15.1 The Fossil Record

- Many creationists point to the Cambrian Explosion as proof in the fossil record of the sudden appearance of animals (as would be predicted by the account rendered in Genesis). But, is this an accurate interpretation of the fossil record? How has life evolved during the Phanerozoic? Most of our knowledge that can be used to answer these questions comes from the fossil record. So before we answer these questions, let's review the basics of what a fossil is.

**Fossil** – Any remains, trace or imprint of an organism that lived in the past and has been preserved in the earth’s crust.

**How does organic matter fossilize:**

- **Compression and impression fossils:** water- or wind-born sediments bury organic matter. Weight of the sediment on top of the organic matter can push the material into the sediment below, creating an impression, e.g., walking on mud leaves a footprint.

- **Permineralized fossils:** form when structures are buried in sediments and dissolved minerals such as silica, calcium carbonate, or iron circulate through the enclosing sediments and precipitate in cavities such as bone marrow cavities and canals once occupied by blood vessels and nerves. The resulting structure looks exactly the same as the original but is much harder and more durable. Dinosaur fossils are the result of permineralization. Permineralization can also occur in plants, e.g., the Petrified Forest National Park in Arizona.

- **Casts and Molds:** form when remains (e.g., bones and shells) decay but leave impressions in the surrounding sediments. If the sediments remain unfilled, a mold is formed. If the mold cavity is filled in by mineral matter forms a cast.

- **Unaltered remains:** form in environments where decomposition, weathering and scavenging by animals does not occur e.g., acidic peat bogs (where iron age humans have been found flesh and hair still intact), permafrost (the Discovery Channel recently had specials on the “Ice Man” and woolly mammoths recovered from such environments), oil saturated tar sands and amber (insects are often preserved so well in amber that wing veins are visible).

Unaltered remains, when found, can provide a wealth of information; however, they are very rare and make up only a small percentage of the fossil record.

The process of fossilization depends upon three things: durability, burial (the burial must be relatively quick to avoid scavengers and weathering) and a lack of oxygen. The fact that burial must occur relatively soon after death, and that there needs to be a lack of oxygen, means that environments such as river deltas, beaches, floodplains,
marshes, lakeshores and sea floors (i.e., water saturated sediments) are where fossils are more likely to form. Durable structures by definition last longer and thus have a greater chance of fossilizing.

**Strengths and Weaknesses of the Fossil Record**

There are three main types of bias in the fossil record:

- **Geographic**-As noted above, organisms that live in lowland or marine environments have a greater chance of fossilization than those organisms living in upland environments.

- **Taxonomic**-The fossil record is dominated by marine organisms (although only 10% of extant organisms are marine). Of the extant phyla, two-thirds lack any sort of mineralized hard parts and are then not likely to become fossils.

- **Temporal**-geological processes, e.g., subduction and erosion, destroys sedimentary layers and the fossils embedded in those sediments. For example marine waters have repeatedly covered central sections of North America. When sea level rises to cover what once was land it is called a transgression. Transgressions result in sediments being laid down (and fossilization can occur). When the water retreats off the land (regression) erosion occurs (and some or all of the fossils lost).

These biases do not mean that the fossil record is not useful. On the contrary, the fossil record is very rich when one considers just how difficult it is for fossilization to occur. As long as these limitations are taken into consideration, a great deal can be deduced from the fossil record.

**15.2 The Cambrian Explosion**

The Cambrian Period, which lasted only 40 million years, produces almost all of the animal phyla currently recognized by taxonomists. This is a geological blink of an eye. To put this into perspective, from the time life first formed on earth (around 3.8 bya) until the start of the Cambrian Period was a period lasting over 3200 million years. This massive radiation of life, according to the fossil record, took place in just over 1% of the time that life had existed.

It should be noted at this point that the geologic time scale was developed in the 19th century based on diagnostic fossils. Dates placed on the time scale (refer to handout) are based on radioisotopic dating conducted in the 20th century. When attempting to answer the question, was the Cambrian explosion truly explosive, we need to keep in mind the limitations of the fossil record. But before answering this question, lets take a look at some of the innovations seen during this geologic time period.
Cambrian Diversification of Body Plans

The Cambrian Period began 544 mya. It is named after the Roman name for Wales, where rocks of this age were first studied. Animals that dominated in this time period included:

- **Trilobites**—these primitive arthropods first appeared in the early Cambrian and had their greatest diversity during the Cambrian and Ordovician Periods. Trilobites ranged from 0.5 mm to nearly 1 m. Most were between 3-10 cm long.
- **Inarticulate Brachiopods**—these coelomate bivalved invertebrates attach themselves to the sea floor by a muscular stalk. They are called inarticulate because they lack a hinge. Articulate, or hinged brachiopods radiated later.
- Other animals living during some portion of this period include small cap-shaped mollusks, and other arthropods in addition to trilobites.

The innovations in body plans that were found in these and other organisms living during this time include:

- Segmented body plans
- Shells
- External skeletons
- Appendages
- Notochords—the earliest known chordates are the animals *Pikaia* and *Cathymyrus*. *Cathymyrus* is found in sediments dated to 535 mya.

**What is the fossil evidence for the Cambrian explosion?**

**Ediacaran Faunas:** These fossils were first discovered in the Ediacara Hills of south Australia in the 1940’s. Since then similar fossil finds have been discovered in some 20 sites from around the world. These rock strata are dated from 565-544 mya, which places these fossils in the late very late Precambrian. What is significant about the fossils is that they are all soft bodied. Whole bodied compression and impression fossils appear to be those of sponges, jellyfish and comb jellies. Trace fossils such as fecal pellets, burrows and tracks may be made by bilaterally symmetric organisms, possibly including primitive arthropods and mollusks or their close relatives.

**Burgess Shale and Chengjiang Faunas:** Burgess Shale faunas, discovered near the town of Field in British Columbia, are dated from 520-515 mya. The Chengjian fauna, from the Yunnan Province in China, are dated from 525-520 mya. These faunas include trilobites and other arthropods, segmented worms, several chordates and at least two species of jawless vertebrates resembling extant hagfish and lampreys.
There is almost no overlap between the Ediacaran and Burgess Shale Faunas. The fossil record suggests that most of the major extant phyla appeared in a geologic instant, all over the world. But is the fossil record providing the entire picture of how and when these phyla evolved?

To help answer this question scientists have turned to molecular data. By calibrating molecular distances in various genes between phyla with the fossil record, scientists have determined that chordates and echinoderms diverged 1000 mya. Protostomes and deuterostomes may have diverged as early as 1200 mya.

So, why does the molecular data suggest that lineages may have split from ancestral taxa up to half a billion years before their appearance in the fossil record? One possibility is that the Cambrian explosion was an explosion of new morphologies, not necessarily new lineages. Many of these lineages that seem to appear suddenly in the fossil record may have existed as small, larvalike organisms that would not readily leave fossils.

So it appears that the Cambrian explosion was not an explosion of new lineages, but of new morphologies. The explosion was also ecological in nature. Ediacaran fauna were mostly sessile filter feeders or predators that floated in the water column feeding on plankton. Burgess Shale fauna had a large assortment of organisms that walked and swam, in addition to the sessile and floating organisms.

**What triggered this morphological and ecological radiation?**

- **Rising oxygen levels** - The key to the rise of multicellular organisms was the rise of oxygen levels in Proterozoic oceans. With increased oxygen availability, larger body plans are possible. Larger body size is necessary in order for tissues to evolve and oxygen is needed to power these larger and mobile body sizes.

- **Evolution of hard parts** - Late Precambrian fossils documents the evolution of shells. Fossil evidence indicates that predation provided the selection gradients favoring mineralized shells. Predation pressure may have favored increased body size, new modes of locomotion as well as mineralized shells.

Much of what occurred during the Cambrian (and during many other times in earth’s history) can be classified as adaptive radiation. Adaptive radiation is defined as: a burst of evolution, with rapid divergence from a single ancestral form, that results from the exploitation of an array of habitats. What factors trigger adaptive radiations?
1. Ecological opportunity - When animals enter a new environment with few competitors and a wide variety of resources, conditions are favorable for rapid diversification and speciation. Darwin’s finches are a good example of this process.

2. Mass extinction - These are events in which 60% of the species that were alive go extinct in the span of a million years. There have been 5 mass extinction events during the Phanerozoic. The most famous of which is the extinction of the dinosaurs at the end of the Cretaceous. The 5 mass extinctions account for only 4% of all extinctions during the Phanerozoic. The other 96% of extinctions that occurred during the Phanerozoic are referred to as background extinctions (extinctions that occurred at a normal rate).

What distinguishes a mass extinction from background extinctions?

- Mass extinctions are global in extent.
- They involve a broad range of organisms (both marine and terrestrial).
- They occur rapidly relative to the expected lifespan of the taxa that are wiped out.

The K-T event (the Cretaceous is often symbolized by a K to separate it from other periods that start with C)

- There is a great deal of evidence that an impact event occurred off of the coast of the Yucatan Peninsula approximately 65 mya. This event may have been the nail in the coffin for dinosaurs, which appeared to be in a decline even before this event.
- It has been estimated that 60-80% of all species went extinct during this time. Prominent taxa that disappeared included: dinosaurs, pterosaurs, ichthyosaurs and plesiosaurs. Marine plankton became extremely scarce and in some localities of North America up to 35% of land plant species became extinct.
- One group that survived was mammals. Only one order of birds survived. Mammals and birds underwent a massive adaptive radiation. This is due to the fact that these two groups, by chance, survived the impact event. When they came out the other side they found a world with niches previously occupied by reptiles (on land, in the sea and in the air) wide open for exploitation. Interestingly, some birds in the early Cenozoic went flightless and became very large. *Andalgalornis* stood two meters tall, had a head the size of a horse and was an impressive predator living in S.America.
- We now have mammals living in the sea that look like ichthyosaurs and birds that look and may behave as did some Pterasaur (think
of the albatrosses). Mammals and birds now occupy every possible niche that was once occupied by reptiles. The power of adaptive radiation and convergent evolution are manifested in the mammals and birds that occupy these niches.

3. Morphological innovations—As noted with the Cambrian explosion, morphological innovations can create adaptive radiations. In the plant world, examples of morphological innovations leading to adaptive radiations are the evolution of land plants from aquatic ancestors in the early Devonian (with the evolution of leaves, vascular tissue and alternating gametophytic and saprophytic generations) and the explosion of flowering plant during the Cretaceous.

The Evolution of Life Through Time: The Highlights

You have received a handout of the geologic ages and some of the major biological events that occurred at various times in the past. This handout can be found on page 38 in your textbook. You must know the difference between the Proterozoic and Phanerozoic Eons, memorize all the Periods, and the Cenozoic Epochs. You should have an idea of when some of the major biological events occurred.

Paleozoic

Cambrian
- Burgess shale fauna. First organisms with hard parts. Trilobites dominate.

Ordovician
- Trilobites begin decline. First jawless fish appear.

Silurian

Devonian

Mississippian
- Similar to Devonian, amphibians radiating on land. Late Mississippian early Pennsylvanian: reptiles appear.

Pennsylvanian

Permian
- Early Permian therapsids (mammal like reptiles) appear. Conifers appear. (late Permian mass extinction in the sea and many amphibians go extinct also).
Mesozoic
  Triassic
  • Late Triassic, first dinosaurs and first mammals.

Jurassic
  • Birds evolve. Marine reptiles diversify (Ichthyosaurs and Pleiosauras). Flying reptiles diversify.

Cretaceous
  • First angiosperms. Primitive prosimian primate (Purgatorius appears). Dinosaurs go extinct at end of Cretaceous.

Cenozoic
  Paleogene
  • Mammals diversify (horses, whales, seals and walruses evolve). Birds take on modern appearance (large flightless birds in Eocene). Prosimian primates diversify and evolve morphologically (muzzle length reduces, brain size increases, eye orbits shift forward). These modifications result in a lemur like animal called Notharctus from which monkeys and apes are derived.

Neogene
  • Late Paleogene early Neogene prosimian-anthropoid transition is taking place. Aegyptopithecus zeuxis dated from 33 to 34 mya had monkey like limbs and tail and a brain larger than that of Notharctus. Grasses evolve in Miocene. Large sharks evolve in Miocene. Poisonous snakes evolve in Miocene. Horses begin evolving greater size as prairie and plains increase. Carnivores grow larger.

Pleistocene
  • Very large mammals: beaver, mammoth, mastodon, elk, ground sloth. Extinction of camels, elephants, horses and giraffes in North America. Hominid evolution occurs.