

Introduction to Botany: BIOL 154

Study guide for Exam 3

Alexey Shipunov

Lectures 18–26

Contents

1	Questions and answers	1
2	Tissues	1
2.1	Origin of tissues	1
2.2	Step four: pipes. Vascular tissues	2
2.2.1	Xylem	2
2.2.2	Phloem	8
3	Movie	16
4	Questions and answers	16
5	Tissues	16
5.1	Secondary cover: periderm	16
5.2	Step five: pumps. Absorption tissues	17
5.3	In addition: secretory tissues	19
6	Leaf	20
6.1	Leaf in general	20
6.2	Leaf morphology	21
7	Questions and answers	27
8	Leaf	27
8.1	Leaf morphology	27
8.2	General characters	32
8.3	Repetitive characters	33
8.4	Terminal characters	35
8.5	Leaves in nature	37
9	Questions and answers	43
10	Leaf	43
10.1	Leaves in nature	43
10.2	Modifications of leaf	45

11 Leaf	55
11.1 Anatomy of leaf	55
12 Questions and answers	57
13 Leaf	57
13.1 Anatomy of leaf	57
13.2 Ecological adaptations of leaves	58
14 Stem and shoot	68
14.1 Plant body	68
15 Questions and answers	69
16 Stem and shoot	70
16.1 Plant body	70
16.2 Anatomy of primary stem	72
17 Questions and answers	76
18 Stem and shoot	77
18.1 Anatomy of the primary stem	77
18.2 Components of shoot	83
18.3 Phyllotaxis	84
19 Root	87
19.1 Root morphology	87
20 Questions and answers	92
21 Root	92
21.1 Root morphology	92
21.2 Anatomy and development of roots	96
21.3 Origins of root tissues	102
21.4 Water transport in roots	102
21.5 Diversity of roots	106

Outline

1 Questions and answers

Previous final question: the answer

What is the difference between collenchyma and sclerenchyma?

- Alive vs. dead
- Primary vs. secondary cell walls

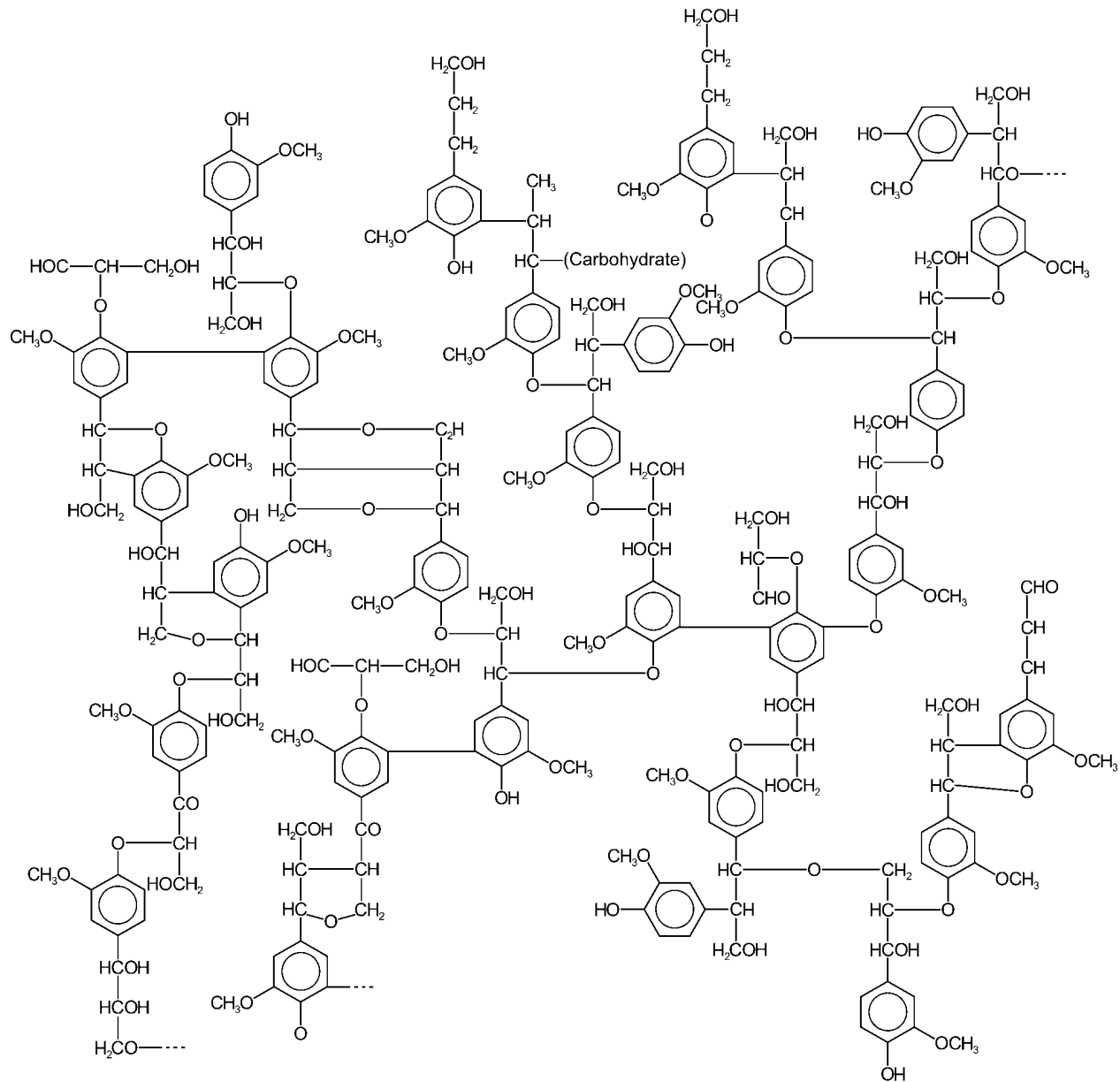
2 Tissues

2.1 Origin of tissues

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

2.2 Step four: pipes. Vascular tissues

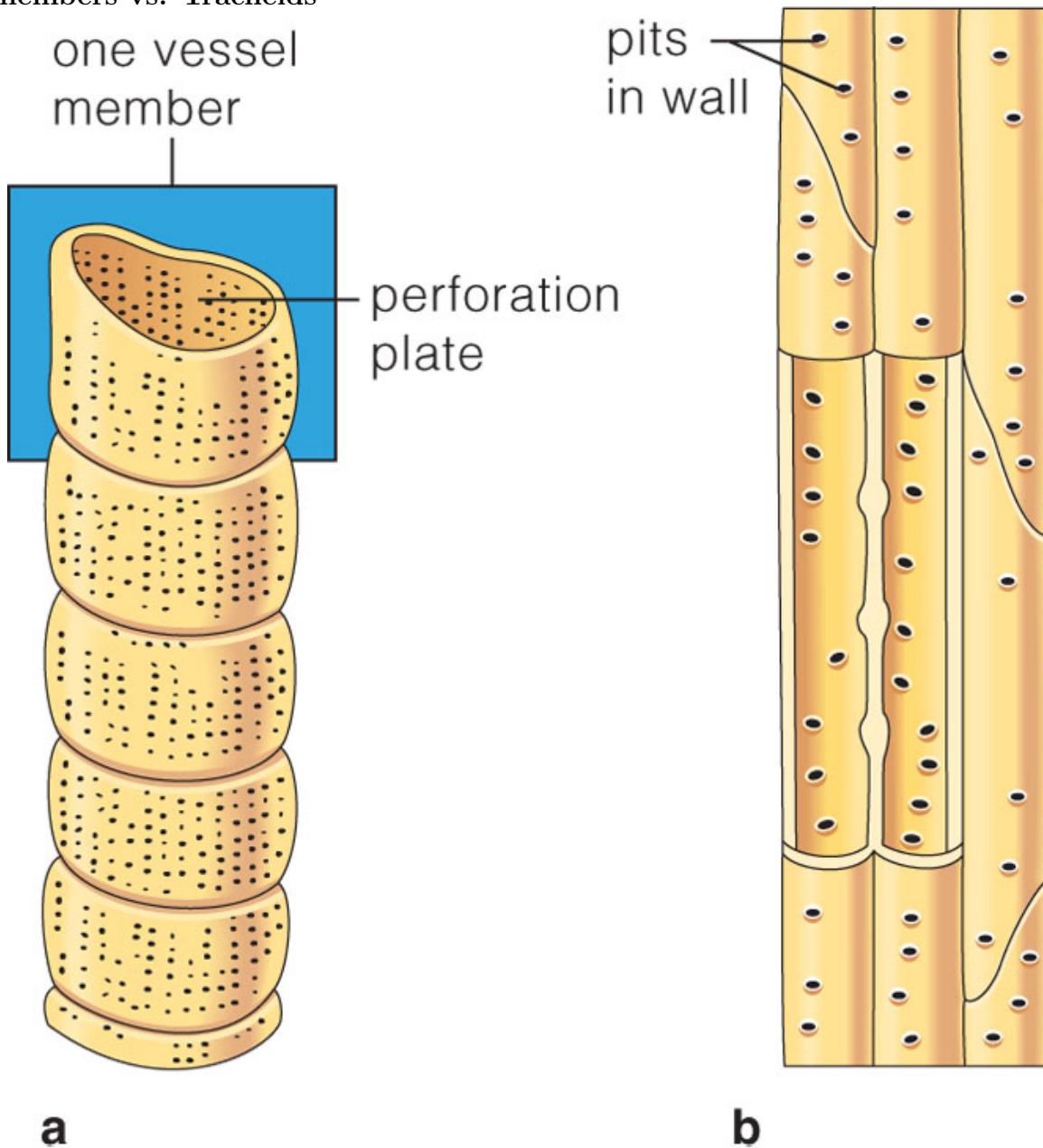
2.2.1 Xylem

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

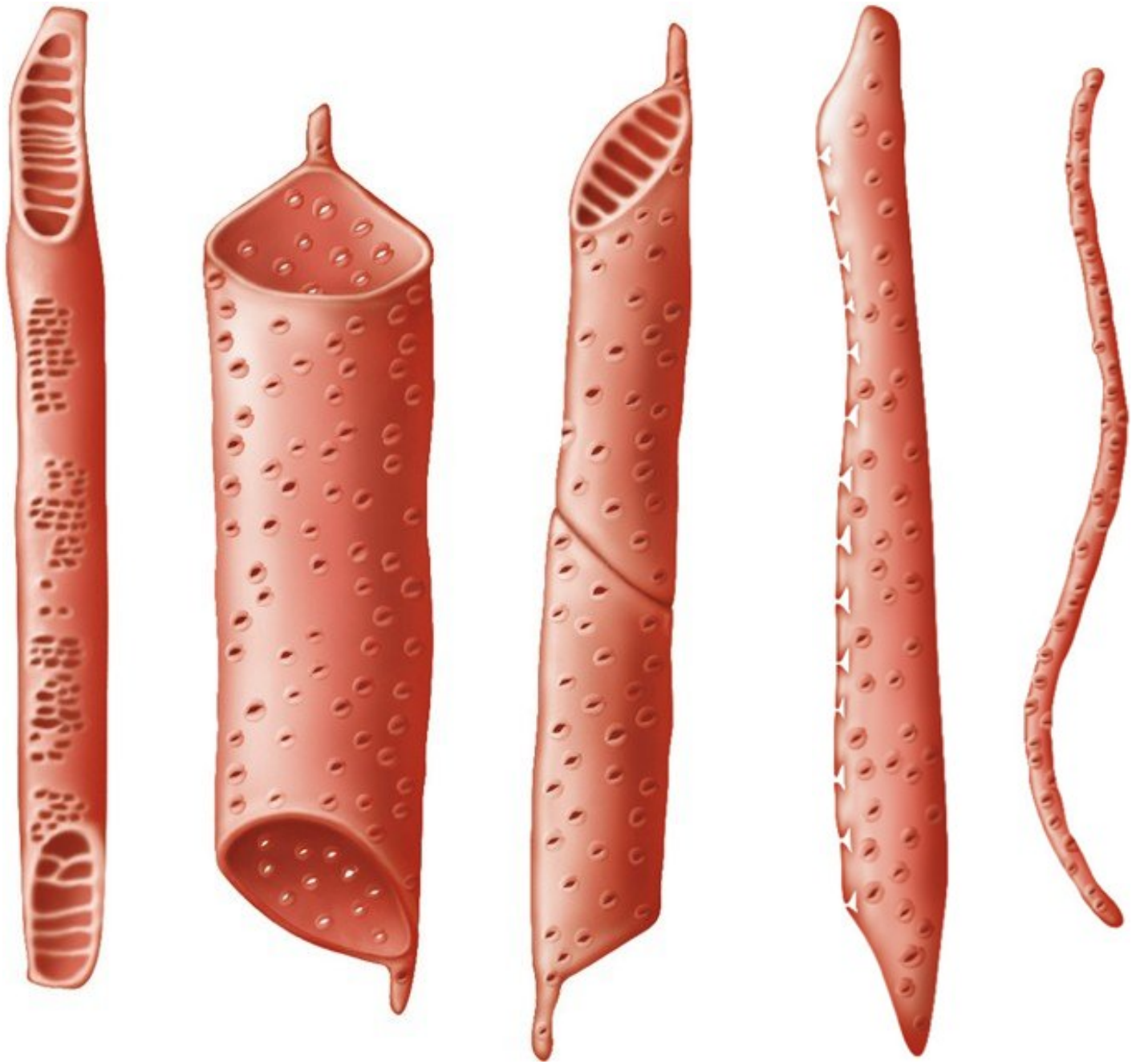
- Xylem elements (except parenchyma) are rich of lignin and are main components of wood
- Main functions: water transport and mechanical support

Vessel members vs. Tracheids

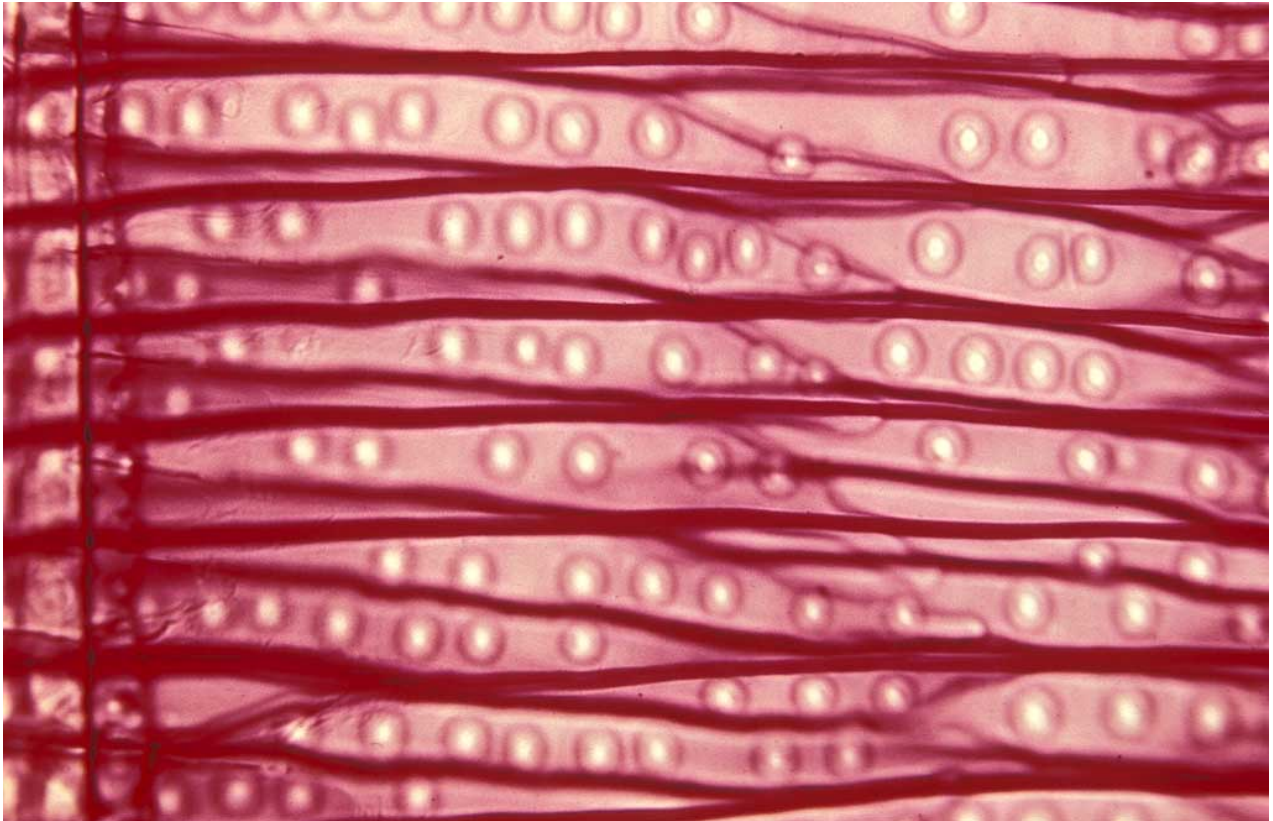


© 2006 Brooks/Cole - Thomson

Vessel members vs. Tracheids

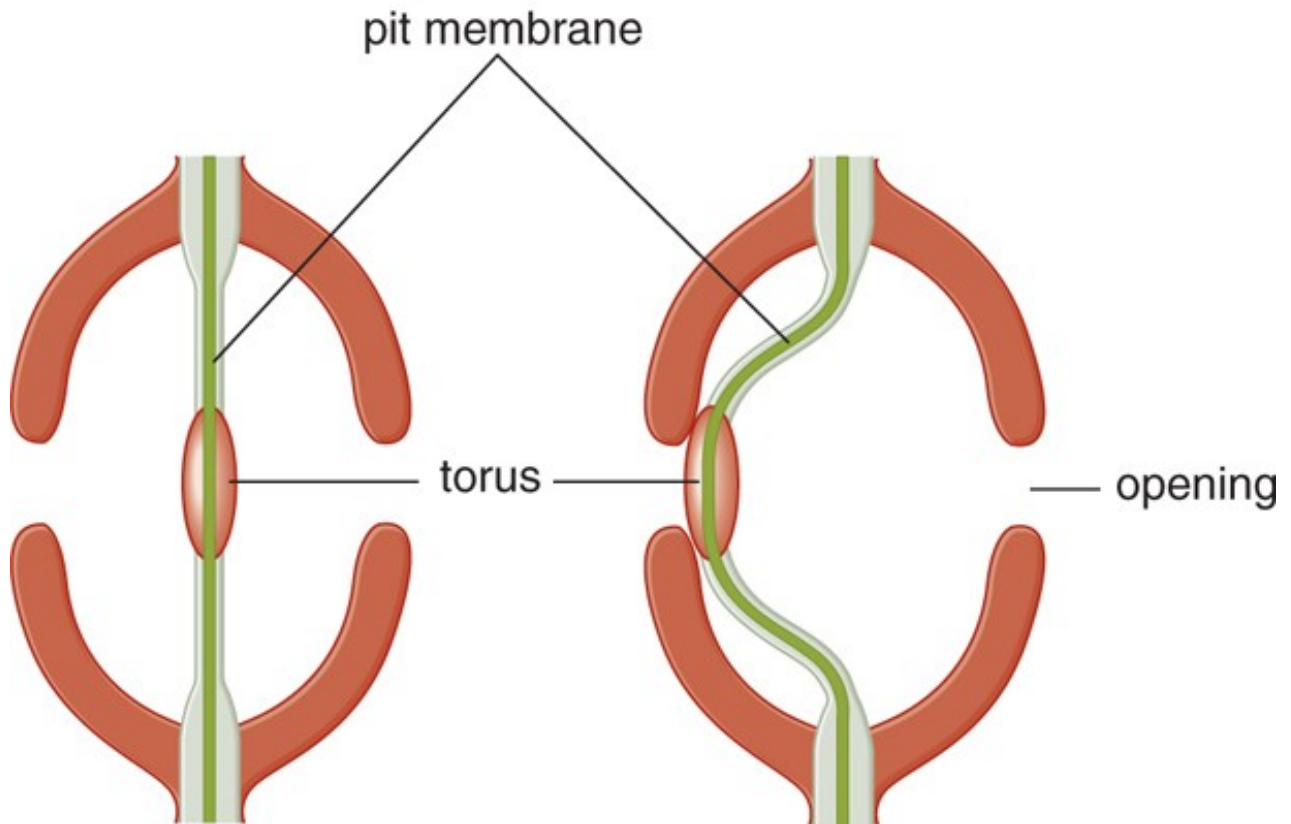


Tracheids



Pine (*Pinus* sp.) tracheids with pits

Pit is NOT a direct connection

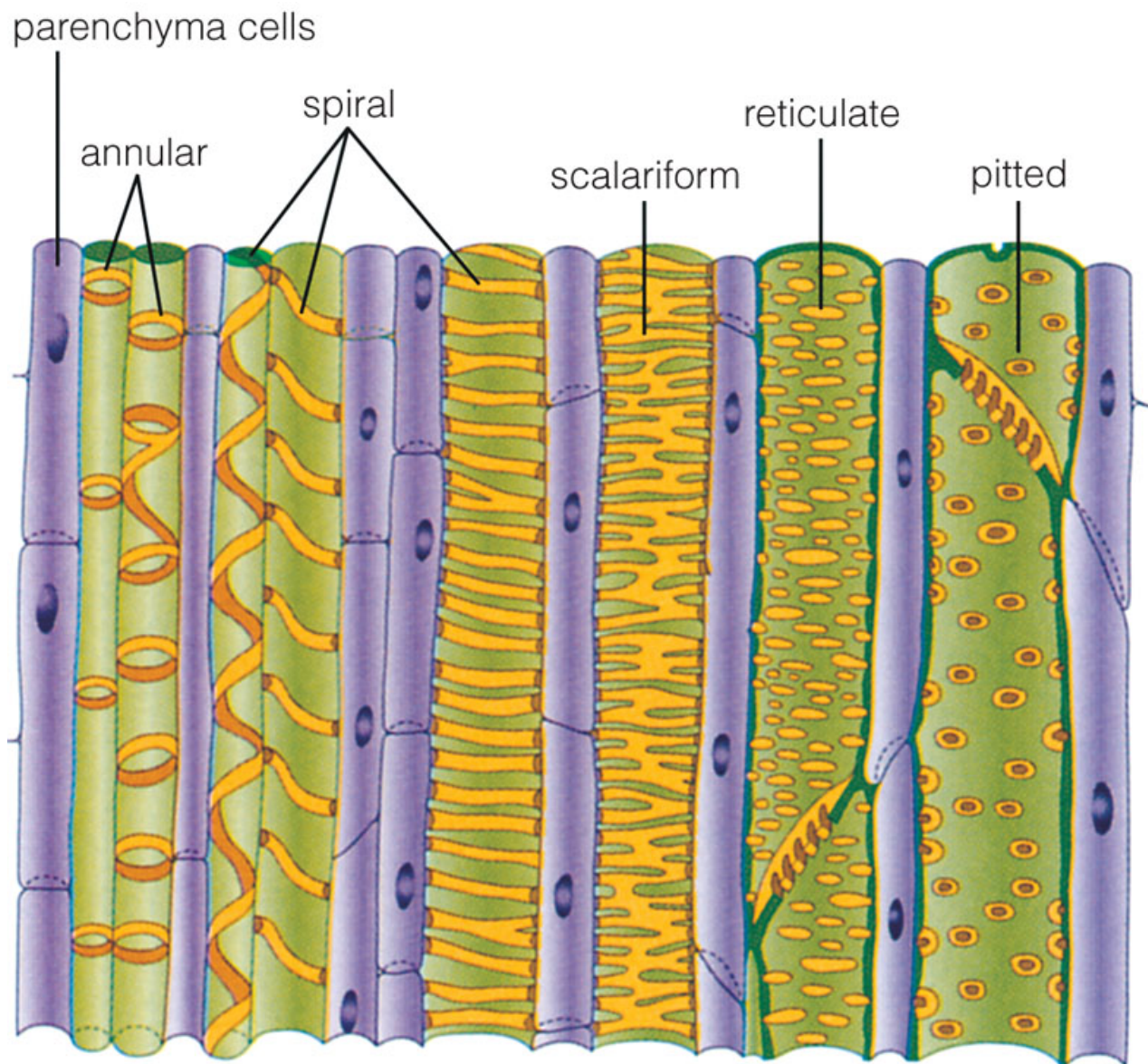


Vessels



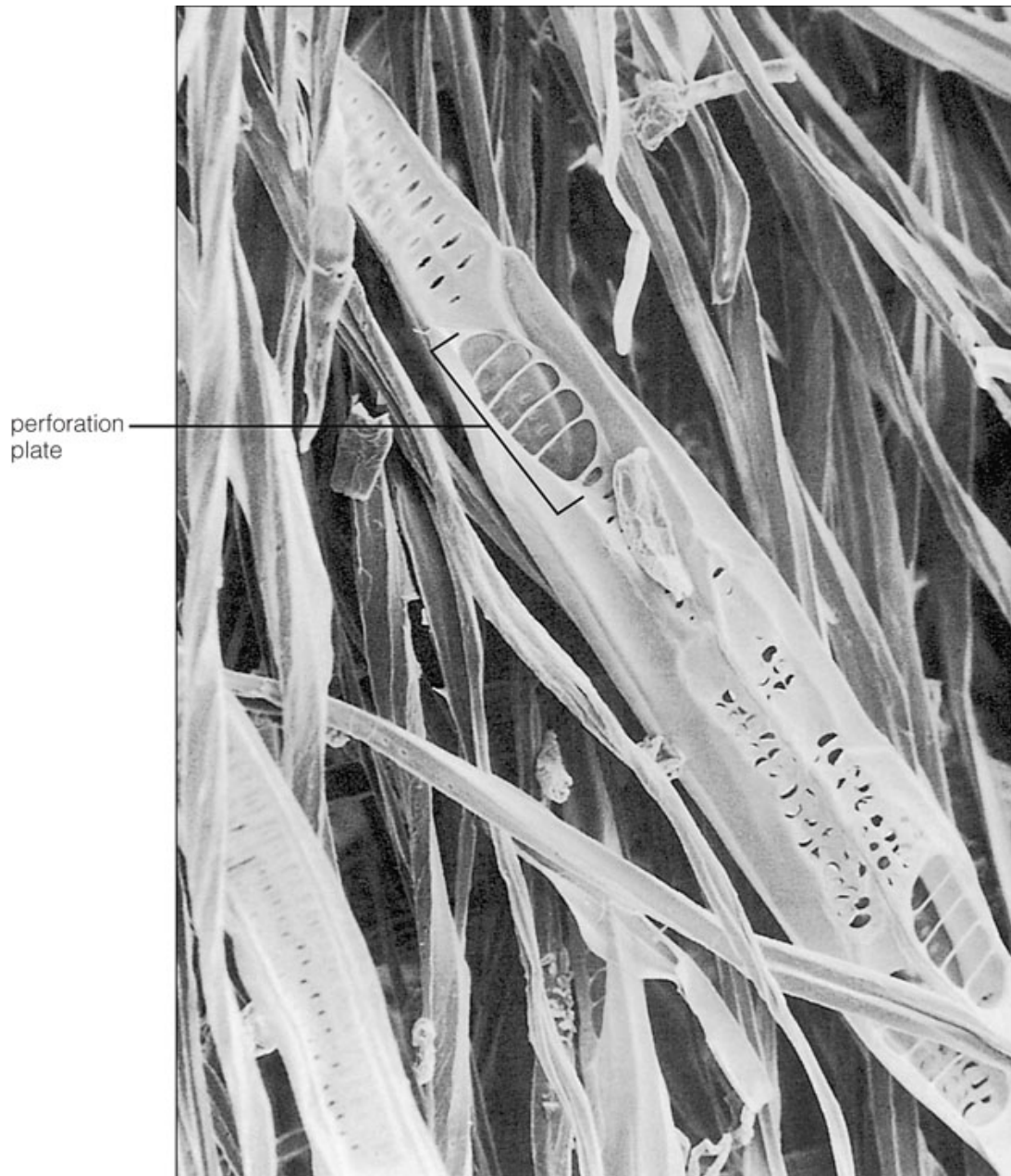
Ash (*Fraxinus americana*) secondary xylem with vessels (LM $\times 26$)

Perforations



© 2006 Brooks/Cole - Thomson

Scalariform perforations: direct connections



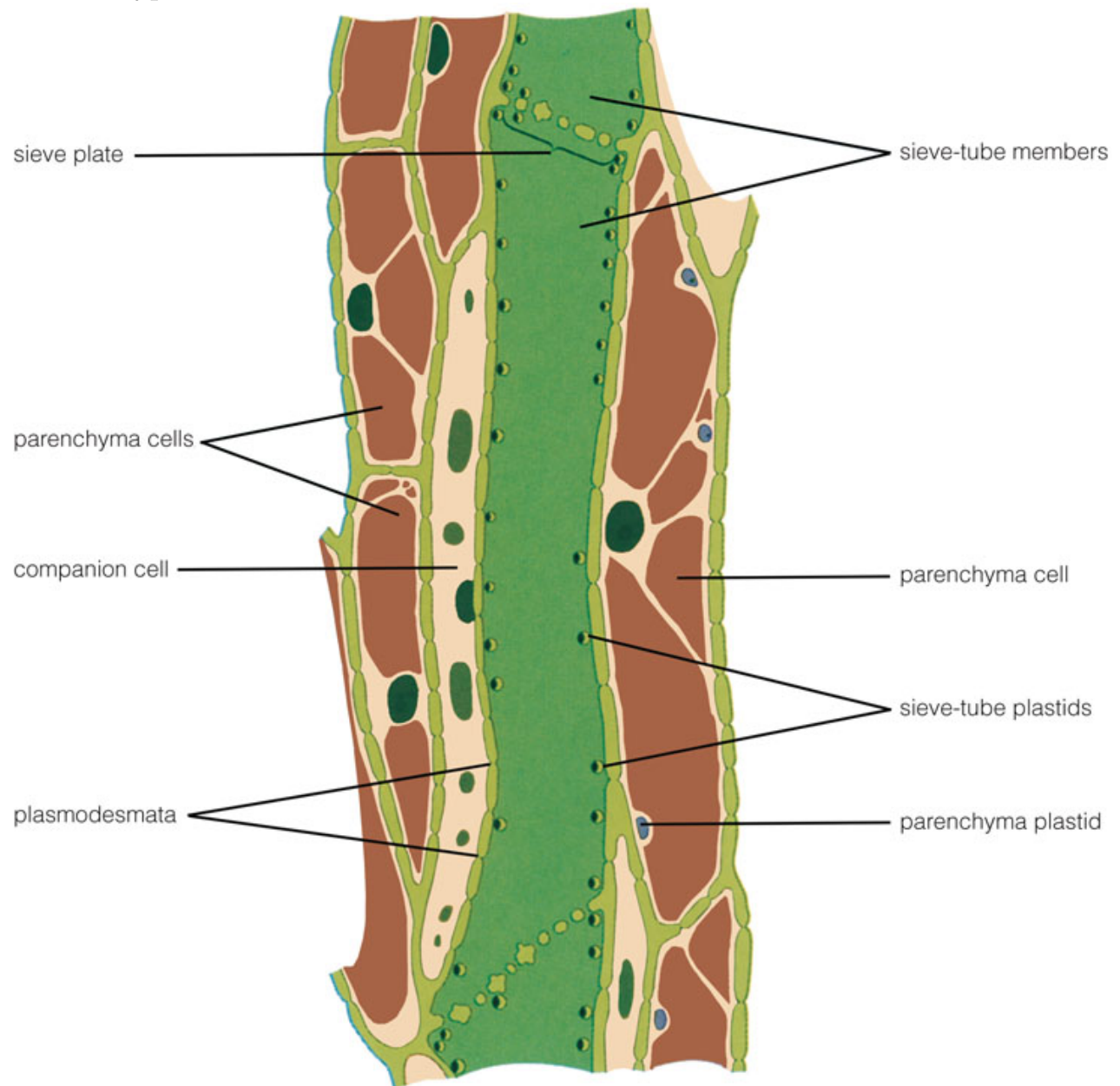
© 2006 Brooks/Cole - Thomson

2.2.2 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



© 2006 Brooks/Cole - Thomson

Sieve tubes and phloem parenchyma

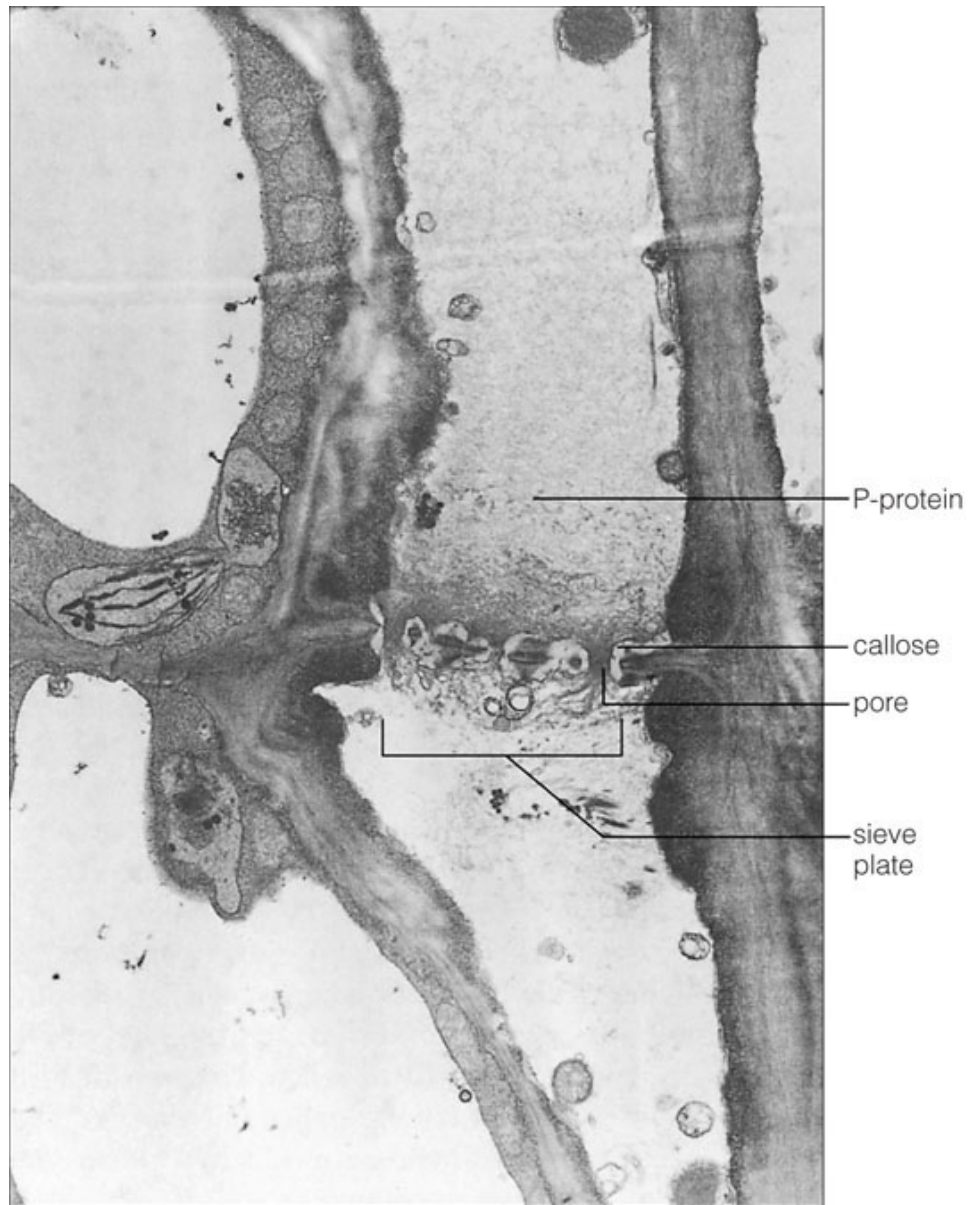
parenchyma cell

sieve-tube member



© 2006 Brooks/Cole - Thomson

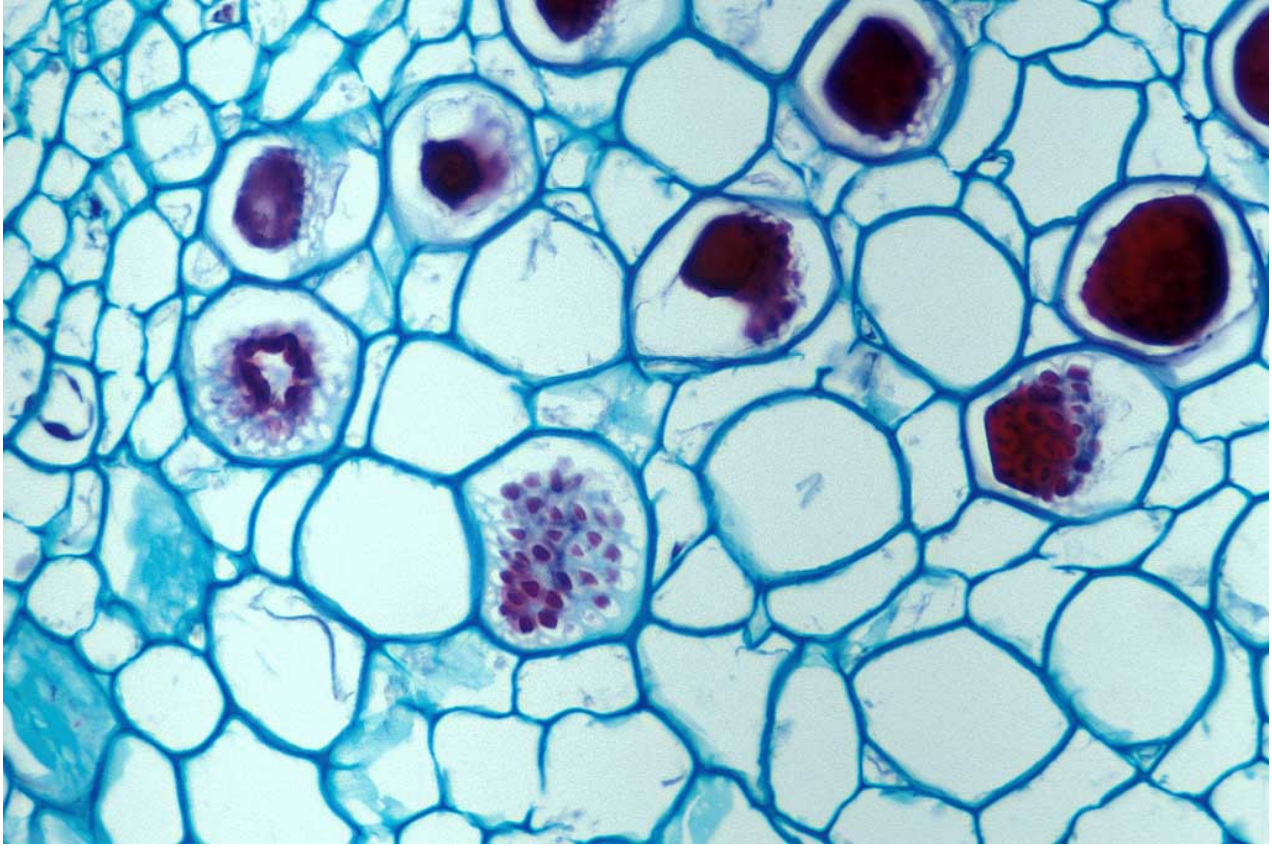
Perforation (sieve) plate



© 2006 Brooks/Cole - Thomson

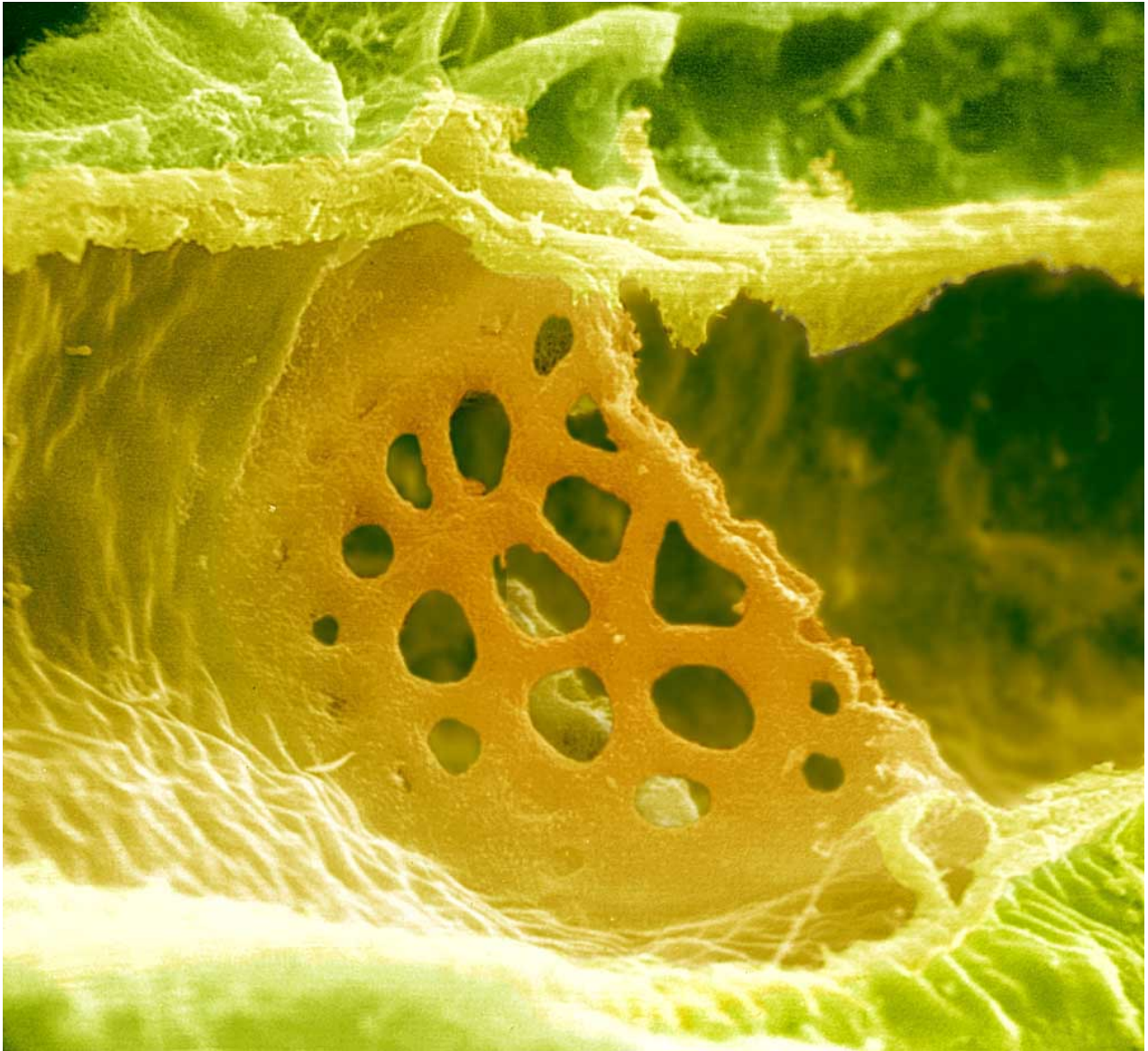
Cross-section (TEM)

Plates: frontal view



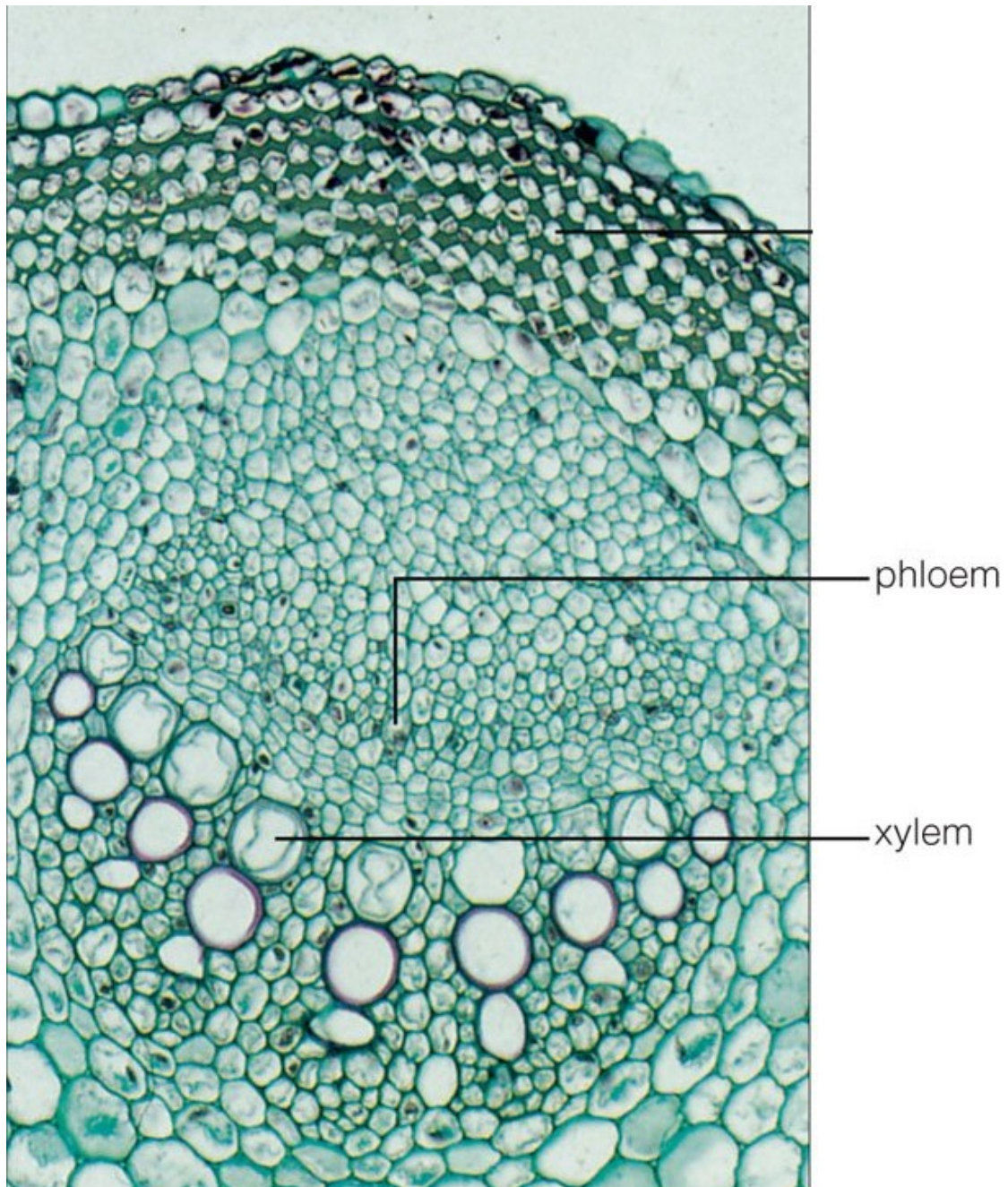
Frontal view (LM)

Plates: pores

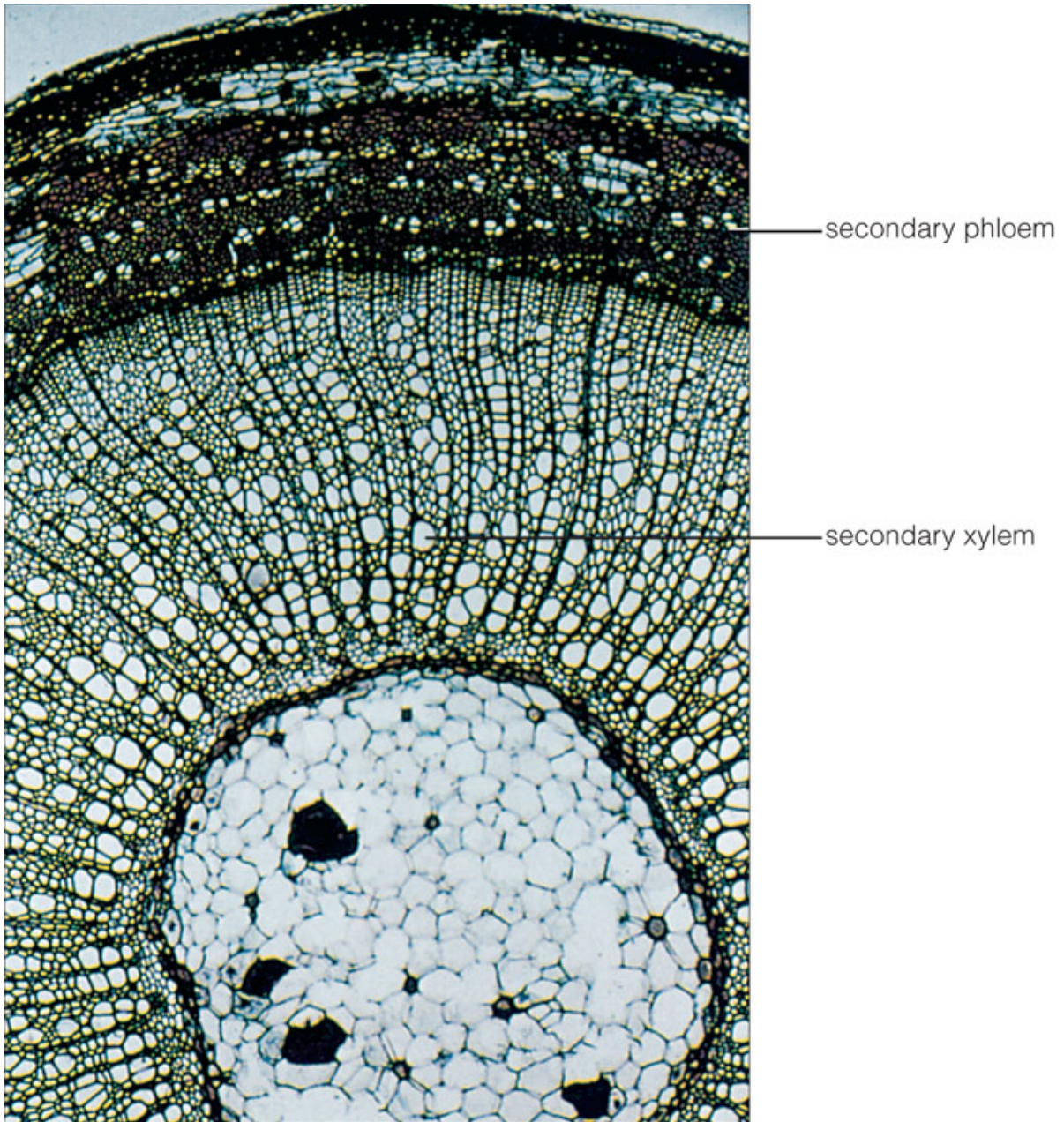


Sieve plate, a pore in the end wall of a sieve-tube member, through which phloem sap flows (SEM $\times 4800$)

Primary vascular tissues



Secondary vascular tissues



© 2006 Brooks/Cole - Thomson

Summary

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]. 2015. Mode of access: http://ashipunov.info/shipunov/school/biol_154

3 Movie

David Attenborough. Private Life of Plants. Episode 2: Growing. https://en.wikipedia.org/wiki/The_Private_Life_of_Plants

Outline

4 Questions and answers

Previous final question: the answer

List two differences between phloem and xylem.

- **State:** dead vs. living cells
- **Transport:** water vs. sugar
- **Direction:** up vs. various
- **Biomass:** big vs. small

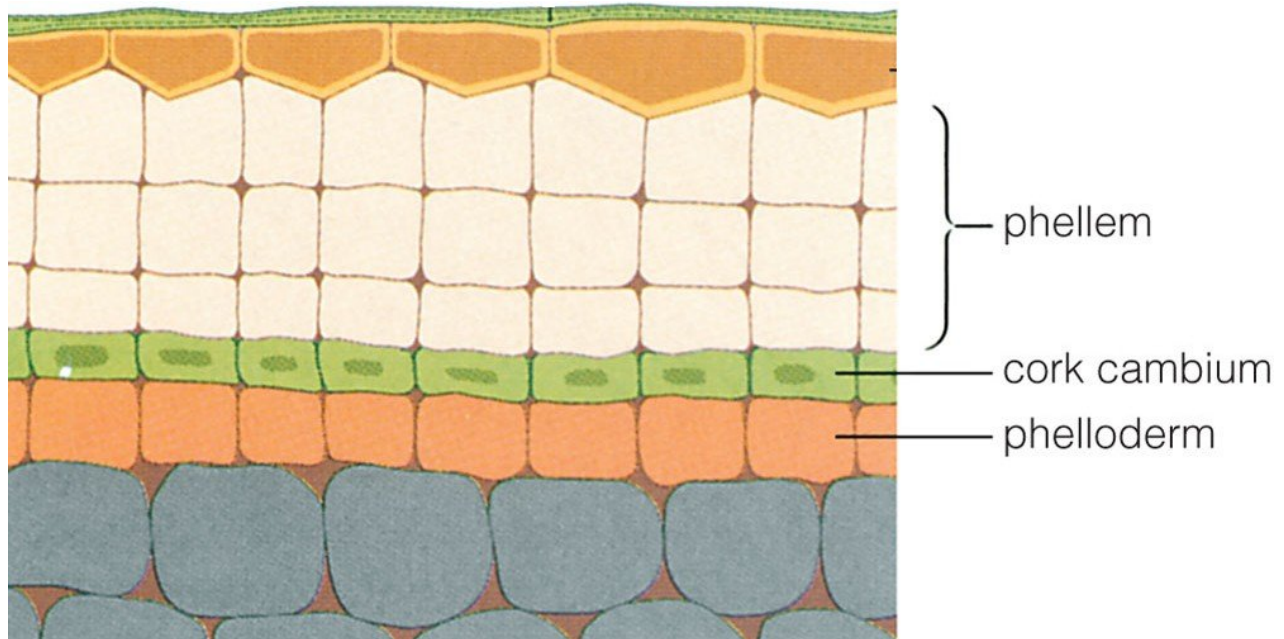
5 Tissues

5.1 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 phel-loderm
- 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

5.2 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

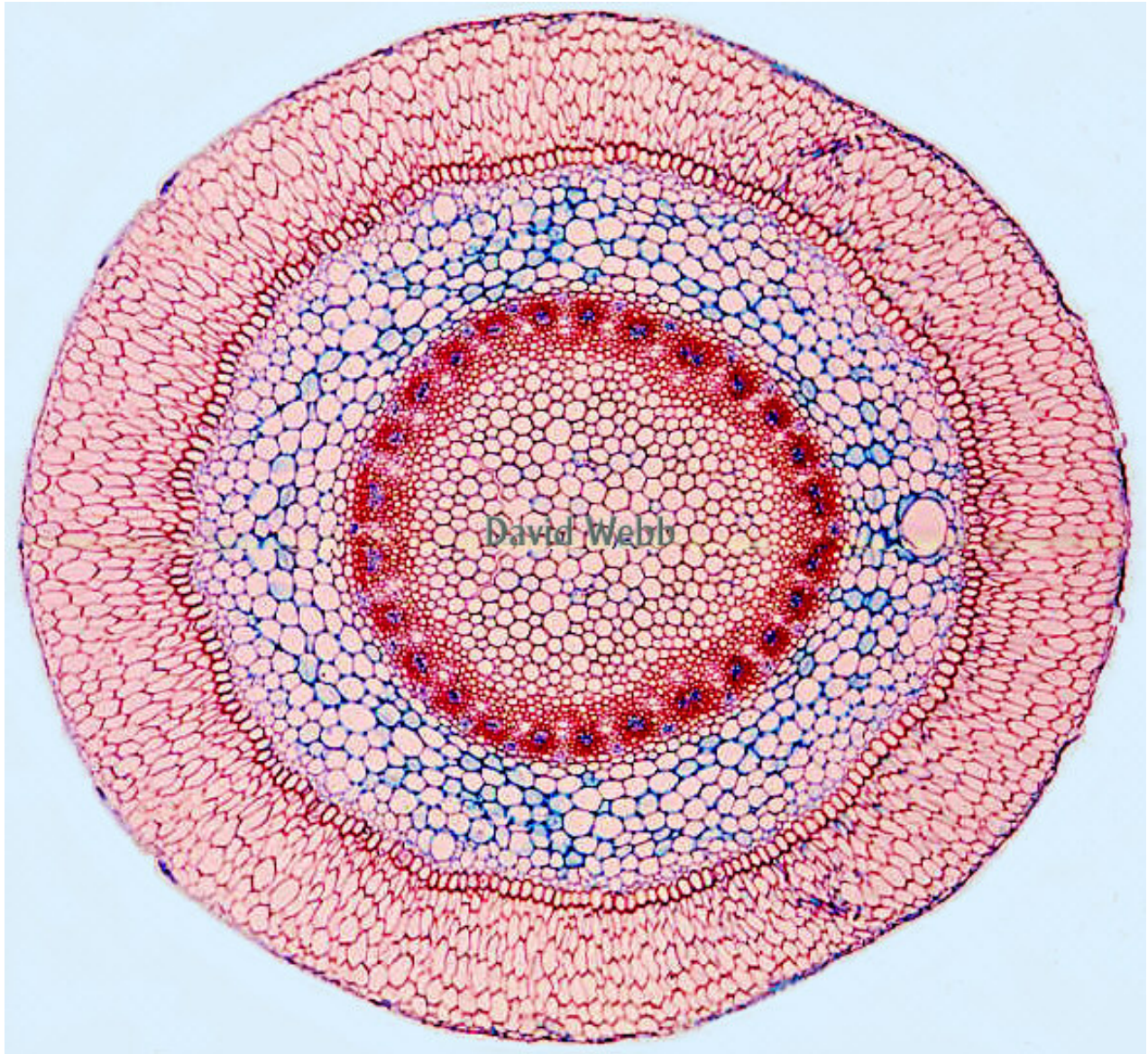
- Always primary, simple tissues
- **Rhizoderm**, or root hairs, originates from protoderm, but life span is much shorter than of epidermis
- **Velamen**, originates from root cortex

Rhizoderm



Root hairs of grass seedlings (LM)

Velamen



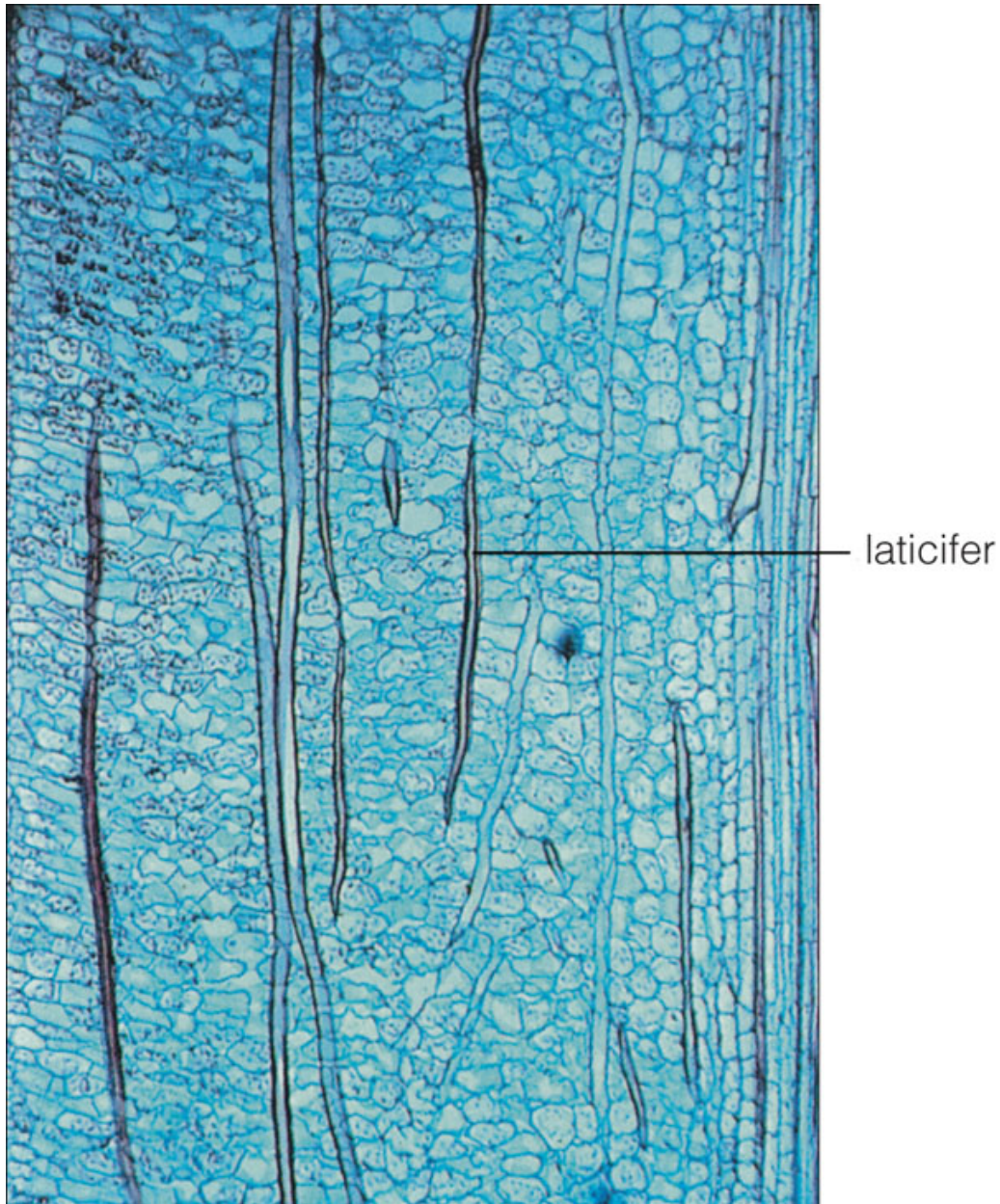
Outer cylinder is a velamen tissue of orchid root (LM, © D. Webb)

5.3 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



© 2006 Brooks/Cole - Thomson

6 Leaf

6.1 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 morphology

6.2 Leaf morphology

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
 - Do not grow by apex
 - Do not produce new leaves
 - Have hierarchical morphology

Hierarchy



Fractals

$n = 0$



$n = 1$



$n = 2$



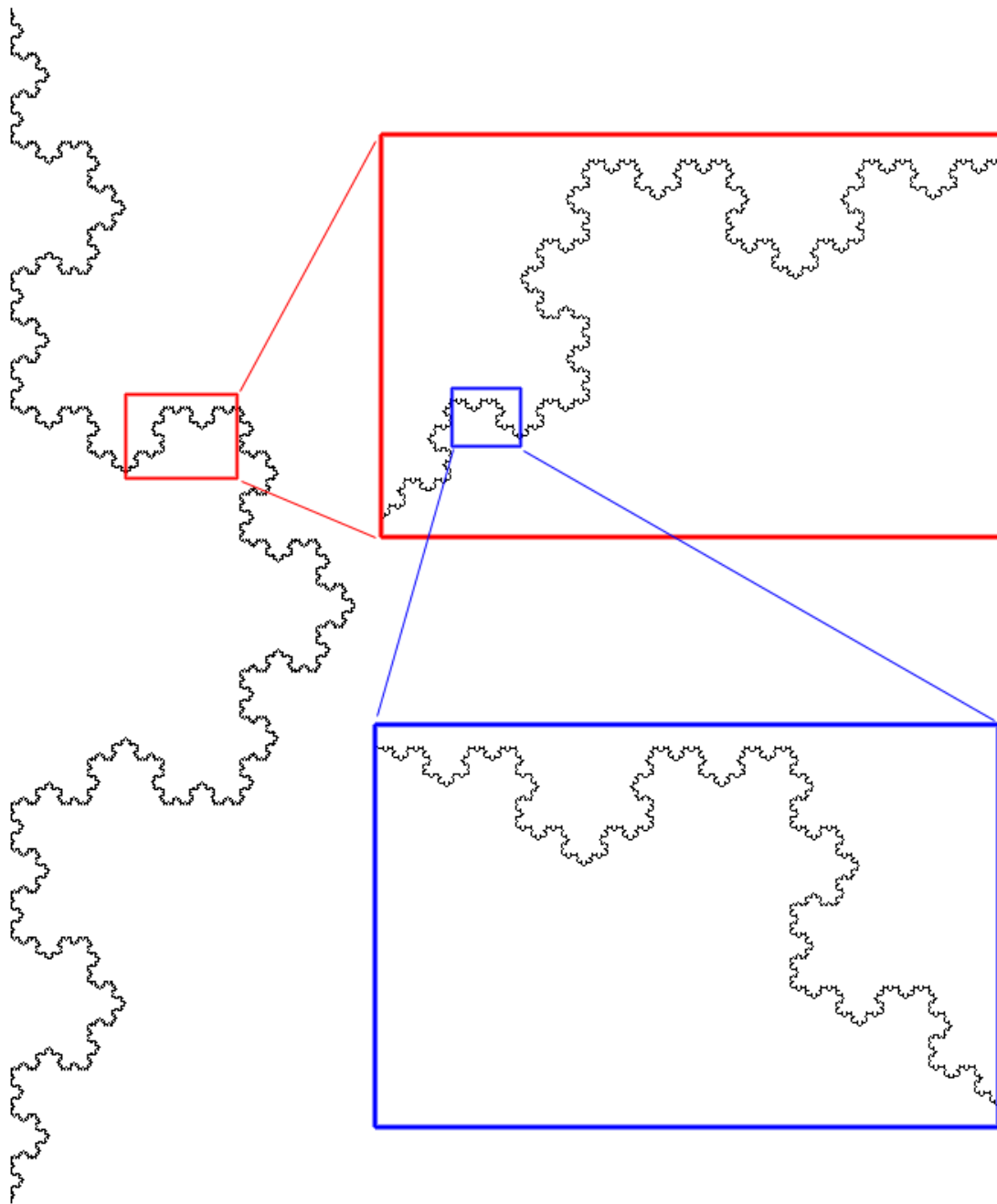
$n = 3$



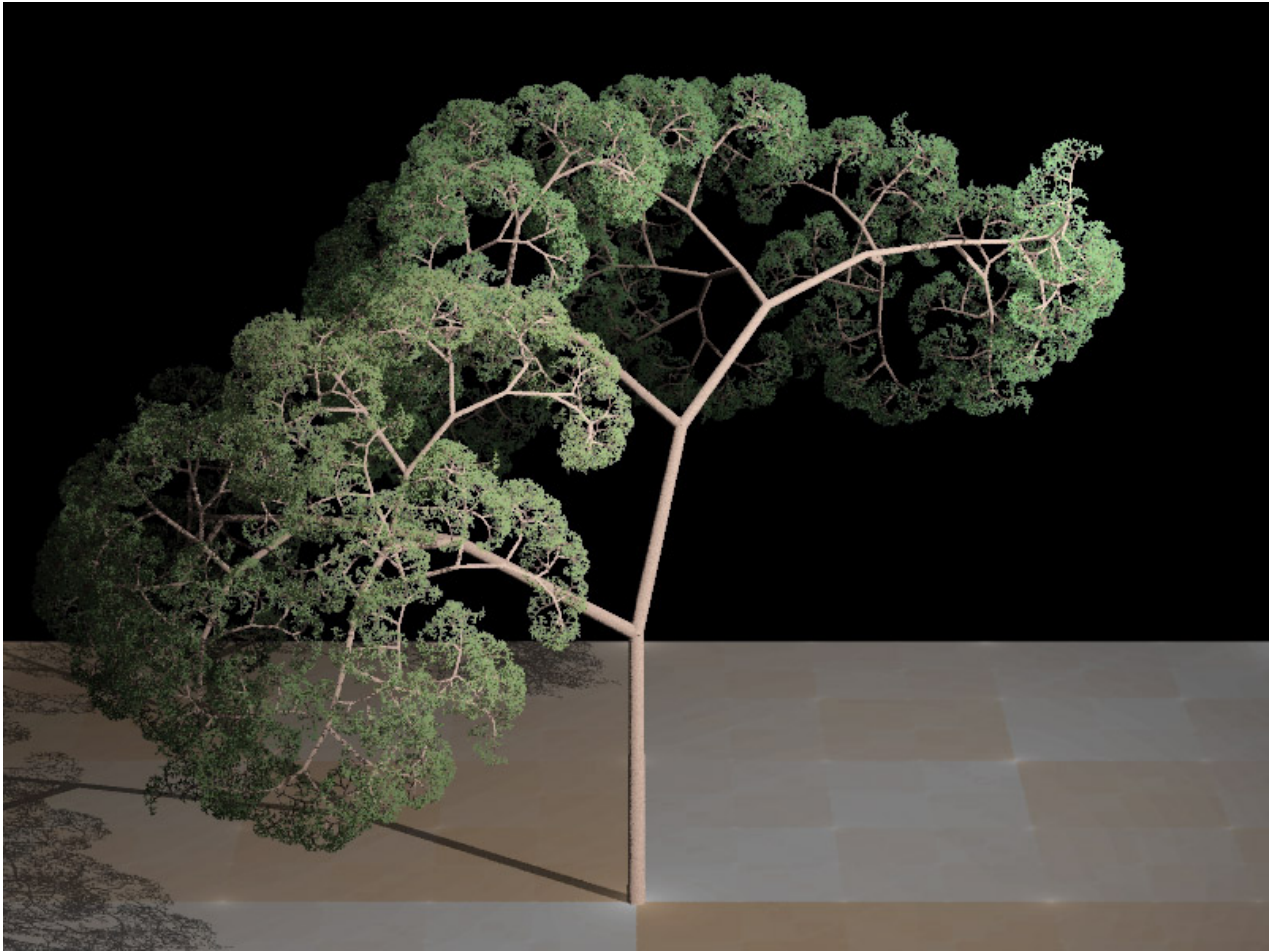
$n = 4$



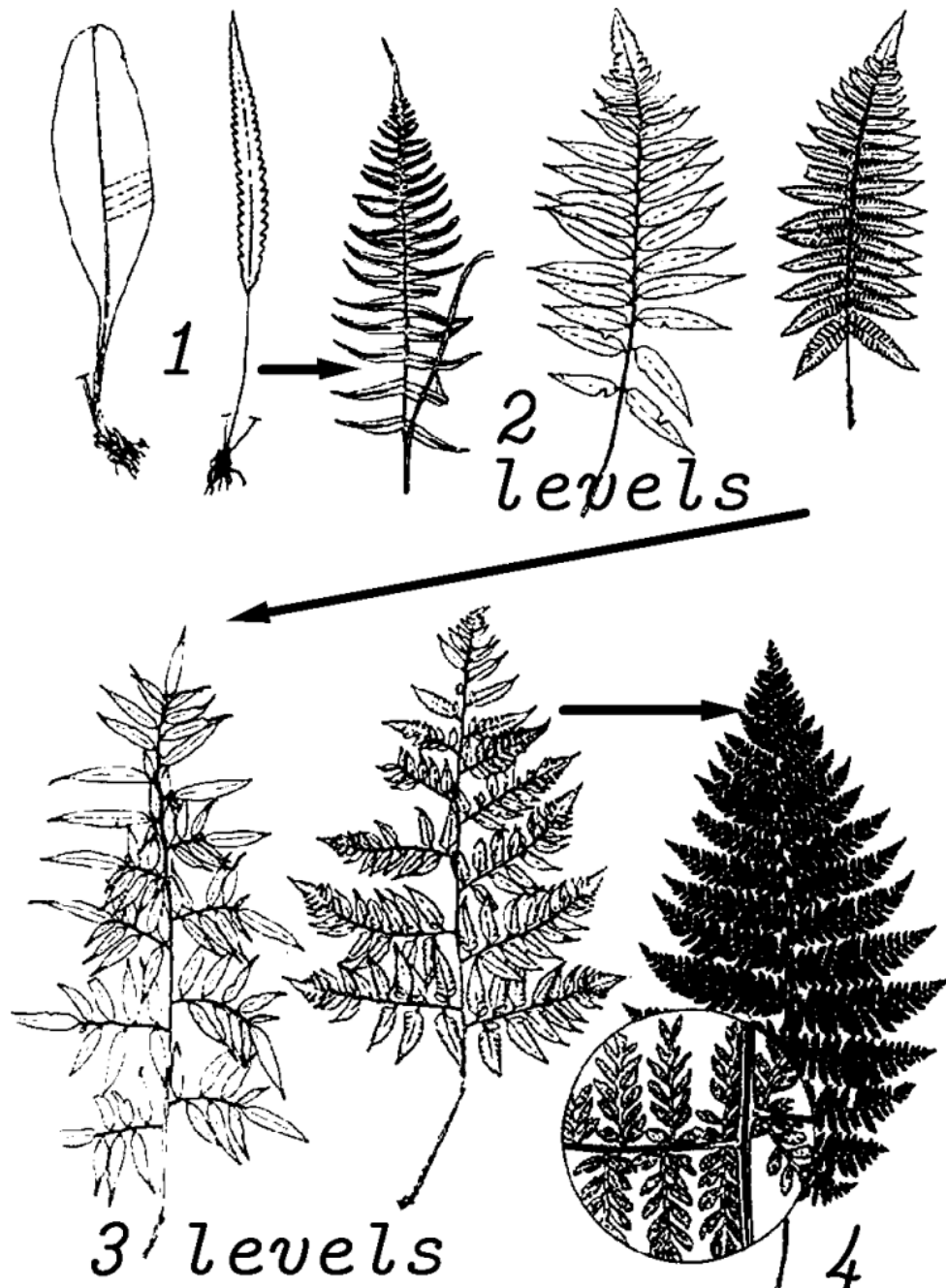
Self-similarity



Realistic tree-like fractal



Hierarchical levels in leaf morphology



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

Summary

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

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2015. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

7 Questions and answers

Previous final question: the answer

Why do poikilohydric plants not need rhizoderm?

- Because they do not care about water

8 Leaf

8.1 Leaf morphology

Hierarchy

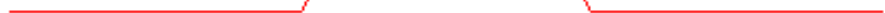


Fractals are hierarchical, with levels

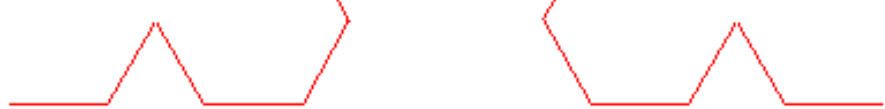
$n = 0$



$n = 1$



$n = 2$



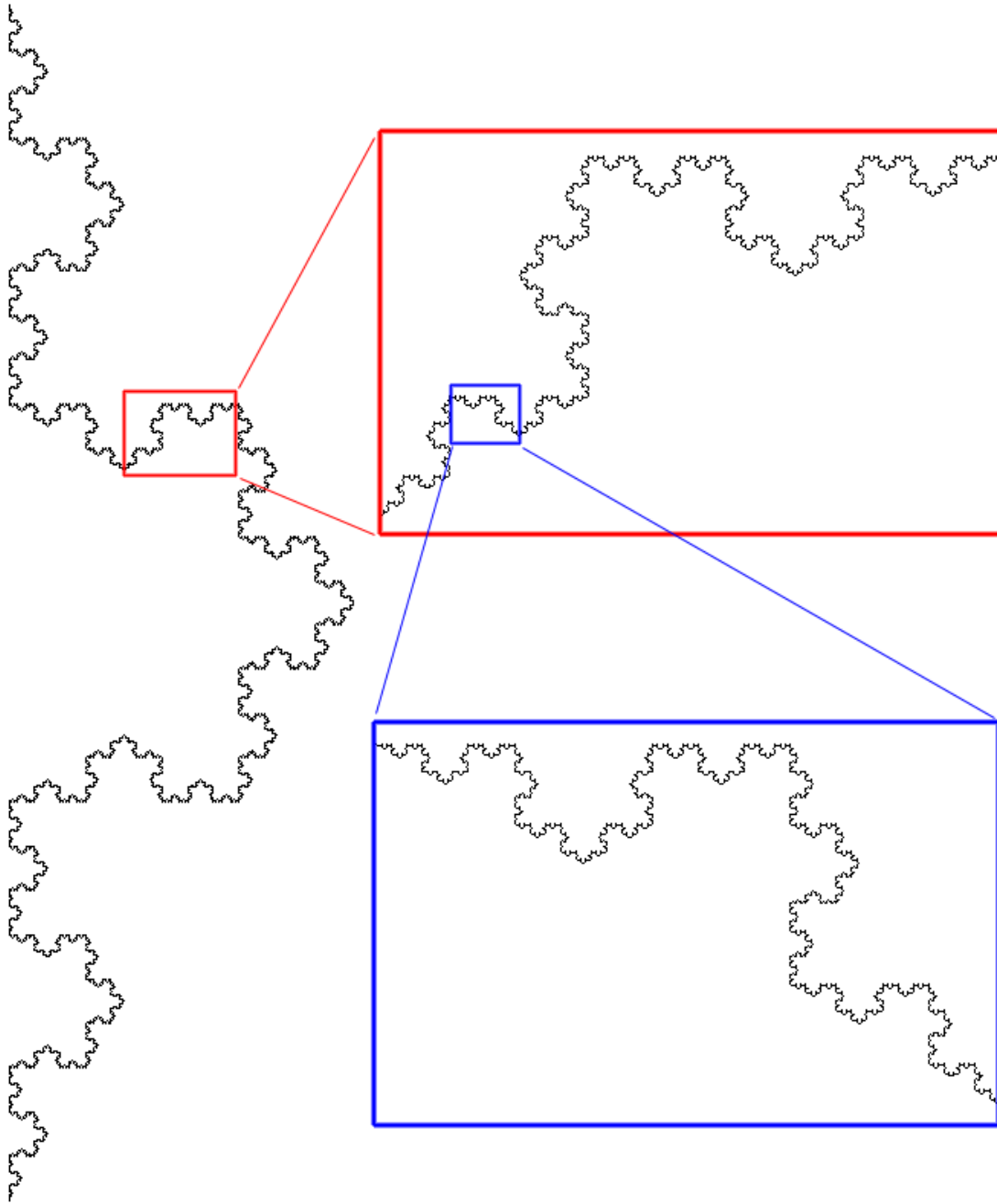
$n = 3$



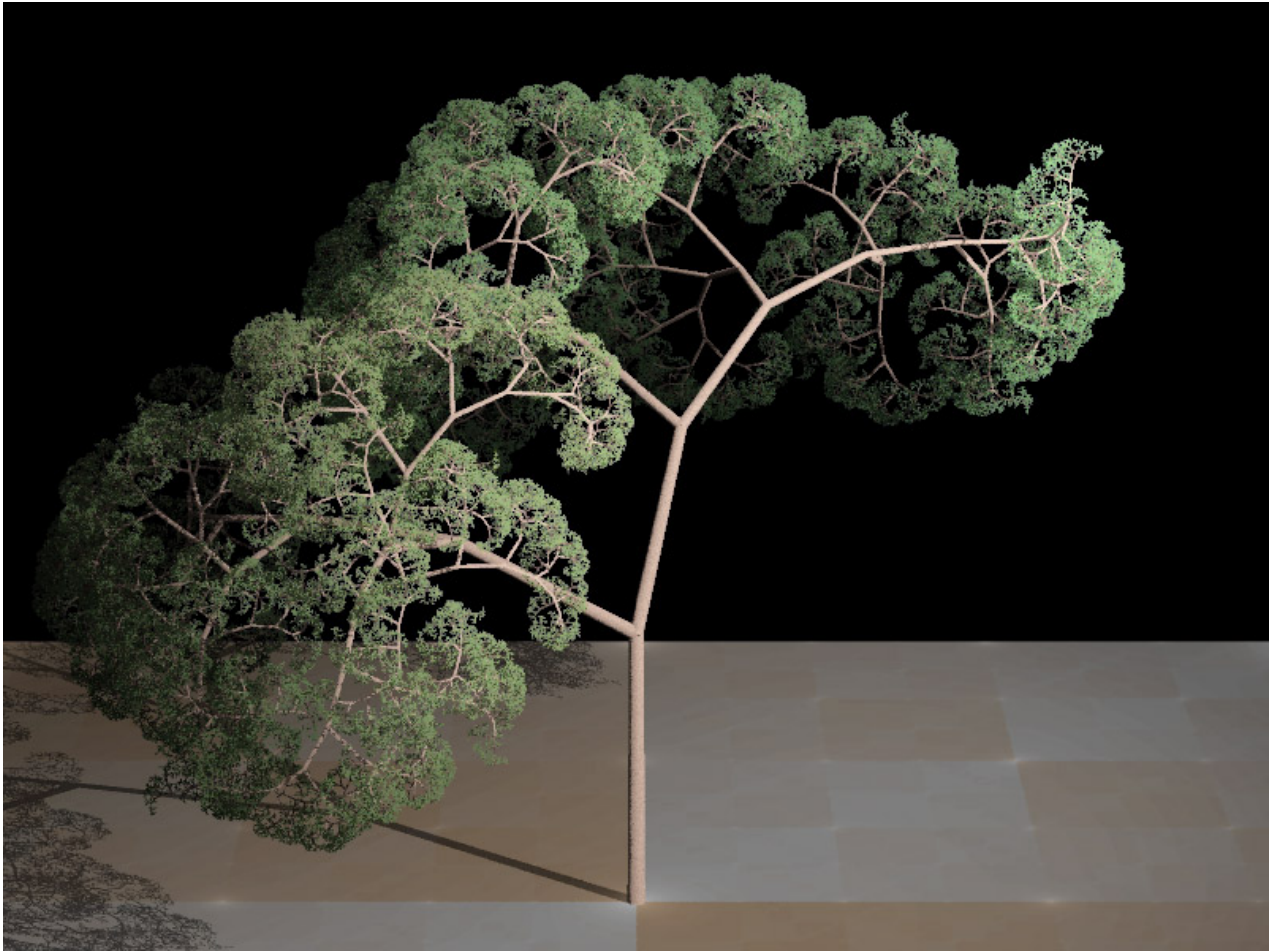
$n = 4$



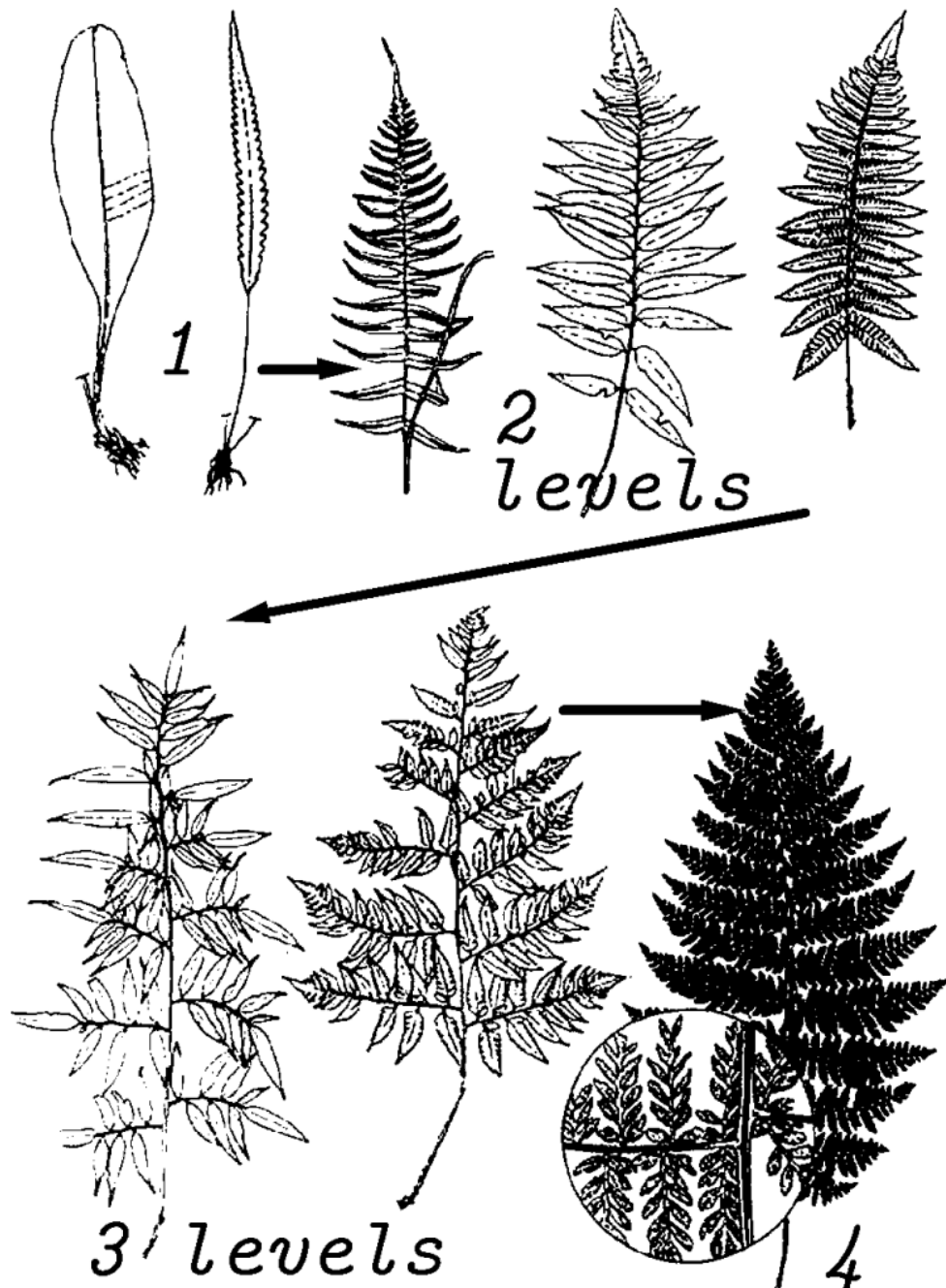
Fractals are self-similar



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

8.2 General characters

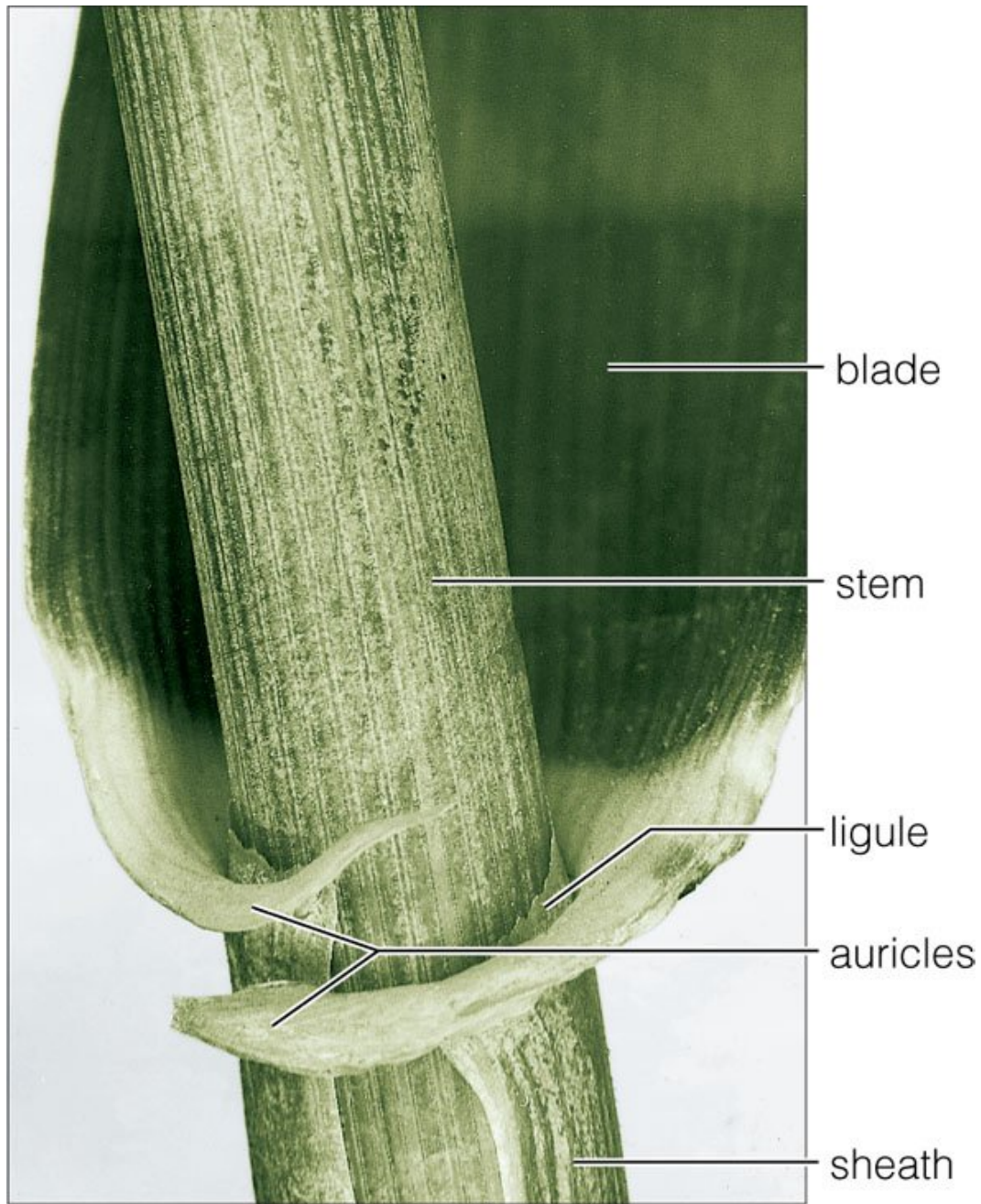
General characters

- 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



8.3 Repetitive characters

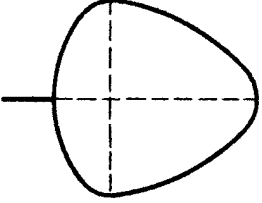
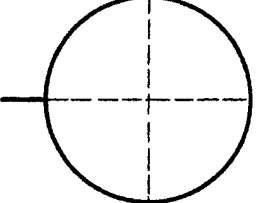
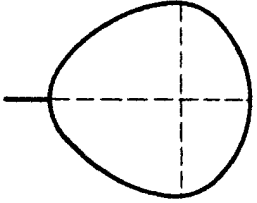
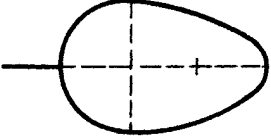
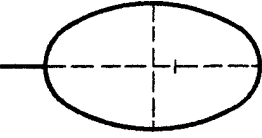
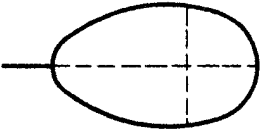

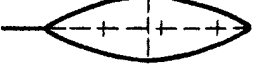
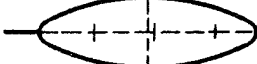
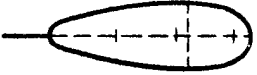
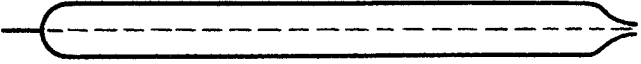
Repetitive characters

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

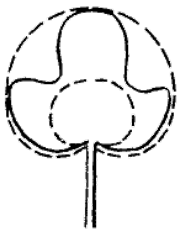
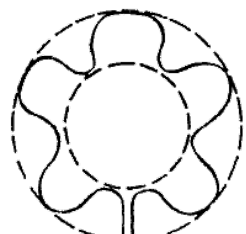
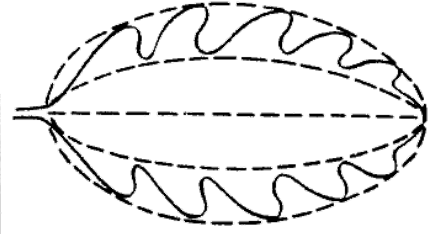

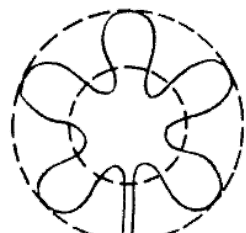
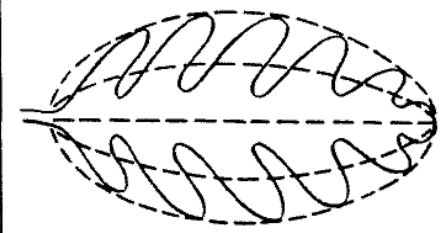
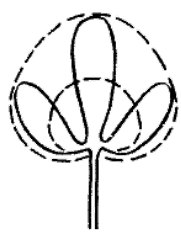
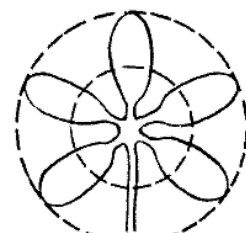
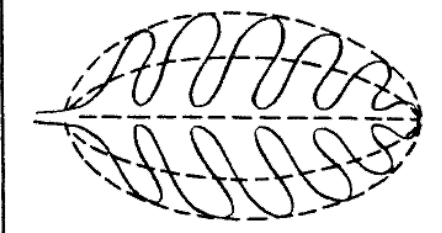
- Shape
- Dissection
- Petiole (stalked/non-stalked etc.)

Repetitive characters of same type may combine

Shape

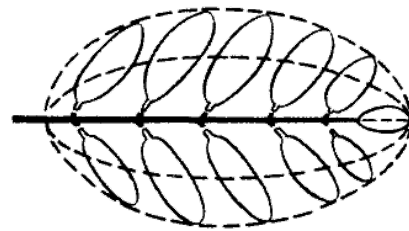
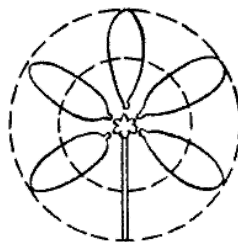
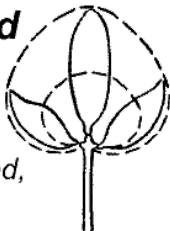
	Maximum width closer to leaf base	Maximum width in the middle	Maximum width closer to the apex
Length = width or slightly more	 Deltate	 Circular	 Cuneate
Length > 1-1.5 x width	 Ovate	 Elliptic	 Obovate
Length > 3-4 x width	 Narrowly ovate	 Lanceolate  Oblong	 Narrowly obovate
Length > 5 x width	 Linear		

Dissection

		Tri-	Palmately	Pinnately
Simple leaves	Lobed (from 1/4 to 3/4)			
				
	Dissected (from 3/4 to midrib)			

Compound leaves

(leaflets stalked, with joints)



8.4 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

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

Plan of leaf description

1. General characters (leaf as a whole):
 - (a) stipules (present / absent, deciduous / not);
 - (b) base (sheath / no sheath, ligule / no ligule, auricles / no auricles)
2. First level of hierarchy: repetitive characters:
 - (a) symmetry (symmetrical / asymmetrical);
 - (b) shape;
 - (c) dissection;
 - (d) petiole (length)
3. Second level of hierarchy
4. Third level of hierarchy and so on
5. 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)

8.5 Leaves in nature

Heterophylly

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

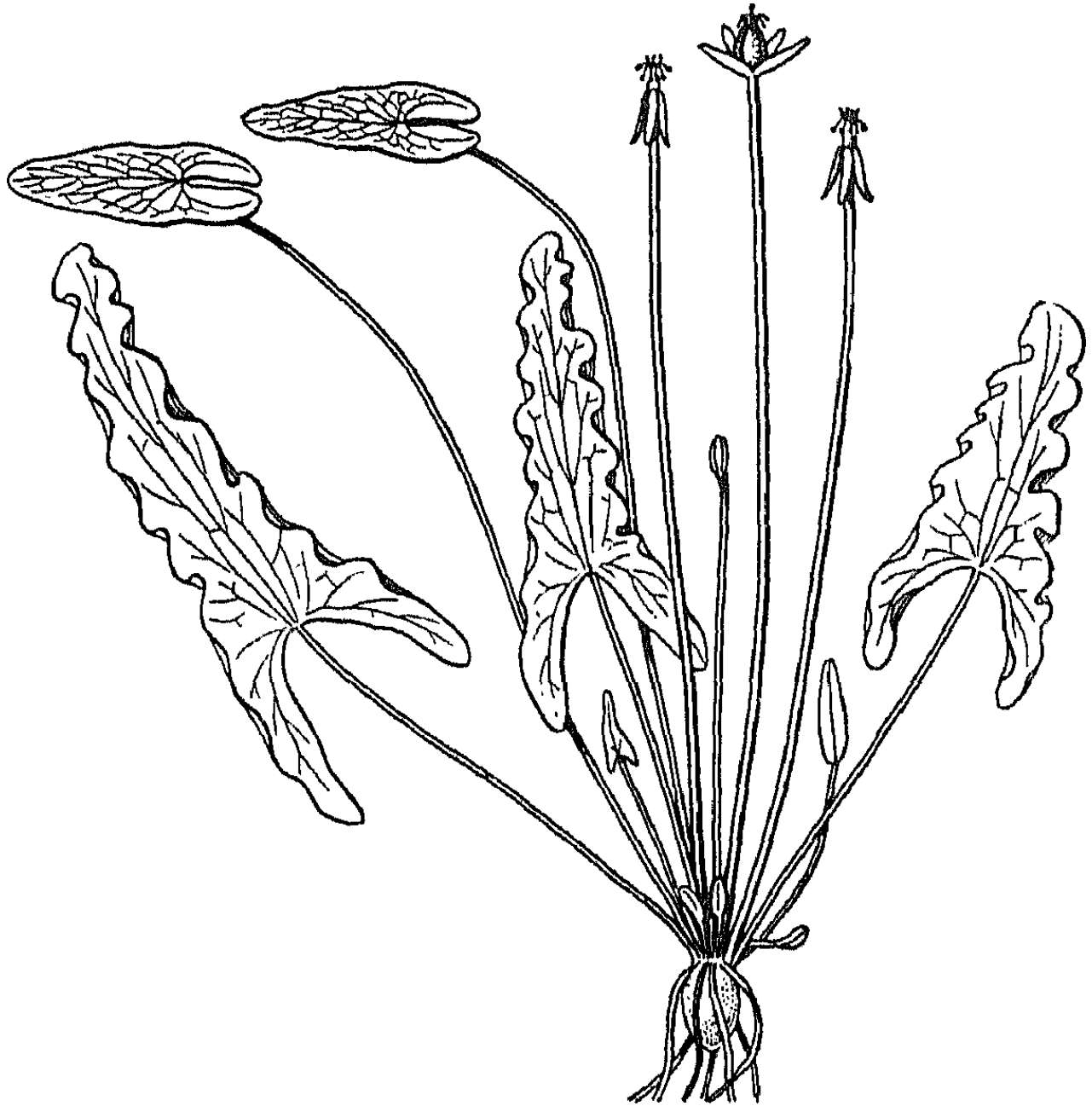
Juvenile leaves of *Juniperus* sp.



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*)



Final question (2 points)

How many levels of hierarchy has this leaf?



Summary

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

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2015. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

9 Questions and answers

Previous final question: the answer

How many levels of hierarchy has this leaf?



- 3

10 Leaf

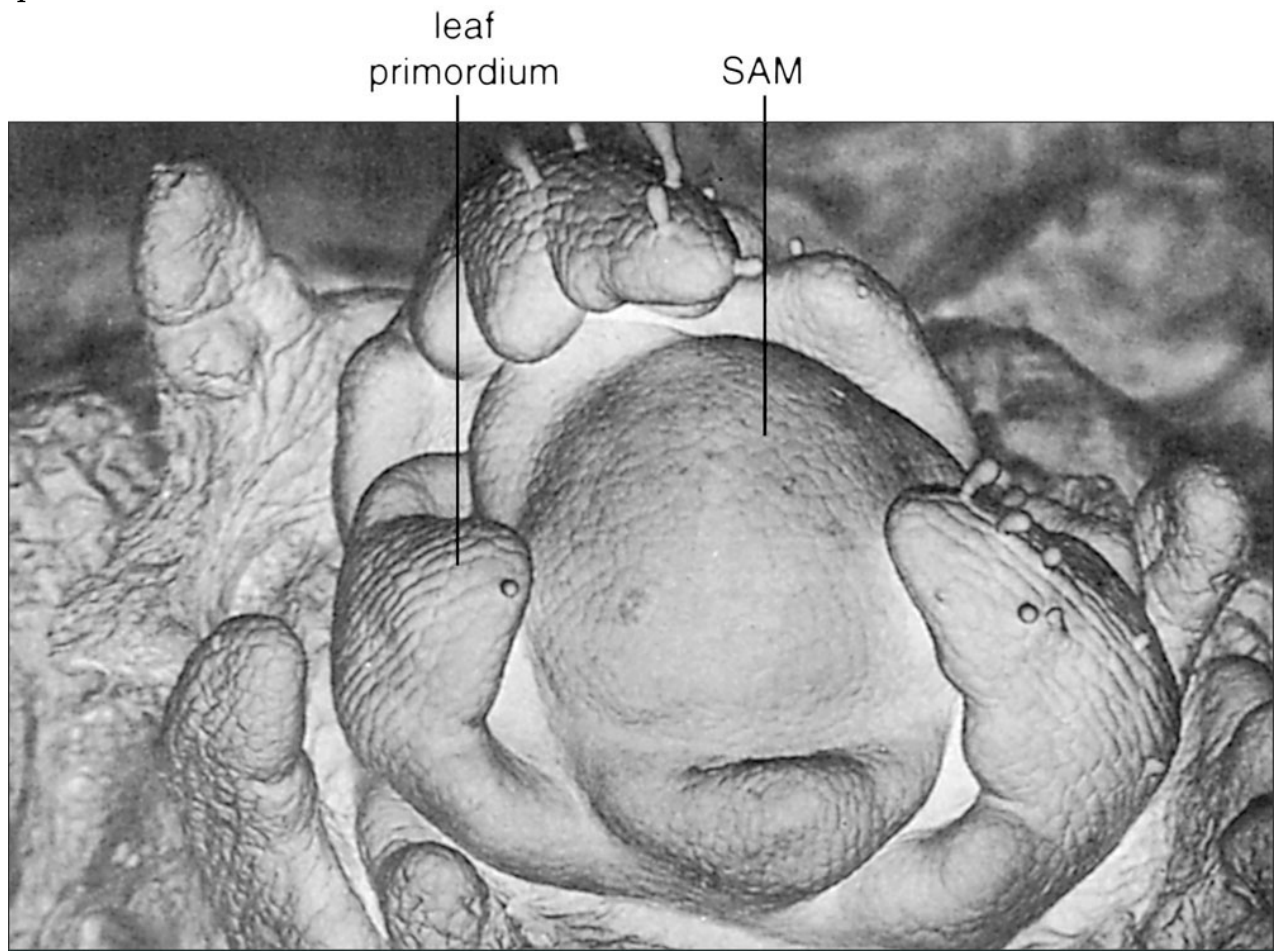
10.1 Leaves in nature

Seasonal life of leaves

- Leaves arise from SAM through leaf primordia

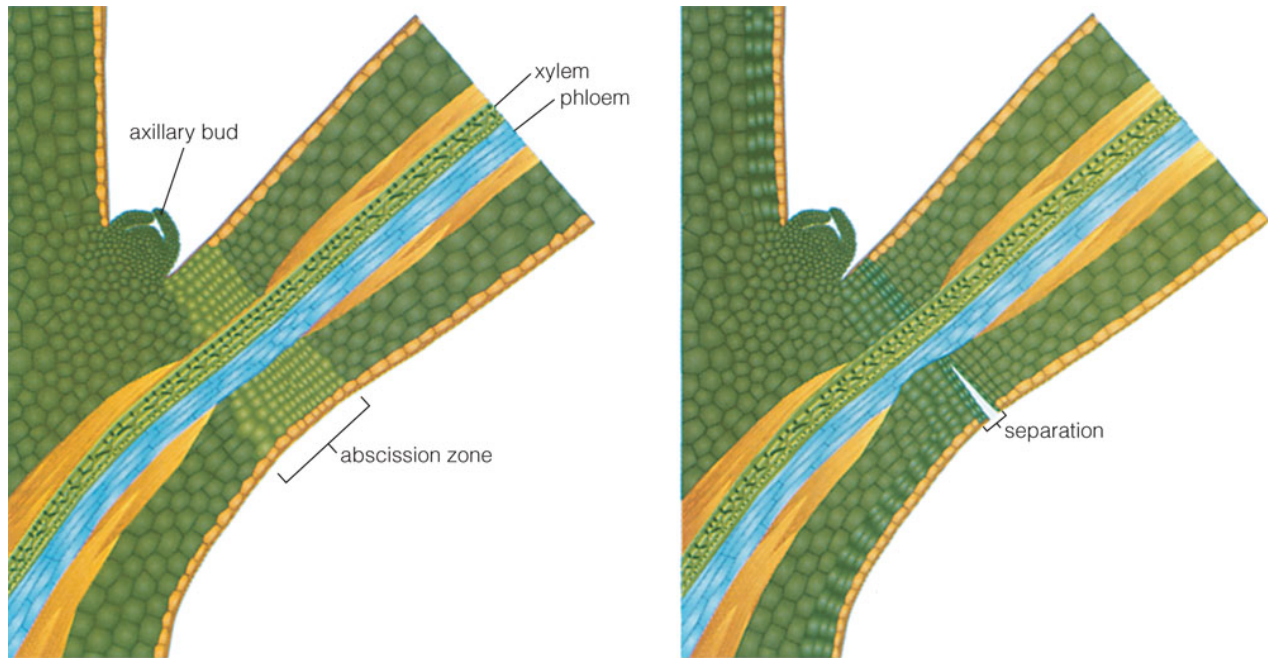
- Old leaves separate from plant in a region called abscission zone

Leaf primordia



© 2006 Brooks/Cole - Thomson

Abscission zone



© 2006 Brooks/Cole - Thomson

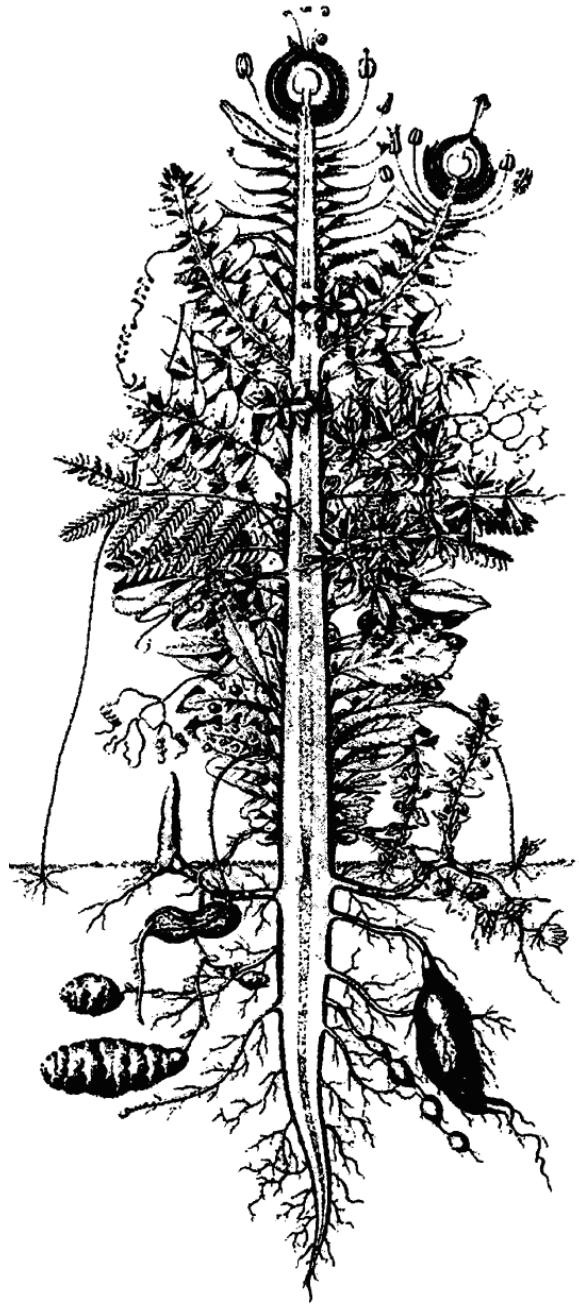
10.2 Modifications of leaf

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.

Urpflanze (another interpretation)



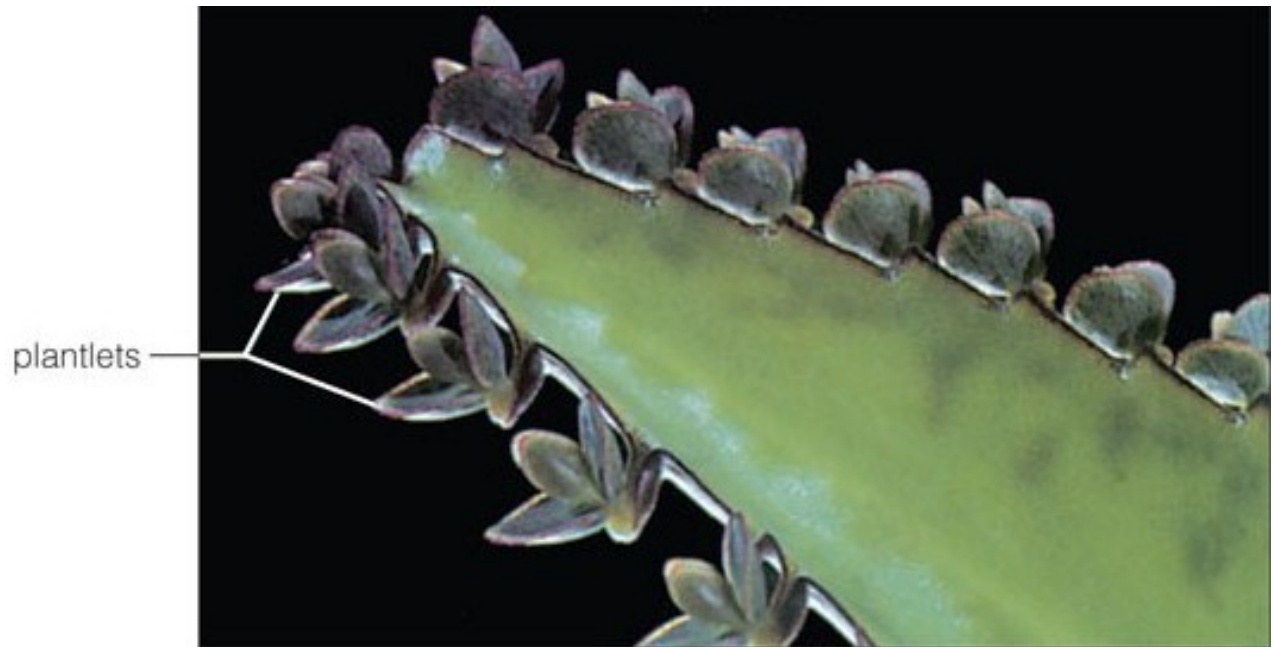
Leaf modifications

- 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 (*Pinguicula* 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

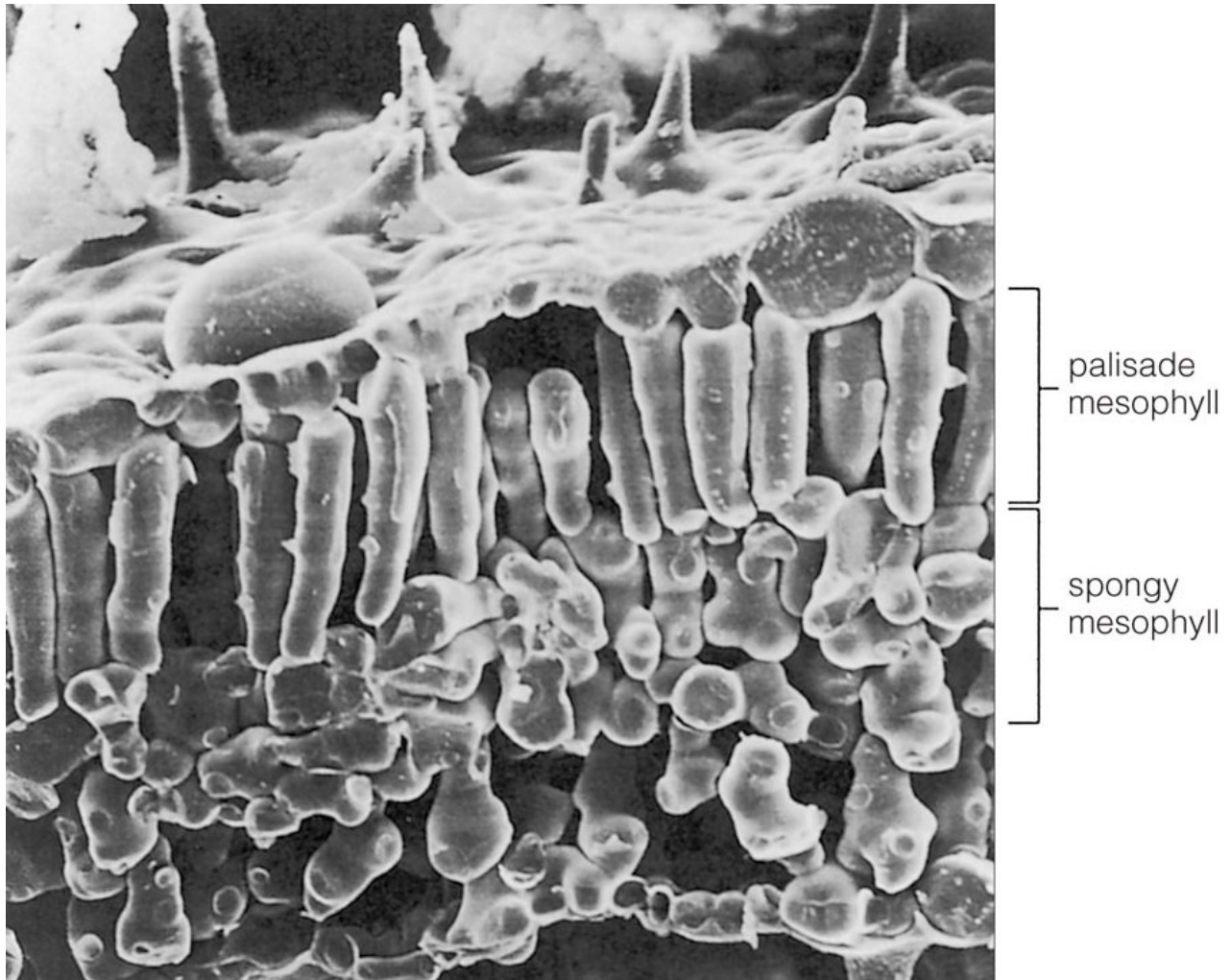
Table of modifications

<i>Function</i>	Stem / shoot	Leaf	Root
Expansion		Plantlets	
Storage		Succulent leaves	
Photosynthesis		DEFAULT	
Defense		Spines, scales	
Support		Leaf tendrils	
Interactions		Traps, “sticky tapes”, urns	

11 Leaf

11.1 Anatomy of leaf

Palisade and spongy cells



Veins/vascular bundles

- Phloem typically faces downwards, xylem—upwards
- Bundles of C_4 -plants have additional bundle sheath cells

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

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2015. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

12 Questions and answers

Previous final question: the answer

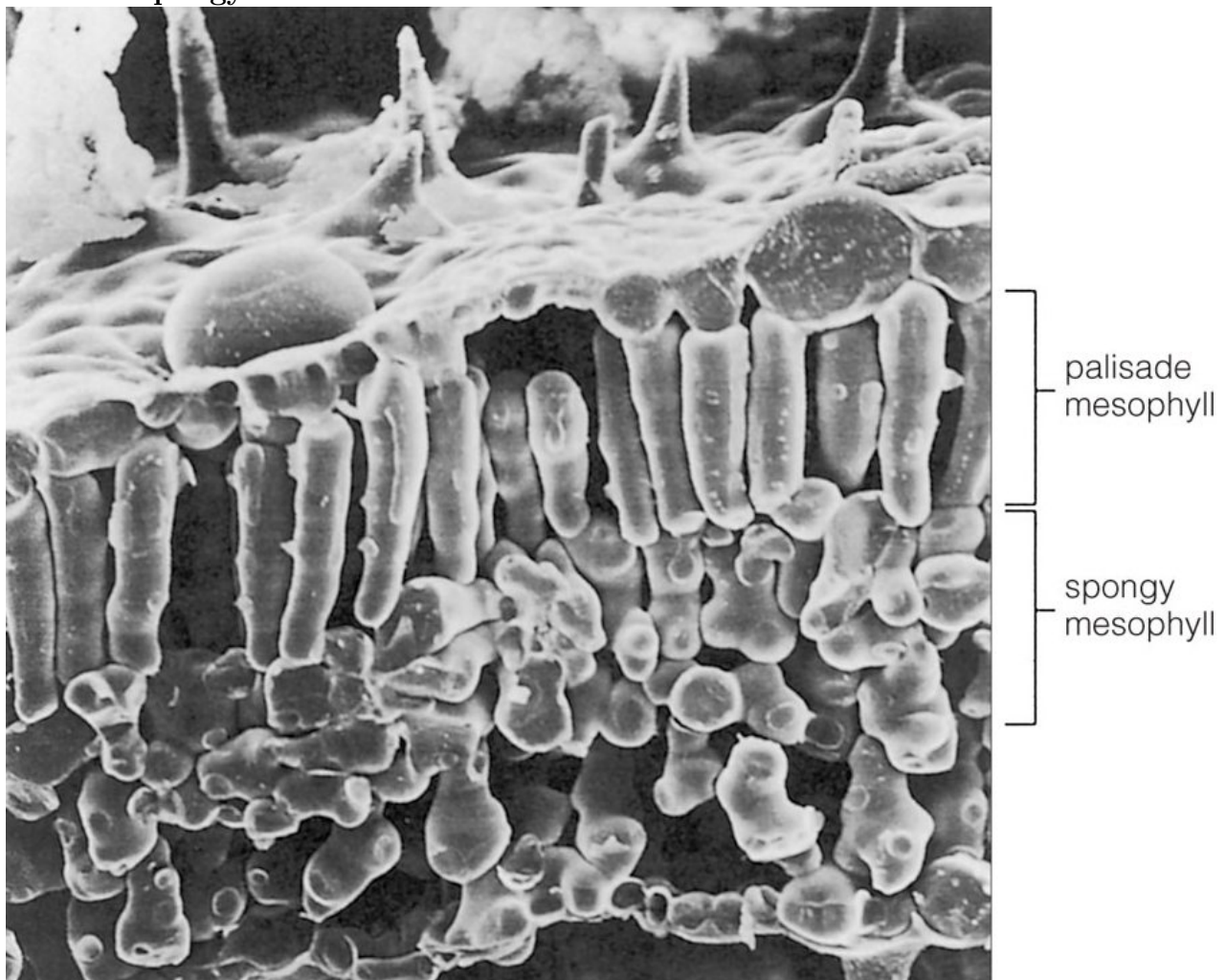
Why do trees drop their leaves in the fall?

- To conserve water which is not available from the soil
- To get rid of unnecessary secondary compounds

13 Leaf

13.1 Anatomy of leaf

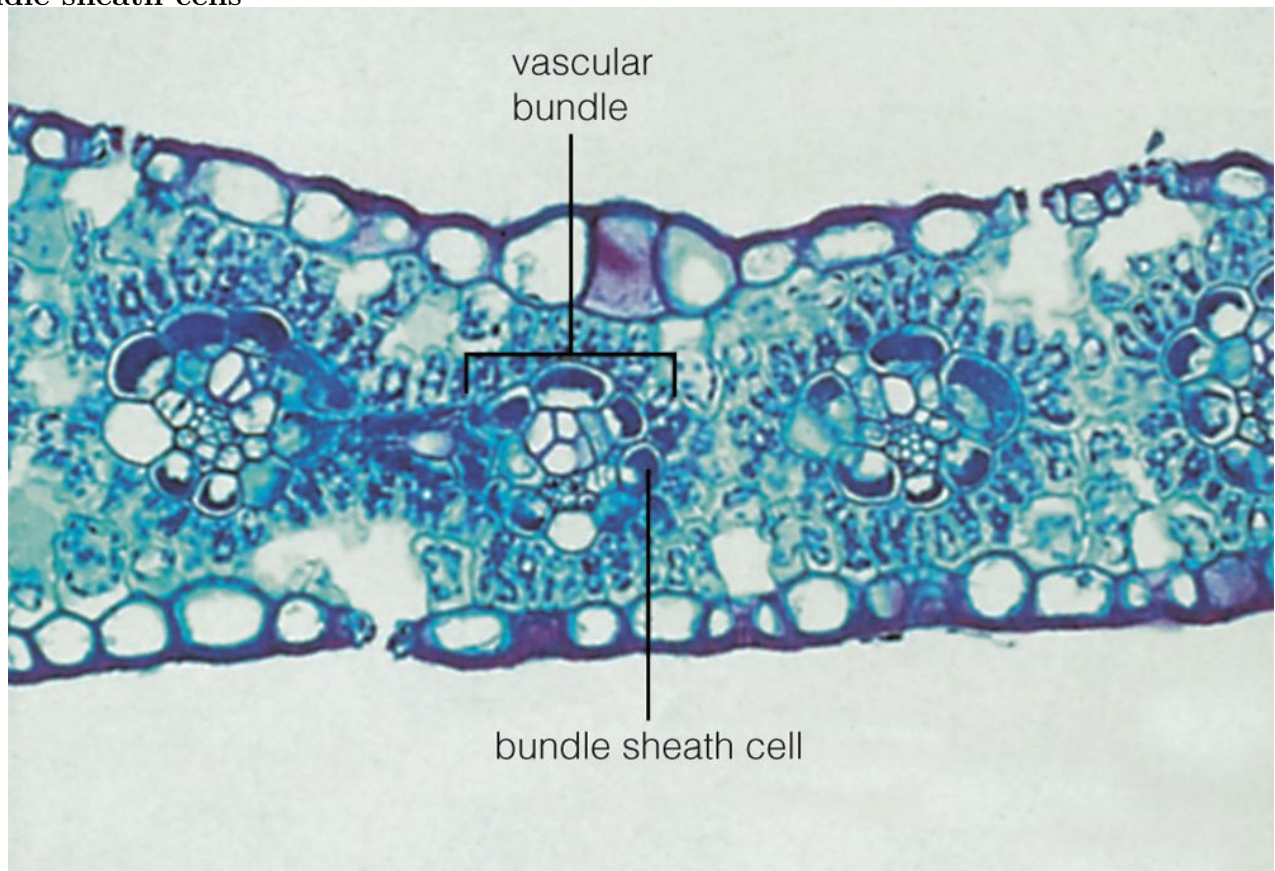
Palisade and spongy cells



Veins/vascular bundles

- Phloem typically faces downwards, xylem—upwards
- Bundles of C_4 -plants have additional bundle sheath cells

Bundle sheath cells

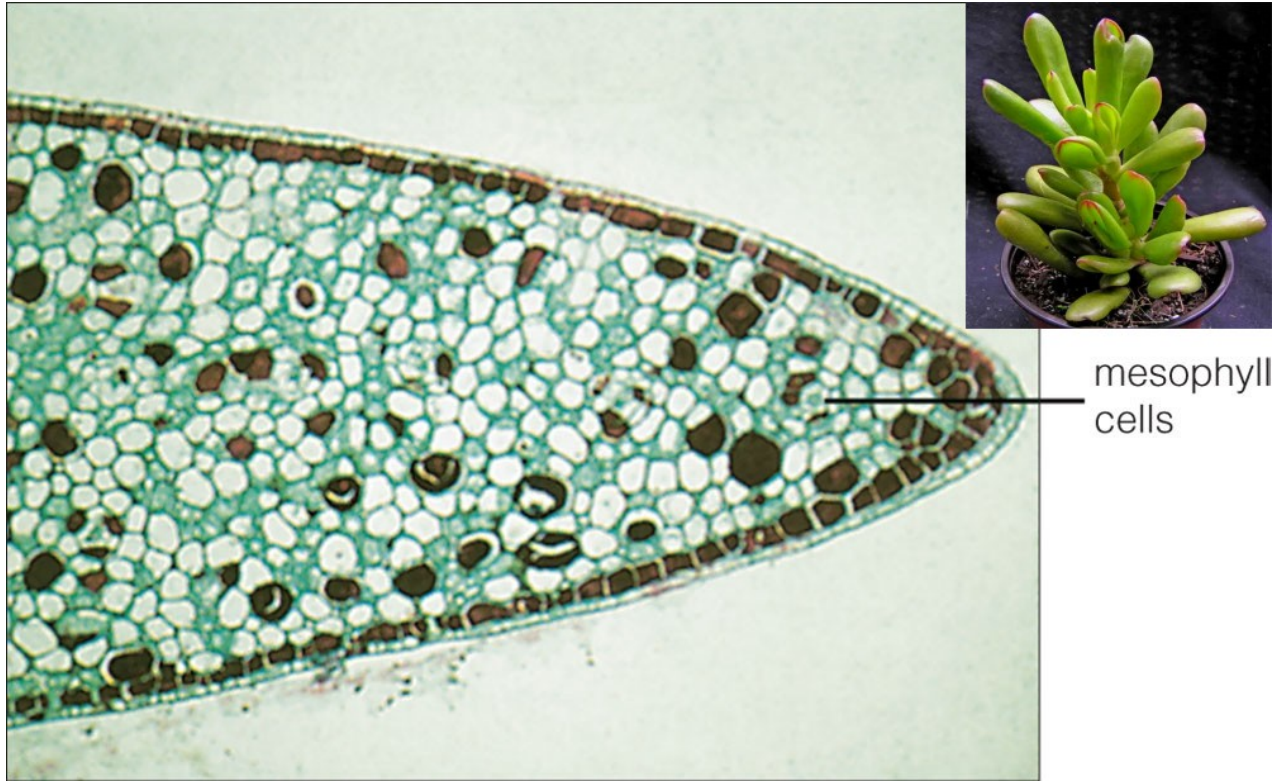


13.2 Ecological adaptations of leaves

Plants and water

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

Leaf succulent (*Crassula argentea*)



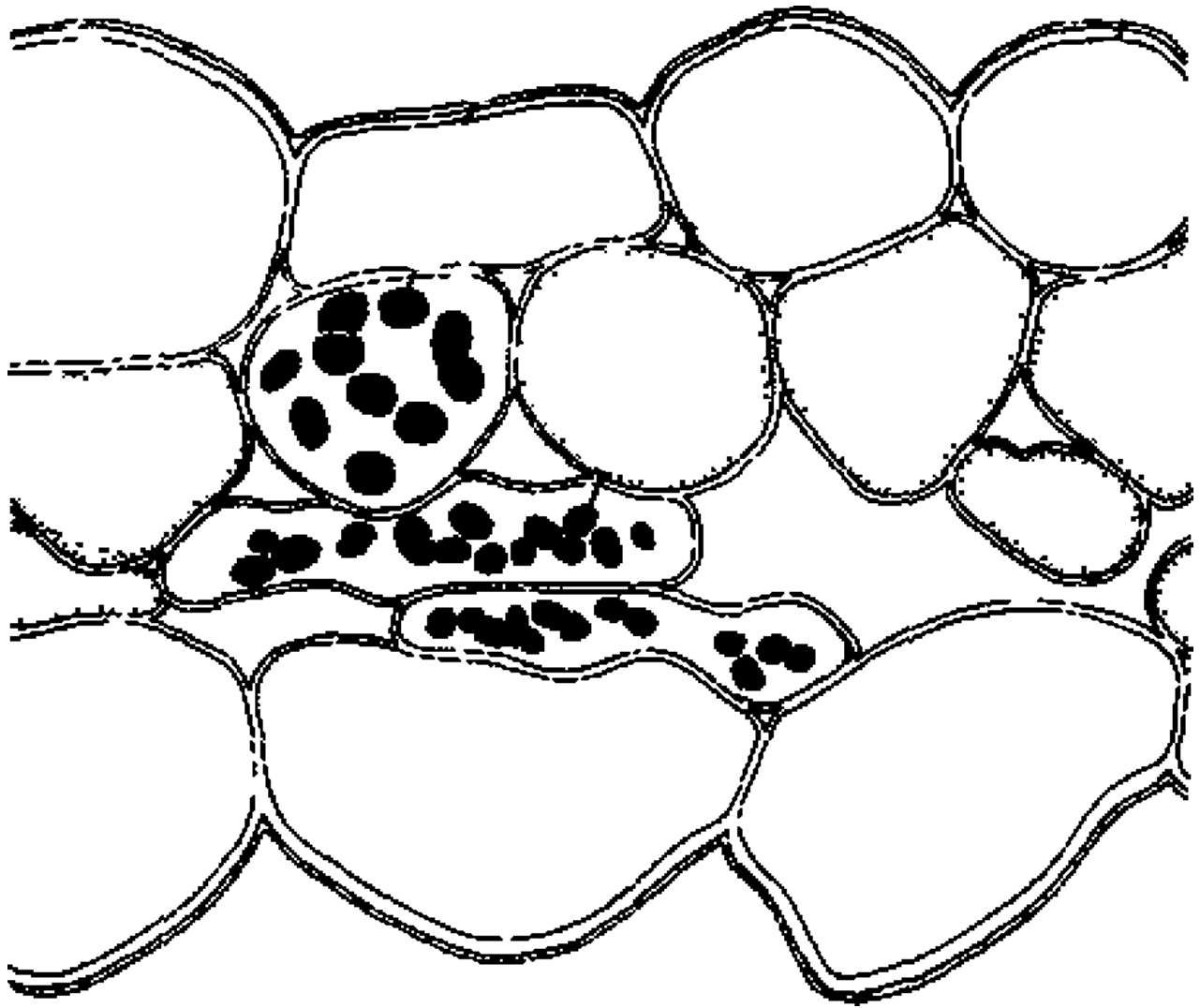
Xerophyte leaf—needle of pine (*Pinus contorta*)

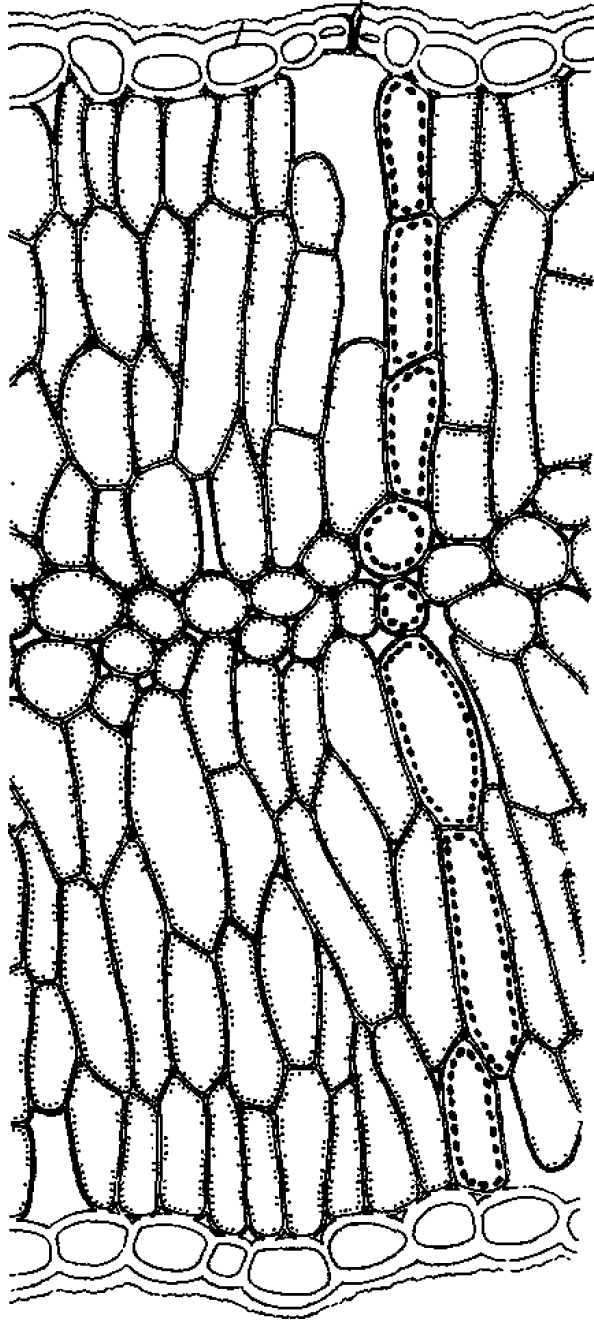


Plants and light

- Sciophytes
- Heliophytes

Sciophyte and heliophyte



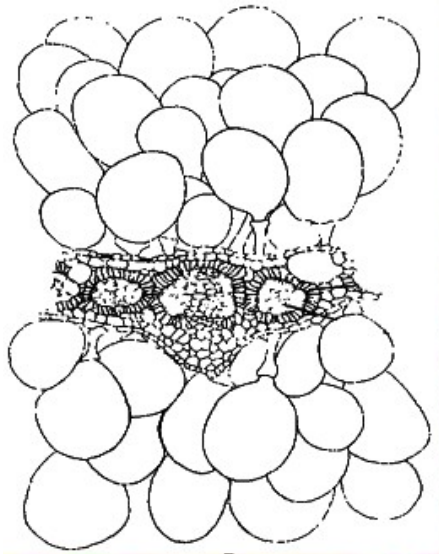


Oxalis acetosella and *Sylphium laciniatum*

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!)

Leaves and metabolism

- Mycoparasites
- Hemiparasites
- Phytoparasites (root and stem)

Mycoparasite



Triuris hyalina from South America

Hemiparasite



Krameria parvifolia from southern Texas

Root parasite



Stem parasite



Cuscuta europaea from Germany

14 Stem and shoot

14.1 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

Summary

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

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2015. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

15 Questions and answers

Previous final question: the answer

Which problems to solve hydrophytes typically have?

- Gases access
- Low light

16 Stem and shoot

16.1 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

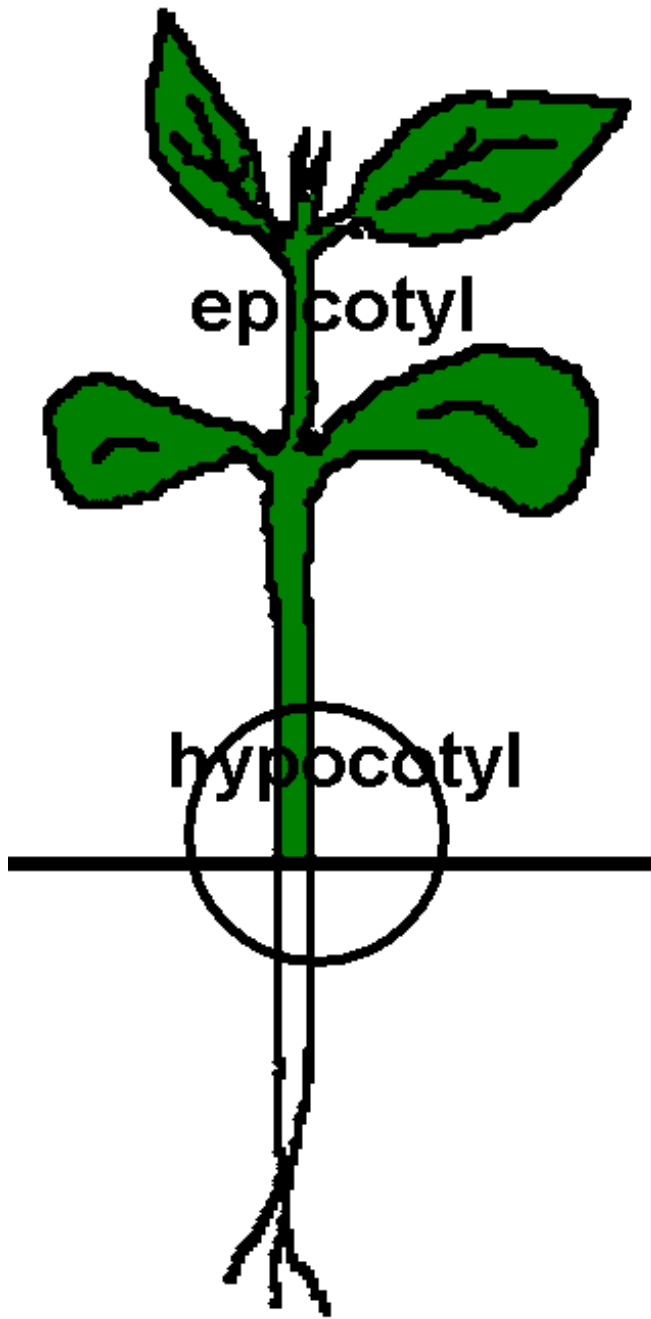
Types of plant body

- **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. Response: 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!

16.2 Anatomy of primary stem

Stem: definition and functions

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

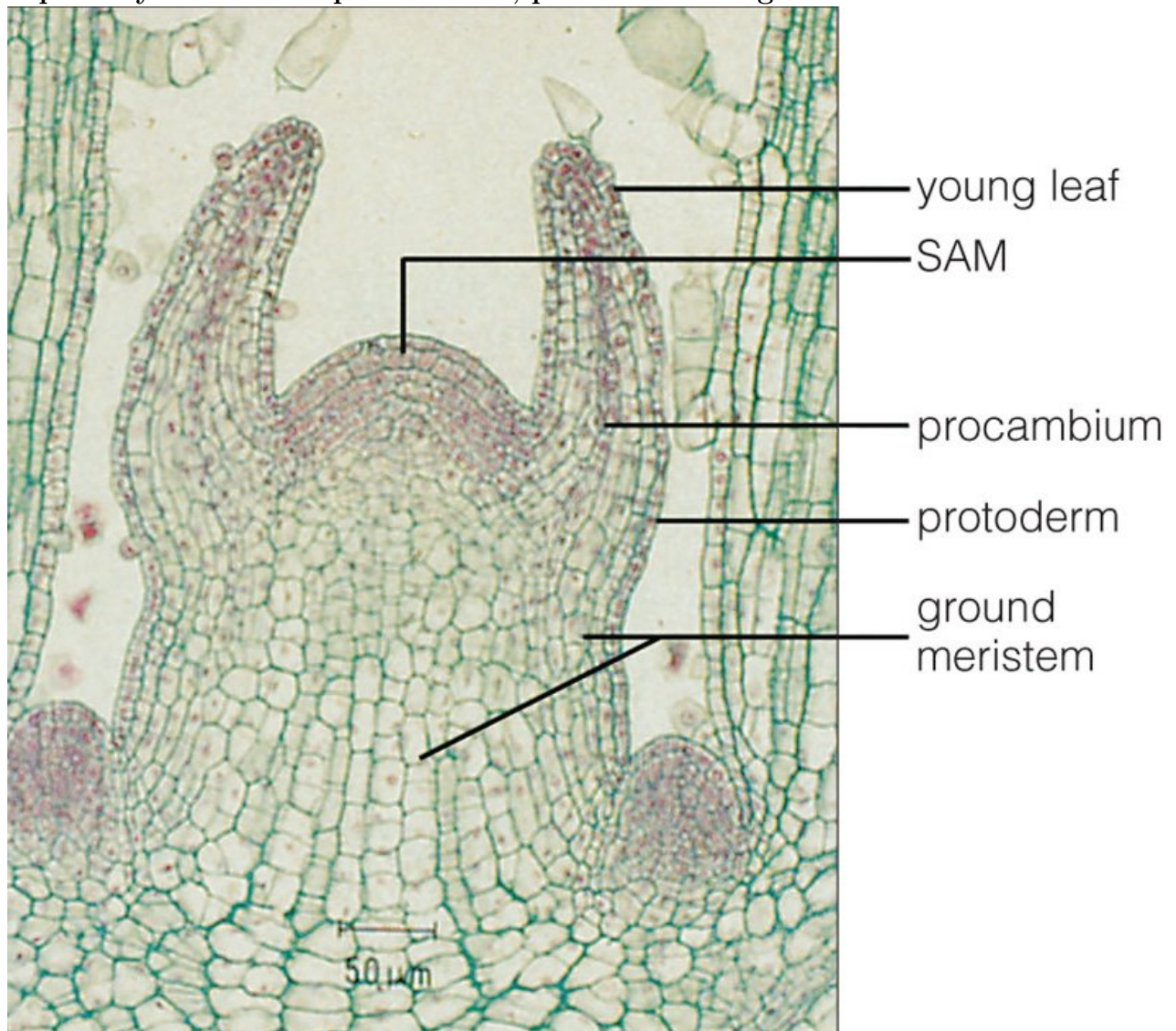
Protoderm to epidermis

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

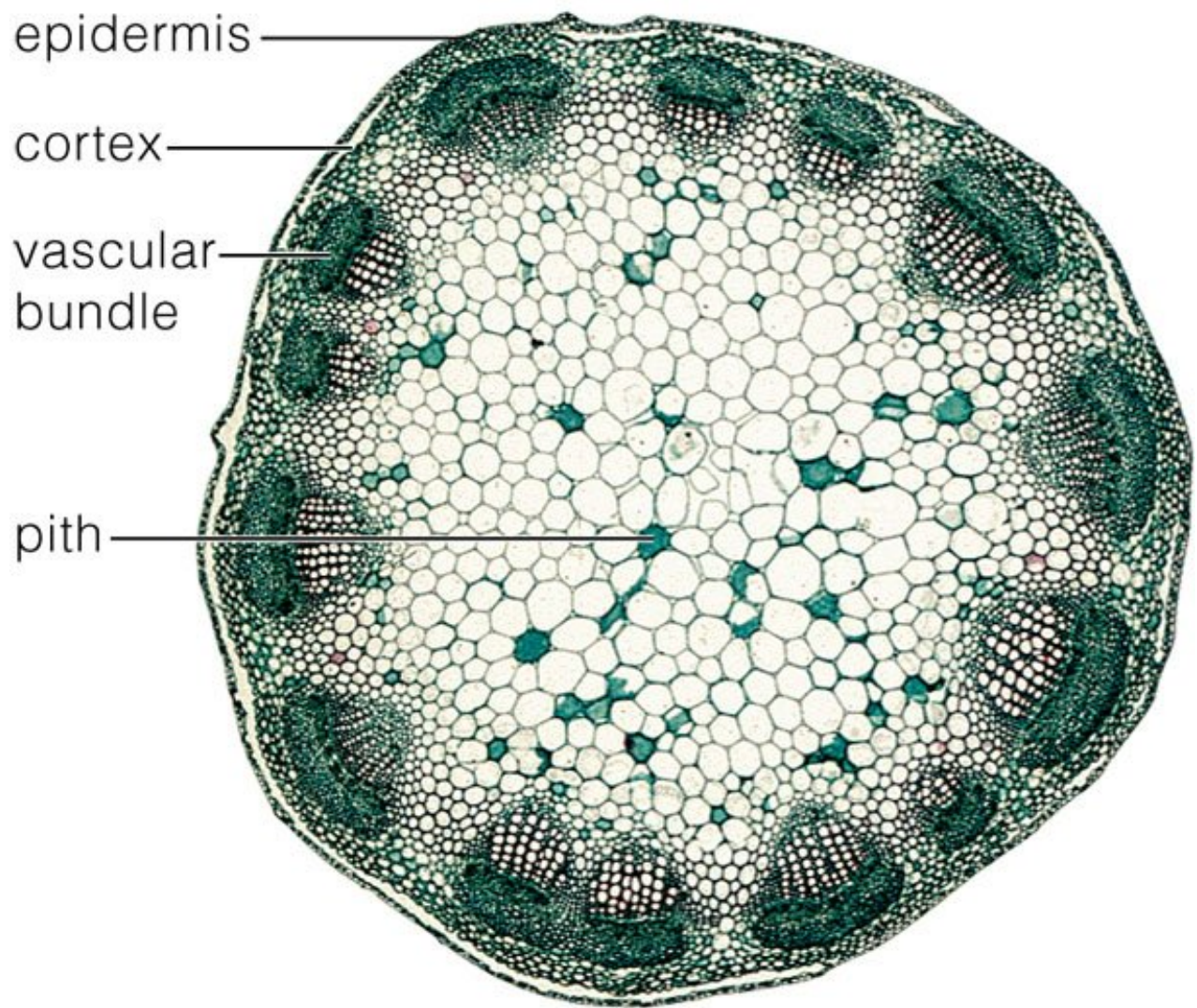
Ground meristem to cortex and pith

- 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

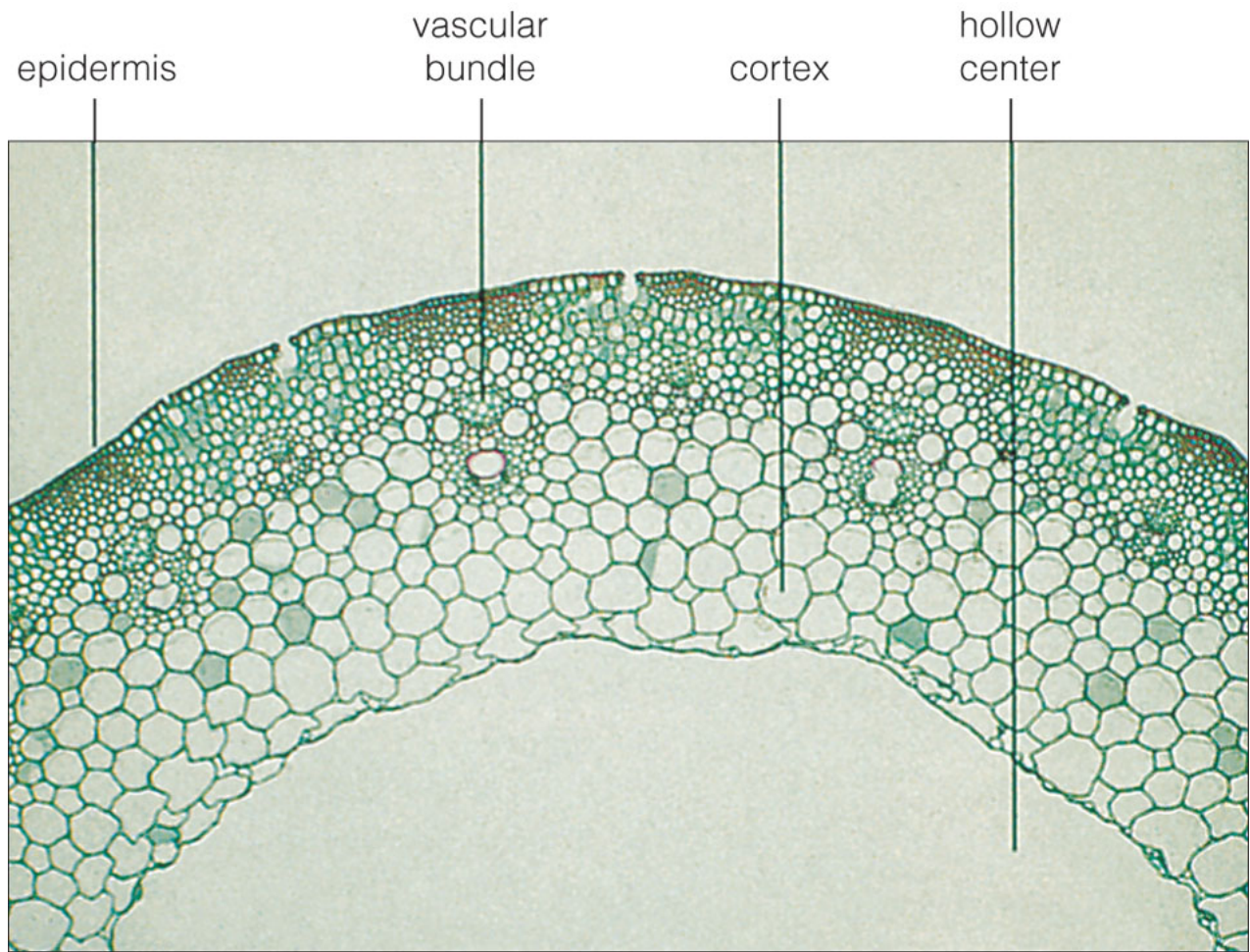
Three primary meristems: procambium, protoderm and ground meristem



Young stem with primary tissues



Older stem with hollow in the center

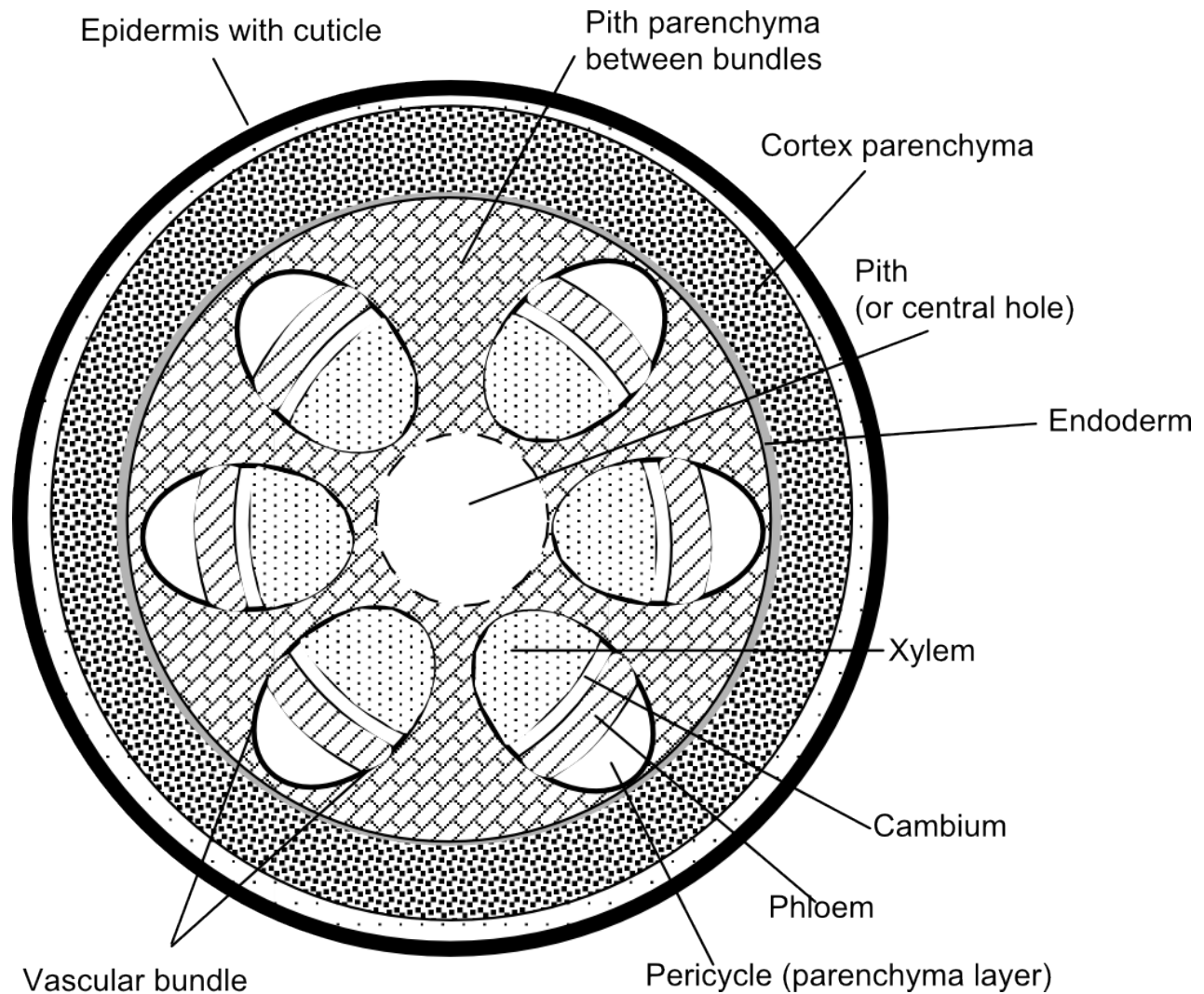


© 2006 Brooks/Cole - Thomson

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**

Primary structure of stem



Summary

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

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2015. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

17 Questions and answers

Previous final question: the answer

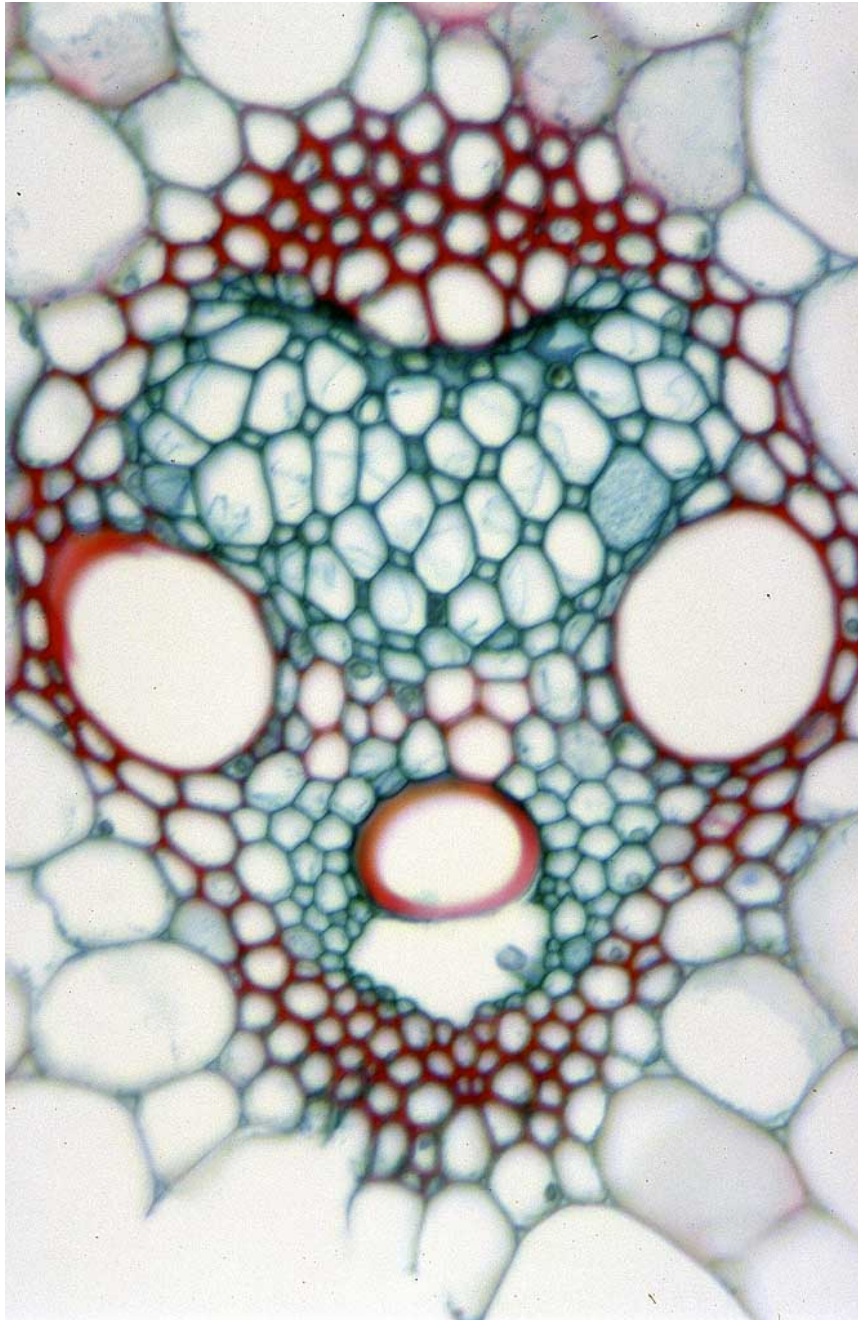
What is a procambium?

- Tissue which appears between cortex and pith and makes xylem and phloem.

18 Stem and shoot

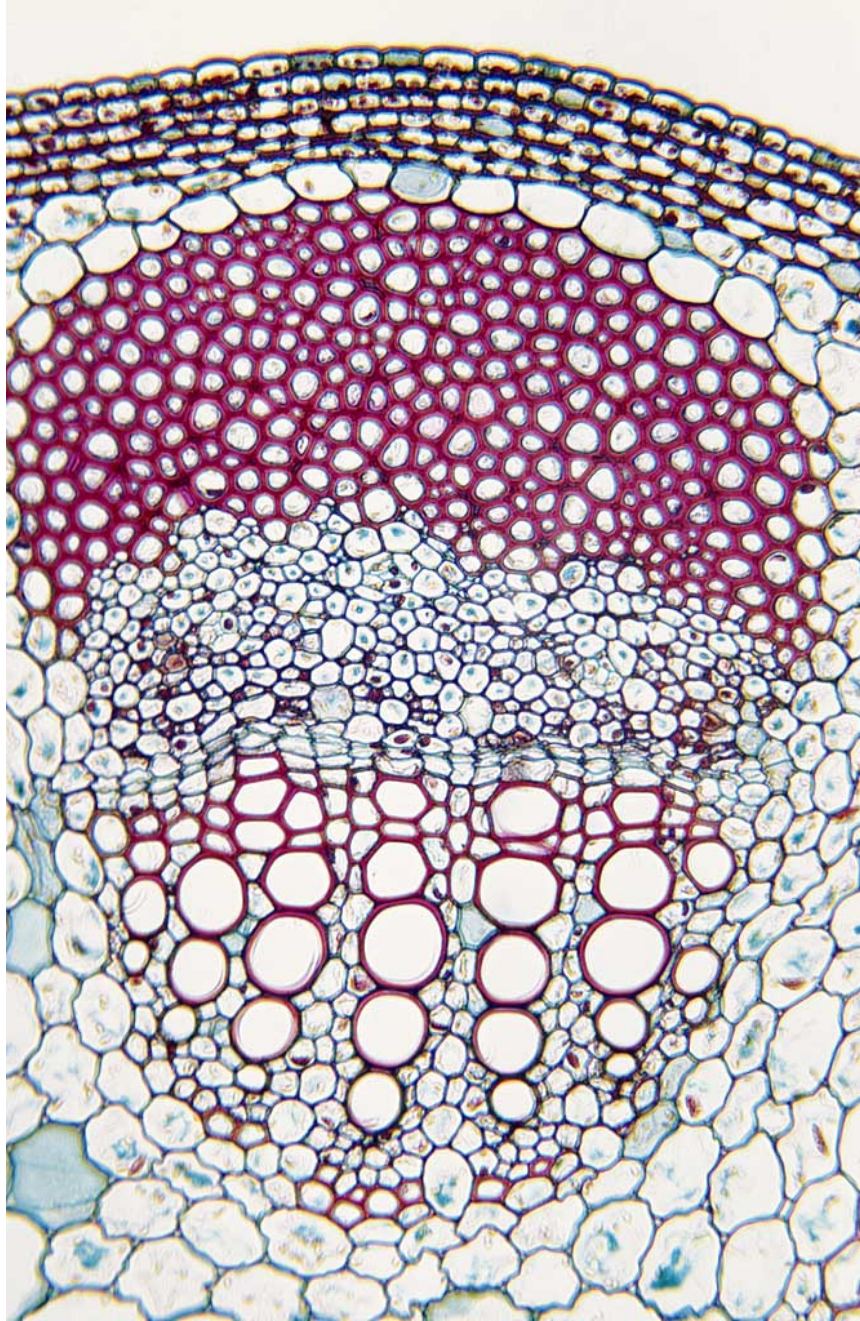
18.1 Anatomy of the primary stem

Vascular bundle (monocot)



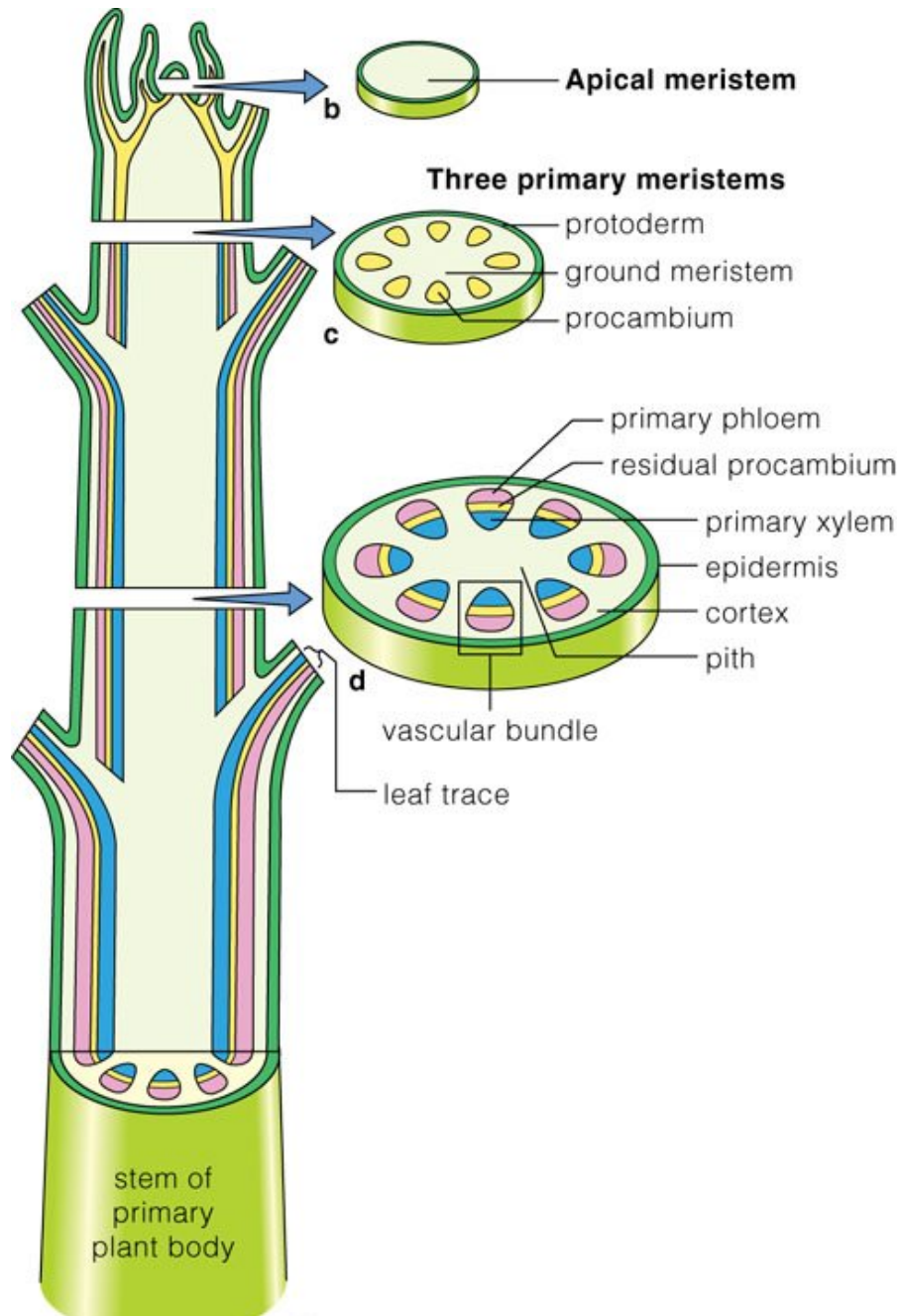
Corn (*Zea mays*) mature stem cross-section showing single vascular bundle, Brightfield (LM ×400)

Vascular bundle (asterid)



Wild Sunflower (*Helianthus* sp.) with nearly mature vascular bundle (LM $\times 35$)

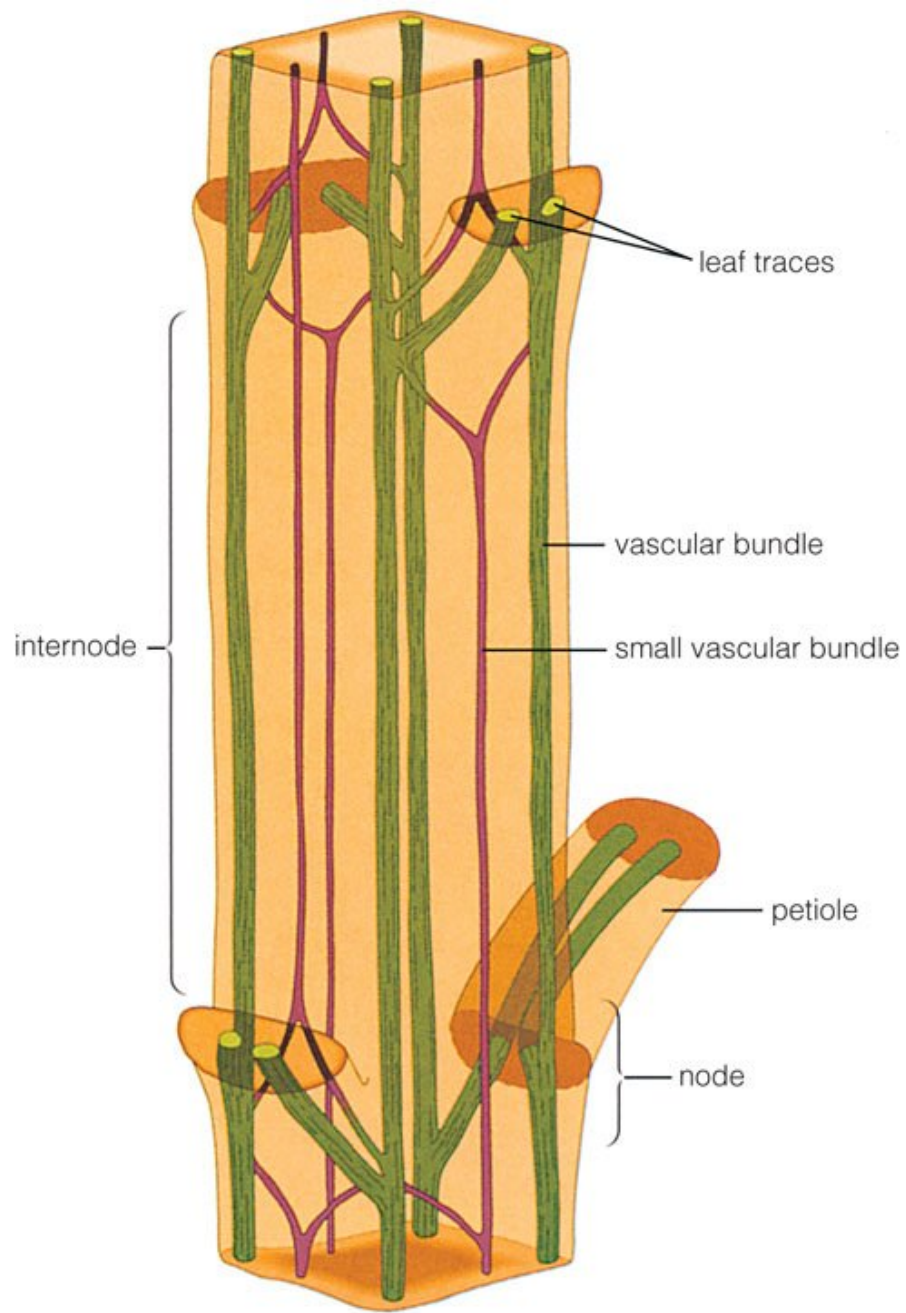
Origin of vascular bundles



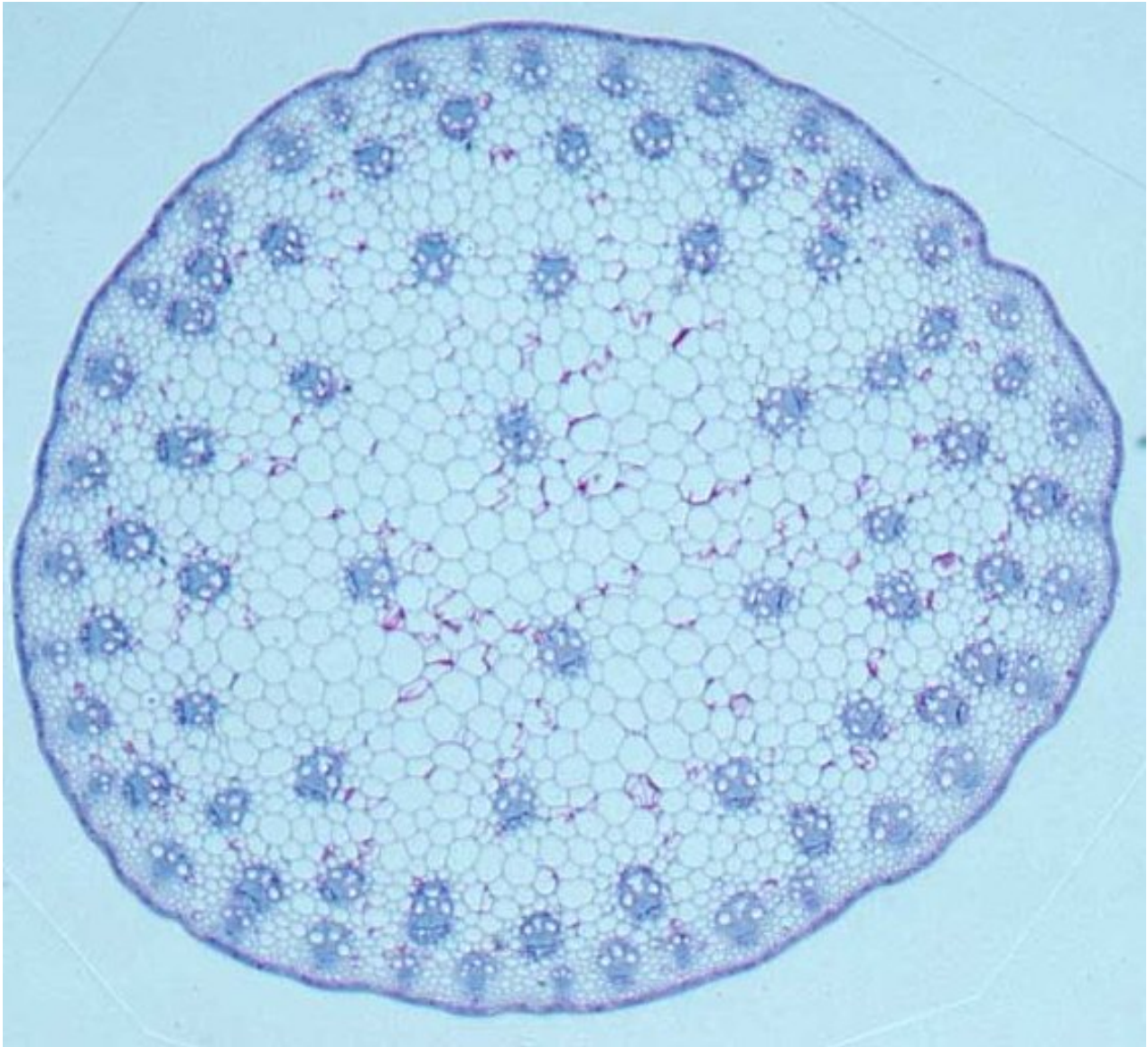
Vascular bundles

- 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

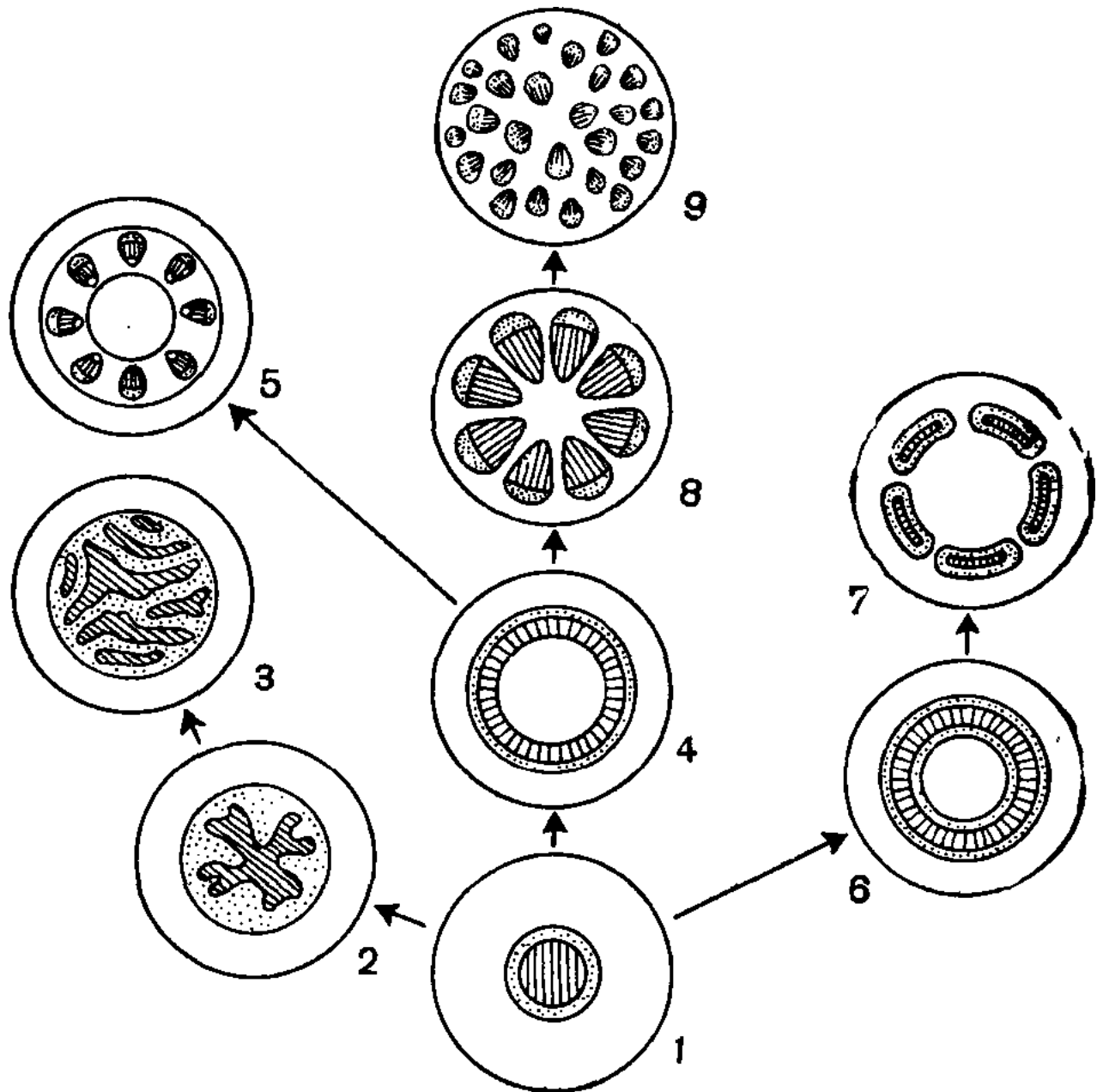


Corn (*Zea mays*) stem (LM $\times 4$)

Steles

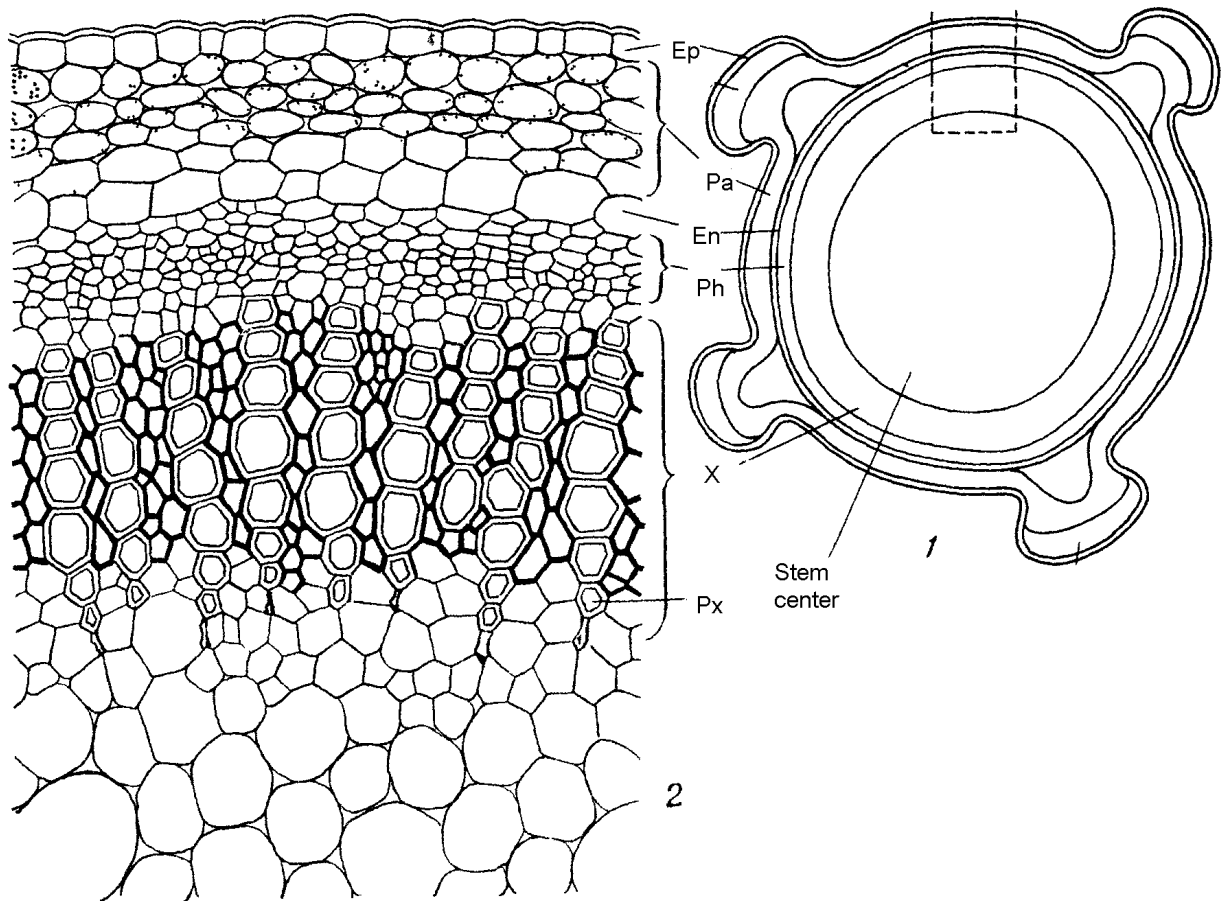
- **Stele** is an overall configuration of primary vascular system of plant stem
- The most important kinds of steles are: **protostele**, **solenostele**, **eustele** and **ataktostele***

Diversity of steles



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

Vascular cylinder: alternative to ring of bundles



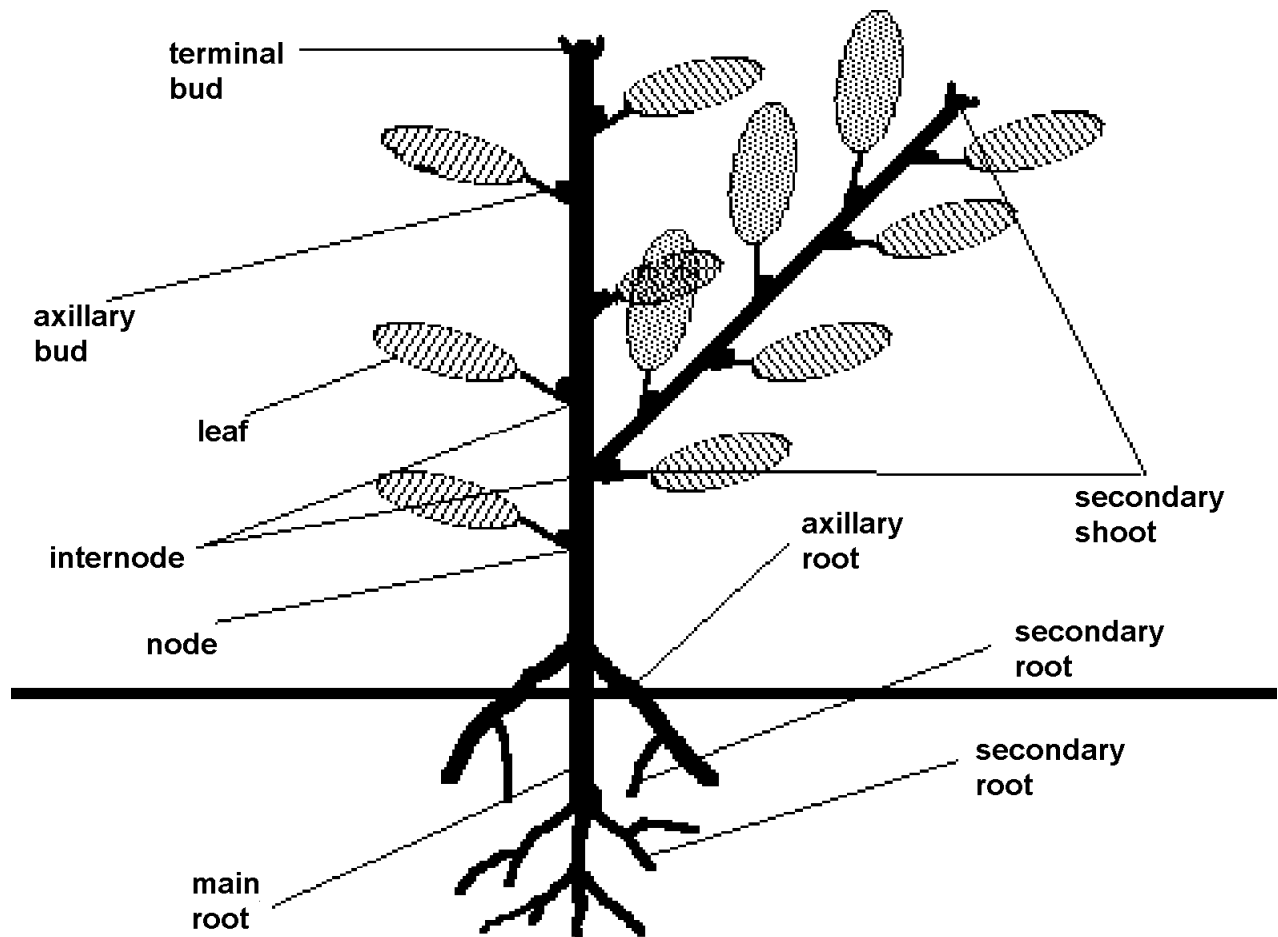
Sometimes, vascular bundles are so dense that they form almost a cylinder. We may call this vascular cylinder “solenostele” (#4 on the scheme of steles)

18.2 Components of shoot

Components of vegetative shoot system

1. Main and secondary shoots
2. Terminal and axillary (lateral) buds
3. Nodes and internodes
4. Leaves

Components of shoot

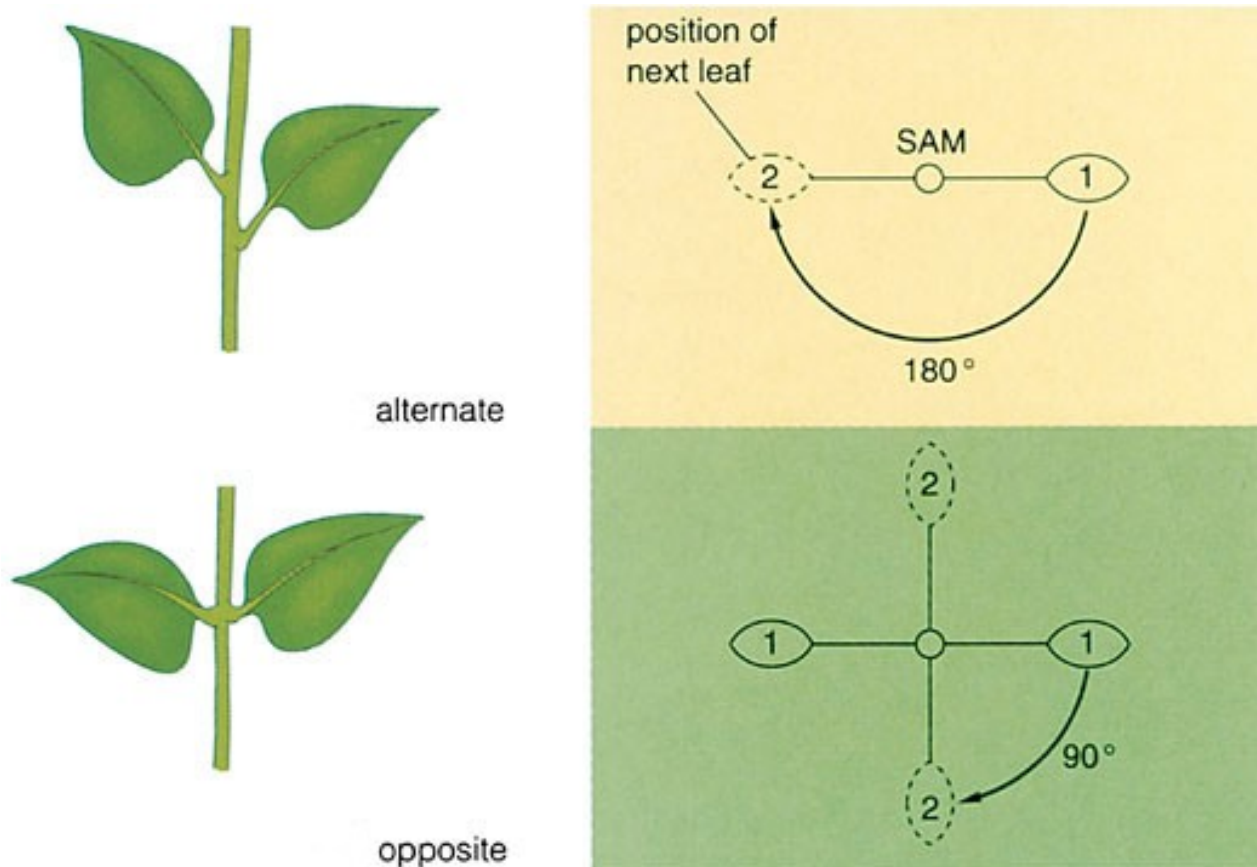


18.3 Phyllotaxis

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 rotate)
- Each type of phyllotaxis has its own *angle of divergence*

Alternate and opposite phyllotaxes



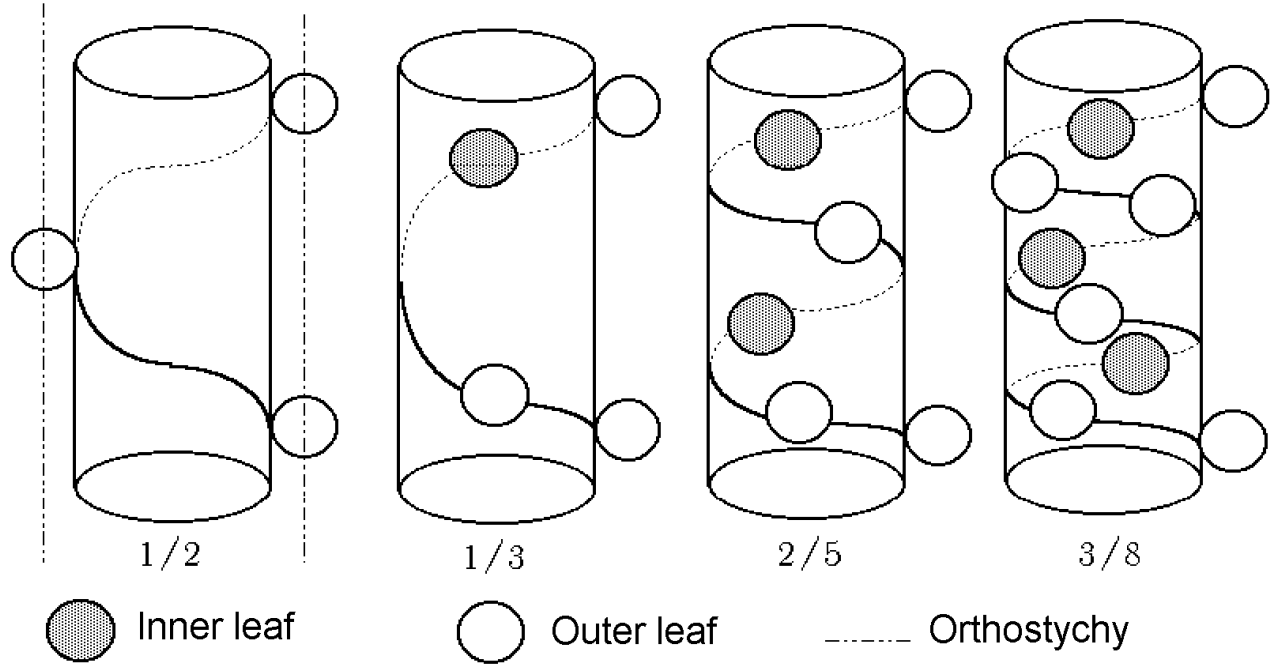
Spiral phyllotaxis: Fibonacci rule

- Multiple types of leaf spiral leaf arrangement mostly follow **Fibonacci rule**
- Formulas of leaf arrangements is very similar to Fibonacci 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)

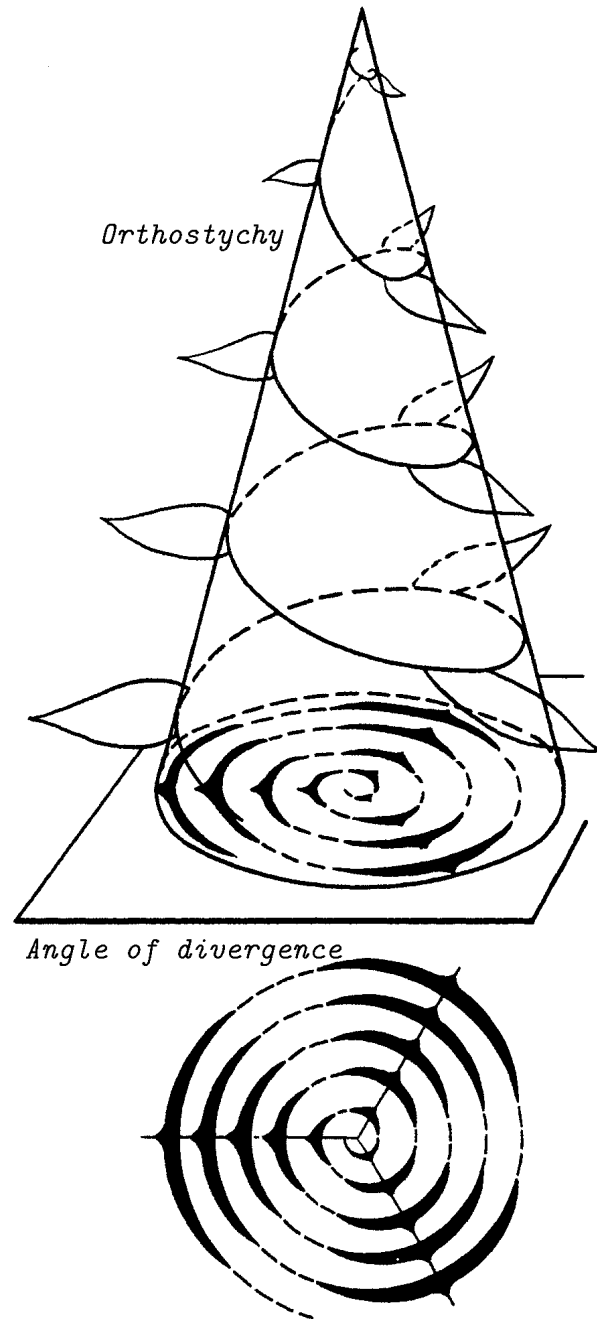
Spiral phyllotaxis: how to make a formula

- 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



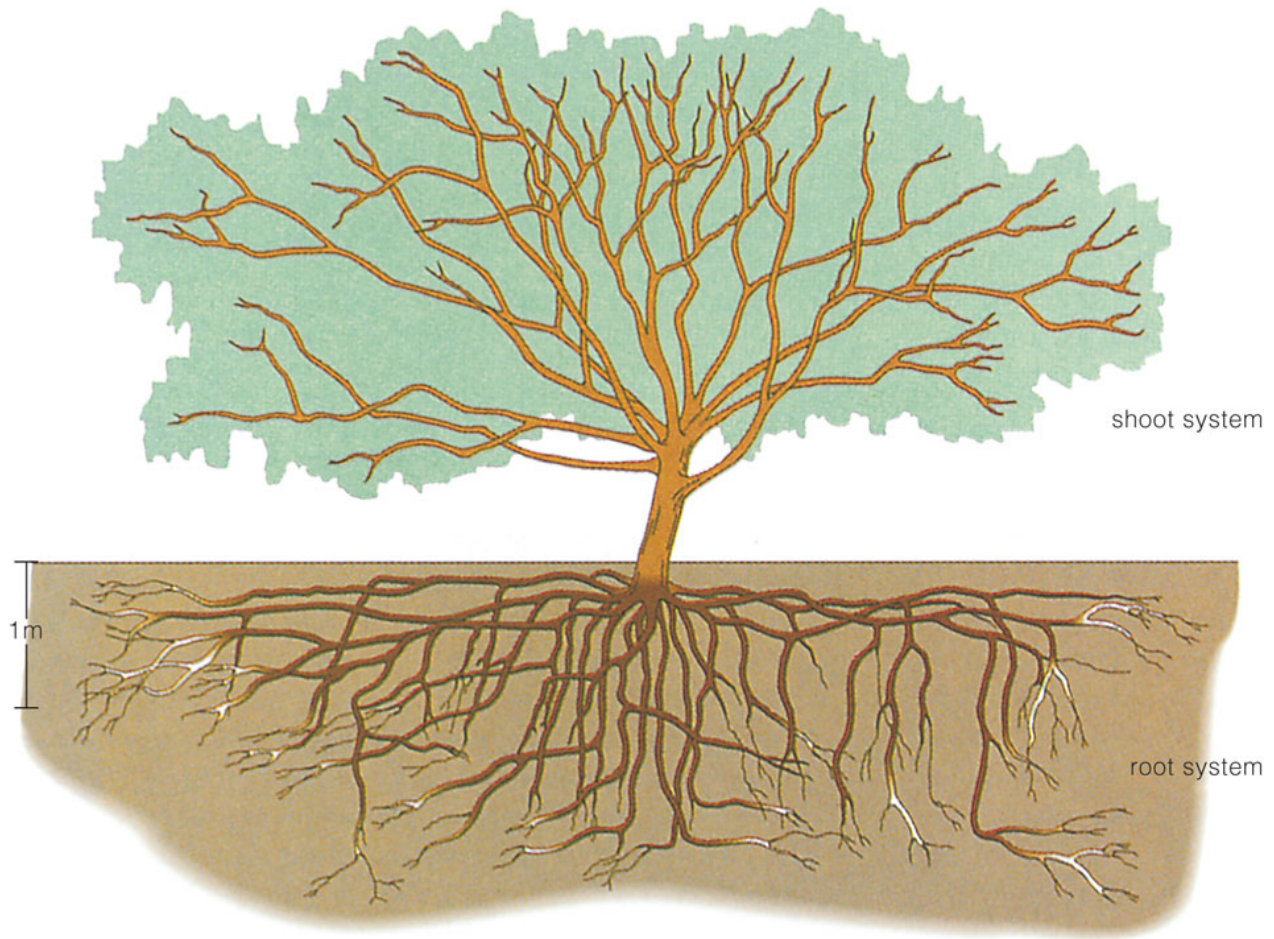
Spiral phyllotaxis: angles of divergence for 1/3



19 Root

19.1 Root morphology

Root system and shoot system



© 2006 Brooks/Cole - Thomson

Definition and functions

- Axial vegetative organ with a function of soil nutrition
- Other functions:
 1. Anchor
 2. Synthesis
 3. Storage
 4. Communication
- Features:
 1. No leaves
 2. Geotropic growth
 3. 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



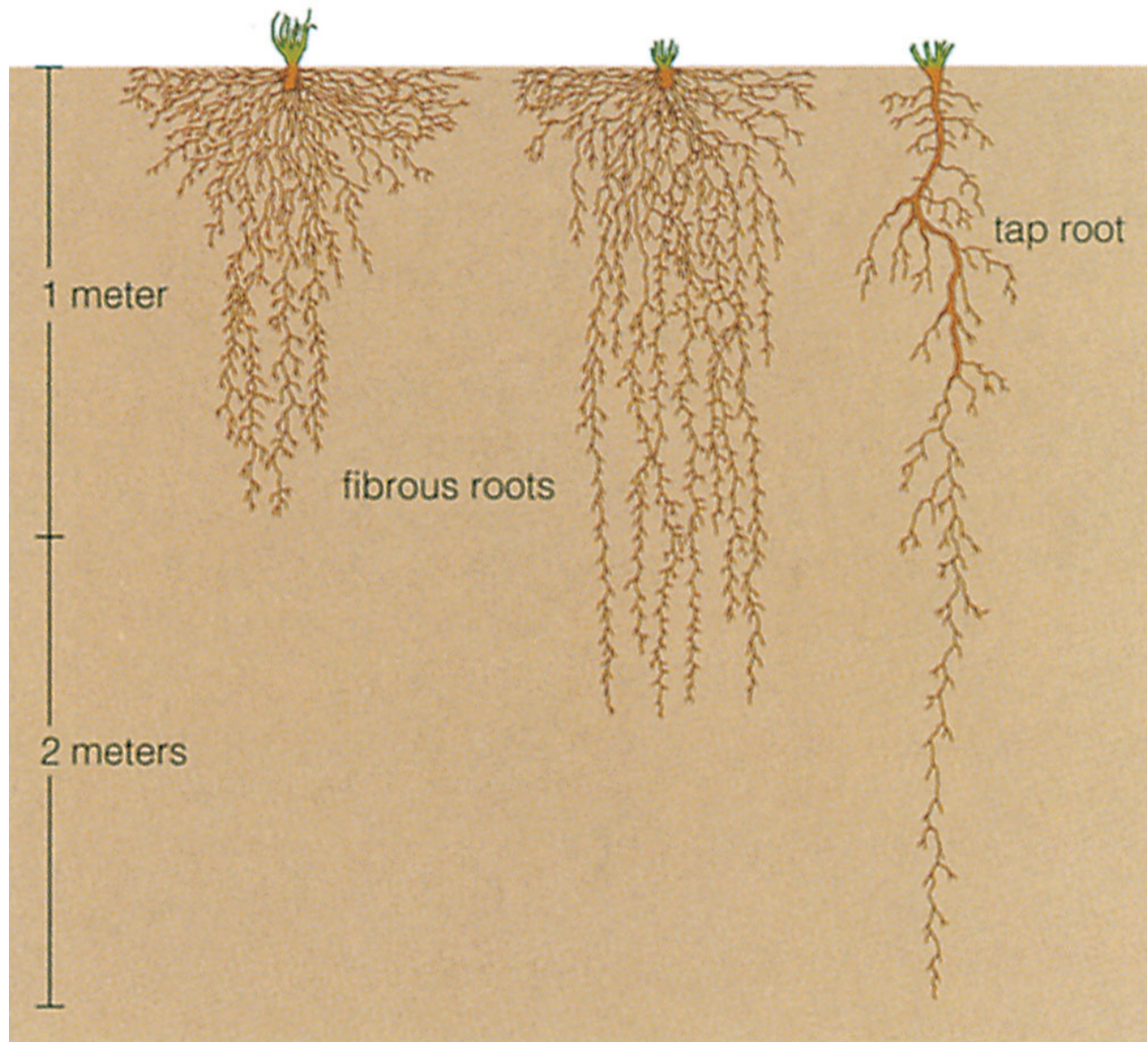
Adventitious roots



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



© 2006 Brooks/Cole - Thomson

Summary

- SAM produces **protoderm** and **ground meristem**, ground meristem differentiates into **cortex** and **pith**
- Procambium forms **vascular bundles** or vascular cylinder
- Outer layers of procambium transform into primary phloem, inner layers — into primary xylem
- Monocot stem usually has dispersed vascular bundles (**ataktostele**)
- Spiral arrangement of leaves follows **Fibonacci** rule

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2015. Mode of access: http://ashipunov.info/shipunov/school/biol_154

Outline

20 Questions and answers

Previous final question: the answer

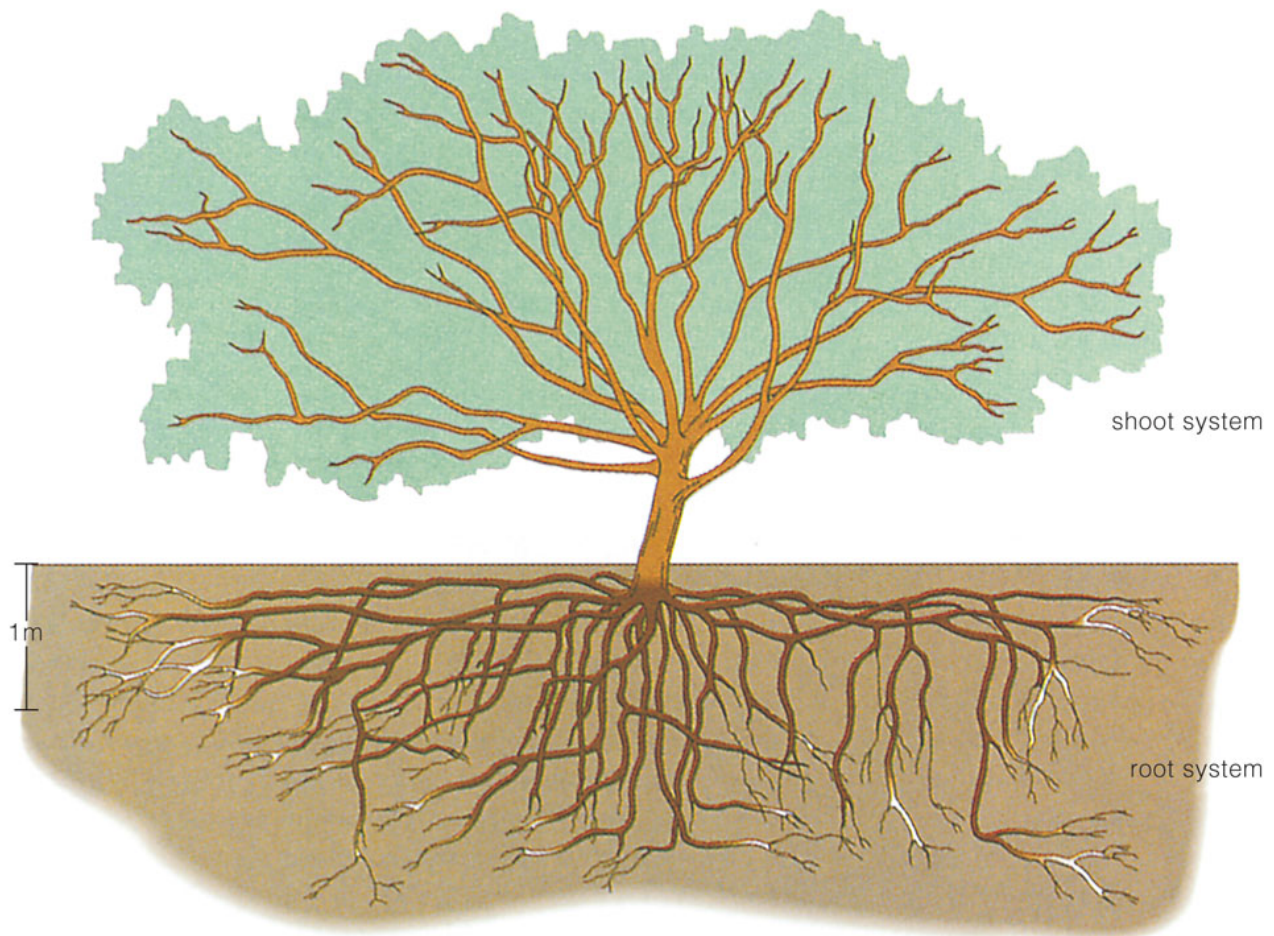
What is angle of divergence?

- Angle between orthostichy: radial planes in which leaves are located around stem.

21 Root

21.1 Root morphology

Root system and shoot system



© 2006 Brooks/Cole - Thomson

Definition and functions

- Axial vegetative organ with a function of soil nutrition
- Other functions:
 1. Anchor
 2. Synthesis
 3. Storage
 4. Communication
- Features:
 1. No leaves
 2. Geotropic growth
 3. 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



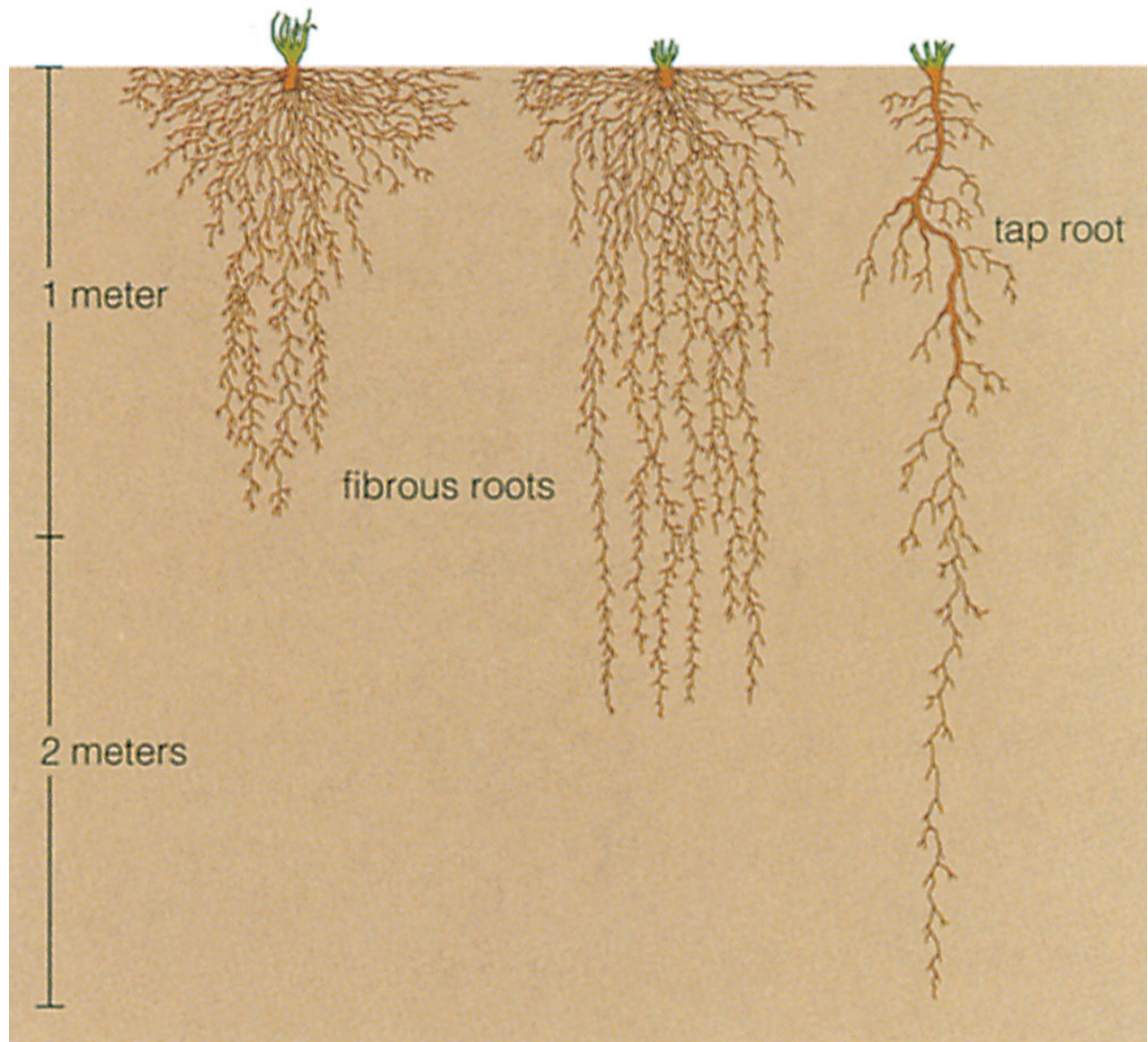
Adventitious roots



Root systems

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

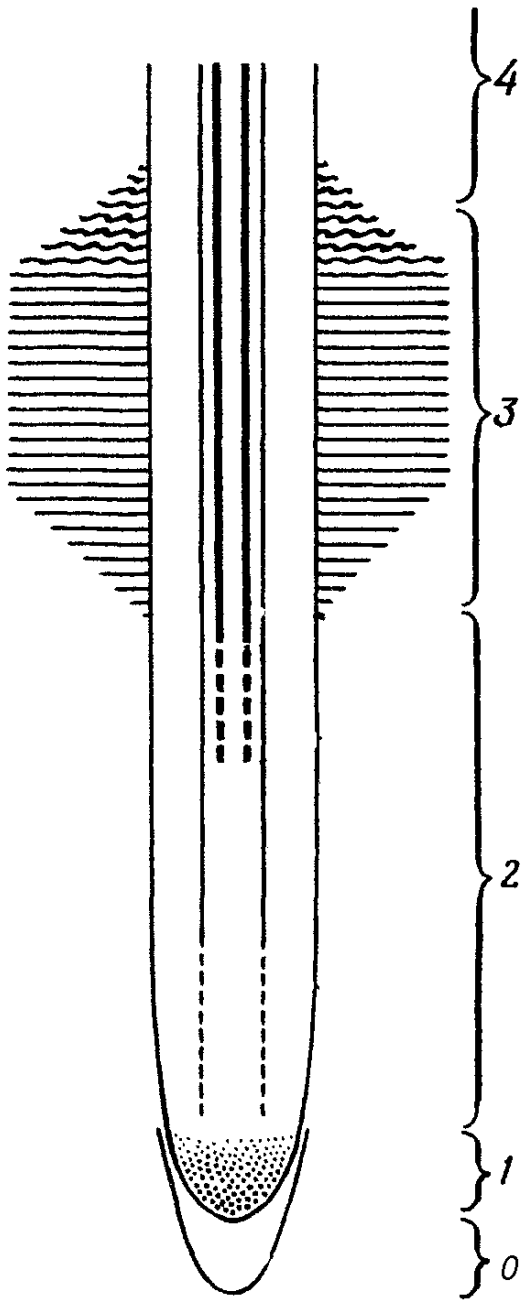
Fibrous and tap root systems



© 2006 Brooks/Cole - Thomson

21.2 Anatomy and development of roots

Root zones



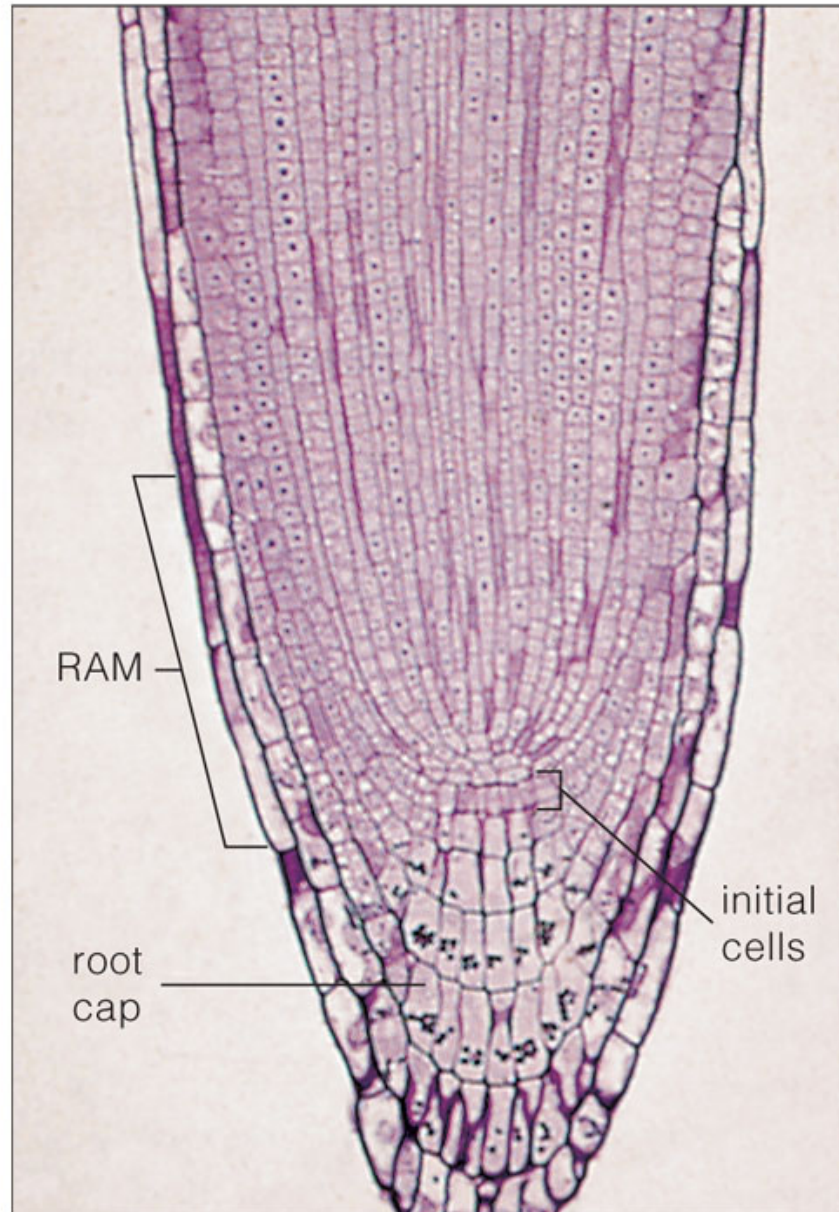
- Root cap
- Root meristem
- Elongation zone
- Absorption zone
- Maturation zone

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



© 2006 Brooks/Cole - Thomson

Periphery of root

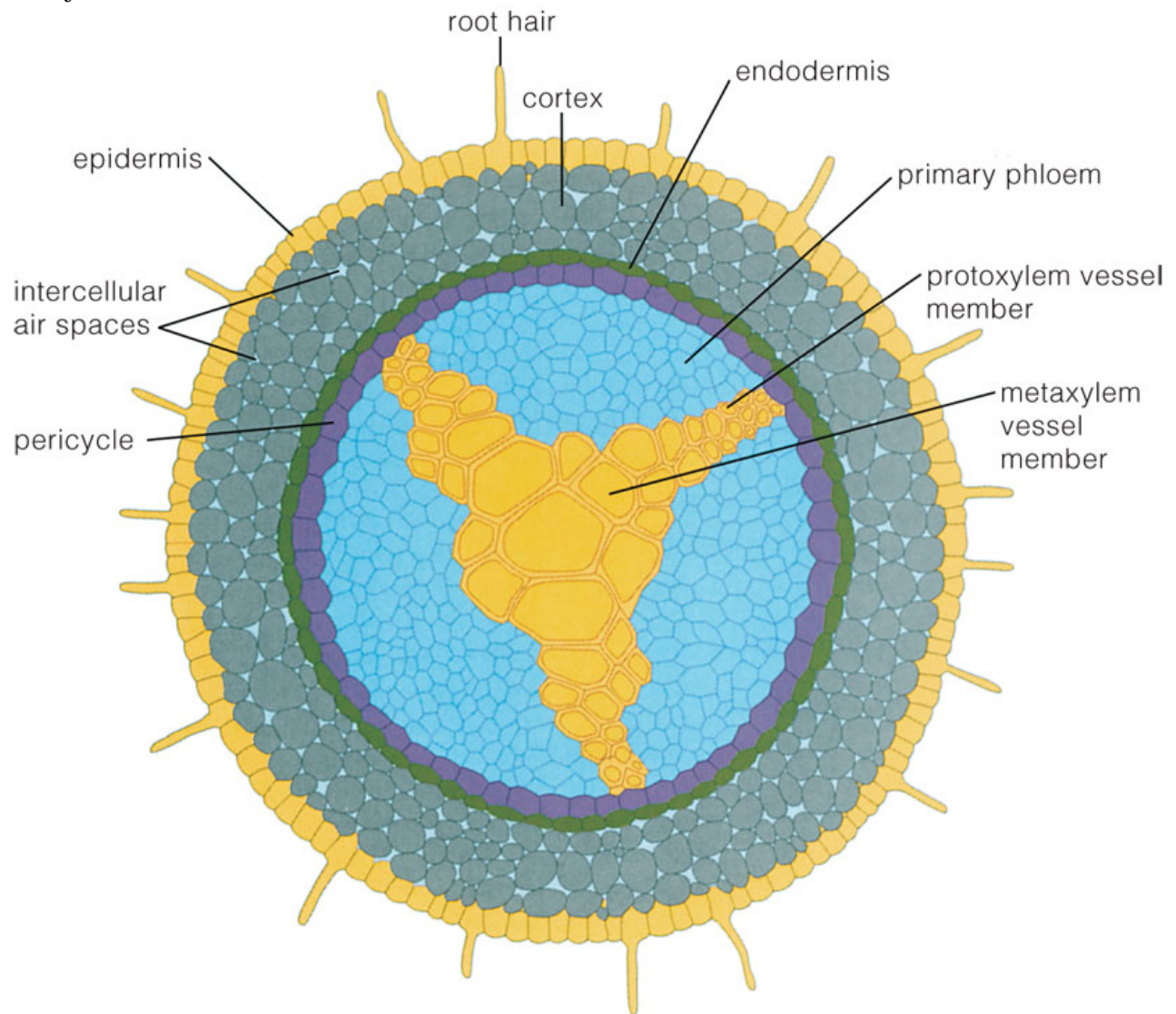
- Rhizoderm (root epidermis): fast-degrading cells
- Cortex, which includes also:
 - Endoderm: 1-cell layer with specialized cell walls, located on the border with vascular cylinder
 - And (sometimes) exoderm: similar to endoderm but located just under rhizoderm

- 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

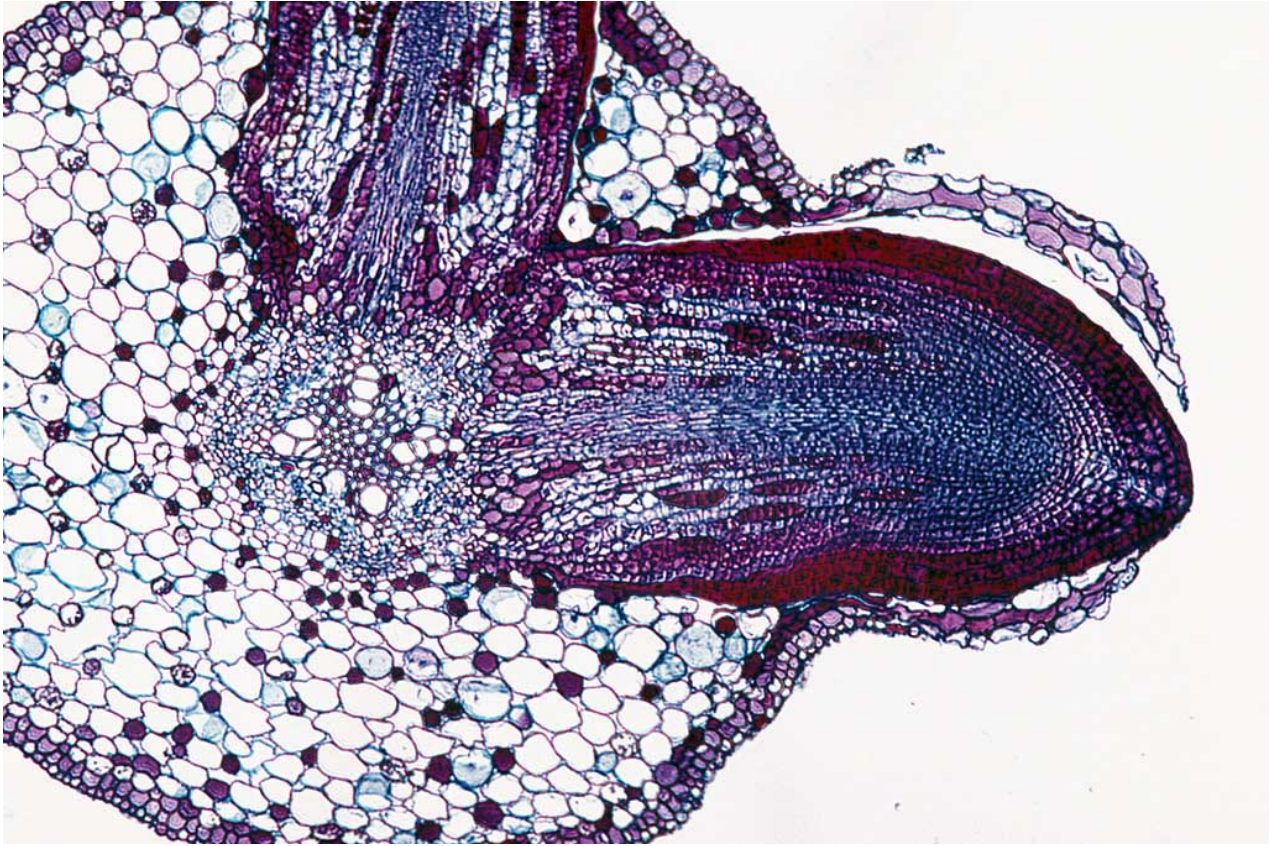


© 2006 Brooks/Cole - Thomson

Pericycle

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

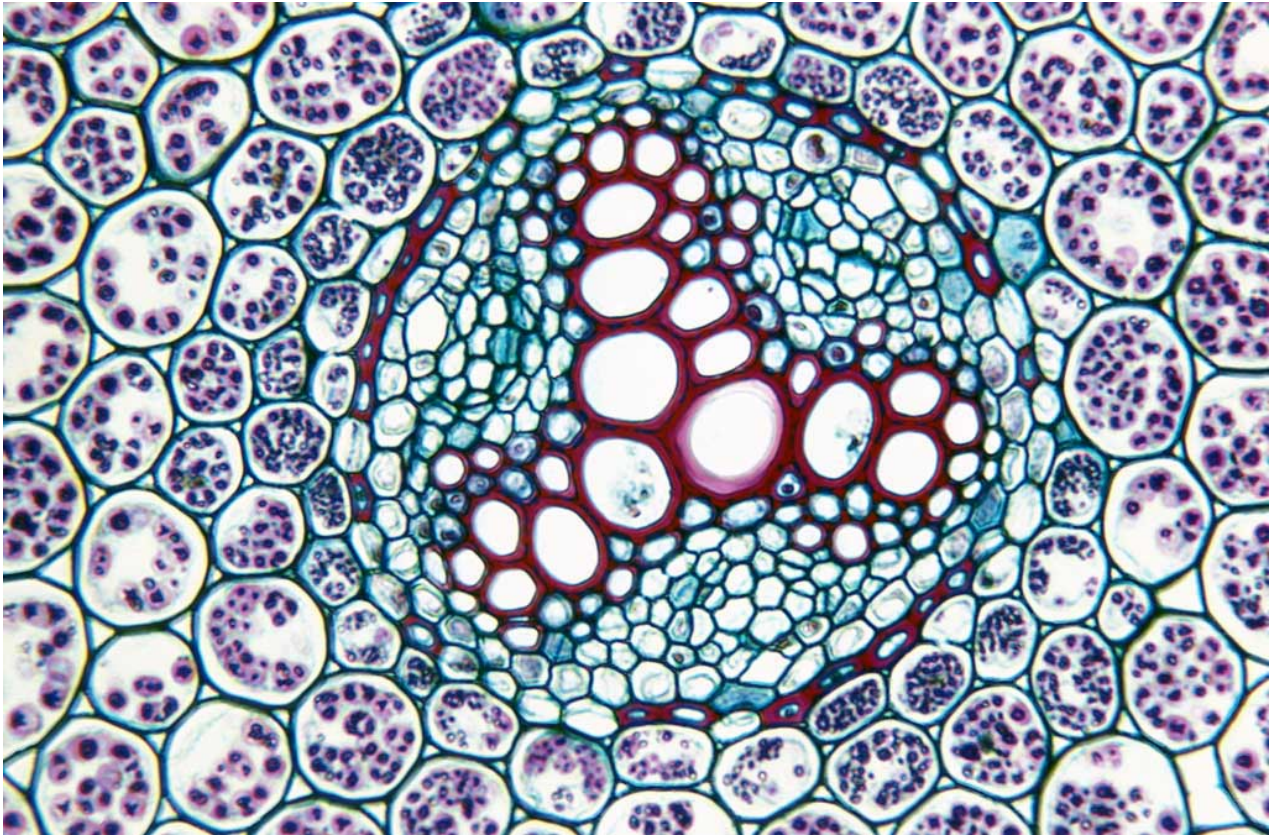
Development of lateral roots



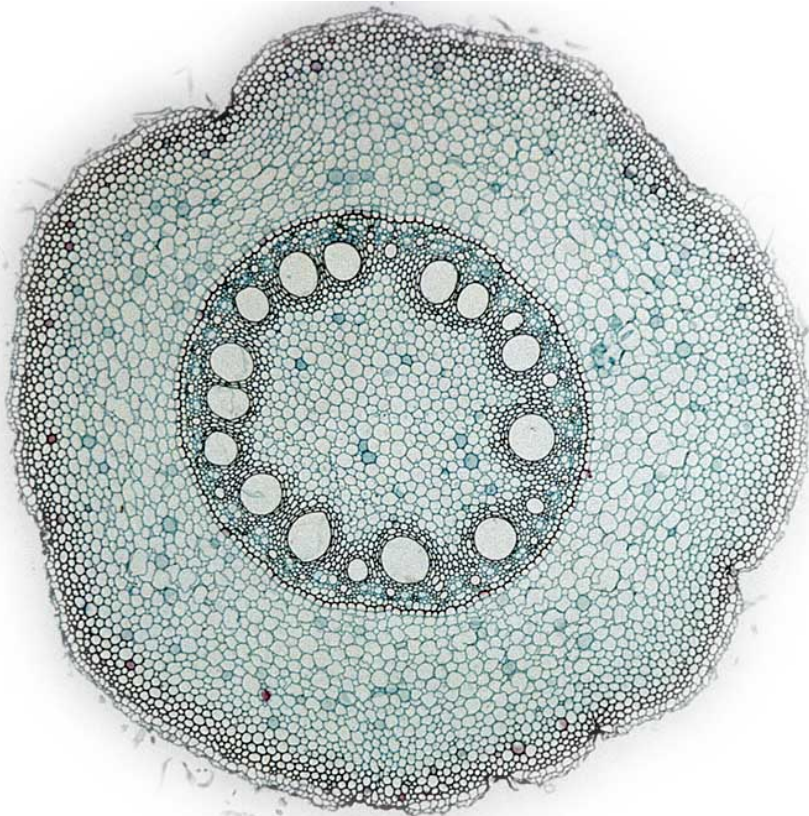
Vascular bundle

- 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.)

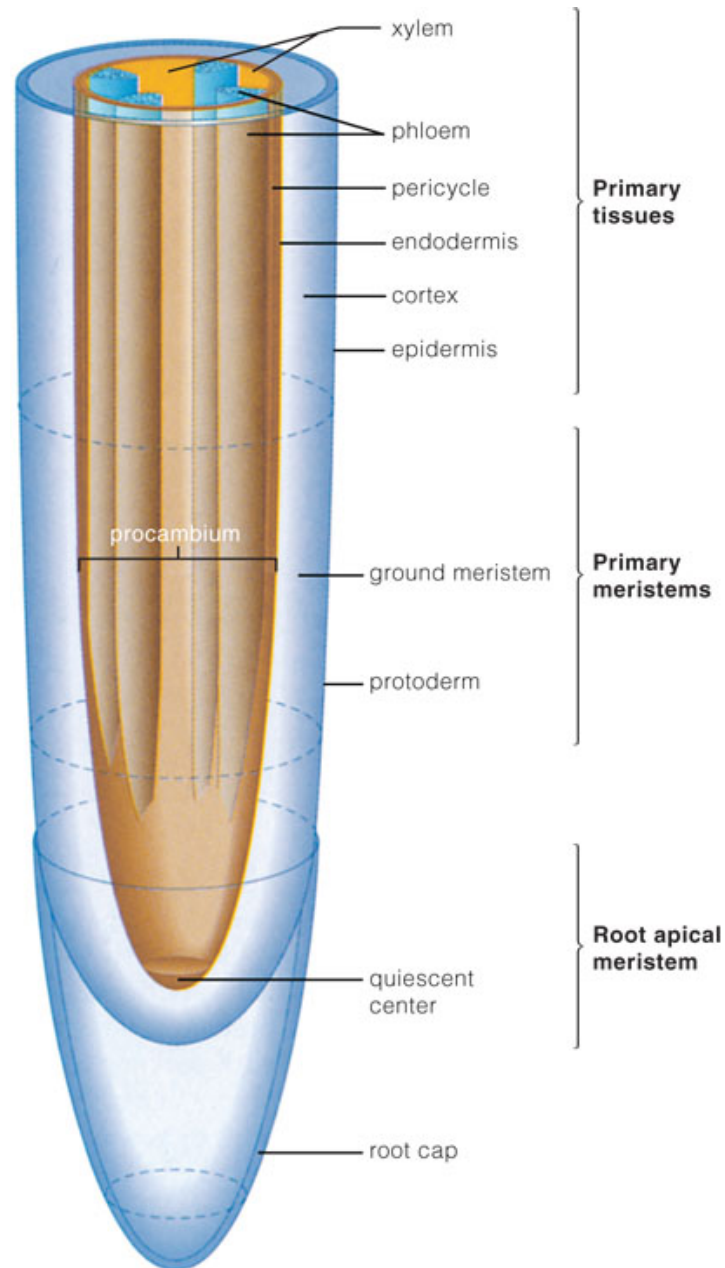


Root of monocot (*Zea mays*)



21.3 Origins of root tissues

Development of tissues



© 2006 Brooks/Cole - Thomson

21.4 Water transport in roots

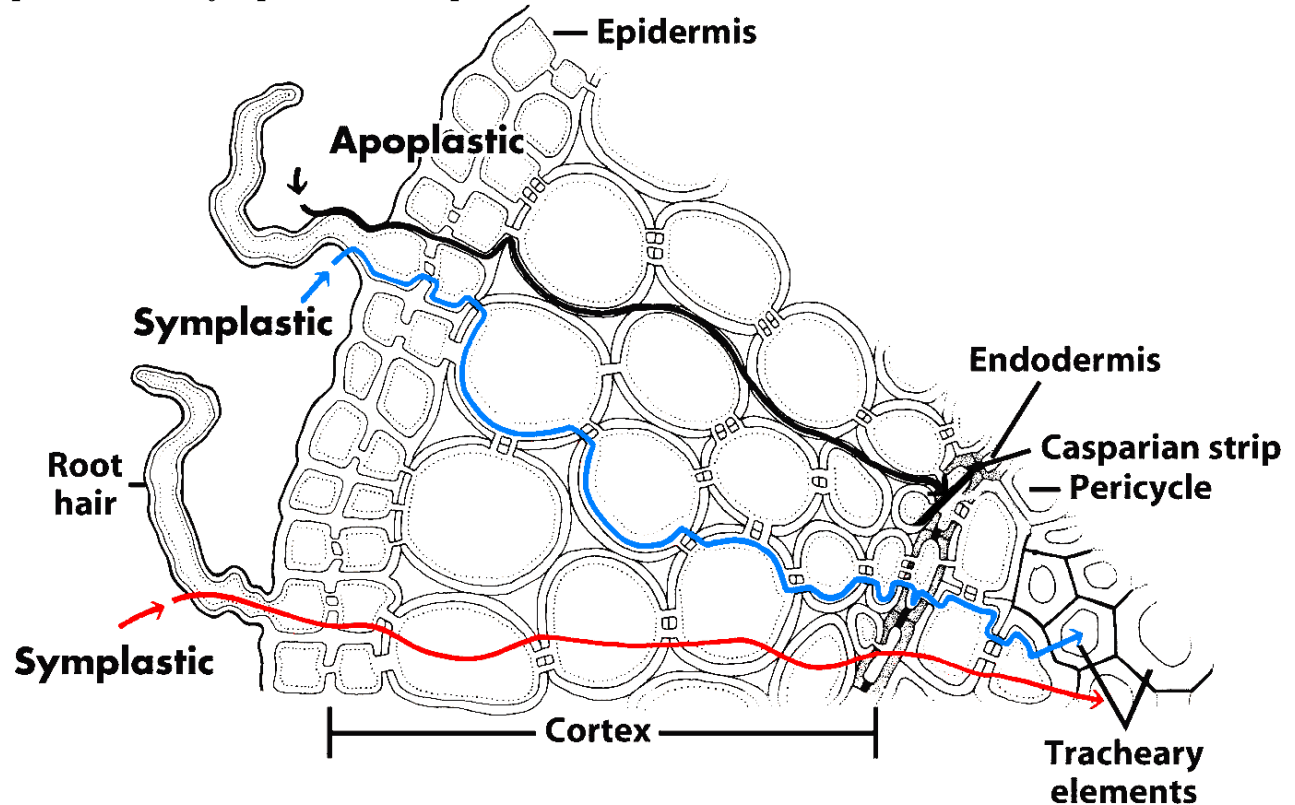
Rhizoderm and osmosis

- 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

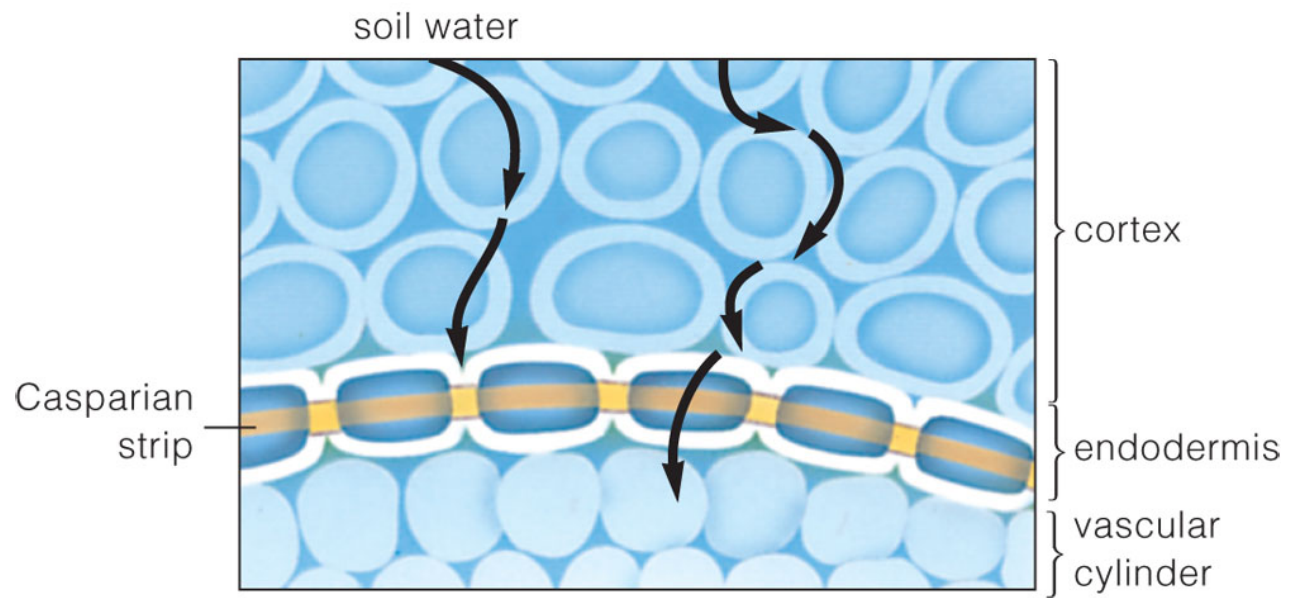
Endoderm and root pressure

- From rhizoderm to endoderm, transport of water is both symplastic and apoplastic
- In the endoderm 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

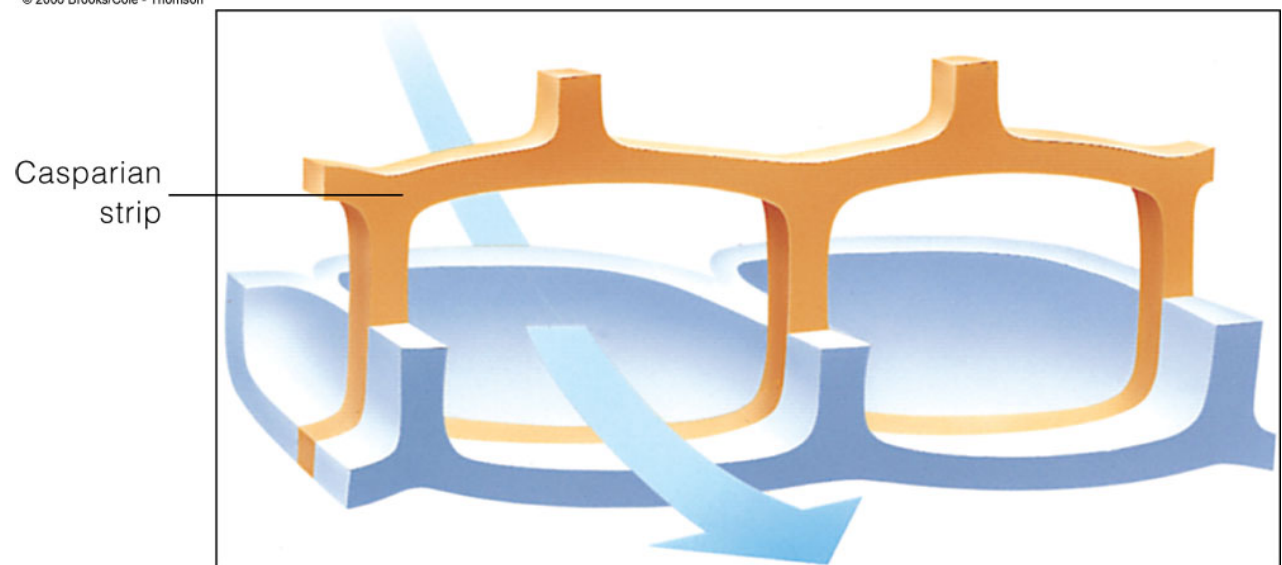
Apoplastic and symplastic transport in the root



Casparian strips

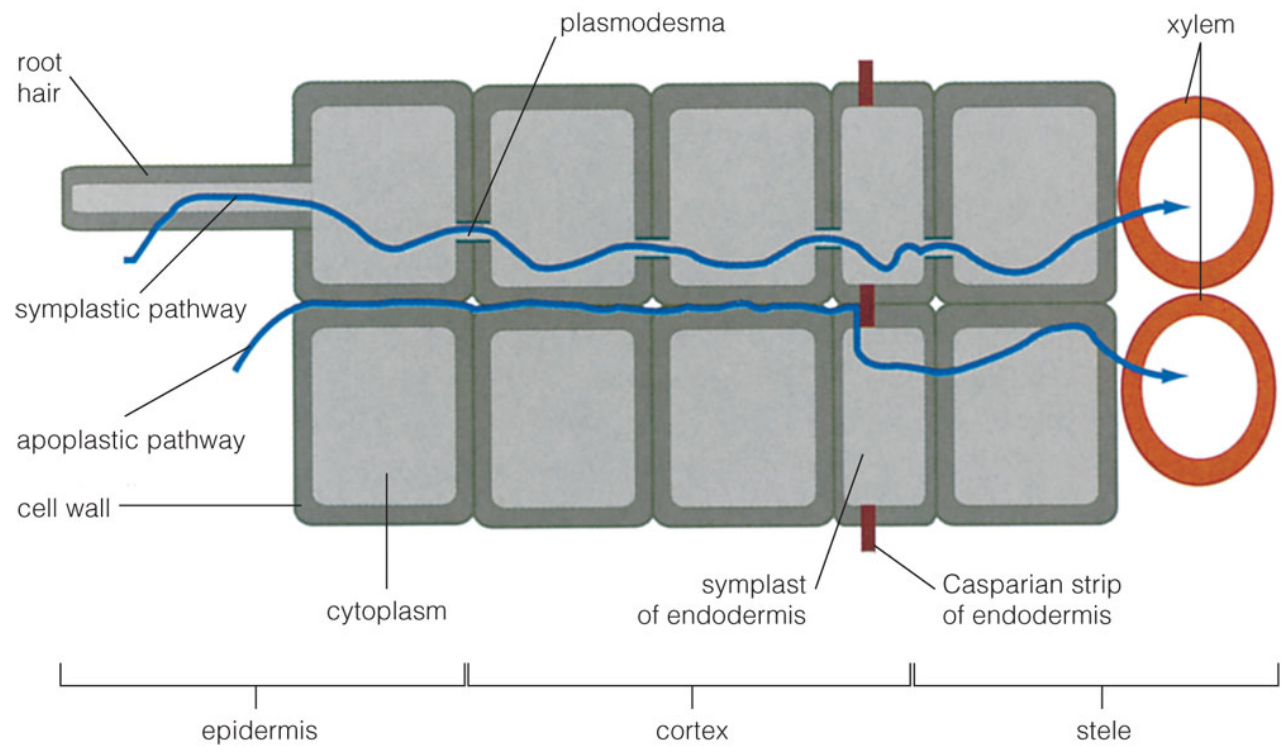


© 2006 Brooks/Cole - Thomson



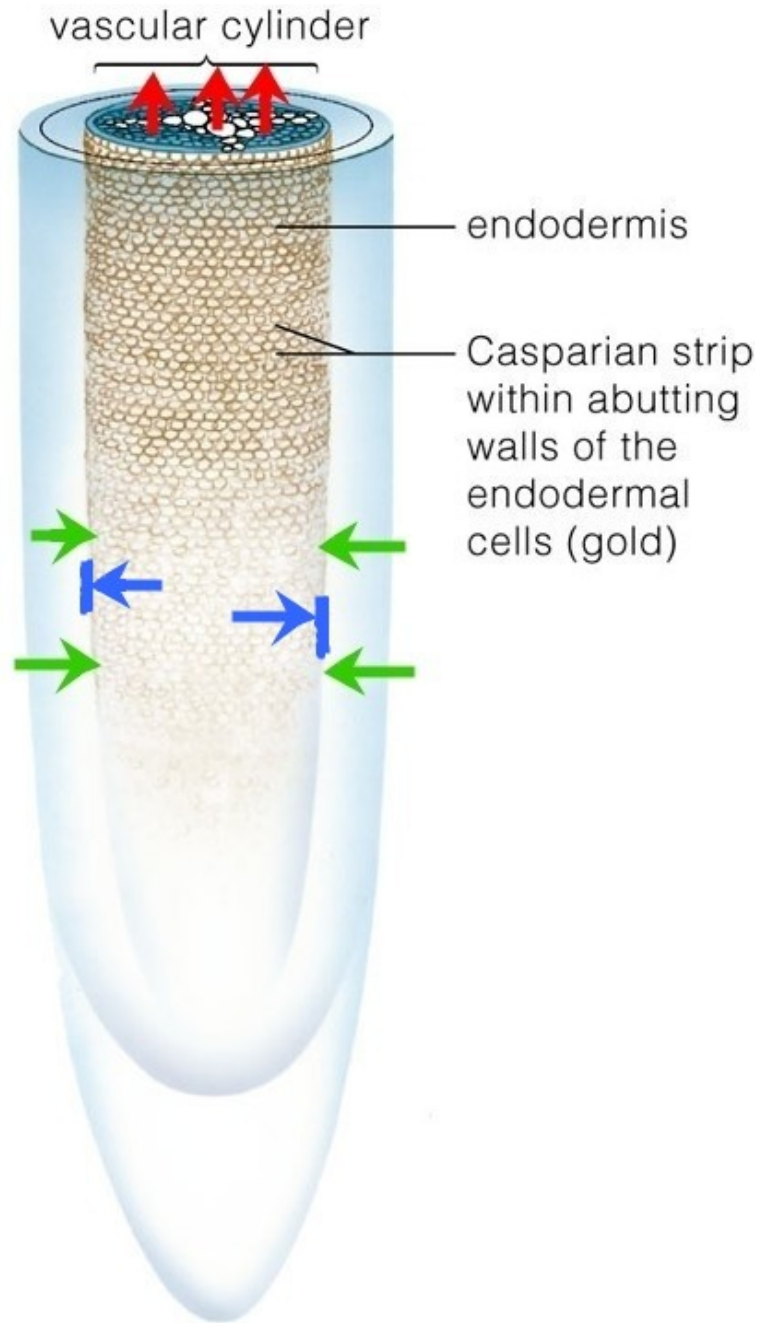
© 2006 Brooks/Cole - Thomson

How Casparian strips are working



© 2006 Brooks/Cole - Thomson

Origin of root pressure



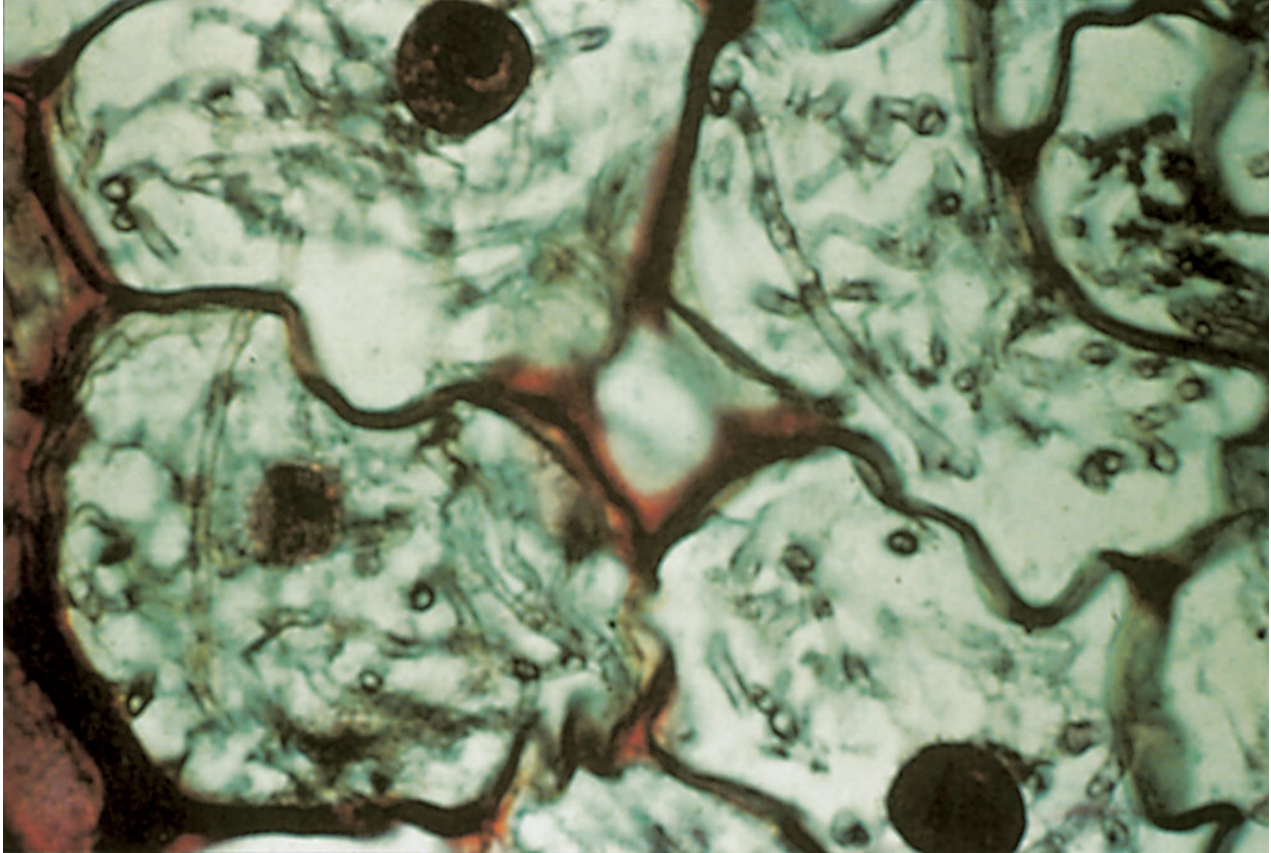
21.5 Diversity of roots

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.—hyacinth, *Taraxacum* spp.—dandelion)
- Storage roots (*Daucus carota*—carrot, *Armoracia officinalis*—horseradish)

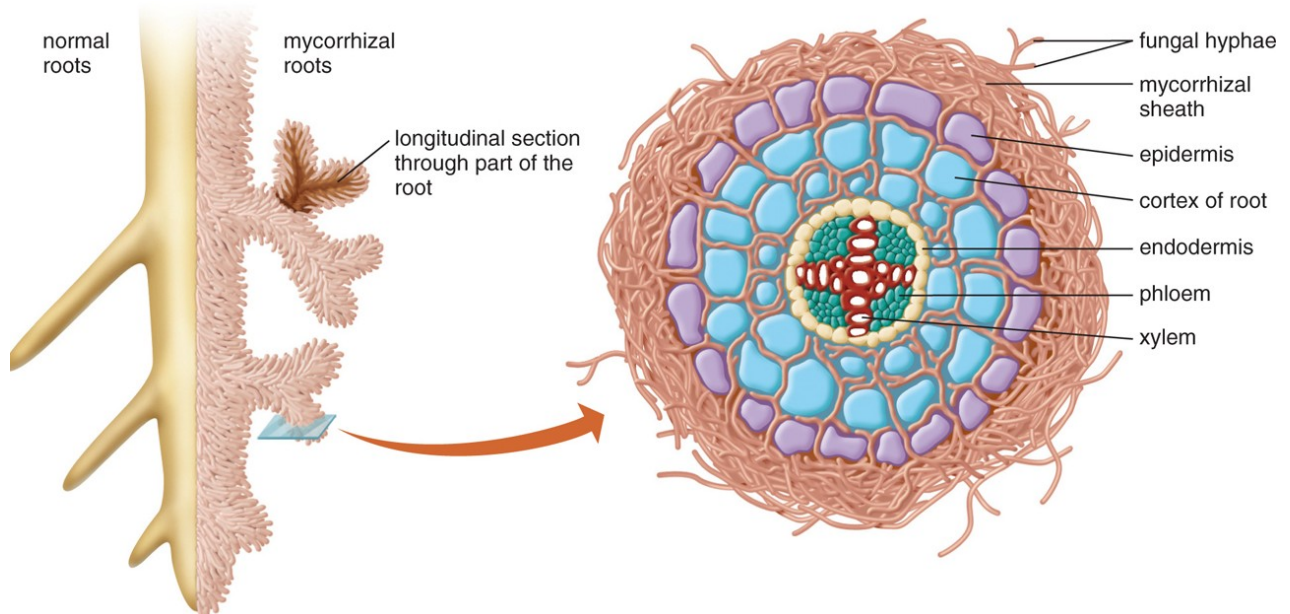
- Supportive roots (many tropical plants)
- Defensive, spiny roots (ivy)
- Photosynthetic roots (some orchids)

Endotrophic mycorrhizae in *Corallorhiza* orchid

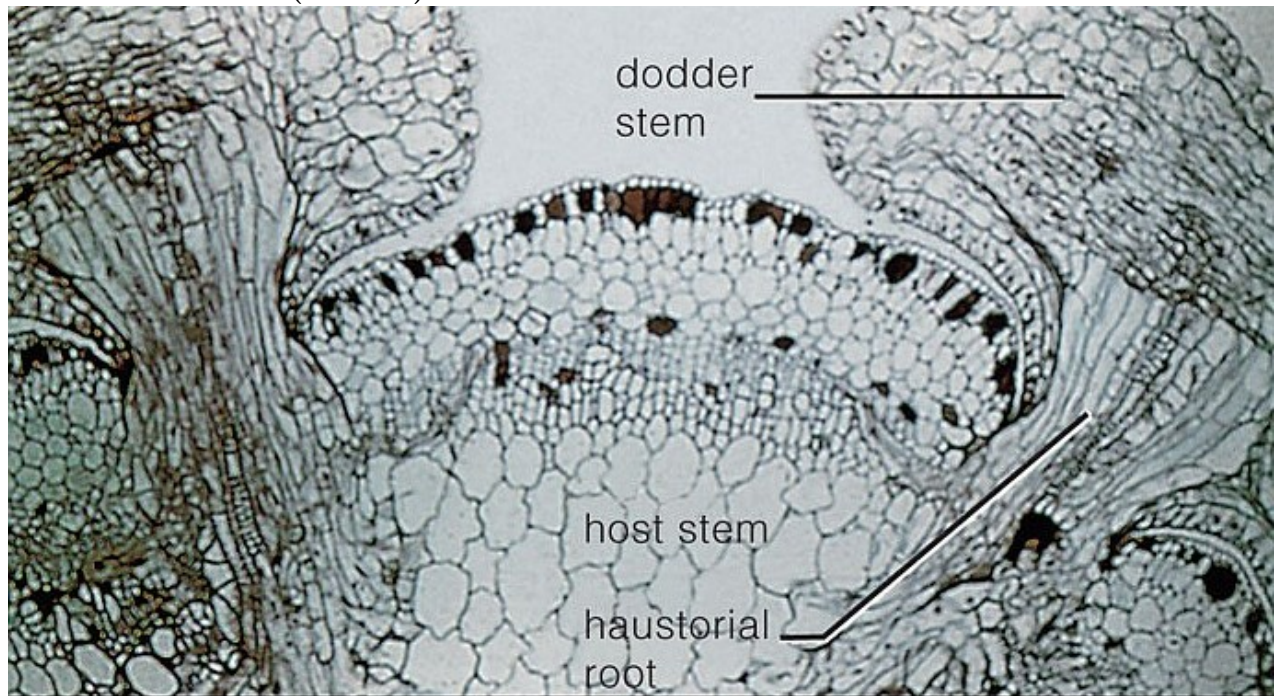


© 2006 Brooks/Cole - Thomson

Ectotrophic mycorrhizae of trees



Hauatoria of *Cuscuta* (dodder)



Nodulated roots of soybean (*Glycine max*)



Contractile roots of *Hyacinthus orientalis*



© 2006 Brooks/Cole - Thomson

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	...	Plantlets	Adventive buds
Storage	...	Succulent leaves	Storage roots
Photosynthesis	...	DEFAULT	Some aerial roots
Defense	...	Spines, scale	Root spines
Support	DEFAULT	Leaf tendrils	Haustoria, aerial and contractile roots
Interactions	...	Traps, "sticky tapes", urns	Mycorrhizae, nodulated roots

For Further Reading

References

- [1] A. Shipunov. *Introduction to Botany* [Electronic resource]. 2015. Mode of access: http://ashipunov.info/shipunov/school/biol_154