Structure of Wood

Society of Wood Science and Technology

Teaching Unit Number 1

Slide Set 2

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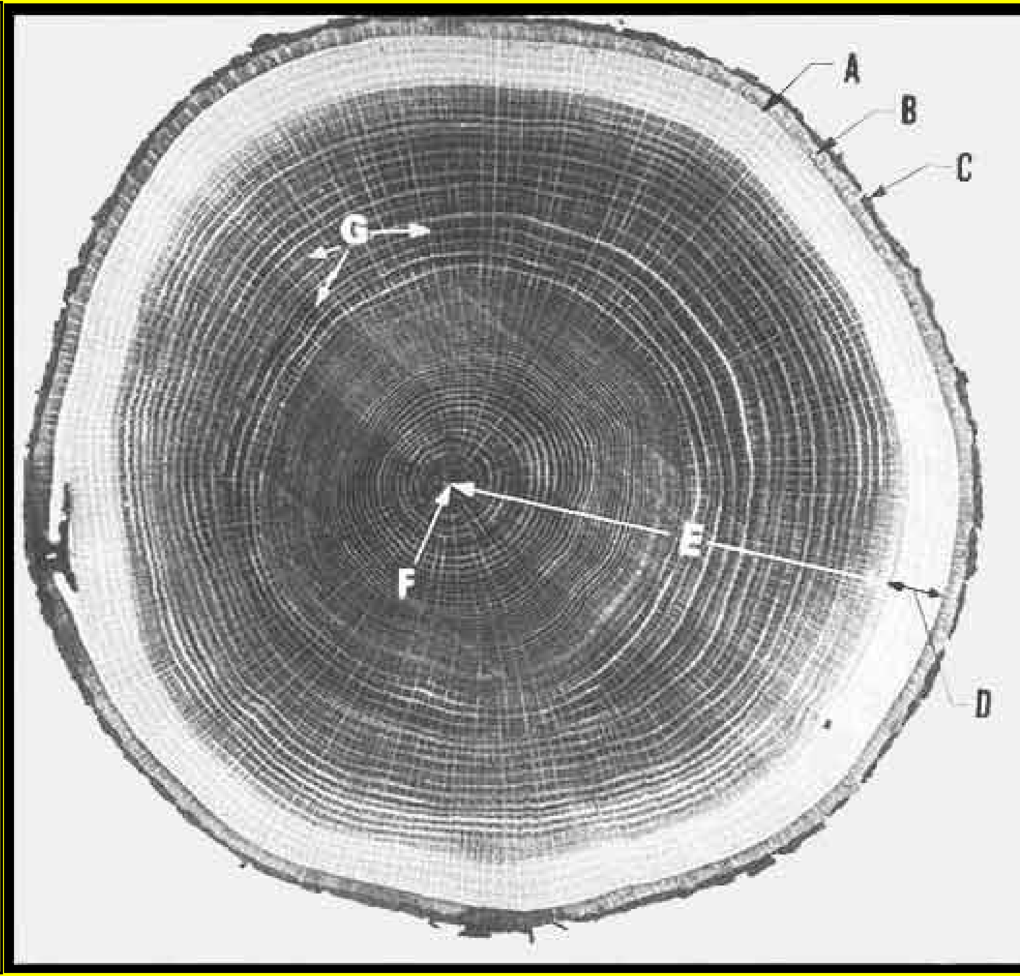
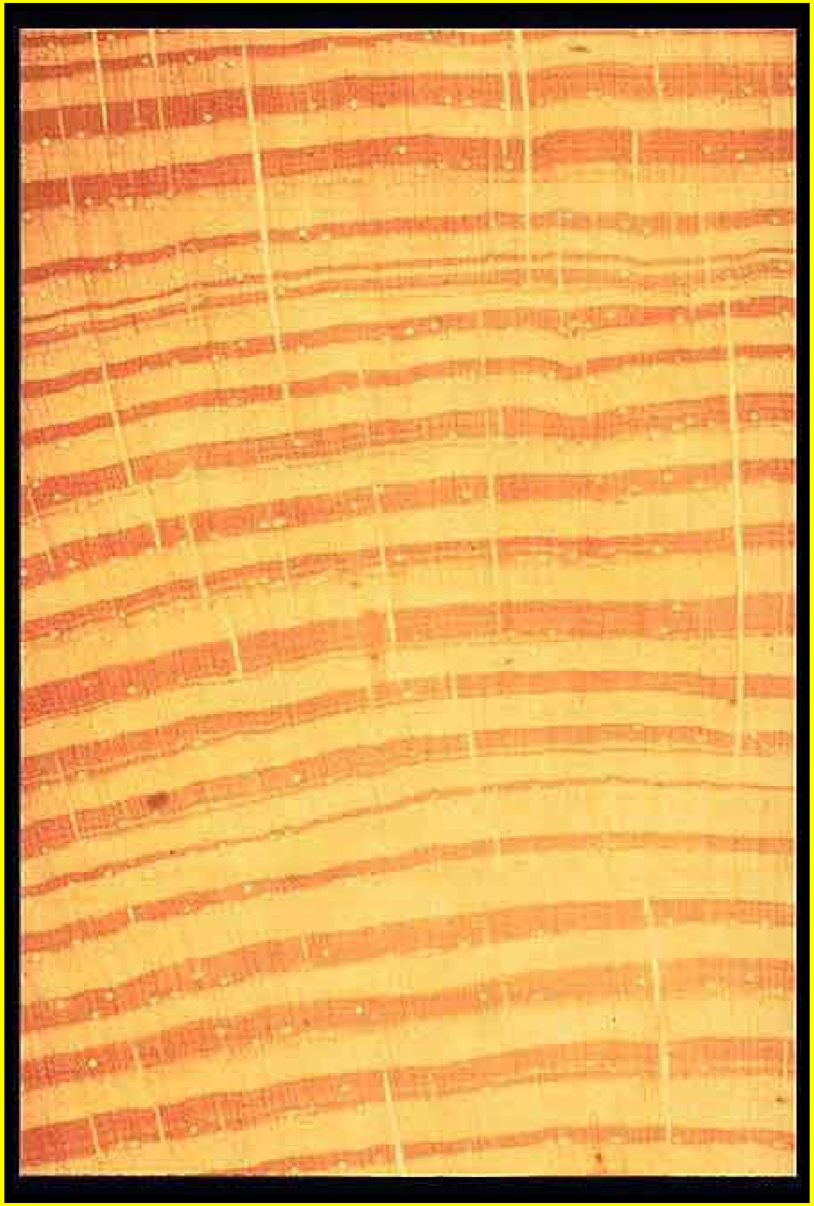
Macroscopic Structure of Wood

Growth Increments

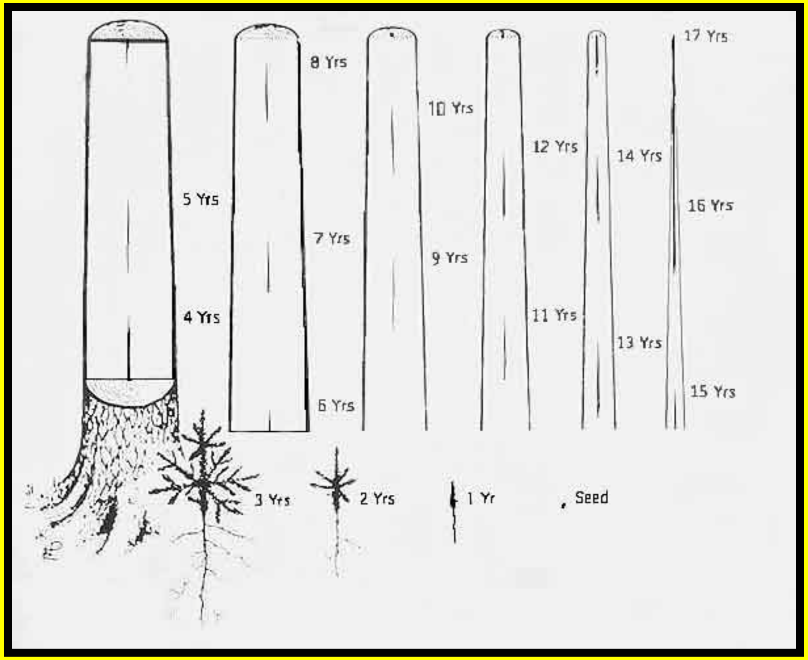
A tree stem consists of three areas; pith, xylem and bark. The central pith (F) is usually barely visible and does not increase in size through the life of the tree. A cylinder of wood, known scientifically as xylem (D "sapwood" plus E "heartwood"), varies in diameter with age and rate of growth. And finally, the bark sheath can be subdivided into inner bark (B which conducts sugars) and outer bark (C that serves as a protective layer). New wood and inner bark are added each year by the activity of a layer of dividing cells (A cambium) sandwiched between the inner bark and sapwood. New bark production is relatively small compared with new wood production, and bark is continually being shed to the outside of the stem, thus in older trees the greatest volume of the stem is wood. Since new wood is added to the outside of existing wood the oldest wood is close to the pith, and the most recent is close to the bark. [Note: G, the fine radiating "spokes", are the wood rays].



In the north temperate zones, cutting any stem surface will show the wood to be composed of a series of concentric bands. These bands are referred to as *growth rings*, and in temperate trees commonly one ring is formed each year. Growth rings actually extend vertically along the stem as a series of concentric cylinders. If the numbers of growth rings on the two ends of a log are counted, more rings will be found on the lower end of the log than on the upper.



Each year a tree grows in height from its tip, although new wood is added along the length of the stem, no previous growth rings are present at the top of the stem. The number of growth rings increases down the stem according to the number of annual height increments. The appearance of growth rings is due to changes in the structure of wood produced through the growing season. Cells produced at the beginning of the season are commonly larger, and so this early wood appears less dense than the latewood produced towards the end of the season.



Although all trees produce concentric layers of wood, not all trees produce visible growth rings, neither are all growth rings necessarily annual. In some trees seasonal changes in wood structure may be so slight that growth rings are not evident. Under conditions of severe drought an annual growth ring may not be produced. On the other hand under continuously favorable conditions, such as the tropics, several growth rings may be produced in a year.

One of the major functions of wood is to conduct water from the roots to the leaves. However, wood does not continue to serve this function indefinitely. At some stage the wood cells may become blocked by air bubbles, other cells, or by deposition of other substances.

Heartwood and Sapwood

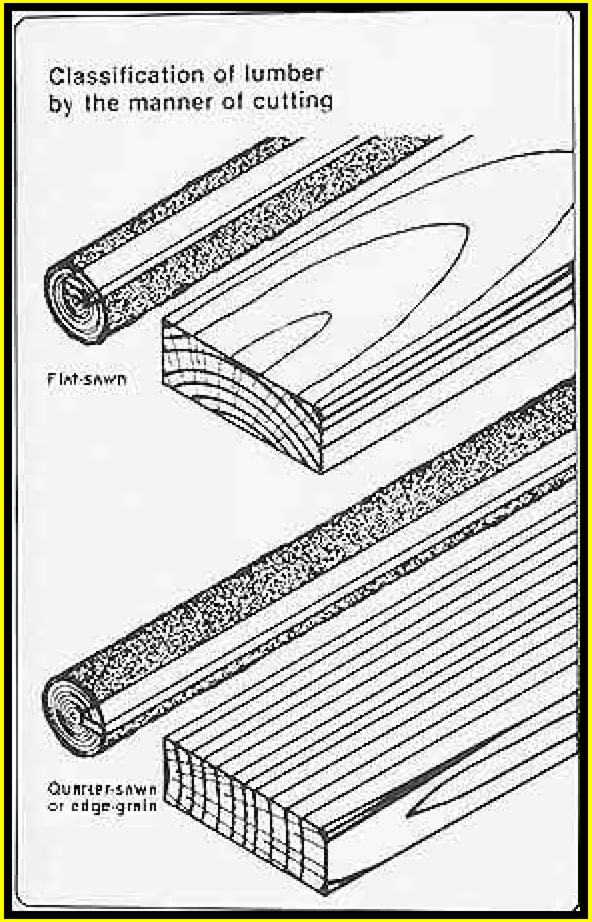
Wood that is functional in water transport is referred to as *sapwood*, and occupies the outer, or more recently formed growth rings (here, the yellowish zone). Wood that is no longer functional in conducting water is referred to as *heartwood* (here, the orange brown zone), and occupies the central stem core.

Each year new wood is formed, some inner-most sapwood becomes non-functional in water transport so that the outer boundary of the heartwood core is continually moving outwards. In general an approximate balance is maintained between new wood formation and conversion of sapwood to heartwood so that there is always adequate conducting tissue

The conversion of sapwood to heartwood is commonly associated with a color change that is due to the deposition of chemical compounds known as *extractives*. The color change varies among species according to the composition of the wood. Some have a rich and beautiful appearance, in other species the color change may be only very slight, and in yet other species there may be no evidence of color change. The extractives also impart a durability to the wood against fungal decay and insect attack. The degree of durability varies widely among different species.

Direction in Wood

Three orthogonal planes (i.e., mutually perpendicular) are recognized, although the stem can of course be cut in any number of intermediate planes. (1) A horizontal, or transverse cut through the stem will reveal the growth rings as concentric circles. In structural lumber, partial growth rings are evident at the ends of timber and the surface is known as end grain. The other two orthogonal planes of wood are longitudinal. (2) A longitudinal cut in a plane through the pith exposes a radial longitudinal surface. In species with distinct growth rings, this surface will appear to have a series of more or less parallel lines. A board cut to expose a radial longitudinal surface is known as a quarter sawn board. (3) A longitudinal cut in a plane at a tangent to the surface of the stem exposes a tangential longitudinal surface. Growth rings here will appear as a series of wavy lines or cones stacked one above another. A board cut to expose a tangential longitudinal surface is known as a plain (or flat) sawn board.



It should be realized that only peeling, as in veneer production, can produce a truly tangential surface, and only the one cut that is in a plane through the pith can produce a truly radial surface.

Intermediate planes of cut are commonly referred to as radial or tangential according to which they more closely approximate.

Differences Between Softwoods and Hardwoods

Trees for timber production are classified as softwoods or hardwoods.

Hardwoods are the most diverse group, they contain both the heaviest and lightest timber examples found in nature. Botanically, softwoods include the conifers that belong to the more primitive group of plants called the Gymnosperms. Interestingly this group of plants is almost wholly composed of trees. Hardwoods belong to the botanical group called the Dicotyledenous Angiosperms, this is a very large group of plants including vegetable and fruit plants, herbaceous flowering plants and weeds as well as trees.

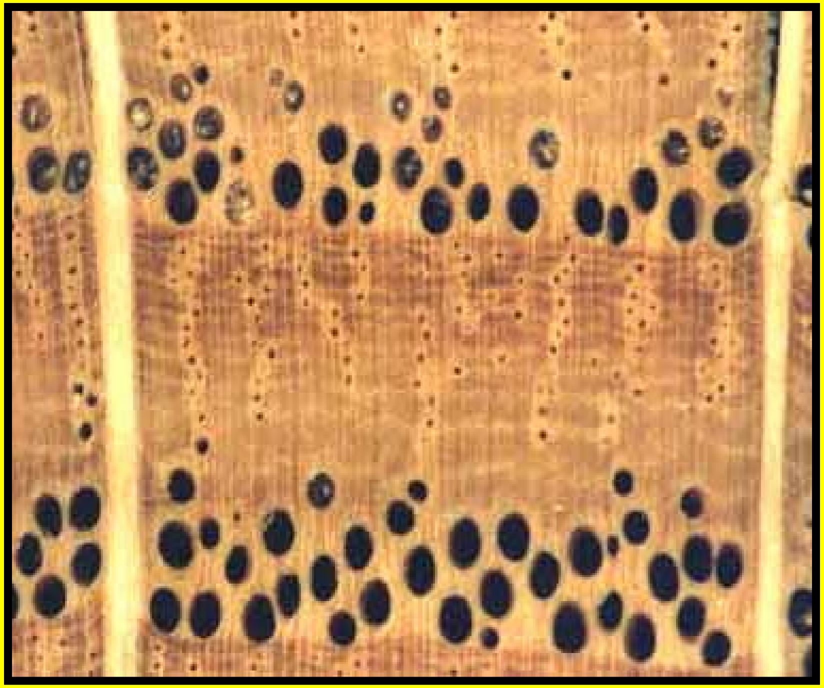
One of the major botanical distinctions between softwoods and hardwoods lies in the structure of their wood.

In softwoods, the cells that serve to transport water also provide the mechanical support for the stem. In hardwoods, some division of labor has evolved, with some cells specializing in water transport, and others in providing mechanical support.

In hardwoods the water conducting cells, known as pores or *vessels*, are commonly very much larger in diameter than the cells, known as *tracheids*, in softwoods. The pores can frequently be seen with the naked eye as a number of pinholes in the transverse surface of the wood. As a result hardwoods are commonly referred to as porous woods, and softwoods as nonporous woods. The differences in the anatomical structure of these two groups can be seen in the following pictures (20 X).

Softwood (20X)

cross section

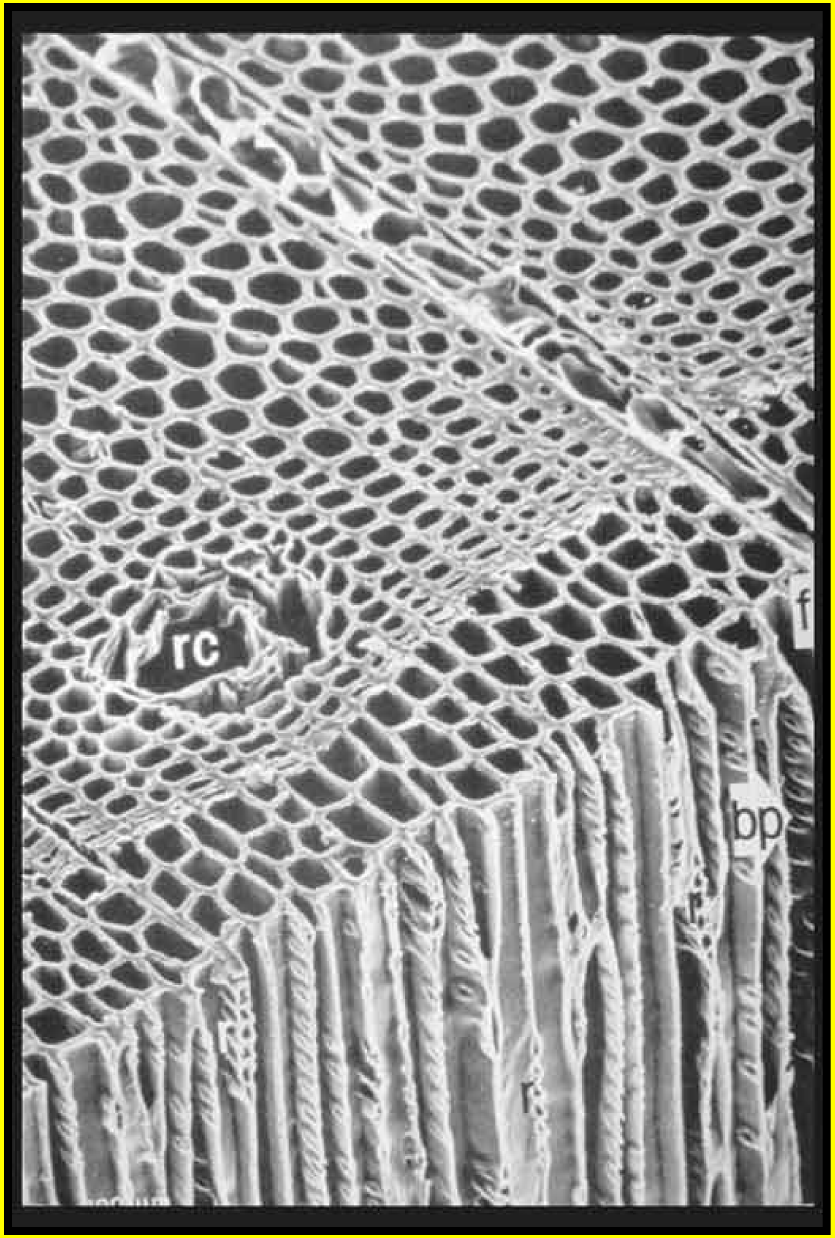


Hardwood (20X)

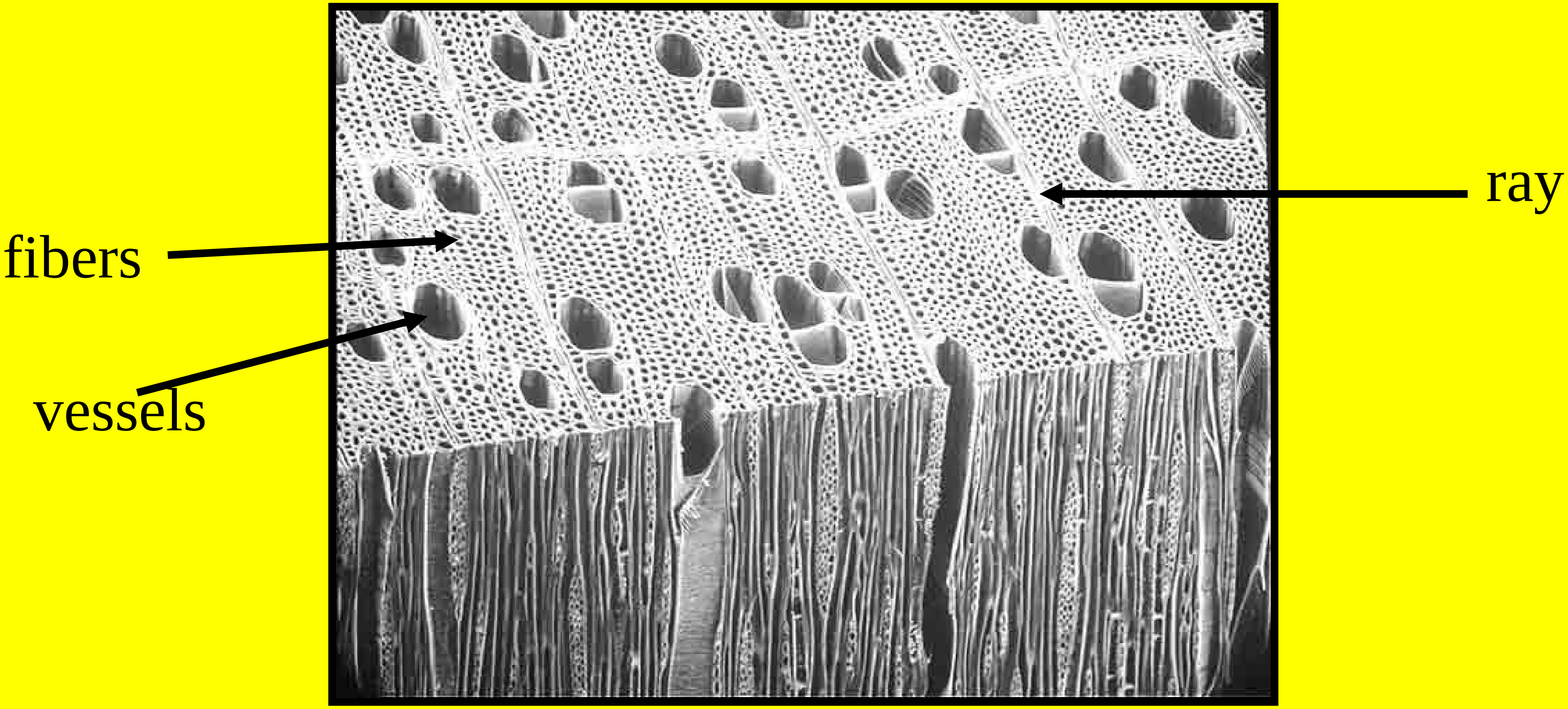
cross section

Microscopic Structure of Wood

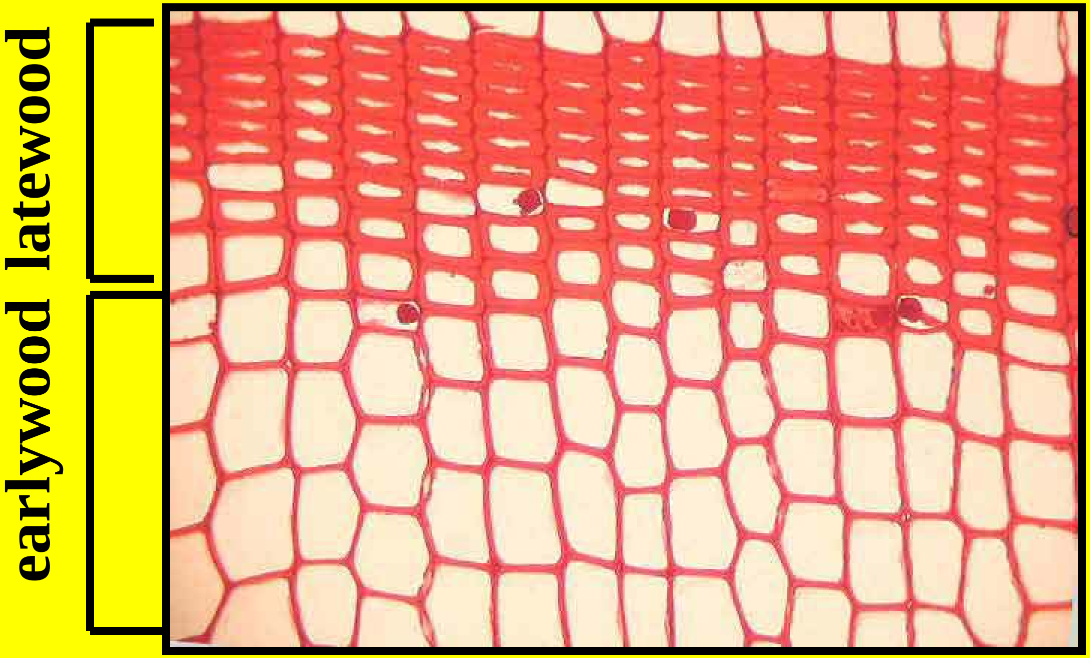
This is a scanning electron micrograph of an eastern spruce wood block, a softwood. Most cells run longitudinally, but some cells, run horizontally. The big hole is called a *resin canal (rc)*. The majority of the cells shown here are called "*longitudinal tracheids*". On different surfaces, the wood structure appears differently. This is called anisotropic or orthotropic structure. This unique structure differs from other raw materials, e.g., metal, plastic, concrete and rocks.

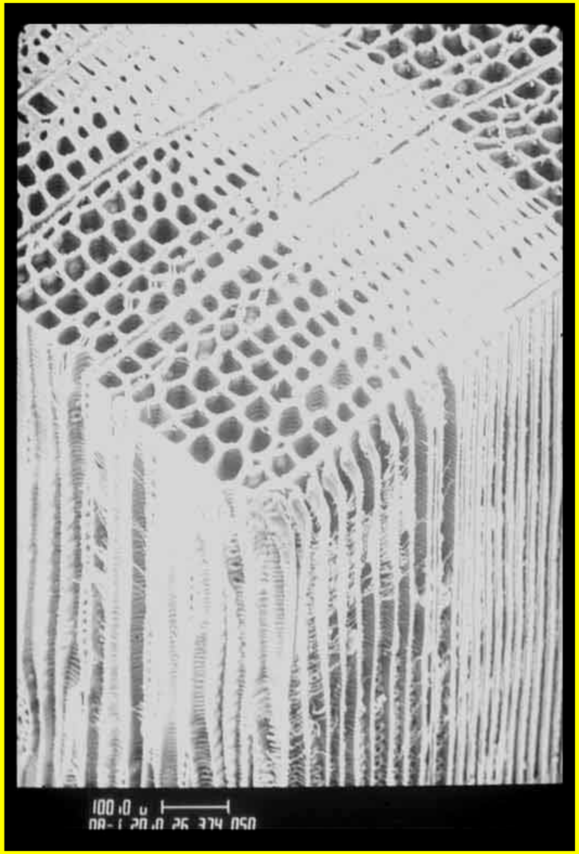


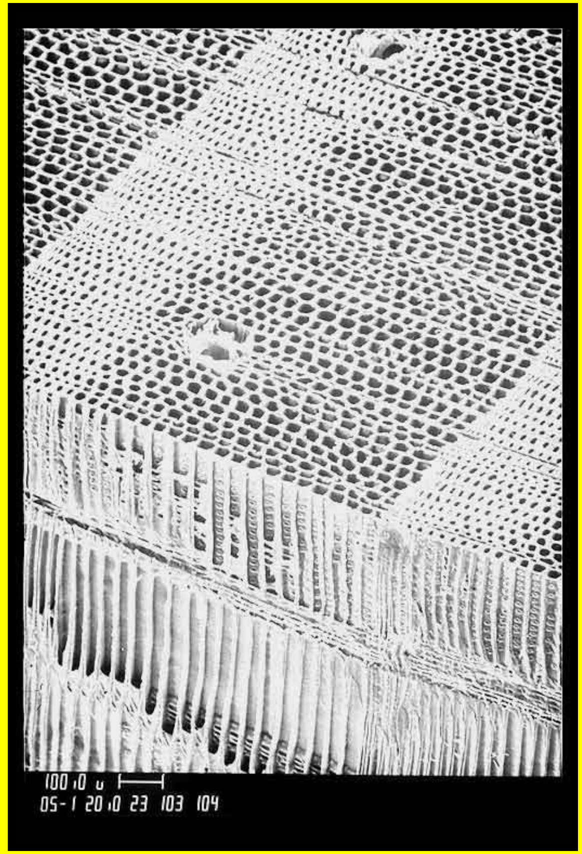
In contrast to softwood, the structure of hardwood is more complicated, due to more cell types existing in hardwoods. This is a 3-D picture of a birch wood block. The large holes represent the *vessel elements*. The small ones are the *fibers*. The lines between the vessel elements on the top of the block are bundles of *ray cells* called *multiseriate rays*.

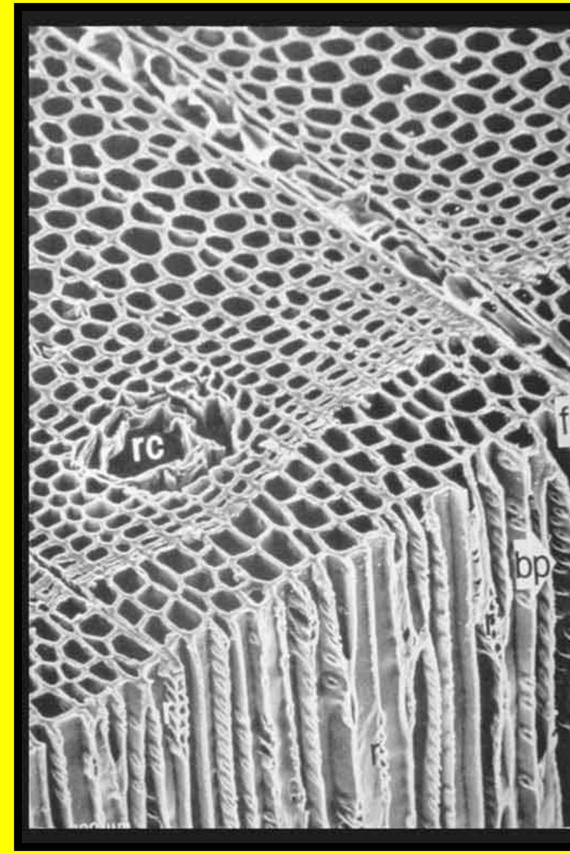


This picture shows a cross section of redwood. It is enlarged 100 times through a light microscope. As you know, a tree produces a ring annually. This ring is composed of two zones, i.e., *earlywood* (light colored area, larger diameter cells) and the *latewood* (dark colored area, smaller diameter cells). The earlywood is produced at the beginning of a growing season with a relatively thin cell wall and a large diameter. The latewood is formed late in the growing season with a relatively thick cell wall and small cavity. This picture also shows that the zones from the earlywood to latewood changes distinctively. This is called an abrupt transition. Some species possess this distinct feature, some are gradual.





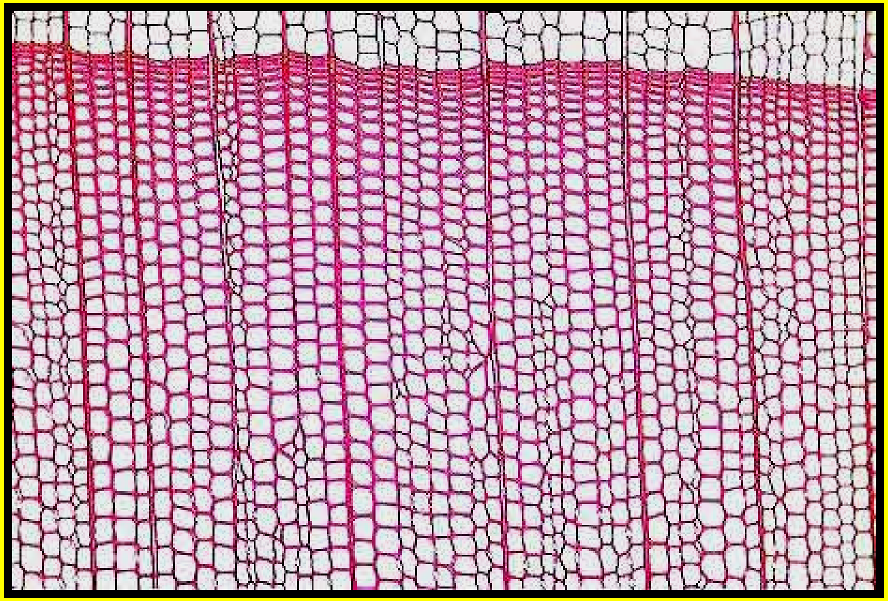




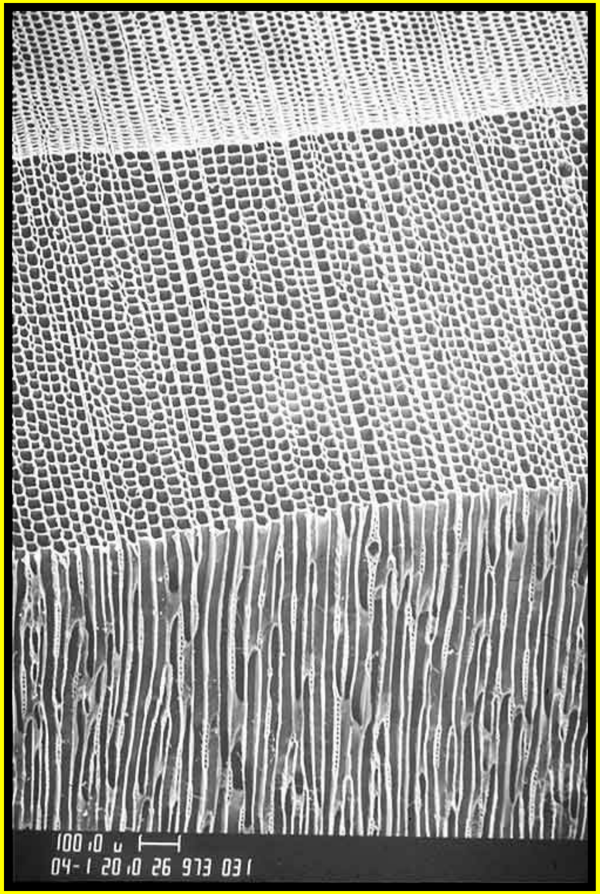
Here is another scanning electron micrograph of a wood which shows the abrupt transition zone from earlywood to latewood. This is Douglas-fir.

Red pine is another species that illustrates the abrupt change of the transition zone. The two large holes on the cross section are resin canals.

In contrast, some species, such as eastern spruce, have a gradual change in cell size from the earlywood to the latewood.



In balsam fir, the transition zone between the earlywood and the latewood displays a gradual change similar to white spruce.

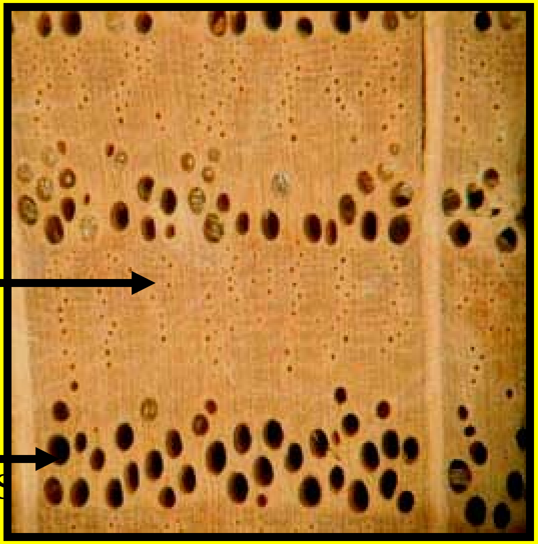


Eastern white pine also shows this gradual transition of cell size from earlywood to latewood.

<u>HARDWOODS</u>

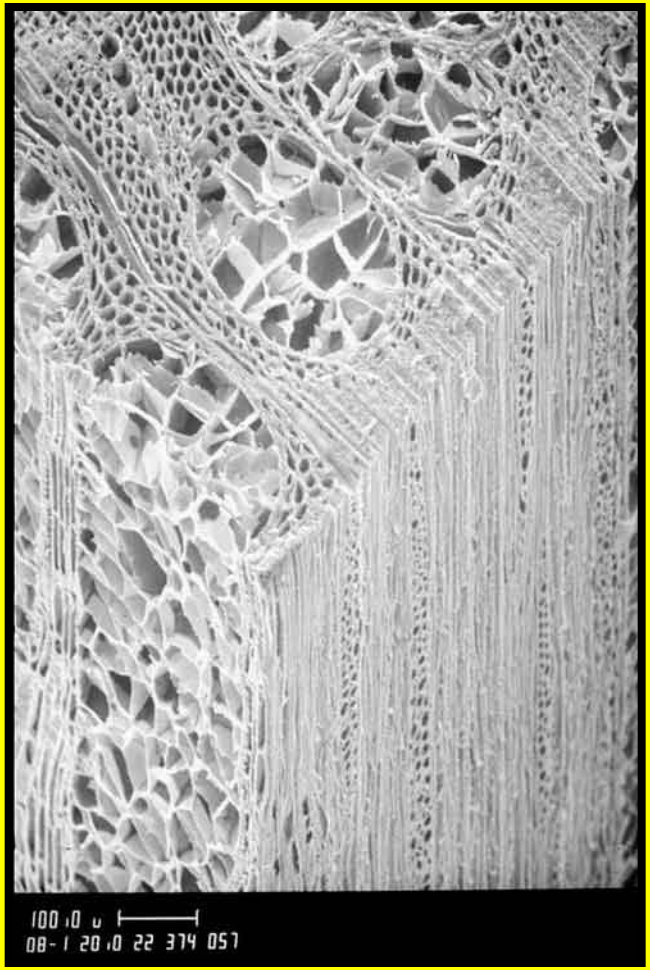
In hardwoods, wood structure is more complicated than softwoods because there are more cell types. This micrograph shows a cross sectional view of red oak (20X). The largest diameter holes in the earlywood zone are cross sectional views of vessel elements. In latewood, these vessel elements are small and sometimes grouped together. Because of this distinctive size and arrangement of the vessel elements, the growth ring is very clear and distinctive. This type of hardwood is called a <u>ring-porous</u> wood.

latewood vessels



earlywood

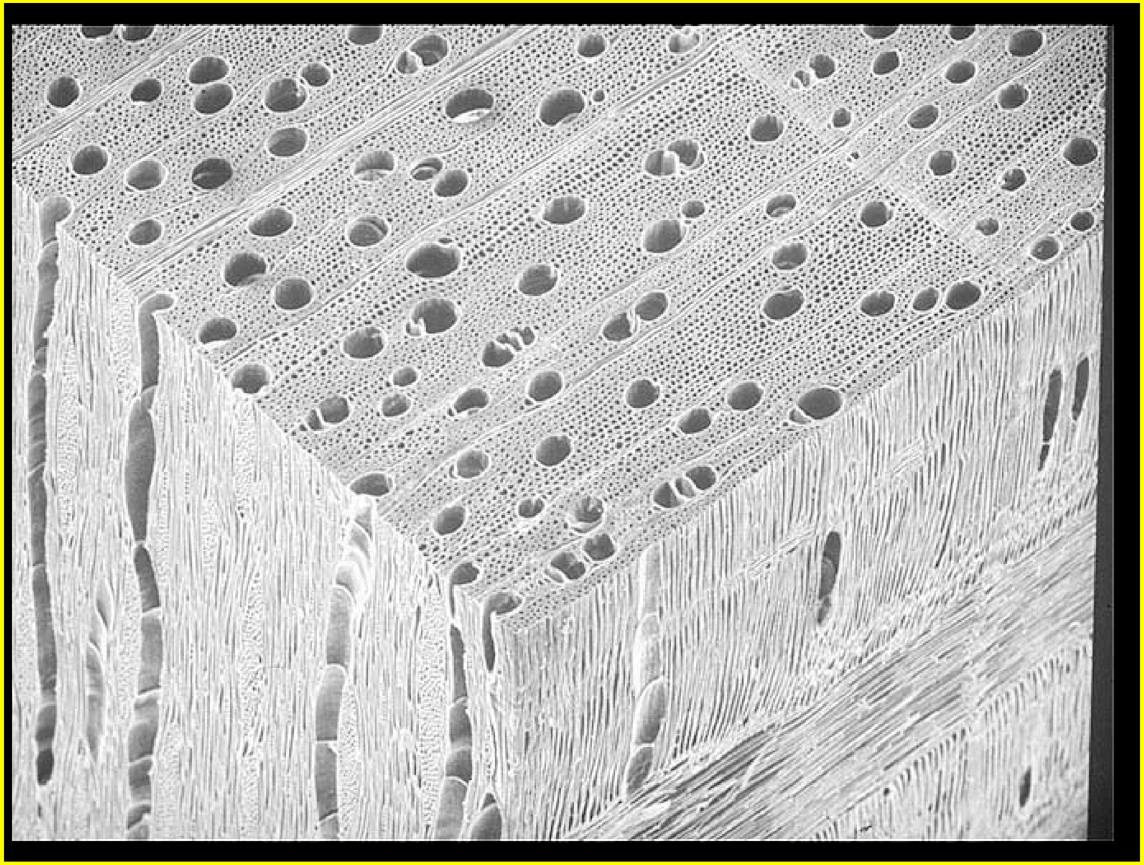
vessel elements



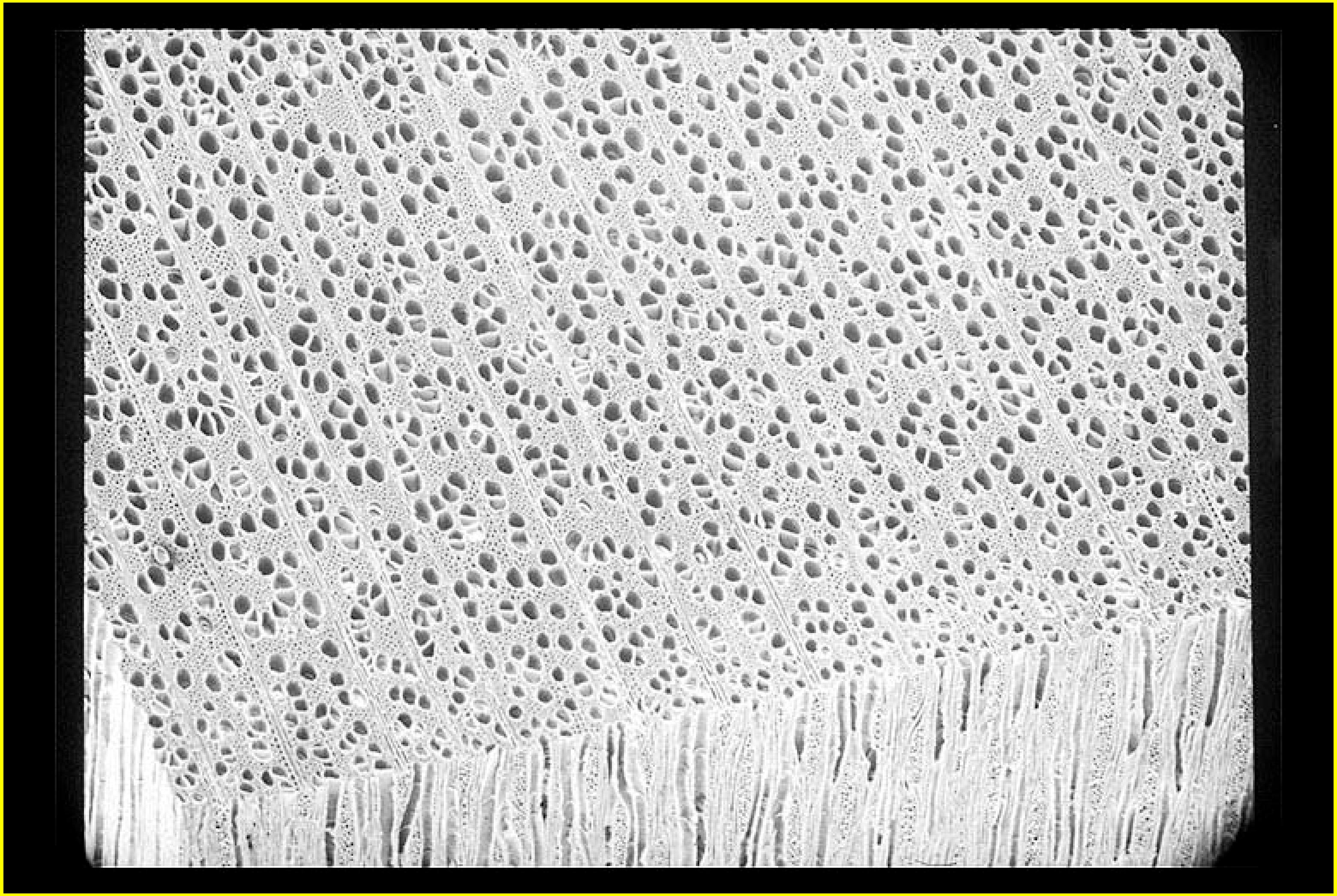
This is Osage-orange. The materials inside the vessel elements are called *tyloses*. Tyloses are ingrowths of adjoining parenchyma (food storage) cells into the vessel elements. Tyloses block the flow of water through the vessels.

White oak is another good example of a ring-porous wood. Large vessel elements are located in the earlywood zone, small vessel elements are in the latewood. Tyloses are visible in the large earlywood vessels.

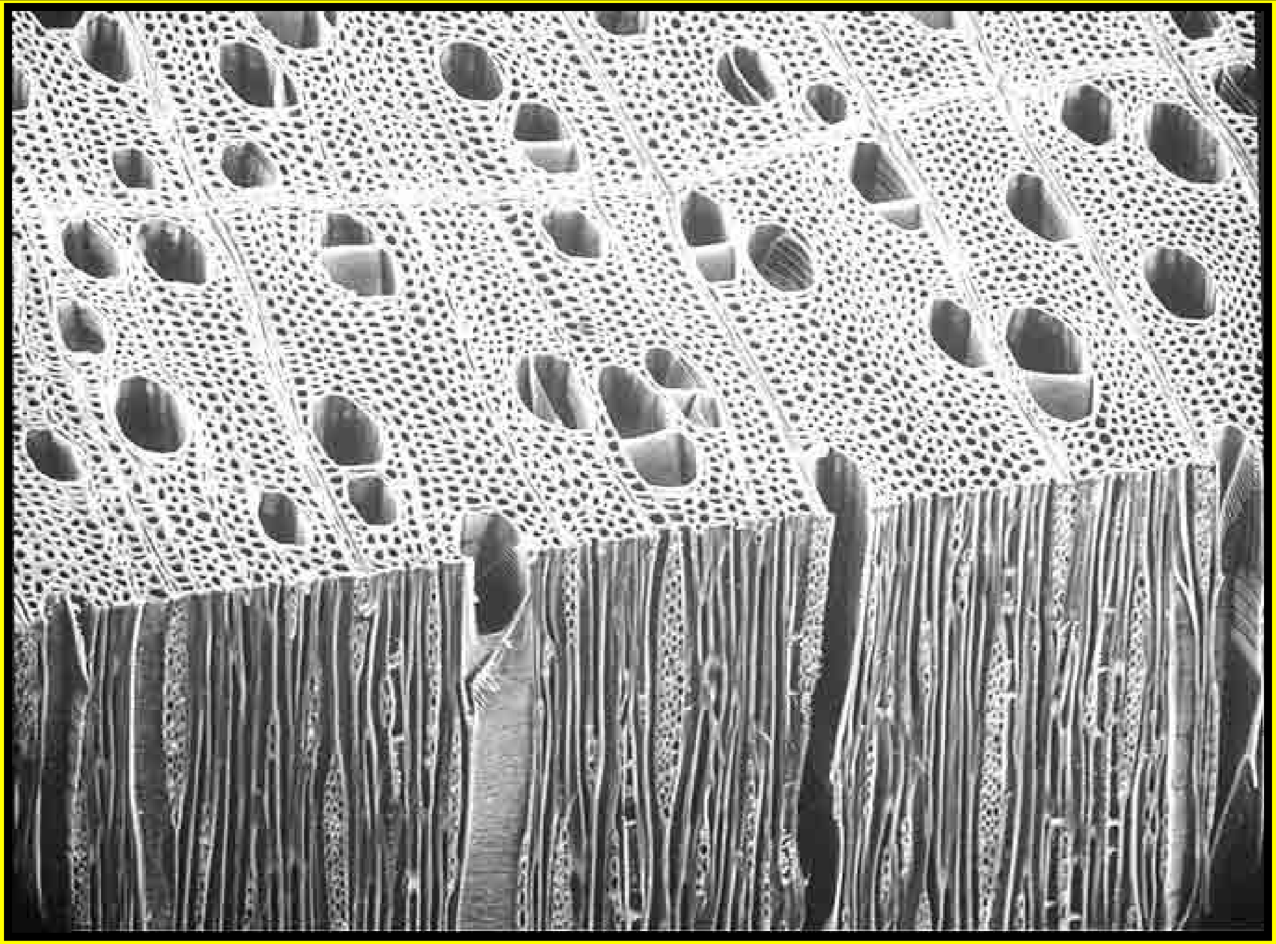
However, in some hardwoods size of vessel elements does not change very much throughout a growing season. A good example of this arrangement is sugar maple. The large circles are the vessel elements. Wood possessing this type of even sized vessel element is called diffuse porous wood.



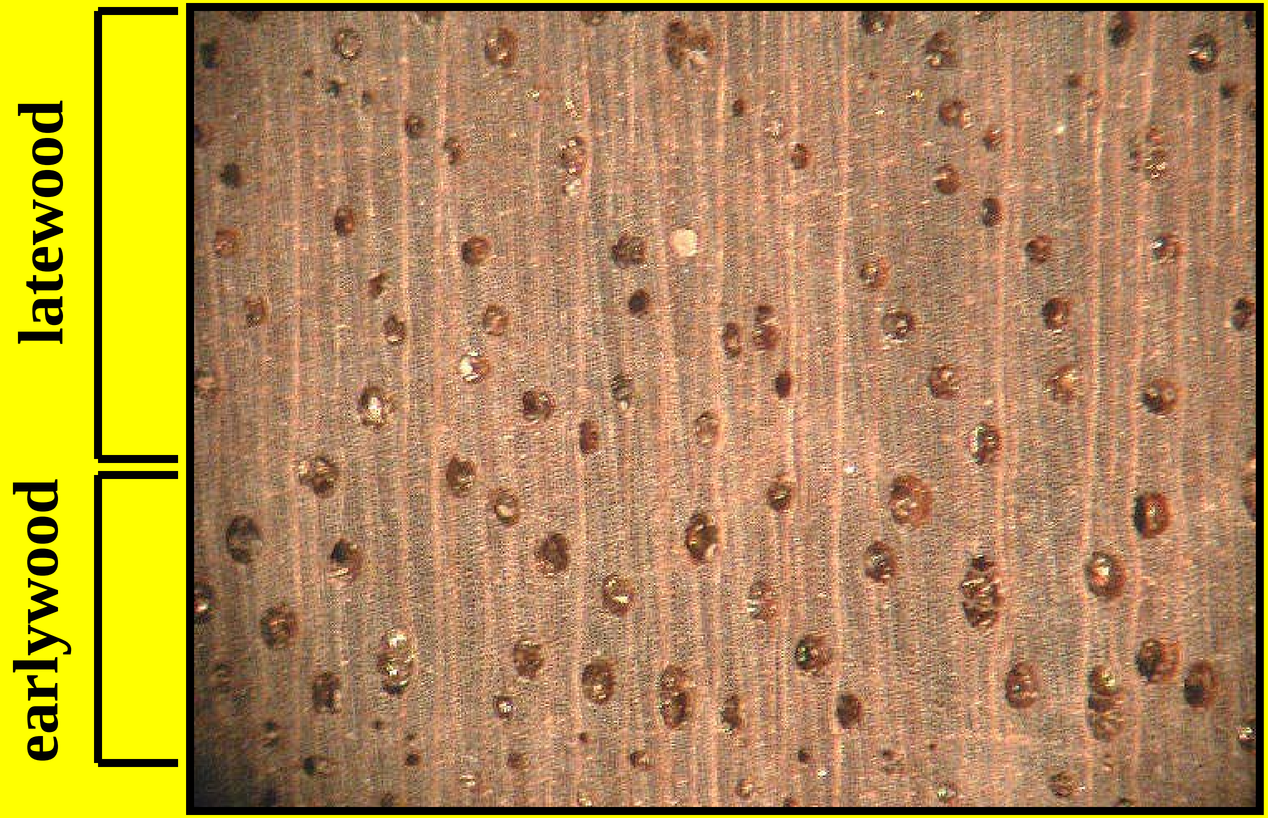
American basswood is another good example of diffuse porous wood.



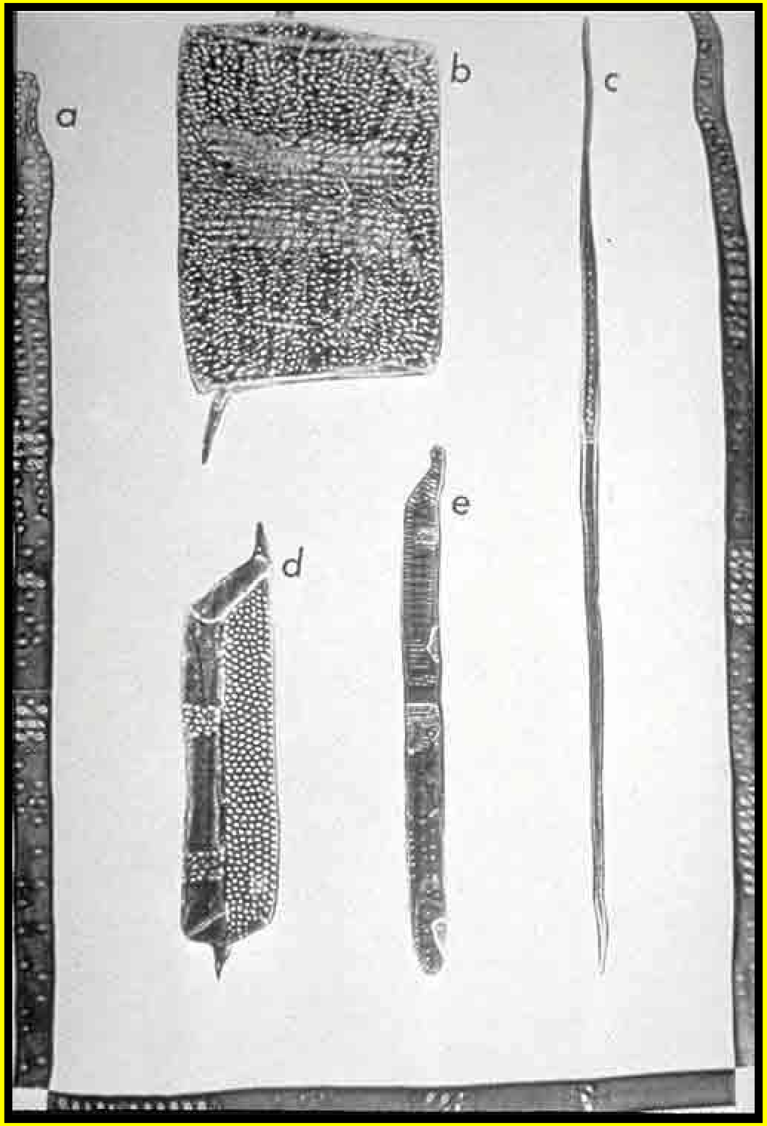
Another diffuse porous wood is sweet birch. The vessel elements in this micrograph are solitary (individual vessels) or grouped in "multiples" of two.



In other hardwoods, the size of the vessel elements change gradually from the early growing season to the late growing season. This type of wood is called <u>semi-ring-porous</u> wood. A good example of this type of wood is walnut. Large vessel earlywood is at the bottom of the picture and smaller vessel latewood is at the top (20X).



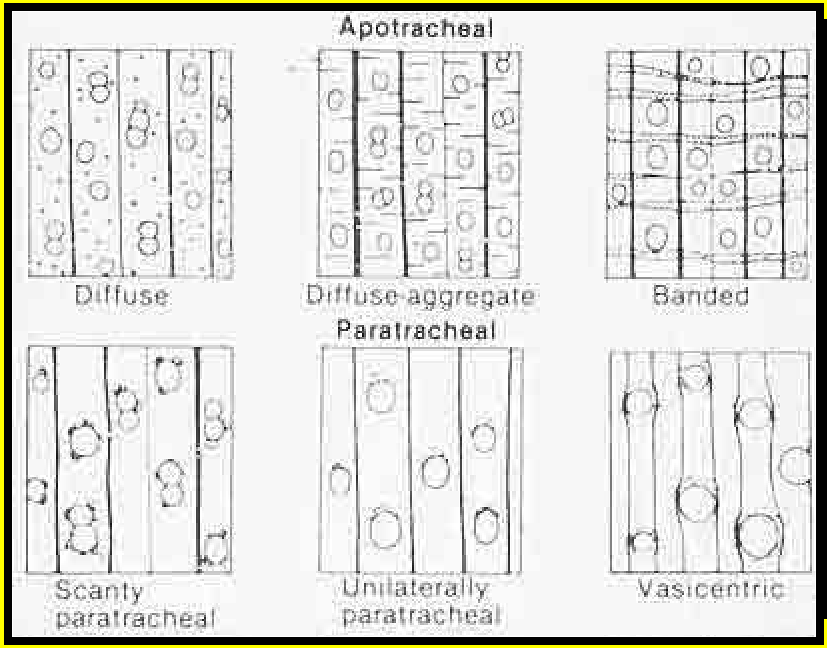
This diagram shows some of the cell types in softwoods and hardwoods. The long cell (a) is called a longitudinal tracheid and accounts for over 90% of the wood volume of softwood. The tracheids are approximately 3 - 5 mm in length and 30 - 50 micrometers in diameter. These long cells, often referred to in the trade as "fibers" are the main cell type which make up writing paper and brown paper bags. In hardwoods, more cell types are found, vessel element (b) is earlywood and (d) is latewood. (c) Represents a hardwood fiber, while (e) is a hardwood tracheid. Hardwood fibers are somewhat similar to softwood tracheids, but are much shorter. The fibers are approximately 1 to 2 mm in length and 20 - 30 micrometers in diameter. Kodak color paper is mainly made of maple and beech fibers. Toilet paper, napkins, and Kleenex are made of poplar fibers.

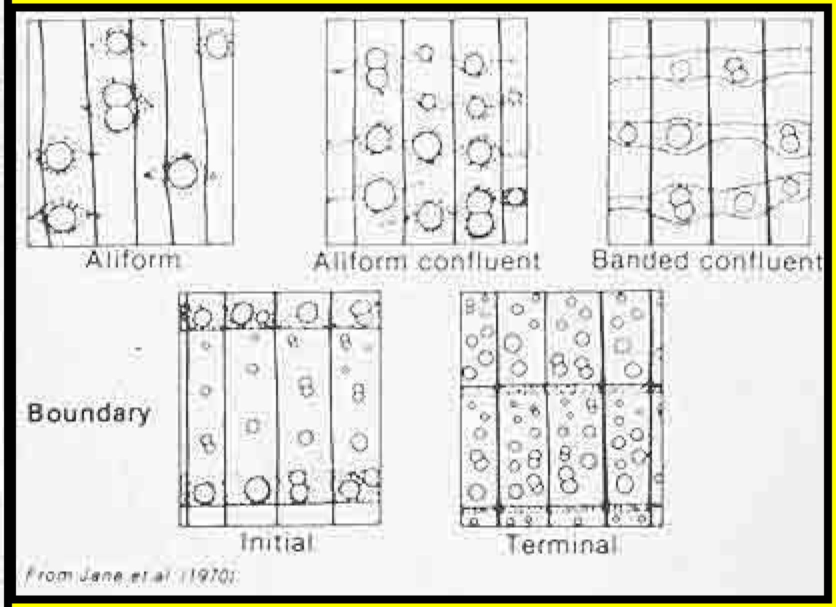


As you have seen in previous slides, hardwood structure is more complicated than softwood. In softwoods, longitudinal tracheids are the major cell type. Therefore, softwood lumber has a uniform appearance. Different softwoods will appear somewhat similar. In hardwoods, because of a greater variety of cell types, appearances are quite different.

Different hardwoods may have their own unique and distinctive patterns. The drawing below shows various types of cell arrangements. The large circles represent the vessel elements. The vertical lines represent the ray cells. The little dots are longitudinal parenchyma cells. Parenchyma are food storage cells. Vessels and rays conduct fluids. Look at the variety of arrangements.

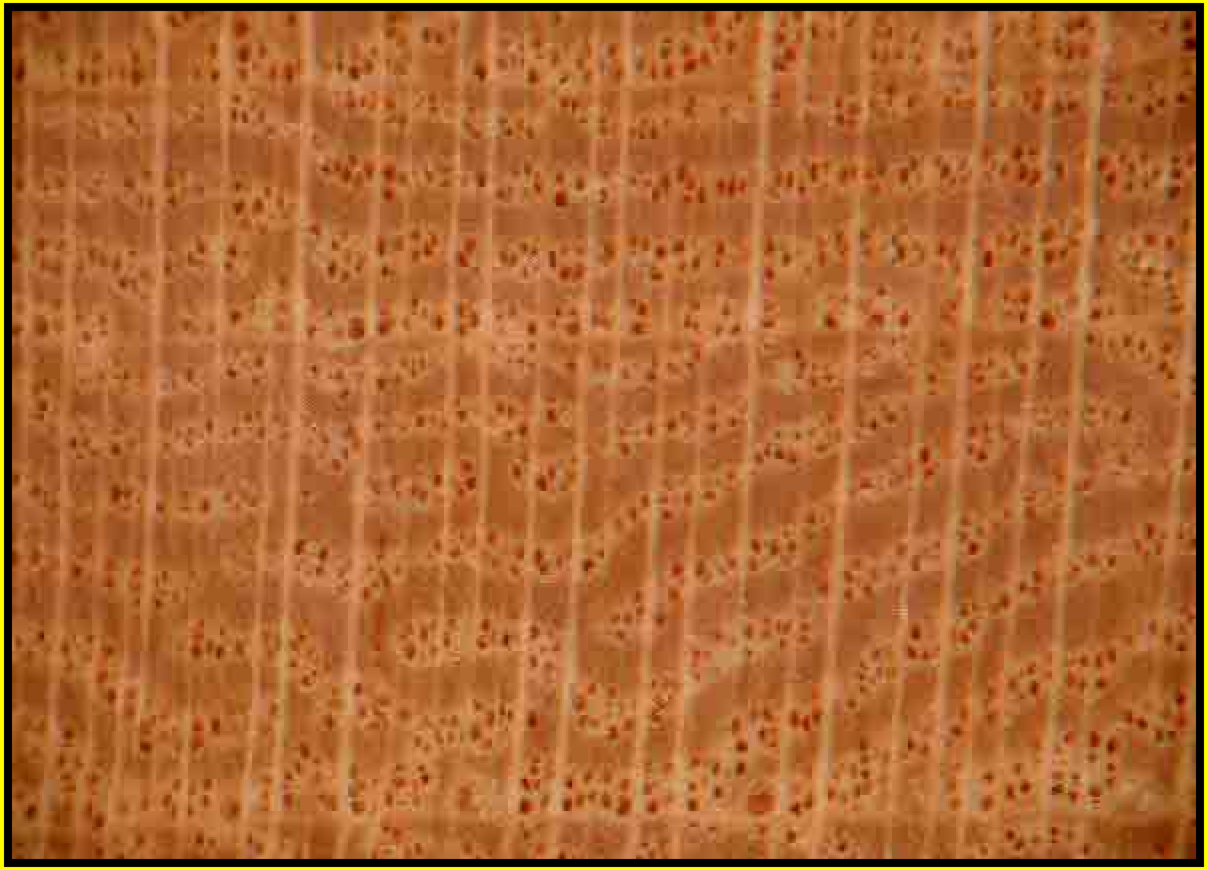
Parenchyma Configurations Occurring in Hardwoods as Seen in Transverse View



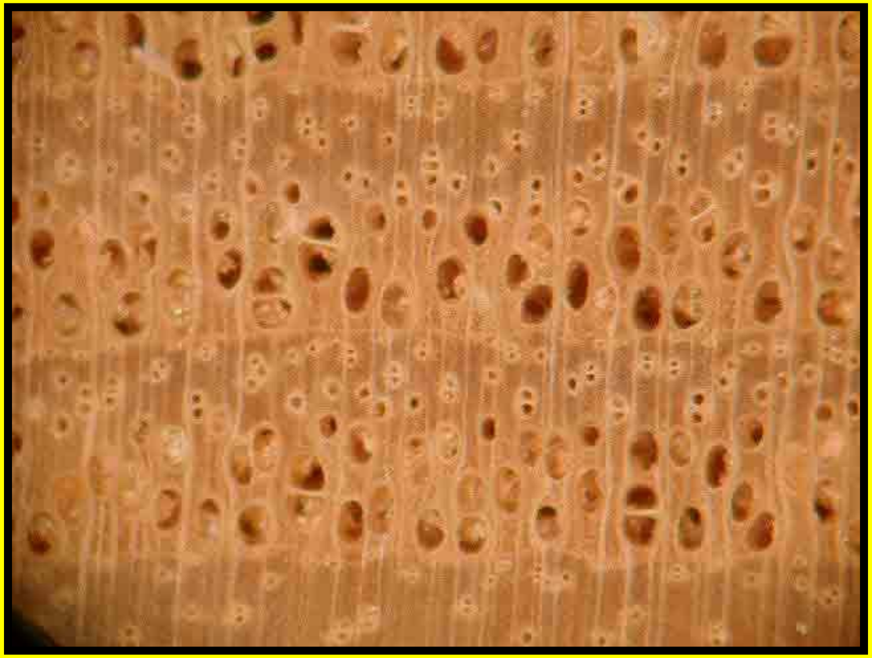


The next five pictures are cross sectional views of hardwoods that illustrate some of the structural detail that can be seen with a hand lens (10 - 16X magnifying glass).

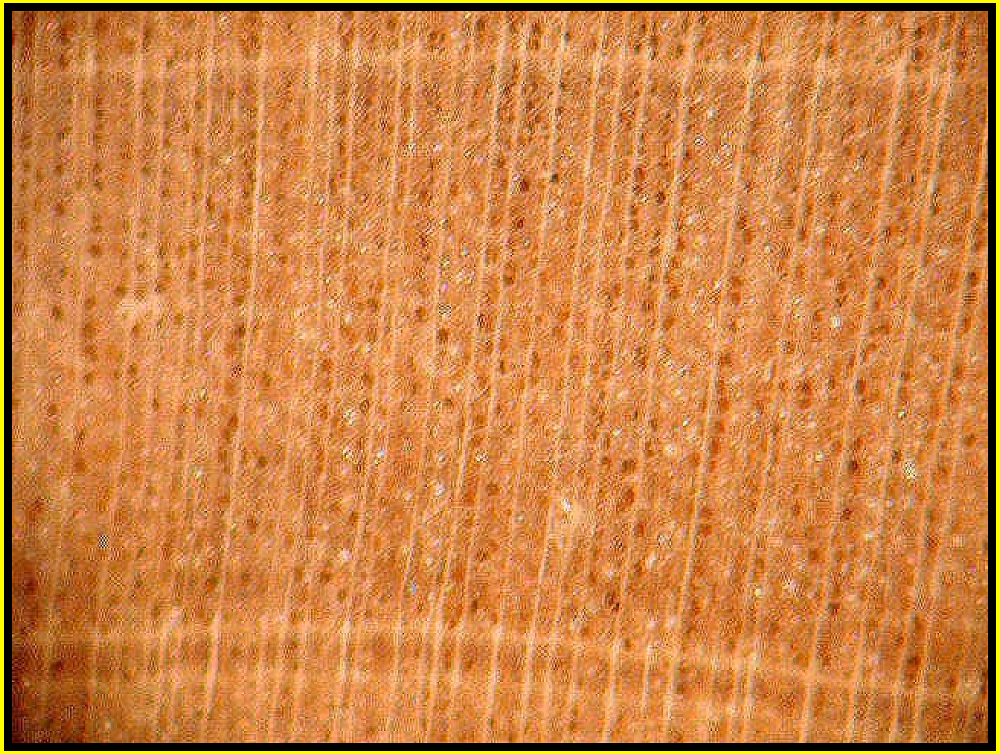
Here is an example of various cell types on the cross-sectional surface of a hardwood. You can see this structure through a regular hand lens (16 X). This is **elm** which is characterized by distinct wavy lines of smaller vessels in the latewood.



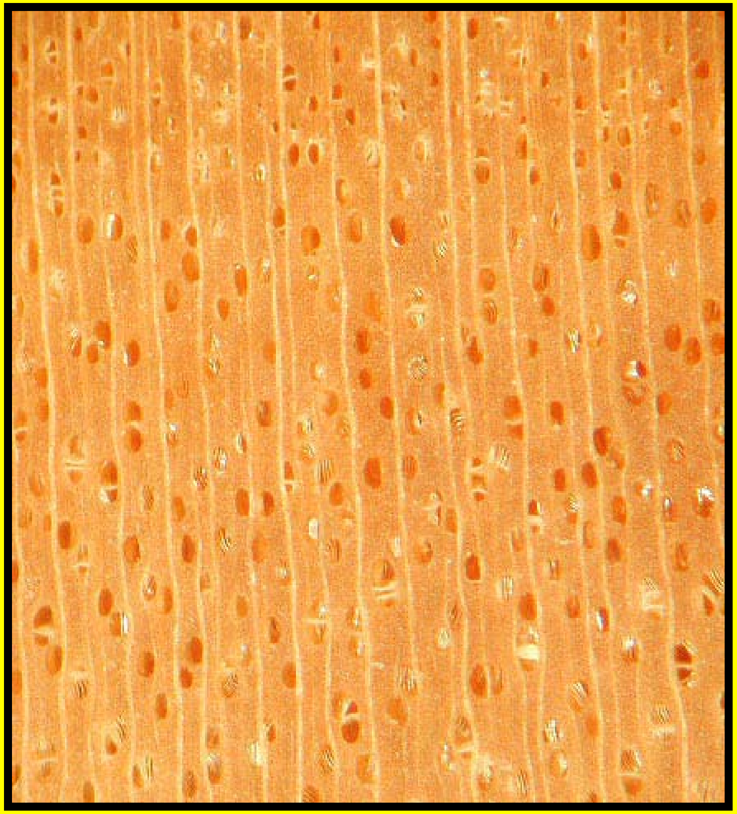
Oak (below) is a hardwood that has distinctive wide rays amongst narrow rays. In the example below, there are two wide rays. Note also the large diameter earlywood vessels and the small latewood vessels, that are arranged in "flame shaped groups" parallel to the rays. (white oak 20X)



In this cross section of ash (above), several rays may be seen, but they are much narrower than those in oak. The latewood vessels are often circled by fine whitish areas which are groups of longitudinal parenchyma cells. 20X



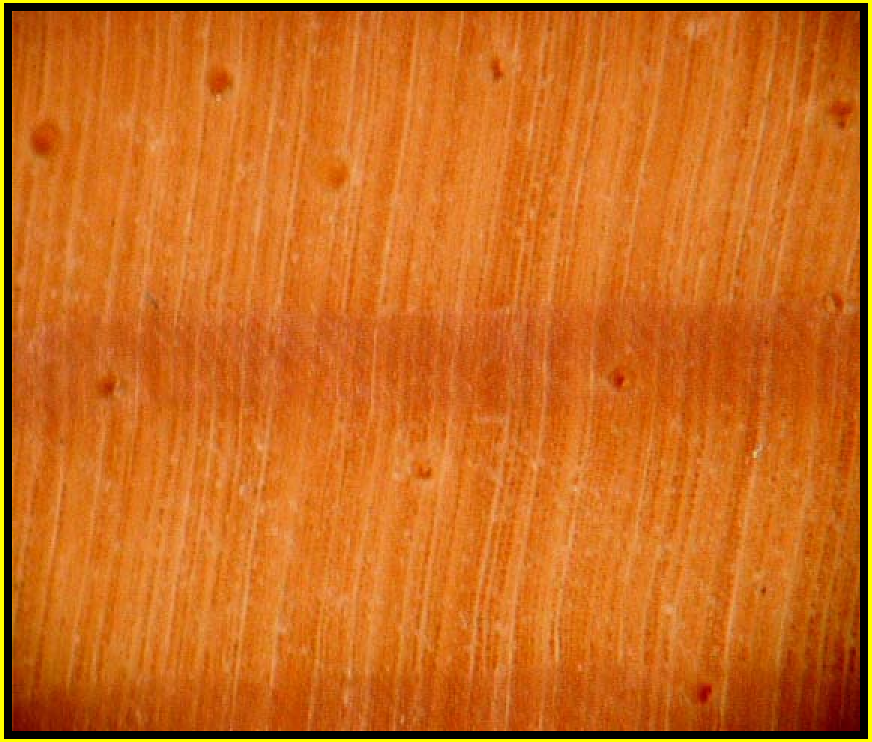
Yellow-poplar has small, diffuse vessel elements and fine rays. The two growth ring boundaries in this photo are readily distinguished as whitish lines, again due to groups of small diameter longitudinal parenchyma cells. 20X



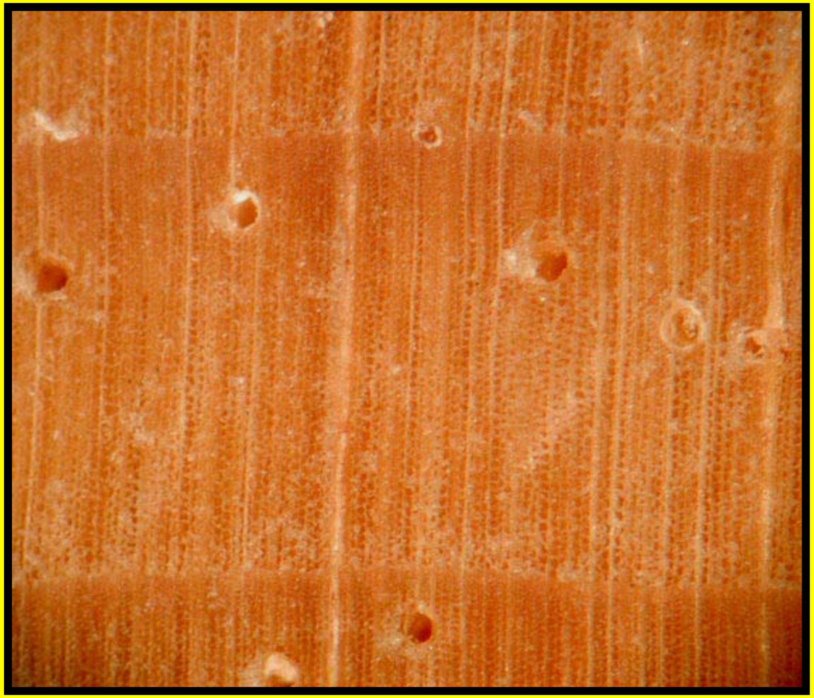
Birch is a diffuse porous hardwood that also has fine rays.20X

SOFTWOODS

Now you know the structure of wood is quite complicated, especially the structure of hard-woods. The structure of soft-woods is much simpler. Here is a close look at pine wood. Most of the cells run vertically and resemble long, straight tubes, these are the tracheids. The circles with a hole at the center (side of specimen) are bordered pit-pairs. These pits are channels through which materials can flow from or into neighboring cells. The block-like holes on top of the specimen are cross sectional views of tracheids. Wood rays are perpendicular to the tracheids.

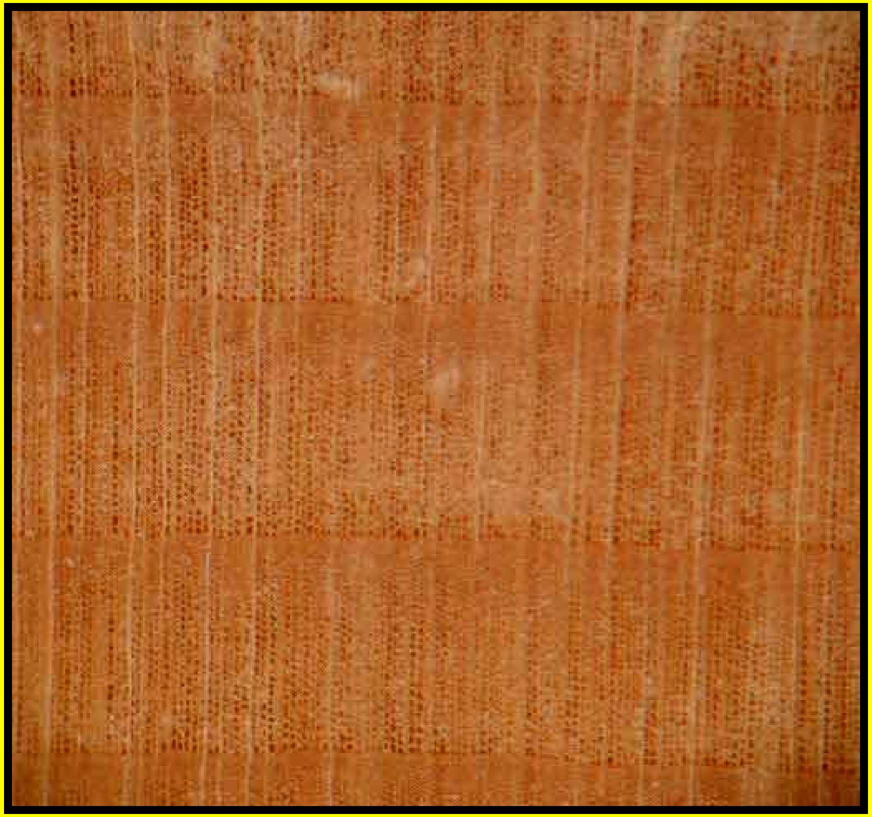


In this view southern yellow pine earlywood is light in color, while latewood is darker brown. The large holes are resin canals. Abrupt transition. 20X



Sugar pine has large resin canals. The growth ring in this sample is primarily earlywood, with somewhat narrow bands of latewood. Gradual transition.20X

Sitka spruce has smaller resin canals than the pines. Note that the canals are located primarily in the latewood (white spots).20X



True fir has no resin canals. Resin canals are found only in pines, spruces, larches, and Douglas-fir.20X

Incense cedar is a wood with a distinctive color and odor. Incense cedar smells like pencils, since pencils are made from this wood.20X

Portions of this eastern hemlock photo shows earlywood tracheids which are large enough to be seen individually. Look for a very fine "honeycomb" structure. Larger diameter tracheids results in a "coarser textured" wood.20X

Ultrastructure of Wood

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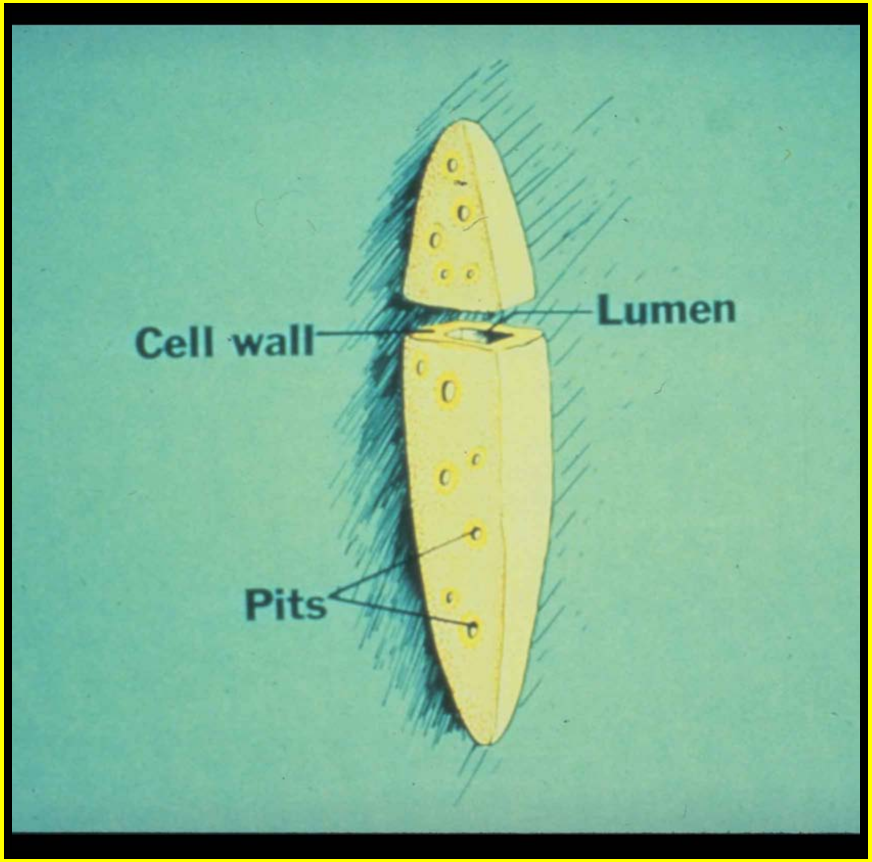
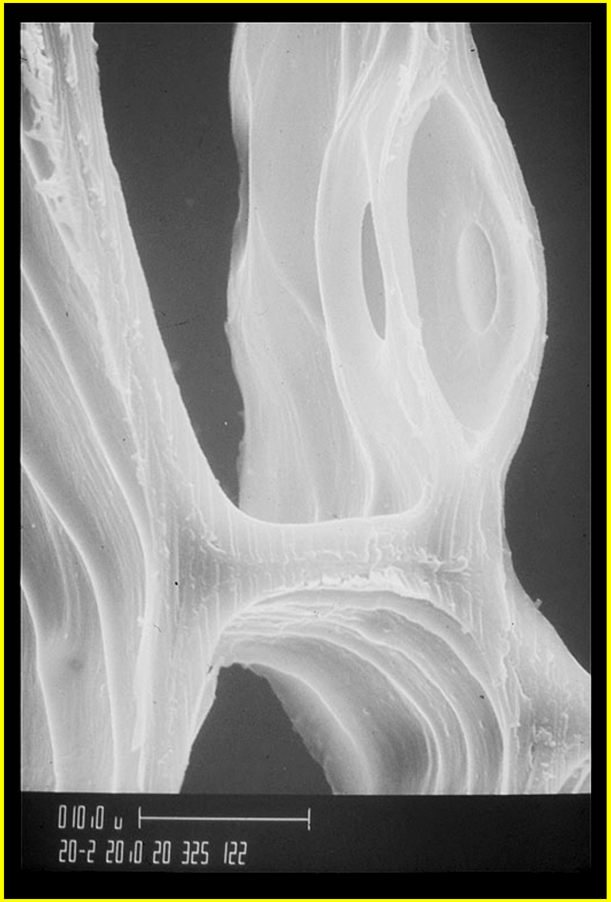
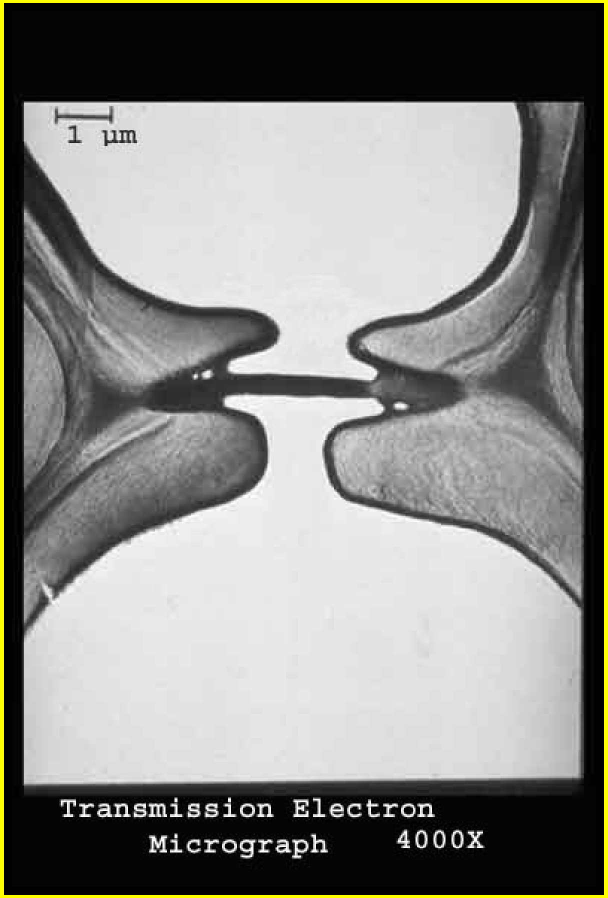
This is a drawing of a single softwood tracheid. Note the pits on the side walls and the "lumen" inside of the hollow cell.

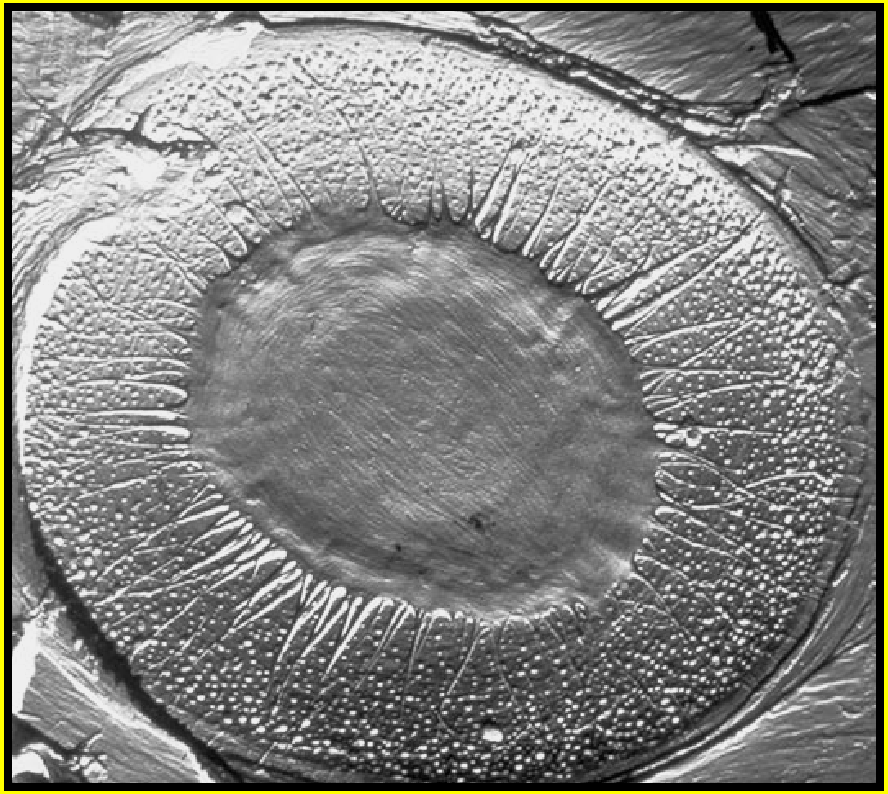




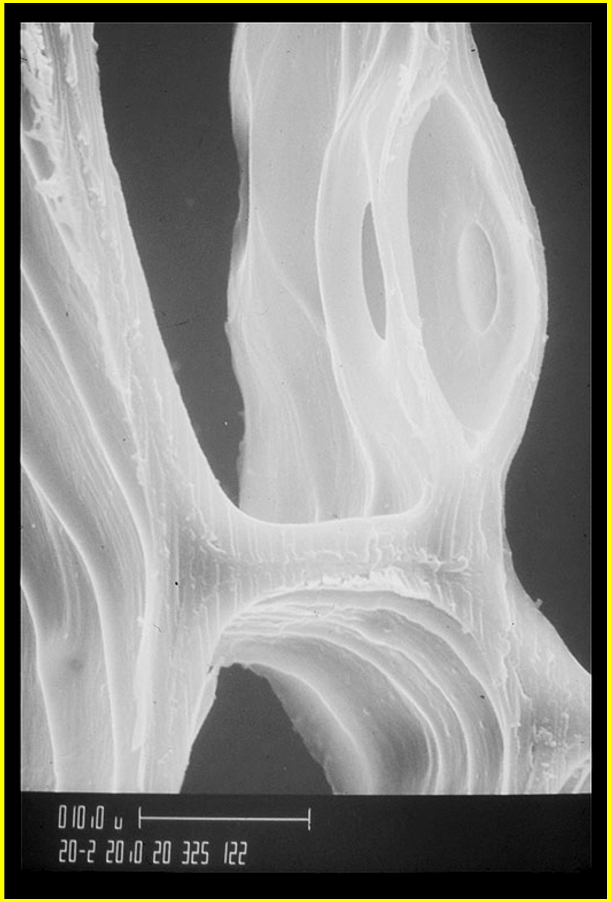


Here are two bordered pits which were observed with a scanning electron microscope. More detail of the structure can by seen in this picture. The two pits form a "pit pair" which is cut open so that we can see the inside or "pit chamber". Portions of three longitudinal tracheid lumens (dark areas) can be seen here.

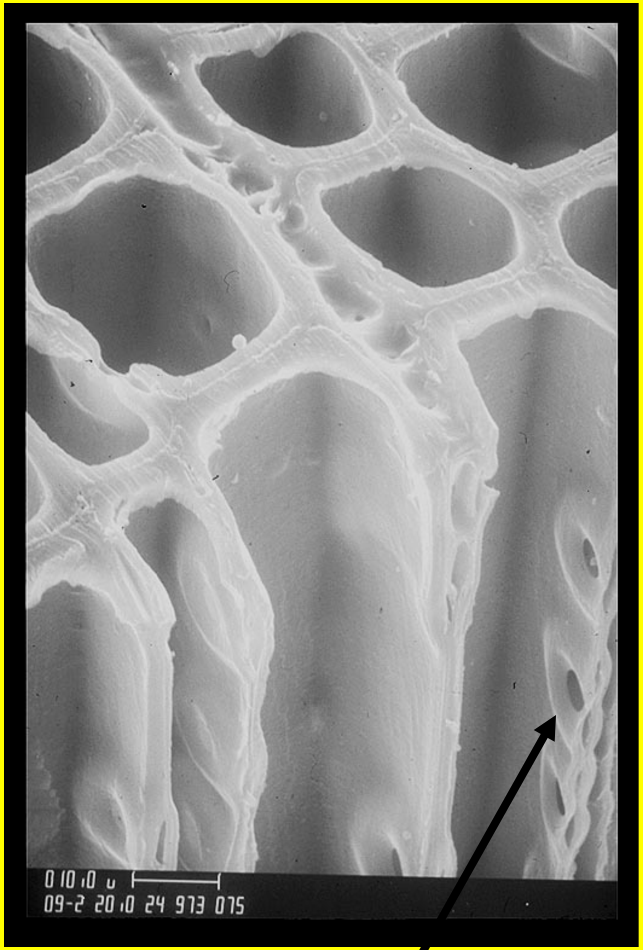
Here is another structural view of a softwood bordered pit pair. Two tracheids are connected by the pit pair. The over-arching pit borders are separated by a central "pit mem-brane" which bisects the pit chamber.



A "face view" of the pit membrane reveals a flat, circular disk suspended by strands, much like a trampoline. The disk is called the torus, and the strands are known as the margo.

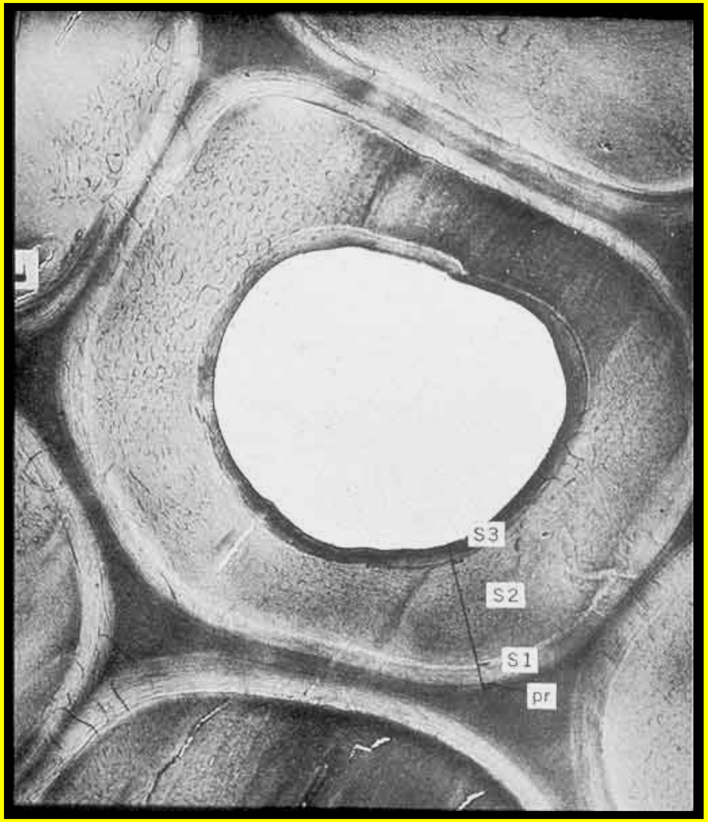


The margo is elastic, and thus the torus can move laterally. Here is a pit pair in which this has happened. This sealed type of pit is called an "aspirated pit". The pathway between the two cells is blocked



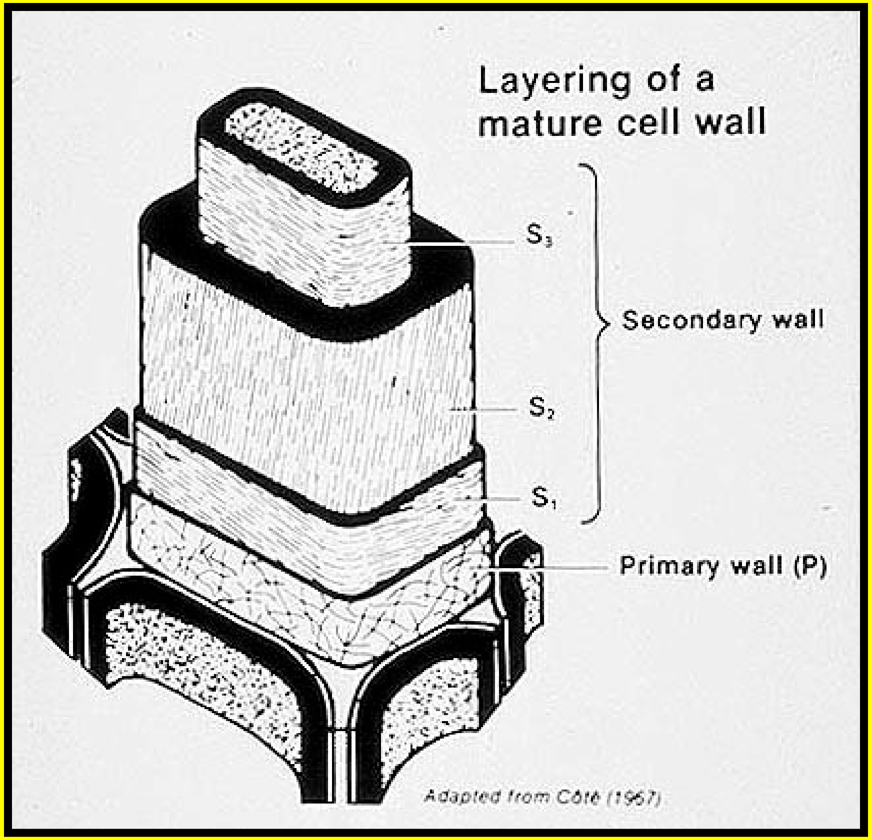
bordered pits

Pit structure is but one of the ultrastructural features of the woody cell wall.



The structure of a cell appears even more complicated if you use the high powered magnification of a transmission electron microscope. The micrograph shows a cross sectional view of a pine tracheid. The cell wall of the tracheid can be divided into various layers as indicated on the picture. The S1, S2, and S3 layers make up the secondary wall. The Pr layer is the primary wall.

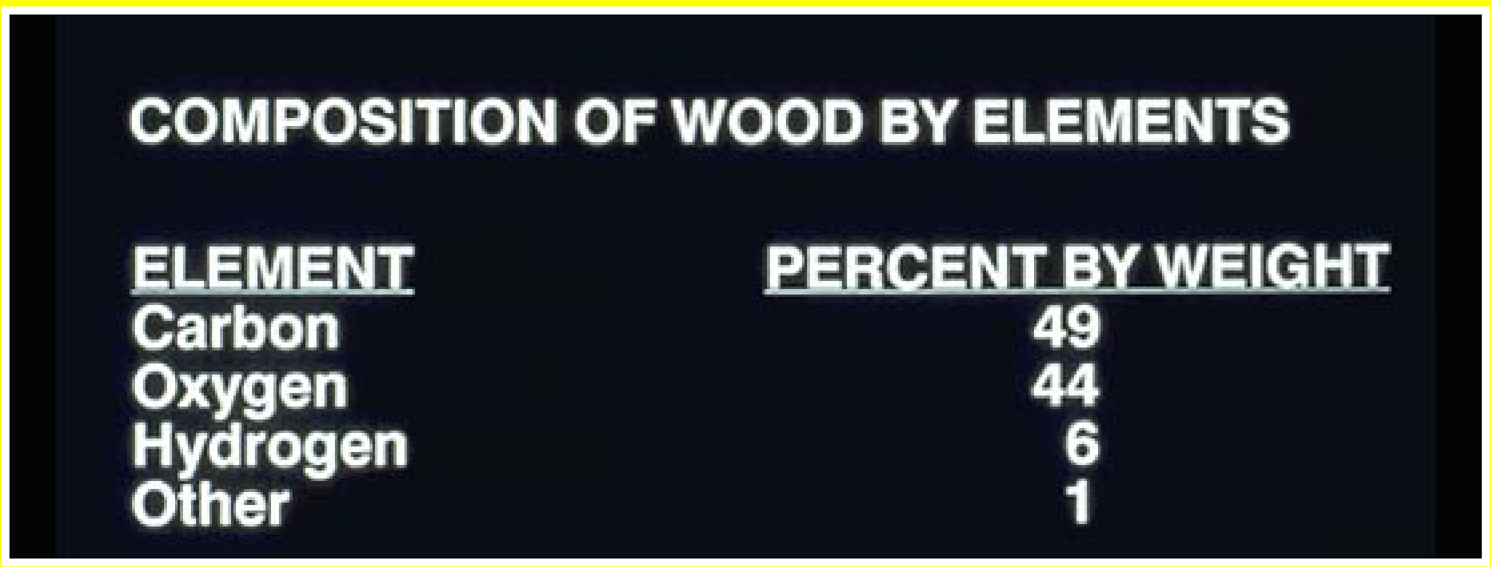
The cell wall is composed of a great number of *microfibrils*, as indicated by the fine lines in this diagram. A microfibril is a bundle of cellulose polymer chains. Orientation of microfibrils is very specific for each layer. As shown here, microfibrils of the S2 layer run more or less parallel to the long axis of the cell, whereas microfibrils of the S1 and S3 run more or less horizontally. Orientation of microfibrils in the primary wall is random. Minute structure of the cell wall largely determines properties of individual fibers as well as wood as a whole.



Wood Chemistry

If we look at still smaller units of structure, we discover the elemental and organic composition of wood.

The three major elements of wood are carbon, oxygen, and hydrogen. They are combined in complex molecules that are then joined into polymers. These polymers provide the structural integrity of wood. In addition, wood contains small quantities of other organic and inorganic compounds.



COMPOSITION OF WOOD BY ELEMENTS

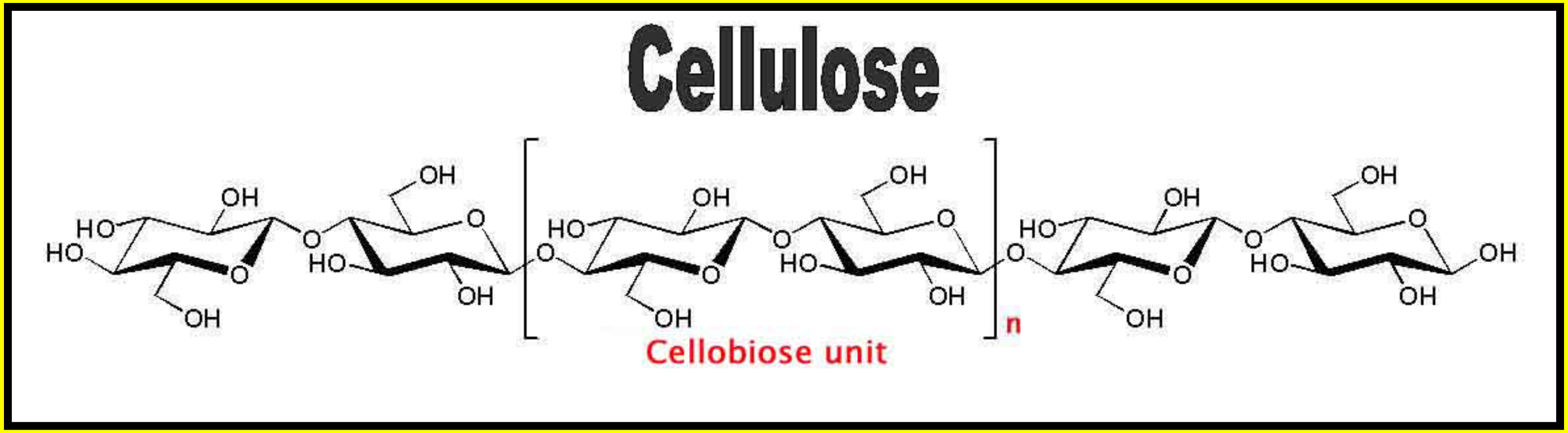
ELEMENT	PERCENT BY WEIGHT
Carbon	49
Oxygen	44
Hydrogen	6
Other	1

The polymers of wood can be classified into three major types: cellulose, hemicellulose, and lignin. The proportion of the three polymers varies between species.

COMPOSITION OF WOOD BY TYPES OF POLYMERS

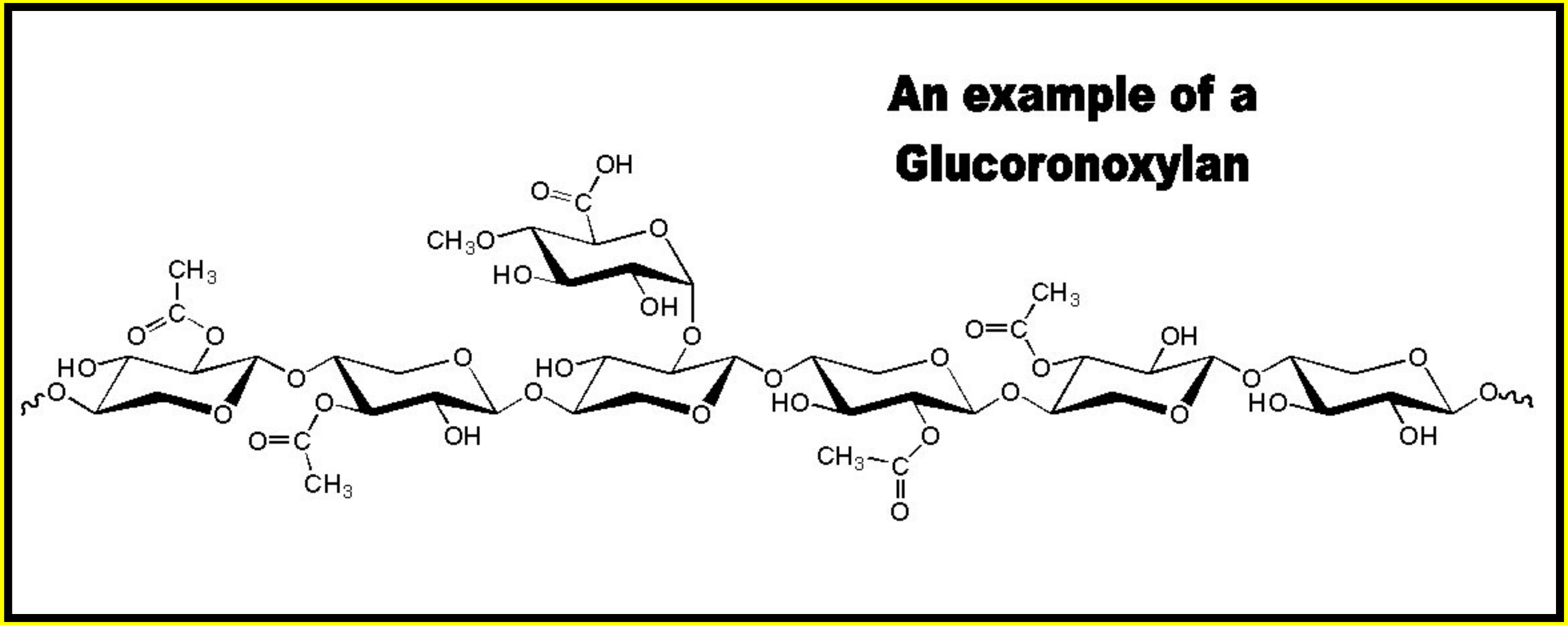
POLYMER	PERCENT OF DRY WEIGHT
Cellulose	40-50
Hemicellulose	20-35
Lignin	15-35

Cellulose is the most important single compound in wood. It provides wood's strength. Cellulose is a product of photosynthesis. In photosynthesis, glucose and other sugars are manufactured from water and carbon dioxide. Glucose is first chemically changed to glucose anhydride by removal of one molecule of water from each glucose unit. These glucose anhydride units then polymerize into long chain cellulose molecules that contain from 5,000-10,000 glucose units. Because of the nature of the bonds between adjacent glucose anhydride units, the basic repeating unit of the cellulose polymer consists of two glucose anhydride units, and is called a cellobiose unit.

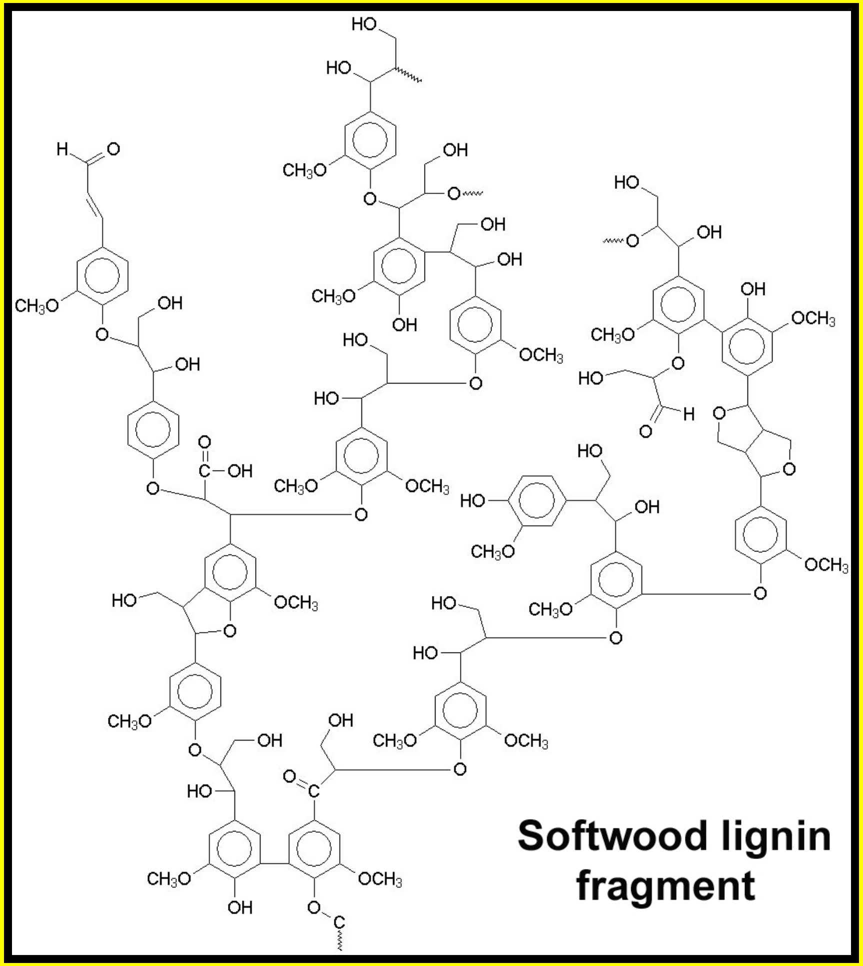


Cellulose polymers are then arranged in a crystalline form where adjacent polymers are bonded together laterally by the hydroxyl groups (OH) that occur in each cellobiose unit. These lateral bonds are not as strong as the end-to-end bonds that join the glucose anhydride units into long chain molecules, but they are strong enough to provide the strength of wood and also affect other physical properties.

Hemicelluloses are a group of compounds similar to cellulose, but with a lower molecular weight, i.e., the number of repeating end-to-end molecules is only about 150 compared to the 5,000-10,000 of cellulose. They are produced from glucose as well as the other sugars (such as galatose, mannose, xylose, and arabinose) produced in photosynthesis. Hemicelluloses are thus a mixture of various polymerized sugar molecules. In some cases the polymers are straight chained like cellulose, but polymers with short side chains are also common.



Lignin is a class of complex, high molecular weight polymers whose exact structure varies. It is an amorphous, i.e., not crystalline, polymer that acts as a binding agent to hold cells together. Lignin also occurs within cell walls to impart rigidity. Like cellulose and hemicellulose, lignin is made from carbon, oxygen, and hydrogen. However, these elements are arranged differently so that they are not classified as carbohydrates. They are instead classified as phenolics, and the polymer is based on the phenylpropane unit.



original source: Adler, E. 1977. Lignin chemistry-Past, present and future. Wood Sci. Technol. 11, 169-218.

There are many other chemical compounds in wood. They usually make up only a small percent of the total composition of wood, but in some cases can be considerably more. In most cases these compounds are not an essential part of the structure of wood. One class of compounds is called extractives, and represents a wide range of classes of compounds. One group of extractives that is important commercially is the oleoresins, from which turpentine and various other oils and rosin are derived. Another group of extractives are polyphenols, which include tannins, flavones, kinos, and lignans.

Other organic compounds include gums, tropolones, fats, fatty acids, and waxes.

There are also inorganic compounds in wood. They are generally called ash as a group. Calcium, potassium, magnesium, manganese, and silicon are common elements in wood. Silicon is important because it is abrasive and causes dulling of machine tools.

Application of Wood Structure

Wood identification is possible with a working knowledge of wood anatomy. Basic knowledge of wood structure is essential to determining the best use for each wood type.

Extending the structure concept to the molecular level permits discovery and use of many chemical compounds which may be isolated or synthesized from wood.

Thus, a study of structure is the foundation upon which wood science and technology is built and is fundamental for a material science approach to wood as a renewable engineering material.

A number of books are available on the topic of wood structure and wood chemistry. A couple of recommend references are:

Core, H.A., W.A. Cote, and A.C. Day. 1979. Wood Structure and Identification, 2nd ed. Syracuse University Press, Syracuse, New York. Note: This book is out of print but occasionally available at used book stores and via the internet.

Fengel, D. and G. Wegener. 1984. Wood: Chemistry, Ultrastructure, Reactions. W. DeGruyter, New York.

Hoadley, R. B. 1990. Identifying Wood: Accurate Results with Simple Tools. Taunton Press, Newtown, CT.

Kozlowski, T.T. and S.G. Pallardy. 1997. Physiology of Woody Plants, 2nd ed. Academic Press, San Diego, CA.

Panshin, A.J. and C. deZeeuw. 1980. Textbook of Wood Technology, 4th ed. McGraw Hill Book Company, New York.

Sjostrom, E. 1981. Wood Chemistry: Fundamentals and Applications. Academic Press, New York.

The Nature of Wood and Wood Products. 1996. CD ROM, Forest Products Society, Madison, WI. http://www.forestprod.org/

Additional information concerning careers in the general field of wood science and technology, including those in production management, process engineering, technical sales, and product development can be obtained by contacting:

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