GEOLOGICAL TIME SCALE

Eon	Era	Period	Epoch	MYA		Life Forms	North American Events
Phanerozoic	Cenozoic (CZ)	Quaternary (Q)	Holocene (H)	0.01	Age of Mammals	Extinction of large mammals and birds Modern humans	Ice age glaciations; glacial outburst floods
			Pleistocene (PE)	2.6			Cascade volcanoes (W) Linking of North and South America (Isthmus of Panama)
		Tertiary (T) Neogene (N)	Pliocene (PL)	5.3		Spread of grassy ecosystems	Columbia River Basalt eruptions (NW) Basin and Range extension (W)
			Miocene (MI)	23.0			
		Paleogene (PG)	Oligocene (OL)	33.9			
			Eocene (E)	56.0			Laramide Orogeny ends (W)
			Paleocene (EP)	66.0		Early primates Mass extinction	
	Mesozoic (MZ)	Cretaceous (K)		145.0	Age of Reptiles	Placental mammals Early flowering plants	Laramide Orogeny (W) Western Interior Seaway (W) Sevier Orogeny (W)
		Jurassic (J)		201.3		Dinosaurs diverse and abundant Mass extinction	Nevadan Orogeny (W) Elko Orogeny (W)
		Triassic (TR)		251.9		First dinosaurs; first mammals Flying reptiles Mass extinction	Breakup of Pangaea begins Sonoma Orogeny (W)
	Paleozoic (PZ)	Permian (P)		298.9	Age of Amphibians		Supercontinent Pangaea intact Ouachita Orogeny (S)
		Pennsylvanian (PN)		323.2		Coal-forming swamps Sharks abundant	Alleghany (Appalachian) Orogeny (E)
		Mississippian (M)		358.9		First reptiles Mass extinction	Ancestral Rocky Mountains (W) Antler Orogeny (W)
		Devonian (D)		419.2	Fishes	First amphibians First forests (evergreens)	Acadian Orogeny (E-NE)
		Silurian (S)		443.8		First land plants Mass extinction	
		Ordovician (O)		485.4	Marine Invertebrates	Primitive fish Trilobite maximum	Taconic Orogeny (E-NE)
		Cambrian (C)		541.0		Rise of corals Early shelled organisms	Extensive oceans cover most of proto-North America (Laurentia)
Proterozoic		Precambrian (PC, W, X, Y, Z)		2500		Complex multicelled organisms Simple multicelled organisms	Supercontinent rifted apart Formation of early supercontinent Grenville Orogeny (E) First iron deposits Abundant carbonate rocks
Archean				4000		Early bacteria and algae (stromatolites)	Oldest known Earth rocks
Hadean				4600		Origin of life Formation of the Earth	Formation of Earth's crust

Fossilization

The method by which fossils are formed is termed as **fossilization**.

Optimal conditions for fossilization are that an organism is buried very soon after its death and in the absence of bacterial or fungal decay, that mineral-rich waters and sediments surround the site, and the immediate environment is cool and hypoxic.

The root of the word fossil derives from the Latin verb 'to dig' (fodere).

A fossil is the mineralized partial or complete form of an organism, or of an organism's activity, that has been preserved as a cast, impression or mold. A fossil gives tangible, physical evidence of ancient life and has provided the basis of the theory of evolution in the absence of preserved soft tissues.

A Pectinatites ammonite,

Mould of a bivalve shell

Preserved insect trapped in amber

Fossil recod

- The totality of fossils - their placement in fossiliferous, rock formations, sedimentary layers (strata)
- Fossil record - important functions of the science of paleontology - vary in size
- A fossil normally preserves only a portion of the deceased organism, bones and teeth of vertebrates, the chitinous or calcareous exoskeletons of invertebrates.
- The **oldest human fossil**, where human refers to *Homo erectus*, *Homo ergaster*, and *Homo georgicus*, was a set of five skulls found in Dmanisi in Georgia between 1999 and 2005. These date back to approximately 1.8 million years ago. The oldest fossil remains depict five different species of microbe, preserved in a 3.5-billion-year-old rock in Australia. These microbes were carbon-dated by researchers at UCLA and the University of Wisconsin-Madison.

Chemofossils

- Chemical Fossils or Chemofossils
- Sometimes it is only chemicals that are left behind, as in the case of carbonization where all other chemical traces slowly disappear, leaving a thin layer of carbon. This phenomenon is known as a carbon film fossil or phytoleim and looks like a careful black or brown tracing of the original organism in two dimensions. Carbon films usually occur at the same time as compression, leaving a fine carbon print on the surface of a rock. In fact, **any organic molecules left behind that prove the existence of past life are considered to be chemical fossils**.

Ichnofossils

- Traces, Tracks and Trails
- Trace fossils, also called ichnofossils, tell us about an organism's behavior rather than representing its anatomical form. Traces are split into four sub-groups – tracks, trails, coprolites, and gastroliths. Tracks are footprints, paw prints or claw prints which become covered with sediment before they are washed away by rain or wave. Trails are not usually made by feet, but by tentacles, the crawling patterns of snakes and worms, or the boreholes of prehistoric beetles. The picture below features a *Tyrannosaurus rex* track.

Trace fossil

Tyrannosaurus rex fossil footprint

Taphonomy

- The process of fossilization is called **taphonomy.**
- First, there is the death of the organism.
- There are certain processes that can happen to the organism before it is buried.
- Processes can include body decay.

What are some factors that can affect fossilization

1. Body construction
2. Environment
3. Predators

How is fossilization dependent upon the environment

- The environment plays a crucial role
- The best scenario
- Area with high rate of sediment deposition
- The environment can also affect where the fossil is found
- Drier environments, lead to erosion

How do fossils form

Four types of process contribute to the formation of a fossil. These are mineralization, carbonization, encrustation and distillation. They occur once an organism has become trapped within the surrounding sediment, and primarily depend on the mineral composition of silt and water.

1. Original soft part of organism
2. Oiginal hard part of organism
3. Altered hard part of organism
4. Traces of organism

Originl soft part of organism

- Organisms are fossilized but under exceptionally favorable conditions. Even soft part of organisms get preserved in a medium that protect them from bacterial decay. Examples:

    i. Ice
    ii. Amber
    iii. Volcanic ash
    iv. Oil Saturated soil

Ice

The best known example of fossil preserved in ice **Wooly Mammoth** of Siberia and Alaska.

Huge elephant like animals died due to glaciation about 23,000 years ago. The first such find was reported in 1779. The ice preservation is so perfect.

Frozen Mammoth in ICE

ii. Amber

- Amber is a natural tree resin that had hardened through various chemical changes. Sometimes this sap surrounds an insect, preserve it with perfect details & look like stone.
- The formation of Amber may trap foreign objects, which are called **inclusions**

iii. Volcanic ash

In AD 79 an eruption of Mount Vesuvius.

Volcanic ash and pumice rained down on the town for about 18 hours, many roofs collapsed under the weight, followed by explosive superheated pyroclastic clouds of toxic gas and debris and remained hidden for over 1600 years.

In 1748, Pompeii was rediscovered not only its houses, but (eventually) some of its citizens - only fragmentary skeletal remains suffocated by volcanic gasses and covered in ash and debris - their bodies eventually decayed inside the hardening matter. This air space essentially formed a mold ash that had surrounded the person retained an imprint of the body.

- air pockets filled with plaster
- The resulting "plaster mummies”
- capture the human tragedy of Pompeii

http://jasonstravels.com/2012/09/17/traveling-to-pompeii-with-the-denver-museum-of-nature-and-science/

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Dog from Pompeii

Pompeii city
http://www.mummytombs.com/pompeii/background.htm

Original hard Part of organisms

- Most of **the animals** have some hard parts

i. **Calcite ($CaCO_3$)**is the most abundant original skeletal material found in fossils

ii. **Aragonite ($CaCO_3$)** is preserved in the shells of some corals and molluscs.

iii. **Tricalcium Phosphate** ($Ca_3(PO_4)_2$) is a chemically resistant mineral found unaltered in vertebrate bones, some arthropods and brachiopods.

iv. **Opal (SiO2H2O)** is amorphous hydrated silica preserved in latter geologic time in some Protozoans and sponges

v. **Chitin** is an organic compound that is resistant to bacterial action and is not readily altered.

Tricalcium Phosphate ($Ca_3(PO_4)_2$)
http://www.thefossilforum.com/index.php?/gallery/image/17509-crocodilian-osteoderms/

CALCITE ($CACO_3$)

http://www.tripadvisor.com/LocationPhotoDirectLink-g191249d585694-i22926045-Dinosaur_Isle-Sandown_Isle_of_Wight_England.html

3- Altered Hard Part

- The original hard structure of many organisms
- The preservation of altered hard part of organisms can be classified as:

i. Carbonization or Distillations

ii. Permineralization or petrification

iii. Replacement

Carbonization or Distillations

The type of fossil in which only the carbon remains in the specimen, volatile elements in organic matter distill away, thin carbon film as the only fossil record especially carbon copies of leaves, the flesh of fish organisms become trapped and squeezed, then form compression.

- Fossils of leaves and insects are often formed by compression. The organic matter may be altered during decay and rock formation.
- Distillation of volatile compounds and the polymerization.
- The thin, dark, film is made of stable, polymerized carbon molecules.

Cone & Needle Compression

Leaf & Seed Compression

Fish Compression

http://petrifiedwoodmuseum.org/carbonization.htm

Permineralization or petrification

Petrified remains are the result of the **replacement of the original remains with very specific minerals**, which must be present in sufficient quantities dissolved in the water source.

Petrification is an older term and rarely used except at certain tourist sites. The process by which the organism's components are replaced by water-soluble minerals is called **mineralization**.

These minerals are most commonly calcium carbonate, silicon dioxide, iron sulfide, iron carbonate and calcium phosphate. As the tissue of the dead, buried organism dissolves, the gaps left behind allow these minerals to seep in.

Soft tissues are generally less well preserved than the petrifaction (or petrification) of hard tissues, depending on the environment and the rate of the replacement process.

Petrified forests, like the one in Arizona shown below, contain stone-like tree stumps, the result of original tissue being replaced with crystalized minerals.

Petrified trees of Arizona

http://www.wisegeek.org/what-is-permineralization.htm

Permineralization or petrification

Replacement

Replacement takes place when water dissolves the original hard parts and replaces them with mineral matter. Bone, shells and wood are often well preserved in this manner.

The most common replacement minerals are calcite, silica, pyrite, hematite and *Aragonite*

This occurs when skeletal material is replaced, molecule by molecule, by some new alien material. The process occurs gradually are Silicification - where calcium carbonate is replaced by silica, and Pyritization - where pyrite replaces calcium carbonate.

Minerals can replace bone, shell, wood, and even soft body parts, due to the action of water and decay.

http://en.wikipedia.org/wiki/Fossil#Wood

Silicified (replaced with silica)

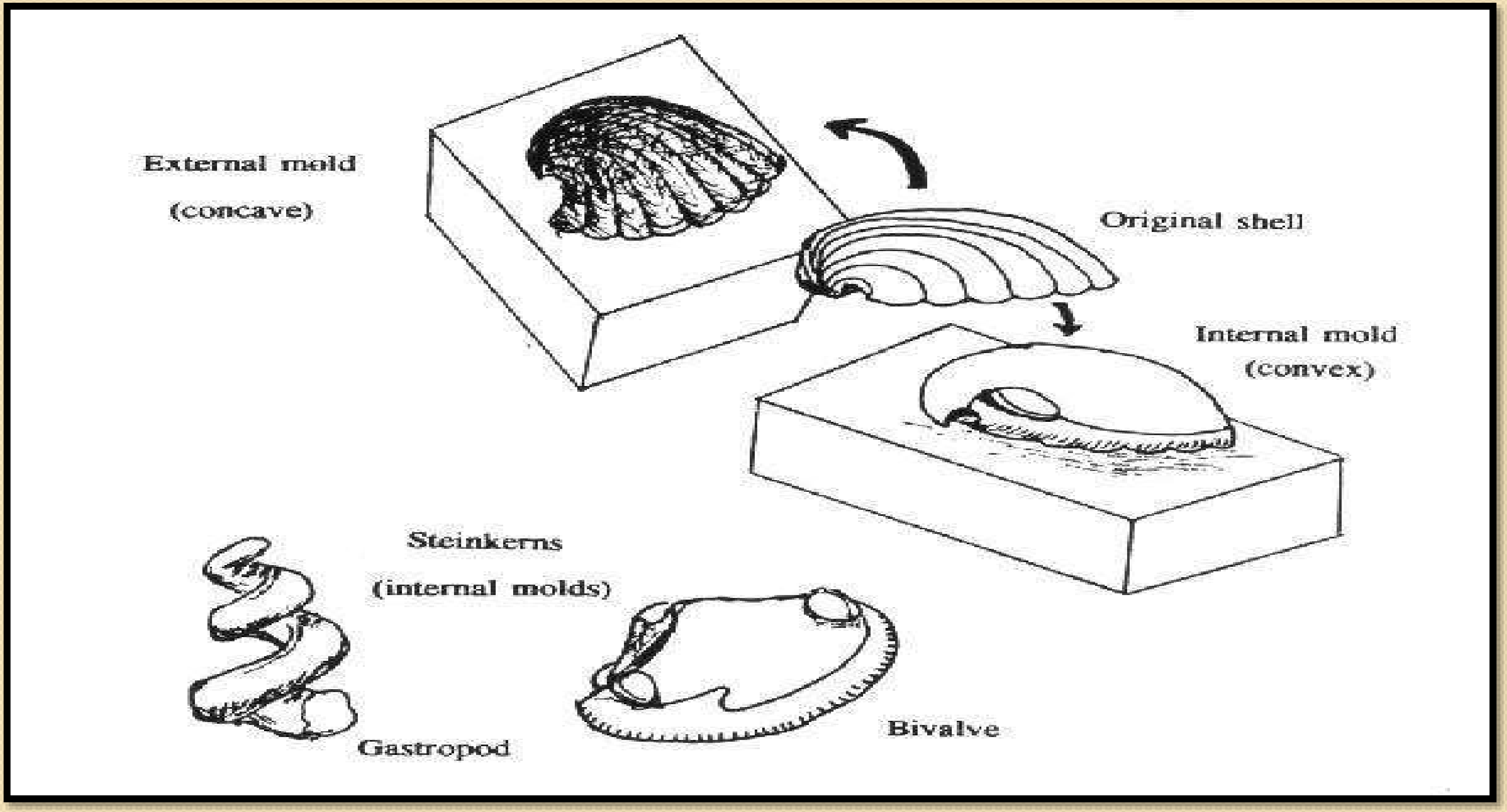
4. Trace of Organisms

- Mold
- Cast
- Tracks & Trails
- Burrows
- Gastroliths

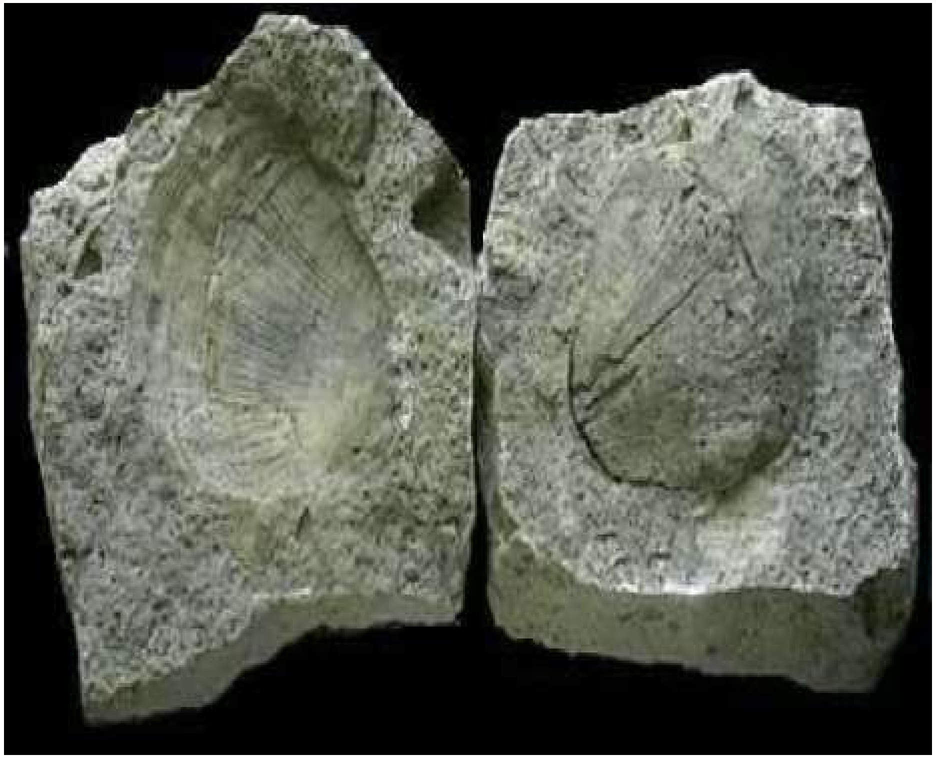
Mold & Cast

- A mold fossil is the **equivalent of a plaster cast mold of a wax model**. If an organism becomes trapped in sediment, decomposition takes place at an extremely slow rate as the sediment dries out and becomes rock. When the rock is cracked open millions of years later, the impression of the organism can be seen outlined in the rock.
- A cast fossil is the equivalent of liquid porcelain poured into a plaster-cast mold.

I. ***natural mold***
II. ***external mold***
III. ***internal mold***

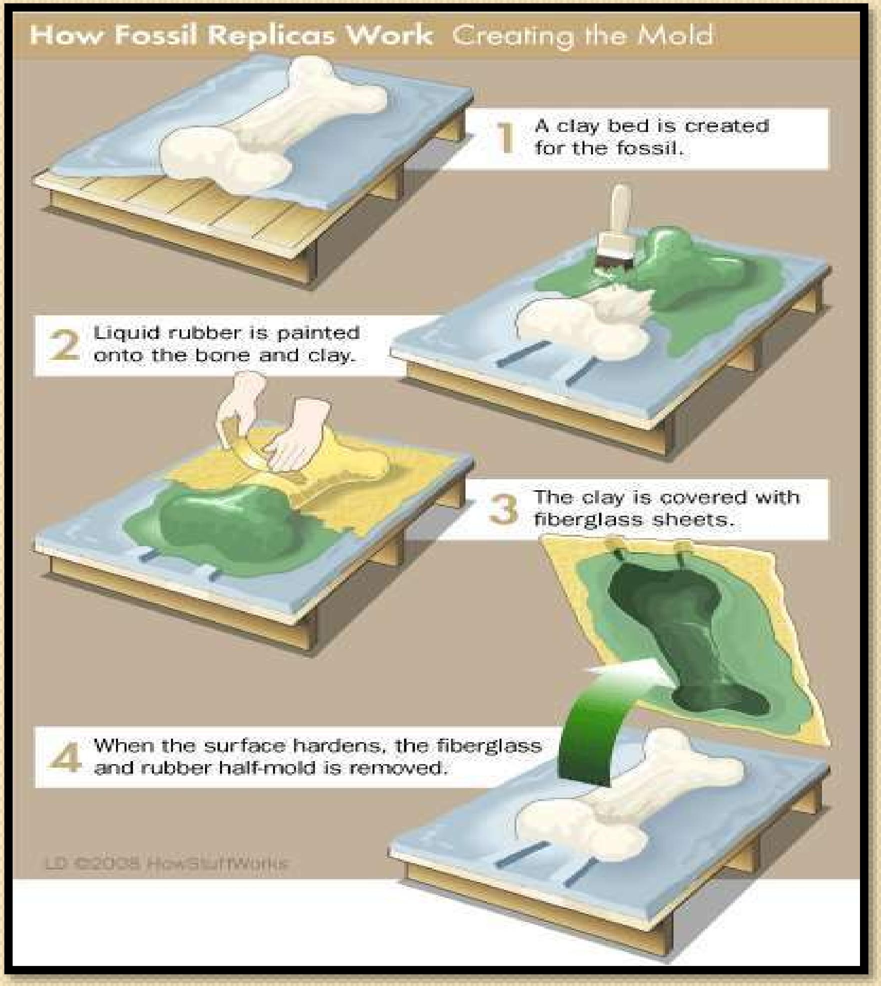


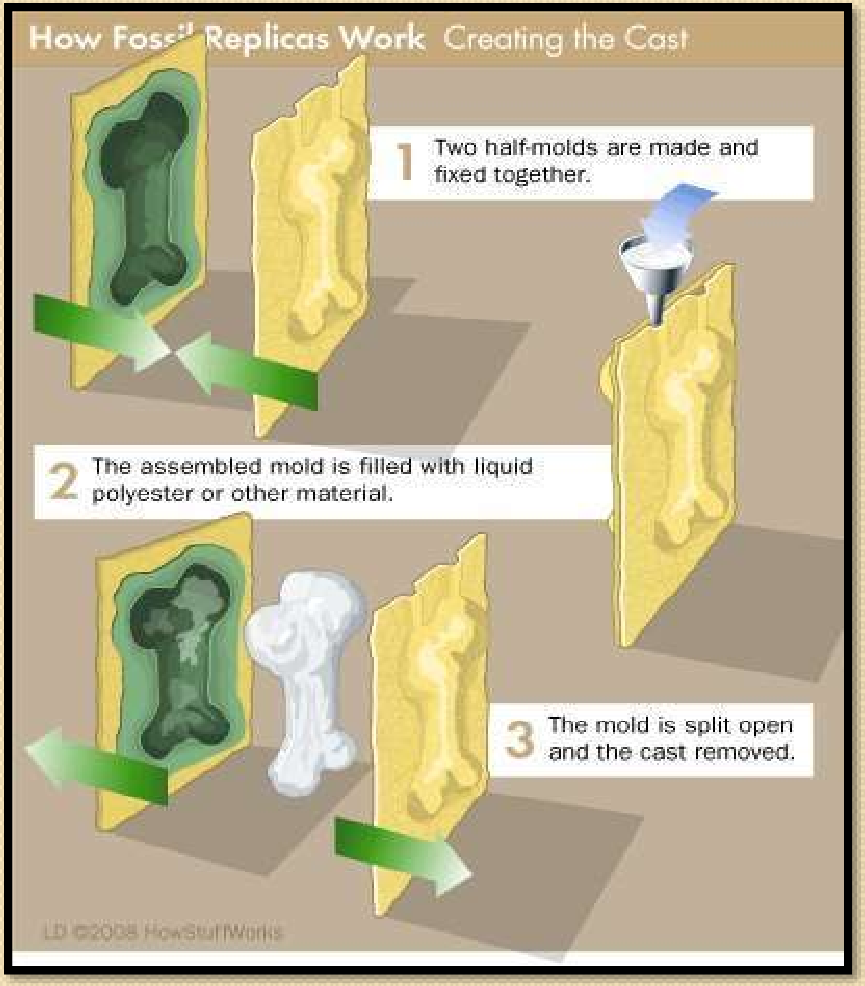
Animals with shells or hard exoskeletons buried in sediments are often acted upon by acid-rich ground water which may dissolve away shells or other organic structures.



http://www.mpm.edu/content/collections/learn/reef/diagenesis.html

Cast & Mold





How mold & cast form?

http://www.guokr.com/post/477970/

Gastroliths

- Modern birds use swallow stones
- muscular stomach
- gastrolithes

Tracks & trails

- particular form of trace fossil
- range from the worm trails to dinosaur
- even the footprints of Stone Age people
- great variety of invertebrate's tracks

Reptile's tracks

http://www.t-rat.com/Pages/FossilPreservation.html

Burrows

- evidence of bottom-living creatures
- labyrinth of hollow tunnels
- filled by silt & preserved
- labyrinth of hollow tunnels
- rarely show much detail

[*http://www.t-rat.com/Pages/FossilPreservation.html*](http://www.t-rat.com/Pages/FossilPreservation.html)

Conclusion

- fossil record does not represent all of the living things
- The reason
- Some organisms may have decayed
- Organisms that live on land or have soft body parts
- fossils provide a piece of Earth's history

Naming of Fossil Plants – Fossil Nomenclature

INTRODUCTION:

The first valid description of Lepidodendron came into existence from the publication of Sternberg in 1820.

Thus, this date has been considered as the starting point of paleobotanical nomenclature.

The whole plant is not preserved, but only detached plant parts like stem, root, cone, leaf, etc. are preserved as fossils.

These detached plant parts are being discovered in different times by different authors.

Thus, the detached plant parts or organs are given name on the basis of Binomial Nomenclature (“generic and specific name”) according to rules of International Code of Botanical Nomenclature which have been framed for living plants.

- Each detached organs or fragments is given a different name.
- Each of these names acquires the status of a genus.
- The generic name in fossils is applicable for only a plant part like root, stem, leaf, cone or other organ, without indicating to what plant is belongs.
- Thus, the genus is termed form genus or artificial genus in contrast to natural genus for living plants.

- A form genus cannot reliably be assigned to a single family; however, it may be assigned to an order or other higher taxonomical rank.
- For example, Stigmaria is a form genus of the order Lepidodendrales which cannot be assigned to any one of the three families: Lepidodendraceae, Sigillariaceae or Bothrodendraceae.

- When the relationships among different organs like stem, root, leaf and reproductive structures are established and can be assigned to the same family, then the genera can be called organ genera.
- For example, stem genus Bucklandia, leaf genus Ptilophyllum, male fructification Weltrichia and female fructification Williamsonia are genetically related and assigned to the same family Williamsoniaceae.
- Thus, all are considered to be organ genera. However, there is no provision in the international rules of botanical nomenclature for the use of organ genera.

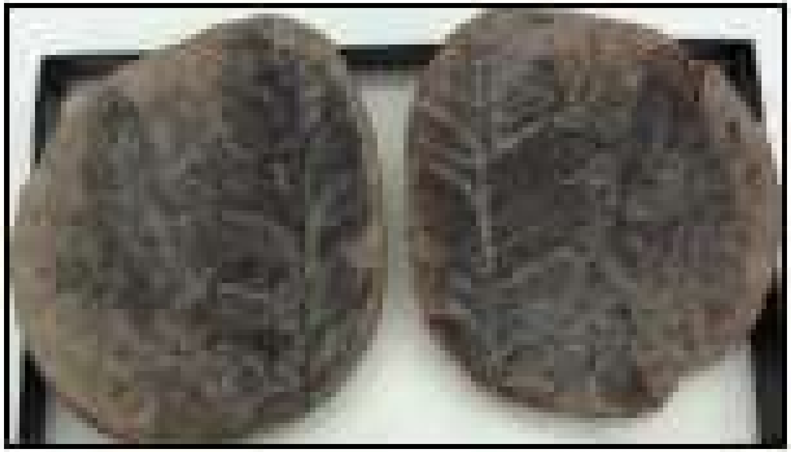
- During reconstruction the palaeobotanists should select the earliest (after 1820) validly published generic name applied to ay one of its parts as per rule of priority.
- He or she will use any one of the form genera as the generic name for the whole organism.

It is difficult for paleobotanists to identify and categorize plant fossils. Usually they only see fragments. As a result, a somewhat artificial classification system was developed, grouping together fossils on the basis of morphological resemblance of the separate parts of fossil plants. Each part may be given a separate name. This name is called a *morphotaxon* or *form genus*. This can at times be confusing, since it is a very different kind of system from the botanical identification and classification of living plants.

Rules for naming form genera

A particular suffix is used for naming a form genus which signifies the organ it belongs. The suffixes applied to different plant parts are as follows:

Suffix	Applied to organ	Examples
Dendron	Stem	*Lepidodendron, Lyginodendron*
Xylon	Woody part	*Dadoxylon, Cardaixylon, Mesoxylon*
Phyllum	Leaf	*Ptilophyllum, Nipaniophyllum, Brachyphyllum*
Pteris	Fern like stem or frond	*Sphenopteris, Lyginopteris, Etapteris, Archaeopteris.*
Spermum	Seed	*Corystospermum, Mitrospermum*
Carpon	Seed or seed like	*Lepidocarpon, Mazocarpon, Calamocarpon*
Carpus	Seed	*Trigonocarpus, Cardiocarpus*
Stoma	Seed	*Lagenostoma, Stamnostoma*
Theca	Microsporangia	*Codonotheca, Aulacotheca, Crossotheca*
Strobus	Cone	*Lepidostrobus, Androstrobus.*



Alethopteris is an extinct genus of seed ferns or pteridosperms. *Part* and *counterpart* fossils here display a part of an *Alethopteris* frond. The fossils create planes of weakness within the nodules, which tend to split open so that one half reveals the upper surface of the plant (part), while the other half contains an impression of the upper surface (counterpart). *Althopteris* is not depicted in the Plant Evolution Mural, although another pteridosperm, *Medulloso*, is seen on Panel 5.

Calamites is a genus of extinct giant horsetails. They were arborescent with secondary growth and woody tissue, enabling them to reach heights of 60 feet or more. The stems were conspicuously jointed and ribbed and, unlike today's horsetails, which have leaves reduced to small scales, *Calamites* had well-developed leaves.

Seen on Panel 5 of the Plant Evolution Mural.

Annularia is the name given to one of the forms of *Calamites* leaves. Seen on Panel 5 of the Plant Evolution Mural.

Psilophyton is an extinct primitive non-seedbearing vascular plant. It is categorized as an herbaceous lycopod—in the plant division Lycopodiophyta. This is one of the earliest plant divisions that has descendent species living today, the clubmosses (although they are not mosses, but more closely related to ferns). First described in 1859, Psilophyton was one of the first fossil plants from the Devonian period to be found. It has true roots, stems, and true leaves, although the leaves were extremely small, known as microphylls. First appearing in the late Early Devonian, Psilophyton became extinct by the end of the Middle Devonian.

Seen on Panel 3 of the Plant Evolution Mural

Sigillaria belongs to a group of extinct, spore-bearing, arborescent plants called tree lycopods, which were prominent in the Late Carboniferous Coal Swamp Forests. They had long, unbranched main trunks, branching only once or twice at the top, unlike *Lepidodendron*, which branched profusely at the top. *Sigillaria* was also shorter, reaching heights of about 60 feet. Seen here is a bark fossil.

Williamsonia was part of an extinct group of gymnosperms called Cycadeoids, because they exhibited much resemblance in growth form to the cycads. Cycadeoids first appeared in the Triassic Period and had died out by the end of the Cretaceous Period. Williamsonia had slender, branching trunks and cones (strobili) that were either unisexual or bisexual (with both seed and pollen-producing structures).

Seen on Panel 6 of the Plant Evolution Mural

Sphenopteris is the form genus name given to particular forms of fern-like foliage. The term was applied to predominantly late Paleozoic foliage types, generally characterized by pinnules constricted at the base. However, this name has been applied to a variety of disparate plants, which have now been identified as including seed ferns as well as true ferns. Attempts have been made to define clusters or subgroups, but the individual species are not well understood and often the fossils are only fragments and not whole fronds. Natural variation inherent in foliage from different parts of the frond, or in different stages of development also confuse the issue. Sphenopteris foliage was very common in the Carboniferous, surviving into the Mesozoic Era.

Although not depicted on the Plant Evolution Mural, Sphenopteris would be seen on Panel 5.

Collipteridium is an extinct genus of seed ferns or pteridosperms. They were vascular plants that bore seeds on fern-like leaves, but they were not ferns, but rather gymnosperms. It was not until the early 1900s that much of the fern-like foliage found in Paleozoic rocks was recognized to belong to plants that bore seeds. Pteridosperms were particularly characteristic of the Carboniferous Period. Mature fronds are speculated to have been over 10 feet long.

Collipteridium is not depicted in the Plant Evolution Mural, although another pteridosperm, *Medullosa*, is seen on Panel 5.

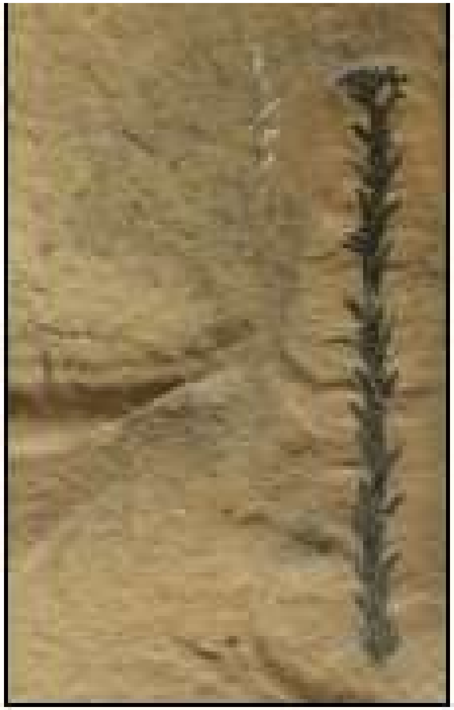
Cordaites were an extinct group of gymnosperms that gave rise to the conifers, e.g., pine, spruce, hemlock, fir, and their relatives. These tall trees are estimated to have grown up to 100 feet tall and had large strap-shaped leaves. They first appeared in the latest part of the Late Devonian and the earliest part of the Early Carboniferous and became common in the Late Carboniferous, dying out by the end of the Permian Period. The name *Cordaites* was originally applied only to the foliage, but is now also used for the stems and the entire plant.
Seen on Panel 5 of the Plant Evolution Mural.

Ginkgophytes are an ancient group of gymnosperms, thought to have originated in the late Paleozoic Era. Large fan-like leaves reminiscent of *Ginkgo* leaves can be found in Carboniferous fossils and have been called *Ginkgophytopsis*, but fossils from that era can be very difficult to interpret. During the Jurassic Period, many species of *Ginkgo* were common, but today they are represented by only a single extant species—*Ginkgo biloba*, the maidenhair tree, so named because its leaves resemble those of the maidenhair fern. *Ginkgo* has distinctive broad leaves that have dichotomous venation.

Although another ginkgophyte, *Sphenobaiera*, is seen on Panel 4 of the Plant Evolution Mural, *Ginkgo* is on Panel 5.

Glossopteris comes from the Greek: γλώσσα *glossa*, meaning tongue, because of the large, tongue-shaped leaves on these 20 foot tall trees. Now extinct, *Glossopteris* is famous as the fossil that led Austrian geologist Eduard Suess to conclude, based on its distribution, that there had once been a large southern continent, which he named Gondwanaland. The past distribution of *Glossopteris* fossils constituted one of the most important pieces of supporting evidence for the theory of Continental Drift, the precursor to the modern theory of plate tectonics.

Seen on Panel 6 of the Plant Evolution Mural.



Pagiophyllum is an extinct member of the Araucariaceae family, which today is restricted to the Southern Hemisphere. This family includes the common houseplant, the Norfolk Island pine. The genus *Pagiophyllum* was extant between 290 and 85 million years ago, with a world-wide distribution. This fossil is approximately 190-200 million years old.

Pecopteris is the form genus name for the leaves of the marattialean fern *Psoronius*. The name is applied to tongue-shaped pinnules (lobes) of the fern frond, which are broadly attached to the rachis (the main axis of the leaf). This is one of the best known Paleozoic tree ferns. Seen on Panel 5 of the Plant Evolution Mural.

Lepidodendron is among the extinct arborescent lycopods. With their secondary growth (woody tissue) they grew to heights of 130 to 150 feet. The massive, erect trunks of some *Lepidodendron* species branched profusely to produce large crowns of leafy twigs. Some leaves reached three feet long, leaving conspicuous leaf bases on the stem surface when they dropped off. It was in fact the distinctive pattern of these leaf base scars that gave it its name— *Lepidodendron* or scale-tree. The bark fossil on display here shows that pattern. Also shown is a fossil featuring smaller stems.

Seen on Panel 5 of the Plant Evolution Mural.

Petrified wood is a permineralization fossil. This kind of fossil forms when a plant part becomes immersed in water containing a high concentration of dissolved minerals (most commonly silica),

which then permeate all the cells and tissues of the plant. Something triggers the precipitation of the dissolved minerals so that they harden around and within the plant fragment. When the mineral is completely solidified, the plant fragment is essentially entombed within solid rock. In these kinds of fossils, scientists can study the internal anatomy of ancient plants. Often this is done by making very thin sections of the fossil.

Cryptozoon is the name given to a form of Cambrian and Precambrian reef-forming rocks. They are composed of alternating light and dark layers of sediment, thought to represent fossilized remains of ancient microbial mat communities growing in the sea. These are examples of trace fossils, which are indicative of activities of living organisms but which do not preserve any remains of the organisms themselves. Also known as Stromatolites, these laminated rocks were widespread during Precambrian times, when the world was dominated by microbial life. Some stromatolites have been found that date back 3.5 billion years ago, thus they are evidence of some of the earliest life on Earth. Today one can see living examples of stromatolite beds in Shark Bay on the west coast of Australia.

Radiocarbon dating

- To calculate the age of the fossils
- One of the most frequent questions a Palaeobotanist or Palaeontologist hears concerns the method for dating sediments containing fossil plants and animals. Present knowledge is based on a long series of efforts to date the ages of various rocks.
- At the present time, the best absolute dating involves the use of naturally occurring radioactive isotopes contained in various minerals that make up a rock. These radioactive isotopes are sometimes referred to as “geological clocks.”

Amongst the physical methods, the C^{14} dating technique for dating organic remains is still unsurpassed in accuracy Normally its dating range is 50,000 years for its short half-life. The technique of C^{14} was developed by W.F.Libby (1955).

The method is based on the fact that C^{14} atoms are continuously produced in the atmosphere as a result of neutron (n), proton (p) reaction induced by slow neutrons of the cosmic ray on the atmospheric nitrogen cycle (N^{14}):

$$^{14}_{7}N + ^{1}_{0}n \rightarrow \left[^{15}_{7}N\right] \rightarrow ^{14}_{6}C + ^{1}_{1}H$$

The newly formed carbon is oxidised to $^{14}CO_2$ and rapidly mixes with atmospheric carbon dioxide ($^{12}CO_2$). Part of the atmospheric $^{14}CO_2$ and $^{12}CO_2$ enter plant tissue as a result of photosynthesis. Animals partake this carbon through the consumption of vegetable matter. The larger part of the $^{14}CO_2$ goes to the ocean where it gets incorporated in the marine carbonates. From the atmosphere which is its birth place, C is distributed globally through the carbon cycle.

All living matter on earth is thus labelled by radiocarbon atoms at a constant level (activity per gm of Carbon). The amount of ^{14}C present in this system is about 1×10 per atom of ordinary carbon (^{12}C). ^{14}C atom will follow the radioactive decay where a neutron is converted to a proton by the ejection of a negatively charged beta (β) particle called a negatron. As a result the nucleus loses a neutron but gains a proton and will converted to a stable Nitrogen atom.

Radioactive decay is a spontaneous process and it occurs at a definite rate characteristic of the source. This rate always follows an exponential law. Thus the number of atoms disintegrating at any time is proportional to the number of atoms of the isotope present at that time

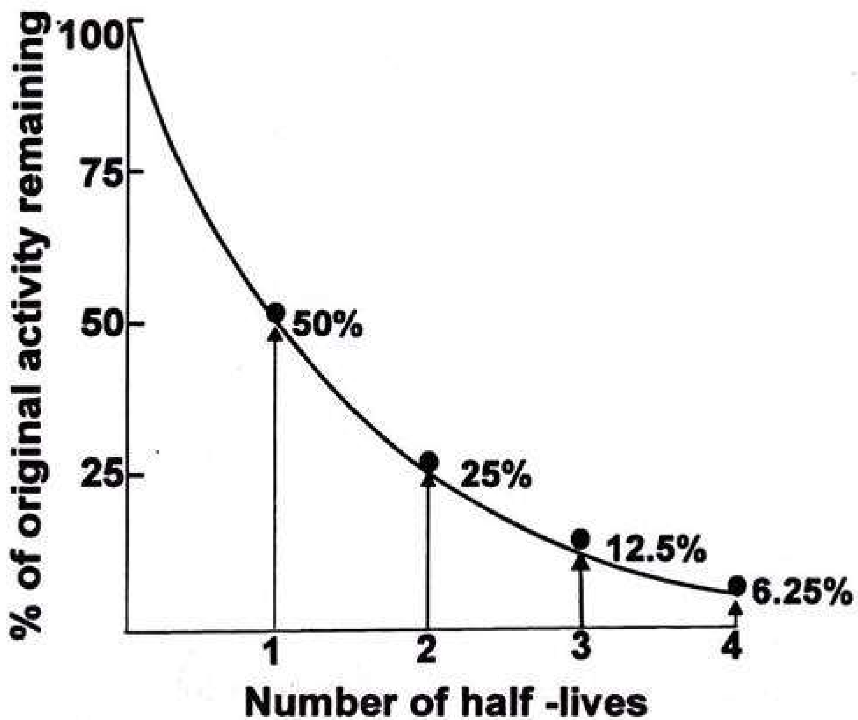


Fig. 13.4 : Diagram showing radioactive decay.

So the exponential curve will give the equation:

$$-\frac{\delta N}{\delta t}=\lambda N$$

Thus the rate of change in the number of radioactive atoms is porportional to the number of atoms present (N) multiplied by the decay constant (λ). This constant is a characteristic of a given isotope and is defined as the fraction of an isotope decaying in unit time (t^{-1}).

By integrating the above equation it can be converted to a logarithmic form:

$$1_t = 1_0 e^{-\lambda t}$$

By measuring the radioactivity of plant samples freshly formed, 1_0 is obtained, remembering that the rate of synthesis of ^{14}C is constant. The present day radioactivity (It) is measured with the sample. It is thus possible to find out 't', the age of the sample, knowing that half life of ^{14}C is 5568 ± 30 years.

n age limit of about 50,000 years applies to this technique because of the short half-life of ^{14}C. This technique obviously has somewhat limited usefulness in Palaeobotany and Palaeontology because bulk of the fossil plant and animal records are much older.

Human influence on the earth has even altered the usefulness of the ^{14}C dating method because combustion of fossil fuels and nuclear testing have artificially altered the ^{14}C content of the total carbon reservoir. Loss or addition of ^{14}C to specimens and apparent fluctuations of past atmospheric ^{14}C abundance also impose limitations on this dating method.

Contributions of Prof. Birbal Sahni (1891- 1949)

Birbal Sahni studied the fossils of the Indian subcontinent and his greatest **contributions** lie in the study of botany of the plants of India as well as paleobotany.

He was also a famous geologist who took interest in archaeology.

Sahni founded the **Birbal Sahni** Institute of Palaeobotany in Lucknow.

Birbal Sahni was the first botanist to study extensively the flora of Indian Gondwana. Sahni also explored the Raj Mahal hills in Bihar, which is a treasury of fossils of ancient plants. Here he discovered some new genus of plants.

Works of Birbal Sahni

Sahni wrote numerous influential papers.

In 1917, Sahni joined Professor Seward to work on a 'Revision of Indian Gondwana plants'.

In 1919 he briefly worked in Munich under the German plant morphologist Goebel.

Sahni served as Professor of Botany at Banaras Hindu University, Varanasi and Punjab University for about a year.

In 1921 he was appointed the first Professor and Head of the Botany Department of the Lucknow University.

In 1929 the University of Cambridge awarded him the degree of Sc. D.

- He made comprehensive studies on Indian Conifers.
- Later, he explored wealth of fossil plants from Rajmahal Hills.
- He studied *Ptilophyllum* and other elements and found that stem *Bucklandia*, leaf *Ptilophyllum* and flower *Williamsonia* belong to the same plant.
- He made reconstruction of *Williamsonia sewardiana*.
- He discovered petrified wood of *Homoxylon rajmahalense*, later, which was named as *Sahnioxylon rajmahalense*.
- He also described *Glossopteris angustifolia* Brongniart, *Palmoxylon sundram* a petrified wood, *Cocos* wood and a water fern *Azolla intertrappea*.
- This was followed by study of Gondwana plants of Salt Range, Karewa flora from Kashmir.

- He instituted a new plant group ‘Pentoxyleae’ which attracted worldwide attention.
- His palaeobotanical studies had given support to continental drift theory.
- In addition he dated some of the rocks of Salt Range to about 40-60 million years, and searched the Deccan traps in Madhya Pradesh and dated them as 62 million years, concluding they belonged to the Tertiary period.

Birbal's foremost ambition was to put palaeobotanical research in India in an organized basis.

Initially he established a museum of plant fossils in 1929.

In 1939 he constituted the committee of Indian Palaeobotanists named as "The Palaeobotanical Society" and convened a meeting to coordinate and develop research fields in India.

The institute initially functioned in the Botany Department of Lucknow University.

But later moved to its present premises at 53 University Road, Lucknow in 1949.

Honours and Awards

Sahni received number of awards and prizes for his significant contributions.

He was the recipient of the Barclay Medal of Royal Asiatic Society of Bengal in 1936, the Nelson Wright Medal of the Numismatic Society of India in 1945 and the Sir C. R. Reddy National prize in 1947.

He was elected fellow of Geological Society of Great Britain.

He also served the editorial board of the Botanical Journal Chronica Botanica.

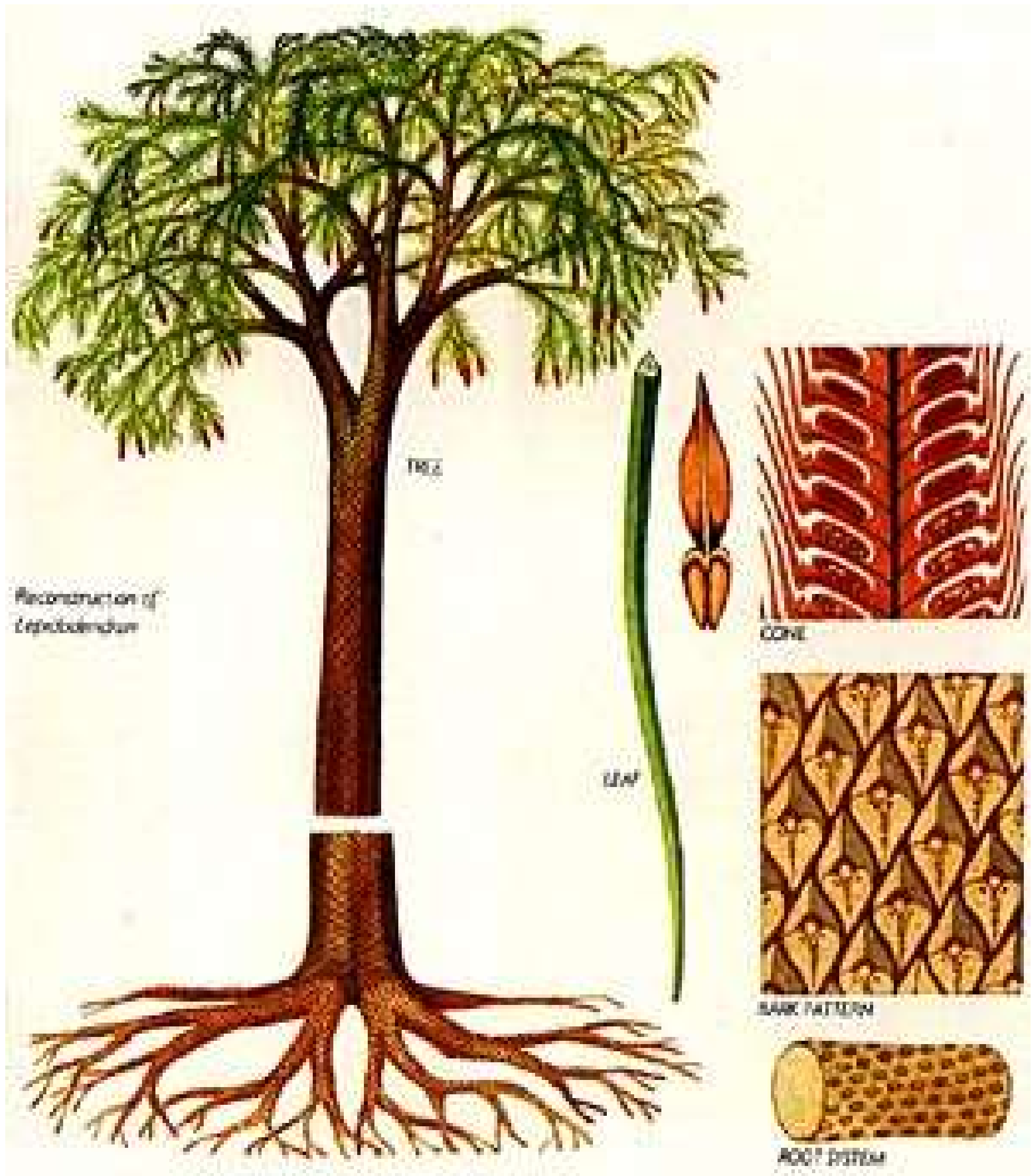
He was elected vice president of the 5th and 6th International Botanical Congress in 1930 and 1935 held at Cambridge and Amsterdam respectively.

In 1936 he was elected as fellow of Royal Society of London.

He was general President of the Indian Science Congress in 1940. He was a founder fellow of the National Institute of Science Academy (now Indian Science Academy, New Delhi).

Lepidodendron, Stigmaria, Lepidocarpon

Lepidodendron



Habit and Habitat of Lepidodendron

- A new groups of arborescent lycopods, popularly known as Lepidodendrales, had evolved from the Middle Devonian lycopods.
- These arborescent plants would grow to 164 ft (50 m) and form extensive coal measures swamp forest of the Northern Hemisphere Euramerican province during the Carboniferous period. Among these, Lepiclodendron was the most successful of all the arborescent members and is the best-investigated genus.

- The Lepidodendron was a large tree (50-60 m tall) with a prominent trunk (up to 35 m height).
- The ultimate dichotomies formed the leaves. The branches and the foliage formed a spreading crown bearing cones at their tips.
- The plant had bipolar growth, thus the main axis developed branches at both ends.
- The aerial branches formed three-dimensional dichotomies bearing branches and foliages, similarly the basal branches formed three-dimensional dichotomies bearing stigmarian root system.

- The stem form-genus is called Lepidodendron which has been reported mostly as casts or compressions. In most species, the trunks attained a height up to 98-115 ft (30-35 m), because the first branching at a distal end appeared up to 30-35 m in height. At the base, the trunks are known to be 3.3 ft (1 m) in diameter. Numerous leaf cushions arrange spirally on the stem surface.
- The leaf cushions-are rhomboidal in shape and broader in their vertical dimension than their transverse length (Fig. 7.39). A leaf scar is situated just above the middle line of the cushion. The leaf scar comprised of a vascular bundle scar at the centre and is flanked by two parichnos scars on either side of the bundle scar just above the middle of the cushion.

- A ligule pit is situated just above the cushion. Two more parichnos scars (infrafoliar parichnos) are situated on either side of the leaf scar at lower level. The parichnos were the longitudinal channels traversing the length of the leaf parallel to the vein which are believed to be aerating organs.

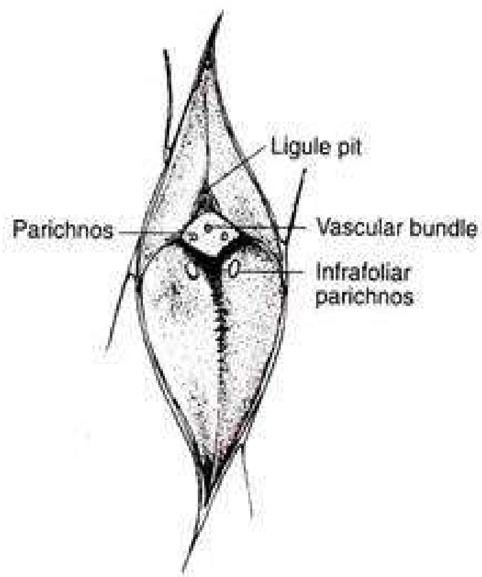


Fig. 7.39 : Leaf cushion of *Lepidodendron*

- T.S. of the permineralised stem shows a protostele or a siphonostele (Fig. 7.40).
- The primary xylem is situated just outside the pith, comprised of metaxylem tracheids.
- The small protoxylem tracheids form vertical ridges at the periphery and leaf traces develop spirally at the steep angle from these protoxylem ridges.
- In most species, secondary growth is characteristic of the genus, which was initiated by the unifacial activity of the cambium.
- Thus, only secondary xylem was produced externally and the cambium did not produce secondary phloem.
- There was massive extrastellar secondary growth by the meristematic activity of cortical parenchyma.

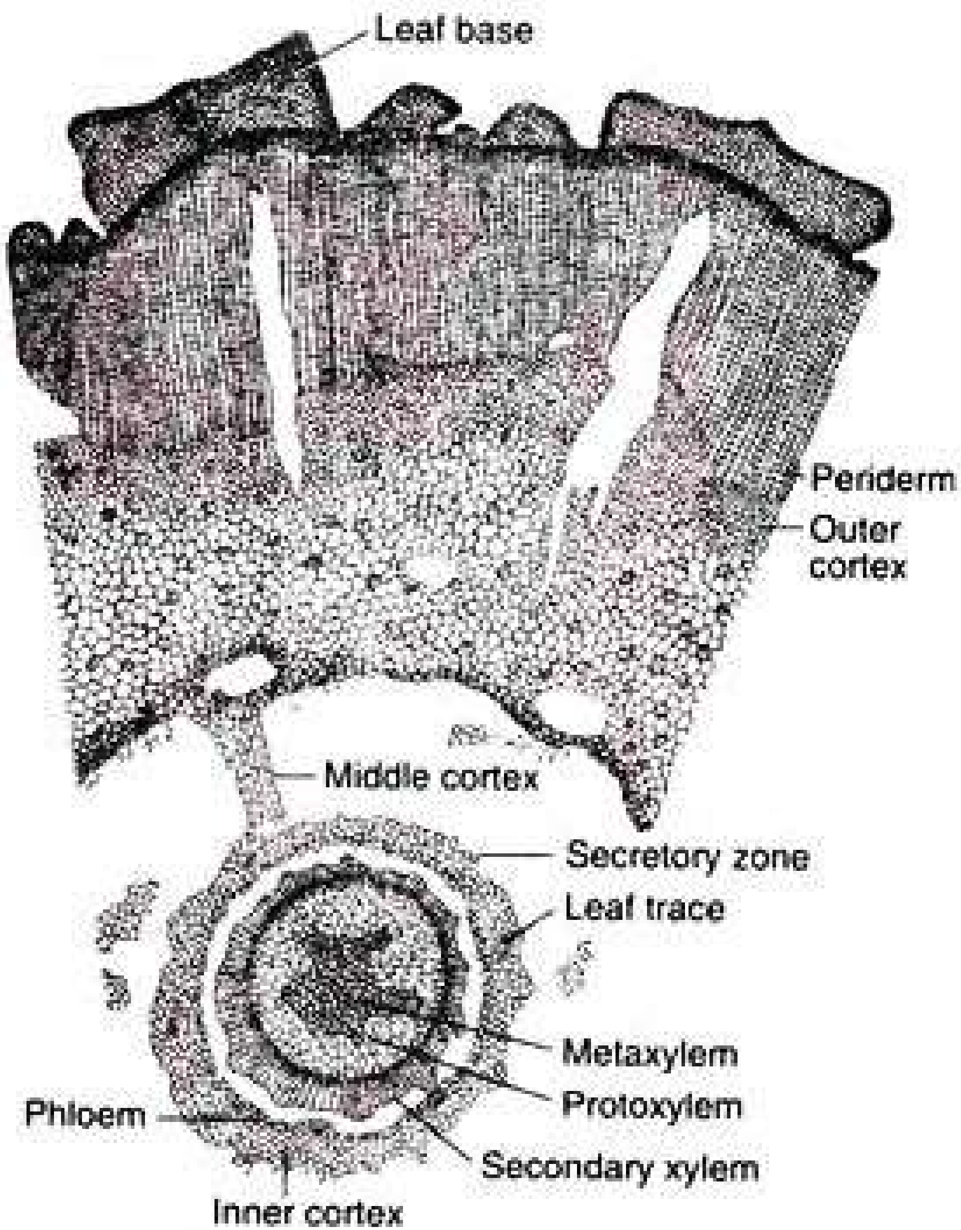


Fig. 7.40 : T.S. of *Lepidodendron* stem

- The periderm thus formed composed of secondary cortex which forms the massive volume of the stem, and exceeds 50% of the volume of the stem. The tracheids are scalariform and have delicate strands of secondary wall material extending between adjacent bars and are termed as fimbrils. The periderm provided the main mechanical support to the stem and branches.
- **The primary cortex is divided into three regions, viz.:**
- (i) The outer cortex, just outside the secondary cortex, bearing leaf cushion,
- (ii) Middle cortex consisting of homogeneous mass of parenchyma cells, interspersed with leaf traces, and
- (iii) The narrowest inner cortex having parenchyma cells. Some of the cells aggregated to form secretory cells.

- The central region of the stem was occupied by the stele which was either protostelic or siphonostelic.
- The protoxylem was exarch and polyarch.
- In many species (L. vasculare) there was a secondary growth initiated by the cambium.
- This produced secondary xylem to the interior and secondary phloem to the exterior.
- The cambial activity was not uniform, as a result there was a tendency for the formation of an eccentric vascular ring.
- The secondary xylem had radial rows of tracheids separated by xylem rays which were uniseriate.

Stigmaria – Root of Lepidodendron

- In all the members of Lepidodendrales, the root-bearing underground axes are called rhizomorph and the detached rhizomorph and their roots are called Sigmaria which are mostly found as siliceous casts or molds. Stigmaria ficoides, the commonest species of Stigmaria, was a large trunk base that divided dichotomously into four large massive descending axes.
- These four axes penetrated the substrate of the swamp shallowly and again formed repeated dichotomous branches in the horizontal plane. The Stigmaria spread over an area of about 20 ft (6 m) across. The younger portions of the Stigmaria had spirally arranged roots, known as Stigmarian rootlets, while the older portions are marked by spirally arranged root scars that might have abscissed.

- Anatomically, the main Stigmarian axes showed a distinct primary vascular system with endarch xylem.
- Secondary growth has been observed by the unifacial activity of cambium which only formed secondary xylem, while abundant extrastelar secondary cortical tissues were produced from the diffuse phellogen.
- In T.S., the free roots and root trace strand showed a monarch collateral vascular bundle comprised of protoxylem, metaxylem and phloem in centripetal sequence.
- The root trace, surrounded by inner cortex, is slightly eccentrically placed within the large cavity formed by the dissolution of the middle cortex, which is again delimited by an outer cortex. The Stigmarian rootlets are comparable with the roots of Isoetes.

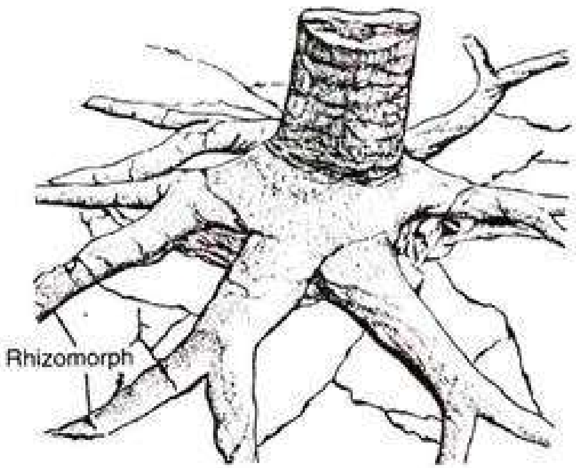
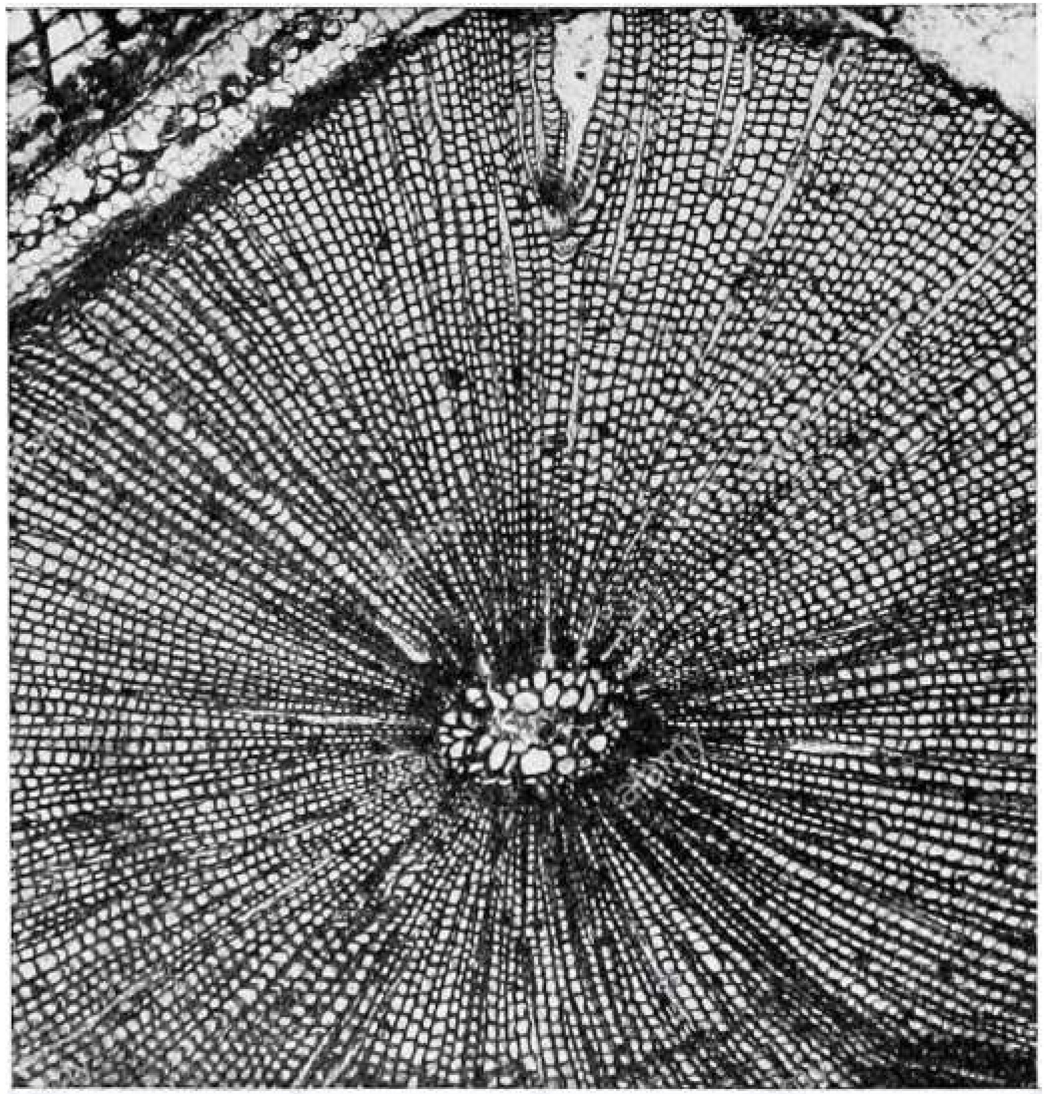


Fig. 7.37 : Stump cast of *Stigmaria*



Leaf:

The leaves were microphyllous ligulate, generally linear, acicular or awl-shaped and were borne on the small penultimate or ultimate branches. The leaves were deciduous and had swollen photosynthetic bases (leaf cushion) that remain attached even after the shedding of laminae. The size of the leaf cushion were related to the diameter of the shoots, the smallest twigs bore smallest leaf cushions.

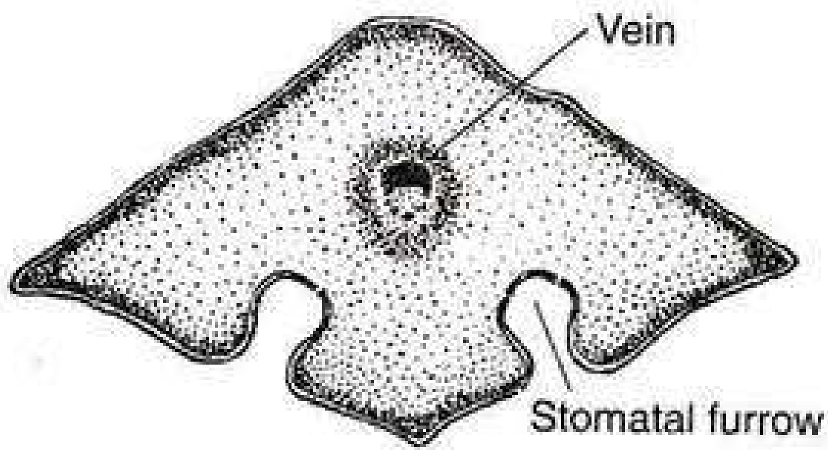


Fig. 7.42 : T.S. of acicular part of *Lepidodendron* leaf

The C.S. of the leaves shows variability in their shape depending upon the place of cross- section. The basal region covering leaf cushion appears to be rhomboidal, while the shapes change from angular rhomboidal to triangular in successive distal positions.

T.S. of the acicular part of the leaves shows two prominent furrows on the abaxial surface. Several rows of stomata were arranged parallel to the long axis on the furrow region. There is a thick-walled, well-developed hypodermis all round the leaf, except the furrows. There are thin-walled mesophyll cells in the centre that encircled the sheathed vein. The sheath is composed of transfusion cells, perhaps made up of tracheidal parenchyma. The centre is occupied by a vascular bundle made up of scalariform xylem and phloem cells.

Reproductive Structure

Lepidodendron formed bisporangiate cones called Flemingites that were borne terminally. The sporophylls were helically attached to the central cone axis. The microsporophylls bearing microsporangia were usually borne in the apical portion, while megasporophylls bearing megasporangia occupied the basal portion of the cones.

Morphologically, both the sporophylls were identical, except for their spore content. The microspores were small, about 25 pm in diameter, with smooth or granular exine. The cones containing only microspores are assigned to the form genus Lepidostrobus, possibly a monosporangiate cone of Lepidodendron.

Lepidocarpon: a False Seed

The female gametophyte of Lepidodendron is called Lepidocarpon.

The fossils of Lepidocarpon have been obtained from the coal strata in England and U.S.A.

Like a spermatophyte (especially gymnosperm), the megagametophyte (Lepidocarpon) is retained within the megasporangiun and the sides of the pedicel were extended to form lateral laminae, called integuments which completely enveloped the sporangium.

This unique feature of Lepidocarpon has not been observed in any other lycopod, thus showing a significant step towards the seed habit.

There were four spores in a sporangium of which only one developed into the female gametophyte. The size of the gametophyte and the fact as to whether it completely or incompletely filled the sporangium are specific characters. Andrews and Pannel (1941) have reported several fertile mega-gametophytes with archegonia at the apex.

The mega-sporangial cavity also showed many spores of which at least some of them were the microspores of Lepidocarpon. This suggests that Lepidocarpon had something like an incipient pollination which is also seen in the extant genus Selaginella.

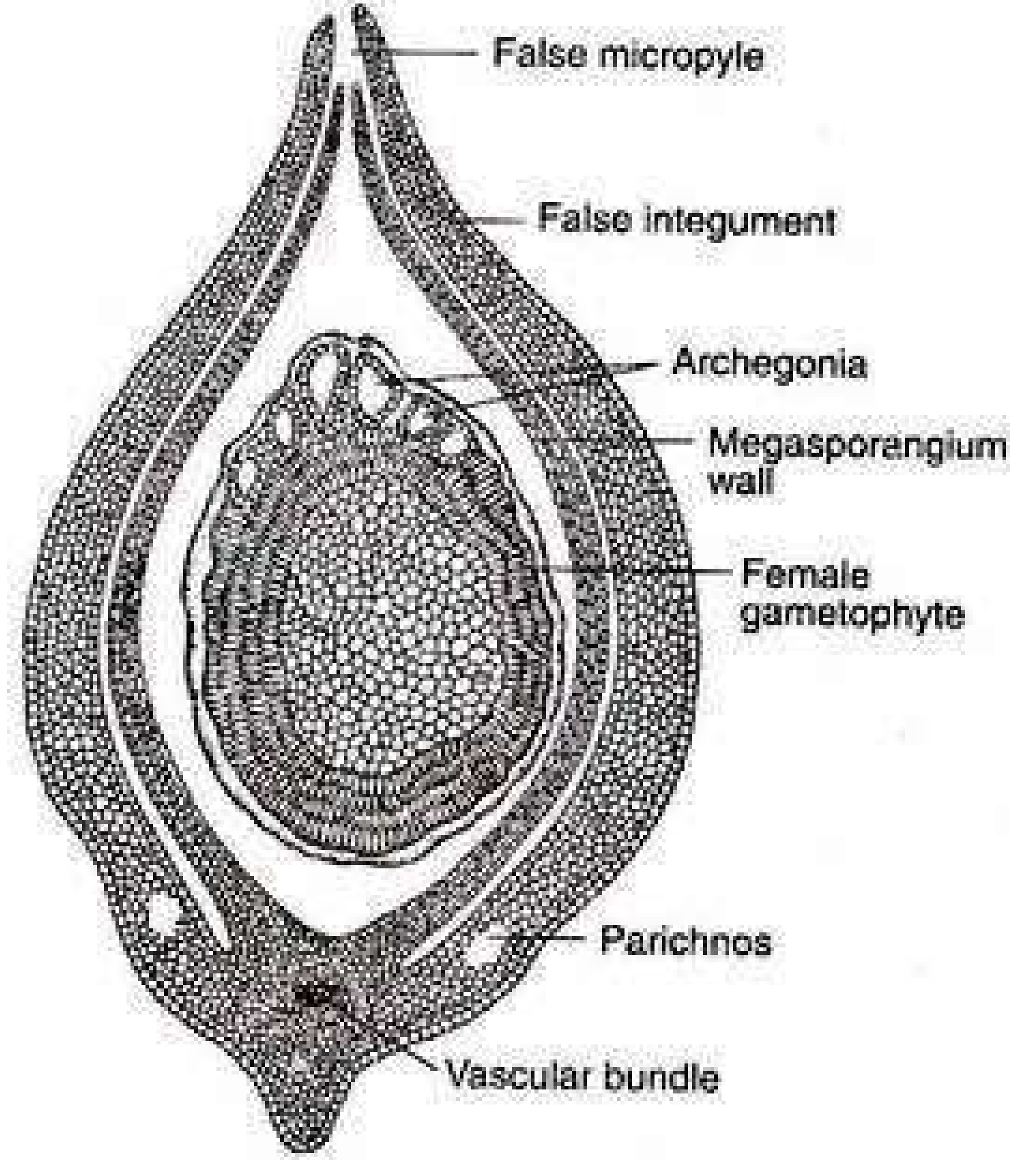


Fig. 7.44 : L.S. of *Lepidocarpon*

WILLIAMSONIA

Occurrence of Williamsonia

- Williamsonia belongs to family Williamsoniaceae of Bennettitales. It has been reported from Upper Triassic period but was more abundant in Jurassic. This was earlier discovered under the name Zamia gigas by Williamson (1870) but has now been named as Williamsonia.
- Professor Birbal Sahni (1932) described W. sewardiana from Rajmahal Hills of Bihar (India). Professor AC. Seward, a well-known palaeobotanist, described W.scotti. Gupta (1943) discovered Williamsonia sahnii from Rajmahal Hills and named if after Professor Birbal Sahni.
- Other reported species from Rajmahal Hills are Williamsonia indica, W. microps and W. santalensis. Bucklandia indica, described from Rajmahal Hills, is now considered to be the stem of Williamsonia sewardiana.

External Features of Williamsonia

- Williamsonia resembled Cycas in appearance, and its best known species is W. sewardiana. A reconstruction of this species was published by Sahni (1932). The leaves of W. sewardiana were like that of Ptilophyllum. The plant had an upright, branched and stout stem covered by persistent leaf bases.
- A terminal crown of pinnately compound leaves was present. For the stem genus Bucklandia, Sharma (1991) opined that features of leaf bases such as their shape, size and arrangement pattern are of taxonomic significance.
- He observed that leaves in Williamsoniaceae show syndetocheilic stomata with rachis possessing collateral endarch vascular bundles arranged in a double U-manner. A distinct constriction was present at the base of lateral shoots.

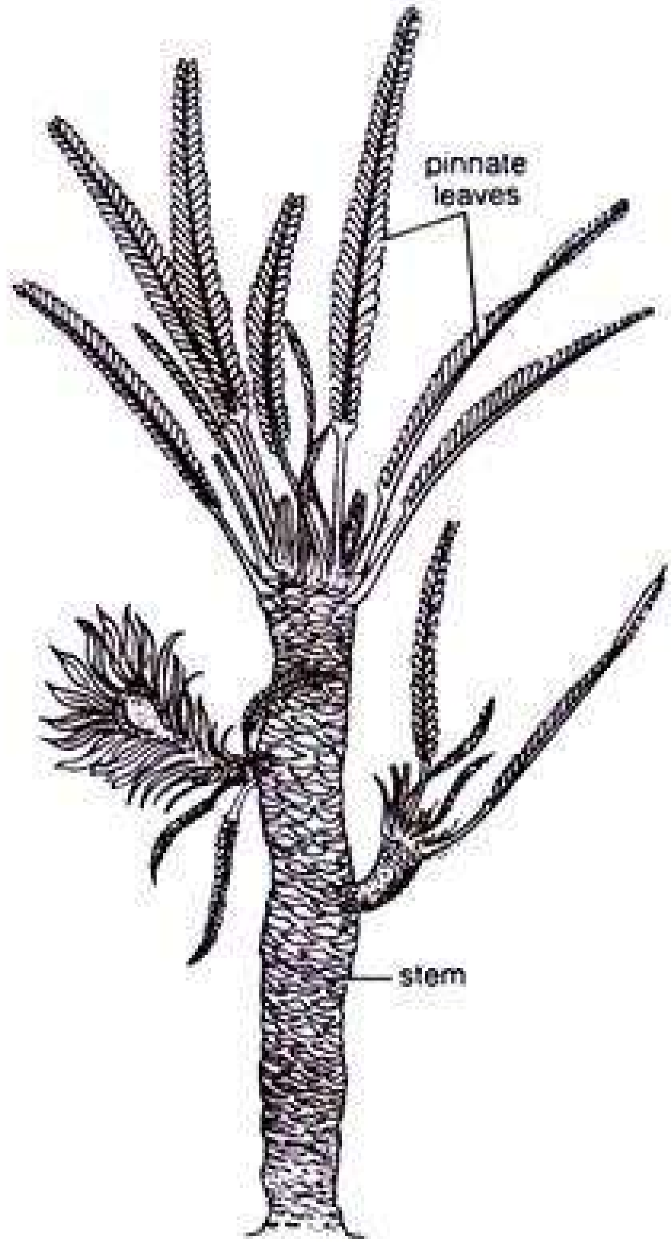


Fig. 6.13. *Williamsonia sewardiana* (after Sahni)

Reproduction in Williamsonia

- The fructifications of Williamsonia were large and attained a diameter of about 12 cm. They were borne on a peduncle. Many spirally arranged bracts were present around the base of the floral axis. In W. gigas the cones were present among the crown of leaf bases while in W. sewardiana they were present on the short lateral branches. Williamsonia plants were unisexual.

Female Flower:

- The female ‘cones’ of Williamsonia gigas and W. sewardiana have been investigated in detail. Instead of ‘strobili’ or ‘cones’, Sporne (1965) has proposed to use the term “flower” in Williamsonia. The structure of female flower of W. gigas is illustrated in Figs. 6.14, 6.15. The conical receptacle was surrounded by many perianth-like bracts. The ovules were stalked.
- The apex of the receptacle was naked and sterile. The nucellus was surrounded by a single vascularize integument, which was fused with the nucellus. The nucellus had a well-marked beak and a pollen chamber. In young ovules the micropylar canal was long and narrow.
- In mature ovules, the canal widened because of the formation of nucellar plug and disappearance of interlocking cells. In the apical part of endosperm, Sharma (1979) observed 2 or more archegonia.

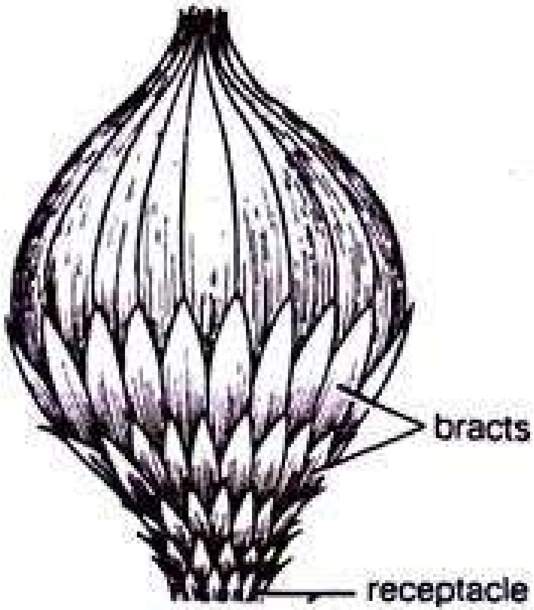


Fig. 6.14. *Williamsonia gigas*. A female flower bud. (after Williamson).

Fig. 6.15. *Williamsonia gigas*. L.S. female flower. (after Williamson).

Male Flower

- Out of several known male flowers of Bennettitales some have been described to belong to Williamsonia. Male fructifications have never been found in actual connection with the plant, and are sometimes referred to the genus Weltrichia.
- Male flowers consisted of a whorl of microsporophyll’s, which were united to form a more or less cuplike structure. In majority of the investigated species (e.g. Williamsonia whitbiensis) the sporophylls were un-branched but in some species (e.g. W. spectabilis) they were also pinnately branched.

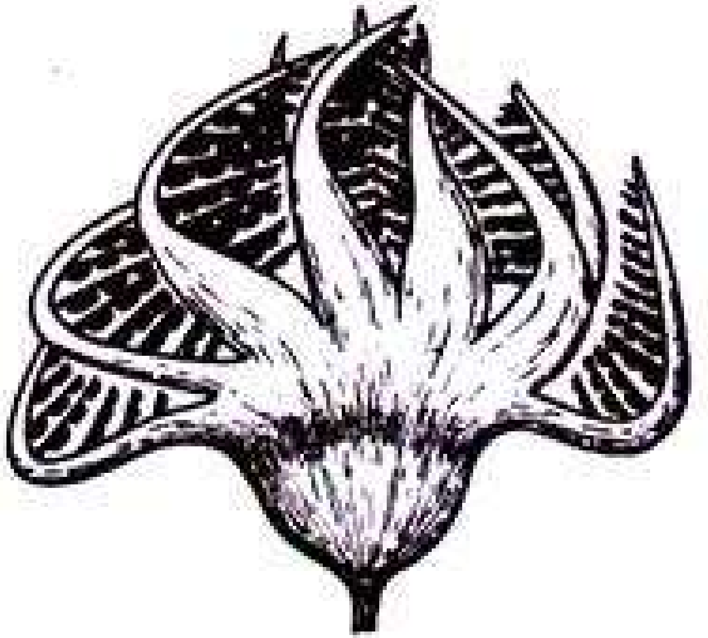


Fig. 6.17. *Williamsonia spectabilis*. Pollen-bearing organs. (after Thomas).

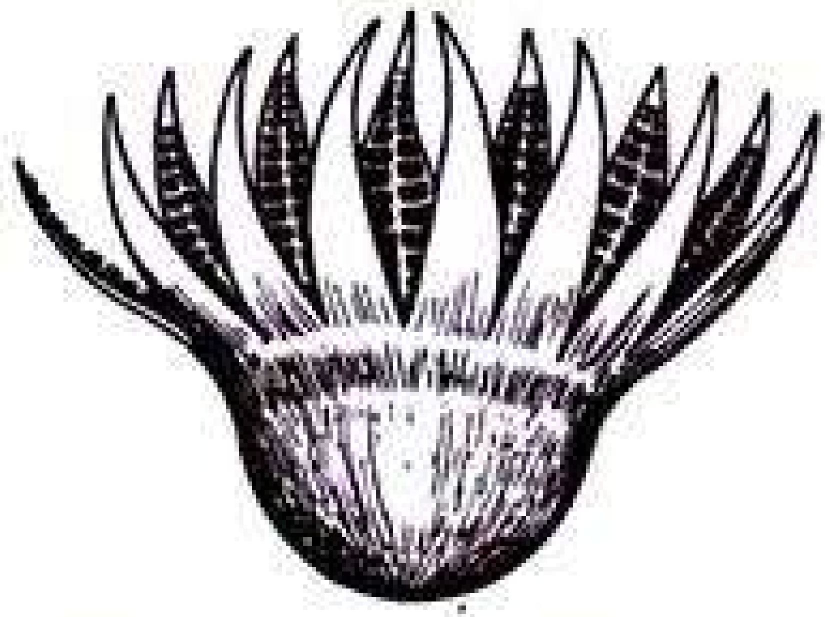


Fig. 6.16. *Williamsonia whitbiensis*. Pollen-bearing organs. (after Nathorst).

- Sitholey and Bose (1953) discovered Williamsonia santalensis from Upper Gondwana (India), and observed that microsporophyll's in the species were bifid. One of the branches of microsporophyll was fertile while the other was sterile. The fertile part had finger-like structures called synangia Each synangium had two rows of chambers enclosing microsporangia. Sharma (1977,1983, 1991) has confirmed the synangiate nature.
- The entire male flower attained a length of about 20 cm., while a single microsporophyll was about 10 cm long. The fertile branch of the bifid sporophvll possessed many purse-like capsules, in each of which there were present many monocolpate pollen grains.

Gingko biloba – a living fossil

- Ginkgo biloba is a tall slender and beautiful tree. It is commonly called Maiden-hair Tree because its new leaves resemble very much like those of Adiantum (called maiden hair fern) both in form and venation.
- It is the oldest living seed plant. It is cultivated for its edible seeds in some parts of China and Japan. Though, Chamberlain (1935) mentioned that it is doubtful whether Ginkgo exits today in the wild state, but Sporne (1965) has stated clearly about Ginkgo biloba that **"if it occurs naturally anywhere, is restricted to a small and relatively inaccessible region in South China".**

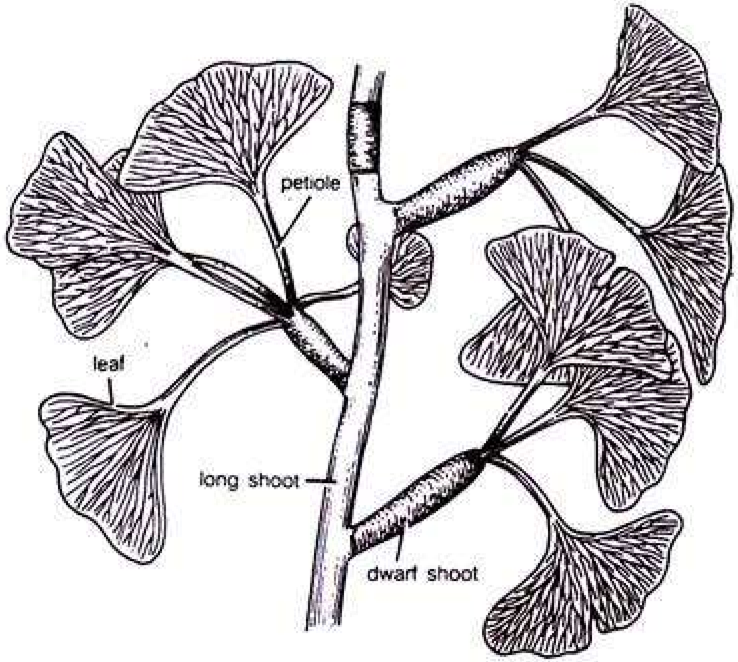


Fig. 10.5. *Ginkgo biloba.* A long shoot bearing dwarf shoots.

Ginkgo: A Living Fossil

Ginkgo is known to have occurred in rocks as old as Triassic or even much earlier. Fossils of its leaves have been identified in the Permian and probably also in the Carboniferous. Ginkgo biloba occurs even today. It is, therefore, referred as living fossil by the botanists. Or, it may also be referred as the oldest living seed plant.

In the words of Professor A C. Seward of University of Cambridge, Ginkgo biloba is **“an assemblage of changelessness, a heritage from worlds of an age, too remote for our human intelligence to grasp, a tree which has in its keeping the secrets of an immeasurable past”.**

Relation to Ferns

The similarities between Ginkgo and ferns are:

- i. The leaves of Ginkgo shows striking similarity with Adiantum (maiden hair fern) in form, shape and venation and hence the name maiden hair tree for Ginkgo tree.
- ii. The sperms are motile and multiciliated.

Relation to Pteridosperms

Ginkgo resembles the pteridosperms in having the following characteristics:

- i. The leaf of Ginkgo may be linked to the wedge-shaped pinnule of pteridosperm.
- ii. There is accumulation of abundant reserve food material and lignification in the integument prior to fertilisation.
- iii. The collar in the ovule of Ginkgo may be linked to the cupule of pteridosperm ovule.

Relation to Cycadales

Ginkgo resembles the Cycadales in having the following characteristics:

i. The stem anatomy shows a broad cortex, large pith and numerous mucilage ducts. Mucilage ducts are also present in leaves, petioles, sporangia, embryos or even in roots.

ii. Both the cotyledonary leaves and foliage leaves bear mesarch xylem.

iii. The presence of nucellar beak with a distinct pollen chamber.

iv. The micro- and megasporophylls are of foliar nature.

v. The sperms are large and motile with spiral band bearing numerous cilia.

vi. The presence of extensive free-nuclear divisions in the early stage of embryogeny.

vii. The embryo with two cotyledons.

Relation to Cordiatales

The similarities between Ginkgo and Cordaitales are:

i. The presence of double leaf trace.

ii. The presence of motile sperms.

iii. The presence of endospermic beak in the mature ovules.

Relation to Coniferales:

The resemblance between Ginkgo and Coniferales are:

i. The plants are tall trees showing excurrent branching.

ii. The branches are dimorphic bearing two types of shoots — long shoots and dwarf shoots.

iii. The presence of pycnoxylic wood.

iv. The mature wood shows pitting and Bars of Sanio.

v. The leaves are with sunken stomata.

vi. The two lateral ears in the pollen exine of Ginkgo may be linked to the wings of Pinus pollen.