The Geologic Timescale: Life Marks Earth’s Ages

- Earth’s history is divided into broad eras, shorter periods, shorter-still epochs.
- Scale begins 4.6 billion years ago when Earth was formed, runs to historical time.

The Geologic Timescale: Life Marks Earth’s Ages

- Geologists used to determine age of rocks based on fossils found in them; that’s why geologic scale is based on fossil history. Radiometric dating has replaced those methods.

The Geologic Timescale: Life Marks Earth’s Ages

- Geologic Scale.
  - Boundaries of eras and periods mark sharp transition in type or abundance of life-forms. In most cases, boundaries mark major extinction events.
    - Permian extinction (in Paleozoic) was greatest of all; wiped out 96 percent of all species.

The Geologic Timescale: Life Marks Earth’s Ages

- Geologic Scale.
  - Boundaries of eras and periods mark sharp transition in type or abundance of life-forms. In most cases, boundaries mark major extinction events.
    - Cretaceous extinction (boundary of Mesozoic and Cenozoic) is more famous; may have been aided by asteroid impact in Yucatan of Mexico; dinosaurs died out,
mammals and flowering plants took over.

The Geologic Timescale: Life Marks Earth’s Ages

• Geologic Scale.
  – Extinctions followed by rapid evolution of new forms of life (new niches to occupy).
    • Cambrian explosion (544 Mya) is most dramatic example; not preceded by great extinction event, however.
    • Rate of evolution can be slow or rapid; slow for much of Earth’s history. All birds, reptiles, fish, plants, and mammals that exist today evolved in the last 14 percent of evolutionary time.

The Geologic Timescale: Life Marks Earth’s Ages

• Whether events in evolutionary history are notable, or pedestrian, hinges on value judgment. Humans occupy one ordinary branch among a multitude of evolutionary branches.
• Three domains of life are Archaea, Bacteria, and Eukarya.
  – Archaea and Bacteria are single-celled organisms, former more primitive, living in extreme environments such as hot springs.
  – Eukarya have single-celled and multicelled forms. All have nuclei, include protists, fungi, plants, and animals.

Tracing the History of Life on Earth: How Did Life Begin?

• How the Earth was formed.
  – Earth was formed about 4.6 billion years ago as ever-larger particles of cosmic dust clumped (accretion); Earth was slammed by meteorites and comets.
  – Early Earth was enormously hot; water in vapor form only.

Tracing the History of Life on Earth: How Did Life Begin?

• How the Earth was formed.
  – Most believe life began in water whether a hot sea or under a glacier (some say Earth was very cold at
this time due to low levels of heat-trapping CO$_2$. It’s been suggested that early life, resembling Archaea, could have arisen in boiling temperatures of deep-sea vents.

Tracing the History of Life on Earth: How Did Life Begin?

- How the Earth was formed.
  - Methane, ammonia, hydrogen sulfide in atmosphere may have been raw materials for production of life’s building blocks—amino acids, fatty acids, sugars, and nucleotides (some say these could have formed de novo, or been carried in ready-made by meteorites; shown that they can carry organic molecules, or in methane and hydrogen sulfide deep-sea vents).

Tracing the History of Life on Earth: How Did Life Begin?

- RNA world scenario of origin of life.
  - RNA molecules (ribozymes) were first macromolecule to be synthesized; encode information, and have catalytic properties so they could self-replicate to produce daughter strand with base complementarity to parent strand.
  - Scientists experimenting with “directed evolution,” starting with large variety of RNA sequences and looking for self-replicating forms to mimic the natural selection among macromolecules that may have created life.

Tracing the History of Life on Earth: How Did Life Begin?

- Life required much greater elaboration beyond self-replicating naked RNA or its precursors. Plasma membrane required to extract energy from surroundings and remove waste, to create basic unit of life, the cell.
The Tree of Life

• Successor of self-replicating macromolecule was universal ancestor of all life.
• Universal ancestor gives rise to Archaea on the one hand, and Bacteria and Eukarya on the other (Archaea different from modern bacteria in fundamental ways).
• Earliest kingdom within Eukarya were the Protista; unknown protists separately gave rise to fungi, animals, and plants.

A Long First Period: The Precambrian

• First signs of life found in carbon signatures in Precambrian rocks about 3.6-3.7 million years old, 3.5 million-year-old carbon signatures indicating photosynthesis, and microfossils of filamentous bacteria aged at 3.2 million years old; evolutionary pace slow in this era. Only Archaea, Bacteria, and some Protista populate oceans; land barren.

A Long First Period: The Precambrian

• Photosynthesis.
  – Most pivotal event of Precambrian for trapping energy in organic molecules.
  – Photosynthesis evolves among cyanobacteria; oxygen is by-product, begins to accumulate in atmosphere, had been almost absent before 2.3 Mya.

A Long First Period: The Precambrian

• Photosynthesis.
  – Oxygen changes playing field—anaerobic organisms die off or become confined to limited oxygen-free zones.
  – As nucleated organisms evolve, aerobic bacteria set up endosymbiotic relationship that culminates in new cell organelle, the mitochondrion; similar endosymbiotic
relationship involving photosynthetic bacteria leads to chloroplasts.

A Long First Period: The Precambrian
• Photosynthesis.
  – Another fallout from photosynthetic oxygen—amount of UV bombarding declines, as oxygen reacts in upper atmosphere to form a UV-filtering shield of ozone.

The Cambrian Explosion
• Cambrian is marked by sudden, enormous increase in diversity of life-forms in fossil record, 544 Mya.
  – Animals evolve—multicelled, heterotrophic; all phyla but one represented in Cambrian rocks.
  – Diversification probably triggered by atmospheric oxygen; larger forms possible.
• Some suggest animal diversification may have begun in Precambrian, but soft-bodied early animals didn’t fossilize well enough.

The Movement onto the Land: Plants First
• Plants emerged from green algae probably in this sequence: Marine algae colonized fresh water, occupied shallow water, land above water line; then made full transition to land. Their descendants developed adaptations to life on land, and today are recognized as plants. Mutually dependent relationship with fungi critical for mineral and water absorption means fungi probably colonized land simultaneously.

The Movement onto the Land: Plants First
• Plant adaptations to land—waxy covering, the cuticle; embryo retained, nourished, protected from dessication, within parent plant (distinctive feature of all plants).
• Earliest plants resembled present-day bryophytes
(mosses, liverworts, hornworts); remained small, ground-hugging.

**The Movement onto the Land: Plants First**
- Seedless vascular plants (ferns, horsetails, club mosses) evolved vascular systems to conduct food and water throughout plant; greater size made possible.
- Seed is evolutionary innovation seen in gymnosperms (ferns, pines, cycads, gingkoes, and related plants 350 Mya) and angiosperms (flowering plants 165 Mya) only; seed protects young embryo, allows it to be carried far and wide, contains food source.

**The Movement onto the Land: Plants First**
- Seed plants also developed pollen as a vehicle for disseminating male gametes; water no longer needed for fertilization.
- Angiosperms emerge about 165 Mya, replacing gymnosperms as dominant vegetation; there are some 260,000 species; flowers and fruit most outstanding innovation of this group.

**The Movement onto the Land: Plants First**
- Angiosperms and animals enter into mutually dependent relationship.
  - Angiosperms use flowers to attract animal pollinators (birds, bees, bats, moths); pollinators deposit pollen from anther (male structure) of one flower to pistil (female structure) of another. Sperm cells borne inside pollen make their way to egg in base of pistil.

**The Movement onto the Land: Plants First**
- Angiosperms and animals enter into mutually dependent relationship.
  - Egg-bearing structure of angiosperm is protected by additional layers of tissue that constitute ovary; after
fertilization ovary develops into fruit; fleshy fruit attracts animals when ripe; animals scatter the seed (fertilized, mature egg-bearing structure) as they eat fleshy ovary walls.

Animals Follow Plants onto the Land

• Animals move onto land some 20 million years after plants; latter provide food and shelter.
• Centipede-like arthropods are first invaders of land; have tough exoskeleton that prevents water loss and protects against solar radiation.

Animals Follow Plants onto the Land

• Other arthropods, wingless insects resembling silverfish, move in next. Winged insects evolve after tens of millions of years; first flying insects resembled dragonflies, cannot fold wing back on body; foldable wings came next; insects enormously diverse. Nearly half of all species known (1.7 million) are insects.
• Primitive “lobed-fin” fish (gnathostome) were the first vertebrates to move to land. They gave rise to tetrapod vertebrates (four limbs) first amphibians, then reptiles, and eventually mammals.

Animals Follow Plants onto the Land

• Reproduction on land requires development of mechanisms to prevent desiccation and hence the development of the amniotic egg.
• First mammals around 210 million years ago, radiate into more environments at the end of the Cretaceous period. First primates estimated by molecular work to 85 Mya, and first fossils from about 55 Mya and had large front-facing eyes, limbs with opposable first digits, and were tree-dwelling.
Essay: Physical Forces and Evolution

• Climate—four mass extinctions linked to global cooling.
• Extraterrestrial objects—most famous example is dinosaur extinction at end of Cretaceous.
• Continental drift—movement of continents in geological timescale as magma moves into valley of Atlantic Ridge spreading North American and European plates. Separates and isolates species like placental mammals from marsupial mammals on Australia and South America.

Essay: Fossils and Molecular Clocks: Dating Life’s Passages

• Use rRNA differences as a molecular clock to discern date of last common ancestor.
• Problem: molecular clock dates often differ drastically from the “fossil dates.” Oldest primate fossils 55 million years old; molecular dating places earliest primates at 90 Mya.

The Evolution of Human Beings

• Paleoanthropology is a field in flux. Two kinds of researchers—paleoanthropologists, who study fossil evidence; and biological anthropologists, who examine ancient and modern DNA sequences.

The Evolution of Human Beings

• Hominids.
  – One branch in family of man-like primates (family Hominidae). Difficult to construct trees with just fossils.
The Evolution of Human Beings

**Hominids.**
- One branch in family of man-like primates (family Hominidae). Difficult to construct trees with just fossils.
- Split from a common primate ancestor with chimps about 6-7 Mya candidates.
  - *Sahelanthropus tchadensis* (informally Toumaï) found in Chad. Smaller canine teeth with thicker enamel and less face sloping than chimps, but no leg fossils yet found.
  - *Orrorin tugenensis* unearthed in Kenya, claim evidence for upright walking.

The Evolution of Human Beings

**Hominids.**
- *Australopithecus* may or may not be directly descended from *Ardipithecus*.
  - *A. anamensis* probably had bipedal stance, not knuckle walkers like apes.
  - “Lucy” (3.18 Mya) is most famous fossil skeleton of *Australopithecus afarensis* bipedal.

The Evolution of Human Beings

**Genus Homo** arose in Africa; most important fossils from Great Rift Valley. First example is *Homo habilis*, whose two most likely direct ancestors are *A. africanus* and *A. garhi* (first toolmakers).

*Homo ergaster*, represented by “Turkana boy,” a 1.6 million-year-old fossil of an adolescent boy, would have reached 6 ft and was first dramatic change seen in *Homo* lineage—larger brain case (30%) than *Homo habilis*. 
The Evolution of Human Beings

• Africa cradle of human species as seen by oldest and most primitive fossil remains, but eventually fossils are found elsewhere. Oldest fossils outside Africa in Java date to 1.6 Mya and are from Homo erectus. Many anthropologists don’t distinguish between H. ergaster and H. erectus; they conclude that H. erectus is just H. ergaster that have migrated out of Africa, so fossils are no longer seen after 1.3 Mya, in Africa. Others support the idea that they are two separate species, with H erectus as an evolutionary dead end, while we evolved from H. ergaster.

The Evolution of Human Beings

• 800,000 years ago evidence of hominids in Europe (Homo antecessor), 700,000 years ago, H. heidelbergensis, 200,000 years ago Neanderthals (H. neanderthalensis) range in Europe parts of the Middle East and Asia, and 40,000 finally Homo sapiens. Homo antecessor believed to have given rise to both Homo antecessor and Homo sapiens while still in Africa. H. heidelbergensis is thought to have given rise to Neanderthals.

The Evolution of Human Beings

• Neanderthals.
  – Famous neanderthal man lived from about 200,000 to 30,000 years ago in Europe and Asia.
  – Extinction at hands of or possibly by competition with modern humans who co-existed in Europe.

The Evolution of Human Beings

• Neanderthals.
  – Neanderthals thrust spears at prey; humans threw spears from a distance. Neanderthals used nothing but stone for tools; Homo sapiens used bone and antler as well as stone. Neanderthals were “foragers” while ancient humans were “collectors.” Humans monitored environment, used “forward planning” placing their campsites near animal migration paths; Neanderthals did not.
The Evolution of Human Beings

- First fully modern *Homo sapiens* fossils 100-200 thousand years ago from Africa, evidence of creative explosion in European remains, African remains elusive but slowing being uncovered (77,000 year old red ochre stone “art”).