Wood

A look at this fundamental material

by R. Bruce Hoadley

Wood comes from trees. Not forgetting this obvious statement will help us work with wood as it really is, not as we wish it were. For wood has evolved as a functional tissue of plants, not as a material to satisfy the needs of woodworkers.

For example, we all know that most of the wood we use comes from the trunk, bole, or stem, as it is sometimes called, not from the unseen root system below or the crown of limbs, branches and twigs that support the foliage. Some of the most prized wood does come from crotches and irregularities, such as burls or knees, but for the most part we prefer the regular grain found in straight trunks.

But sometimes we come across a board that is different from other boards. It warps severely, or pinches our saw blade as we rip it, or doesn't take a finish quite like the other boards. What we're working with is a piece of reaction wood — wood taken from a trunk that is leaning or from a branch that doesn't grow straight up (by definition most branches are made of reaction wood).

This is an extreme case, but it does illustrate why it's important to remember where wood comes from and also to know something about its anatomical structure. As woodworkers, we usually know far more about our tools than we do about our materials. But as the architect Frank Lloyd Wright once said, "We may use wood with intelligence only if we understand it."

Understanding the difference between sapwood and heartwood, between earlywood and latewood, between "hardwoods" and "softwoods," between ray cells and longitudinal cells, between ring-porous woods and diffuse-porous woods, between vessels and fibers, and so on, may give us a better understanding of why wood behaves as it does, especially when we're trying to shape it, finish it, or preserve it.

Perhaps the best place to start is at the molecular level. Wood is a cellulose material, as is cotton. And because it's cellulosic, it is hygroscopic — it absorbs water readily and swells and shrinks accordingly (therein much of the problem of the "movement of wood").

The cellulose material that wood is composed of is pretty much the same for all species. It's not until we start looking at wood at the cellular level that different woods start to look "different." (And even here this is not necessarily the case. The sapwood of many species can look very much alike. Then it's not until the sapwood turns into dead heartwood that differences among some species really become apparent).

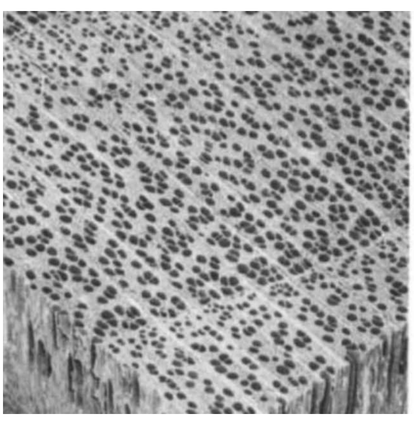
In any event, the cellulosic material is arranged into tubular cells that run longitudinally along the length of the trunk or branch. There are three varieties of such cells — vessels, tracheids, and fibers. Vessels have a large diameter, thin walls, and are very short (but they stack together like drainage tiles). At the other extreme are fibers — narrow diameter, thick walls, and long. In between are tracheids — moderate diameter, moderate thickness, and also very long.

Because they're so large in diameter, vessels are good for conducting sap up the tree, but their thin walls don't contribute much to mechanical support. On the other hand, the thick walls of fibers make them good for support, but their narrow diameter doesn't do much for sap conduction.

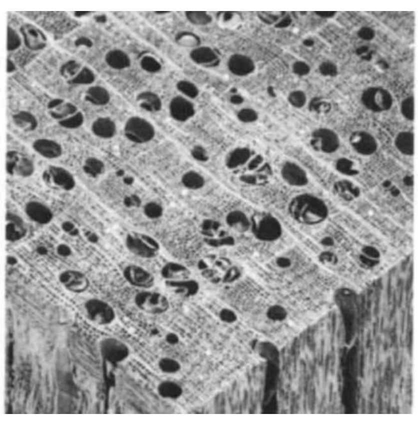
In between are the all-purpose tracheids, which can provide both sap conduction and physical support moderately well. In fact, one distinction between the so-called hardwoods and softwoods is this difference in cell structure. Softwoods, or conifers, are composed mainly of all-purpose tracheids. They are believed to have evolved earlier than hardwoods. Hence their more primitive structure, with no cell specialization. On the other hand hardwoods, or deciduous trees, do have cell specialization — vessels for sap conduction, fibers for support, and tracheids for both.

The tracheids of conifers are about 100 times as long as they are wide. Thus their excellent paper-making qualities. Among

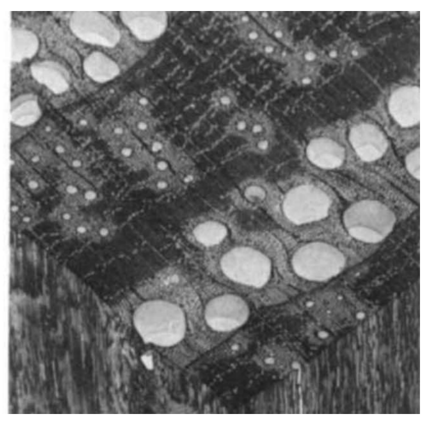
Cherry (diffuse porous)



Black walnut (semi-ring porous)



Red oak (ring porous)



Variations in porosity between earlywood and latewood can create problems in staining. Conifers such as Douglas fir (left) have earlywood that is lighter but more porous than the latewood. Therefore, stain reverses the grain effect, as in a photographic negative. With hardwoods like red oak (right), the earlywood pores are already darker. Lines in the light latewood are rays.

conifer species, however, there can be a three-fold range of diameters, from fine red cedar to coarse redwood. This texture range due to tracheid diameter also affects the smoothness of surface or evenness of staining that can be achieved in woodworking.

If wood were composed strictly of these longitudinal cells, whether vessels, tracheids, or fibers, it would be much less complex than it really is, and really much different, for consider how and where a tree grows.

Growth occurs in the thin layer of reproductive tissues, called the cambium, that separates the wood from the bark. This tubular reproductive sheath, several cells thick, migrates ever outward, leaving behind layers of newly formed wood (which remain fixed in place forever), and also forms new bark in front of it (which will eventually be crowded out by the newer bark cells, and by the ever-expanding girth).

The cambial cells vary in content with the growing seasons. During growth the content is quite fluid; during dormancy there is a thickening. As a result, wood cut in summer usually loses its bark upon drying, while winter-cut wood does not, an important fact for those wishing to incorporate bark into their woodworking projects.

In addition to vertical movement through the sapwood, there must be provision for horizontal sap movement. That's where the ray cells come in. They are oriented radially outward from the center or pith and are stacked vertically in groups called rays to form flattened bands of tissue. The rays not only carry the nutrients horizontally through the sapwood, but also store carbohydrates during the winter.

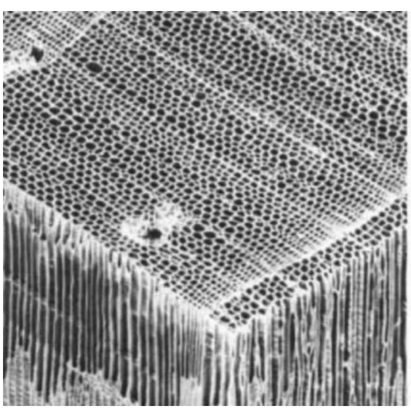
The rays are not great in number — typically they represent less than 10 percent of the wood volume — but they are significant for more than food conduction and storage. Their size — ranging from microscopically small in all softwoods to visibly big in many hardwoods — helps in wood identification. (For example, in red oak rays are less than one inch high; in white oak, they're one to four inches.) And structurally they influence the shrinkage of wood and the formation of checks.

Wood cells shrink and expand mainly across their girth, not their length, as they give off or take on moisture. That's why wood moves across the grain, not with the grain. But because ray cells are aligned across the grain (radially) they inhibit the longitudinal cells from expanding as much in a radial direction (towards or away from the center) as in a tangential direction (around the circumference). In effect, the radial cells act as restraining rods imbedded in the wood. That's why wood contracts or expands only half as much radially as tangentially.

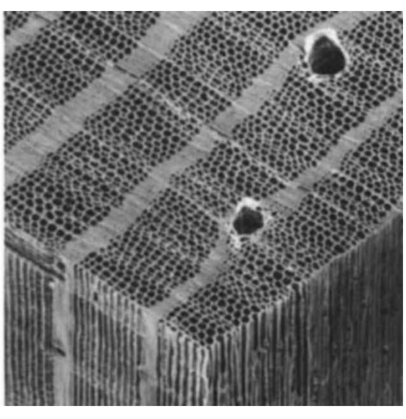
The rays also form planes of weakness in hardwoods. End and surface checks, as well as internal honeycombing, will regularly develop through the rays in woods like oak.

So far we've discussed mainly the shape of wood cells, not

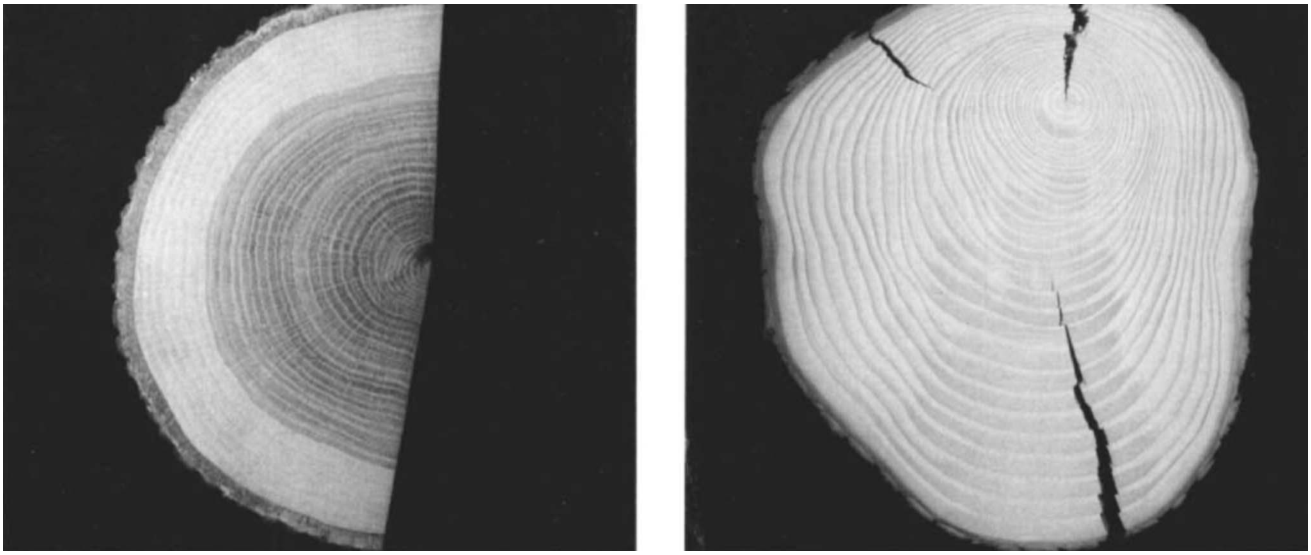
Eastern white pine (even grain)



Southern yellow pine (uneven gram)



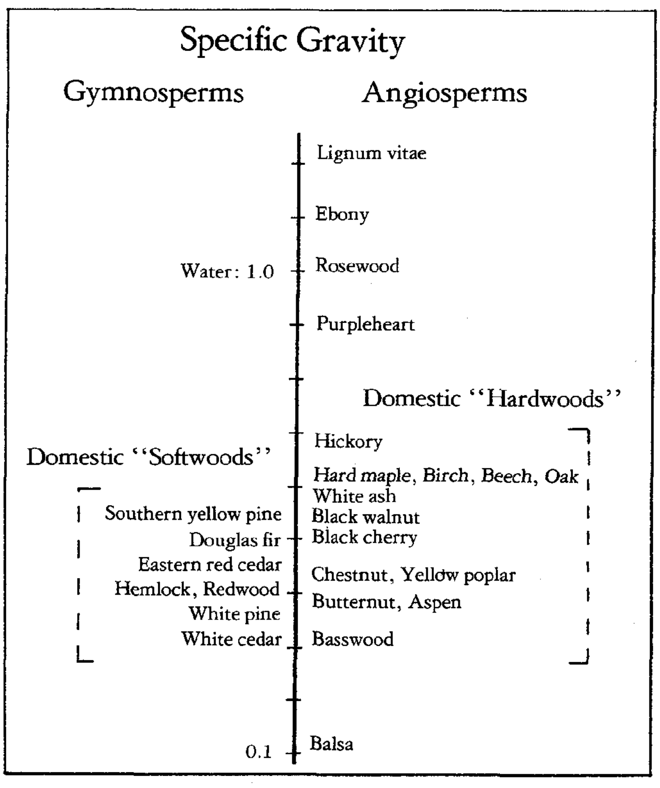
Earlywood/latewood variations are clearly visible in scanning electron microscope photographs. All the samples are oriented the same way, with the growth rings parallel to the right-hand face. Large "holes" in the pines are resin canals that help in sealing over injuries in the living trees. Pictures are from Structure and Identification of Wood, *by Core, Cote, and Day, a book to be published by the Syracuse University Press.*



Red oak half-cross-section (before shrinkage) shows pith dot at center, dark heartwood, light sapwood, and cambium sheath where bark and sapwood meet. Rays are clearly visible in the heartwood radiating outward. At right is the section from a leaning hemlock tree. Reaction wood appears as abnormally wide latewood on lower side of rings.

whether they're alive or dead. Live cells, called parenchyma, contain living protoplasm and are capable of assimilating and storing carbohydrates. In softwoods or conifers, the parenchyma are generally limited to the ray cells, but in hardwoods, longitudinal vessels and tracheids, as well as ray cells, can be parenchyma. It differs from species to species.

But in general, most longitudinal cells lose their protoplasm soon after development by the cambium and become non-living prosenchyma useful for sap conduction or mechanical support, but not for food storage. (When such a change takes place, the cell wall structure remains unchanged. Only the protoplasm in the center cavity of the cell disappears.)



Differences in the specific gravity (the density relative to water) shows that the range of densities of domestic "hardwoods" and "softwoods" overlaps.

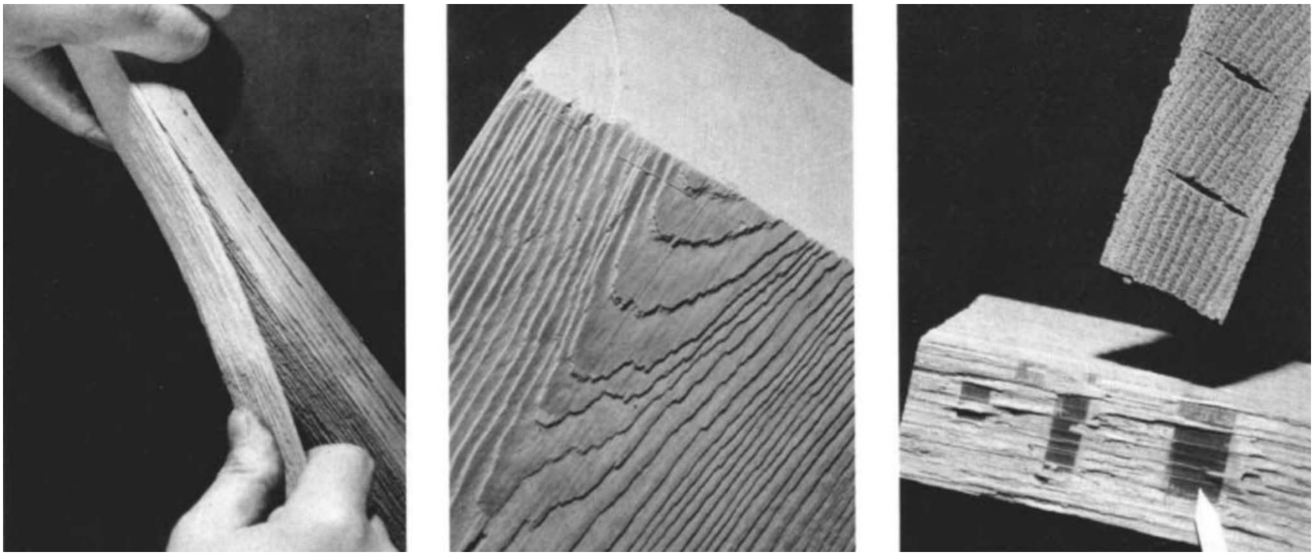
Thus the wood nearest the cambium, where sap conduction and food storage can take place, is called sapwood. As the tree grows and the oldest sapwood is no longer needed for water conduction, a gradual transition to heartwood occurs. This transition is accompanied by the death of parenchyma and loss of both food storage and conductive functions, with the heartwood serving the tree only as a supporting column.

Heartwood formation is accompanied by the deposition in the cell walls of chemical additives called extractives which can change the color of the wood. Whereas most sapwood is a cream to light yellow or light tan color, extractives are responsible for any rich browns, reddish or other contrasting dark colors the heartwood may have, as is characteristic of species like walnut, cherry, or red cedar. In some woods, such as spruce or basswood, the extractives may be insignificant or colorless so that there is little color difference between heartwood and sapwood.

Heartwood extractives can make changes other than color. Some extractives may be toxic to decay fungi and thus impart decay resistance to heartwood, as in redwood. Sapwood not only lacks decay resistance, but is attractive to stain fungi and certain powder post beetles because of the stored carbohydrates in the parenchyma cells.

In some species the original sapwood moisture content is remarkably higher, but the permeability of sapwood is usually greater, so that it loses moisture faster, but also absorbs preservatives or stains better. On the other hand, because of the bulking effect of extractives — they occupy molecular space within the cell wall — the shrinkage of heartwood may be less than that of sapwood.

For the woodworker, the heartwood-sapwood distinction is important. But what about the more general "hardwood-softwood" distinction? The names themselves are misleading because balsa wood is really a "hardwood" and hard southern pine is really a "softwood." While softwoods are generally evergreens, and hardwoods are generally deciduous, this is not always the case. The precise distinction is that the seeds of softwoods (gymnosperms — all conifers plus the familiar ginkgo tree) are naked (as in a pine seed), while for



Basket-makers take advantage of weak early wood (after pounding) of quarter-sawed ash to separate it into strips (left). Severely raised grain on pith side of flat-sawed hemlock (center) results from harder latewood being compressed into softer earlywood during planing, then springing back later. Honeycomb checks in red oak (right) can cause failure along large ray.

hardwoods (angiosperms), they are encapsulated (as in a walnut or acorn).

The hardness and softness of wood does come into play when we consider earlywood and latewood. Earlywood is that grown early in the season, when the moisture needed for rapid growth is present. In conifers, this means those longitudinal tracheid cells have thinner walls and larger cavities to favor conduction of sap. As latewood develops later in the growing season, the tracheids develop thicker walls (and in effect, denser wood). In other words, there is less airspace in latewood.

To a woodworker, what is also important is how this transition between latewood and earlywood occurs. Soft pines (e.g. eastern white, western white, and sugar) are characterized by fairly even grain, with gradual transition from earlywood to latewood. The result is fairly low average density with pleasing uniformity of wearing and working properties. By contrast, species such as the hard pines (e.g. southern yellow pine, pitch pine, red pine) Douglas fir, larch and hemlock are notably uneven-grained. In southern yellow pine there is a three-to-one ratio in the densities of the latewood versus earlywood. Thus the difficulty of machining it and the woodcarver's preference for the soft pines.

The latewood-earlywood differentiation can also present problems in staining — especially in conifers. In natural wood the latewood appears dark, the earlywood light. But earlywood is more porous, so that it absorbs stain more readily and thus stains darker than the latewood. The effect is to reverse the grain pattern, giving us the grain that would appear in a photographic negative. We've probably all seen this happen in the conifers such as pine or Douglas fir. However, in certain hardwoods, the large vessel size found in early wood makes it appear darker. Therefore, stain merely accentuates this darkness, rather than reversing it.

Hardwoods have a wider variety of longitudinal cells so there is less consistency in the differentiation between early wood and latewood. Rather than a change in the size of the tracheids, there is a change in the distribution of the larger vessels and smaller fibers. In some woods, the large vessels appear only during early growth, the fibers mainly during late growth (along with smaller vessels). This results in sharply defined rings of growth and the classification "ring-porous hardwoods" (such as oak, elm, ash, chestnut, catalpa). As in southern yellow pine, there is a sharp difference in the densities of the earlywood and latewood.

By contrast, there are also the "diffuse-porous hardwoods" (where the pores or vessels are evenly distributed throughout the growth ring). The relative pore size, or "texture," may vary from the finest (or invisible) pores in gum, maple or aspen, to medium (or barely visible) in birch, and to coarse (or conspicuous) in mahogany. Although the vessels remain open in many species (e.g. red oak), in other species (e.g. white oak, locust) the vessels of the heartwood become blocked by bubble-like obstructions called tyloses that occur as sapwood changes to heartwood. These tyloses have a profound effect on the liquid permeability of the wood. That's why white oak is good for casks, but red oak is not.

The last distinction of interest to woodworkers is that of "reaction wood" found in leaning trees and in branches. The usual symptoms are eccentricity of ring shape and abnormally high longitudinal shrinkage, causing severe warpage in drying, as well as unexpected hidden stresses. In softwoods, the reaction wood is found on the underside and is called compression wood. It's also brittle. In hardwoods, it's found on the upper side, and is called tension wood, which machines with a microscopic wooliness resulting in a blotchiness when stained.

Perhaps all this shows that wood is no simple subject to talk about. Take the word "grain" for example. Normally, we mean the alignment of the longitudinal cells, because wood splits "along the grain." In the same context we have such terms as spiral grain, cross grain, wavy grain and interlocked grain. But grain can also refer to the uniformity of the growth ring structure. Douglas fir is an "uneven-grained" wood while basswood is "even-grained." Sometimes grain refers to the ray cell structure, as in the "silver grain" of white oak cut radially — slicing along the rays, in effect. And sometimes we refer to the "open grain" of oak and the "closed grain" of cherry when we're really talking about the texture caused by the presence or absence of large vessels. Finally, there is the "grain" of rosewood — not really grain, but figure, caused by the extractives in the heartwood.

So the word "grain" is not so clearcut and simple as it seems. Neither is the study of wood.