Biological Evolution

Darwinian Evolution
and
Natural Selection

Major Concepts

1. Linnaean Classification and Genetic Analysis

2. Fossils

3. Radioactive Dating

4. Fossil Record

5. Theory of Evolution

   Random, Inheritable Variations

   Natural Selection

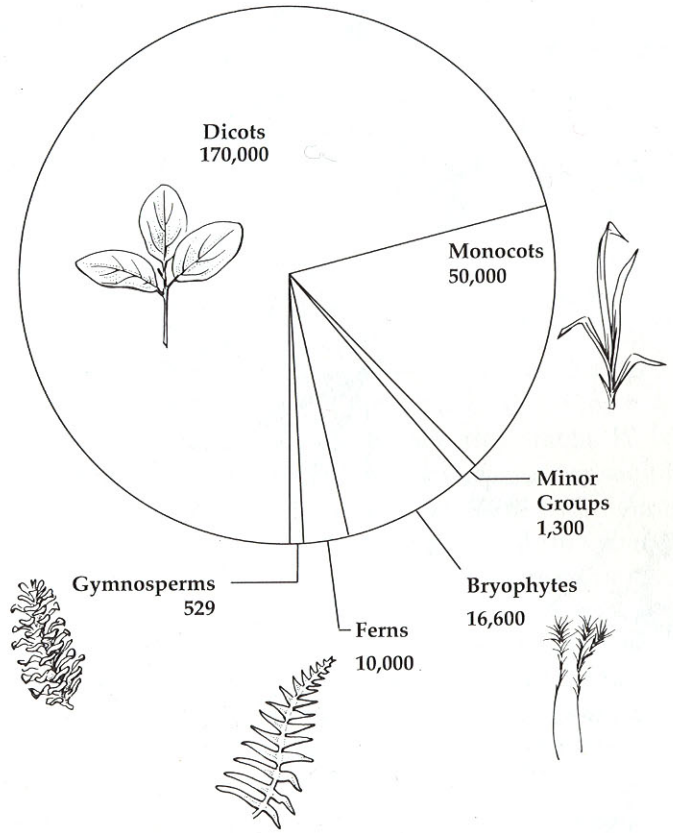
Major Concepts, cont.

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)

Number of Living Species of Higher Plants Currently Known

(According to Major Group)

HIGHER PLANTS: TOTAL SPECIES, 248,000



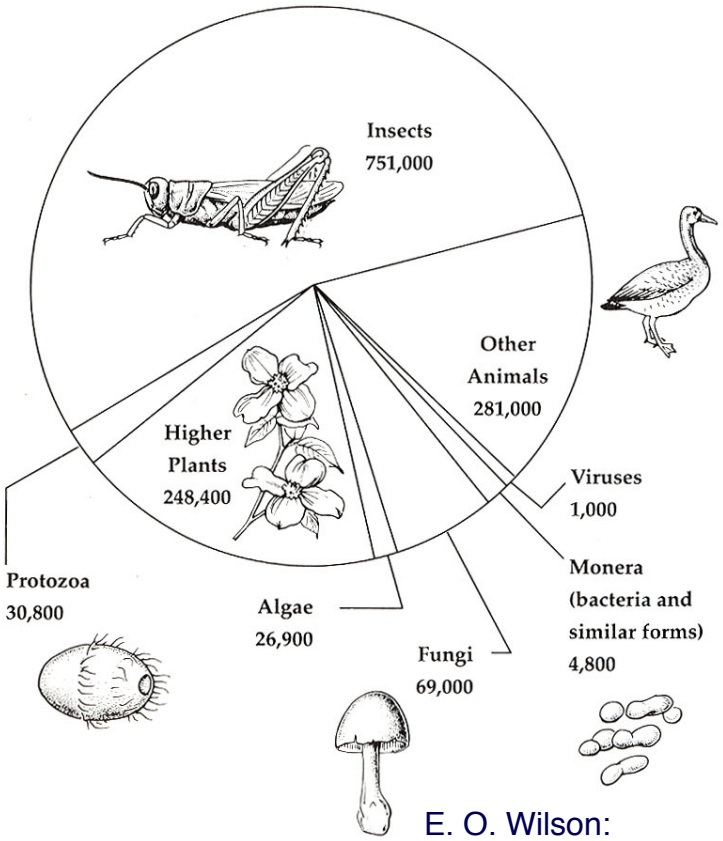
The plant diversity of the world consists primarily of angiosperms (flowering plants), which in turn make up grasses and other monocots and a huge variety of dicots, from magnolias to asters and roses. Most flowering plants live on the land; algae (26,900 known species) prevail in the sea.

Number of Living Species of All Kinds of Organisms Currently Known

(According to Major Group)

ALL ORGANISMS: TOTAL SPECIES, 1,413,000

1.7×10^6 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 ?

Diversity of Life

More than 1.7×10^6 species known

Estimates of at least 9×10^6

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)

$\Rightarrow$Common ancestor

Origin of Diversity?

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

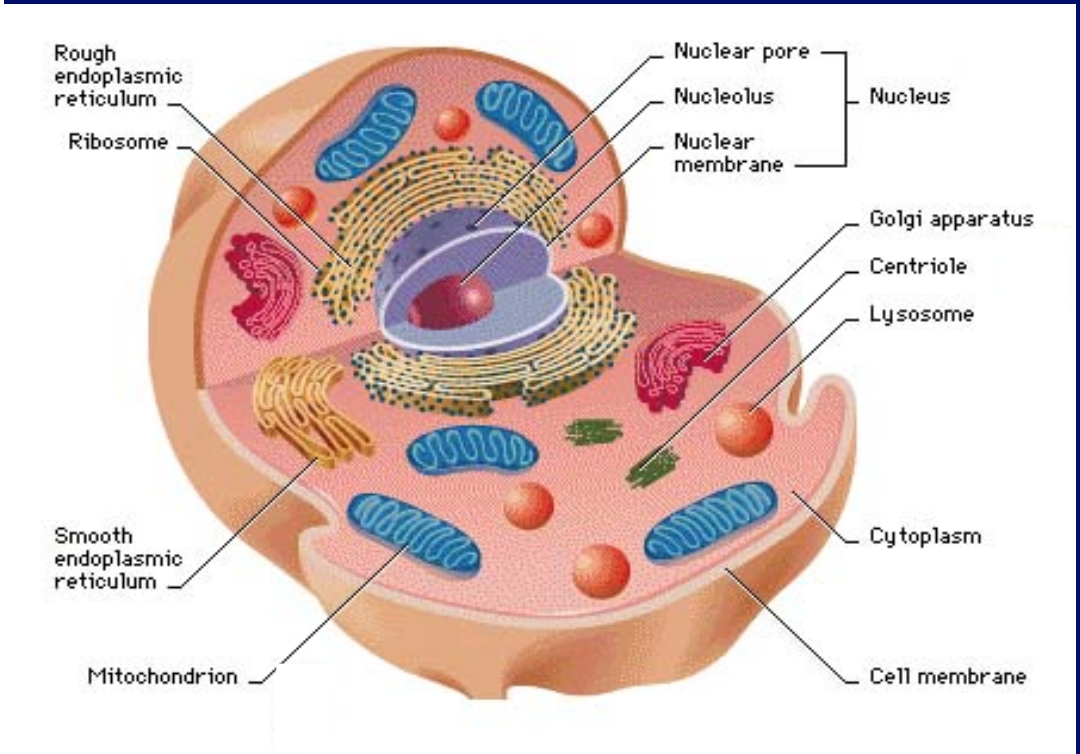
Five Kingdoms

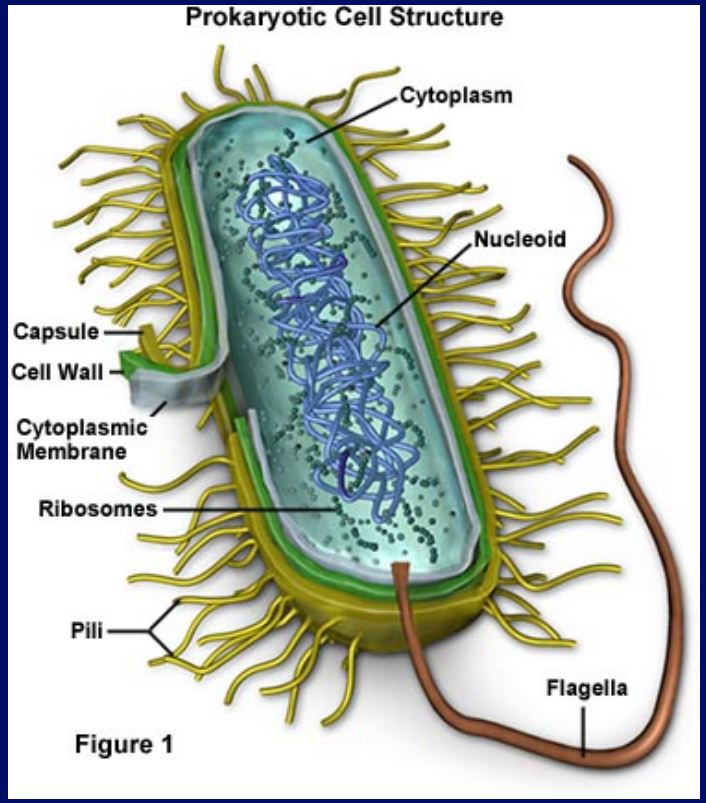
Prokaryotes → Archaea
Prokaryotes → Bacteria

Eukaryotes

- Protoctists: Eukaryote Micro-organisms + immediate descendents
- Fungi
- Plants
- Animals

Reminder: Eukaryote and Prokaryotes





First appeared ~ 1.5 - 2 × 10^9 years ago
complex structure, ~ 10^4 - 10^5 genes

First appeared
~ 3 - 4 ×10^9 years ago
Few thousand genes

Genetic Analysis

- Adds quantitative information to morphological classifications
  - Archaea are **very** different from bacteria
  - Clarified family tree of animals
    - Recent version in Science, 339, 764
  - Humans share 93% to 99% of DNA with chimpanzees
- Large amounts of non-coding DNA can confuse
- Timescales do not always agree
- Genes and fossils being analyzed together

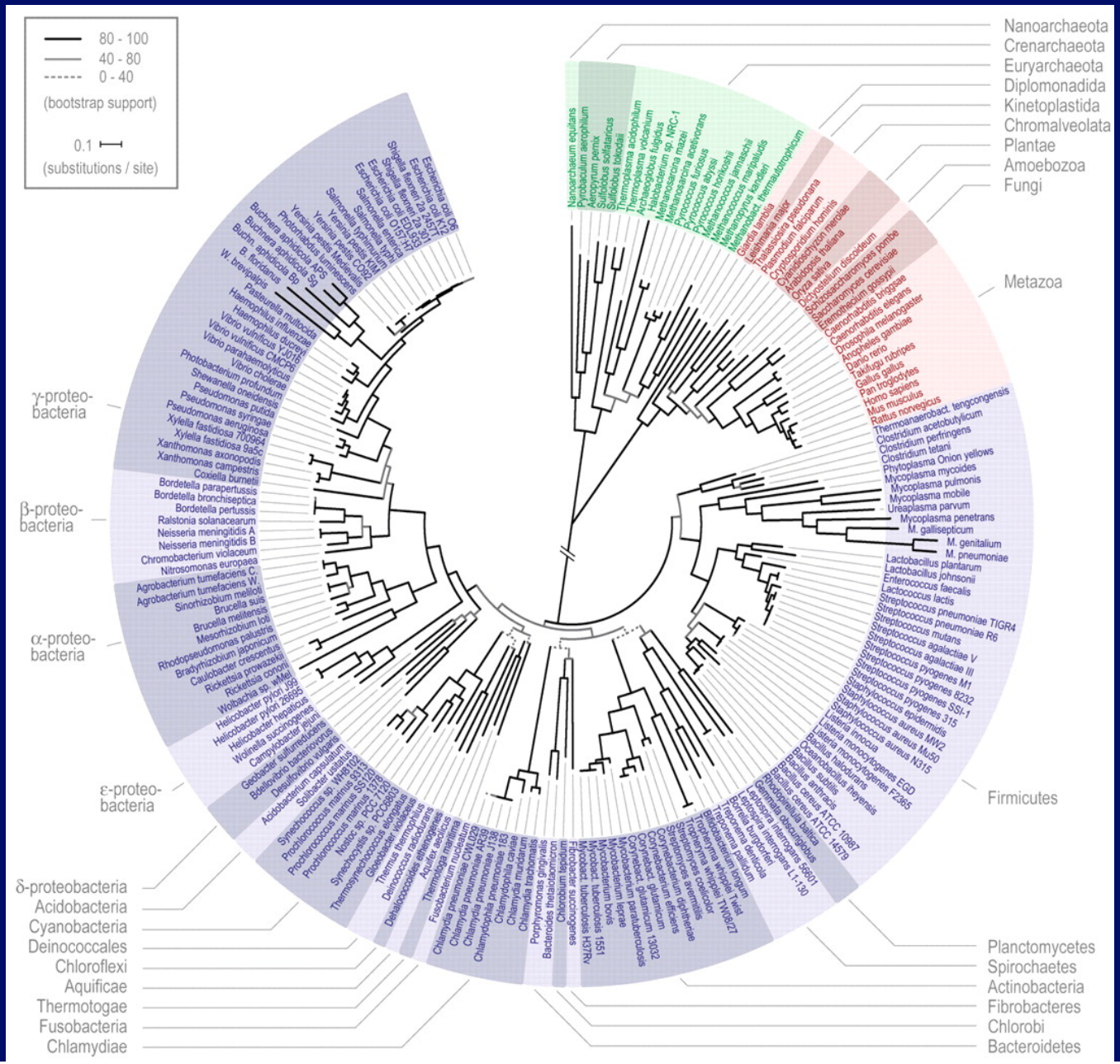
Examples of Classification

	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

Overall Structure

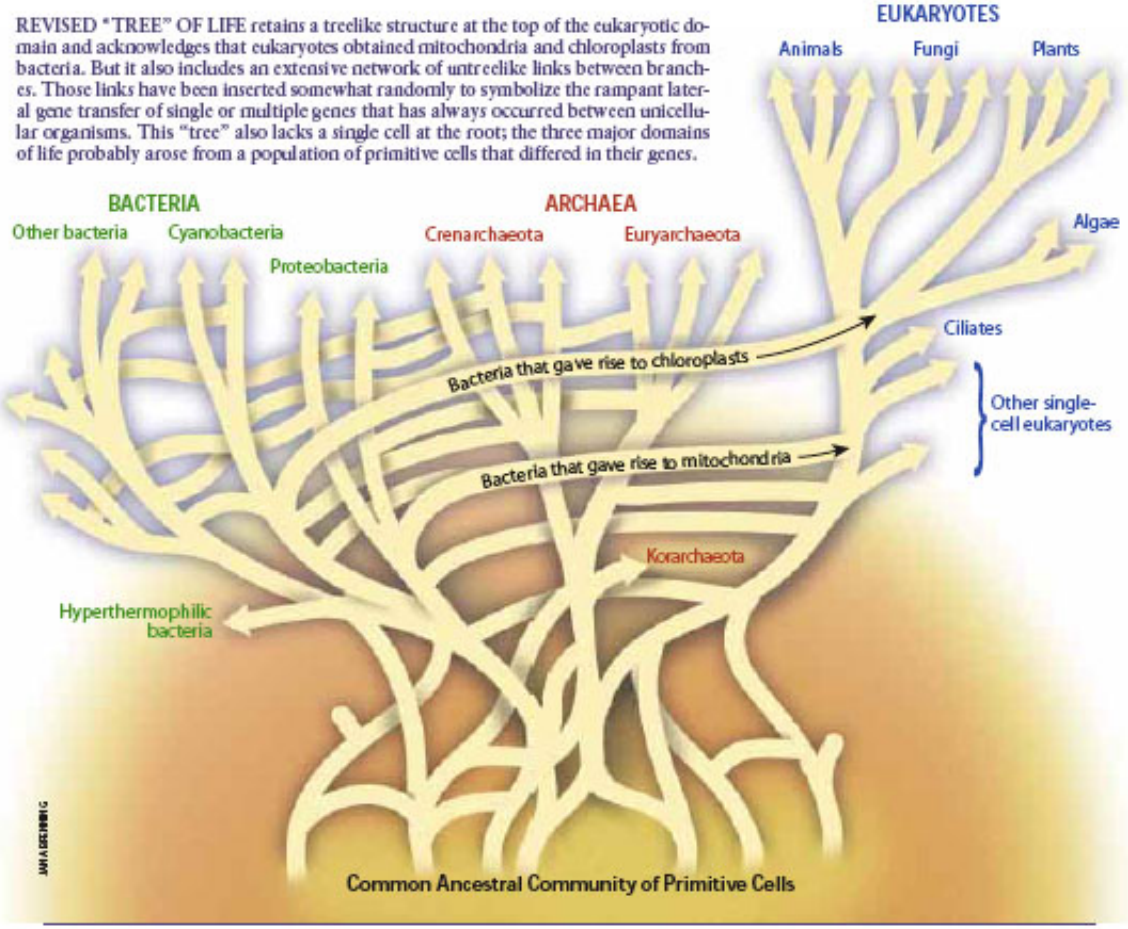
- Phylum represents basic body plan
  - e.g. radial or bilateral symmetry (chordates)
  - More phyla in sea (35) than on land (10)
- Domain most fundamental
  - Root of tree of life lies between archaea and bacteria
  - Eukaryotes closer to archaea

Tree of Life



Ciccarelli et al. 2006
Science, 311, 1283

Web may be better metaphor than tree



The Author

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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 RACHET 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.

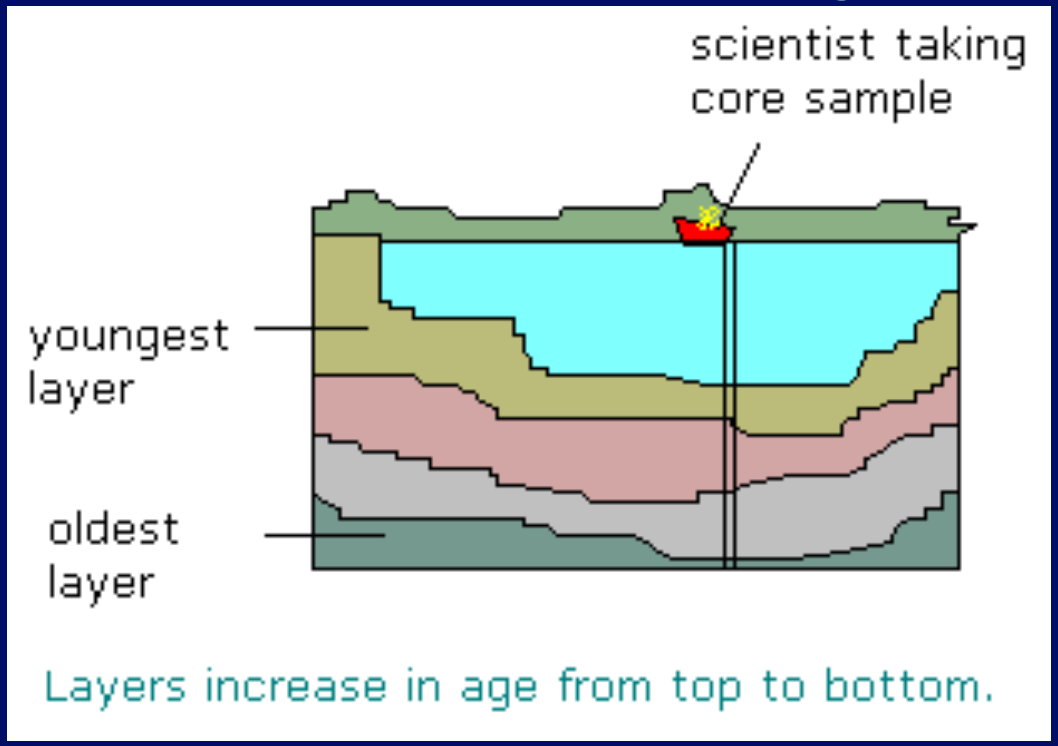
PHYLOGENETIC CLASSIFICATION AND THE UNIVERSAL TREE. W. Ford Doolittle in *Science*, Vol. 284, pages 2124–2128; June 25, 1999.

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

Fossils

- Preservation of hard parts (bones, teeth, …)
- Petrification (minerals replace organic matter)
- Molds (can preserve shape of soft parts)
- Organic matter preserved (bogs, ice, sand)
- Some DNA survives (only for recent)
- Bacteria
  - Microfossils
  - Colonies (Stromatolites)
- Isotopic ratios characteristic of life

Dating Fossils



Relative Dating
Deeper layers
are (usually)
older

absolute dates from radioactive decay

e.g., ^{14}C produced by cosmic rays

C.R. + $^{14}N \longrightarrow {}^{14}C$, decays back to ^{14}N (1/2 in 5,730 yr)

Works to < 60,000 yr

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

e.g., $^{40}K \longrightarrow {}^{40}Ar$ (1200 Myr), $^{235}U \longrightarrow {}^{207}Pb$ (700 Myr)

Decay of Radioactive Atoms

BOX 5.1 *continued*

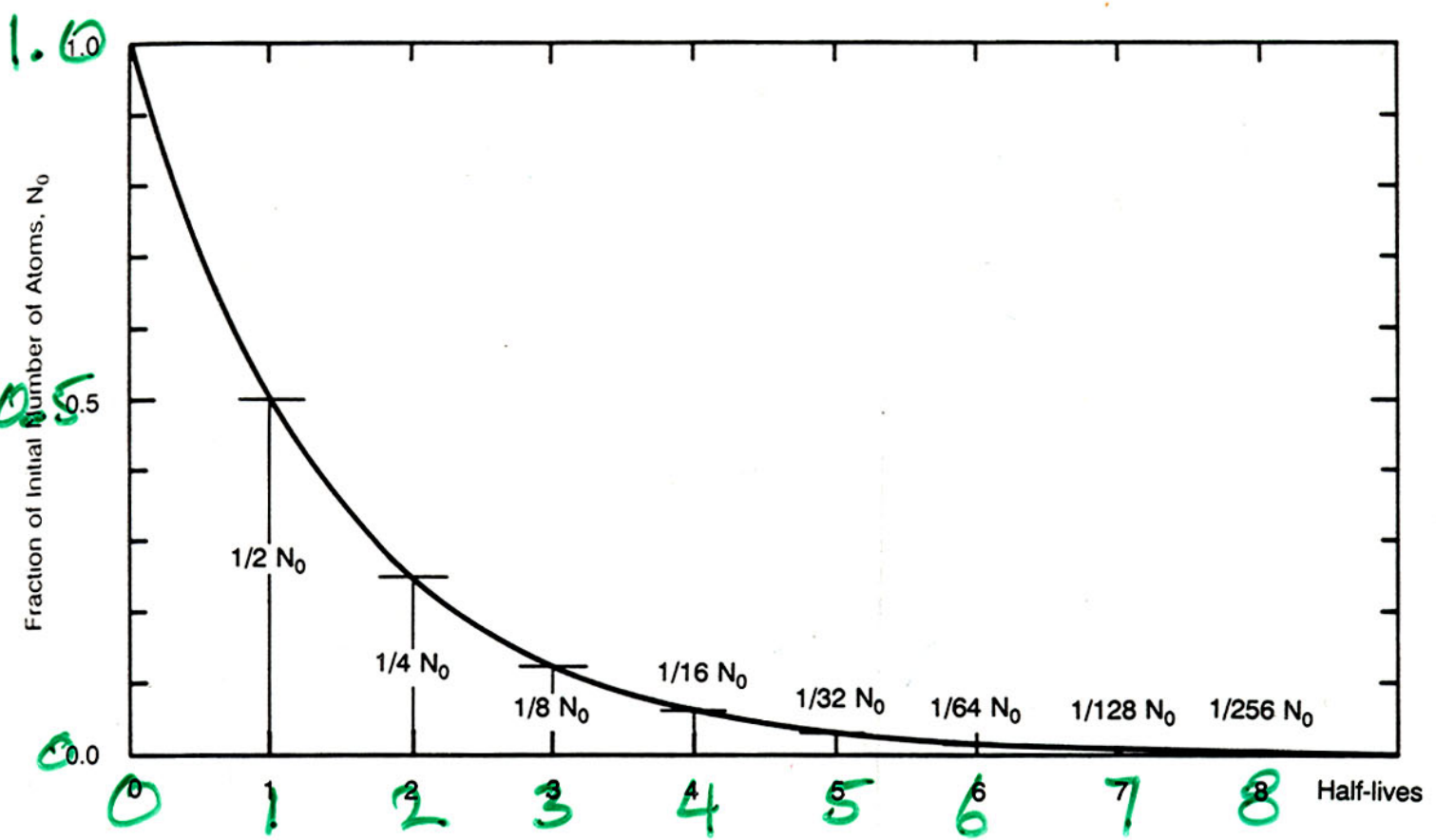


Figure A. Decay of radioactive atoms. At time zero, there is a given number of radioactive atoms, N_0. The atoms decay into their offspring products at rates such that after one halflife, half the N_0 atoms remain; after two halflives one-quarter of the N_0 atoms remain; and so forth.

OF HALF-LIVES

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

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

The Oldest Life

- Oldest stromatolites 3500 Myr ago
- Oldest certain to be microbial 3000 Myr ago
  - cyanobacteria
- Oldest microfossils (3800 Myr ago, maybe)
- Isotopic ratios suggest life by 3800 Myr ago

Stromatolites

Current (Australia)

Fossil (Australia, 3.2-3.6 Gyr old)

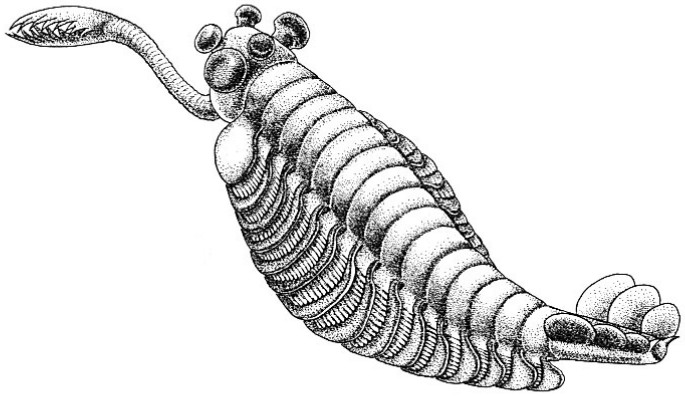
Microbial Mats Preserved

3500 Myr old 2900 Myr old Contemporary

Science 15 Nov. 2013

Fossils from Burgess Shale ~ 530 Myr Ago

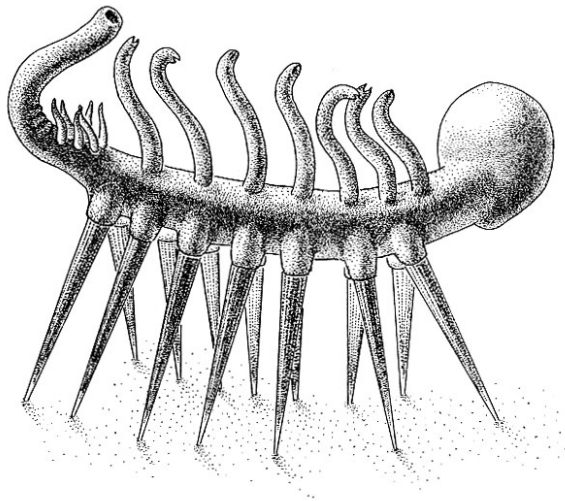
126 | WONDERFUL LIFE (S.J. Gould)



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

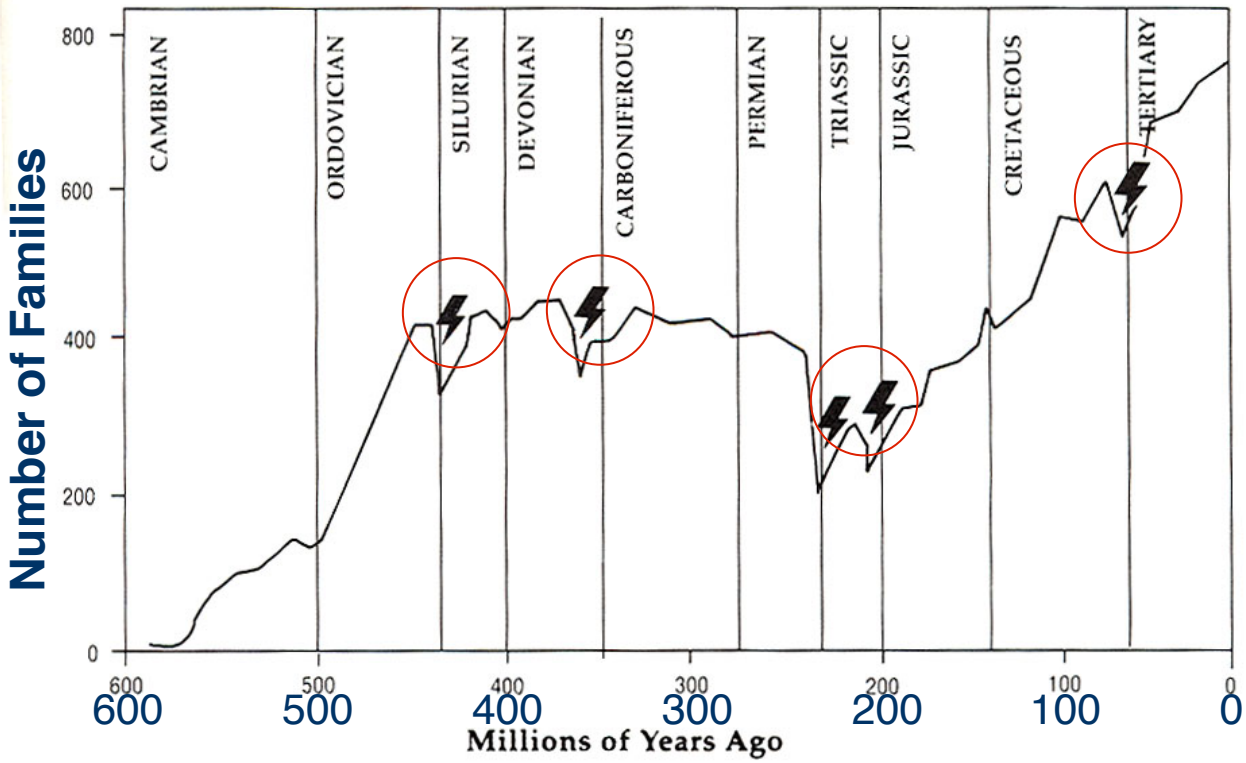


3.34. *Hallucigenia,* supported by its seven pairs of struts, stands on the sea floor. Drawn by Marianne Collins.

Correct Version of Hallucigenia

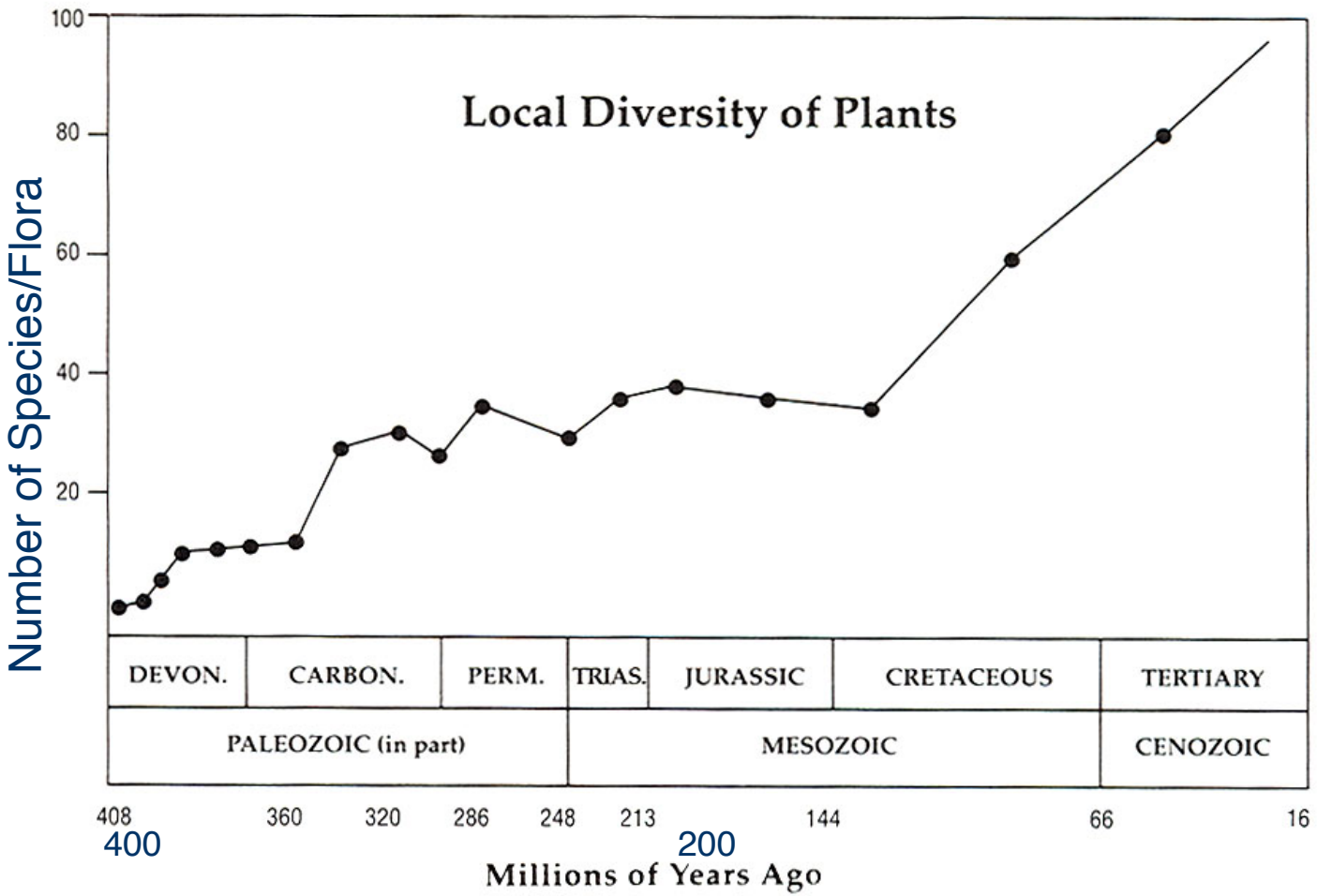
Diversity Rising

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”

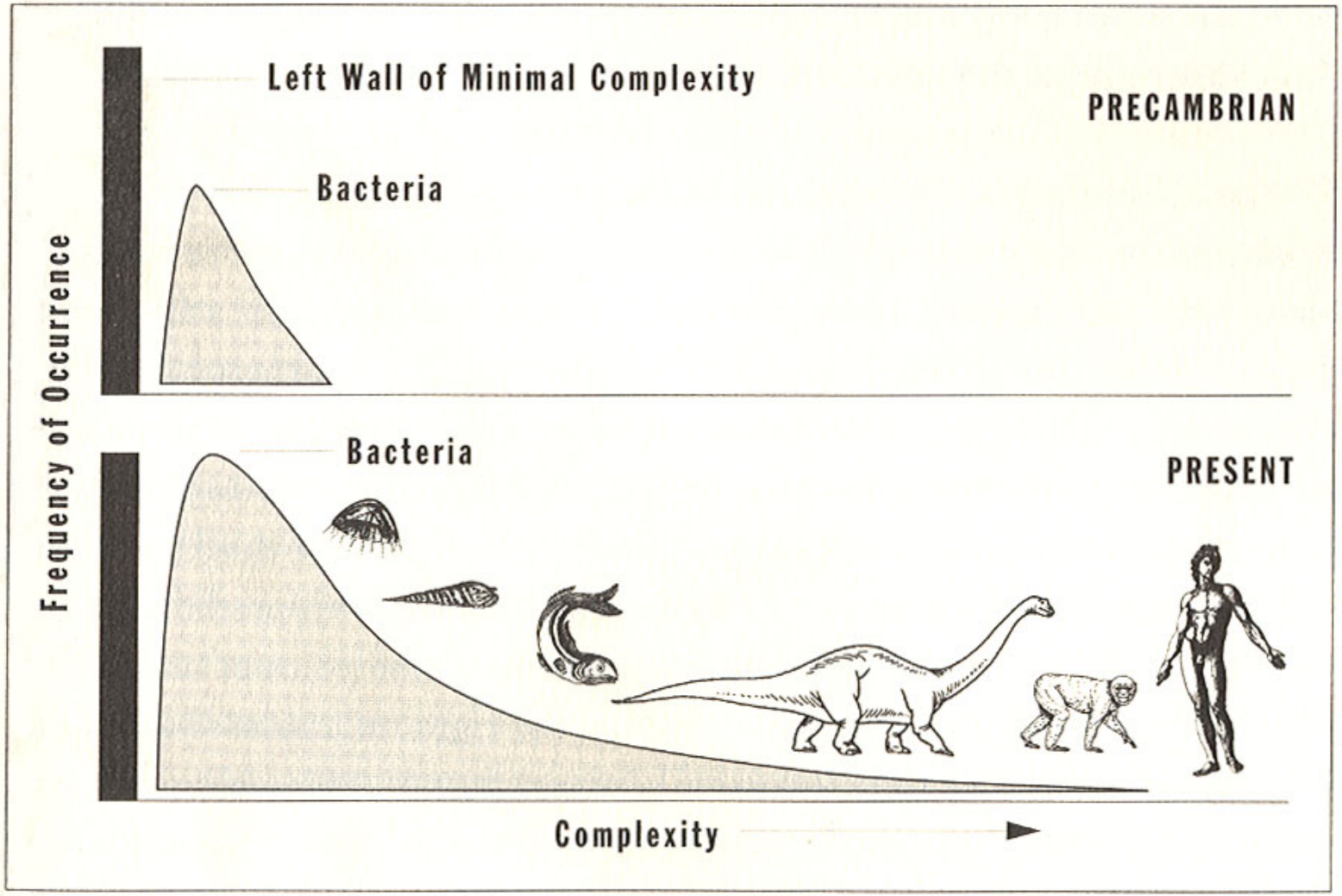


FIGURE 29

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

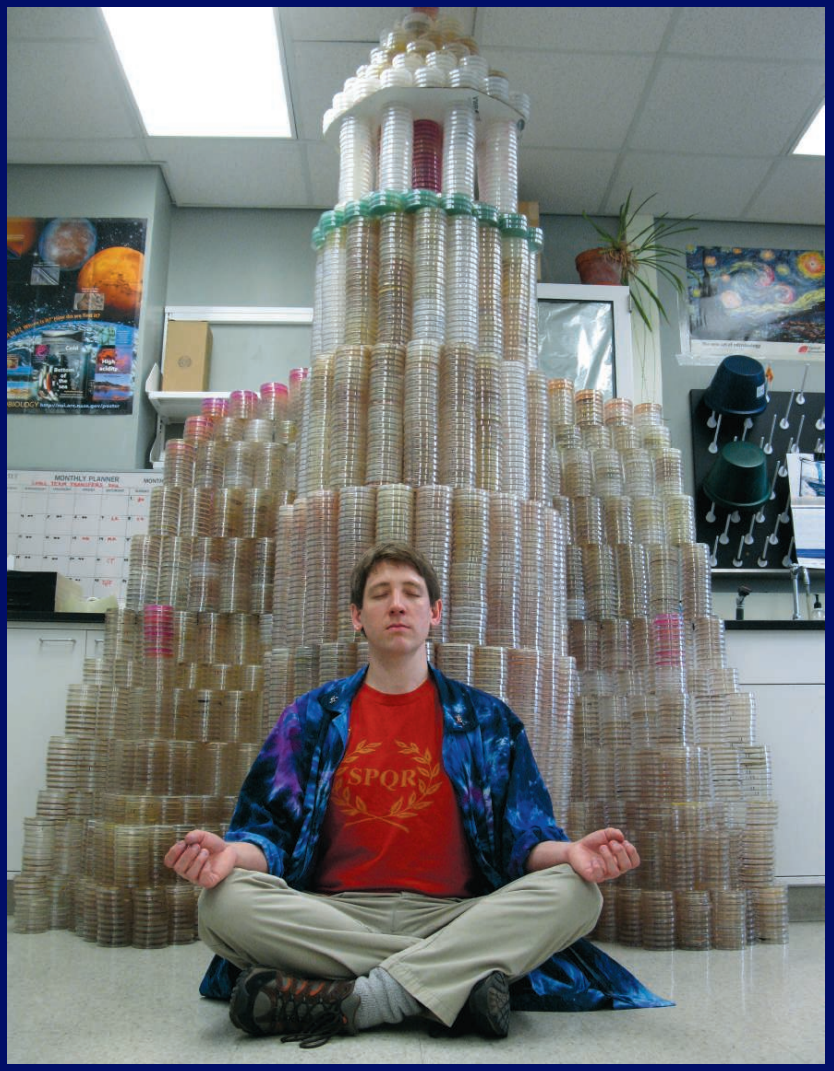
Gradualism vs. Punctuated Equilibrium

Speciation: the role of geographical isolation

Ecological niches

Evolution in Action

- 25 year experiment by Richard Lemski
  - (Science, 15 Nov. 2013)
  - 58,000 generations of E. Coli
    - Equivalent to 1 Myr of human evolution
    - Fixed environment: glucose, citrate, …
    - All 12 lines increased fitness (70% faster doubling)
    - One developed new capability to use citrate
    - A new species? (E. coli can’t use it)

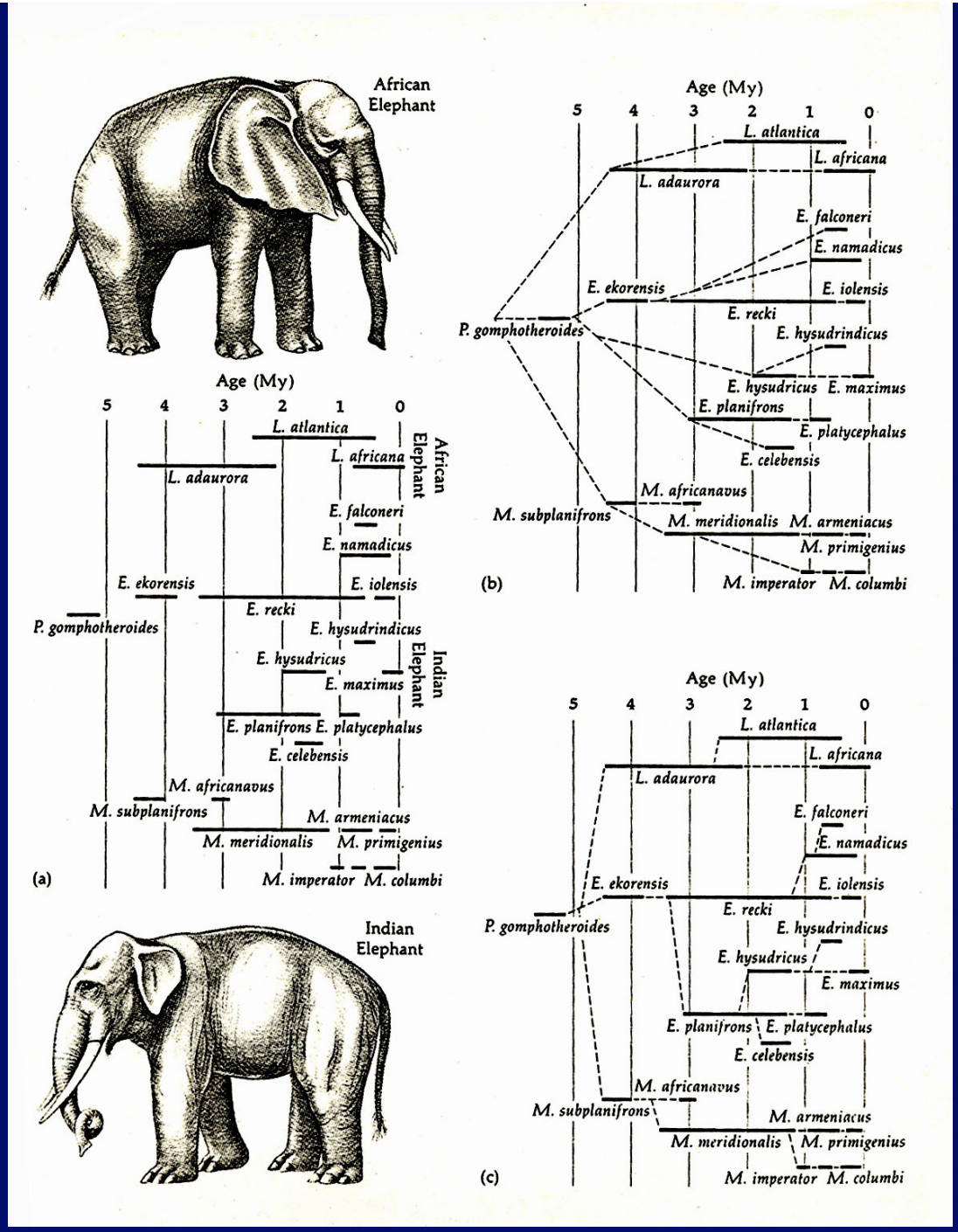


Pictured: Zachary Blount used all these petri dishes to study how one flask of bacteria

The Graduate Student and all the Petri dishes used to figure out how the bacteria “learned” to use citrate

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
- 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

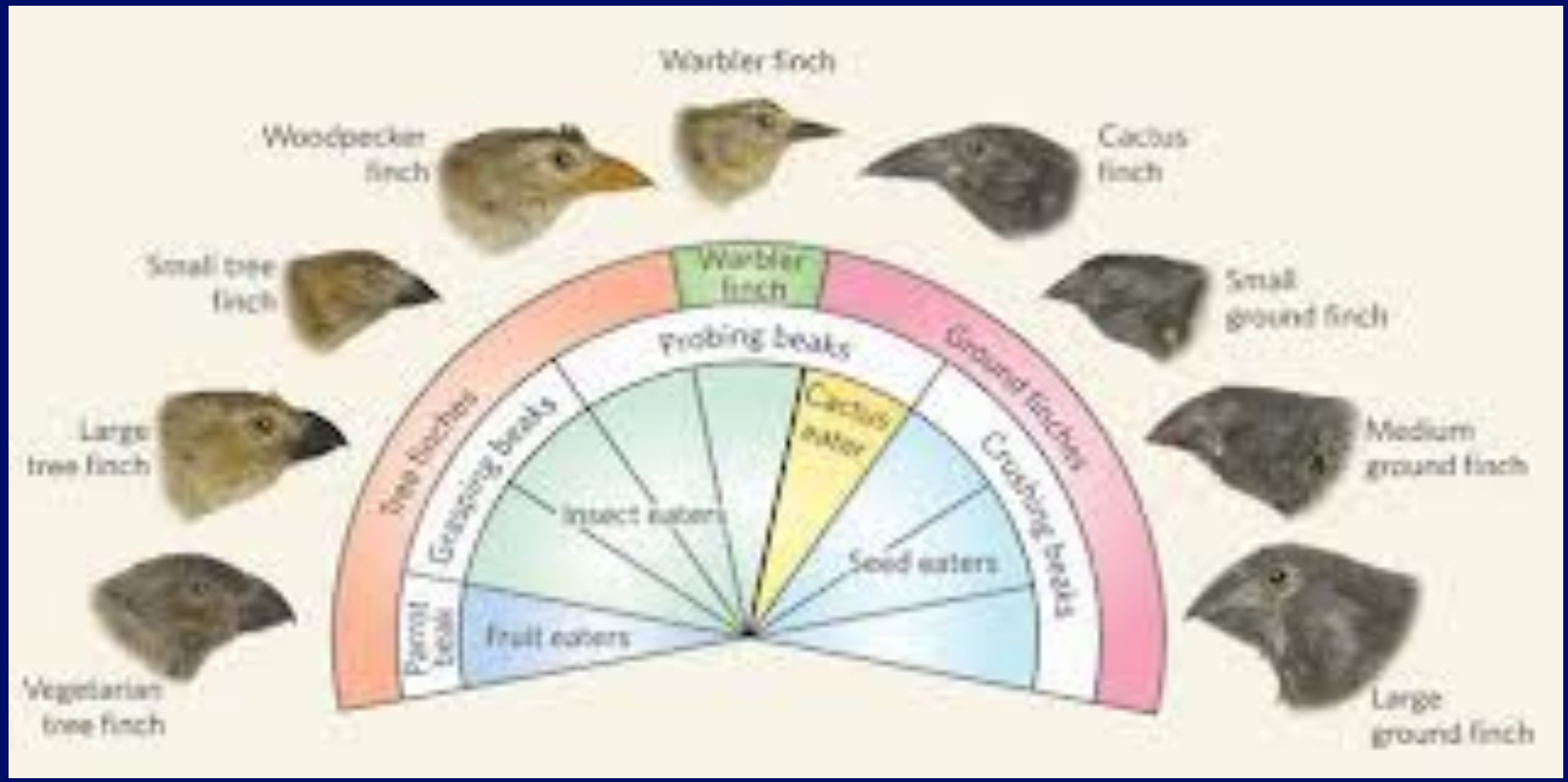
Speciation

- 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

The Origin of Species

- Galapagos Islands
  - 0.4 to 7 Myr old volcanic islands
  - Darwin collected birds from various islands
  - Looked and acted quite different
  - Upon return, ornithologist told him they were all closely related species.
  - Idea of “natural selection” by new environment
  - Beaks highly adapted to food source
  - Called “finches” but family is still disputed

Diversification of Beaks



One is a “vampire finch” (not shown)


Land Iguana

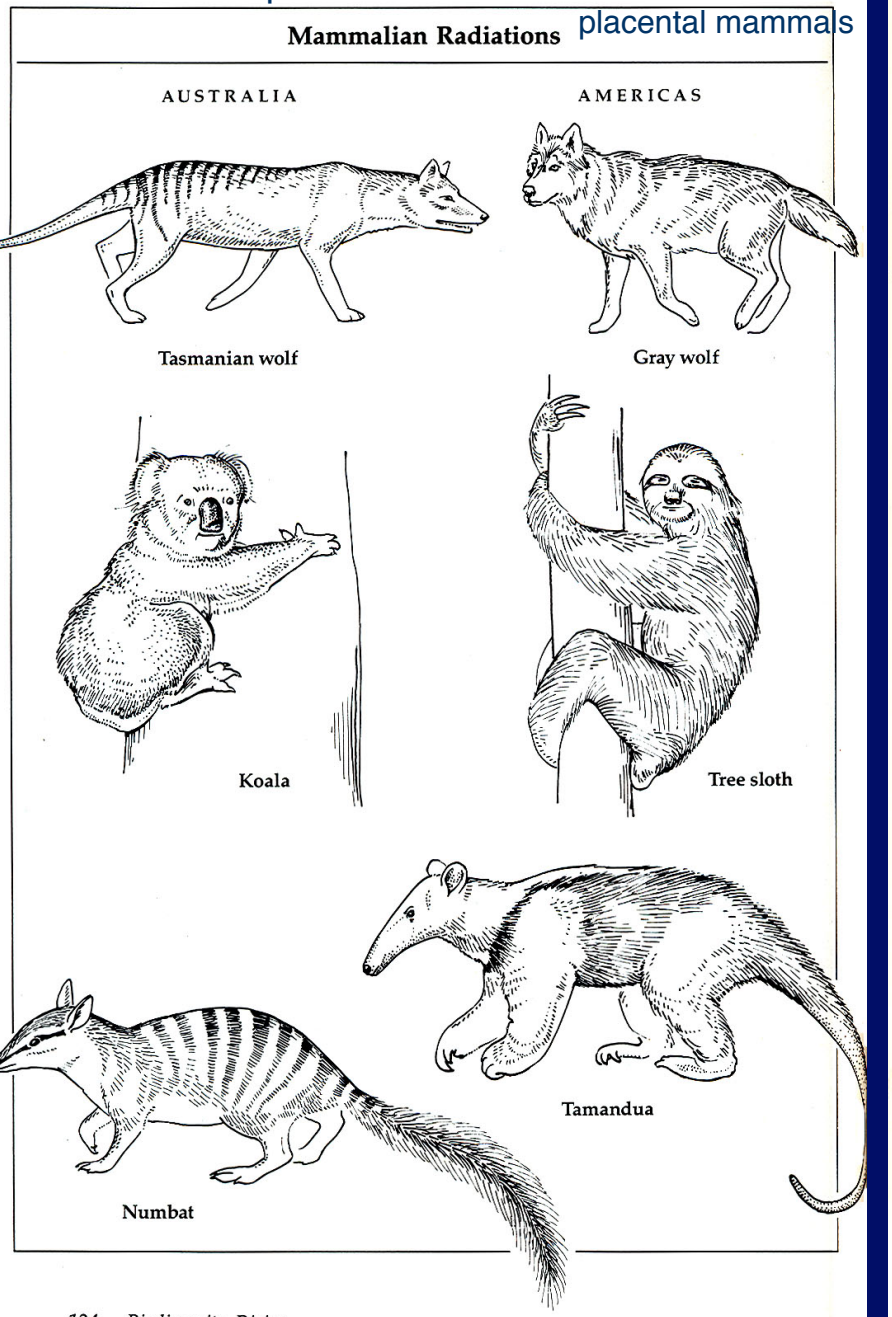

Marine Iguanas

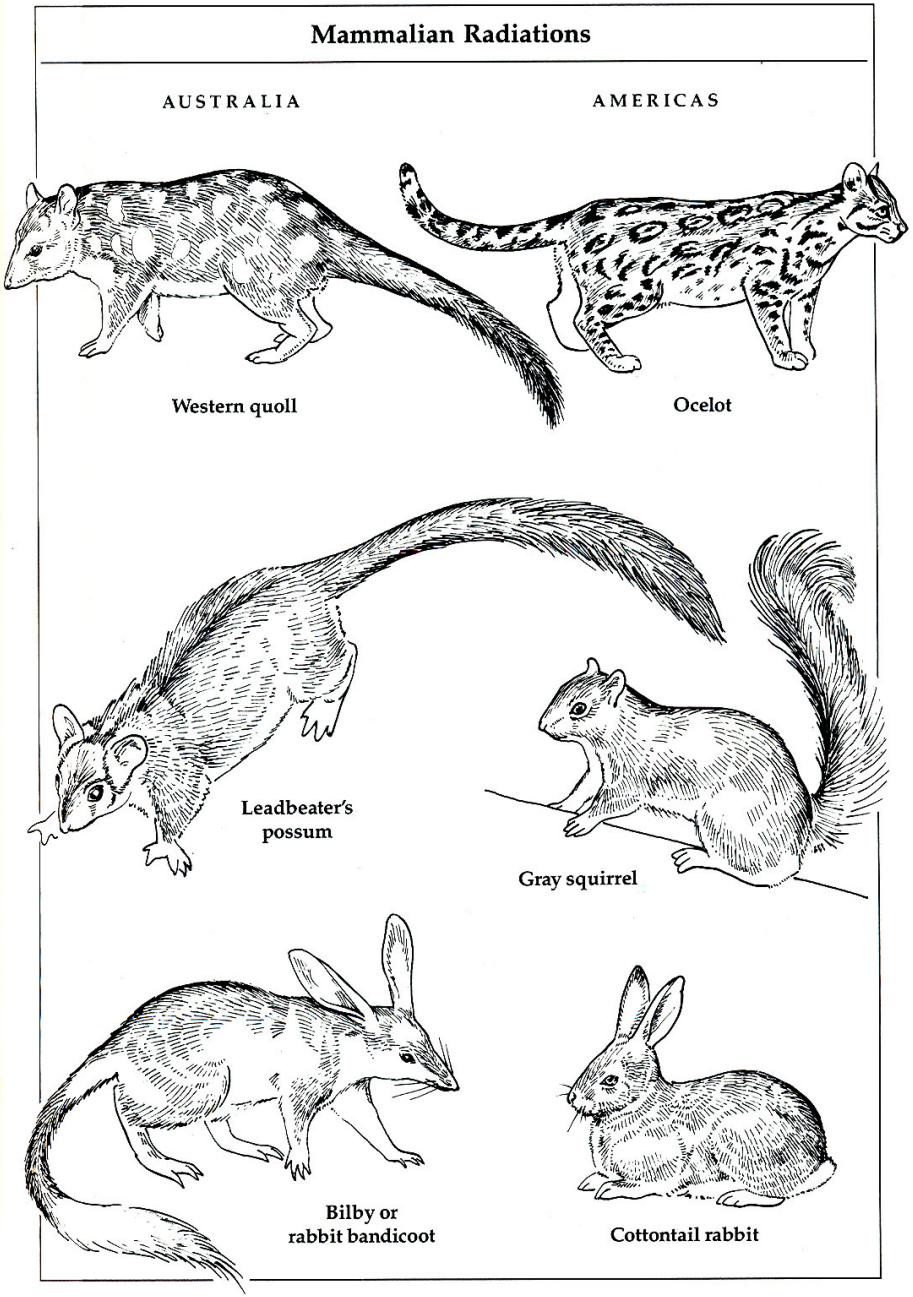
Ecological Niches

- “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

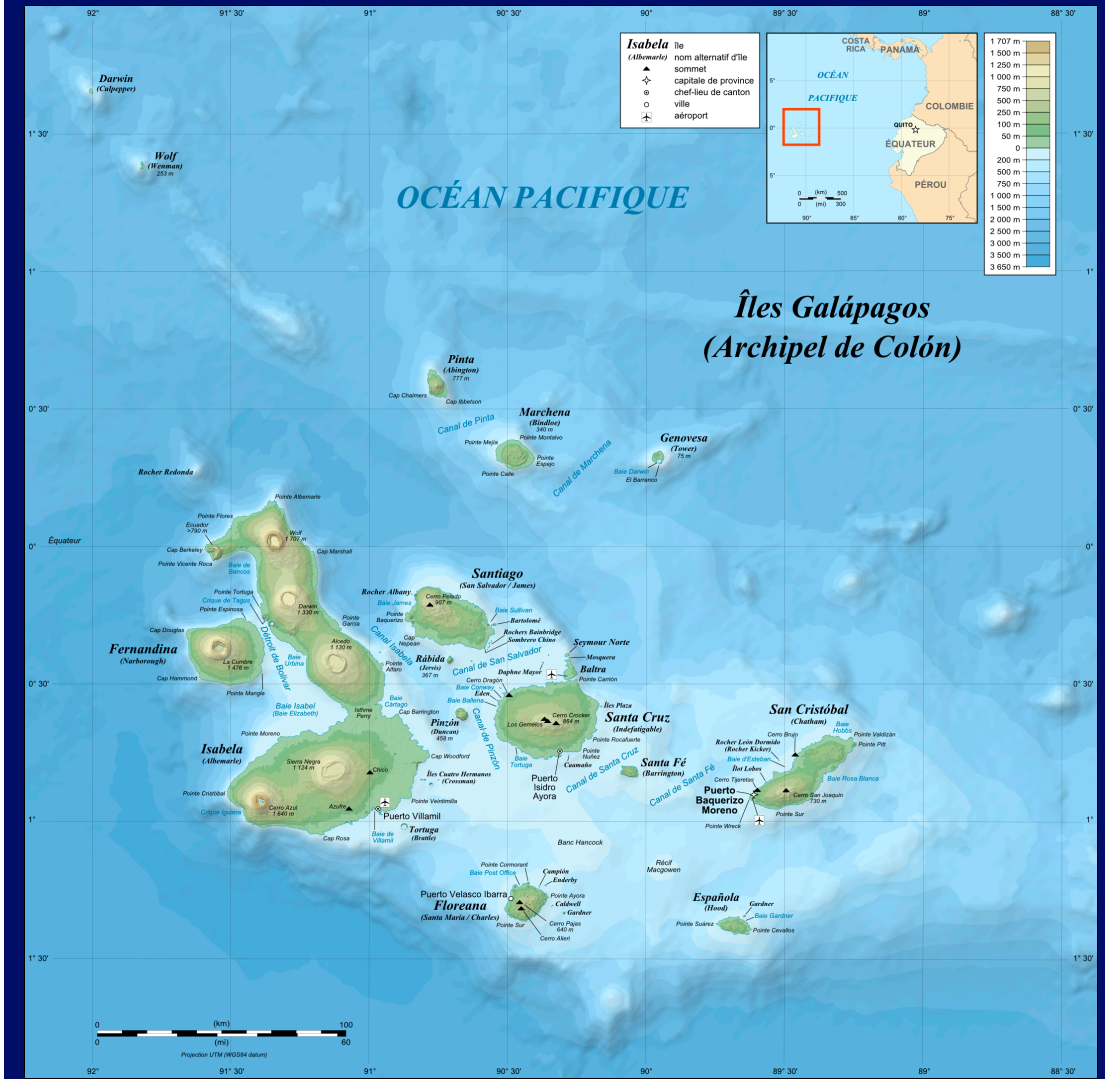
Australian Marsupials

World continent placental mammals





Location of the Galapagos



About 500 miles west of Ecuador.
Cape Verde Islands about 350 miles west of Africa.
Similar environment.
Completely different plants and animals

Darwin's Conclusion in Origin of Species

I believe this grand fact can receive no sort of explanation on the ordinary view of independent creation; whereas on the view here maintained, it is obvious that the Galapagos Islands would be likely to receive colonists, whether by occasional means of transport or by formerly continuous land, from America; and the Cape de Verde Islands from Africa; and that such colonists would be liable to modification;—the principle of inheritance still betraying their original birthplace.

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

Evolution: Theory or Fact?

- Facts
  - fossils and ages are facts
  - Order of origins of groups (fossil record) is a fact
  - 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?
  - Galapagos organisms like those in Ecuador, not Cape Verde islands?

Evolution and Religion

- Vatican Conference on Evolution
  - Mar 3-7, 2009
  - On occasion of 150 years since Origin of Species
  - Explored compatibility

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**


Any Questions?!