

## 1. Introduction

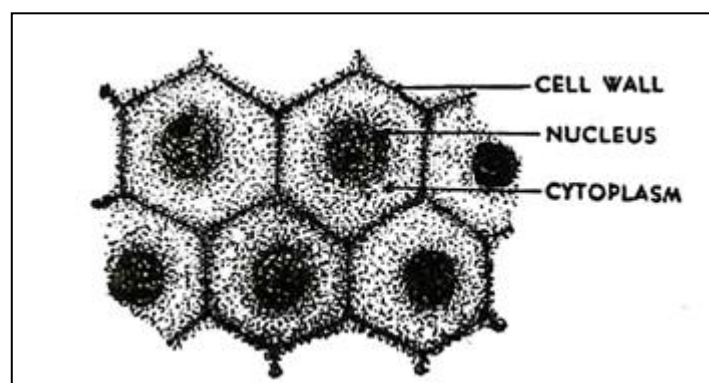
The plant kingdom is characterized, at the structural level, first by its cells, and then by the organization of its tissues. **Tissues are formed from meristems**, organized masses of young, isodiametric, undifferentiated cells. They represent a grouping of cells sharing the same embryonic origin and the same appearance, and they are the site of active, oriented cell divisions (they indefinitely retain their embryonic characteristics "**stem cells**" because certain meristematic cells do not differentiate) (Figure 2). Tissues can be divided into several structural or functional categories to give rise to organs (stem, leaf, root, etc.). Meristems are present in all plants, but their functioning differs.

### 1.1. Meristems Growth Tissue or Cell Division Tissue

#### 1.1.1. Primary Meristems or Apical Meristems

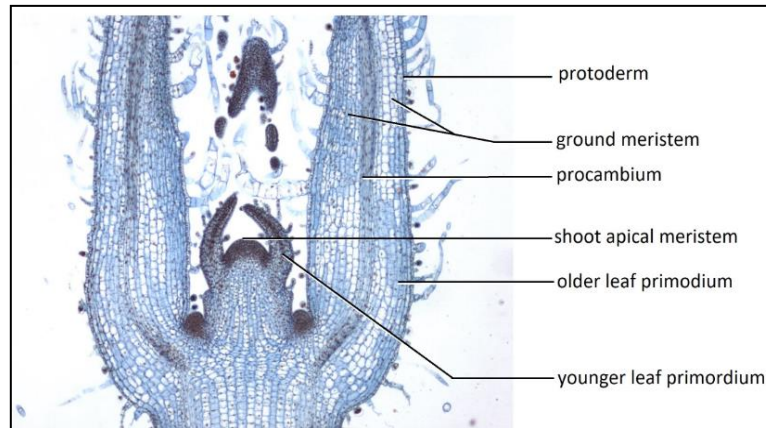
They are of embryonic origin and form during embryogenesis. Meristems are located at the terminal portions of organs the "**vegetative apex.**" There are root apical meristems and shoot apical meristems, and sometimes lateral ones at the base of leaves (**axillary meristems**) (Figure 3). They typically allow **longitudinal growth** of plants, forming **the primary structure**. The tissues derived from them undergo little thickening in the absence of secondary meristems.

The cells of primary meristems are **small and isodiametric**. They are perfectly tightly packed (**no intercellular spaces**) (Figure 1).



**Figure 1:** Meristematic cell (primary meristem)





**Figure 4:** Shoot meristem (cauline meristem)



**Figure 5:** Shoot buds of a branch opening.

#### 1.1.1.2. Root Meristem

The root meristem gives rise to the tissues of the root and the root cap; it is **exclusively histogenic**. It does not produce lateral organs and is therefore **not organogenic**.

Lateral roots form endogenously at some distance from the apex, originating from the **pericycle** (the cell layer located between the cortex and the stele). This promotes the branching of the root (Figures 6–7–8).

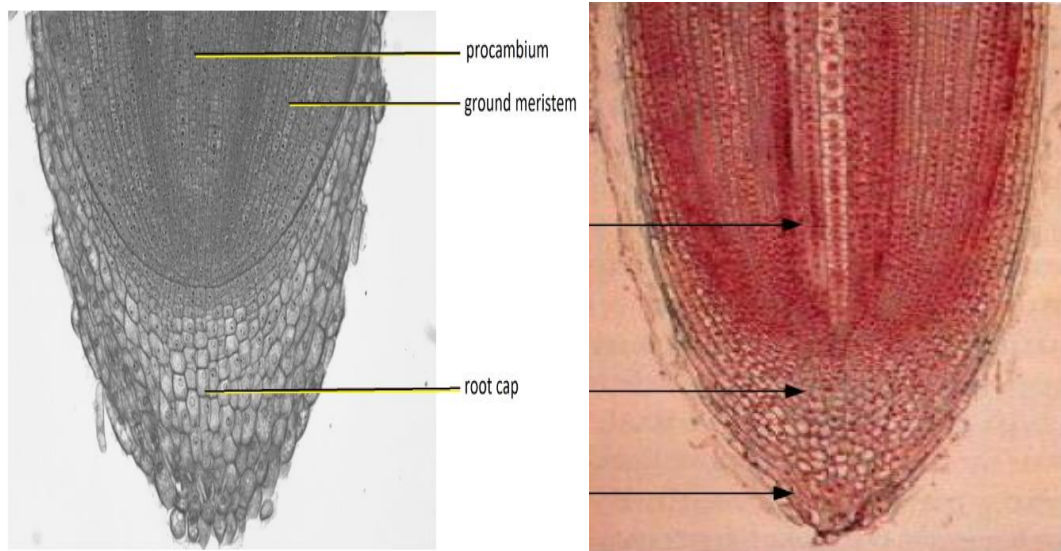


Figure 6: Root meristem

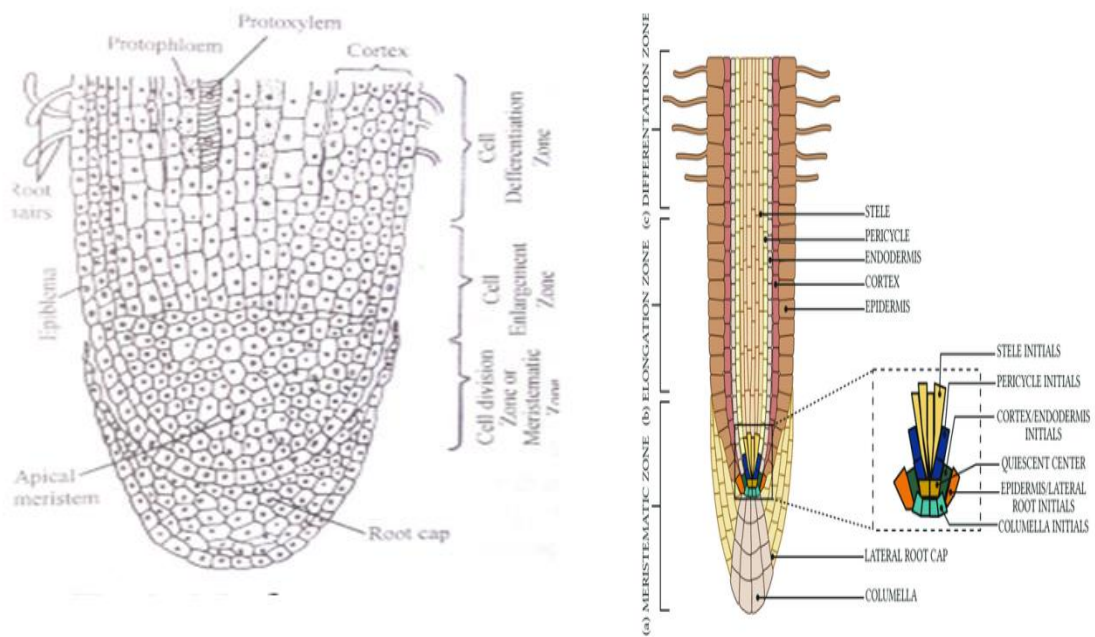
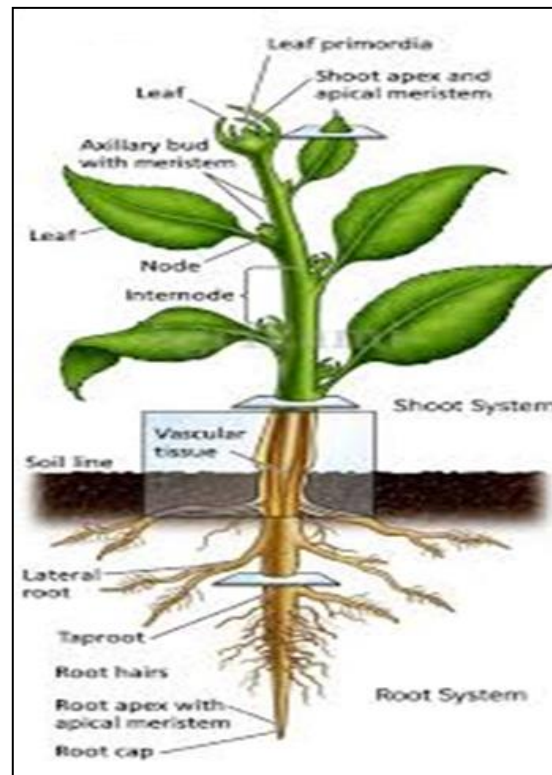


Figure 7: Root Apical Meristem (RAM)



**Figure 8:** Histogenic and organogenic functions of primary meristems

### 1.1.2. Secondary Meristems

After the primary meristems, secondary meristems appear. The activity of secondary meristems modifies the primary structures, which thus become secondary structures. They are represented by **the phellogen and the cambium**, which constitutes **the secondary structure**. Their role is to ensure the growth in thickness of the stems and roots of **dicotyledonous Angiosperms**. Notably, **monocotyledonous Angiosperms do not possess them**.

Secondary meristems consist of generative layers in the form of rings made of cells capable of dividing rapidly. Their cells differ from primary meristem cells in their:

- Rectangular shape;
- Cell contents;
- Central vacuole and nucleus, which occupies a lateral position.

**Two secondary meristems differentiate late in plants** (Figures 9–10–11):

**A/ Vascular cambium (libero-ligneous generative zone)**. The cambium is located between the xylem and phloem. It is responsible for the formation of **secondary vascular tissues**. It displays mitotic activity oriented **radially**, responsible for the formation of secondary xylem (**wood**) toward the **interior** and secondary phloem (**bast/bark**) toward the **exterior**.

The cambium is composed of a single layer of cells, in the form of a cylinder sometimes called the "cambial ring."

**B/ Cork cambium (phellogen - subero-phellodermous generative zone).** The phellogen is responsible for the formation of **secondary protective tissues**. It is found in the cortex (peripheral margin). It is responsible for the production of cork (**suber**) toward the exterior and **phelloderm** toward the **interior**.

**NOTE: Herbaceous plants do not possess secondary meristems.**

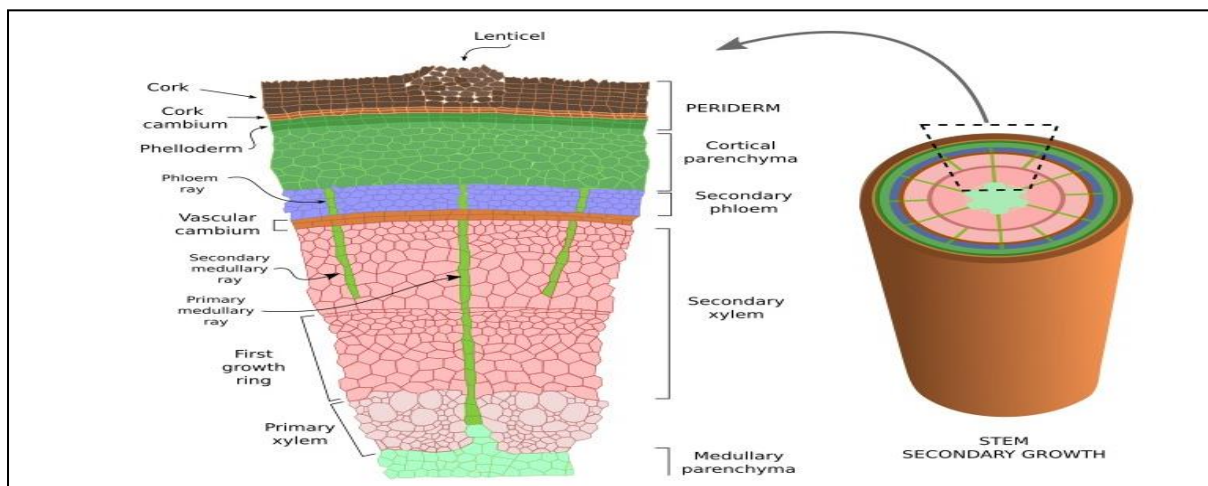


Figure 9: Location of secondary tissues

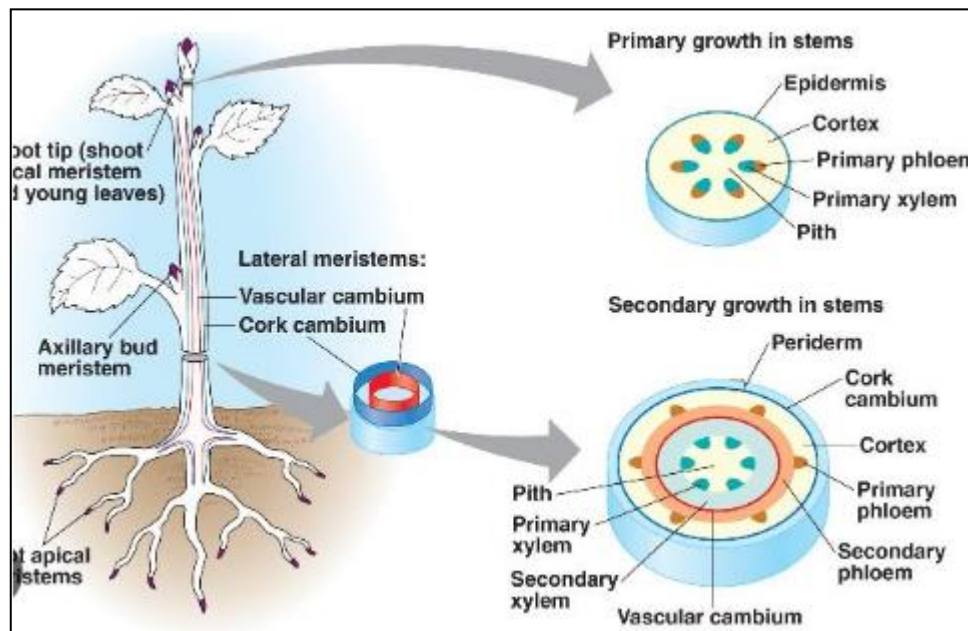
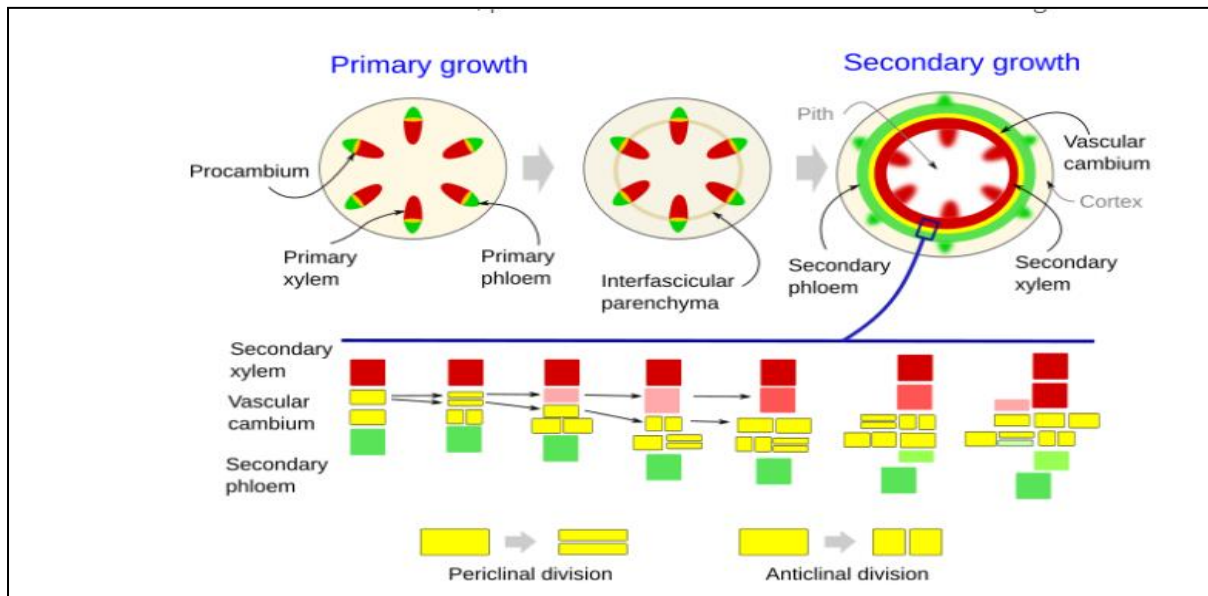


Figure 10: Secondary meristem



**Figure 11:** Schematic representation of the division mode of cambial cells

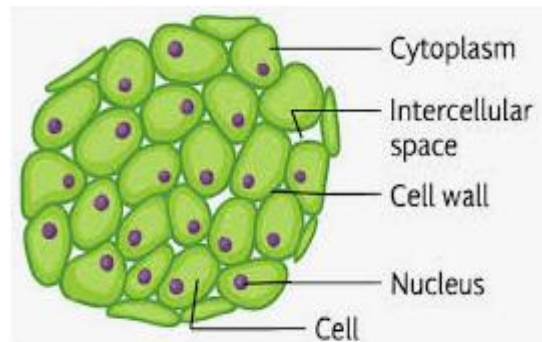
## 1.2. Filling Tissues / Parenchymatous Tissues (Parenchyma) / Ground Tissues

Parenchymas arise from the activity of primary meristems. They are the most abundant tissues, composed of large, living cells that are isodiametric or elongated **but do not divide**. Their vacuoles are very well developed, but their **pectocellulosic walls are thin and flexible due to the absence of a secondary wall. Cells may be tightly packed** but often show gaps forming **intercellular spaces (meatuses)**, or large spaces (lacunate parenchyma). Parenchyma is found in the cortex (cortical parenchyma) or in the pith (medullary parenchyma) of stems and roots, in the mesophyll of leaves, and in the flesh of fruits.

These tissues are classified by function as: chlorophyllous parenchymas, which carry out photosynthesis; storage parenchymas, located more internally, which accumulate organic compounds (carbohydrates, lipids, proteins); aquiferous parenchymas, which store water; and aerenchymatous parenchymas, which store air.

### 1.2.1. Chlorophyllous Parenchyma (Chlorenchyma) or Photosynthetic Parenchyma

These are characterized by the presence of numerous chloroplasts in their cells (ensuring photosynthesis). The cells of the chlorophyllous parenchyma leave intercellular spaces (meatuses) between them and take on a rounded shape (Figure 12). They can also be separated by large lacunae facilitating gas exchange. Chlorophyllous parenchymas are abundant in aerial organs, particularly in leaves and young stems (Figures 13–14).



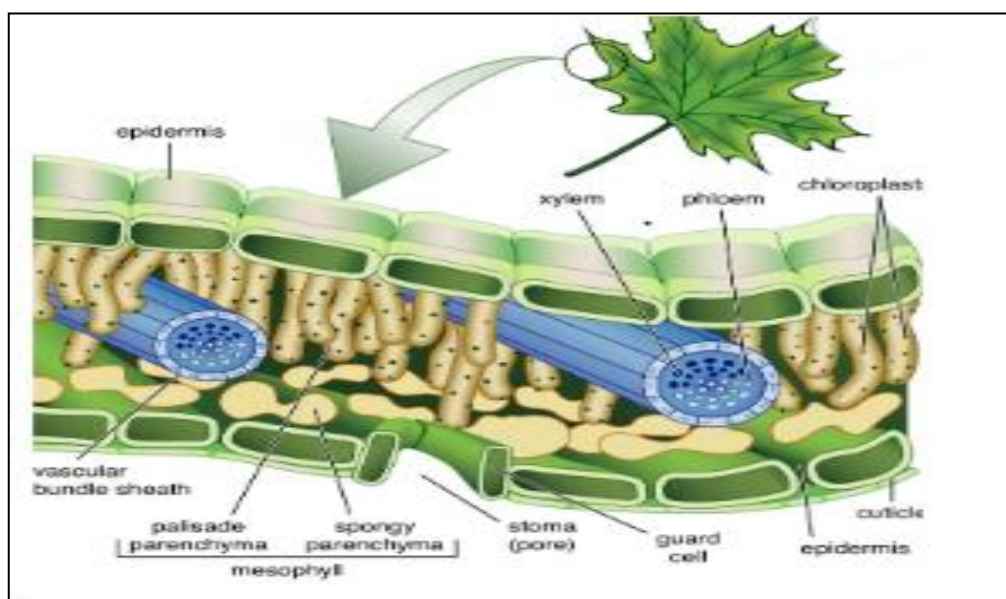
**Figure 12:** Presence of intercellular spaces (meatuses) between cells of the chlorophyllous parenchyma.

### 1.2.1.1. Palisade Chlorophyllous Parenchyma

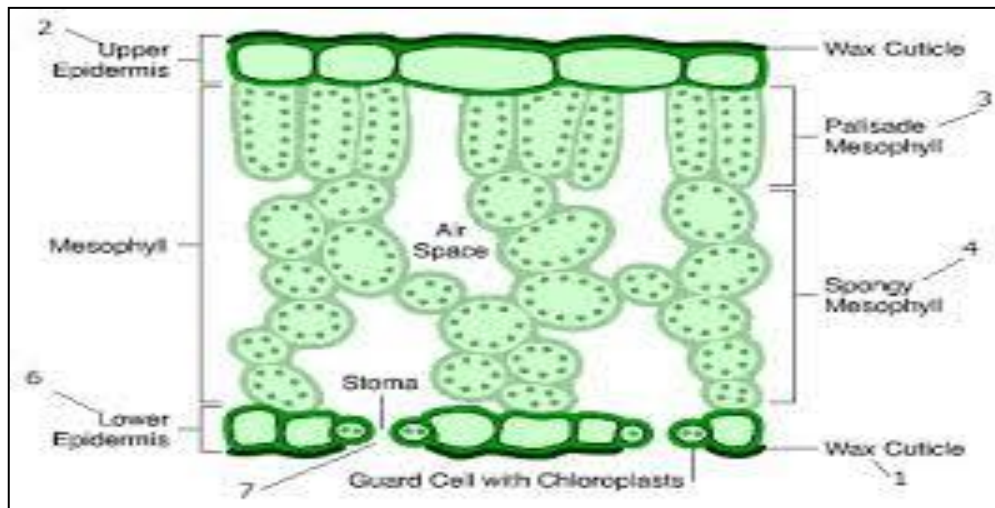
The palisade chlorophyllous parenchyma is composed of elongated cells tightly packed against one another, without intercellular spaces. The cells located on the side of the **upper leaf surface** contain **numerous chloroplasts**, which **enables photosynthesis**. The palisade parenchyma is surrounded by the epidermis and traversed by veins.

### 1.2.1.2. Lacunate Chlorophyllous Parenchyma

The lacunate chlorophyllous parenchyma is found on the **lower leaf surface**. It is composed of more or less rounded or star-shaped cells, characterized by a **reduced number of chloroplasts**, between which large lacunae are present to facilitate gas exchange through the stomata.



**Figure 13:** Chlorophyllous parenchyma



**Figure 14:** Palisade and lacunate chlorophyllous parenchyma in a leaf

### 1.2.2. Storage Parenchyma

Storage parenchymas are abundant in underground organs; they are also found inside stems, in fruits and seeds that accumulate energy reserves (starch in plastids, sugars, glycosides and proteins in vacuoles, and lipids in the cytoplasm). They also play a role in tissue regeneration and wound healing.

Storage parenchymas are made up of **living cells** with **non-pigmented plastids** and a reduced membrane system. They produce large starch grains in their stroma from the products of photosynthesis from aerial organs. They then mobilize and release these reserves later during growth resumption to sustain the plant's tissues. Reserves may also take the form of **carbohydrates** (sugar beet), **starch** (potato), **lipids** (peanut seeds), **proteins** (cereal grains), and others such as water and air (Figure 15).



**Figure 15:** Nutritive storage parenchyma

**A/ parenchyma containing starch grains; B/ potato cells**

### 1.2.3. Aquiferous Parenchyma

The aquiferous parenchyma consists of large cells with intercellular spaces, equipped with a very well-developed vacuole. It is abundant in the stems or leaves of succulent plants

(succulents / "fat plants"). Certain plants use the water stored in this tissue during drought periods (Figure 16).

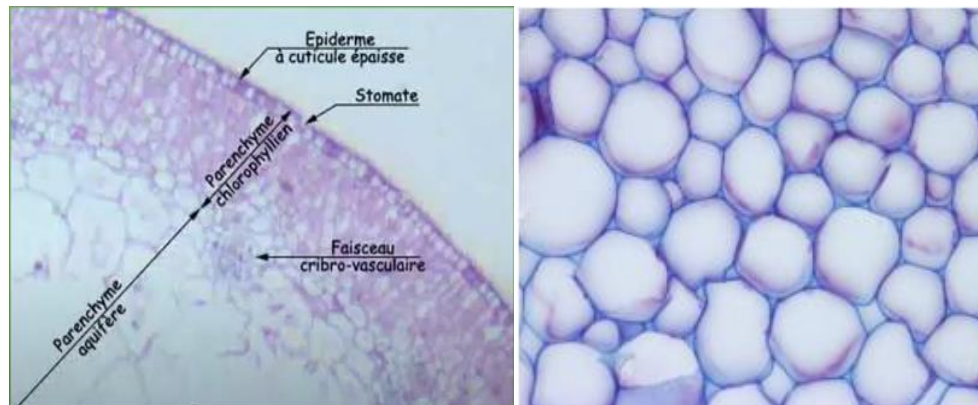


Figure 16: Aquiferous parenchyma

#### 1.2.4. Aerenchymatous Parenchyma

These are lacunate tissues found frequently in aquatic plants, where large lacunae store air:  $\text{CO}_2$  and  $\text{O}_2$  for gas exchange (Figure 17).

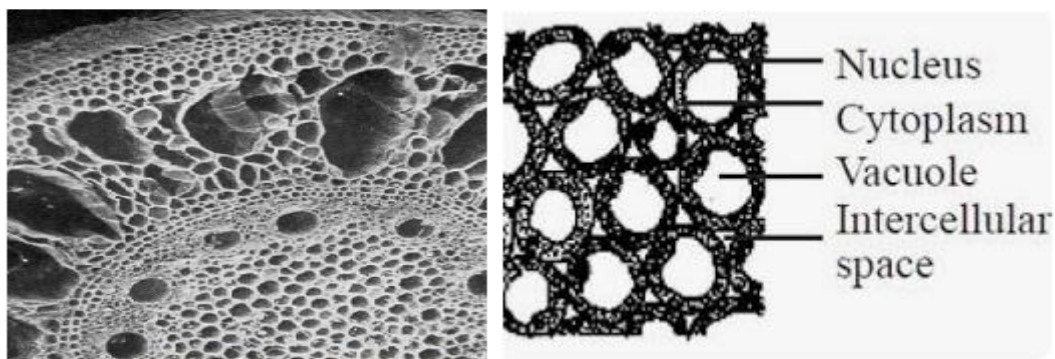


Figure 17: Aerenchymatous parenchyma

### 1.3. Protective Tissues, Surface Tissues, or Covering Tissues

These are surface and covering tissues that protect the plant against external aggressions.

#### 1.3.1. Primary Protective Tissues

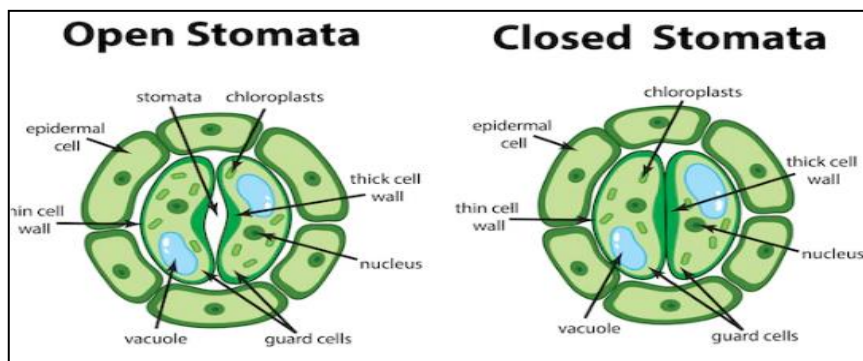
##### 1.3.1.1. Epidermis (Epidermal Layer)

The epidermis is a **primary plant tissue**, superficial and compact, formed by a continuous layer of tightly packed cells that cover the aerial portions of a plant and provide protection against desiccation and all kinds of external aggressions, while allowing gas exchange with the atmosphere.

The outer cellulosic wall of epidermal cells is often thickened or even lignified, and is covered by a highly hydrophobic lipid film (cutin and wax) constituting the **cuticle**, which

forms a protective film over the surface. In particular, waxes form a multitude of crystalline projections making the surface non-wettable. The epidermis is a living tissue interrupted by **stomatal cells** in the leaves and sometimes in hairs. However, **there are no chloroplasts**. Stomatal density is usually highest in the epidermis located on **the lower surface of leaves**, where it can reach **200 to 300 stomata per mm<sup>2</sup>**. Stomatal cells control, through their movements, exchanges between the environment and the substomatal cavity by modifying the dimensions of the ostiole. Light and low CO<sub>2</sub> levels promote opening. Conversely, drought and a water deficit cause closure (Figures 18–19–20).

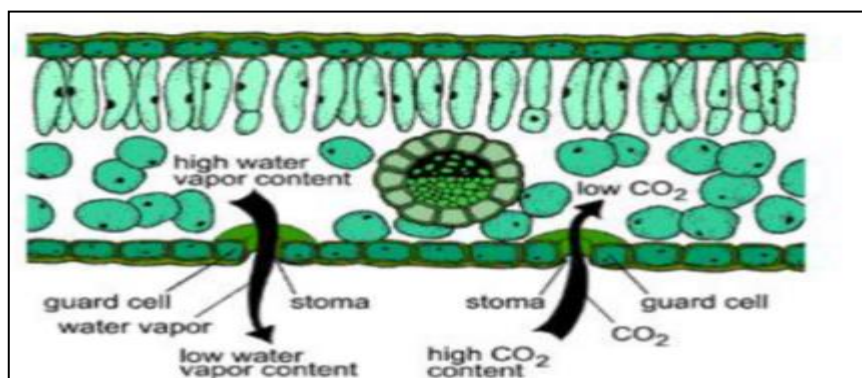
Under normal physiological conditions, a daily rhythm of opening (daytime) and closing (nighttime) is thus established, modulated at each moment by surrounding environmental conditions.



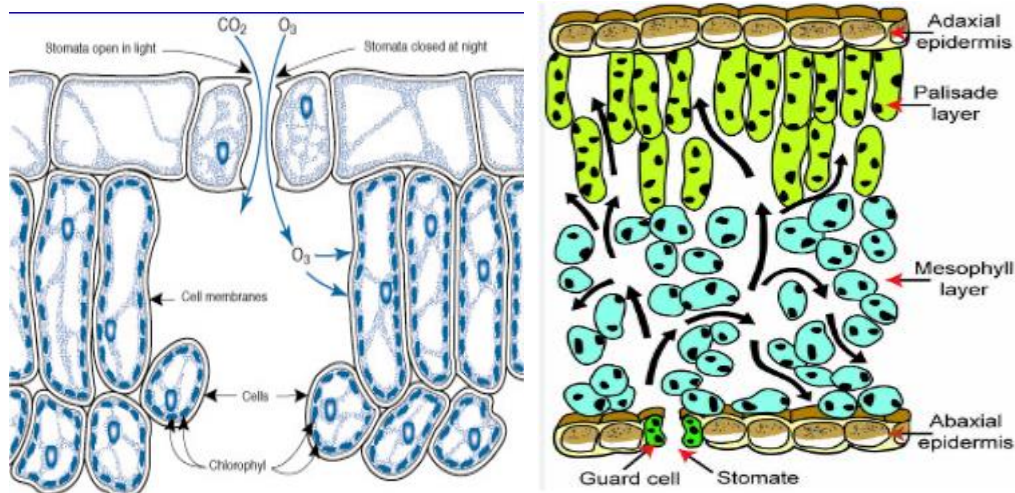
**Figure 18:** Stomatal valve movements

**Two types of stomata are distinguished:**

- a) **Aeriferous stomata**, which ensure transpiration (the loss of water as vapor).
- b) **Aquiferous stomata (hydathodes)**, which ensure guttation (the loss of water in liquid form).



**Figure 19:** Epidermal cells

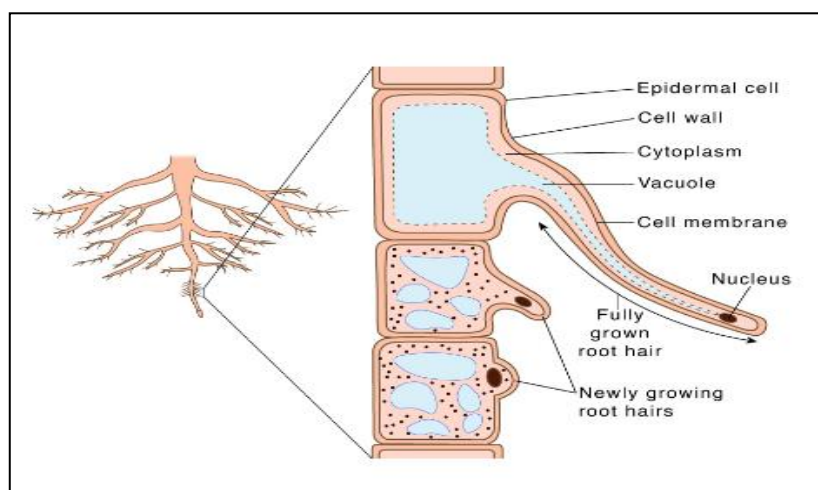


**Figure 20:** Stomata on the epidermis and the substomatal cavity.

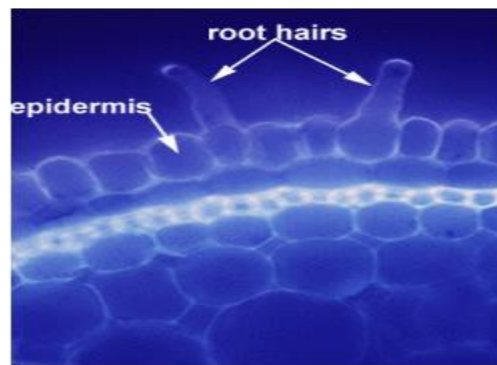
### 1.3.1.2. Rhizodermis or Piliferous Layer

This is a unistratified covering tissue of the root hair zone, with a thin cellulosic wall; it is equivalent to the epidermis of aerial parts, sometimes called the **root epidermis**. Unlike the epidermis, it **lacks a cuticle and stomata**.

When the root is young, many highly stretched and very permeable rhizodermal cells (the piliferous layer) replace the epidermal cells and form **root hairs** (hypertrophied cells in the absorbing zone) specialized in the collection of water and mineral salts present in the soil (Figure 21). Some plants bear epidermal hairs; these hairs may be unicellular or multicellular (Figure 22). They may be either secretory hairs or protective hairs.



**Figure 21:** Root hairs of the rhizodermis

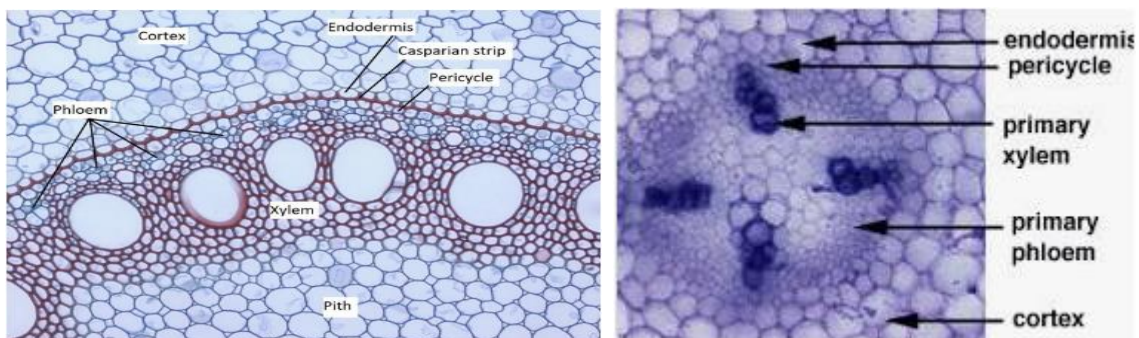


**Figure 22:** Some epidermal cells can, by elongating, form hairs.

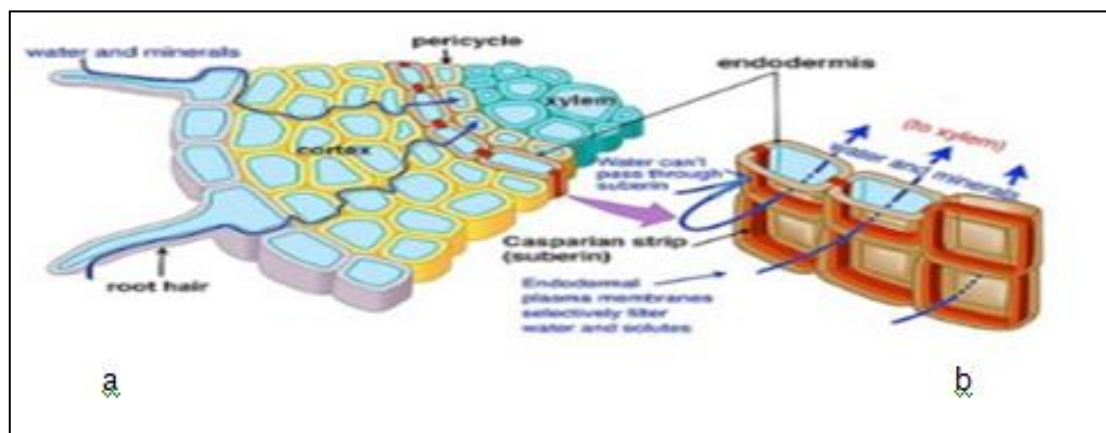
### 1.3.1.3. Endodermis

The presence of the endodermis within organs is quite variable and it is not strictly a root tissue. It corresponds to the **innermost part of the plant cortex**, in young stems and young roots, often consisting of **a single cell layer** (Figures 23 -24).

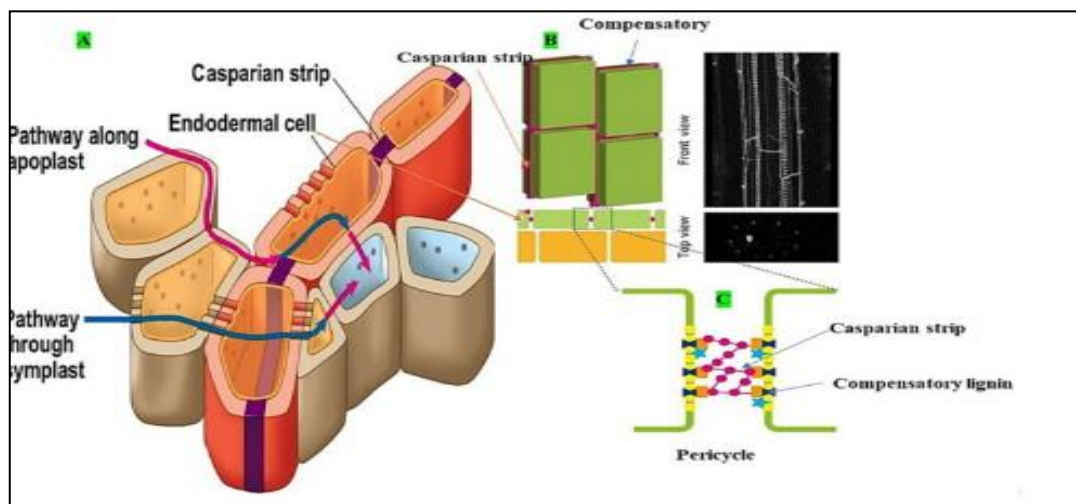
As the plant ages, the endodermis becomes increasingly lignified, forming **Casparian strips (suberin bands)**, which ensure selectivity of absorbed substances by preventing **apoplastic pathways (= permissive)** and forcing **symplastic pathways (= restrictive)**.



**Figure 23:** Endodermal cells



(a) Water and mineral salts can progress between the cells of the rhizodermis and the cortex, but they must pass through the interior of the endodermal cells due to the presence of the Casparian strip. (b) The Casparian strip forces water and dissolved minerals from the soil to pass through the endodermal cells rather than between them.



**Figure 24:** Endodermis and the Casparian strip

### 1.3.2. Secondary Protective Tissues

#### 1.3.2.1. Suber (Cork)

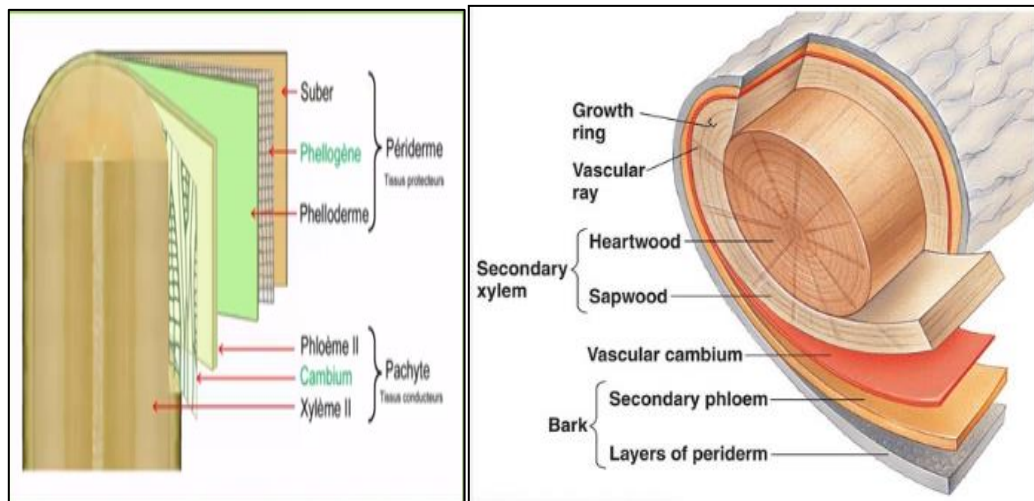
The suber (or cork) is the second replacement tissue for epidermal cells; it can also replace the piliferous layer. The suber never appears initially, but is found in organs undergoing secondary growth in thickness (on stems and roots). The formation of suber requires **suberization of its constituent cells** (cellulose becomes impregnated with suberin, causing cell death).

#### 1.3.2.2. Periderm

During secondary tissue formation, the epidermis disappears and is replaced by the **periderm**. The latter is composed of the **phellogen, phelloderm, and cork**.

**The phellogen** is the birthplace of the secondary tissues that will replace the epidermal tissues of primary growth. The phellogen develops in both directions: outward to give **cork** and inward to give **phelloderm**.

**The phelloderm** is composed of cells with a rectangular cross-section, aligned with the phellogen cells located below. It is formed by one to two cell layers maximum, with thin, typically cellulosic walls (Figure 25).



**Figure 25:** Secondary protective tissues and secondary vascular tissues

#### 1.4. Supporting Tissues / Mechanical Tissues

Supporting tissues consist of thick-walled cells, which confer a certain rigidity, especially in herbaceous plants. Supporting tissues **provide both flexibility and rigidity** to plant organs, mainly in aerial parts such as the stem and leaf.

##### 1.4.1. Collenchyma

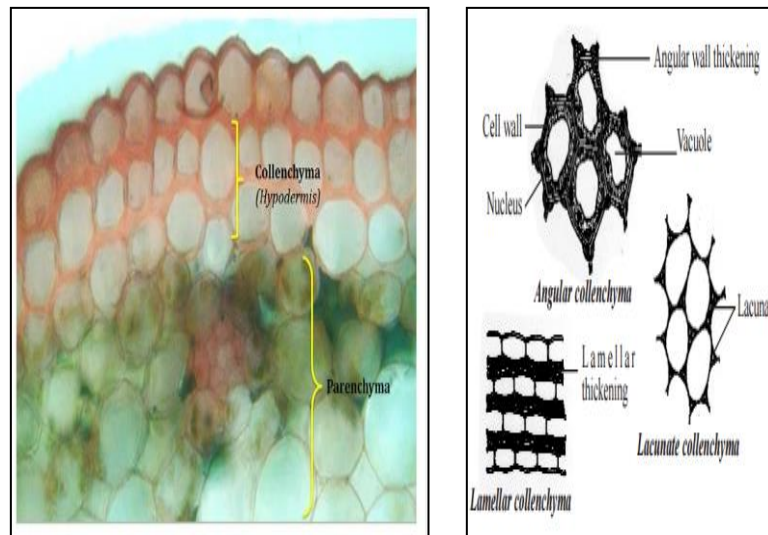
This is the living supporting tissue of **young and growing organs**, mainly aerial parts. It forms very early in a **peripheral position** (external), generally located in rings or patches beneath the epidermis of stems and petioles, or adjacent to vascular bundles in petioles or leaf blades. It is characterized by more or less elongated cells tightly packed against each other, **lacking secondary walls**, whose primary walls are thickened by cellulose deposits. This confers great resistance to bending and tension, while also giving elasticity and flexibility to the plant.

Three types of thickening can be distinguished:

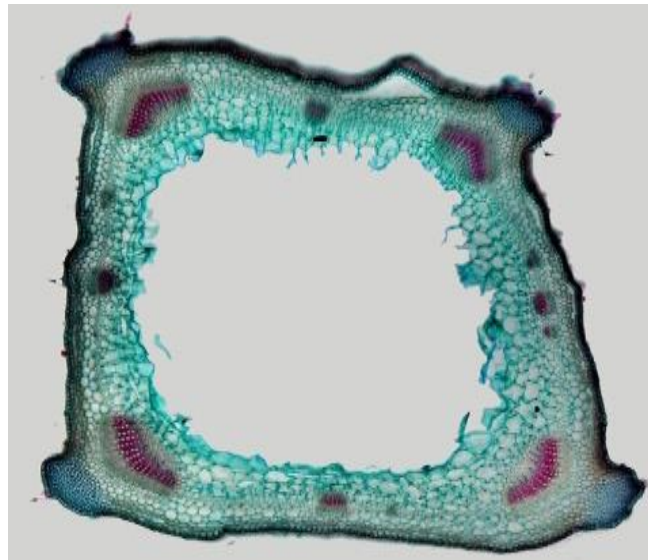
\***Annular:** cellulose deposit evenly distributed all around the wall.

\***Angular:** cellulosic thickening of the wall at the angles (Figure 27).

\***Tangential or lamellar:** thickening of tangential walls (only the walls parallel to the outer surface) (Figure 26).



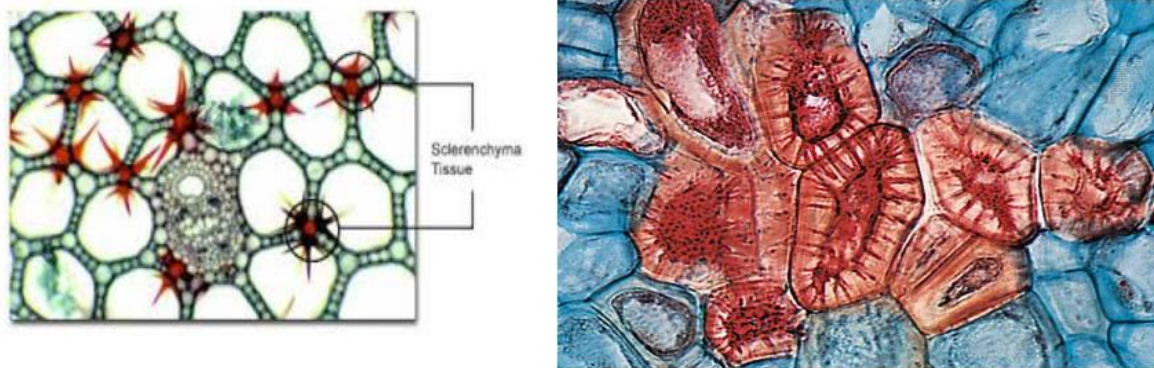
**Figure 26:** Different types of collenchyma



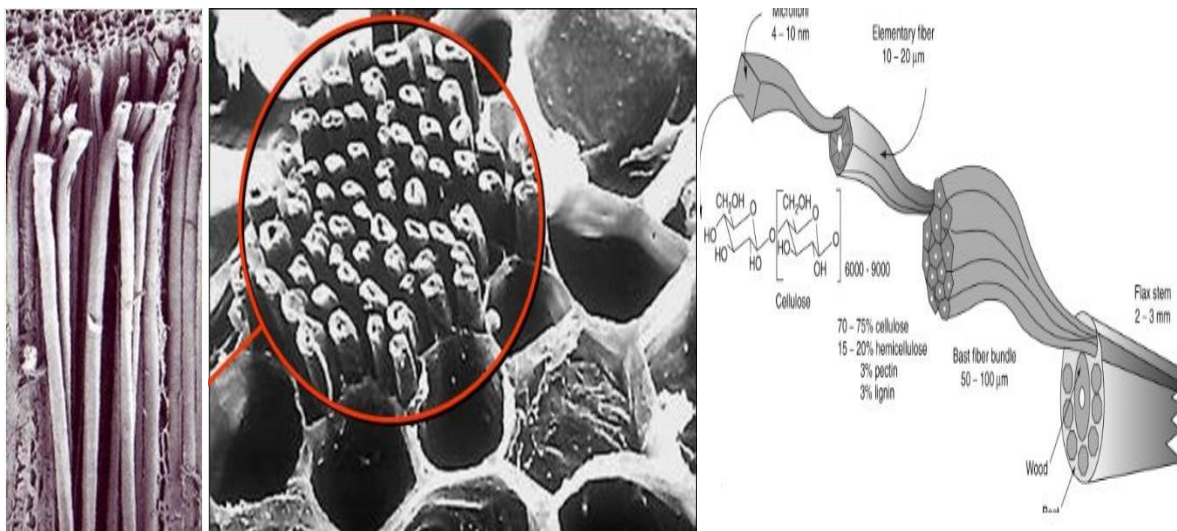
**Figure 27 :** Collenchyma (angular)

#### 1.4.2. Sclerenchyma

This is the supporting tissue of organs **whose elongation is complete**. It is a fairly diverse group of supporting cells, or **sclerocytes**, sharing the property of producing a particular type of wall that confers great hardness — "**stone cells**." Sclerenchyma is generally found deeper than collenchyma (Figure 28). It is a primary tissue consisting of **dead cells** whose walls are thickened by lignin deposits (thick, rigid secondary wall impregnated with lignin in the form of fibers), conferring hardness and rigidity to the plant. Sclerocytes form a ring or bundles and are widely distributed in vascular plants and in organs adapted to drought (Xerophytes). Outside of wood, they constitute the hardest and toughest territories of the plant: seed coats, fruit pits, thorns and spines of leaves and stems.



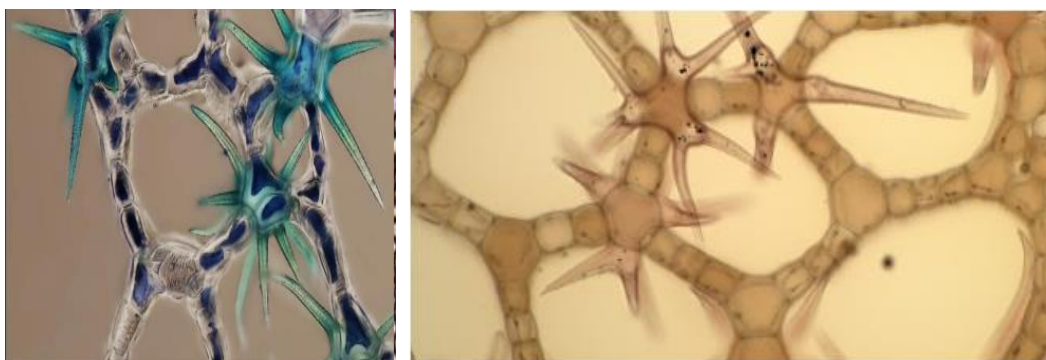
**Figure 28: Sclerenchyma**



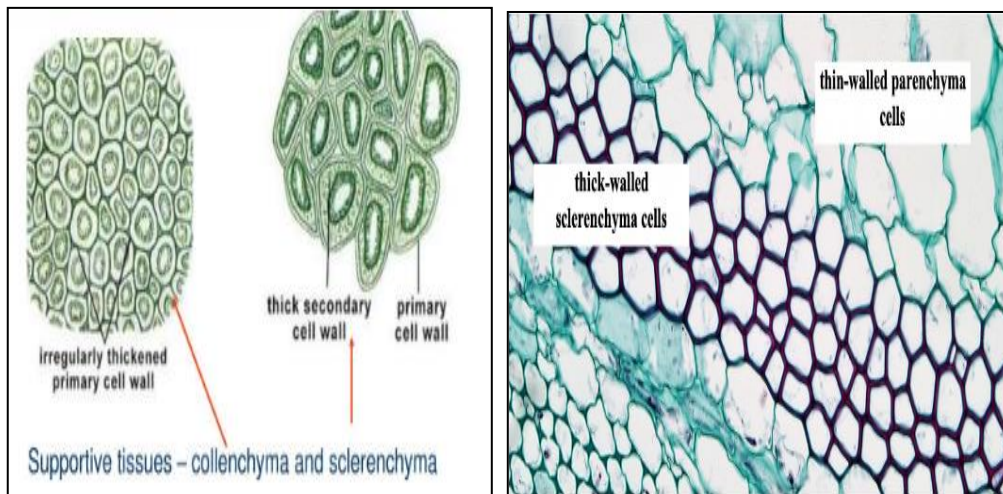
**Figure 29: Sclerenchyma cells grouped in bundles forming plant fibers (Each cell may be a few mm in length).**

The cells of the sclerenchyma are often grouped in bundles forming **plant fibers** (Figure 29). When these cells have irregular shapes, they are called **sclereids**.

**NOTE: Sclereids** are short cells of variable, often star-shaped forms, isolated in parenchymas, grouped in clusters or in continuous layers. They ensure the rigidity or consolidation of organs (Figure 30).



**Figure 30: Sclerenchyma cells of irregular shape (Sclereid)**



a/ Collenchyma cells; b/ Sclerenchyma cells

**Figure 31:** Supporting tissues

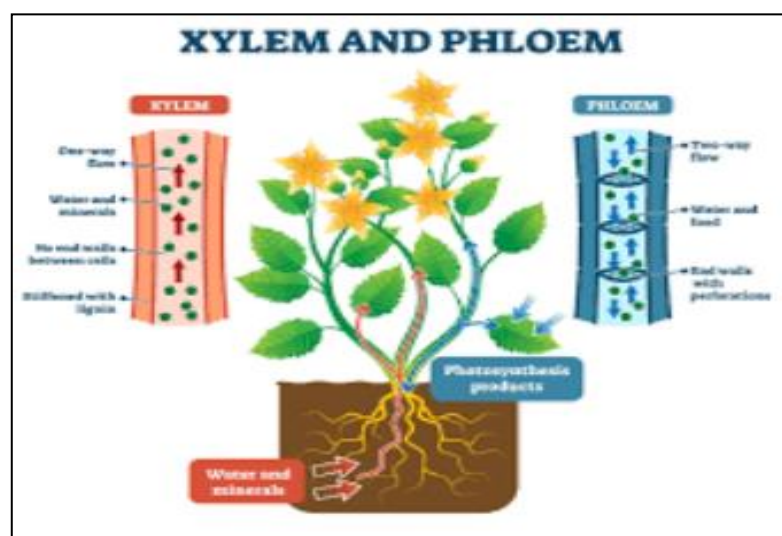
**NOTE:** In plants with significant secondary tissues, such as trees, the supporting role is no longer carried out by either collenchyma or sclerenchyma, but by secondary vascular tissues.

## 1.5. Vascular Tissues

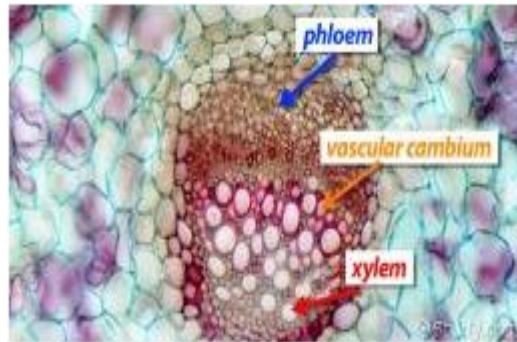
### 1.5.1. Primary Vascular Tissues

In Angiosperms, there are 2 types of vascular vessels: **phloem** and **xylem**. The cells of vascular tissue are long cells arranged end to end, forming long columns. These cells allow the passage of sap throughout the plant organism (Figures 32–33).

- **Xylem** conducts **raw sap** (water + mineral salts) drawn from the soil by the roots, to the photosynthesizing organs.
- **Phloem** conducts **elaborated sap** (organic substances from photosynthesis) to all organs of the plant.



**Figure 32:** Circulation of sap in the xylem and phloem



**Figure 33:** Xylem and Phloem

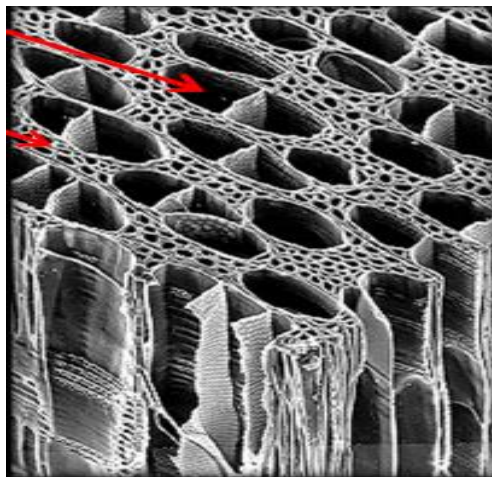
Primary **xylem** and primary **phloem** are the two types of primary vascular tissues in herbaceous plants. They are grouped into bundles (sets of thin, elongated, and bound tubes). A vascular bundle (criblé-vascular bundle) is the combination of xylem and phloem.

#### 1.5.1.1. Xylem

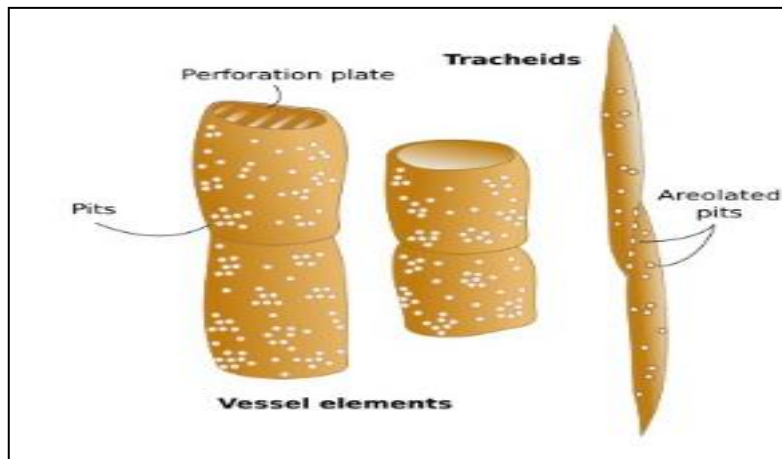
This is the vascular tissue that conducts raw sap. The cells have regularly thickened and lignified walls. It is composed of two types of conducting cells (Figures 34-35):

**1.5.1.1/ a- Tracheids:** These are dead, elongated, parallel cells, less rich in lignin. Their ends are beveled, and sap circulates via perforations and pits in a **zigzag pattern (tortuous/chicane circulation)**.

**1.5.1.1/ b- Tracheae (vessels):** These consist of dead cells, fairly wide and shorter than those of tracheids, arranged in parallel. Their ends are open and sap **circulates freely in the vertical direction**.



**Figure 34:** Xylem cells



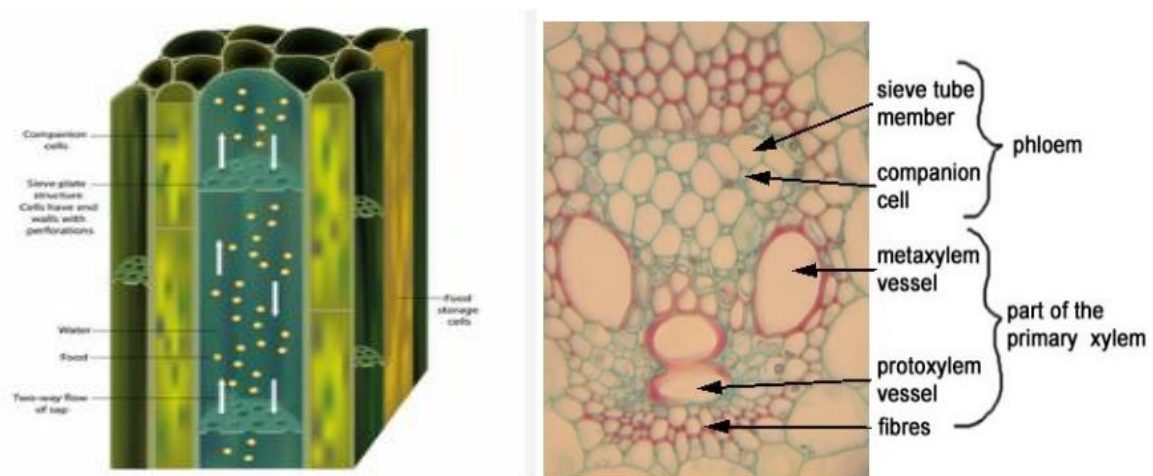
**Figure 35:** Xylem elements

### 1.5.1.2. Phloem

It primarily ensures the circulation of **elaborated sap**, that is, sap enriched with substances from photosynthesis. This vascular tissue is composed of small **living cells** with slightly thickened cellulosic walls (Figure 36).

**1.5.1.2/a- Sieve tubes:** These are living cells **lacking a nucleus** but having retained their cellulosic wall and cytoplasm; they are elongated longitudinally and arranged end to end. They have a thick pectocellulosic wall. The transverse walls are riddled with pores called **sieves**, allowing sap to transit.

**1.5.1.2/b- Companion cells:** These are living cells **with a nucleus**. They are narrow and elongated. Considered associated with sieve tube cells, they communicate with each other **via plasmodesmata**, thereby performing all the necessary functions that the sieve tubes can no longer fulfill, and participating in the control of sap circulation at their level.



**Figure 36:** Phloem cells

1.5.2. Secondary Structure

Xylem and phloem are closely associated and form the vascular system that ensures correlations between the different parts of the plant. A generative zone called the **vascular cambium (libero-ligneous cambium)** forms between the primary xylem and primary phloem; its differentiation gives rise to secondary vascular tissues called: **secondary xylem (wood: annual rings)** directed toward the **interior (rhythmic centripetal growth)** and **secondary phloem (bast: flattened cells, like the pages of a book)** directed toward the **exterior (rhythmic centrifugal growth)**.

These secondary vascular tissues are responsible for the transport of raw sap and elaborated sap in the plant. They are present in the older organs of dicotyledonous Angiosperms (stem, leaf and root) and also serve a supporting role. (Figures 37–38–39)

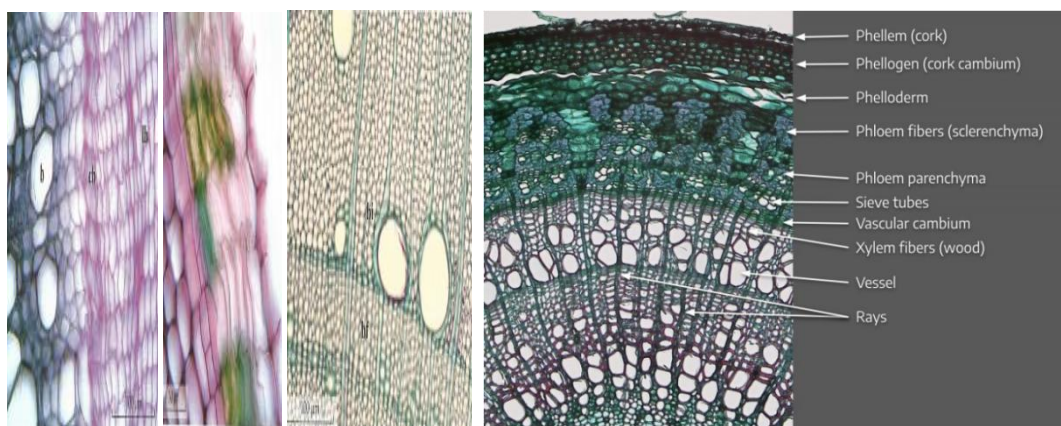


Figure 37: Representation of a/ phellogen and cork, b/ cambium, c/ phloem (wood)

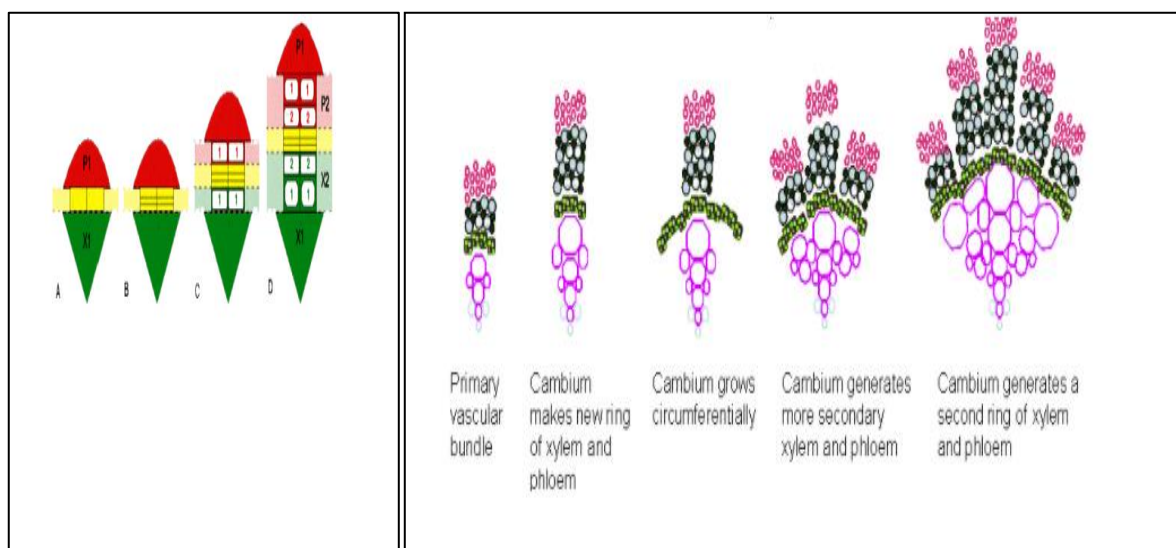
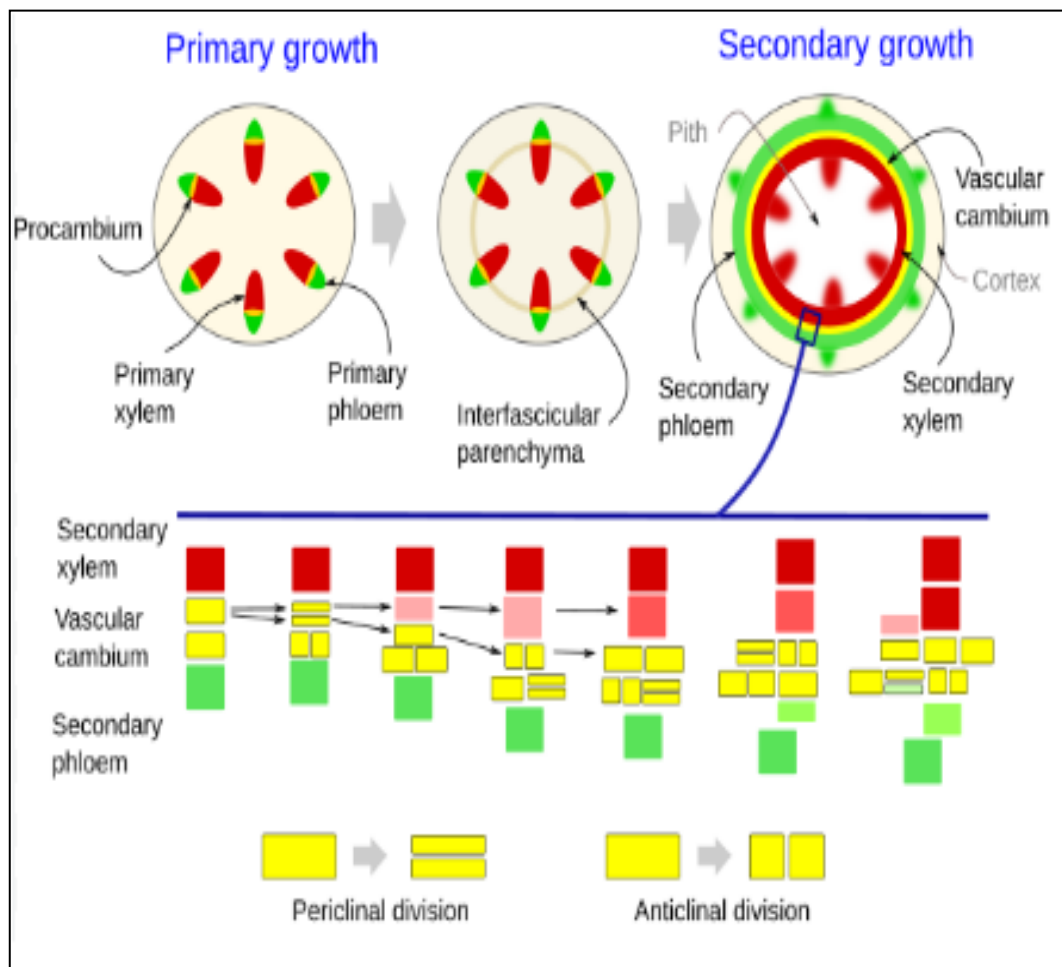


Figure 38: Functioning of the vascular cambium (stem)



**Figure 39:** Functioning of the cambium in the formation of secondary structure

### 1.6. Secretory Tissues

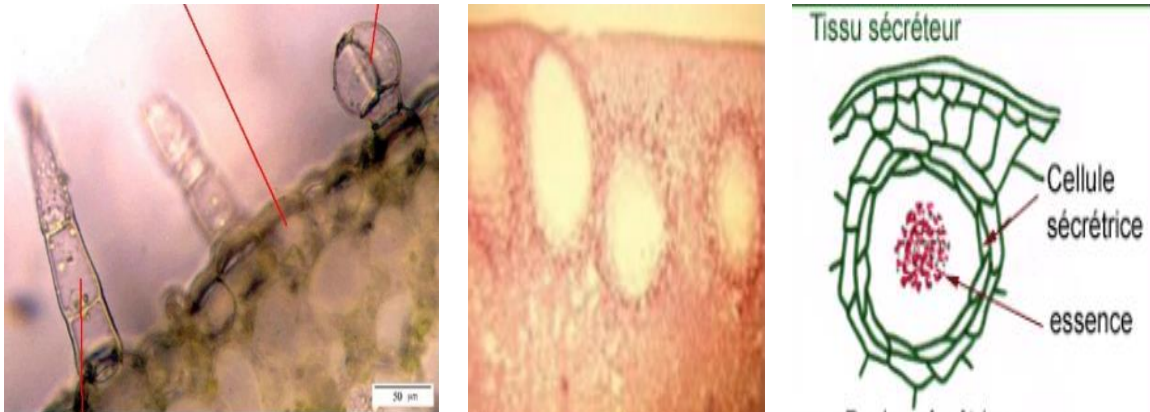
These correspond to secretory canals or hairs, secretory cells, cavities or storage parenchymas. They are highly varied in both form and mode of release, and can be located in all tissues.

Some cells isolated in parenchyma or grouped in cavities or tubes synthesize substances (Figure 41). They may either store the products or secrete them into plant organs, such as volatile essences that produce the fragrances of certain plants (rose petals, thyme, rosemary).

These tissues may accumulate the synthesized products within their own cells, or expel them into cavities formed within the organs. Two categories of secretory tissues can be distinguished (Figure 40):

-**External secretory tissues** such as the **epidermis** and **secretory hairs**.

-**Internal secretory tissues** such as secretory cells: isolated within parenchymas (e.g., tannin cells); cavities, which are spherical spaces located in the parenchymas of leaves, stems, and fruits of certain species (e.g., orange peel, mandarin, lemon pericarp, and resins from pine leaves and stems); and secretory canals.



**Figure 40:** A/ Secretory hair (External secretory tissue); B/ Schizolysigenous secretory cavity of Citrus fruit (Internal secretory tissue)

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