Complex Tissues in Plants

Xylem and Phloem

Complex tissues - introduction

- The complex tissues are heterogeneous in nature, being composed of different types of cell elements. The latter remain contiguous and form a structural part of the plant, adapted to carry on a specialized function.
- Xylem and phloem are the complex tissues which constitute the component parts of the vascular bundle. They are also called vascular tissues.

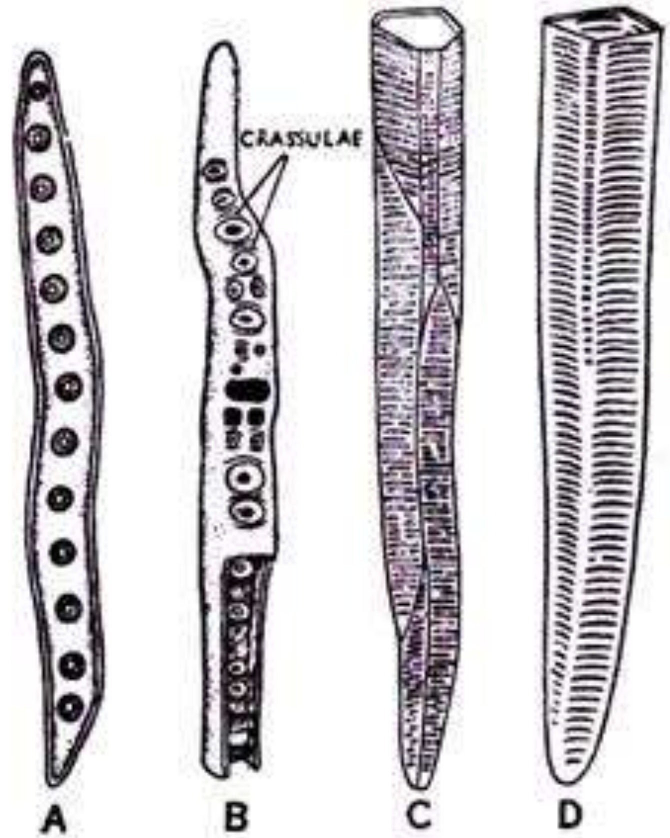
Xylem

- Xylem is a complex tissue forming a part of the vascular bundle. It is primarily instrumental for conduction of water and solutes, and also for mechanical support. Primary xylem originates from the procambium of apical meristem, and secondary xylem from the vascular cambium. As a complex tissue it consists of different types of cells and elements, living and non-living.
- The tissues composing xylem are tracheids, tracheae or vessels, fibres, called xylem fibres or wood fibres, and parenchyma, referred to as xylem or wood parenchyma. Of the above mentioned elements only the parenchyma cells are living and the rest are dead. A term hadrome was once used for xylem. It included the elements excepting the fibres.

Xylem - Tracheids

- A tracheid is a very much elongate cell occurring along the long axis of the organ. The cells are devoid of protoplast, and hence dead. A tracheid has a fairly large cavity or lumen without any contents and tapering blunt or chisel-like ends.
- The end walls usually do not uniformly taper in all planes. Tracheids are round or polyhedral in cross section. They are really the most primitive and fundamental cell- types in xylem from phylogenetic point of view. The wood of ancient vascular plants was exclusively made of tracheids. This is the only type of element found in the fossils of seed-plants.
- The wall is hard, moderately thick and usually lignified. Secondary walls are deposited in different manners, so that the tracheids may be annular, spiral, reticulate, scalariform or pitted. But pits of the bordered type are most abundant. Through these pits they establish communication with adjoining tracheids and also with other cells, living or non-living.
- The nature of the pits on the walls of the tracheids is variable; in lower vascular plants the pits are elongated giving them scalariform appearance, those of gymnosperms and angiosperms have round pits with well-developed borders. Tracheids occur both in primary and secondary xylem.

- Due to the presence of central lumen and hard lignified wall tracheids are nicely adapted for transport of water and solutes. They also serve as supporting tissue.
- A typical fibre differs from a tracheid in more pronounced thickening of the wall and correspondingly much smaller lumen, as well as in reduction of the size of the pits. An intermediate type of cell element, called fibre-tracheid, is found in some plants.
- They have smaller pits with reduced or vestigial borders. In some cases protoplast persists up to the mature stage, and may even divide, so that transverse partition walls are noticed within the original wall. These are called septate fibre-tracheids.



Tracheids. A. A tracheid with bordered pits. B. A part showing bordered pits with crassulae. C & D. Parts with scalariform thickening.

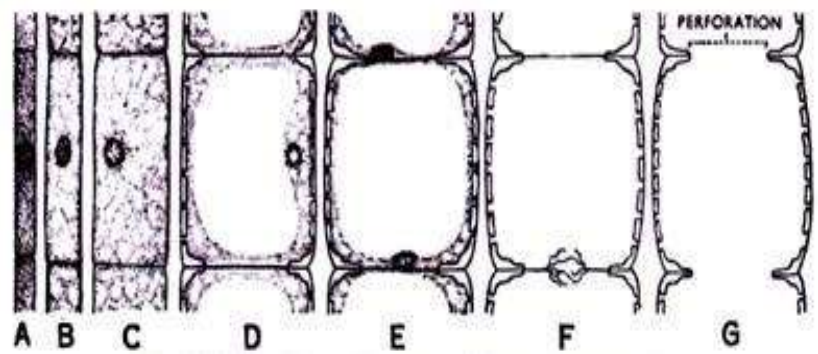
Xylem - Vessels

- A trachea or vessel is formed from a row of cylindrical cells arranged in longitudinal series where the partition walls become perforated, so that the whole thing serves like a tube.
- In tracheids the only openings are the pit-pairs, whereas the vessels are distinct 'perforate' bodies. Thus translocation of solutes becomes more easy in a vessel, as it proceeds more or less in a straight line.
- Like tracheids these elements are devoid of protoplast and have hard and lignified cell-wall with different types of localised thickenings. Some forms intermediate between typical tracheids and vessels have been noticed. These elements, analogous to fibre-tracheids, are called vessel-tracheids.
- As usual the cells grow and secondary walls are laid down, only the primary walls where perforations will take place remain uncovered. The secondary walls undergo lignification and other changes.
- The protoplast in the mean time becomes progressively more and more vacuolated and ultimately dies and disappears. The primary walls swell due to increase of pectic intercellular substance and break down, thus forming the continuous vessel.

- It should be noted that a vessel or trachea arises from a group of cells, unlike a tracheid, which is an elongate ‘imperforate’ single cell. The individual cells taking part in the formation of the vessel are called vessel elements.
- The walls of the vessels are thick, hard and lignified. The secondary walls are deposited in different patterns, so that the thickenings may be ring-like, spiral, scalariform, reticulate or pitted. The pits are mostly of bordered types.
- Tracheids are more primitive than the vessels. In fact, in the primitive types of vessels the form of a tracheid is maintained, but with advance in evolutionary line the diameter of a vessel may so much increase that it may become drum-shaped in appearance.
- Comparative studies on the dicotyledons have revealed that evolution of vessel members have proceeded from the long narrow elements with tapering ends to short ones with wider cavities having transverse or inclined end-walls which ultimately dissolved.
- In some dicotyledons belonging to the families Winteraceae, Trochodendraceae and Tetracentraceae and others of the lowest taxonomic group, curiously the vessels are absent . They do not occur in some xerophytes, parasites and aquatic plants. These have been interpreted as cases of reduction of xylem tissues involving evolutionary loss. In monocotyledons vessels are not present in secondary xylem (which tissue is lacking in many monocotyledons). Here vessels first appeared in the roots and then extended to the aerial organs.
- These are the most important elements of xylem. They are primarily adapted for easy transport of water and solutes, and, secondarily, for mechanical support.

Vessels - A- with Multiple perforations,
B, C, & D – with Single perforation

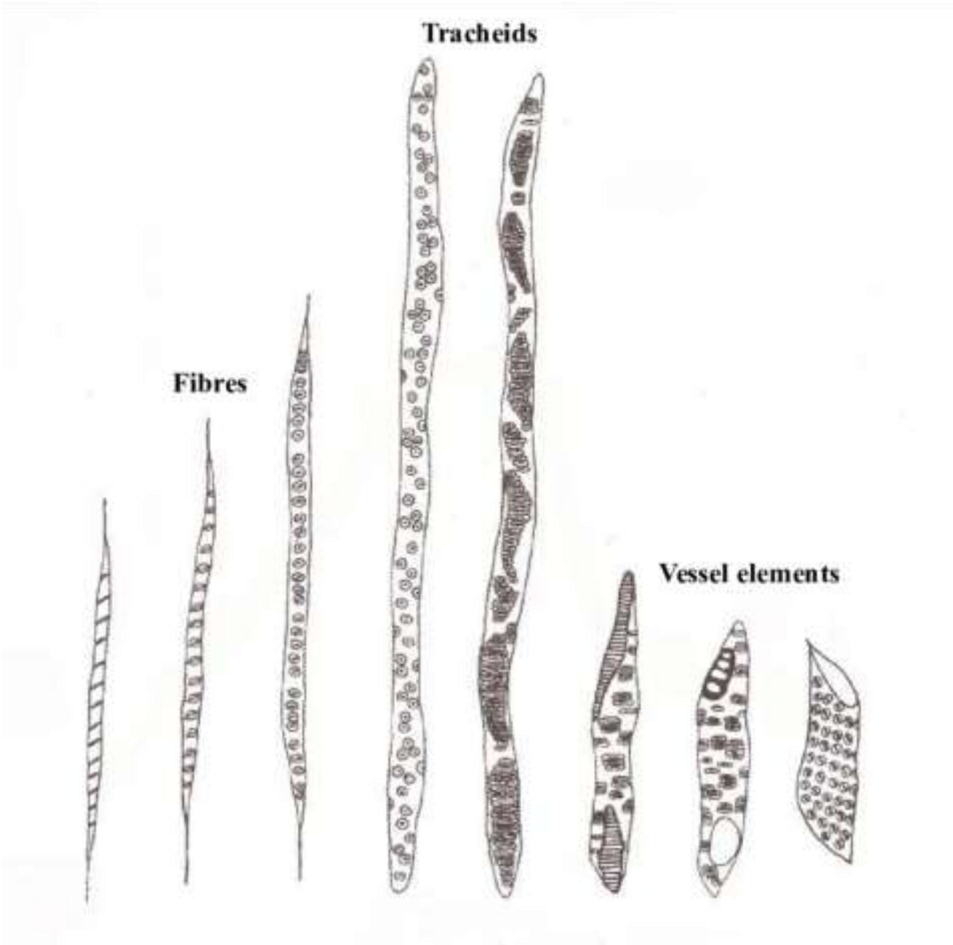
Ontogeny of Vessels



Xylem Fibres

- Some fibres remain associated with other elements in the complex tissue, xylem, and they mainly give mechanical support. As previously stated, fibres are very much elongated, usually dead cells with lignified walls.
- Xylem fibres or wood fibres are mainly of two types: fibre-tracheids and libiriform fibres which usually intergrade, so much so that it is difficult to draw a line of demarcation between them.
- Fibre-tracheids, as already reported, are intermediate forms between typical fibres and tracheids; they possess bordered pits, though the borders are not well-developed. Libiriform fibres ate narrow ones with highly thickened secondary wall.
- The central lumen is almost obliterated and pits are simple. They resemble the phloem fibres, and hence the name. They occur abundantly in many woody dicotyledons.

Xylem - Components



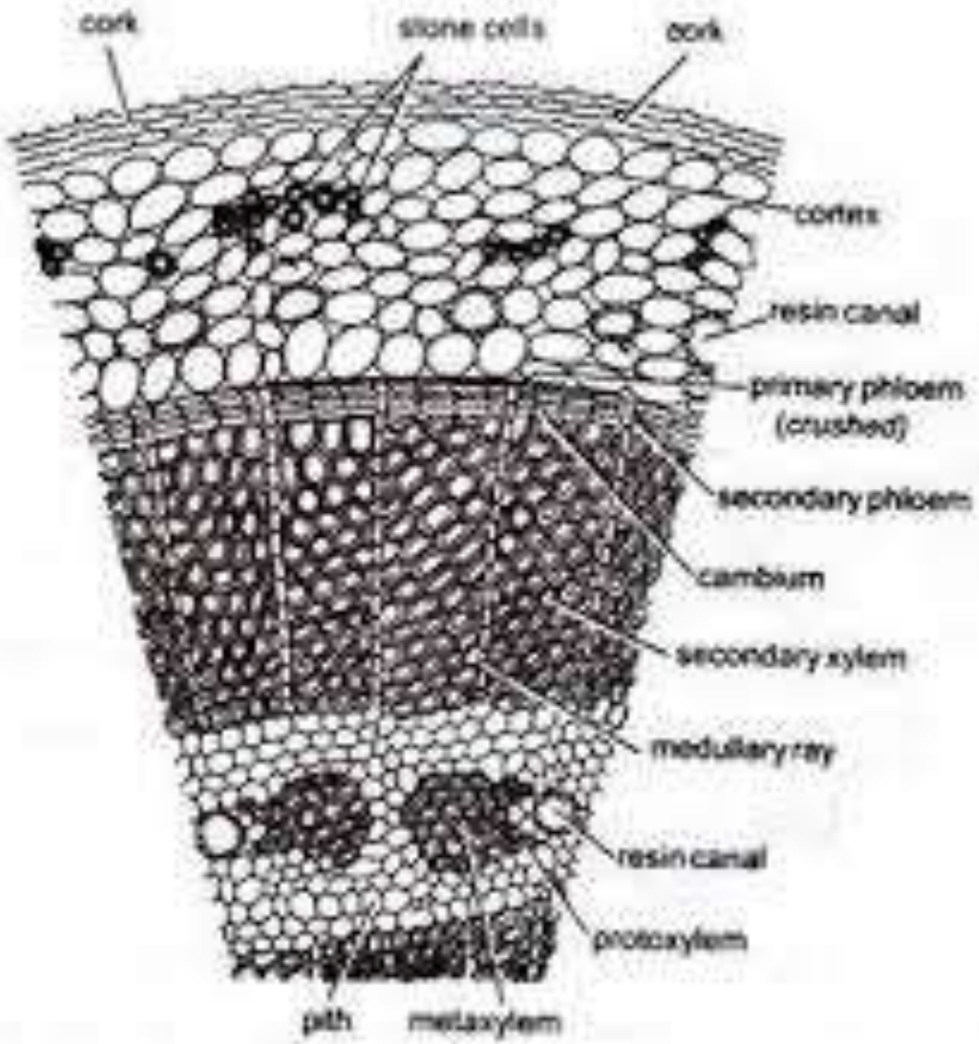
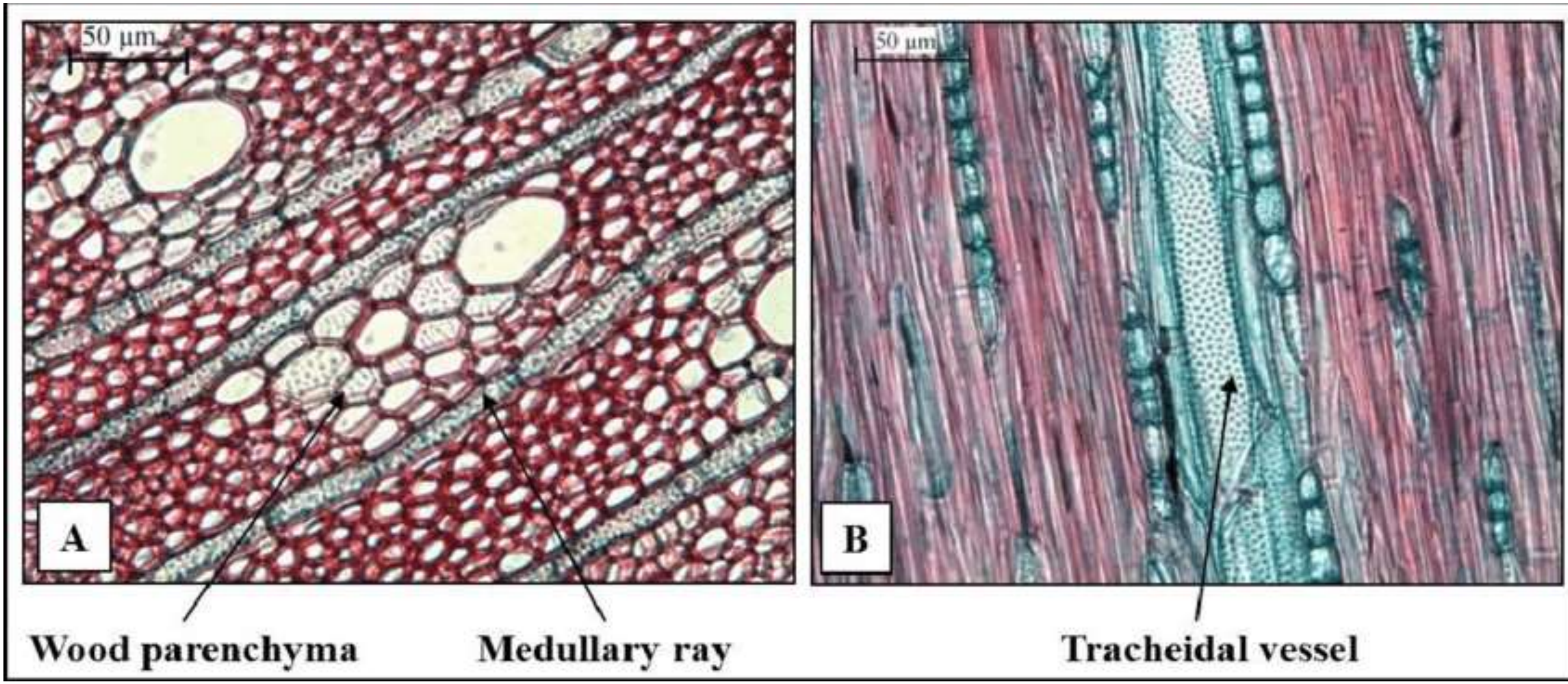


Fig. 30. Pinus. T.S. old root.



50 μm
A
50 μm
B
Wood parenchyma
Medullary ray
Tracheidal vessel

Xylem Parenchyma

- Living parenchyma is a constituent of xylem of most plants. In primary xylem they remain associated with other elements and derive their origin from the same meristem. In secondary xylem parenchyma occurs in two forms: xylem parenchyma is somewhat elongate cells and lie in vertical series attached end on end; ray parenchyma cells occur in radial transverse series in many woody plants.
- Parenchyma is abundant in the secondary xylem of most of the plants, excepting a few conifers like Pinus, Taxus and Araucaria. These are the only living cells in xylem.
- The cells may be thin-walled or thick-walled. If lignified secondary wall is present, the pit-pairs between the cells and the adjacent xylem element may be bordered, half-bordered or simple. Between two parenchyma cells the pit is obviously simple.
- These cells are particularly meant for storage of starch and fatty food; other matters like tannins, crystals, etc., may also be present. As a constituent part of xylem they are possibly involved in conduction of water and solutes and mechanical support.

Phylogeny of Tracheary Elements

The tracheary elements have developed during the evolution of land plants. In the lower vascular plants the function of conduction and support were combined in the tracheids.

With increasing specialisation woods evolved with conducting elements—the vessel members being more efficient in conduction then in providing mechanical support. On the other hand fibres evolved as principal supporting tissue.

Thus from the primitive tracheids two lines of specialisation diverged—one toward the vessel and the other toward the fibre.

The following structural features may be taken as the basis in support of the evolution of the tracheary elements from primitive tracheids which are usually long imper forate cells with small diameter, angular in cross-section, having lignified scalariformly pitted walls.

(i) The primitive vessels are also elongate bodies like the tracheids with rather small diameter and tapering ends. Similar condition is still noticed in lower dicotyledons. With evolutionary advance they gradually become shorter and wider, often becoming drum-shaped in appearance.

(ii) The wall of the primitive tracheid is rather thin, more or less of equal thickness, and it is angular in cross-section. Same condition prevails in primitive vessels. With progressive advance considerable thickening appeared and the vessels became circular or nearly so in cross-section.

(iii) In the primitive vessels the perforation plates are multiple, usually scalariform with numerous bars, and oblique end-walls. Progressive increase in specialisation led to gradual decrease in the number of bars and their ultimate disappearance, so that the perforation plates become simple with transverse end-walls. These are positively advanced characters.

(iv) The pitting of the vessel wall also changed from early scalariform arrangement, characteristic of tracheids, to small bordered pit pairs, first in opposite (arranged in transverse rows) and ultimately in alternate (arranged spirally or irregularly) pattern. Moreover the pit pairs between vessels and parenchyma changed from bordered to half-bordered and then to simple.

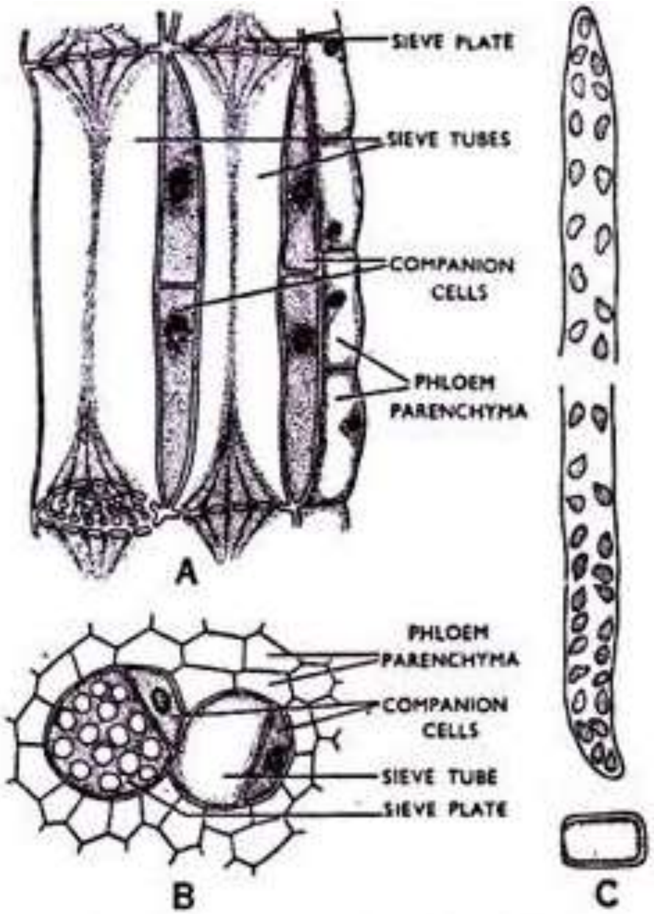
In the specialisation of the xylem fibres adapted for more efficient support there has been steady increase in thickness of the wall leading to decrease in cell-lumen. The pits changed from elongate to circular, the borders becoming reduced and functionless, and ultimately disappeared. Thus the evolutionary sequence was from tracheids, through fibre-tracheids to libiriform fibres.

Phloem

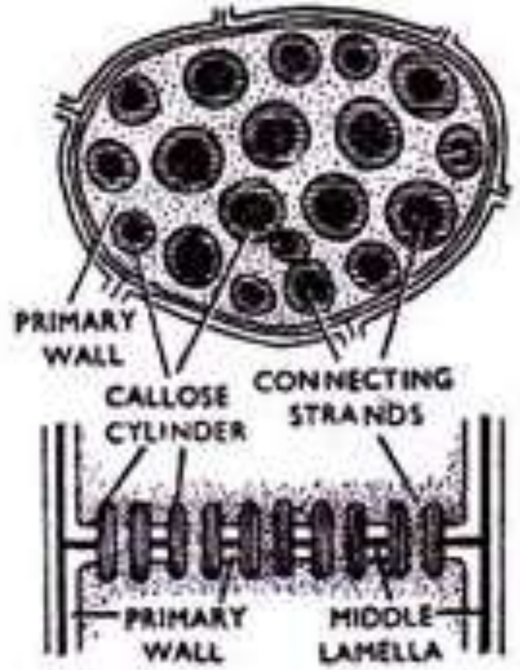
- The other specialised complex tissue forming a part of the vascular bundle is phloem It is composed of sieve elements, companion cells, parenchyma and some fibres. Sclerotic cells may also be present.
- Phloem is chiefly instrumental for translocation of organic solutes—the elaborated food materials in solution. The elements of phloem originate from the procambium of apical meristem or the vascular cambium.
- Two terms, bast and leptome, have been used for phloem, though they are not exactly synonymous with it. Bast, derived from the word ‘bind’, was introduced before the discovery of sieve elements; it mainly meant the fibres. The soft-walled parts of phloem, obviously excluding the fibres, were referred to as leptome.

Phloem - Sieve Elements

- The most important constituents of phloem are the sieve elements, the sieve tubes and sieve cells. From ontogenetic point of view a sieve tube resembles a vessel and a sieve cell a tracheid.
- Sieve tubes are long tube-like bodies formed from a row of cells arranged in longitudinal series where the end-walls are perforated in a sieve-like manner. The perforated end-walls are called the sieve plates, through which cytoplasmic connections are established between adjacent cells.
- The perforations or sieve areas, as they are called, may be compared to the pit fields of the primary wall with plasmodesmata connections. But the sieve areas are more prominent than pit fields and the connecting strands are more wide and conspicuous.



Sieve elements. A. Sieve tubes in l.s. B. Same in t.s. C. Sieve cell in l.s. and t.s.



Sieve tube. Structure of sieve area of an angiosperm in surface (upper) and sectional (lower) views (diagrammatic).

- In sectional view sieve areas appear like thin places on the wall through which the connecting strands pass from one cell to another. The sieve plate or the perforated end-wall is really the primary walls of two cells with the middle lamella in between them. The end-walls may be obliquely inclined or transverse.
- A sieve plate is called simple, if it has only one sieve area, whereas the plate may be compound with several sieve areas arranged in scalariform, reticulate or other manners. Though rare, the sieve areas may occur on the side walls as well. From evolutionary point of view simple sieve plates on transverse end-walls are more advanced characters than compound plates on oblique walls.
- The cylindrical cells which take part in the formation of the sieve tube are called sieve tube elements. Like vessel elements the sieve tubes have also undergone decrease in length with evolutionary advance.
- Sieve cells, which may be compared to the tracheids, are narrow elongated cells without conspicuous sieve areas. They usually have greatly inclined walls, which overlap in the tissue, sieve areas being more numerous in the ends.
- Sieve cells are more primitive than the sieve tubes. They occur in lower vascular plants and gymnosperms. In fact, sieve tubes have evolved from the sieve cells, as vessels have evolved from the tracheids, and so sieve tubes occur in all angiosperms. In monocotyledons, unlike the xylem elements, sieve tubes first appeared in the aerial organs, the course being from the leaves to the stem and, lastly, to the roots.

Phloem - Companion Cells

- Companion cells remain associated with the sieve tubes of angiosperms, both ontogenetically and physiologically. These are smaller elongate cells, having dense cytoplasm and prominent nuclei. Starch grains are never present.
- They occur along the lateral walls of the sieve tubes. A companion cell may be equal in length to the accompanying sieve tube element or the mother cell may be divided transversely forming a series of companion cells.
- A sieve tube element and a companion cell originate from the same mother cell. Their functional association is evident from the fact that companion cells continue so long the sieve tubes function, and die when the tubes are disorganised.
- The companion cells are so firmly attached to the sieve tubes that they cannot be normally separated by maceration. In transverse section it appears as a small triangular, rectangular or polyhedral cell with dense protoplast.
- In pteridophytes and gymnosperms some small parenchymatous cells remain associated with sieve cells, which are known as albuminous cells. They die in natural course when the sieve cells become functionless. Thus the relation between sieve Cells and albuminous Cells is similar to that existing between sieve tubes and companion cells, excepting that they have no common origin.
- Companion cells occur abundantly in angiosperms, particularly in the monocotyledons. They are absent in some primitive dicotyledons and also in the primary phloem of some angiosperms. The wall between the sieve tube and companion cell is thin and provided with primary pit fields.

Phloem - Parenchyma

- Besides companion cells and albuminous cells, a good number of parenchyma cells remain associated with sieve elements.
- These are living cells with cellulose walls having primary pit fields. They are mainly concerned with storage of organic food matters. Tannins, crystals and other materials may also be present.
- The parenchyma cells of primary phloem are somewhat elongate and occur with the sieve elements along the long axis. In secondary phloem they may be of two types.
- Those which occur in vertical series are called phloem parenchyma; and others occurring in horizontal planes are known as ray cells, the position being just like the parenchyma and ray cells of secondary xylem.
- The cell wall is primary, composed of cellulose. Parenchyma is absent in the phloem of monocotyledons.

Phloem - Fibres

- Sclerenchymatous fibres constitute a part of phloem in a large number of seed plants, though they are rare in pteridophytes and some spermatophytes.
- They occur both in primary and secondary phloem. These are typical elongated cells having interlocked ends, lignified walls with simple pits.
- The fibres of primary phloem are essentially similar to those occurring in cortex and secondary phloem.
- They are of considerable commercial importance, as these fibres are abundantly used for the manufacture of ropes and cords.
- The flax fibres, unlike others, have non-lignified walls. Sclerotic cells are often present in primary phloem. They probably develop from parenchyma with the age of the tissue. So it is a case of ‘secondary sclerosis’

Xylem – Key Points

1. It conducts water or sap.
2. Xylem also provides mechanical strength.
3. Xylem is usually found deep in the plant.
4. In older plants, xylem often constitutes bulk of the plant body.
5. The conducting or tracheary cells are dead.
6. Xylem is made up of three types of dead cells (vessels, tracheids, xylem fibres).
7. There are one type of living cells (xylem parenchyma).
8. The conducting cells have lignin thickening in the wall.
9. Conducting elements are of two types, vessels and tracheids.
10. Tracheary elements have different types of wall thickenings.
11. Vessels are devoid of septa.

Phloem – Key Points

1. Phloem conducts organic food.
2. Phloem has no mechanical function.
3. Phloem is usually situated towards the outer side of the plant.
4. Phloem always forms a small part of the plant body.
5. The conducting cells are living.
6. Phloem contains only one type of dead cells (phloem fibres).
7. There are three types of living cells (sieve tube cells, companion cells and phloem parenchyma).
8. Wall of the sieve tube does not possess lignin.
9. Conducting elements are of one type, sieve tubes.
10. Wall thickenings are absent in the conducting channels.
11. Sieve tubes have bulging and porous septa.

Cambium - Origin

- The primary vascular skeleton is built up by the maturing of the cells of the procambium strands to form xylem and phloem.
- The plants which do not possess secondary growth, all cells of the procambium strands mature and develop into vascular tissue.
- In the plant which have secondary growth later on, a part of the procambium strand remains meristematic and gives rise to the cambium proper.
- In roots the formation of cambium differs from that in stems because of the radial arrangement of the alternating xylem and phloem strands.
- Here the cambium arises as discrete strips of tissue in the procambium strands inside the groups of primary phloem.
- Later on, the strips of cambium by their lateral extension are joined in the pericycle opposite the rays of primary xylem.
- The secondary tissue formation is most rapid beneath the groups of phloem so that the cambium, as seen in the transverse section of older roots, soon forms a circle.

Fascicular and Inter-fascicular Cambium

- In stems the first procambium that develops from promeristem is usually found in the form of isolated strands. In some plants these first formed strands soon become, united laterally by additional similar strands formed between them and by the lateral extention of the first-formed strands.
- During further development this procambial cylinder gives rise to a cylinder of primary vascular tissue (xylem and phloem) and cambium. Later on, a cylinder of secondary vascular tissue is formed that arises in strands as does the primary cylinder.
- In Ranunculus and some other herbaceous plants, the procambium strands, and the primary vascular tissues, do not fuse laterally but remain as discrete strands.
- More often in herbaceous stems the cambium extends laterally across the intervening spaces until a complete cylinder is formed.
- Where such extension occurs, the cambium arises from inter-fascicular meristematic cells derived from the apical meristem.
- The strips of cambium that arise within collateral bundles are known as fascicular cambium, and the cambial strips found in between the bundles are known as inter-fascicular cambium.

Duration of Cambium

- The duration of the functional life of the cambium varies greatly in different species and also in different parts of the same plant.
- In a perennial woody plant the cambium of the main stem lives from the time of its formation until the death of the plant.
- It is only by the continued activity of the cambium in producing new xylem and phloem that such plants can maintain their existence.
- In leaves, inflorescenes and other deciduous parts, the functional life of the cambium is short. Here all the cambium cells mature as vascular tissue.
- The secondary xylem is directly found upon the secondary phloem in such bundles.

Function of Cambium

- The meristem that forms secondary tissues consists of an uniseriate sheet of initials that form new cells usually on both sides.
- The cambium forms xylem internally and phloem externally. The tangential division of the cambial cell forms two apparently identical daughter cells.
- One of the daughter cells remains meristematic, i.e., the persistent cambial cell, the other becomes a xylem mother cell or a phloem mother cell depending upon its position internal or external to the initial.
- The cambium cell divides continuously in a similar way; one daughter cell always remains meristematic, the cambium cell, whereas the other becomes either a xylem or a phloem mother cell.
- Probably there is no definite alternation and for brief periods only one kind of tissue is formed.
- Adjacent cambium cells divide at nearly the same time, and the daughter cells belong to the same tissue. This way, the tangential continuity of the cambium is maintained.

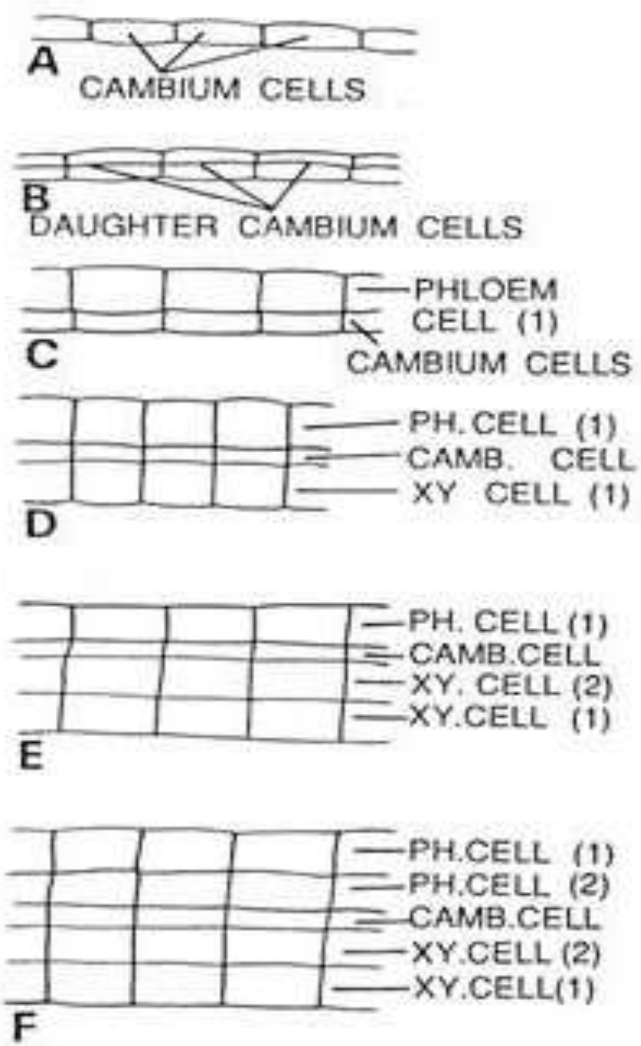
Structure of Cambium

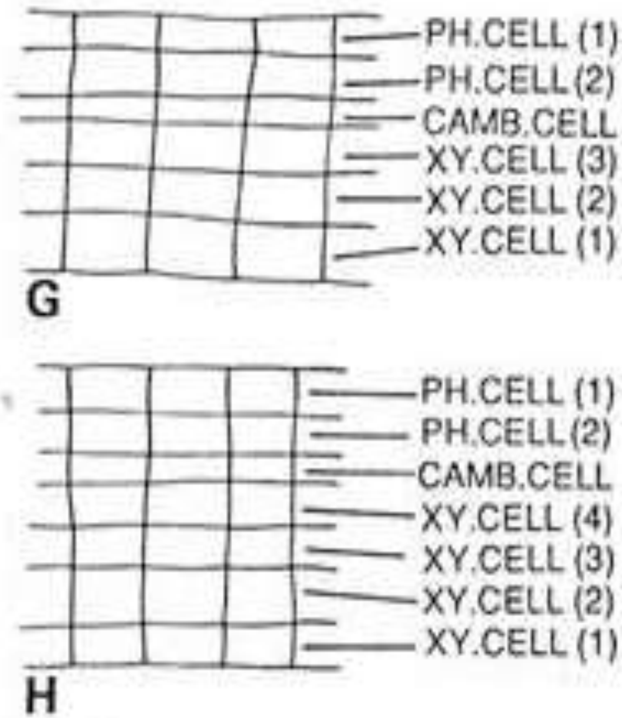
There are two general conceptions of the cambium as an initiating layer:

1. That it consists of a uniseriate layer of permanent initials with derivatives which may divide a few times and soon become converted into permanent tissue;
2. That there are several rows of initating cells which form a cambium zone, a few individual rows of which persist as cell forming layers for some time. During growing periods the cells mature continuously on both sides of the cambium it becomes quite obvious that only a single layer of cells can have permanent existence as cambium.

Other layers, if present, function only temporarily and become completely transformed into permanent cells. In a strict sense, only the initials constitute the cambium, but frequently the term is used with reference to the cambial zone, because it is difficult to distinguish the initials from their recent derivatives.

Cambial Activity– Formation of Xylem and Phloem





The cambium. A—H, diagrams showing the formation of xylem and phloem by the cambium, and changes in position of phloem and cambium by this activity.

Cellular Structure of Cambium

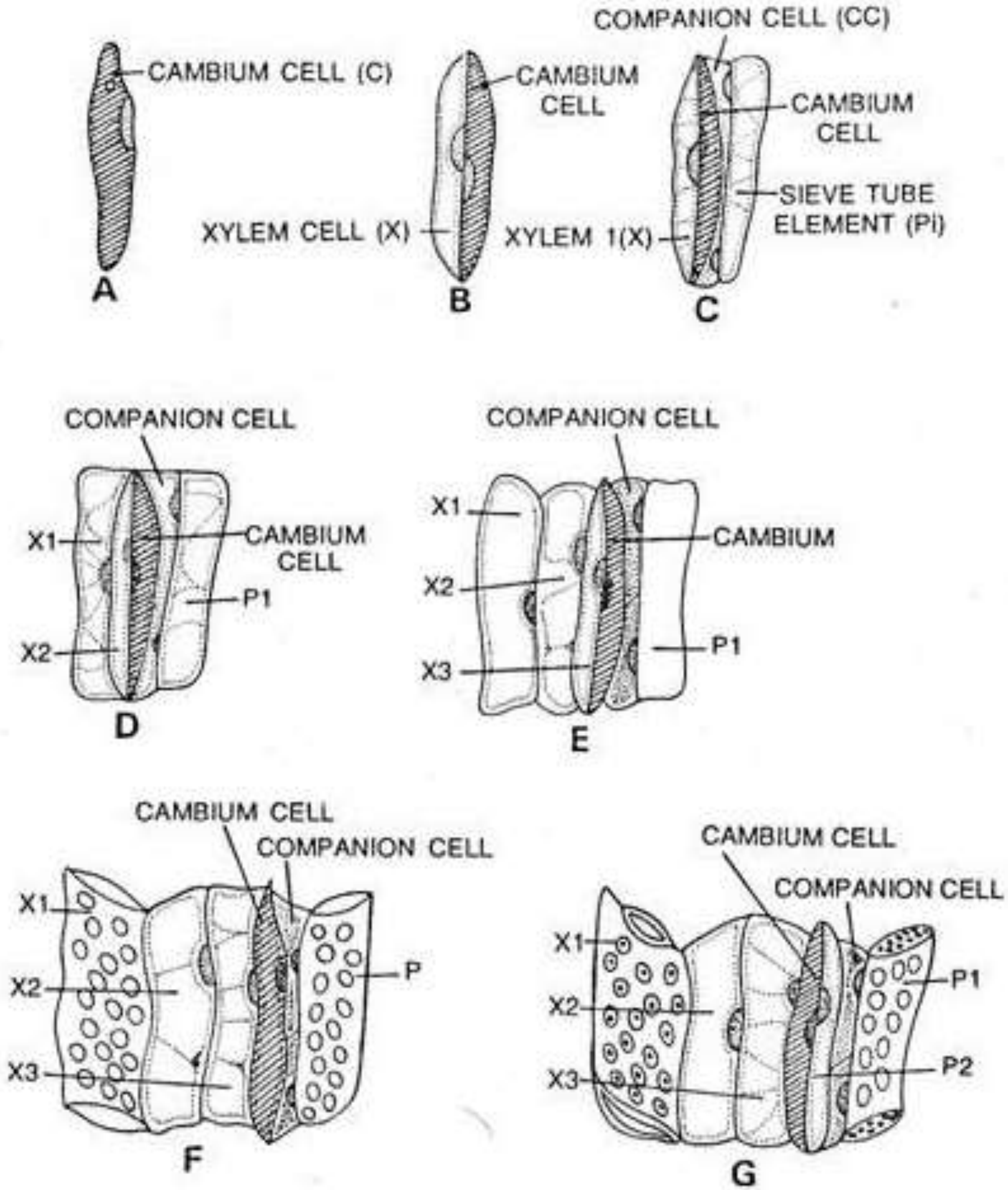
There are two different types of cambium cells:

1. The ray initials, which are more or less isodiametric and give rise to vascular rays; and
2. The fusiform initials, the elongate tapering cells that divide to form all cells of the vertical system.

The cambial cells are highly vacuolated, usually with one large vacuole and thin peripheral cytoplasm.

The nucleus is large and in the fusiform cells is much elongated. The walls of cambial cells have primary pit fields with plasmodesmata.

The radial walls are thicker than tangential walls, and their primary pit fields are deeply depressed.



The cambium. Differentiation of phloem and xylem from vascular cambium. A—G, diagrams as seen in radial section, showing stages in differentiation of vascular cambium cells.

Cell Division in Cambium

- With the result of tangential (periclinal) divisions of cambium cells the phloem and the xylem are formed.
- The vascular tissues are formed in two opposite directions, the xylem cells towards the interior of the axis, the phloem cells toward its periphery.
- The tangential divisions of the cambium initials during the formation of vascular tissues determine the arrangement of cambial derivatives in radial rows.
- Since the division is tangential, the daughter cells that persist as cambium initials increase in radial diameter only.
- The new cambium initials formed by transverse divisions increase greatly in length; those formed by radial divisions do not increase in length.
- As the xylem cylinder increases in thickness by secondary growth, the cambial cylinder also grows in circumference.
- The main cause of this growth is the increase in the number of cells in tangential direction, followed by a tangential expansion of these cells.

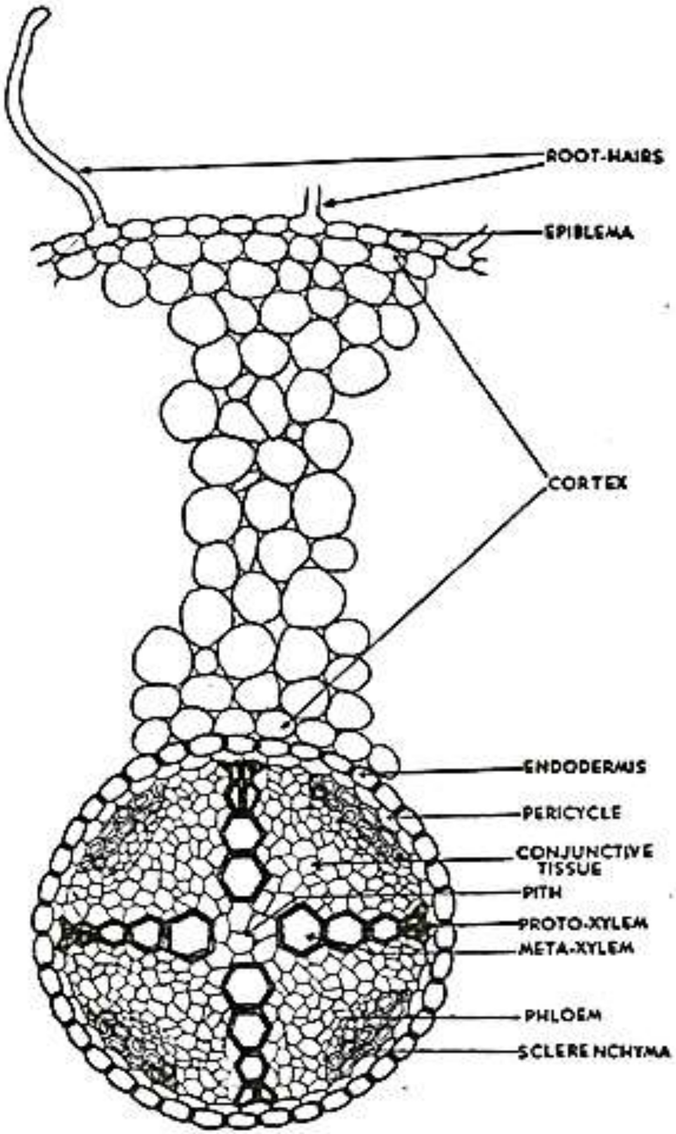
Primary Structure of Dicot root (Vigna)

The parts are: 1. Epiblema 2. Cortex 3. Endodermis 4. Pericycle 5. Vascular Strand 6. Pith.

Epiblema or Piliferous Layer (Rhizodermis):

- It is the outermost layer of the root. It is made of compactly arranged thin-walled flattened and slightly elongated parenchymatous cells.
- Epiblema of root differs from the epidermis of stem in being devoid of distinct cuticle and stomata. Some cells of the epiblema give rise to thin-walled tubular outgrowths called root hairs. They are called trichoblasts. Trichoblasts are generally smaller than other epiblema cells.
- The root hairs lie in between the soil particles and are in contact with the soil water. Root hairs possess a gummy pectic layer on the outside for cementing with soil particles and retaining water on the surface. Due to the presence of root hairs, the epiblema is also called piliferous layer (L. pilus— hair, ferre— to carry).
- The root hairs and thin-walled epiblema cells absorb water and minerals salts from the soil. Root hairs commonly do not live for more than one week. With their death the epiblema cells become suberized and cutinised.

T.S. of Primary Root of Dicot (Gram)



Cortex:

- It lies below the epiblema. The cortex is made up of many layers of thin walled parenchyma cells. The parenchyma cells are rounded. They enclose intercellular spaces for diffusion of gases. The cells of the cortex store food. They also conduct water from the epiblema to the inner tissue

Endodermis:

- Endodermis is usually considered to be the innermost layer of the cortex. It is made up of a single layer of barrel-shaped cells which do not enclose intercellular spaces. The cells are rich in starch grains.
- The young endodermal cells possess a band of thickening which runs along their radial and tangential walls. This band of thickening is called casparian strip (after Caspary, 1865). It is made up of both suberin and lignin (Esau, 1965).
- In a transverse section, the casparian strip appears in the form of small lenticular swellings on the radial walls only. Casparian strips prevent plasmolysis of endodermal cells. Due to the presence of casparian strips, the endodermal cells do not allow wall to wall movement of substances between cortex and pericycle.
- Substances must enter the cytoplasm of endodermal cells. As a result, endodermis functions as a biological check post. All tissues on the inner side of endodermis constitute stele. It consists of pericycle, vascular bundles and pith.

Pericycle:

- Endodermis is followed by one layers of pericycle.
- Pericycle is believed to represent the outer boundary of vascular strand.
- The cells of pericycle are thin-walled and parenchymatous in the young root.
- Pericycle is a very important layer. A part of the vascular cambium is formed by the pericycle.
- The cork cambium also develops from it. All lateral roots originate from the pericycle.

Vascular Strand or Cylinder:

- Inner to the pericycle are found a four alternately arranged bundles of xylem (tetrarch) and phloem.
- They are equal in number and lie on different radii. Such vascular bundles are called radial bundles.
- The various xylem bundles put together give a stellate or star-shaped appearance.
- The number of rays is equivalent to the number of xylem bundles (and phloem bundles).

- Protoxylem or the first formed xylem lies in contact with pericycle and at the tip of the rays while metaxylem or later formed xylem is present towards the centre of the root. Such a xylem is called exarch (L. ex— outside, Gk. arche— beginning).
- The metaxylem elements of different xylem bundles may lie separate from one another so that a pith is present in the centre of the root (e.g., Gram, Bean).
- However, usually the xylem bundles extend along the radii so that metaxylem elements of different bundles meet in the centre to form a solid starshaped structure. In such a case the pith is absent.
- Xylem is made up of vessels and a few tracheids. Vessels and tracheids are polygonal in outline.
- Protoxylem elements are fewer, smaller and narrower. The metaxylem elements are larger and wider. They have pitted thickenings while protoxylem possesses spiral, annular, reticulate or scalariform thickenings.
- **Xylem performs two important functions:**
- (i) Mechanical strength,
- (ii) Conduction of water and mineral salts to the shoot.

- In between the two adjacent xylem bundles is found a phloem bundle. It is oval in outline.
- Phloem and xylem bundles are separated from each other by one or more layers of small thin walled cells called conjunctive parenchyma or tissue.
- Later on the conjunctive tissue becomes meristematic to form vascular cambium.
- Phloem consists of sieve tubes, companion cells and phloem parenchyma.
- It conducts organic food from the shoot to the root and its branches. Fibres may occur outside the phloem in some roots (e.g., Gram).
- Radial arrangement of vascular bundles is a mechanism to keep the xylem bundles in direct contact with the outer tissues of the root which conduct water absorbed by the root hairs to the inside.

Pith:

- It is often absent. When present, the pith is quite small. The latter is made of parenchyma cells. Intercellular spaces are absent. The cells store food as well as waste materials.

Primary Structure of Monocot root (Maize)

Epidermis: It is uniseriate, composed of a row of tabular cells attached end on end without having intercellular spaces.

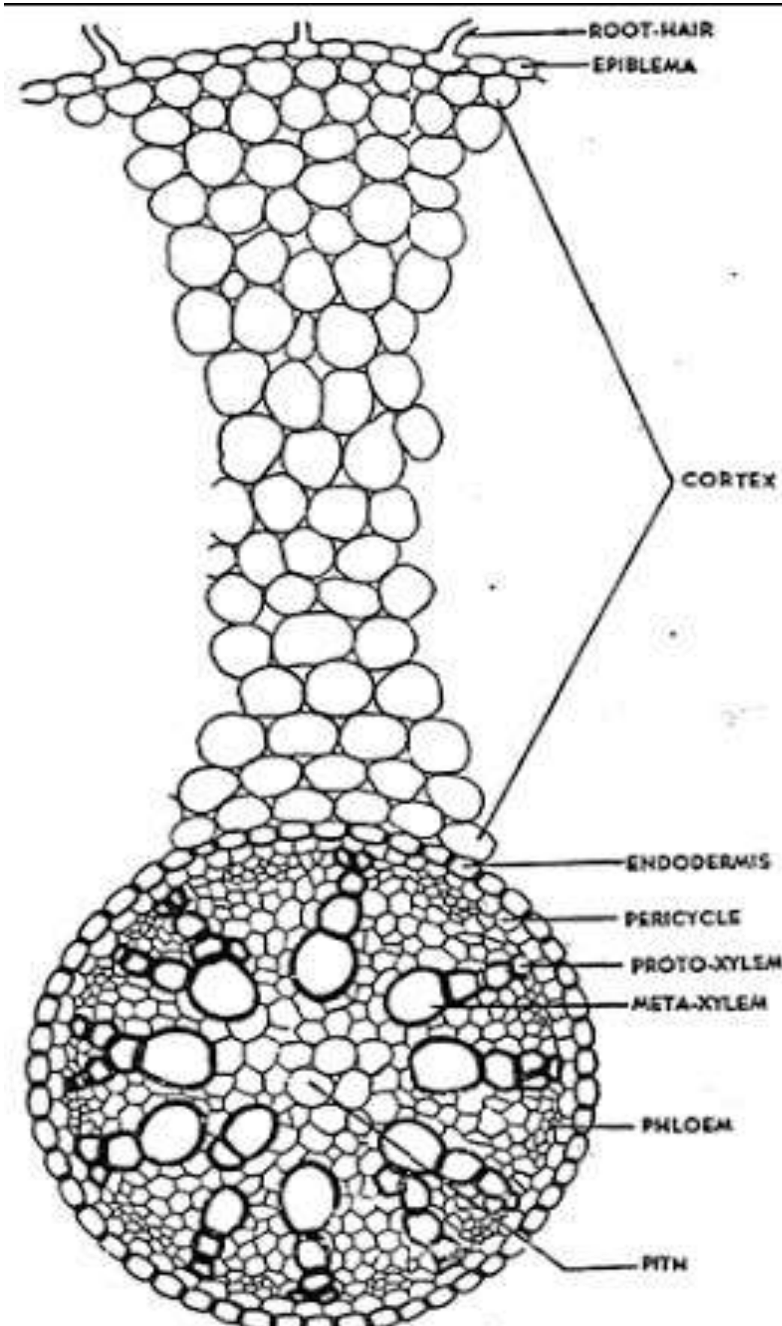
Cortex: The cortex is quite massive, as in other roots, and mainly consists of unspecialised parenchyma with profuse schizogenously formed spaces. In a slightly old root a few layers of cortex next to epiblema undergo chemical changes like suberisation, and thus give rise to a zone meant for protecting the internal tissues. This band is known as exodermis.

- Formation of exodermis may be initiated before the epiblema loses its function, but once epiblema is decayed exodermis takes over the function of protection.
- The last layer of cortex is the endodermis. It is composed of barrel-shaped compactly set cells with conspicuous Casparian strips.
- Due to secondary thickening the endodermal cells may have considerably thick radial and inner walls. In that case some thin-walled cells usually occur against the protoxylem groups; obviously they are meant for ready diffusion of fluids. These are known as passage cells or transfusion cells.

Stele:

- The pericycle is uniseriate, and, it is partly sclerenchymatous.
- Vascular bundles are as usual polyarch with a pretty good number of Xylem and phloem strands.
- Parenchyma cells associated with xylem undergo sclerosis and thus become thick-walled.
- The central portion is occupied by a large pith—made of loosely-arranged parenchyma cells containing abundant starch grains.

T.S. of Monocot Root (Maize)



Primary stem of Dicot stem (Tridax)

The following are the eight main parts of primary dicot stem in plants.

1. Epidermis
2. Hypodermis
3. General Cortex
4. Endodermis
5. Pericycle
6. Vascular Strand
7. Medullary or Pith Rays
8. Pith or Medulla.

Epidermis:

- Epidermis is the outermost layer of the stem. It is made up of compactly arranged elongated parenchymatous cells, which look rectangular-barrel shaped in a transverse section. The cells are transparent and devoid of chloroplasts.
- The outer walls are convex, thickened and cutinised. On the outer side they possess a layer of cuticle. The internal walls of the epidermal cells are thin. The radial walls are thick towards the outer side and gradually become thin towards the inner side. Pits occur in the radial walls.
- The epidermis of Sunflower stem bears several un-branched multicellular hair or trichomes. Like epidermis, they are covered by cuticle. At places the epidermis contains minute pores called stomata or stomata's.
- Each stomate or stoma (sing, of stomata) has a pair of specialised kidney shaped cells called guard cells. The guard cells have a few chloroplasts. By their swelling, the two guard cells can form a pore in between them.

The various functions of the epidermis are:

- (i) Protection of internal tissues,
- (ii) Prevention of entry of harmful organisms,
- (iii) Minimising surface transpiration by having thick cuticle,
- (iv) Exchange of gases through the stomata,
- (v) Protection against excessive heating up and sudden changes in temperature with the help of hair (as in Sunflower).

The tissue between epidermis and pericycle is called Cortex. It has three parts hypodermis, general cortex and endodermis.

Hypodermis:

- The hypodermis is made of 3-4 layered sub-epidermal collenchyma tissue.
- Its cells possess extra cellulose thickening in various regions-on the tangential walls (lamellate collenchyma).
- Collenchyma cells are green and enclose small intercellular spaces.

Hypodermis functions in:

- (i) Providing mechanical strength as well as, flexibility,
- (ii) Storage of food and
- (iii) Manufacture of food with the help of chloroplasts.

Hypodermis is absent or inconspicuous below the stomata.

General Cortex:

- It is a few to several cells in thickness. The cortex is made up of thin walled oval or rounded parenchymatous cells. They enclose intercellular spaces.
- In the young green stem, the outer cortical cells possess chloroplasts (chlorenchyma) and manufacture food. However, major function of the cortex is storage of food.
- In Tridax, the cortex contains a number of longitudinally running oil ducts. Each oil duct has a channel which is lined by an epithelium of small glandular cells.

Endodermis:

- It is a wavy layer of one cell in thickness. The endodermis lies at the innermost boundary of cortex.
- It is made up of barrel-shaped cells which do not enclose intercellular spaces.
- Casparian strips are generally absent. The endodermal cells often contain conspicuous starch grains as food reserve. Therefore, the stem endodermis is also called starch sheath.

Pericycle:

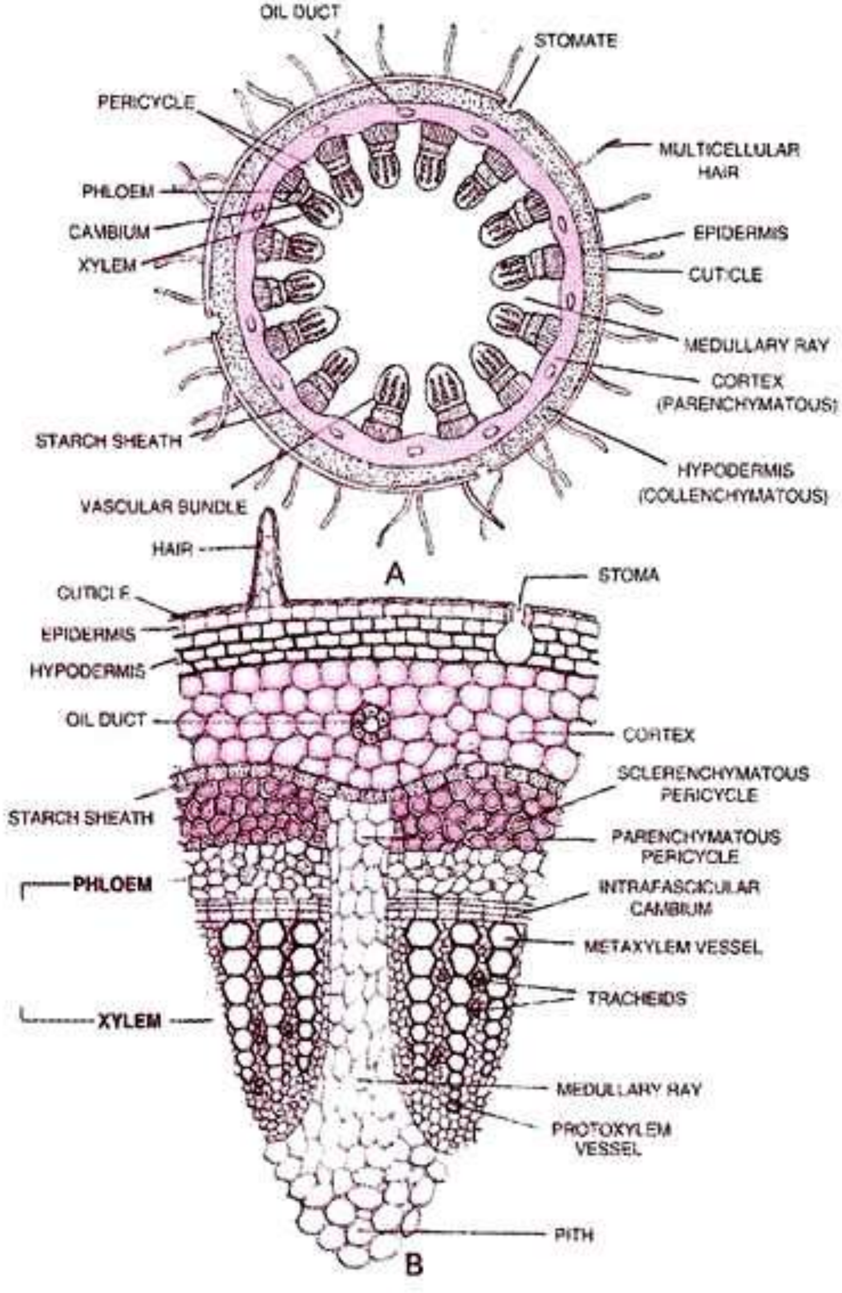
- It is few layered thick tissue. It lies inner to endodermis and outside the vascular strand. The pericycle is heterogenous. It is made up of both parenchyma and sclerenchyma fibres. Sclerenchyma lies on the outside of vascular bundles in the form of semicircular to semilunar patches called bundle caps.
- As the bundle caps are associated with phloem part of vascular bundles, the sclerenchymatous pericycle is also called hard bast. Parenchymatous pericycle is present outside medullary rays.

Vascular Strand:

- The vascular strand is in the form of eustele or a ring of vascular bundles present around the central pith and inner to the pericycle.
- The vascular bundles are definite in number. They are obtusely wedge shaped.
- Each vascular bundle consists of phloem (primary) on the outside, xylem towards the inner side and strip of cambium in between the two.
- Phloem and xylem tissues lie on the same radius.
- Such vascular bundles are known as conjoint (with both phloem and xylem), collateral (phloem and xylem on the same radius) and open (with a strip of cambium in between phloem and xylem).

(a) Phloem:

- It lies towards the pericycle on the outer side of vascular bundle.
- Phloem consists of sieve tubes, companion cells, phloem parenchyma and some phloem fibres.
- The companion cells and phloem parenchyma are connected with sieve tubes through pits.
- They help in the lateral flow of the organic food.
- The companion cells also control the functions of the sieve tubes. The sieve tubes conduct organic food longitudinally.


OIL DUCT
STOMATE
PERICYCLE
MULTICELLULAR HAIR
PHLOEM
CAMBIUM
XYLEM
EPIDERMIS
CUTICLE
MEDULLARY RAY
CORTEX (PARENCHYMATOUS)
STARCH SHEATH
HYPODERMIS (COLLENCHYMATOUS)
VASCULAR BUNDLE
A
HAIR
STOMA
CUTICLE
EPIDERMIS
HYPODERMIS
OIL DUCT
CORTEX
SCLERENCHYMATOUS PERICYCLE
STARCH SHEATH
PARENCHYMATOUS PERICYCLE
PHLOEM
INTRAFASCICULAR CAMBIUM
METAXYLEM VESSEL
TRACHEIDS
XYLEM
MEDULLARY RAY
PROTOXYLEM VESSEL
PITH
B

(b) Xylem:

- It is found towards the pith or the inner portion of the vascular bundles. Xylem consists of two parts, smaller protoxylem (of narrow elements) and larger meta-xylem (of broader elements). Protoxylem or first formed xylem lies at the tip of meta-xylem towards the pith or centre of stem. Therefore, xylem is endarch (development centrifugal).
- Xylem consists of tracheids, vessels, xylem parenchyma and xylem fibres. Out of these only the xylem parenchyma cells are living. They are smaller in size than the parenchyma cells found outside the bundles. Xylem parenchyma cells store food and help in the lateral conduction of the sap.
- Vessels are present in the form of a few radial rows. They are angular in outline. The vessels of the protoxylem region are smaller and possess annular or spiral thickenings. These thickenings make the protoxylem vessels elastic and capable of stretching during the elongation of stem. The vessels of meta-xylem have pitted thickenings.
- Tracheids are present in between and around the radial rows of vessels especially of the meta-xylem region. Xylem fibres lie scattered amongst the tracheids. The vessels, tracheids and xylem fibres, all provide mechanical strength to the stem.
- However, the most important function of xylem is the conduction of water and mineral substances. This is carried out by two tracheary elements, vessels and tracheids.

Cambium:

- It is the left out portion of pro-cambium. Cambium is in the form of a narrow strip of primary meristematic cells that lie between the phloem and the xylem of a vascular bundle. It is called intra-fascicular or fascicular cambium.
- Cambial cells are thin- walled fusiform cells which appear rectangular in transverse section.

Medullary or Pith Rays:

- They are the radial strips of parenchyma which are present between adjacent vascular bundles. The medullary rays connect the pith with pericycle and cortex. The ray cells are larger than cortical cells. They are polygonal in outline.
- Intercellular spaces are small. Ray cells make intimate contact with the conducting cells of both phloem and xylem through pits. The medullary rays help in the radial conduction of food and water. They also transport gases from pith to cortex and vice versa.

Pith or Medulla:

- It forms the centre of the stem. The pith is made up of polygonal oval or rounded parenchyma cells which enclose intercellular spaces. The pith cells store food.

Primary Structure of Monocot Stem (Maize)

Epidermis:

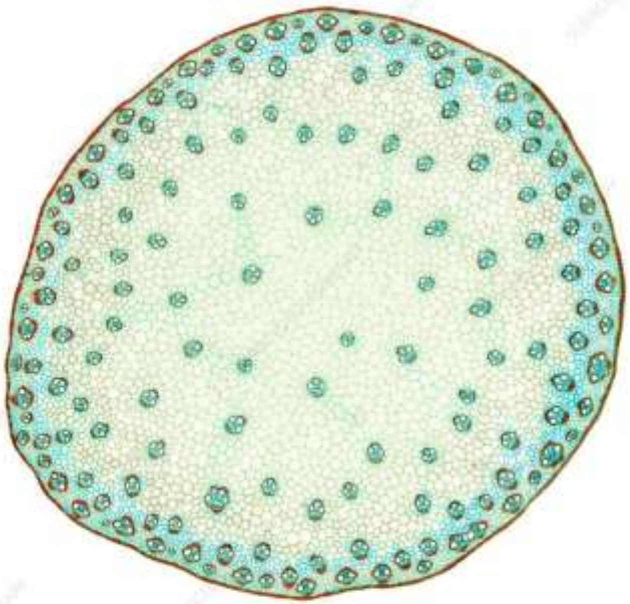
- It is as usual single-layered with cuticularised outer walls. Few stomata are seen in epidermis. Multicellular hairs are absent.

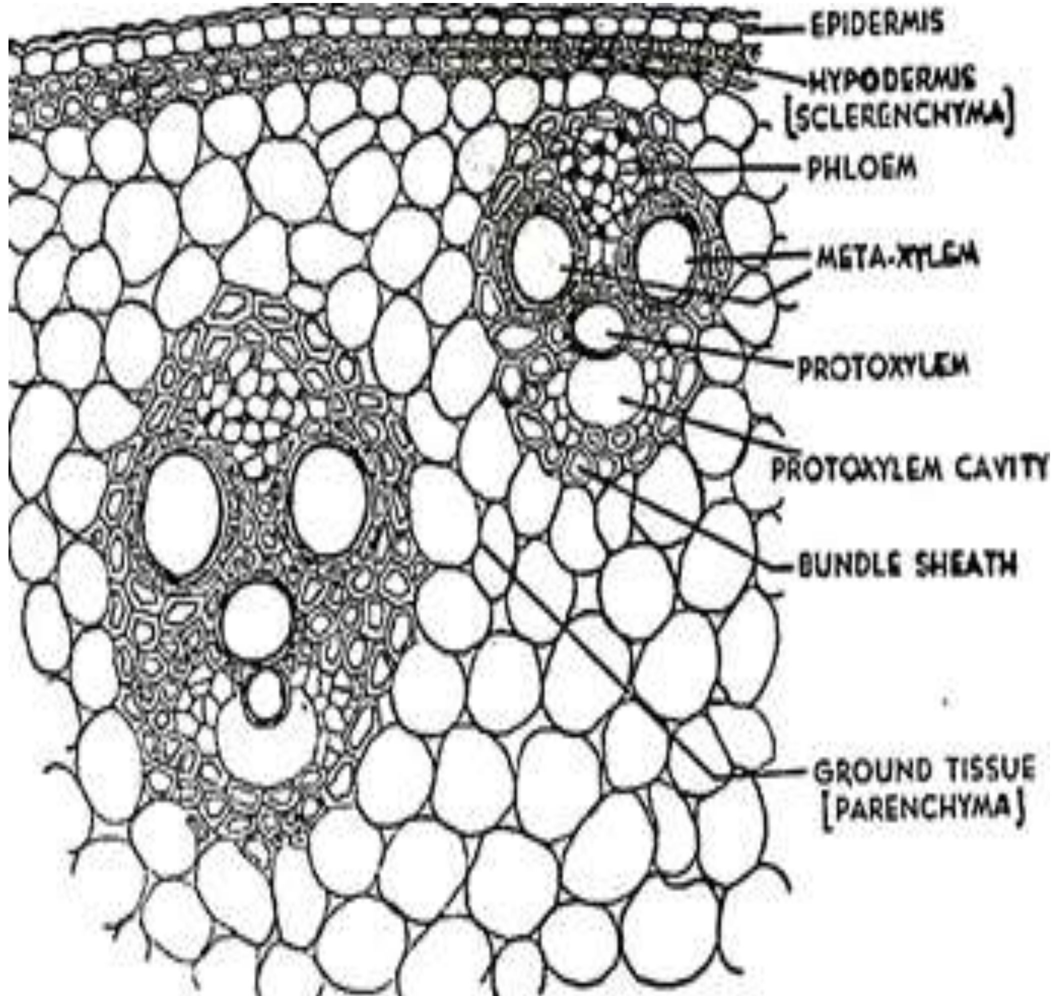
Ground Tissues:

- Next to epidermis there are two or three layers of sclerenchyma forming the hypodermis. Ground tissues internal to hypodermis are all parenchymatous in nature showing the primary body no differentiation into cortex, starch sheath, etc. They are simply called ground tissue.

Vascular Bundle:

- Bundles are numerous and scattered in the ground tissue, more crowded towards the periphery than towards the centre. The bundles are collateral closed. That is why monocotyledons usually do not grow in thickness. Xylem has the usual elements. Two metaxylem vessels lie outwards and two protoxylem vessels towards the centre.
- Their arrangement is more or less like the letter Y. Beneath the lowest protoxylem there is a cavity called protoxylem cavity. Phloem is much smaller and is composed of only sieve tubes and companion cells, phloem parenchyma being absent. The whole bundle remains surrounded by sclerenchymatous tissue forming what is called the bundle sheath.





Portion of transverse section of maize stem.

Leaf Anatomy – Dicot and Monocot

- The foliage leaves are characterised by green colour, thinness and flatness. They develop as protrusions from the shoot apex and are organs of limited growth.
- Leaves are very important vegetative organs, as they are chiefly concerned with the physiological process, photosynthesis and transpiration. Like other organs they also exhibit three tissue systems.
- Epidermal tissue system consists of the epidermal layers occurring on the adaxial (upper) and abaxial (lower) sides.
- Occurrence of stomata and outgrowths are distinctive features. The ground tissue system is known as mesophyll tissue.
- It is often differentiated into columnar palisade parenchyma on the adaxial side and irregular or isodiametric spongy parenchyma on this differentiation in mesophyll is referred to as dorsiventral, what is very common in dicotyledons.
- One with undifferentiated mesophyll, as commonly found in the monocotyledons, is known as an isobilateral leaf.
- The vascular tissue system is composed of vascular bundles which are usually collateral and closed.

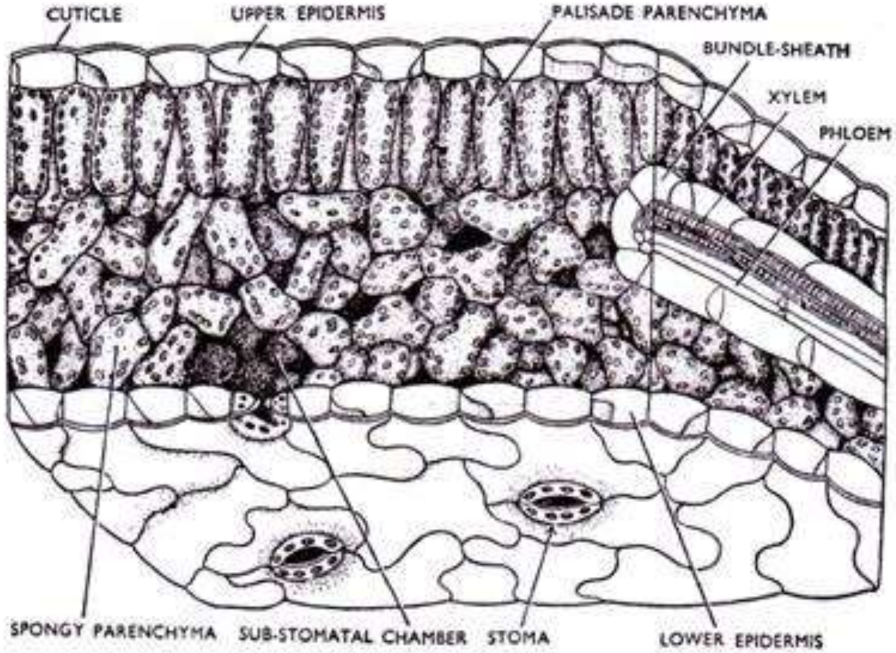


FIG. 613. Diagram of a dorsiventral leaf showing the tissues.

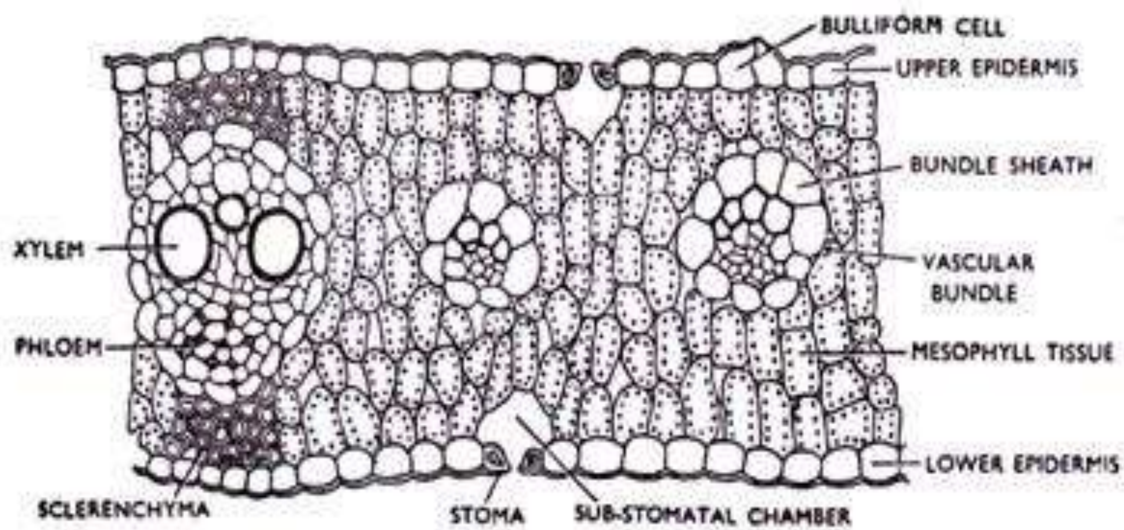


FIG. 619. A portion of leaf of *Zea* (maize) in transverse section.

Dicot Leaf

Epidermis: present - upper as well as lower surfaces. One-celled thick upper and lower epidermal layers consist of barrel-shaped, compactly arranged cells. A thick cuticle is present on the outer walls of epidermal cells. Comparatively, thick cuticle is present on the upper epidermis. Stomata are present only on the lower epidermis.

Mesophyil: differentiated into palisade and spongy parenchyma. Palisade lies just inner to the upper epidermis. It is composed of elongated cells arranged in two layers. The cells of palisade region are compactly arranged and filled with chloroplasts. At some places the cells are arranged loosely and leave small and big intercellular spaces. Palisade cells are arranged at a plane at right angle to the upper epidermis, and the chloroplasts in them are arranged along their radial walls. Parenchymatous cells are present above and below the large vascular bundles. These cells interrupt the palisade layers and are said to be the extensions of the bundle sheath. Spongy parenchyma region is present just below the palisade and extends upto the lower epidermis. The cells of spongy parenchyma are loosely arranged, filled with many chloroplasts and leave big intercellular spaces.

Vascular Region: Many large and small vascular bundles are present. Vascular bundles are conjoint, collateral and closed. Each vascular bundle is surrounded by a bundle sheath. Bundle sheath is parenchymatous and in case of large bundles it extends upto the epidermis with the help of thin-walled parenchymatous cells. The xylem is present towards the upper epidermis and consists of vessels and xylem parenchyma. Protoxylem is present towards upper epidermis while the metaxylem is present towards the lower epidermis. Phloem is situated is present towards the lower epidermis and consists of sieve tubes, companion cells and phloem parenchyma.

Monocot leaf - Polianthus

- **Epidermis:**
- Both the epidermal layers are uniseriate, composed of compactly-arranged rectangular cells with rounded cuticularised outer walls. Stomata are present on both the epidermal layers.
- **II. Mesophyll:**
- It as usual forms the main bulk of the leaf, and is composed of iso-diametric cells with intercellular spaces. Chloroplasts are abundantly present. Thus the differentiation of mesophyll into palisade and spongy cells is absent; all the cells are of spongy type.
- **III. Vascular bundles:**
- These are present at regular intervals. The bundles are collateral and closed ones with xylem and phloem. A few sclerenchyma cells are present at the two ends of the bundles. The bundles remain surrounded by a row of parenchyma cells devoid of chloroplasts, which forms the bundle sheath.

Types of Stomata

- The stomata are minute pores which occur in the epidermis of the plants.
- Each stoma remains surrounded by two kidneys or bean shaped epidermal cells the guard cells.
- The stomata may occur on any part of a plant except the roots. The epidermal cells bordering the guard cells are called accessory cells or subsidiary cells.

Ranunculaceous or Anomocytic:

- Type A — (Anomocytic = irregular celled). In this type the stoma remains surrounded by a limited number of subsidiary cells which are quite alike the remaining epidermal cells. The accessory or subsidiary cells are five in number.

Cruciferous or Anisocytic:

- Type B – (Anisocytic = unequal celled). In this type stoma remains surrounded by three accessory or subsidiary cells of which one is distinctly smaller than the other two.

Rubiaceous or Paracytic:

- Type C – (Paracytic = parallel celled). In this type, the stoma remains surrounded by two subsidiary or accessory cells which are parallel to the long axis of the pore and guard cells.

Caryophyllaceous or Diacytic:

- Type D – (Diacytic = cross celled)-In this type the stoma remains surrounded by a pair of subsidiary or accessory cells and whose common wall is at right angles to the guard cells.

Gramineous:

- The gramineous stoma possesses guard cells of which the middle portions are much narrower than the ends so that the cells appear in surface view like dump-bells. They are commonly found in Gramineae and Cyperaceae of monocotyledons.

Coniferous Stomata:

- They are sunken and appear as though suspended from the subsidiary cells arching over them. In their median parts the guard cells are elliptical in section and have narrow lumina. At their ends they have wider lumina and are triangular in section. The characteristic of these guard cells is that their walls and those of the subsidiary cells are partly lignified and partly non-lignified.

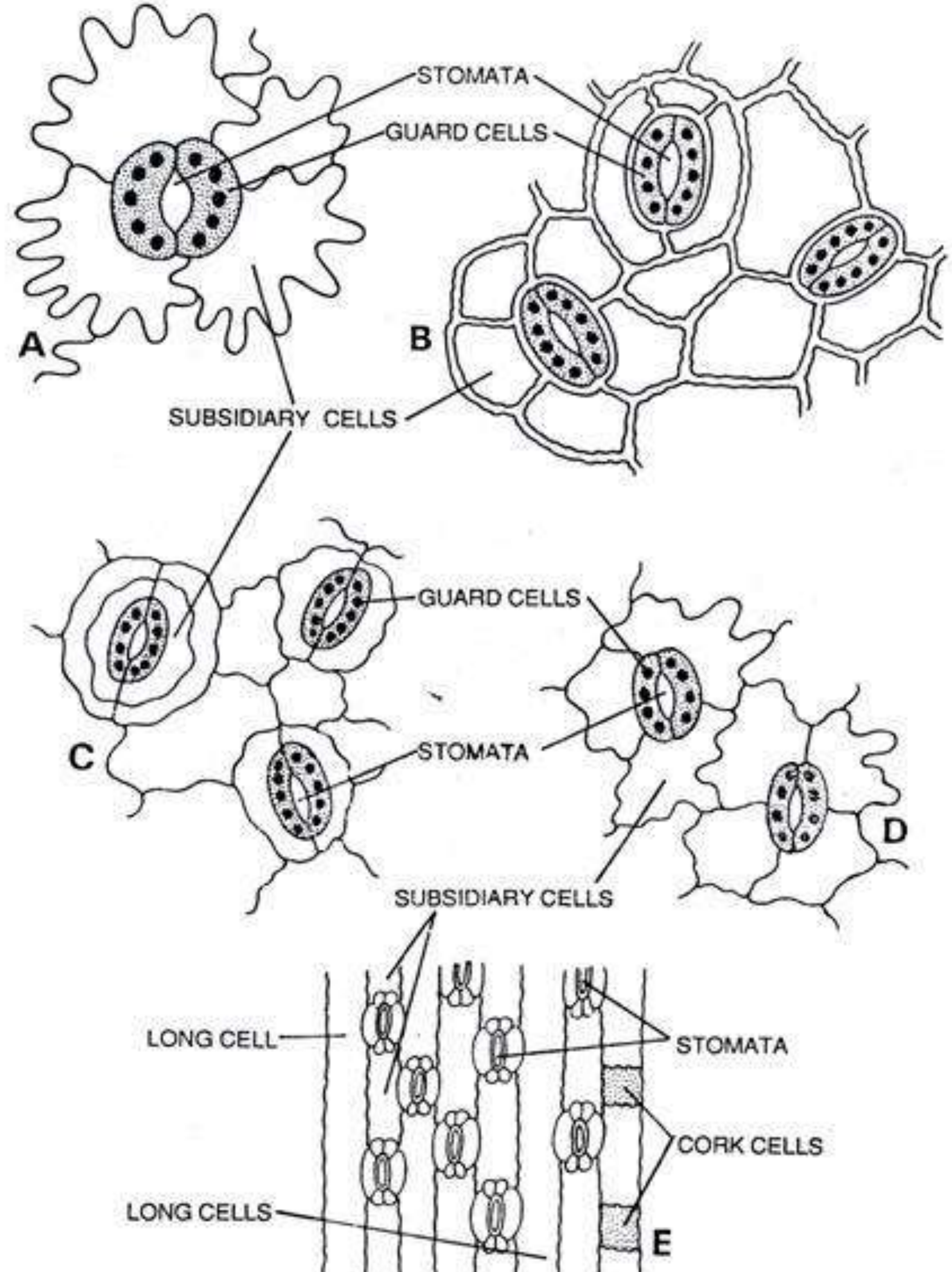
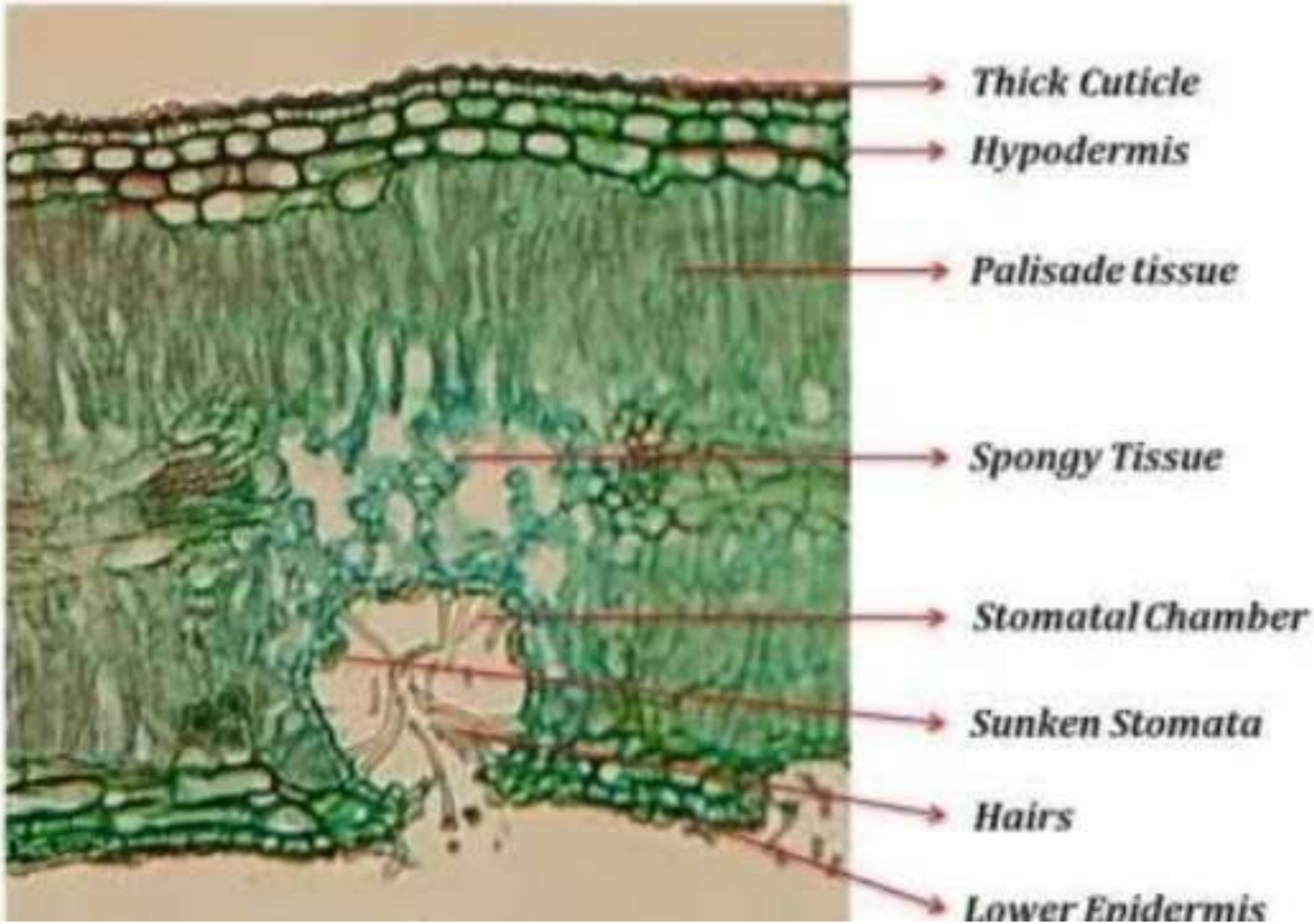


Fig. 37.15. Stomata—types of stomata. A, anomocytic or irregular celled type (ranunculaceous type); B, anisocytic or unequal celled type (cruciferous type); C, paracytic or parallel celled type (rubiaceous type); D, diacytic or cross-celled type (caryophyllaceous type); E, gramineous type.

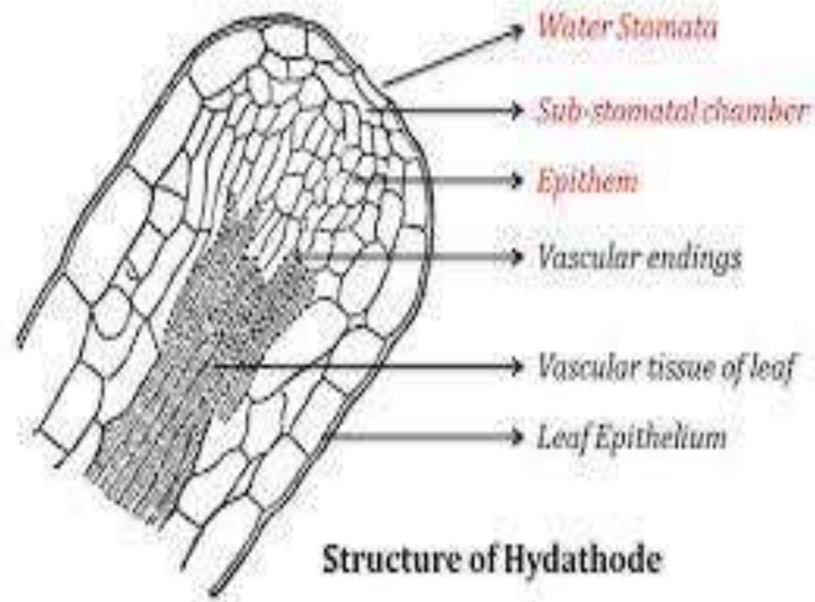
Nerium Leaf T.S.



Hydathodes

- A pore that exudes water on the surface or margin of a leaf of higher plants.A type of gland found in plant leaves that is responsible for the secretion of water into the external environment.
- Hydathodes occur on the leaves of only a few plants.
- Hydathodes occur on the margins and tips of the leaves.
- Subsidiary cells are absent.
- Cells bordering a water pore are usually achlorophyllous.
- Hydathodes possess permanent pores because the guard cells surrounding them are immobile.
- Hydathodes send out liquid water.
- Small quantities of solutes also pass out dissolved in guttated liquid.
- Hydathode possesses loosely arranged epithem cells below its pore.
- Hydathodes contain a vein ending.

Guttation in Some Leaves



Structure of Hydathode