Lecture 16
Part 1
Chapter 21. How Evolution Works

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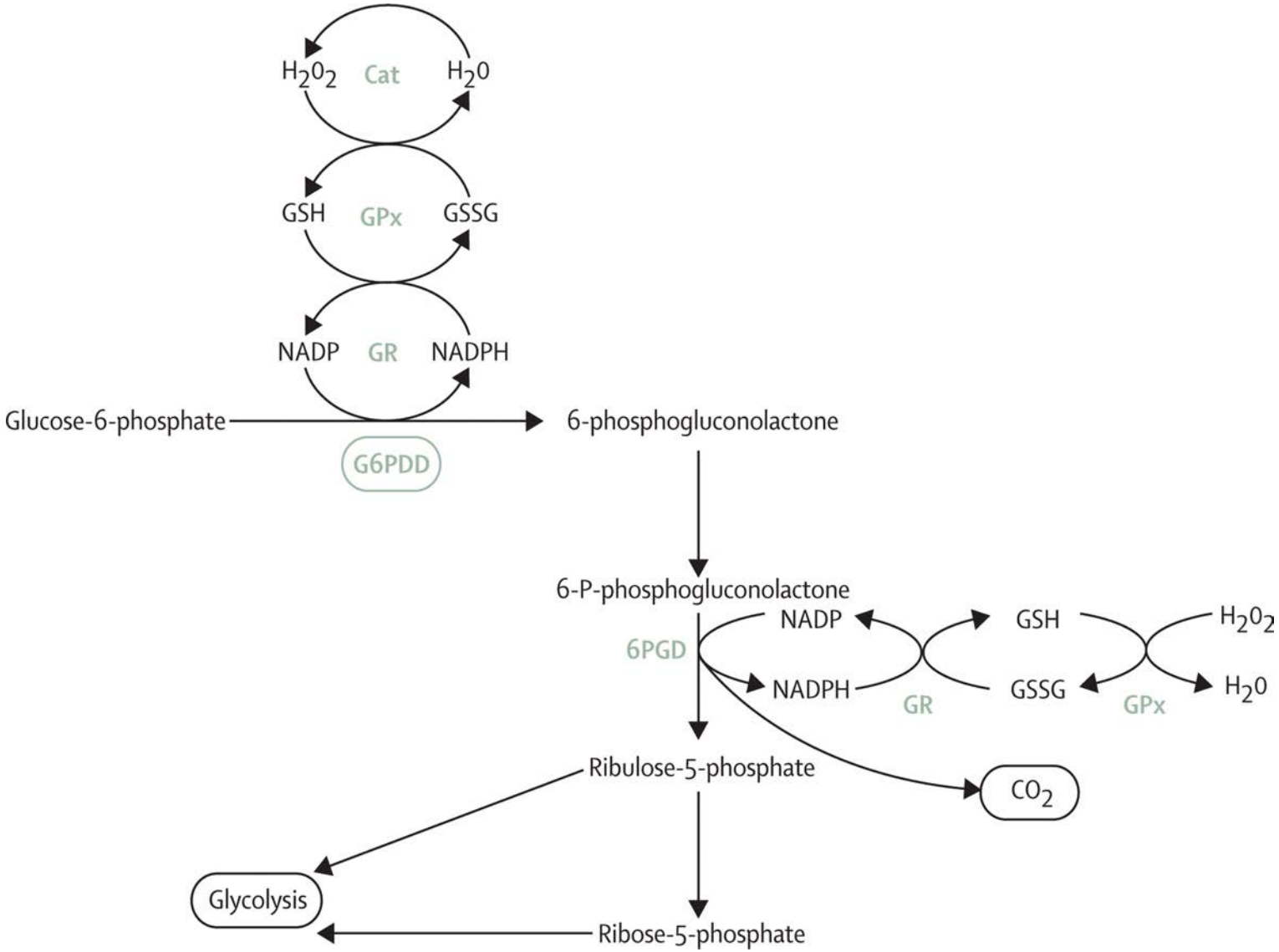
12/28/2017

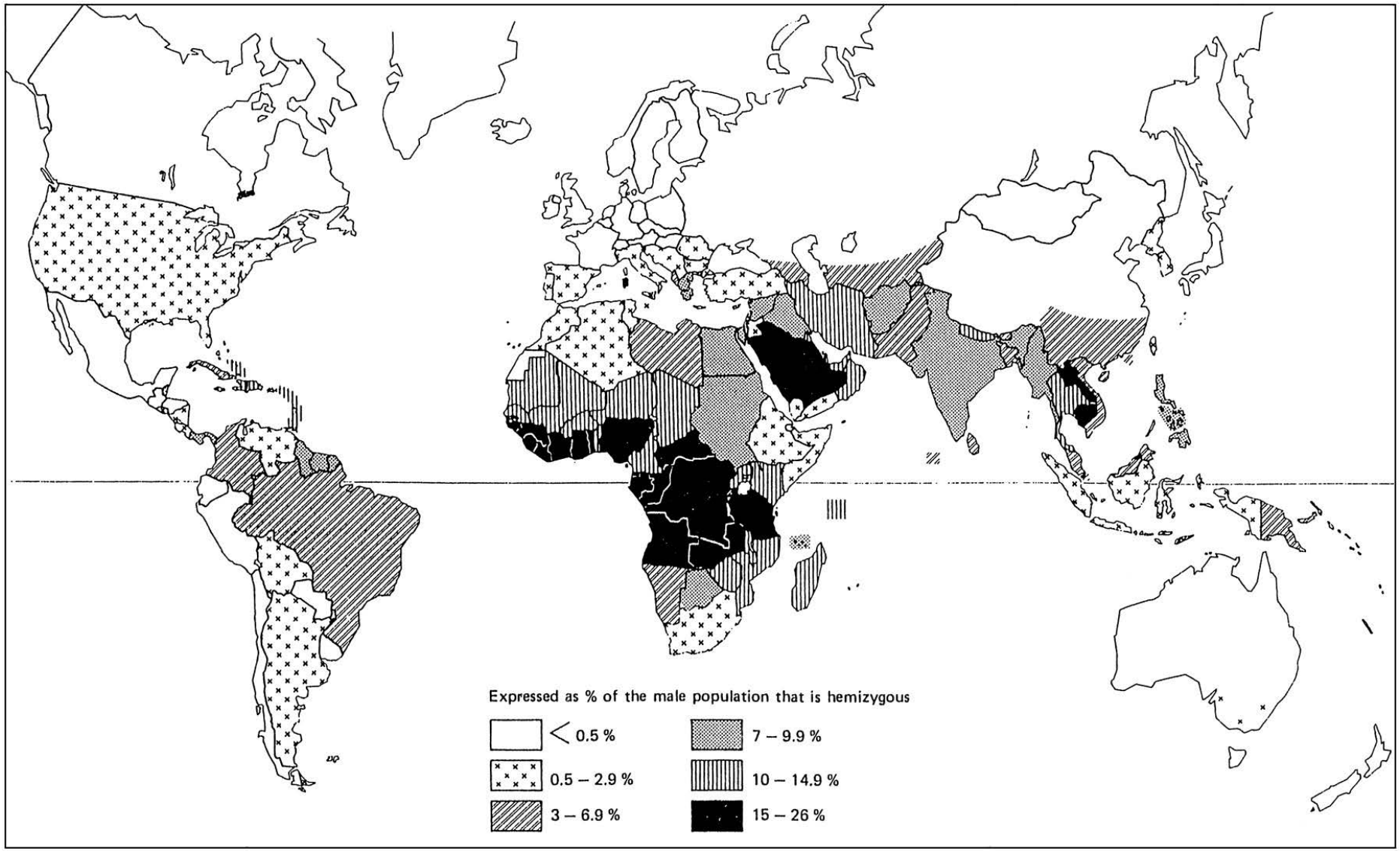
蠶豆症

- 葡萄糖-6-磷酸脫氫酶缺乏症，又名G6PD缺乏症（Glucose-6-Phosphate Dehydrogenase deficiency），俗稱蠶豆症，是一種常見的先天遺傳性疾病。患者由於遺傳基因的先天缺陷，無法正常地分解葡萄糖。除此以外，部份藥物和化學物如蠶豆、樟腦、臭丸、龍膽紫（紫藥水）、薄荷都會令患者出現急性溶血反應，症狀包括黃疸、精神不佳，嚴重時會出現呼吸急速、心臟衰竭，甚至會出現休克而有生命危險。

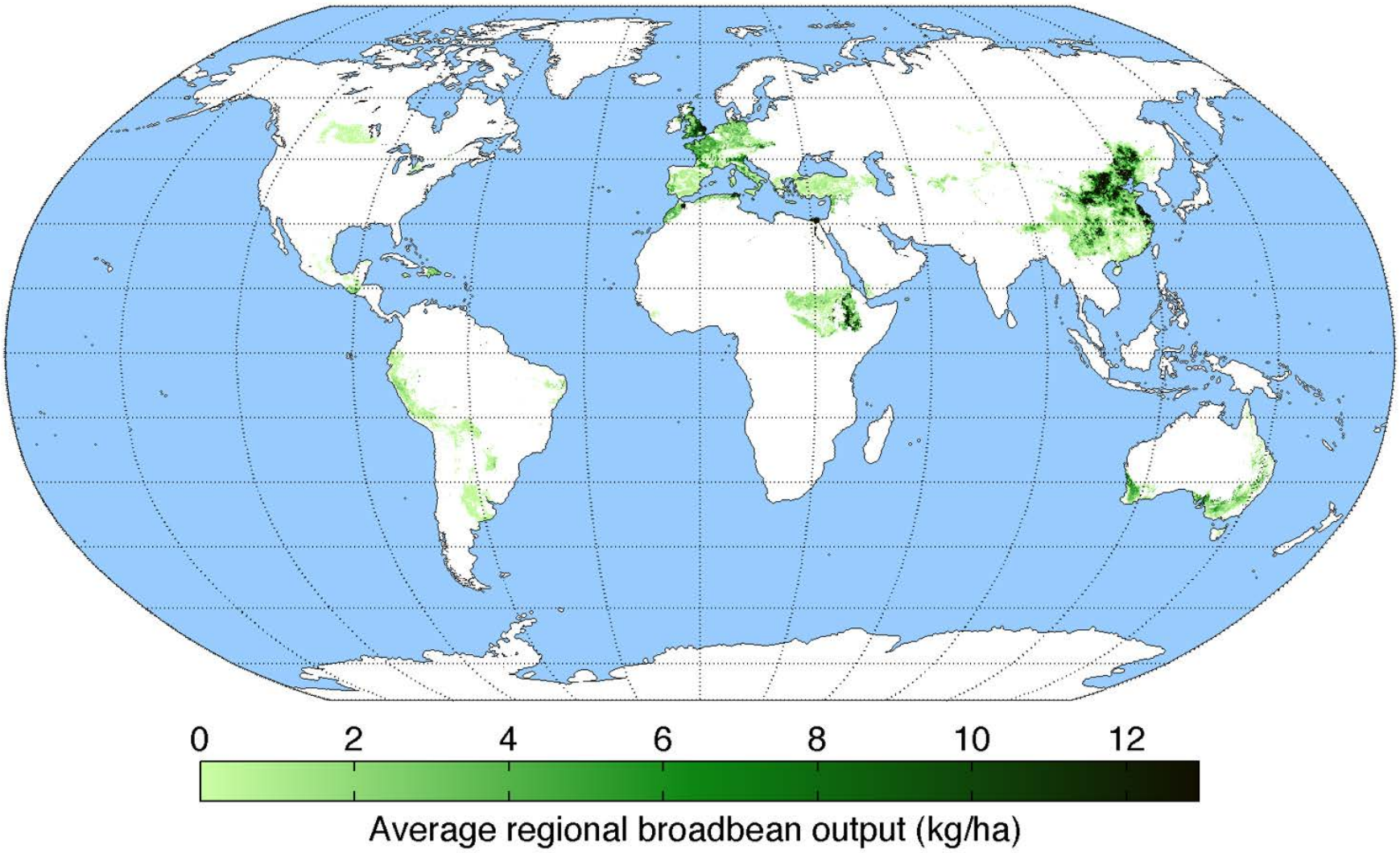
Pentose phosphate pathway



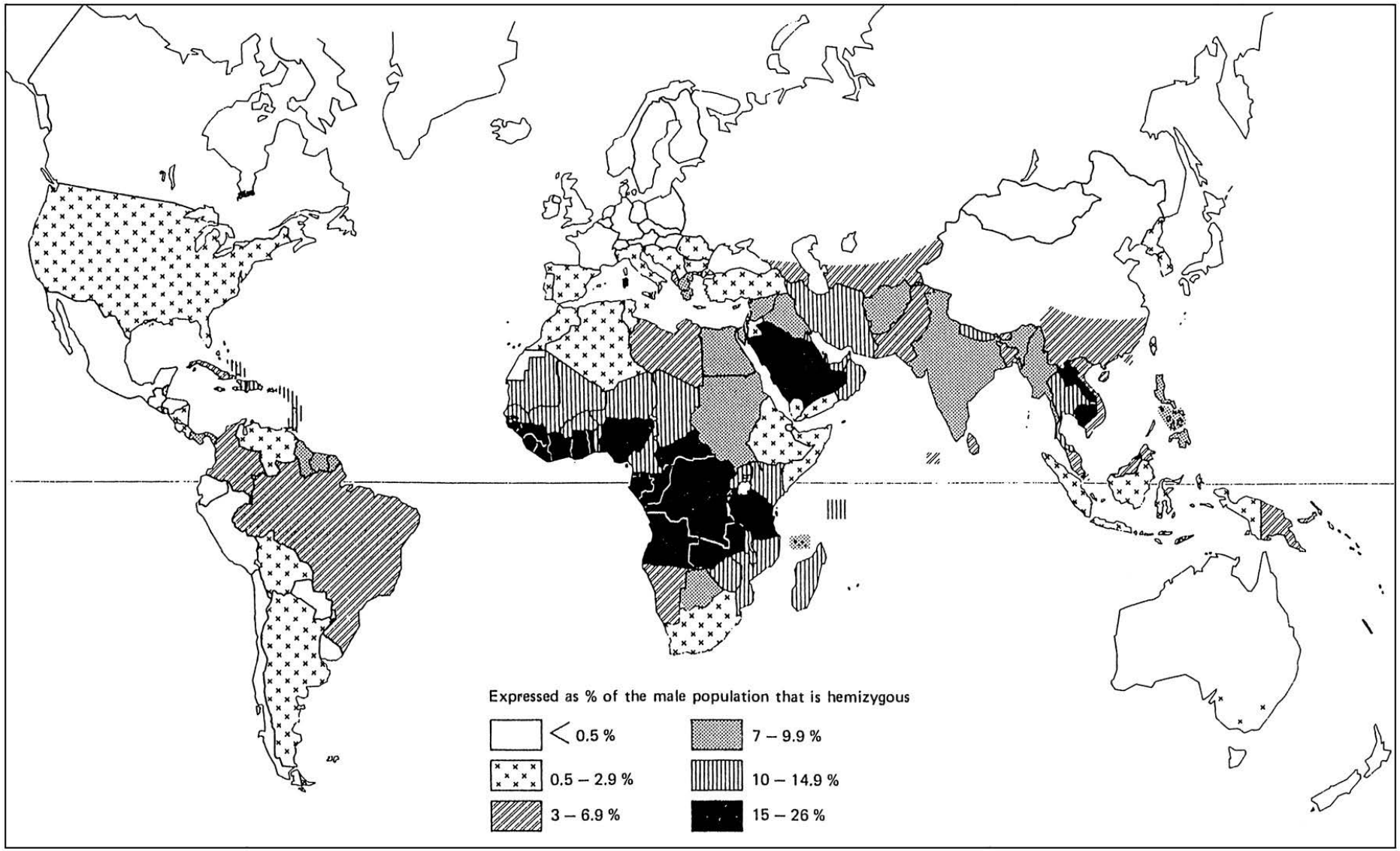
World map distribution of G6PD deficiency



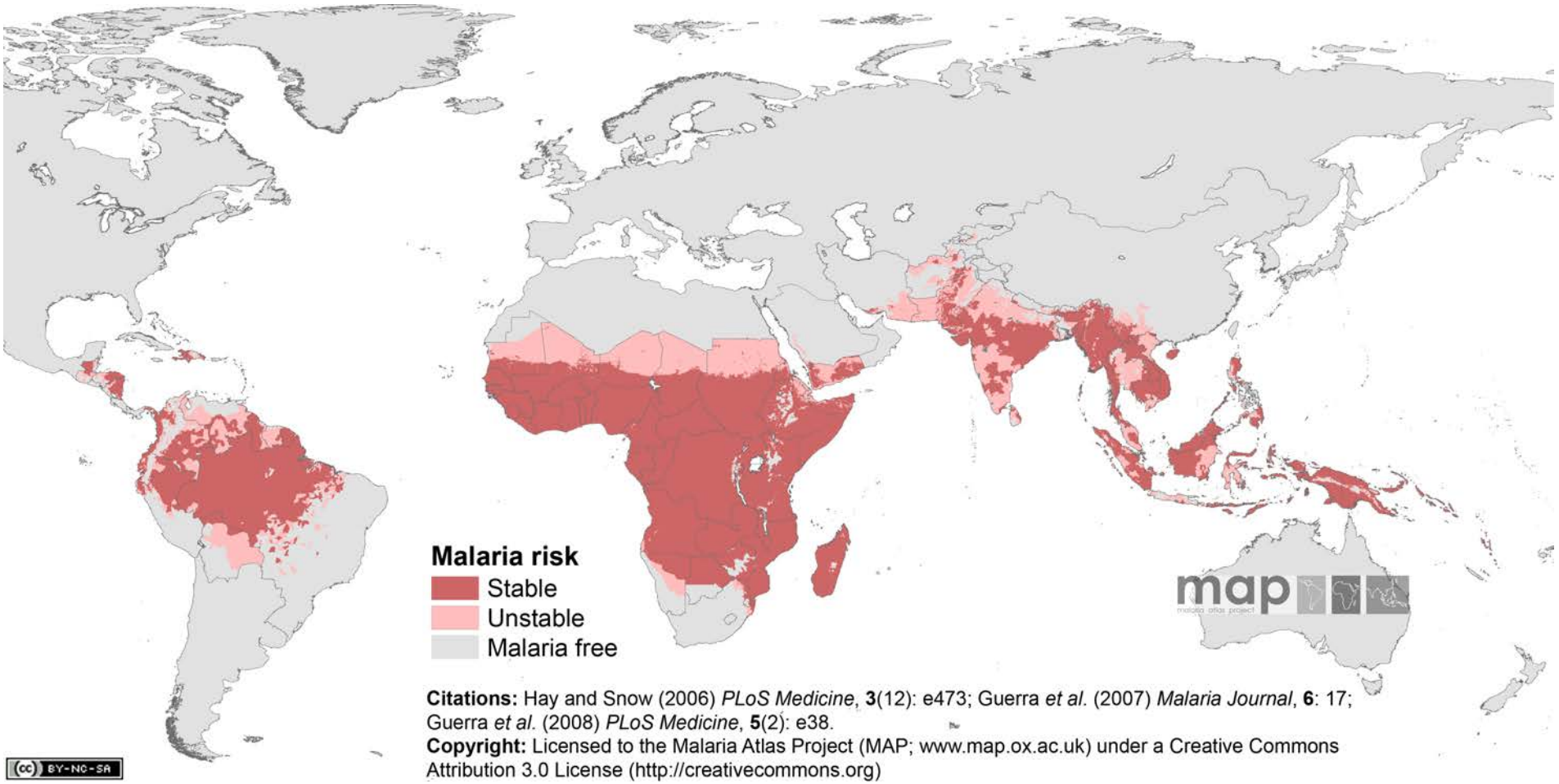
Worldwide broad bean yield



World map distribution of G6PD deficiency



Malaria Risk Map



Citations: Hay and Snow (2006) *PLoS Medicine*, **3**(12): e473; Guerra *et al.* (2007) *Malaria Journal*, **6**: 17; Guerra *et al.* (2008) *PLoS Medicine*, **5**(2): e38.

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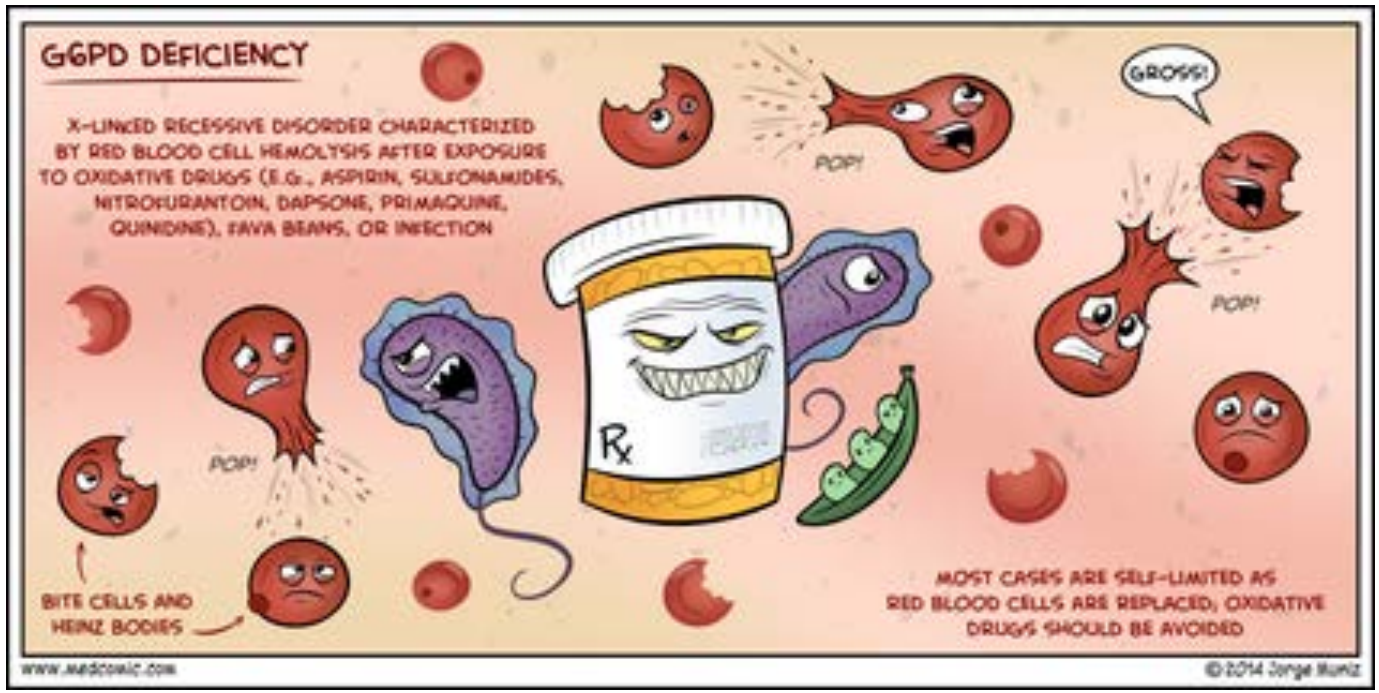
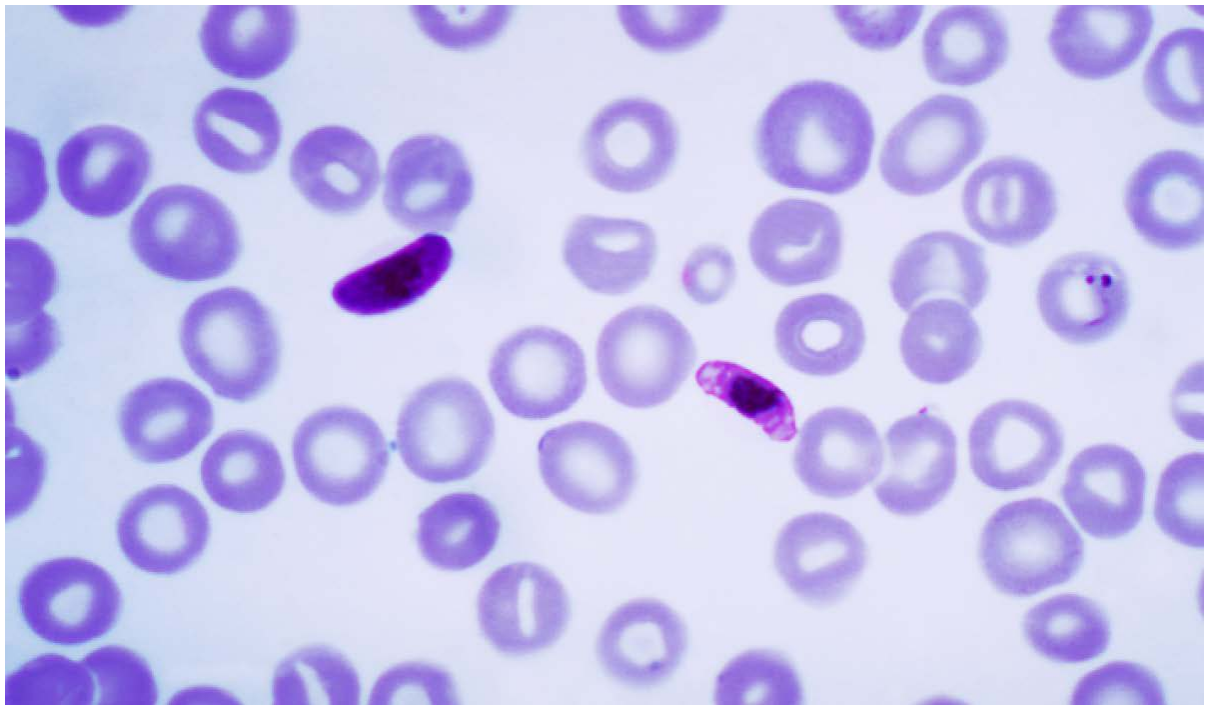
Glucose-6-phosphate dehydrogenase deficiency

- Carriers of the G6PD allele appear to be protected to some extent against malaria, and in some cases affected males have shown complete immunity to the disease. This accounts for the persistence of the allele in certain populations in that it confers a selective advantage.



Glucose-6-phosphate dehydrogenase deficiency

- In vitro studies have shown that the *Plasmodium falciparum* is very sensitive to oxidative damage. The genetic defect confers resistance due to the fact that the G6PD-deficient host has a higher level of oxidative agents that, while generally tolerable by the host, are deadly to the parasite.

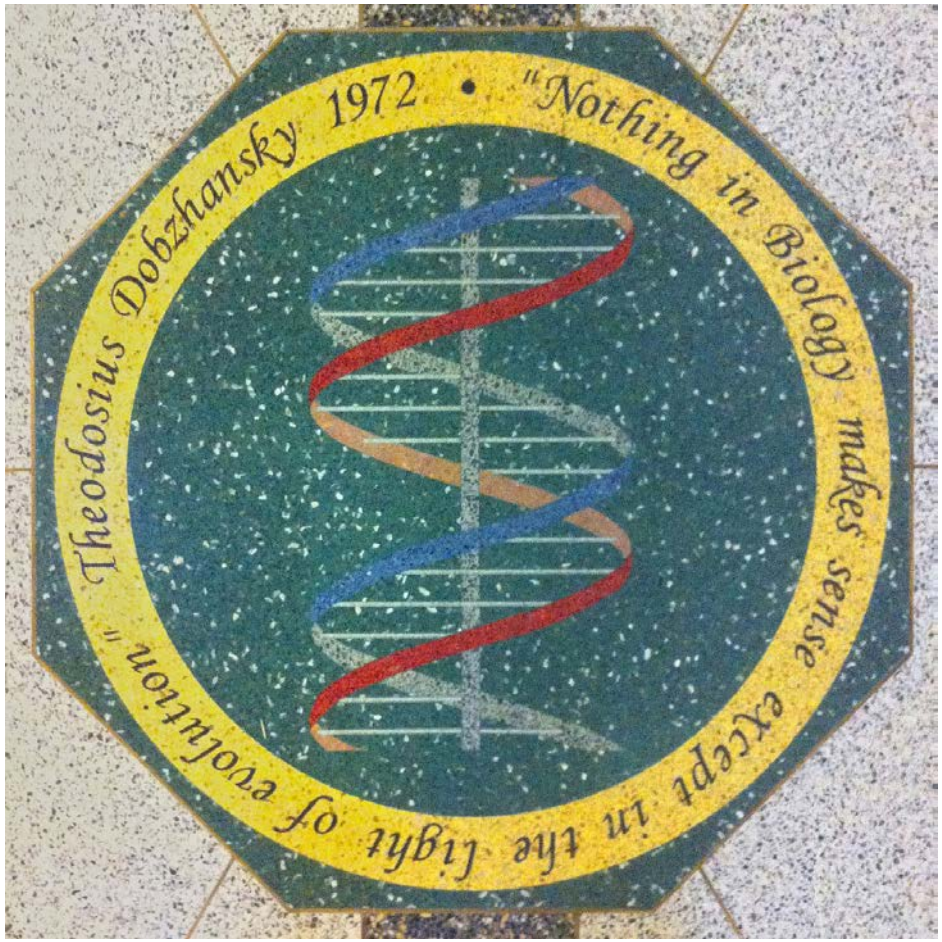


WHY?

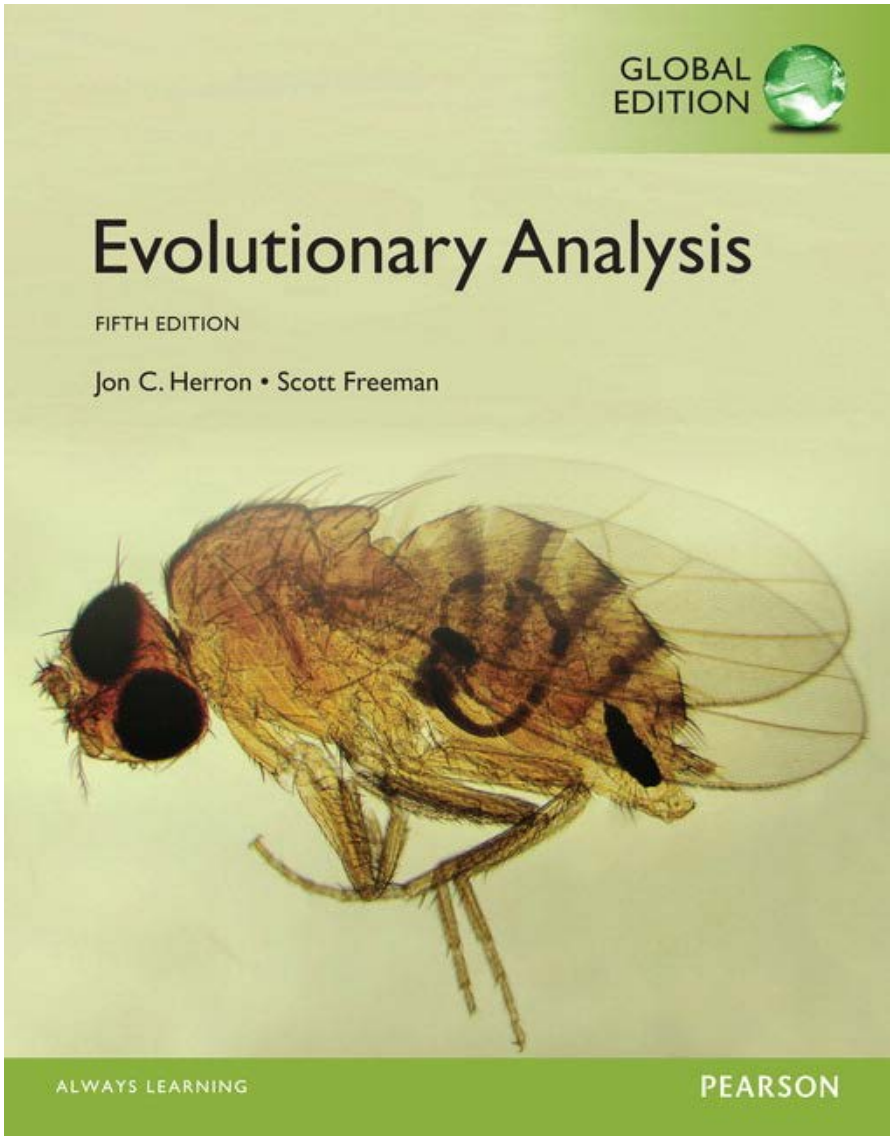
WHAT? WHEN?
WHERE? HOW?

Nothing in Biology Makes Sense Except in the Light of Evolution

Theodosius Dobzhansky (1900–1975)



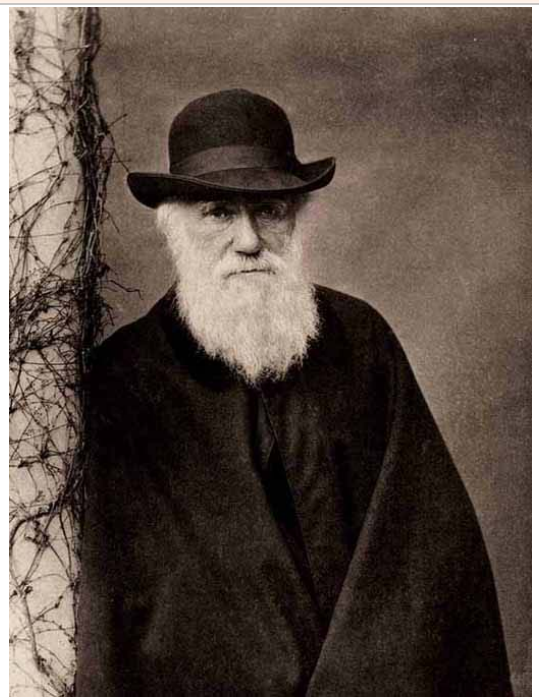
LS315200 演化生物學 Evolutionary Biology

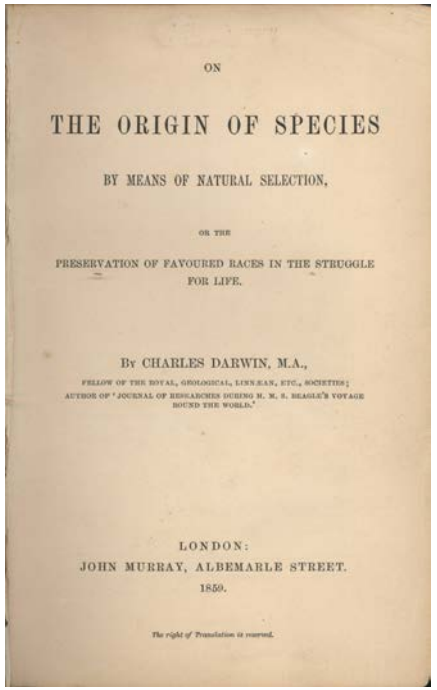


Endless Forms Most Beautiful

- A new era of biology began in 1859 when Charles Darwin (1809 – 1882) published *The Origin of Species*

- *The Origin of Species* focused biologists' attention on the great diversity of organisms





ON

THE ORIGIN OF SPECIES

BY MEANS OF NATURAL SELECTION,

OR THE

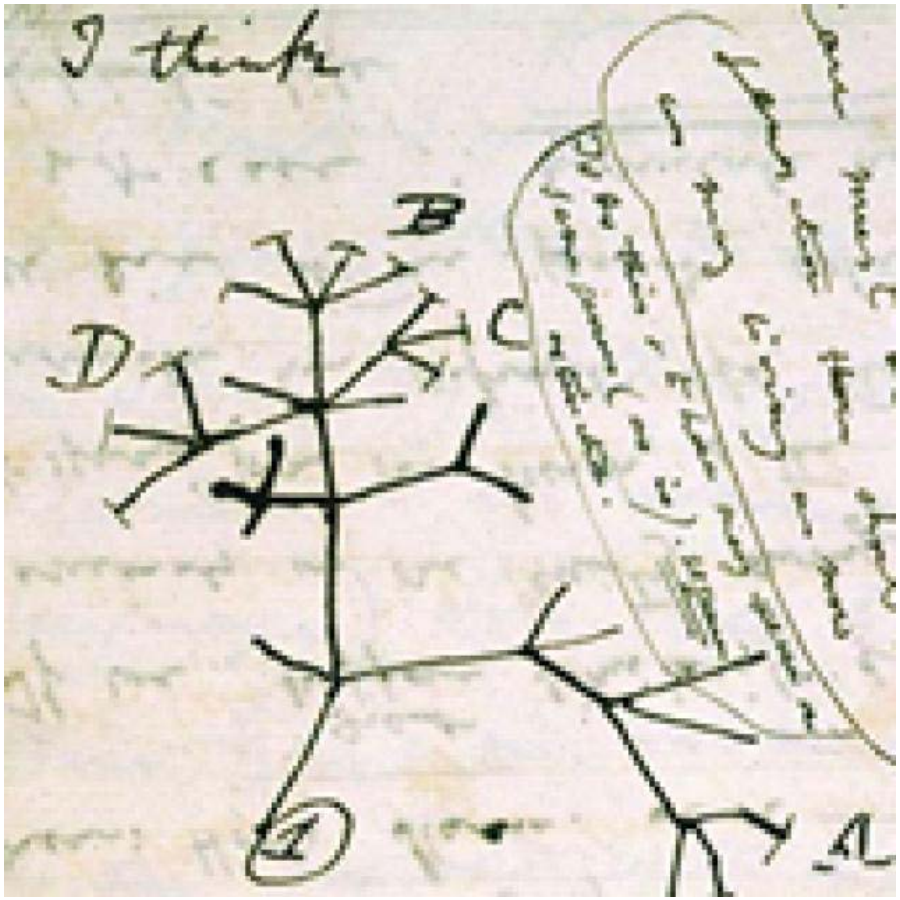
PRESERVATION OF FAVOURED RACES IN THE STRUGGLE FOR LIFE.

By CHARLES DARWIN, M.A.,

FELLOW OF THE ROYAL, GEOLOGICAL, LINNEAN, ETC., SOCIETIES;
AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

- Darwin noted that current species are descendants of ancestral species
- **Evolution** (演化) can be defined by Darwin's phrase *descent with modification*
- Evolution can be viewed as both a pattern and a process



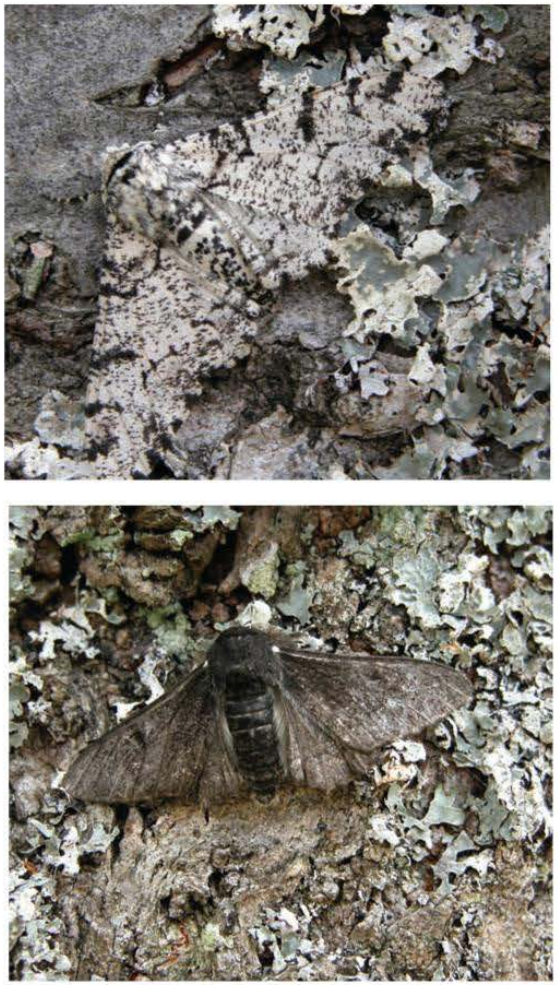


FIGURE 1.38. *Biston betularia,* the peppered moth, in its typical (*top*) and melanic (*bottom*) forms. Haldane theorized that the melanic form had a greater chance of survival because it was better camouflaged against the darkened tree trunks in polluted areas.

1.38, courtesy of James Mallet, University College London

Evolution © 2007 Cold Spring Harbor Laboratory Press

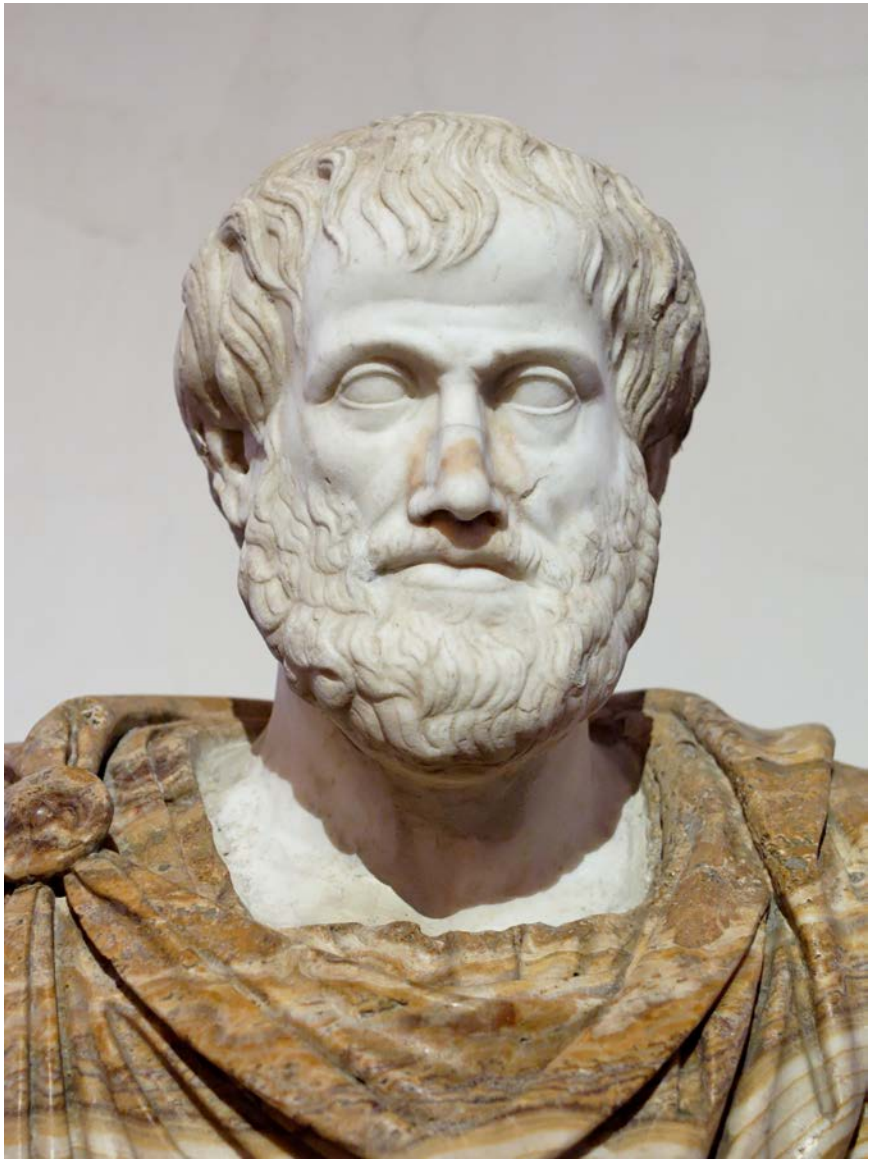
Concept 21.1: The Darwinian revolution challenged traditional views of a young Earth inhabited by unchanging species

- Darwin's ideas had deep historical roots

Great chain of being

Scala Naturae and Classification of Species

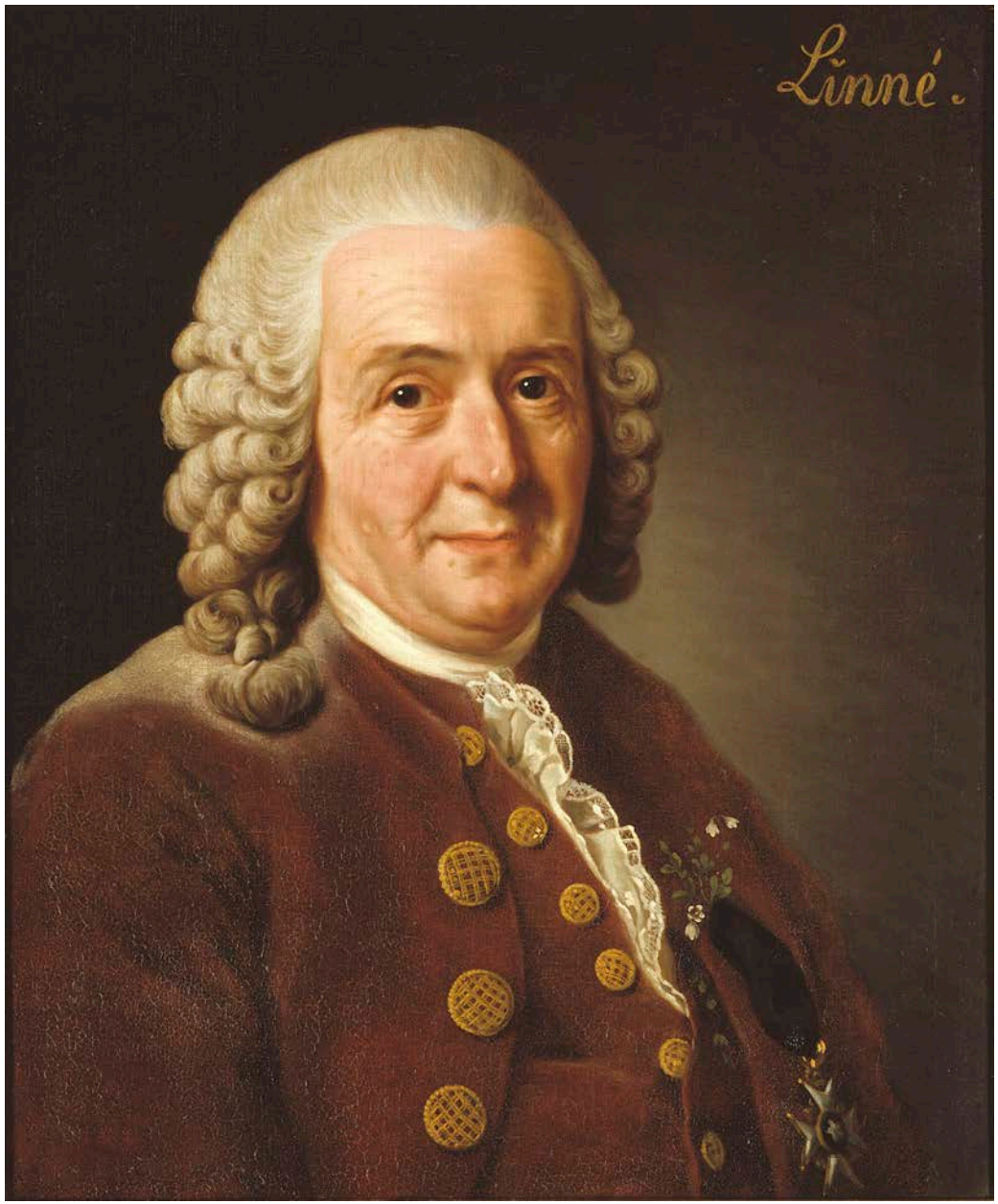
- The Greek philosopher Aristotle (384–322 BC) viewed species as fixed and arranged them on a *scala naturae*
- The Old Testament holds that species were individually designed by God and therefore perfect



- Carolus Linnaeus interpreted organismal adaptations as evidence that the Creator had designed each species for a specific purpose

- Linnaeus was the founder of taxonomy, the branch of biology concerned with classifying organisms

- He developed the binomial format for naming species (for example, *Homo sapiens*)

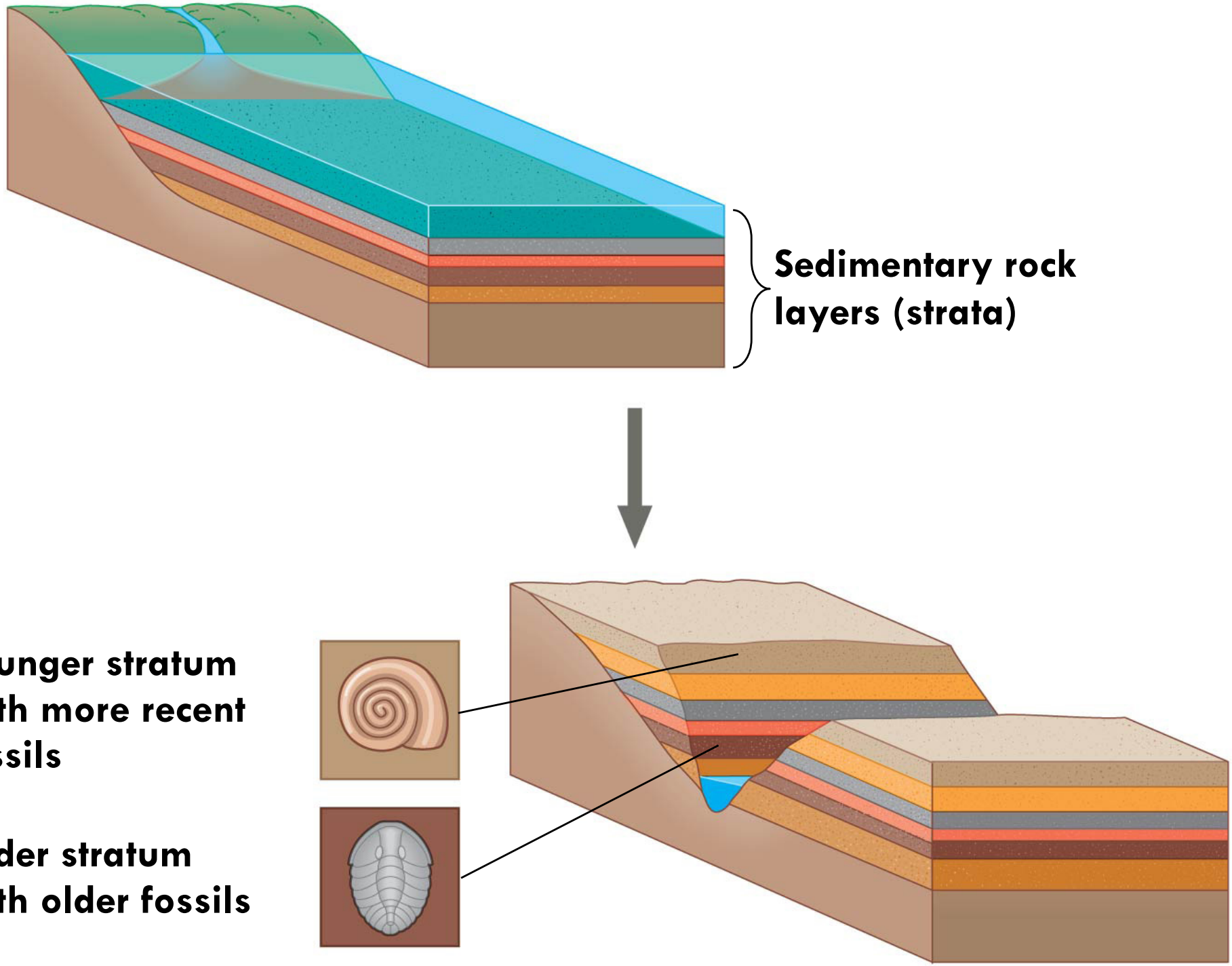


Ideas About Change over Time

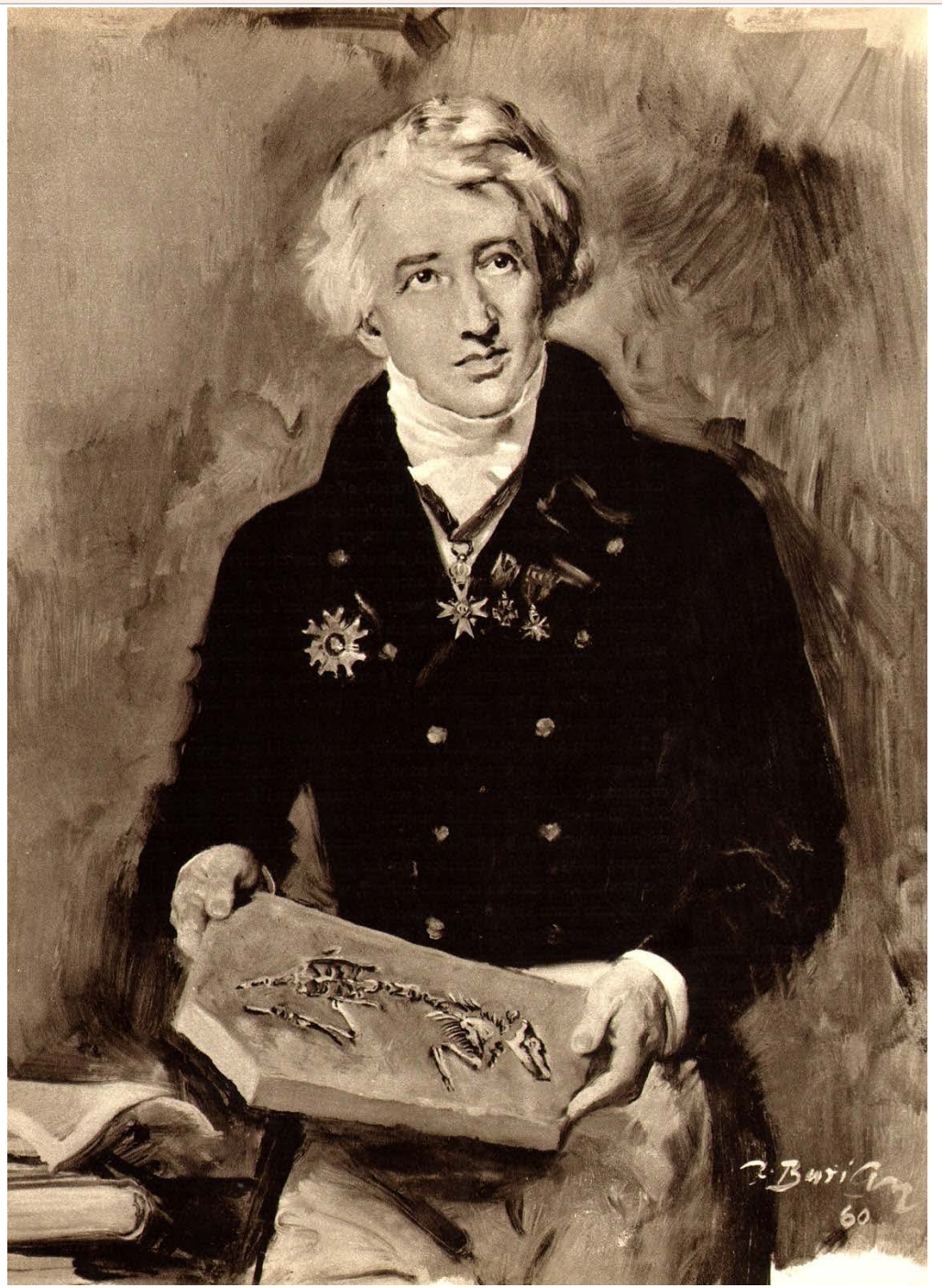
- The study of **fossils** (化石) helped to lay the groundwork for Darwin's ideas

- Fossils are remains or traces of organisms from the past, usually found in sedimentary rock, which appears in layers called **strata (地層)**

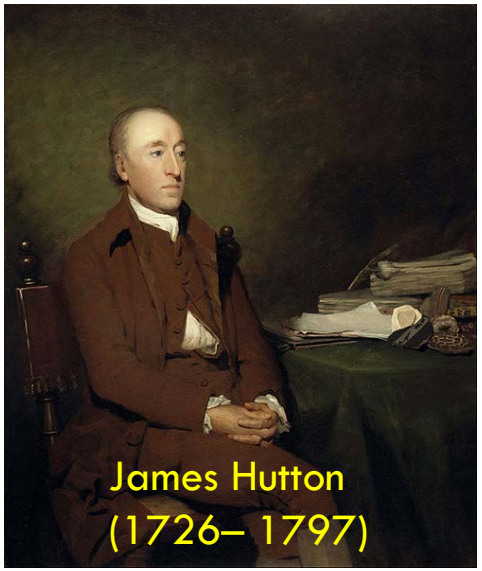
Figure 21.3

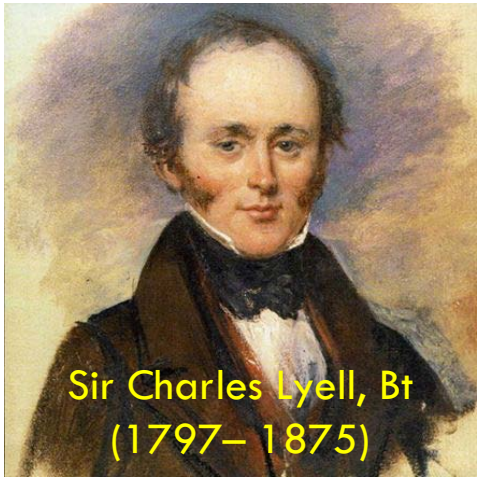


- **Paleontology,** the study of fossils, was largely developed by French scientist Georges Cuvier (1769–1832)
- Cuvier speculated that the boundaries between strata represent catastrophic events
- **Paleontology** or **Paleobiology (古生物學)** is not **archaeology (考古學)**



- Geologists James Hutton and Charles Lyell perceived that changes in Earth's surface can result from slow continuous actions still operating today, and at the same rate
- This view strongly influenced Darwin's thinking


James Hutton
(1726– 1797)


Sir Charles Lyell, Bt
(1797– 1875)

Lamarck's Hypothesis of Evolution

- Lamarck (1744-1829) hypothesized that species evolve through use and disuse of body parts and the inheritance of acquired characteristics

- The mechanisms he proposed are unsupported by evidence

Figure 21.4

Concept 21.2: Descent with modification by natural selection explains the adaptations of organisms and the unity and diversity of life

- Some doubt about the permanence of species preceded Darwin's ideas

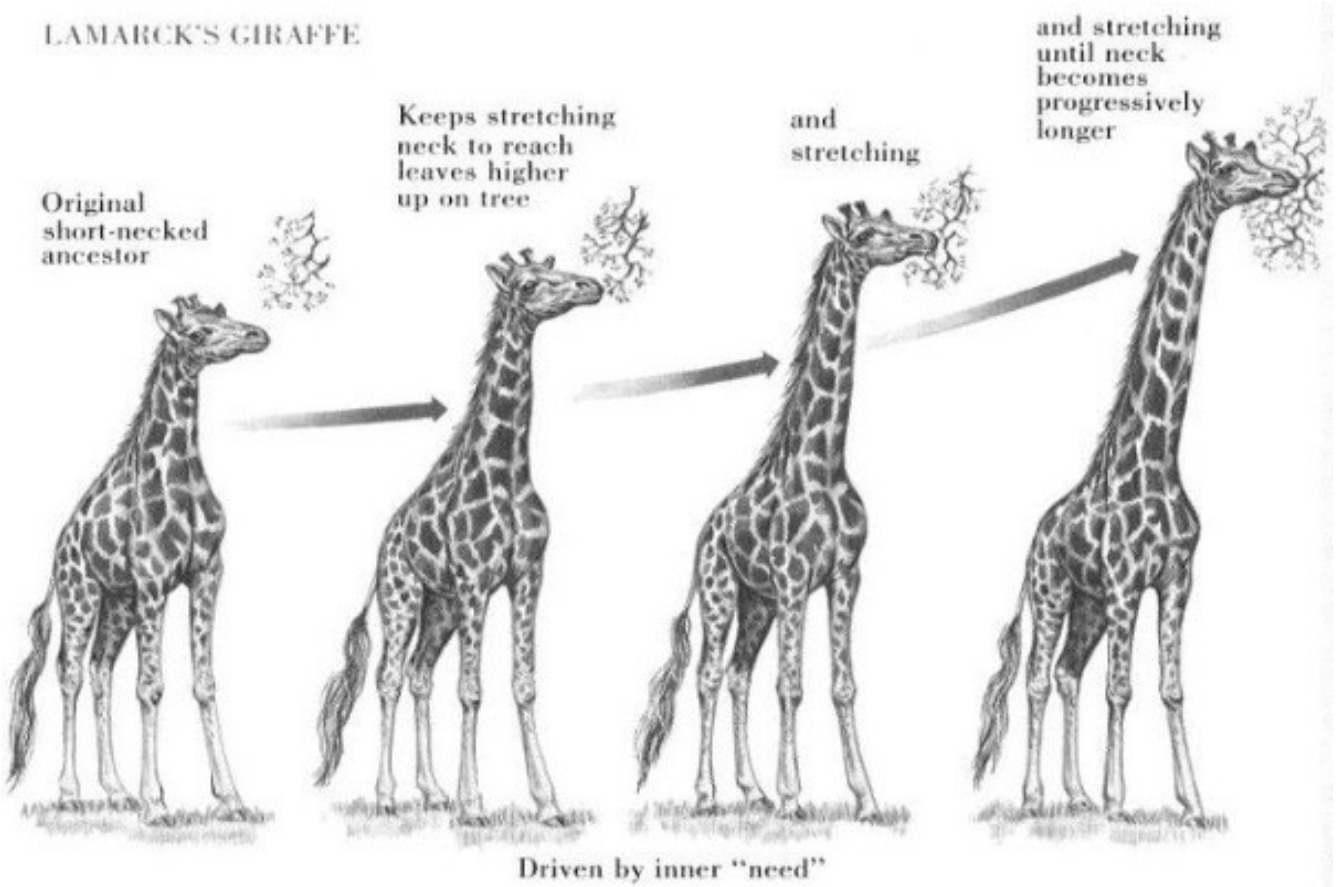


Figure 21.2

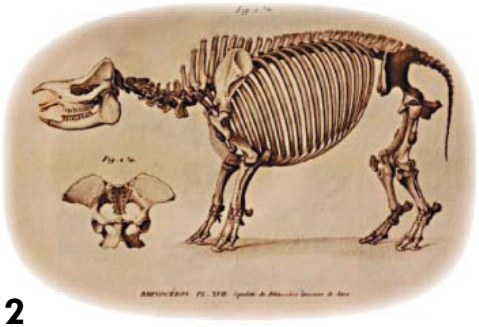
1790

1795
Hutton proposes his principle of gradualism.

1798
Malthus publishes "Essay on the Principle of Population."

1809
Lamarck publishes his hypothesis of evolution.

1809
Charles Darwin is born.



1812
Cuvier publishes his extensive studies of vertebrate fossils.

1830
Lyell publishes *Principles of Geology*.

1831–1836
Darwin travels around the world on HMS *Beagle*.

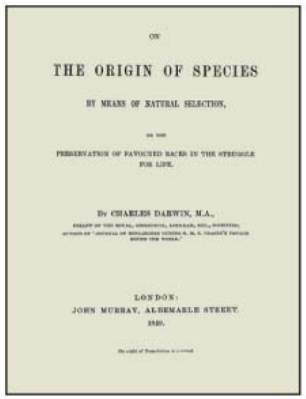
Marine iguana in the Galápagos Islands

1844
Darwin writes his essay on descent with modification.

Sketch of a flying frog by Wallace

1858
While studying species in the Malay Archipelago, Wallace (shown above in 1848) sends Darwin his hypothesis of natural selection.

1859
On the Origin of Species is published.

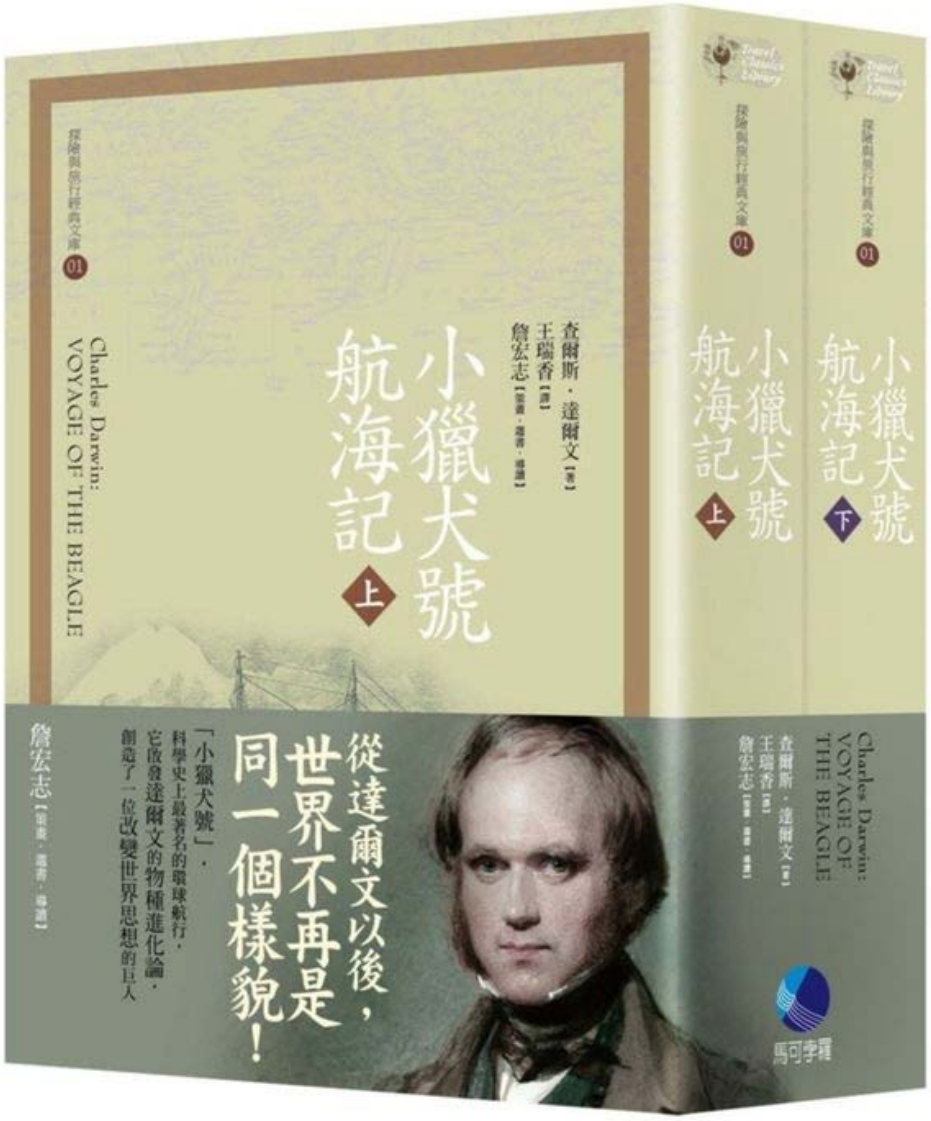


1870

Darwin's Research

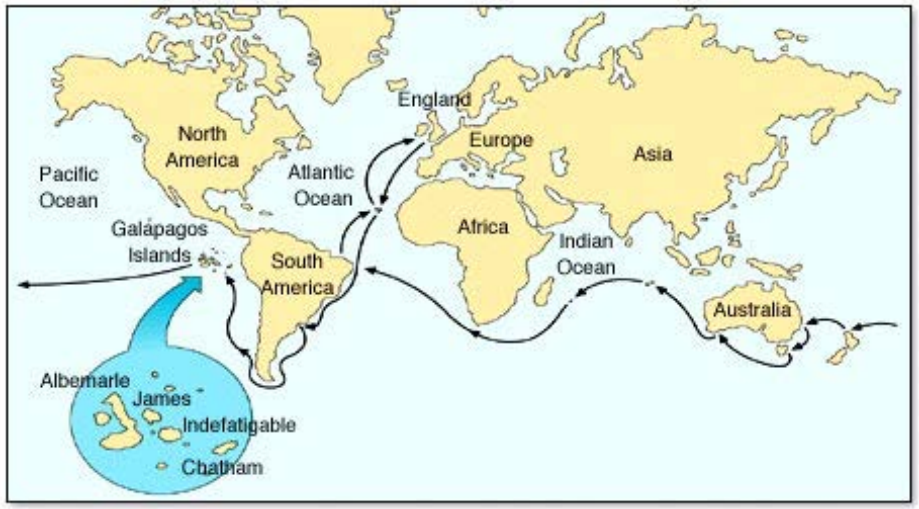
- As a boy and into adulthood, Charles Darwin had a consuming interest in nature
- Darwin first studied medicine (unsuccessfully), and then theology at Cambridge University
- After graduating, he took an unpaid position as naturalist and companion to Captain Robert FitzRoy (1805–1865) for a 5-year around the world voyage on the *HMS Beagle*

小獵犬號航海記
The Voyage of the Beagle

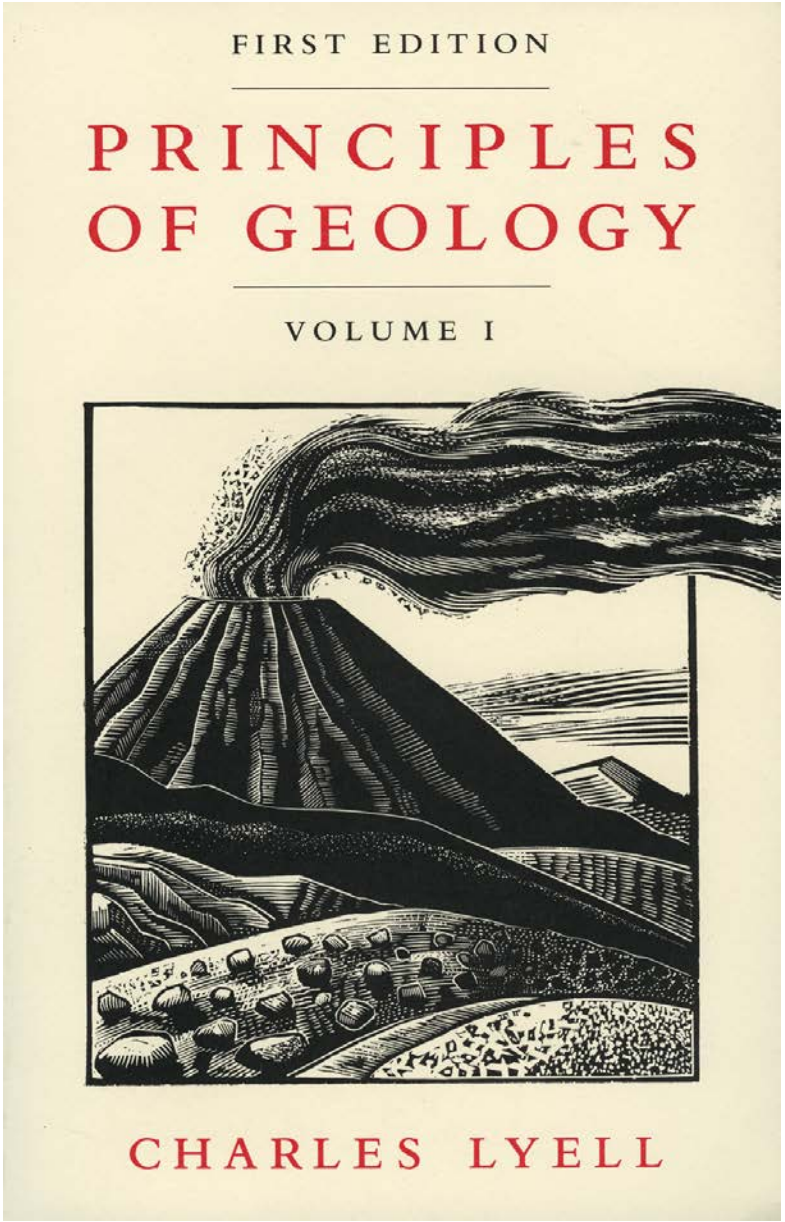


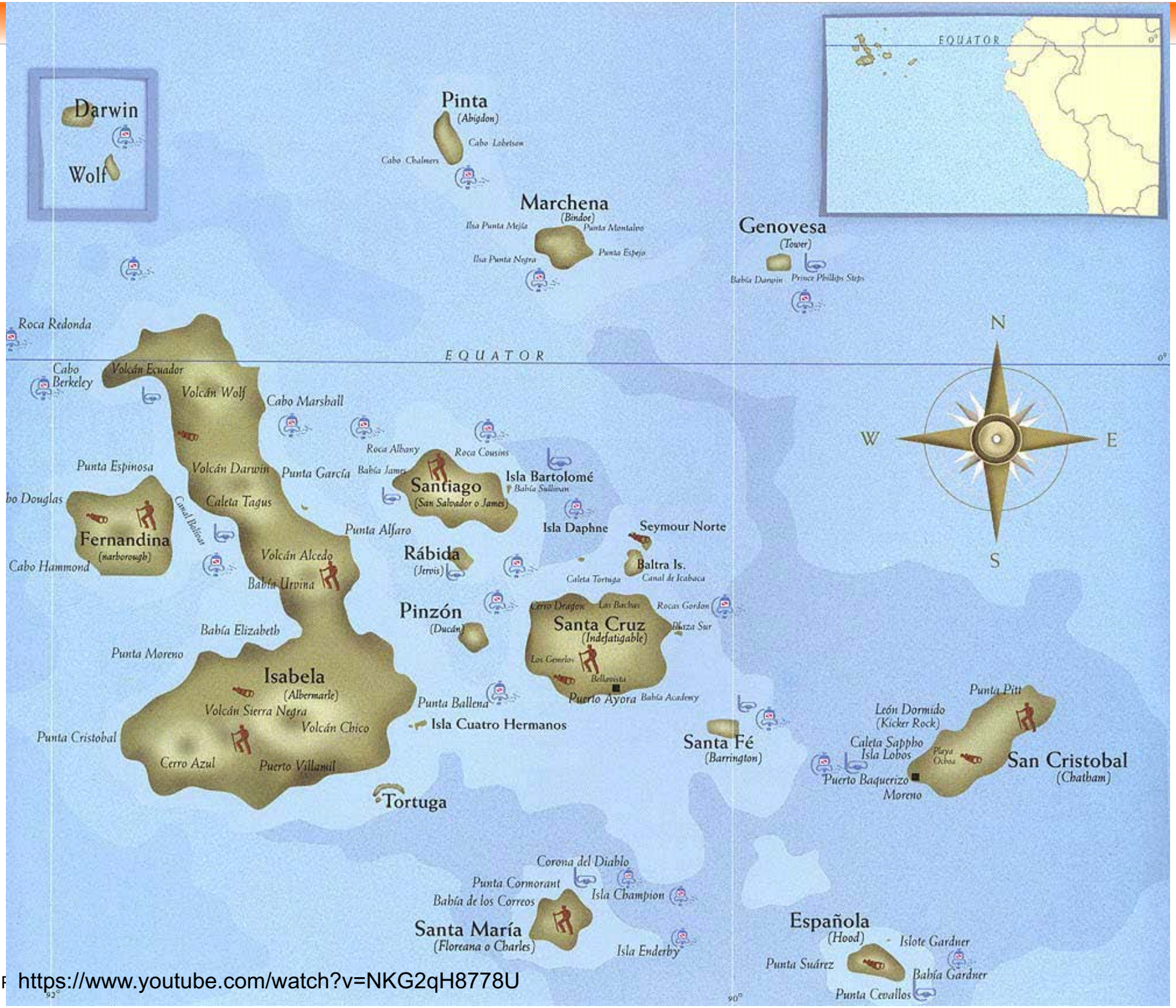
The Voyage of the Beagle

- During his travels on the *Beagle*, Darwin collected specimens of South American plants and animals
- He observed that fossils resembled living species from the same region, and living species resembled other species from nearby regions
- He experienced an earthquake in Chile and observed the uplift of rocks



- Darwin was influenced by Lyell's *Principles of Geology* and thought that the earth was more than 6,000 years old
- His interest in geographic distribution of species was kindled by a stop at the Galápagos Islands west of South America
- He hypothesized that species from South America had colonized the Galápagos and speciated on the islands





 https://www.youtube.com/watch?v=NKG2qH8778U

Figure 21.5

Darwin's Focus on Adaptation

- In reassessing his observations, Darwin perceived **adaptation** to the environment and the origin of new species as closely related processes

- From studies made years after Darwin's voyage, biologists have concluded that this is what happened to the Galápagos finches

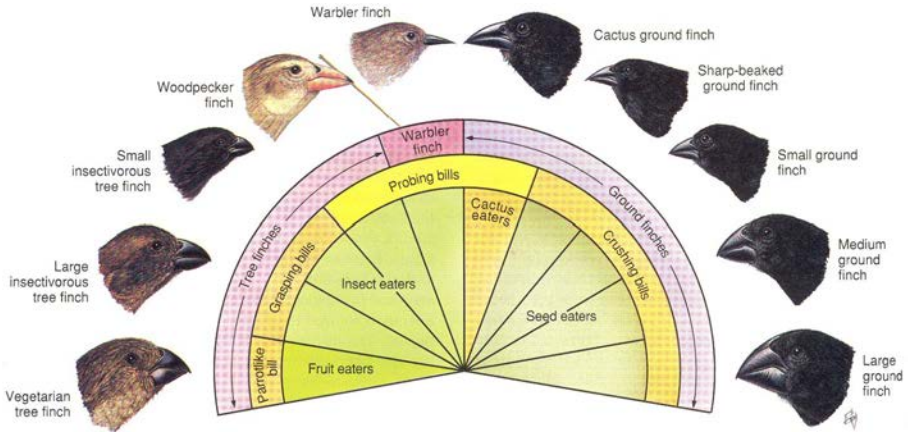


Figure 21.6

(a) Cactus-eater

(b) Insect-eater

(c) Seed-eater

- In 1844, Darwin wrote an essay on **natural selection** as the mechanism of descent with modification, but did not introduce his theory publicly
- Natural selection is a process in which individuals with favorable inherited traits are more likely to survive and reproduce
- In June 1858, Darwin received a manuscript from Alfred Russel Wallace (1823–1913), who had developed a theory of natural selection similar to Darwin's
- Darwin quickly finished *The Origin of Species* and published it the next year

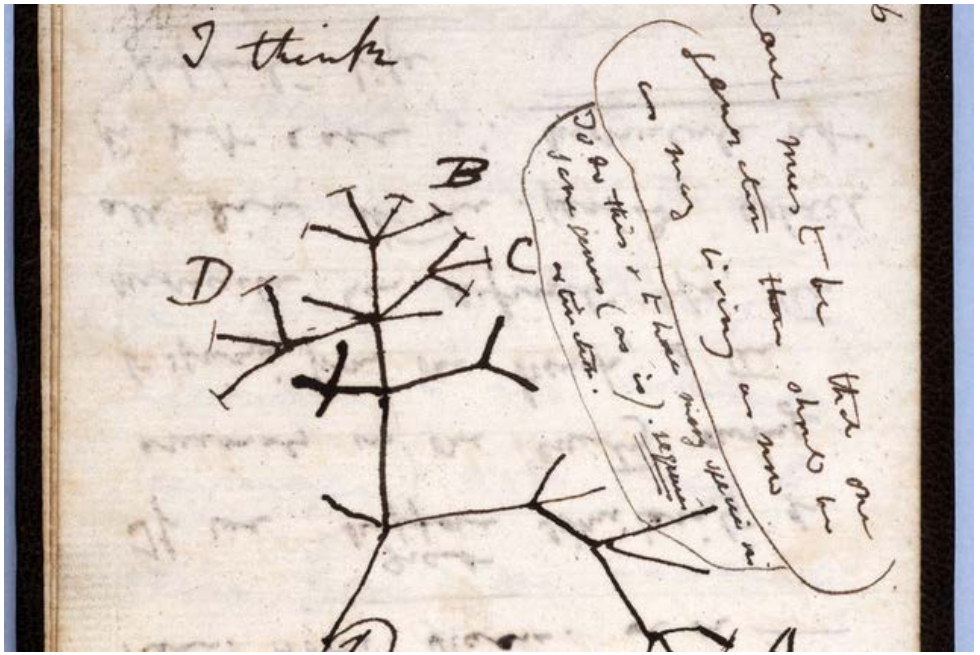
The Origin of Species

- Darwin explained three broad observations
  - The unity of life
  - The diversity of life
  - The match between organisms and their environment

Descent with Modification

- Darwin never used the word *evolution* in the first edition of *The Origin of Species*
- The phrase *descent with modification* summarized Darwin's perception of the unity of life
- The phrase refers to the view that all organisms are related through descent from an ancestor that lived in the remote past

- In the Darwinian view, the history of life is like a tree with branches representing life's diversity
- Darwin reasoned that large morphological gaps between related groups could be explained by this branching process and past extinction events



物種起源

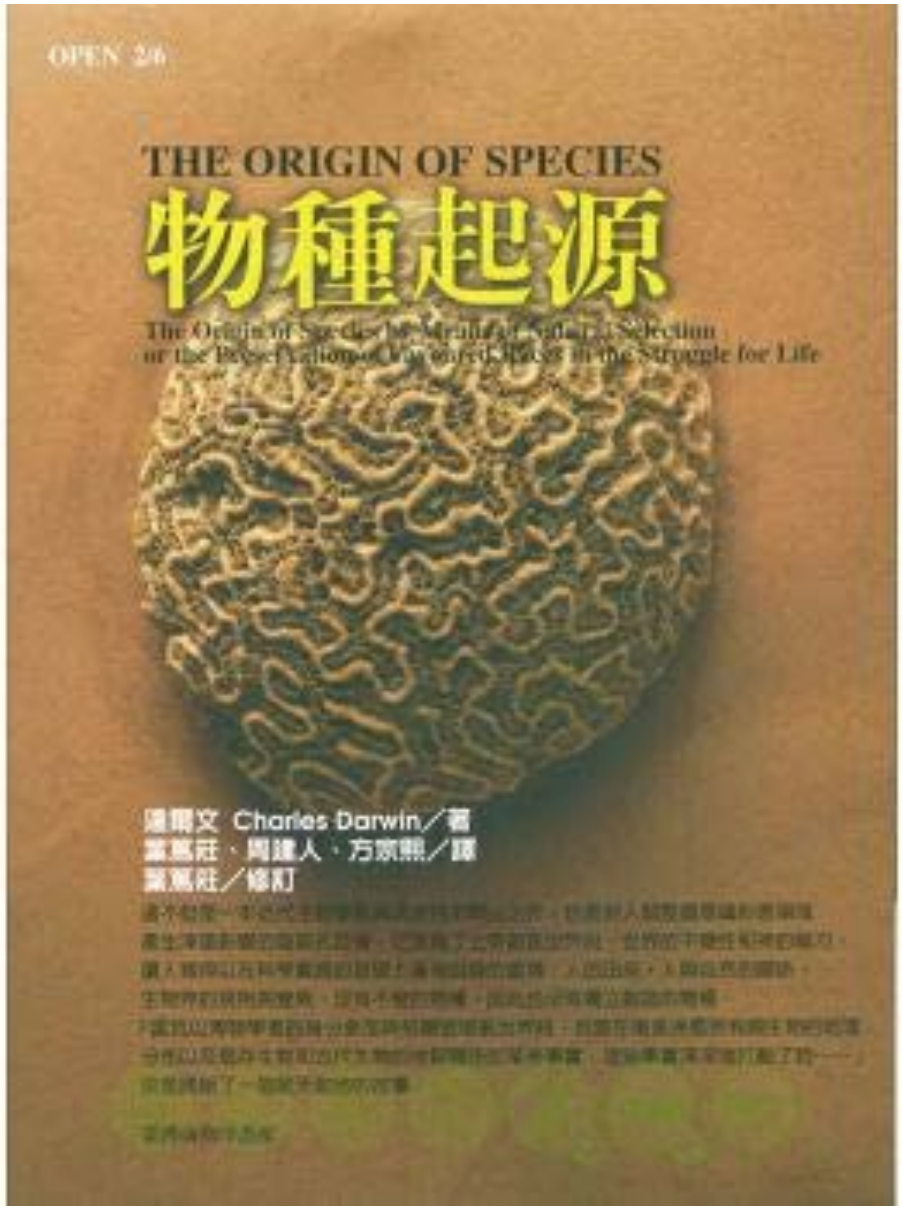
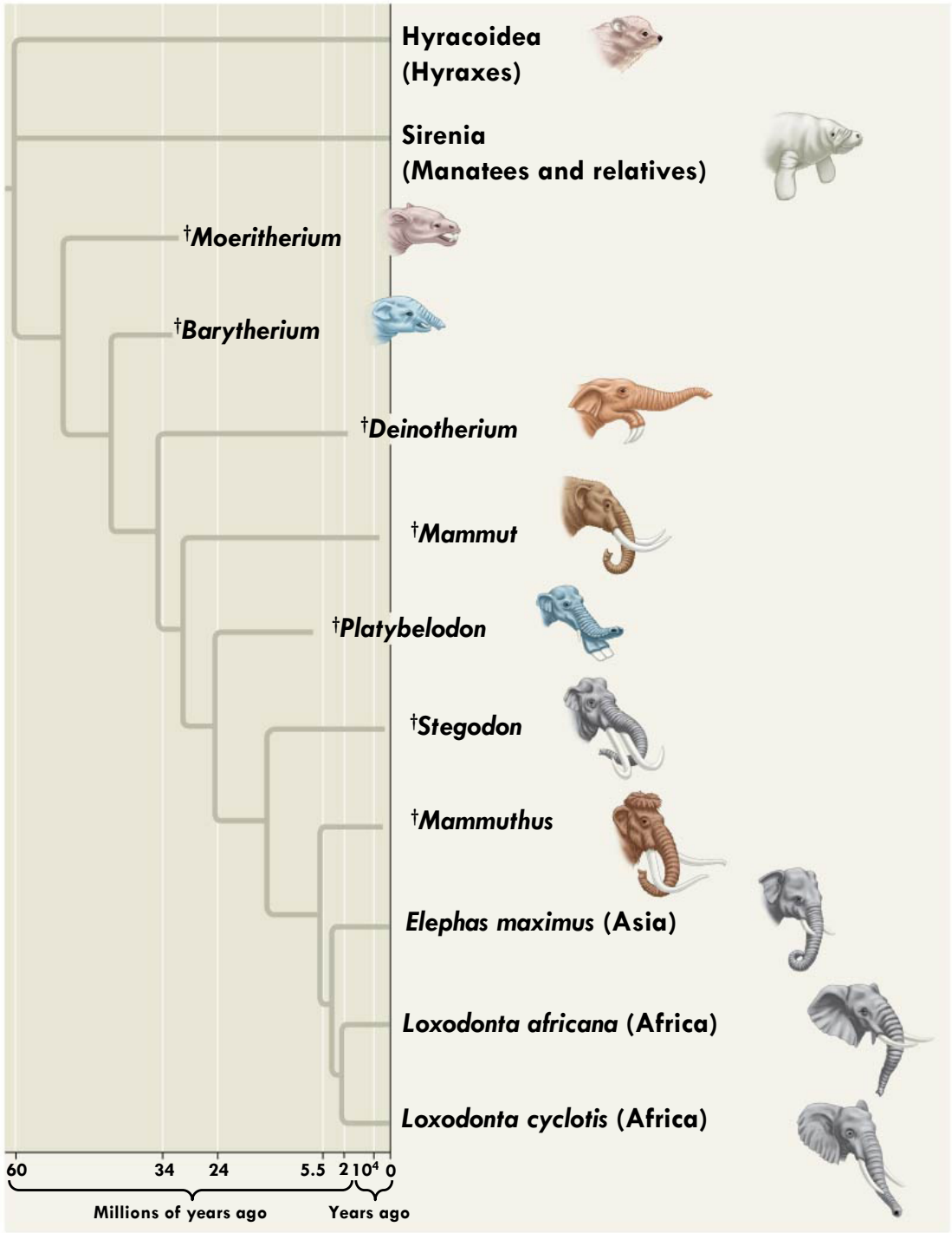


Figure 21.8



Artificial Selection, Natural Selection, and Adaptation

- Darwin noted that humans have modified other species by selecting and breeding individuals with desired traits, a process called **artificial selection**
- Darwin drew two inferences from two observations

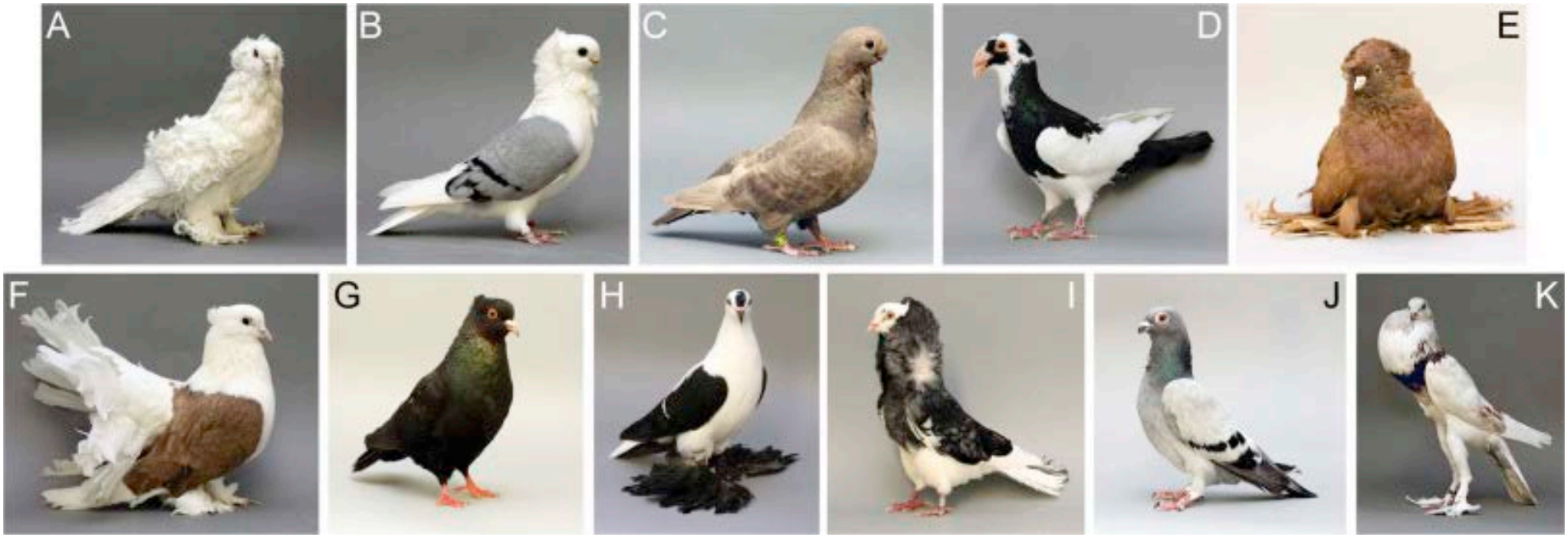


Figure 21.9

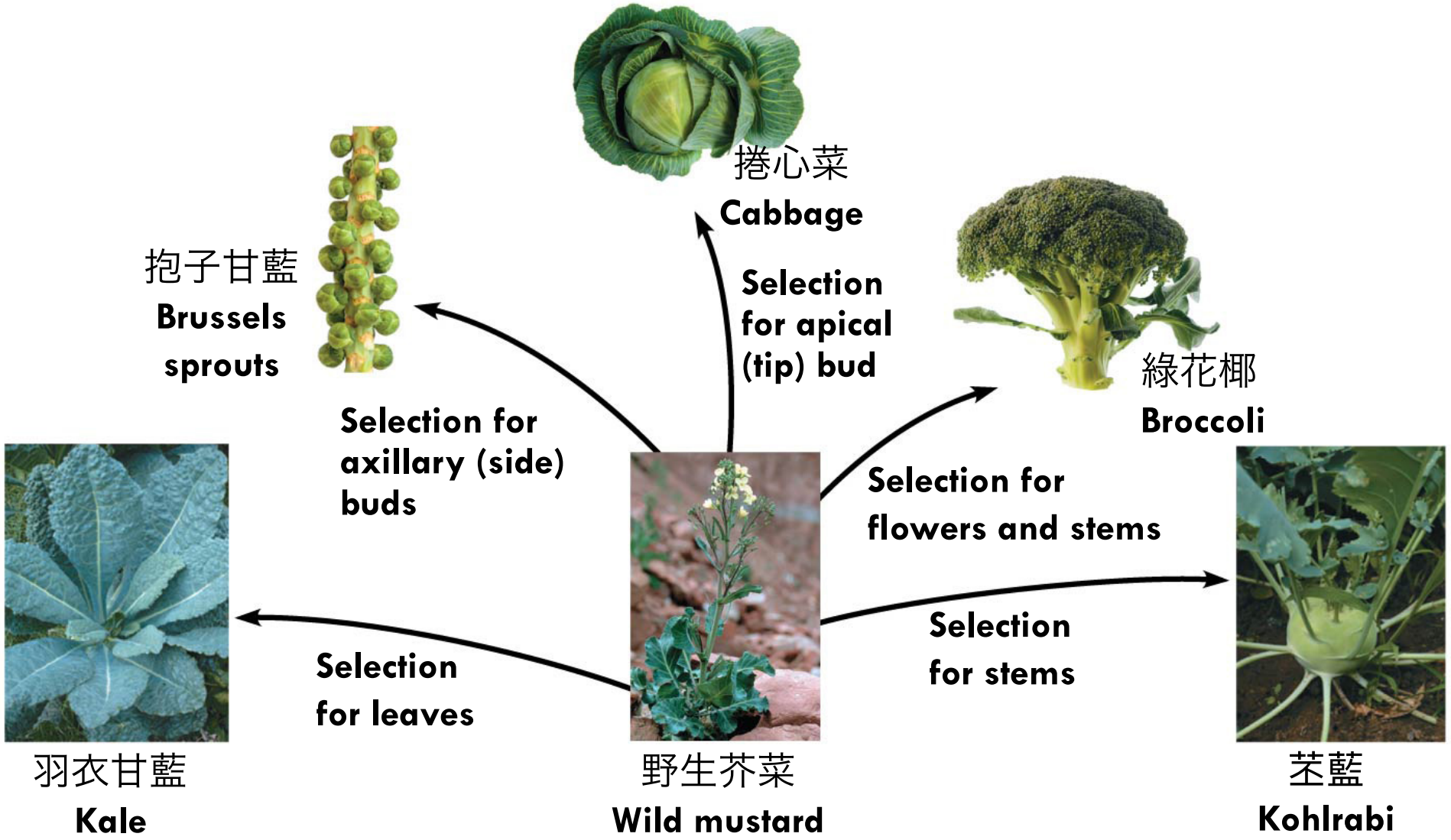


Figure 21.9

捲心菜
Cabbage

Selection for apical (tip) bud

綠花椰
Broccoli

抱子甘藍
Brussels sprouts

Selection for axillary (side) buds

羽衣甘藍
Kale

Selection for leaves

野生芥菜
Wild mustard

Selection for flowers and stems

Selection for stems

茎藍
Kohlrabi

Figure 21.9

捲心菜
Cabbage

抱子甘藍
Brussels sprouts

Selection for apical (tip) bud

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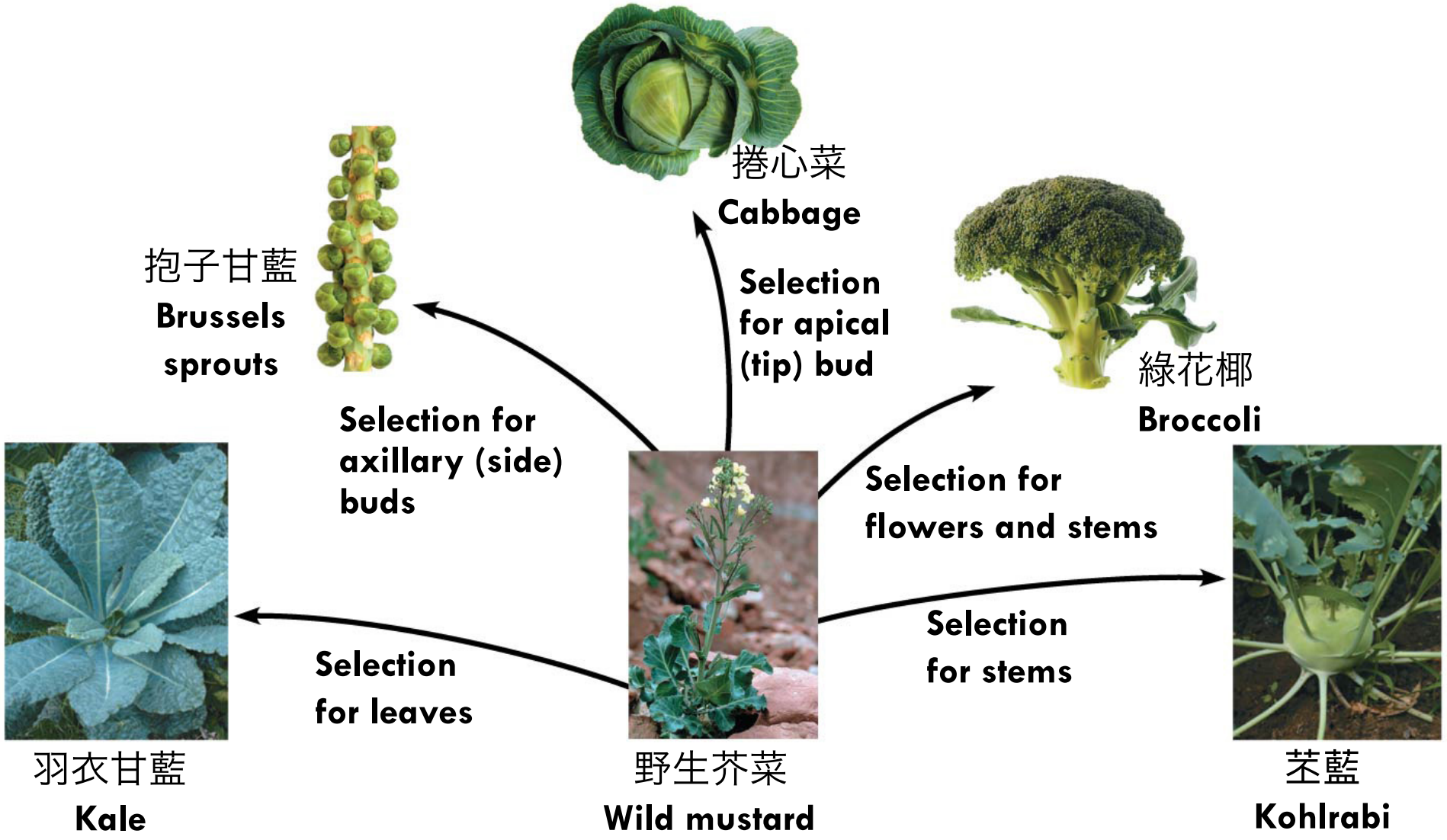
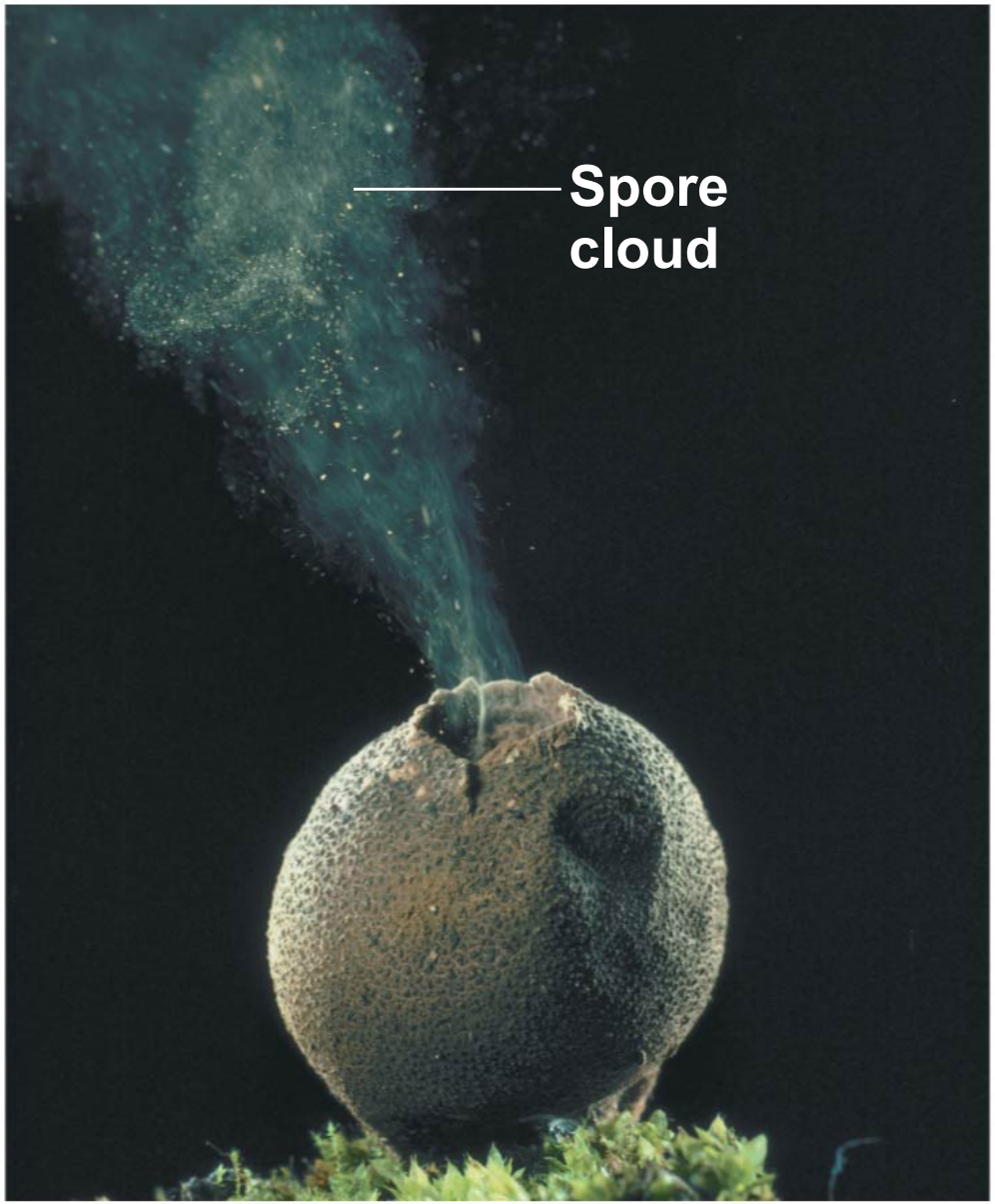


- **Observation #1:**
  Members of a population often vary in their inherited traits

Figure 21.10

- **Observation #2:** All species can produce more offspring than the environment can support, and many of these offspring fail to survive and reproduce

Figure 21.11



- **Inference #1:** Individuals whose inherited traits give them a higher probability of surviving and reproducing in a given environment tend to leave more offspring than other individuals

- **Inference #2:** This unequal ability of individuals to survive and reproduce will lead to the accumulation of favorable traits in the population over generations

- Darwin was influenced by Thomas Malthus (1766 – 1834), who noted the potential for human population to increase faster than food supplies and other resources

- If some heritable traits are advantageous, these will accumulate in a population over time, and this will increase the frequency of individuals with these traits

- This process explains the match between organisms and their environment

Natural Selection: *A Summary*

- Individuals with certain heritable traits survive and reproduce at a higher rate than other individuals
- Natural selection increases the match between organisms and their environment over time
- If an environment changes over time, natural selection may result in adaptation to these new conditions and may give rise to new species

Figure 21.12

A flower mantid in Malaysia

A flower-eyed mantid in South Africa

A leaf mantid in Borneo

- Note that individuals do not evolve; populations evolve over time
- Natural selection can only increase or decrease heritable traits that vary in a population
- Adaptations vary with different environments

Concept 21.3: Evolution is supported by an overwhelming amount of scientific evidence

- New discoveries continue to fill the gaps identified by Darwin in *The Origin of Species*
- There are four types of data that document the pattern of evolution
  - Direct observations
  - Homology
  - The fossil record
  - Biogeography

Direct Observations of Evolutionary Change

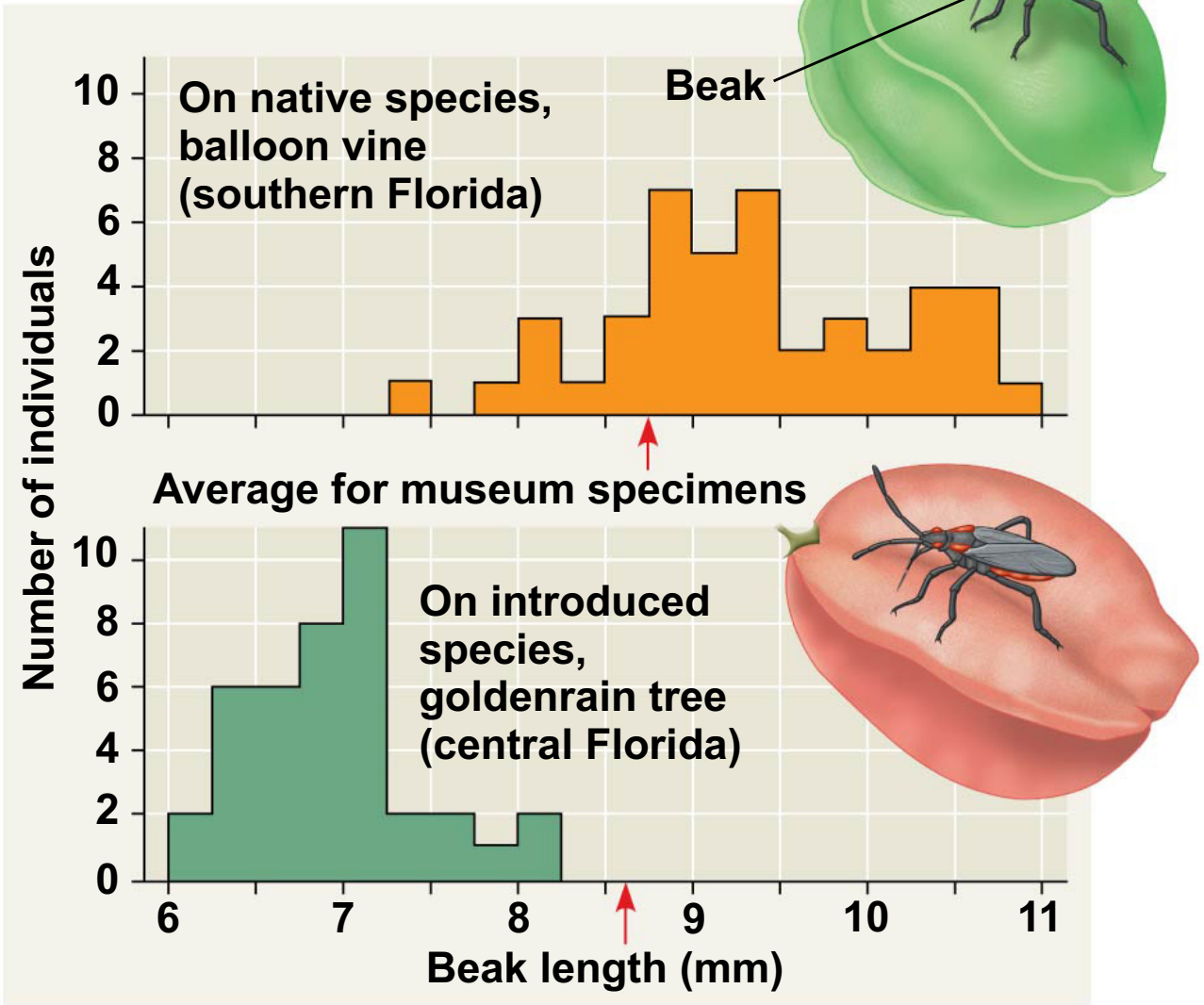
- Two examples provide evidence for natural selection: natural selection in response to introduced plant species, and the evolution of drug-resistant bacteria

Figure 21.13

Field Study

Soapberry bug with beak inserted in balloon vine fruit

Results



Natural Selection in Response to Introduced Species

- Soapberry bugs (椿象) use their "beak" to feed on seeds within fruits

- Feeding is most effective when beak length is closely matched to seed depth within the fruit

- In southern Florida soapberry bugs feed on the native balloon vine (倒地鈴) with larger fruit; they have longer beaks

- In central Florida they feed on the introduced goldenrain tree (欒樹) with smaller fruit; they have shorter beaks

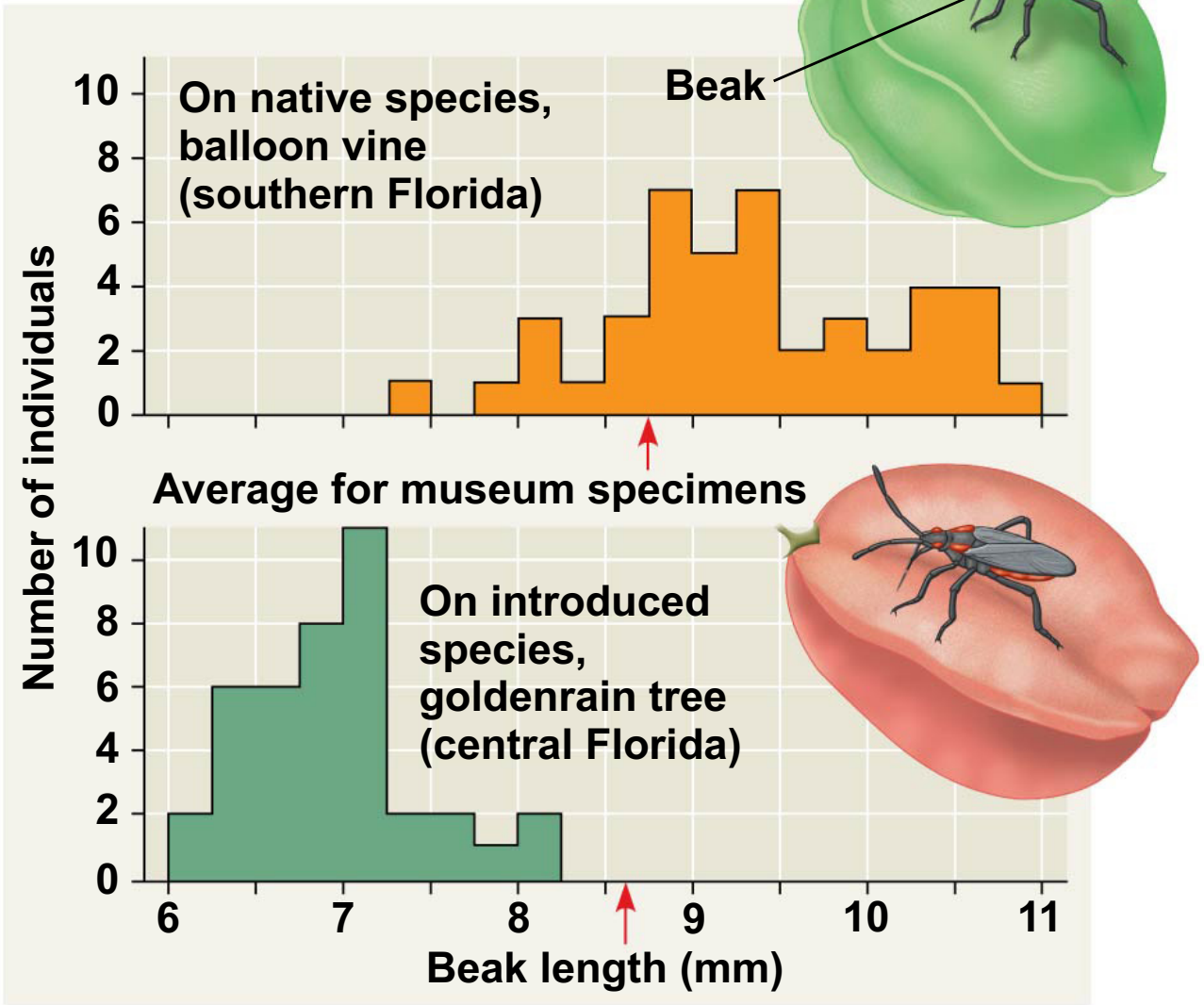
- Correlation between fruit size and beak size has also been observed in Louisiana, Oklahoma, and Australia

Figure 21.13

Field Study

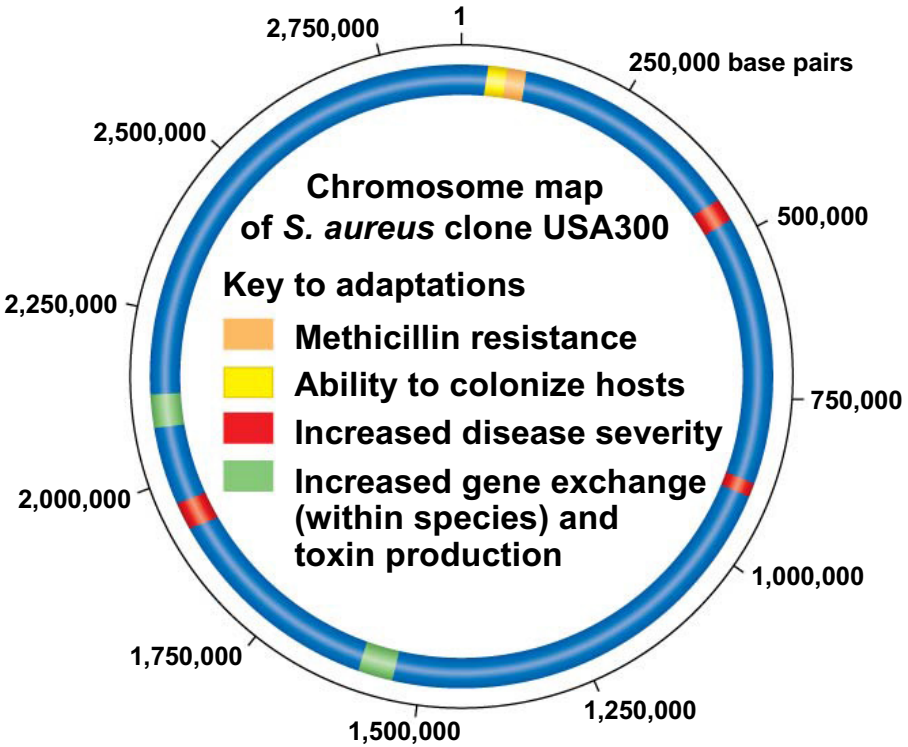
Soapberry bug with beak inserted in balloon vine fruit

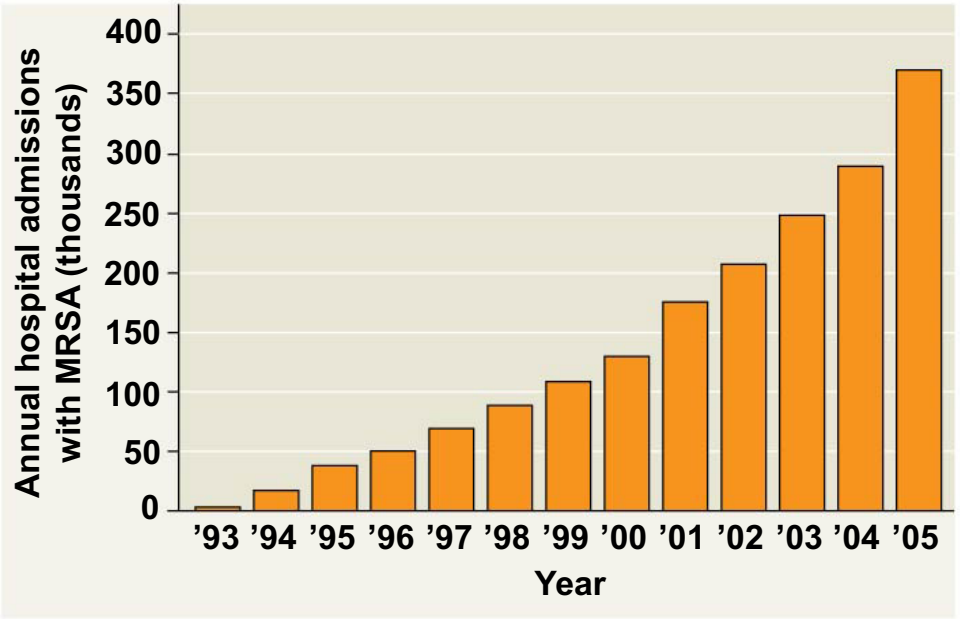
Results



- In all cases, beak size has evolved in populations that feed on introduced plants with fruits that are smaller or larger than the native fruits
- These cases are examples of evolution by natural selection
- In Florida this evolution in beak size occurred in less than 35 years

Figure 21.14





The Evolution of Drug-Resistant Bacteria

- The bacterium *Staphylococcus aureus* (金黄色葡萄球菌) is commonly found on people
- One strain, methicillin-resistant *S. aureus* (MRSA) is a dangerous pathogen
- Resistance to penicillin (青黴素) evolved in *S. aureus* by 1945, two years after it was first widely used
- Resistance to methicillin (甲氧苯青黴素) evolved in *S. aureus* by 1961, two years after it was first widely used

- Methicillin works by inhibiting a protein used by bacteria to produce cell walls
- MRSA bacteria use a different protein in cell wall production
- When exposed to methicillin, MRSA strains are more likely to survive and reproduce than nonresistant *S. aureus* strains
- MRSA strains are now resistant to many antibiotics

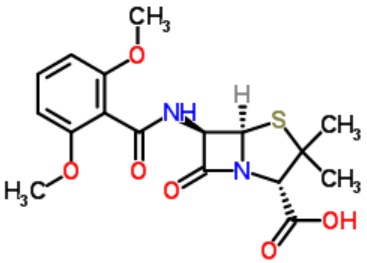
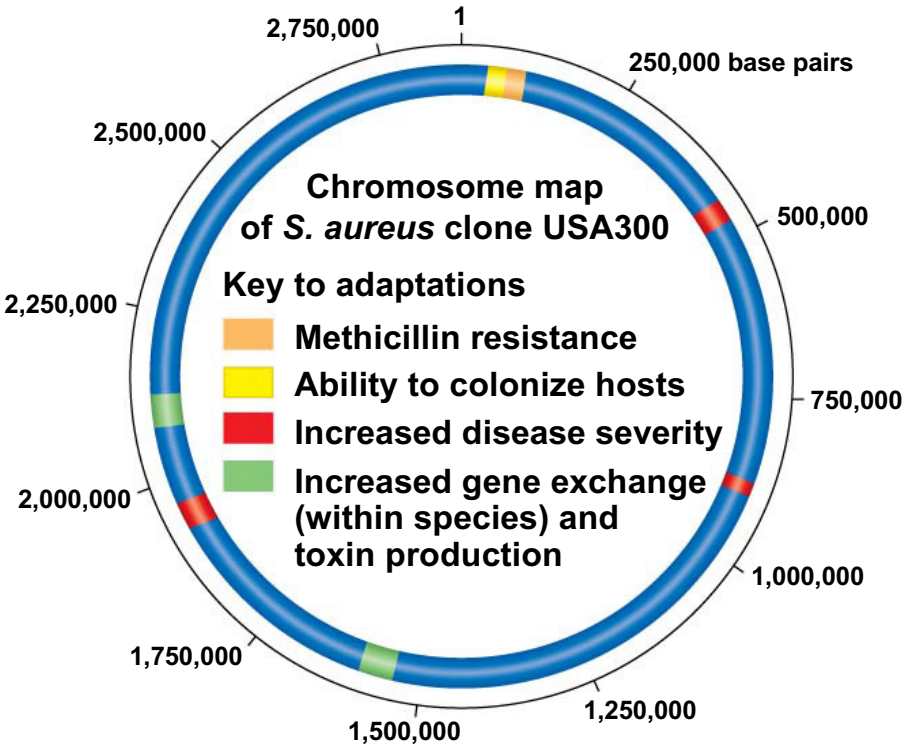
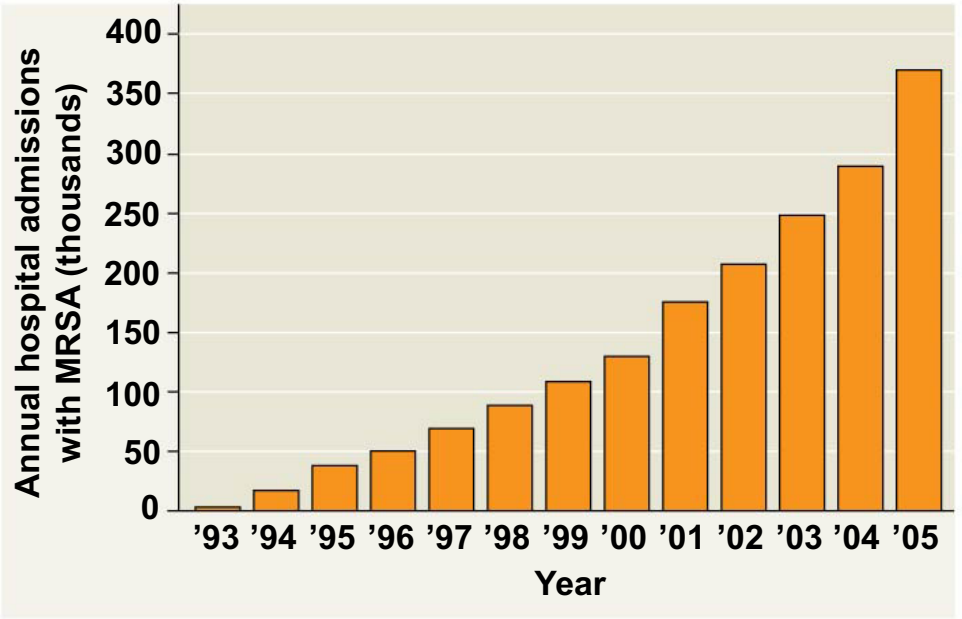


Figure 21.14





- Natural selection does not create new traits, but edits or selects for traits already present in the population
- The current, local environment determines which traits will be selected for or selected against in any specific population

Homology

- **Homology** is similarity resulting from common ancestry

Anatomical and Molecular Homologies

- **Homologous structures** are anatomical resemblances that represent variations on a structural theme present in a common ancestor

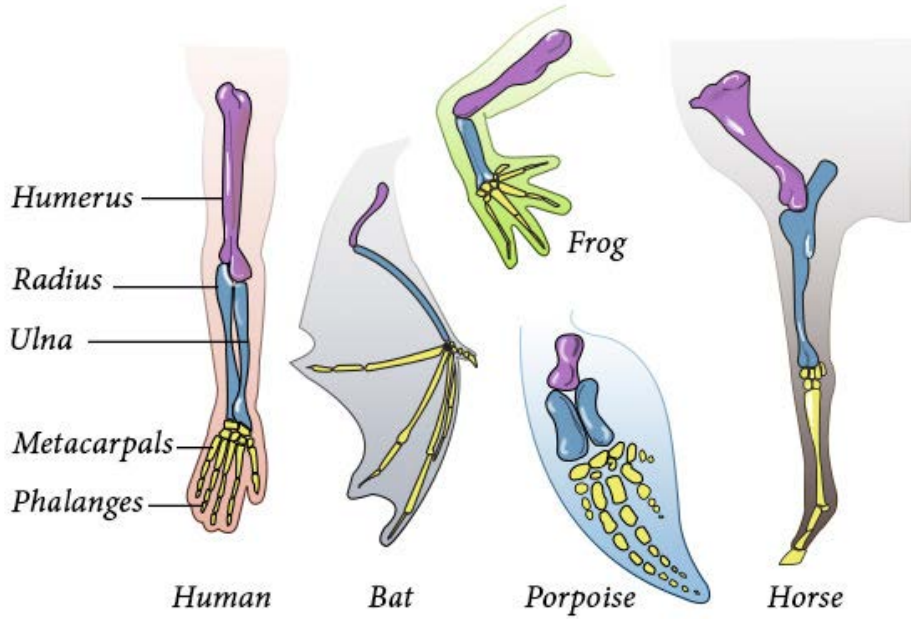
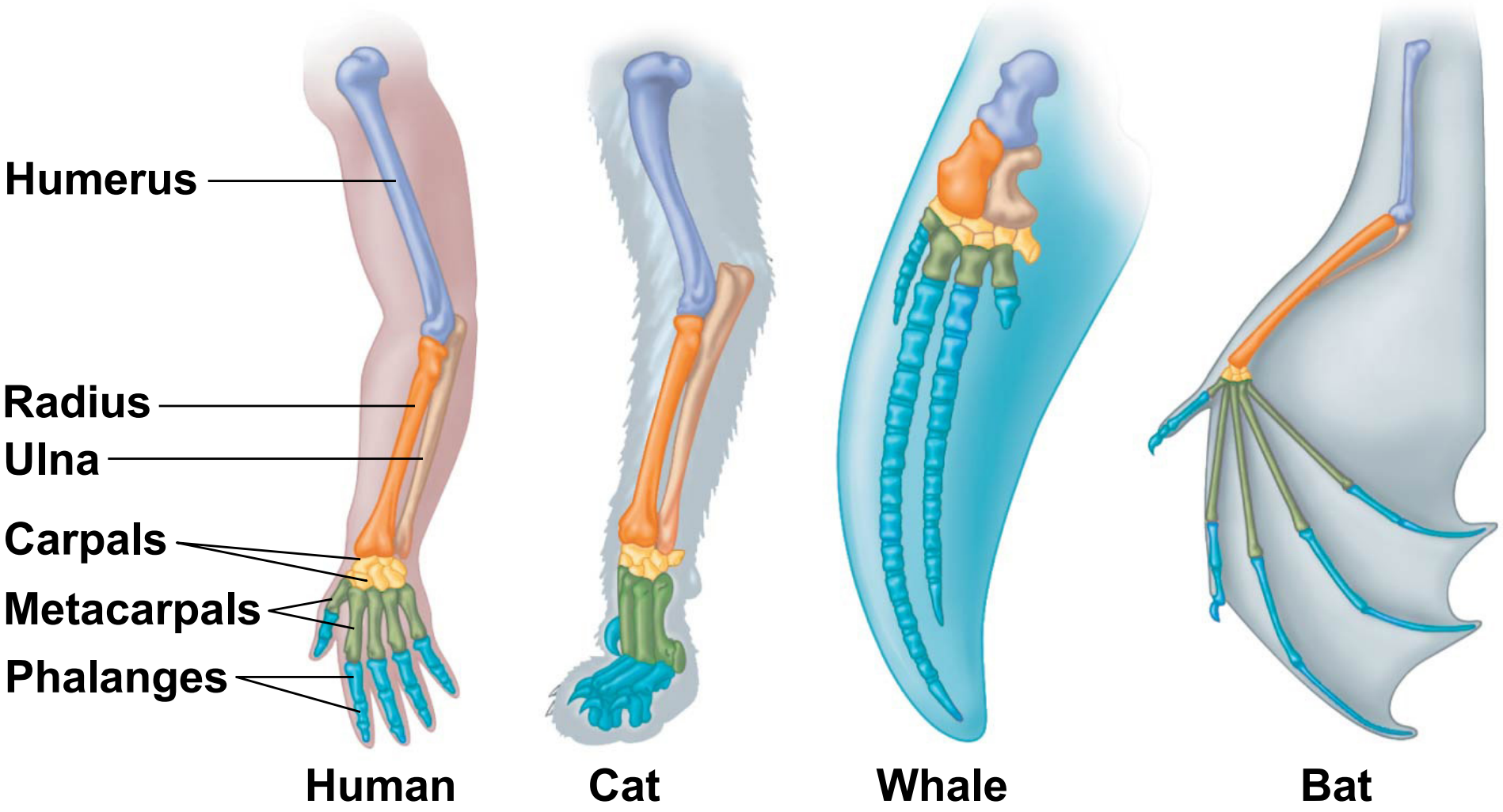


Figure 21.15



- Comparative embryology reveals anatomical homologies not visible in adult organisms
  - For example, all vertebrate embryos have a post-anal tail and pharyngeal arches

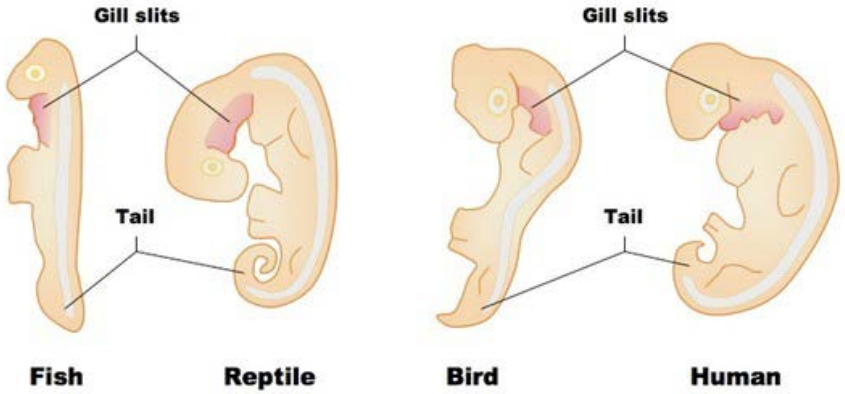
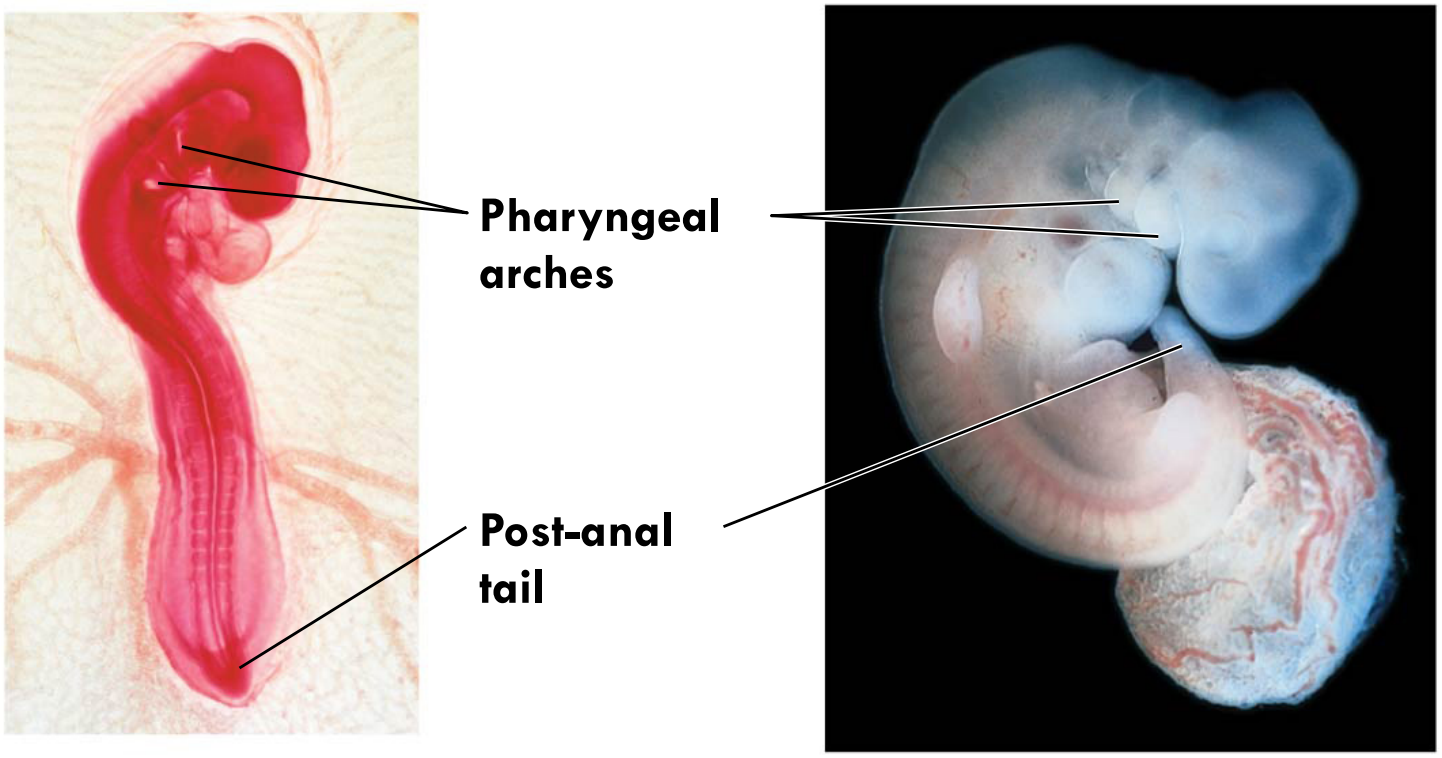


Figure 21.16



- **Vestigial structures** are remnants of features that served important functions in the organism's ancestors

- Examples of homologies at the molecular level are genes shared among organisms inherited from a common ancestor

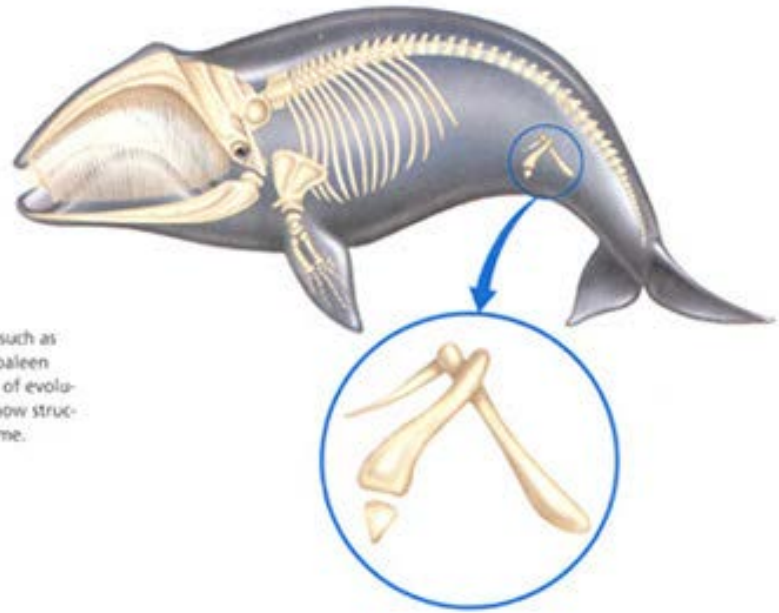
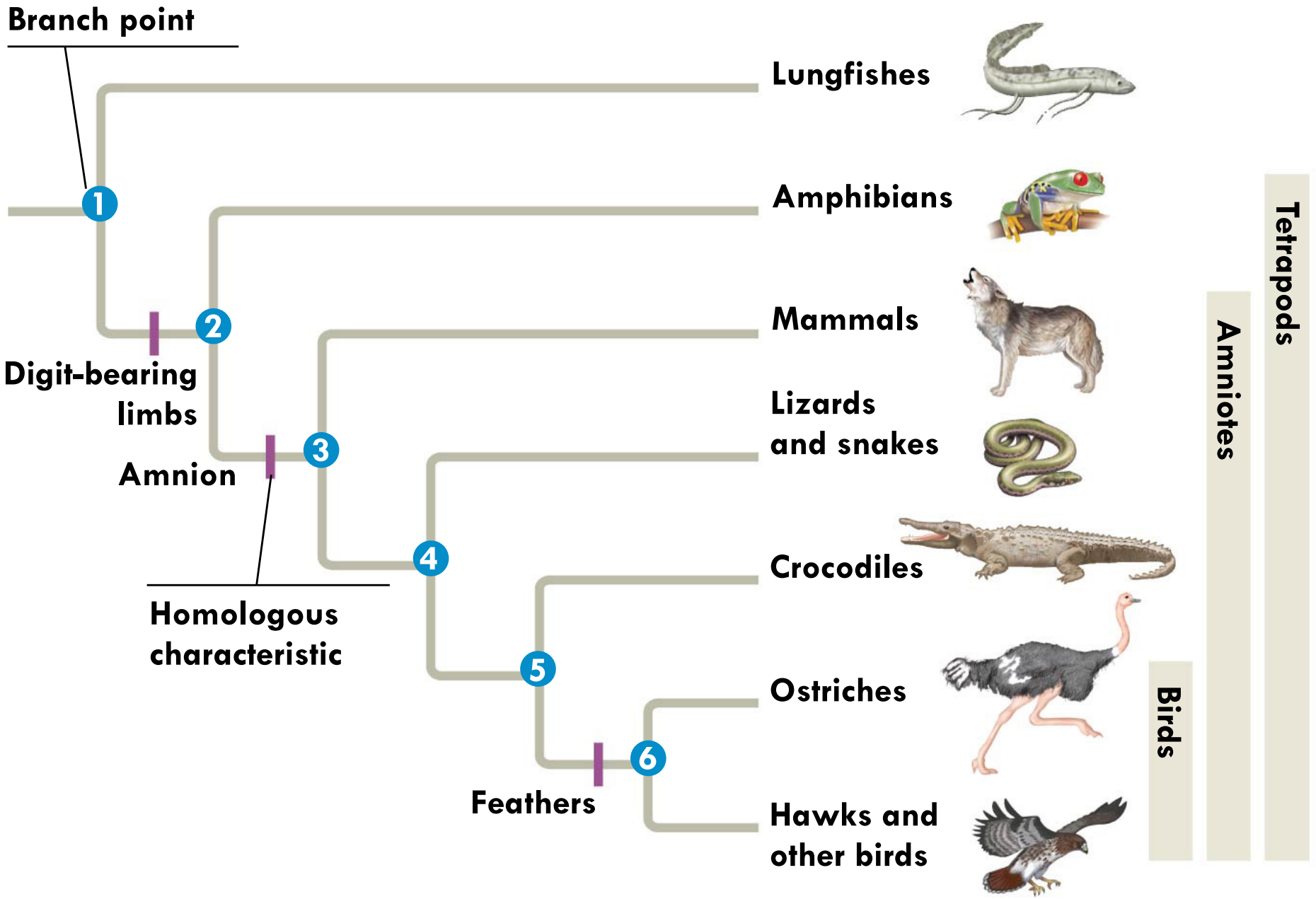


Figure 15.8
Vestigial structures, such as pelvic bones in the baleen whale, are evidence of evolution because they show structural change over time.

Homologies and "Tree Thinking"

- **Evolutionary trees** are hypotheses about the relationships among different groups
- Homologies form nested patterns in evolutionary trees
- Evolutionary trees can be made using different types of data, for example, anatomical and DNA sequence data

Figure 21.17



A Different Cause of Resemblance: Convergent Evolution

- **Convergent evolution** is the evolution of similar, or **analogous**, features in distantly related groups
- Analogous traits arise when groups independently adapt to similar environments in similar ways
- Convergent evolution does not provide information about ancestry

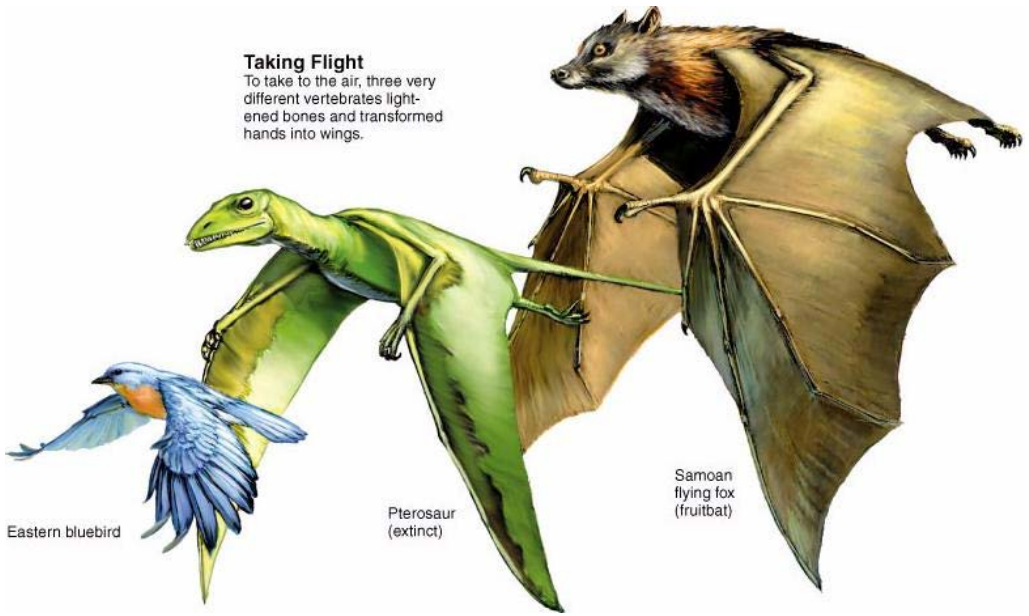
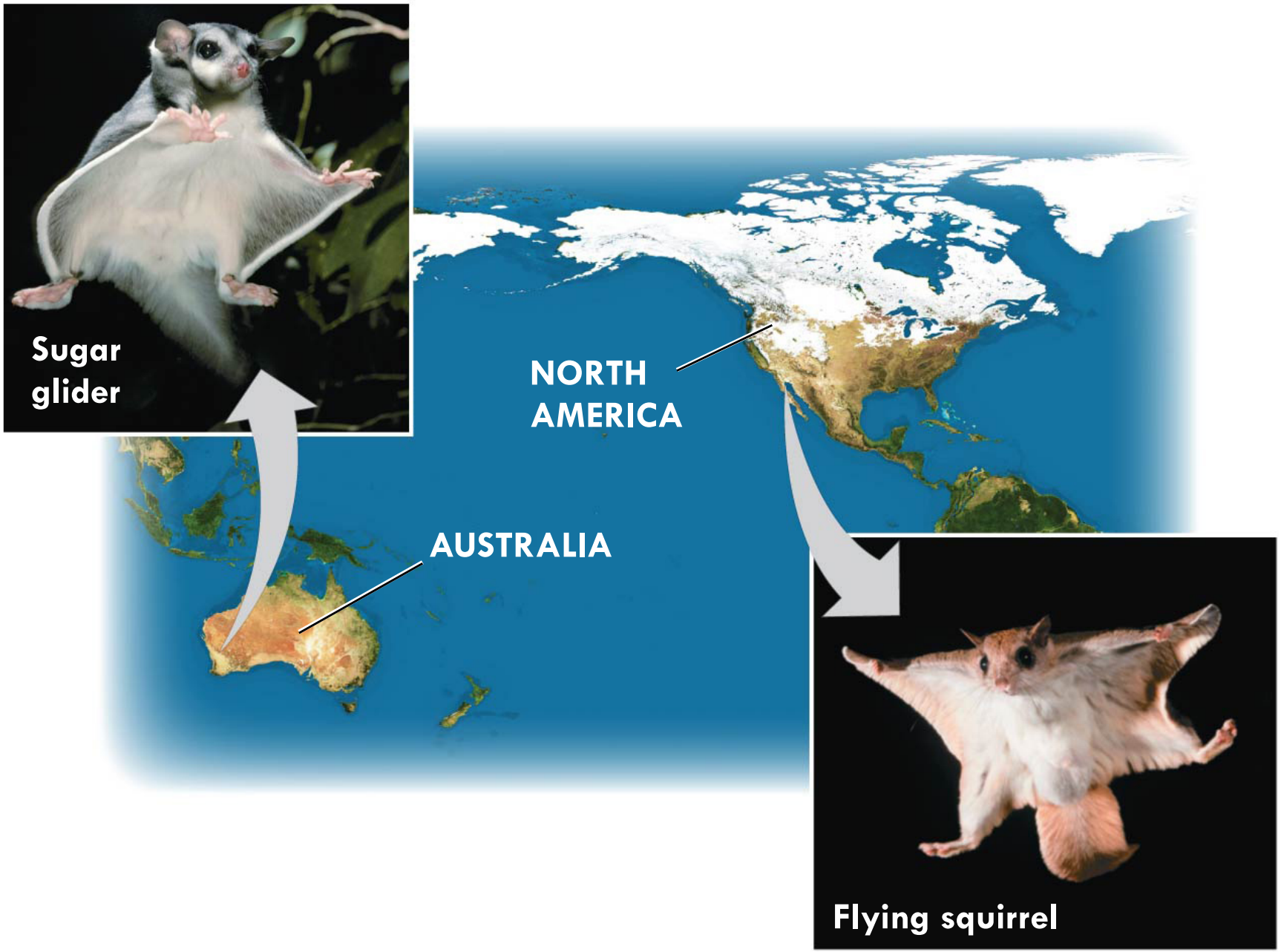


Figure 21.18



Marsupials	Placentals
 Native cat (*Dasyurus*)	 Ocelot (*Felis*)
 "Anteater" (*Myrmecobius*)	 Anteater (*Myrmecophaga*)
 "Mouse" (*Dasycercus*)	 Mouse (*Mus*)
 Flying phalanger (*Petaurus*)	 Flying squirrel (*Petaurus*)
 Tasmanian wolf (*Thylacinus*)	 Wolf (*Canis*)

FIGURE 22.7. Marsupials in Australia and **placental mammals** on other continents have converged to occupy a similar range of ecological niches.

The Fossil Record

- The fossil record provides evidence of the extinction of species, the origin of new groups, and changes within groups over time

Figure 21.20

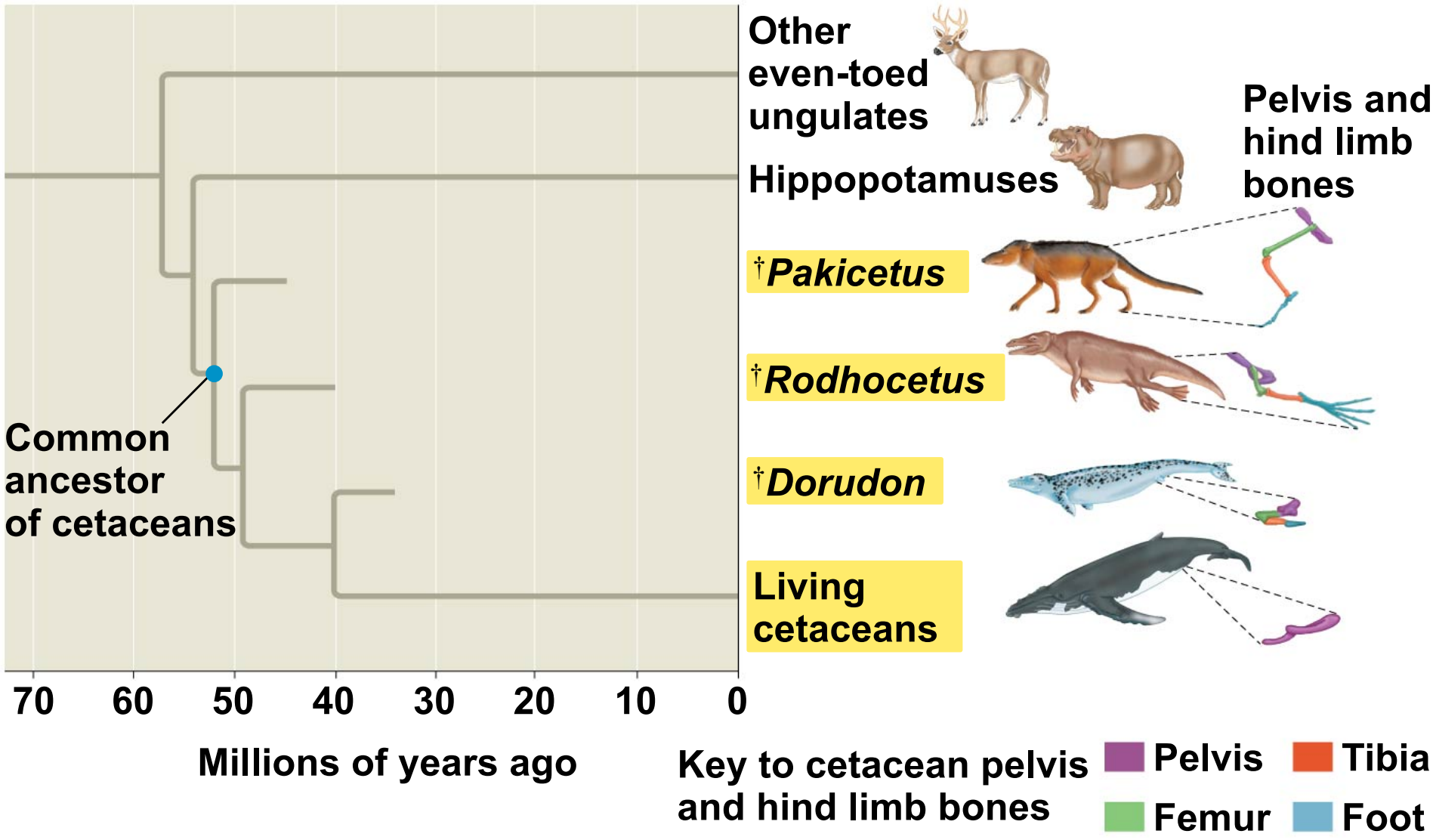


Figure 21.19

Astragalus 踝骨

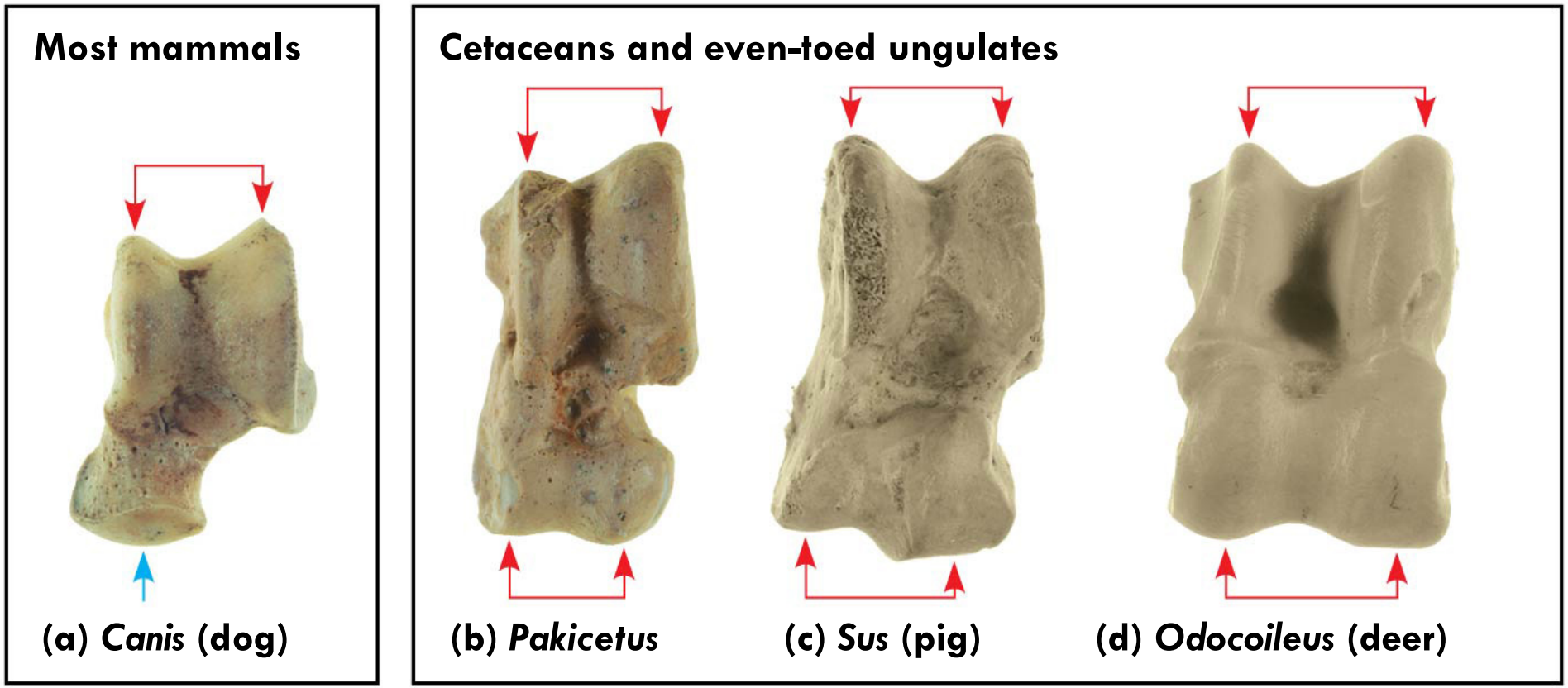


Figure 21.20

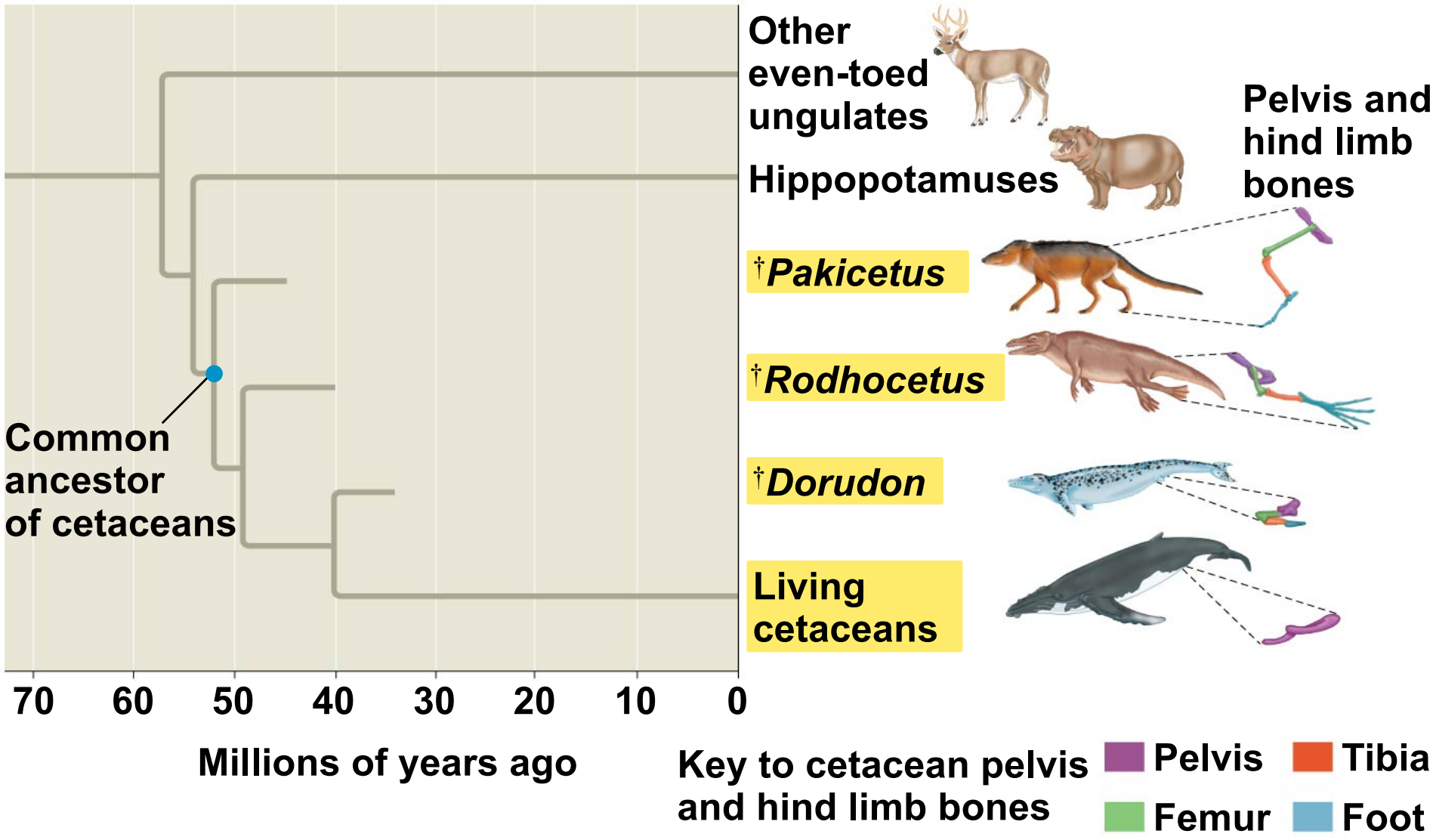
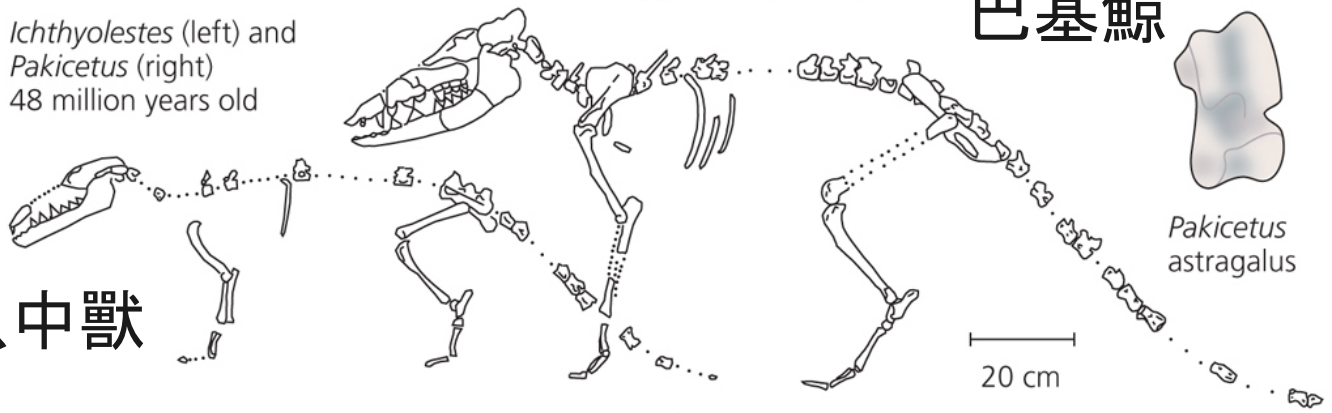


Figure 4-32

Whales are artiodaclyls

巴基鯨

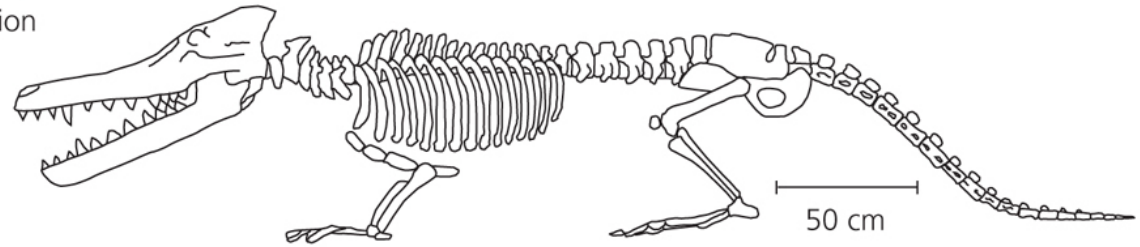
Ichthyolestes (left) and
Pakicetus (right)
48 million years old



Pakicetus
astragalus

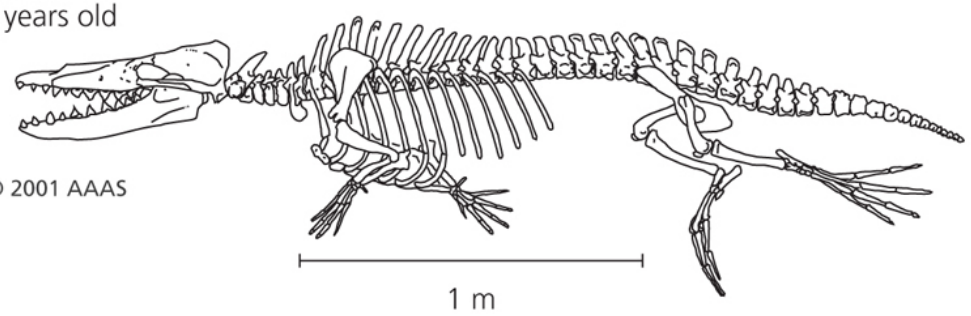
魚中獸

Ambulocetus
48–47 million
years old



走鯨

Rodhocetus
47 million years old



羅德侯鯨

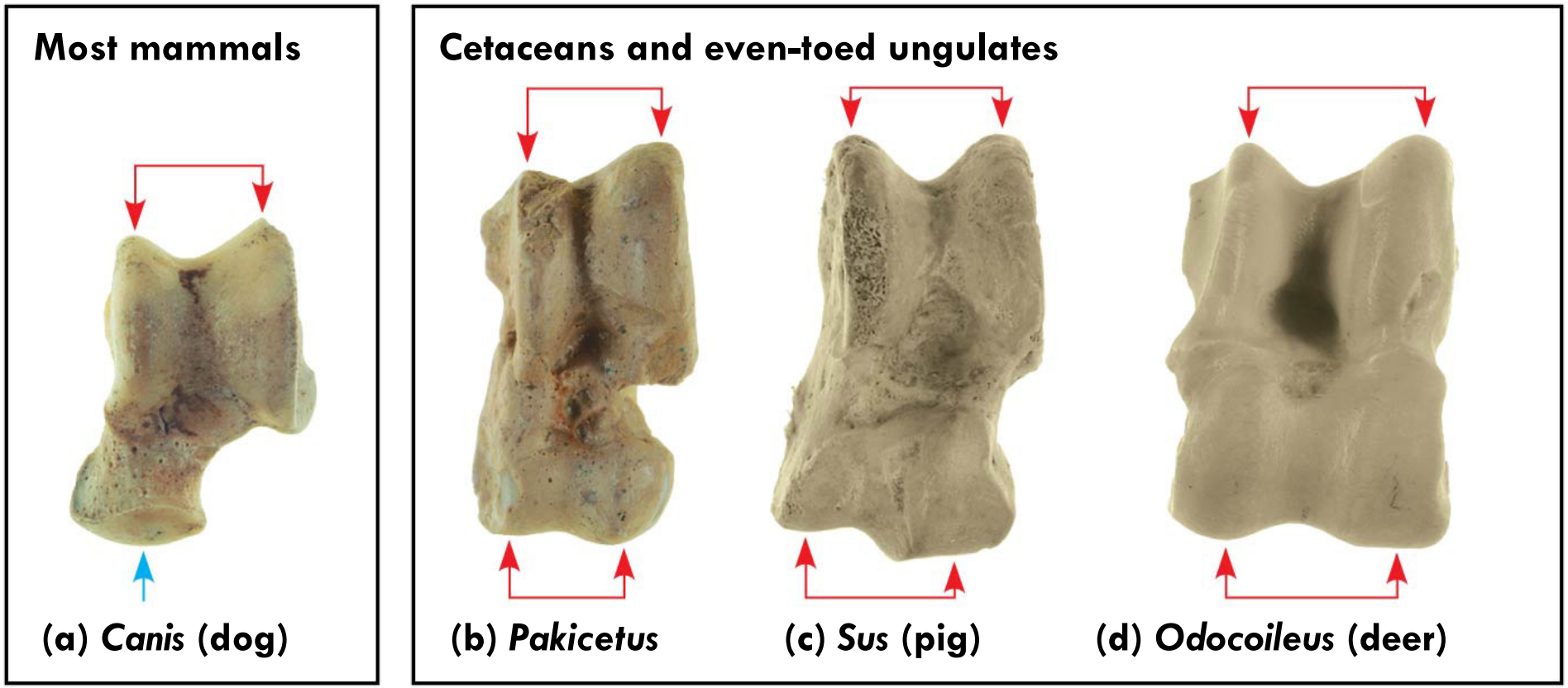
Rodhocetus
astragalus

Basilosaurus
38 million years old

龍王鯨

Figure 21.19

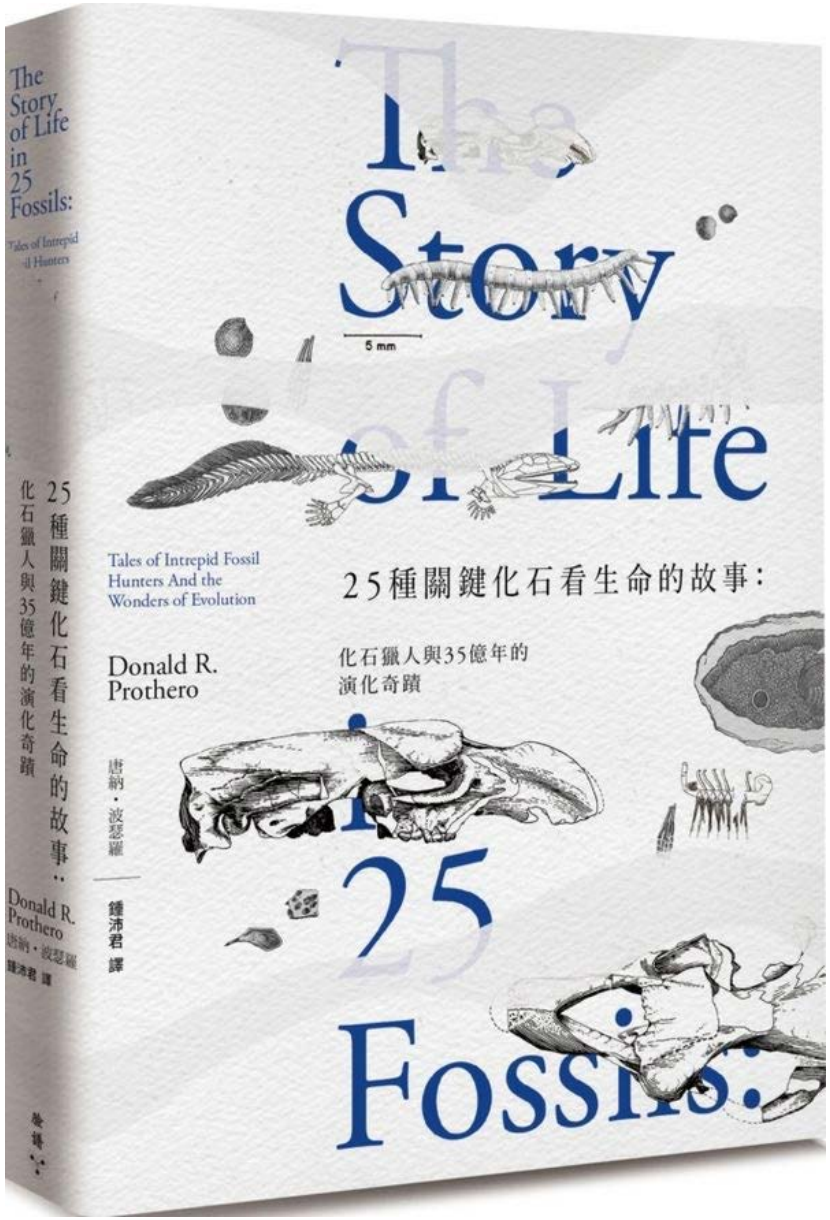
Astragalus 踝骨



- Fossils can document important transitions
  - For example, the transition from land to sea in the ancestors of cetaceans

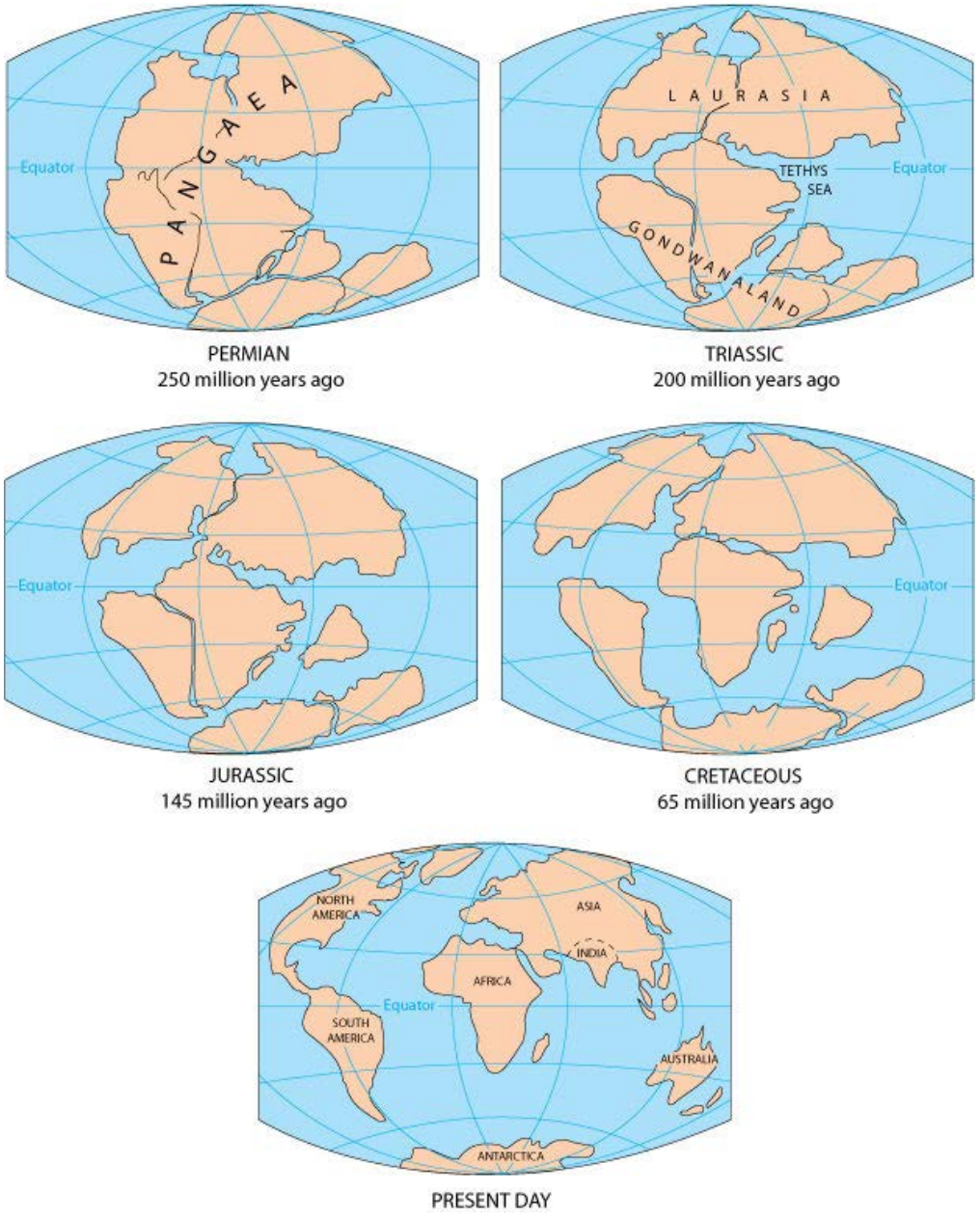
25種關鍵化石看生命的故事：化石獵人與35億年的演化奇蹟

The Story of Life in 25 Fossils: Tales of Intrepid Fossil Hunters And the Wonders of Evolution



Biogeography

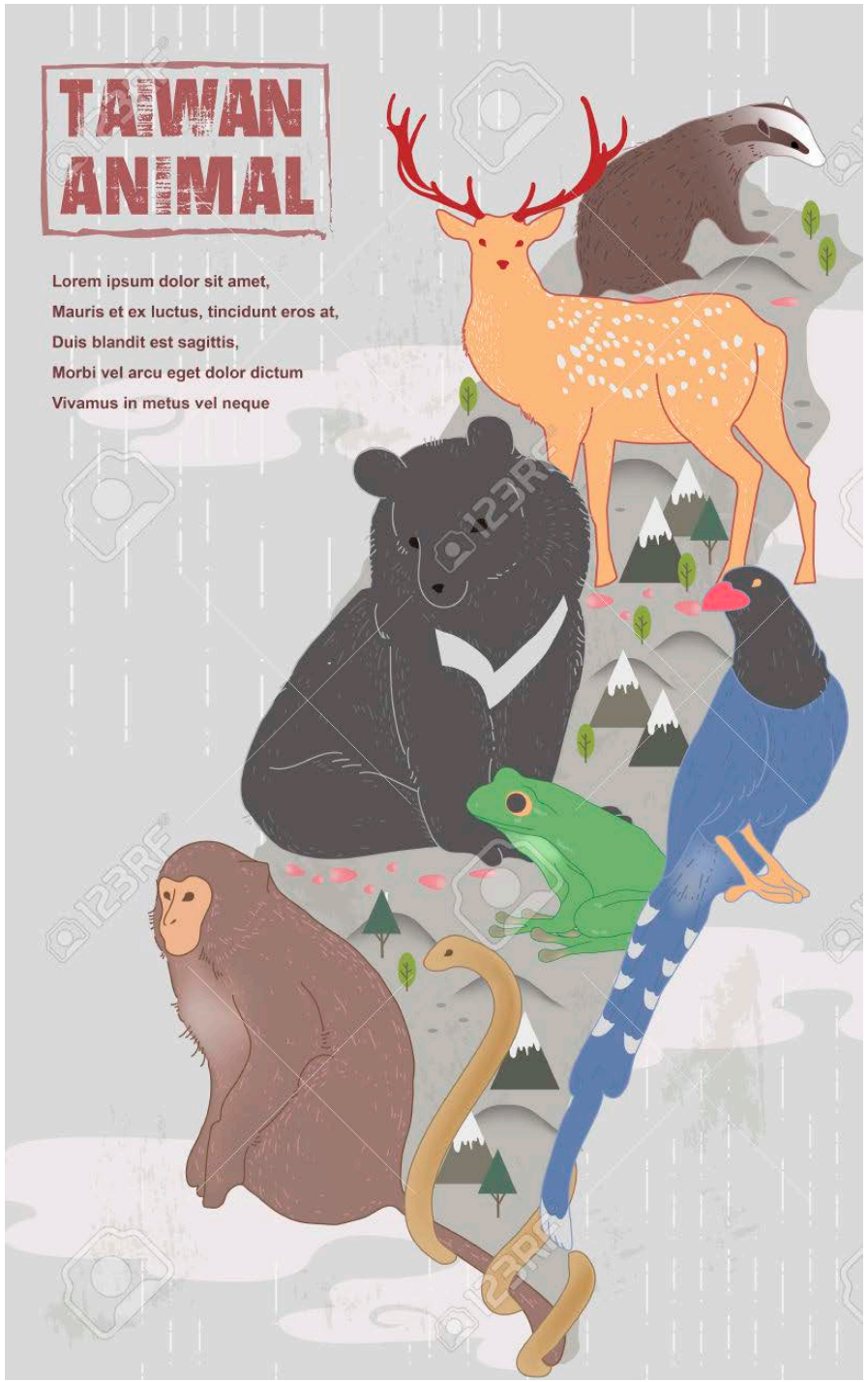
- **Biogeography**, the scientific study of the geographic distribution of species, provides evidence of evolution
- Earth's continents were formerly united in a single large continent called **Pangaea**, but have since separated by continental drift
- An understanding of continent movement and modern distribution of species allows us to predict when and where different groups evolved



- **Endemic** species are species that are not found anywhere else in the world

- Islands have many endemic species that are often closely related to species on the nearest mainland or island

- Darwin explained that species from the mainland colonized islands and gave rise to new species as they adapted to new environments



What Is Theoretical About Darwin's View of Life?

- In science, a theory accounts for many observations and data and attempts to explain and integrate a great variety of phenomena
- Darwin's theory of evolution by natural selection integrates diverse areas of biological study and stimulates many new research questions
- Ongoing research adds to our understanding of evolution