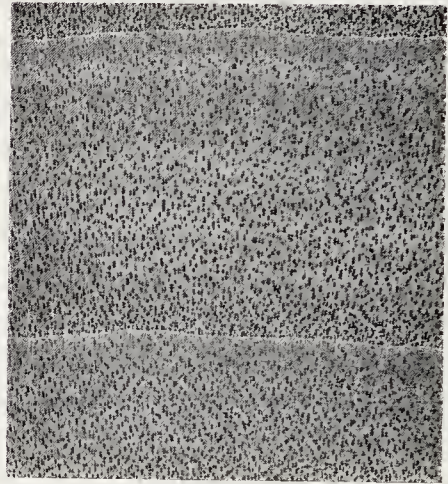


Figure 11-125 *Populus tremuloides* Michx. (x—5x)

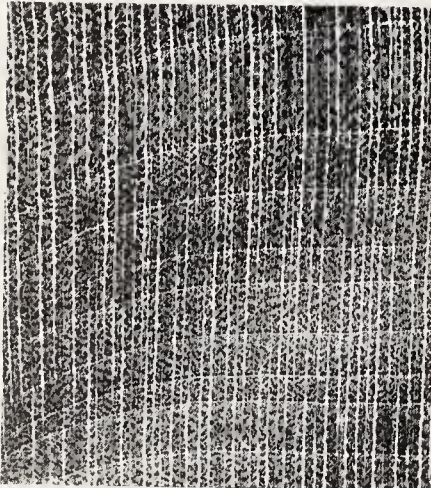


Figure 11-126 *Prunus serotina* Ehrh. (x—5x)



Figure 11-127 *Quercus alba* L. (t—natural size)

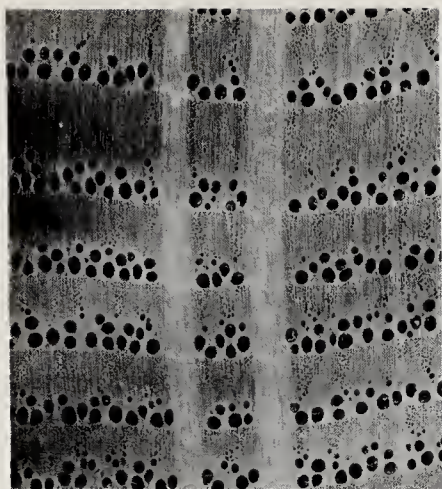


Figure 11-128 *Quercus bicolor* Willd.
(x—5×)

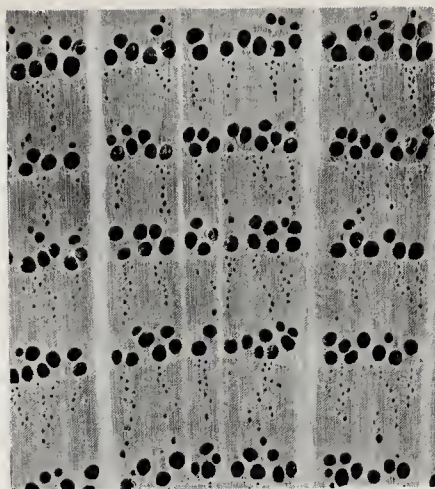


Figure 11-129 *Quercus coccinea*
Muenchh. (x—5×)

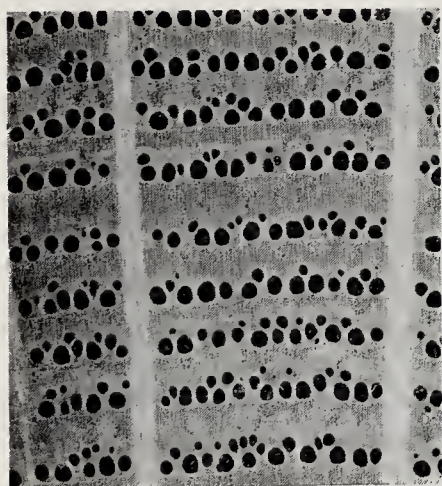


Figure 11-130 *Quercus stellata*
Wangenh. (x—5×)

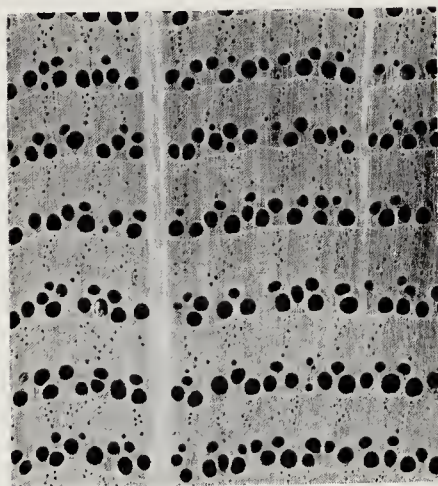


Figure 11-131 *Quercus velutina* Lam.
(x—5×)

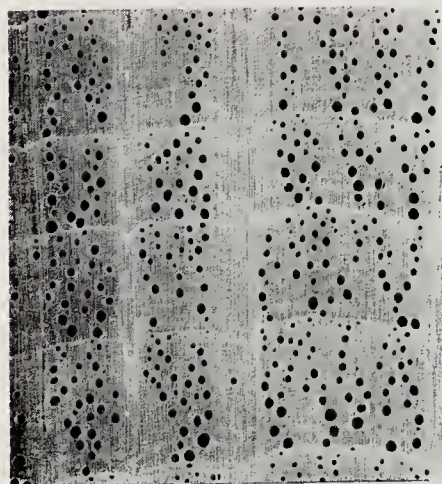


Figure 11-132 *Quercus virginiana*
Mill. (x—5×)

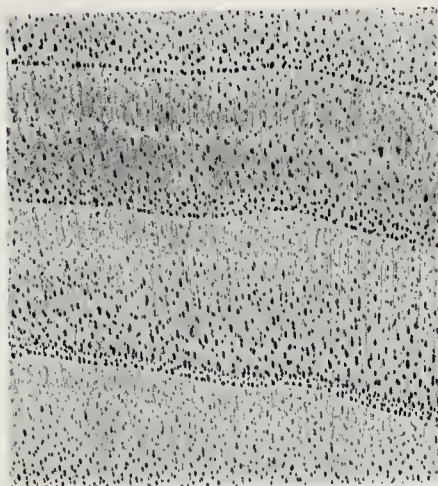


Figure 11-133 *Rhamnus purshiana*
DC. (x—5×)



Figure 11-134 *Robinia pseudoacacia* L. (x—5×)

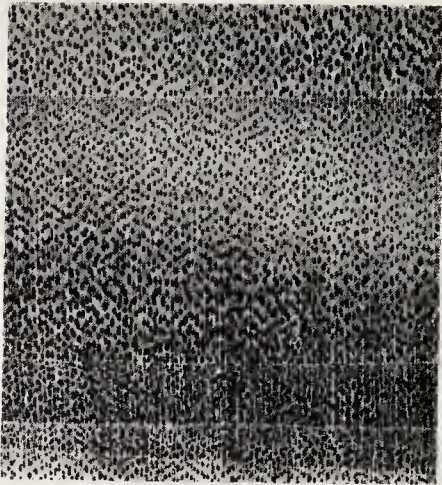


Figure 11-135 *Salix nigra* Marsh. (x—5×)

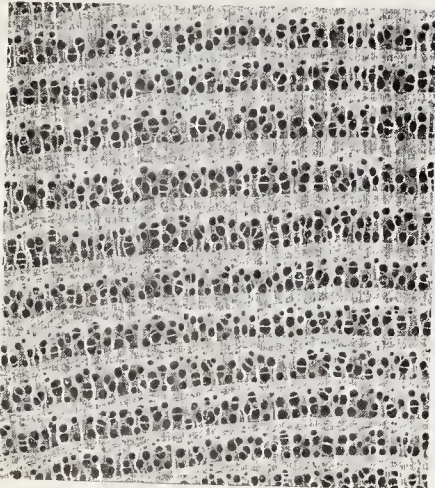


Figure 11-136 *Sassafras albidum* (Nutt.) Nees. (x—5×)

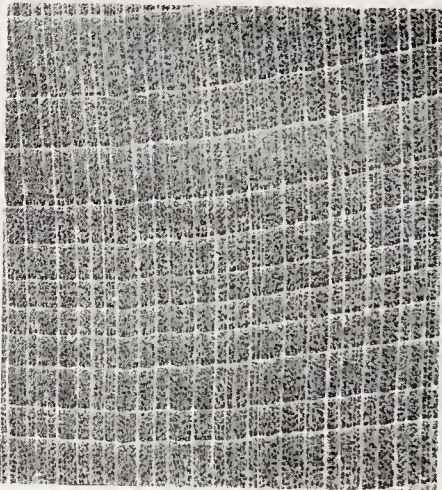


Figure 11-137 *Tilia americana* L. (x—5×)

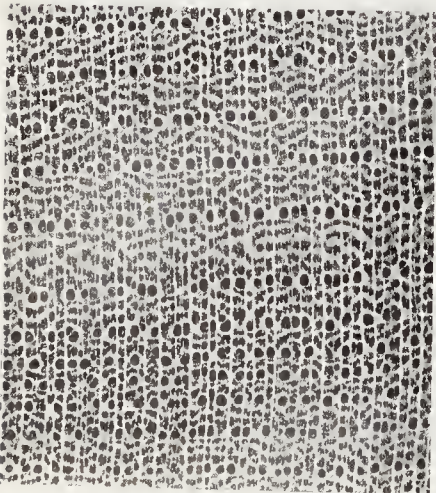


Figure 11-138 *Ulmus americana* L. (x—5×)

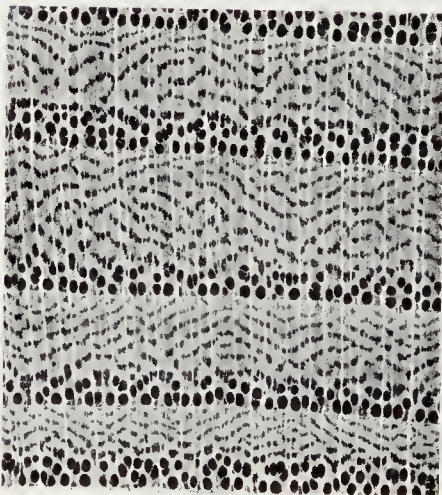


Figure 11-139 *Ulmus rubra* Mühl. (x—5×)

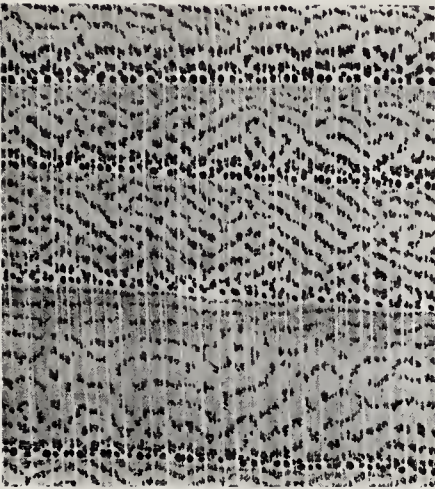


Figure 11-140 *Ulmus thomasi* Sarg.
(x—5×)

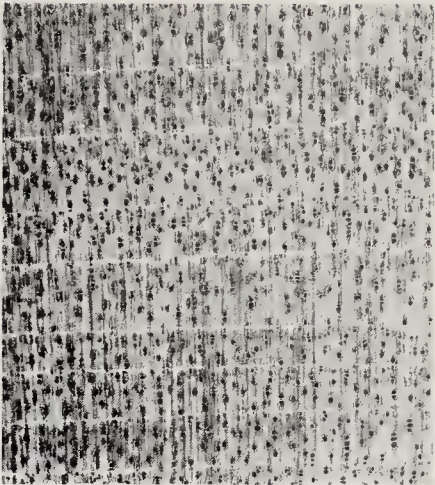


Figure 11-141 *Umbellularia californica* (Hook. & Arn.) Nutt.
(x—5×)

V KEY TO HARDWOODS—MINUTE FEATURES*

- 1

Early-wood vessels obviously larger than those in the late wood (x); wood ring-porous

2
- 1

Early-wood vessels not larger or but slightly larger than those in the late wood (x); wood diffuse-porous.

34
- 2

Broad rays of the oak type present.

3
- 2

Broad rays of the oak type absent

4
- 3

Late-wood vessels not numerous, thick-walled, rounded (thicker-walled than the surrounding cells); tyloses sparse or absent in the early-wood vessels in the heartwood.
Red oak—*Quercus* spp. Desc. p. 565.
- 3

Late-wood vessels numerous, thin-walled, angular (as thin-walled as the surrounding cells, or thinner-walled); tyloses abundant in the early-wood vessels in the heartwood.
White oak—*Quercus* spp. Desc. p. 568.
- 4

Early-wood vessels grading in size into those of the late wood; early-wood zone not sharply defined; the transition from early to late wood more or less gradual; wood semi-ring-porous . .

5
- 4

Early-wood vessels not grading in size into those of the late wood (or if so, the first-formed early-wood vessels much larger than those in the outer portions of the ring); early-wood zone sharply defined, the transition from early to late wood abrupt; wood typically ring-porous.

14

*This key is designed to separate the more important North American hardwoods on features requiring the use of a compound microscope.
The key is accompanied by a series of 20 photomicrographs at 400x (Figs. 11-142 to 11-161) illustrating the intervessel pitting in hardwoods.

- 5 Rays 1–6 seriate; parenchyma included in the body of the growth ring, or wanting (x) 6
- 5 Rays uniseriate; parenchyma marginal (x) 12
- 6 Parenchyma relatively abundant; vessels without spiral thickening or the spirals restricted to those of the late wood; largest vessels more than 100 μm in diameter* (ranging from 120–300) 7
- 6 Parenchyma extremely sparse or wanting; vessels with spiral thickening (Fig. 11-142); largest vessels less than 100 μm in diameter (ranging from 60–90)
- Black cherry**—*Prunus serotina* Ehrh. Desc. p. 592.
- 7 Intervessel pits vested, similar to those in *Robinia pseudoacacia* (see Fig. 11-145).
- Yellowwood**—*Cladrastis kentukea* (Dum.-Cours.) Rudd. Desc. p. 597.
- 7 Intervessel pits not vested 8
- 8 Late-wood vessels with spiral thickening, those in the outer portion of the growth ring associated with parenchyma forming tangential, several seriate, more or less continuous bands, with 1 or more bands in the outer portion of the ring consisting entirely of parenchyma.
- Catalpa**—*Catalpa* spp. Desc. p. 627.
- 8 Late-wood vessels without spiral thickening, solitary or in radial groups of 2–4; apotracheal parenchyma present throughout the growth ring. 9
- 9 Rays storied (t); intervessel pits minute, with the apertures of 2 to several frequently joined laterally (Fig. 11-143).
- Common persimmon**—*Diospyros virginiana* L. Desc. p. 621.
- 9 Rays unstoried (t); intervessel pits of normal size, rounded or angular, apertures not joined laterally (see Fig. 11-144) 10
- 10 Lines of banded parenchyma conspicuous, 1–4-seriate; fibers with maximum diameter of less than 25 μm .
- Pecan hickory group**—*Carya* spp. Desc. p. 540.
- 10 Lines of banded parenchyma inconspicuous, usually uniseriate; fibers with maximum diameter of more than 25 μm . . . 11
- 11 Parenchyma frequently crystalliferous; ray cells mostly round (t); late-wood vessels with reticulate thickenings (r) giving appearance of gashlike pits.
- Black walnut**—*Juglans nigra* L. Desc. p. 538.
- 11 Parenchyma not crystalliferous; ray cells mostly elliptical (t); late-wood vessels without reticulate thickenings.
- Butternut**—*Juglans cinerea* L. Desc. p. 537.
- 12 Rays essentially homocellular (see Fig. 5-13a) 13
- 12 Rays essentially heterocellular (see Fig. 5-13b).
- Willow**—*Salix* spp. Desc. p. 547.

*The diameter stated is always the tangential diameter.

- 13 Vessels 30–145 per sq mm, the largest 75–150 μm in diameter.
Cottonwood—*Populus* spp. Desc. p. 543.
- 13 Vessels 85–180 per sq mm, the largest 50–100 μm in diameter.
Aspen—*Populus* spp. Desc. p. 546.
- 14 Late wood figured with concentric, wavy, more or less continuous bands of porous tissue composed largely of vessels (x) 15
- 14 Late wood without concentric bands of vessels (x) or occasionally with interrupted bands in the outer portion of the growth ring consisting of vessels and appreciable amounts of parenchyma; apotracheal parenchyma sometimes present. . 19
- 15 Large early-wood vessels in 1 row 16
- 15 Large early-wood vessels in several rows 17
- 16 Large early-wood vessels with maximum diameter of over 200 μm .
American elm—*Ulmus americana* L. Desc. p. 572.
- 16 Large early-wood vessels with maximum diameter of less than 200 μm .
Hard elms—*Ulmus* spp. Desc. p. 575.
- 17 Rays 1–6-seriate, essentially homocellular 18
- 17 Rays 1–13-seriate, essentially heterocellular.
Hackberry—*Celtis* spp. Desc. p. 576.
- 18 Early-wood zone consisting essentially of large pores.
Slippery elm—*Ulmus rubra* Mühl. Desc. p. 573.
- 18 Early-wood zone consisting of large and small pores.
American elm—*Ulmus americana* L. Desc. p. 572.
- 19 Rays uniseriate or rarely in part biseriate 20
- 19 Rays 1 to many-seriate. 21
- 20 Early-wood vessels usually in 1 row, the largest 150–200 μm in diameter.
Giant chinkapin—*Castanopsis chrysophylla* (Dougl.) A. DC. Desc. p. 560.
- 20 Early-wood vessels in several rows, the largest 240–360 μm in diameter.
American chestnut—*Castanea dentata* (Marsh.) Borkh. Desc. p. 559.
- 21 Rays 1–4-seriate 22
- 21 Rays 1–5- or more-seriate. 27
- 22 Parenchyma banded (x), in concentric rows distributed throughout the body of the growth ring.
Hickory—*Carya* spp. Desc. p. 540.
- 22 Parenchyma not banded or, if banded, the rows restricted to short broken lines in the outer portion of the ring 23
- 23 Late-wood vessels in part with scalariform perforation plates; rays with oil cells.
Sassafras—*Sassafras albidum* (Nutt.) Nees. Desc. p. 587.
- 23 Vessels in early and late wood with simple perforation plates; rays without oil cells 24

- 24 Early-wood vessels completely occluded with tyloses; tyloses small, appearing cellular 25
- 24 Early-wood vessels open or only partly occluded with tyloses; tyloses large, not appearing cellular 26
- 25 Intervessel pits vested (Fig. 11-145).
Black locust—*Robinia pseudoacacia* L. Desc. p. 599.
- 25 Intervessel pits not vested (Fig. 11-146); crystals in parenchyma.
Osage-orange—*Maclura pomifera* (Raf.) Schneid. Desc. p. 579.
- 26 Late-wood vessels with spiral thickening; vessels in the outer part of the growth ring associated with parenchyma forming tangential, several-seriate, more or less continuous bands (1 or more bands in the outer portion of the ring occasionally consisting entirely of parenchyma); fibers with maximum diameter of more than 25 μm (range from 16–32).
Catalpa—*Catalpa* spp. Desc. p. 627.
- 26 Late-wood vessels without spiral thickening, solitary or in radial rows of 2 to several; fibers with maximum diameter of less than 25 μm (range from 12–22).
Ash—*Fraxinus* spp. Desc. pp. 623 to 627.
- 27 Parenchyma banded (x), in concentric, 1–4-seriate bands distributed throughout the body of the growth ring (x); late-wood vessels solitary or in radial rows of 2–3, without spiral thickening.
Hickory—*Carya* spp. Desc. p. 540.
- 27 Parenchyma not banded (x); late-wood vessels solitary, in radial rows, in nests, or in interrupted bands consisting largely of vessels or of vessels and parenchyma, with spiral thickenings 28
- 28 Early-wood vessels in 1 row.
Yellowwood—*Cladrastis kentukea* (Dum.-Cours.) Rudd. Desc. p. 597.
- 28 Early-wood vessels in several rows 29
- 29 Early-wood vessels in the heartwood partly or wholly occluded with tyloses, with or without gummy deposits 30
- 29 Early-wood vessels without tyloses or tyloses only occasionally present, sometimes with gummy deposits 33
- 30 Early-wood vessels partly occluded with tyloses; tyloses large, not appearing cellular 31
- 30 Early-wood vessels completely occluded with tyloses; tyloses small, appearing cellular 32
- 31 Fibers 20–52 μm in diameter, not gelatinous; rays 1–6-seriate (mostly 2–3).
Catalpa—*Catalpa* spp. Desc. p. 627.
- 31 Fibers 18–26 μm in diameter, frequently gelatinous; rays 1–8-seriate (mostly 5–7).
Red mulberry—*Morus rubra* L. Desc. p. 578.
- 32 Intervessel pits vested.
Black locust—*Robinia pseudoacacia* L. Desc. p. 599.

- 32 Intervessel pits not vested, crystals in parenchyma.
Osage-orange—*Maclura pomifera* (Raf.) Schneid. Desc. p. 579.
- 33 Rays 1–14-seriate, the tallest more than 1200 μm in height; porous tissue toward the outer margin of the growth ring consisting of small vessels embedded in short, tangential bands of parenchyma.
Honeylocust—*Gleditsia triacanthos* L. Desc. p. 596.
- 33 Rays 1–7-seriate, the tallest less than 1200 μm in height; porous tissue toward the outer portion of the growth ring consisting mostly of vessels.
Kentucky coffeetree—*Gymnocladus dioica* (L.) K. Koch. Desc. p. 594.
- 34 Early-wood vessels somewhat larger than those in the late wood; wood semi-diffuse-porous. 35
- 34 Vessels exhibiting little or no variation in size (except in extreme outer portion of certain species); wood typically diffuse-porous 46
- 35 Rays 1 to many-seriate; parenchyma present in the body of the ring, or wanting. 36
- 35 Rays uniseriate; parenchyma confined to the outer margin of the ring 44
- 36 Longitudinal parenchyma relatively abundant; vessels without spiral thickening or the spirals restricted to those of the late wood; largest vessels more than 100 μm in diameter (100–320). 37
- 36 Longitudinal parenchyma absent or extremely sparse; vessels throughout the ring with spiral thickening (Fig. 11-142); largest vessels less than 100 μm in diameter (70–90).
Black cherry—*Prunus serotina* Ehrh. Desc. p. 592.
- 37 Intervessel pits vested.
Yellowwood—*Cladrastis kentukea* (Dum.-Cours.) Rudd. Desc. p. 597.
- 37 Intervessel pits not vested 38
- 38 Late-wood vessels with spiral thickening, those toward the outer margin of the ring associated with parenchyma forming tangential, several-seriate, more or less continuous bands (1 or more bands in the outer portion of the ring occasionally consisting entirely of parenchyma).
Catalpa—*Catalpa* spp. Desc. p. 627.
- 38 Late-wood vessels without spiral thickening, solitary or in radial groups of 2–4; banded parenchyma present, the lines closely spaced throughout the growth ring. 39
- 39 Rays storied (t); intervessel pits minute, 2 to several frequently joined (coalescent apertures, Fig. 11-143).
Common persimmon—*Diospyros virginiana* L. Desc. p. 621.
- 39 Rays unstoried (t); pits on vessel walls of normal size, generally not joined laterally (Fig. 11-144). 40

- 40 Lines of banded parenchyma conspicuous, 1–4-seriate. . . . 41
- 40 Lines of banded parenchyma inconspicuous, usually uniseriate 43
- 41 Rays of 1 type, 1–5-seriate; vessels solitary and in short radial rows (x).
Water hickory—*Carya aquatica* (Michx. f.) Nutt. Desc. p. 540.
- 41 Rays of 2 types, uniseriate and broad, the latter sometimes aggregate, up to 50 plus cells in width; vessels in streamlike clusters which extend for some distance radially across several rings when they are evident 42
- 42 Largest vessels 100 to 160 µm in diameter; banded parenchyma in 1–4-seriate lines; most of broad rays distinctly aggregate.
Tanoak—*Lithocarpus densiflorus* (Hook. & Arn.) Rehd. Desc. p. 562.
- 42 Largest vessels 200–280 µm in diameter; banded parenchyma in 1–2 (mostly 1)-seriate lines; broad rays distinctly aggregate.
Live oak—*Quercus virginiana* Mill. Desc. p. 564.
- 43 Small vessels with reticulate thickenings on radial faces.*
Black walnut—*Juglans nigra* L. Desc. p. 538.
- 43 Small vessels lacking reticulate thickenings on radial faces.
Butternut—*Juglans cinerea* L. Desc. p. 537.
- 44 Rays essentially homocellular (Fig. 5-13a) 45
- 44 Rays essentially heterocellular (Fig. 5-13b)
Willow—*Salix* spp. Desc. p.547.
- 45 Vessels 30–145 per sq mm, the largest 75–150 µm in diameter.
Cottonwood—*Populus* spp. Desc. p. 543.
- 45 Vessels 85–180 per sq mm, the largest 50–100 µm in diameter.
Aspen—*Populus* spp. Desc. p. 546.
- 46 Widest rays more than 8-seriate. 47
- 46 Widest rays never more than 8-seriate (aggregate rays when present not considered) 48
- 47 Rays of 1 type, intergrading in size, 1–14-seriate (mostly 3–14); intervessel pits not crowded (Fig. 11-150).
Sycamore—*Platanus occidentalis* L. Desc. p. 591.
- 47 Rays of 2 types; narrow rays 1–5-seriate; broad rays 15–25 plus-seriate; intervessel pits crowded (Figs. 11-151).
American beech—*Fagus grandifolia* Ehrh. Desc. p. 557.
- 48 Rays of 2 types, simple and aggregate, aggregate rays often at wide intervals 49
- 48 Rays of 1 type, simple. 50
- 49 Simple rays uniseriate or rarely in part biseriate; perforation plates scalariform with 15 plus thin bars; intervessel pits not crowded (Fig. 11-148).
Red alder—*Alnus rubra* Bong. Desc. p. 555.
- 49 Simple rays 1–4-seriate (mostly 1–2); perforation plates predomi-

*For further explanation see pages 177 and 538.

- nantly simple; scalariform perforation plates sporadic, with 3–6 thick bars; intervessel pits crowded (Fig. 11-149).
- American hornbeam**—*Carpinus caroliniana* Walt. Desc. p. 549.
- 50 Perforation plates exclusively simple. 51
- 50 Perforation plates exclusively scalariform, or simple and scalariform and sometimes reticulate 65
- 51 Rays 1–8-seriate 52
- 51 Rays uniseriate. 62
- 52 Parenchyma absent or extremely sparse 53
- 52 Parenchyma fairly abundant to abundant, sometimes restricted to the outer face of the ring 55
- 53 Vessels solitary and in more or less irregular groups of 2 to several which are frequently oblique to the rays, generally more numerous and crowded in the early wood, 100–180 per sq mm.
- Black cherry**—*Prunus serotina* Ehrh. Desc. p. 592.
- 53 Vessels solitary and in radial rows of 2–5, seldom contiguous in the tangential plane, quite evenly distributed as groups throughout the ring, 20–90 per sq mm 54
- 54 Rays of 2 widths, the narrow uniseriate (rarely 2–3-seriate) and numerous, the broad 3–8-seriate (mostly 5–7).
- Hard maple**—*Acer* spp. Desc. p. 603.
- 54 Rays intergrading in width, 1–5-seriate (mostly 3–4), the uniseriate rays sparse (especially in bigleaf maple).
- Soft maple**—*Acer* spp. Desc. pp. 605 to 608.
- 55 Parenchyma in the body of the ring at least in part banded apotracheal. 56
- 55 Parenchyma in the body of the ring never banded. 57
- 56 Vessels unevenly distributed, frequently in radial rows of 2–6 plus (x) which are often further aggregated into flame-shaped groups; rays 1–3-seriate, the tallest less than 1000 µm in height.
- Eastern hophornbeam**—*Ostrya virginiana* (Mill.) K. Koch. Desc. p. 550.
- 56 Vessels quite evenly distributed, the radial grouping not pronounced (x); rays 1–6-seriate, the tallest more than 1000 µm in height.
- Basswood**—*Tilia* spp. Desc. p. 611.
- 57 Intervessel pits vested.
- Yellowwood**—*Cladrastis kentukea* (Dum.-Cours.) Rudd. Desc. p. 597.
- 57 Intervessel pits not vested 58
- 58 Paratracheal parenchyma abundant, forming a 1–3-seriate sheath; rays typically heterocellular, frequently with oil cells; fibers in part septate.
- California-laurel**—*Umbellularia californica* (Hook. & Arn.) Nutt. Desc. p. 586.

- 58 Paratracheal parenchyma absent or sparse and then forming a broken uniseriate sheath; rays homocellular to heterocellular; fibers not septate 59
- 59 Marginal parenchyma absent.
Cascara buckthorn—*Rhamnus purshiana* DC. Desc. p. 610.
- 59 Marginal parenchyma present 60
- 60 Marginal parenchyma conspicuous, forming a line 1 to several cells in thickness; pitting on the vessel walls generally scalariform, the pits linear, 12–50 µm in diameter (Fig. 11-153).
Magnolia—*Magnolia* spp. Desc. p. 581.
- 60 Marginal parenchyma inconspicuous and restricted to a more or less continuous uniseriate line, or sporadic; pits on the vessel walls orbicular to hexagonal, 4–10 µm in diameter (Fig. 11-154) 61
- 61 Rays of 2 widths, the narrow uniseriate (rarely 2–3) and numerous, the broad 3–8-seriate (mostly 5–7).
Hard maple—*Acer* spp. Desc. p. 603.
- 61 Rays intergrading in width, 1–5-seriate (mostly 3–4), the uniseriate rays sparse (especially in bigleaf maple).
Soft maple—*Acer* spp. Desc. p. 607.
- 62 Largest vessels 40–60 µm in diameter, with or without spiral thickening; intervessel pits of medium size (Fig. 11-155); parenchyma marginal and paratracheal (restricted to occasional cells); rays and longitudinal elements storied or unstoried.
Buckeye—*Aesculus* spp. Desc. p. 608.
- 62 Largest vessels 60–160 µm in diameter, without spiral thickening; intervessel pits large (Fig. 11-156); parenchyma strictly marginal; rays and longitudinal elements unstoried . 63
- 63 Rays essentially homocellular 64
- 63 Rays essentially heterocellular.
Willow—*Salix* spp. Desc. p. 547.
- 64 Vessels 30–145 per sq mm, the largest 75–150 µm in diameter.
Cottonwood—*Populus* spp. Desc. p. 543.
- 64 Vessels 85–180 per sq mm, the largest 50–100 µm in diameter.
Aspen—*Populus* spp. Desc. p. 546.
- 65 Spiral thickening in the vessels and at least in some of the fibers 66
- 65 Spiral thickening restricted to the vessels, vessel ends, or absent. 67
- 66 Vessels arranged in radial strings or clusters which often extend across the rings; the wider rays are high, many 30 or more cells in height.
American holly—*Ilex opaca* Ait. Desc. p. 601.
- 66 Vessels solitary or in multiples of 2 to several, frequently further aggregated into tangentially aligned clusters or bands,

the zones of pores then alternating with bands of fibrous tissue; broader rays low, under 25 cells in height.

Pacific madrone—*Arbutus menziesii* Pursh. Desc. p. 620.

67 Rays typically heterocellular, the upper and lower margins of the broad rays consisting of 1–5 plus rows of upright cells; upright cells of the broad rays 30–100 μm in height along the grain . . . 68

67 Rays homocellular to hererocellular; when heterocellular the upper and lower margins of the broad rays generally consisting of 1 to several (mostly 1) rows of upright cells; upright cells of the broad rays generally less than 60 μm in height along the grain . 70

68 Rays 1–8-seriate; uniseriate rays usually consisting entirely of upright cells; apotracheal parenchyma relatively abundant; spiral thickenings in vessels absent.

Dogwood—*Cornus* spp. Desc. p. 616.

68 Rays 1–4-seriate; uniseriate rays consisting of both upright and procumbent cells, apotracheal parenchyma relatively sparse; spiral thickenings restricted to the vessel ends 69

69 Pits on the vessel walls (t) in transverse rows of 1–3, frequently linear through coalescence, the pit contour generally rounded (Fig. 11-158); interfiber pits conspicuously bordered, large (7–9 μm in diameter); longitudinal traumatic gum canals sometimes present.

Sweetgum—*Liquidambar styraciflua* L. Desc. p. 589.

69 Pits on the vessel walls (t) in transverse rows of 1–5 plus, seldom linear, the pit contour frequently angular to rectangular (Fig. 11-160); interfiber pits inconspicuously bordered, small (3–4 μm in diameter); traumatic gum canals absent.

Tupelo—*Nyssa* spp. Desc. p. 613.

70 Pits on the vessel walls orbicular to elliptical to rectangular or linear; medium-size to large (4–50 μm in diameter). 71

70 Pits on the vessel walls orbicular to hexagonal, minute (2–4 μm in diameter); spiral thickenings in vessels absent. Fig. 11-159).

Birch—*Betula* spp. Desc. p. 552.

71 Parenchyma paratracheal or apotracheal diffuse, or both, the cells scattered; scalariform perforation plates with 10–50 bars; spiral thickenings in vessels or vessel ends. 72

71 Parenchyma marginal, the band 1 to several cells in thickness; scalariform perforation plates with 6–10 bars; spiral thickening in vessels absent 74

72 Spiral thickening in the vessels restricted to the tapering ends of the members; perforation plates exclusively scalariform; rays 6–13 per mm (x) 73

72 Spiral thickening in the vessels not restricted to the tapering ends of the elements; perforation plates simple and scalariform; rays 3–5 per mm (x).

Sourwood—*Oxydendrum arboreum* (L.) DC. Desc. p. 618.

- 73 Pits on the vessel walls (t) in transverse rows of 1–3, frequently linear through coalescence, the pit contour generally rounded (Fig. 11–158); interfiber pits conspicuously bordered, large (7–9 μm in diameter); longitudinal traumatic gum canals sometimes present.

Sweetgum—*Liquidambar styraciflua* L. Desc. p. 589.

- 73 Pits on the vessel walls (t) in transverse rows of 1–5 plus, seldom linear, the pit contour frequently angular to rectangular (Fig. 11–160); interfiber pits inconspicuously bordered, small (3–4 μm in diameter); longitudinal traumatic gum canals absent.

Tupelo—*Nyssa* spp. Desc. p. 613.

- 74 Bars of scalariform perforation plates thick (more than 1 μm); pits on the vessel walls linear, frequently extending across the vessel, 12–50 μm in diameter (similar to Fig. 11–153).

Southern magnolia—*Magnolia grandiflora* L. Desc. p. 581.

- 74 Bars of scalariform perforation plates thin (less than 1 μm); pits on the vessel walls orbicular to elliptical or linear, seldom extending across the vessel, 6–40 (usually 6–20) μm in diameter (Fig. 11–161).

Yellow-poplar—*Liriodendron tulipifera* L. Desc. p. 584.

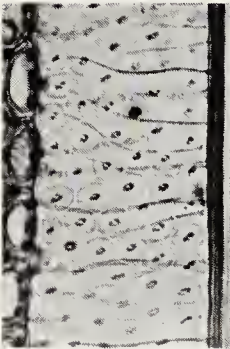


Figure 11-142

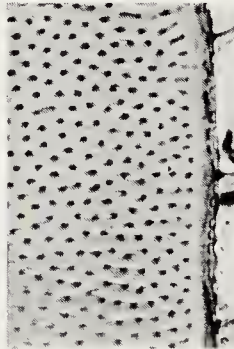


Figure 11-143

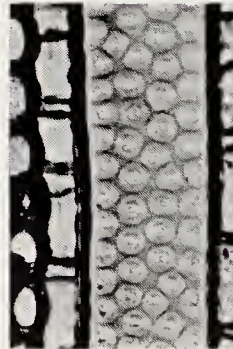


Figure 11-144



Figure 11-145

Figure 11-142 Portion of the wall of a vessel element (t) from the wood of black cherry, *Prunus serotina* Ehrh., showing intervessel pitting and spiral thickening. (400 $\times$)

Figure 11-143 Portion of the wall of a vessel element (t) from the wood of common persimmon, *Diospyros virginiana* L., showing minute intervessel pits with coalescent apertures. (400 $\times$)

Figure 11-144 Portion of the wall of a vessel element (t) from the wood of shagbark hickory, *Carya ovata* (Mill.) K. Koch, showing intervessel pitting. The punctate appearance of the pits is the result of artifacts and is not vesturing. (400 $\times$)

Figure 11-145 Portion of the wall of a vessel element (t) from the wood of black locust, *Robinia pseudoacacia* L., showing vested intervessel pits. (400 $\times$)

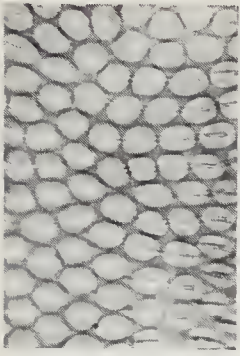


Figure 11-146

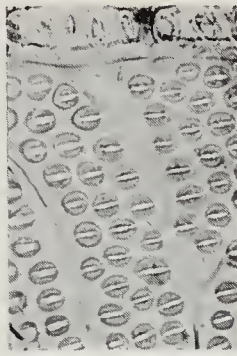


Figure 11-147



Figure 11-148

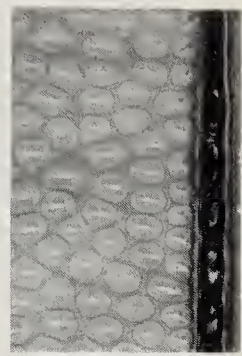


Figure 11-149

Figure 11-146 Portion of the wall of a vessel element (*t*) from the wood of osage-orange, *Maclura pomifera* (Raf.) Schneid., showing intervessel pits with coalescent apertures. (400×)

Figure 11-147 Portions of the walls of three vasicentric tracheids and a wood ray (*r*) from the wood of Shumard oak, *Quercus shumardii* Buckl., showing intertracheary pitting. The pits have a punctate appearance because of artifacts; they are not vested. (400×)

Figure 11-148 Portion of the wall of a vessel element (*t*) from the wood of red alder, *Alnus rubra* Bong., showing widely spaced intervessel pitting. (400×)

Figure 11-149 Portion of the wall of a vessel element (*t*) from the wood of American hornbeam, *Carpinus caroliniana* Walt., showing crowded, angular intervessel pitting. (400×)



Figure 11-150

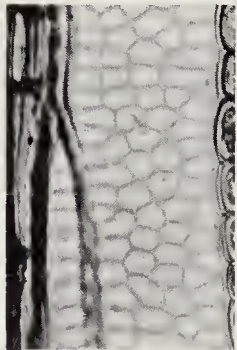


Figure 11-151

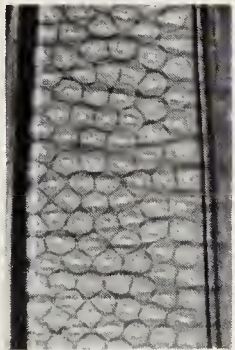


Figure 11-152

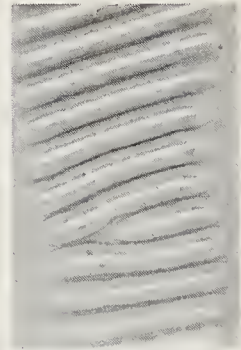


Figure 11-153

Figure 11-150 Portion of the wall of a vessel element (*t*) from the wood of sycamore, *Platanus occidentalis* L., showing widely spaced intervessel pitting. (400×)

Figure 11-151 Portions of the walls of two vessel elements (*t*) from the wood of American beech, *Fagus grandifolia* Ehrh., showing crowded intervessel pits. (400×)

Figure 11-152 Portions of the wall of a vessel element (*t*) from the wood of basswood, *Tilia americana* L., showing crowded intervessel pits and spiral thickening. (400×)

Figure 11-153 Portion of the wall of a vessel element (*t*) from the wood of cucumbertree, *Magnolia acuminata* L., showing scalariform intervessel pitting. (400×)



Figure 11-154

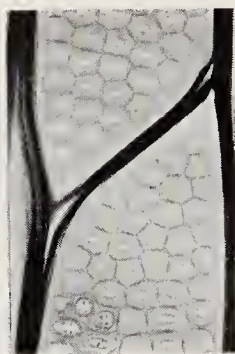


Figure 11-155



Figure 11-156

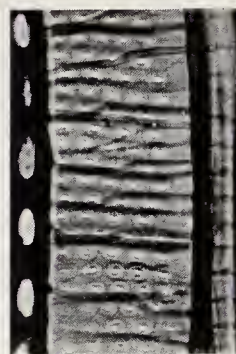


Figure 11-157

Figure 11-154 Portion of the wall of a vessel element (t) from the wood of silver maple, *Acer saccharinum* L., showing intervessel pitting. (400×)

Figure 11-155 Portions of the walls of two vessel elements (t) from the wood of yellow buckeye, *Aesculus octandra* Marsh., showing medium-sized intervessel pits. The pits in the upper right corner are punctate because of artifacts and are not vested. (400×)

Figure 11-156 Portion of the wall of a vessel element (t) from the wood of eastern cottonwood, *Populus deltoides* Bartr. ex. Marsh., showing large intervessel pits. (400×)

Figure 11-157 Portion of the wall of a vessel element (t) from the wood of American holly, *Ilex opaca* Ait., showing intervessel pitting and spiral thickening. The portion of a fiber at the right of the picture also shows spiral thickening. (400×)

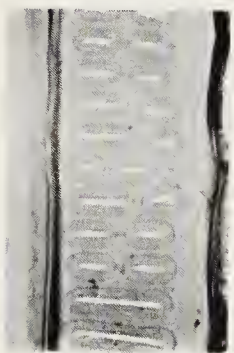


Figure 11-158

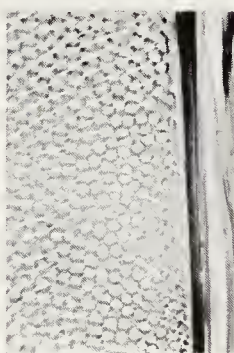


Figure 11-159



Figure 11-160

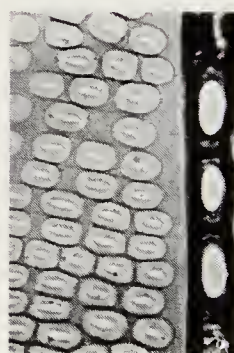


Figure 11-161

Figure 11-158 Portion of the wall of a vessel element (t) from the wood of sweetgum, *Liquidambar styraciflua* L., showing oval and linear intervessel pits. (400×)

Figure 11-159 Portion of the wall of a vessel element (t) from the wood of yellow birch, *Betula alleghaniensis* Britton, showing small intervessel pits with coalescent apertures. (400×)

Figure 11-160 Portion of the wall of a vessel element (t) from the wood of black tupelo, *Nyssa sylvatica* Marsh., showing opposite intervessel pitting. (400×)

Figure 11-161 Portion of the wall of a vessel element (t) from the wood of yellow-poplar, *Liriodendron tulipifera* L., showing opposite intervessel pitting. (400×)

DESCRIPTIONS OF HARDWOODS
BY SPECIES

In the case of the hardwoods, the great complexity of kinds and sizes of the cells, coupled with considerable variation in their dimensions in the same growth ring, as well as in different parts of the stem, makes definite numerical values not very meaningful. Values are presented, therefore, by the general descriptive terms which can be related to a range of numerical values by reference to the tables which follow.

Detailed numerical information on the anatomical features of hardwoods is presented in Tables 5-2, 5-3, 5-7, and 11-3.

Distribution of the Pores as Seen in Cross
Section

Class	Number per sq mm
Very few	Less than 16
Few	16-25
Moderately few	26-50
Moderately numerous	51-75
Numerous	76-100
Very numerous	More than 100

Tangential Diameter of the Pores in Mi-
crometers, Including the Thickness of
the Walls

Class	Tangential diameter, μm
Very small	Less than 50
Small	51-100
Medium	101-150
Large	151-200
Very large	201-300
Extremely large	More than 300

Tangential Diameter of the Fibers in
Micrometers, Including the Thickness
of the Walls

Class	Tangential diameter, μm
Fine	Up to 16
Medium	16-25
Coarse	26-30
Very coarse	More than 30

Table 11-3 Anatomical Data for Hardwoods^a

Species	Vessels												Tracheids, vasicentric (26)												
	General				Pore arrangement ^b				Perforations		Pits						Tracheids, vascular (25)								
	(1) Heartwood distinct ^c	(2) Heartwood odor distinctive ^d	(3) Ring-porous	(4) Semi-ring-porous	(5) Diffuse-porous	(6) Early-wood pores 1 row	(7) Predominantly solitary	(8) Multiples	(9) Chains	(10) Wavy bands	(11) Nested	(12) Spirals present		(13) Simple	(14) Scalariform	(15) More than 10 bars		(16) Opposite	(17) Alternate	(18) Scalariform	(19) Less than 5 μm	(20) Less than 12μm	(21) More than 12 μm	(22) Linear	(23) Vestured
Acer spp., hard maple	+				+		+	+				+	+				+	+		+					
Acer spp., soft maple	+				+		+	+				+	+				+	+		+					
Aesculus spp.	s ^e				+			+				+	+					+		+					
Alnus rubra					+			+			s			+	+	+	s		+						
Arbutus menziesii	+				+	+	s	+				+		+	g		+	+							
Betula spp.	+				+			+						+	+	+		+							
Carpinus caroliniana	+				+			+	s			+	+	s			+	+		+	s				
Carya spp.	+		+	+				+					+	+				+							

(1) (2) (3) (4) (5) (6) (7) (8) (9) (10) (11) (12) (13) (14) (15) (16) (17) (18) (19) (20) (21) (22) (23) (24) (25) (26)

<i>Castanea dentata</i>	+	+										+	s			+			+					+
<i>Castanopsis chrysophylla</i>	+	+			+		f					+	s			+			+					+
<i>Catalpa</i> spp.	+	+	+	+					s	+	±	+				+			+					
<i>Celtis</i> spp.	+	+	+						+		+	+				+			+			+		
<i>Cladrastis kentukea</i>	+			+			+			+	+	+				+			+	s	+			
<i>Cornus</i> spp.	+				+		+						+		+				+					
<i>Diospyros virginiana</i>	s			+			+					+				+	+							
<i>Fagus grandifolia</i>	s			+		+	+						s			+			+					
<i>Fraxinus</i> spp., white ash	+	+	+			s	+					+			s	+			s					+
<i>Fraxinus nigra</i>	+	+	+			s	+					+				+			s					+
<i>Gleditsia triacanthos</i>	+	+	+				s			+	+	+				+			+		h	+		
<i>Gymnocladus dioica</i>	+	+	+							+	+	+				+			+		+			
<i>Ilex opaca</i>	s			+				+			+		+			+			s					
<i>Juglans cinerea</i>	+		+				+					+				+	+		+					

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	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)	(26)
<i>Ostrya virginiana</i>	+				+			+	S			+	+	S			+			+	S					
<i>Oxydendrum arboreum</i>	+				+		+					+	+	+	^g		+			+						
<i>Platanus occidentalis</i>	+				+		+	+					+	S			+			S						
<i>Populus</i> spp., aspen	S	^e		S	+		+	+					+				+			+	S					
<i>Populus</i> spp., cottonwood	S	^e			+			+					+				+			+	S					
<i>Prunus serotina</i>	+		S	S	+	S		+			+	+	+				+			+			^h			
<i>Quercus</i> spp., red oaks	+		+				^j						+				+			+						+
<i>Quercus</i> spp., white oaks	+		+				^j				+		+				+			+			^m			+
<i>Quercus virginiana</i>	+				+		+						+				+			+						+
<i>Rhamnus purshiana</i>	+				+			+				+	+				+			+						
<i>Robinia pseudoacacia</i>	+		+							S	+	+	+				+			+		+	^m			
<i>Salix nigra</i>	+			S	+			+					+				+			+	S					
<i>Sassafras albidum</i>	+	+	+				S	+					+	S			+			+						

Table 11-3 Anatomical Data for Hardwoods (Continued)

Species	General					Pore arrangement ^b					Perforations			Pits							Miscellaneous (24)	(25) Tracheids, vascular	(26) Tracheids, vasicentric			
	(1) Heartwood distinct ^c	(2) Heartwood odor distinctive ^d	(3) Ring-porous	(4) Semi-ring-porous	(5) Diffuse-porous	(6) Early-wood pores 1 row	(7) Predominantly solitary	(8) Multiples	(9) Chains	(10) Wavy bands	(11) Nested	(12) Spirals present	(13) Simple	(14) Scalariform	(15) More than 10 bars	(16) Opposite	(17) Alternate	(18) Scalariform	(19) Less than 5 μm	(20) Less than 12μm				(21) More than 12 μm	(22) Linear	(23) Vestured
<i>Tilia</i> spp.	s	e			+			+				+	+	+				+		+						
<i>Ulmus americana</i>	+		+			+				+		+	+	+				+		+						
<i>Ulmus rubra</i>	+	s	+									+	+	+				+		+						
<i>Ulmus torosii</i>	+		+			+				+		+	+	+				+		+						
<i>Umbellularia californica</i>	+	+			+		s	+				s	+	+				+		+						

	Fibers			Parenchyma								Rays														
Species	Libriform (27)	Fiber tracheids (28)	Septate (29)	Spirals (30)	Rare or absent (31)	Marginal (32)	Paratracheal-scanty (33)	Paratracheal-vasicentric (34)	Paratracheal-aliform (35)	Paratracheal-confluent (36)	Apotracheal-diffuse (37)	Apotracheal diffuse-in-aggregate (38)	Banded (39)	Uniseriate (40)	Up to 4-seriate (41)	Widest 5-10-seriate (42)	Widest more than 10-seriate (43)	Aggregate (44)	Homocellular (45)	Heterocellular (46)	Storied (47)	Sheath cells (48)	Oil cells (49)	Ray-vessel pitting 1 st (50)	Ray-vessel pitting 11 th (51)	Ray-vessel pitting 111 th (52)
Acer spp., hard maple	+	+				+	+				+			+		+				+						+
Acer spp., soft maple	+	+				+	+				+			1+	+	s				+	+					+
Aesculus spp.	+	s				+	+							+						+		1+		+		
Alnus rubra		+				s	+				+			+					+	+					+	+
Arbutus menziesii		+	1+	1+			s							1 ^p	+	s				+					+	
Betula spp.		+				s					+	+				+				+					+	+
Carpinus caroliniana		+				s						+	+		+					+	s				+	
Carya spp.	+	+				+	+						+		+	s				+	s					+

Table 11-3 Anatomical Data for Hardwoods (Continued)

	Fibers				Parenchyma									Rays												
	(27) Libriform	(28) Fiber tracheids	(29) Septate	(30) Spirals	(31) Rare or absent	(32) Marginal	(33) Paratracheal-scanly	(34) Paratracheal-vasicentric	(35) Paratracheal-aliform	(36) Paratracheal-confluent	(37) Apotracheal-diffuse	(38) Apotracheal diffuse-in-aggregate	(39) Banded	(40) Uniseriate	(41) Up to 4-seriate	(42) Widest 5-10-seriate	(43) Widest more than 10-seriate	(44) Aggregate	(45) Homocellular	(46) Heterocellular	(47) Stored	(48) Sheath cells	(49) Oil cells	(50) Ray-vessel pitting I ⁿ	(51) Ray-vessel pitting II ⁿ	(52) Ray-vessel pitting III ⁿ
Species	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)	(45)	(46)	(47)	(48)	(49)	(50)	(51)	(52)
<i>Castanea dentata</i>	+	+					+				+		+	+					+						+	
<i>Castanopsis chrysophylla</i>	+	+					+				+		+	+					+						+	
<i>Catalpa</i> spp.	+					+		+	+				+		+	s			+	s					+	
<i>Celtis</i> spp.	+							+			+					+	+			+						
<i>Cladrastis kentukea</i>	+					+		+			+			+		+				+				+		
<i>Cornus</i> spp.		+					+					+	+	+		+				+						+
<i>Diospyros virginiana</i>	+					+		+				+	+		+				+	+	+	+				+
<i>Fagus grandifolia</i>		+									+	+	+				+		+							
<i>Fraxinus</i> spp., white ash	+					+	+								+				+						+	+

	(27)	(28)	(29)	(30)	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)	(41)	(42)	(43)	(44)	(45)	(46)	(47)	(48)	(49)	(50)	(51)	(52)
<i>Fraxinus nigra</i>	+														+				+							+
<i>Gleditsia triacanthos</i>	+					+	+		+	+	+					+	s		+							+
<i>Gymnocladus dioicus</i>	+					+		+	+	+					+	+			+							+
<i>Ilex opaca</i>		+		+			+				+			+						+						+
<i>Juglans cinerea</i>		+				+	+	+			+	+			+				+	s						+
<i>Juglans nigra</i>		+				+	+	+			+	+			+	s			+	s						+
<i>Liquidambar styraciflua</i>		+					+				+			+	+				+	+					+	
<i>Liriodendron tulipifera</i>	+	+				+									+	s			+	+					+	
<i>Lithocarpus densiflorus</i>	+	+					+				+	+		+			+	+	+						+	
<i>Maclura pomifera</i>	+					s		+	+	+					+	s			+						+	
<i>Magnolia</i> spp.		+				+									+	s			+	+					+	
<i>Morus rubra</i>	+							+	+		+								+	+					+	
<i>Nyssa</i> spp.		+					+				+				+					+						+
<i>Ostrya virginiana</i>	+					s						+			+			+	+	s					+	
<i>Oxydendrum arboreum</i>		+					s				+			+		+				+						

Table 11-3 Anatomical Data for Hardwoods (Continued)

	Fibers				Parenchyma								Rays													
Species	Libriform (27)	Fiber tracheids (28)	Septate (29)	Spirals (30)	Rare or absent (31)	Marginal (32)	Paratracheal-scanty (33)	Paratracheal-vasicentric (34)	Paratracheal-aliform (35)	Paratracheal-confluent (36)	Apotracheal-diffuse (37)	Apotracheal diffuse-in-aggregate (38)	Banded (39)	Uniseriate (40)	Up to 4-seriate (41)	Widest 5-10-seriate (42)	Widest more than 10-seriate (43)	Aggregate (44)	Homocellular (45)	Heterocellular (46)	Storied (47)	Sheath cells (48)	Oil cells (49)	Ray-vessel pitting 1 ⁿ (50)	Ray-vessel pitting 11 ⁿ (51)	Ray-vessel pitting 111 ⁿ (52)
<i>Platanus occidentalis</i>		+					+				+	+		+			+			+						+
<i>Populus</i> spp., aspen	+					+								+						+					+	
<i>Populus</i> spp., cottonwood	+					+								+						+					+	
<i>Prunus serotina</i>		+			+		s				s				+	s				+	s					+
<i>Quercus</i> spp., red oaks	+	+					+				+	+	+	+			+			+					+	
<i>Quercus</i> spp., white oaks	+	s					+				+	+	+	+			+			+					+	
<i>Quercus virginiana</i>	+	+					+						+	+	+		+	+		+					+	

Table 11-4 Comparative Physical Data for Hardwoods Native to the United States

Common name of wood ^a (1)	Sp gr, average		Weight, lb/cu ft		Shrinkage based on green dimension, % ^b				Index classes to mechanical properties ^c											
	Green (2)	12% (3)	Green (4)	12% (5)	Volume (6)	T (7)	R (8)	T/R (9)	Bending strength (10)	Compression as a post (11)	Hardness (12)	Stiffness (13)	Shock resistance (14)	Splitting (15)	Screw holding (16)	Ability to stay in place (17) ^d	Drying defects (18) ^e	Machining qualities (19) ^f	Joining qualities (20) ^g	Durability Rating (21) ^h
Alder, red Ash, black Ash, white Aspen, quaking Basswood, American	0.37	0.41	46	28	12.6	7.3	4.4	1.7	4	4	4	3	5	4	4	3	2	G	2	S
	0.45	0.49	52	34	15.2	7.8	5.0	1.6	4	4	4	3	3	3	3	4	3	G	3	S
	0.55	0.60	48	42	13.3	7.8	4.9	1.6	2	2	2	2	3	2	2	3	3	G	3	S
	0.35	0.38	43	26	11.5	6.7	3.5	1.9	5	5	5	4	5	5	4	3	2	G	1	S
	0.32	0.37	42	26	15.8	9.3	6.6	1.4	5	4	5	3	5	4	4	3	2	A	2	S
Beech, American Birch, paper Birch, yellow Buckeye, yellow Buckthorn, cascara	0.56	0.64	54	45	17.2	11.9	5.5	2.2	2	3	3	2	3	2	2	4	3,4,5	G	4	S
	0.48	0.55	50	38	16.2	8.6	6.3	1.4	4	4	4	3	3	4	2	4	2	G	2	S
	0.55	0.62	57	43	16.8	9.5	7.3	1.3	2	3	3	1	3	3	2	4	2	A	4	S
	0.33	0.36	49	25	12.5	8.1	3.6	2.2	5	5	5	4	5	4	5	3	2	A	2	S+
	0.50	0.52	50	36	7.6	4.6	3.2	1.4	4	3	3	5	2	3	2	4	3	A	4	S
Butternut California-laurel Catalpa, northern Cherry, black Chestnut, American	0.36	0.38	46	27	10.6	6.4	3.4	1.9	5	4	5	4	5	4	4	2	2	A	2	S
	0.51	0.55	54	39	12.4	8.6	2.9	2.9	4	3	2	5	2	2	2	3	3,4	A	4	S
	0.38	0.41	41	29	7.3	4.9	2.5	2.0	4	4	4	4	3	4	4	3	2	A	3	R
	0.47	0.50	45	35	11.5	7.1	3.7	1.9	2	3	3	2	4	3	3	3	2	A	3	R
	0.40	0.43	55	30	11.6	6.7	3.4	2.0	5	4	4	4	5	4	3	2	2	G	1	R
Chinkapin, giant Cottonwood eastern Dogwood flowering	0.42	0.46	61	32	13.2	7.4	4.6	1.6	3	3	4	3	4	4	3	3	3	A	3	S
	0.37	0.40	49	28	13.9	9.2	3.9	2.4	5	4	5	3	5	4	4	4	3,5	P	1	S
	0.64	0.73	64	51	20.8	11.8	7.4	1.6	2	2	1	3	2	3	1	5	2	A	3	S

Table 11-4 Comparative Physical Data for Hardwoods Native to the United States

Common name of wood ^a (1)	Sp gr, average		Weight, lb/cu ft		Shrinkage based on green dimension, % ^b				Index classes to mechanical properties ^c											
	Green (2)	12% (3)	Green (4)	12% (5)	Volume (6)	T (7)	R (8)	T/R (9)	Bending strength (10)	Compression as a post (11)	Hardness (12)	Stiffness (13)	Shock resistance (14)	Splitting (15)	Screw holding (16)	Ability to stay in place (17) ^d	Drying defects (18) ^e	Machining qualities (19) ^f	Gluing qualities (20) ^g	Durability rating (21) ^h
Elm, American	0.46	0.50	54	35	14.6	7.2	4.2	2.3	3	4	3	3	3	2	2	5	3	P ⁺	2	S
Elm, rock	0.57	0.63	53	44	14.9	8.1	4.8	1.7	2	2	2	3	2	2	2	5	3	P ⁺	2	S
Elm, slippery	0.48	0.53	56	37	13.8	8.9	4.9	1.8	2	3	3	3	3	2	2	5	3	P	2	S
Hackberry	0.49	0.53	50	37	13.8	8.9	4.8	1.9	4	4	3	4	3	2	2	4	3	G	2	S
Hickory, shagbark	0.64	0.72	64	50	16.7	10.5	7.0	1.4	1	1	1	1	1	2	2	5	3	G	4	S
Holly, American	0.50	0.57	57	40	16.9	9.9	4.8	2.1	4	4	3	4	2	2	2	4	2,4	G	3	S
Honeylocust	0.60	0.67	61	44	10.8	6.6	4.2	1.6	2	2	1	3	3	1	2	2	3,4	A	3	M ⁺
Hophornbeam, eastern	0.63	0.70	60	49	19.4	10.0	8.5	1.2	2	3	2	3	1	3	1	5	3	A	4	S
Hornbeam, American	0.58	0.70	53	49	19.1	11.4	5.7	2.0	4	4	2	4	1	3	1	5	3	A	4	S
Locust, black	0.66	0.69	58	48	10.2	7.2	4.6	1.6	1	1	1	1	3	2	1	2	2	A	4	R ⁺
Madrone, Pacific	0.58	0.65	60	45	18.1	12.4	5.6	2.2	3	3	2	4	3	2	2	5	3	P	4	S
Magnolia, southern	0.46	0.50	59	35	12.3	6.6	5.4	1.2	4	4	3	3	2	3	3	4	2	A	2	S
Maple, red	0.49	0.54	50	38	12.6	8.2	4.0	2.0	3	3	3	1	4	3	2	3	3,4	A	3	S
Maple, sugar	0.56	0.63	56	44	14.7	9.9	4.8	1.9	2	2	2	1	3	1	2	4	3,4	G	4	S
Oak, live	0.80	0.88	76	62	14.7	9.5	6.6	1.4	1	1	1	1	2	1	1	4	3,4,5	P	4	R
Oak, red ⁱ	0.57	0.62	64	43	14.7	8.9	4.2	2.1	2	3	2	2	3	2	2	4	3,4,5	G	3	S ⁺
Oak, white ^k	0.59	0.67	63	45	15.9	9.2	5.3	1.7	2	2	2	3	3	2	1	4	3,4,5	G	3	R

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17) ^d	(18) ^e	(19) ^f	(20) ^g	(21) ^h
Osage-orange	0.76	0.80	62	56	9.2		...	...	1	1	1	1	1	1	1	3	3	A	4	R+
Persimmon, common	0.64	0.74	63	52	19.1	11.2	7.9	1.4	2	2	1	2	3	2	1	4	3	A	4	S
Sassafras	0.42	0.46	44	31	10.3	6.2	4.0	1.6	4	4	4	4	3	3	3	3	2	A	3	R
Sourwood	0.50	0.55	53	38	15.2	8.9	6.3	1.4	3	3	3	2	3	2	2	4	2	A	3	S
Sweetgum	0.46	0.52	55	35	15.8	10.2	5.8	1.9	3	3	3	3	3	3	3	4	3	A	2	S+
Sycamore, American	0.46	0.49	52	34	14.1	8.4	5.0	1.5	4	4	3	3	4	3	3	4	3,4	P	3	S
Tupelo, black	0.46	0.50	45	35	14.4	8.7	5.1	1.8	3	3	3	3	4	3	2	5	3	P	3	S
Walnut, black	0.51	0.55	58	38	12.8	7.8	5.5	1.4	2	2	2	2	3	2	2	2	2,5	G	3	R
Willow, black	0.36	0.39	50	26	13.9	8.7	3.3	3.1	5	5	5	5	3	4	4	3	3	P	1	S
Yellow-poplar	0.40	0.42	46	30	12.7	8.2	4.7	1.8	4	4	4	3	4	4	4	2	2	A	1	S

^aCommon names according to "Check List of Native and Naturalized Trees of the United States," U.S. Department of Agriculture Handbook 41, 1953. See text for scientific names.

^bShrinkage values are for change from green to oven-dry.

^cCoding of mechanical properties according to index classes:

Column no.	Mechanical property	Index classes				
		5	4	3	2	1
10	Modulus of rupture in bending, green wood, psi	<6000	6000 to	7000 to	8000 to	11,000 +
11	Maximum crushing strength parallel, green wood, psi	<2200	2200 to	3000 to	3600 to	4500 +
12	Side hardness, green wood, lb	< 400	400 to	600 to	900 to	1200 +
13	Modulus of elasticity in bending, psi × 1000	< 800	800 to	1000 to	1300 to	1500 +
14	Height of drop with 50-lb hammer, in	15 to	25 to	35 to	50 to	70 +
15	Load, lb/in of width to split green wood	< 150	150 to	250 to	350 to	450 +
16	Nail and screw withdrawal as function of sp gr OD	< 0.40	0.40 to	0.45 to	0.55 to	0.70 +

^dDimensional changes with moisture in normal use ranges from Class 1 with little change, to Class 5 with greatest dimensional change.

^eDrying defects classed as follows: 1. Slight warping and little dimensional change. 2. Distinct warping. 3. Pronounced warping. 4. Tendency to check and split. 5. Subject to collapse and honeycombing.

^fMachining qualities: G = good to excellent, smooth surface. A = average. P = poor, requiring care to be acceptable.

^gGluing qualities: 1. Glues very easily. 2. Glues well. 3. Requires control. 4. Difficult to glue, requires close control.

^hHeartwood durability ratings: R = resistant to decay, M = moderate resistance to decay, S = low decay resistance. + indicates high rating within the group.

ⁱIndicates commercial red oak as weighted averages for black, laurel, pin, northern red, scarlet, water, and willow oaks.

^jIndicates commercial white oak as weighted averages for bur, chestnut, post, swamp chestnut, white, and swamp white oaks.

Sources: "Wood Handbook," U.S. Department of Agriculture Handbook 72, 1974 and U.S. Dep. Agric. Bull. 479, 1935, except for cols. 9 and 18.