Plant growth and development

Growth is a progressive or irreversible increase in **mass**, **weight** or **volume** of an **organism**, **organ** or **cell** as expressed in terms or units of **length**, **volume**, **weight** or **area** is (**quantitative**).

Differentiation is a term given to describe any case in which the meristematic cells are transformed into two or more types of cells, organs or tissues different from each other in shape, structure or function, (**qualitative**).

Development is the irreversible change in state such as embryogenesis, juvenile, adult vegetative and adult reproductive.

So

Development is a term given to describe the overall quantitative and qualitative changes of an organism during its life cycle.

Places of Growth

- **In single cell organisms:** Increase of protoplasm → cell enlargement → division.

- **In multicellular organism** such as higher plants; growth takes place in meristematic regions only.

The components of growth at the cell level

The components of growth at the cell level are:-

1. Cell **Division.**
2. Cell **Enlargement.**
3. Cell **Differentiation.**

1. Cell division

Cell division occurs in Meristematic Cells (Stem Cells).

- **Primary** (at the end, or tip, of each growing stem and root)
  - ➢ **Shoot Apical Meristem** (SAM).
  - ➢ **Root Apical Meristem** (RAM).

- **Secondary**
  - ➢ **Axillary Buds.**
  - ➢ **Vascular Cambium** (produces vascular tissue, increases the thickness of stems over time; is between xylem & phloem).
  - ➢ **Cork Cambium** (produces the outer covering of stems).
  - ➢ **Pericycle** (root).

2. Cell Enlargement

Cell Enlargement occurs in cells adjacent to meristems.

- **Internode growth - Shoot.**
- **Zone of Elongation – Root.**

- **Turgor Pressure.**
  - H_2O Uptake.
  - Cell Wall Loosening.
  - new cell walls.

3. Cell Differentiation

Cell Differentiation:-

- **Cessation of Cell Enlargement.**
- **Secondary cell walls.**
  - Xylem - Vascular tissue
  - Fibers
- **Epidermal cells.**
  - root hairs
  - leaf hairs
  - guard cells
- **Leaves, Flowers.**
- **Fruit, Tubers, Bulbs, etc.**

Types of meristems

1. **Apical meristem:** growth in length is restricted to the tip (e.g. stem and root)
2. **Lateral meristem:** result in secondary growth (or radial growth). Two type of cambium are involved: **vascular cambium** and **cork cambium.**
3. **Intercalary meristem:** meristems are embedded between differentiated tissues (leaf axil and bases of internodes).

Types of Growth

- **Indeterminate growth:** is the ability to divide and grow for a long time as in stem and root. This type of growth is also called **Indefinite** or **Unlimited** growth**.**

- **Determinate growth:** Division stops at maturity as in leaf, flower and fruit. This type of growth is also called **Definite** or **limited** growth.

Patterns of Growth

- **Annuals:-** plants grow from seed to maturity; flower; produce seeds; and die all in the period of one growing season such as marigolds, corn, and peas plants.

- **Biennials:-** plants that usually live for 2 years. During the first growing season, they grow roots, stems & leaves and in the second season, they produce flowers, and thus seeds such as sugar beets, carrots and turnips plants.

- **Perennials**; plants that live for more than two year like trees and shrubs, because they live for indefinite periods of time .

  1- Woody plants.

  2- Herbaceous.

Monocarpic and Polycarpic

- **Monocarpic:-** plant flowers and produces seeds only once before dying.

- **Polycarpic:-** plant reproduces seeds more than once in its lifetime.

- **Monocarpic perennial:-** plant lives for two or more years, then flowers once, sets seed and dies.

- **Polycarpic perennial:-** lives for a number of years, often very many years, flowering and setting seed annually throughout its life.

Xylem Growth

The new ring of xylem tissue formed during every growing season, plus the older xylem, become the **wood** of trees.

- **Sapwood:-**xylem is called **sapwood** as long as it conducts water (young wood).

- **Heartwood:-** with-time, the xylem becomes "clogged up" with tars, resins, etc. and is no longer able to conduct water, at this time called **heartwood** (old wood).

- **Annual rings** are formed because **large xylem** cells form during the **spring**, and **smaller xylem** cells form during late summer and fall, the large cells of **spring** wood look "**lighter**" than the **smaller** cells of **summer wood**.

Q. Why the phloem layer is thinner than that of the xylem in trees?

- The phloem layer, never becomes as thick as the xylem because the cambium makes only 1 phloem cell for every 6-8 xylem cells and phloem has thin walls; crushed as the stem grows thicker.

Methods of measuring growth

1. **Length:** for organs growing in one direction such as shoot and root.

2. **Dry weight:** good but not suitable for etiolated plants.

3. **Fresh weight:** used in some cases, but it is variable with time.

4. **Area:** useful for organs that grow in two directions like leaves.

Factors affecting growth and development

- **Internal factors:** such as genetic factor, hormones, age, nutritional status.

- **Ecological (external factors):** such as temperature, photo period and intensity, water availability…etc.

Growth Kinetics

- Rate of growth is not constant during the life cycle of an organism.

- **Theoretically**, in single cell organisms , such as bacteria , yeasts, grown under fixed ecological and nutritional condition, the rate of **cell division** is expected to **be constant** (i.e. the no. of cell is **expected to increase exponentially**).
- **In reality**, several factors limit the growth such as nutrient deficiency or production of toxic substances during growth.

Therefore, the growth follows a **sigmoid curve**, which also applies for multicellular organisms.

Sigmoid Growth Curve

1. Sigmoid curve with respect to time, the curve can be divided into:-

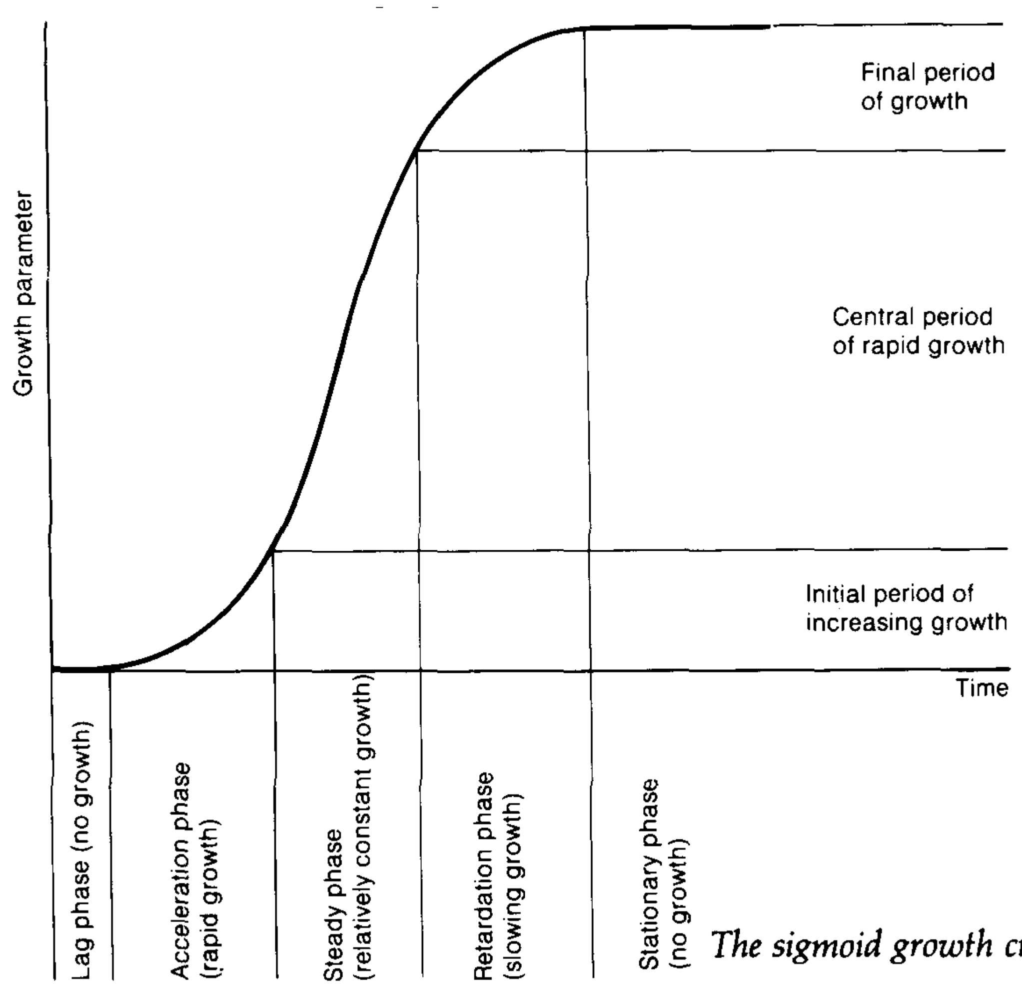
1- Lag phase.

2- Acceleration phase.

3- steady phase.

4- Retardation phase.

5- Stationary   phase.



The sigmoid growth curve

Sigmoid Curve

2. Sigmoid Curve: with respect to growth rate, the curve can be divided into:-

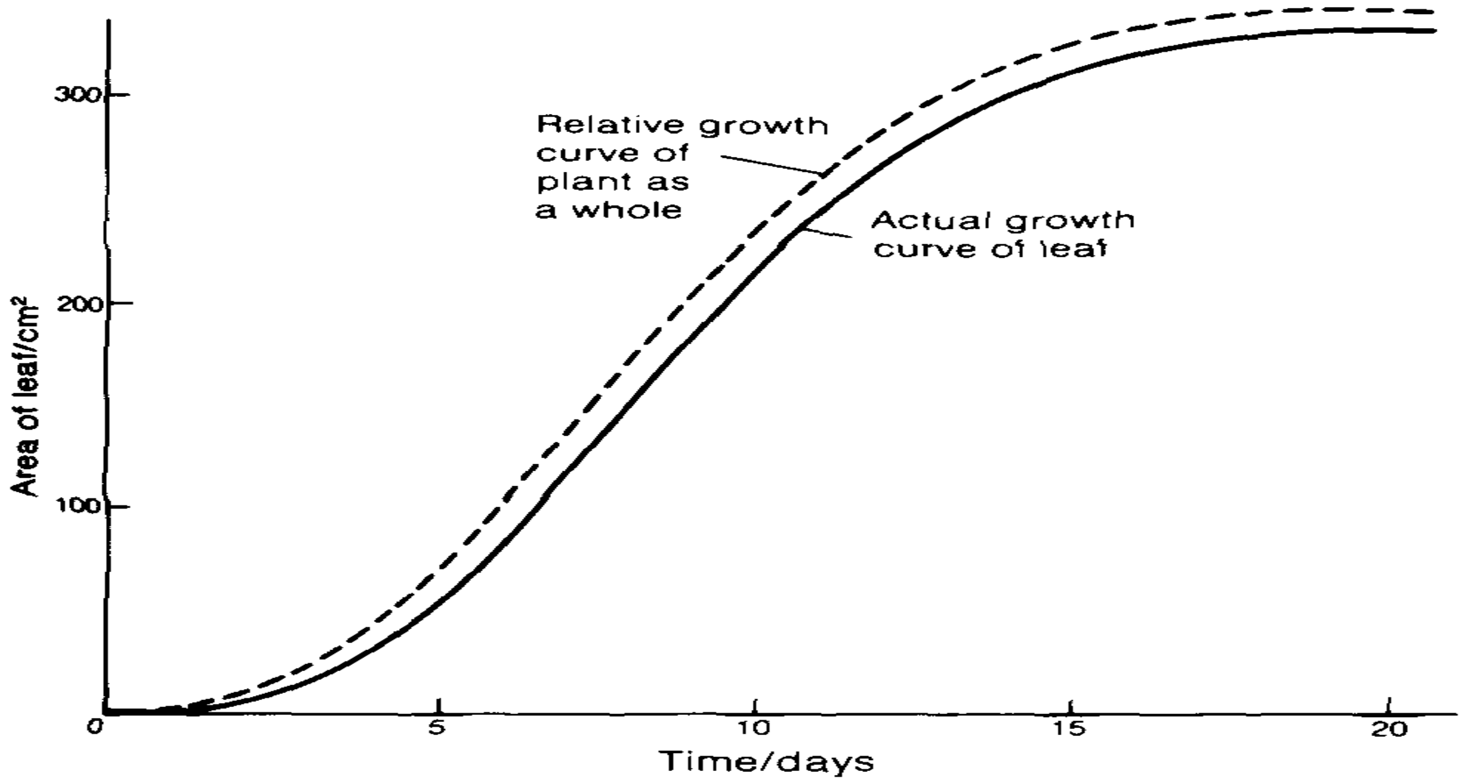
A. Initial period of increasing growth:- slow growth at first, because there are so few cells that even when dividing rapidly the actual increase in size is small.

B. Central period of rapid growth:- as the number of cells becomes larger, the size increases more quickly because more cells carry out division.

C. Final period of growth:- a limit to rapid growth due to genotype, external factors like food. Growth rate decreases and stops when no. of cell dividing = no. of cells dying.

Growth Curves

1- Isometric growth curve; e.g. leaves of most plant grow at the rate as the organism as a whole.



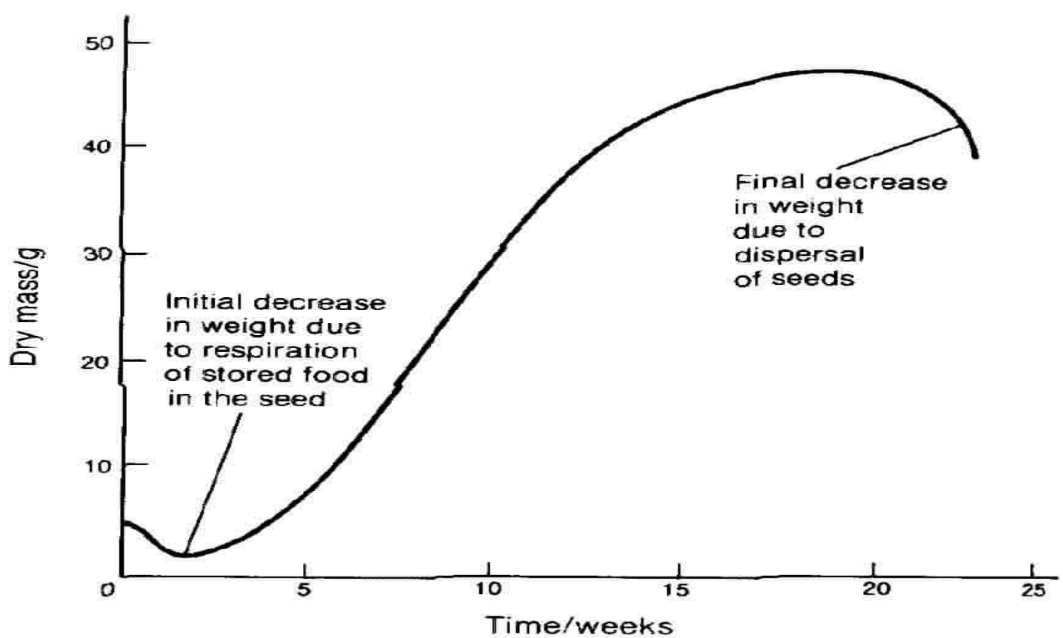
Isometric growth as shown by a cucumber leaf

2. Annual plant growth (Limited Growth Curve).

1- **Initial negative growth** during germination due to respiration of food reserves in the seed;

2- **Positive growth** started because green leaves have grown above ground and photosynthesis is faster than that of respiration.

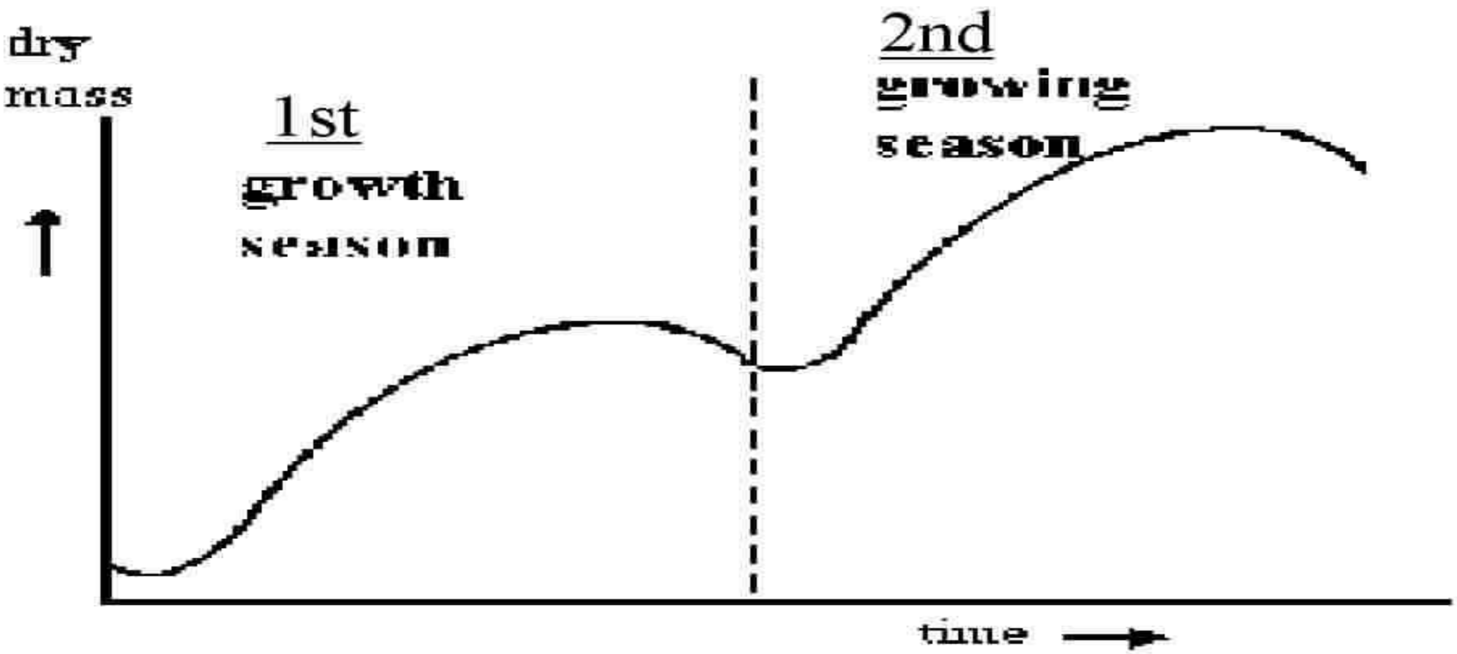
3- **Final decrease** in dry mass due to the dispersal of fruits and seeds a typical S-shaped (**sigmoid**) curve.



Annual plant growth curve, e.g. Pea

3. Biennial plants:

- 1st season: produces green leaves, photosynthesis occur, food stored underground and at the
- 2nd season, stored food is used to produced flowers & seeds. Growth curve: 2 sigmoid curves joined together, example: carrot.



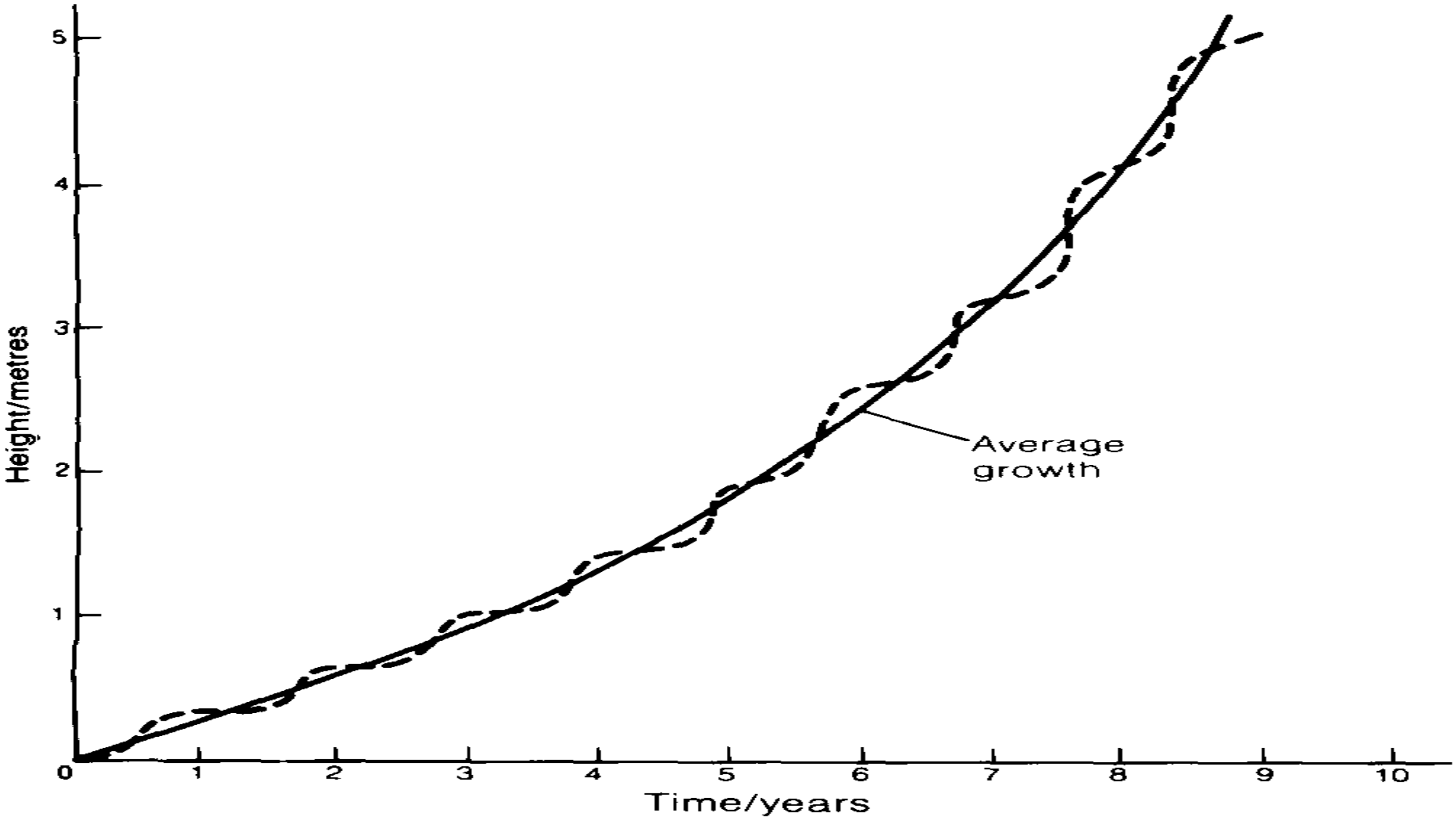
Growth Curve of A Biennial Plant

4. Perennial Plant Growth Curve: may live for many years, two types:- herbaceous and woody.

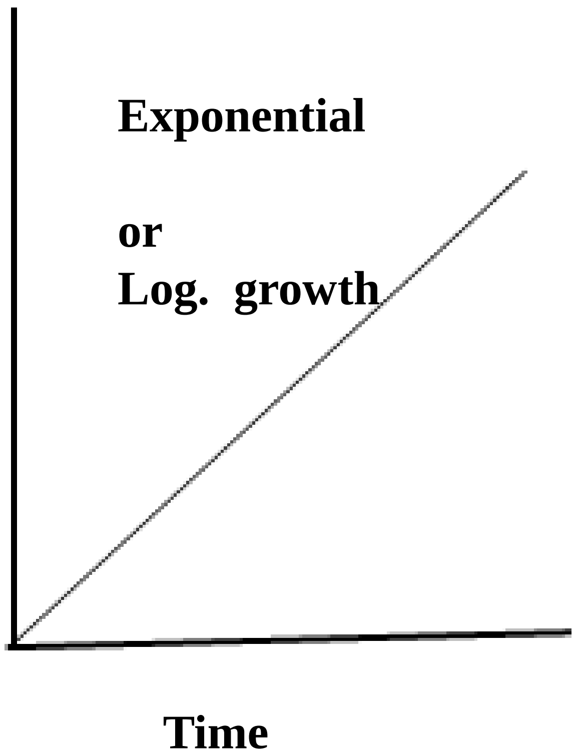
- **herbaceous perennials**, the aerial shoots die away in autumn but develop underground storage organs (**perenating organs**) to survive the winter, e.g. tubers.
- **woody perennials**, they persists above ground throughout the year; grow continues from year to year, e.g. trees.

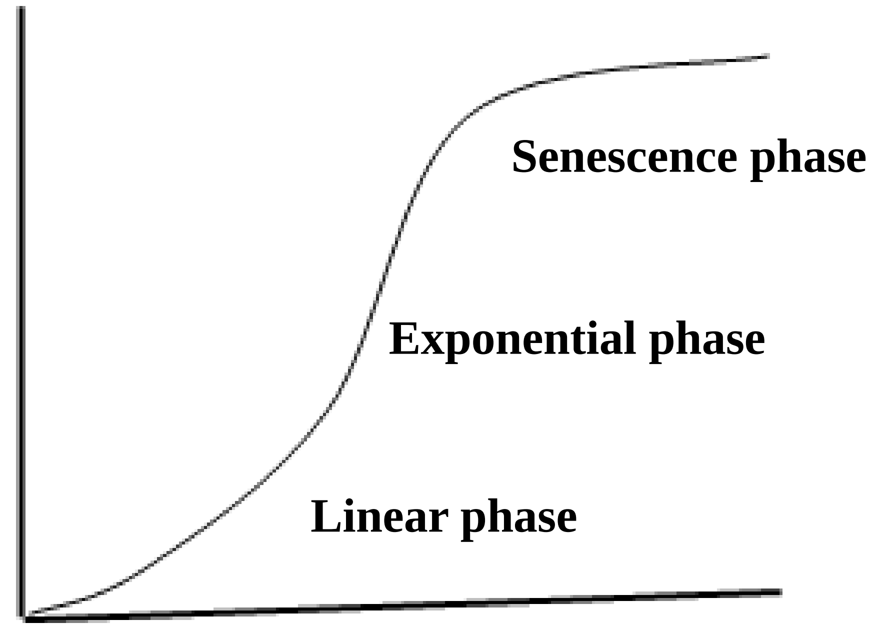
Growth curve: a cumulative series of sigmoid curves, each of which represents one year's growth .Variations occur from year to year according to environmental conditions: cold dry year has less growth than a mild wet year.

The annual growth follows a normal sigmoid curve. Variations occur from one year to the next according to environmental conditions. In a cold dry year for example there will be less growth than in a mild, wet one.



Perennial plant growth curve





Sigmoid growth curve

Absolute growth rate=Amount of growth per unit time.
Relative growth rate = Amount of growth per unit time per unit area.

Factors should be available for plant normal growth

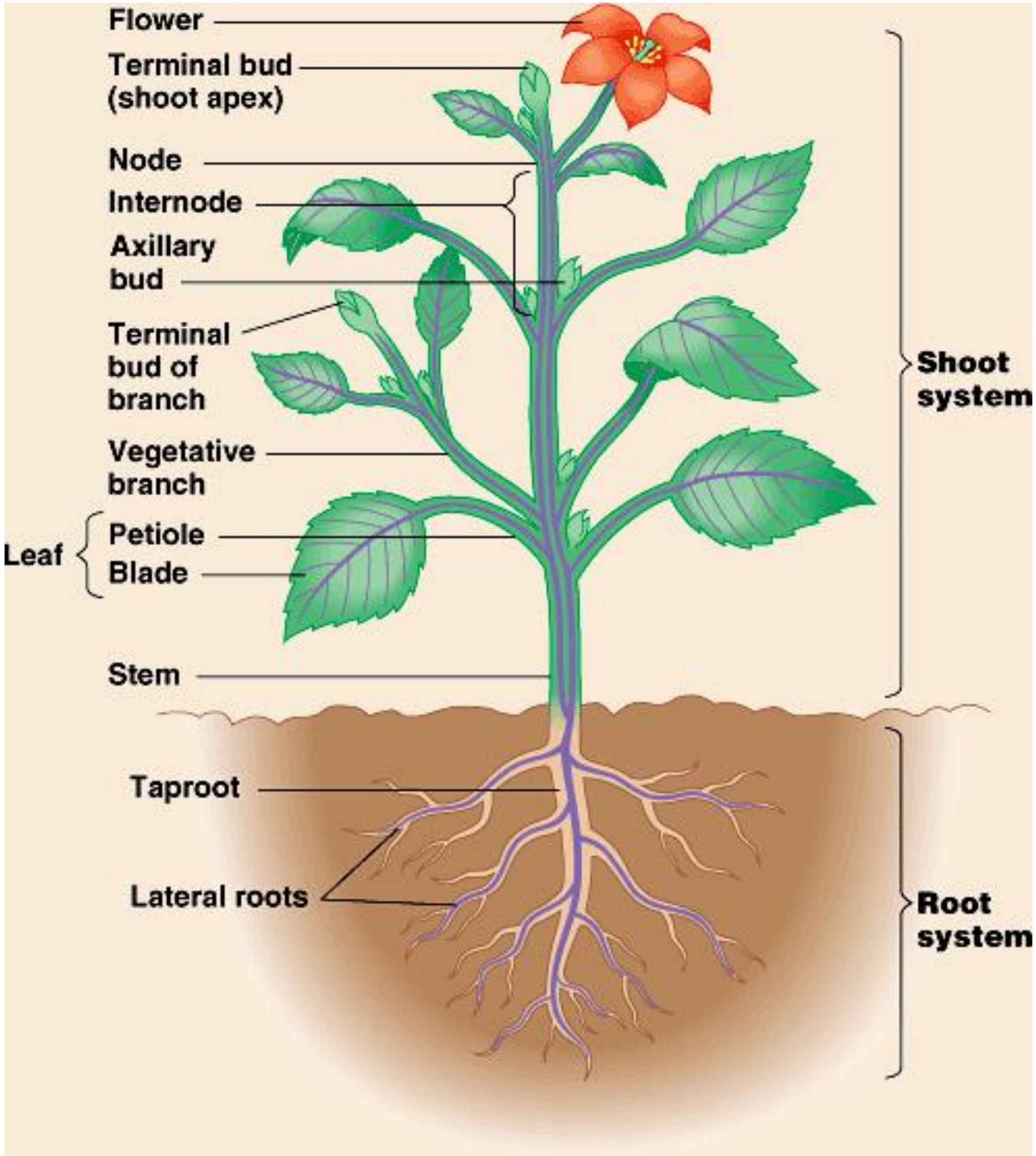
1. **Raw materials:** includes essential elements, water, CO_2, O_2 *etc*.

2. **Building blocks:** includes carbohydrates, proteins, amino acids, fatty acids.

3. **Energy sources:** such as inorganic phosphates, turgor pressure... *etc*.

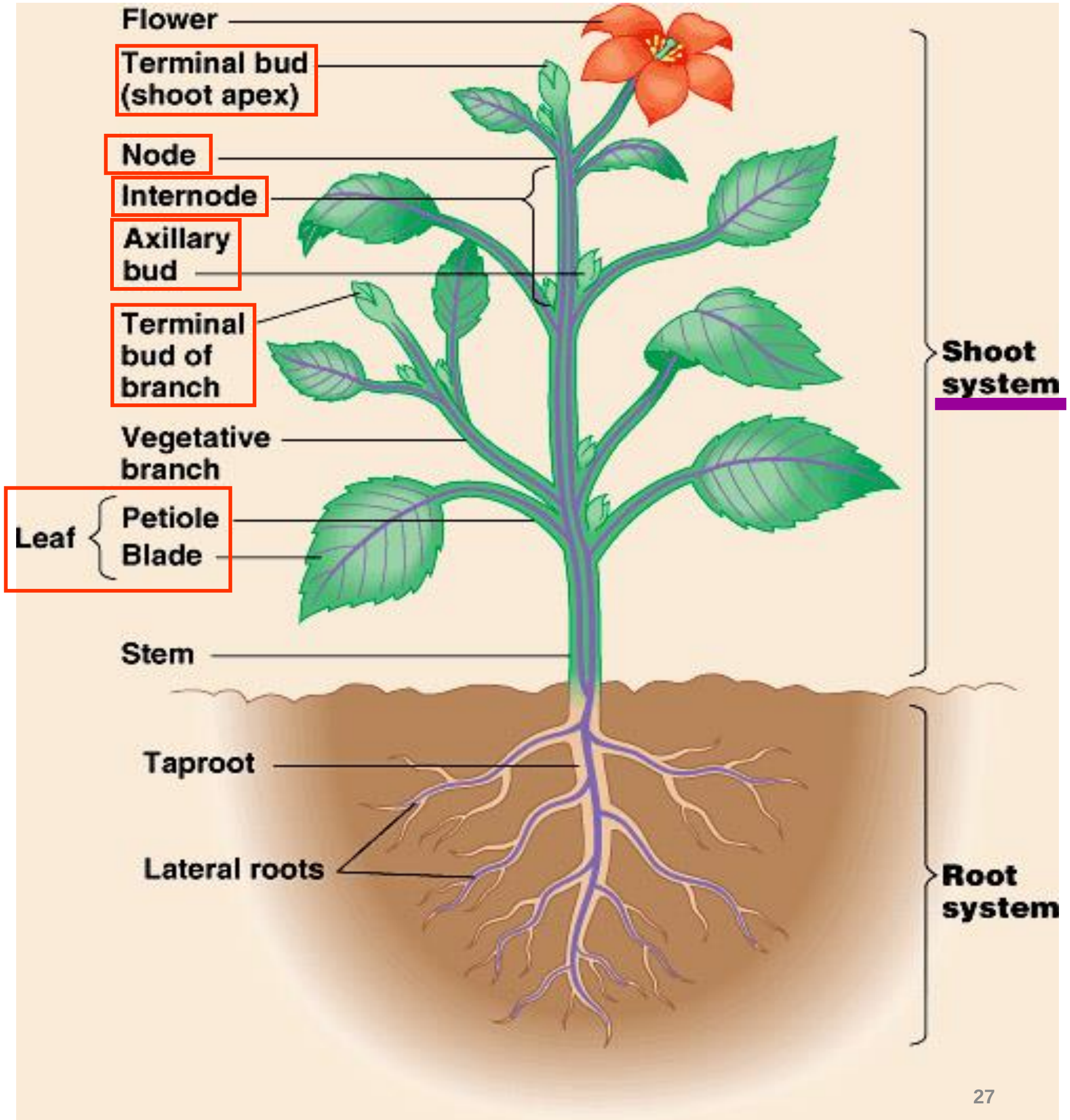
4. **Catalysts:** such as enzyme and co-factors.

Organ systems of flowering plants



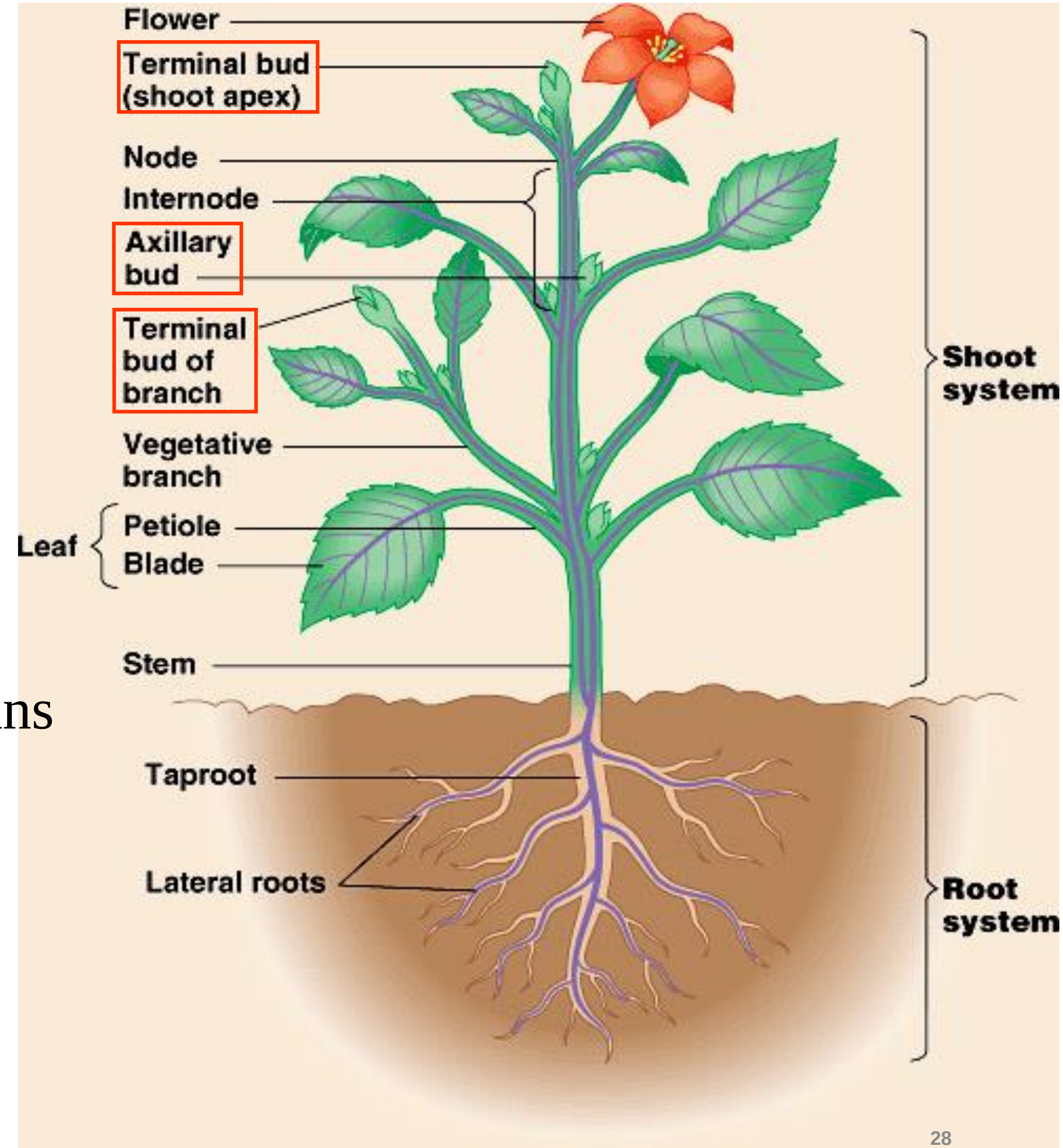
Organ systems of flowering plants

Terminal buds generally exercise apical dominance over axillary buds



Organ systems of flowering plants

- Undifferentiated meristematic cells occur in buds
- Whole plant growth is indeterminate
- but growth of some organs is determinate

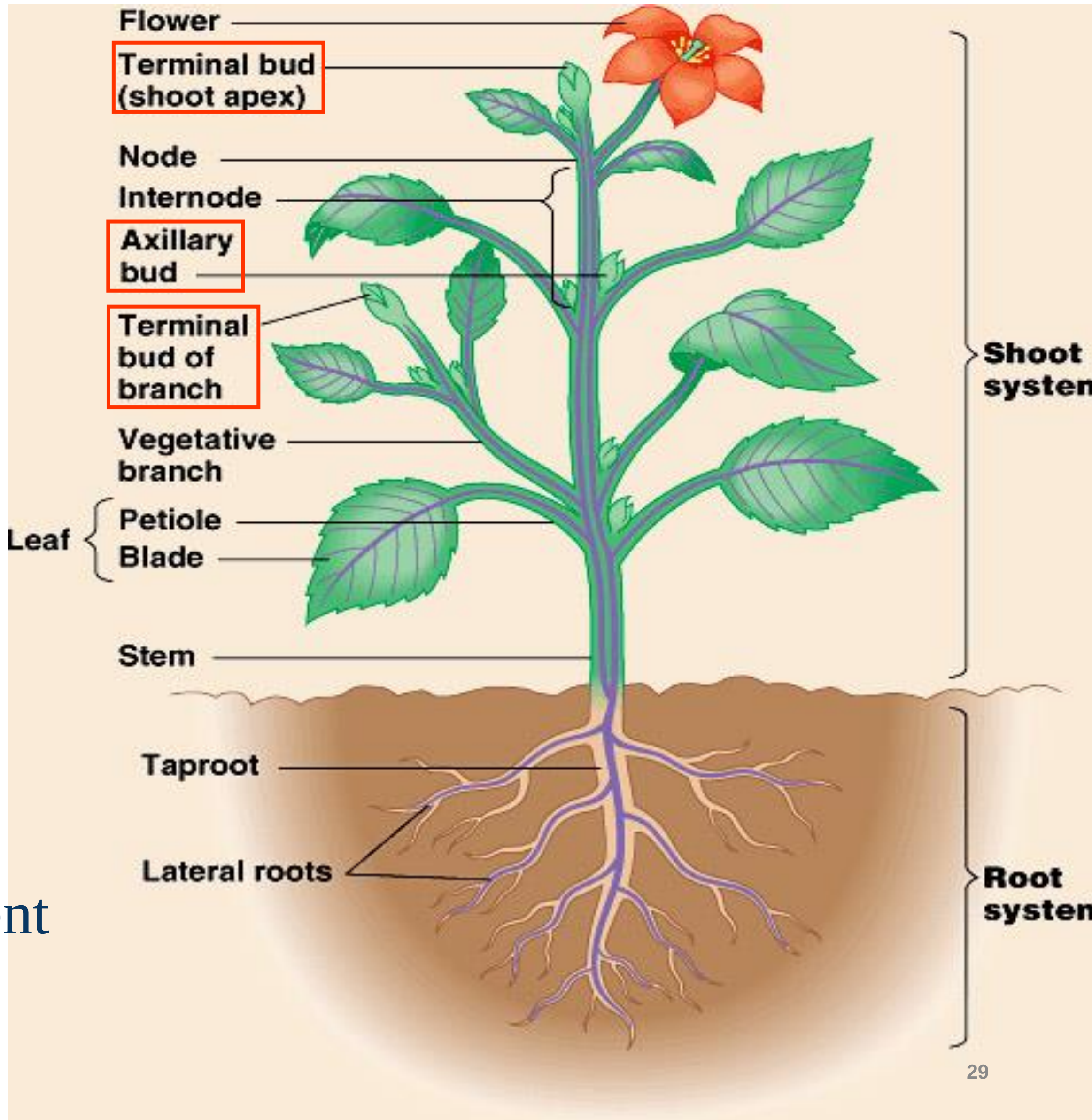


Organ systems of flowering plants

When a cell divides, the daughter cells grow…

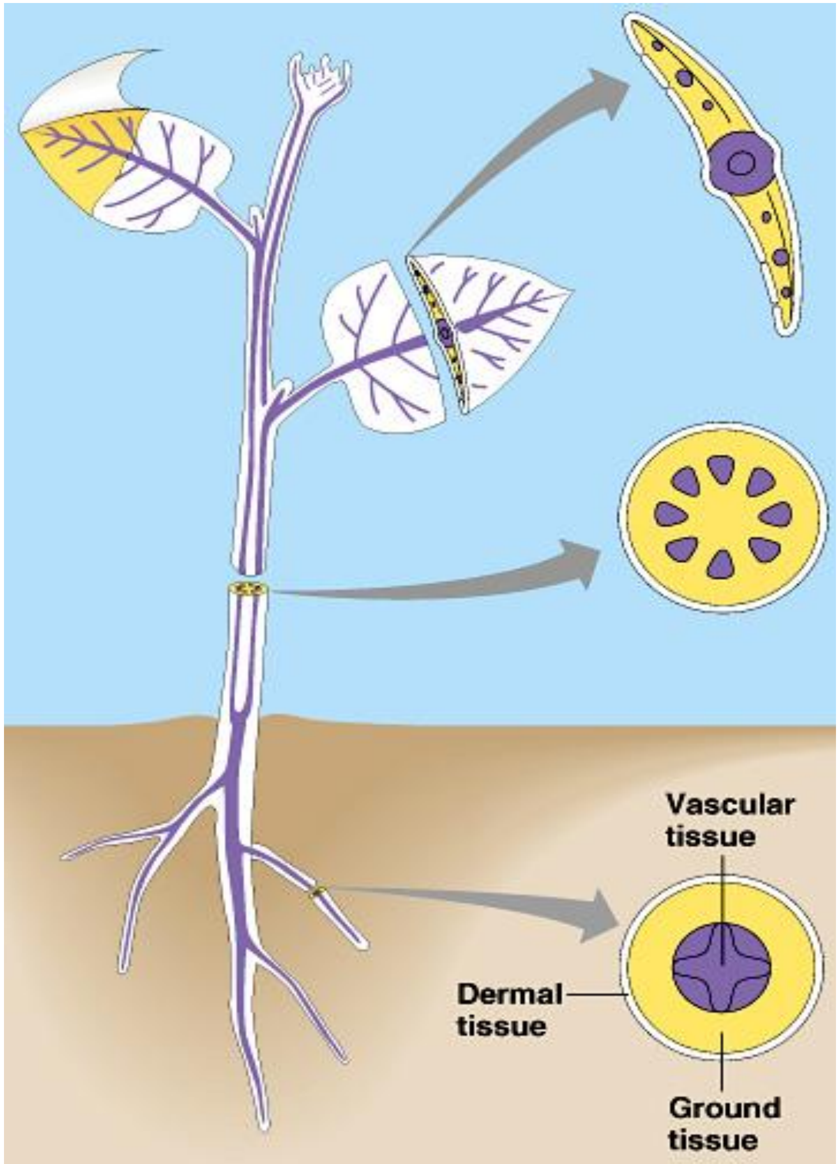
and they may differentiate (specialize),

depending especially on where they are located during development



Differentiated cells contribute to 3 tissue systems

1. **Dermal tissue.**
2. **Vascular tissue.**
3. **Ground tissue.**



1. Dermal tissue (epidermis)

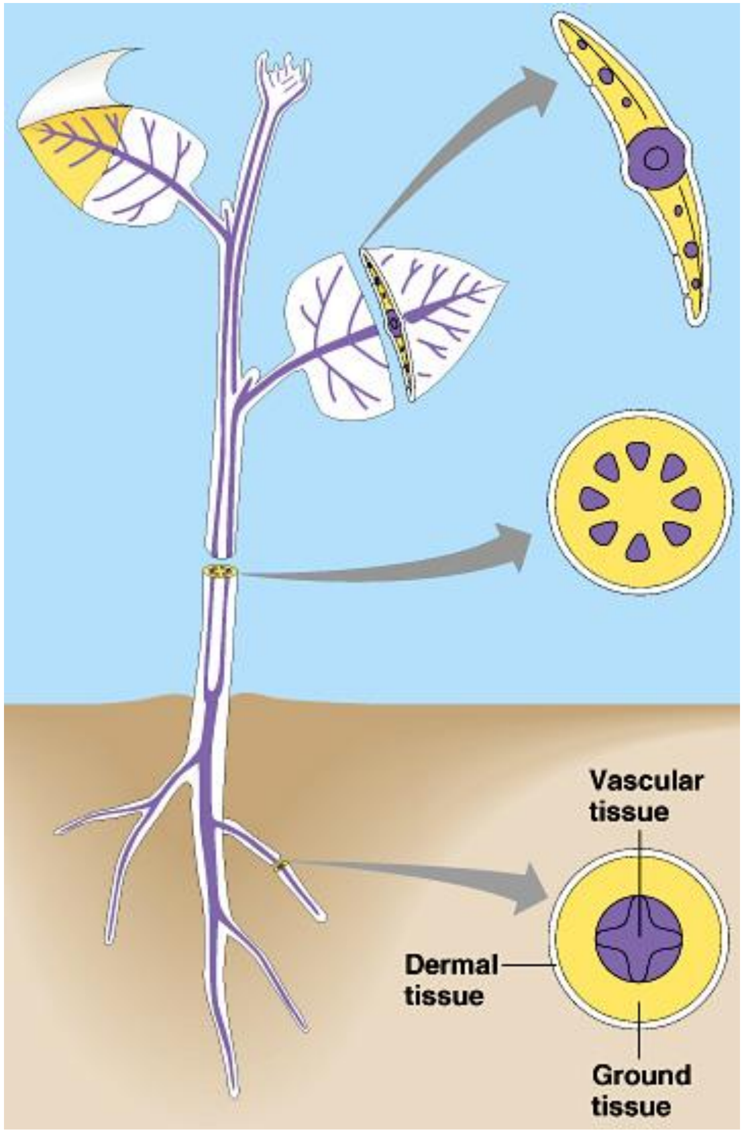
Generally a single cell layer that covers the plant.

- Absorption in root system.
- Water retention in shoot system, aided by waxy cuticle.

Differentiated cells contribute to 3 tissue systems

2. Vascular tissue.

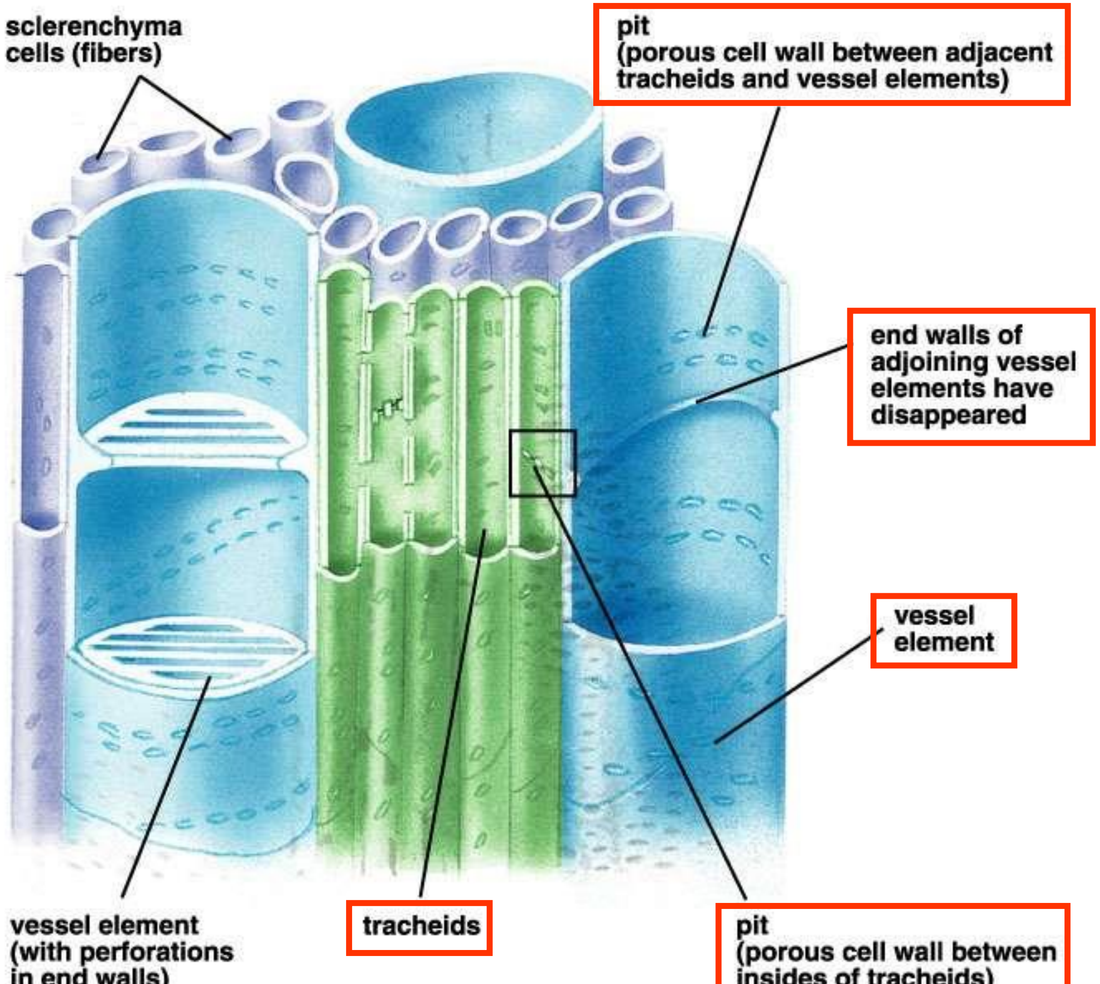
- **Xylem** – transports water and dissolved minerals.
- **Phloem** – transports sugars dissolved in water.



Differentiated cells contribute to 3 tissue systems

Vascular tissue / Xylem

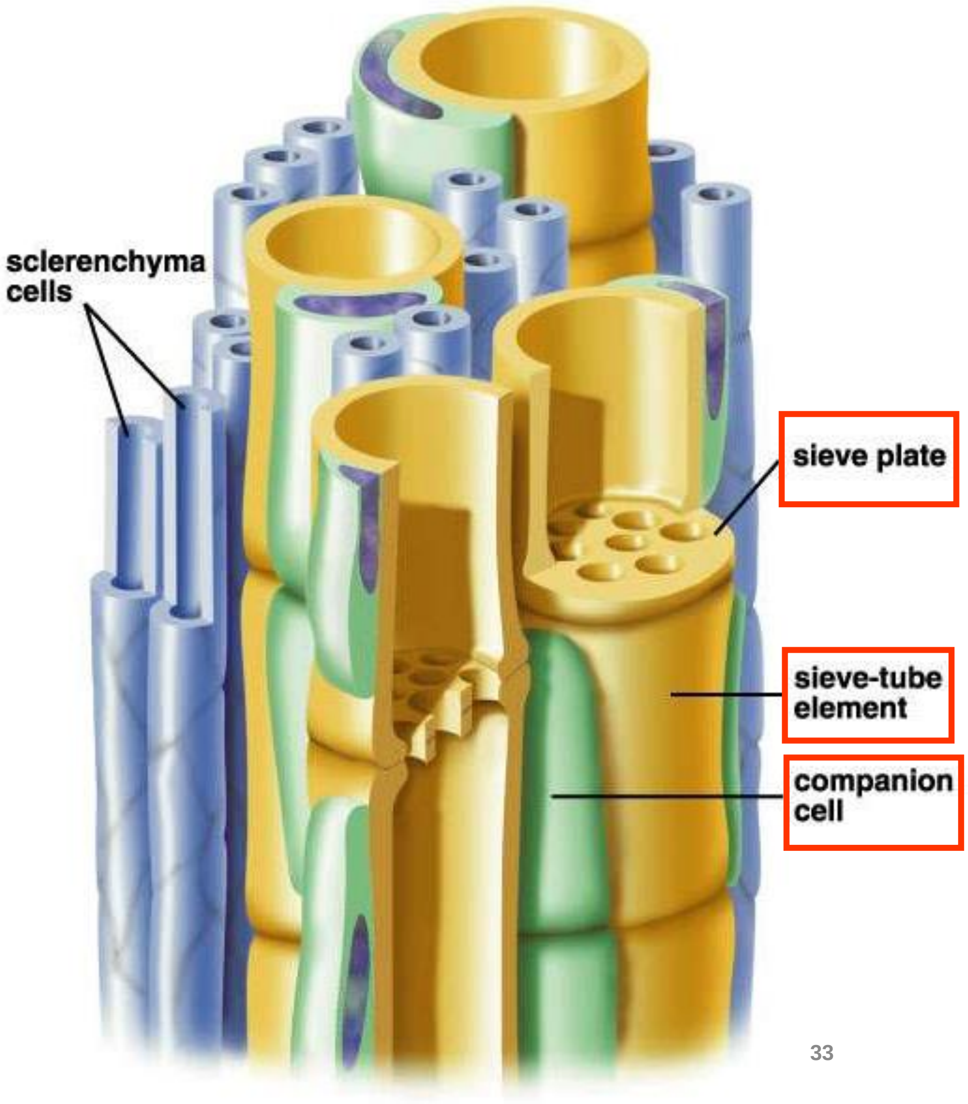
Cells are dead at functional maturity.



Differentiated cells contribute to 3 tissue systems

Vascular tissue / Phloem

Cells are alive at functional maturity.

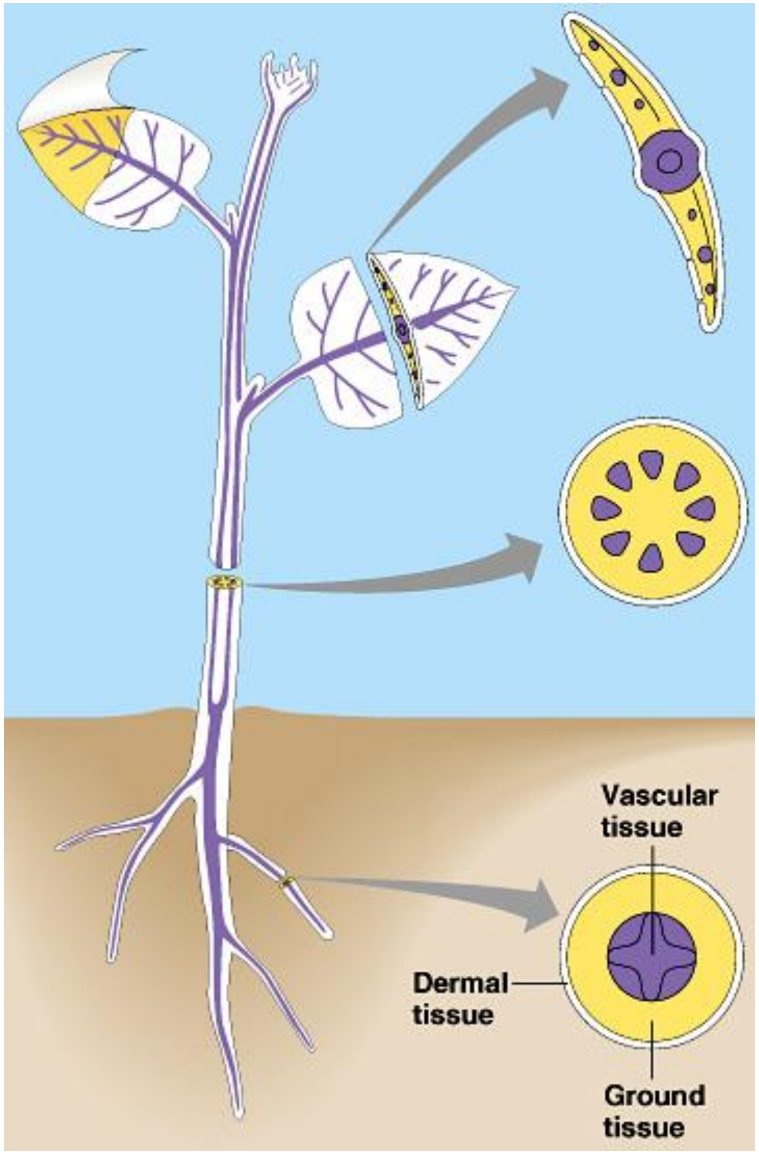


Differentiated cells contribute to 3 tissue systems

3. Ground tissue.
All non-epidermal, non-vascular tissue.

Three principal cell types:-

1. **Parenchyma**
2. **Collenchyma**
3. **Sclerenchyma**

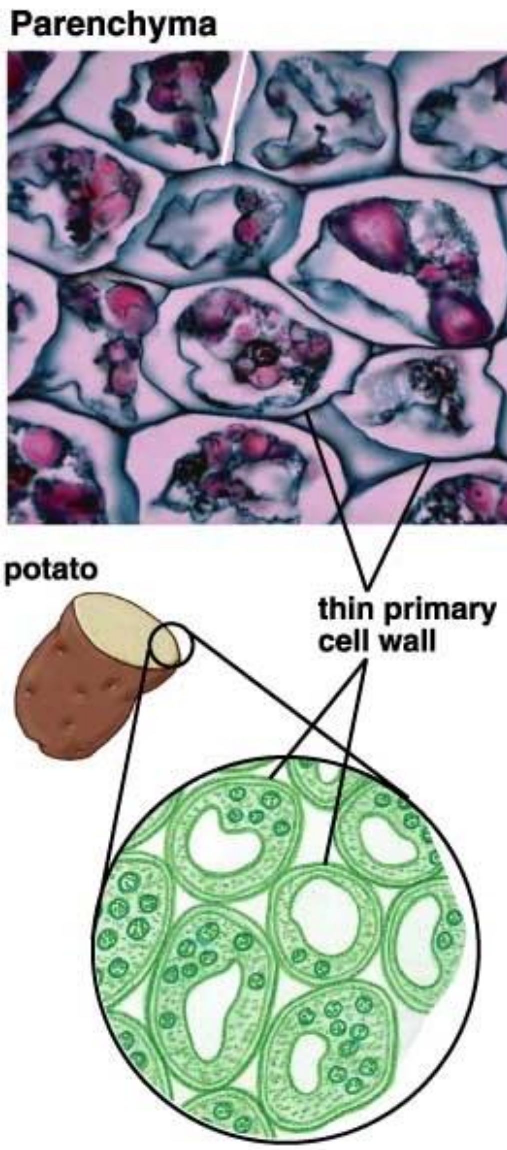


Differentiated cells contribute to 3 tissue systems

Ground tissue.

1. Parenchyma.

- Thin-walled, live cells.
- Perform most metabolic functions of plant.
    - Photosynthesis.
    - food storage.
    - synthesis and secretion.

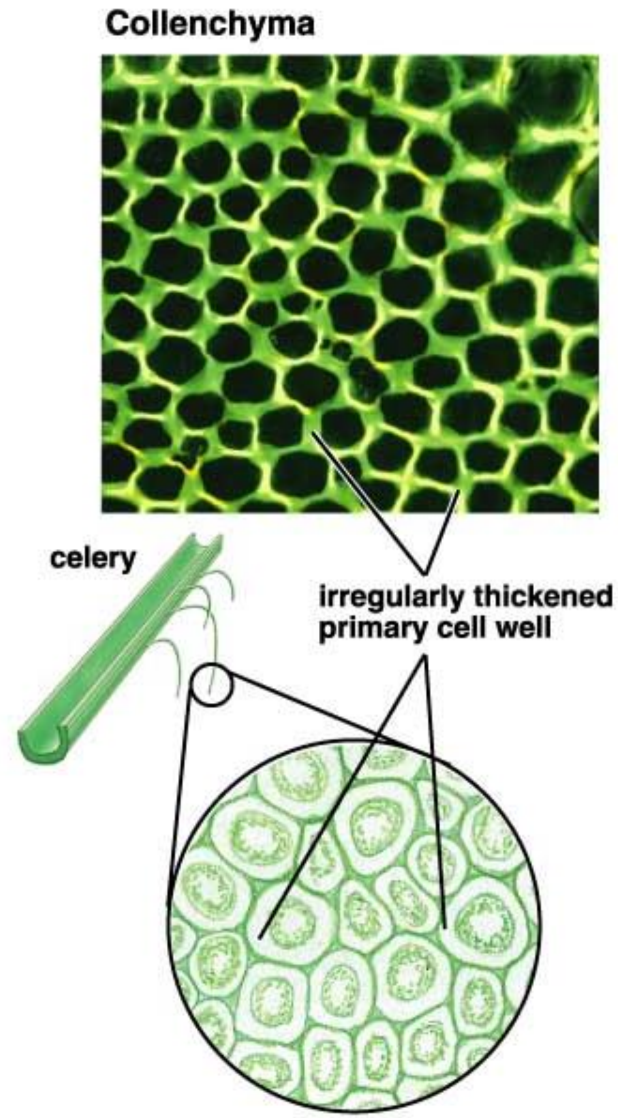


Differentiated cells contribute to 3 tissue systems

Ground tissue

2. Collenchyma

- Cells with unevenly thickened walls that lack lignin.
- Alive at maturity.
- Grouped into strands or cylinders to aid support without constricting growth.

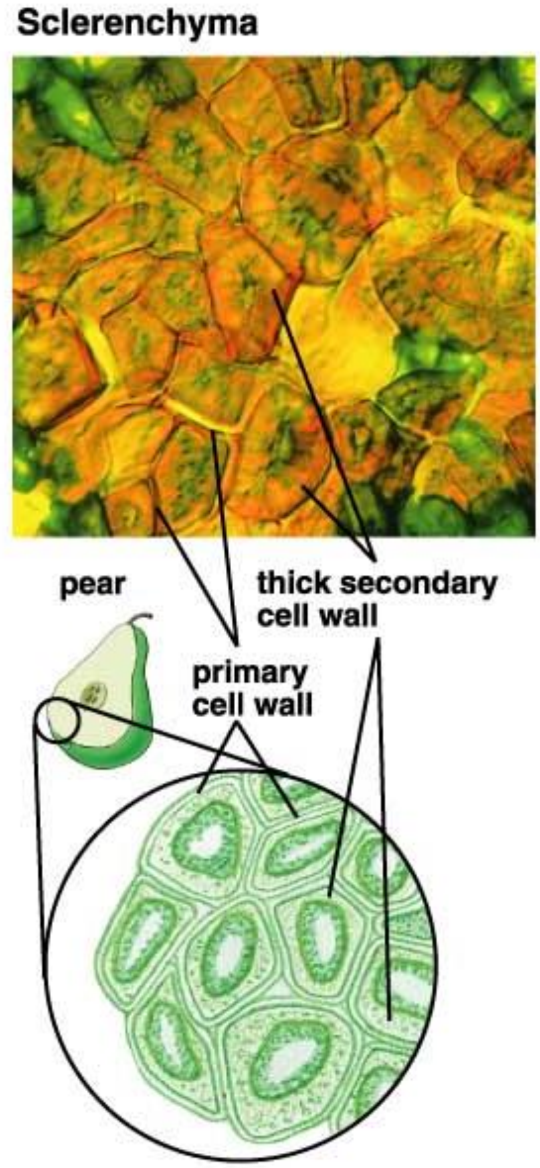


Differentiated cells contribute to 3 tissue systems

Ground tissue

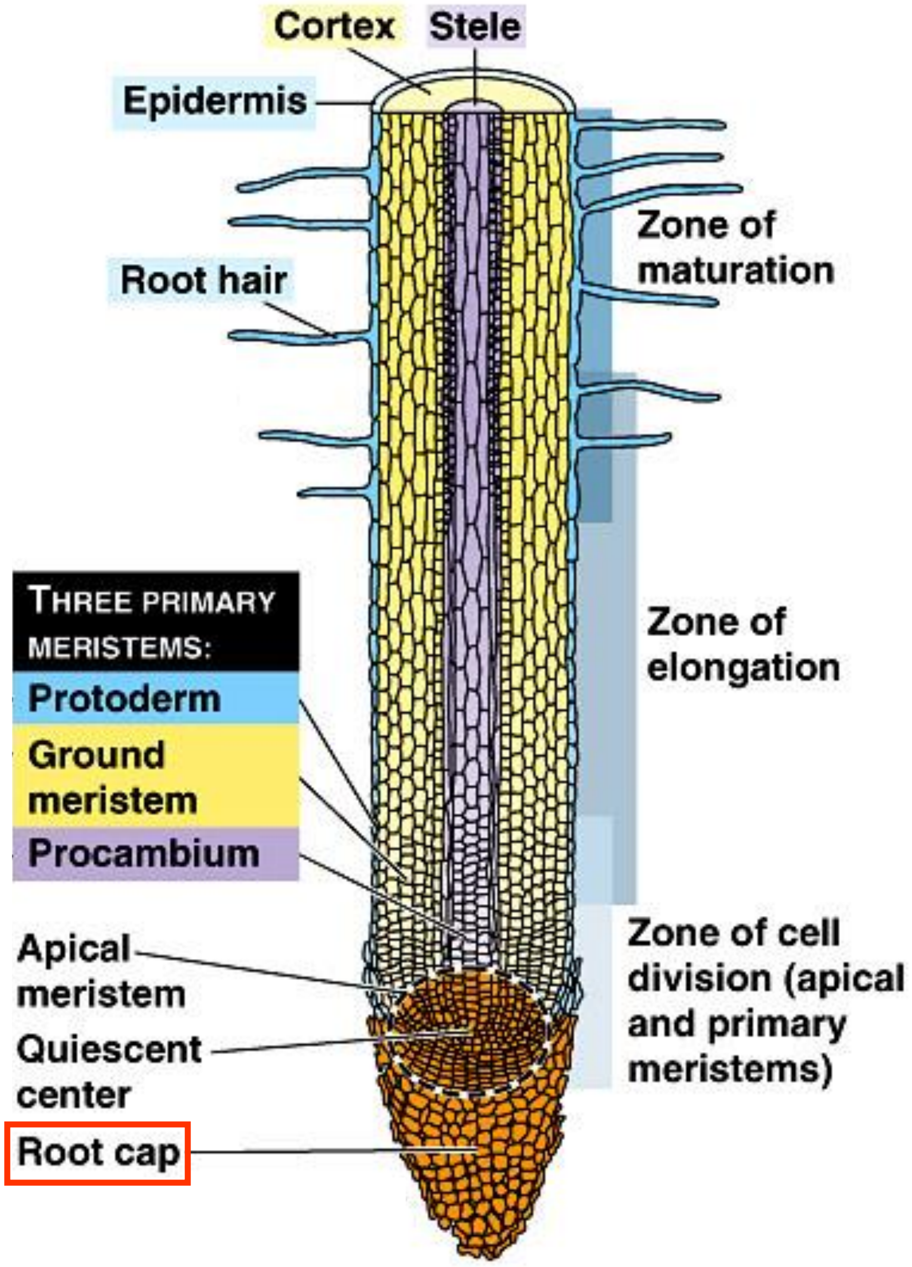
3. Sclerenchyma

- Very thick walls, hardened with lignin
- Dead at maturity.
- Give strength and support to fully grown parts of the plant.
- Fibers occur in groups.
- Sclereids impart hardness to nutshells and the gritty texture to pears.



Primary growth in roots

Primary growth in roots lengthens roots from the tips

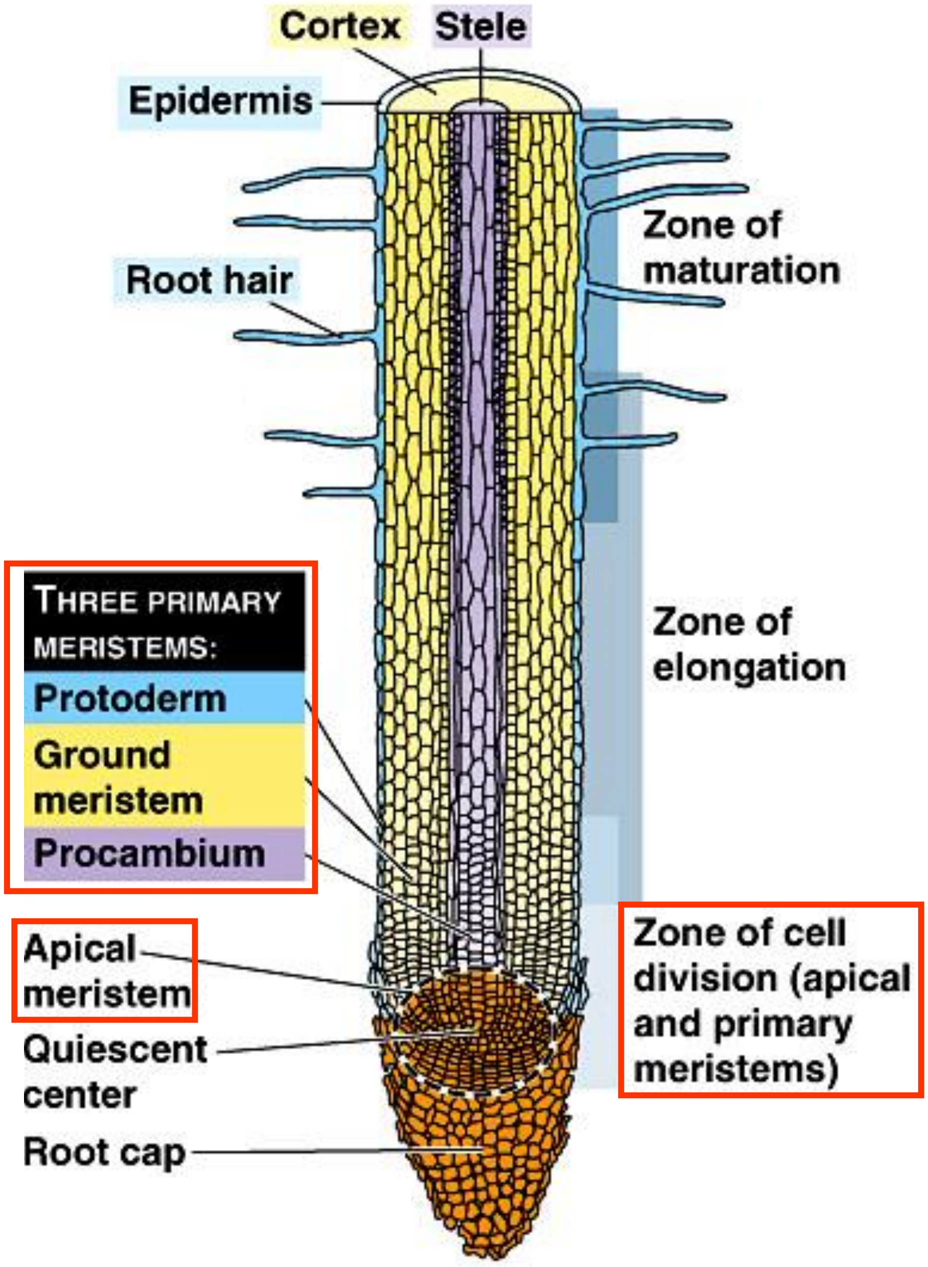


The **root cap** continually sloughs off

Primary growth in roots

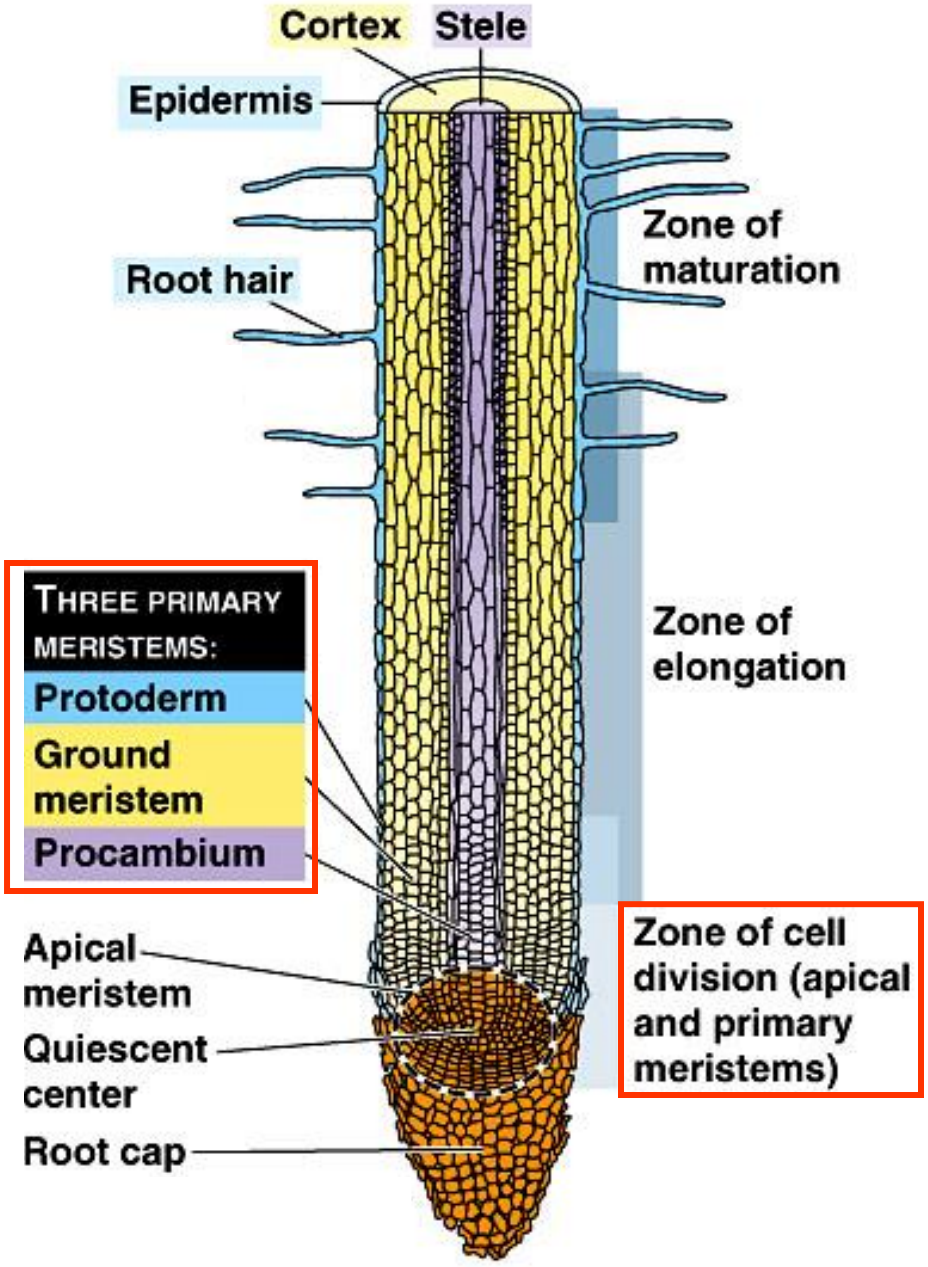
The **apical meristem** produces three primary meristems

1. Protoderm
2. Ground meristem
3. procambium



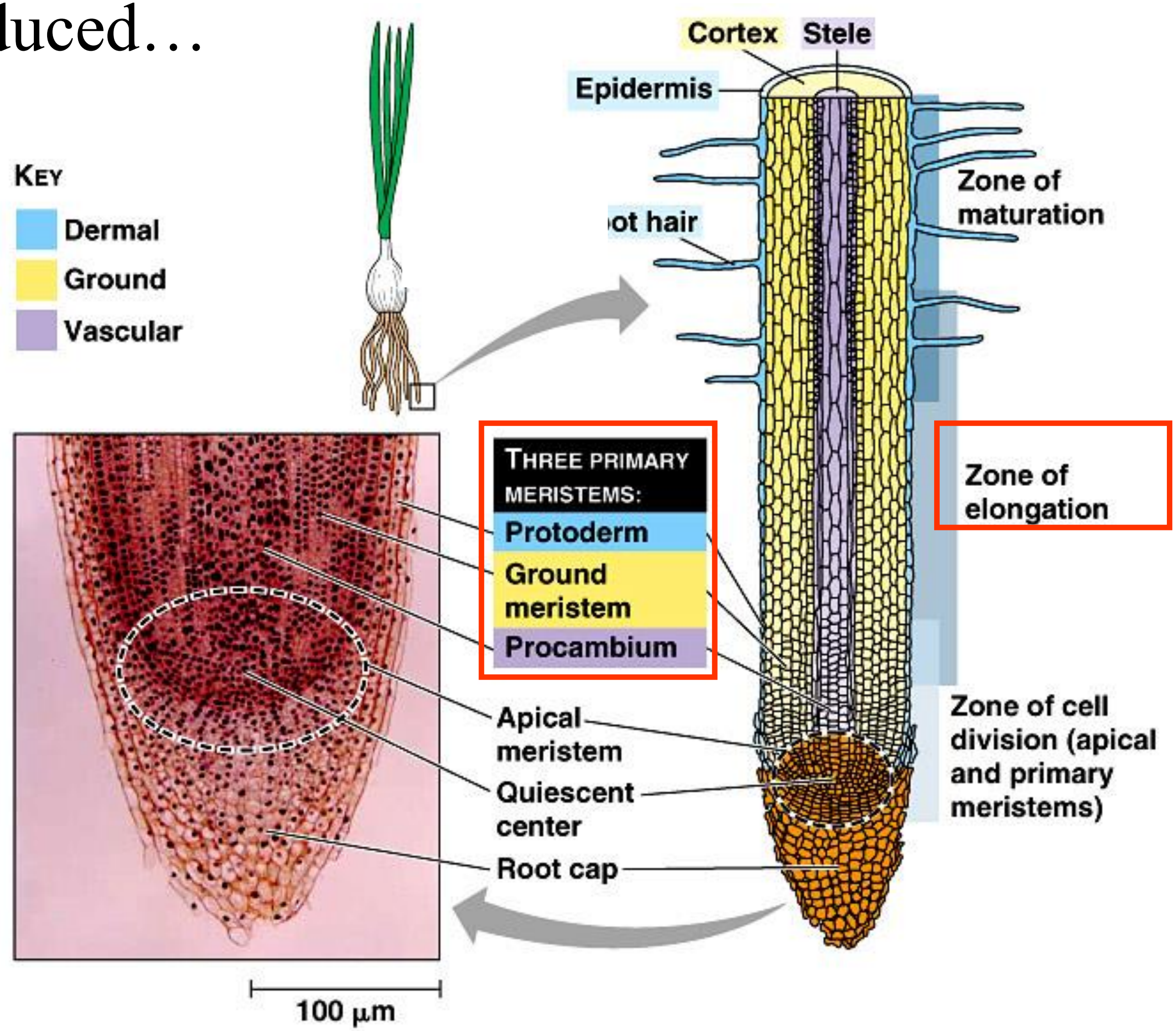
Primary growth in roots

The cells are produced…



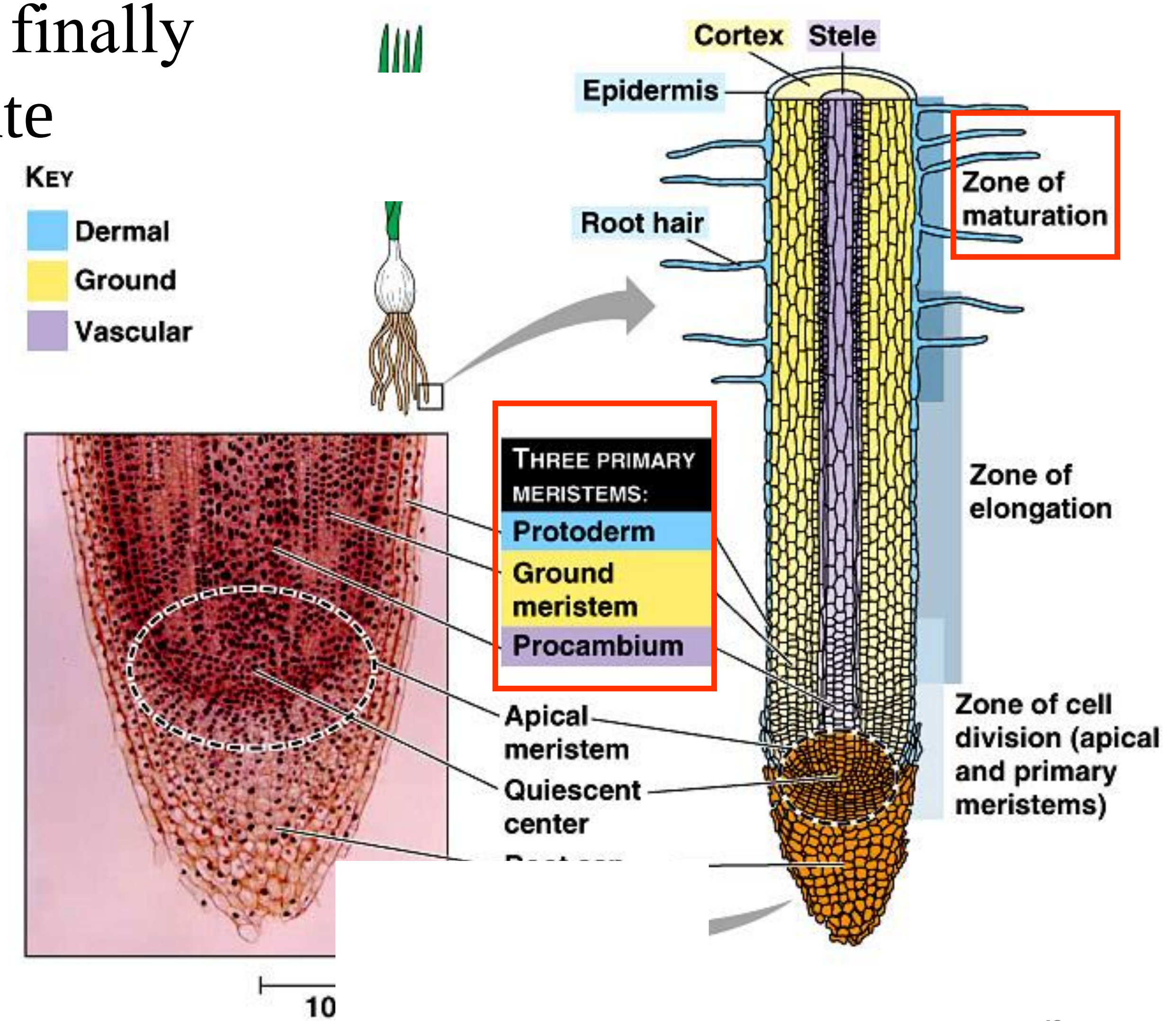
Primary growth in roots

The cells are produced…
then elongate…



Primary growth in roots

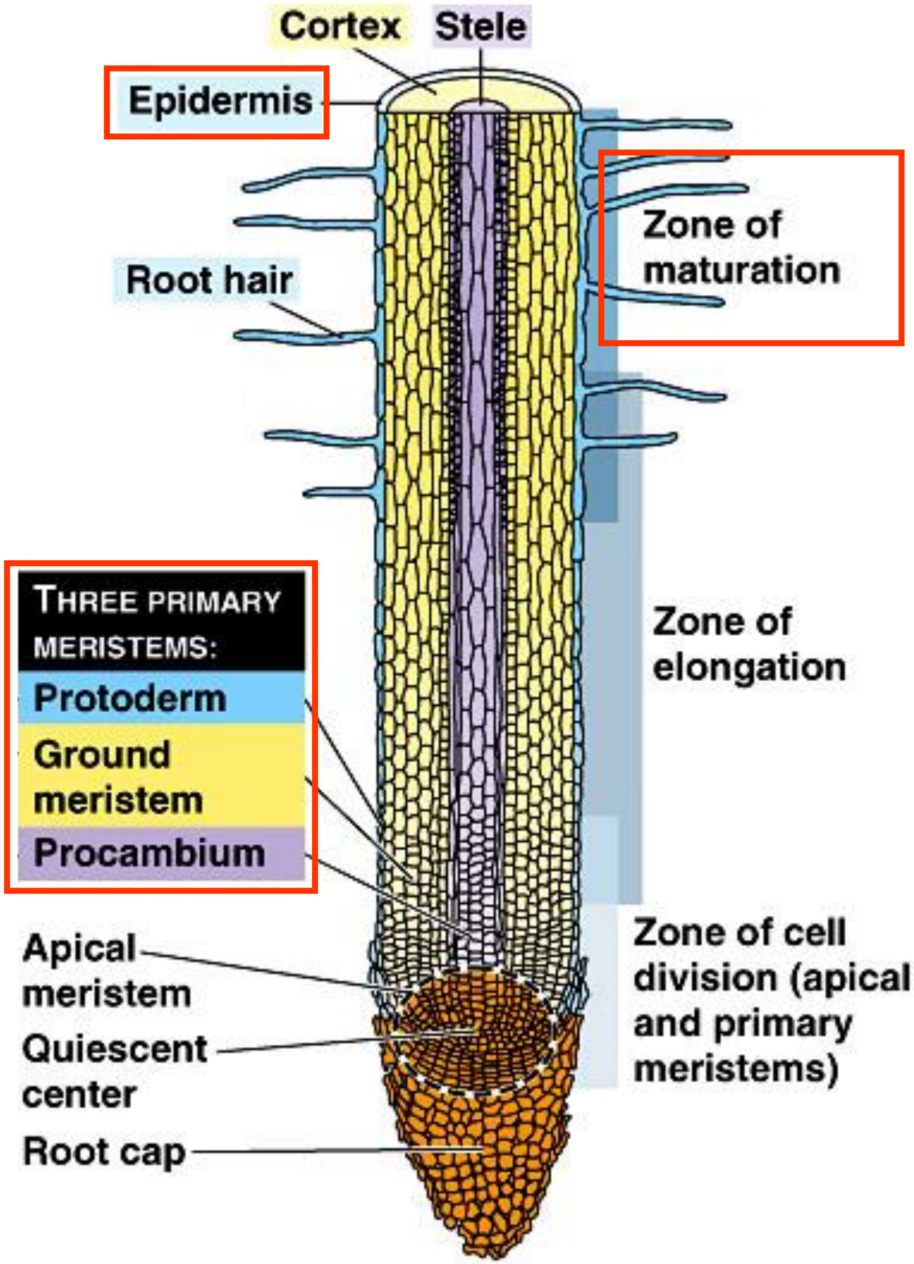
The cells are produced… then elongate… and finally mature & differentiate



Primary growth in roots

The cells are produced… then elongate… and finally mature & differentiate

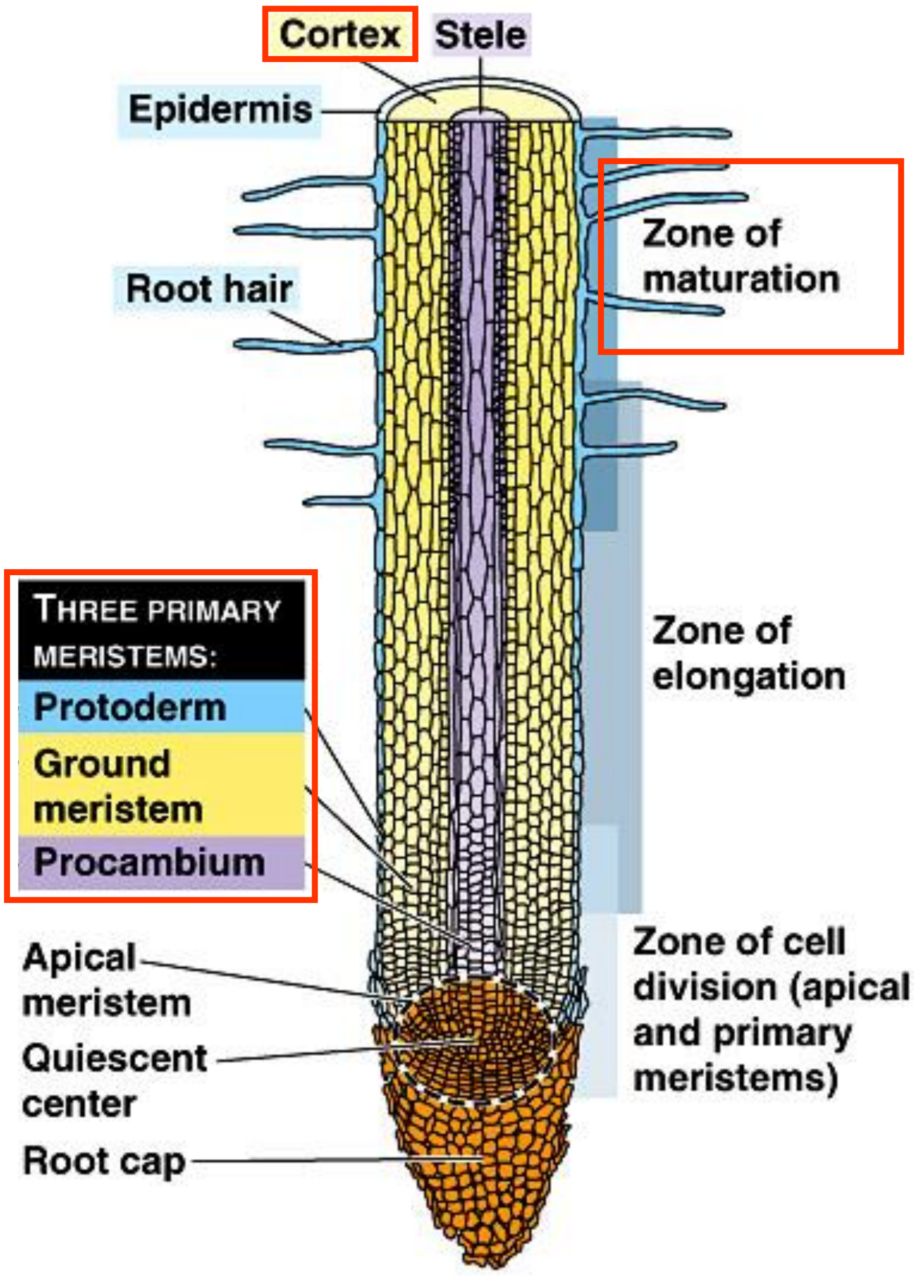
1. **Protoderm** cells become the **epidermis**



Primary growth in roots

The cells are produced…
then elongate…

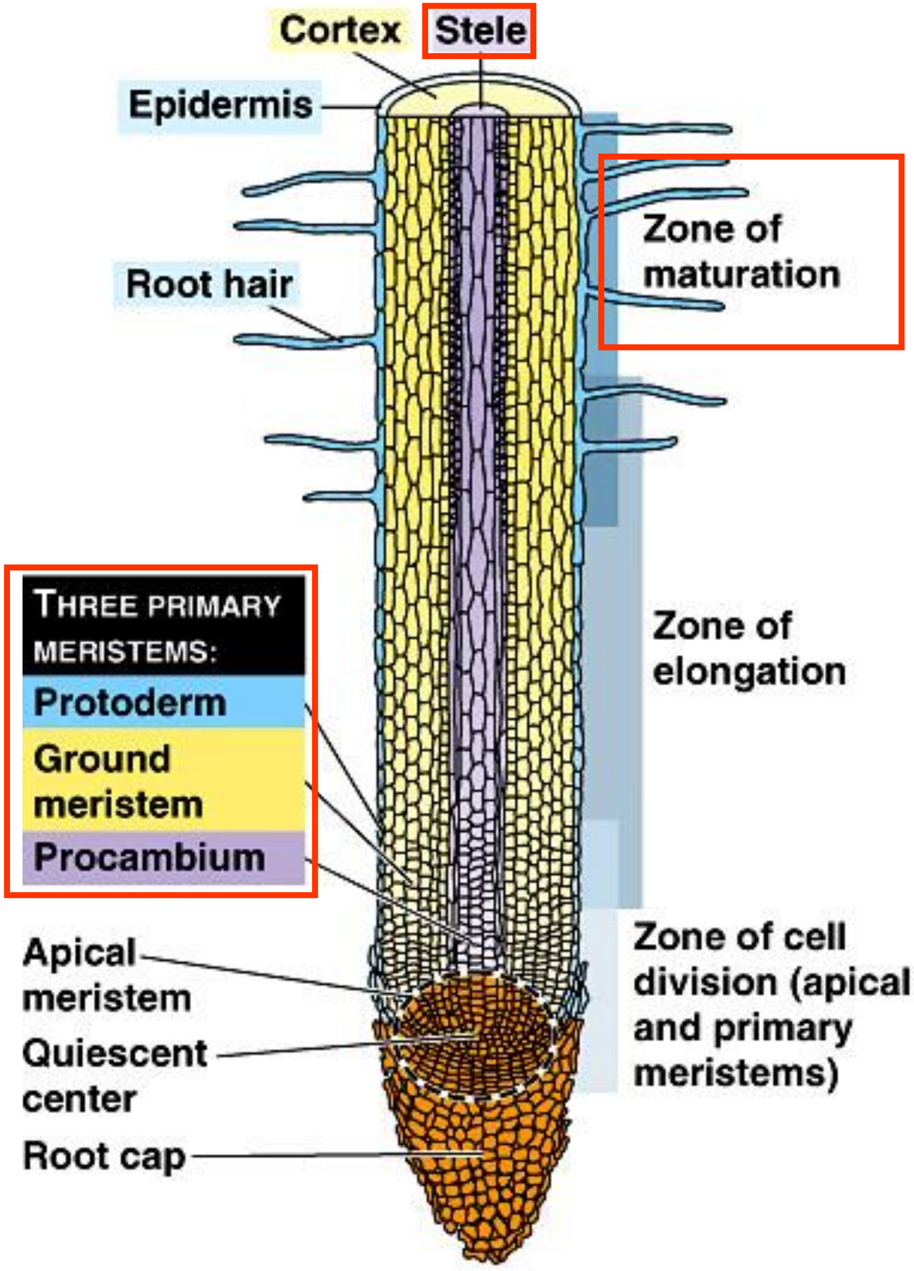
1. **Protoderm** cells become the **epidermis**
2. **Ground meristem** cells become the **cortex**



Primary growth in roots

The cells are produced… then elongate… and finally mature & differentiate

1. **Protoderm** cells become the **epidermis**
2. **Ground meristem** cells become the **cortex**
3. **Procambium** cells become the vascular **stele**

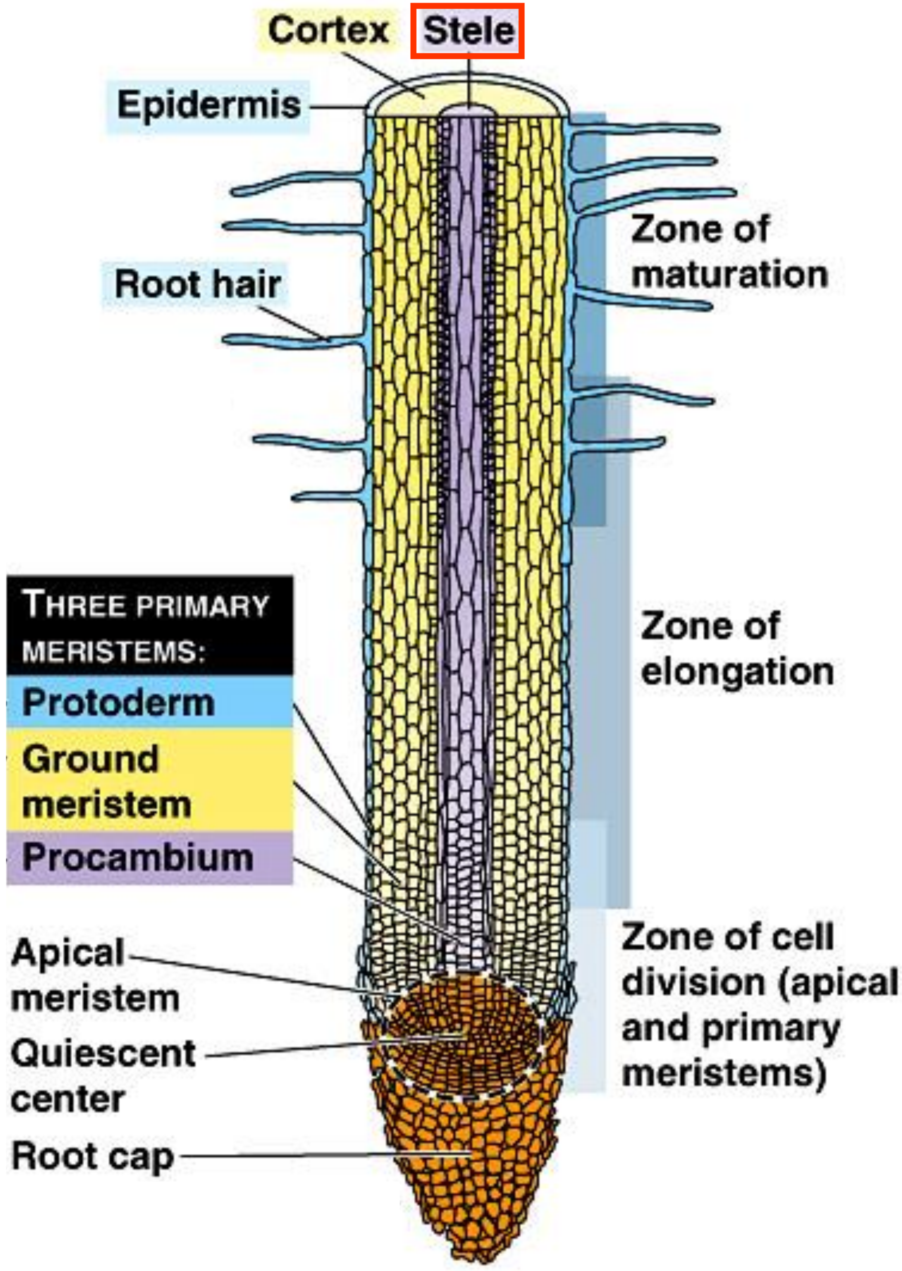


Primary growth in roots

Pericycle

Outermost layer of stele

These cells retain meristematic capabilities, and can produce lateral roots.

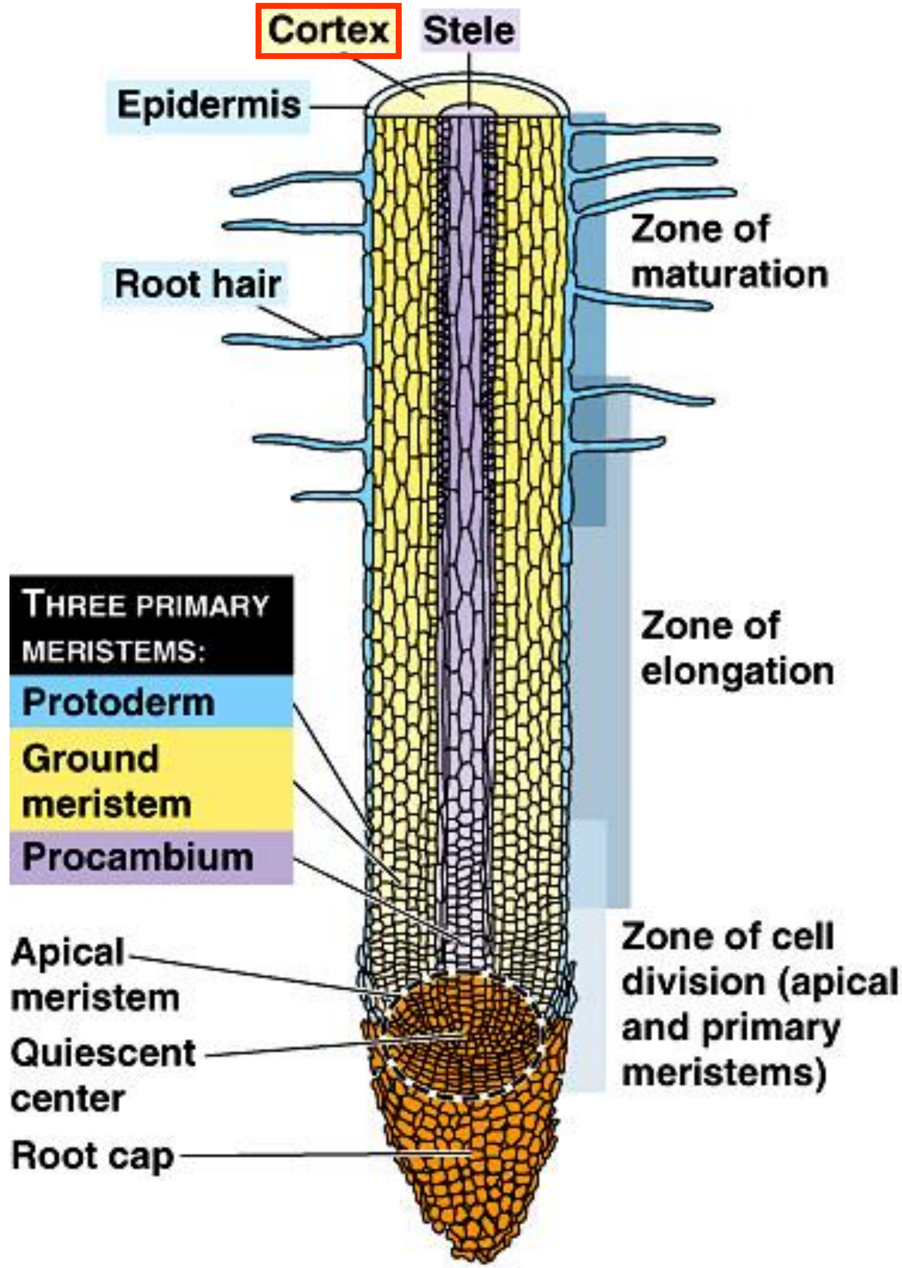


Primary growth in roots

Endodermis

Innermost layer of cortex

These cells regulate the flow of substances into the vascular tissues of the stele



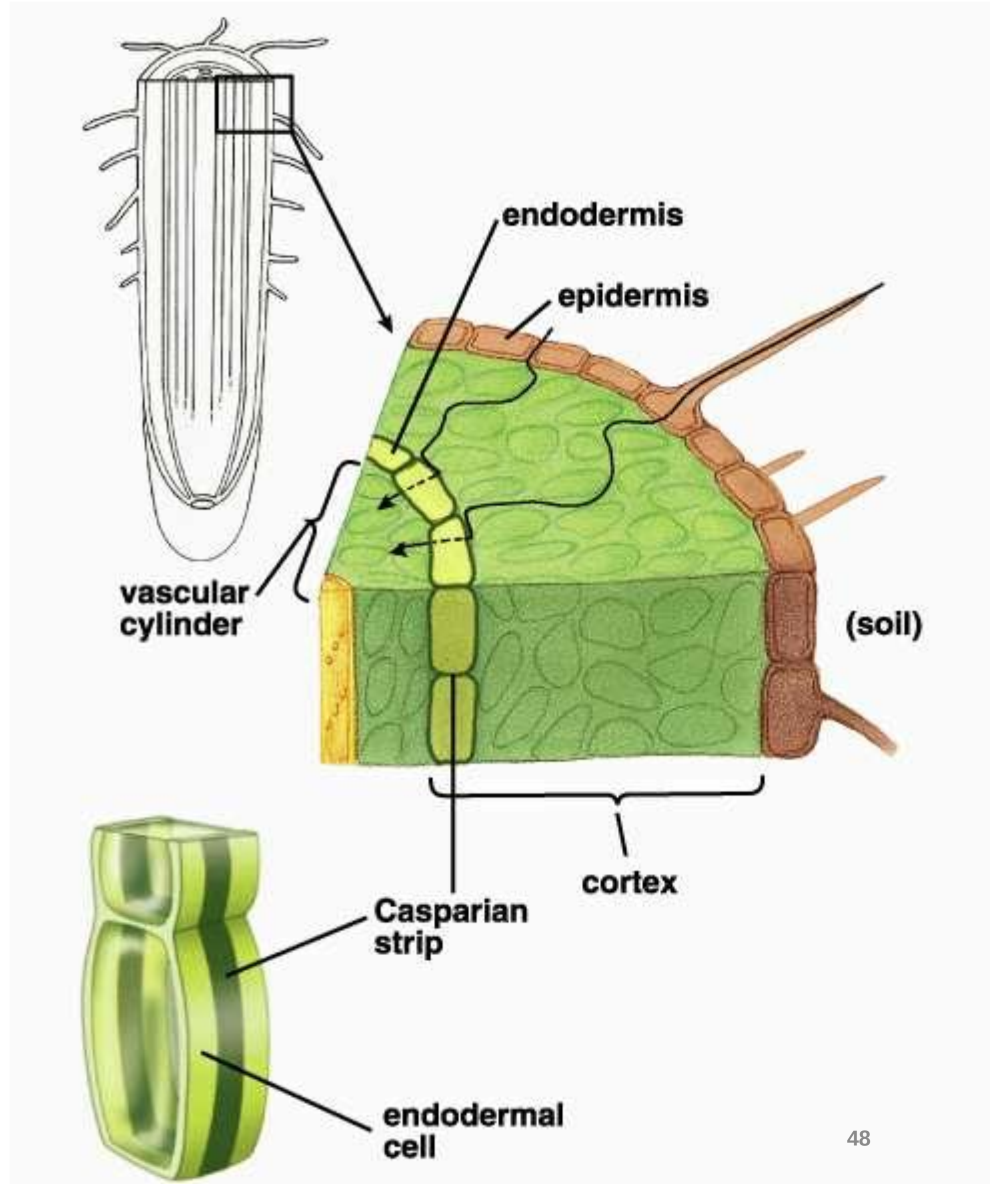
Primary growth in roots

Endodermis

Innermost layer of cortex

These cells regulate the flow of substances into the vascular tissues of the stele

Casparian strip disallows flow of substances except through the endodermal cells themselves

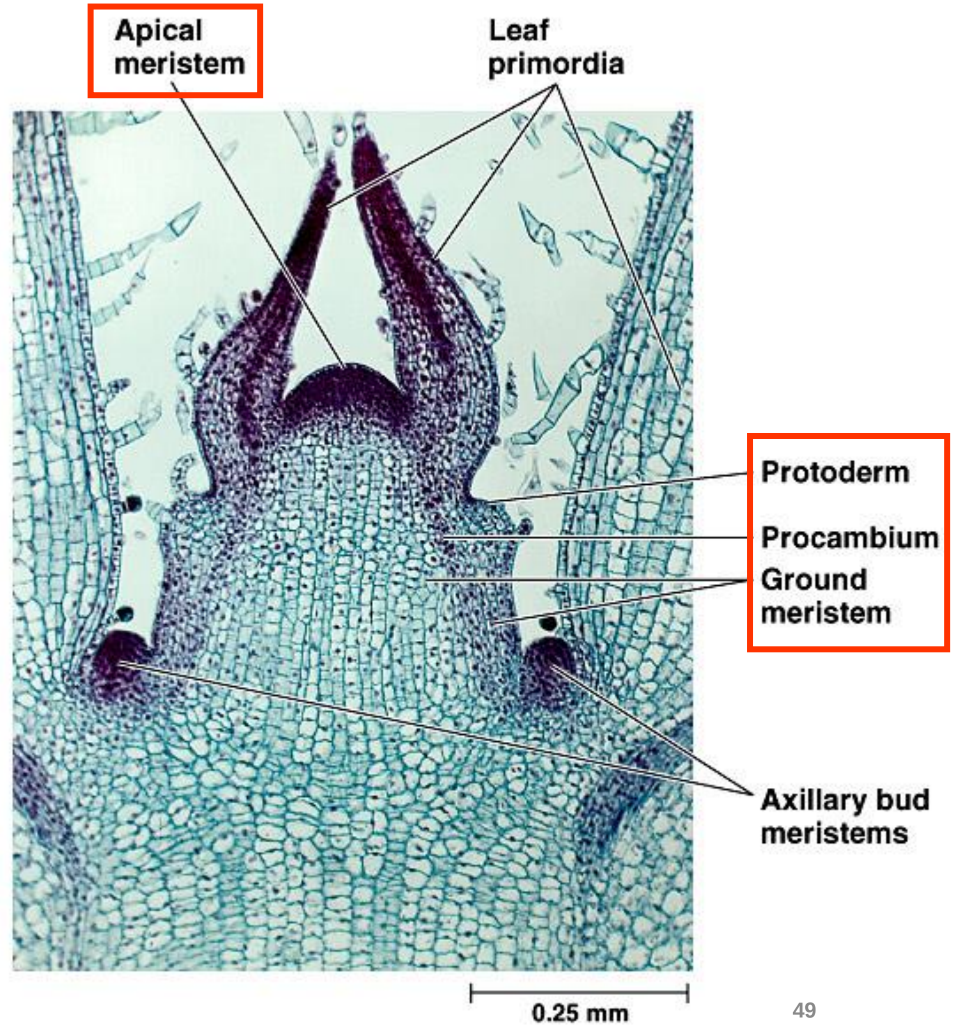


Primary growth in shoots

Primary growth in shoots lengthens shoots from the tips

The **apical meristem** produces the same three primary meristems as in the roots:

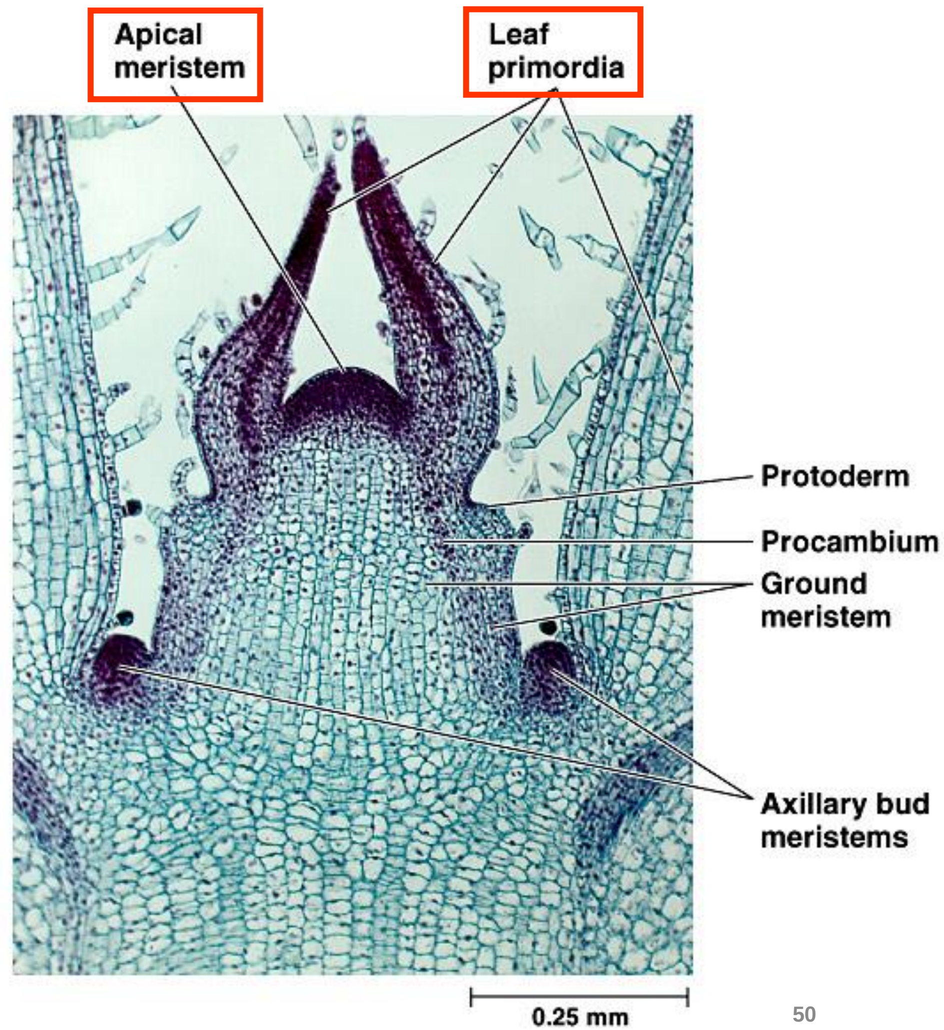
1. Protoderm
2. Ground meristem
3. Procambium



Primary growth in shoots

Primary growth in shoots lengthens shoots from the tips

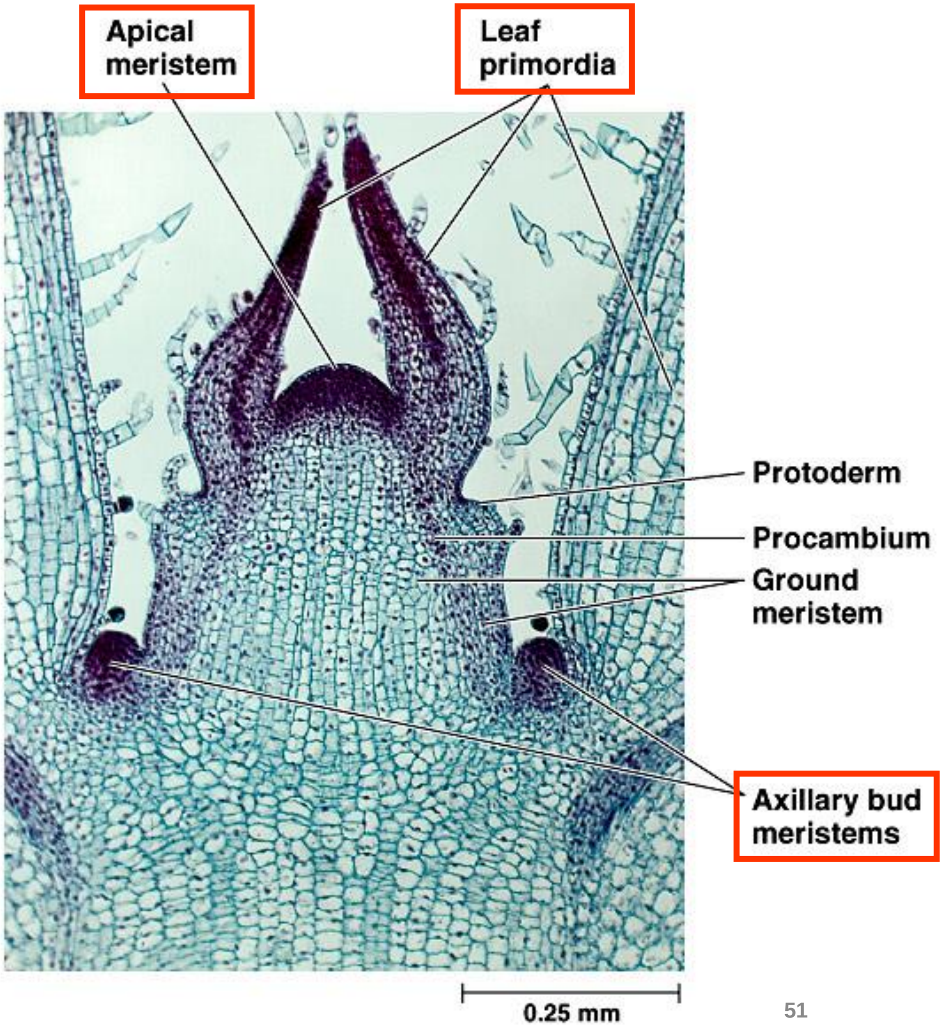
1. Leaves arise from **leaf primordia** on the flanks of the **apical meristem**



Primary growth in shoots

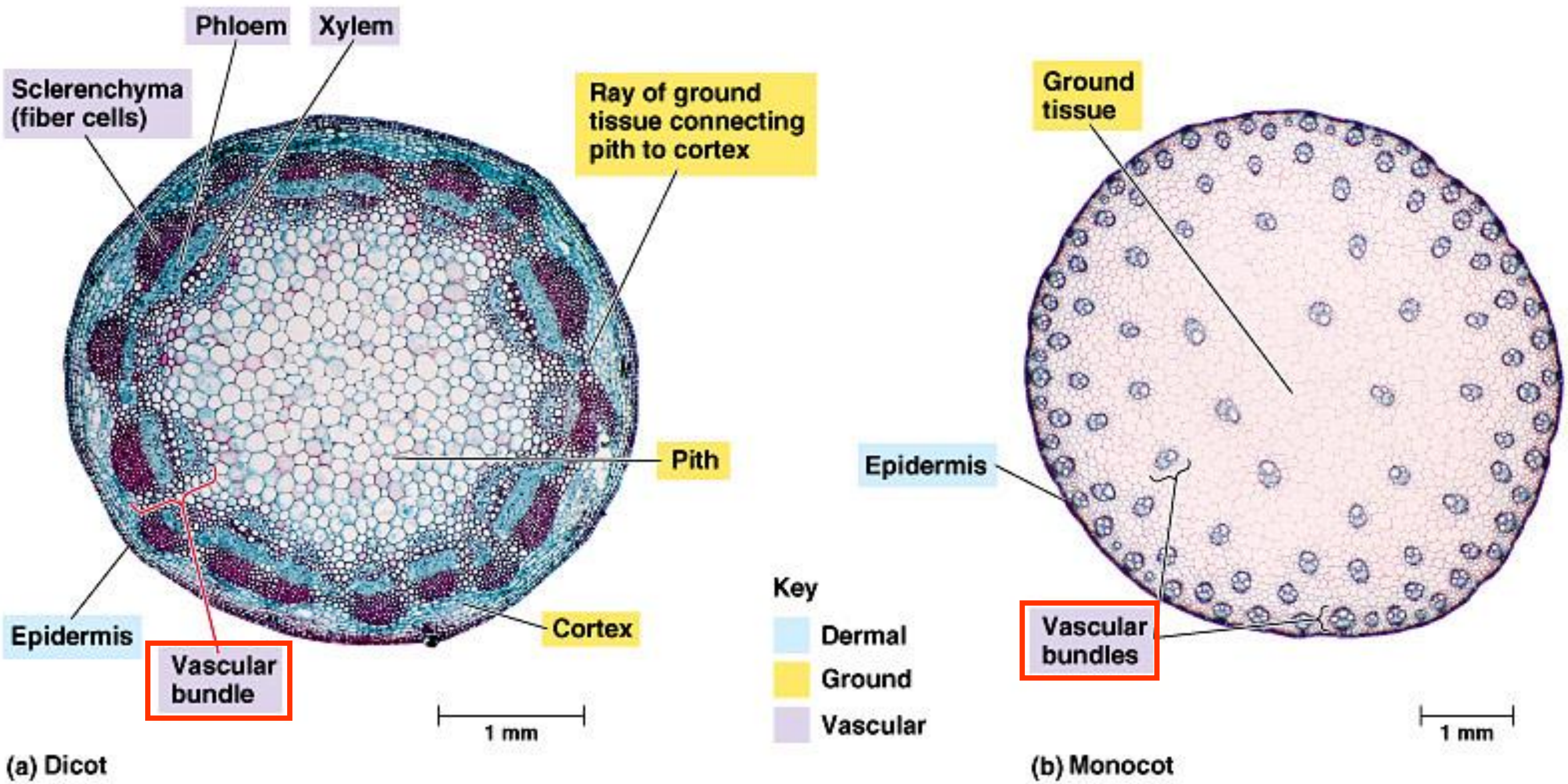
Primary growth in shoots lengthens shoots from the tips

2. Axillary buds (that could produce **lateral branches**) develop from islands of **meristematic cells** left at the bases of **leaf primordia**



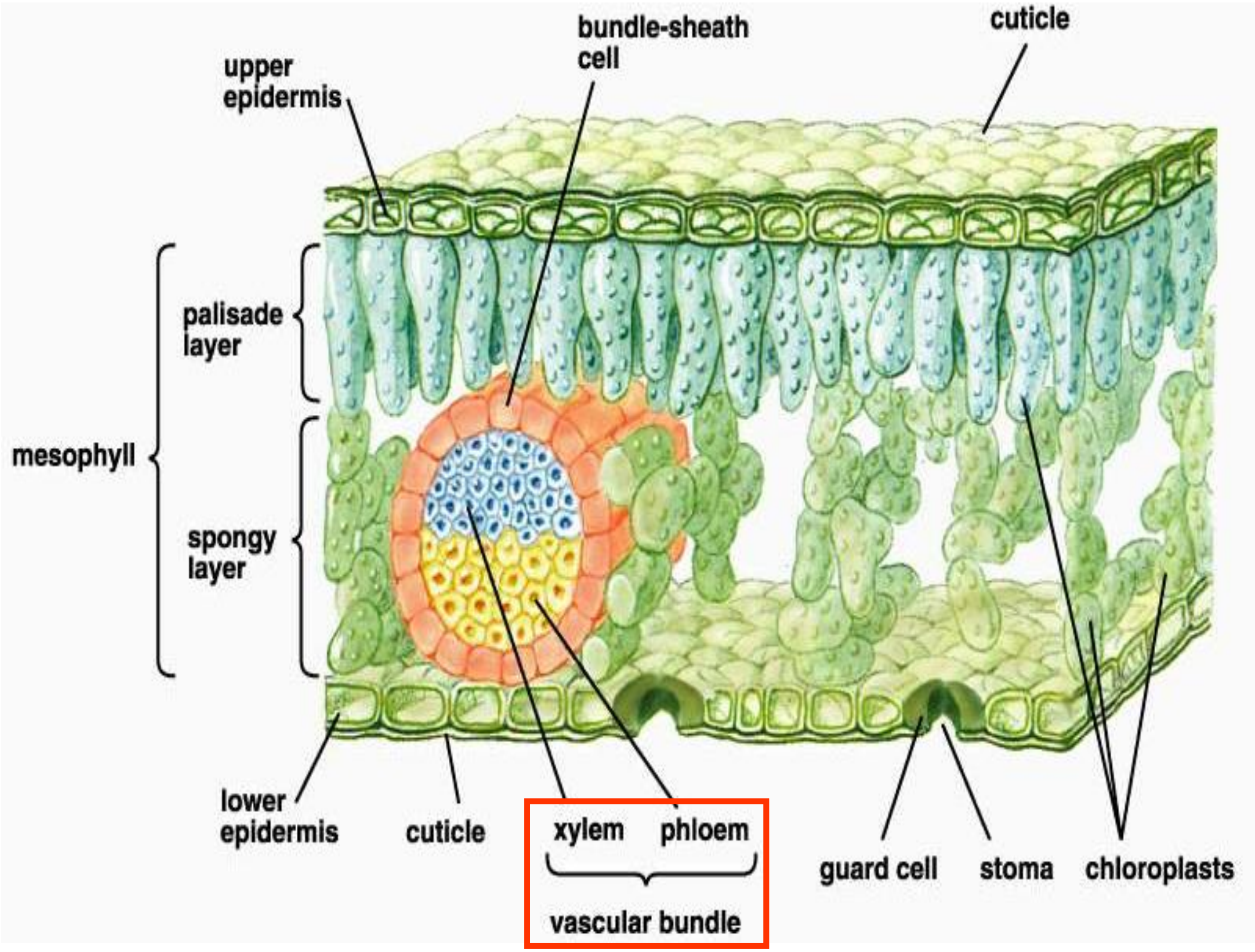
Primary growth in shoots / stem

3. **Procambium cells** develop into **vascular bundles**



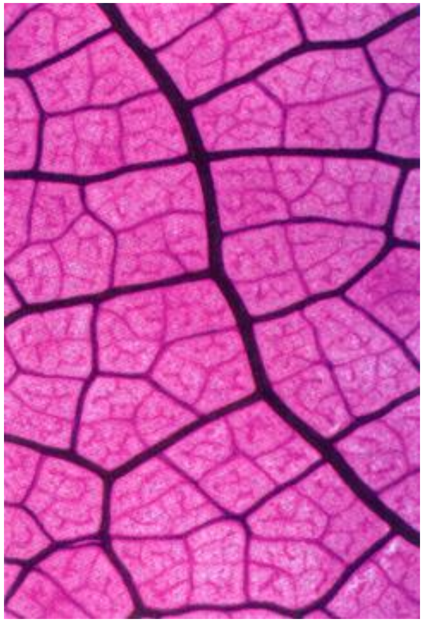
Primary growth in shoots / leaf

Procambium cells develop into **vascular bundles**



Primary growth in shoots / leaf

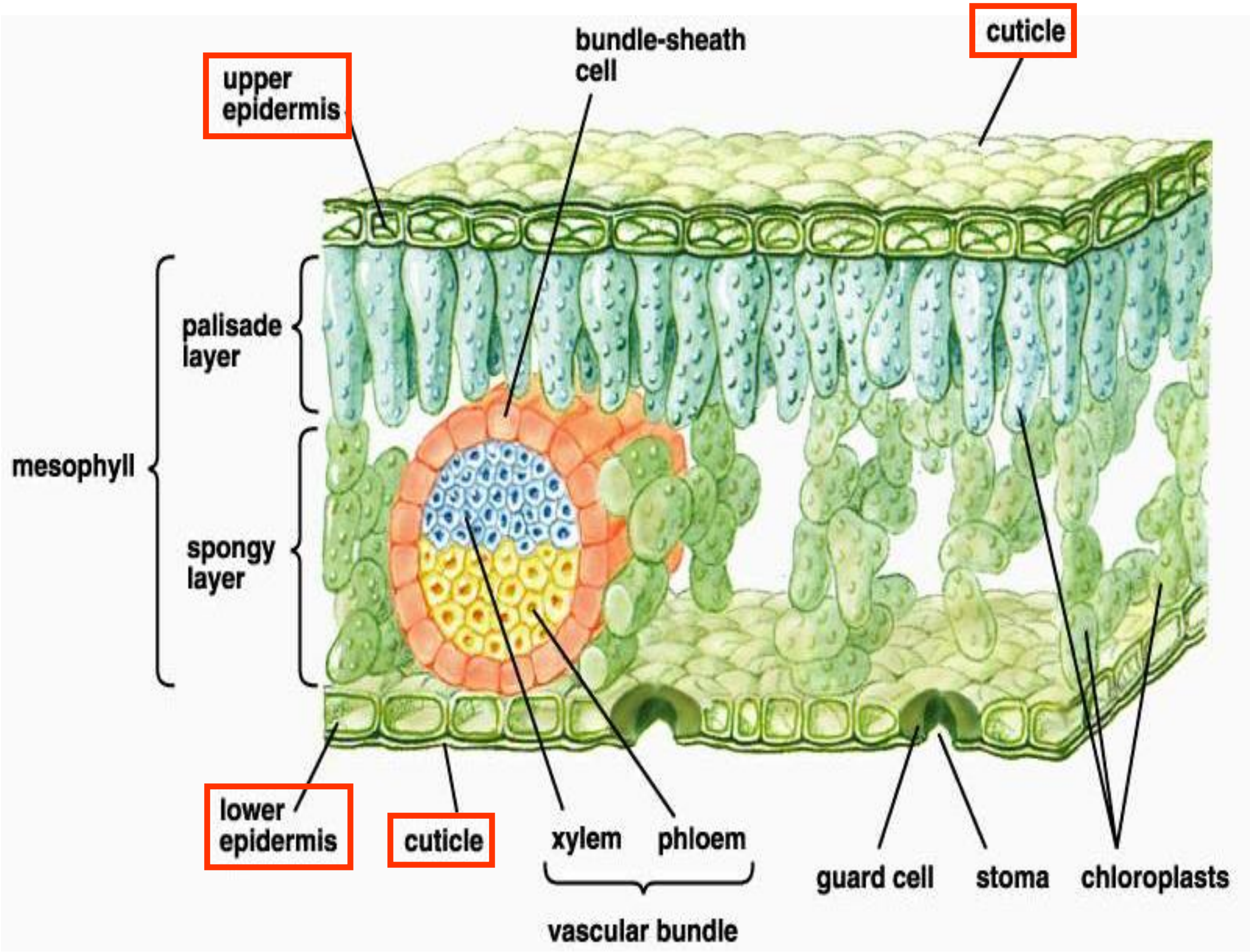
Procambium cells develop into **vascular bundles**



The "veins" in leaves

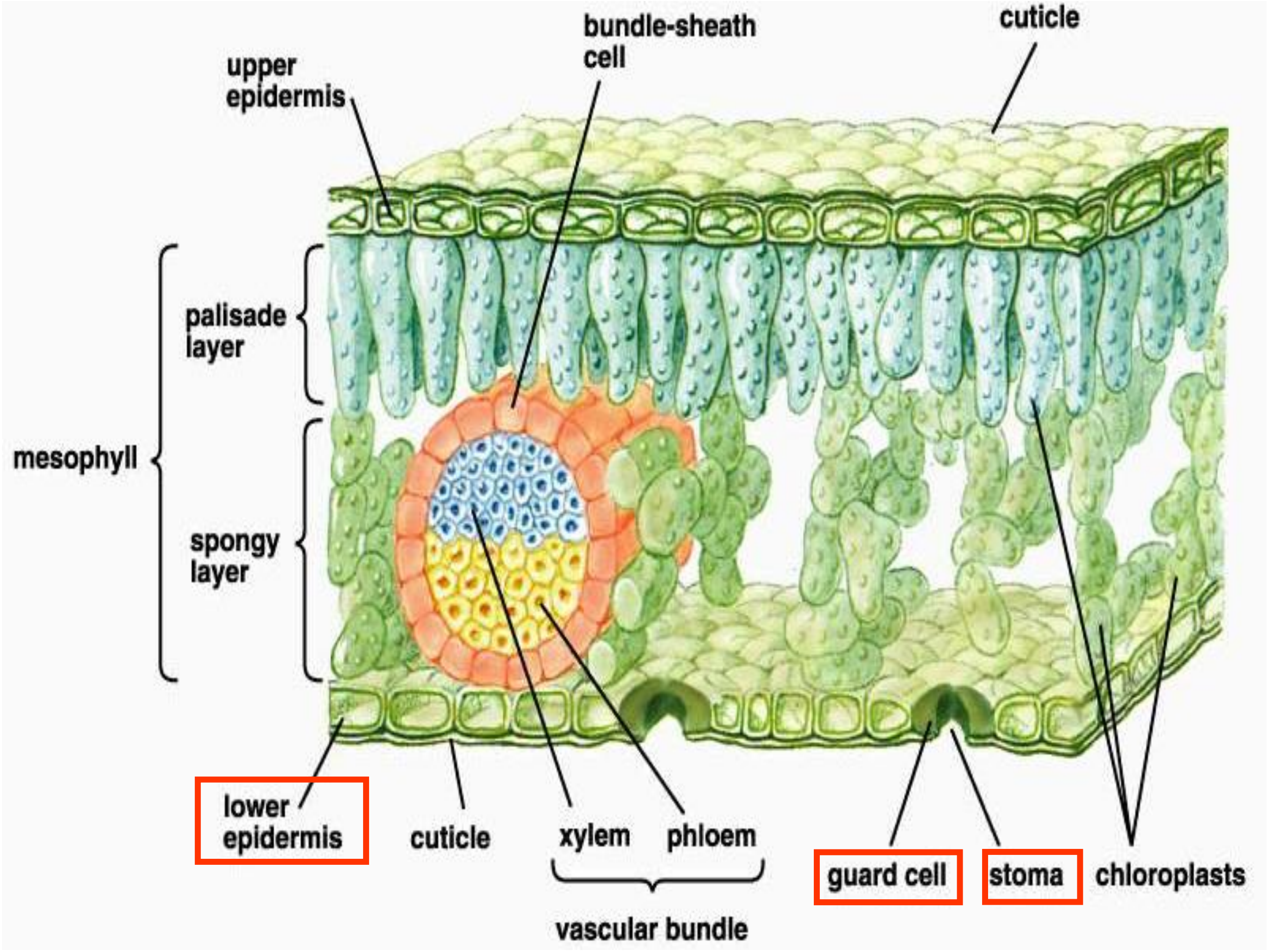
Primary growth in shoots / leaf

Protoderm cells develop into **epidermis**



Primary growth in shoots / leaf

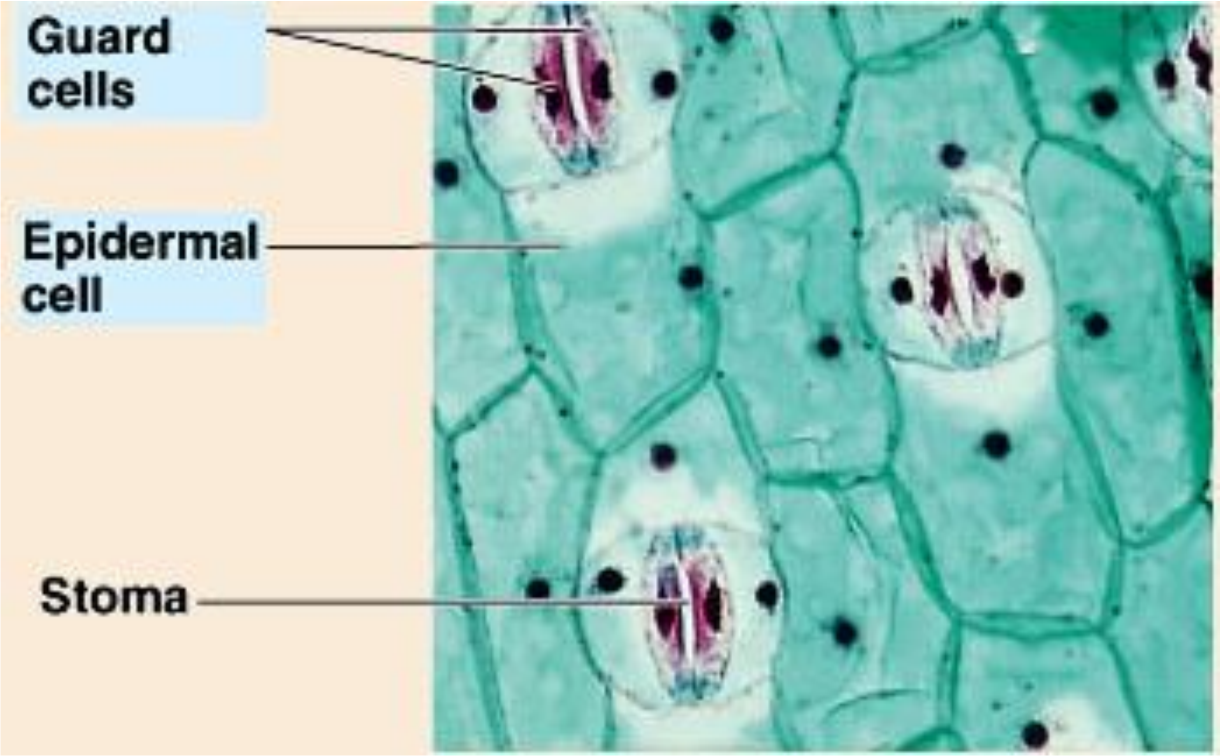
Protoderm cells develop into **epidermis**



Some epidermal cells are **guard cells** surrounding **stomata**

Primary growth in shoots / leaf

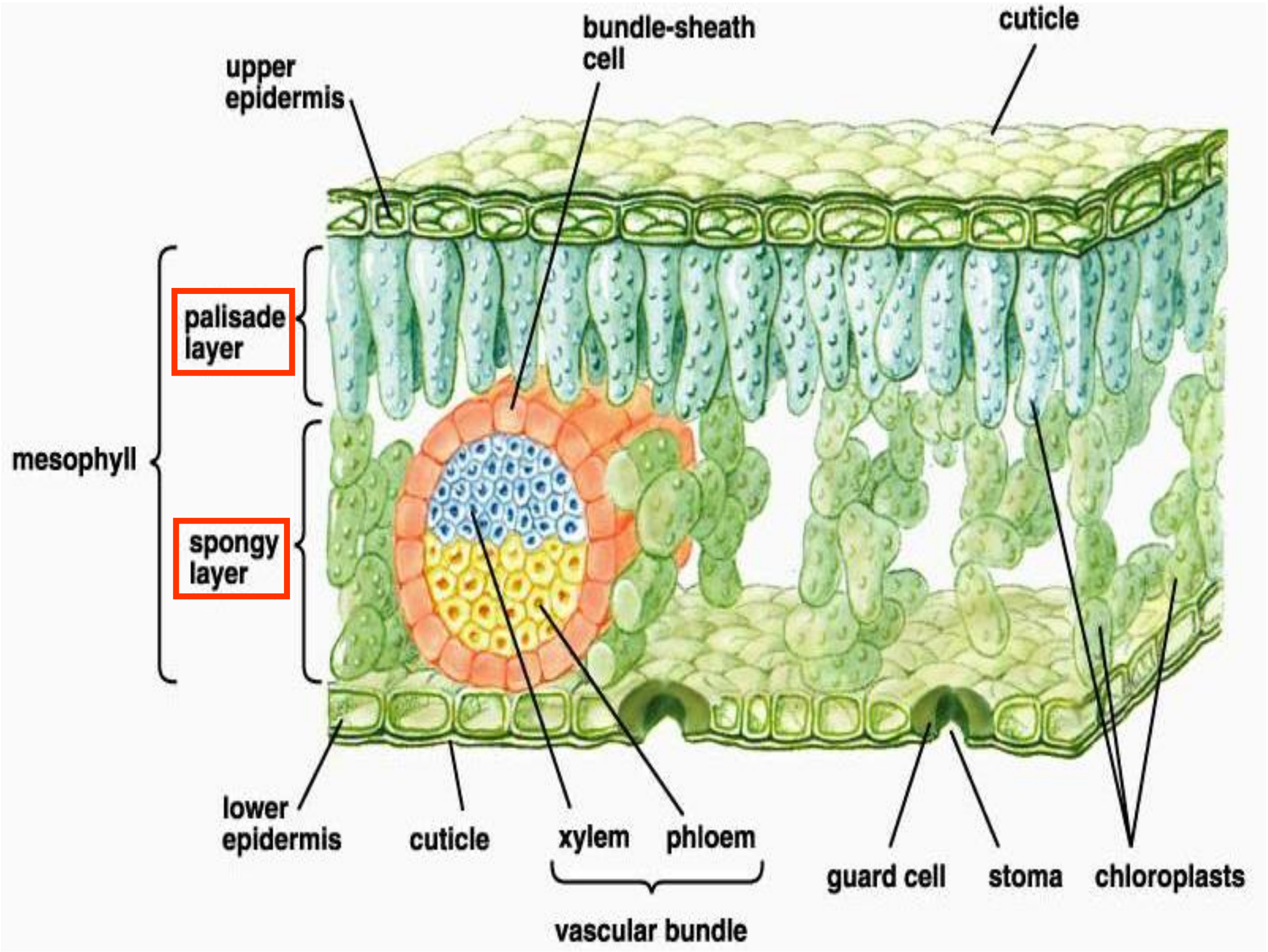
Protoderm cells develop into **epidermis**



Some epidermal cells are **guard cells** surrounding **stomata**

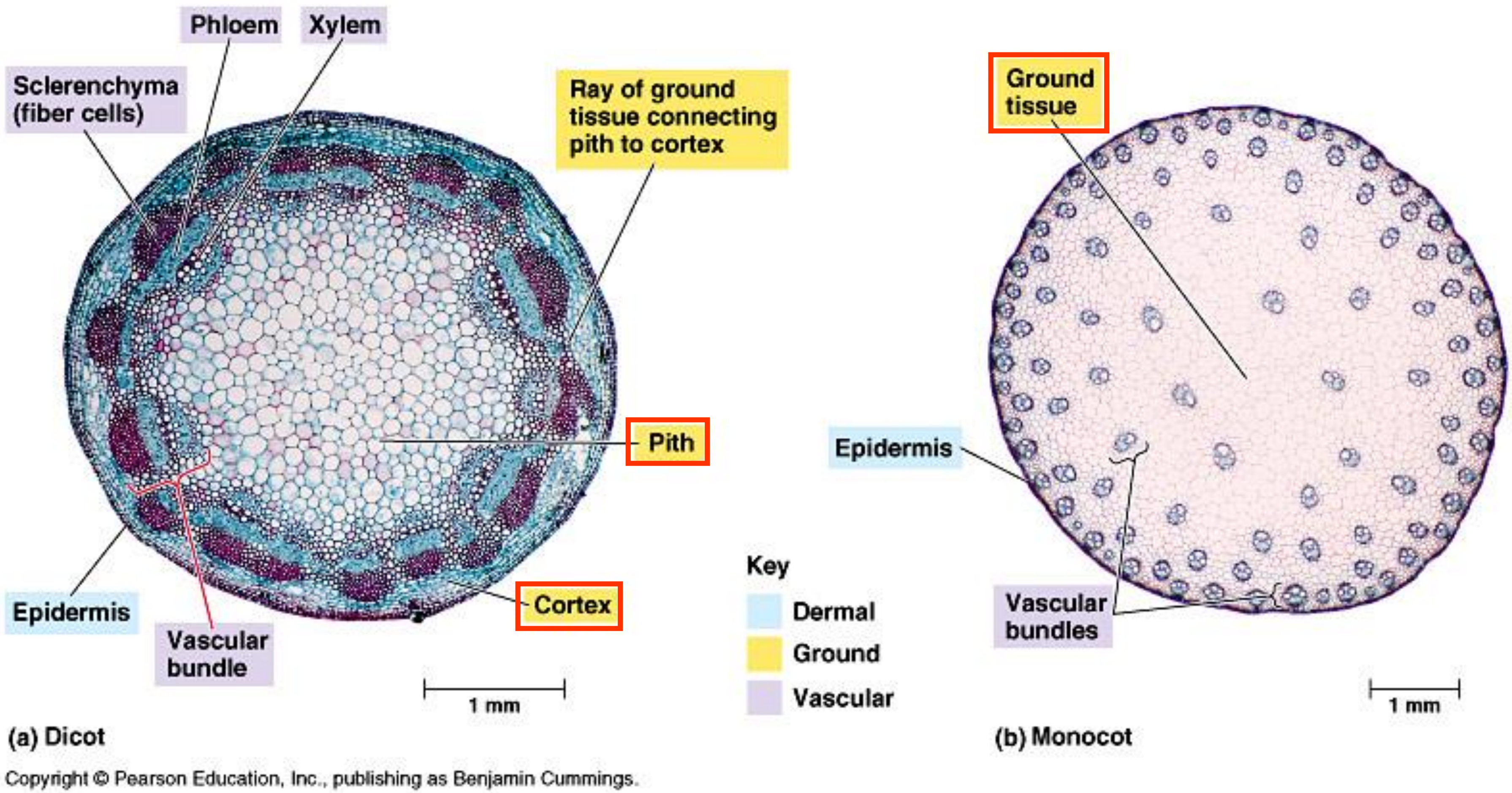
Primary growth in shoots / leaf

Ground meristem cells develop into **ground tissues**



Primary growth in shoots

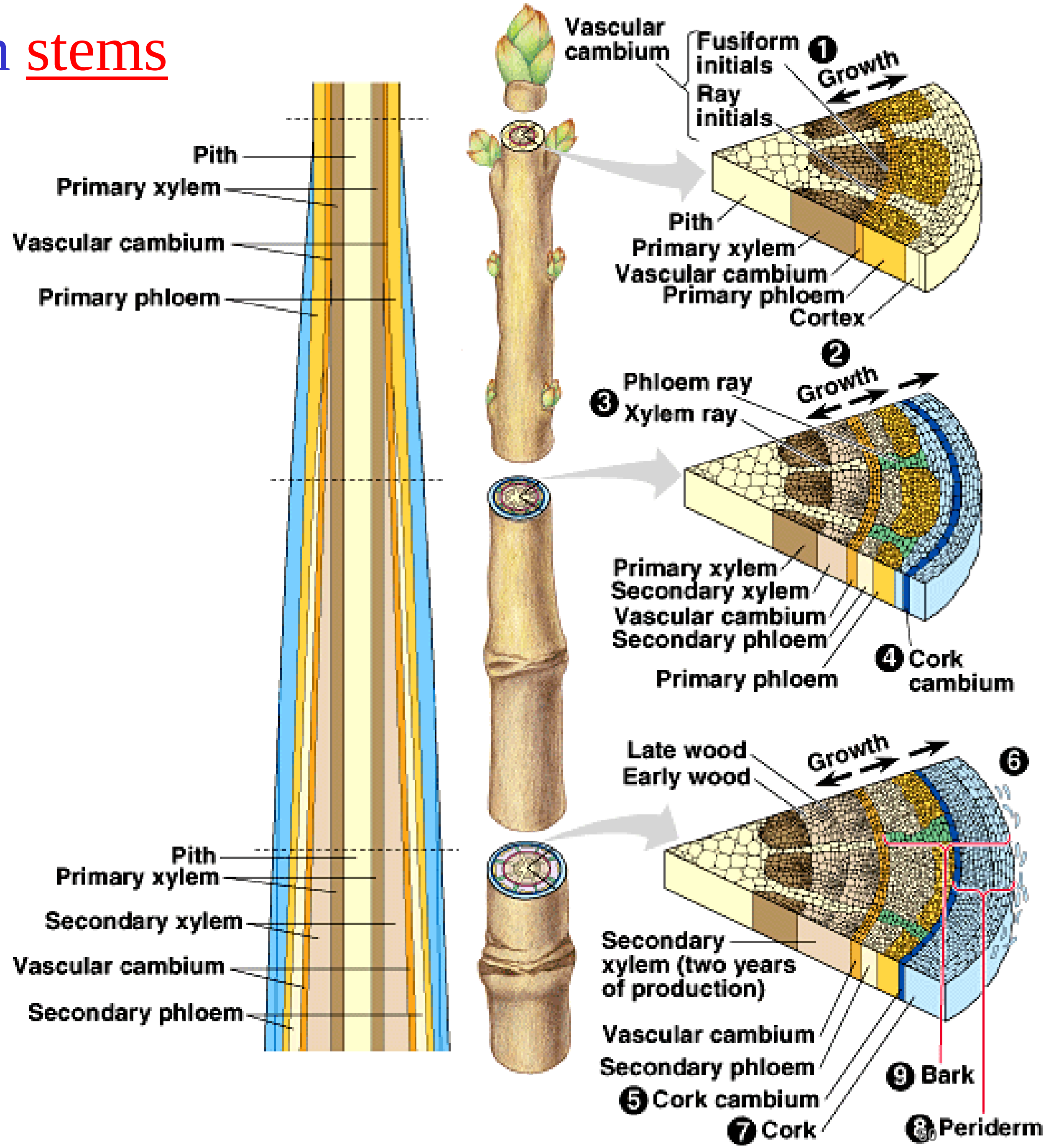
Ground meristem cells develop into **ground tissues**



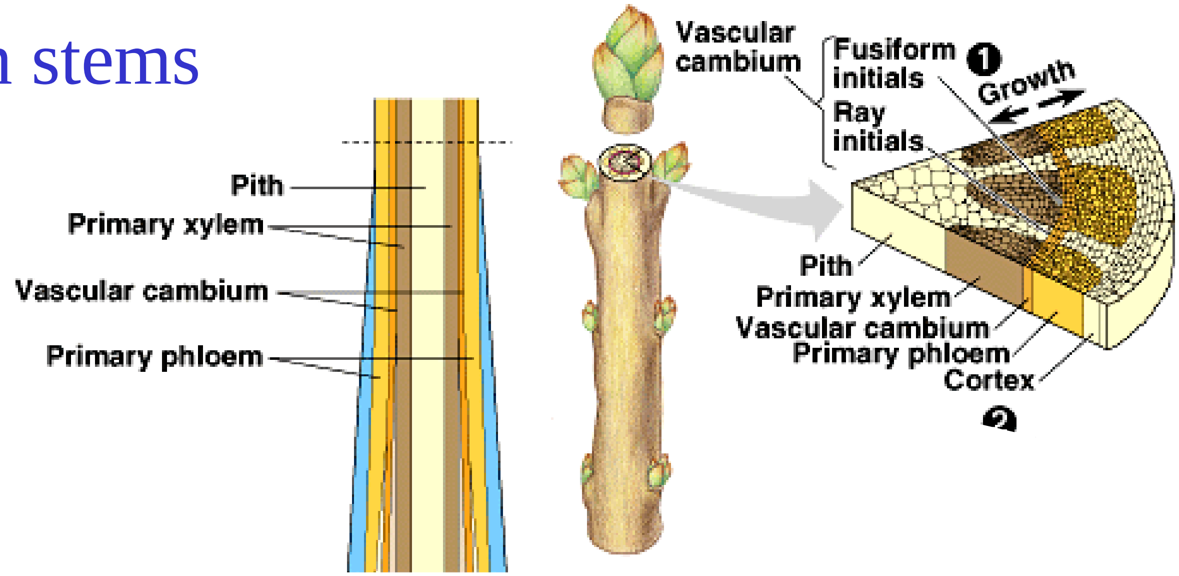
In dicot stems these are the **pith** and **cortex**

Secondary growth in stems

Girth growth

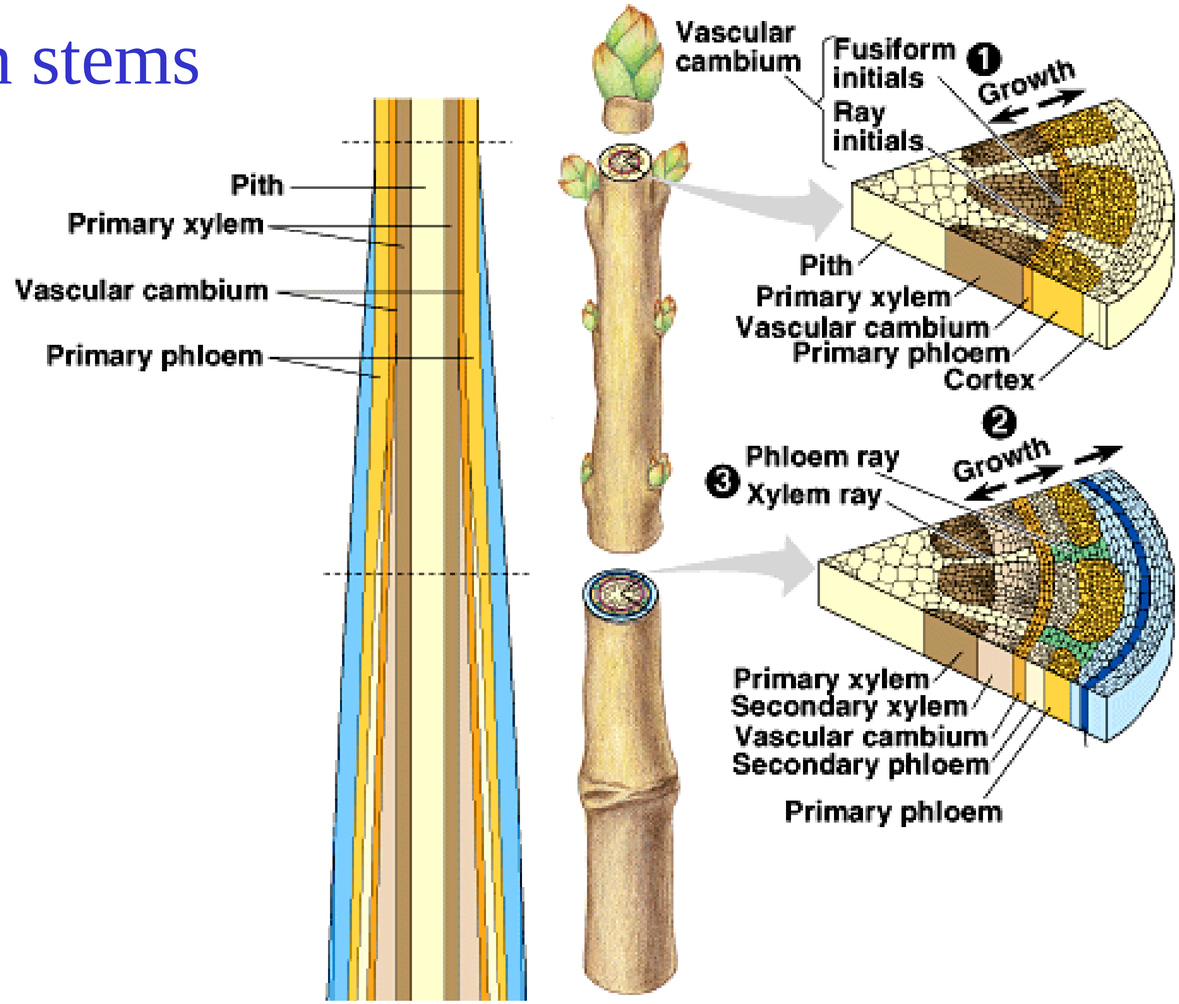


Secondary growth in stems



Primary growth at a branch tip lays down **apical** and **axillary meristems** for further lengthening, as well as a **lateral meristem**: the **vascular cambium**

Secondary growth in stems

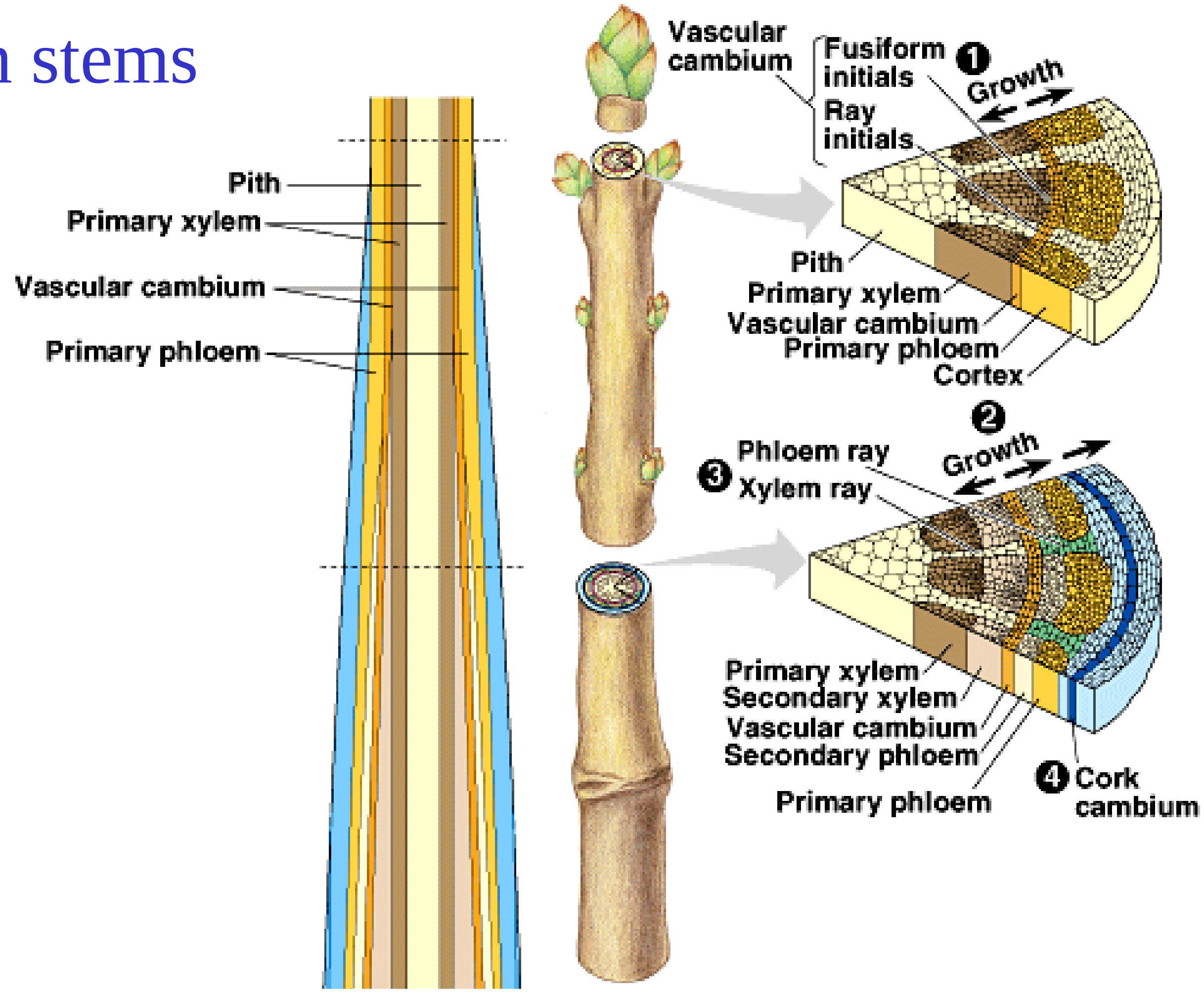


The **vascular cambium** produces **secondary xylem** to the inside and **secondary phloem** to the outside

Secondary growth in stems

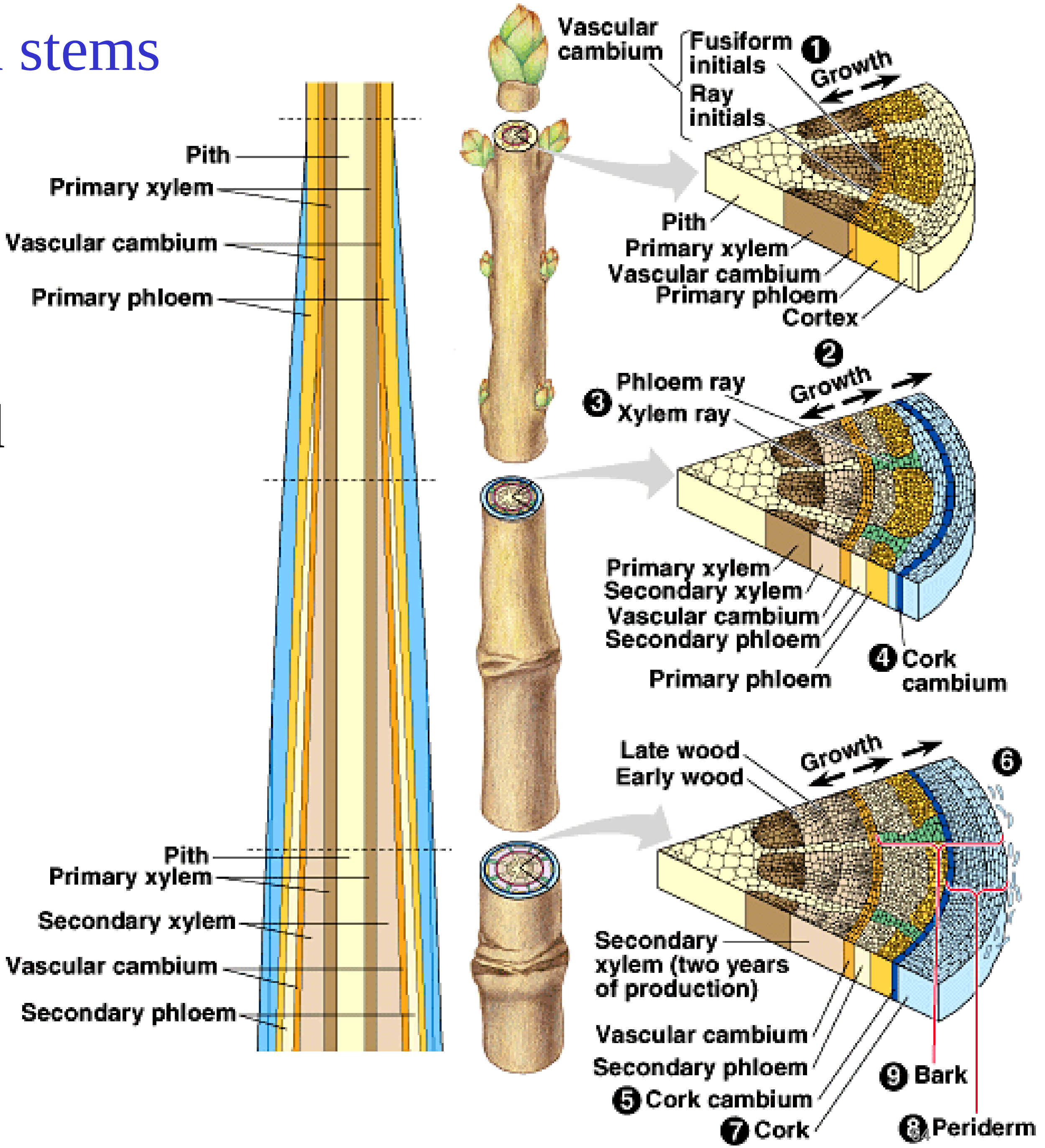
A second **lateral meristem** develops from the **cortex**: the **cork cambium**

Cork cambium produces **cork cells** that replace the **epidermis**



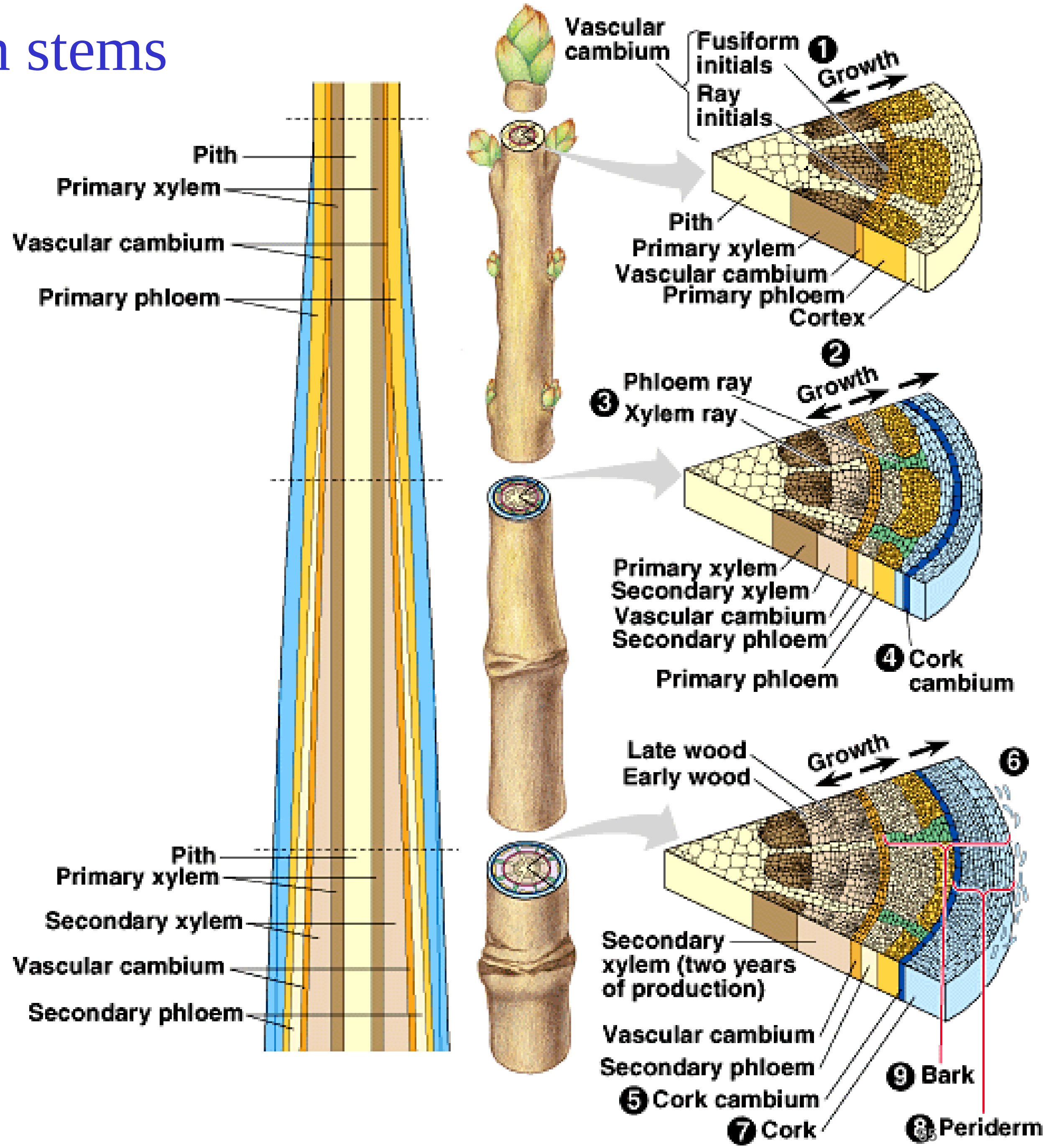
Secondary growth in stems

As the stem continues to expand its girth, the tissues outside the **cork cambium** rupture and slough off



Secondary growth in stems

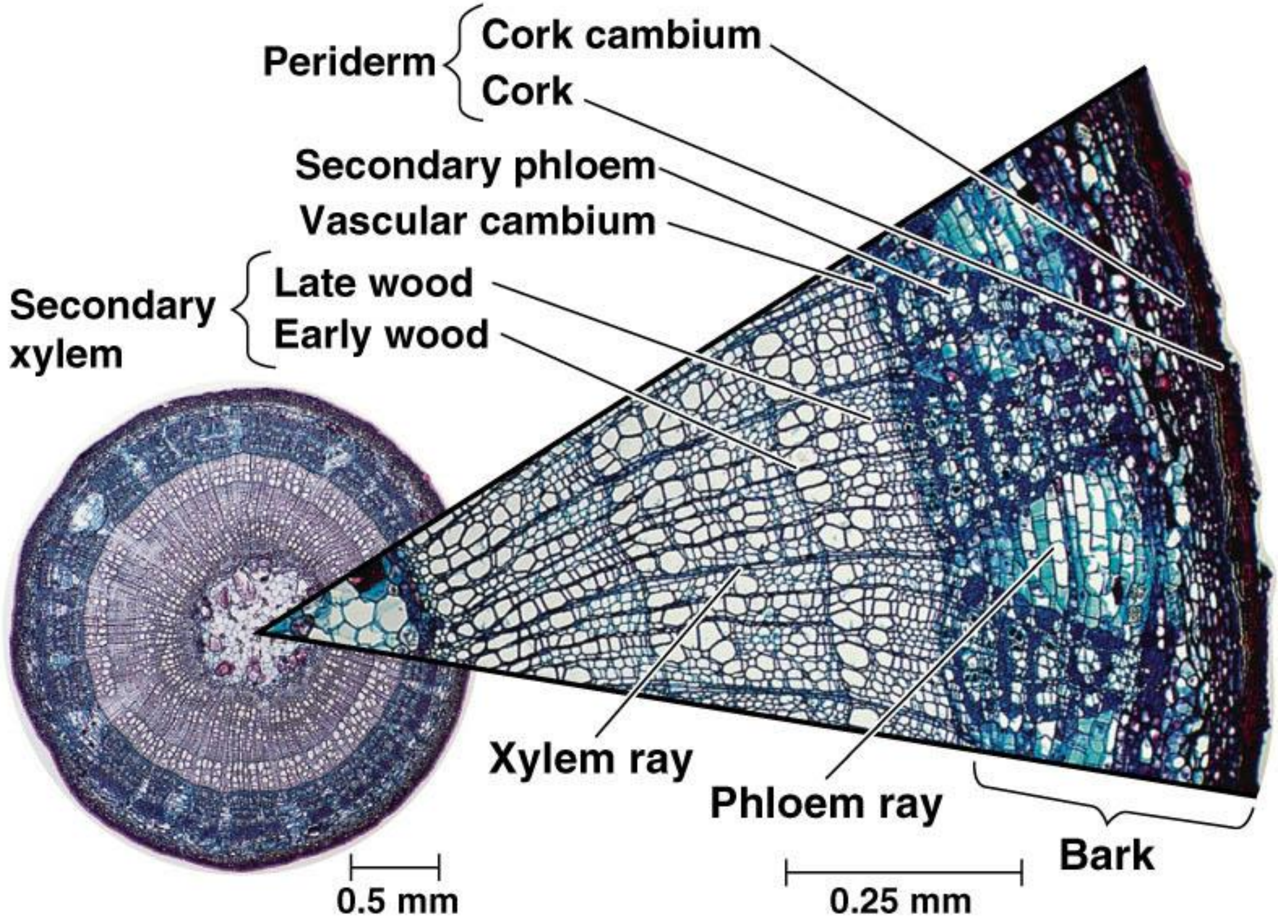
As the stem continues to expand its girth, the **cork cambium** reforms in deeper layers of cortex tissue, and then in **secondary phloem** when the primary cortex is gone



Secondary growth in stems

Periderm: **Cork cambium** and **cork**

Bark: All tissue outside **vascular cambium**

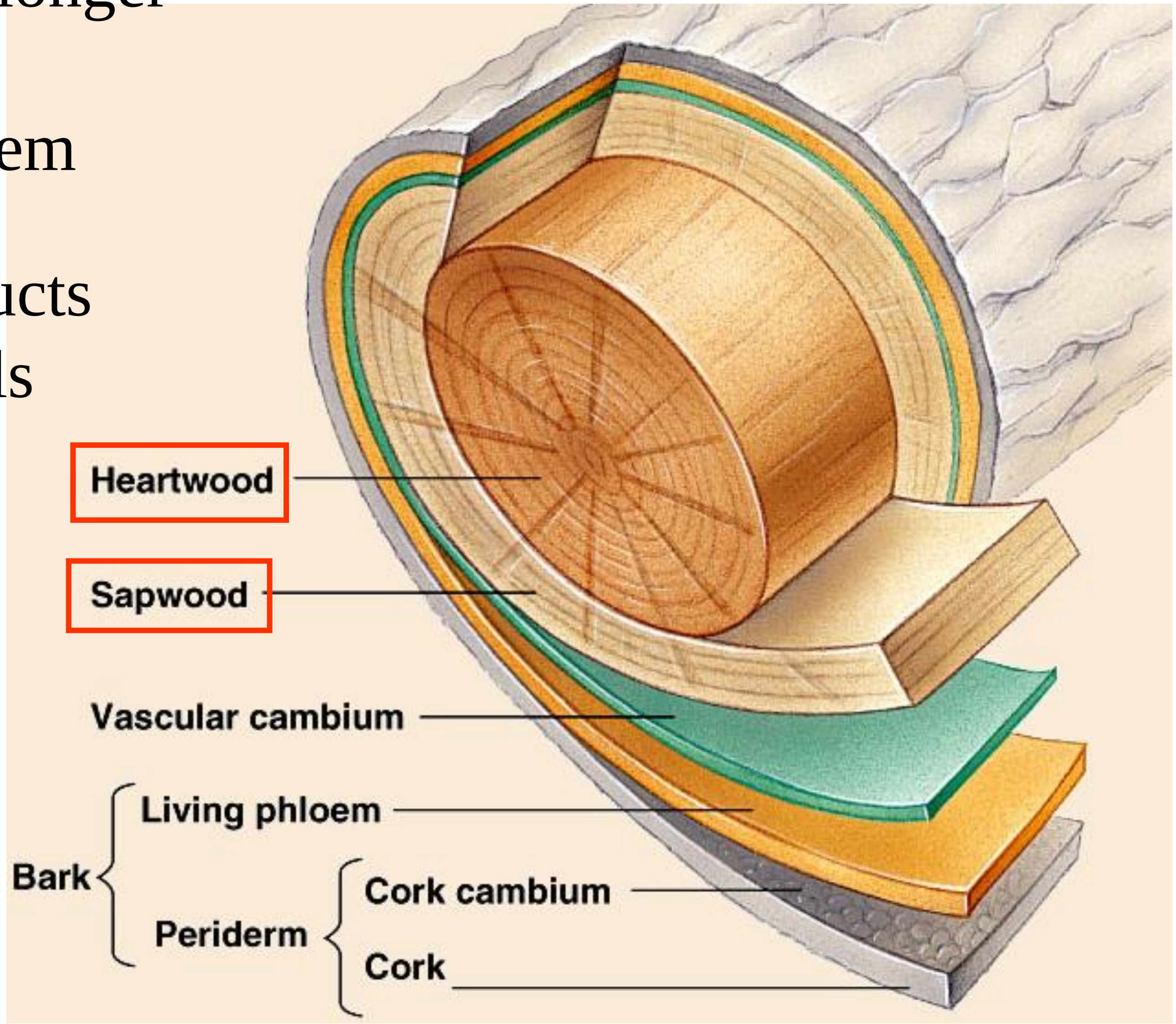


What is “wood”?

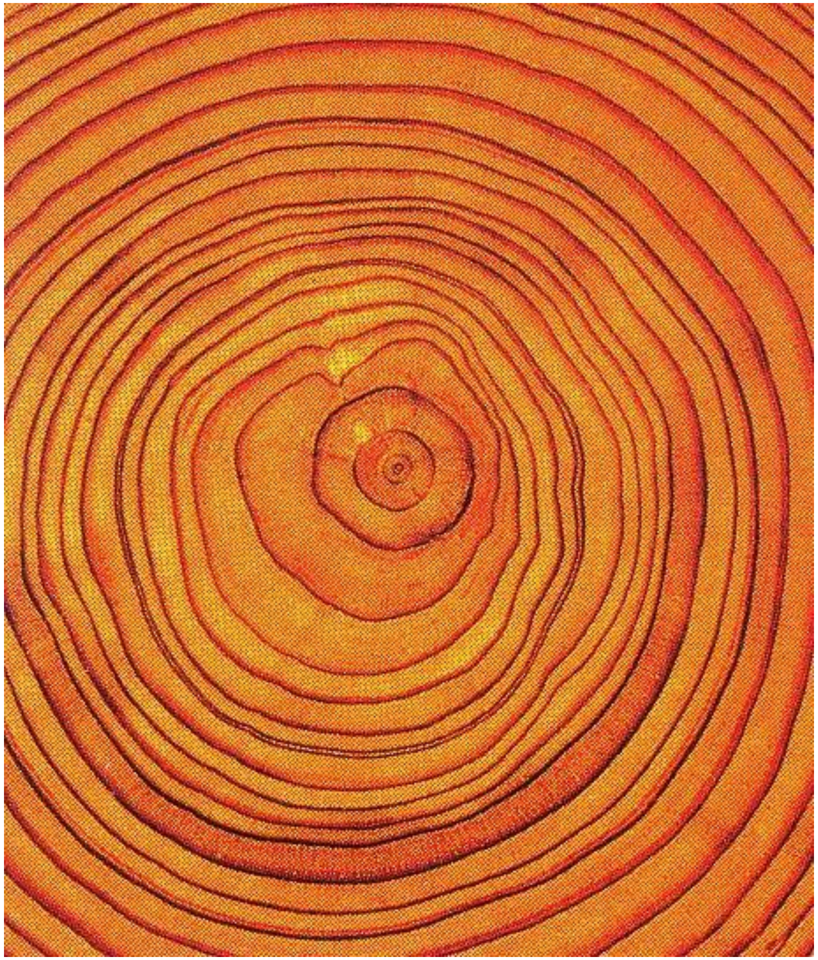
wood = secondary xylem

Heartwood: No longer conducts water,
but strengthens stem

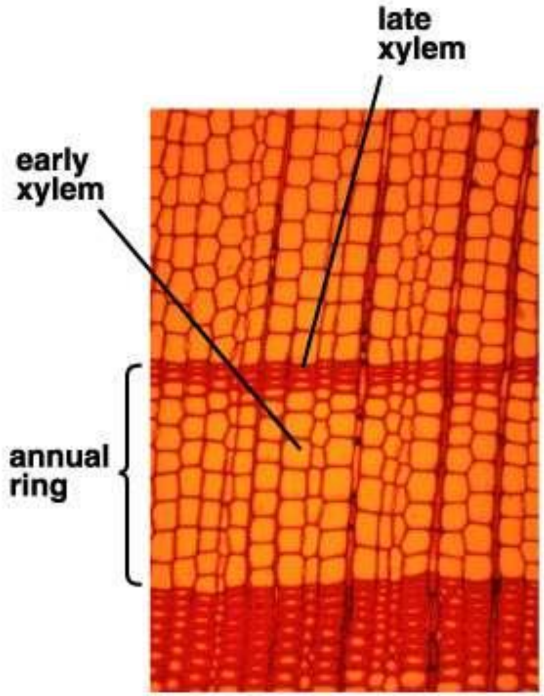
Sapwood: Conducts water and minerals

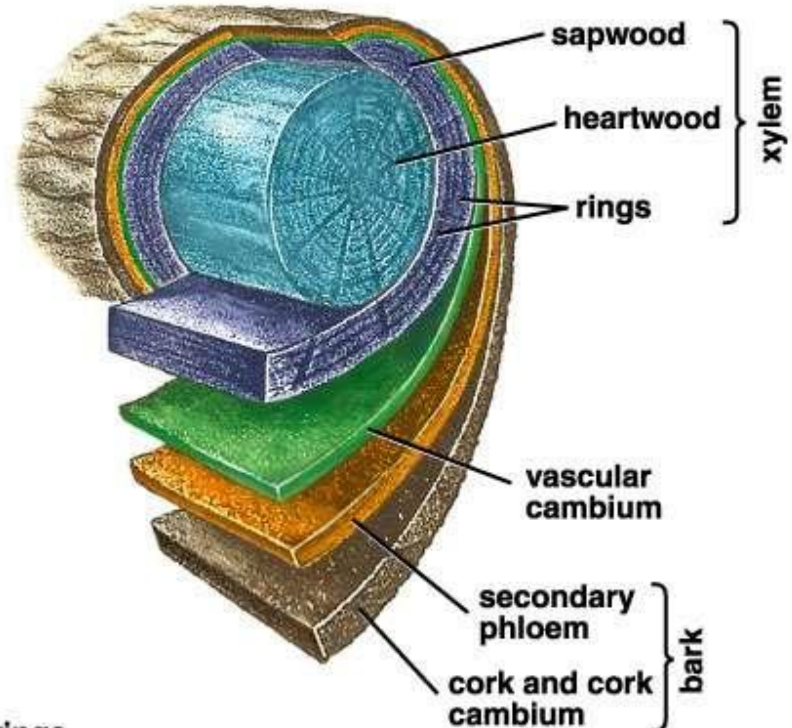


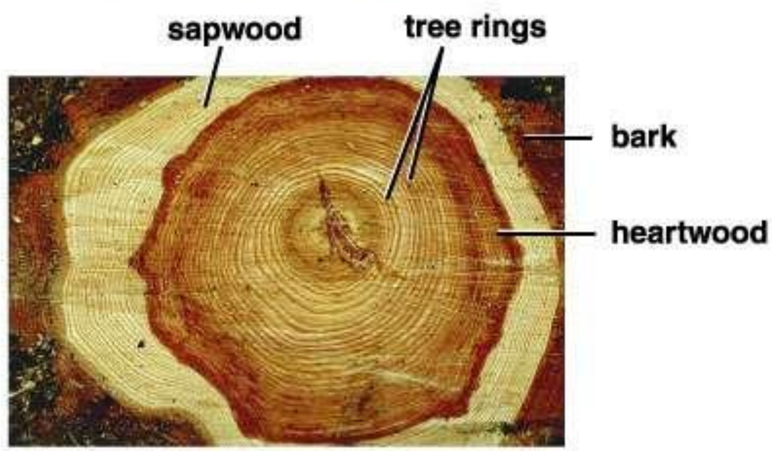
Why do trees have rings?



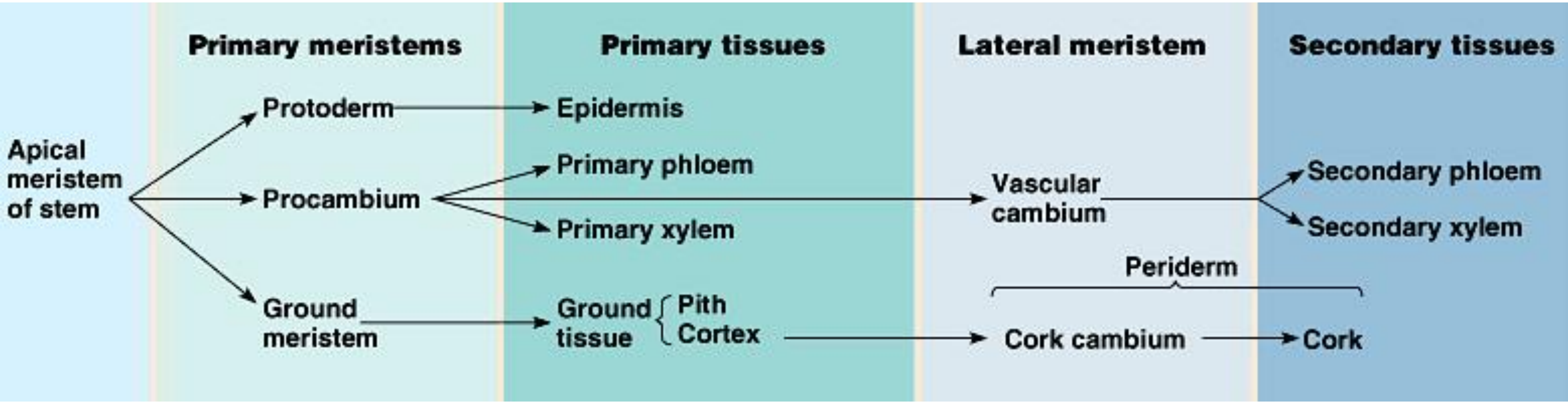
Seasonal differences in the rate of xylem production produce annual rings







Summary of 1º and 2º growth in a woody stem



Growth – increase in mass by cell division and cell expansion

Differentiation – specialization

Morphogenesis – the development of body form and organization

Development – all the changes that progressively produce an organism’s body (growth, differentiation, *etc*.)

If all cells of a body contain the same set of genes, how do they differentiate, and how does morphogenesis occur?

Differential expression of genes owing to differences in the environment each cell experiences

If all cells of a body contain the same set of genes, how do they differentiate, and how does morphogenesis occur?

For example, positional information determines whether the cells produced by an apical meristem become protoderm, ground meristem, or procambium

If all cells of a body contain the same set of genes, how do they differentiate, and how does morphogenesis occur?

Every step in development requires input from both genes and the environment!