Introduction to Botany: BIOL 154
Study guide for Exam 3

Alexey Shipunov

Lectures 20–26

Contents

Outline

1 Tissues

1.1 Origin of tissues

Origin of tissues and organs of plants: first steps

Why did plants go to the land? Which problems did they meet and how did they resolve them? What was the plant way of acquiring tissues comparing with animals?

1.2 Tissues basics

Definition of tissues and organs

- **Tissue** is a union of cells which have common origin, function, and similar morphology
- **Organ** is a union of different tissues which have common function(s) and origin

Simple and complex tissues

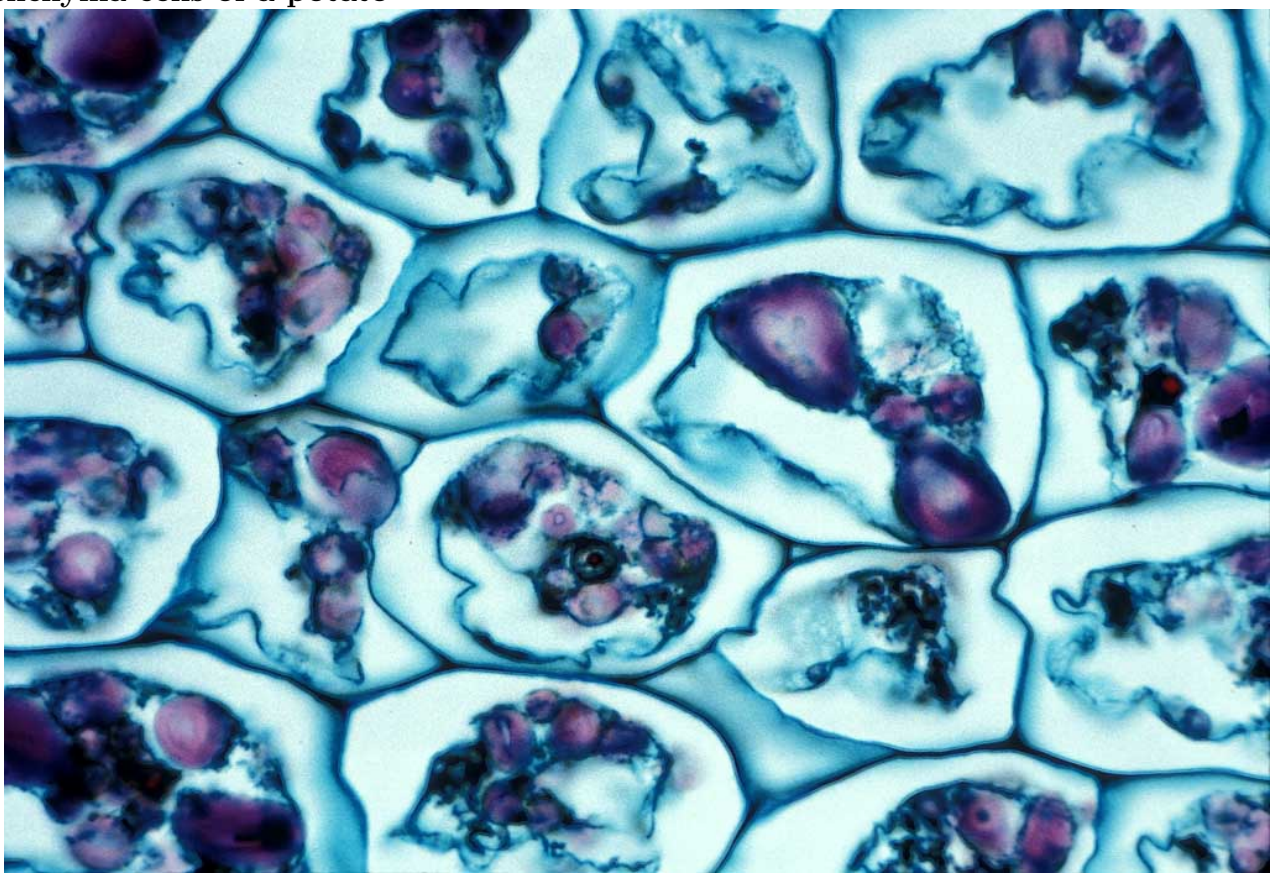
- **Simple tissues** have only one kind of cells
- **Complex tissues** have more than one cell type. This tissue type is unique for plants

1.3 First tissues: parenchyma and epidermis

Parenchyma (ground, main tissue)

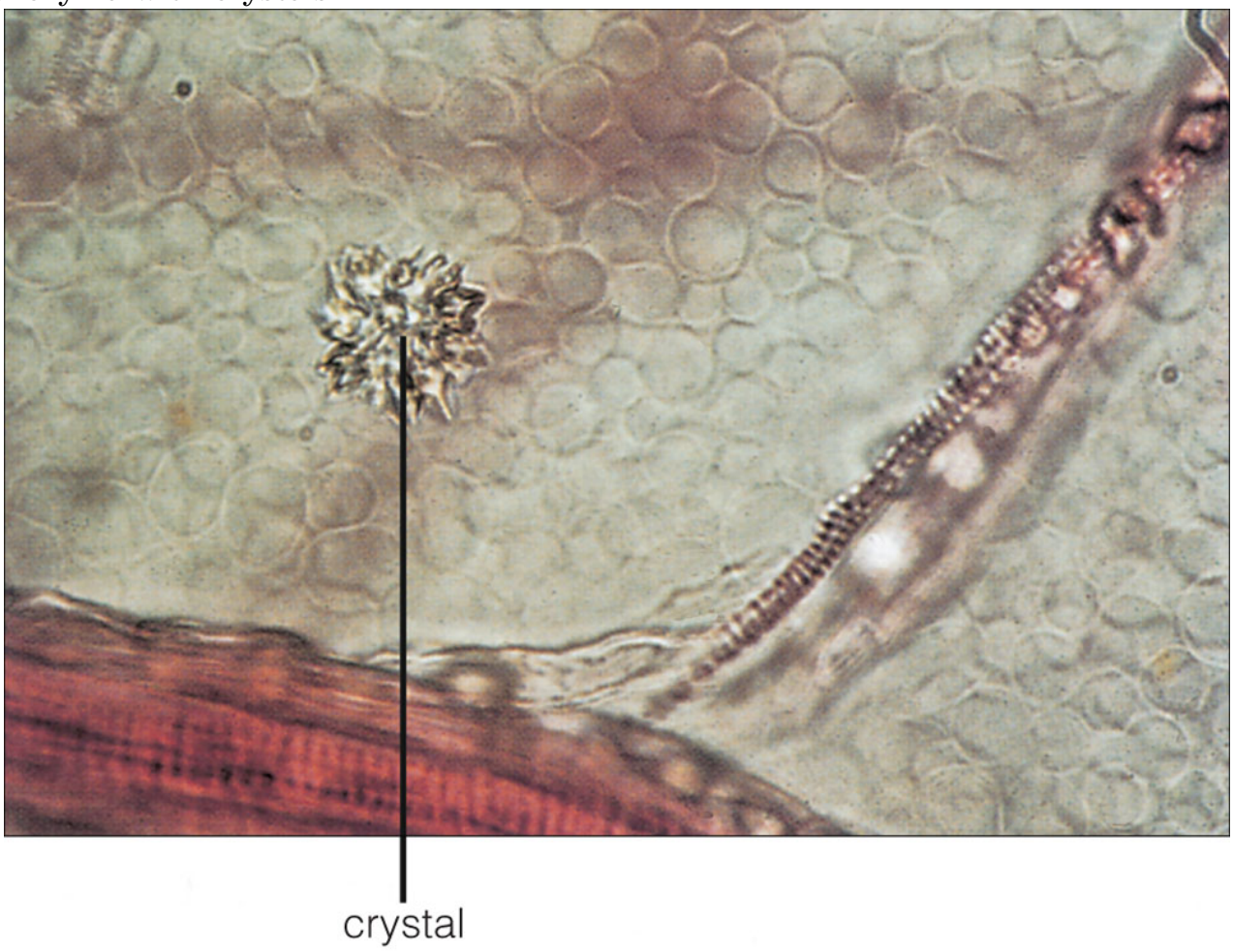
- Spherical or elongated cells
- Thin primary cell wall
- Sometimes, crystal inclusion bodies
- Main functions: photosynthesis and storage

Parenchyma cells of a potato



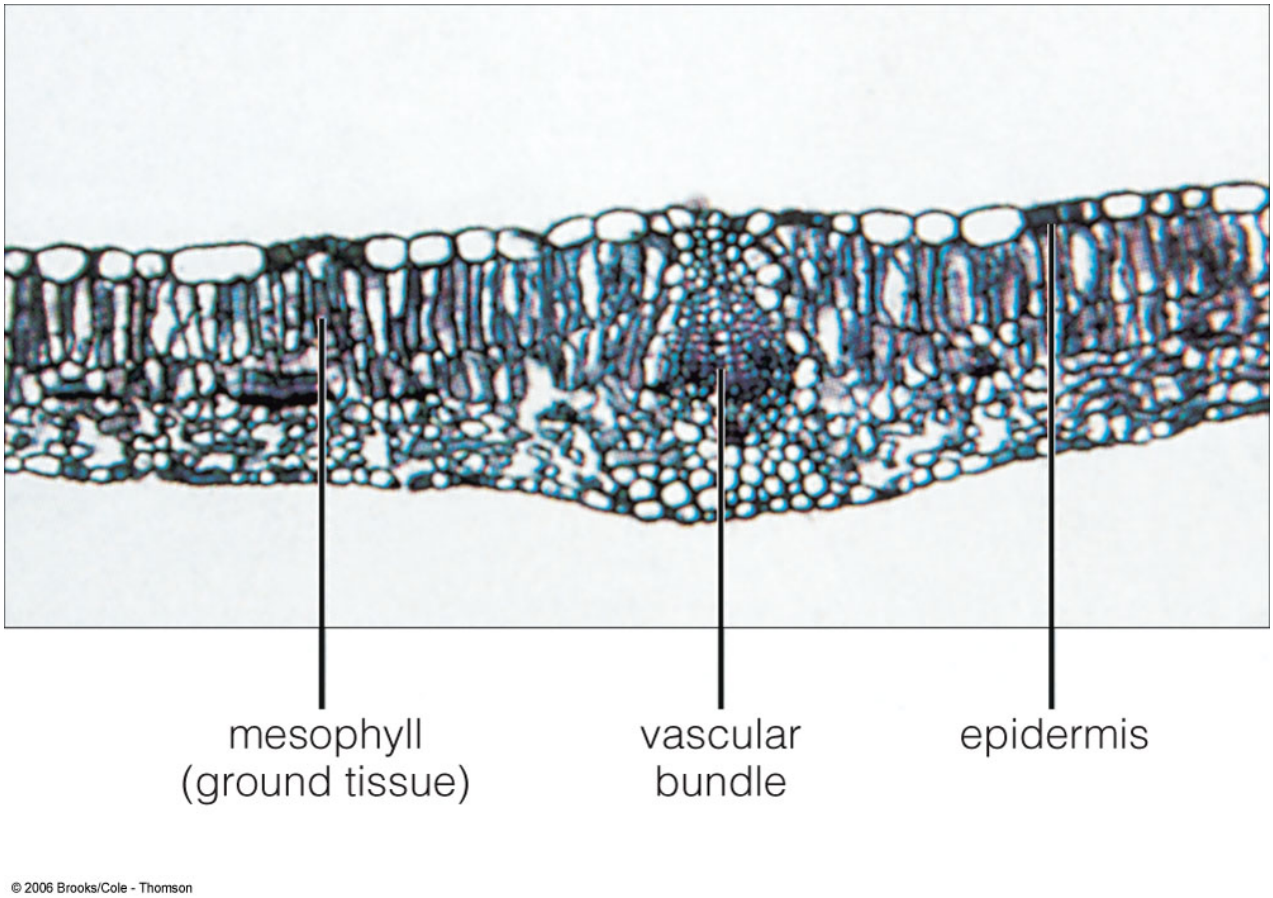
Parenchyma cells of a potato; the central cell shows obvious nucleus with starch stained purple (LM ×83)

Parenchyma with crystals



Parenchyma cells often include crystals (e.g., of calcium oxalate)

Photosynthetic parenchyma

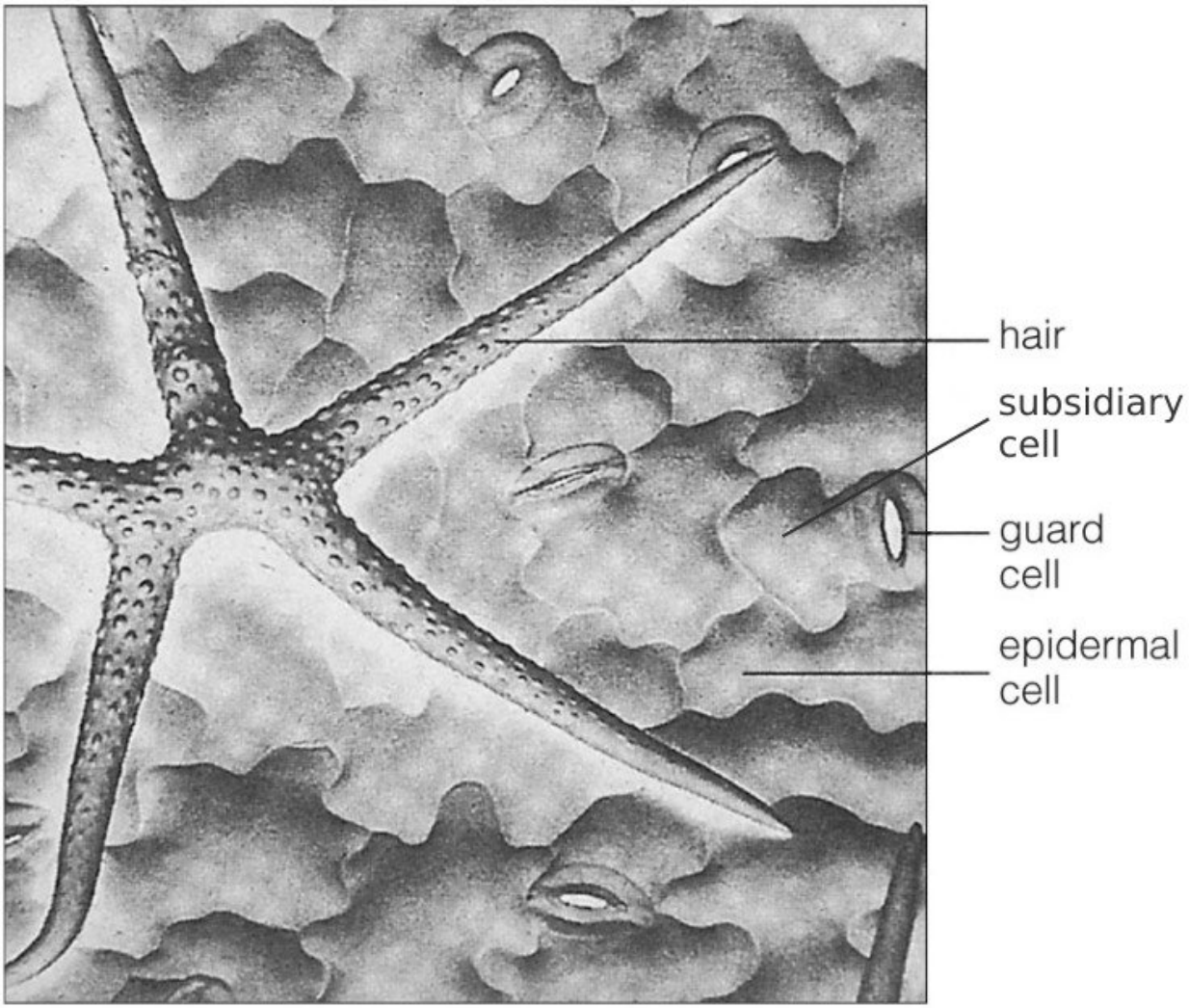


Photosynthetic parenchyma (mesophyll) in lilac (*Syringa vulgaris*) leaf

Epidermis: the complex tissue

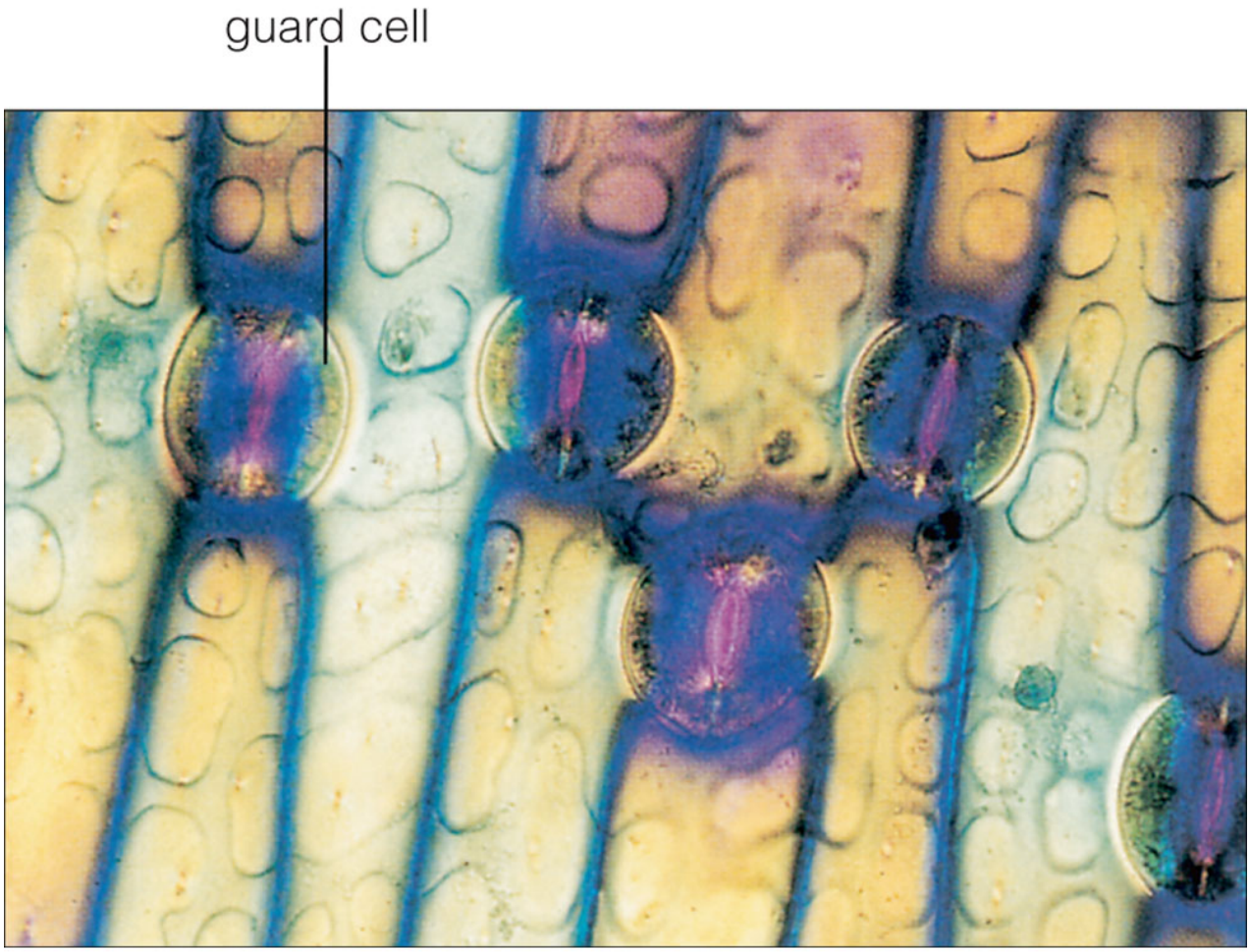
- Complex tissue of different cell types:
  A. Epidermal cells
  B. Stomata cells:
     – Guard cells
     – Subsidiary cells
  C. Trichomes
- Shapes and chemical compounds vary
- Main functions: gas exchange, transripration, defense

Epidermal cells



Three kinds of Shepard's purse (*Capsella bursa-pastoris*) epidermal cells

Stomata



Stomata with guard cells and pores (*Iris* sp.)

More about plants$_2$ classification

- Mosses (Bryophyta)
- Ferns and allies (Pteridophyta)
- Seed plants (Spermatophyta)
  - Conifers (Pinopsida)
  - Some other classes of seed plants
  - Angiosperms (Magnoliopsida)
    - Monocots (Liliidae)
    - Other subclasses of angiosperms (together: "dicots")

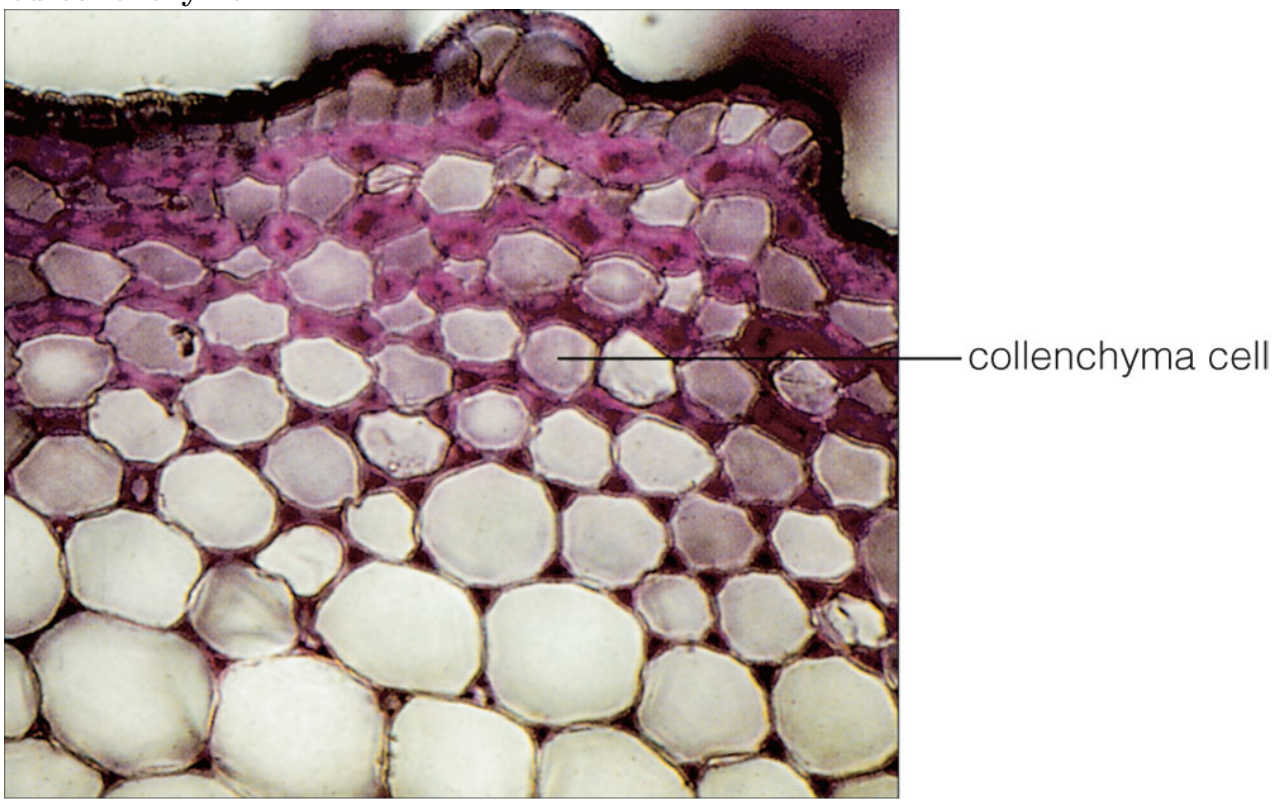
1.4 Step two: skeleton. Supportive tissues

Collenchyma: living supportive tissue

- Elongated cells

- Thick primary cell wall (pectins + cellulose)
- Main functions: mechanical support of young stems and leaves

Angled collenchyma

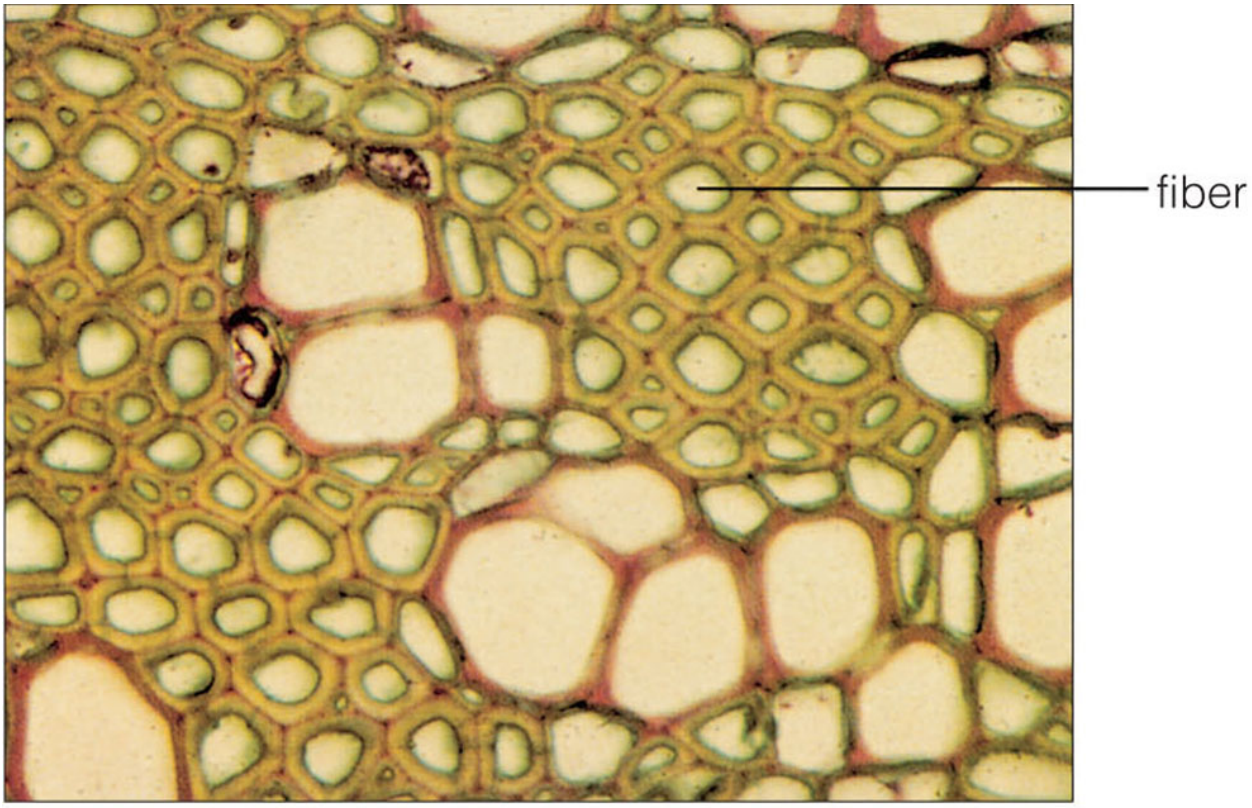


Collenchyma cells of marigold (*Calendula officinalis*)

Sclerenchyma: dead supportive tissue

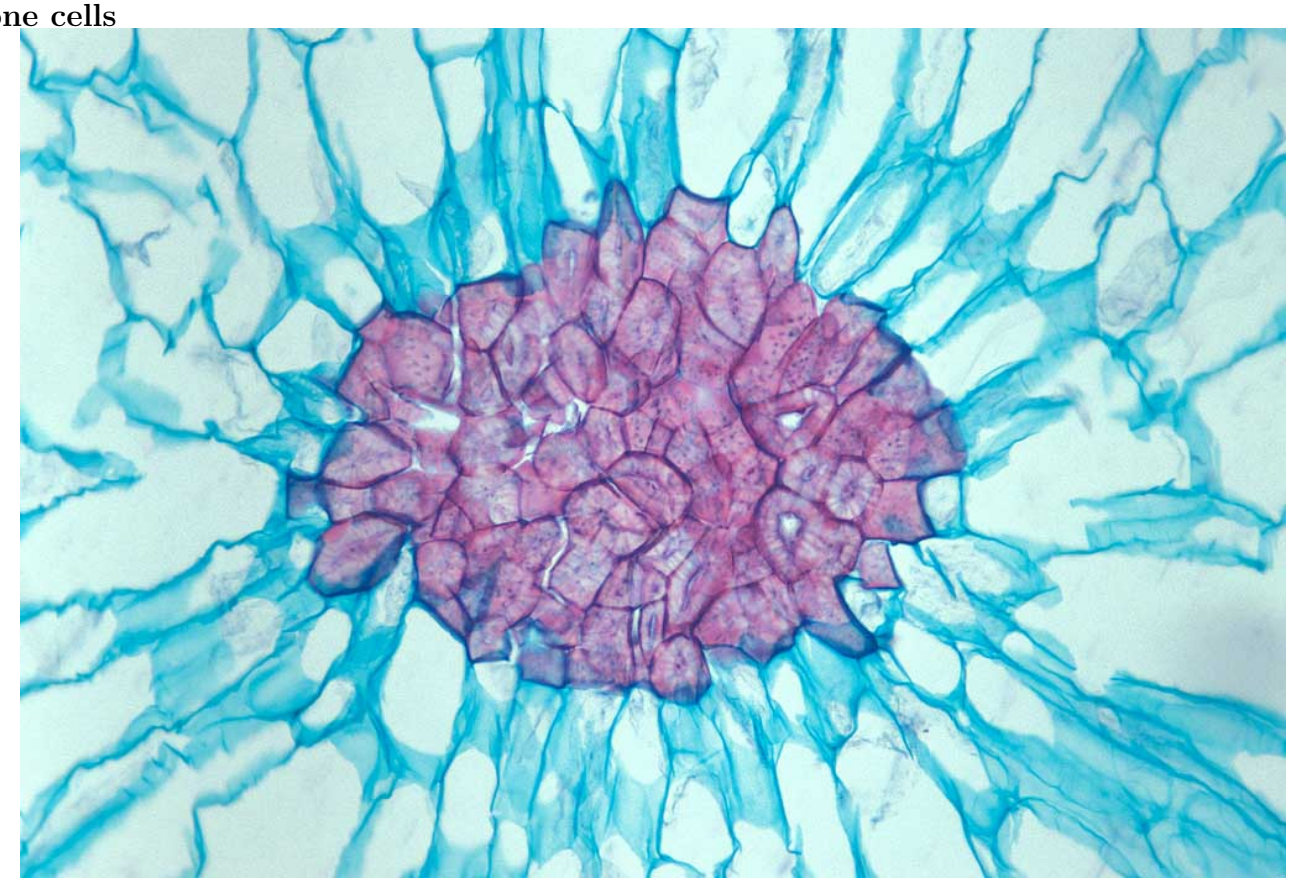
- Long cells (sclerenchyma fibers) or short crystal-like cells (sclereids)
- Dead cells with thick secondary cell wall, rich of lignin
- Supports weight of older plant organs, makes fruits non-edible before they become rip, makes stems firm

Sclerenchyma fibers



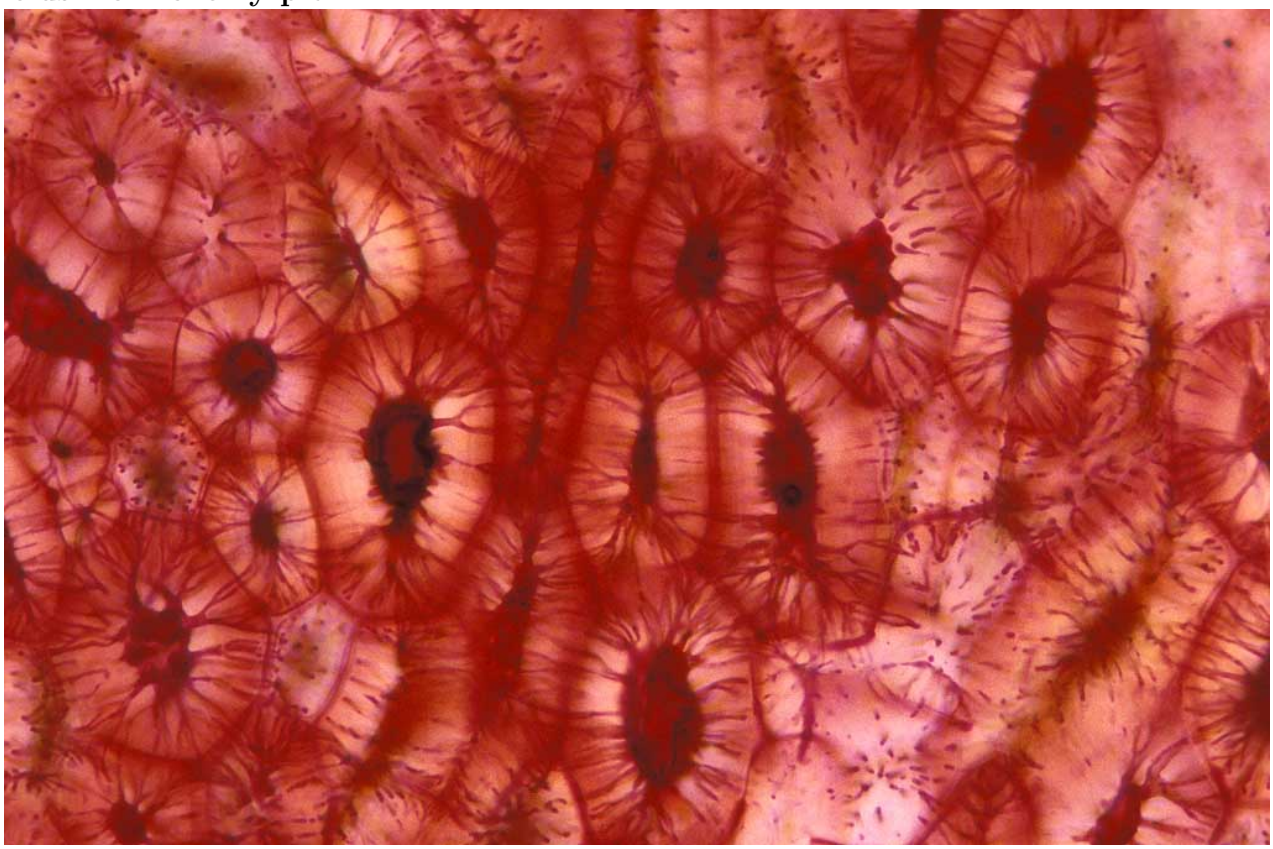
Cross-section of sclerenchyma fibers in geranium (*Pelargonium* sp.)

Stone cells



Stone cells (kind of sclereids) in pear fruit (*Pyrus communis*)

Sclereids from cherry pit



Sclereids from cherry (*Prunus* sp.) pit (LM ×400)

1.5 Step three: construction sites. Meristems

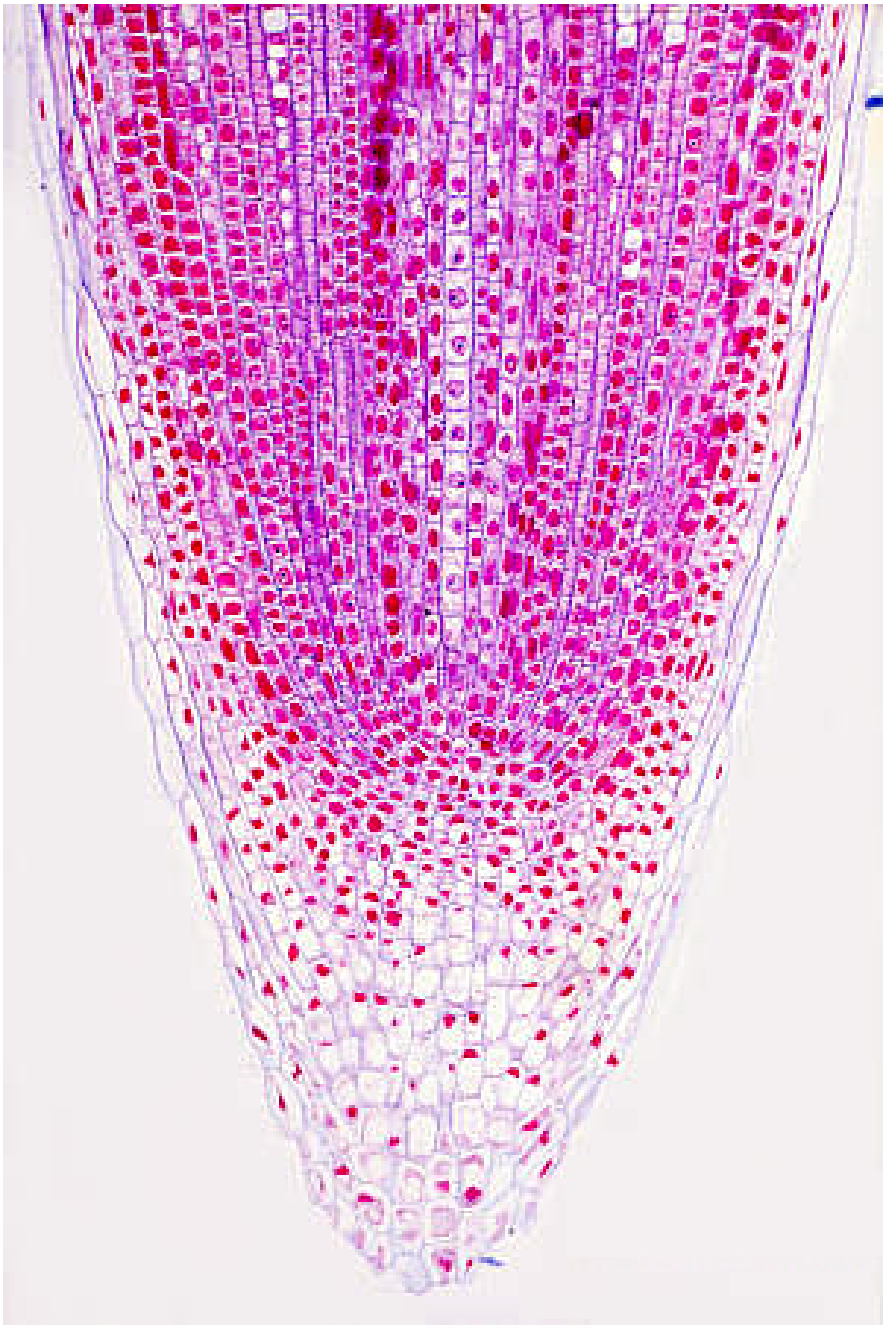
Meristems: apical

- Centers of plant development
- Locate on the very ends of roots (RAM) and shoots (SAM)
- Produce intermediate primary meristems which form all primary tissues

SAM

Coleus sp. stem apical meristem (LM ×100); primordia (embryonic leaves) are visible.

RAM



Corn (*Zea mays*) root apical meristem (© D. Webb)

Lateral meristem: cambium

- Originates from procambium which in turn originates from apical meristems
- Usually arises between two vascular tissues
- Main function: thickening. Produces secondary vascular tissues

Primary and secondary tissues

- Primary tissues originate from stem or root apex through primary meristems
- Secondary tissues originate from lateral meristems

Additional meristems

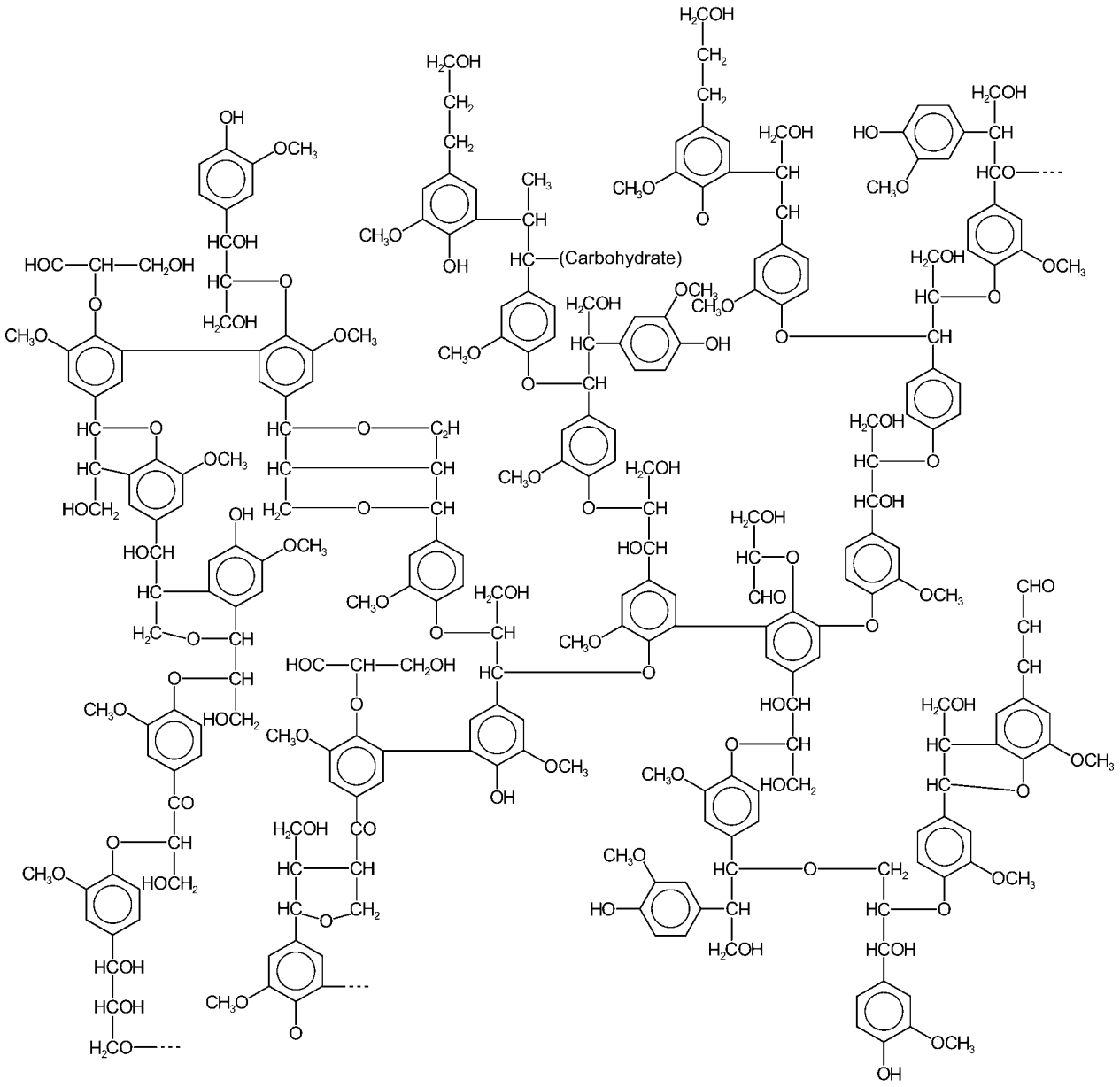
- **Intercalary** meristems: locate in stems, regulates stem elongation
- **Marginal** meristems are leaf-specific, they regulate leaf shape
- **Repair** meristems help to cure wounds, they form buds and roots in unusual places

1.6 Origin of tissues: the summary

Origin of tissues and organs of plants: first steps

- Plants were pushed on land for many reasons, including competition
- First challenge: drying. Response: **epidermis** and **parenchyma**.
- Second challenge: new level of competition. Response: growing up!
- Problem: big weight. Response: **collenchyma**.
- Competition grows, plants growing even higher. Weight grows. They also need to get rid of turgor dependency. Response: use lignin not only for epidermis surface (cuticle) but also for secondary cell walls—**sclerenchyma**.
- Competition grows again, plants need to grow faster. Solution: **meristems**.
- Size of plant is too big for plasmodesmata transportations. Solution: vascular tissues, **xylem** and **phloem**.

Lignin



Phenolic and other "plastic" compounds (e.g., lignin) were initially developed for spore distribution with a wind, then used in cuticle, then in the secondary cell walls.

1.7 Step four: pipes. Vascular tissues

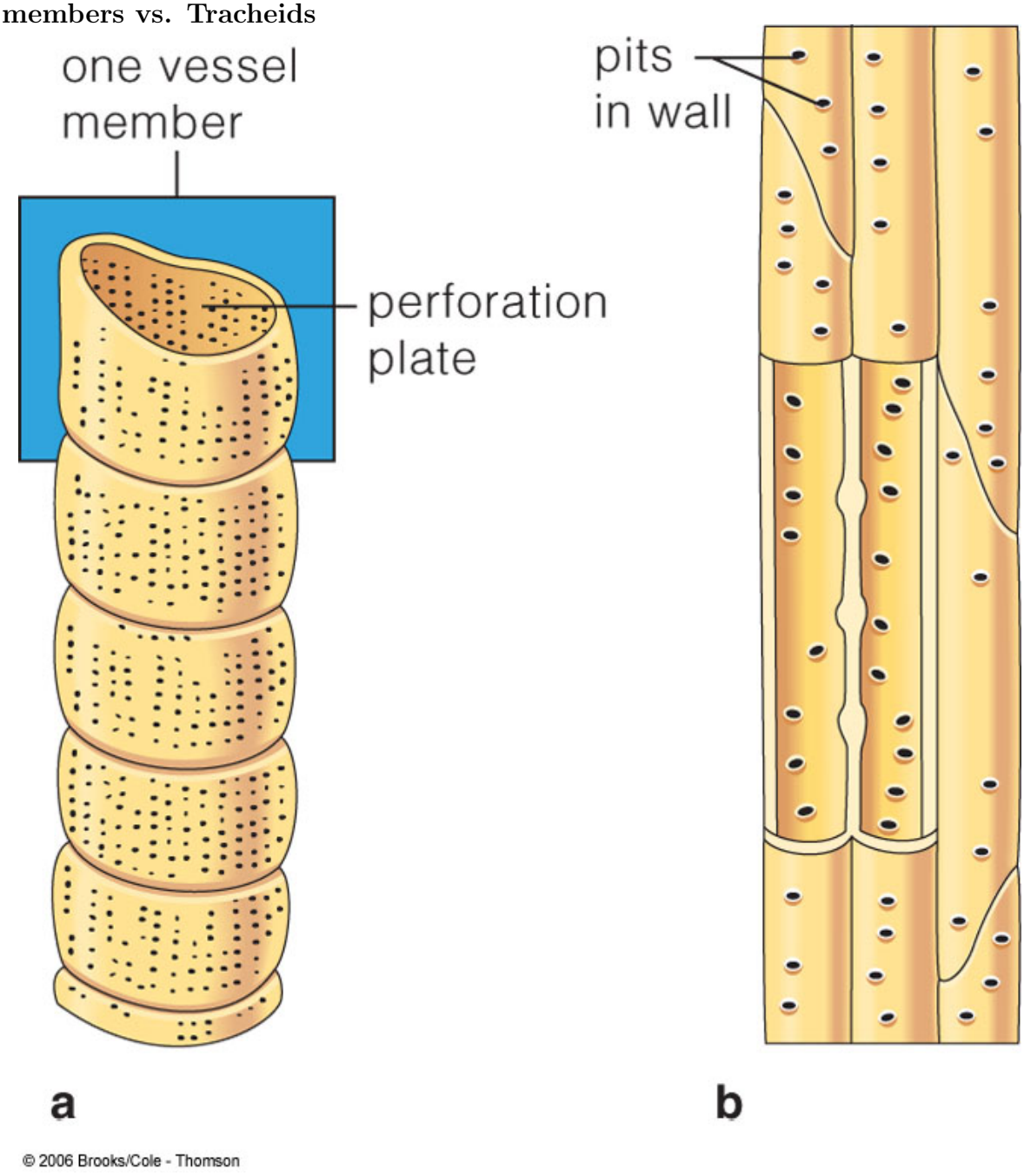
1.7.1 Xylem

Vascular tissues: Xylem

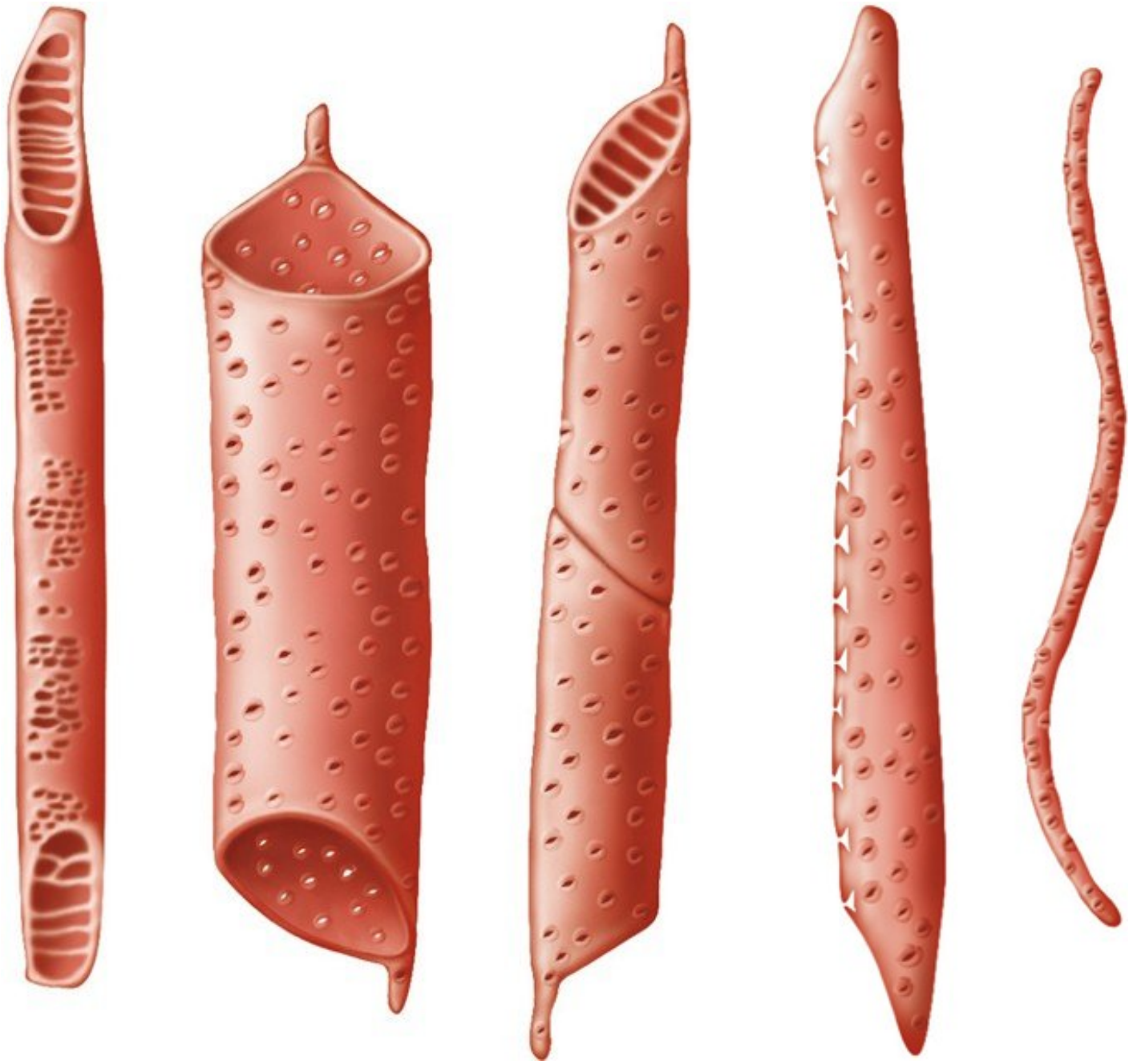
- Occurs in vascular bundles or vascular cylinder
- Types of cells: **tracheary elements** (tracheids and vessel members), **fibers**, and **parenchyma**
- Tracheids have pits; vessel members have perforations; all of them are dead cells
- Gymnosperms have only tracheids; flowering plants have tracheids + vessel elements together
- In flowering plants, primary xylem has mostly tracheids and vessels with scalariform perforations; secondary xylem has mostly vessels with open perforations

- Xylem elements (except parenchyma) are rich of lignin and are main components of wood
- Main functions: water transport and mechanical support

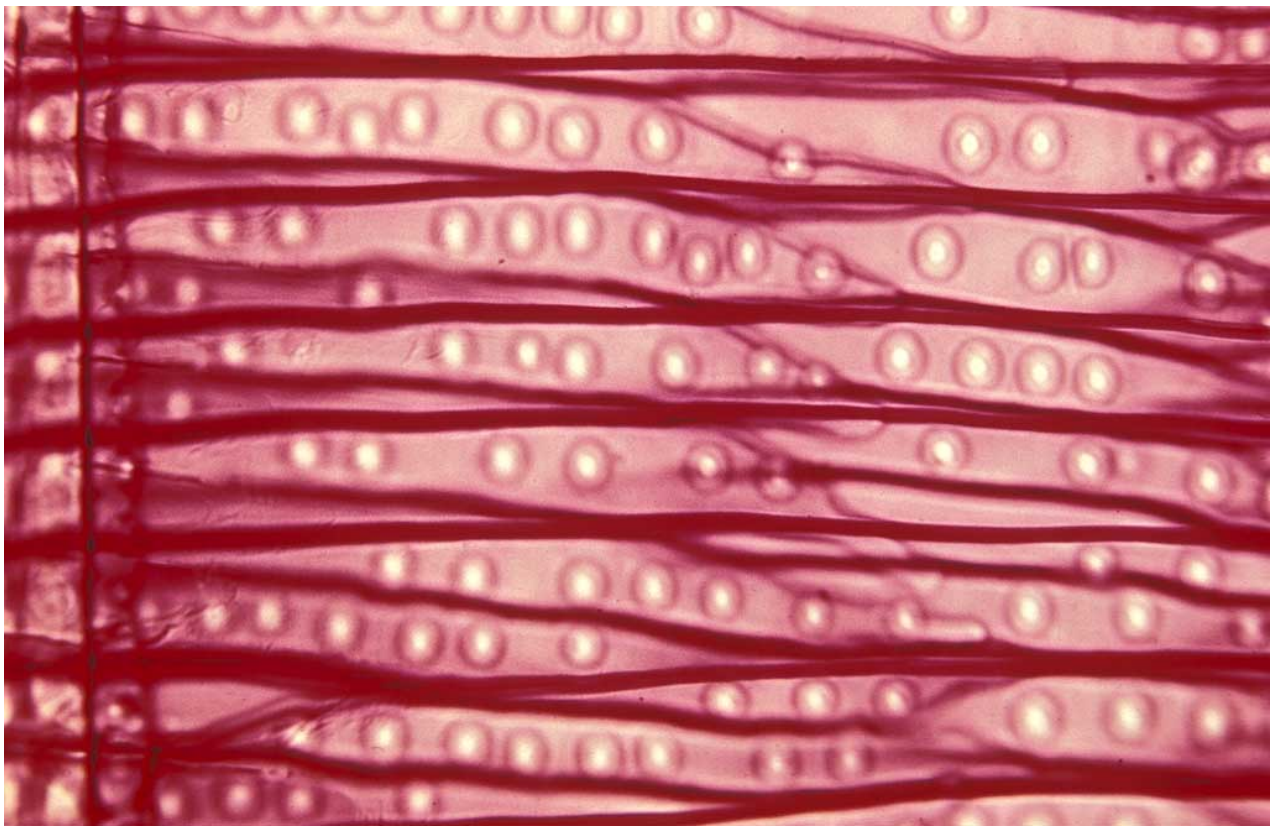
Vessel members vs. Tracheids



Vessel members vs. Tracheids

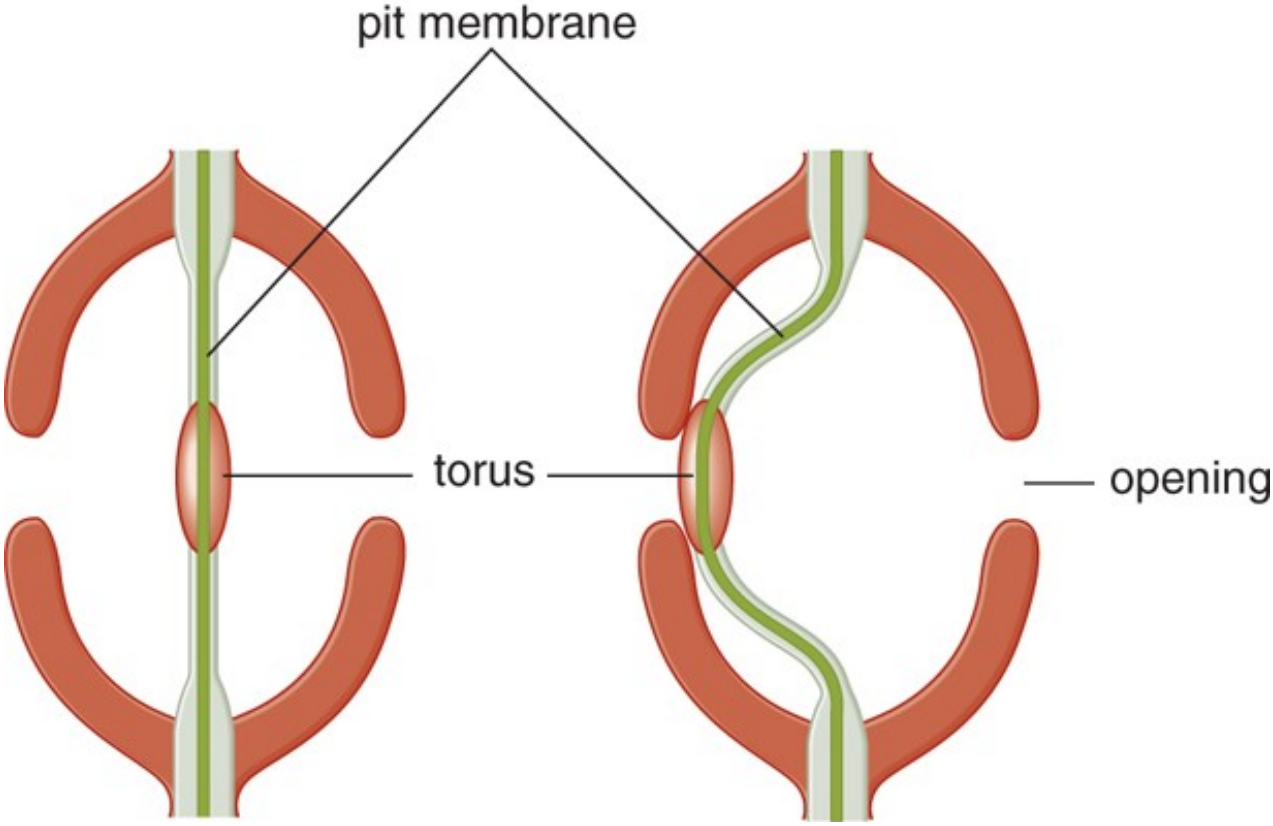


Tracheids



Pine (*Pinus* sp.) tracheids with pits

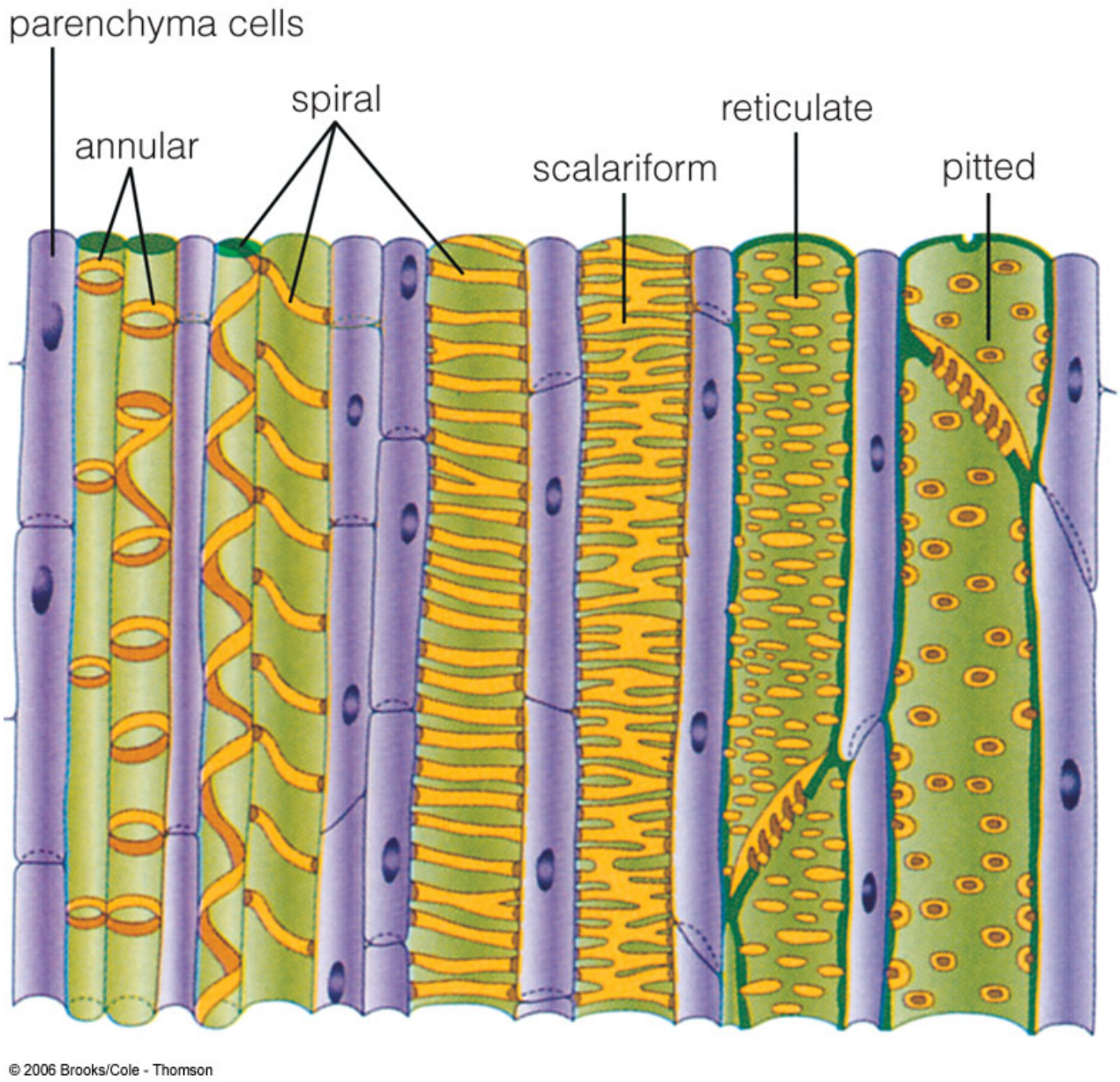
Pit is NOT a direct connection



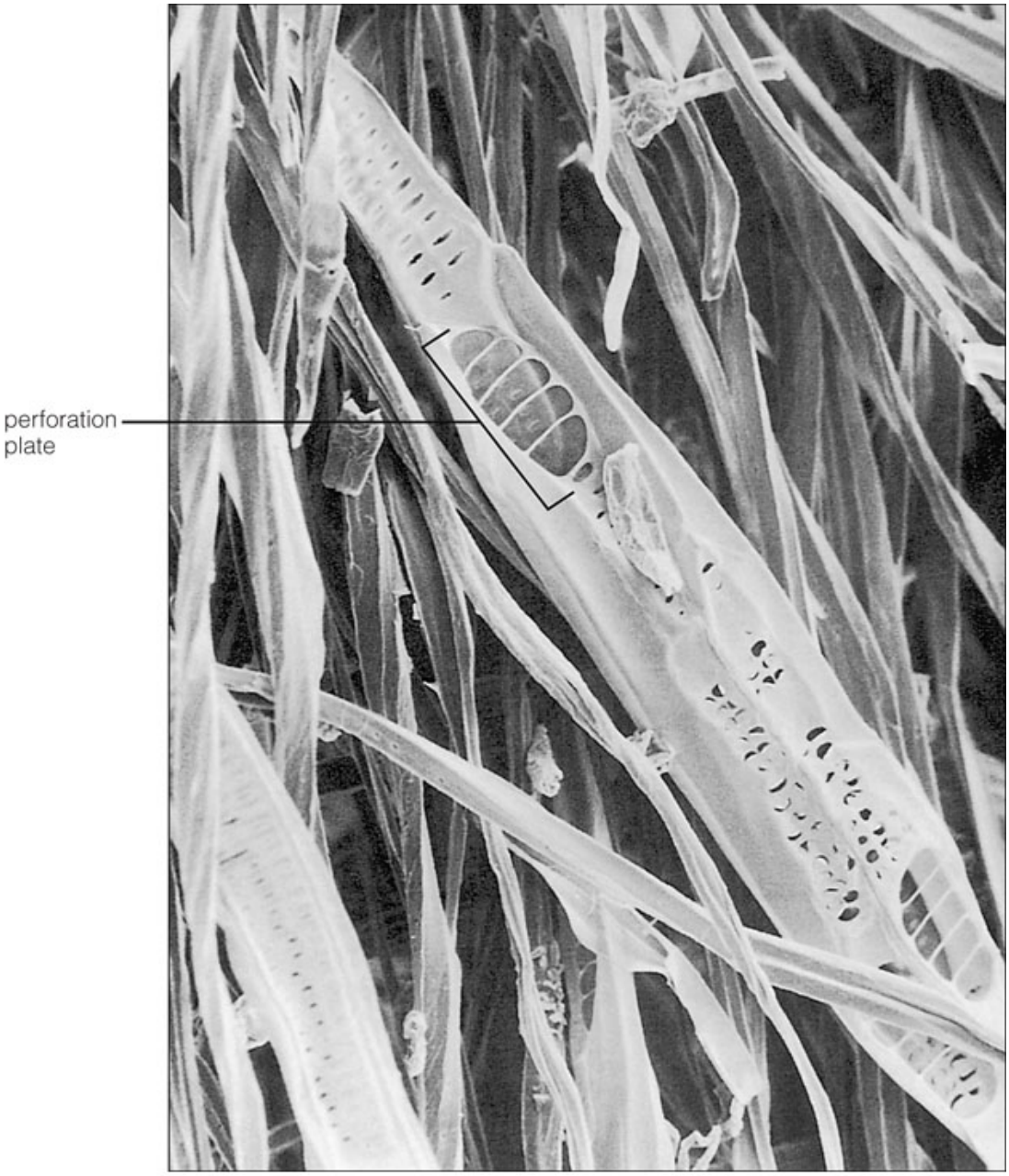
Vessels

Ash (*Fraxinus americana*) secondary xylem with vessels (LM ×26)

Perforations



Scalariform perforations: direct connections

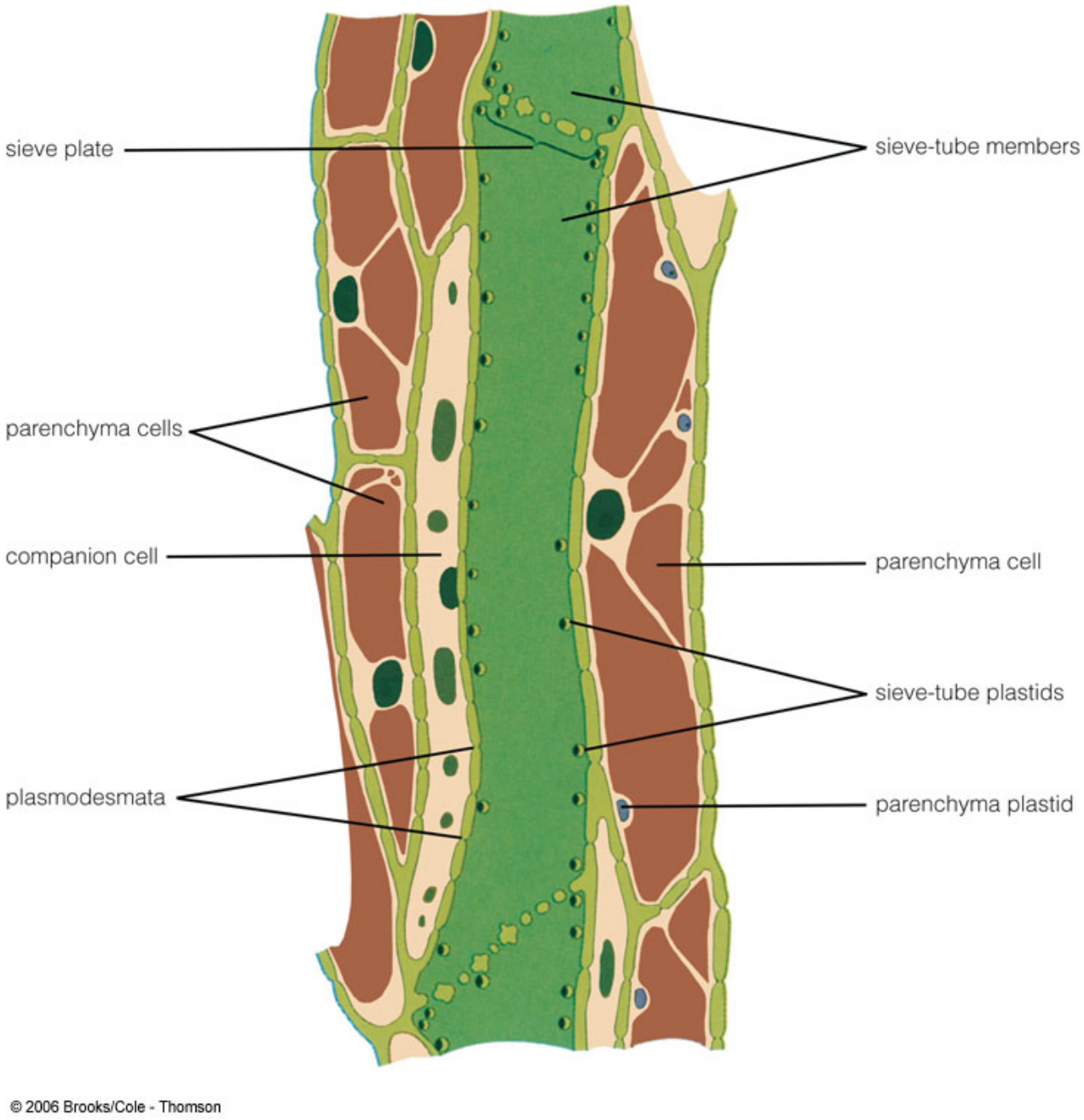


1.7.2 Phloem

Phloem

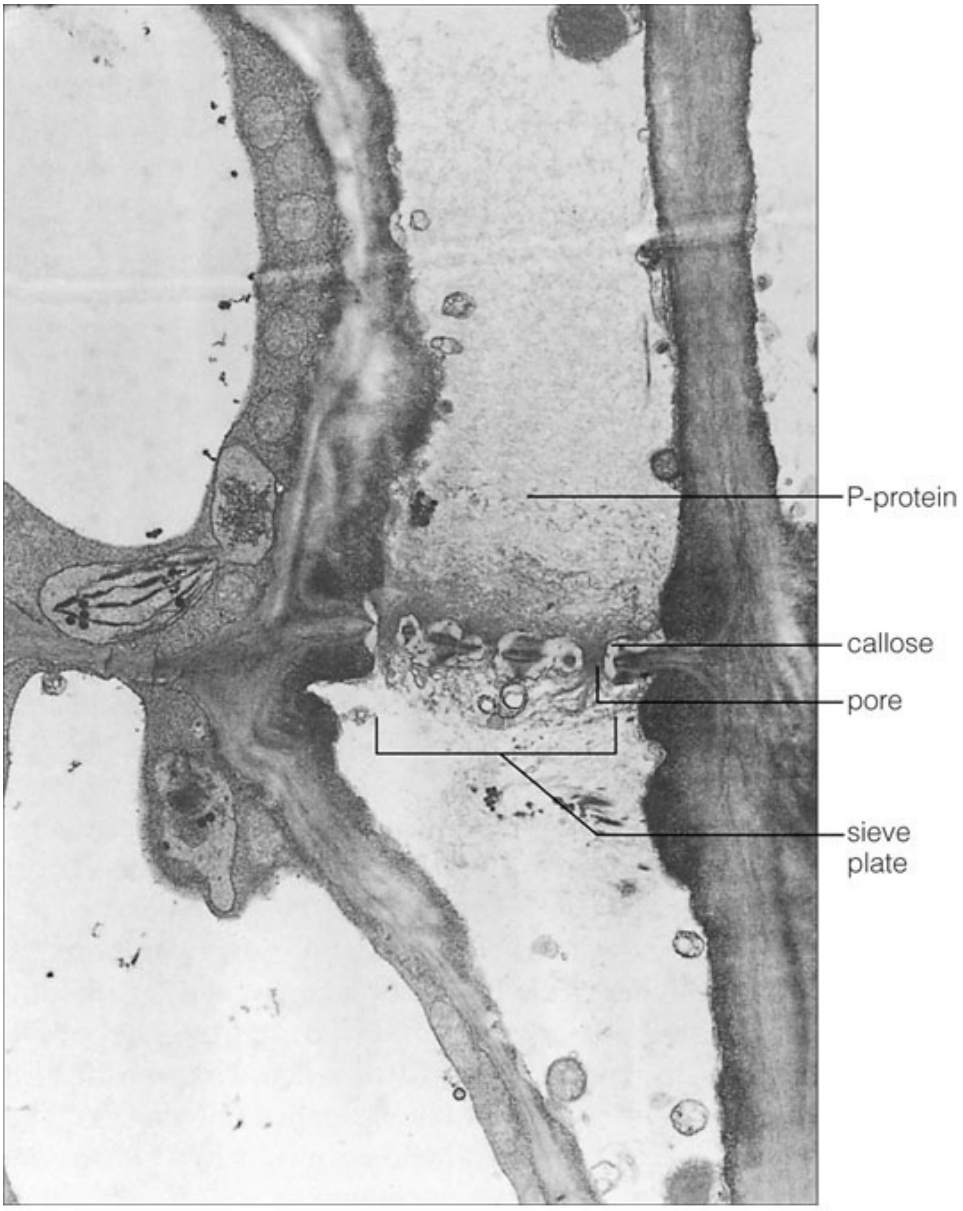
- Usually occurs adjacent to a xylem
- Types of cells: **sieve tube cells**, **companion cells**, **fibers** and **parenchyma**
- Sieve tube cells have plastids and perforation (sieve) plates between cells but no nuclei, companion cells have nuclei
- However, in gymnosperms there are *no* companion cells and sieve tube cells *have* nuclei
- Secondary phloem usually has more fibers than primary phloem
- Main functions: sugar transport and mechanical support

Phloem cell types



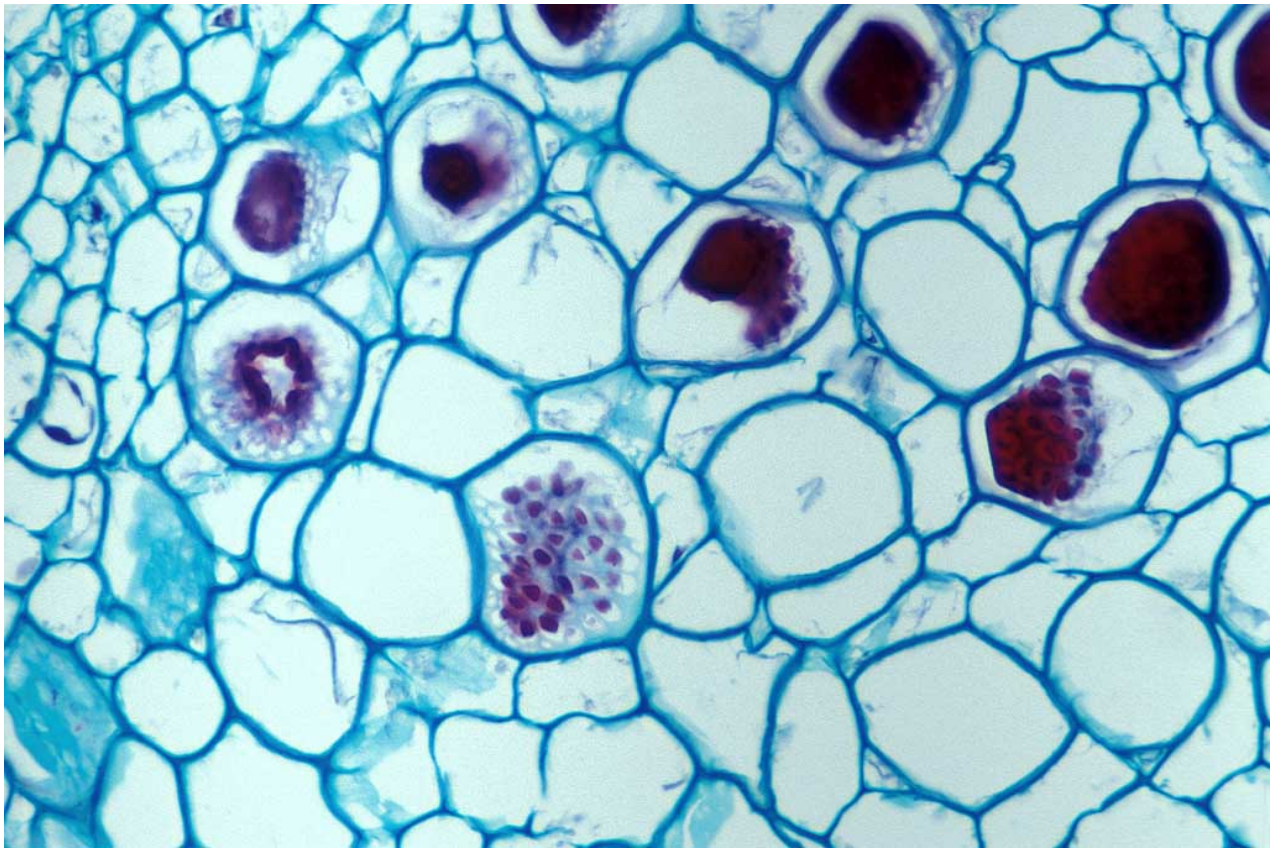
Sieve tubes and phloem parenchyma

Perforation (sieve) plate



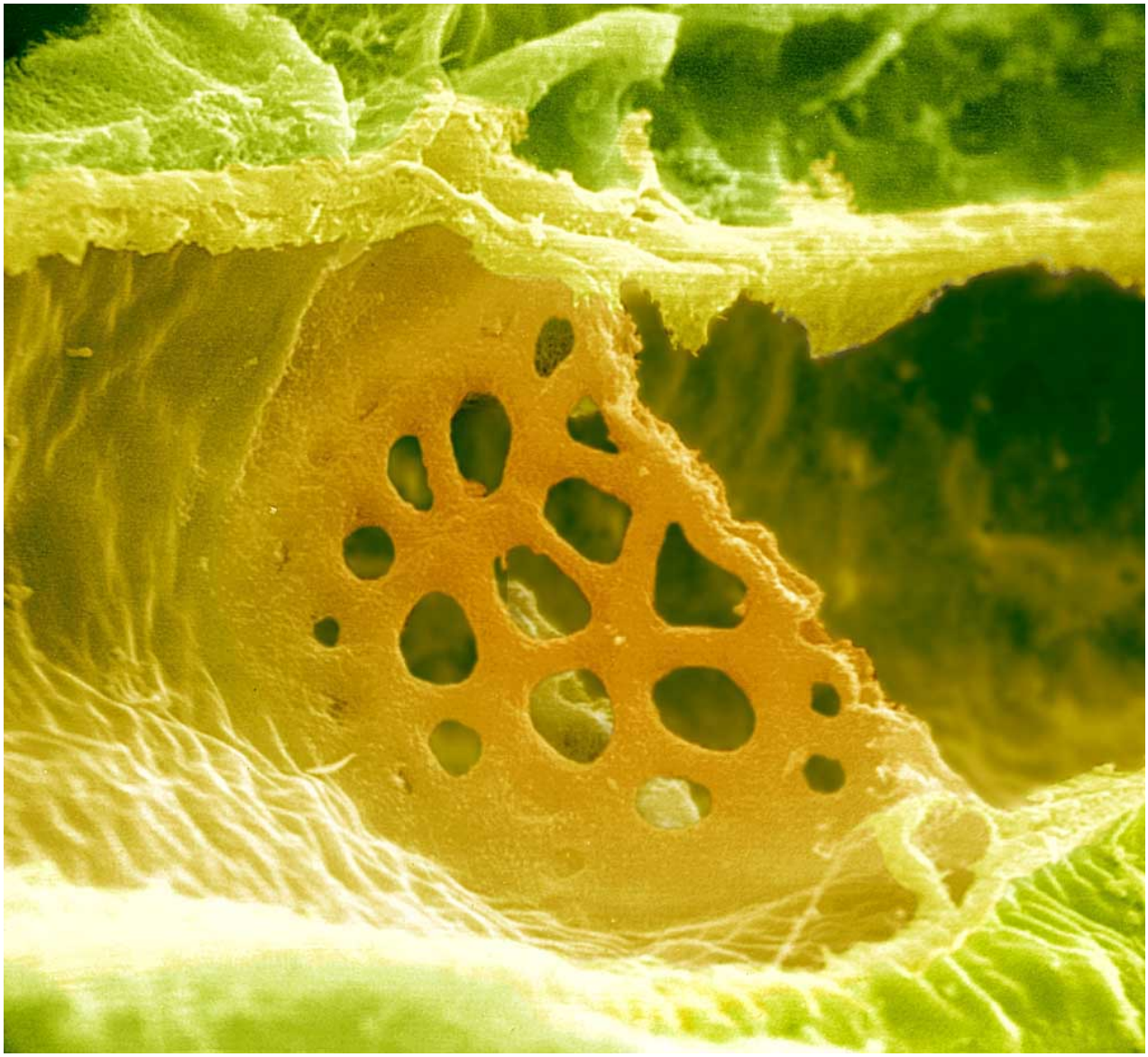
Cross-section (TEM)

Perforation plates: frontal view



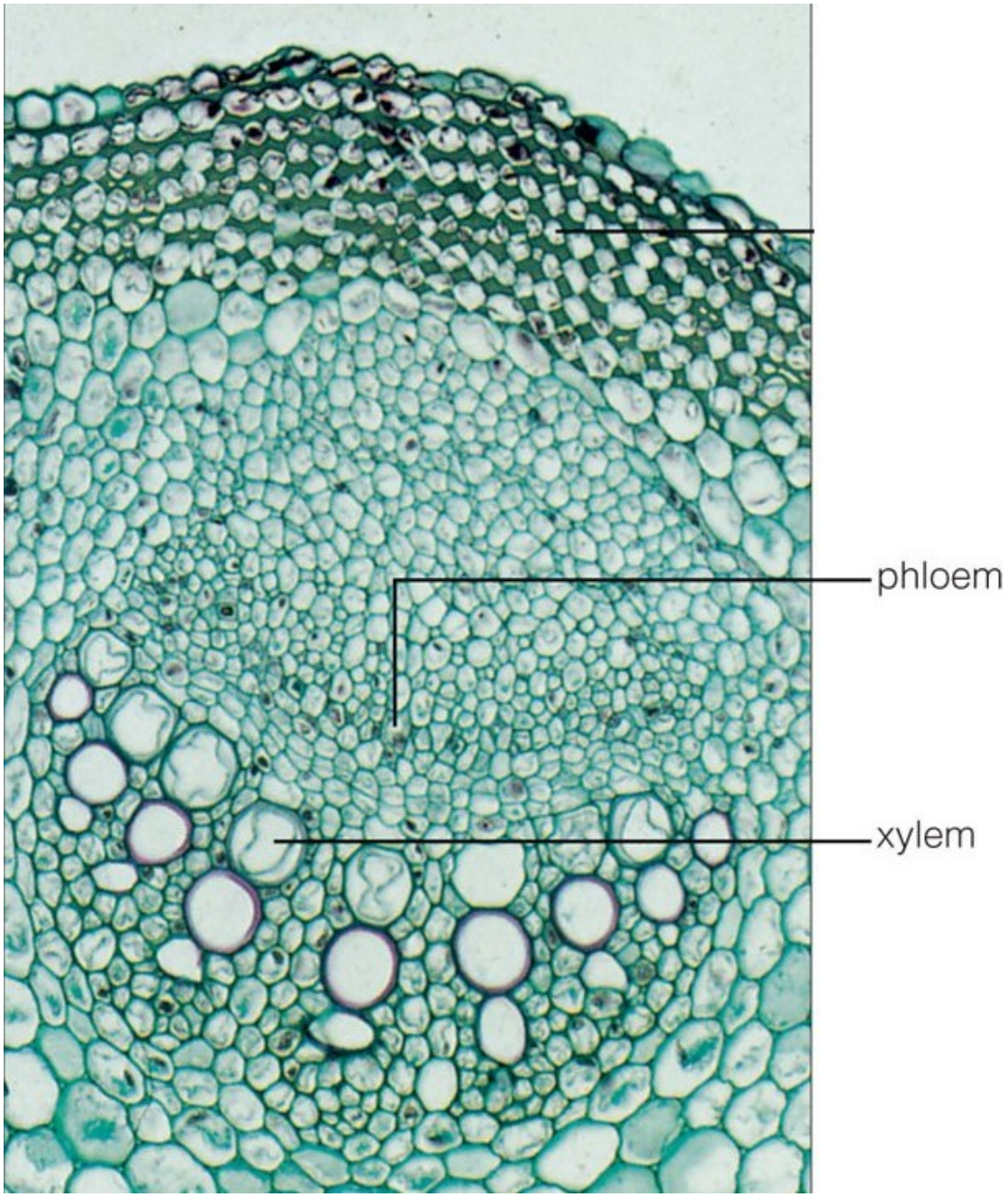
Frontal view (LM)

Plates: pores

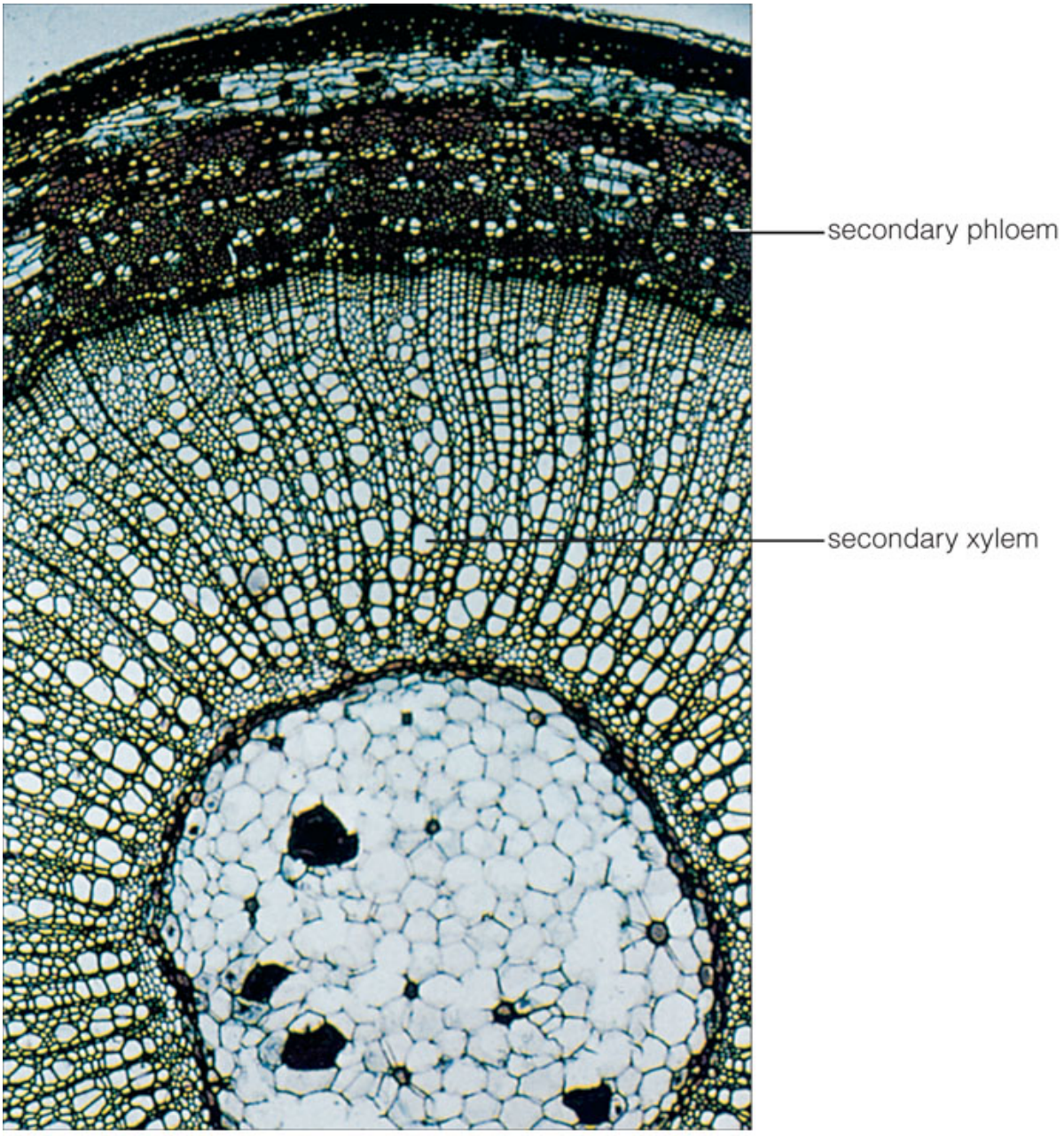


Sieve plate, a pore in the end wall of a sieve-tube member, through which phloem sap flows (SEM ×4800)

Primary vascular tissues



Secondary vascular tissues

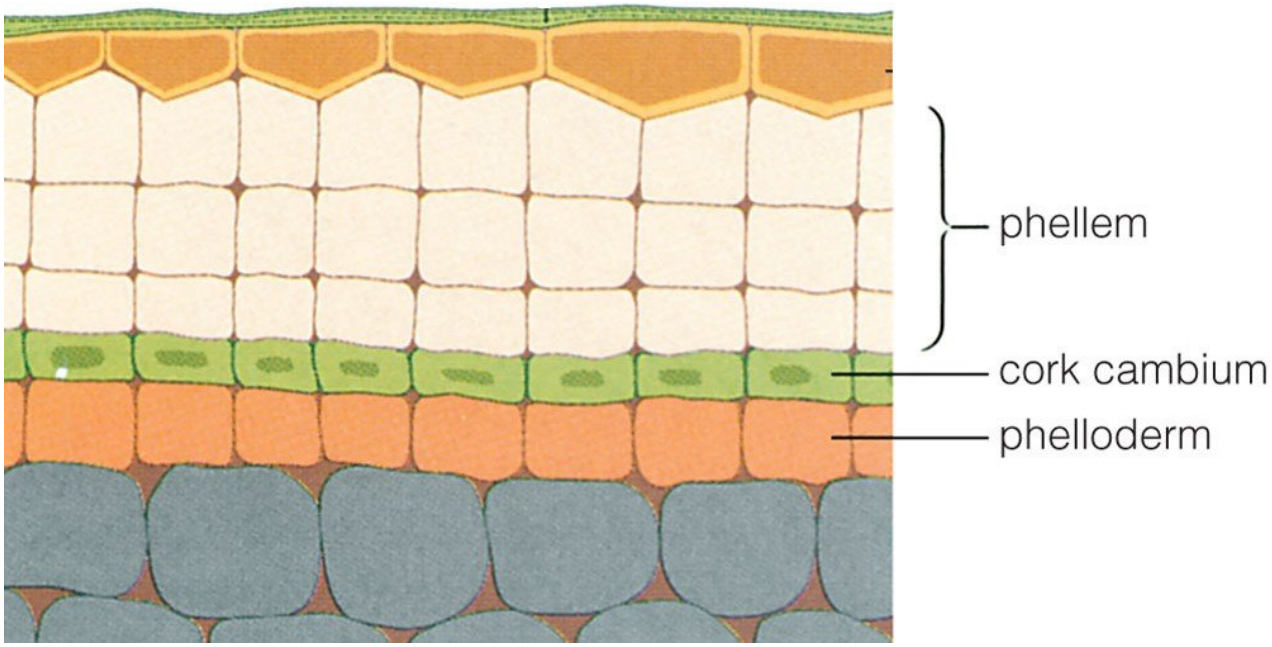


1.8 Secondary cover: periderm

Secondary dermal tissue: Periderm

- Secondary dermal tissue
- Arises inside the stem ground tissue (cortex), closer to surface
- Complex tissue: includes phellem (cork in the strict sense), cork cambium (phellogen), and phelloderm
- Old periderm includes some other tissues and becomes a bark
- Cells of phellem are dead cells rich of suberin
- Main function is defense

Three cell types of periderm



Cork cambium is another lateral meristem; *phellem* and *phelloderm* are main components of periderm

1.9 Step five: pumps. Absorption tissues

Poikilo- and homoiohydricity

- **Poikilohydric** plants do not save water, they survive even complete desiccation
- **Homoiohydric** plants save water, they always have similar water content and do not survive after desiccation
- Compare with poikilo- and homoiothermic animals (reptiles vs. mammals)

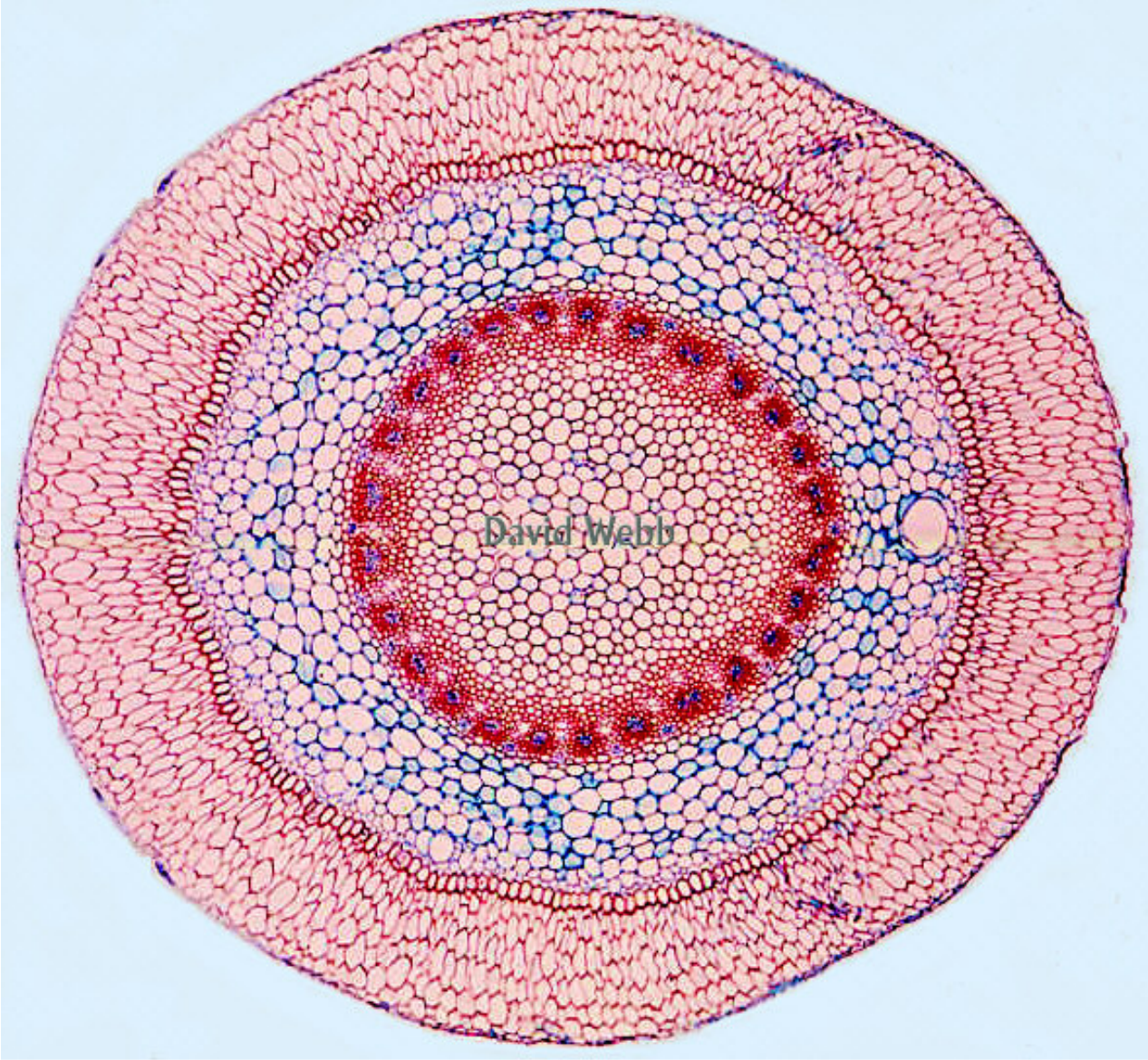
Absorption tissues

- Always primary, simple tissues
- **Rhizodermis**, or root hairs, originates from protoderm, but life span is much shorter than of epidermis
- **Velamen**, originates from root cortex

Rhizodermis

Root hairs of grass seedlings (LM)

Velamen



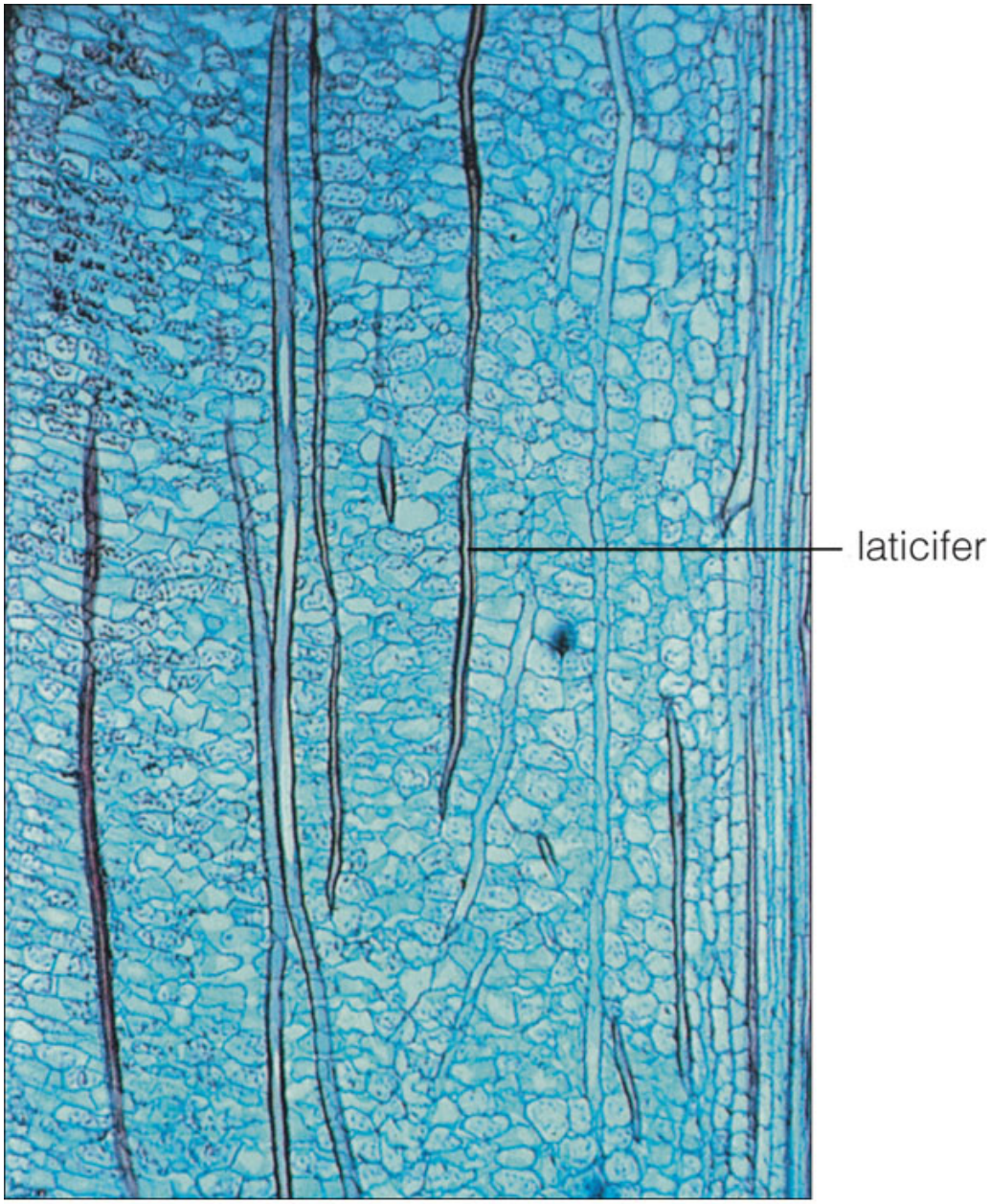
Outer cylinder is a velamen tissue of orchid root (LM)

1.10 In addition: secretory tissues

Secretory tissues

- Primary, simple or complex tissues
- Spreading across plant body, concentrating in leaves and young stems
- May secrete latex, volatile oils, mucus and other chemicals
- Functions vary: attraction or dis-attraction, communication, defense etc.

Laticifers



Quiz question (3 points)

Name 3 forces which drove plants on land.

Summary 1

- The structure of plant body, its organs and tissues is a result of land colonization
- **Complex tissues** have different cell types, **secondary tissues** originate from lateral meristems (i.e., cambium)
- **Parenchyma**, or ground tissue, is a main component of young plant organs
- **Epidermis** is a complex tissue which includes stomata

Summary 2

- **Collenchyma** and **sclerenchyma** are simple supportive tissues
- **Secondary tissues** originate from lateral meristems (i.e., cambium)
- **Xylem vs. phloem**:
  - **State**: dead vs. living cells
  - **Transport**: water vs. sugar
  - **Direction**: up vs. down
  - **Biomass**: big vs. small

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

2 Questions and answers

2.1 Quiz

Quiz question (3 points)

Name 3 forces which drove plants on land

- Competition between plants
- General availability of light
- Temperature / gas conflict (or how hungry whales and coke relate)

2.1.1 Phloem

Phloem

- Usually occurs adjacent to a xylem
- Types of cells: **sieve tube cells**, **companion cells**, **fibers** and **parenchyma**
- Sieve tube cells have plastids and perforation (sieve) plates between cells but no nuclei, companion cells have nuclei
- However, in gymnosperms there are *no* companion cells and sieve tube cells *have* nuclei
- Secondary phloem usually has more fibers than primary phloem
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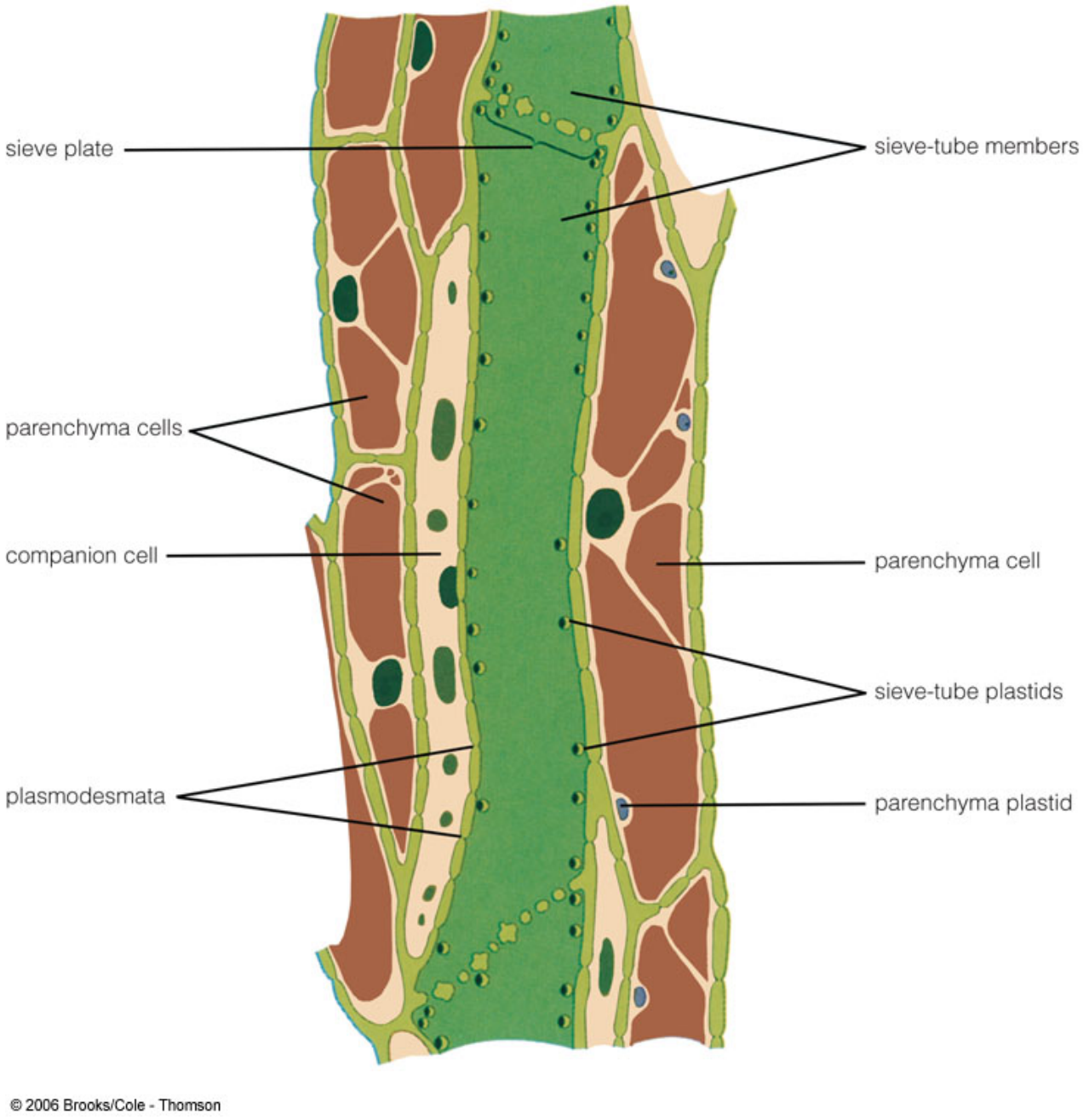
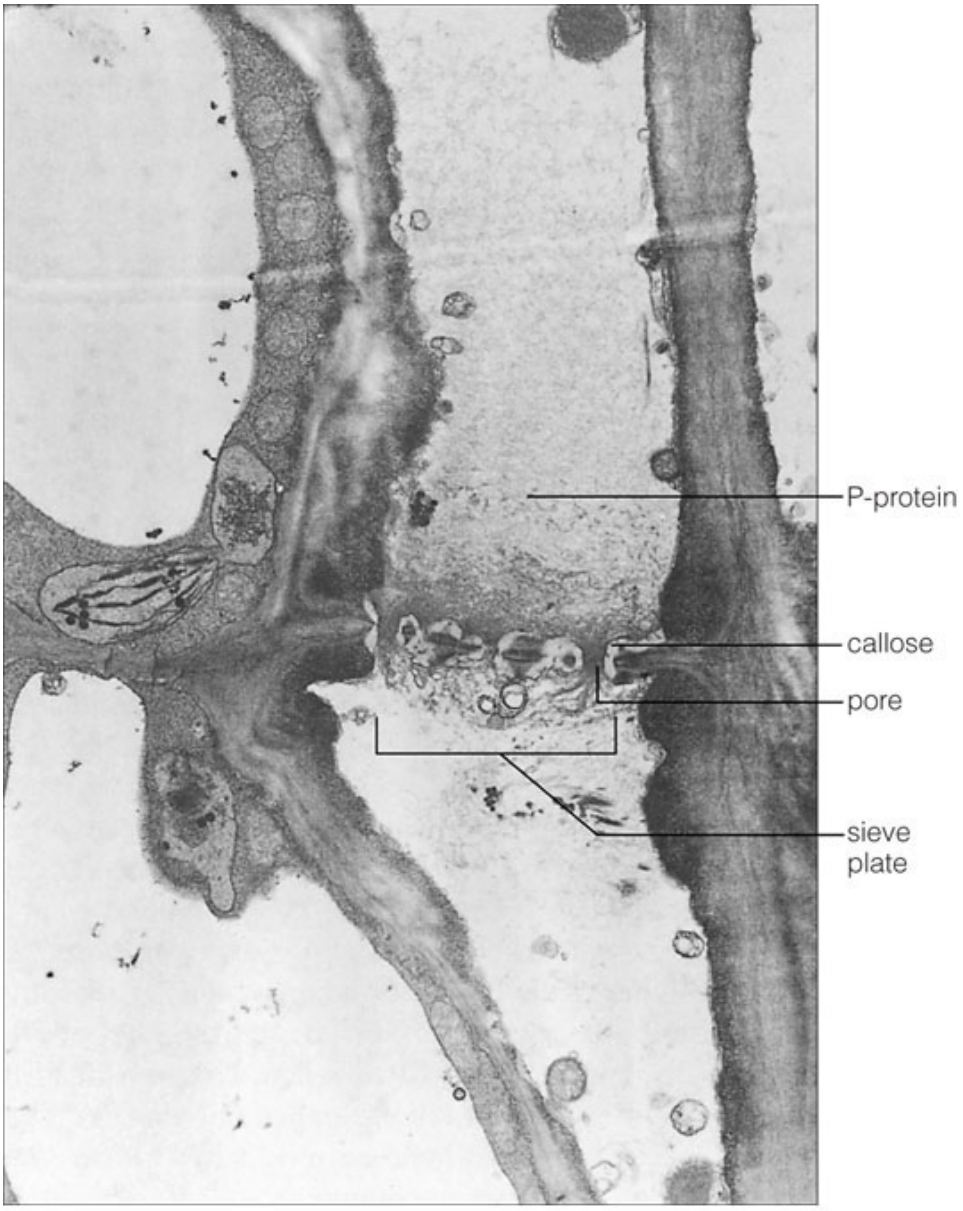
Phloem cell types



Sieve tubes and phloem parenchyma

Perforation (sieve) plate



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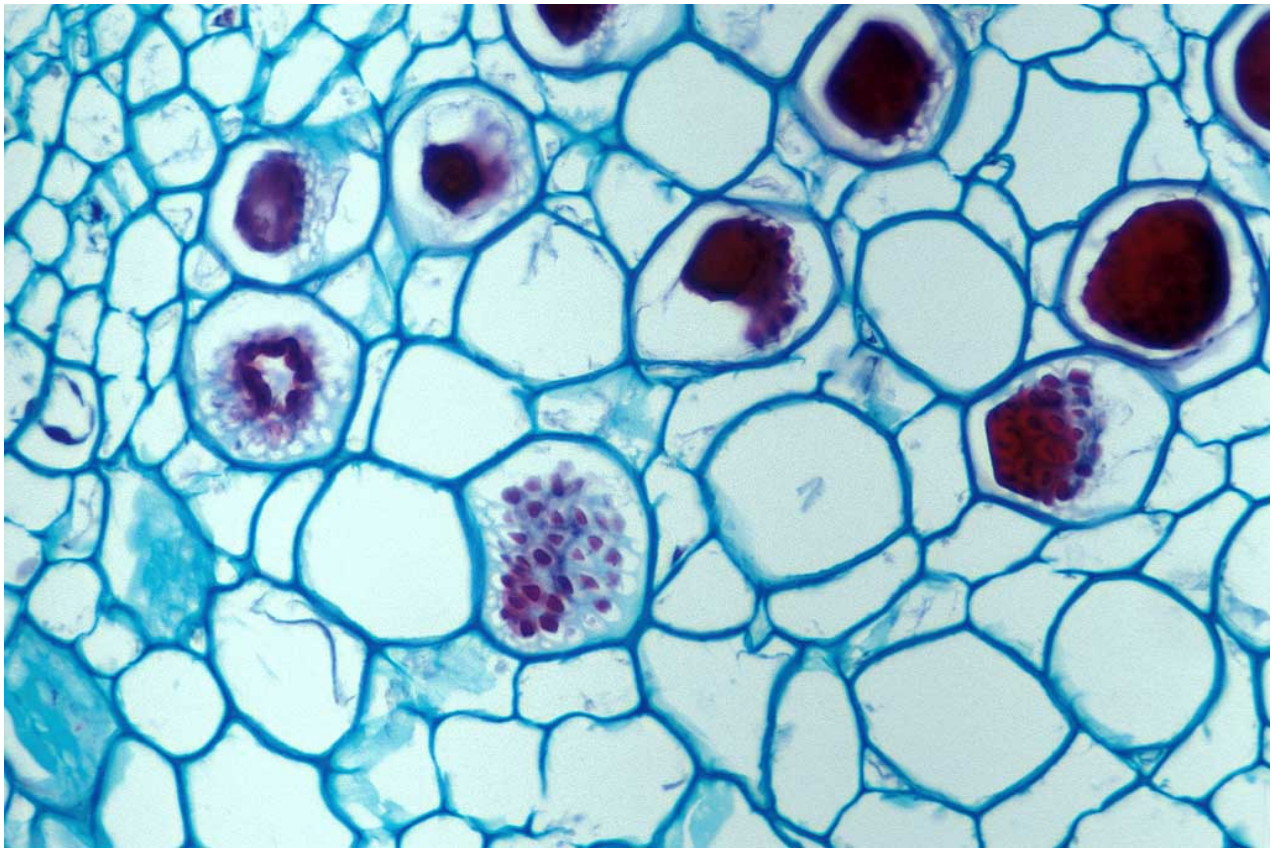
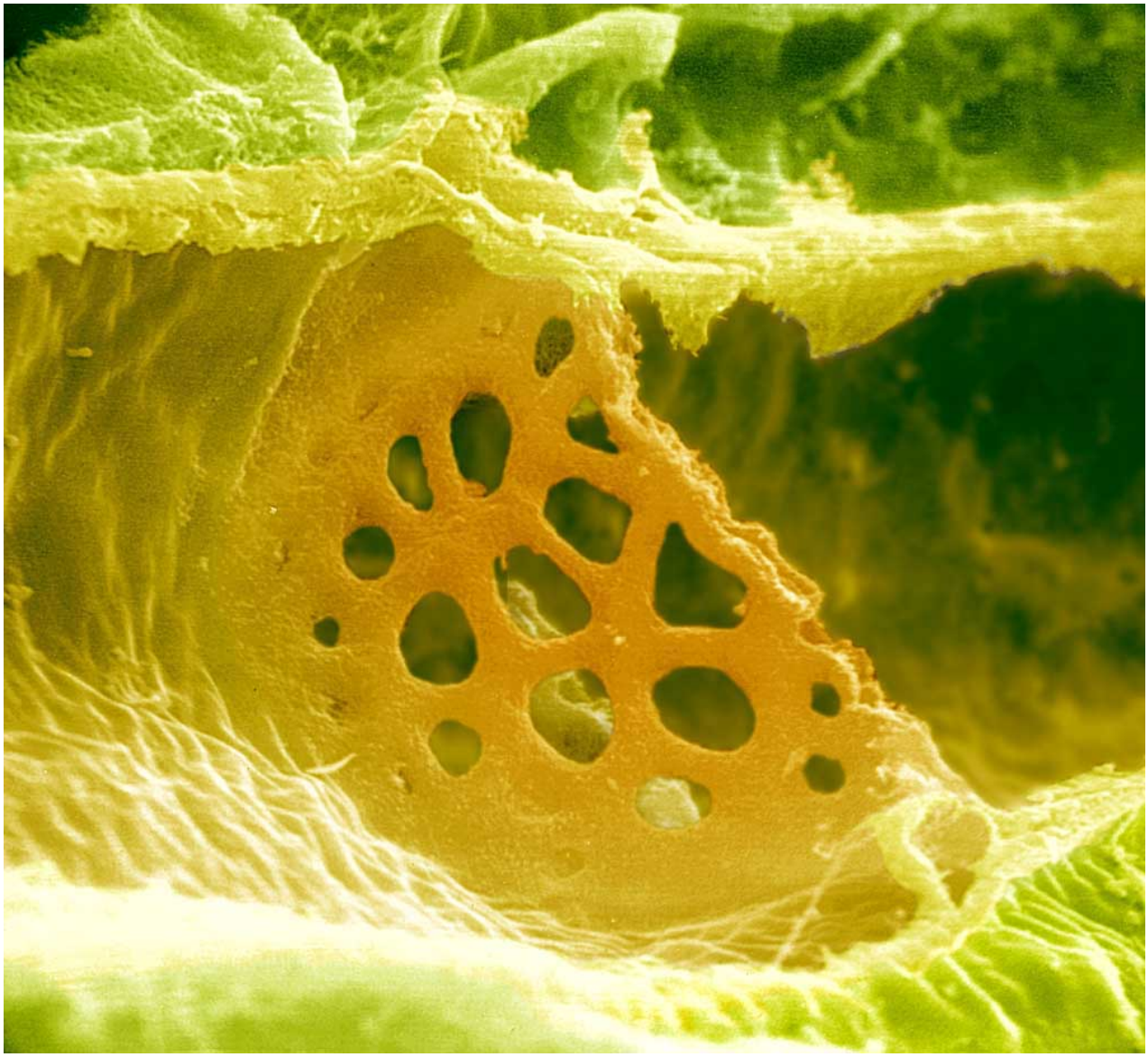


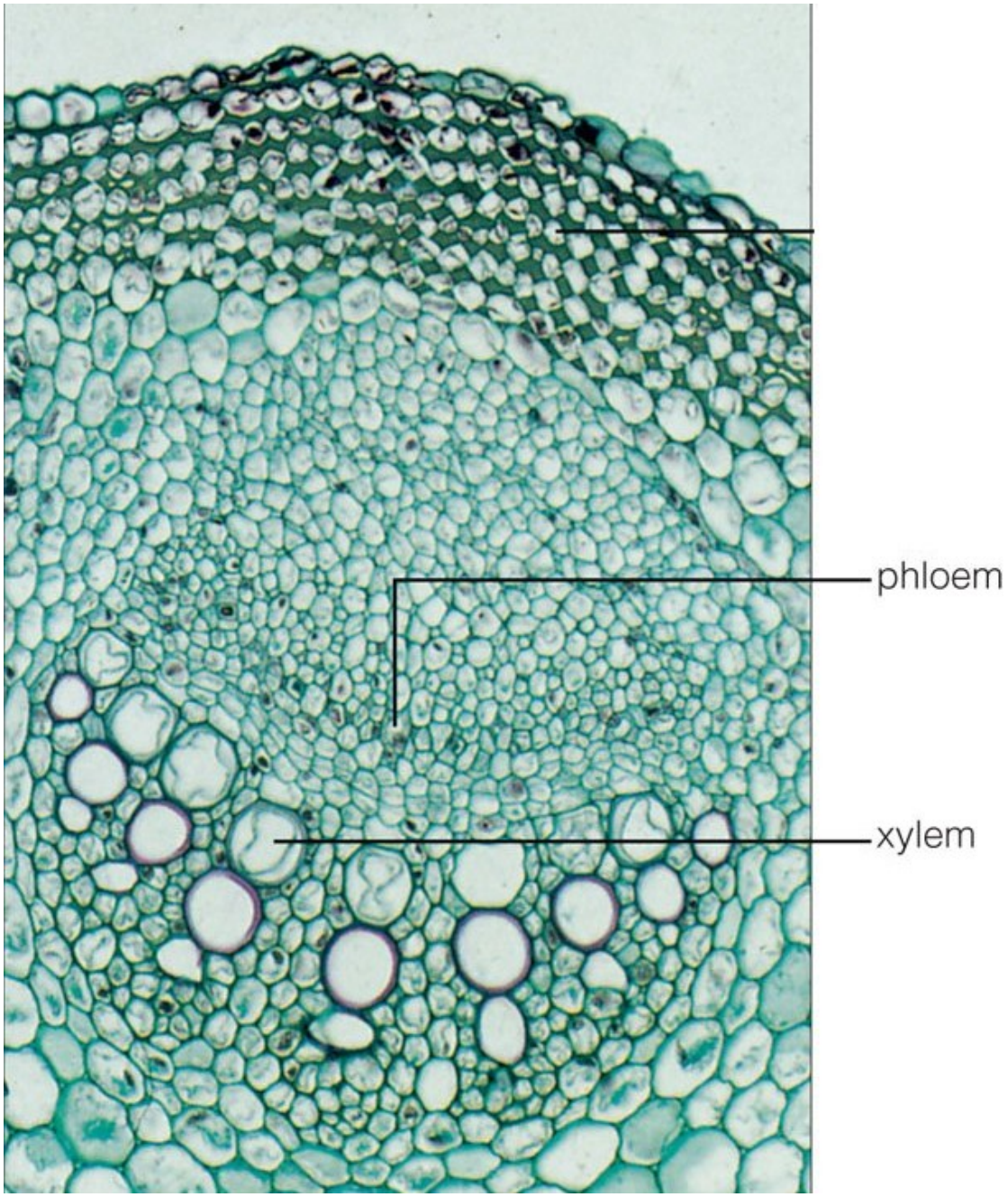
Frontal view (LM)

Plates: pores

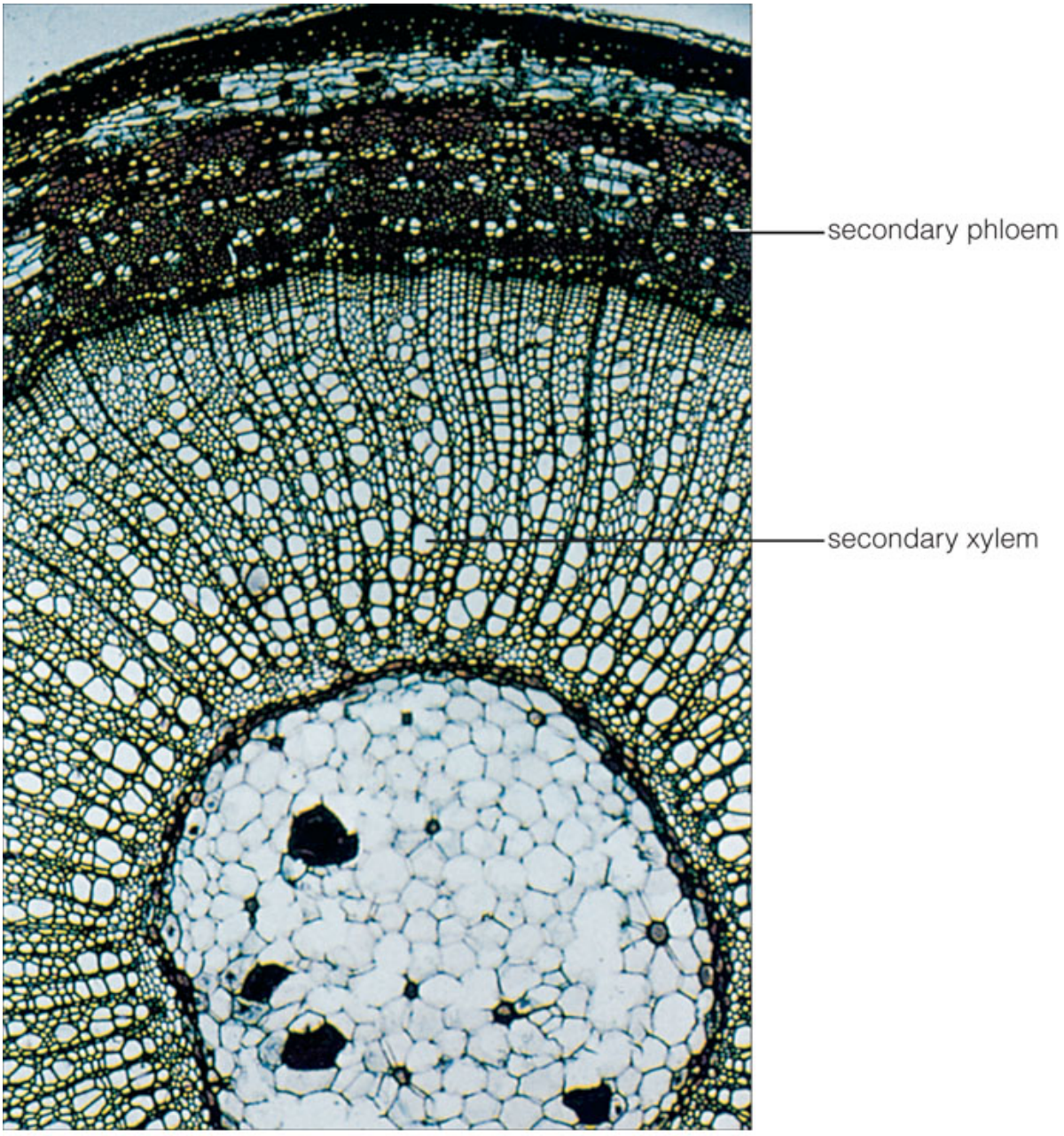


Sieve plate, a pore in the end wall of a sieve-tube member, through which phloem sap flows (SEM ×4800)

Primary vascular tissues



Secondary vascular tissues



2.2 Secondary cover: periderm

Secondary dermal tissue: Periderm

- Secondary dermal tissue
- Arises inside the stem ground tissue (cortex), closer to surface
- Complex tissue: includes phellem (cork in the strict sense), cork cambium (phellogen), and phelloderm
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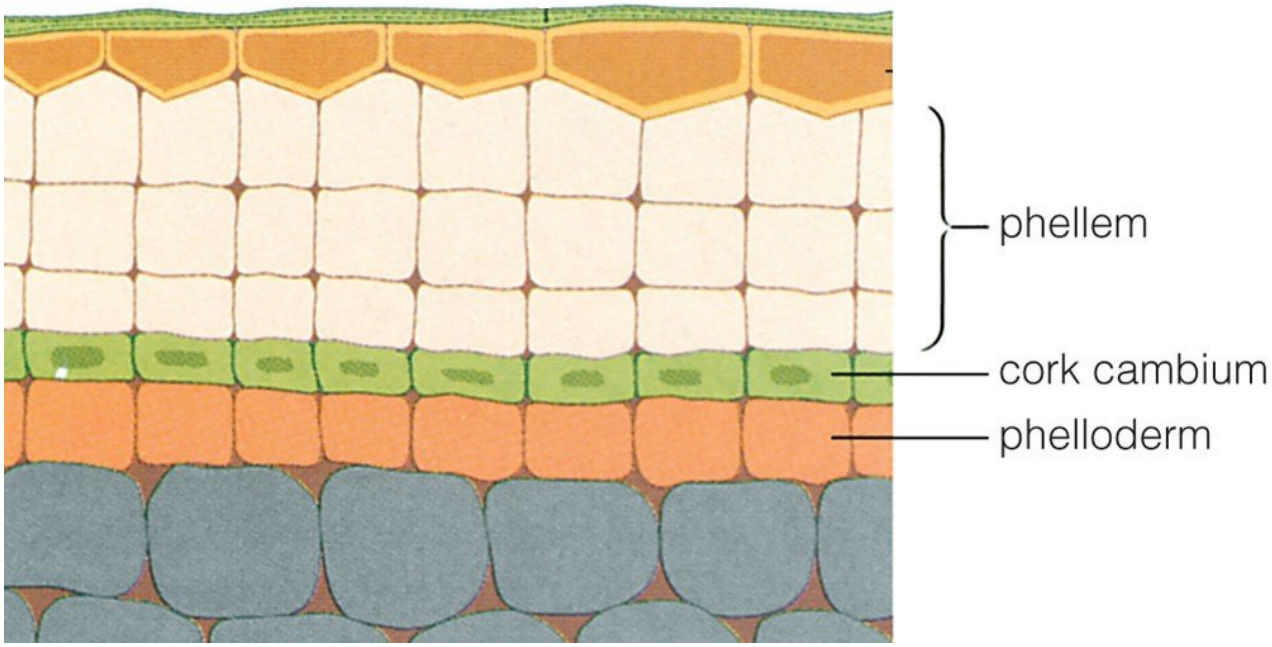
Three cell types of periderm



Cork cambium is another lateral meristem; *phellem* and *phelloderm* are main components of periderm

2.3 Step five: pumps. Absorption tissues

Poikilo- and homoiohydricity

- **Poikilohydric** plants do not save water, they survive even complete desiccation
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Absorption tissues

- Always primary, simple tissues
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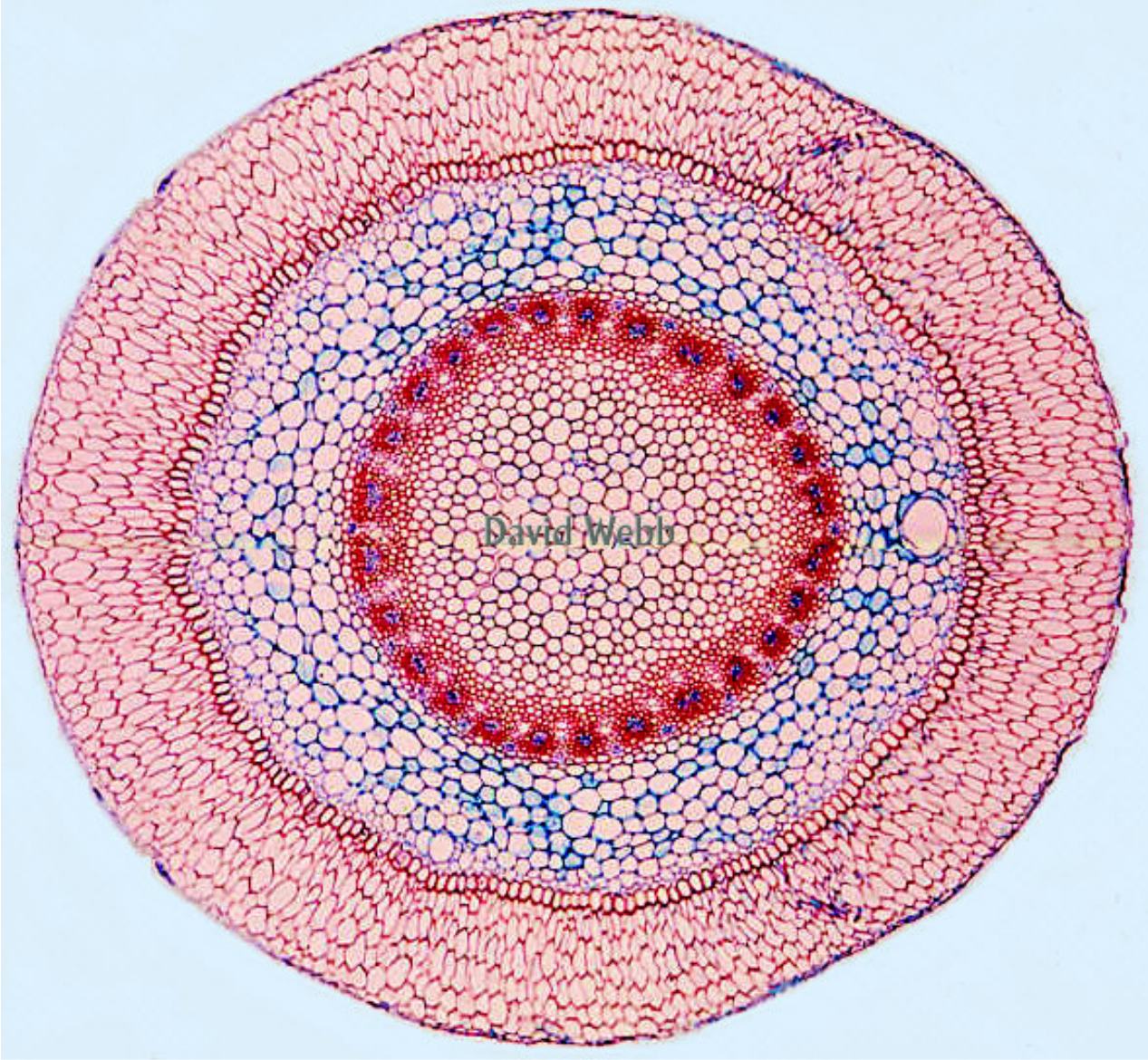
- **Velamen**, originates from root cortex

Rhizodermis

Root hairs of grass seedlings (LM)

Velamen



Outer cylinder is a velamen tissue of orchid root (LM)

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Secretory tissues

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- May secrete latex, volatile oils, mucus and other chemicals
- Functions vary: attraction or dis-attraction, communication, defense etc.

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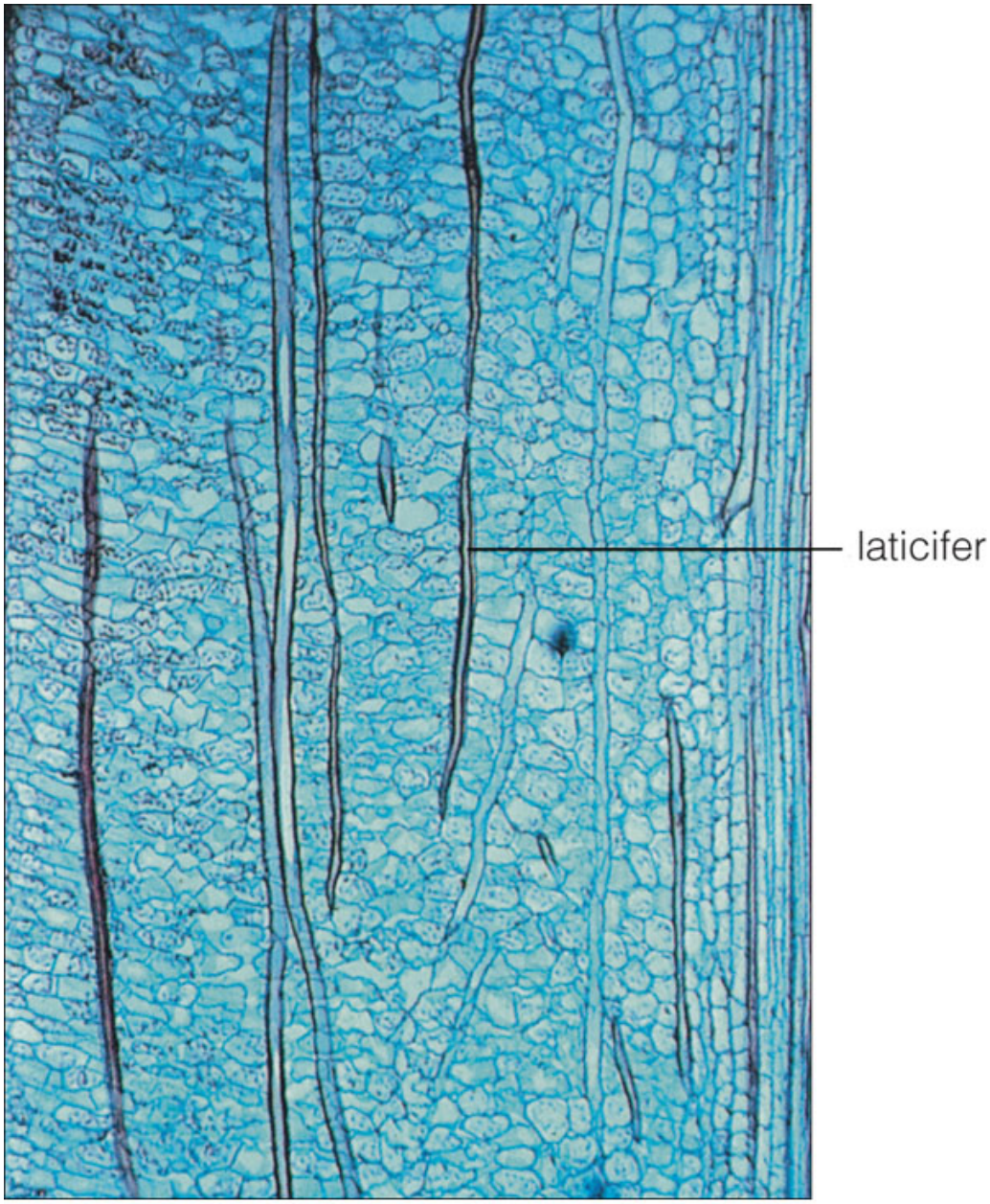

Summary

- **Epidermis** is a complex tissue which includes stomata
- **Collenchyma** and **sclerenchyma** are simple supportive tissues
- **Secondary tissues** originate from lateral meristems (i.e., cambium)
- **Xylem vs. phloem**:
  - **State**: dead vs. living cells
  - **Transport**: water vs. sugar
  - **Direction**: up vs. down
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Final question (3 points)

Name 3 differences between xylem and phloem.

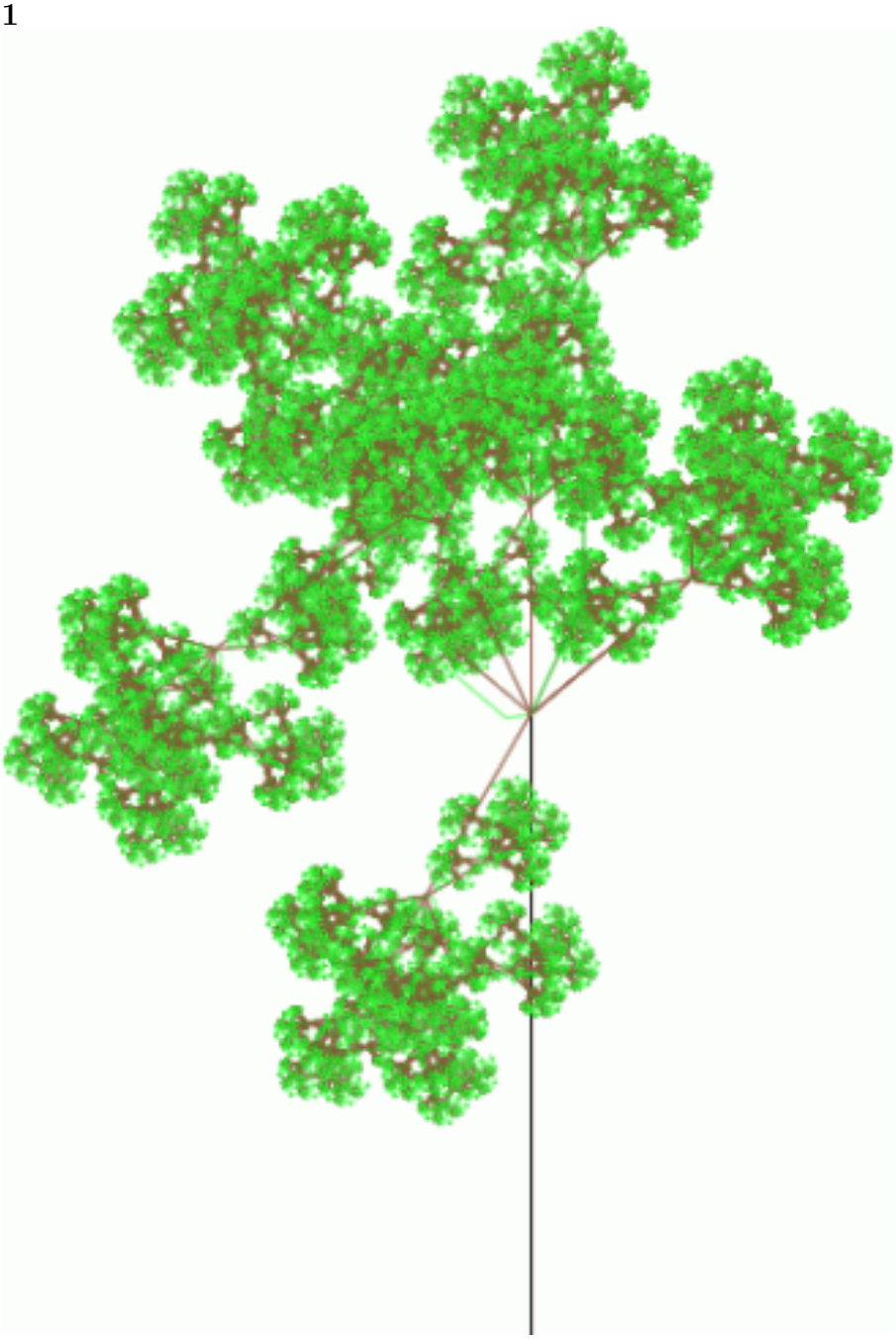
For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

1



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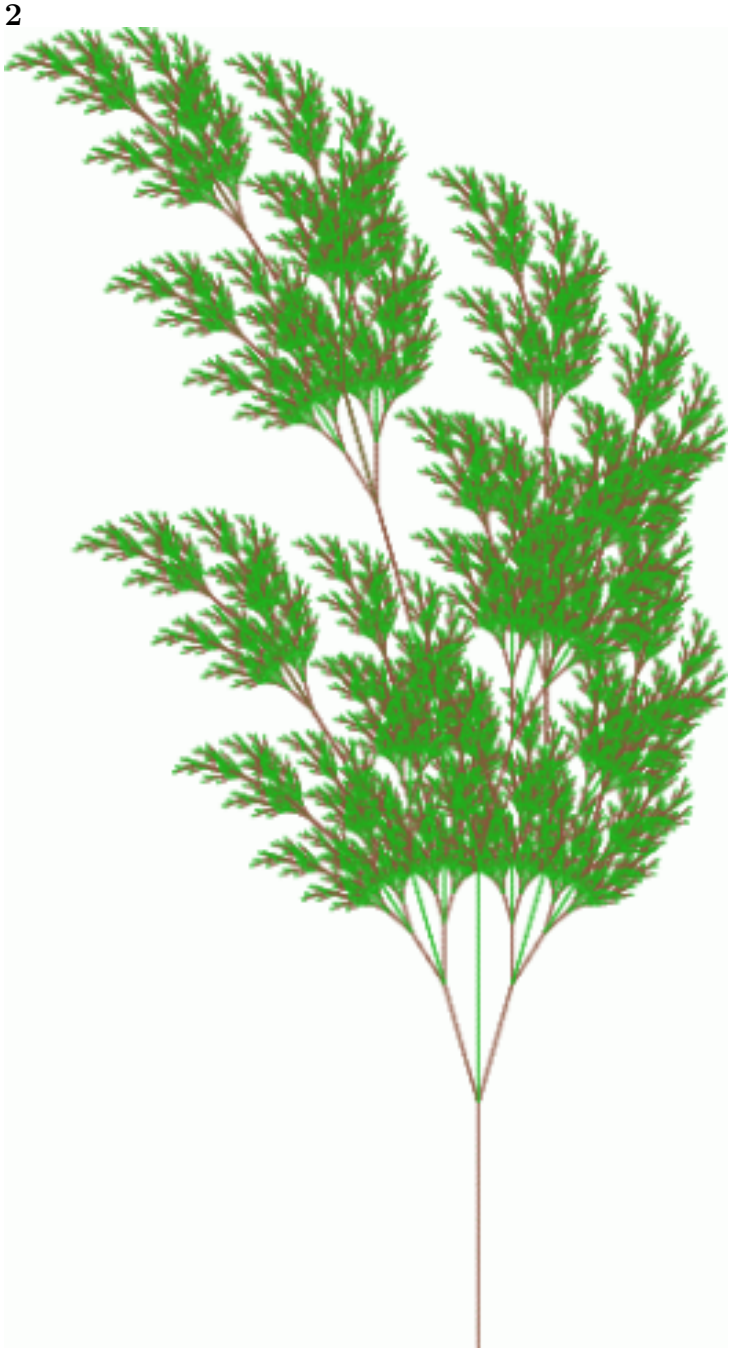

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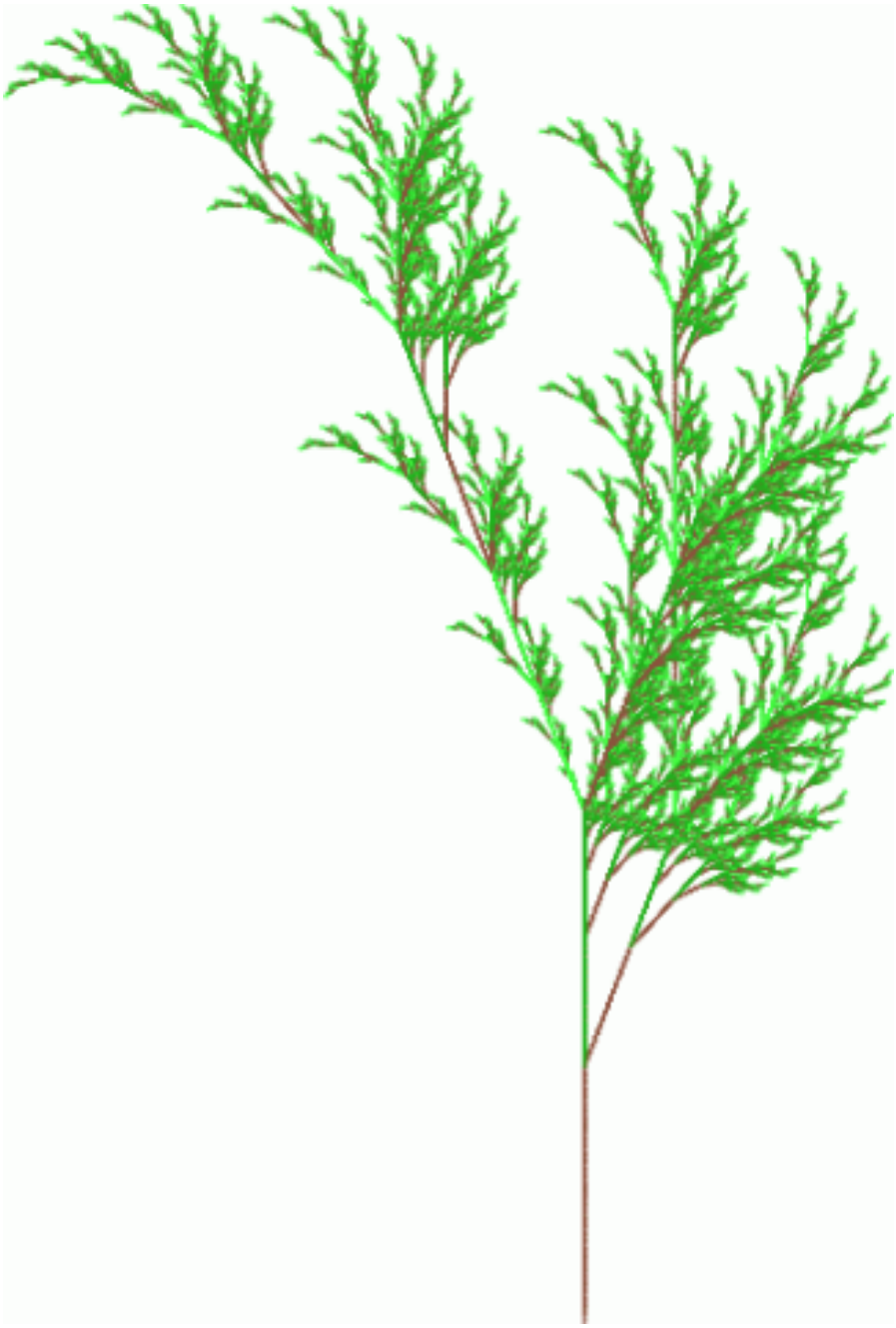

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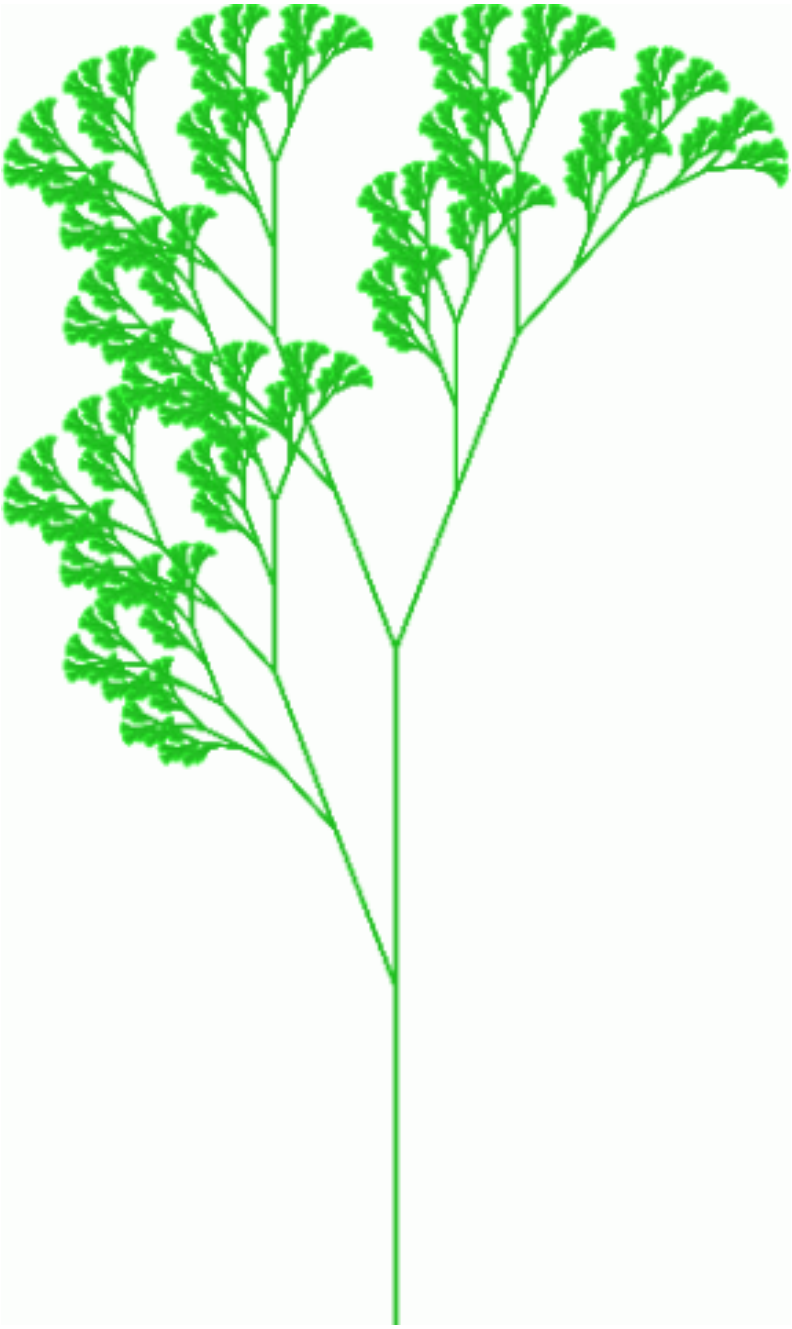

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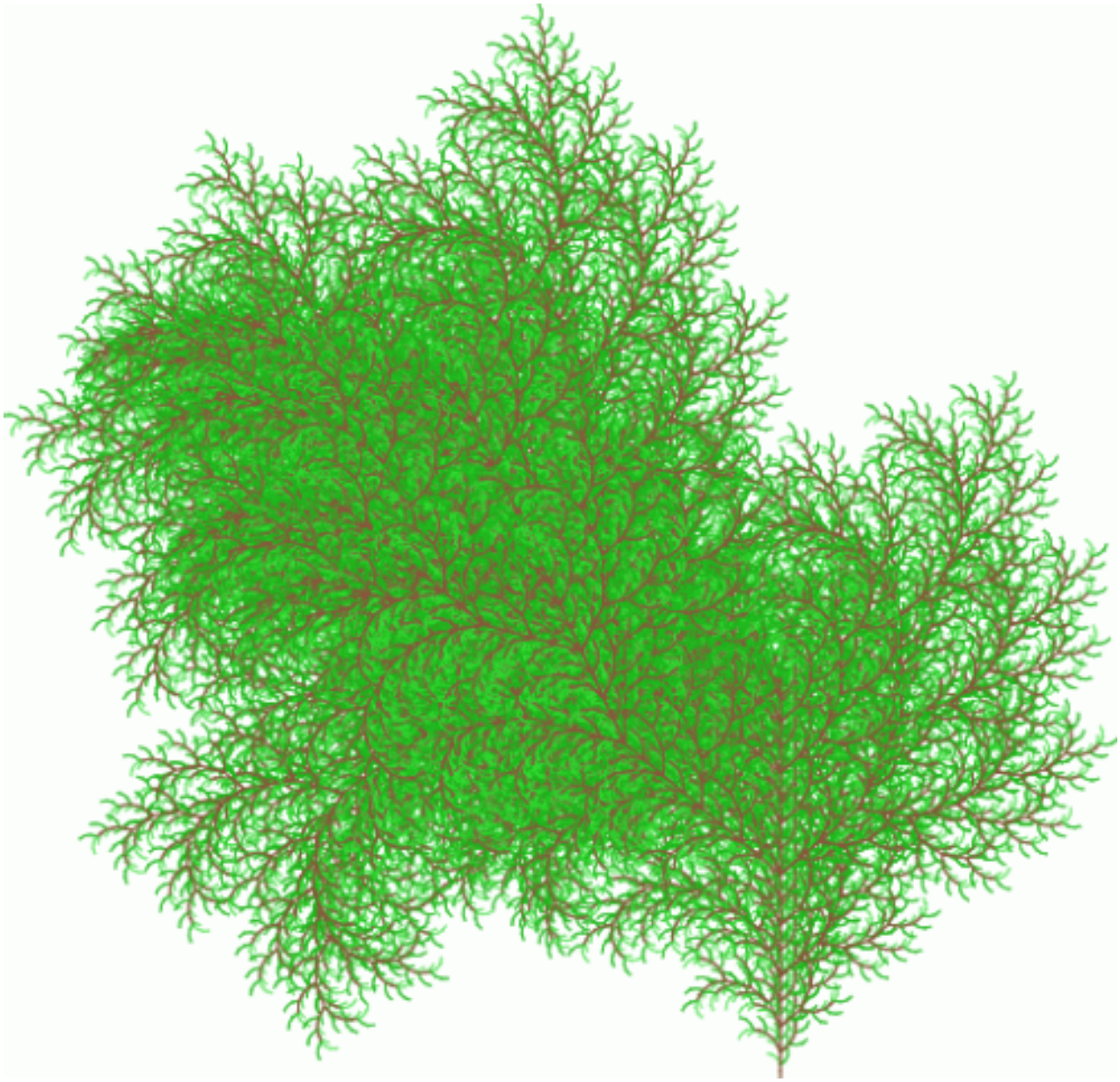

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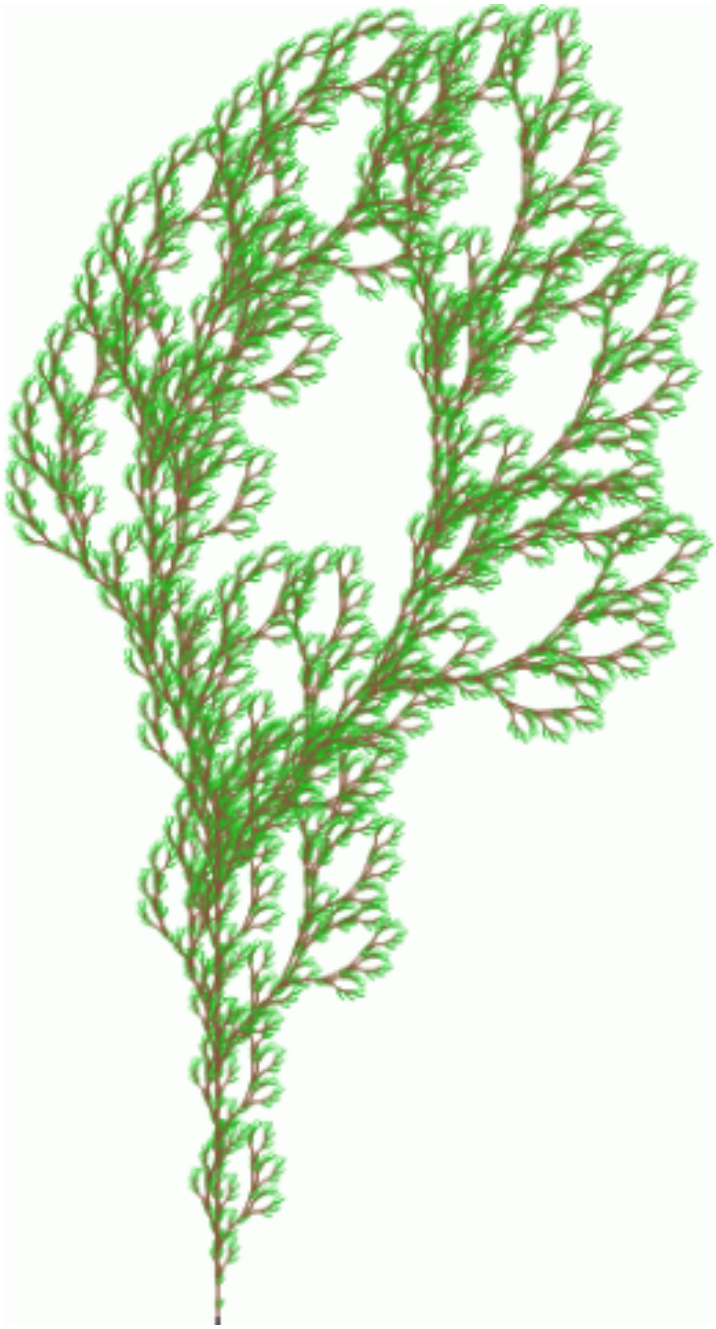

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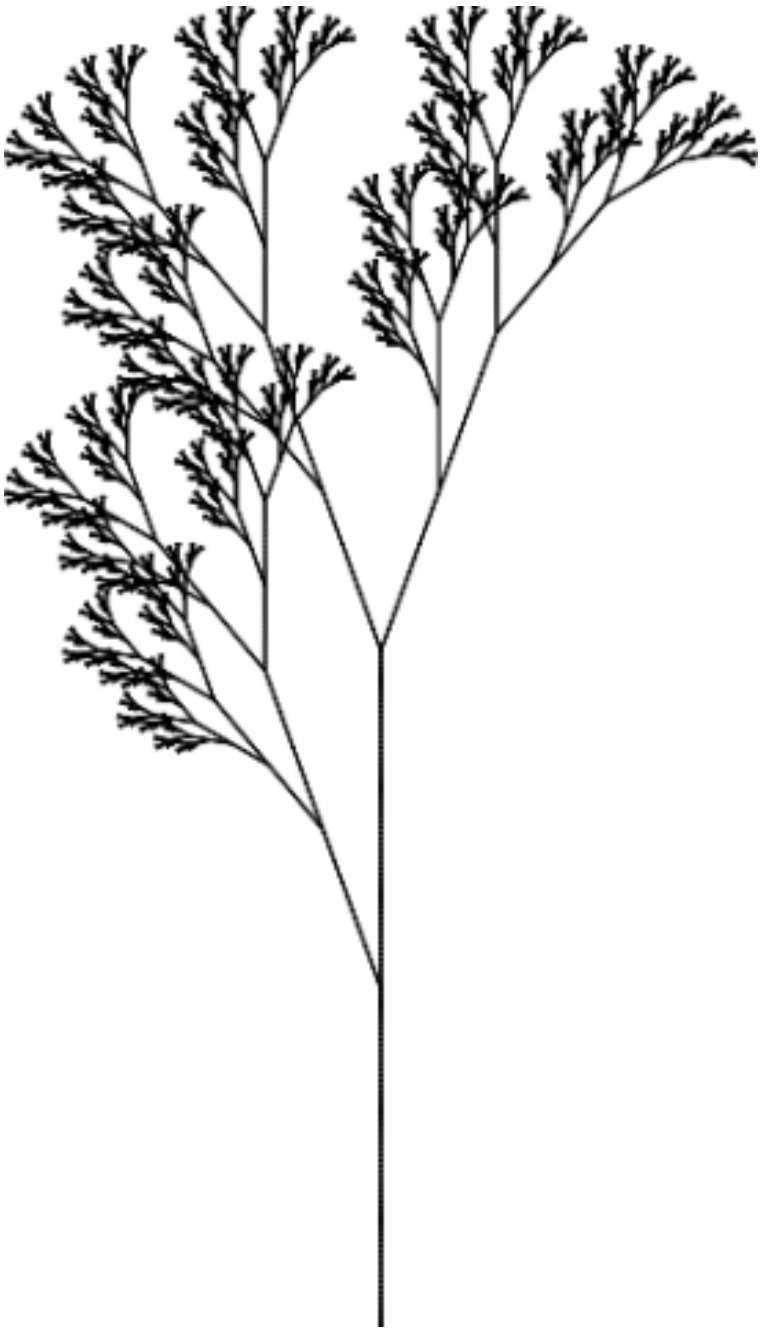

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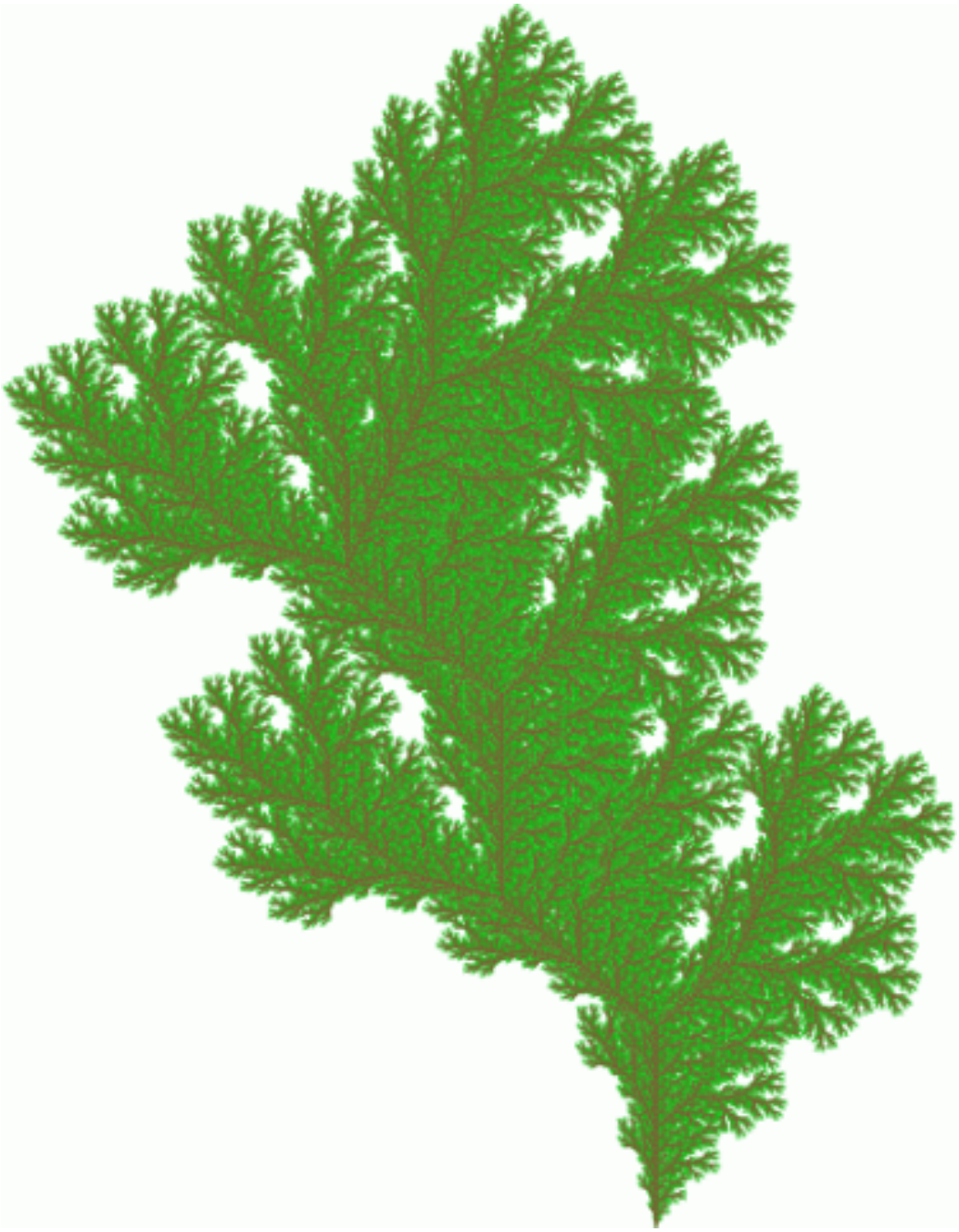

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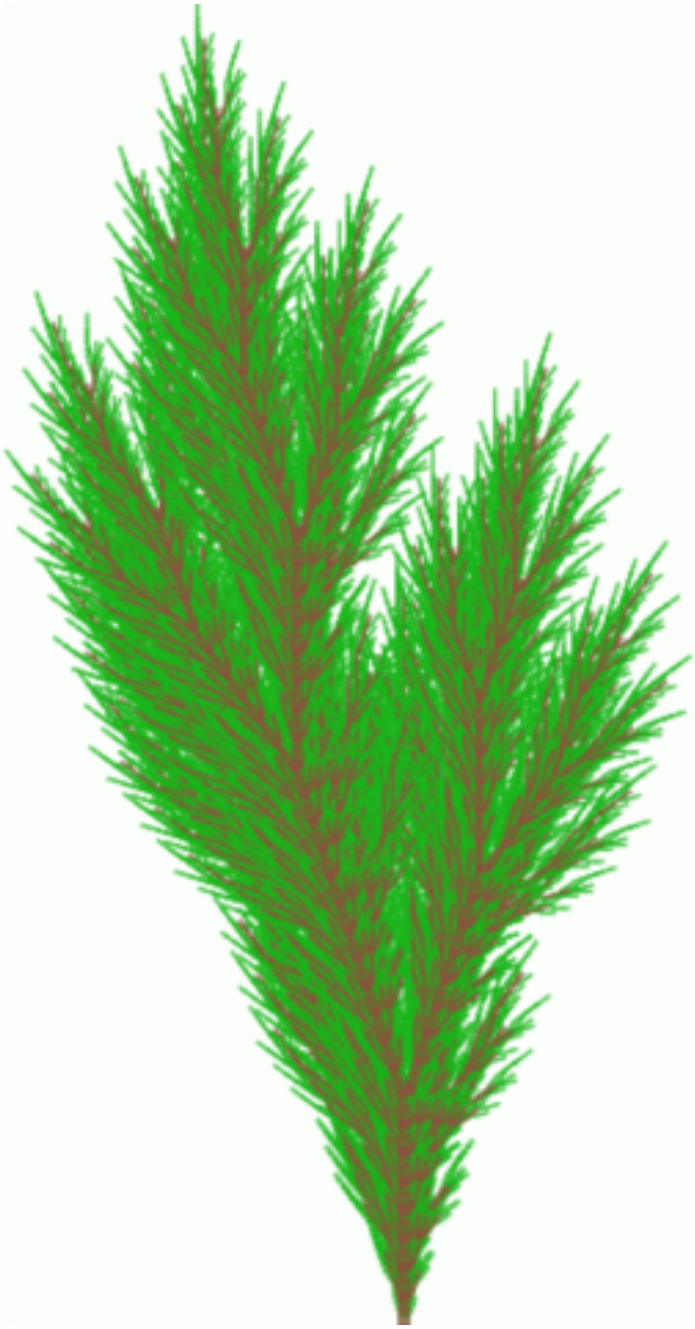

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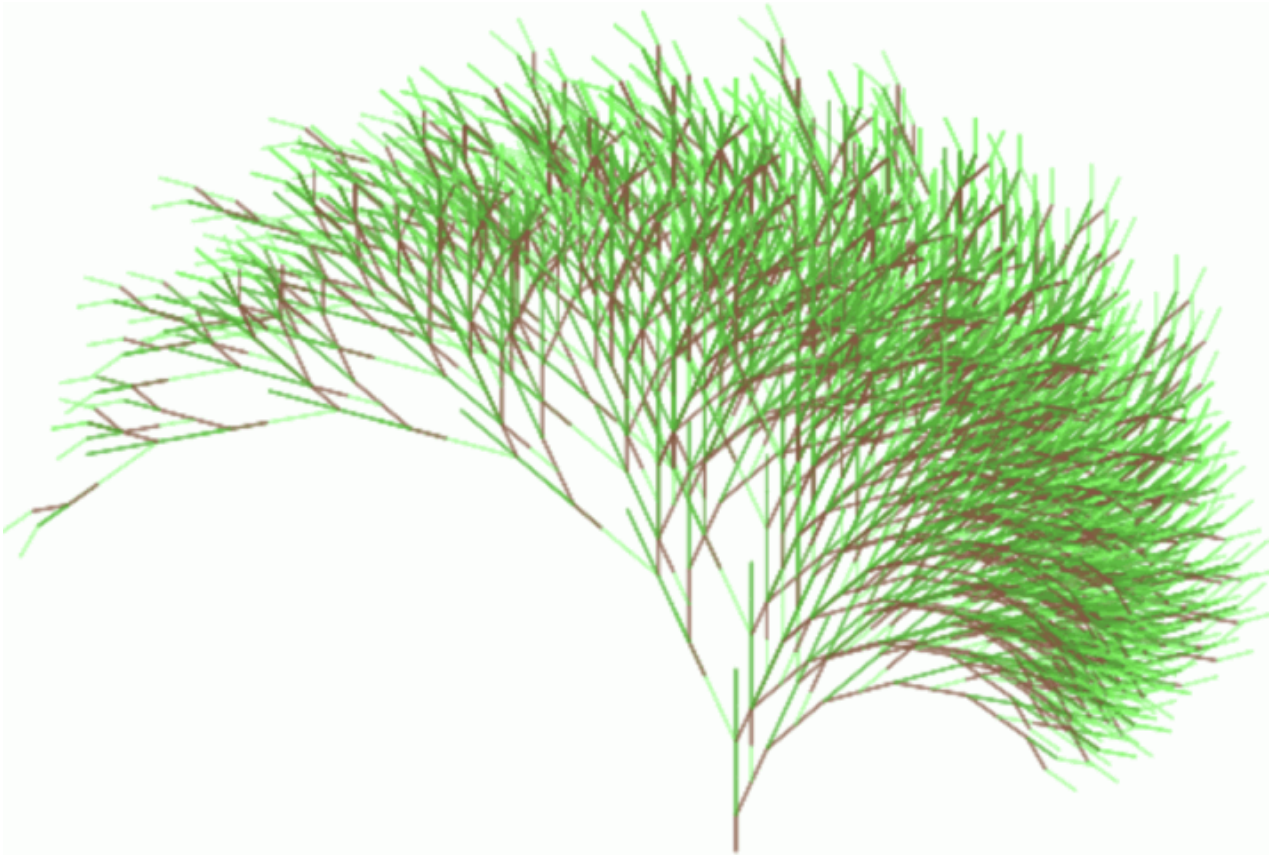

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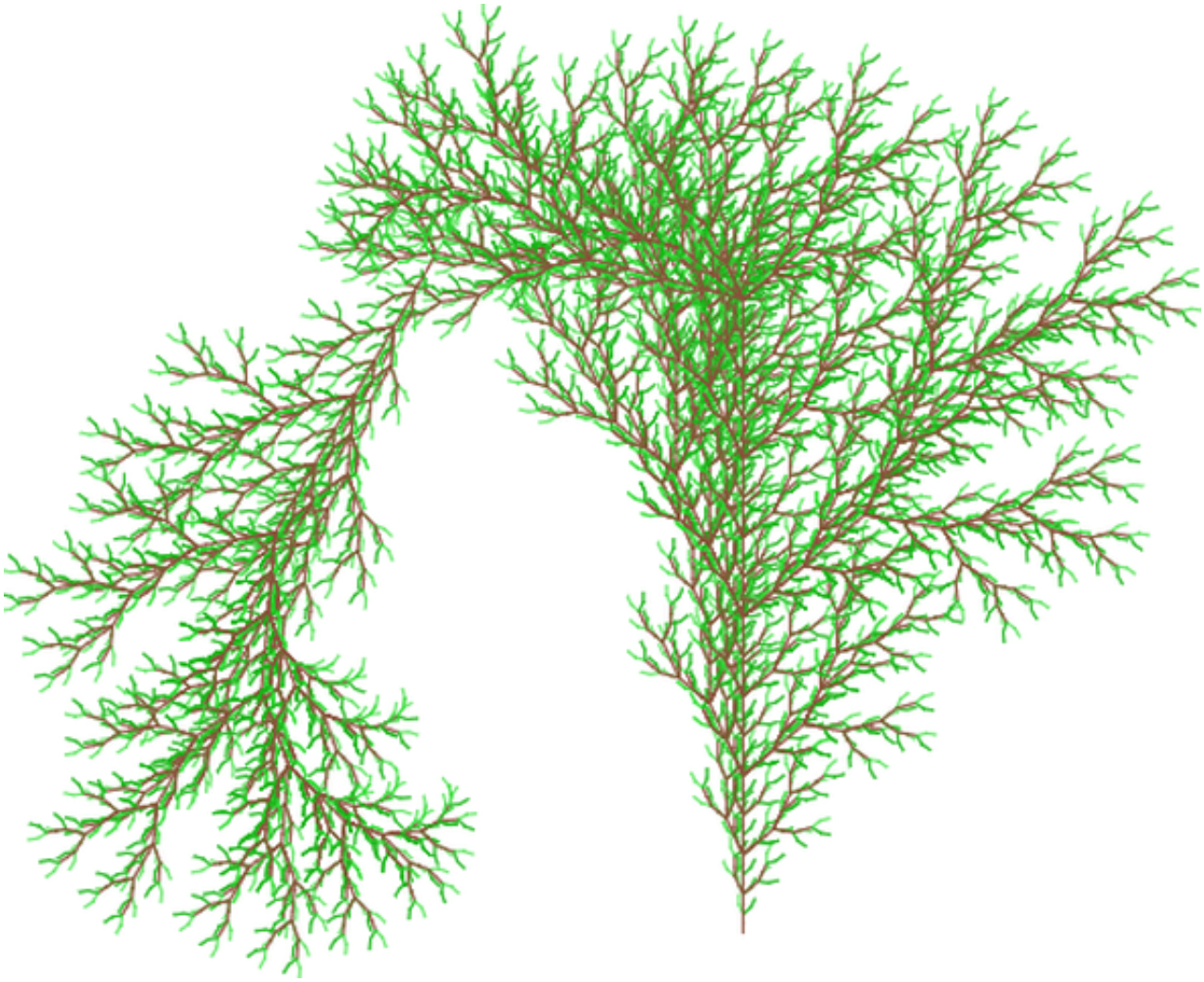

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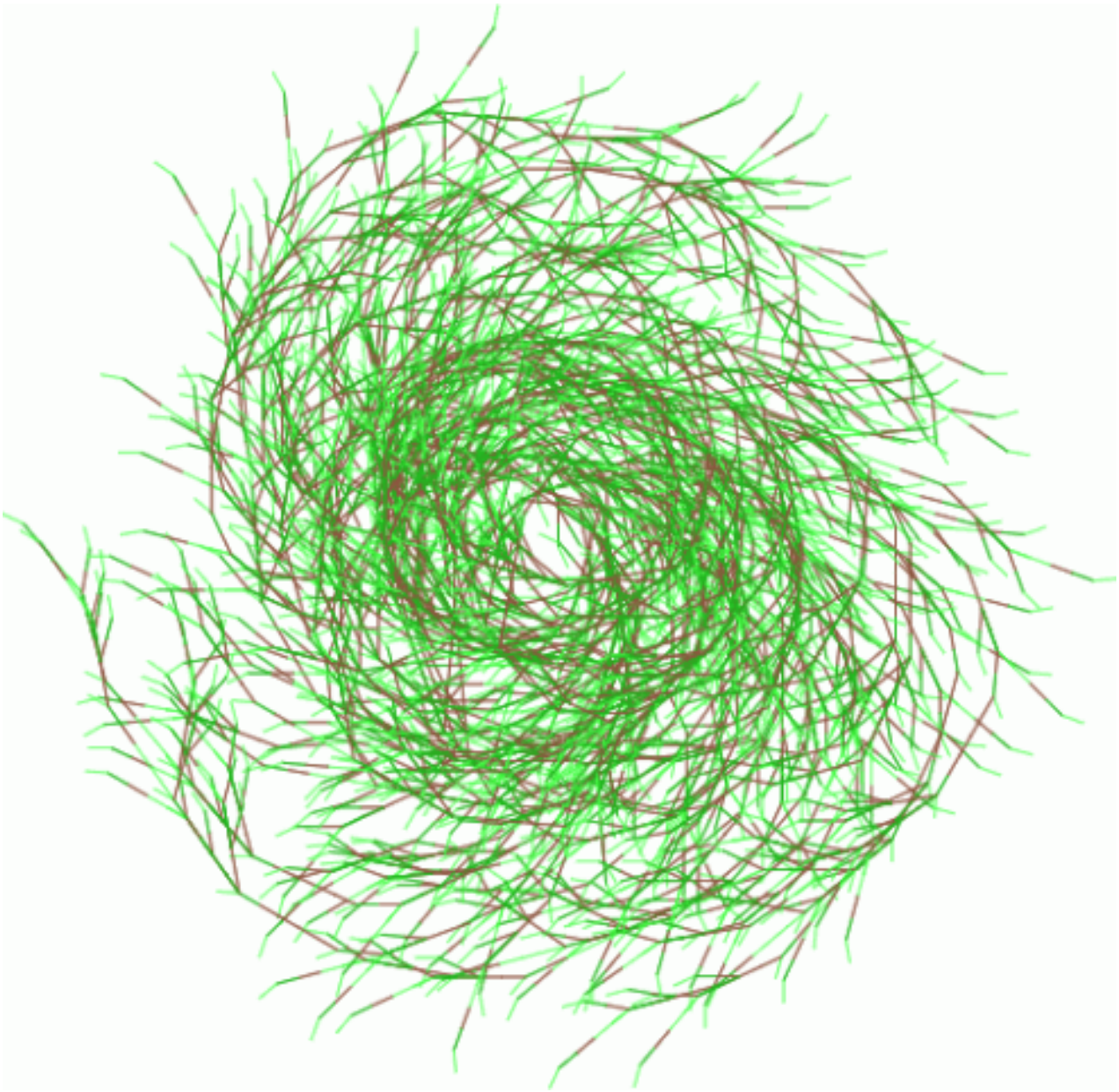

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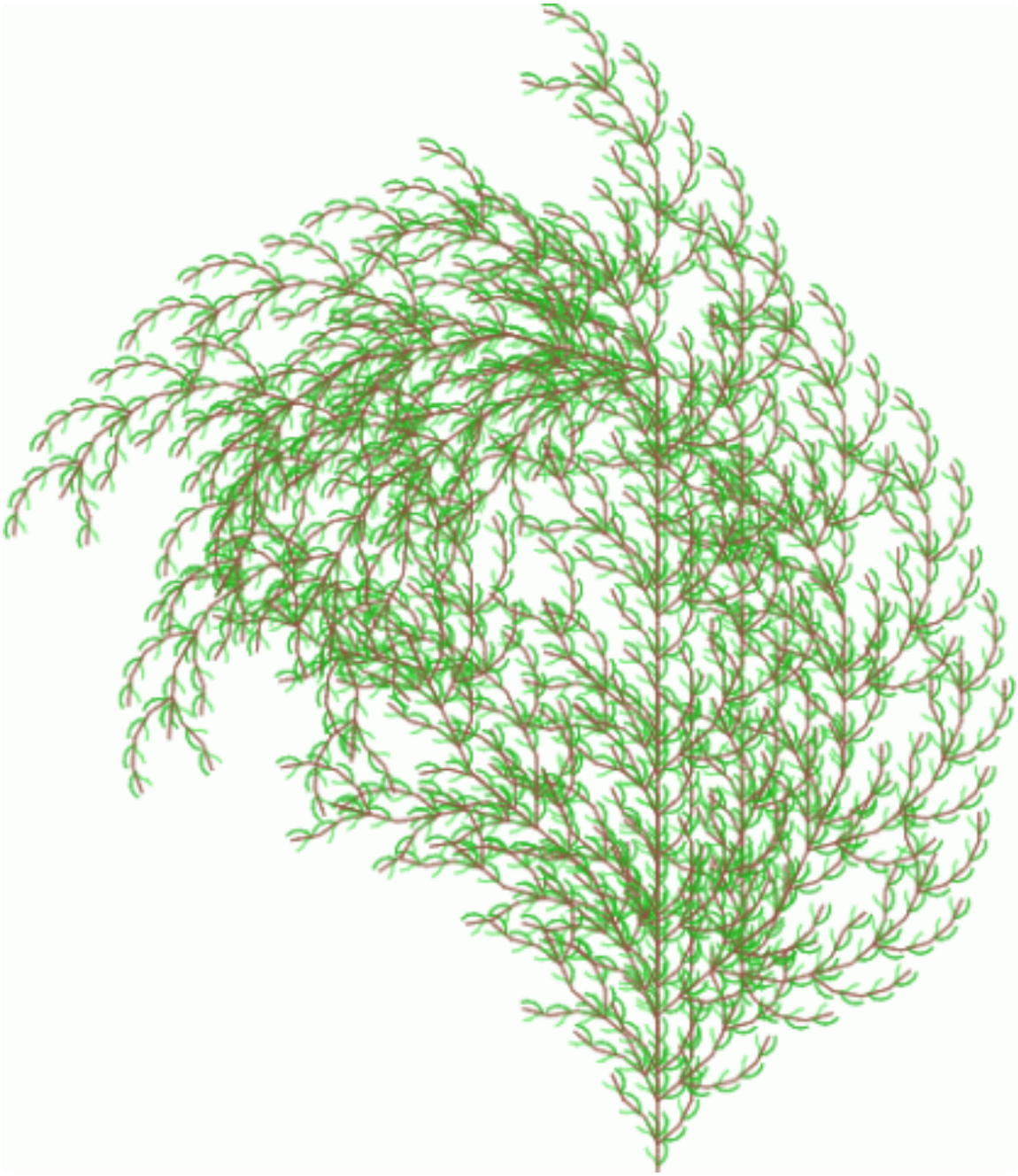

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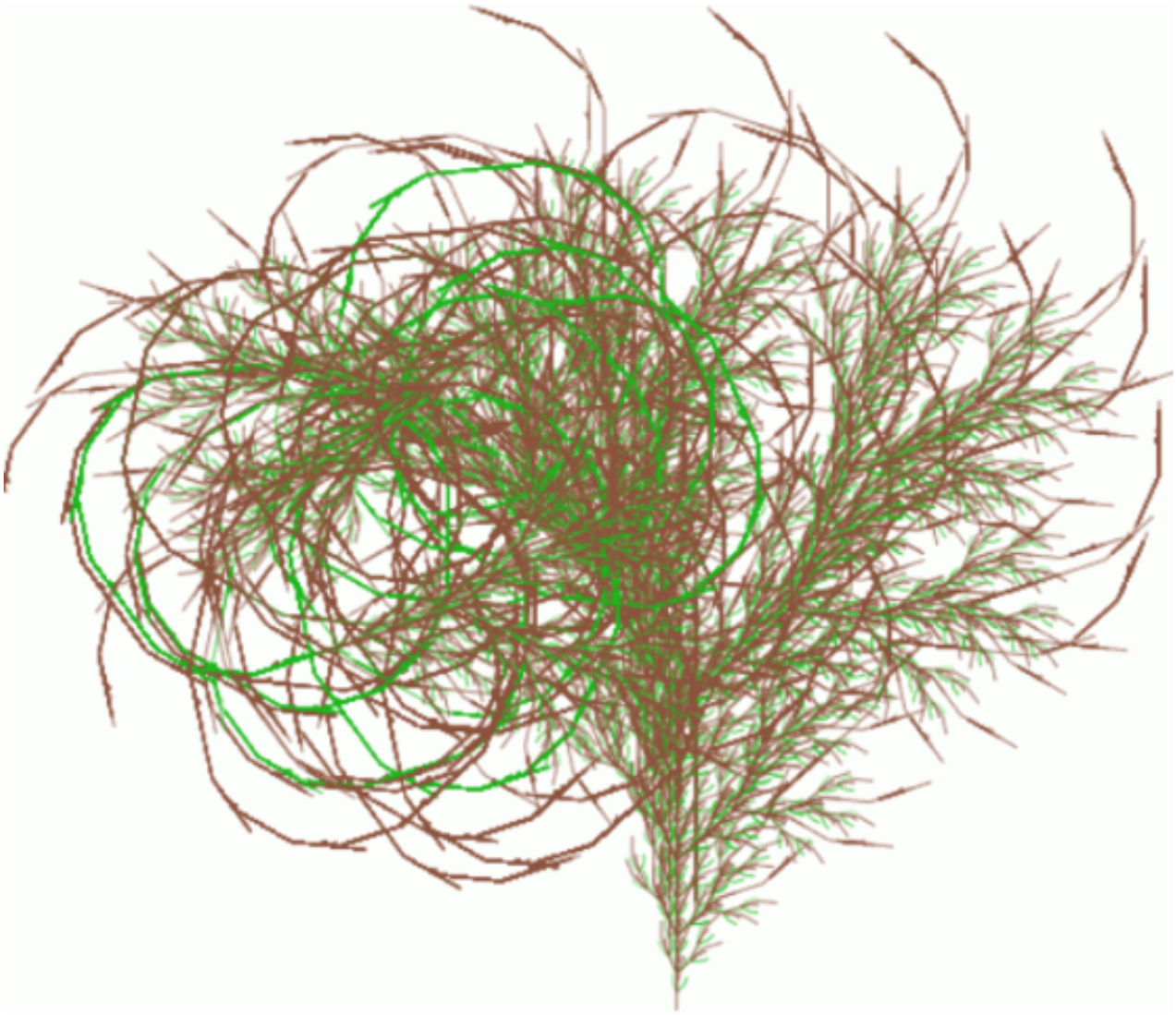

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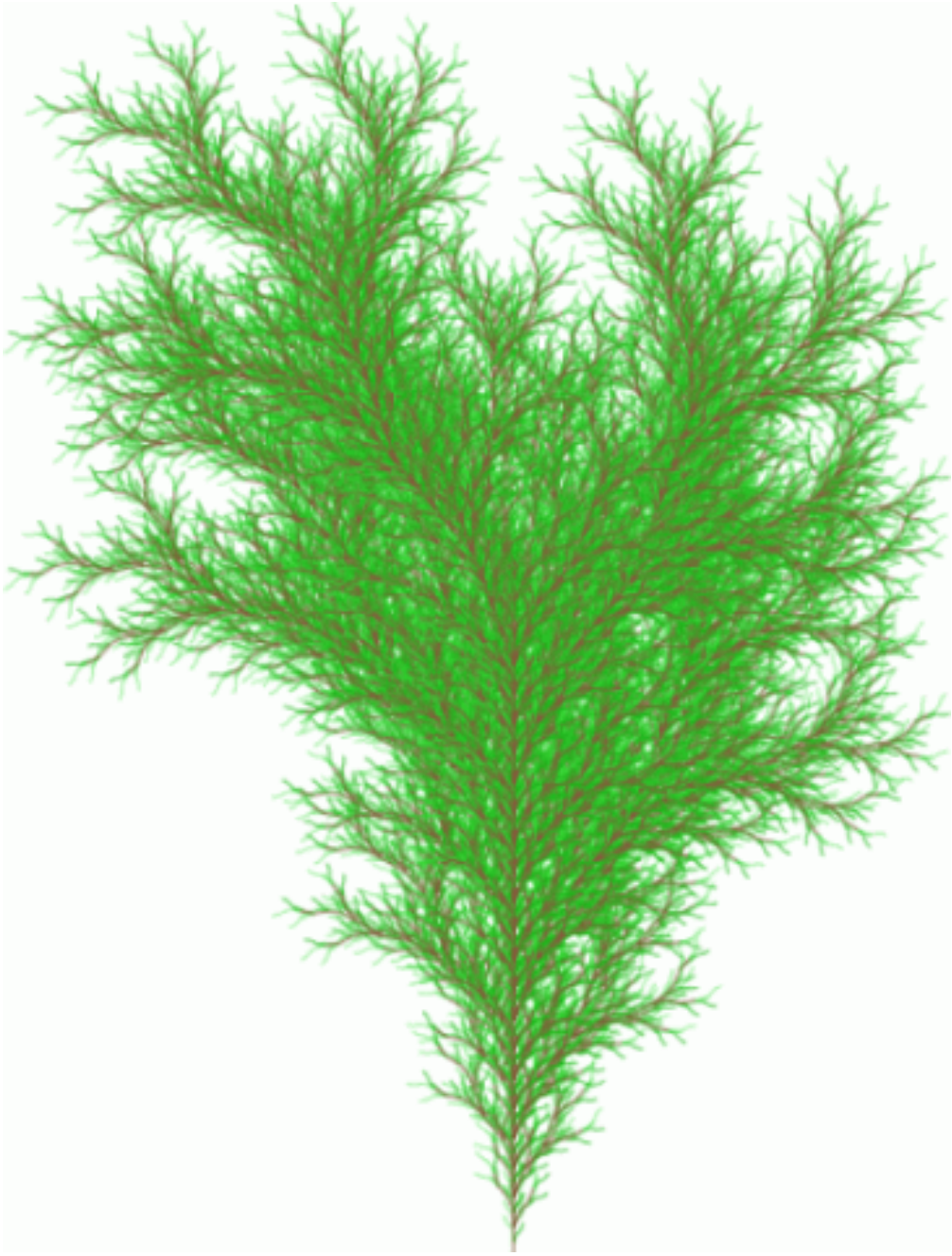

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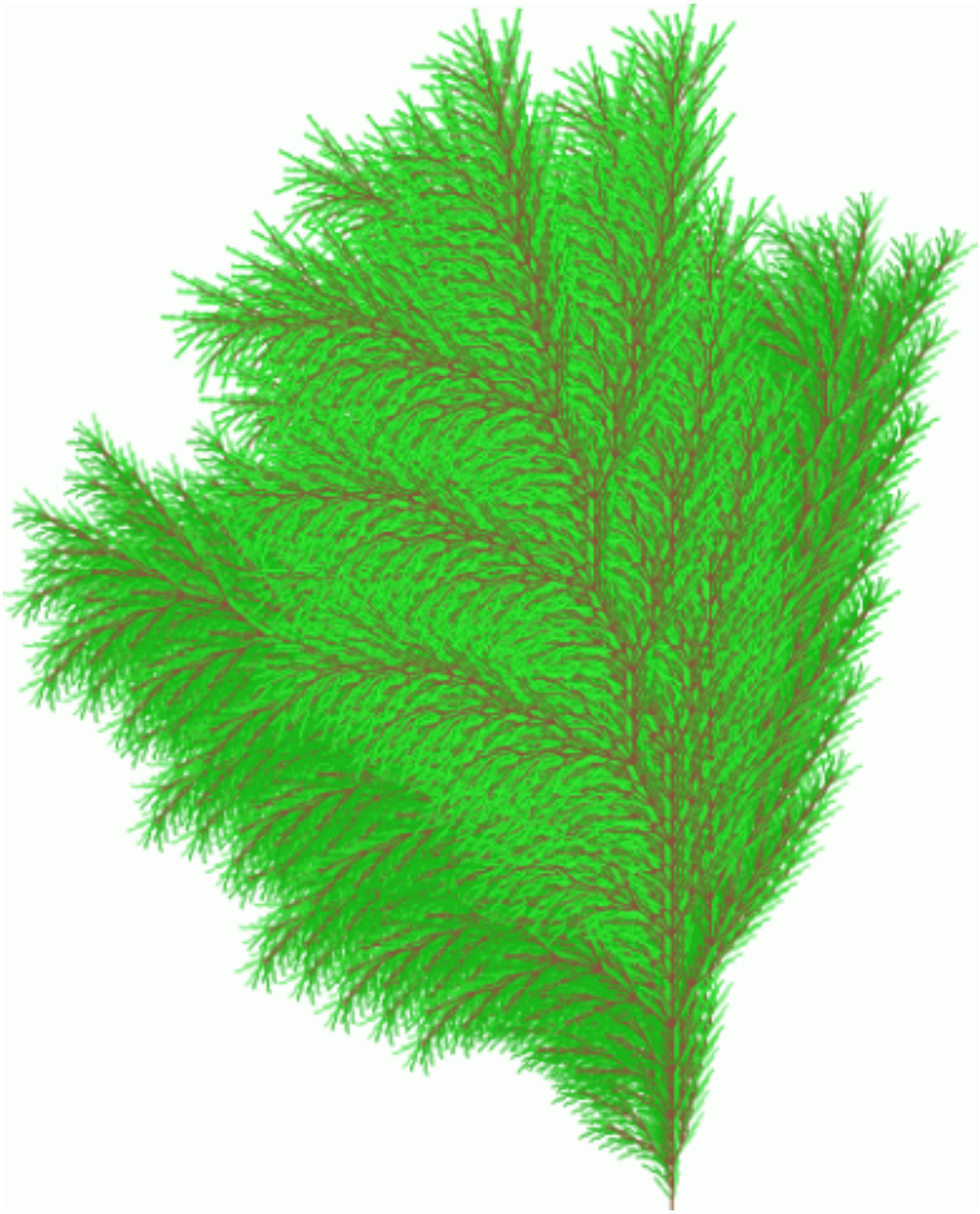

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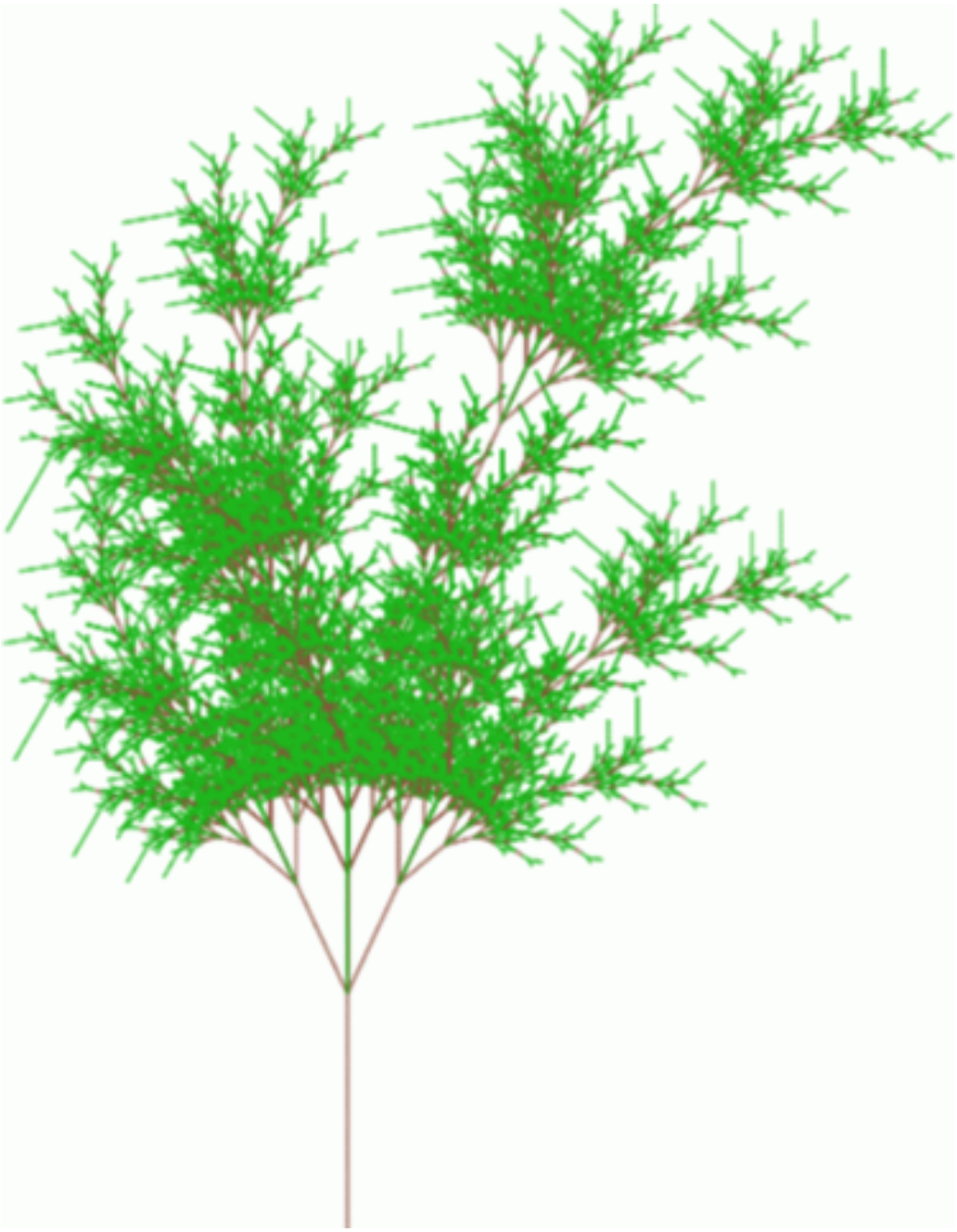

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3 Leaf

3.1 Leaf in general

Definition, functions and features

- Lateral flattened organ of shoot with restricted growth
- Functions:
  - Photosynthesis
  - Respiration
  - Transpiration

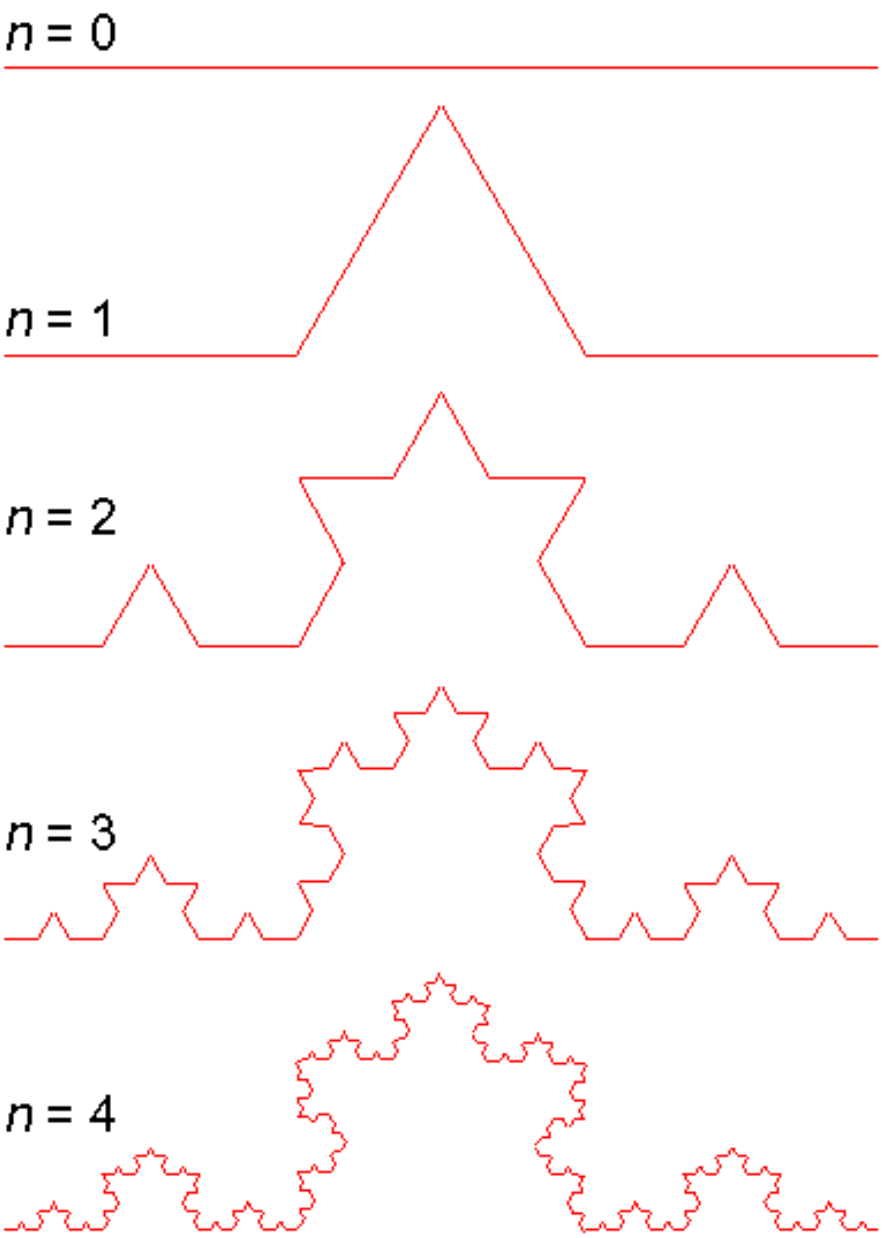
  - Synthesis of secondary chemicals

- Features:
  - Have bud in the axil (remember compound leaves)
  - Do not grow by apex
  - Do not produce new leaves
  - Have hierarchical (fractal) morphology

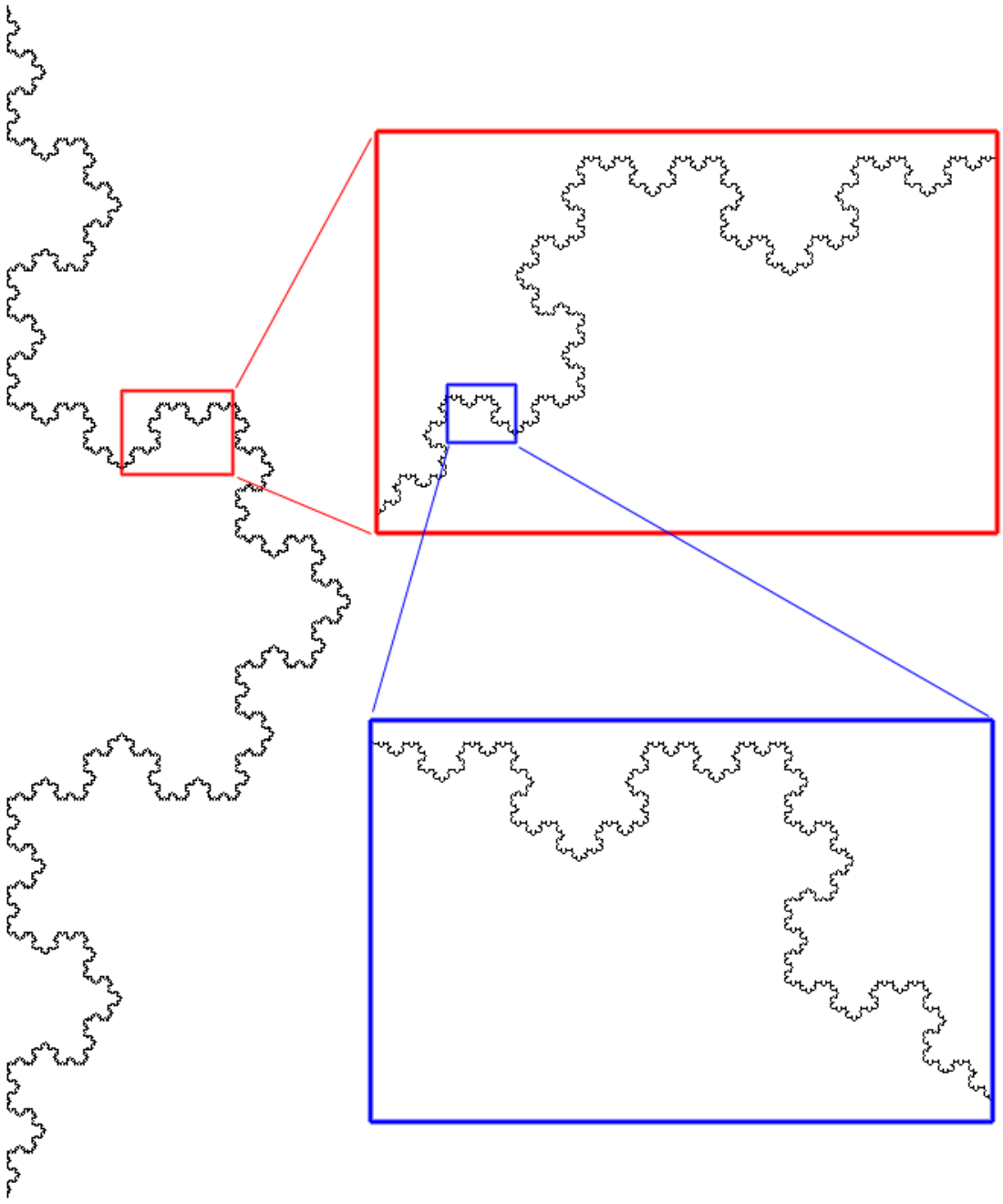
3.2 Leaf morphology

Hierarchy

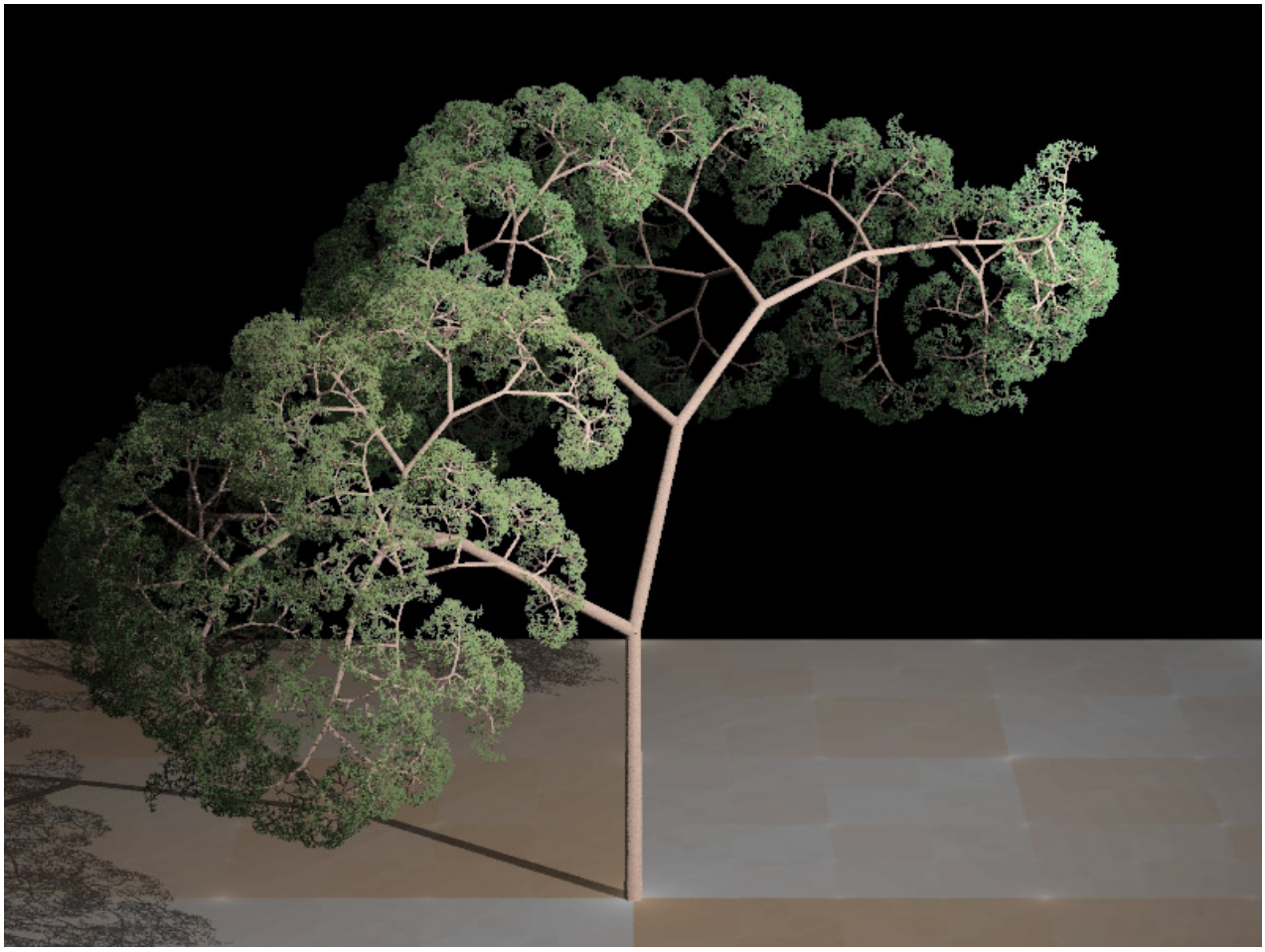
Fractals are hierarchical



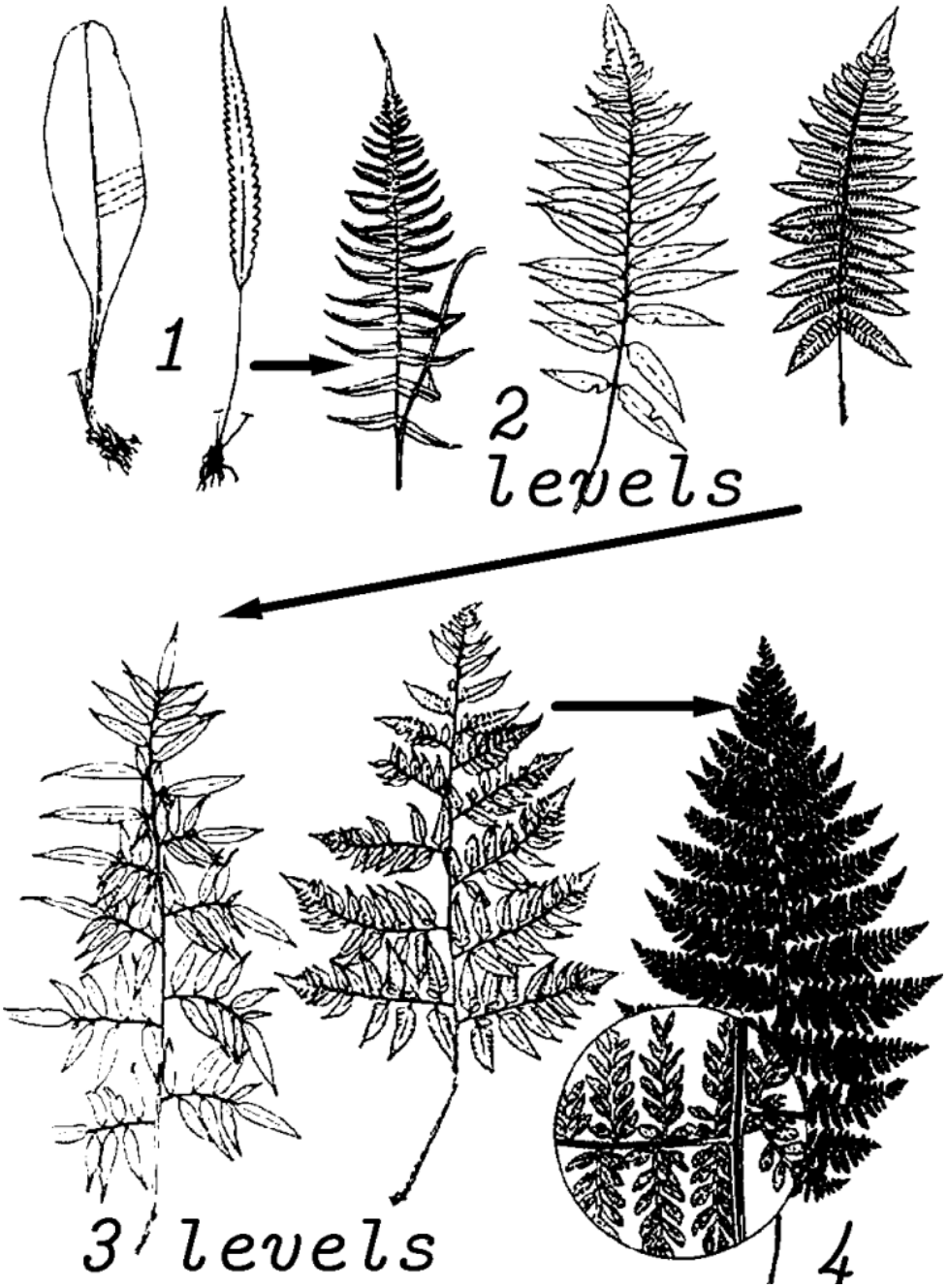
Fractals are self-similar



Fractals could be just like plants



And leaves could be just like fractals, with levels



Types of leaf characters

- General: applicable only to the whole leaf
- Terminal: applicable only to the terminals (e.g., terminal leaflets)
- Repetitive: repeating on each level of hierarchy

Hierarchy in leaf morphology

- **General** and **terminal** characters do not depend on hierarchy
- **Repetitive** characters may be different on each step of hierarchy

- Therefore, leaf description should state that "on first level of hierarchy, the shape is ..., on the second level, the shape is ..."
- It is possible that each level has different repetitive characters

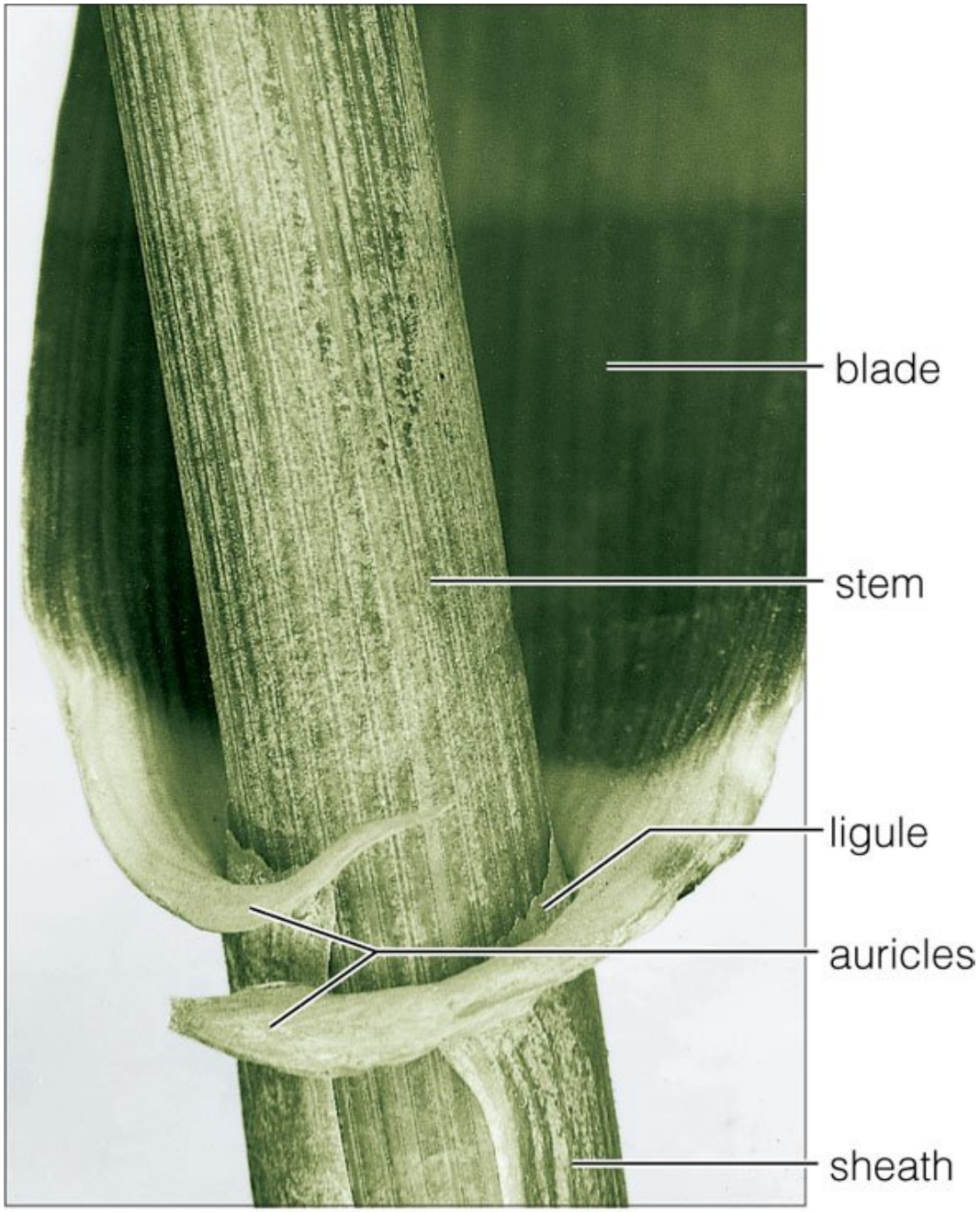
3.3 General characters

General characters

- General characters apply to the whole leaf
- Stipules (present or not, how many etc.)
- Other leaf base organs (sheath, ocrea, ligules etc.)

Stipules

Leaf base



3.4 Repetitive characters

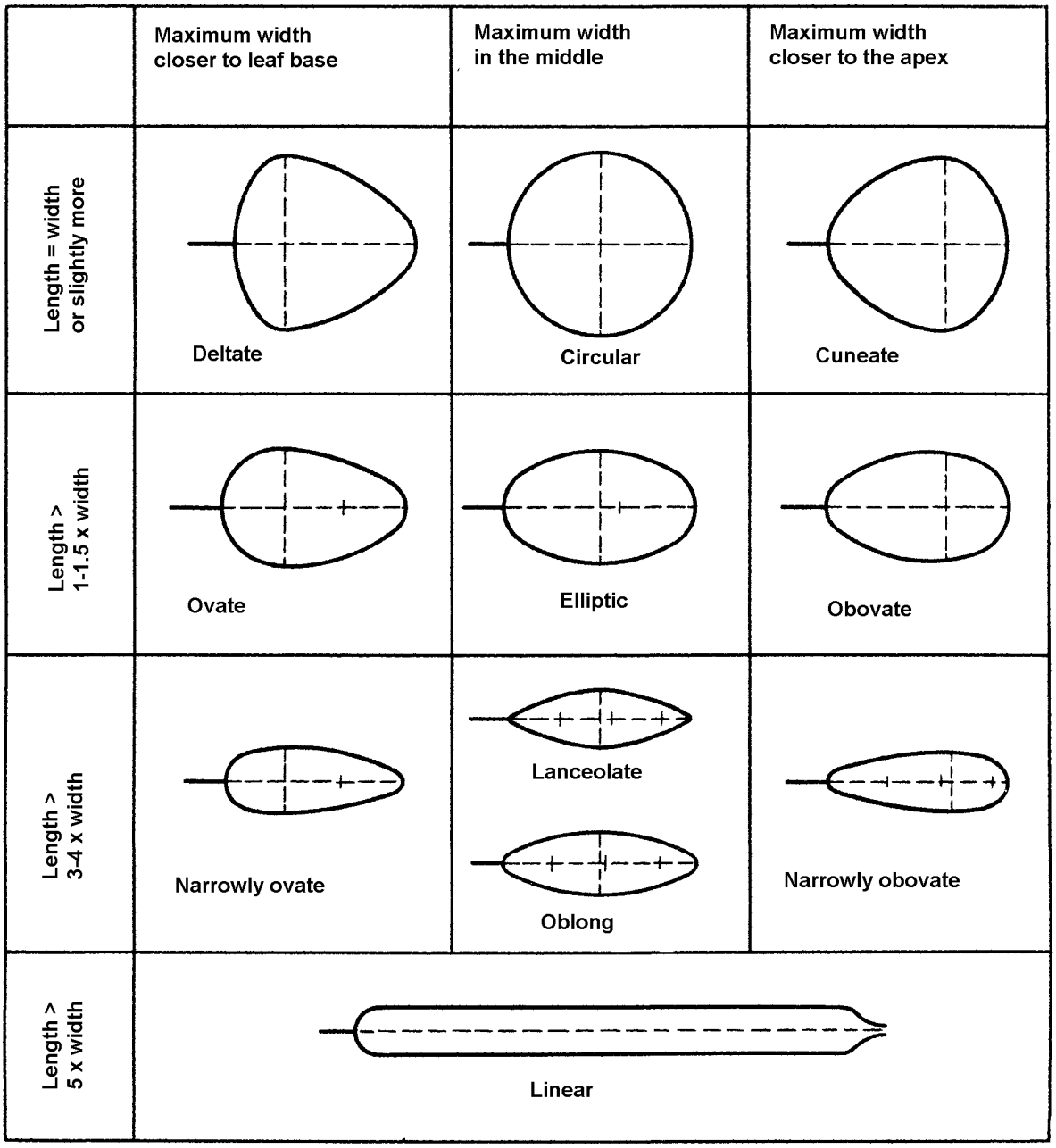
Repetitive characters

Repetitive characters are the same on each level of leaf hierarchy:

- Shape
- Dissection
- Petiole (stalked/non-stalked etc.)

Repetitive characters of same type may combine

Shape



3.5 Repetitive characters

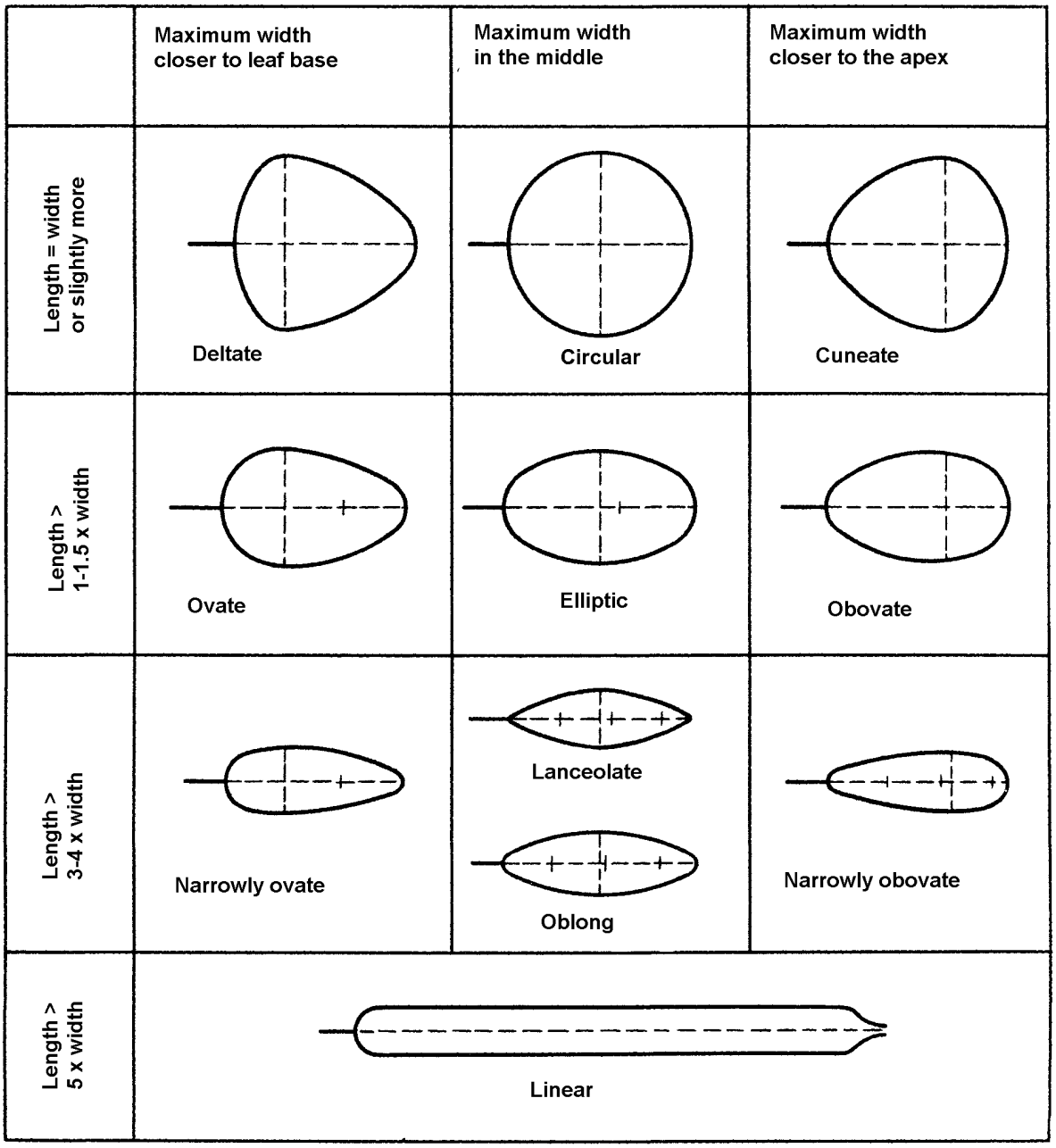
Repetitive characters

Repetitive characters are the same on each level of leaf hierarchy:

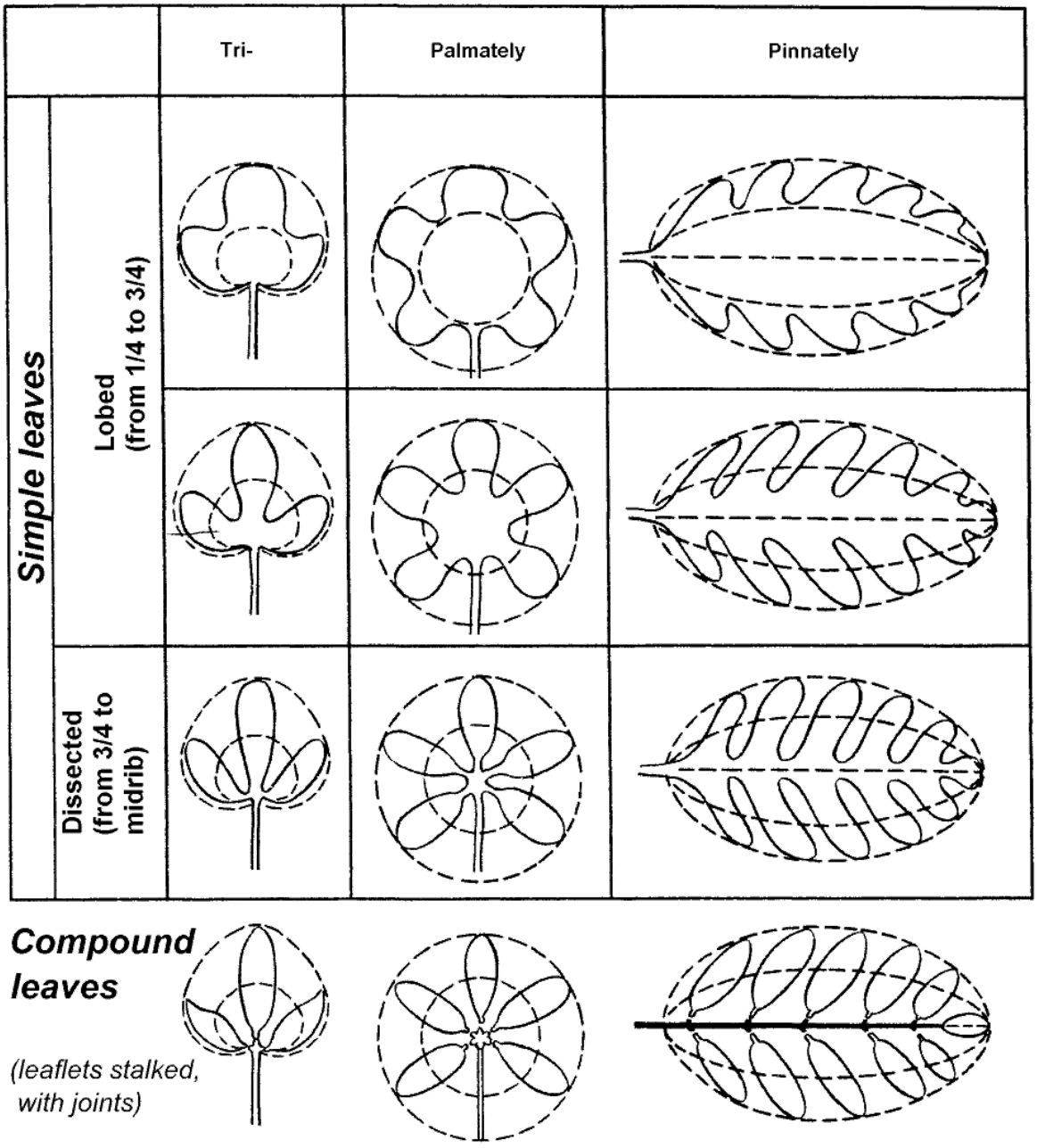
- Shape
- Dissection
- Petiole (stalked/non-stalked etc.)

Repetitive characters of same type may combine

Shape



Dissection



3.6 Terminal characters

Terminal characters

Terminal (leaflet) characters are applicable only to terminal parts (normally, leaflets) of leaves:

- Form of base
- Form of tip
- Type of margin
- Surface
- Venation

Terminal characters: base of leaf blade

- Rounded
- Truncate (straight)
- Cuneate
- Cordate
- Sagittate

Terminal characters: leaf apex

- Rounded
- Mucronate
- Acute
- Obtuse
- Acuminate
- Retuse

Terminal characters: leaf margin

- Without teeth: smooth
- With teeth
  - Dentate
  - Serrate
  - Crenate
- Could be double-dentate, triple-serrate etc.

Terminal characters: leaf venation

Lateral veins \ Main vein	No	One	Several
No	Apodromous	Hypho-	Acro-
Several	Dichotomous	Ptero-	Actino-

Plan of leaf description

A. General characters (leaf as a whole):

   (a) stipules (present / absent, deciduous / not);

   (b) base (sheath / no sheath, ligule / no ligule, auricles / no auricles)

B. First level of hierarchy: repetitive characters:

   (a) symmetry (symmetrical / asymmetrical);

   (b) shape;

   (c) dissection;

   (d) petiole (length)

C. Second level of hierarchy

D. Third level of hierarchy and so on

E. Terminal characters (leaflets):

   (a) base [of leaf blade] (rounded, truncate, cuneate, cordate, sagittate);

   (b) apex (rounded, mucronate, acute, obtuse, acuminate, retuse);

   (c) margin (whole, dentate, serrate, crenate; degree of order);

   (d) surface (color, hairs etc.);

   (e) venation (apo-, hypho-, acro-, ptero-, actinodromous)

Summary

- Leaves have **general**, **repetitive** and **terminal** characters

Quiz question (... points)

...

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

4 Leaf

4.1 Leaf morphology

Plan of leaf description

A. General characters (leaf as a whole):

   (a) stipules (present / absent, deciduous / not);

   (b) base (sheath / no sheath, ligule / no ligule, auricles / no auricles)

B. First level of hierarchy: repetitive characters:

   (a) symmetry (symmetrical / asymmetrical);

   (b) shape;

   (c) dissection;

   (d) petiole (length)

C. Second level of hierarchy

D. Third level of hierarchy and so on

E. Terminal characters (leaflets):

   (a) base [of leaf blade] (rounded, truncate, cuneate, cordate, sagittate);

   (b) apex (rounded, mucronate, acute, obtuse, acuminate, retuse);

   (c) margin (whole, dentate, serrate, crenate; degree of order);

   (d) surface (color, hairs etc.);

   (e) venation (apo-, hypho-, acro-, ptero-, actinodromous)

4.2 Leaves in nature

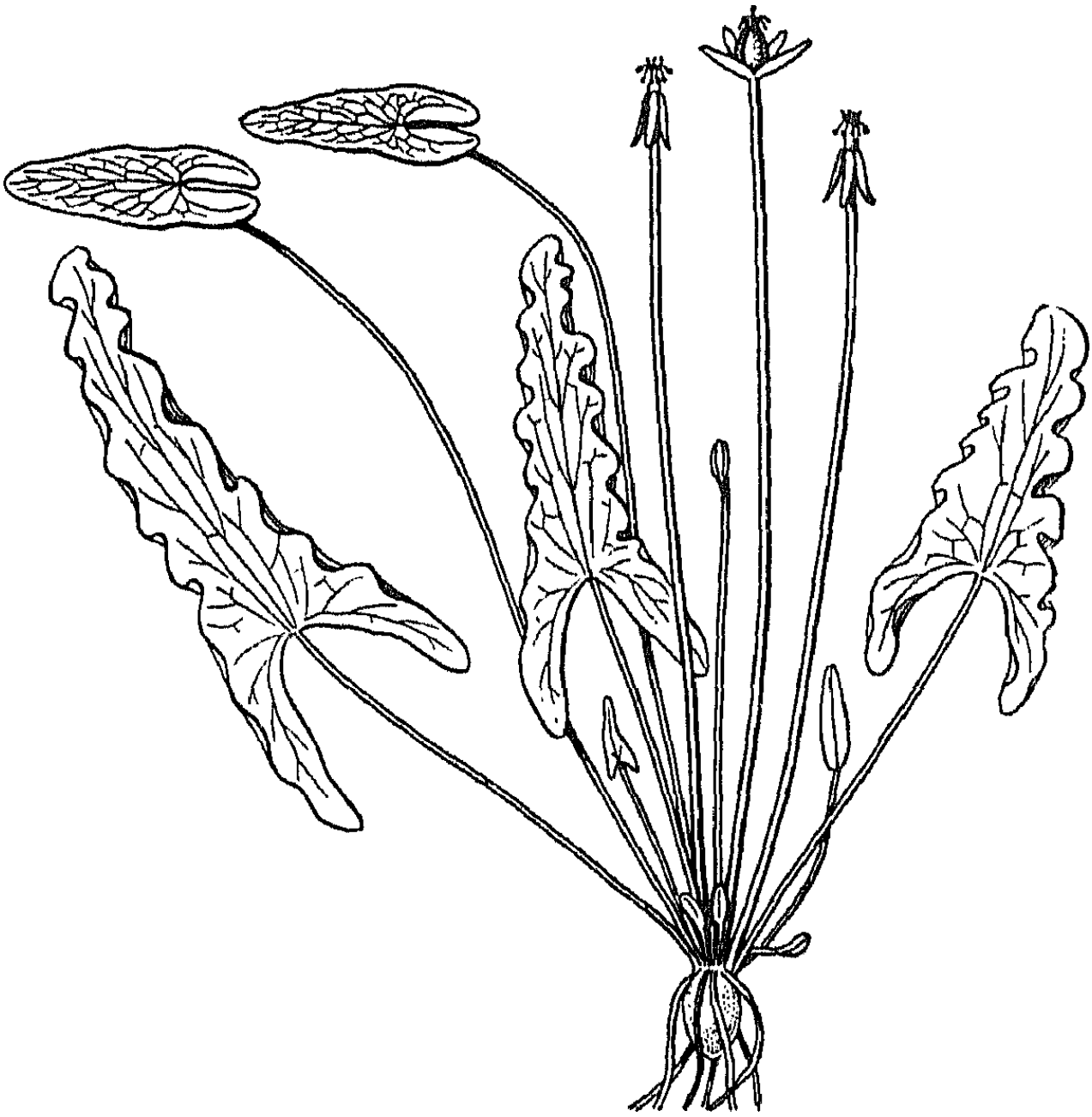
Heterophylly

- Juvenile and adult leaves
- Water and air leaves
- Sun leaves and shade leaves

Juvenile leaves of *Juniperus* sp.

Juvenile leaves of *Eucalyptus* sp.

Submerged and floated leaves of *Ondinea*



Leaf mosaic

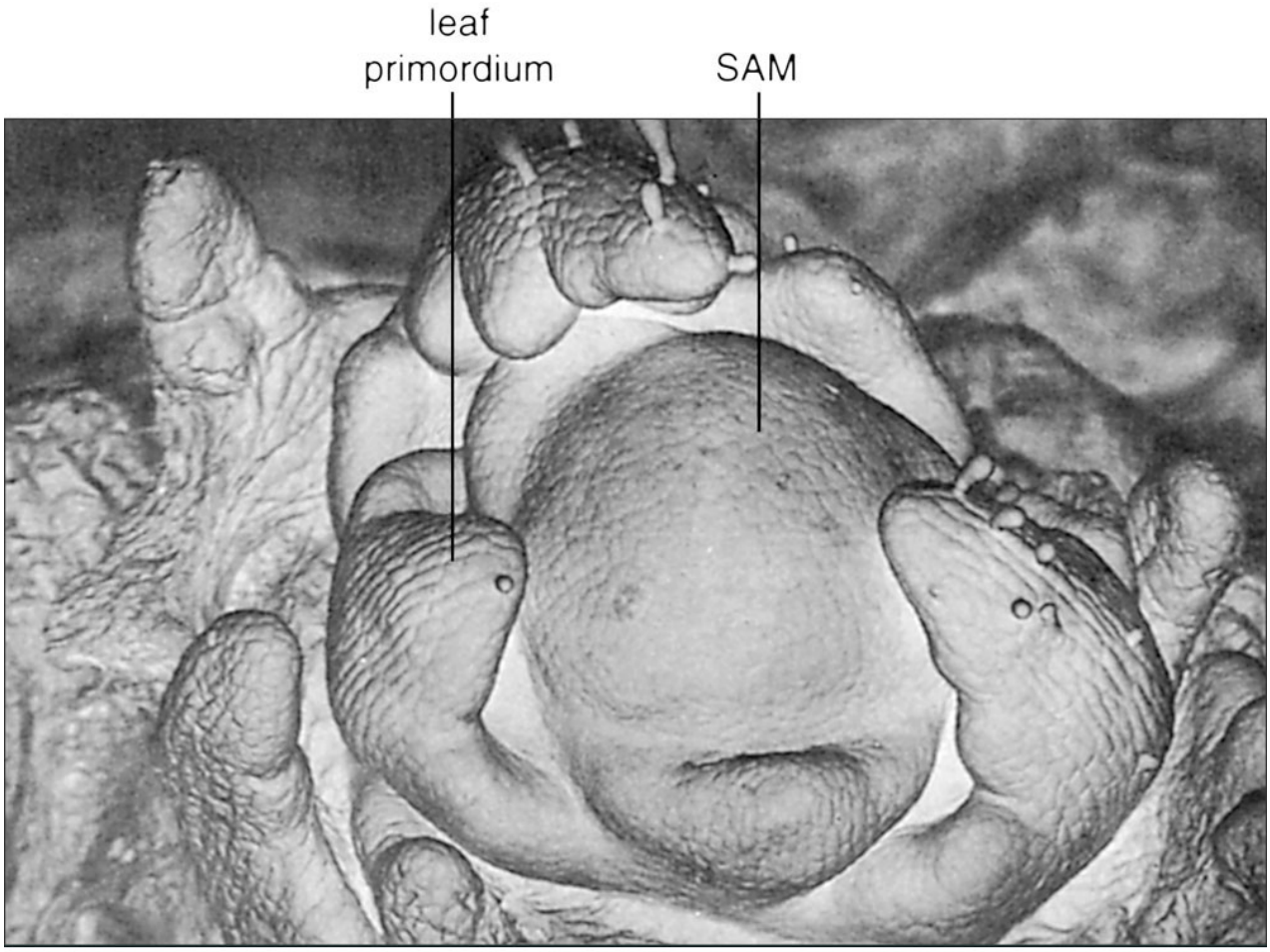
- Distribution of leaves of plants in a single plane, usually perpendicular to light rays
- Provides the least shading of leaves by one another

Leaf mosaic of red maple (*Acer rubrum*)

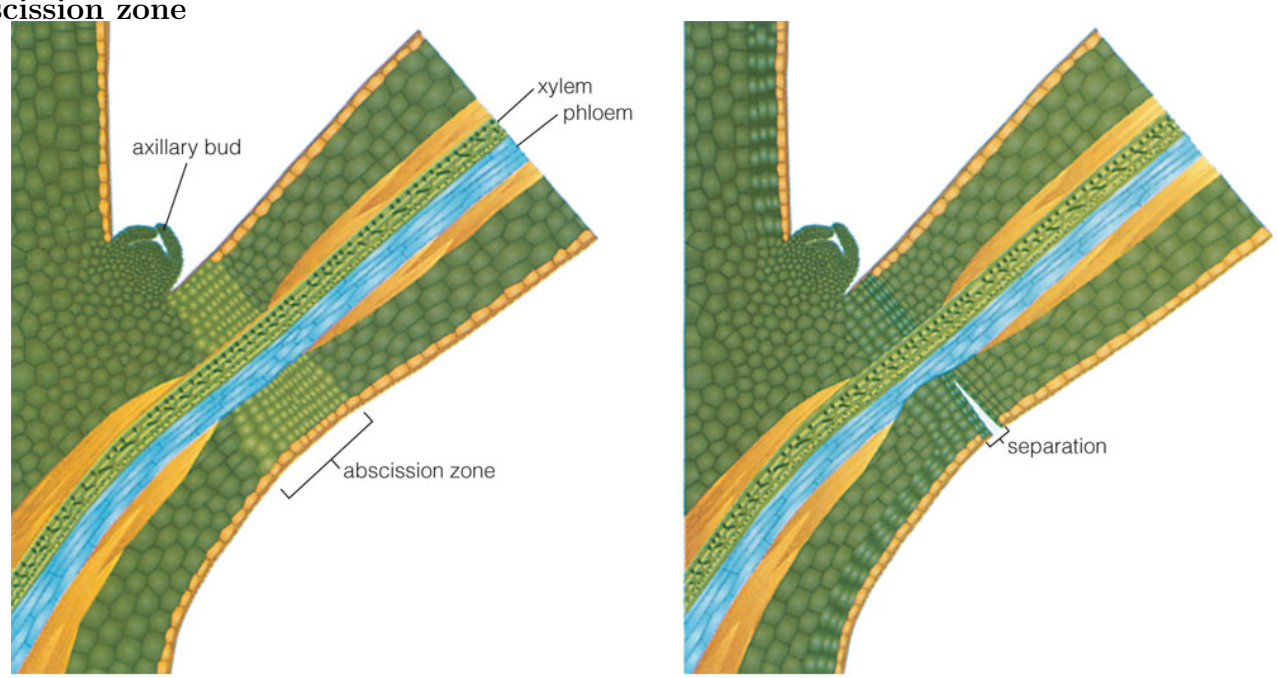
Seasonal life of leaves

- Leaves arise from SAM through leaf primordia
- Old leaves separate from plant in a region called abscission zone

Leaf primordia



Abscission zone



4.3 Modifications of leaf

Goethe's theory of modification

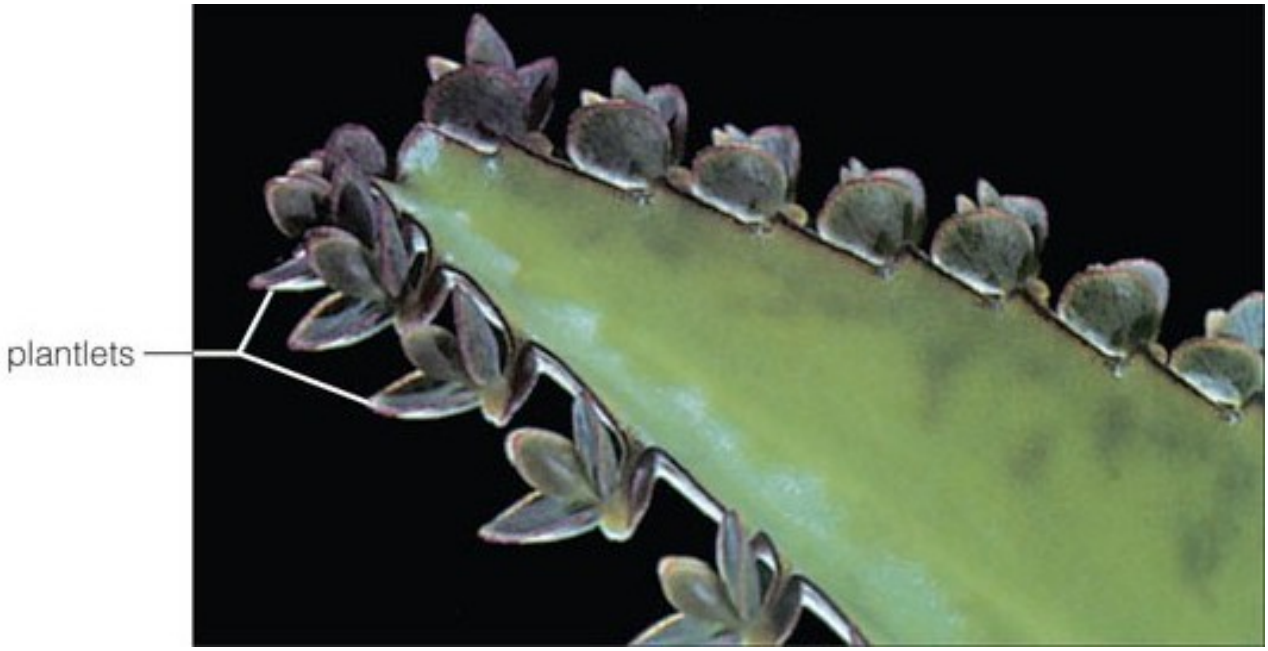
Famous German poet and writer Johann Wolfgang Goethe is also a founder of plant morphology. He invented an idea of "primary plant" ("Urpflanze") where all organs were modifications of one primordial organ.

Leaf modifications

- Spines
- Tendrils
- Succulent leaves
- Traps
- Plantlets

Tendrils of sweet pea (*Lathyrus odoratus*)

Plantlets on the leaf of *Kalanchoe pinnata*



Leaf of Venus flytrap (*Dionaea muscipula*)

Everything is possible when plant needs nitrogen!

Venus flytrap in work

Urn leaf of yellow pitcher plant (*Sarracenia flava*)

***Sarracenia flava* on Buttercup Fields, Mississippi**

Prey in the urn

Urn leaf of purple pitcher plant (*Sarracenia purpurea*)

Hairs prevent insects from climbing out of leaf

"Cobra Lily" (*Darlingtonia californica*)

Sticky tape leaf of butterwort (*Pingiucula* sp.)

Leaf margins are slowly rolling

Sticky tape/trap leaf of sundew (*Drosera intermedia*)

Leaves are constantly open and close and finally digest the glued insects

Table of modifications

Function	Stem / shoot	Leaf	Root
Expansion		Plantets	
Storage		Succulent leaves	
Photosynthesis		DEFAULT	
Defense		Spines, scales	
Support		Leaf tendrils	
Interactions		Traps, "sticky tapes", urns	

Summary

- Leaves have **general**, **repetitive** and **terminal** characters
- **Heterophylly** is a co-existence of different types of leaves on the same plant
- **Abscission zone** helps the separation of leaf at the end of season

Quiz question (... points)

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

5 Questions and answers

5.1 Quiz

Quiz question (2 points)

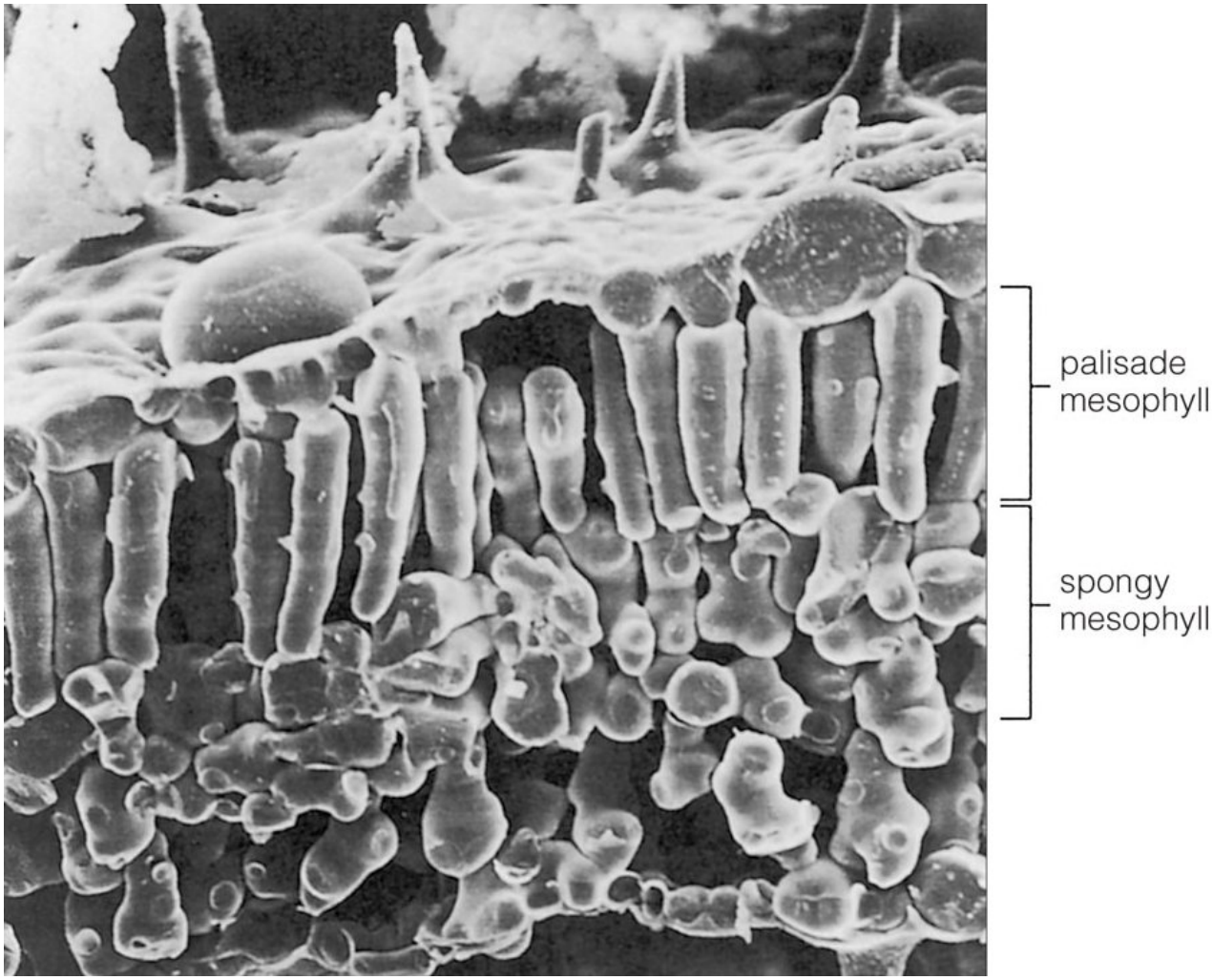
...

- ...

6 Leaf

6.1 Anatomy of leaf

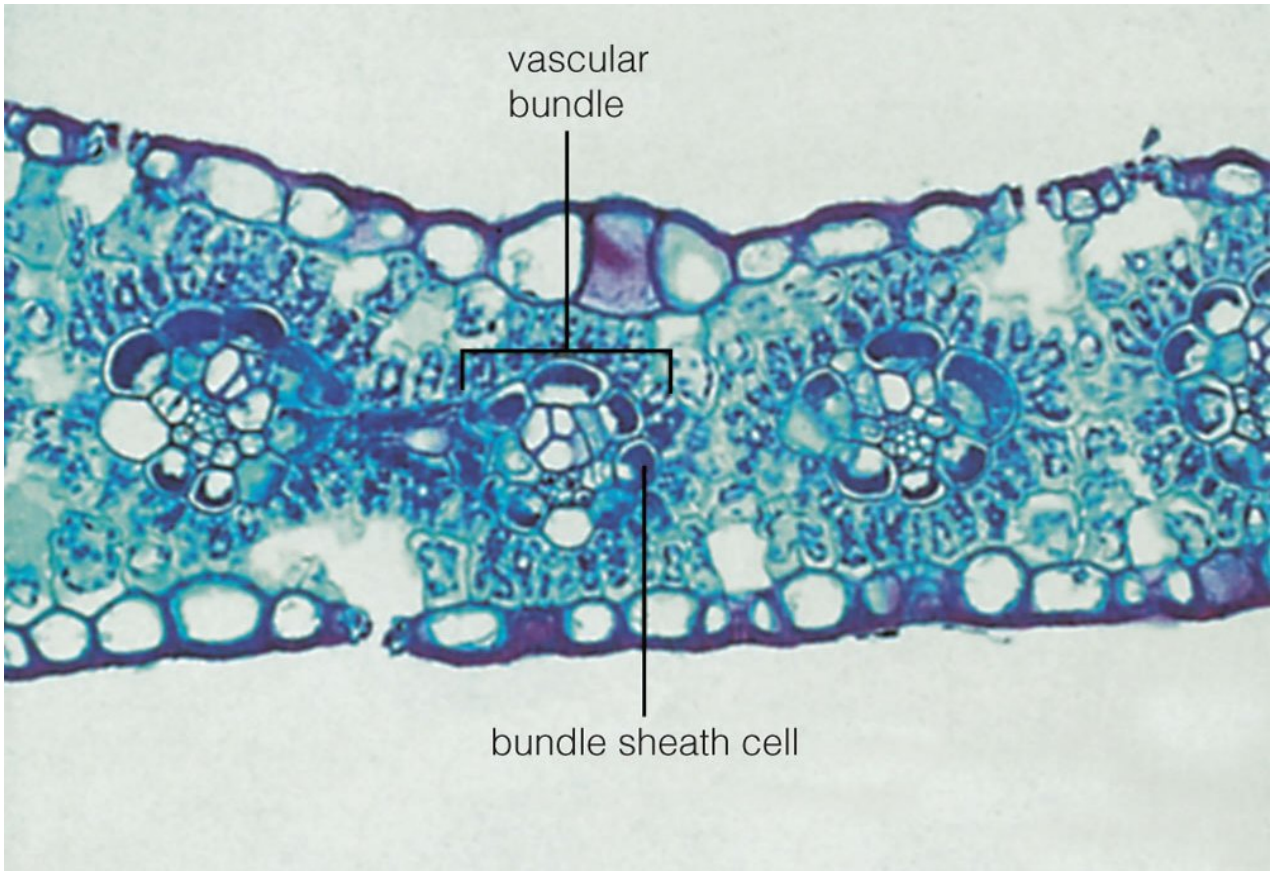
Palisade and spongy cells



Veins/vascular bundles and stomata

- Phloem typically faces downwards, xylem—upwards
- Bundles of C_4-plants have additional bundle sheath cells
- Stomata work with the "bacon principle"

Bundle sheath cells

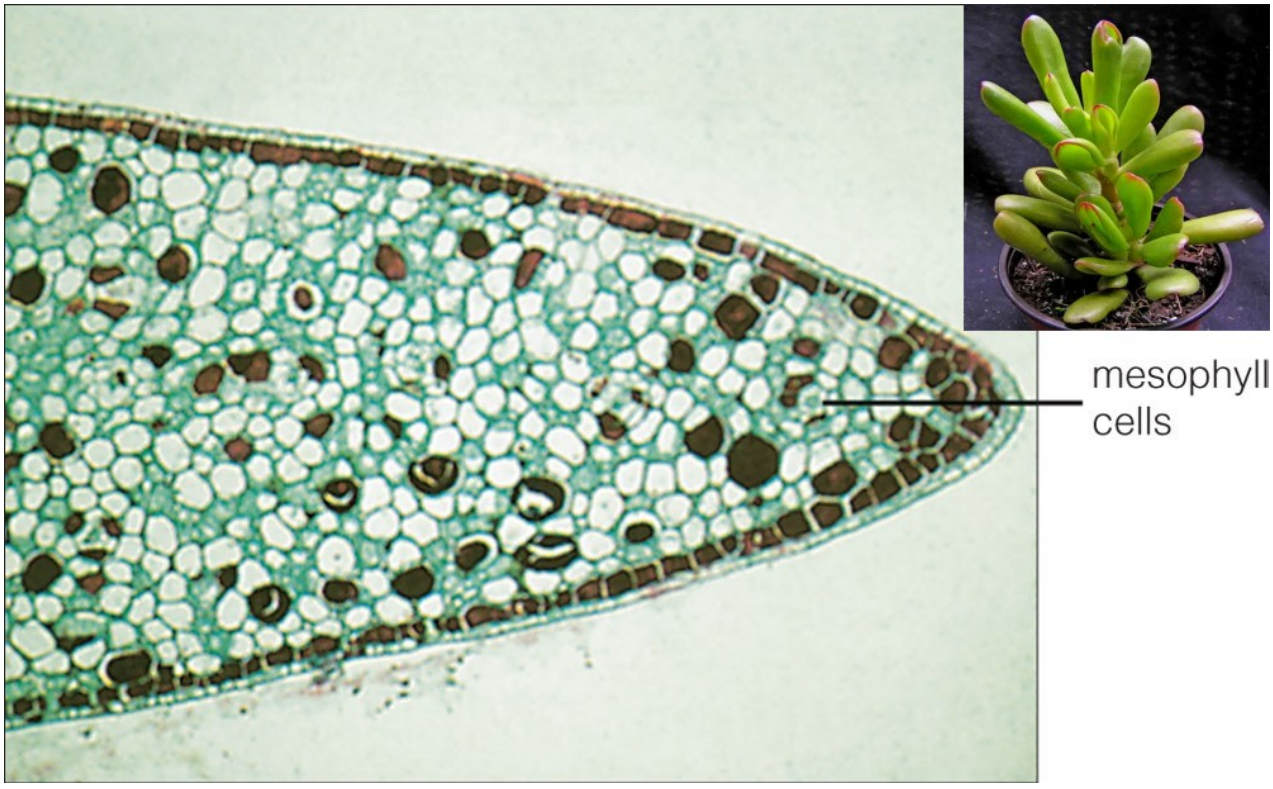


6.2 Ecological adaptations of leaves

Plants and water

- Xerophytes: sclerophytes and succulents (stem and leaf)
- Mesophytes
- Hygrophytes
- Hydrophytes

Leaf succulent (*Crassula argentea*)



Xerophyte leaf—needle of pine (*Pinus contorta*)

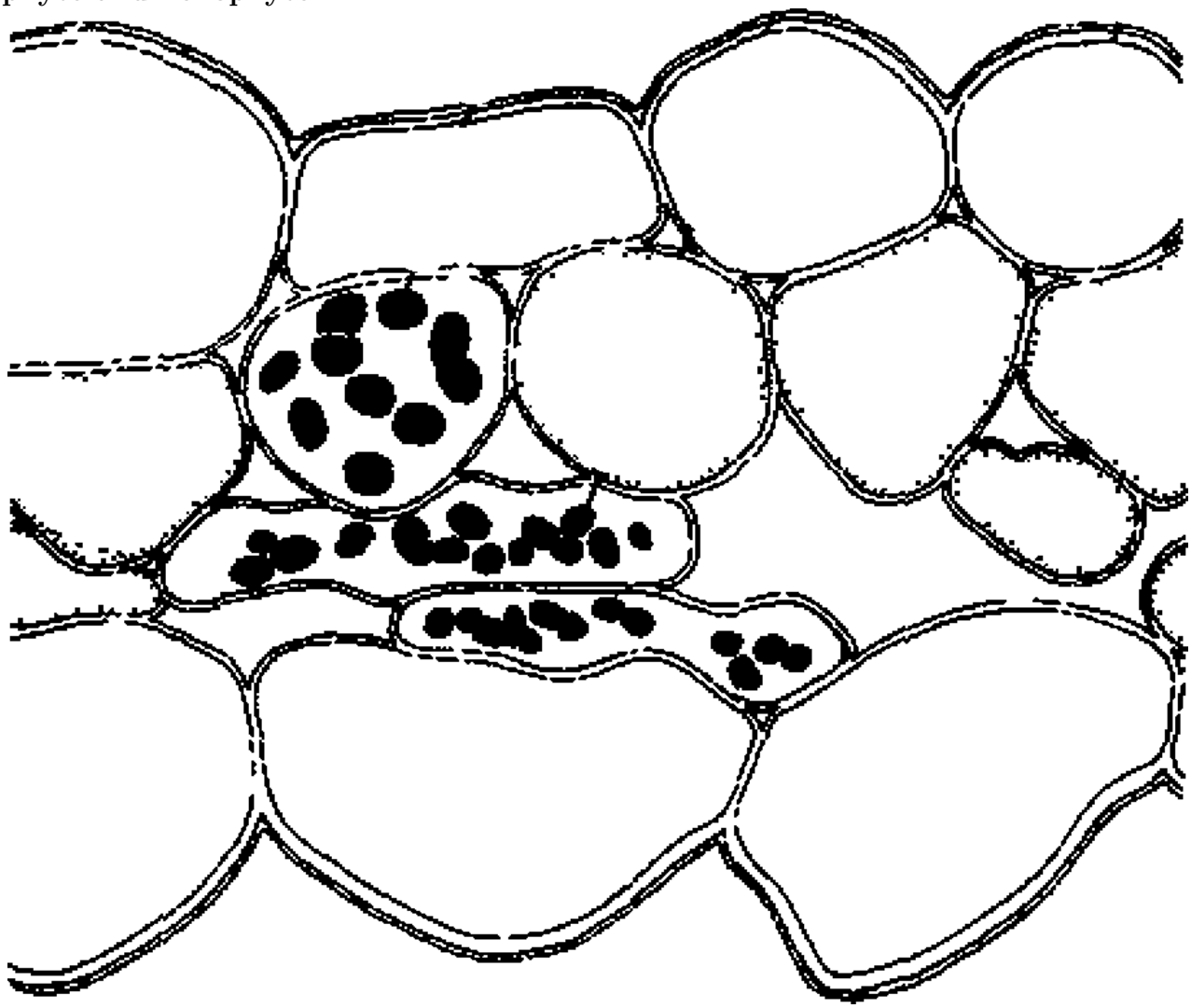
7 Leaf

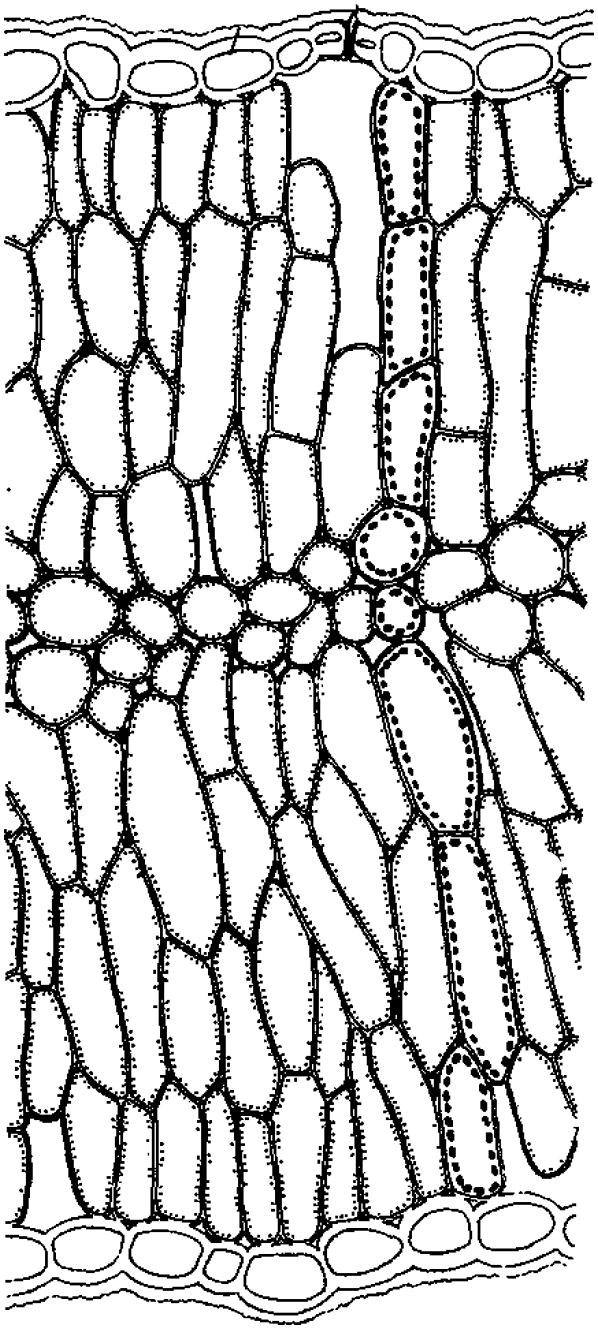
7.1 Ecological adaptations of leaves

Plants and light

- Sciophytes
- Heliophytes

Sciophyte and heliophyte





Oxalis acetosella and *Sylphium laciniatum*

Leaves and soil

- Halophytes (accumulate, excrete or avoid NaCl)
- Nitrate halophytes (grow on soils rich of $NaNO_3$)
- Oxylophytes (grow on acidic soils)
- Calciphytes (grow on chalk soils rich of $CaCO_3$)

Leaf of salt-accumulating halophyte

Atriplex prostrata

Leaves and substrate

- Psammophytes (grow on sand)
- Petrophytes (grow on rocks)
- Rheophytes (grow in fast springs)

Rheophyte

Macarenia clavigera from Venezuela

River with rheophytes

They are flowering, too

Podostemum ceratophyllum (may be found even in ND!)

Podostemum in North Carolina

Leaves and metabolism

- Mycoparasites
- Hemiparasites
- Phytoparasites (root and stem)

Mycoparasite

Triuris hyalina from South America

Hemiparasite

Krameria parvifolia from southern Texas

Root parasite

Hydnora africana from South Africa

Stem parasite

Cuscuta europaea from Germany

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

8 Stem and shoot

8.1 Plant body

Structure of plant body: the first glance

- Shoot system (aboveground part: stems, leaves, buds, flowers, fruit)
- Root system (below-ground part: main roots and branches)
- Exceptions:
  - Some mosses and even ferns have only shoot system
  - Liverworts and hornworts frequently have only leaf-like thallus

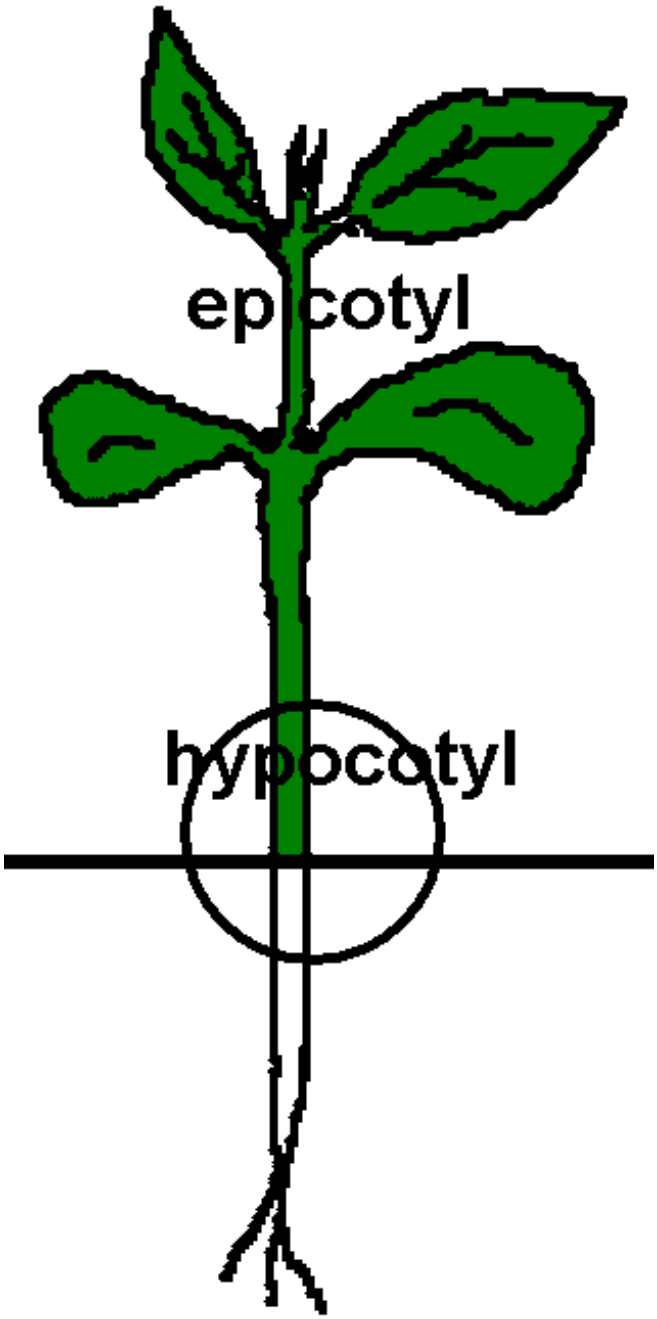
Types of plant body

- **Thallus** (flat, with non-differentiated organs)
- **Shoot** body (roots are absent)
- **Bipolar** body (root and shoot systems)

Organs of bipolar plant

- **Leaf**: flat lateral organ with restricted growth
- **Stem**: axial aerial organ with continuous growth
- **Root**: soil organ modified for absorption
- **Floral unit** (FU): stable element of generative system

Non-organs



- *Hypocotyl*: transition between stem and root
- *Epicotyl*: first internode of plant
- *Bud*: shoot "embryo"
- *Fruit*: temporary structure, ripe FU
- *Seed*: chimeric structure, has two or three genotypes

Organ systems: final

- Shoot system: vegetative and generative
- Root system

Origin of tissues and organs of plants

- Land colonization. Challenge: drying. Response: **epidermis** and **parenchyma**. Thallus body plan.
- New level of competition. Response: shoot body plan. Problem: big weight. Solution: **collenchyma**.
- Competition grows again. Respose: grow higher. Weight grows. Response: use dead cells in **sclerenchyma**.
- Competition grows again. Response: grow faster. Solution: **meristems**.
- Size of plant is too big for plasmodesmata transportations. Solution: vascular tissues, **xylem** and **phloem**. Here plants with sporophyte dominance win the competition.
- Size of plant is too big for osmotic absorption of water. Solution: **absorption tissues**, roots, bipolar body plan. Now they are independent from water as much as possible—with an exception of generative system...
- Shoot system make leaves, stems and **branches**. Plants are facing new challenge!

Summary

- Water deficit results in either sclerophyte or succulent adaptations
- Water excess results in hygrophyte or even hydrophyte adaptations

9 Shoot

9.1 Stem

Stem: definition and functions

- Axial vegetative organ of shoot with functions of support and transportation
- Other functions:
  A. Photosynthesis
  B. Storage
- Features:
  A. Radial structure
  B. No root hairs
  C. Continuous growth

9.2 Development of stem tissues

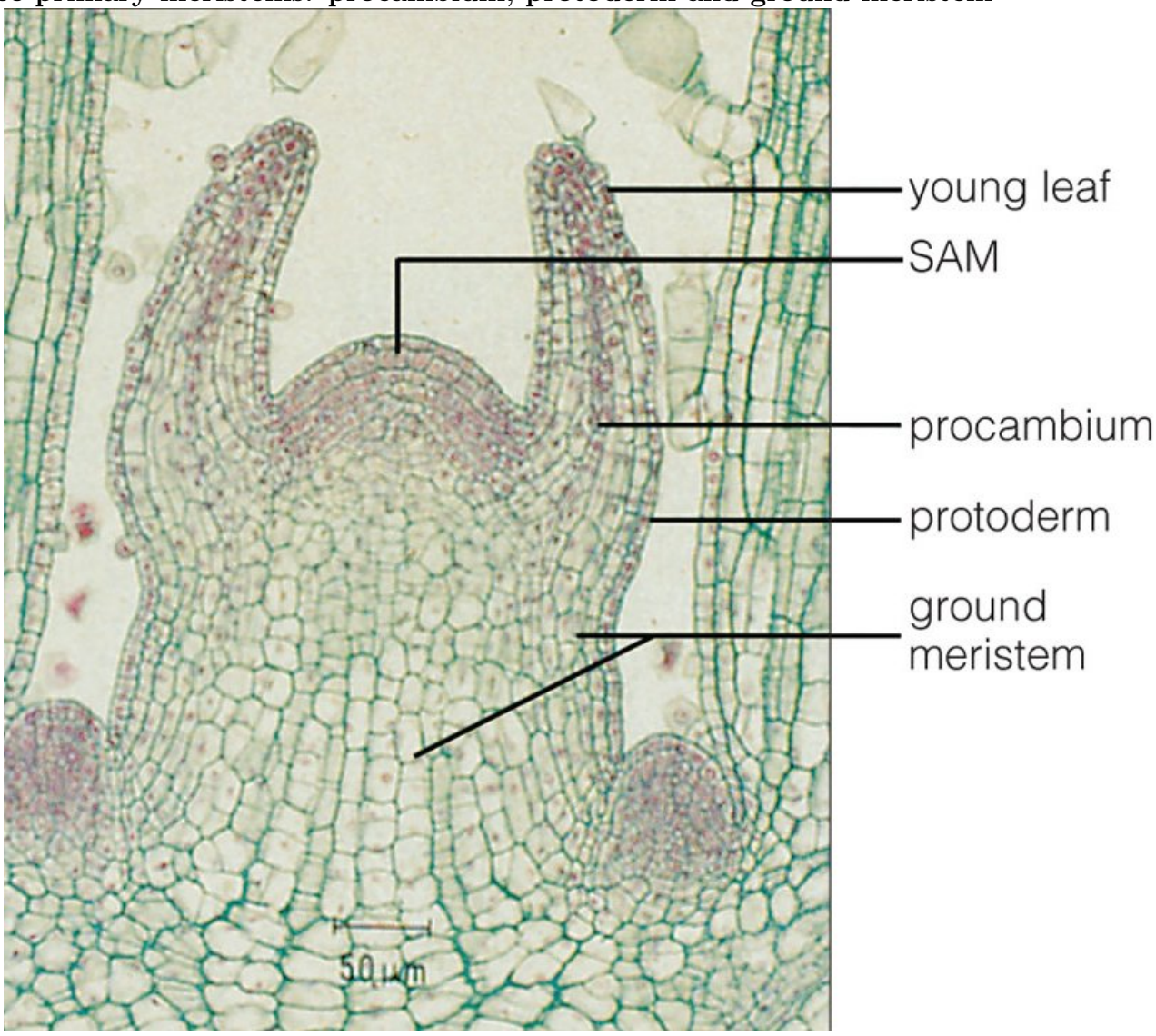
Protoderm to epidermis

- Stem apex meristem (SAM) produces **protoderm**
- Protoderm cells differentiate into epidermal cells

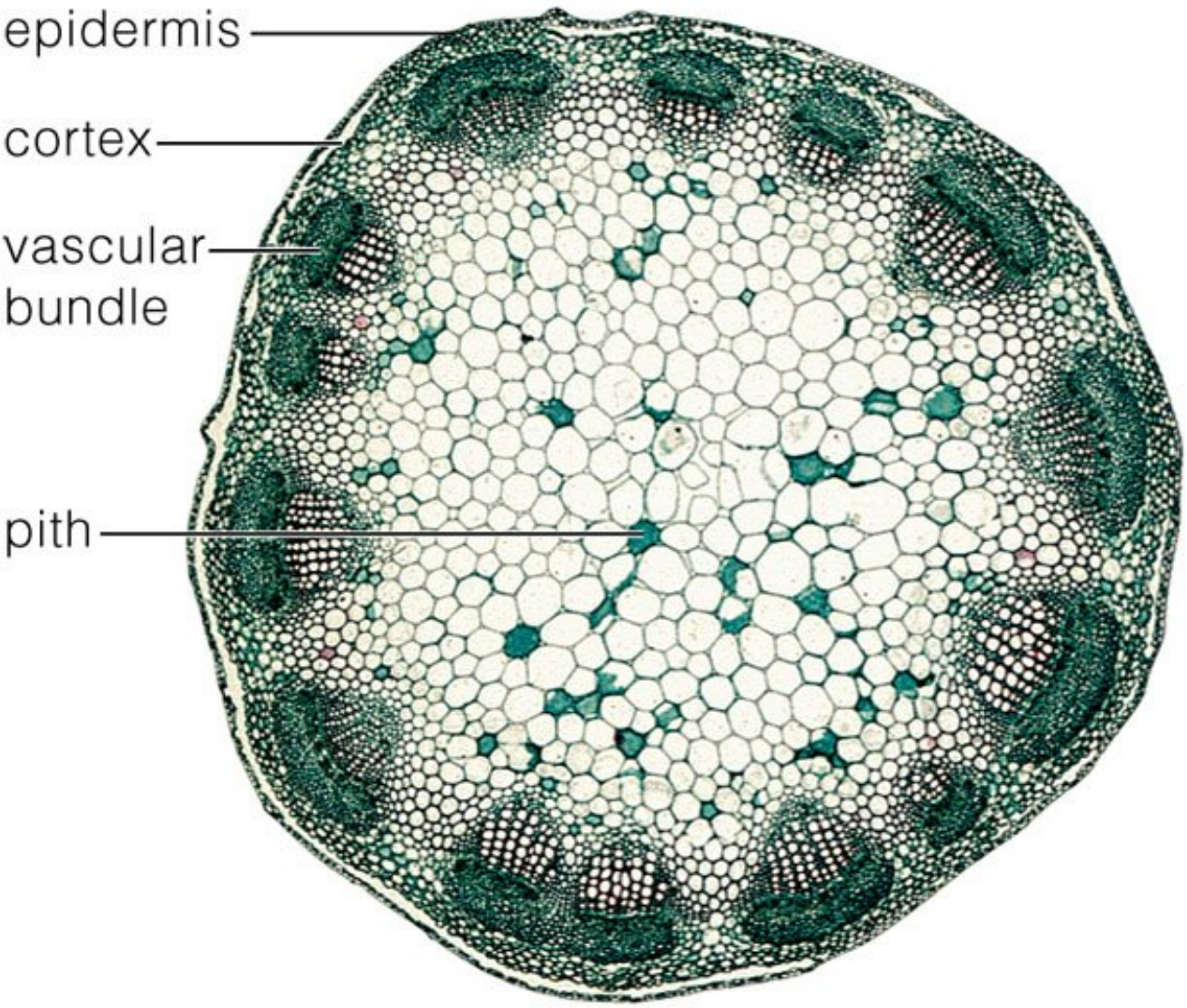
Ground meristem to cortex and pith

- SAM produces also **ground meristem**
- Ground meristem differentiates into **cortex** and **pith**
- Procambium raises between cortex and pith, it forms vascular bundles or vascular cylinder

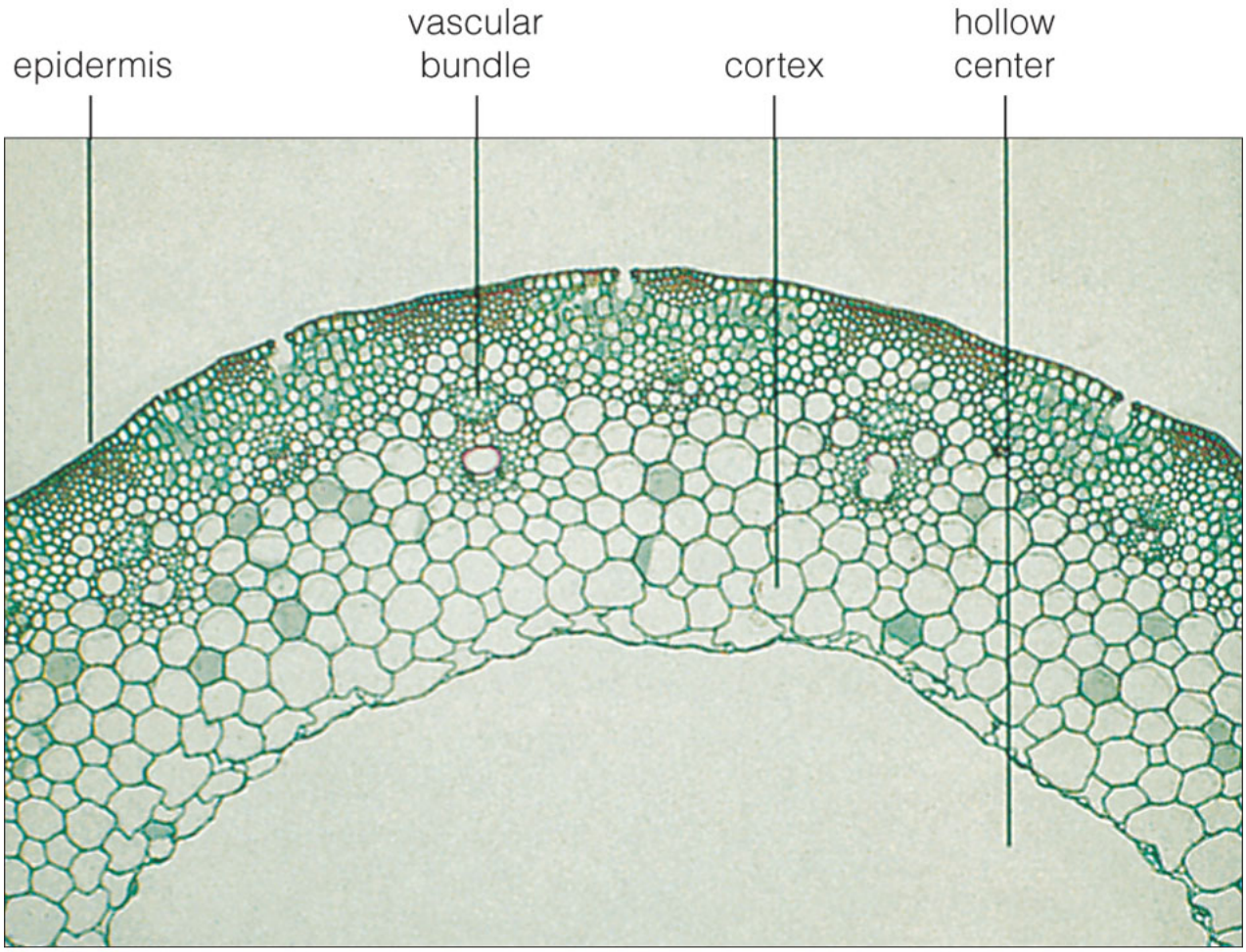
Three primary meristems: procambium, protoderm and ground meristem



Young stem with primary tissues



Older stem with hollow in the center

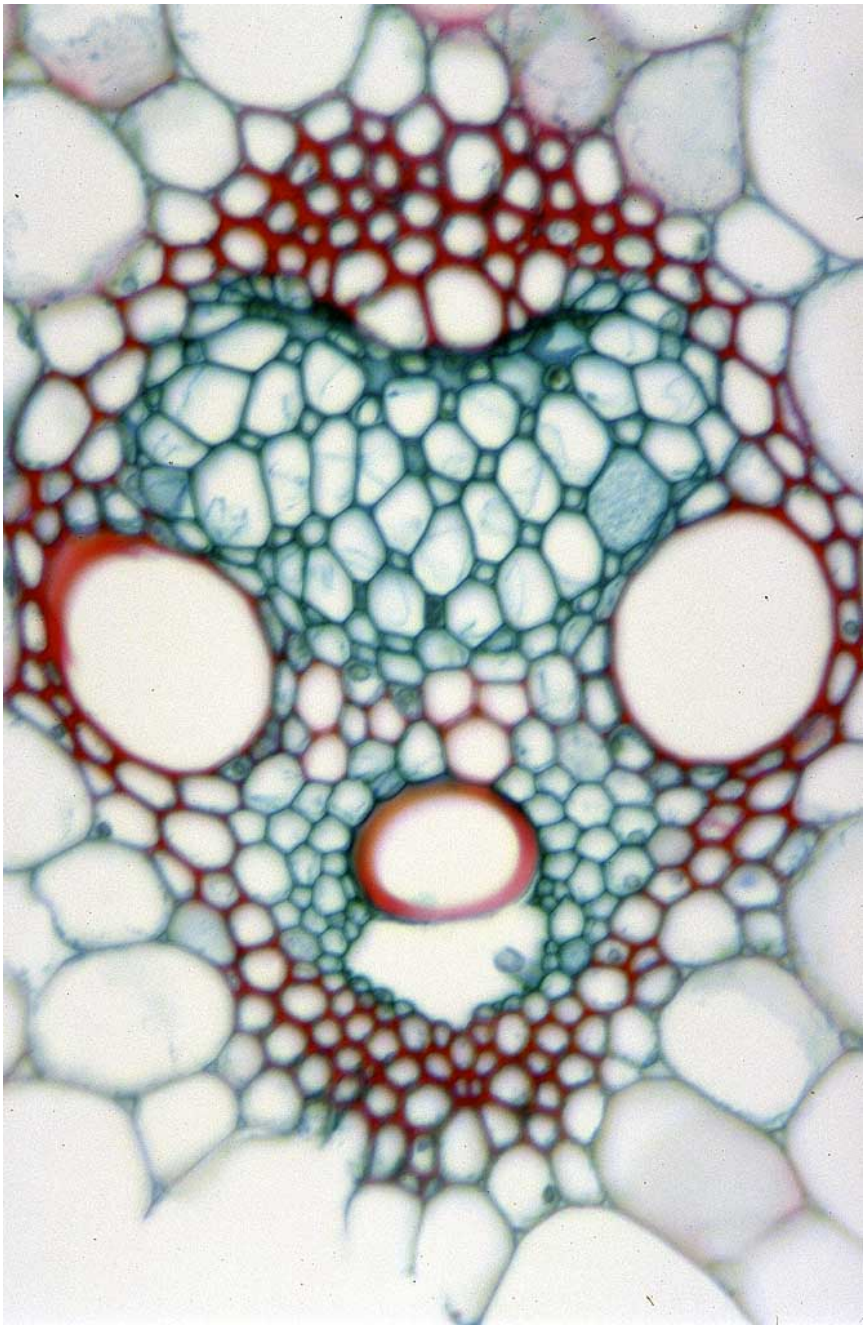


Procambium to xylem and phloem

- Outer layers of procambium form **primary phloem**
- Inner layers become **primary xylem**
- Middle layer could be completely spent **or** will make cambium for the secondary thickening
- Sometimes outermost layers of procambium form **pericycle** (parenchyma cells)
- In some cases, inner layers of cortex could form **endoderm**

9.3 Anatomy of the primary stem

Vascular bundle (monocot)



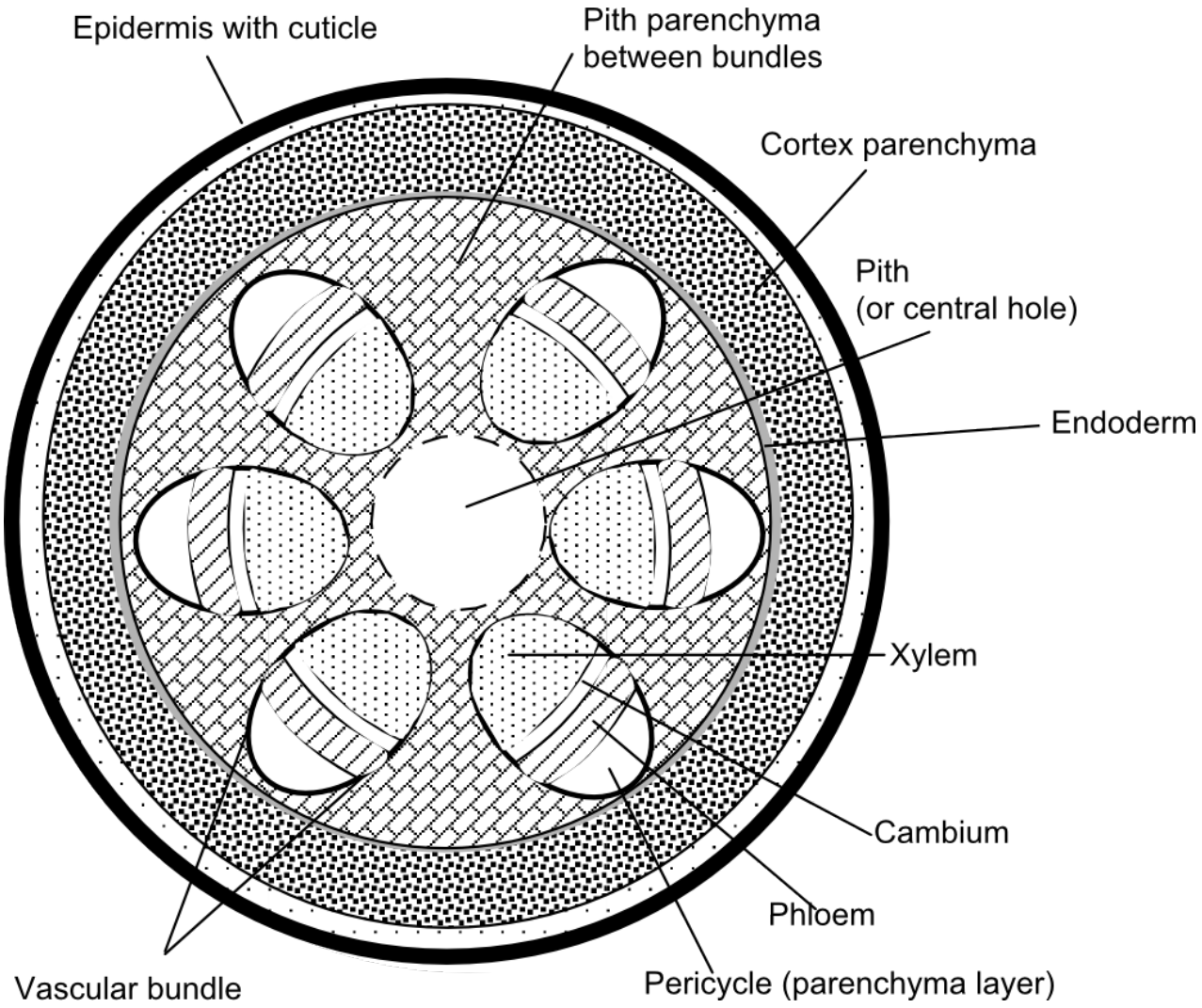
Corn (*Zea mays*) mature stem cross-section showing single vascular bundle, Brightfield (LM ×400)

Summary

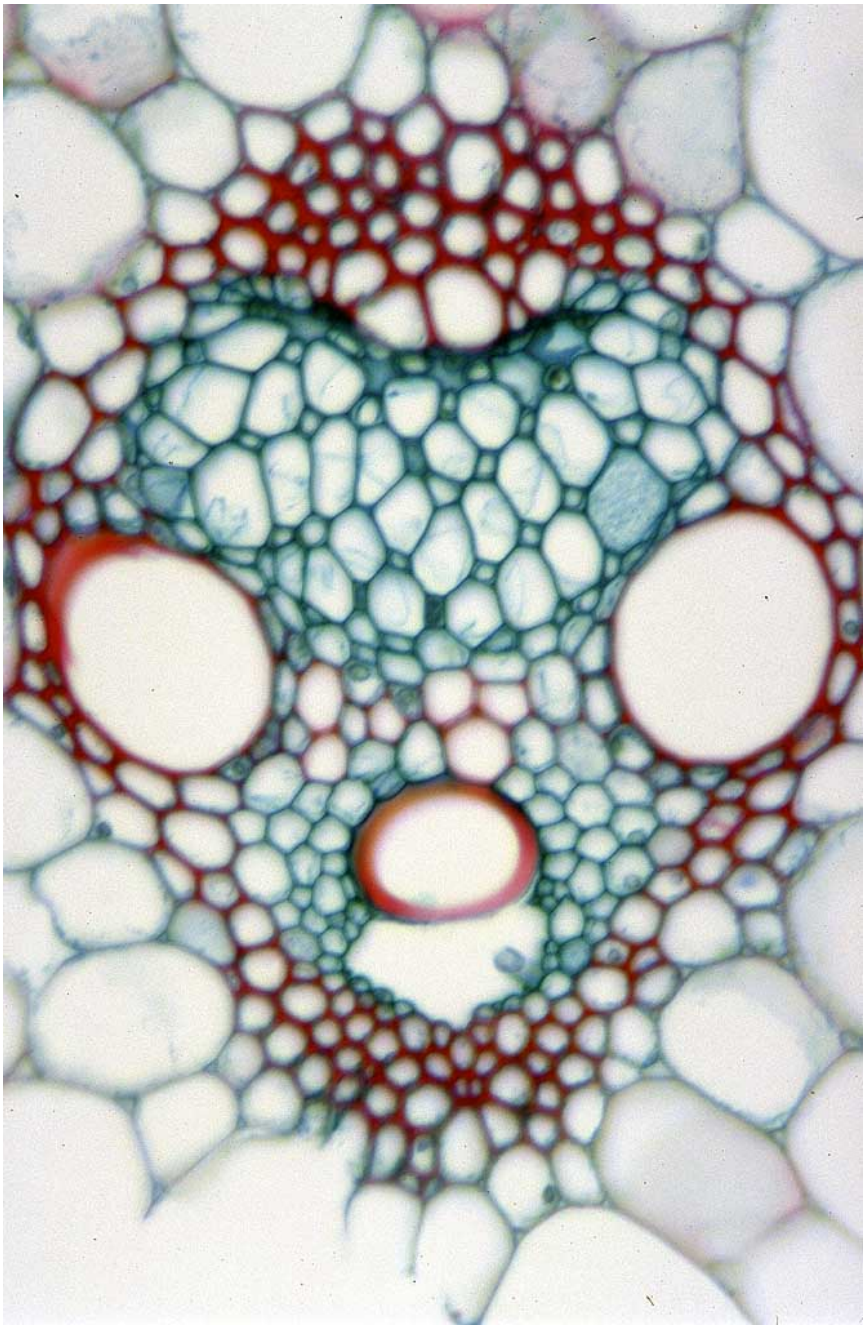
- SAM produces **protoderm** and **ground meristem**, ground meristem differentiates into **cortex** and **pith**
- Procambium forms **vascular bundles** or vascular cylinder

9.4 Anatomy of the primary stem

Primary structure of stem

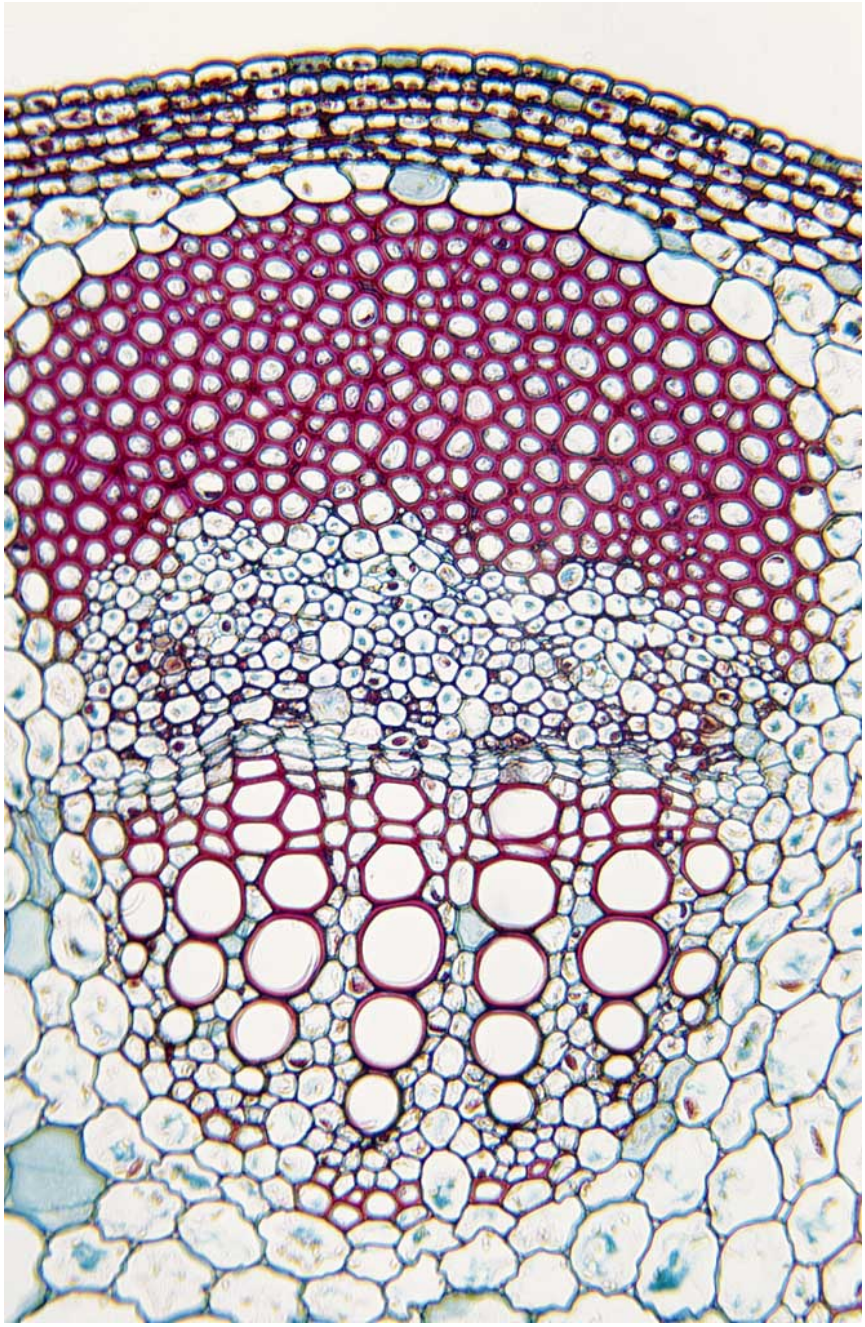


Vascular bundle (monocot)



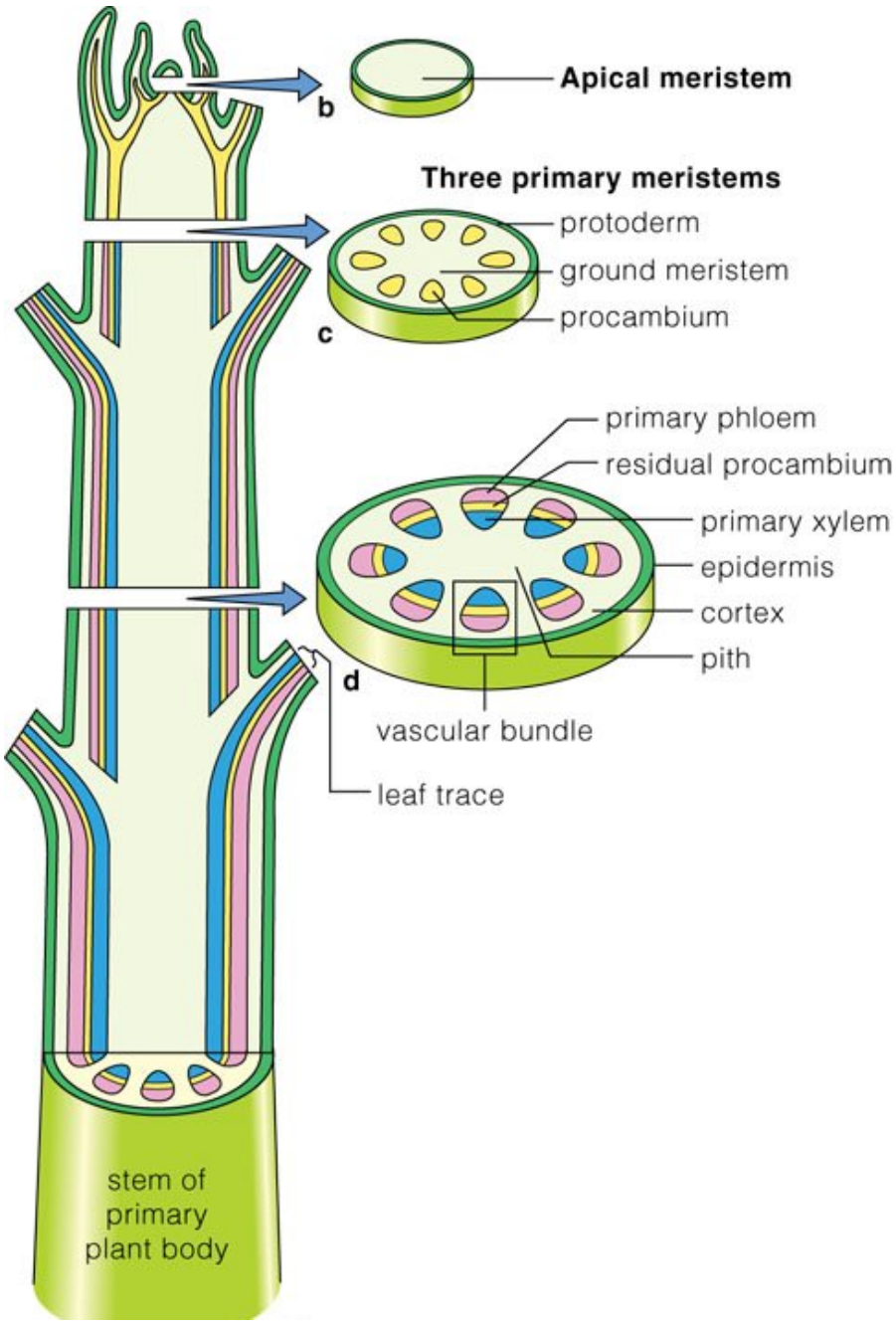
Corn (*Zea mays*) mature stem cross-section showing single vascular bundle, Brightfield (LM ×400)

Vascular bundle (asterid)



Wild Sunflower (*Helianthus* sp.) with nearly mature vascular bundle (LM ×35)

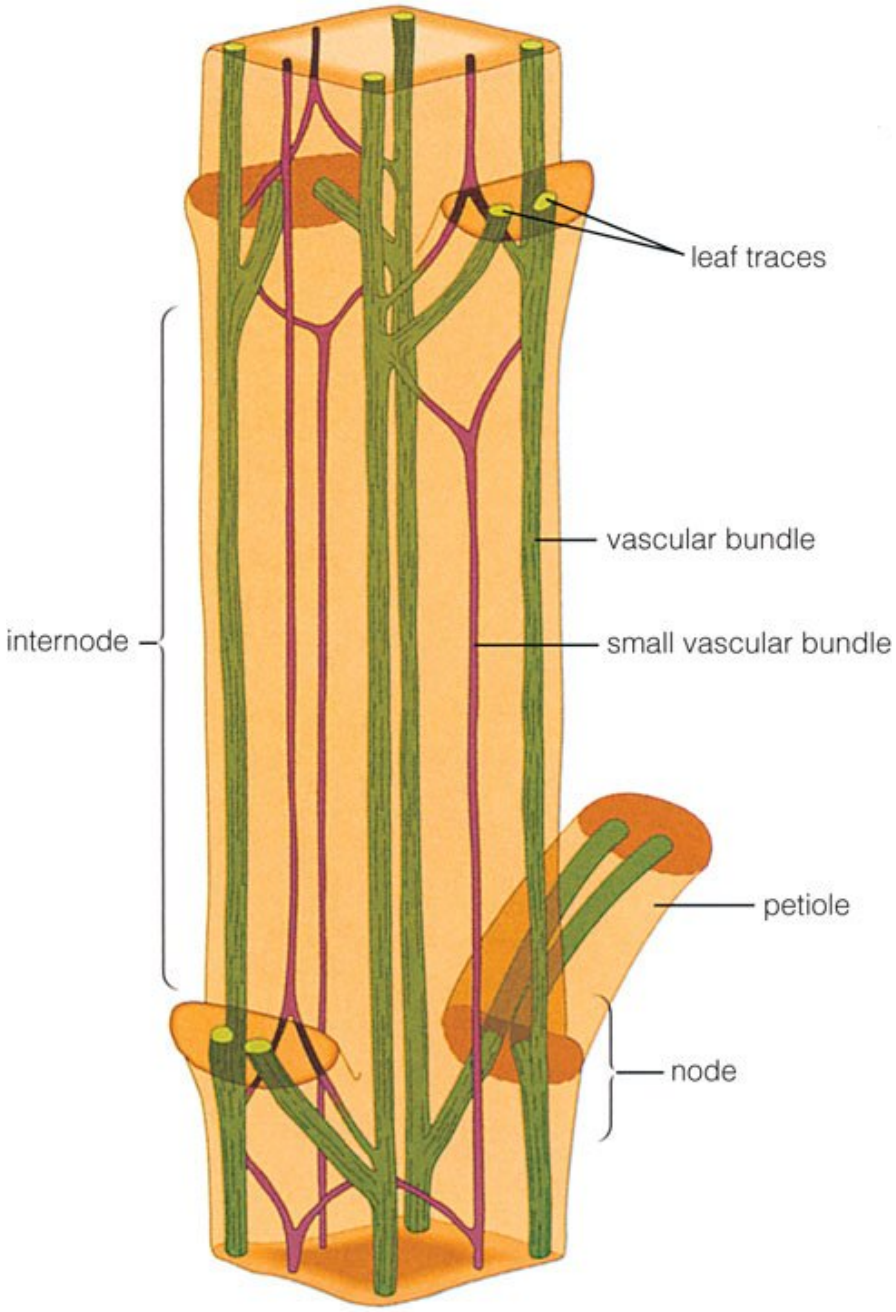
Origin of vascular bundles



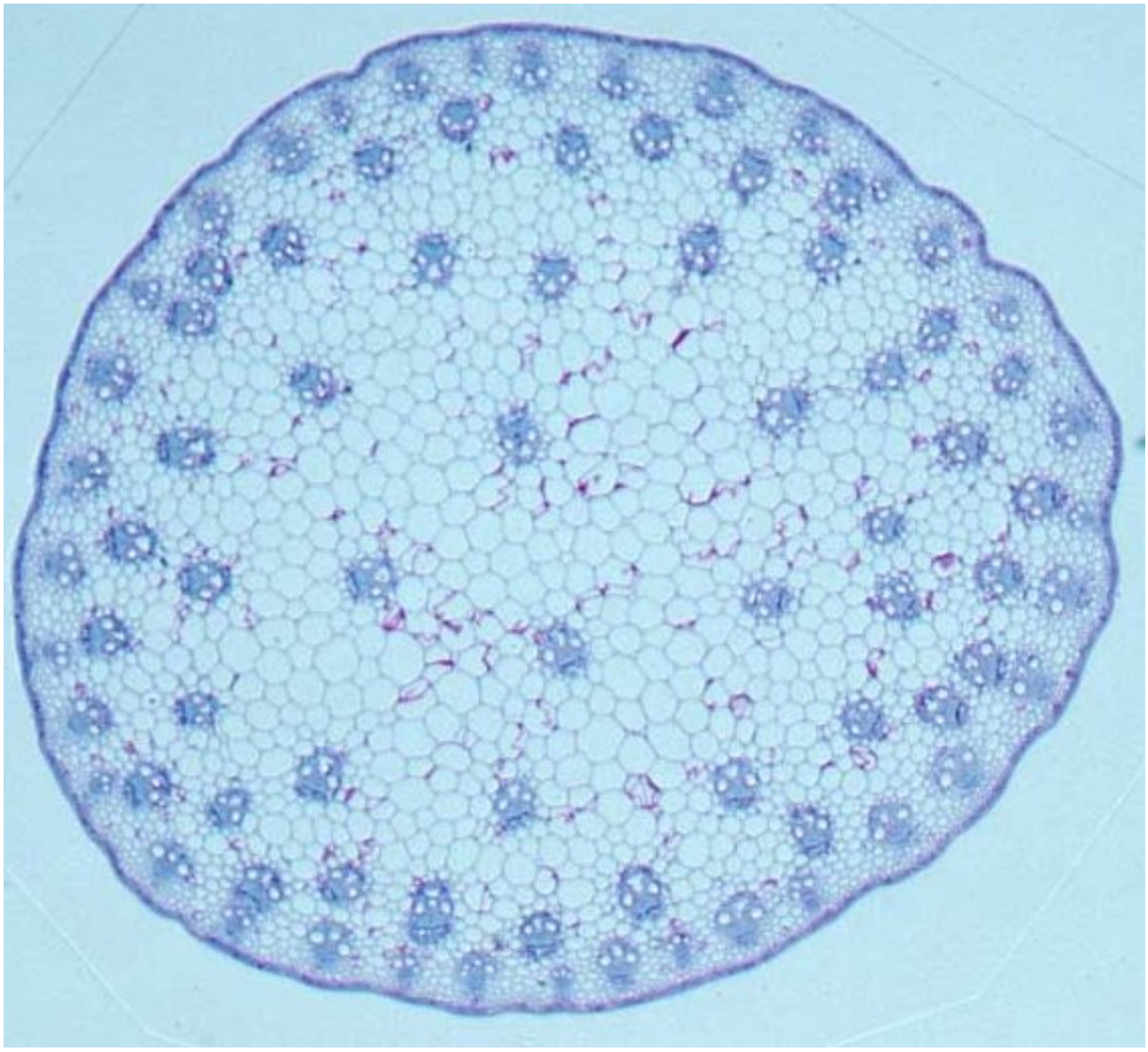
Vascular bundles

- Vascular bundles connect leaves and stems
- In many plants, they form **ring** on the cross-section of stem ("dicot" stem)
- Monocot stems usually have **dispersed** vascular bundles

Vascular bundles and leaf traces



Monocot stem

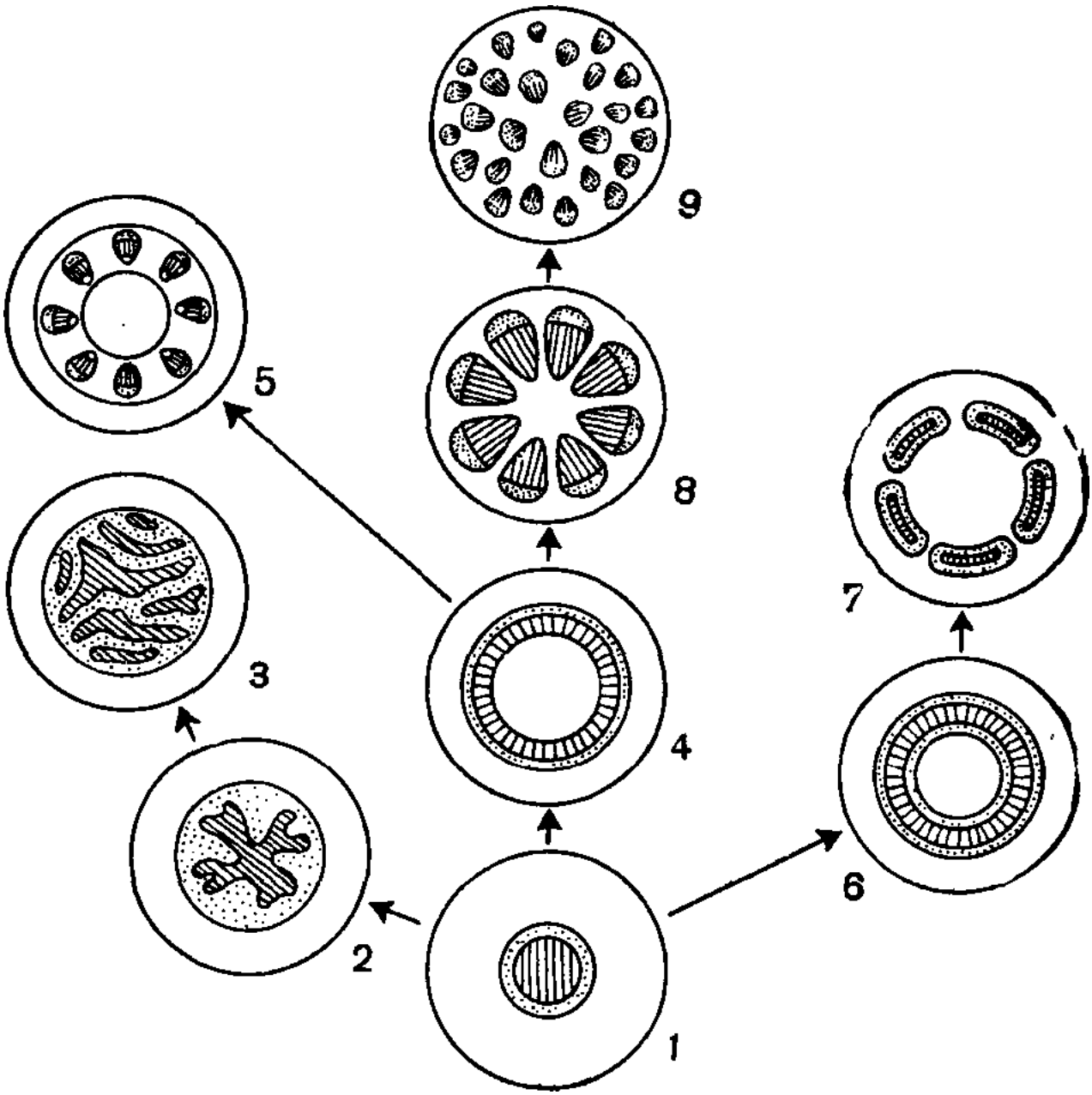


Corn (*Zea mays*) stem (LM ×4)

Steles

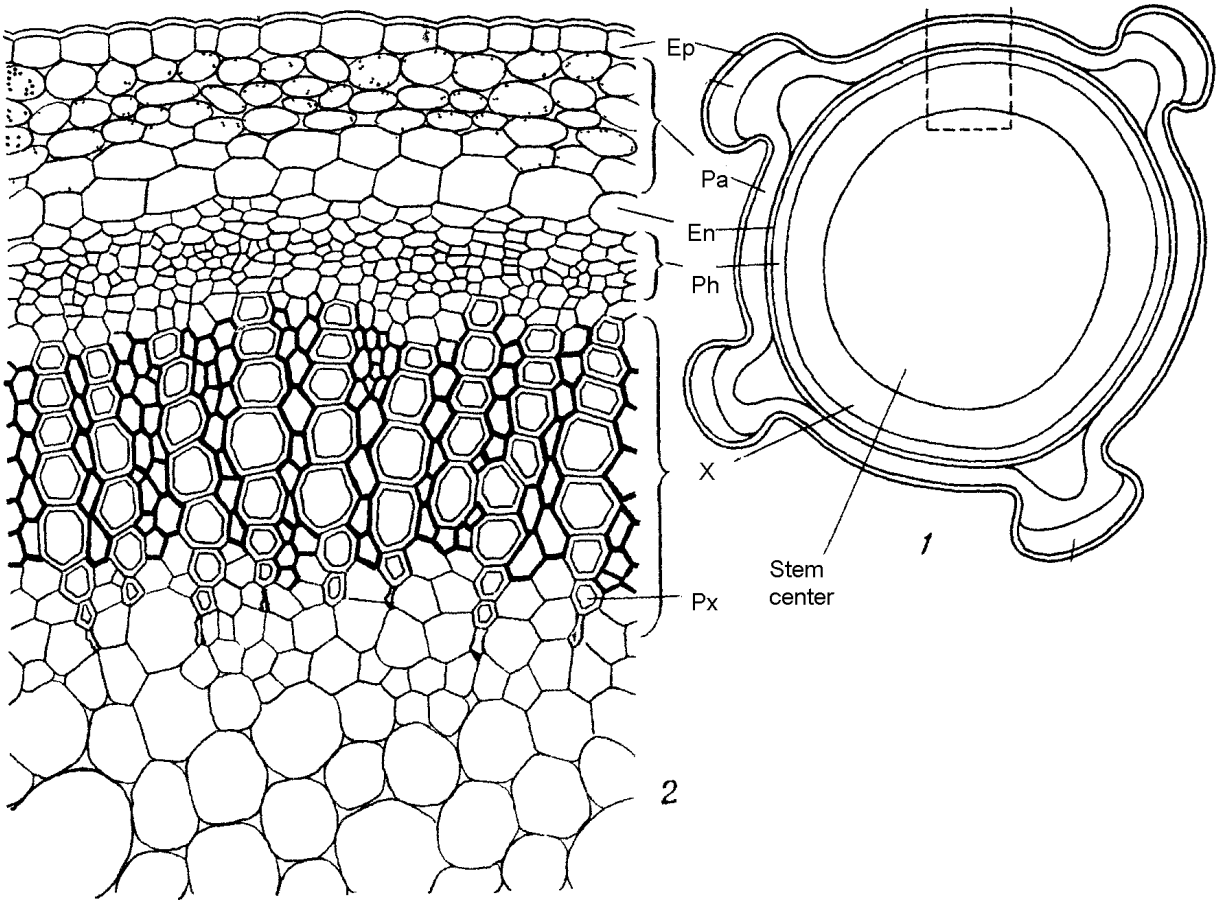
- **Stele** is an overall configuration of primary vascular system of plant stem
- The most important kinds of steles are: **protostele**, **solenostele**, **eustele** and **ataktostele**

Diversity of steles



(1) is protostele, (4) solenostele, (8) eustele ("dicot" stem), (9) ataktostele (monocot stem)

Vascular cylinder: alternative to ring of bundles



Sometimes, vascular bundles are so dense that they form almost a cylinder. We may call this vascular cylinder "solenostele" (#4 on the scheme of steles)

9.5 Components of shoot

Components of vegetative shoot system

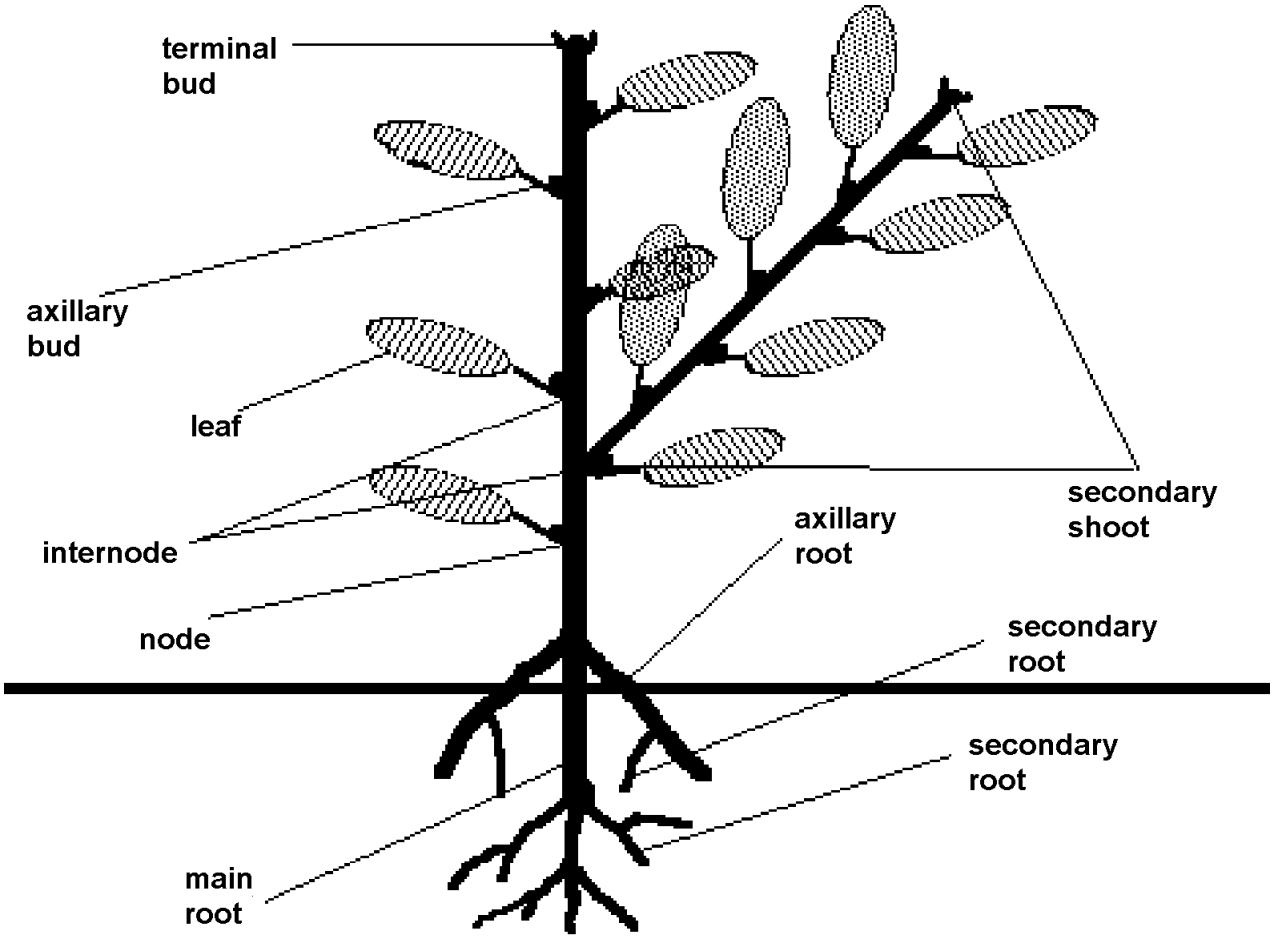
A. Main and secondary shoots

B. Terminal and axillary (lateral) buds

C. Nodes and internodes

D. Leaves

Components of shoot

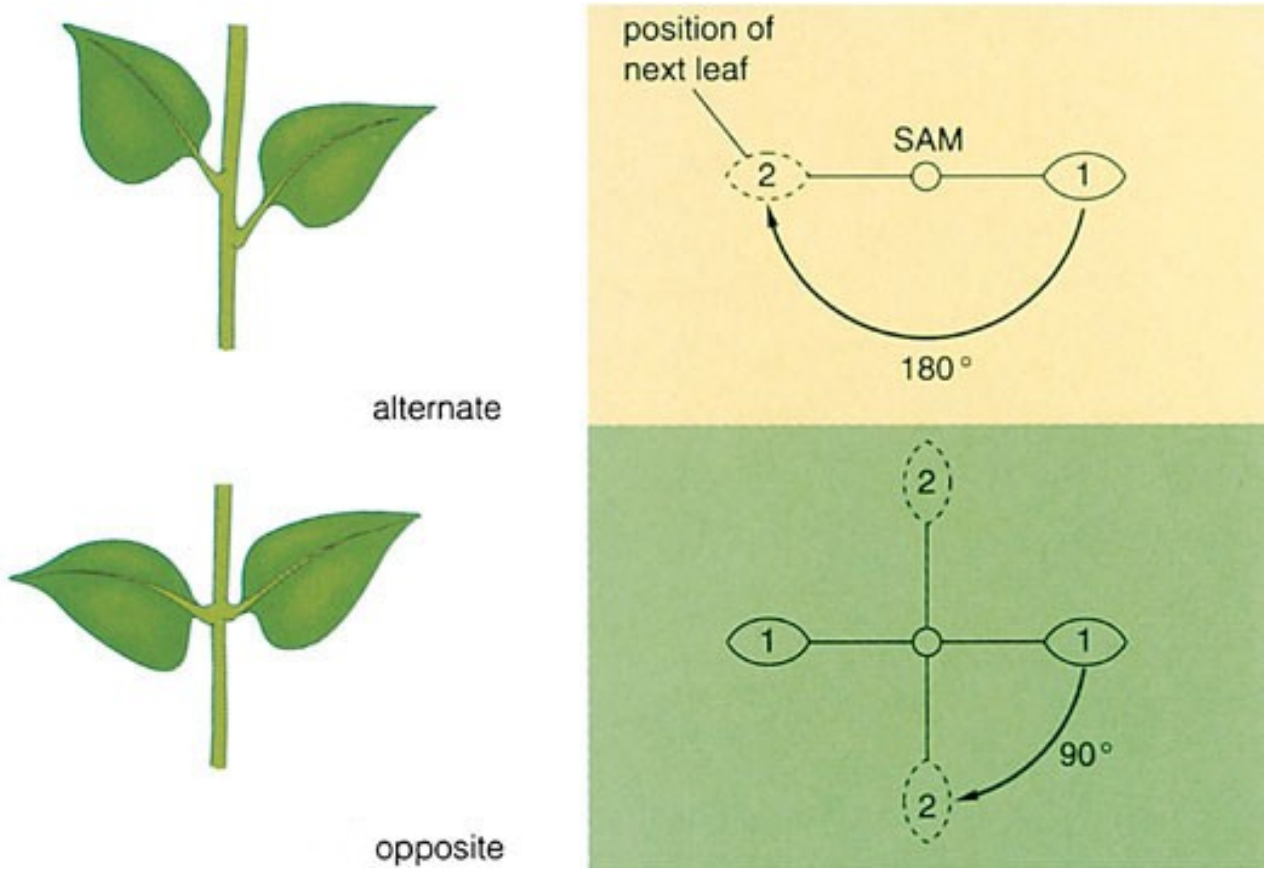


9.6 Phyllotaxis

Arrangement of leaves: phyllotaxis

- One leaf per node: **spiral**, or **alternate** arrangement
- Two leaves per node: **opposite** arrangement, they may be:
  - All in same plane
  - Each pair will rotate on 90°
- >2 leaves per node: **whorled** arrangement (each whorl can also rotates)
- Each type of phyllotaxis has its own *angle of divergence*

Alternate and opposite phyllotaxes



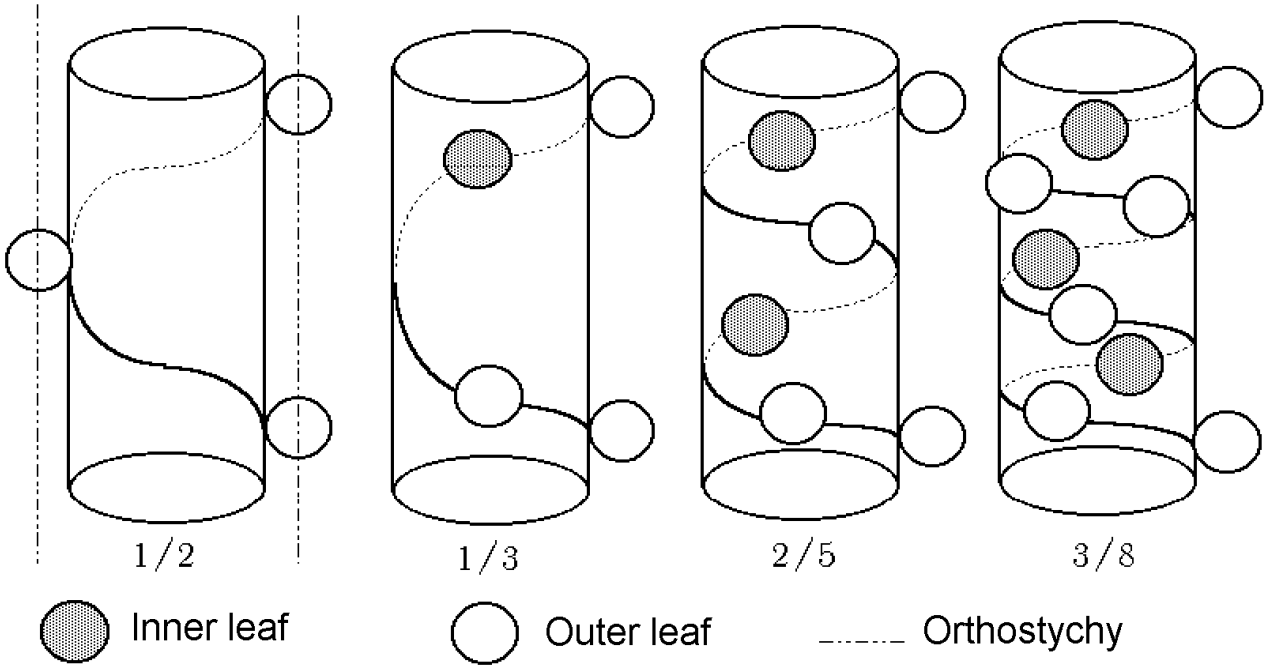
Spiral phyllotaxis: Fibonacci rule

- Multiple types of leaf spiral leaf arrangement mostly follow **Fibonacci rule**
- Formulas of leaf arrangements is very similar to Finobacci fractions: $\frac{1}{2}$, $\frac{1}{3}$, $\frac{2}{5}$, $\frac{3}{8}$, $\frac{5}{13}$, *et cetera*
- Numerator is number of spiral circulations, denominator is number of leaves in a series (counted from zero)
- Denominator gives the number of **orthostychy** (this is plural)

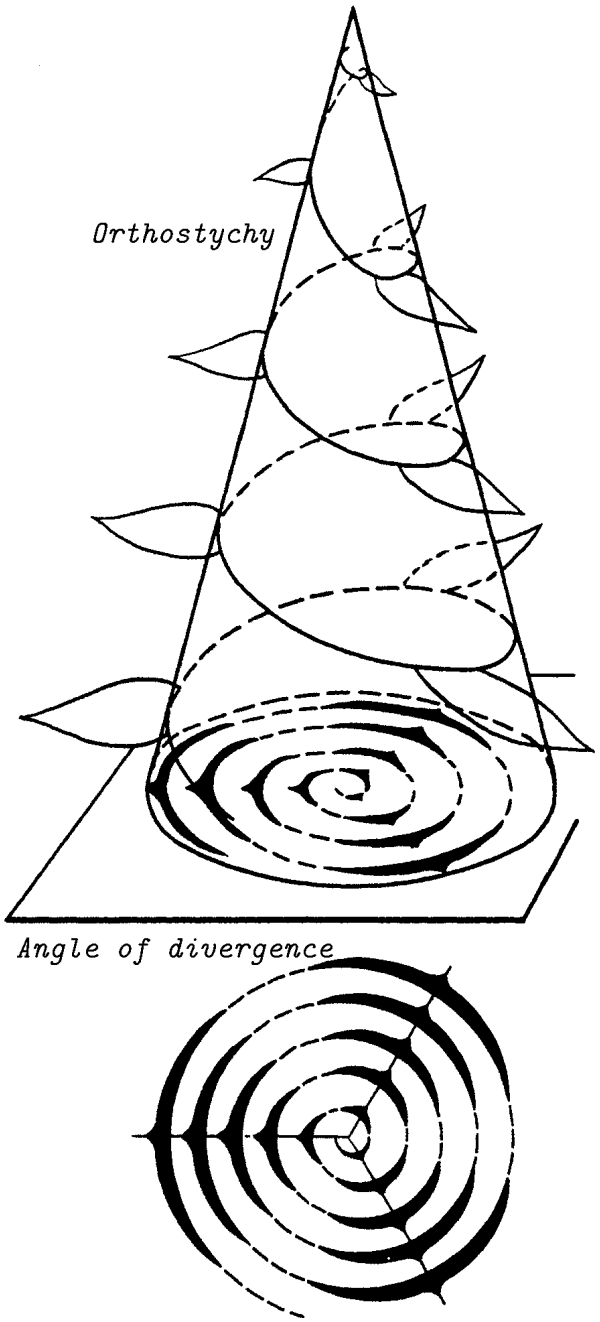
Spiral phyllotaxis: how to make a formula

- Take a branch, find any leaf (it will be leaf #0)
- Find the second one which is located in the same position (exactly above or exactly below leaf #0)
- Count how many leaves are in this series (start from 0), this will be a denominator
- Imagine (or use a real thread) a spiral which go from leaf #0 to the last leaf of series, count how many times this spiral circulate the stem—this is a numerator

Spiral phyllotaxis: orthostychy



Spiral phyllotaxis: angles of divergence for 1/3



Final question (2 points)

What is procambium?

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`

Outline

10 Questions and answers

10.1 Quiz

Quizes

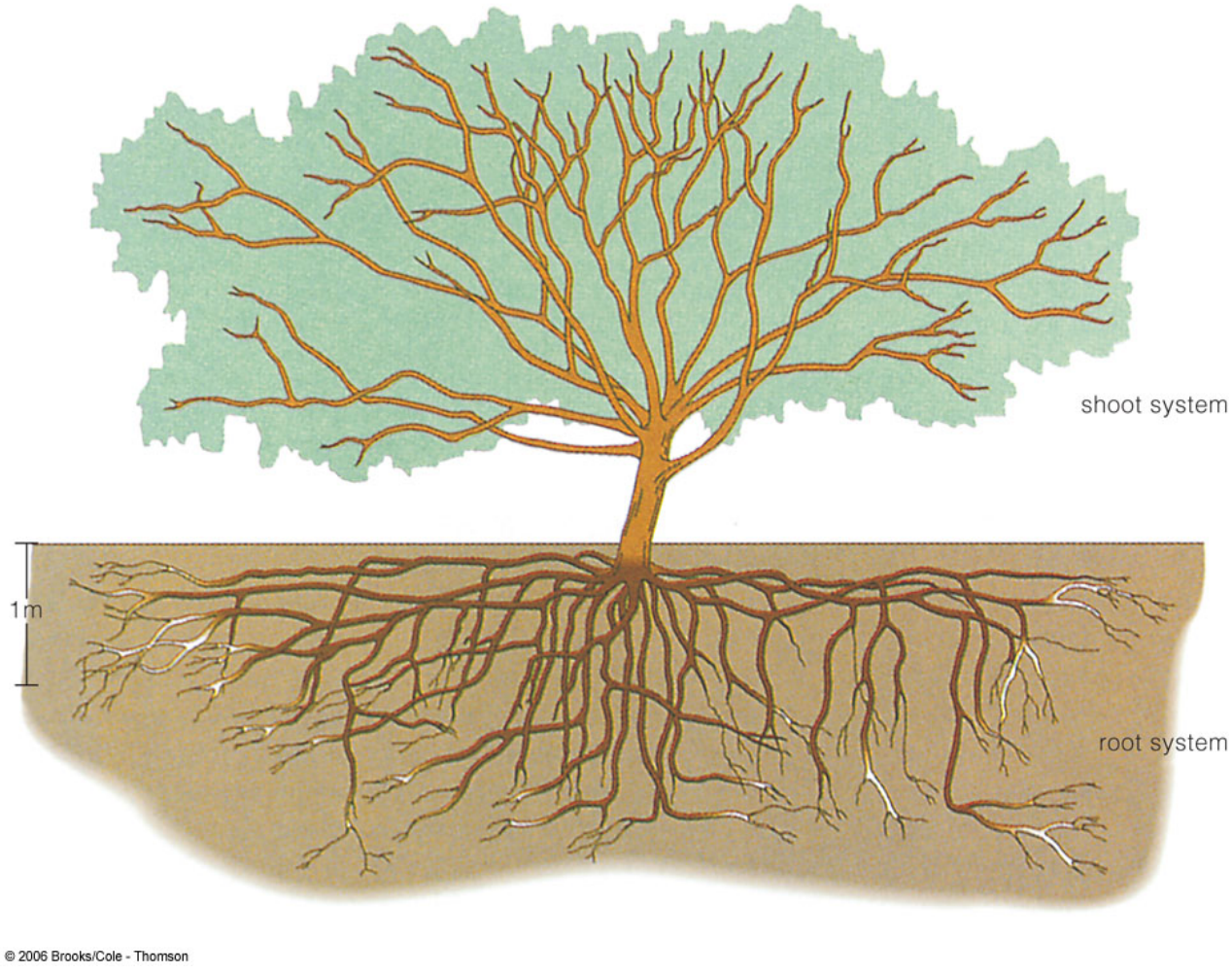
...

- ...

11 Root

11.1 Root morphology

Root system and shoot system



Definition and functions

- Axial vegetative organ with a function of soil nutrition
- Other functions:

    A. Anchor

B. Synthesis
C. Storage
D. Communication

- Features:

A. No leaves
B. Geotropic growth
C. Locates in soil or water

Types of roots

- Primary root: originates from root of seedling
- Secondary (lateral) roots: originate from primary roots
- Adventitious roots: originate from stems

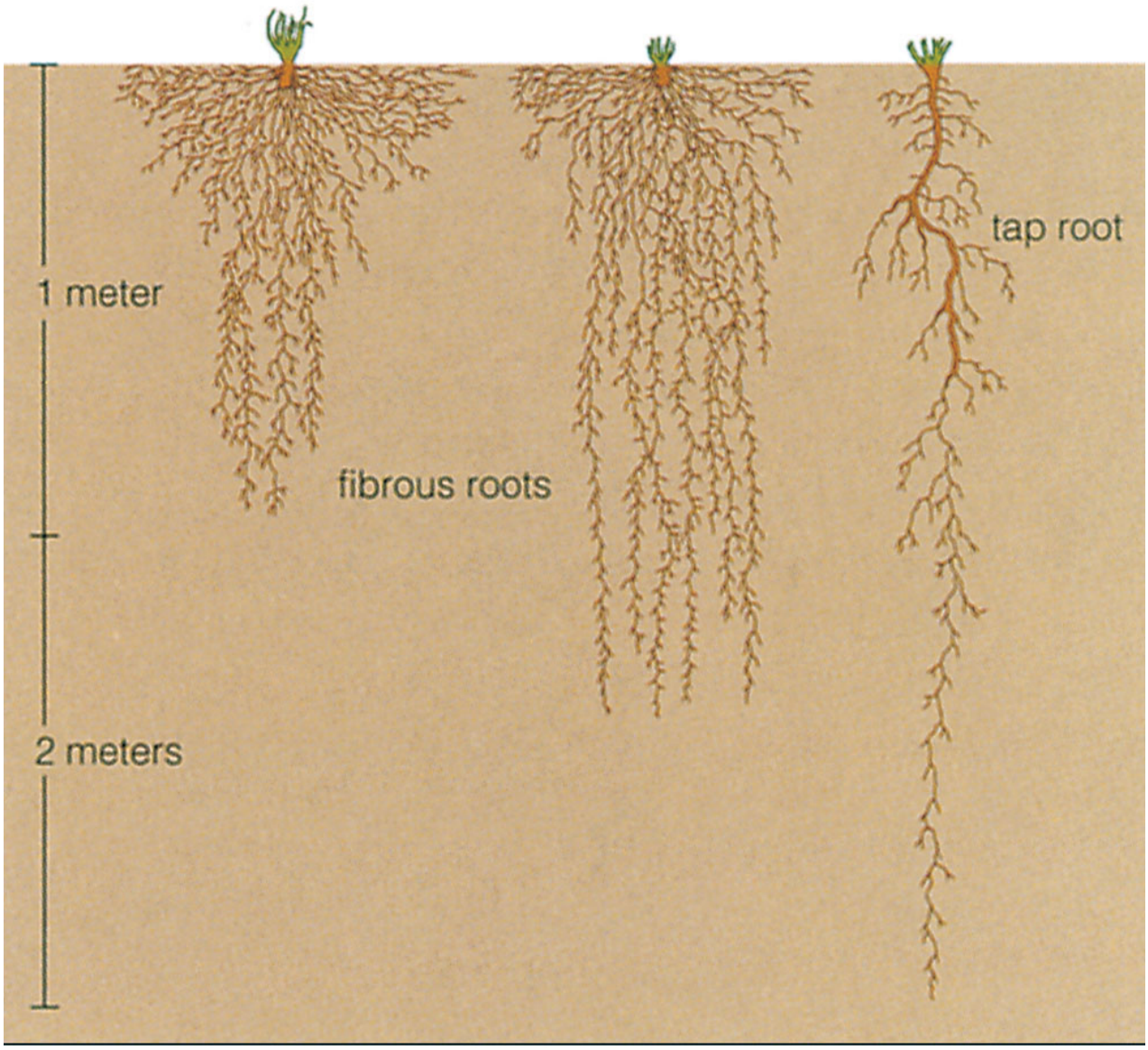
Primary root

Adventitious roots

Root systems

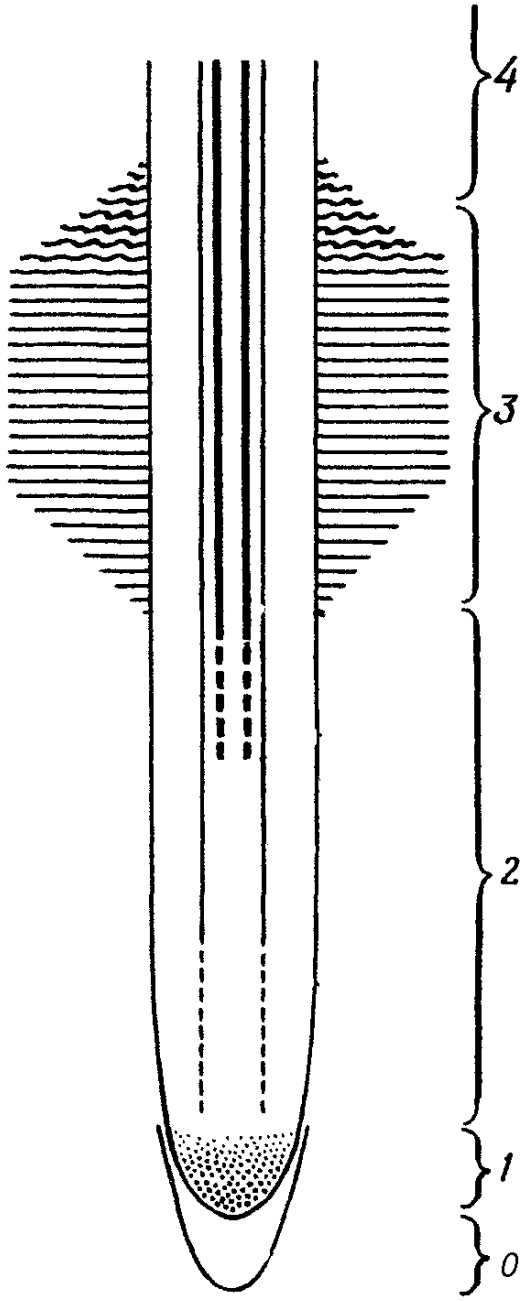
- Tap root system: with well developed primary root (most seed plants)
- Fibrous root system: without clearly visible primary root (monocots, ferns)

Fibrous and tap root systems



11.2 Anatomy and development of roots

Root zones



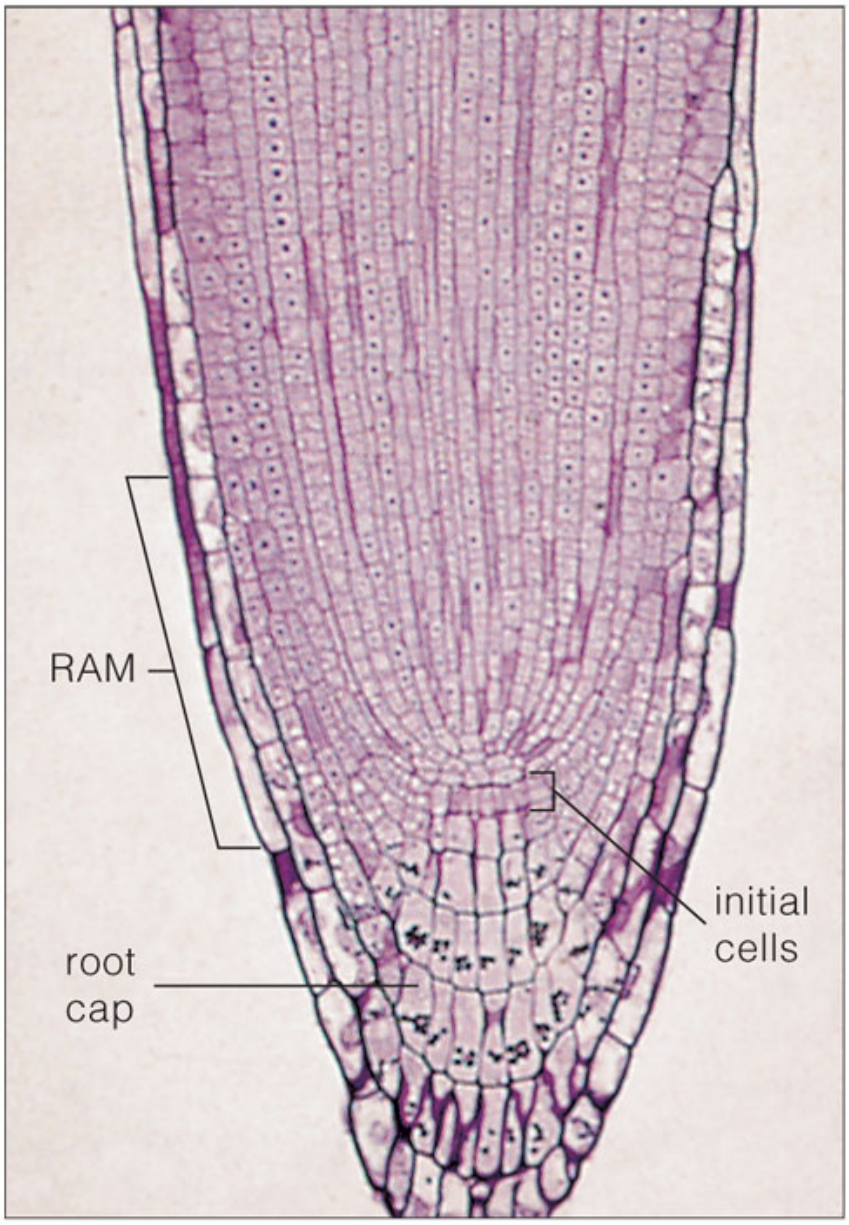
- Root cap
- Root meristem
- Elongation zone
- Absorption zone
- Maturation zone

Structure of root tip

- Initial cells (quiescent center)
- RAM

- Root tip growing both forward (root cap) and backward (other root tissues), initial cells determine the direction of growth
- If root tip touch barrier, it starts to make rotating movements

Root tip



Periphery of root

- Rhizodermis (rhizoderm, root epidermis): fast-degrading cells
- Cortex, which includes also:
  - Endodermis (endoderm): 1-cell layer with specialized cell walls, located on the border with vascular cylinder

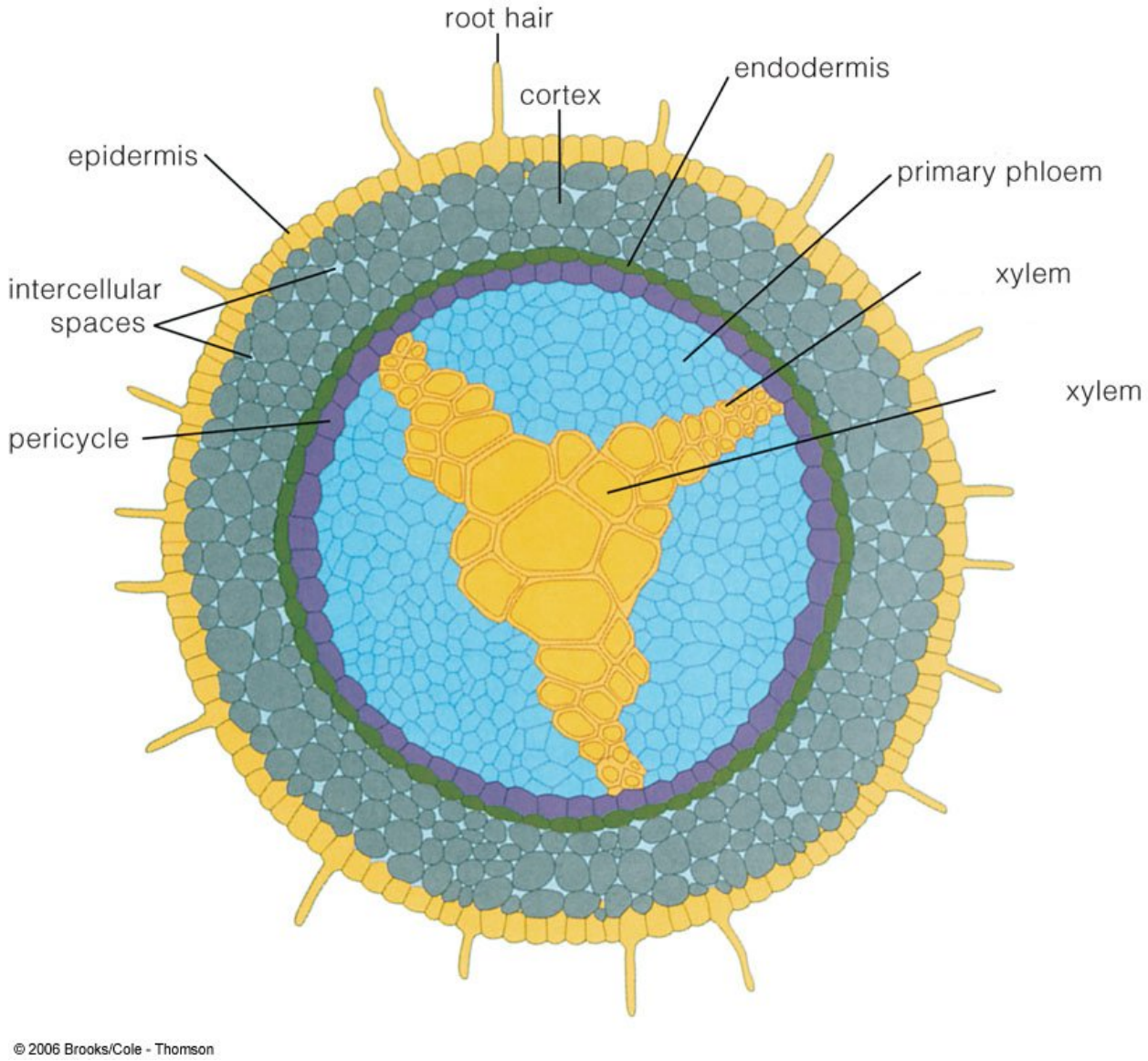
  - And (sometimes) exodermis (exoderm): similar to endoderm but located just under rhizodermis

- In some plants (i.e., orchids), cortex modified into velamen

Root center: vascular cylinder

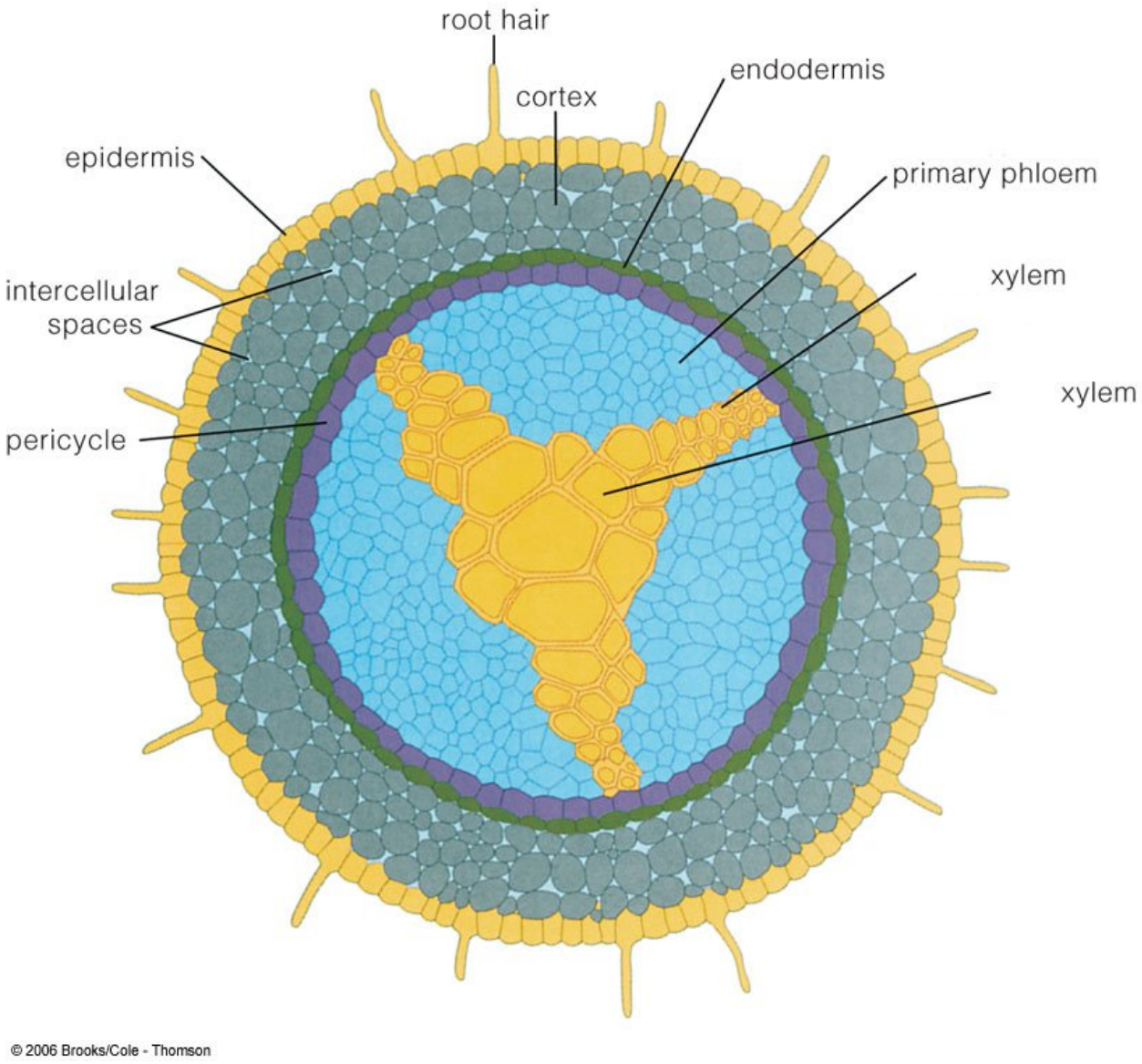
- Pericycle
- Vascular tissues located in the center
- No central hollow, central parenchyma presents in monocot roots

Anatomy of root



11.3 Anatomy and development of roots

Anatomy of root

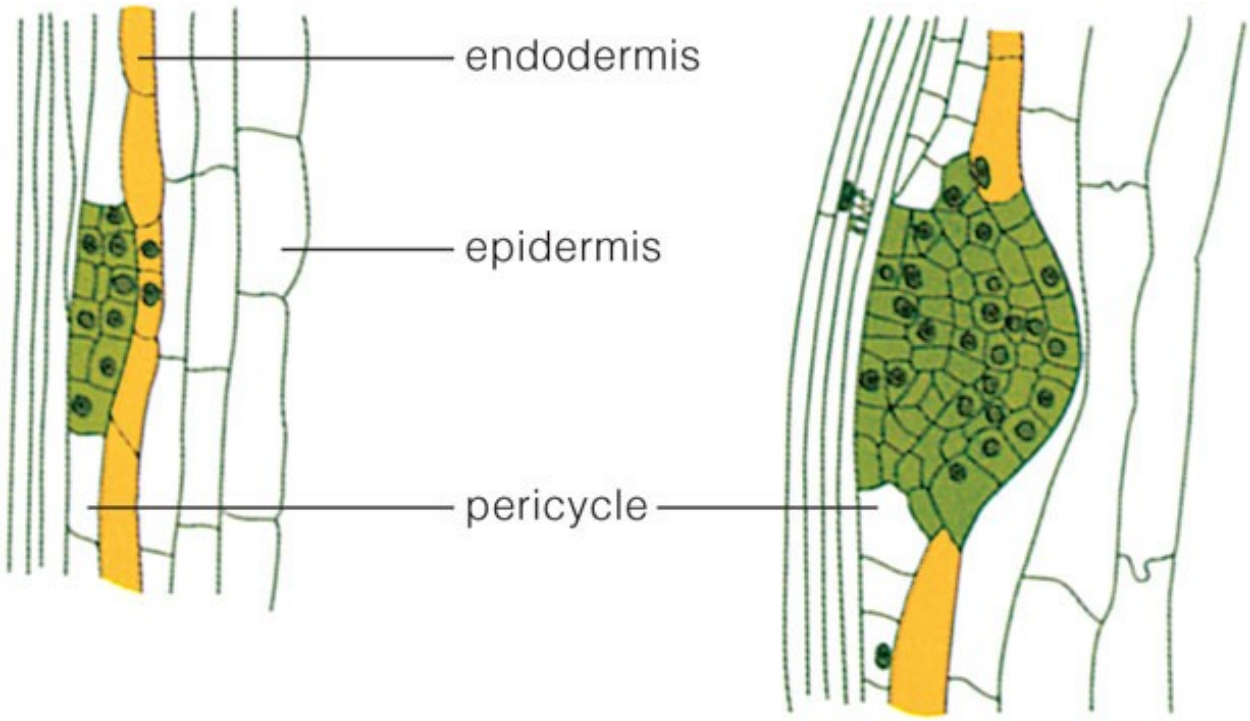


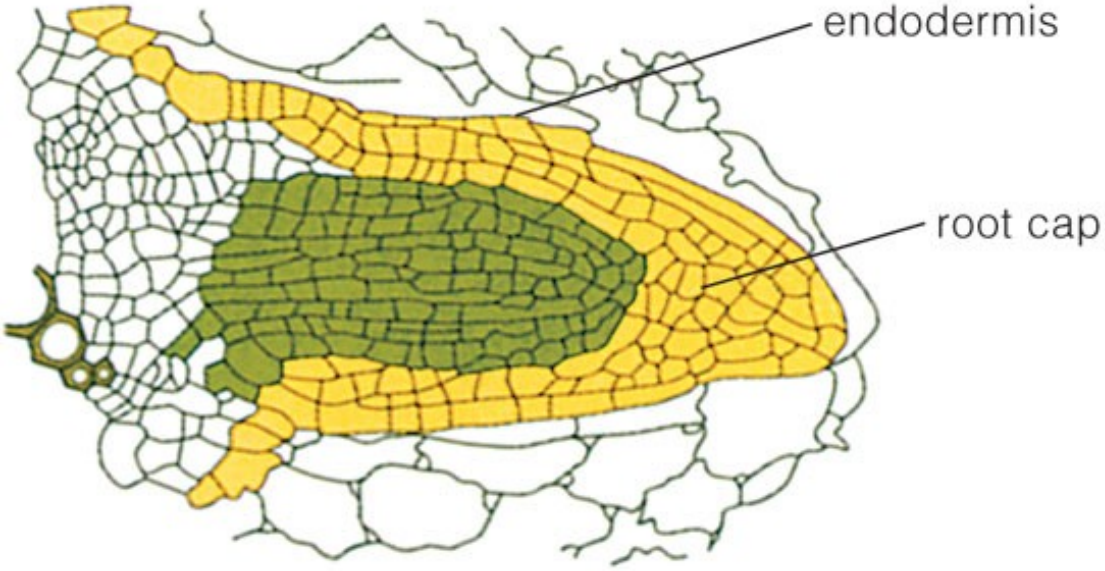
Pericycle

- Long-lived parenchyma cells served as half-meristem
- Initiates development of lateral roots
- Contributes to vascular cambium
- Contributes to cork cambium

Development of lateral roots

Development of lateral roots (step by step)

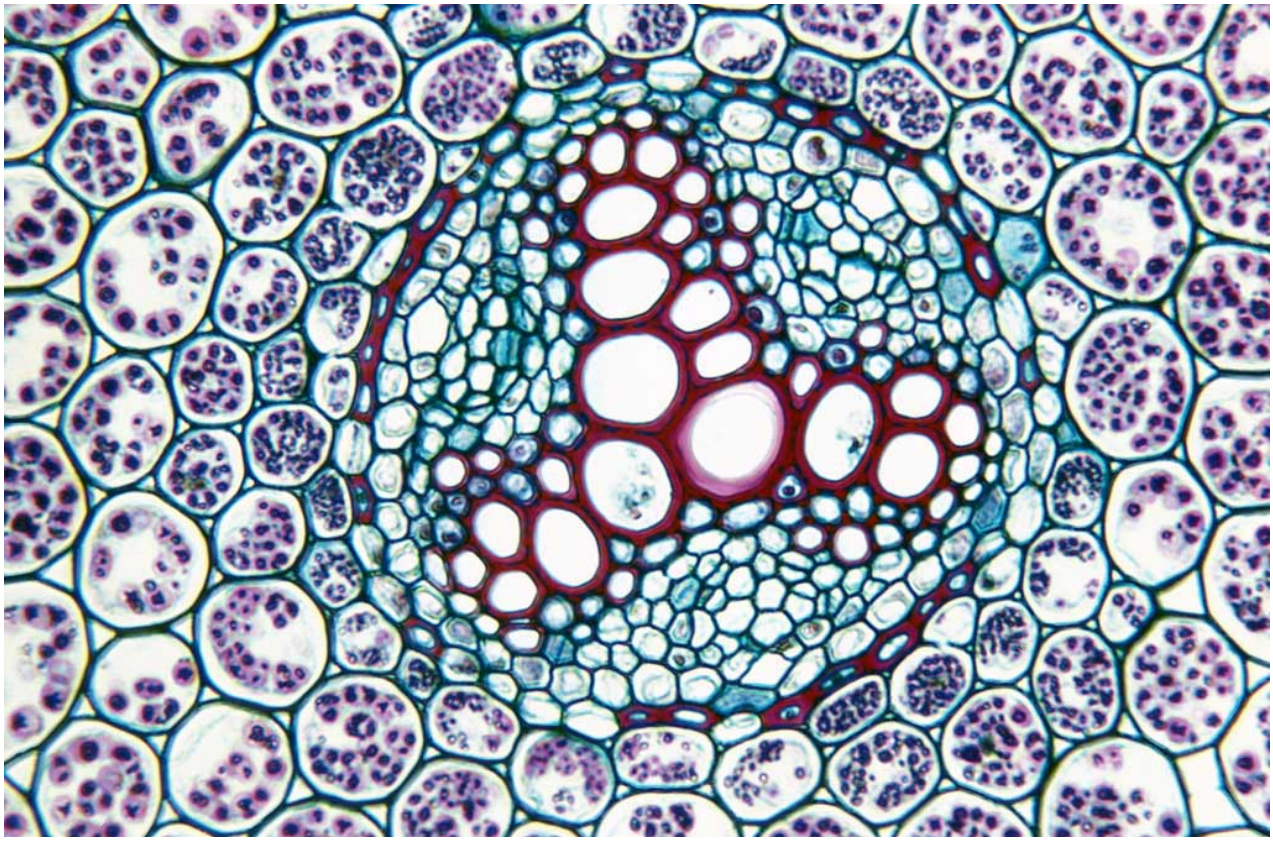




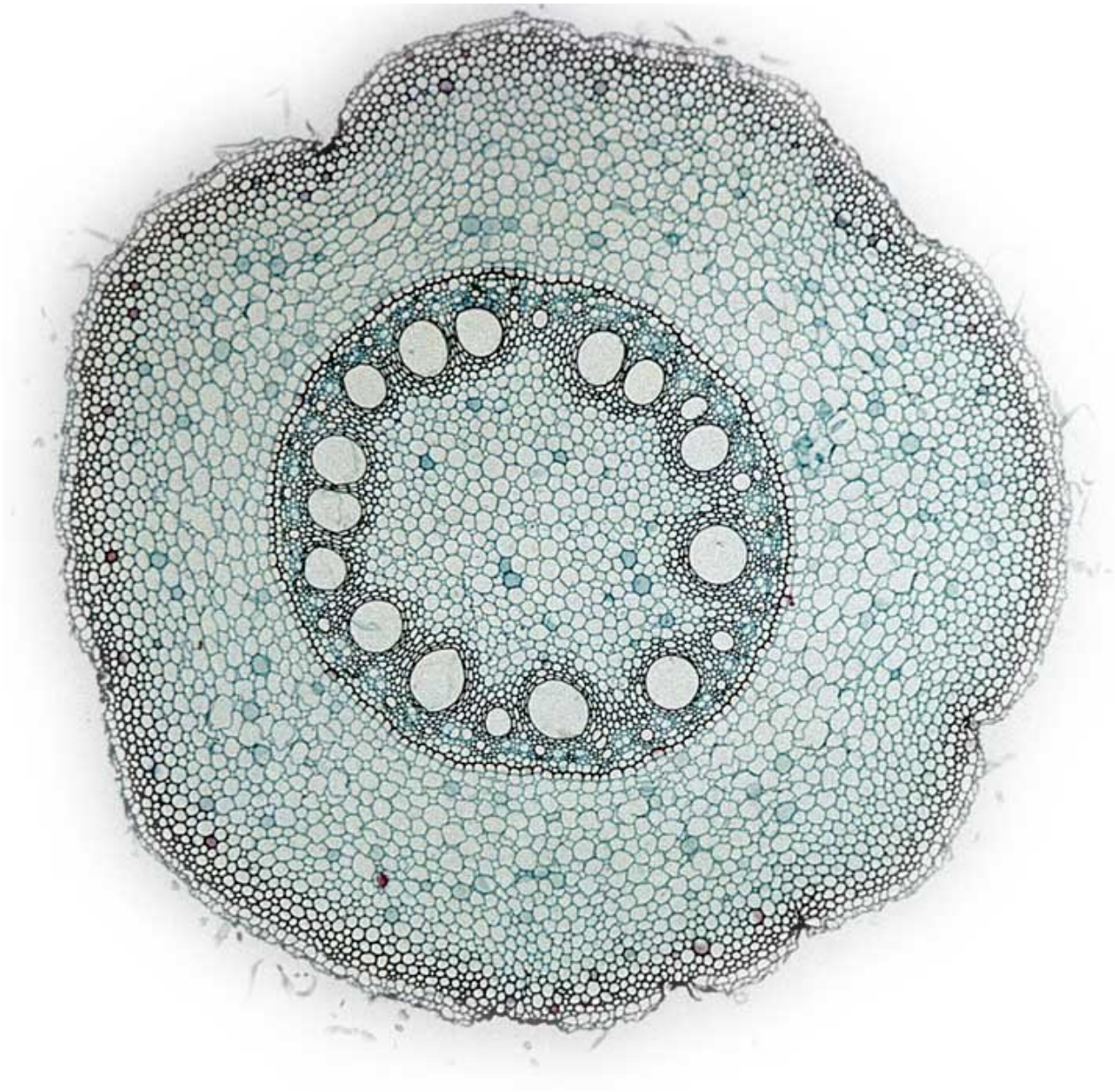
Vascular bundle

- Only one!
- Has radial (star-like) symmetry
- Xylem arranged in rays, multiple in monocots, 2-4 in other plants

Radial structure of root vascular bundle in buttercup (*Ranunculus* sp.)

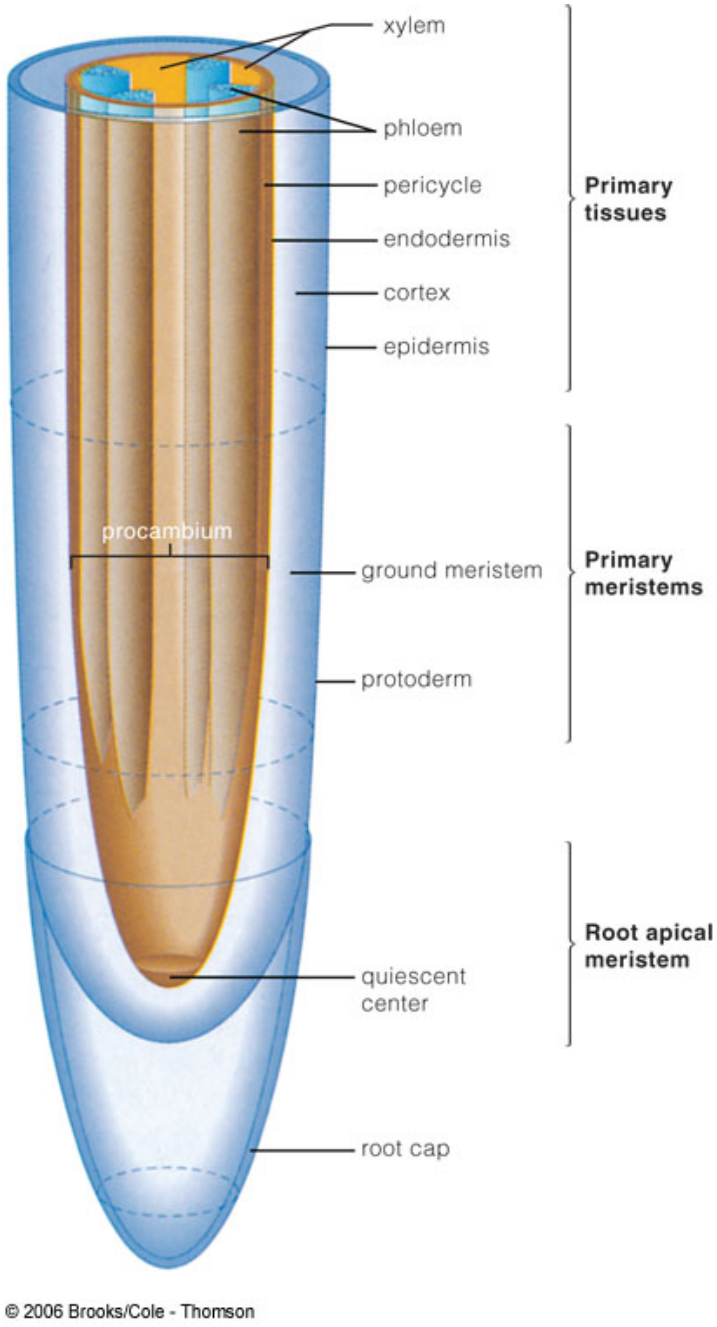


Root of monocot (*Zea mays*



11.4 Origins of root tissues

Development of tissues



In essence, development of tissues in root is analogous to stem.

11.5 Water transport in roots

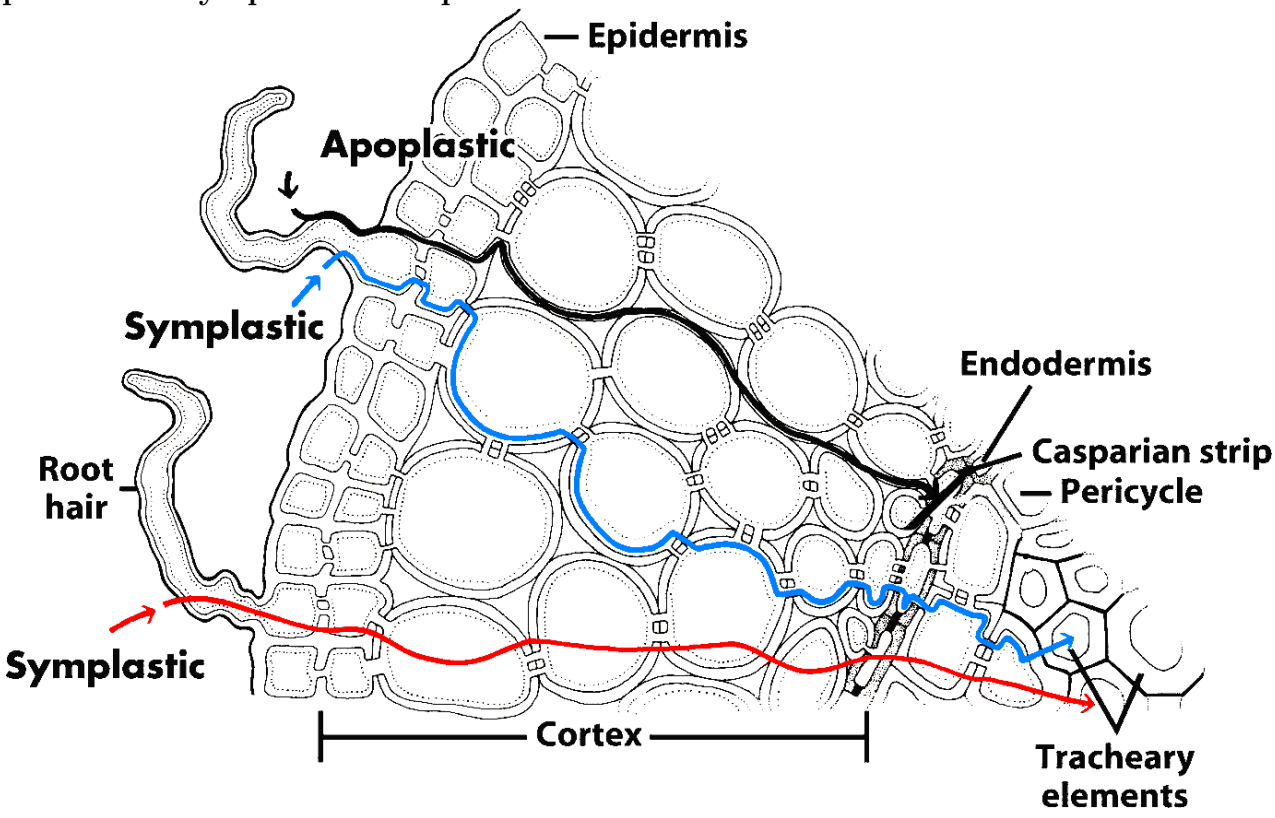
Rhizodermis and osmosis

- The existence of root hairs dramatically increases the surface of absorption
- Every root hair cell increase the internal concentration of large molecules, typically organic acids
- Process of concentration requires ATP
- As a result, osmosis water flow starts from soil to root cells

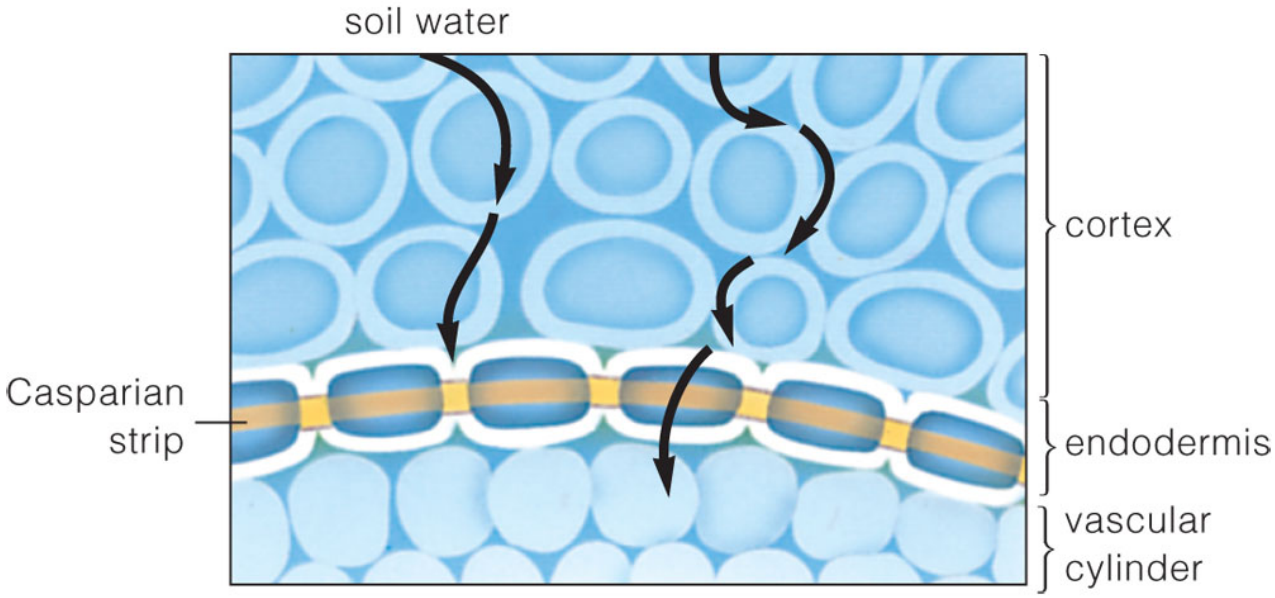
Endodermis and root pressure

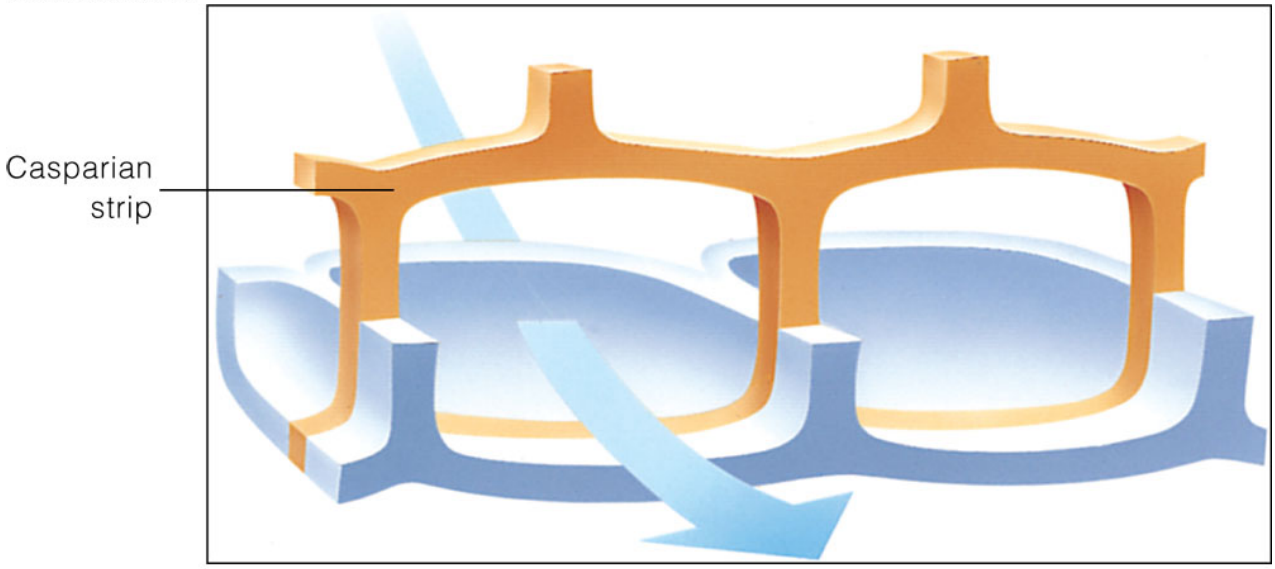
- From rhizodermis to endodermis, transport of water is both symplastic and apoplastic
- In the endodermis cells, Caspari stripes stop apoplastic transport and therefore forced symplastic transport
- This is a high-energetic process requires ATP
- As a result, water will be pushed up from root: this is the root pressure

Apoplastic and symplastic transport in the root

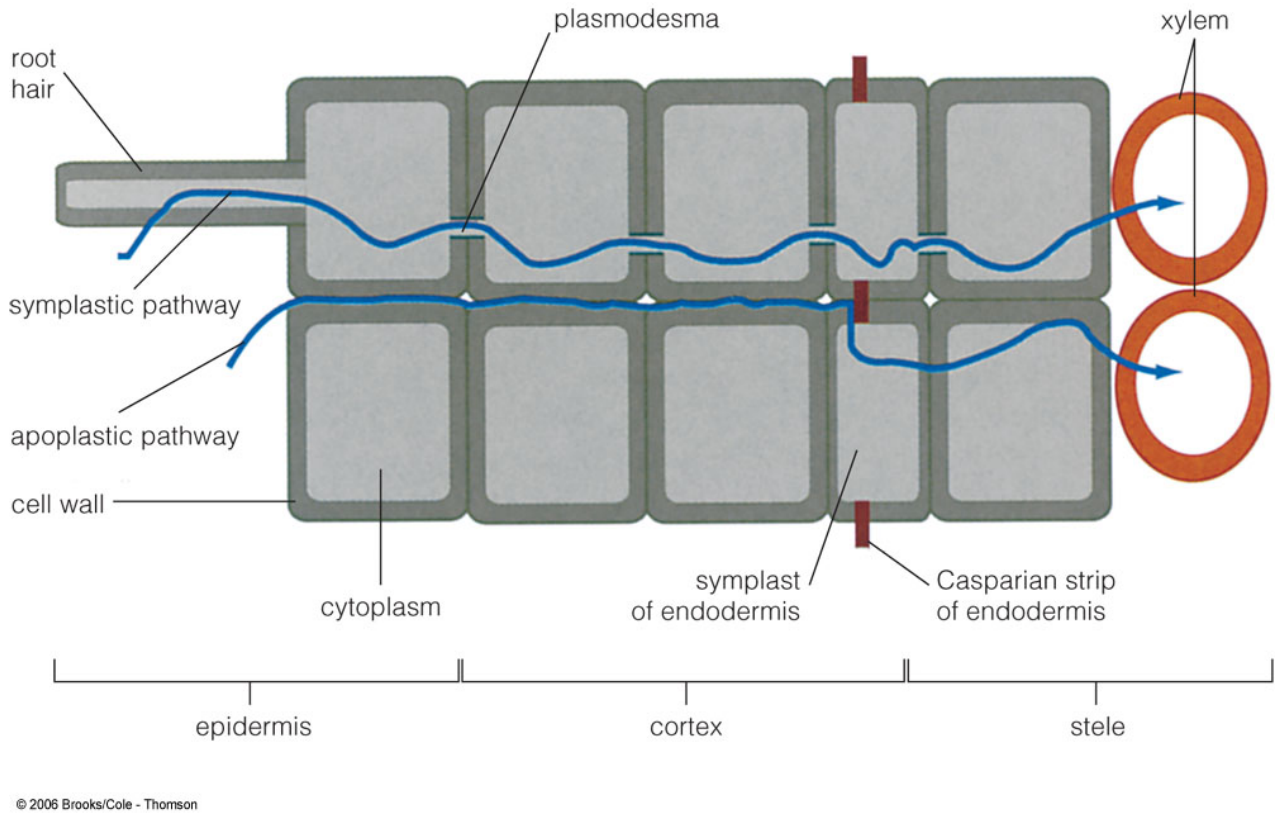


Casparian strips

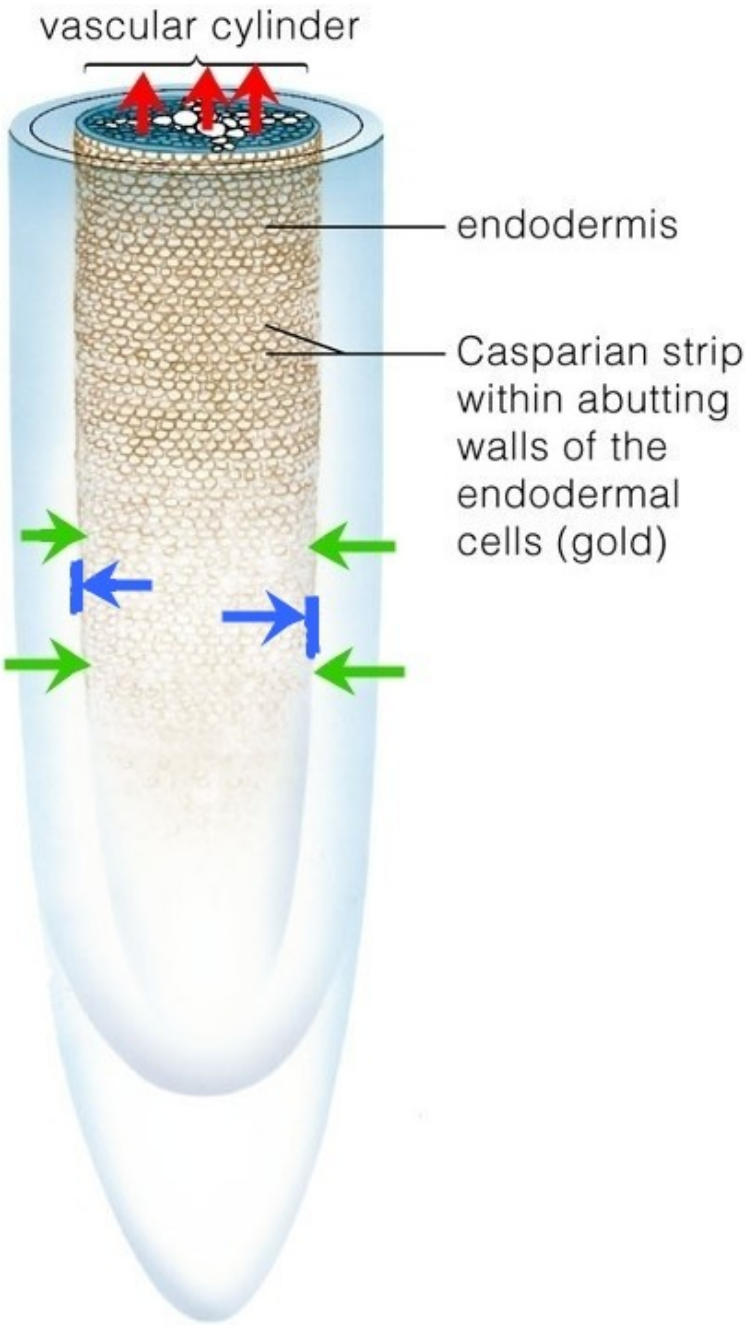




How Casparian strips are working



Origin of root pressure



Water flow in plants

- Plants need water:
  - To supply photosynthesis
  - To cool via transpiration
  - To obtain required minerals
- Water flows because of:
  - Root pressure
  - Capillarity force
  - Transpiration "suction"

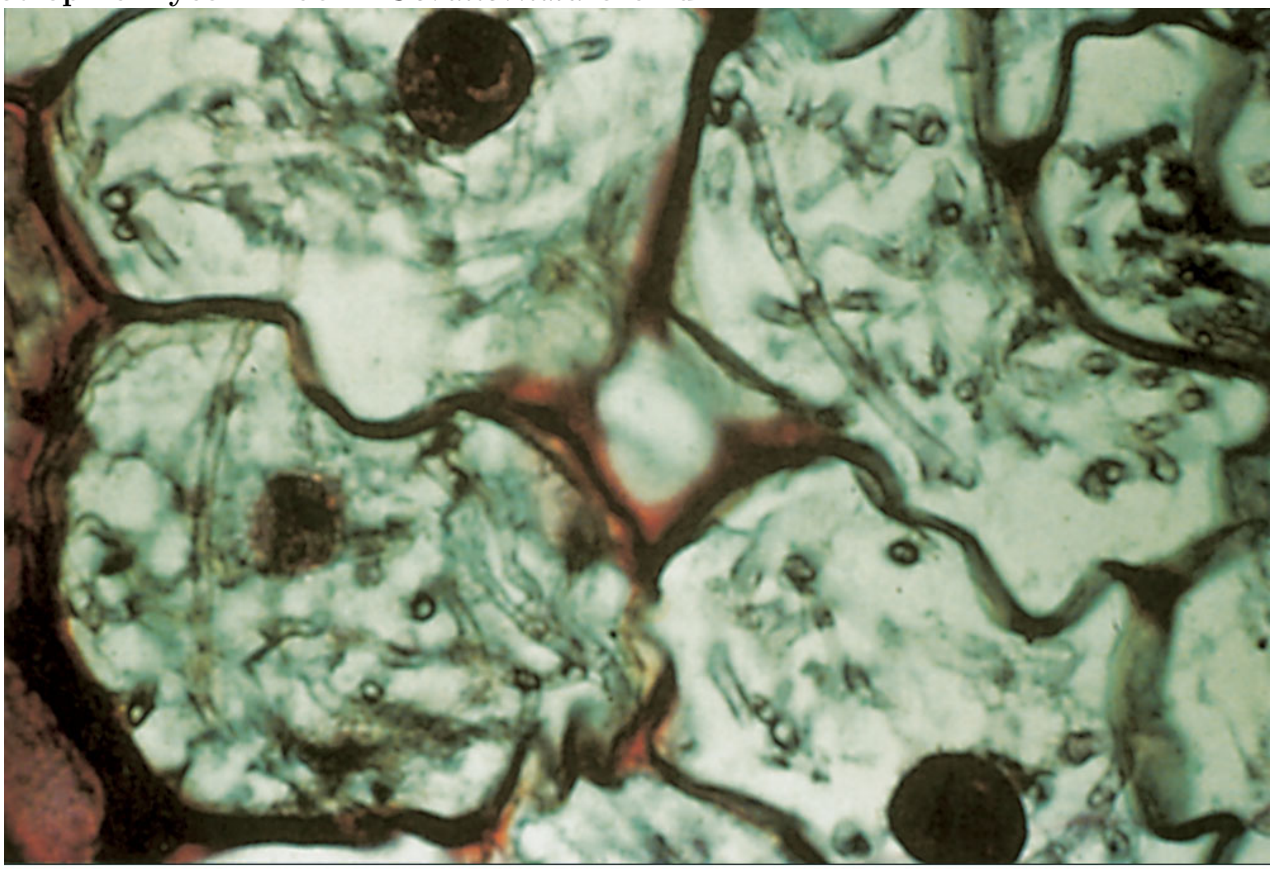
11.6 Diversity of roots

Modifications of roots

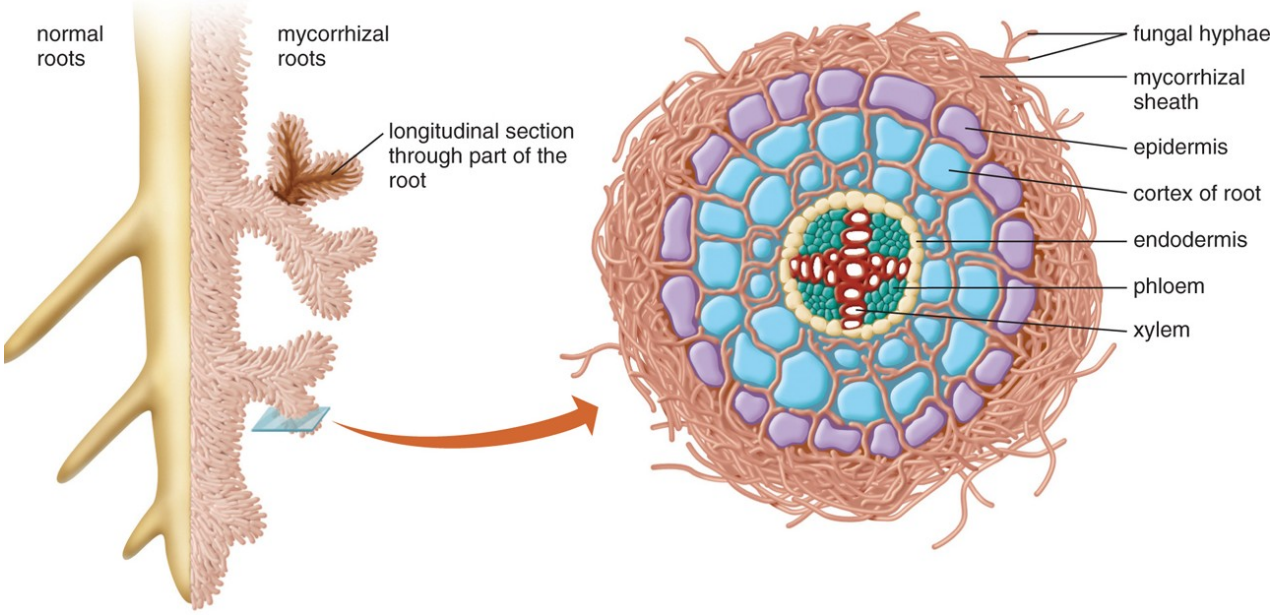
- Adventive buds with root origin (many plants)
- Mycorrhizae: endotrophic (grasses, orchids) and ectotrophic (trees)
- Haustoria (parasites like Cuscuta—dodder plant)
- Root nodules (legumes, Fabaceae family)
- Contractile roots (*Hyacinthus* spp.—hyacynth, *Taraxacum* spp.—dandelion)
- Storage roots (*Daucus carota*—carrot, *Armoracia officinalis*—horseradish)
- Supportive roots (many tropical plants)
- Defensive, spiny roots (ivy)
- Photosynthetic roots (some orchids)

11.7 Diversity of roots

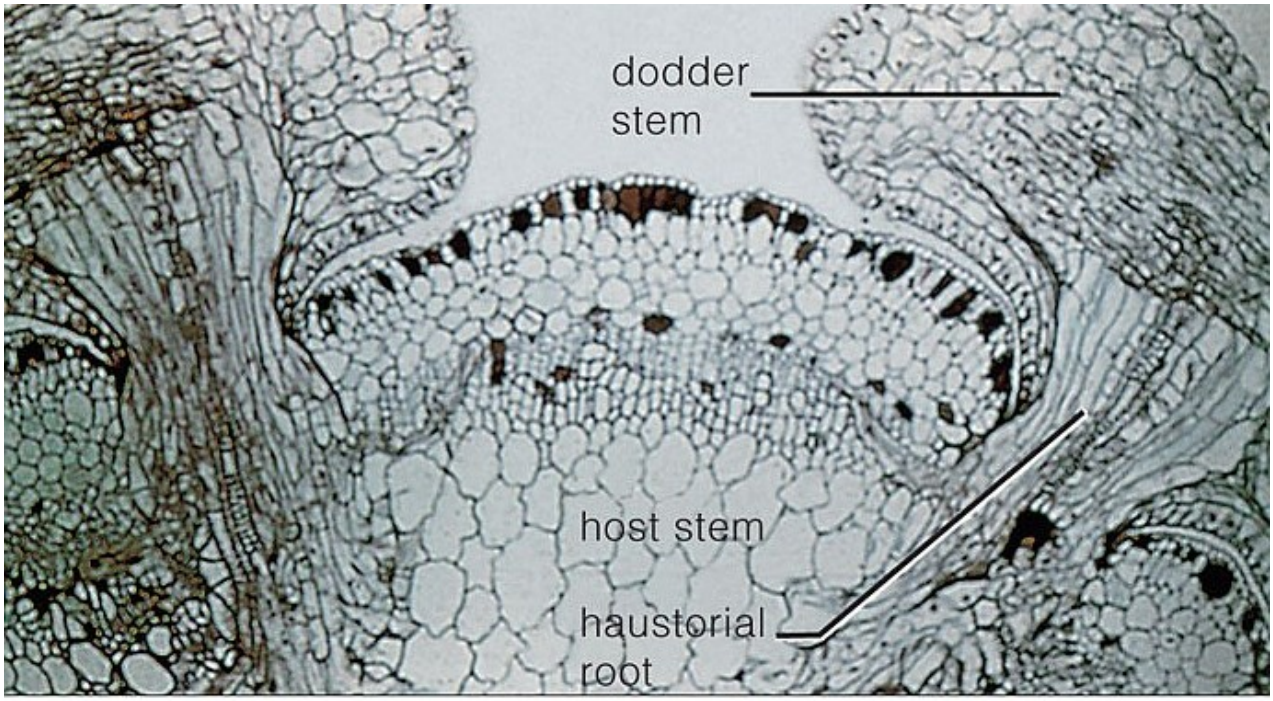
Endotrophic mycorrhizae in *Corallorhiza* orchid



Ectotrophic mycorrhizae of trees



Haustoria of *Cuscuta* (dodder)



Nodulated roots of soybean (*Glycine max*)

Contractile roots of *Hyacinthus orientalis*

Supportive roots of mangrove plants

Supportive roots of *Pandanus* sp.

Defensive spiny roots of ivy (*Hedera* sp.)

Photosynthetic aerial roots of orchids

Table of modifications

Function	Stem	Leaf	Root
Expansion	...	Plantets	Adventive buds
Storage	...	Succulent leaves	Storage roots
Photosynthesis	...	DEFAULT	Some aerial roots
Defense	...	Spines, scale	Root spines
Support	DEFAULT	Leaf tendrils	Aerial and contractile roots
Interactions	...	Traps, “sticky tapes”, urns	Mycorrhizae, haustoria, nodulated roots

Summary

- Vascular tissues of root is a modified protostele or solenostele (in monocots).

- Root hairs, Casparian strips, capillarity and transpiration work together to make water flow in plant.
- Root-related part of water flow is the **root pressure**.
- Roots have not less modifications than leaves.

For Further Reading

References

[1] A. Shipunov. *Introduction to Botany* [Electronic resource]. Mode of access: `http://ashipunov.info/shipunov/school/biol_154`