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E- Practical cum Teaching Manual of Wood Anatomy

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PREFACE AND ACKNOWLEDGEMENTS

Wood is technically a secondary xylem formed by the axial and radial tissues derived from the fusiform initials and ray initials, respectively. Being a complex tissue it is composed of vessel, tracheids, fiber and xylem parenchyma. In gymnosperms, the axial features have the abundance of tracheids and small amount of fiber and parenchyma, however in angiosperm it has abundance of vessels followed by fiber, tracheids and parenchyma. These vessels and tracheids are responsible for conduction of water–minerals and provide mechanical support to leaving tree.

These features can be categorised into macro features like density, hardness, Bark, heartwood-sapwood, texture, color etc. and Micro features like size and arrangement of vessel, parenchyma, ray etc. These unique anatomical characteristics are important in determining many of the properties of the species, such as strength, dimensional stability, acoustical, conductivity, and ease of utilization for various applications. These unique anatomical characteristics/features, allow a trained eye to identify the species. Each species has unique cellular structure that creates differences in wood properties and ultimately determines the suitability for a particular use. Cellular characteristics provide a blueprint for accurate wood identification.

The manual is prepared with an aim to cover the practical part of wood anatomy subject of B.Sc. Forestry. It has covered all the major topics like Tissue, Tissue system, Monocot and dicot anatomy, secondary growth, wood formation, Macro and micro features of woods and wood identification. In developing the material for this manual authors have relied upon the literature from several sources which is highly acknowledged. Some of the help came from discussion, field visit and various other sources. The author extends his gratitude to Dr. (Prof.) Narendra Pratap Singh Hon'ble Vice Chancellor, Dr. A.C.Mishra Director of Research Banda University of Agriculture & Technology Banda. Dr. A.K Shrivastva Director PMEC, Dr. Sanjeev Kumar Dean CoF, and Dr. Yogesh Y. Sumthane Assistant Professor FPU for their encouragement to write this manual. The Author also would like to thank all those, who have helped in anyway in preparation of this manual.

(Mohammed Nasir)

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1. Study of Anatomical Structure of Dicot Stem

Epidermis:

Epidermis is the outermost covering of the stem. It is represented by a single layer of compactly arranged, barrel-shaped parenchyma cells. Intercellular spaces are absent. The cells are slightly thick walled. Epidermis shows the presence of numerous multi-cellular projections called trichomes. The epidermis also contains numerous minute opening called stomata, which are mainly involved in transpiration.

Hypodermis:

Hypodermis is a region lying immediately below the epidermis. It is represented by a few layers of collenchyma cells with angular thickenings. The cells are compactly arranged without any intercellular spaces. Hypodermis provides mechanical support and additional protection.

Cortex:

Cortex is the major part of the stem represented by several layers of loosely arranged parenchyma cells. Intercellular spaces are prominent. Cortex is the major storage organ in the stem.

Endodermis:

Endodermis is the innermost layer of cortex represented by compactly arranged barrel shaped cells, without any intercellular spaces. The endodermis is wavy in appearance. The cells are richly deposited with starch grains and hence, endodermis is commonly described as starch sheath.

Stele:

Stele is the central cylinder of the stem, consisting of pericycle, medullary rays, pith and vascular bundles.

a. Pericycle:

Pericycle is the outermost covering of the stele, which lies immediately below the endodermis. It is represented by a few layers of compactly arranged sclerenchyma cells. Above each vascular bundle, the pericycle forms a distinct cap-like structure known as bundle cap.

b. Medullary Rays: Found in between the vascular bundles. They are meant for the storage of food.

c. Pith:

Pith is the innermost part of the stem formed by a group of loosely arranged parenchyma cells. Intercellular spaces are prominent. The pith is also meant for storage of food.

d. Vascular bundles:

They are eight in number, arranged in form of a broken ring. The vascular bundles are conjoint, collateral and open. Xylem is on the inner surface and phloem on the outer surface. Xylem is described as endarch.

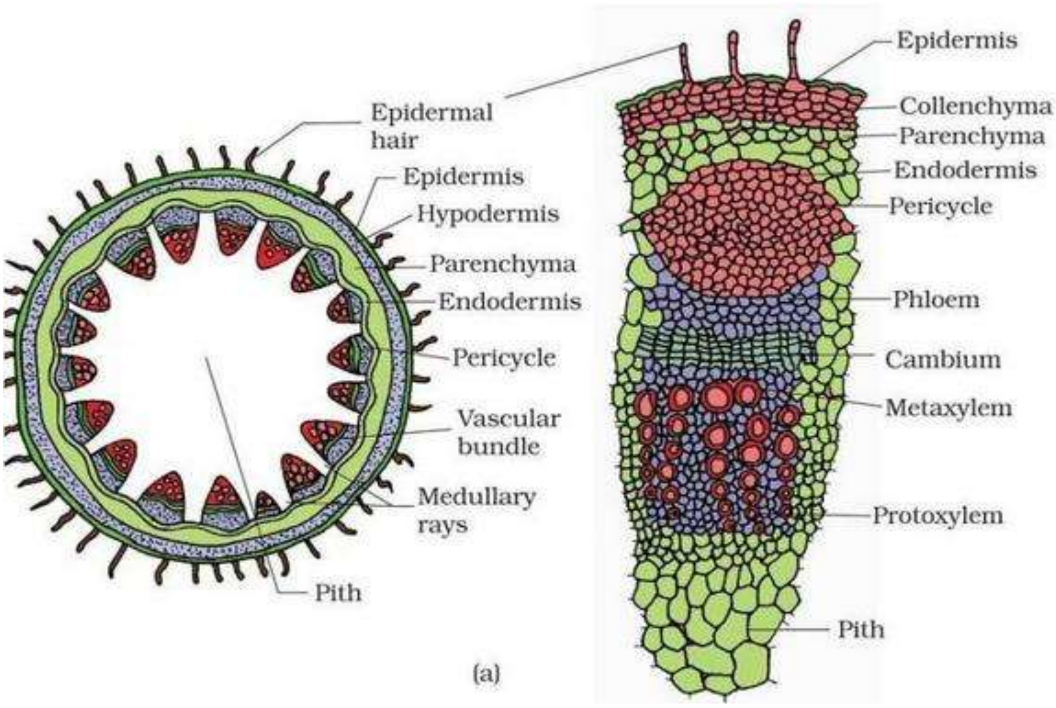


Figure 1-1: A microscopic model structure of dicot stem

Diagnostic Features of a Young Dicot Stem

* Presence of cuticle and trichomes.

* Presence of stomata.

* Presence of a hypodermis made up of collenchyma.

* Presence of a wavy endodermis containing numerous starch grains.

* Presence of a bundle cap above each vascular bundle, formed by sclerenchyma.

* Presence of eight vascular bundles, arranged in the form of a broken ring.

* Presence of conjoint, collateral and open vascular bundles with an endarch xylem.

2. Study of Anatomical Structure of Monocot

Epidermis:

Epidermis is the outermost covering of the stem represented by a single layer of compactly arranged, barrel-shaped parenchyma cells. Intercellular spaces are absent. Trichomes are absent. A cuticle is present. The epidermis contains numerous minute openings called stomata.

Hypodermis: Hypodermis is a region that lies immediately below the epidermis. It is represented by a few layers of compactly arranged sclerenchyma cells.

Ground Tissue:

Ground tissue is a major component of the stem. It is undifferentiated. The ground tissue is represented by several layers of loosely arranged parenchyma cells enclosing prominent intercellular spaces. The ground tissue is meant for storage of food.

Vascular Bundles:

They are found irregularly scattered in the ground tissue. Each vascular bundle has a covering called bundle sheath formed by a single layer of sclerenchyma cells. The vascular bundle encloses both xylem and phloem. Xylem is found towards the inner surface and phloem towards the outer surface. Cambium is absent. Hence the vascular bundles are described as conjoint, collateral and closed. Phloem parenchyma is absent.

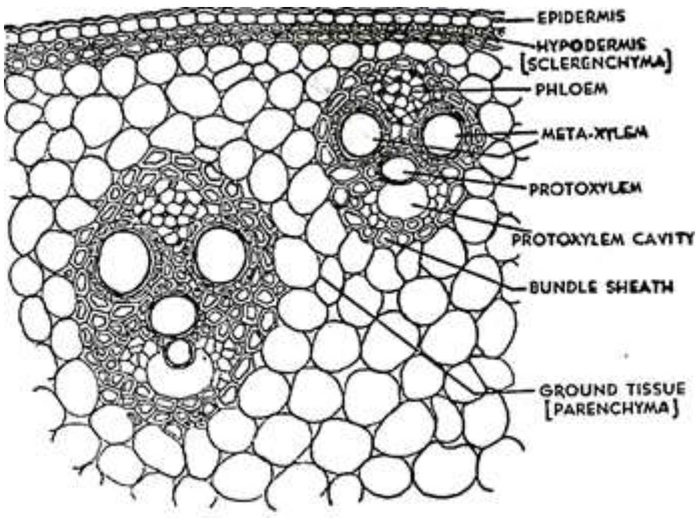


Figure 2-1: A cross section of monocot stem (*Zea mays*).

Diagnostic Features of a Monocot Stem

* Absence of trichomes.
* Presence of stomata.
* Presence of a hypodermis made up of sclerenchyma.
* Presence of undifferentiated ground tissue.
* Presence of numerous vascular bundles irregularly scattered with cerifugal arrangement.
* Vascular bundles are conjoint, collateral & closed with endarch xylem.
* Presence of only two protoxylem & two metaxylem vessels in each bundle.
* Presence of a lysigenous cavity.
* Absence of phloem parenchyma.
* Presence of a bundle sheath made up of sclerenchyma.

Anatomical differences between Dicot and Monocot Stem

Characters	Dicot Stem (Sunflower)	Monocot Stem (Maize)
Epidermis a). Trichomes b). Cuticle	 Present Present	 Absent Present

Hypodermis	Made up of Collenchyma	Made up of Sclerenchyma
Ground tissue	Differentiated into cortex, endodermis, pericycle, medullary rays and pith	Undifferentiated
Vascular bundles a). Number b). Arrangement c). Bundle cap d). Bundle sheath	Eight In the form of a broken ring Present Absent	Numerous Irregularly scattered; Absent Present
Nature of the Vascular Bundles	Conjoint, Collateral and open with endarch xylem	Conjoint, Collateral and closed with endarch xylem
Pith	Pith is distinct and centrally located	not differentiated

3. Study of Anatomical Structure of Dicot Root

Epiblema:

Epiblema is the outermost covering of the root formed by single layer of compactly arranged, barrel-shaped, parenchyma cells. The cells are characteristically thin-walled since they are involved in absorption of water. A cuticle and stomata are absent. Some of the epiblema cells are produced into long unicellular projections called root hairs. Hence, the epiblema is also known as piliferous layer.

Cortex:

Cortex is a major component of the ground tissue of root. It is represented by several layers of loosely arranged parenchyma cells. Intercellular spaces are prominent. The cortex is mainly meant for storage of water. The cells also allow a free movement of water into the xylem vessels.

Endodermis:

It is the innermost layer of cortex formed by compactly arranged barrel-shaped cells. Some of the cells in the endodermis are thin-walled and are known as passage cells. The passage cells allow water to pass into the xylem vessels. The remaining cells in the endodermis are characterised by the presence of thickening on their radial walls. These thickenings are known as casparian thickenings. They are formed by the deposition of a waxy substance called suberin. The casparian thickenings play an important role in creating and maintaining a physical force called root pressure.

Stele:

Stele consists of pericycle, conjunctive tissue and vascular bundles.

Pericycle:

Pericycle is a region that lies immediately below the endodermis. It is represented by a single layer of parenchyma cells.

Conjunctive Tissue:

Conjunctive tissue is represented by a group of radially arranged parenchyma cells found in between the vascular bundles. The cells are specialised for storage of water.

Vascular Bundles:

Vascular bundles are described as radial and tetrarch. There are four bundles each of xylem and phloem occurring alternately. Xylem is described as exarch.

Pith:

Pith is absent in the older root.

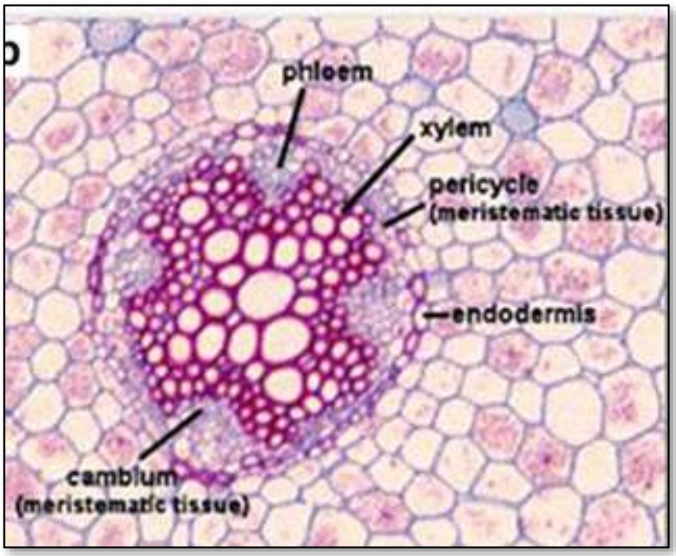


Figure 3-1: transverse section from the middle of a root of a dicotyledonous plant

Diagnostic Features of a Dicotyledonous Root

* Presence of thin walled cells in the epiblema.

* Absence of cuticle, and stomata.

* Presence of unicellular root hairs.

* Absence of hypodermis.

* Presence of passage cells and casparian thickenings in the endodermis.

* Presence of uniseriate pericycle made up of parenchyma.

* Presence of conjuctive tissue.
* Absence of pith.
* Presence of radial vascular bundles exhibiting tetrach condition with exarch xylem.

4. Study of Anatomical Structure of Monocot Root

Epiblema: Epiblema is the outermost covering of the root formed by a single layer of compactly arranged, barrel-shaped parenchyma cells. The cells are characteristically thin-walled since they are involved in absorption of water. A cuticle and stomata are absent. Some of the epiblema cells are produced into long unicellular projections called root hairs. Hence, epiblema is also known as piliferous layer.

Cortex: Cortex is a major component of the ground tissue of root. It is represented by several layers of loosely arranged parenchyma cells. Intercellular spaces are prominent. The cortex is mainly meant for storage of water. The cells also allow a free movement of water into the xylem vessels.

Endodermis:

It is the innermost layer of cortex formed by compactly arranged barrel-shaped cells. Some of the cells in the endodermis are thin-walled and are known as passage cells. The passage cells allow water to pass into the xylem vessels. The remaining cells in the endodermis are characterised by the presence of thickening on their radial walls. These thickenings are known as casparian thickenings. They are formed by the deposition of a waxy substance called suberin. The casparian thickenings play an important role in creating and maintaining a physical force called root pressure.

Stele:

Stele is the central cylinder of the root consisting of pericycle, conjunctive tissue, pith and vascular bundles.

Pericycle: Pericycle is the outermost covering of the stele represented by a single layer of parenchyma cells.

Conjunctive tissue: It is represented by loosely arranged parenchyma cells found in between the vascular bundles. The cells are specialized for storage of water.

Pith:

Pith is the innermost region of the root representing the central axis. It is composed of few loosely arranged parenchyma cells.

Vascular bundles: Vascular bundles are radial in arrangement. There are eight bundles each of xylem and phloem. Hence, the condition is described as polyarch. Xylem is described as exarch.

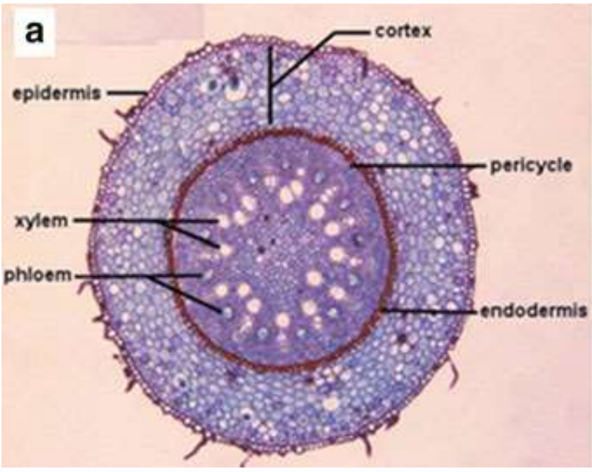


Figure 4-1: transverse section from the middle of a root of a monocotyledons plant

Diagnostic Features of a Monocot Root

* Presence of thin walled cells in the epiblema.

* Absence of cuticle and stomata.

* Presence of unicellular root hairs.

* Presence of passage cells and casparian thickenings in the endodermis.

* Presence of parenchyma cells in the pericycle.

* Presence of conjuctive tissue.

* Presence of a distinct pith.

* Presence of radial vascular bundles with polyarch condition and an exarch xylem.

Anatomical differences between Dicot and Monocot Root

Characters	Dicot Root	Monocot Root
Xylem bundles	Vary from 2-6; rarely more	Numerous (Polyarch)
Pith	Small or Absent	Large and Well developed
Pericycle	Gives rise to lateral roots and Secondary meristems *i.e.,* Cambium and Cork cambium	Gives rise to lateral roots
Cambium	Appears later as a secondary meristem	Altogether absent

5. Study of Secondary Growth in Plants

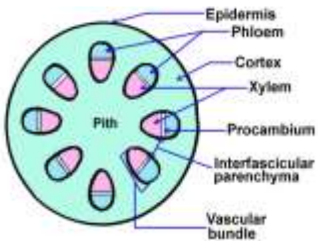
Introduction:

Secondary growth is defined as growth in plants that results from the activity of a cambium producing increase especially in diameter, is mainly responsible for the bulk of the plant body, and supplies protective, supporting, and conducting tissue.

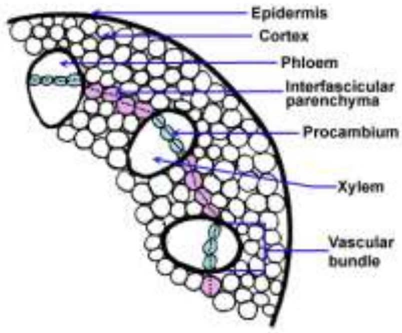
In many vascular plants, secondary growth is the result of the activity of the two lateral meristems, the cork cambium and vascular cambium. Arising from lateral meristems, secondary growth increases the girth of the plant root or stem, rather than its length.

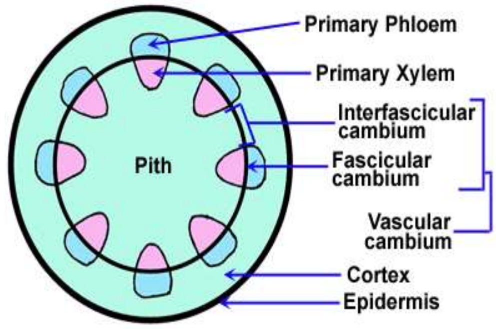
Secondary growth in Dicotyledonous stem

Secondary growth begins with the initiation of the vascular cambium, a cylinder of meristematic tissue that produces additional xylic and phloic tissues. The cells that eventually form the vascular cambium come from two sources, the procambium in the vascular bundles and the interfascicular parenchyma cells between vascular bundles. The diagram below shows the positions of these two populations of cells in a stem with only primary growth.



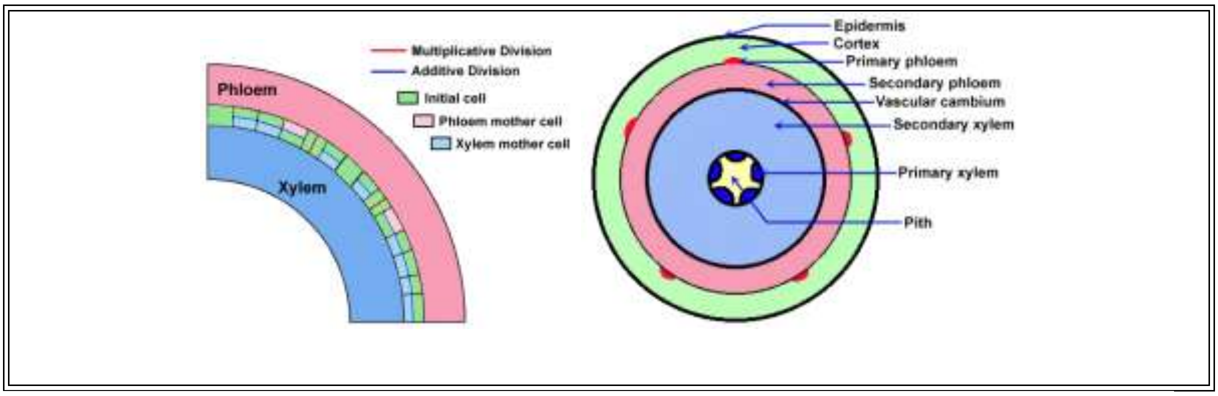
The vascular cambium forms when the cells of interfascicular parenchyma dedifferentiate and divide periclinally, in a plane parallel to the surface of the stem. The cells in the procambium divide in a similar fashion. The following diagram depicts the periclinal divisions in the procambium and the interfascicular parenchyma (Left figure). The two populations of dividing cells unite to form a continuous ring of dividing cells, the vascular cambium (Right figure).

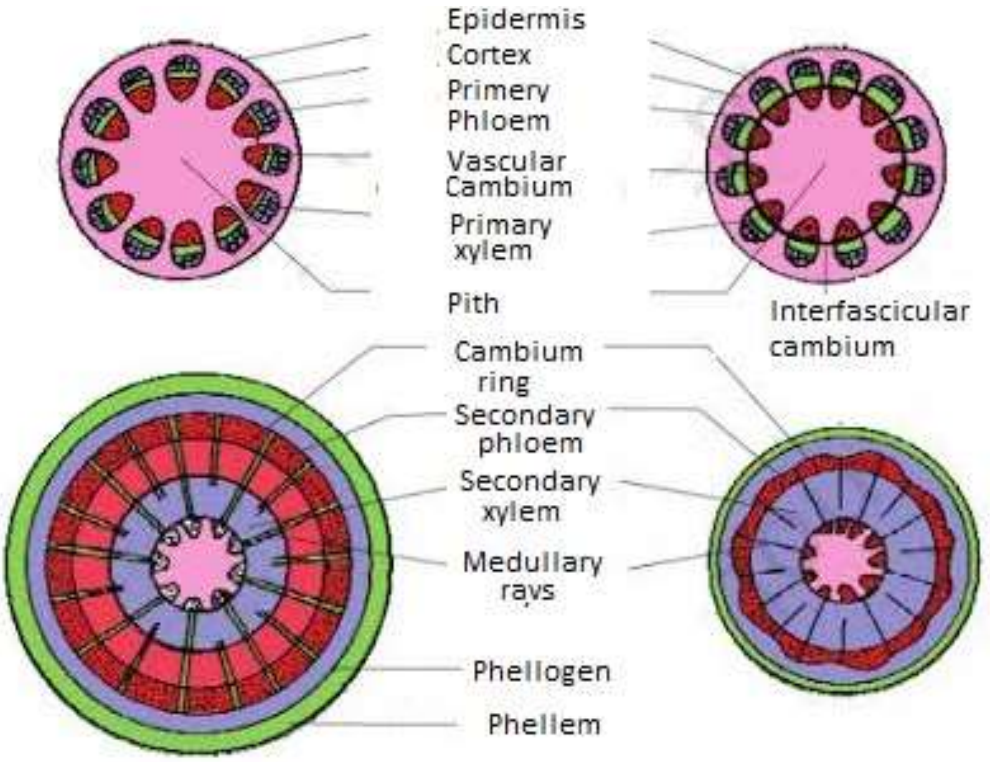




If we look closely at the cells of the vascular cambium we see two patterns of division. Initial cells can undergo multiplicative divisions (red line in the following diagram) or they can undergo additive divisions (blue line). Multiplicative divisions produce more initial cells and result in the increased circumference of the vascular cambium. Of the two cells produced from an additive division one is retained as an initial cell that will divide again, and the other will become a phloem mother cell or a xylem mother cell. These mother cells will differentiate into their respective cell types. (Left figure)

After significant activity in the vascular cambium, a stem exhibiting secondary growth might look like the following diagram. The primary xylem is in the center of the stem, while the primary phloem is pushed outward by the new cells that arise from the vascular cambium. Eventually, the primary phloem is crushed into the cortex. The secondary xylem differentiates from the cells that divide off the vascular cambium towards the inside of the stem, while the secondary phloem differentiates from the cells that divide towards the outside of the stem (Right figure).





Secondary Growth in Dicot stem

6. Wood identification and its importance

Introduction:

Wood is a porous and fibrous structural tissue found in the stems and roots of trees and other woody plants. Wood is sometimes defined as only the secondary xylem in the stems of trees. The branch deals with study of internal structure of an organism or object is known as anatomy.

Wood anatomy

Wood anatomy deals with the internal structure of wood including wood formation and wood properties.

Importance and scope of wood anatomy

Wood anatomical studies not only help in correct identification of a timber but also to assess its quality and suitability for diverse end uses. It is considered as the fundamental basis for all timber studies. Its direct importance is in the field of wood identification, wood utilisation, paper and pulp, taxonomy, paleobotany etc. It also supplement the researcher in field of silviculture and genetic tree improvement.

In India, we have over 1200 tree species producing wood. the identification of these on the basis of morphological characters may be simpler but after felling and conversion of logs, their identity can be ascertain by a wood anatomist only. Before using a timber it is necessary to know exactly what that wood is and what properties it have. The internal structure of a species is highly specific just like thumb impression in human by way of which exact identity of a timber can be established.

Peoples are using timber since drawn of civilization and they are able to recognise some of the common timbers like teak, sal, sissoo, deodar, babool etc from their general appearance and physical properties like colour, weight, odour etc. But this procedure is not easy or nor practicable when hundreds of timber are involved. The physical features are not always reliable as they may vary within same timber or different timber appearance can be made similar by artificial treatment. The best identity of timber is only from anatomical structure. This study leads to proper identification of wood which in turn play an important role in efficient wood utilization. Example, Indian fir and spruce were found suitable for aircraft and ship buildings.

The studies of the tissues associated with gum and resin production has lead in development better and more efficient method of taping. These studies have also lead to find out reasons for seasoning defects like warping twisting etc. These also help in removing the sawing defects, application of wood preservation i.e. penetrability and treatability of wood. In paper and pulp studies a new method of cleavage of tissue in bamboo through anatomical studies have lead to increase in yield of pulp from 35-70%. It is true wood anatomical studies that not only identification but also quantitative estimation of the raw material is used in indigenous paper making. The identification also lead in solving the special problem related to currency note, revenue paper, bill document etc.

Wood anatomical studies also plays a vital role in determining pulp sheet properties like flexibility, tensile strength, tear, printability, bend ability etc of different raw materials. All these properties are affected by fiber properties which are studied in wood anatomy.

Wood anatomical studies have been found to be wide significance in archaeological studies. It help to about type of vegetation, climate, prevailing in older times through studies of growth rings. Archaeological department carried out different ancient studies with the help of wood anatomist. In throwing the light over the past civilization and vegetation changes, during last 4000 years. E.g. highly decorated wooden coffin made up of deodar/rosewood. It shows that herpans not onlyacquainted with scented wood for coffee making but also trade connection with south India. The effect of thinning, pruning, spacing, site quality and other silviculture practices on wood characteristics is also studied under wood anatomy. Different tree improvement studies have been carried out for improving the wood quality especially specific gravity and others which are heritable. This effect of improvement or feedback of the tree breeder is only given by the wood anatomist.

7. Preparation of three-dimension Wood Sample for Identification

Introduction

Wood is a biological product of growth in trees, due to height growth (primary) and diameter growth (secondary growth). A tree trunk converted into log, consists of bark, wood and pith. In between bark and wood lies cambium (generative) the growing layer, which is not visible to naked eye. Wood cylinder, which is encircled by bark, consists of sapwood and heartwood, both of which contain annual rings (part of the stem formed in a year).

The timber sample to be examined may be out of convenient size, easy for handling. A rectangular piece of wood 3-5 cm square or rectangular in transverse (cross) section about 5-10 cm long may be the minimum optimum size.

The sample selected for study should be first trimmed in vertical direction (with reference to the main axis of the standing tree); along the radial longitudinal section of wood and tangential longitudinal section of wood. For identification most revealing and important surface is transverse surface or end surface. To prepare this surface for examination under hand lens, hold the sample firmly in left hand in vertical position with pith side pointing downwards; towards the holder. The knife is to be held firmly in right hand with thumb impressed hard against the inner side of the sample. To make a good, clean cut the blade slightly tilted downwards. While doing so, care should be taken to see that right thumb is kept well below the upper edge of the sample, so that knife may not damage the finger. A good cut is essential. Slight crushing of the tissues resulting from a blunt knife or bad cut, is likely to obliterate some of the structural details, which are so important for correct identification. Sometimes it is preferable to use sharp and thin razor blades, when timber is extremely soft or hard.

To examine the exposed area under hand lens, the lens is held close to the eye in one hand and the specimen to be examined is slowly raised till the end surface comes sharply into focus, showing clearly the structural details. Most of the structural details of diagnostic value are visible on transverse section (end surface). Some like ripple marks; horizontal resin canals, *etc.* are visible on longitudinal plane, especially on tangential-longitudinal surface.

Characteristics of wood observed under different surfaces

Transverse surface/Cross section of wood: A transverse or cross section of a stem is normally circular. Three parts may be distinguished: Pith, Wood (Sapwood and Heartwood, Early wood, Late wood, Annual rings), Bark, resin canals and Gum Canals.

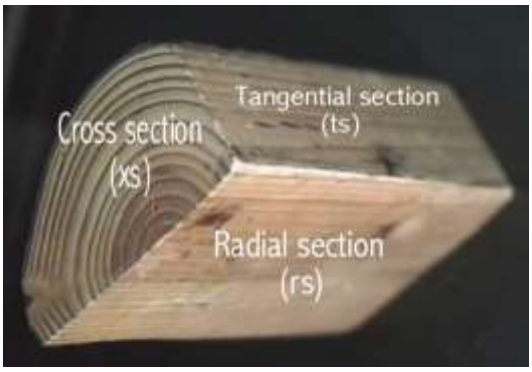
All woods possess rays which, on a Cross section, appear as lines extending in the general direction from pith to bark. In some hardwoods, such as Oak and Sycamore, the rays are wide and very conspicuous. In others (and in all softwoods) they are more or less fine and sometimes difficult to distinguish-even with a hand lens. Careful observations reveal that all rays do not start from the pith. They may start within one growth ring, but once started they usually continue towards the bark, which they also enter.

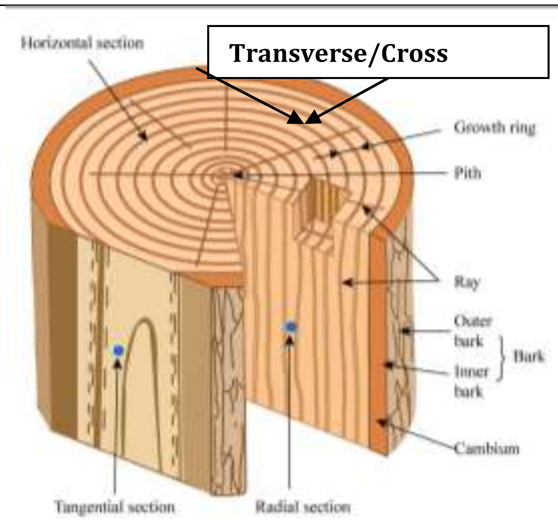
Radial and tangential surface: radial and tangential sections produce surfaces that are characteristically different from each other and from cross sectional surfaces.

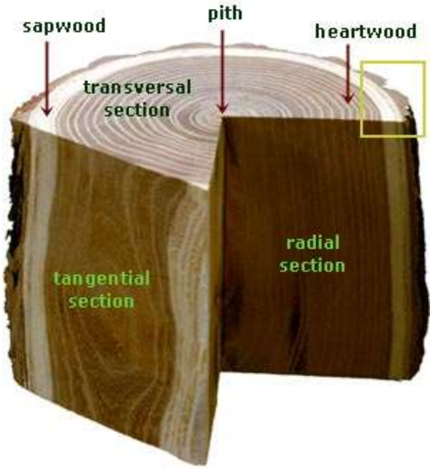
A radial surface is produced by sectioning a stem through its pith. The various features such as pith, growth rings, earlywood and latewood, heartwood and sapwood, inner and outer bark appear as longitudinal strips, but some (pith, sapwood or heartwood, bark) may not be represented in a given sample., depending on its location. Resin canals and gum canals when present and the larger pores of hardwoods show as fine longitudinal lines or indentations of different colour. The rays run crosswise. In woods posseing wide rays, these appear as large, conspicuous flecks*; in case of Oak, a characteristic decorative figure, known as Silver grain is thus produced.*

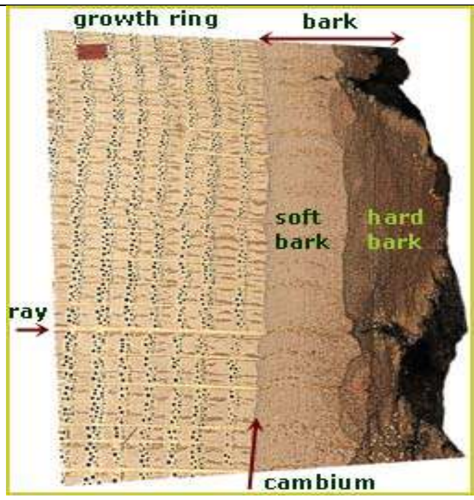
A distinctly different picture is represented by sectioning wood in a tangent to the growth rings. The tangential surface has a more or less pronounced wavy appearnce, depending on the contrast between earlywood and latewood. The pith is not exposed, but all other macroscopic features may be represented according to the level of sectioning in relation to the pith. The rays, cut transversly, appear as longitudinal, often spindle shaped lines of varying length and width; accordingly they may be conspicuos with nacked eye or difficult to see even with a hand lens.

Presence of various defects may greatly modify the appearnce, particularly in the radial and tangetial surfaces. Such surfaces may also be modified intentionally by sectioning not at truly radial or tangential planes. Practical use of this possibility is made in the manufacture of decorative veneer.


Cross section
(xs)
Tangential section
(ts)
Radial section
(rs)


Horizontal section
Transverse/Cross
Growth ring
Pith
Ray
Outer bark
Inner bark
Bark
Cambium
Tangential section
Radial section


sapwood
pith
heartwood
transversal section
tangential section
radial section


growth ring
bark
soft bark
hard bark
ray
cambium

8. Classification of Woods into Porous and Non Porous Groups

Introduction

Vessels are series of cells with open ends placed one above the other, forming a continuous tube, like the sections of drain pipe, running in the direction of the long axis of the tree. Their function is to conduct sap (water and mineral nutrients) from the soil and roots to the crown. On the longitudinal surfaces or broad faces of timber the vessels frequently show up as long fine scratches or grooves, especially in coarse textured woods like Kokko and Mango. When cut across, they appear on the end surface of wood as small, circular or somewhat oval openings or holes, usually visible to the eye or under a hand lens, and are therefore known as Pores. The occurrence of pores or vessels is a constant feature of all broadleaved trees and it is for this reason that all broad leaved species is known as Porous woods. On the other hand, in Conifers (softwoods), vessels or pores are completely absent and the wood is known as Non Porous woods. In the trade non porous woods are known as Softwoods, while porous woods are known as Hardwoods. It should be noted here that the terms “Hardwoods” and “Softwoods” have no relation to the relative hardness or softness of the timber but merely refer to the class of trees which produce them, namely, broadleaved species and conifers.

Classification Porous Woods based on arrangement of pores

1. **Ring Porous wood:**

In ring porous woods, the pores formed during the early part of the growth season are distinctly larger than those of the latewood and forms, as it were a distinct belt or ring at the beginning of the growth ring. These woods typically have distinct figures and patterns, and the uneven uptake of stain (the large pores soak up more colour) make the figure more pronounced. These are also known as open-grain woods. *e.g.,* Teak, Mulbery, Toon, Ash

2. Diffuse Porous wood:

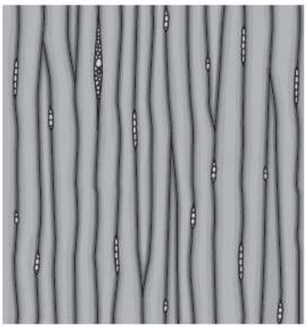
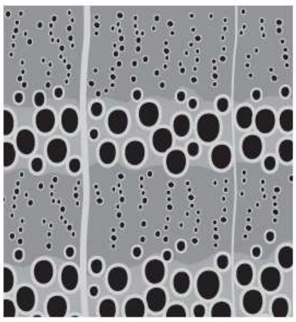
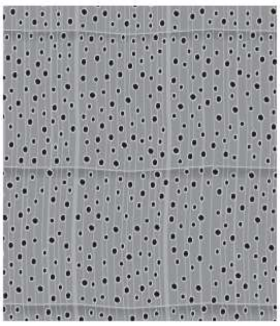
The majority of the India hardwoods, however, do not show any appreciable difference in the size of earlywood and latewood pores, which are distributed more or less uniformly throughout the growth ring and are known as diffuse porous woods.

Most domestic diffuse-porous woods have relatively small-diameter pores, but some tropical woods of this type (e.g. mahogany) have rather large pores. These woods usually have even uptake of stain (there seems to be no scientifically proven explanation of the cause of blotching). These are also known as closed-grain woods. *e.g.,*Sal, Haldu/Heddi, Maple, Cherry, Yellow Poplar

3. Semi Ring Porous wood:

In some species (e.g. black walnut and butternut), pores are large in the earlywood and smaller toward the latewood, but without the distinct zoning seen in ring-porous woods.

Also, some species that are usually ring-porous (e.g. cottonwood) occasionally tend toward semi-ring porous.

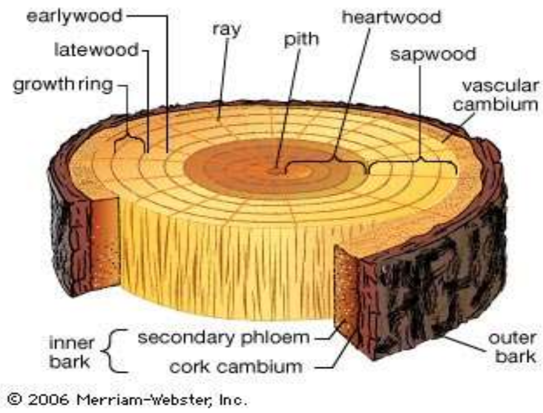
			
Non Porous wood	Ring Porous wood	Diffuse porous wood	Semi Ring Porous wood

9. Introduction to Wood Anatomy: Study of Macroscopic Features of Wood

Introduction

Structural features of wood that can be seen with the unaided eye may be known as Macroscopic/Gross features of wood. Many of these can best be studied on the cut end surface of a log or on the stump of newly felled tree.

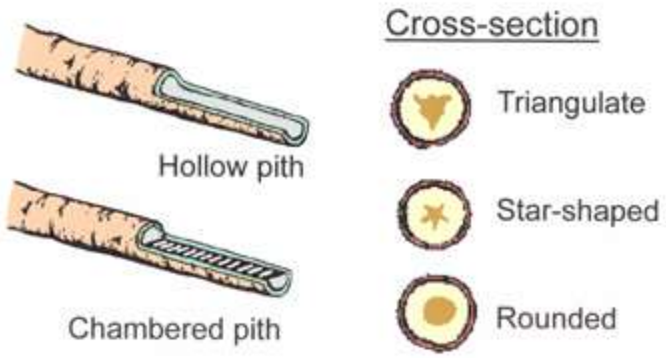
A transverse or cross section of a stem is normally circular. Three parts may be distinguished; namely outermost is the bark surrounding a central cylinder of wood with the pith in middle.



Bark: Bark varies in thickness, colour and appearance in different species. it usually shows two distinct regions; an outer protective zone of corky nature consisting of dead and dying cells and an inner living portion which is actively associated with conduction and storage of food materials required for growth.

Pith:

Pith is soft core found near about centre of the log. In softwoods pith is fairly uniform, but in hardwoods its shape, colour and structure vary. It may be round, oval, triangular or squarish in shape and is usually not more than 0.6 cm in diameter. The colour is commonly some shade of brown (black to whitish), though in some trees it may be pinkish, greyish or yellowish. Usually twigs and young stems have proportionately larger pith than that found in mature trees.



Sapwood and Heartwood:

The woody cylinder shows, as a rule, two well marked zones; an outer light coloured portion known as “Sapwood” and an inner or central darker coloured portion known as “Heart wood”. Colour distinction, however, is not always a true criterion.

Growth Rings (annual Rings):

Most wood show on the stump or the cut end surface of the logs a number of concentric marks. These may be faint and barely visible, or distinct and prominent to the eye, depending upon the species, and are known as Growth Marks. The interval between two such consecutive growth marks represents the wood laid down by the tree during a growing season and is commonly referred to as a “Growth Ring” or “Annual Ring”.

Early wood and Late wood:

Within a growth ring, the wood towards, or that formed in the early part of the growth season, is termed as “Early wood/Spring wood”. The wood towards the outside, which is laid down in the later part of the season, is known as “Late wood/Summer wood/Autumn wood”.

Grain:

Grain in wood refers to the general direction or alignment of cells, and should not be confused with *texture which is related primarily to the size of the cells*. Depending on the actual alignment of the wood elements in relation to the axis of the tree or main axis of the piece, the grain may be described as Cross, Straight, Diagonal, Spiral, Wavy, Curly, Interlocked (Sal) and Irregular (or wild).

Texture:

Texture pertains to the relative size of cells and their proportion in unit volume (wood elements). Common terms used in describing texture are as follows;

Coarse Texture: Mango, Hollock (*Terminalia myriocarpa*), Kokko (Siris; *albizia lebbeck*)

Fine Texture: Box wood (*Buxus spp.*), Gardenia, Sandal, Haldu (*Adina cardifolia*)

Even Texture: Most of the tropical woods show even texture

Uneven Texture: Mulbery, Ash (*Fraxinus spp*), Toon, Teak and Coniferous woods (Occurs generally in case of some ring porous woods and coniferous woods with conspicuous and sharply delimited late wood like Chir)

10. Study of Diagnostic Features of Wood -Physical Properties

Introduction

Physical properties of wood generally denotes inherent qualities such as the appearance, odour, colour and also its reaction of sound, light, heat, electricity, *etc.* Physical properties have sometimes been predominantly responsible for the numerous uses of wood, such as for musical instruments, decorative surfaces, insulating media, *etc.*

1. Weight and Density

Density:

Density is defined as "weight of a unit volume of the material and is expressed as kg/cu. m (or lb/cu.ft)

Relative density/Specific gravity: is defined as "the ratio of the weight of the material to the weight of an equal volume of water at 4° C.

$$\text{Specific Gravity (S)} = \frac{W_o}{V_S}$$

W_o = Weight of Oven dry wood

V_S = Volume in green condition (Usually obtained by weight of an equal volume of water by immersion method)

$$\text{Oven dry weight of wood } (W_o) = \frac{W_m}{1 + \frac{m}{100}}$$

W_m = Weight of wood

m = Moisture content

Common temperate woods range in specific gravity (based on oven dry weight and green volume) from about 0.30 to 0.90.

Classification of wood/timber based on density and specific gravity

1. Very light 2. Light 3. Moderately heavy
4. Heavy 5. Very Heavy 6. Extreamly heavy

2. Porosity:

Porosity of a wood is a measure of relative size and abundance of cell cavities (Lumen). Wood with *Thin cell walls and large cell cavities is more porous and lighter; Thick cell walls and small cell cavities is less porous and denser*. Wood is generally more porous in transverse surface than in radial or tangential surface.

3. Colour:

The colour in wood is due to infiltration of chemical products. Natural colour indicates soundness of timber; any discolouration may be due to fungal attack.

- ❖ Colour in wood, though very variable, sometimes helps in identification of wood.

  e.g., Indian Teak and Burma Teak
- ❖ Generally wood darkens on exposure to sun and weather {sapwood darkens more (chemical changes occur)} *e.g.,* Teak, Mulberry, Toon
- ❖ Difference between colour of heartwood and sapwood *e.g.,* Ebony and Rosewood

4. Lustre/Sheen:

Lustre is the manner in which the surface of the wood reflects light. Lustre depends on the ability of the cell walls to reflect light. This property is not present in all timbers. Lustrous timbers are more durable, but do not take polish easily.

5. Grain:

Pertains to alignment of wood cells or direction of fibres with regard to vertical axis of the tree or Grain denotes direction of wood elements.

Grain may be *Diagonal, Spiral, Straight, Curly or Wavy, Irregular and Interlocked*

6. Texture:

Texture pertains to the relative size of cells and their proportion in unit volume (wood elements). In the most basic terms, the wood texture describes how a wood feels. Given an equal amount of sanding and smoothing operations, different woods will feel smoother than others. Some will still feel somewhat soft and rough (what is described as coarse texture), while others will feel very smooth and glassy (referred to as a fine texture).

Texture therefore may be described as

a. Fine texture b. Coarse texture c. Even texture

d. Uneven texture e. With intermediate shades

7. Figure:

is used to describe the natural design or pattern on wood surface. *Figure refers to the distinctive pattern produced on longitudinal surface of timber as a result of different tissues and direction of the grain.*

Figure may be attractive due to differences in the reflective property of different surfaces. *More attractive figure may be produced by structural abnormalities*. *Grain deviations, burls* (rounded out growths on stem) and *Crotches* (forked portions of stem), eccentric growth, uneven deposition of colour and other irregularities may produce beautiful figure.

8. Odour:

Odour in wood is due to deposition of volatile extraneous materials (oils, resins and chemical substances) in wood (heartwood).

Many woods exhibit characteristic odour, which is sometimes helpful for identification. *Odour is more prominent in greenwood than seasoned wood* (*e.g.,* deodar, Pines). Sandal, Eucalyptus, Cedar woods have peculiar odours. Teak exhibits odour like burnt leather. Chemicals present in *C. camphora* have property of repelling moths and insects.

9. Taste:

Taste is distinct property of some woods, closely related to odour; it is due to presence of volatile substances. Taste is more pronounced in fresh material; it is also more distinctive in heartwood than in sapwood. Taste is very useful in selecting wood for containers of foods and drinks, ice cream spoons, pencils, *etc.*

10. Hardness:

It signifies the resistance offered, by a wood specimen, to penetration by another body, *i.e.,* resistance to indentation and not to cutting as is commonly understood, which depends on *nature of grain, presence of silica and other substances*.

Hardness is considered here as a feature which may be simply judged by pressing with a thumb nail. The ensuing ease or difficulty with which the *thumb nail can indent wood is taken as a measure of its hardness.Hardness is closely related to weight; heavier woods are harder.*

Classification of woods based on hardness

a. Extremely hard b. Very hard c. Hard

d. Moderately soft

e. Soft f. Very soft g. Extremely soft

11. Study of Diagnostic Features of Wood -Microscopic Features of Hardwood and Softwood

Introduction

Wood is composed of a multitude of minute units, called cells. Their recognition became possible only after the invention of the microscope. Robert Hooke, observed first the cells of cork in 1665. It has been computed that one cubic foot (1/35 m^3) of spruce wood contains about 10-14 billion cells. This corresponds to 350-500 billion cells per cubic meter

A cell mainly consists of cellulose, hemicelluloses and lignin. When these cells are first formed they are all similar in shape and size. As the growth continues, differentiation of cell is going to takes place which leads to change in shape, size and structure according to the function they perform. Depending upon the functions they perform various types of cells are classified as *Vessels, fibres, tracheids, parenchyma*, *etc*. The size, proportion and arrangement of different kinds of wood elements vary with different types of timbers. No two woods have exactly the same anatomical structure and patterns like human finger print.

Microscopic Features of Softwoods

Softwoods possess simpler structure, with presence of only tracheids, parenchyma, rays and resin canals. Their relative arrangement of these cells is also simple.

Tracheids:

Tracheids are long pointed cells (2-5 mm long) constitutes the major component of softwoods, making up over a 90% of the volume of the wood. They serve both conduction and mechanical function in softwoods. They are provided with large bordered pits with thick wall and closed tapered overlapping ends.

The tracheids of softwoods are mostly or exclusively vertical. In some species a few tracheids may be placed horizontally in association with rays. The former are called vertical or axial tracheids, and the later horizontal or Ray tracheids.

2. Axial Parenchyma:

These are short, rectangular or brick shaped cells with comparatively thin walled cell with simple pits. Their main function is storage and conduction of food material. These parenchyma cells are oriented in the vertical like tracheids with the long axis parallel to grain; hence they are referred as Longitudinal or Axial Parenchyma.

Axial parenchyma is not present in all softwoods. In some softwoods, it may be entirely absent (Pine, Spruce, Yew), *absent or very sparse (Hemlock, Fir, Douglas fir),* or present in variable propotions (Redwood, Baldcypress, Cypress, Cedars). When present, parenchyma cells may be diffuse among the tracheids; Zonate or Banded, *i.e., in tangential lines or bands;* and boundary (Initial or terminal), if placed at the bounderies of growth rings.

3. Rays:

rays are important identification features in conifers. Most rays in conifer are uniseriate, *i.e., they consist of a single vertical tier of cells.* The rays of conifers are composed of parenchyma cells alone or of parenchyma cells and tracheids.

4. Resin canals:

These are long tubular cavities found in the wood, which serve as storage organs for waste products of metabolic activity like resins. It is a characteristic feature of many softwoods; the resin is formed in parenchyma cells and in some species in resin canals and resin ducts. These are cavities in wood, lined with an epithelium of parenchyma cells. The epithelial cells secrete resin into the canals. *e.g., Pines, Spruce, Douglas fir, Larch, Deodar*

Microscopic Features of Hardwoods

Vessels or Pores (7-55%):

Vessels are specialised water conducting cells, which are stacked one on other with perforation plate at the joined ends forming a continuous tube running in the direction of long axis of the tree. on the transeverse section, vessels appear as large openings and are often known as Pores. They are much shorter than tracheids and can be arranged in various patterns.

Based on arrangement of pores hardwoods are divided into;

a). Ring porous woods b. Diffuse porous woods c. Semi ring porous woods

Arrangement of Pores: Random, Tangential, Radial, Diagonal/Oblique, Dendritic or flame like

2. Fibres (27-56%):

Fibres are long, narrow, elongated, slender, vertically aligned thick walled cells with pointed tapering ends, which makes bulk of wood by weight in most hardwoods. Their main function is to give mechanical support to the tree and they are absent in softwoods.

3. Ray cells (5-25%):

Rays are varying in both size and number of rays in case of hardwoods. Some hardwoods have only Uniseriate rays (Willow, Poplar), but in the majority the rays are Multiseriate (More than one cell wide). In some timbers rays are comparatively uniform in size; they may be relatively small and not visible to the naked eye (Birch) or they may be broad and high, conspicuous to the naked eye, as in plane. Very broad rays give rise to the handsome “Silver figure” of quarter sawn timber (Oaks and Australian silky oak). Rays are sometimes arranged in regular storeys or tiers that appear on tangential surfaces as wavy, parallel, horizontal lines, known as “Ripple marks” (Bijsal).

4. Parenchyma cells (0-23%):

These are short, rectangular or brick shaped cells with comparatively thin walled cell with simple pits. Their main function is storage and conduction of food material. These parenchyma cells are oriented in the vertical like tracheids with the long axis parallel to grain; hence they are referred as Longitudinal or Axial Parenchyma. *Based on relationship with porestwo major types of axial parenchyma are found in hardwoods.*

a. Paratracheal parenchyma: Parenchyma cells are associated with pores or direct contact with vessels. i). Vasicentric ii). Aliform/Eyelet iii). Conflent

b). Apotracheal Parenchyma: Parenchyma cells are not associated with pores or vessels, which are separated by rays and fibre cells.

i). Terminal/Marginal ii). Diffuse iii). Reticulate/Net like/Banded

5. Tracheids (0-23%):

These are slender, elongated, thin walled cells with closed ends. Lengthwise they are shorter than fibres and larger than vessels. provides mechanical support and conduction. These occurs next to vessel elements and are intermixed with parenchyma cells, hence they are known as Vesicentric tracheids.

6. Gum Canals or Gum Ducts:

Normal resin canals or gum ducts are comparatively infrequent in hardwoods, but they are constant features of families such as Dipterocarpaceae. They may occur either as vertical canals in the wood, or horizontally in the rays, in the same species.

7. Latex Canals:

these are special cells or tubes, concerned with the storage of latex, occur in the ray tissue of certain species. they are usually invisible to the naked eye, but where they can be detected they are a helpful feature in identification. *e.g., Rubber, Alstonia scholoris*

8. Included Phloem:

A few timbers contain strands or layers of phloem tissue included in the secondary xylem, as a result of abnormal development of the cambium. This phloem tissue is known as Included phloem.

9. Tyloses:

These are the infiltration products are formed by ingrowths of adjoining parenchyma cells into the pore cavity when the vessels cease to be functional during process of heartwood formation. With handlens they appear as glistening foam like structures in Sal. The greater durability of heartwood has often been attributed to tyloses.

12. Study of Diagnostic Features of Soft Tissues/Wood Parenchyma

These are short, rectangular or brick shaped cells, with comparatively thin walls and simple pits, whose function is storage and conduction and food material.

They are oriented in the same direction as fibres and vessels, with their long axis parallel to the grain. Therefore, sometimes they also referred to as longitudinal parenchyma to distinguish from the parenchyma cells of the rays, which are arranged horizontally. They are found both in both porous and non-porous woods.

A. Apotracheal types:

These are independent of the distribution of the pores

1. Terminal or Initial type:

Parenchyma cells are *arranged in a continuous line of narrow band, which may be formed either at the beginning or at the end of the growth season.*

e.g., Champ (*Michelia champaka*) and Satin wood (*Chloroxylon swietenia*), *Laurel*

2. Diffuse type:

When soft tissues occur as isolated cells or small groups of 2-3 cells scattered throughout ground mass of the wood, the arrangement is described as "Diffuse".

e.g., Dillenia (*Dillenia spp.*), Haldu, Cypress (*Cupressus torulosa*)

3. **Reticulate or Netlike type:**

   In some woods, parenchyma cells, instead of being scattered, may form fine, more or less evenly spaced, tangential lines, which together with the rays give rise to a characteristic pattern somewhat resembling the meshes of net. Such distribution is known as “Reticulate”or “Netlike”and clearly seen under a hand lens as in Ebony and Pali (*Palaquium spp.*).

B. Paratracheal types:

In these soft tissues are closely associated with the vessels.

1. **Vasicentric type:**

   Here the soft tissues form a narrow but complete sheath, more or less of uniform thickness all around, surrounding the pores. It is distinctly visible under lens, appearing as a light coloured border or halo round the pores.

   e.g., Babul (*Acacia nilotica*/*Acacia Arabica*)

2. **Aliform or Eyelet type:**

   The parenchyma surrounding the pores, instead of being uniformly thick and narrow, may extend sideways as wing like lateral extensions.

   e.g., Kokko (*Albizia lebbek*), Mundani (*Acrocarpus fraxinifolius*) and Mango

Not infrequently, aliform and vasicentric may be found in the same timber. A further development of the aliform type, in which the wing extensions of adjacent pores become confluent or connected together, is known as “Aliform confluent”. *e.g., Dalbergia sissoo,* Sandan/Karimutla

3. **Banded type:**

When soft tissues are arranged in continuous tangential bands, alternating with fibre layers throughout the growth ring. The band may be relatively broad or narrow, straight or wavy, and confluent or independent of the pores.Banded structure is conspicuous in Palas (*Butea monosperma*), Fig (*Ficus spp.*) and Narikel (*Pterygota alata*)

The arrangement of parenchyma may not always be as well marked and distinctive as in the various timbers given above as typical illustration of each type; more than one type may occur and intergrade in the same wood.

The anatomical features described above afford the only reliable basis for field identification of timber. Some physical properties like weight, hardness, colour, odour, *etc.* may, in a few cases, be of some help as supplementary aids, but they have to be used with caution.

13. Study of Diagnostic Features of Wood (Horizontal Elements-Rays)

Introduction

Rays are group of thin walled horizontally oriented parenchyma cells, which are originated from ray initials of vascular cambium, extending from bark to pith. The primary function of these ray cells are lateral movement of sap or food (biochemicals) and little quantity of water. Rays present in the sapwood are responsible for movement of food synthesized in leaves to cambium or inner bark.

In transverse section, they appear as lines extending from bark towards pith through cambium. In radial view or section, the rays look like brick walls and sometimes filled with dark coloured substances. In the tangential section, wood rays are appears as vertical lines which are scattered over the field without definite arrangement and which indicate the height and thickness of rays.

Classification of Rays

I. Based on height and thickness of rays

a. Uniseriate ray: Rays with one cell wide

b. Biseriate ray; Rays with two cell wide

c. Multiseriate ray; Rays with many cell wide

II. Rays are composed of one or two type of cells, based on this rays are categorised as

a. Homocellular (homogeneous) rays: Rays consisting of radially elongated parenchyma cells of practically equal height, or of cells all squarish or upright.

b. Heterocellular (heterogeneous) rays: Rays are made up of squarish or upright cells, or if ray tracheids are present, the rays are Heterocellular (heterogeneous) rays.

The rays of conifers are composed either of parenchyma cells alone, or of parenchyma cells and tracheids. The rays of conifers are mostly uniseriate, occasionally biseriate. The presence of resin duct in a ray makes the normally uniseriate ray appear several cell wide, such rays containg resin ducts are called Fusiform rays.

In the Angiosperms, rays composed of one kind of cell are called holocellular and those containing procumbent and upright cells heterocellular. In hardwoods rays of varying width may be present in the same species and *there is a much greater variation in hardwoods than softwoods*. In hardwoods, average ray volume range from 5% (Basswood) to about 30% (Oak). *In softwoods tha range is from about 5 to 10%* of the total volume of the wood.

III. Based on visibility

1. Broad to very broad: Rays mostly prominent to eye

   e.g., Semul, Papita

2. Moderately broad: Rays are visible to eye and prominent under hand lens

   e.g., Teak, Sal, Gurjan (*Dipterocarpus spp.*)

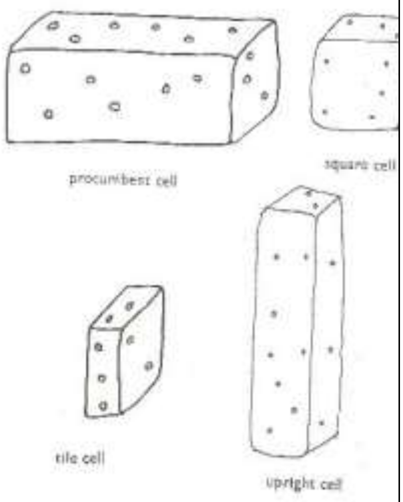
3. Fine to very fine: Rays are not visible or indistinct to eye and visible only under lens

   e.g., Ben teak (Nandi), Laurel, Ebony

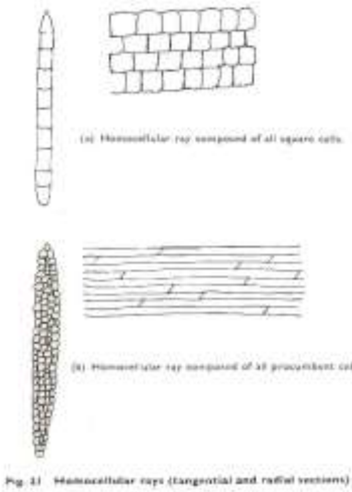
IV. Based on Frequency

1. Numerous closely spaced: when rays 10 or more per mm: *e.g.,* Bijsal, Ben teak, Ebony

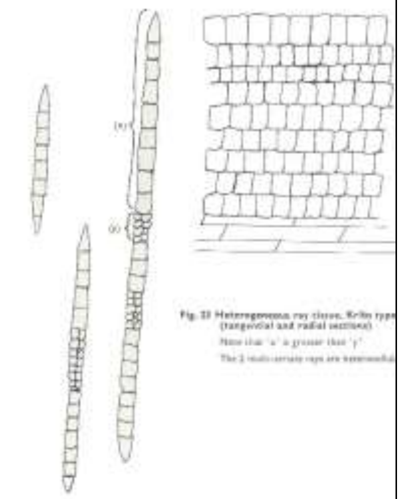
2. Few widely spaced: When rays are less than 5 per mm: *e.g.* Aini (Hebbalasu), Semul



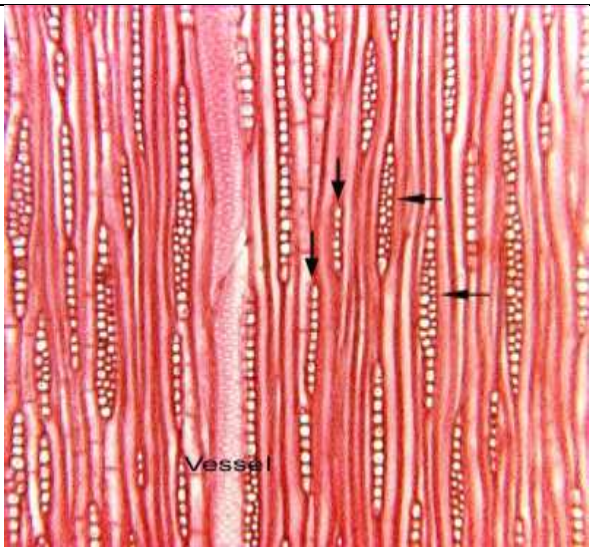
a. Types of Ray cells



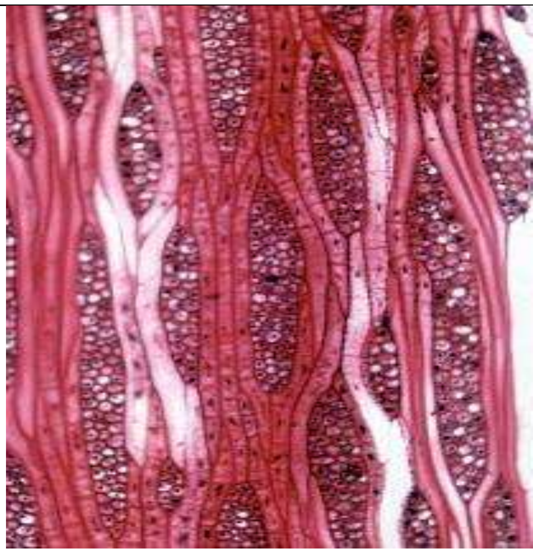
b. Homocellular ray



c. Hetero-cellular ray



Uniseriate and Biseriate Rays



Multi-seriate rays

14. How to Describe Wood

After knowing the general, physical and anatomical (microscopic) features of wood, which are found in various timbers, find out the features of given wood sample and record your observations correctly.

If the specimen is old, open the fresh surface to know the actual colour (as colours will fade due to prolonged opening to sunlight) and odour if any and any other revealing characters like ripple mark, fluorescence, *etc.*

Make a good smooth cut with a sharp knife, or blade, on the transverse surface, preferably near one edge. With the hand lens examine the surface which is cut focusing carefully so that little cells are sharply visible.

Examine whether the cells are in near uniform rows similar in appearance with one cell more or less directly over the other (non porous), or if the cells are staggered and not similar in appearance and porous, all the bigger cells (vessels) are of more or less similar size (diffuse porous0 or these are definitely smaller and bigger in size in the same growth ring (*i.e.,* Ring Porous).

On the confirming wood is porous examine whether wood is ring porous or semi ring porous or diffuse porous, by observing the growth ring.

The following pro-forma will help in describing timbers

1. Sapwood Heartwood distinct

2. Colour

a. Length coloured

b. Yellow

c. Shades of brown

d. Shades of red

e. Other colours; Black, Purple, *etc*

f. Nottled/Streaked

3. Hardness

a. Soft to very soft

b. Moderately hard

c. Hard to very hard

4. Weight

a. Light to very light

b. Moderately heavy

c. heavy to very heavy

5. Odour:

Mention distinct odour if any. Freshly cut or polished surface will permit real odour

6. Lustre:

Shining or Dull (observe the radial surface)

7. Grain:

a) Straight
b) Interlocked
c) Wavy
d) Curly
e) spiral
f) Diagonal

8. Fluorescence:

9. Texture:

a) Fine
b) Medium coarse
c) Coarse
d) Even
e) Uneven
f) Oily/Greasy

10. Rays

a. Size of the rays:

Broad to very broad

Moderately broad

Fine broad

b. Distribution of rays:

Numerous closely spaced

Few widely spaced

11. Porous or Non porous: If, porous, describe nature of pores

12. Pores

a. Size of pores:

Very large

Large to Medium

Small to very small

c. Distribution of pores:

Scanty

Moderately numerous

Very numerous

c. Arrangement of pores:

i). Exclusively solitary

ii). Solitary & Short radial multiples

iii). Long radial multiples/chain   iv). Tangential clusters

v). Oblique groups

d. Inclusion in pores

i). Coloured deposits: Yellow white Chalky ` Red

ii). Tyloses: Abundant or Scanty

13. Soft tissues: Apotracheal or Paratracheal

a. Distribution of soft tissues

Indistinct/Absent   Diffuse/Scattered

Diffuse in aggregate/in fine lines   Delimiting the growth rings

b. Arrangement of soft tissues

Vasicentric   Aliform   Confluent narrow

Confluent broad   Banded narrow   Banded broad

14. Ripple Marks; Present or Absent

15. Resin/Gum canals: Present or Absent

16. a). Radial canals: Visible or Not

b). Vertical canals: Scattered small

c). Vertical canals: Scattered large

15. Dichotomous Key for Identification

A Key for Identification of Important Indian Timbers

1	Wood Non Porous		2
1	Wood Porous		7
	2	Resin Canals Present	3
	2	Resin Canals Absent	6
3	Resin Canals scattered		4
3	Resin canals in long tangential bands, wood strongly aromatic. DEODAR (*Cedrus deodara*)		
	4	Resin canals fairly large, distinctly visible to the eye, fairly numerous. Wood with pronounce resinous odour	5
	4	Resin canals minute, not visible to the eye, scanty, wood lustrous; without any resinous odour. SPRUCE (*Picea smithiana*)	
5	Wood yellow to pale reddish brown. Transition from early wood to latewood abrupt. CHIR PINE *(Pinus roxburghii*)		
5	Wood with pinkish tinge. Transition from early wood to late wood gradual. BLUE PINE (*Pinus wallichiana*)		
	6	Wood without any odour. No distinction between sap wood and heart wood. FIR (*Abies pindrow*)	
	6	Wood with distcint pleasant odour. CYPRESS (*Cupressus torulosa*)	
7	Wood ring porous or semi-ring porous		8
7	Wood diffuse porous		13
	8	Belt of early wood pores broad and very conspicuous, with abrupt transition to late wood. Late wood pores in cluster. Wood golden yellow turning brown on exposure. MULBERY (*Morus alba*)	

	8	Belt of early wood porese rather narrow and not conspicuous with usually gradual transition to late wood. Late wood pores single or in short radial multiples.	9
9	Tyloses very conspicuous, all vessels heavily plugged. Ray prominent to the eye, broad. Wood creamy white to yellowish or buff. GAMHARI (*Gmelina arborea*)		
9	Tyloses absent or if present not conspicuous, only some vessels are filled. Rays indistinct or just visible to eye, medium or extremely fine. Wood red, reddish brown or golden brown.		10
10	Soft tissues indistinct or inconspicuous, Rays fairly broad under lens, distinct		11
10	Soft tissues distinct, aliform to confluent often forming numerous wavy bands. Rays extremely fine under lens, just visible.		12
11	Wood yellowish or golden brown. Dull with characteristic smell. Pores partly filled with tyloses. TEAK (*Tectona grandis*)		
11	Wood pinkish or Reddish brown. Pores often filled with reddish brown deposits. TOON (*Cedrella toona*)		
	12	Ripple marks present, soft tissues mostly in fine wavy lines. Pores often filled with dark radish deposit. HONNE (*Pterocarpus marsupium*)	
	12	Ripple marks absent, soft tissues mostly aliform to confluent. Pores partly filled with tyloses. BENTEAK (*Lagerstroemia lanceolata*)	
13	Gum ducts present (even traumatic should be taken in to consideration)		14
13	Gum ducts absent		17
	14	Gum duct in long tangential bands resembling growth	15

		marks. Wood hard to very hard	
	14	Gum ducts in singles or in short tangential groups of 2-6. Wood soft to moderately hard	16
15	Pores small, indistinct or just visible to the eye, partially filled with tyloses. Rays rather fine, very hard. HOPEA (*Hopea parviflora*)		
15	Pores large, distinctly visible to the eye, all heavily plugged with tyloses. Rays fairly broad, distinct without lens, wood coarse textured, hard. SAL (*Shorea robusta*)		
	16	Gum ducts scattered, usually single, filled with whitish gum appearing as white dots. Wood moderately soft, light brownish grey. VELLAPNEY (*Vateria indica*)	
	16	Gum ducts are short tangential row of 2-6, sometimes more, surrounded by conspicuous soft tissue. Wood moderately hard, reddish brown. GURJAN (*Dipterocarpus spp.*)	
17	Ripple marks always present, well defined and distinct		18
17	Ripple marks absent, if present, usually poorly defined irregular and indistinct		21
	18	Terminal or initial parenchyma always present, prominent, forming continuous line delimiting growth ring. Porous minute, visible only under hand lens, without any soft tissues round them, often in long radial multiples or chains. SATIN WOOD (*Chloroxylon swietenia*)	
	18	Terminal or initial parenchyma absent, or indistinct. Pores medium sized to large, visible to the eye, always with distinct soft tissues round them, mostly solitary and in short multiples.	19

19	Wood yellow or yellowish grey. Pores often filled with white deposits. KANJU (*Holoptelea integrifolia*)		
19	Wood yellowish, reddish or golden brown with darker streaks. Pores often filled with dark reddish brown deposits.		20
	20	Soft tissues forming conspicuous “eyelets” and sometimes connecting them. SANDAN (*Ougeniadalbergiodes*)	
	20	Soft tissues forming distinct wavy or straight tangential bands. Water extract gives yellowish blue fluorescence. BIJASAL (*Pterocarpus marsupium*)	
21	Porese usually in characteristic oblique groups. Soft tissues in short or long thick and wavy bands ending abruptly.		22
21	Pores in oblique groups usually absent		23
	22	Wood moderately hard, moderately heavy, light reddish brown with dark streaks. POON (*Calophyllum spp.*)	
	22	Wood very hard, very heavy, deep reddish brown, dull and rather fine textured. MESUA (*Mesua ferrea*)	
23	Rays broad, distinctly visible to the eye, conspicuous under lens		24
23	Rays very fine to medium, not at all visible to just visible to the eye, fairly distinct under lens.		27
	24	Soft tissues distinct to the eye in prominent wavy or straight tangential bands of the same width as rays. Wood creamy white. NARIKEL (*Sterculia alata*)	
	24	Soft tissues not distinct or indistinct to the eyes.	25
25	Tyloses absent or inconspicuous		26
26	Soft tissues in fine, closely spaced, somewhat broken tangential lines forming reticulum. Wood soft, light, creamy white to pale yellow or buff. SEMUL (*Bombax malabarica*)		

26		Soft tissue round the pore, vasicentric. Wood hard, heavy, light reddish brown. BABUL (*Acacia nilotica*)	
27		Pores minute, not at all visible to indistinct or just visible to the eye.	28
27		Pores fairly large, distinctly visible to the eye. Wood medium coarse to coarse textured	34
28		Pores not at all visible to the eye. Wood creamy white to some shades of yellow	29
28		Pores just visible to the eye. Wood usually with some shades of brown, grey or red	30
	29	Pores individually indistinct even under hand lens, wood usually pale yellowish white. BOX WOOD (*Buxus semipervirens*). GARDENIA (*Gardenia spp.*)	
	29	Pores individually distinct under hand lens. Wood deep yellow to brownish yellow. HALDU/HEDDI (*Adina cardifolia*)	
30		Soft tissues clearly visible to the eye, forming distinct tangential band delimiting the growth ring (terminal or initial). Wood yellowish brown with greenish tinge. CHAMP (*M. chamapaca*)	
30		Soft tissues indistinct to the eye, but visible under hand lens, no delimiting growth ring.	31
	31	Soft tissues predominantly paratracheal, *i.e., round the pores or connecting them*	32
	31	Soft tissues predominantly Apotracheal, in fine broken interrupted tangential lines forming net like structure.	33
32		Soft tissues mostly vasicentric to aliform, sometimes connecting the pores. Rays very fine under lens. Wood usually	

	yellowish or olive grey. AXLEWOOD (*Anogeissus latifolia*)		
32	Soft tissues mostly in somewhat wavy bands connecting pores. Rays fairly broad under lens. Wood reddish or brownish grey. JAMAN (*Eugenia jambolane*), (*Syzygium cumini*)		
	33	Pores usually in long radial multiples. Rays very fine, closely spaced. Wood pik or pinkish grey. EBONY (*Diospyros spp.*)	
	33	Pores mostly solitary. Rays not so fine under lens, somewhat-widely spaced. Wood dark reddish brown, often with greasy feel. SUNDRI (*Heriteria spp.*)	
34	Soft tissues predominantly paratracheal in fine tangential lines forming reticulum with rays		35
34	Soft tissues predominantly paratracheal *i.e.,* round the pores or connecting them		36
	35	Lines of soft tissues very closely spaced. Just visible under lens. Wood pale yellowish white KUTHAN (*Hymenodactyon excelsum*)	
	35	Lines of soft tissues somewhat widely spaced distinct under lens. Wood light red to reddish brown. Moderately hard, moderately heavy. PALI (*Palaquium ellipticum*), (*Dichopsis elliptice*)	
36	Soft tissues often in wavy lines connecting pores		37
36	Soft tissues mostly confined around the pores, rarely connecting them		38
	37	Wood purplish brown, often with characteristic sweet smell. ROSEWOOD (*Dalbergia latifolia*)	
	37	Wood golden brown to deep brown with dark streaks without any characteristic scent. SISSOO (*Dalbergia	

		sissoo)	
38	Wood light coloured, usually pale yellowish or pinkish or brownish grey. Soft tissues round the pores forming eyelets and also in fairly distinct tangential bands at regular intervals resembling growth marks, but often ending abruptly. MANGO (*Mangifera indica*)		
38	Wood dark coloured, usually of a dark shade of brown often with darker streaks		39
	39	Initial parenchyma always present, prominent under handlens forming a continuous line delimiting growth rings. LAUREL (*Terminalia tomentosa*)	
	39	Initial parenchyma absent, if present discontinuous and inconspicuous even under hand lens.	40
40	Rays very fine under lens, very closely and evenly spaced. Soft tissues predominantly vasicentric, vessel lines not conspicuous, wood medium fine textured, hard. IRUL (*Xylia xylocarpa*)		
40	Rays moderately broad under lens, somewhat widely and evenly spaced. Soft tissues predominantly aliform. Vessel lines very conspicuous, wood coarse textured, moderately hard. KOKKO (*Albizia lebbeck*)		