Inquiry into Life

Eleventh Edition

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Chapter 27
Lecture Outline

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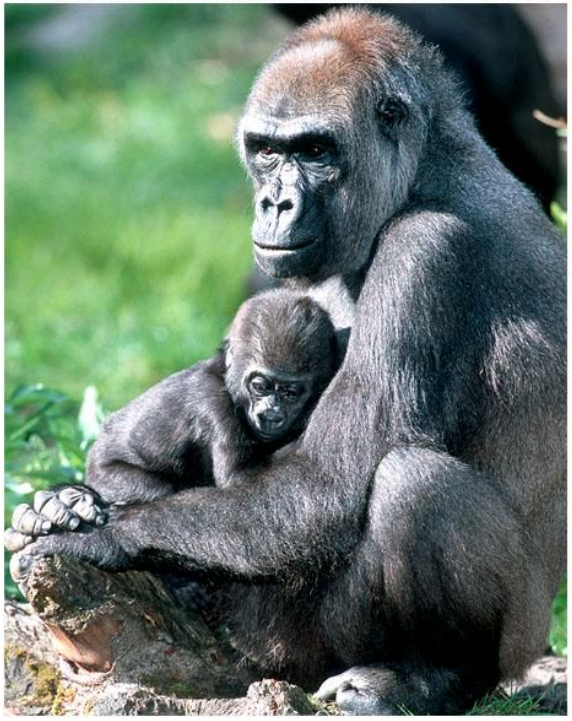


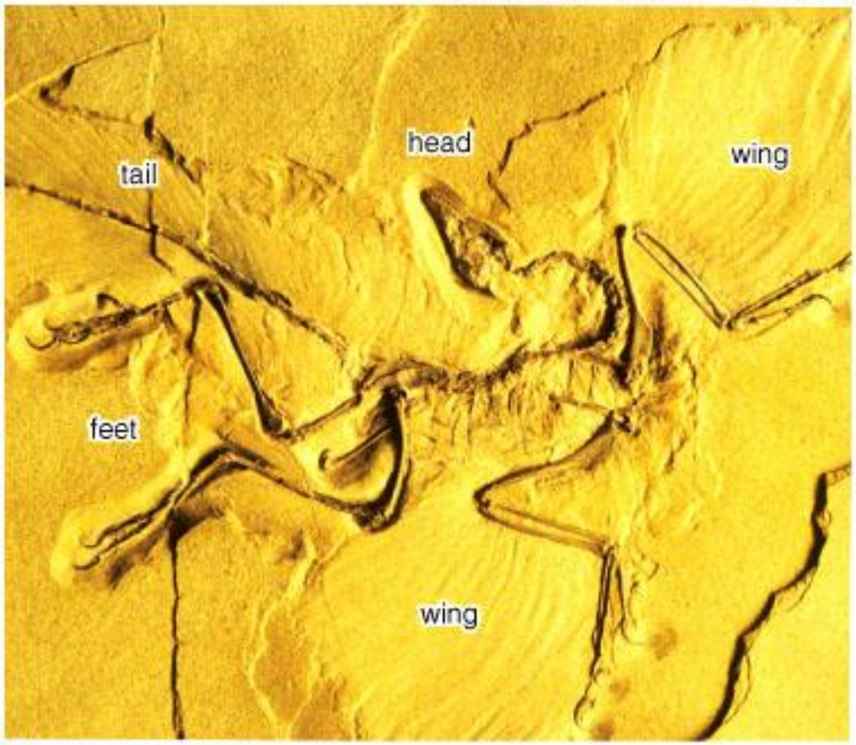
27.1 Evidence of evolution

- Overview
  - Evolution encompasses common descent and adaptation
    - Common descent
      - All organisms are composed of cells
      - All take chemicals and energy from the environment
      - All reproduce, respond to stimuli, and evolve
  - Earth is approximately 4.5 billion years old
    - Prokaryotes arose about 3.5 billion years ago
    - Eukaryotes about 2.1 billion years ago, but multicellularity came much later at 700 million years ago
      - Most evolutionary events occurred in less than 20% of the history of life!

Evidence of evolution cont'd.

- Fossil evidence
  - Hard body parts are preserved in most cases
  - Often embedded in sedimentary rock-deposited in layers called strata
    - Strata represent eras in geological time
    - Each stratum is older than the one above and younger than the one below
  - Transitional fossils
    - Especially significant- represent evolutionary links

Transitional fossils



a.

b.

- Fig. 27.1

Evidence of evolution cont'd.

- Geological time scale
  - History of Earth is divided into eras
    - Based on dating of fossil evidence
      - Relative dating method-noting which layer a group of fossils comes from
      - Absolute method-radioactive carbon dating
  - The geological time scale is shown on the following slide
    - Note the examples of principal plant and animal life during each era

Geological timescale

TABLE 27.1 THE GEOLOGICAL TIMESCALE: MAJOR DIVISIONS OF GEOLOGICAL TIME WITH SOME OF THE MAJOR EVOLUTIONARY EVENTS OF EACH GEOLOGICAL PERIOD

Era	Period	Epoch	Millions of Years Ago	Plant Life	Animal Life
		Holocene	0–0.01	Destruction of tropical rain forests by humans accelerates extinctions	AGE OF HUMAN CIVILIZATION
Cenozoic* (from the present to 66.4 million years ago)	Neogene			*Significant Mammalian Extinction*	
		Pleistocene	0.01–2	Herbaceous plants spread and diversify	Modern humans appear
		Pliocene	2–6	Herbaceous angiosperms flourish	First hominids appear
		Miocene	6–24	Grasslands spread as forests contract	Apelike mammals and grazing mammals flourish; insects flourish
		Oligocene	24–37	Many modern families of flowering plants evolve	Browsing mammals and monkeylike primates appear
	Paleogene	Eocene	37–58	Subtropical forests thrive with heavy rainfall	All modern orders of mammals are represented
		Paleocene	58–66	Angiosperms diversify	Primitive primates, herbivores, carnivores, and insectivores appear
				Mass Extinction of Dinosaurs and Most Reptiles	
	Cretaceous		66–144	Flowering plants spread; coniferous trees decline	Placental mammals appear; modern insect groups appear
Mesozoic (from 66.4 to 245 million years ago)	Jurassic		144–208	Cycads and other gymnosperms flourish	Dinosaurs flourish; birds appear
				Mass Extinction Affects All Life Forms	
	Triassic		208–245	Cycads and ginkgoes appear; forests of gymnosperms and ferns dominate	First mammals appear; first dinosaurs appear; corals and molluscs dominate seas
				Mass Extinction Affects All Life Forms	
	Permian		245–286	Conifers appear	Reptiles diversify; amphibians decline
	Carboniferous		286–360	Age of great coal-forming forests: club mosses, horsetails, and ferns flourish	Amphibians diversify; first reptiles appear; first great radiation of insects
				Mass Extinction Affects All Life Forms	
Paleozoic (from 245 to 570 million years ago)	Devonian		360–408	First seed ferns appear	Jawed fishes diversify and dominate the seas; first insects and first amphibians appear
	Silurian		408–438	Low-lying vascular plants appear on land	First jawed fishes appear
				Mass Extinction Affects All Life Forms	
	Ordovician		438–505	Marine algae flourish	Invertebrates spread and diversify; jawless fishes, first vertebrates appear
	Cambrian		505–570	Marine algae flourish	Invertebrates with skeletons are dominant
			570	Multicellular organisms appear	
			2,100	First complex (eukaryotic) cells appear	
			3,100–3,500	First prokaryotic cells in stromatolites appear	
Precambrian time (from 570 to 4,600 million years ago)			4,500	Earth forms	

*Many authorities divide the Cenozoic era into the Tertiary period (contains Paleocene, Eocene, Oligocene, Miocene, and Pliocene) and the Quaternary period (contains Pleistocene and Holocene).

- Table 27.1

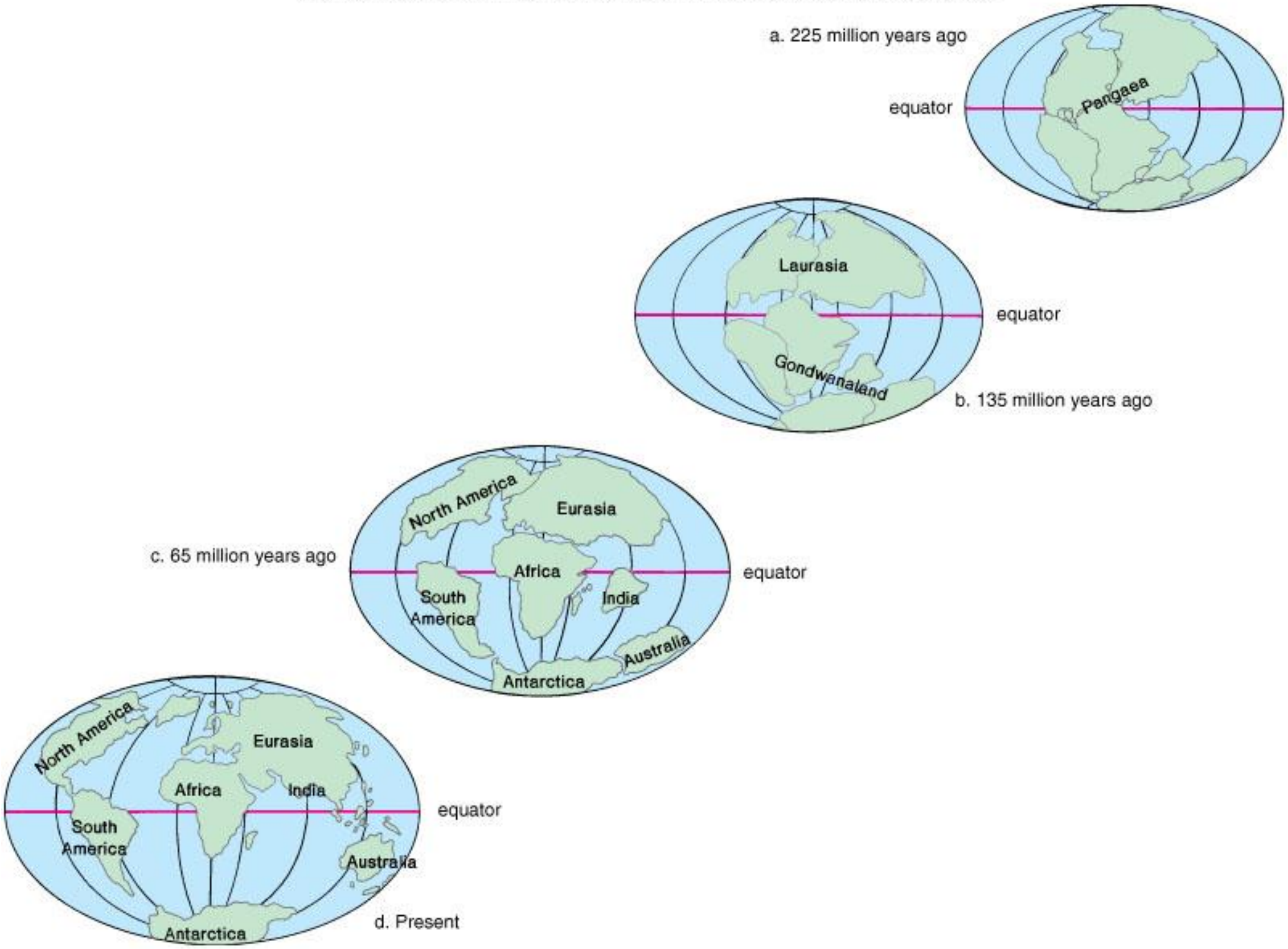
Evidence of evolution cont'd.

- Mass extinctions
  - Large numbers of species become extinct in a short period of time
    - Remaining species may spread out and utilize niches left vacant
  - Mass extinction occurred in Cretaceous period
    - Clay from that period is high in iridium, an element in meteorites
    - Proposed that meteorites hit Earth and dust filled the atmosphere
      - Blocked sunlight, plants died
  - It is proposed that many mass extinctions have resulted from extra-terrestrial events
    - However, a current one may be due to human encroachment

Evidence of evolution cont'd.

- Biogeographical evidence
  - Study of distribution of plants and animals
  - Earth has 6 biogeographical regions
    - Each has its own distinctive mix of species
      - Barriers prevented evolving species from migrating to other regions
  - Continental drift-positions of continents and oceans has shifted through time
    - 225 million years ago continents were one land mass
    - Distribution of fossils and existing species allows us to determine approximate timeline

Continental drift

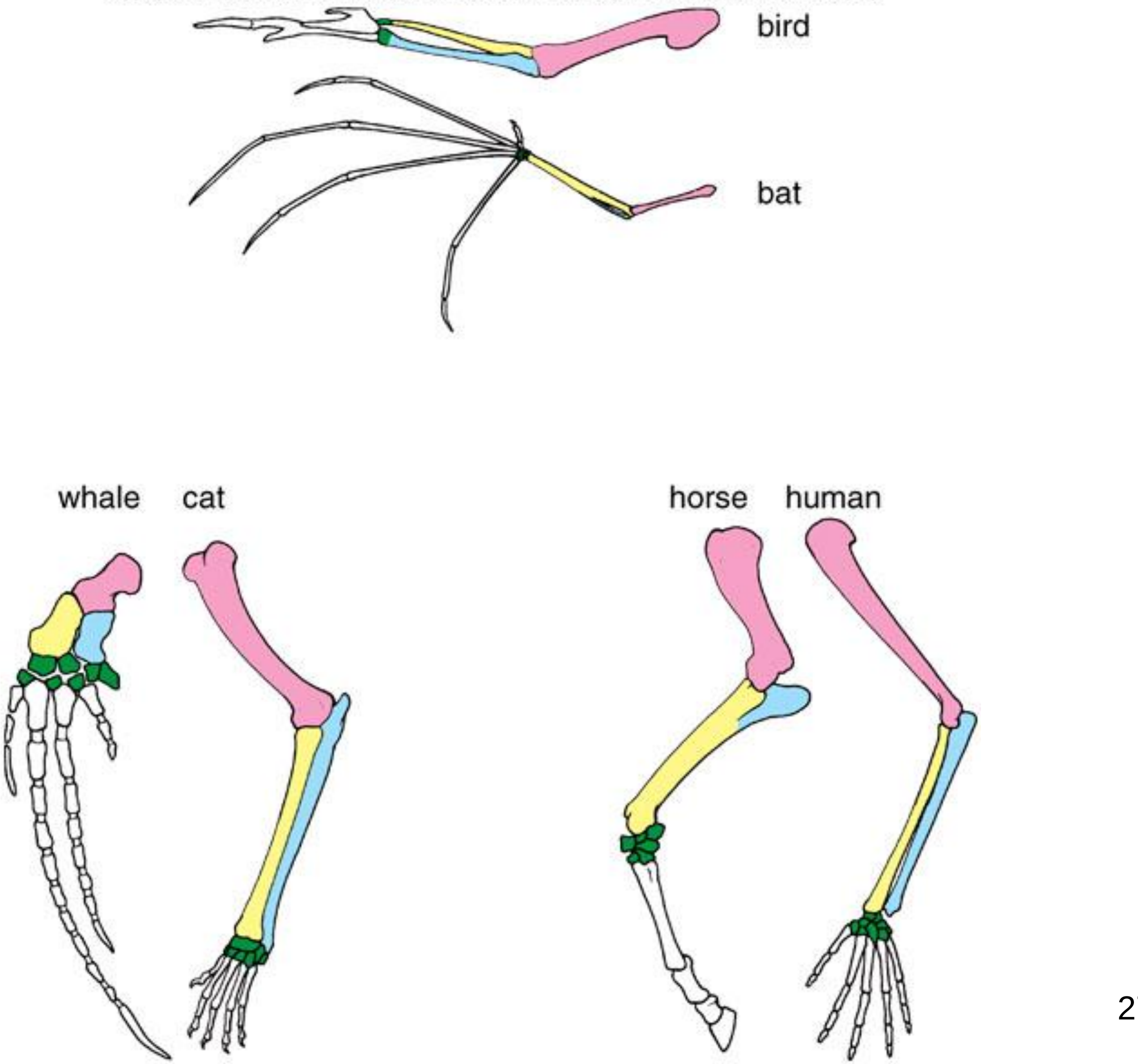


- Fig. 27.3

Evidence of evolution cont'd.

- Anatomical evidence
  - Common descent offers explanation for anatomical similarities
    - Homologous structures- have same function and same basic structure, indicating a common ancestor
      - Ex: human arm and whale forelimb
    - Analogous structures- same basic function but different origins
      - Ex: wing of bird and wing of bee
    - Vestigial structures-anatomical structures fully functional in one group and reduced, nonfunctional in another
      - Humans have a tailbone (coccyx) but no tail
  - Homology extends to embryonic structure
    - Gill slits, notocord, pharyngeal pouches

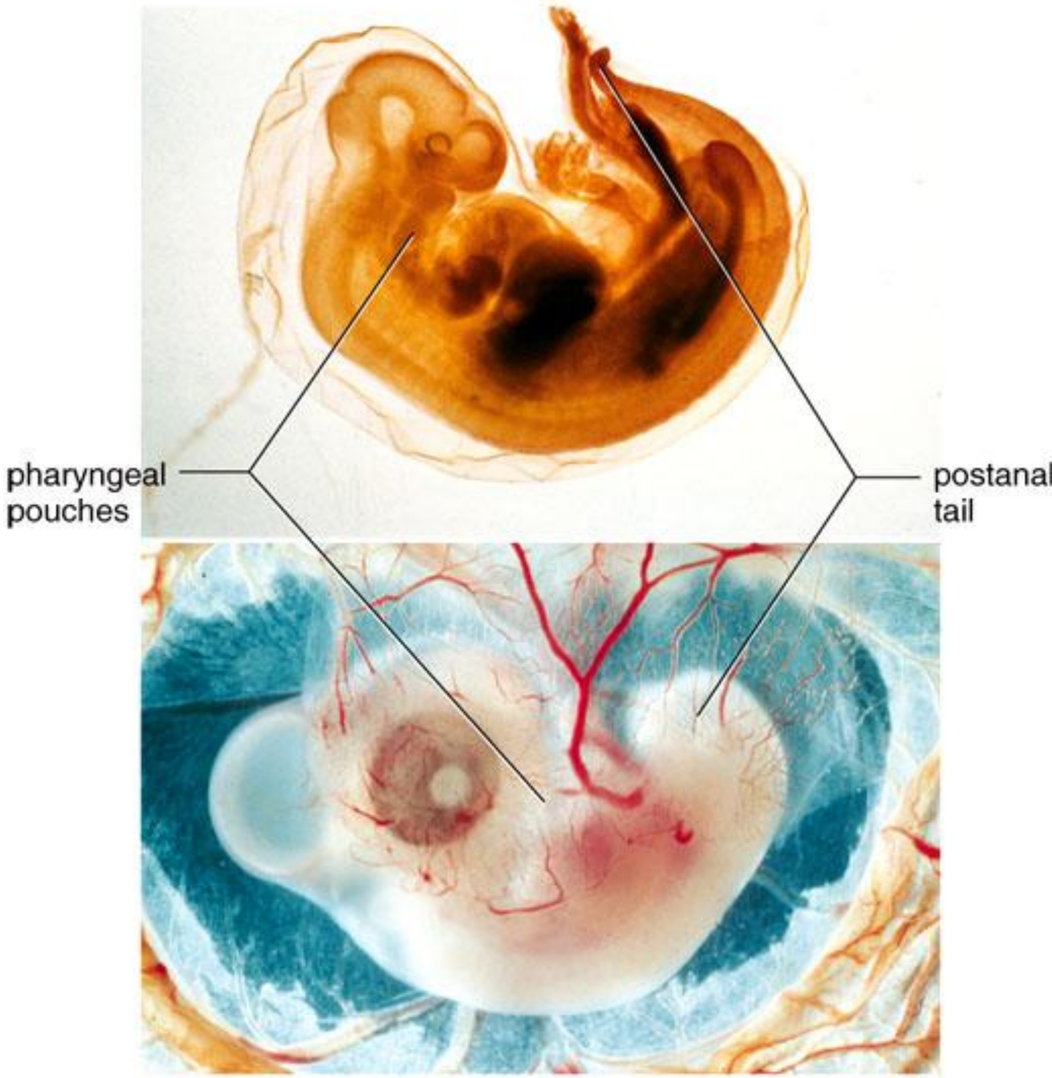
Bones of the vertebrate forelimb



- Fig. 27.4

Significance of developmental similarities

Pig embryo



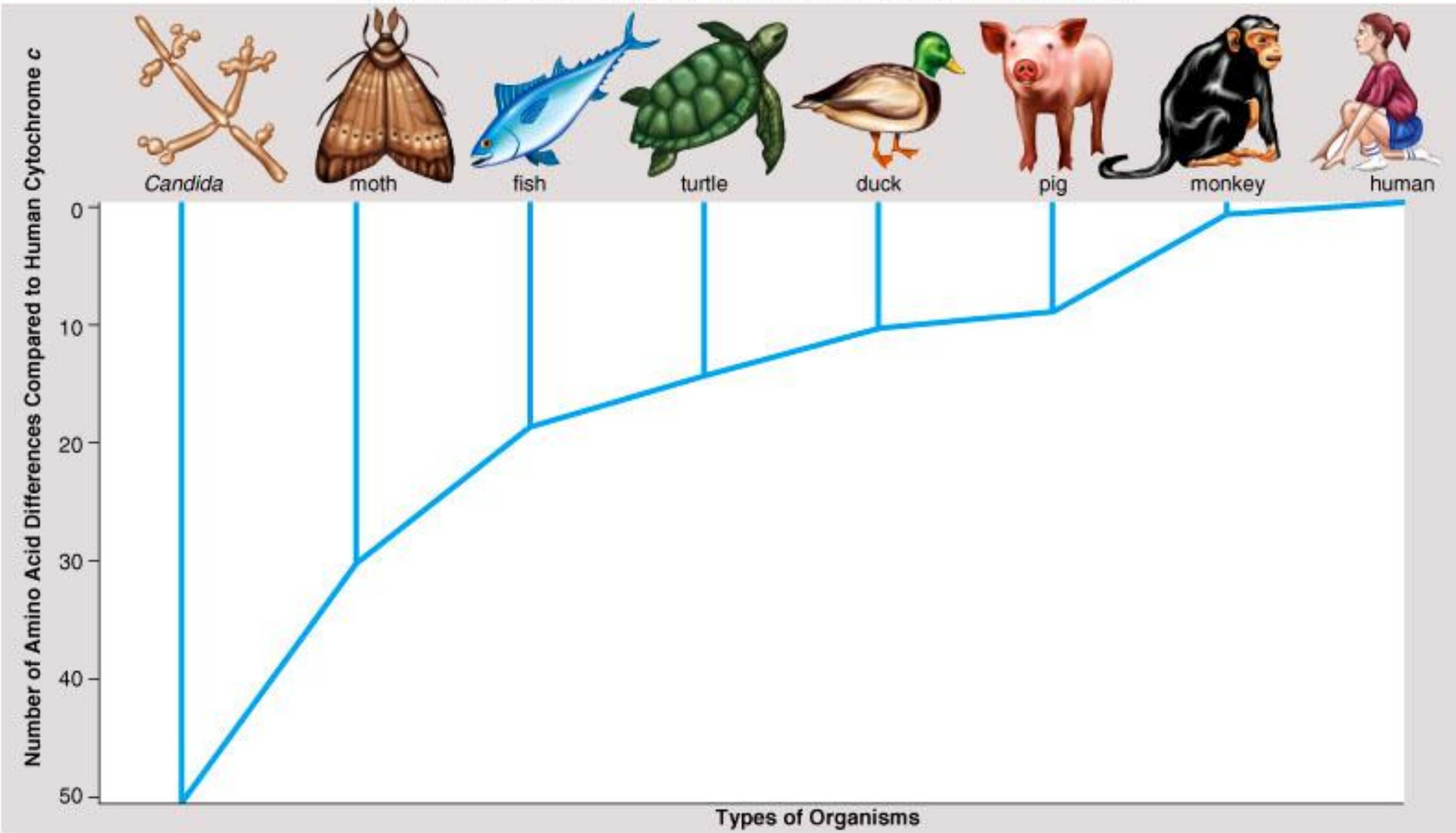
Chick embryo

- Fig. 27.5

Evidence of evolution cont'd.

- Biochemical evidence
  - All organisms use same basic biochemical molecules
    - DNA
    - ATP
    - Identical or nearly identical enzymes
  - Many developmental genes are shared
  - Degree of similarity between DNA base sequences and amino acid sequences indicates the degree of relatedness
- Evolution is one of the great unifying theories of biology

Significance of biochemical differences

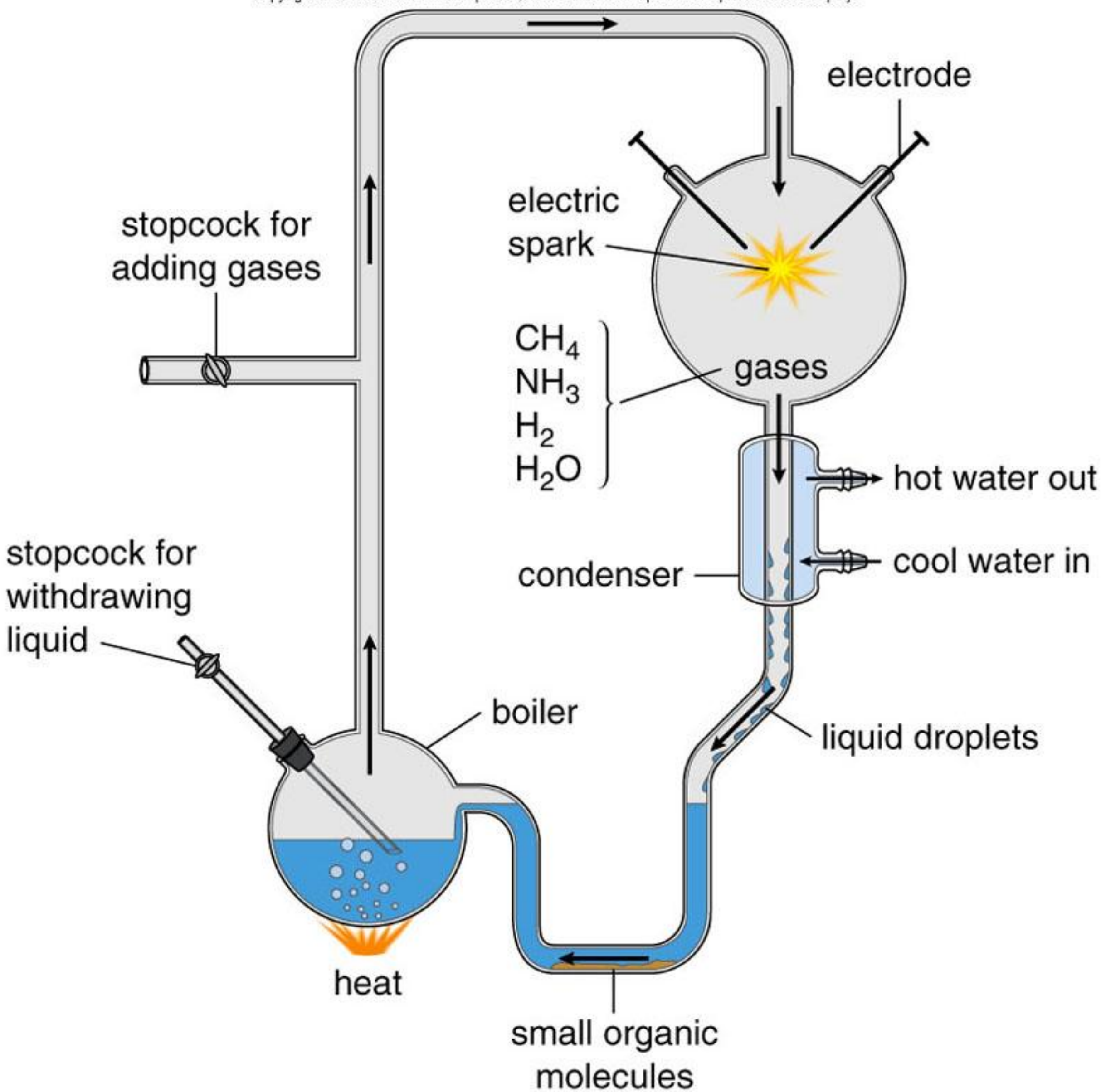


- Fig. 27.6

27.2 Origin of life

- Evolution of small molecules
  - Miller experiment-simulated conditions of early Earth
    - Placed inorganic chemicals methane, ammonia, and hydrogen in a closed system
      - Applied heat and circulated it by an electric spark
      - Yielded amino acids and organic acids
    - Supports hypothesis that inorganic chemicals in the absence of oxygen and in presence of strong energy can result in organic molecules
  - The formation of small organic molecules was the first step in the origination of cells
  - Small molecules then gave rise to larger molecules and finally macromolecules

Stanley Miller's apparatus and experiment



- Fig. 27.8

Origin of life cont’d.

- Macromolecules
  - RNA-first hypothesis
    - In some instances RNA can function as both a substrate and an enzyme
    - Some viruses use RNA as genetic material
    - therefore, if RNA evolved first it could function as both genes and enzymes
  - Protein-first hypothesis-Sidney Fox’s experiments
    - Amino acids can form polypeptides when exposed to dry heat
    - Could have occurred when amino acids collected in puddles and were exposed to sunlight-formed proteinoids
      - Proteinoids have catalytic ability
      - Form microspheres when introduced back into water

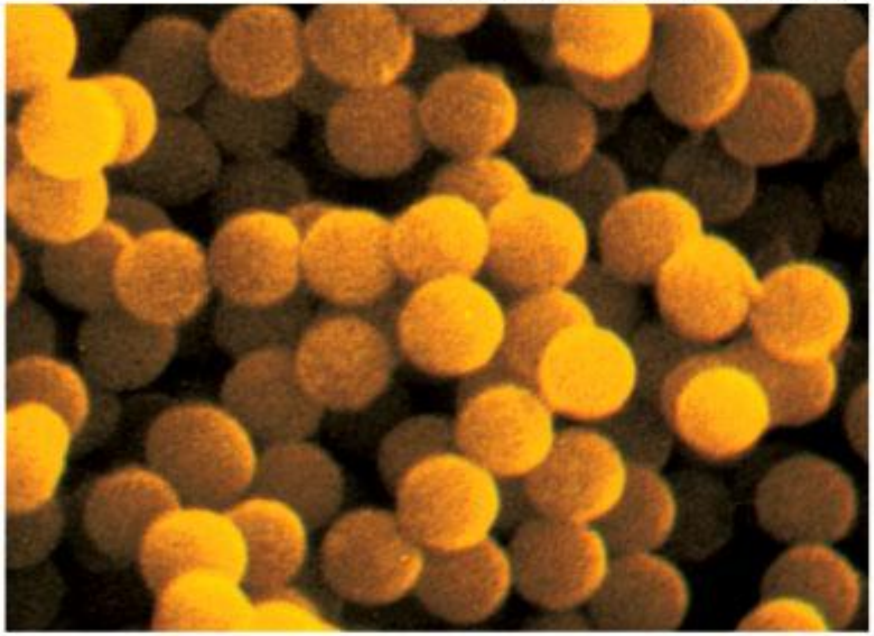
Origin of life cont'd.

- Macromolecules cont'd.
  - Cairnes-Smith hypothesis
    - Clay attracts small organic molecules and also contains iron and zinc
    - Iron and zinc may have served as inorganic catalysts for polypeptide formation
    - Clay also collects energy from radioactive decay and releases it under specific environmental conditions
      - Could have served as energy source for polymerization
    - This hypothesis suggests that both proteins and RNA formed at the same time

Origin of life cont'd.

- The protocell
  - Precursor of cells
  - Proposed structure-a protein-lipid membrane; carried on energy metabolism
  - If microspheres are exposed to lipids, an association occurs resulting in a protein-lipid membrane-based on Fox's hypothesis
  - Aleksandr Oparin's experiments
    - Under specific conditions of pH, ionic composition, and temperature concentrated mixtures of macromolecules form coacervates
      - Coacervate droplets absorb and incorporate many substances
      - May form a semi permeable boundary around droplet
  - In lipid environment, phospholipids are known to automatically form liposomes-may be the way plasma membranes first formed

Protocell anatomy



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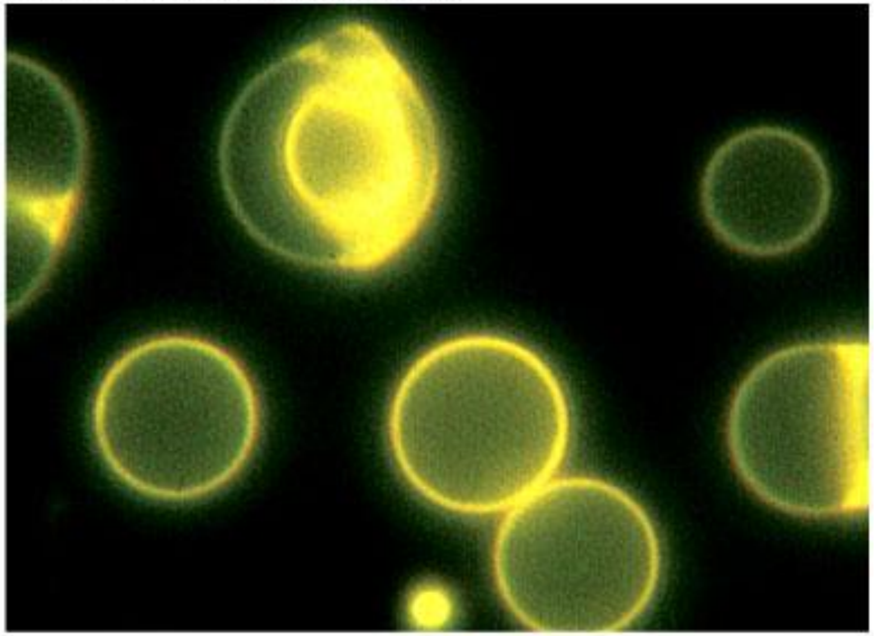


b.

- Fig. 27.10

Origin of life cont'd.

- The heterotroph hypothesis
  - Nutrition was plentiful in the ocean
  - Protocells were most likely heterotrophs
    - Implies that heterotrophs preceded autotrophs
  - Protocells probably used preformed ATP at first
    - Natural selection favored those that could extract ATP from carbohydrates
    - Fermentative process because oxygen was not available
  - Fox's experiments showed microspheres have some catalytic activity- protocells may have also
  - Oparin showed that coacervates can take in enzymes if available
  - These may indicate mechanisms by which glycolysis may have evolved

Origin of life cont'd.

- The true cell
  - Membrane-bounded structure that can produce proteins that allow DNA replication
    - DNA directs protein synthesis and information flows from DNA to RNA to protein
  - RNA-first hypothesis suggests that RNA developed before DNA, so first true cell would have had RNA genes
    - Some viruses have RNA genes- reverse transcriptase produces DNA from RNA
    - Suggests a mechanism as to how cells evolved to have DNA genes
  - Protein-first hypothesis suggest proteins evolved first
    - Complex enzymatic processes may have been necessary for formation of DNA and RNA
    - Enzymes may have been needed to produce nucleotides and nucleic acids

Origin of life cont'd.

- The true cell cont'd.
  - The Cairnes-Smith hypothesis suggests RNA and protein evolved at the same time
    - RNA genes could replicate because proteins were already present to catalyze the reactions
    - But this supposes that two unlikely spontaneous processes would occur at once- formation of RNA and formation of protein
  - Once protocells had genes that could replicate, they became true cells

27.3 Process of evolution

- Microevolution- a change in gene frequencies within a population
  - Population genetics
    - Population- all members of a species occupying a particular area at the same time
      - Mating is purely random
      - Genes are passed on according to Mendel's laws
    - Gene pool- the sum total of all alleles of all genes in a population
  - Hardy and Weinberg used the binomial equation $p^2+2pq+q^2$ to calculate the genotype and allele frequencies in a population
  - Predicts that gene frequencies will remain constant from generation to generation
  - This is illustrated in the following slide of Fig. 27.11

Using the Hardy-Weinberg equation

$$p^2 + 2pq + q^2$$

p^2 = frequency of homozygous dominant individuals
p = frequency of dominant allele
q^2 = frequency of homozygous recessive individuals
q = frequency of recessive allele
$2pq$ = frequency of heterozygous individuals

Realize that $p + q = 1$ (There are only 2 alleles.)
$p^2 + 2pq + q^2 = 1$ (These are the only genotypes.)

Example

An investigator has determined by inspection that 16% of a human population has a recessive trait. Using this information, we can complete all the genotype and allele frequencies for the population, provided the conditions for Hardy-Weinberg equilibrium are met.

Given: q^2 = 16% = 0.16 are homozygous recessive individuals

Therefore,
$q = \sqrt{0.16} = 0.4$ = frequency of recessive allele
$p = 1.0 - 0.4 = 0.6$ = frequency of dominant allele
$p^2 = (0.6)(0.6) = 0.36$ = 36% are homozygous dominant individuals
$2pq = 2(0.6)(0.4) = 0.48$ = 48% are heterozygous individuals
or
$= 1.00 - 0.52 = 0.48$

(84% have the dominant phenotype)

- Fig. 27.11

Process of evolution cont'd.

- The Hardy-Weinberg law
  - Equilibrium of allele frequencies in a gene pool will remain constant in each generation of a large sexually reproducing population as long as the following 5 conditions are met
    - No mutations occur
    - No genetic drift occurs-random changes in gene frequency
    - No gene flow
    - Mating is random
    - No selection is occurring
  - In real life these conditions are virtually never met
  - Hardy-Weinberg law gives us a baseline by which to access whether or not evolution has occurred
    - Any change in allele frequencies indicates evolution

Microevolution

a. Original population: 10% dark-colored phenotype.

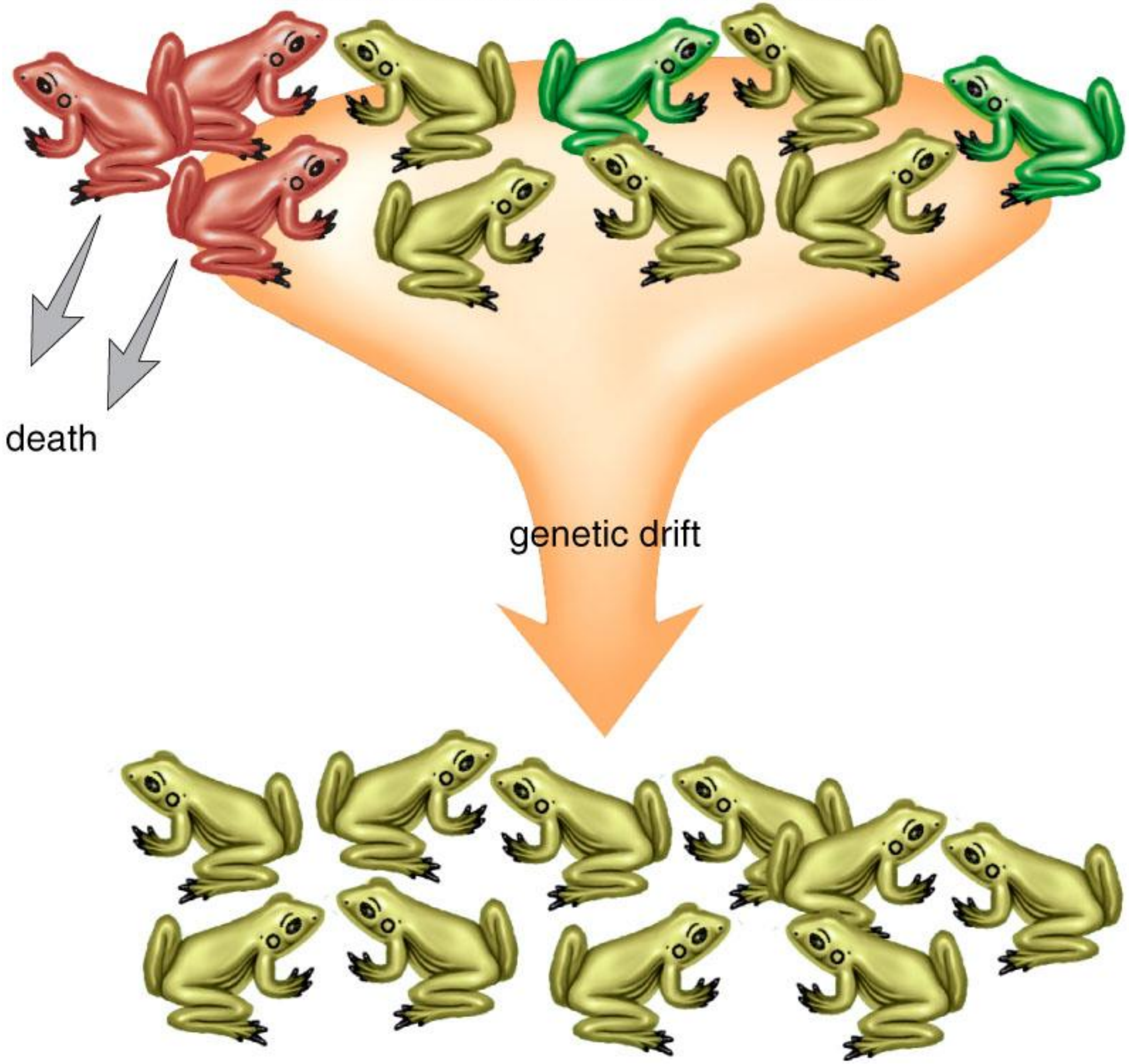
b. Several generations later: 80% dark-colored phenotype.

- Fig. 27.12

Process of evolution cont'd.

- Five agents of evolutionary change
  - Mutations
    - Only source of new alleles in a population
    - Can be an adaptive variation
  - Genetic drift
    - Change in allele frequencies due to chance
    - 2 main mechanisms
      - Founder effect-a few individuals found a colony and their collective genes represent only a fraction of the original gene pool
      - Bottleneck effect-population is subjected to near extinction by a disaster and so only a few genotypes contribute to next generation

Genetic drift



- Fig. 27.13

Founder effect

- Fig. 27.14

Process of evolution cont’d.

- Five agents of evolutionary change cont’d.
  - Gene flow
    - Movement of alleles between populations
    - Keeps the gene pools of 2 or more populations similar
  - Nonrandom mating
    - Occurs when individuals pair up according to phenotype or genotype
    - Inbreeding is an example-increases frequency of recessive abnormalities

Process of evolution cont'd.

- Five agents of evolutionary change cont'd.
  - Natural selection
    - Process by which populations adapt to their environment
    - Charles Darwin explained evolution through natural selection
    - Evolution by natural selection requires the following
      - Variation-members of a population differ
      - Inheritance-differences are inheritable
      - Differential adaptedness-some differences have a survival benefit
      - Differential reproduction-better adapted individuals survive to reproduce more offspring

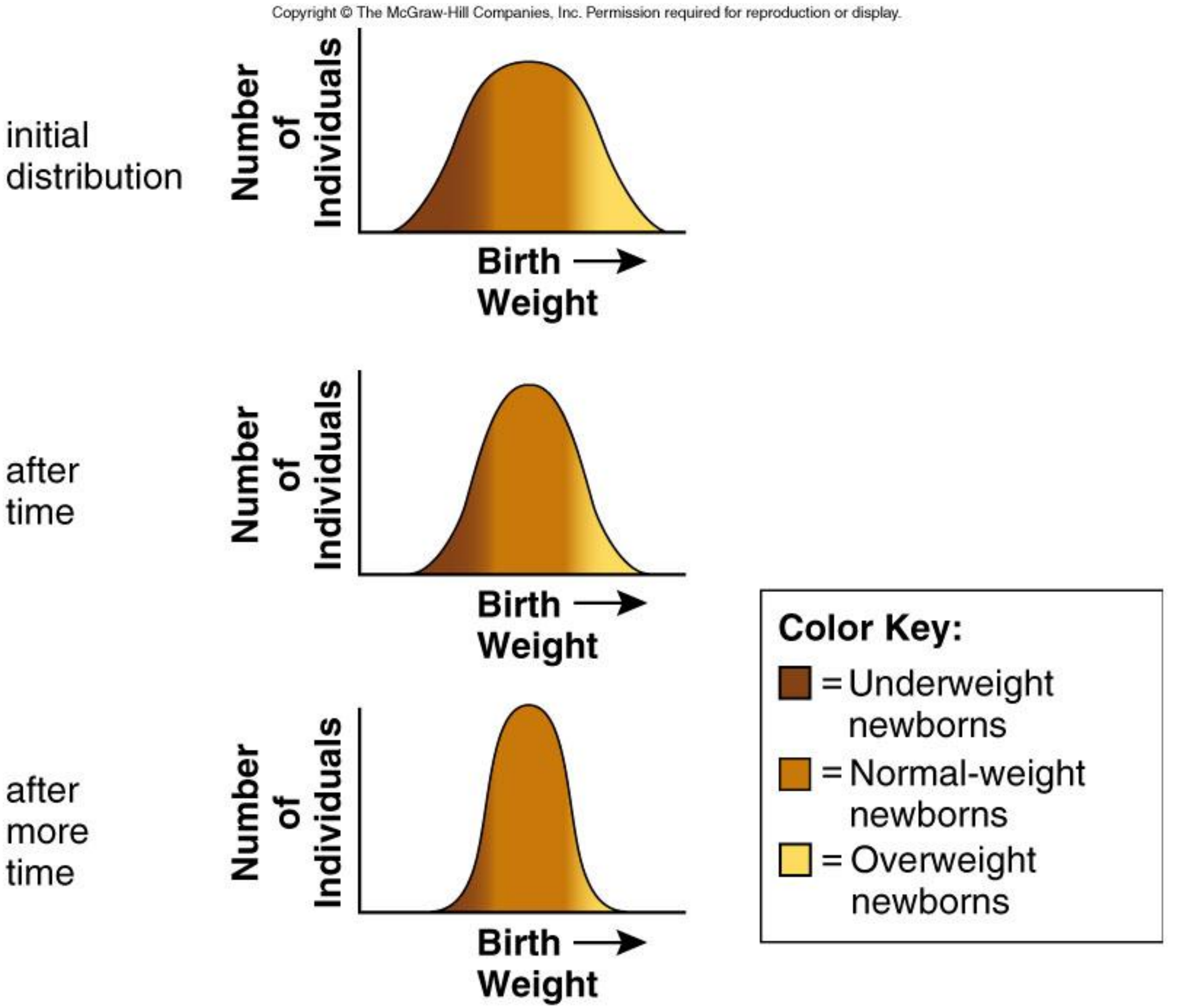
Process of evolution cont'd.

- Natural selection cont'd.
  - Fitness- measured by the number of fertile offspring produced by an individual
    - Variations that can contribute to fitness can arise from
      - Mutation
      - Crossing over
      - Independent assortment
  - Most traits on which natural selection acts are controlled by polygenic inheritance
      - Range of phenotypes which follows a bell-shaped curve

Process of evolution cont'd.

- Natural selection cont'd.
  - Stabilizing selection
    - Occurs when an intermediate, or average, phenotype is favored
    - Improves adaptation of population to a stable environment
    - Extreme phenotypes are selected against
    - Ex: birth weight of human infants

Stabilizing selection

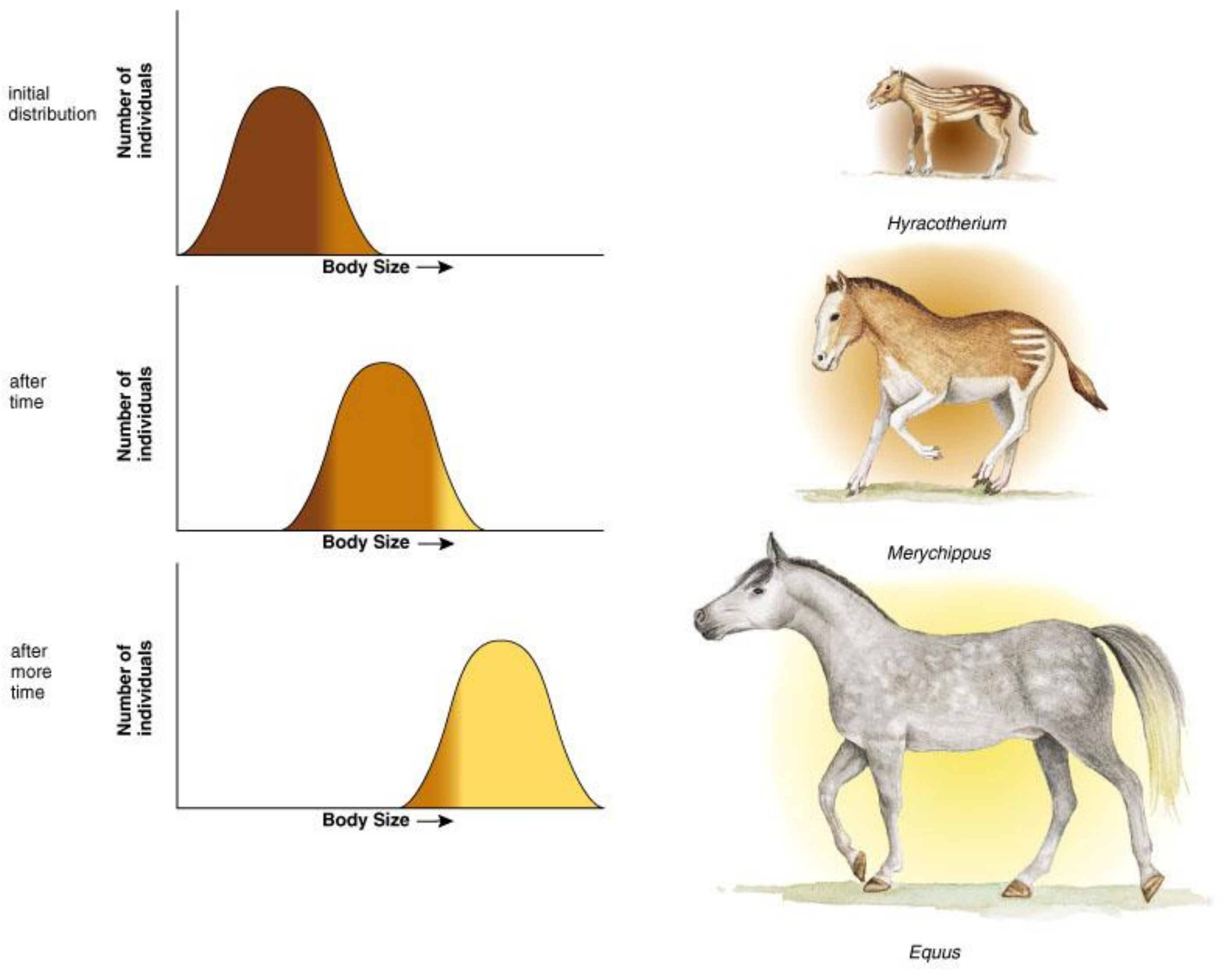


- Fig. 27.15

Process of evolution cont'd.

- Natural selection cont'd.
  - Directional selection
    - One extreme phenotype is favored
    - Distribution curve shifts in that direction
    - Can occur when population is adjusting to a changing environment
    - Ex: evolution of the horse

Directional selection

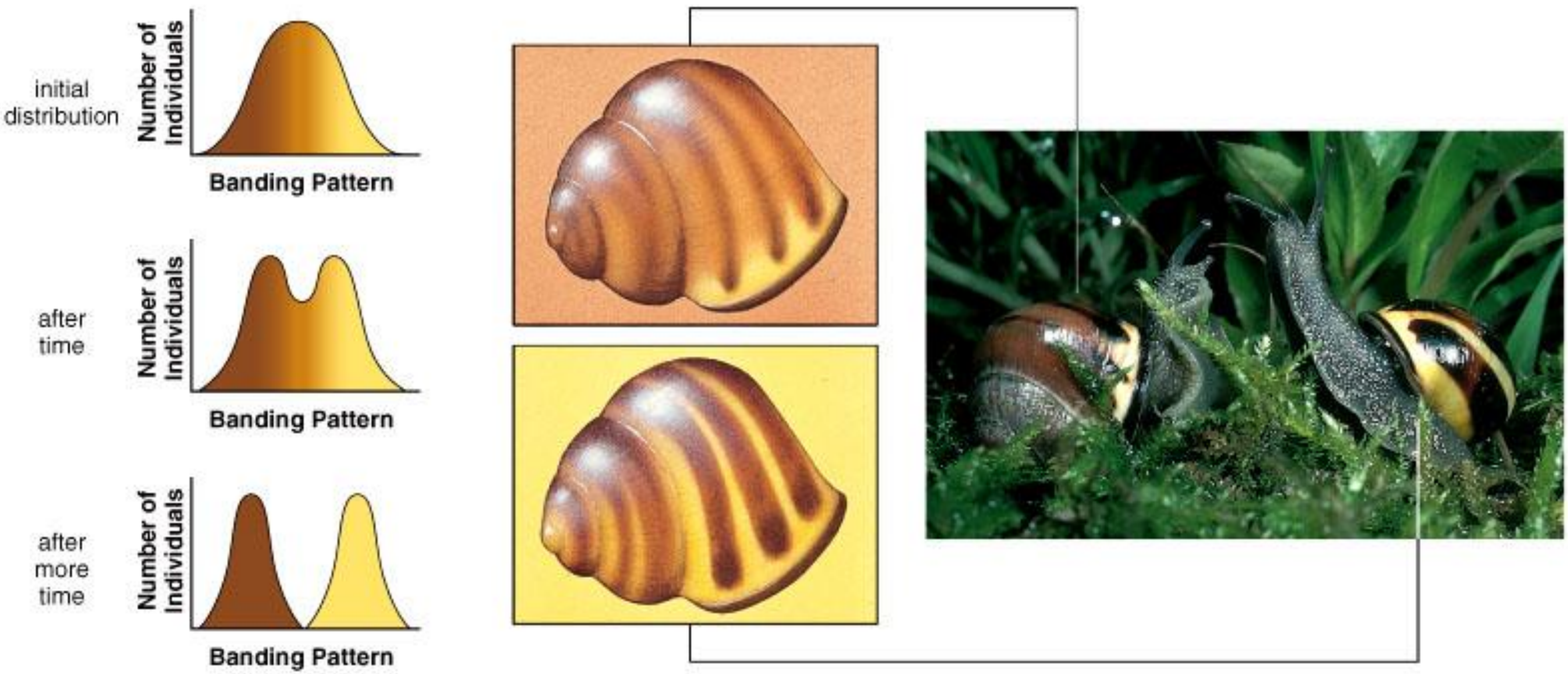


- Fig. 27.16

Process of evolution cont'd.

- Natural selection cont'd.
  - Two or more extreme phenotypes are selected
  - Ex: British land snails
- In summary
  - Mutations, genetic drift, gene flow, nonrandom mating, and natural selection are agents of evolutionary change
  - Only natural selection results in adaptation

Disruptive selection



- Fig. 27.17

Process of evolution cont'd.

- Maintenance of variation
  - Sickle cell disease is good example of how variation is sometimes maintained
    - People homozygous for sickle cell trait die from sickle-cell disease
    - People homozygous for normal RBC's in malaria endemic areas die from malaria
    - People who are heterozygous are protected from both severe sickle cell disease and from malaria
      - Since these people have one normal allele and one sickle allele, both are maintained in the gene pool
      - The favored heterozygote keeps the two homozygotes equally present in the population
  - Balanced polymorphism-ratio of 2 or more phenotypes remains the same

27.4 Speciation

- Overview
  - Species-a group of interbreeding subpopulations that share a gene pool and are isolated reproductively from other species
    - Premating isolating mechanisms- reproduction is never attempted
      - Habitat isolation
      - Temporal isolation
      - Behavioral isolation
      - Mechanical isolation
    - Postmating isolating mechanisms-reproduction may take place but it does not produce fertile offspring
      - Gamete isolation
      - Zygote mortality
      - Hybrid sterility
      - F_2 fitness

Reproductive isolating mechanisms

TABLE 27.2 REPRODUCTIVE ISOLATING MECHANISMS

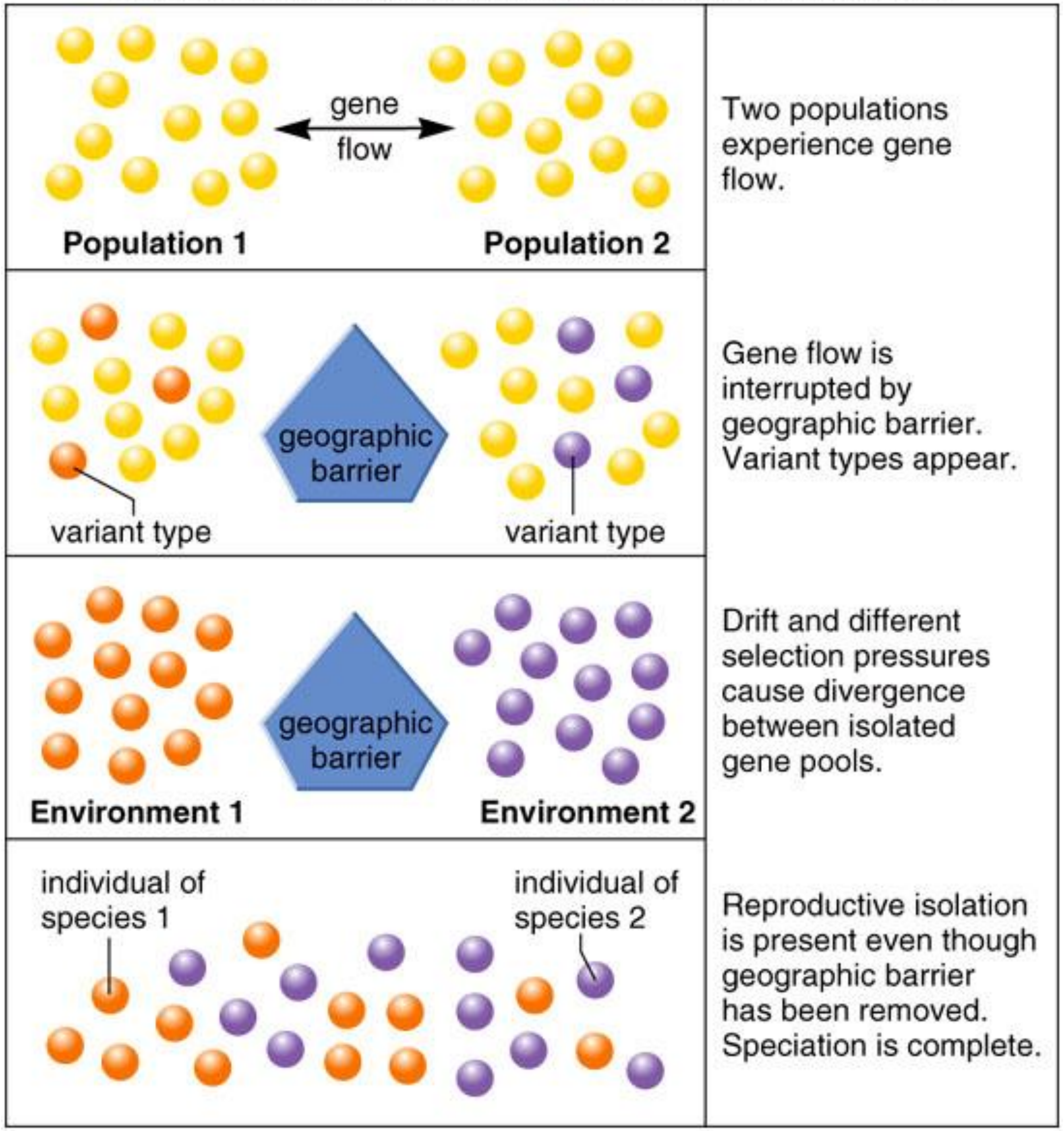
Isolating Mechanism	Example
Premating	
Habitat isolation	Species at same locale occupy different habitats
Temporal isolation	Species reproduce at different seasons or different times of day
Behavioral isolation	In animals, courtship behavior differs, or they respond to different songs, calls, pheromones, or other signals
Mechanical isolation	Genitalia unsuitable for one another
Postmating	
Gamete isolation	Sperm cannot reach or fertilize egg
Zygote mortality	Fertilization occurs, but zygote does not survive
Hybrid sterility	Hybrid survives but is sterile and cannot reproduce
F_2 fitness	Hybrid is fertile, but F_2 hybrid has reduced fitness

- Table 27.2

Speciation cont'd.

- Process of speciation
  - Occurs when on species give rise to two species
    - Occurs when reproductive isolation develops
  - Allopatric speciation- geographical barriers separate a population into 2 groups
    - Premating and then postmating isolating mechanisms occur
  - Sympatric speciation-occurs without geographical barriers
    - 2 subgroups of a population become reproductively isolated
    - Best illustrated in plants- multiplication of chromosome number in one individual may lead to asexual reproduction and offspring with the same multiple chromosome number- isolates them from others

Allopatric speciation

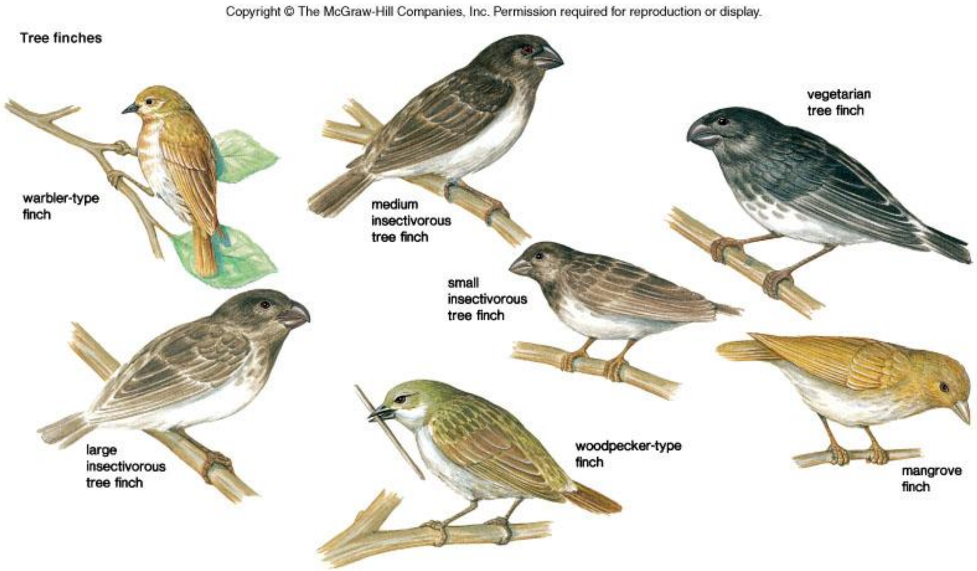


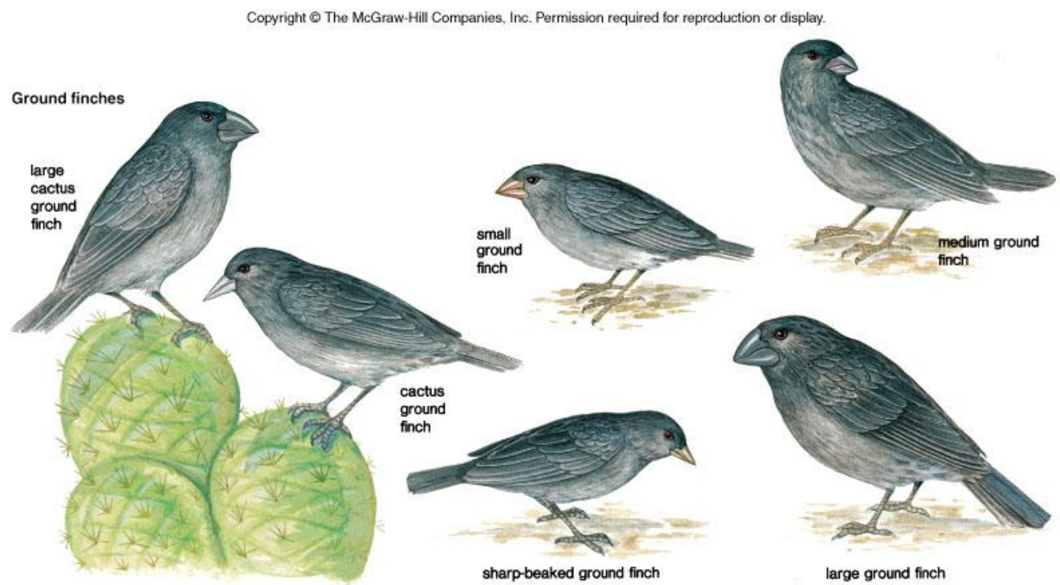
- Fig. 27.18

Speciation cont'd.

- Adaptive radiation
  - A specific type of speciation which gives rise to many new species
  - Galapagos Islands finches- studied by Darwin
    - Example of adaptive radiation
    - Mainland finches migrated to one of the islands
      - Reproduced and eventually spread to all the islands
      - Subjected to different environmental selection pressures
    - Gave rise to many species of finches which differ primarily in beak shape
      - Adapted to allow use of different food sources

The Galapagos finches



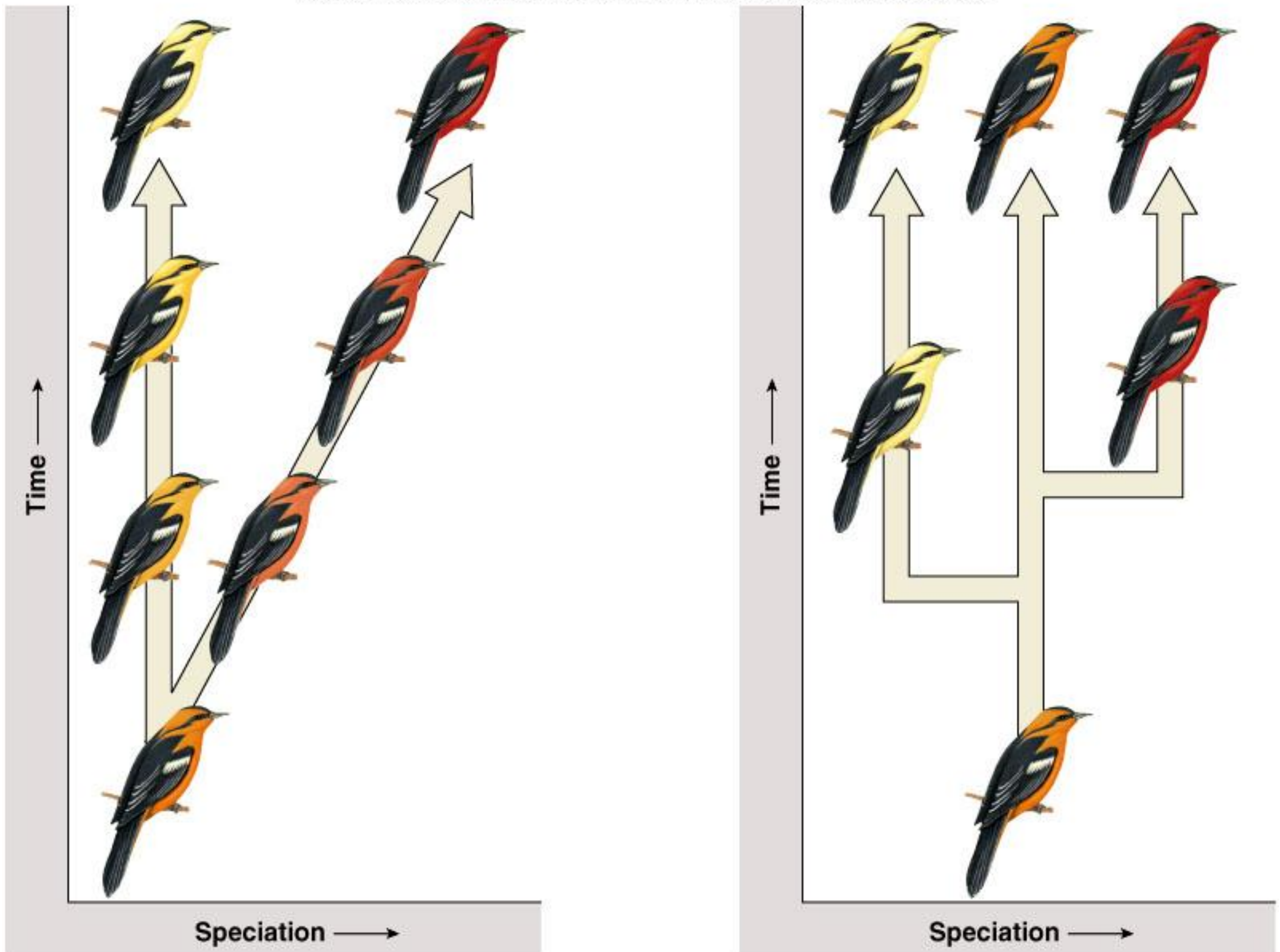


- Fig. 27.19

Speciation cont'd.

- The pace of speciation- two hypotheses
  - Phyletic gradualism-change is slow but steady before and after a divergence
    - explains why so few transitional fossils are found
    - Reproductive isolation cannot be detected in fossils
  - Punctuated equilibrium-stasis is punctuated by speciation
    - Occurs relatively rapidly
    - Also can explain lack of transitional fossils
      - Rapid development of changes does not result in recognizable transitional links
  - These hypotheses are illustrated on the following slide

Phyletic gradualism versus punctuated equilibrium



a. Phyletic gradualism

b. Punctuated equilibrium

- Fig. 27.20

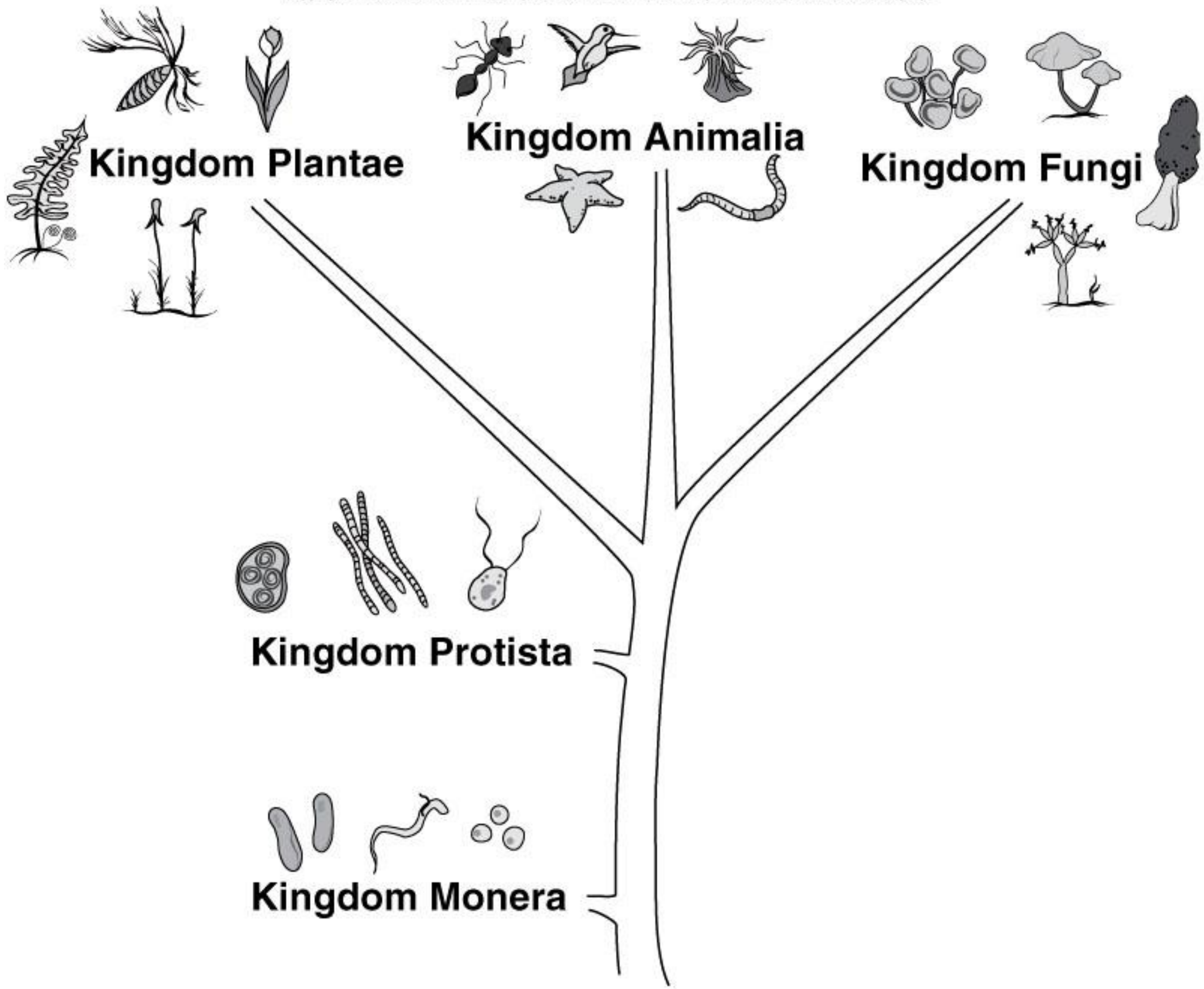
27.5 Classification

- Overview
  - Assignment of species to a hierarchy of categories
  - From general to specific these are: domain, kingdom, phylum, class, order, family, genus, species
    - Should reflect phylogeny
      - Species within a genus are more closely related than those in different genera for example

Classification cont'd.

- Five-kingdom system
  - Placed into a kingdom based on mode of nutrition, type of cell, level of organization
    - Kingdom Monera- prokaryotes
    - Kingdom Protista-eukaryotic single-celled and multi-celled plant-like, animal-like, and fungal-like organisms
    - Kingdom Fungi- multicellular heterotrophic saprophytic organisms
    - Kingdom Plantae- multicellular photosynthetic organisms
    - Kingdom Animalia- multicellular heterotrophic animals

Five-kingdom system of classification

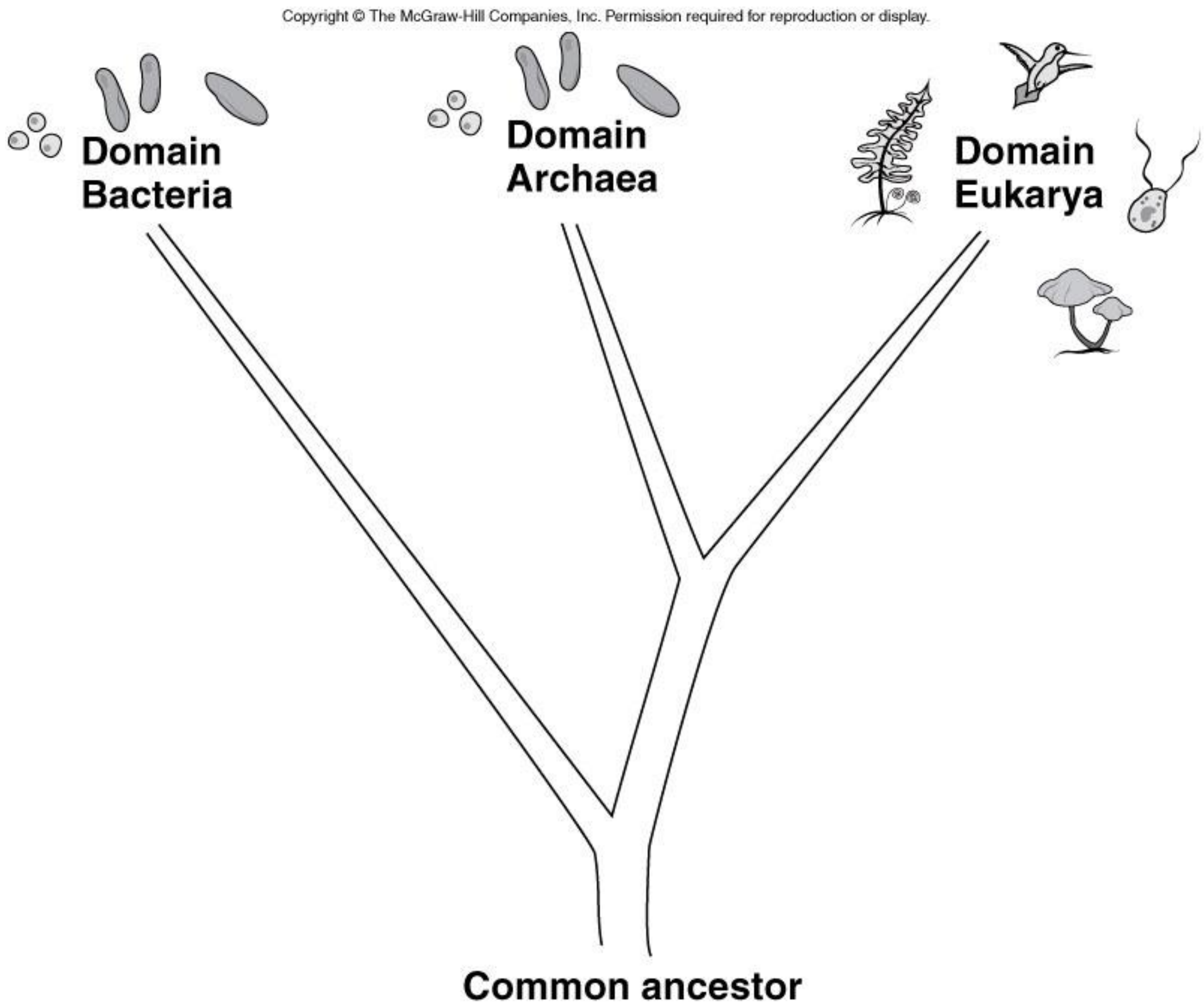


- Fig. 27.21

Classification cont'd.

- Three-domain system
  - Based on rRNA
  - Domain Bacteria
    - "normal" bacteria
  - Domain Archae
    - Archaebacteria that survive in very harsh environments
  - Domain Eukarya
    - Eukaryotic organisms

Three-domain system of classification

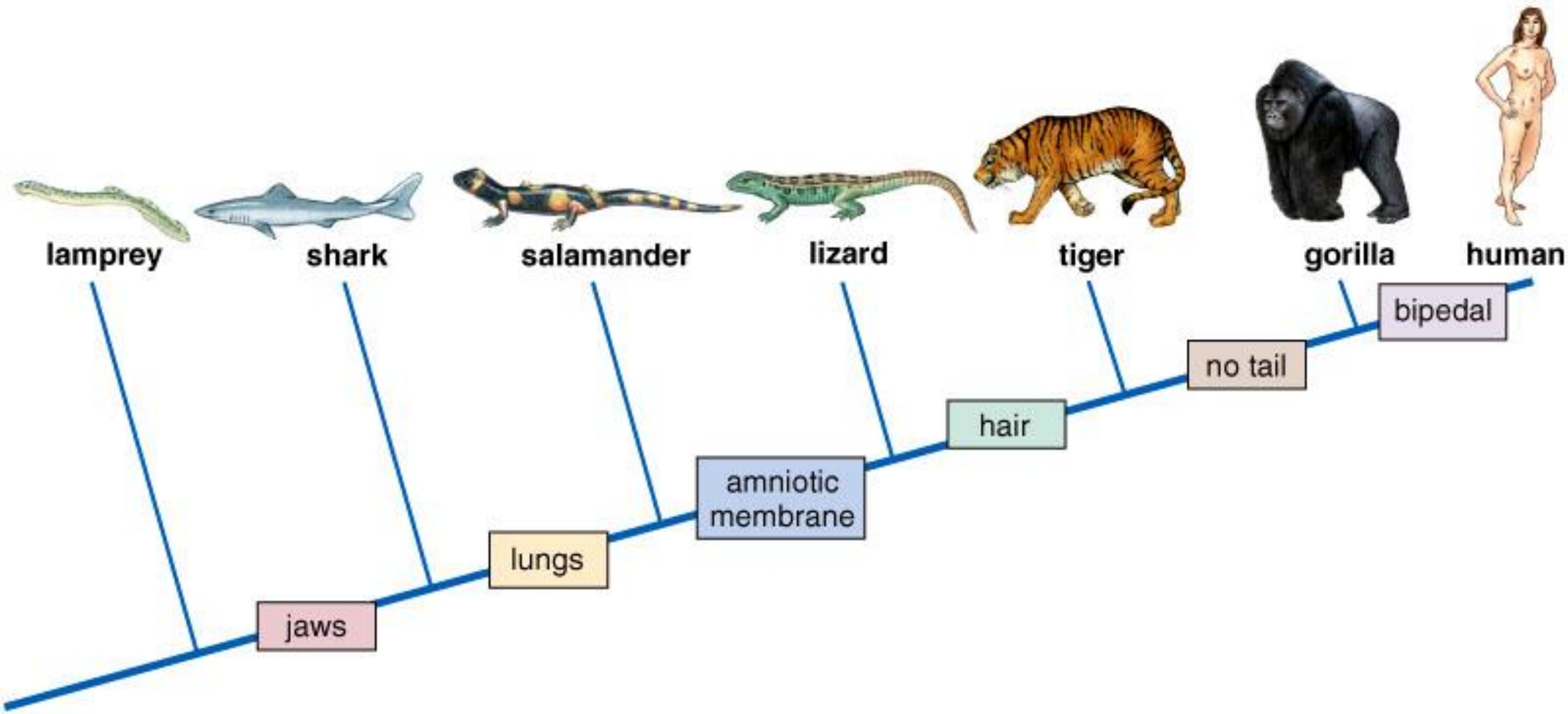


- Fig. 27.22

Classification cont'd.

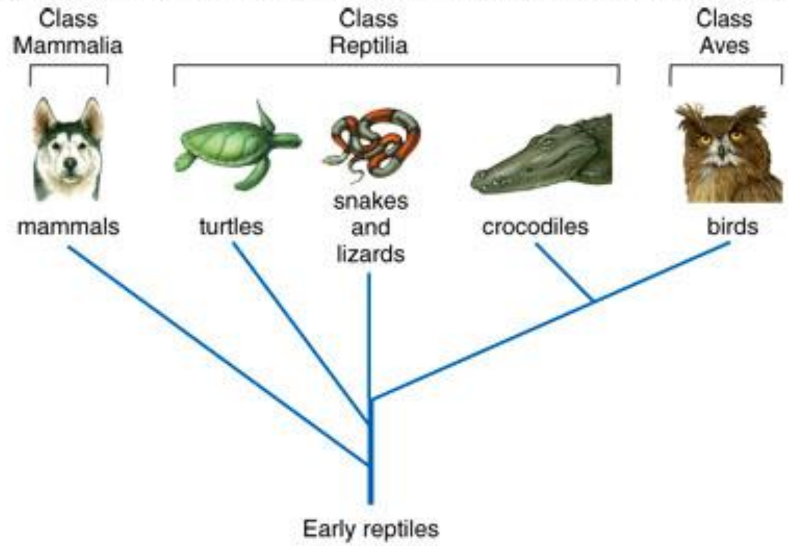
- Cladistics and phylogeny
  - Cladistics
    - Clad-portion of a cladogram
      - Contains a common ancestor and all descendant species
      - All organisms in a clad exhibit the same characteristic
      - Arranged with the least amount of branching possible
  - Traditionalists
    - Also consider descent from a common ancestor
      - But include consideration of amount of evolutionary change when grouping organisms
  - The following 2 slides illustrate cladograms and a traditional systematics diagram

Cladogram

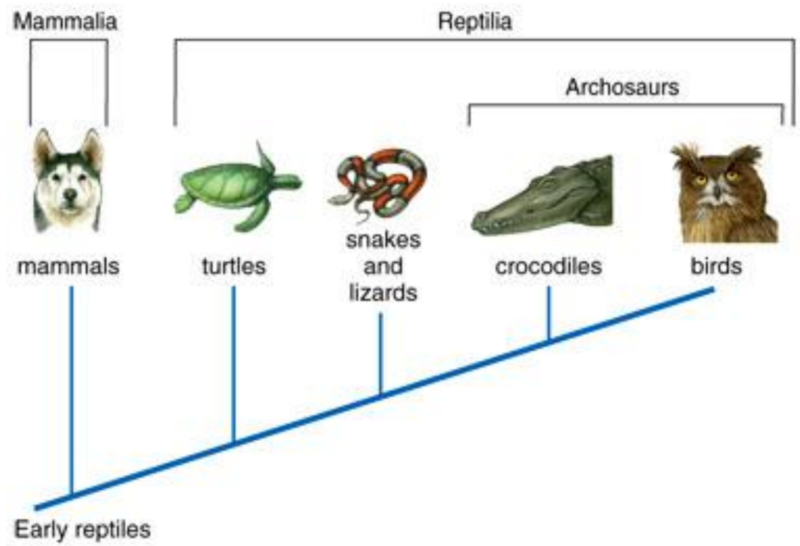


- Fig. 27.23

Traditionalists versus cladists



a. Traditional systematics



b. Cladistic systematics

- Fig. 27.24