

GEOL 102: Historical Geology
Overview of Major Groups of Fossil Forming Organisms

Prokaryote-Grade Organisms

Bacteria (also called Eubacteria)

Prokaryotes, diverse habits (heterotrophs, chemolithotrophs, phototrophs, etc.). Some anaerobic, some aerobic.

- **Cyanobacteria** (“blue-green algae”) (Proterozoic-Quaternary): aerobic phototrophs; major oxygen producers. Associated with the formation of **stromatolites** (although nearly any biofilm former could potentially produce stromatolites). Via endosymbiosis, some cyanobacteria were incorporated as **plastids** in eukaryotes: most significant, as **chloroplasts**.
- **α -proteobacteria**: (?Archean-Quaternary): wide variety of habits. Of importance for this course, some are anaerobic phototrophs (including some of the oldest forms of photosynthesizers); others (free-living aerobic heterotrophs) include the ancestors of **mitochondria** in eukaryotes via endosymbiosis.

Archaea (also called Archaeobacteria)

Prokaryotes, many are extremophiles, most are anaerobic. Based on features of their DNA synthesis (among others), archaeans are probably more closely related to Eukaryota than to Bacteria. It is possible that Archaea is paraphyletic with respect to Eukaryota, and that the prokaryotic ancestors of the main cell (but not the mitochondria or plastids) of eukaryotes.

Eukaryotes

Eukaryota (also called Eukarya)

Nucleated, have many organelles (esp. mitochondria). All are aerobic. Phototrophic forms have chloroplasts (symbiotic cyanobacteria).

Unicellular Eukaryote Fossil-formers

- **Diatoms** (Jurassic-Quaternary; more abundant in Cenozoic than in Mesozoic; freshwater Paleogene-Quaternary): phototrophs; siliceous shells (frustules) accumulate to form **diatomite**
- **Coccolithophorids** (Jurassic-Quaternary; amazingly abundant in Cretaceous): phototrophs; calcareous plates (**coccoliths**) accumulate to form **chalk**
- **Foraminiferans** (“forams”) (Cambrian-Quaternary): heterotrophs; “armored amoebas”; have calcareous shells (**test**) that grow by addition of new chambers; tests accumulate to form **foraminiferal ooze**, very important index fossils. Some major groups of forams include:
 - **Fusulinids** (Carboniferous-Permian): giant enrolled benthic forams; useful index fossils for Pennsylvanian and Permian.
 - **Nummulitids** (Paleogene-Quaternary; most abundant in Eocene-Oligocene): gigantic coiled benthic forams, mostly of Tethyan region; useful Cenozoic index fossils

- **Planktonic forams** (technically “globogerinids”; Jurassic-Quaternary): small planktonic forams; major components in the zooplankton from Cretaceous onward
- **“Acritarchs”**: (Calymnian-Permian, but rare after Devonian): spiky organic-walled microfossils; at least some are the eggs of animals; others may be the resting stages of some unicellular form (such as dinoflagellates)

Plants: “Algae”

Plants in the broad phylogenetic sense (Plantae or Primiplantae) represent a major clade of eukaryotes. “Algae” are simply all members of Plantae that do not live on land. Basal members of the various plant groups are often unicellular, but the red algae and some green algae (including land plants) are multicellular. All are phototrophs, and have chloroplast. (In fact, all non-plant phototrophic eukaryotes actually have symbiotic plants rather than just symbiotic cyanobacteria.) Rhodophytes (“red algae”) have a fossil record back to Ectasian; green algae not before the Cambrian. A major fossilizing group of algae:

- **Receptaculitids** (“honeycomb coral”) (Ordovician-Permian): multicellular marine green algae with a calcareous internal skeleton; major components of reefs in early and middle Paleozoic

Plants: Primitive Land Plants

Land plants (technically **Embryophyta**) show up in the Ordovician (with possible spore evidence in the Cambrian). They are descendants of freshwater green algae. The fossil record contains many stages of plant evolution. All land plants are phototrophs and multicellular.

- **Basal land plants** (“bryophytes”: a paraphyletic grouping) (Ordovician-Quaternary): live on land, but have no vascular tissue (and thus no good stalks, stems, roots, etc.). Liverworts, hornworts, true mosses, etc. Reproduce by means of spores.
- **Vascular plants** (technically Tracheophyta) (Silurian-Quaternary): vascular tissue, stems, roots, bark (for larger plants). Two major branches are:
 - Clubmosses (technically Lycophyta) (Silurian-Quaternary): reproduce by spores; covered with small leaflets rather than true leaves. An important fossilizing group is:
 - **Scale trees** (technically Lepidodronales) (Carboniferous): enormous, tree-sized wetlands trees of the coal swamps of the Carboniferous. Much of the coal from the coal swamps is from scale trees
 - Euphyllophyta (Devonian-Quaternary): plants with true leaves. Two major divisions within this group are:
 - **Ferns** (technically Pteridophyta) (Devonian-Quaternary): Still reproduce by spores. Major fossilizers include:
 - **Horsetails** (technically Sphenopsida) (Carboniferous-Quaternary): tough stems; reproduce by shoots. The Carboniferous **segmented tree** *Calamites* was a horsetail the size of a small tree

- “**Tree ferns**” (various groups) (Carboniferous-Quaternary): not a single group, but several types of true ferns convergently evolved a tree-like form at different points in plant history
- **Woody plants** (technically Lignophyta) (Devonian-Quaternary): have specialized highly vascular tough lignin-rich tissue (**wood**) allowing them to grow tall. The most primitive woody plants—such as Devonian *Archaeopteris*—still reproduced by spores. All more advanced woody plants were seed plants

Plants: Seed Plants

Seed plants (technically Spermatophyta) reproduce by **pollen** (containing the sperm cells) fertilizing specialized female organs containing the egg cells: the embryo produced is protected by a **seed**. The oldest seed plants are Devonian. Current evidence is unclear whether the living non-flowering seed plants (conifers, cycads, ginkgos, gnetophytes) form a monophyletic clade Acrogymnospermae or if instead these “**gymnosperms**” are a paraphyletic grouping with respect to the flowering plants. There definitely do appear to be fossil gymnosperms (that is, non-flowering seed plants) which are more closely related to flowering plants than to any living group of gymnosperm regardless of the monophyly or not of acrogymnosperms. The major groups of fossilizing seed plants are:

- “**Seed ferns**” (various groups) (Devonian-Cretaceous): not a clade, but rather a grade of any seed plant that isn’t clearly a flowering plant or one of the “classic” gymnosperm groups. Typically have fern-like leaves (hence the name). Some seed ferns (such as the Devonian-Carboniferous medullosans) branched off the seed plant line before classic gymnosperms and flowering plants diverged; others (including the famous Permian *Glossopteris*) are early members of the flowering plant-branch.
- **Cordiaites** (technically Cordiales) (Devonian-Permian; most abundant in Carboniferous): close relatives of the conifers; first major upland trees and shrubs. Some grew in excess of 30 m tall.
- **Conifers** (Pinophyta or Coniferophyta) (Carboniferous-Quaternary): includes pines, cypresses, redwoods, junipers, etc., etc.
- **Ginkgos** (Ginkgophyta) (Permian-Quaternary; most abundant in Jurassic-Cretaceous)
- **Cycads** (Cycadophyta) (Permian-Quaternary)
- **Bennettitaleans** (Bennettitales) (also called “cycadeoids”) (Triassic-Cretaceous): superficially resemble cycads, but more closely related to flowering plants
- **Angiosperms** (Angiospermae or Anthophyta, “flowering plants”) (Cretaceous-Quaternary; possible body fossils from Jurassic and possible pollen from Triassic): have specialized organs (**flowers**) that attract pollinators, who carry pollen to other flowers to fertilize them. Seeds are wrapped in nutty or succulent **fruit**. Dominate modern floras. Two important angiosperm groups of note:
 - **Grasses** (Poaceae or Gramineae) (latest Cretaceous-Quaternary): grow from base of leaf rather than tip; leaves contain bits of silica

- **Composites** (also called “asteraceans”, Compositae or Asteracea) (Paleogene-Quaternary, but most abundant Neogene-Quaternary): daisies, sunflowers, garden vegetables of most types, etc.; flowers of the meadows

Animals: Primitive Non-Bilaterian Animals

Animals (“Animalia”, or sometimes “Metazoa”) are multicellular heterotrophs. Their closest relatives are choanoflagellates (a group of zooplankton). The majority of advanced animals are **bilaterians** (“worms” in the broadest sense): animals with a front end, a back end, a left-to-right symmetry, and a top-to-bottom symmetry. Additionally, bilaterians typically have a mouth at one end, a gut running through the body, and an anus at the other end.

However, primitive animals do not have this body plan. The oldest definite animal fossils are from the Ediacaran. All the animals here are aquatic, and the vast majority is marine. The following are major groups of non-bilaterian animals:

- **Sponges** (“poriferans”) (Cryogenian-Quaternary): suspension feeders in which water comes in through pores on the inside to be picked up by flagellated cells on the inside; essentially living sacs. Shape of sac is held together by **spicules** that might be **siliceous**, **calcareous**, or made of the protein **sponging**. Recent work has shown that sponges are not a monophyletic group: some are more closely related to eumetazoans (advanced animals) than they are to the other sponge groups. Major fossilizing sponges include:
 - **Glass sponges** (technically “hexactinellids”) (Ediacaran-Quaternary): siliceous spicules with three rays (like jacks). Oldest known animals; far more common in Ediacaran-Devonian than later in Earth History.
 - **Archaeocyathids** (Cambrian; nearly all from Early Cambrian): calcareous skeleton, shaped like one small ice cream cone inside a slightly larger cone, held together by **septa** (partitions). Major reef formers of the Early Cambrian.
 - **Stomatoporoids** (Cambrian-Devonian; most common in Silurian-Devonian): calcareous skeletons, forming mound-like masses. Major reef formers of the middle Paleozoic (along with tabulate corals). Post-Devonian “stromatoporoids” turn out to be from different groups of calcareous sponges.
- **Vendobionts** (Ediacaran): possibly animals; possibly massive single-celled organisms; possibly an entirely-extinct branch of multicellular life. Probably not be a single clade. Bodies formed by series of air mattress-like quilting. May have feed by absorbing mats below, by suspension feeding, by symbiosis, or some other means.
- **Cnidarians** (Cnidaria) (Ediacaran-Quaternary): includes jellyfish, corals, sea anemones, hydras, and their relatives. Have a gut with a single opening, fringed by stinging tentacles. Suspension feeders and/or passive predators. Some live entire life attached to surface as a **polyp**; others float around with tentacles underneath them as **medusa**; some alternate between polyp and medusa. Cnidarians are soft bodied, so typically are

only preserved by impressions. However, the **corals** produce calcareous skeletons, and so have an excellent fossil record:

- **Horn corals** (also called **rugose corals** or **tetracorals**, technically Rugosa) (Ordovician-Permian; most common Silurian-Devonian): mostly solitary, with very large polyps.
- **Tabulate corals** (Tabulata) (Cambrian-Permian; most common Silurian-Devonian): exclusively colonial, with very small polyps. Major reef formers (along with stromatoporoid sponges) in middle Paleozoic.
- **Scleractinian corals** (Scleractinia or Hexacorallia, also called **hexacorals**) (Triassic-Quaternary): modern corals, mostly but not exclusively colonial. Major reef formers of Jurassic, Early Cretaceous, and Cenozoic

Animals: Protostomes

The bilaterians divide into two major groups, protostomes and deuterostomes. The features to distinguish them aren't significant to this course. Based on embryo evidence from the Doushantou Formation, both Protostomia and Deuterostomia are present by the Ediacaran. The major fossilizing groups of protostomes are:

- Panarthropoda (Cambrian-Quaternary): exoskeleton of chitin which is **molted; jointed limbs** which are modified into many different uses (gills, legs, mouth parts, antennae, etc.); eyes. Includes:
 - **Anomalocaridids** (Anomalocaridida) (Cambrian-Devonian): possibly paraphyletic, have very large **grasping arms** used to catch prey. At up to 1 m long, were the first large-bodied predators in Earth's history. Until discovery of a Devonian form possibly belonging to this group, anomalocaridids were known only from the Cambrian. Lack of mineralized hard-parts means that these are only preserved in *Lagersätten*.
 - **Arthropods** (Arthropoda) (Cambrian-Quaternary): By far the most numerous group of animals in Earth history! Major fossilizing arthropods are:
 - **Trilobites** (Trilobitaa) (Cambrian-Permian): exoskeleton of calcite makes them wonderful fossilizers. Wide variety of life habits: suspension feeders, predators, scavengers, swimmers, burrowers, etc.
 - **Myriapods** (Myriapoda) (?Ordovician, definitely Silurian-Quaternary): centipedes, millipedes, and relatives. First major group of terrestrial animals. During Devonian and Mississippian 2 m long **arthropleurids** (“godzillipedes”) were the largest terrestrial herbivores the world had seen up to that point
 - **Eurypterids** (Eurypterida, “water scorpions”) (Cambrian-Permian, most important Silurian-Devonian): large predatory arthropods (including 2.5 m forms: largest arthropods ever). Most lived in water, but some were adapted to life on land. Close relatives of, and possibly ancestral to, the **arachnids** (true scorpions, spiders, etc.) (Silurian-Quaternary)

- **Crustaceans** (Crustacea or Pancrustacea) (Cambrian-Quaternary): mostly marine (where they are the most common of all animal groups), some freshwater, a few branches terrestrial. Important fossilizers among the crustaceans are:
 - **Hexapods** (Hexapoda) (Devonian-Quaternary): terrestrial crustaceous with six walking legs. The most important group of hexapods is:
 - **Insects** (Insecta) (Devonian-Quaternary; abundant Carboniferous-Quaternary): winged hexapods. The most common group of animals on land. Recent studies show insects are specialized terrestrial crustaceans.
 - **Decapods** (Decapoda) (Permian-Quaternary; abundant Jurassic-Quaternary): what most of us think about when we hear “crustacean”: prawns, crabs, lobsters, crayfish. Have more heavily mineralized carapace than most non-trilobite arthropods.
- **Bryozoans** (Bryozoa) (?Cambrian, definitely Ordovician-Quaternary): colonial suspension feeders; use a tentacled structure called **lophophore** to capture particles of food; live in small chambers. Exclusively aquatic, mainly marine. Major fossilizing bryozoans include:
 - **Stony bryozoans** (technically Stenolaemata) (Ordovician-Quaternary; most abundant Ordovician-Triassic): form calcareous skeletons. Grow in a wide variety of forms. Minor components of middle Paleozoic reefs, and important components of Permian reefs. One notable group within the stony bryozoans are:
 - **Lacy bryozoans** (technically Fenestrata): (Ordovician-Permian): formed lacy fronds through which water passed. Often found on soft muddy surfaces.
 - **Cheilostomes** (Cheilostomata) (Jurassic-Quaternary; abundant Cretaceous-Quaternary): major modern group; forms encrusting sheets or mats.
- **Brachiopods** (Brachiopoda) (Cambrian-Quaternary): solitary suspension feeders; have two shells protecting a **lophophore** which captures particles of food. Once considered close relatives of bryozoans; while still a possibility, is not strongly supported by the evidence. Far more common in the Paleozoic than today. Strictly marine or estuarine. Among the major groups are:
 - **Lingulates** (Lingulata or Linguliformes) (Cambrian-Quaternary): have paired **calcium phosphatic** shells and long tail-like **pedicle**; motile infaunal forms. Nearly unchanged throughout their history.
 - **Articulate brachiopods** (Articulata or Rhynchonelliformes) (Cambrian-Quaternary): have paired **calcitic** shells; one has an opening for a short **pedicle** and is called the **pedicle valve**; the other has an internal **brachidium** (lophophore support) and is called the **brachial valve**. Sessile: some attached to surfaces by short pedicle, others sat in soft sediment. Phenomenally abundant in Ordovician-Permian seas (major reef formers in Permian); common in Triassic and Jurassic seas; rare in Cretaceous and Cenozoic seas.

- **Mollusks** (Mollusca) (?Ediacaran-Quaternary): “shellfish” in the strictest sense. Ancestrally have a **belly-foot** for “squidging” over the seafloor, a **radula** for rasping algae, and gills around the body to breath. *Kimberella* of the Ediacaran may be an early mollusk whose radula was not mineralized; Cambrian forms include non-shelled mollusks with mineralized radula. Starting in the Early Cambrian are mollusks with small chitinous, and later **calcareous sclerites** (tiny armor plates). However, most Phanerozoic either have large **calcareous shells** or are the descendants of shelled mollusks. The shells (and presumably the sclerites) are formed by the **mantle**: a specialized tissue on the body surface surrounding the gills. Major groups of mollusks include:
 - **Chitons** (Polyplacophora) (Cambrian-Quaternary): retain the ancestral habit of algae-scraping squidgers. Have a series of eight plates down the back. Strictly marine.
 - **“Monoplacophorans”** (Cambrian-Quaternary): not a single group, but a grade of primitive mollusks in which there is a single shell. Includes the ancestors to all more advanced mollusks. Marine.
 - **Gastropods** (Gastropoda) (Cambrian-Quaternary): snails, sea slugs, slugs, and their allies. Primitive forms retain the ancestral algae-scraping habit, but include swimming sea slugs, predatory sea snails (Cretaceous-Quaternary), and terrestrial snails and slugs (Devonian-Quaternary).
 - **Cephalopods** (Cephalopoda) (Cambrian-Quaternary): predatory mollusks with **chambered shells**. Basal form benthic squidger, but all later forms nektonic. Strictly marine. Largest brains among invertebrates. Major fossilizers include:
 - **“Nautiloids”** (Cambrian-Quaternary): paraphyletic grade of predatory shelled non-ammonoid cephalopods. Top predators of Ordovician (perhaps 10 m long!)
 - **Ammonoids** (Ammonoidea) (Devonian-Cretaceous): planktonivorous shelled cephalopods with complex sutures. Phenomenally abundant in Permian-Cretaceous, major index fossils.
 - **Coleoids** (Coleoidea) (Devonian-Quaternary): predatory cephalopods with internalized shells. Includes modern cuttlefish, squid, and octopi. Major extinct group:
 - **Belemnoids** (Belemnoidea) (Carboniferous-Cretaceous; abundant Jurassic-Cretaceous): have solid internal **guard** (or **rostrum**)
 - **Bivalves** (Bivalvia or Pelecypoda) (also called “pelecypods”) (Cambrian-Quaternary): clams in the broad sense. Epifaunal or infaunal suspension feeders; mainly marine, but a few freshwater. Have **left** and **right valves**. Use **gills** to capture food particles. Important fossilizing clam groups include:
 - **Rudists** (Hippuritoida) (Jurassic-Cretaceous; abundant Late Cretaceous): giant reef-forming clams; major reef formers of the Late Cretaceous.
 - **Inoceramids** (Inoceramida) (Cretaceous): giant scallop-like epifaunal clams.

- **Scallops** (Pectinidae) (Devonian-Quaternary; abundant Cretaceous-Quaternary): epifaunal, capable of swimming short distances
- **Oysters** (Ostreidae) (Triassic-Quaternary): epifaunal, often attached, heavily mineralized. Important fossil subgroup was **coiled oysters** (Gryphaeidae) (Jurassic-Cretaceous), which typically lived on soft sediment

Animals: Invertebrate Deuterostomes

The remaining animals are the deuterostomes. Ancestrally many were attached suspension feeders, but several became motile. The major fossilizing deuterostomes are:

- **Hemichordates** (Hemichordata) (Cambrian-Quaternary): relatively rare suspension feeders, traditionally allied with chordates but now considered closer to echinoderms. One group of great importance as fossils:
 - **Graptolites** (Graptolithina) (Cambrian-Carboniferous): exclusively colonial, planktonic or benthic attached, suspension feeders with organic-walled chambers. Rapid evolutionary change, distinctive forms, and widespread dispersal makes them excellent index fossils (especially in Ordovician)
- **Echinoderms** (Echinodermata) (Cambrian-Quaternary): lose their bilateral symmetry after larvae; early forms have three-fold spiral symmetry but most advanced forms have **pentamerous** (five-fold) symmetry. Body uses a **water vascular system** as a combination hydraulic power/skeleton system. Skeleton is formed of plates of **calcite**. Ancestrally ate by using **tube-feet** to suspension feed, but advanced groups show wide variety of life styles. Ancestrally benthic and relatively sessile. A wide variety of bizarre Cambrian-Ordovician groups, and many important groups from throughout the Phanerozoic:
 - **Blastoids** (Blastoidea) (Ordovician-Permian; most abundant in Mississippian): stalked; compact bodies with tiny tentacles
 - **Crinoids** (Crinoidea, “sea lilies”) (Ordovician-Quaternary): stalked; bodies branch out into five (or multiple of five) arms lined with tentacles and tube-feet. Major suspension-feeders in middle Paleozoic, middle Mesozoic, and the deep sea today. Suffered devastation at end of Permian, which nearly wiped out group. Feather stars (Triassic-Quaternary) are stalkless crinoids.
 - Eleutherozoans (Eleutherozoa) (Cambrian-Quaternary): non-stalked, free-living echinoderms, including:
 - **Ophiuroids** (Ophiuroidea) (“brittle stars”) (Ordovician-Quaternary): relatively fast suspension feeders with five long arms and a compact central body
 - **Asteroids** (Asteroidea) (“star fish” or “sea stars”) (Ordovician-Quaternary): predatory echinoderms; entire body divided into (normally) five arms
 - **Echinioids** (Echinoidea) (“sea urchins”, “sea biscuits”, and “sand dollars”) (Ordovician-Quaternary): encased in hard shell (**test**), and often covered with spines. Ancestrally are symmetrical (**regular**) epifaunal algae scrapers. Starting in the Jurassic, several groups of

irregular infaunal sediment feeders evolve: these include the heart urchins, the sea biscuits, and the **sand dollars** (Paleogene-Quaternary)

- **Holothuroids** (Holothuroidea, “sea cucumbers”): worm-like benthic sediment feeders.
- Chordates (Chordata) (Cambrian-Quaternary): primitive chordates are soft-bodied suspension feeders, still seen in the sessile (as adult) tunicates and the swimming lancelets. Most important group of chordates is:
 - Craniates (Craniata) (Cambrian-Quaternary): have **heads** with **eyes**, **brains**, **nostrils**, organs of balance. Nektonic. Primitive craniates include the living and extinct hagfish. More advanced craniates are the vertebrates

Animals: Vertebrates

Vertebrates (Vertebrata) (Cambrian-Quaternary) have internal skeleton of **cartilage** (ancestrally) or **bone**, divided into separate **vertebrae**. Primitive vertebrates lack jaws. Jawless vertebrates include:

- Lampreys (Petromyzontida) (Devonian-Quaternary): lack of bone makes them difficult to fossilize. Include parasitic and suspension feeding forms
- **Conodonts** (Euconodontia) (Cambrian-Triassic): known mostly from their **elements** (bony biting mouth parts). Major index fossils for much of Paleozoic and Triassic. Predators on tiny animals.
- **“Ostracoderms”** (Ordovician-Devonian): paraphyletic group of jawless fish with **bony exoskeleton**. Includes ancestors of jawed vertebrates.

The remaining vertebrates are the **gnathostomes** (Gnathostomata), and are characterized by having jaws. The major gnathostome groups are:

- **“Placoderms”** (Silurian-Devonian): jawed fish generally lacking true teeth (a few newly discovered specimen shows some simple teeth) and heavily armored front parts of the body. Recently shown to be a paraphyletic series relative to toothed gnathostomes.
- **“Acanthodians”** (Silurian-Permian, most common in Devonian): jawed and toothed fish with spines in each fin. Recently recognized to be a paraphyletic series, including stem-chondrichthyans, stem-actinopterygians, and presumably the outgroups to these two together.
- **Chondrichthyans** (Chondrichthyes, “cartilaginous fish”) (Silurian-Quaternary): sharks and their allies. Toothed, but skeleton is cartilage rather than bone.
- **Osteichthyans** (Osteichthyes, “bony vertebrates”) (Silurian-Quaternary): have internal skeleton of bone, and a lung. Two major divisions:
 - **Actinopterygians** (Actinopterygii, “ray fins”) (Silurian-Quaternary; abundant Devonian-Quaternary): major group of living fish. In many the lung no longer functions as a respiratory organ, and is lost or evolves into the swim bladder. Major group of ray-finned fish is:
 - **Teleosts** (Teleostei) (Jurassic-Quaternary): fish which can protrude their mouths. Vast majority of living fish are teleosts. Major radiation of freshwater teleosts begins in Paleogene

- **Sarcopterygians** (Sarcopterygii, “lobe fins”) (Devonian-Quaternary): have series of long bones supporting the fins. Ancestrally aquatic (life habit retained in lungfish (Devonian-Quaternary) and coelacanths (Devonian-Quaternary)), but some became adapted to life at land. Series of transitional forms in Devonian freshwater and seawater (*Tiktaalik* with **wrists** and **ankles**; *Acanthostega* with **fingers** and **toes**; etc.) document the rise of the fully terrestrial tetrapods:

Tetrapods (Tetrapoda, land vertebrates) (Carboniferous-Quaternary): have **necks, digits, and live adult life stage on land** (or descend from animals that did). Primitive tetrapods, including ancestors of today’s **amphibians** (Carboniferous-Quaternary), laid eggs in water and had aquatic larvae. However, one group of tetrapods became fully terrestrial:

- **Amniotes** (Amniota) (Carboniferous-Quaternary): have **amniotic** (shelled) **egg, claws**. Entire life cycle is on land. Amniotes include:
 - **Reptiles** (Reptilia or Sauropsida) (Carboniferous-Quaternary): dominant group of animals during Mesozoic Era. Important fossil reptile groups include:
 - **Euryapsids** (Euryapsida, marine reptiles) (Triassic-Cretaceous): retain young inside the body. Include the fully-marine **ichthyosaurs** (Ichthyopterygia) (Triassic-Cretaceous) and **plesiosaurs** (Plesiosauria) (Triassic-Cretaceous)
 - **Mosasaurs** (Mosasauroidae) (Cretaceous): honest-to-goodness marine lizards
 - **Archosaurs** (Archosauria) (Triassic-Quaternary): reptiles with advanced respiration and four-chambered hearts. Archosaurs were dominant land vertebrates of the Mesozoic. Many archosaur groups may have been warm-blooded. Three major groups of archosaurs are:
 - **Crurotarsans** (Crurotarsi) (Triassic-Quaternary): dominant group of archosaurs of the Triassic. Survive from Jurassic-Quaternary in the form of **crocodilians** (Crocodylomorpha)
 - **Pterosaurs** (Pterosauria) (Triassic-Cretaceous): flying reptiles, including the true **ptero-dactyls** (Pterodactyloidea) (Jurassic-Cretaceous)
 - **Dinosaurs** (Dinosauria) (Triassic-Quaternary): including:
 - **Ornithischians** (Ornithischia) (“bird-hipped dinosaurs”) (Triassic-Cretaceous; abundant Jurassic-Cretaceous): herbivores including beaked, duckbilled, plated, armored, and horned groups
 - **Sauropodomorphs** (Sauropodomorpha) (Triassic-Cretaceous): long-necked herbivores, including the largest land animals of all time
 - **Theropods** (Theropoda) (Triassic-Quaternary): diverse group of bipedal, mostly carnivorous forms. Includes giant predators, but also specialized small feathered forms. The latter include the **birds** (Avialae) (Jurassic-Quaternary)

- **Synapsids** (Synapsida) (Carboniferous-Quaternary): dominant group of Permian terrestrial vertebrates. Include the specialized **therapsids** (Therapsida) (Permian-Quaternary), which in turn include the:
 - **Mammals** (Mammaliformes) (Triassic-Quaternary): furry, warm-blooded, large-brained. Most of mammal history was spent as diverse but small-bodied forms in the shadow of the dinosaurs. After K/Pg extinction, three major (and a few minor) groups of mammals survived and diversified:
 - **Multituberculates** (Multituberculata) (Jurassic-Paleogene): important group of early mammals; includes some early tree-dwelling gnawing forms
 - **Marsupials** (Marsupalia) (Paleogene-Quaternary): dominant group in Australasia and Paleogene-Neogene South America. Stem-relatives of the marsupials are present in the Cretaceous and Paleogene (and presumably in the Jurassic).
 - **Placentals** (Placentalia) (Paleogene-Quaternary): dominant group in rest of world. Includes such diverse groups as rodents, bats, elephants, odd and even-toed hoofed mammals (including whales), carnivorans, and primates. Stem-relatives of the placentals are present in the Jurassic, Cretaceous, and Paleogene.