

# Biological Evolution

Darwinian Evolution  
and  
Natural Selection

# Major Concepts

1. Linnaean Classification
2. Fossils
3. Radioactive Dating
4. Fossil Record and Genetic Analysis
5. Theory of Evolution
  - Random, Inheritable Variations
  - Natural Selection

# Major Concepts, cont.

6. Examples of Evolution

7. Gradualism and Punctuated Equilibrium

8. Mass Extinctions

9. Sex and Evolution

10. Timescales

11. Estimate of  $f_i$  (includes next lecture)

# Diversity of Life

More than  $1.8 \times 10^6$  species known

Mostly Insects!

More species on land than in sea (~10 times)

Bacteria & other prokaryotes? (hard to count)

Samples of DNA in nature: > 99% unidentified

Similarity at biochemical level (genetic code)

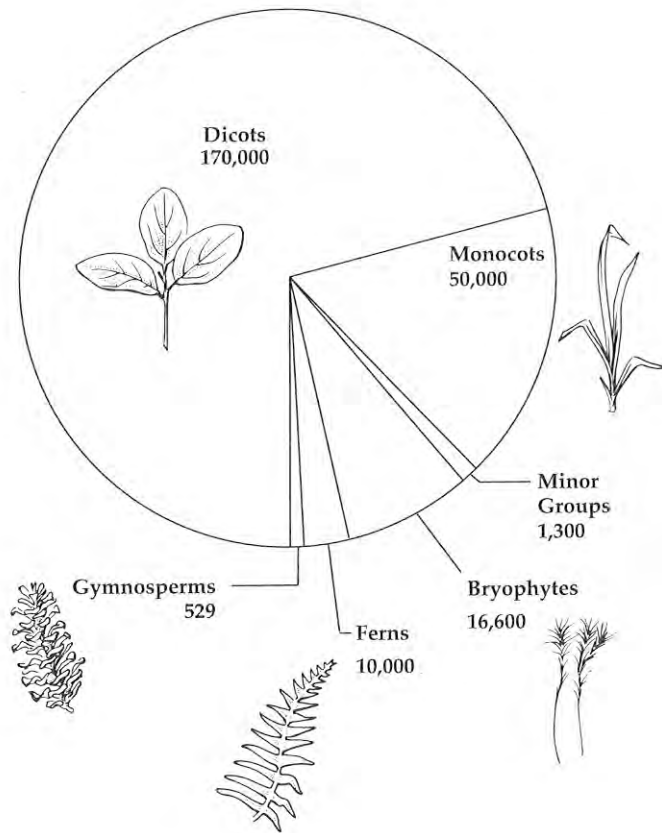
⇒ Common ancestor

Origin of Diversity?

## Number of Living Species of Higher Plants Currently Known

(According to Major Group)

HIGHER PLANTS: TOTAL SPECIES, 248,000



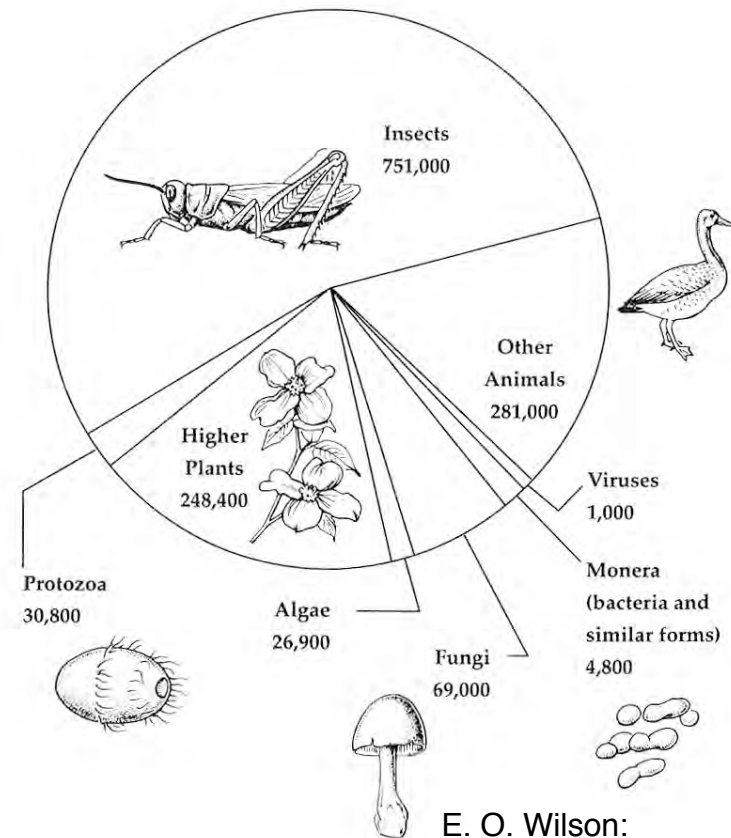
The plant diversity of the world consists primarily of angiosperms (flowering plants), which in turn make up grasses and other monocots and a huge variety of dicots, from magnolias to asters and roses. Most flowering plants live on the land; algae (26,900 known species) prevail in the sea.

## Number of Living Species of All Kinds of Organisms Currently Known

(According to Major Group)

ALL ORGANISMS: TOTAL SPECIES, 1,413,000

$1.8 \times 10^6$  known



E. O. Wilson:  
The Diversity of Life

Insects and higher plants dominate the diversity of living organisms known to date, but vast arrays of species remain to be discovered in the bacteria, fungi, and other poorly studied groups. The grand total for all life falls somewhere between 10 and 100 million species.

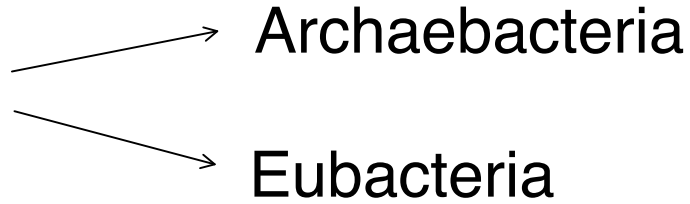
$10^7 - 10^8$  ?

# Hierarchical Classification

- Originally by Linnaeus
- Based on outward form
- Now can be checked with genetic analysis
- Lower levels imply closer relationship
- Higher levels are more inclusive
- Until recently, kingdom was highest level
- Traditionally 5 kingdoms

# Five Kingdoms

Prokaryotes



Protoctists:

Eukaryote Micro-organisms  
+ immediate descendents

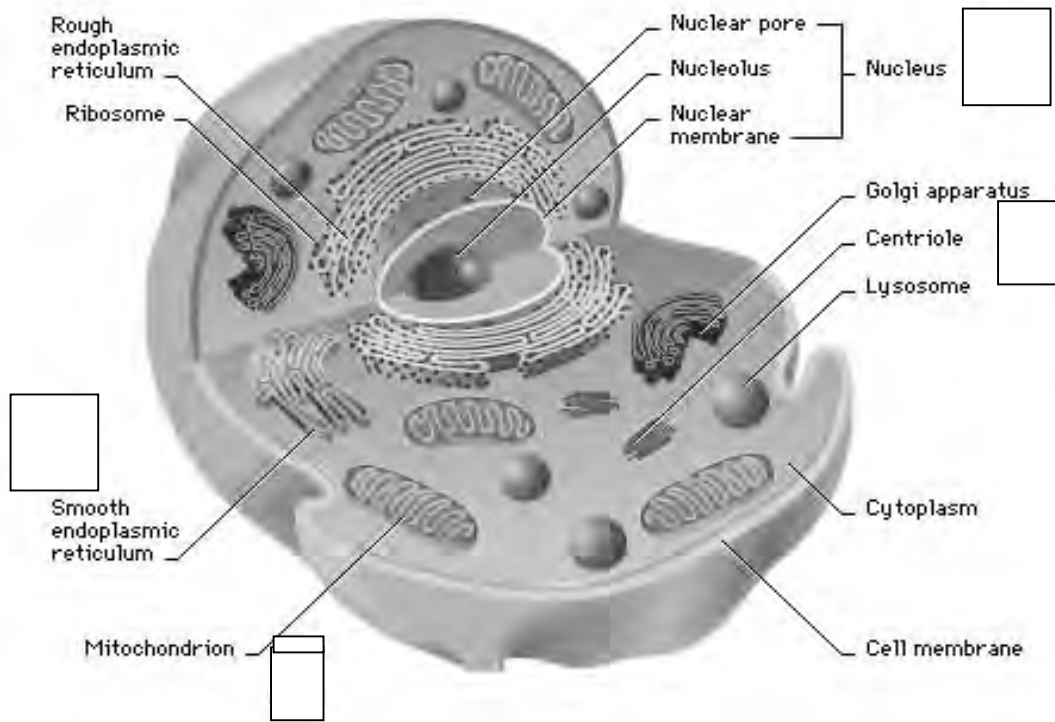
Eukaryotes

Fungi

Plants

Animals

# Reminder: Eukaryote and Prokaryotes



First appeared  $\sim 1.5 - 2 \times 10^9$  years ago  
 complex structure,  $\sim 10^4 - 10^5$  genes

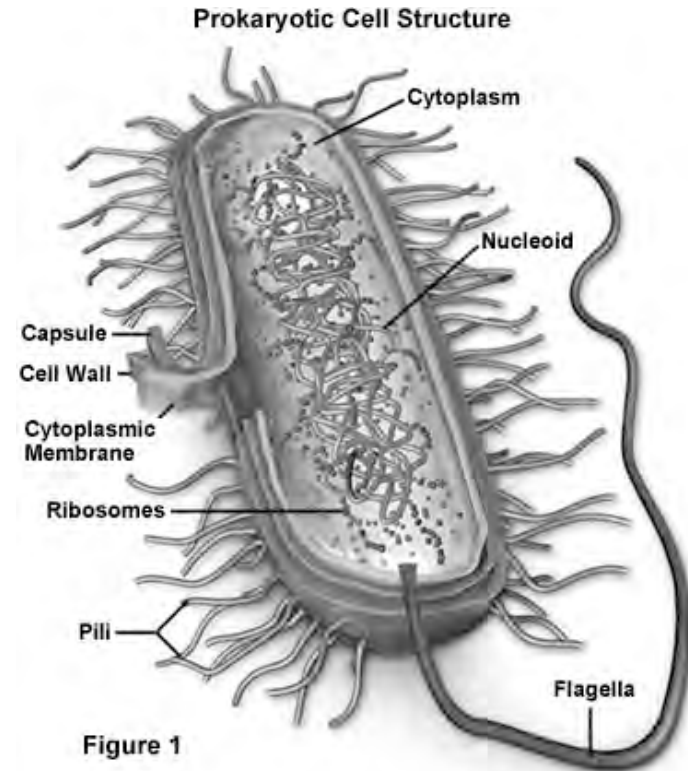


Figure 1

First appeared  
 $\sim 3 - 4 \times 10^9$  years ago  
 Few thousand genes



# Genetic Analysis

Sequencing nucleic acids —————>

New information on genetic distance of species  
e.g., chimpanzees and humans share 99% of DNA

Shows that “archaebacteria” are very different  
from other (true) bacteria

—————> 3 domains (new highest level)

Archaea

Eubacteria

Eukaryotes  
(Eukarya)

# Examples of Classification

	Human Beings	Garlic
Domain	Eucarya	Eucarya
Kingdom	Animalia	Plantae
Phylum	Chordata	Angiospermophyta
Class	Mammalia	Monocotyledonheae
Order	Primates	Liliales
Family	Hominidae	Liliaceae
Genus	Homo	Allium
Species	Sapiens	Sativum

## The Oldest Life (based on genetic analysis)

More phyla in sea (35) than on land (10)

Root of tree of life lies between Archaea  
& Eubacteria - closer to Archaea

Adapted to heat

Evidence for life back to  $3.8 \times 10^9$  yr ago Earth  
was still being bombarded

Some challenges to oldest fossils; secure to

About  $2.8 \times 10^9$  yr ago

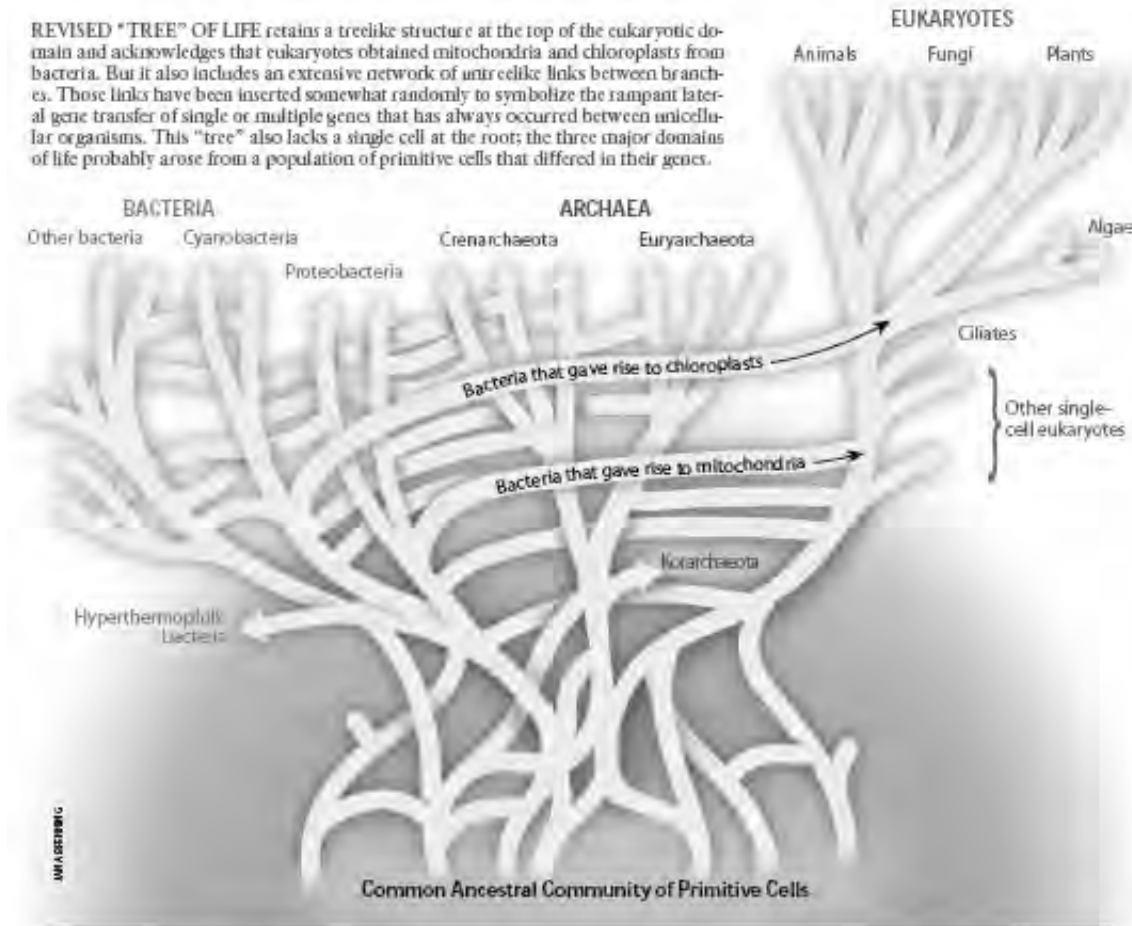
# Mandala of Life





# Web may be better metaphor than tree

REVISED "TREE" OF LIFE retains a treelike structure at the top of the eukaryotic domain and acknowledges that eukaryotes obtained mitochondria and chloroplasts from bacteria. But it also includes an extensive network of unicellular links between branches. Those links have been inserted somewhat randomly to symbolize the rampant lateral gene transfer of single or multiple genes that has always occurred between unicellular organisms. This "tree" also lacks a single cell at the root; the three major domains of life probably arose from a population of primitive cells that differed in their genes.



Lateral transfer of genes:  
 Very common among prokaryotes  
 Also in eukaryotic cell (organelles)

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## Further Information

THE UNIVERSAL ANCESTOR. Carl Woese in the *Proceedings of the National Academy of Sciences*, Vol. 95, No. 12, pages 6854-6859; June 9, 1998.  
 YOU ARE WHAT YOU EAT: A GENE TRANSFER RACKET COULD ACCOUNT FOR BACTERIAL GENES IN EUKARYOTIC NUCLEAR GENOMES. W. Ford Doolittle in *Trends in Genetics*, Vol. 14, No. 8, pages 307-311, August 1998.  
 PHYLOGENETIC CLASSIFICATION AND THE UNIVERSAL TREE. W. Ford Doolittle in *Science*, Vol. 284, pages 2124-2128; June 25, 1999.

# Fossils

Hard parts: bones, teeth, ...

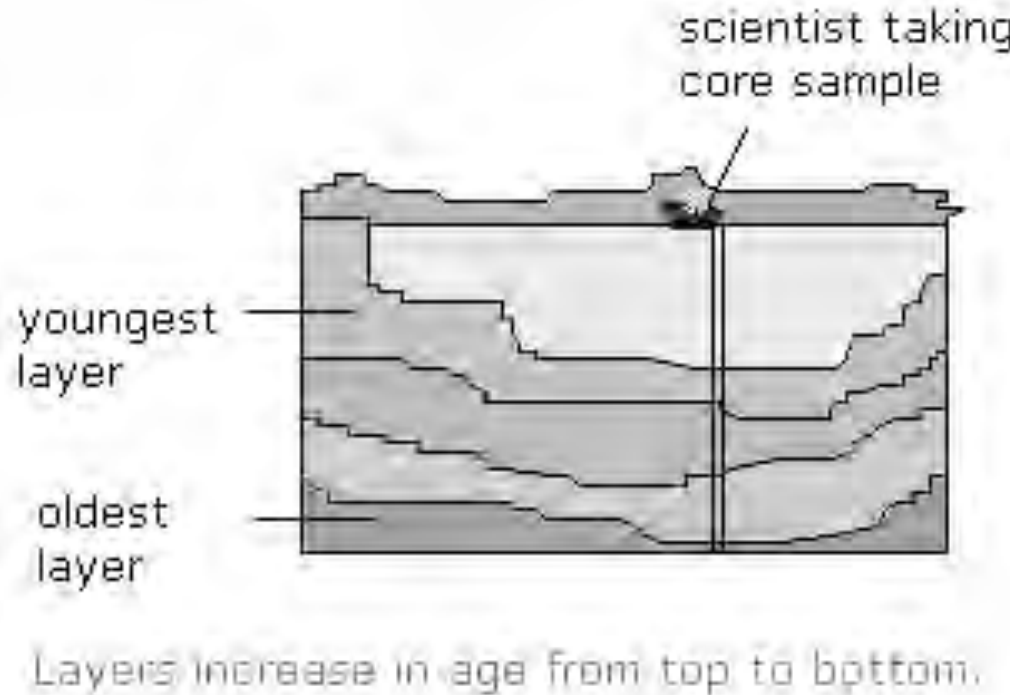
petrification → minerals

Molds → petrification (preserves soft parts)

Bacteria - stromatolites, microfossils

Isotopic ratios - characteristic of life

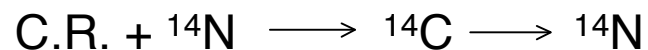
# Dating Fossils



## Relative Dating

Radioactive decay → absolute dates

e.g.  $^{14}\text{C}$  produced by cosmic rays



Works to  $\lesssim 60,000$  yr

1/2 in 5,730 yr

For older fossils, get date of layers above & below from volcanos -

e.g.  $^{40}\text{K} \longrightarrow {}^{40}\text{Ar}$ , ...



# Decay of Radioactive Atoms

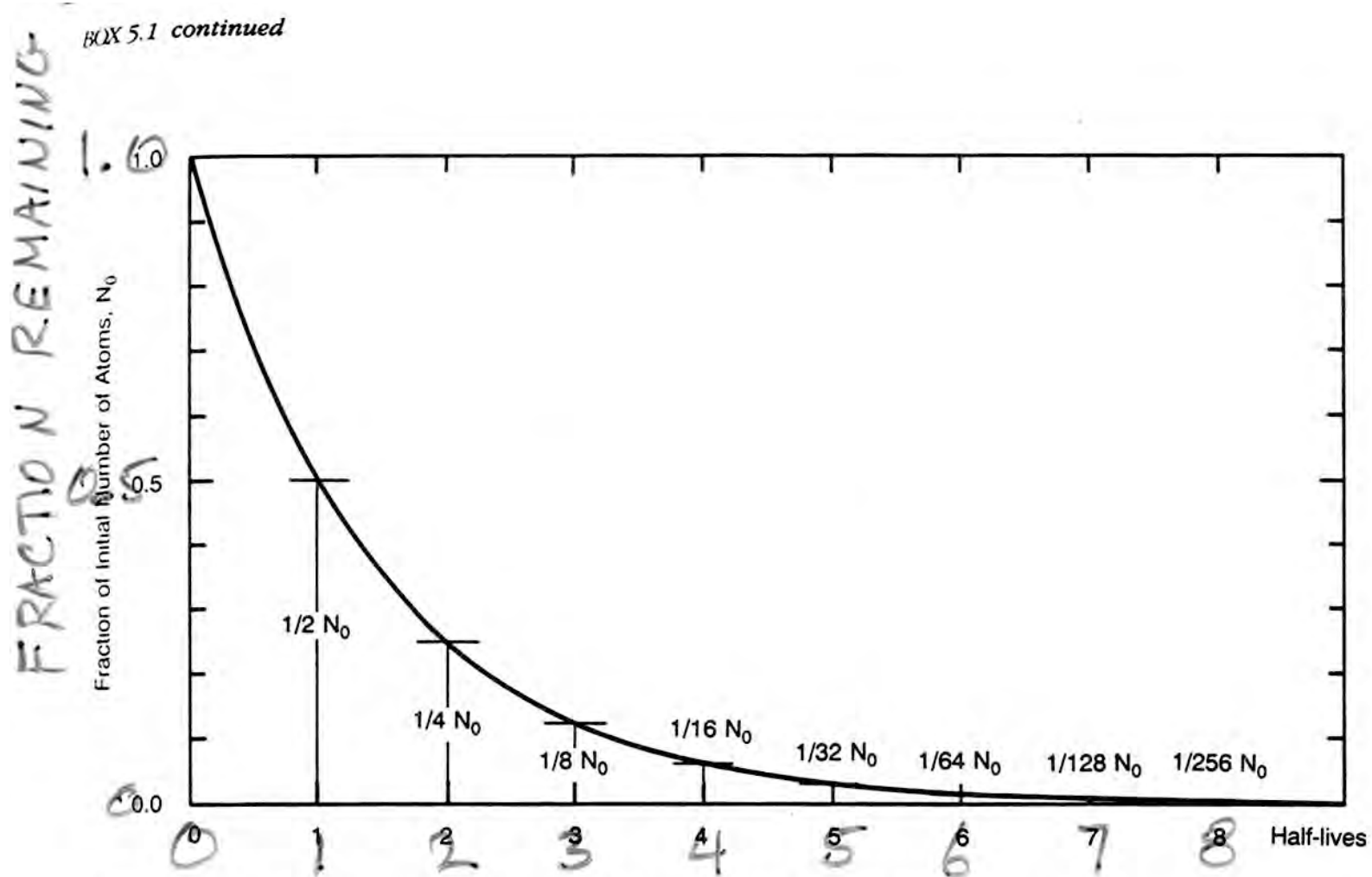


Figure A. Decay of radioactive atoms. At time zero, there is a given number of radioactive atoms,  $N_0$ . The atoms decay into their offspring products at rates such that after one half-life, half the  $N_0$  atoms remain; after two half-lives one-quarter of the  $N_0$  atoms remain; and so forth.

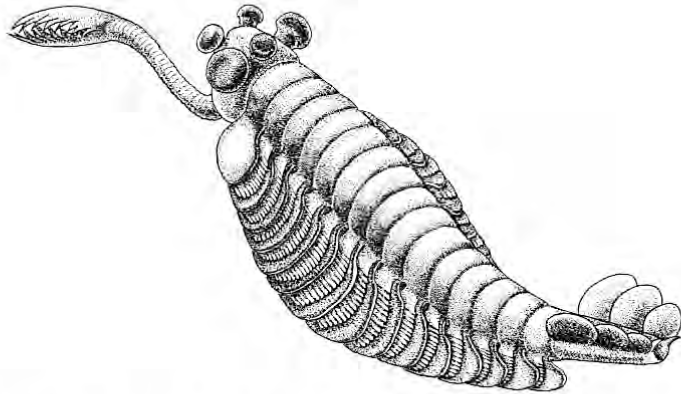
# OF HALF-LIVES

<b>Era</b>	<b>Period</b>	<b>Myr Ago</b>	<b>Life Forms</b>	<b>Events</b>
<b>Cenozoic</b>	<b>Quaternary</b>	<b>2</b>	<b>H. sapiens</b>	<b>Ice Ages</b>
	<b>Tertiary</b>	<b>65</b>	<b>Primates</b>	<b>Extinction of Dinosaurs</b>
<b>Mesozoic</b>	<b>Cretaceous</b>	<b>136</b>	<b>Birds</b>	<b>South Atlantic open to 1900 miles.</b>
	<b>Jurassic</b>	<b>190</b>		<b>North Atlantic open to 600 miles</b>
	<b>Triassic</b>	<b>225</b>	<b>Mammals</b>	<b>Continental Drift</b>
<b>Paleozoic</b>	<b>Permian</b>	<b>280</b>	<b>Reptiles</b>	<b>Pangaea breaks up</b>
	<b>Carboniferous</b>	<b>345</b>	<b>Amphibians</b>	<b>Formation of coal</b>
	<b>Devonian</b>	<b>395</b>	<b>Insects</b>	
	<b>Silurian</b>	<b>430</b>	<b>Land Plants</b>	
	<b>Ordovician</b>	<b>500</b>	<b>Fish (Chordata)</b>	<b>Burgess Shale forms</b>
<b>Precambrian</b>	<b>Cambrian</b>	<b>543</b>	<b>Trilobites</b>	
		<b>545</b>	<b>Small Shelly fossils</b>	
		<b>580</b>	<b>Ediacarans</b>	
		<b>600-800</b>		<b>Snowball Earth episodes</b>
	<b>0</b>	<b>Multicellular life</b>		

<b>Myr Ago</b>	<b>Era</b>	<b>Fossil Group</b>	<b>Event</b>
<b>Now</b>	<b>Cenozoic</b>		
	<b>Mesozoic</b>		
	<b>Paleozoic</b>	<b>Burgess Shale</b>	<b>Macroscopic Life</b>
		<b>Hiacara</b>	<b>Snowball Earth</b>
	<b>Precambrian</b>		
<b>1000</b>		<b>Bitter Springs</b>	<b>Worm tracks (?)</b> <b>Multicellular Algae</b>
		<b>Beck Spring Dolomite</b>	<b>Eukaryotes certain</b>
		<b>McArthur Group</b>	<b>Sexual Reproduction (?)</b>
<b>2000</b>	<b>Proterozoic</b>	<b>Gunflint Chert</b>	<b>Eukaryotes possible</b> <b>Oxygen-Rich Atmosphere</b> <b>Snowball Earth</b> <b>Formation of continents</b>
<b>3000</b>		<b>Bulawayan</b>	
		<b>Fig Tree</b>	
		<b>Onverwacht</b>	
		<b>Warrawoona</b>	<b>Autotrophs-Stromatolites</b> <b>Life Begins (?)</b> <b>(Prokaryote Heterotrophs)</b>
<b>4000</b>	<b>Archean</b>		<b>Formation of oceans</b> <b>Bombardment decreases</b> <b>Frequent impacts</b>
	<b>Euclean</b>		<b>Formation of Earth</b>
<b>5000</b>			

# Fossils from Burgess Shale ~ 530 Myr Ago

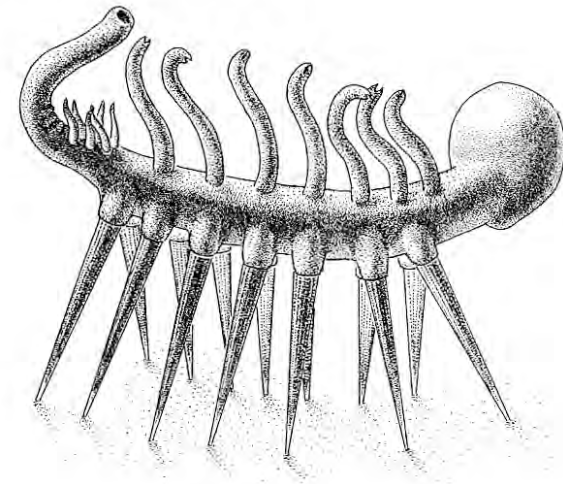
126 | WONDERFUL LIFE (S.J. Gould)



3.21. *Opabinia*, showing the frontal nozzle with terminal claw, five eyes on the head, body sections with gills on top, and the tail piece in three segments. Drawn by Marianne Collins.

Many basic body plans (phyla) tried out in Cambrian; some did not survive; never attempted again.

154 | WONDERFUL LIFE



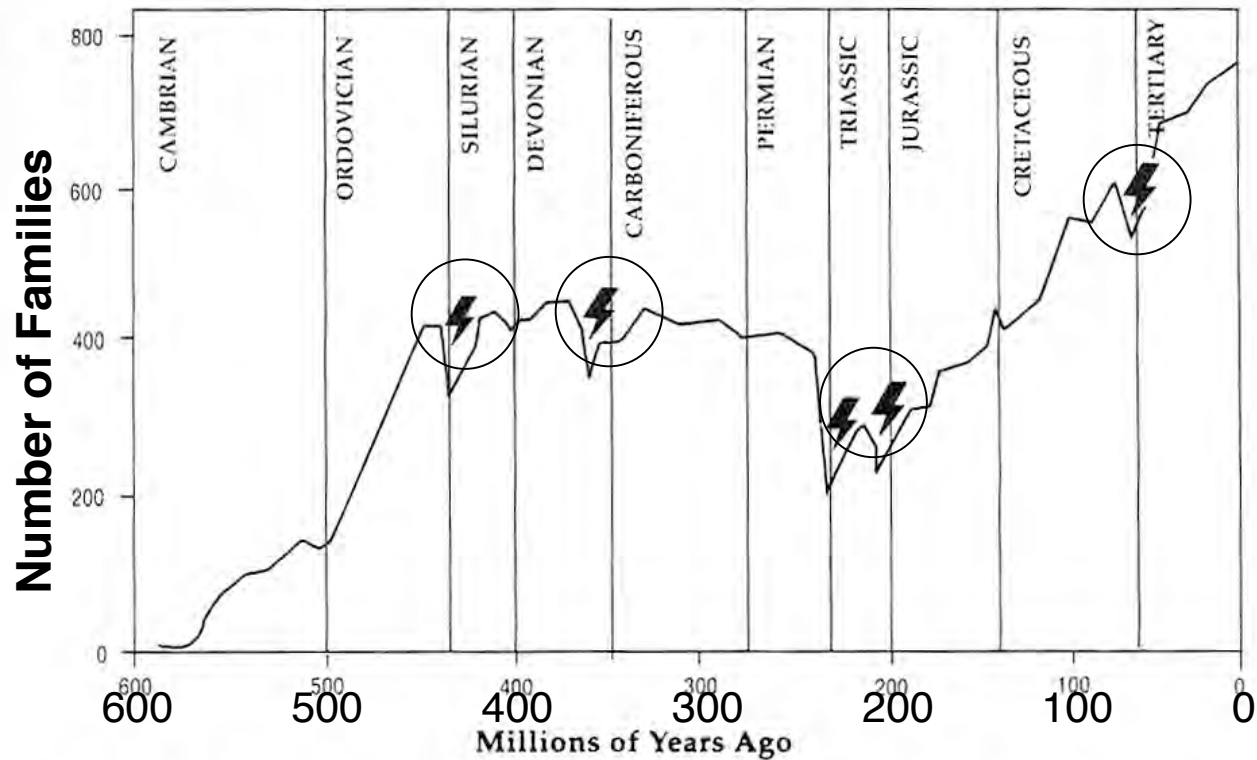
3.34. *Hallucigenia*, supported by its seven pairs of struts, stands on the sea floor. Drawn by Marianne Collins.

# Correct Version of Hallucigenia



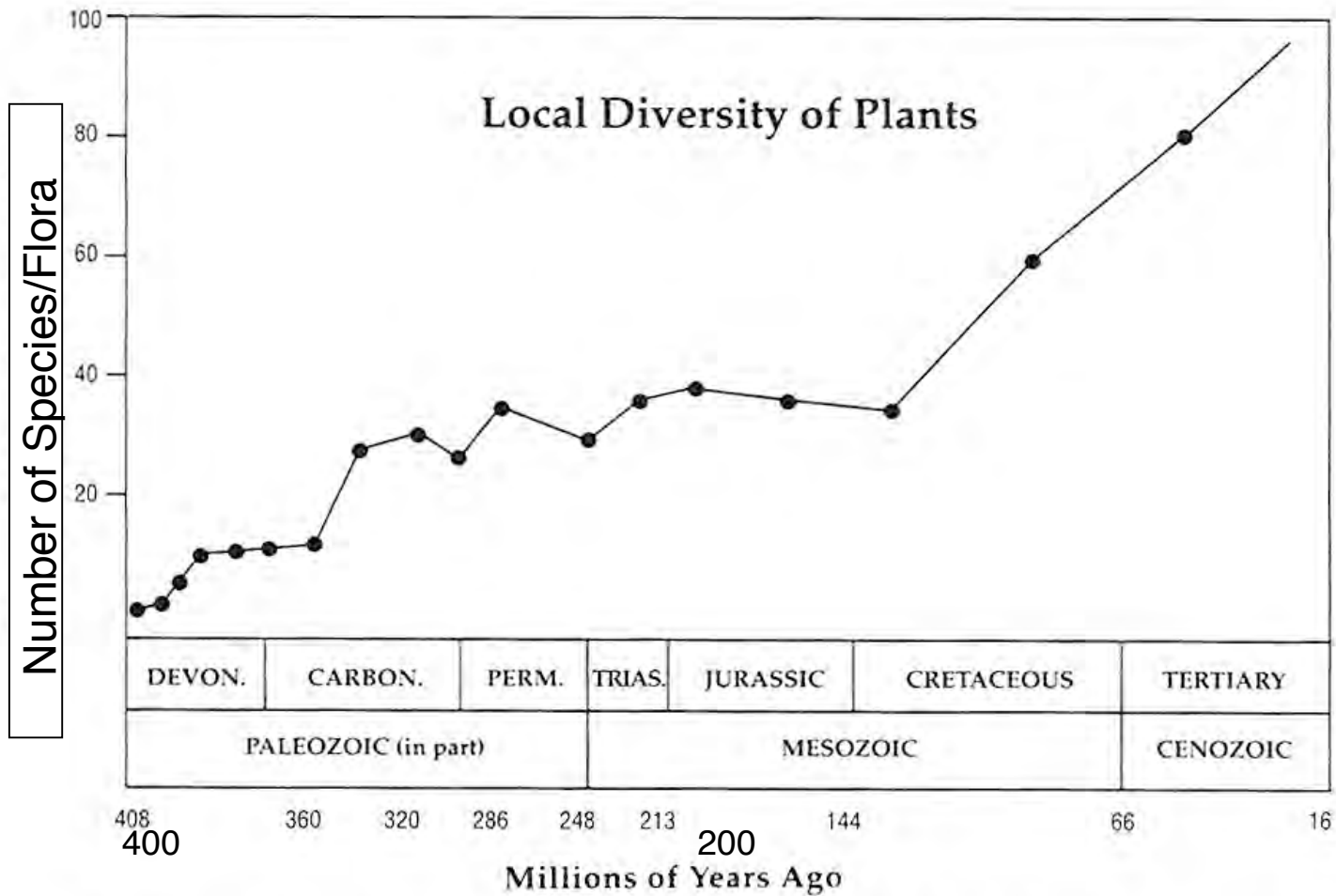
# Diversity Rising

Major  
extinctions



Biological diversity has increased slowly over geological time, with occasional setbacks through mass global extinctions. There have been five such extinctions so far, indicated here by lightning flashes. The data given are for families (groups of related species) of marine organisms. A sixth major decline is now underway as a result of human activity.

E. O. Wilson:  
The Diversity of Life



The average number of plant species found in local floras has risen steadily since the invasion of the land by plants 400 million years ago. The increase reflects a growing complexity in terrestrial ecosystems around the world.

E. O. Wilson:  
The Diversity of Life

# Summary of Fossil Record

Simple organisms first, more complex later

Prokaryotes, eukaryotes, multi-cellular

Not deterministic “progress”

Recent (last 150 Myr) rise in diversity caused by  
flowering plants and insect hosts

Some organisms become more complex

Many stay about the same

Increase in diversity and a “left wall of minimal  
complexity”



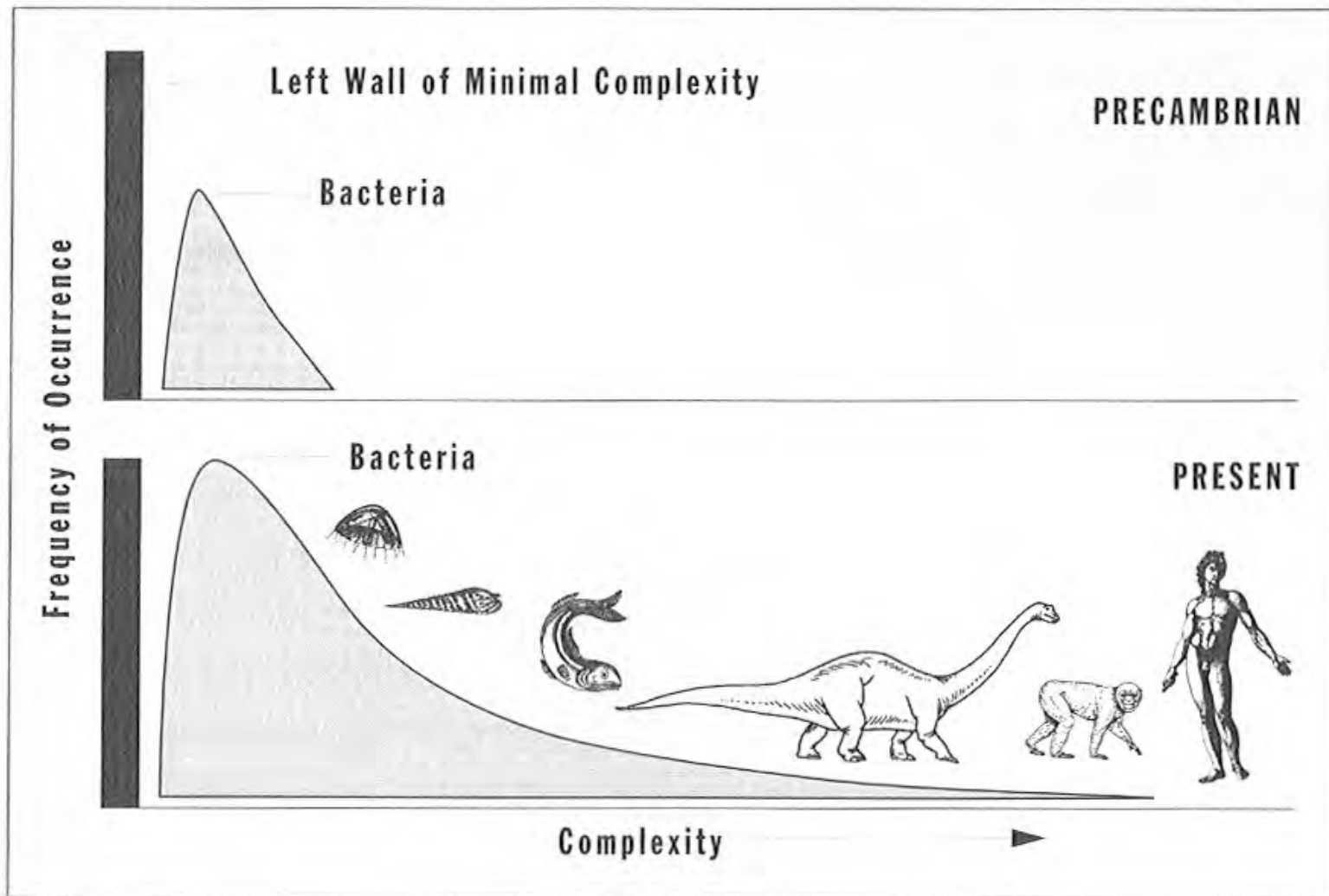


FIGURE 29

The frequency distribution for life's complexity becomes increasingly right skewed through time, but the bacterial mode never alters.

S. J. Gould

# Theory of Evolution

Developed independently by Darwin and Wallace

Based on earlier ideas, but key feature was the role of selection

Two Key ingredients:

1. Random, inheritable variations
2. Natural Selection (competition for scarce resources produces “survival of the fittest”)

1. Mutation is ultimate source of variation  
(but sexual reproduction produces great variation without many mutations)

2. Selection

Organism level → species gradually evolves

Species level → (speciation + extinction)

“Life” evolves

Topics:

Sexual Reproduction

Gradualism vs. Punctuated Equilibrium

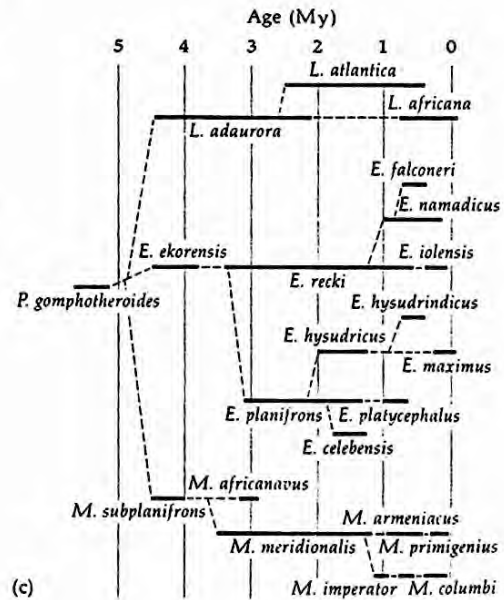
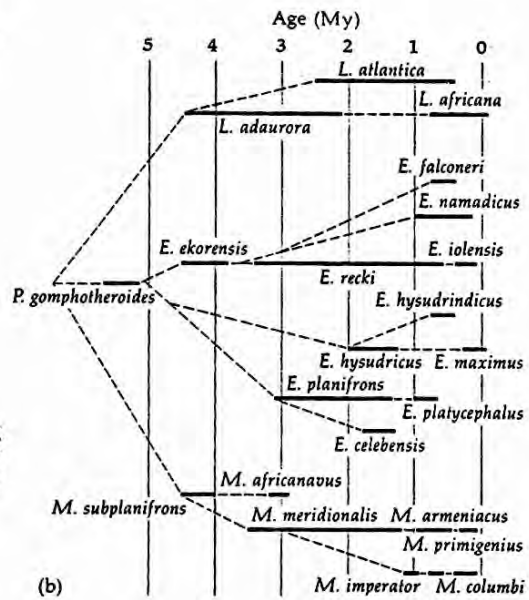
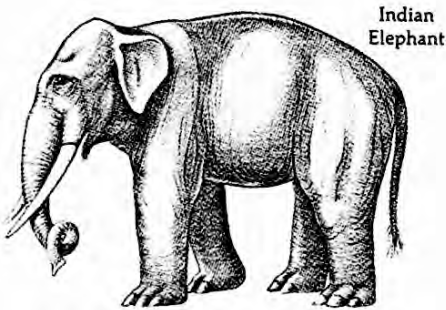
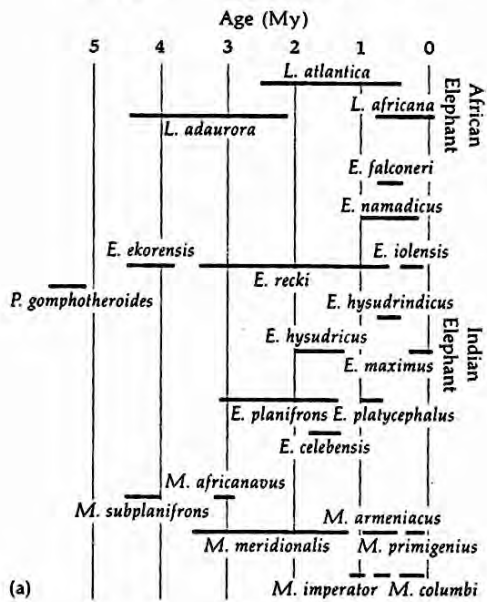
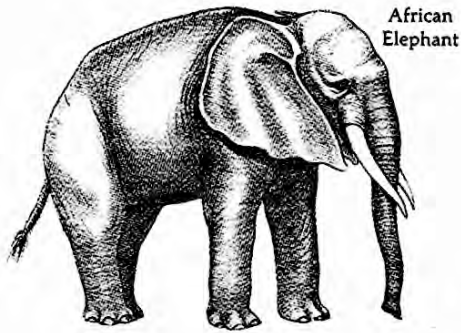
Speciation: the role of geographical isolation

Ecological niches

# Why Sex?

## (Or why do males exist?)

- Sexual reproduction (meiosis) allows more variation
  - Allows favorable mutations from two lines to combine
  - Protects against harmful mutations
- But, if only females, more gene copies, more efficient reproduction
  - Short term fitness might favor asexual
- Recent studies in water fleas indicate that protection against harmful mutations is key feature
- “Males are allowed to exist after all, because they help females get rid of deleterious mutations.”
  - Science, 311, 960 (Feb. 17, 2006)



Elephants and relatives

Gradualist

Punctuated  
Equilibrium

# Speciation

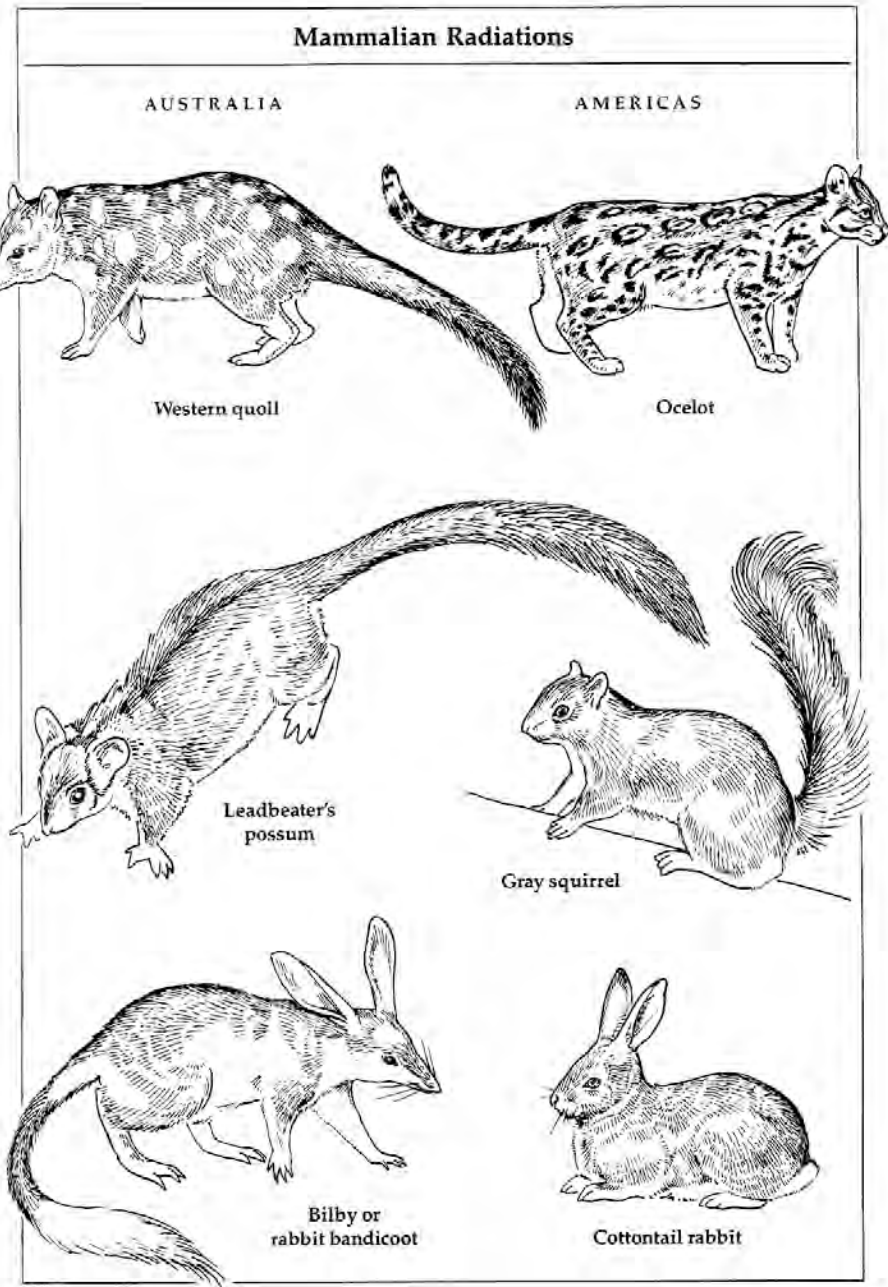
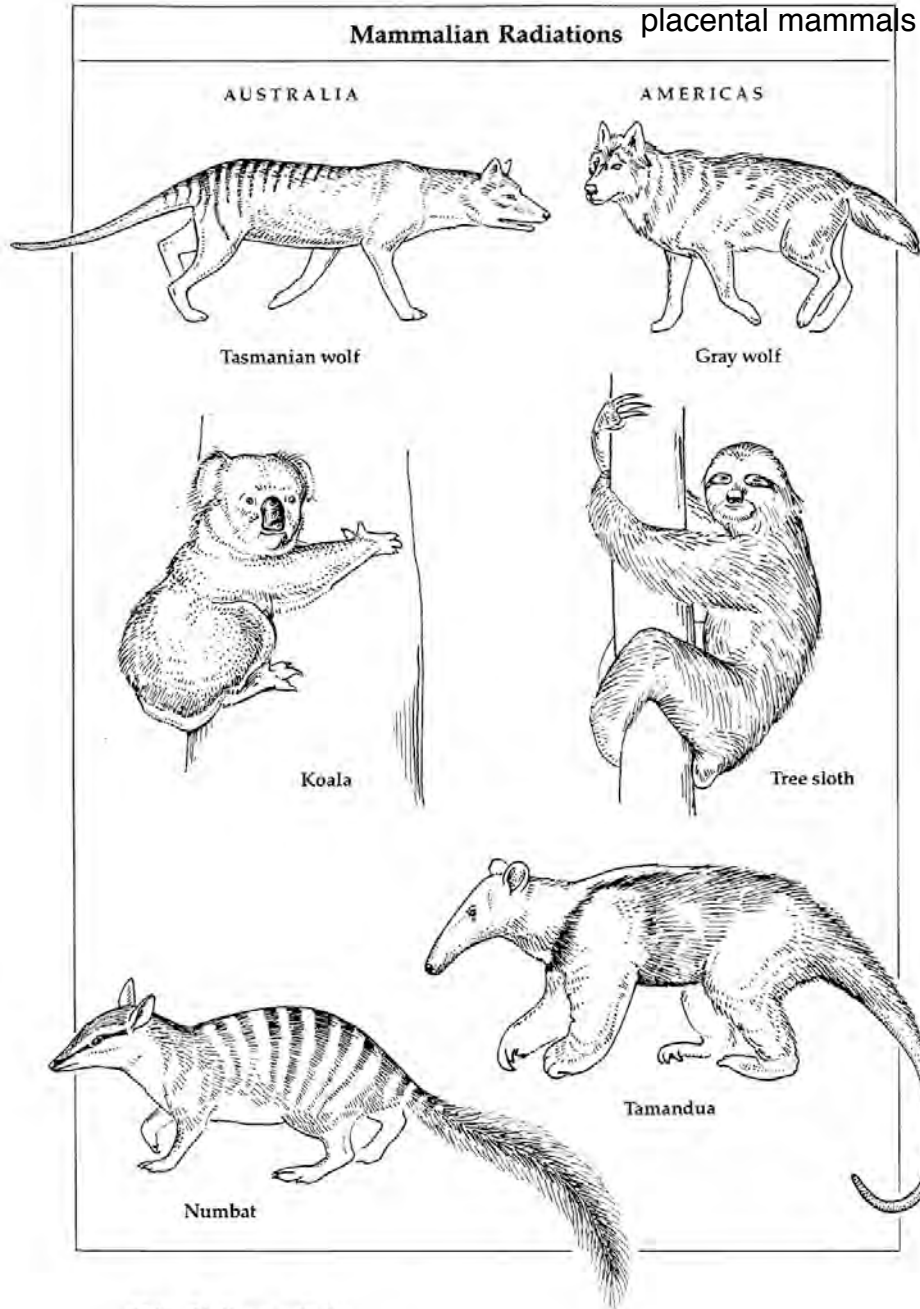
- Darwin's "Origin of Species" did not explain
- Modern synthesis – Ernst Mayr
  - Geographic isolation
    - Islands
    - Mountaintops
  - Genetic drift
    - Varieties no longer interfertile: new species
- Adapting to different, but close environments
  - Hybrids are not well adapted

# Ecological Niches

- “Niche” (a way of making a living)
  - Different food source
  - Different microclimate
  - Species diversity high when environment is complex
- Convergence
  - With long geographic isolation
  - Find similar types of animals
  - From very different evolutionary sources

# Australian Marsupials

World continent  
placental mammals





# Statements about Evolution

True or False (& Why?)

1. People who move to the south and adapt to hot weather are an example of evolution
2. Almost all species that ever lived are now extinct
3. Extinction represents a failure of evolution
4. A natural catastrophe, like an asteroid impact or an ice age, is needed to cause natural selection
5. Evolution always selects more complex, intelligent organisms for survival
6. Major diversification of surviving groups usually follows a mass extinction

## Purpose in Evolution?

**“That our earth is the only planet in the stellar universe where the development of organized and intelligent life exists, that our sun is in all probability the center of the whole material universe, and that the supreme end and purpose of this vast universe was the production and development on our earth, of the living soul in the perishable body of man, are the conclusions which Dr. Alfred Russel Wallace sets forth in an article in the current number of the ‘Fortnightly Review’.”**

- **From the International Herald Tribune, March 5, 1903**

# Evolution: Theory or Fact?

- Facts
  - fossils and ages are facts
  - Order of origins of groups are facts
  - Genetic relationships are facts
- Theory (explanation of facts)
  - Variations and selection
  - Theory makes predictions
  - Predictions are checked
  - Theory is refined

## **IF** Intelligent Design were a scientific theory...

- Assume a silicon chip designed life on Earth
- Would such a theory predict:
  - Increase in complexity with time in fossil record?
  - Continued speciation?
  - Vestigial legs in whales?
  - Genomes full of genes from other organisms? ... and full of non-coding DNA?