Genetics and Evolution  IB 201

Cambrian Explosion, the Fossil Record and Extinction

**History of Life** is represented unevenly in the fossil record. Enormous gaps exist in the organisms that have been preserved over time, eons of time. The earth is 4,550 million years old (abbreviated Ma for *mega anna*), but only at about 550 Ma are there good records of the first appearance of hard-shelled animals, including trilobites (lobster-like marine organisms) and mollusks. Between 550 and the 40 Ma comprising the Cambrian period, most of the major phyla appear in the fossil record. This rapid burst of organic diversity of multicellular organisms, known as the **Cambrian explosion**, occurred within only 0.9% of the overall history of the planet. The remaining time since then represents approximately 14% of the overall history of the earth. The eon that preceded the Cambrian boundary is known as the **Precambrian**, and represents the other 85% of earth’s history (approx. 4 billion years).

**Geological Time Scale**

To appreciate this massive radiation and put it into perspective with the overall history of the earth, it is necessary to understand the geological history of the planet. The 4.5 billion years since the earth was formed has been divided into a hierarchical scale of time periods (see F&H, p. 58). The scale was based originally on different distinctive rock strata found beneath the surface of the earth, each layer with a unique set of plant and animal fossils (*index fossils*), which represent different time intervals. The earliest intervals are associated with the deeper layers of rock, the more recent time intervals correspond to the upper layers. This was known as the Law of **Superposition** (younger above, older below). The relative age of each interval, each with their unique fossils, have more recently been assigned absolute dates based on the technique of radiometric dating (see F&H, pp. 58-top 62).

**Geological Time Intervals** (eons, eras, periods, epochs, stages) \[= e \ e \ p \ e \ s\]

- **Eon 1: Precambrian**—4,550 – 5,550 Ma (4.55 - 5.55 billion yrs) \[Ma = mega anna\]
- **Eon 2: Phanerozoic**—550 Ma - Present
  - **Era 1: Paleozoic** (lasted 292 million years)
    - *Periods*: Cambrian, Ordovician, Silurian, Devonian, Missippian, Pennsylvanian, and Permian \[C O S D M P P E\]
  - **Era 2: Mesozoic** (186 million yrs)
    - *Periods*: Triassic, Jurassic, Cretaceous
  - **Era 3: Cenozoic** (65 million yrs to present)
    - *Period*: Tertiary
      - Epochs: Paleocene, Eocene, Oligocene, Miocene, Pliocene \[P E O M P\]
    - *Period*: Quatermary
      - Epochs: Pleistocene, Holocene

**Familiarize yourselves with the different fossil flora and fauna of each geological interval, including the first bacteria, first land plants, first dinosaurs, first apes, earliest *Homo*, etc.**
**Darwin’s Dilemma**—the abrupt absence of apparent fossils in the strata below the Cambrian layer (the oldest rocks) looked like a void in the history of life, and in Darwin’s view, posed a threat to his theory that all organisms, living and extinct, evolved from earlier common ancestors. Where were the Precambrian ancestors?

Although recognized as a dilemma in the mid-1800’s, it wasn’t until the mid-1900’s that significant Precambrian fossils were found. These were not large, multi-celled organisms, but rather minute **microfossils**, extremely difficult to find and study.

**Where Have all the Fossils Gone?** The fossil record largely due to chance contingencies:

- **Erosion**—rocks weather away and are carried to oceans where they settle (70% of earth surface covered by oceans). Eroded rock formations leave **gaps**. Nowhere does a continental rock sequence cover all ages.

- **Plate tectonics**—movement of continental masses over the globe destroys ocean sediments and contorts the land masses. Oldest ocean deposits are young—not more than 250 Ma. Although the plates move only 3 cm/yr, they move apart with sudden jerks, causing earthquakes. The collision of plates causes sediments to be pushed deep into the magma and melted; they bubble up to form mountains such as the Himalayas ans Andes.

- **Recycling**—99.9% of all organic matter is recycled (death, decay, reabsorption). The 0.01% not recycled is the pool that fossils come from. Fossils are unrecycled pieces of dead organisms, but only the hard parts that resist decay: shells, bones, teeth, chitin of insects.

Precambrian microfossils (e.g., cyanobacteria and single-celled algae) are even more vulnerable

- **Biology and Geology conspire to obscure**
  - Must be buried to escape recycling
  - Escape being crushed and compacted
  - Tiny and hard to detect
  - When detected, require painstaking preparation to see microfossils

**Cambrian Explosion of Animals: Diversification of Body Plans**

1a- Diploblast: 2 embryonic tissues—radial symmetry (echinoderms) or asymmetric (sponges)

1b- Triploblast: 3 embryonic tissues—bilateral symmetry (left/right)

**Tissues—ectoderm, endoderm, mesoderm**

2a- Coelomate—true coelom—body cavity fluid-filled (improved swimming, crawling)
2b- Pseudocoelomate—body cavity not of mesoderm
2c- Acoelomate—no body cavity

3a- Protostome—during gastrulation of embryo mouth area forms first
3b- Deuterostome—gastrulation forms mouth secondarily, after anal region
Important discoveries:

**Ediacaran Fauna** (South Australia)—565 Ma: (Martin Glaessner in 1950)
oldest known fossils of multicelled animals; all soft-bodied—sponges, jellyfish, etc

**Burgess Shale** (Canadian Rockies)—520-515 Ma: (C. D. Walcott in 1909)
trilobites (arthropods), molluscs, chordates, jawless lampreys

Questions:

1. What are some of the morphological innovations in organisms that occurred during or just before the Cambrian explosion?

2. What ecological interactions may have influenced the evolution of the Cambrian forms?

References

(pp. 663-677).


Extinction

Background Extinctions
Most organisms exist over geological time for a limited time span. They may be found in the fossil record of one geological period and not the next. New species are added, old ones disappear. The rates of extinction are not the same at all times, but there is an ongoing, constant and relatively low rate of species loss that comprises most extinction — this is known as background extinction.

Cause: genotypes have limits to capacity to change; sudden change in environment (climate, arrival of new predator or pathogen, etc.) may be fatal. If a population is unable to produce enough offspring to replace loss from natural causes, the population will go extinct. Background extinctions are mostly the result of biological causes and natural selection. Single species are lost.

- 96% of all extinction is background
- independent of geological age of the taxa
- rates are constant within a group, highly variable across groups
- species (marine) with wide geographic ranges survive longer over geological time than species with narrow geographic ranges, suggesting that broad ranging spp. can survive chance environmental changes, new diseases, etc. better than those that are restricted to small ranges.
- Smaller populations are generally more vulnerable to extinction (Mayr 2001)

Mass Extinctions: Geological time—Phanerozoic
There have been occasional periods over geological time in which a catastrophic number of species and organisms went extinct very rapidly across the entire planet. These events are due to physical causes and chance. Higher taxa (class, order, family, etc.) are lost. Mass extinctions have the following characteristics:

- global events in which 60% or more of the species went extinct rapidly, during a span of 1 My
- biological catastrophes
- only 4% of all extinction is a mass event
- 5 mass extinctions have occurred
  - end of Ordovician (~440 Ma) → >20% all organisms went extinct
  - late Devonian (~365 Ma) → >20% all organisms
  - end of Permian (250 Ma) → >50% all organisms
  - end of Triassic (~215 Ma) → >20% all organisms
  - Cretaceous-Tertiary (K-T) (65 Ma) → >15% all organisms

How do mass extinctions occur?
Different causes for each event; most of the causes are not really known

K-T event is inferred to have been the result of an asteroid (10 km wide) impact
Evidence that an asteroid struck Earth is not controversial
- High concentrations of iridium (abundant element in meteorites) in K-T boundary sediments
- Discovery of microtektites (glass particles created on impact) in K-T sediments
- Shocked (deformed on impact) quartz particles found in K-T boundary layer
- Crater found off Yucatán Peninsula 180 km diam; microtektites 65 Ma; and geomagnetic anomalies outlining crater detected from space

Evidence that the asteroid caused the mass extinction of life is controversial
- Production of H₂S₀₄ from anhydrite and seawater upon impact → acid rain
- SO₂ (sulfur dioxide) scatters solar radiation—could lead to global cooling
- Additional cooling caused by dust-sized rock particles
- Soot deposits in K-T layer suggests widespread wildfires—soot in atmosphere would have accentuated global cooling—earth cold & dark
- Impact would cause massive earthquakes → volcanoes → global cooling
- Huge (4 km high) tidal wave (tsunami) caused on impact
- Global cooling and darkening would greatly reduce oceanic phytoplankton—primary producers
- Temp regimes in Atlantic ocean massively disrupted

Scenario: immediately following the impact, marine and terrestrial biota decimated
Over time (500,000), ecological disruption caused the decline of many groups

Patterns of K-T Extinction
- 60-80% of all species became extinct at end of Cretaceous
- Loss of taxa not evenly distributed
  - prominent terrestrial dinosaurs and flying pterosaurs disappeared, but not the less dominant mammals, amphibians, turtles and crocodiles.
  - Few birds survived but insects did fine (at least higher taxa)
  - Forest communities reduced, replaced by ferns
  - Plant spp. extinction greater in N. Am.—presumably occupied splash zone
  - Bivalves and gastropods that had widespread geographic ranges were less likely to go extinct

Local Extinctions on Islands: Human Impact Over History
Most documented extinctions from the recent past have occurred on islands, but some prominent continental exceptions even in North America (passenger pigeons, Carolina parakeet, ivory-billed woodpecker, some species of buffalo, mastodon, etc.
Have humans in the past caused extinction that would rival one of the 5 mass extinctions? Apparently not—nothing like the 50%-90% of spp. lost during one of the Big Five.
Figures show percentages of .005% (insects) - .5% (vertebrates) extinction (Table 17.1, F&H) since 1600
However, evidence over past 2,000 years shows major human effects:

- 2,000 spp. (20%) of birds in Pacific region gone due to human colonization of islands
  - 60 endemic spp on Hawaiian Islands went extinct 1,500 yrs ago after settlers came
  - 44 spp. (including flightless moas) extinct on New Zealand after humans arrived
  - 6/27 spp. on island of ‘Eua
  - 20 endemic spp. on each of seven best-studied islands of central Polynesia
  - 4 spp. of rails (small flightless birds) left out of thousands on islands
  - 20 vertebrate taxa extinct on Galápagos after humans arrived in 1800
  -- before that time only a few populations over 4,000-8,000 yrs disappeared
  -- 1600-1990s 486 animal and 600 plant species became extinct

- Human role in overuse of local resource—early and modern societies
  - Charred bird bones found at archeological digs in Hawaii

- Human introduction of invasive (“pest”) species, such as pigs, dogs, rats (found at dig sites) – islands lacked mammal predators before humans arrived—devastated flightless bird populations. Pest spp. have no natural predators to control their populations. Predatory snails and ants on Hawaiian Islands implicated in extinction

- Human role in habitat destruction—continues today
  -- slash and burn agriculture and irrigation of fields for crops by European colonists before 1700s of Hawaii destroyed forests
  -- tropical forests decimated in New and Old World

**Current Human Impact**

Most concern is over habitat loss due to increasing population

6 billion growing 1.6% per year = doubling every 40 yrs

Current estimates suggest that current extinction rates occurring at 100 to 1000 times the normal background extinction rates. If these continue over the centuries, there will be extinction levels that rival the Big Five from the fossil record.

1/3 all North American plant and animal species threatened (extinct, endangered or vulnerable)

Most at risk: freshwater mussels, crayfish, amphibians, freshwater fish (extinction rate = 4% per decade)

Loss of N Am freshwater animals similar to extinctions of tropical forest species

**Tropical Forests**

-- Tropical forests occupy only 7% of land area on Earth but contain half of the species
-- Human impact more recent in tropics, currently have highest pop growth rates
-- Highest rates of habitat loss
-- Africa and Americas 1980-1990: 0.7% tropical forest lost per year
-- Asian tropical forest worse: 1.1% loss per year
-- Amazon forest largest continuous forest on Earth—forest destruction loss per year equal in size to state of Connecticut (15,000 sq km 1978-1988)
Questions:

2. Other than the K-T mass extinction, what causes have been proposed for some of the other Big Five extinction events?

3. Is extinction a natural process? If so, how does the natural process compare to the current rate of extinction?

4. What is pseudoextinction?

4. What other mechanisms are thought to cause extinction of species.

References
(Chap. 17, pp. 684-696).

References for PowerPoint

Hawaiian Island fossil birds, snails, and big-headed ant photos from ppt slides from Rosemary Gillespie, Director, Essig Museum of Entomology, University of California, Berkeley