



# Darwin's Abominable Mystery

. . . origin of angiosperms . . .

*Read Saquet et al. 2017. The  
ancestral flower of angiosperms and  
its early diversification. Nature  
Communications*



# Great Mysteries to Zoologists

*Rise of the birds from a dinosaur lineage*

*Archaeopteryx*

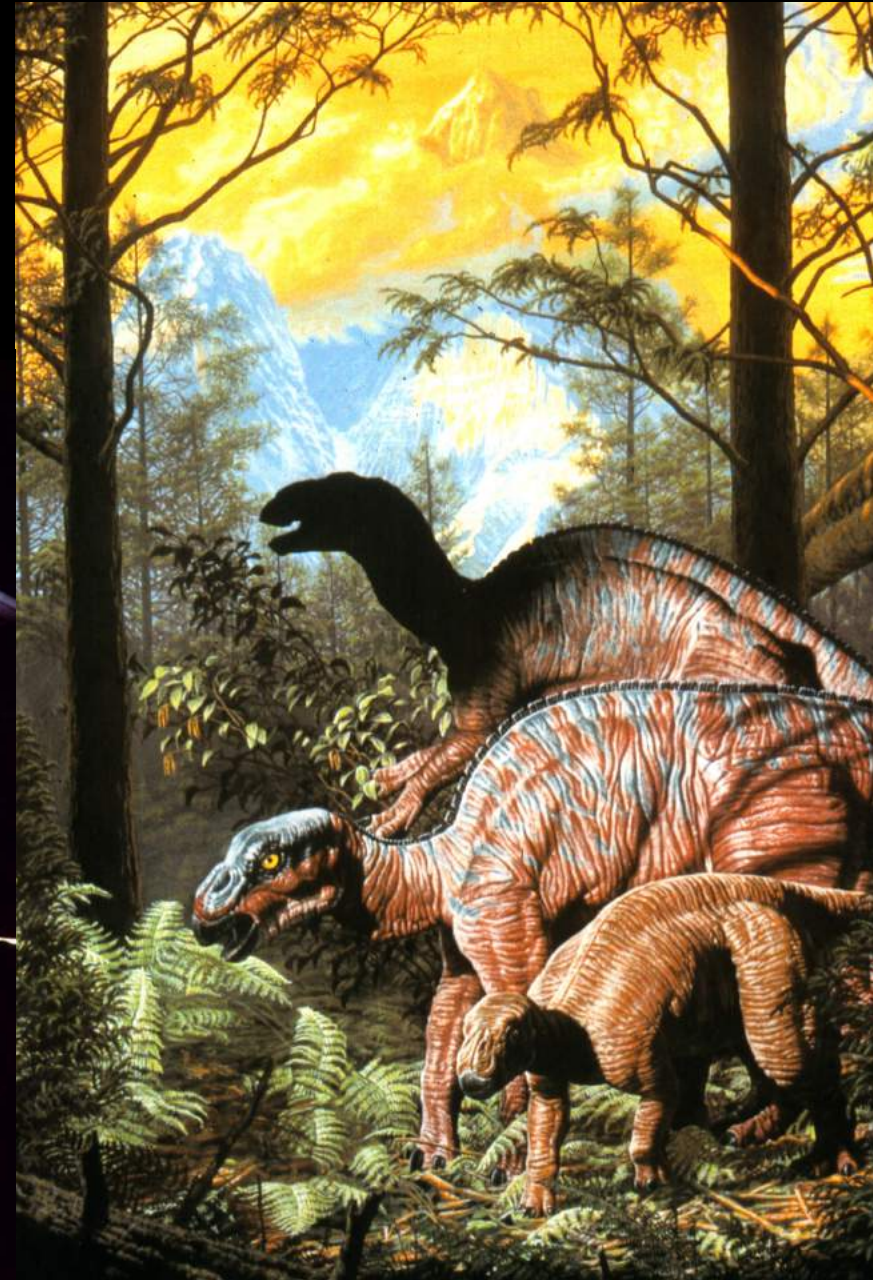
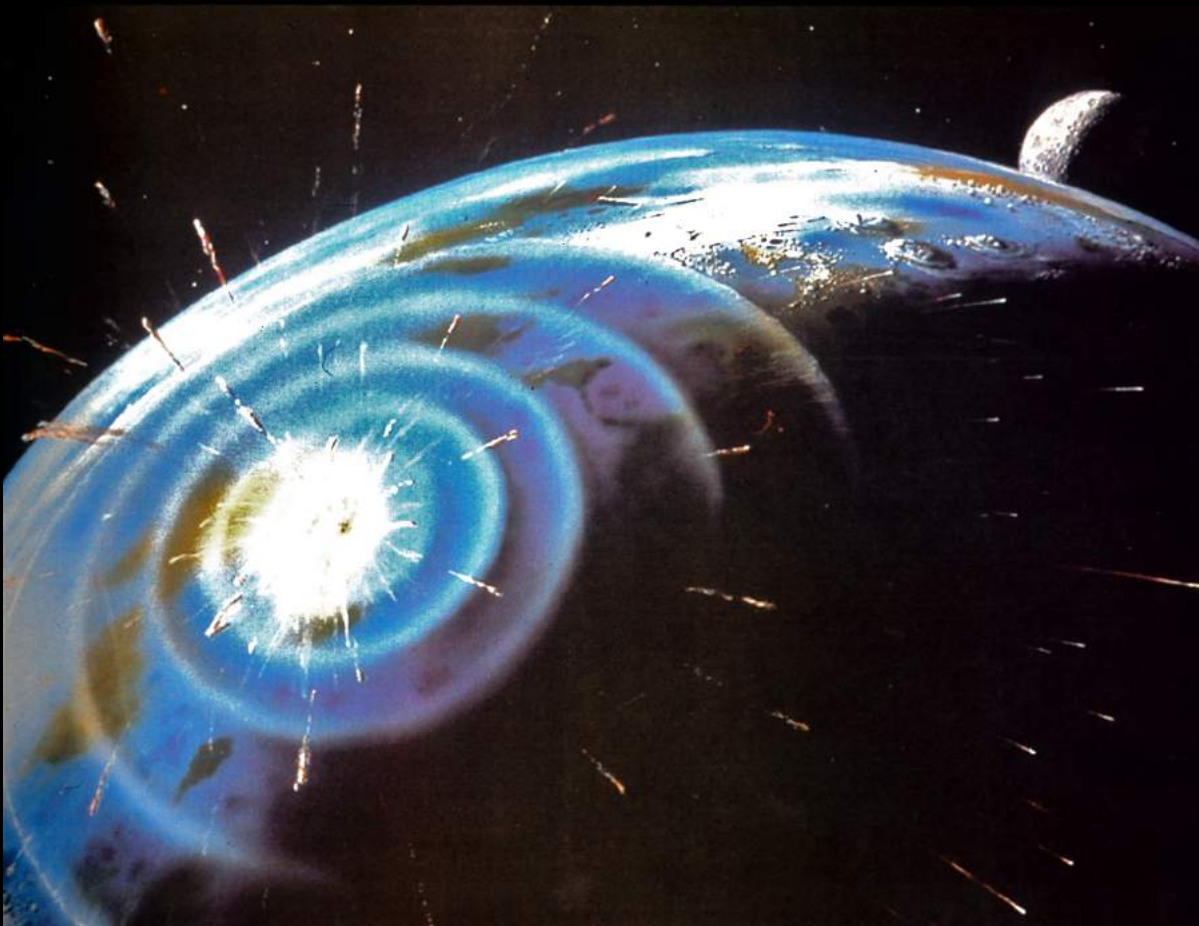




# Great Mysteries to Zoologists

*Demise of the non-avian  
dinosaur lineage*

*Edmontosaurus*

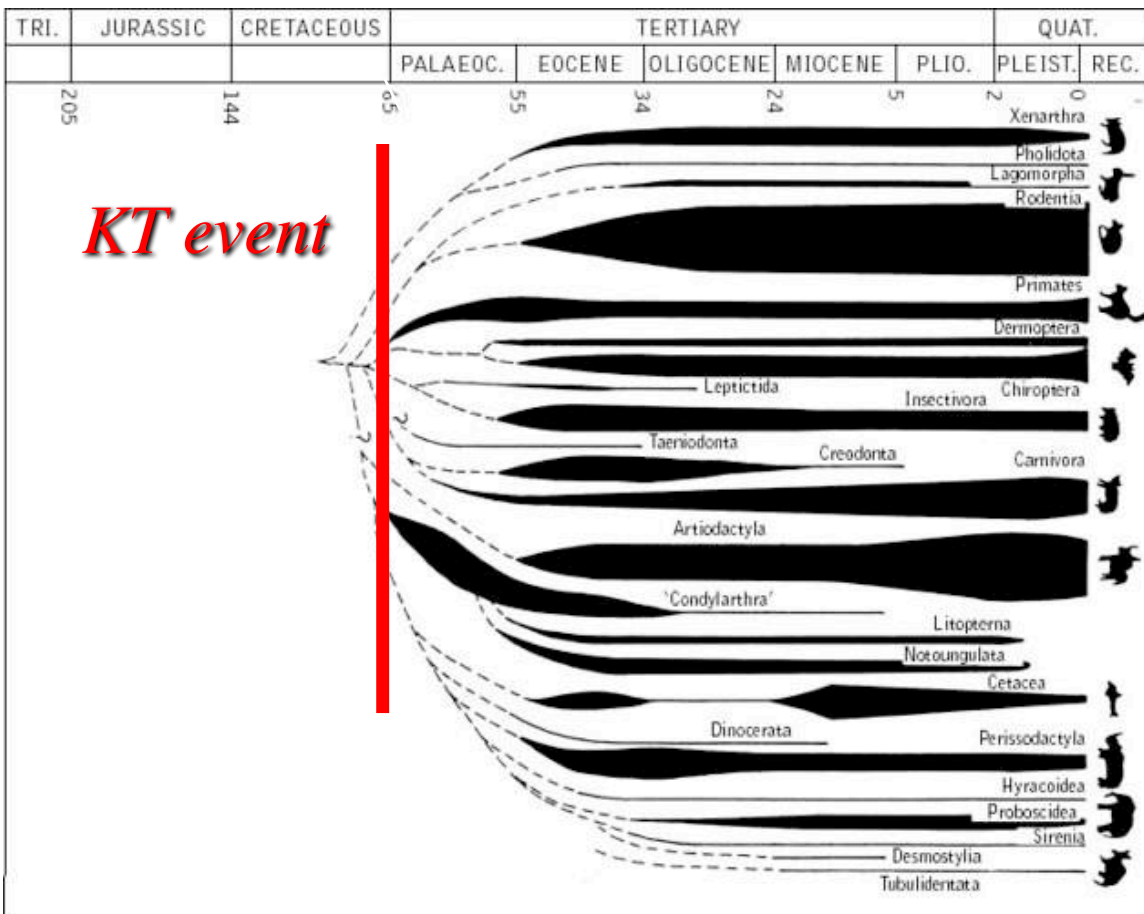




# Great Mysteries to Zoologists

*Adaptive radiation of mammals after dinosaurs*

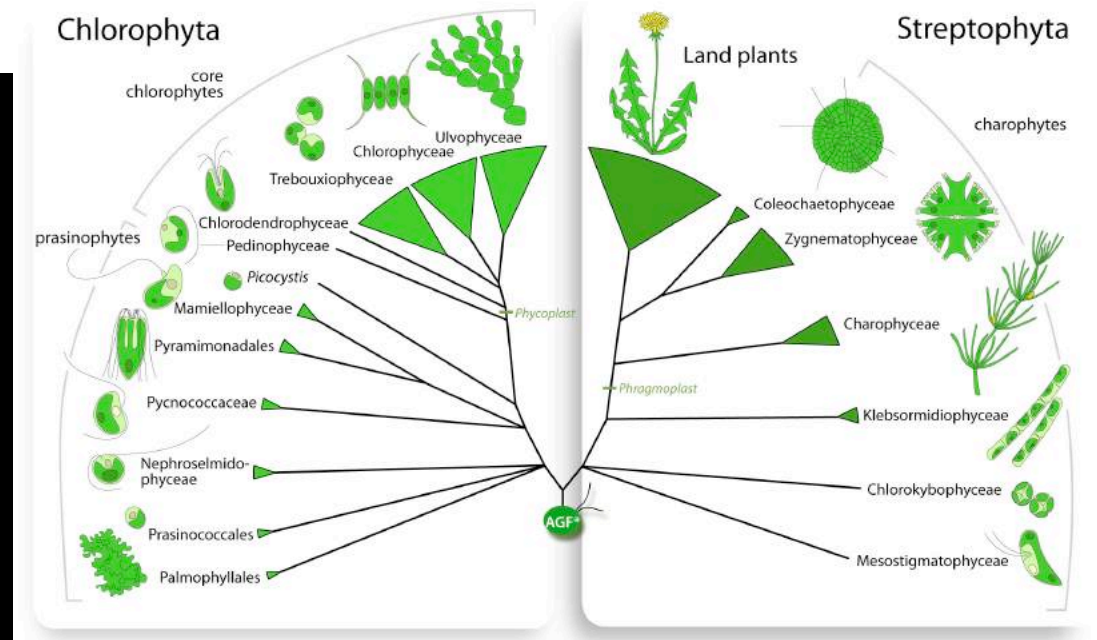
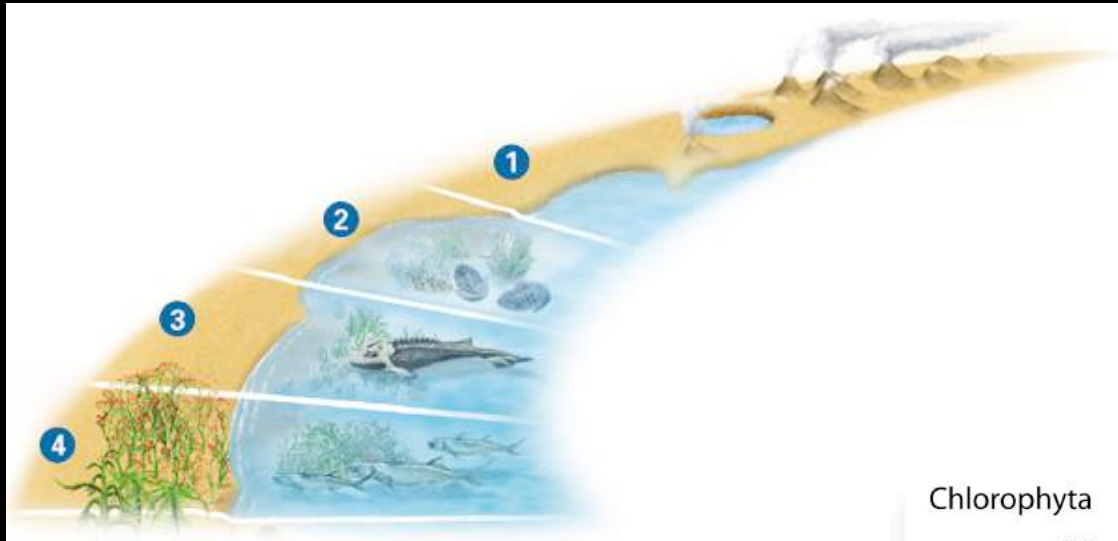
*Eocene in Kansas*





# Great Mysteries to Botanists

## Origin of land plants





# Greatest Mystery to Botanists

*Origin and rise of  
angiosperms*

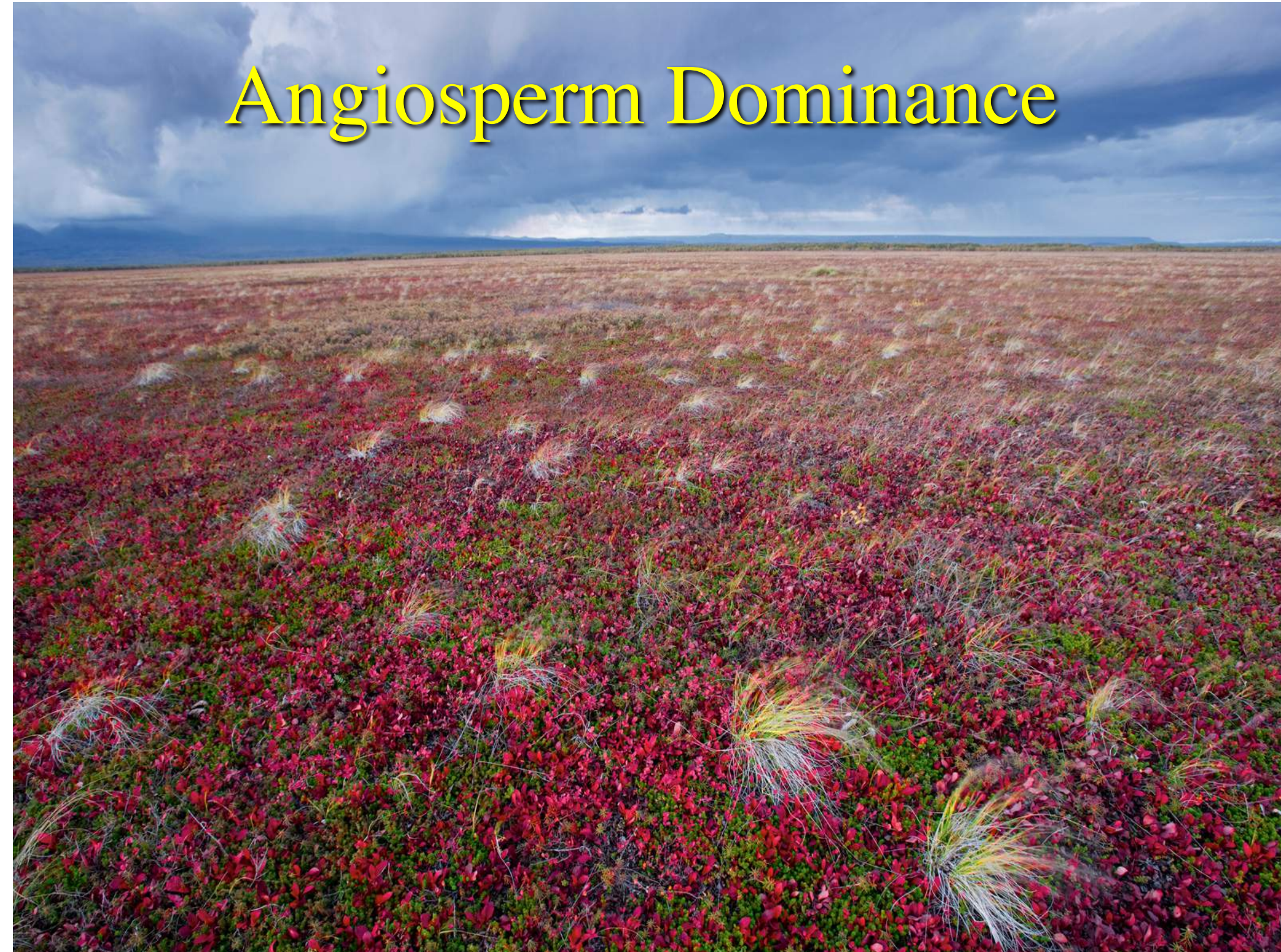




# Angiosperm Dominance



# Angiosperm Dominance





# Angiosperm Dominance





# Angiosperm Dominance





# Angiosperm Dominance





# Gymnosperm Dominance



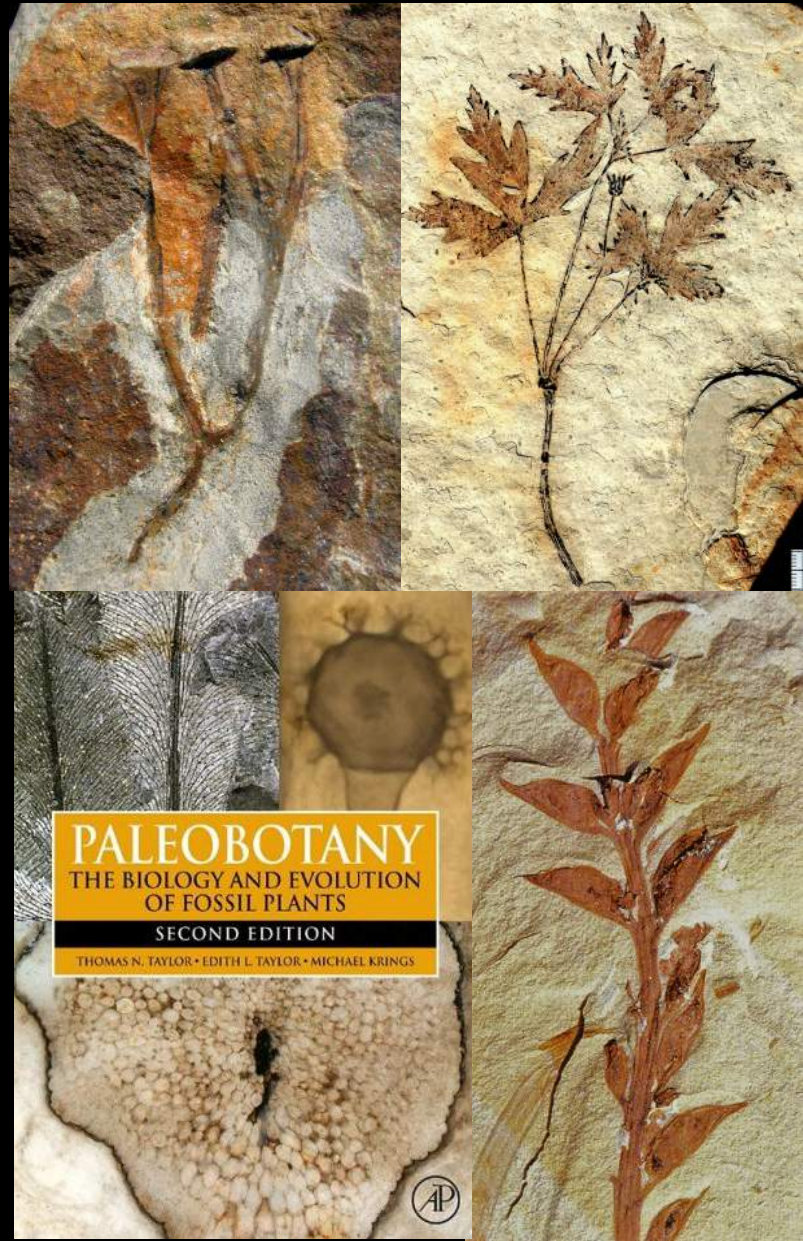
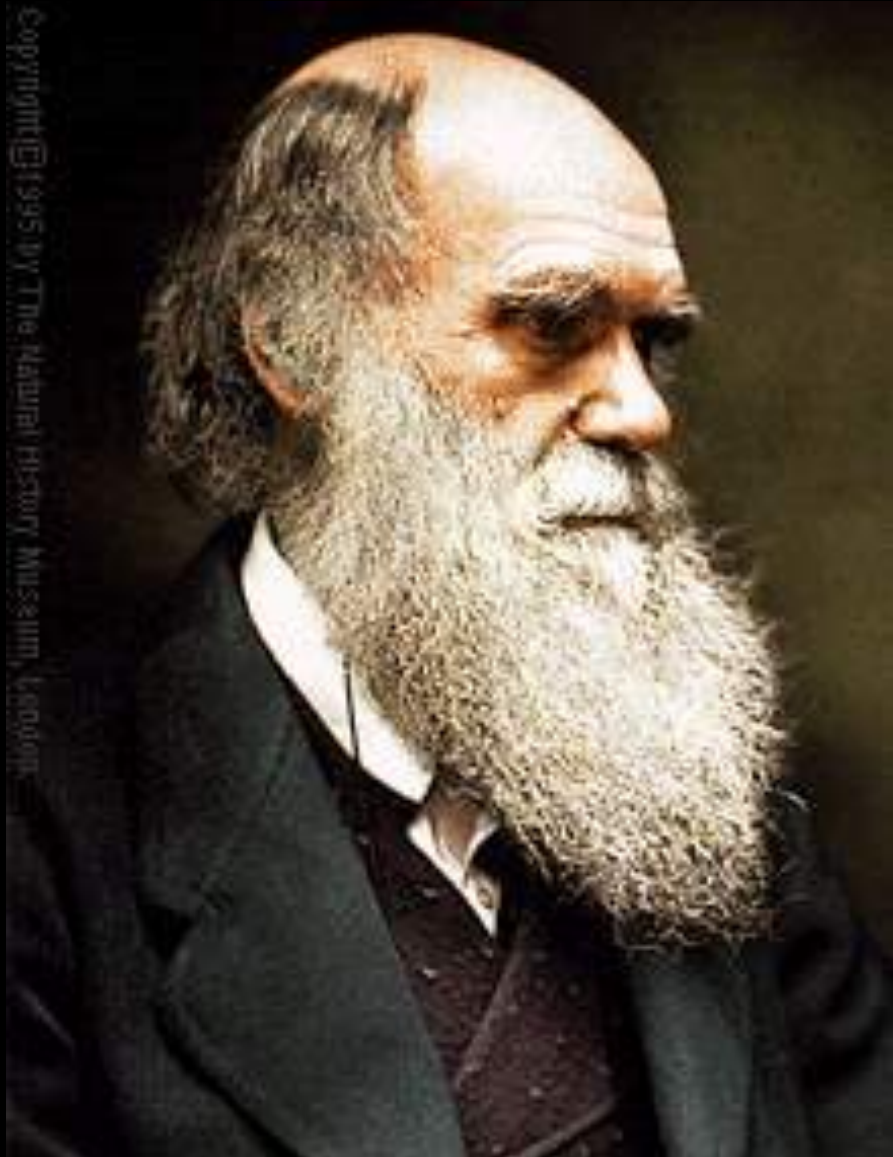
# Gymnosperm Dominance





# Angiosperms have NOT always dominated

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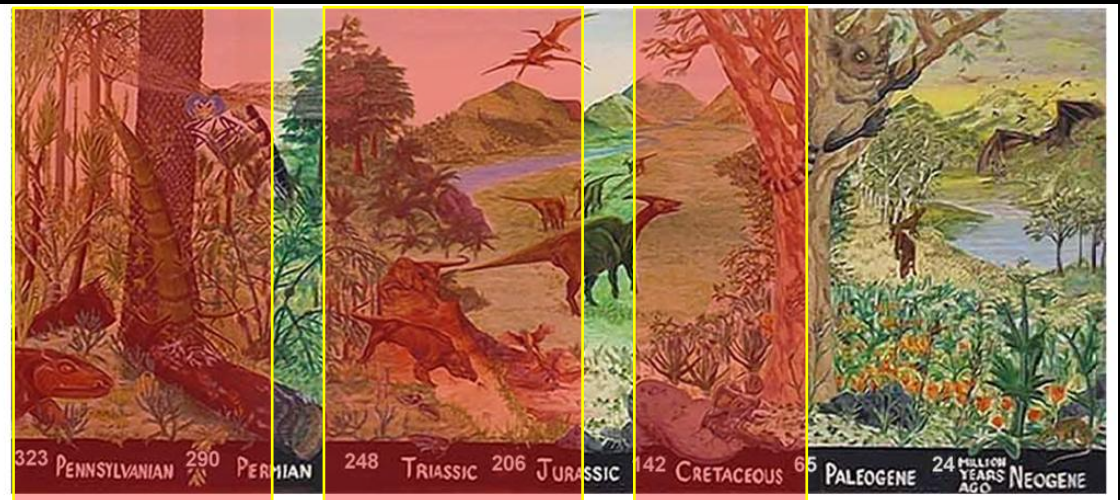
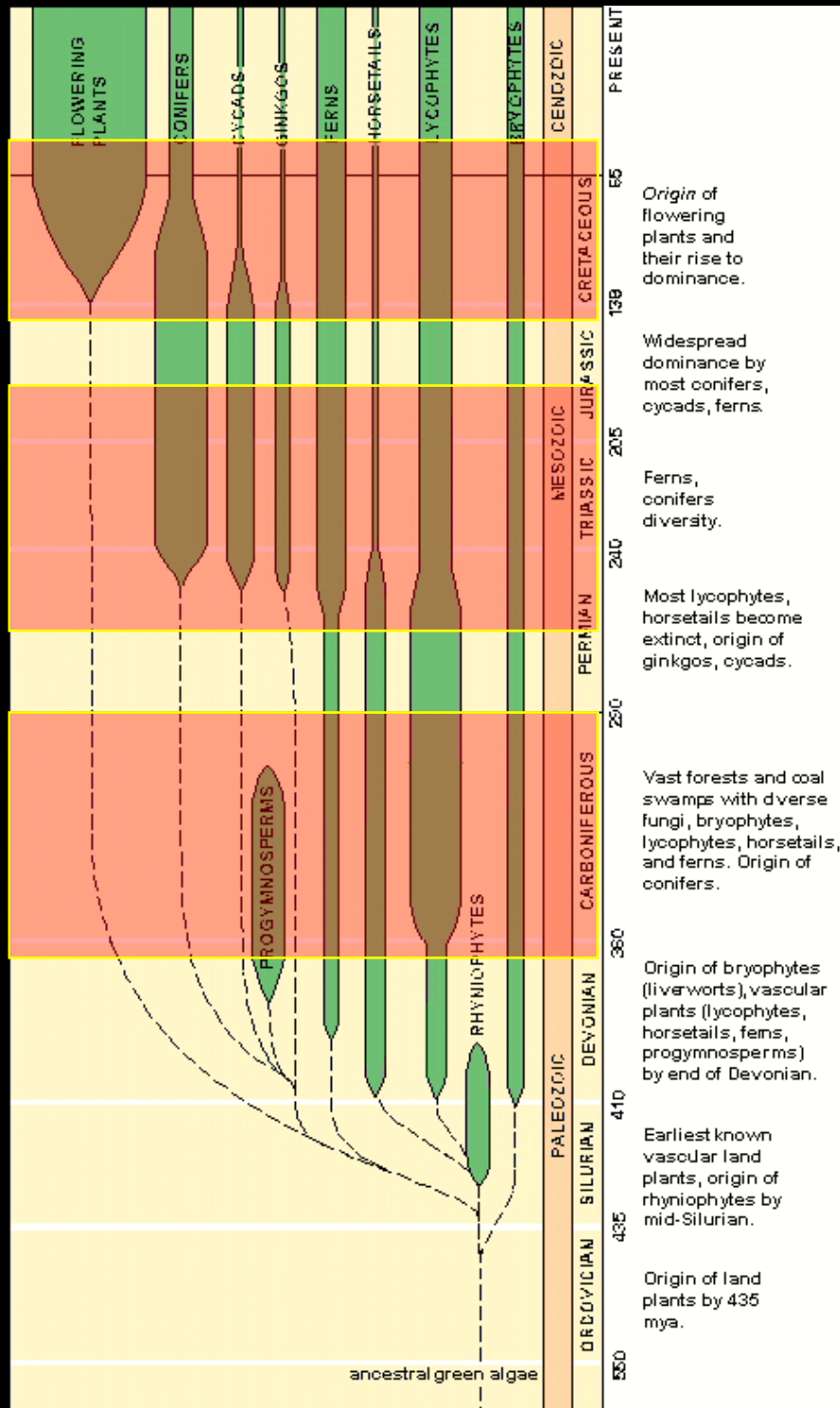




# Fossil Record

as seen by Charles Darwin

- tree-like lycopods, horsetails, primitive gymnosperms - the **Carboniferous**
- ferns, cycads, ginkgos, conifers - the **Triassic/Jurassic**
- flowering plants suddenly show up at **start of Cretaceous**

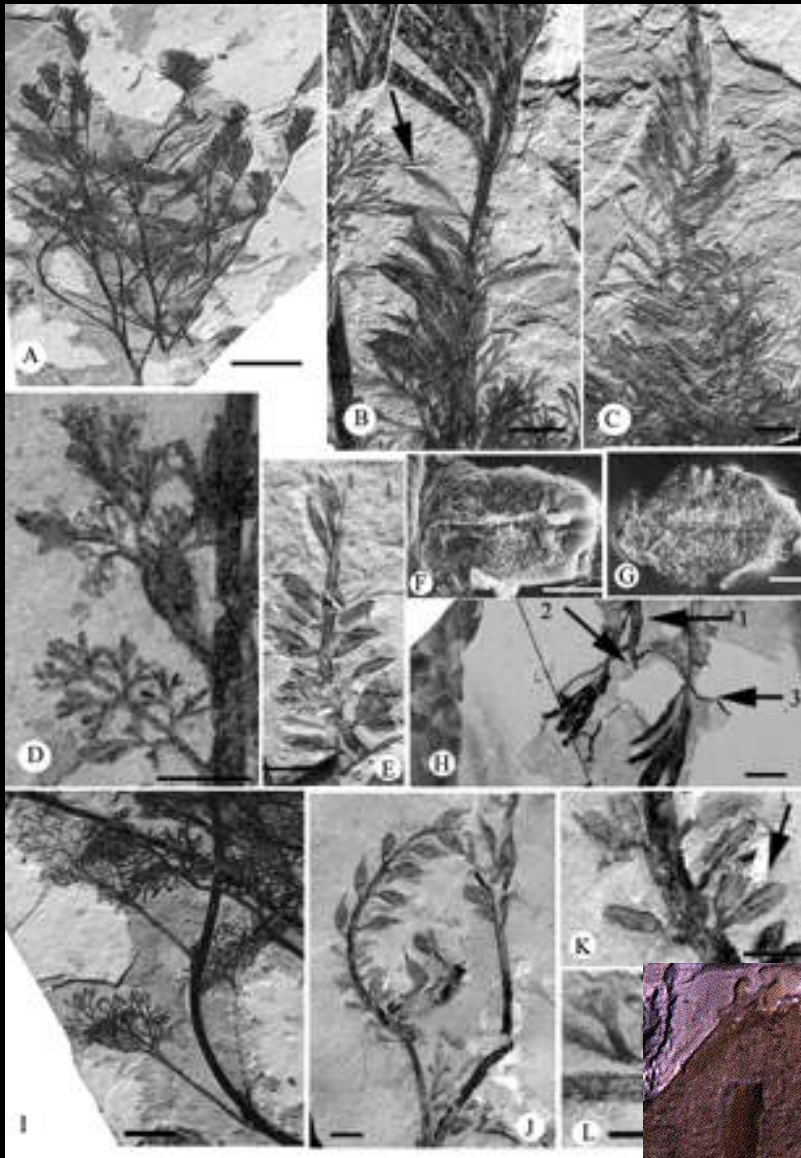




# Fossil Record

as seen by Charles Darwin

- by mid-Cretaceous, 50 families of angiosperms seen
  - including 5 monocot
  - including 4 ament/catkin bearing

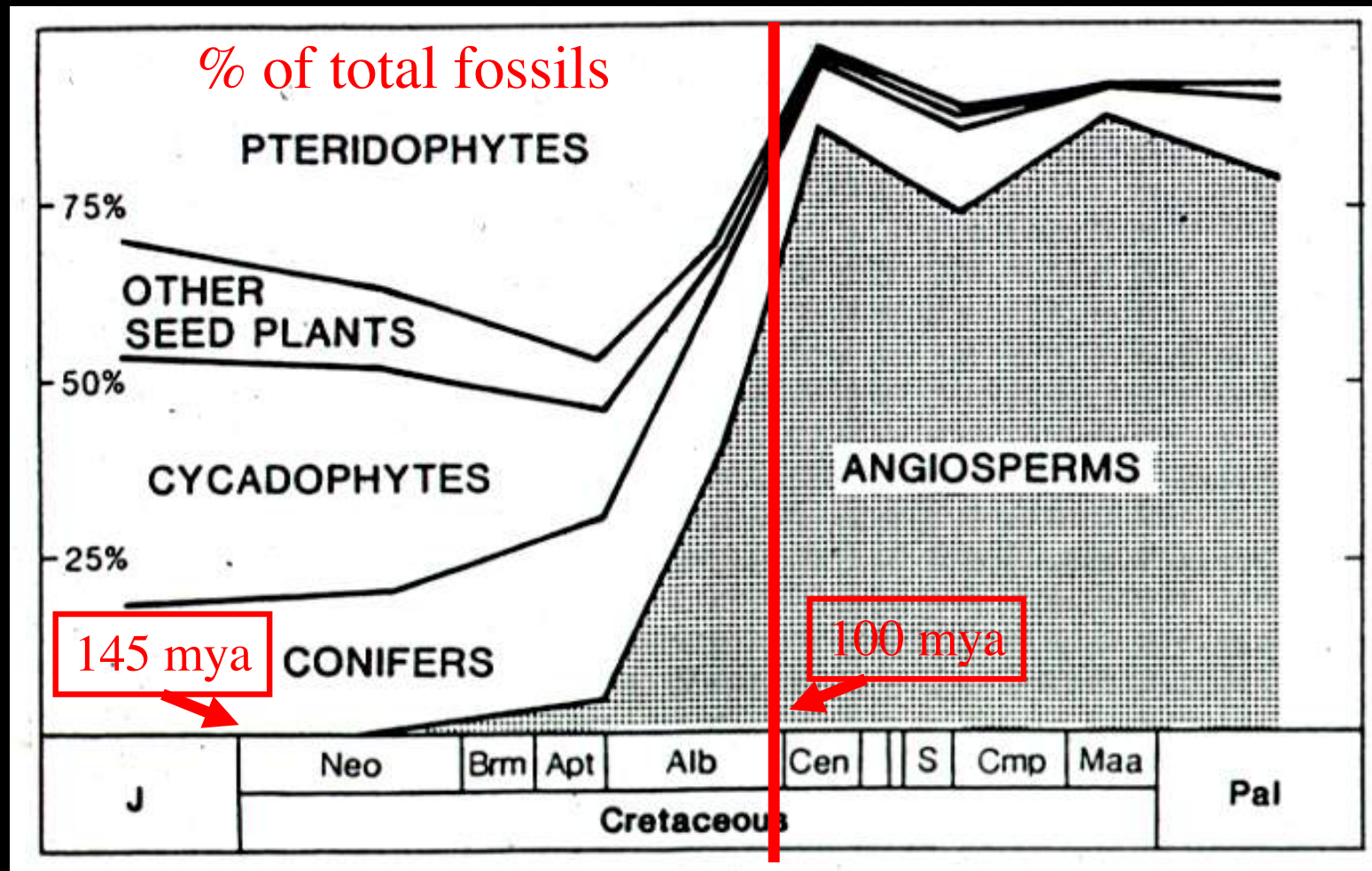




# Fossil Record

as seen by Charles Darwin

- by mid-Cretaceous, angiosperms also dominate the face of the earth (based on fossil diversity)





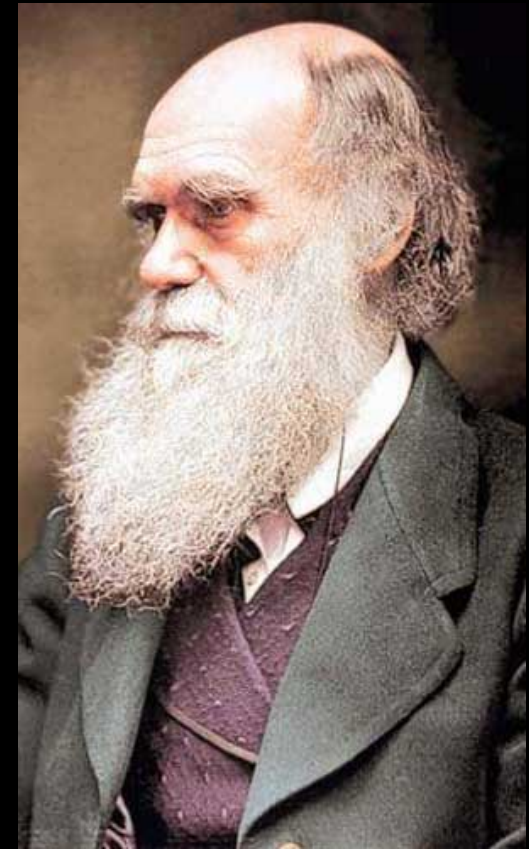
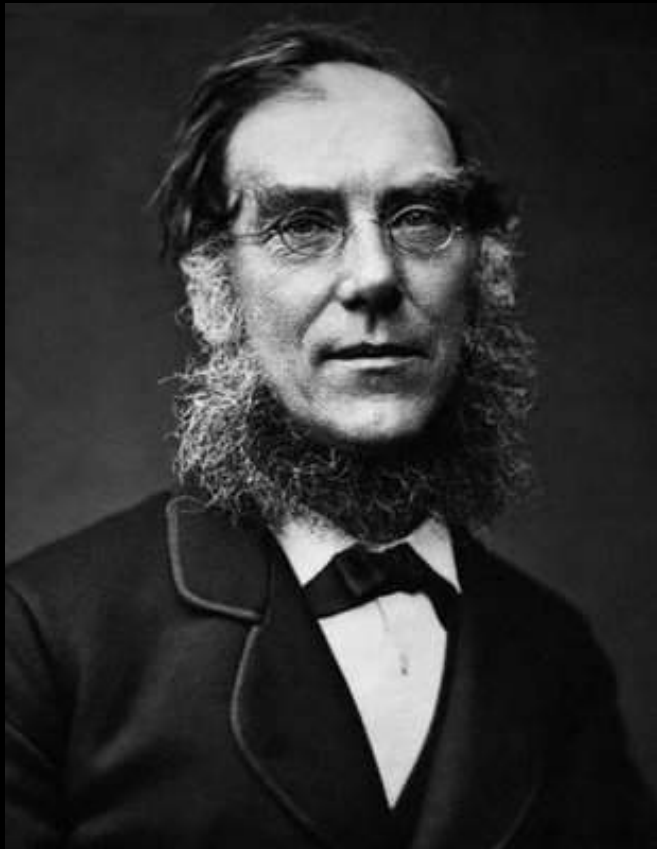
# the Abominable Mystery

*“The rapid development, as far as we can judge, of all the higher plants within recent geological time is **an abominable mystery**”*

(Darwin, 1879, in a letter to Hooker)

## Joseph Dalton Hooker

Director of the Kew Royal Botanic Garden and good friend of Darwin (the only acknowledged person in the “*Origin of Species*”)



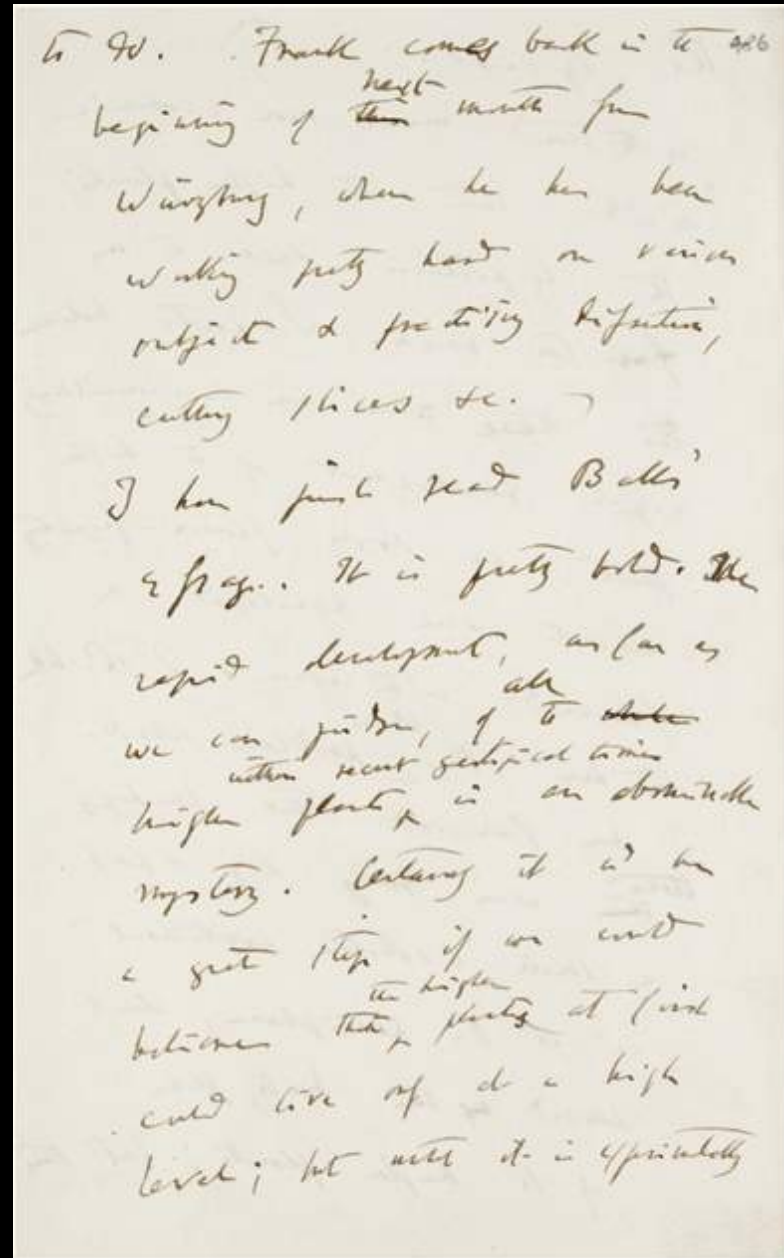


# the Abominable Mystery

(page 3, letter of 22 July 1879)

- Continues with speculations on how to answer the mystery

- originated in alpine conditions
- originated in isolated tropical island
- arose in response to rise of 'flower-frequenting insects'



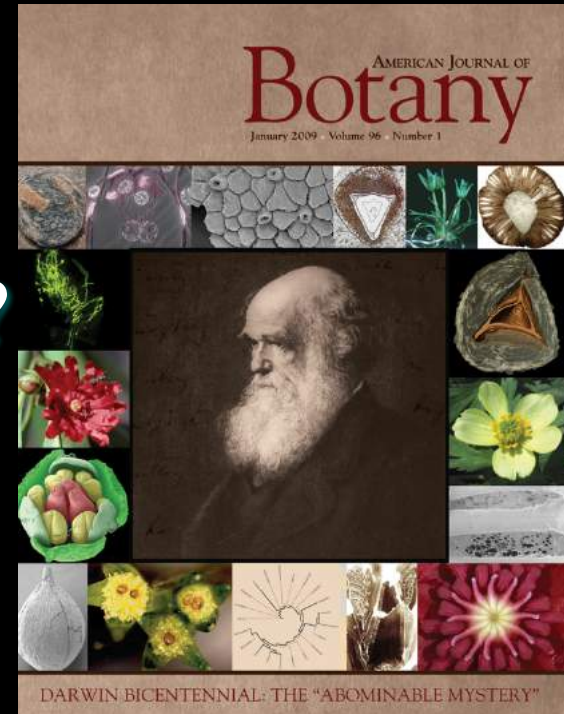
to 90. Frank comes back in to see  
beginning of <sup>next</sup> ~~the~~ month from  
Würzburg, then he has been  
working pretty hard on various  
subjects & preparing lectures,  
cutting slices &c. &c.

I have just read Bell's  
& page. It is pretty bold. The  
rapid development, as far as  
we can judge, of <sup>all</sup> the  
higher plants <sup>within recent geological times</sup> is an abominable  
mystery. Certainly it is a  
great step if we could  
believe that <sup>the higher</sup> plants at first  
could live up to a high  
level; but still it is apparently



# the 2019 Questions

1. **When** did the Angiosperms arise?
2. **What** were the first Angiosperms?
3. **Where** did the Angiosperm arise?
4. **From what** Gymnosperm clade did the Angiosperms arise ?
5. **Why** did they take over the world's flora?

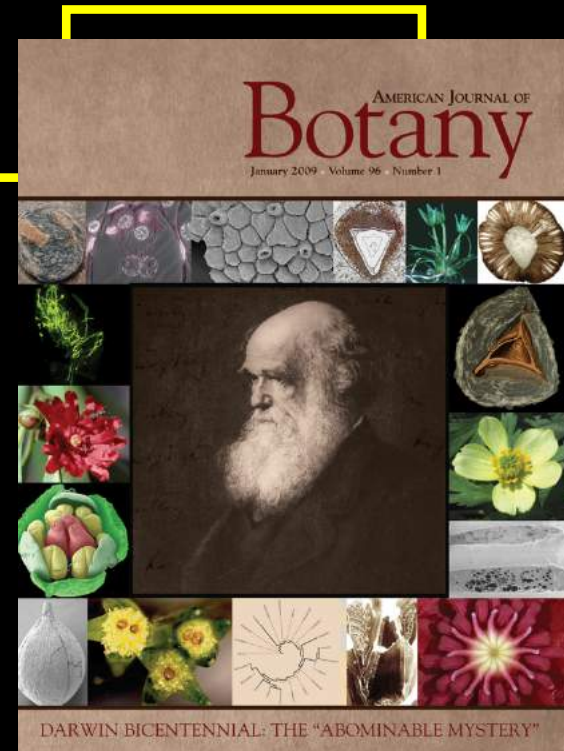


**2009 AJB**  
**volume**



# the 2018 Evidence

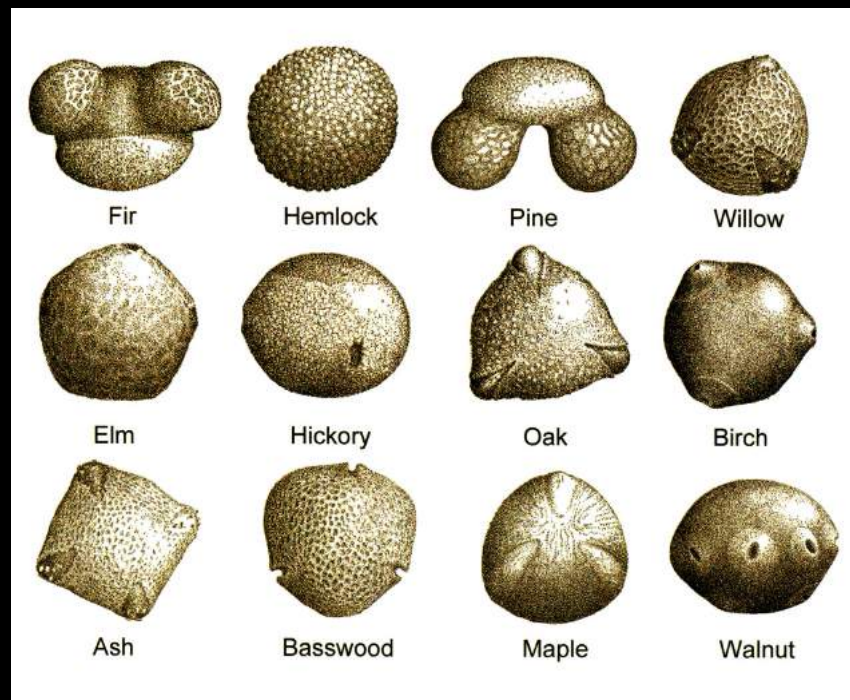
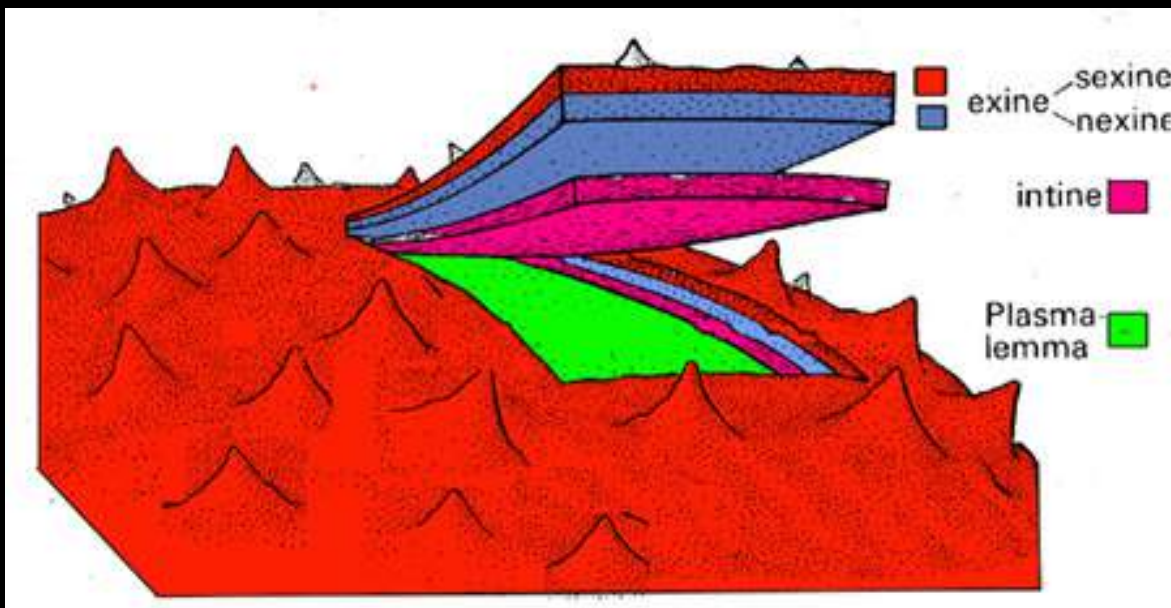
1. Modern fossil record
2. Geographical distributions
3. Morphological phylogenetics
4. Evo-devo studies of flowers
5. Molecular phylogenetics
6. Molecular “clocks”





# Pollen Record

- **ubiquitous** - preserves well due to **exine** layer
- often **diagnostic** to specific gymnosperm or angiosperm groups





# Pollen Record

- **ubiquitous** - preserves well due to **exine** layer
- often **diagnostic** to specific gymnosperm or angiosperm groups
- but **different levels** of production and fossilization

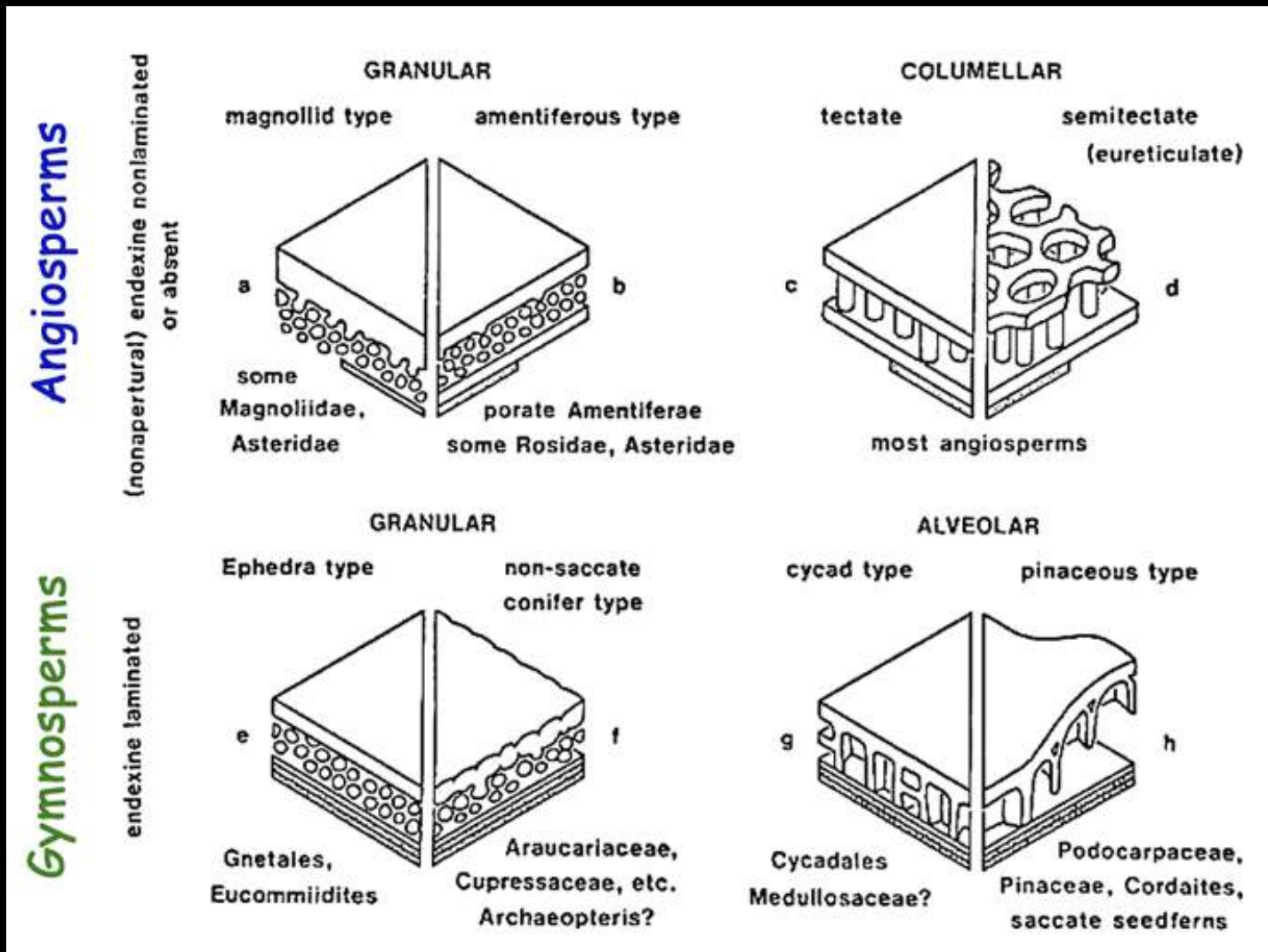


- little *Senecio* pollen in tropics
- abundant pine pollen in lake sediments



# Pollen Record

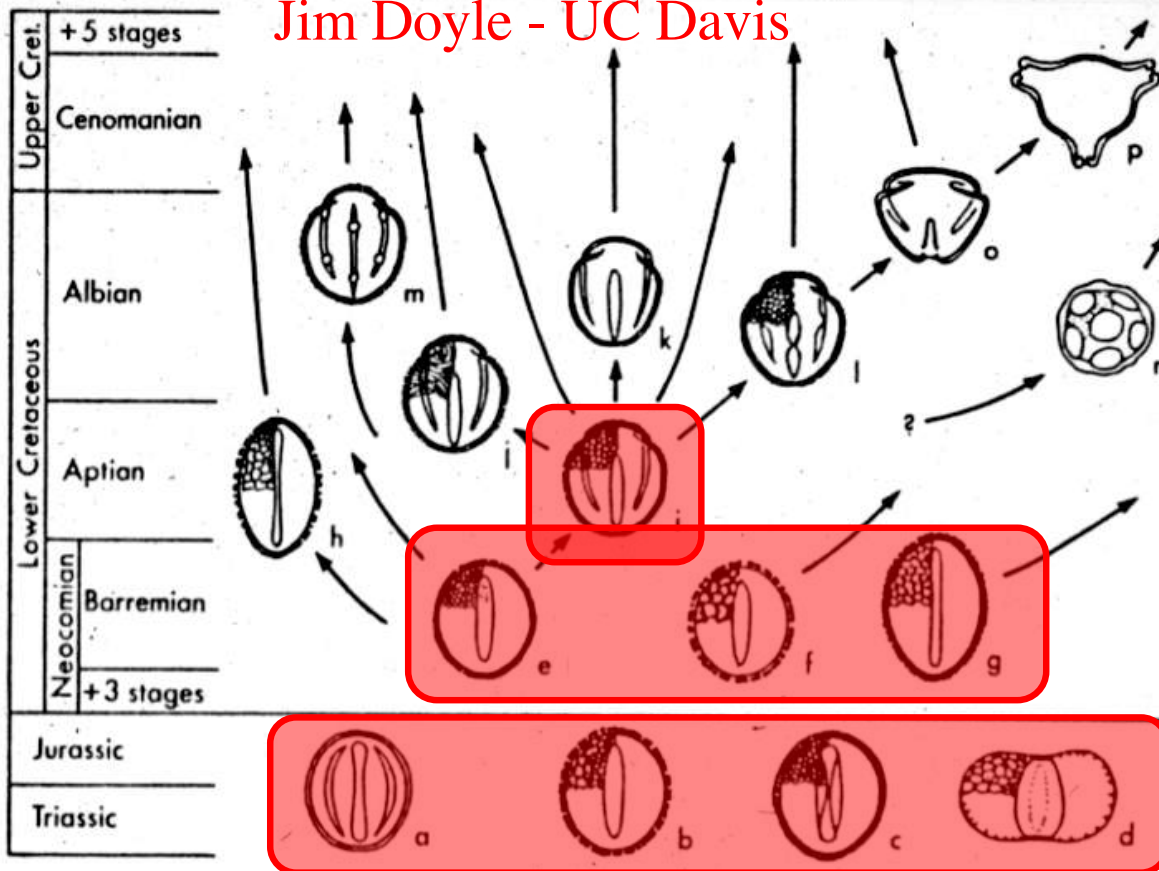
- gymnosperm vs. early angiosperm pollen differentiation often **requires TEM vs. SEM** visualization - both one pored





# Pollen Record

Jim Doyle - UC Davis



*Figure 1* Time distribution and presumed relationships of principal Early Cretaceous and Cenomanian angiosperm pollen types (*e-p*), and selected pre-Cretaceous pollen types (*a-d*). *a*: *Eucommiidites*; *b*: Triassic reticulate-columellar monosulcate of Cornet (30); *c*: cycad-type alveolar monosulcate; *d*: saccate alveolar pollen of Caytoniaceae and *Corystosperma*ceae; *e*: *Clavatipollenites*; *f*: *Retimonocolpites*; *g*: *Stellatopollis*; *h*: *Liliacidites*, a possible monocot; *i*: reticulate tricolpate; *j*: striate tricolpate; *k*: smooth tricolpate; *l*: grain with tricolporate tendency; *m*: tricolpodiorate; *n*: polyporate; *o*: smooth, oblate-triangular tricolporate; *p*: early member of triporate *Normapolles* complex.



- all pre-Cretaceous pollen = gymnosperm
- Neocomian (**130 mya**) = oldest angiosperm single pored pollen (**basal angiosperms**)
- Barr.-Aptian (**125 mya**) = oldest tricolpate pollen (**eudicots**)



# Pollen Record

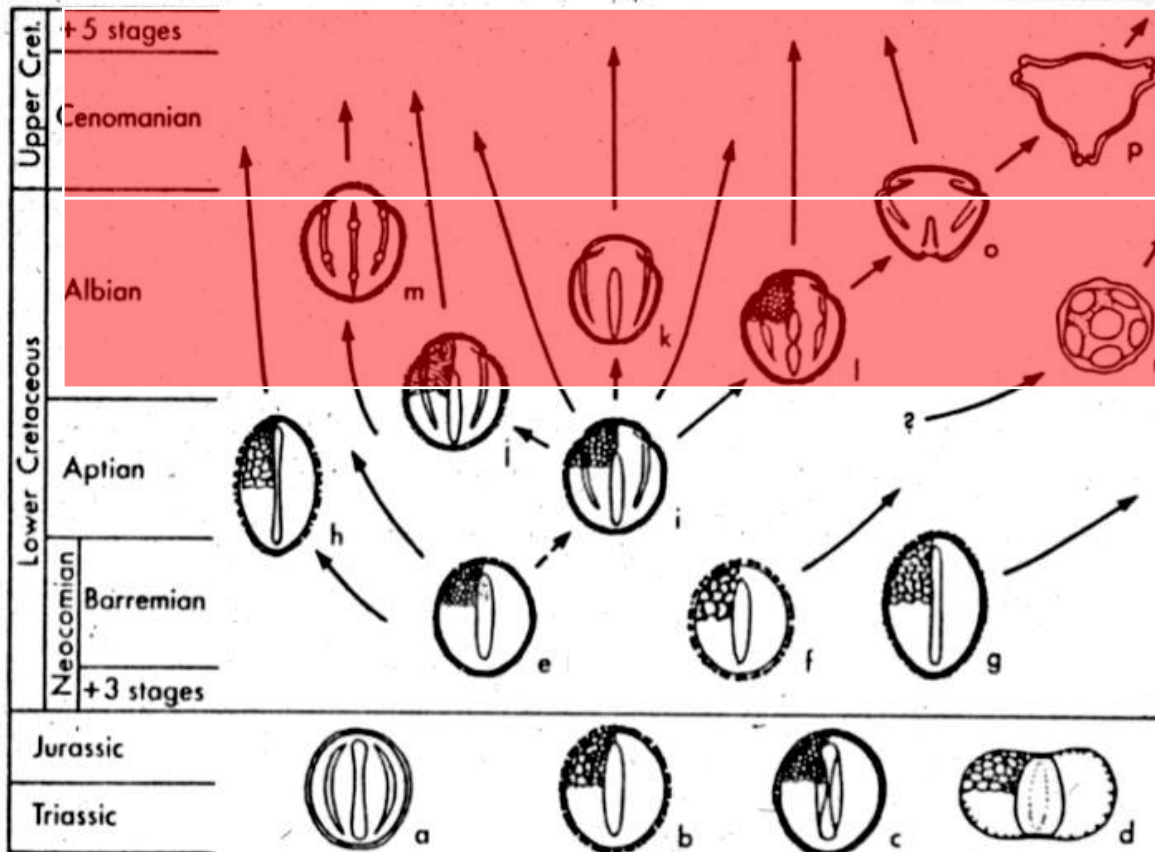


Figure 1 Time distribution and presumed relationships of principal Early Cretaceous and Cenomanian angiosperm pollen types (e-p), and selected pre-Cretaceous pollen types (a-d). a: *Eucommiidites*; b: Triassic reticulate-columellar monosulcate of Cornet (30); c: cycad-type alveolar monosulcate; d: saccate alveolar pollen of Caytoniaceae and *Corystospermaceae*; e: *Clavatipollenites*; f: *Retimonocolpites*; g: *Stellatopollis*; h: *Liliacidites*, a possible monocot; i: reticulate tricolpate; j: striate tricolpate; k: smooth tricolpate; l: grain with tricolporate tendency; m: tricolpodiorate; n: polyporate; o: smooth, oblate-triangular tricolporate; p: early member of triporate Normapolles complex.

Albian (110 mya)  
diversity

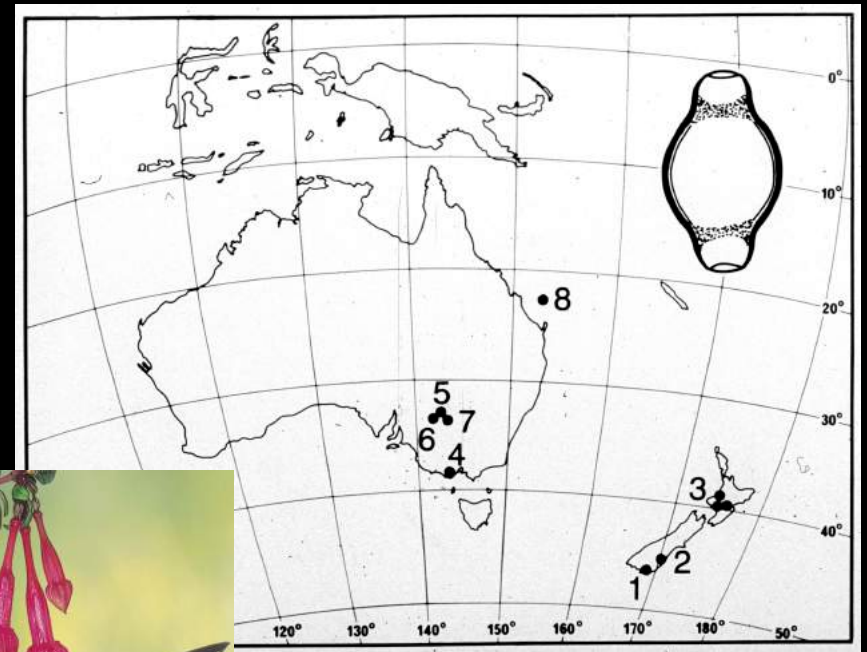
- magnoliids
- monocots
- cordate-leaved eudicots
- aments - wind pollinated

Upper Cretaceous (100 mya) - **angiosperm pollen dominates**

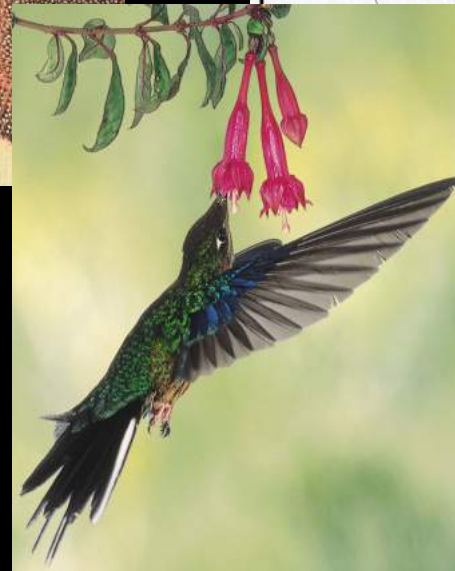


# Pollen Record

- pollen diversification continues through Upper Cretaceous into Tertiary



- family Asteraceae first seen in mid Eocene: 47 mya

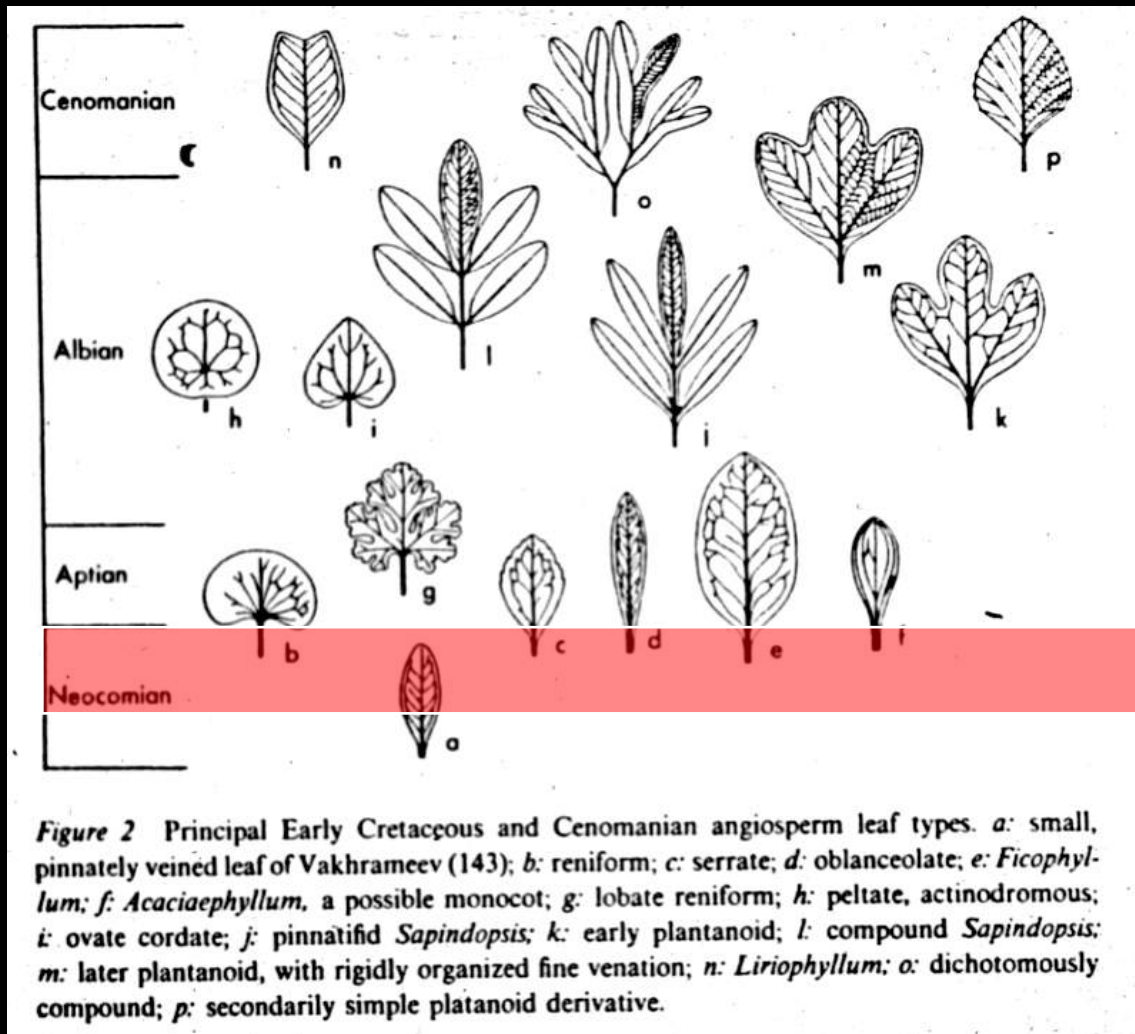


- genus *Fuchsia* (Onagraceae) first seen 30 mya in Oligocene

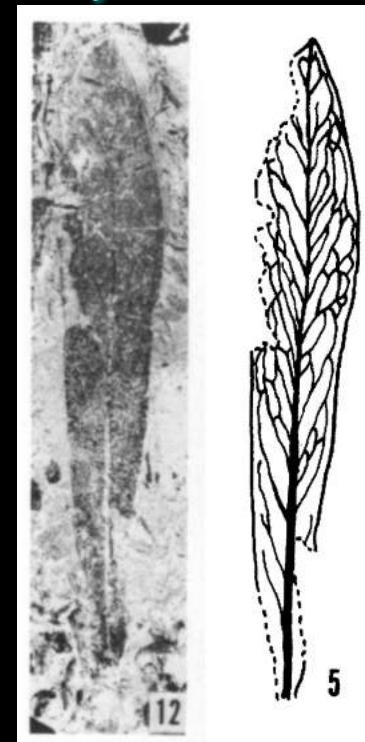


# Leaf Record

- consistent trends emerge with leaf fossils



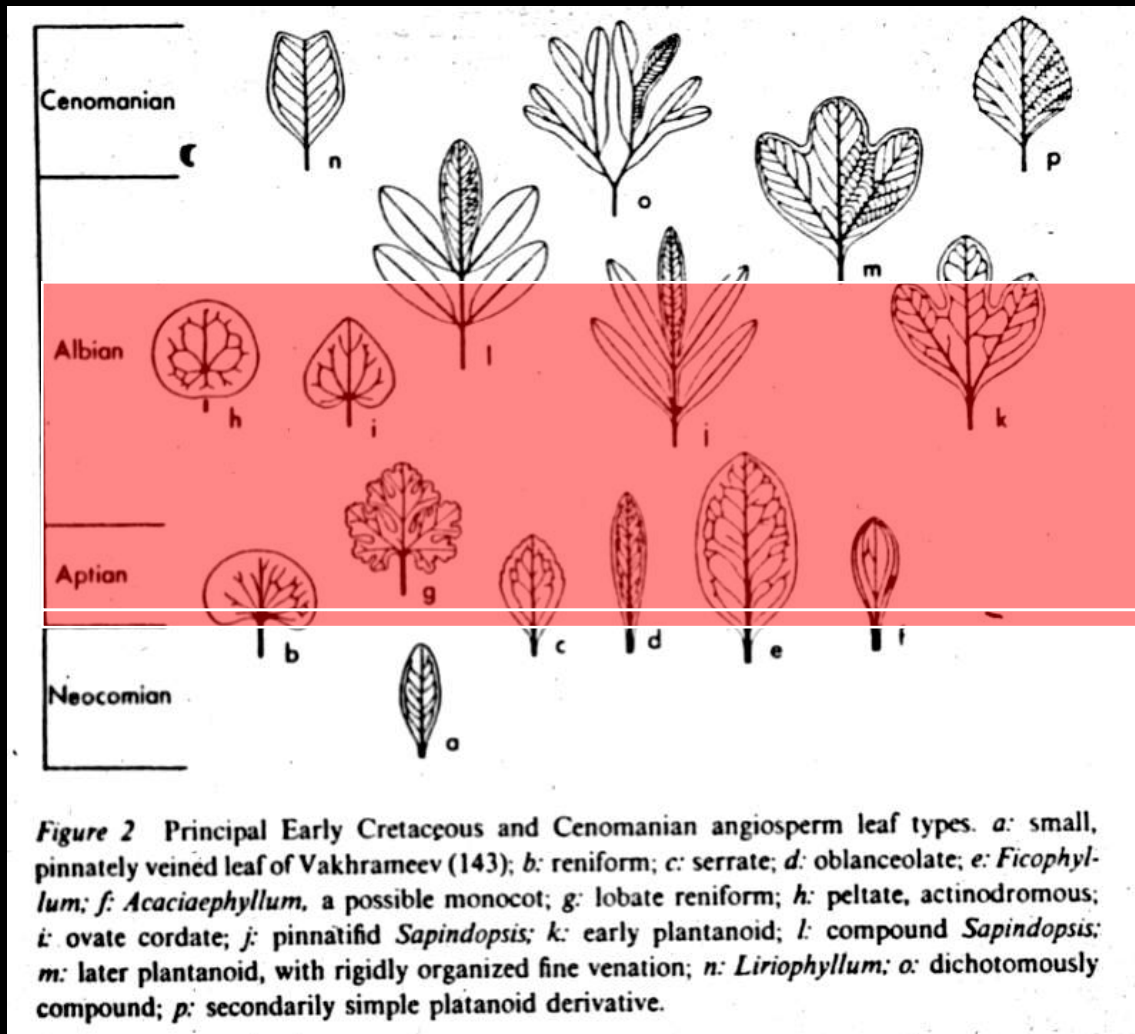
- Neocomian (**130 mya**) *Rogersia* (basal angiosperm) simple, pinnately veined, entire





# Leaf Record

- consistent trends emerge with leaf fossils



- early Aptian (**125 mya**) *Archaeo-**fructus*** (basal angiosperm) palmately compound
- Aptian to Albian (**120-110 mya**) = **magnoliids** (pinnate veins), **cordates** (palmate veins), **monocots** (parallel veins)



# Leaf Record

- consistent trends emerge with leaf fossils



great leaf diversity within 15my

- early Aptian (**125 mya**) *Archaeofructus* (basal angiosperm) palmately compound
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# Leaf Record

- consistent trends emerge with leaf fossils

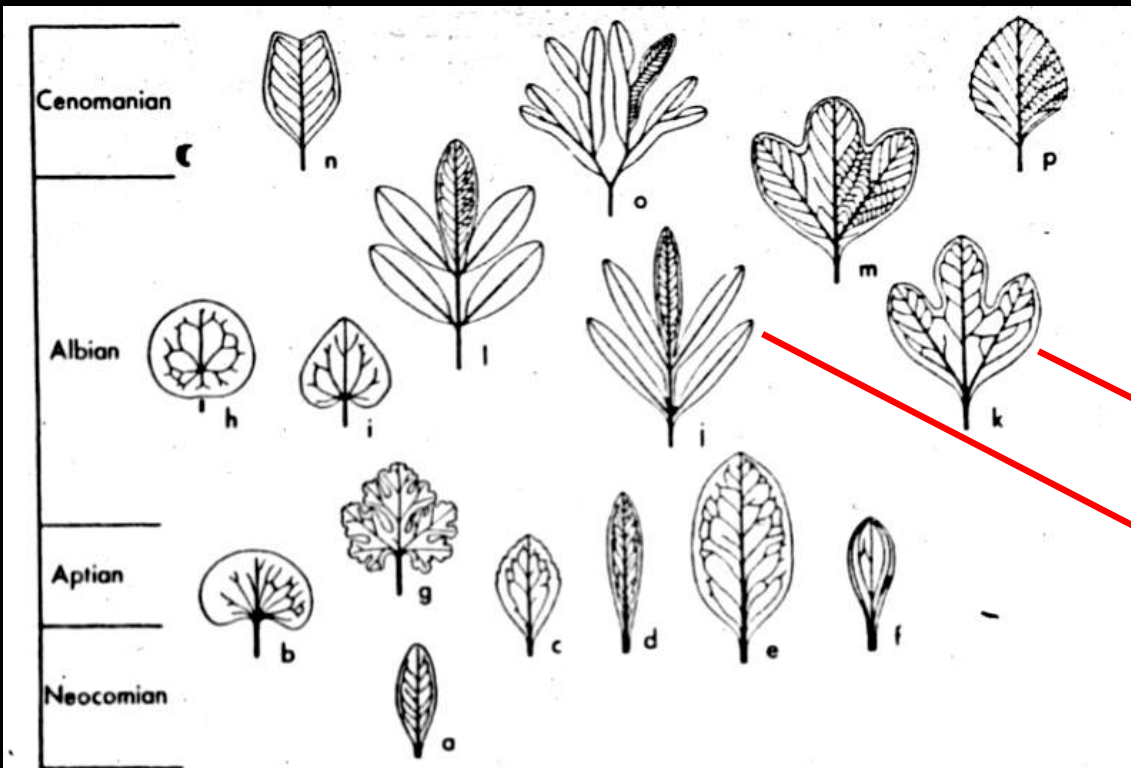


Figure 2 Principal Early Cretaceous and Cenomanian angiosperm leaf types. *a*: small, pinnately veined leaf of Vakhrameev (143); *b*: reniform; *c*: serrate; *d*: oblanceolate; *e*: *Ficophyllum*; *f*: *Acaciaephyllum*, a possible monocot; *g*: lobate reniform; *h*: peltate, actinodromous; *i*: ovate cordate; *j*: pinnatifid *Sapindopsis*; *k*: early plantanoid; *l*: compound *Sapindopsis*; *m*: later plantanoid, with rigidly organized fine venation; *n*: *Liriophyllum*; *o*: dichotomously compound; *p*: secondarily simple platanoid derivative.

- by Upper Cretaceous (100 mya) a variety of **primitive eudicot leaves** are seen

*Platanoid* - lobed

*Sapindopsis* - compound





# Leaf Record

- consistent trends emerge with leaf fossils

- by Upper Cretaceous (100 mya) a variety of **primitive eudicot leaves** are seen

Eastern Colorado  
100 mya — Cretaceous



*Liriophyllum*



*Sapindopsis*

*Protophyllum*





# Flower Record

- the “**Magnolia = primitive**” idea has biased the way paleobotanists have looked at the fossil record
  1. bisexual flower
  2.  $\infty$  spirally arranged stamens & carpels
  3.  $\infty$  perianth parts
  4. cone-like receptacle
  5. beetle pollination
- what does the fossil record actually say?





# Flower Record

- large flowered, insect-pollinated flowers are seen (such as these 98-90 mya mid-late Cretaceous fossils) . . .



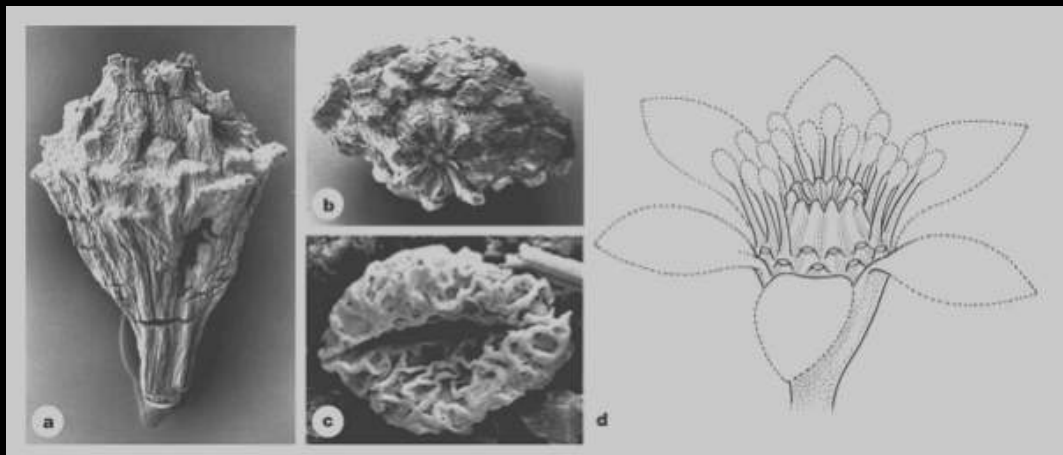
*Archaeanthus* (Magnoliaceae) –  
from Kansas 98-95 mya

Magnoliaceae with  
stingless bee – 90 mya



# Flower Record

- large flowered, insect-pollinated flowers are seen (such as these 95-85 mya late Cretaceous fossils) . . .
- . . . but the earliest and most numerous are small, bisexual or unisexual, wind or insect-pollinated



**Science Times**  
The New York Times

## In Tiny Fossils, Botanists See Flowery World

Empty Lot Yields Trove of Ancient Plants

Insects like the *Meliponini* bee may have evolved along with Cretaceous-era flowers whose fossils were recently discovered in New Jersey.

The *Paleoclasia chavelieri*, above and in electron microscope image to left, could have been pollinated by the *Meliponini* bee. Its modern relative, the *Clusia guatemalensis*, is at right.

**By CAROL KAESUN YOON**

“Nearly 80 million years ago, on what is now an empty lot in Sayreville, N.J., a flower-filled tropical forest stood in flames, its many blossoms burning and smoldering away into sooty oblivion, but one paleontological perpetuity did, as scientists now know: the trees that periodically swept these woods as long ago preserved its trunks as perfect charcoal fossils, creating the most scientific and exquisitely preserved cache of ancient flowers in the world.”

Botanists at Cornell University have already uncovered more than 200 species of fossil flowers of the site, including ancient relatives of cactuses, cactuses, rose, azaleas, water lilies, oaks, juniper plants and magnolias. These charcoal flowers, preserved in breathtaking three-dimensional detail right down to the level of the individual cell, are revealing not only how ancient relatives of modern plants looked but also, in some cases, how they lived at that time when the dinosaurs still roamed New Jersey.

Researchers say the findings are turning botanical lore on its head by revealing that the great diversification of flowering plants, which are the most species-rich and important group of plants on earth, took place at least 80 million years ago, some 20 million years earlier than previously suspected.

Some of the findings suggest that insects were diversifying right along with the plants, providing support for the theory that an interaction between these two groups, which together account for most of the species on earth, may have driven their mutual and explosive diversification.

The site “is a very special place,” said Dr. David Dilcher, paleontologist at the University of Florida, who was not involved in the work. “This is a time when flowering plants were beginning to diversify, caught right in the act. We never realized that until this group started producing the results that they’re getting from this locality.”

Dr. Mark Chase, molecular biologist at Royal Botanic Gardens at Kew in England, who uses fossil flowers to date origins of plants he studies, said, “Based on what they’re doing we’re getting some major changes in our thinking.” But he acknowledges the discovery provides much more near-term data.

Dr. William I. Crist, a paleobotanist at Cornell University, said that finding even one complete fossil flower was “the equivalent of finding a new dinosaur track.”

“It’s a fairly amazing thing,” he added.

Dr. Crist said there were likely to be billions of charcoal fossil flowers at the site, representing a diversity of species comparable to a tropical rain forest. “Plants, unlike leaves or pollen, are good sources of information often containing all the crucial features needed to identify plants.”

Until recently, most paleontologists did not even believe flowers were likely to be preserved as fossils. In fact, so widely did these fossils mean that paleobotanists worked for years in other more standard fossils, impressions left in rocks at the New Jersey site, without recognizing the charcoal flowers.

But there is another good reason earlier

The ancient *Triarida*, shown in a reconstruction above and a scanning electron microscope image below left, had large pollen sacs. A modern *Triarida* is at right.

**Actual Size**

*PALEOCLELIA*  
OPEN FLIGHT  
DIVERSITY

*TRIARID*  
SPECIES 2  
OPEN-CORP  
DIVERSITY

*CRETACEOUS*  
BEE  
HEAD  
COMPOUND EYE  
OF BEE

**Modern forests**

**Diversification of flowering plants**

**Flowering plants**

**Cycads (gymnosperms) conifers (gymnosperms)**

**200 Million**

**Conifer trees**

**100 Million**

**Gymnosperms, ferns, trees (flowerless)**

**50 Million**

**Seed plants, ferns, mosses**

**10 Million**

**Angiosperm plants**

**100 Million years ago**

Michael Rostman, an illustrator, consulted with paleobotanists to recreate this scene of *Triarida* growing in a Cretaceous rain forest. The mature plants would be about three inches high.

Continued on Page 6



# Flower Record

- what are the earliest fossil flowers?

## Fossil, After 120 Million Years, Is Believed the Oldest Flower

By JOHN NOBLE WILFORD

A tiny fossilized plant, barely one inch tall and resembling today's black pepper plant, has been identified by scientists at Yale University as the oldest known flower. It lived 120 million years ago and its flower was probably a drab green or beige — hardly the thing to inspire nosegays for dinosaurs.

Botanists were not so much surprised to find a fossil flower more than five million years older than anything previously discovered as they were by the plant's humble size and appearance. Textbooks and museum murals depicting scenes of prehistoric life, reflecting the traditional hypothesis, usually picture showy magnolia-like flowers with large, shiny foliage.

Because the fossil had characteristics of the two major branches of modern flowering plants, scientists said the plant could be their common ancestor and represent a kind of missing link needed to understand plant evolution. Nearly all the world's plants that bear seed, about a half million species, are likely descendants of the small plant.

"This insignificant-looking flowering herb is packed with information about plant evolution that could be of incalculable value," said Dr. Leo J. Hickey, a paleobiologist at Yale University who made the discovery with Dr. David W. Taylor, a Yale botanist.

able value," said Dr. Leo J. Hickey, a paleobiologist at Yale University who made the discovery with Dr. David W. Taylor, a Yale botanist.

### Plant Grows Near Melbourne

The discovery, being reported today in the journal *Science*, was made after Dr. Taylor saw a published description of the fossil, which had been dug up in southeastern Australia near Melbourne and labeled a fern. Examining detailed photographs of the fossil under a microscope, Dr. Taylor and Dr. Hickey identified the plant as a flowering angiosperm — with fruit surrounding its seeds.

"We're looking at the origin of flowering plants, which are the dominant plants on earth," Dr. Hickey said yesterday in a telephone interview.

The scientists said the plant grew in scraggly underbrush on the edge of a pond in the Koonwarra area of Australia; it had a mild climate and probably was a perennial with an underground stem. Similar flowering plants can be found today in marshes. Gardeners as well as botanists might recognize similarities between the Koonwarra plant and wild yams, cat briar, lizard's tail, and the black pepper plant.

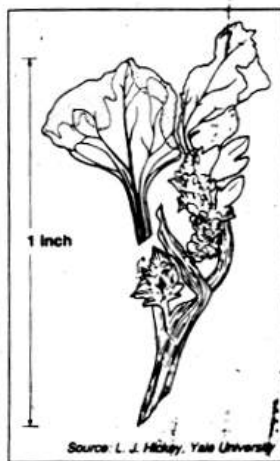
Dr. Peter Crane, an authority on plant evolution at the Field Museum of Natural History in Chicago, said the finding was "certainly interesting and important." But he cautioned that the fossil was not well preserved, which could prevent scientists from determining the plant's structure in more detail.

### More Diversity in Early Flowers

"We're starting to see pretty clearly that by no means everything then was put together like a magnolia flower," Dr. Crane said. "There was more diversity in early flowering plants. If anything, the evidence favors the view that magnolias evolved slightly later than had been assumed."

The earliest flowering plants may date back to 130 or 140 million years ago, scientists estimate. It has been determined that some fossil pollen from that period came from flowering plants. But the full plants and flowers of anything that old have yet to be identified.

Most current studies have concentrated on flowering plants from about 100 million years ago, when they were becoming abundant forms of vegetation. The dogma, as Dr. Crane put it, had been that the primordial flowers probably grew on shrubs or trees. In addition to the flowers resembling the southern magnolia, plants of that early period were members of modern groups composed of avocado, bay leaves and sycamore.



The New York Times/Masa Iken/Feb. 9, 1990

Artist's rendering of the fossil of the oldest known flower, called the Koonwarra plant.

1990 - Leo Hickey

- 120 mya - Australia
- small, unisexual flowers
- placed into Piperales (pepper, wild ginger)



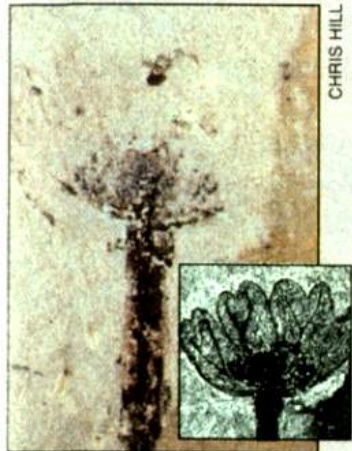
# Flower Record

- what are the earliest fossil flowers?

## The World's Oldest Flower

A British scientist claims to have discovered the world's oldest flower in 130-million-year-old clay rocks in the south of England.

Flowering plants or angiosperms, which range from grasses to oaks, reproduce via ovules borne in an enclosed cavity. They have dominated the world's vegetation for the last 65 million years, but paleobotanists still argue over fundamental questions such as which group is the most primitive and from what did they evolve.



**Ancient bloom.** Cretaceous flower imprint in English clay. Inset: computer-enhanced image. Actual size is 7 mm.

The new find, reported by paleobotanist Chris Hill in the February issue of *Cretaceous Research*, bolsters the notion, first suggested by U.S. scientists 6 years ago, that the plants started small.

Some scientists have suggested that the earliest flowering plants were large, woody, magnolialike shrubs. But the new

Hill was prompted to search rock formations called Weald Clay in southern England after reading a report in *Science* (9 February 1990, p. 702) by David Taylor and Leo Hickey of Yale University. Their analysis of angiospermlike fossil plants from this geologic period, the Cretaceous, in Australia indicated that early flowering plants may have been simple, fragile herbs with small reproductive organs—that is, flowers.

Hill's plant fossil, found at the Smokejacks Brickworks in Surrey, seems to fulfill this prediction. It was a relatively small (25 cm high) herb. Most important, it combines a primitive fernlike anatomy and leaves with more advanced branching and small flowerlike reproductive structures. It probably lived in water (it was found in waterland sediment, and some leaves resemble those of modern aquatic plants). Hill, who has christened his find *Bevhalstia pebja*, says that its form is quite unlike any other plant from the Early Cretaceous.

David Batten, an expert on Cretaceous pollen at the University of Wales, says the find is "interesting because it forms a continuation of the macrofossil record of angiospermlike plants deeper into the Lower Cretaceous." Pollen believed to be from angiosperms had already been located at this level, but no flowers. Now that Hill has found a flower, the hunt is on for pollen that will clinch its identification.

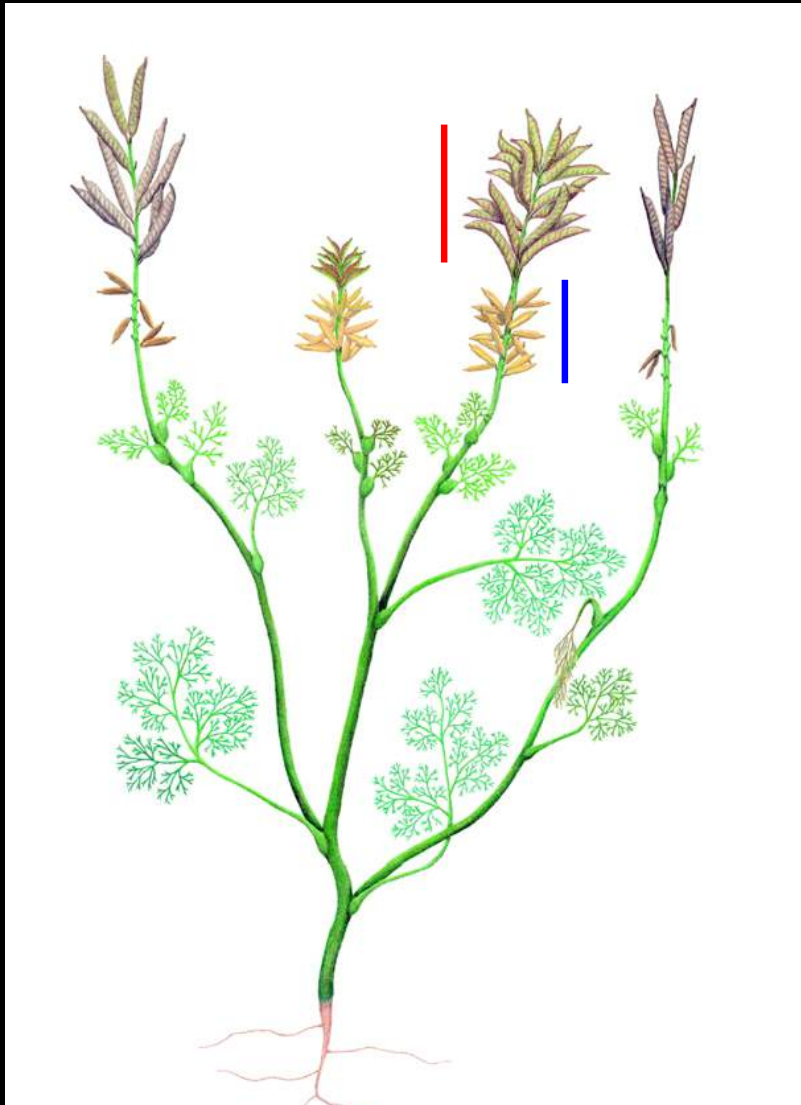
1996 - Chris Hill

- *Bevhalstia pebja*
- 130 mya - England
- small, 25cm aquatic herb
- dissected leaves
- *most not convinced it is an angiosperm*



# Flower Record

- what are the earliest fossil flowers?



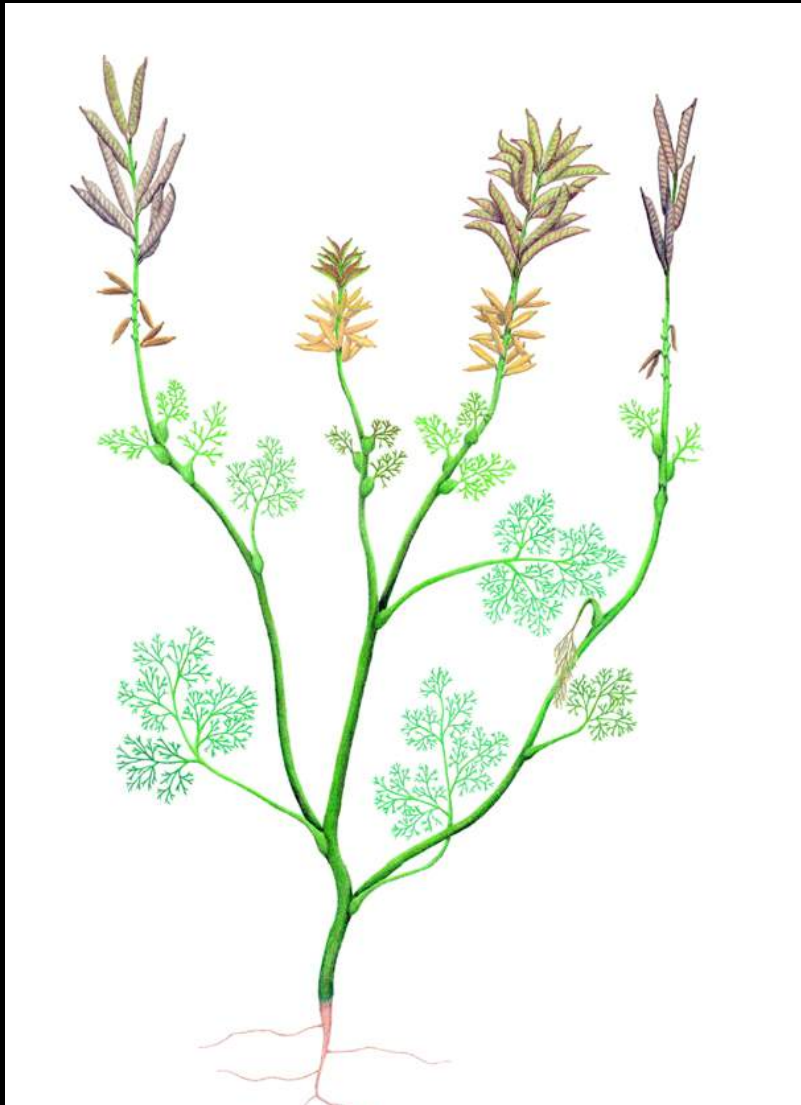
1998 - David Dilcher & Chinese colleagues

- *Archaeofructus*
- 125 [135 1<sup>st</sup>] mya - China
- small, dissected leaves
- **stamens** and **carpels** on long axis

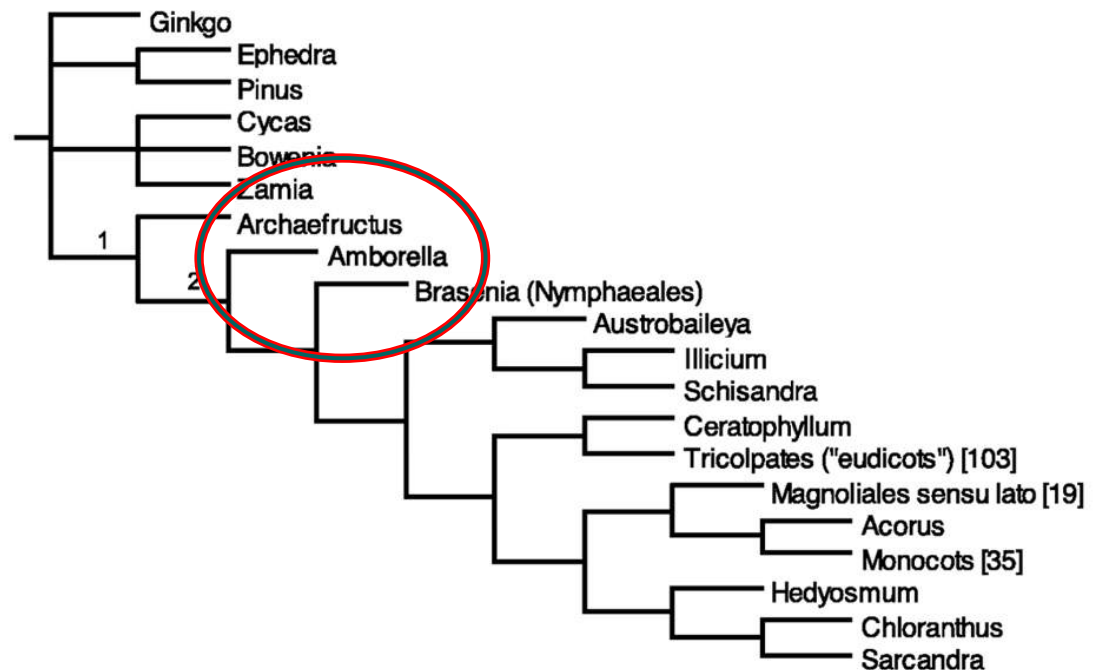


# Flower Record

- what are the earliest fossil flowers?



- morphology phylogenetic analyses place it before *Amborella*





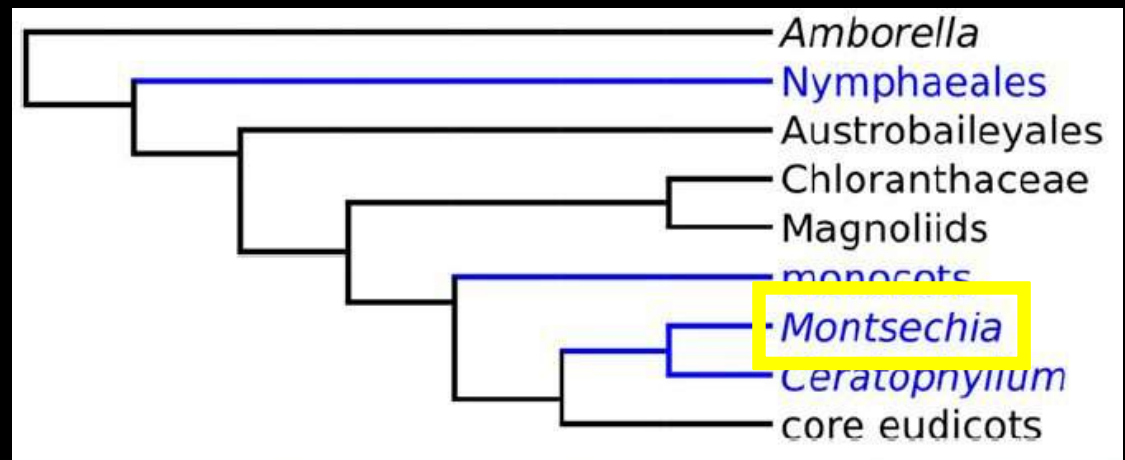
# Flower Record

- what are the earliest fossil flowers?



2015 - David Dilcher & Spanish colleagues

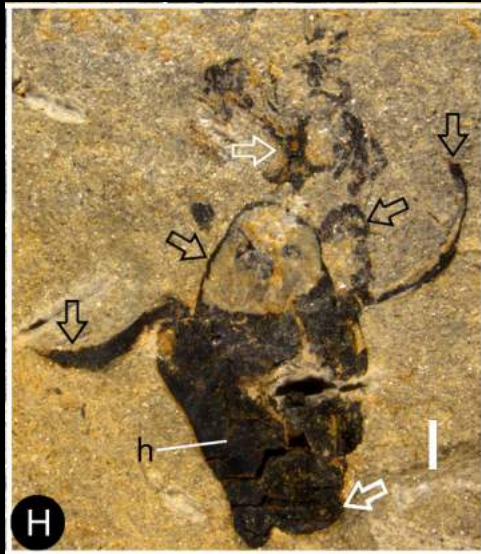
- *Montsechia*
- 125-130 mya - Pyrenes
- aquatic, fruiting





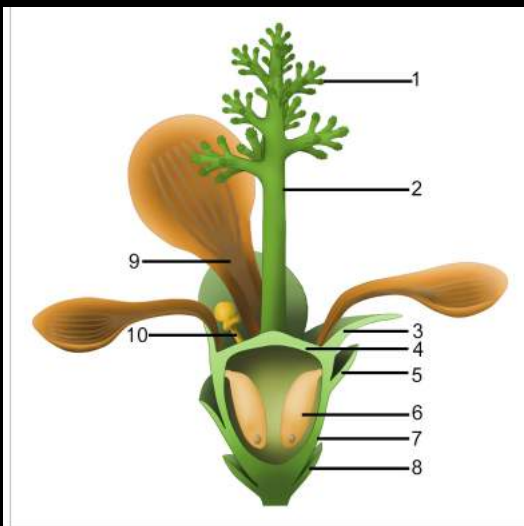
# Flower Record

- what are the earliest fossil flowers?



2018 – Qiang Fu & Chinese colleagues

- *Nanjinganthus*
- 174 mya Jurassic! - China



**Figure 11.** Idealized reconstruction of *Nanjinganthus*. 1, branches of dendroid style; 2, dendroid style; 3, sepal; 4, ovarian root; 5, scale; 6, seed; 7, cup-form receptacle/ovary; 8, bract; 9, petal; 10, unknown organ (staminode?). DOI: <https://doi.org/10.7554/eLife.38927.019>



RESEARCH ARTICLE

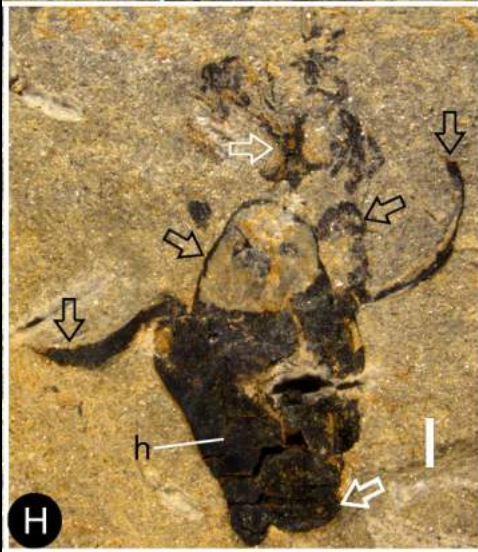


## An unexpected noncarpellate epigynous flower from the Jurassic of China

Qiang Fu<sup>1</sup>, Jose Bienvenido Diez<sup>2</sup>, Mike Pole<sup>3</sup>, Manuel García Ávila<sup>2,4</sup>, Zhong-Jian Liu<sup>5\*</sup>, Hang Chu<sup>6</sup>, Yemao Hou<sup>7</sup>, Pengfei Yin<sup>7</sup>, Guo-Qiang Zhang<sup>5</sup>, Kaihe Du<sup>8</sup>, Xin Wang<sup>1\*</sup>

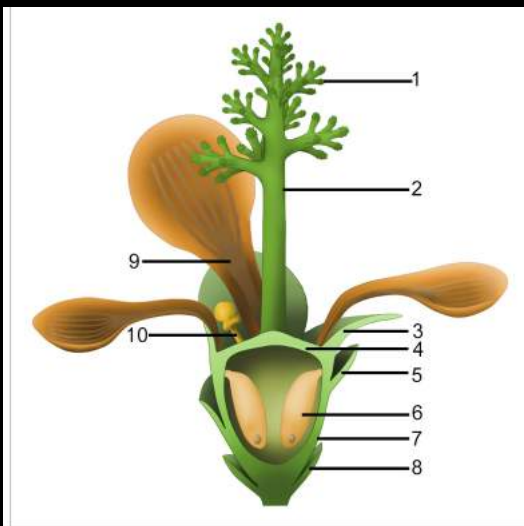
# Flower Record

- what are the earliest fossil flowers?



2018 – Qiang Fu & Chinese colleagues

- *Nanjinganthus*
- **174 mya Jurassic! - China**
- fierce debate!



**Figure 11.** Idealized reconstruction of *Nanjinganthus*. 1, branches of dendroid style; 2, dendroid style; 3, sepal; 4, ovarian root; 5, scale; 6, seed; 7, cup-form receptacle/ovary; 8, bract; 9, petal; 10, unknown organ (staminode?). DOI: <https://doi.org/10.2554/eLife.38927.019>

**Hunting the Snark: the flawed search for mythical Jurassic angiosperms**

**Richard M. Bateman**

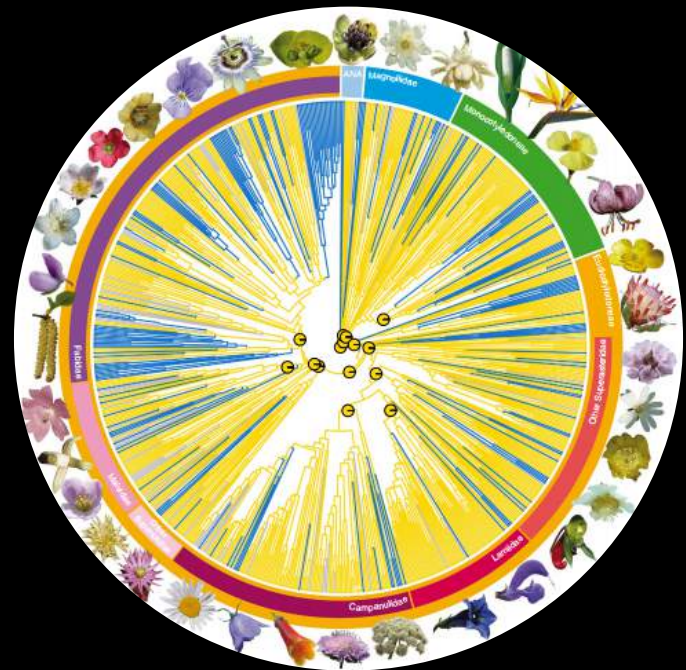
Jodrell Laboratory, Royal Botanic Gardens Kew, Richmond, Surrey, TW9 3DS, U.K.



# Flower Record

- what did the earliest flower look like **based on morphological analyses?**

2017 – Herve Sauquet et al.  
(**reading!**)



# Summary of Angiosperm Evolution

## 1. **When** did the Angiosperms arise?

- Fossils - after boundary of Jurassic and Cretaceous  
– 130 mya
- DNA - some molecular clocks suggest >200 mya

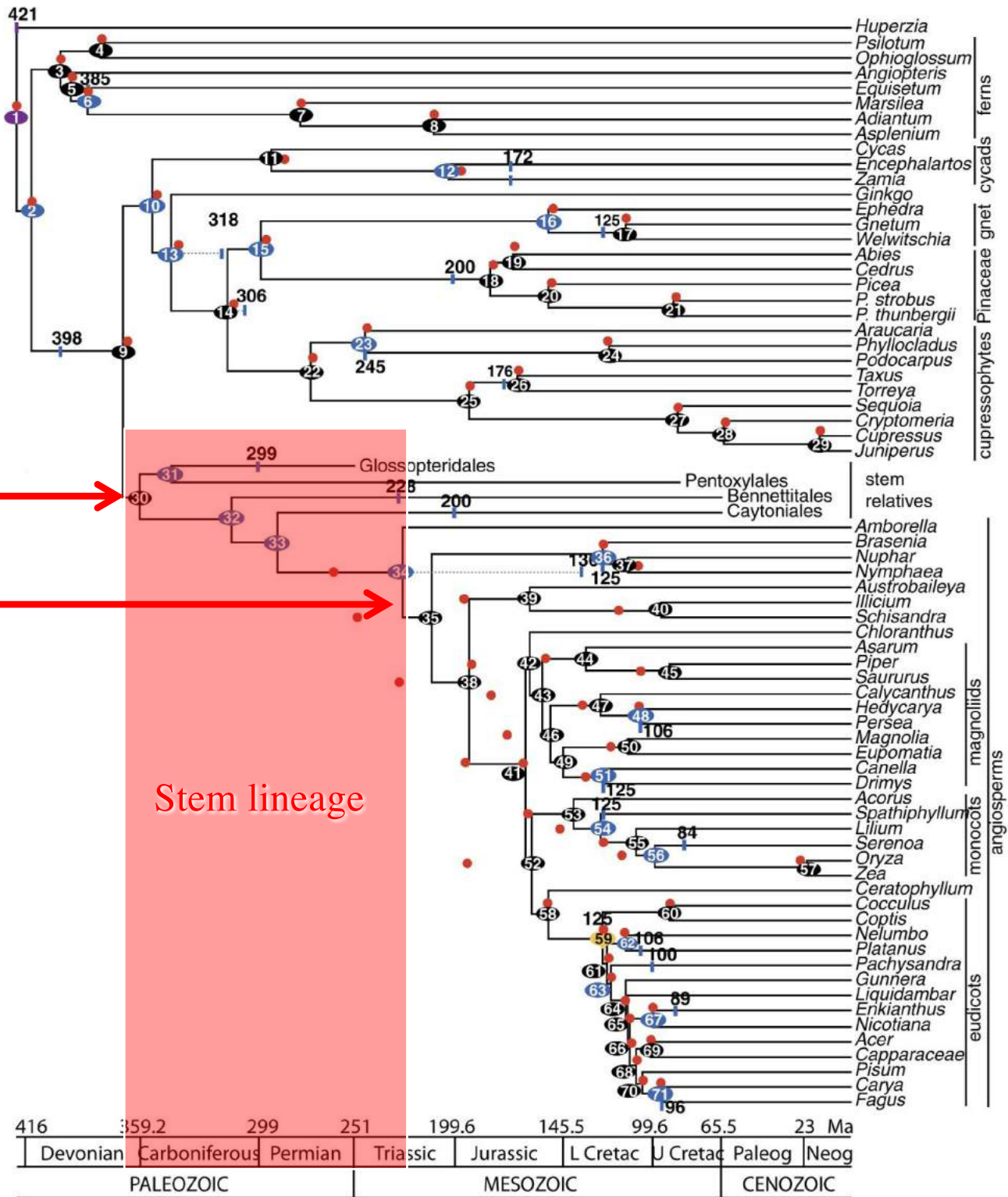


- stem node with living gymnosperms
- crown node of living angiosperms

350 mya

225 mya

Stem lineage



Magallón 2010

# Summary of Angiosperm Evolution

## 1. **When** did the Angiosperms arise?

- perhaps older but unseen (in fossil record) radiation of angiosperms
- perhaps older radiation but we can't tell them apart from ancestors (share features of gymnosperms and some but not all of angiosperms)
- perhaps “molecular clock” methods are flawed – not really that old



# Summary of Angiosperm Evolution

## 2. **What** were the first Angiosperms?

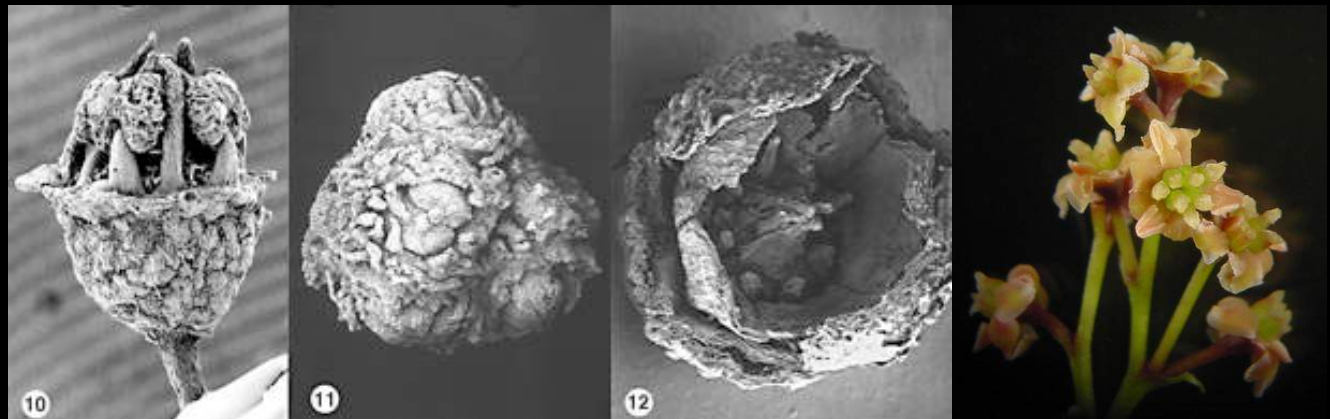
- “*Magnolia* = primitive” **not justified**
- *Amborella* and water lilies are first **extant** taxa to separate



# Summary of Angiosperm Evolution

## 2. **What** were the first Angiosperms?

- “*Magnolia* = primitive” not justified
- *Amborella* and water lilies are first **extant** taxa to separate
- earliest **extinct** fossils are small, probably aquatic plants





# Summary of Angiosperm Evolution

## 3. **Where** did the Angiosperms arise?

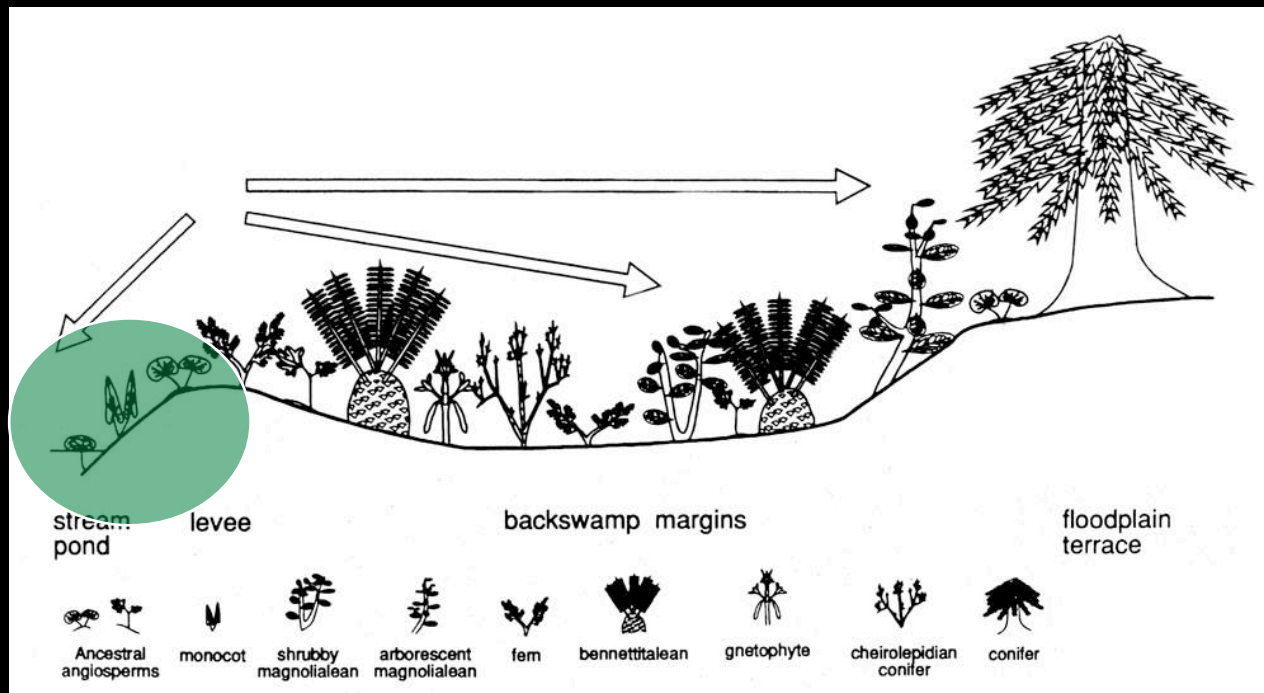
- Australasia if based on earliest diverging **extant** families
- earliest (**extinct**) fossils come from many areas - China, England, Australia (most **tropical or subtropical or warm temperate in early Cretaceous**)



# Summary of Angiosperm Evolution

## 3. **Where** did the Angiosperms arise?

- likely in wet margins of gymnosperm dominated forests





# Summary of Angiosperm Evolution

## 4. From what Gymnosperms did they arise?

- **no consensus** based on extant lineages!



conifers



cycads



ginkgoes



gnetales

- **Gnetales** have been the favorites for some time (vessels, double fertilization, broad leaves) . . .

*Gnetum*



*Ephedra*



*Welwitschia*



- but this “**Anthophyte**” hypothesis is strongly **rejected** by DNA sequence data!

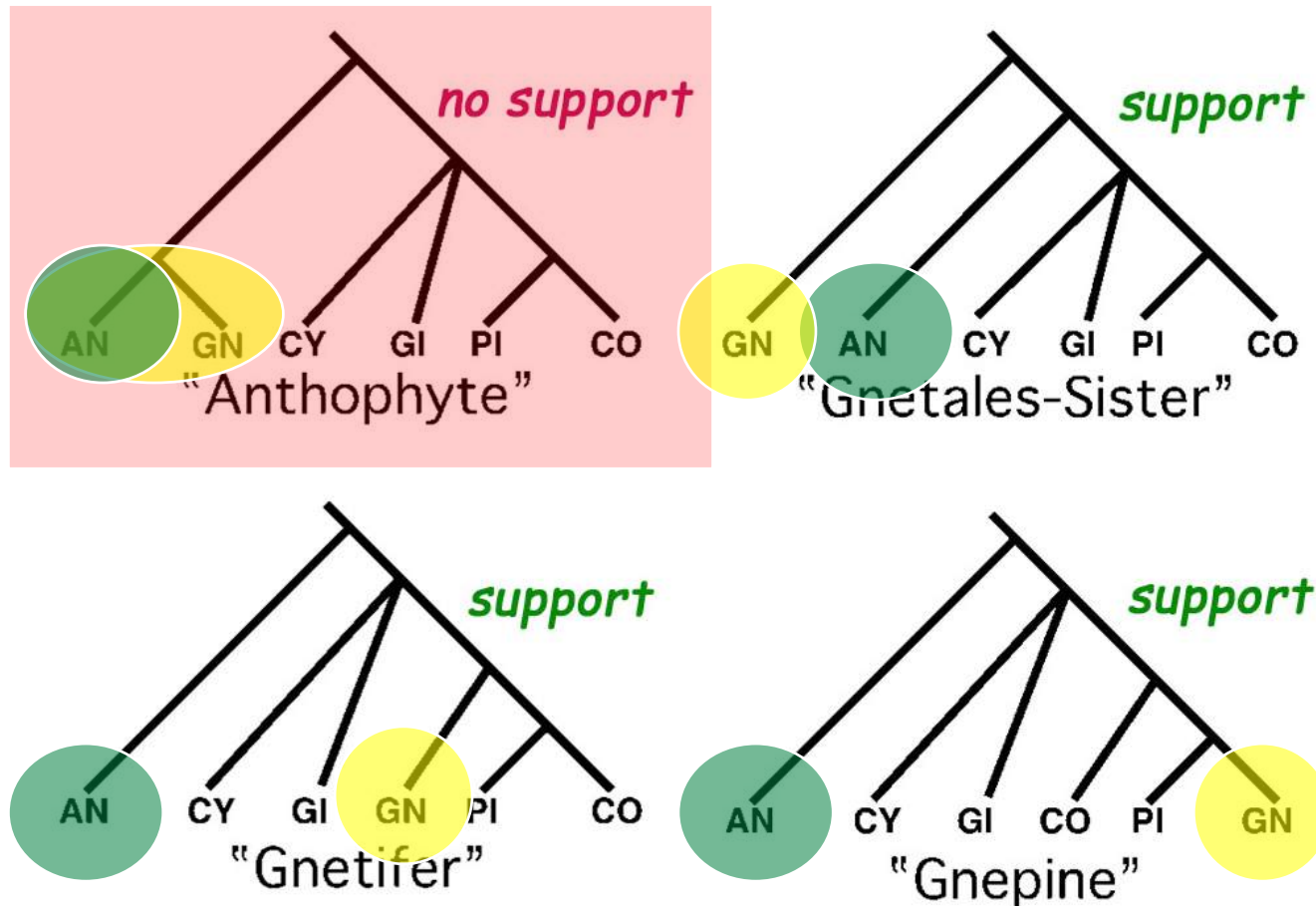
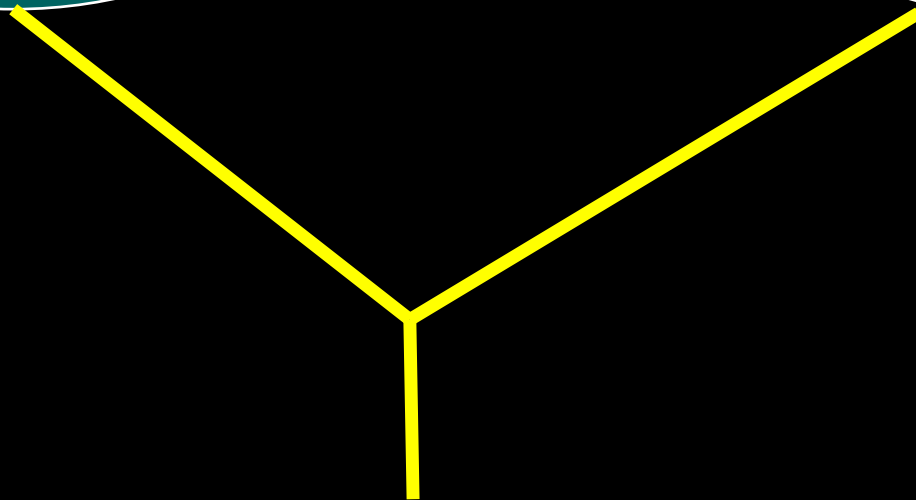


Fig. 1. Four major hypotheses of relationships among extant seed plant lineages. AN = angiosperms; CY = cycads; GI = *Ginkgo*; GN = Gnetales; PI = Pinaceae; CO = non-Pinaceae conifers.

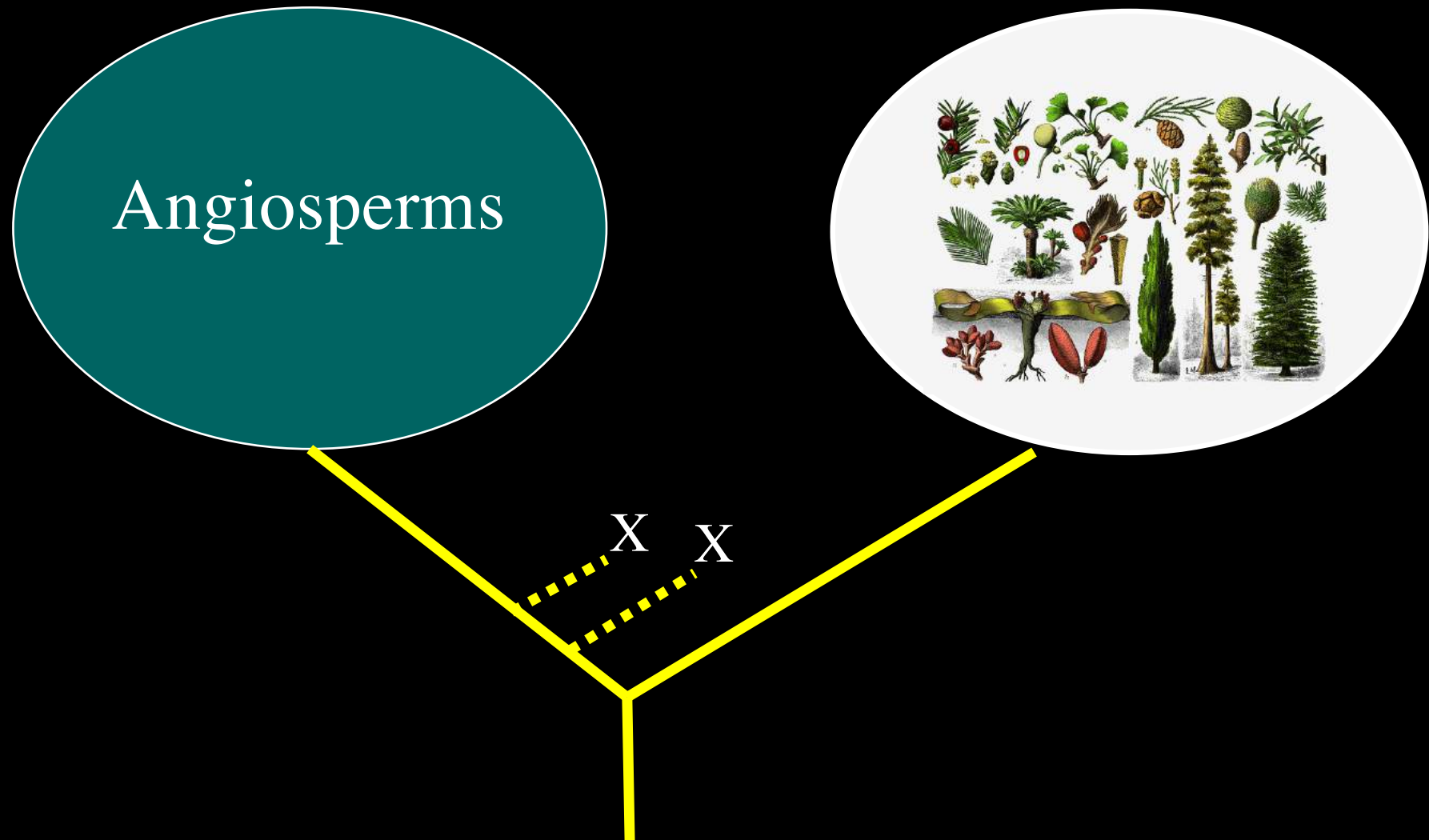
- 2018 Next Generation Sequence data place ALL living gymnosperms as a monophyletic lineage

Angiosperms





- likely that Angiosperms arose from a now **extinct** Gymnosperm lineage



- likely that Angiosperms arose from a now **extinct** Gymnosperm lineage such as **Bennettitales** or other “**seed fern**” groups

Bennettitales (Cycadeoid or “cycad like”)  
Seed “Ferns”

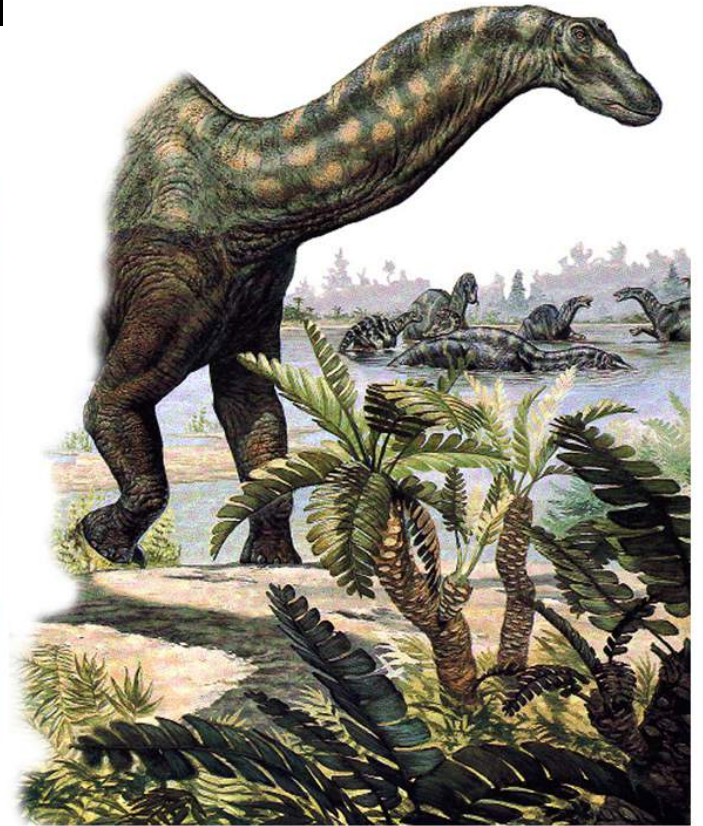


*Williamsonia*



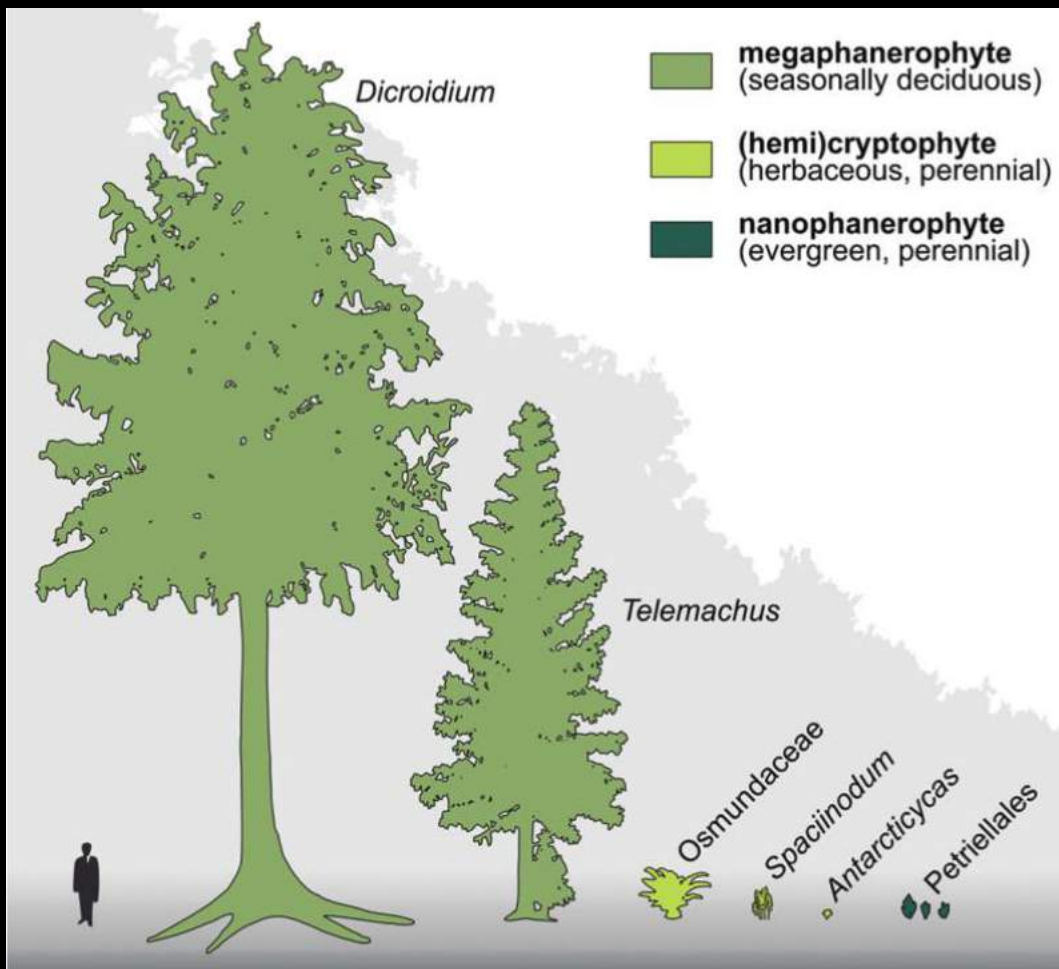
*Seed fern fossils - 320 mya*

*Pentoxylon (Jurassic)*





- likely that Angiosperms arose from a now **extinct** Gymnosperm lineage **or the understory Petriellales**



# Summary of Angiosperm Evolution

## 5. Why did Angiosperms dominate quickly?

- BIG story! We will deal with it throughout the course
- vessel elements?
- mycorrhizal interactions with fungi?
- the flower as a “key innovation”?
- genome duplication(s)?
- co-evolution with animal pollinators?







# Darwin's Abominable Mystery

.. would he be satisfied had he  
lived to be 210 ? ..

Yes . . . but questions  
remain

