Lecture Outline: Broad Patterns Of Evolution

I. **Macroevolution and Microevolution**
- A. Definition of Microevolution
  1. Change in allele frequency in a population over generations
  2. A change in the values of P and Q in the Hardy-Weinberg model
  3. Evolution occurring at the population level
- B. Definition of Macroevolution
  1. Evolution at broader levels, above the population level
  2. Involves huge taxa and much bigger evolutionary trends

II. **The Geological Record and the History of Life**
- A. Earth and Universe Age
  1. Age of the Universe is roughly 14 billion years
  2. Age of the Earth is about 4.6 billion years (4,600 million years)
- B. Hierarchical Arrangement of Geologic Time Spans
  1. Eons (biggest spans)
  2. Eras
  3. Periods
  4. Epochs
- C. Major Eons
  1. Hadian Eon
     - a. Pre-biological and completely lifeless
     - b. Named because the Earth was extremely hot ("hellish")
  2. Archan Eon
  3. Proterozoic Eon
  4. Phanerozoic Eon
     - a. The current eon
     - b. Includes almost all familiar life, spanning the last half billion years
- D. Timeline of Life
  1. Earth begins (4.6 billion years ago)
  2. No life for roughly the first billion years
  3. Beginning of life (3.5 billion years ago) based on fossil evidence
  4. Life started in the oceans

5. Original organisms were prokaryotes, dominating for almost two billion years
6. First eukaryotic cells appeared roughly 1.8 billion years ago
7. Life invaded land only 500 million years ago
8. Oldest fossils are stromatolites, remains of prokaryotic colonies

III. **Dating Fossils**

A. Relative Dating

1. Determining if one fossil is older or newer than another
2. Based on strata: fossils in deeper stratum are relatively older

B. Absolute Dating (Radiometric Dating)

1. Determining the absolute age in years
2. Relies on radioactive isotopes in nature

C. Isotopes

1. Atoms of the same element that differ in the number of neutrons
2. The number of protons defines the element (e.g., Helium has exactly two protons)
3. Radioactive isotopes are unstable and decay into other substances

D. Half-life

1. The amount of time required for half of the original radioactive isotope (parent isotope) to decay
2. Each isotope has a specific half-life value
3. Decay is relative (half of what remains), resulting in a curve, not a linear rate

E. Application as a Molecular Clock

1. Living organisms continuously take in isotopes from their surroundings, establishing a radioactive signature
2. Upon death, intake stops, and the decay clock begins
3. By measuring the remaining fraction of the parent isotope, the number of half-lives that have passed can be determined to calculate the fossil's absolute age

IV. **Examples of Macroevolutionary Change**

A. Evolution of the Mammalian Ear

1. Original function of certain skull bones (300 million years ago): Forming a hinge for the jaw in jawed creatures (reptiles and amphibians)
2. Change in mammalian lineage: Over millions of years, these bones changed shape, location, and function
3. New function: Bones evolved into the auditory ossicles (malleus, incus, and stapes, or hammer, anvil, and stirrup)
4. The auditory ossicles are tiny bones in the middle ear that amplify sound waves

B. Factors Determining Taxon Size
    1. Speciation: Creation of new species (increases group size)
    2. Extinction: Permanent loss of species (decreases group size)

V. **Plate Tectonics and Continental Drift**
  A. The Earth's crust is composed of thin "rafts" floating on a liquid interior (mantle and core)
  B. Plate tectonics involves the continuous, slow movement of these land masses
  C. Biological Significance
    1. Organisms are passengers on the rafts
    2. Continental movement leads to isolation between groups, which is a mechanism for allopatric speciation
  D. History of Continents
    1. 250 million years ago: All land masses were fused into one supercontinent called **Pangaea** ("all of Earth")
    2. 100 million years ago: Pangaea split into two major land masses: Laurasia and Gondwana
    3. Continents have periodically collided and separated many times throughout Earth's history

VI. **Adaptive Radiation**
  A. Definition: The amount of speciation occurring within a lineage in a given amount of time
  B. Represented on a phylogenetic tree by the widening or flaring out of a lineage
  C. Examples of Unequal Adaptive Radiation
    1. Frog lineages: One lineage created significantly more species (310) than the other (100)
    2. Mammals
      a. Mammals include Monotremes, Marsupials, and Eutherians
      b. Monotremes (the basal lineage) show the least adaptive radiation
      c. Eutherians (which include humans) have been the most successful branch, accounting for the majority of mammal species
    3. Hawaiian Islands (Plants)
      a. New volcanic islands appear suddenly, representing unexploited habitats
      b. Lack of competition allows natural selection to operate rapidly
      c. Ancestral species radiate into many different species in a short geologic time

VII. **Extinction and Mass Extinction Events**
  A. Background Extinction Rate
    1. Extinction is naturally occurring throughout life history
    2. The normal rate is a low baseline level
  B. Mass Extinction Events
    1. Defined as a drastic, sudden increase in the rate of extinction

2. Five major events have occurred in the last 500 million years

C. The Big Five Mass Extinctions
   1. **Permian Extinction** ("P")
      a. The largest mass extinction ever
      b. Occurred at the end of the Permian period
      c. Eliminated 90% of groups of organisms
      d. Major contributing factor was out-of-control volcanic activity leading to global warming
   2. **Cretaceous Extinction** ("C")
      a. Occurred 65.5 million years ago
      b. Eliminated three-fourths (75%) of all groups
      c. Killed almost all non-avian dinosaurs; the only survivors were birds
      d. Opened up possibilities for the explosion of mammalian species
      e. Caused substantially by a massive object (asteroid) collision that blocked photosynthesis, leaving a detectable scar off the coast of Mexico

D. Current Extinction Crisis
   1. Extinction rates are currently increasing rapidly, suggesting the beginning of a sixth mass extinction
   2. This current event is primarily caused by human activity
   3. The causes (global warming) are comparable to those of the Permian extinction

E. Ecological Effects of Mass Extinction: Surviving populations show an increased percentage of predators

F. Relationship Between Extinction Rate and Temperature
   1. Data shows that four of the five historical mass extinctions occurred during periods of warmer temperatures
   2. This reinforces the severe danger posed by human-caused global warming

VIII. **Developmental Genes and Macroevolution**

A. Principle: Large morphological differences (macroevolution) can arise from small genetic differences, especially in regulatory genes

B. Genetic Similarity
   1. Humans and chimpanzees are genetically 98-99% identical
   2. Despite similarity, they are drastically different morphologically (e.g., brain case size vs. jaw size)

C. Heterochrony
   1. Definition: Differences in developmental timing (Greek *hetero* = different, *cron* = time)
   2. Causes one body part to develop faster or slower than others using the same basic set of genes

D. Role of Developmental Genes
   1. Genes are not always expressed (turned on)
   2. Developmental genes (regulatory genes) code for proteins that act as switches, turning other genes on or off during development
   3. Differences in when and where these switches are activated lead to drastic morphological changes
E. Specific Examples of Heterochrony
   1. Bat Wings: The arm and hand bones greatly outpace the growth of the rest of the body to form the wing structure
   2. Pedomorphosis
      a. Definition: The condition (-*osis*) of retaining a juvenile (*pedo*-) form (*morph*-) in adulthood
      b. Example: A salamander retaining its gills throughout its adult life
F. Homeotic Genes (*Hox* Genes)
   1. A type of developmental gene that controls the development of major body parts
   2. Differences in the activation fraction of *Hox* genes explain morphological variations, such as the number of legs in arthropods (e.g., six legs in *Drosophila* vs. many legs in brine shrimp)

IX. **Evolution of Complex Structures**

A. Complex structures, such as the eye, evolve gradually through incremental steps, rather than in one major mutation
B. Each intermediate step provides an evolutionary advantage
C. Evolution works by adjusting pre-existing structures rather than designing entirely from scratch
D. Stepwise Evolution of the Eye
   1. Simple light-sensing patch of pigmented cells (detects presence or absence of light)
   2. Invagination (inpocketing) of the patch: Allows the organism to sense the direction of light, as cells in the shade are unilluminated
   3. Further invagination, containing a water droplet: The droplet acts as a rudimentary lens, bending light rays (refraction) and leading to the first image formation
   4. Sealed structure with an actual cellular lens: Improves focus
   5. Addition of muscles connected to the lens: Allows for accommodation (autofocusing) by changing lens thickness (like in human eyes) or position (like in fish eyes)
E. Convergence: The advantages provided at each step are so significant that eyes have evolved independently (analogous structures) in many different lineages