Fossils and Fossilization

Fossils are the remains and traces of ancient plants and animals. Fossils are formed when ancient plant and animal remains become hardened and fixed within sedimentary rock or sometimes volcanic ash. Some of the most interesting fossils are formed when huge tree stumps, perfectly formed pollen grains, shells, or the bones of ancient fishes (see Fig. 8.2), reptiles or mammals, become saturated and hardened with minerals such as silica or calcite, and in this way are “transformed into stone”. In general the type of material in which the remains are buried usually depends on where the organisms lived e.g. the bones and shells of marine animals are common as fossils because they fell on the ocean floor after death. Under such conditions they were covered by soft mud which later hardened to shales and limestone of later geologic time. The soft mud are less likely to damage the organism (organic remains). Certain fine-grained rocks e.g. limestone have faithfully preserved delicate specimens as birds, insects and jelly fishes. George Curvier (1769-1832) is considered ‘Father of paleontology’, who studied fossils scientifically to develop phylogenies.

Types of fossils:

Based on the mode of formation of fossils, they can be categorized in several types. Fossilization is a rare phenomenon, which takes place under specialized conditions. The study of natural process of death, burial, decomposition, preservation and transformation into fossil is called taphonomy. Fossils are the only direct evidence of the biological events in the history of earth and hence important in the understanding and construction of the evolutionary history of
different groups of animals and plants.

1. Petrifaction: Petrifaction is molecule-by-molecule replacement of organic matter by inorganic compounds, viz. silica, calcium carbonate or iron pyrites. It literally means “turned into stone” and takes place in buried situations, particularly at the bottom of lakes, ponds or sea, where there are sediments rich in calcium carbonate and silica. Over millions of years, inorganic matter replaces the entire bony material, making an exact replica of the original. By this time sediments transform into sedimentary rocks, in which fossils can remain preserved for a long time. Most of the old fossils are petrified, e.g. shells of mollusks, arthropods and fish skeletons.

2. Molds and Casts: A mold forms when hard parts of an organism are buried in the sediment such as sand, silt or clay. The hard part completely dissolves overtime, leaving behind a hollow area of organism shape.
A cast forms as a result of the mold. Water with dissolved minerals and sediments fills the mold’s empty space or cavity. The cavity is known as incrustation and the mineral sediments that are left in the mold make a cast. A cast is opposite to its mold. These fossils are suitable for the study of the morphology of fossil plants.

3. Preservation of footprints: When animals walk on wet soil and sand, they leave trail of footprints or limbless animals and worms may leave tracks and trails in mud. If these footprints are covered by volcanic ash, they can be preserved for a long time as the clay containing footprints and the volcanic ash covering it will harden to form different types of rocks. Mary Leakey discovered footprints of prehistoric man along with those of giraffes, elephants, guinea fowls etc. in Kenya.

4. Trace Fossils/ Ichnofossils : Ichnofossils**/** Trace fossils are marks left by an animal or plant that has made an impression. These fossils include nests, burrows, footprints or any other markings of the animal's time on the earth. The structure of the animal or plant remains as a mineral form. The colors of the minerals that replace the form can be dazzling. Sometimes they are made into art and jewellery.

5. Amber: fossilized resin of more than 20 million years old. The intermediate state of amber is called **copal** (less than 20 million years) old. The resin, before becoming amber can trap insects, arachnids, pollen… in this case is considered a double fossil.

6. Carbon Fossils: All living things contain an element i.e. carbon. When an organism dies and is buried in sediment, the materials that make the organism break down and eventually only the carbon remains. The thin layer of carbon left behind can show an organism's delicate parts like leaves or plant e.g. fern fossil 300 million years old.

7. Chemical fossils: are fossil fuels like oil and coal, which are formed by the accumulation of organic matter at high pressures and temperatures along with the action of anaerobic bacteria (bacteria that don't use oxygen for metabolism).

8. Pseudofossils: Sometimes watery solutions of various minerals speed through the sediments and it takes the shape of some plant part or animal. Their study shows that they are neither plants nor animals. Such fossils are called pseudofossils.

9. Impressions: Impressions of body parts, skin, feathers, leaves etc. are formed when they are
pressed hard against the soft clay, which subsequently hardens to form rock. Fossil of *Archaeopteryx* is such an impression. More bird fossils in the form of impressions have been discovered in China recently, e.g. fossils of *Sinosauropteryx, Caudipteryx* and *Confusiusornis.*

10. Living fossils: name given to today's living organisms very similar to species extinct. The most famous case is the coelacanth, it was believed extinct for 65 million years until it was rediscovered in 1938, but there are other examples such as nautilus.

Index fossils: Fossils that are found in undisturbed sedimentary rocks and in short geological time period generally lie in recognizable strata of older rocks below and

subsequently formed layers above. Based on the presence of such fossils in rocks, age of other fossils in the same rock can be determined without dating, because such fossils are an index to a particular geological period. Ammonites are considered good index fossils as different species represent
specific geological periods in rocks.

Determination of age of fossils:

There are two main methods determining a fossils age, relative dating and absolute dating. Relative dating is used to determine a fossils approximate age by comparing it to similar rocks and fossils of known ages. Absolute dating is used to determine a precise age of a fossil by using radiometric dating to measure the decay of isotopes, either within the fossil or more often the rocks associated with it.

1. Relative Dating: The fossils are dated according to the context in which they are found, if they are associated with other fossils (guide fossils) or objects of known age and it depends on the stratum they are found.
In geology, stratums are different levels of rocks that are ordered by their depth: according to **stratigraphy**, the oldest ones are found at greater depths, while the modern ones are more superficial, as the sediments have not had much time to deposit on the substrate. Obviously if there are geological disturbances dating would be wrong if there were only this method.

2. Absolute Dating: This methods are more accurate and are based on the physical characteristics of matter. Most absolute dates for rocks are obtained with radiometric methods. These use radioactive minerals in rocks as geological clocks.

Radiometric Dating: Radioactive Clock Method, or radiometric dating, which was devised by Boltwood in 1907 and later by Rutherford in 1955. The rate of disintegration of radioactive material is always constant and is not affected by the environmental factors. The time taken by 50% of the radioactive material to disintegrate into stable element is known as its half-life. If we know the half-life of an element, then the age of the fossil can be calculated by finding out the ratio of radioactive element and its stable daughter element using scintillation counter or Geiger-Muller counter.

They are based on the rate of decay of radioactive isotopes in rocks and fossils. Isotopes are atoms of the same element but with different number of neutrons in their nuclei. Radioactive isotopes are unstable, so they are transformed into more stable ones at a rate known to scientists emitting radiation. Comparing the amount of unstable isotopes to stable in a sample, scientist can estimate the time that has elapsed since the fossil or rock formed.

- **Radiocarbon (Carbon-14) or Carbon Dating:** in living organisms, the relationship between C12 and C14 is constant, but when they die, this relationship changes: the uptake of C14 stops and decay with a discomposing rate of 5730 years. Knowing the difference between C12 and C14 of the sample, we can date when the organism died. The maximum limit of this method are 60,000 years, therefore only applies to recent fossils.
- **Aluminum 26-Beryllium 10:** it has the same application as the C14, but has a much greater decaying period, allowing datings up to 10 datings millions of years, and even up to 15 million years.
- **Potassium-Argon (^{40}K/^{40}Ar)**: is used to date rocks and volcanic ash older than than 10,000 years old. This was the method used to date the Laetoli footprints, the first traces of bipedalism of our lineage left by *Australopithecus afarensis*.
- **Uranium Series (Uranium-Thorium)**: various techniques with uranium isotopes. They are shed in mineral deposits in caves (**speleothems**) and in calcium carbonate materials (such as corals).
- **Calcium 41**: allows to date bones in a time interval from 50,000 to 1,000,000 years.

Different radioactive materials have different half-life and, therefore, age of recent as well as very old fossils can be determined by selecting the appropriate radioactive element, provided that the element is present in that particular rock.

The table below shows characteristics of some common radiometric dating methods. Geologists choose a dating method that suits the materials available in their rocks. There are over 30 radiometric methods available.

Dating method	**Material dated**	**Age range dated**
Carbon-14 to nitrogen-14 (radiocarbon)	Organic remains, archaeological artefacts	Up to 60,000 years ago
Luminescence	Tephra, loess, lake sediments	Up to 100,000 years ago
Fission track	Tephra	10,000 to 400 million years ago
Potassium-40 to argon-40	Volcanic rocks	20,000 to 4.5 billion years ago
Uranium-238 to lead-206	Volcanic rocks	1 million to 4.5 billion years ago

All radiometric dating methods measure isotopes in some way. Most directly measure the amount of isotopes in rocks, using a mass spectrometer. Others measure the subatomic particles that are emitted as an isotope decays. Some measure the decay of isotopes more indirectly. For example, fission track dating measures the microscopic marks left in crystals by subatomic particles from decaying isotopes. Another example is luminescence dating, which measures the energy from radioactive decay that is trapped inside nearby crystals.

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