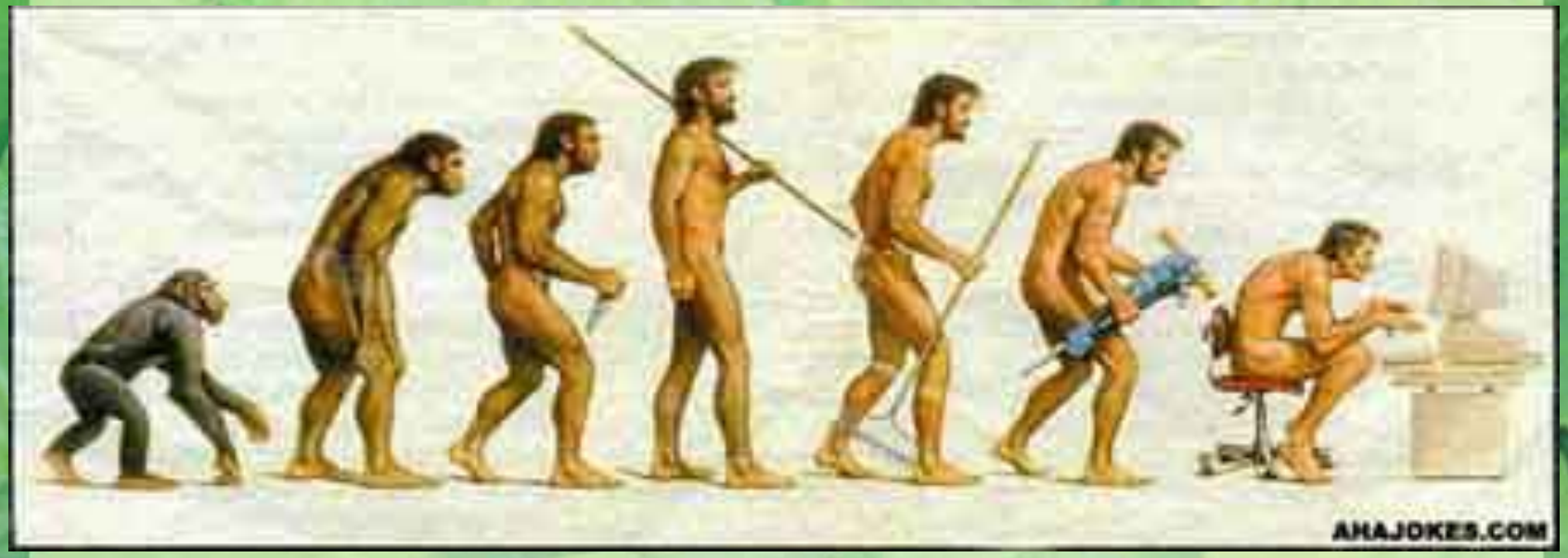
Chapter 4



THIS PHOTO IS EXTREMELY MISLEADING AND IS NOT AN ACCURATE REPRESENTATON OF EVOLUTION

Mechanisms of Population Change

4.1 Adaptation, Variation, and Natural Selection

- Organisms that live long enough to reproduce will pass on their traits to the next generation
- Those organisms that are best adapted to their environments will be most likely to survive
- Adaptations can be either a structure, behaviour, or physiological process that helps an organism survive

Structural Adaptations

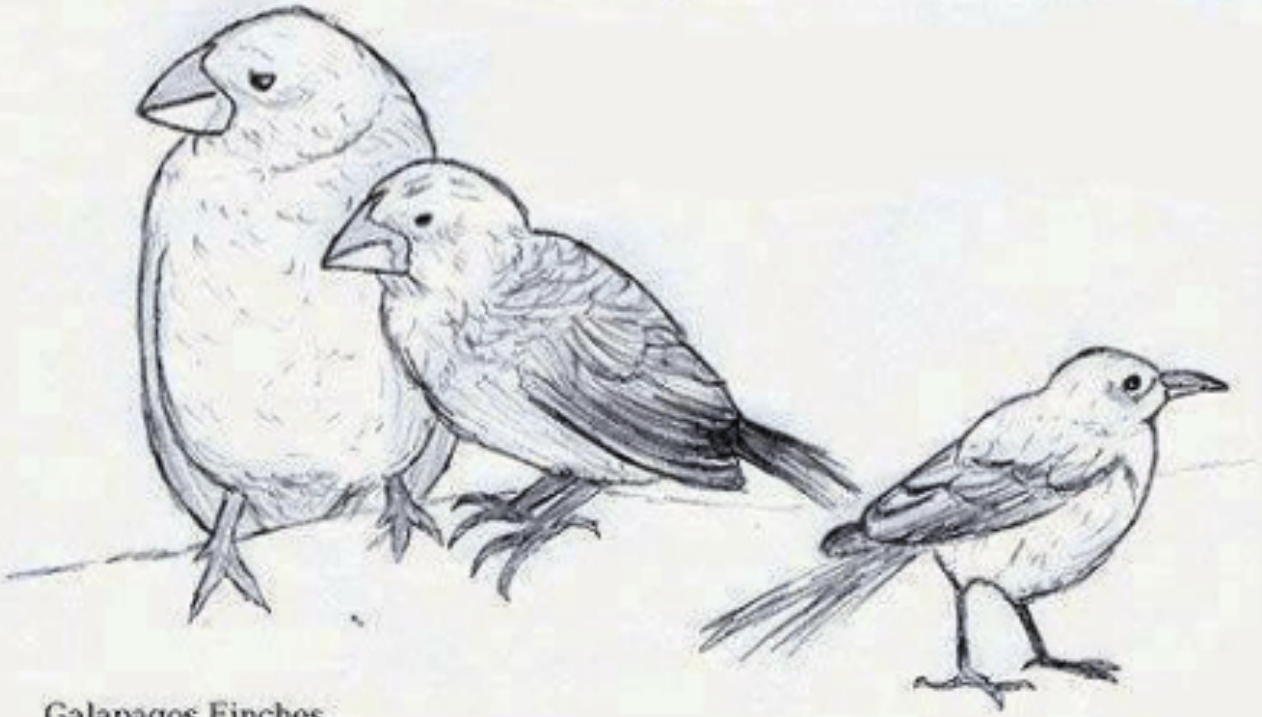
- Structures that come from a change in DNA of the organism and result in a physical change to their anatomy that improve their ability to survive and reproduce
  - Ex: webbed feet, camouflage, opposable thumbs, mimicry

Owls Fly Silently

Mom, why does brother's beak look different than mine?

I always worried you'd ask about this one day.

It's a secret, so you can't tell anyone, but your brother's adapted.



Galapagos Finches

Behavioural Adaptations

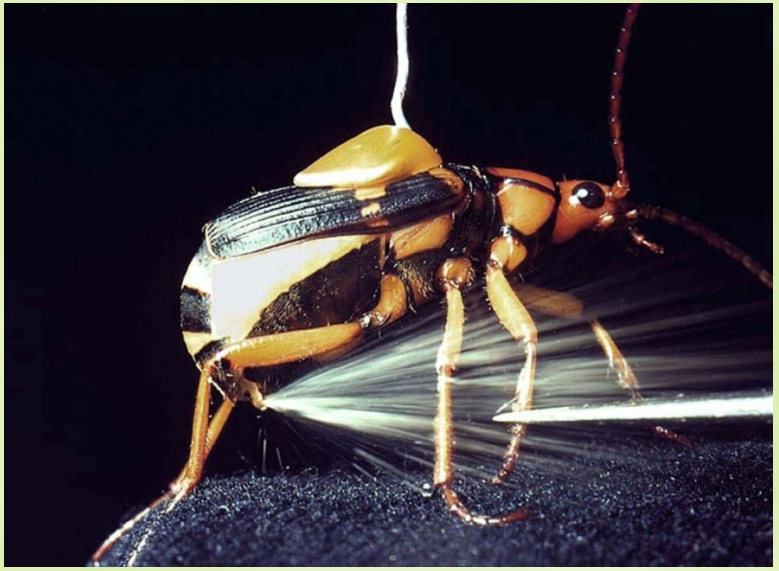
- Adaptation that results from a combination of experience and instinct. It is a change in the way an organism acts in response to an environmental stimulus.
  - Ex: hibernation, migration, mimicry, phototropism

Physiological Adaptations

- Adaptations that result from changes to internal body systems of an organism.
  - Ex: most mammals make similar hormones, counter-current exchange, cows have 4 stomachs, pheromones, venom production

Bombardier Beetle and its Wicked Farts…

- The chemistry of the spray is truly amazing. The irritant chemical is formed just prior to launch by mixing the contents of two separate glands.
- One contains hydrogen peroxide and hydroquinone, while the other harbors a mixture of enzymes known as catalases and peroxidases that can react with hydrogen peroxide to form oxygen gas and water.
- When the contents of the two glands are mixed, oxygen forms and in turn reacts with hydroquinone to convert it to benzoquinone. This reaction is so highly exothermic that the chemical mixture can reach a temperature of 100 degrees C. Pressure due to the buildup of oxygen then causes the hot mixture of water and benzoquinone to be expelled with a “pop,” much to the woe of any attacking ants.



Bombardier Beetle

Bombardier Beetle 2

The Source of Adaptations

- Adaptations are due to the gradual change in the characteristics of a population over time
- Although genetic variations (DNA) can result in adaptations, not all variations are beneficial

Review on Adaptations

Variation Within Species

- Variation is the result of genetic changes (mutations) and recombinations
- The recombination of genes can occur during sexual reproduction (parental genes interact differently depending on combination)

Mutations and Variation

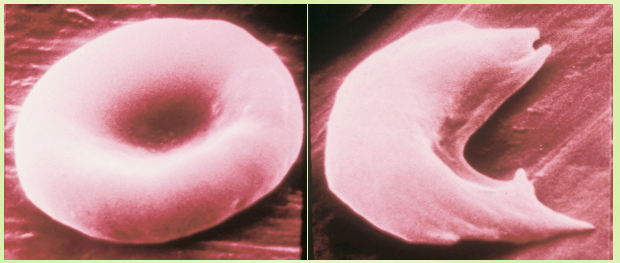
- However, ultimately, all variation is due to mutations
- Changes in the genetic code result in slightly different genes than the genes present in other organisms
- DNA mutations can occur from errors in copying the DNA, and damage from radiation or mutagens

The Effect of Mutations

- Genes code for amino acids that make up proteins
- A change in the genetic code will alter the sequence of amino acids that forms a protein
- This change in the amino acid sequence will change the shape of the protein, which changes its action
- Some mutations occur in somatic cells (the cells that make up body tissues). These mutations will disappear when the organism dies
- However, if mutations occur in germ line cells (those that produce sperm or eggs), the mutations will be passed on to the next generation

Mutations and Selective Advantage

- A mutation may provide an individual with an advantage or a disadvantage, or neither (neutral).
- It can happen that a mutation first offers no advantage, or even a disadvantage, and becomes favorable for the organism over time.
- **This more commonly happens when the organism's environment is changing.**
- **Selective advantage** – mutations that help an individual to be better able to survive.



A mutation in a red blood cell gene causes sickle cell disease. Carriers of this gene who do not exhibit the disease have an increased resistance to malaria.

Case Study: Venom-Resistant Squirrels

- In California, some ground squirrels have developed a mutation that makes them more resistant to rattlesnake venom
- Therefore, the ground squirrels with the mutation have a greater chance of survival and therefore will pass on their traits to the next generation
- Ultimately, the majority of the squirrel population will have this beneficial adaptation because they are more likely to survive to reproduce

Case Study: Pesticide Resistance

- In 1955, the World Health Organization initiated a widespread program to kill malaria-carrying mosquitoes using DDT
- This program was initially very successful in decreasing mosquito populations, but they quickly reappeared
- Because of the reduced effectiveness of DDT and its negative environmental effects, the spraying program was discontinued
- Why did DDT lose its effectiveness?

Case Study: “Superbugs”

- In 1928, Sir Alexander Fleming discovered that penicillin could be used to kill bacteria
- Penicillin was first used as a medicine in 1941
- By 1945, there were already reports of penicillin-resistant strains of bacteria
- There are now bacterial strains that are resistant to all known antibiotics
- What factors contributed to the development of antibiotic-resistant bacteria?

Natural Selection

- **Natural Selection** is the process by which populations change over time.

- It consists of several distinct ideas:

1. Overproduction
2. Struggle for existence (competition)
3. Variations
4. Environmental changes which lead to survival of the fittest
5. Formation of a new species (speciation)

Theory of Natural Selection

1) **Overproduction** – more offspring produced than can possibly survive (the environment has limited resources)

Turtles lay up to 200 eggs!

Theory of Natural Selection

2) **Struggle** for **existence** (Competition) – organisms compete within and between species for limited resources because of overproduction.

Theory of Natural Selection

3) **Variation** – inherited differences in traits occur among members of the same species.

Variation exists in all populations and the genetic differences are passed on to the next generation

Theory of Natural Selection

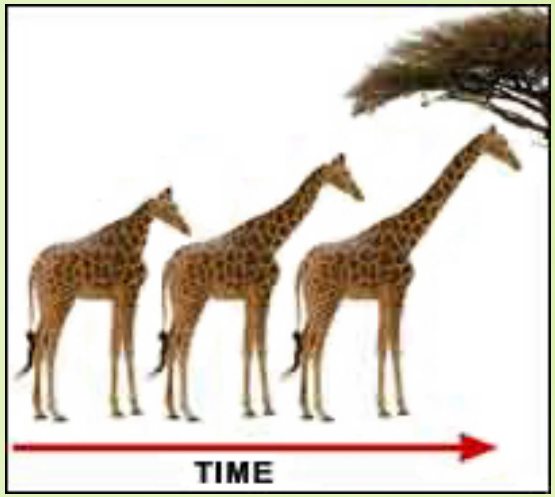
4) **Survival of the Fittest** – surviving organisms are ones better able to compete, survive and reproduce.

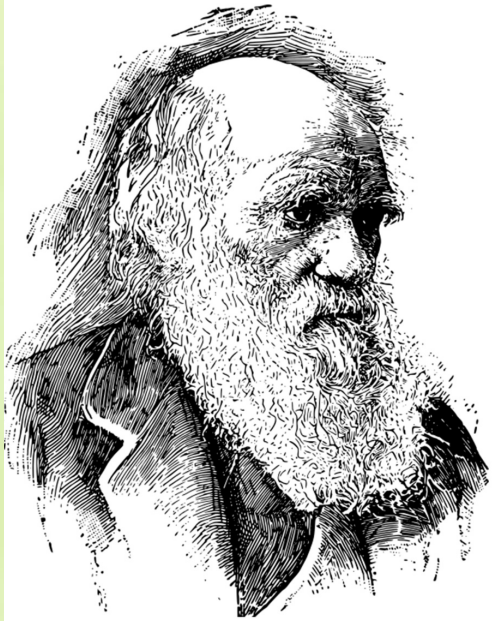
   The others die without leaving offspring (natural selection)

   - Only those organisms that **live long enough to reproduce** will pass their DNA for the 'desirable' traits onto their offspring.
   - Those organisms less suited will die before reproducing
   - The population becomes more "fit" over time.

Ex: Giraffes

- Began with short necks
- Those that were BORN with slightly longer necks got more food and were better fighters
- Could grow stronger to outrun predators and survived to have babies!





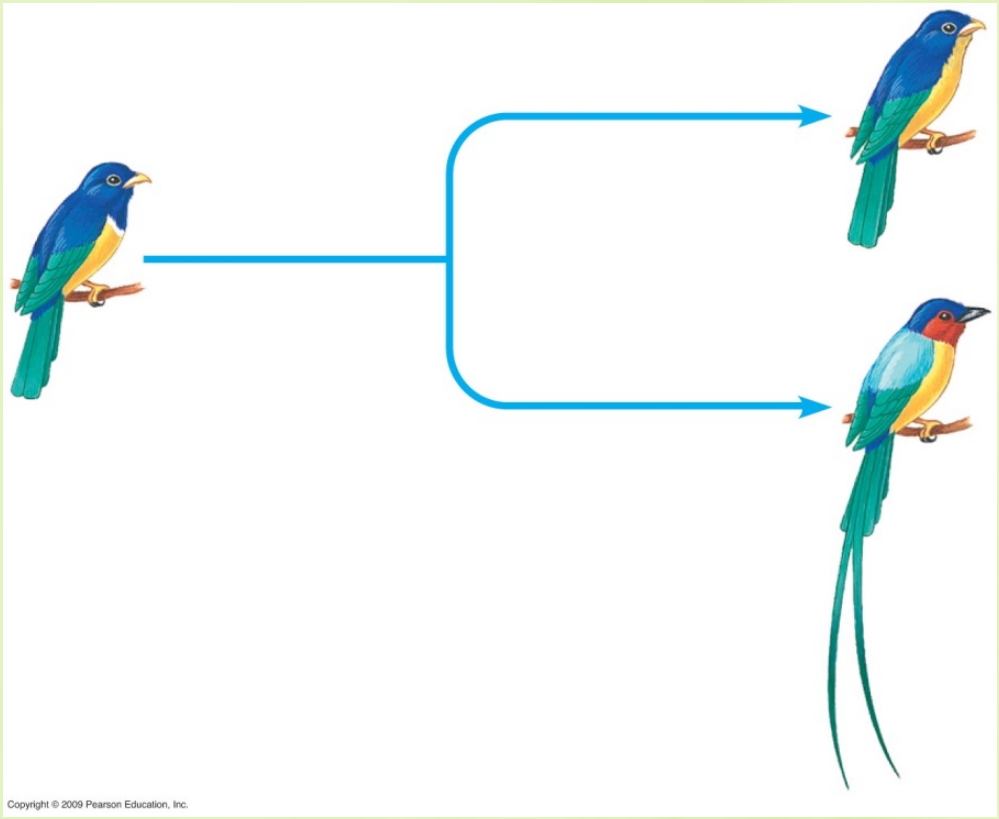
Find food.

Don't die.

Have sex.

Theory of Natural Selection

5) **Speciation** – over numerous generations, new species arise by accumulation of inherited variations of traits; considered new species when members cannot interbreed



Natural Selection

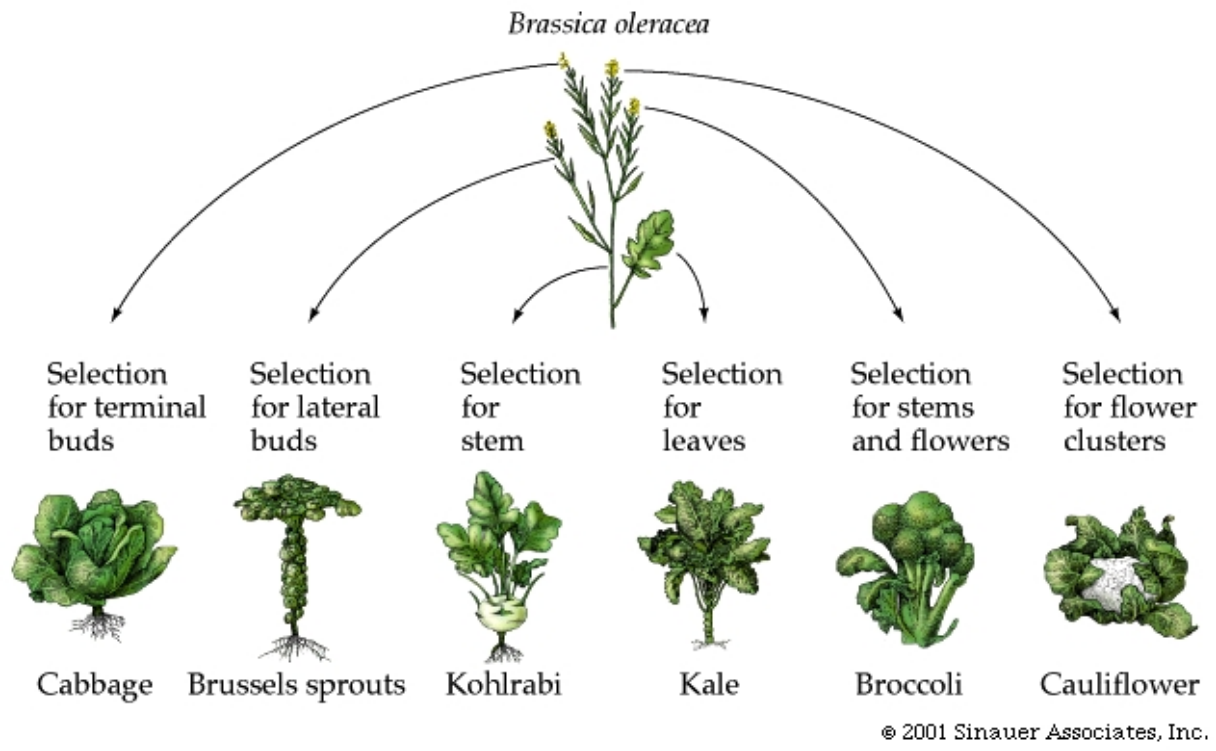
- **The environment is constantly changing.**
- Those individuals that possess variations that allow them to tolerate, or thrive, in the environmental change, will survive and reproduce (survival of the fittest)
- In this way the environment exerts **selective pressure** on a population.
- As time passes, individuals that are "**selected" for success** continue reproducing and passing along the successful mutation. After time, many of the offspring in the next generation will have this new trait, or adaptation

Example: Selective Pressure

- In a population of grasses, some of the grasses are better adapted to survive drought conditions
- If a drought occurs, it exerts a selective pressure that favours those plants that are drought-resistant
- This causes a change in the makeup of the population, as the drought-resistant plants will survive and pass on this resistance to their offspring

Artificial Selection

- Human intervention in the breeding of plants and animals to ensure that desirable traits (like seed size, taste, coloration, etc) are represented or magnified in successive generations.



Natural Selection

- Natural selection does not describe changes happening to *individuals*
- *Individuals do not change* during their lifetimes.
- *Species change* over several generations.
- So…how do new traits appear?
  - Mutations create new genes (DNA)
  - Sexual reproduction produces new combinations of genes

4.2 Developing a Theory to Explain Change

- Over 2000 years ago, the most important Greek philosophers (Plato and Aristotle) believed that life existed on Earth in a perfected and unchanged form

Creationist Theories

- Creationists believe that God created all organisms in their original state during a period of creation
- This particular period can vary, depending on literal interpretation (a 6-day creation followed by a day of rest) or more figurative interpretations (each day corresponding to a longer period of time)
- Literal creationists believe that the Earth is between 5000 and 6000 years old
- They attribute massive geological changes to cataclysmic events, such as the biblical flood (found in Genesis, chapters 6 – 9)
- However, there is a diverse range of creationist views

Developing the Theory of Natural Selection

- The theory of natural selection has developed over many centuries
- Because of the influence of the Roman Catholic Church in Europe, few evolutionary theories appeared until the 1700s

Comte de Buffon

- One of the first people to challenge the idea that life forms do not change
- In 1749 he published *Histoire Naturelle* in which he noted to similarities between humans and apes and speculated that they may have a common ancestor.
- He also went on to suggest that the Earth was much older than the 6000 years as was commonly believed.

Georges Cuvier

- Largely credited with developing the science of paleontology in 1800's
- Was the first to establish **extinction** as fact
- To explain his findings, he proposed that over the course of history, many destructive natural events such as floods or volcanic eruptions (which he called revolutions) may have killed numerous species each time

Catastrophism **(5 mass extinctions)**
TED mass extinction
6 crazy mass extinctions

Georges Cuvier

As he examined layers of rock, or strata, he noted several important things:

- Each stratum has a unique group of fossil species
- The deeper he looked, the more dissimilar the species were from current life forms.
- As he worked from one layer to the next, he found that new species would appear and other species would disappear, or become extinct
- Theory of superposition


What is this? It's sooooo cute!
It's a new species, sir we call it the "dog"
I want them on Earth Now!
Sir, they couldn't possibly proliferate with all the dinosaurs roaming arou-
NUKE THE LIZARDS

Charles Lyell

- Suggested, unlike Cuvier, that the geological processes that occur on Earth take long times, meaning the Earth was quite old
- Proposed that geological events are slow, continuous, and can result in substantial changes over time.
- Concluded this meant the Earth wasn't just older than 6000 years… it was ANCIENT


[redacted] ▶ [redacted]gainst
Science
17m •
The earth is 4000 years old.
Change my mind.
8 Comments
Like
Comment
[redacted]
The half-life of uranium-238 is 4.5 billion years. It decays into radium-226, which in turn decays into radon-222. Radon-222 becomes polonium-210, which finally decays into a stable nuclide, lead.
The existence of lead as an element disproves the 4000 year old myth
Like
Reply
5

Catastrophism

- Catastrophism is the idea that the Earth has been subject to sudden, violent, events that have been large enough to have worldwide effects (think volcanoes)
  - Nothing is certain!
- This contrasts with uniformitarianism (**gradualism**) which says that slow, gradual, consistent processes are what have shaped Earth's surface (think erosion)
  - All processes have been occurring as they are
  - Requires long periods of time
- Today, these ideas are combined

Transmutation of Species

- Cuvier and Lyell were firm believers that species were unchangeable
- Buffon and Lamarck believed in what was called the **transmutation** of species
  - Species were not fixed as they are, but could change over time.

Jean-Baptiste Lamarck

- Proposed that animals evolved through continued use of an organ or limb. Disuse of organs/limbs resulted in “de-evolution” of them…until they disappeared entirely.
- Basically proposed that acquired characteristics could be passed on to the next generation
- With a greater understanding of cells, genes, heredity by the end of the 1800’s, Lamarck’s mechanism for inheritance was rejected.

Lamarck

1. **Law of Use and Disuse**: organisms can change their body features during their lifetimes to satisfy their needs.
2. **Acquired characteristics are inherited**: those characteristics changed during the lifetime of an individual can be passed on to offspring
   - Ex) Giraffes are able stretch their necks to reach leaves and this trait is passed on to their offspring.

5 myths of evolution

ACQUIRED TRAITS

DEFINITION

Acquired traits are characteristics or attributes that organisms develop during their lifetime due to experiences and environmental influences. Unlike inherited traits, which are passed down through genes, acquired traits are not present at birth and can be influenced by individual behavior and interactions with the environment.

EXAMPLES

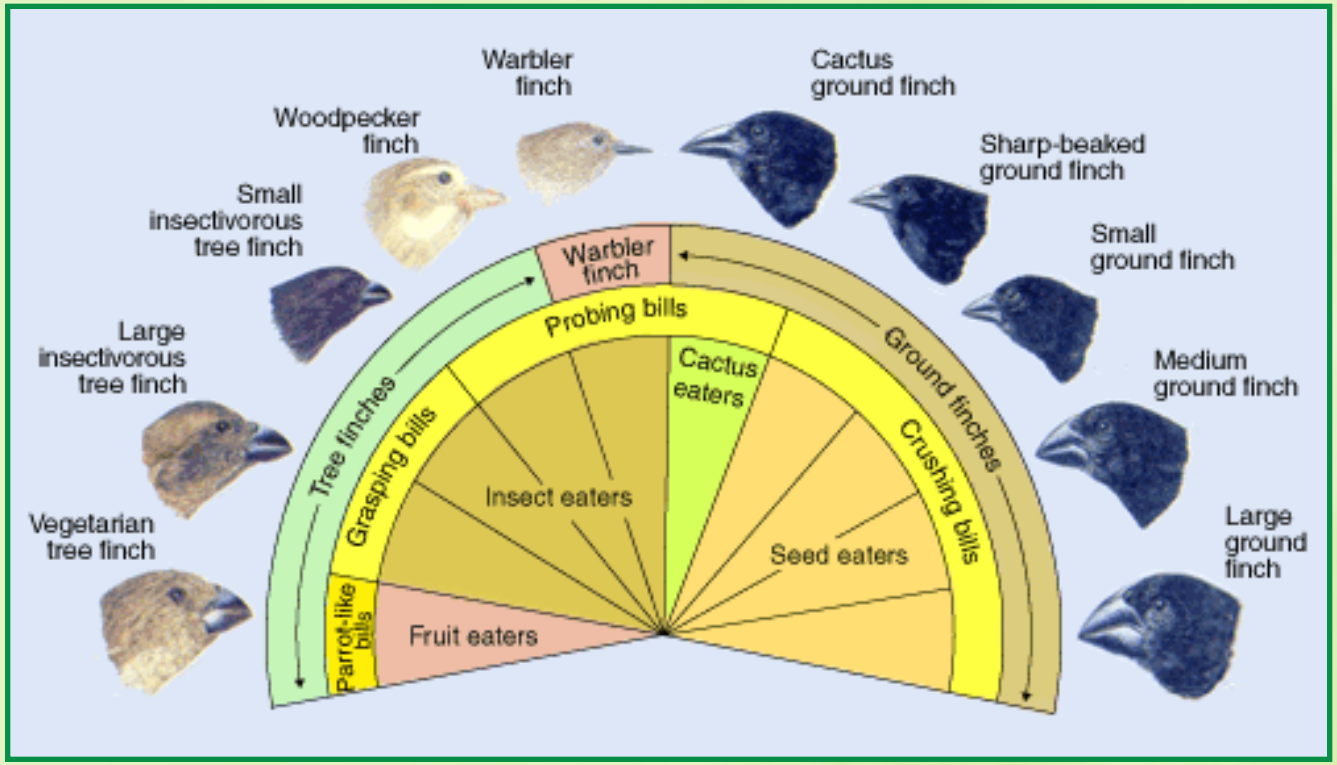
- Reading skills
- Playing a musical instrument
- Speaking a second language
- Cooking skills
- Knowledge of history
- Bodybuilding results
- Driving skills
- Painting or drawing skills

Charles Darwin

- In 1831, a young Darwin traveled aboard the HMS *Beagle* on a voyage to map the coastline of South America
- He made observations of wildlife and geography of various countries and recorded the differences and similarities from place to place

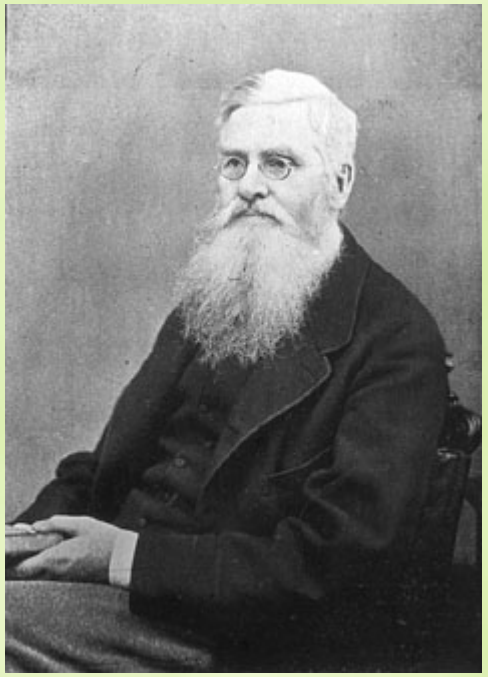
Darwin

- On the Galapagos Islands, he noticed finches had adapted to eat blood, use sticks in holes, drill holes, among other adaptations



Alfred Russel Wallace

- At the same time that Darwin was studying his observations made on the Beagle voyage, Wallace was studying organisms in South America and Malaysia
- While delirious with malaria, Wallace came to similar conclusions as Darwin (that were currently unpublished) - that the mechanism that drove the transmutation of species was natural selection.



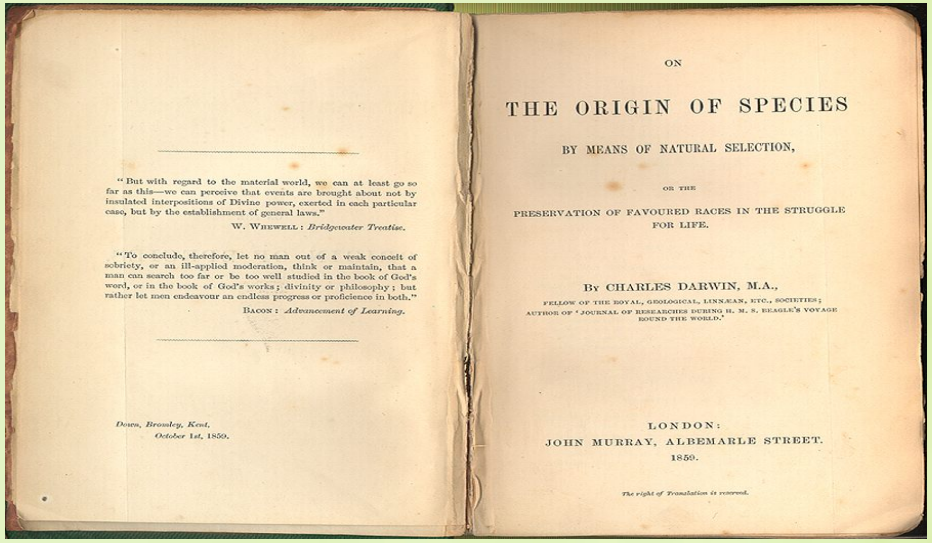
The Theory of Evolution by Natural Selection

- Both Darwin and Wallace were influenced by Thomas Malthus' *Essay on the Principles of Population* that stated that populations produced more offspring than an environment could support
- Darwin and Wallace reasoned that competition for limited resources would select for favorable traits
- Therefore, a proportion of the population would have these traits
- As time passed, a greater proportion of the population would have these beneficial traits as they improved their chances of surviving and reproducing

Darwin

- Darwin formally proposed that evolution occurred by natural selection and published his theory in *The Origin of Species* in 1859

As many more individuals of each species are born than can possibly survive; and as, consequently, there is a frequently recurring struggle for existence, it follows that any being, if it vary however slightly in any manner profitable to itself, under the complex and sometimes varying conditions of life, will have a better chance of surviving, and thus be *naturally selected*. From the strong principle of inheritance, any selected variety will tend to propagate its new and modified form.



"But with regard to the material world, we can at least go so far as this—we can perceive that events are brought about not by insulated interpositions of Divine power, exerted in each particular case, but by the establishment of general laws."
W. Whewell: *Bridgewater Treatise.*

"To conclude, therefore, let no man out of a weak conceit of sobriety, or an ill-applied moderation, think or maintain, that a man can search too far or be too well studied in the book of God's word, or in the book of God's works; divinity or philosophy; but rather let men endeavour an endless progress or proficience in both."
Bacon: *Advancement of Learning.*

Down, Bromley, Kent,
October 1st, 1859.

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, LINNÆAN, ETC., SOCIETIES; AUTHOR OF 'JOURNAL OF RESEARCHES DURING H. M. S. BEAGLE'S VOYAGE ROUND THE WORLD.'

LONDON:
JOHN MURRAY, ALBEMARLE STREET.
1859.

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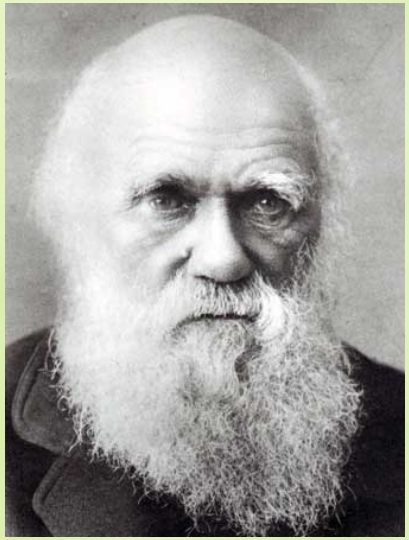


Darwin's *On the Origin of Species*

- Darwin's book proposed two main ideas based on his observations:

1. Present forms of life have descended from ancestral species
2. The mechanism for modification is natural selection that takes place over a long period of time

Darwin's *On the Origin of Species*

- **Remember, evolution by natural selection consists of several distinct ideas:**

1. **Overproduction**
2. **Struggle for existence (competition)**
3. **Variations**
4. **Survival of the fittest**
5. **Formation of a new species (speciation)**

Evidence of Evolution

- **Evolution** is the process by which populations of living things change over a series of generations.
- Evolution results in diversity.
- **A. Direct evidence of evolution:** The visible evidence that takes us **back in time** and shows how an organism has changed is the direct evidence of evolution. Example: Paleontological evidence (Fossils). Fossil gives us traces of reptiles evolving into birds.
- **B. Indirect evidence of evolution:** The evidence that shows some kind of **evolutionary connection** between organisms is indirect evidence of evolution.Example: anatomical, embryological, morphological, and molecular.
- Indirect evidences of evolution are **those evidences that can be derived from inferences**.

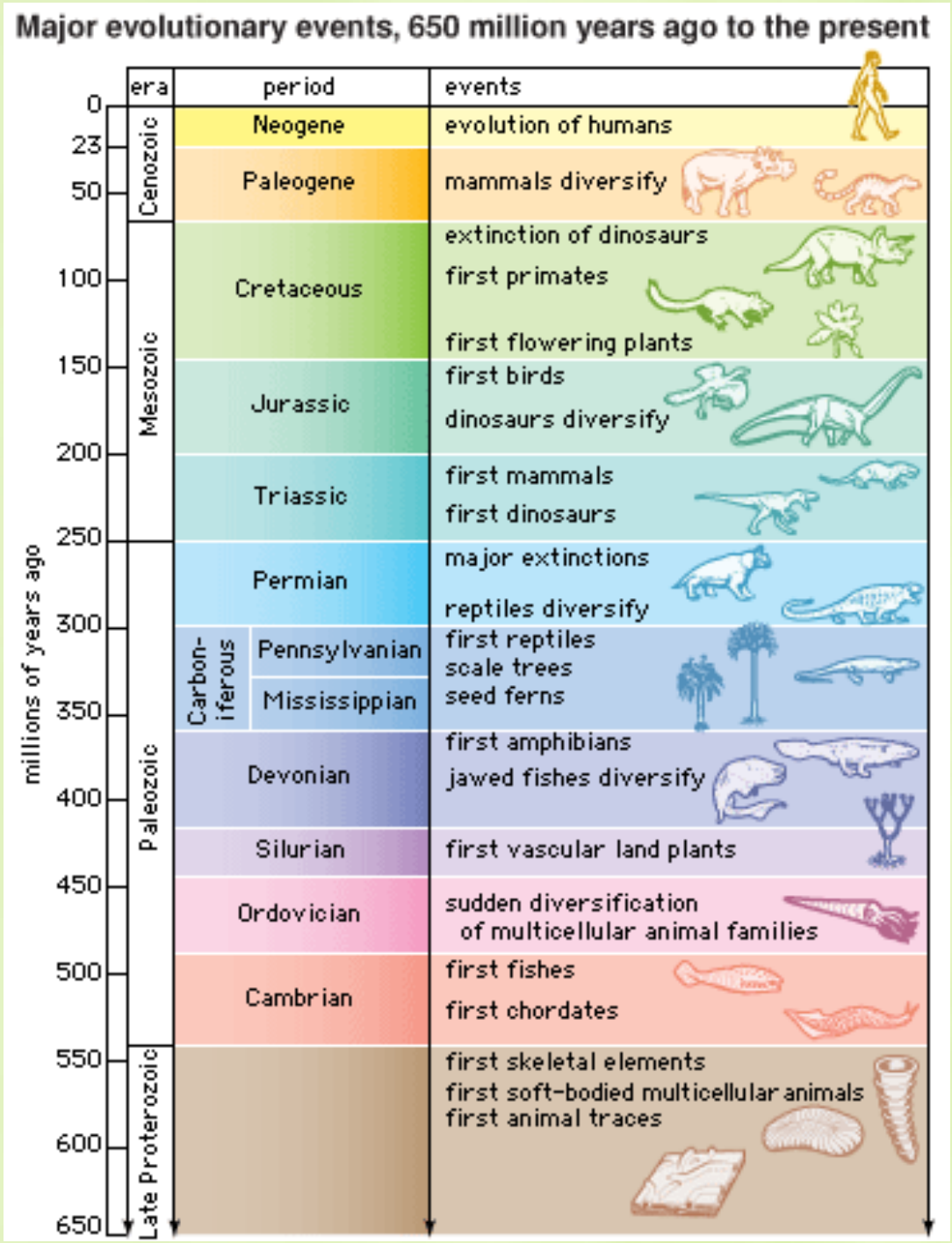
Direct Evidence: Fossils

- Paleontology is the study of fossils, which are the remains, impressions and traces of organisms from past geological ages.
- Fossils are formed within sedimentary rock
- The layer in which a fossil is found often is indicative of the age of that particular specimen
- Radioactive dating is used to estimate the age of rocks based on the decay of radioactive isotopes. The relative quantities of isotopes are measured, and calculations are based on "normal" amounts of those isotopes.

Finding Lucy

Direct Evidence: Fossils

- Fossils found in layers of rock near the surface appear to be much more closely related to modern species than fossils found in older layers
- Fossils appear in chronological layers, so probable ancestors of a particular species would lie beneath the rock layers in which the more current species is found
- Not all organisms appear in the fossil record at the same time, which indicates that different species evolved at different times


Major evolutionary events, 650 million years ago to the present
millions of years ago
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50
100
150
200
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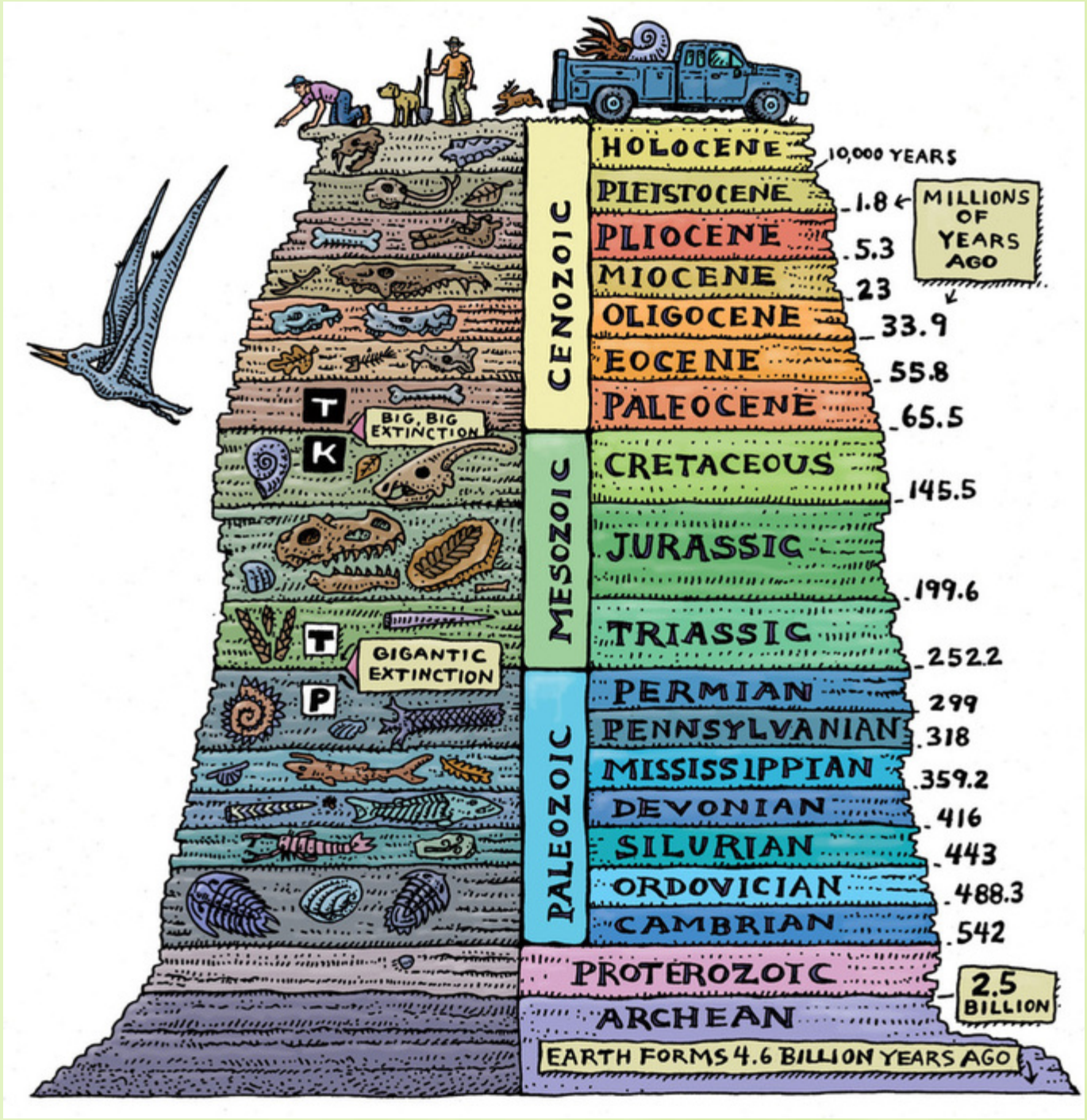
650
era
period
events
Cenozoic
Mesozoic
Paleozoic
Late Proterozoic
Neogene
Paleogene
Cretaceous
Jurassic
Triassic
Permian
Carbon-iferous
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
evolution of humans
mammals diversify
extinction of dinosaurs
first primates
first flowering plants
first birds
dinosaurs diversify
first mammals
first dinosaurs
major extinctions
reptiles diversify
first reptiles
scale trees
seed ferns
first amphibians
jawed fishes diversify
first vascular land plants
sudden diversification
of multicellular animal families
first fishes
first chordates
first skeletal elements
first soft-bodied multicellular animals
first animal traces


HOLOCENE
10,000 YEARS
PLEISTOCENE
1.8
MILLIONS OF YEARS AGO
PLIOCENE
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EOCENE
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PALEOCENE
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T
BIG, BIG EXTINCTION
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JURASSIC
199.6
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MESOZOIC
T
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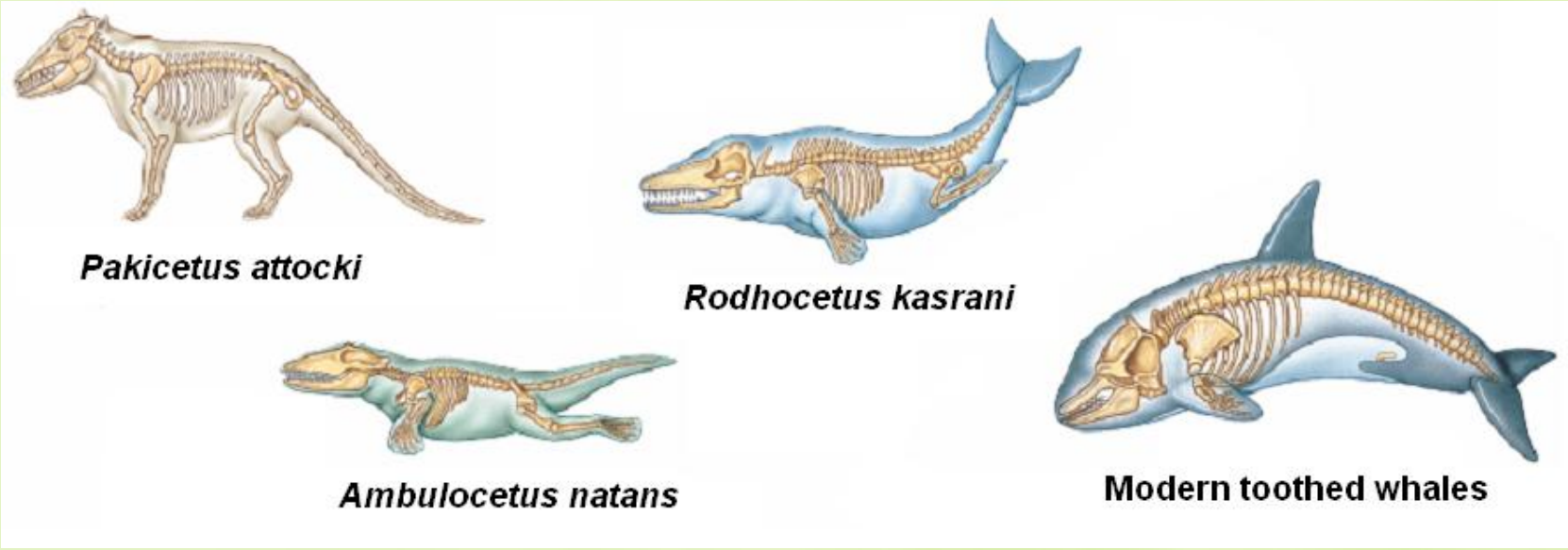
PERMIAN
299
PENNSYLVANIAN
318
MISSISSIPPIAN
359.2
DEVONIAN
416
SILURIAN
443
ORDOVICIAN
488.3
CAMBRIAN
542
PALEOZOIC
PROTEROZOIC
2.5 BILLION
ARCHEAN
EARTH FORMS 4.6 BILLION YEARS AGO

Transitional Fossils

- Often there were apparent gaps in the fossil record
- Over time, transitional fossils are found that fill the gaps and link different species together

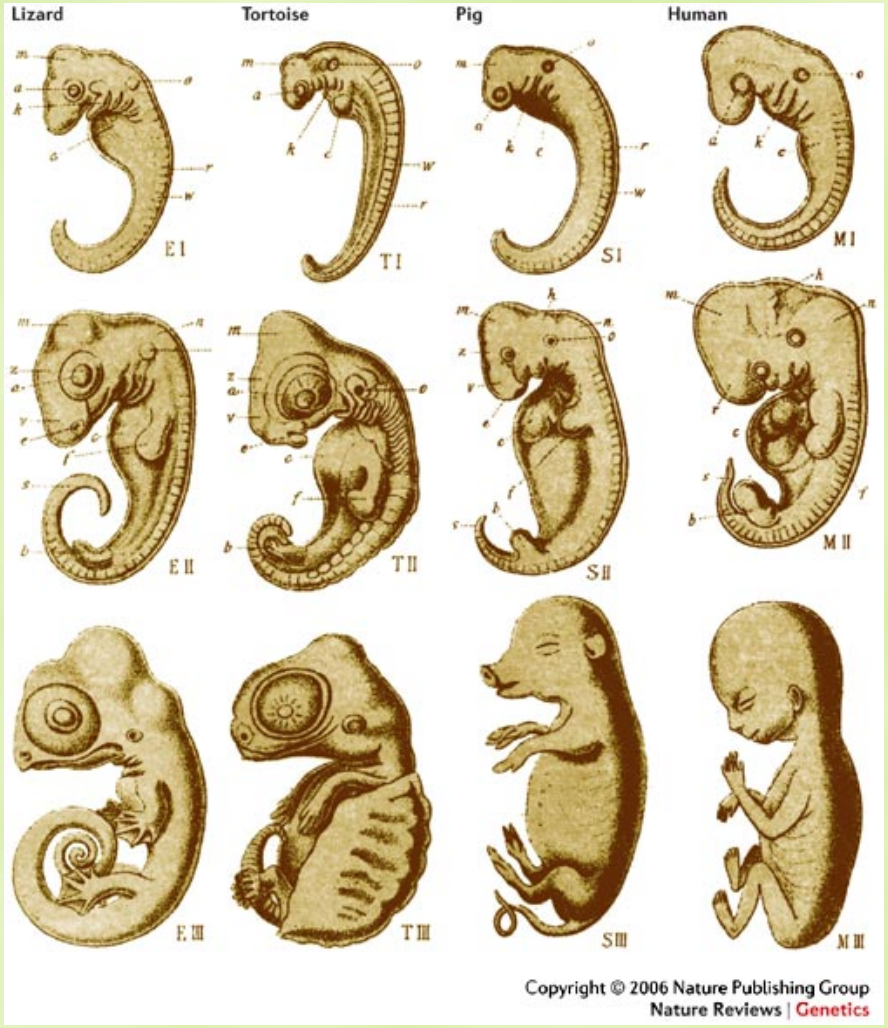


Indirect Evidence for Evolution

1. Embryology
2. Morphology
    a) Homologous structures
    b) Analogous structures
3. Vestigial Structures
4. Molecular biology
5. Biogeography

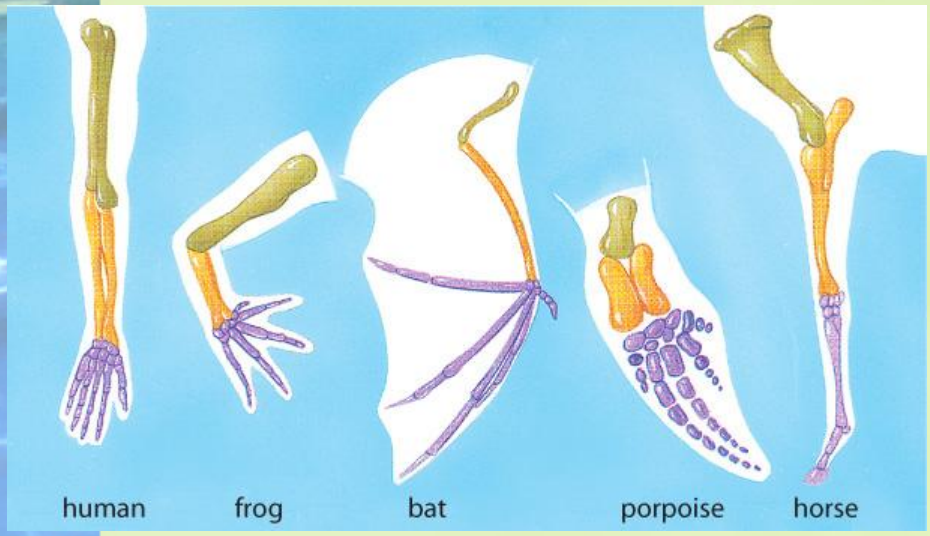
Embryology

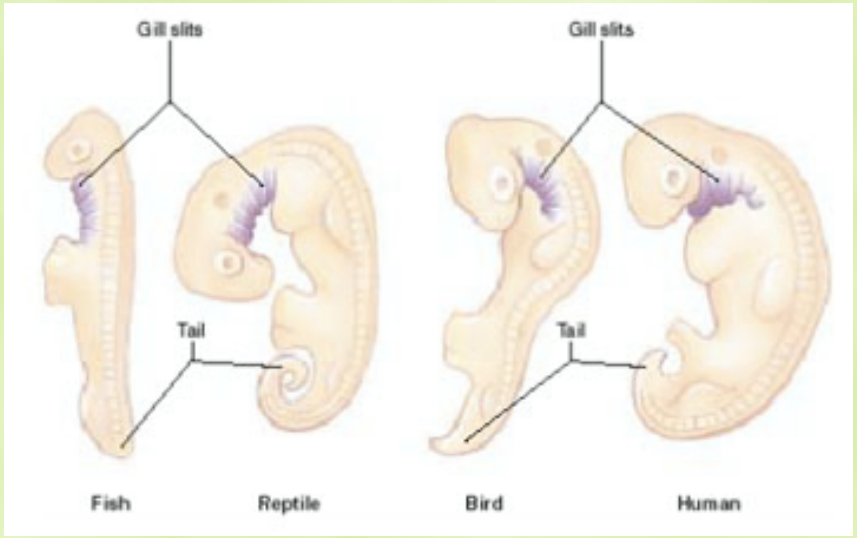
- The study of organisms in the early stages of development
- Most vertebrate embryos are similar to each other at some point in their development
- This points to a common ancestral origin



Morphology: Homologous Structures

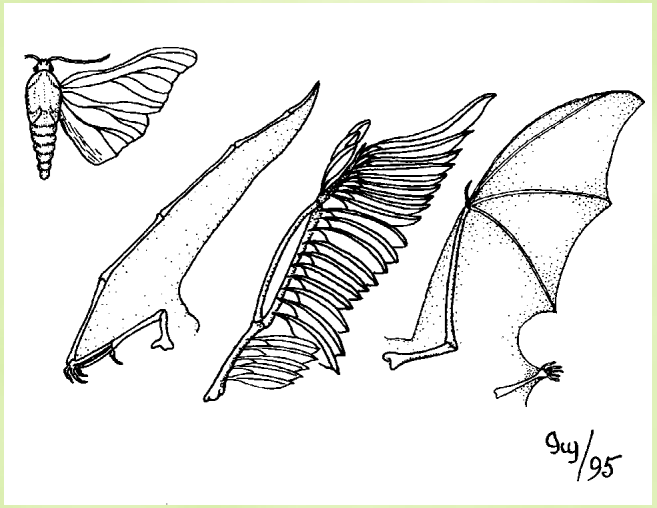
- Structures that originate from the same ancestor, but evolve or develop differently.
- Have common origins even in the embryo (eg. gill slits, forelimbs of vertebrates)
- Evidence of a common ancestor





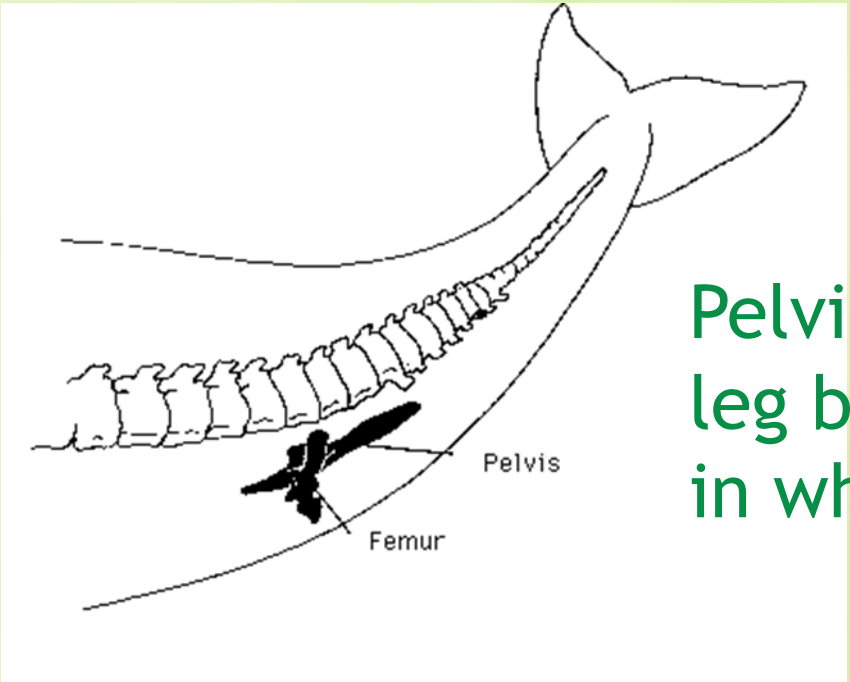
Morphology: Analogous Structures

- Similar functional structures, but develop from different embryological structures
- These organisms do NOT descend from a common ancestor
- Caused by *convergent evolution* in species (ie: pandas / human opposable digits)
- ex: wings of insects, birds and bats



Vestigial Structures

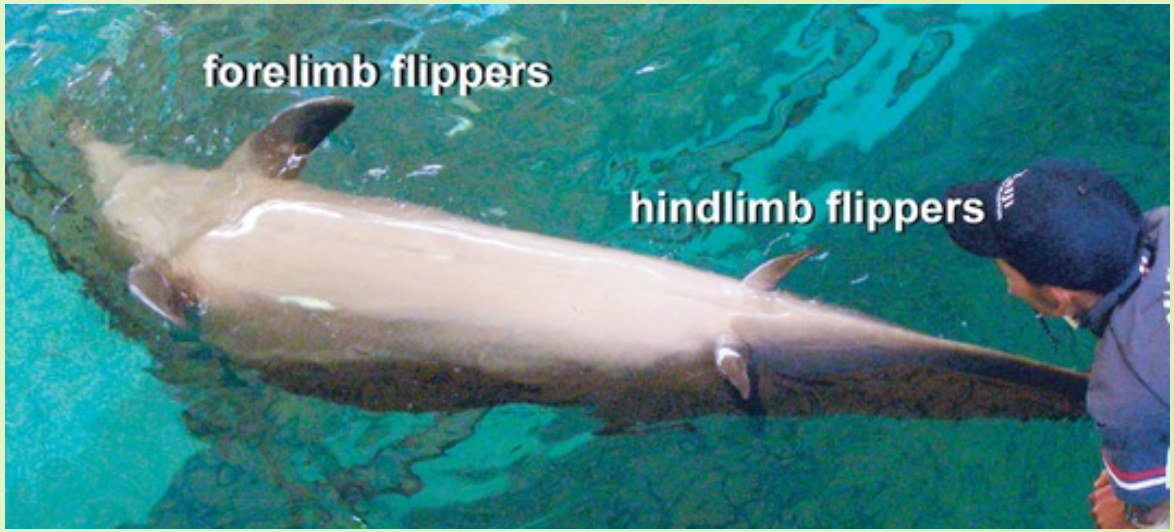
- Are structures present in organisms that have no present day functions
- May be ‘left over’ from previous evolutionary stages



Pelvis and leg bones in whales

Vestigial Structures

Limb buds and claws in snakes

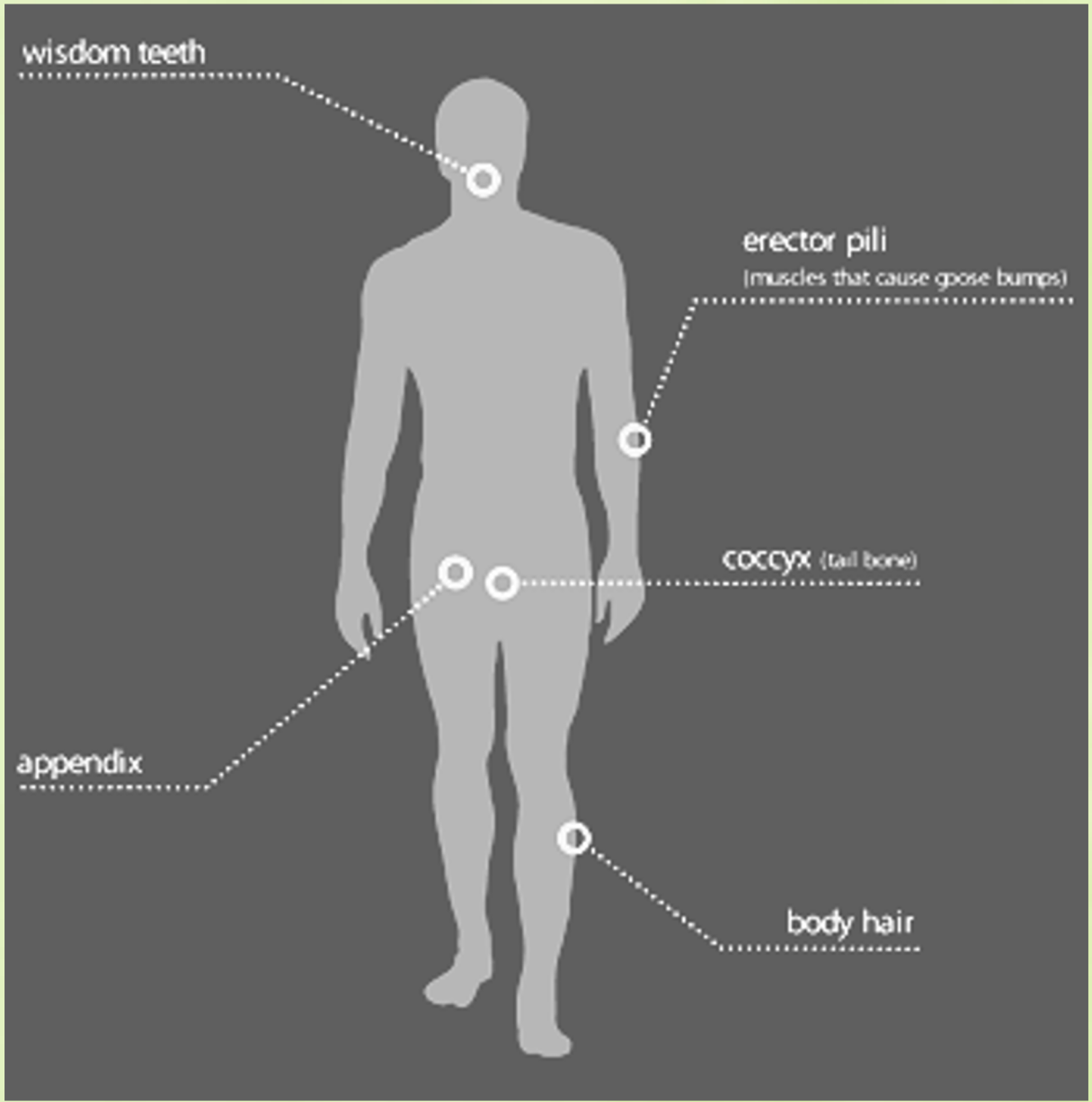


Hind limbs on dolphins

Human Vestigial Structures

Hiccups

hiccup girl



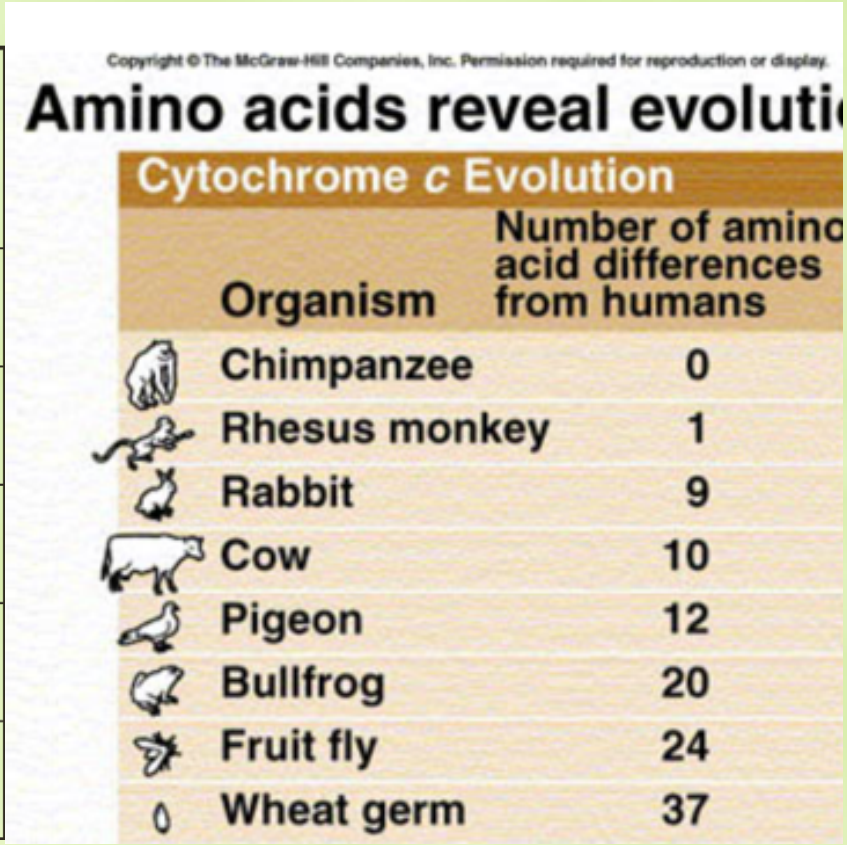
Molecular Biology

- Evolutionary relationships can be studied and traced using DNA
- We have learned that some traits are shared by all organisms:
- **Cell Design:** all eukaryotic cells contain a nucleus, cell membranes made of similar material, and mitochondria
- **Proteins:** many organisms contain the same or similar proteins and enzymes that perform similar functions in their bodies. (ex: insulin)
- **Genetic Material:** many organisms share a significant portion of DNA. This points to a common ancestor.

Molecular Biology

- Recent advances in DNA profiling and protein sequencing has allowed us to study the similarities in common molecules

Primate	No. Of Amino Acids Different From Humans
Chimpanzee	Identical
Gorilla	1
Gibbon	3
Rhesus Monkey	8
Squirrel Monkey	9



Genetics

- When Darwin proposed his theory of evolution, very little was understood regarding genetics or DNA
- We now know the following:

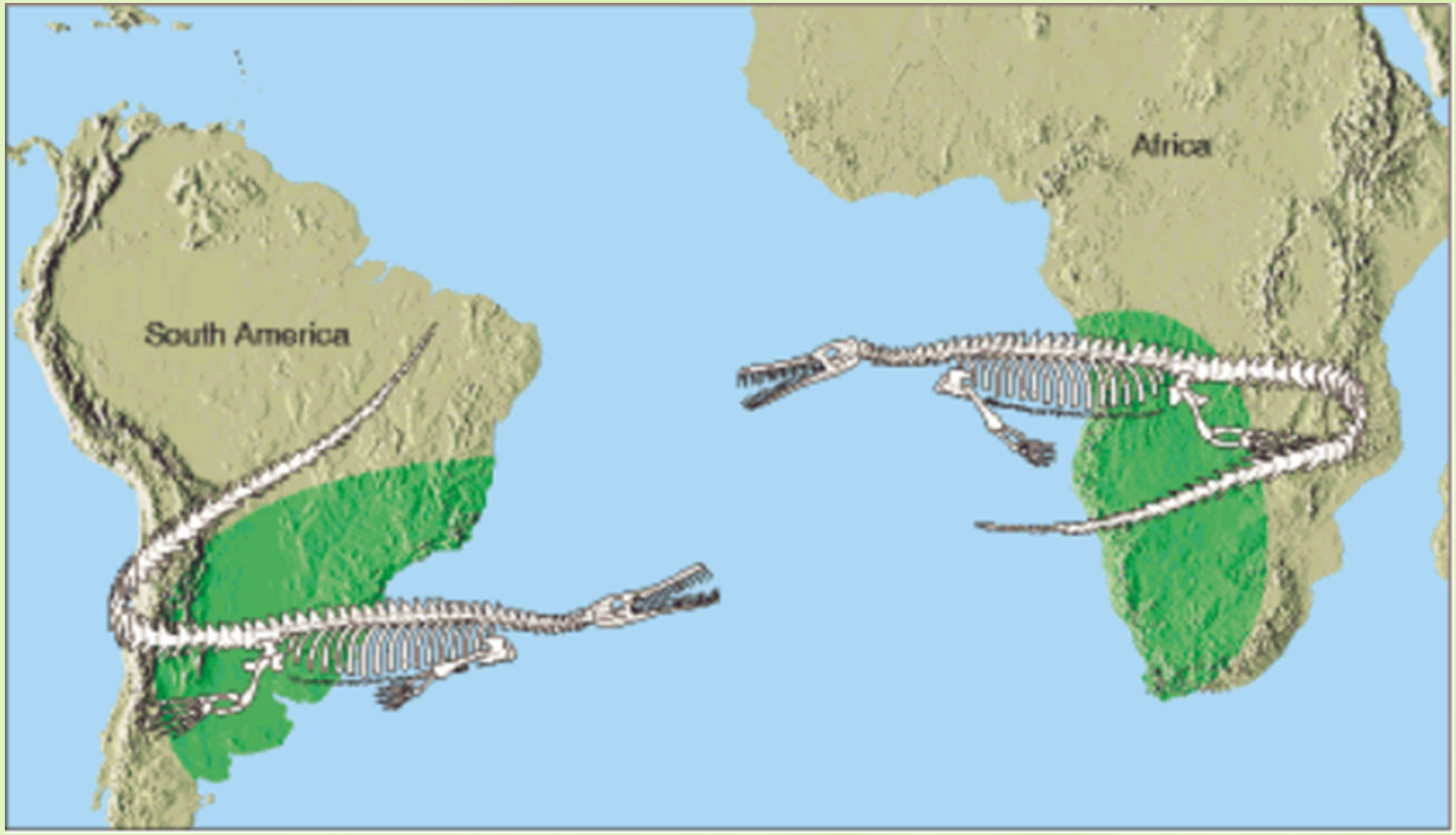
1. Species pass on their traits to offspring using genetic material (DNA)
2. The genetic material can randomly change (mutations), leading to variation in traits

The Scopes Trial

- In 1925, John Scopes was arrested and put on trial for teaching Darwin's evolutionary theory in his High School Biology class in Dayton, Tennessee
- He was convicted and fined $100

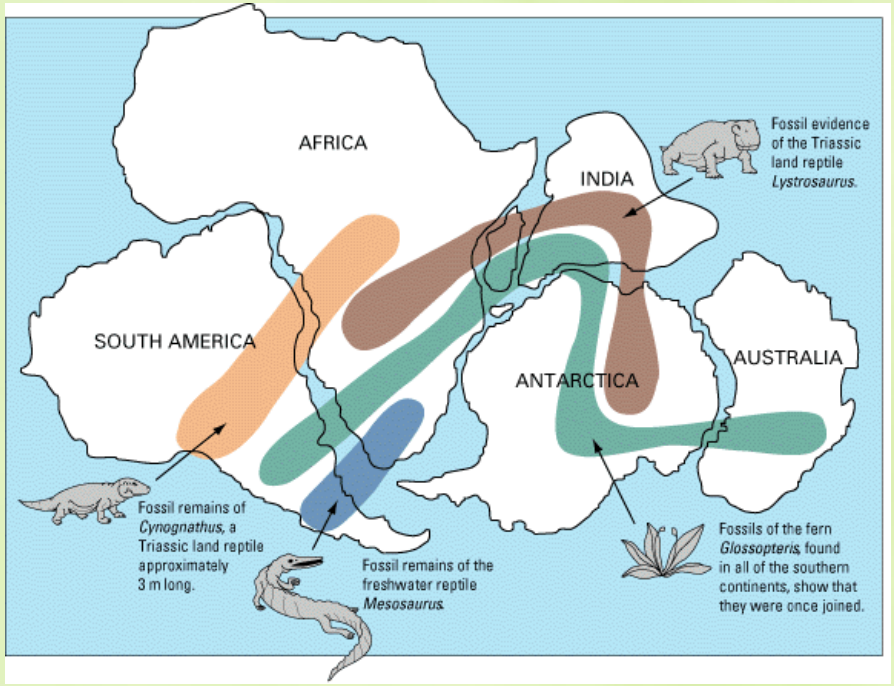
Biogeography

- study of geographical distribution of plants and animals



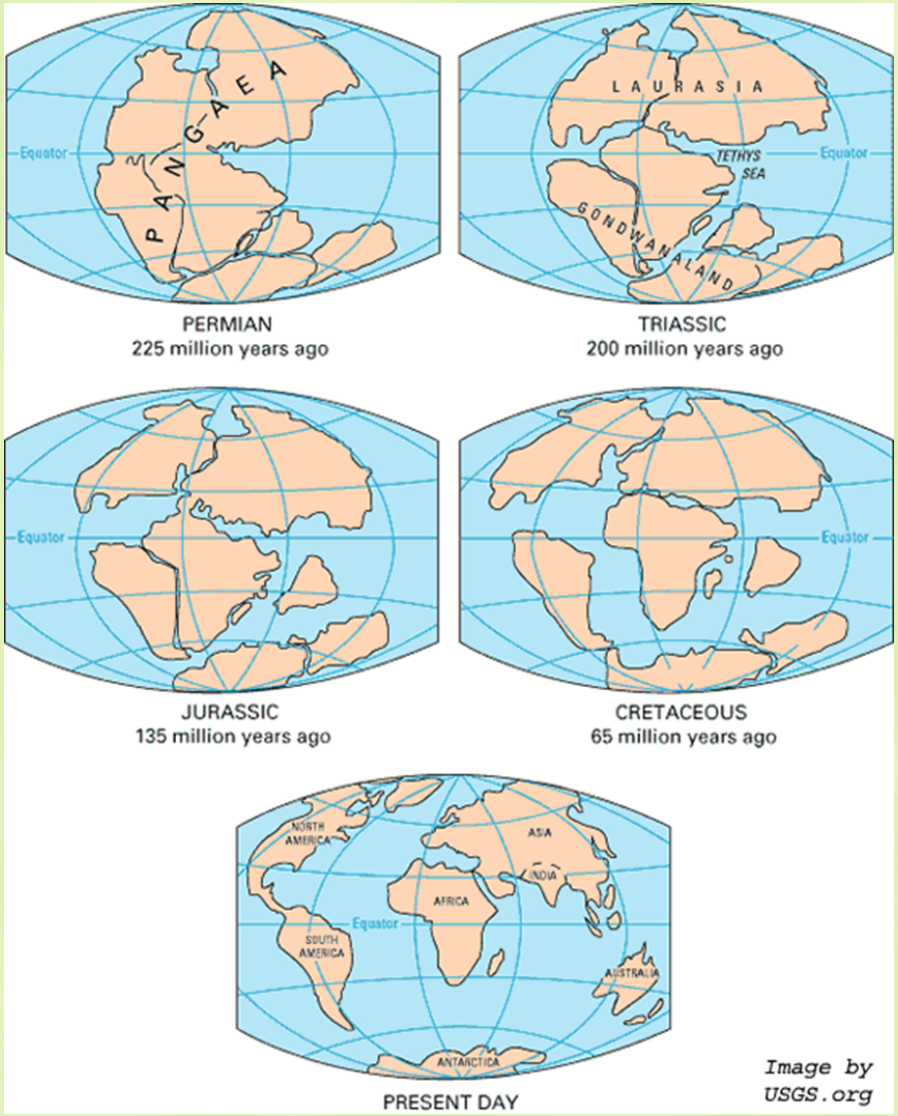
Biogeography

- **Wegener's Theory of Continental Drift**
  - Started in 1912 but reappeared/accepted 1960s
  - all continents were once joined into one supercontinent called "Pangaea", then broke apart and continue to move apart today



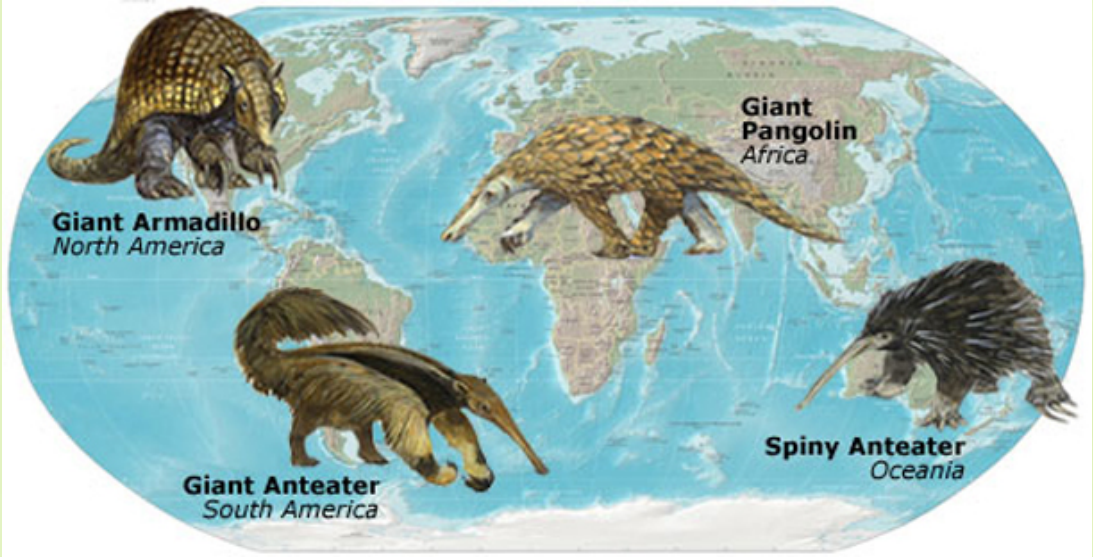
Continental Drift

- Climate and other environmental factors affect distribution patterns of organisms over the "short term" (thousands of years).
- Changes in the positions of continents (continental drift) occur over longer periods of time (millions of years).



Continental Drift

- Differences in the distribution of reptiles and amphibians compared to mammals are explained by the super continent theory
  - animals that evolved before the break up (reptiles and amphibians) are widely distributed
  - those that evolved after the breakup (mammals) are more limited in distribution



Continental Drift

- Amidst the frigid expanse of the North Atlantic Ocean lies a land of fire and ice – Iceland. This island nation sits right over the Mid-Atlantic Ridge, a **divergent plate boundary** that extends from the Arctic to the tropics.

- The **Mid-Atlantic Ridge** forms a spectacular underwater mountain range, stretching over 16,000 kilometers (10,000 miles). In Iceland, this underwater ridge reaches above sea level, creating an impressive landscape of volcanoes, geothermal springs, and geysers.

- Iceland's rift valley, most part of which is hosted in the **Thingvellir National Park,** is an example of this ongoing geological drama. Visitors can walk along the crest of the rift valley, literally standing on the boundary between two continents.

Continental Drift

Iceland's rift valley, most of which is hosted in the Thingvellir National Park

Examples of Biogeographical Evidence

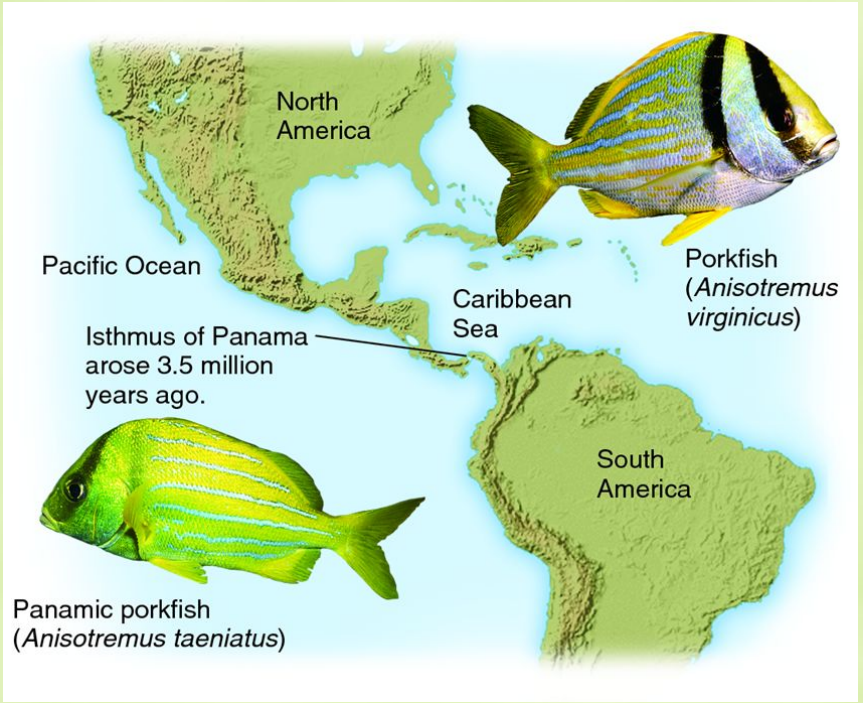
- Darwin studied finches in the Galapagos Islands. Different islands had different finches, each with unique forms of their beaks.
- He attributed this to the food found in the environment on different islands.
- Variations in beaks that were beneficial on their island would result in more success, and be more likely passed on

Isolation of Populations

- For speciation to occur, species must be prevented from breeding
- Therefore, there must be biological or geographical barriers that prevent breeding
- If the populations are separated for a long enough time, changes occur in the populations through natural selection

Geographical Barriers

- These keep populations physically separated
- These physical barriers only need to be present long enough for speciation to occur
- Examples of geographical barriers:
  islands, mountain ranges, continent separation, removal/destruction of land bridges, new river formation



Biological Barriers

- Biological barriers occur between species that share the same geographical ranges
- Examples may include:
  - physical incompatibility
  - structural or molecular blockage of the formation of a zygote

The love song of the male golden orb spider is a mating behavior specific to the species.
Other species that do not produce the characteristic song are eaten by the female when they attempt to mate with her.

Reproductive Isolation

- Therefore, different species are reproductively isolated from other species
- This can be due to a number of different factors:

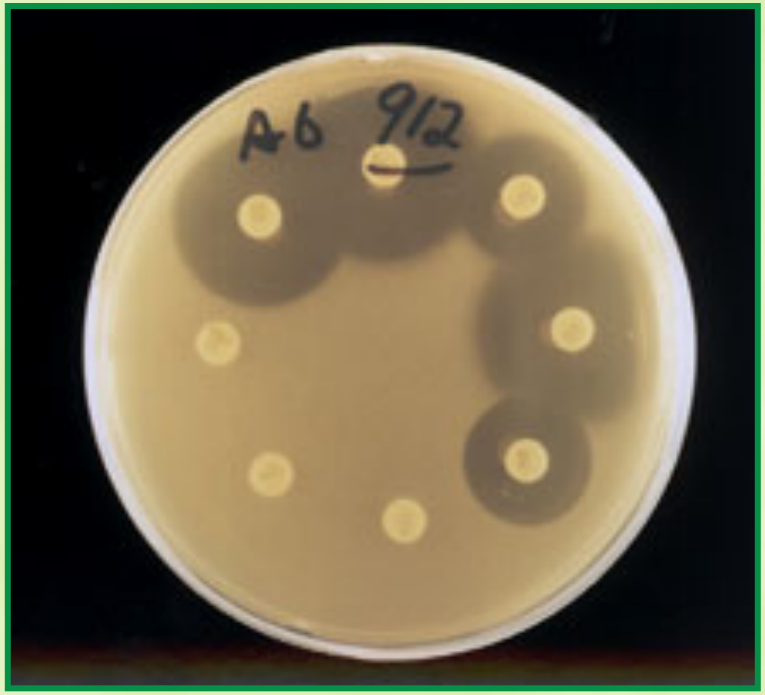
1. **Habitat Isolation** – includes geographical barriers that prevent physical contact
2. **Temporal Isolation** – some species are fertile at different times of the year
3. **Behavioural Isolation** – some species require a mating ritual in order to recognize as a suitable partner **Boobie dance**
4. **Physiological Isolation** – some species' anatomy are not compatible or may require a certain pheromone to attract mates. Even if offspring were conceived, they are often sterile.

4.3 How Species Form

- Recall: A species is a group of individuals capable of interbreeding and producing fertile offspring
- Over time, individuals of a species develop mutations that lead to small changes in the offspring from generation to generation, referred to as *microevolution*.
- Many microevolution events can eventually lead to speciation (creation of a new species)

Microevolution

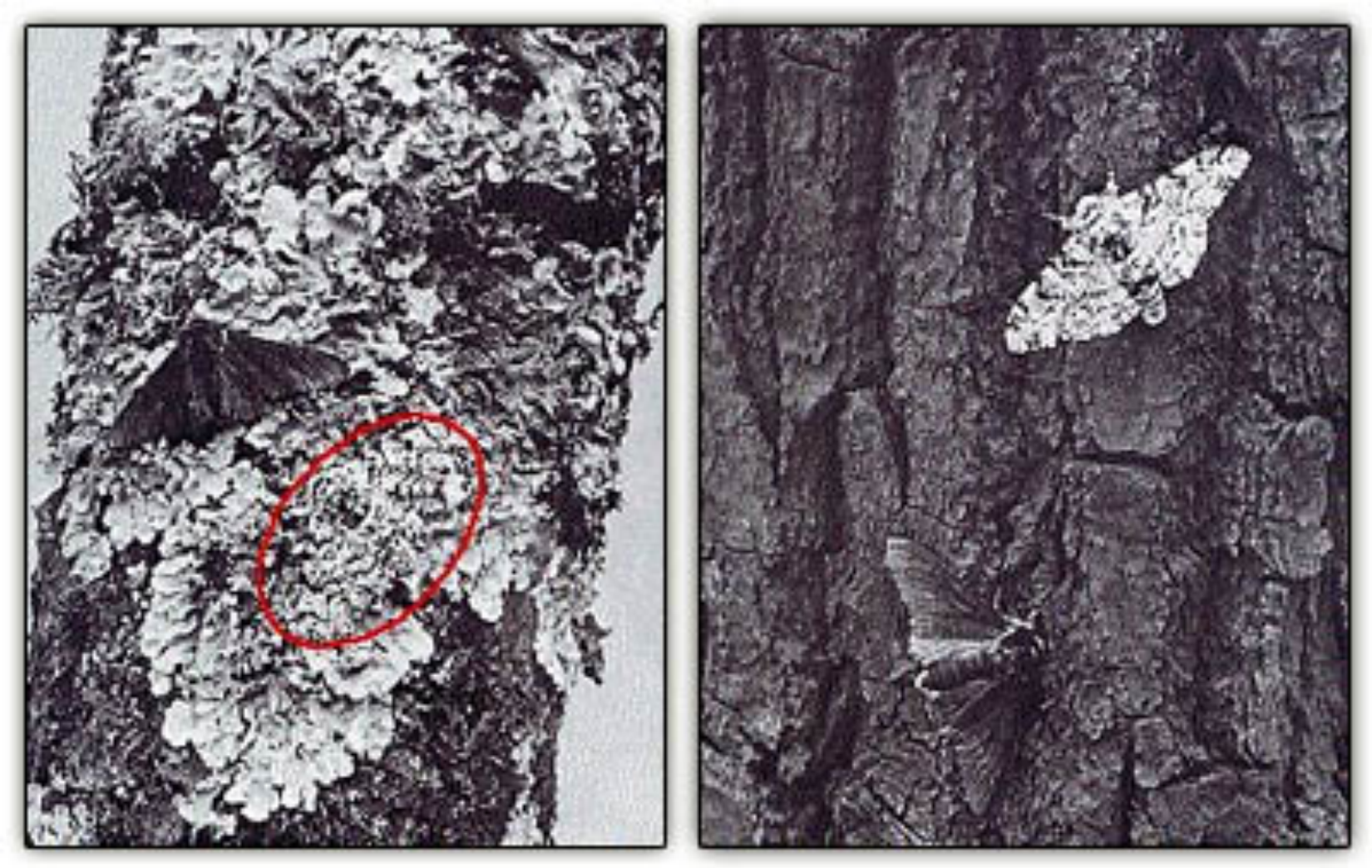
- Is the changing of an organism (population of organisms) over time **without** a change in species
- eg. Antibiotic resistance



Case Study - Peppered Moths

- Were white with black spots (a few were darker)
- Industrial revolution lead to increased soot on tree trunks very rapidly

Peppered Moths



Peppered Moths

- Within a few years, virtually all the moths were black
- Story may be simplified, but many other examples exist:

Ex. Fish becoming more oblong after net fishing introduced in AB lakes

– Elephants being born without tusks

Evidence Wrap Up

Peter and Rosemary Grant – Finches Galapagos (leads into speciation)

Macroevolution

- Species differences become so great that they are no longer able or no longer interested in interbreeding

Speciation

- Speciation, the formation of a new species, may result from the accumulation of changes in a population over time.
- Liger
- Liger Napoleon

How Species Form

- There are two general pathways that can lead to the creation of a new species

1. Transformation
2. Divergence

Species Formation

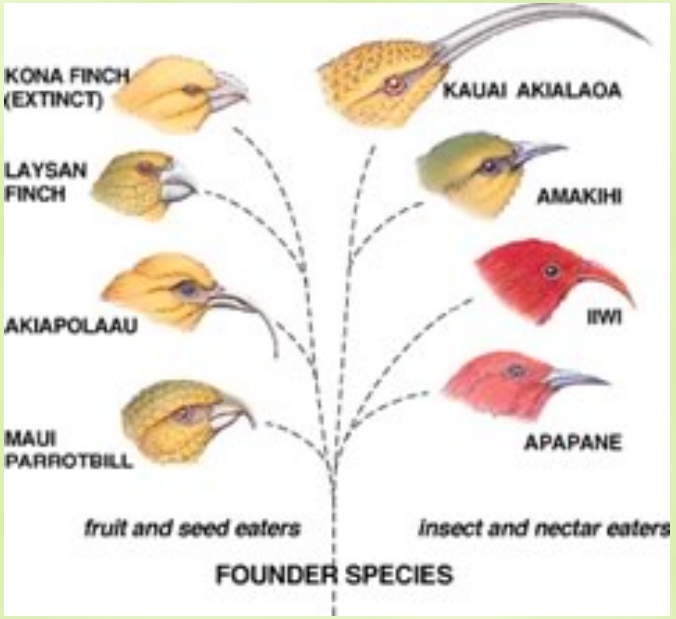
1. Transformation:
   - over many generations, genetic variations accumulate and the ancestral species is replaced by the emergence of a “better version”, a descendent that outcompetes its ancestors.

Species Formation

2. Divergence:
   - when a species undergoes evolutionary changes through reproductive isolation, resulting in 2 (or more) different species coexisting at the same time. They both experience different natural selections and both replace their ancestor species.
   - Divergence (aka adaptive radiation) increases biological diversity because it increases the number of species

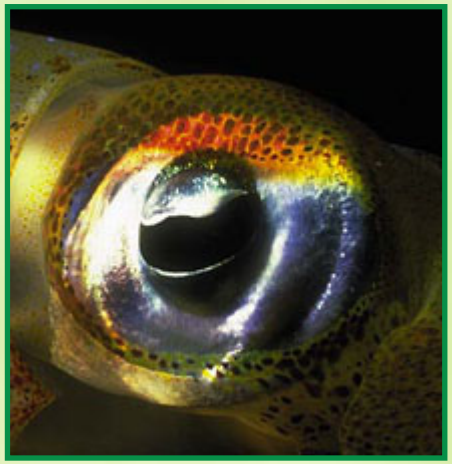
Speciation in Reproductively Isolated Populations

- A single founder species can produce a number of different new species
- This occurs when the offspring are reproductively isolated (and thus prevented from interbreeding) and develop variations



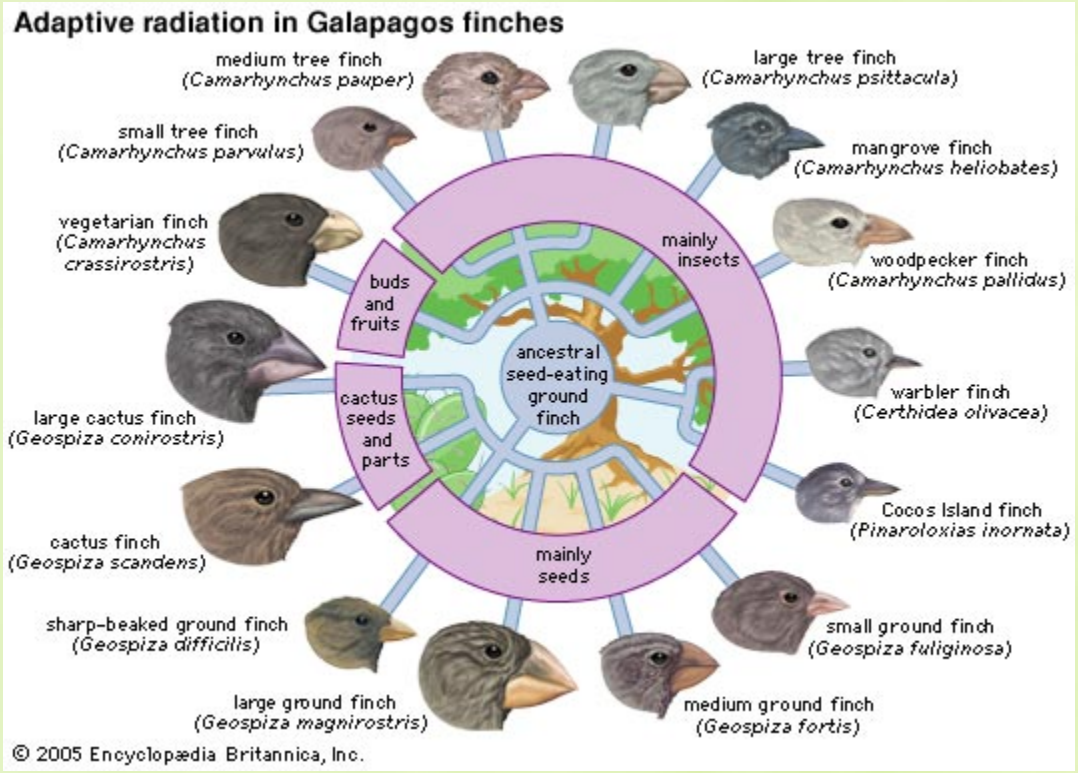
Convergent Evolution

- Very different species may also develop similar adaptations due to similar needs in their environment
- Eg. Squid and human eye



Adaptive Radiation

- Adaptive radiation is the diversification of a common ancestral species into a variety of differently adapted species



The Speed of Evolution

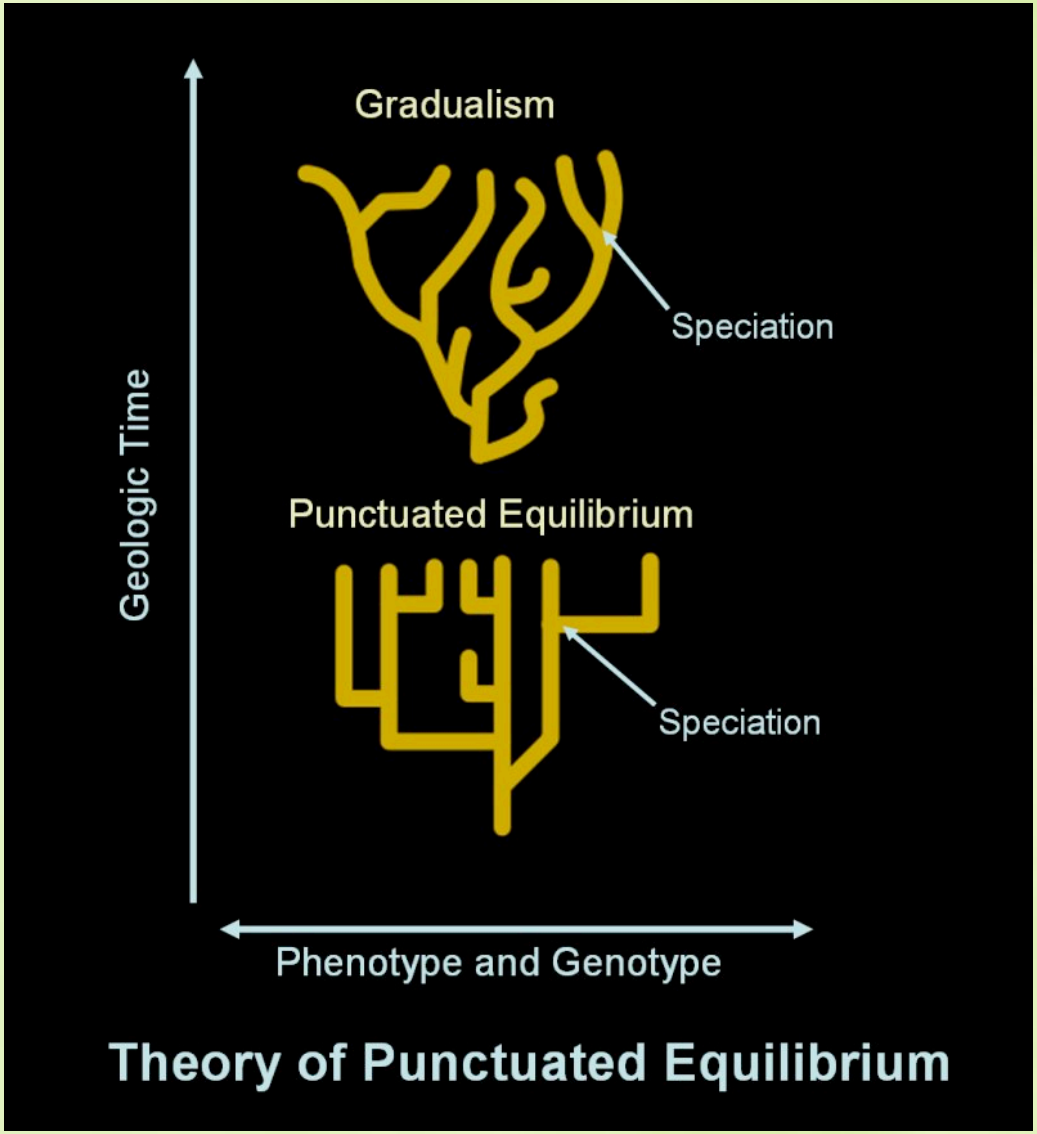
- Since Darwin's time, evolutionary biologists have suggested that evolution is very slow
- This would indicate that the large differences we see between species now are the sum of all of the small changes over a long period of time
- However, sudden changes seen in the fossil record do not support this in some cases

The Pace of Evolution

- **Gradualism:** gradual changes occurred in a steady, linear way over time.

- **Punctuated equilibrium:** there were long periods of equilibrium, interrupted by faster paced periods of speciation. According to this theory, species undergo most of their morphological changes when they first diverge from their parent species.

Gradualism vs. Punctuated Equilibrium



The Pace of Evolution