BOTANY- PG (2nd SEMESTER)- PAPER- BOT203: UNIT-1: PLANT ANATOMY

Wood anatomy

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WOOD

- Secondary xylem is a complex tissue, known also as **wood**. The study of wood by preparing sections for microscopic observations is defined as **xylotomy**.
- Secondary xylem is derived from the **vascular cambium**. It develops in **stems and roots of gymnosperm and angiosperm-dicotyledonous plants** as a consequence of **secondary growth**. The cells composing wood are mainly thick walled.
- **Cell cytoplasm** deposits the thickening materials during differentiation. Later cytoplasm dies and leaves the cells of wood devoid of any living contents.
- Woods are divided into two main groups -- **porous and non-porous** based on the **presence or absence of vessels or pores. Non-porous wood** predominate in gymnosperm where predominantly **tracheids with a small amount of parenchyma** compose the wood. Example: pines, spruces and firs where the texture of wood is uniform and a carpenter works with ease. So non-porous wood or gymnospermous wood is referred to as softwood.
- In contrast angiosperm dicotyledonous wood exhibits a variety of cell types including thick-walled fibres. It is sometimes difficult to work with such type of wood. So **porous wood or angiosperm-dicotyledonous wood is referred to as hardwood**. These two terms hardwood and softwood are traditionally used in timber trade. But the terms, however, are misleading. Woods with soft and hard texture can be found in both groups of plants. The terms have no relation to the relative hardness or softness of timber. These terms-hardwood and softwood are applicable only to porous and non-porous wood respectively. As for example the wood of *Ochroma*, *Bombax ceiba* and *Pterocymbium tinctorium* are soft to very soft. These plants belong to angiosperm and their wood is referred to as hardwood by definition as the wood is porous. On the other hand the woods of *Cedrus deodara* and *Pinus roxburghii* are very hard. These plants belong to gymnosperm and their wood is referred to as softwood by definition as the wood is non-porous.

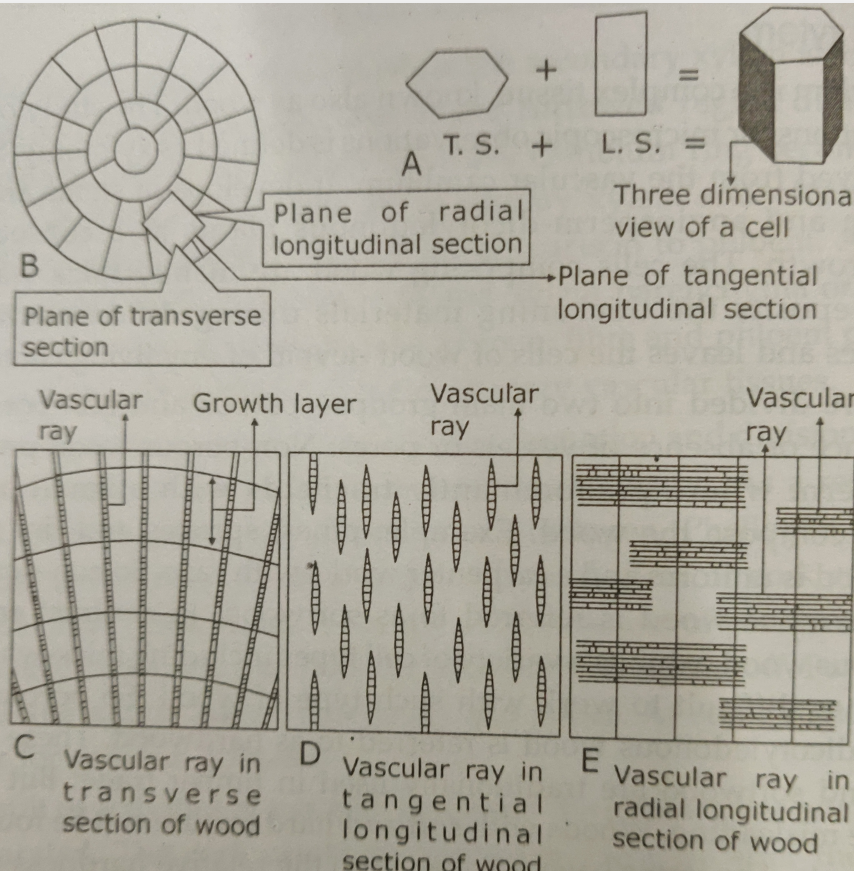


Figure 20.10

A. With the images of l. s. & t. s. the three dimensional view of a cell can be obtained. B. Diagram pointing the planes of section of wood. C., D. & E. The appearance of ray parenchyma in different planes.

- **Wood contains all the types of cells that are observed in primary xylem but no new ones**. The only difference between primary- and secondary xylem is the **origin and arrangement of elements of xylem**. Secondary xylem originates from vascular cambium whereas procambium gives rise to primary xylem. The arrangement of wood cell types is either along-the-axis' -called axial system or 'across-the-axis' -termed radial system. The arrangement reflects to that of the fusiform- and ray initials of cambium that form wood cell types. Fusiform initial gives rise to elements of axial system and ray initial forms the cells present on the radial system.

- The cambium that forms wood is composed of spindle shaped fusiform initials and the isodiametric ray initials. The ray initials from the ray parenchyma cells, which compose the horizontal or radial tissue system. The fusiform initials lie parallel to the long axis and give rise to tracheary elements, fibres and axial parenchyma that form the vertical or axial tissue system. The living cells of axial and radial systems are interconnected to form a continuous system.

Ray parenchyma-

- Ray parenchyma cells are of various shapes and the two most common forms are where the longest axis of the cell is either vertical or radial. The former one, where the longest axis is oriented vertically, is called erect or upright ray cells. The latter one is termed as procumbent ray cells where the longest axis is oriented radially. Ray cells may also be square or isodiametric, Square cells are considered as morphologically equivalent to erect cells. In a radial longitudinal section the parenchyma cells appear as fine horizontal lines. So a transverse or radial longitudinal section reveals the longitudinal axis of ray cells. The transverse section of ray cells is obtained from tangential longitudinal section (TLS).

- In TLS ray parenchyma appears variously, for instance: (i) Uniseriate: the ray cells are entirely one cell in width, Ex. *Salix, Pinus* etc. (ii) Biseriate: any portion of the ray masses is two cells wide and (iii) Multiseriate: any portion of the ray masses is more than two cells in width, e.g. Quercus. The TLS reveals that the biseriate and multiseriate ray gradually become uniseriate at both its upper and lower edges.

- Uniseriate and multiseriate rays both may be either unicellular or heterocellular (Fig. 20.11). In dicotyledons the homocellular rays consists of (1) erect cells only, (2) procumbent cells only. (3) square cells an erect and square cells only. In heterocellular type procumbent and square or procumbent and erect cells occur. The entire ray system may consist of either unicellular or heterocellular types, or of combinations of two.

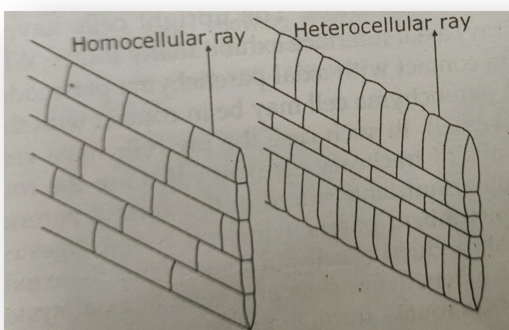


Figure 20.11
Diagrammatic figures of ray parenchyma cells in tangential and radial longitudinal sectional view. Redrawn from Cutler, 1978, p. 20 & 21.

In gymnosperm xylem rays are almost exclusively uniseriate. The ray cells may be (Fahn, 1987) (i) monocellular: rays consist of parenchyma cells only, ex. and ray tracheids, ex. Pinus. The ray tracheids (Fig. 20.12B) have bordered pits and are devoid of protoplasts in contrast to ray parenchyma. They are multiseriate only if they contain resin canals. Ray tracheids are horizontal, rectangular cells that look somewhat like parenchyma cells. They have lignified walls and in Pinus the lignifications may be in form of teeth or band that project in the cell lumen.

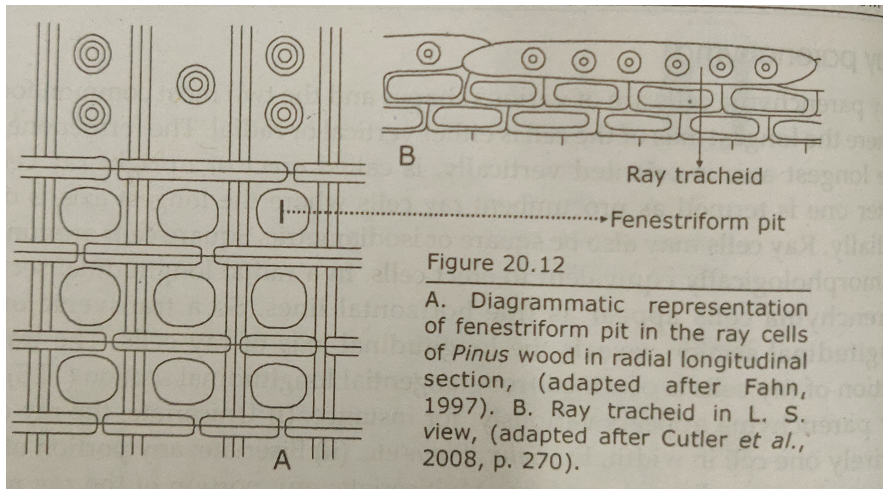


Figure 20.12

A. Diagrammatic representation of fenestriform pit in the ray cells of *Pinus* wood in radial longitudinal section, (adapted after Fahn, 1997). B. Ray tracheid in L. S. view, (adapted after Cutler *et al.*, 2008, p. 270).

- In angiosperm ray cells may be homogeneous (ex. Populus) where all the cells are procumbent, i.e. the longest axis is oriented in radial direction or heterogeneous (ex. Olea) where the ray cells are procumbent and square or oriented vertically. These two terms-homogeneous and heterogeneous are more or less similar to homocellular and heterocellular ray cells respectively of gymnospermous wood.

- The ray cells of Pinus have very large pits with very narrow border that appears as more or less circular or rectangular areas throughout the width of the cells. These are known as fenestriform pits (Fig. 20.12A) whose surface view is obtained in radial longitudinal section.

- Initially ray parenchyma cells are living and serve in storage and aeration. They store carbohydrates and other nutrients. These substances are transported radially within the wood over short distances. The upright cells have direct connection with axial cells. The ray/axial interface exhibit many forms. When the upright ray parenchyma cell is in contact with axial parenchyma plasmodesmata exist between them. The upright parenchyma cell may be in contact with the axial tracheary elements (tracheid or vessel). In such case the ray cells have very thin walls while pits occur on the walls of tracheary elements. Pits are the routes of transport of carbohydrates and other nutrients stored in the upright parenchyma cells. The stored starch in the procumbent parenchyma cell is first digested into sugar and then transferred to axial conducting cells. In some plants there exists no connection between procumbent parenchyma cells and cells of axial system. In such cases the transfer of nutrients is routed through upright parenchyma cells.

Axial parenchyma-

The distribution of axial parenchyma is very characteristic in dicotyledonous wood. Parenchyma may lie independent of vessels or they are distinctly associated with them. These two forms are known as apotracheal and paratracheal respectively. The common apotracheal forms are

(i) diffuse parenchyma: parenchyma cells appear as single cell or as small uniseriate band throughout the growth ring (ex. *Quercus*);

(ii) banded or paratracheal parenchyma:parenchyma cells appear concentric bands (ex. *Hicoria*).

(iii) boundary parenchyma: parenchyma may appear at the beginning or end of the growth ring and accordingly termed as initial parenchyma (ex. *Ceratonia, Zygophyllum*) and terminal parenchyma (ex. *Magnolia, Salix* etc.)

Paratracheal parenchyma may be (Fig. 10.2):

(1) Scanty (ex. *Acer*): The parenchyma cells do not form a continuous sheath surrounding the vessel.

(2) Vasicentric parenchyma (ex. *Tamarix*): The parenchyma cells form continuous sheath around the vessel of different width.

(3) Aliform parenchyma (ex. Acacia); Vasicentric parenchyma extends laterally as wings.

Annual ring-

Most trees and shrubs of temperate origin show **characteristic growth layers**, often called growth rings or annual rings of secondary xylem. Growth rings appear as concentric rings seen in transverse section of stems, each ring represents a year's growth of secondary xylem. The **concentric rings** are formed at the **straight parts of stems under uniform conditions** whereas **the eccentric rings** appear as a result of **adverse natural calamities**. The activity of cambium is a seasonal phenomenon. The periodic activity and quiescence of cambium lead to the formation of annual or growth rings. These rings are distinguishable with an unaided eye because of the differences in structure and colours between the secondary xylem formed at the early and late parts of a growth season. As each ring represents a year's growth, the approximate age of a plant can be ascertained by counting the number of growth-rings.

In temperate perennial plants, the activity of cambium begins in the spring. The wood produced during this period is the **early wood**, often called spring wood. The spring wood is less dense, consists of thin-walled elements and possesses vessels with large lumen. The cells of wood, produced at the late parts of growth season, possess thicker walls and vessels with smaller diameter. These are **late wood**, also known as summer or autumn wood. The early wood and late wood, formed in one growth season, together constitute the growth ring or annual ring. The early wood and late wood of the same season gradually merge with each other and with adjacent growth rings also. But a sharp line of demarcation exists between the late wood of one growth season and early wood of next season.

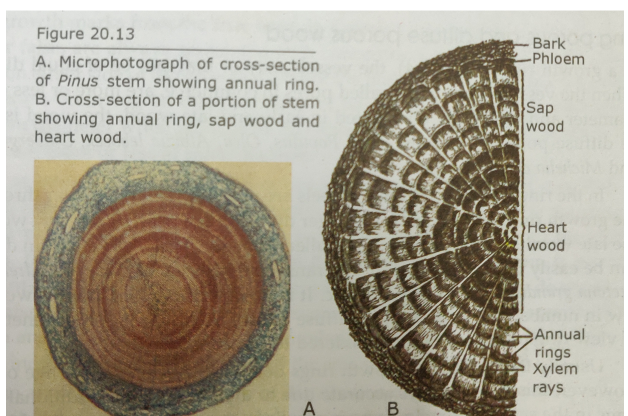


Figure 20.13
A. Microphotograph of cross-section of *Pinus* stem showing annual ring.
B. Cross-section of a portion of stem showing annual ring, sap wood and heart wood.

In *Tilia, Ceratonia, Zygophyllum* etc. a few layers of wood parenchyma is present between the growth rings and these parenchyma form the division line between the rings. It was possible to determine accurately the age of *Pinus longifolia, Tectona grandis, Terminalia tomentosa*, *Acacia catechu* and *Bombax malabaricum* (Chowdhury, 1939). The annual rings were carefully counted and the false rings, which occasionally develop in the above species, were properly located and omitted from counting. There was a common belief that growth rings are formed only in deciduous trees and the evergreen trees are without them. However, Chowdhury (1939) reported the formation of growth rings in both evergreen (e.g. *Michelia champac*a) and deciduous trees (e.g. *Cedrela toona, Albizia lebbeck* and *Dalbergia sissoo*). Annual rings are also formed in tropical genera namely, *Bursera* (Burseraceae), *Citharexylum* (Verbenaceae), *Rapanea* (Myrsinaceae) and *Swietenia* (Meliaceae).

In some plants woods are formed without growth-rings, e.g. *Baccharis* (Asteraceae), *Laguncularia* (Combretaceae), *Rhizophora* (Rhizophoraceae), *Manilkara* (Sapotaceae) and *Pisonia* (Nyctaginaceae) etc.

Ring porous and diffuse porous wood-

In a growth ring the vessels may or may not be of equal diameter.

- When the vessels, sometimes called pores, are more or less of same diameter and uniformly distributed in early and late wood, the wood is said to be **diffuse porous wood**; ex. Acer, *Populus*, *Olea, Albizia lebbeck, Dalbergia sissoo* and *Michelia champaca* etc.

- In the **ring porous wood**, the **vessels are not of equal in diameter** throughout the growth ring. The **vessels with larger diameter are present on early wood** and the **late wood shows vessels with smaller diameter.** These variations in diameter can be easily being observed in the transverse sections of stem of *Cedrela toona, Tectona grandis, Quercus, Fraxinus* etc. It is observed that ring porous woods are few in number in comparison to diffuse porous wood. From phylogenetic point of view ring porous wood is considered to be more advanced.

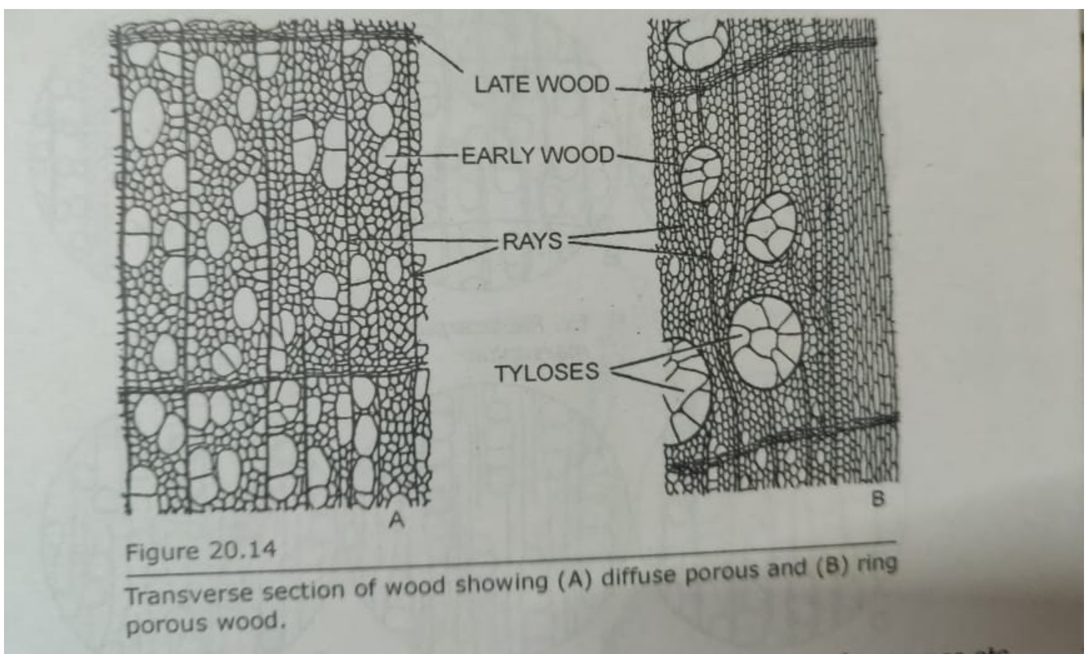


Figure 20.14
Transverse section of wood showing (A) diffuse porous and (B) ring porous wood.

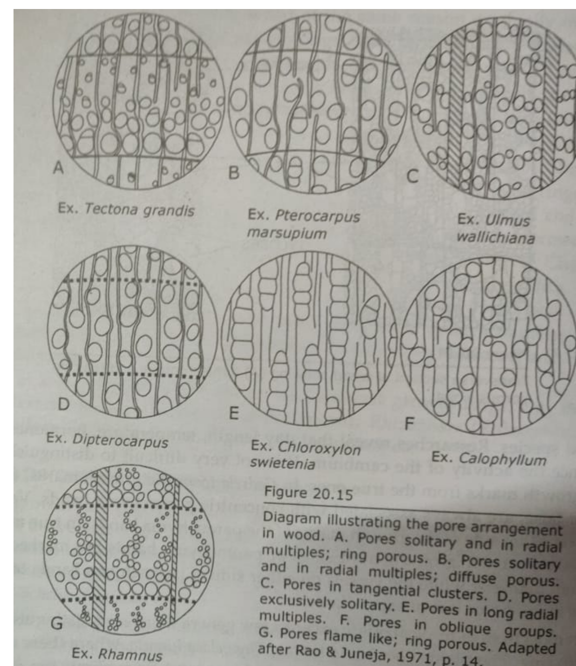


Figure 20.15
Diagram illustrating the pore arrangement in wood. A. Pores solitary and in radial multiples; ring porous. B. Pores solitary and in radial multiples; diffuse porous. C. Pores in tangential clusters. D. Pores exclusively solitary. E. Pores in long radial multiples. F. Pores in oblique groups. G. Pores flame like; ring porous. Adapted after Rao & Juneja, 1971, p. 14.

Why growth rings are not always accurate measure of the age of the plant?

Usually the number of growth rings denotes the approximate age of a tree. However, this is not always accurate due to the formation of additional growth rings in the same season. In *Tamarix aphylla* two growth rings are developed in a single season. More than one growth rings formed per annum is also reported in *Avicennia*. Additional growth rings may be developed due to adverse natural calamities like draught, frost, defoliation, flood, and mechanical injury or due to infection, and biotic factors that disturb the plants when the activity of cambium is either checked or stimulated; when stimulated additional rings are formed, termed false annual ring. When two or more rings are formed in one season they are often called as double or multiple annual rings respectively. False rings may be formed both in temperate and tropical species. Researches reveal that day length, temperature, hormones etc. influence the activity of the cambium. It is not very difficult to distinguish the false growth marks from the true ones. In *Cedrela toona* the growth marks, either true or false, are always associated with concentric parenchyma bands. Vessels occur on either side of the growth marks of the parenchyma bands. In true marks, the vessels occurring on different sides of parenchyma bands are markedly of different diameter while the vessels on either side of parenchyma bands of false marks are more or less of same diameter.

The link between wood anatomy and taxonomy-

The size, shape, arrangements and the relative amount of constituent elements of secondary xylem of most trees are genetically labelled. Thus secondary xylem provides characters to identify an unknown timber. With the aid of these characters a key can be formulated by which timbers can be identified. A key can be made by using punched-card system and the computer. Usually a dichotomous key is formulated using the same principle as is followed in plant taxonomy (vide Lawrence, 1967 p226 for details). Dichotomous key is very popular and is used all over the world. But it has limited scope and is applicable only to a small group of timber. Fahn (p. 369-370) illustrated a dichotomous key to identify woods. Rao and Juneja (1971) proposed a dichotomous to identify fifty important timbers of India. They schematically represented a dichotomous key for eight timbers only and commented that even a novice may not have difficulty in following the principle and working of a dichotomous key. The dichotomous key is illustrated in Fig. 20.16. It is customary to present a dichotomous key in a running form and it is illustrated in Box 20.2.

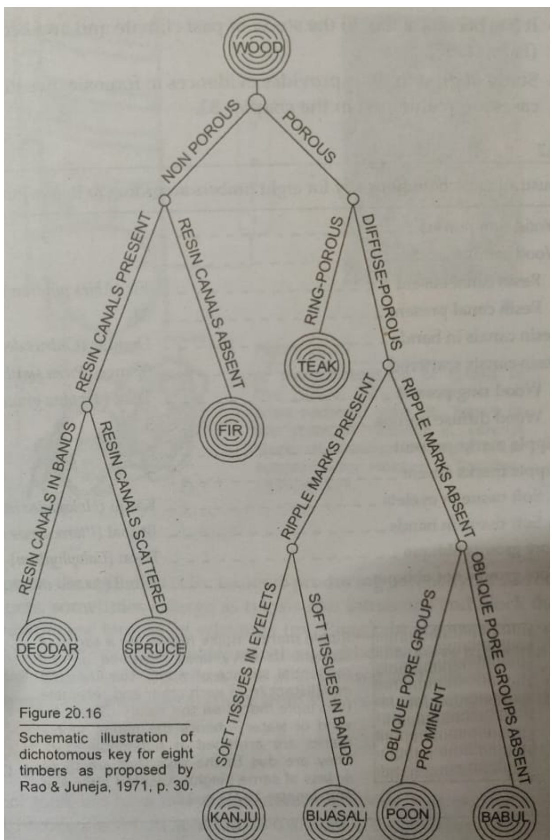


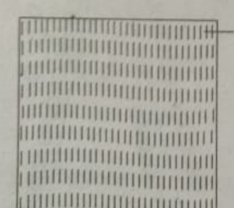
Figure 20.16

Schematic illustration of dichotomous key for eight timbers as proposed by Rao & Juneja, 1971, p. 30.

Box 20.2

Illustrating dichotomous key for eight timbers according to Rao & Juneja, 1971.

1. Wood non porous	2
1. Wood porous	4
2. Resin canal absent	Fir (*Abies pindrow*)
2. Resin canal present	3
3. Resin canals in bands	Deodar (*Cedrus deodara*)
3. Resin canals scattered	Spruce (*Picea smithiana*)
4. Wood ring porous	Teak (*Tectona grandis*)
4. Wood diffuse porous	5
5. Ripple marks present	6
5. Ripple marks absent	7
6. Soft tissue in eyelets	Kanju (*Holoptelea integrifolia*)
6. Soft tissue in bands	Bijasal (*Pterocarpus marsupium*)
7. Pore groups oblique	Poon (*Calophyllum*)
7. Pore groups not oblique	Babul (*Acacia nilotica*)



Ripple marks: ripple marks are a series of straight to wavy lines observed on the tangential surface of wood. The lines are equidistant from each other and resemble the ripple marks on the sands caused by wind or water - hence the name. Ripple marks are arranged in horizontal rows. They are due to the rays that are more or less of same height. Adapted after Rao and Juneja, 1971, p. 21.

Importance of studying growth rings-

Analysis of growth rings, also referred to as dendrochronology, has many uses. They are mentioned below-

- Foresters often estimate the age of a tree by counting the numbers of growth rings.
- Pattern of the growth-ring-patterns the quality of timber can be ascertained.
- Study of growth-rings is used as a means of dating of wood, e.g.g. oak. Oak wood is used in house construction and in the backing of old pictures. A chronology of at least one thousand years has been established in oak wood.
- Growth ring analysis is also used as a check of radio-carbon dating.
- It has become a tool in the study of past climate and archaeological dating
- Study of growth rings provides evidences in forensic investigation

Tylosis

In many plants several axial or ray parenchyma surround the tracheary elements. Some of them protrude into tracheary elements through the pit. These ingrowths are called tyloses (singular-tylosis or tylose). Several tyloses may be formed in the vessel formed by the surrounding parenchyma. The tyloses increase, come in contact with one another, completely fill and block the vessel. As a result the tracheary elements become inactive. The nucleus and some amount of cytoplasm flow to the tyloses. The walls may remain thin or lignin may deposit. The lumens of tracheary element with numerous tyloses (Fig. 20.17) appear as network (ex. Quercus).

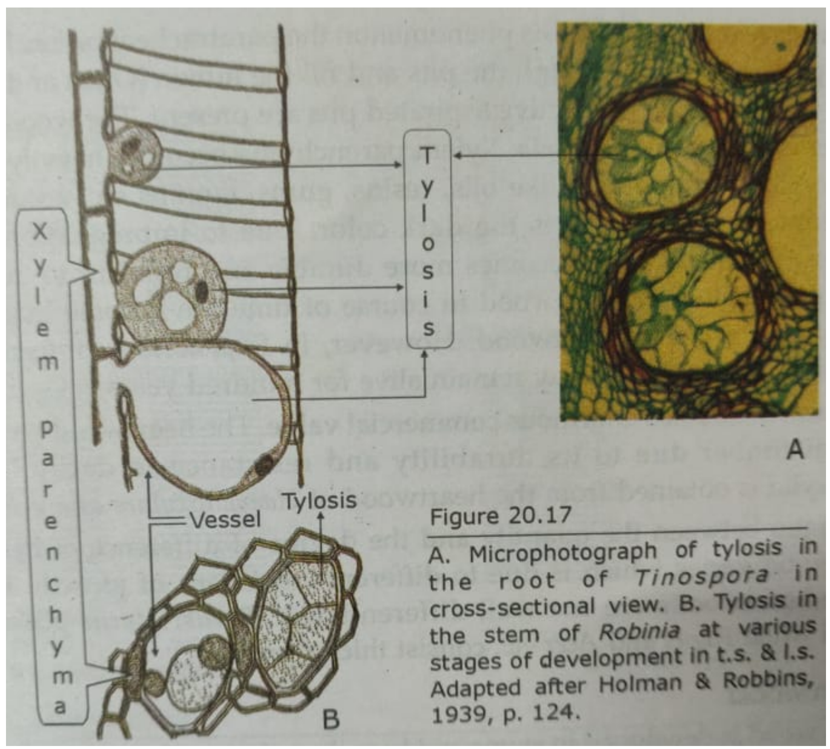


Figure 20.17

A. Microphotograph of tylosis in the root of *Tinospora* in cross-sectional view. B. Tylosis in the stem of *Robinia* at various stages of development in t.s. & l.s. Adapted after Holman & Robbins, 1939, p. 124.

Tylosoid-

- In gymnosperm, the epithelial cells, i.e. resin producing parenchyma surrounding the resin ducts, sometimes enlarge as tylosis-like intrusions and block the duct.
- These ingrowths are termed as tylosoids (ex. Pinus). In angiosperm (ex. Vitis, Bombax etc.) parenchyma proliferates into the neighboring sieve tubes in a tylose like manner. These proliferations are also known as tylosis. Tylosis of gymnosperm and angiosperm differ from tyloses in not protruding through pits.

Sapwood and Heartwood-

The wood of some old trees where considerable amount of secondary xylem has developed, becomes differentiated into two regions- the peripheral region called sapwood and the innerzone termed heartwood.

- The sapwood also called alburnum, is of lighter colour and consists of the active outer secondary xylem which is mainly concerned with translocation and storage of food. These are the youngest formed wood and are softer in texture than the heartwood. The sapwood contains living parenchyma and water-filled tracheary elements; it is full of 'xylem sap'-from where the name is derived.
- The inner heartwood also termed as duramen, in contrast to sapwood, is dark colored, hard in texture and contains inactive elements of primary and secondary xylem. Tyloses develop in the tracheary elements of some wood and block the lumen. The lumen may also be blocked by another method referred to as gummosis (ex. Prunus). In this phenomenon the paratracheal parenchyma cells produce gum that flows through the pits and fill the lumen. In gymnosperm, non-active aspirated pits are present. The wood loses cell sap, water and reserve materials. Xylem parenchyma becomes heavily lignified Various organic compounds like oils, resins, gums, tannins etc. accumulate In the cell lumen, which imparts the dark color. Due to impregnation of these substances, the heartwood becomes more durable and resistant to decay. The living xylem elements of sapwood in course of time die become inactive and gradually converted to heartwood.

- The heartwood has enormous commercial value. The heartwood yieds good quality of timber due to its durability and resistance to decay. The dye haemotoxylin is obtained from the heartwood of *Haematoxykum campechianum.*
- The ratio between the quantity and the degree of difference of heartwood and sapwood varies which is due to different conditions of growth. In *Abies, Picea* the heartwoods are not well differentiated. *Taxus, Morus* possess thin sapwood while *Fagus* and *Acer* etc. consist thick sapwood.

Reaction wood

Reaction wood is developed in stems and branches of a tree that are under stress. Gravity causes lateral stress. In response to such stress dicots and gymnosperm plants produce reaction wood and thus prevent the branches from drooping and becoming pendant Reaction wood appears in three different forms according to the nature of plants. They are referred to as tension wood, compression wood and contrasting wood.

- **Tension wood-** Tension wood, as the name implies, develops under tension. It is formed in dicotyledonous deciduous trees on the upper side of leaning hardwood tree branches. It is also formed on the curved side of the stem. A cross section of a branch having tension wood reveals that the wood is lighter in colour than normal wood. The growth rings are eccentric and much wider on the upper Side of a branch than normal wood. Gelatinous fibres compose tension wood. The cell wall of these fibres have little or no lignin and high cellulose content (Fig. 20.18) that fills most of the volume of lumen of cells. The content of hemicellulose is also different from that of normal wood. The tension wood has fuzzy appearance. This is due to the fact that when tension wood is sawed the fibres tend to pull out giving a fuzzy or villous surface.

- **Compression wood-** the compression wood that is formed in conifers is referred to as compress. Compression wood is formed on the underside softwood tree branches in response to compression stress. A cross-section branch having compression wood reveals that the wood is darker in colour the normal wood. The growth rings are wider than normal. In this wood the trachea are short. In cross-sectional view the tracheids are round and spaces occur beta the corners of them. The compression wood has less cellulose. It is enriched in lignin, as a result it has higher ductility than the normal soft wood.

- **Contrasting wood-** the wood that develops on the opposite side of reaction wood is referred to as contrasting wood. In softwood conifer trees it develops on the outer side and in hardwood deciduous trees it develops on the under side of the leaning branch. The contrasting wood exhibits thin growth rings, long tracheids with square and rectangular cross-sectional walls and thick inner layer in the structure of the secondary wall.

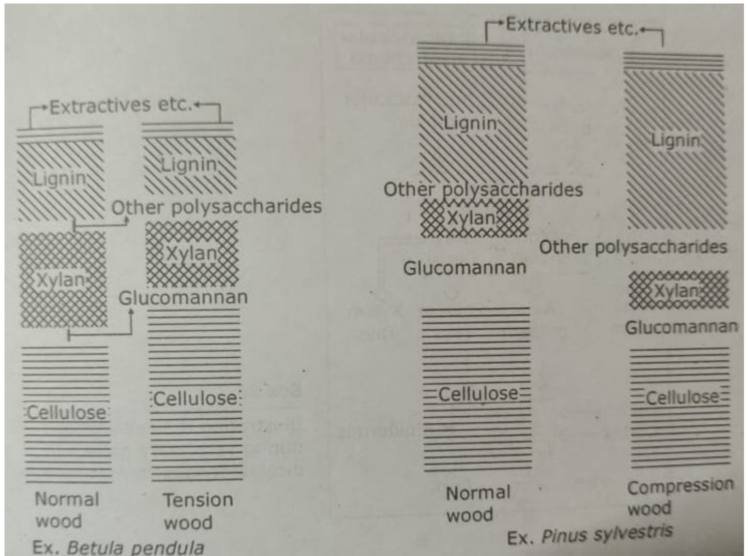


Figure 20.18
Diagrammatic comparison of the main structural constituents in normal wood, compression wood and tension wood. Glucomannan, xylan and other polysaccharides together represent the relative mass percentage of hemicelluloses. Adapted after Kettunen, 2006, p. 108 & 110.

Reference-

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