

# 22

## The History of Life on Earth



# 28

## Protists and the Dawn of the Eukarya



### The History of Life on Earth

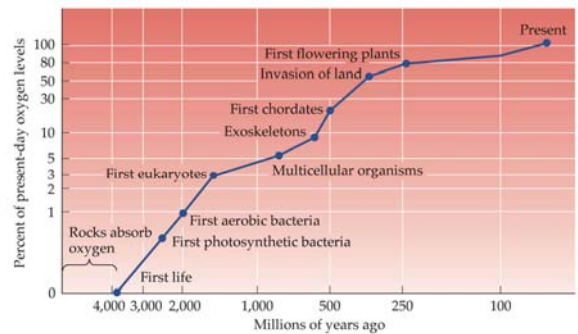
- Origin of Multicellularity
- Chapter 22
  - Defining Biological Evolution
  - Determining Earth's Age
  - The Changing Earth
  - Major Patterns in the History of Life on Earth
  - The Fossil Record
  - Rates of Evolutionary Change within Lineages
  - The Future of Evolution

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Figure 22.4 Larger Cells Need More Oxygen



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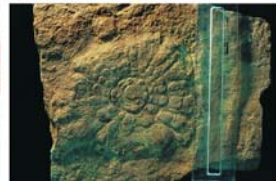
### Multicellularity and Ediacaran Fauna 600 mya



Figure 22.8 Ediacaran Animals

*Spriggina flouderisi*

*Marosmites*

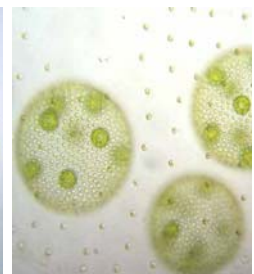


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### *Volvox carteri*

Juvenile female

Mature mother with Babies Inside



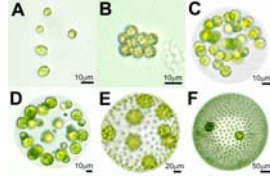
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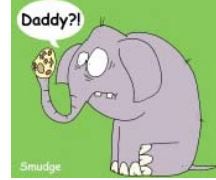
### Origin of Multicellularity

- Multicellularity is a complex trait
- Reduce this complexity to a set of steps each advantageous
  - Group formation
  - Colonial life in groups
  - Groups increase in size
  - Cells within groups specialize
  - Conflict mediation of the tragedy of the commons
  - Spatial organization within groups
  - Group becomes indivisible and hence an individual



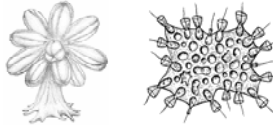
### Origin of Multicellularity

- Multicellularity is a complex trait
- Happened many times
  - Myxobacteria 2000 mya
  - Major groups 600-1000 mya
    - Origins in these major groups are obscured by 100's of millions of years of evolution afterwards
  - Protists
    - More recent examples of multicellular forms

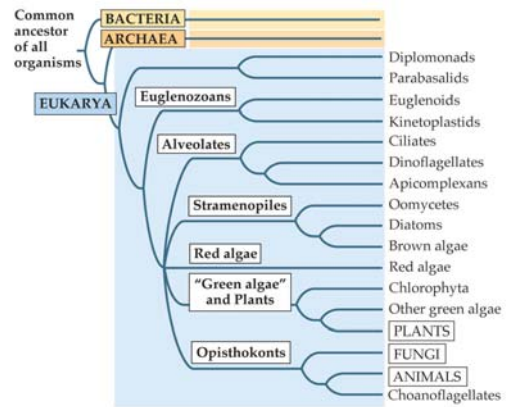


### Simple Colonial Systems in Protists and Prokaryotes

- Myxobacteria
- Proterospongia
- Slime molds
- Volvocine algae

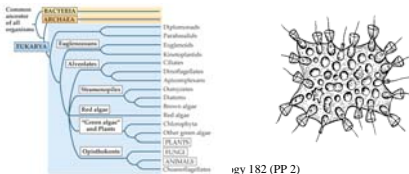


### Figure 28.9 Major Protist Groups in an Evolutionary Context

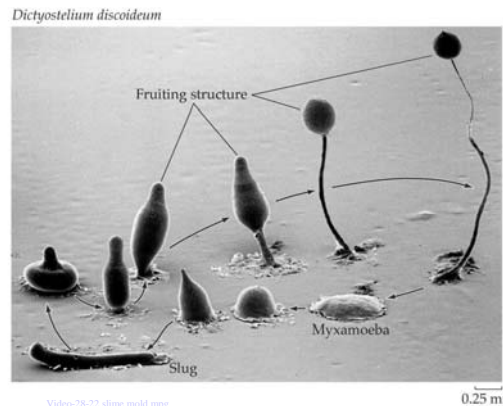


### Choanoflagellida

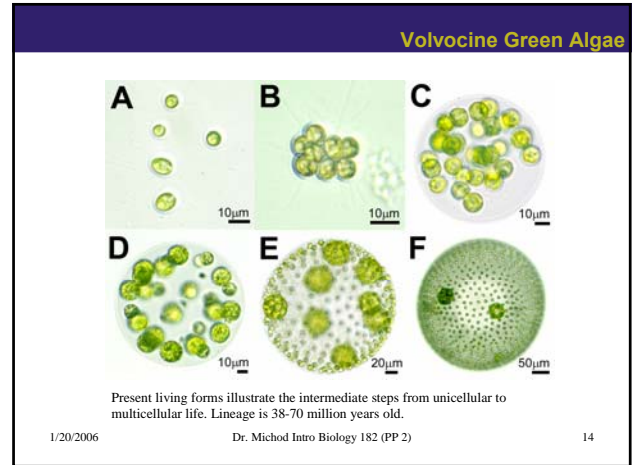
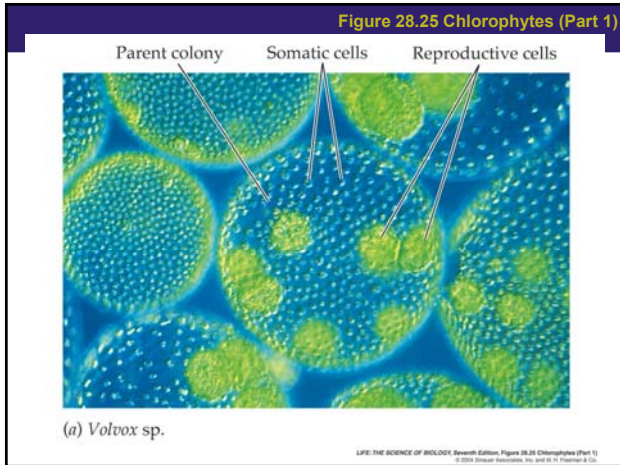
- The Choanoflagellida are protists with flagella and a body type similar to a characteristic type of sponge cell.
- The Choanoflagellida are sister to the animal kingdom.



### Figure 28.32 A Cellular Slime Mold



Video: 28.32 slime mold.mpeg



**Group Formation**

- Why form groups?
  - Predation  
[Video-04-20 rotifer feeding.mpg](#)
  - Homeostasis
  - Advantages of specialization
- How do groups form?
  - Cells stick together after cell division
  - Video of volvocine green algae forming groups  
[Video-01-05 volvocine algae.mpg](#)
- How do groups become individuals?

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**Fitness**

- Fitness = Survival x Reproduction
  - Survival depends on motility
  - Reproduction depends on growth of the reproductive cell
- Ancestral unicellular state
  - Survival and reproduction separated in time, motile → reproductive
  - Reproductive cells grow large and divide

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**Scenario Origin Multicellularity**

- Motility is useful for the group
- Motility costs reproduction
- In a group, more motile cells are 'altruistic' in the sense that they benefit the group but reproduce more slowly than less motile cells
  - Flagella = altruism
- Less motile cells are selfish
- How to keep some cells motile all the time, so the group doesn't sink while it is reproducing?
- Tragedy of the commons, again

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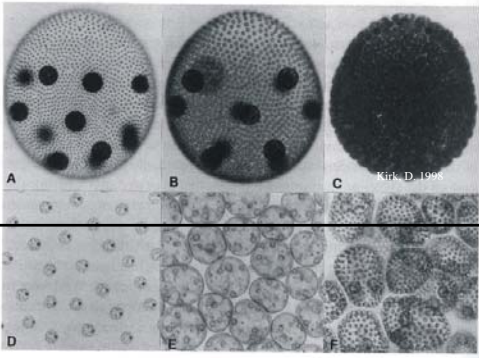
**Conflict Mediation in Cell Groups**

- How to keep cells cooperating in the group?
- Kin selection
- Policing
  - Familiar to us in our human societies
  - Immune system in humans and other animals
  - Programmed cell death
  - Starve motile cells to keep them from growing and reproducing in *Volvox*

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## Cooperation & Conflict in *Volvox carteri*

- Conflict mediation in the group
  - Clonal groups (kin selection)
  - Soma doesn't divide, *regA* gene starves somatic cells and prevents them from reproducing
  - Two functions (motility & reproduction) separated in space
- *regA* is an "altruistic" gene
  - Mutations in gene are selfish (see figure)
  - Where did the gene come from?



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## How Does a Group Become an Individual?

- Cell Specialization
  - If cells specialize in either survival or reproduction, then they will not be able to survive and reproduce on their own
  - If cells specialize, the group becomes indivisible and an individual.
  - Only the group will have fitness by virtue of the specialization of its member cells, who, by themselves have no fitness
- Why would cells specialize?
  - Kin selection
    - ◻ If they are clonally descended from a single cell they will all be genetically related (nearly identical genetically) and share the same interests
  - Conflict mediation
    - ◻ Advantages of division of labor and germ soma specialization
    - ◻ Multitask. Do two or more things at once
    - ◻ Be motile, exchange nutrients, excrete waste, while reproducing

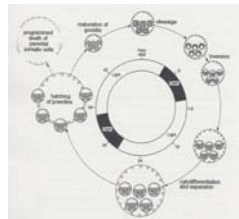
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## Motility in *Volvox carteri*

- Upward swimming speed
- Sinking speed (mass)
- Measure during development
  - 2 hours after hatching
  - 14 hours after hatching



Volvox carteri wild type  
 Mean N = 2201 ± 93  
 Mean S/R = 185 ± 11  
 Mean Germ cells = 11.5 ± 0.2

Research Credits:  
 C. Solari, J. Kessler

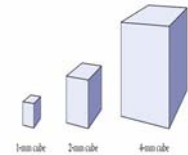
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## Cell Surface to Volume Ratio

- There is another kind of problem with multicellularity besides internal conflict among cells
- As most objects get bigger, volume increases more rapidly than surface area
- Life's processes occur inside (in the volume) and require exchange of nutrients and waste with the environment
- Exchange with the environment happens at the surface
- So there is a problem as organisms get big and locally compact



| Surface area                 | 6 sides × 1² = 6 mm² | 6 sides × 2² = 24 mm² | 6 sides × 4² = 96 mm² |
|------------------------------|----------------------|-----------------------|-----------------------|
| Volume                       | 1³ = 1 mm³           | 2³ = 8 mm³            | 4³ = 64 mm³           |
| Surface area-to-volume ratio | 6/1                  | 3/1                   | 1.5/1                 |

pp. 62-63 from text

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## Colony Size & Exchange with the Environment

- As colonies increase in size, resource acquisition and waste removal is a problem
- Surface area to volume ratio (see Ch. 4)
- Flagella help solve this problem
- Videos using particle image velocimetry to study flagella-driven flows surrounding colonies of three *Volvox* species

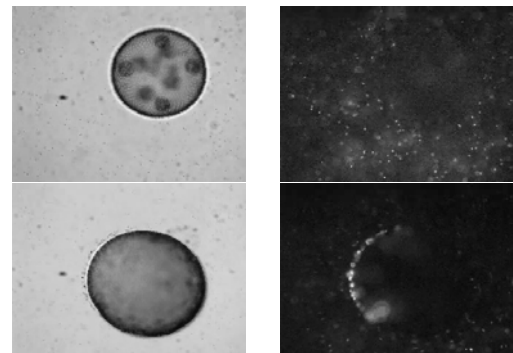
[Video-04-17 volvox flagella.mpg](#)

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## Flagella-driven Flows & Transport

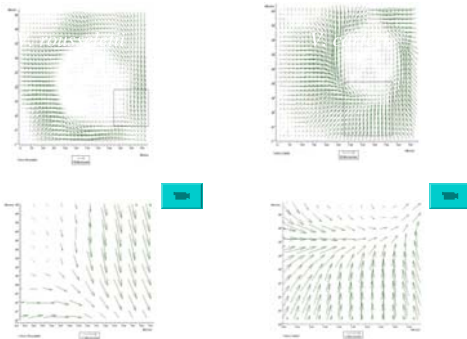


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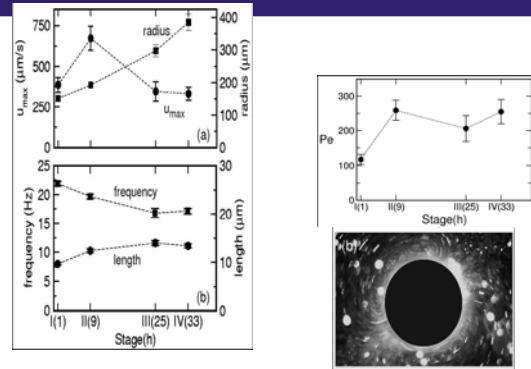
## Calculate Flagella-driven Flows & Transport



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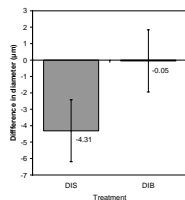
## Flagellar Mixing During Development



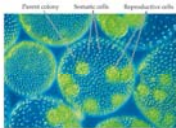
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## Productivity Increases with Flagellar Mixing



- Deflagellated colonies in still (DIS) and bubbling (DIB) medium
- Measure increase in reproductive cell diameter during the growth phase
- Ordinate is reproductive cell growth relative to normal flagellated colonies in still medium



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## Conclusions of Experiments

- Flagellar action cost individual cells within the group.
  - Flagella interfere with reproduction of the flagellated cells
- Flagellated somatic cells benefit the group
  - Movement through the environment while reproducing (can do 2 things at once)
  - Interaction with environment through mixing of surrounding fluid
    - Exchange nutrients, get ride of waste
    - Germ cell growth depends upon effective interaction with its environment

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## Summary Origin of Multicellularity

- Group formation
- Colonial life in groups
- Groups increase in size
- Cells within groups specialize in essential tasks of the group
- Group can do two or more things at once
- Conflict mediation of the tragedy of the commons
- Spatial organization within groups
- Group becomes indivisible and hence an individual

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## Defining Biological Evolution

- Understanding evolution is important because the features of all organisms are best understood in the light of evolution.
- It is also important because humans are becoming powerful agents of evolutionary change.

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## Defining Biological Evolution

- **Biological evolution** is a change over time in the genetic composition of a population of organisms.
- Some changes can occur rapidly enough to be manipulated experimentally; others take place over very long time frames.
- An understanding of the long-term patterns of evolutionary change requires thinking in time frames spanning many millions of years and imagining conditions on Earth that are very different from those we observe today.

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## Determining Earth's Age

- Imagine the problem of understanding time and the past...
- The age of rocks can be determined.
- **Fossils** are remains of ancient organisms contained within rocks.
- In general, fossils of similar ages are found in similar strata across the earth.

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Figure 22.1 Young Rocks Lie on Top of Old Rocks



LIFE: THE SCIENCE OF BIOLOGY, Seventh Edition, Figure 22.1 Young Rocks Lie on Top of Old Rocks  
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## Determining Earth's Age

- Radioactivity provides a way to date rocks.
- Radioactive isotopes decay in a predictable pattern over long periods of time.
- The time it takes for half of a radioactive isotope to decay is that isotope's **half-life**.
- Each radioisotope has a characteristic half-life.

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## Determining Earth's Age

- To use a radioisotope to date a past event, the concentration of the isotope at the time of that event must be known or estimated.
- In the case of  $^{14}\text{C}$ , we know that the ratio of  $^{14}\text{C}$  to  $^{12}\text{C}$  is relatively constant in the environment and living organisms. When an organism dies,  $^{14}\text{C}$  is no longer taken up by the cells, and the ratio of  $^{14}\text{C}$  to  $^{12}\text{C}$  decreases through time.
- $^{14}\text{C}$  can be used to date fossils (and sedimentary rocks they were deposited in) less than 50,000 years old.

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## Determining Earth's Age

- Sedimentary rocks are unreliable for dating.
- To date sedimentary rocks, geologists look for lava flows between sedimentary layers. The lava can be dated by the decay of potassium-40 to argon-40.
- When radioactive dating methods are not applicable, alternative approaches and observations are used, including paleomagnetism, continental drift, sea level changes, and molecular clocks.

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### Determining Earth's Age

- Using information from these dating methods, geologists have divided Earth's history into eras and periods.
- Boundaries between the divisions are based on major differences in the fossil organisms contained in the layers.
- The divisions were established before the actual ages of the eras and periods were known.
- In the **Precambrian** era, early life evolved.

Figure 22.2 Sea Levels Have Changed Repeatedly

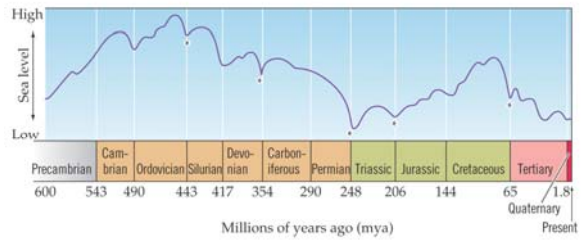
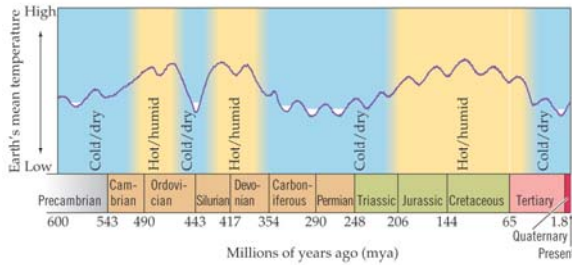


Figure 22.5 Hot/Humid and Cold/Dry Conditions Have Alternated Over Earth's History



### Animation of Continental Drift



Table 22.1 Earth's Geological History (Part 1)

| 22.1 Earth's Geological History (Part 1) |             |               |                      |  |
|--|-------------|---------------|----------------------|--|
| RELATIVE TIME SPAN                       | ERA         | PERIOD        | ONSET                | MAJOR PHYSICAL CHANGES ON EARTH  |
| Cenozoic                                 | Cenozoic    | Quaternary    | 1.8 mya <sup>a</sup> | Cold/dry climate; repeated glaciations   |
|  |             | Tertiary      | 65 mya               | Continents near current positions; climate cools   |
|  | Mesozoic    | Cretaceous    | 144 mya              | Northern continents attached; Gondwana drifts apart; meteorite strikes Yucatan Peninsula         |
|  |             | Jurassic      | 206 mya              | Two large continents form: Laurasia and Gondwana; climate warm                                   |
|  |             | Triassic      | 248 mya              | Pangaea begins to drift apart; hot/humid climate   |
|  | Paleozoic   | Permian       | 290 mya              | Continents aggregate into Pangaea; large glaciers form; dry climates form in interior of Pangaea |
|  |             | Carboniferous | 354 mya              | Climate cools; marked latitudinal climate gradients  |
|  |             | Devonian      | 417 mya              | Continents collide at end of period; asteroid probably collides with Earth                       |
|  |             | Silurian      | 443 mya              | Sea levels rise; two large continents form; hot/humid climate                                    |
|  |             | Ordovician    | 490 mya              | Gondwana moves over South Pole; massive glaciation, sea level drops 50 m                         |
| Precambrian                              | Precambrian | Cambrrian     | 543 mya              | O <sub>2</sub> levels approach current levels  |
|  |             |               | 600 mya              | O <sub>2</sub> level at >5% of current level   |
|  |             |               | 1.5 bya <sup>a</sup> | O <sub>2</sub> level at >1% of current level   |
|  |             |               | 3.8 bya              | O <sub>2</sub> first appears in atmosphere   |

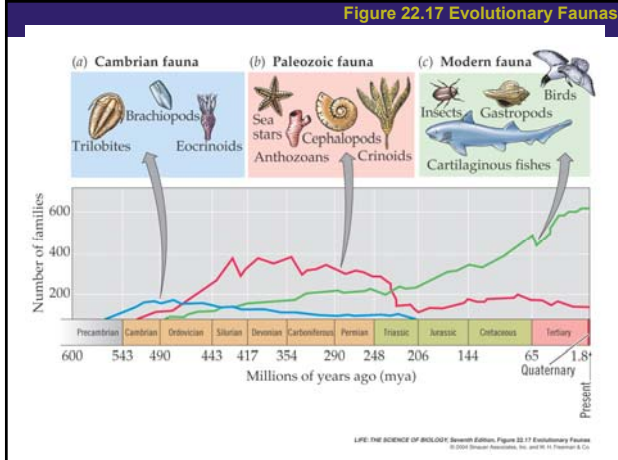
<sup>a</sup>mya, million years ago; bya, billion years ago.

Table 22.1 Earth's Geological History (Part 2)

| 22.1 Earth's Geological History (Part 2) |             |               |                      |  |
|--|-------------|---------------|----------------------|--|
| RELATIVE TIME SPAN                       | ERA         | PERIOD        | ONSET                | MAJOR EVENTS IN THE HISTORY OF LIFE  |
| Cenozoic                                 | Cenozoic    | Quaternary    | 1.8 mya <sup>a</sup> | Humans evolve; many large mammals become extinct   |
|  |             | Tertiary      | 65 mya               | Diversification of birds, mammals, flowering plants, and insects   |
|  | Mesozoic    | Cretaceous    | 144 mya              | Dinosaurs continue to diversify; flowering plants and mammals diversify; Mass Extinction at end of period (~75% of species disappear)                |
|  |             | Jurassic      | 206 mya              | Diverse dinosaurs; radiation of ray-finned fishes  |
|  |             | Triassic      | 248 mya              | Early dinosaurs; first mammals; marine invertebrates diversify; first flowering plants; Mass Extinction at end of period (~90% of species disappear) |
|  | Paleozoic   | Permian       | 290 mya              | Reptiles diversify; amphibians decline; Mass Extinction at end of period (~90% of species disappear)   |
|  |             | Carboniferous | 354 mya              | Extensive "fern" forests; first reptiles; insects diversify  |
|  |             | Devonian      | 417 mya              | Fishes diversify; first insects and amphibians; Mass Extinction at end of period (~75% of species disappear)   |
|  |             | Silurian      | 443 mya              | Jawless fishes diversify; first ray-finned fishes; plants and animals colonize land  |
|  |             | Ordovician    | 490 mya              | Mass Extinction at end of period (~75% of species disappear)   |
| Precambrian                              | Precambrian | Cambrrian     | 543 mya              | Most animal phyla present; diverse algae   |
|  |             |               | 600 mya              | Eukaryotic fauna   |
|  |             |               | 1.5 bya <sup>a</sup> | Eukaryotes evolve; several animal phyla appear   |
|  |             |               | 3.8 bya              | Origin of life; prokaryotes flourish   |

<sup>a</sup>mya, million years ago; bya, billion years ago.

Figure 22.17 Evolutionary Faunas



### The Changing Face of Earth

- Earth's atmosphere has also changed since the time the planet formed when little or no free oxygen was present.
- Oxygen concentrations began to increase significantly about 2.5 billion years ago when some prokaryotes evolved the ability to split water as a source of hydrogen ions for photosynthesis. The waste product is  $O_2$ .
- One lineage of these oxygen-generating bacteria evolved into the **cyanobacteria**. These organisms formed rocklike structures called **stromatolites**.
- The cyanobacteria liberated enough  $O_2$  to allow the evolution of oxidation reactions as the energy source for the **synthesis of ATP**.

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### The Changing Face of Earth

- As life continued to evolve, the physical nature of the plant was irrevocably changed.
- Living organisms not only added  $O_2$  to the atmosphere but also removed  $CO_2$  from it.
- An atmosphere rich in  $O_2$  made possible the evolution of larger cells and more complex organisms.
- About 1,500 mya,  $O_2$  concentrations became high enough for large eukaryotic cells to flourish and diversify.
- By 750–700 mya,  $O_2$  had increased to levels that could support multicellular organisms.

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