Macroevolution

Macroevolution

Up to now, evolution that we have been considering is *microevolution.*

- The "dividing line" between microevolution and macroevolution is speciation.
- Types of changes that happen with *macroevolution*:
  - Origins of new organs.
  - Origins of new body plans.
  - Origins of new and higher taxa (groups above the species level).
- Almost always need the *fossil record* to study macroevolution.

Fossils and Fossilization

Fossils include traces of past life, preserved in stone or other materials.

- There is a wide range of fossils and fossil evidence, including:
  - Hard structures embedded in sedimentary rocks.
  - Mineralized and permineralized body parts.
  - Impressions of organisms.
  - Trace fossils, e.g., burrows and trackways.
- Fossilization is a very rare event.
  - Many organisms do not fossilize well.
  - Many ancient environments were not conducive to fossilization.
- Many fossils are destroyed before they are found.

Types of Fossils

1. Compression and impression fossils: organic material buried in sediment.

- The weight of the substrate forms an impression of the organic material.
- Yields a two-dimensional fossil.

Top: *Carpopenaeus callirostris* (shrimp) *Cyclobatis longicaudatus* (stingray skeletal elements) Cenomanian Formation, Hjoula, (Hakel), Lebanon Mesozoic Era, late Cretaceous Period (about 65-80 Mya).

Bottom: *Heptagenia* sp. (mayfly nymphs).Yixian Formation, Liaoning Province, China Mesozoic Era, Cretaceous Period (about 95 Mya).

Types of Fossils

2. Permineralized fossils*:* Dissolved minerals precipitate in the cells while organic material is buried.

- Can preserve fine details.

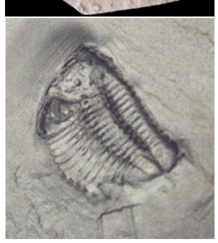
Top: *Thalassina anomala* (mangrove lobster) Gunn River, Australia. Cenozoic Era, Quaternary Period, Recent Epoch (about 4,000 years ago).

Center: *Mazoglossus ramsdelli* (hemichordate 'acorn worm'). Francis Creek Shale, Carbondale Formation, Braidwood. IL. Paleozoic Era, Carboniferous Period (about 300 Mya).

Bottom: *Maotianshania cylindrica* (priapulid). Maotienshan Shale, Chengjiang, Yunnan Province, China Paleozoic Era, early Cambrian Period (about 570 Mya).

Types of Fossils

3. Casts and molds*:* Original organic material decays, and leaves an empty space (mold).



Top: *Hunanolenus genalatus* (trilobite). Hunan Province, China. Paleozoic Era, Cambrian Period (470-570 Mya).

Bottom: *Chotecops* sp. Hunsruckschiefer Formation, Bundenbach, Germany. Paleozoic Era, Devonian Period (360-409 Mya).

Types of Fossils

4. Unaltered remains: Remains are preserved in environments that discourage decay or weathering.

Top: *Turritella terebralis* and *Eutriofusis burdigalensis*. France. Cenozoic Era, Tertiary Period, early Miocene Epoch (about 20 Mya).

Center: Terrestrial isopod (pillbug) in amber. Dominican Republic. Cenozoic Era, Tertiary Period, Oligocene Epoch 23-35 Mya.

Bottom: *Exogyria* sp. (bivalve). Tsunami Deposits, Braggs, AL. Mesozoic Era, late Cretaceous Period (65 Mya).

Macroevolution

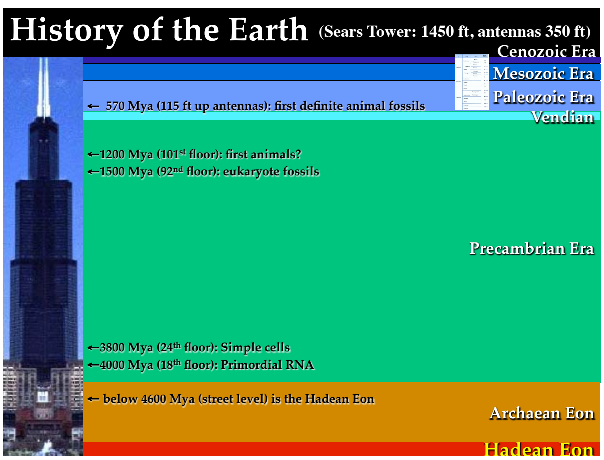
'Biases' in the Fossil Record

- *Environmental*: most fossils come from lowland and marine habitats.
  - These organisms are most likely to live where floods and sedimentation can bury them.
  - Terrestrial species are much less likely to become fossilized (especially in tropical areas).
- *Taxonomic*: organisms with mineralized hard parts (bones or shells) much are more likely to become fossilized.
  - Marine organisms dominate the fossil record, but make up only 10% of today's species.
  - Reproductive structures of plants unlikely to be preserved, but pollen often is. Occasionally animal embryos as as well.
- *Temporal*: older rocks are rarer than newer rocks, because:
  - Earth's crust is constantly recycled by vulcanism and plate tectonics.
  - Water and wind erosion destroys exposed fossils.

Geographical Time Scale

- Time divisions were determined by 19th century scientists by grouping characteristic (index) fossils together.
- *Origin of Life*: almost certainly began earlier than 3.5 billion years ago, almost as soon as physical conditions made life possible.

Era	Period		Epoch	Myr BP (approx)
Cenozoic	Quaternary		Recent	0.01
			Pleistocene	1.8
	Tertiary	Neogene	Pliocene	5
			Miocene	24
		Paleogene	Oligocene	37
			Eocene	54
			Paleocene	65
Mesozoic	Cretaceous			144
	Jurassic			213
	Triassic			248
Paleozoic	Permian			286
	Carboniferous		Pennsylvanian	320
			Mississippian	360
	Devonian			408
	Silurian			438
	Ordovician			505
	Cambrian			590



Landmarks of Macroevolution

- *Origin of Life*: almost certainly began earlier than 3.5 billion years ago, almost as soon as physical conditions made life possible.
- *Life would have these characteristics:*
  - Acquires and transforms energy to resist entropy.
  - Grows and develops.
  - Reproduces.
  - Evolves.
- *To maintain itself over time, life must have:*
  - A heritable code of instructions that can be transmitted over time.
  - That code must manifest itself physically in the organism.
  - That code must be able to change over time.

Landmarks of Macroevolution

How did life begin? Must rely on indirect evidence:

- The earliest life would have had to replicate and do biological work.
  - In present-day cells, what replicates?
  - In present-day cells, what does biological work?
- *Very important breakthrough*:
  - In the early 1980's, Altman and Cech independently discovered ribozymes, that were RNA molecules that could break and reform chemical bonds that hold strings of nucleic acids intact. They won the Nobel Prize.
  - Scientists now think that during the early history of life, Earth was an "RNA world," in which RNA molecules lived freely, replicated, and operated as enzymes.

Landmarks of Macroevolution

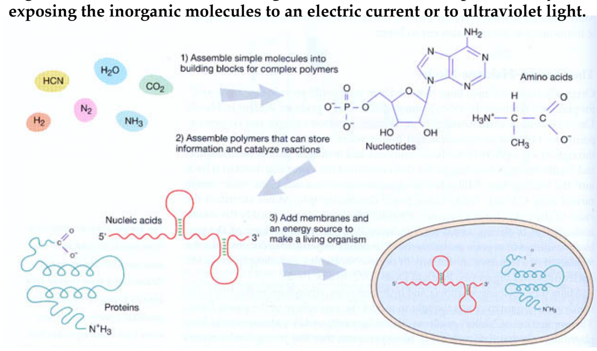
How were RNA sequences eventually formed from inorganic molecules?

- Scientists think that one or both of two processes were responsible for the presence of organic molecules on Earth:
  - Under favorable conditions, simple organic molecules formed from organic molecules on Earth.
  - Organic molecules were transported to Earth by meteors, asteroids, or other interplanetary structures.
- Scientists think that "RNA World" probably was not the first self-replicating system, and that RNA evolved from a more primitive chemical system.
- The *Oparin-Haldane model* suggests how organic molecules might have formed:

Macroevolution

Oparin-Haldane Model

Starting with inorganic molecules in an aqueous environment, simple organic molecules (amino acids, sugars, nucleotides) can be produced by exposing the inorganic molecules to an electric current or to ultraviolet light.



Landmarks of Macroevolution

Origin of cells

- **Earliest evidence of prokaryotic cells appear in fossil record about 3.5 billion years ago:**
  - **Earliest evidence is physiochemical.**
- **Evolutionary advantages of cell membranes:**
  - **Allow better maintenance of internal conditions. Biological products of molecules remain within the cell membrane, unavailable to "selfish" molecules that use resources made by other molecules, but make none of their own.**
  - **Metabolic enzymes can be arranged spatially, so metabolic reactions can operate more efficiently.**

Landmarks of Macroevolution

Origin of eukaryotic cells

- **Eukaryotic cells do not appear in fossil record until about 1.8 billion years ago:**
- **Newly-evolved structures of eukaryotic cells:**
  - **Membrane-bound nucleus with chromosomes.**
  - **Membrane-bound organelles e.g., mitochondria, chloroplasts.**
- **It is thought that mitochondria and chloroplasts originated as bacteria that lived symbiotically within early eukaryotic cells:**
  - **Mitochondria have circular chromosomes like bacteria.**
  - **RNA gene sequences from mitochondria and chloroplasts are similar to those of bacteria.**

Landmarks of Macroevolution

Origin of Multicellular Life

- **First multicellular organisms appear in the fossil record between 670 to 550 Mya (some potential trace fossils are older).**
- **General belief is that the increased amount of oxygen in the atmosphere made larger body size and higher metabolic rates possible.**
- **Atmospheric oxygen first started increasing more than 2 billion years ago.**
- ***At first, oxygen was probably poisonous to organisms.* Rates of extinction may have been high, and followed by evolution of new forms of life able to tolerate (*and make use of!*) oxygen.**

Landmarks of Macroevolution

Cambrian Explosion

- **Almost all animal phyla first appear in the fossil record during the Cambrian period, that lasted 40 million years: *only 0.8% of the Earth's history!***
- **Evolution of:**
  - **Large, multicellular organisms (including macropredators).**
  - **Numerous body structures, e.g., gills, legs, shells, exoskeletons, mouthparts.**
  - **Specialized tissues: muscles, nerves.**
  - **Other morphological and physiological mechanisms.**

Landmarks of Macroevolution

Movement onto land

- **"Life at the water's edge" during the Ordovician Period, about 450 Mya. *Arthropod animals* and *vascular plants* were the first organisms to colonize land.**
  - **Plants needed to develop spores resistant to dryness. Tracheid cells to transport water and nutrients.**
  - **Animals needed to develop mechanisms to breathe, resist gravity, and avoid heat, UV light, and desiccation. Arthropods were the dominant land animals from the Silurian until the Devonian.**
  - **Land vertebrates (amphibians) evolved during the Devonian, about 350 Mya. Began to be dominated by the reptiles in the Carboniferous because of the development of the amniote egg. Mammals and birds followed.**

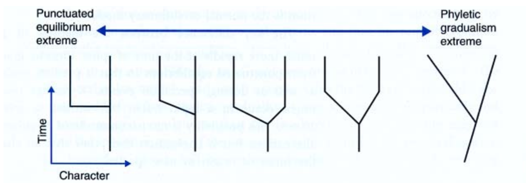
Macroevolution

Macroevolutionary Patterns

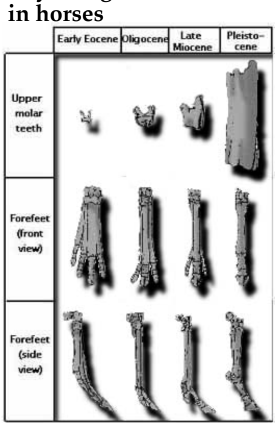
Rates of evolution vary

- Evolution often faster within rather than between speciation events.
- Structurally more complex forms often evolve faster than simpler forms.
- Some taxonomic groups evolve faster than others.
- *Adaptive radiation* is one macroevolutionary pattern in which evolution occurs rapidly:
  - Occurs when a single ancestral species diversifies into a large number of descendant species that occupy many environmental conditions.
  - Can occur as a result of ecological opportunities (chance introduction to or creations of novel environments) or extinction events that eliminate established taxa.
  - Changes in morphology allow exploitation of new environments.

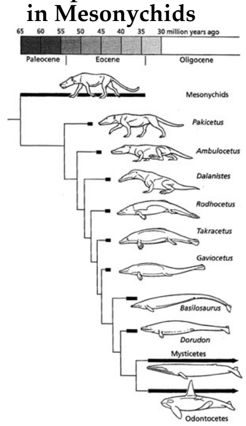
- The fossil record usually shows new species appearing suddenly, with little or no apparent change in between new species. Darwin and others attributed this pattern to gaps in the fossil record:
  - In 1972, Eldredge and Gould proposed the theory of *punctuated equilibrium*, saying that evolution during speciation events was much faster than between speciation events.
  - In *phyletic gradualism* (sensu Darwin) evolution is theorized to be more constant and gradual between and within speciation events.
- In nature, patterns of evolution rates are probably somewhere in between these extremes.



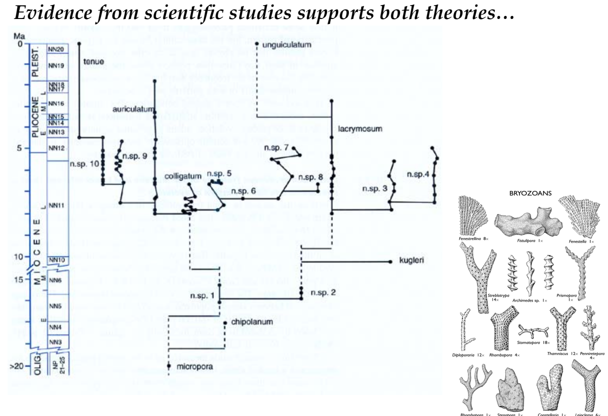
Phyletic gradualism in horses



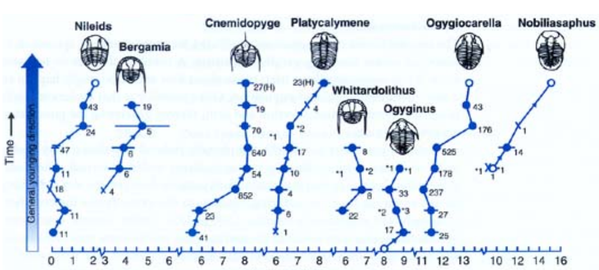
Adaptive Radiation in Mesonychids



Evidence from scientific studies supports both theories…



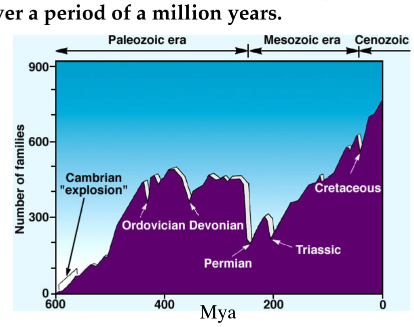
Punctuated equilibrium in bryozoans



Phyletic gradualism in trilobites

Extinction

- The diversity of life on Earth is a balance between speciation and extinction. In the fossil record, there are 5 *mass extinctions*, in which greater than 60% of the species became extinct over a period of a million years.
- But the mass extinctions account for only about 4% of all of the extinctions in the fossil record. 96% are so-called *background extinctions*.



Macroevolution

Background Extinctions

- **Within large taxonomic groups (such as phyla), the probability of each species going extinct is about the same, regardless of how long the species have existed.**
- **In marine organisms, invertebrate species with a planktonic larval stage (disperse long distances) have lower extinction rates than species that develop directly from the egg (disperse short distances).**
  - **Species that are able to disperse over long distances have great colonizing ability--this may reduce the chance of extinction.**
  - **This trend may apply to species other than marine organisms, but hasn't been demonstrated.**
- **Marine invertebrates with large geographic ranges have a lower rate of extinction.**
  - **These species are probably less vulnerable to isolated events that can cause extinction--species with small ranges are vulnerable.**

The "Sixth Extinction"

<u>First wave of extinction caused by humans</u>: extinction of many species on islands:

- **Occurred from before historical time to between 1600-1700 CE. Caused by:**
  - **Habitat destruction and modification (especially agriculture).**
  - **Introduction of new predators (e.g., pigs, dogs, and rats)**
  - **Direct predation by humans (overhunting and particularly overfishing still continues)**

The "Sixth Extinction"

<u>Second (current) wave of extinction caused by humans</u>:

- **Ultimate cause is exponential increase in human population.**
- **Proximate cause is habitat loss. Tropical rain forests under most immediate threat, for two reasons:**
  - ***High species diversity* - Tropical rain forests occupy 7% of the Earth's land area, but contain at least 50% of its species.**
  - ***Have not been exposed to earlier extinctions*- Other habitats in temperate regions have been through an "extinction filter" due to extinctions caused by humans, and in some cases glaciation.**
- **Global warming, introduced diseases/pathogens, and pesticides are showing an increasing effect.**