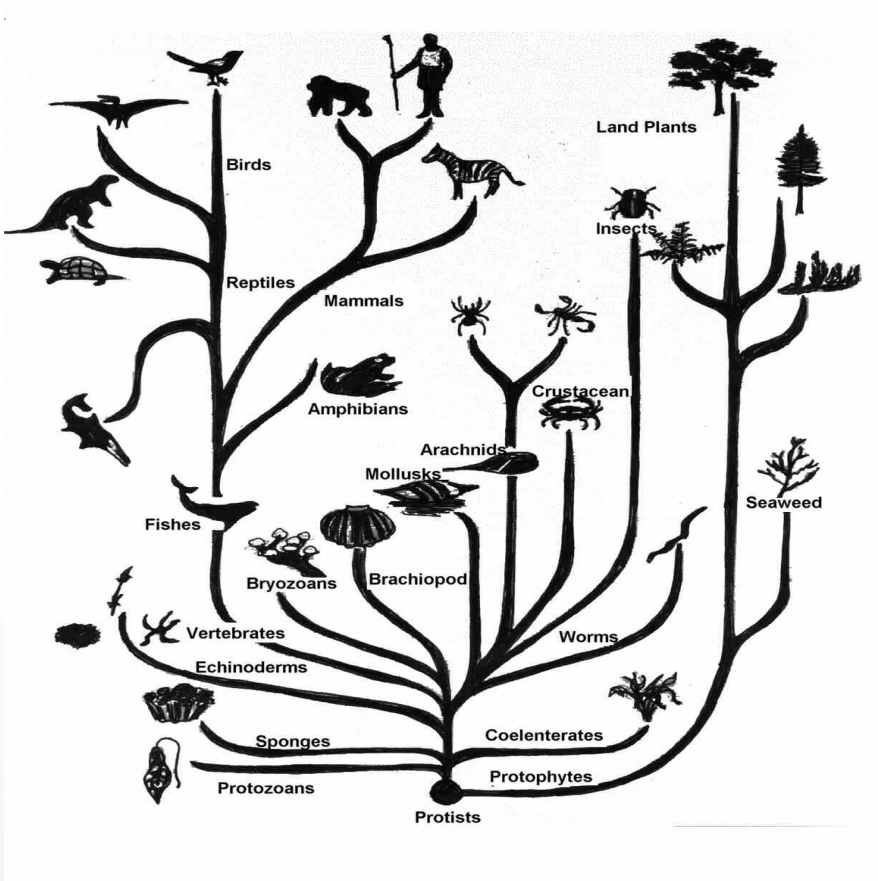
Biological evolution



Overview

Define biological evolution

Tenets of evolution: random mutation, reproduction, selection

Diversity of life & classification

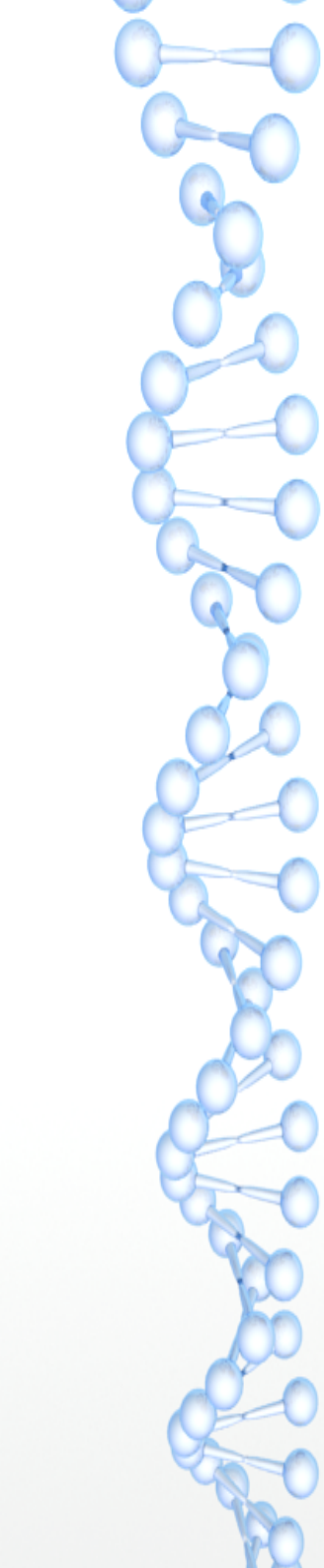
Evidence of evolution

Convergent / Contingent Evolution

“Theory”, “Law”, and the scientific method

Biological Evolution

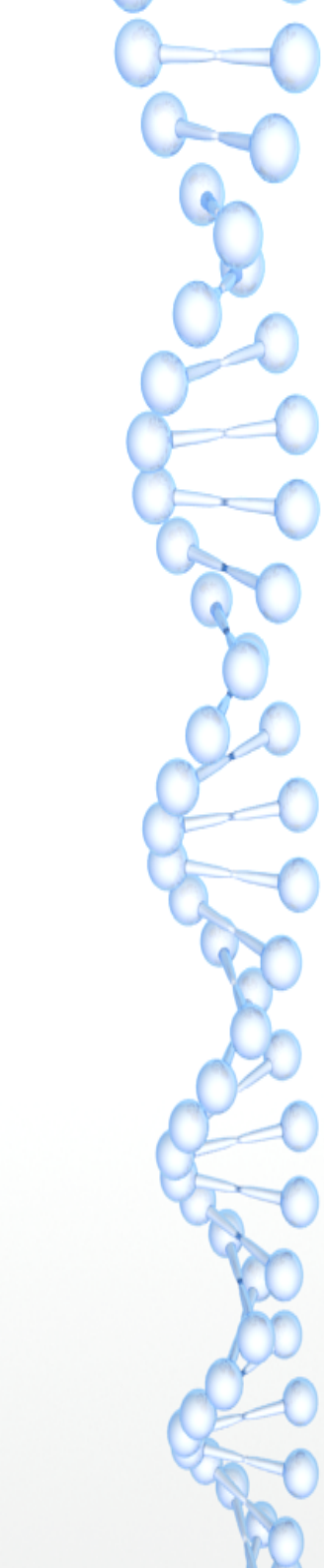
The changes in a population over time that result from random mutations of inheritable information due to selection pressure or genetic drift.



Inheritable Information

DNA or other nucleic acids are methods of storing information: they contain codes for proteins and other useful structures such as important RNA sequences like tRNA.

Nucleic acids are copied (inherited) when creating offspring.



Random Changes

When being copied, there are occasionally errors in the process. This happens at a rate of 1 error for every million bases copied (a rate of 10^{-6}).

These errors may result in a beneficial, neutral, or harmful change in the relevant protein or structure.

Example: Changes in the 3rd base of a codon often have no effect on which amino acid is incorporated. In some cases, a change in amino acid may also have no effect.

Selection Pressure

Selection pressure results from competition for resources.

Harmful mutations are selected against if they prevent an organism from producing viable offspring.

Beneficial mutations are selected for if they result in an organism producing more viable offspring.

Forms of selection pressure

Natural

The physical conditions or other organisms in the environment cause the death of organisms before they can produce offspring, or result in non-viable offspring.

Sexual

Organisms of a particular species prefer to select a mate based on observable traits, or there is direct competition for mating rights within a species.

Genetic Drift

In an environment for which there is no selection pressure for a given trait, random mutations may result in changes to the trait over time.

Sex, or why do men exist?

Sex requires two entire organisms instead of one

- Uses more total energy – seems disadvantageous.

Advantages of sex

- More combinations can be tried more quickly.
- Multiple copies of the same gene allows one to change with less of a chance of impairing the organism.
- May be a method of repairing DNA.

Sex: protection from parasites?

Morran et al. Science 333 (2011)

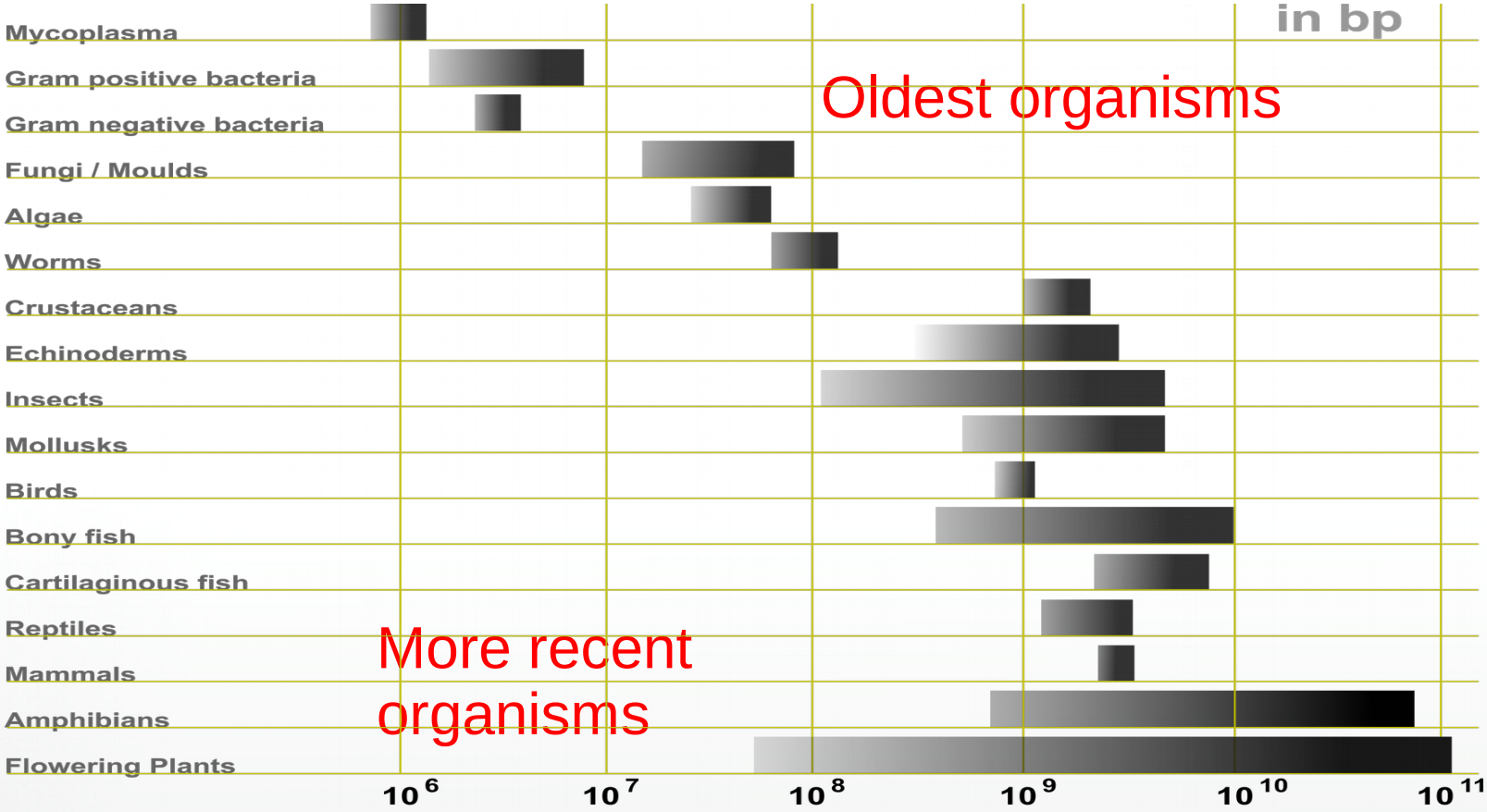
C. elegans (a microscopic roundworm) genetically manipulated to reproduce sexually, self-fertilization, or both.

Introduced each population to parasite *S. Marcescens*.

- Those with sexual reproduction survived and co-evolved with parasite. Those without died off.
- Sex is favorable in some circumstances, but this doesn't explain ubiquity of sex.

Increasing Complexity

Complexity: amount of information stored in the genetic code.



Question:

Imagine we time travel back to the early Earth and find one of the first bacteria. We then time travel ahead 1 billion years. Will that strain of bacteria have evolved into something:

a) More Complex
b) Equally Complex
c) Less Complex
d) It could be any of the above

Classification and Diversity of Life

Carolus Linnaeus published a classification scheme for living organisms (*Systema Naturae*).

A form of this classification scheme is still used today. The scheme is hierarchical, grouping similar organisms together.

Modern taxonomic classification

	Humans	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

Modern classification

System was originally based only on observable features (i.e. how a species looked).

Linneaus classified Humans and apes together under Primates because of the similarity of appearance.

Modern system now informed by genetic analysis.

Each level represents a group with a common ancestor

Domains

Domains are a recent addition to the classification scheme.

Three domains:

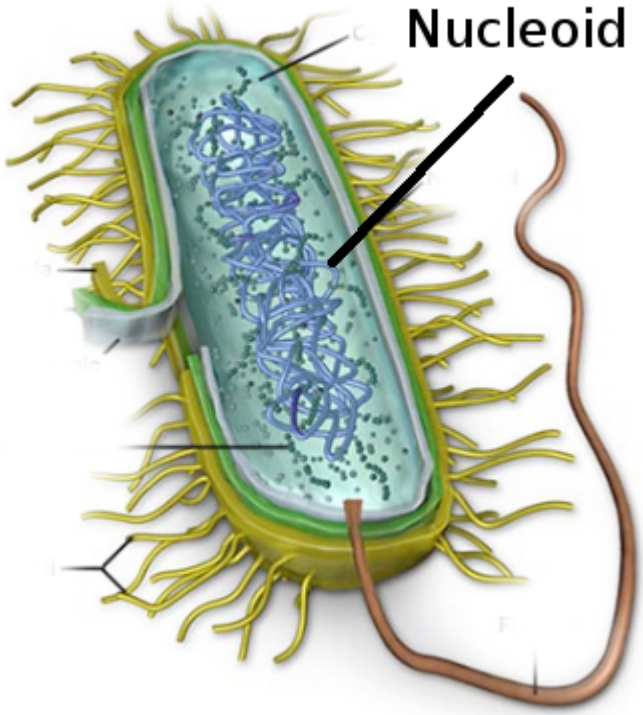
Eukaryotes (Eukarya)

Archaea

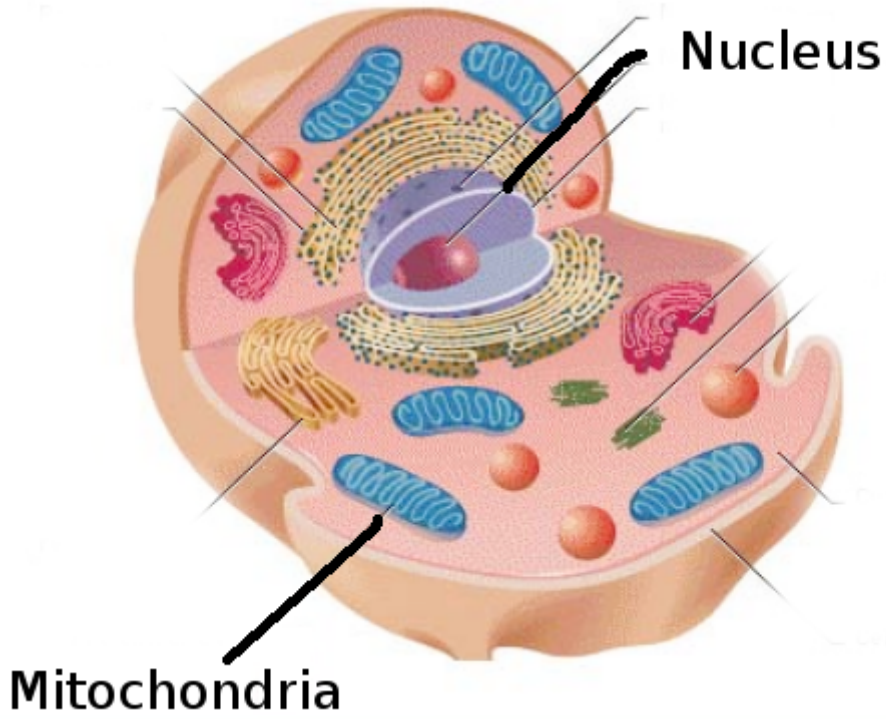
Prokaryotes (Prokarya)

Domains

Prokaryote



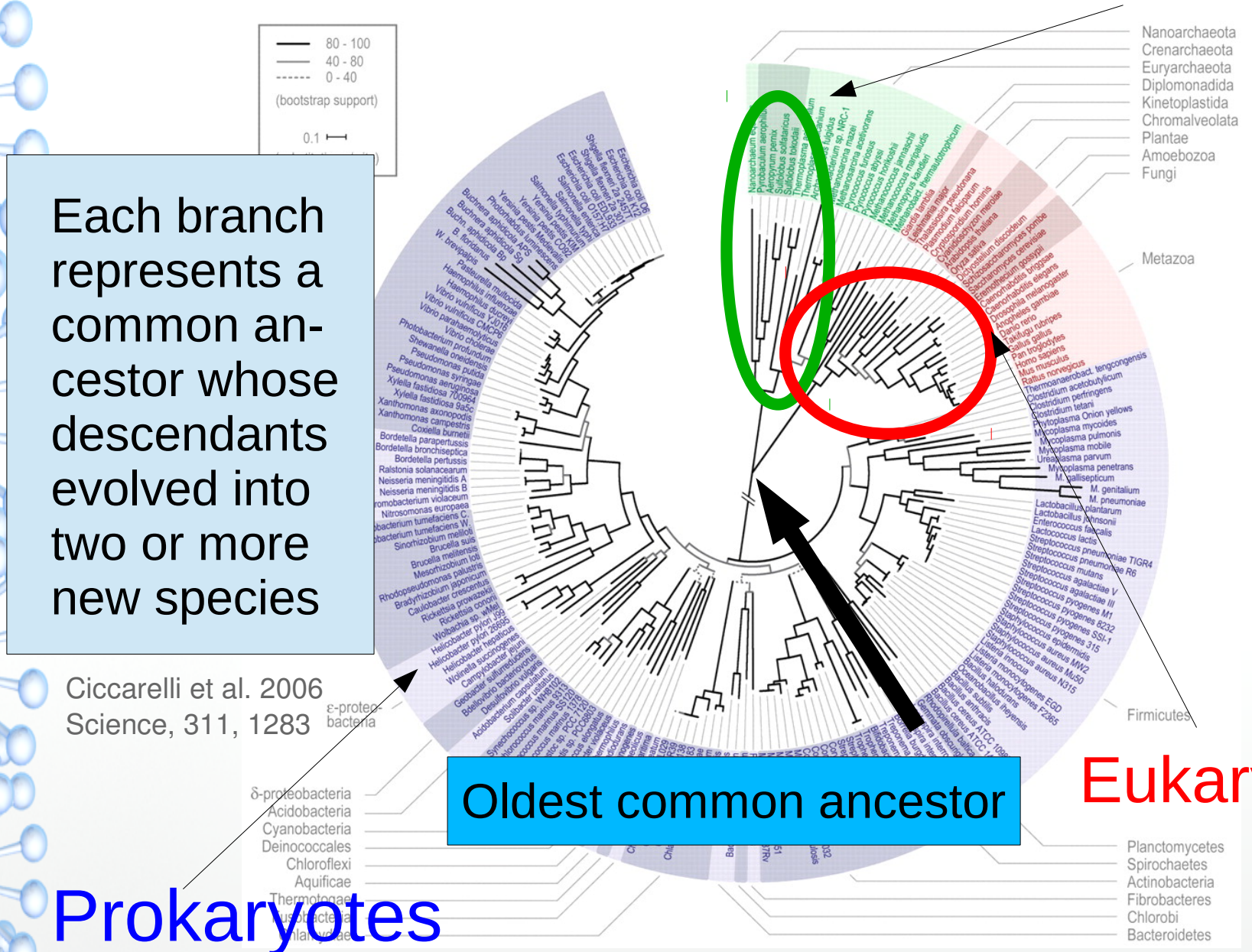
Eukaryote



	Prokaryote	Eukaryote
First appeared (10^9 years BCE)	3-4	1.5-2
# of genes	~1000	10^4 - 10^5

Tree of life: genetically sequenced species

Archaea



Each branch represents a common ancestor whose descendants evolved into two or more new species

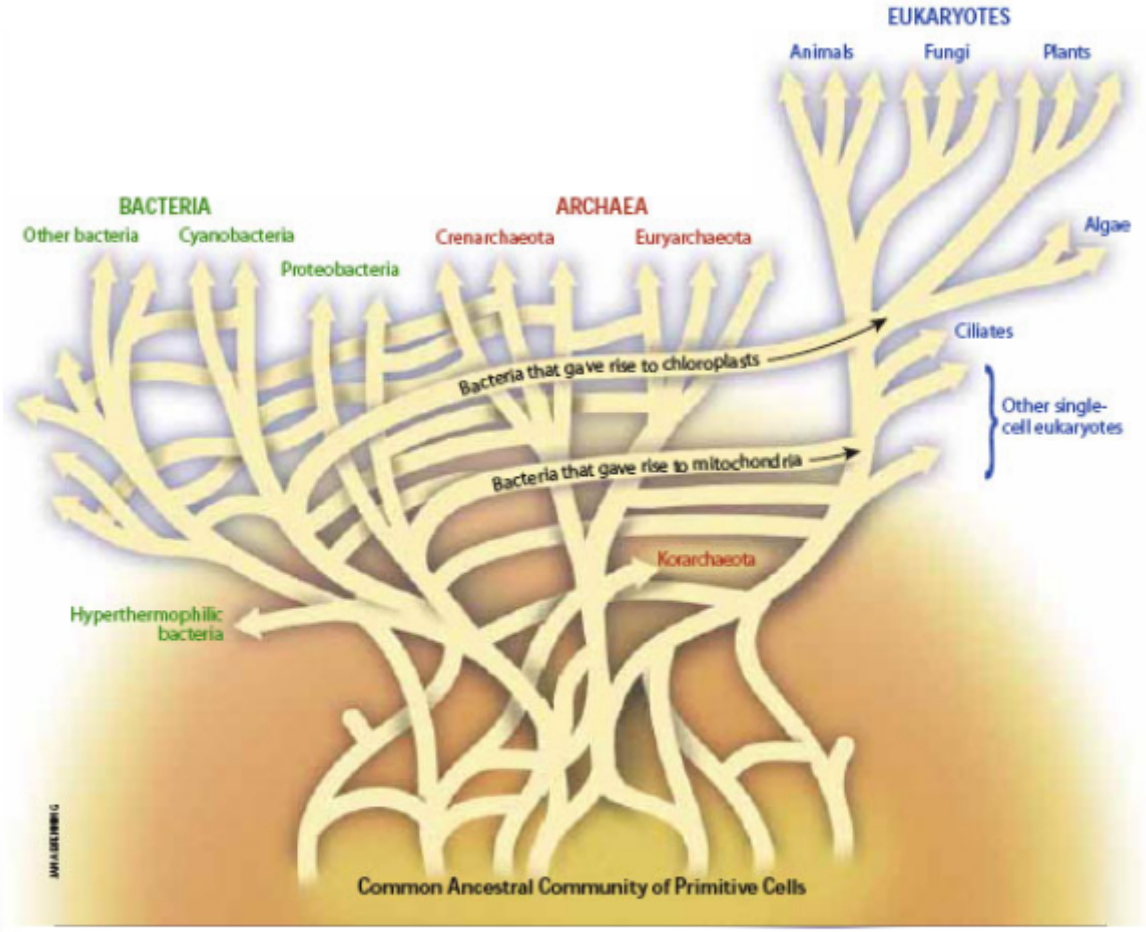
Ciccarelli et al. 2006
Science, 311, 1283

Oldest common ancestor

Eukaryotes

Prokaryotes

Web of life



Non-sexual gene transfer (lateral transfer) occurs among prokaryotes, archaea, organelles of eykaryotes

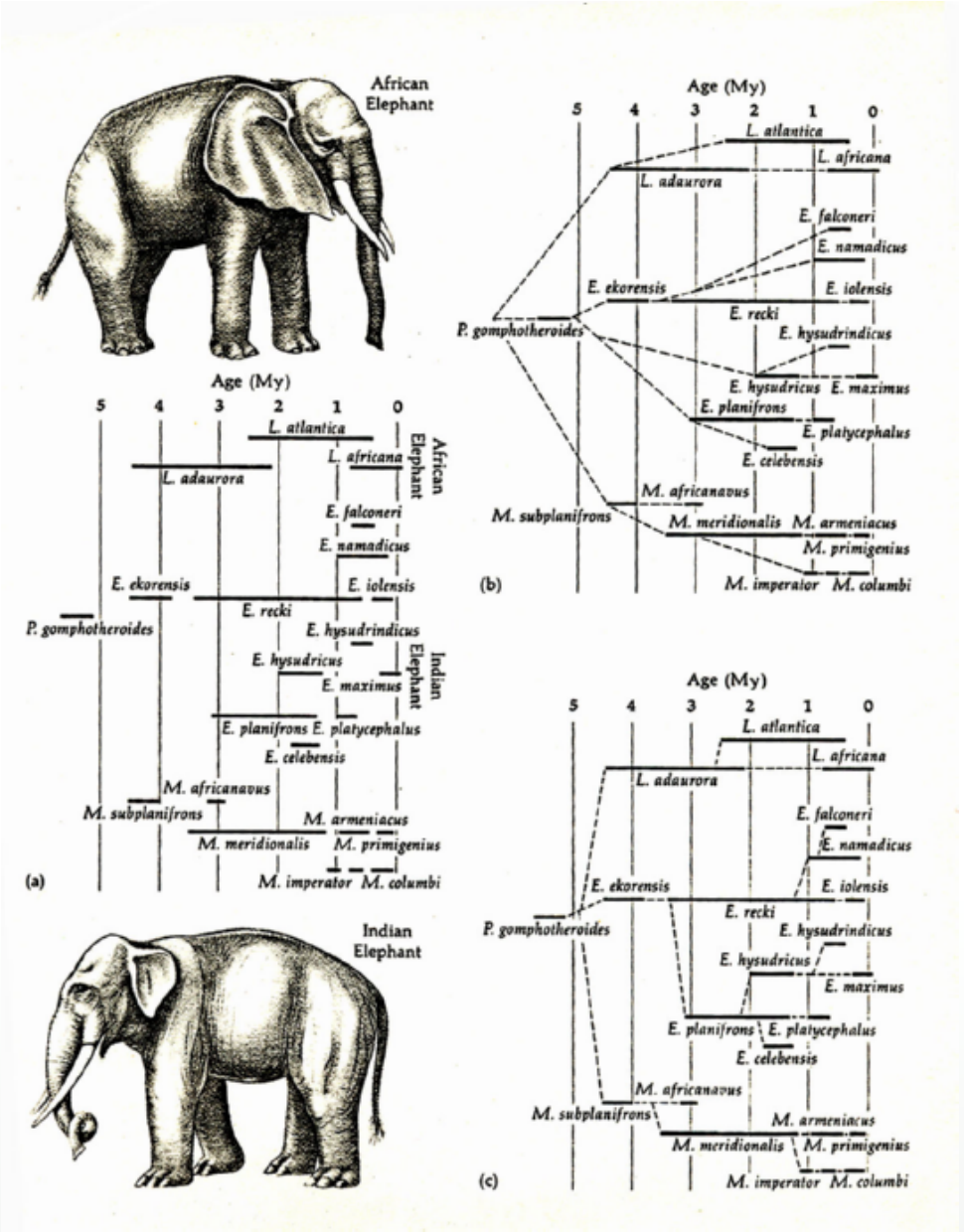
Number of species

- Mora et al. (2011) PLOS Biology 9(8)
- Eukaryotes: 8.7± 1.3 million
  - only 1.2 million known
    - 72% of plants
    - 12% of animals
    - 7% of fungi
    - 9% of marine species
- Prokaryotes and archaea: unknown
  - About 10,000 known
  - Probably millions

Speciation: gradual or rapid?

Gradualism: slow but significant changes

Punctuated equilibrium: minimal changes over long periods, interrupted by rapid changes



Question

Gradualism is the idea that species arise slowly over time and there are many intermediate changes. How do the tenets of evolution play a role in this process?

Question

Punctuated equilibrium is the idea that species arise rapidly over time and there are few intermediate changes. How do the tenets of evolution play a role in this process?

Evidence of evolution

Genetics:

Similarity of genes inside domains

- ~99% of genes common between chimpanzee and human (Family *Hominidae*).
- ~50% of genes common between fruit fly (*drosphilia*) and humans (Kingdom *Animalia*).
- ~20% of genes common between baker's yeast and humans (Domain *Eukarya*).

Mutations in DNA accumulate at a roughly constant rate over time. A *very* simple approach to finding a common ancestor can be done by dividing the number of base pairs that are changed by the rate of change.

- Humans have about 3 billion base pairs.
- Mutation rate is about 150 per generation, or about 2.5×10^{-7} % per year.
  - 1% change ~ 4 million years
  - 50% change ~ 200 million years
  - 80% change ~ 300 million years
  - [larger changes less reliable – may be off by a factor of about 2]

Evidence of Evolution

Bacteria

- Antibiotic resistant strains of common bacteria have developed.
  - Consider a population of 10^6 bacteria, of which ten are resistant to a particular antibiotic. This bacteria is 0.001% of the population. Without selection pressure, this population will change randomly and may die out.
  - When a 99.99% effective antibiotic is applied, 100 bacteria survive, 10 of which are the resistant strain. These now represent 10% of the population.
  - The population regrows to 10^6 bacteria, thus there are now 10^5 of the resistant strain.
  - The antibiotic is reapplied. 90 non-resistant and all of the resistant bacteria survive, so there are 100,090 bacteria, of which the resistant strain represent 99.9%.

Evidence of evolution

Experimental

- Richard Lenski
  - Lenski (2003) Plant Breeding Reviews 24(2):225-65
  - Blount et al. (2008) Proc. NAS 105 (23): 7899-906
  - 58,000 generations of E. coli (equivalent to about 1 million years of human life)
  - Fixed environment containing glucose (sugar, energy source used by E. coli) & citrate (not usable by E. Coli, but needed for other reasons)
  - Method:
    - Place E. Coli in growth medium in incubator.
    - Each day (~6.5 generations), transfer 1% of population to new flask of fresh growth medium.
    - Freeze representative sample of remaining population as “frozen fossil record”
    - Perform tests to determine “mean fitness” (how well adapted they are to the experimental environment).

Evidence of evolution

Experimental

Richard Lemski (continued)

Results:

By about generation 20,000:

- all of the E. Coli grew 70% faster than the first generation.

  More specialized for living on glucose than first generation.

By generation 34,000 a strain had developed which could metabolize the citrate.

- Conclusion

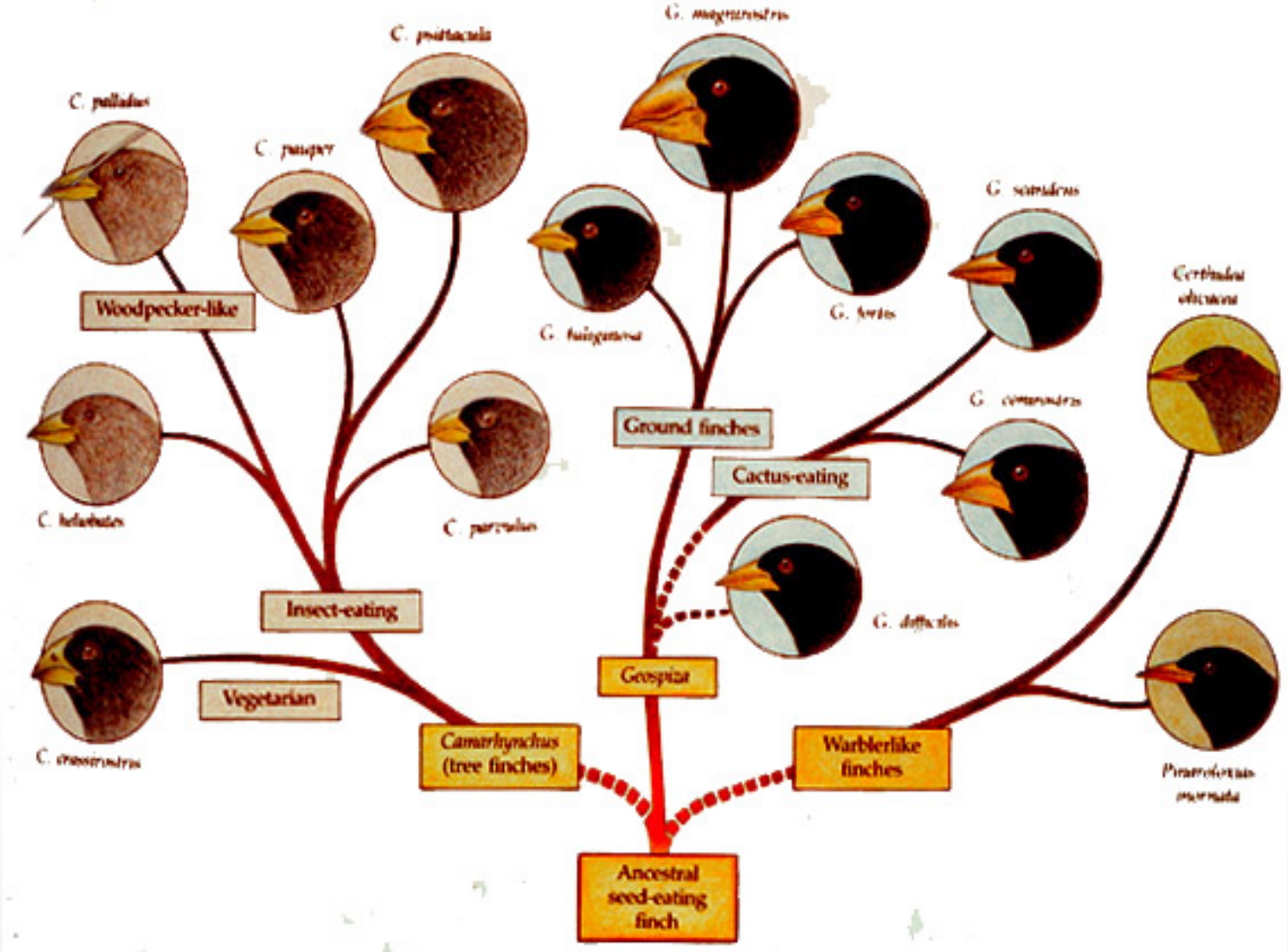
  In a population in a given fixed environment, mutations may occur which allow a portion of the population to occupy a different ecological niche

Evidence of Evolution

Observational

Darwin's voyage to Galapagos Islands

Darwin's Finches



Darwin

From *On The Origin of Species* (Darwin)

The most striking and important fact for us in regard to the inhabitants of islands, is their affinity to those of the nearest mainland, without being actually the same species. ... There are twenty-six land birds, and twenty-five of these are ranked by Mr. Gould as distinct species, supposed to have been created here; yet the close affinity of most of these birds to American species in every character, in their habits, gestures, and tones of voice, was manifest.... The naturalist, looking at the inhabitants of these volcanic islands in the Pacific, distant several hundred miles from the continent, yet feels that he is standing on American land. Why should this be so?

... 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.

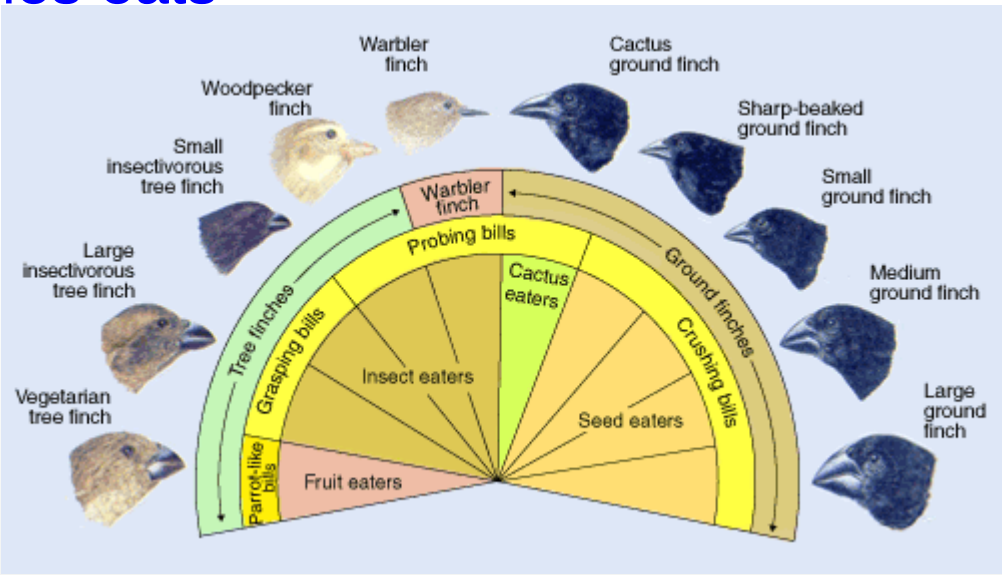
Darwin's Finches

Explanation:

A small population of birds from the mainland reached the islands, perhaps blown out to sea by a strong storm?

Geographic isolation and new environment leads to the birds becoming specialized for particular niches (a specific microclimate or set of food resources).

The differences in beak size correspond to the food that each species eats



Evidence of evolution

Geological Record

Fossils

- Preserved tissue (usually bones, teeth, etc.) or mold (overall shape and features of organism)
- Petrification – replacement of organic material with minerals
- In special circumstances, soft tissue may be preserved (mummification by freezing or dry environment, oxygen free environment)
- DNA can be extracted from some very recent fossils

Dating fossils

Fossils are usually found in sedimentary rock, the layers of which accumulate over time.

The depth of the fossil is indicative of the time at which it is buried. This is a method of finding the relative time between fossils in the same rock formation.

A more precise way to determine the age of fossils is to look at radioactive materials, such as ^{14}C or Uranium.

Radiometric dating

^{14}C occurs naturally in the Earth's atmosphere, and is replenished by cosmic rays.

$$\frac{^{14}C}{^{12}C}$$

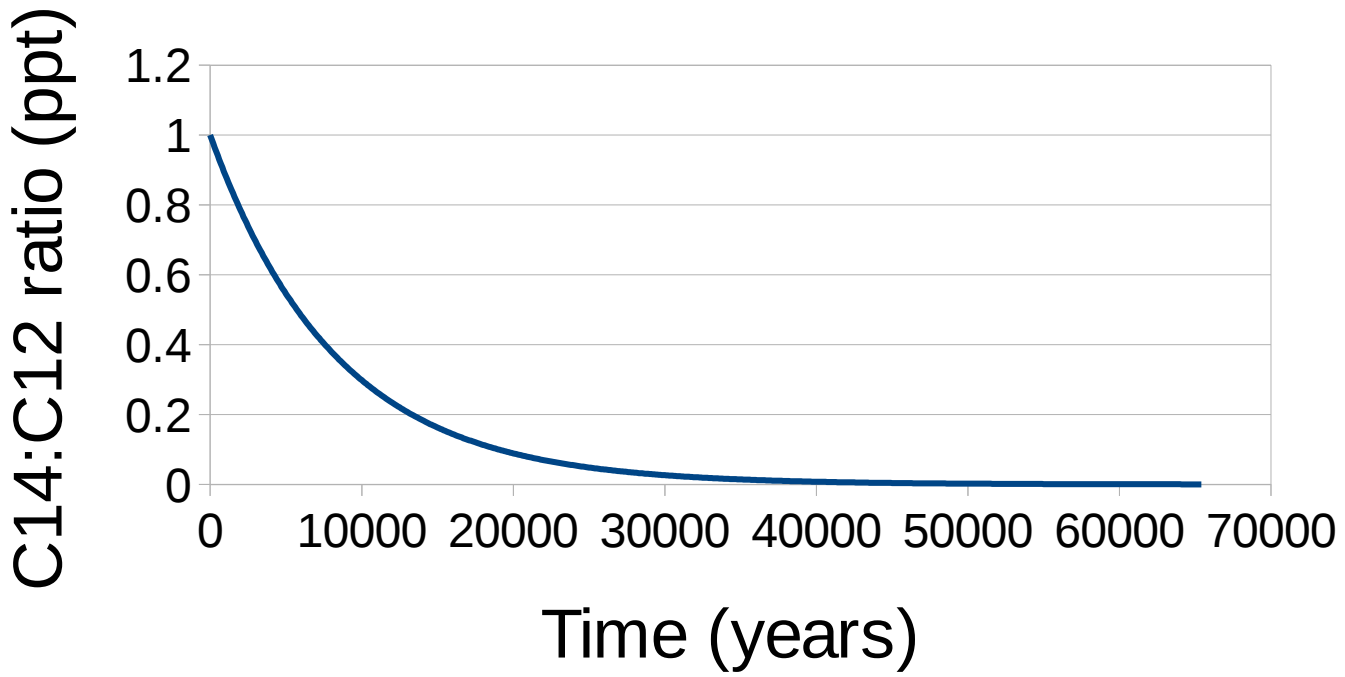
Atmosphere: 1 part per trillion (ppt)

This gets incorporated into organic material through respiration.

When an organism dies, it no longer incorporates ^{14}C into its body. The ^{14}C radioactively decays, decreasing the ^{14}C:^{12}C ratio.

Radioactive decay

Half-life: the time it takes 50% of a material to decay.



Longer lived elements

Isotope	Half-life (years)
Carbon-14	5,740
Uranium-235	34,300
Uranium-234	80,000
Uranium-238	700 million
Potassium-40	1.2 billion
Rubidium-87	50 billion

Finding different fossils over time

Era	Period	Myr Ago	Life forms
Cenozoic	Quaternary	2	Earliest humans (homo)
		4	Oldest hominid
	Tertiary	65	Primates
Mesozoic	Cretaceous	136	Birds
	Triassic	225	Mammals
Paleozoic	Permian	280	Reptiles
	Carboniferous	345	Amphibians
	Devonian	395	Insects
	Silurian	430	Land Plants
	Ordovician	500	Fish
	Cambrian	543	Trilobites
Precambrian		545	Small shelly fossils
		580	Ediacarans
		600-800	Multicellular life

Comparable to estimate from genetic mutation rate

Oldest fossils

Stromatolites

Modern (Australia)

Fossil
(1.8 billion years old)

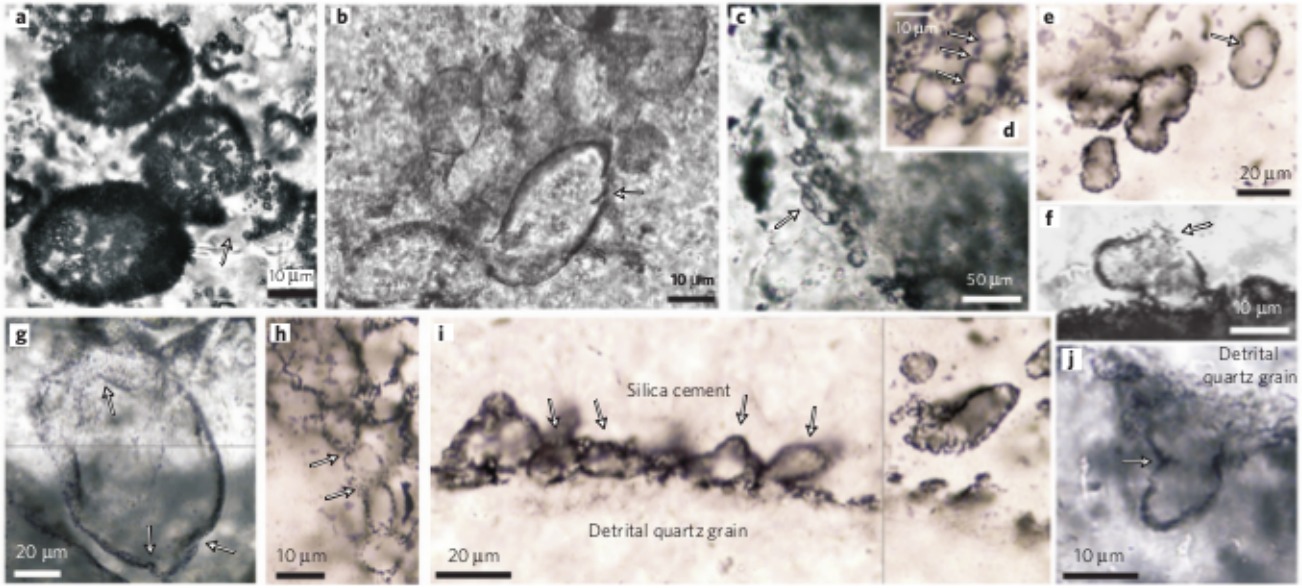
Older fossilized stromatolites to about 3.4 billion years ago

Image credit: Paul Harrison

Microfossils

Wacey et al., (2011) *Nature Geoscience* 4

3.4 billion year old fossilized cells



Cambrian Explosion

First soft-bodied animals (sponges) may have appeared about 650 My ago.

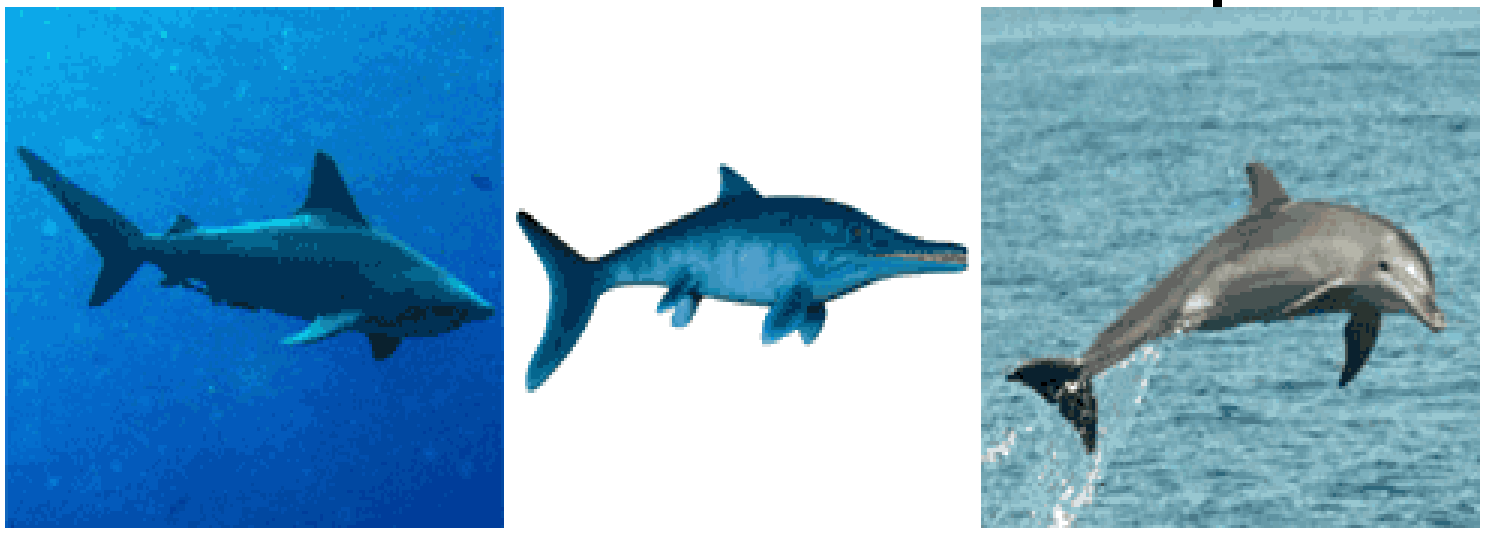
Burrowing creatures appeared in the Ediacaran, about 565 My ago.

Rapid diversification 543 My ago. Most modern phyla appeared at this time. The first hard shells and skeleton-like features

Burgess shale is location of many, varied fossils, dated to 505 My ago.

Convergent Evolution

Organisms occupying the same niche will develop similar features

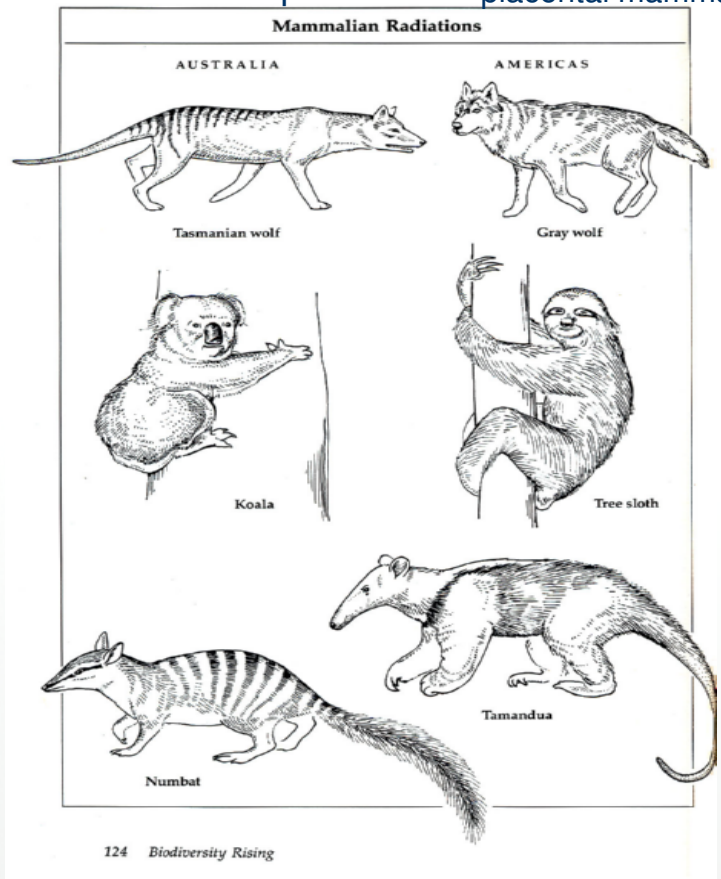


Convergent Evolution: Australia vs the Americas

Australia tends to be geographically isolated, yet mammals which fill the same nice look similar, despite very different evolutionary paths.

Australian Marsupials

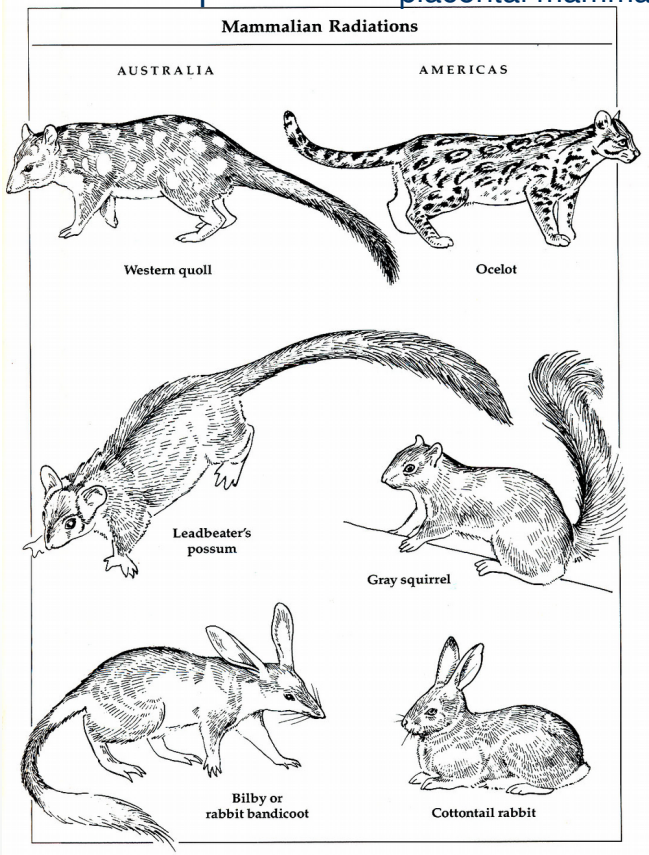
World continent placental mammals



124 *Biodiversity Rising*

Australian Marsupials

World continent placental mammals



Adaptive Radiation 125

Evolution as a theory

Theory (n)

- Colloquially: an idea or hypothesis
- Science: a hypothesis which has been tested by a variety of means, which is shown to be valid by a wide body of evidence.

Theory vs. Law

Newton's law of gravity

- Gravity is a force acting between two masses.
- Prediction: light (which has no mass) would not be affected by gravity

Einstein's theory of relativity

- Gravity is a warp in space caused by the total energy contained within a body. In the low energy limit, the force is equivalent to that predicted by Newton.
- Prediction: light will be affected by gravity because it is moving through space.

Numerous tests have shown Einstein's version to be more correct than Newton's version. e.g. gravitational lensing requires Einstein's version or gravity.

A “law” and “theory” in science are just different terms for the same concept: an explanation of how nature works.

Scientifically testable

For something to be considered a theory, it must be testable. That is: you must be able to make predictions from the theory, and test those predictions.

Testing can be done through experiment or observations of nature.

Evolution, Creationism, Intelligent Design

	Evolution	**Creatio-nism**	**Intelligent Design**
Genetic code changes	Yes	No	Yes
Speciation	Yes	No	Yes
Number of species	Large number	?	Minimal number necessary
Convergence	Yes	No	No
Complexity	Generally increases over time, though individual lines may decrease (random variation)	Fixed	Monotonically increases over time
Complexity of humans	No specific prediction, humans arose through random chance	?	Most complex
Sex	Develops by chance if reproductively favorable	?	Unnecessary

Summary

- Evolution
  - proceeds through random changes to a population.
  - requires inheritance (genetic information)
  - selection pressure or genetic drift result in changes to expressed traits.
  - Generally leads to increasing complexity
  - Convergent evolution leads to similar traits for a similar niche
- Evidence
  - Similarity of genetic code
  - Observed distribution of species
  - Fossil record
    - Dated by relative depth and radiometric methods
  - Experimental (Morran's roundworms & parasites, Lenski's E. Coli)
  - Existence of sex, convergent evolution.
- Evolution as a theory
  - A theory makes predictions about the world
  - Testable with evidence