(2) Vacuole

① Definition: vacuole is a kind of complex aqueous solution enveloped by tonoplast full of cellular fluid and containing a variety of organic and inorganic substances; it is one of the obvious differences between plant and animal cell structures.

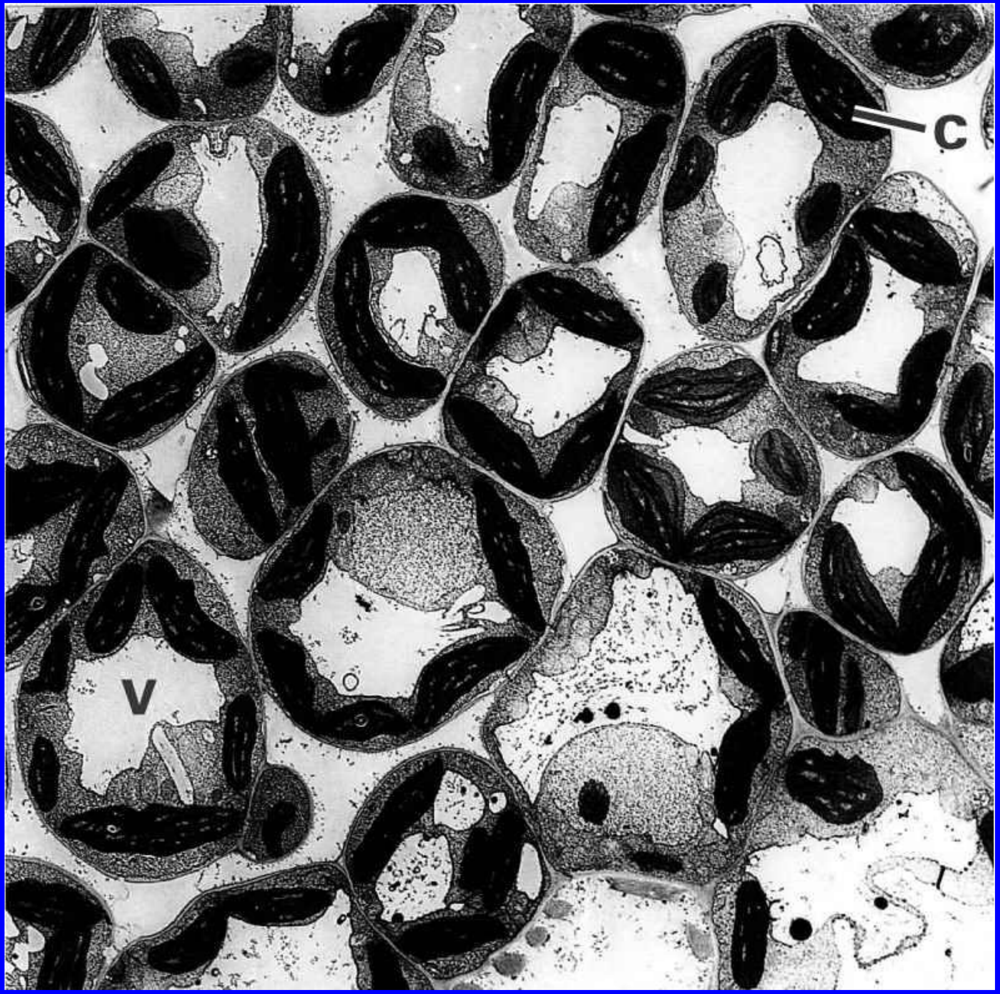
② Function:

Store cellular metabolites and excretions;

The cellular fluid is hypertonic, so that cells are at full capacity of carrying out normal physiological activities and resisting drought and cold.

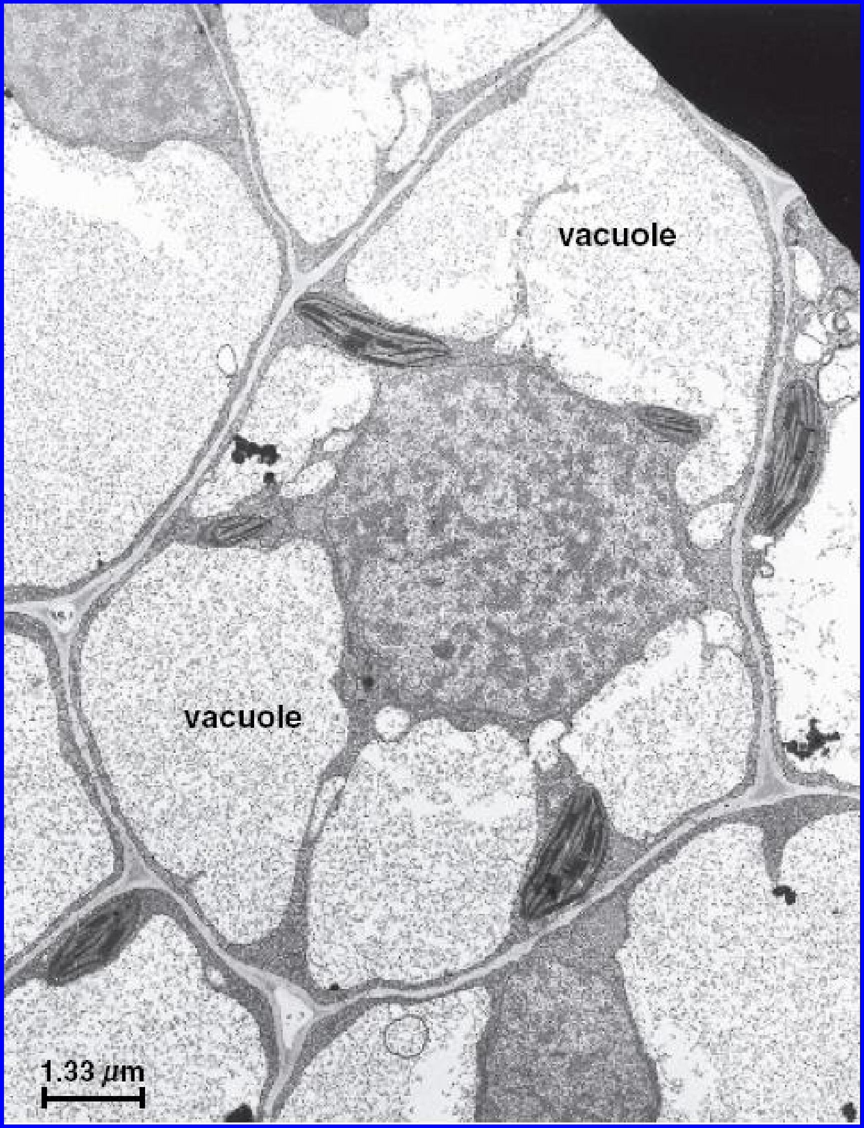
Participate in the biochemical cycle of endomembrane system material, cell differentiation & aging and other important life processes.

It is conducive to gas and nutrients exchange between the protoplasts and the external environment.



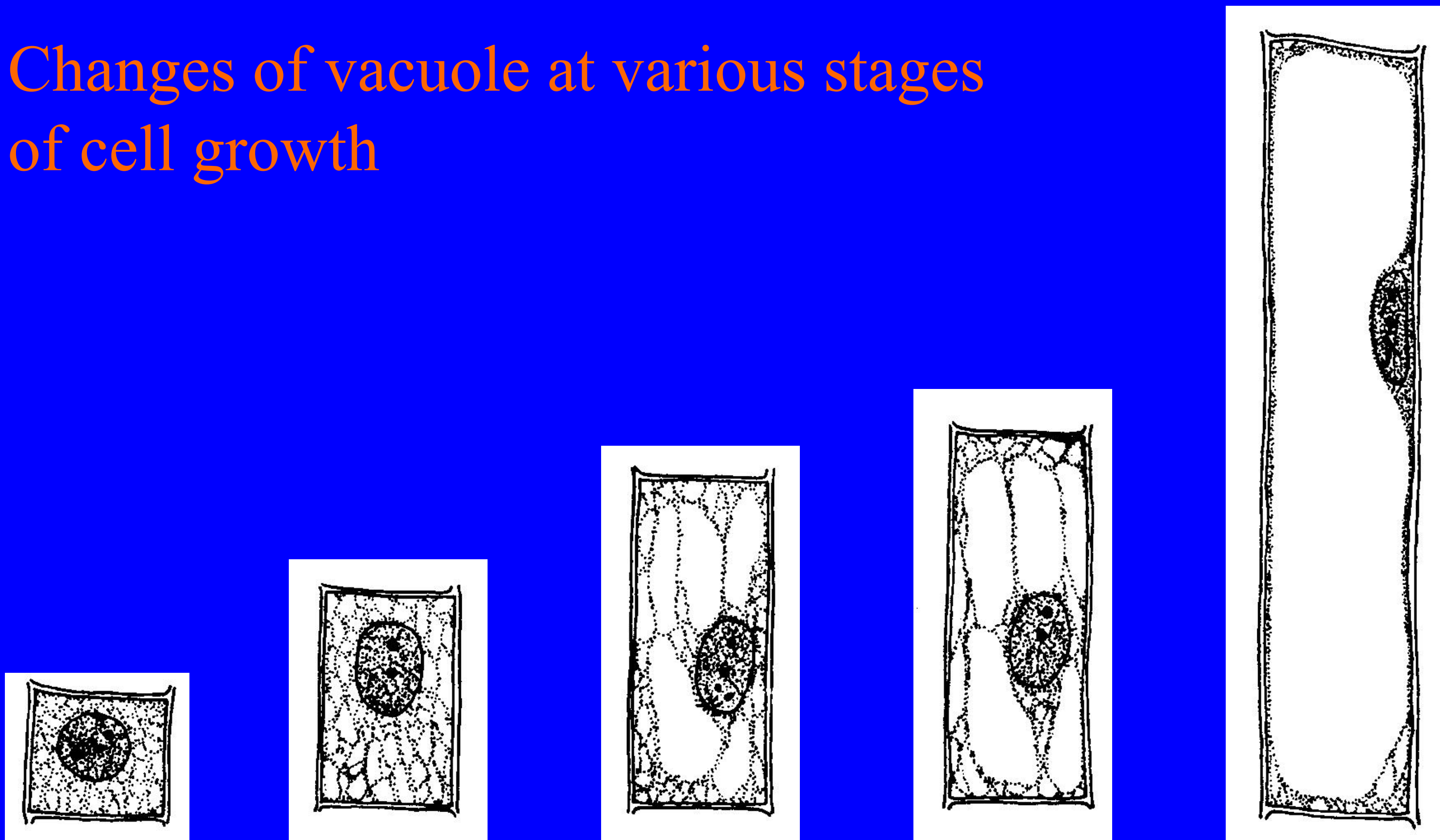
TEM showing a cross-sectional view of spongy mesophyll cells in a bean leaf illustrating the large amount of cell volume occupied by the central vacuoles (V).

Parenchyma cell from a tobacco (*Nicotiana tabacum*) leaf, with its nucleus "suspended" in the middle of the vacuole by dense strands of cytoplasm. The dense granular substance in the nucleus is chromatin. (From Evert 2006)



Tannin-containing vacuole in leaf cell of the sensitive plant (*Mimosa pudica*). The electron-dense tannin literally fills the central vacuole of this cell. (From Evert 2006)

Changes of vacuole at various stages of cell growth



(3) Other organelles

- ♣ Mitochondrion (more than 100 types of enzyme, the power plant)
- ♣ Endoplasmic reticulum (smooth type, rough type; forming a tight channel, protein synthesis, synthesis of cell wall substance.)
- ♣ Golgi apparatus (related to the secretory function of cells)
- ♣ Ribosome (free and attached, multiple series in protein synthesis).
- ♣ Lysosome (containing a variety of hydrolases, storage material utilization, cell differentiation and aging)
- ♣ Spheroplast (non-unit membrane, fat storage)
- ♣ Microsomes (peroxisome and glyoxysome)
- ♣ Microtubules and microfilaments (microtrabecular system, related to cell shape maintenance, wall formation and growth, and cell and organelle movement)

(4) Relationship among various organelles

- Organelles have functional division, but they are interconnected and interdependent.
- They are also interconnected in structure and origin.
- Evolutionary significance of endomembrane system membranes: compartmentalization; huge surface area, ensuring orderly and efficient biochemical reaction; substance and information transmission system.

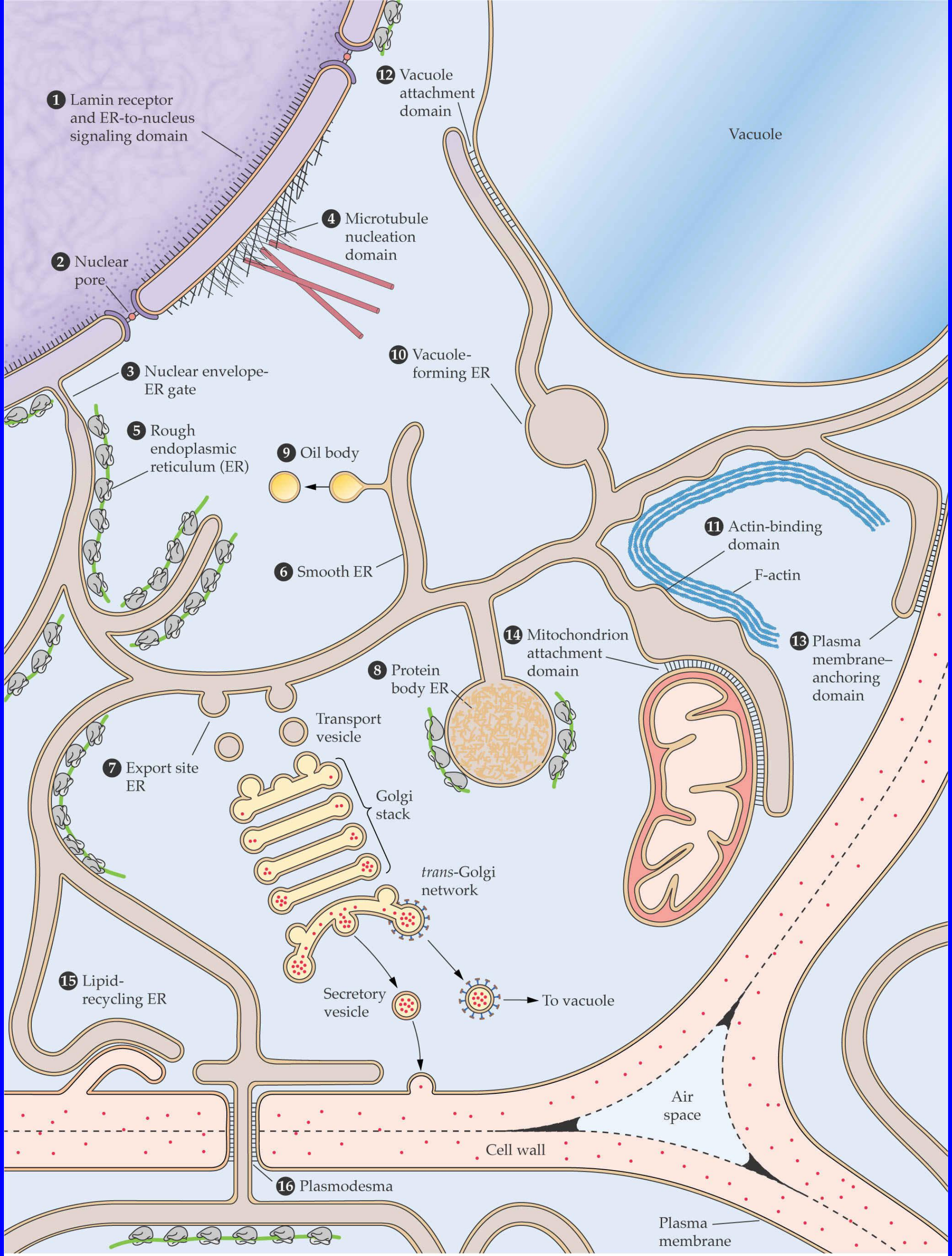
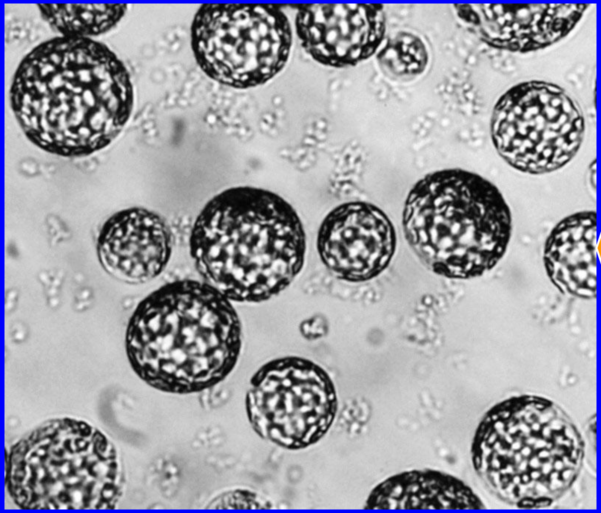


Diagram illustrating the functional domains of the plant ER systems.

(II) Cell wall

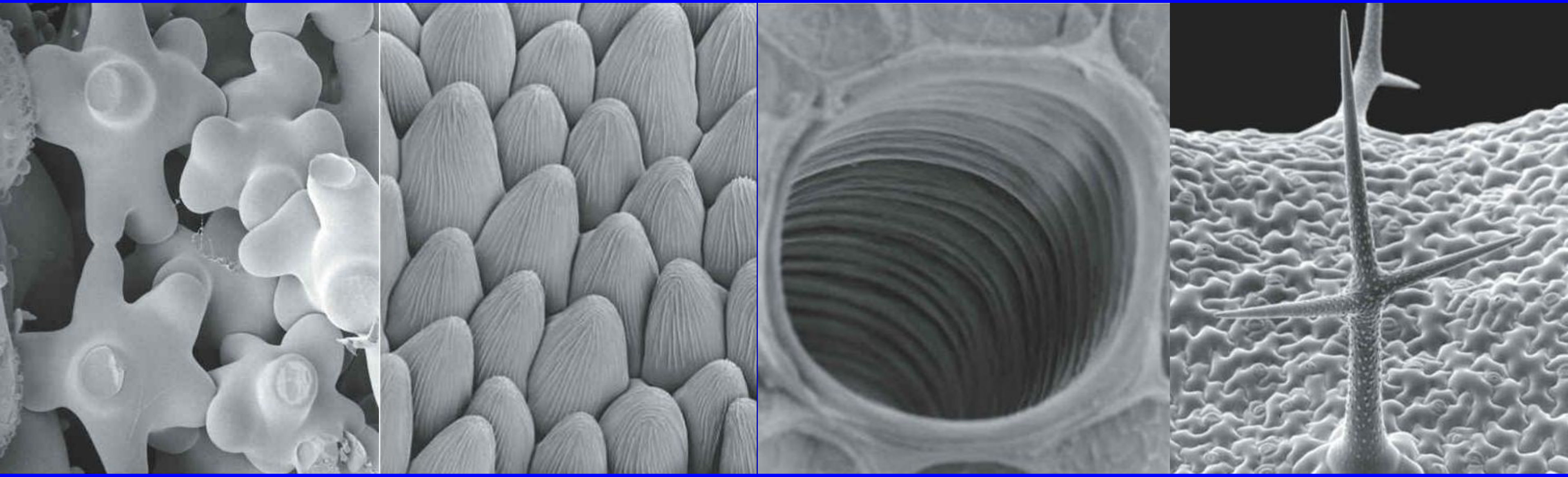
1. Definition: cell wall is a tough shell enveloping the cell protoplast and is composed of non-living substances secreted by protoplasts. Participate in wall growth, substance absorption, intercellular recognition, wall decomposition at the time of cell differentiation, and defend from pathogenic bacteria invasion.

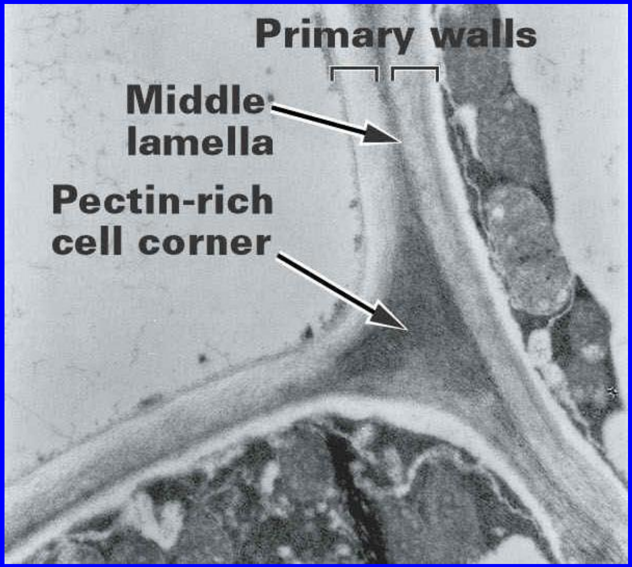
Chapter II Plant Cells and Tissues - Morphology of Cells



Without its wall, a protoplast adopts a spherical form.

A developing cell can change its wall architecture to provide myriad forms.





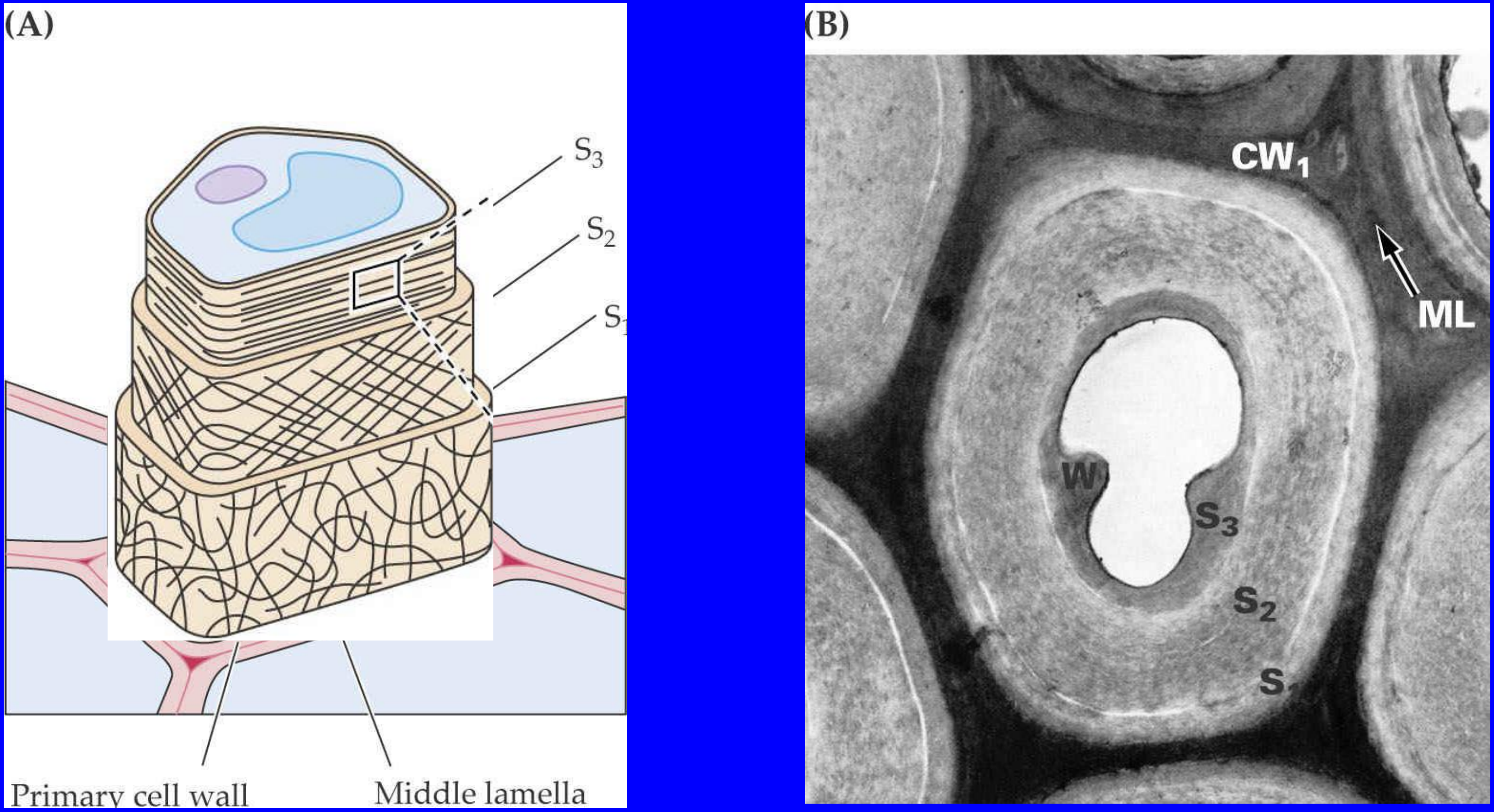
2. Level

Intercellular layer (the outermost pectin layer, with strong hydrophilicity and plasticity)

Primary wall (a cell wall layer composed of cellulose, hemicellulose and pectin secreted by protoplast before stopping growth of cells;

it is thin and soft, with large plasticity)

Secondary wall (a cell wall layer composed of cellulose and a small amount of hemicellulose that is formed inside the primary wall through accumulation after stopping growth of cells; it often contains lignin, and is thick and hard, with three (outer, middle and inner) layers in total.



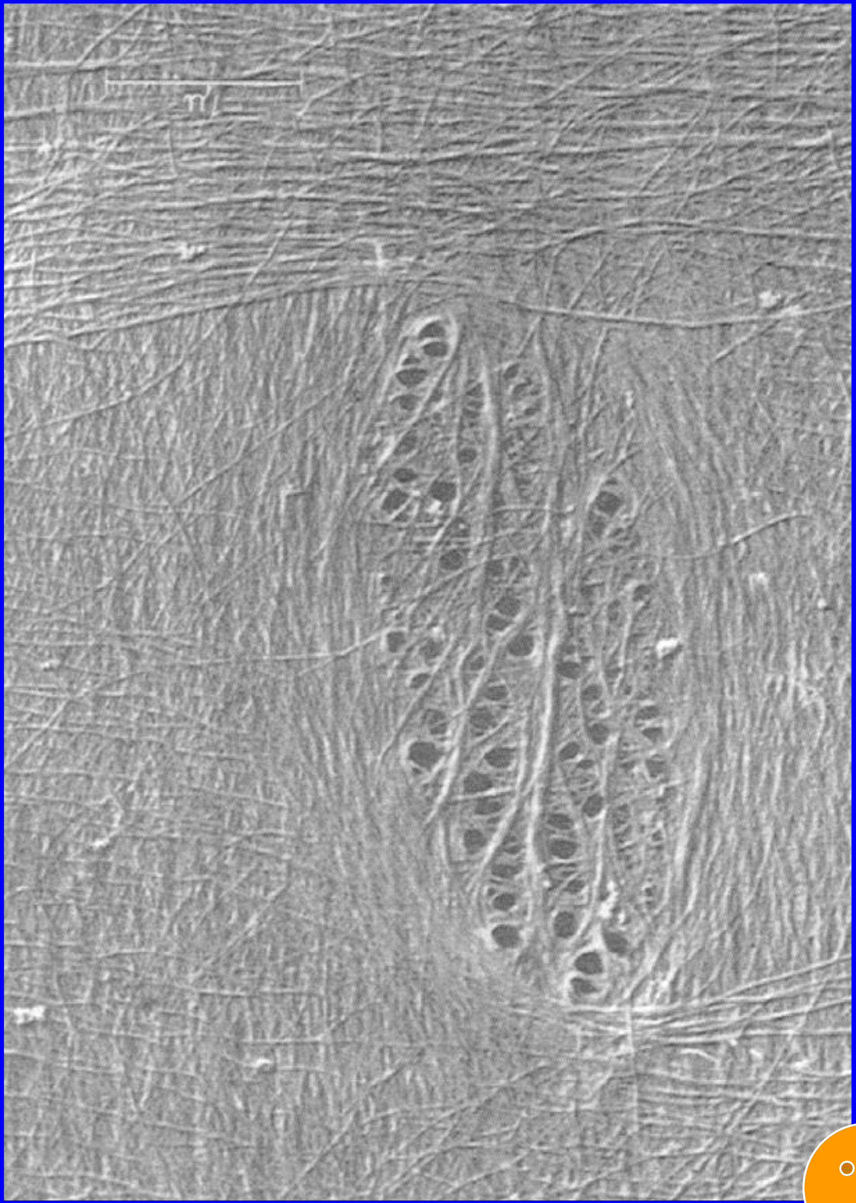
When they have achieved their final size and shape, some cells elaborate a multilayered secondary wall within the primary wall.

3. Pit and plasmodesmata

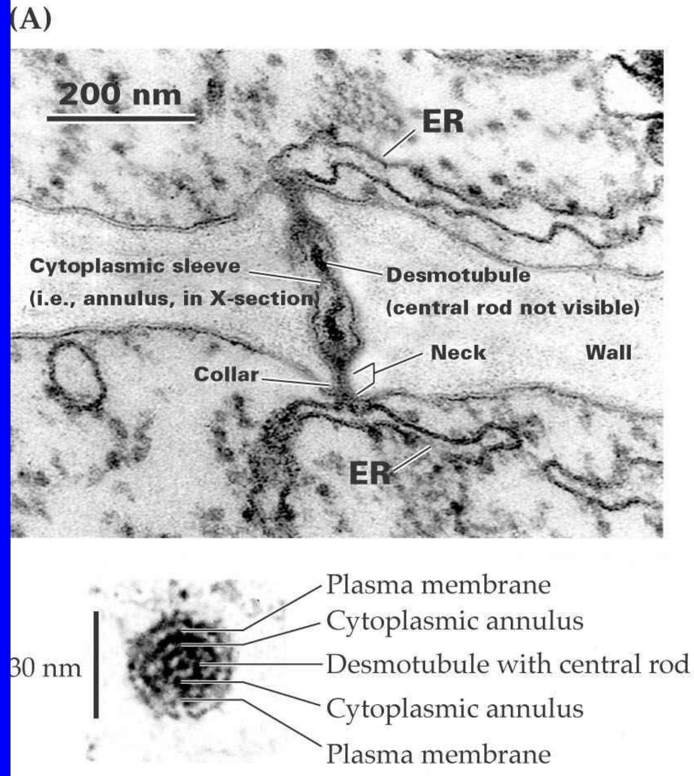
(1) Primary pit field: primary wall has some noticeably recessed areas.

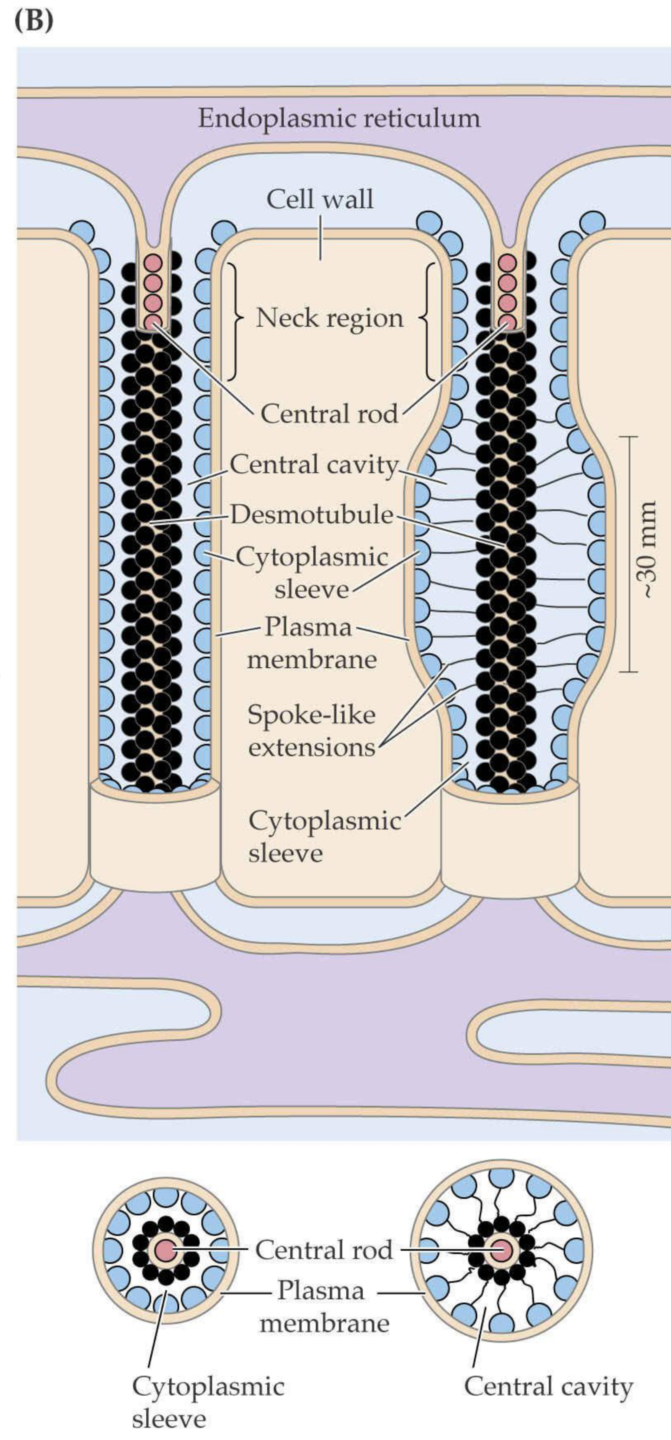
（2）Plasmodesmata: plasmodesmata is the protoplasm fibril threading through pores on walls of adjacent cells; it is a direct connection bridge for substance and information among cell protoplasts, and an important guarantee for a multicellular plant to become a unitary organism in structure and function.

Electron micrograph of primary wall of a parenchyma cell from oat, *Arena* (Gramineae), coleoptile. The parallel-oriented microfibrils at top occurred in one of the angles of the cell. Other microfibrils show a random orientation. Plasmodesmatal pores are clustered in a primary pit field, ×26,000. Reprinted with permission from Böhmer (1958), *Planta* 50, 461-497.

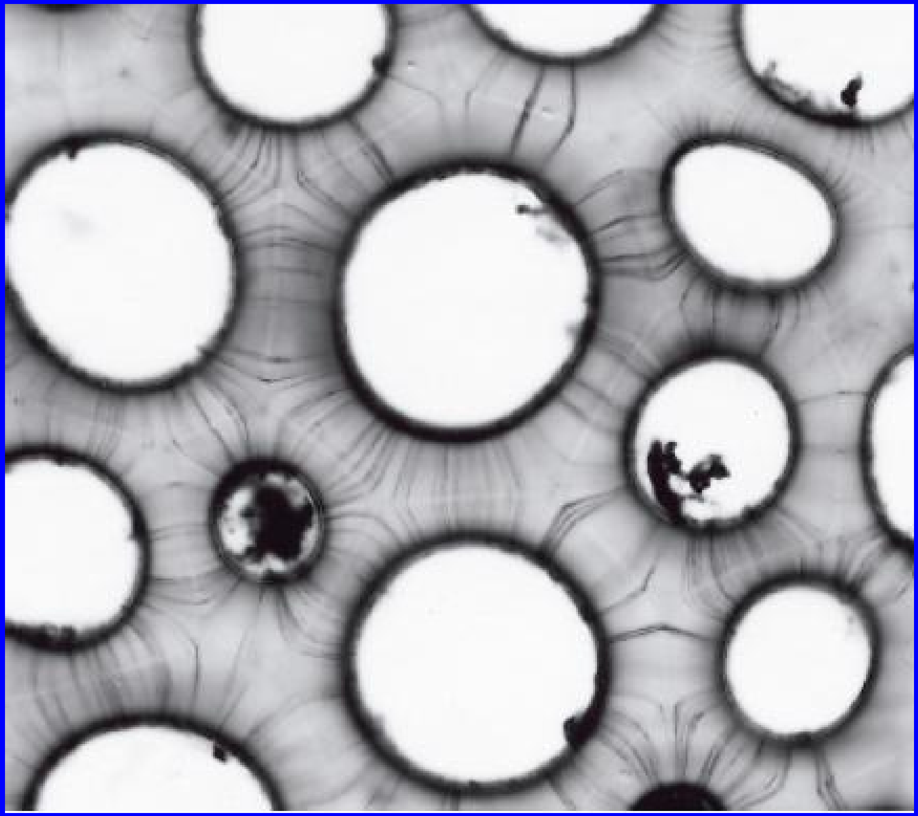


Chapter II Plant Cells and Tissues - Morphology of Cells





Electron micrographs of plasmodesmata in longitudinal and cross-sections (A), and a model of plasmodesmal substructure of tobacco leaves (B).



Light micrograph of plasmodesmata in the thick primary walls of persimmon (*Diospyros*) endosperm, the nutritive tissues within the seed. The plasmodesmata appear as fine lines extending from cell to cell across the walls. (×620) (From Evert 2006)

(3) Pit: the area on primary wall that is not covered by the secondary wall at all at the time of secondary wall formation.

① Component:

Pit cavity: the cavity formed by the secondary wall and opening towards the cell compartment.

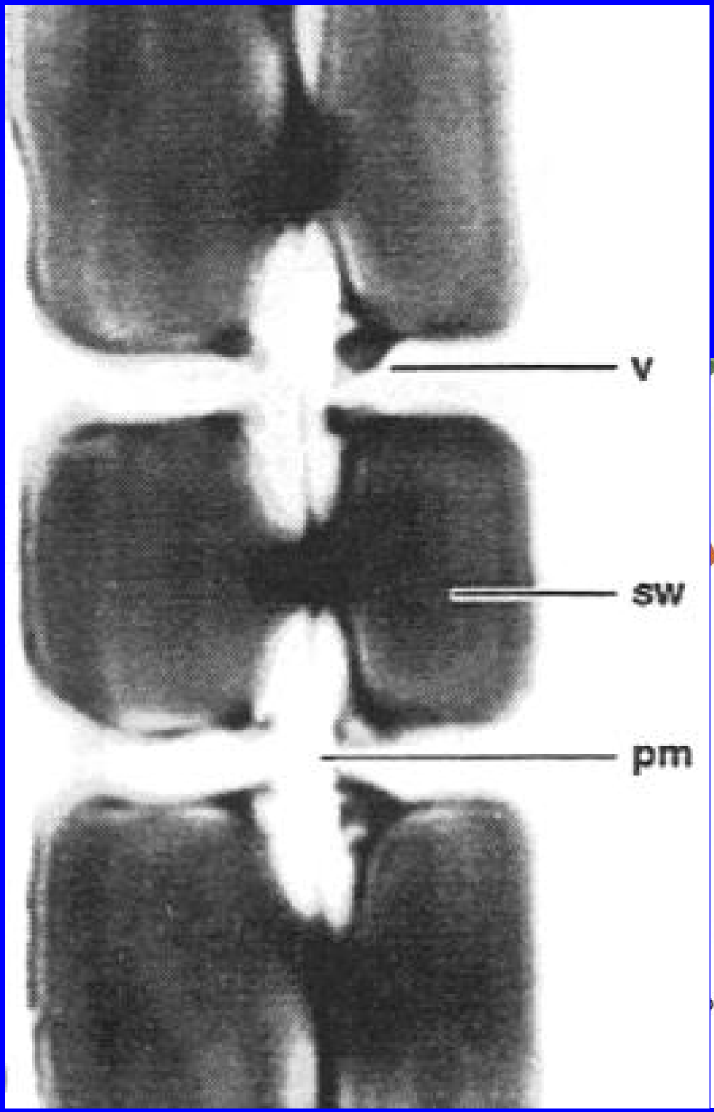
Pit membrane: the primary wall and intercellular layer portion at cavity bottom. Some membranes with thickened primary wall are specialized into pit plug, and the surrounding membranes are called plug edge.

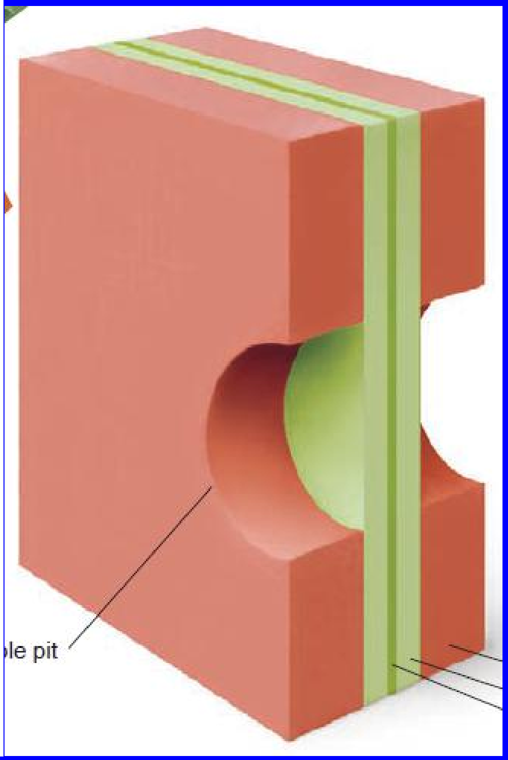
② Category:

Simple pit:

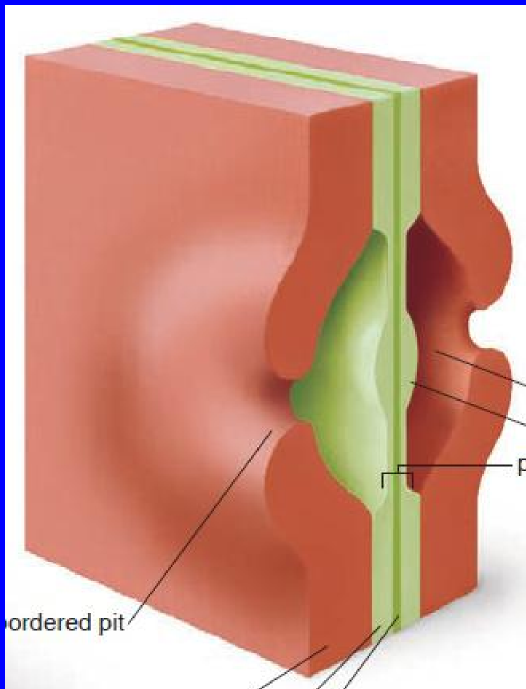
Bordered pit: bordered pit is the pit with obviously decrescent orifice due to the vaulted edge formed through cambered extension of secondary wall beyond the pit cavity.

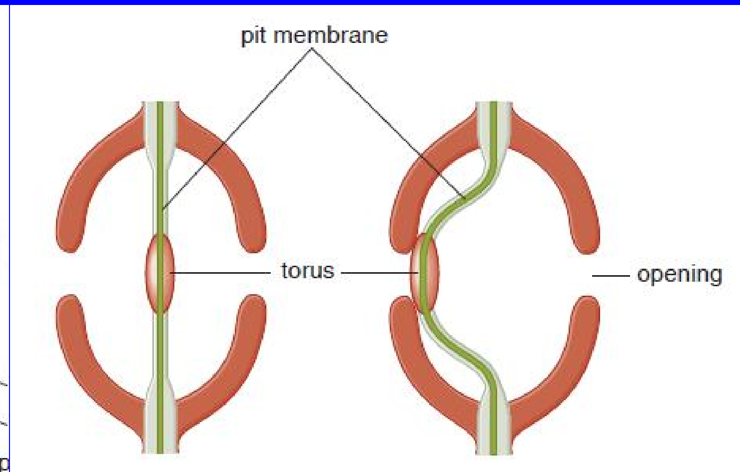
③Pit pair: The pits of two adjacent cells often appear oppositely, the two opposite pits are called pit pair.

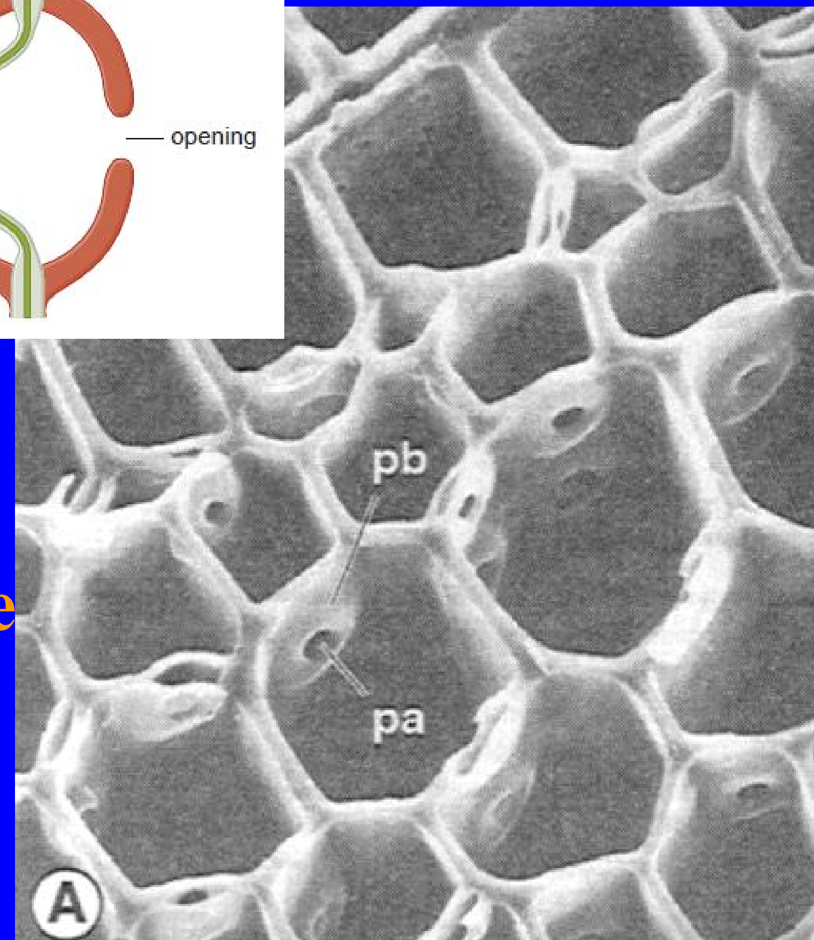




Light microscope sectional view of vestured pits in *Terminalia chebula*. ×ca. 3000. Abbreviations: pm, pit membrane, sw, secondary wall; v, vesture.

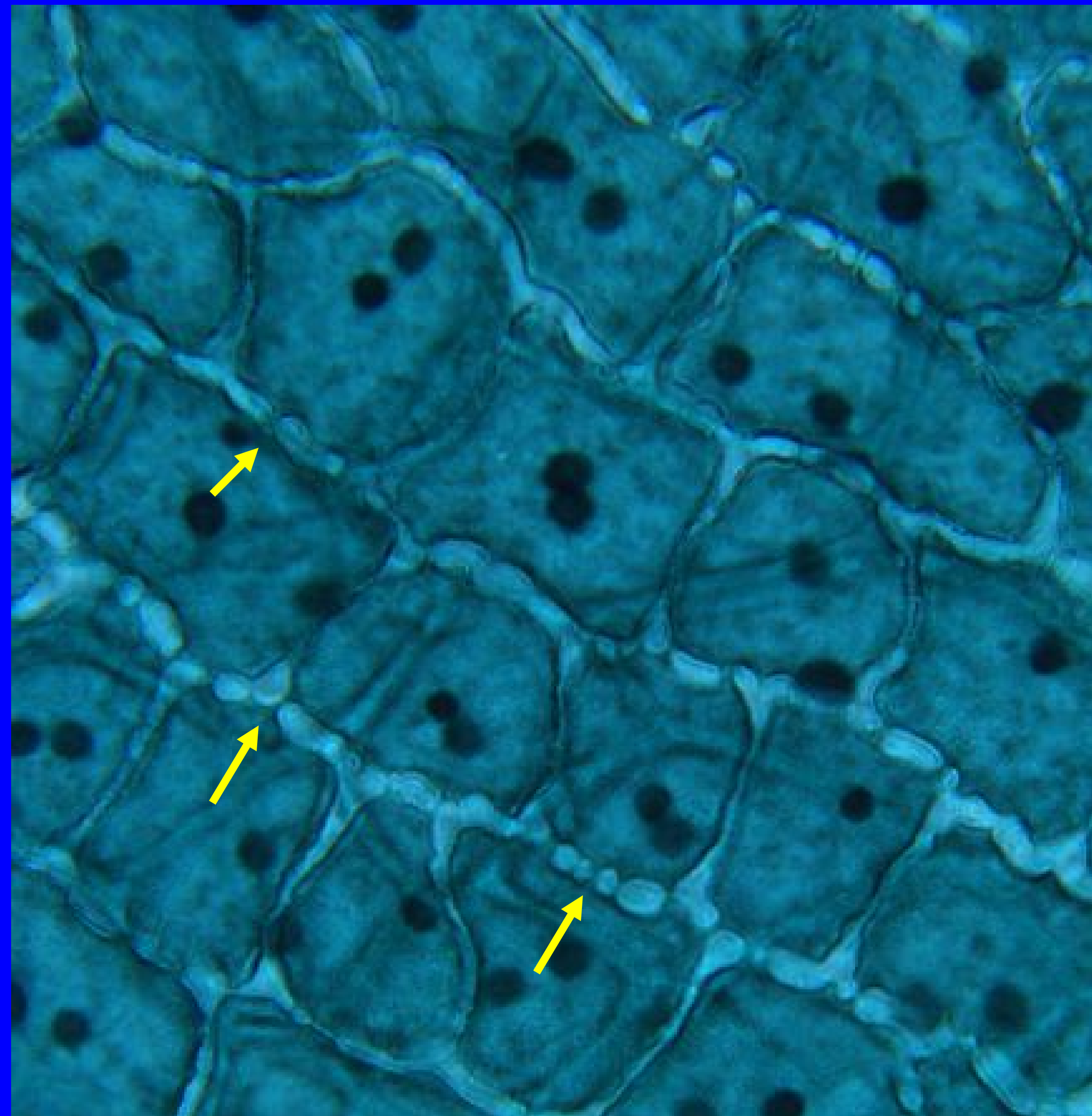






SEM of wood of eastern spruce (*Picea*) showing tracheids with circular bordered pit pairs on the lateral walls. Pit apertures (pa) and pit borders (pb) are visible, ×1300

Photomicrograph of chili fruit epidermis showing the pit pairs indicated by arrows.



4. Chemical components of cell wall:

Major components: cellulose, formed through glucosyl connection (β-1, 4-glucosidic bond)

Minor components: pectin, hemicellulose, and other noncellulosic polysaccharides (all are hydrophilic substances)

Other substances: cutin, suberin, lignin, mineral;

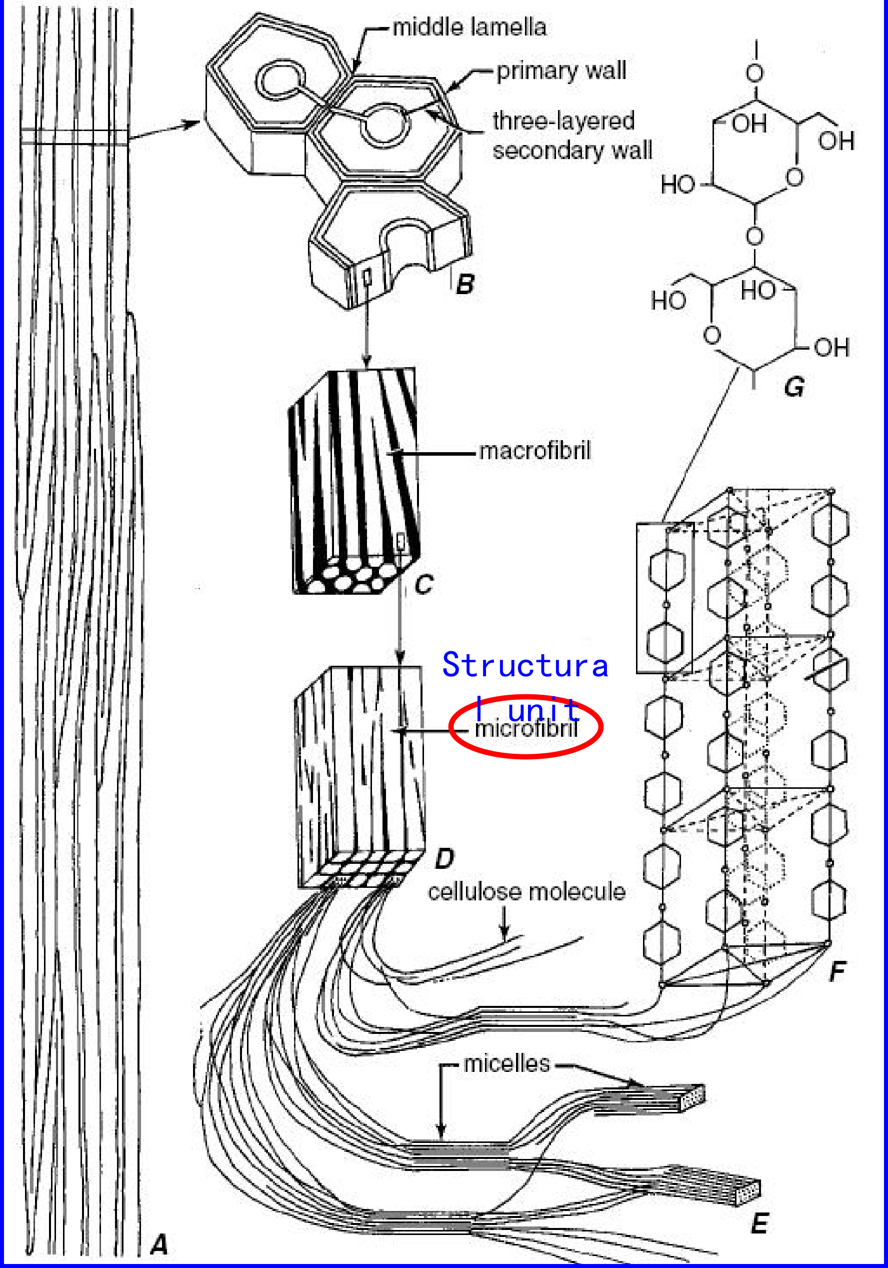
5. Submicroscopic structure of cell wall

(1) Cellulose molecules→ Cellulose molecular beam (micelle)→Microfibril (a structural unit composing cell wall)→macrofibril

(2) Microfibril of different cell wall layer has different orientation.

Primary wall: reticular arrangement, and mostly in parallel with the long axis of cells.

Secondary wall: the same orientation in outer, medium and inner layers, and mostly inclined to the long axis at an angle.



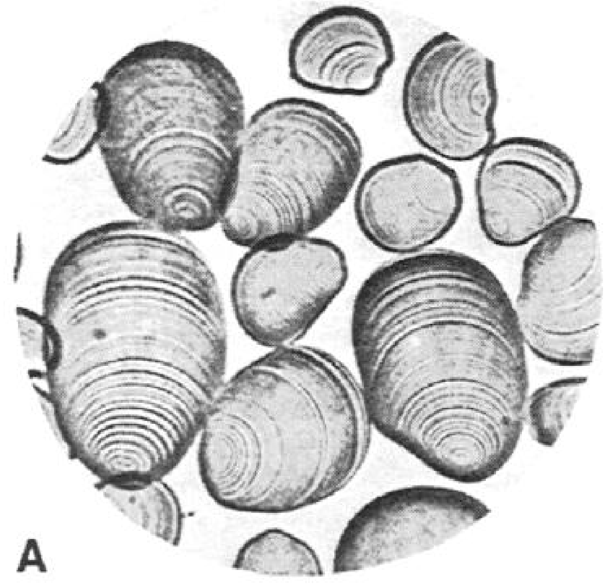
Detailed structure of cell walls. A, strand of fiber cells. B, transverse section of fiber cells showing gross layering: a layer of primary wall and three layers of secondary wall. C, fragment from the middle layer of the secondary wall showing microfibrils (white) of cellulose and interfibrillar spaces (black), which are filled with noncellulosic materials. D, fragment of a macrofibril showing microfibrils (white), which may be seen in electron micrographs. The spaces among microfibrils (black) are filled with noncellulosic materials. E, structure of microfibrils: chain-like molecules of cellulose, which in some parts of microfibrils are orderly arranged. These parts are the micelles. F, fragment of a micelle showing parts of chain-like cellulose molecules arranged in a space lattice. G, two glucose residues connected by an oxygen atom-a fragment of a cellulose molecule. (From Esau, 1977)

IV. Ergastic substances of plant cells

(I) Definition: it is the product of protoplast metabolism of cells, and can be produced and disappeared in different periods of cell activities; they can be stored products or waste.

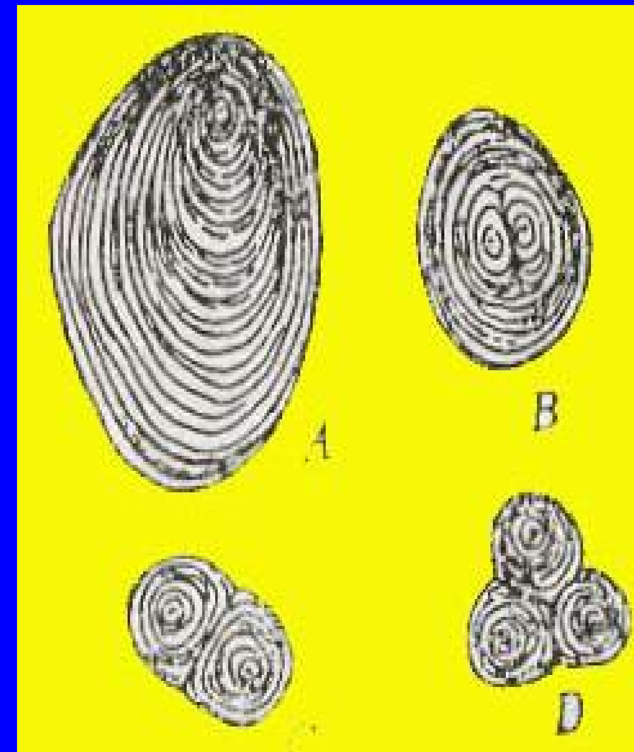
(II) Starch: it is the most common storage form of carbohydrates, and is formed by polymerization of glucose molecules.

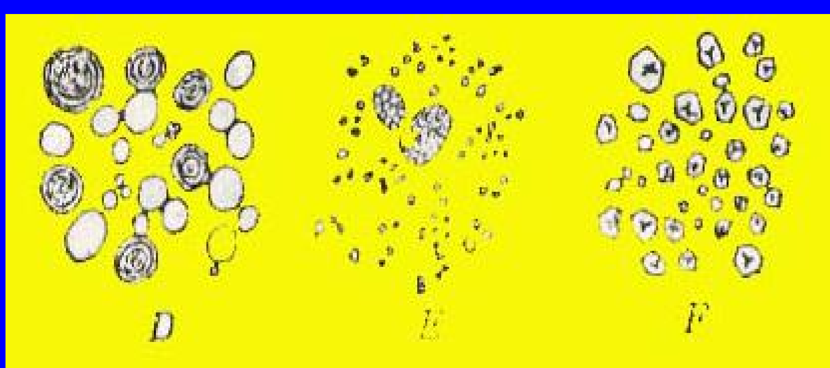
1. Starch grain: starch exists in cells in granular form, and is called starch grain. All parenchyma cells contain starch grains, which centrally exist in all kinds of storage organs. The morphological structure with annular striations

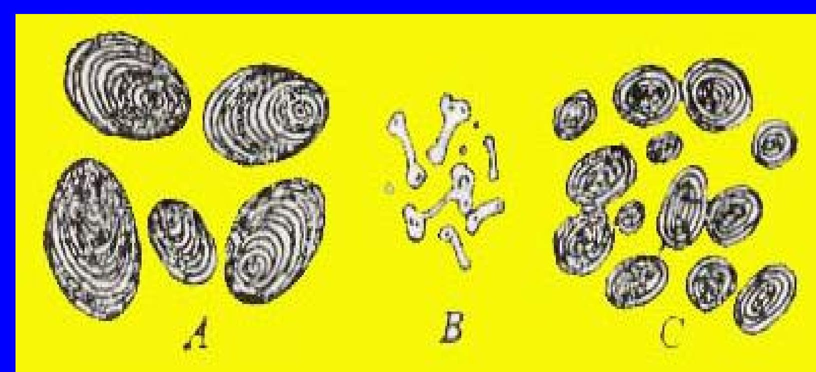


2. Type of starch grain

- Simple starch grain: one hilum and multiple annular striations
- Compound starch grain: more than two hilums and respective annular striations
- Half compound starch grain: more than two hilums and respective annular striations, with common annular striations.



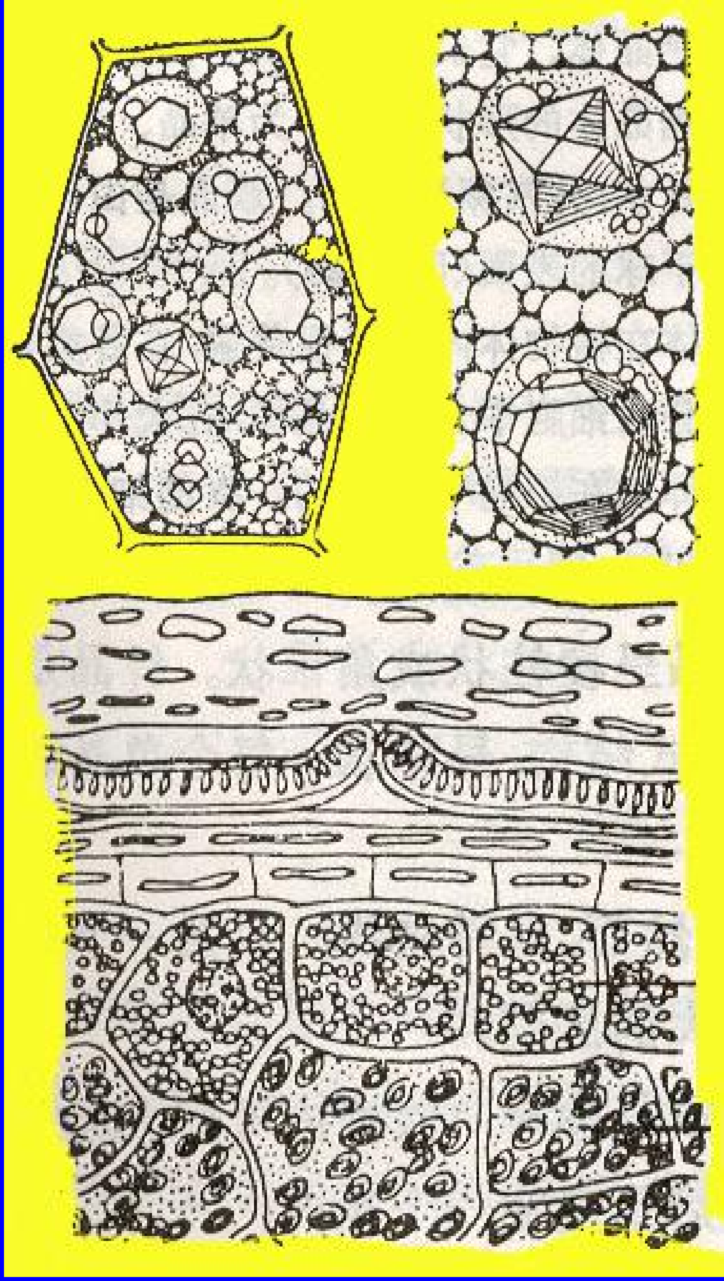




(III) Protein: storage protein in cells is in a solid state, and it can be crystal or amorphous.

Aleurone grain: amorphous protein is usually a spherical grain formed through being wrapped by a membrane, and is called aleurone grain.

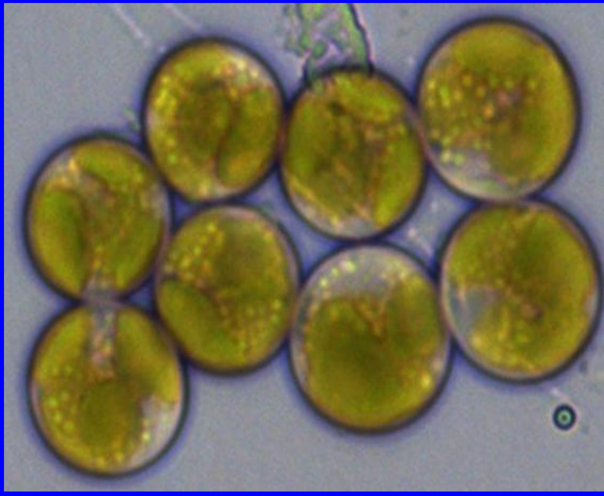
Aleurone layer: aleurone grains are intensively distributed in one or several outmost cell layers of grain seeds, thus is called aleurone layer.



(IV) Fats and oils

Storage substance containing maximum energy and in the smallest volume, which exists in cytoplasm, and sometimes also in chloroplast.

- Fats: solid state at room temperature.
- Oils: liquid state at room temperature.



(V) Crystals

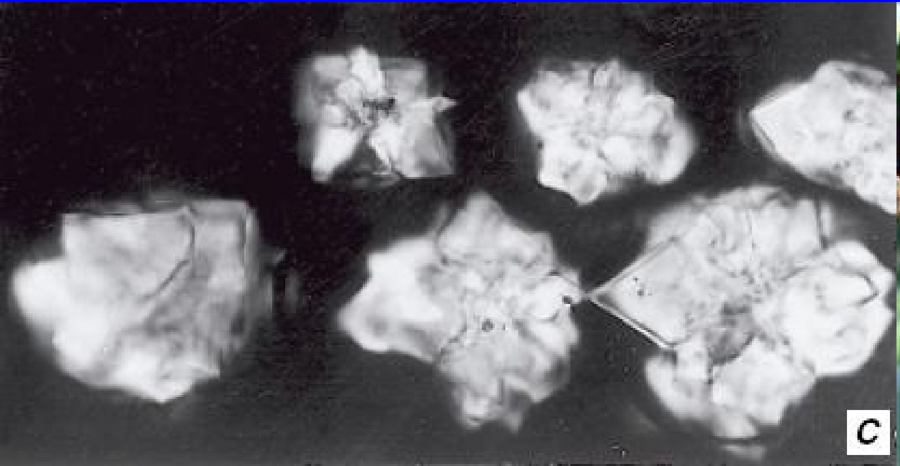
Inorganic salts often form crystals. Calcium oxalate crystal is one of the common crystals, while calcium carbonate crystal is one of the uncommon crystals. It is the accumulation of metabolic waste in vacuole, and can protect cells from being poisoned.

Types:

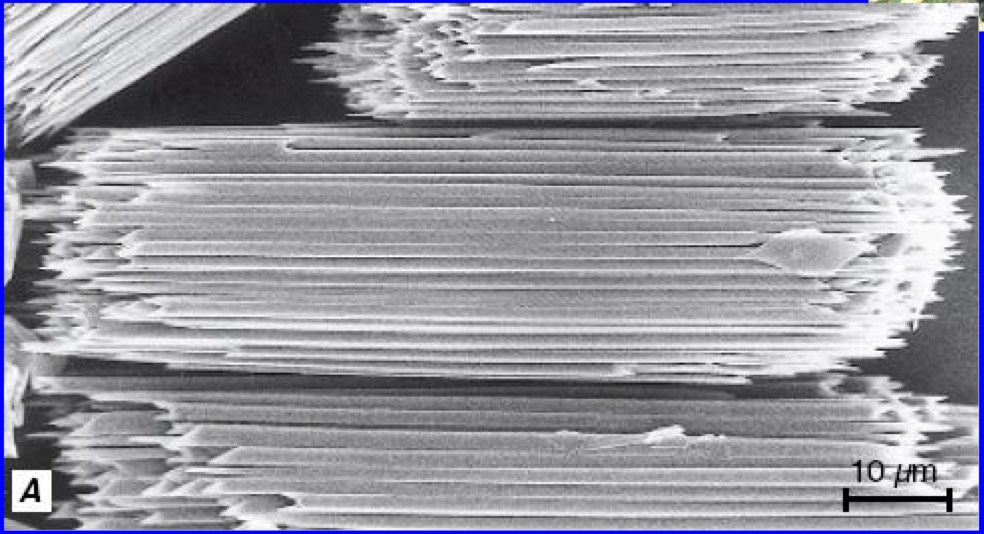
- Single crystal: prismatic or pyramidal
- Acicular crystal: acicular shape crystal with two sharp tips, and is usually accumulated in beam.
- Cluster crystal: compound structure formed through combination of many single crystals, and is spherical.

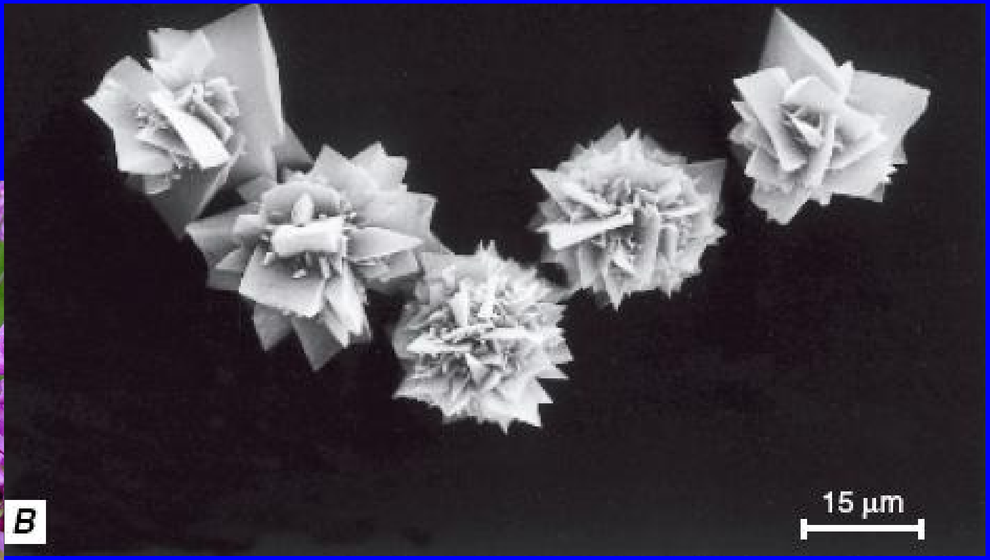
Chapter II Plant Cells and Tissues - Morphology of Cells

Calcium oxalate crystals seen in polarized light. A, prismatic crystals in phloem parenchyma of root of *Abies*. B, raphides in leaf of *Vitis*. C, druses in cortex of stem of *Tilia*. (A, ×500; B, C, ×750.) (From Evert 2006)

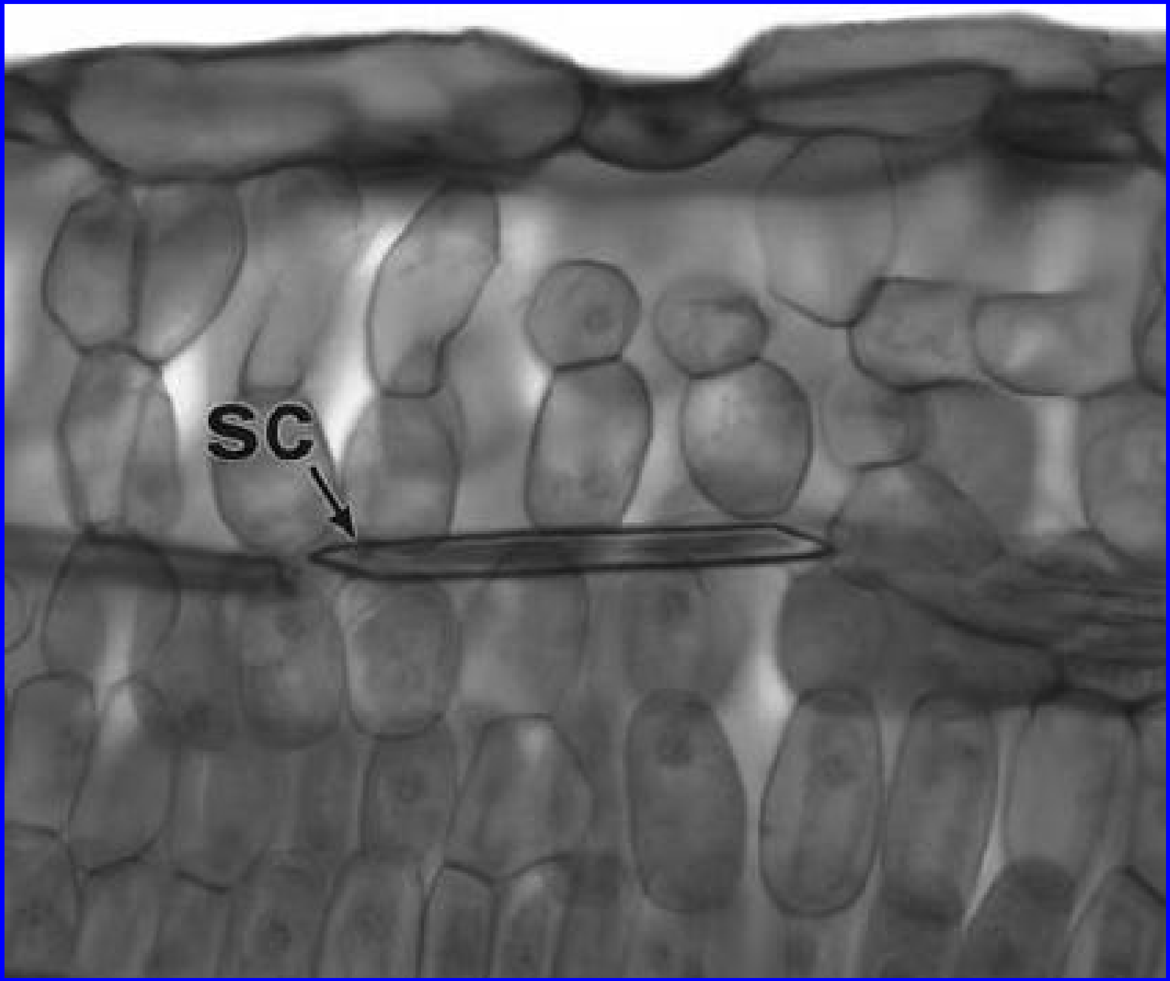


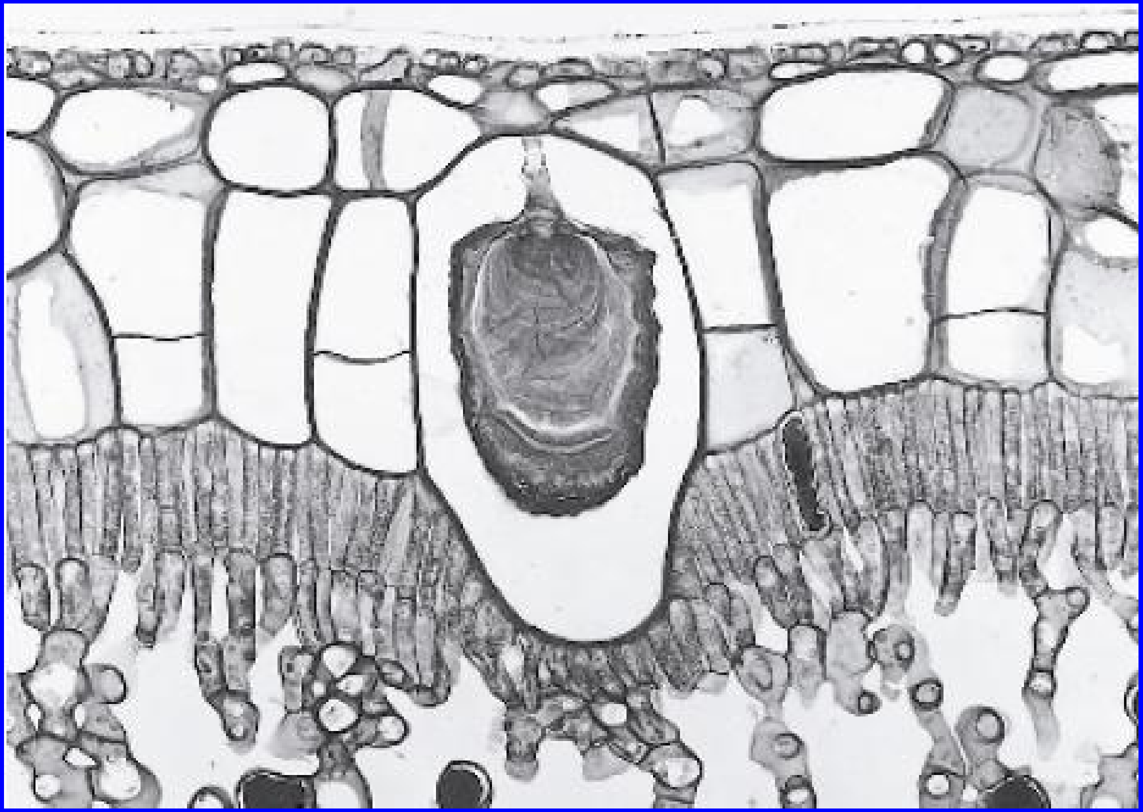
Scanning electron micrographs (A) of raphide bundle isolated from grape (*Vitis mustangensis*) fruit and (B) druses from *Cercis canadensis* epidermal cells. (A, from Arnott and Webb, 2000. ?2000 by The University of Chicago. All rights reserved.; B, courtesy of Mary Alice Webb)





Crocus cancellatus **(Iridaceae), longitudinal section of leaf showing crystal idioblast containing styloid crystal (sc). Scale =50 µm.**





Calcium carbonate crystal. Transverse section of upper portion of rubber plant (*Ficus elastica*) leaf blade showing club-shaped cystolith in enlarged epidermal cell, the lithocyst. The cystolith consists mostly of calcium carbonatedeposited on a cellulose stalk. (×155) (From Evert 2006)

I. Plant Cell Growth

1. Definition: refers to cell volume growth, including longitudinal and horizontal extension of cells.
2. In the growing process, cells will be obviously increased in volume, accompanying with internal structure change:
   (1) With obvious increase in vacuolization and strong metabolic capability, the product can be accumulated in the vacuole, resulting in absorption of large amount of water.
   (2) Change of other organelles, .e.g thin polioplasm turning into thick polioplasm and proplastid turning into plastid, and change of the thickness and composition of cell wall.
3. Cell growth is limited, and is controlled by genes.

II. Differentiation of plant cells

1. Definition: the specialization of cell structure and function is called cell differentiation.
2. Individual development: it is the the result of the continuous division, growth and differentiation of plant cells.
3. Phylogenetic development: with the evolution of plants, cell division becomes more detailed, cell differentiation becomes more violent, and the internal structure of frond becomes more complicated.

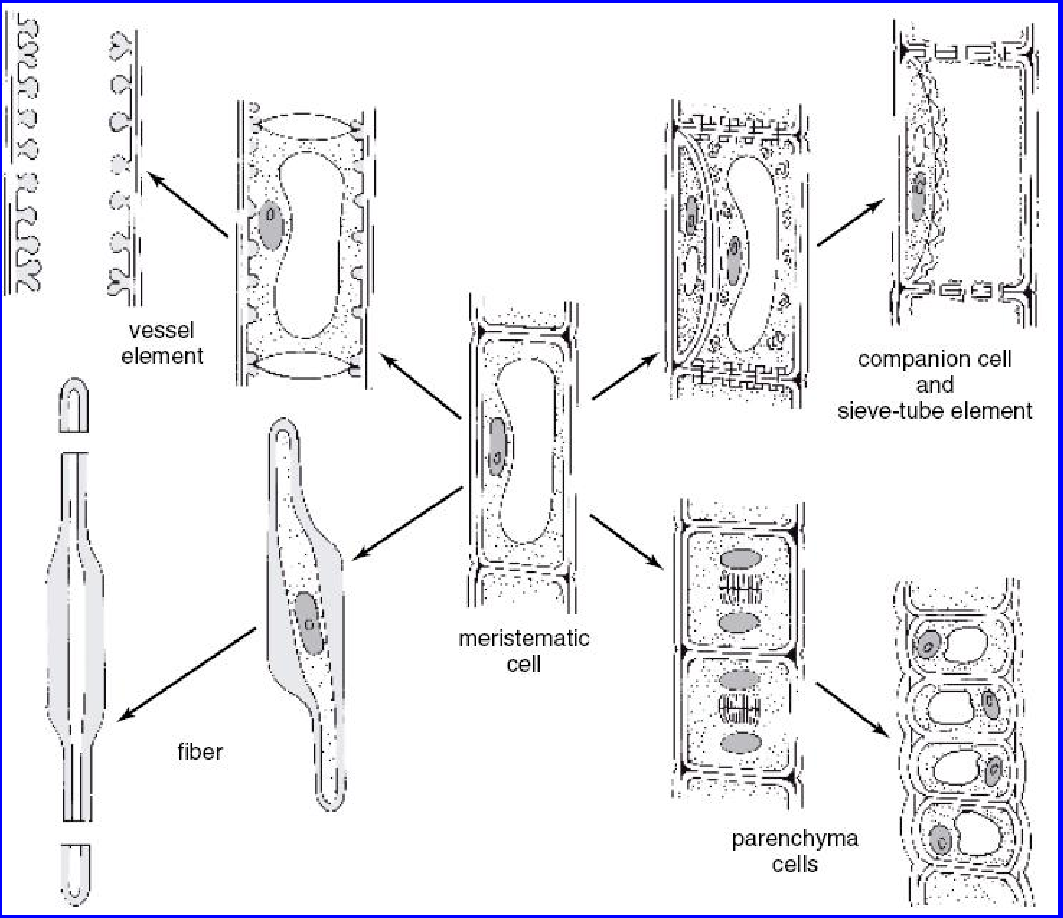
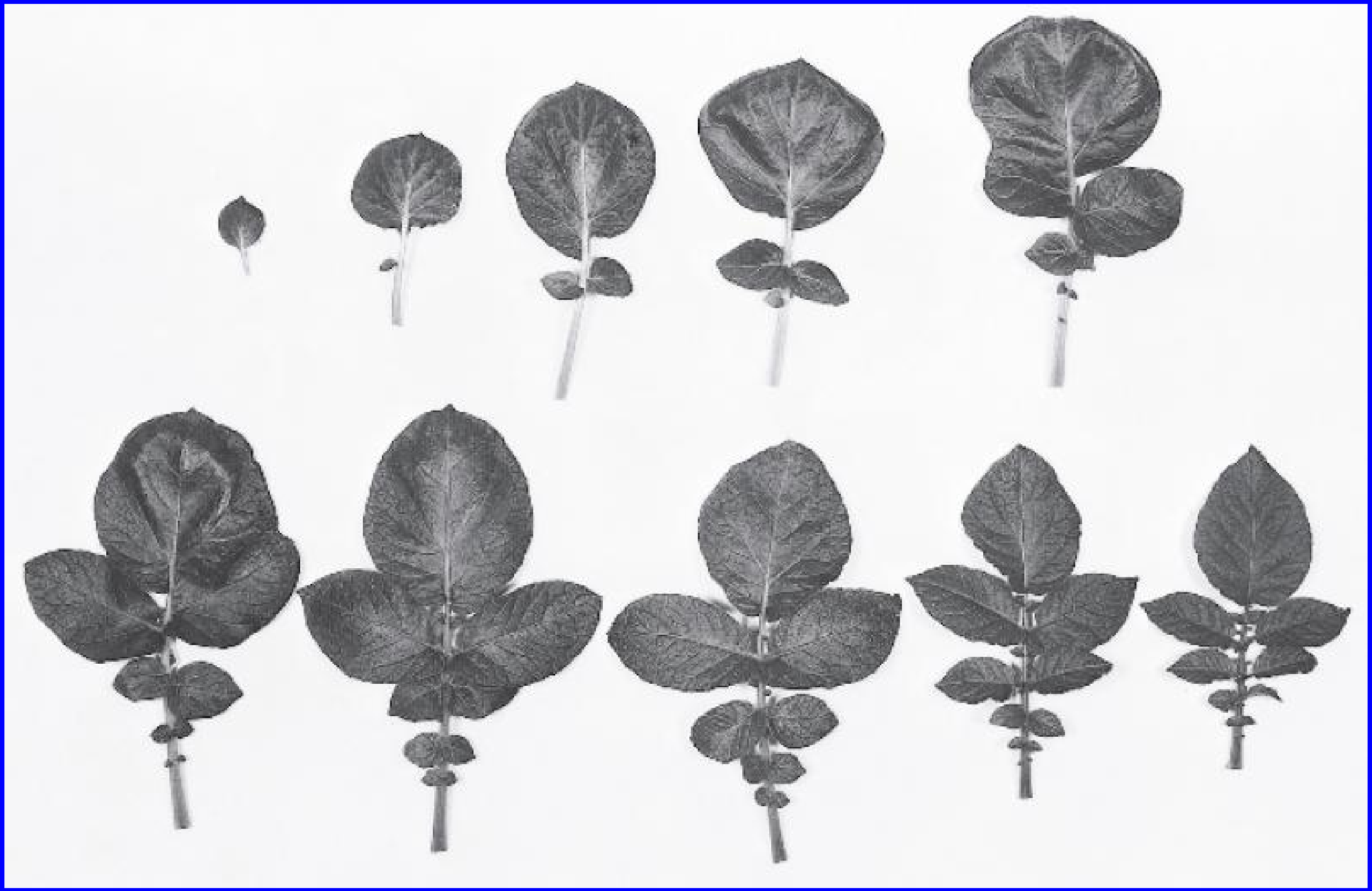
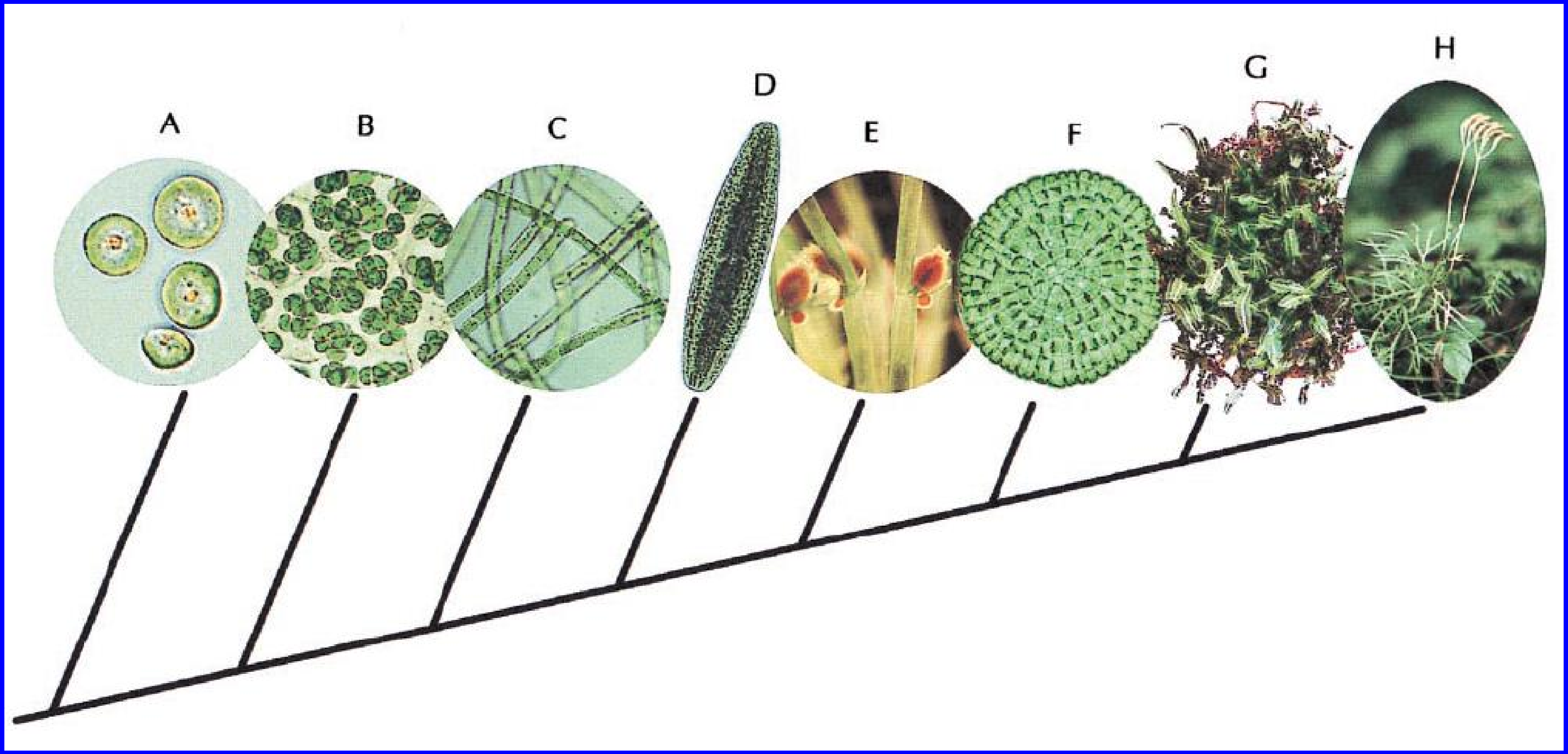


Diagram illustrating some of the cell types that may originate from a meristematic cell of the procambium or vascular cambium. The meristematic cell depicted here (at the center), with a single large vacuole, is typical of the meristematic cells of the vascular cambium. Procambial cells typically contain several small vacuoles. The meristematic cells or precursors of all these cells had identical genomes. The different cell types become distinct from one another because they express sets of genes not expressed by other cell types. Of the four cell types depicted here, the parenchyma cells are the least specialized. Both the mature vessel element, which is specialized for the conduction of water, and the mature fiber, which is specialized for support, lack a protoplast. The mature sieve-tube element, which is specialized for the transport of sugars and other assimilates, retains a living protoplast but lacks a nucleus and vacuole. It depends on its sister cell, the companion cell, for life support. (From Raven et al., 2005)



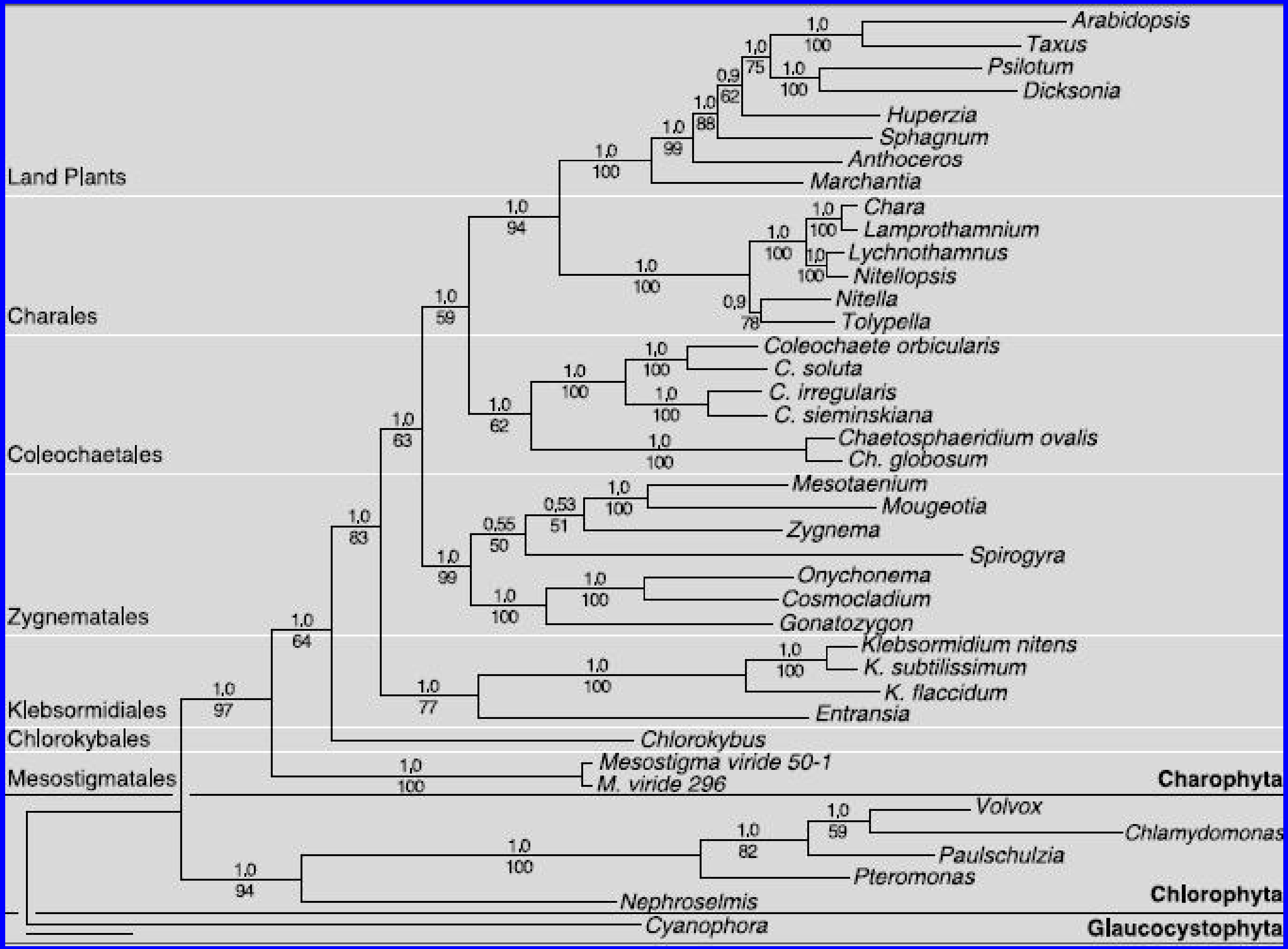
First 10 leaves from the main shoot of a potato plant (*Solanum tuberosum*). The leaves undergo a transition from simple to pinnately compound. (×0.1. From McCauley and Evert, 1988)



Increase in body complexity of charophyceans (*A-F*) and early divergent plants (*G* and *H*) is suggested by a phylogenetic model based on molecular data including tubulin (16) and *rbc*L sequences, a gene transfer event, and several intron insertion events (14). (*A*) Unicellular flagellate *Mesostigma* (whose divergence may, however, have preceded that of the charophycean lineage*)*; (*B*) colonial *Chlorokybus*; (*C*) unbranched filament *Klebsormidium*; (*D*) unicellular desmid *Netrium*, belonging to a group (Zygnematales) that also includes unbranched filaments); (*E*) *Chara*, a branched filament with tissue at nodes (indicated by the presence of orange gametangia); (*F*) *Coleochaete*, a planar tissue-like species is shown; (*G*) *Pallavicinia*, representing liverworts, an early divergent plant group; (*H*) *Lycopodium*, an early divergent tracheophyte (vascular plant). (From Graham et al. 2000)

Chapter II: Plant Cells and Tissues--Cell Growth and Differentiation

Phylogenetic relationships for Charophyta determined by Bayesian inference from the combined four-gene data set. The maximum likelihood tree (-ln=5 64499.87863) was of identical topology.



Posterior probabilities are noted above branches and maximum likelihood bootstrap values are below branches. The topology is drawn with *Cyanophora* rooting the tree. Branch lengths are mean values and are proportional to the number of substitutions per site (bar, 0.05 substitutions/site).

- What are the similarities and differences between primary walls and secondary walls of plant cells?

- What are the same and different structures between plant and animal cells?