National Park Service
U.S. Department of the Interior

Prince William Forest Park
Triangle, VA 22172

A Petrified Prospectus

A Scientific Look Into the Petrified Wood Specimines of Prince William Forest Park.

Produced by the Eric Junger, Geoscientist-In-Parks Volunteer
National Park Service, 2008

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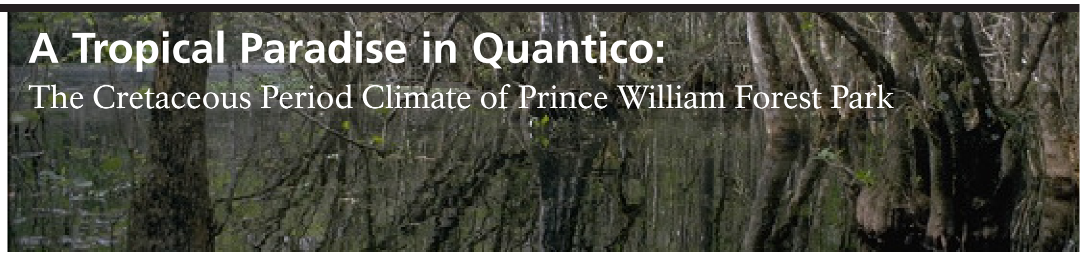


A Tropical Paradise in Quantico:

The Cretaceous Period Climate of Prince William Forest Park

When visitors come to Prince William Forest Park they are typically impressed by the dense trees, diverse foliage, the rolling hills, and the tranquil streams that stretch from one end of the park to the other. It would be hard to imagine that the idyllic scene present today is far removed from the hot, humid, sulphuric and occasionally chaotic world that existed millions of years ago.

The Cretaceous Period

Scientific data suggests that the earth is 4.6 billion years old; to put that into perspective, if that entire timeframe were to be compressed into a 24-hour period than humans as a species have only existed for approximately 10 seconds. This immense timeframe has been divided into various eons, periods and epochs as a way of understanding the variations of life and climate that existed in this changing world.

Many people today are aware of the Mesozoic era because this period holds the periods known to dinosaur lovers the world over, the Triassic, Jurassic and Cretaceous. In this era we saw the rise of dinosaurs and other colossal creatures both on land and in air. This particular period is of importance to Prince William Forest Park because much of the landforms we see today were created during this timeframe, and two of the largest fossil specimens found within the park come from that time as well.

Cretaceous Climate in Prince William Forest Park

"The planet during the Cretaceous was very different than it is today," says Adina Paytan, an assistant professor of geological and environmental sciences at Stanford. "Not only were dinosaurs present, but the climate was extremely warm and global sea levels were significantly higher than they are today. Understanding how the atmosphere, land and ocean system interacted while in this global greenhouse mode is very relevant if we want to understand the fate of our future climate."

Core sampling of glaciers have provided ice from which data suggests that the volcanic activity over the entire planet was at the highest levels found within the earth's climatic history. The scientists found that from 120 million years ago to 105 million years ago, then again from 95 million years ago to 80 million years ago, the fraction of sulfur-34 dipped even more precipitously, suggesting a sharp reduction in the amount of organic matter buried in the ocean and used by sulfate-reducing bacteria. These changes in the productivity of ocean life suggest that the Earth's atmosphere may have gone through fluctuations in available oxygen.

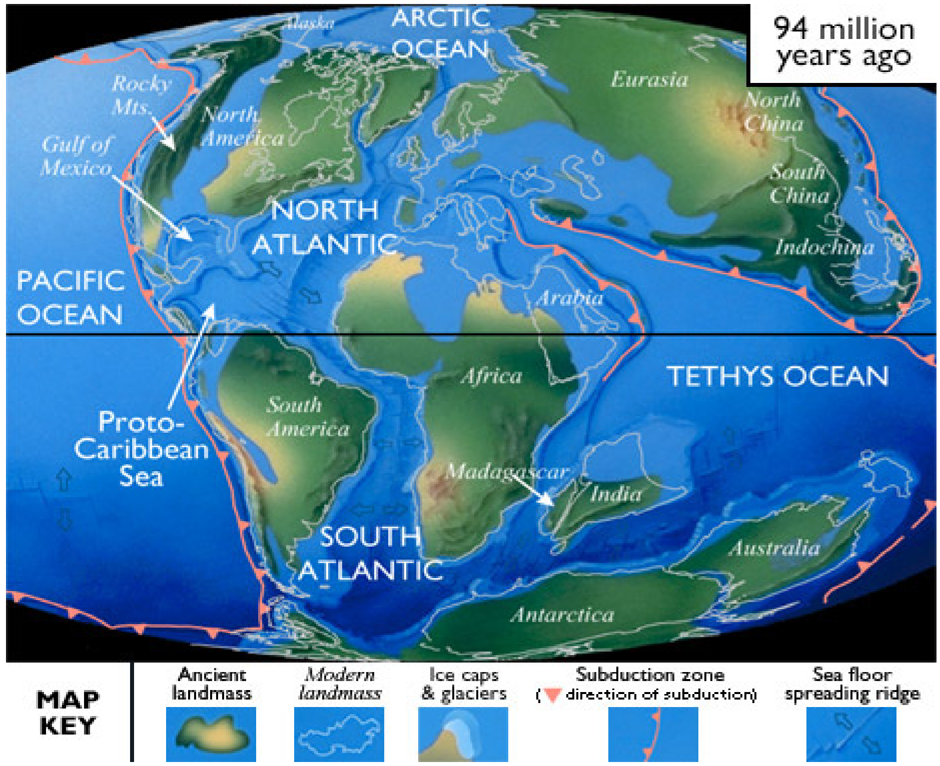
The Berriasian epoch (145 to 140 million years ago) showed a cooling trend that had been seen in the last epoch of the Jurassic. There is evidence that snowfalls were common in the higher latitudes and the tropics became wetter than during the Triassic and Jurassic. Glaciation was however restricted to alpine glaciers on some high-latitude mountains, though seasonal snow may have existed further south.

After the end of the Berriasian, however, temperatures increased again, and these conditions were almost constant until the end of the period. This trend was due to intense volcanic activity which produced large quantities of carbon dioxide. The development of a number of mantle plumes (locations where liquid mantle squeezed upwards towards the seafloor) across the widening mid-ocean ridges further pushed sea levels up, so that large areas of the continental crust were covered with shallow seas. The Tethys Sea connecting the tropical oceans east to west also helped in warming the global climate. Warm-adapted plant fossils are known from localities as far north as Alaska and Greenland, while dinosaur fossils have been found within 15 degrees of the Cretaceous South Pole.

Most of the land mass was at or around sea level until the mid-Cretaceous (about 100 million years ago), a time of high tectonic

GEOLOGIC TIME CHART of VIRGINIA

Time (Ma)	Eon	Era	Period	Epoch	Events
0.011	Phanerozoic	Cenozoic	Quaternary	Holocene	Chesapeake Bay forms
1.8				Pleistocene	Dramatic climate oscillations, Rise & fall of sea-level cutting scarps along major rivers
5.0			Tertiary	Pliocene	Marine sedimentation in Yorktown Fm.
23				Miocene	Chesapeake group, erosional interval
38				Oligocene	erosional interval
54				Eocene	Chesapeake Bay Impact Structure
				Paleocene	
65					erosional interval
146		Mesozoic	Cretaceous		Shallow sea covers eastern Virginia
208			Jurassic		Atlantic Ocean opens, East flowing rivers (James, Roanoke, etc.) develop
245			Triassic		Atlantic rifting begins- Deposition of sediments in rift-basins
286		Paleozoic	Permian		**ALLEGHANIAN OROGENY**- Alleghanian mountain building due to continental collision (P, BR, & V&R)
325			Pennsylvanian		Coals deposited in coastal swamps (AP), Alleghanian orogeny begins (Petersburg granite emplaced- Piedmont)
360			Mississippian		Passive margin sedimentation in V&R
410			Devonian		**ACADIAN OROGENY**- Sediment shed from Acadian mountains deposited in Valley & Ridge
440			Silurian		Taconic highlands eroded development of west-facing passive margin
505			Ordovician		**TACONIC OROGENY**- affects rocks of the Piedmont, BR, & V&R
			Cambrian		
544					Carbonate deposition on passive margin (V&R)
650	Proterozoic	Neoproterozoic			600-550: Late phase of Iapetan rifting (Catoctin basalts extruded) 750-700: Early phase of Iapetan rifting (Mt. Rogers volcanics, Mechum River sediments)
900					1100-950: **GRENVILLIAN OROGENY**
1600		Mesoproterozoic			
2500		Paleoproterozoic			
3800	Archean				**Atmosphere develops**
4500	Hadean				**Formation of the Earth and cooling of the crust**



activity (continental plate movement) and accompanying volcanic activity. This is when many mountain ranges were formed, including California's Sierra Nevadas, the Rocky Mountains in the western USA and the European Alps. The sea levels rose during the mid-Cretaceous, covering about one-third of the land area. Toward the end of the Cretaceous, there was a drop in sea level, causing land exposure on all continents, more seasonality, and greater extremes between equatorial and polar temperatures. Also, the continents were taking on their modern-day forms.

A very gentle temperature gradient from the equator to the poles meant weaker global winds, contributing to less upwelling and more stagnant oceans than today. This is evidenced by widespread black shale deposition and frequent anoxic (oxygen-depleted) events. Sediment cores show that tropical sea surface temperatures may have briefly been as warm as 42 °C (107 °F), 17 °C (31 °F) warmer than at present and that they averaged around 37 °C (99 °F). Meanwhile deep ocean temperatures were as much as 15 to 20 °C (27 to 36 °F) higher than today's. This is important for Prince William County Forest Park because during the upper Cretaceous period, when our fossil trees were growing, the area was largely swamps with tremendously high humidity and daily temperatures over 100° daily. The swamp-like environment, coupled with the touching landmasses, allowed for a broad distribution of animals and explains why the same sorts of fossils found along the Virginia shoreline are the same as those found along the northwestern coast of Africa.

When one observes the Cretaceous period rocks that are widely exposed throughout the United States one can see that a small section of these rocks lay right in the area of Quantico.

Fauna of the Cretaceous Period

The first placental mammals appeared at the beginning of the Cretaceous. The Cretaceous saw the rise and extinction of the toothed birds, Hesperornis and Ichthyornis. The earliest fossils of birds resembling loons, grebes, cormorants, pelicans, flamingos, ibises, rails, and sandpipers were from the Cretaceous. The Cretaceous period was the heyday of the dinosaurs. Huge carnivores like Tyrannosaurus rex and Giganotosaurus appeared, as did Triceratops and many, many others. There was a tremendous diversity in dinosaur species. Mammals were flourishing, and flowering plants developed and radically changed the landscape.

Flora of the Cretaceous Period

During the Cretaceous, primitive flowering plants (anthophytes, also called angiosperms) continued to develop (they evolved about 140 million years ago, during the late Jurassic period). Flowering plants (like magnolia, ficus, credneria, sassafras, viburnum) quickly outnumbered the other plants, mostly ferns, horsetails, trees (i.e. conifers and gingkos), and cycads, changing the environment tremendously. The extinction of bennettitaleans (a major group of plants) also occurred at this time.

The Fossil Trees of Prince William Forest Park

This brings us to the topic of the fossil trees discovered within Prince William Forest Park and the environment they lived in. The species of tree is believed to be that of Taxodium distichum, or what we know as the Bald Cypress. Part of this opinion is founded in the fact that the fossil trees were found in the only area within the park where Cretaceous period sediments are found, that being the northeastern corner of the park. Taxodium were proliferate during the region during that timeframe, and a side-by-side comparison of the fossils against their present-day counterparts makes the distinction rather easy.

Bald cypress is a large, slow-growing but long-lived, deciduous conifer, which frequently reaches 100 to 120 feet in height and 3 to 6 feet in diameter. Its trunk is massive, tapered and buttressed. The leaves are alternate, linear and flat with blades generally spreading around the twig. The bark is thin and fibrous with an interwoven pattern of narrow flat ridges and narrow furrows. Its male and female flowers form slender tassle-like structures near the edge of the branchlets. Bald cypress trees produce cone fruit, and there are approximately 5,200 seeds per pound. It develops a taproot as well as horizontal roots that lie just below the surface and extend 20 to 50 feet before bending down. It develops knees that grow above water providing additional support.

An examination of the base of the large trunk section of the fossil tree easily demonstrates the taproot of the tree, and *(see bottom left photo)* a fine layer of quartz has developed within the inner wall of the taproot, which typically has a sort of void within its structure, allowing for the larger crystal formation over time during petrification.

Age Determination in Fossil Specimens

The larger of the two specimens, which has the truck section intact, measures an average of two feet in diameter at the distal (narrow) end and 3’4” to 4’6” in variation across the bottom of the trunk. The length of the large specimen is approximately 6’ on the average. On the distal end is a section of rings that are clearly visible and cover approximately 5” of radius before the mineralization of the tree obliterates the ring structures. There is a distinct bark ring surrounding the large specimen which varies in thickness between 1-1/2” to 1-3/4” and almost 3” thick on the trunk end. Allowing for this thick bark at the distal end, there is then a total of 40 rings clearly seen in the five inches of radius that is visible. Assuming that the rate of growth of the tree was normal and regular, without droughts or other interferences, we can say that the ring density is approximately eight rings per inch, given 40 rings within 5 inches seen. With a radius of 12 inches, subtracting 1 inch for bark, that would give us 11” of tree left, placing the approximate age of the tree at around 88-90 years of age before falling.

There are no rings visible on the other fossil due to the mineralization and likely fracture of the ends at time of collapse. Because these fractured ends will lead to a blurring of rings and heavier mineralization, a more accurate ring count can be made in both cases by making a cross-section of each of the specimens perpendicular to the long axis of the specimens. Calculating the circumference of the second specimen using geometric formulas it is determined that the fossil has a circumference of a minimum of 6’. The diameter is an estimate because there are deformities in the outer surface of the tree with unequal mineralization.

The Chesapeake Bay Impact Event

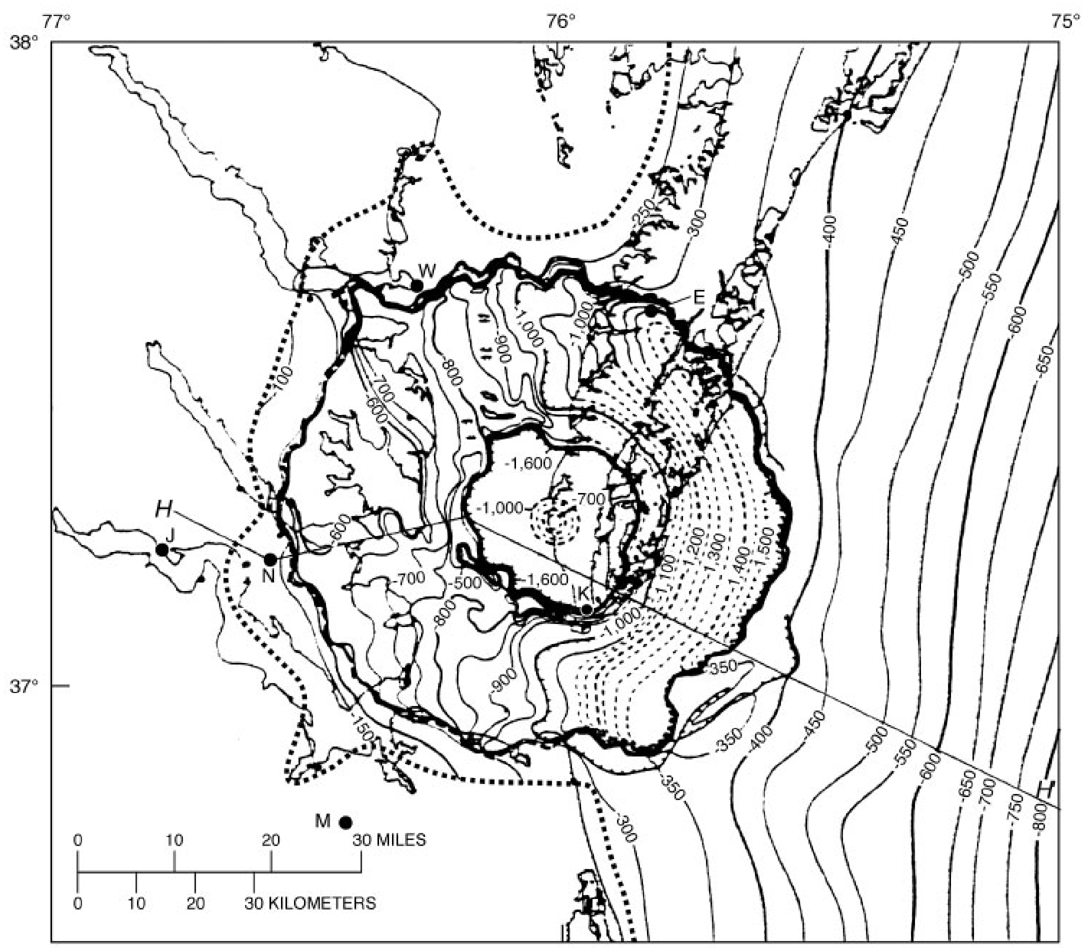
The Chesapeake Bay Impact Event
As has been previously mentioned, the Cretaceous period is marked with major climactic changes and events that shaped the landform and the flora and fauna that inhabited it. And just as there is impressive scientific data to support the theory that the collision of a large bolide (meteorite) with the earth was responsible for the destruction of the dinosaurs, there also seems to be proof that the Chesapeake Bay itself suffered a similar but smaller meteor impact event.

The immense Chesapeake Bay impact structure lies hidden beneath the shallow waters of the Chesapeake Bay and a thin veneer of Coastal Plain sediments. This complex 85-km-wide (~50 mile) impact crater is the largest in the United States, yet was not discovered until the early 1990's. The crater is centered under the Chesapeake Bay approximately 8 km (5 miles) west of the town of Cape Charles on the Eastern Shore.

It includes an inner basin surrounded by a ring of raised basement rock, encircled with a flat-floored terrace zone and bounded along the outer rim by a zone of concentric faulting.

The crater is cut into ~650 m (~2000 feet) of Early Cretaceous to late Eocene sedimentary material and at least a kilometer (~3000 feet) of the underlying granodioritic basement rocks. Much of the crater is filled with a chaotic sedimentary deposit known as the Exmore breccia. The Exmore breccia contains angular clasts of older sedimentary material, and granitic to metamorphic basement rocks in a sandy matrix.

Shocked quartz grains and impact derived glass also occur in the Exmore breccia. This deposit is interpreted to be impact ejecta that partially infilled the crater immediately after impact.



The Chesapeake Bay Impact Crater (CBIC) was created approximately 35 Million years ago, when a comet or meteorite struck the inner continental shelf producing a complex impact crater, ejecting large amounts of debris, and generating a series of gigantic tsunamis that spread the debris over most of the U.S. Atlantic shelf (the coastline was then west of the present-day Fall Line; Poag, Powars, Poppe, and Mixon, 1994). It is likely that the tsunamis reached and possibly overran the Blue Ridge Mountains. The high-velocity impact left an immense crater that is almost 1.3 mi deep and is partly filled with debris and tsunami deposits. The crater is underlain and surrounded by fractured and faulted basement rock.

Since the formation of the crater, younger marine and non-marine sediments deposited on the Coastal Plain completely burying the structure. Although geologists had long recognized anomalous features associated with Coastal Plain sediments in southeastern Virginia it was not until seismic surveying under the Chesapeake Bay and detailed examination of deep sedimentary cores that the crater was revealed. Differential movement along the outer crater rim affected later sediment deposition. The exposures of large cross-bedded bio-fragmental sand exposed in the bluffs near Yorktown are interpreted to be shoal deposits that formed in response to rotation of underlying slump blocks along the outer crater rim 4 to 5 million years ago.

Although hidden below the surface the Chesapeake Bay impact crater is still affecting the region as briny groundwater associated with the crater is a problem for many deep water wells in eastern Virginia to this day.

Poag, C. W., Powars, D. S., Poppe, L. J., Mixon, 1994, Meteoroid mayhem in Ole Virginny: Source of the North American tektite strewn field: Geology, v. 22, p. 691-694.

Johnson, G. H., Kruse, S. E., Vaughn, A. W., Lucey, J. K., Hobbs, C. H. III, Powars, D. S., 1998, Postimpact deformation associated with the late Eocene Chesapeake Bay impact structure in southeastern Virginia: Geology, v. 26, p. 507-510.

A Bald Cypress Fact Sheet

Alternate Names
southern-cypress, swamp-cypress, red-cypress, yellow-cypress, white-cypress, tidewater red-cypress, gulf-cypress

Uses
Erosion Control: Riverine swamps of bald cypress reduce damage from floods and act as sediment and pollutant traps as they cause floodwaters to spread out, slow down, and infiltrate the soil.

Timber: Its wood is valuable for building construction, fence posts, planking in boats, river pilings, doors, blinds, flooring, shingles, garden boxes, caskets, interior trim and cabinetry.

Wildlife: Its seeds are eaten by wild turkey, wood ducks, evening grosbeak, squirrels, waterfowl, and wading birds. Cypress domes provide unique watering places for a variety of birds and mammals and breeding sites for frogs, toads, salamanders, and other reptiles. Yellow-throated warblers forage in the Spanish moss often found hanging on the branches. Its tops provide nesting sites for bald eagles, ospreys, herons, and egrets.

Site Rehabilitation: It has potential for rehabilitating margins of surface-mined lakes. Cypress domes can serve as tertiary sewage treatment facilities for improving water quality and recharging groundwater.

Beautification: This species has been planted as a water tolerant tree species used for shading and canopy closure in mosquito control programs. It has been successfully planted throughout its range as an ornamental and along roadsides.

Status
Please consult the PLANTS Web site and your State Department of Natural Resources for this plant's current status (e.g. threatened or endangered species, state noxious status, and wetland indicator values).

Description
Bald cypress is a large, slow-growing but long-lived, deciduous conifer, which frequently reaches 100 to 120 feet in height and 3 to 6 feet in diameter. Its trunk is massive, tapered and buttressed. The leaves are alternate, linear and flat with blades generally spreading around the twig. The bark is thin and fibrous with an interwoven pattern of narrow flat ridges and narrow furrows. Its male and female flowers form slender tassle-like structures near the edge of the branchlets. Bald cypress trees produces cone fruit, and there are approximately 5,200 seeds per pound. It develops a taproot as well as horizontal roots that lie just below the surface and extend 20 to 50 feet before bending down. It develops knees that grow above water providing additional support.

Adaptation and Distribution

Bald cypress is generally restricted to very wet soils consisting of muck, clay or fine sand where moisture is abundant and fairly permanent. It is usually found on flat or nearly flat topography at elevations less than 100 feet above sea level. Its thin bark offers little protection against fire and during years of drought when swamps are dry, fire kills great numbers of cypress.

Bald cypress is widely distributed along the Atlantic Coastal Plain from southern Delaware to southern Florida, westward along the lower Gulf Coast Plain to southeastern Texas. Inland, it grows along streams of the southeastern states and north in the Mississippi valley to southeastern Oklahoma, southeastern Missouri, southern Illinois, and southwestern Indiana. For a current distribution map, please consult the Plant Profile page for this species on the PLANTS Website.

Establishment
Establishment of bald cypress stands can be accomplished by either seeds or sprouts. Seeds are produced annually and good seed production occurs about every 3 years. Seeds are dispersed more frequently by flood waters. Under swamp conditions, the best seed

germination generally takes place on a sphagnum moss or a wet-muck seedbed. On better drained soils, seed usually fails to germinate due to lack of surface water. Soil saturated for 1 to 3 months after seedfall is required for germination. Seedlings require light for good growth, thus control of competing vegetation is necessary.

Bald cypress will produce vigorous sprouts from the stumps of both young and old trees, following disturbance.

Management

The best management practice for regenerating this species is canopy thinning. Through thinning, competition is controlled and overhead light is provided for newly germinated seedlings. Nutria, a swamp rodent, often clips or uproots newly planted seedlings before the root systems are fully established, thus killing them. Control of nutria population is necessary.

Severe fire after logging or drainage destroys seeds and roots in the soil, favoring willows and hardwoods to take over.

Pests and Potential Problems

Brown pocket rot known as "pecky cypress" which is caused by the fungus Stereum taxodi attacks the heartwood. The forest tent caterpillar (Malacosma disstria) and fruit-tree leafroller (Archips argyrospila) larvae build webs and feed on needles causing dieback and eventually death.

Prepared By & Species Coordinator:
USDA NRCS Plant Materials Program
Edited: 05Feb2002 JLK; 060818 jsp

For more information about this and other plants, please contact your local NRCS field office or Conservation District, and visit the PLANTS Web site<http://plants.usda.gov> or the Plant Materials Program Web site <http://Plant-Materials.nrcs.usda.gov>

http://www.ucmp.berkeley.edu/IB181/VPL/Pres/Pres2.html

Conditions Required for Plant Fossil Preservation

Three conditions are required for the preservation of plant fossils:

1. Removing the material from oxygen-rich environment of aerobic decay;

2. "Fixing" the organic material to retard anaerobic decay;

3. 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).

As you look at the various modes of preservation in lab, note the characteristics of the rock matrix in which plant material is preserved. Note color, grain size (i.e., sand, silt, clay), mineral composition (quartz, clay, mica, organic-rich, organic-poor), and any other unusual features. If you aren't familiar with the basic features of sedimentary rocks, they may start out all looking the sameÉdon't worry. Take some extra time to make systematic observations of each specimen: What color is it? Can you see the sediment grains with your naked eye? With a hand lens? How would you classify them (round or angular)? Is the rock shiny or dull? Does it have uniform or mixed composition? Do you notice sedimentary layers or other features (ripple marks, animal tracks)? Just be patient; you'll train your eye to recognize rock types in no time.

Types of Plant Fossils

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:

o Compressions -- 2-dimensional, with organic material (VG 1:1)(VG 1:2) .

o Impressions -- imprints, 2-dimensional, devoid of organic matter (VG 1:1)(VG 1:3) .

o Casts and Molds -- 3-dimensional, may have a surface layer of organic material (VG 1:4) (VG 1:5).

o Permineralization -- 3-dimensional, tissue infiltrated by minerals allowing internal preservation (VG 1:6)(VG 1:7) .

o Compactions -- 3 dimensional, reduced volume, flattened, wholly organic (VG 1:8) .

o Molecular Fossils -- non-structural, preserves organic compounds.

Each type of plant fossil carries different types of anatomical and biological information. Consequently, to piece together the most complete picture of an ancient plant, paleobotanists hope for the same type of plant or plant part will be preserved in several different styles.

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 (VG 1:1) , 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 (VG 1:2). 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.

Study the assortment of compressions available. Note color, texture, and type of deformation (usually flattening) experienced by each specimen. Notice distortion in original morphology is introduced by flattening.

Examine samples of coal, noting their weight, texture and surface features (dull vs. shiny). Identify discrete plant parts in the different ranks (essentially grades of metamorphism) of coal. Coal geologists recognize a continuum of degree of metamorphism in coal: peat - lignite - bituminous coal (A-C) - anthracite. 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. Study thin sections of coal at the microscope. Can you identify specific plant parts in the thin sections? Study samples of fusain (fossil charcoal).

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. Study the specimens of impressions, noting the several categories of plant parts represented. Because of their shape, texture, and abundance, leaves are among the most common organ preserved in impression (VG 1:1). 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 (VG 1:3) . 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 Molds

When sediment is deposited into cavities left by the decay of plant parts, a cast results (VG 1:4). A mold is essentially a cavity left in the sediment by the decayed plant tissue. Molds are generally unfilled, or may be partially filled with sediment. Casts and molds 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 mold. Casts and molds may be found together with the cast filling the mold.

Molds are formed when soft sediment surrounding the structure lithifies or hardens before the structure decays. When the mold 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 molds record external (or sometimes internal) organ features well, but provide no cellular or tissue information. Unlike compressions/impressions, molds 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 (VG 1:5).

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 (VG 1:6). 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, for the purpose of this course, 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 (VG 1:7)) 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 (VG 1:9), where whole regions of peat were permineralized. Called coal balls (because of their sometimes round or ellipsoidal shape (VG 1:10)) 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 mold-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 an 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. Examine specimens of Tertiary fruits and seeds, and thin sections made from them. Pollen and spores are also preserved as compactions (VG 1:8). 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 (Moldowan 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

http://www.ucmp.berkeley.edu/IB181/VPL/Pres/Pres2.html

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