Stem & Root Anatomy

Cellular Structure of Vascular Plants

See Article About Plant Textile Fibers
See Article About The Anatomy Of Wood
Go To Wood/Plant Fiber Crossword Puzzle

Vascular plants contain two main types of conduction tissue, the xylem and phloem. These two tissues extend from the leaves to the roots, and are vital conduits for water and nutrient transport. In a sense, they are to plants what veins and arteries are to animals. The structure of xylem and phloem tissue depends on whether the plant is a flowering plant (including dicots and monocots) or a gymnosperm (polycots). The terms dicot, monocot and polycot are summarized in the following table.

Class Monocotyledoneae: Monocots

Flower parts in 3's or multiple of 3's; one cotyledon inside seed; parallel leaf venation; includes Lilium, Amaryllis, Iris, Agave, Yucca, orchids, duckweeds, annual grasses, bamboos and palms.

Class Dicotyledoneae: Dicots

Flower parts in 4's or 5's; 2 cotyledons inside seed; branched or net leaf venation; contains the most species of flowering herbs, shrubs and trees; includes roses (Rosa), buttercups (Ranunculus), clover (Trifolium), maple (Acer), basswood (Tilia), oak (Quercus), willow (Salix), kapok (Ceiba) and many more

basswood (**Tilia**), oak (**Quercus**), willow (**Salix**), kapok (**Ceiba**) and many more species.

Gymnosperms: Plants With Naked Seeds

Gymnosperms include pines (**Pinus**), spruce (**Picea**), fir (**Abies**), hemlock (**Tsuga**) and false hemlock (**Pseudotsuga**). Some of the coniferous genera (division Coniferophyta) are the most important timber trees in the world. Since these species have several cotyledons inside their seeds, they are conveniently referred to as polycots.

Review The Classification Of Plants
[The Five Kingdoms Of Life](#)
[The Major Divisions Of Life](#)
[Diversity Of Flowering Plants](#)

Xylem and phloem tissues are produced by meristematic cambium cells located in a layer just inside the bark of trees and shrubs. In dicot stems, the cambium layer gives rise to phloem cells on the outside and xylem cells on the inside. All the tissue from the cambium layer outward is considered bark, while all the tissue inside the cambium layer to the center of the tree is wood. Xylem tissue conducts water and mineral nutrients from the soil upward in plant roots and stems. It is composed of elongate cells with pointed ends called tracheids, and shorter, wider cells called vessel elements. The walls of these cells are heavily lignified, with openings in the walls called pits. Tracheids and vessels become hollow, water-conducting pipelines after the cells are dead and their contents (protoplasm) has disintegrated. The xylem of flowering plants also contains numerous

fibers, elongate cells with tapering ends and very thick walls. Dense masses of fiber cells is one of the primary reasons why angiosperms have harder and heavier wood than gymnosperms. This is especially true of the "ironwoods" with wood that actually sinks in water.
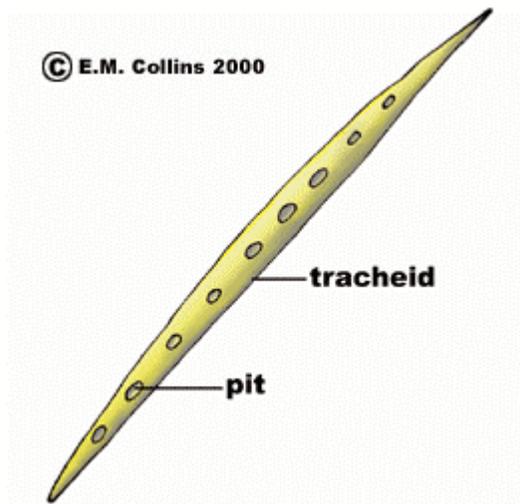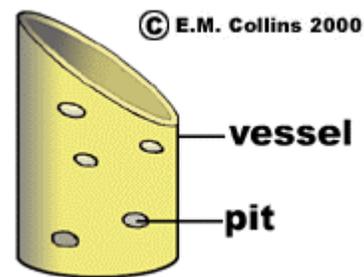
Xylem Tracheid   Xylem Vessel Element

A recent article in **Science** Vol. 291 (26 January 2001) by N.M. Holbrook, M. Zwieniecki and P. Melcher suggests that xylem cells may be more than inert tubes. They appear to be a very sophisticated system for regulating and conducting water to specific areas of the plant that need water the most. This preferential water conduction involves the direction and redirection of water molecules through openings (pores) in adjacent cell walls called pits. The pits are lined with a pit membrane composed of cellulose and pectins. According to the researchers, this control of water movement may involve pectin hydrogels which serve to glue adjacent cell walls together. One of the properties of polysaccharide hydrogels is to swell or shrink due to imbibition. "When pectins swell,

pores in the membranes are squeezed, slowing water flow to a trickle. But when pectins shrink, the pores can open wide, and water flushes across the xylem membrane toward thirsty leaves above." This remarkable control of water movement may allow the plant respond to drought conditions.

Spiral thickenings in the secondary walls of vessels and tracheids gives them the appearance of microscopic coils under high magnification with a light microscope.
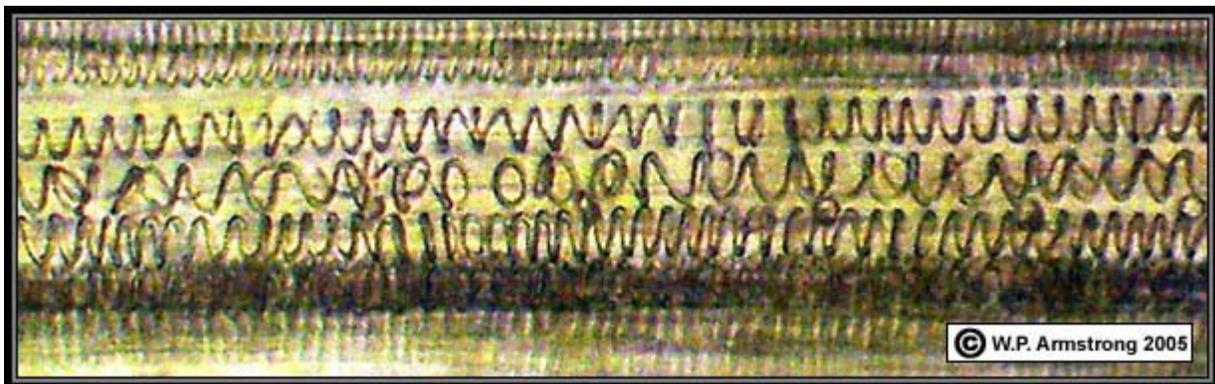
Magnified horizontal view (400x) of an inner perianth segment of a **Brodiaea** species in San Marcos showing a primary vascular bundle composed of several strands of vessels. The strands consist of vessels with spirally thickened walls that appear like minute coiled springs. Although this species has been called **B. jolonensis** by San Diego botanists for decades, it appears to be more similar to **B. terrestris** ssp. **kernensis**. This species contains at least 3 strands of vessels per bundle, while **B. jolonensis** only has one strand per bundle.

The water-conducting xylem tissue in plant stems is actually composed of dead cells.

In fact, wood is essentially dead xylem cells that have dried out. The dead tissue is hard and dense because of lignin in the thickened secondary cell walls. Lignin is a complex phenolic polymer that produces the hardness, density and brown color of wood. Cactus stems are composed of soft, water-storage parenchyma tissue that decomposes when the plant dies. The woody (lignified) vascular tissue provides support and is often visible in dead cactus stems.
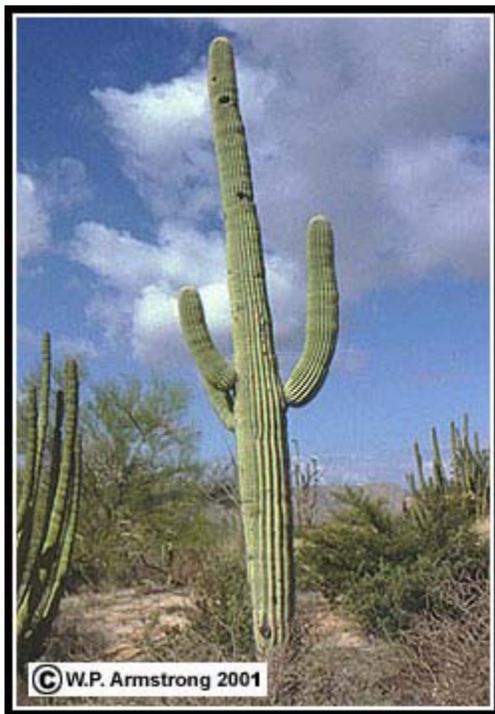
Left: Giant saguaro (**Carnegiea gigantea**) in northern Sonora, Mexico. The weight of this large cactus is largely due to water storage tissue in the stems. Right: A dead saguaro showing the woody (lignified) vascular strands that provide support for the massive stems.

See Article About Hardwoods
See Specific Gravity Of Wood

Phloem tissue conducts carbohydrates manufactured in the leaves downward in plant stems. It is composed of sieve tubes (sieve tube elements) and companion cells. The perforated end wall of a sieve tube is called a sieve plate. Thick-walled fiber cells are also associated with phloem tissue.

In dicot roots, the xylem tissue appears like a 3-pronged or 4-pronged star. The tissue between the prongs of the star is phloem. The central xylem and phloem is surrounded by an endodermis, and the entire central structure is called a stele.

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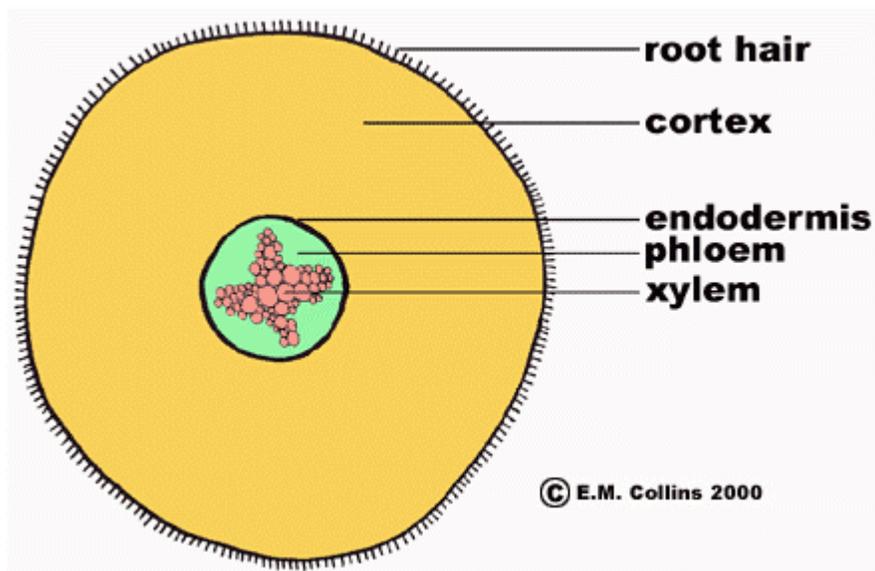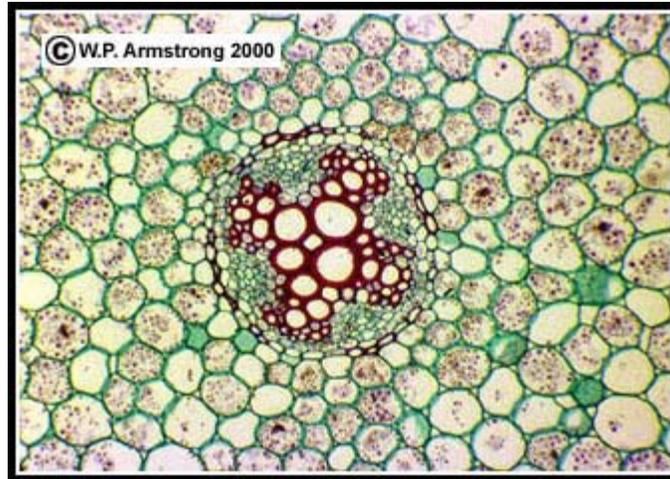
Microscopic view of the root of a buttercup (**Ranunculus**) showing the central stele and 4-pronged xylem. The large, water-conducting cells in the xylem are vessels. [Magnified Approximately 400X.]

In dicot stems, the xylem tissue is produced on the inside of the cambium layer. Phloem tissue is produced on the outside of the cambium. The phloem of some stems also contains thick-walled, elongate fiber cells which are called bast fibers. Bast fibers in stems of the flax plant (Linum usitatissimum) are the source of linen textile fibers. Gymnosperms generally do not have vessels, so the wood is composed essentially of tracheids. The notable exception to this are members of the gymnosperm division Gnetophyta which do have vessels. This remarkable division includes Ephedra (Mormon tea), Gnetum, and the amazing Welwitschia of Africa's Namib Desert.

See Article About Welwitschia

Pine stems also contain bands of cells called rays and scattered resin ducts. Rays and resin ducts are also present in flowering plants. In fact, the insidious poison oak

allergen called urushiol is produced inside resin ducts. Wood rays extend outwardly in a stem cross section like the spokes of a wheel. The rays are composed of thin-walled parenchyma cells which disintegrate after the wood dries. This is why wood with prominent rays often splits along the rays. In pines, the spring tracheids are larger than the summer tracheids. Because the summer tracheids are smaller and more dense, they appear as dark bands in a cross section of a log. Each concentric band of spring and summer tracheids is called an annual ring. By counting the rings (dark bands of summer xylem in pine wood), the age of a tree can be determined. Other data, such as fire and climatic data, can be determined by the appearance and spacing of the rings. Some of the oldest bristlecone pines (**Pinus longaeva**) in the White Mountains of eastern California have more than 4,000 rings. Annual rings and rays produce the characteristic grain of the wood, depending on how the boards are cut at the saw mill.
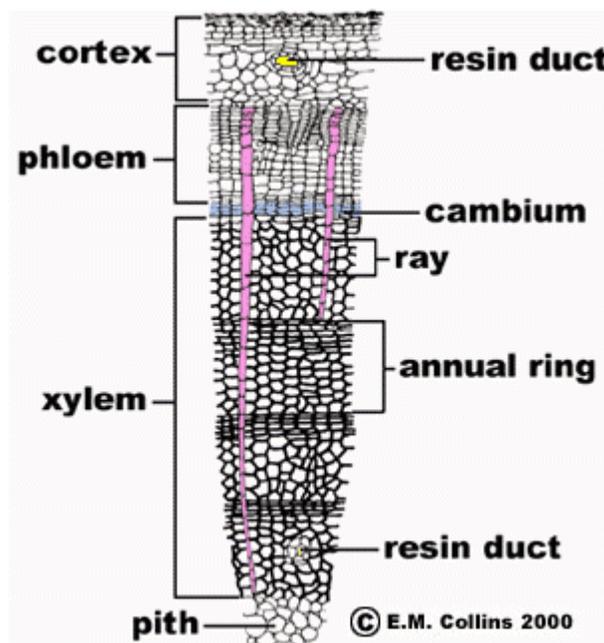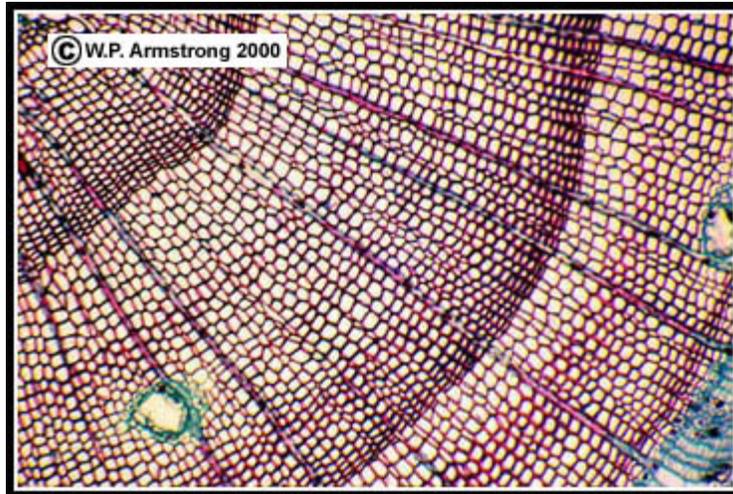
Microscopic view of a 3-year-old pine stem (**Pinus**) showing resin ducts, rays and three years of xylem growth (annual rings). [Magnified Approximately 200X.]

A cross section of loblolly pine wood (**Pinus taeda**) showing 18 dark bands of summer xylem (annual rings).

See Article About The Anatomy Of Wood
See Resin Ducts In Poison Oak Stem
See World's Oldest Living Shrub

Angiosperms typically have both tracheids and vessels. In ring-porous wood, such as oak and basswood, the spring vessels are much larger and more porous than the

smaller, summer tracheids. This difference in cell size and density produces the conspicuous, concentric annual rings in these woods. Because of the density of the wood, angiosperms are considered hardwoods, while gymnosperms, such as pine and fir, are considered softwoods.

The following illustrations and photos show American basswood (**Tilia americana**), a typical ring-porous hardwood of the eastern United States:

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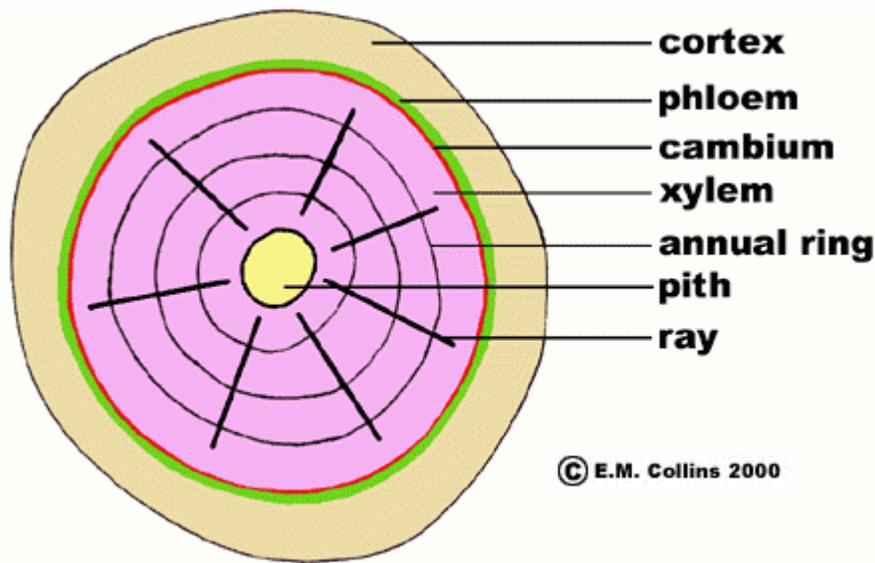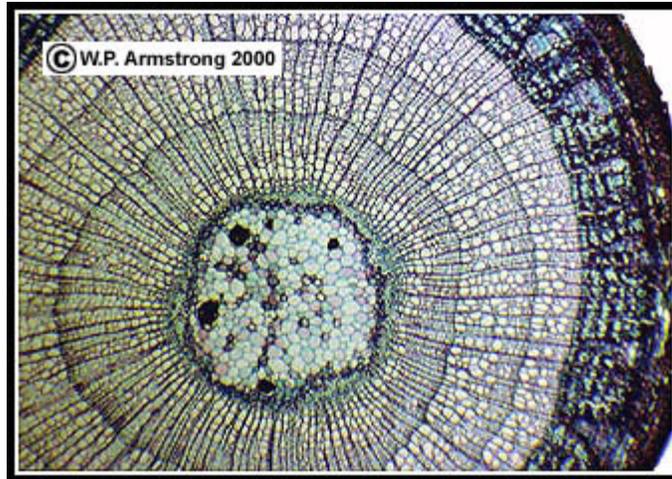
A cross section of the stem of basswood (**Tilia americana**) showing large pith, numerous rays, and three distinct annual rings. [Magnified Approximately 75X.]
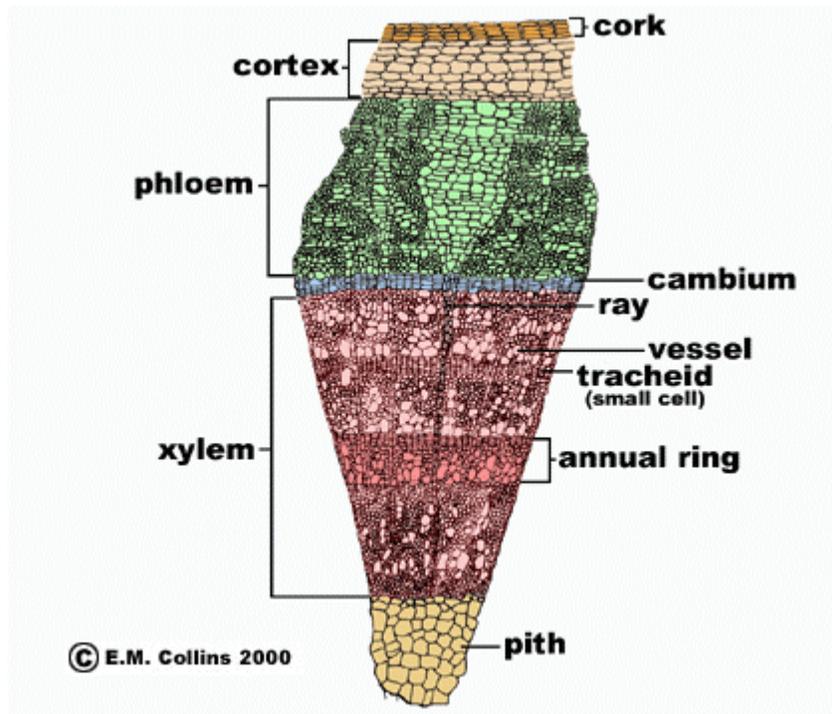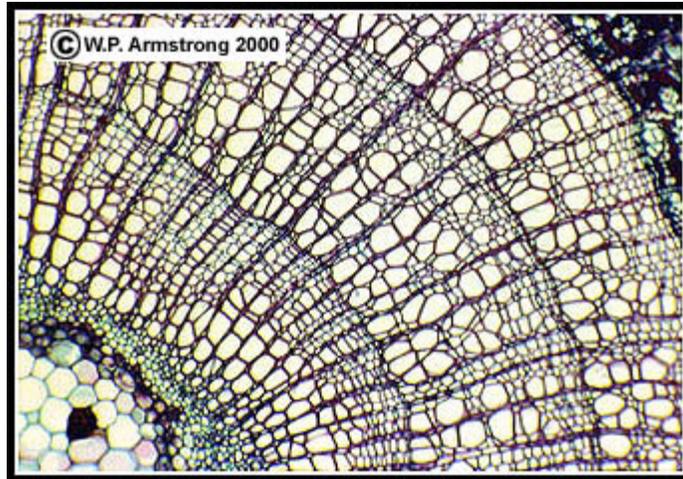
A cross section of the stem of basswood (**Tilia americana**) showing pith, numerous rays, and three distinct annual rings. The large spring xylem cells are vessels.

Lack Of Visible Annual Rings In Tropical Trees?

Anatomy Of Monocot Stems

Monocot stems, such as corn, palms and bamboos, do not have a vascular cambium and do not exhibit secondary growth by the production of concentric annual rings. They cannot increase in girth by adding lateral layers of cells as in conifers and woody dicots. Instead, they have scattered vascular bundles composed of xylem and phloem tissue. Each bundle is surrounded by a ring of cells called a bundle sheath. The structural strength and hardness of woody monocots is due to clusters of heavily lignified tracheids and fibers associated with the vascular bundles. The following illustrations and photos show scattered vascular bundles in the stem cross sections of corn (**Zea mays**):

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Cross section diagram of corn stem vascular bundle with labels:

- primary phloem
- companion cell } phloem
- sieve plate
- sieve tube
- vessel
- vessel
- tracheid } xylem
- vessel
- bundle sheath
- lacuna
- parenchyma

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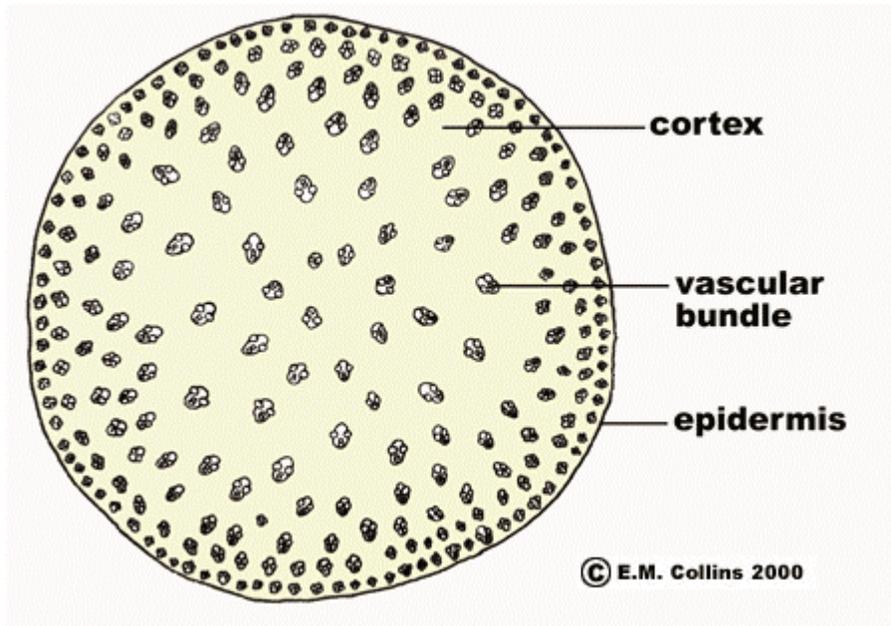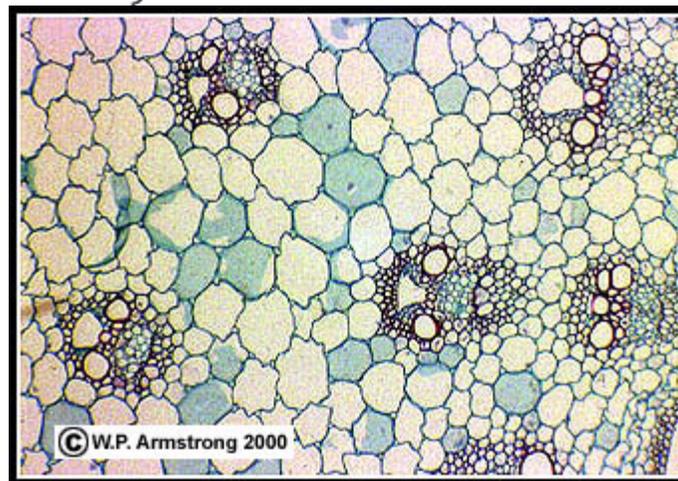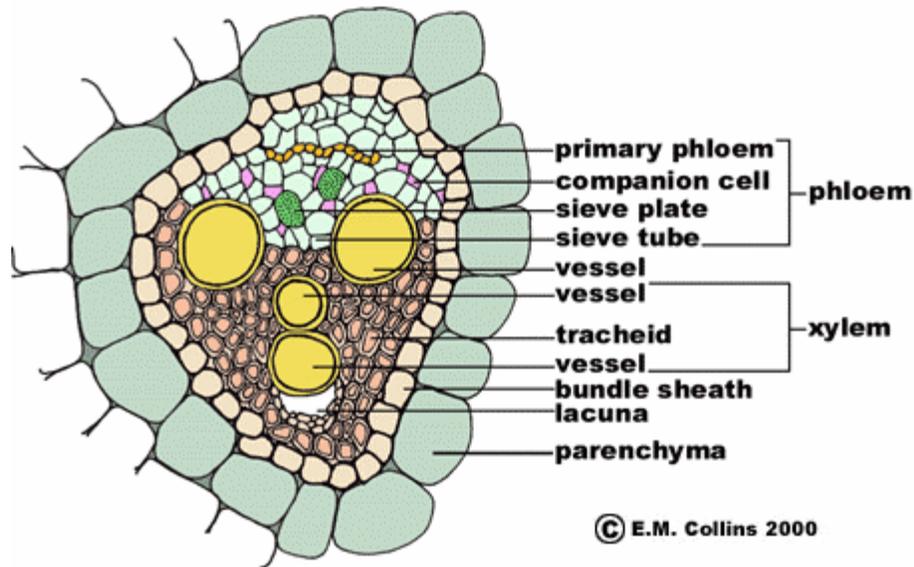
A cross section of the stem of corn (**Zea mays**) showing parenchyma tissue and scattered vascular bundles. The large cells in the vascular bundles are vessels. [Magnified Approximately 250X.]

Unlike most monocots, palm stems can grow in girth by an increase in the number of parenchyma cells and vascular bundles. This primary growth is due to a region of actively dividing meristematic cells called the "primary thickening meristem" that surrounds the apical meristem at the tip of a stem. In woody monocots this meristematic region extends down the periphery of the stem where it is called the "secondary

thickening meristem." New vascular bundles and parenchyma tissue are added as the stem grows in diameter.

The massive trunk of this Chilean wine palm (**Jubaea chilensis**) has grown in girth due to the production of new vascular bundles from the primary and secondary thickening meristems.

Palm Wood

The scattered vascular bundles containing large (porous) vessels are very conspicuous in palm wood. In fact, the vascular bundles are also preserved in petrified palm.
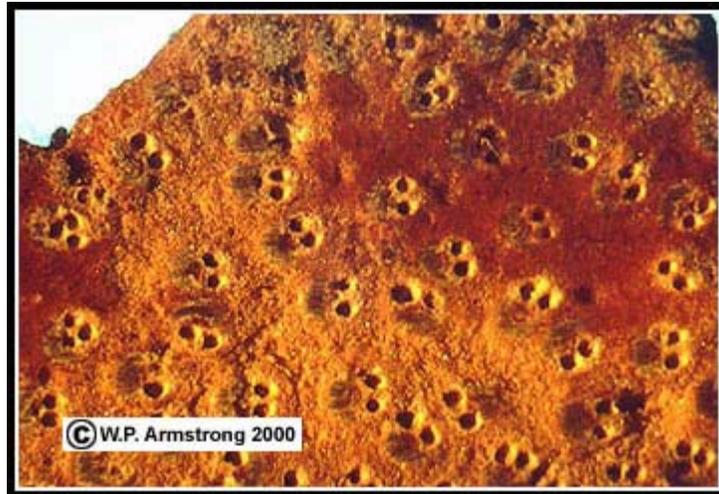
Cross section of the trunk of the native California fan palm (**Washingtonia filifera**)

lignified cells.
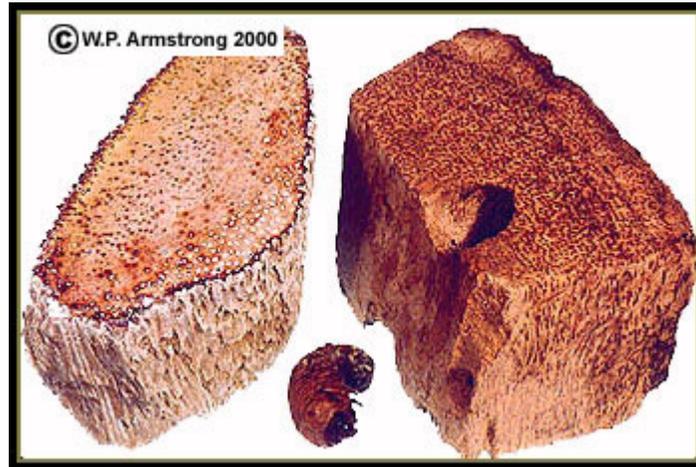
Right: Cross section of the trunk of a California fan palm (**Washingtonia filifera**) showing scattered vascular bundles that appear like dark brown dots. The dot pattern also shows up in the petrified **Washingtonia** palm (left). The pores in the petrified palm wood are the remains of vessels. The large, circular tunnel in the palm wood (right) is caused by the larva of the bizarre palm-boring beetle (**Dinapate wrightii**) shown at bottom of photo. An adult beetle is shown in the next photo.

An adult palm-boring beetle (**Dinapate wrightii**)

Read About The Palm-Boring Beetle
Read About The Anatomy Of Wood

Bamboo Wood

Bamboo Cutting Board
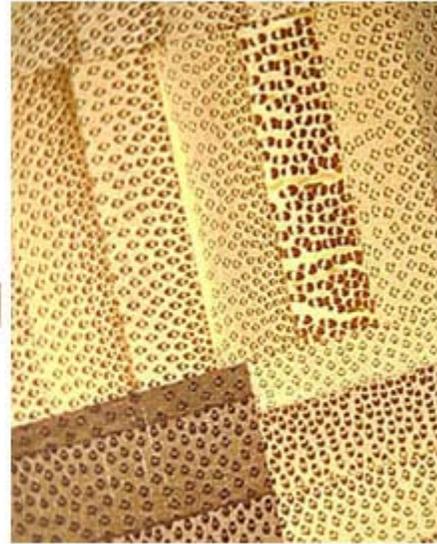
**Magnified View of Cutting Board
Showing Many Vascular Bundles**

A beautiful cutting board made from numerous flattened strips of bamboo (**Phyllostachys pubescens**) glued together. Through a specialized heating process, the natural sugar in the wood is caramelized to produce the honey color. Vascular bundles typical of a woody monocot are clearly visible on the smooth cross section. The transverse surface of numerous lignified tracheids and fibers is actually harder than maple.

Cutting board available from Totally Bamboo™ website: http://www.totallybamboo.com/

Bamboos: Remarkable Giant Grasses

A 270 Million-Year-Old Petrified Tree Fern

During the Carboniferous Era, approximately 300 million years ago, the earth was

dominated by extensive forests of giant lycopods (division Lycophyta), horestails

(division Sphenophyta) and tree ferns (division Pterophyta). Much of the earth's coal reserves originated from massive deposits of carbonized plants from this era. Petrified trunks from Brazil reveal cellular details of an extinct tree fern (**Psaronius brasiliensis**) that lived about 270 million years ago, before the age of dinosaurs. The petrified stem of **Psaronius** does not have concentric growth rings typical of conifers and dicot angiosperms. Instead, it has a central stele composed of numerous arcs that represent the vascular bundles of xylem tissue. Surrounding the stem are the bases of leaves. In life, **Psaronius** probably resembled the present-day **Cyathea** tree ferns of New Zealand.
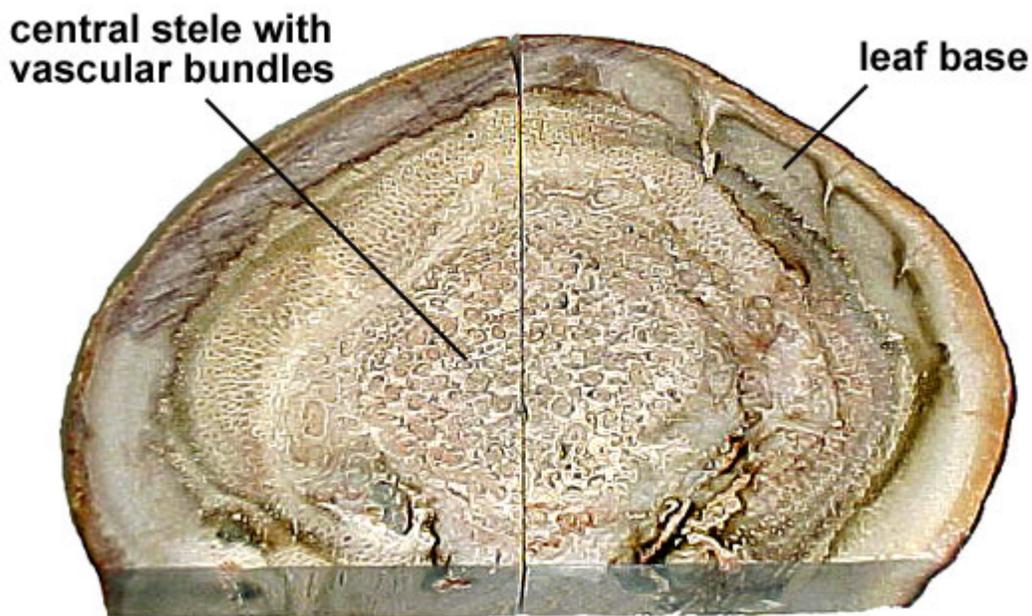
A petrified trunk from the extinct tree fern **Psaronius brasiliensis**. The central stele region contains arc-shaped vascular bundles of xylem tissue. The stem is surrounded by leaf bases which formed the leaf crown of this fern, similar to present-day **Cyathea** tree ferns of New Zealand. This petrified stem has been cut and polished to make a pair of bookends.
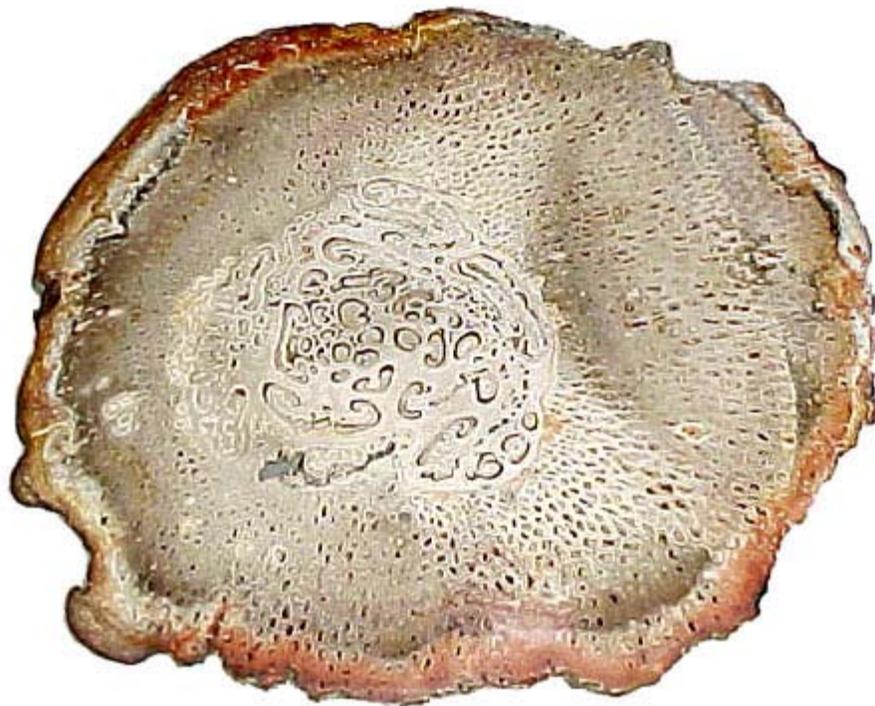
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A well-preserved stem section from the extinct tree fern **Psaronius brasiliensis**. Note the central stele region containing arcs of xylem tissue (vascular bundles). The structure of this stem is quite different from the concentric growth rings of conifers and dicots, and from the scattered vascular bundles of palms.

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