Plant Anatomy BIO 311

Welcome to the BIO 311 Plant Anatomy website. Students can use this site to review the cell and tissue types seen in lab. The photomicrographs included in the 'Lab Review Slides' are accompanied by a brief descriptions and questions about the specimens. Many terms are linked to an online glossary.

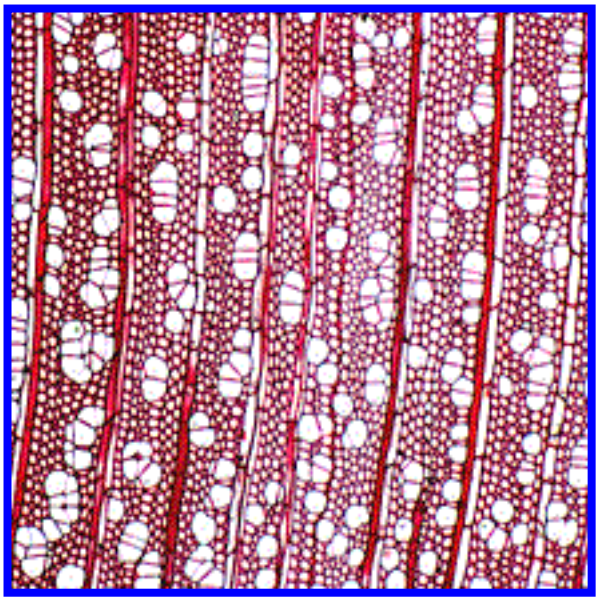
BIO 311 will next be offered in the Fall semester, 2002.

Alison Roberts (aroberts@uri.edu)

SITE CONTENTS

Course information
- Contact information
- Syllabus (from Fall 2002)
- Lab schedule (from Fall 2002)
- Other anatomy links

Laboratory review slides
- Text listing of all slides
- Thumbnail gallery of slides listed by lab



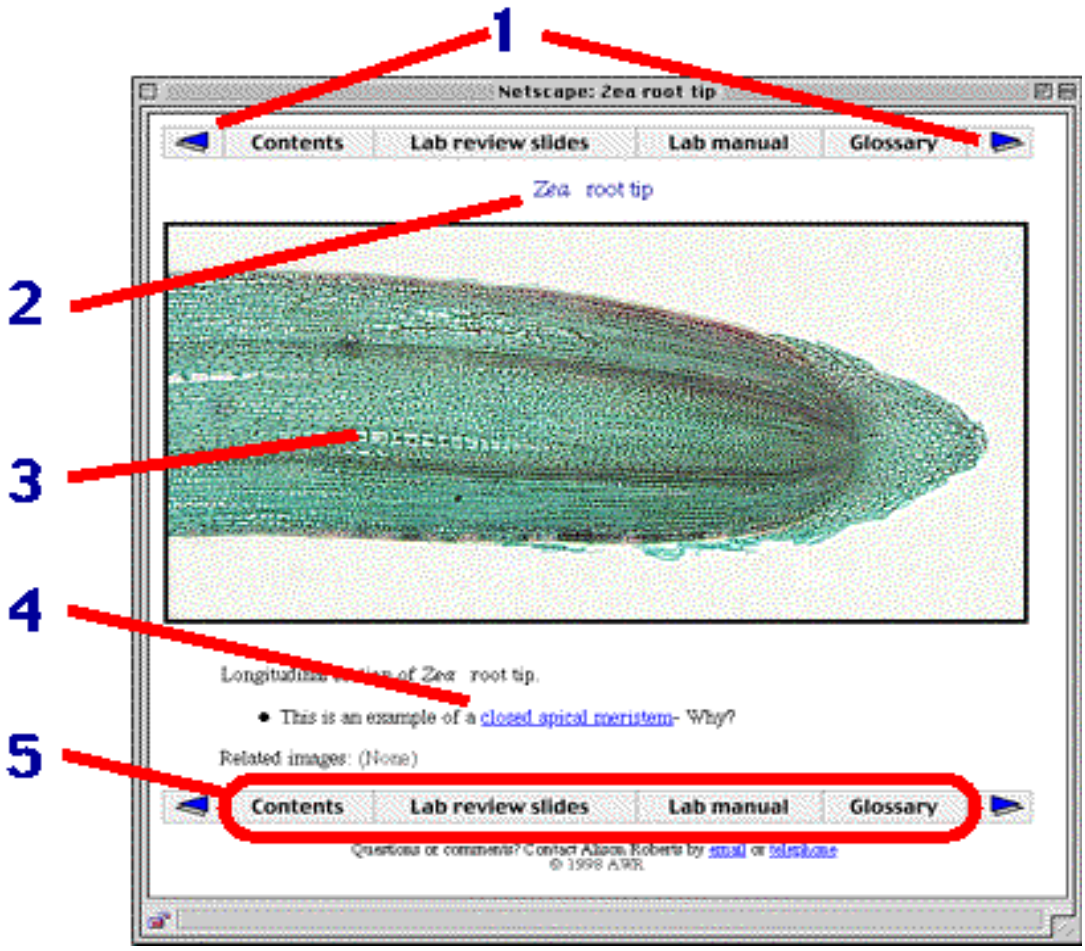
Lab manual (from Fall 2002)

Glossary of terms

To view photomicrographs of plant anatomy slides, you should visit the "Lab review slides" section. These images (saved in GIF format) are displayed in a window similar to the one shown below.

A few notes...

1. "**Previous Slide**" and "**Next Slide**" arrows: click these buttons to view the previous and next photomicrographs in the series. Images are arranged in the order that they are presented in lab. Note that these button are **not** the same as the "Back" and "Forward" buttons on your browser! The previous slide and next slide buttons are only available on pages with photomicrographs.
2. **Image title**
3. **Image**: in GIF format
4. **Description and questions**: click the underlined text to see glossary definitions
5. **Navigation buttons**: click these buttons to visit different areas with the site. (These are duplicates of the buttons at the top of the page.)



If you find problems with this site or have suggestions for improvements, please contact Alison Roberts at aroberts@uri.edu.

Alison Roberts (aroberts@uri.edu)

Plant Anatomy BIO 311

IMAGE LISTS

The slides listed below are organized by lab topic. Click on the slide numbers to view a photomicrograph and sample questions. You can also choose to view this list as thumbnail images organized by lab. (Thumbnail images may take longer to load.) Information about how the images were prepared for the web is available at the bottom of this page.

LAB TOPICS

LAB 1 Introduction to plant structure

(No slides)

Return to top of page

LAB 2 Plant cells

View Mesophyll cells from *Zinnia*
View Section of red pepper
View Starch grains from bean embryo
View Epidermal peel of *Tradescantia* showing purple pigment in the vacuoles

View Cross section of a pine needle
View Bright field and polarization micrographs of a stem section of *Aloe*
View Bright field and polarization micrographs of a stem section of *Myriophyllum*
View Section of pear fruit
View Circular-bordered pits from pine wood
View Electron micrograph of plasmodesmata

Return to top of page

LAB 3 Meristems, growth, & differentiation

View Longitudinal section of *Elodea* shoot apical meristem
View Longitudinal section of *Equisetum* shoot apex
View Longitudinal section of *Lonicera* shoot apex meristem
View Cross section of *Salvia* shoot apex
View Developmental sequence of leaf initiation in *Coleus*
View Longitudinal section of *Zea* shoot apical meristem
View Cross section of *Syringa* shoot apex
View Longitudinal section of *Allium* root tip
View Longitudinal section of *Botrychium* root tip
View Longitudinal section of *Zea* root tip
View *Capsella* embryo

Return to top of page

LAB 4 Dermal tissue system

View *Clivia* leaf
View *Castalia* leaf
View *Coleus* leaf
View *Nerium* leaf with guard cells and stomatal crypts
View *Zea mays* leaf x.s.
View Begonia leaf x.s.
View Orchid aerial root
View Epidermal peel of sedum
View Epidermal peel of sorghum
View Trichomes of *Eleagnus* leaf
View *Salvia* shoot apex
View Venus fly trap
View Glands on the stem of *Limonium*

Return to top of page

LAB 5 Ground tissue system

View *Syringa* leaf cross section
View *Castalia* leaf cross section
View *Myriophyllum* stem cross section
View Storage parenchyma in bean cotyledon
View Storage parenchyma in bean cotyledon
View Persimmon endosperm
View Succulent leaf of tumble weed
View Section of avocado
View Cross section of *Ranunculus* root
View Cross-section of castor bean stem
View Bean stem cross section
View *Sambucus* stem cross section
View Fibers (extraxylary) in *Yucca* leaf
View Cross-section of *Hoya* stem
View Cross-section of *Castalia* leaf
View Bean seed coat cross section
View Maceration of bean seed coat

Return to top of page

LAB 6 Vascular tissues: xylem

View Squashed vascular bundle from *Zinnia* stem
View Major vein in cleared *Zinnia* leaf
View Minor vein in cleared *Zinnia* leaf
View Tracheids from *Pinus*, a gymnosperm
View Large vessel in ash wood showing several vessel
View Vessel elements of *Liriodendron* sectioned in two different planes
View Vessel element from *Ephedra*, an unusual gymnosperm
View Tracheids, fiber tracheids, and xylary (libriform) fibers

Return to top of page

LAB 7 Vascular tissues: phloem

View Cross section of *Cucurbita* phloem
View Longitudinal section of *Cucurbita*
View Cross section of *Vitis* phloem
View Longitudinal section of *Vitis* phloem
View Sieve elements of *Cucurbita* stained with IKI and aniline blue

Return to top of page

LAB 8 Anatomy of stems

View Stem x.s. of *Helianthus* (sunflower)
View Stem x.s of *Medicago* (alfalfa), a typical dicot
View Stem x.s. of *Asparagus*, a typical monocot
View Stem x.s. of *Psilotum*, a fern
View Stem x.s. of *Adiantum* (a fern)
View Stem x.s. of *Polypodium* (a fern)
View Stem x.s. of *Trifolium* (clover)
View Stem x.s. of *Cucumis* (cucumber)
View Stem x.s. of *Lycopersicon* (tomato)

Return to top of page

LAB 9 Anatomy of leaves

View Leaf x.s. of *Syringa* (lilac)
View Paradermal section of *Syringa* palisade mesophyll.
View Paradermal section of *Syringa* spongy mesophyll
View Paradermal section of *Syringa* minor vein
View Leaf x.s. of *Zea mays*
View Leaf x.s. of *Bouteloua*, a C4 grass
View Leaf x.s. of *Poa*, a C3 grass
View Leaf x.s. of pine
View Leaf x.s. of *Taxus* (yew, a conifer)
View Leaf x.s. of *Podocarpus* (a conifer)
View Immature leaves of *Syringa*
View Higher magnification view of immature *Syringa* leaf

Return to top of page

LAB 10 Anatomy of roots

View Cross-section of immature *Ranunculus* root (buttercup)
View Higher magnification view of immature *Ranunculus* stele
View Cross-section of mature *Ranunculus* root
View Higher magnification view of mature *Ranunculus* stele
View Root x.s. of *Zea mays* (corn)
View Root x.s. of *Salix* (willow)
View Higher magnification view of *Salix* root
View Branch root with vascular connections to primary root
View Stem x.s. of *Lycopersicon* (tomato)

Return to top of page

LAB 11 Organ modification

Return to top of page

LAB 12 Vascular cambium

View Vascular bundle from stem of *Ranunculus*
View Vascular bundle from the stem of *Medicago* (alfalfa)
View Stem cross-section of *Phaseolus* (common bean) with secondary growth
View One-year-old stem of *Tilia*
View Annual rings in two-year-old stem of *Tilia*
View Xylem rays in three-year-old stem of *Tilia*
View Mature primary root stele of *Salix* (willow)
View Secondary root of *Salix*
View Secondary stem of *Metasequoia* showing pith.
View Secondary root of *Metasequoia*
View Cambium from *Pinus* with fusiform and ray initials
View Cambium from *Juglans* (walnut) with fusiform and ray initials
View Cambium from *Robinia* (black locust)

Return to top of page

LAB 13 Secondary growth

View Pine wood with annual rings and resin ducts
View Pine wood rays
View Pine wood showing bordered pits
View Wood from *Chaemaecyparus*, a gymosperm
View Chaemaecyparus wood with axial parenchyma, tracheids and bordered pits
View *Magnolia* wood
View *Magnolia* wood with axial vessels and rays
View *Magnolia* wood with scalariform perforation plates
View Ash wood
View Ash wood
View Ash wood with axial vessels, simple perforation plates, and rays
View Red oak wood with axial fibers, axial vessels, rays, annual rings
View Red oak wood with uniseriate and multiseriate rays
View White oak wood with ray and axial parenchyma
View Three year old *Tilia* stem
View *Pelargonium*stem with primary growth only
View *Pelargonium* stem showing initiation of cork cambium
View *Pelargonium* stem with cork cambium and cork
View *Pelargonium*stem with cork and cork cambium
View Lenticel of *Sambucus*

Return to top of page

This site was prepared for the web by Eric Roberts.

Contents | Lab review slides | Lab manual | Glossary

Alison Roberts (aroberts@uri.edu)

Plant Anatomy BIO 311

LAB MANUAL INFORMATION

The table of contents, lab schedule and an electronic copy of the lab manual in Adobe Acrobat pdf ('portable document format') are available for viewing online. The lab manual is also available for downloading and printing.

In order to view or print the pdf file, you must have the Acrobat Reader application and web browser extension installed on your computer. These programs, and instructions for installing them, are free and available from the Adobe Systems.

- View lab schedule for Fall, 2002
- View lab manual table of contents.
- Visit Adobe Systems to download the Acrobat Reader and the Acrobat web browser extension.
- View BIO 311 manual in pdf format.

LAB SCHEDULE FALL 2002

LAB	MONTH	DATES	READING *	TOPIC
1	Sept.	10	15-22	Introduction to plant structure
2		17	42-7, 52-6	QUIZ, Plant cells
3		24	84-96	Meristems, growth, & differentiation
4	Oct.	1	107-109	QUIZ, Dermal tissue system
5		8	62-67	Ground tissue system

6		15	76-78	Vascular tissues: xylem
7		22	72-75	QUIZ, Vascular tissues: phloem
8		29	123-125	Anatomy of stems
9	Nov.	5	102-112	QUIZ, Anatomy of leaves
10		12	138-140	Anatomy of roots
11		19		Organ modification
12		26	126-131, 141-3	Vascular cambium
13	Dec.	3	79-83	QUIZ, Secondary growth

*Reading from Bowes, B. G. (2000) **A Color Atlas of Plant Structure**, Iowa State University Press, Ames, IA, 192 p.

LAB MANUAL CONTENTS

Laboratory schedule
Lab 1 - Introduction to the plant body
- Use of the microscope
- Free hand sectioning
- Cytochemical stains
- Laboratory drawings

Lab 2 - Plant cells
Lab 3 - Meristems, growth and differentiation
Lab 4 - Dermal tissue system
Lab 5 - Ground tissue system
Lab 6 - Vascular tissues: xylem
Lab 7 - Vascular tissue: phloem
Lab 8 - Anatomy of stems
Lab 9 - Anatomy of leaves
Lab 10 - Anatomy of roots
Lab 11 - Organ modification
Lab 12 - Vascular cambium
Lab 13 - Secondary growth
- Planes of section in wood
- Wood characteristics chart

Alison Roberts (aroberts@uri.edu)

GLOSSARY

How this glossary is organized

This entries in this glossary are not arranged alphabetically, but are instead grouped according to related concept. If you want to locate specific words, use your browsers "Search" or "Find" command.

Contents

Environmental Modifications

Organ Specialization

Wood

LEVELS OF ORGANIZATION IN THE PLANT BODY

cells: the smallest living unit of an organism. The outer boundary of a plant cells is defined by a rigid cell wall
tissues/tissue systems: groups of cells that share a similar function, such as transport (vascular tissue) or protection (dermal tissue)
organs:

> **root**: the portion of a plant axis produced by the root apical meristem.
> **stem**: the portion of a plant axis produced by the shoot apical meristem
> **leaf**: a lateral appendage of the stem produced by the shoot apical meristem.
> **floral organs**: modified leaves specialized for reproduction.

organism: any individual living creature, either multicellular or unicellular

---

PLANT CELLS

organelle: (literally "little organ") a region within a cell where specialized metabolic tasks occur; typically surrounded by a membrane.

> **plastids**: a group of organelles characterized by a double membrane envelope and a complex of internal membranes. Plastids contain DNA and replicate autonomously.
>
> > **proplastids**: specialized for dividing to form new plastid, usually found in meristematic cells.
> > **chloroplast**: contains chlorophyll, internal membranes organized as grana, specialized for photosynthesis.
> > **chromoplast**: contains red, orange, or yellow carotenoid pigments, impart color to fruits, etc.
> > **amyloplast**: contains large amounts of starch, but no chlorophyll, specialized for storage.
> > **elaioplast:** contains oil droplets, usually found in fruits or

seeds.

vacuole: membrane bound organelle that typically occupies a large volume of the cell cytoplasm. Vacuoles may contain:

anthocyanins: red, blue or purple pigments that are water soluble.

tannins: phenolic compounds than complex with protein; function in plant defense.

crystals: usually composed of calcium oxalate. Types are classified according to shape and include:

raphide crystals: needle-like, may inhibit herbivory.

druse crystals: granular.

cell wall: a rigid layer of cellulose and other polysaccharides, proteins and sometime lignin on the outside of the plasma membrane of a plant cell.

primary cell wall: a cell wall layer deposited while a cell is growing; typically extensible.

secondary cell wall: innermost layer of a cell wall deposited after cell enlargement has ceased, often lignified.

Casparian strip: a band of suberin within the anticlinal walls of endodermal and exodermal cells.

cuticle: a water repellent layer that coats the outer cell walls of the epidermis on aerial parts of plants, composed of cutin with a surface coating of wax.

mucigel: a slime sheath secreted by roots.

polysaccharide: a polymer composed of sugars.

cellulose: the structural (microfibrillar) portion of the plant cell wall. Cellulose is a polymer of glucose.

hemicellulose: the alkali-soluble portion of the cell wall matrix.

pectin: the hot-water-soluble portion of the cell wall matrix.

lignin: an aromatic polymer that rigidifies may secondary cell walls. Ligin is stained red by phloroglucinol solutions.

Intercellular connections:

plasmodesma(ta): cytoplasmic channels lined with plasma membrane that connect the protoplasts of adjacent cells across the cell wall.

pit: a region where the secondary cell wall is absent, but the primary cell wall is present.

simple pit: a pit that is not bordered, may be round or slit-shaped.

circular-bordered pit: a round pit with a thickened margin.

TISSUES AND CELL TYPES OF THE PLANT BODY

ground tissue system: tissues derived from the ground meristem. All are simple tissues composed of a single type of cell, which is named after the tissue. The tissues of the ground tissue system include:

parenchyma: tissues composed of cells with thin primary cell wall. Types include:

chlorenchyma: contains chloroplasts and functions in photosynthesis.

aerenchyma: contains large intracellular air spaces and functions in gas exchange.

endodermis: characterized by a suberized Casparian strip; regulates transport of materials into the vascular bundles of most roots and some leaves and stems.

storage parenchyma: characterized by large accumulations of storage products such as starch, protein, oil, hemicellulose, or water.

collenchyma: tissues composed of cells with unevenly thickened primary cell walls that strengthen growing organs. Types are classified according to the arrangement of the wall thickenings and include.

angular collenchyma: cell wall is thickest in the corners.

lamellar collenchyma: cell wall is thickest on two opposite sides.

lacunar collenchyma: cell wall is thickest in the corners, intercellular air spaces present.

sclerenchyma: tissues composed of cells with thick, secondary cell wall that are usually lignified. Types are classified according to cell shape and include:

fiber: long, straight and thin, often occurring in bundles. Sometimes called "**extraxylary fibers**" to distinguish them from xylary fibers, which look similar, but have a different evolutionary origin.

sclereids: variable in shape, but not like fibers. Types are classified according to shape and include:

brachysclereids: also called stone cells, length and width nearly equal.

astrosclereids: star shaped, with several projecting arms.

trichosclereids: hair-like, similar to a fibers, except branched.

macrosclereids: column shaped, longer than wide.

osteosclereids: bone shaped, elongated with swollen ends.

Secretory structures:

hydathode: a structure in the margins of leaves that secretes water.

oil cavities: a cavity lined with cells that secrete oils.

resin duct: a tube lined with cells that secrete resin.

laticifer: a secretory structure that produces latex.

latex: a milky fluid of unspecified composition.

dermal tissue system: Tissues derived from the protoderm or cork cambium that cover the surface of the plant body. The dermal tissues are complex (composed of several cell types) and include:

epidermis: a complex tissue that is usually a single cell layer thick and composed of the following cell types.

ordinary epidermal cells: the least specialized cells of the epidermis (i.e. cells that are NOT specialized as guard cells, root hairs, trichomes, etc.). May secrete a cuticle.

guard cells: cells that surround and control the size of stomatal pores.

stomate (plural: stomata): an opening defined by pairs of guard cells that controls gas exchange and water loss.

subsidiary cells: cells adjacent to guard cells that are distinct in appearance from ordinary epidermal cells.

trichomes: cells that project from the surface of the epidermis. Types include:

unicellular trichome: consists of one cell.

multicellular trichome: consists of several cells.

secretory (glandular) trichome: secretes a substance.

root hair: specialized unicellular trichome found in roots.

Specialized epidermal cells and structures:

multiple epidermis: an epidermis that is more than one cell layer thick.

multistratose epidermis: a multiple epidermis in which all layers are derived from the protoderm.

hypodermis: a layer or layers of cells beneath the epidermis that is derived from the ground meristem, but distinct in appearance from adjacent ground tissue. May be called an *endodermis* if it has a Casparian strip.

velamen: a multistratose epidermis found in aerial roots.

bulliform cells: ---

lithocysts: literally translated "rock cells", cells containing a granule of calcium carbonate called a **cystolith**.
silica cells: cells in the epidermis of grasses that contain silica deposits.
nectary: a gland that secretes nectar.

vascular tissue system: Tissues derived from the procambium or vascular cambium that transport water and photosynthate. The vascular tissues are complex (composed of several cell types) and include:

xylem: the water-conducting tissue of plants.
tracheary element: a conducting cell of the xylem, characterized by an elongated shape and lignified secondary cell wall.
vessel element: a tracheary element with perforation plates.
perforation plate: the end wall of a vessel element where the secondary cell wall was not deposited and the primary cell wall has been digested.
foraminate: contains several round perforations.
scalariform: contains several elongated perforations such that the remaining cell wall resembles the rungs of a ladder.
simple: contains a single perforation.
vessel: a long tube of vessel elements connected by perforation plates
tracheid: a tracheary element that lacks perforations plates, water flows from between tracheids through pits.
fiber tracheid: a cell in the xylem that is intermediate between a tracheid and a libriform fiber.
libriform fiber: a cell in the xylem that is very long and thin and has simple pits, sometimes called "**xylary fibers**" to distinguish them from extraxylary fibers, which look similar, but have a different evolutionary origin.

phloem: the photosynthate-conducting tissue of plants.

sieve element: a conducting cell in the phloem.

sieve-tube member: a sieve element with perforation plates, characteristic of angiosperms.

sieve plate: the end wall of a sieve-tube element that is perforated by sieve plate pores.

sieve plate pore: an enlarged plasmodesma that perforates a sieve plate.

sieve tube: a long tube of sieve elements (also called sieve tube members) connected by sieve plates.

sieve cell: a sieve element that lacks perforation plates, characteristic of gymnosperms.

p-protein: a stringy protein within sieve elements that blocks sieve plate pores when the sieve tube is damaged.

companion cells: a cell in the phloem that is connected to a sieve-tube member by numerous plasmodesmata.

albuminous cells: a cell the phloem that is connected to a sieve cell by numerous plasmodesmata.

DEVELOPMENTAL TERMINOLOGY

indeterminant growth: a type of growth characterized by production of an unlimited number of organs.
differentiate: become specialized for a particular function
meristem: a defined region where new cells arise in predictable pattern; localized regions of cell division
primordium: a cell or organ in its initial stage of development.

leaf primordium: arises at the shoot apical meristem.
axillary bud primordium: arises in the axil of a leaf primordium.
lateral root primordium: arises in the pericycle.

adventitious: arising at an unexpected location.
Planes of cell division:

anticlinal: perpendicular to the surface.
periclinal: parallel to the surface.

phyllotaxy: the pattern of leaf initiation at the apical meristem.
plastochron: the time between the initiation of one leaf and the initiation of the next.
callus: an irregular proliferation of cells.

MERISTEMS

apex: the tip of something, usually a shoot, root or leaf.
meristematic region: a general zone in which cell division is frequent.
apical initial: a cell that, when it divides, leaves one of the daughter cells in the apical meristem.

- **apical cell:** the single initial in the apical meristems of most seedless vascular plants.

primary meristem: a meristem that is present in the embryo of a plant; generally responsible for increase in the length of plants

- **root apical meristem:** a meristem located at the apex of a root.
  - **root cap:** a thimble-shaped mass of cells that covers the root apical meristem.
  - **open:** no distinct boundary separates the root cap from the root proper.
  - **closed:** root cap is distinct from the root proper.
- **shoot apical meristem:** a meristem located at the apex of a shoot.
  - **tunica:** the outer layer(s) that divide only anticlinally.
  - **corpus:** the inner layers that divide anticlinally or periclinally.
  - **apical dome:** the part of the apical meristem interior to the leaf primordia.

secondary meristem: a meristem that arise from tissues produced by a primary meristem; generally responsible for increase in thickness of plants

- **vascular cambium:** a sheet-like meristem that produces secondary xylem and secondary phloem.
  - **residual procambium:** procambium located between mature xylem and phloem.
  - **fascicular cambium:** arises within vascular bundles.
  - **interfascicular cambium:** arises between vascular bundles.
  - **fusiform initial:** an elongated cell in the vascular cambium, produces elements of the axial system.
  - **ray initial:** an isodiametric cell in the vascular cambium,

produces elements of the ray system.
storied cambium: fusiform initials aligned with one another.
non-storied cambium: fusiform initials not aligned with one another.

cork cambium (phellogen): a sheet-like meristem that produces cork.

primary meristematic tissue: a group of cells beneath the apical meristem that has become distinct in appearance from neighboring groups of cells, a precursor to one of the tissue systems:

procambium: develops into the vascular tissue system.
protoderm: develops into the dermal tissue system.
ground meristem: develops into the ground tissue system.

THE ORGANIZATION OF ROOTS STEMS AND LEAVES

vascular bundle (vascular strand): a strand of tissue containing primary xylem and primary phloem.

axial bundle: a major vascular bundle in the shoot or root.
leaf trace: a vascular bundle that connects a leaf to the axial vascular system.
leaf gap: in a siphonostele, a break in the vascular cylinder above the point where a leaf trace arises.
vein: a vascular bundle in a leaf.
sympodium: an axial bundle and its leaf and branch trace.
Bundle types based on arrangement of xylem and phloem:
collateral bundle: contains a mass of phloem toward the exterior and a mass of xylem toward the interior
bicollateral bundle: contains one mass of xylem and two masses of phloem, one toward the interior and one toward the exterior.

stele: the arrangement of vascular bundles in roots and stems.

protostele: a single central vascular bundle.
polyarch: a protostele with many arms of xylem, most common in monocots.
siphonostele: a cylinder of vascular tissue with a central parenchymatous pith.
dictyostele: a siphonostele with numerous leaf gaps; superficially appears to be composed of vascular bundles.

eustele: a ring of vascular bundles surround a pith.
atactostele: a complex three dimensional network of vascular bundles; superficially bundles appear to be scattered.

Leaves:

palisade mesophyll: the region of ground tissue in a leaf where the chlorenchyma cells are elongated and arranged perpendicular to the epidermis, usually in the upper half of the leaf.
spongy mesophyll: the region of ground tissue in a leaf where parenchyma cells are branched and intercellular air spaces are extensive, usually in the lower half of the leaf.
bundle sheath: the layer of tightly-packed cells that surround the vascular tissue in leaves.
bundle sheath extension: a group of cells that connect a vein to the epidermis in a leaf.
abscission zone: a region of the petiole
- **protective layer:** the layer of cells that produce suberin to seal the petiole before abscission.
- **separation layer:** the layer of cells that secrete cell wall degrading enzymes forming a weak point where an abscising leaf can drop off.

epidermis: the epidermis contains stomata arranged in one of the following ways:
- **amphistomatic:** stomata in upper and lower epidermis.
- **epistomatic:** stomata in the upper epidermis only.
- **hypostomatic:** stomata in the lower epidermis only.
- **clustered stomata:** stomata occur in groups.
- **sunken stomata:** stomata located below the surface of the epidermis.
- **stomatal crypts:** a pit containing several stomata.

Roots and stems:

cortex: ground tissue between the vascular bundle and epidermis.
pith: ground tissue in the center of a stem.
pericycle: in roots, the layer of cells between vascular tissue and endodermis that gives rise to lateral roots and vascular cambium.

Flowers and fruits:

Floral organs: all are modified leaves.
receptacle: the tip of a floral stem, supports the floral organs.
sepal: outermost and most leaf-like, usually encloses the rest of the flower in

the bud.

petal: interior to sepals, usually conspicuous to attract pollinators.

stamen: interior to petals, produces the pollen.

filament: stalk-like portion of the stamen.

anther: pollen-bearing portion of the stamen.

pollen sac: one of four cavities in an anther that contain pollen.

pollen: the male gametophyte, includes two cells:

tube nucleus: located within the tube cell.

generative cell: divides to form two sperm.

tapetum: a layer of nutritive cells that lines the pollen sac.

pistil: innermost, bears the ovules, may occur singly or in clusters.

stigma: the portion of the pistil that receives the pollen.

style: the portion of the pistil through which the pollen tube grows.

ovary: the portion of the pistil that bears the ovules.

carpel: a unit of the pistil consisting of a single modified leaf, a simple pistil consists of one carpel and a compound pistil consists of fused carpels.

locule: a cavity containing ovules, in a compound ovary there is one locule per carpel.

ovule: an embryo sac with egg surrounded by nucellus and two integuments.

embryo sac: the eight-celled megagametophyte of flowering plants.

integuments: the outer protective layer of the ovule.

micropyle: an opening in the integuments through which a pollen tube enters.

nucellus: the inner nutritive layer of the ovule.

Classification of flowers by ovary position:

hypogynous: sepals, petals and stamens attached to the receptacle below the ovary.

epigynous: sepals, petals and stamens attached to the top of the ovary.

perigynous: sepals, petals and stamens attached to a hypanthium.

hypanthium: a cup-shaped extension of the receptacle.

Fruits and seeds:

seed: a mature ovule, includes:

embryo: a young plant present in the seed before germination.

radicle: the root portion of the embryo.

plumule: the shoot portion of the embryo.

cotyledon: the first leaves of an embryo, may or may not resemble true leaves.

coleorhiza: in monocots, a sheath that covers the

radicle.
coleoptile: in monocots, a sheath the covers the plumule.

seed coat: the outermost layer of a seed, develops from the integuments.

endosperm: a triploid nutritive tissue that develops in the ovule, may be absorbed by the before the seed matures.

fruit: a mature ripened ovary. In practice, most plant parts that contains seeds are fruits.

funiculus: the stalk that attaches a seed to the inside of a fruit.

ENVIRONMENTAL MODIFICATION

xeromorphic: characters that are advantageous is dry environments.
hydromorphic: characters that are advantageous in wet environments.
halomorphic: characters that are advantageous in saline environments.
xerophyte: a plant with xeromorphic features.
mesophyte: a plant with neither hydromorphic nor xeromorphic features.
hydrophyte: a plant with hydromorphic features.
succulent: having large amounts of water storage tissue.
leaf dimorphism: leaves of two distinct types produced by the same plant, examples include:

sun/shade leaves: leaves in the sunnier parts of trees are distinct from more shaded leaves.

air/water leaves: in aquatic plants, leaves that grow below the water surface are distinct from those formed above the surface.

heteroblastic leaves: leaves produced during one stage of development are distinct from those formed at another stage, for example leaf from may change when a plant flowers.

ORGAN SPECIALIZATIONS

aerial root: a root that grows in air, common in epiphytes.
cataphyll (bud scale): a leaf modified to protect a dormant bud.
cladode: a stem that is leaf-like in appearance.
contractile root: a root that contracts to pull the crown of the plant below the soil surface.
corm: an underground stem that is upright.
haustorial root: a root that is modified for absorbing water or nutrients from another plant.

mycorrhizae: a symbiotic relationship between plant roots and fungi.

- **endomycorrhizae:** fungal mycelia are internal.
- **ectomycorrhizae:** fungal mycelia are external

phyllode: a leaf that consists of an enlarged midrib and lacks blades.
prop roots: roots that help support a plant from above ground.
rhizome: an underground stem.
root nodules: structures that develop on the roots of plants that form symbiotic associations with nitrogen-fixing bacteria.
spine: a stem of leaf modified for protection.
storage root: a root modified to store relatively large amounts of food.
tendril: a stem of leaf modified to coil around other plants or objects.
trap: a leaf modified to trap insects to supply the plant with nitrogen.
tuber: a swollen underground stem, such as a potato

WOOD

secondary xylem: water-conducting tissue produced by the vascular cambium, wood.
secondary phloem: photosynthate-conducting tissue produced by the vascular cambium, inner bark.
axial system: cells elongated parallel to the organ axis, develop from fusiform initials.

- **axial vessels:** vessels of the axial system, may be:
  - **clustered:** several vessel occur in a bundle.
  - **solitary:** vessels separated by other types of cells.
- **axial parenchyma:** parenchyma cells of the axial system.

ray system: cells elongated radially, develop from ray initials.

- **uniseriate rays:** rays that are one cell wide.
- **multiseriate rays:** rays that are more than one cell wide.
- **homocellular rays:** rays consisting on one type of cell.
- **heterocellular rays:** rays consisting of more that one type of cells, possibilities include:
  - **ray parenchyma:** parenchyma cells of the ray system, may be:
    - *procumbent cells*: elongated parallel to the ray.
    - *upright cells*: elongated perpendicular to the ray.
  - **ray tracheids:** tracheids of the ray system.

annual ring: the portion of a woody stem produced in one year.

diffuse porous: annual rings contain large vessel throughout.
ring porous: large vessels present only in inner portion of an annual ring.

anomalous secondary growth: secondary tissue that are not produced by a vascular cambium.
secondary vascular bundles: vascular bundles that do not develop from procambium.
periderm: the cork cambium and the tissues in produces, outer bark.

cork (phellem): cells produced by the cork cambium that have suberized cells walls and are dead at maturity.
lenticel: a region of the periderm where cells are loosely packed, allows gas exchange.

Contents | Lab review slides | Lab manual | Glossary

Alison Roberts (awrobrts@uriacc.uri.edu)

BIO 311
Plant Anatomy
Lab Manual

Dr. Alison Roberts
Department of Biological Sciences
University of Rhode Island

Fall 2002

CONTENTS

LABORATORY SCHEDULE

Fall semester, 2002

Lab	Month	Day	*Reading	Subject
1	Sept.	10	15-22	Introduction to plant structure
2		17	42-47, 52-56	**QUIZ,** Plant cells
3		24	84-96	Meristems, growth, & differentiation
4	Oct.	1	107-109	**QUIZ,** Dermal Tissue system
5		8	62-67	Ground tissue system
6		15	76-78	Vascular tissues: xylem
7		22	72-75	**QUIZ,** Vascular tissues: phloem
8		29	123-125	Anatomy of stems
9	Nov.	5	102-112	**QUIZ,** Anatomy of leaves
10		12	138-140	Anatomy of roots
11		19		Organ modification
12		26	126-131, 141-143	**QUIZ,** Vascular cambium
13	Dec.	3	79-83	Secondary growth

Bowes, B. G. (2000) *A Color Atlas of Plant Structure*, Iowa State University Press, Ames, IA, 192 p. Available at the URI Bookstore.

LAB 1 - INTRODUCTION TO THE PLANT BODY

Introduction

Your objectives for this first laboratory are to: 1) learn how to make free-hand sections and examine them with the light microscope, 2) record your observations as labeled drawings, 3) begin to distinguish the cells that compose the tissues of stems, roots, and leaves, and 4) review the terminology used to describe the structure of seeds, seedlings and growing plants.

It takes practice to make good free-hand sections in which you can distinguish the features of the various cells that make up plant organs. Your ability to see these features will also depend on proper adjustment of your microscope, particularly the condenser. Your lab instructor will evaluate your sectioning and microscope technique and offer suggestions for improvement.

Your drawings for this and most other labs will be prepared on 5X8" index cards according to the format at the end of this lab. Preparing these cards will help you organize the information presented in lab. The completed cards will help you review for quizzes and exams.

The cells of the vascular plant body can be divided into three **tissue systems**, which differ in position, development and function. The **dermal tissue system** consists of cells that cover the surface of the plant. The **vascular tissue system** includes the conducting cells that move water and nutrients throughout the plant. The remaining cells make up the **ground tissue system**. When you finish this exercise, you should be able to identify the three tissue systems in stems, roots, and leaves. You should also gain a sense of the continuity of these tissue systems throughout the plant. You will see that the dermal tissue system forms a continuous covering from root to leaf. The vascular tissue system could not transport water from the roots to the leaves unless conducting vessels were continuous throughout the plant.

Part 1 – Tissue systems

Refer to the instructions for free-hand sectioning at the end of this lab. Make several cross-sections from the stem of your bean plant, stain with toluidine blue, and prepare a wet mount. Look at your stem sections under the microscope and identify the outermost layer of cells. This is the **epidermis**, a component of the dermal tissue system. Just inside the epidermis is a ring of **vascular bundles**, which make up the vascular tissue system. The ground tissue system occurs in two regions: the **cortex** (between epidermis and vascular bundles) and the **pith** (center of stem).

Card 1-1: Prepare a pie-slice drawing of a bean stem cross section (refer to instructions at the end of this lab). Label the tissue systems.

Make free-hand cross sections of the root of your bean plant and stain and mount them. Using the compound microscope, identify the three tissue systems. How does the arrangement of the tissue systems differ in stems and roots?

Card 1-2: Prepare a pie-slice drawing of a bean root cross section. Label the tissue systems.

Make free-hand cross sections of a bean leaf by placing a piece of it between two blocks of carrot root. Stain and mount your sections. Using the compound microscope, identify the three tissue systems. Which tissue system composes the leaf veins?

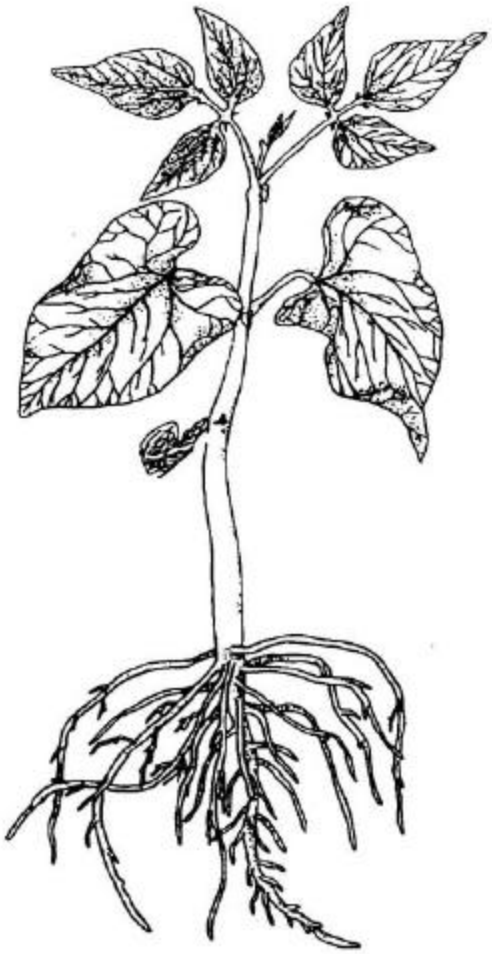
Card 1-3: Prepare a drawing of a bean leaf cross section. Label the tissue systems.

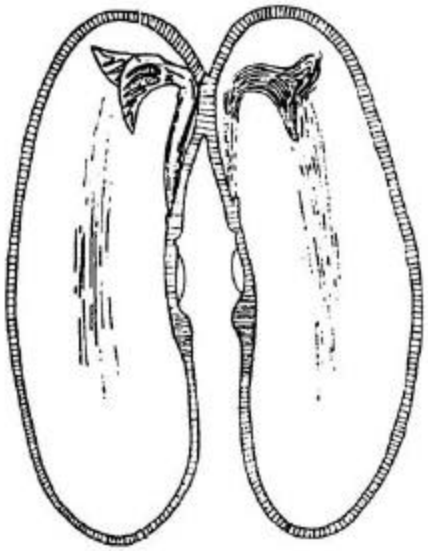
Plant cell types differ in (1) size, (2) shape, (3) cell wall thickness and composition and (4) characteristics of the protoplast. How many different cell types can you find in your sections? On the back of each card, list the cell types found in each tissue systems. Use the names of the cell types if you remember them from BIO 112/102. Otherwise, list the characteristics of each cell type that distinguish it from others (i.e. 1-4 above).

Part 2 – Terminology review

Examine soaked bean seeds, seedlings and mature bean plants. Identify each of the structures listed below. Finally, label each structure on the diagrams provided.

simple leaf	**axillary bud**	**shoot apex**	**radicle**
leaf blade	**compound leaf**	**taproot**	**plumule**
petiole	**leaflet**	**lateral root**	**hypocotyl**
vein	**node**	**root apex**	
midrib	**internode**	**embryo**	
axil	**phytomere**	**cotyledons**	





USE OF THE MICROSCOPE

Identify the following parts of the microscope with the help of the instructor.

- -on/off switch and brightness control knob (rheostat)
- -condenser with diaphragm adjustment lever
- -condenser adjustment knob
- -stage with stage control knobs
- -coarse (outer) and fine (inner) focus adjustment knobs
- -objective turret with 10X, 40X and 100X lenses
- -eyepieces with focusing and interpupillary distance adjustments

Follow these instructions to use the microscope.

1. Before plugging in the microscope, make sure the on/off switch is turned off and that the brightness control is at the lowest setting. Plug in the power cord.

2. Check that the 10X objective is in position. Place a slide on the stage and center the specimen with the stage control knobs.

3. Turn on the light and use the rheostat to adjust the light so that it is comfortable for your eyes.

4. For normal viewing, the condenser should be in the full up position. This is accomplished using the condenser adjust knob.

5. Use the coarse and fine focus knobs to focus the specimen.

6. Adjust the interpupillary distance until comfortable and read the measurement on the interpupillary distance scale (write down this number for next time!). Use you interpupillary distance measurement to adjust the focus on the RIGHT eyepiece. Now, close your left eye and focus on the specimen using the coarse and fine focus adjustment knobs. Close your right eye and focus on the specimen using the focusing ring on the LEFT eyepiece. **If you haven't used binocular microscopes before, you may have difficulty looking at the specimen with both eyes at first. Once you get used to it, a binocular scope is more comfortable.** Adjust the eyepieces and interpupillary distance carefully, and force yourself to use both eyes. You will avoid eye strain in the long run.

7. To change magnification, turn the turret to the next higher objective using the ring. These microscopes are **parfocal**, meaning that as you change objectives you should be very close to perfect focus. **Do not** use the coarse focus adjustment knob with any objective other that the 10X objective. The 100X objective is for oil immersion only.

8. Finally, you can adjust the contrast using the condenser diaphragm adjustment lever. Notice that contrast increases as you move the lever to the right. Do not use the condenser diaphragm to adjust the brightness--this adjustment should be made with the rheostat.

9. Before removing the slide, turn the turret to the 10X objective.

Return the microscope to the cabinet after you:

1. Check that your slide is removed and that the 10X objective is in place.

2. Turn the brightness control to the lowest setting and turn off the power switch.

3. Unplug and fold the power cord.

A note on cleaning lenses. If you use the microscope properly, you normally will not need to clean the objectives. If they become dirty, use **only lens paper** to clean them. Eyepieces also can be cleaned with lens paper.

FREE HAND SECTIONING

Note: Wear gloves and safety glasses when using stains. Dispose of slides in the sharps disposal container. Dispose of left-over stains in the chemical waste bottle.

Materials:
1. Razor blades
2. Forceps and plastic drinking straws cut at an angle to use as spatulas.
3. Spot plate for staining.
4. Clean slides and coverslips.
5. Toluidine blue (0.05% aqueous) and other stains as necessary.
6. Finger bowl with water and paper towels.
7. Dropper bottle containing water.
8. Kimwipes.

Procedure:
1. Sit comfortably with your forearms resting on the bench and your elbows close to your sides. Hold tissue between your thumb and forefinger.

2. Wet razor blade, fingers and tissue with water from the finger bowl. Water should drip from your fingers during sectioning.

3. Cut the tissue quickly and smoothly in the plane desired. Now section slowly by drawing the razor blade toward you in a smooth slicing motion; the razor should rest on the tip of your thumb. Use your thumb to control the thickness and evenness of the sections. **This takes practice**. Concentrate on getting very thin portions of some sections. It is not necessary to obtain complete cross sections.

4. Transfer sections to a water-filled depression in the spot plate **before they dry**. Do not dull the razor blade by touching it to the spot plate; use your spatula.

5. Transfer sections to a depression containing toluidine blue and stain for 15 seconds. Do not use stain that has begun to precipitate due to evaporation.

6. Rinse sections in a depression containing water.

7. Mount sections on clean slides in a drop of water. To apply the coverslip, hold it at an angle and touch the water drop with one edge. Lower the coverslip slowly to avoid air bubbles. Semi-permanent mounts can be made by fixing tissue in phosphate-buffered glutaraldehye, mounting in glycerol jelly and sealing the coverslip with nail polish.

CYTOCHEMICAL STAINS

General staining
1. Immerse sections in toluidine blue solution (0.05% in water) for about 15 seconds.
2. Transfer to water.
3. Mount in water.

Starch
1. Immerse sections in IKI solution (2% potassium iodide, 0.2% iodine in water) for about 15 seconds.
2. Transfer to water.
3. Mount in water.

Protein
1. Immerse sections in naphthol blue black solution (1% in 7% acetic acid) for about 1 minute.
2. Transfer to 7% acetic acid.
3. Transfer to water.
4. Mount in water.

Lipids
1. Immerse sections in Sudan black B solution (saturated solution in 70% ethanol--about 0.1%) for about 1 minute.
2. Transfer to 70% ethanol.
3. Transfer to water.
4. Mount in water.

Lignin
1. Immerse sections in phloroglucinol solution (saturated solution in 20% HCl--about 0.1%) for 1-2 minutes.
2. Transfer to water.
3. Mount in water.

Callose (sieve plates)
1. Immerse sections in IKI solution (see starch above) for 2 minutes.
2. Transfer to water.
3. Transfer to aniline blue solution (0.1% in water) for five minutes.
4. Transfer to water.
5. Mount in water.

ANATOMICAL DRAWINGS

"Why do I have to do all of these drawings?" This question has entered the mind of every plant anatomy student. This section explains the purpose of anatomical drawings and helps you prepare drawings that record your observations effectively.

So, why drawings? When you make anatomical drawings, you develop several useful skills including the ability to:

A. interpret complex information,
B. identify diagnostic features that distinguish among similar structures, and
C. represent and communicate this information in visual form.

These skills have applications in many fields. Your employer will probably never ask you about the difference between a tracheid and a vessel element, but he or she may well ask you to examine a complex problem, identify the important points among a confusing array of details, and present your analysis to coworkers. Sound familiar?

Easy steps to better drawings. The purpose of a drawing is to convey information, first to your lab instructor who will evaluate whether you understood the specimen you were asked to draw, and then to yourself as a record of what you will need to recognize when you take exams. A useful drawing includes just the right amount of detail. You can accomplish this by using the following steps to plan your drawings.

1. Select the magnification and field of your drawing according to what you are asked to illustrate. Given the very same prepared slide, you might be asked to illustrate:

A. a cell type,
B. an arrangement of cells within a tissue, or
C. an arrangement of tissues within an organ.

The resulting drawings should be very different.

2. Include details that distinguish the subject from other similar structures. Given the assignments in A-C above, your drawings might be designed as follows:

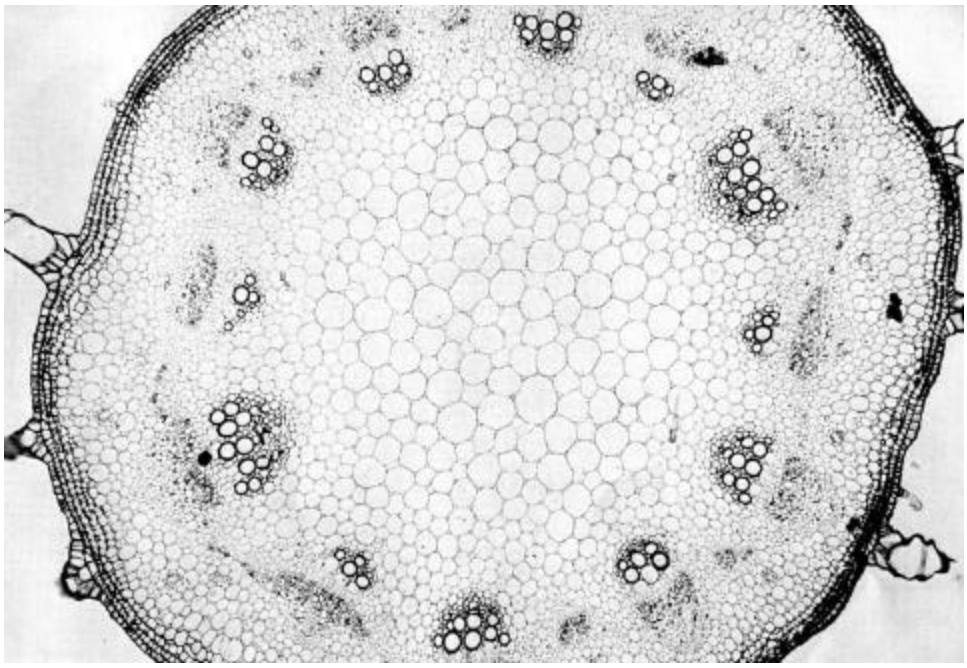
A. Include details of individual cells (a brachysclereid should look different from an astrosclereid).
B. Draw outlines of individual cells with enough detail to distinguish among cell types.
C. You may not need to draw individual cells at all. If the point is to show how vascular bundles are arranged in a stem, you need only outline boundaries of vascular bundles.

3. Represent form, proportion, and spatial relationships accurately.

4. Use insets when information at more than one level of organization must be conveyed.

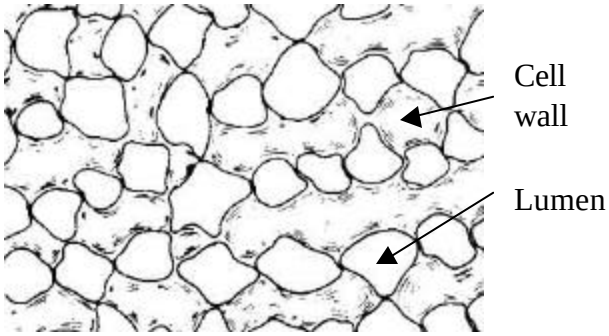
5. Label distinguishing features.

Examples: Three drawings based on a cross-section of *Helianthus* stem.

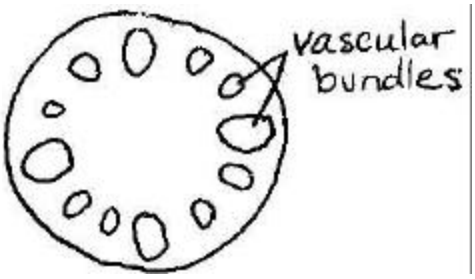


Photograph of a cross section of *Helianthus* stem (c.s.). Mag. 50X.

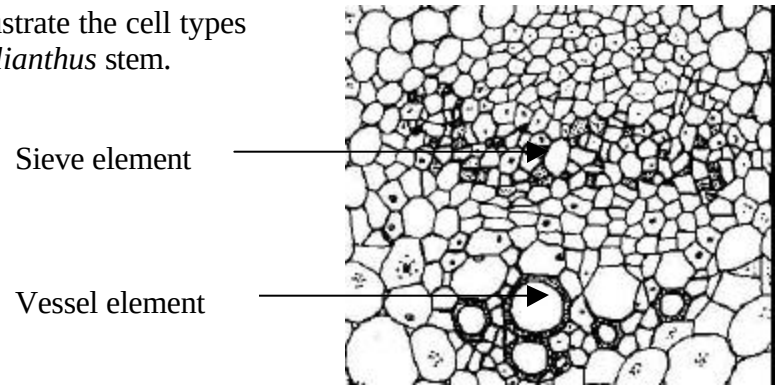
1. Draw a diagram to illustrate the structure of collenchyma cells in *Helianthus* stem.



2. Draw a diagram to illustrate the arrangement of vascular bundles in *Helianthus* stem



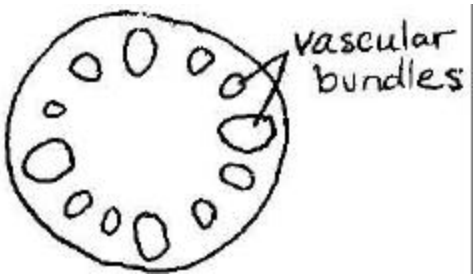
3. Draw a diagram to illustrate the cell types found in the xylem of *Helianthus* stem.



Lab assignments:

Prepare drawings for 311 labs on 5X8" note cards using the following format:

Card number: 1-2 Name: Botany Bob
Date: 9/12/01 Lab section: 02



Vascular bundles in *Helianthus* stem

Sometimes you will be asked to answer questions on the back of the card.

Cards will be graded on the following criteria:

1. Is the subject shown at an appropriate magnification?
2. Is the context clear?
3. Is the level of detail?
4. Are the appropriate structures labeled?
5. Answers to questions.

Cards will be returned promptly so that you can use them for studying.

LAB 2 - PLANT CELLS

Introduction

To understand the structure and function of plant tissues, you must first understand the structure and function of the cells that compose them. Much of what we know about cells has been learned using biochemical techniques and electron microscopy. These topics will be covered in lecture. This lab focuses on the aspects of plant cell structure that can be observed with a light microscope. Light microscopy has a very important advantage over electron microscopy, namely the light microscope can be used to observe *living* cells. The disadvantage of the light microscope is that the resolution can never be better than 0.2 µm. After completing this lab you should have an enhanced understanding of the dynamic nature of cells. You will also be introduced to some of the variation in structure found among plant cells.

Part 1 - Plant cells in motion

Remove a stamen from a flower of *Tradescantia* or *Rhoeo* (onion epidermis may be used if flowers are not available). Notice the fine white hairs on the filament. Remove the anther and make a wet mount of the filament. Examine the stamen hairs using the compound microscope. Each stamen hair is composed of a file of cells. Focus carefully on a single cell and notice the large **nucleus**. If you watch the cytoplasm carefully you should see small particles moving in a process called **cytoplasmic streaming**. Cytoplasmic streaming is driven by the same proteins that are responsible for muscle movement, **actin** and **myosin**. The moving particles are coated with myosin, which moves them along cables of actin using energy derived from ATP. Try to remember the movement that occurs in living plant cells as you look at prepared slides throughout the semester.

Card 2-1: Draw a stamen hair cell and label the nucleus, cytoplasm, and vacuole.

Part 2 - Plastids

Plastids are derived from **proplastids**, which are self-replicating organelles found in meristematic cells. The most familiar plastid is the chlorophyll-containing photosynthetic organelle the **chloroplast**. Other types of plastids include **chromoplasts**, which contain red, orange or yellow carotenoid pigments and **amyloplasts**, which store large amounts of starch. The leaf cells of plants that have germinated in the dark contain **etioplasts**, which develop into chloroplasts as soon as as the leaves are exposed to light.

Chloroplasts: Make a wet mount of isolated *Zinnia* mesophyll cells and examine it with the compound microscope. The green, disk-shaped bodies are chloroplasts.

Amyloplasts: Embryos often contain large amounts of stored starch. Why? Examine a prepared slide of *Sagittaria* embryo and identify starch grains. Each amyloplast contains several starch grains, but the boundaries of the organelles are usually not visible with the light microscope.

Card 2-2: Draw and label comparative diagrams of chloroplasts (*Zinnia*), and amyloplasts (*Sagittaria*).

Chromoplasts: Make wet mounts of slices of green and red peppers. The plastids in the green pepper are chloroplasts, but the chloroplasts have redifferentiated into chromoplasts in the red pepper. The red-orange **carotenoid** pigments in these plastids are **hydrophobic** (lipid soluble).

Card 2-3: Draw and label diagrams of cell containing chloroplasts and chromoplasts in green and red peppers, respectively.

Part 3 - Vacuoles:

Vacuolar pigments: In contrast to chromoplasts, **vacuoles** contain **anthocyanin** pigments, which are **hydrophilic** (water soluble). Peel a piece of epidermis off of a red onion bulb or a *Tradescantia* leaf and prepare a wet mount. The red-violet pigments you see are contained within the vacuole. In addition to containing pigments and other materials, vacuoles function similarly to the lysosomes of animal cells.

Tannins: The vacuoles of some cells accumulate phenolic substances called **tannins**. These compounds complex with proteins (the basis for their ability to tan leather) and help protect plants against insects and pathogens. Examine a prepared slide of pine leaf an identify the red-staining tannin cells

Card 2-4: Draw and label comparative drawings of cells with pigmented vacuoles (*Tradescantia*) and vacuoles containing tannins (pine leaf).

Crystals: Some cells accumulate crystalline calcium oxalate in their vacuoles. Proposed functions of stored calcium oxalate include inhibition of predation and calcium storage. Crystalline materials are best viewed with polarized light. Use polarizing filters to examine a wet mount of *Diffenbachia* stem. The needle-like crystals or **raphides** are responsible for this plant's common name "dumb-cane." If the plant is eaten, the crystals lodge in the tongue causing it to swell. **Druse** crystals can be identified in sections of *Begonia* petiole.

Card 2-5: Draw and label comparative drawings of cells with raphide crystals (*Diffenbachia*) and druse crystals (*Begonia*).

Part 4 - Cell walls

Growing plant cells produce **primary cell walls** composed predominantly of **polysaccharides**. Some cell types produce a **secondary cell wall** that may become impregnated with an aromatic polymer called **lignin**. Cells with primary cell walls and those with lignified secondary cell walls can be observed in the flesh of pear fruit. Obtain a small piece of pear flesh and place it on a slide with a drop of **phloroglucinol** (Caution: the phloroglucinol is dissolved in 20% HCl). Place a coverslip over the material and press gently to spread the cells. Examine the slide with the compound microscope. The phloroglucinol reacts with lignin to produce a red color, staining

only cells with secondary cell walls. The cells that appear unstained have only primary cell walls. Save this slide! You will be asked to look at it again in the next section.

Card 2-6: Draw a diagram that distinguishes cells with primary cell walls only from those with secondary cell walls.

Part 5 - Intercellular connections

Plasmodesmata: Cells with primary cell walls are connected to one another by channels called **plasmodesmata** that perforate the primary cell wall. These channels are lined with plasma membrane and they contain cytoplasm. Plasmodesmata are often clustered in thin regions of the cell wall known as **primary pit fields**. Plasmodesmata are not visible with the light microscope, but they can be seen in electron micrographs.

Simple pits: Connections between cells with secondary cell walls are called **pits**. These are areas where secondary cell wall material was not deposited so only the primary cell wall or **pit membrane** separates the cells. Unlike the plasmodesmata described above, pits do not contain plasma membrane or cytoplasm. **Simple pits** are visible in the sclereids of pear. Take another look at the slide that you stained with phloroglucinol and note that the channels are continuous from one cell to another. Now examine a prepared slide of pear fruit in which simple pits are visible in face view and in side view.

Card 2-7: Draw diagrams to illustrate simple pits in face view and in side view. Label the secondary cell wall, cell lumen and simple pits.

More complex pits called **circular bordered pits** can be examined in sections of pine wood (see radial section for face view, tangential section for side view).

Card 2-8: Draw labeled diagrams to illustrate circular bordered pits in face view and in side view.

LAB 3 - MERISTEMS, GROWTH, AND DIFFERENTIATION

Introduction

In this lab you will learn about the organization and function of the apical meristems of roots and shoots. Before you get started some clarification of terminology is in order. A **shoot apex** or **root apex** refers simply to the tip of a shoot or root. A **meristematic region** is a site of cell division and growth, but its boundaries are not discrete. An **apical meristem** is a discrete group of cells that divide in an organized manner, thus establishing the pattern of the apex and supplying cells to the rest of the meristematic region. Finally, **apical initials** are cells that divides to produce (1) a cell that stays in the meristem and (2) a cell that divides further to produce new tissues.

Part 1 - Dissection of the shoot apex

Use modeling to mount an *Elodea* shoot apex under the dissecting microscope. While observing with the microscope, remove the leaves from the shoot apex. Eventually you will uncover the **apical dome** surrounded by tiny **leaf primordia**. Notice the orderly arrangement of leaf primordia around the apical dome. The shoot apical meristem forms cells basipetally to increase the length of the stem and laterally to produce leaves. Compare the three-dimensional shoot apex with a prepared slide of a longitudinal section of the *Elodea* shoot apex. Even though we will be examining prepared slides, remember that the shoot apex is 3 dimensional and constantly changing. An apical meristem retains a similar *organization* over time, but the *population of cells* of which it is composed changes constantly. This exercise should help you interpret the prepared slides that you will examine next.

Card 3-1: Draw diagrams of living and sectioned shoot tips of *Elodea*. Label apical dome and leaf primordia.

Part 2 - Organization of the shoot apical meristem

The shoot apical meristems of different plants vary in size, shape, and organization. You will examine two distinct types today, but there are many other variations.

The apical meristems of the seedless vascular plants (e.g. ferns) feature a single apical initial called the **apical cell**, which provides the precursors for all other cells of the meristem. Examine the prepared slide of the shoot apex of *Equisetum* and identify the apical cell. Refer to your lecture notes to review how the apical cell functions.

Card 3-2: Draw a labeled diagram of an *Equisetum* shoot apical meristem.

The shoot apical meristems of angiosperms are more complex in structure and function than those of seedless vascular plants. Examine a prepared slide of *Coleus* stem tip and notice the layered structure of the apical dome. The outermost layers (**L1** and **L2**) consist of cells that divide in an **anticlinal orientation** (perpendicular to the surface). The cells of the **L3** layer can divide in any orientation. Each of these layers arises from separate **apical initials**. Now

distinguish the radial zones (**central zone**, **peripheral zone** and **rib zone**) within the *Coleus* shoot apical meristem. Which zone contains the cells that function as apical initials?

Card 3-3: Draw two diagrams of *Coleus* shoot apical meristems, one to illustrate layers L1, L2 and L3 and another to illustrate the radial zones. On the back of the card, describe the functions of each of the layers and radial zones .

The pattern of initiation of leaf primordia determines the pattern of leaf arrangement (phyllotaxy) in the mature plant. Compare the shoot apex of *Coleus* (which has opposite leaves) with that of *Ginkgo* (which has alternate leaves).

Card 3-4: Draw comparative drawings of shoot tips from a plant with opposite leaves (*Coleus*) and a plant with alternate leaves (*Ginkgo*).

Part 3 - The root apex

Examine the root apex of water hyacinth or *Zebrina* and note the prominent **root cap**. In contrast to the shoot apical meristem, the root apical meristem forms cells apically as well as basipetally. This type of organization is necessary to supply cells to the root cap, which constantly sloughs-off cells as the root penetrates the soil. Another difference is that the root apical meristem does not give rise to lateral organs. Lateral roots arise from deep within mature regions of the root. Note that there are no lateral roots in the region just above the root cap.

Card 3-5: Draw a diagram of a root apex and label the root cap and lateral roots.

Part 4 - Organization of the root apical meristem

As with shoot apical meristems, the organization of root apical meristems varies among taxa. We will examine two examples.

The root apical meristems of seedless vascular plants have an **apical cell** as does the shoot apical meristem. In addition to several basipetal cutting faces, the root apical cell has one cutting face directed distally that contributes cells to the root cap. Study a prepared slide of *Botrychium* root.

Card 3-6: Draw a diagram of a *Botrychium* root tip. Label the apical cell and root cap.

Like shoot apical meristems, the root apical meristems of flowering plants are more complex than those of seedless vascular plants. Examine the prepared slide of *Zea* root tip and note the boundary between the root cap and the rest of the root. The outermost layer of the root tip itself will become the dermal tissue system of the root. Now identify the developing vascular cylinder in the center of the root. Where the vascular cylinder meets the boundary between the root and the root cap, there is a small group of cells call the **quiescent center**. Surrounding the quiescent center are the apical initials that produce the cells of the root cap, epidermis, vascular cylinder and ground tissue.

Card 3-7: Draw a diagram of a *Zea* root tip and label the root cap, vascular cylinder, dermal tissue, ground tissue, quiescent center and apical initials.

Part 5 - Primary meristematic tissues

Cells produced by the apical meristems of the shoots and roots give rise to the **primary meristematic tissues** as they begin to differentiate. The primary meristematic tissues can be identified in the region just basal to the apical meristem. Examine the prepared slide of the root apex of *Zea*. The cells at the surface are the **protoderm** and will give rise to the dermal tissue system. The elongated strands of cells are the **procambium** and will give rise to the vascular tissue system. The remaining cells form the **ground meristem** and will give rise to the ground tissue system. These tissues are also recognizable in the shoot apex and in the embryo. Examine the longitudinal section of *Coleus* shoot tip and the slide of the *Capsella* embryo and identify the primary meristematic tissues.

Card 3-8: Draw diagrams and label the primary meristematic tissues in *Zea* root apex, *Coleus* shoot apex, and *Capsella* embryo.

LAB 4 – DERMAL TISSUE SYSTEM

Introduction

As cells derived from the apical meristems begin to mature they become specialized for particular functions; that is they **differentiate**. Differentiation leads to the formation of **tissues**, which are groups of cells that function together. Whereas cells within the apical meristems look similar, the cells that compose the primary meristematic tissues can be distinguished by their appearance. The cells that compose the mature tissues are even more distinctive. The table below illustrates the developmental relationships among plant tissues:

Primary meristems	Primary meristematic tissues	Mature tissues	Tissue systems
root apical meristem shoot apical meristem	protoderm	epidermis (complex)	DERMAL
	ground meristem	parenchyma (simple) collenchyma (simple) sclerenchyma (simple)	GROUND
	procambium	xylem (complex) phloem (complex)	VASCULAR

The epidermis, a **complex tissue** composed of several types of cells, forms a barrier between a plant and its external environment. The epidermis forms when protoderm cells derived from the L1 layer of the apical meristem differentiate and it is usually just one cell layer thick. Its functions are diverse including gas exchange, reduction of water loss, and protection against herbivores and pathogens.

Part 1 - Cell types of the epidermis

Pavement cells fit tightly together and secrete a water-repellent cuticle that reduces water loss and pathogen invasion. **Stomata** are required for uptake of carbon dioxide in photosynthetic tissues and their apertures are regulated by **guard cells**. Other cells of the epidermis may be specialized as hairs or **trichomes**. Prepare an epidermal peel of the leaf provided and identify the cell types.

Card 4-1: Draw a diagram of the peel as viewed under the compound microscope and label the cell types.

Part 2 - Pavement cells and cuticle

Pavement cells form the outermost cell layer of a plant and were named for their resemblance to paving stones used for garden paths. Pavement cells lack chloroplasts and are covered by a

cuticle that may be very thick in xeric-adapted plant. Examine the prepared slide of *Yucca* leaf and identify pavement cells and cuticle.

Card 4-2: Draw a diagram of pavement cells with cuticle in *Yucca* leaf.

Occasionally the shoot epidermis may be more than one cell layer thick. This occurs if cells derived from the L1 layer divide periclinally forming two layers of protoderm that differentiate into a **multiple epidermis**. Cut free-hand sections of *Begonia* leaf to observe a multiple epidermis. How can you tell that the inner layer of epidermis is not part of the ground tissue of the leaf?

Card 4-3: Draw a labeled diagrams to illustrate a multiple epidermis in *Begonia* leaf.

Part 3 - Guard cells and stomata

Guard cells control the point of entry of carbon dioxide and the point of exit of water vapor in leaves and stems. In dicots, a pair of kidney-shaped guard cells surround the **stomatal pore**. In grasses the guard cells are dumbbell-shaped. In some cases the epidermal cells adjacent to the guard cells are distinct from ordinary epidermal cells and are termed **subsidiary cells**. A **stomatal apparatus** includes guard cells, stomatal pore and subsidiary cells. Prepare epidermal peels of jade plant and corn, mount them in water, and examine them with the compound microscope.

Card 4-4: Draw diagrams of stomatal apparatus from jade plant and corn and label the component structures.

Part 4 – Trichomes and glands

Trichomes are cells that project out of the plane of the epidermis. **Root hairs** are trichomes found on the root epidermis of most plants. Corn seedlings have been germinated in water to demonstrate root hairs. Make a wet mount and examine them with dissecting and compound microscopes.

Card 4.5: Draw a diagram of a corn seedling with root hairs.

Plants have a wide variety of specialized trichomes. Examine the leaf surfaces of each plant with the dissecting microscope. Then make epidermal peels to examine with the compound microscope. Trichomes on leaves and stems reduce water loss and may take many forms. The simple trichomes of geranium are **straight** and those of bean are **hooked**. Compare the velvety feel of geranium leaf with the sticky feel of bean leaf. Elaborate multicellular trichomes can be **branched** as in *Eleagnus* (Russian olive), or **peltate** as in *Tillandsia* (Spanish moss).

Card 4.6: Draw diagrams to distinguish between the following types of trichomes: straight, hooked, branched or peltate.

Secretory trichomes produce a variety of compounds. Examples of plants with secretory trichomes include tobacco and *Drosera* (sundew). Can you identify the functions of these trichomes?

Card 4.7: Draw diagrams to illustrate the secretory trichomes of tobacco and *Drosera* (sundew). On the back of the card, describe the function of each structure.

Glands, like secretory trichomes, produce a variety of compounds. However, unlike trichomes, they do not rise above the epidermal surface. The glands of *Dionea* (Venus fly trap) secrete digestive enzymes and those of *Limonium* (sea lavender) secrete salt. The **nectaries** of flowers are also glands.

Card 4.8: Draw diagrams to illustrate the glands of *Dionea* (Venus fly-trap), *Limonium* and honeysuckle flower. On the back of the card, describe the function of each structure.

LAB 5 – GROUND TISSUE SYSTEM

Introduction

This lab focuses on the tissues of the ground tissue system. These are **simple tissues**, in that they contain only one cell type. They develop from the ground meristem and fill the space between the epidermis and the vascular bundles. Functions are diverse and include suppport, storage and photosynthesis.

Part 1 - Classification of plant cell types

The simple tissues take their names from their component cell type. Plant cells are classified in three groups on the basis of cell wall thickness and composition.

Parenchyma cells have thin primary cell walls.

Collenchyma cells have unevenly-thickened primary cell walls and occur in bundles.

Sclerenchyma cells have thick secondary cell walls containing lignin. The protoplasts die as sclerenchyma cells mature.

Cell wall thickness can be determined easily with the microscope, but stains are needed to determine the cell wall composition. In lab 2 you used **phloroglucinol** to stain lignified cells. As a review, make a section of pear flesh, stain with phloroglucinol, and note the position of sclerenchyma cells. Phloroglucinol stains only lignified cells, so it is helpful to see how sclerenchyma stains with the more generalized stain **toluidine blue**. Stain some pear flesh with toluidine blue and note the color of the sclerenchyma cells that you identified with phloroglucinol. Prepared slides have been stained with a combination of **saffranin and fast green**. What color does lignin stain with this combination?

Card 5-1: Sketch color-coded drawings of pear flesh stained with phloroglucinol, toluidine blue, and saffranin/fast green and identify sclerenchyma cells and parenchyma cells.

Part 2 - Parenchyma

Among the major classes of plant cells, parenchyma includes the greatest diversity of structure and function. Whereas the primary function of collenchyma and sclerenchyma cells is support, parenchyma cells may function in photosynthesis, storage, secretion and a variety of more specialized tasks. In this exercise you will examine several types of simple parenchyma tissues.

Chlorenchyma, parenchyma tissue specialized for photosynthesis, is rich in chloroplasts. Examine the prepared slide of *Ligustrum* leaf. The closely packed cells below the upper epidermis are a type of chlorenchyma called **palisade mesophyll**. Chlorenchyma also occurs in green stems, unripe fruits (like the peppers you saw in lab 2) and some aerial roots.

Aerenchyma, parenchyma tissue specialized for gas exchange, is characterized by large intercellular air spaces. Examine the prepared slide of *Ligustrum* leaf once more, this time concentrating on the **spongy mesophyll** located between the palisade mesophyll and the lower epidermis.

Card 5-2: Draw a diagram of a *Ligustrum* leaf and label chlorenchyma and aerenchyma.

Aerenchyma is especially well developed in aquatic plants, where it functions in both floatation and gas exchange. Examine aerenchyma in the following plants: 1) *Nymphaea* (water lily) leaf, 2) *Juncus* (bullrush) leaf , 3) Water hyacinth petiole, and 4) *Myriophyllum* stem.

Card 5-3: Draw diagrams to illustrate different arrangements of aerenchyma. What features do all aerenchyma tissues share? What features distinguish different types of aerenchyma?

Storage parenchyma may store starch (in amyloplasts), oil (in oil bodies or plastids), protein (in protein bodies or cytoplasmic granules), hemicellulose (in cell walls), or water (in vacuoles). Prepare specimens as described in the table below.

Card 5-4: After examining each specimen, complete the table by identifying the storage product (e.g. starch, protein, etc.), the storage compartment (e.g. vacuole, cell wall etc.), and the appearance of the stored material (e.g. color and form).

Tissue	Preparation	Storage product	Storage compartment	Appearance
Bean cotyledons	Stain with IKI			
Bean cotyledons	Stain with naphthol blue black			
Avocado fruit	stain with Sudan IV			
Jade plant leaves	Free-hand section			
Persimmon endosperm	Prepared slide			

The **endodermis** is the innermost layer of the root cortex and consists of cells characterized by a **Casparian strip**. This band of suberin blocks the apoplastic flow of water into the stele of the root. Identify the endodermis in the prepared slide of *Pyrus* (pear) root.

Card 5-5: Draw a diagram of the endodermis from *Pyrus* root. Label the features that distinguish this tissue from others.

Part 3 - Collenchyma

Collenchyma tissue consists of elongated cells with unevenly thickened primary cell walls. The walls of collenchyma cells are rich in hemicellulose and pectin, but contain no lignin. Layers of cellulose microfibrils in the walls alternate between longitudinal and transverse orientations. The resulting plasticity of collenchyma cell walls provides flexible support. Thus, collenchyma usually occurs in bundles in regions that are growing, such as young stems, or that must remain flexible after growth ceases, such as petioles.

Card 5-6: Examine collenchyma from *Sambucus* (elderberry) stems and celery petioles and draw examples of each.

Part 4 - Sclerenchyma

Lignified secondary cell walls and absence of the protoplast are characteristics of sclerenchyma cells. The two types of sclerenchyma are **fibers** and **sclereids**. Fibers are typically long and thin and sclereids occur in a variety of shapes and sizes. Since lignified secondary cell walls are elastic rather than plastic, sclerenchyma is suited for support in mature non-growing tissues and may function in protection as well. Extraxylary fibers occur in bundles in ground tissue. Like the sclereids from which they evolved, extraxylary fibers have simple pits. As you will see in the next lab, **xylary fibers** have slit-shaped pits, a clue that they evolved from tracheids. Examine the following types of sclerenchyma: 1) **brachysclereids** (*Hoya* stem), 2) **astrosclereids** (*Nymphaea* leaf), 3) **extraxylary fibers** (*Yucca* leaf).

Card 5-7: Draw diagrams to illustrate the differences between brachysclereids, astrosclereids and extraxylary fibers.

The seed coat of bean consists of several layers of sclereids. Look at the prepared slide of *Phaseolus* (bean) seed and see how many different types of sclereids you can recognize in the seed coat. Also place a drop of macerated bean seed coat on a slide and examine it to see separated sclereids. The rectangular sclereids are **macrosclereids** and the sclereids that are shaped like dog bones are **osteosclereids.**

Card 5-8: Draw a diagram of bean seed coat and label macrosclereids and osteosclereids.

LAB 6 - XYLEM

Introduction

The vascular tissues (xylem and phloem) are complex tissues that may contain parenchyma cells and fibers in addition to conducting cells. Both tissues occur together in bundles that are continuous throughout the plant. In lab 7 you will learn more about the phloem. This exercise focuses on the cell-types and organization of the xylem, the tissue that functions in transport of water and minerals and also provides support.

Part 1 - Cell types of the xylem

The water conducting cells of the xylem are know collectively as **tracheary elements**. In addition to tracheary elements, the xylem of most plants contains **parenchyma** cells and **xylary fibers**. Examine a prepared slide of *Sambucus* (elderberry) stem. Identify the xylem tissue and its component cell types. What characteristics distinguish these cell types.

Card 6-1: Draw a diagram of *Sambucus* xylem and label the cell types.

Part 2 - Development of primary xylem

Tracheary elements are characterized by intricately patterned lignified secondary cell walls that prevent collapse of the conducting tubes due to tension generated by transpiration. Remember that lignified secondary cell walls are elastic. As a result the tracheary elements that mature in elongating tissues (**protoxylem**) deposit secondary cell walls in patterns such that the cells remain extensible. Tracheary elements that mature after elongation has ceased (**metaxylem**) deposit secondary cell walls in less extensible patterns.

Separate a few vascular bundles from boiled petioles of celery, stain with toluidine blue, and *squash* them between a slide and cover slip. Using your lecture notes, see how many different types of tracheary elements you can identify.

Card 6-2: Note the length, diameter and secondary cell wall pattern and make labeled drawings of each type of tracheary element.

The relationship between tissue expansion and the pattern of secondary cell wall thickenings is also evident in leaves. Examine a prepared slide of a cleared leaf. Note that tracheary elements in leaves have annular and spiral thickenings and that some tracheary elements show evidence of having stretched. What does this say about the relationship between tissue expansion and xylem differentiation?

As a model for the effect of tissue elongation on xylem vessels, you can stretch the vascular bundles of banana or dogwood leaf. Break a piece of leaf perpendicular to a vein and gently pull the pieces apart. Mount the resulting *threads* in water and examine with the compound microscope.

Card 6-3: Draw labeled diagrams of proxylem tracheary elements before and after they have been stretched.

Part 3 - Evolution of tracheary elements and xylary fibers

Tracheary elements can be further subdivided into **vessel elements,** which are interconnected by open **perforation plates** and **tracheids**, which have no perforation plates. Tracheids are considered the more primitive form and are the only conducting cells in the xylem of gymnosperms. However, tracheids have adaptive advantages, particularly in dry environments, and have been retained in angiosperms along with vessel elements.

Xylary fibers resemble the extraxylary fibers examined in lab 4 in that they are long, thin and have a thick secondary cell wall. However, they differ in pit structure and evolutionary origin. Xylary fibers evolved from tracheids and their slit-shaped pits are modified circular bordered pits. The longest, thinnest, thickest-walled xylary fibers are called **libriform fibers**. The structure of **fiber-tracheids** is intermediate between libriform fibers and tracheids.

You can gain an appreciation for the diversity of xylem cell types by examining macerations of wood from *Quercus*, *Liriodendron* and *Pinus*. Copy the table below and fill it in as you examine the macerations and identify the following cell characteristics: **tracheids**, **vessel elements**, **fibers** (including **fiber tracheids** and **libriform fibers)**, **simple perforation plates**, **scalariform perforation plates**, **circular bordered pits** and **slit pits**. Which characteristics are considered more primitive and which are considered more advanced? What are the adaptive advantages of the different types of pits and perforation plates?

	Vessel elements	Tracheids	Xylary fibers
Pinus	X		X
Liriodendron			
Quercus			

LAB 7 - PHLOEM

Introduction

The phloem functions in the transport of sugars from photosynthesis and a wide variety of other compounds such as amino acids and hormones. Unlike tracheary elements, the conducting cells of the phloem are alive at maturity, a characteristic that is essential for conduction by the **pressure flow mechanism**. The materials carried by the phloem are precious, and plants have evolved elaborate mechanisms to prevent leakage resulting from injury. In this exercise you will examine phloem tissue and learn more about the mechanisms that prevent sap leakage following injury.

Part 1 - Cell types of the phloem

Sieve elements are the sugar-conducting cells of the phloem. Sap flows between sieve elements through **sieve plate pores** (modified plasmodesmata). The sieve elements in angiosperms, occur in files, have terminal **sieve plates** and are enucleate. These sieve elements are closely associated with **companion cells**, which play an important role in phloem loading. Parenchyma cells and fibers are also common in phloem tissue.

The stems of *Cucurbita* (pumpkin) contain large sieve elements in phloem bundles that occur both on the outside *and* on the inside of the xylem (this relatively unusual arrangement is called a bicollateral bundle). Examine cross sections of *Cucurbita* stem and identify: sieve elements, sieve plates, companion cells and parenchyma cells. Examine longitudinal sections of *Cucurbita* phloem. Sieve elements can be recognized by red-staining "**p-protein plugs**". Also identify sieve plates and companion cells.

Card 7-1: Draw diagrams from cross and longitudinal sections to illustrate the types of cells found in *Cucurbita* phloem. Label each cell type as well as sieve plates, sieve-plate pores and p-protein.

The sieve elements in the phloem of *Vitis* (grape vine) are very large. Whereas the sieve plates of *Cucurbita* are perpendicular to the long axis of the sieve element, in *Vitis* they occur at a 45^{o} angle. Thus, when you look at a *Vitis* stem cross section, the appear to bisect very large sieve elements.

Card 7-2: Draw diagrams of *Vitis* sieve elements in cross section and in longitudinal section. Label sieve plates, sieve-plate pores and p-protein.

Part 2 - Callose

A characteristic of fixed sieve elements is **wound callose**, which forms within the sieve plate pores when tissues are prepared for sectioning. These callose plugs prevent leakage of phloem contents when a plant is injured by insects or grazing animals. Callose can be detected using aniline blue and fluorescence microscopy or aniline blue/IKI and bright-field microscopy. Stain sections of squash stem as directed and examine for callose using the microscopes available.

Card 7-3: Draw a diagram of squash sieve elements stained with aniline blue/IKI. Label sieve plates, sieve plate pores and callose.

Part 3 - P-protein

Sieve elements contains a slimy protein called p-protein. When a sieve tube is injured, p-protein surges against the sieve plates, blocking the sieve plate pores and forming the p-protein plugs that you observed in part 1. The DNA of every cell in the plant contains the gene that codes for p-protein. However, only in sieve elements is that gene transcribed and translated to produce p-protein. To prove this point, you will use a specific antibody and a technique called immunofluorescence to determine the location of p-protein in the stems of broccoli. The instructions for this exercise will be distributed in lab.

LAB 8 - ANATOMY OF STEMS

Introduction

Stems support photosynthetic leaves and reproductive structures above the substrate, thus increasing photosynthetic and reproductive efficiency. In addition, stems supply water and minerals to shoots via the xylem and photosynthate to roots via the phloem. In this lab exercise you will examine the general structure of stems in a variety of different types of plants.

Part 1 - Organization of the dicot stem

Examine the prepared slide of *Helianthus* (dicot) stem x.s. and identify the following tissues and regions: epidermis, ground tissue (parenchyma, collenchyma, sclerenchyma, cortex, pith), vascular tissue (xylem, phloem).

Card 8-1: Draw a diagram *Helianthus* stem and label the tissues.

Part 2 - Vascular bundles

Vascular bundles contain both xylem and phloem, but these tissues are arranged differently within the stem bundles of different plants. Plants also differ in the relative positions of proto/meta xylem and phloem.

For **cards 8-2** to **8-5**, draw a single stem vascular bundle from the specified plant and label protoxylem, metaxylem, protophloem, metaphloem, fibers and procambium (if present).

Card 8-2: *Helianthus* (sunflower, a dicot)--Collateral bundles

Card 8-3: *Zea mays* (corn, a monocot)--Collateral bundles

Card 8-4: *Cucurbita* (pumpkin, a dicot)--Bicollateral bundles

Card 8-5: *Polypodium* stem (a fern)--Amphicribral bundles

Part 3 - Steles

The arrangement of vascular bundles in a stem or root is know as the **stele**. Examine stem cross sections from the following species as examples of stelar types. Then, construct a DICOTOMOUS KEY that could be used to classify the different types of steles. Remember that although dictyosteles and eusteles both appear to consist of isolated bundles, they evolved separately from an ancestral protostelic plant. Also notice that eusteles and atactosteles are not as different as it may first appear. You should also understand the difference between true **leaf-gaps** (as found in ferns) and what have come to be called "leaf gaps" in angiosperms.

Protostele - *Psilotum* (primitive vascular plant)
Siphonostele - *Adiantum* (a fern)
Dictyostele - *Polypodium* (a fern)
Eustele - *Helianthus* (a dicot)
Eustele - *Pinus* (a conifer)
Atactostele - *Zea mays* (a monocot)

KEY:

A.

AA

B.

BB.

C.

CC.

D.

DD.

Part 3 - Nodal anatomy

Nodes are where vascular bundles leave the stem to enter leaves. Study the nodal anatomy of *Pelargonium* and *Coleus* by mounting a portion of a stem containing a node upside-down in clay under the dissecting microscope. Serial-section the stem with a razor blade and note changes in the stele. How do differences in the two plants relate to the observation that *Pelargonium* has large stipules? Identify "**leaf gaps**", **leaf traces, axial bundles** and the **nodal type** for each. Then look at the prepared slide of a *Zea* node and note the complexity. Due to the sheathing nature of grass leaves, many traces enter a single leaf.

Card 8-6: Choose *Pelargonium* or *Coleus* and draw a diagram to illustrate a three dimensional reconstruction of your serial sections. Label your drawing.

LAB 9 - ANATOMY OF LEAVES

Introduction

Leaves are the primary organs of photosynthesis in most plants. In this lab you will learn about the structure of leaves and their development following formation of leaf primordia at the shoot apical meristem.

Part 1 - Leaf anatomy in dicots, monocots, and conifers

Dicot leaves typically have **netted venation** and may be simple or compound. Examine the examples provided and identify the **base**, **stipules**, **petiole** and **lamina**. Examine the x.s. of *Ligustrum* (privet) leaf and identify: **midrib**, **upper** and **lower epidermis**, **palisade** and **spongy mesophyll**, **vascular bundles** (**xylem**, **phloem**, **bundle sheath**, **bundle sheath extensions**). How can you tell the **adaxial** from the **abaxial** surface? Now look at the **paradermal section** and identify the same tissues. Pay particular attention to the vascular bundles, which you can now see in longitudinal section, and the difference in packing of spongy and palisade mesophyll. Which type of mesophyll has the greatest volume of intercellular spaces per total volume? Which has the greatest free surface area per total volume?

Card 9-1: Draw diagrams of Ligustrum leaf in cross and longitudinal section. Label the tissues and structures in boldface type above. On the back of the card, describe the differences between palisade and spongy mesophyll.

Monocot leaves are characterized by **parallel venation** and sheathing leaf bases. Examine the examples provided and identify the **sheath**, **ligules** and **lamina**. Examine the prepared slide of *Zea* (corn) leaf and identify the different tissues as you did for the dicot leaf. Is the distinction between palisade and spongy mesophyll obvious? How does this relate to the orientation of these leaves on the plant? What is the function of the enlarged bundles sheath cells in this plant? Compare leaf anatomy of *Zea* (C4) with that of *Triticum* (wheat, C3). How do the bundle sheath cells differ? What functional difference is related to this structural difference?

Card 9-2: Draw diagrams of *Triticum* leaf and *Zea* leaf in cross section. Label tissues and structures as you did for *Ligustrum* leaf. On the back of the card, describe the structure and function of bundle sheath cells in C3 and C4 grasses.

The leaves of most conifers (gymnosperms) are non-deciduous and therefore tough and leathery. Examine the examples of conifer leaves. Now examine the prepared slide of pine leaf x.s. Identify as many tissues as you can including the single **vascular bundle**. These leaves exhibit a variety of adaptations including: (1) **sunken stomata**, (2) **folded parenchyma**, (3) an **endodermis**, (4) **transfusion tissue** between the vascular bundles and endodermis, (5**) resin ducts**. Identify these adaptations and think about the functions of each. Compare the anatomy of *Pinus* leaf with that of *Taxus*.

Card 9-3: Draw diagrams of *Pinus* leaf and *Taxus* leaf in cross section. Label tissues and structures, as well as special adaptations in boldface type above. On the back of the card, describe how these specializations help protect the leaves against winter conditions.

Varying stomatal position is one way that plants have adapted to increase water use efficiency. Many leaves like those of *Ligustrum* (card 9-1) are **hypostomatic** with all or most stomata on the shaded lower surface. **Sunken stomata**, as seen in *Pinus* (card 9-3) and **stomatal crypts**, as seen in the prepared slide of *Nerium* (oleander) leaf, further reduce water loss. Examine the prepared slide of *Zea* (corn) leaf to see an example of **amphistomatic** position, in which stomata occur on both surfaces of the leaf. Floating leaves, such as those of water lily (*Nymphaea*) are **epistomatic** with stomata on the upper surface.

Card 9-4: Draw diagrams to illustrate differences in stomatal position in *Ligustrum*, *Pinus*, *Nerium*, *Zea* and *Nymphaea* leaves. On the back of the card, describe the relationship between stomatal arrangement and leaf orientation in *Ligustrum*, *Zea* and *Nymphaea* leaves.

Part 2 - Leaf development

The development of a typical dicot leaf is illustrated in the slides of *Syringa* (lilac) leaf buds, in which several stages in the development of leaf primordia and you leaves can be viewed in cross section. Can you tell at what stage vascularization occurs? What changes can you note as you look at progressively older leaves? Compare the prepared slides of young *Syringa* leaf with that of mature *Syringa* leaf. Pay particular attention to the amount of air space in each tissue. What developmental scenario could lead to the arrangement of air spaces seen in mature leaves?

Card 9-5: Draw diagrams of several stages in the development of *Syringa* leaf. Label the tissues as they become distinct. On the back of the card, describe the process through which air spaces form in the spongy mesophyll.

Monocot leaves have a prolonged period of development during which they elongate from a **basal meristem**. Examine the prepared slide of *Zea* node. Can you identify the basal meristem in the leaves? How does vascular tissue in the leaf become connected to that in the stem? Can you see how the basal meristem forms parallel veins?

Card 9-6: Draw a diagram of a *Zea* node. Label the basal meristem and mature and developing vascular tissue.

The final stage in the development of deciduous leaves is **abscission**. This process is controlled in such a way as to minimize the vulnerability of the plant to pathogens and xylem cavitation. Examine the prepared slide of an abscission zone. Identify the **protective layers** and the **separation layer**. What other characteristics of the abscission zone have evolved to minimize injury?

Card 9-7: Draw a diagram of an abscission zone and label the protective and separation layers.

Part 3 - Heterophylly and heteroblasty

Leaves from the same plant can be influenced by their microenvironment. Compare **sun leaves** and **shade leaves** mounted on the same slide. Then compare **air leaves** and **water leaves** in the demonstration.

Card 9-8: Draw diagrams of *Juglans* (walnut) sun and shade leaves. Label as many differences as you can find between these leaves.

You saw one example of **heteroblastic leaves** in the very first lab. The first true leaves of bean plants are **simple** and later formed leaves are **compound**. Look at the plants provided for other examples.

LAB 10 - ANATOMY OF ROOTS

Introduction:

Roots anchor plants in the soil and absorb and conduct water and nutrients. Lateral roots do not arise in a predetermined pattern as do lateral shoots. The site of lateral root formation is influenced by heterogeneity in the soil microenvironment, so root systems are highly variable. The anatomical structure of roots, however, is quite uniform. In addition to the absence of apically derived lateral appendages, roots are distinguished from stems by the presence of a root cap and vascular organization. In this lab you will examine the general anatomy of roots and the origin of lateral and adventitious roots.

Part 1 - Generalized root anatomy and development

To get an idea of how the morphology of the root system differs in monocots and dicots, examine the seedlings of radish and barley that have been germinated in Petri dishes. **Tap root systems** are common in dicots. Identify the tap root on the radish seedling. **Fibrous root systems** are characteristic of monocots. Note the absence of a dominant tap root on the barley seedling. Also note where of the roots on the barley seedling originate. Roots originating from stem tissue are **adventitious roots** (a.k.a. **nodal roots**, **crown roots**, **prop roots**). For both seedlings identify: **root cap**, **root hairs**, **seminal** (primary) **root**, **lateral** (secondary) **roots**. You may also detect the slimy **mucigel** secreted by the roots.

Card 10-1: Draw labeled diagrams to illustrate the differences between a tap root system and a fibrous root system.

Examine the prepared slides of mature and immature *Ranunculus* root x.s. Identify the following in the immature root: **epidermis**, **cortical parenchyma**, **endodermis**, **pericycle**, **phloem**, **protoxylem**. Now examine the mature root and identify the same tissues plus **metaxylem**. The differences between the mature and immature roots are most obvious in the xylem, endodermis and cortex. What type of xylem maturation does this root have? What changes occur in the endodermis and what is the functional significance of these changes? What type of stele does this root have?

Card 10-2: Draw diagrams of immature and mature *Ranunculus* roots. Label the tissues and structures in boldface above. On the back of the card, describe the changes that occur as the root matures.

The following examples illustrate some of the common anatomical variations among angiosperm primary roots:

Zea mays - **Polyarch** stele with a parenchymatous pith. Note the alternating protoxylem and phloem and the large metaxylem elements. This type of stele is interpreted as a **protostele** in which the central xylem differentiated as parenchyma; here the pith differentiates from procambium, not ground meristem as is the case in stems. This is a common pattern in monocots, especially those with large diameter roots. Note also the sclerified **hypodermis**.

Smilax (monocot) - Polyarch stele with central xylem. Roots of this plant have highly sclerified exodermis and endodermis with **passage cells**. Note the crystal cells in the outer cortex.

Psilotum stem - Just to remind you of the similarity between the stem anatomy of this primitive, rootless plant and that of angiosperm roots. Can you identify the endodermis?

Card 10-3: Draw diagrams of *Zea* root and *Smilax* root and label the tissues. On the back of the card, explain variations in the organization of protosteles as seen in *Ranunculus* root, *Zea* root, *Smilax* root, and *Psilotum* stem.

Part 2 - Development of root systems

Lateral root origin: Examine a prepared slide of *Pistia* or *Salix* root with developing branch roots. Where do the meristematic cells appear to be located? Identify the vascular connection between the lateral root and the stele of the primary root. Can you see a root cap? What happens to epidermal, cortical and endodermal tissue during this process?

Card 10-4: Draw a labeled diagram of a developing lateral root. On the back of the card, explain the process of lateral root development.

Adventitious root origin: Make a free-hand section of a *Zebrina* node such that you section an adventitious root longitudinally. From what tissue was the adventitious root derived. How do vascular connections become established? Adventitious root development can be seen cross sections of *Lycopersicum* (tomato) stem. How does the origin of adventitious roots compare with that of branch roots?

Card 10-5: Draw a labeled diagram of a developing adventitious root. On the back of the card, explain the process of adventitious root development and how it differs from lateral root development.

Part 4 - Roots and microorganisms

Nodules - The symbiotic relationship between the bacterium *Rhizobium* and plants in the legume family form nodules that function in nitrogen fixation. Section the nodules and examine with the compound microscope.

Mycorrhizae - Examine the examples of symbiotic associations. Can you tell which are **ectomycorrhizae** and which are **endomycorrhizae**?

Card 10-6: Explain the structure and function of root nodules and mycorrhizae.

LAB 11 - ORGAN MODIFICATION

Introduction

You now know that plants have only three different types of organs: leaves, stems, and roots. The differences among species represent modifications of these organs resulting from adaptation to particular environmental conditions or specialized functions. In the first part of this lab you will examine plants that live in various environments and identify the adaptations that have evolved to allow the plants to cope with environmental stresses. In the second part you will examine a variety plant organs that serve specialized functions.

Part 1 - Environmental adaptations

Plants that are adapted to dry or xeric environments are called **xerophytes.** Similarly plants adapted to aquatic environments are called **hydrophytes** and those adapted to more moderate conditions are **mesophytes**. **Halophytes** are adapted to saline conditions and share many characteristic with xerophytes. They also tend to be succulent. For each of the plants in the table below, decide whether its is a xerophyte, hydrophyte, mesophyte or halophyte. Identify its adaptive features. Pay particular attention to stomatal location, thickness of mesophyll layers and epidermal layers, amount of intercellular air space, surface area:volume ratio, fibrousness and relative size of leaves and stems.

Species	Type	Adaptive features
Ephedra (Mormon tea)		
Aloe		
Salicornia (pickleweed)		
Myriophyllum		
Nymphaea (water lily)		
Ligustrum (privet)		
Ammophila (beach grass)		
Nerium (oleander)		
Pinus (pine)		

Part 2 - Functional adaptations

The organs you will examine in the this part of the lab serve specialized functions not generally associated with leaves, stems, or roots. Some have been modified so dramatically that they no longer resemble the organ from which they arose. Your first task is to determine whether the specialized organs is a leaf, a stem, or a root. Second, describe the function of the organ. Finally, describe the structural modifications that have taken place such as reduction or proliferation of a particular tissue, sclerification, etc.

Modified organs	Specimen preparation	Organ	Function	Structural modifications
Storage root	*Daucus* (carrot): make a cross section			
Prop roots	corn stalk			
Phyllodes	*Acacia*			
Cladodes	*Ruscus*: Note the axillary buds in the center of the "leaf"			
Aerial root	Orchid			
Spines	Cactus			
Spines	Honey locust			
Spines	Euphorb			
Traps	Venus fly trap: Live specimen and prepared slide			
Cataphylls (bud scales)	Dormant branch: Live specimen and prepared slide			
Plantlets	Kalanchoe			
Tuber	potato			
Rhizome	Iris			

Corm	Gladiolus			
Bulb	Onion			
Tendril	Pea			
Tendril	Grape			
Flower petals	Various			

Part 3 - Flower anatomy

The flower is a modified shoot bearing floral organs (**sepals**, **petals**, **stamens** and **carpels**), all of which are modified leaves. The seed is enclosed in a modified leaf called a **carpel**. As the seed matures, the carpel develops into the **fruit**, which protects the seed and aids in its dispersal. Monocots typically bear floral organs in groups of 3 or multiples of 3. Dicots typically bear floral organs in groups of 4 or 5. Examine the prepared slide of anemone flower. Identify: sepals, petals, stamens (with vascular bundles, **filaments**, **anthers**, **pollen sacs**, **tapetum** and **pollen grains**) and carpels (with vascular bundles, **stigma**, **style**, **ovary** and **ovules**).

Card 11-1: Draw a labeled diagram of an anemone flower.

LAB 12 - VASCULAR CAMBIUM

Introduction

Many small, herbaceous annuals have no secondary growth at all. However, plants that grow large or persist for several years require a larger stem diameter for support, increased amounts of vascular tissue to supply greater numbers of branches and leaves, and a means to replace vascular tissues that cavitate due to winter freezing. Some monocots are large and perennial, even without secondary growth. These plants have adapted specialized strategies for increasing their girth and vascular supply. However, dicots and gymnosperms undergo secondary growth through activation of a secondary meristem called the **vascular cambium**.

The most obvious function of the vascular cambium is to produce **secondary xylem** and **secondary phloem**. The vascular cambium arises through division of cells of the **residual procambium** and ground tissues and forms a cylinder that separates **primary xylem** from **primary phloem**. Cells of the vascular cambium divide **periclinally** to produce the secondary vascular tissues and **anticlinally** as required to keep up with the increasing girth of the stem or root. At the end of the growing season the vascular cambium may go dormant only to be reactivated in following seasons. In this lab you will see how vascular cambium is initiated in stems and roots and examine the organization of cambial initials.

Part 1 - Initiation of the vascular cambium in stems

First examine a prepared slide of a mature stem of *Ranunculus*, an annual dicot with no secondary growth. Can you identify undifferentiated tissues between the xylem and phloem? Notice also the fibers that completely surround the vascular bundles.

Next look at the prepared slide of *Helianthus* (sunflower) stem with separate bundles. Can you identify radially layered cells between the xylem and phloem that appear to have divided recently? Can you identify similar cells among the parenchyma between the vascular bundles? This is where the **fascicular cambium** and **interfascicular cambium** are initiated.

Card 12-1: Prepare a drawing that illustrates the differences in stem vascular bundles between a plant without secondary growth (*Ranunculus*) and a plant with secondary growth (*Helianthus*). Label fascicular cambium and interfascicular cambium.

Now examine a prepared slide of an old *Helianthus* stem and notice the changes that have taken place. Identify the cylindrical **vascular cambium**, which formed as the fascicular and interfascicular cambia merged. Also identify **pith**, **primary xylem**, **secondary xylem**, **secondary phloem** and **primary phloem**.

The slide containing sections of *Sambucus* stem shows more extensive development of secondary vascular tissues. Identify **pith**, **primary xylem**, **primary phloem**, **xylem rays**, **phloem rays**, **axial elements** of the **secondary xylem** and **secondary phloem**, and **vascular cambium**.

Card 12-2: Draw a diagram of *Sambucus* stem with secondary growth and label the tissues shown in boldface type above.

Part 2 - Initiation of the vascular cambium in roots

Examine the prepared slides of two stages in the development of *Pyrus* (pear) roots. First note that *Pyrus* is unusual in have two endodermal layers, on of which accumulates phenolics. Can you identify where the vascular cambium arises? Label **secondary xylem**, **secondary phloem** and **vascular cambium**.

Card 12-3: Draw diagrams of *Pyrus* root with early secondary growth and mature *Pyrus* root. Label the tissues and show where the vascular cambium originates.

Part 3 - Structure of cambial initials

Examine prepared slides of vascular cambium from *Robinia* (black locust) and *Juglans* (walnut). These are planar sections of a cylindrical cambium, so each section contains differentiating secondary xylem and phloem as well as cambial initials. Look for patches of cells that lack the features of tracheary elements or sieve elements. Identify **fusiform initials** and **ray initials**. What cells do each type of initial give rise to? What differences do you note in the arrangement of cambial initials in the different species?

Card 12-4: Draw diagrams of the cambium of *Robinia* and *Juglans*.

Part 4 - Woody stems and roots

Although cambium initiation differs in roots and stems, the resulting secondary vascular tissues are strikingly similar. Examine prepared slides of wood stems and roots of *Tilia*.

Card 12-5: Draw diagrams of a woody root and a woody stem of *Tilia*. Label similarities and differences.

LAB 13 - SECONDARY GROWTH

Introduction

What most people call "wood", plant anatomists know as **secondary xylem**. Secondary xylem has the same cell types and the same functions as primary xylem. However, secondary xylem develops from the vascular cambium and its organization is different from that of primary xylem. Specifically, secondary xylem consists of an axial system that develops from fusiform initials and a radial system that develops from ray initials.

The outer part of a woody stem or root is commonly known as **bark**, but actually consists of two distinct tissues, the **secondary phloem** and the **periderm**. As the diameter of a woody stem increases, the bark must expand radially to accommodate the enlarged circumference of the wood. The developmental processes that accomplish this radial expansion are revealed in the cellular organization of the secondary phloem The secondary phloem, like the secondary xylem, arises from the vascular cambium and consists of an axial system and a ray system. The periderm arises from a meristem known as the **cork cambium**.

Part 1 - Structure of woody stems

Examine the wood blocks provided and identify: **axial elements**, **ray elements**, **annual rings** and **bark**. You cannot see the vascular cambium, but you should be able to tell where it is.

You should be familiar with **cross-sections** by now. A longitudinal section of wood cut on a radius is called a **radial section** and contains rays sectioned longitudinally. A longitudinal section of wood cut on a tangent is a **tangential section** and shows rays in cross-section. Using wood blocks and the included diagram, make sure you understand the different types of sections.

Part 2 - Secondary xylem

The structure of wood is influenced by phylogeny, environmental pressures, and its origin in the vascular cambium. Keep these factors in mind as you examine the anatomy of different types of wood. The following is a list of general characteristics to look for when examining wood anatomy:

<u>Axial system</u>:
1. Cell types present - tracheids, vessel elements, fibers, parenchyma.
2. Characteristics of vessels (if present) - perforation plate type, diameter, length.
3. Characteristics of fibers (if present) - These vary from fiber-tracheids to libriform fibers with all intermediate states possible. Fibers can be distinguished by the structure of their pits.
4. Arrangement of vessels -
   ring porous or **diffuse porous**
   solitary vessels or **clustered vessels**.
5. Presence of absence of parenchyma - (**axial parenchyma** is axially elongated)

Ray system:
1. **Uniseriate** or **multiseriate**
2. **Homocellular** or **heterocellular**
    gymnosperms - heterocellular rays have parenchyma and tracheids.
    angiosperms - heterocellular rays have **procumbent** and **upright** cells

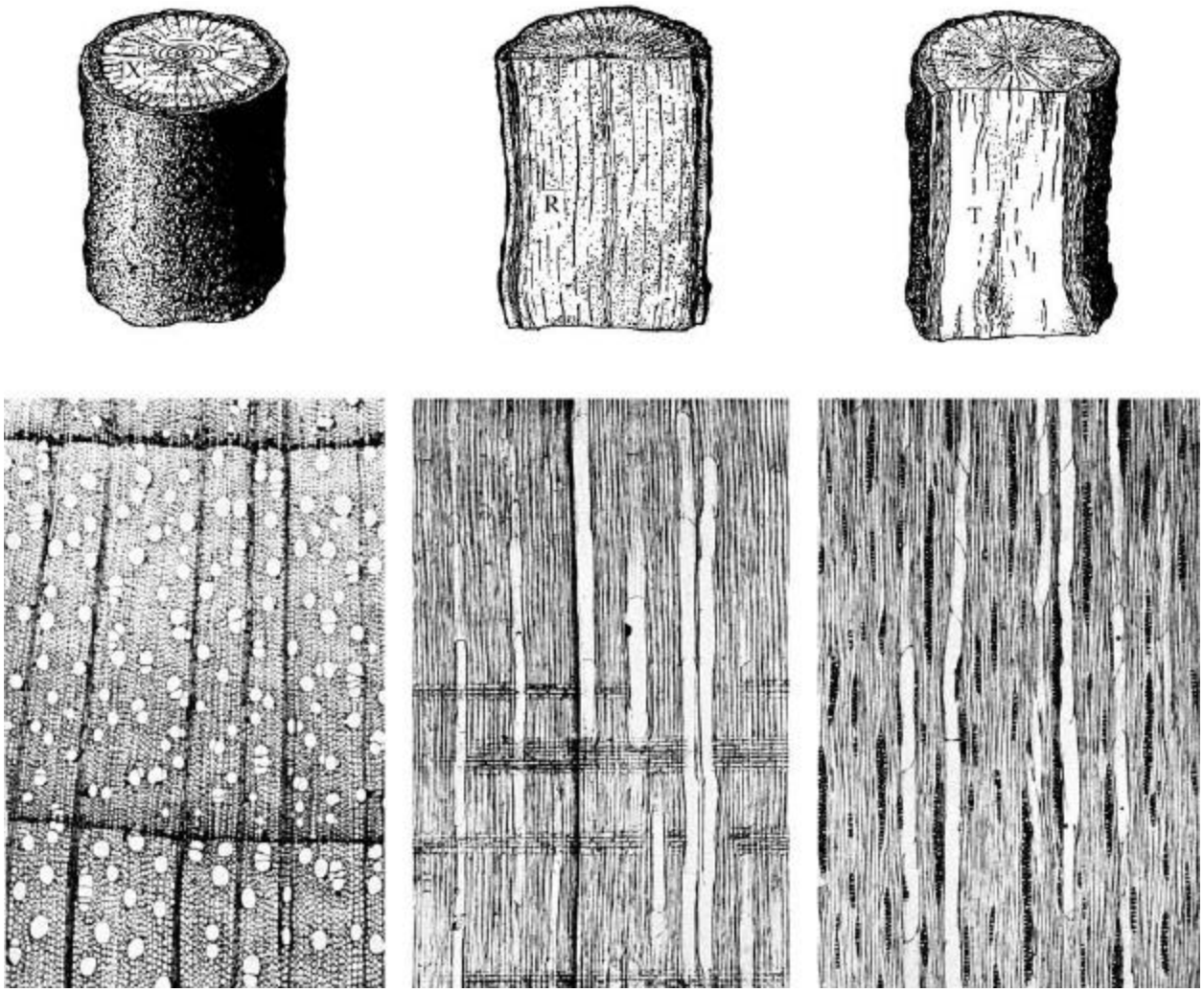
Thin sections of wood provide different kinds of information depending on the plane in which they are cut. Examine cross, radial and tangential (XRT) sections and macerations of the following woods. Copy the chart on the following page and fill in the characteristics of each on the included chart.

Pinus (gymnosperm)
Magnolia or *Liriodendron* (angiosperms)
Quercus (angiosperms)

If you have time to look at others, choose from: *Tilia, Chamaecyparus, Acer,* or *Juglans.*

PLANES OF SECTION IN WOOD

Illustrations of cross (X), radial (R) and tangential (T) sections of wood.
(From: R. H. Holman and W. W. Robbins, **A Textbook of General Botany**, Wiley and Sons, Inc., New York, 1924.



WOOD CHARACTERISTICS CHART

	Pinus	*Magnolia*	*Quercus*
Axial cell types			
Vessel type			
Fiber type			
Vessel arrangement			
Axial parenchyma			
Ray type			

Part 3 - Secondary phloem

The secondary phloem functions in both transport and protection and this dual function is reflected in the cell types present. Examine a cross section of *Tilia* stem and identify the following cell types: phloem fibers, sieve elements, companion cells, axial parenchyma, and ray parenchyma. Now look carefully at the phloem.

Card 13-1: Draw a diagram of the secondary phloem of *Tilia* and label the cell types. One the back of the card explain: 1) the relationship between xylem rays and phloem rays, and 2) the role of phloem rays in radial expansion of the phloem.

Part 4 - Cork cambium and periderm

The **cork cambium** can develop from cells of the epidermis, cortex, primary phloem or secondary phloem. This meristem produces **cork**, which replace the function of the epidermis in the growing stem. Examine the development of cork cambium by comparing prepared slides of *Sambucus* stem with and without cork. Look for dividing cells just below the epidermis. Notice that the developing cork cells are arranged in radial files that do not coincide with the epidermal cells.

Card 13-2: Draw labeled diagrams to illustrate the development of cork cambium and cork in *Sambucus*.

Gases must be able to penetrate the cork to reach growing cells below. This is accomplished by **lenticels**, which are clusters of loosely-packed cells produced by the cork cambium. Look at the bark samples on display to see different types of lenticels. Now, examine the prepared slide of a *Sambucus* lenticel.

Card 13-3: Prepare a labeled drawing of a *Sambucus* lenticel.

The texture of bark (e.g. smooth, scaly, fibrous) depends on the structure of the cork cambium. Examine the bark samples on display and try to envision the organization of the cork cambium that produced each type.

Plant Anatomy BIO 311

THUMBNAIL IMAGE LIST

The slides shown below are organized by lab topic. Click on an image to view a larger version of the photomicrograph and sample questions. You can also choose to view a text listing of these images. (The text list is probably better for slow internet connections.)

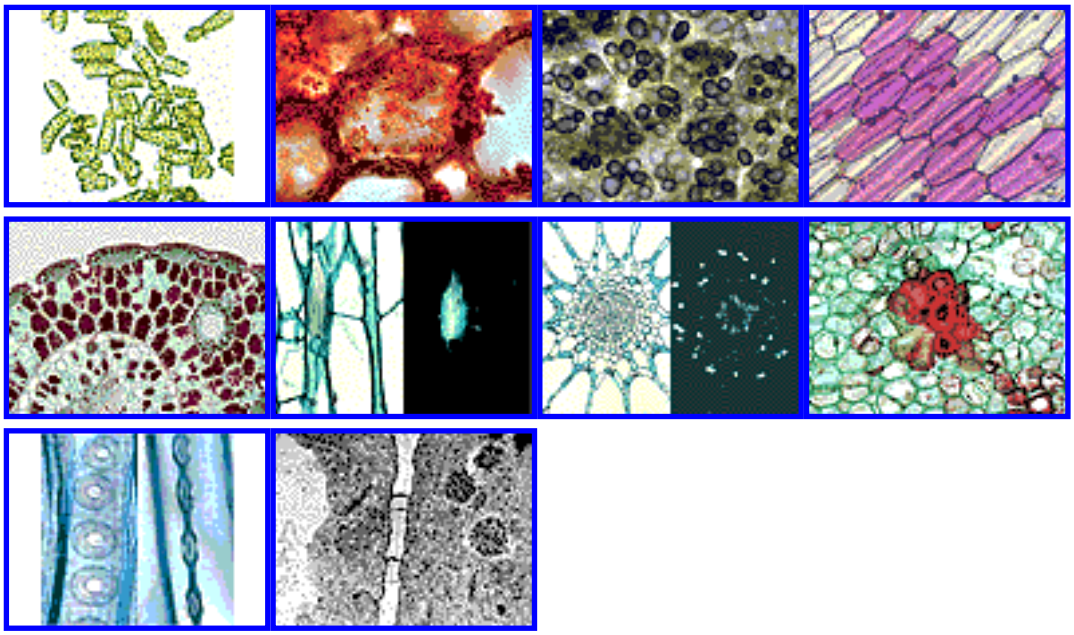
LAB TOPICS

LAB 1 Introduction to plant structure

(No slides)

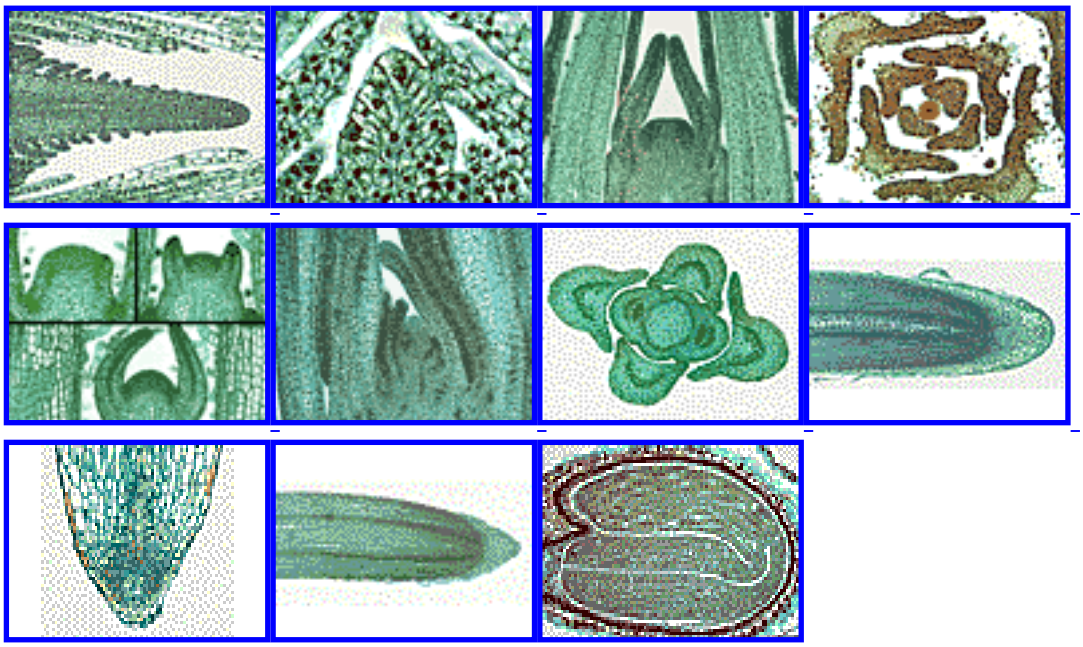
[Top]

LAB 2 Plant cells



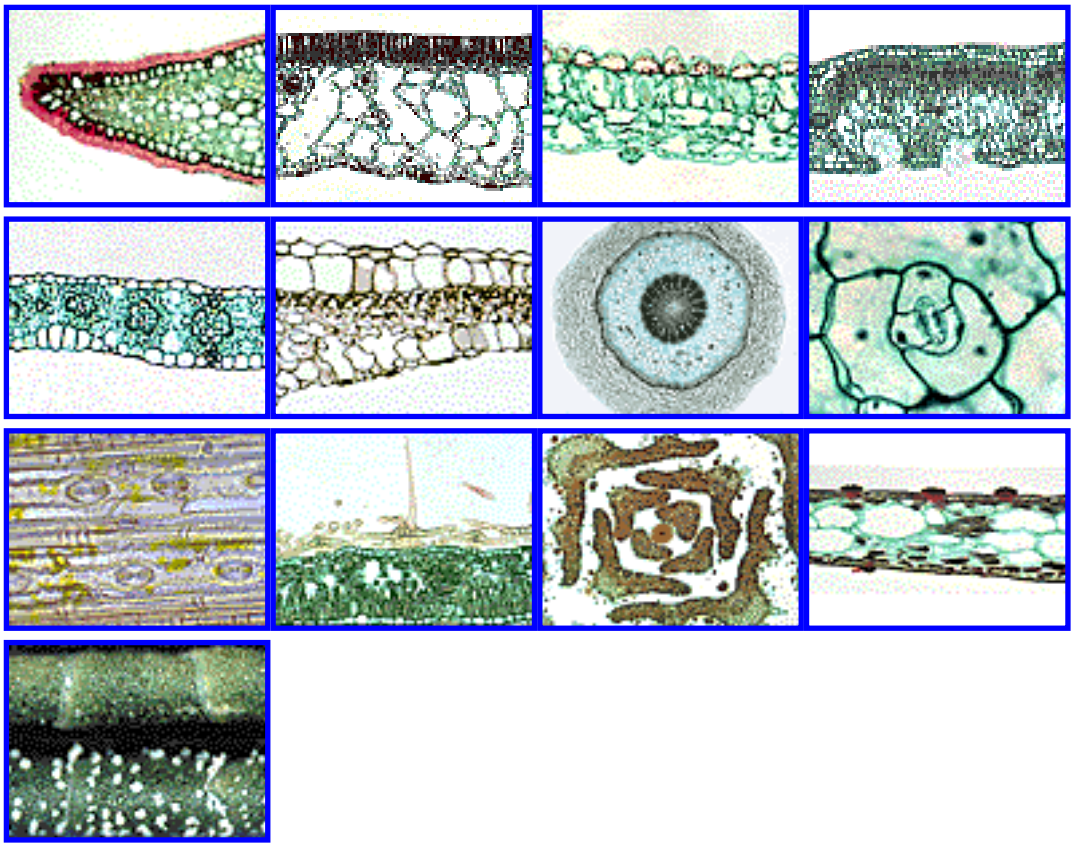
[Top]

LAB 3 Meristems, growth, & differentiation



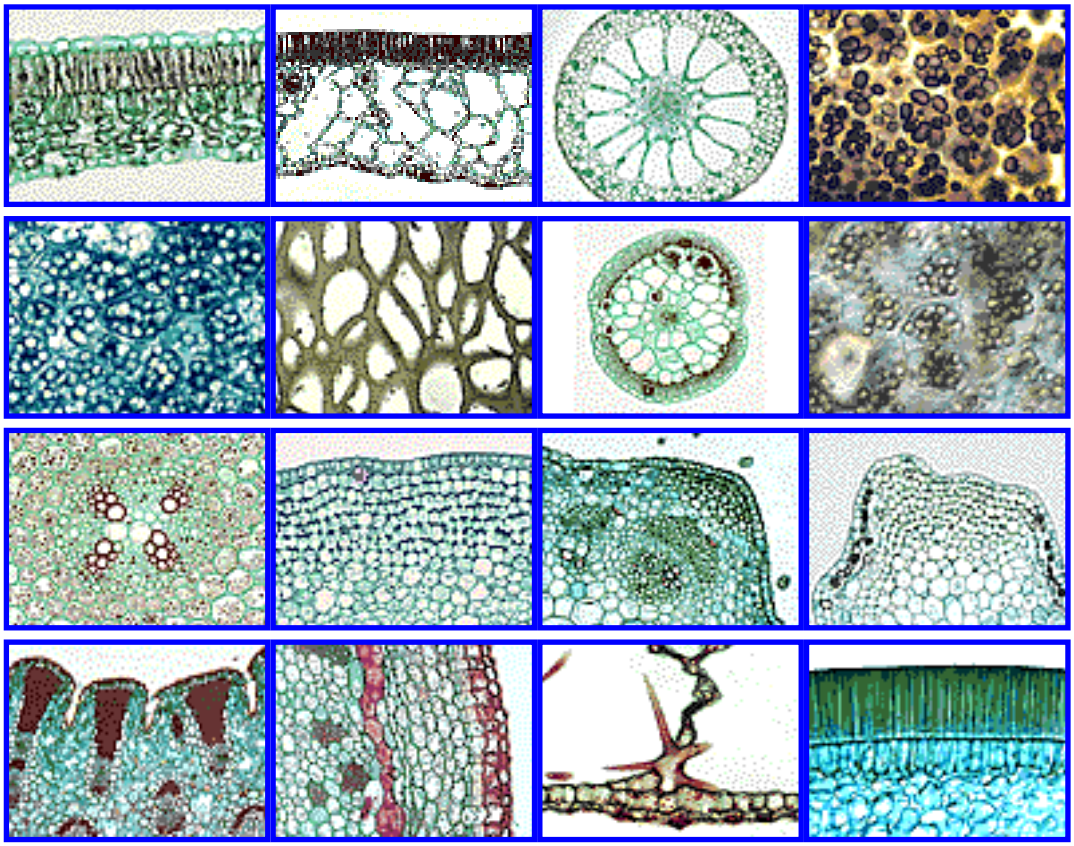
[Top]

LAB 4 Dermal Tissue System



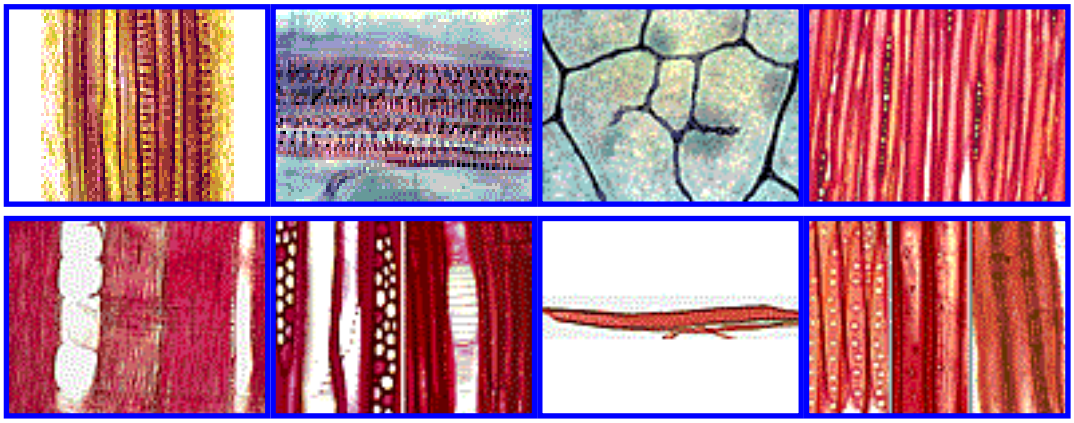
[Top]

LAB 5 Ground Tissue System



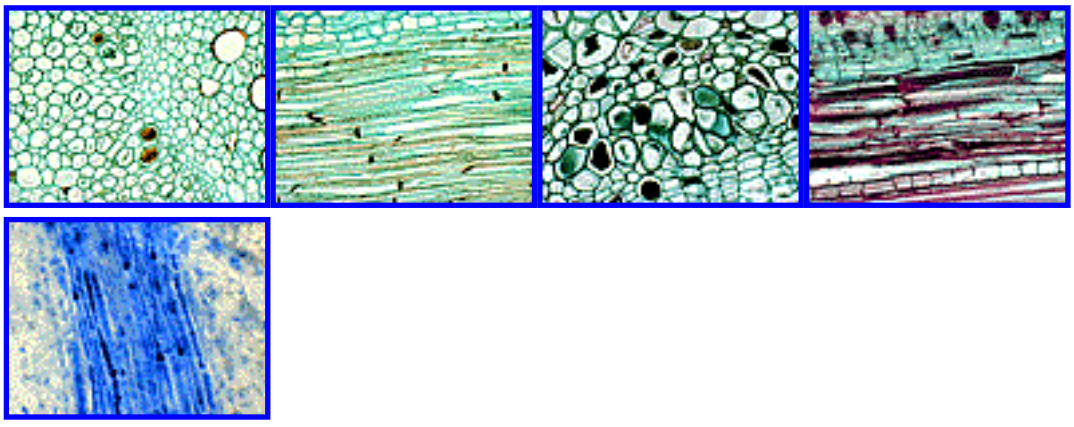
[Top]

LAB 6 Vascular tissues: xylem



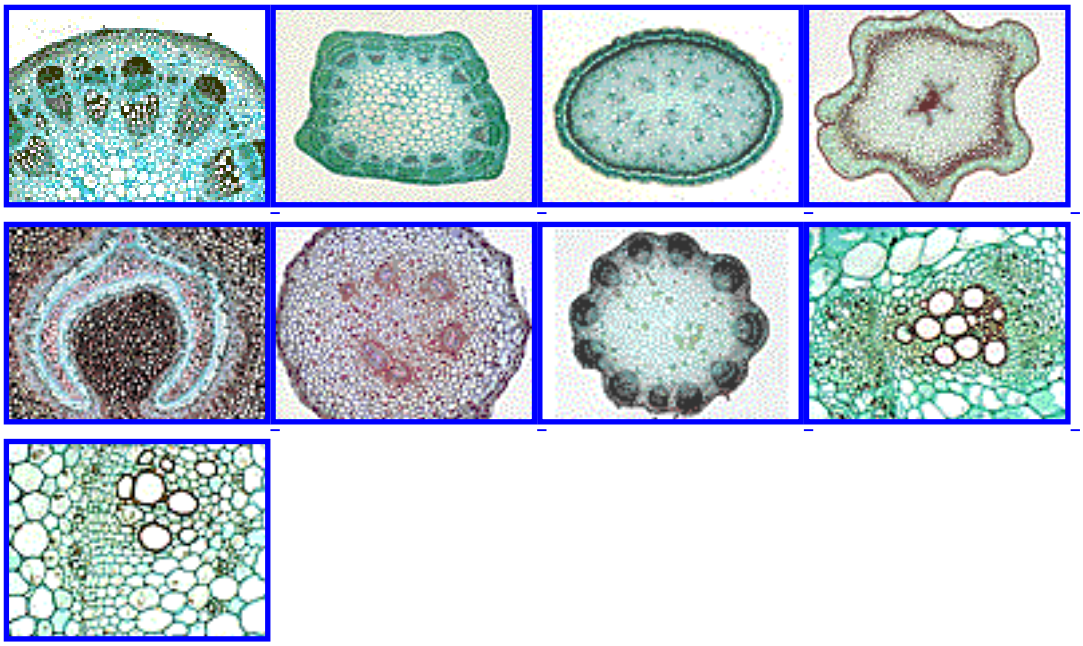
[Top]

LAB 7 Vascular tissues: phloem



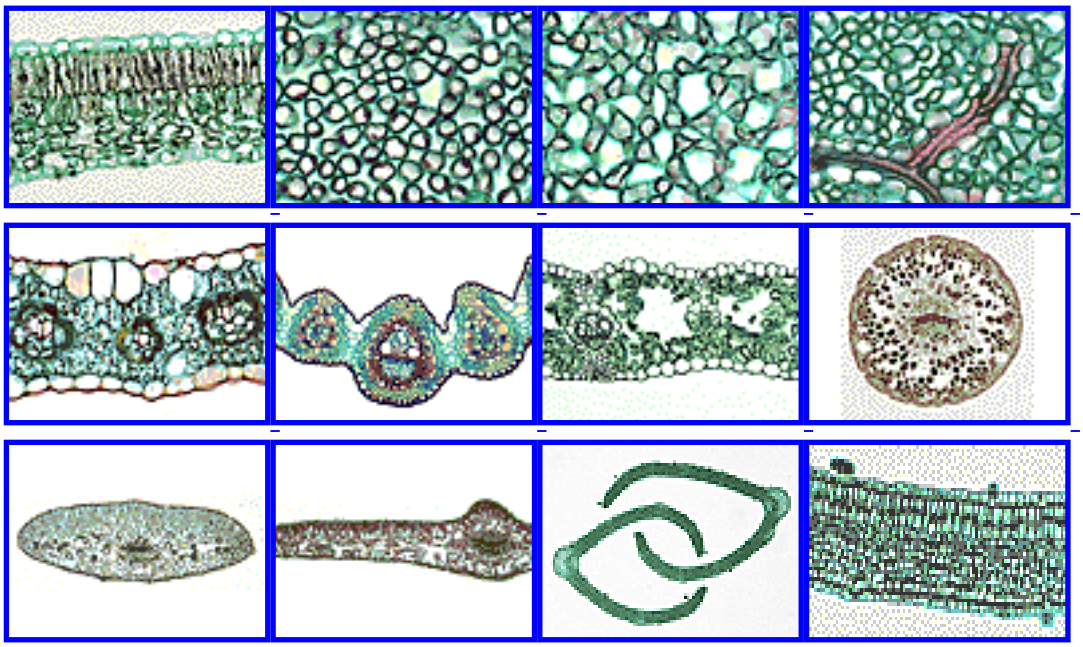
[Top]

LAB 8 Anatomy of stems



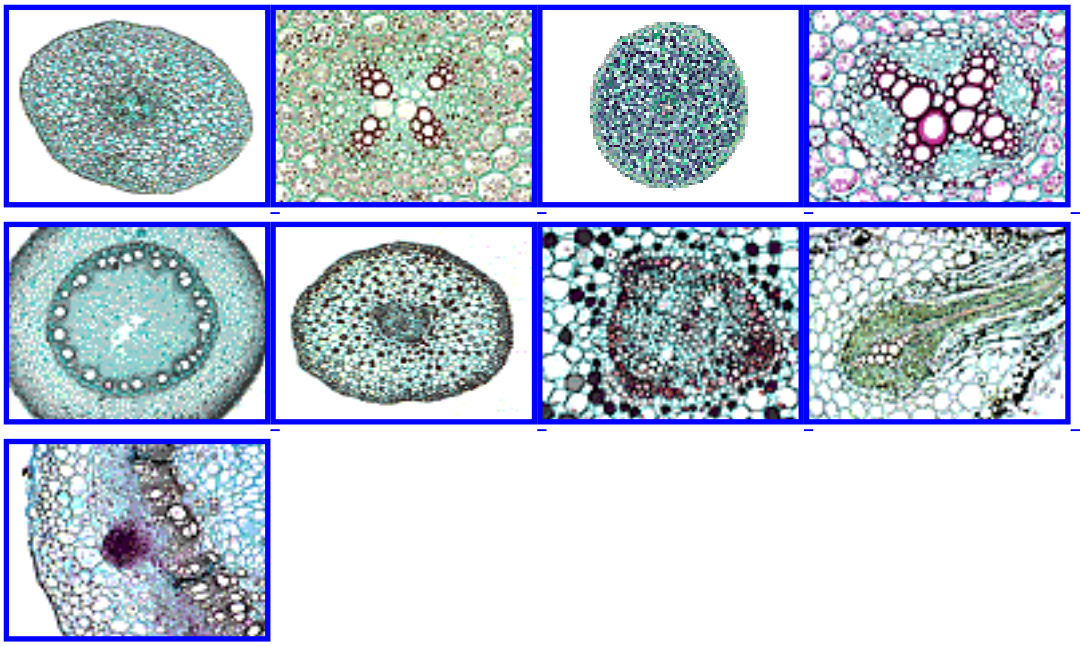
[Top]

LAB 9 Anatomy of leaves



[Top]

LAB 10 Anatomy of roots



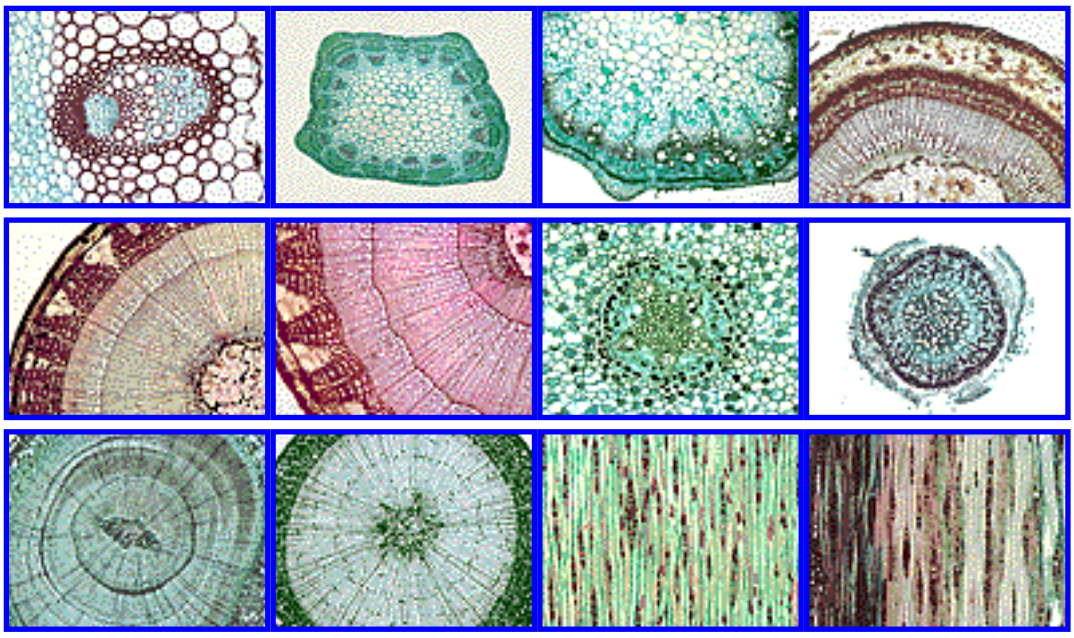
[Top]

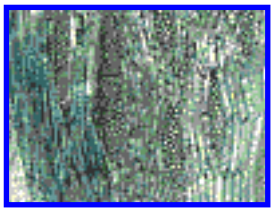
LAB 11 Organ Modification

(No slides)

[Top]

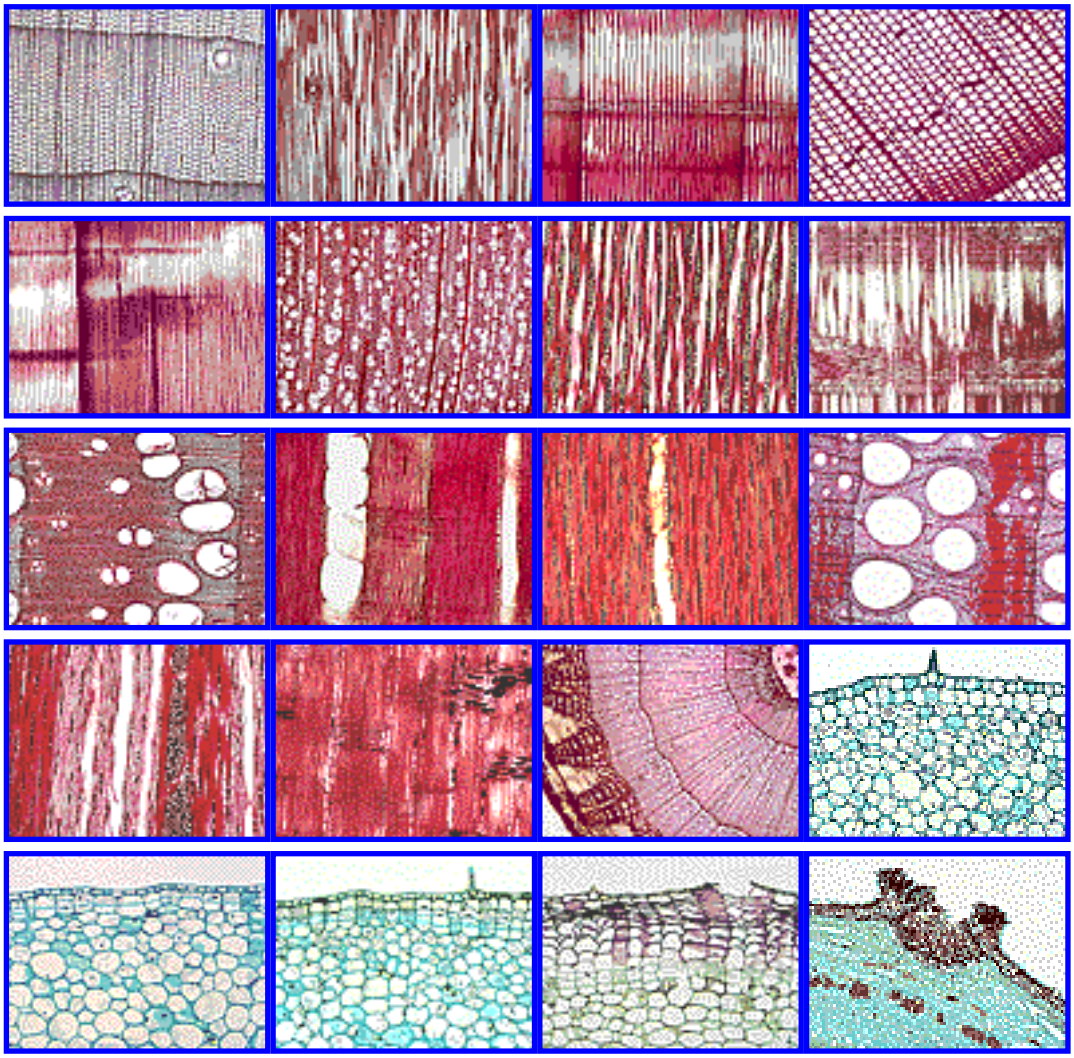
LAB 12 Vascular Cambium





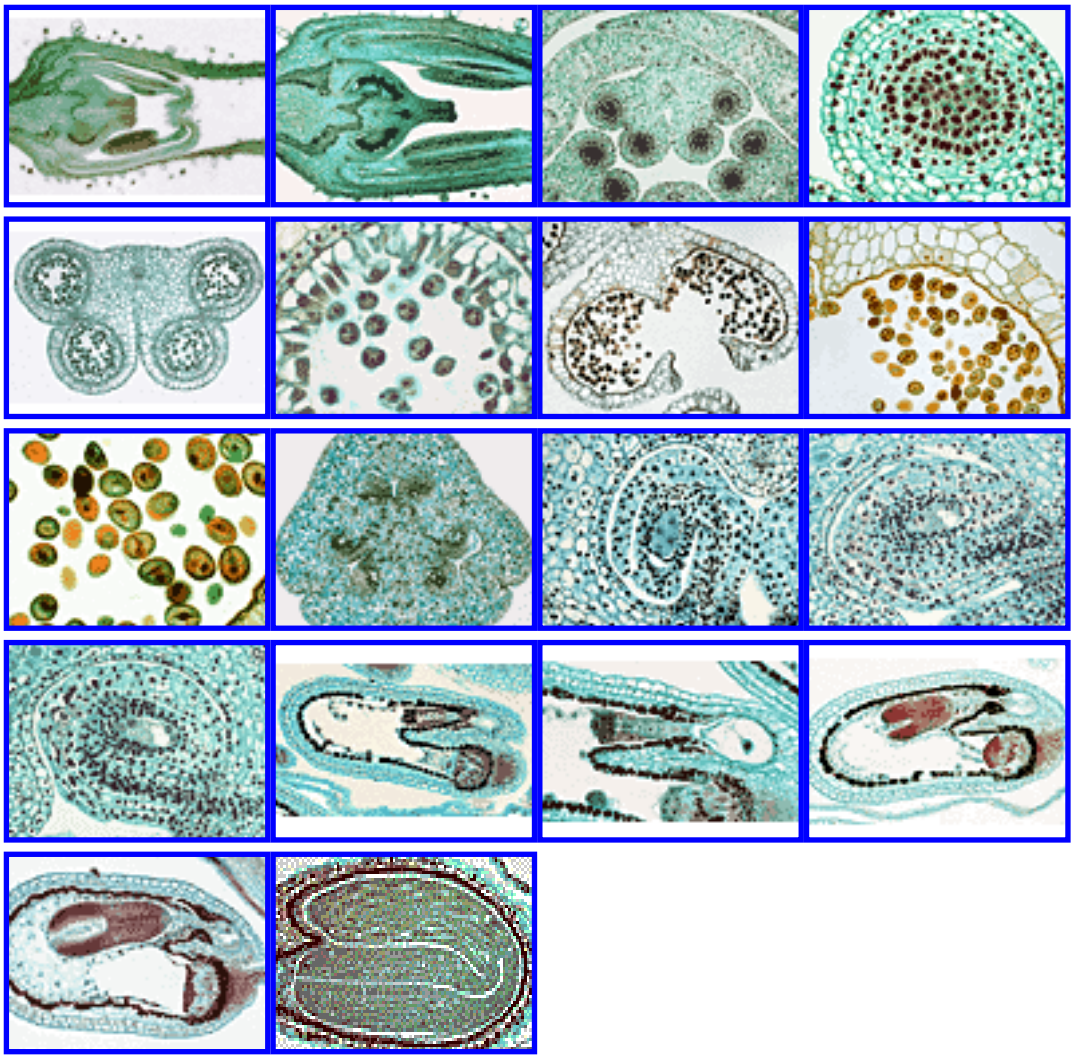
[Top]

LAB 13 Secondary Growth



[Top]

EXTRA: Flowers, friuts, and seeds

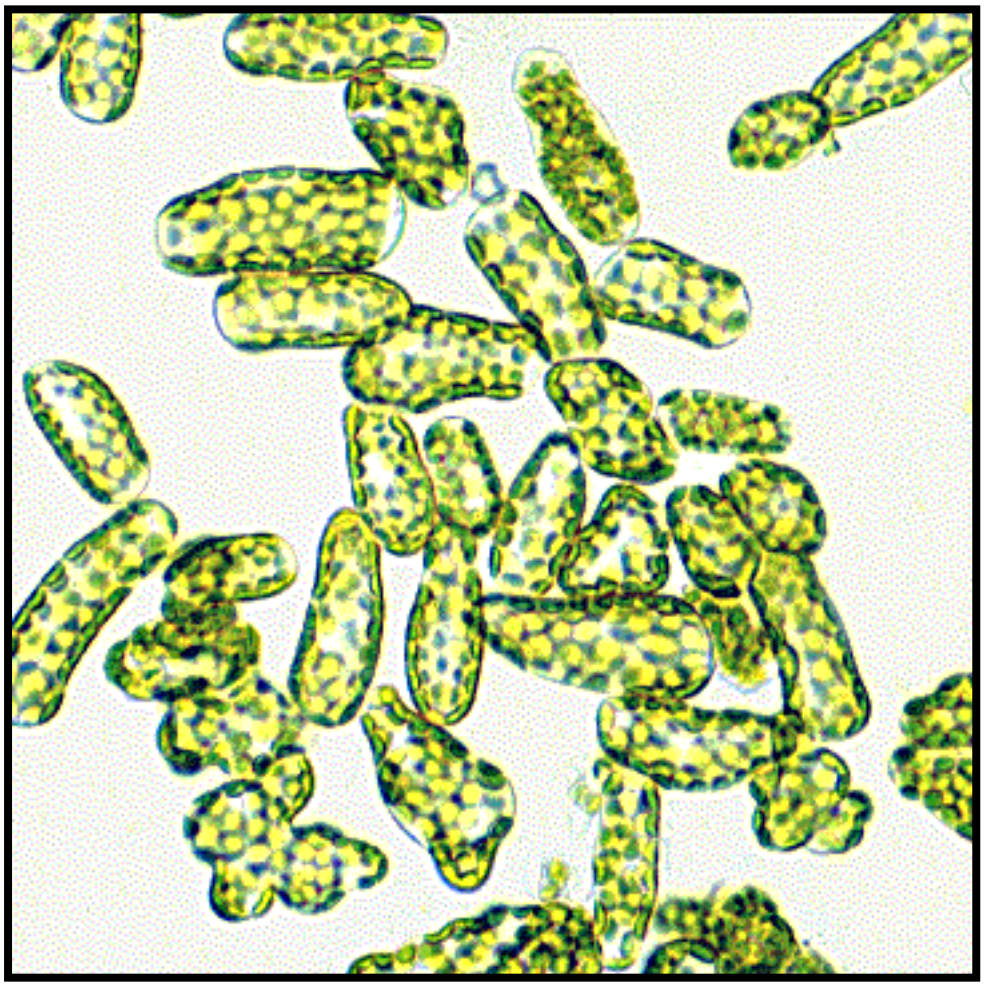


[Top]

Contents | Lab review slides | Lab manual | Glossary

Alison Roberts (aroberts@uri.edu)

Zinnia mesophyll cells



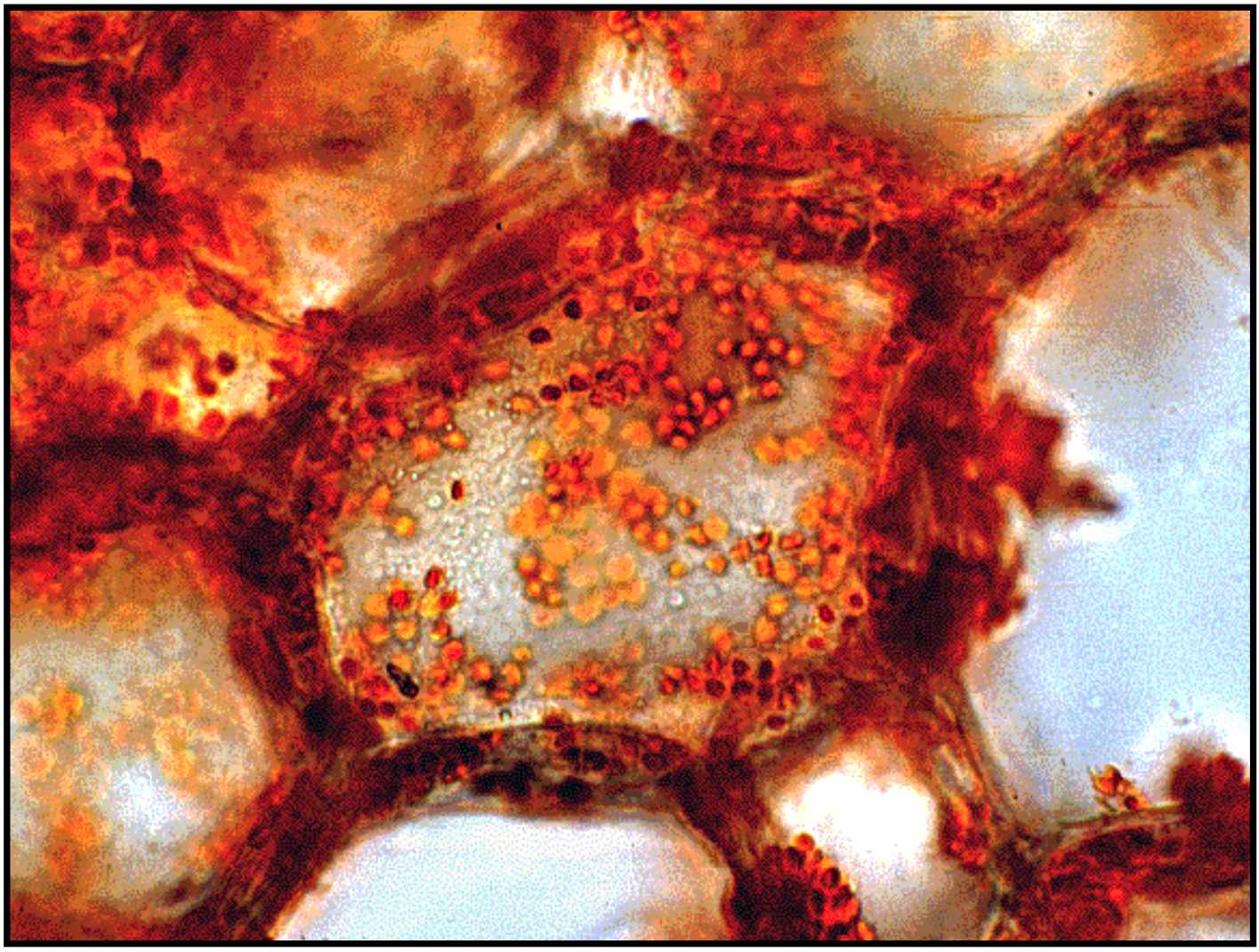
Zinnia mesophyll cells. The cells were separated from each other by gently grinding young leaves in mannitol using a mortar and pestle.

- What is the name and function of the green organelles in these cells?
- How do these organelles compare with etioplasts in structure? in function?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Section of red pepper



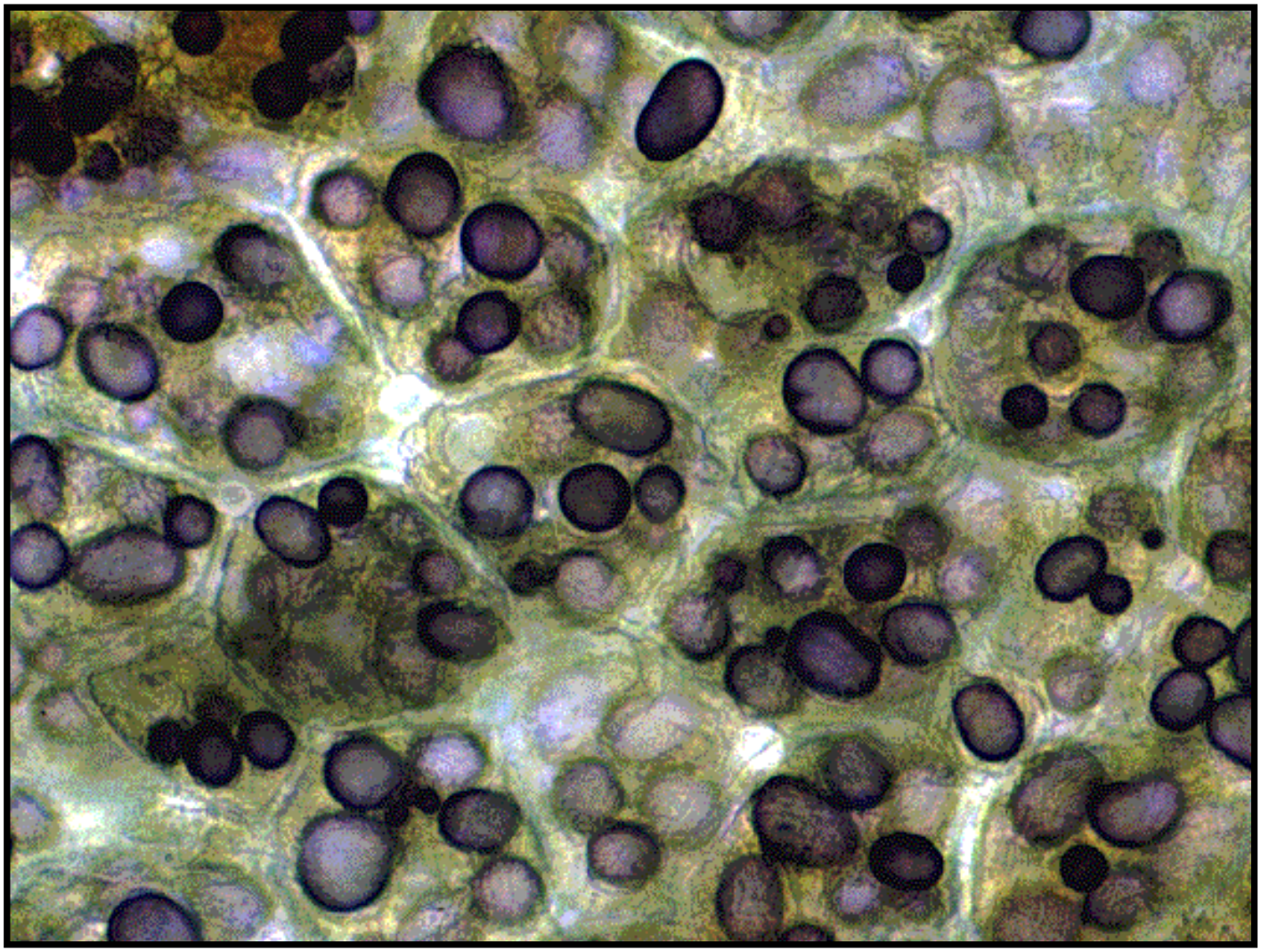
Section of red pepper.

- What is the name and function of the red-orange organelles in these cells?
- Is this pigment hydrophilic or hydrophobic?
- What is the name for the class of pigments contained in these organelles?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Starch grains from bean embryo



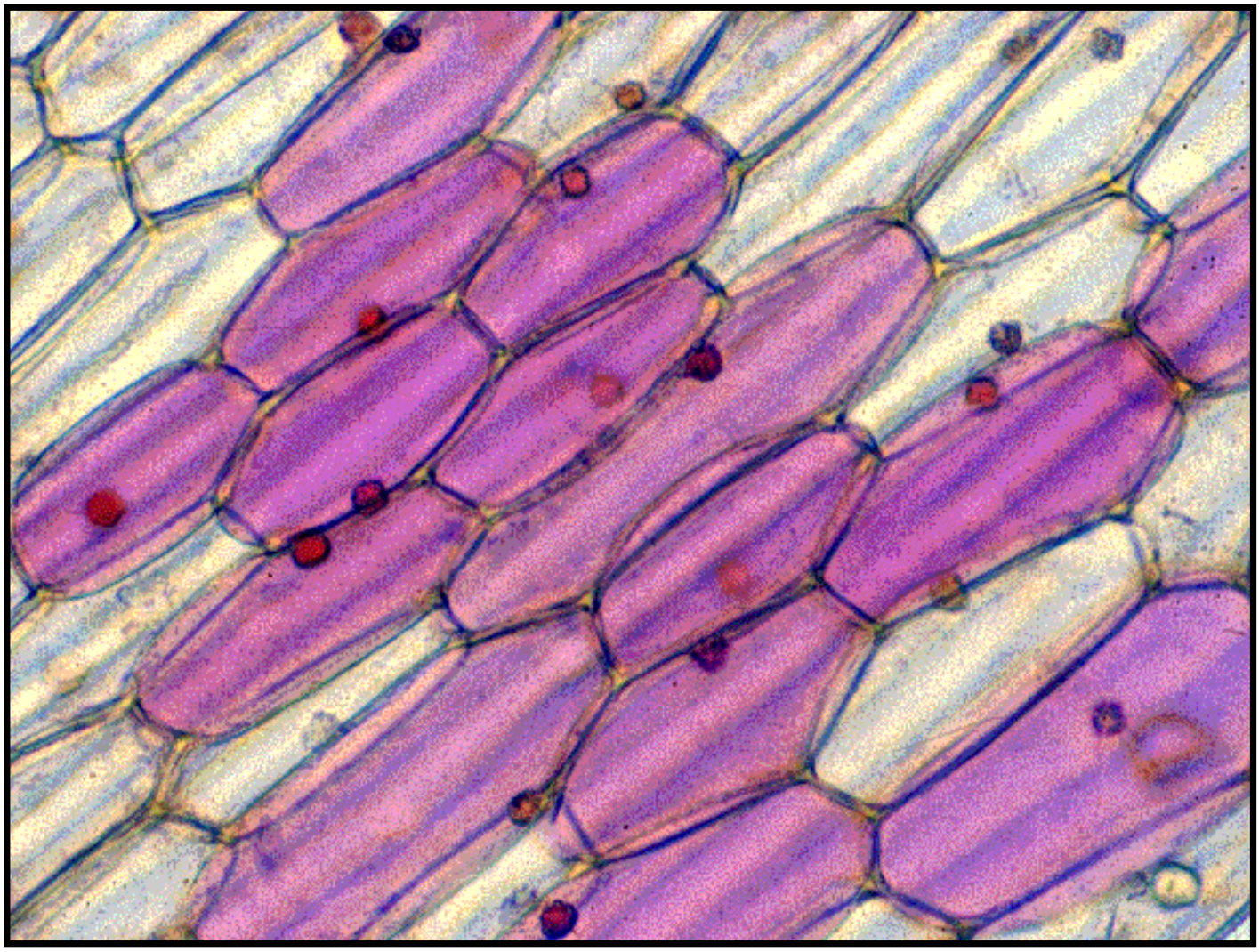
Starch grains from bean embryo. The starch grains have been stained dark purple by iodine.

- What organelles are the starch grains associated with?
- What is the function of these organelles?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Epidermal peel of *Tradescantia*



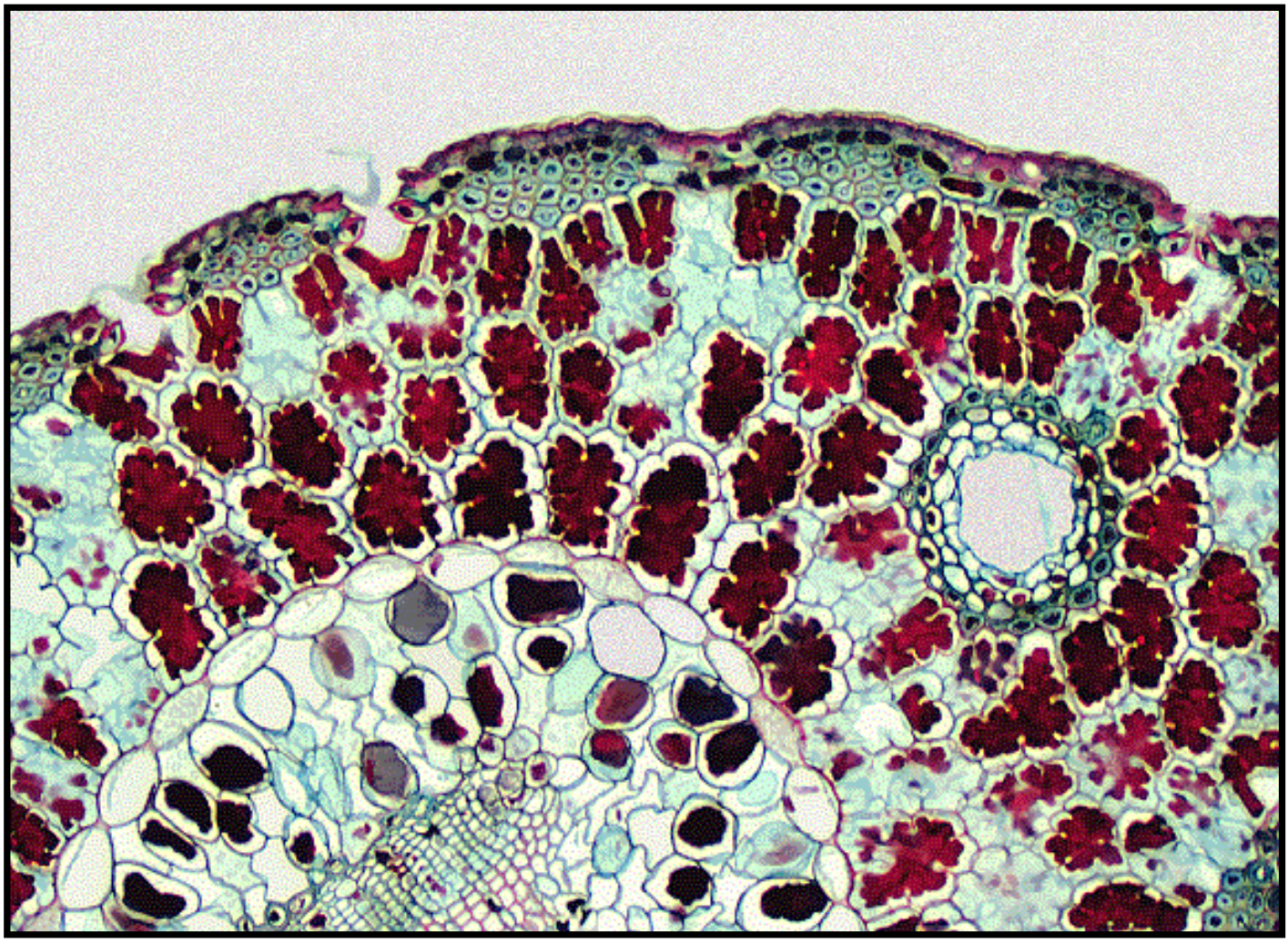
Epidermal peel of *Tradescantia* showing purple pigments in the vacuoles.

- Are these pigments hydrophilic or hydrophobic?
- What is the name for this class of pigments?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Cross section of a pine needle



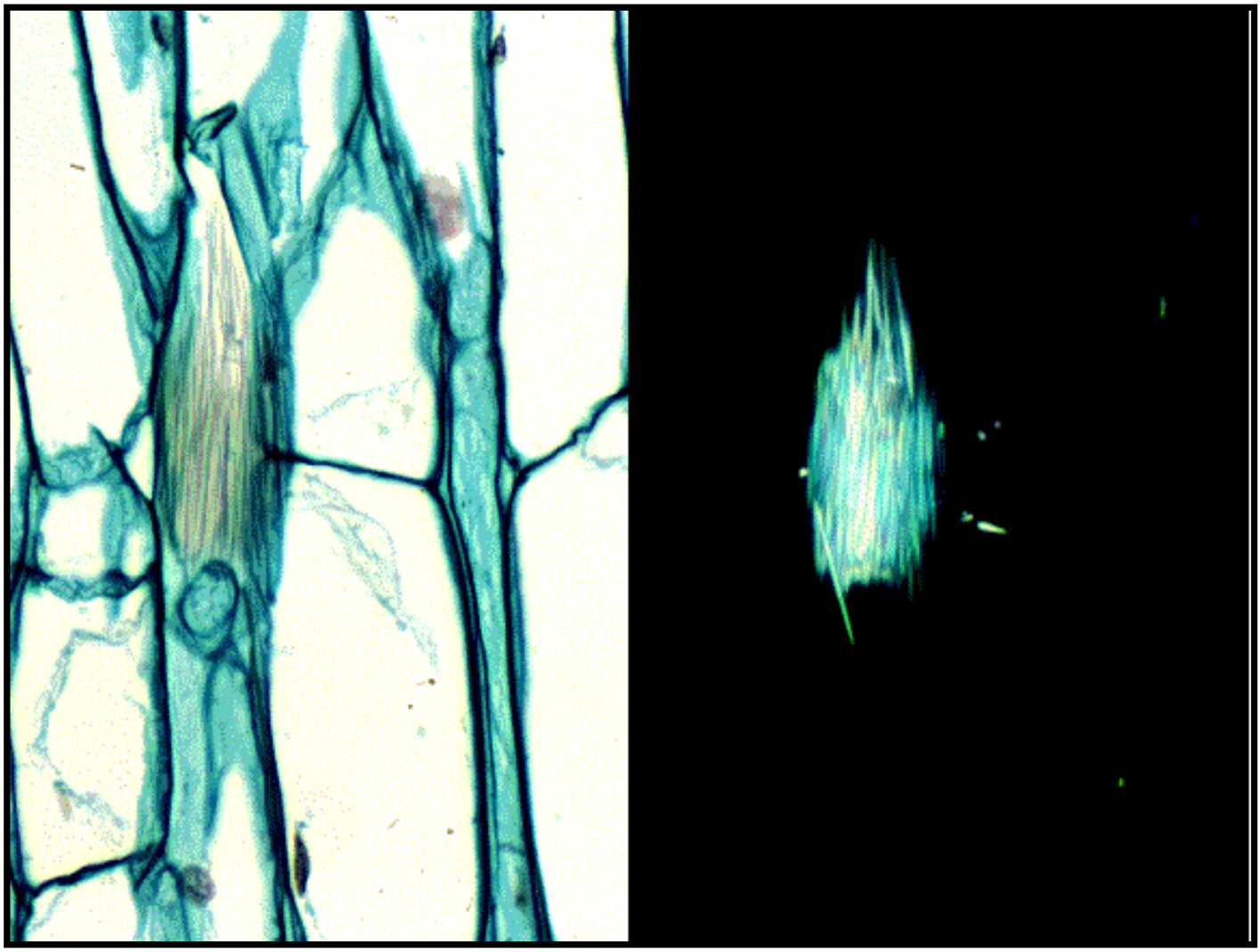
Cross section of a pine needle.

- Identify tannin cells.
- What is the function of these cells?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Brightfield and polarization micrographs *Aloe* stem



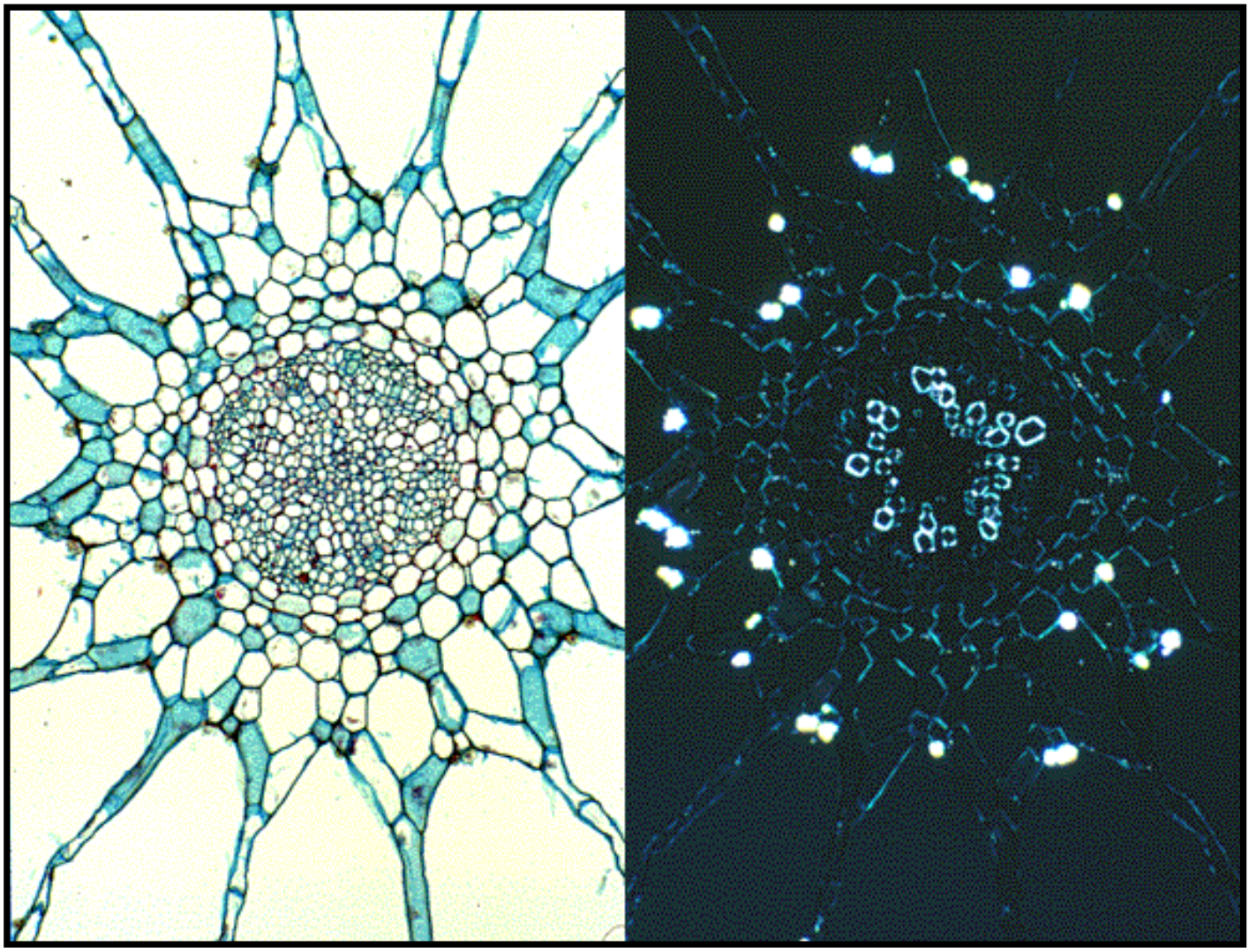
Bright field (left) and polarization (right) micrographs of a stem section of *Aloe*.

- The structure that appears bright with polarization is a bundle of raphide crystals.
- What is the function of the crystal cells?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Brightfield and polarization micrographs of *Myriophyllum*stem



Bright field (left) and polarization micrographs (right) of a stem section of *Myriophyllum*.

- What type of crystals are shown here?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Section of pear flesh

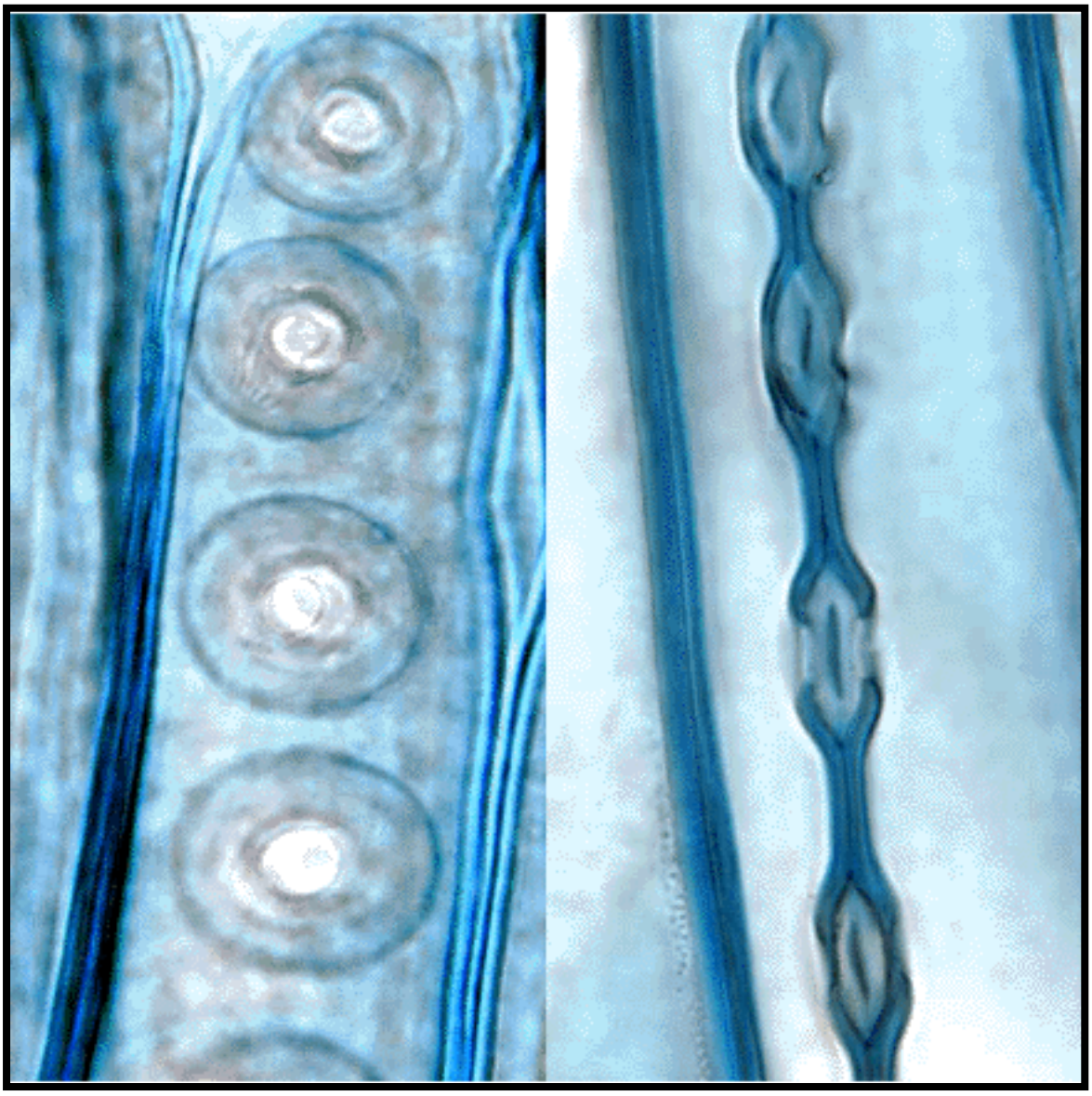
Section of pear flesh.

- Identify cells with primary walls and those with secondary walls.
- How would these two different types of cells look if the tissue were stained with phloroglucinol?
- Locate pits (cross and longitudinal views are visible).
- Which cells contain red-staining tannins in the vacuoles?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Circular-bordered pits in pine wood



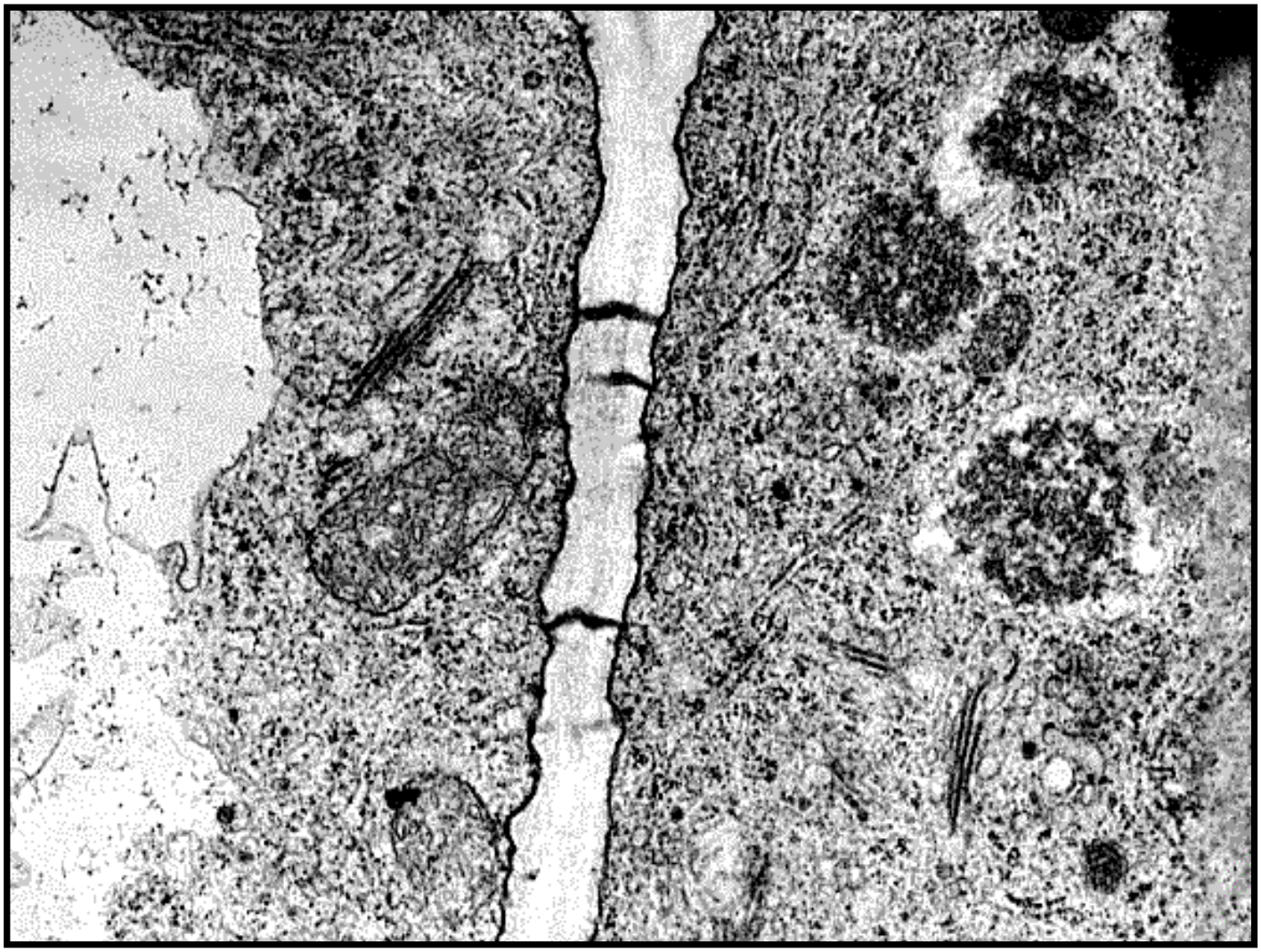
Circular-bordered pits from pine tracheids as seen in face view (left) and in side view (right).

- Identify the secondary cell wall, primary cell wall, and pit.
- How do circular-bordered pits differ from simple pits? In what ways are they similar?

Related images: (None)

Alison Roberts (aroberts@uri.edu)

Electron micrograph of plasmodesmata



Electron micrograph of plasmodesmata.

- How do they differ from pits?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Elodea shoot apical meristem

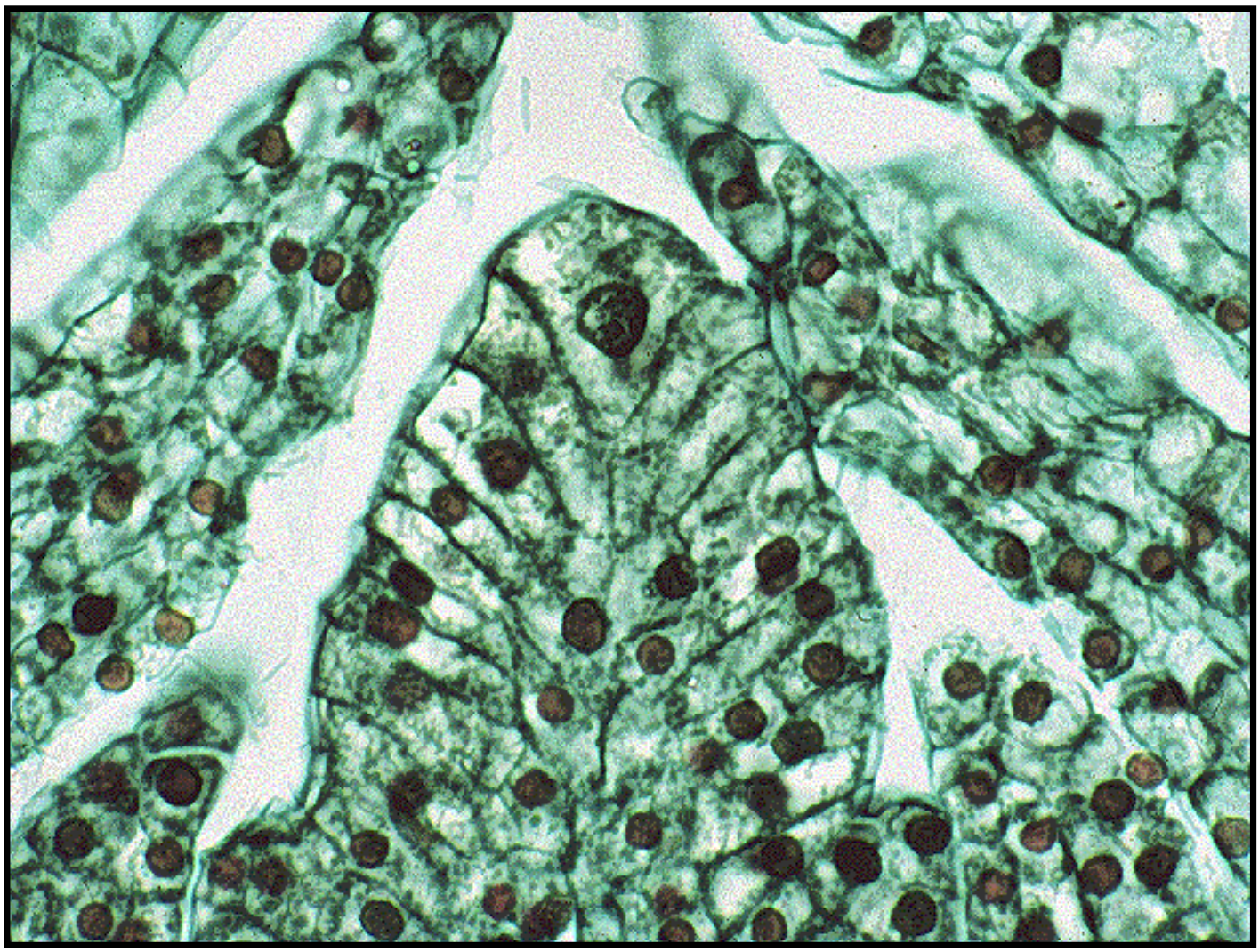
Longitudinal section of *Elodea* shoot apical meristem.

- Locate leaf primordia and the apical dome.
- What is unusual about the shape of this meristem?

Related images: *Equisetum* shoot apical meristem, *Lonicera* shoot apex meristem, Salvia shoot apical meristem

Alison Roberts (awrobrts@uriacc.uri.edu)

Equisetum shoot apical meristem



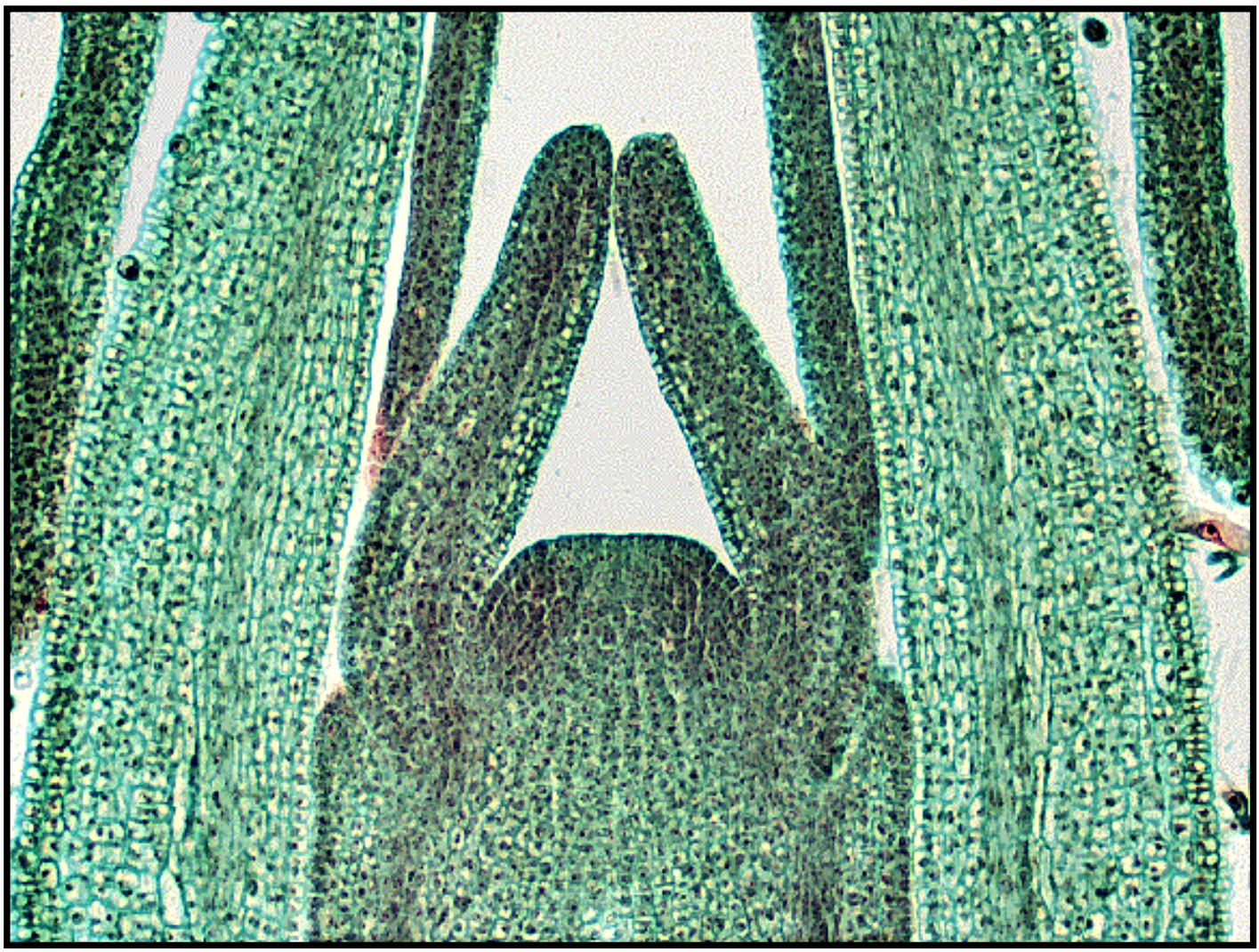
Longitudinal section of *Equisetum* shoot apical meristem.

- Identify the apical cell.
- The apical cell is an apical initial. Why?
- What kinds of plants are characterized by this apical organization?

Related images: *Elodea* shoot apical meristem, *Lonicera* shoot apex meristem, Salvia shoot apical meristem

Alison Roberts (awrobrts@uriacc.uri.edu)

Lonicera shoot apex



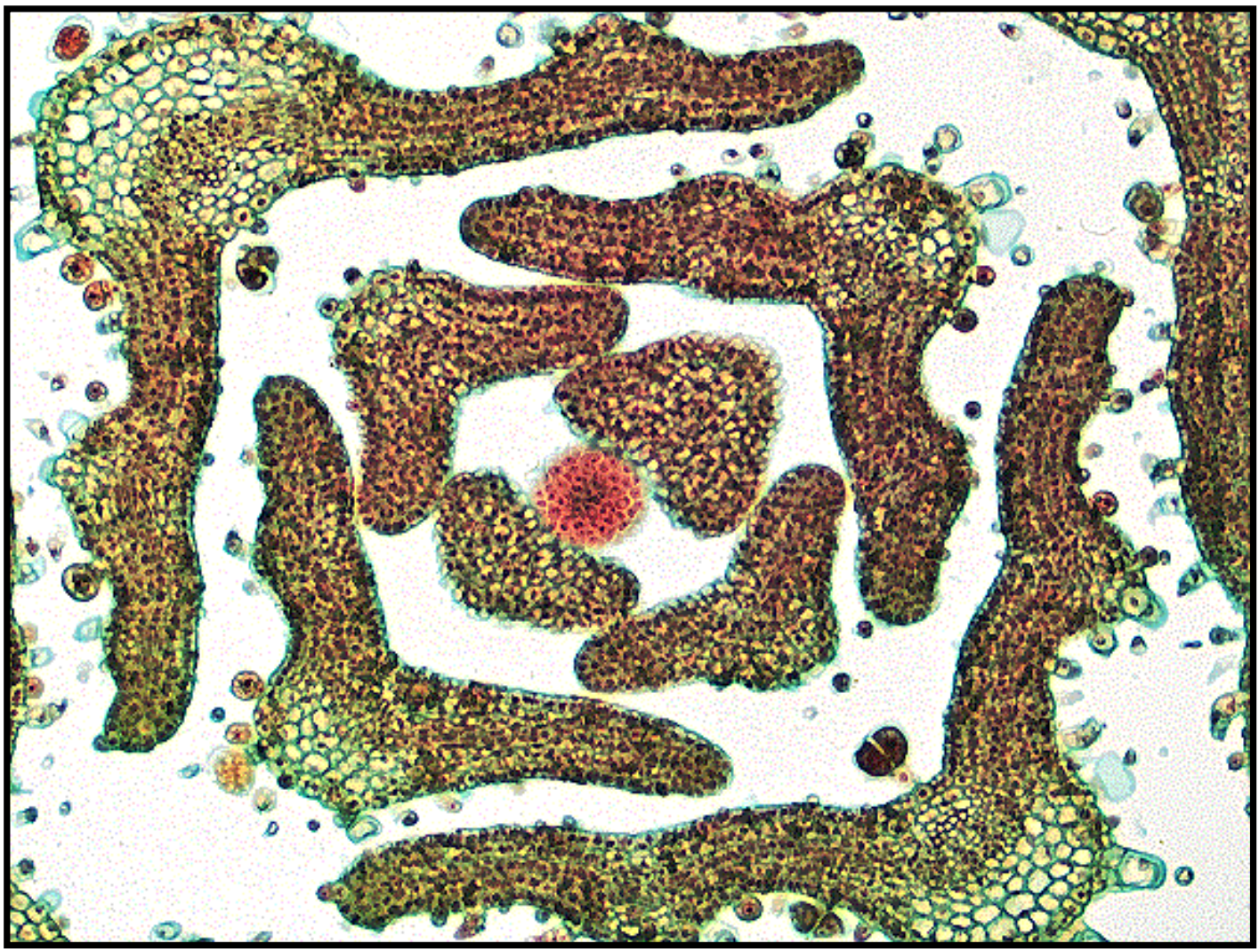
Longitudinal section of *Lonicera* shoot apex.

- Identify peripheral zone, central zone, and rib zone.
- Which zone contains the apical initials?
- What are the functions of the other zones?
- The shoot apical meristems of many flowering plants have three layers. Identify these layers. What are they called?
- Locate the primary meristematic tissues including strands of procambium, ground meristem, and protoderm.

Related images: *Elodea* shoot apical meristem, *Equisetum* shoot apical meristem, Salvia shoot apical meristem

Alison Roberts (awrobrts@uriacc.uri.edu)

Salvia shoot apical meristem



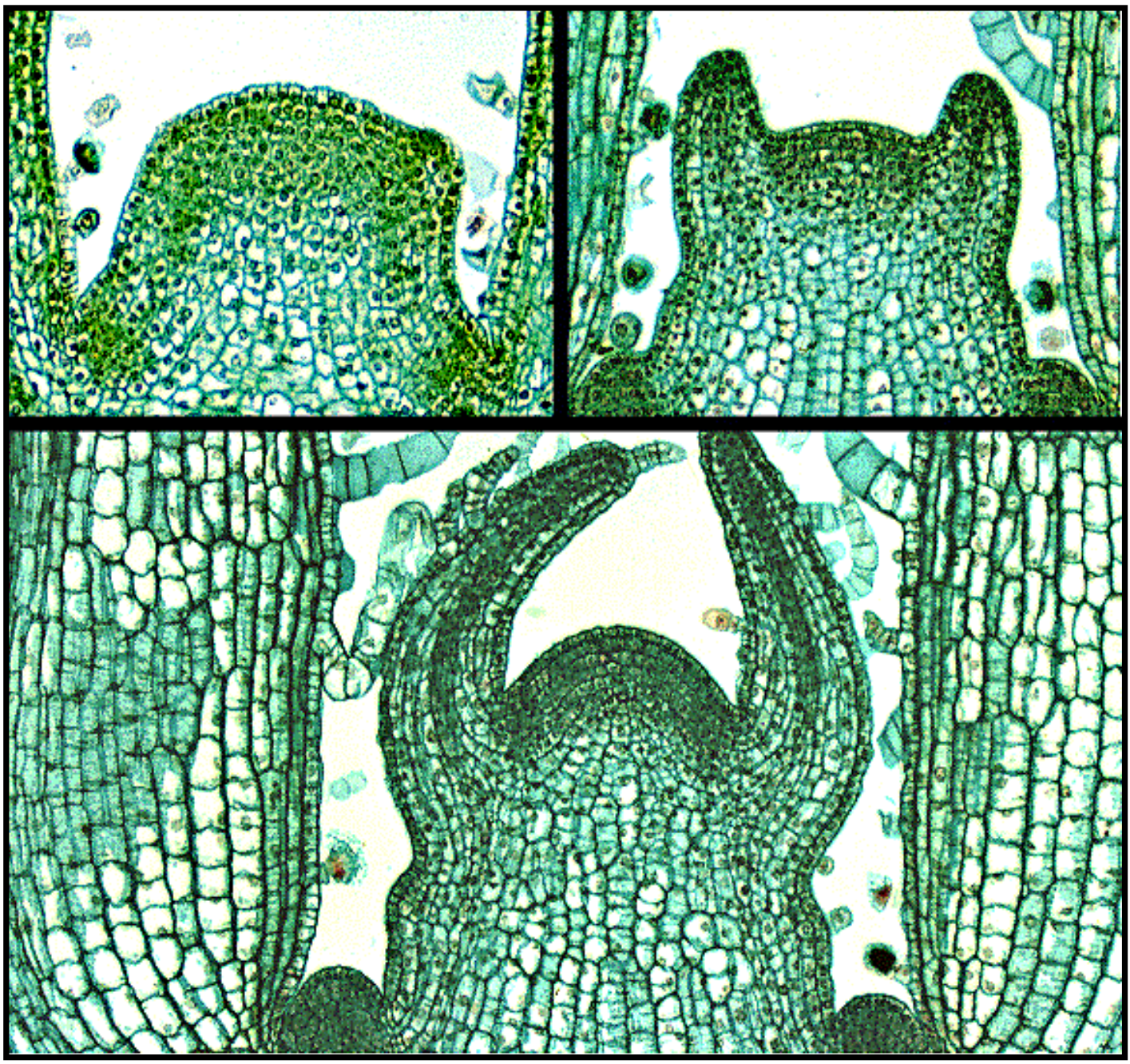
Cross section of *Salvia* shoot apical meristem.

- Identify the apical dome and leaf primordia.

Related images: *Elodea* shoot apical meristem, *Equisetum* shoot apical meristem, *Lonicera* shoot apex meristem

Alison Roberts (awrobrts@uriacc.uri.edu)

Leaf initiation in *Coleus*



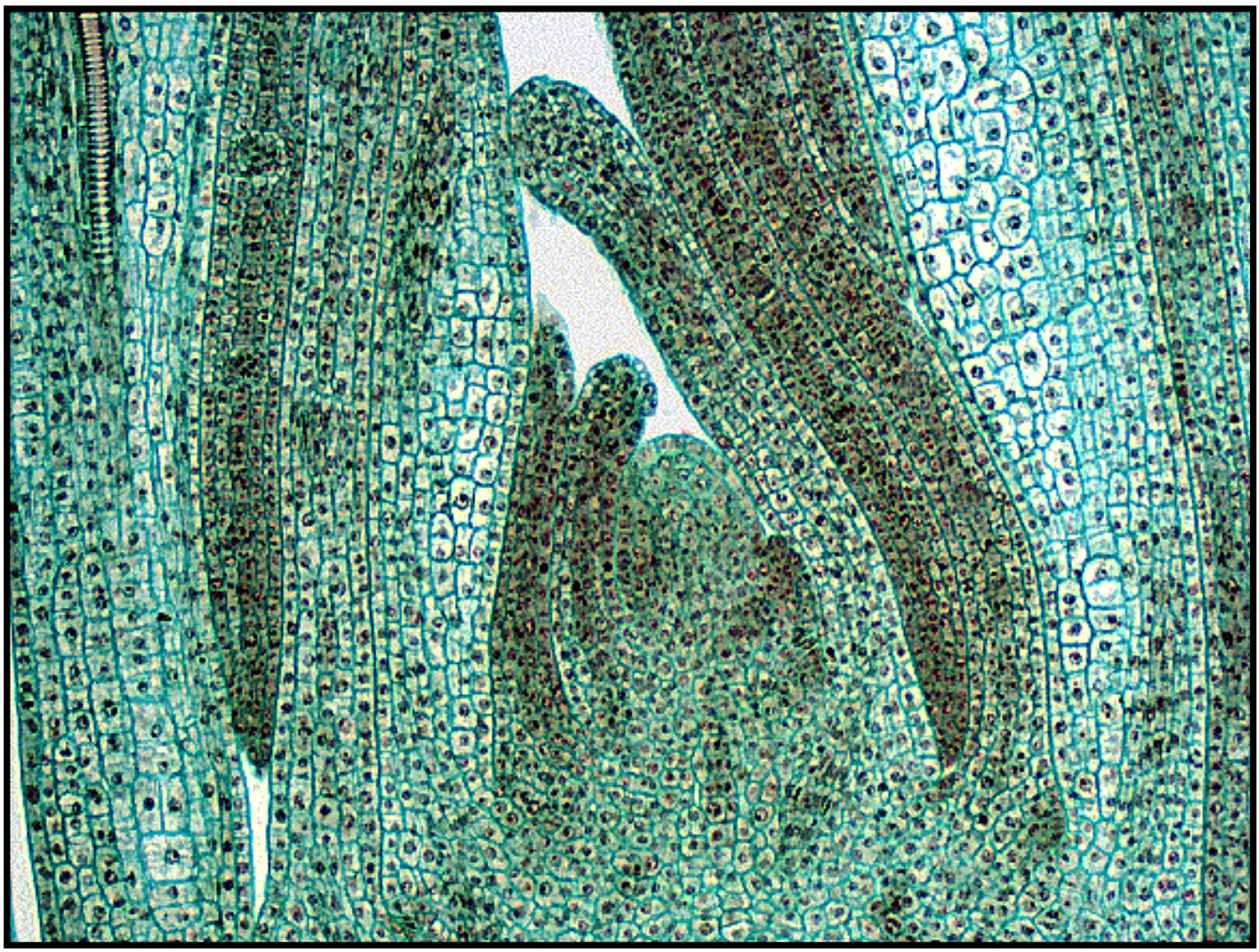
Developmental sequence of leaf initiation in *Coleus*.

- Note the changes in the size and shape of the apical dome and leaf primordia throughout the sequence.
- Identify leaf primordia and axillary bud primordia.
- What type of phyllotaxy does this plant have?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Zea shoot apical meristem



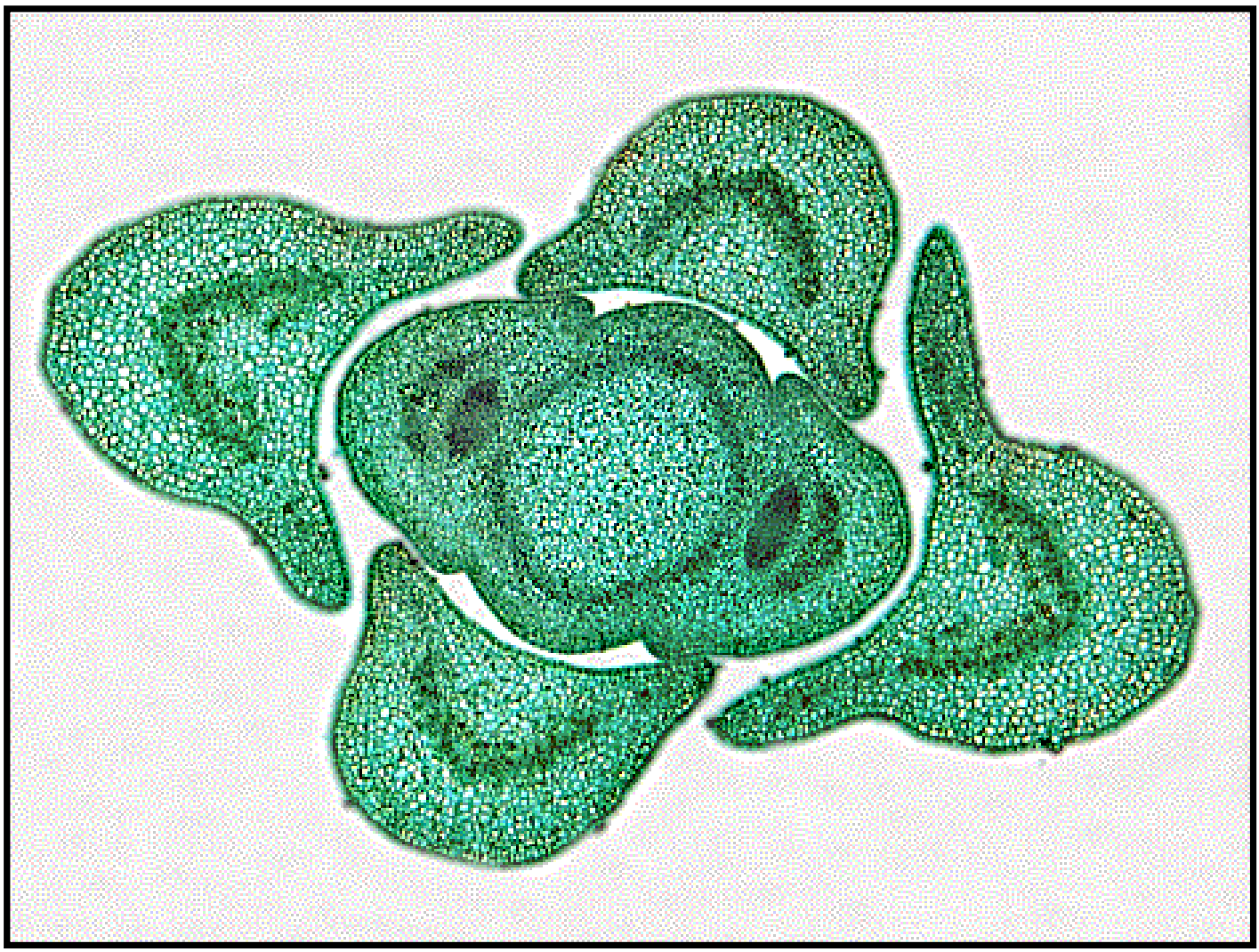
Longitudinal section of *Zea* shoot apical meristem.

- What type of phyllotaxy does this plant have?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Syringa shoot tip



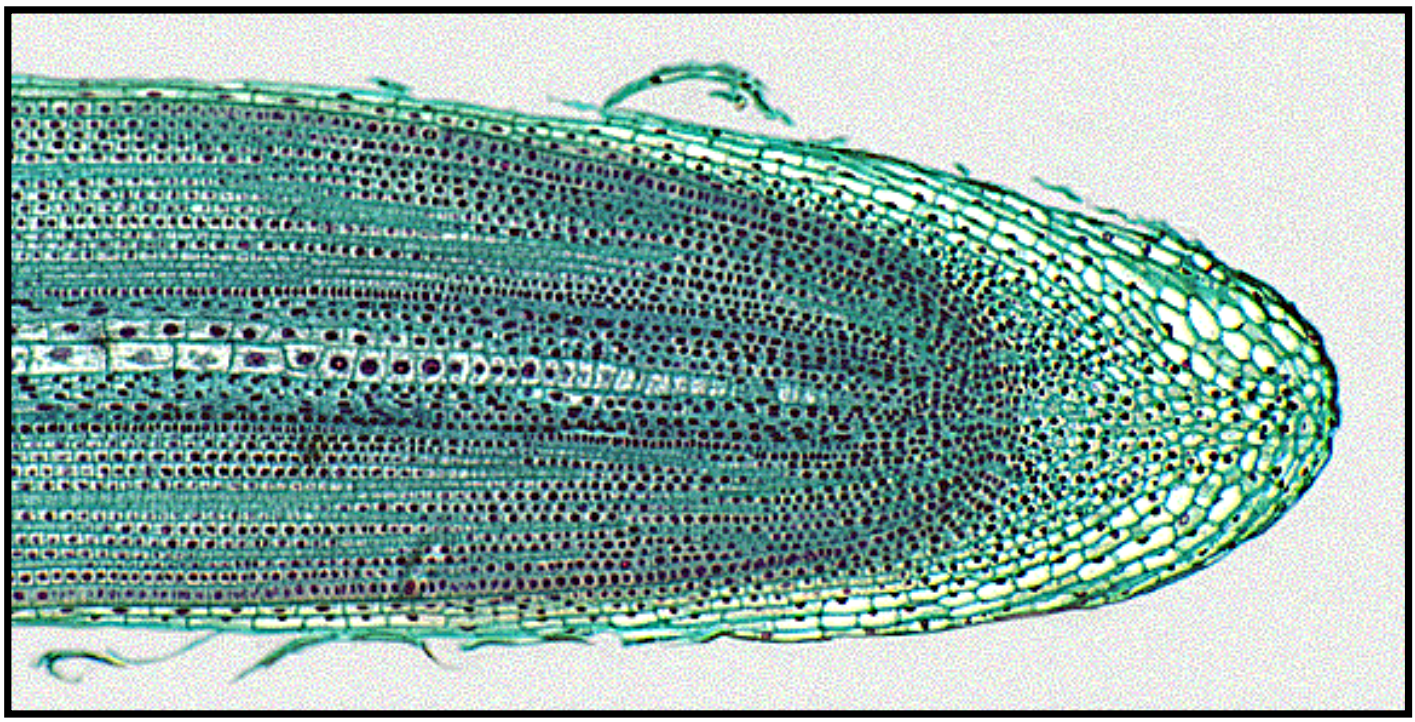
Cross section of *Syringa* shoot tip.

- Identify procambium and developing vascular strands leading to the leaves and the axillary buds.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Allium root tip



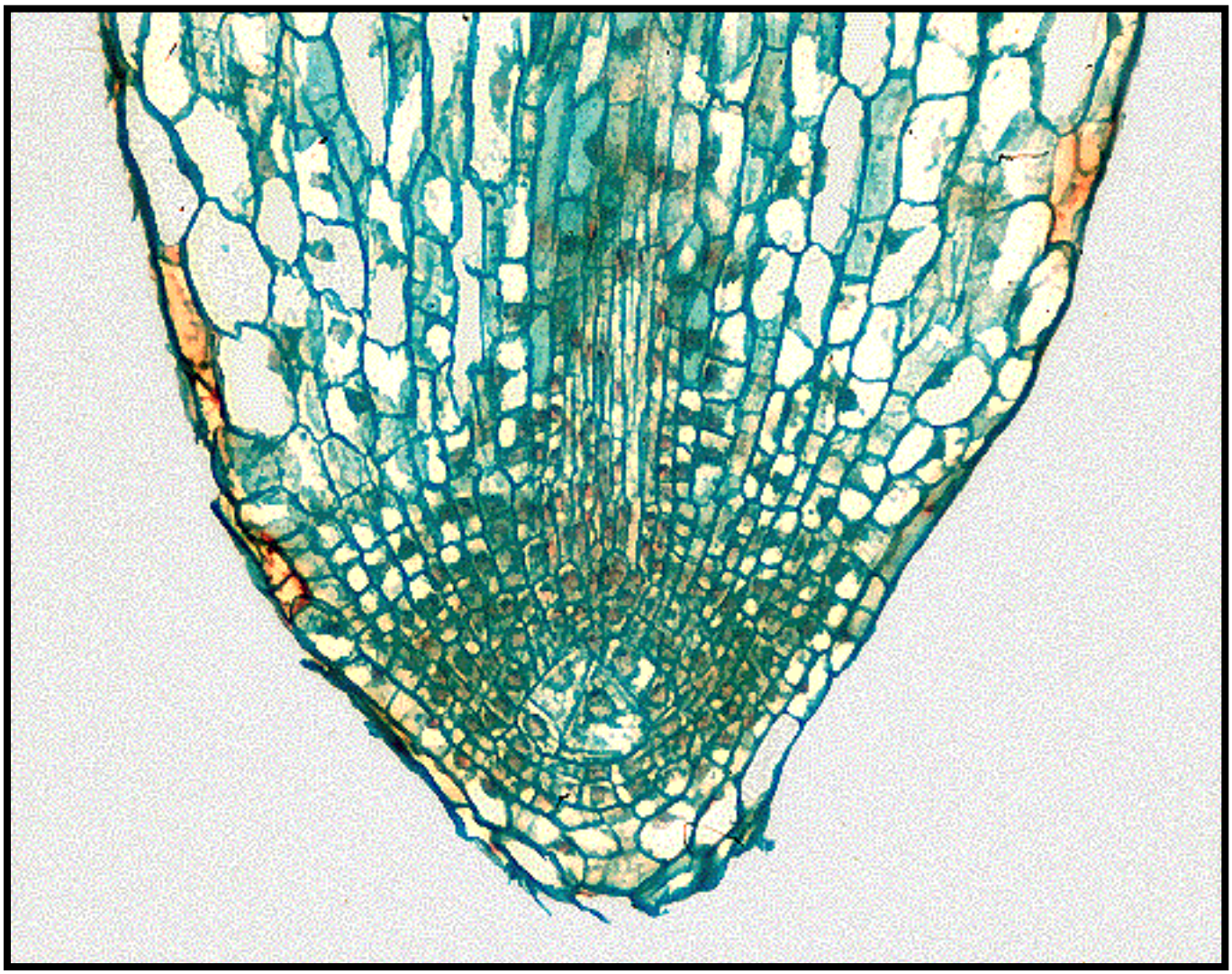
Longitudinal section of *Allium* root tip.

- Identify apical meristem, root cap, procambium, ground meristem, and protoderm.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Botrychium root tip



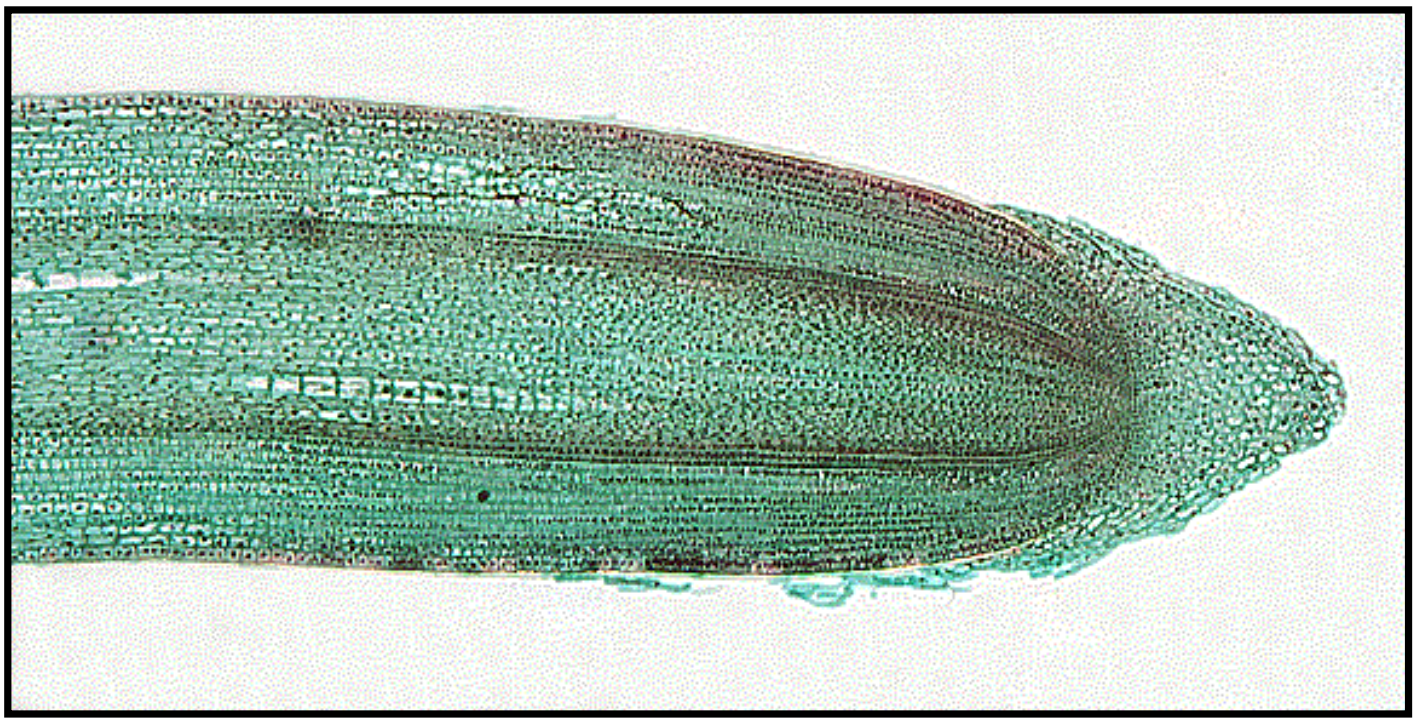
Longitudinal section of *Botrychium* root tip.

- What type of apical organization does this plant have?
- Identify apical intial(s).

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Zea root tip



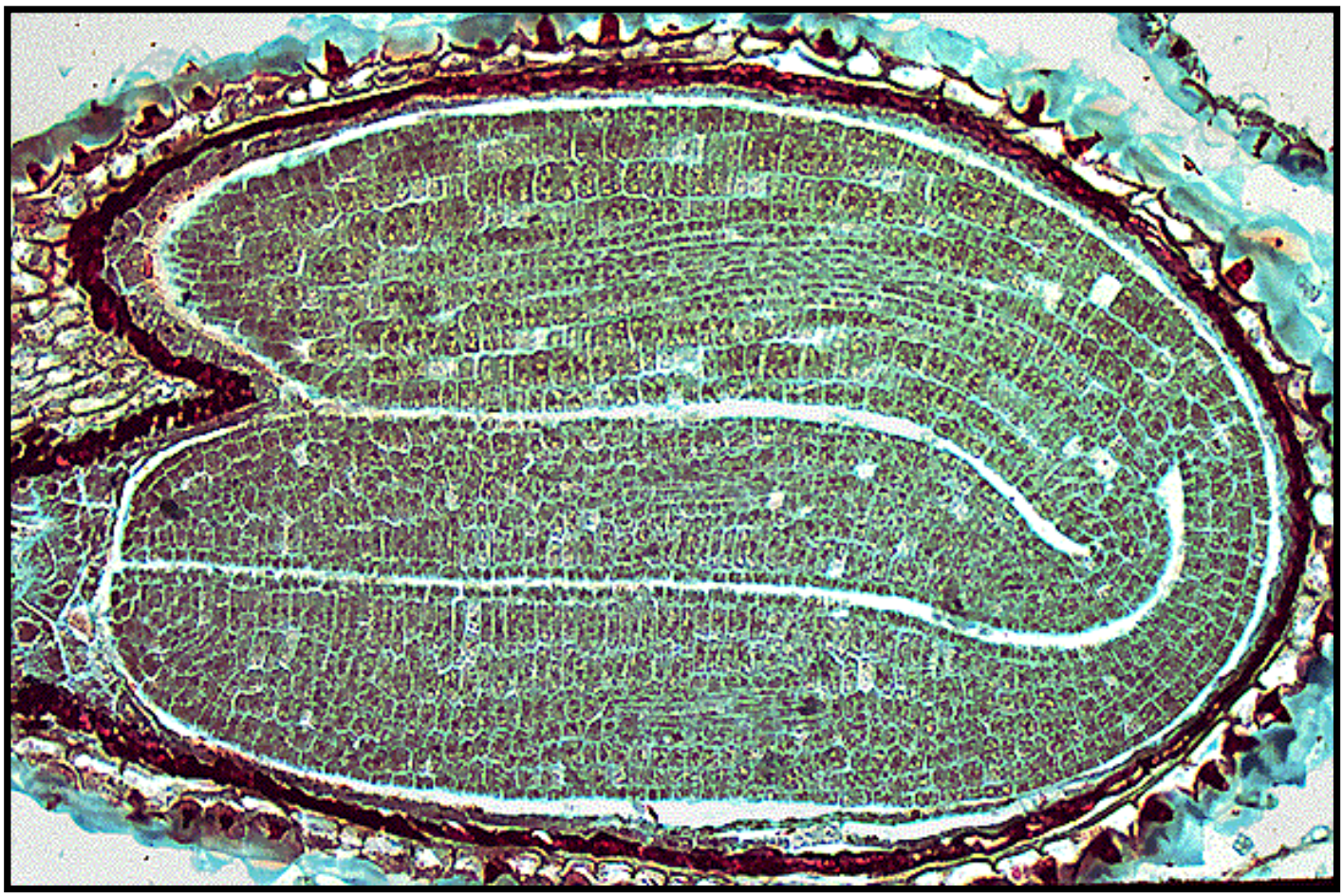
Longitudinal section of *Zea* root tip.

- Locate the cells in this root tip that divide slowest.
- What is this group of cells called?
- What is the function of this group of cells?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Capsella embryo



Capsella embryo.

- Locate root and shoot apical meristems and the three primary meristematic tissues.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Clivia leaf cross section

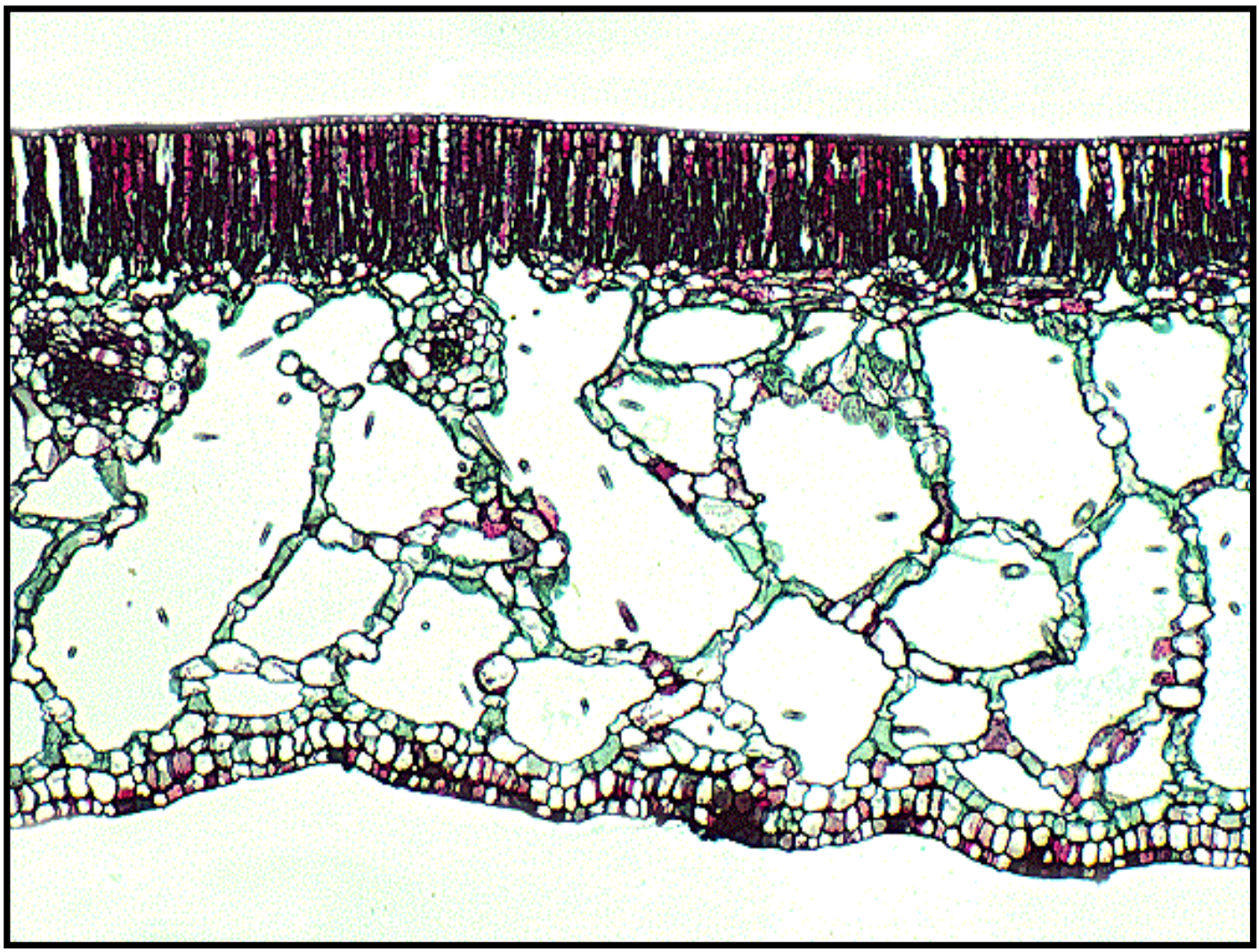
Leaf of *Clivia*.

- What is the yellow-orange colored material on the leaf surface?
- What is its function?
- What type of cells secreted this material?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Castalia leaf



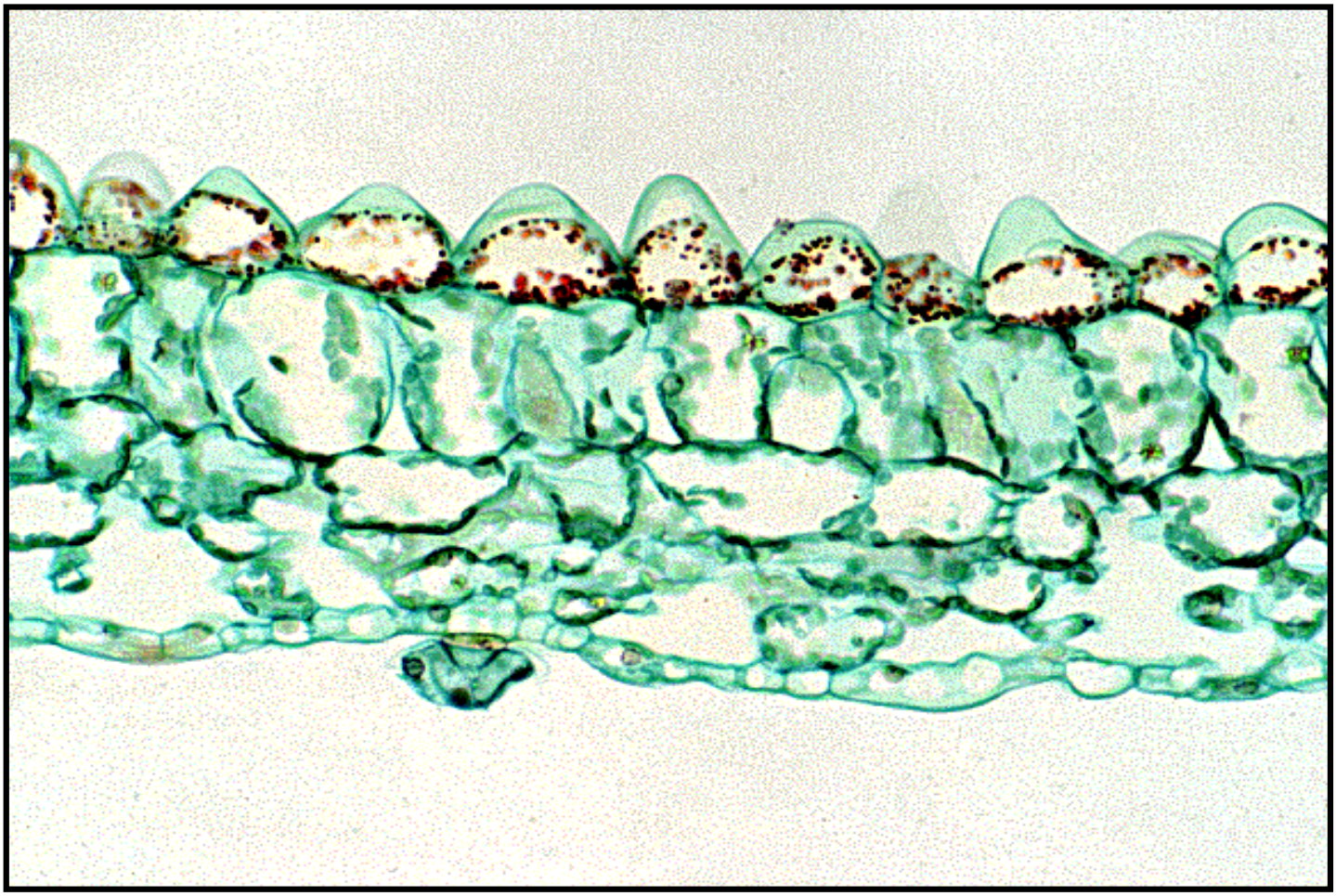
Castalia leaf.

- What characteristic of this leaf leads to its classification as epistomatic?
- In what kind of environment is this plant likely to be found?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Coleus leaf



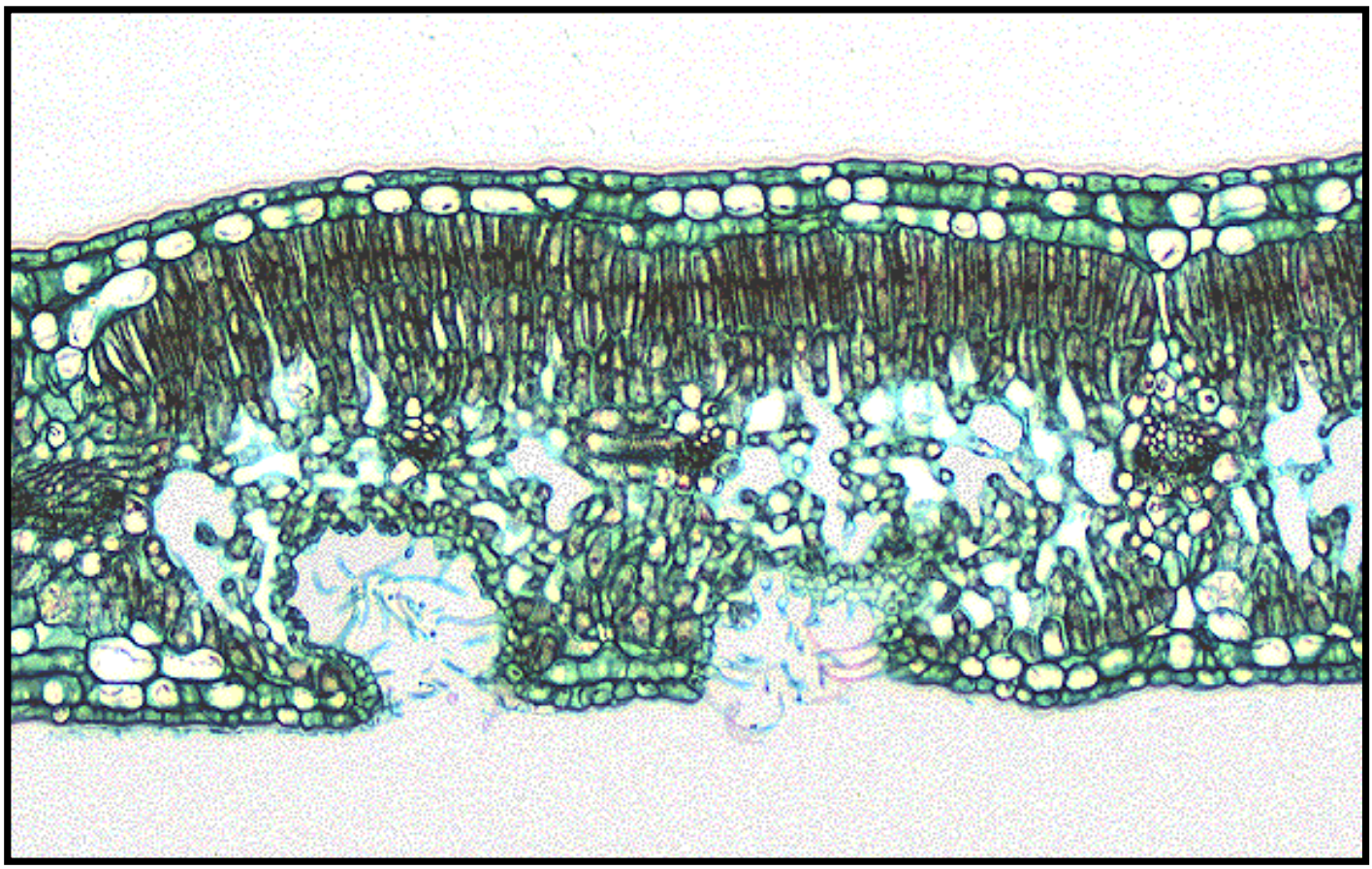
Coleus leaf cross section.

- Where are the stomata on this leaf?
- How would you classify this leaf in relation to stomatal position?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Nerium leaf



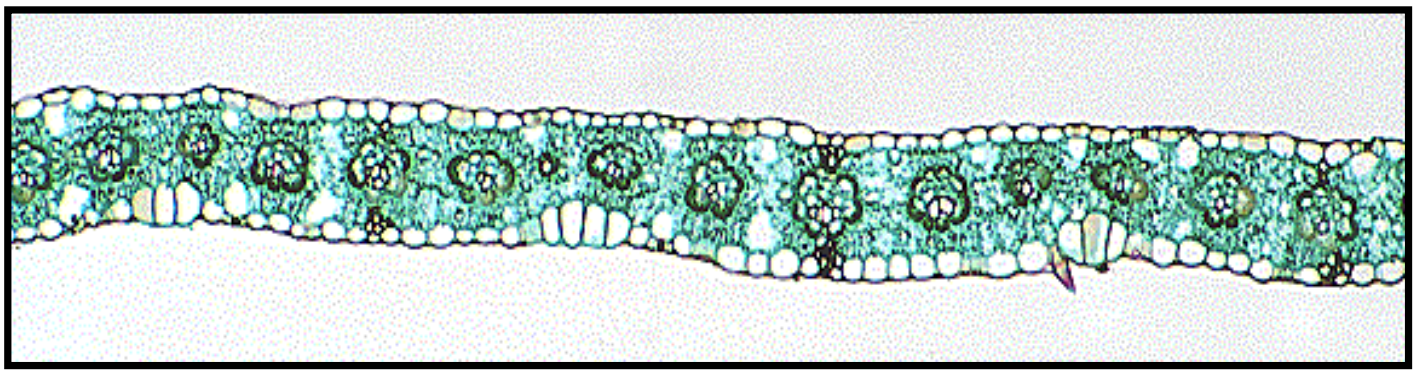
Cross section of *Nerium* leaf.

- Identify the guard cells , trichomes and stomatal crypts.
- How does the placement of stomata in crypts help this plant survive in a dry environment?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Zea mays leaf x.s.



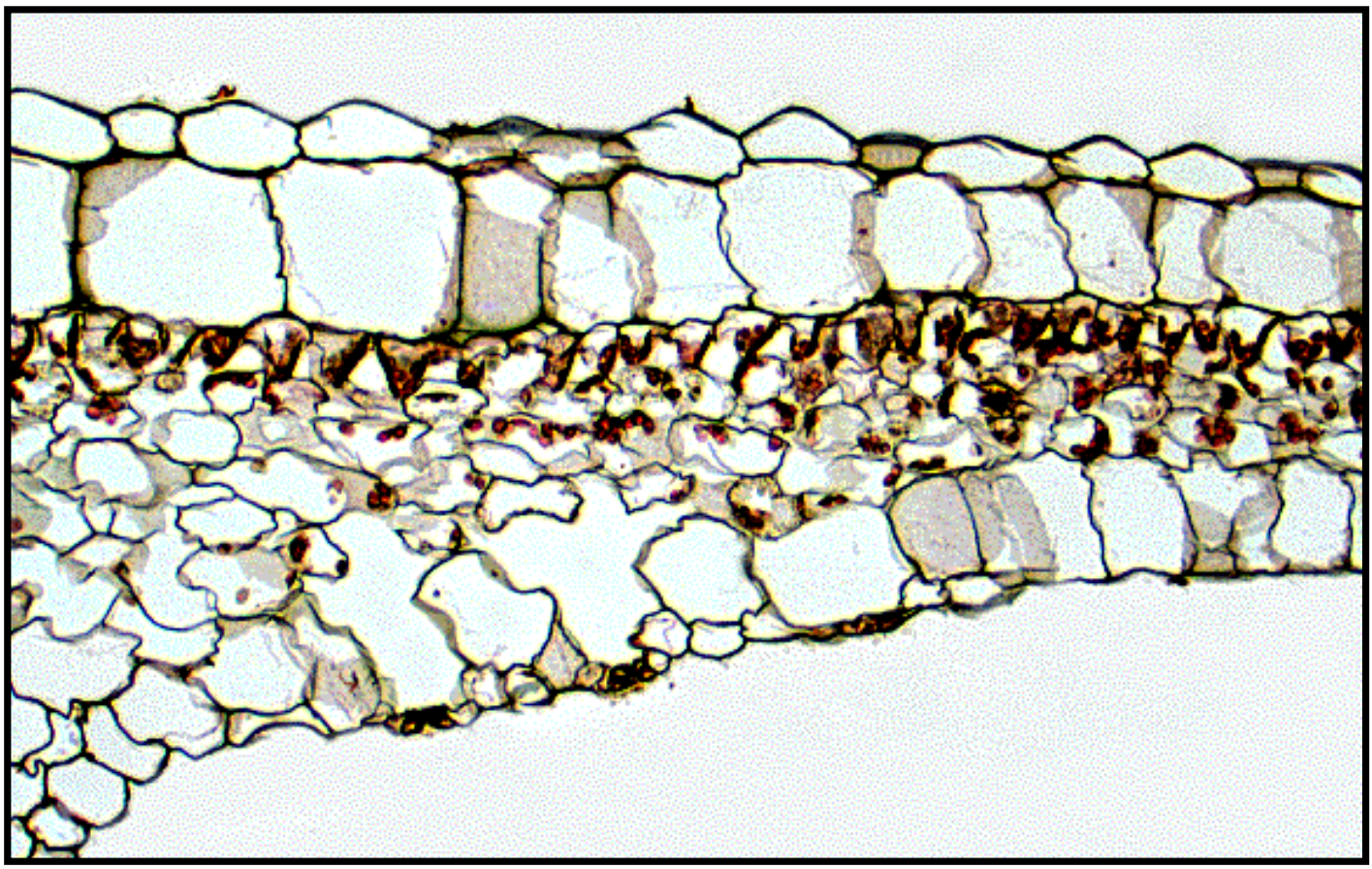
Leaf x.s. of *Zea mays* (corn). The leaves of many monocots, such as this *Zea*, have stomata on both the upper and lower surfaces (stomata on lower surface can be identified by locating the substomatal chambers).

- How is the stomatal position related to the position of the leaves on the plant?
- How would you classify this leaf in relation to stomatal position?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Begonia leaf x.s.



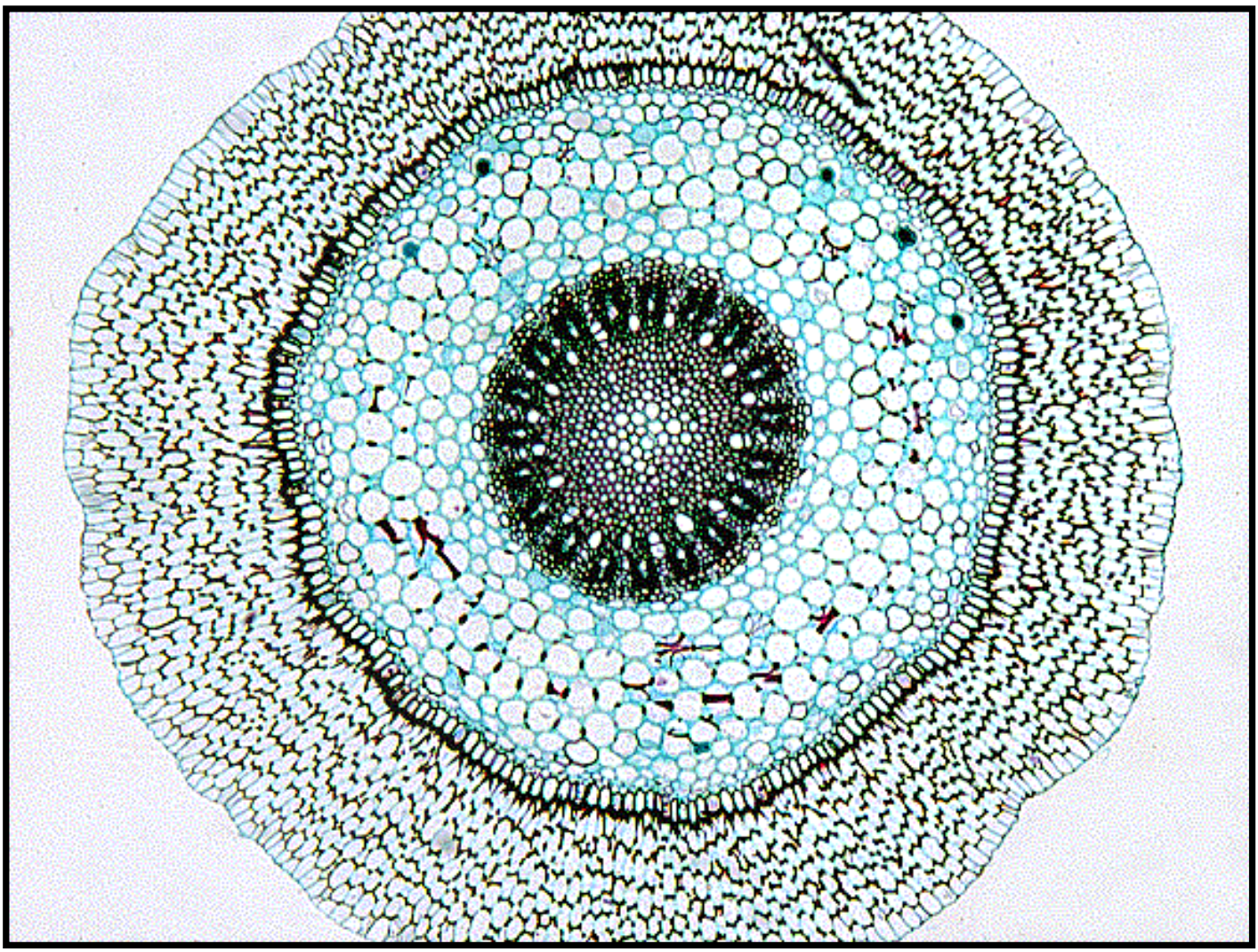
Begonia leaf cross section.

- Identify the multiple epidermis.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Aerial root of orchid



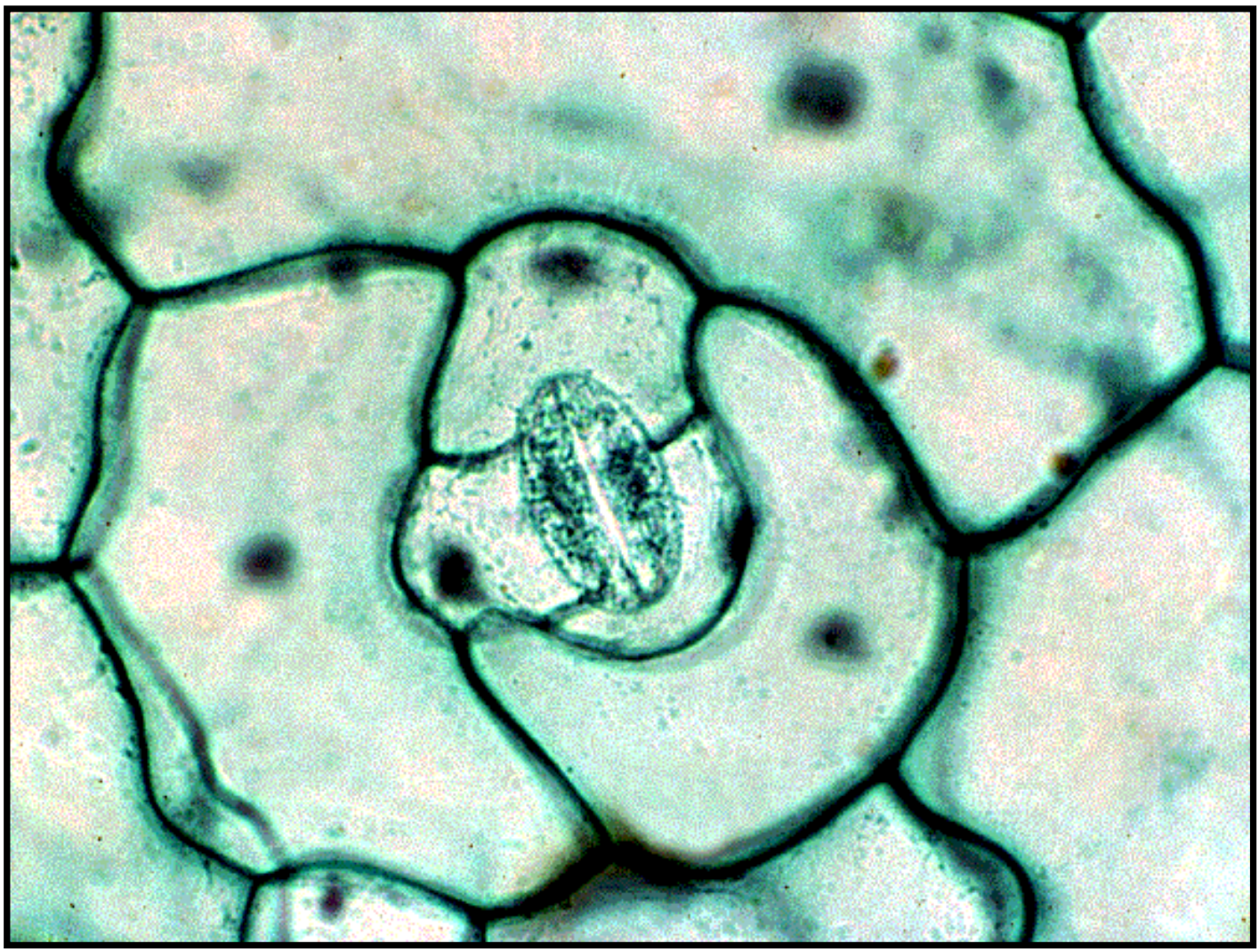
Aerial root of orchid.

- The thick multiple epidermis on this orchid root is called a velamen.
- From which primary meristematic tissue did the velamen arise?
- In what ways does the epidermis on this aerial root differ from that of a typical root epidermis?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Epidermal peel of sedum



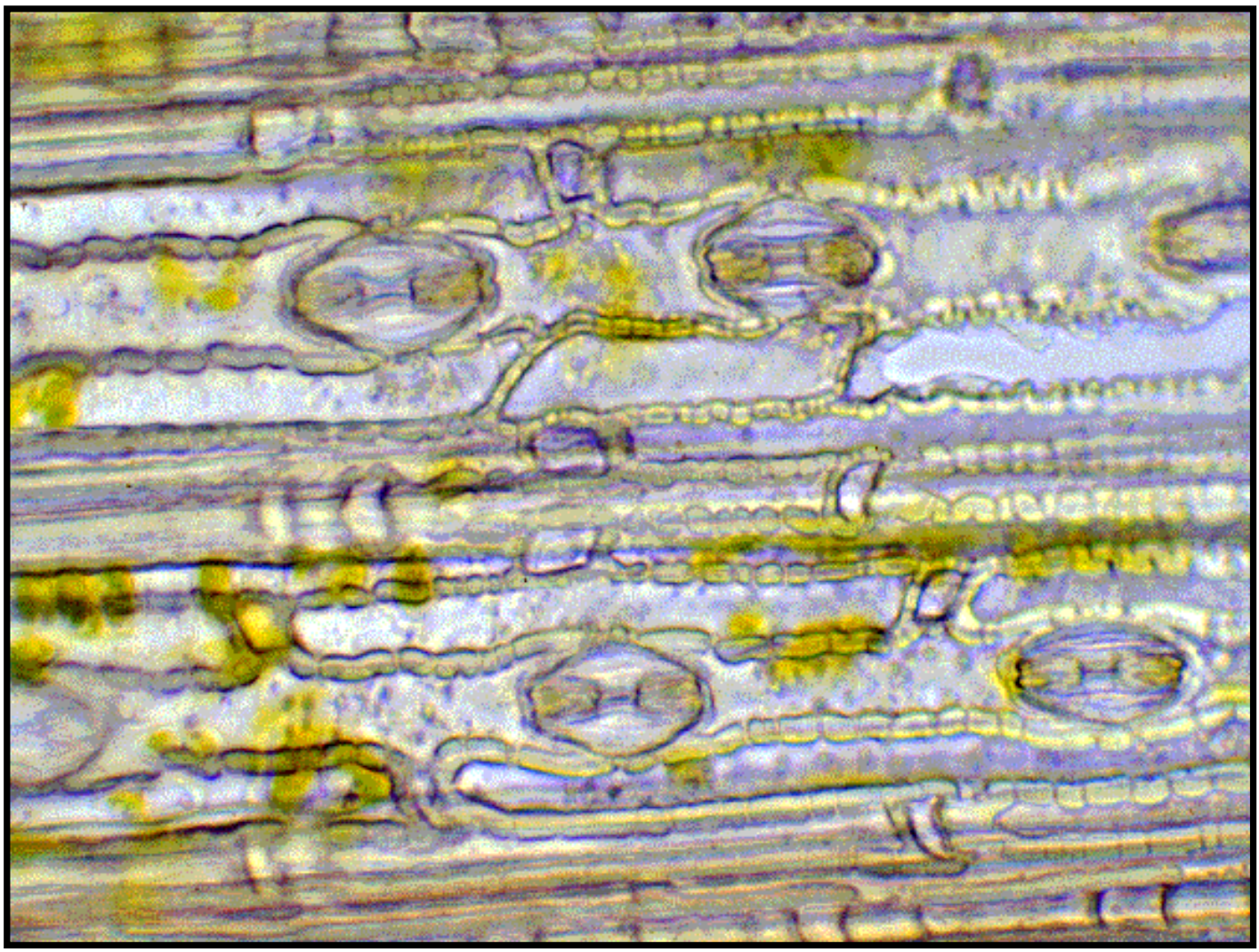
Epidermal peel of sedum.

- Identify guard cells, subsidiary cells, and pavement cells.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Epidermal peel of sorghum



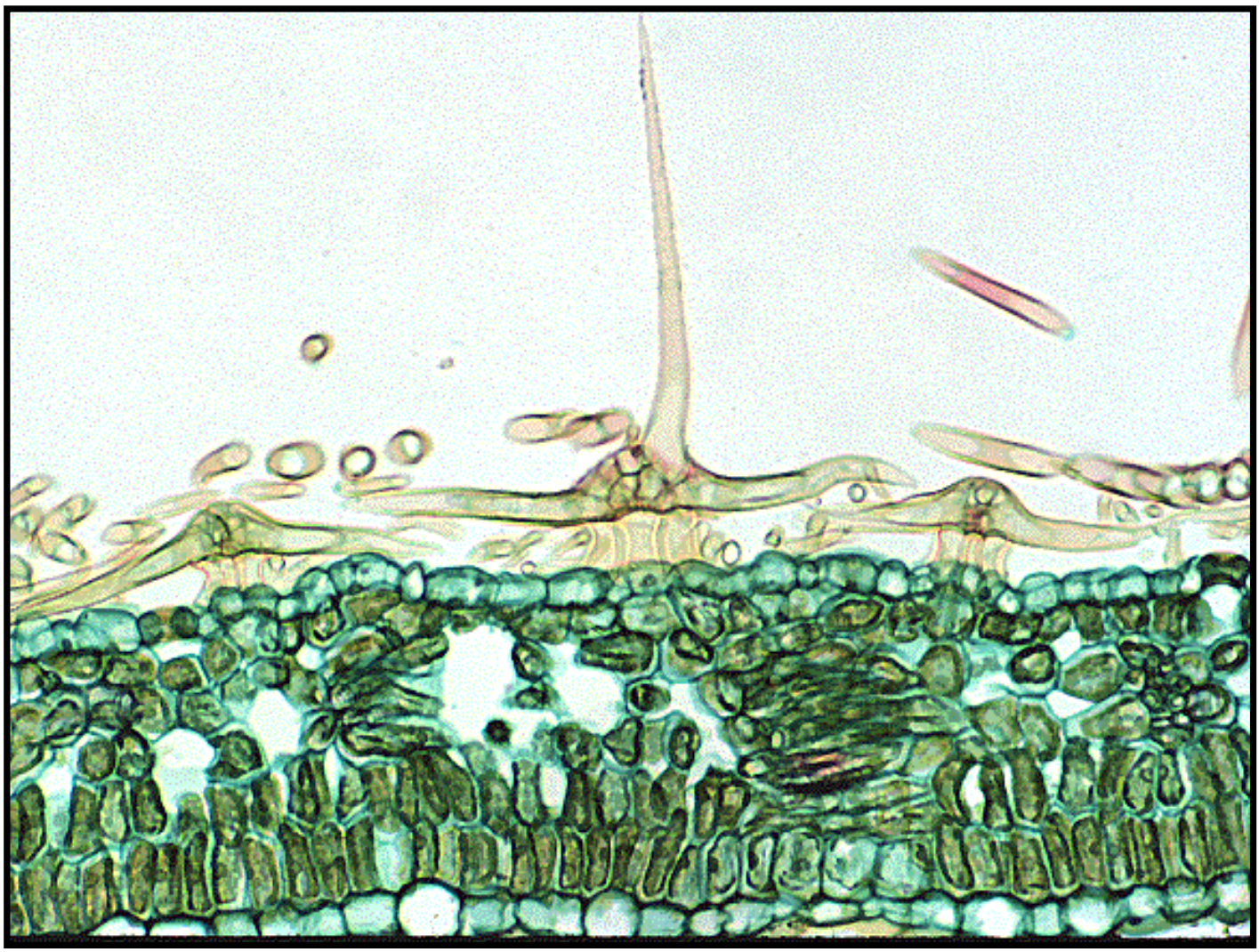
Epidermal peel of sorghum.

- In what way are the guard cells of this monocot distinctive?
- Identify guard cells, subsidiary cells, and pavement cells.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Eleagnus leaf showing trichomes



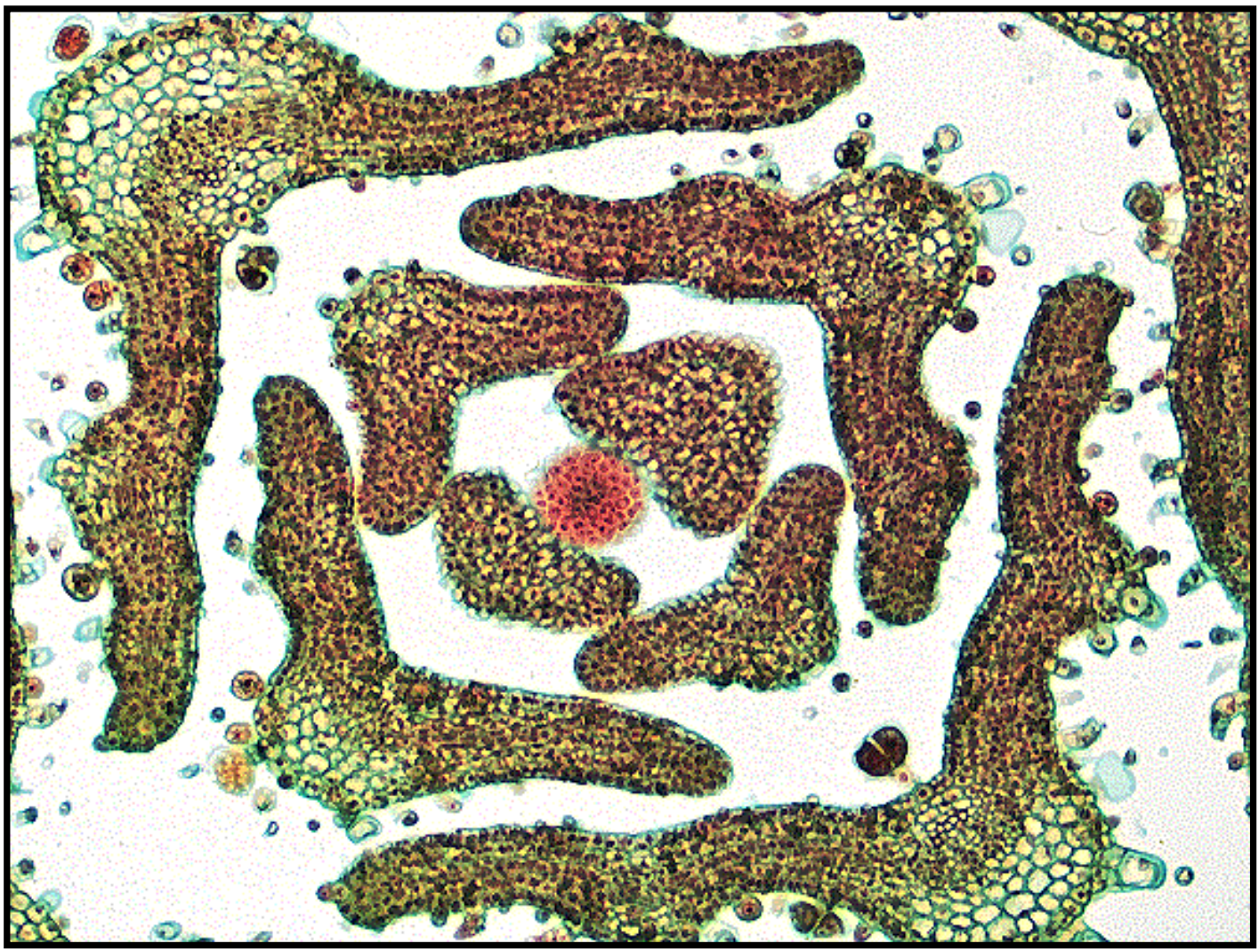
Eleagnus ("Russian olive") leaf

- Identify the multicellular, branched trichomes.
- What is the function of these trichomes?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Salvia shoot apex



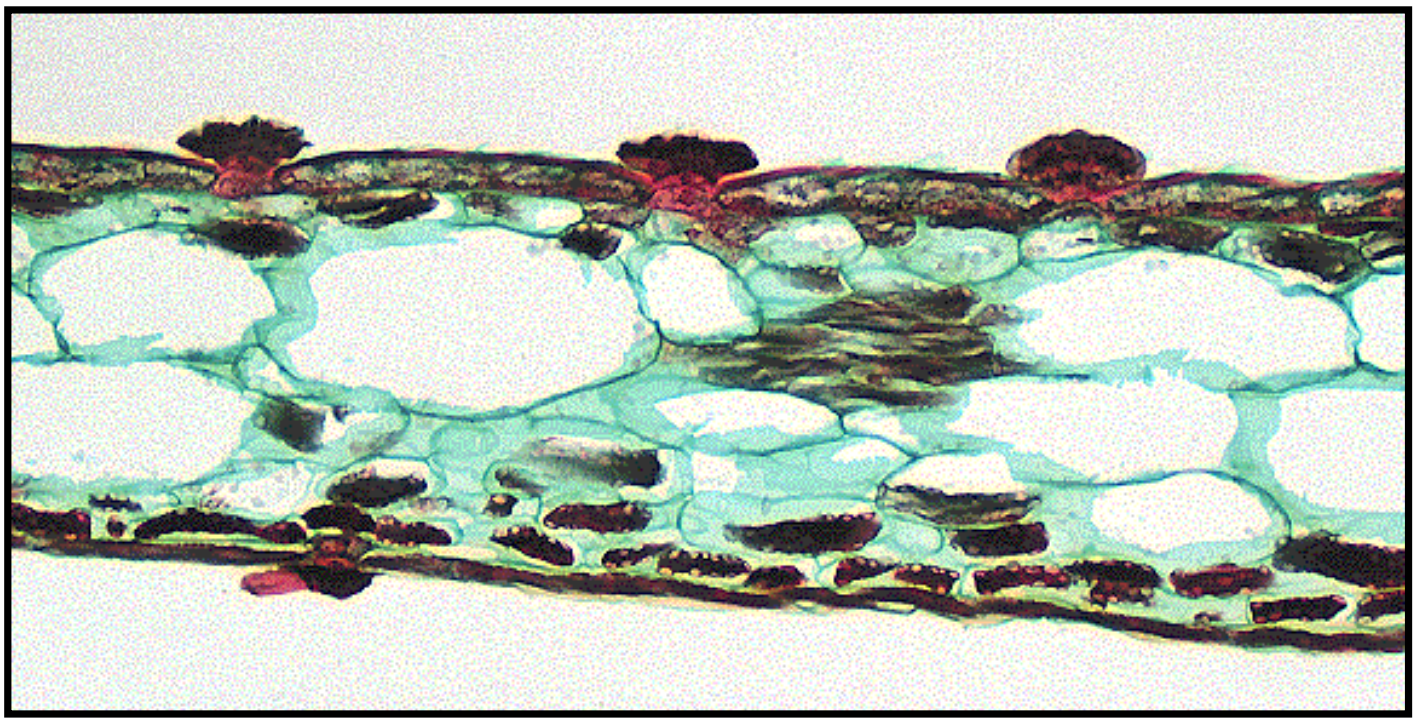
Salvia shoot apex.

- Identify multicellular and secretory trichomes.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Venus fly trap



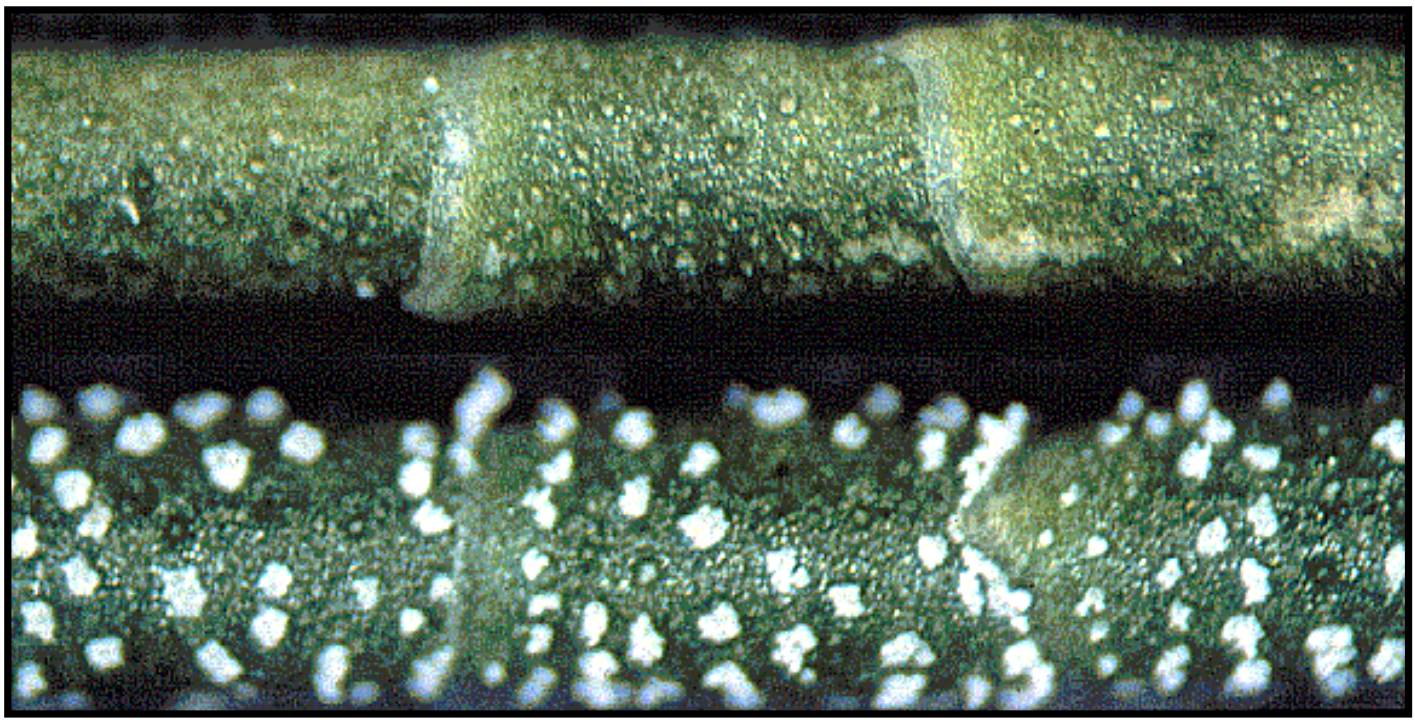
Venus fly trap

- Identify the glands that secrete digestive enzymes.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Glands on the stem of *Limonium*



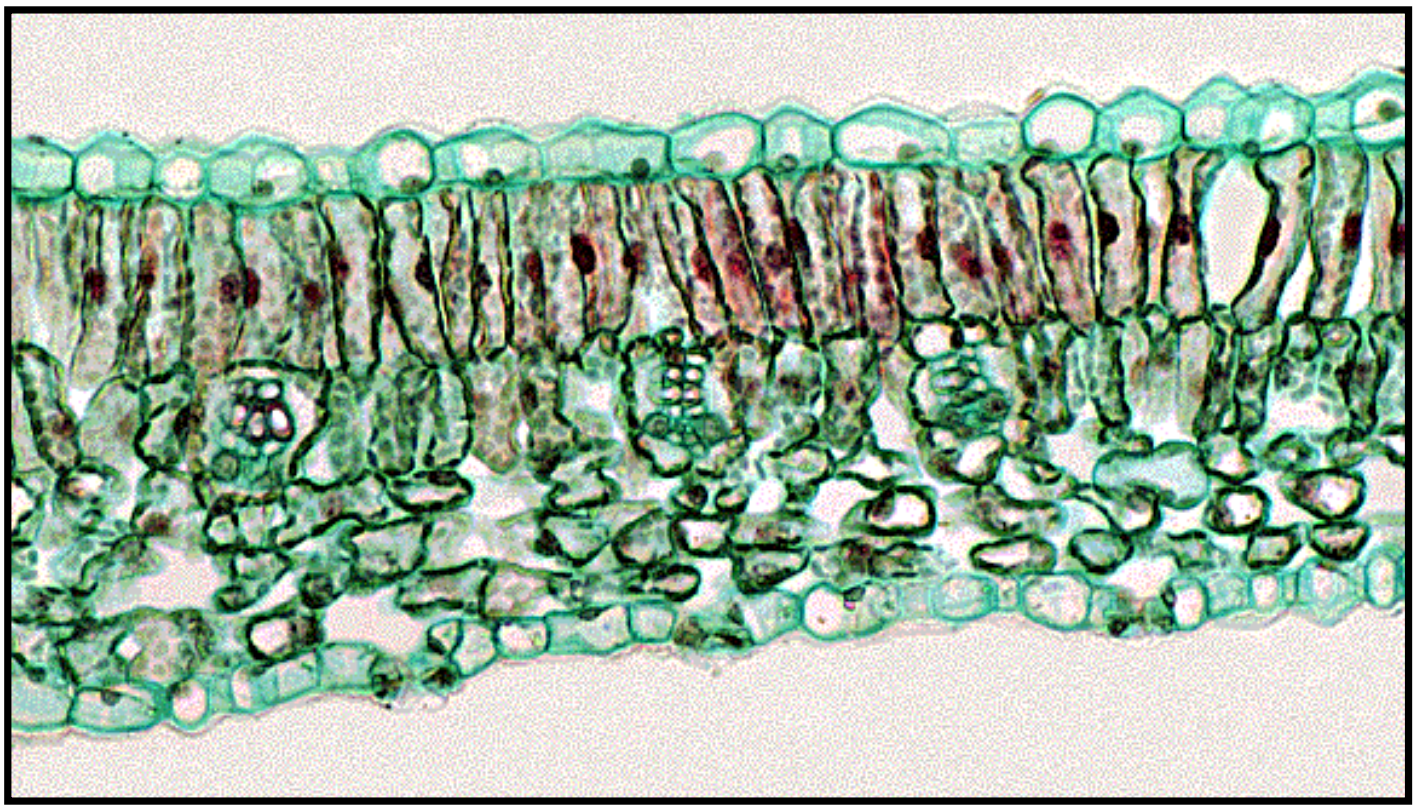
Glands on the stem of *Limonium*. (Original photgraph courtesy of Dr. Page Owen of Connecticut College.)

- What substance has been secreted by the glands in the stem at the lower part of the picture?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Syringa leaf



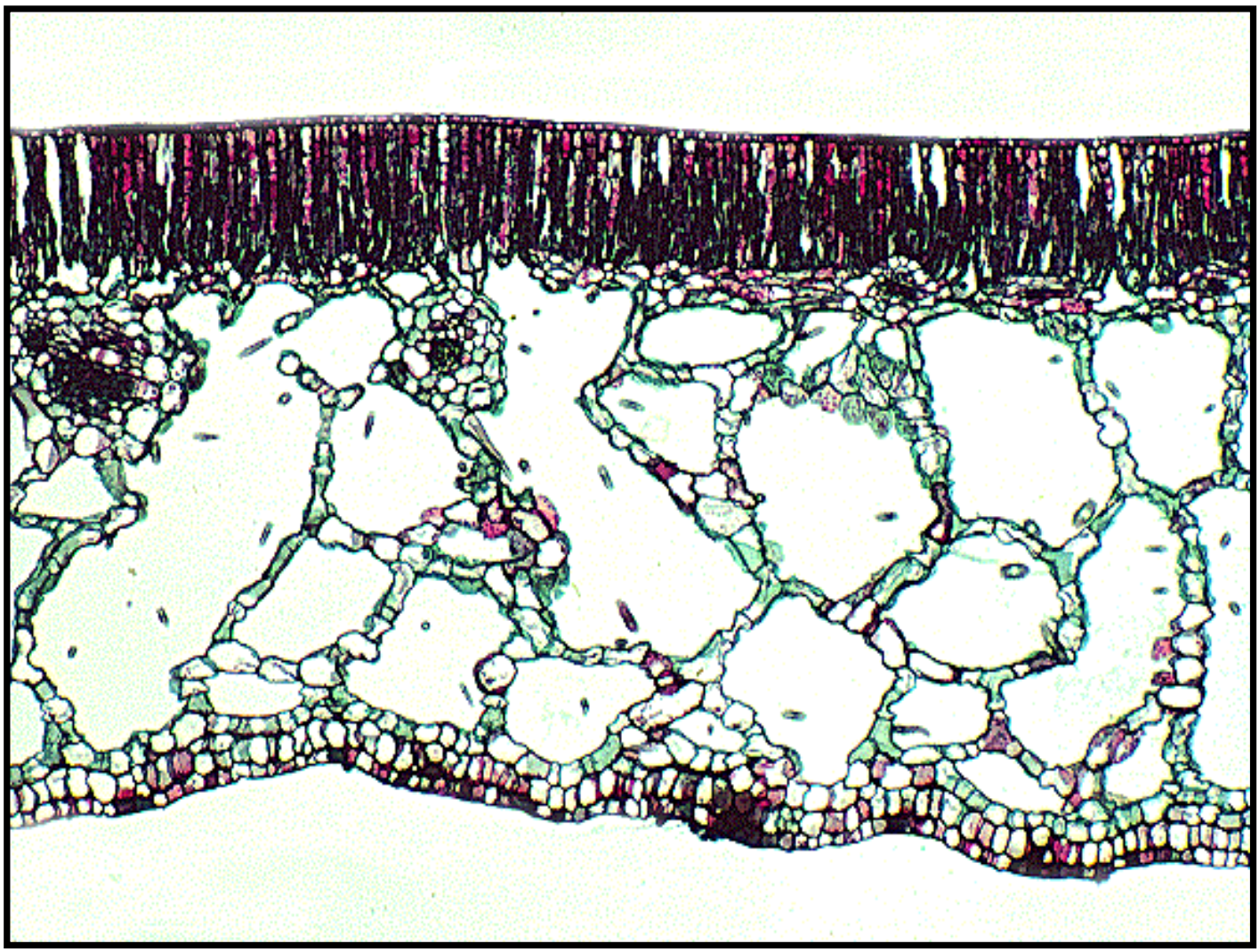
Syringa leaf cross section.

- Identify chlorenchyma and aerenchyma.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Castalia leaf cross section



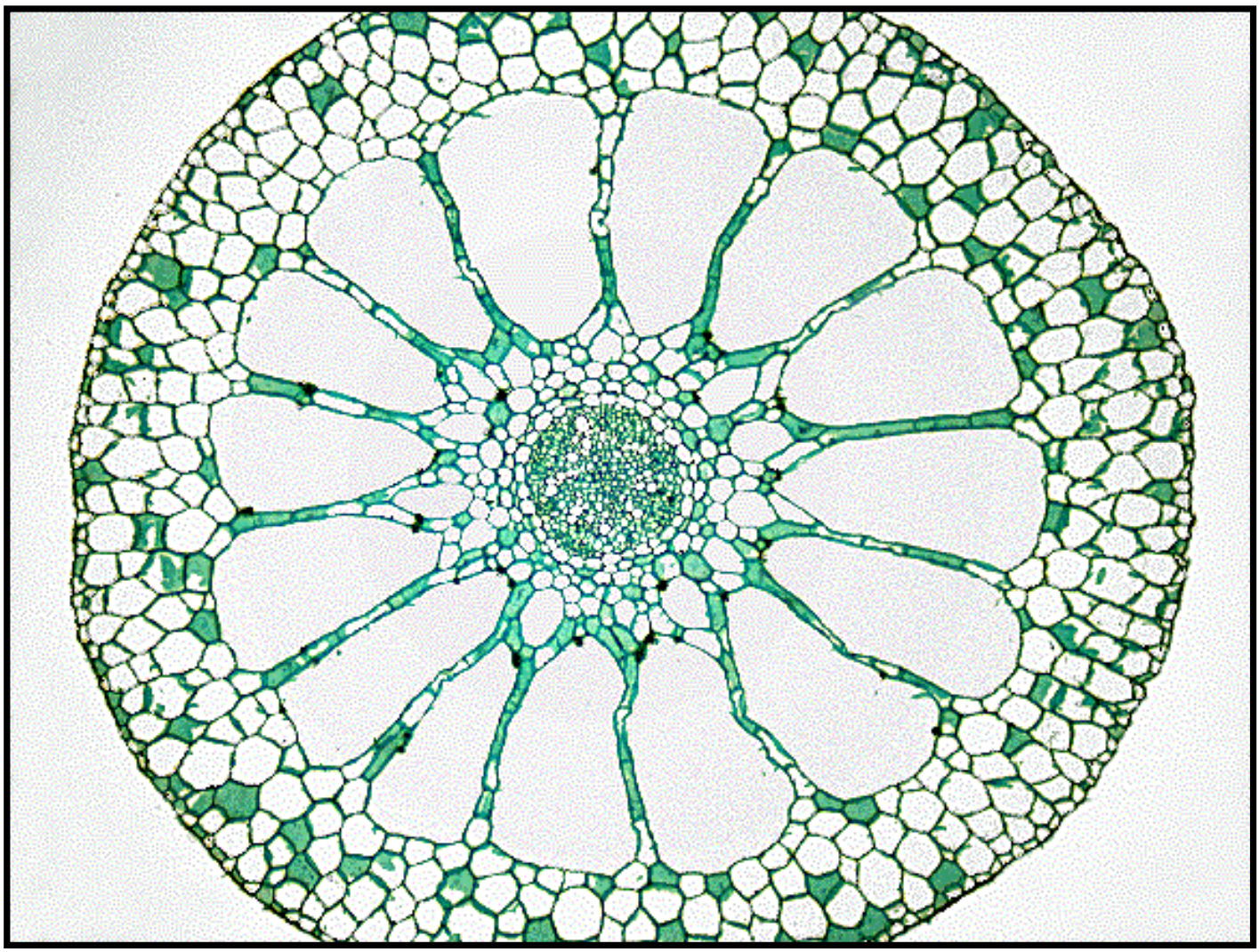
Castalia leaf cross section.

- Identify aerenchyma.
- Describe the environment to which this plant is adapted.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Myriophyllum stem



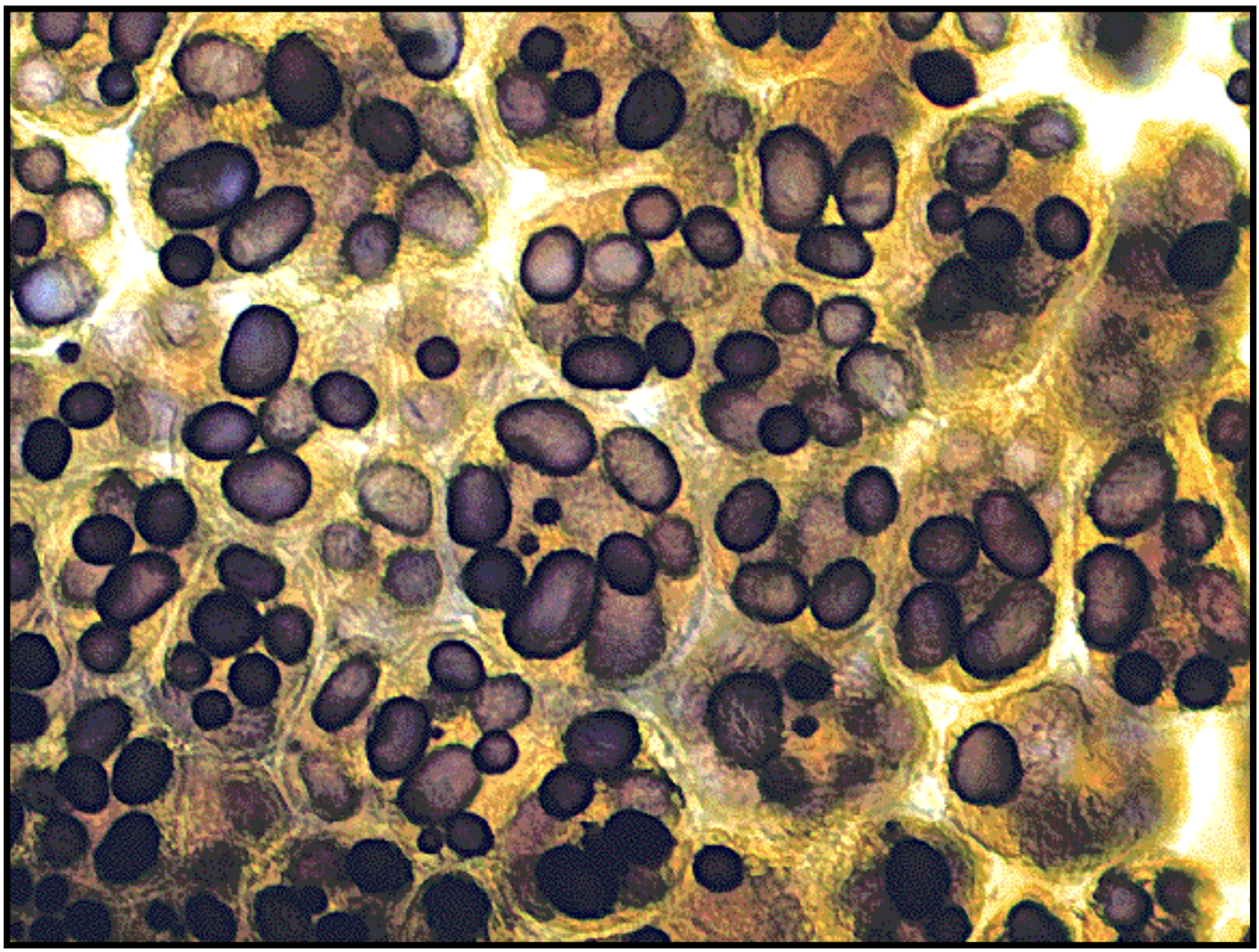
Myriophyllum stem cross section.

- Identify aerenchyma.
- What is the function of this tissue?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Storage parenchyma in bean



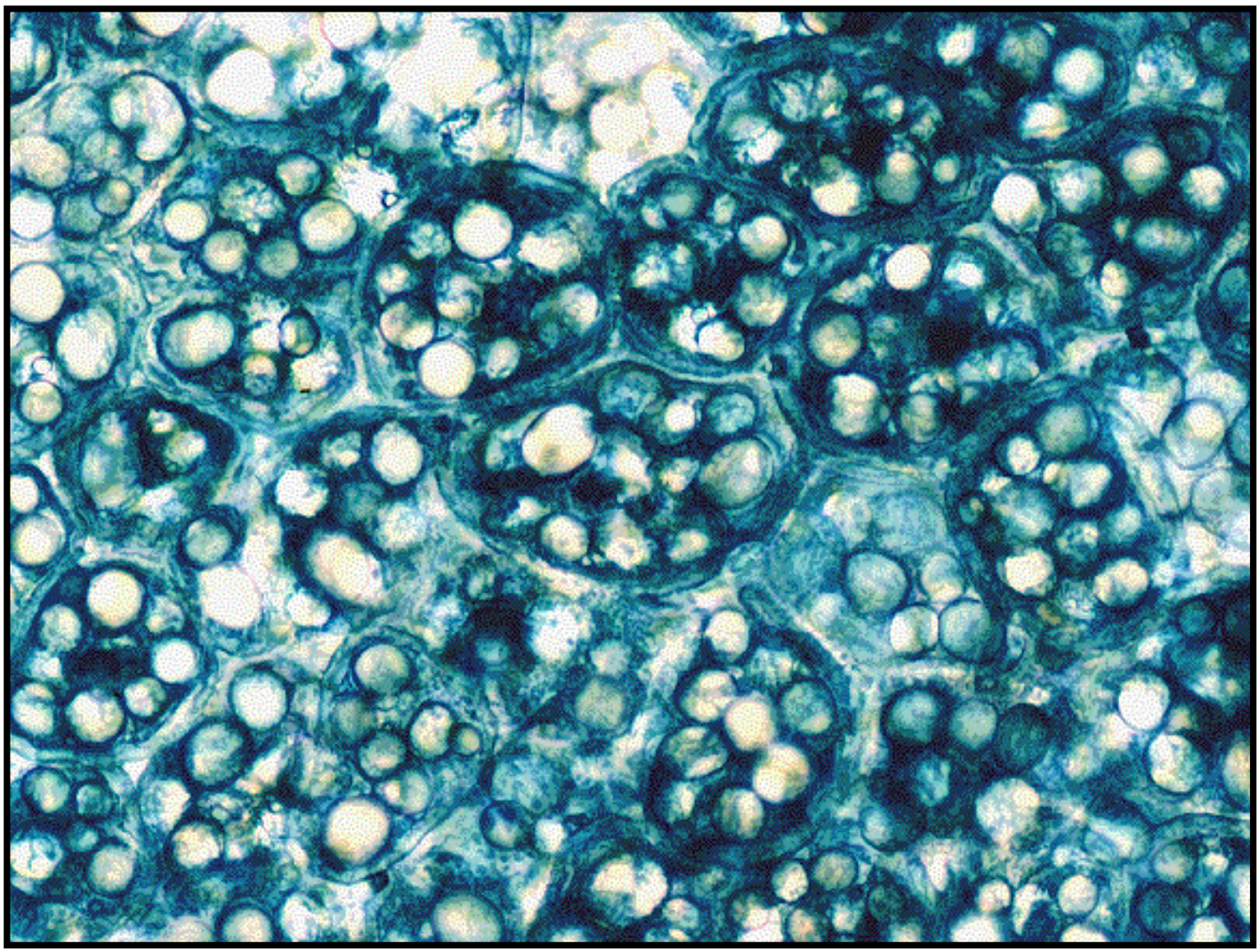
Storage parenchyma in bean cotyledon.

- The purple structures are starch grains.
- What is this tissue stained with?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Storage parenchyma in bean cotyledon



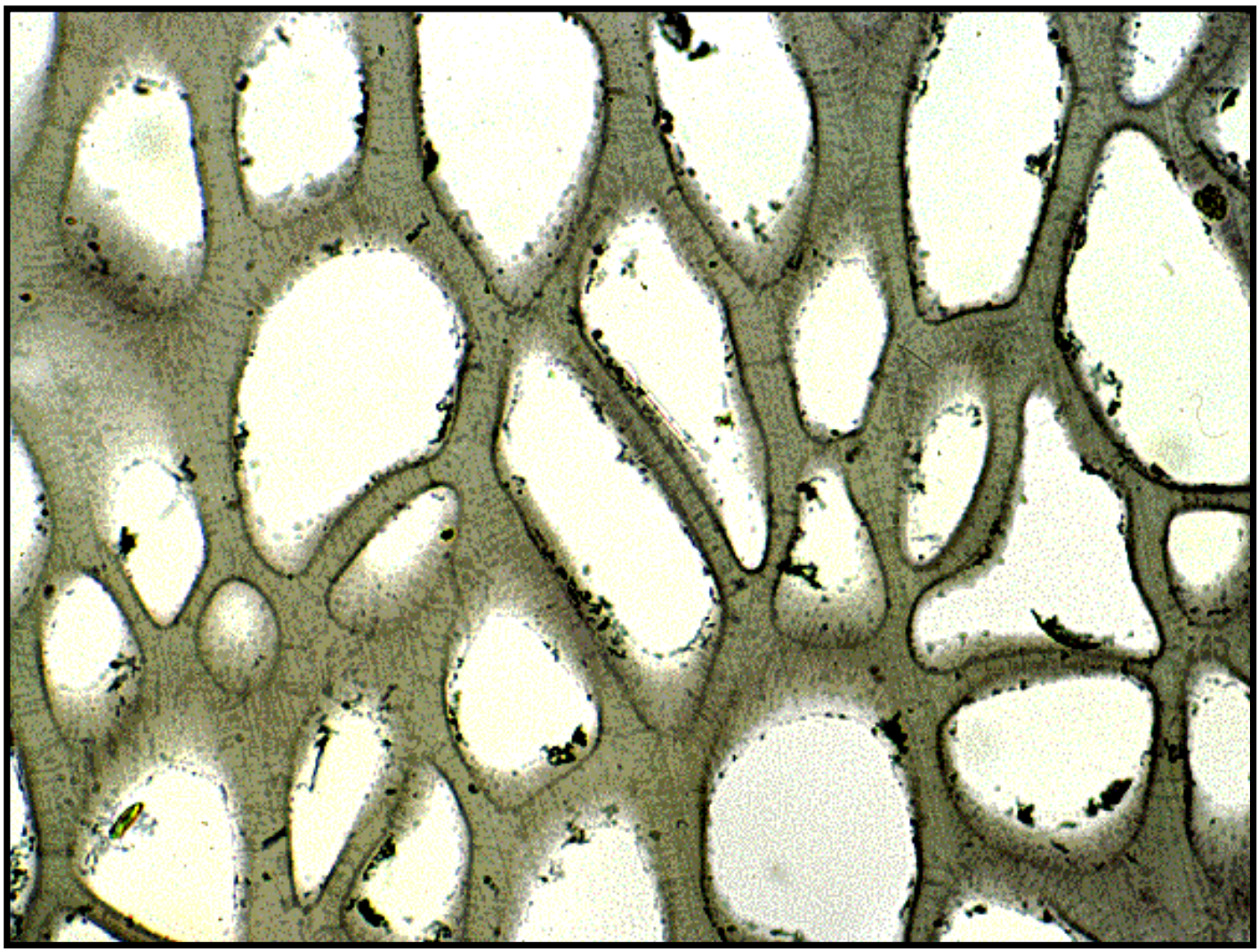
Storage parenchyma in bean cotyledon.

- The blue fibrillar material in protein.
- What is this tissue stained with?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Persimmon endosperm



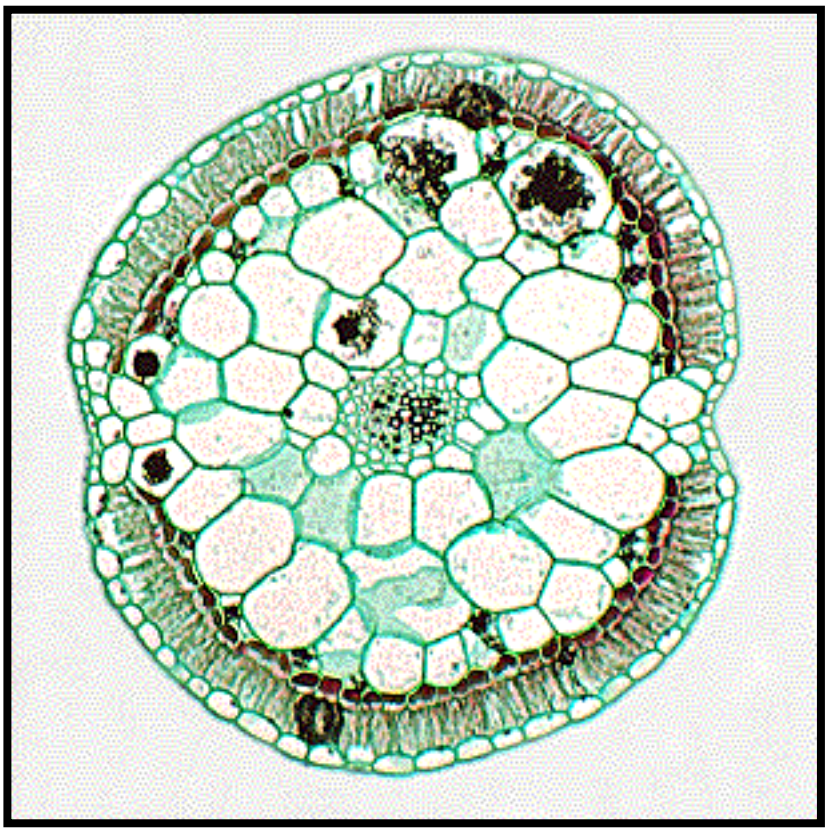
Persimmon endosperm.

- What material are the thick primary cell walls composed of?
- What is the function of this tissue?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Succulent leaf of tumble weed



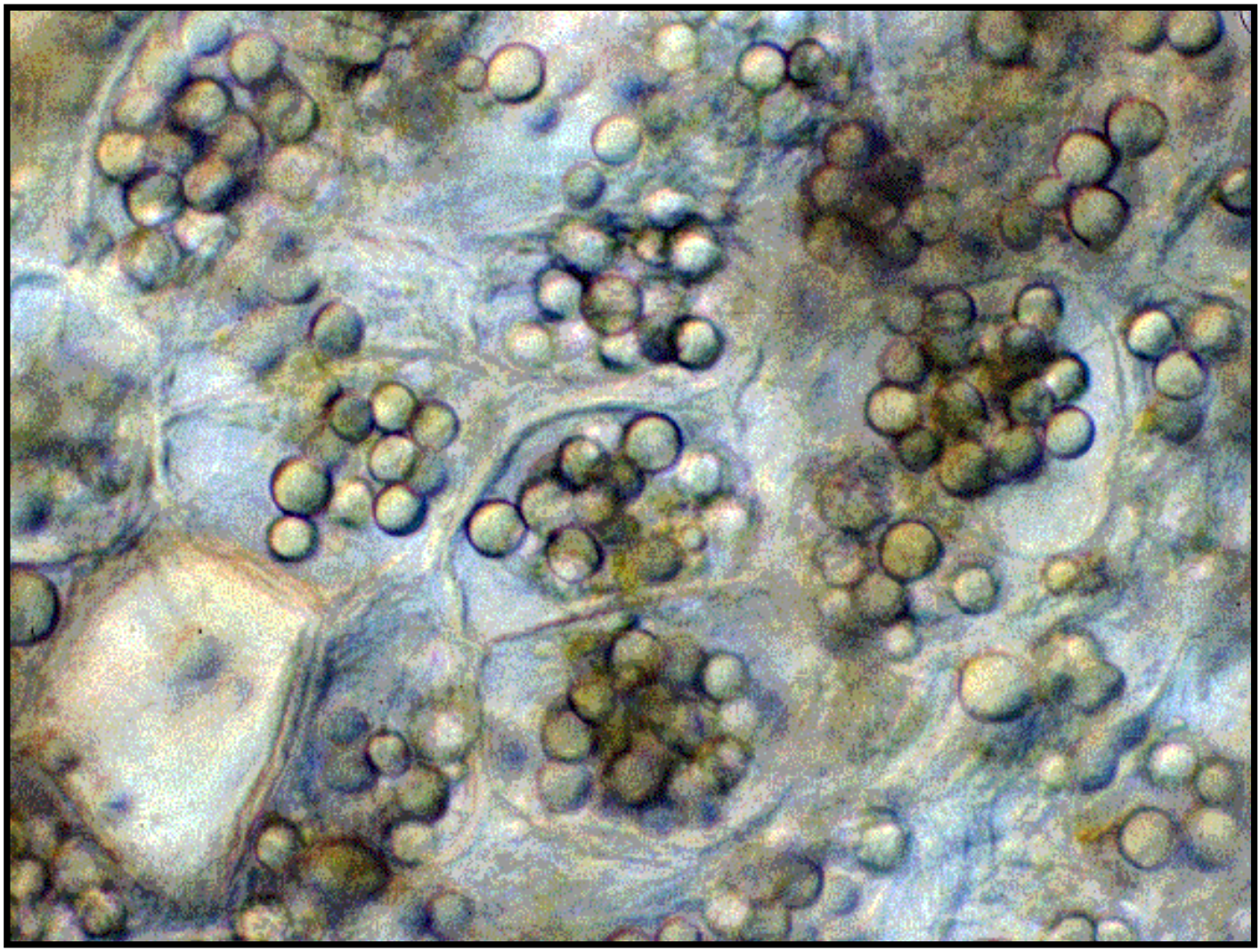
Succulent leaf of tumble weed.

- What is the name of the tissue that contains large cells?
- What is the function of this tissue?
- How does this tissue differ from aerenchyma?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Section of avocado fruit



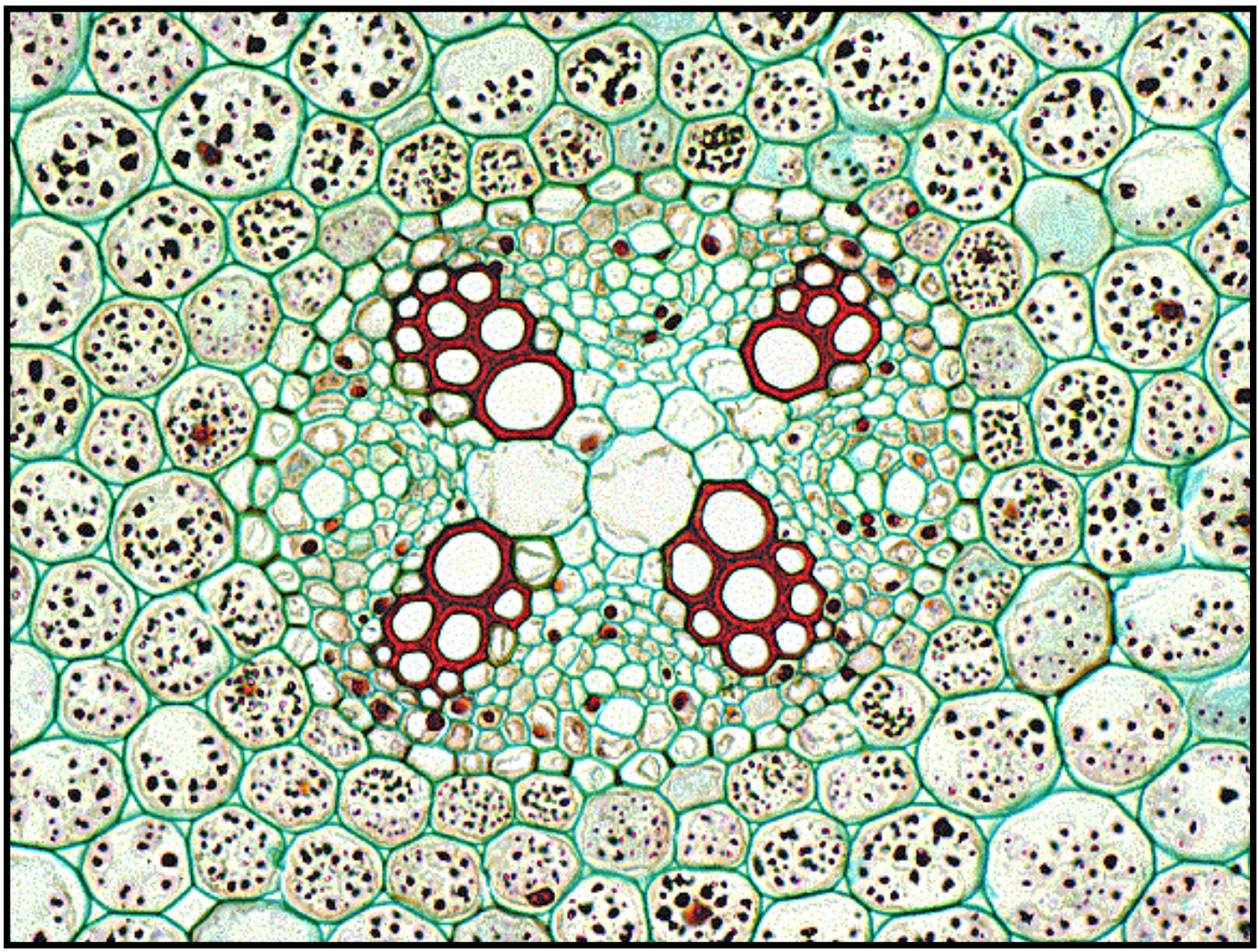
Section of avocado fruit.

- What is the function of the spherical structures in this tissue?
- How can they be distinguished from starch grains?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Cross section of *Ranunculus* root



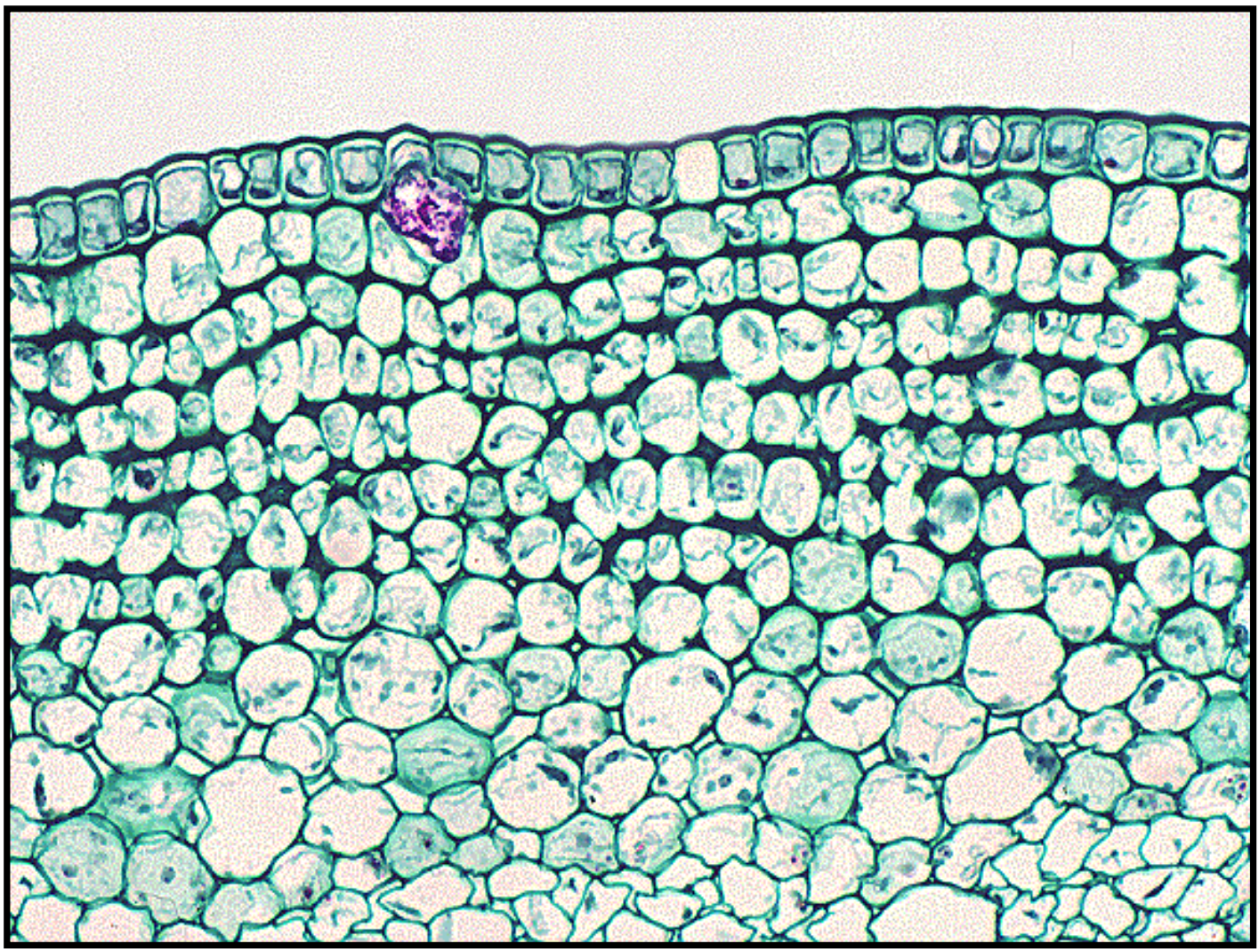
Cross section of *Ranunculus* root.

- Identify the endodermis.
- What is the Casparian strip?
- What is the function of the endodermis?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Cross-section of Castor bean stem



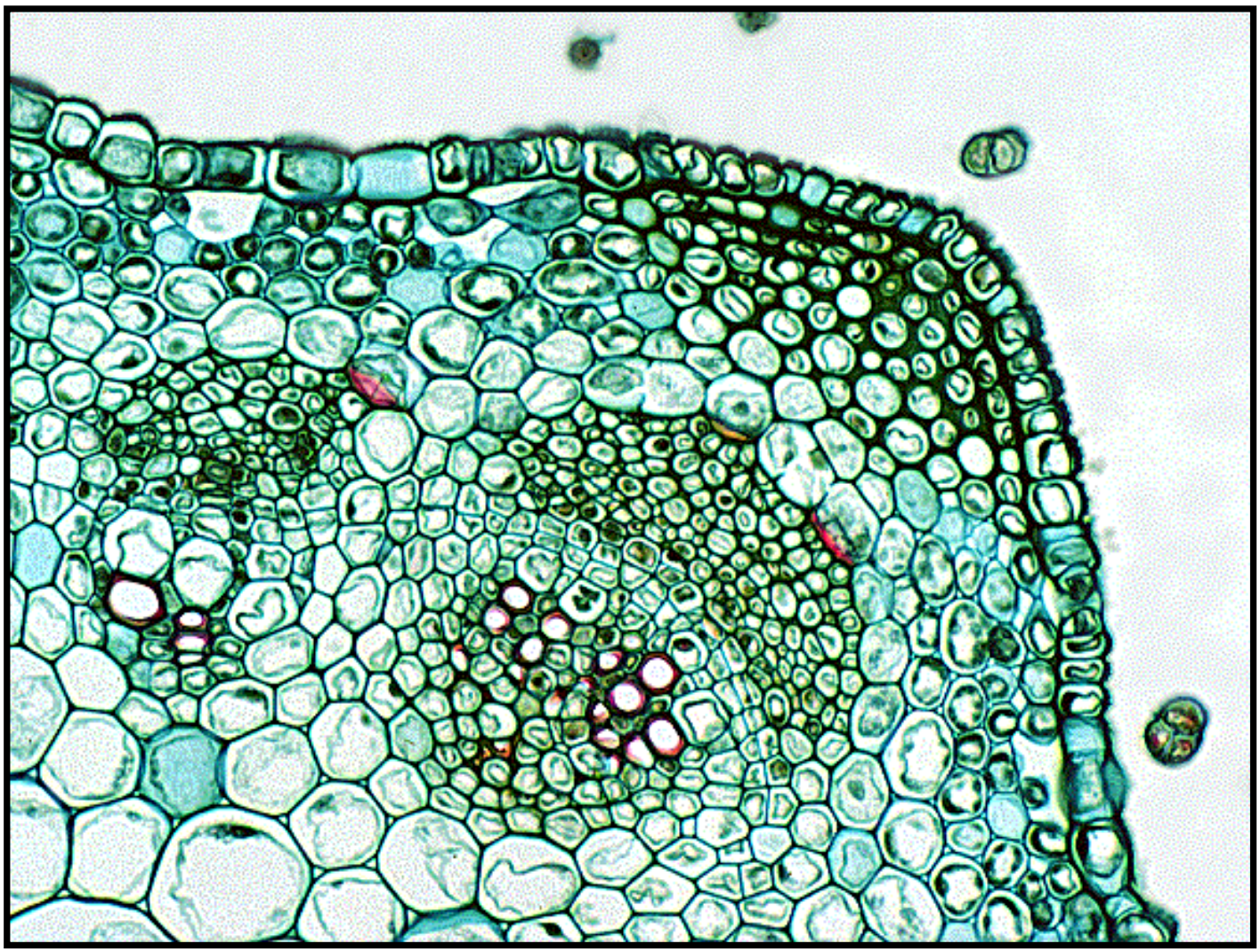
Cross-section of castor bean stem.

- What is the tissue just below the epidermis?
- What is the function of this tissue?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Bean stem cross section



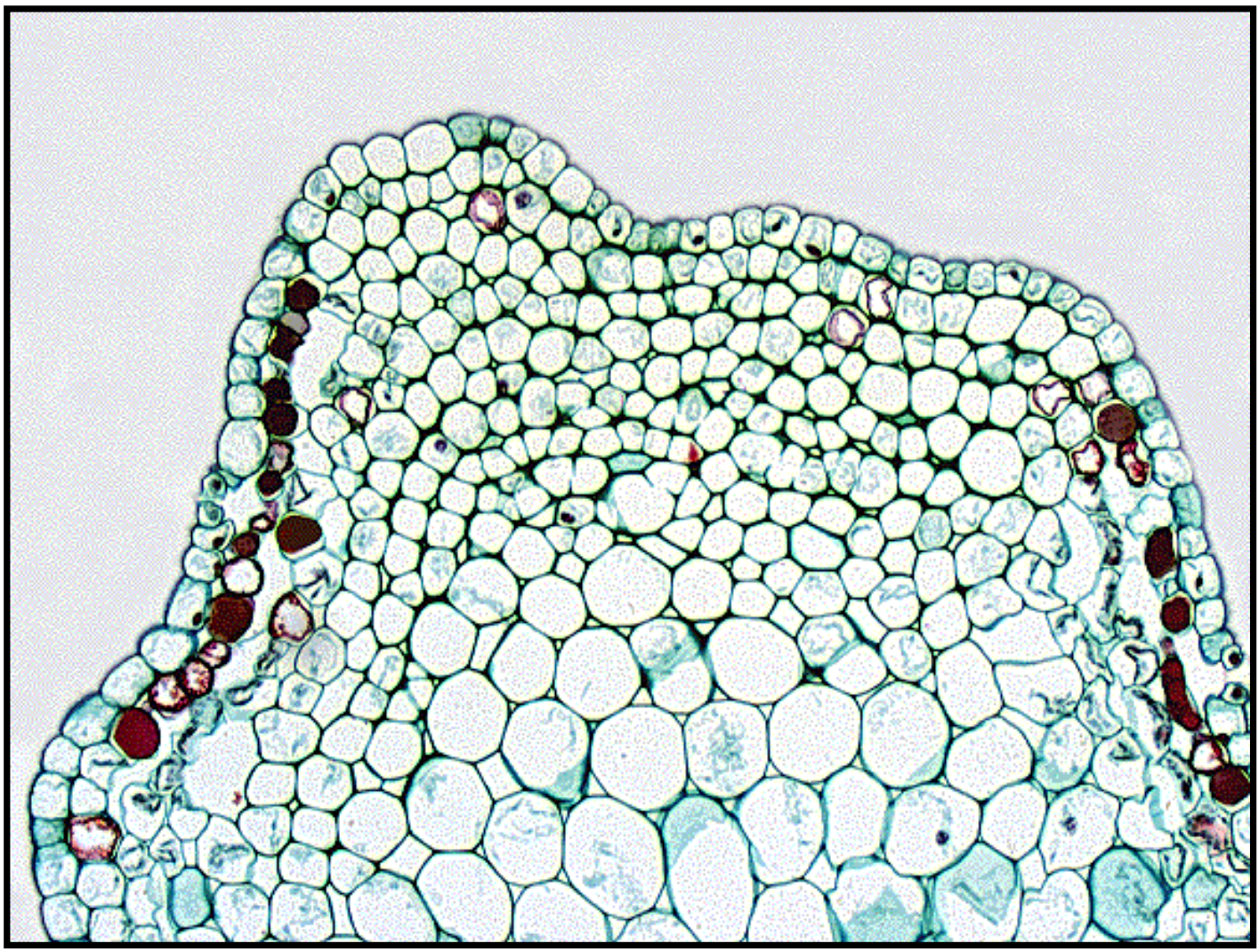
Bean stem cross section.

- Identify the collenchyma.
- How does the cell wall composition of collenchyma differ from that of fibers?
- How does the function of collenchyma differ from that of fibers?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Sambucus stem cross section



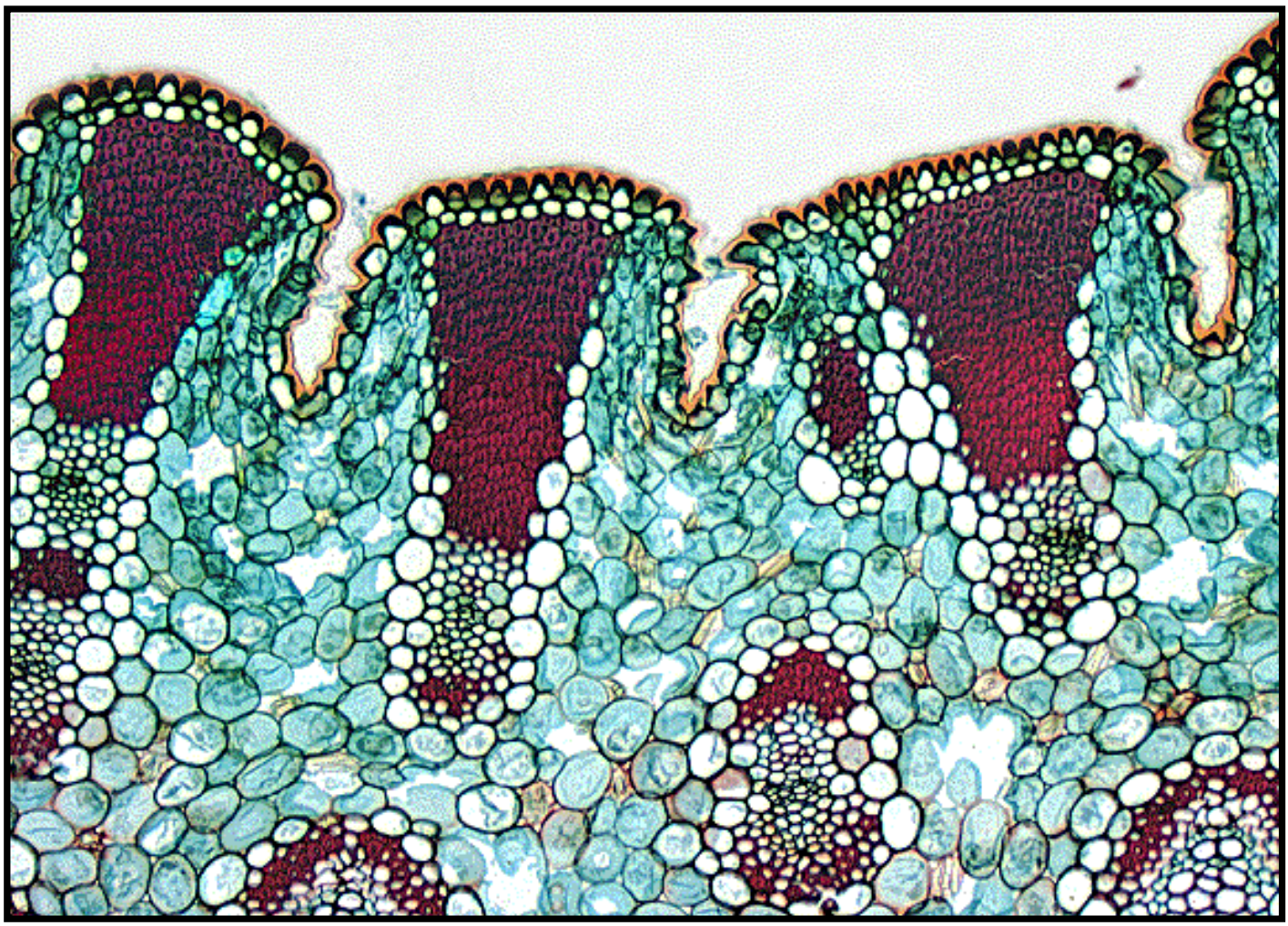
Sambucus stem cross section.

- Identify the collenchyma tissue.
- What characteristics distinguish collenchyma from parenchyma?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Extraxylary fibers in *Yucca* leaf



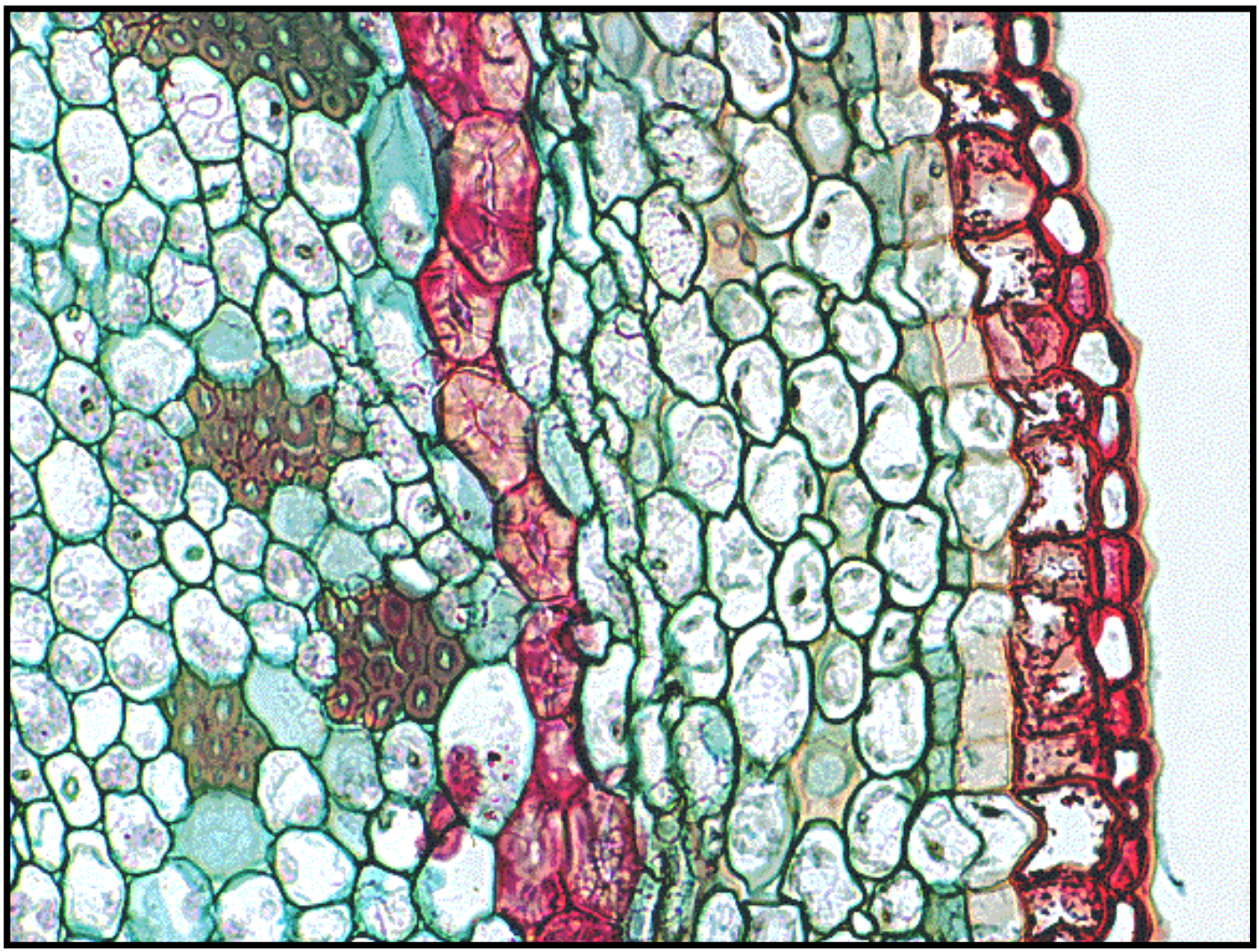
Extraxylary fibers in *Yucca* leaf stained with saffranin and fast green.

- What compound in the cell walls of fibers causes them to stain red?
- How would you expect the fibers to look if they had been stained with phloroglucinol?
- How would you expect the fibers to look if they had been stained with toluidine blue?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Cross-section of *Hoya* stem



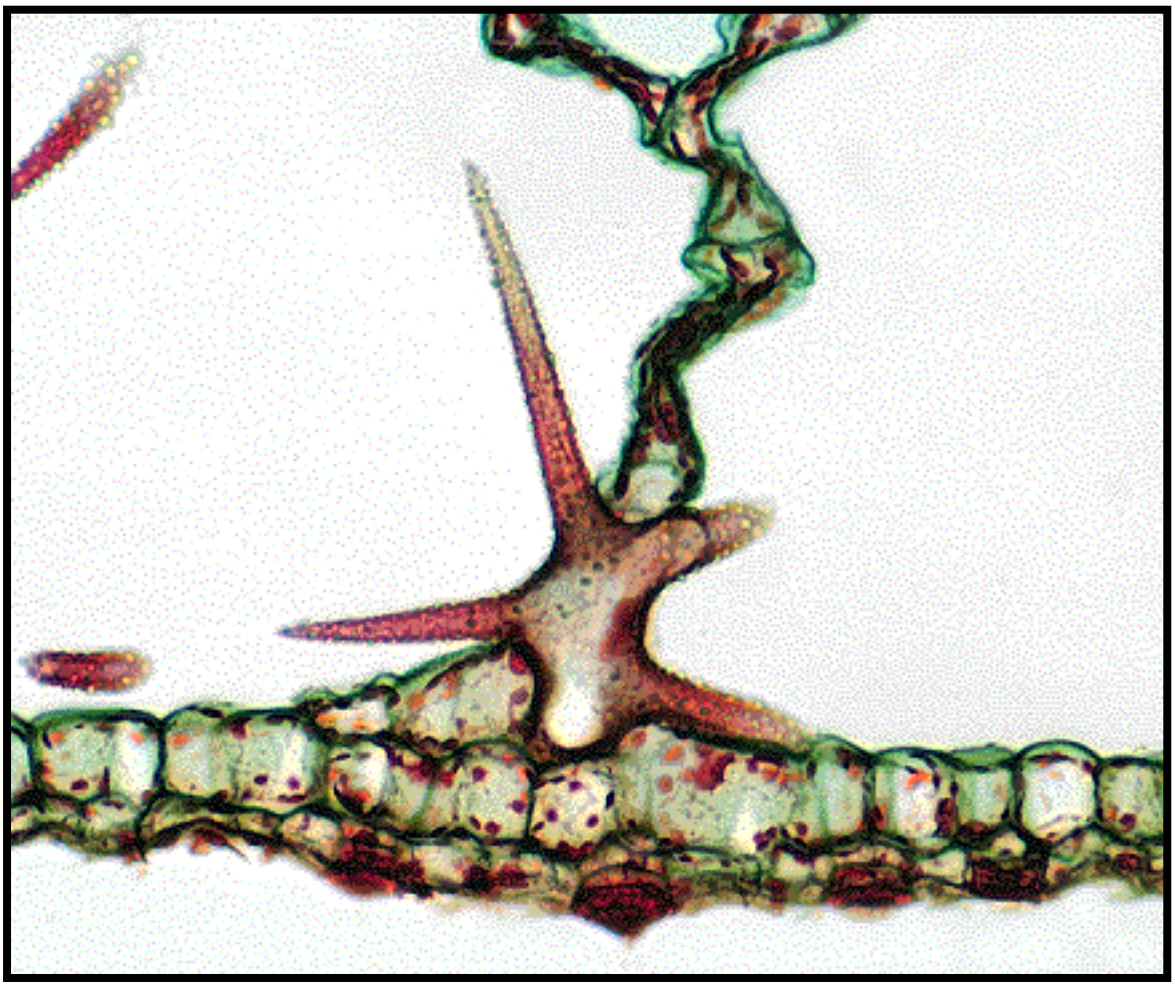
Cross-section of *Hoya* stem.

- Identify extraxylary fibers and sclereids in this slide.
- How would these two cell types differ if viewed in longitudinal section?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Cross-section of *Castalia* leaf



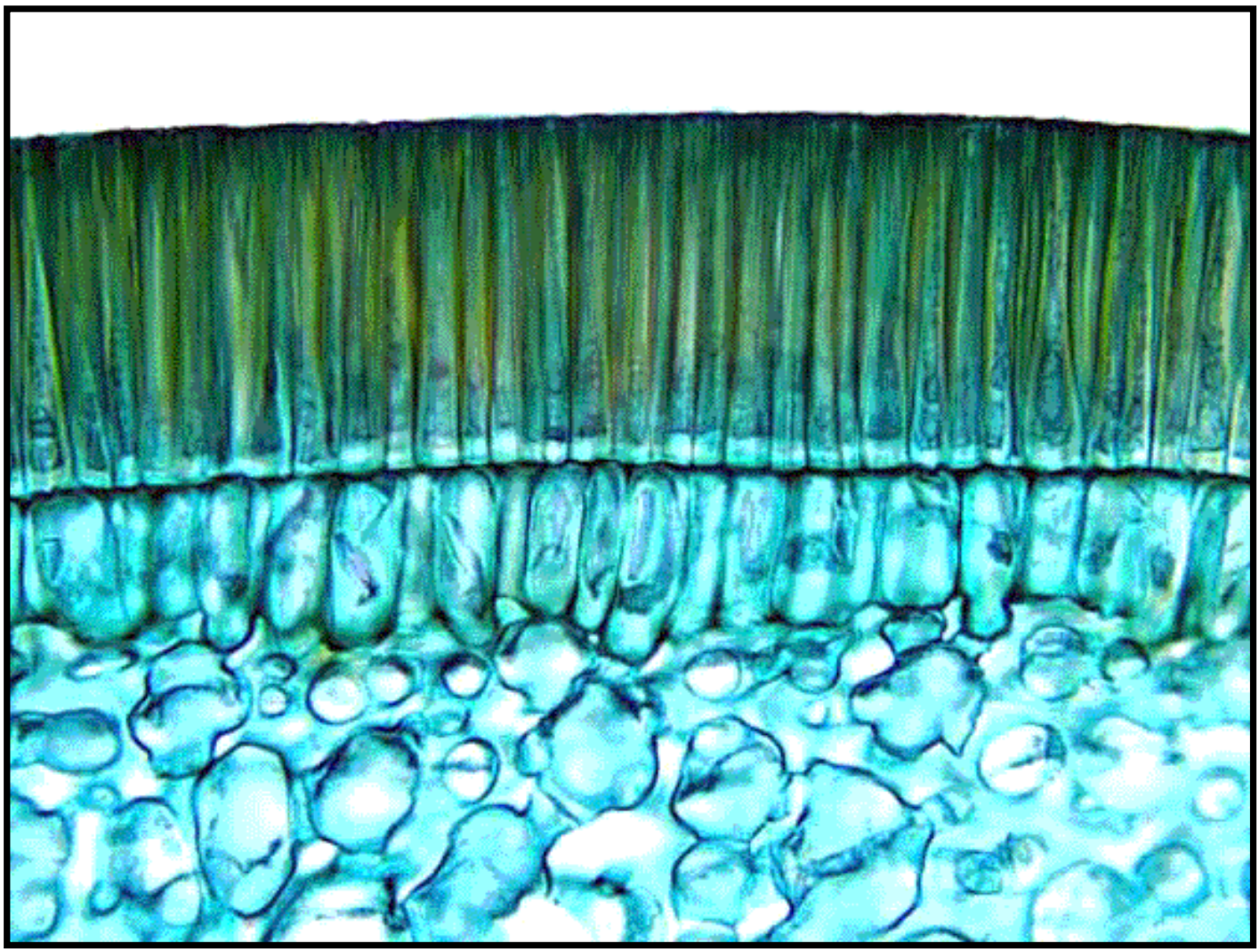
Cross-section of *Castalia* leaf.

- What is the name for the cell with long projections?
- What is its function?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Phaseolus (bean) seed coat



Cross section of the seed coat of a bean. Macrosclereids form the surface layer with an underlying layer of osteosclereids.

- What is the function of these sclereids?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Maceration of bean seed coat

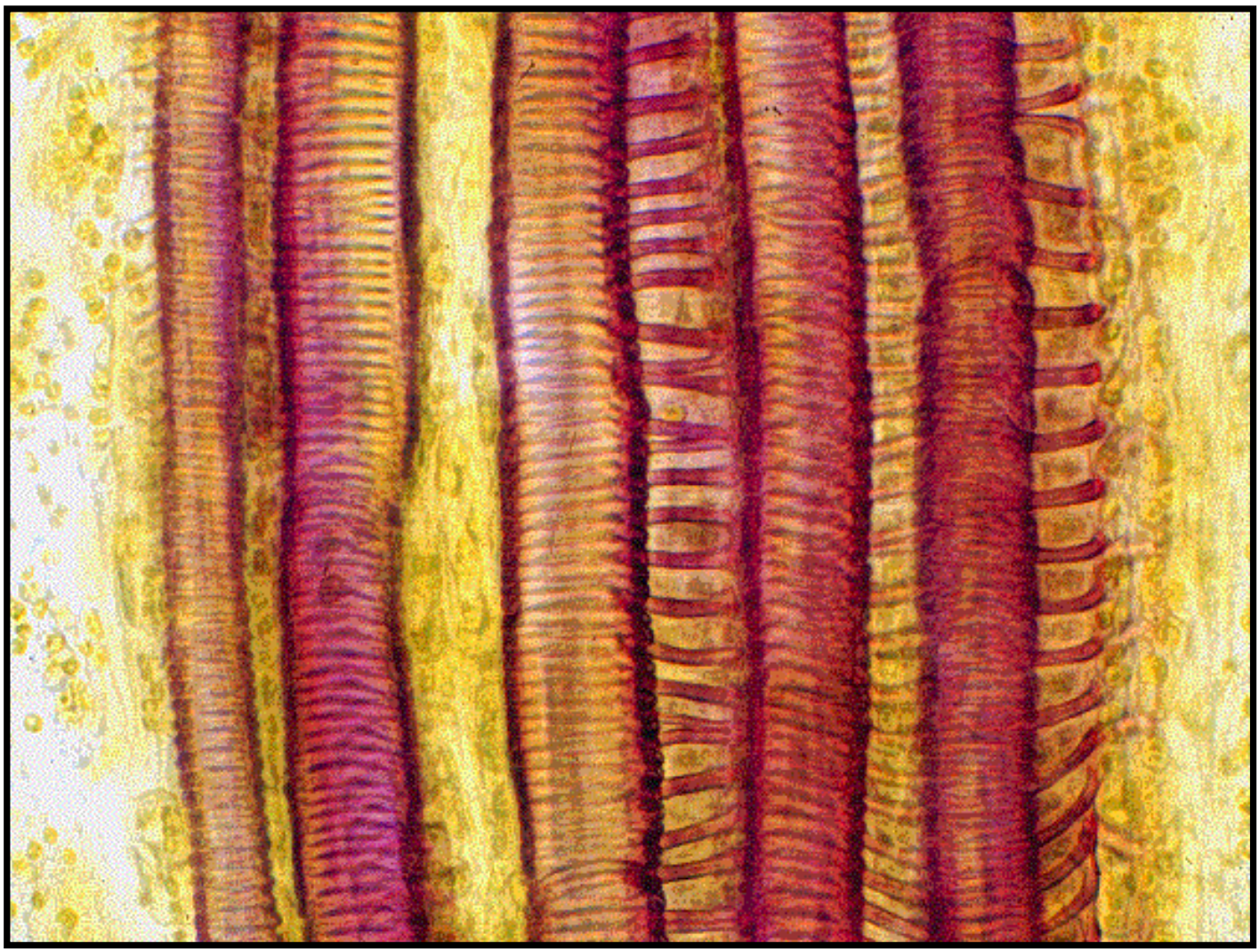
Maceration of bean seed coat.

- Identify macrosclereids and osteosclereids.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Vascular bundle from *Zinnia* stem



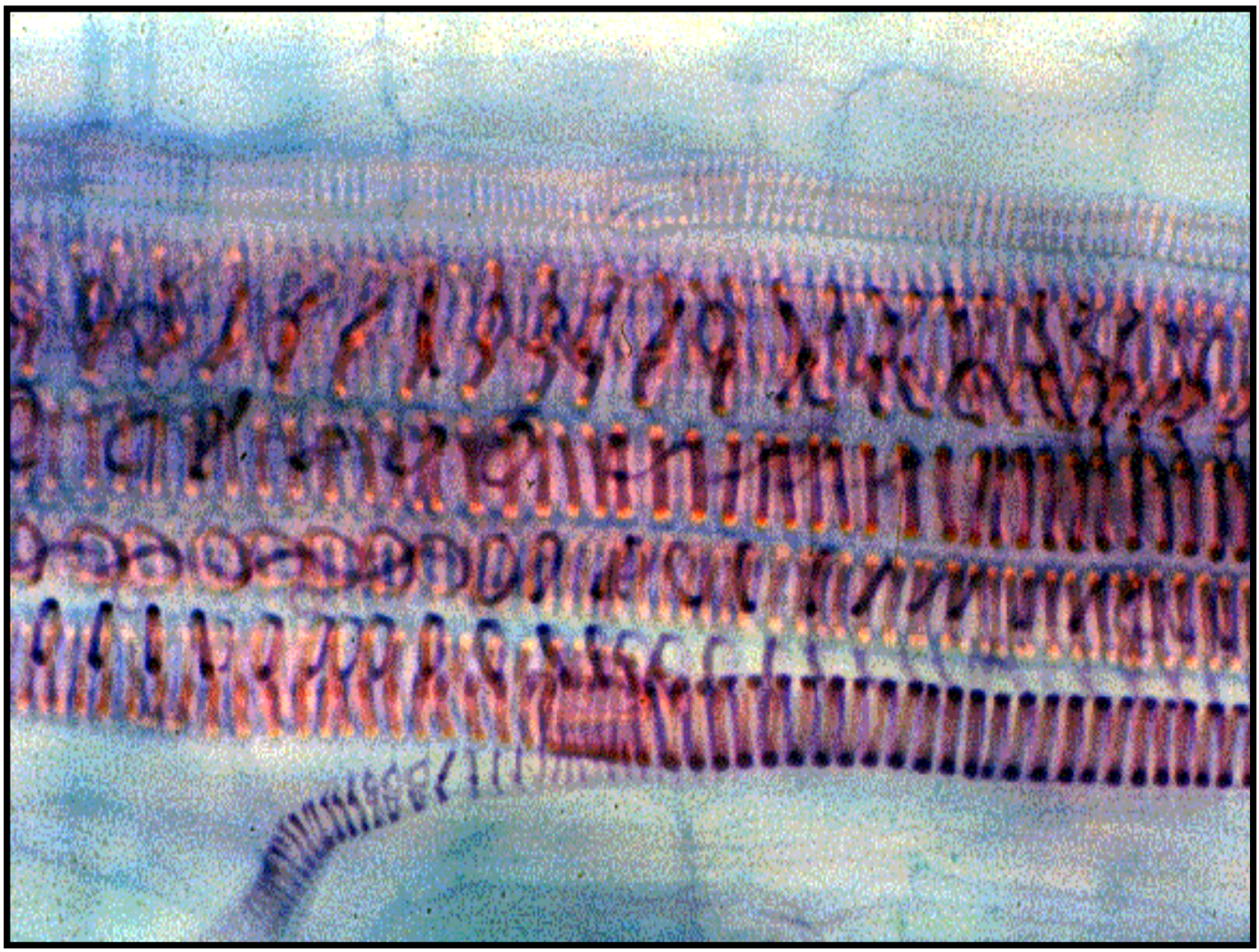
Squashed vascular bundle from *Zinnia* stem stained with phloroglucinol.

- How many different patterns of secondary cell wall reinforcement can you identify?
- Are there other types that are not shown here?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Major vein in cleared *Zinnia* leaf



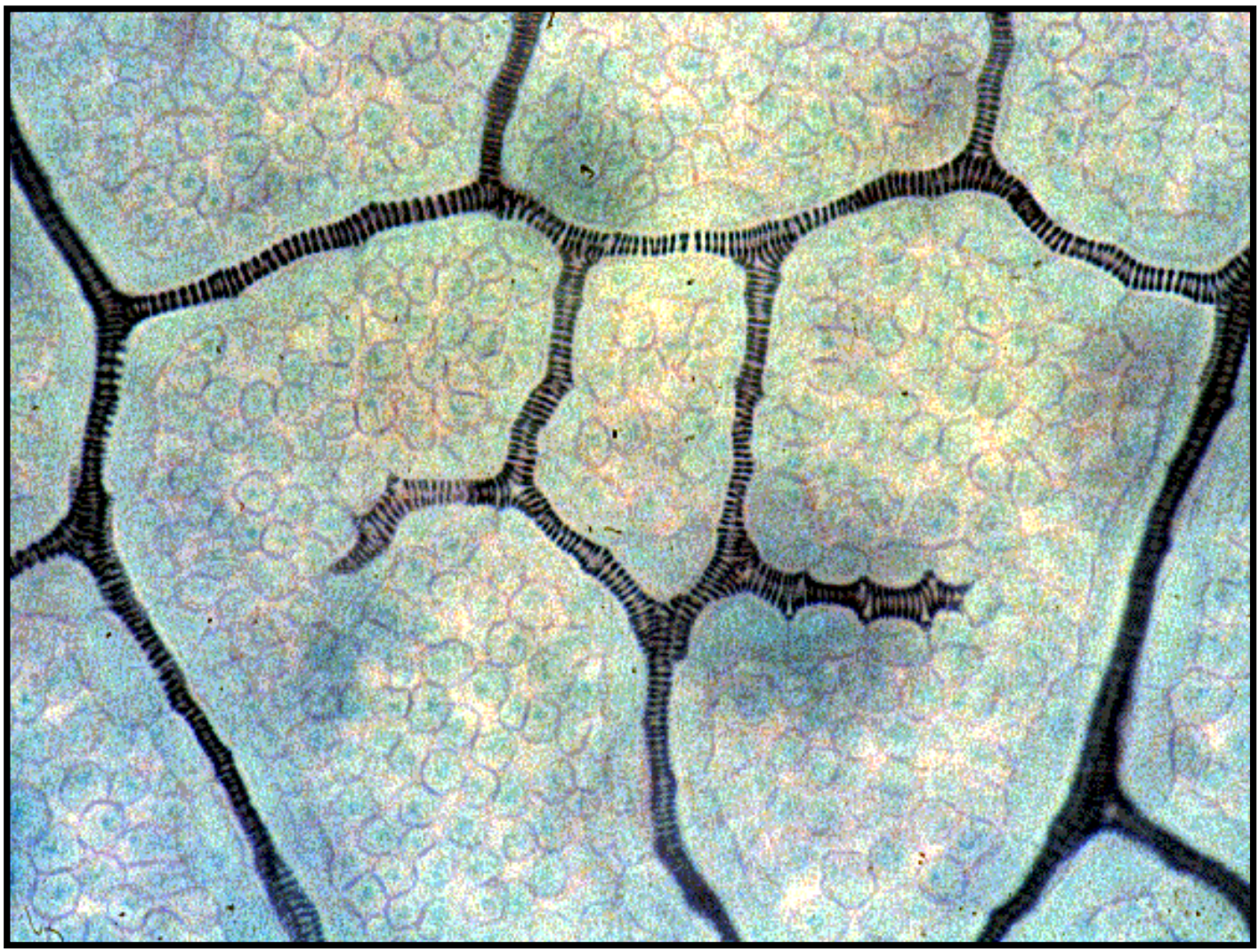
Major vein in cleared *Zinnia* leaf.

- What does the appearance of the vessels tell you about the relative timing of leaf expansion and vascular differentiation?

Related images: Minor vein in cleared *Zinnia* leaf

Alison Roberts (awrobrts@uriacc.uri.edu)

Minor vein in cleared *Zinnia* leaf



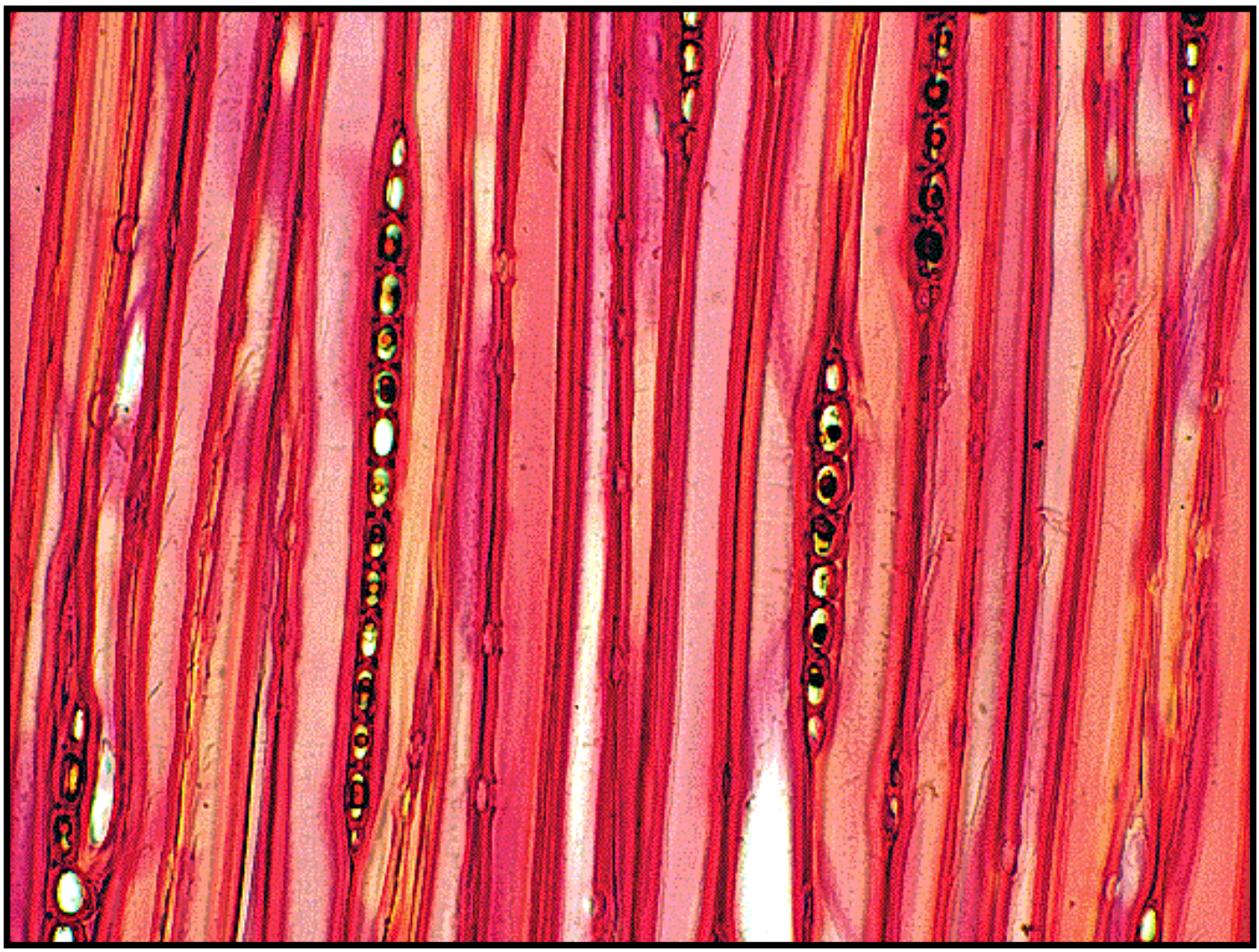
Minor vein in cleared *Zinnia* leaf.

- Identify individual tracheary elements.

Related images:Major vein in cleared *Zinnia* leaf

Alison Roberts (awrobrts@uriacc.uri.edu)

Pine tracheids



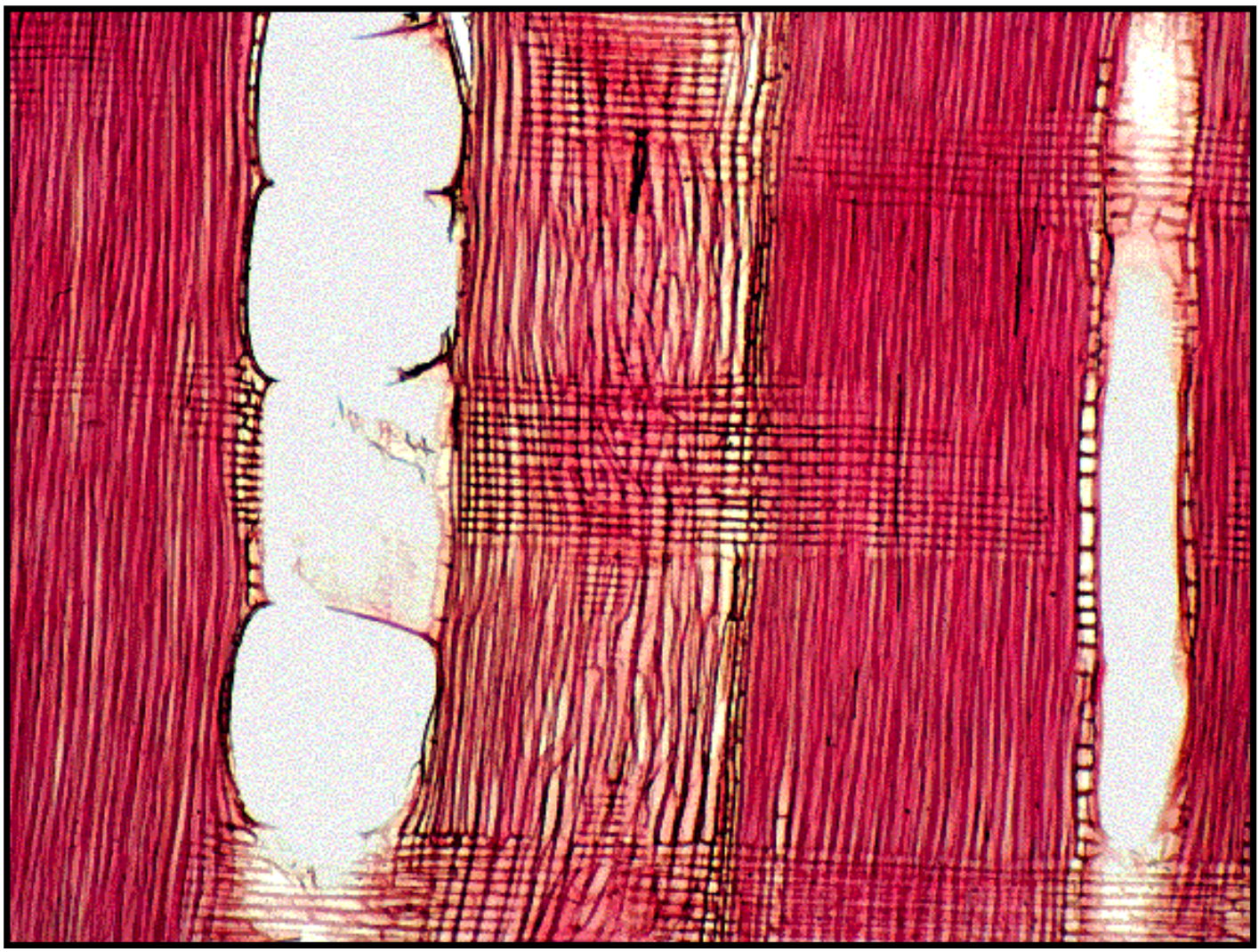
Tracheids from pine, a gymnosperm.

- Identify pits and notice the cell shape.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Large vessel in ash wood



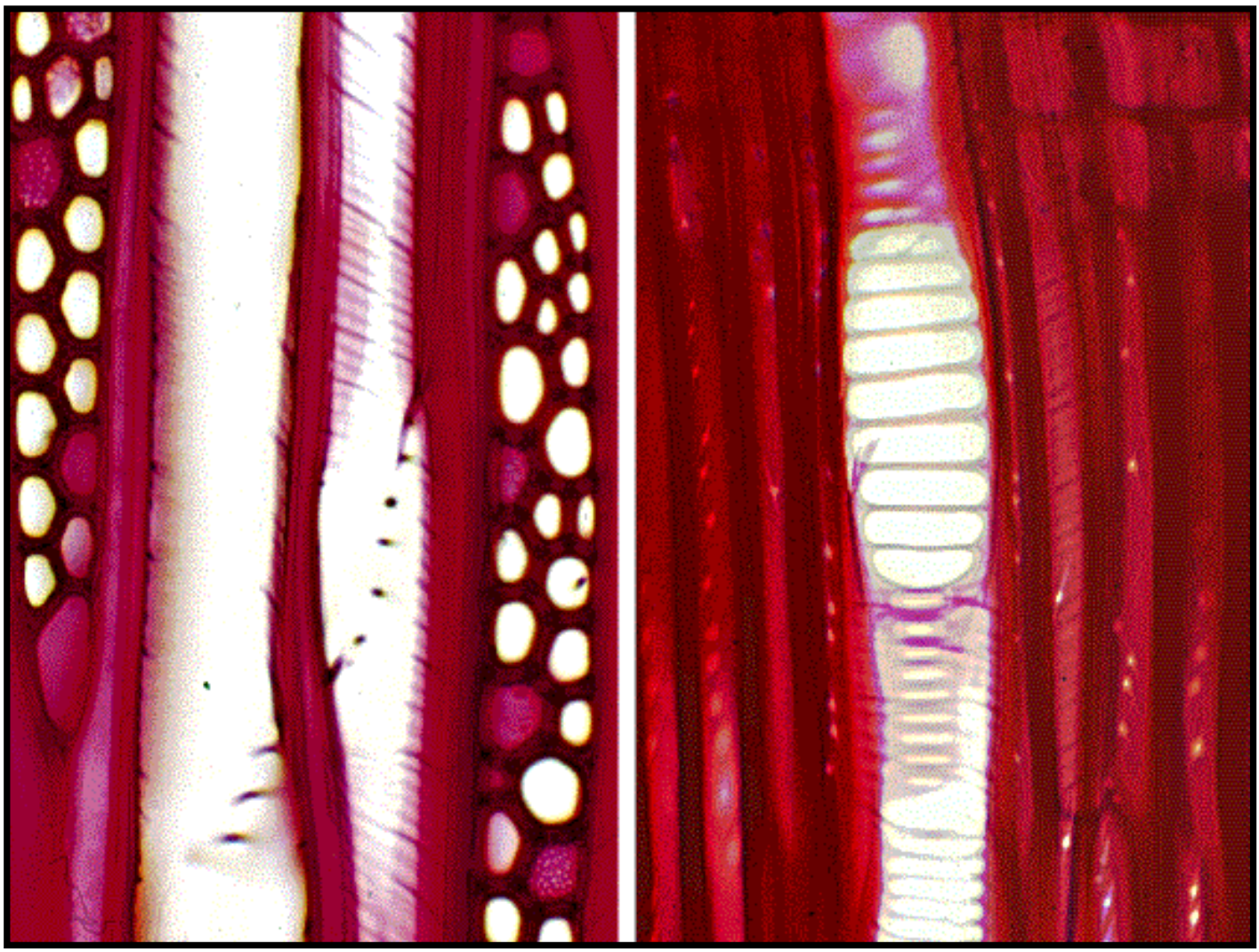
Large vessel in ash wood showing several vessel elements.

- Identify perforation plates. What type are they?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Liriodendron vessel elements



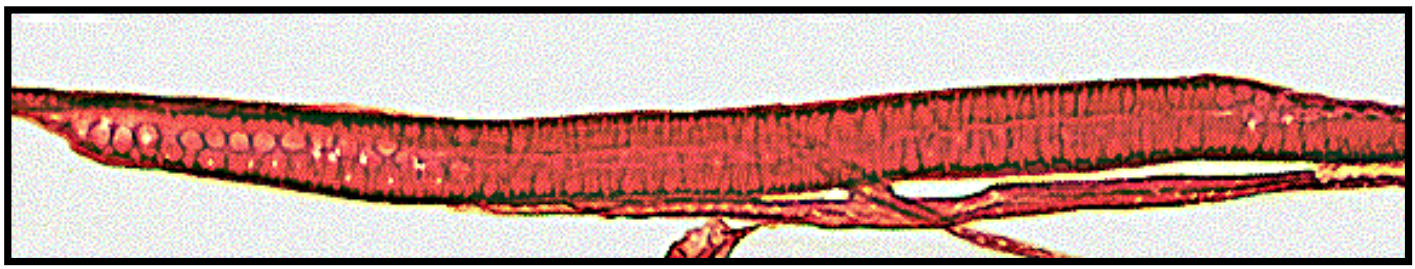
Vessel elements of *Liriodendron* sectioned in two different planes.

- What is the perforation plate type?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Ephedra vessel element



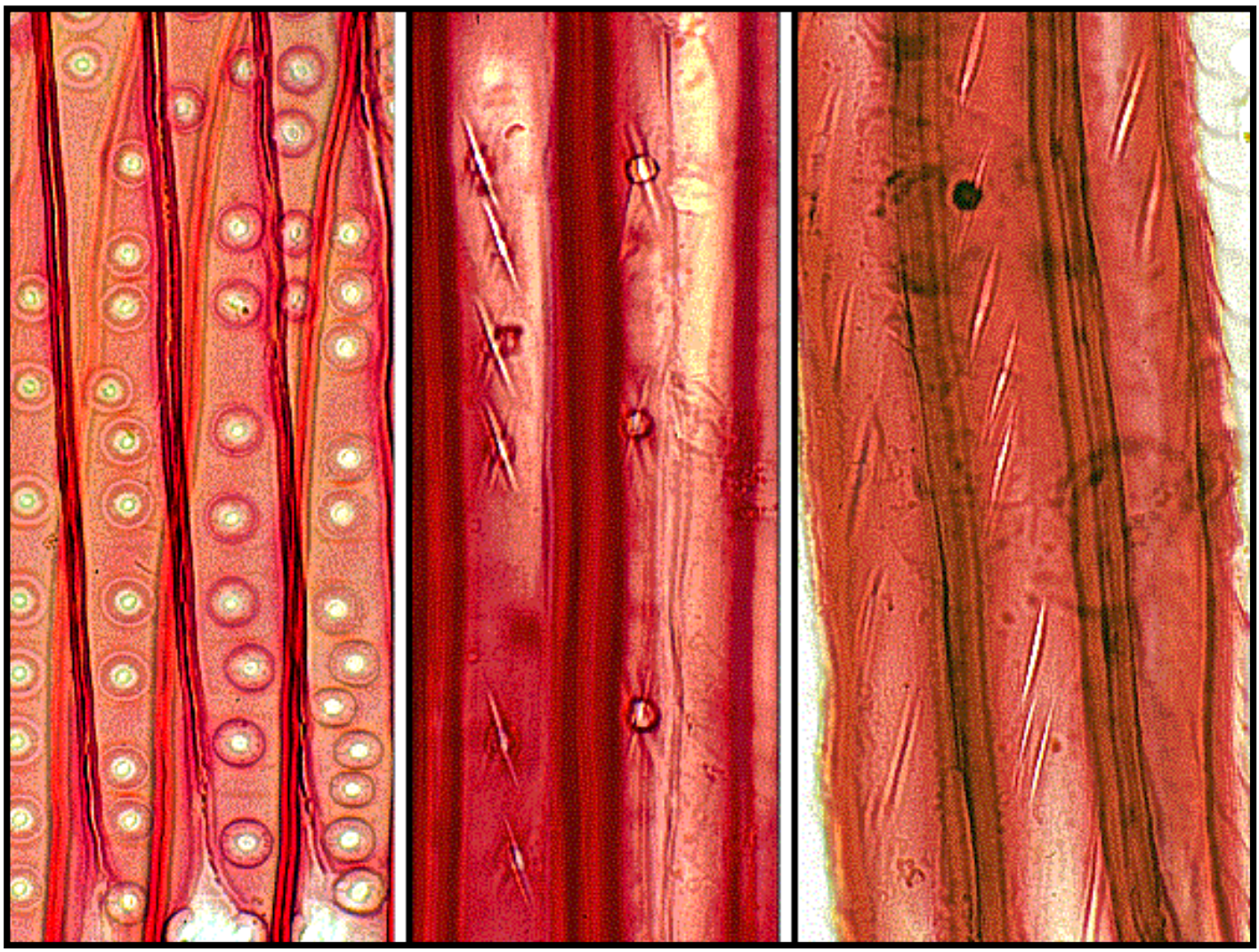
Vessel element from *Ephedra*, an unusual gymnosperm. These vessels have foraminate perforation plates.

- Locate the perforations.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Tracheids, fiber tracheids, and xylary (libriform) fibers



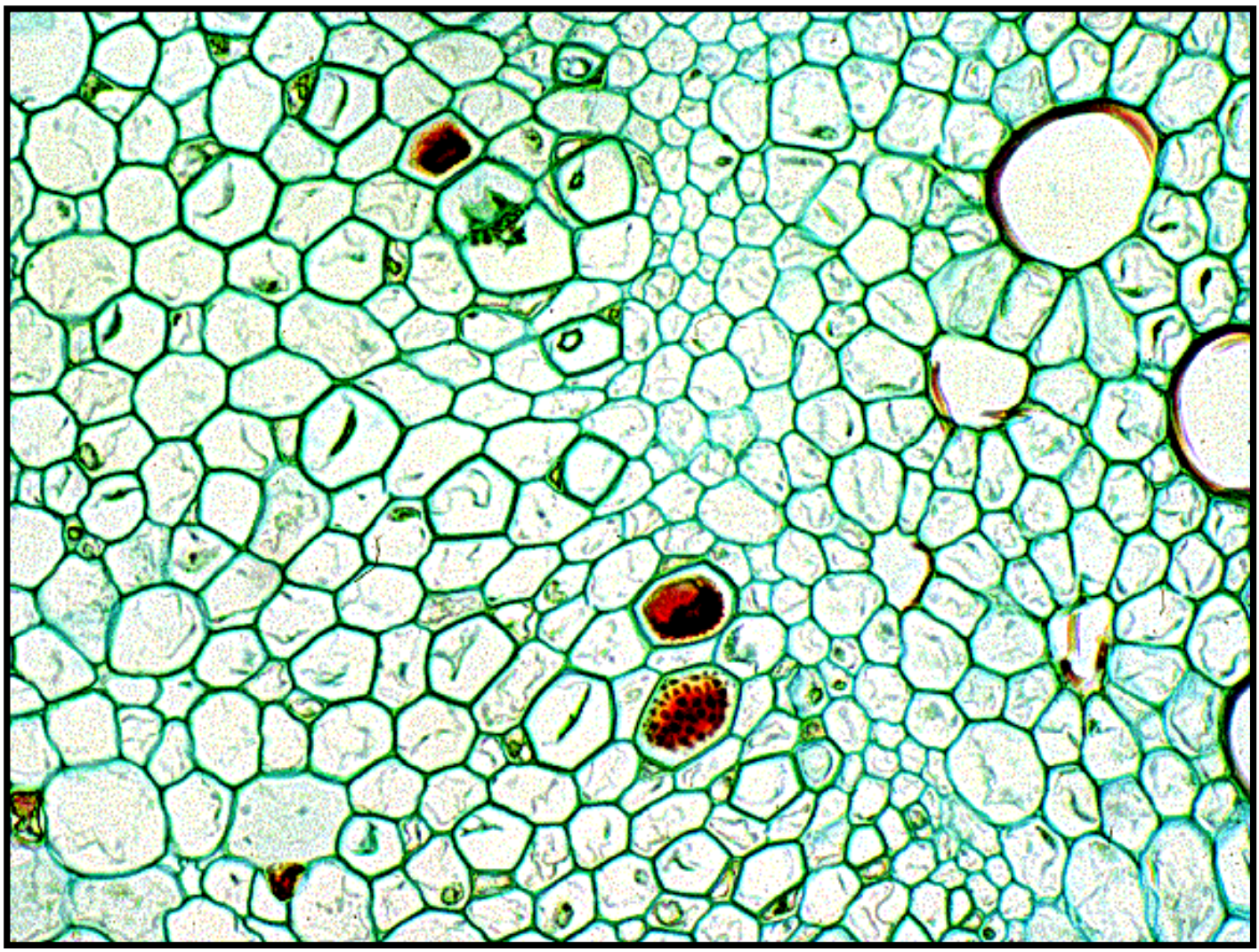
Tracheids, fiber tracheids, and xylary (libriform) fibers.

- Identify pits. How can you distinguish these cell types?
- How do xylary fibers differ from extraxylary fibers?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Cross section of *Cucurbita* phloem



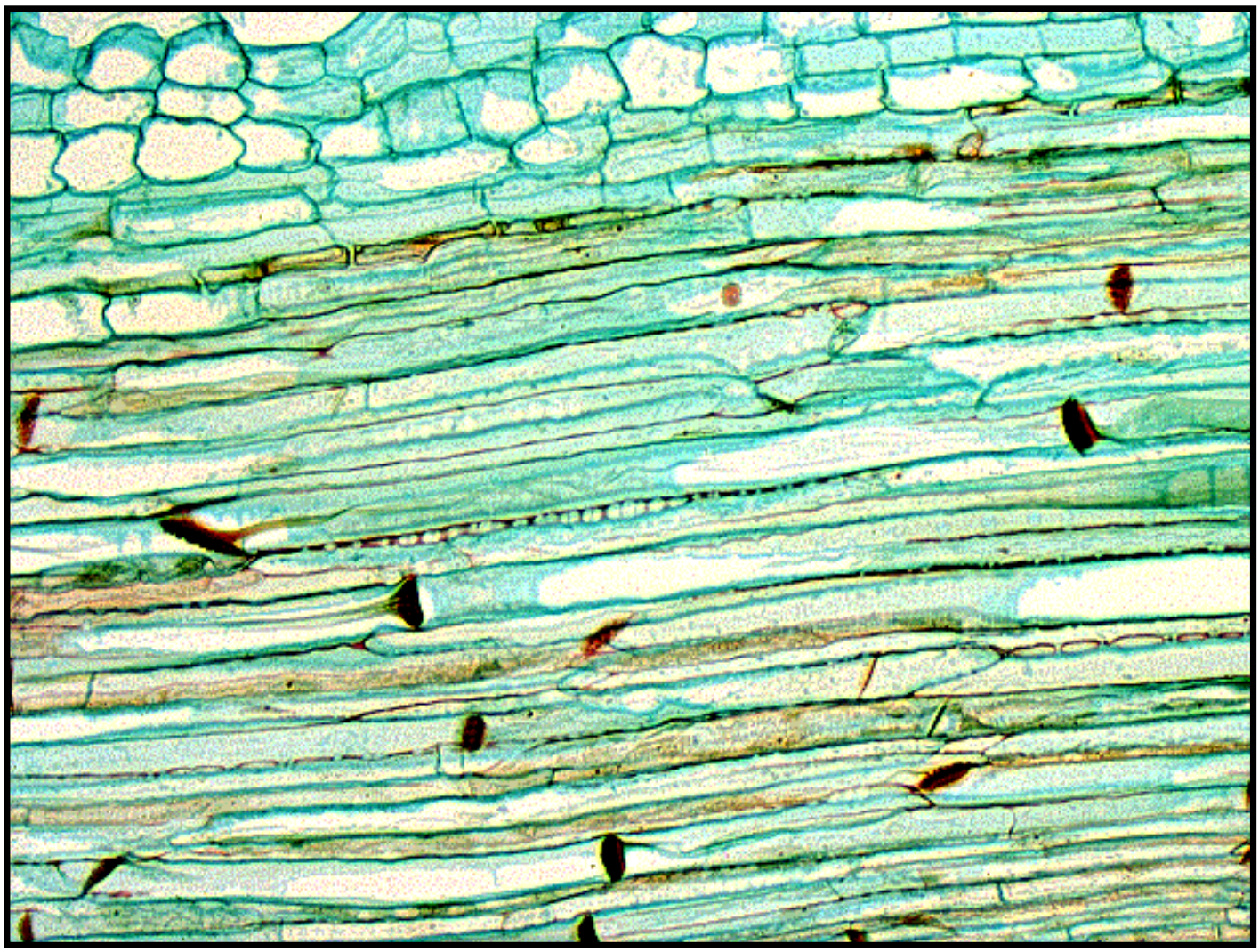
Cross section of *Cucurbita* phloem.

- Identify sieve plate, sieve tube elements, companion cells and p-protein.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Longitudinal section of *Cucurbita* phloem



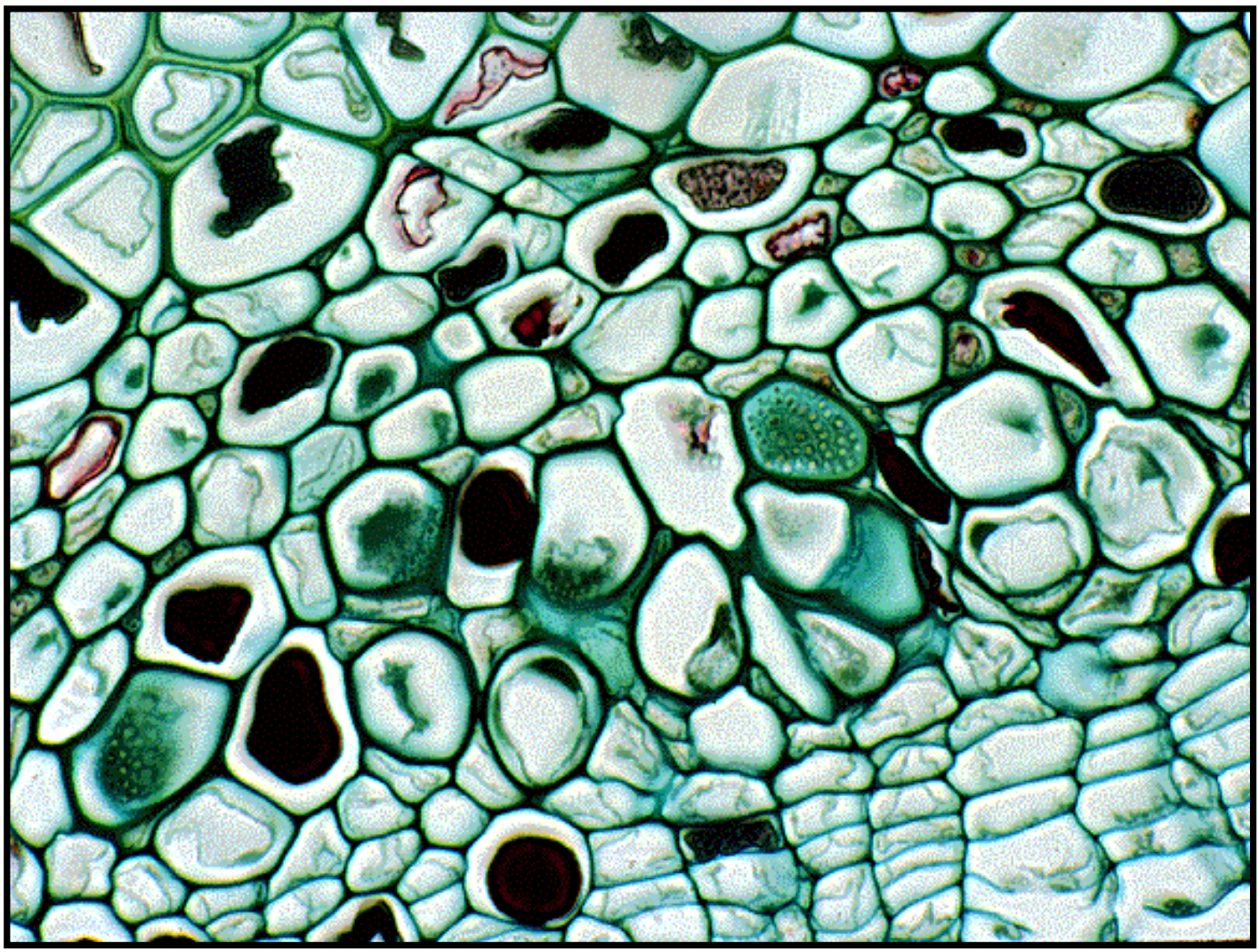
Longitudinal section of *Cucurbita* phloem.

- Identify sieve plate, sieve tube elements, companion cells and p-protein.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Cross section of *Vitis* phloem.



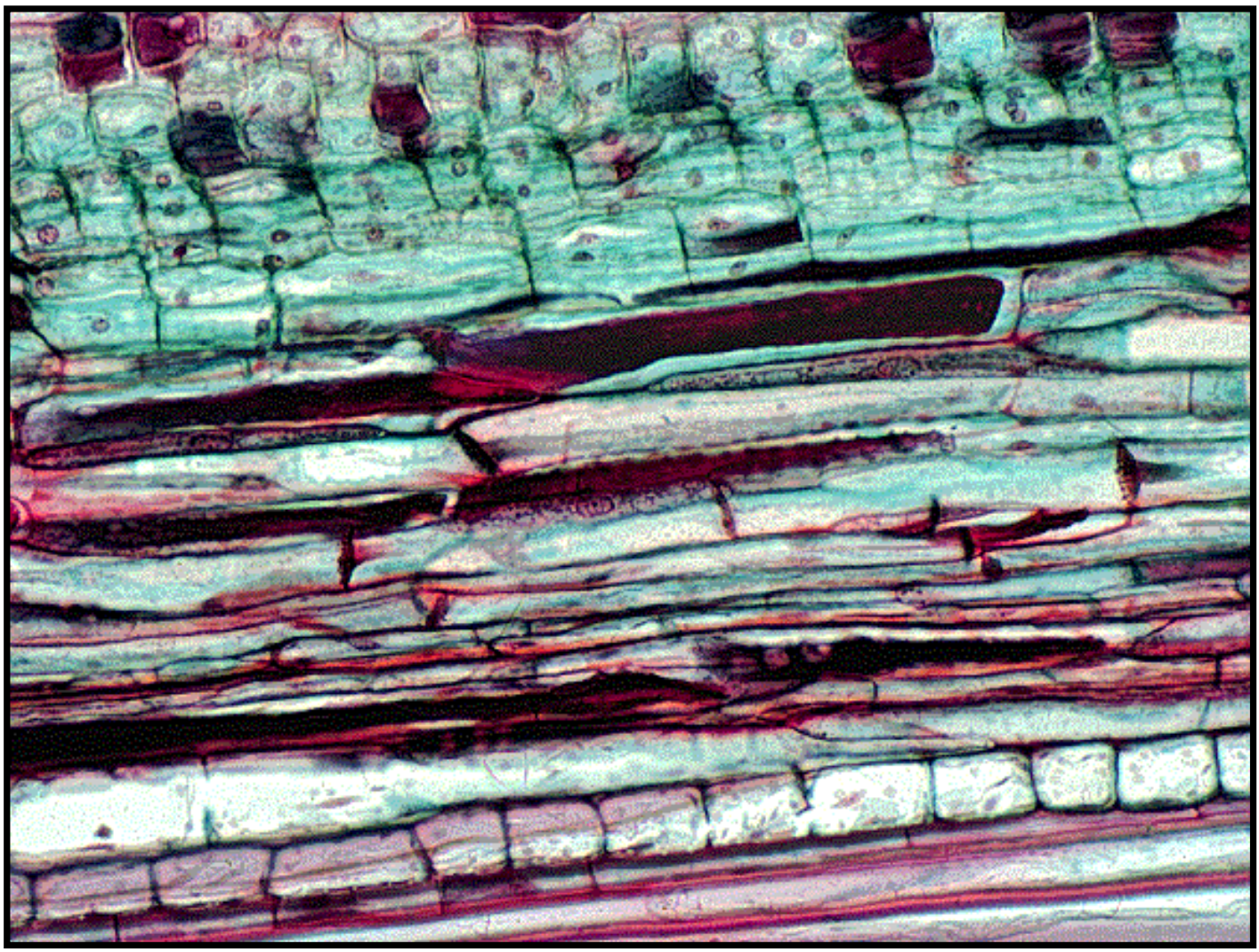
Cross section of *Vitis* (grape) phloem.

- Identify sieve plate, sieve tube elements, companion cells and p-protein.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Longitudinal section of *Vitis* phloem



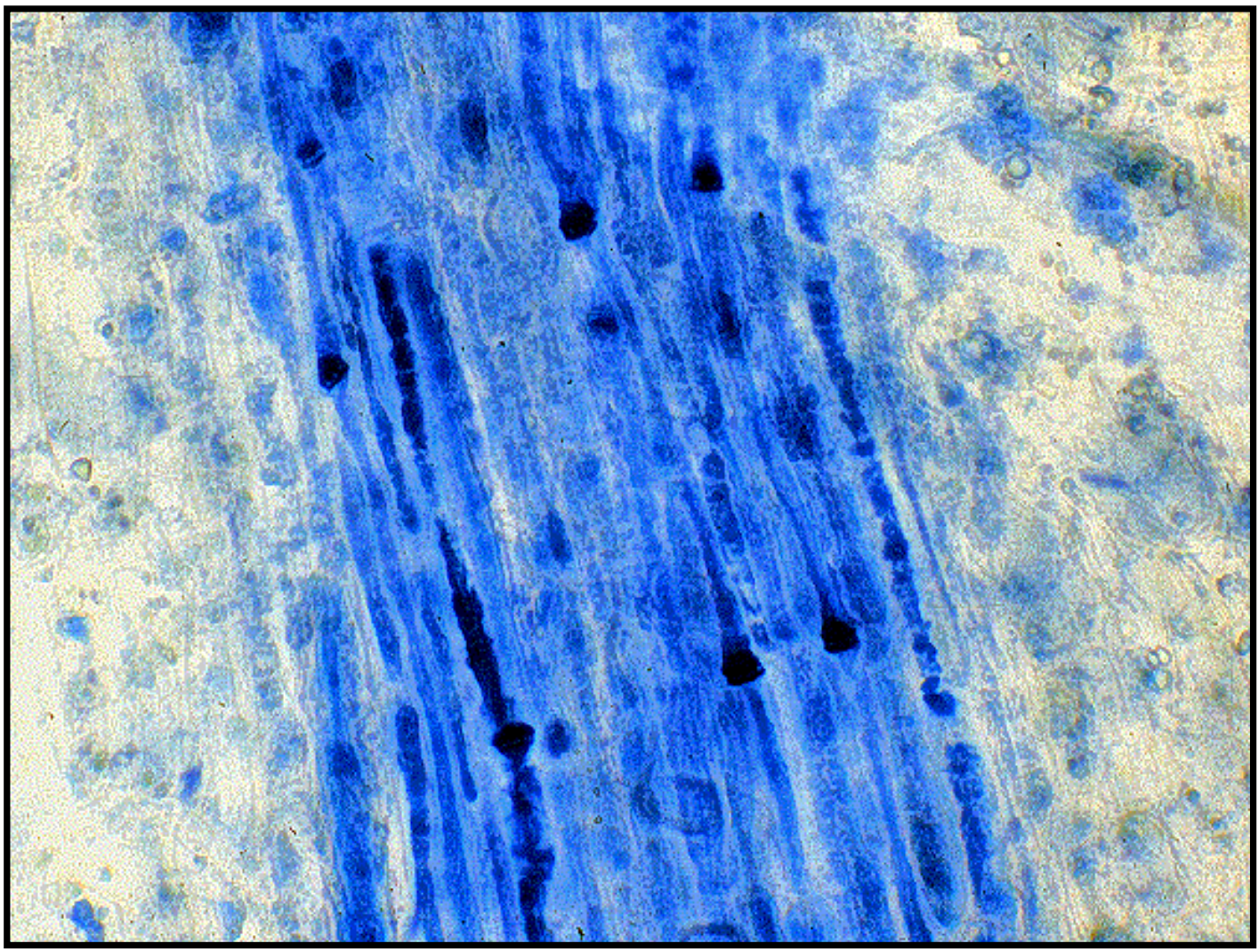
Longitudinal section of *Vitis* (grape) phloem.

- This plant has compound sieve plates, although you can't tell from this picture.
- Identify sieve plates, sieve tube elements, companion cells and slime plug.
- What stain did we use in lab to identify sieve plates in fresh material? What compound is this stain specific for?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Sieve elements of *Cucurbita*



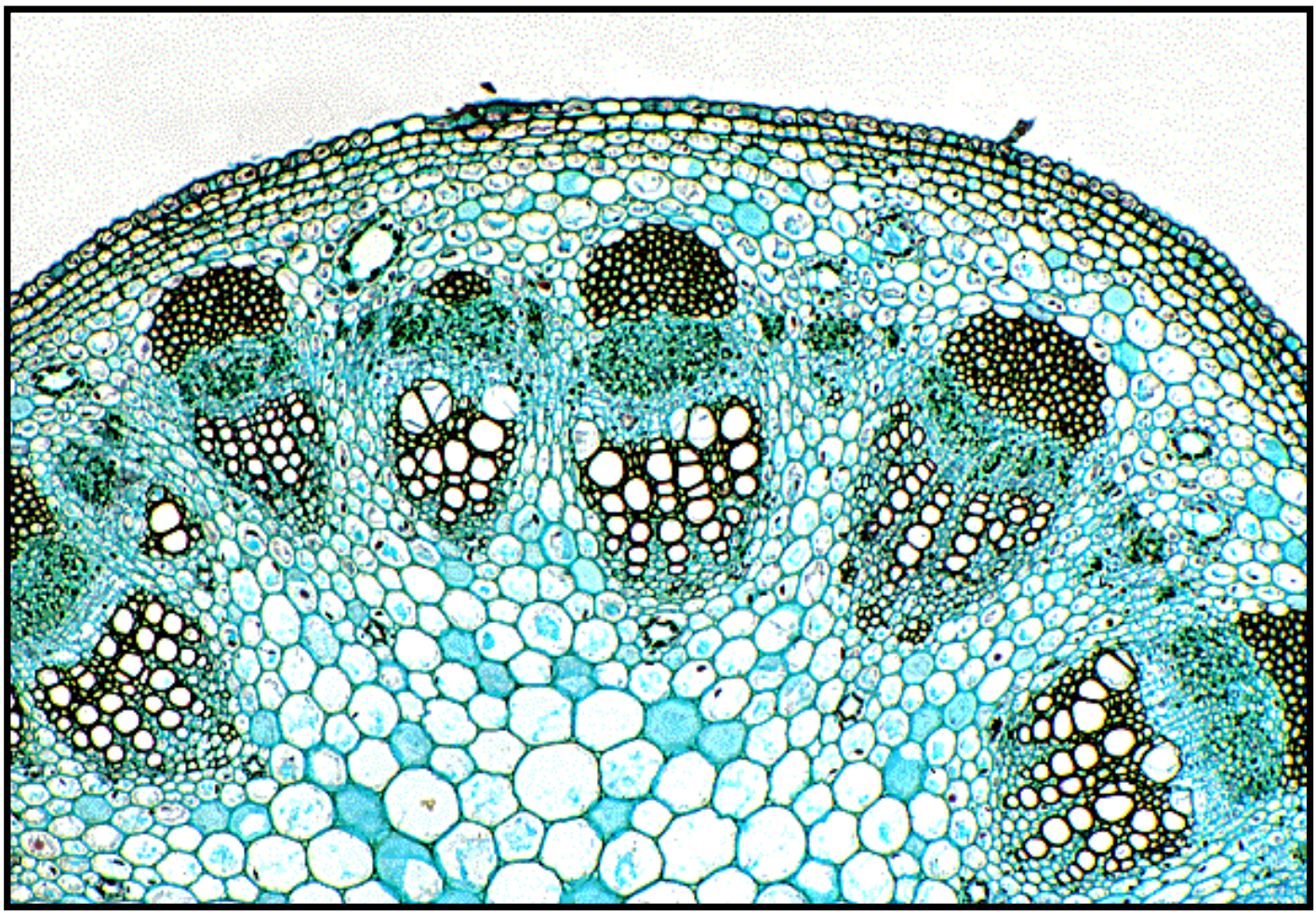
Sieve elements of *Cucurbita* stained with IKI and aniline blue.

- What compounds are these stains used to demonstrate?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Helianthus*



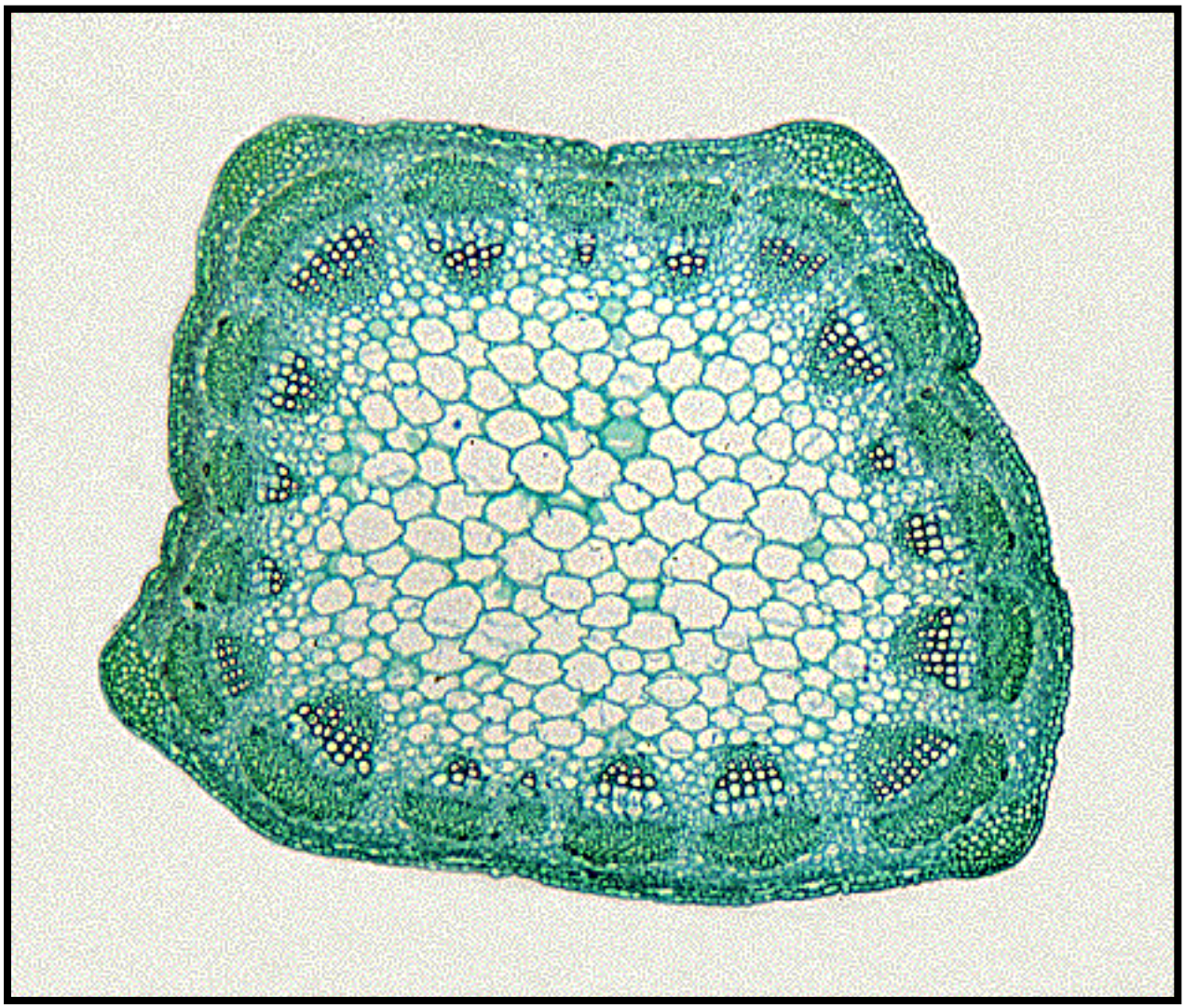
Stem x.s. of *Helianthus* (sunflower).

- Identify the following regions: epidermis, pith, cortex, collenchyma, xylem, phloem, fiber bundles.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem of *Medicago*



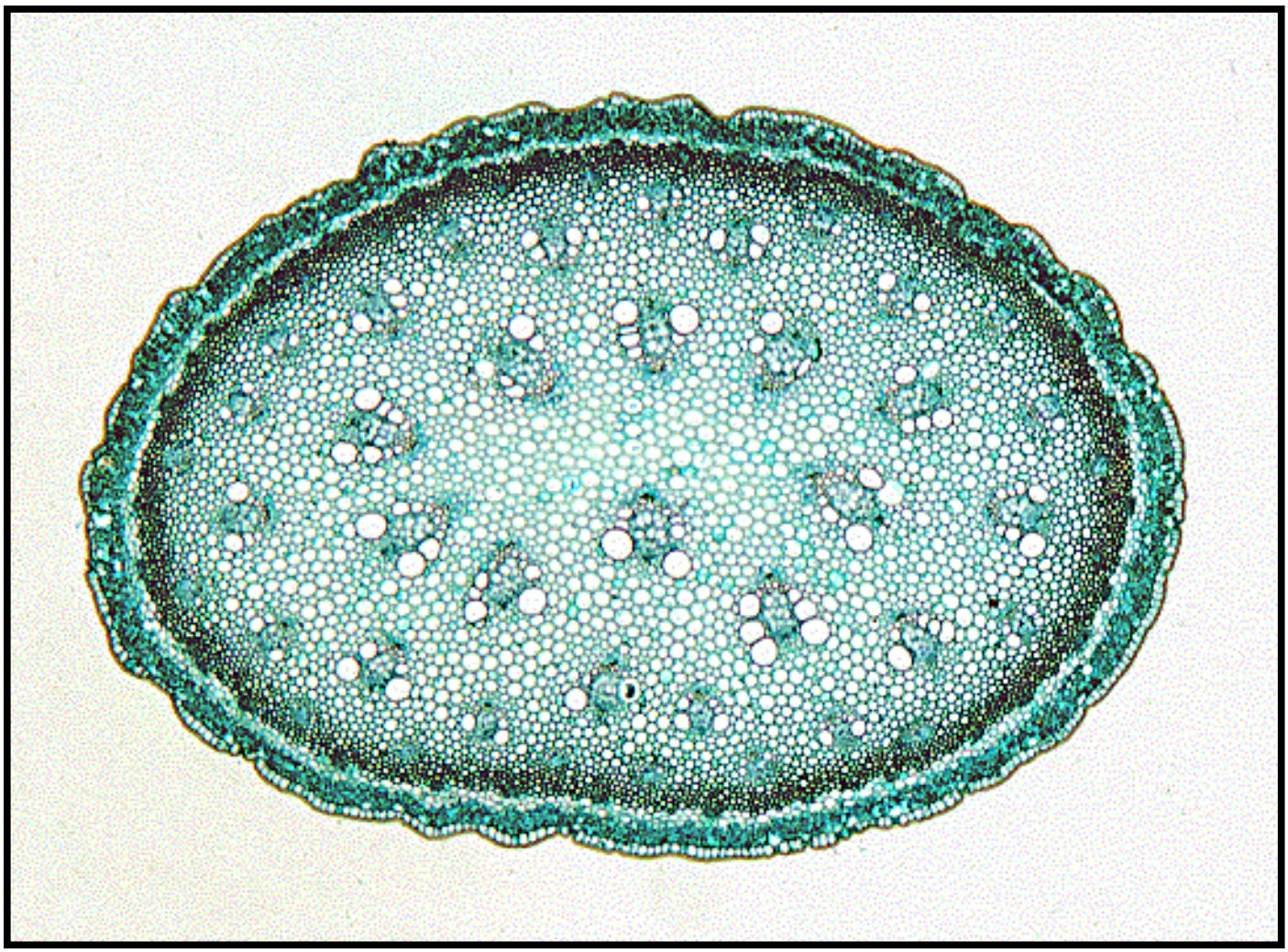
Stem cross section of *Medicago* (alfalfa), a typical dicot.

- Note the arrangement of stem bundles.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Asparagus*



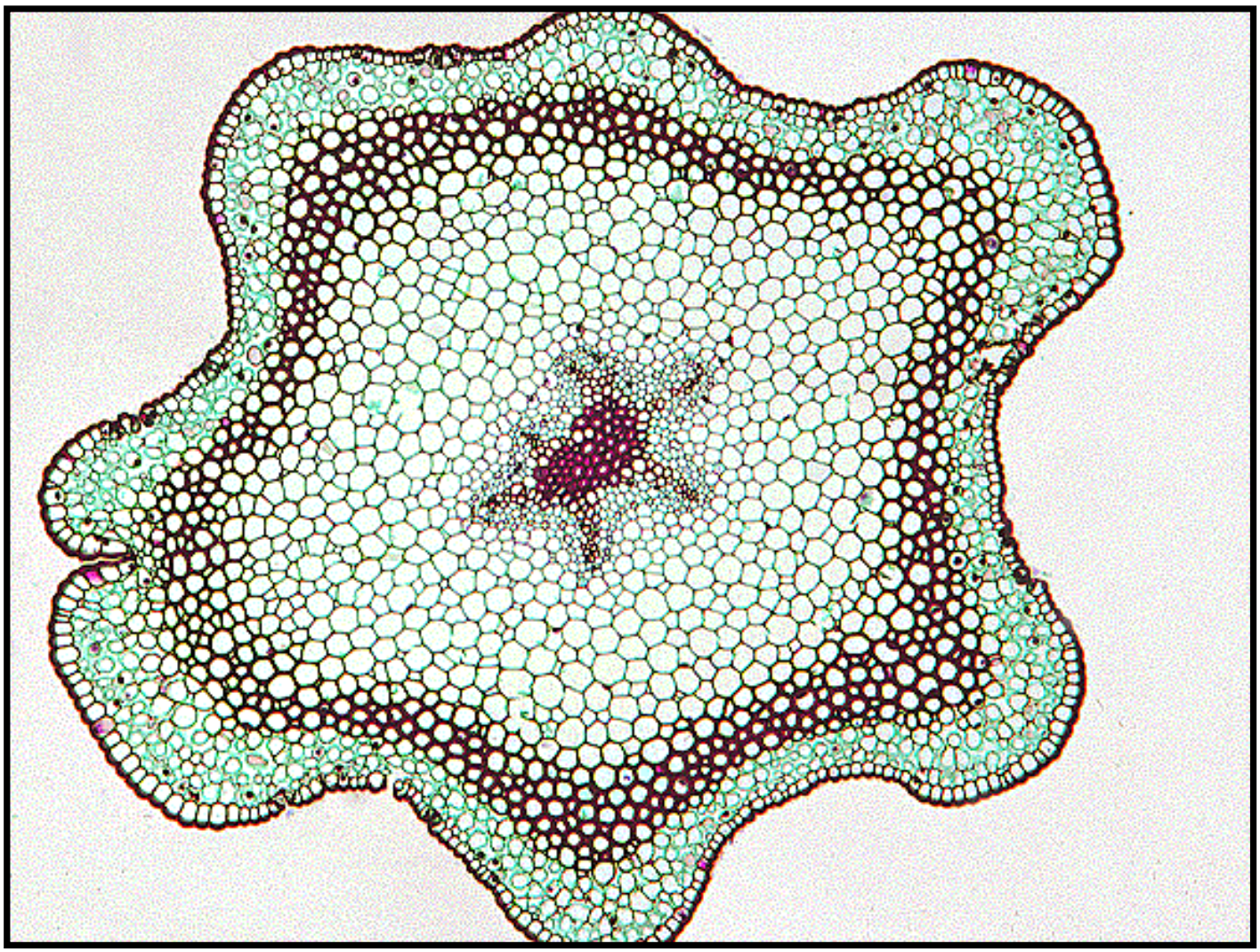
Stem cross section of *Asparagus*, a typical monocot.

- Note the arrangement of stem bundles.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Psilotum*



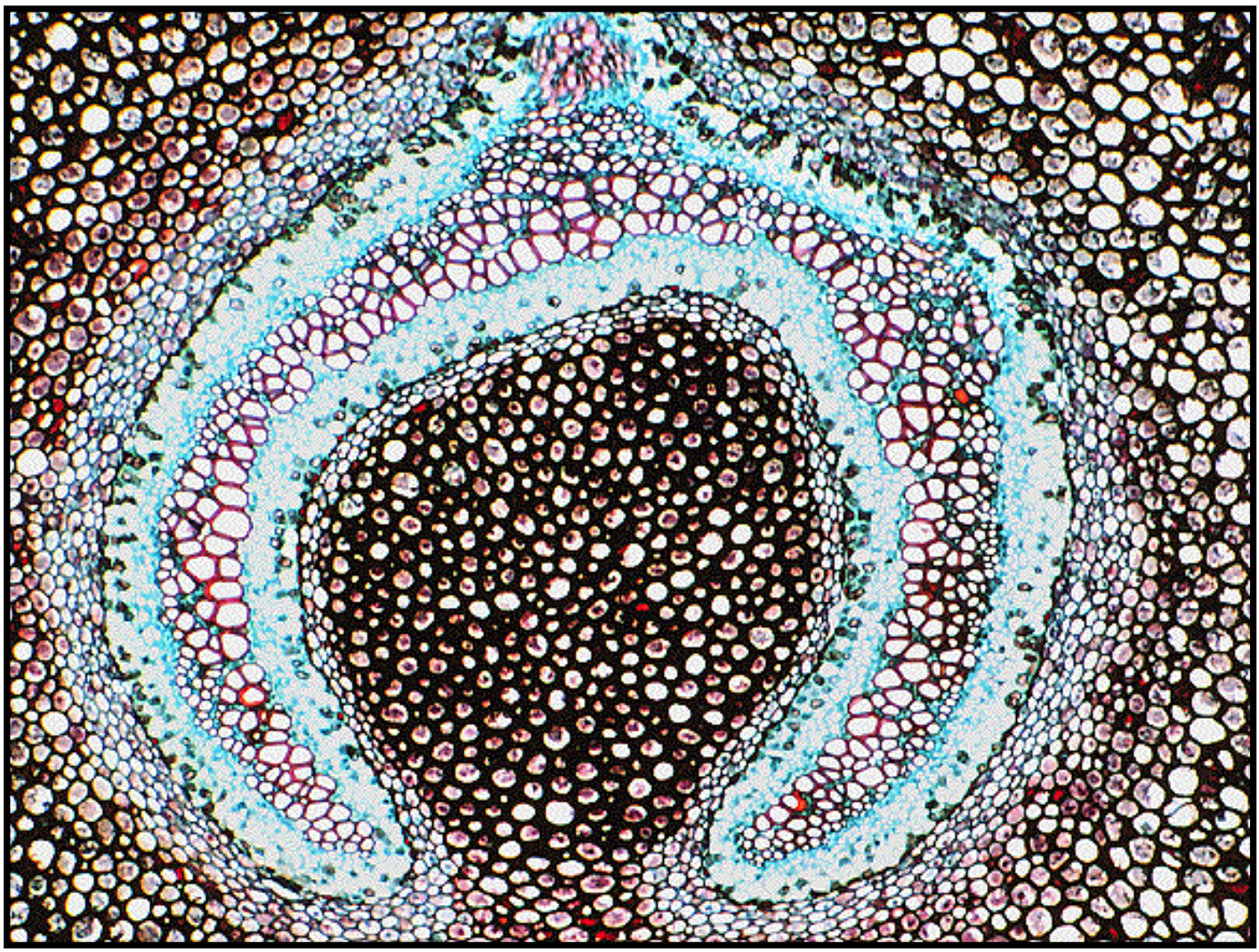
Stem cross section of *Psilotum* ("whisk fern").

- What type of stele is shown?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Adiantum*



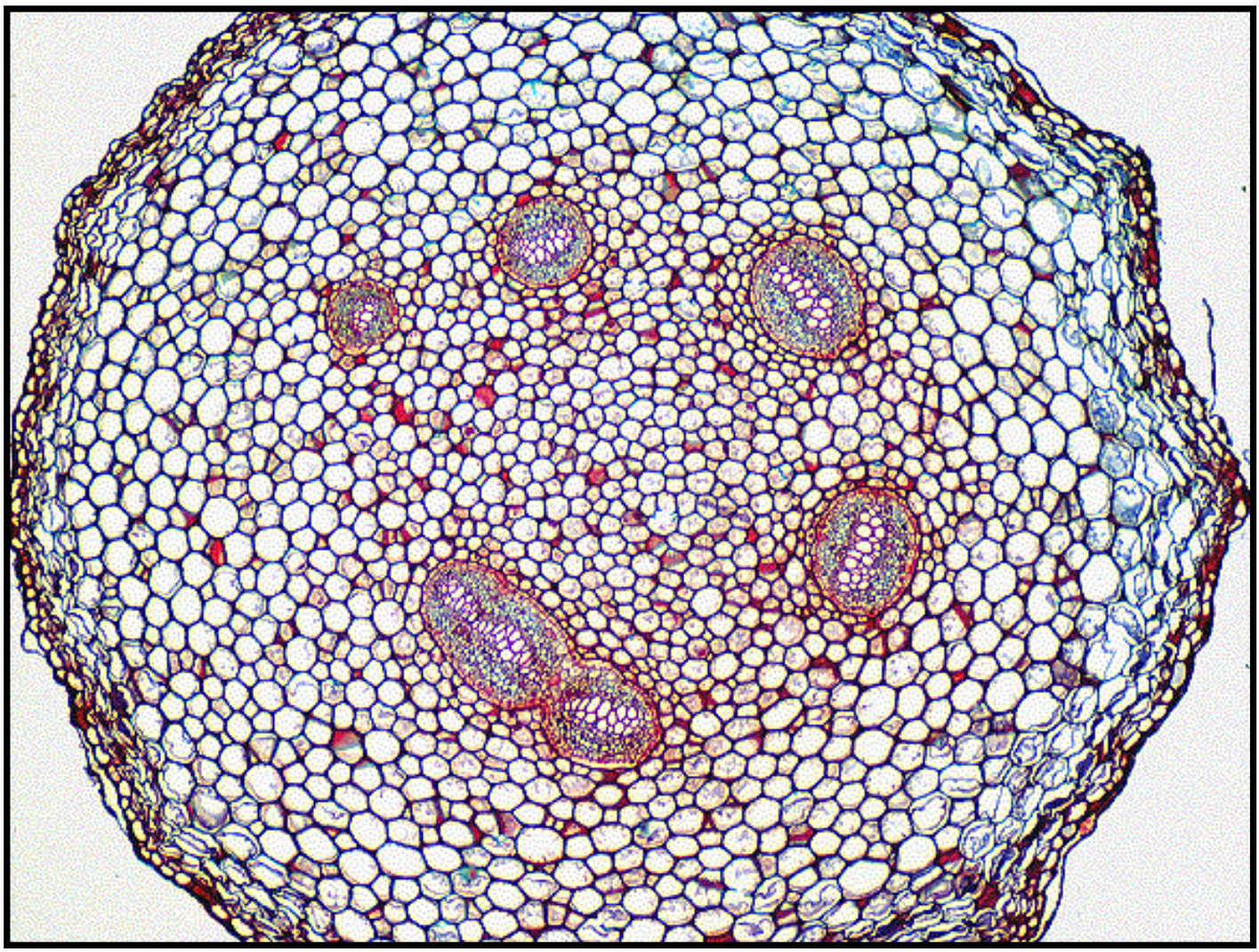
Stem x.s. of *Adiantum* ("Maidenhair fern").

- What type of stele is shown?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Polypodium*



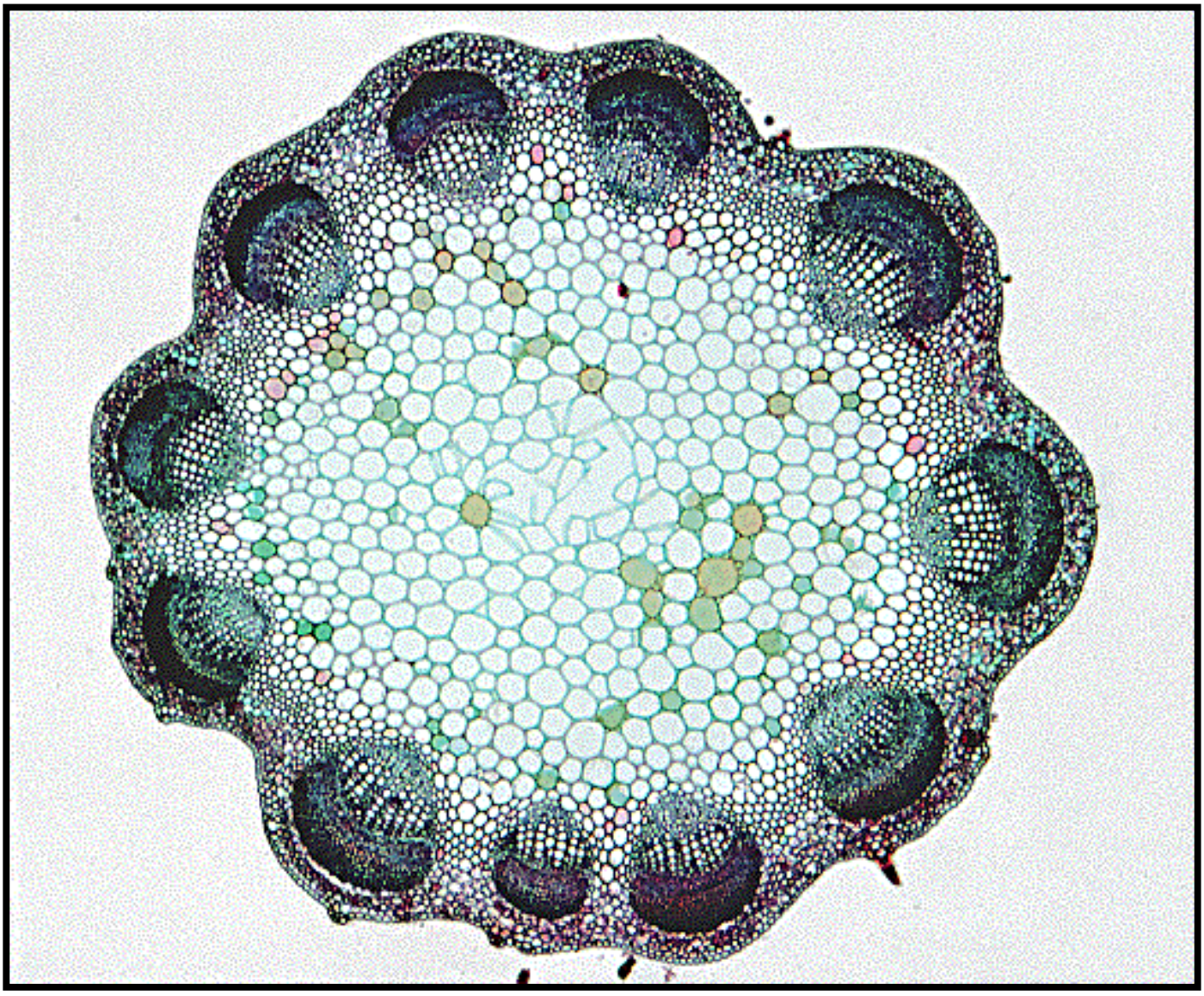
Stem cross section of *Polypodium* (a fern).

- What is the stele type?
- What is the bundle type?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Trifolium*



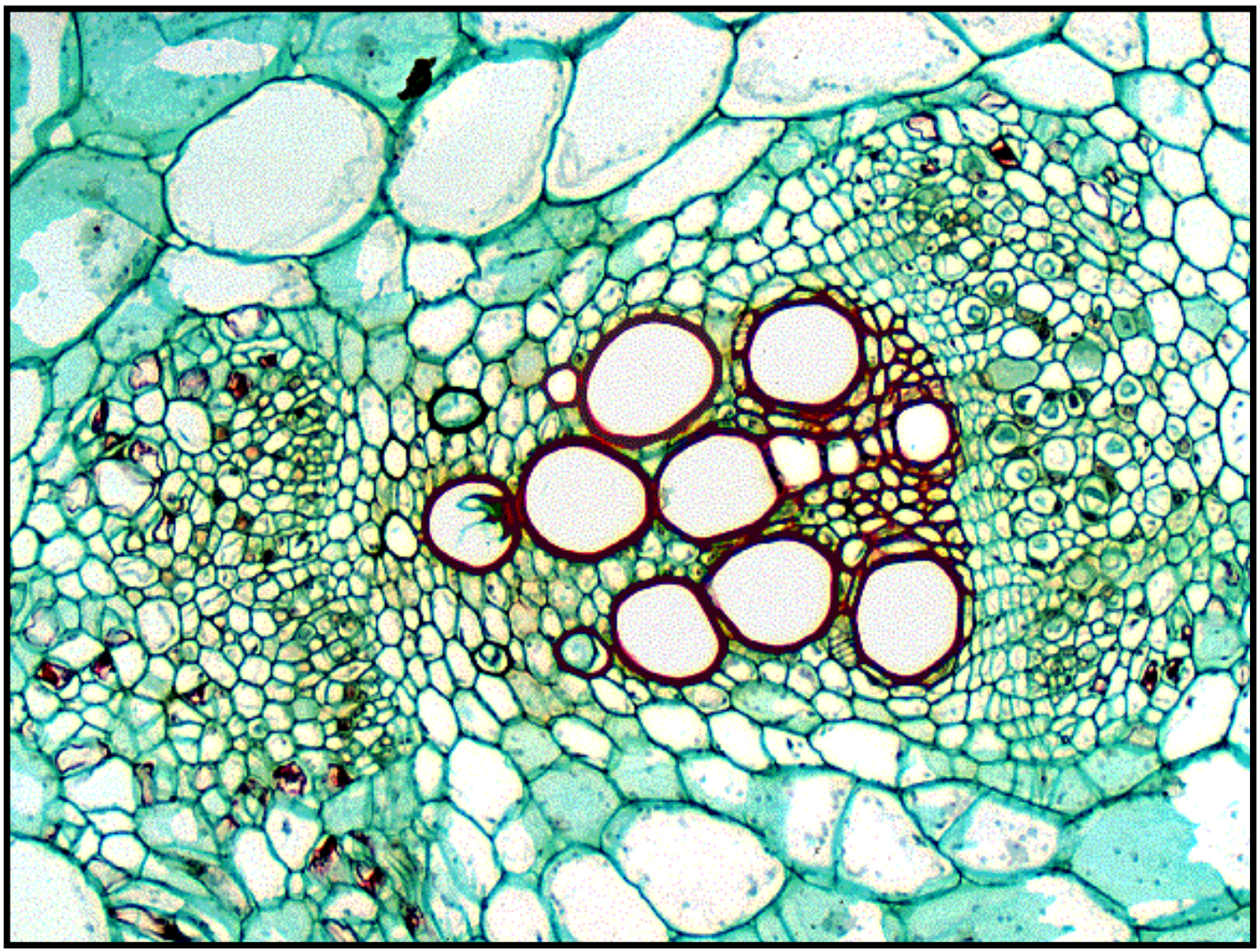
Stem x.s. of *Trifolium* (clover).

- What is the stele type?
- What is the bundle type?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Cucumis*



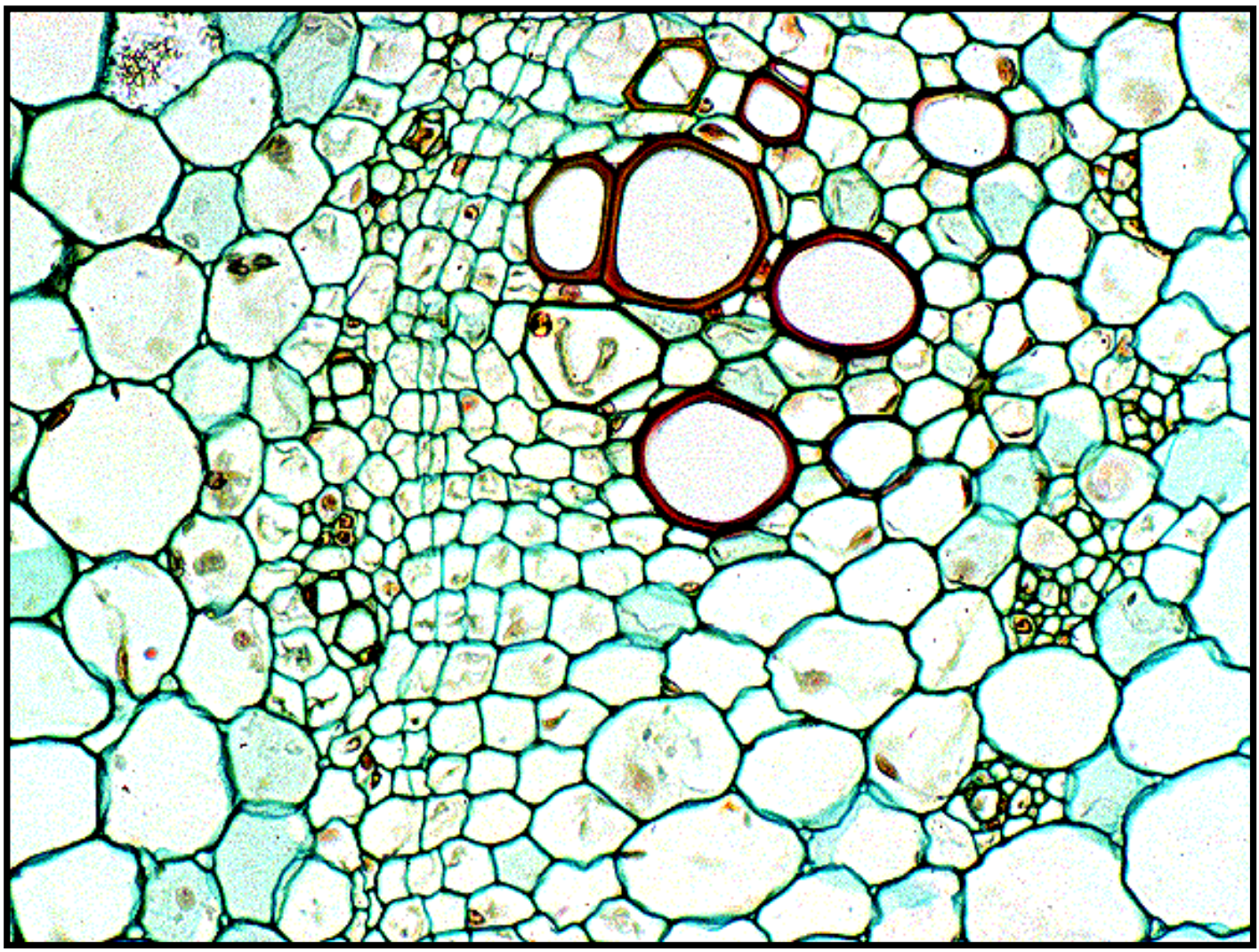
Stem x.s. of *Cucumis* (cucumber).

- What is the bundle type?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Lycopersicon*



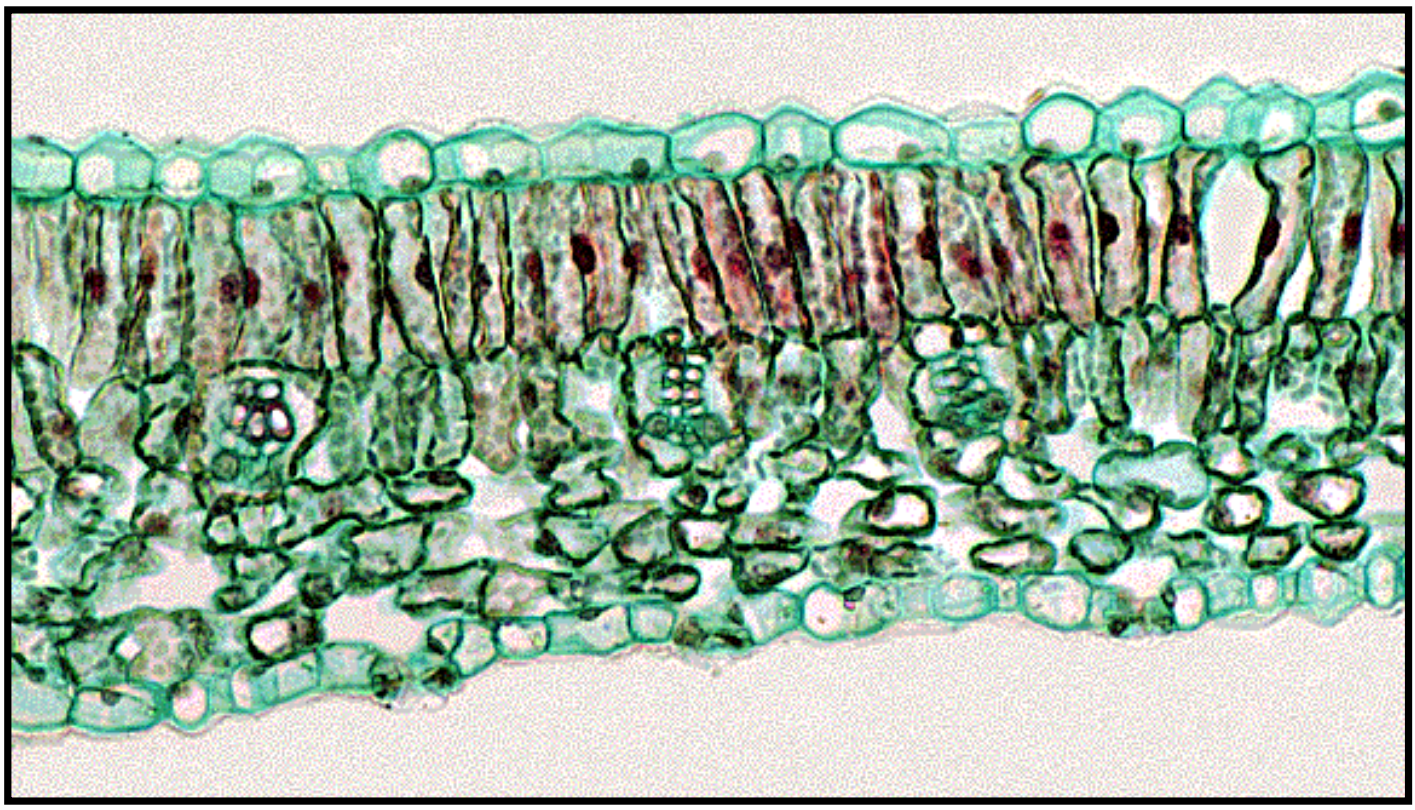
Stem cross section of *Lycopersicon* (tomato).

- Identify the isolated phloem strands.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Leaf x.s. of *Syringa*



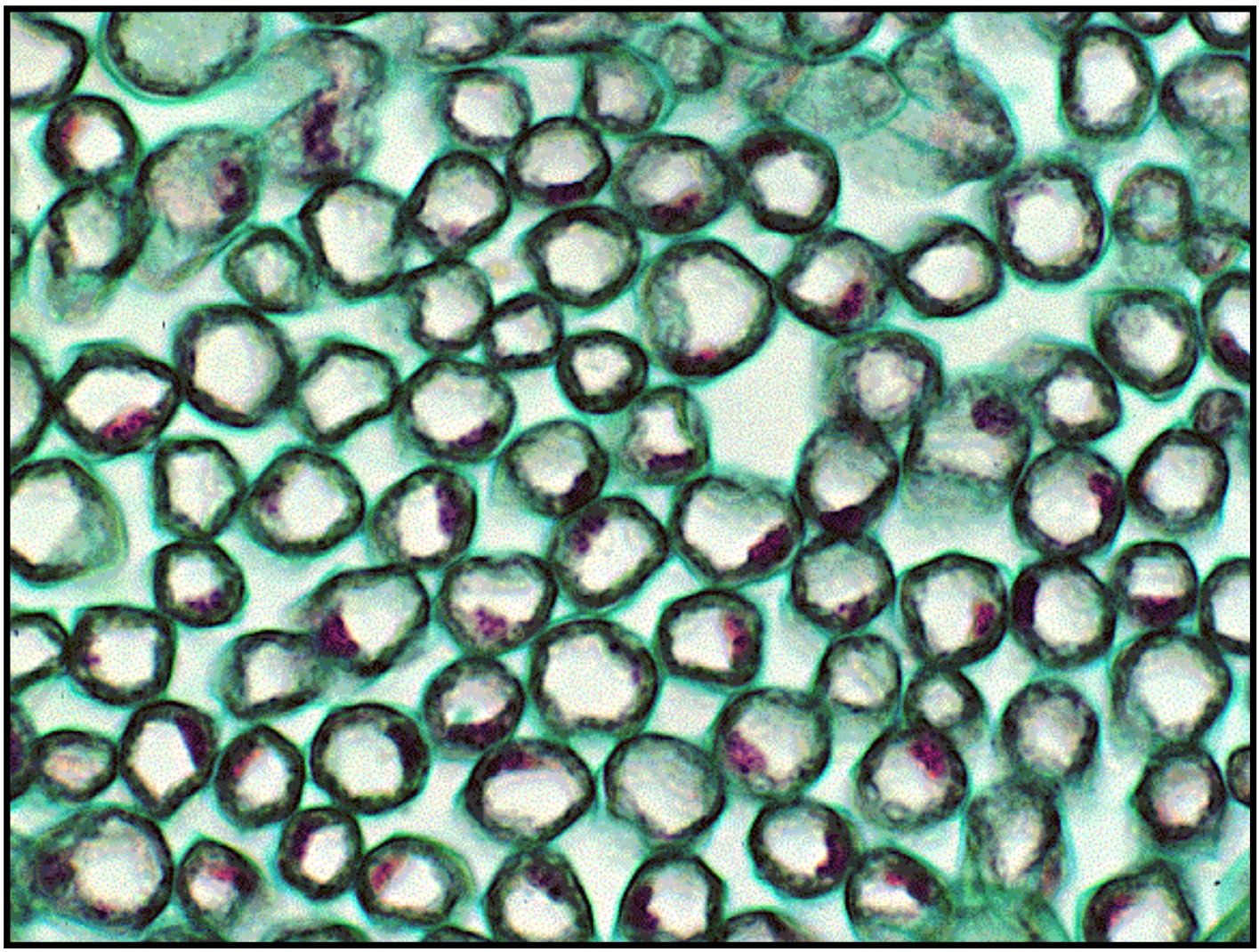
Leaf x.s. of *Syringa* (lilac).

- Identify: adaxial epidermis, abaxial epidermis, guard cells, substomatal chamber, palisade mesophyll, spongy mesophyll, xylem, phloem, bundle sheath.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Paradermal section of *Syringa* palisade mesophyll

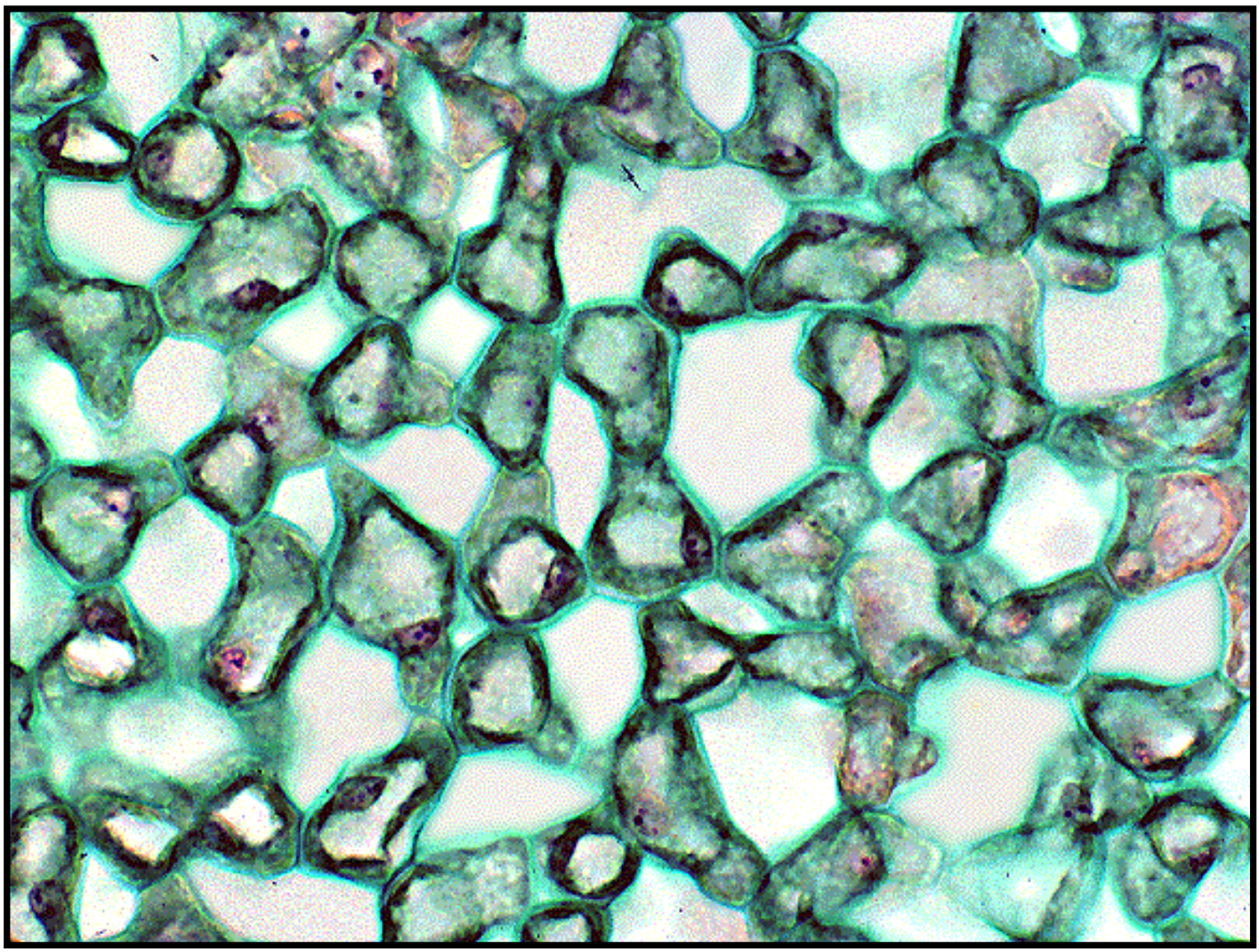


Paradermal section of *Syringa* palisade mesophyll

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Syringa spongy mesophyll



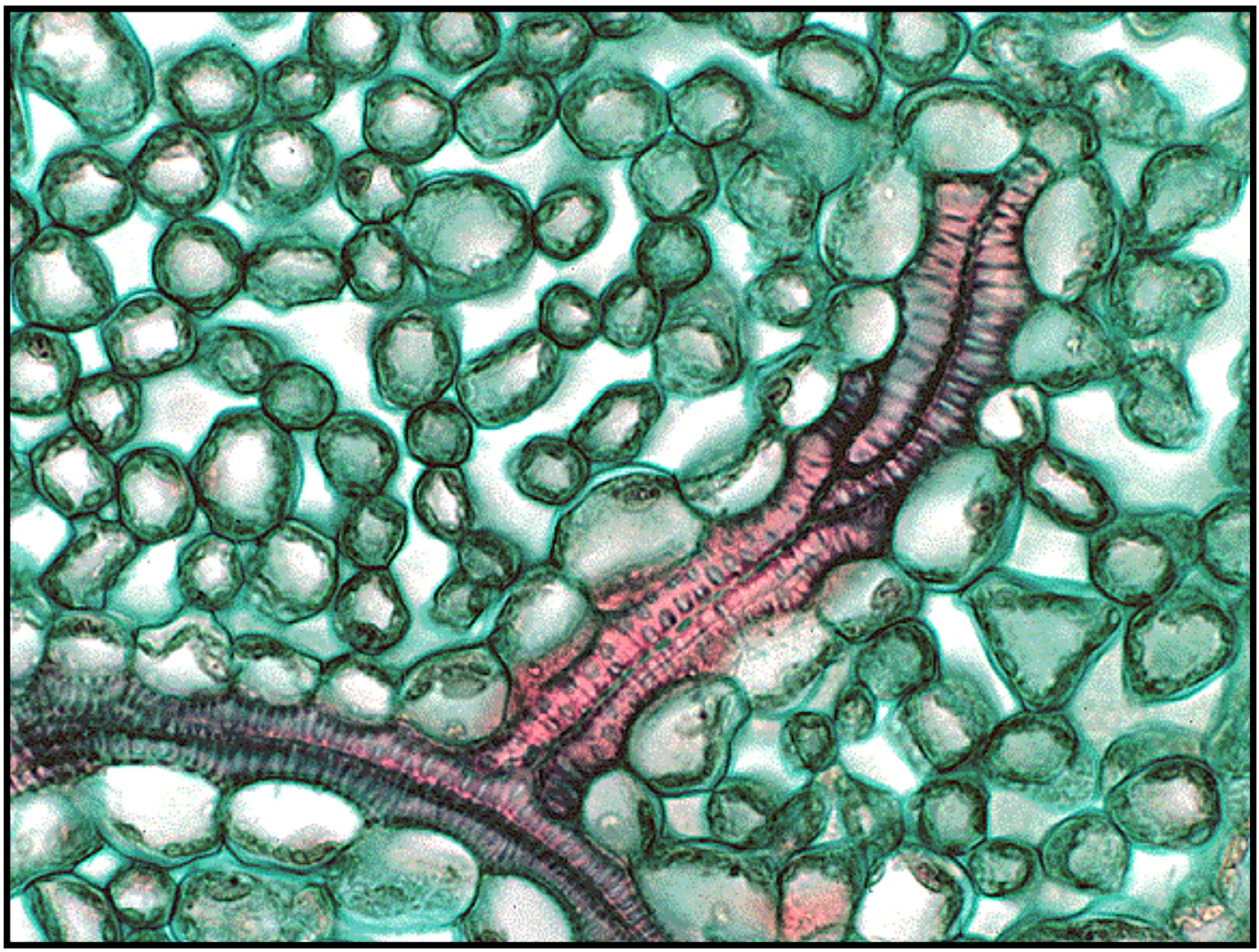
Syringa (lilac) spongy mesophyll.

- How does this tissue differ from palisade mesophyll in structure and function?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Syringa minor vein



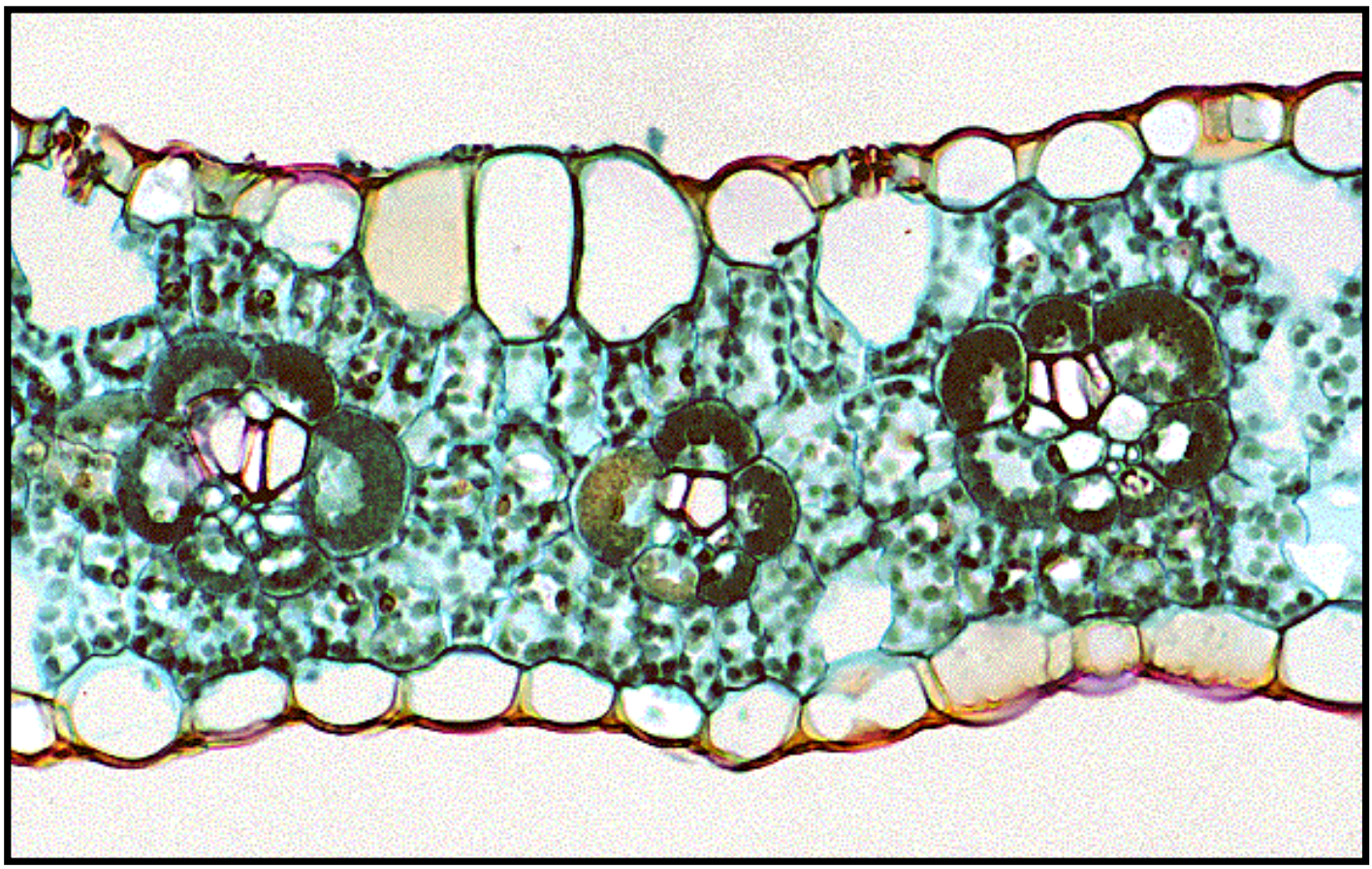
Syringa minor vein.

- Identify: tracheary elements, bundle sheath cells, palisade mesophyll, spongy mesophyll.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Leaf x.s. of *Zea mays*



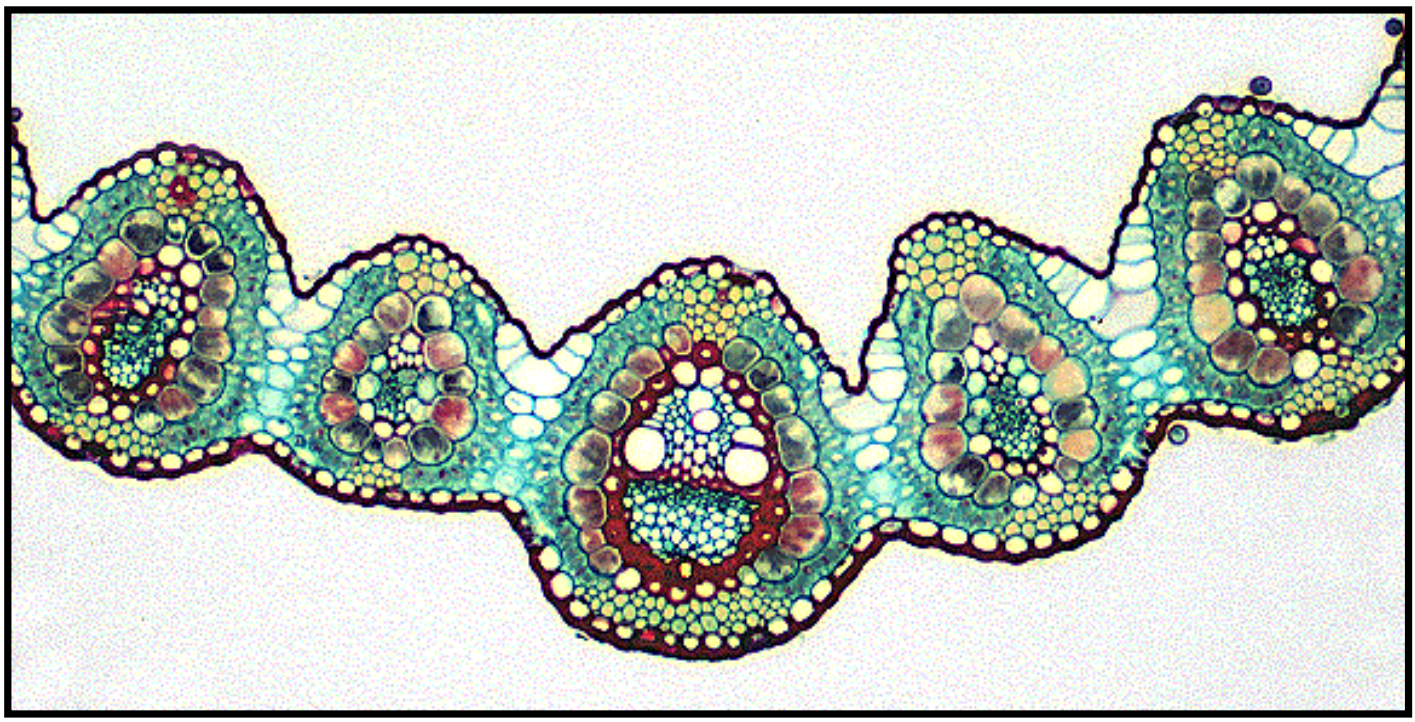
Leaf cross section of *Zea mays* ("corn").

- Identify: epidermis, bulliform cells, guard cells, mesophyll, bundle sheath, xylem, phloem.
- Note the lack of differentiation of the mesophyll into palisade and spongy layers.
- How can you tell which is the adaxial epidermis?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Leaf x.s. of *Bouteloua*



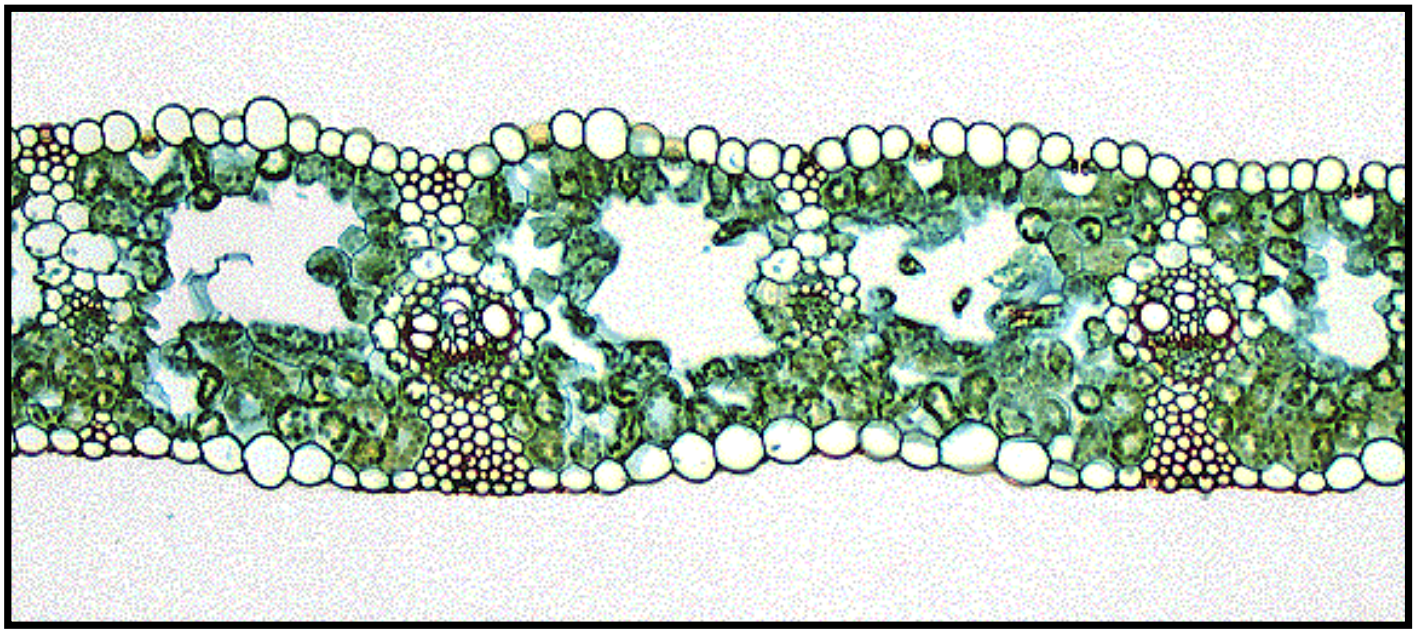
Leaf cross section of *Bouteloua*, a grass that undergoes C4 photosynthesis.

- Note the large bundle sheath cells with distinctive chloroplasts.
- What is the function of these specialized bundle sheath cells?
- This leaf also has distinctive bulliform cells.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Leaf x.s. of *Poa*



Leaf cross section of *Poa*, a C3 grass.

- Note that the bundle sheath cells are small and contain no specialized chloroplasts.
- This leaf also has bundle sheath extensions.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Leaf x.s. of pine

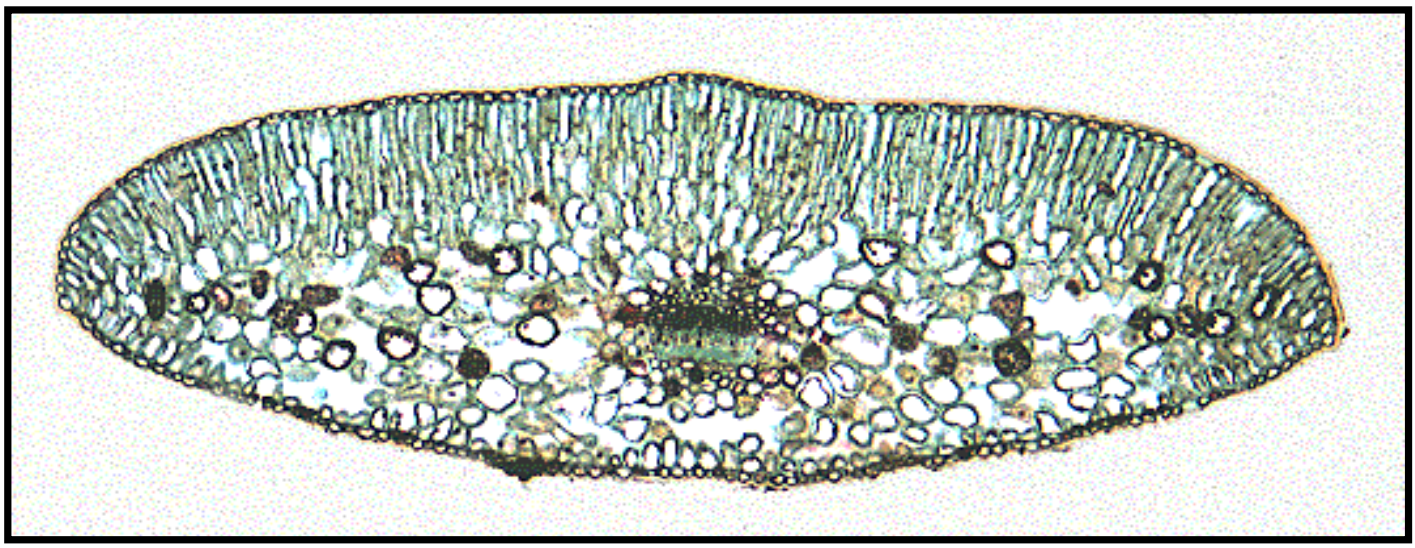
Leaf cross section of pine

- Identify: epidermis, sclerified hypodermis, sunken stomata, mesophyll, resin ducts, endodermis, xylem, phloem.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Leaf x.s. of *Taxus*



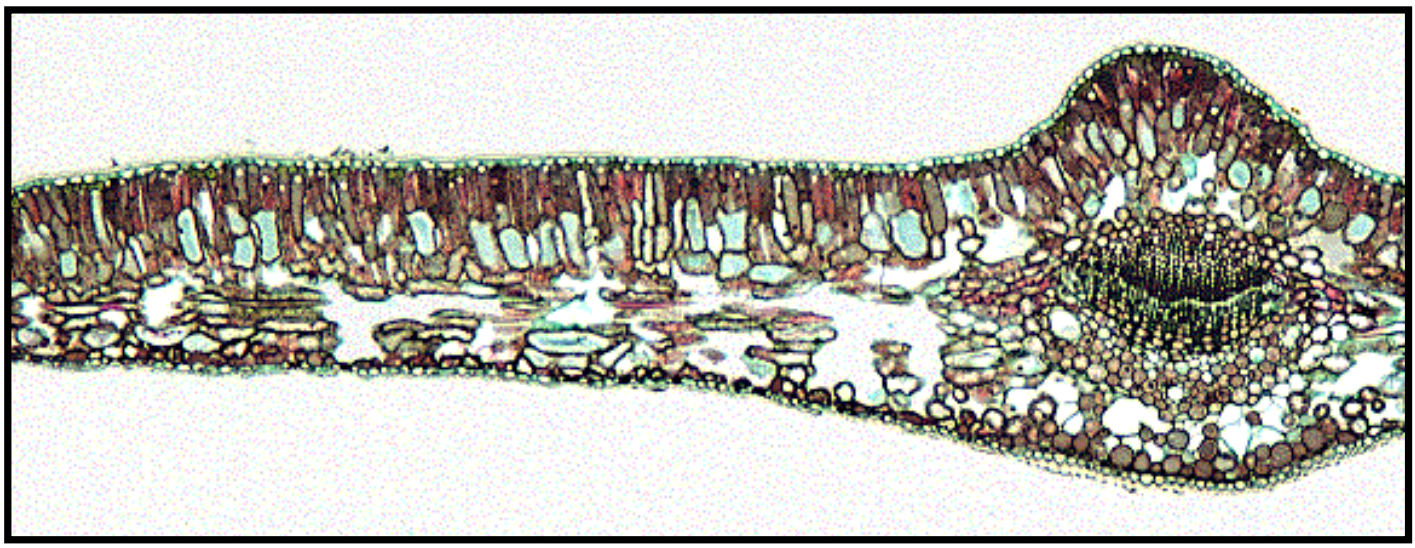
Leaf cross section of *Taxus* (yew, a conifer).

- Note that this leaf is broader than that of the pine, but still contains only one vascular bundle.
- The mesophyll is differentiated into palisade and spongy layers.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Leaf x.s. of *Podocarpus*



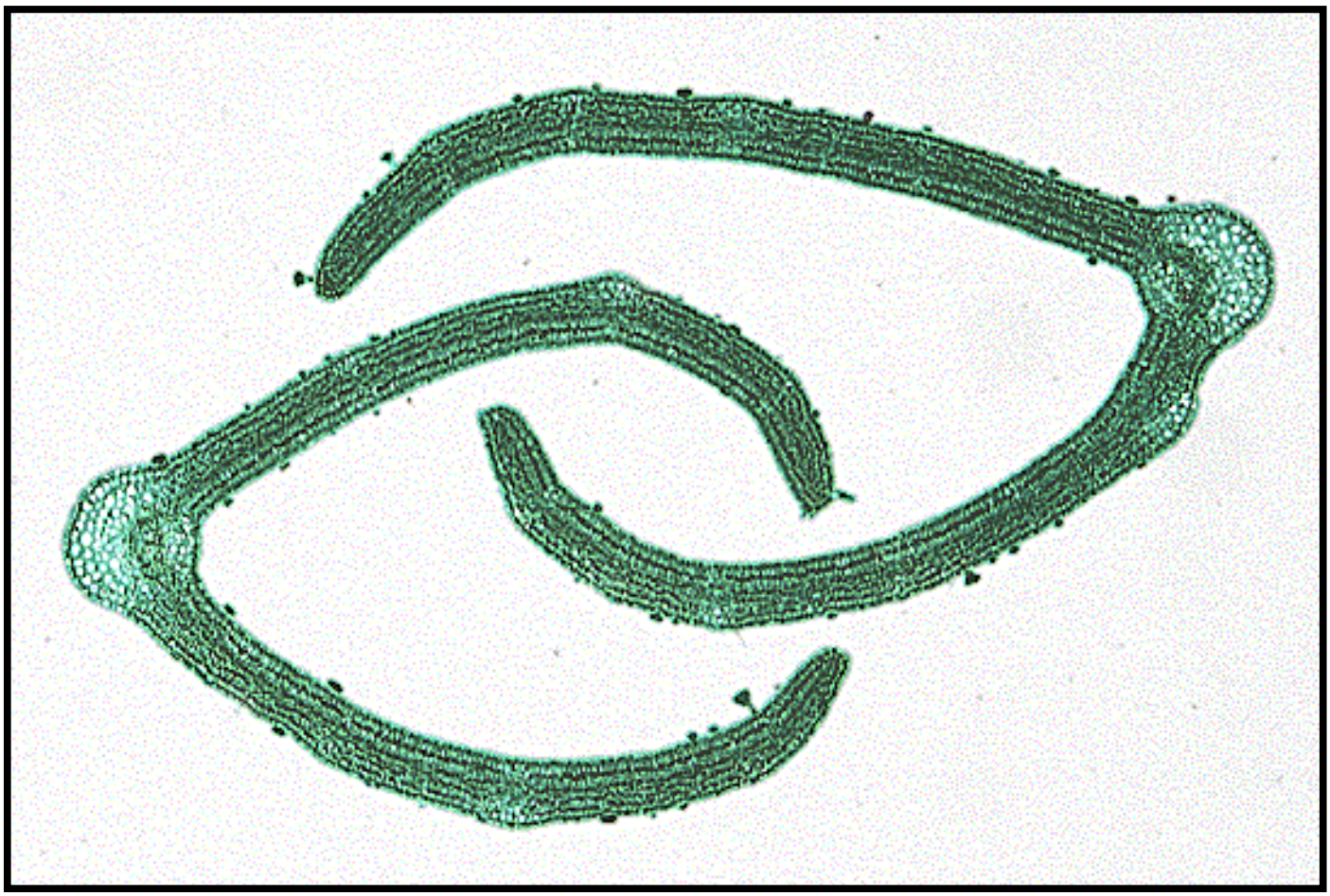
Leaf cross section of *Podocarpus* (a conifer).

- This leaf is still broader, yet contains only one vascular bundle.
- Identify as many tissues as you can.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Immature *Syringa* leaves

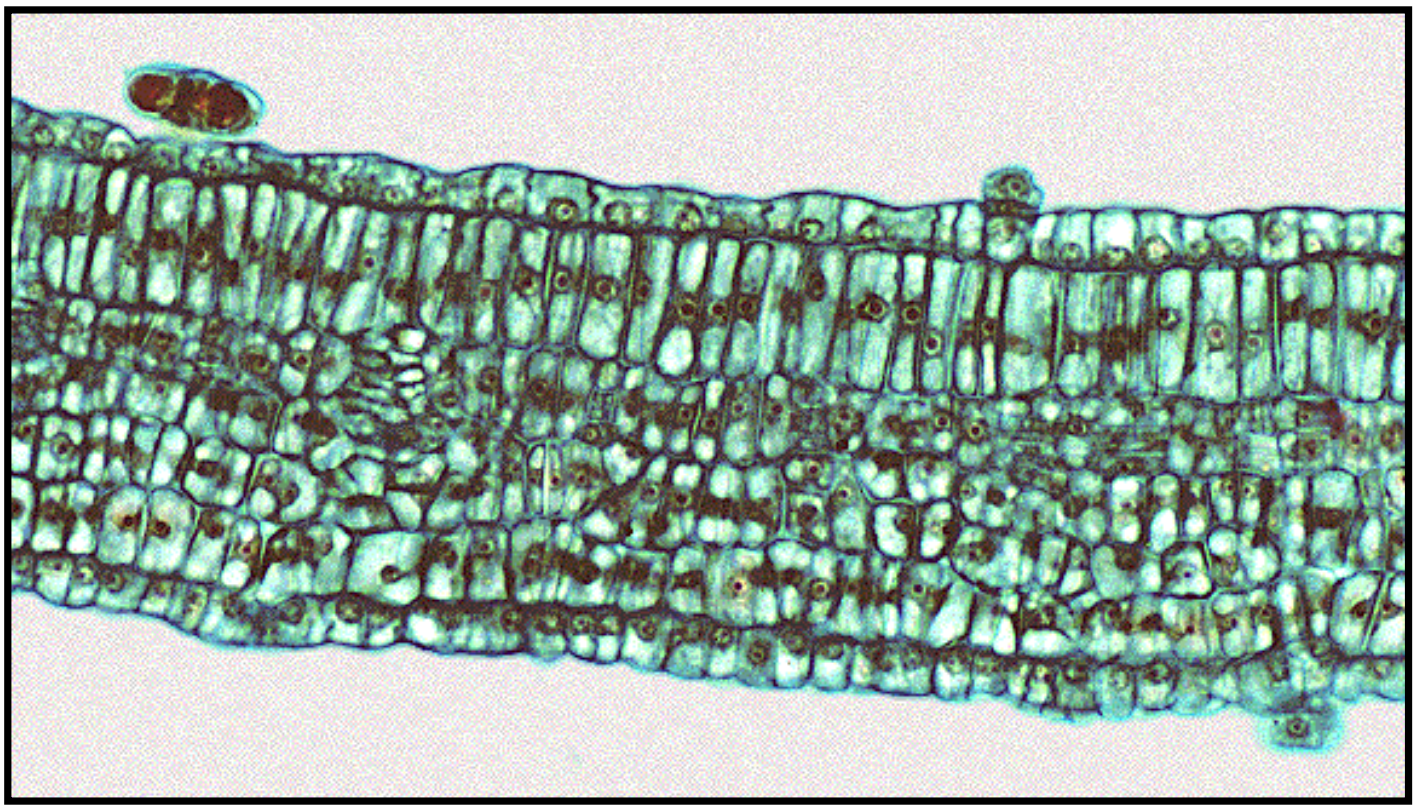


Immature *Syringa* (lilac) leaves.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Immature *Syringa* leaf



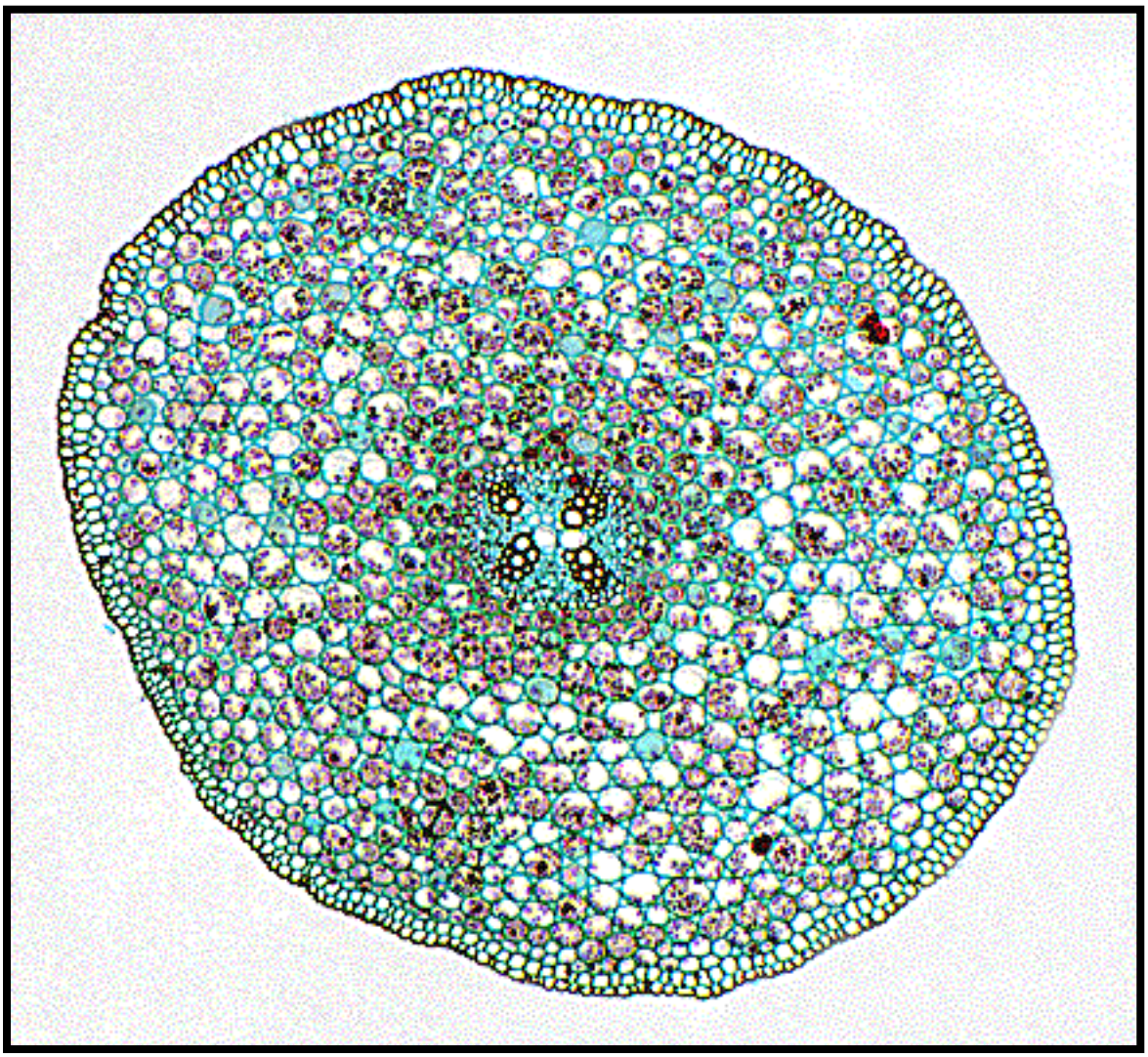
Immature *Syringa* (lilac) leaf.

- Note that all tissues are present, but intercellular air spaces have not yet formed.
- What processes lead to formation of the air spaces?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Ranunculus root x.s.



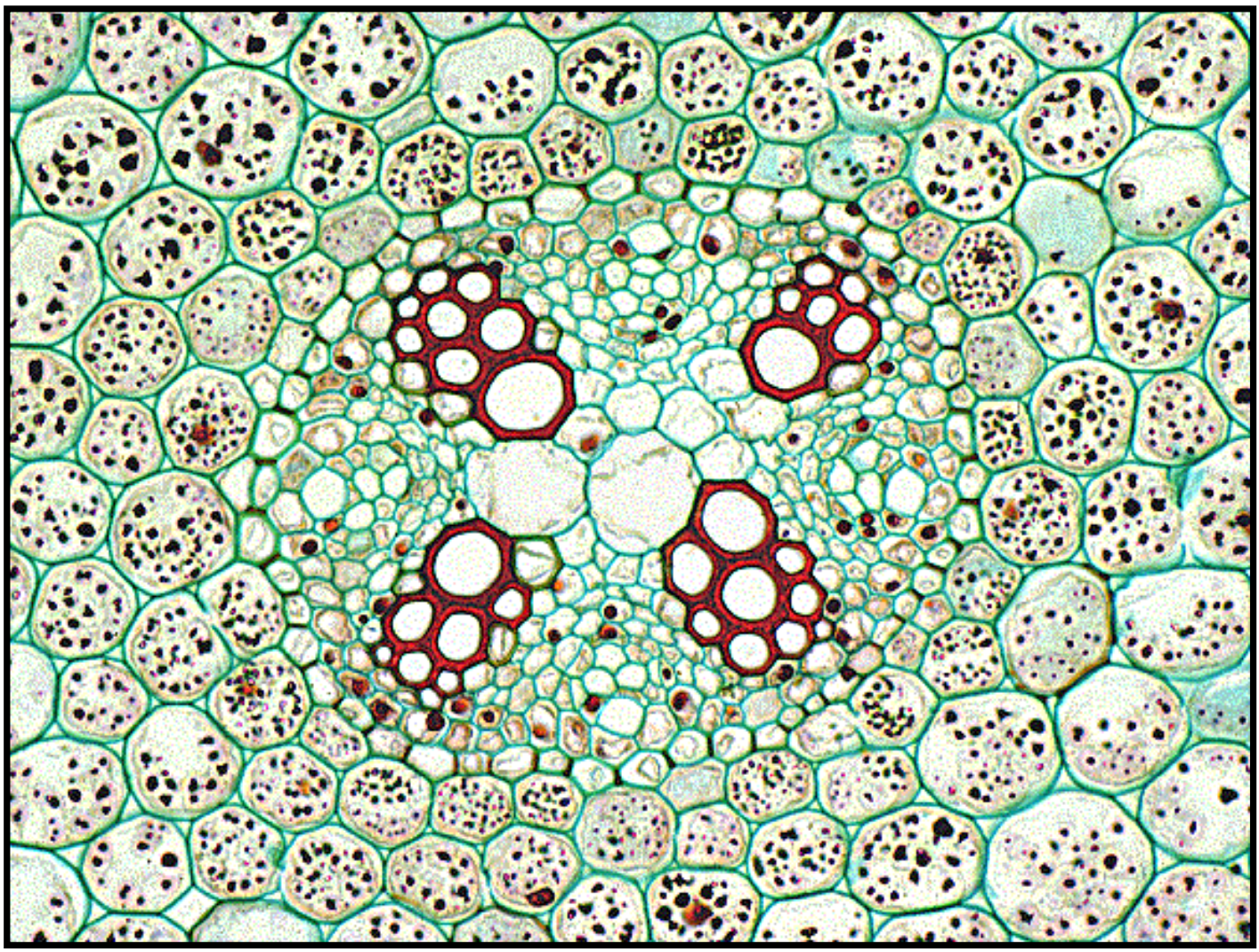
Cross-section of immature *Ranunculus* root (buttercup).

- Identify: epidermis, cortex (storage parenchyma), stele.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Higher magnification view of immature *Ranunculus* root stele



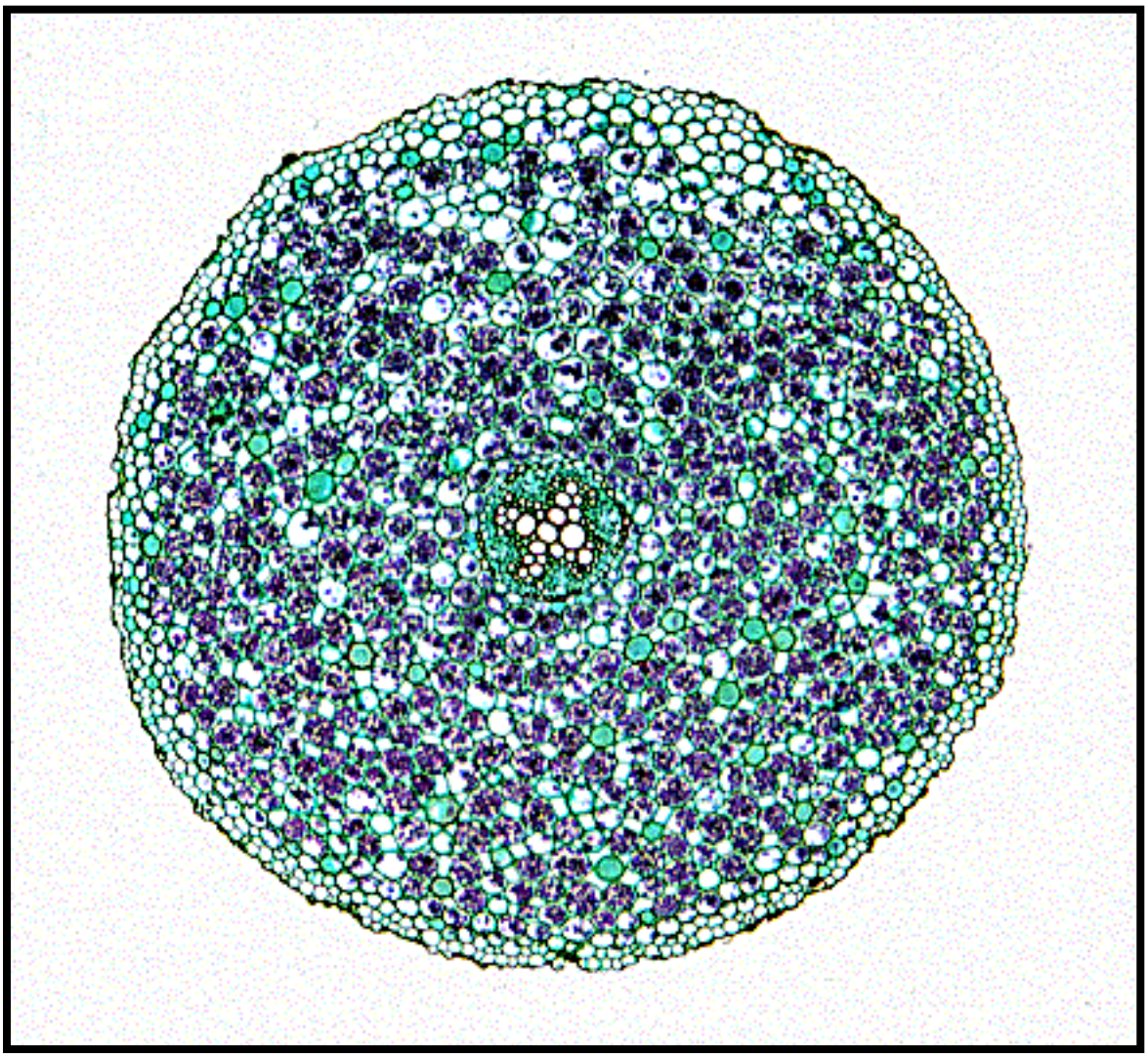
Higher magnification view of immature *Ranunculus* root stele.

- Identify: protoxylem, phloem, pericycle, endodermis, Casparian strip.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

X.s. of mature *Ranunculus* root



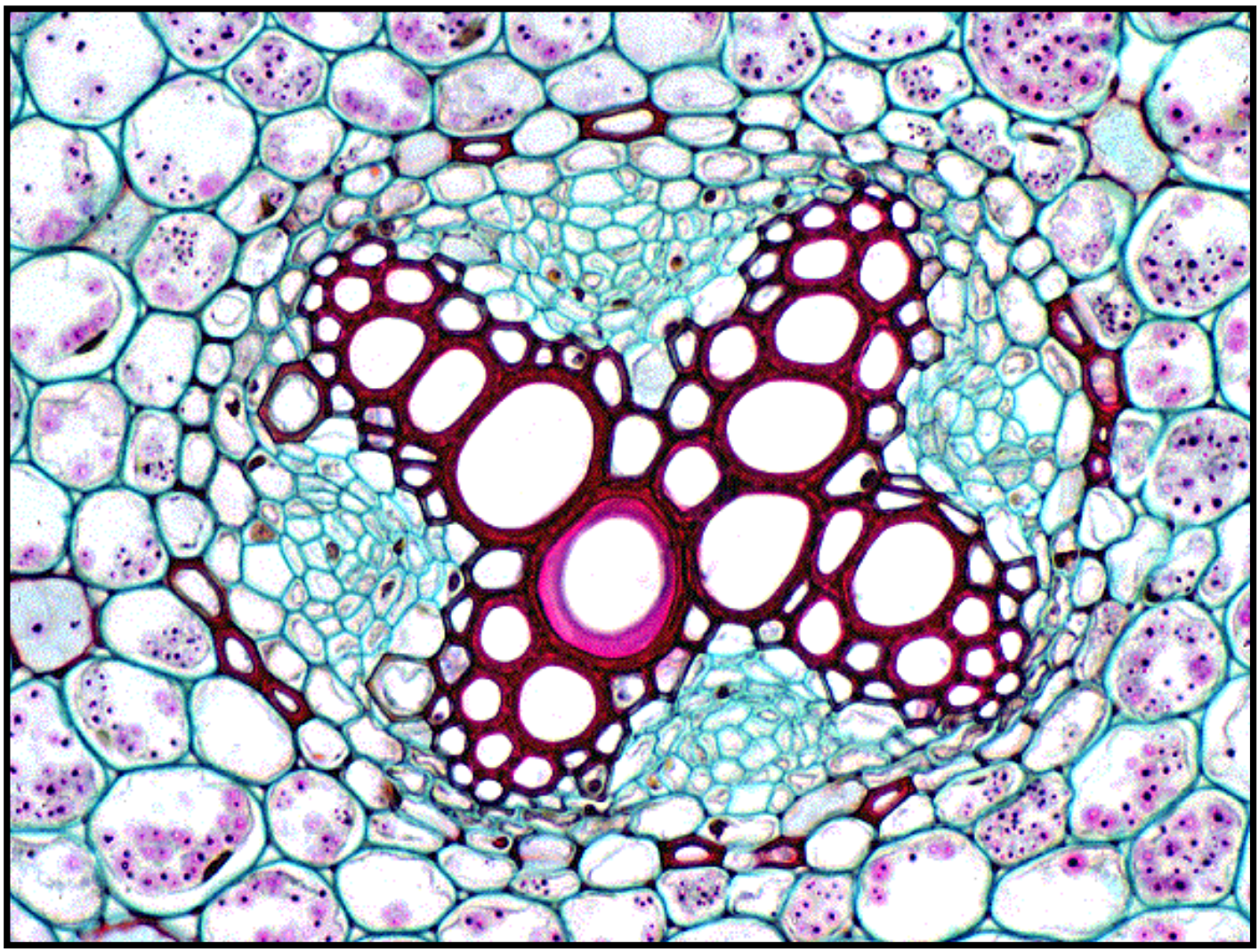
Cross-section of mature *Ranunculus* root

- Identify the tissues present in the section.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Mature *Ranunculus* stele



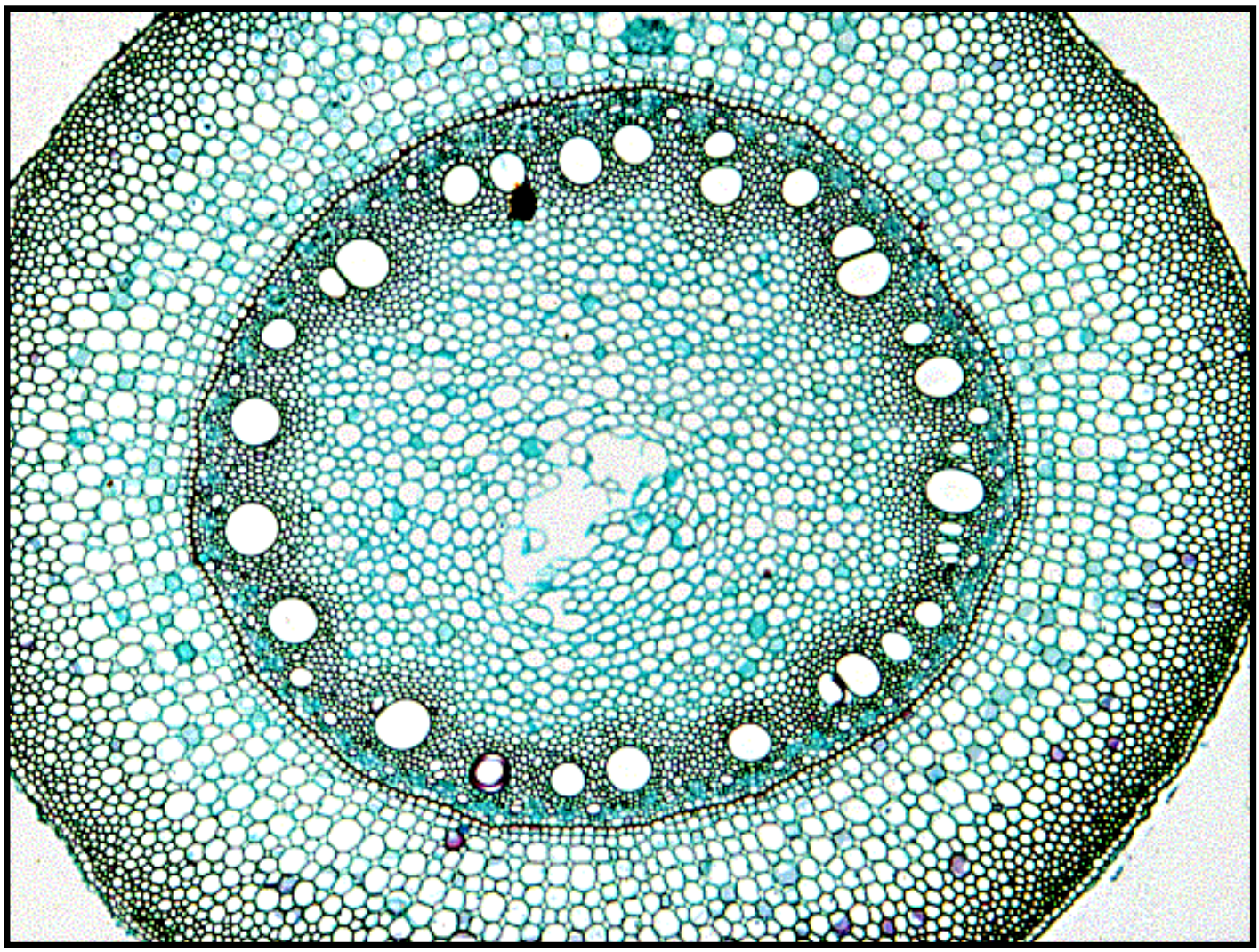
Higher magnification view of mature *Ranunculus* stele

- Identify: protoxylem, metaxylem, phloem, pericycle, endodermis.
- In what ways is the endodermis of this mature root different from that of the immature root?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Root x.s. of *Zea mays*



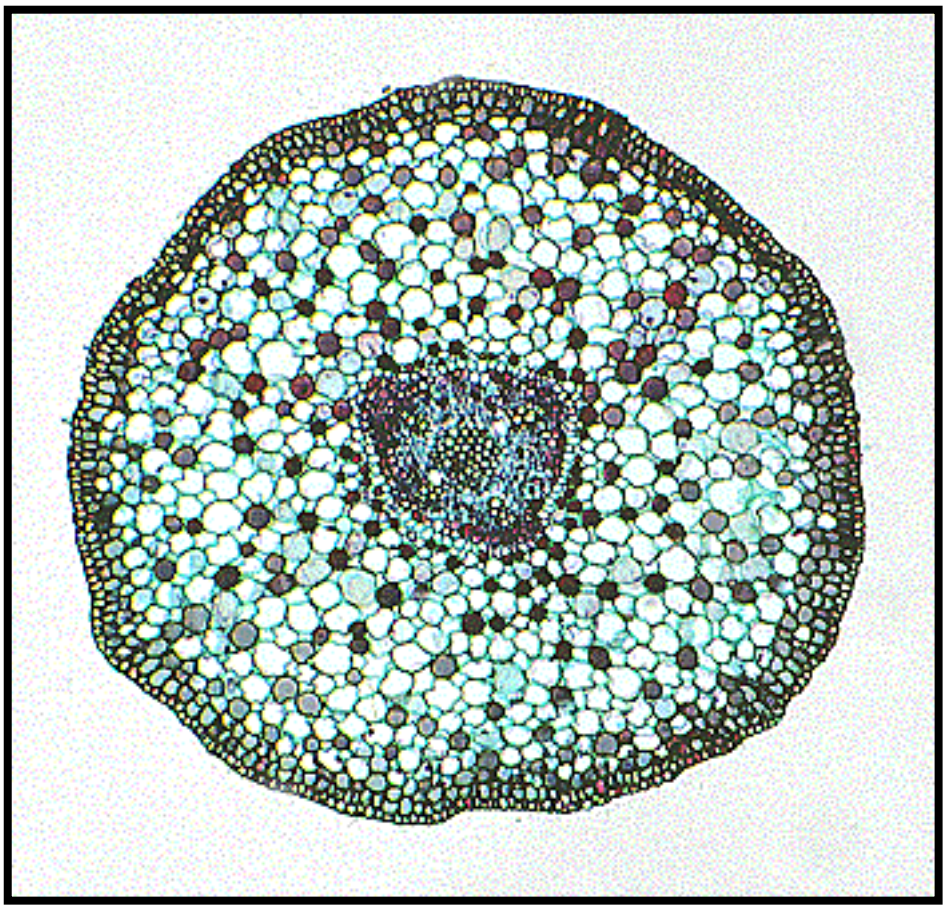
Root cross section of *Zea mays* (corn).

- Identify: epidermis, sclerified hypodermis, cortex, polyarch stele, endodermis, vessel elements, phloem, pith.
- Why is this stele considered a protostele even though a pith is present?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Root x.s. of *Salix*



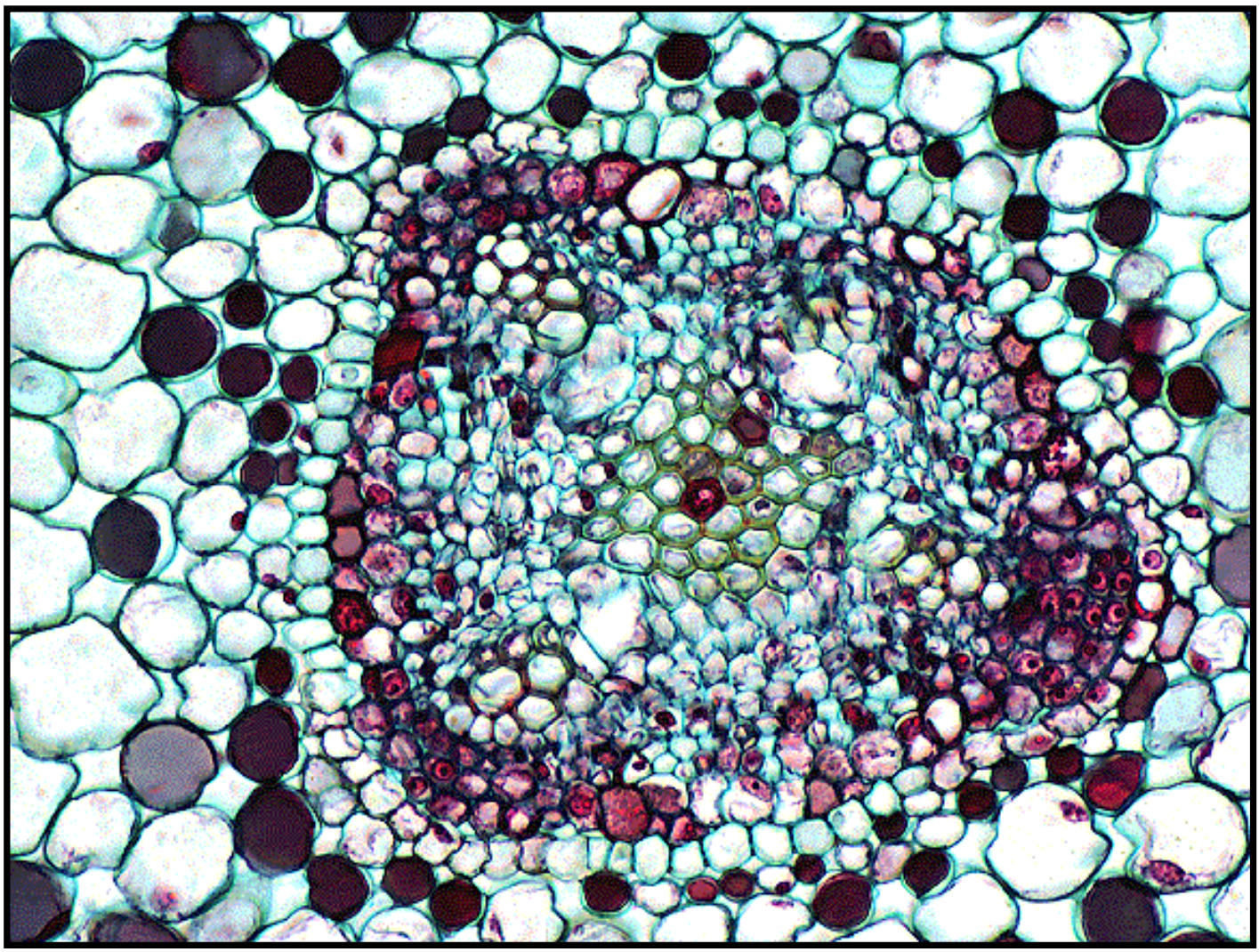
Root cross section of *Salix* (willow).

- Identify the lateral root primordia.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Salix root showing lateral root primordia



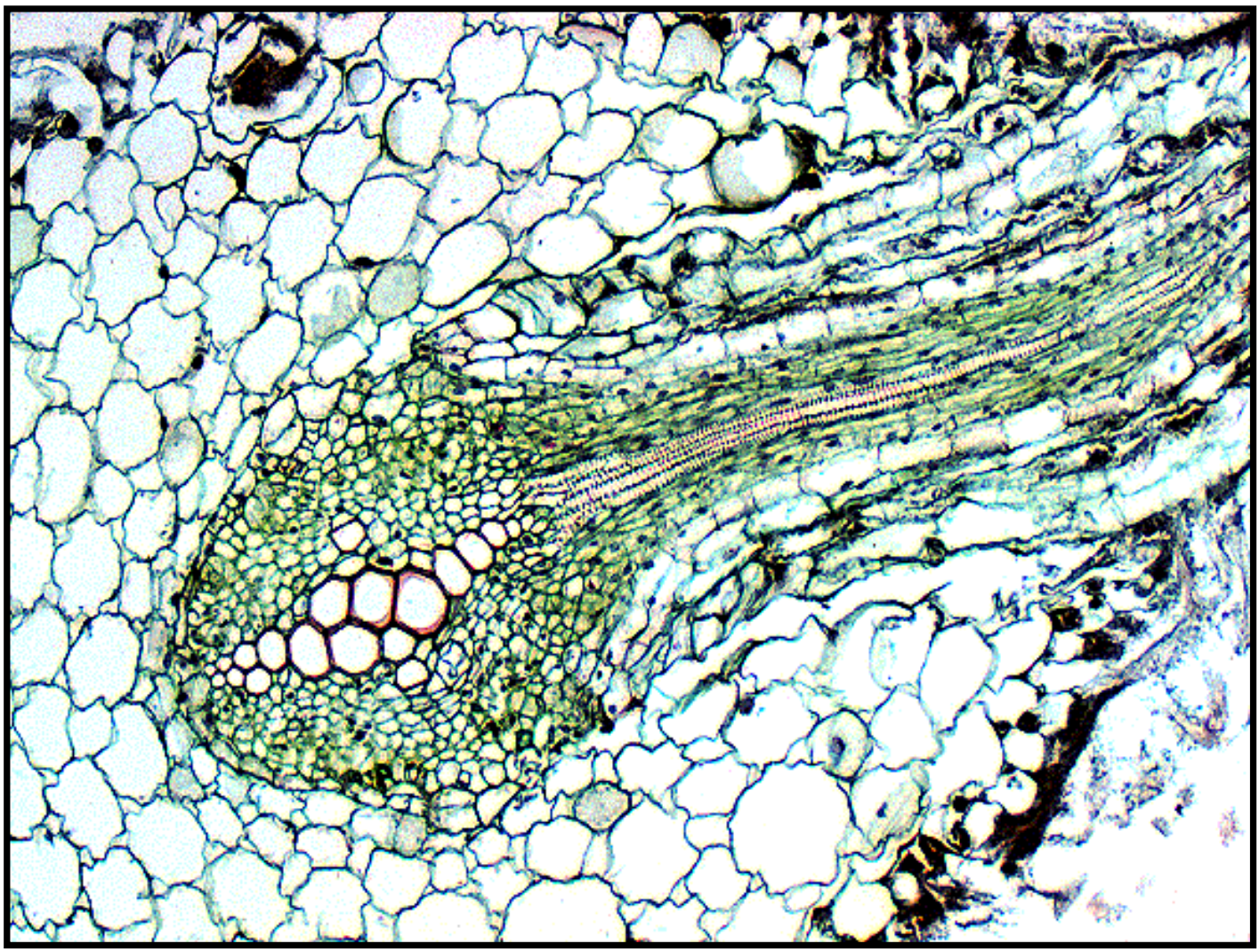
Higher magnification view of *Salix* root.

- In which tissue do the lateral root primordia arise?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Branch root



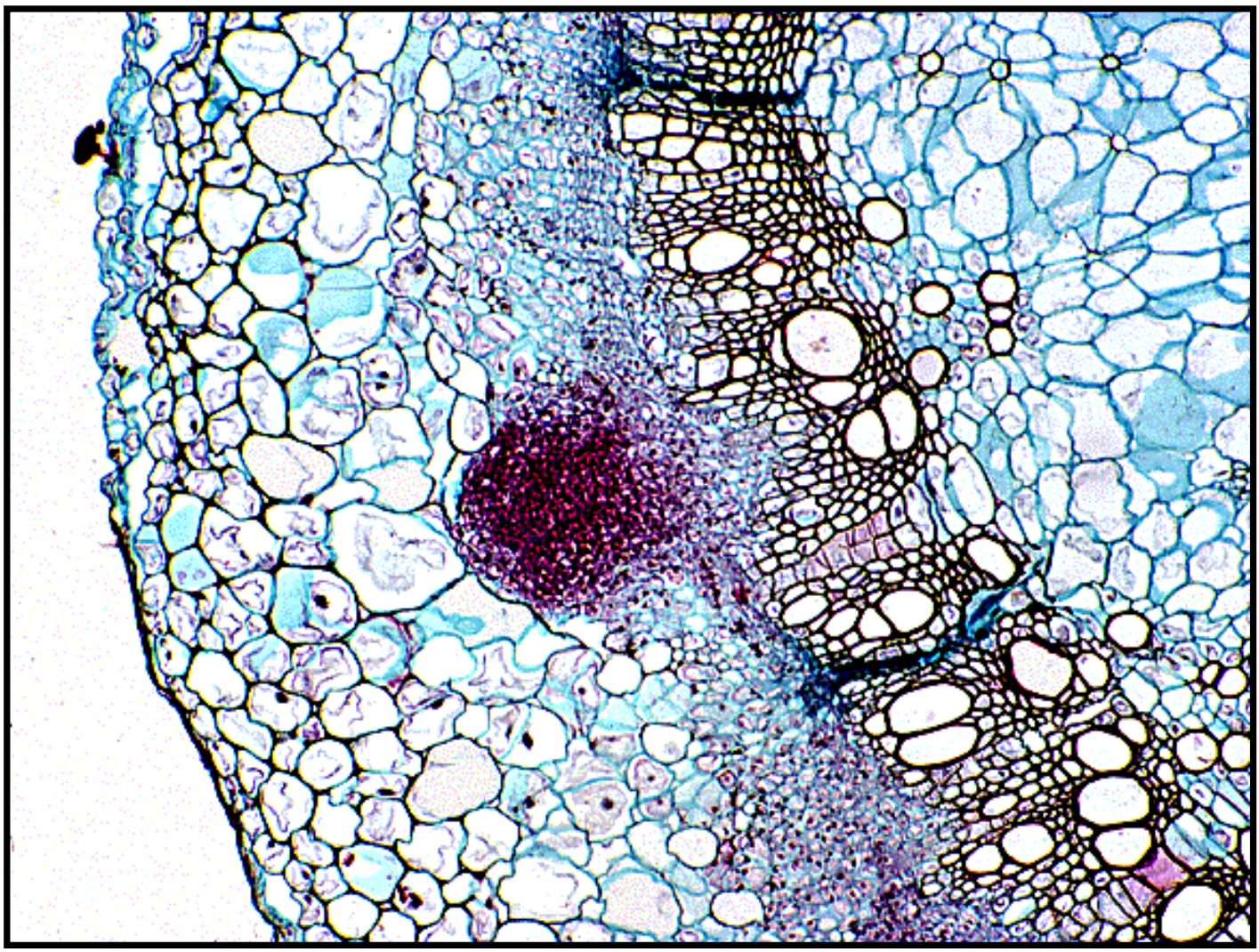
Branch root showing vascular connections with the primary root.

- What happens to the cortex and epidermis when a branch root emerges?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Lycopersicon* with adventitious root primordium



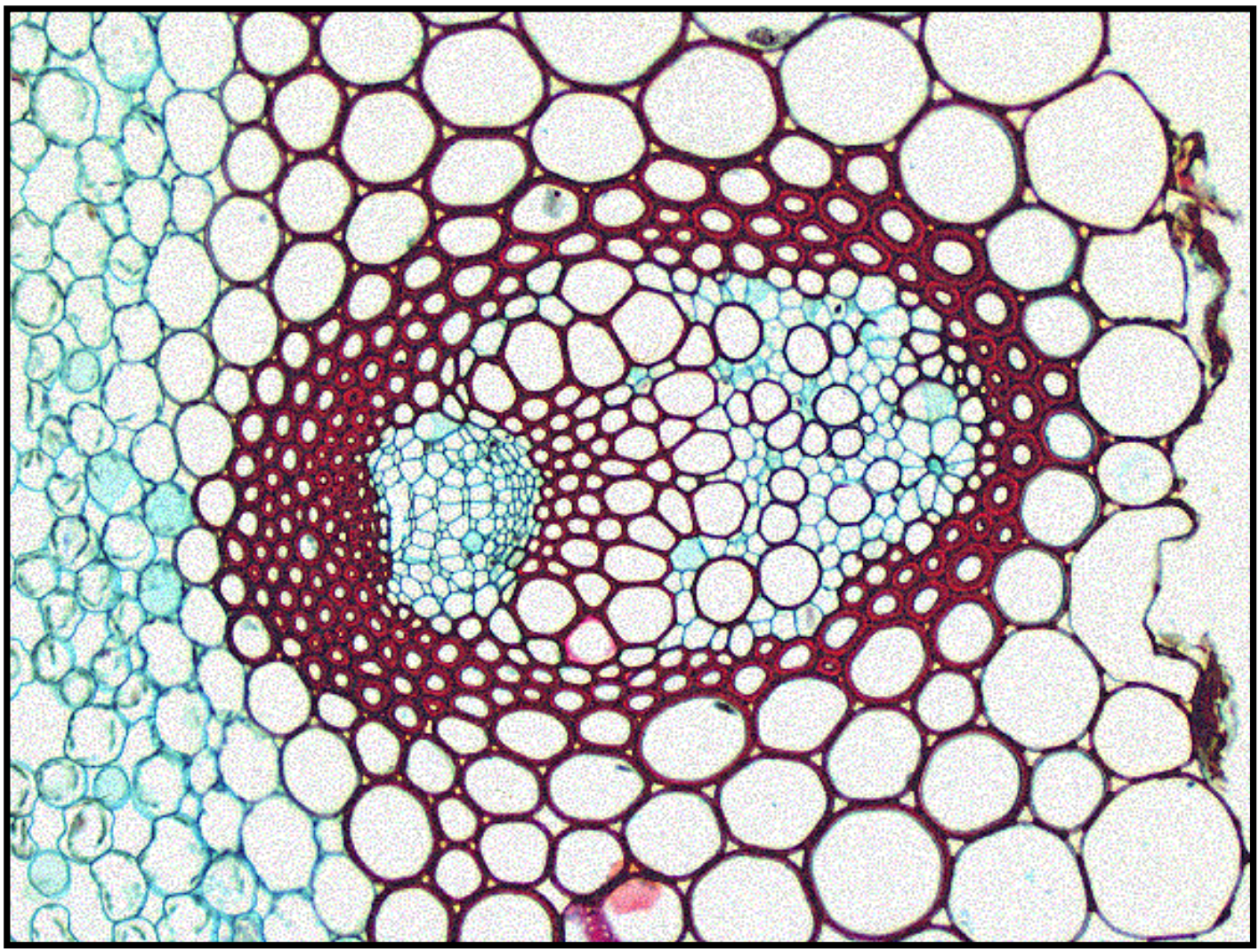
Stem cross section of *Lycopersicon* (tomato).

- Identify the adventitious root primordium.
- In which tissue does it appear to arise?
- What is the difference between a lateral (branch) root and an adventitious root?

Related images:
(None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Vascular bundle from *Ranunculus* stem



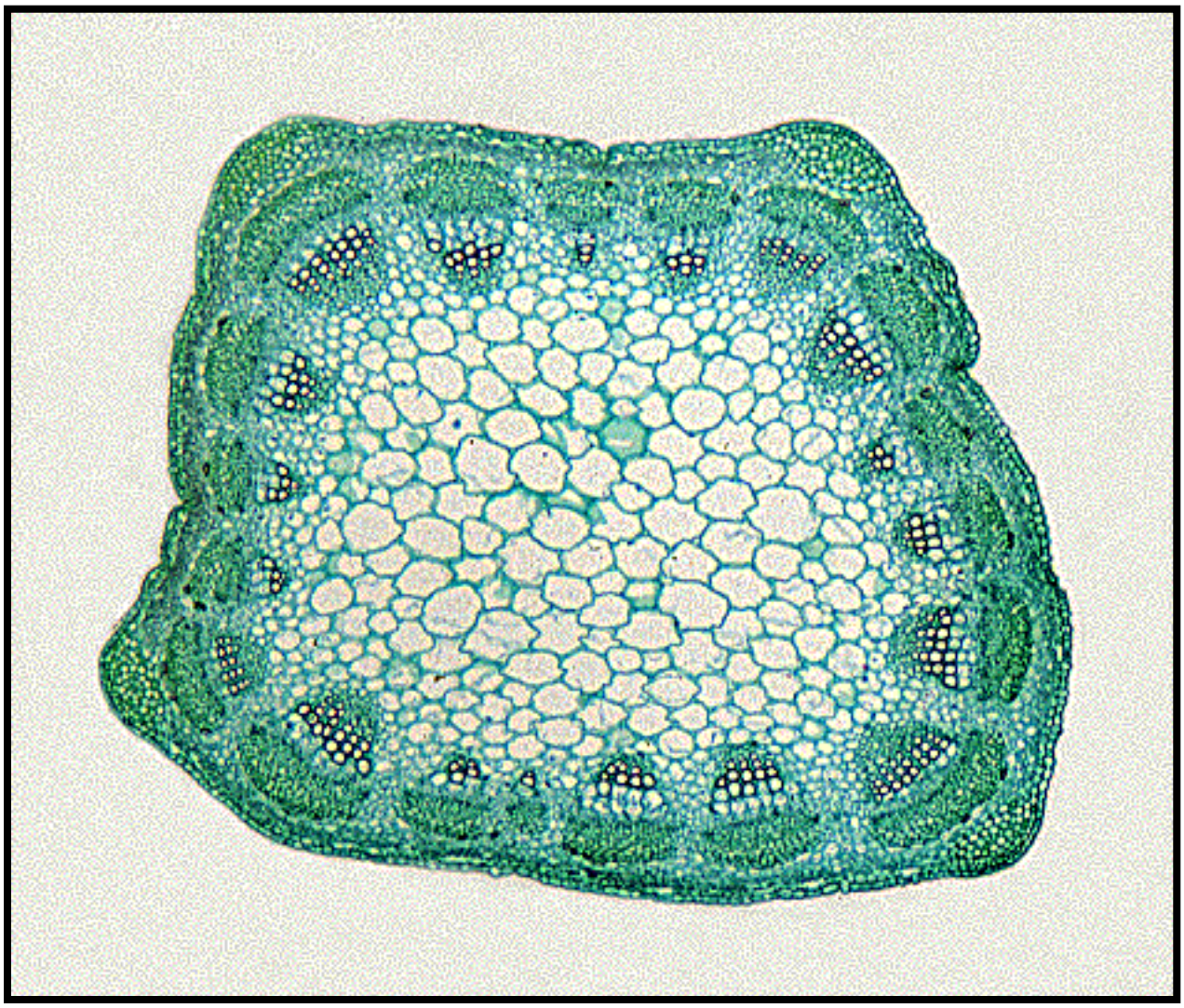
Vascular bundle from *Ranunculus* stem, an herbaceous annual.

- Note the absence of undifferentiated cells between the xylem and phloem and the fibers that completely surround the bundle.
- This plant will never have secondary growth.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Vascular bundles from *Medicago* stem



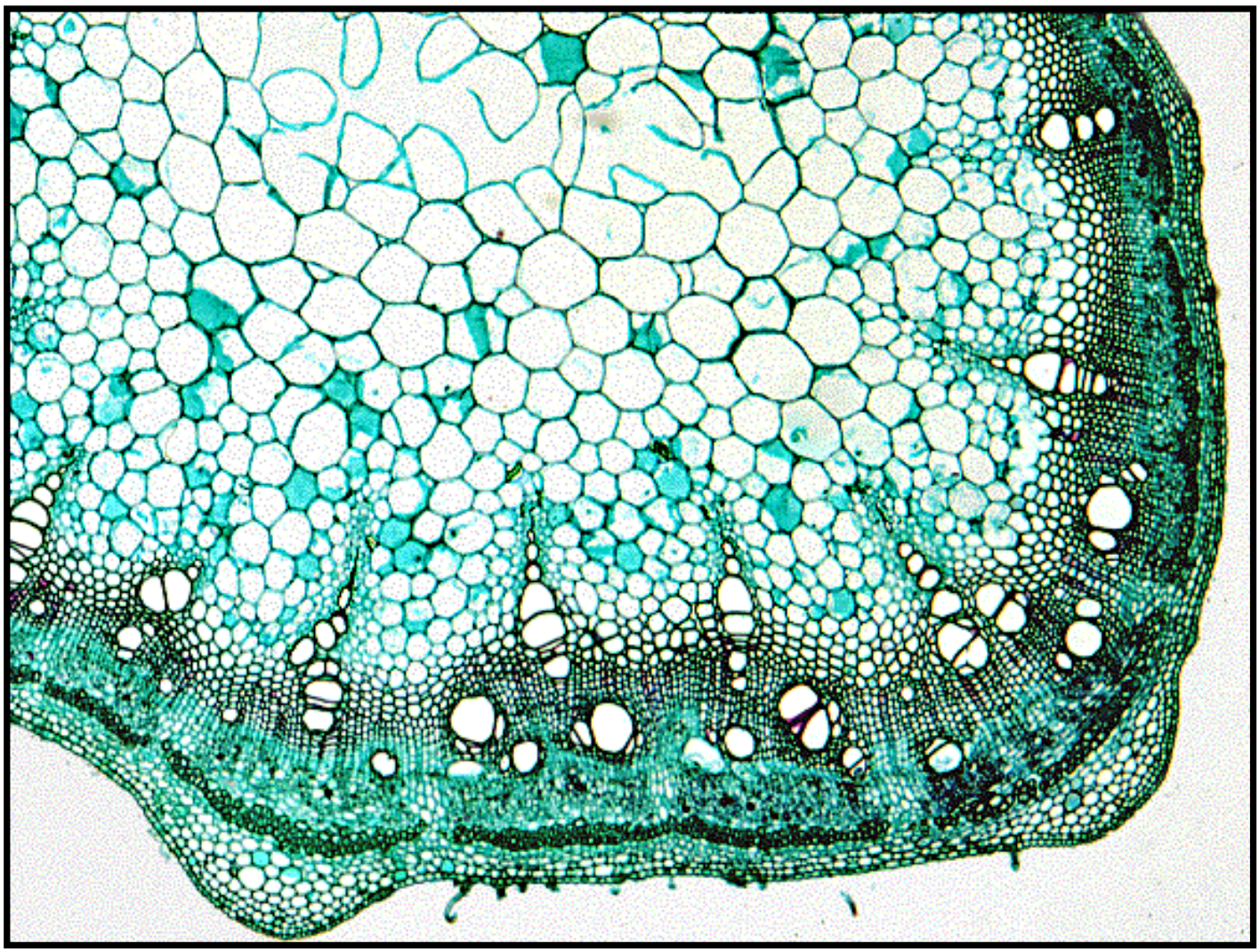
Vascular bundles from the stem of *Medicago* (alfalfa).

- Note the undifferentiated cells between the xylem and phloem in the vascular bundle.
- Some of these cells appear to have undergone periclinal division.
- What is the name of this region of dividing cells?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Stem x.s. of *Phaseolus*



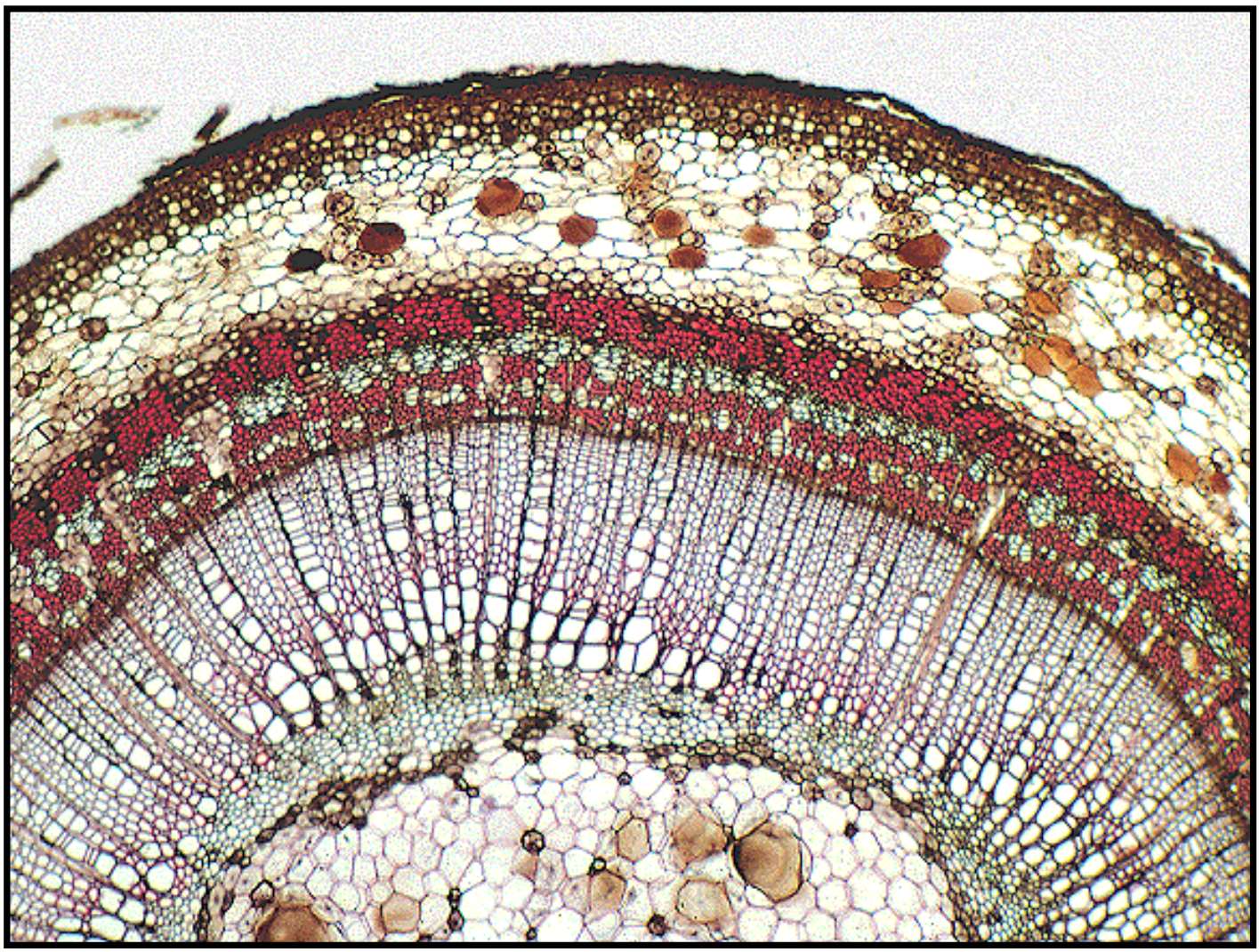
Stem cross-section of *Phaseolus* (common bean) with secondary growth.

- Identify: primary xylem, primary phloem, secondary xylem, secondary phloem, cambial zone.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

One-year-old stem of *Tilia*



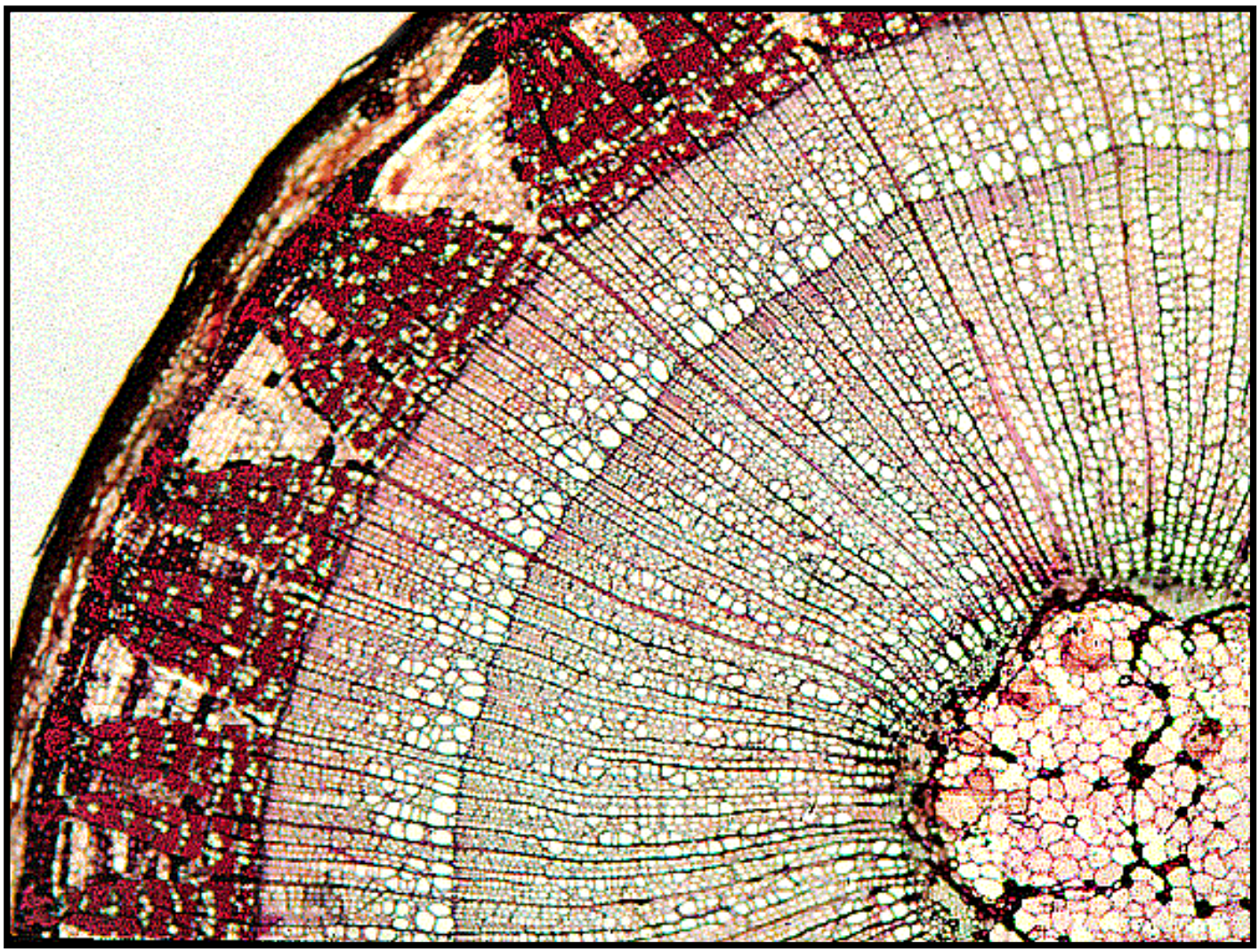
One-year-old stem of *Tilia* (linden).

- Identify: pith, xylem rays, axial vessels, phloem rays (dilated), phloem fibers, conducting cells of the phloem, cambial zone, cortex, cork.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Two-year-old stem of *Tilia*



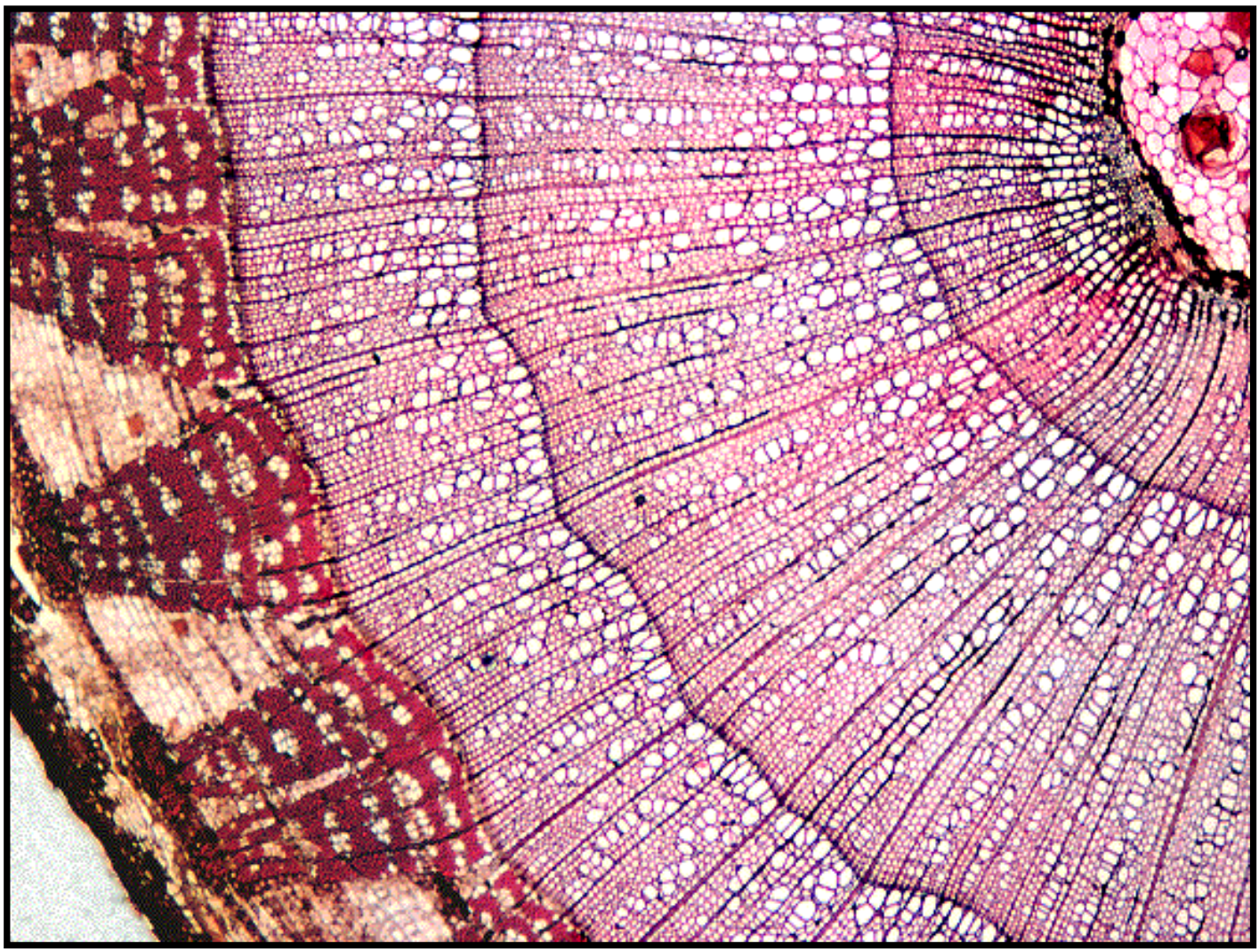
Two-year-old stem of *Tilia*.

- Identify annual rings.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Three-year-old stem of *Tilia*



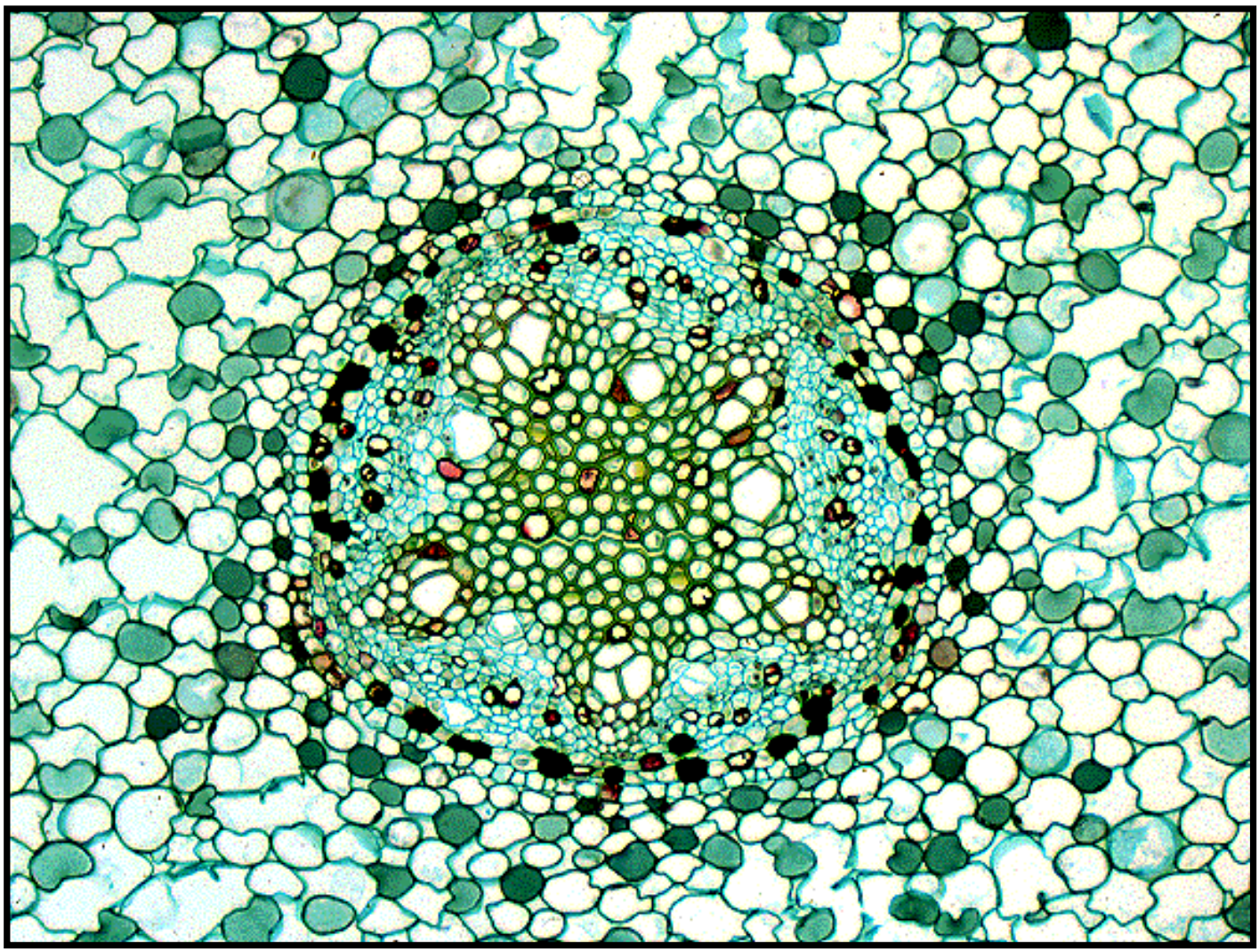
Cross section from three-year-old stem of *Tilia* sp. (linden or basswood tree)

- Note that some xylem rays start in the outer annual rings.
- Why does this occur?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Mature primary root stele of *Salix*



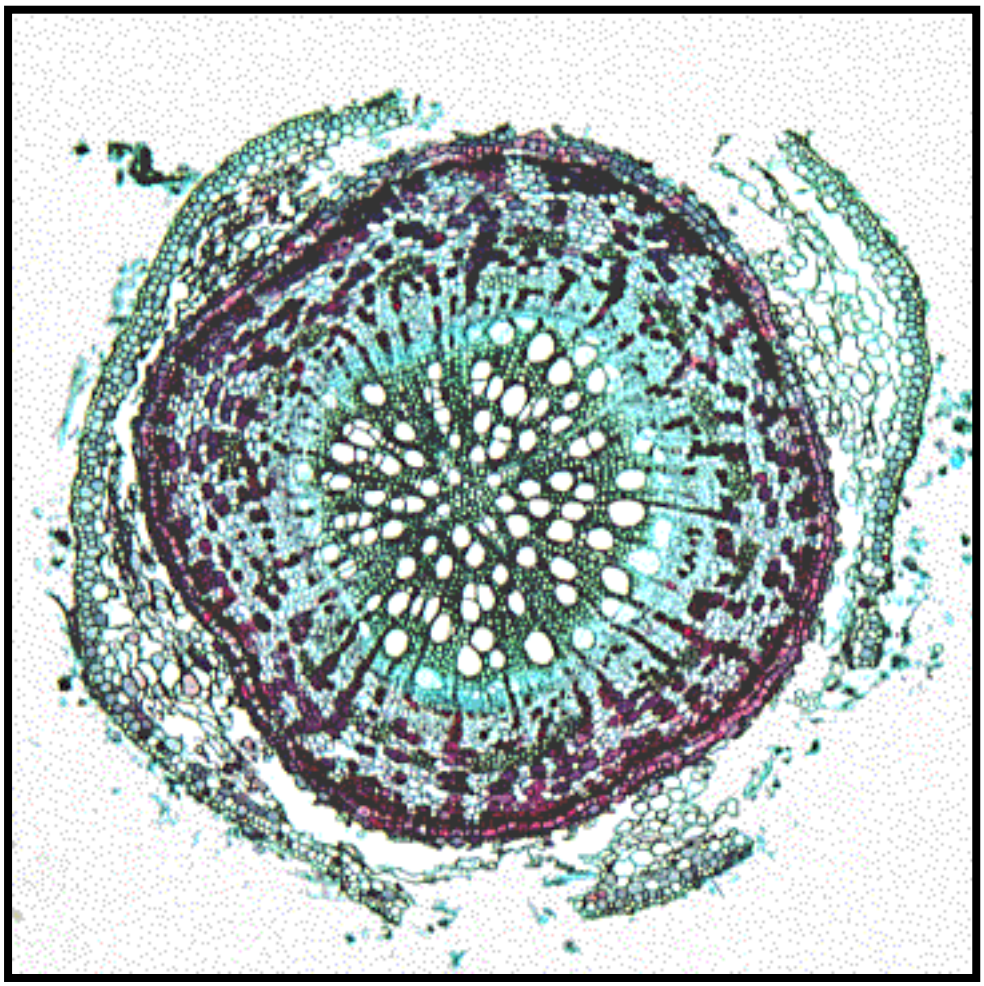
Mature primary root stele of *Salix* (willow).

- Where will the vascular cambium arise?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Secondary root of *Salix*



Secondary root of *Salix*.

- Identify: secondary xylem, secondary phloem, cambial zone, cork, cortex, epidermis.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Secondary stem of *Metasequoia*

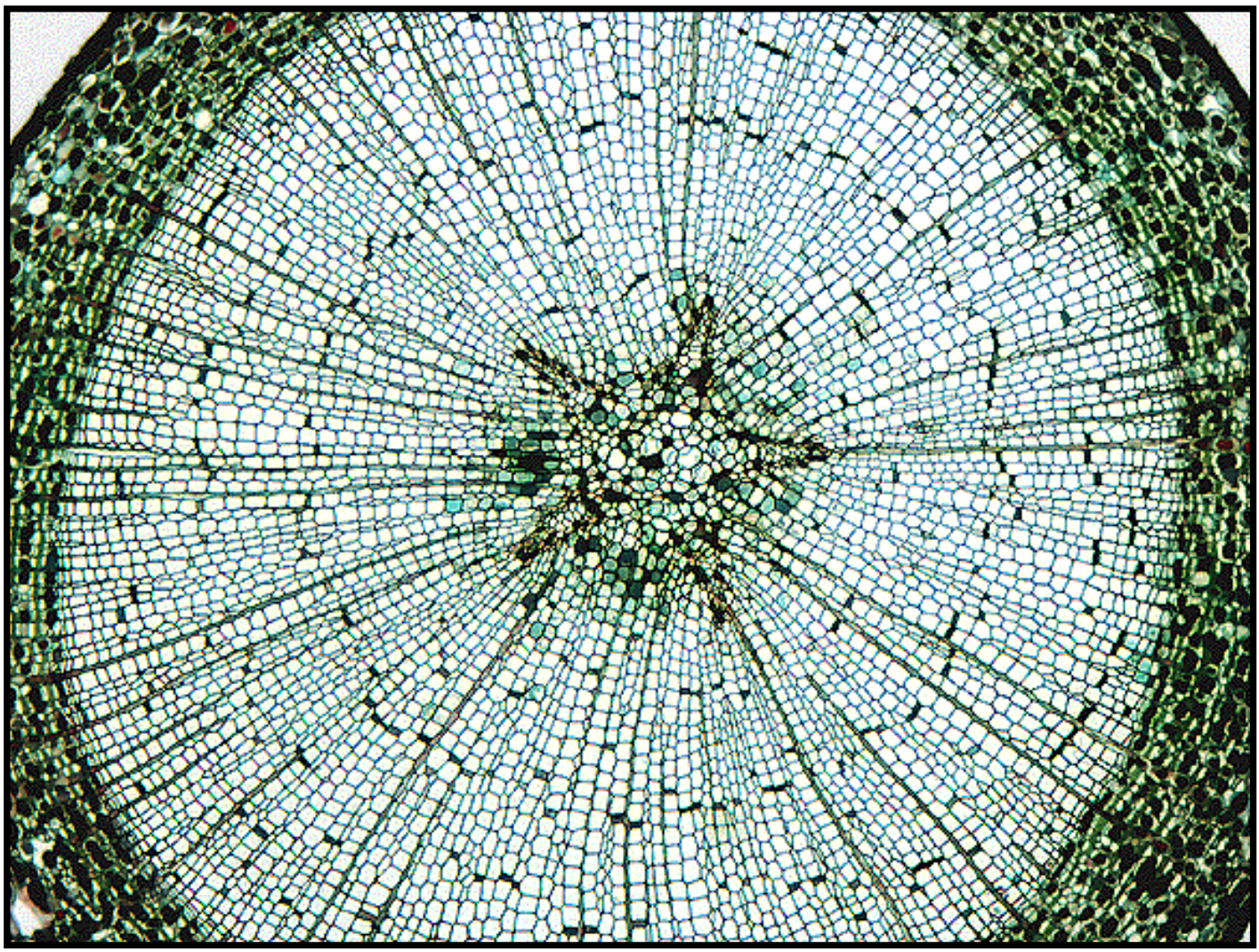
Secondary stem of *Metasequoia*, the "Dawn Redwood".

- Note the pith.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Secondary root of *Metasequoia*



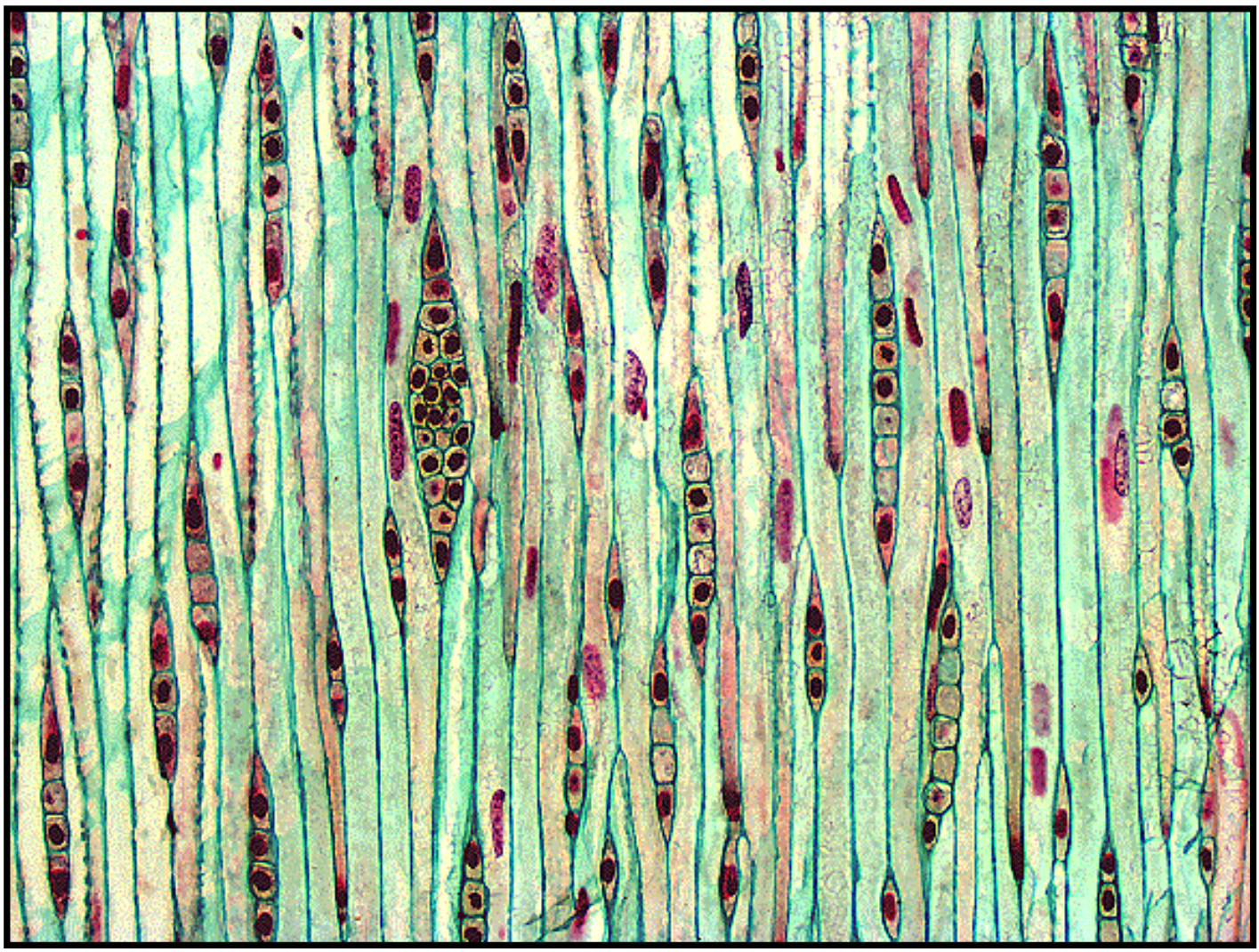
Secondary root of *Metasequoia*, the "Dawn Redwood".

- Note the absence of a pith.
- The pentarch primary xylem is distinguishable.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Cambium from *Pinus*



Cambium from *Pinus*.

- Identify: fusiform initials, ray initials.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Cambium from *Juglans*

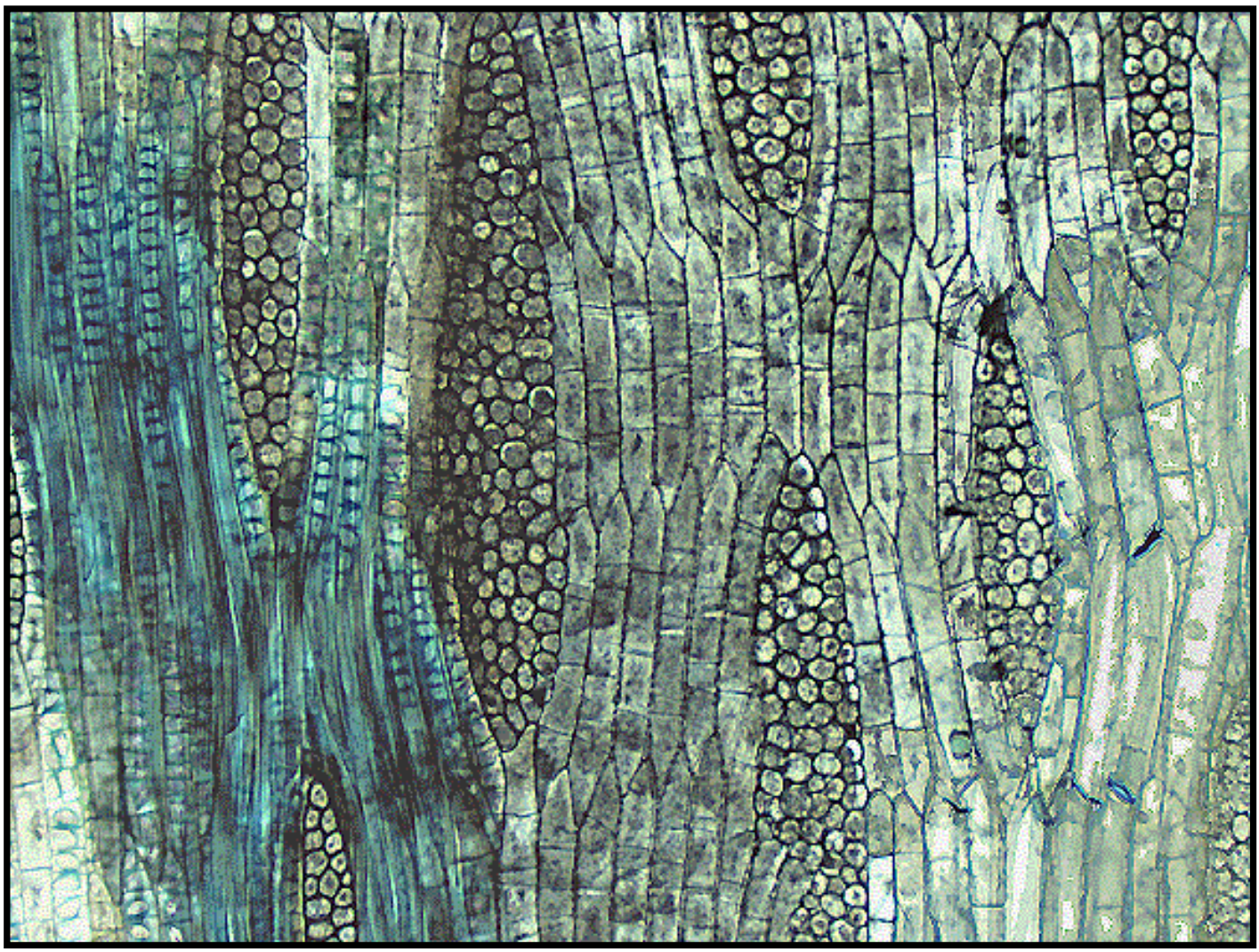
Cambium from *Juglans* (walnut).

- Identify: fusiform initials, ray initials.
- Is this cambium storied or non-storied?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Robinia cambium



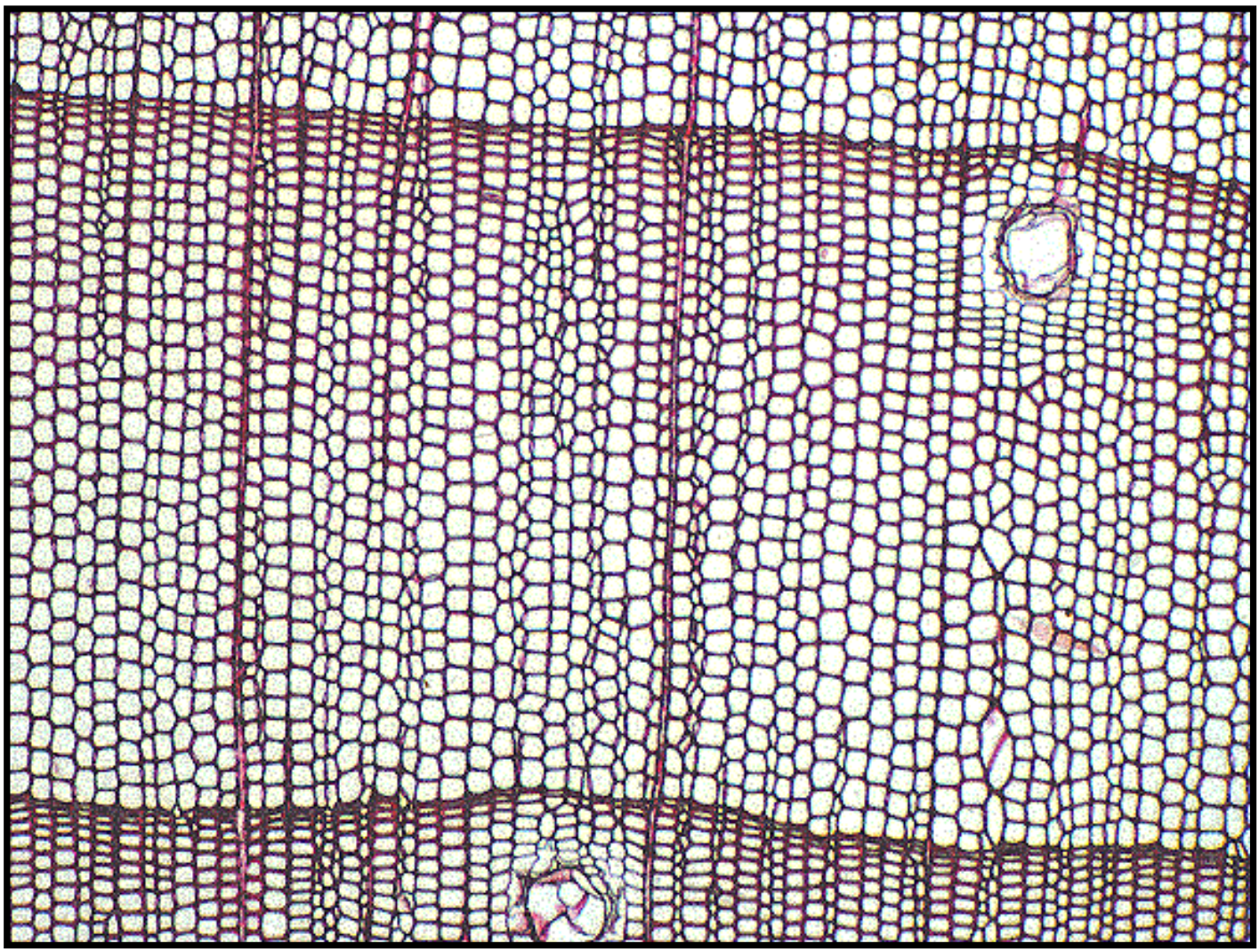
Cambium from *Robinia* (black locust).

- Identify: fusiform initials, ray initials.
- Is this cambium storied or non-storied?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pine wood



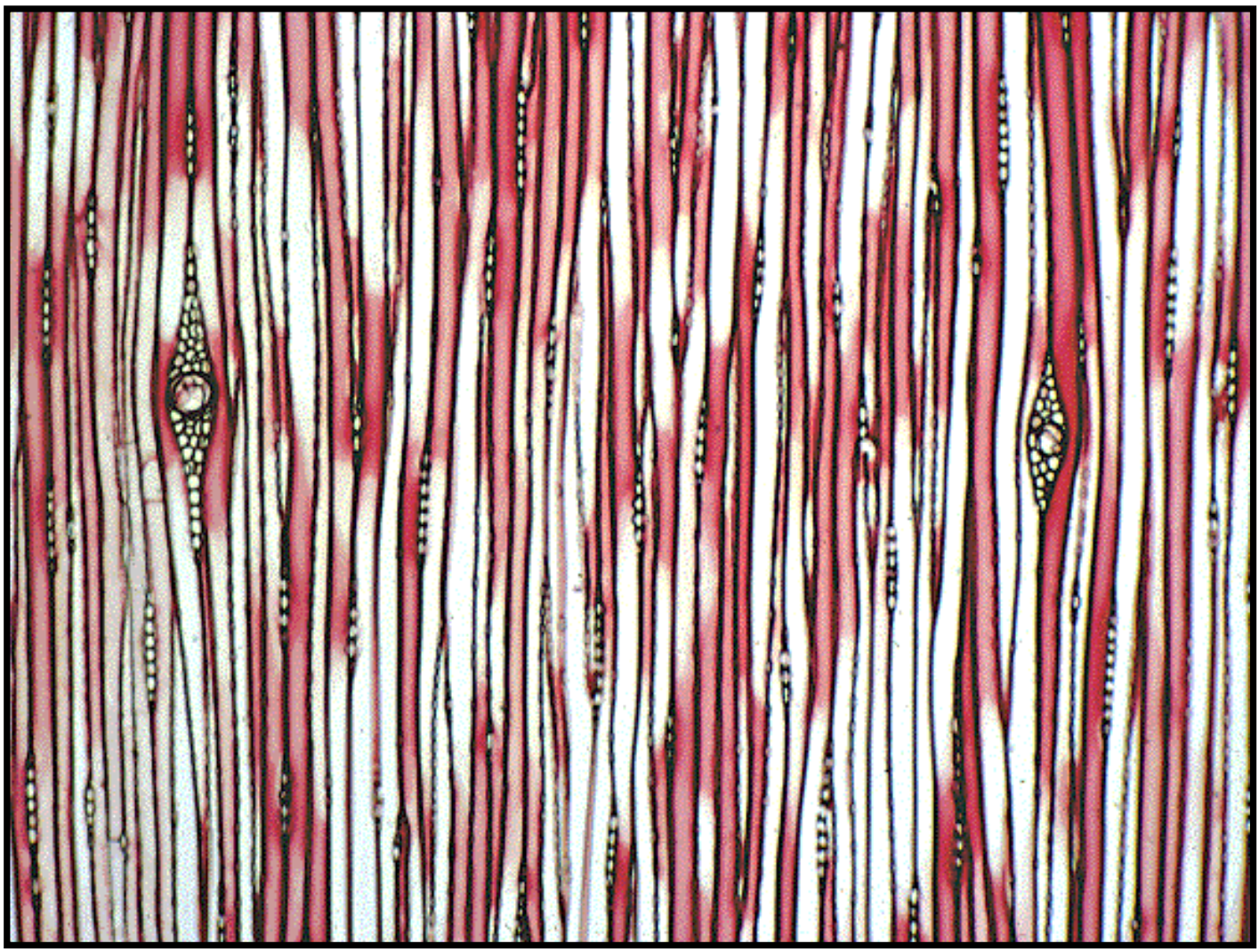
Pine wood.

- Identify annual rings and resin ducts.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pine wood



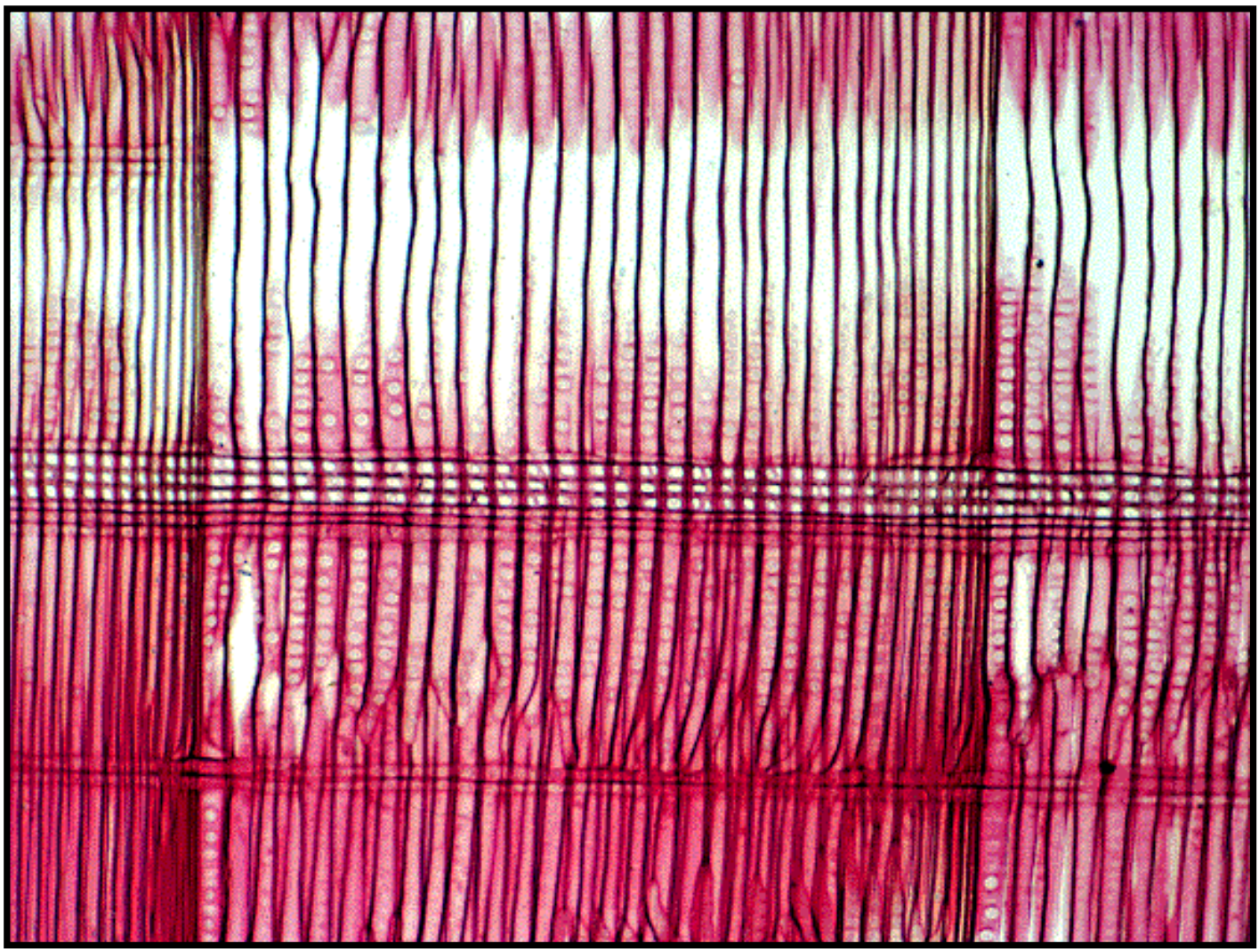
Pine wood showing rays.

- Are rays uniseriate or multiseriate?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pine wood showing bordered pits



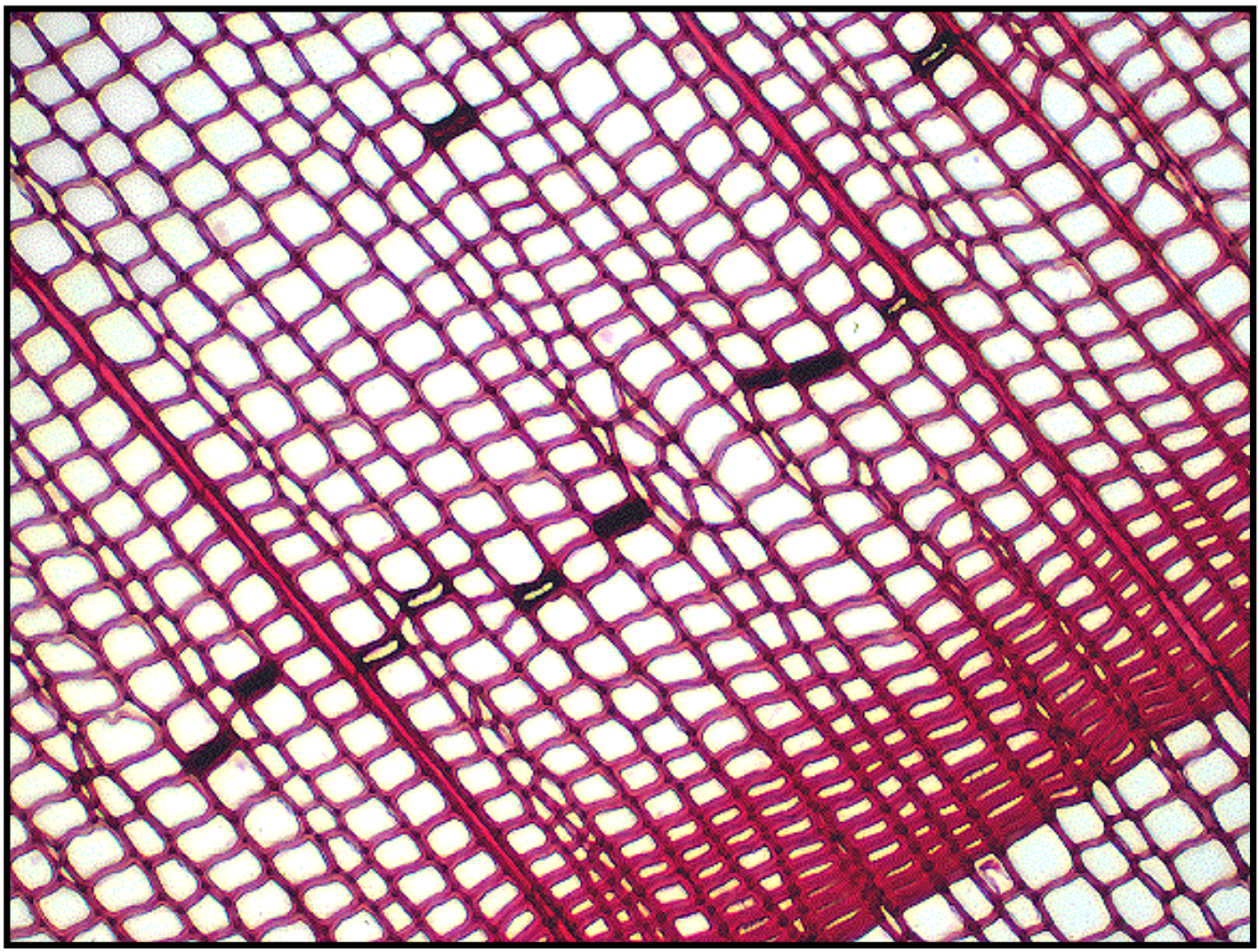
Pine wood.

- Identify bordered pits.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Chaemaecyparus wood



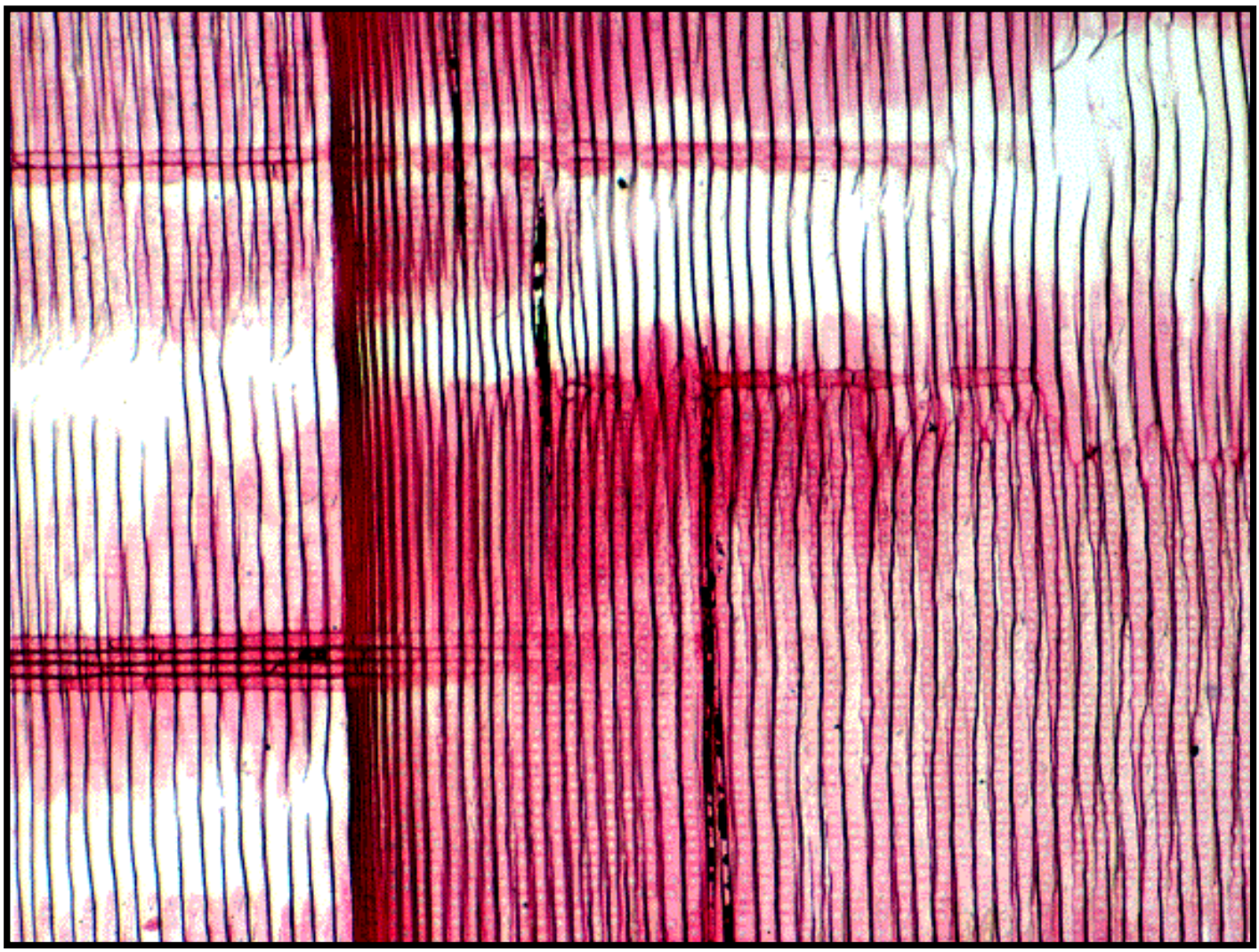
Chaemaecyparus wood.

- This is a gymosperm--what is unusual about it?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Chaemaecyparus wood



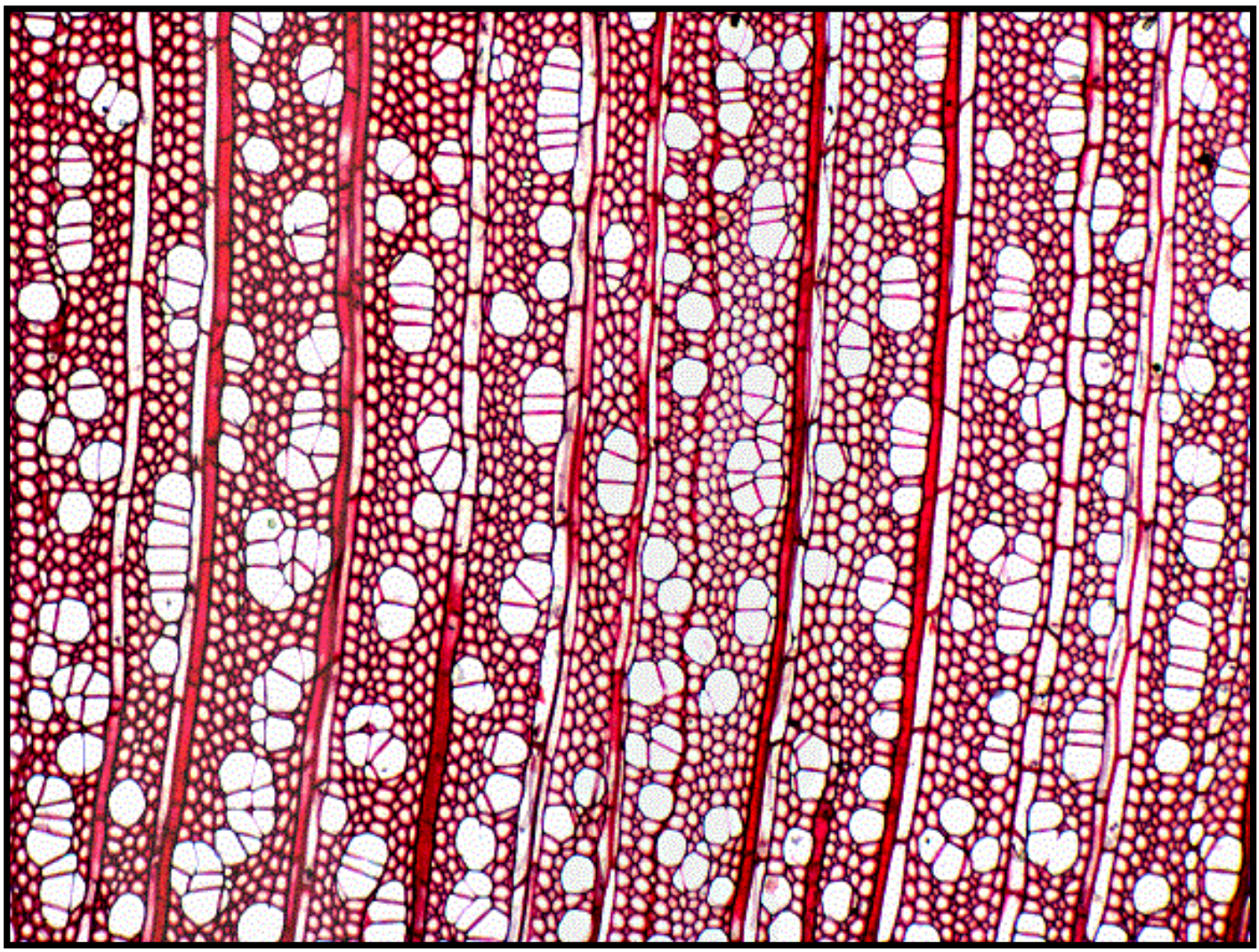
Chaemaecyparus wood.

- Identify axial parenchyma, axial tracheids with bordered pits.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Magnolia wood



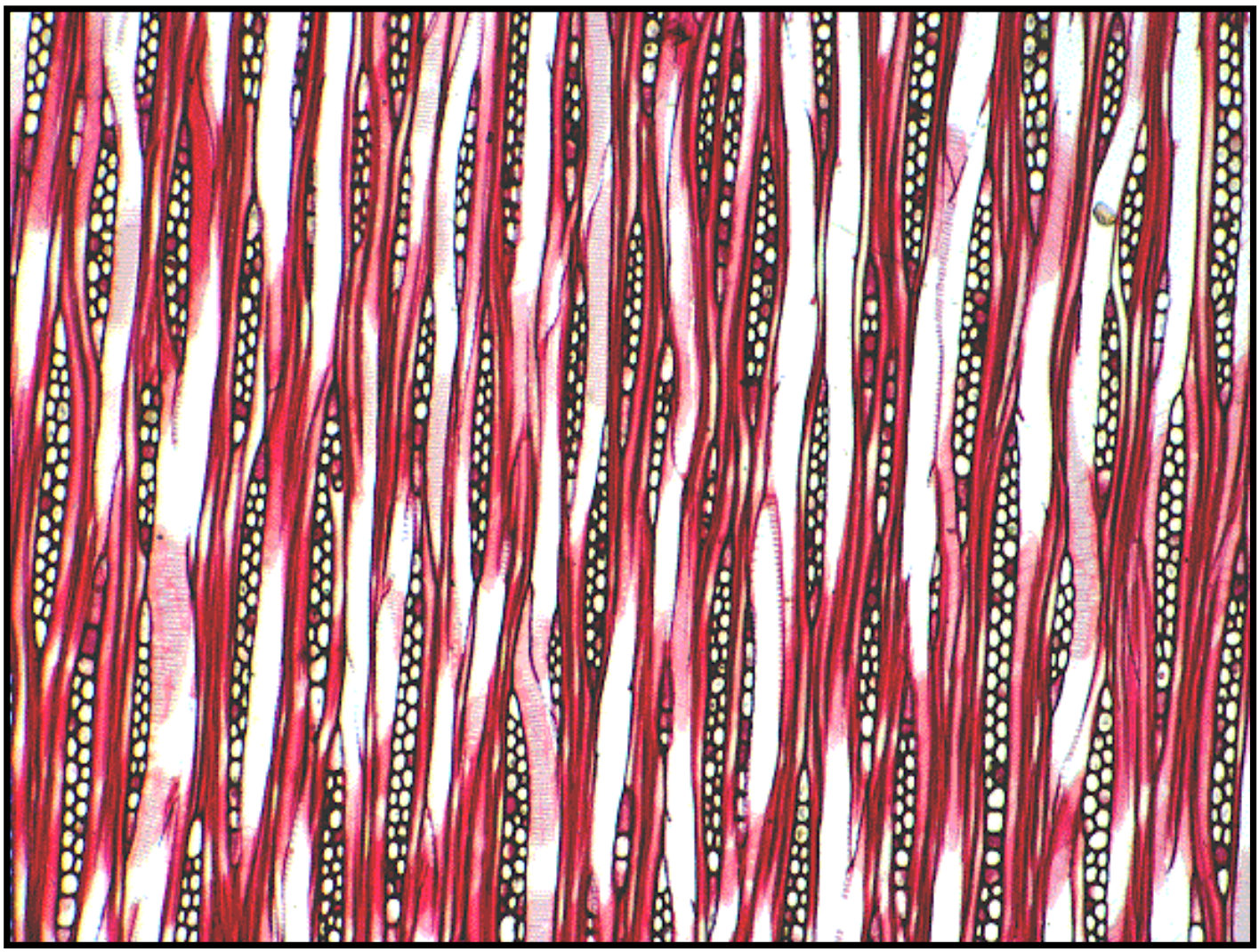
Magnolia wood.

- Is this wood ring porous or diffuse porous?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Magnolia wood



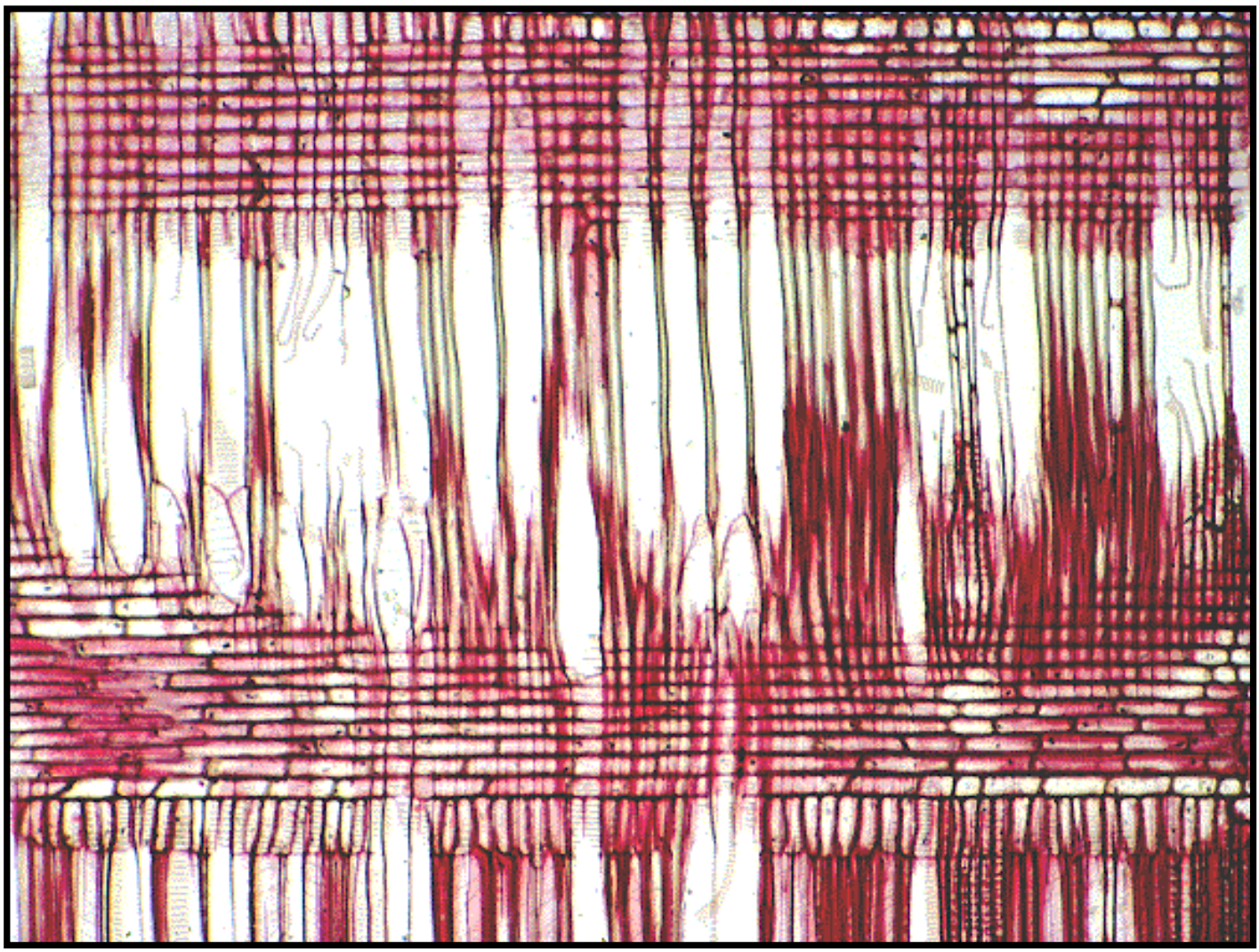
Magnolia wood.

- Identify: axial vessels, rays.
- Are the rays uniseriate or multiseriate?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Magnolia wood



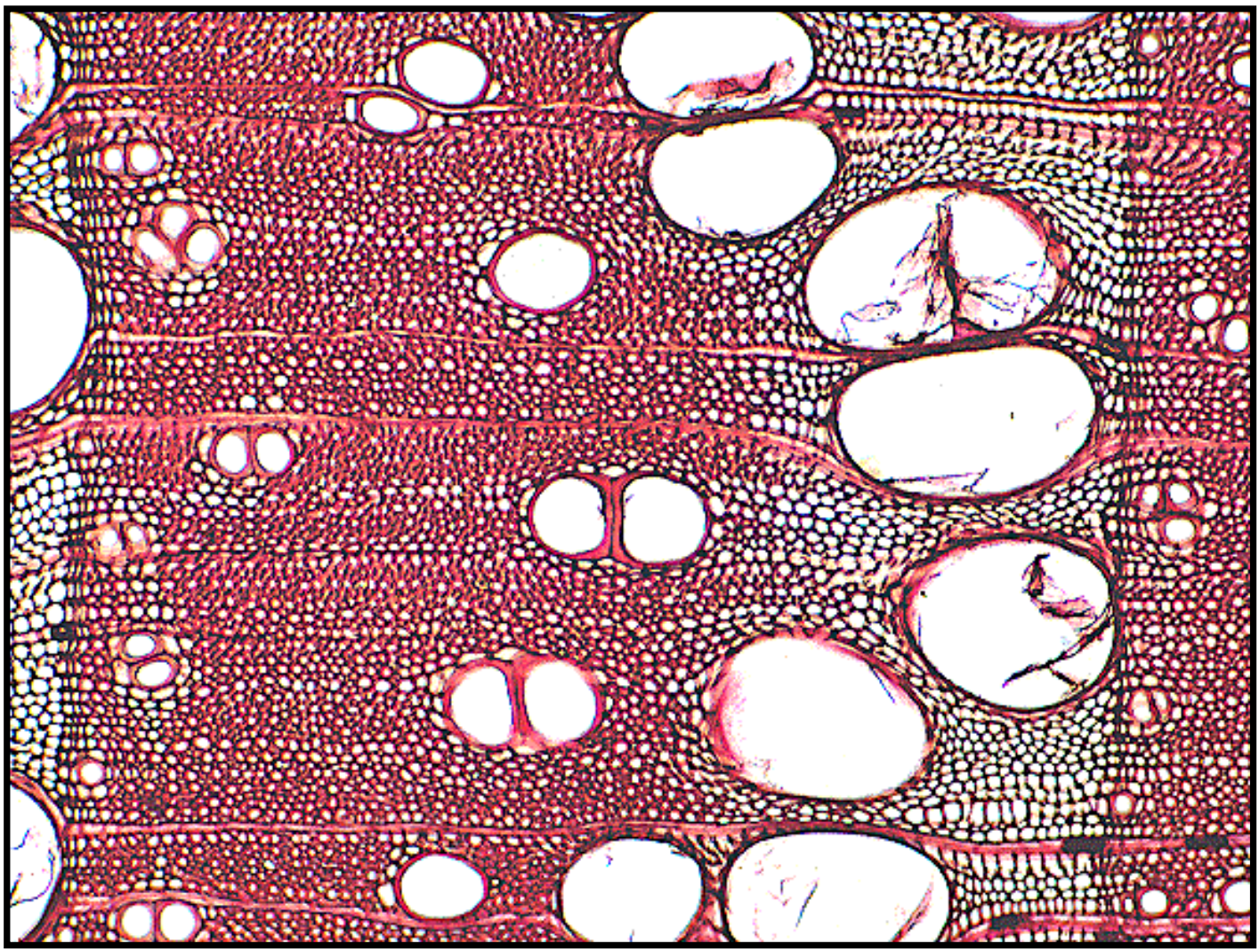
Magnolia wood.

- Identify: axial vessels, scalariform perforation plates, rays, procumbent cells, upright cells.
- Are the rays homocellular or heterocellular?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Ash wood



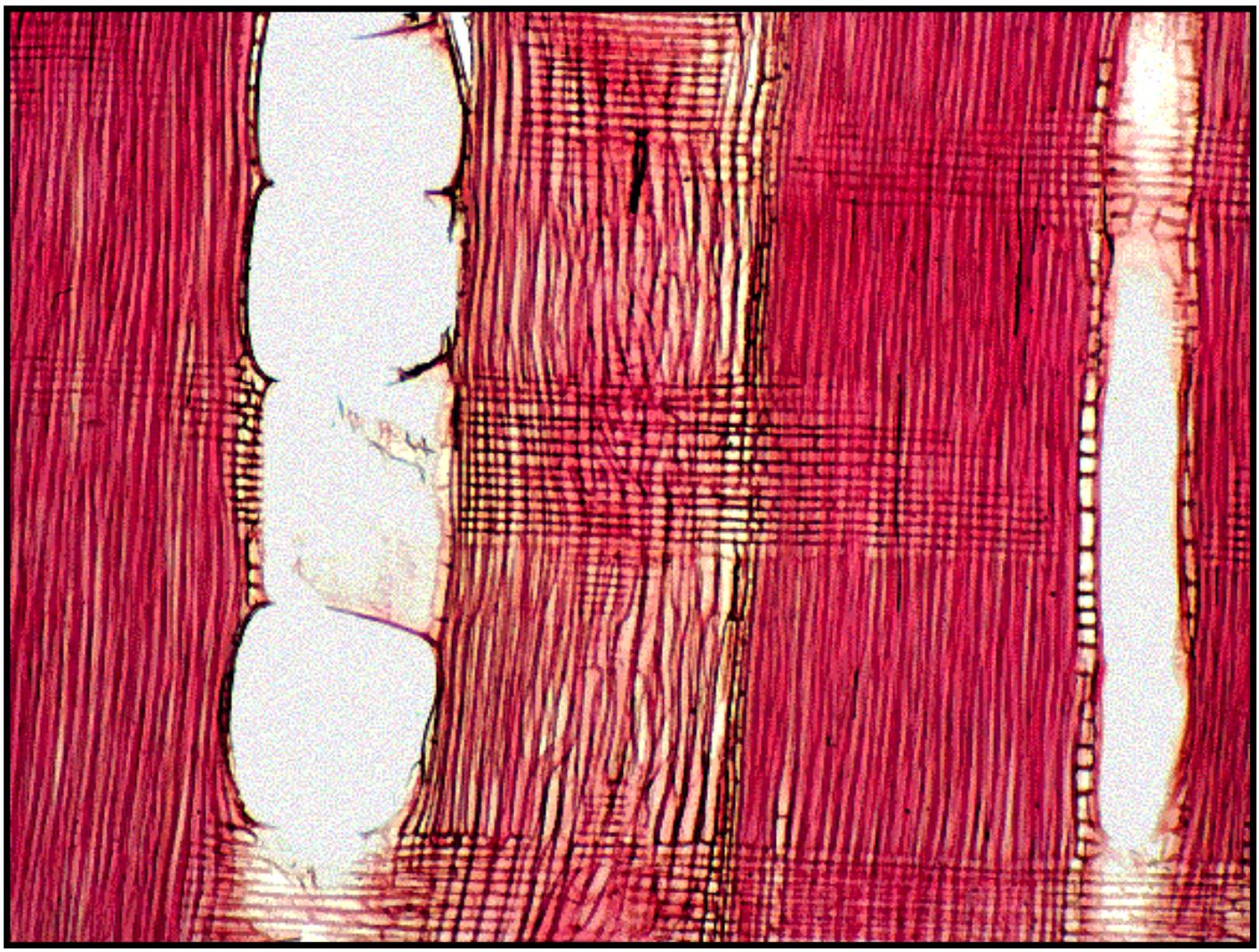
Ash wood.

- Identify: axial vessels, rays, spring wood, summer wood.
- Is this wood ring porous or diffuse porous?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Ash wood



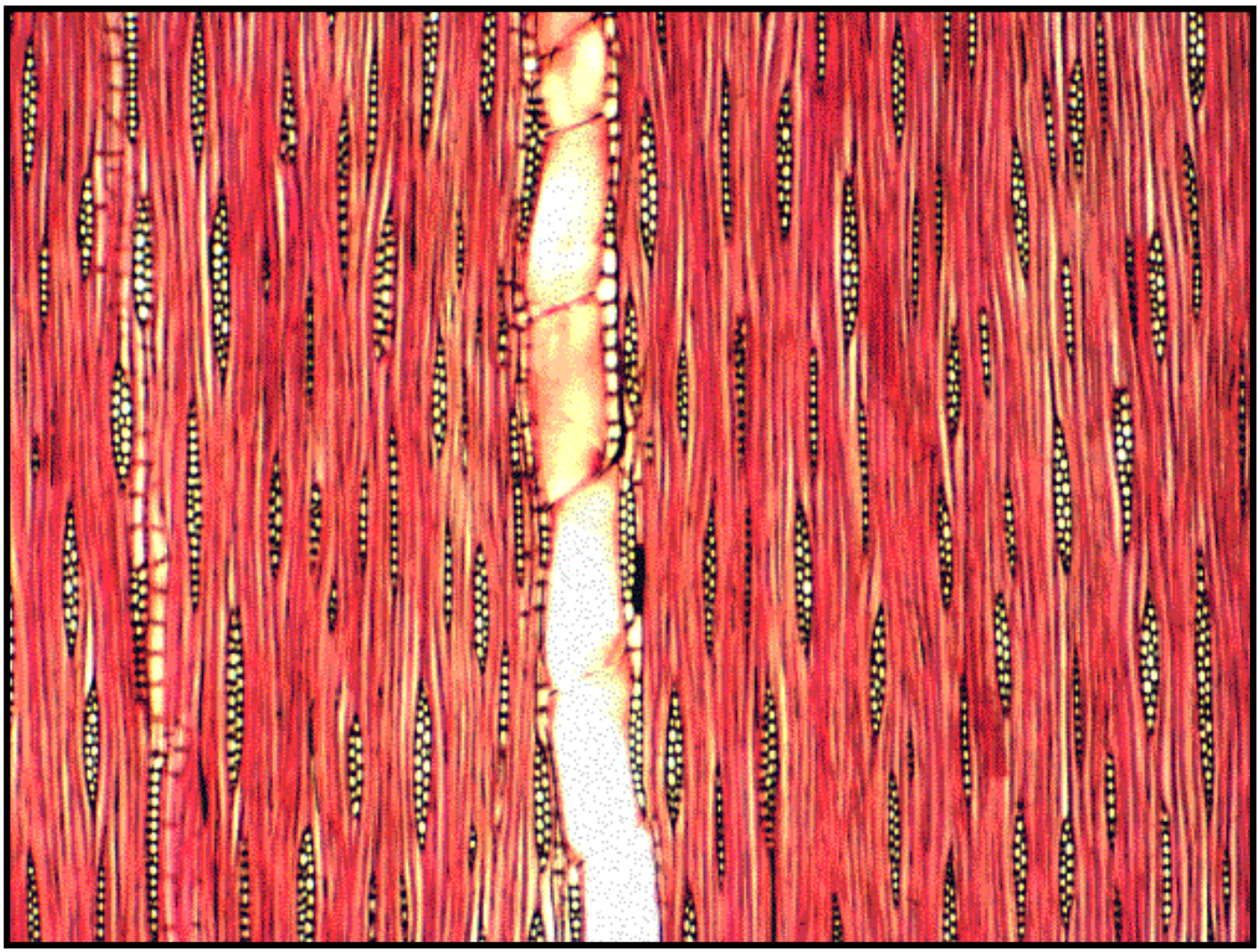
Ash wood.

- Identify: axial vessels, simple perforation plates, uniseriate rays, multiseriate rays.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Ash wood



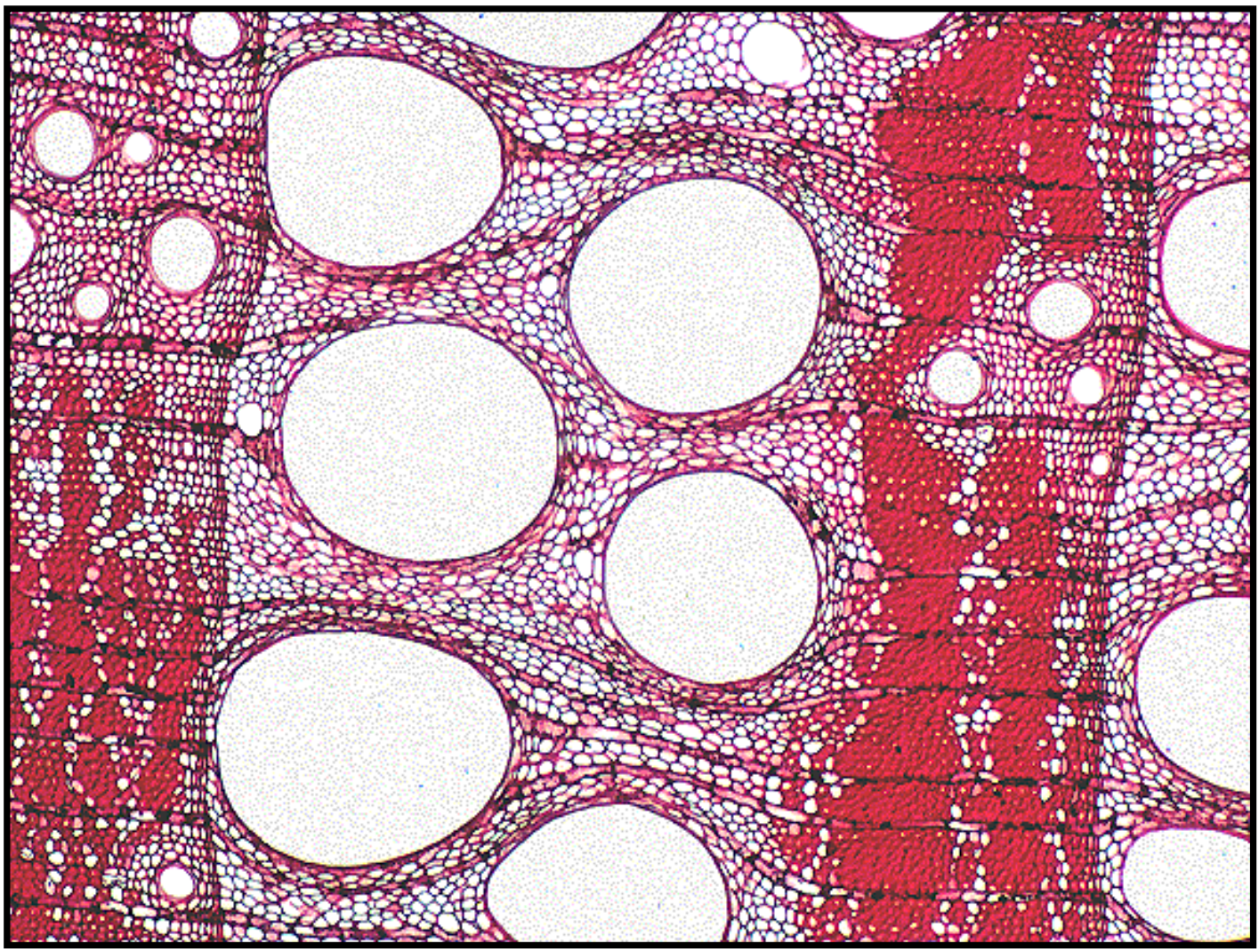
Ash wood.

- Identify: axial vessels, simple perforation plates, rays.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Red oak wood



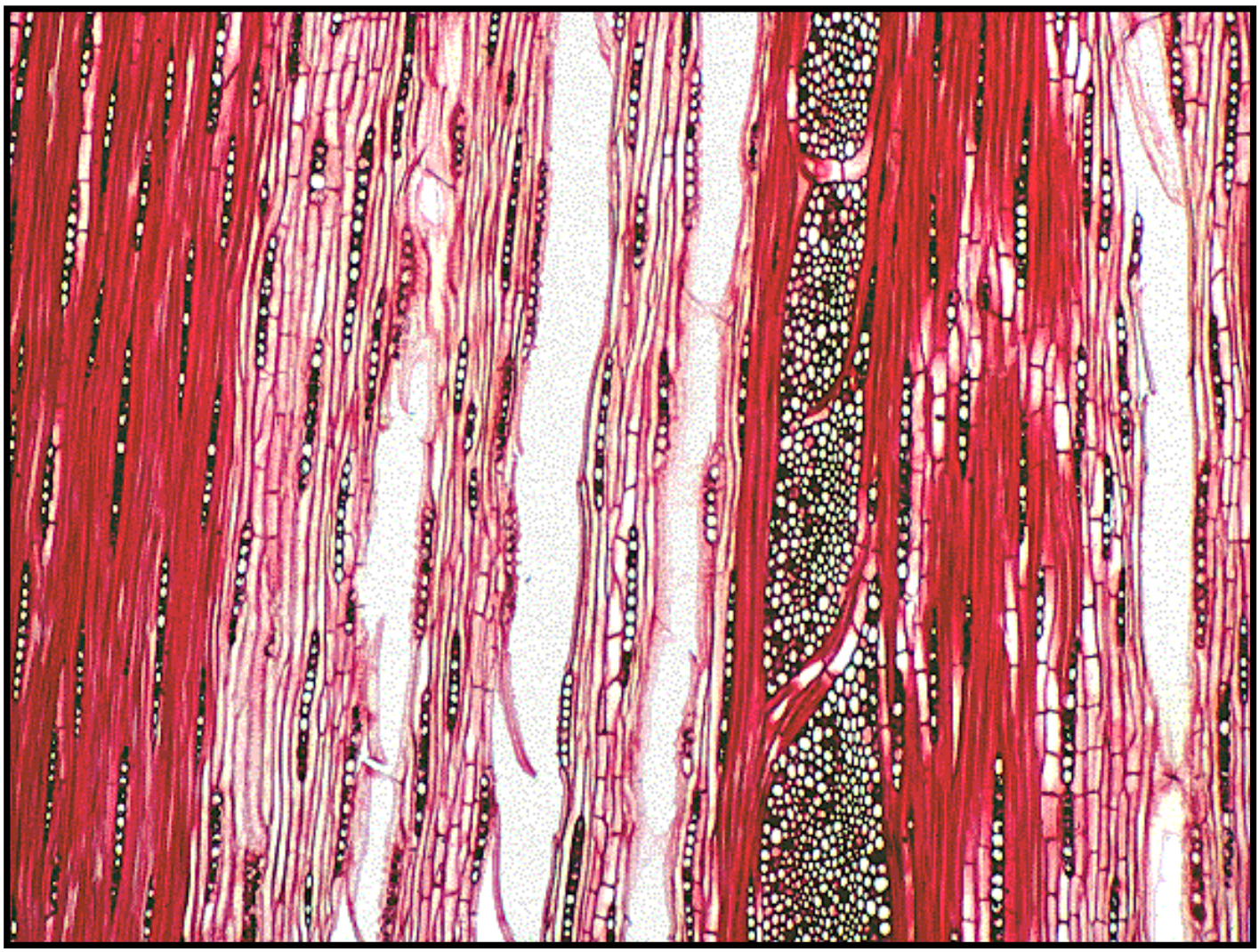
Red oak wood.

- Identify: axial fibers, axial vessels, rays, annual rings.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Red oak wood



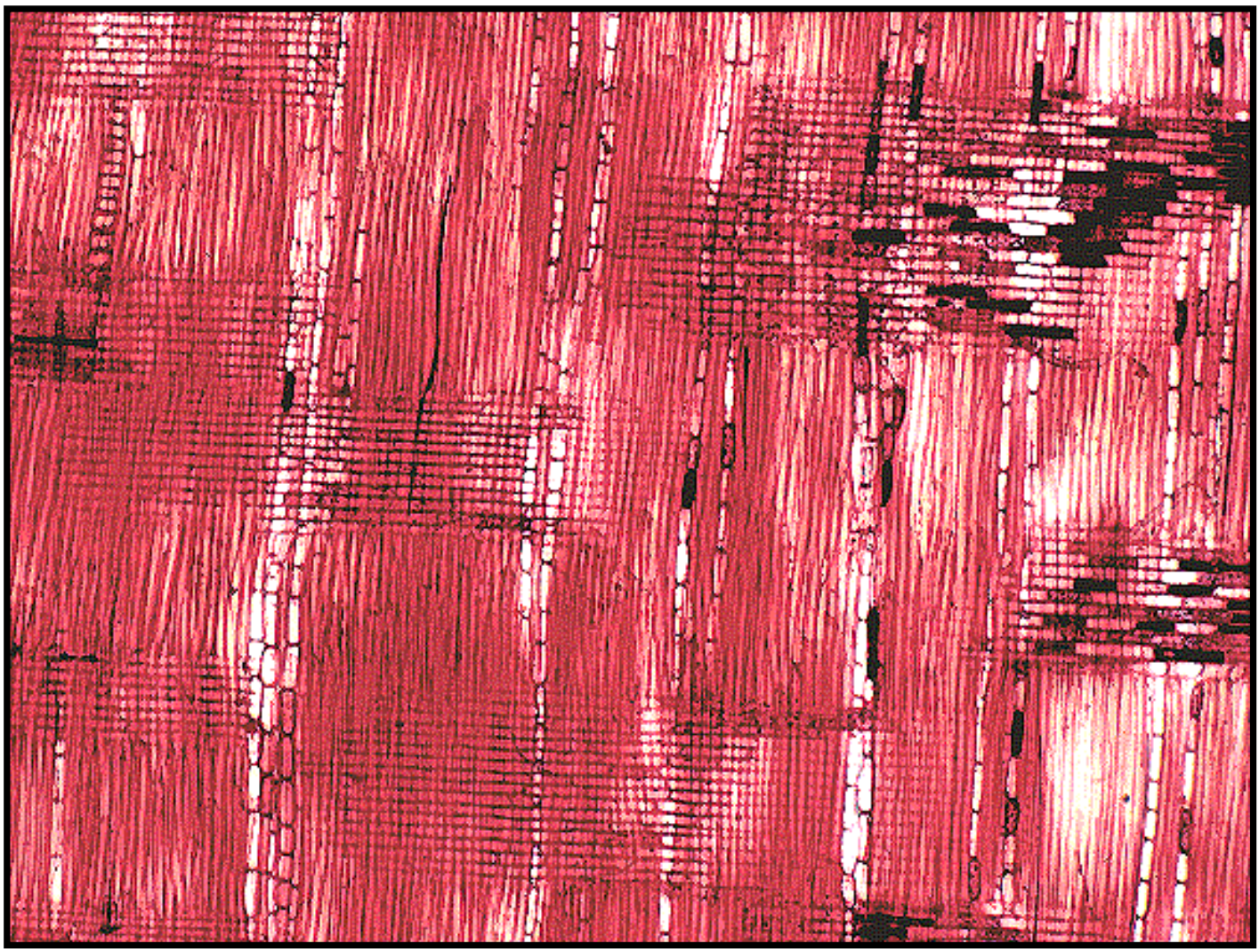
Red oak wood.

- Identify: axial vessels, uniseriate rays, multiseriate ray.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

White oak wood



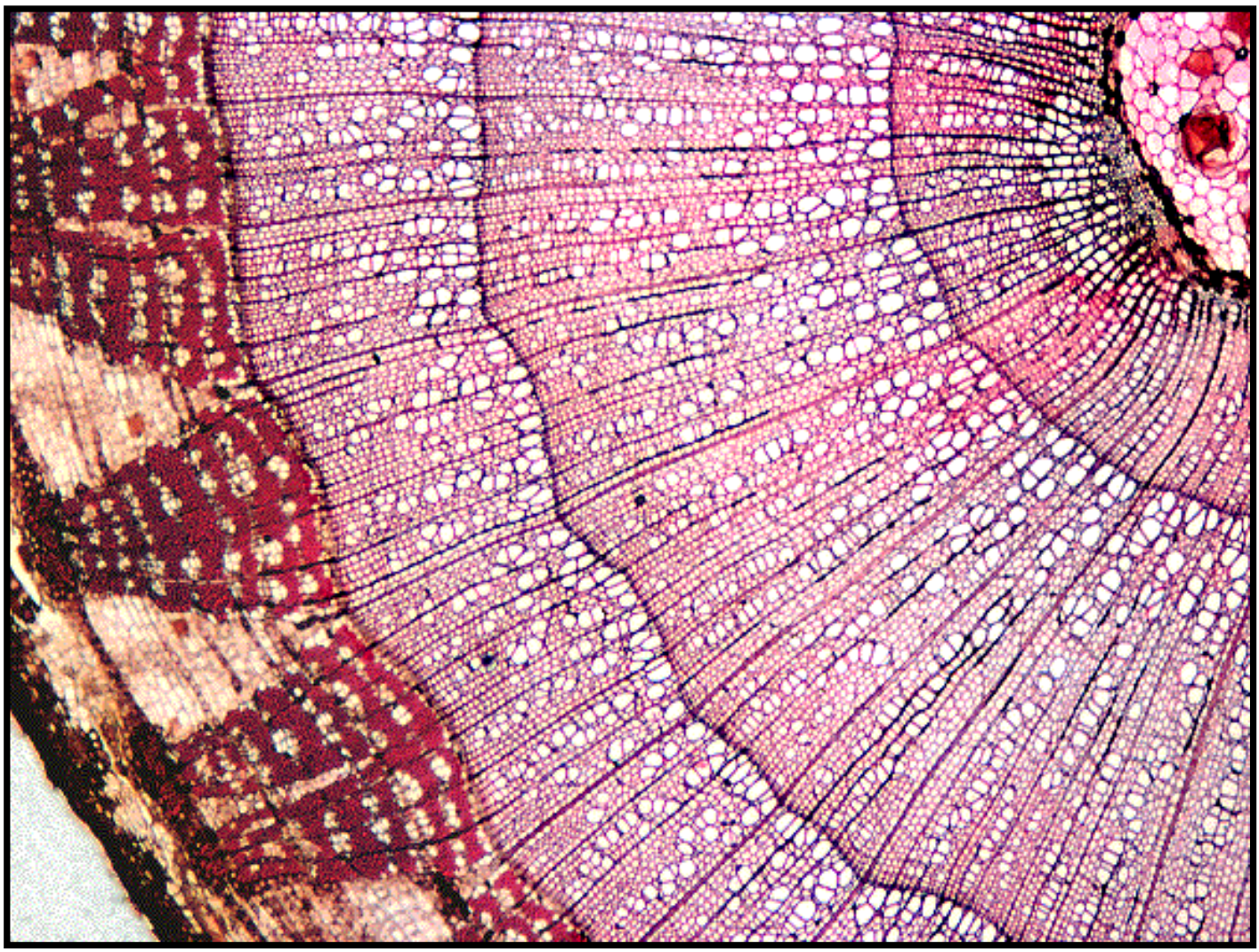
White oak wood

- Identify: ray parenchyma, axial parenchyma.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Three year old *Tilia* stem

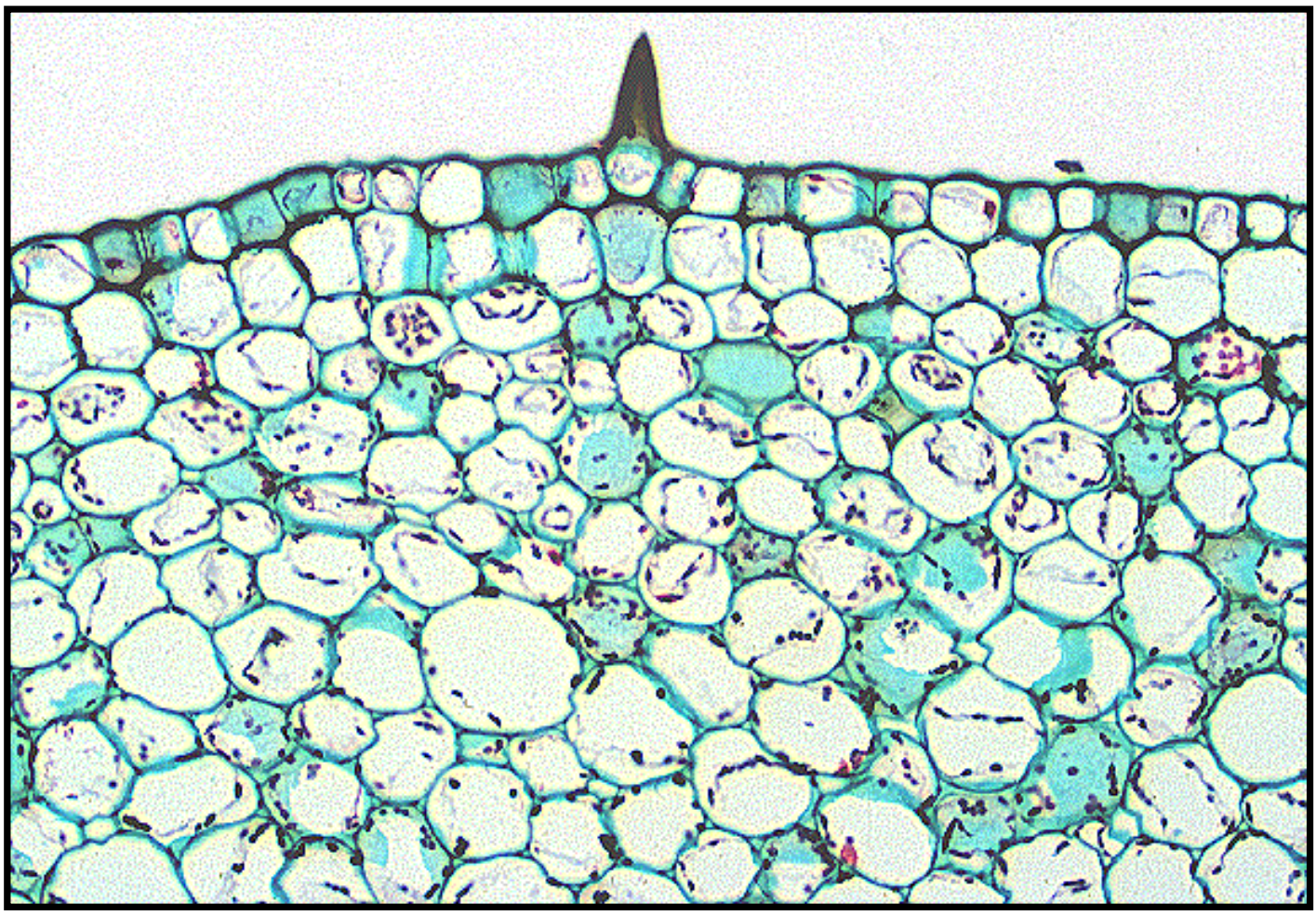


Three year old *Tilia* stem.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pelargonium stem showing primary growth only



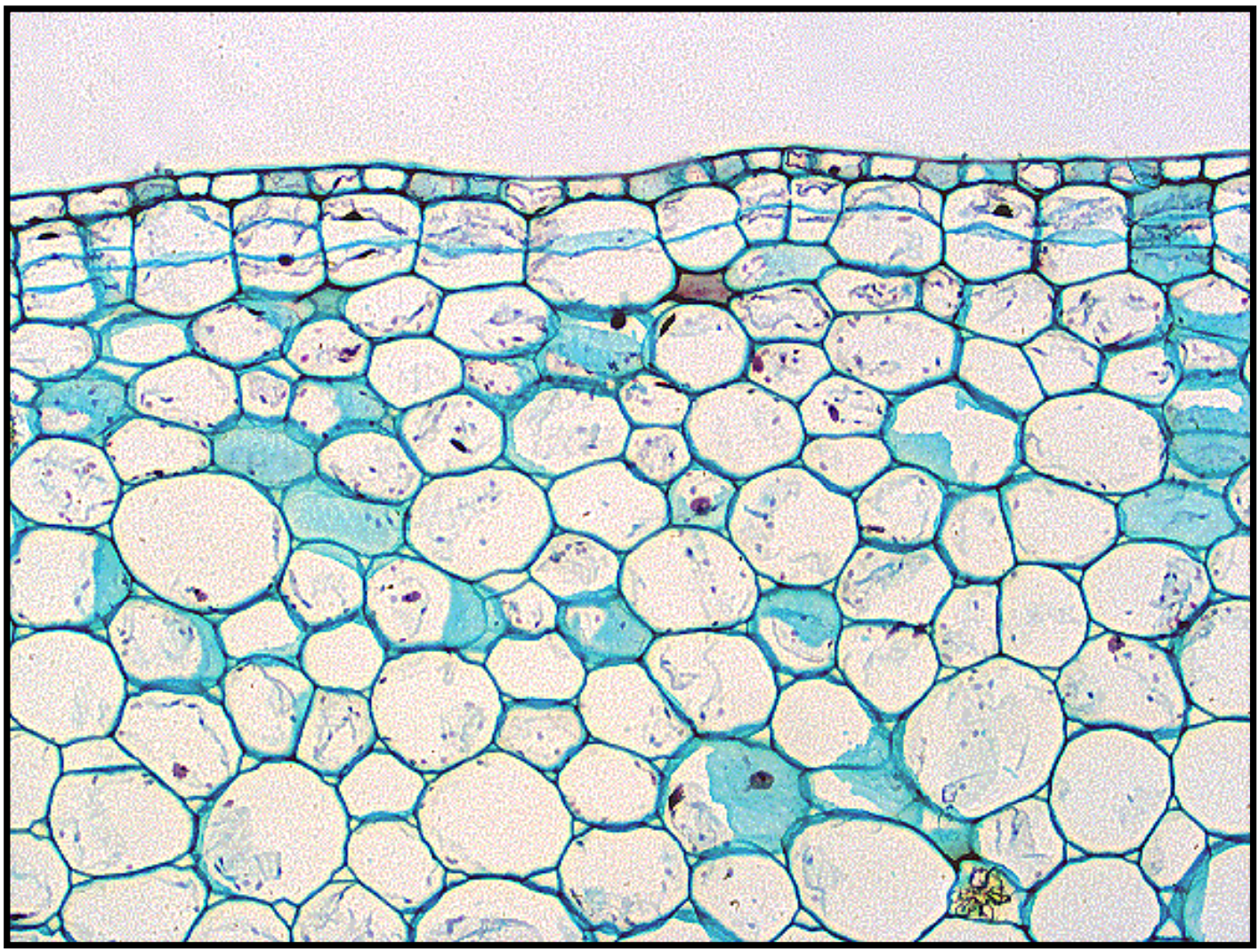
Pelargonium (Geranium) stem showing primary growth only.

- Identify the epidermis.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Initiation of cork cambium in *Pelargonium*



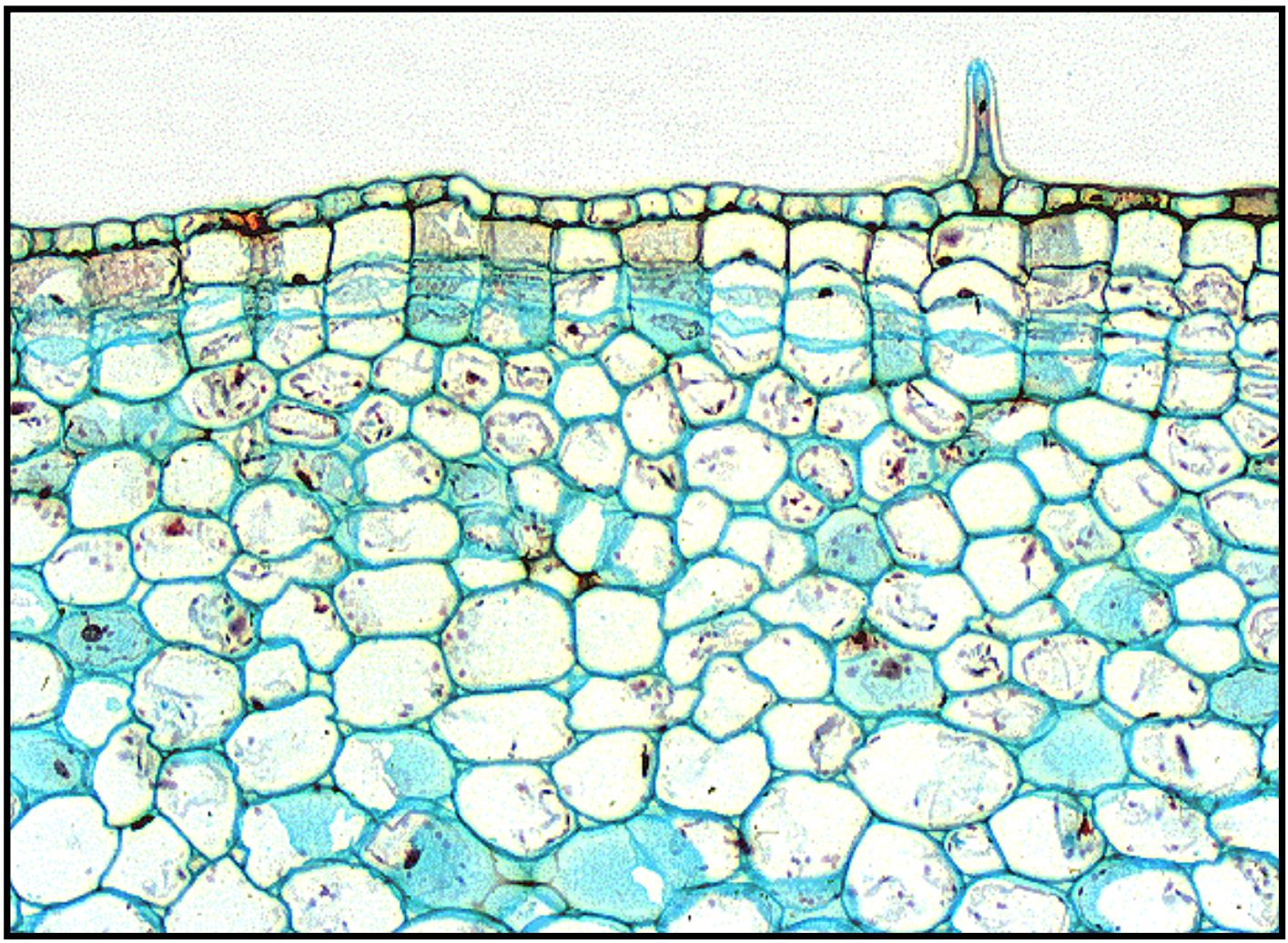
Pelargonium (geranium) stem showing the initiation of cork cambium.

- In which tissue does the cork cambium arise?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pelargonium stem with cork cambium and cork



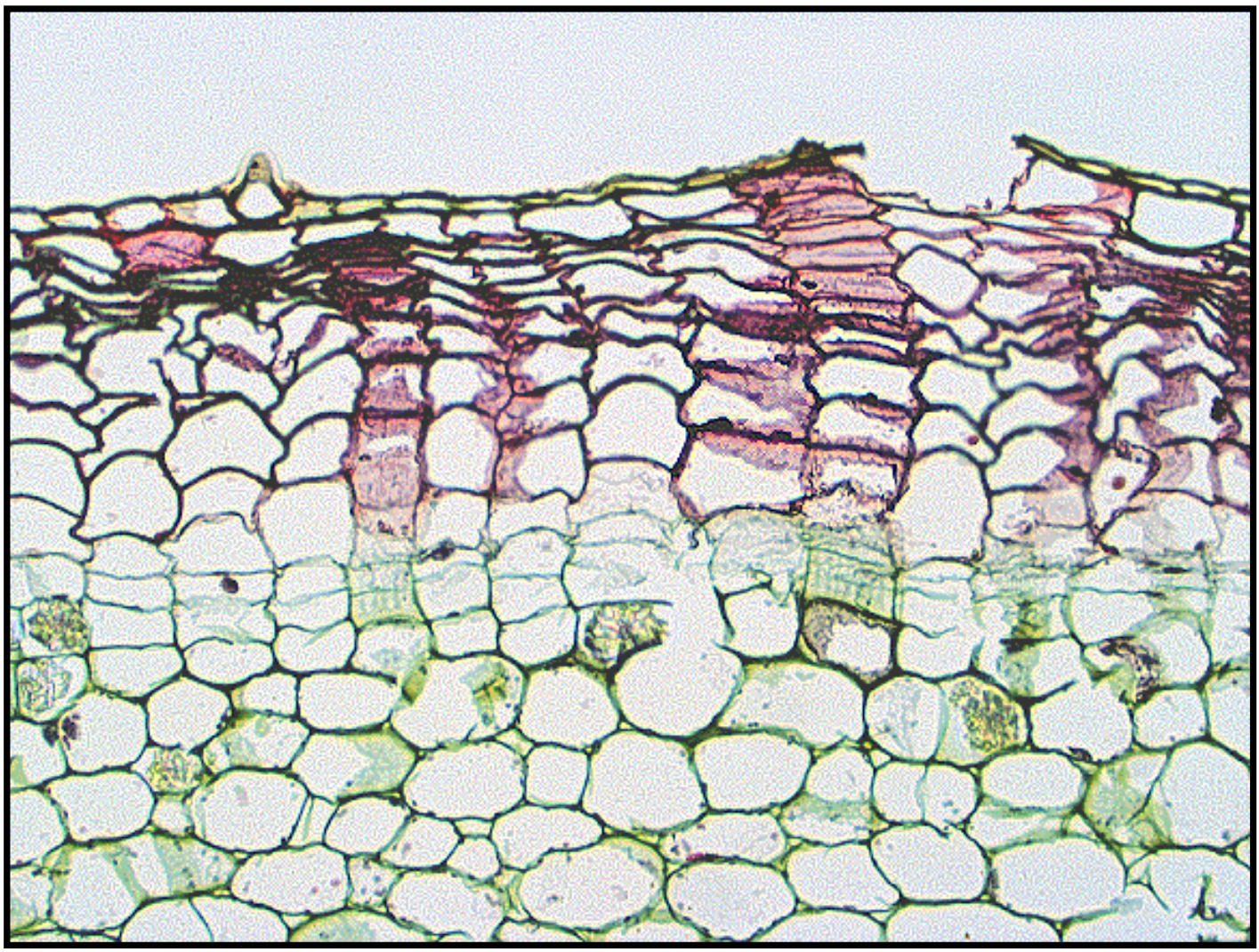
Pelargonium (geranium) stem with cork cambium and several layers of cork.

- How can you distinguish the cork from the cortex?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pelargonium stem with cork and cork cambium



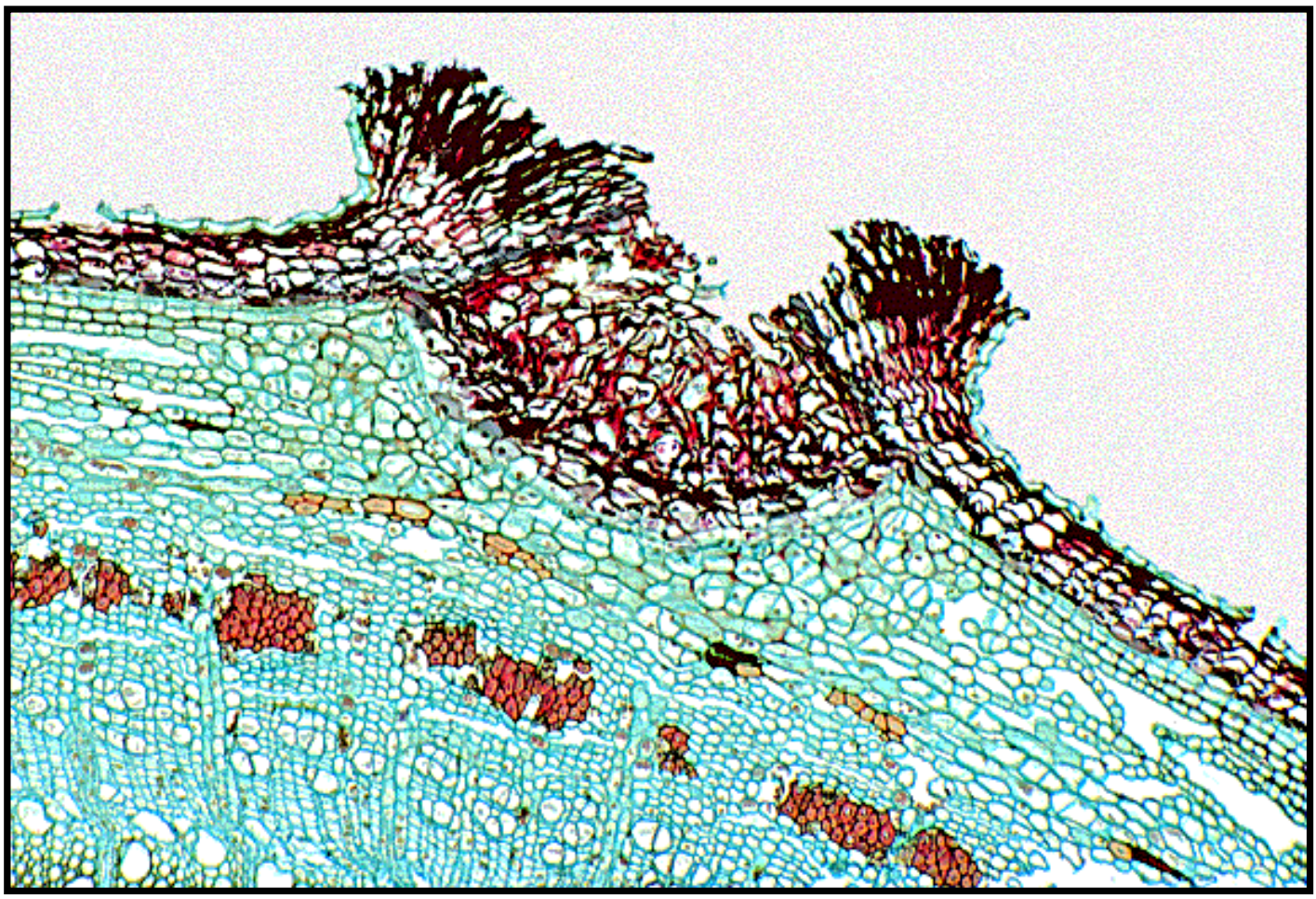
Pelargonium (geranium) stem with cork and cork cambium.

- Note that the epidermis is tearing and peeling away.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Lenticel of *Sambucus*



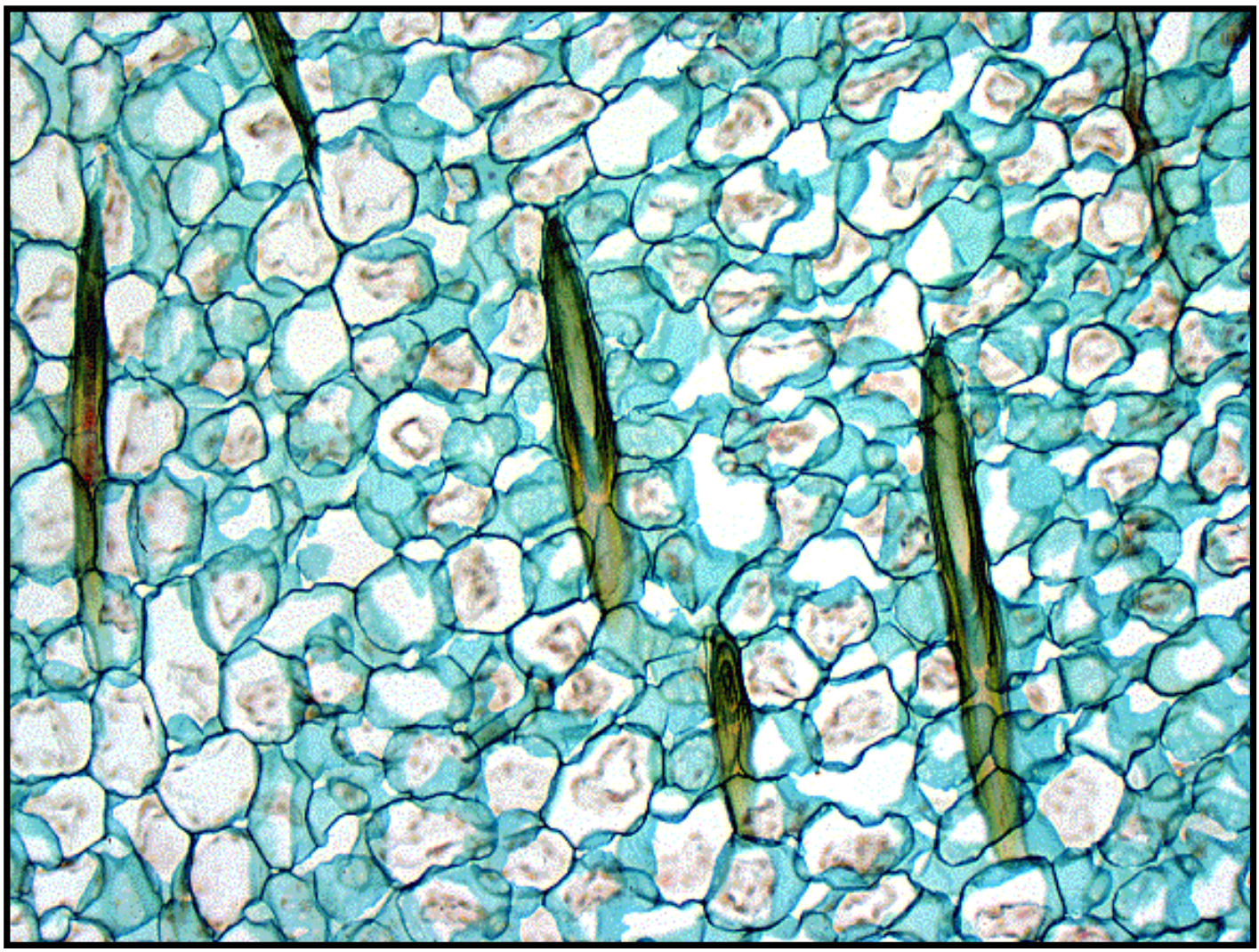
Lenticel of *Sambucus*.

- Identify the complementary cells.
- What is the function of lenticels?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Euphorbia stem showing laticifers



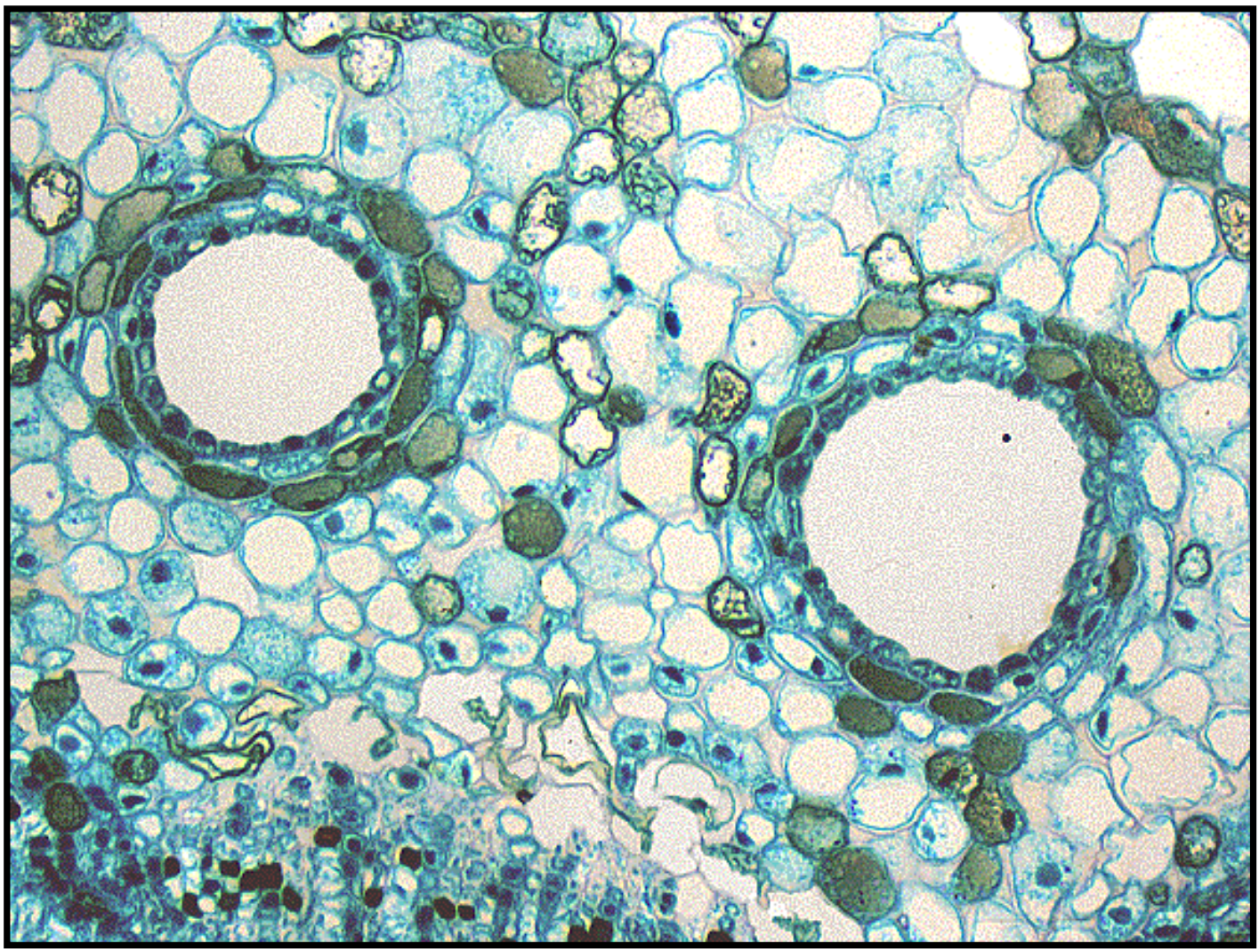
Euphorbia stem.

- When cut, the stems of many euphorbs ooze a milky white latex.
- Identify laticifers.
- What is latex? What is an advantage of producing latex?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pine stem showing resin duct



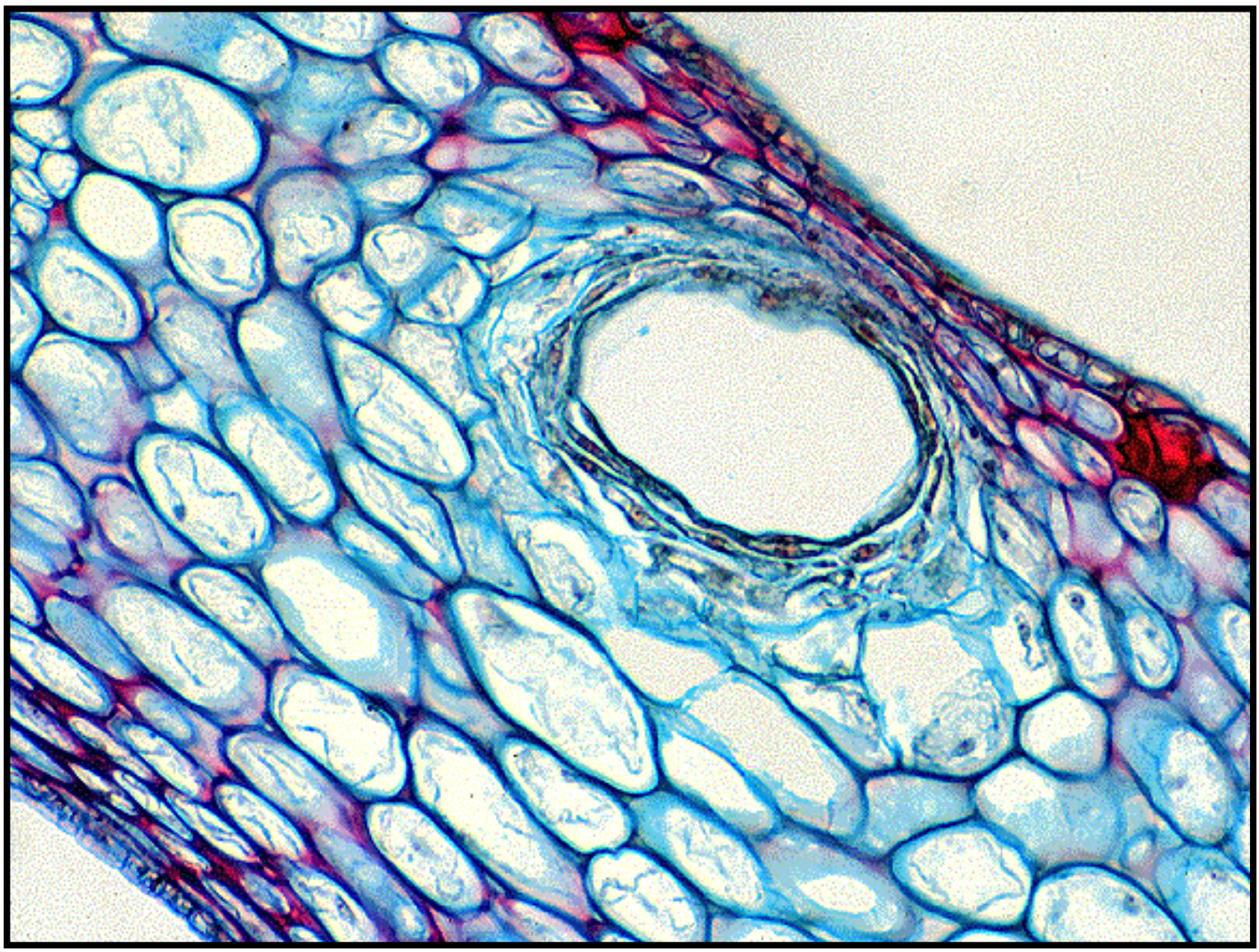
Pine stem.

- Identify the resin duct.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Citris fruit



Citris fruit rind.

- Identify oil cavity and secretory cells.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Longitudinal section of tomato flower

Longitudinal section of tomato flower.

- Identify receptacle, sepals, petals, stamens, carpels.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Longitudinal section of tomato flower

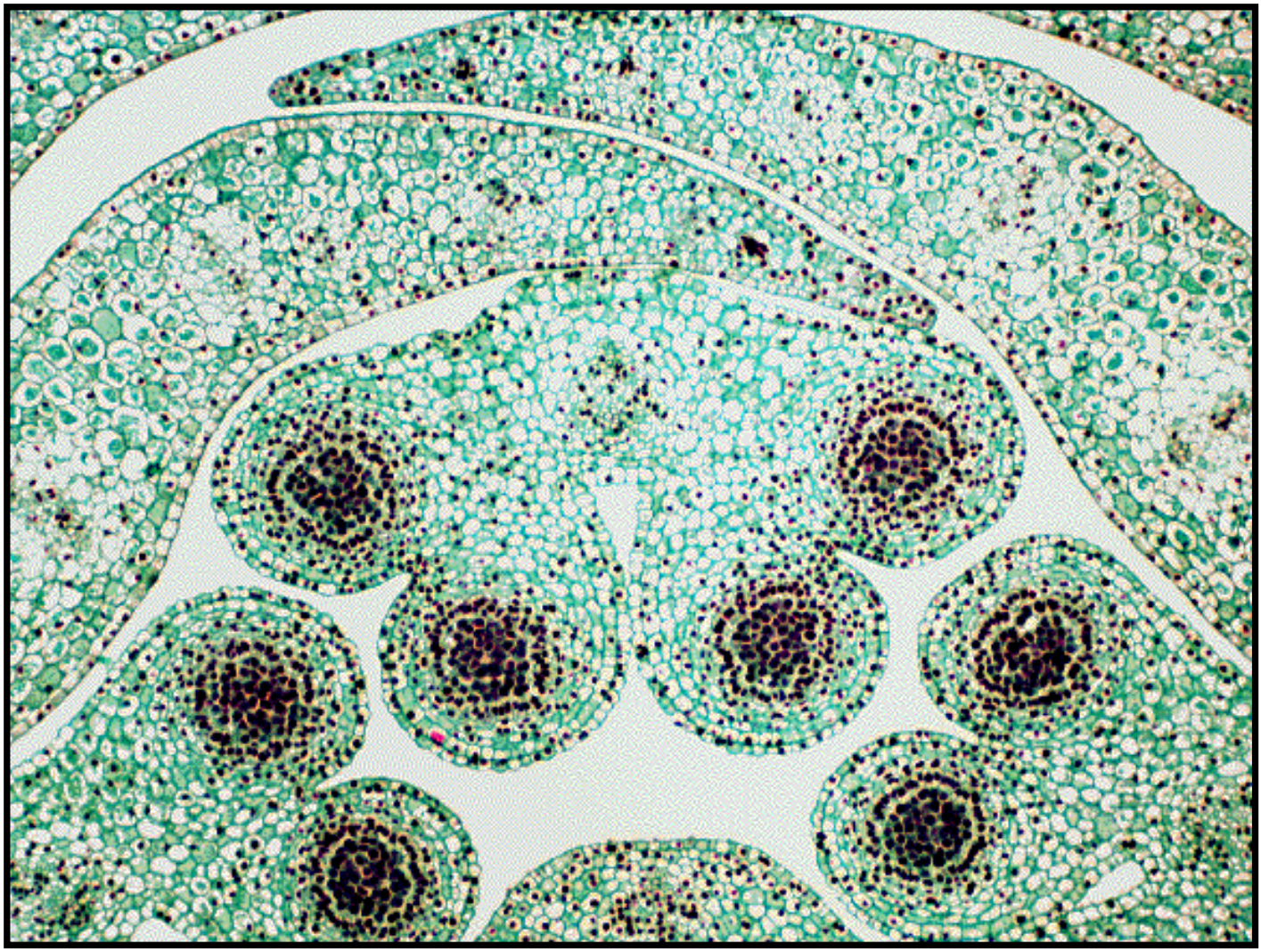
Longitudinal section of tomato flower.

- Identify anther, filament, stigma, style, ovary, ovules.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Very young lily anther



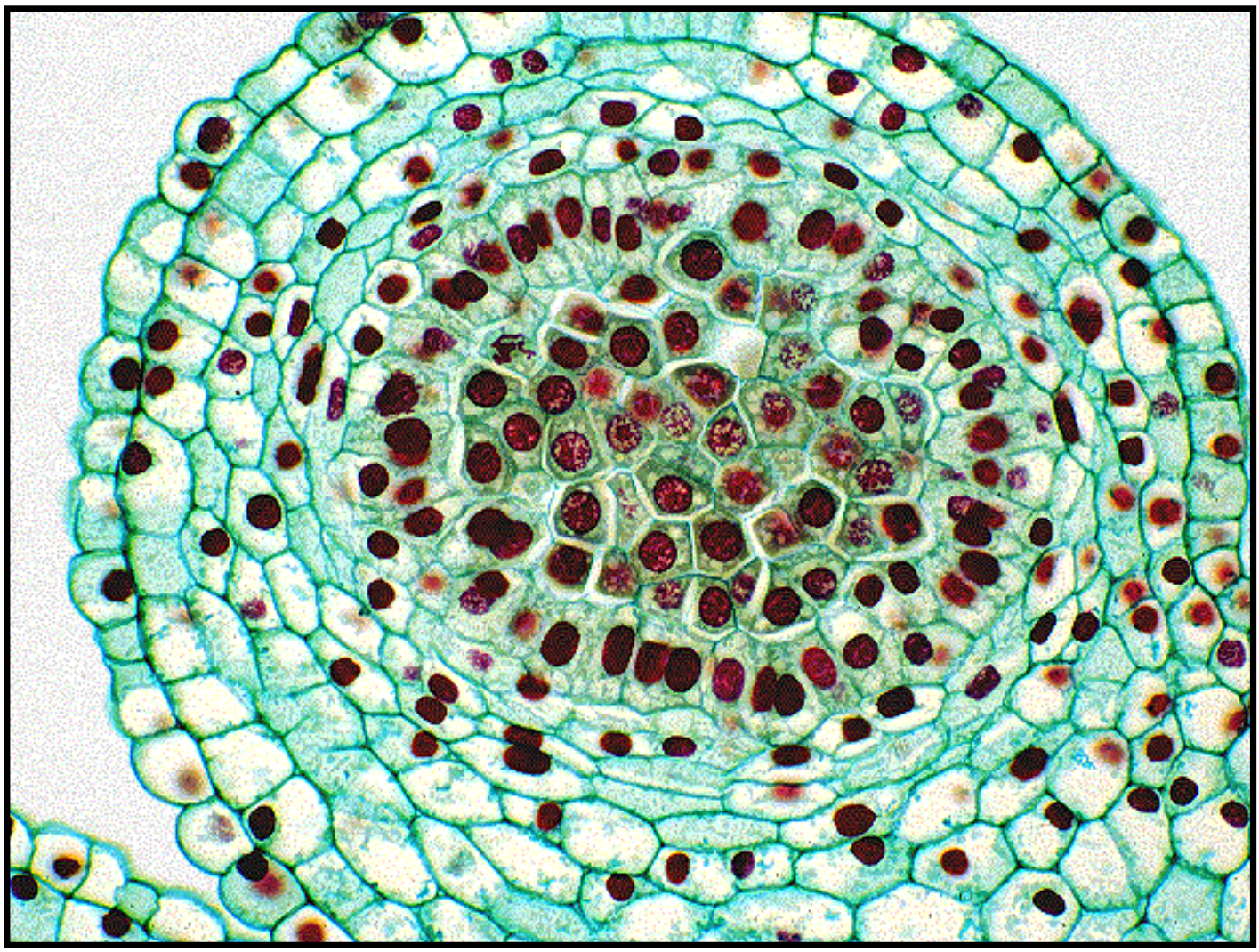
Very young lily anther.

- Identify pollen sacs, vascular bundle, epidermis.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pollen sac of very young lily anther



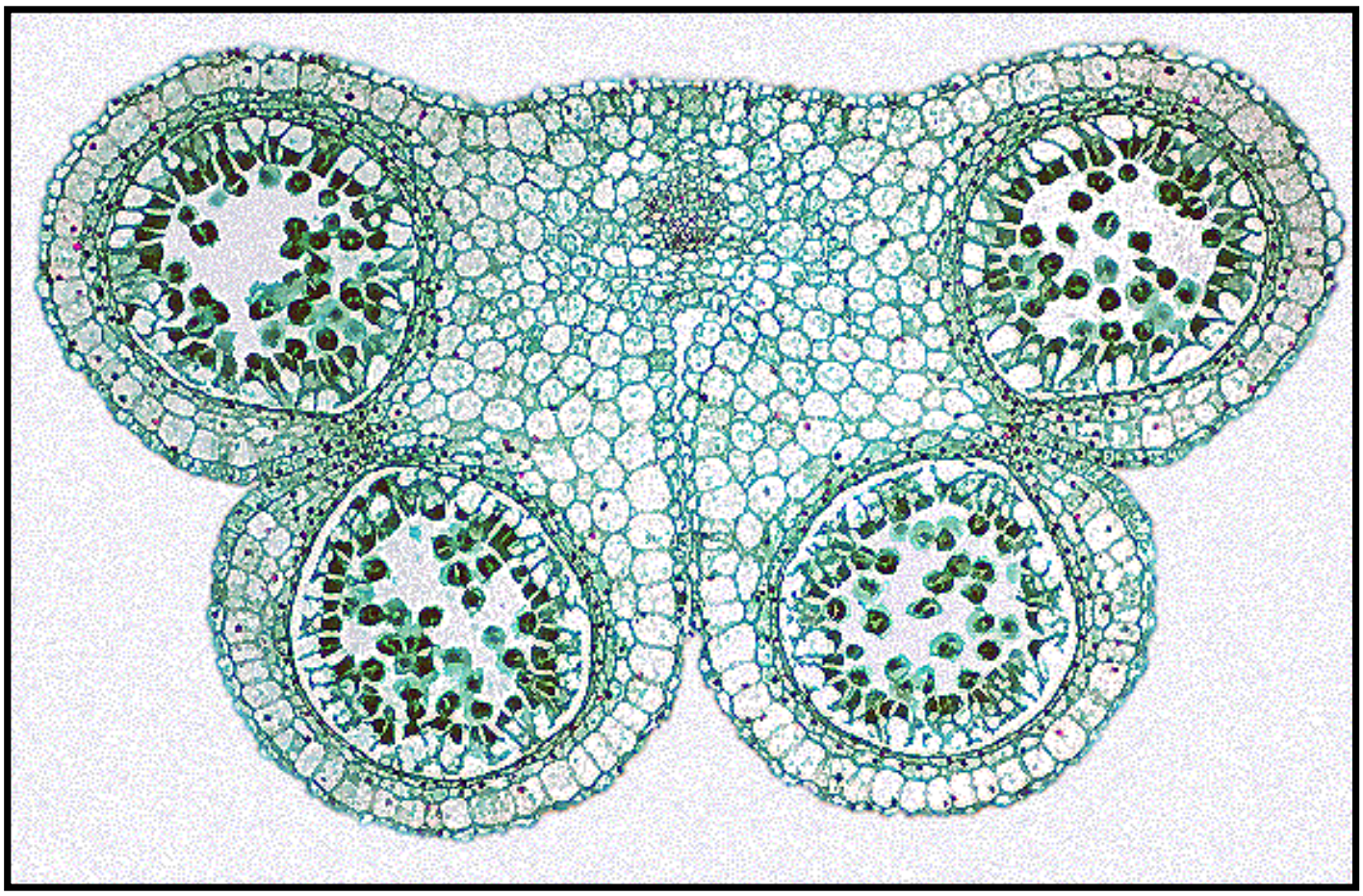
Pollen sac of very young lily anther.

- Identify tapetum, microsporocytes.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Maturing lily anther



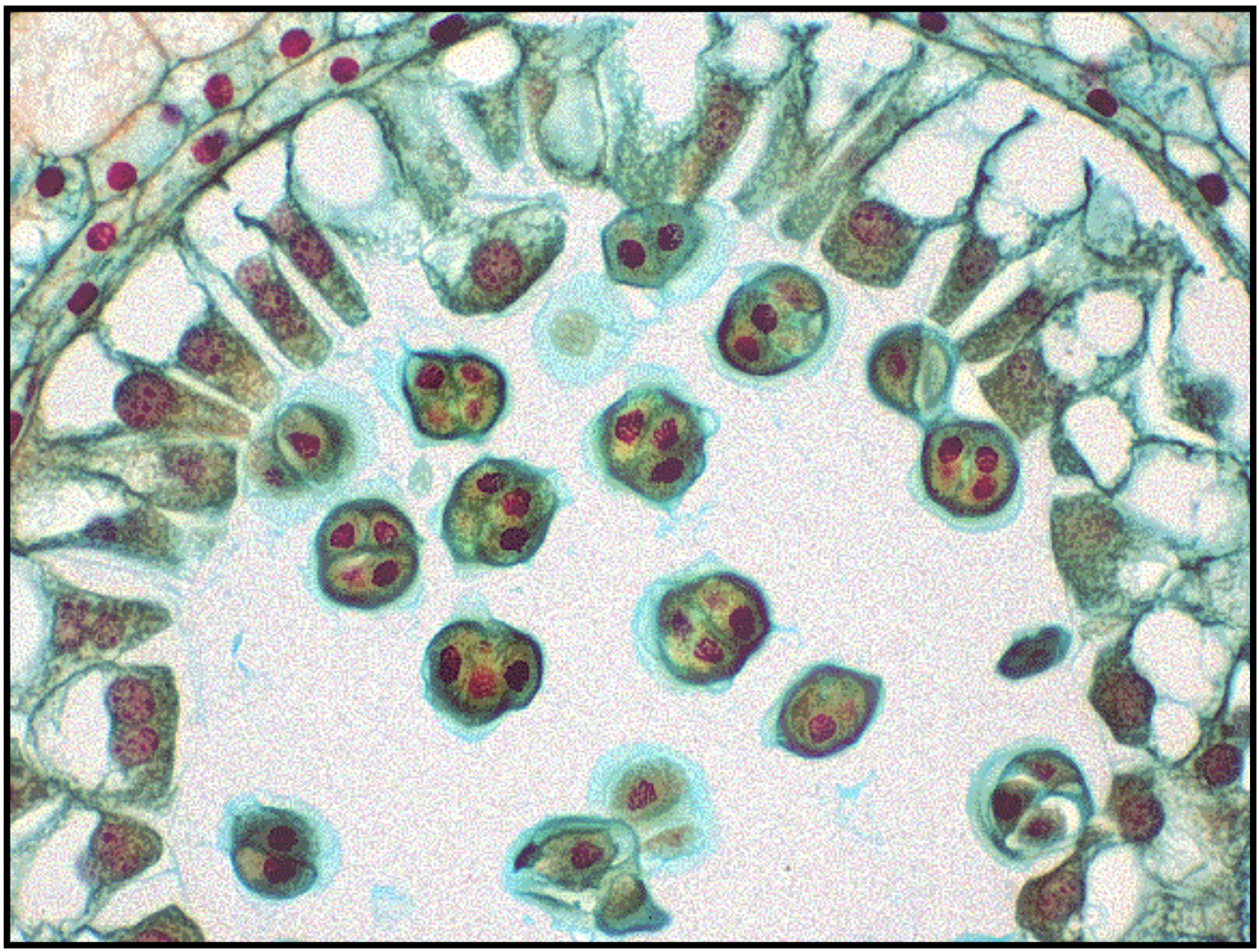
Maturing lily anther.

- Identify the region where dehiscence will occur.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pollen sac of maturing lily anther



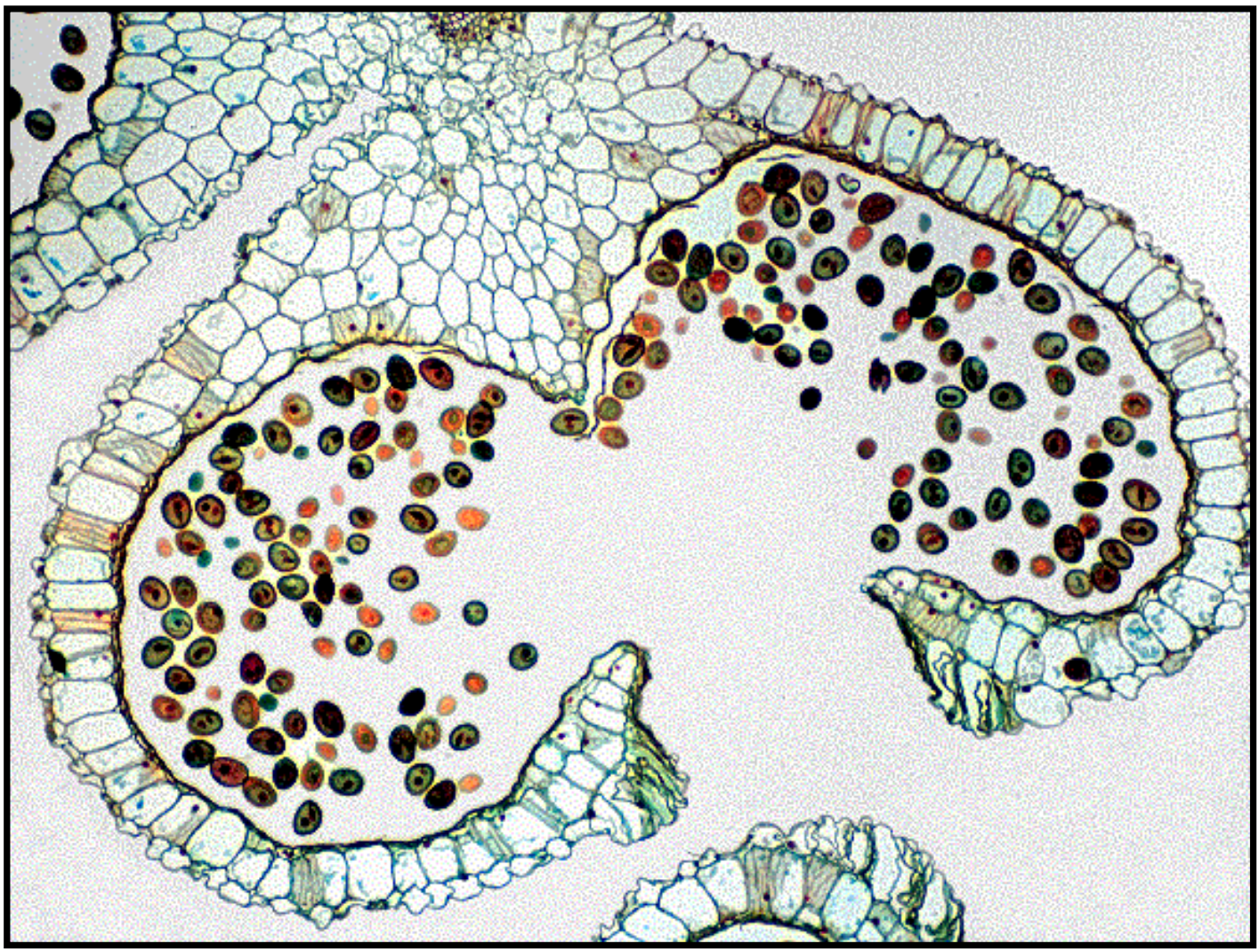
Pollen sac of maturing lily anther.

- Identify microspores.
- Are they haploid or diploid?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Mature lily anther after dehiscence

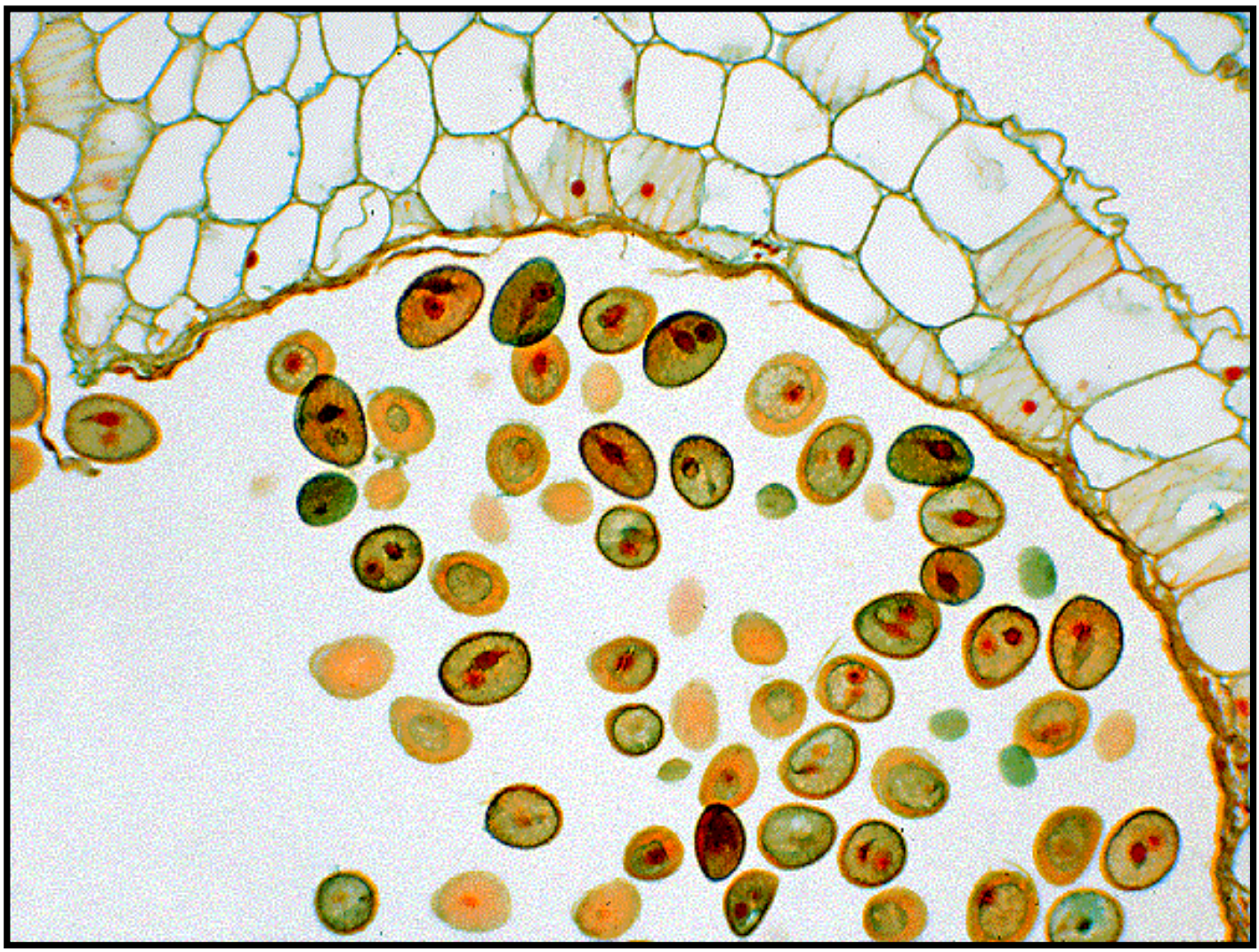


Mature lily anther after dehiscence.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Mature lily anther



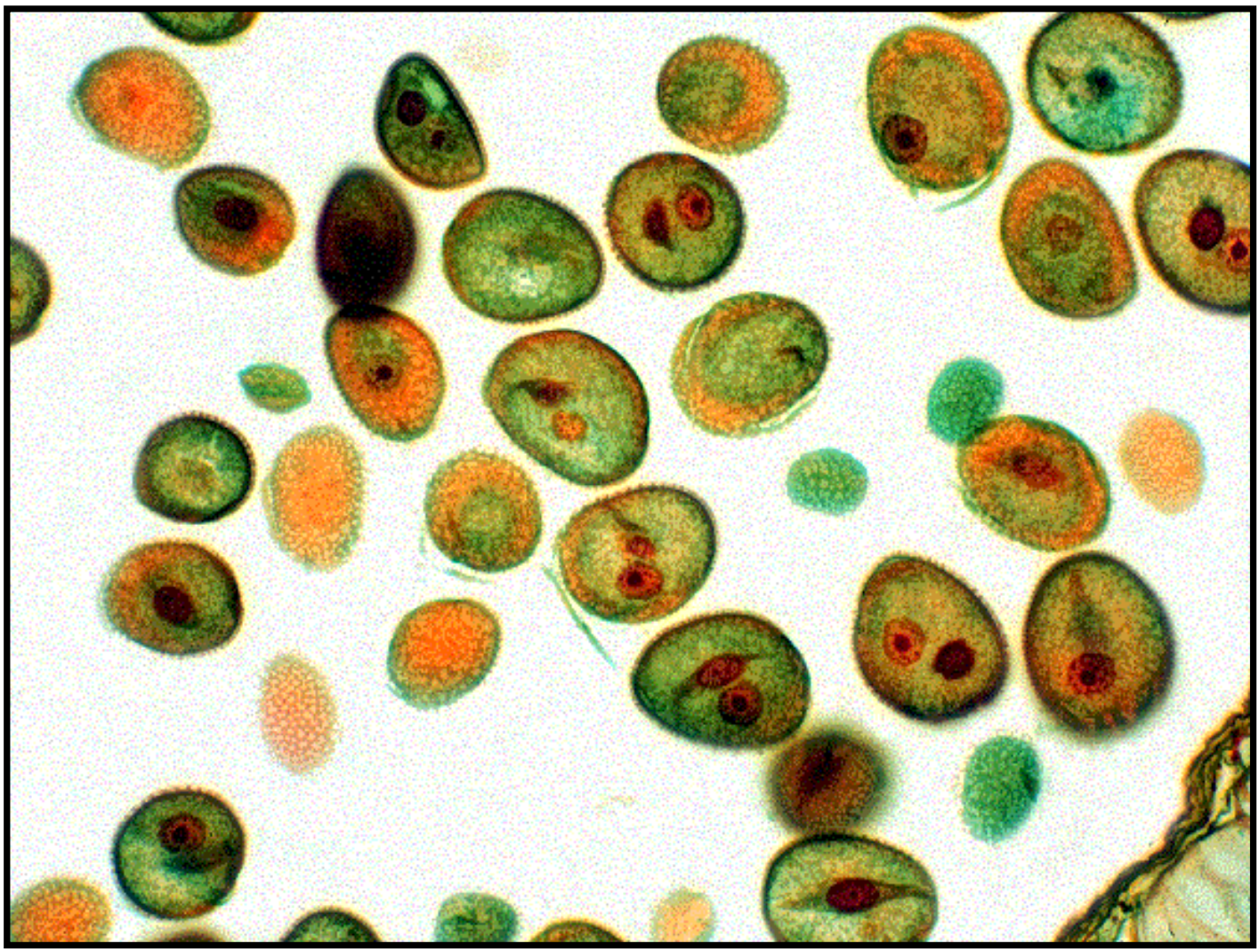
Mature lily anther.

- Identify pollen grains.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Pollen grains



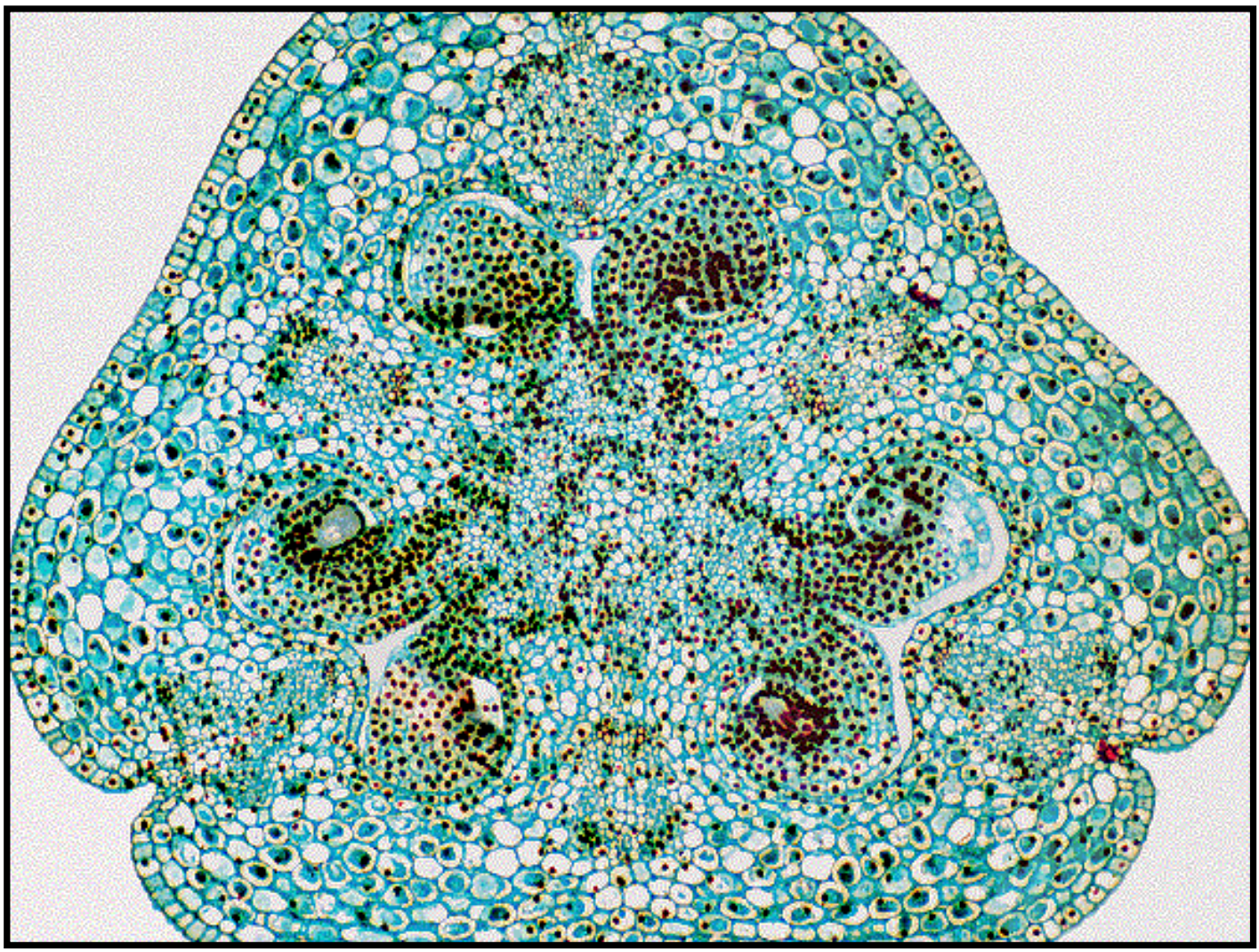
Pollen grains.

- Identify tube nucleus, generative nucleus, ornamented wall.
- Are these nuclei haploid or diploid?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Lily ovary x.s.



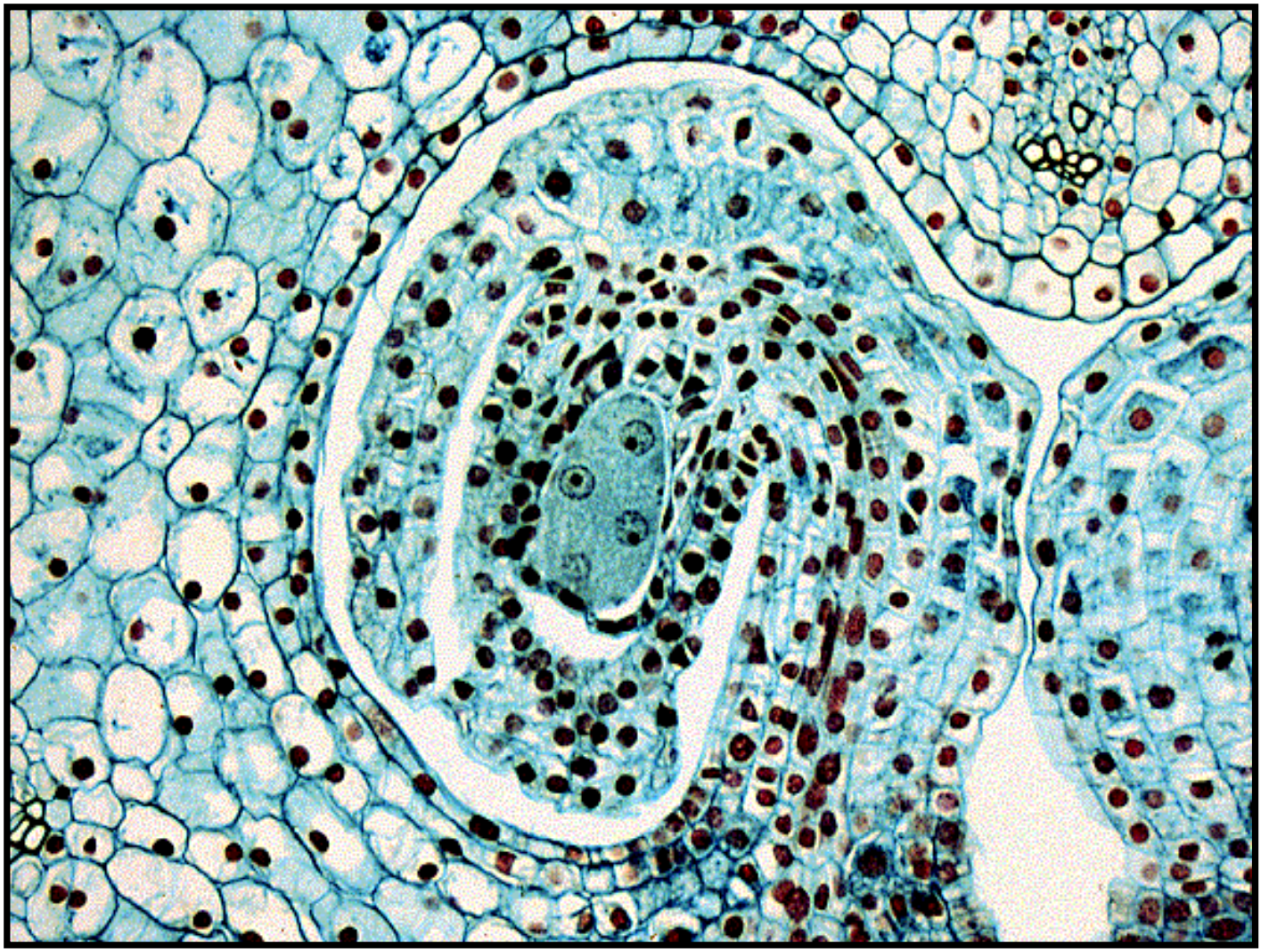
Cross section of lily ovary.

- Identify carpels, ovules, megasporocytes.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Lily ovule



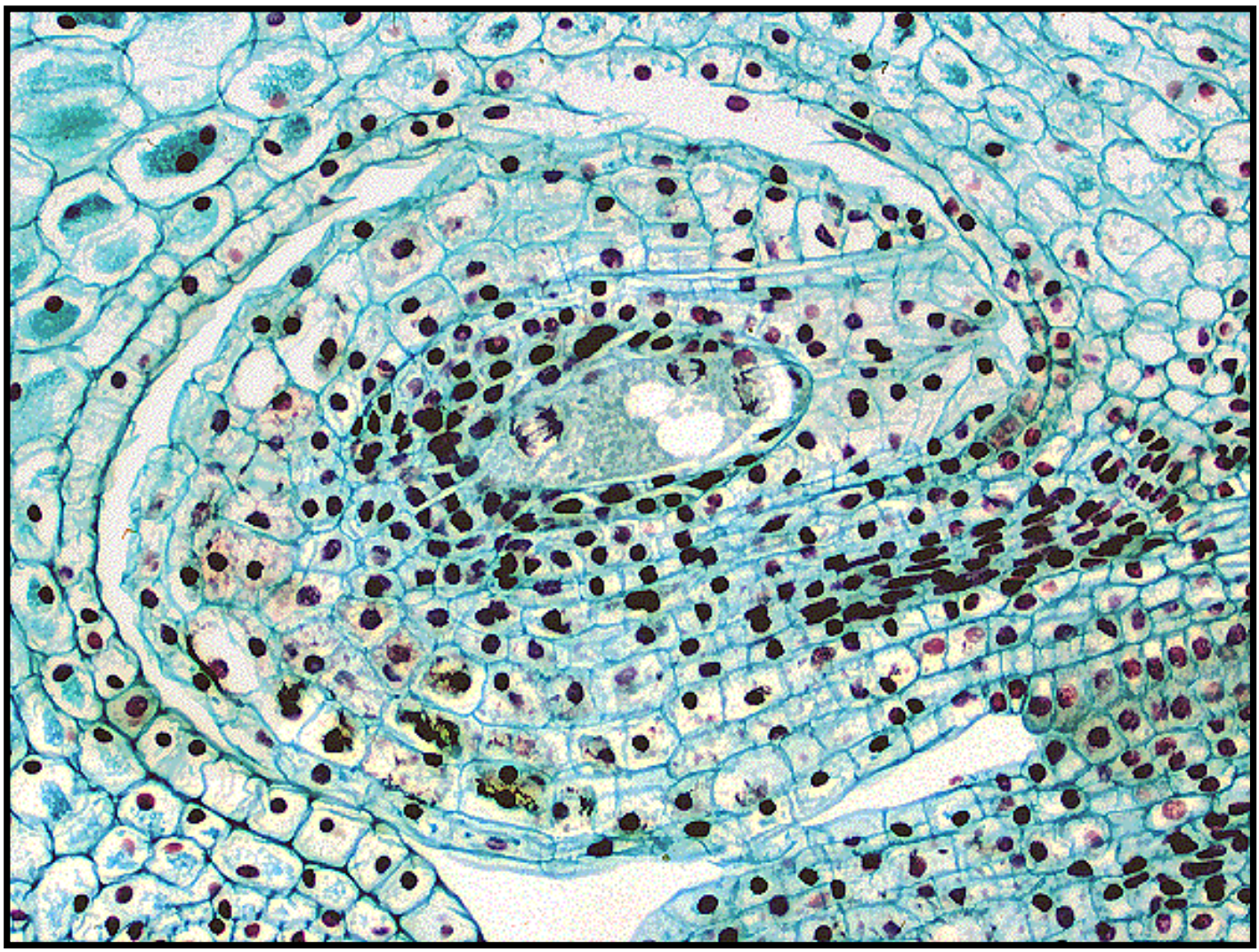
Lily ovule.

- Identify integuments, micropyle, embryo sac.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Lily ovule with dividing megaspores



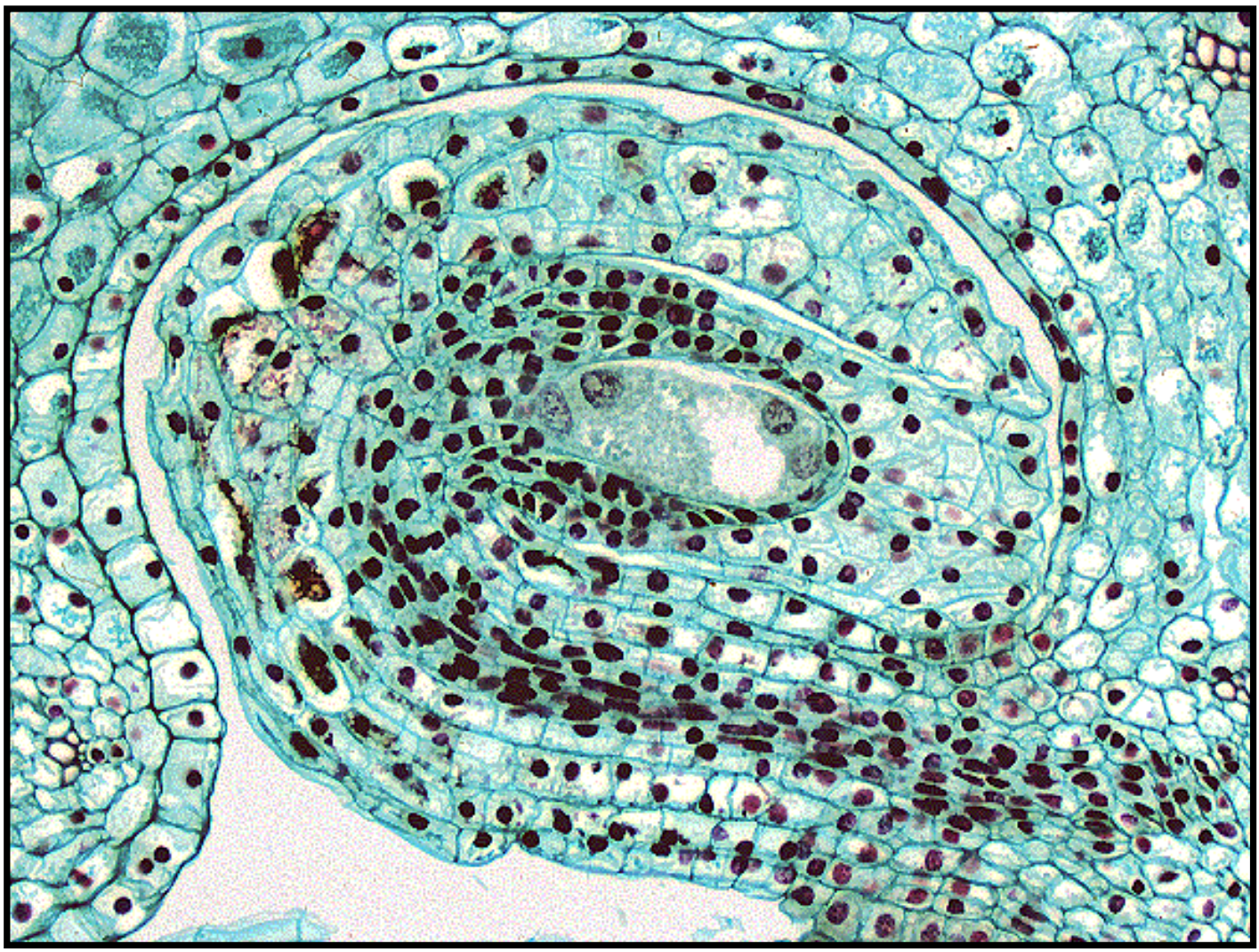
Lily ovule with dividing megaspores.

- Are the megaspores haploid or diploid?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Mature lily embryo sac



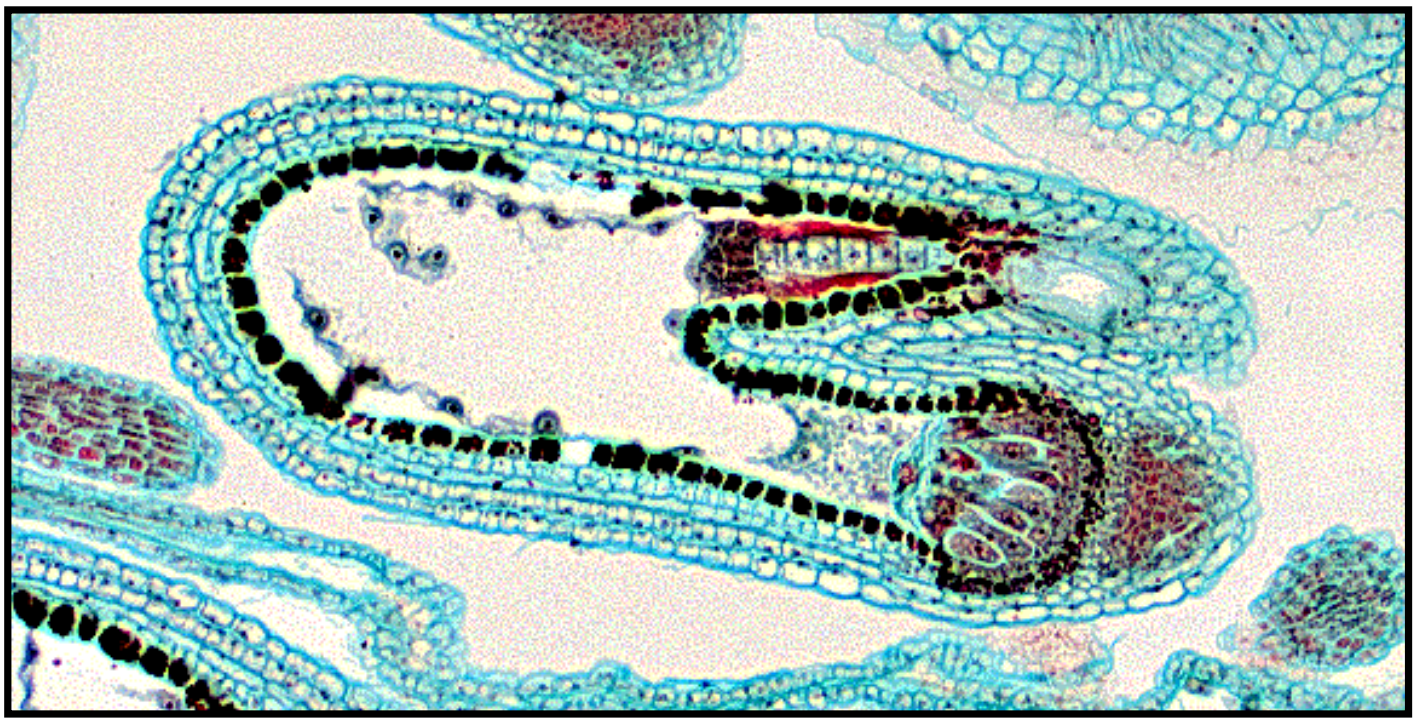
Mature lily embryo sac.

- How many nuclei can you see?
- How many nuclei does a mature embryo sac really contain?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Capsella ovule with developing embryo



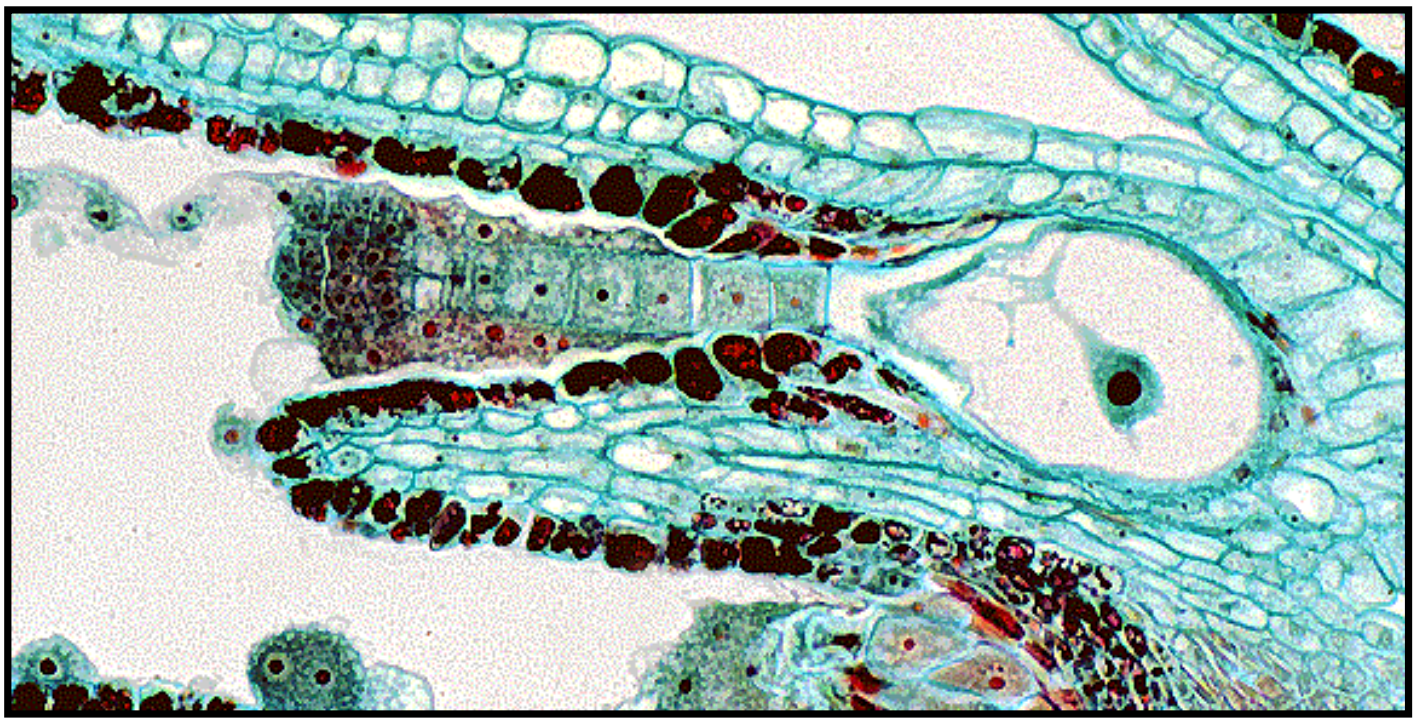
Capsella ovule with developing embryo.

- Identify integuments, suspensor, embryo, endosperm nuclei.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Capsella ovule with globular embryo



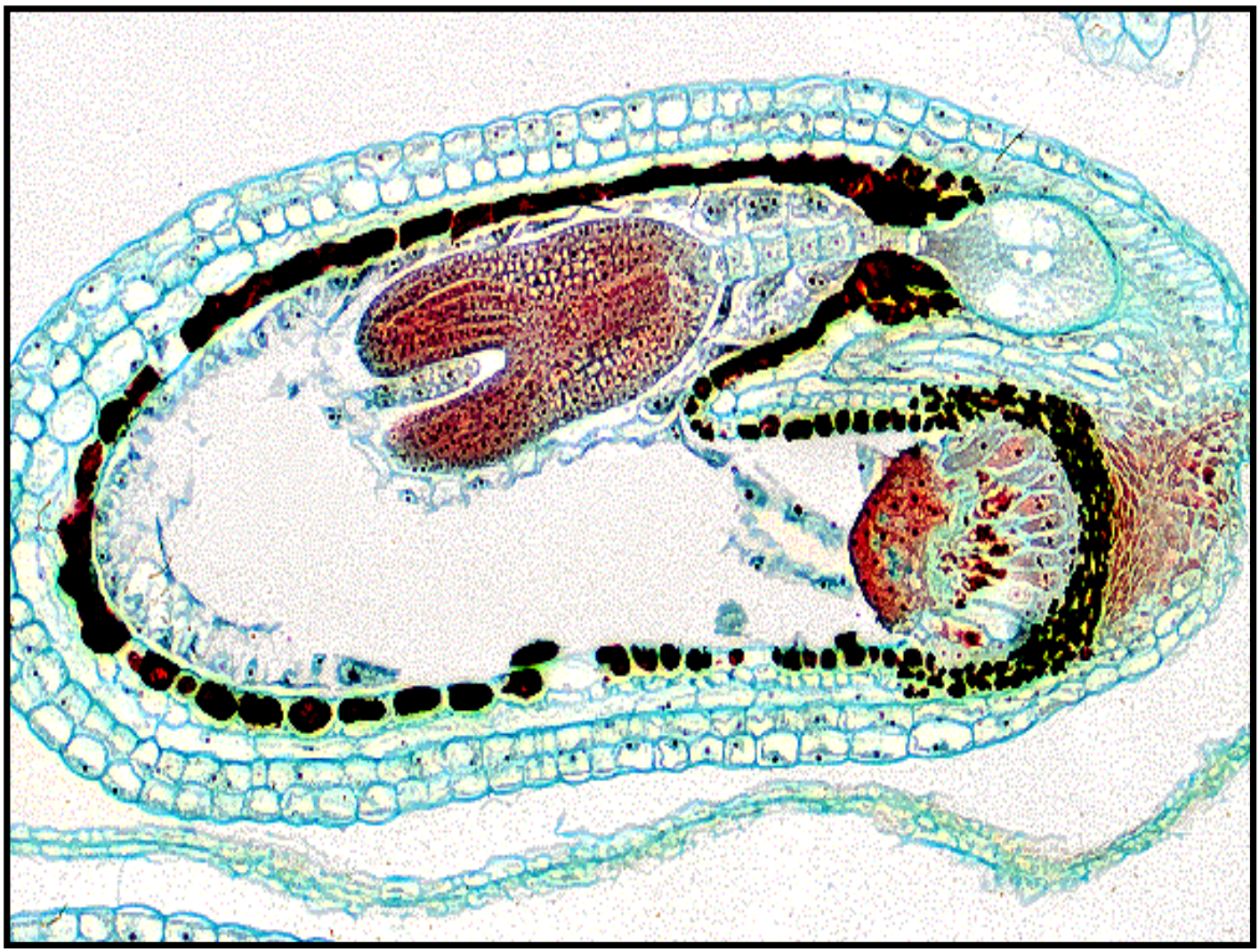
Capsella ovule with globular embryo.

- Which tissue will become the seed coat?

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Capsella ovule with heart stage embryo



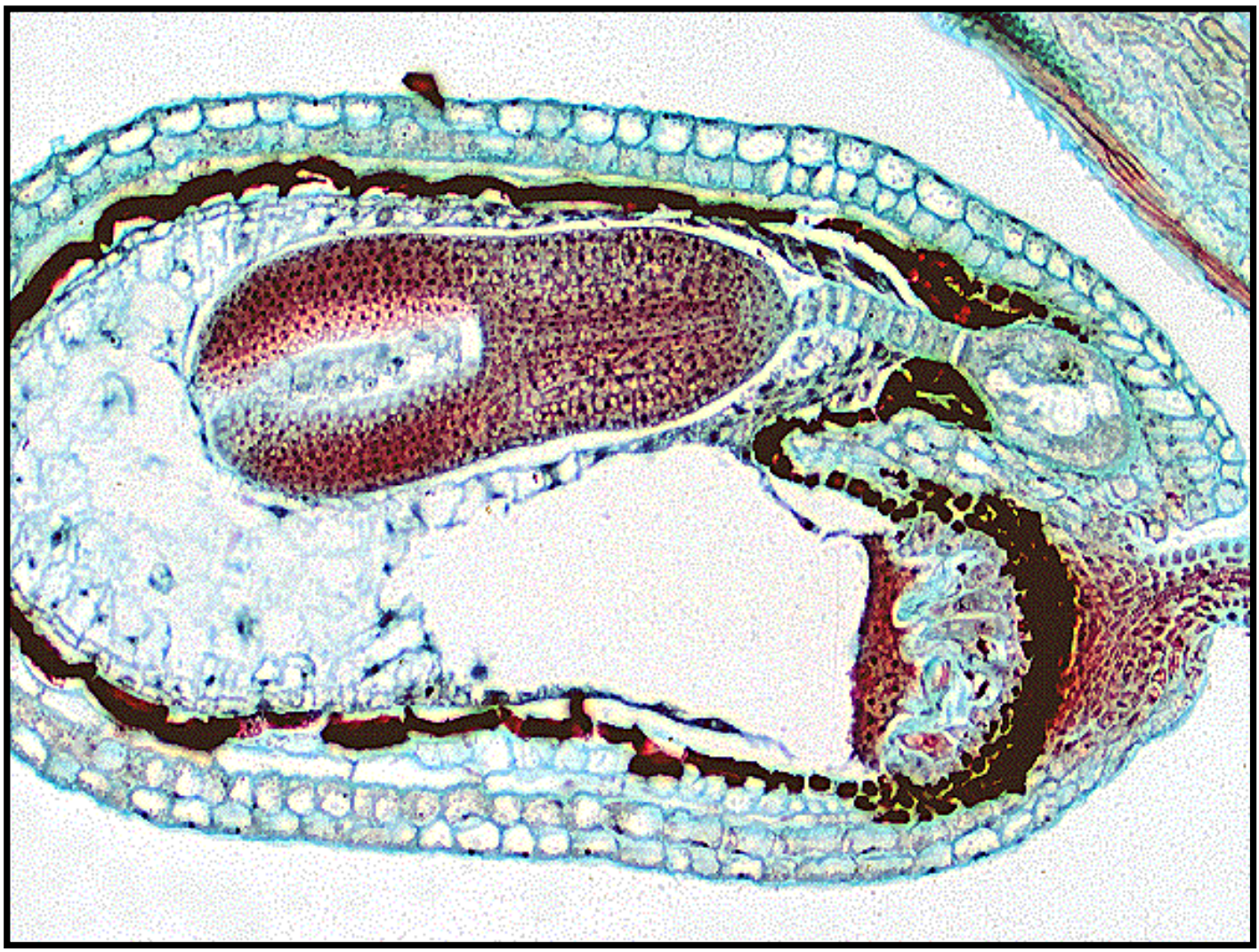
Capsella ovule with heart stage embryo.

- Identify cotyledons.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Capsella ovule with torpedo stage embryo



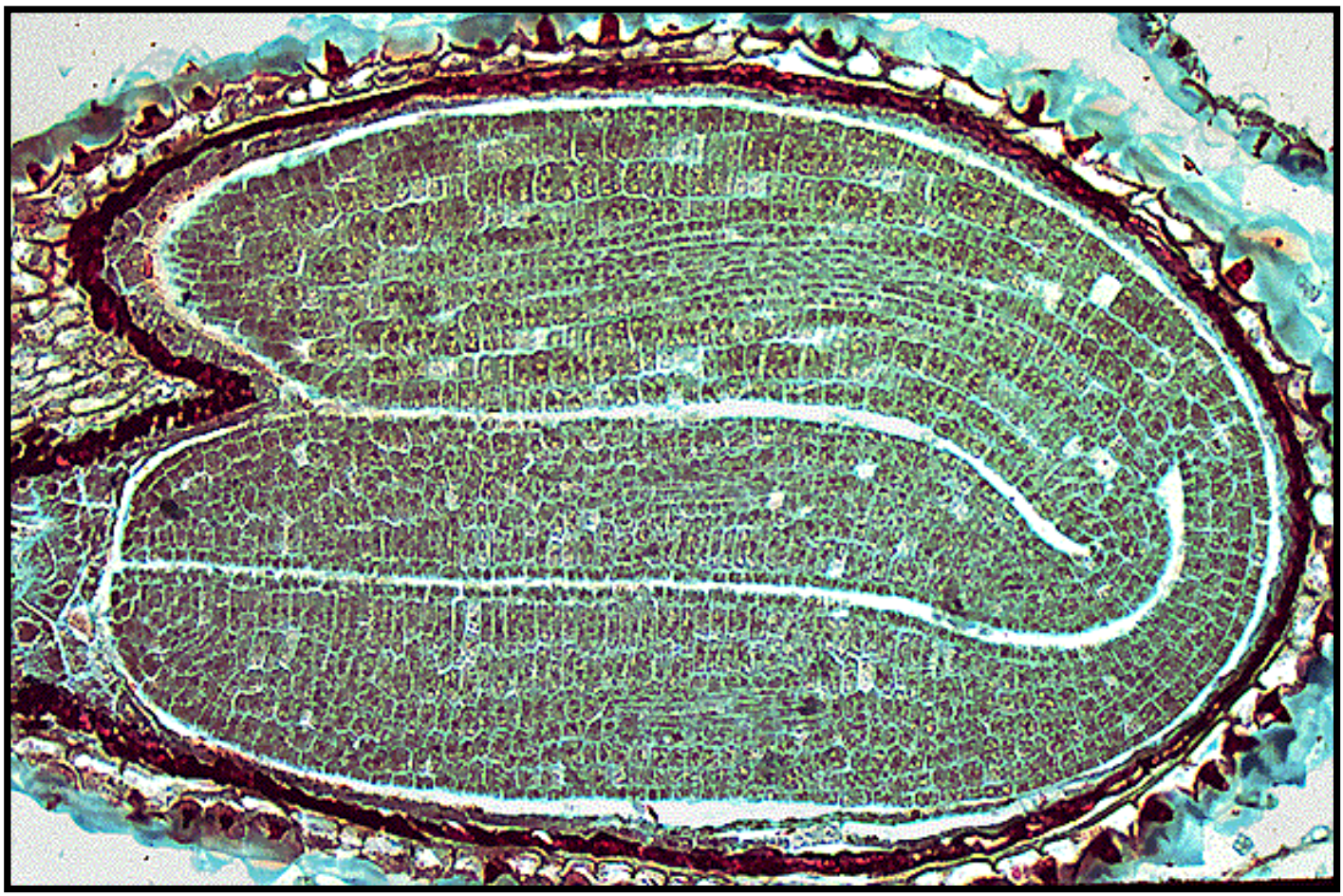
Capsella ovule with torpedo stage embryo.

- Identify procambium.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Mature seed of *Capsella*



Mature seed of *Capsella*.

- Identify: cotyledons, radicle, plumule, hypocotyl, protoderm, ground meristem, procambium, seed coat.

Related images: (None)

Alison Roberts (awrobrts@uriacc.uri.edu)

Plant Anatomy BIO 311

This page contains class inforamtion for Plant Anatomy (BIO 311) taught at the University of Rhode Island in Fall 2002. It includes: contact information, course syllabus, lab schedule, and a small list of course related links.

CONTACT INFORMATION

Dr. Alison Roberts
Department of Biological Sciences
University of Rhode Island
Kingston, RI 02881

Telephone: (401) 874-4098
E-mail: aroberts@uri.edu
Office location: 203 Ranger Hall
Office hours: Tuesday 1:00-2:00 PM; Wednesday 1:00-3:00 PM
Class meeting times: Monday and Wednesday, 12:00-12:50 PM, Room 103 Ranger Hall

Teaching Assistant: Ken Uhnak (404 Ranger Hall, 874-2631, kuhn8500@postoffice.uri.edu)

SYLLABUS & LECTURE SCHEDULE

Sept.	4	Introduction to plant structure and development	Bowes pp. 9-11
	9	The plant cell: cell wall	Bowes pp. 30-31; 1*
	11	The plant cell: protoplast	Bowes pp. 26-29
	16	The plant genome	2*

	18	Shoot apical meristems	Bowes pp. 84-85; 3* pp. S265-8
	23	Root apical meristems	Bowes pp. 85-86; 3* pp. S268-72
	25	Epidermis	Bowes pp. 98-99, 4*
	30	Parenchyma and collenchyma	Bowes pp. 57
Oct.	2	Sclerenchyma	Bowes pp. 58
	7	**EXAM I**	
	9	Xylem	Bowes pp. 60-61
	14	Columbus Day, classes do not meet	
	16	Xylem evolution	
	21	Phloem	Bowes p. 59
	23	Anatomy of stems	Bowes pp. 117-118
	28	Anatomy of leaves	Bowes pp. 97-100
	30	Leaf development	5*
Nov.	4	Differentiation of epidermal structure	6*
	6	Anatomy of roots	Bowes pp. 133-134, 7*
	11	Veteran's Day, classes do no meet	
	13	**EXAM II**	
	18	Phyllotaxy	8*
	20	Primary vascular differentiation	9*
	25	Vascular cambium	Bowes pp. 118-119
	27	Secondary xylem	
Dec.	2	Bark	Bowes pp. 119
	4	Structure and evolution of flowers	Bowes pp. 145-150; 10*
	9	Flower development	11*
	12	FINAL EXAM: Thursday 8:00-11:00 AM	

REFERENCES

Text:

Bowes, B. G. (2000) *A Color Atlas of Plant Structure*, Iowa State University Press, Ames, IA, 192 p., available at the URI Bookstore.

Lab manual:

An electronic copy of the lab manual is available online as an Adobe Acrobat (pdf) file.

Other:

1. The Multiple Steps in Construction of the Cell Plate Following Mitosis (http://www.plantphys.net/article.php?ch=1&id=21)

2. Taiz, L, Zeiger, E (2002) Plant Physiology, 3rd edition, Chapter 14: Gene Expression and Signal Transduction, pp. 1-2, 5-11 (http://www.plantphys.net/pdf/ch14.pdf)

3. Nakajima, K, Benfey, PN (2002) Signaling in and out: control of cell division and differentiation in the shoot and root. Plant Cell 14:S265-S276 (http://www.plantcell.org/cgi/reprint/14/suppl_1/S265.pdf)

4. Plant Tissue Systems: Dermal, Ground, and Vascular (http://www.plantphys.net/article.php?ch=1&id=19)

5. Howell, SH (1998) Molecular Genetics of Plant Development, Chapter 6: Leaf development, pp. 136-157.

6. Glover, BJ (2000) Differentiation in plant epidermal cells. J. Exp. Bot. 51(344):497-505 (http://jxb.oupjournals.org/cgi/reprint/51/344/497.pdf)

7. Observing Roots below Ground (http://www.plantphys.net/article.php?ch=t&id=44)

8. Steeves, TA, Sussex, IM (1989) Patterns in Plant Developments, 2nd edition, Chapter 7: Organogenesis in the shoot: leaf origin and position, pp. 109-121.

9. Howell, SH (1998) Molecular Genetics of Plant Development, Chapter 6: Vascular development, pp. 312-125.

10. Flower Structure and the Angiosperm Life Cycle (http://www.plantphys.net/article.php?ch=t&id=18)

11. Taiz, L, Zeiger, E (2002) Plant Physiology, 3rd edition, Chapter 24: The control and flowering, pp. 560-565.

COURSE INFORMATION

Plant anatomy is the study of plant structure, but structure is best understood in the context of function and development. You can expect to leave BOT 311 with a greater appreciation for how plants grow, survive, and interact with their environment.

Lecture and lab:

The best way to learn plant anatomy is to examine plants, dissect them, and look at their tissues under the microscope. For this reason, the laboratory is a critical element of this

course. The purpose of the lectures is to provide background material and information on what to look for as you examine the laboratory material. For best results, plan on attending all lectures and labs. Lab material will be put away after class on Tuesday. It will not be possible to make up labs.

Grading:

Your course grade will be based on your performance on the following:

Your best 7 out of 8 quiz and homework scores:	20%
Two midterm exams:	40%
Laboratory exercises:	20%
Final exam:	20%

Your final percentage score will be converted to a letter grade using the following scale:

90-100% **A**(+/-), 80-89% **B**(+/-), 70-79% **C** (+/-), 60-69 % **D**, <60% **F**

Quizzes:

Quizzes will be given at the beginning of class on the dates shown on the lecture schedule. Quiz questions may include identification of cell types or tissues on slides projected on a screen, or short-answer questions on the function or development of tissues or structures. In addition, three homework assignments will be distributed in class. Your lowest quiz or homework score will be dropped. If you miss a quiz, you will receive a "0", the first of which will be dropped as your lowest score. Please plan to take all quizzes as scheduled.

Midterm exams:

Midterm exams will consist of both practical and short-answer sections, which will be similar to those on quizzes. Please make every effort to take the midterm exams at the scheduled times.

Laboratory assignments:

Your laboratory assignments will be graded each week. In this way you will get regular feedback on your understanding of the material. Required drawings and discussion questions will be outlined at the beginning of each lab. Do not be concerned if you do not consider yourself to be an artist. Simple drawings with clear, concise labels are usually the most helpful. Your completed lab work must be turned in to your T.A. at the end of each

lab. Each lab exercise is worth about 1.5% of your final course grade. Please bring to each lab: 5X8" index cards (you will need about 70 cards to complete all assignments for the semester) and colored pencils (optional, but very helpful).

Final exam:

The final exam will be cumulative and will include practical and short-answer questions. The date and time of the final exam are listed in the course schedule.

Review opportunities:

At times you may feel that you would like to review the lab material itself, rather than relying on your notes and the textbook. The following opportunities will be provided:
Lab reviews: Photographs and accompanying review questions are available at this site.
Review sessions: These will be scheduled shortly before midterm and final exams. Come prepared to test yourself!
Do not neglect one of your best study resources, your classmates! You are encouraged to work with others during and between labs.

Just a few rules:

1. Please arrive on time and ready to work.
2. Microscopes and prepared slides are delicate and expensive. Please handle them carefully.
3. Food and drinks are **not** allowed in any URI classroom. This is especially important in laboratories where harmful chemicals may be used.
4. At the end of the lab period, please clean up your work area. Return microscopes to the case and prepared slides to their trays.
5. Study hard and enjoy yourself!

LAB SCHEDULE

An electronic copy of the lab manual is available online at the lab manual page.

LAB SCHEDULE FALL 2002

LAB	MONTH	DATES	READING *	TOPIC
1	Sept.	10	15-22	Introduction to plant structure
2		17	42-7, 52-6	QUIZ, Plant cells
3		24	84-96	Meristems, growth, & differentiation
4	Oct.	1	107-109	QUIZ, Dermal tissue system
5		8	62-67	Ground tissue system
6		15	76-78	Vascular tissues: xylem
7		22	72-75	QUIZ, Vascular tissues: phloem
8		29	123-125	Anatomy of stems
9	Nov.	5	102-112	QUIZ, Anatomy of leaves
10		12	138-140	Anatomy of roots
11		19		Organ modification
12		26	126-131, 141-3	Vascular cambium
13	Dec.	3	79-83	QUIZ, Secondary growth

*Reading from Bowes, B. G. (2000) **A Color Atlas of Plant Structure**, Iowa State University Press, Ames, IA, 192 p.

OTHER LINKS

URI Sites and Resources

- URI home page
- Department of Biological Sciences
- Alison Roberts faculty page
- URI Library Resources home page
- Library hours

General Plant Anatomy

- The Plant Anatomy Archive contains photographs of various plant structures.
- The Revision Modules in Plant Anatomy is an interactive site for reviewing plant structure.
- The Virtual Plant Cell is an interactive site with basic information on plant cell structure.

Search Engines

- Google
- Google image search (use box in middle of page)

Alison Roberts (aroberts@uri.edu)