Chapter 29

Plant Diversity I: How Plants Colonized Land

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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Overview: The Greening of Earth

- Looking at a lush landscape, it is difficult to imagine the land without any plants or other organisms
- For more than the first 3 billion years of Earth's history, the terrestrial surface was lifeless
- Since colonizing land, plants have diversified into roughly 290,000 living species
- Plants supply oxygen and are the ultimate source of most food eaten by land animals

Fig. 29-1

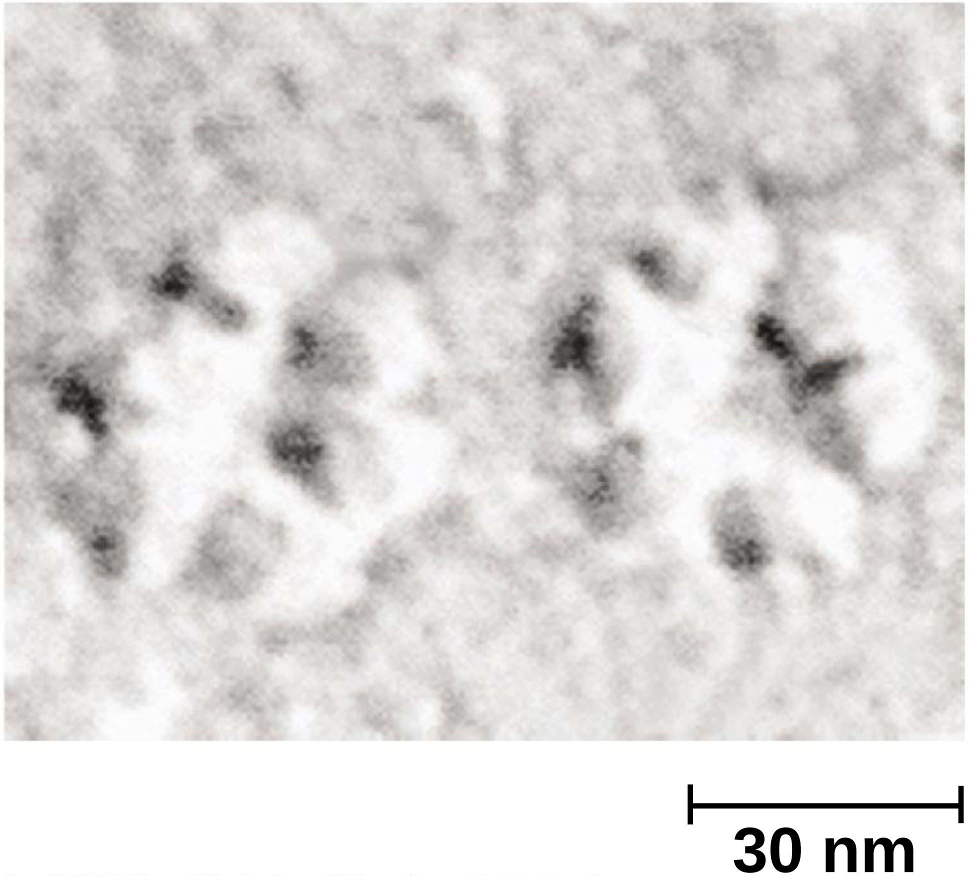
Concept 29.1: Land plants evolved from green algae

- Green algae called charophytes are the closest relatives of land plants

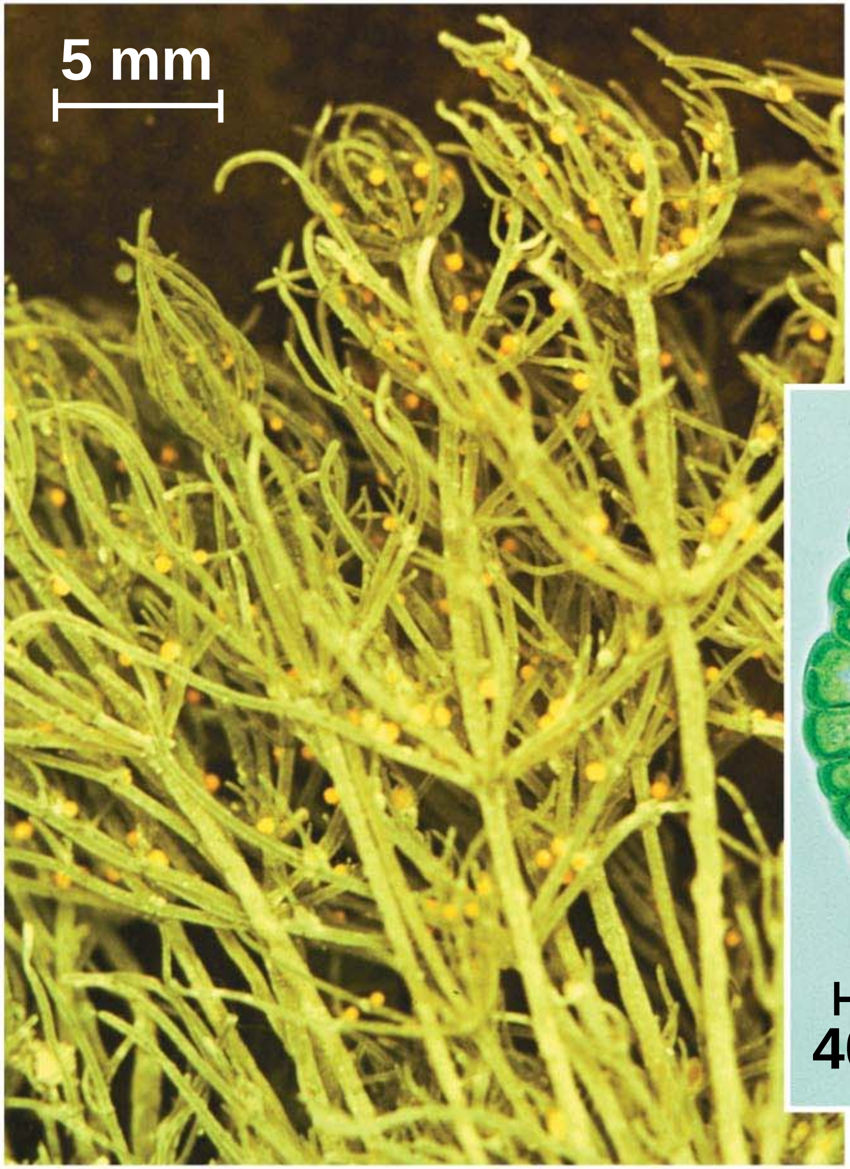
Morphological and Molecular Evidence

- Many characteristics of land plants also appear in a variety of algal clades, mainly algae
- However, land plants share four key traits only with charophytes:
  - Rose-shaped complexes for cellulose synthesis
  - Peroxisome enzymes
  - Structure of flagellated sperm
  - Formation of a **phragmoplast**

Fig. 29-2

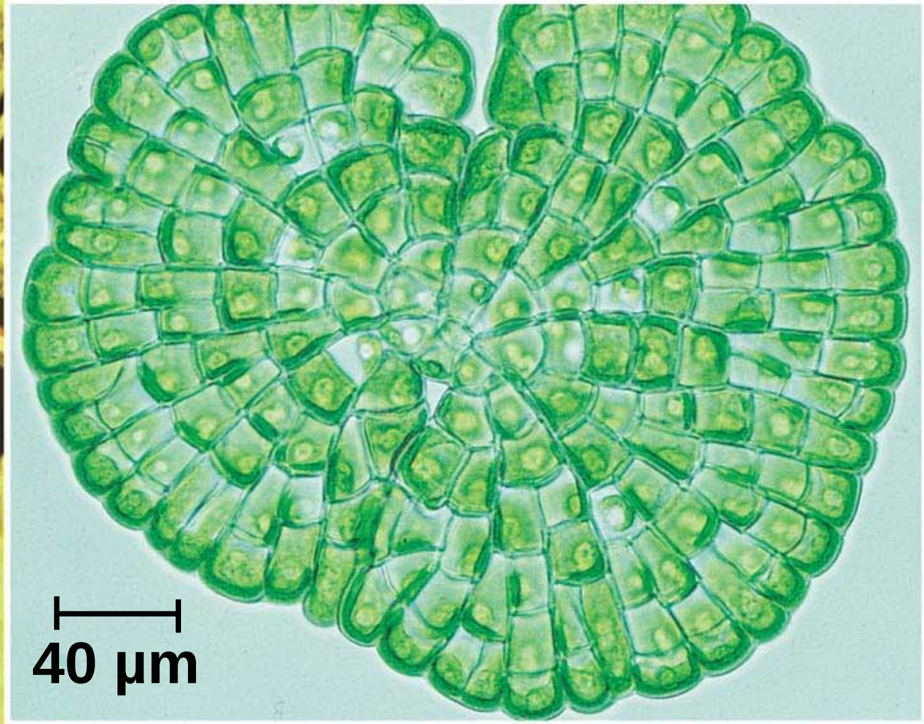


- Comparisons of both nuclear and chloroplast genes point to charophytes as the closest living relatives of land plants
- Note that land plants are not descended from modern charophytes, but share a common ancestor with modern charophytes



◀ ***Chara*** **species, a pond organism**

▼ ***Coleochaete orbicularis*, a disk-shaped charophyte that also lives in ponds (LM)**

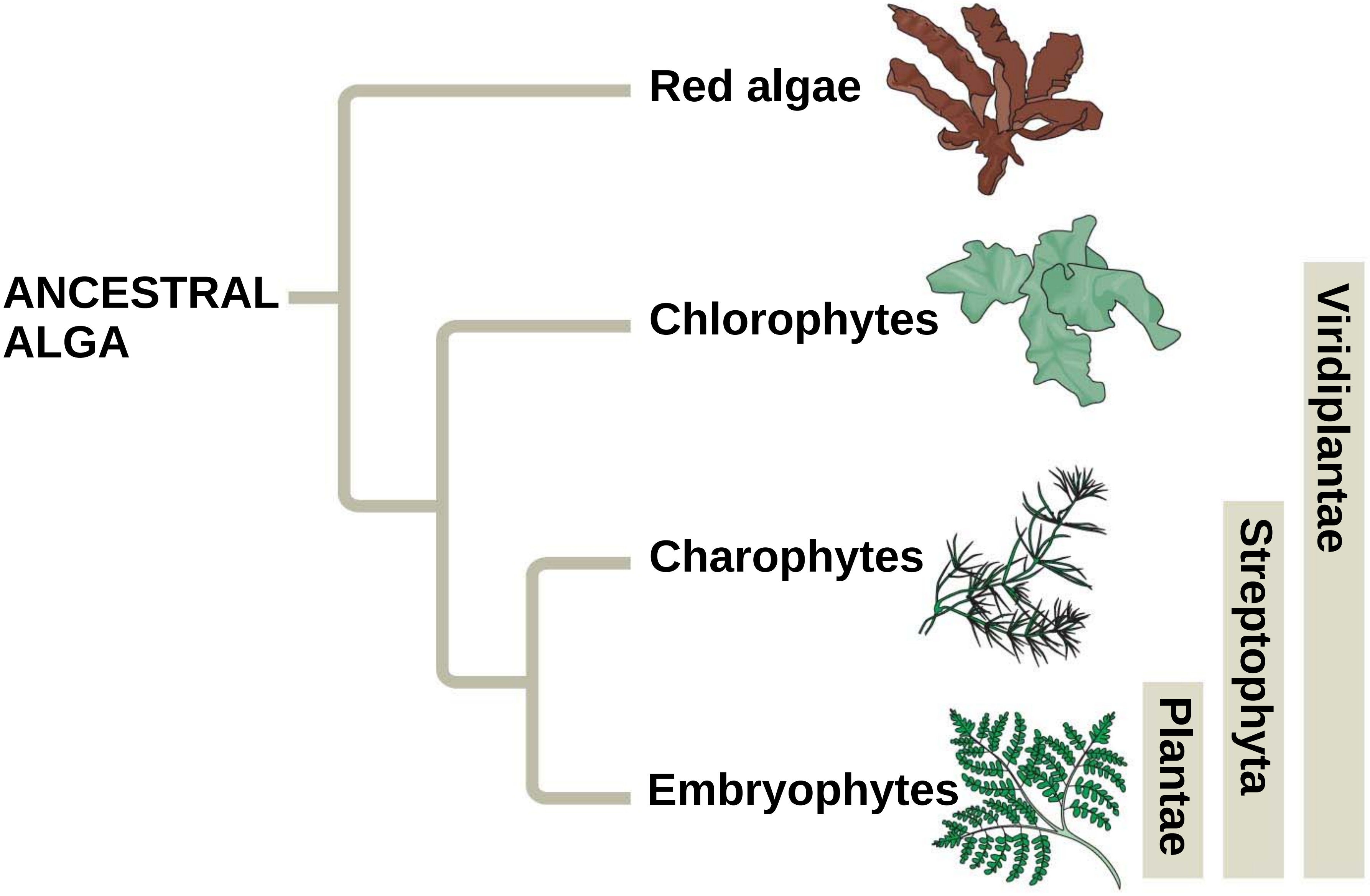


Adaptations Enabling the Move to Land

- In charophytes a layer of a durable polymer called **sporopollenin** prevents exposed zygotes from drying out
- The movement onto land by charophyte ancestors provided unfiltered sun, more plentiful CO_2, nutrient-rich soil, and few herbivores or pathogens
- Land presented challenges: a scarcity of water and lack of structural support

- The accumulation of traits that facilitated survival on land may have opened the way to its colonization by plants
- Systematists are currently debating the boundaries of the plant kingdom
- Some biologists think the plant kingdom should be expanded to include some or all green algae
- Until this debate is resolved, we will retain the embryophyte definition of kingdom Plantae

Fig. 29-4



ANCESTRAL ALGA
Red algae
Chlorophytes
Charophytes
Embryophytes
Plantae
Streptophyta
Viridiplantae

Derived Traits of Plants

- Four key traits appear in nearly all land plants but are absent in the charophytes:
  - Alternation of generations (with multicellular, dependent embryos)
  - Walled spores produced in sporangia
  - Multicellular gametangia
  - Apical meristems

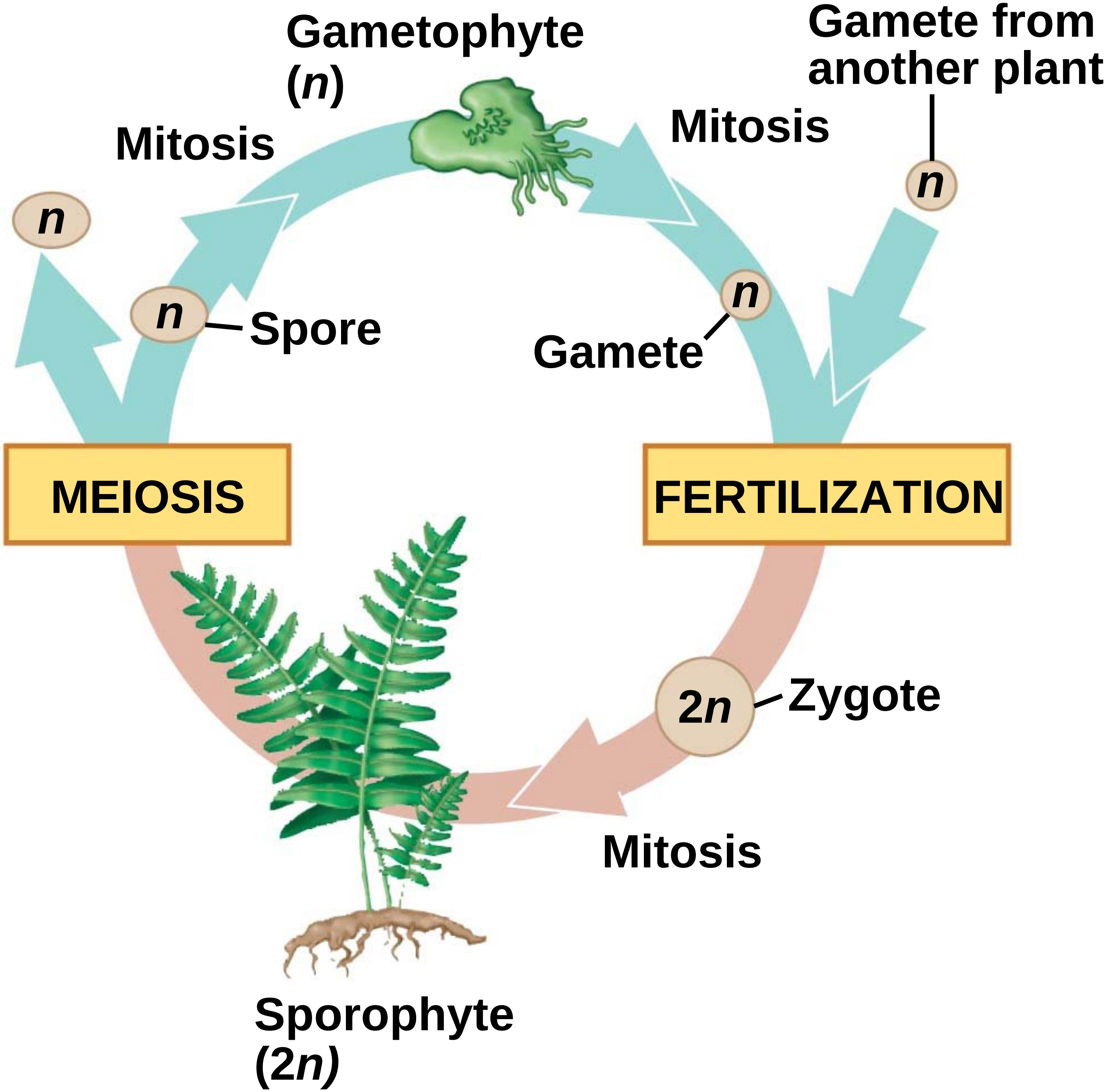
- Additional derived traits such as a **cuticle** and secondary compounds evolved in many plant species
- Symbiotic associations between fungi and the first land plants may have helped plants without true roots to obtain nutrients

Alternation of Generations and Multicellular, Dependent Embryos

- Plants alternate between two multicellular stages, a reproductive cycle called **alternation of generations**
- The **gametophyte** is haploid and produces haploid gametes by mitosis
- Fusion of the gametes gives rise to the diploid **sporophyte**, which produces haploid **spores** by meiosis

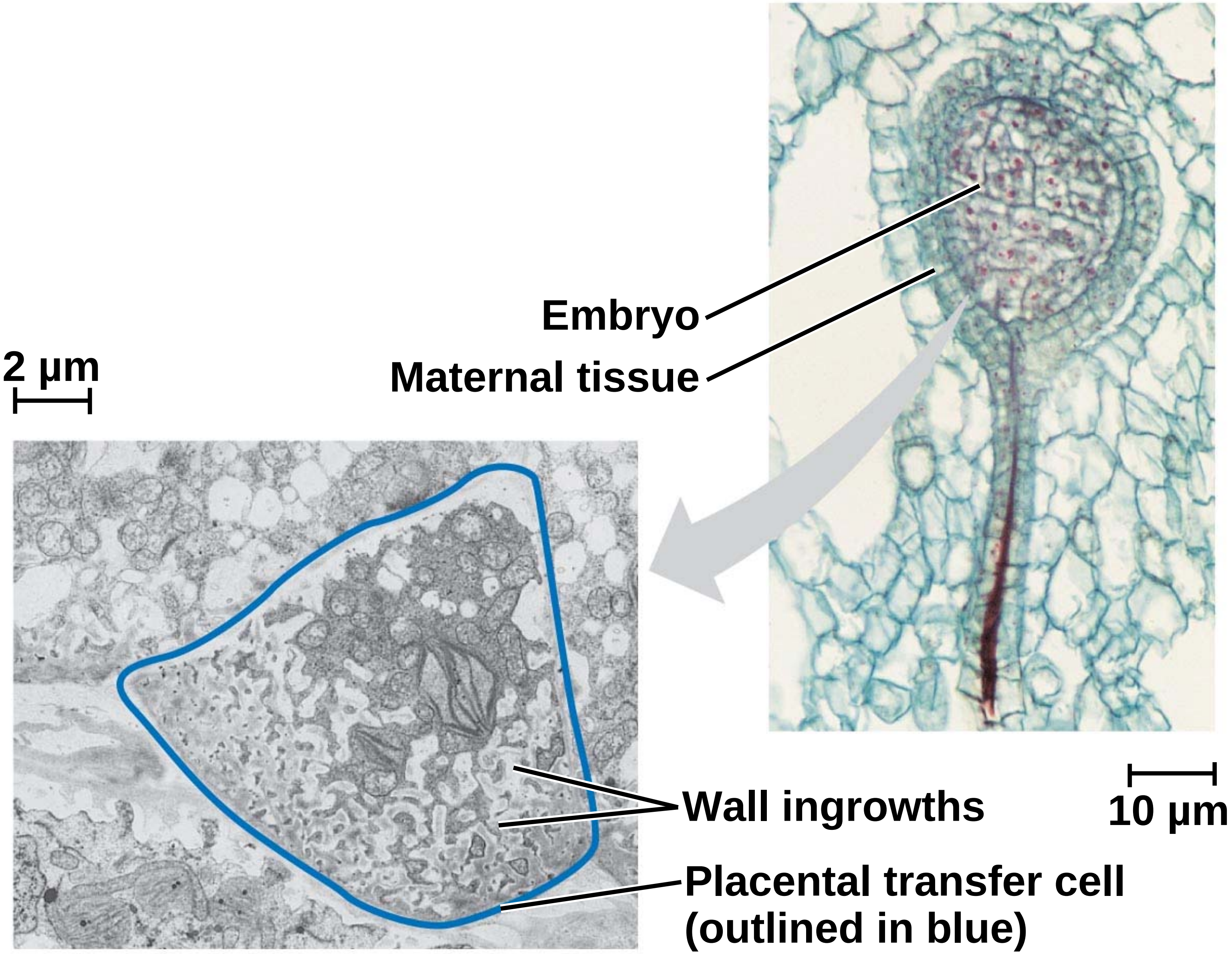
- The diploid embryo is retained within the tissue of the female gametophyte
- Nutrients are transferred from parent to embryo through **placental transfer cells**
- Land plants are called **embryophytes** because of the dependency of the embryo on the parent

Fig. 29-5a



Alternation of generations

Fig. 29-5b

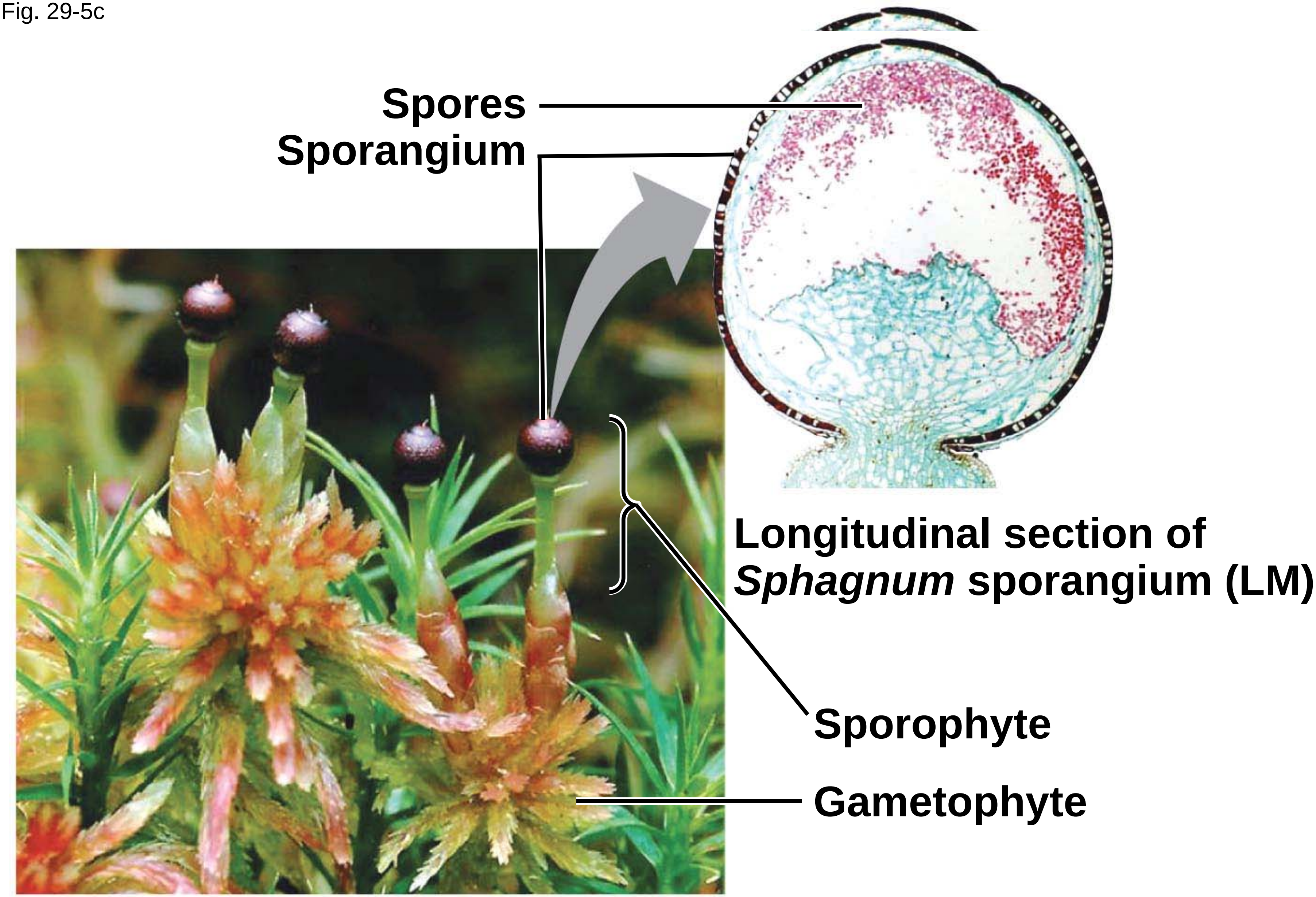


Embryo (LM) and placental transfer cell (TEM)
of *Marchantia* (a liverwort)

Walled Spores Produced in Sporangia

- The sporophyte produces spores in organs called **sporangia**
- Diploid cells called **sporocytes** undergo meiosis to generate haploid spores
- Spore walls contain sporopollenin, which makes them resistant to harsh environments

Fig. 29-5c

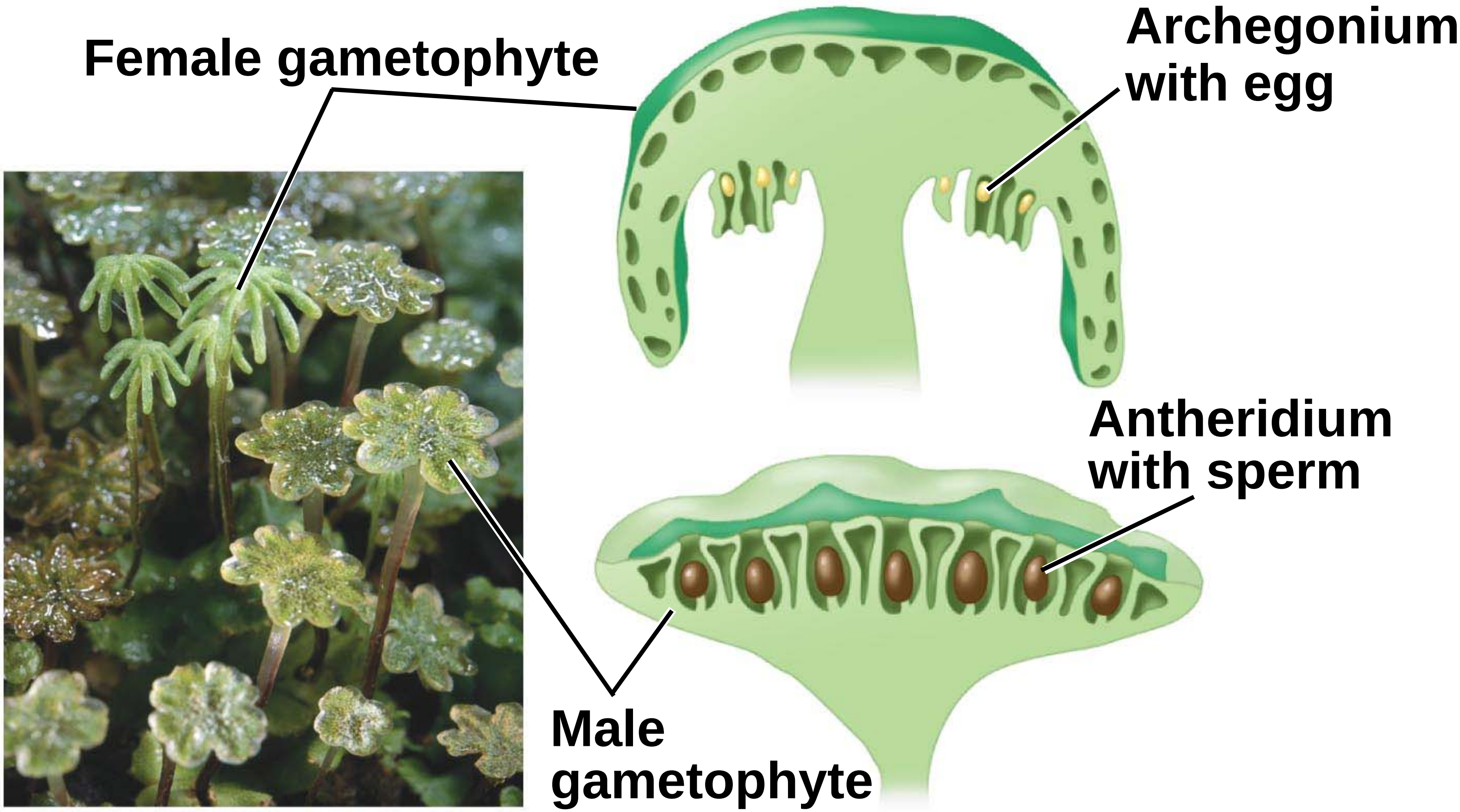


Sporophytes and sporangia of *Sphagnum* (a moss)

Multicellular Gametangia

- Gametes are produced within organs called **gametangia**
- Female gametangia, called **archegonia**, produce eggs and are the site of fertilization
- Male gametangia, called **antheridia**, are the site of sperm production and release

Fig. 29-5d

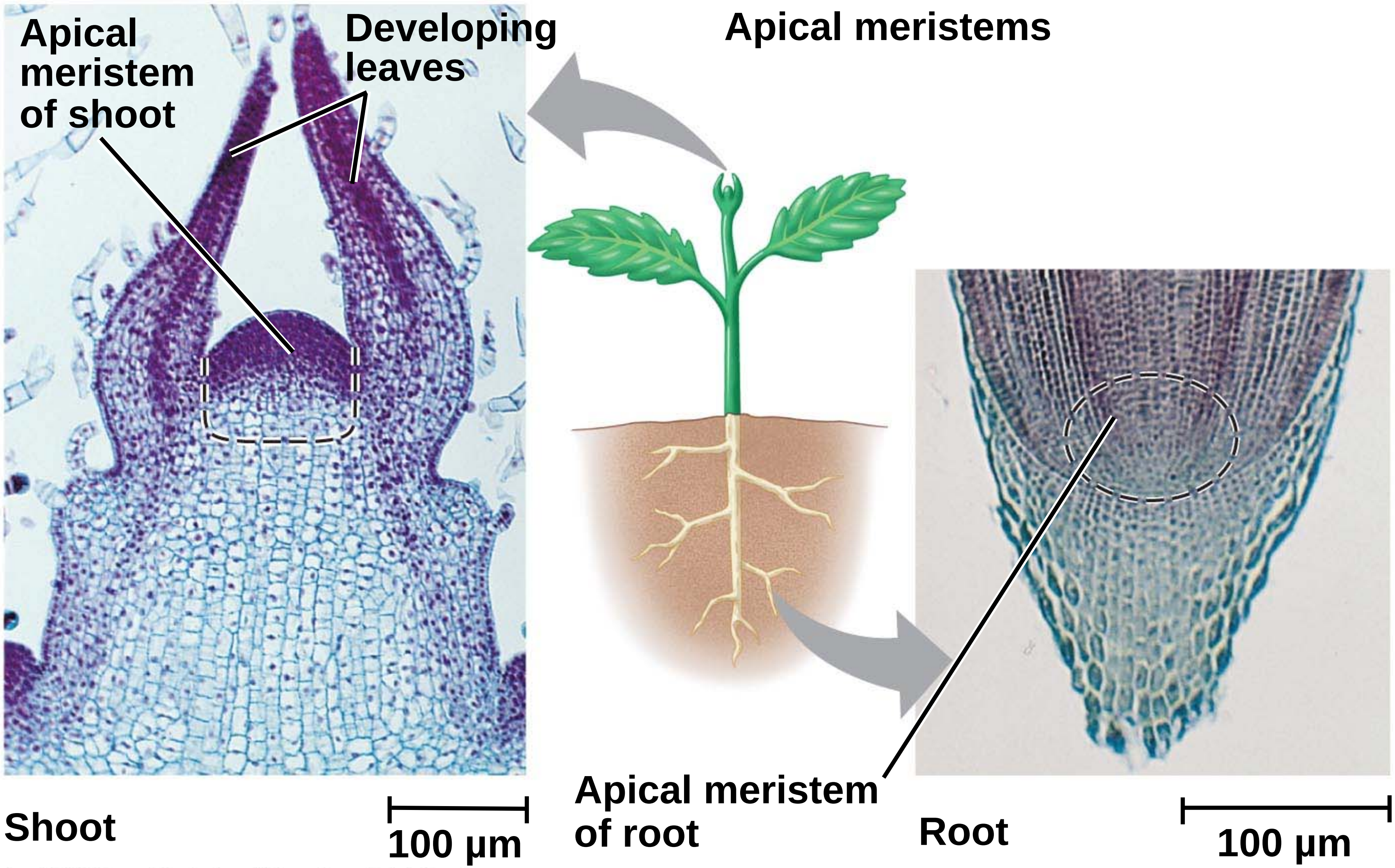


Archegonia and antheridia of *Marchantia* (a liverwort)

Apical Meristems

- Plants sustain continual growth in their **apical meristems**
- Cells from the apical meristems differentiate into various tissues

Fig. 29-5e

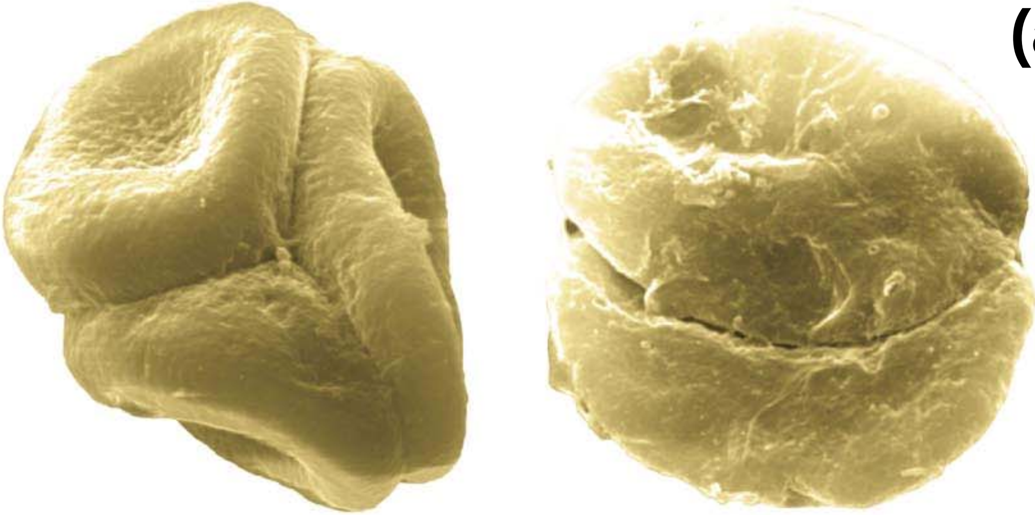


Apical meristem of shoot
Developing leaves
Apical meristems
Shoot
100 µm
Apical meristem of root
Root
100 µm

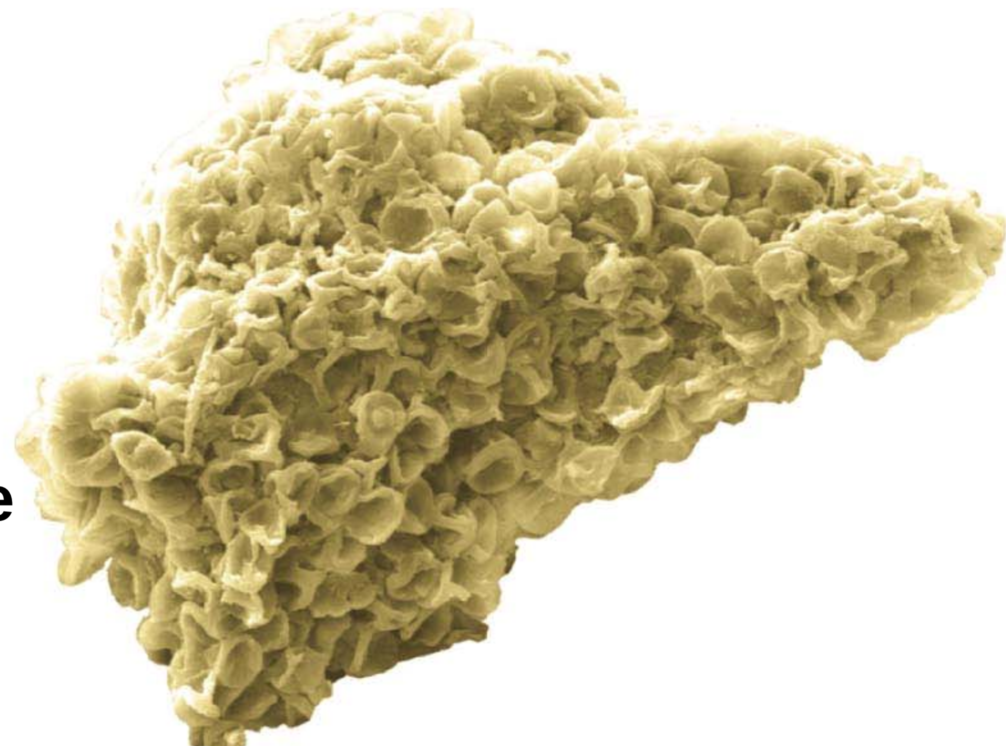
The Origin and Diversification of Plants

- Fossil evidence indicates that plants were on land at least 475 million years ago
- Fossilized spores and tissues have been extracted from 475-million-year-old rocks

Fig. 29-6



(a) Fossilized spores



(b) Fossilized sporophyte tissue

- Those ancestral species gave rise to a vast diversity of modern plants
- Land plants can be informally grouped based on the presence or absence of **vascular tissue**
- Most plants have vascular tissue; these constitute the **vascular plants**
- Nonvascular plants are commonly called **bryophytes**

- **Seedless vascular plants** can be divided into clades
  - **Lycophytes** (club mosses and their relatives)
  - **Pterophytes** (ferns and their relatives)
- Seedless vascular plants are paraphyletic, and are of the same level of biological organization, or **grade**

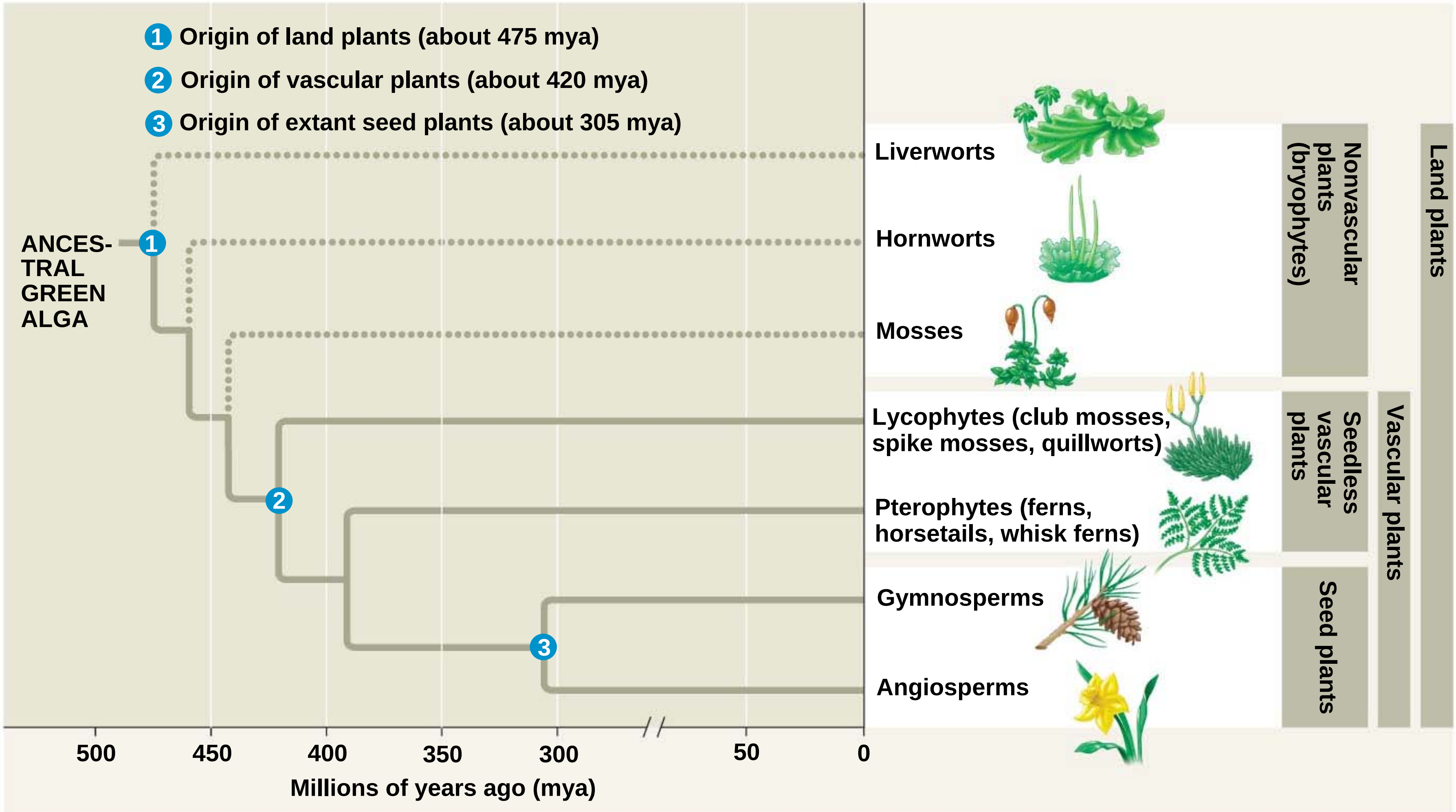
- A **seed** is an embryo and nutrients surrounded by a protective coat
- Seed plants form a clade and can be divided into further clades:
  - **Gymnosperms**, the “naked seed” plants, including the conifers
  - **Angiosperms**, the flowering plants

Table 29-1

Table 29.1 Ten Phyla of Extant Plants

	Common Name	Estimated Number of Species
Nonvascular Plants (Bryophytes)		
Phylum Hepatophyta	Liverworts	9,000
Phylum Anthocerophyta	Hornworts	100
Phylum Bryophyta	Mosses	15,000
Vascular Plants		
Seedless Vascular Plants		
Phylum Lycophyta	Lycophytes	1,200
Phylum Pterophyta	Pterophytes	12,000
Seed Plants		
Gymnosperms		
Phylum Ginkgophyta	Ginkgo	1
Phylum Cycadophyta	Cycads	130
Phylum Gnetophyta	Gnetophytes	75
Phylum Coniferophyta	Conifers	600
Angiosperms		
Phylum Anthophyta	Flowering plants	250,000

Fig. 29-7

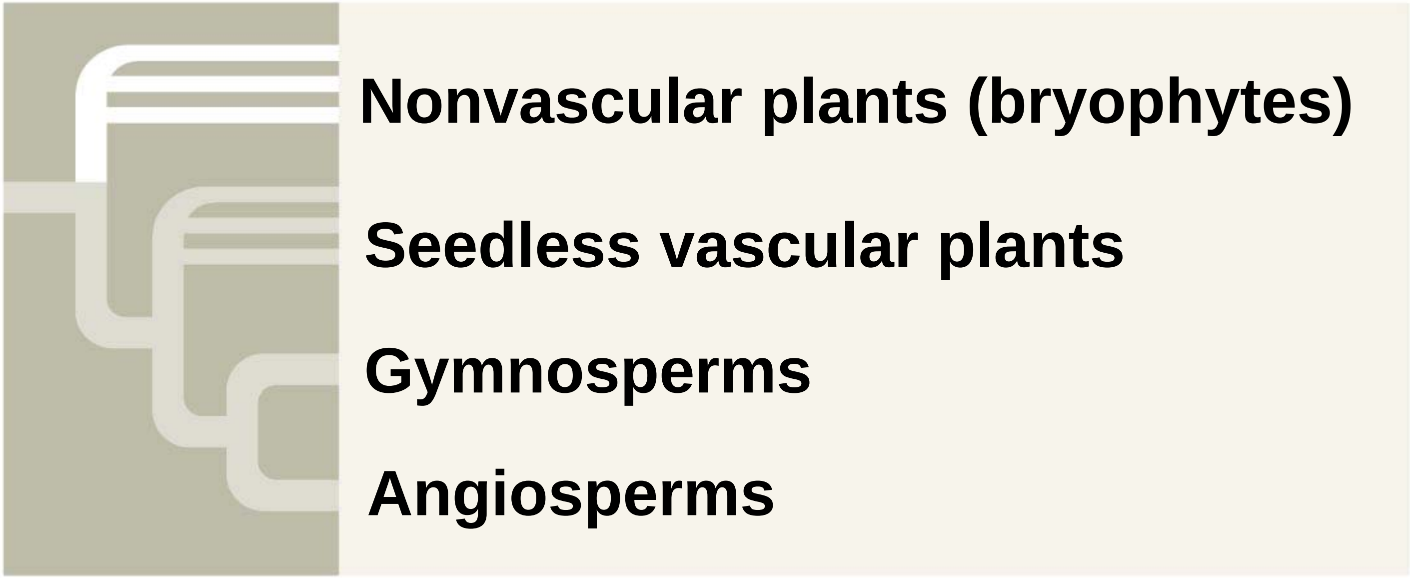


1 Origin of land plants (about 475 mya)
2 Origin of vascular plants (about 420 mya)
3 Origin of extant seed plants (about 305 mya)
ANCES-
TRAL
GREEN
ALGA
Liverworts
Hornworts
Mosses
Lycophytes (club mosses, spike mosses, quillworts)
Pterophytes (ferns, horsetails, whisk ferns)
Gymnosperms
Angiosperms
Nonvascular plants (bryophytes)
Seedless vascular plants
Seed plants
Vascular plants
Land plants
500
450
400
350
300
50
0
Millions of years ago (mya)

Concept 29.2: Mosses and other nonvascular plants have life cycles dominated by gametophytes

- Bryophytes are represented today by three phyla of small herbaceous (nonwoody) plants:
  - **Liverworts**, phylum Hepatophyta
  - **Hornworts**, phylum Anthocerophyta
  - **Mosses**, phylum Bryophyta
- Mosses are most closely related to vascular plants

Fig. 29-UN1

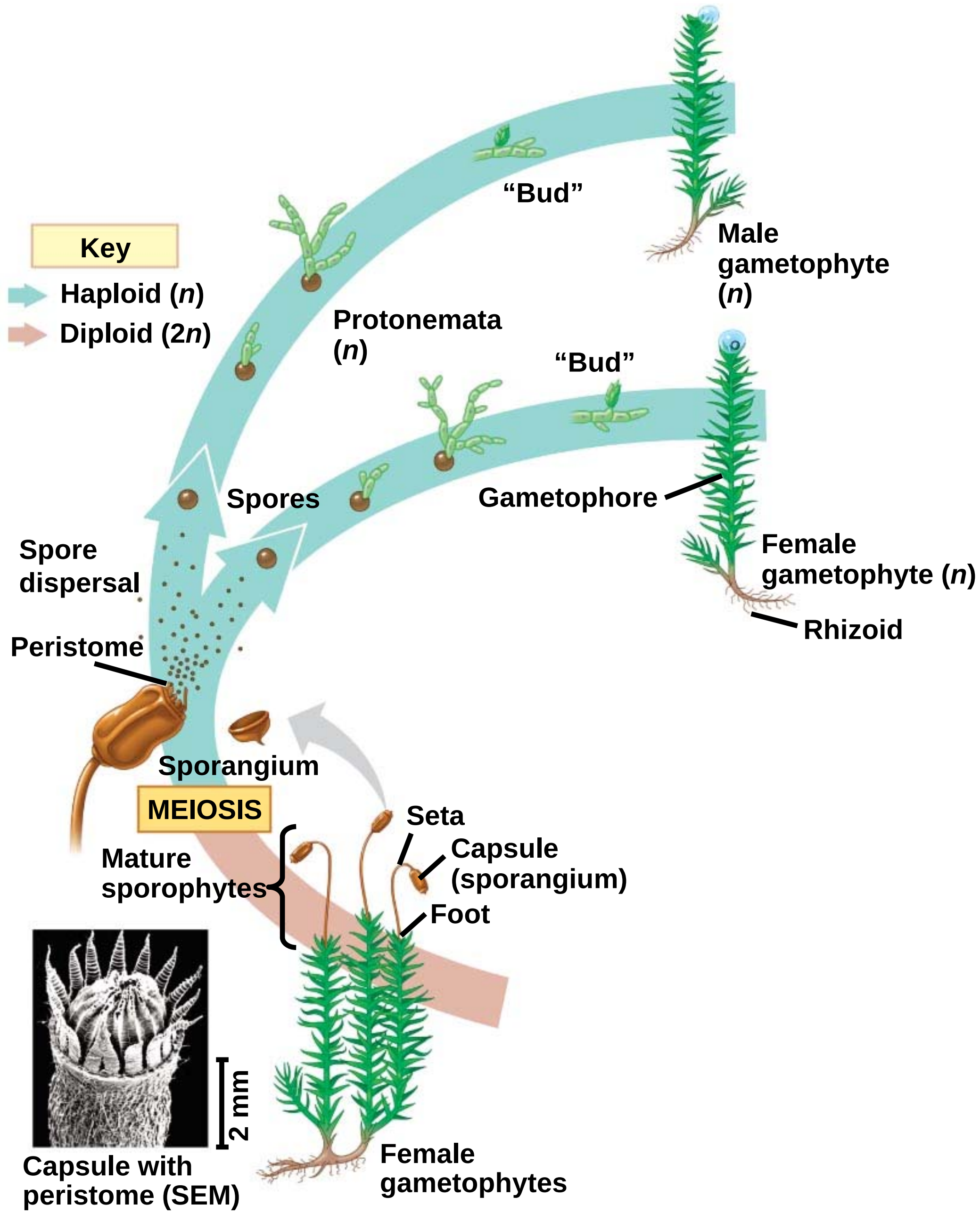


Nonvascular plants (bryophytes)
Seedless vascular plants
Gymnosperms
Angiosperms

Bryophyte Gametophytes

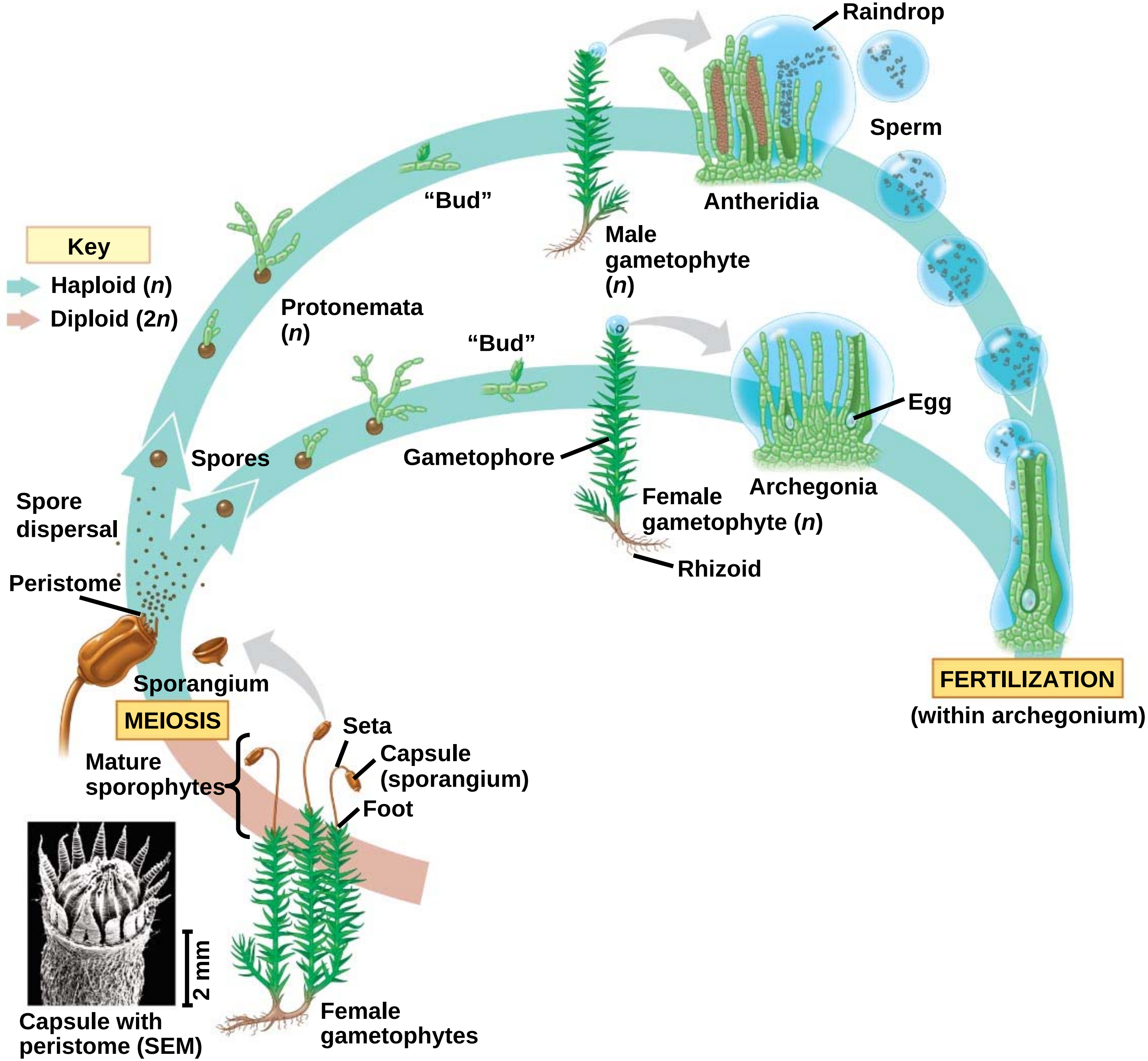
- In all three bryophyte phyla, gametophytes are larger and longer-living than sporophytes
- Sporophytes are typically present only part of the time

Fig. 29-8-1



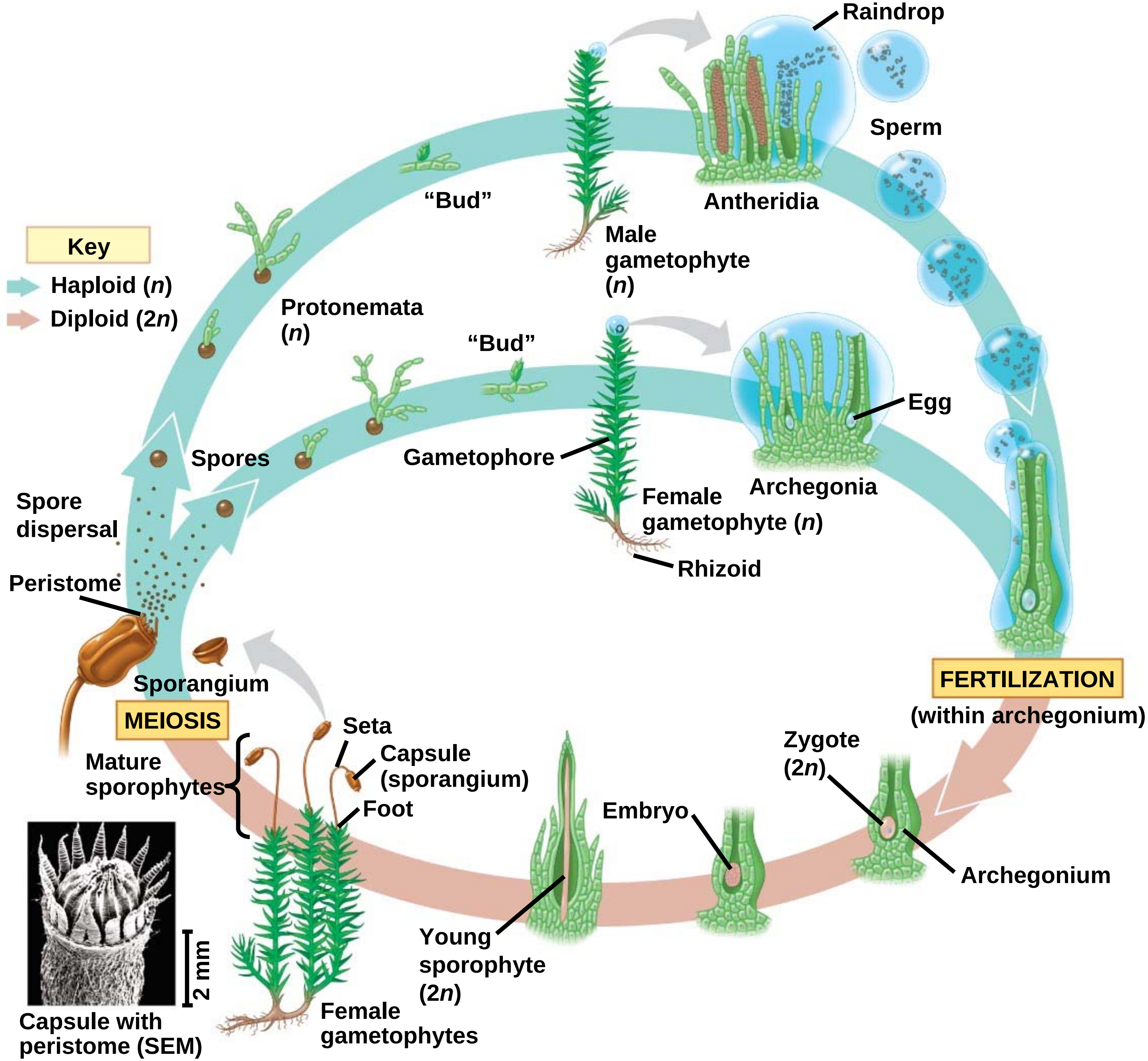
Key
Haploid (n)
Diploid (2n)
"Bud"
Male gametophyte (n)
Protonemata (n)
"Bud"
Spores
Gametophore
Spore dispersal
Female gametophyte (n)
Rhizoid
Peristome
Sporangium
MEIOSIS
Seta
Capsule (sporangium)
Mature sporophytes
Foot
2 mm
Capsule with peristome (SEM)
Female gametophytes

Fig. 29-8-2



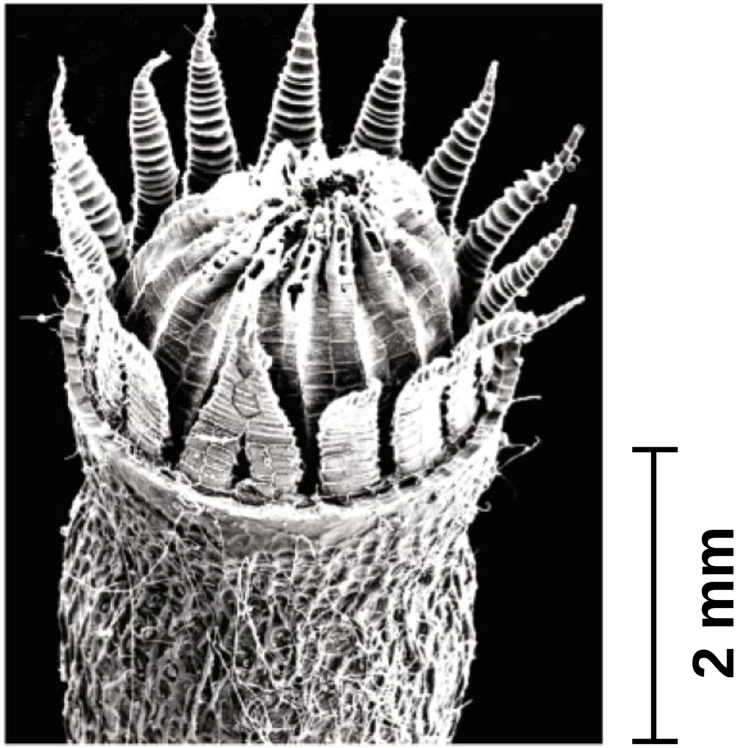
Raindrop
Sperm
"Bud"
Antheridia
Male gametophyte (n)
Key
Haploid (n)
Diploid (2n)
Protonemata (n)
"Bud"
Egg
Spores
Gametophore
Archegonia
Female gametophyte (n)
Spore dispersal
Rhizoid
Peristome
Sporangium
FERTILIZATION
(within archegonium)
MEIOSIS
Seta
Capsule (sporangium)
Mature sporophytes
Foot
2 mm
Capsule with peristome (SEM)
Female gametophytes

Fig. 29-8-3



Raindrop
Sperm
Antheridia
"Bud"
Male gametophyte (n)
Key
Haploid (n)
Diploid (2n)
Protonemata (n)
"Bud"
Egg
Spores
Gametophore
Archegonia
Spore dispersal
Female gametophyte (n)
Rhizoid
Peristome
Sporangium
FERTILIZATION
(within archegonium)
MEIOSIS
Seta
Capsule (sporangium)
Zygote (2n)
Mature sporophytes
Foot
Embryo
Archegonium
2 mm
Young sporophyte (2n)
Capsule with peristome (SEM)
Female gametophytes

Fig. 29-8a



Capsule with peristome (SEM)

- A spore germinates into a gametophyte composed of a **protonema** and gamete-producing **gametophore**
- **Rhizoids** anchor gametophytes to substrate
- The height of gametophytes is constrained by lack of vascular tissues
- Mature gametophytes produce flagellated sperm in antheridia and an egg in each archegonium
- Sperm swim through a film of water to reach and fertilize the egg

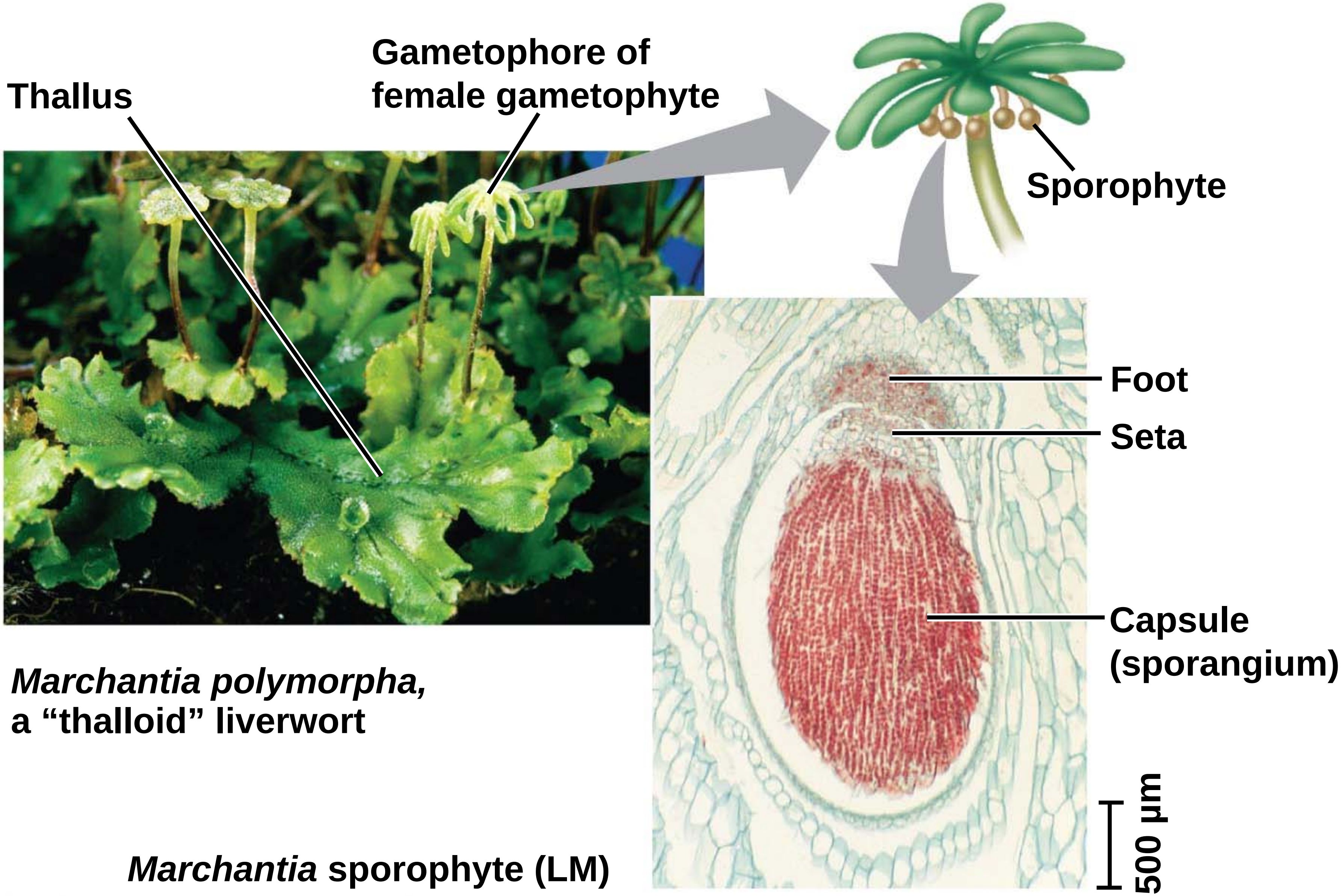
PLAY

Animation: Moss Life Cycle

Bryophyte Sporophytes

- Bryophyte sporophytes grow out of archegonia, and are the smallest and simplest sporophytes of all extant plant groups
- A sporophyte consists of a **foot**, a **seta** (stalk), and a sporangium, also called a **capsule**, which discharges spores through a **peristome**
- Hornwort and moss sporophytes have **stomata** for gas exchange

Fig. 29-9a



***Marchantia polymorpha*, a “thalloid” liverwort**

***Marchantia* sporophyte (LM)**

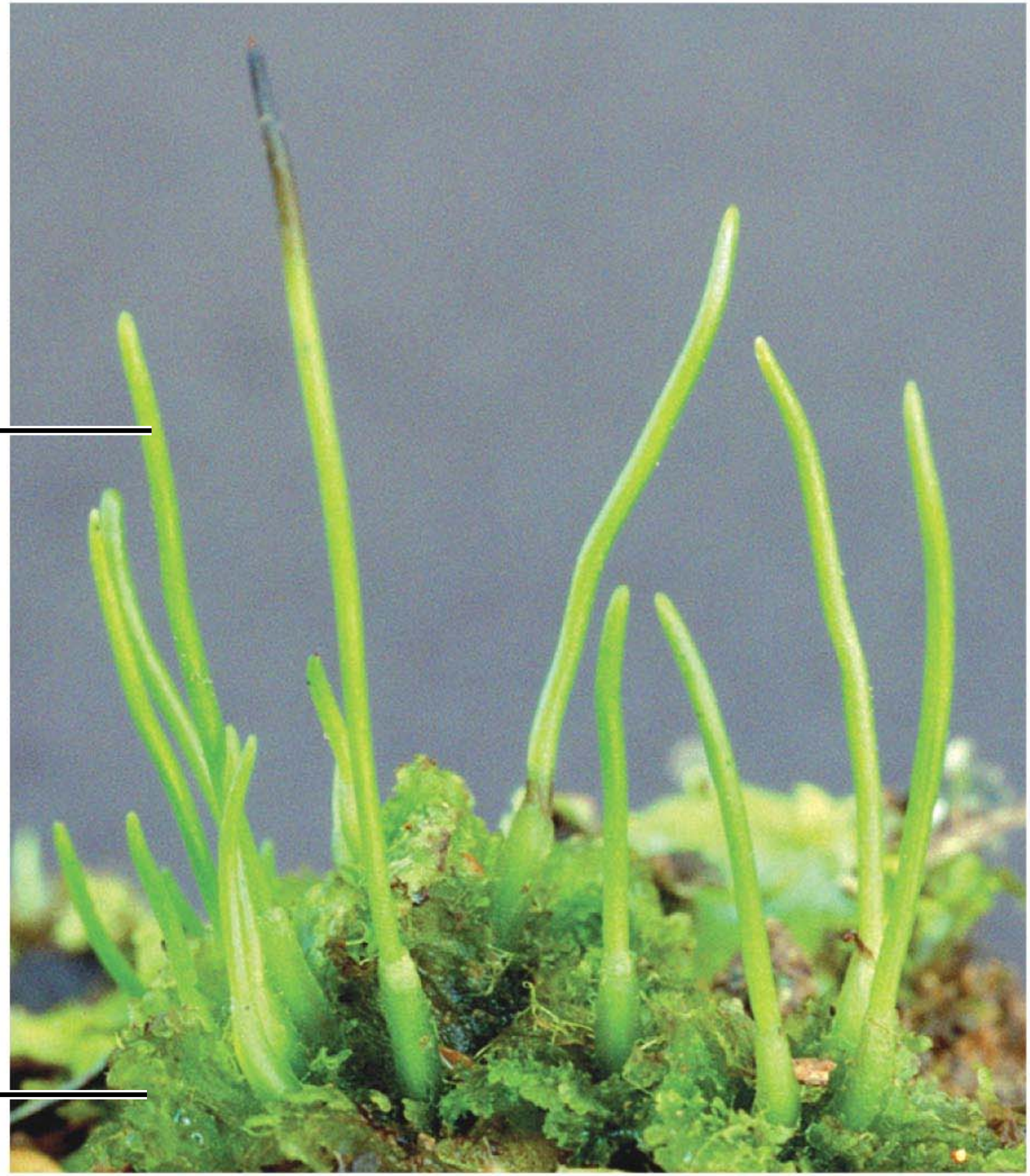
Fig. 29-9b

***Plagiochila deltoidea*, a "leafy" liverwort**

Fig. 29-9c

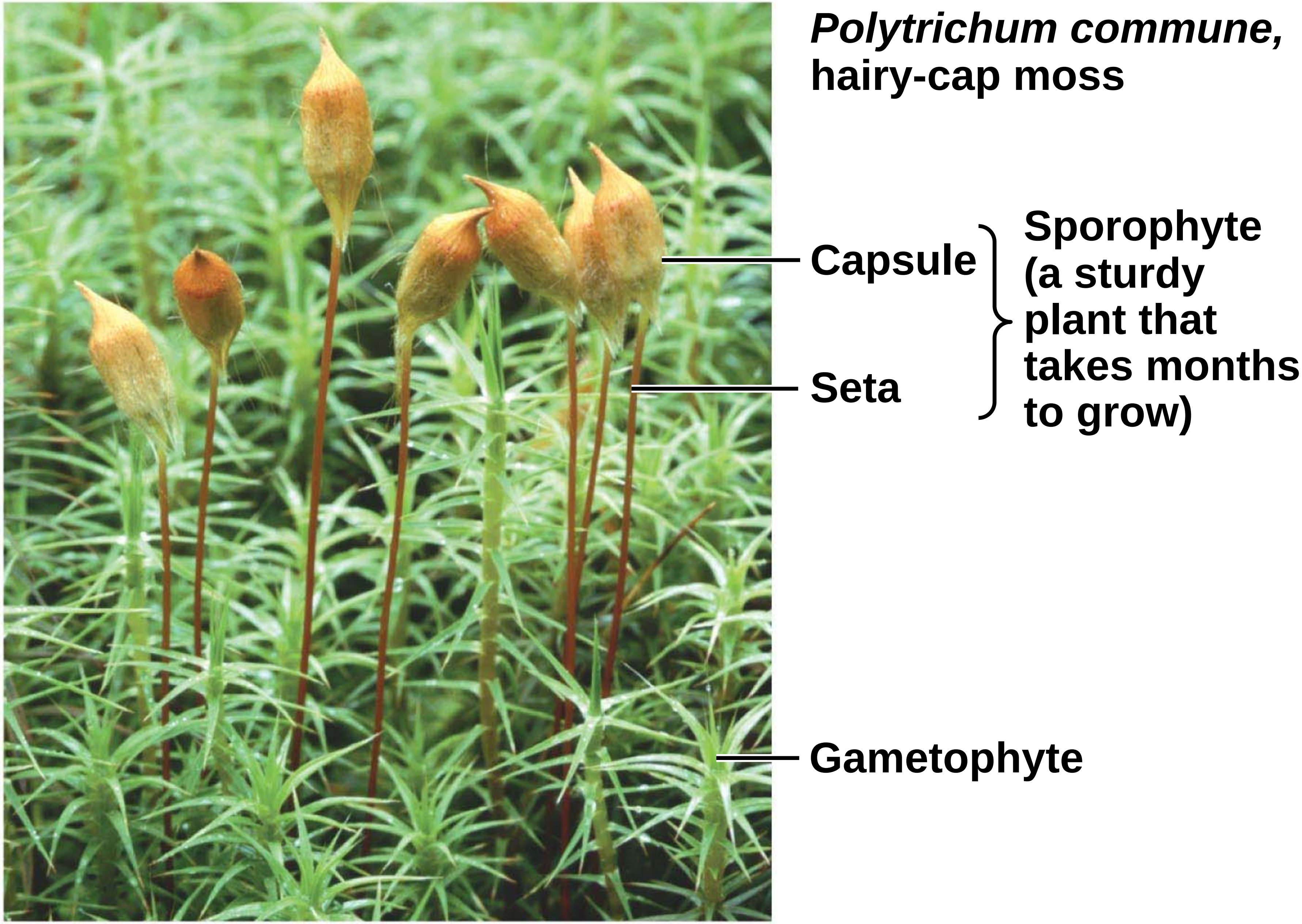
An *Anthoceros* hornwort species

Sporophyte



Gametophyte

Fig. 29-9d

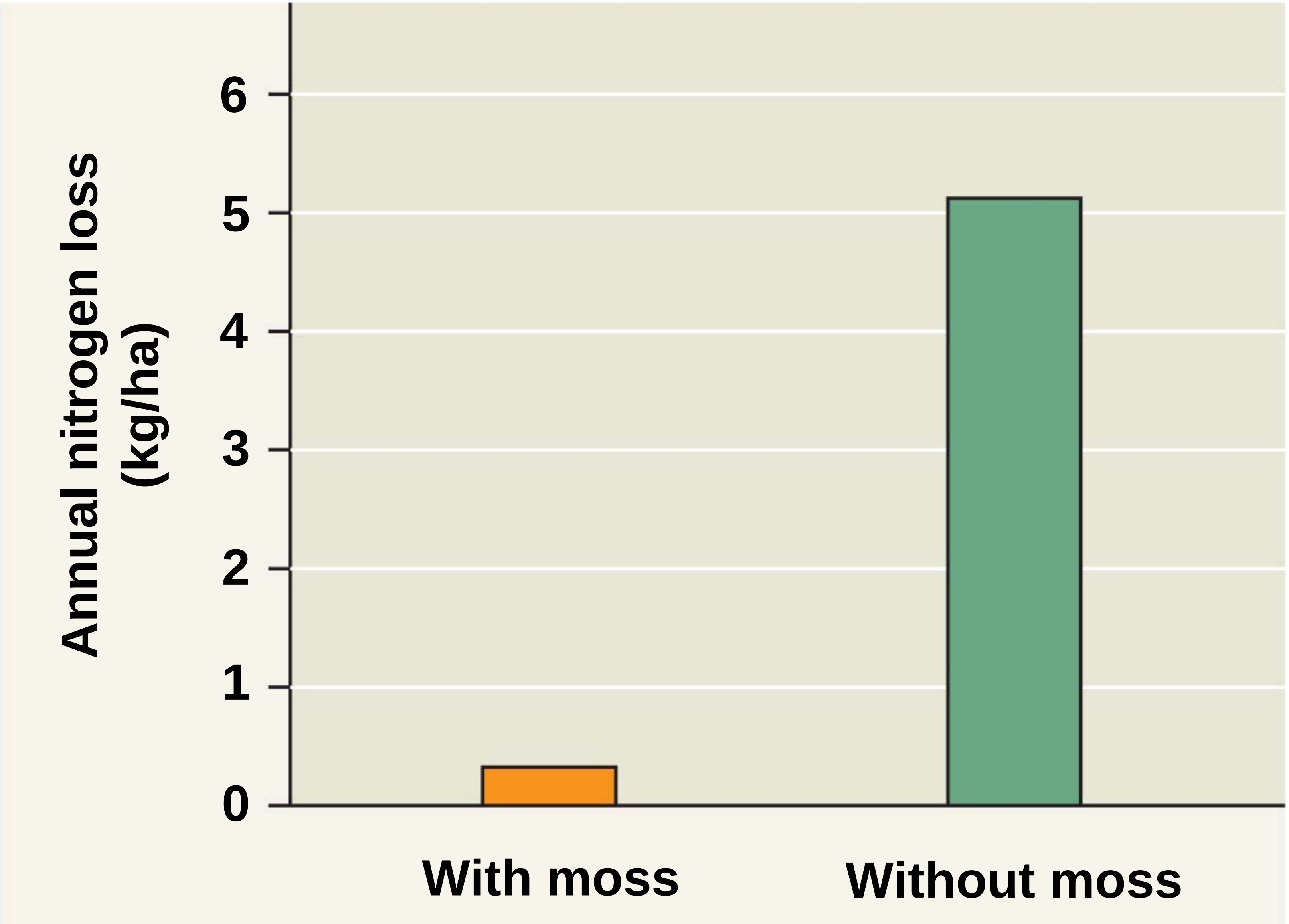

Polytrichum commune,
hairy-cap moss
Capsule
Seta
Sporophyte
(a sturdy
plant that
takes months
to grow)
Gametophyte

The Ecological and Economic Importance of Mosses

- Moses are capable of inhabiting diverse and sometimes extreme environments, but are especially common in moist forests and wetlands
- Some mosses might help retain nitrogen in the soil

Fig. 29-10

RESULTS



- *Sphagnum*, or “peat moss,” forms extensive deposits of partially decayed organic material known as **peat**
- *Sphagnum* is an important global reservoir of organic carbon

Fig. 29-11

(a) Peat being harvested

(b) "Tollund Man," a bog mummy

Fig. 29-11a

(a) Peat being harvested

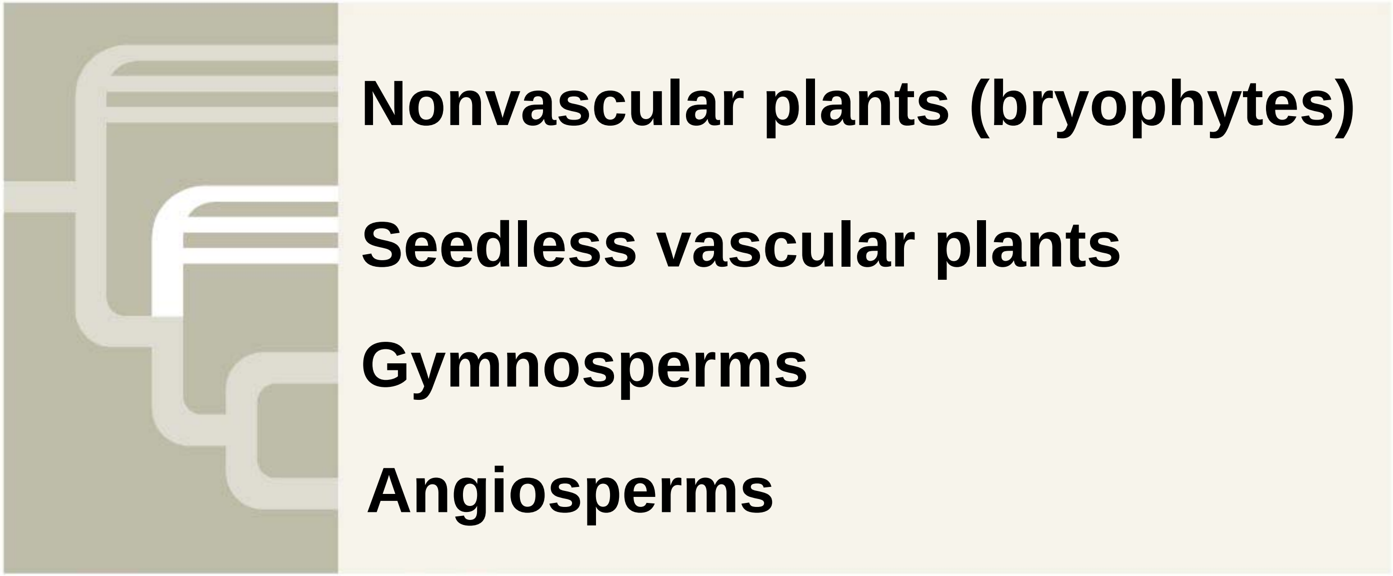
Fig. 29-11b

(b) “Tollund Man,” a bog mummy

Concept 29.3: Ferns and other seedless vascular plants were the first plants to grow tall

- Bryophytes and bryophyte-like plants were the prevalent vegetation during the first 100 million years of plant evolution
- Vascular plants began to diversify during the Devonian and Carboniferous periods
- Vascular tissue allowed these plants to grow tall
- Seedless vascular plants have flagellated sperm and are usually restricted to moist environments

Fig. 29-UN2

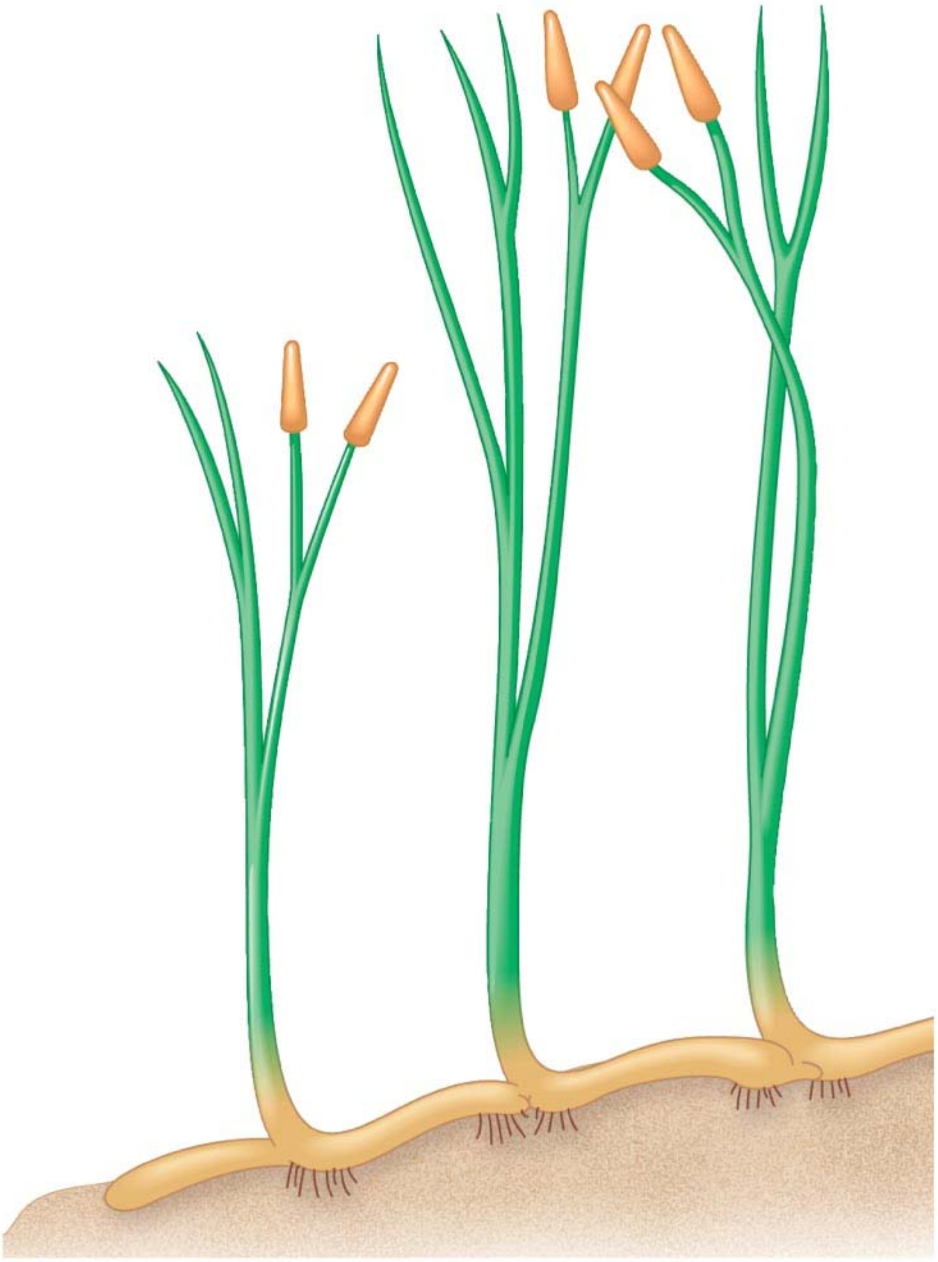


Nonvascular plants (bryophytes)
Seedless vascular plants
Gymnosperms
Angiosperms

Origins and Traits of Vascular Plants

- Fossils of the forerunners of vascular plants date back about 420 million years
- These early tiny plants had independent, branching sporophytes
- Living vascular plants are characterized by:
  - Life cycles with dominant sporophytes
  - Vascular tissues called xylem and phloem
  - Well-developed roots and leaves

Fig. 29-12



Sporophytes of *Aglaophyton major*

Life Cycles with Dominant Sporophytes

- In contrast with bryophytes, sporophytes of seedless vascular plants are the larger generation, as in the familiar leafy fern
- The gametophytes are tiny plants that grow on or below the soil surface

PLAY

Animation: Fern Life Cycle

Fig. 29-13-1

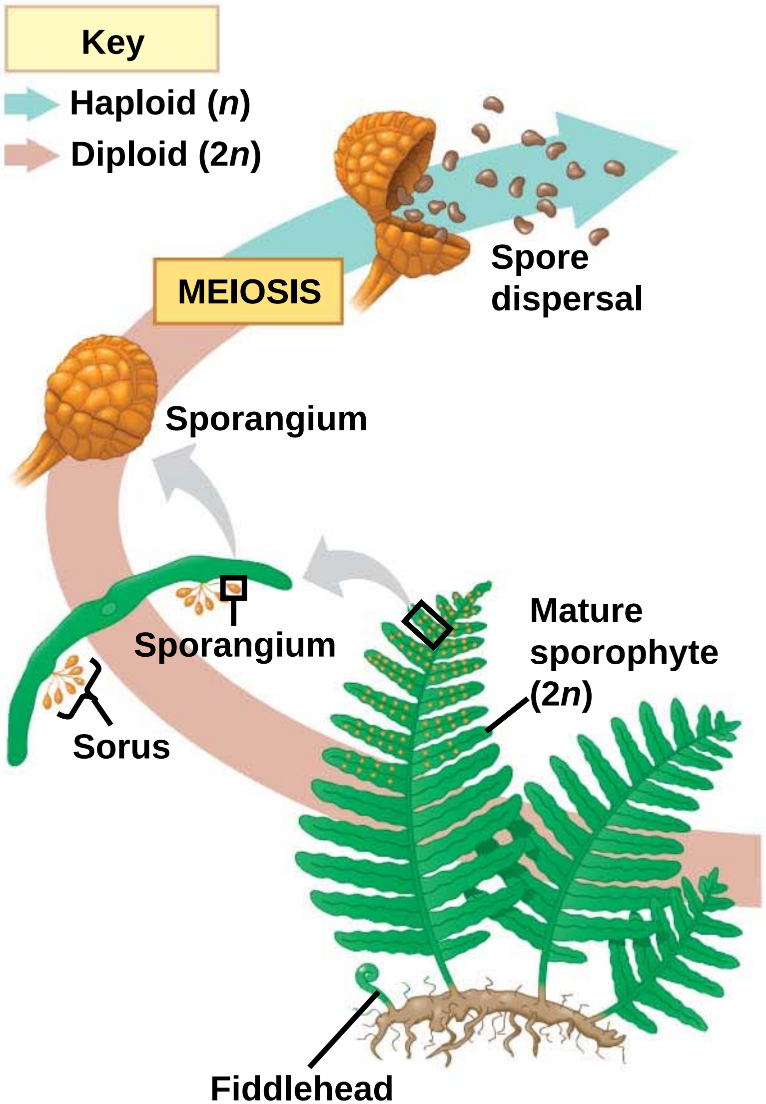

Key
Haploid (n)
Diploid (2n)
MEIOSIS
Spore
dispersal
Sporangium
Sporangium
Sorus
Mature
sporophyte
(2n)
Fiddlehead

Fig. 29-13-2

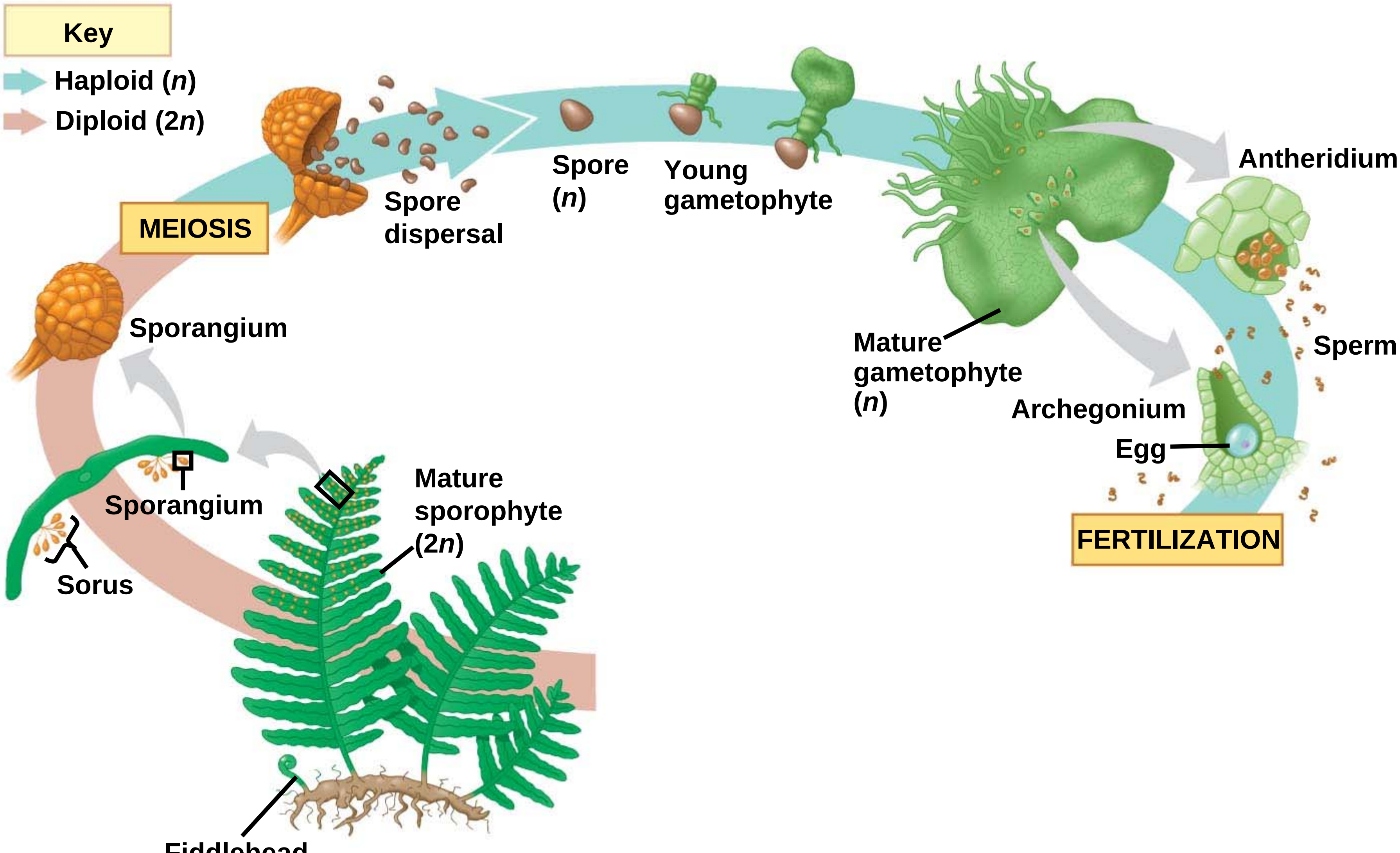
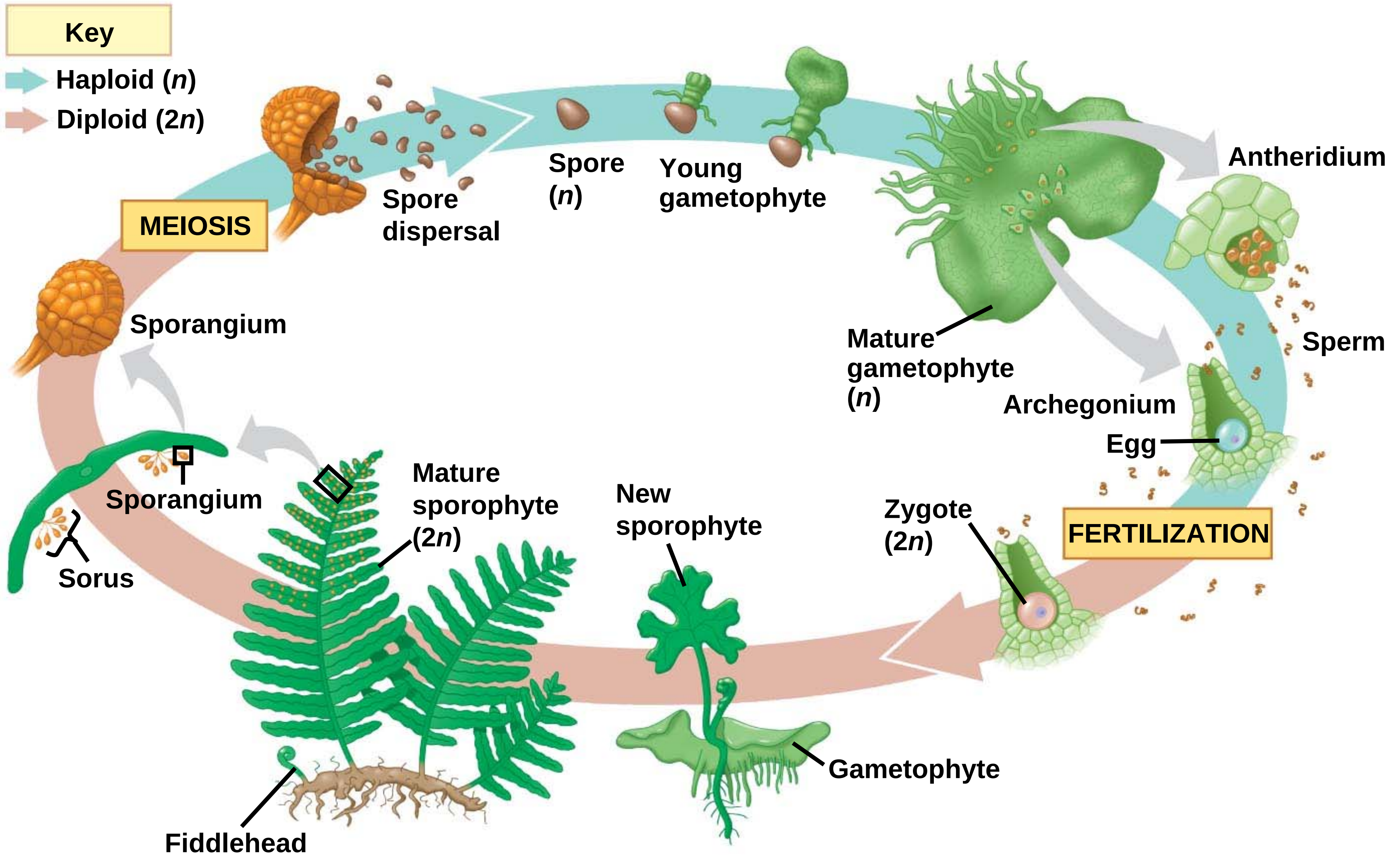

Key
Haploid (n)
Diploid (2n)
MEIOSIS
Spore dispersal
Spore (n)
Young gametophyte
Antheridium
Sperm
Mature gametophyte (n)
Archegonium
Egg
FERTILIZATION
Sporangium
Sporangium
Sorus
Mature sporophyte (2n)
Fiddlehead

Fig. 29-13-3



Key
Haploid (*n*)
Diploid (2*n*)
MEIOSIS
Spore dispersal
Spore (*n*)
Young gametophyte
Antheridium
Sperm
Mature gametophyte (*n*)
Archegonium
Egg
FERTILIZATION
Zygote (2*n*)
New sporophyte
Gametophyte
Mature sporophyte (2*n*)
Sporangium
Sporangium
Sorus
Fiddlehead

Transport in Xylem and Phloem

- Vascular plants have two types of vascular tissue: xylem and phloem
- **Xylem** conducts most of the water and minerals and includes dead cells called **tracheids**
- **Phloem** consists of living cells and distributes sugars, amino acids, and other organic products
- Water-conducting cells are strengthened by **lignin** and provide structural support
- Increased height was an evolutionary advantage

Evolution of Roots

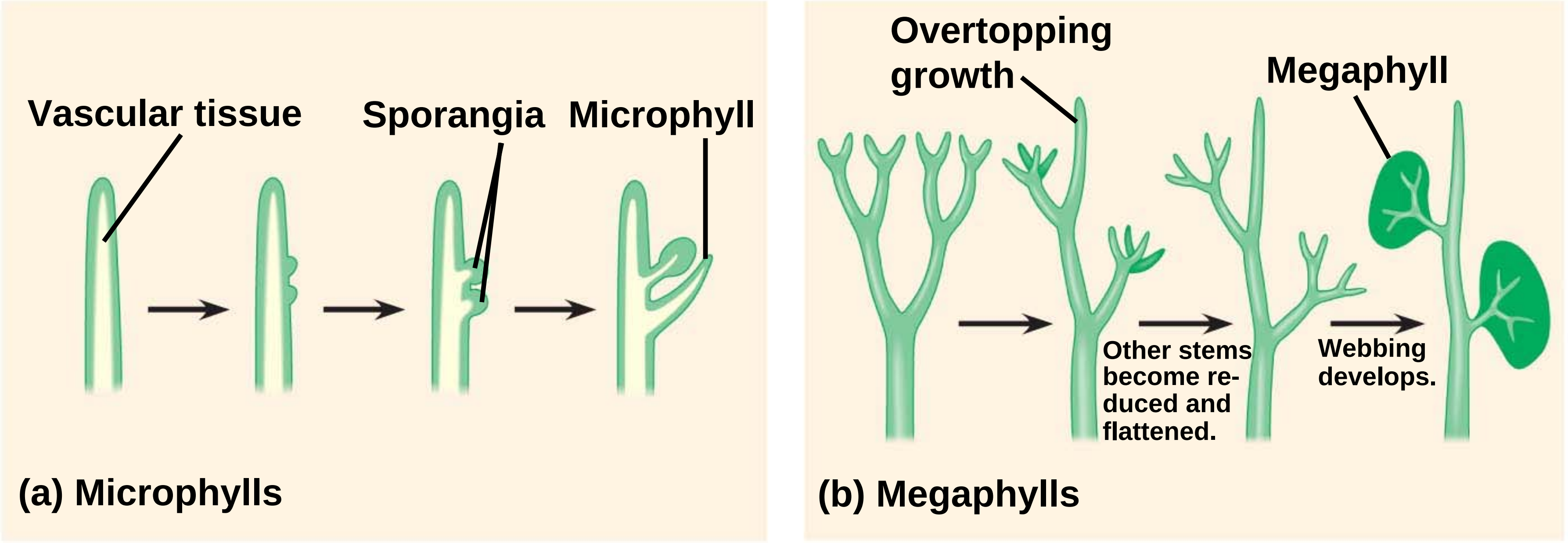
- **Roots** are organs that anchor vascular plants
- They enable vascular plants to absorb water and nutrients from the soil
- Roots may have evolved from subterranean stems

Evolution of Leaves

- **Leaves** are organs that increase the surface area of vascular plants, thereby capturing more solar energy that is used for photosynthesis

- Leaves are categorized by two types:
  – **Microphylls**, leaves with a single vein
  – **Megaphylls**, leaves with a highly branched vascular system
- According to one model of evolution, microphylls evolved first, as outgrowths of stems

Fig. 29-14

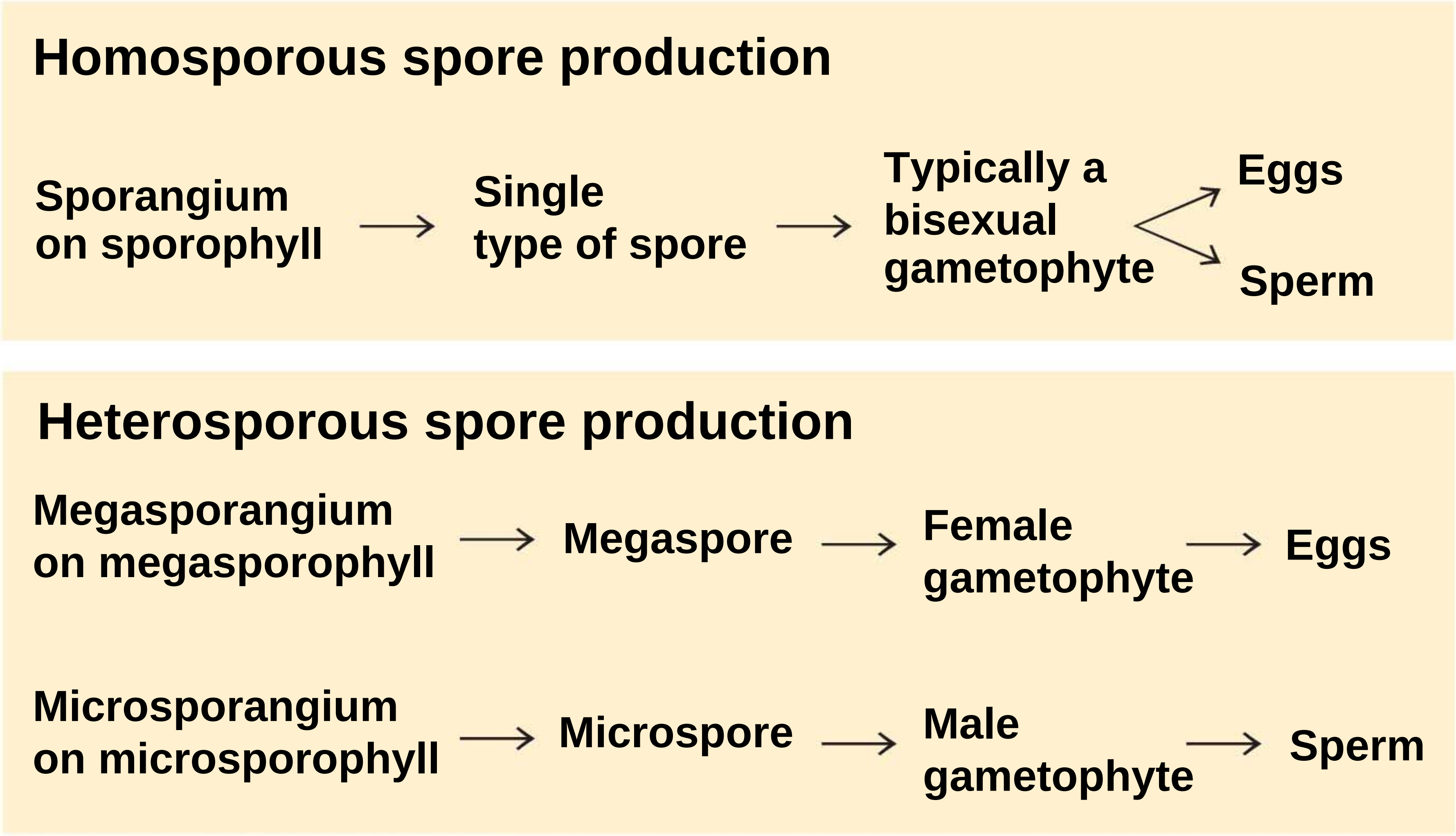

Vascular tissue
Sporangia
Microphyll
(a) Microphylls
Overtopping growth
Megaphyll
Other stems become re- duced and flattened.
Webbing develops.
(b) Megaphylls

Sporophylls and Spore Variations

- **Sporophylls** are modified leaves with sporangia
- **Sori** are clusters of sporangia on the undersides of sporophylls
- **Strobili** are cone-like structures formed from groups of sporophylls

- Most seedless vascular plants are **homosporous**, producing one type of spore that develops into a bisexual gametophyte
- All seed plants and some seedless vascular plants are **heterosporous**
- Heterosporous species produce **megaspores** that give rise to female gametophytes, and **microspores** that give rise to male gametophytes

Fig. 29-UN3


Homosporous spore production
Sporangium on sporophyll
Single type of spore
Typically a bisexual gametophyte
Eggs
Sperm
Heterosporous spore production
Megasporangium on megasporophyll
Megaspore
Female gametophyte
Eggs
Microsporangium on microsporophyll
Microspore
Male gametophyte
Sperm

Classification of Seedless Vascular Plants

- There are two phyla of seedless vascular plants:
  - Phylum Lycophyta includes club mosses, spike mosses, and quillworts
  - Phylum Pterophyta includes ferns, horsetails, and whisk ferns and their relatives

Fig. 29-15a

Lycophytes (Phylum Lycophyta)

Selaginella apoda, a spike moss

Isoetes gunnii, a quillwort

Diphasiastrum tristachyum, a club moss

Fig. 29-15b

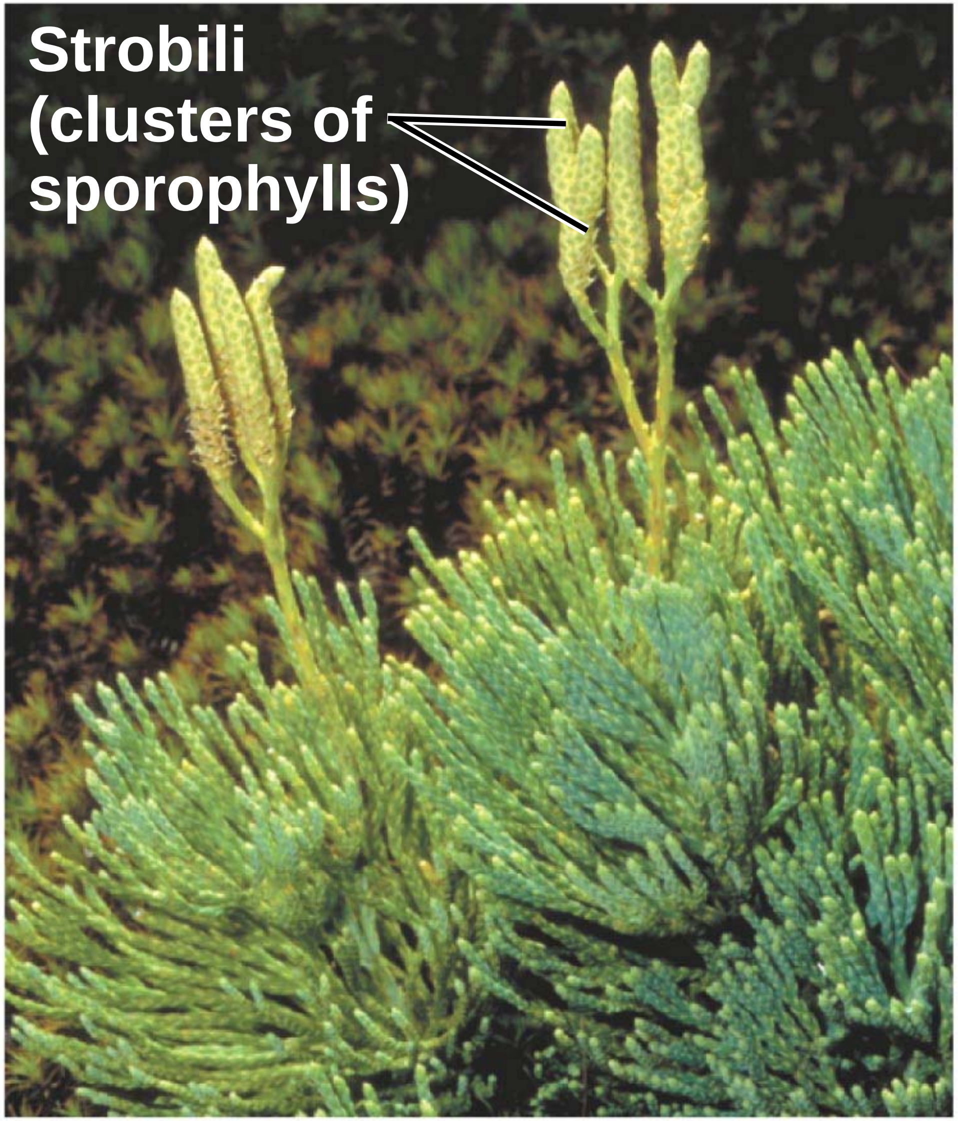
***Selaginella apoda*, a spike moss**

Fig. 29-15c

***Isoetes gunnii*,**
a quillwort

Fig. 29-15d

2.5 cm

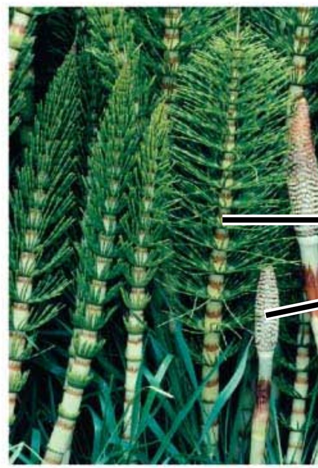


***Diphasiastrum tristachyum*, a club moss**

Fig. 29-15e

Pterophytes (Phylum Pterophyta)

Athyrium filix-femina, **lady fern**



Equisetum arvense, **field horsetail**

Psilotum nudum, **a whisk fern**

Fig. 29-15f

25 cm

Athyrium filix-femina,
lady fern

Fig. 29-15g

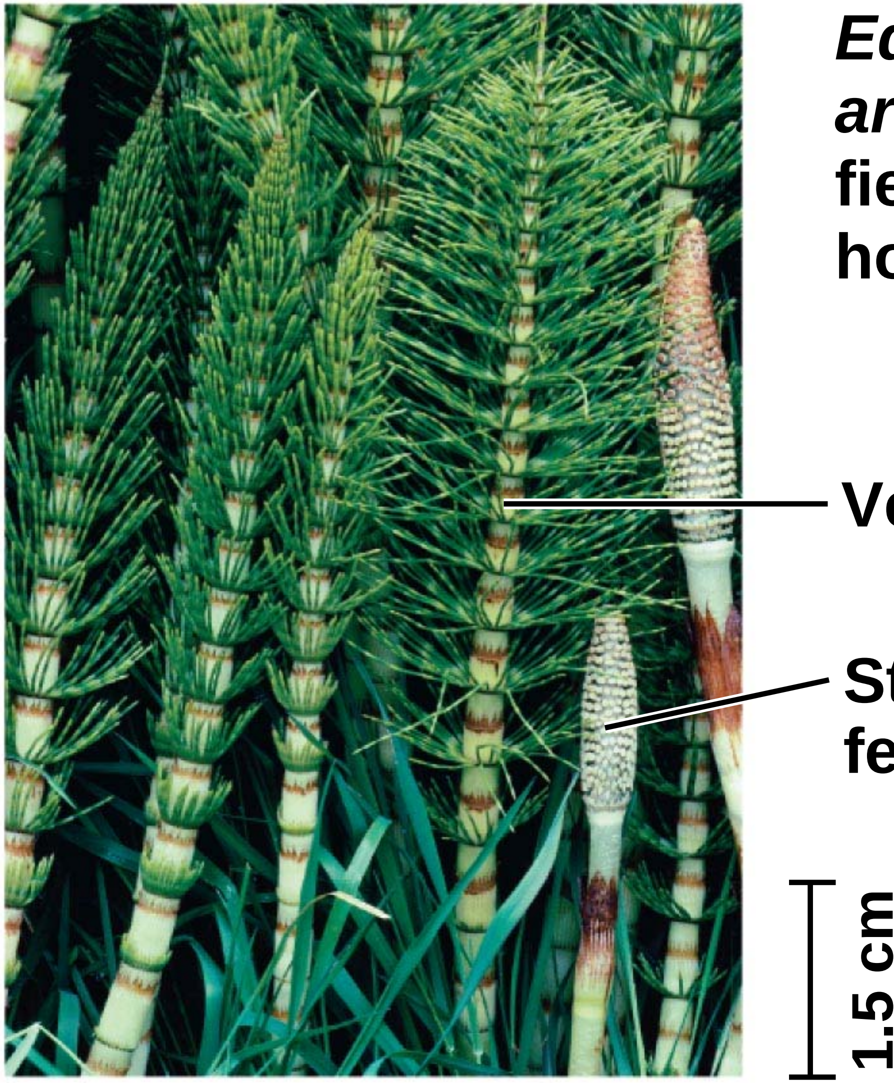

Equisetum arvense, field horsetail
Vegetative stem
Strobilus on fertile stem
1.5 cm

Fig. 29-15h

Psilotum nudum,
a whisk fern

2.5 cm

Phylum Lycophyta: Club Mosses, Spike Mosses, and Quillworts

- Giant lycophytes thrived for millions of years in moist swamps
- Surviving species are small herbaceous plants
- Club mosses and spike mosses have vascular tissues and are not true mosses

Phylum Pterophyta: Ferns, Horsetails, and Whisk Ferns and Relatives

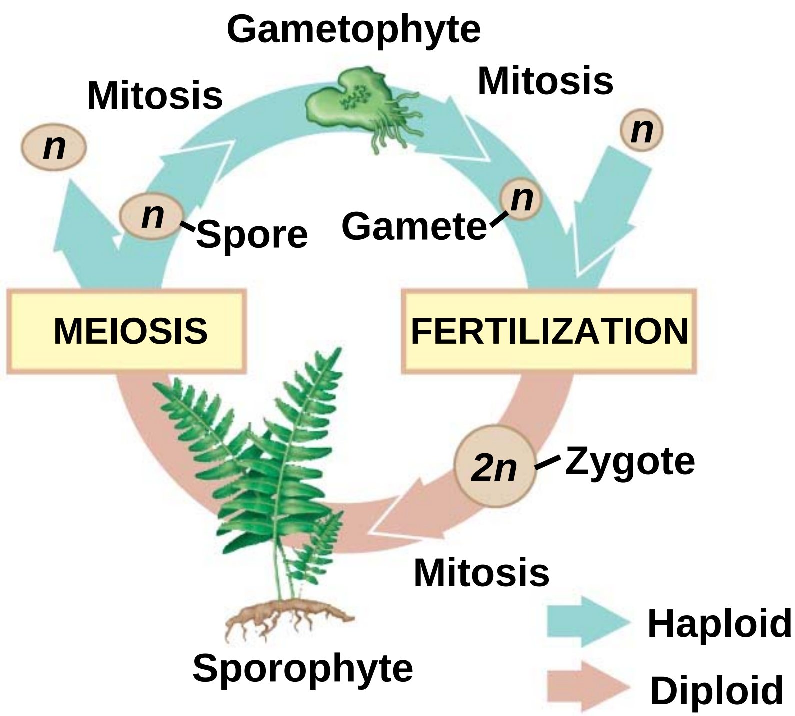
- Ferns are the most diverse seedless vascular plants, with more than 12,000 species
- They are most diverse in the tropics but also thrive in temperate forests
- Horsetails were diverse during the Carboniferous period, but are now restricted to the genus *Equisetum*
- Whisk ferns resemble ancestral vascular plants but are closely related to modern ferns

The Significance of Seedless Vascular Plants

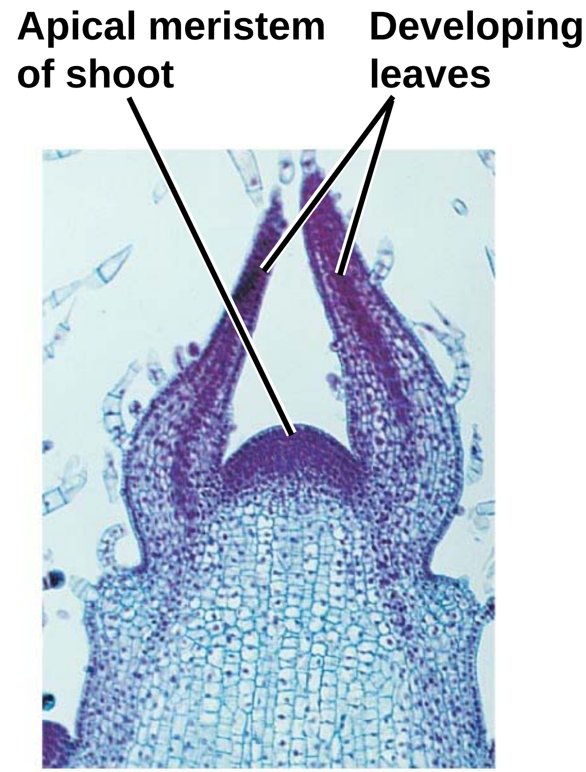
- The ancestors of modern lycophytes, horsetails, and ferns grew to great heights during the Devonian and Carboniferous, forming the first forests
- Increased photosynthesis may have helped produce the global cooling at the end of the Carboniferous period
- The decaying plants of these Carboniferous forests eventually became coal

Fig. 29-16

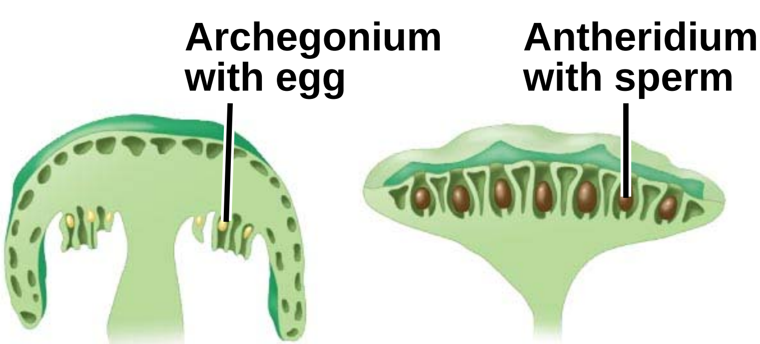
Fig. 29-UN4



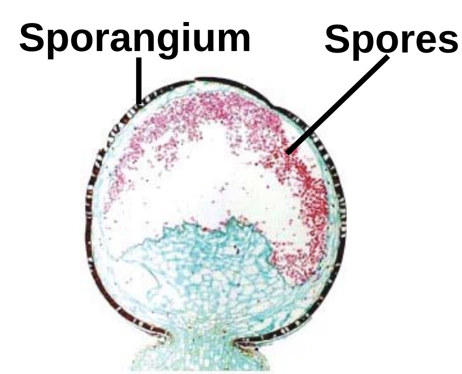
1 Alternation of generations



2 Apical meristems

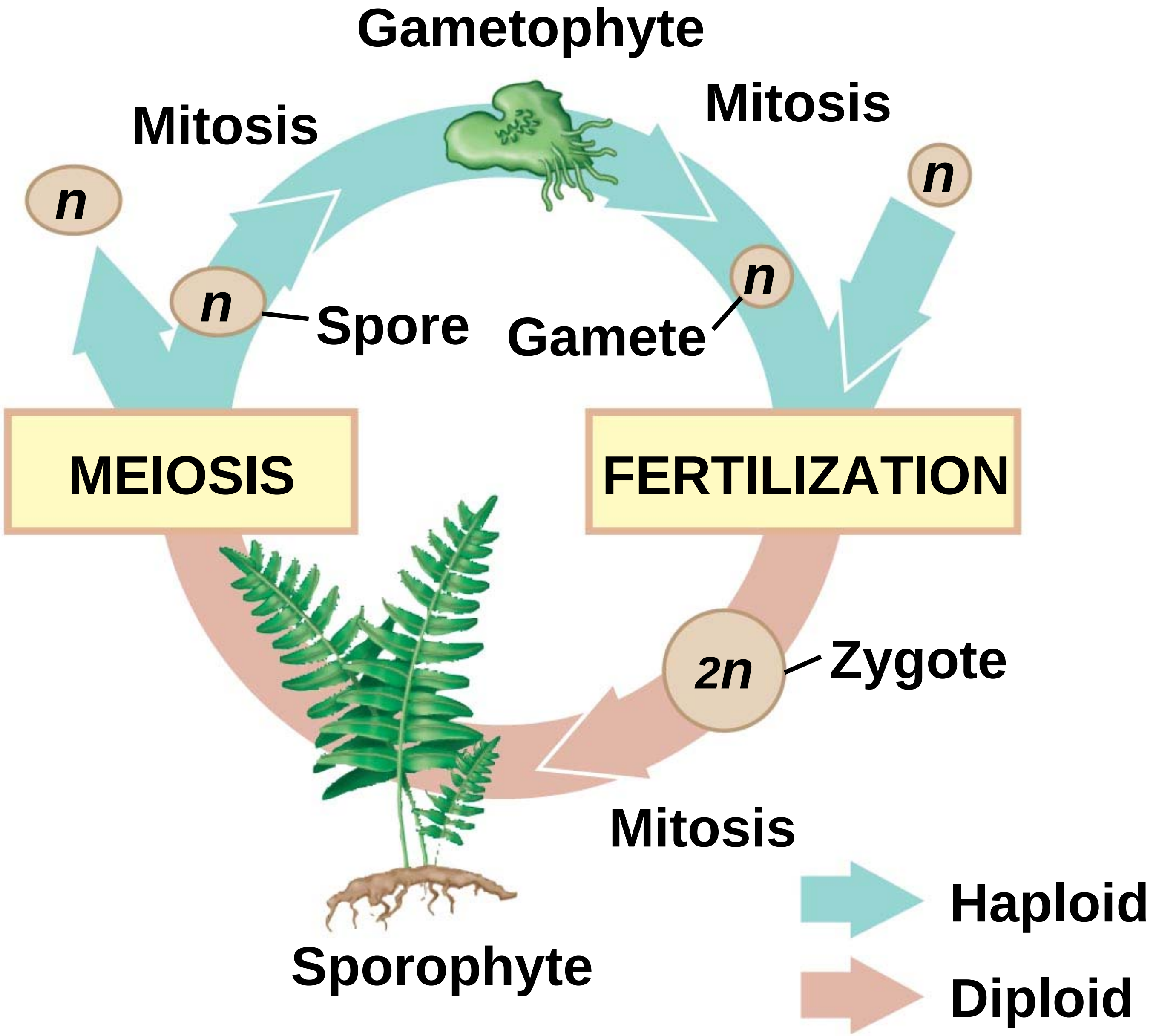


3 Multicellular gametangia



4 Walled spores in sporangia

Fig. 29-UN4a

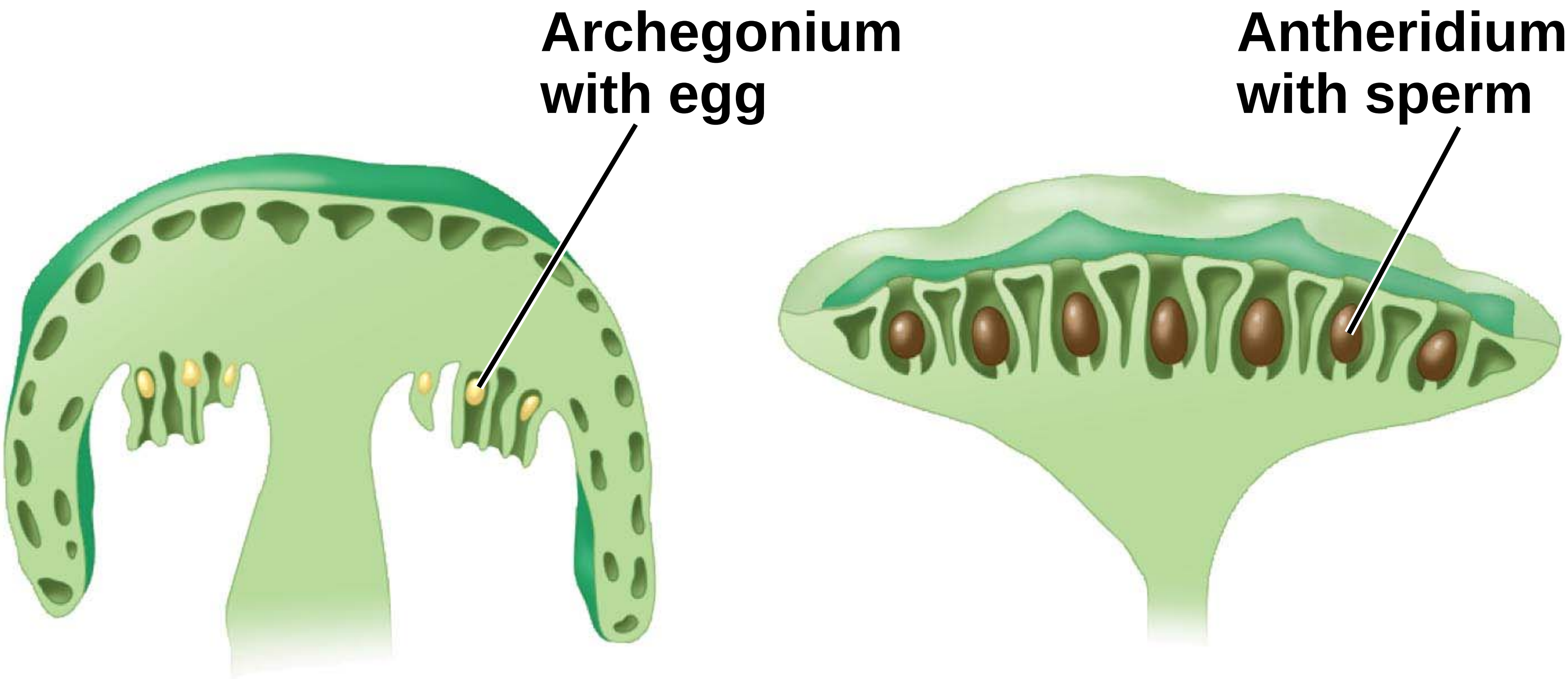


Alternation of generations

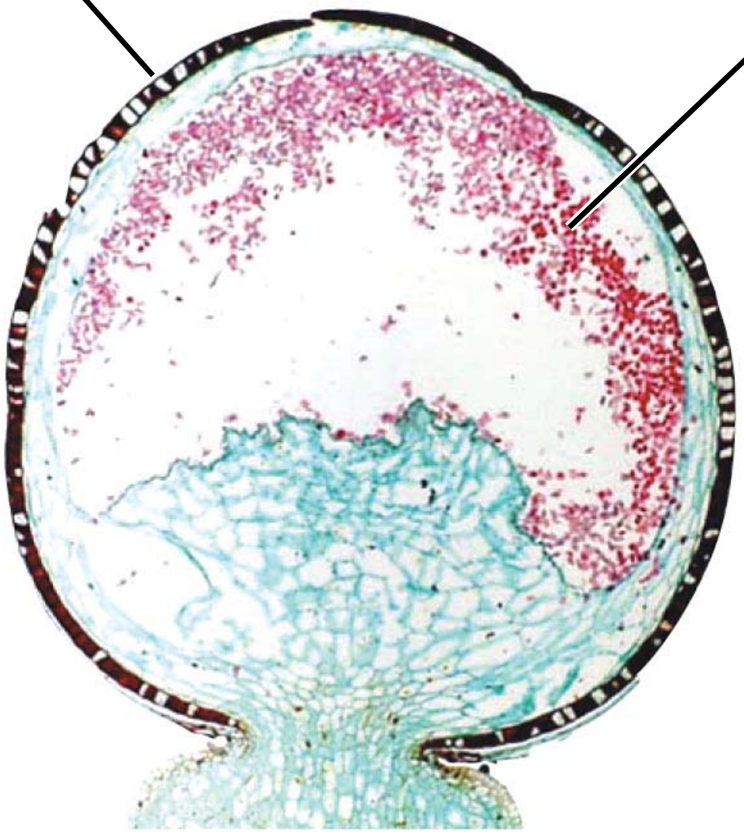
Fig. 29-UN4b

Apical meristems

Fig. 29-UN4c



Multicellular gametangia



Walled spores in sporangia

You should now be able to:

1. Describe four shared characteristics and four distinct characteristics between charophytes and land plants
2. Distinguish between the phylum Bryophyta and bryophytes
3. Diagram and label the life cycle of a bryophyte
4. Explain why most bryophytes grow close to the ground and are restricted to periodically moist environments

5. Describe three traits that characterize modern vascular plants and explain how these traits have contributed to success on land

6. Explain how vascular plants differ from bryophytes

7. Distinguish between the following pairs of terms: microphyll and megaphyll; homosporous and heterosporous

8. Diagram and label the life cycle of a seedless vascular plant