Palaeobotany: Basic Concepts

Palaeobotany (from the Greek words Paleon = old and botany = study of plants), is the branch of paleontology or paleobiology dealing with the recovery and identification of plant remains from geological contexts, and their use for the biological reconstruction of past environments (paleogeography), and both the evolutionary history of plants, with a bearing upon the evolution of life in general. Palaeobotany is important in the reconstruction of ancient ecological systems and climate, known as paleoecology and paleoclimatology respectively; and is fundamental to the study of green plant development and evolution. Palaeobotany has also become important to the field of archaeology, primarily for the use of phytoliths in relative dating and in paleoethnobotany.

Kaspar Maria von Sternberg, the "father of Palaeobotany," (1761–1838), was a Bohemian (from the historical region in central Europe, now part of the Czech Republic), theologian, mineralogist, and botanist. He established the Bohemian National Museum in Prague and is deemed to be the founder of modern Palaeobotany. Adolphe-Théodore Brongniart (1801-1876) was a French botanist whose classification of fossil plants drew surprisingly accurate relations between extinct and existing forms prior to Charles Darwin's principles of organic evolution. His work earned him the distinction as the founder of modern classification in paleobotany. Prof Birbal Sahni (1891-1949) is known as the Father of Indian Palaeobotany. He established the school of Palaeobotany in the Department of Botany at University of Lucknow which later on became the Birbal Sahani Institute of Palaeobotany (BSIP) and has now been renamed as Birbal Sahni Institute of Palaeosciences.

Plant fossils

A plant fossil is any preserved part of a plant that has died long ago. Such fossils may be prehistoric impressions that are many millions of years old, or bits of charcoal that are only a few hundred years old. Prehistoric plants are various groups of plants that lived before recorded history (before about 3500 BC).

Types of Fossils / Modes of Preservation

Six broad categories of plant fossils are commonly recognized. Although these categories seem well-defined, a given fossil may fall into several categories or may elude them all. Consequently, these categories should be thought of as broad modes of preservation rather than shoe boxes into which all fossils must go. When thinking about types of fossils and modes of preservation, it is more important to consider what types of biologically interesting information is or is not present than to fret over strict classifications. With that caveat, the basic types of plant fossils include:

1. **Compressions** -- 2-dimensional, with organic material
2. **Impressions** -- imprints, 2-dimensional, devoid of organic matter
3. **Casts and Moulds** -- 3-dimensional, may have a surface layer of organic material
4. **Permineralization** -- 3-dimensional, tissue infiltrated by minerals allowing internal preservation
5. **Compactions** -- 3 dimensional, reduced volume, flattened, wholly organic
6. **Molecular Fossils** -- non-structural, preserves organic compounds.

Compressions:

Compressions are plant parts that have suffered physical deformation such that the three-dimensional plant part is compressed to more-or-less two-dimensions. Compressions retain organic matter, usually more or less coalified. Compressions of leaves, for example, differ from impressions in that some organic substance, often cuticle, is preserved. Peat, lignite, and coal are essentially compressions of thick accumulations of plant debris relatively free of encasing mineral sediment.

Compressions are excellent records of external form, especially for planar structures like leaves. They often preserve cuticle that can be recovered by dissolving the mineral matter in hydrofluoric acid (HF) or disaggregating in mild peroxide. The cuticle retains the imprint of epidermal cells, but other than this, cellular information can seldom be recovered from compressions. Consequently, compressions generally preserve plants at the organ, organism, and/or environment level. In addition, because compressions preserve organic material, carbon isotopic studies can be performed on compressions. From these studies, paleobotanists can sometimes recognize the biochemical signature of C3, C4, and CAM photosynthetic physiology in extinct species.

Peat is an accumulation of virtually unaltered plant material, while anthracite is nearly pure carbon with little trace of the original plant material. All materials can be burned for fuel, but the energy content per weight increases with degree of metamorphism and the proportion of impurities generally decreases.

Impressions

Impressions are two-dimensional imprints of plants or their parts found, most commonly, in fine-grained sediment such as silt or clay. Impressions are essentially compressions sans organic material. If the sediment is very fine-grained, impressions may faithfully replicate remarkable details of original external form, regardless of subsequent consolidation of the sediment. Because of their shape, texture, and abundance, leaves are among the most common organ preserved in impression. Impressions may also occur if, when layers of rock are split apart, the organic material adheres to only one side of the rock. In this case, the side with organic material is the compression, known as the "part", while the corresponding impression known as the "counterpart".

One particularly interesting type of impression forms in "dirty" sand. In this type of sediment, relatively coarse sand grains are mixed with silt and clay. This type of sediment is common in river and flood plain environments so is important for terrestrial plant preservation. When a leaf falls into this type of sediment and begins to decay, the first organic bonds to break leave charged molecular tails hanging off the leaf surface. This charged tail attracts clay particles with opposite charge that linger within the sediment. The clay migrates to the leaf surface, coating the organic structure. This has two remarkable consequences: First, further decay is retarded because clay is occupying sites of organic reaction. Second, the fine clay allows remarkable detail to be preserved. Because most of the sediment is relatively coarse (sand), the organic material is lost later, but an exquisitely detailed impression is retained in the clay film. This mode of preservation is important in the Dakota Sandstone flora of Cretaceous age. It is also important in the preservation of remarkable animal fossils such as the Jurassic bird Archaeopteryx and the strange Cambrian invertebrates of the Burgess Shale.

Impressions, like compressions, record information about external shape and morphology of plant organs. However, because they lack organic material, cuticle and organic carbon cannot be recovered from them. In cases of impressions in very fine-grained sediment, some cellular detail can be recovered by making a latex of silicone rubber cast of the impression.

Casts and Moulds

When sediment is deposited into cavities left by the decay of plant parts, a cast results. A mould is essentially a cavity left in the sediment by the decayed plant tissue. Moulds are generally unfilled, or may be partially filled with sediment. Casts and moulds commonly lack organic matter, but a resistant structure like periderm may be preserved as a compression on the outside of the cast or the inside of a mould. Casts and moulds may be found together with the cast filling the mould.

Moulds are formed when soft sediment surrounding the structure lithifies or hardens before the structure decays. When the mould fills in with sediment that subsequently hardens, a cast is formed. Casts of an internal hollow structure like a pith cavity are also common. Pith casts can be confusing because you are looking at the inside of the fossil-what in life would have been empty space. Like compressions and impressions, casts and moulds record external (or sometimes internal) organ features well, but provide no cellular or tissue information. Unlike compressions/impressions, moulds and casts often are truer records of the original three-dimensional shape of the structure. Casts of ancient trees are among the most impressive plant fossils.

Permineralizations

Permineralization occurs when the plant tissues are infiltrated with mineral-rich fluid. Minerals (commonly silica, carbonate, phosphate or pyrite or rarely other minerals) precipitate in cell lumens and intercellular spaces, thus preserving internal structures of plant parts in three dimensions. This type of preservation is known as "structural preservation". Because organic material (commonly cell walls but in some cases finer detail) is preserved, permineralizations can yield detailed information about the internal structure of the once-living plant. When mineral matter actually replaces the cell-wall and other internal structures, the preservation may be called **petrifaction**. In petrified specimens, cellular details are lost with the organic material of the cell wall. Please note that we are using these words in a precise, scientific sense. "Petrified" also has a colloquial meaning that might encompass what we distinguish as "permineralized". Therefore, permineralized wood preserves the cellular detail of wood anatomy and the lignin of cell walls that has been "fixed" by a mineral in-filling. This is much like bioplastic in-filling cellular structures when one makes a histological thin section. Petrified wood, on the other hand, lacks such cellular preservation.

Silica permineralization (silification) commonly occurs in areas where silica-rich volcaniclastic sediments are weathering, for example the famous upright trees in Yellowstone National Park or nearby Calistoga, California. Silification is also an important preservational mode for Precambrian microbial remains deposited in near-shore marine environments.

Permineralization with calcium carbonate (calcite or dolomite) is particularly common in Carboniferous coal seams, where whole regions of peat were permineralized called **coal balls** (because of their sometimes round or ellipsoidal shape) or **widow makers** (because of their tendency to drop out of mine roofs onto the heads of unsuspecting miners). These fossils commonly preserve a hodge-podge of plants and plant organs.

Permineralizations in pyrite (an iron-sulfur mineral) are particularly important in Devonian rocks where coal balls and well-preserved compactions are rare or unknown. These pyritized fossils often occur in the presence of sea water (a source of sulfur), and are characteristic of plant tissues washed into marine basins. Pyrite permineralizations offer a challenge to the museum curator because iron in pyrite exists in a reduced state and tends to oxidize when exposed to air. Upon oxidization, most of the structures are lost. This is called "pyrite disease" in fossils and is characterized by a mould-like appearance on the cut surface of the coal ball. To prevent destruction, the surface can be coated with a sealant. Coal balls can also be stored in a low-oxygen medium like glycerin or antifreeze.

Permineralization with phosphate is uncommon for land plants, but can be important in some types of marine settings.

Compactions

In peat, brown coals (lignite), middens and soft sediments, plant remains may retain their external form with only slight volume reduction due to compaction. Such tissues are not mineralized, retain resistant organic material, and may show unidirectional compression (flattening). Internal structure, especially of thick-walled, hard fruits is sometimes well preserved. These fossils may be sectioned by microtome or embedded and treated much like living tissues. Compactions are most common in the youngest plant fossils. Pollen and spores are also preserved as compactions. The material making up their outer shells (sporopollenin) is extremely resistant to decay and can remain for hundreds of millions of year practically unaltered in the rock record. However, the pollen and spore shells, once spherical, are flattened by the compressive forces of lithification.

Molecular Fossils

As more becomes known about the chemistry of modern plants, paleobotanists have begun to examine the fossil record for corresponding chemical data. For example, characteristic breakdown products of chlorophylls and lignins have been found in well-preserved fossil leaves. Lipids and their derivatives have also been recovered from sediments. Some carbohydrate break-down products may also survive in sediment. A special class of these, oleananes, are formed by flowering plants, some ferns and lichens. An increase in abundance of these molecules in sediments of mid to Late Cretaceous age is used to document the increasing abundance of flowering plants (Mouldowan et al, 1994). In another stunning example, genetic material was recovered from Tertiary leaves, and the age of material from which DNA and RNA is recovered seems to be greater with every issue of Nature. As testament to the anoxic requirement for preservation of most molecular fossils, the RNA recovered from fossil leaves degrades within a few seconds when exposed to air, so special preparation techniques were developed to harvest and transport the material to the lab for processing.

Molecular fossils are recovered and studied using chromatographic techniques, mass spectrometry, and spectrophotometry. The preservation of these chemical products is highly variable, and depends on oxygen levels during deposition, temperatures experienced by the rocks since preservation, and many other physical and chemical factors. In a similar vein, geochemists have investigated the chemistry of petroleum and its precursors in an attempt to understand its formation.

Fossil DNA and RNA have also been making headlines in the scientific press. In some exceptional cases, genetic material or proteins have been sufficiently well-preserved to permit their use in the reconstruction of evolutionary relationships, in much the same way as one might sequence living organisms. However, much of this work is controversial due to the difficulty of preserving and isolating these fragile molecules. Also, contamination by other materials is a common and difficult to recognize problem.

A more mainstream application of organic chemistry to the study of ancient plants is that of stable carbon isotopes. During photosynthesis, plants reduce carbon from carbon dioxide to form organic molecules. This ratio of carbon-12 to carbon-13 in the resulting compounds gives information on the proportion of these isotopes in the atmosphere (interesting for geological questions relating to global carbon cycling) and about the physiology of the plant itself. In lecture we will discuss several applications of these techniques.

Conditions necessary for fossilization

For fossilization to occur, certain conditions must be met. It can only happen after death and normally only affects hard tissues such as shells and bones. In the global cataclysm, organisms that became fossils died either before or after they were buried in the flood sediments. Immediately after death, an organism experiences necrolysis (the decay and breakup up of the organism). Under normal circumstances today the organism suffers destruction by three primary agents--biological, mechanical and chemical (diagenesis)—both before and after they are buried.

Three conditions are required for the preservation of plant fossils:

1. **Reducing Atmosphere :** Removing the material from oxygen-rich environment of aerobic decay;
2. **Aseptic Environment**: "Fixing" the organic material to retard anaerobic decay;
3. **Sudden Burial**: Introducing the fossil to the sedimentary rock record (a.k.a., burial).

Consequently, plant fossils are generally preserved in environments very low in oxygen (e.g., anaerobic sediment) because most decomposers (e.g., fungi, most decomposing bacteria and invertebrates) require oxygen for metabolism. Such sediments are commonly gray, green or black rather than red, a sedimentary signal of oxygen-rich conditions. The "fixing" requirements means that plant material must fall into an environment rich in humic acids or clay minerals, which can retard decay by blocking the chemical sites onto which decomposers fasten their degrading enzymes. Plant material can also be "fixed" by removing degradable organic compounds during the process of charring by wildfire. This is a common and spectacular mode of preservation for flowers. Plant material can then be incorporated into the rock record in areas where sediment is being deposited, which usually, but not always, requires the presence of water. Consequently, streams, flood plains, lakes, swamps, and the ocean are good candidates for fossil-forming systems. Plant fossils are commonly preserved in fine-grained sediment such as sand, silt, or clay, or in association with organic deposits such as peat (coal).

Techniques for Study of Plant Fossils

The following points highlight six main sophisticated techniques which are employed these days to study the fossils in laboratory. The techniques are:

1. Ground Thin Section Technique:

The specimen to be studied is cut into small-sized sections. Its surfaces are smoothed with 400-carborundum. The smooth surface of the section of the specimen is mounted on a glass slide. It is warmed and coated with melted resin. The latter hardens upon cooling.

The fastened specimens are cut to form very thin slices which are ground on revolving 100-carborundum lap. Liquid resin-mounting medium is used for mounting the sections.

2. **Peel Technique:**

The first step of this technique involves the etching of the fossil surface with the help of some mineral acids (e.g., hydrofluoric acid) and the final step involves transfer of the exact fossil structure.

Another mixture usually used for etching is prepared by mixing butyl acetate (1000ml), nitrocellulose (115gm), toluol (10ml), amyl alcohol (200ml) and dehydrated castor oil (5ml). Before using for etching purposes, this mixture is aged for at least two weeks.

After etching the specimen surface is washed with water, dried and covered with nitrocellulose. Wait for a few hours. The so formed film will dry during this period. It is peeled off from the specimen and studied.

3. Transfer Technique:

Delicate fossil materials are studied by this technique using cellulose film transfer method. Peel solution is coated on the delicate fossil material present on the rock surface. When the solution dries, the portion of the rock having fossil material is removed. 25% hydrofluoric acid is then used for dissolving the rock material.

4. Maceration Technique:

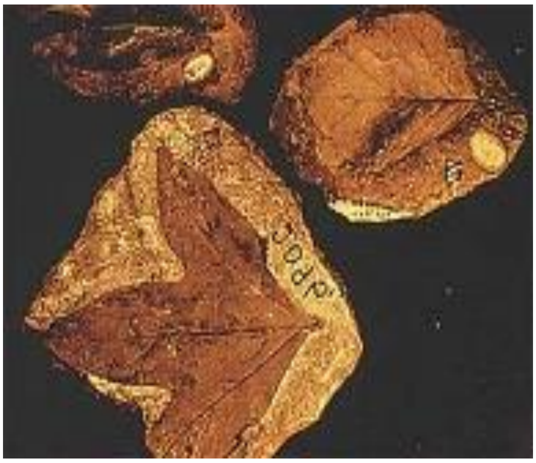
In the usual method of maceration technique, the fossil material is immersed in a mixture of 5% KOH and Cone. HNO3 for one week. The material is then washed thoroughly with water so that the acid is completely removed. It is then incubated with the solution of NaOH. Hydrofluoric acid is used for cleaning the thus separated cuticularized parts of the fossil material.

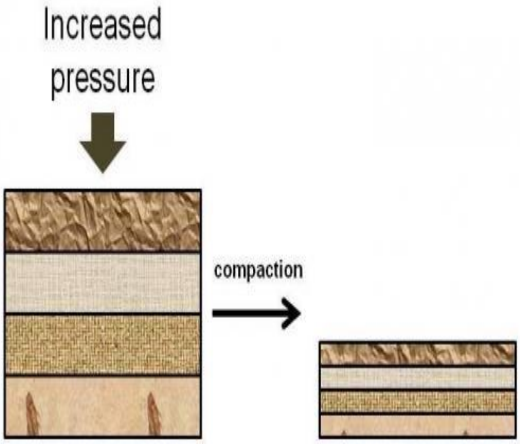
5. X-ray Technique:

Highly sensitive celluloid films are used to obtain X-ray photographs of the fossil specimens.

6. Microtomy Technique:

Fossil specimens, specially their macerated tissues, are embedded in celloidin or wax before microtomy. Sectioning of the embedded material is done by usual process of microtomy. The sectioned materials are stained and studied.



Increased pressure
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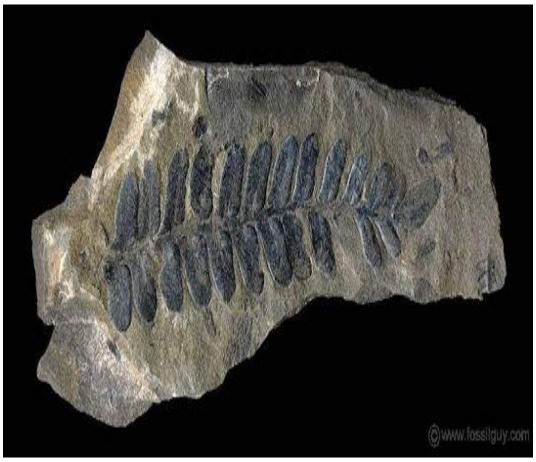
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Standard Stratigarphic Scale / Geological Time Scale

Stratigraphy is a sub-discipline of geology. A Global Standard Stratigraphic Age, abbreviated GSSA, is a chronological reference point and criterion in the ‘geologic age record’ used to define the boundaries between different geological periods, epochs or ages on the overall geologic time scale.

GSSAs, and the generally more recent and preferred benchmark Global Boundary Stratotype Section and Point GSSPs are defined by the International Commission on Stratigraphy (ICS) under the auspices of their parent organization, the International Union of Geological Sciences (IUGS), and are used primarily for time dating of rock layers older than 630 million years ago, lacking a good fossil record.

The geologic record becomes unclear if we go earlier to 542 million years ago. This is because the Earth's crust in geological time scales is constantly being recycled by tectonic and weathering forces, and older rocks and especially readily accessible exposed strata that can act as a time calibration are rare.

For more recent periods, a Global Boundary Stratotype Section and Point (GSSP), largely based on paleontology and improved methods of fossil dating, is used to define such boundaries. In contrast to GSSAs, GSSPs are based on important events and transitions within a particular stratigraphic section. In older sections, there is insufficient fossil record or well preserved sections to identify the key events necessary for a GSSP, so GSSAs are defined based on fixed dates and selected criteria.

What is the Geologic Time Scale?

The geological time scale is a system of chronological dating that relates geological rock strata to time, and is used by geologists, paleontologists, and other Earth scientists to describe the timing and relationships of events that have occurred during Earth's history.

How is Geological Time organized?

The largest spanning time periods are Eons, which last for billions of years

Eons are divided into Eras, which last for 100s of millions of years

Eras are divided into Periods, which last 10s of millions of years

Periods are divided into Epochs, which last for millions of years

Epochs are divided into Ages, which last 100s of thousands of years

└Eons: billions of years (Ga)

  └Eras: 100s of millions of years (Ma)

    └Periods: 10s of millions of years (Ma)

      └Epochs: millions of years (Ma)

        └Ages: 100s of thousands of years (Ka)

ERA	**MAJOR DIVISIONS**	**PERIODS**	**EPOCHS**	**DOMINANT FAUNA**	**ADVANCES IN PLANT LIFE**
COENOZOIC	QUATERNARY	RECENT	HOLOCENE 0.01 MYA	MODERN MAMMALS	Dominance of Herbs
			PLEISTOCENE 1.8 MYA	AGE OF BIRDS AND MAMMALS	Specialization of Herbs
	TERTIARY	LATE TERTIARY	PLEIOCENE 5.3 MYA		Rise of Herbs
			MIOCENE 23.8 MYA		Restriction of plant distribution
		EARLY TERTIARY	OLIGOCENE 33.7 MYA		Dispersal of woody angiosperms
			EOCENE 54.8 MYA		Development of flowering plants
			PALAEOCENE 65 MYA		Modernization of angiosperms
MESOZOIC	LATE MESOZOIC	UPPER CREATCEOUS 66 MYA		AGE OF REPTILES	Dominance of Angiosperms, Fall of Gymnosperms
		MIDDLE CRETACEOUS 101 MYA			Rapid Development of Angiosperms
		LOWER CRETACEOUS 144 MYA			Origin of Angiosperms
	EARLY MESOZOIC	JURASSIC 206 MYA			Dominance of Cycads and Conifers
		TRIASSIC 248 MYA			Disappearance of Seed Ferns. Increase in Cycads, Conifers and Ginkgoales
PALAEOZOIC	LATE PALAEOZOIC	PERMIAN 290 MYA		AMPHIBIANS	Rise of Conifers and Cycads
		UPPER CARBONIFEROUS 323 MYA			Dominance of Ferns, Calamitales, Lepidodendrales and Gymnosperms
		LOWER CARBONIFEROUS 373 MYA			Development of Lycopods, Calamitales and Seed Ferns
	MIDDLE PALAEOZOIC	DEVONIAN 417 MYA		FISHES	Psilotopsida, Lycopsida, Sphenopsida, Ferns, Bryophytes and some Algae
		SILURIAN 443 MYA			First known land plant
	EARLY PALAEOZOIC	ORDOVICIAN 490 MYA			Marine and Green Algae, Rise of Green Plants
		CAMBRIAN 540 MYA			Probable Green Algae origin
PROTEROZOIC	COMPRISES ABOUT 88% OF GEOLOGICAL TIME. THE PROTEROZOIC AND ARCHAEZOIC ERAS ARE TOGETHER ALSO KNOWN AS PRECAMBRIAN.			MARINE INVERTEBRATES	Prokaryotic Algae and Bacteria
ARCHAEZOIC	4500 MYA			UNICELLULAR ANIMALS	Unicellular Algae
	5400 MYA			First one celled organism Origin of Earth	

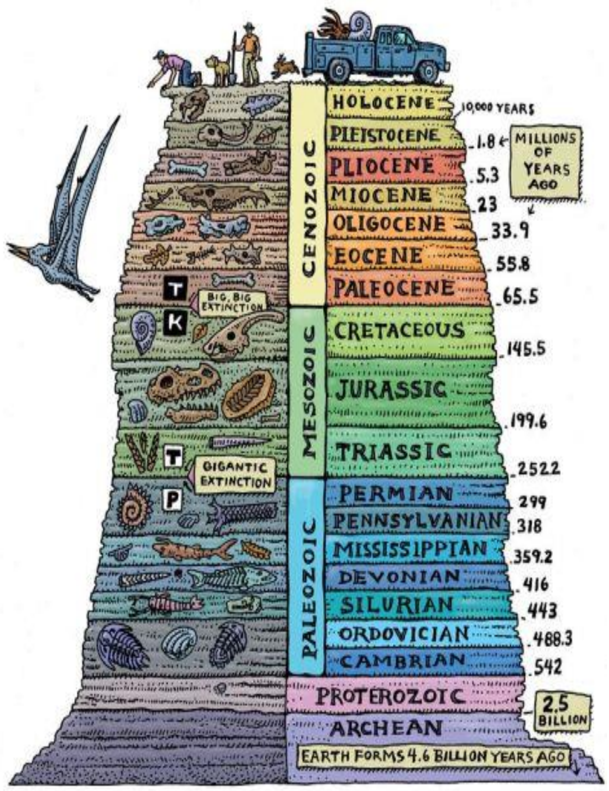
DATING FOSSILS

To determine the age of fossils there are indirect methods (relative dating) and direct (absolute dating). As there is no perfect method and accuracy decreases with age, the sites are often dated with more than one technique.

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.

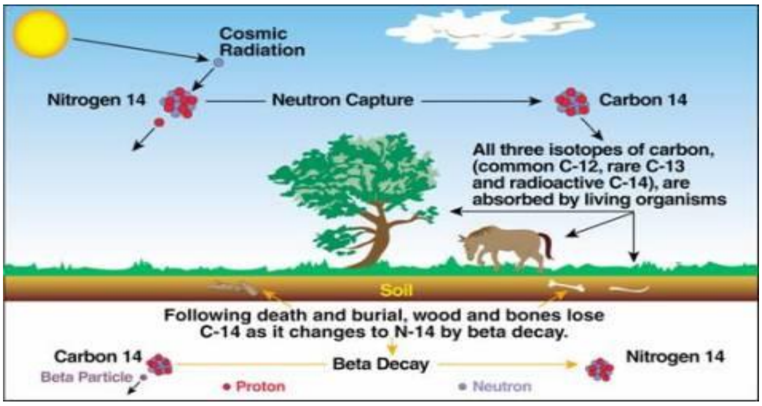


ABSOLUTE DATING

This methods are more accurate and are based on the physical characteristics of matter.

RADIOMETRIC DATING

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 a more stable ones at a rate known to scientists emitting radiation. Comparing the amount of unstable isotopes to stable in a sample, scientists can estimate the time that has elapsed since the fossil or rock formed.

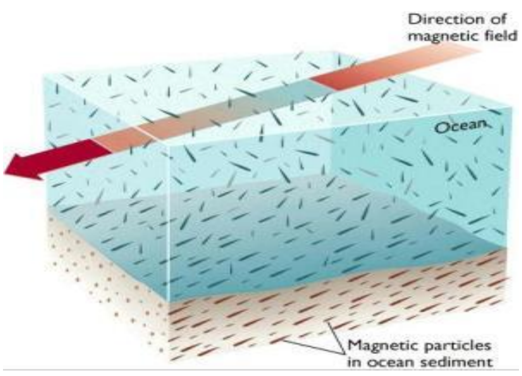


Carbon-14 cycle.

- **Radiocarbon (Carbon-14)**: 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 decomposing 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.
- **Aluminium 26-Beryllium 10:** it has the same application as the C14, but has a much greater decaying period, allowing dating up to 10 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 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 sed 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.

PALEOMAGNETIC DATING

The magnetic north pole has changed throughout the history of Earth and its geographical coordinates are known in different geological eras. Some minerals have magnetic properties and are directed towards the north magnetic pole when in aqueous suspension, for example clays. But when laid on the ground, they are fixed to the position that the north magnetic pole was at the time. If we look at what coordinates are oriented such minerals at the site, we can associate it with a particular time.



Deposition of magnetic particles oriented towards the magnetic north pole.

This dating is used on clay remains and as the magnetic north pole has been several times in the same geographical coordinates, you get more than one date. Depending on the context of the site, you may discard some dates to reach a final dating.

THERMOLUMINESCENCE DATING AND OPTICALLY STIMULATED LUMINESCENCE (OSL)

Certain minerals (quartz, feldspar, calcite etc) accumulate in its crystal structure changes due to radioactive decay of the environment. These changes are cumulative, continuous and time dependent to radiation exposure. When subjected to external stimuli, mineral emits light due to these changes. This luminescence is weak and distinct as apply heat (TL), visible light (OSL) or infrared (IRSL).

Fluorite's thermoluminescence.

Samples that were protected from sunlight and heat of more than 500 ° C can be dated by this method, otherwise the "clock" is reset as the energy naturally releases.

ELECTRON PARAMAGNETIC RESONANCE (ESR)

The ESR (electro spin resonance) involves irradiating the sample and measuring the energy absorbed by the sample depending on the amount of natural radiation which it has been subjected during its history. It is a complicated process and needs much expertise.

Reconstruction of Fossil plants

Plants produce leaves and flowers in the spring, flowers mature into fruits in the summer, and leaves and other organs tend to abscise annually. Thus, it is difficult to find in the fossil record all organs or plant parts in connection to each other. While in animals there is usually a size correlation between organ and animal, so much that the rule is used to estimate body sizes and create reconstructions of extinct animals, such correlation does not exist in plants. Nevertheless, numerous examples of whole plant reconstruction based on extensive collection of fossil parts have been published through the years; and the picture of past plants has become more complete and appropriate.

Methods to reconstruct plants

Two methods have been used to reconstruct plants:

1) Through organic connections among the different organs; this is the most spectacular and it is widely accepted eg sporangia were found in organic connection with the axes of *Rhynia gwynne-vaughanii.*

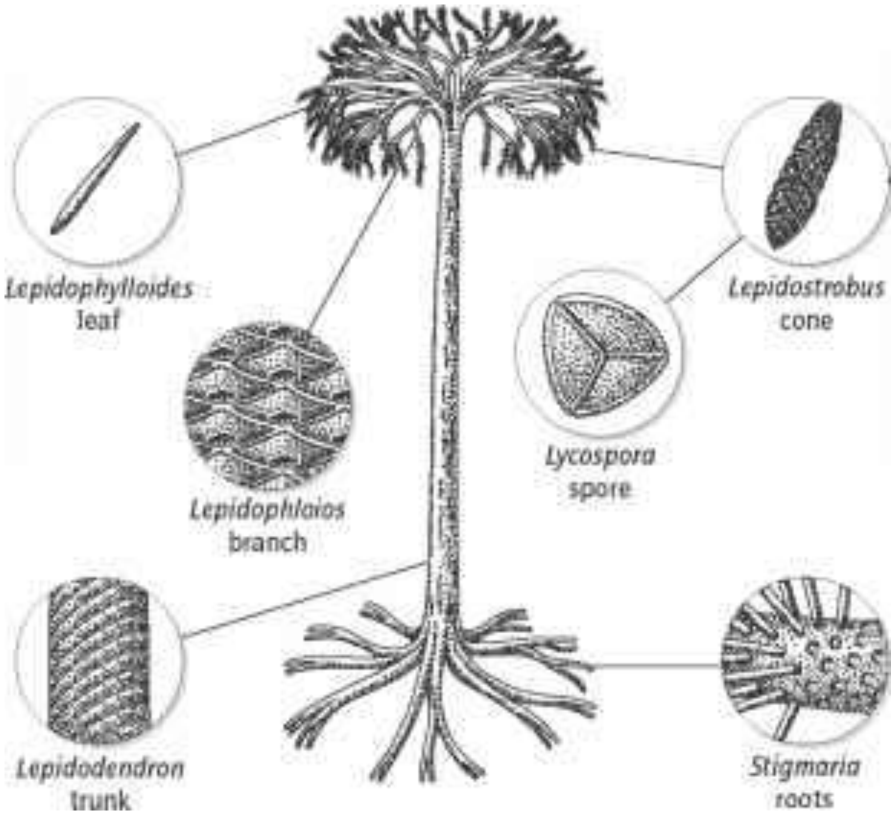
2) Common occurrence of organs in more than one locality where a single plant organ of a particular group is present, suggesting that the particular organs belong together.

In the latter case the argument can be strengthened by similarities of epidermal anatomy. Two of the most significant examples of plant reconstruction lead to the recognition of Pteridosperms and Progymnosperms, both from the Upper Paleozoic.

Fossils represent an alternative to understand life, both present and past. The organisms that we find today as fossils lived on Earth prior to the appearance of mankind; as men keep discovering them, the interpretations of what they represent changes enormously. This in turn stimulates the imagination and encourages the production of more knowledge and the advancement of science. In the last few decades, the interpretation of fossils has become a challenge since their discussion goes beyond the idea of representing evidence of past life. They are the only direct source of information to interpret how past life existed and interacted, and are the greatest model to compare life historical moments, including the thoroughly studied extant life.

Paleobotanical studies demonstrated that plants indeed changed through time. The definition of new groups and the understanding of their parts and organs produced impressive changes in plant concepts, as well as in the relationships among them, with other organisms, and with the environment. It was certainly important to uncover that during the Carboniferous, ferns were not as diverse or abundant as suggested by the large amount of fronds and pinna present in the sediments. Even today it would be difficult to reconstruct a progymnopserm or a pteridosperm based only on the study of extant plants; even numerical analyses which may suggest the presence of these groups have been so far unable to assemble one. The reinterpretation of the fossil record of that time allowed a better understanding in different aspects of the reproductive biology of those plants and their impact in other plants that followed them.

The abundance of fern and fern-like leaves in Devonian and Carboniferous rocks suggested that Pteridophytes were extremely important at that time, but the discovery of organs in organic connection demonstrated the presence of plant groups that were not even hypothesized at that time. Their recognition changed dramatically our understanding of diversity, plant evolution, and the relationships among plant groups. While Pteridosperms were plants that had stems with eusteles, naked seeds like the maidenhair tree (*Ginkgo biloba*), secondary growth, and frond-like leaves like ferns, Progymnosperms reproduced through spores like ferns, but their wood was more similar to that of conifers. Understanding other Mesozoic groups has been equally challenging. However, the process of assembling different plant organs also allowed the recognition of several distinct groups sometimes included in the concept of Mesozoic Pteridosperms. This is the case of the Glossopteridales, Caytoniales, Corystospermales, Peltaspermales, Bennetitales or Pentoxylales. All these groups further contributed to expand our understanding of past plant diversity and have been widely used to propose different relationships among group of plants, including angiosperms.



Reconstruction of the Fossil Plant of *Lepidodendron*

Compiled by

Dr. Vivek Singh