

"GIMNOSPERMAS"

Gifford & Foster (1989)

Mauseth (1995)

Progymnospermophyta (fóssil)

Pteridospermophyta (fóssil)

Cycadeoidophyta
(=Bennettitales) (fóssil)

Cycadophyta

Ginkgophyta

Pinophyta (=Coniferophyta)

Gnetophyta

CLASSIFICAÇÕES

GIFFORD & FOSTER 1989 MAUSETH 1995 Filos	BRESINSKY et al. 2012 Subdivisão Spermatophytina	CHASE & REVEAL 2009 Classe Equisetopsida (=Embryopsida)
Progymnospermophyta Pteridospermophyta Cycadeoidophyta Cycadophyta Ginkgophyta Pinophyta (=Coniferophyta) Gnetophyta	 Cl. Cycadopsida Cl. Ginkgopsida Cl. Coniferopsida	 Subcl. Cydadidae Subcl. Gynkgooidae Subcl. Pinidae Subcl. Gnetidae

PINOPHYTA
viventes:
PINALES
630 espécies



Triássico 200 m.a.

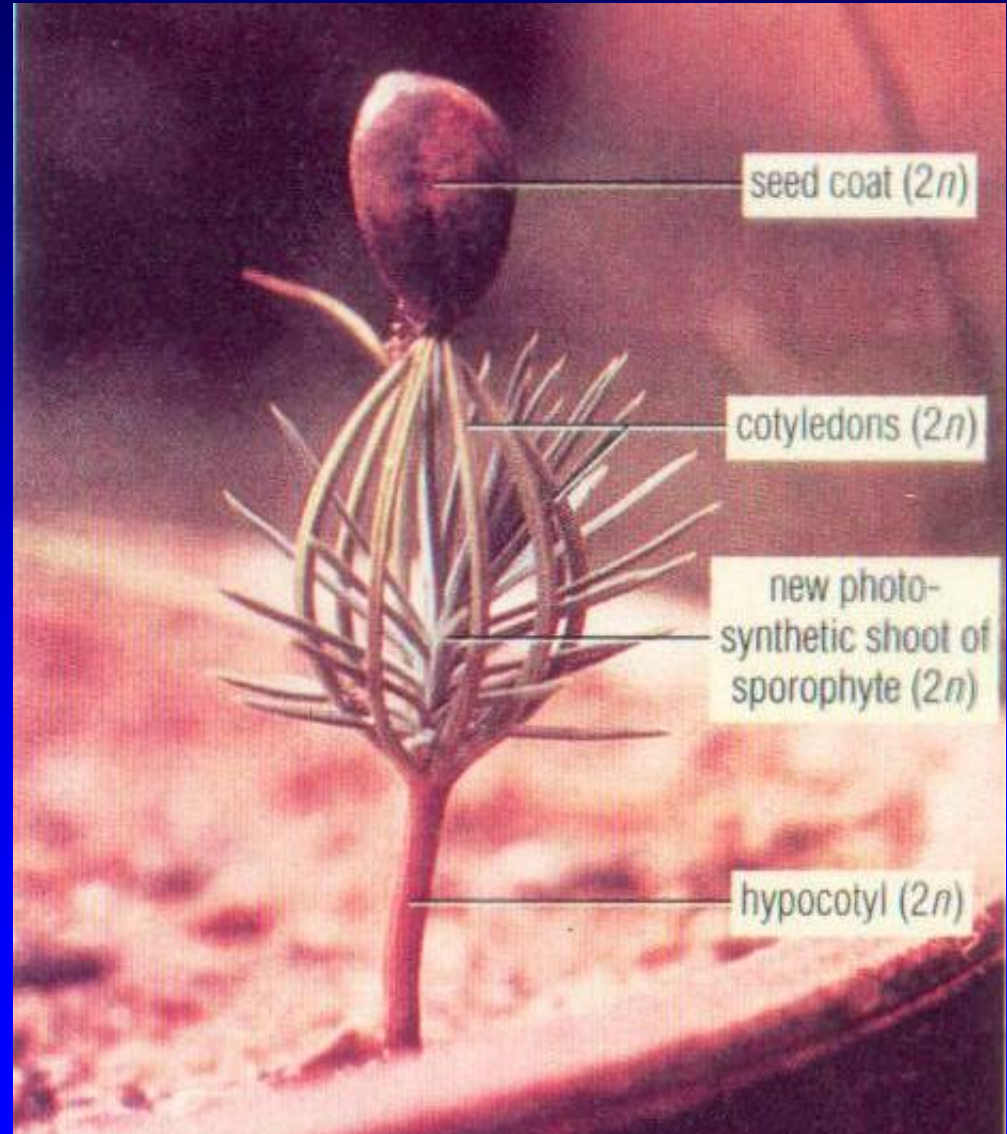
Coníferas dominantes

**Atualmente - Floresta Boreal
(Taiga)**



NOVIDADES EVOLUTIVAS (sinapormorfias)

♦ germinação epígea

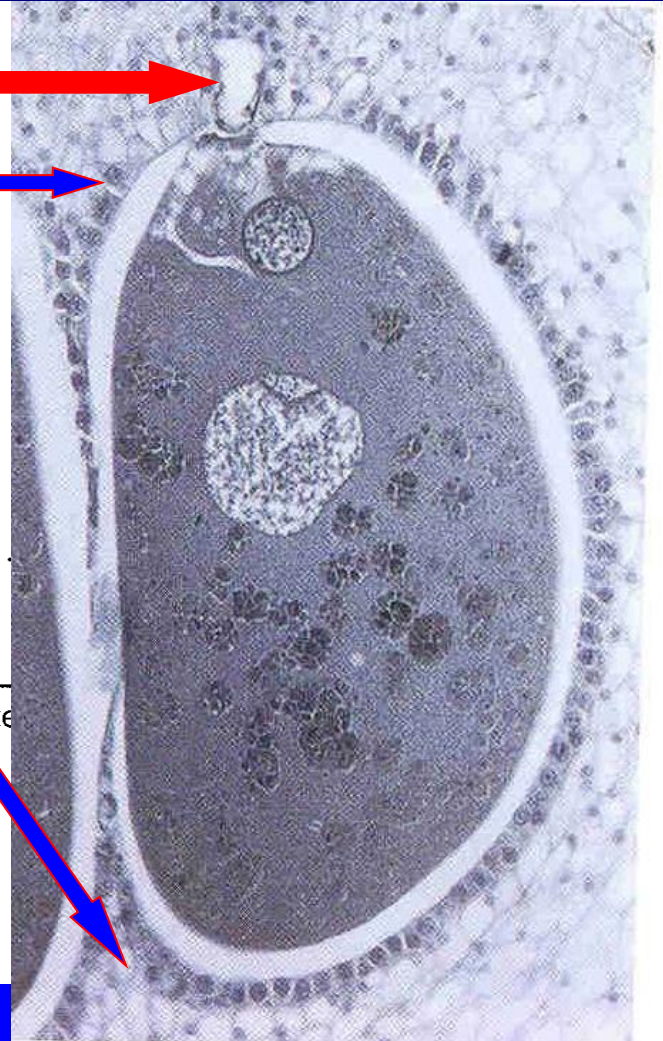
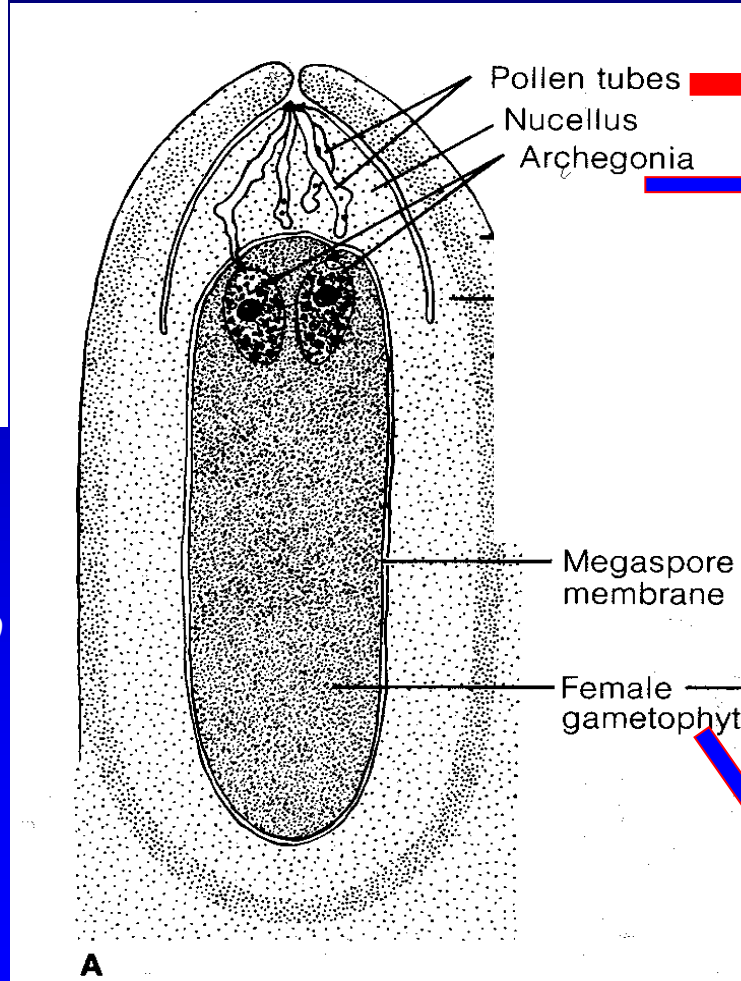
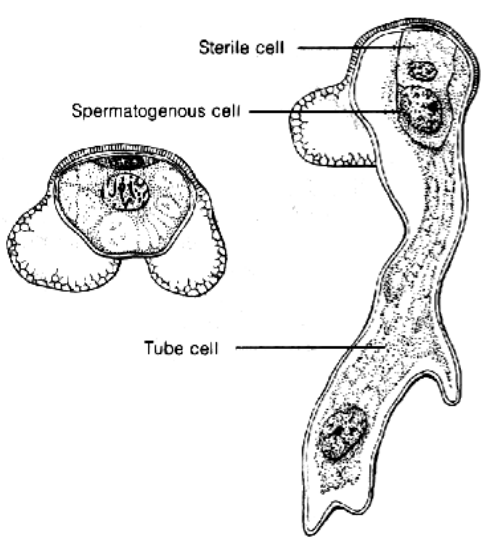


Perry & Moton 1996

NOVIDADES EVOLUTIVAS

♦ sifonogamia

♦ gametas masculinos não flagelados
(células espermáticas)

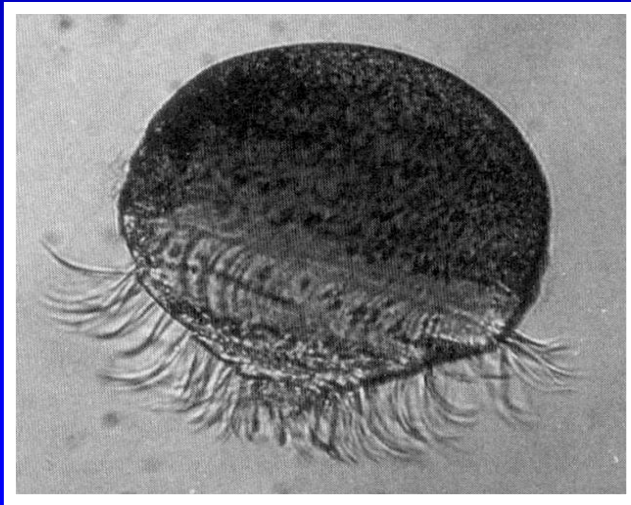
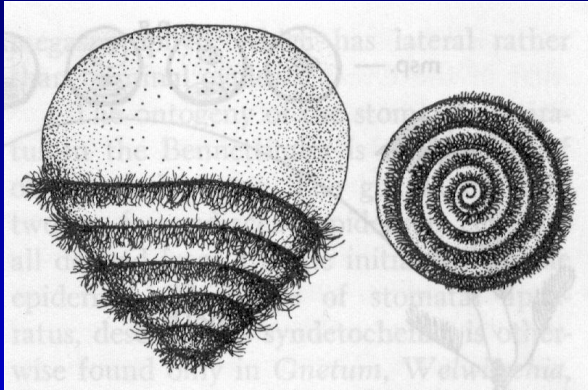


Tubo polínico em
Pinus nigra
Gifford & Foster 1989

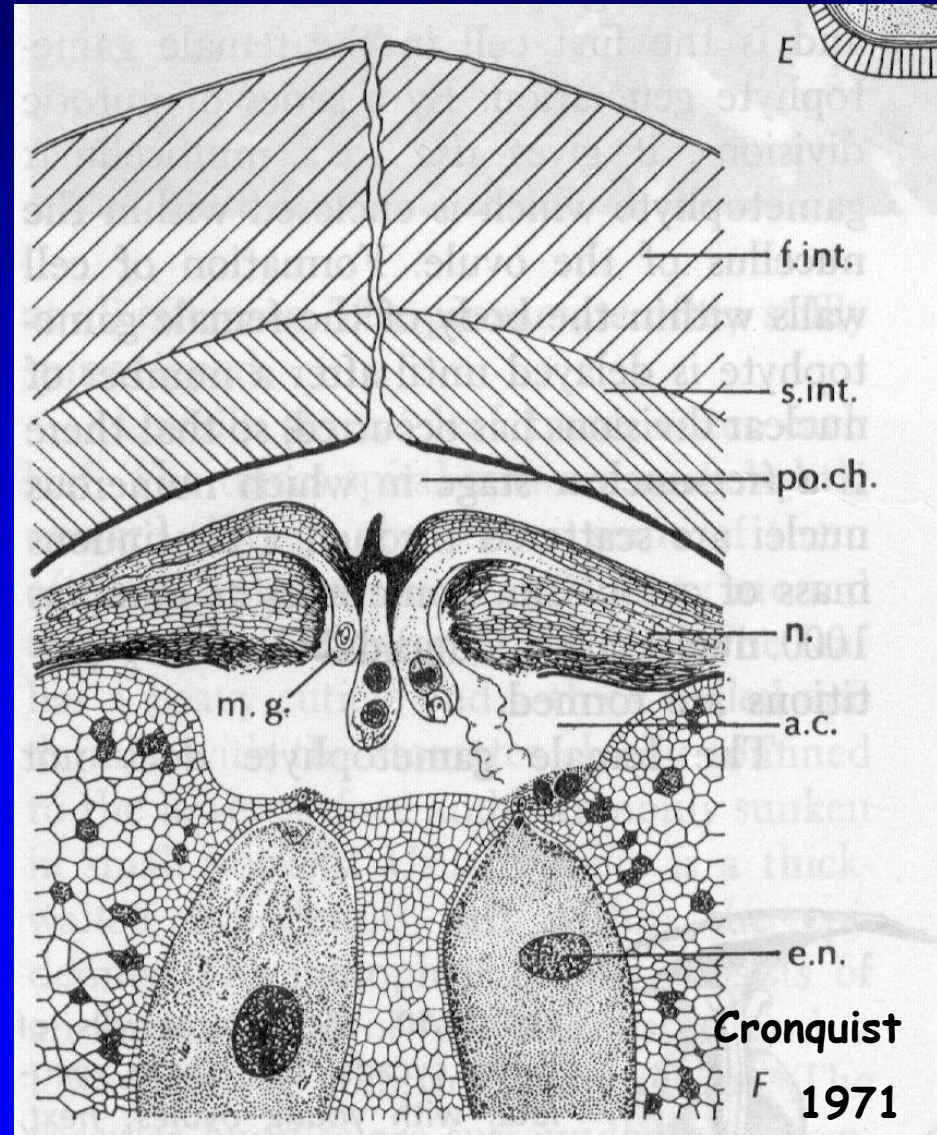
CYCADOPHYTA -

assifonogamia

- óvulos com câmara polínica e câmara arquegonial
- anterozóides multiflagelados



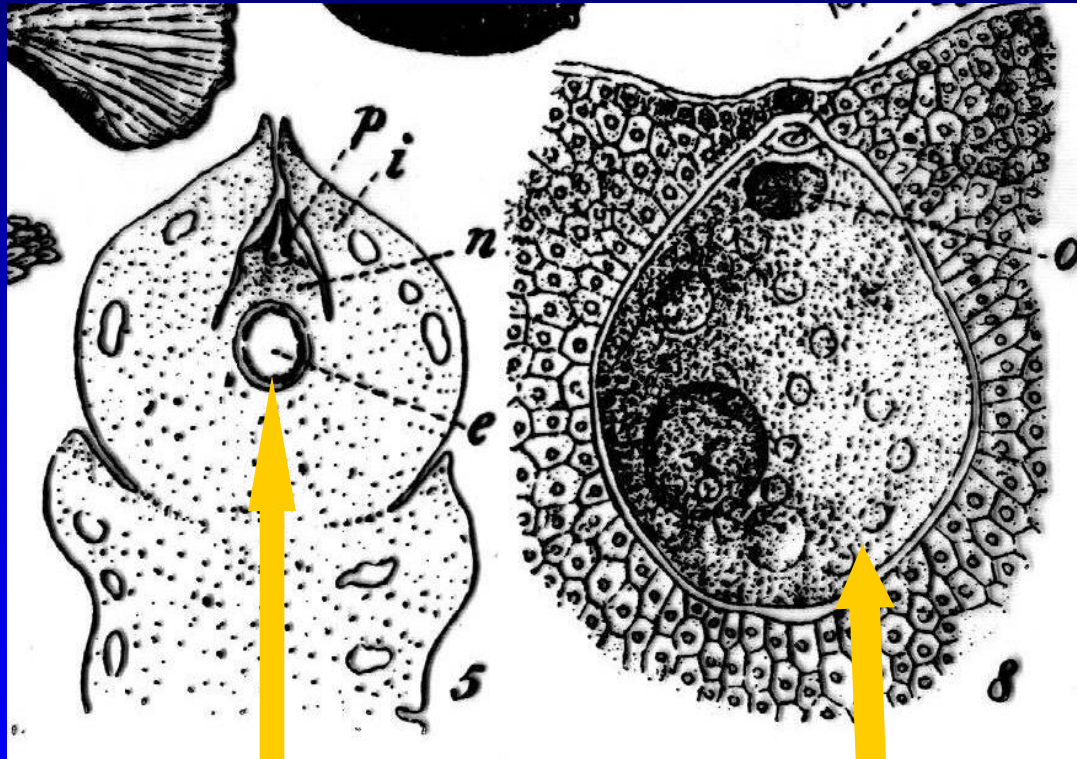
Gameta masculino de *Zamia integrifolia* (Gifford & Foster 1989).



- Óvulo unitegumentado
- Câmaras polínica e arquegonial
(assifonogamia)

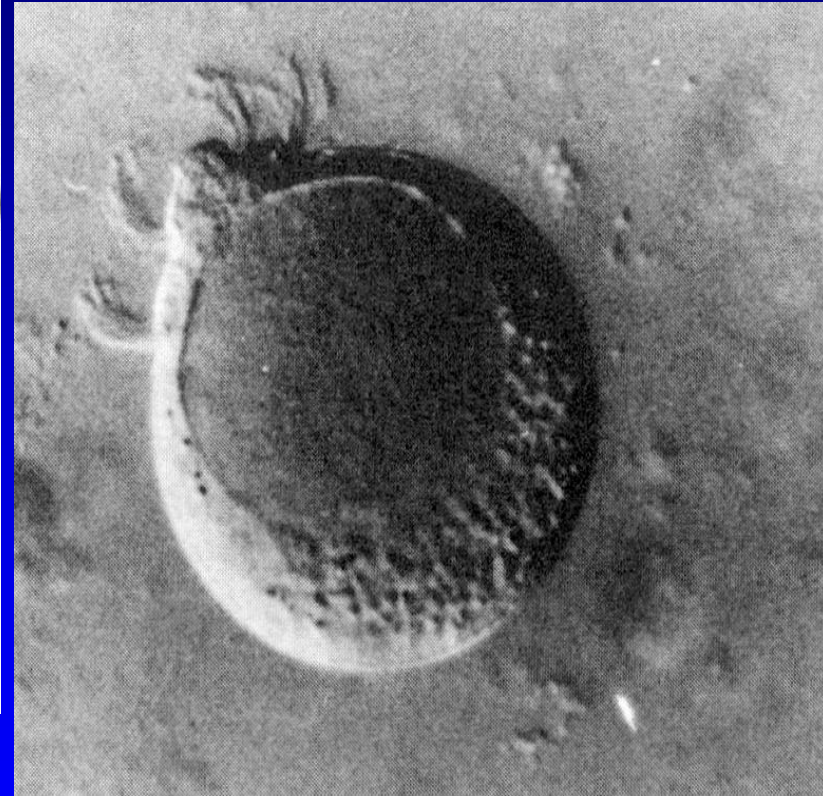
GINKGOPHYTA

gametas masculinos
flagelados



Arquegônio com oosfera

Gametófito feminino



Gifford & Foster 1989

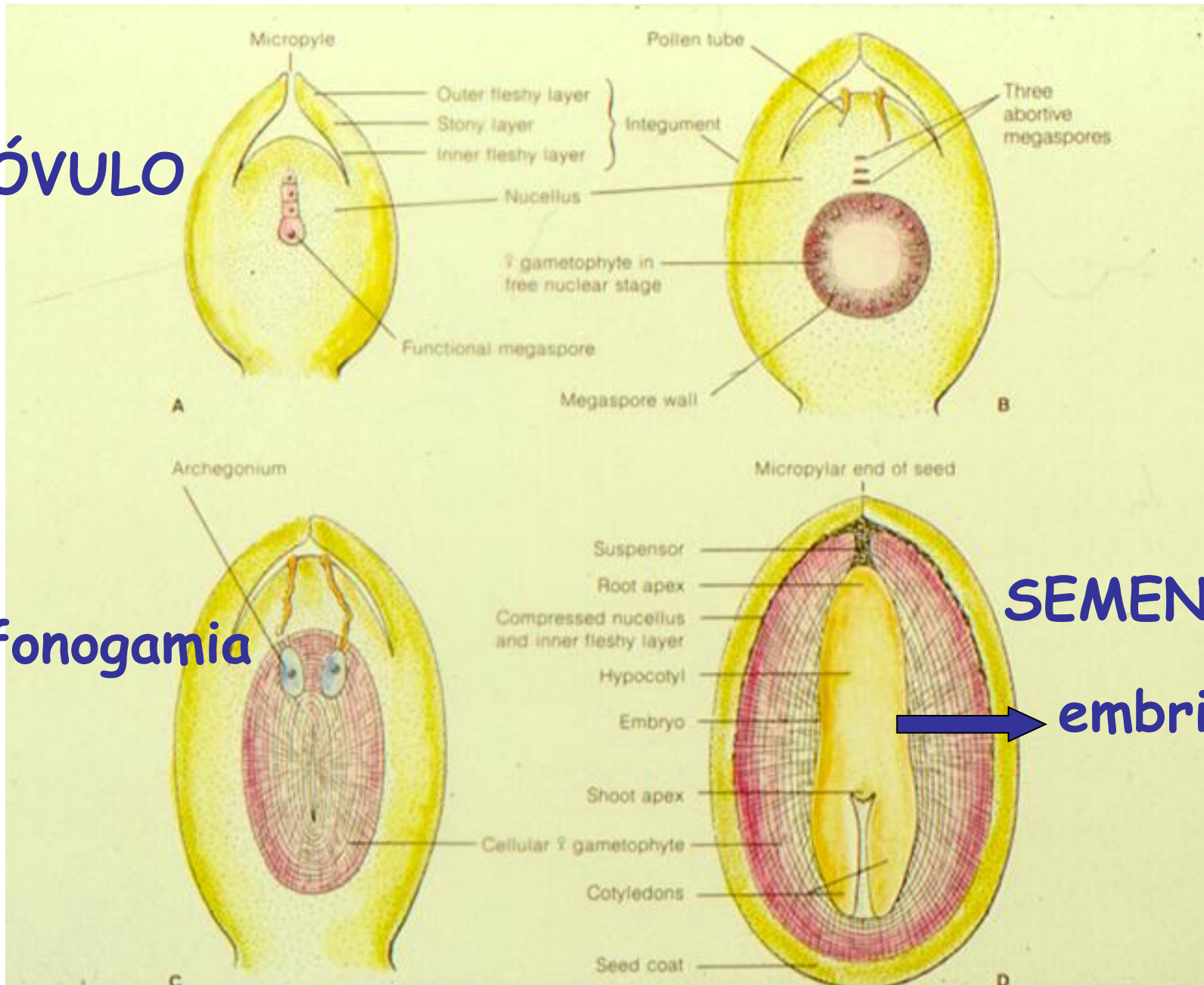
Do óvulo à semente - Pinófitas

ÓVULO

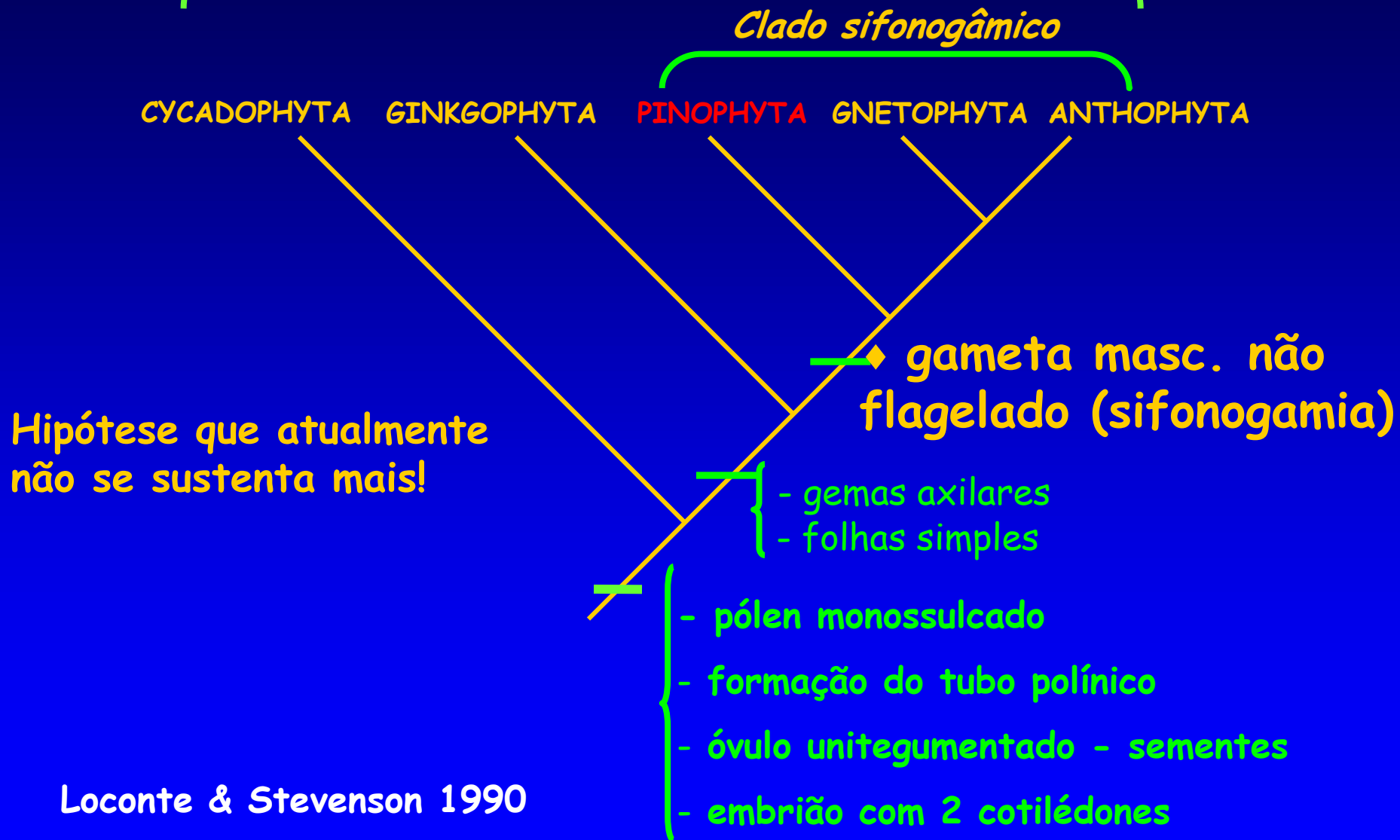
sifonogamia

SEMENTE

embrião

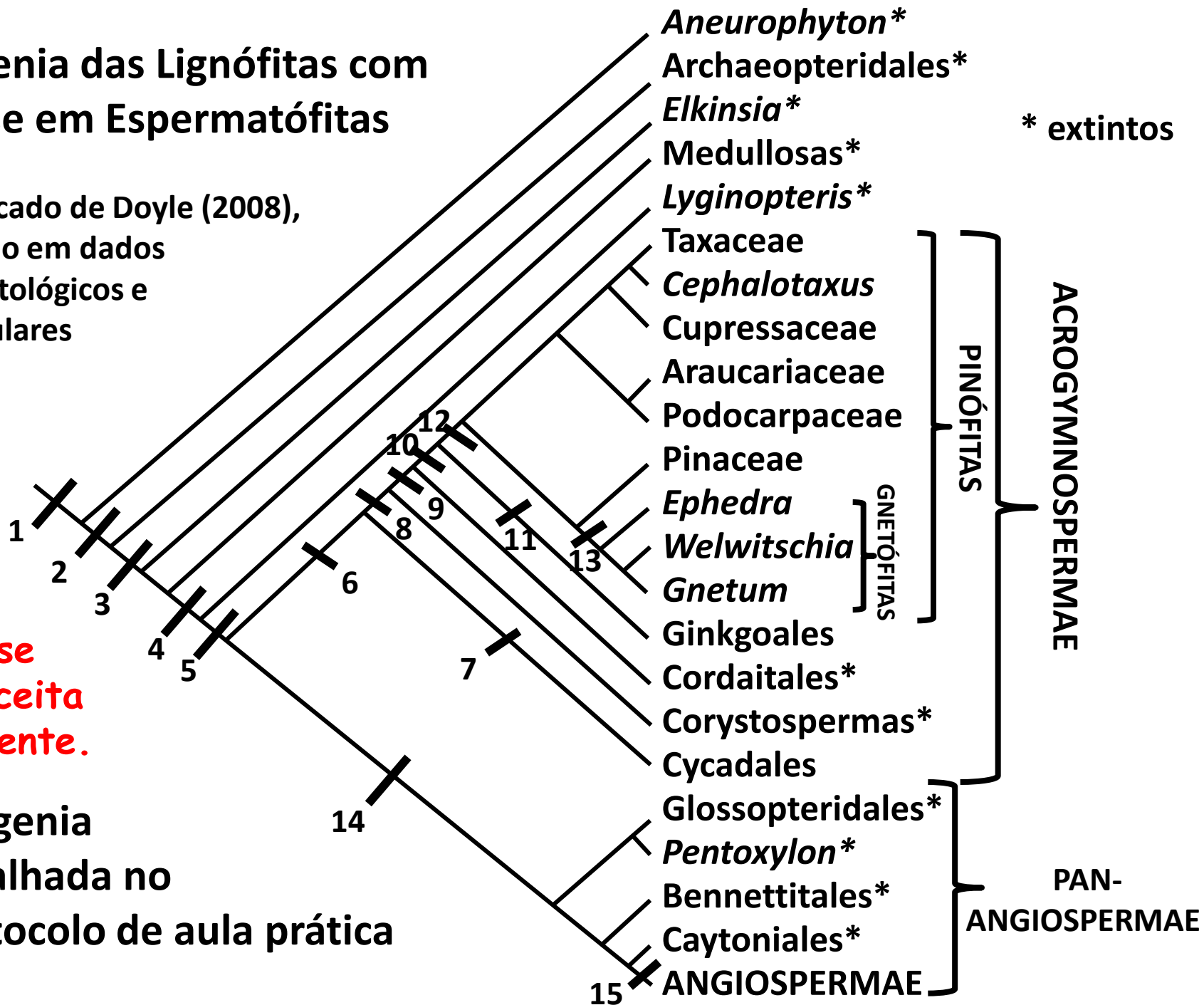


ESPERMATÓFITAS



Filogenia das Lignófitas com ênfase em Espermatófitas

Modificado de Doyle (2008), baseado em dados paleontológicos e moleculares



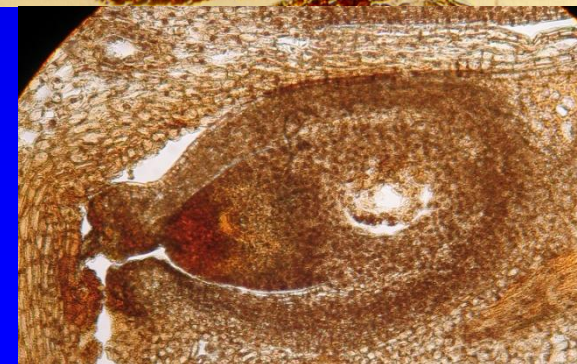
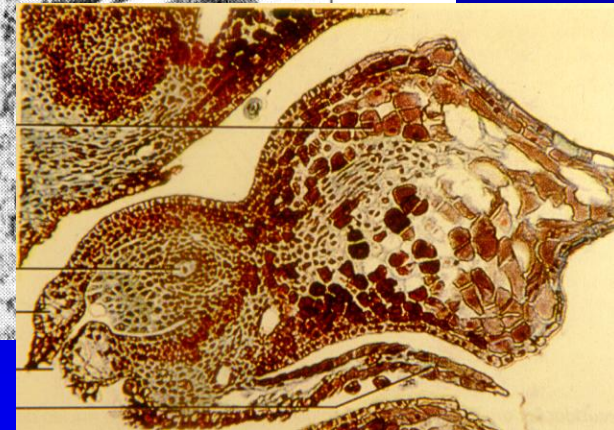
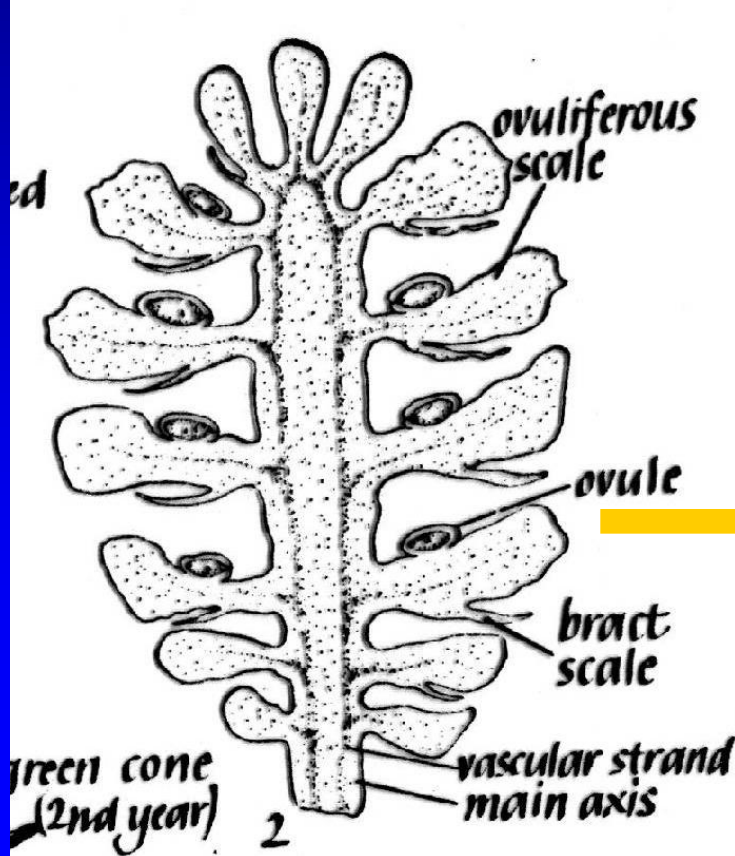
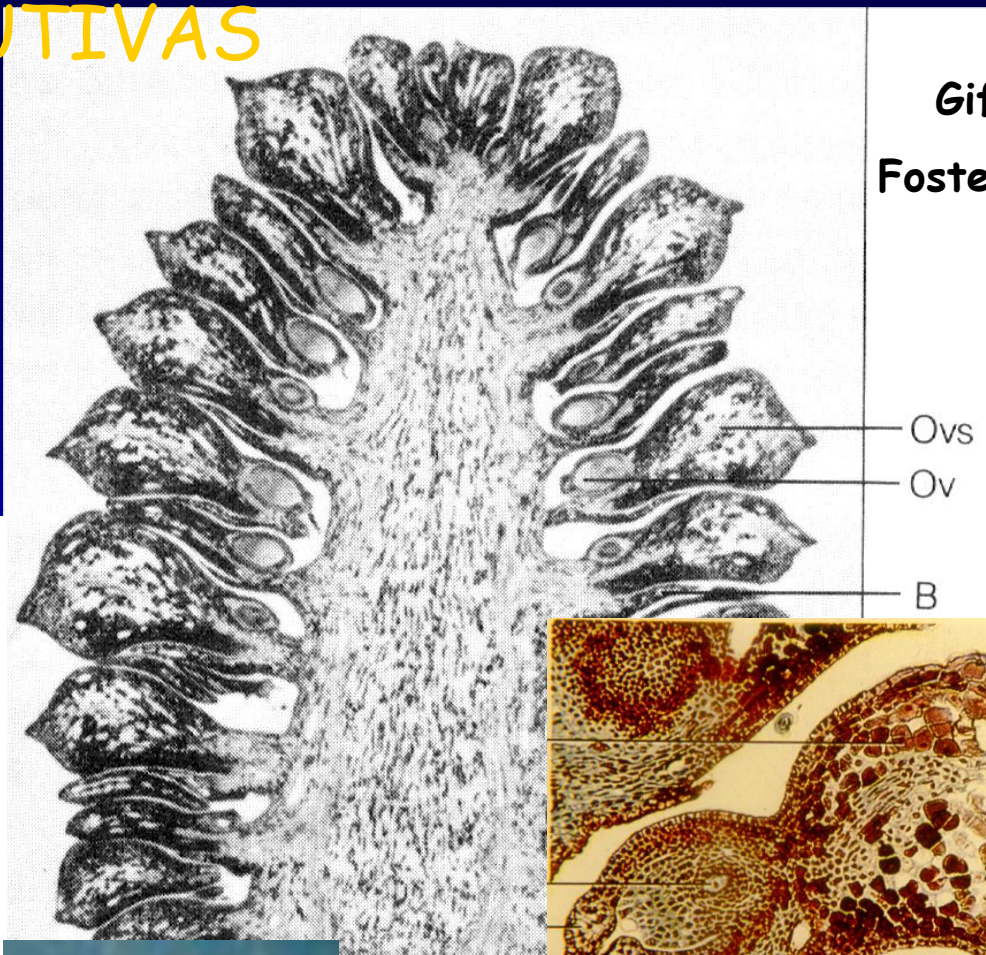
NOVIDADES EVOLUTIVAS de Pinófitas

♦ megastróbilo
composto = CONE

(eixo com escamas ovulíferas
e bracteais)

Pinus

Gifford &
Foster 1989



Megastróbilo composto (CONE): origem

- devemos examinar 2 grupos extintos, provavelmente relacionados aos ancestrais das coníferas (Pinófitas):

CORDAITALES - Carbonífero Superior ao Permiano

VOLTZIALES - Carbonífero Superior ao Jurássico

Cordaitales (PINOPHYTA)

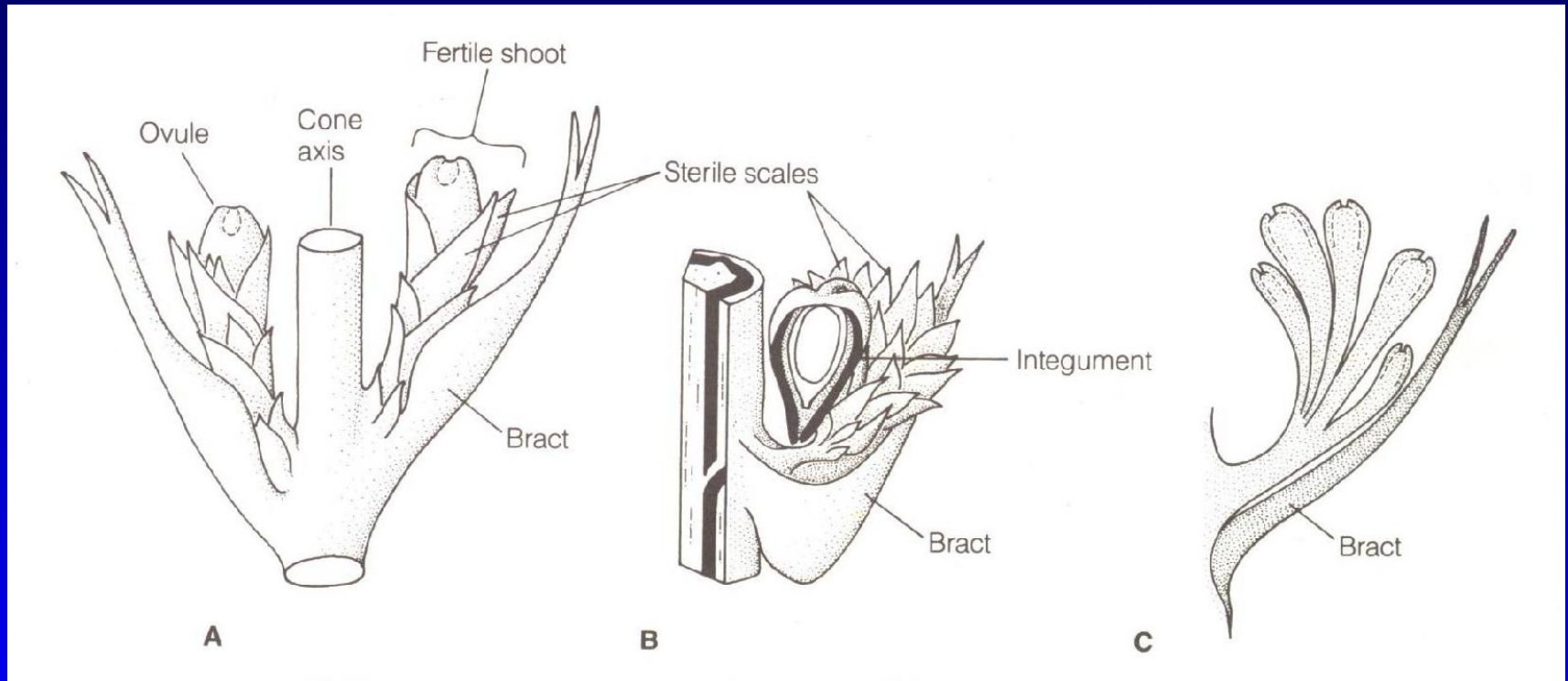


Cordaites



Carbonífero 300 m.a.

Megastróbilo composto (CONE): origem



A, B. Lebachia

C. Ernestiodendron

Gifford & Foster 1989

Voltziales

-

extintas

Megastróbilo composto (CONE): origem

The evolution of female conifer cones



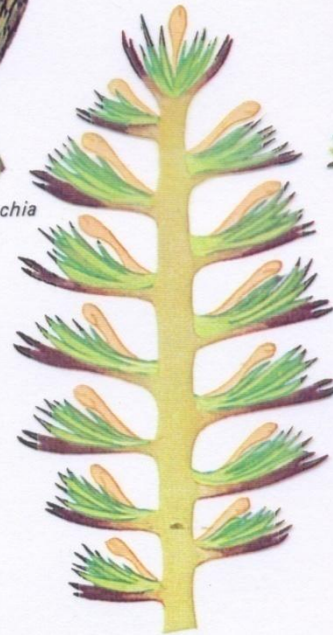
Cordiaianthus

Female cordaite cones such as *Cordiaianthus* had two rows of shoots on a central stem. Each shoot had sterile leaves and stalked ovules, above a leaf bract. *Lebachia*, an early conifer, had smaller shoots above forked bracts. Its ovules had shorter stalks and were protected by the leaves, which had partly fused and become scale like. The main cone stem was shorter, crowding shoots and bracts closer together.



Lebachia

- cone stem
- ovuliferous scale
- ovule
- bract scale



Cordaitales – extintas

Mauseth1989

Escama bracteal = folha modificada

Escama ovulífera = ramo fértil reduzido

PINALES



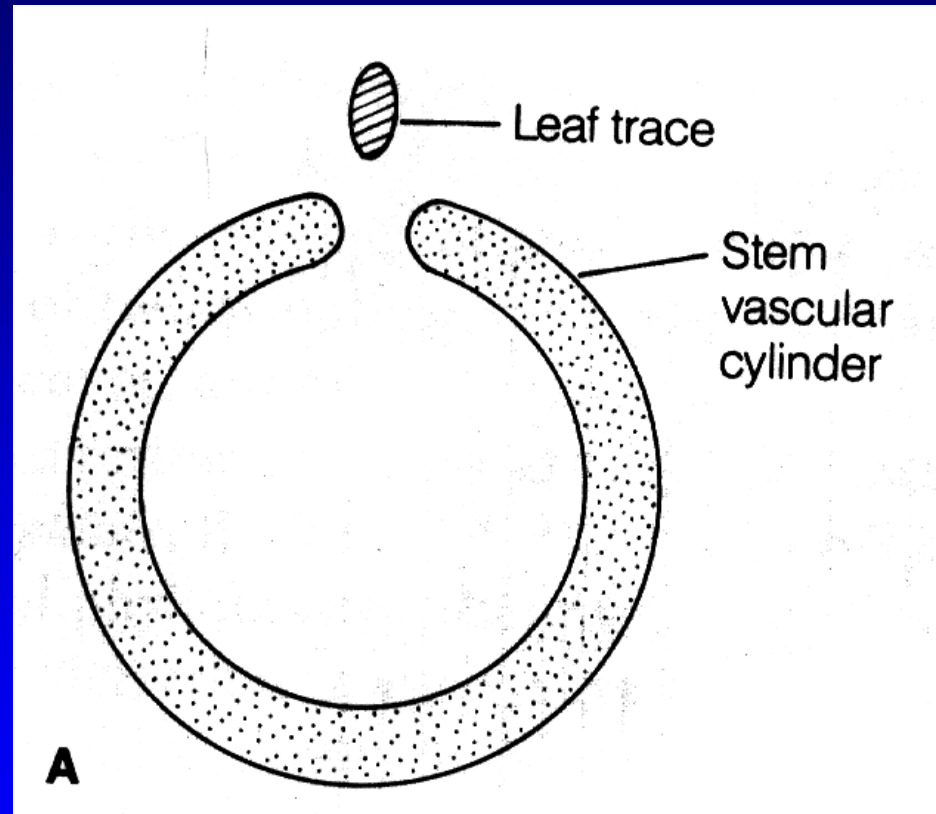
Triásico 200 m.a.

Coníferas dominantes

PINALES

POSSÍVEIS SINAPOMORFIAS

- ♦ nós unilacunares

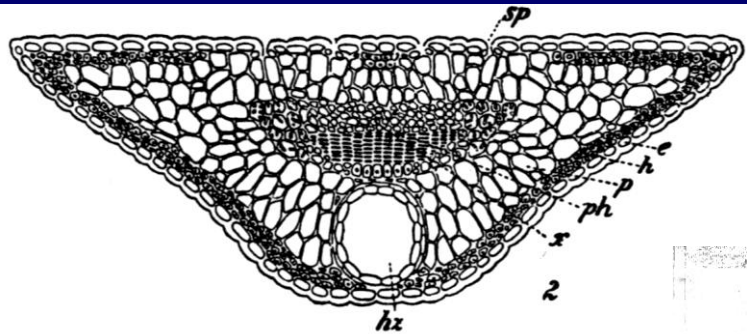


Gifford & Foster 1989

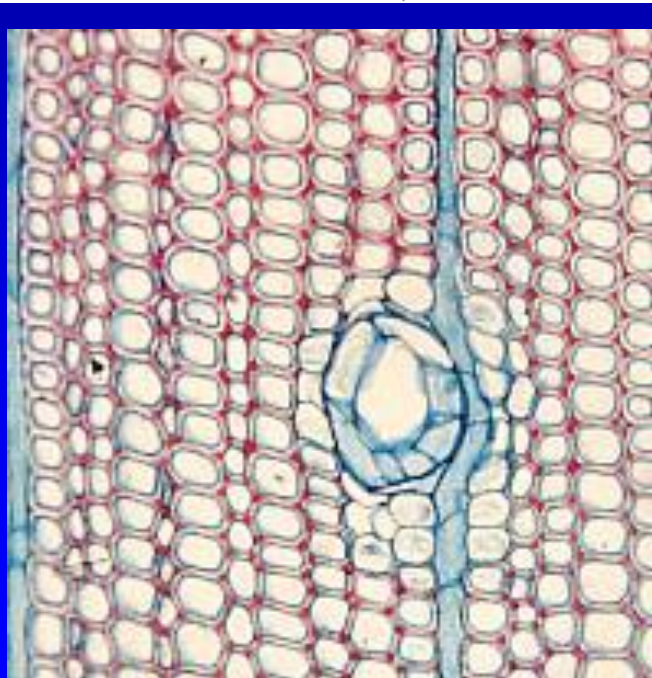
PINALES

SINAPOMORFIAS

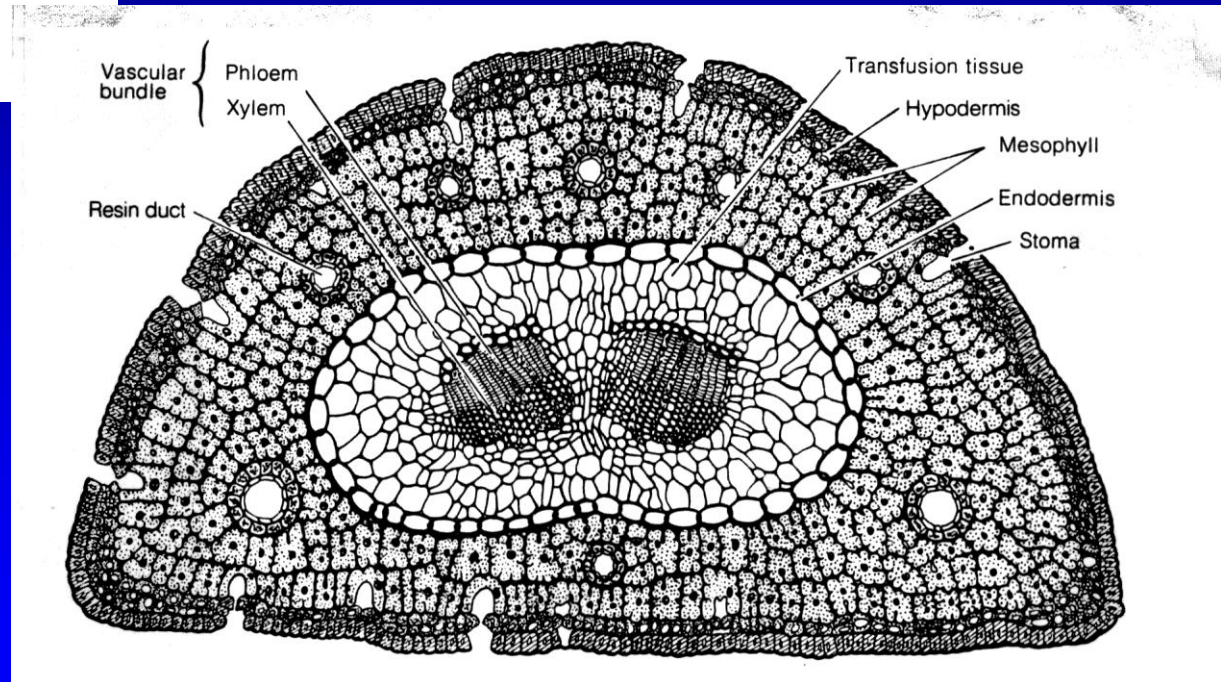
◆ canais resiníferos
no lenho e folhas



*Juniperus
communis*



Lenho de *Pinus*



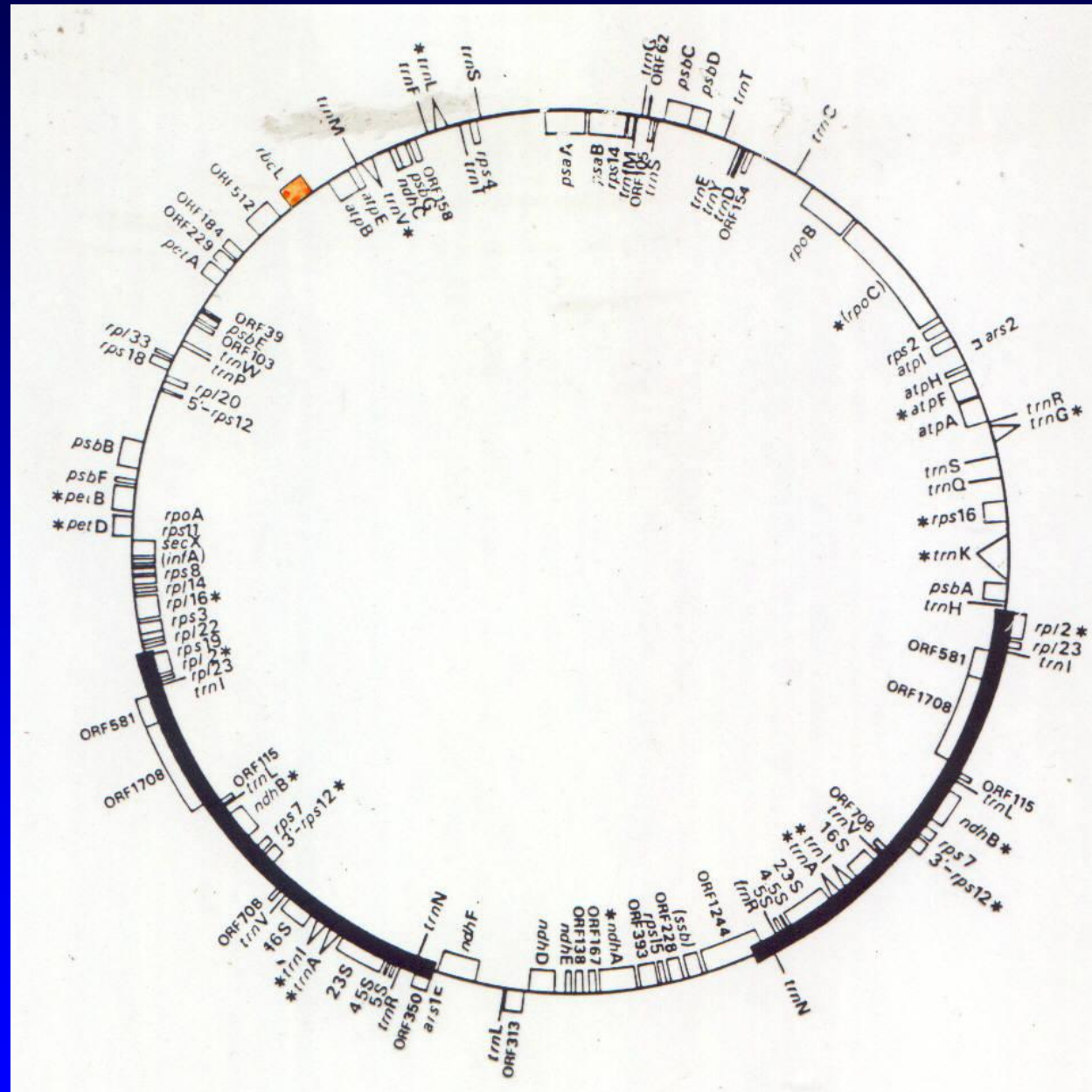
Corte transversal de folha de *Pinus nigra*
(Chamberlain 1935)

Sinapomorfia de Pinales

PERDA da sequência
repetida invertida do
DNA plastidial

Mapa da molécula
circular de DNA do
tabaco (*Nicotiana
tabacum*)

Olmstead & Palmer
1991, baseado em
Shinozaki *et al.* 1986



PINALES

CARACTERES DIAGNÓSTICOS

- plantas lenhosas

Pinus longaeva - árvore
mais velha do mundo

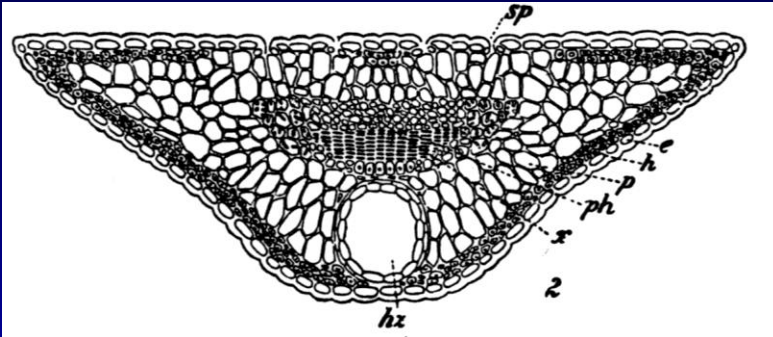


*Araucaria
angustifolia*



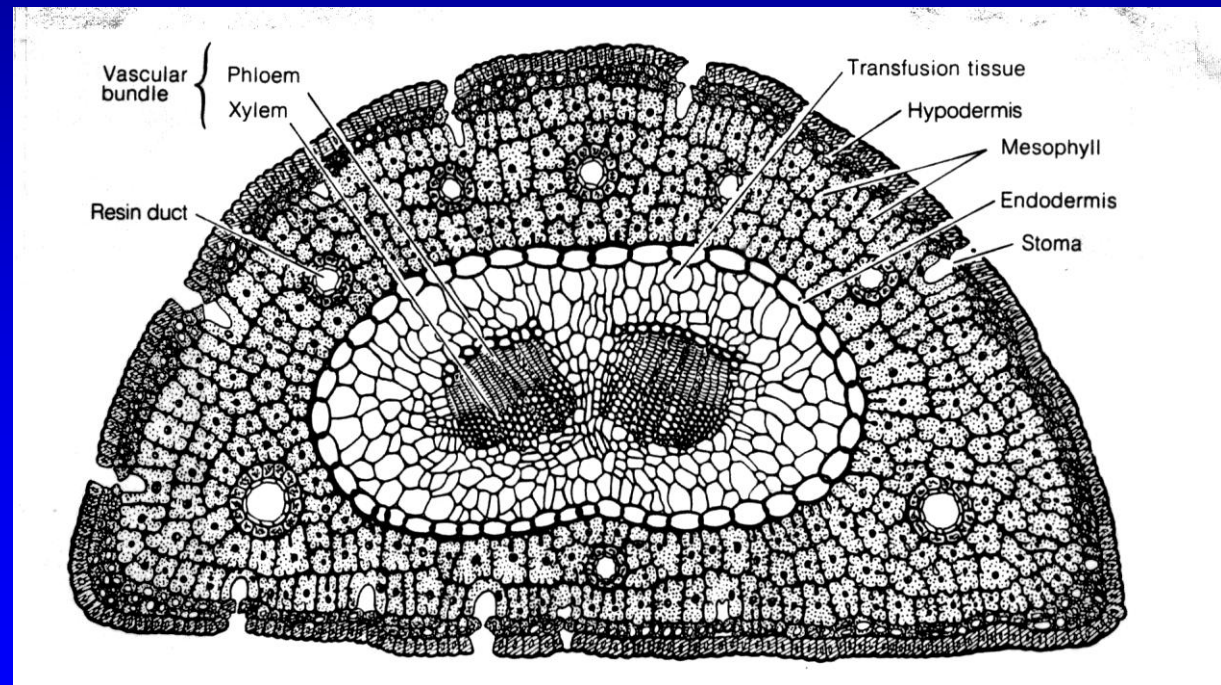
*Cupressus
sempervirens*

PINALES



Corte transversal de folha de *Juniperus communis*

♦ folhas escleromorfas,
geralmente uninérveas

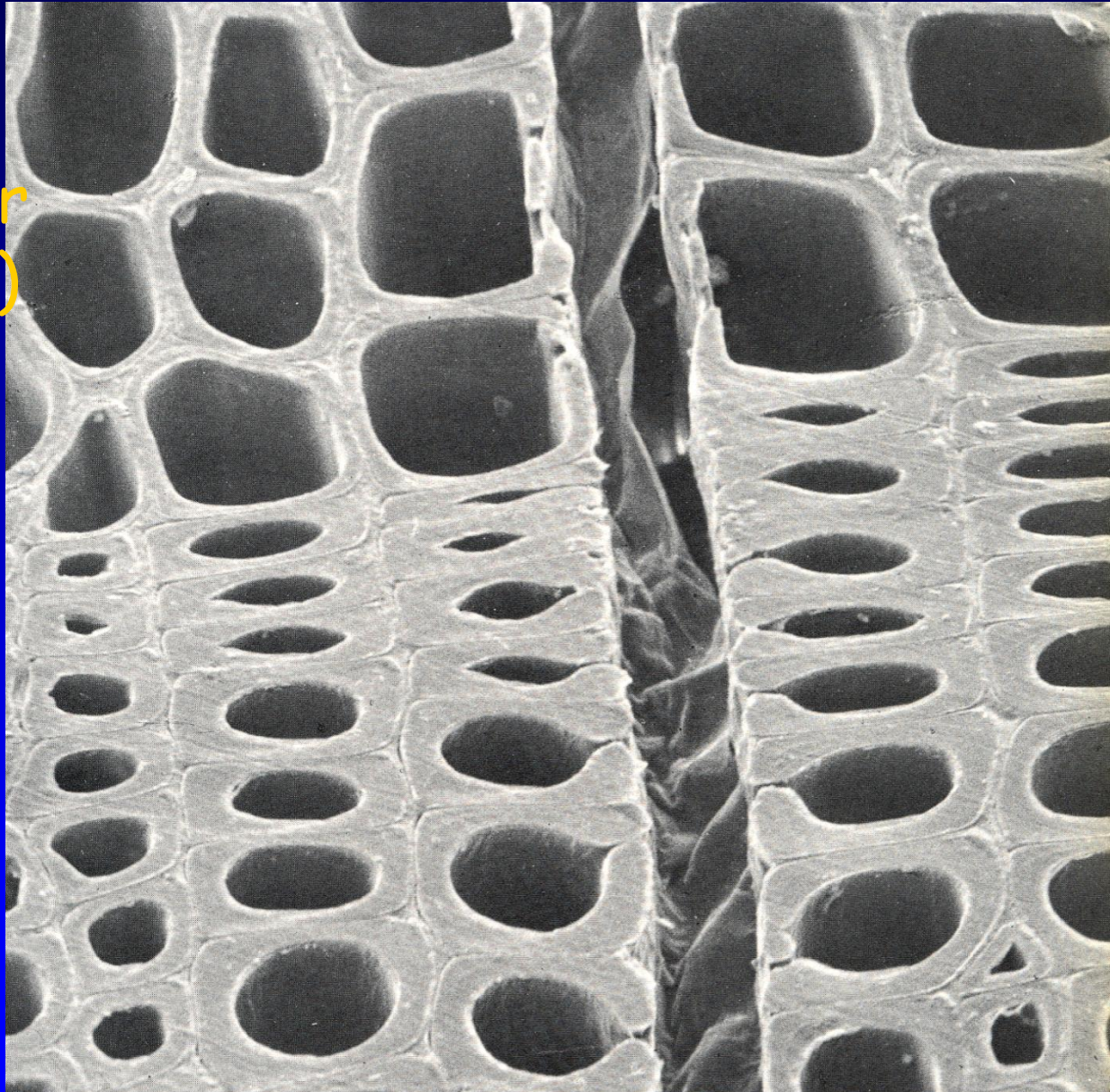


Corte transversal de folha de *Pinus nigra*
(Chamberlain 1935)

PINALES

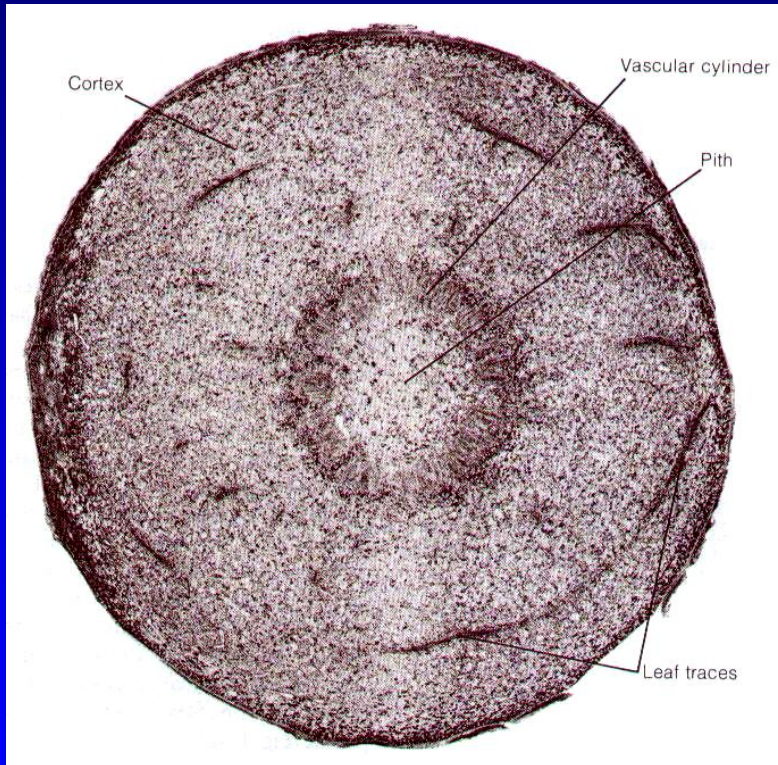
Raios unisseriados
no sistema vascular
(pouco parênquima)

Caráter
compartilhado
com
Ginkgófitas

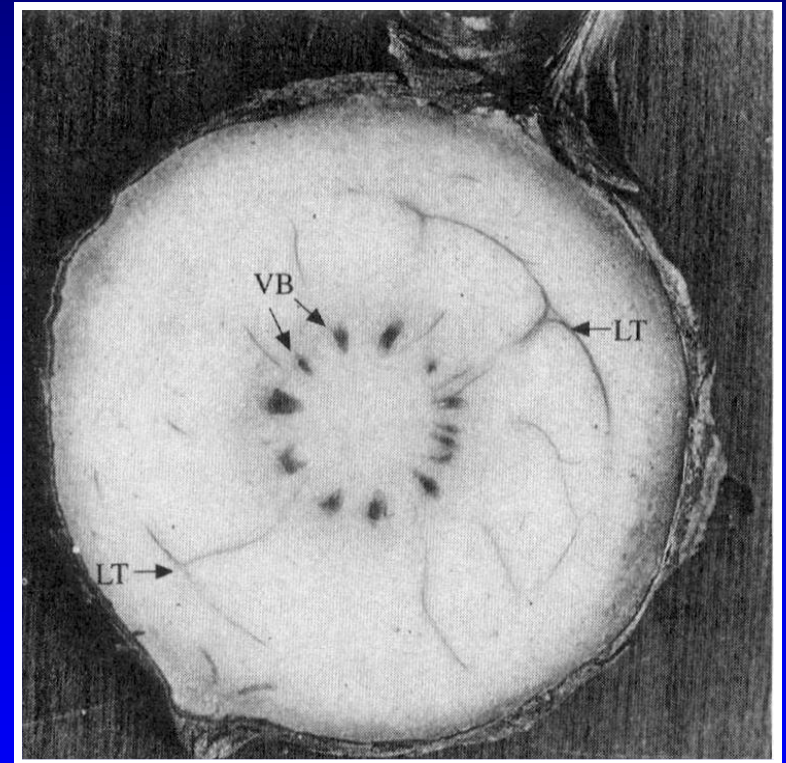


Lenho de Pinófitas e Ginkgófitas em forte contraste com CYCADOPHYTA:

↓ caule com muito parênquima



Corte transversal de caule de *Zamia* sp.
(Gifford & Foster 1989)



Corte transversal de um caule de *Zamia integrifolia* (Norstog & Nicholls 1997)

PINOPHYTA

PINALES



- Araucariaceae
- Cephalotaxaceae
- Cupressaceae
- Pinaceae
- Podocarpaceae
- Taxaceae

PINOPHYTA, PINALES

PINACEAE

Família dos pinheiros
10 gêneros/220 spp.

Pinus (100 spp.)

Abies (40)

Picea (40)

Larix (10)

Tsuga (10)

Pseudotsuga (5)

- Limitadas ao Hemisfério Norte, clima temperado



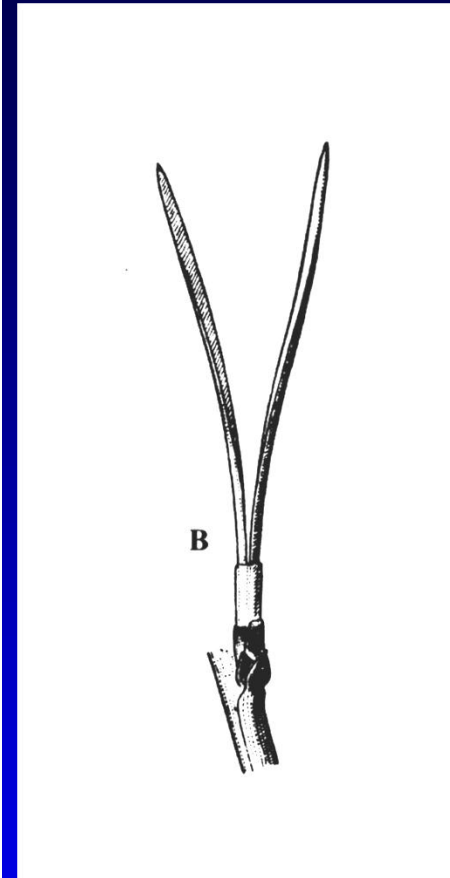
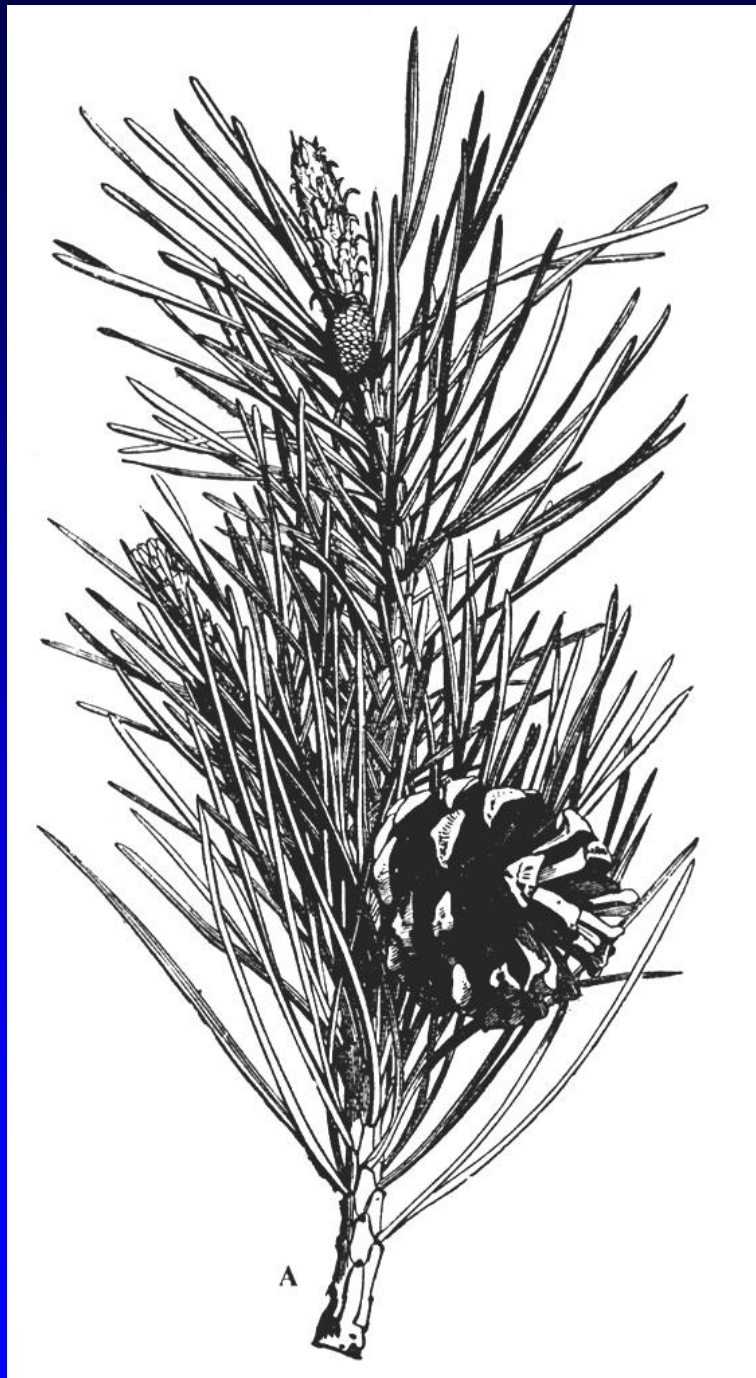
Distribuição geográfica do gênero *Pinus* (Krüssman 1995)

PINACEAE

CARACTERES DIAGNÓSTICOS

- árvores ou raramente arbustos
- ramos verticilados ou opostos (raramente alternos)

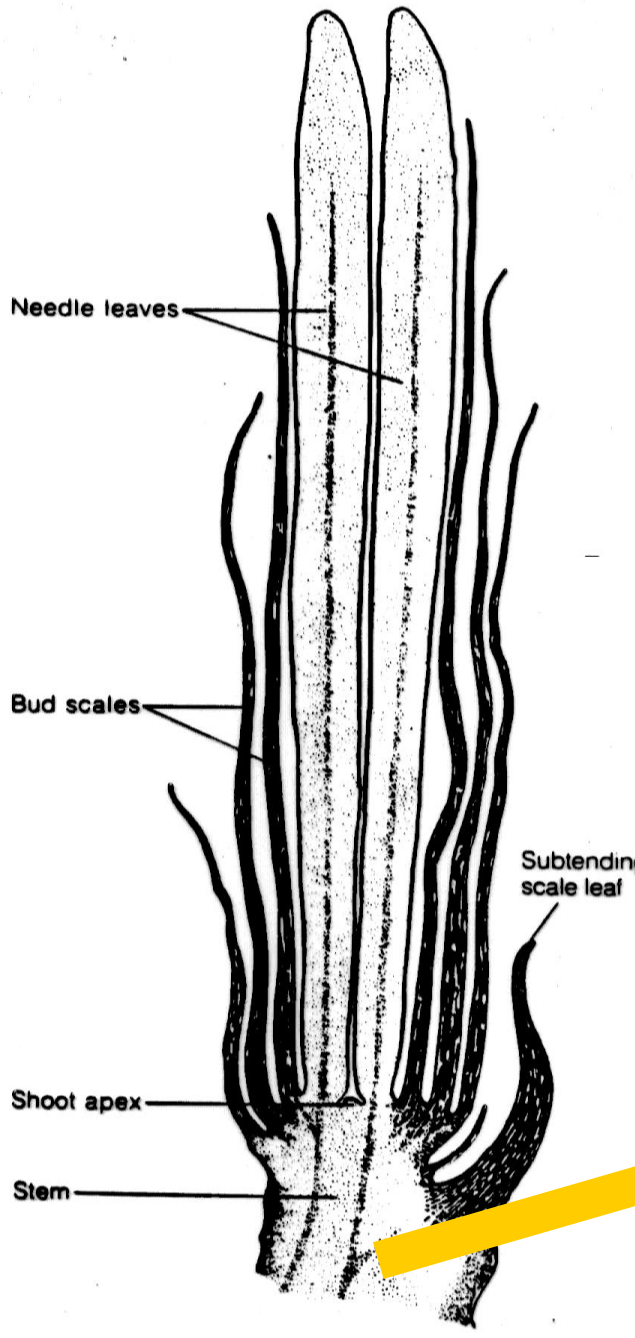
Kubitzki 1990



PINACEAE

- folhas simples, lineares a aciculares (raramente estreito-ovadas), alternas (folhas agrupadas de 2-5 em *Pinus*)

- canais resiníferos

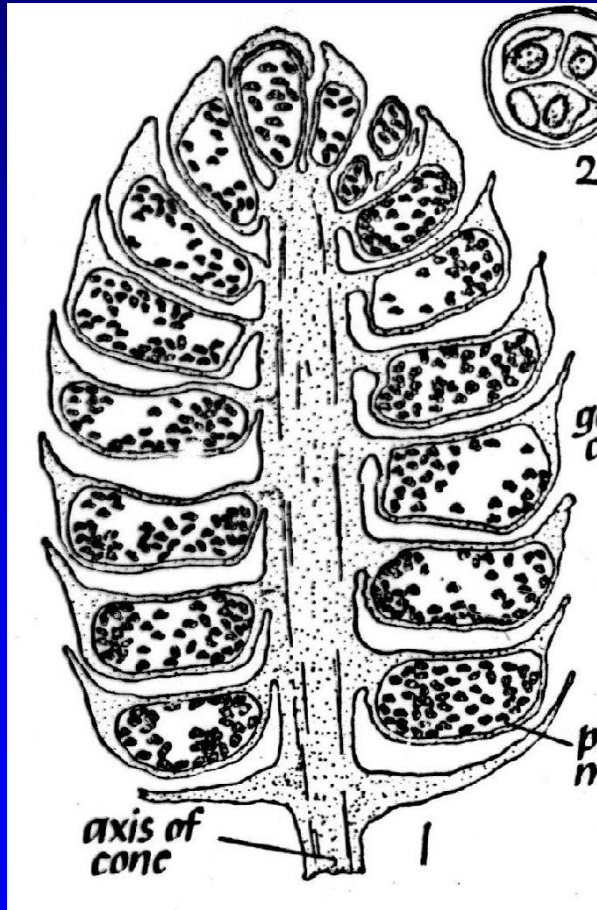


braquiblasto

Chamberlain 1935

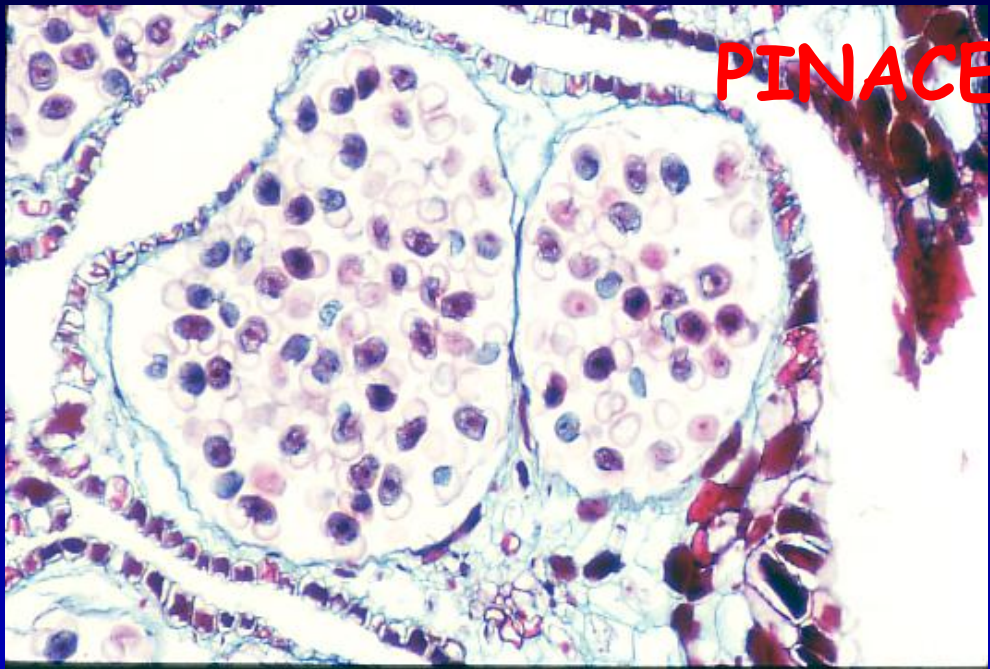
PINACEAE

- monóicas

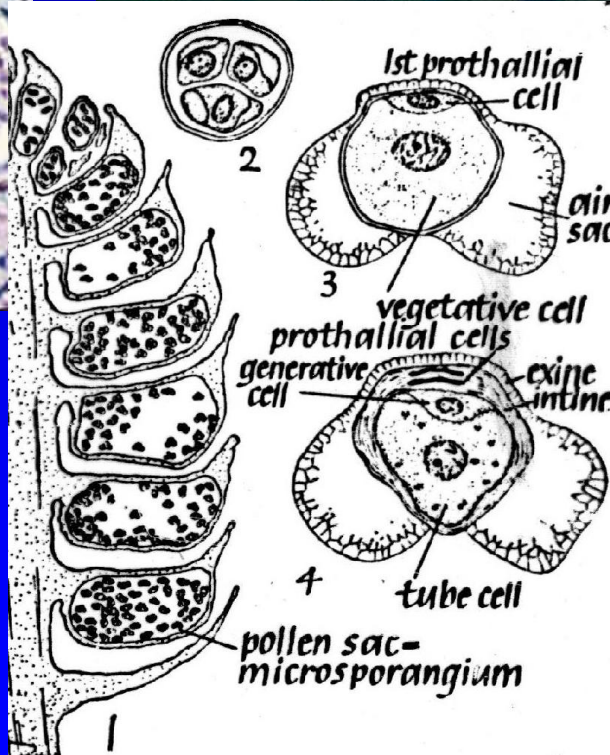


- microstróbilos com microsporofilos
espiralados

PINACEAE



- microsporofilos com 2 microsporângios
- anemofilia

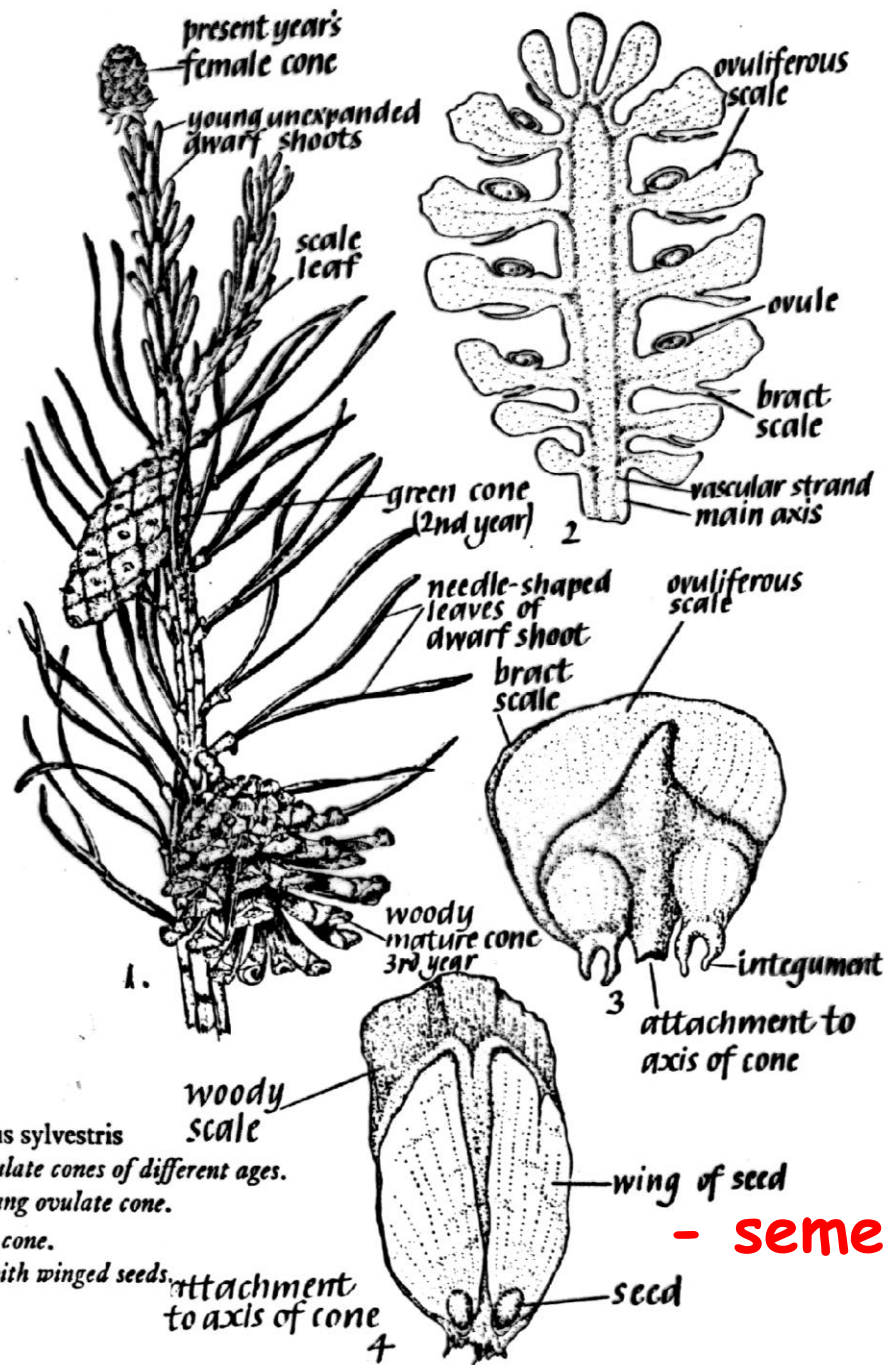


pólen com 2 sacos aéreos



PINACEAE

- escama ovulífera com 2 óvulos



Pinus sylvestris

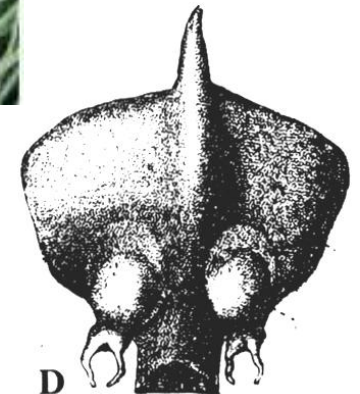
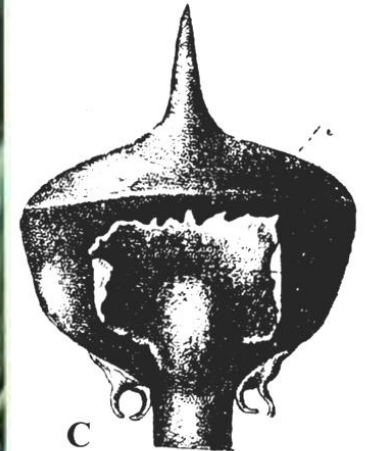
ovulate cones of different ages.

young ovulate cone.

late cone.

le with winged seeds.

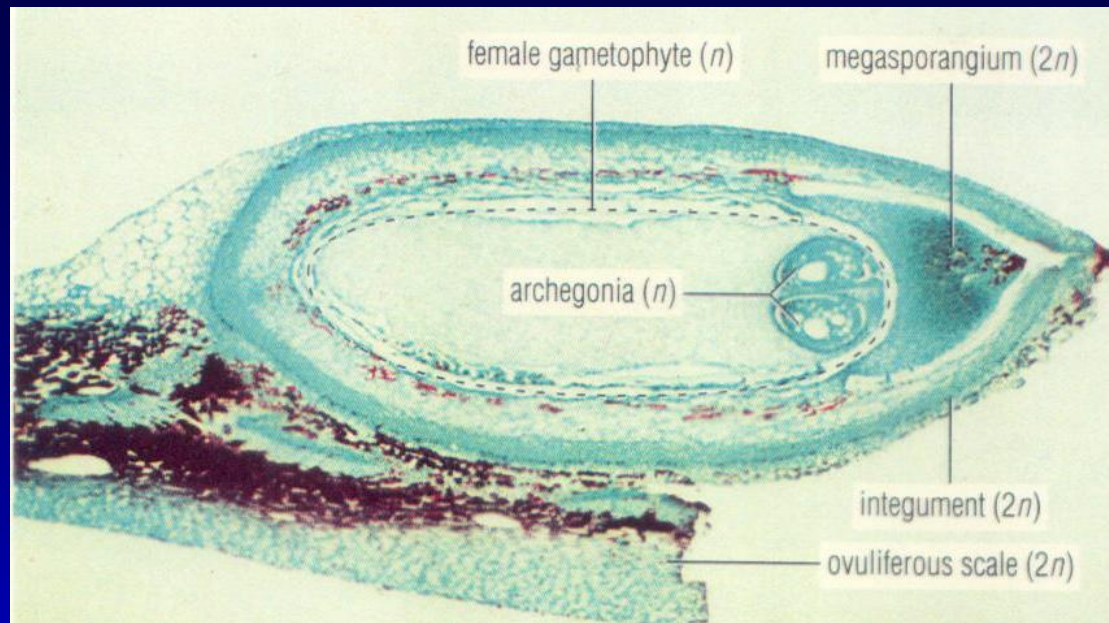
- semente alada



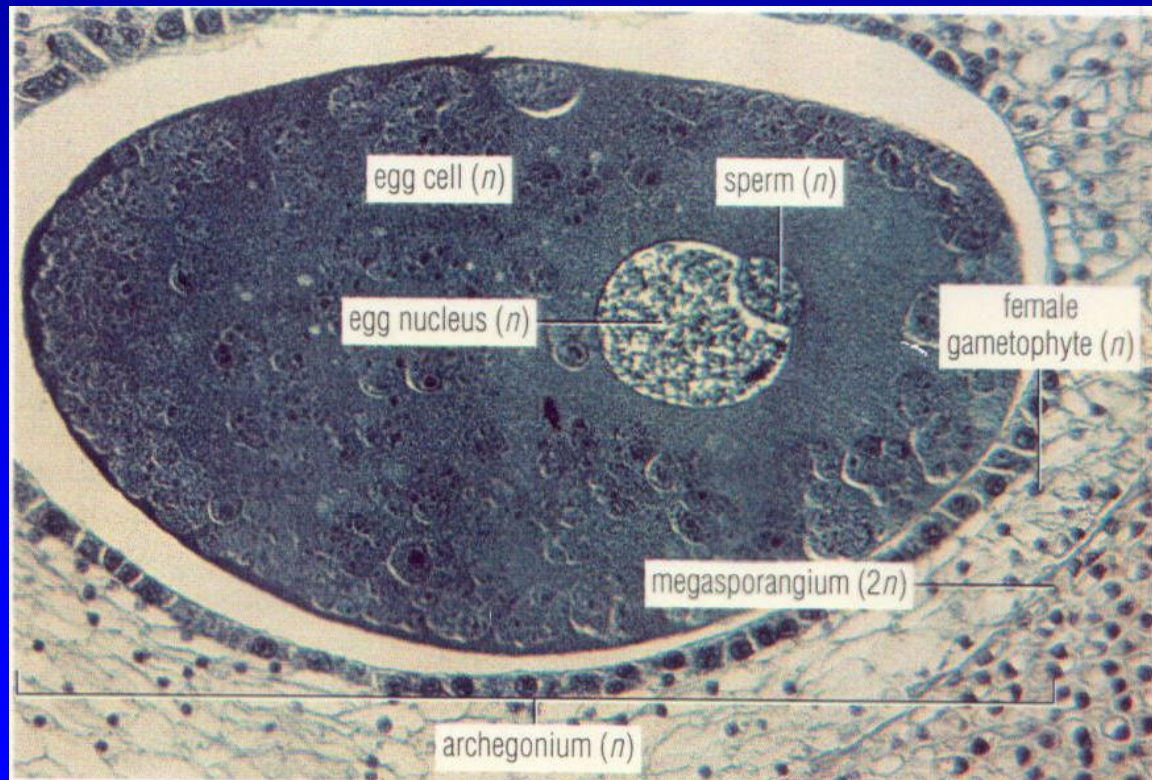
PINACEAE

Pinus

óvulo



fecundação da
oosfera



Perry & Morton 1996

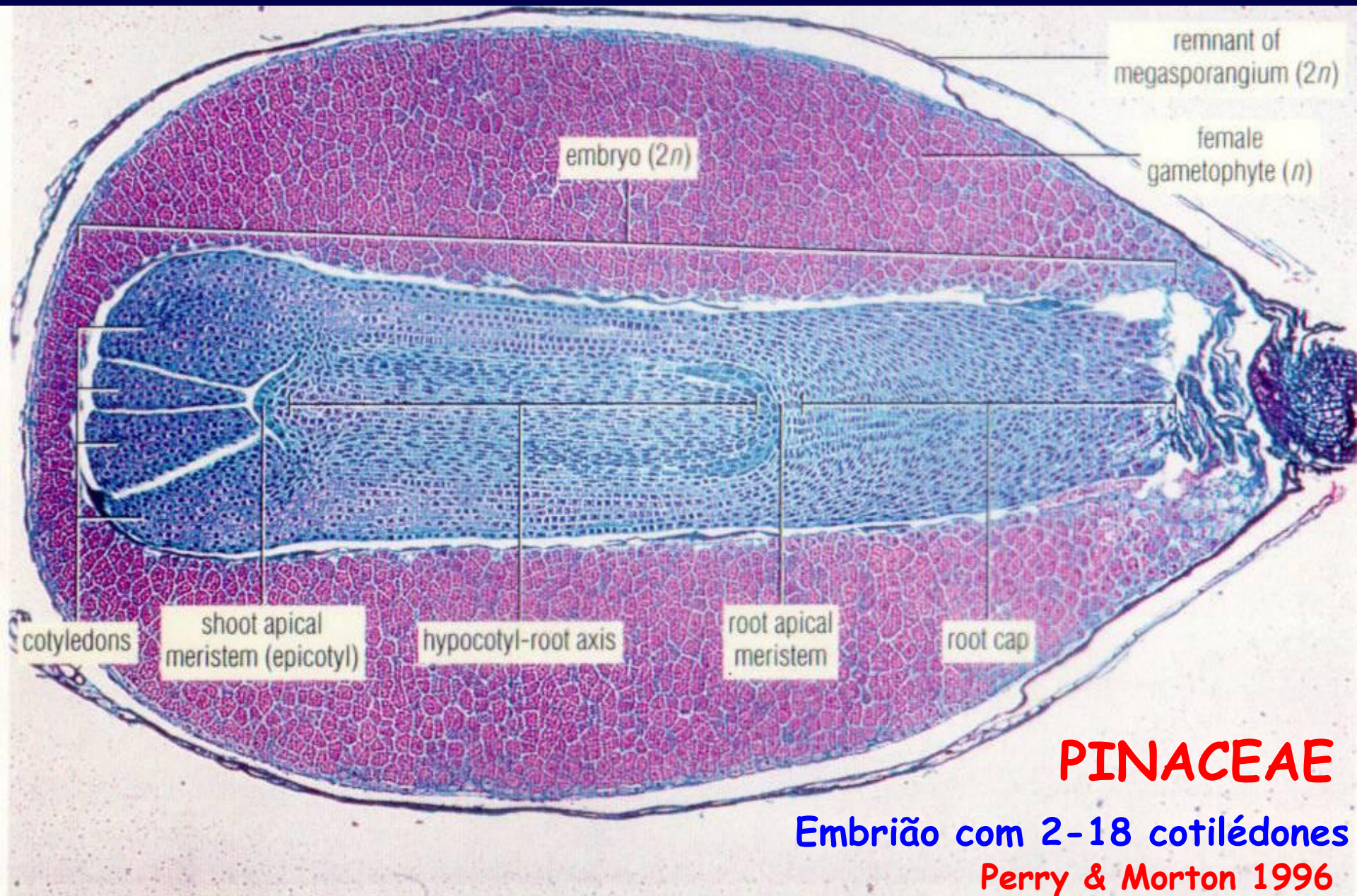
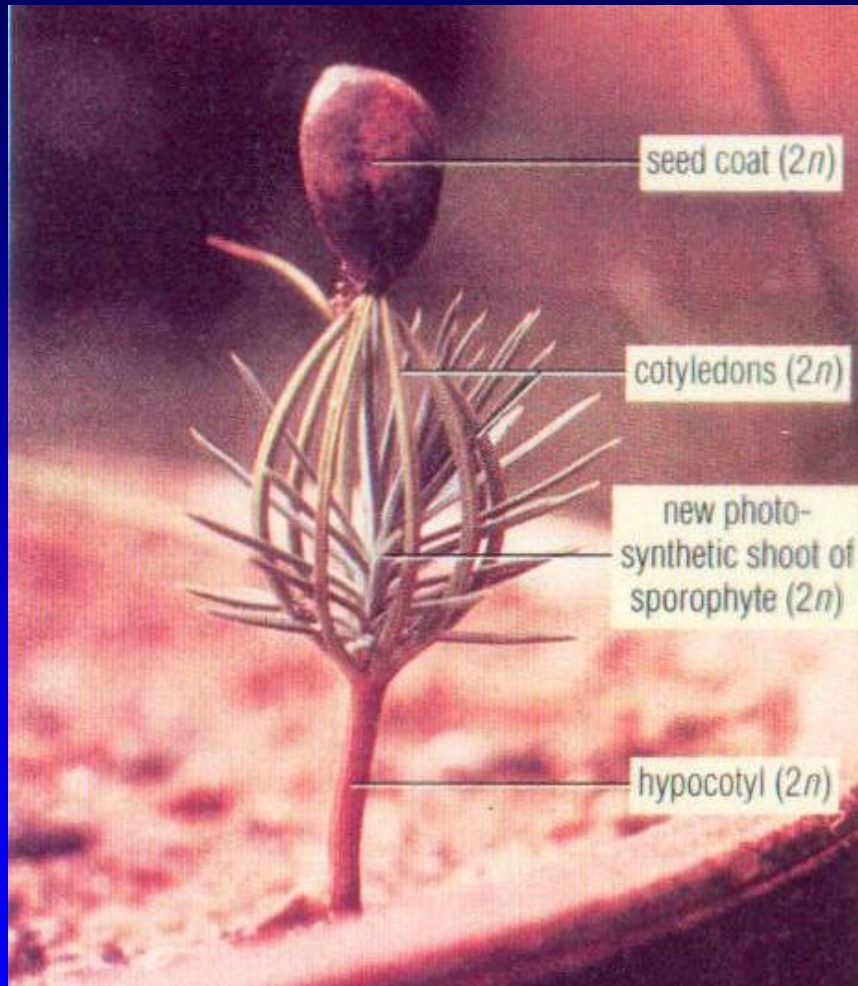
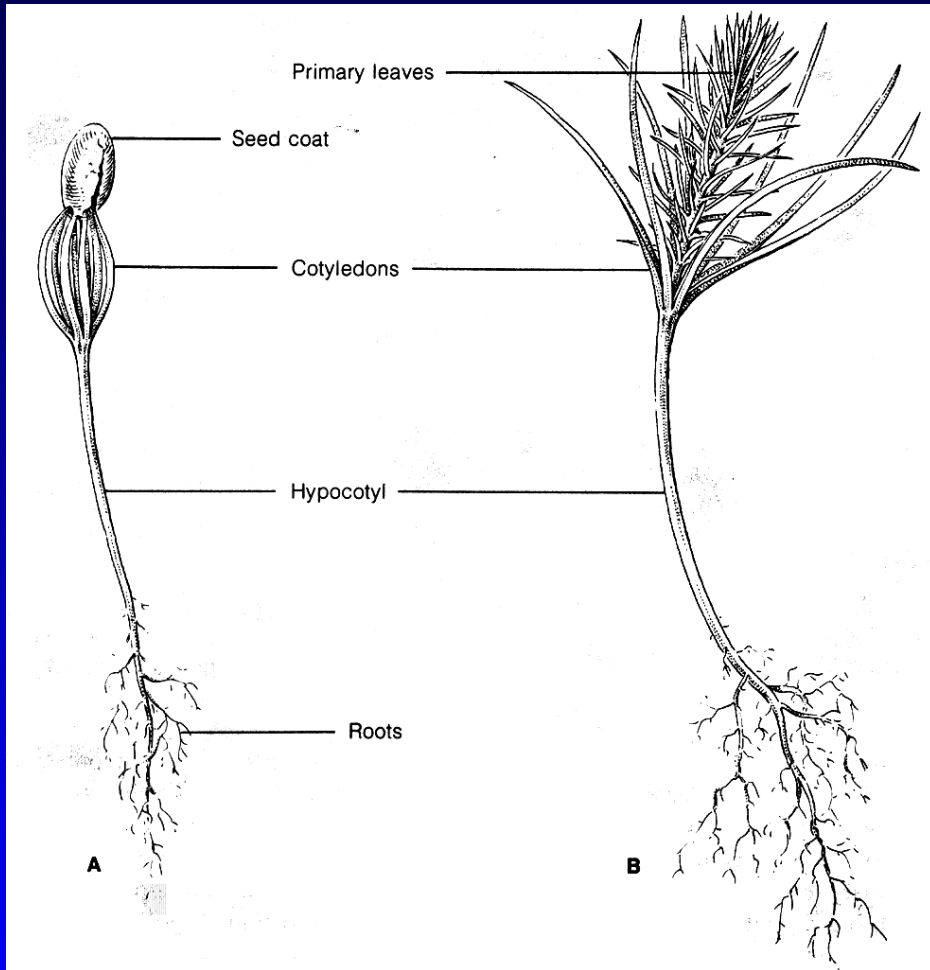


Figure 57d *Pinus*, seed containing embryo. The hard seed coat was removed during slide preparation (prep. slide, l.s., 30 $\times$). (Photo courtesy Biodisc, Inc.)

PINACEAE

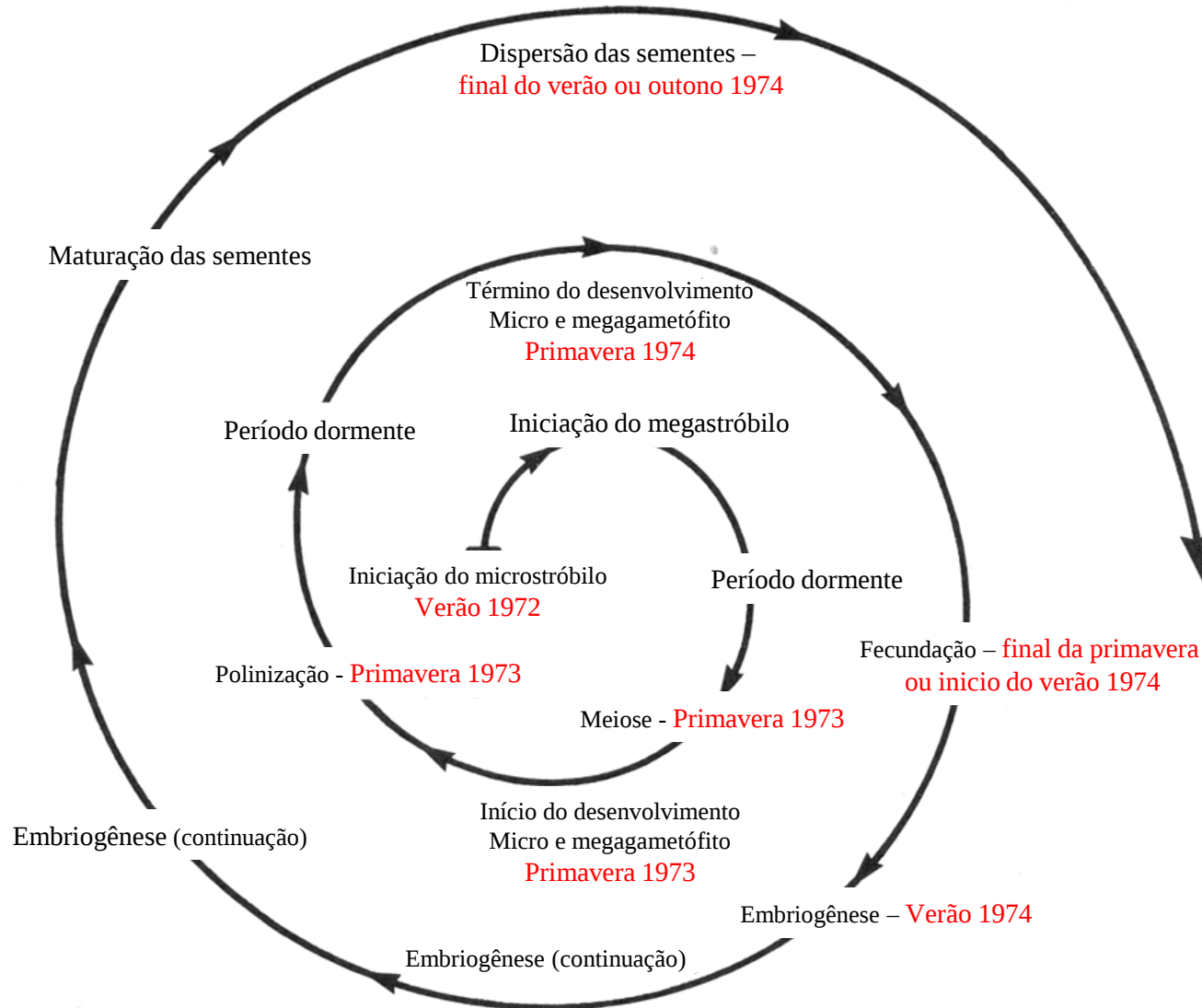


Perry & Morton 1996



Plântulas de *Pinus edulis*
(Gifford & Foster 1989)

Etapas da reprodução - *Pinus*



Modificado de Gifford & Foster 1989

PINACEAE - importância econômica:

-madeiras úteis (*Pinus*, *Pseudotsuga*, *Picea*, *Tsuga*, *Larix* e *Abies*)

-celulose

- muito cultivadas como ornamentais

Larix sp.



Cedrus libanii

PINACEAE

importância econômica

A resina sintetizada por coníferas é fonte natural abundante de TERPENOS, que são metabólitos secundários com cerca de 30.000 compostos, com importantes funções na planta: atuam na sinalização e defesa contra injúria, contra a herbivoria (repelentes), nas interações químicas entre plantas, como reguladores de crescimento, componentes estruturais de membranas celulares.

Alguns terpenos constituem metabólitos farmacologicamente importantes e outros são empregados na indústria química fina de sabores e fragrâncias.



Pinus - coleta de resina

PINACEAE

importância econômica

A produção de oleoresina em escala comercial é atividade essencialmente extrativista e rentável,
em função do alto valor agregado de seus principais subprodutos:
o breu (fração sólida) e a terebintina (fração volátil).

Em termos mundiais, coníferas (particularmente *Pinus* spp.) vêm sendo exploradas para a produção de resina desde a década de 70.

No Brasil, a extração de resina teve início na década de 80 em plantações de *Pinus elliottii* com a utilização de incentivos fiscais.

Produtores mundiais: China em primeiro lugar, seguida do Brasil e Indonésia em segundo lugar,
(exportadores de goma resina).

Brasil: safra de 2007/2008 - produção total de goma resina: 106.366 toneladas,
movimentando mais de 40 milhões de dólares;
a maior produção ocorre em São Paulo (45.928 ton) e no Rio Grande do Sul (19.600 ton)

www.resb.com.br

PINOPHYTA, PINALES

CUPRESSACEAE

Família dos
ciprestes e das
sequóias

29 gêneros/130 spp.

Juniperus (50 spp.)

Callitris (15)

Cupressus (13)

Chamaecyparis (8)

Thuja (5)

Taxodium (3)

Sequoia (1)

Sequoiadendron (1)



Cupressus sempervirens



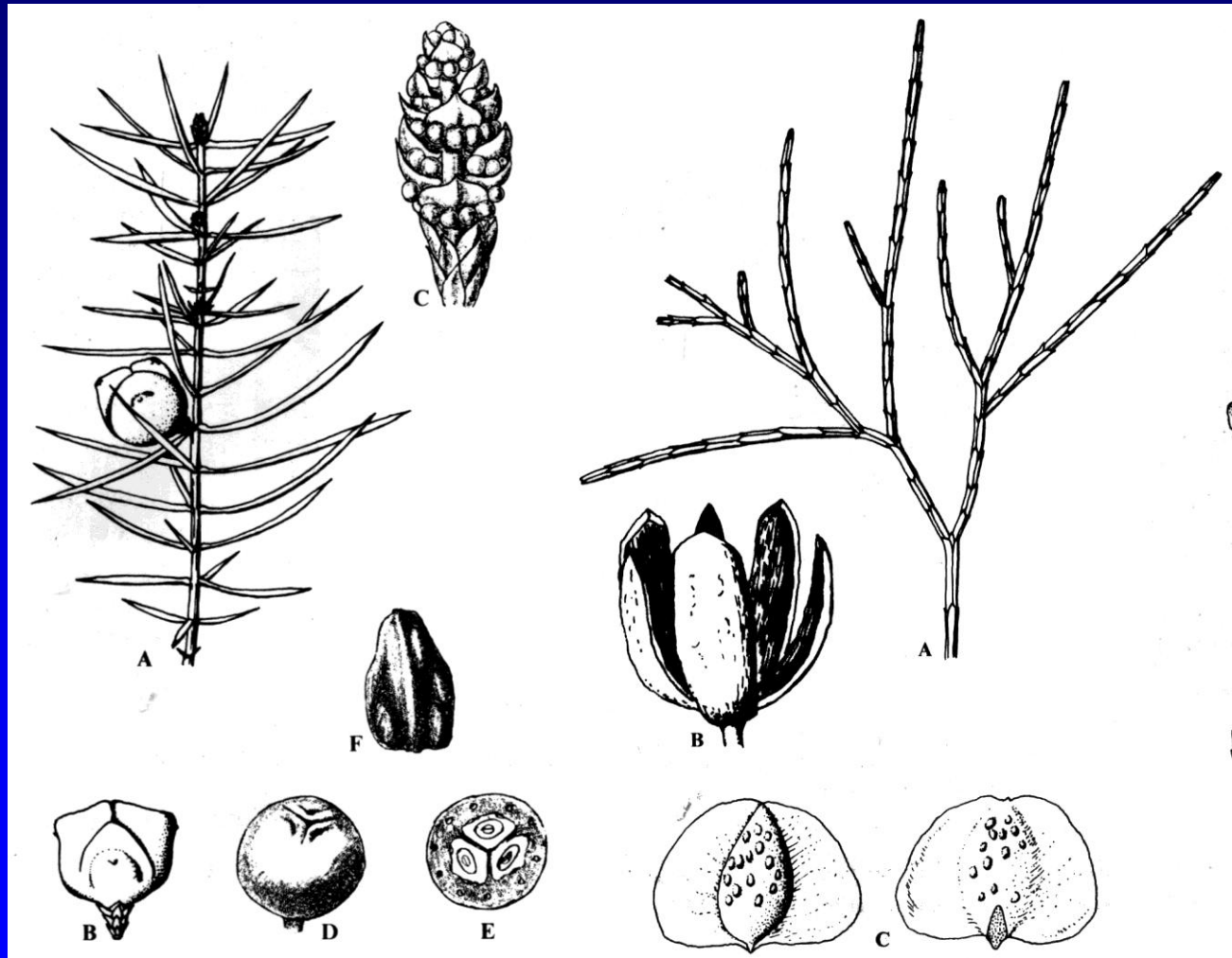
Sequoiadendron giganteum

- Família de climas quentes a frios

CARACTERES DIAGNÓSTICOS - CUPRESSACEAE

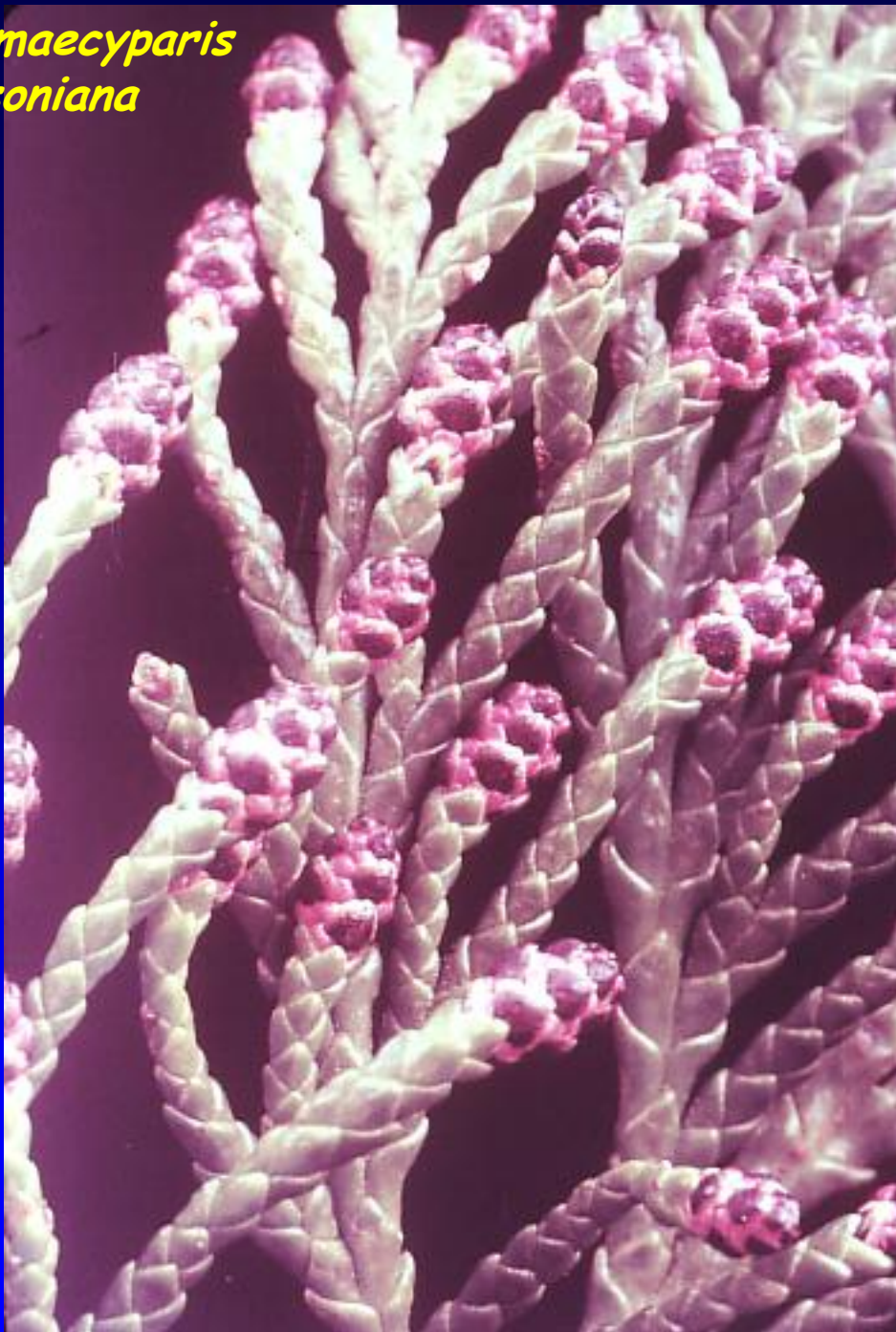
- árvores ou arbustos; madeira e folhagens geralmente aromáticos
- folhas alternas, opostas ou verticiladas, escamiformes ou lineares.

- plantas monóicas (dióicas em *Juniperus*)



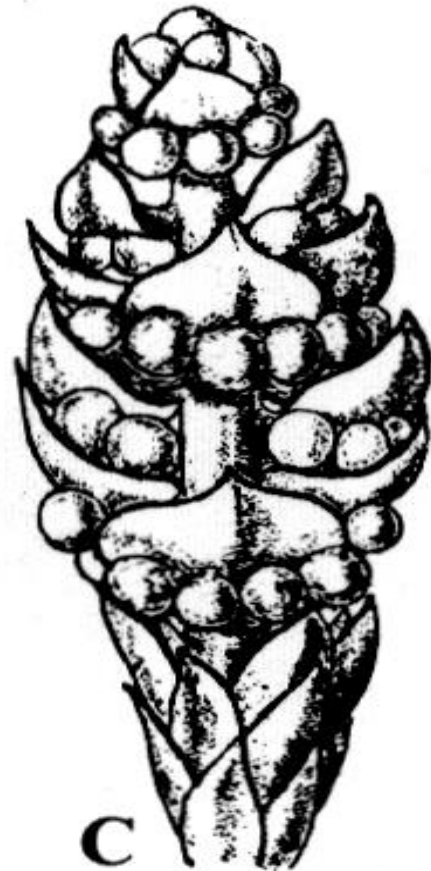
Espécies de *Juniperus* e *Callitris* (Kubitzki 1990)

*Chamaecyparis
lawsoniana*



CUPRESSACEAE

-microstróbilos:
2-10 microsporângios
na face abaxial





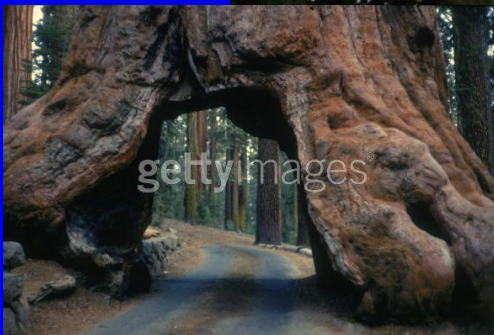
Sequoiadendron giganteum

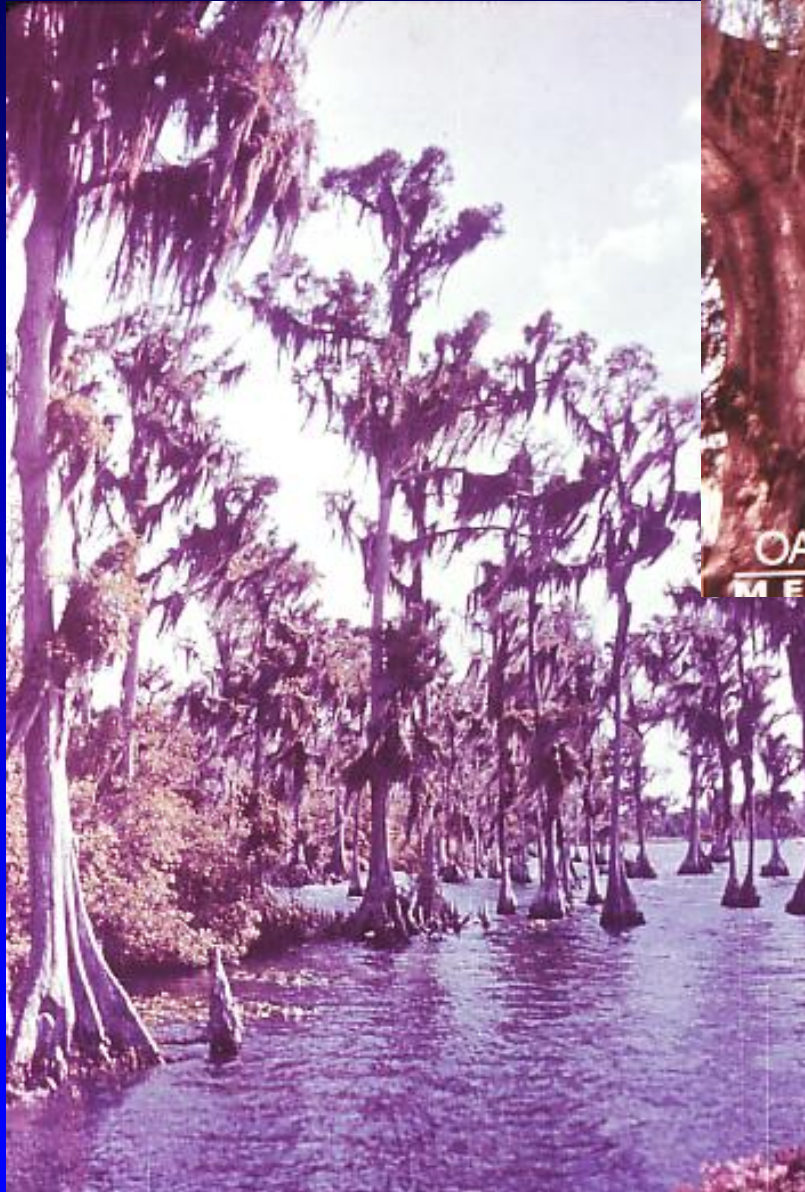
Sequoia sempervirens

CUPRESSACEAE

PINALES, PINOPHYTA

Plantas mais altas e compactas da Terra





Taxodium distichum

CUPRESSACEAE

cipreste-dos-pântanos

Cone com
escamas fundidas

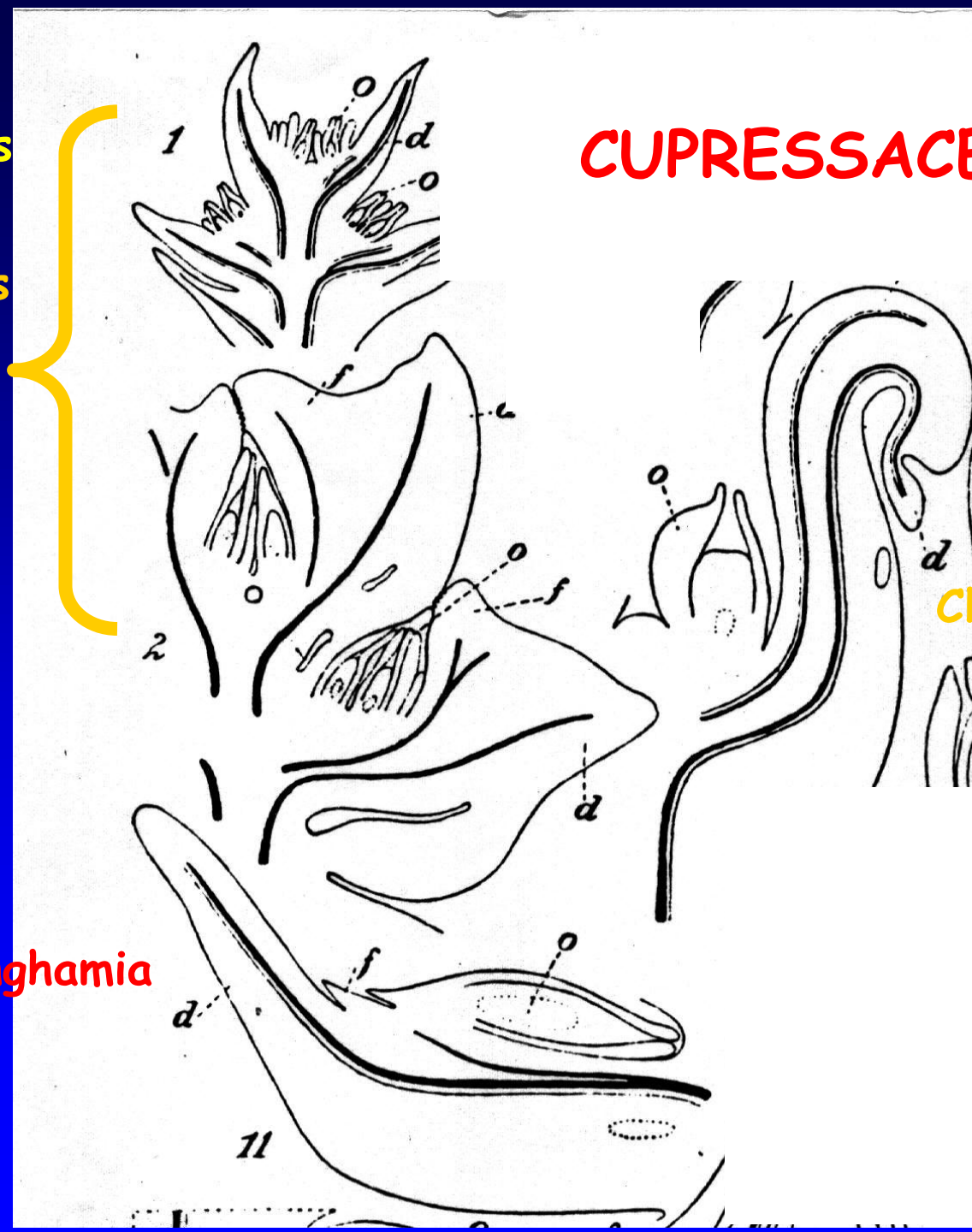
Cupressus

CUPRESSACEAE

Chamaecyparis

-escama ovulífera
com 1-20 óvulos

Cunninghamia



Gifford &
Foster
1989

CUPRESSACEAE

Juniperus



-Importância econômica:

- ornamentais:

Cupressus,
Juniperus, *Thuja*

- madeira valiosa (*Cryptomeria*, *Juniperus*, *Sequoia*,
Taxodium, *Thuja*)

PINOPHYTA, PINALES

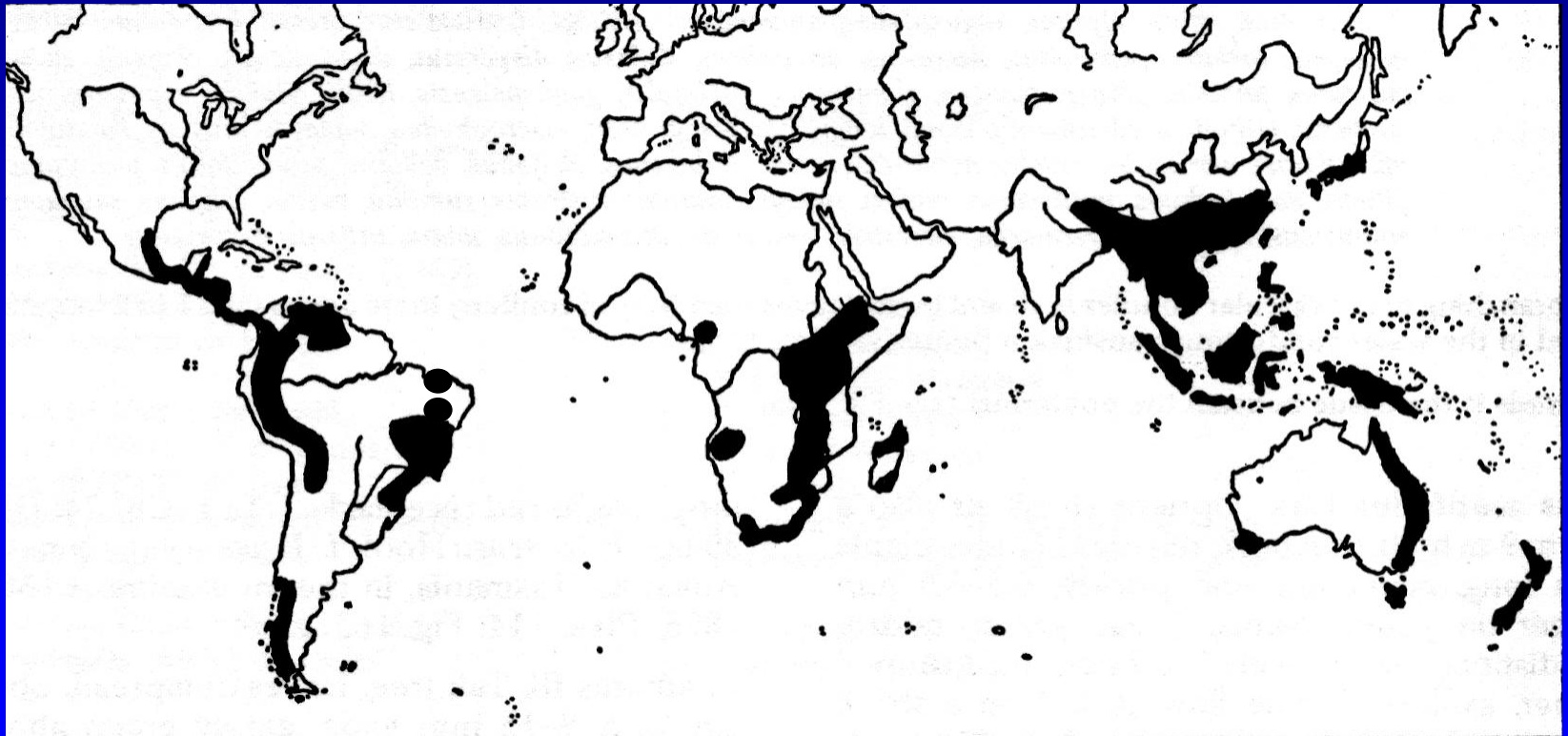
PODOCARPACEAE

17 gêneros/170 spp.

Podocarpus (100 spp.)

Dacrydium (20)

- Plantas tropicais e subtropicais, especialmente no Hemisfério Sul e no Velho Mundo



Distribuição geográfica de *Podocarpus* (Krüssman 1995)

PODOCARPACEAE

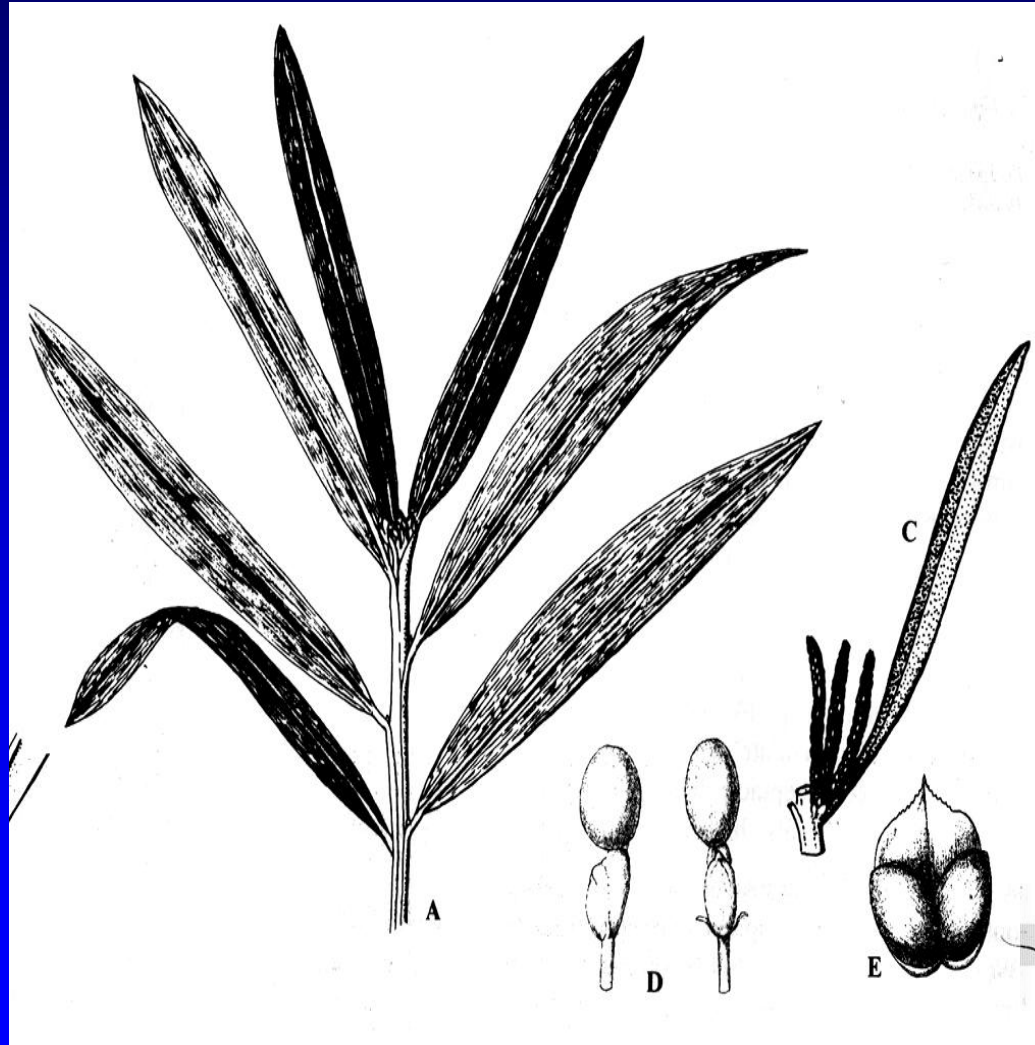
CARACTERES DIAGNÓSTICOS

- arbustos ou árvores; folhas simples, alternas, lineares a escamiformes

- plantas dióicas (raramente monóicas)

- microstróbilo cilíndrico

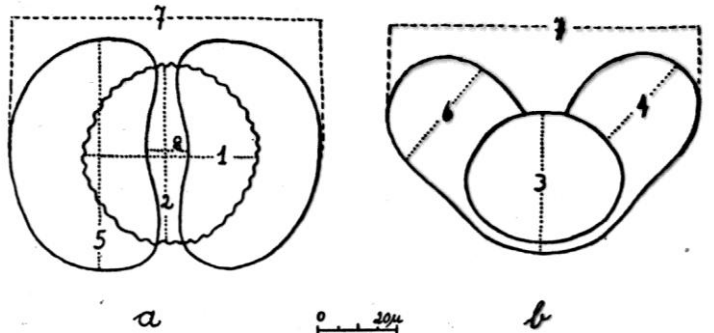
- madeira valiosa (*Dacrydium* e *Podocarpus*)



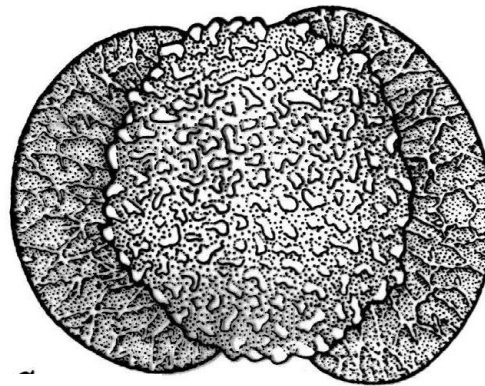
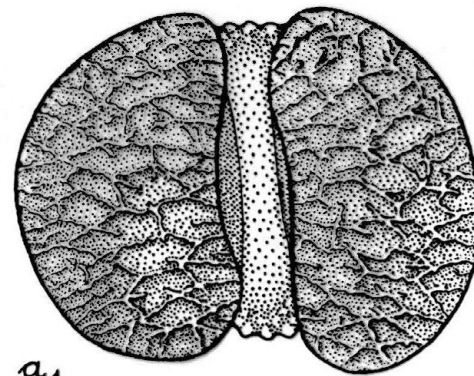
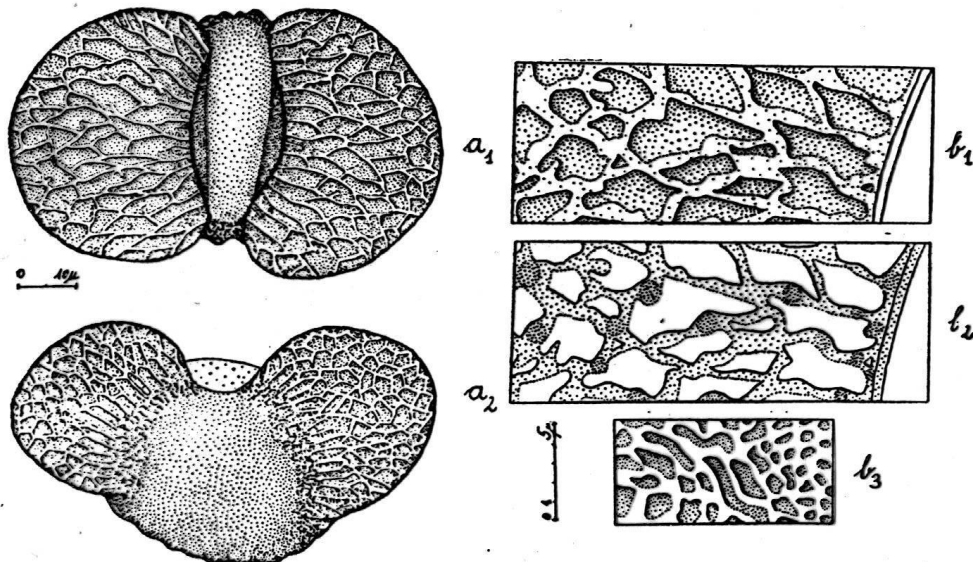
A-D. *Podocarpus macrophyllus*; E. *P. sellowii* (Kubitzki 1990)

PODOCARPACEAE

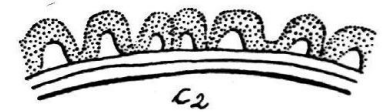
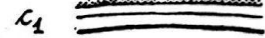
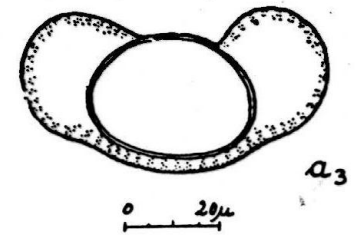
pólen com 2 sacos aéreos



Podocarpus sellowii

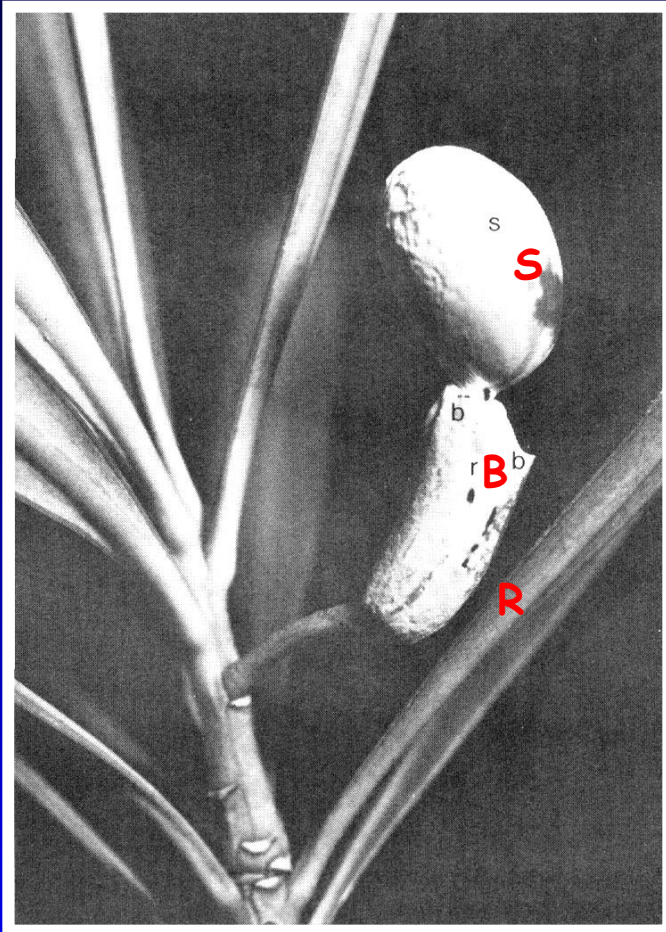


0 10 μ



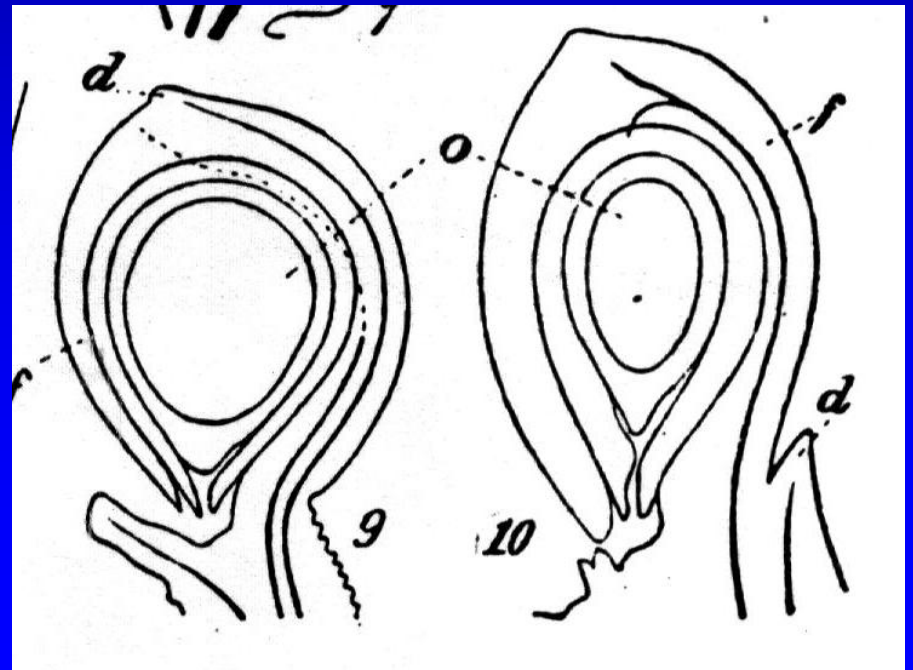
Podocarpus lambertii

Barth 1962

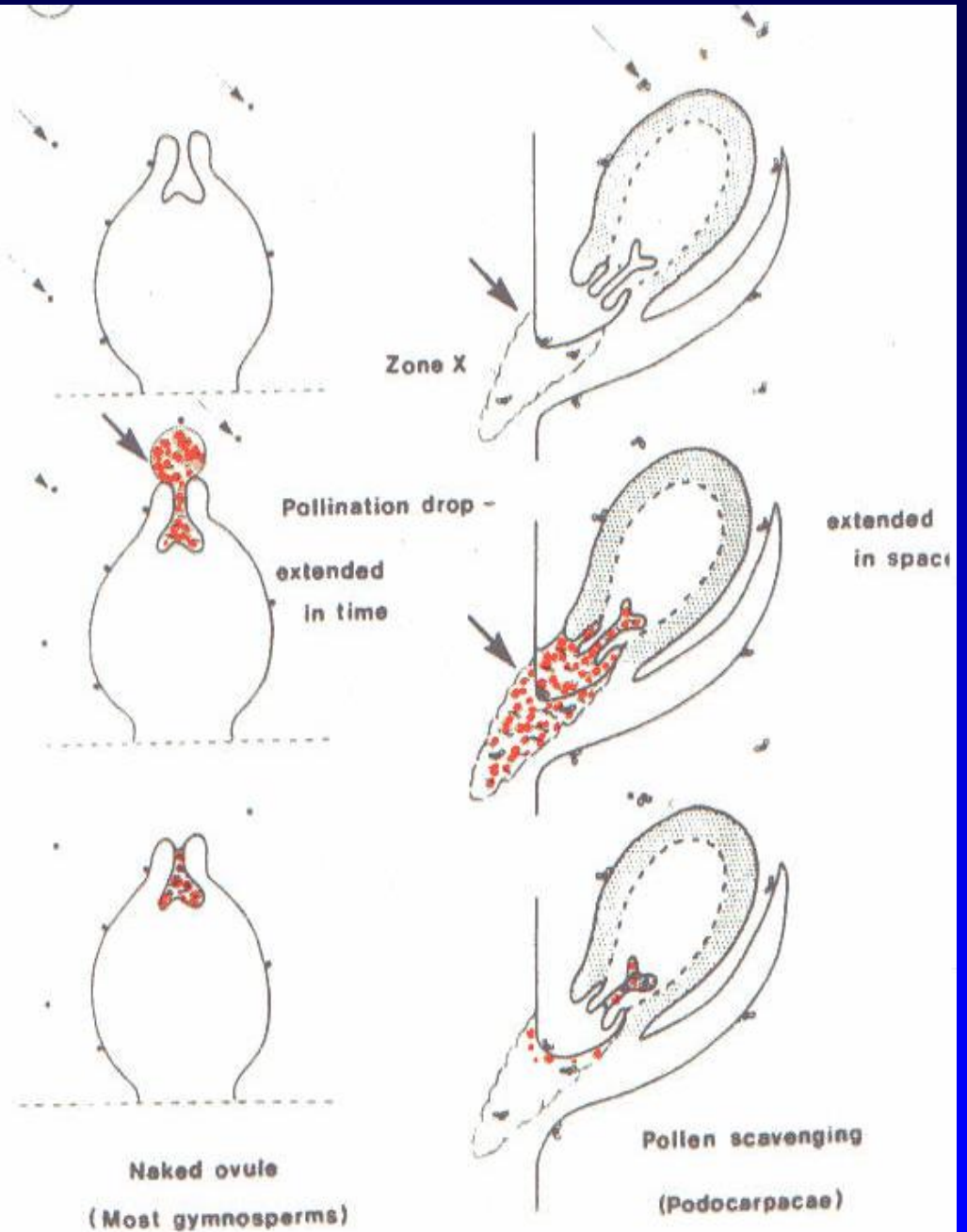


Cone maduro de *Podocarpus*
Gifford & Foster 1989

-escama ovulífera com 1
óvulo



Tomlinson *et al.*
1991



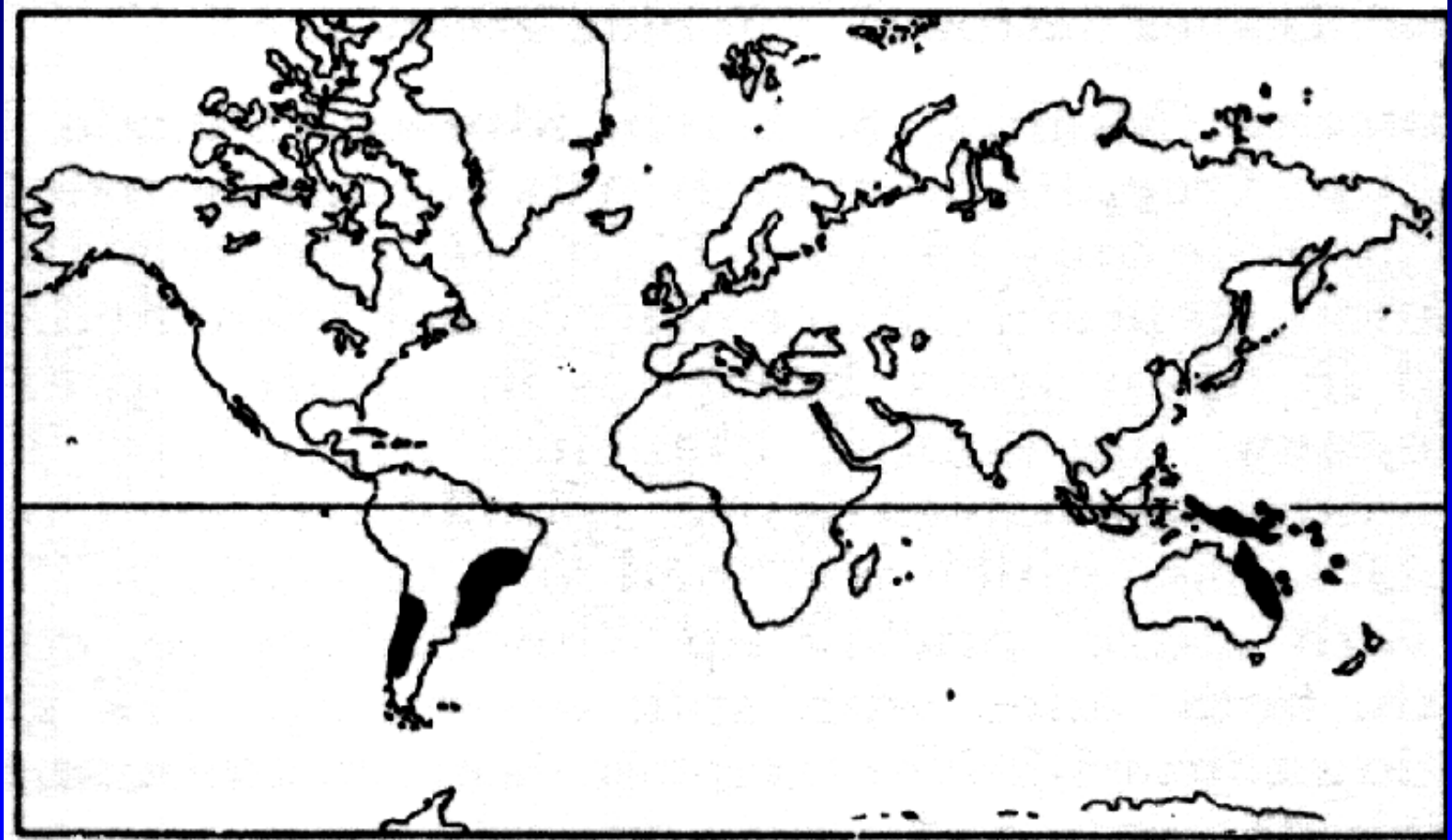
PINOPHYTA, PINALES

ARAUCARIACEAE

Araucaria

Agathis

- Restritas ao Hemisfério Sul



Distribuição geográfica do gênero *Araucaria* (Krüssman 1995)

ARAUCARIACEAE

Araucaria bidwillii

Araucaria angustifolia



Araucaria columnaris
Pinheiro-de-Norfolk



PINOPHYTA, PINALES - ARAUCARIACEAE
Araucaria angustifolia



ARAUCARIACEAE

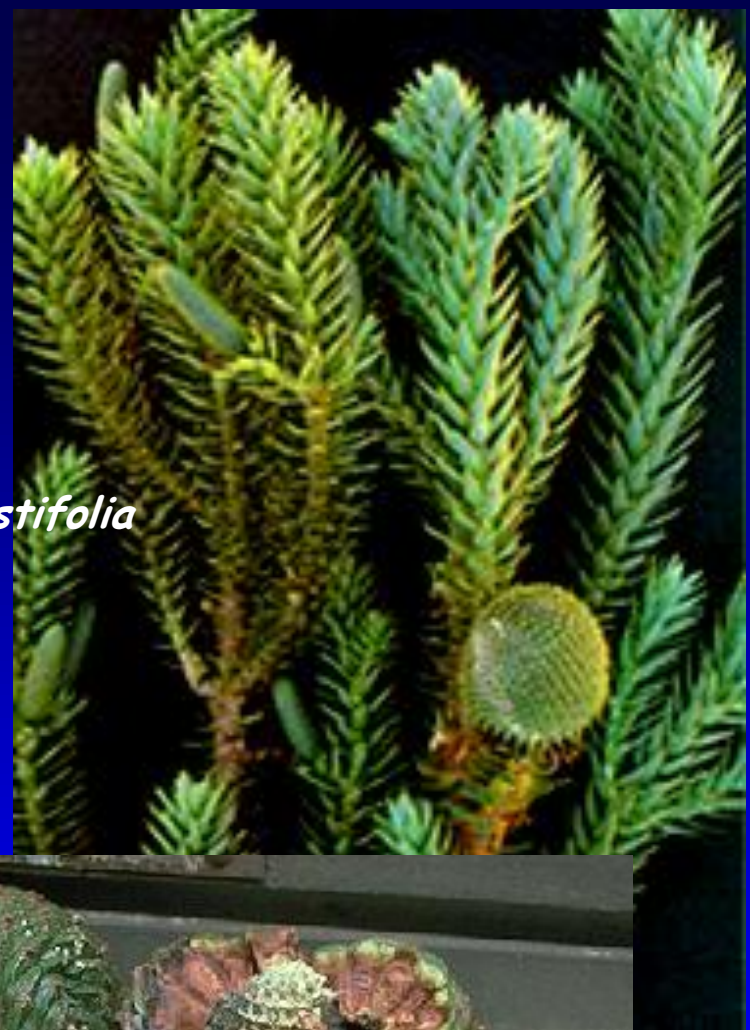
CARACTERES DIAGNÓSTICOS

- árvores com folhas lineares ou largas, opostas ou espiraladas

- plantas dióicas

- escamas ovulíferas e bracteais soldadas, recobrimdo o óvulo e formando o "pinhão"

- microsporofilos com 8 microsporângios



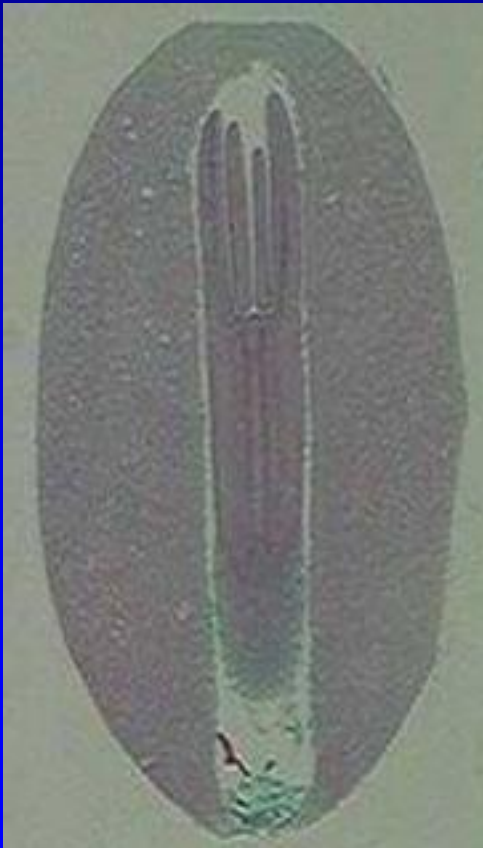
Araucaria angustifolia



Araucaria bidwillii



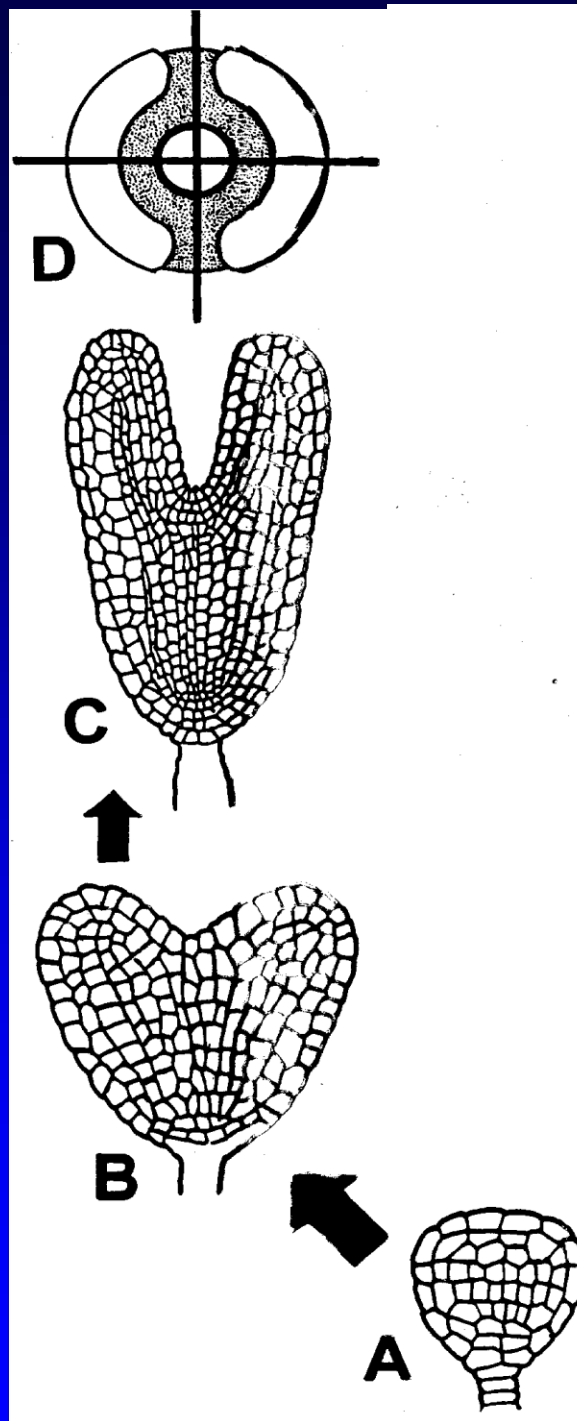
→ pinhão = semente



A porção
comestível
corresponde a
quais estruturas?

Embrião nas espermatófitas

Gifford & Foster 1988,
Yamashita 1976



PINOPHYTA, PINALES

TAXACEAE

Taxus baccata

fonte de taxol (antitumoral)



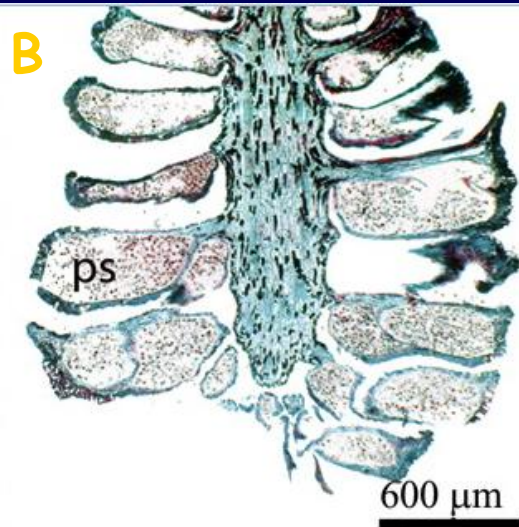
Pinus johannis, PINACEAE



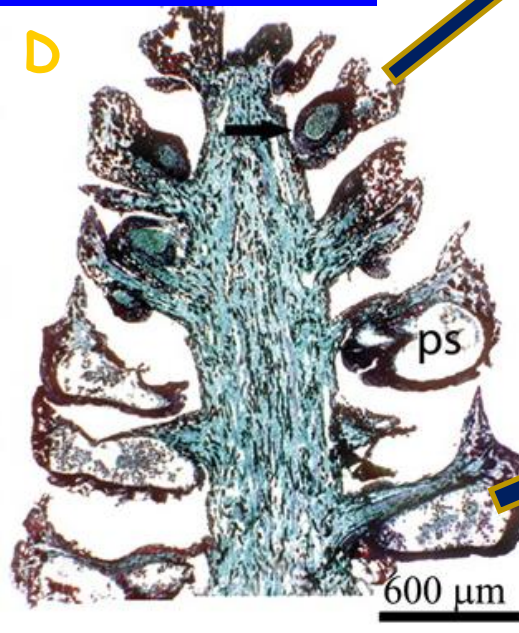
Fig. 1. Disposition of pollen, ovulate, and bisporangiate cones of *Pinus johannis*. (A) Cluster of pollen cones. (B) Ovulate cones develop on the tip of whorled lateral shoots. (C) Bisporangiate cones (arrows) interspersed with cluster of microstrobili of an individual initially monoecious predominately male. (D) Bisexual cone (arrow) originated at the top of the shoot alongside megastrobili in individual initially monoecious predominately female.

Pinus johannis, PINACEAE

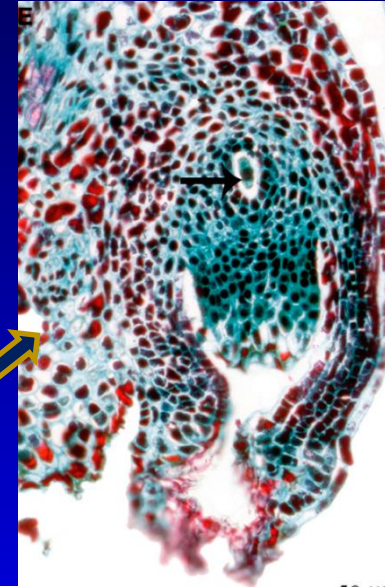
A,B: microstróbilo "normal"



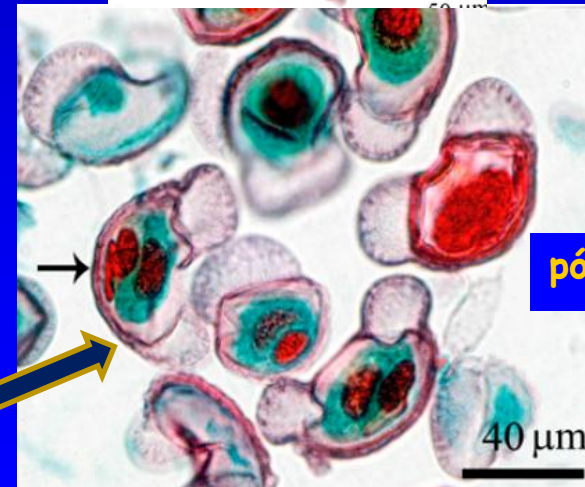
C,D: estróbilo bisporangiado (ou "bissexauo")



Distribuição espacial e viabilidade de órgãos produtores de pólen ou de óvulos em muitos gêneros de gimnospermas sugere existência de um mecanismo comum a todas espermatófitas (presença de genes homólogos com os das angiospermas?).



óvulo



pólen

Flores-Rentería et al. 2011

Gifford & Foster (1989)

Mauseth (1995)

Progymnospermophyta (fóssil)

Pteridospermophyta (fóssil)

Cycadeoidophyta
(=Bennettitales) (fóssil)

Cycadophyta

Ginkgophyta

Pinophyta (=Coniferophyta)

Gnetophyta

GNETOPHYTA - Permiano ao Recente

3 ordens {
EPHEDRALES
GNETALES
WELWITSCHIALES

ANASPERMAE

CYCADOPHYTA GINKGOPHYTA PINOPHYTA **GNETOPHYTA** ANGIOSPERMAS

?

- germinação epígea
- gameta não-flagelado
- sifonogamia

- gemas axilares
- folhas simples

- formação de sementes
- dioicia
- pólen monossulcado
- formação do tubo polínico
- óvulo unitegumentado ortótropo
- sementes com sarcotesta e esclerotesta
- embrião com 2 cotilédones

Hipótese que atualmente
não se sustenta mais!

Loconte & Stevenson 1990

GNETÓFITAS - Sinapormorfias

♦ elementos de vaso

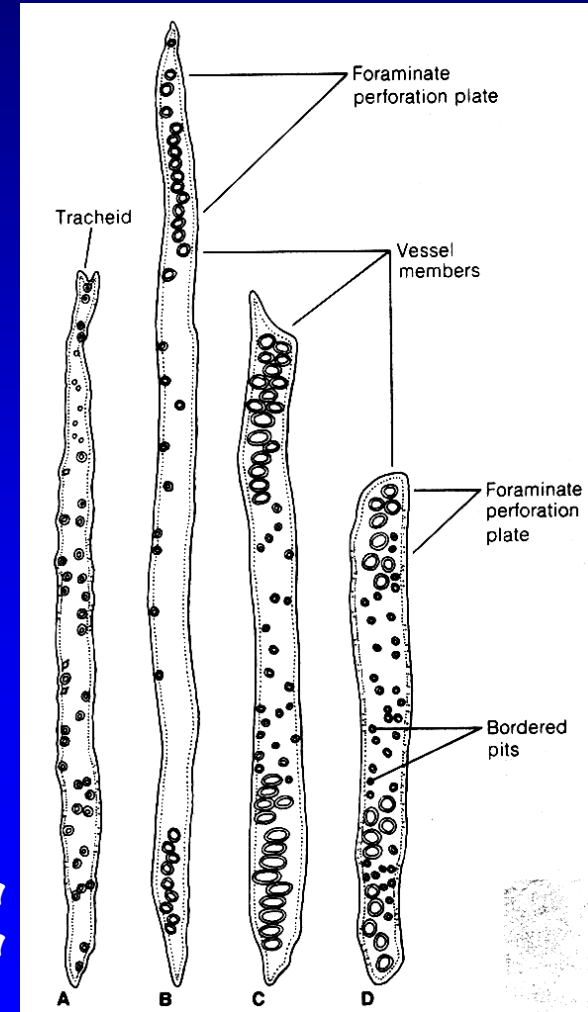
♦ diferem dos vasos de angiospermas
por terem perfurações foraminadas



Corte de caule de
Gnetum, uma liana
foto V. Angyalossy

Elementos traqueais
de *Ephedra*
californica

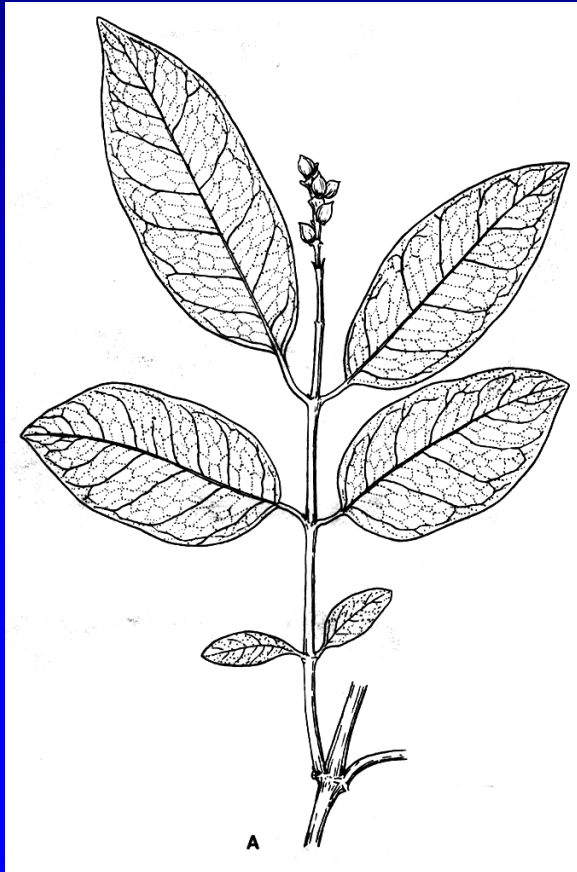
Gifford & Foster 1986



GNETÓFITAS- SINAPORMORFIAS

♦ folhas opostas

(verticiladas em *Ephedra*)

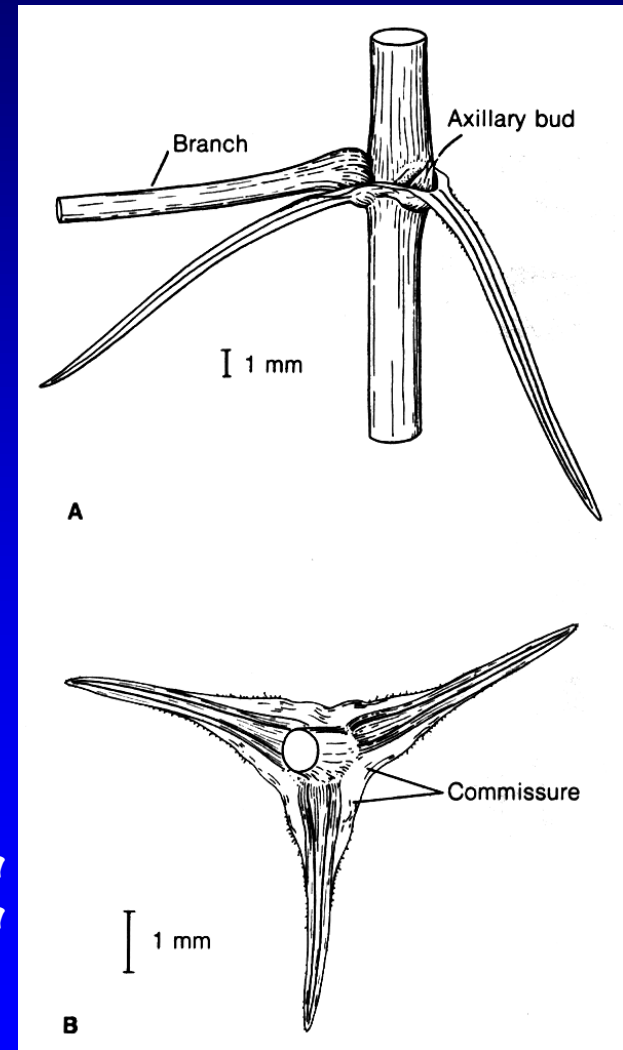


Ramo de *Gnetum indicum* (Gifford & Foster 1989)

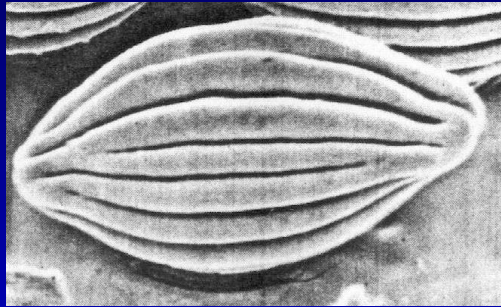
♦ folhas com
bainha

Folhas de *Ephedra foliata*

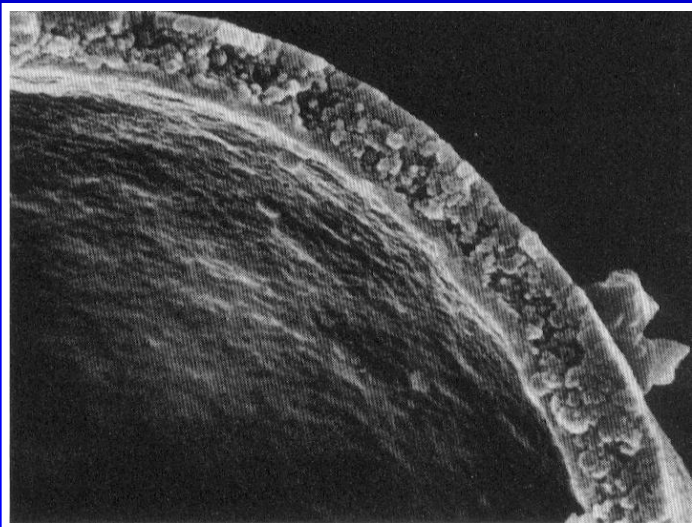
♦ múltiplas gemas
axilares



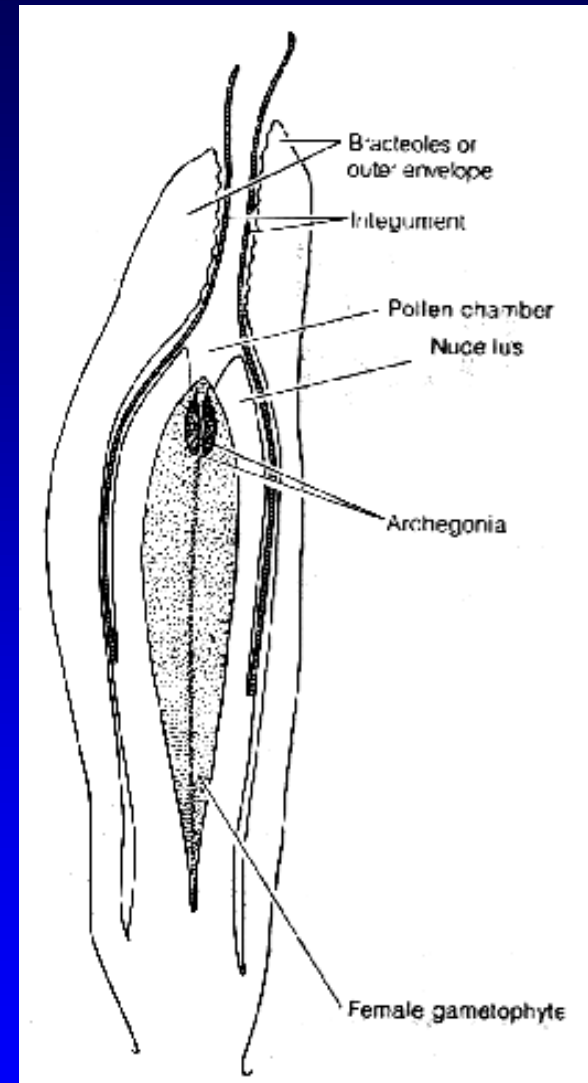
GNETÓFITAS- SINAPORMORFIAS



♦ pólen estriado, com
ectexina granular



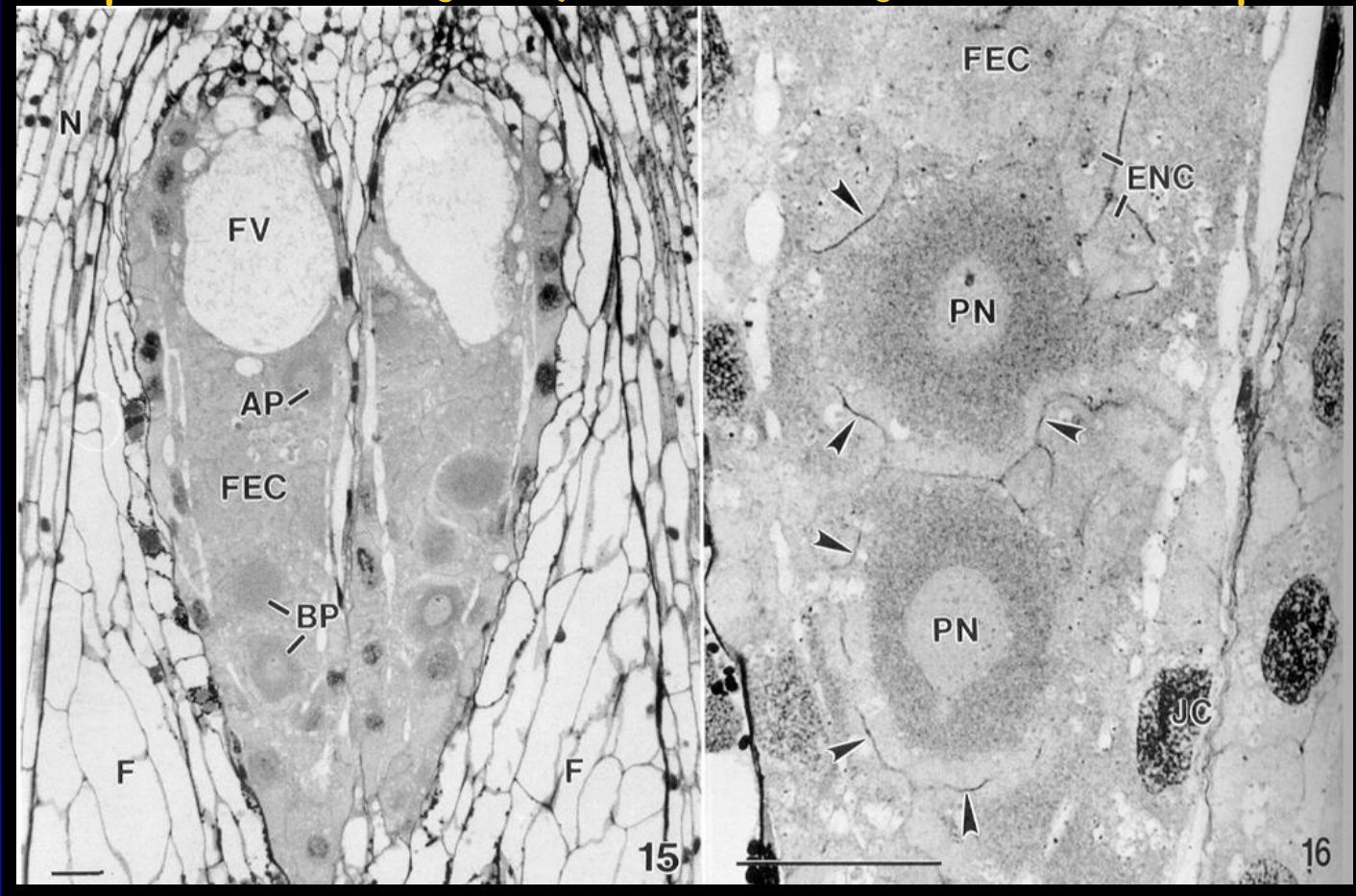
♦ micrópila tubular



óvulo de *Ephedra foliata*
(Gifford & Foster 1989)

GNETÓFITAS - Sinapormorfias

- ♦ sifonogamia
- ♦ dupla fecundação (sem formação de endosperma)



1. Dois arquegônios em *Ephedra trifurca* ; 2. Dois dos 8 zigotos num óvulo de *E. trifurca* (AP= proembrião basal derivado da dupla fecundação e BP= proembrião derivado da primeira fecundação (Friedman 1994)

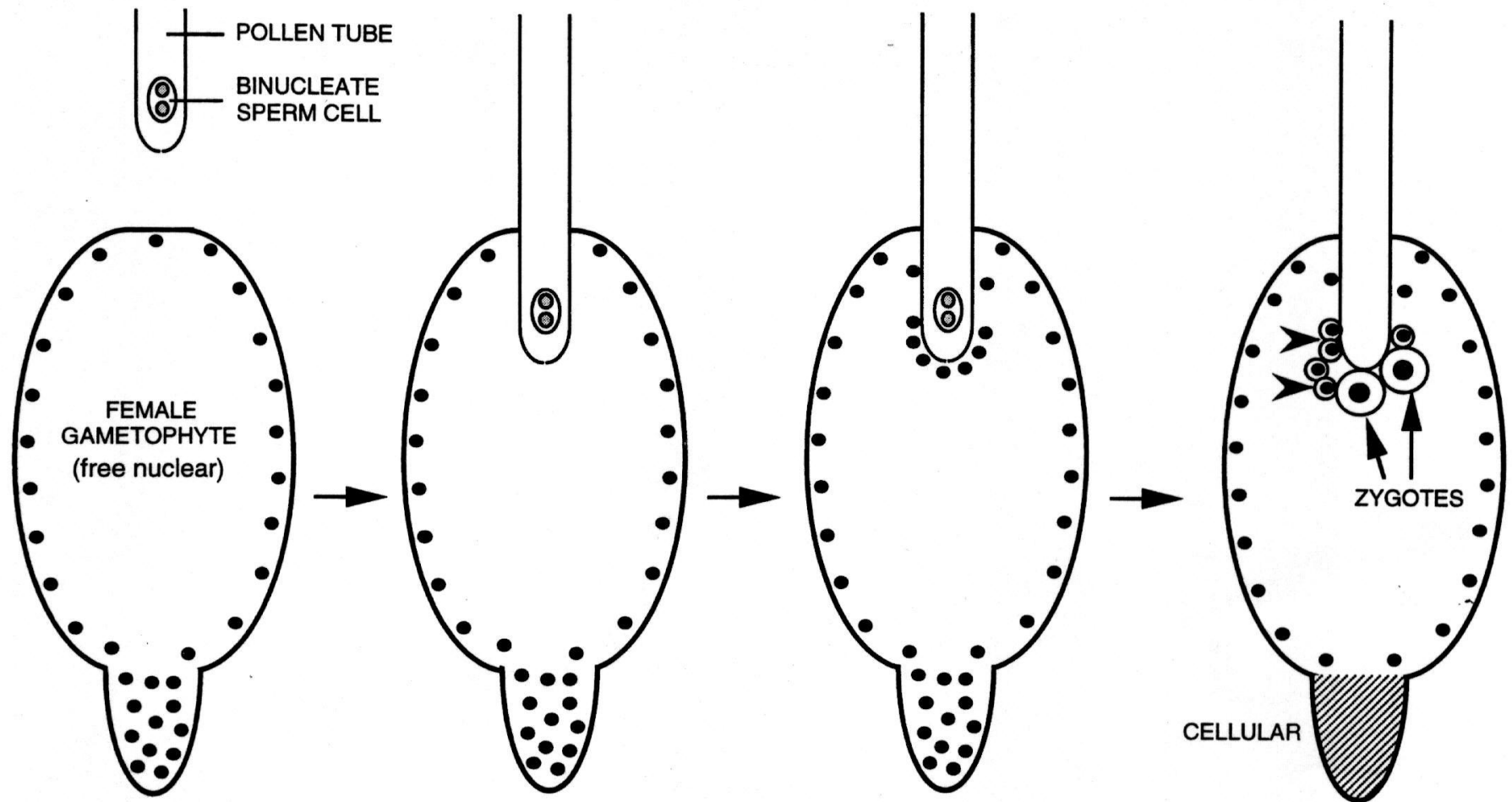
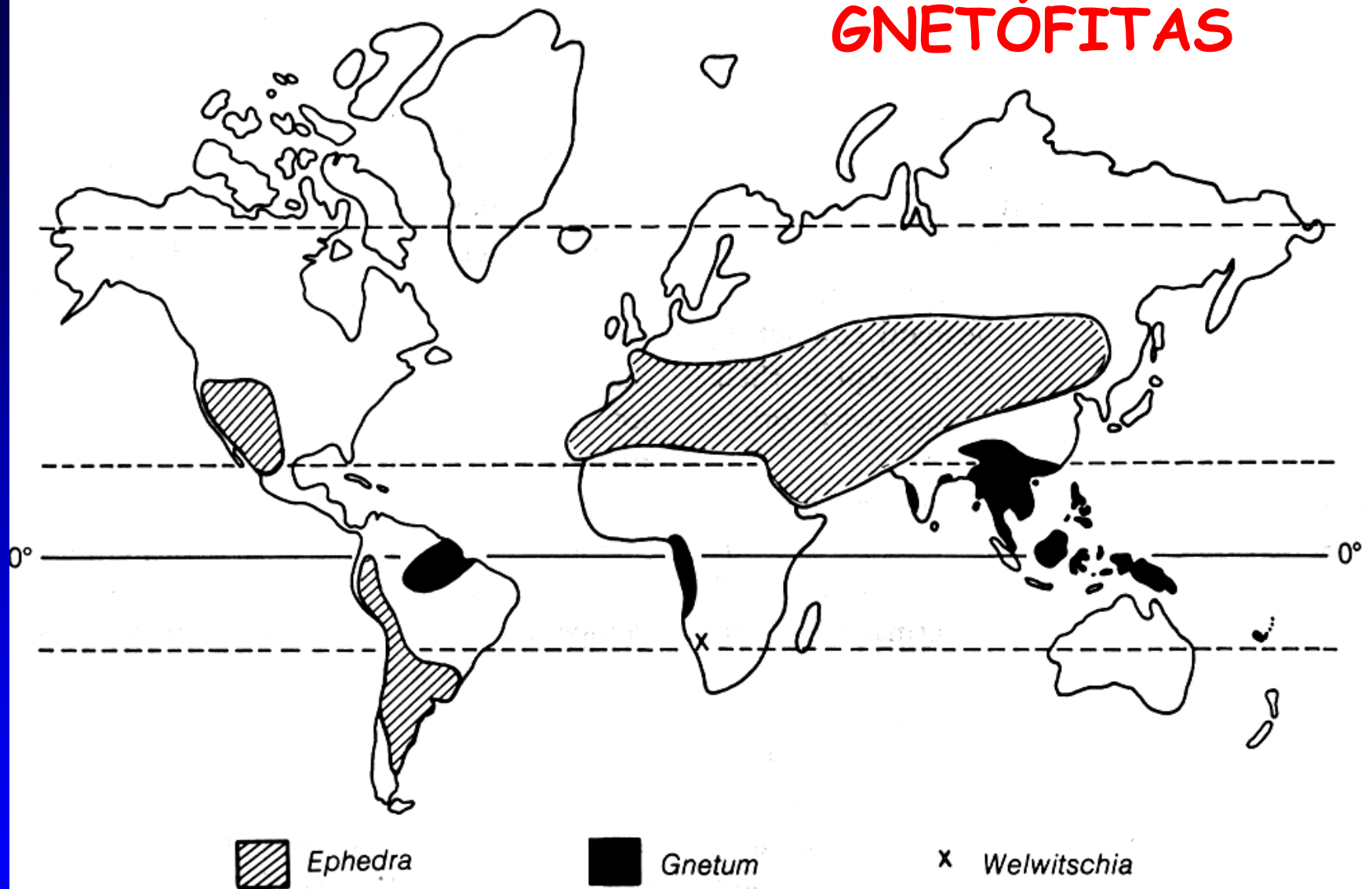


Fig. 33. Diagram illustrating double fertilization in *Gnetum gnemon*. Binucleate sperm cells are produced within pollen tubes that enter a coenocytic female gametophyte. Shortly after pollen tubes enter, free nuclei within the female gametophyte migrate around the tips of pollen tubes. None of the female nuclei differentiate as eggs and all represent potential gametes. Pollen tubes discharge both sperm nuclei into surrounding female cytoplasm and each sperm nucleus fuses with a separate female nucleus. Double fertilization results in the formation of two viable zygotes. Although unfertilized female nuclei may become cellular (arrowheads), they are clearly distinguishable from diploid zygotes. Concurrent with fertilization, the chalazal region of the female gametophyte becomes cellular and will eventually enlarge and serve to nourish developing embryos. As many as six pollen tubes may fertilize a single female gametophyte.

GNETÓFITAS



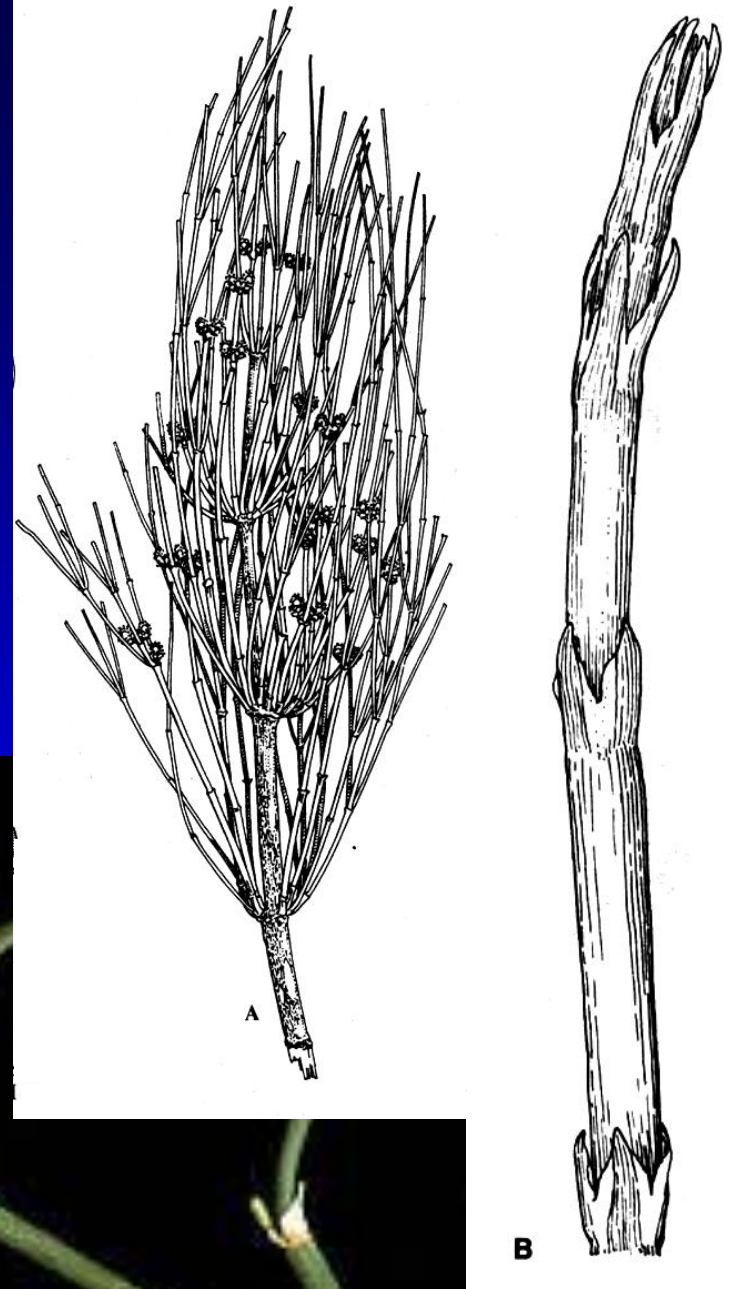
Distribuição dos gêneros *Ephedra*, *Gnetum* e *Welwitschia*
(Gifford & Foster 1989)

EPHEDRALES GNETÓFIAS

EPHEDRACEAE: *Ephedra* (50 spp.)

CARACTERES DIAGNÓSTICOS

- arbustos muito ramificados, geralmente escandentes
- ramos verticilados ; geralmente verdes e fotossintetizantes
- folhas opostas ou verticiladas, reduzidas ou escamiformes, fundidas basalmente numa bainha
- fonte da droga efedrina



EPHEDRACEAE - *Ephedra*

- plantas principalmente dióicas
- microstróbilo com agrupamentos de 1-10 anteróforos; brácteas opostas

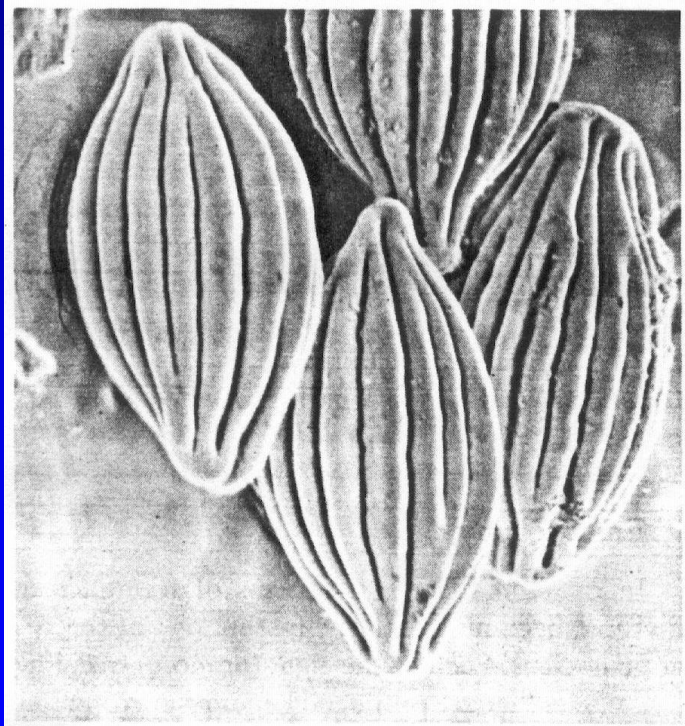
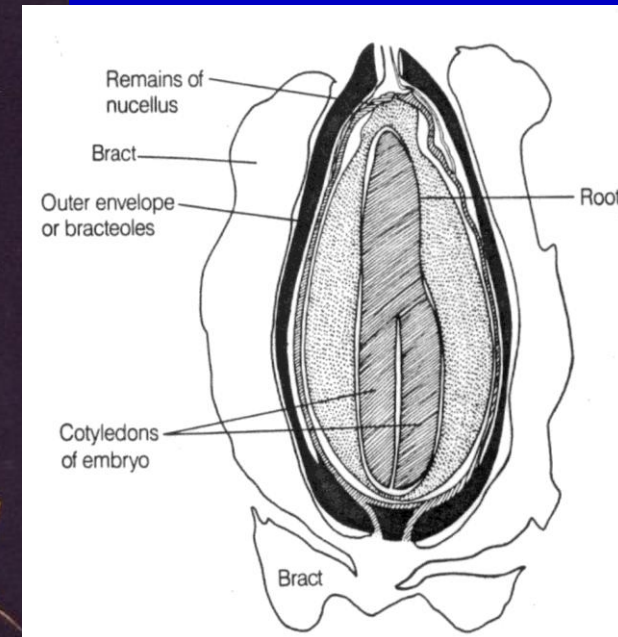
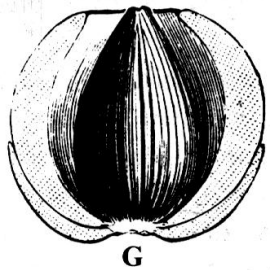
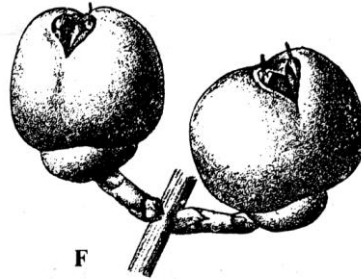
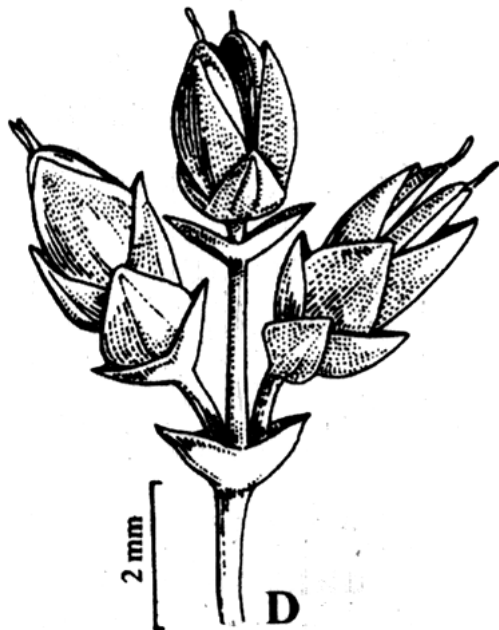
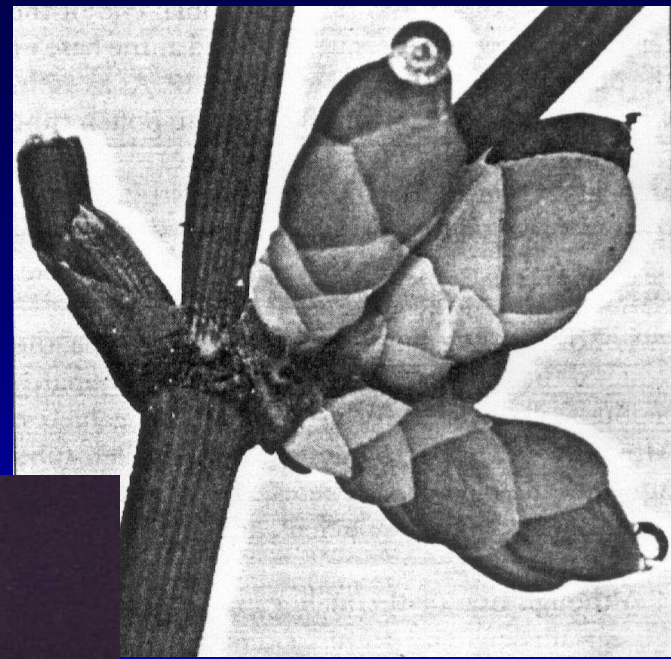


FIGURE 18-15 Scanning electron micrograph of a group of pollen grains of *Ephedra* sp. Note the prominent longitudinal (meridional) ridges characteristic of the pollen of this genus ($\times 700$).



-EPHEDRACEAE - *Ephedra*

- megastróbito com invólucro de brácteas opostas ao redor dos óvulos
- sementes 1-2(-3) por invólucro



GNETALES - GNETACEAE

GNETÓFITAS

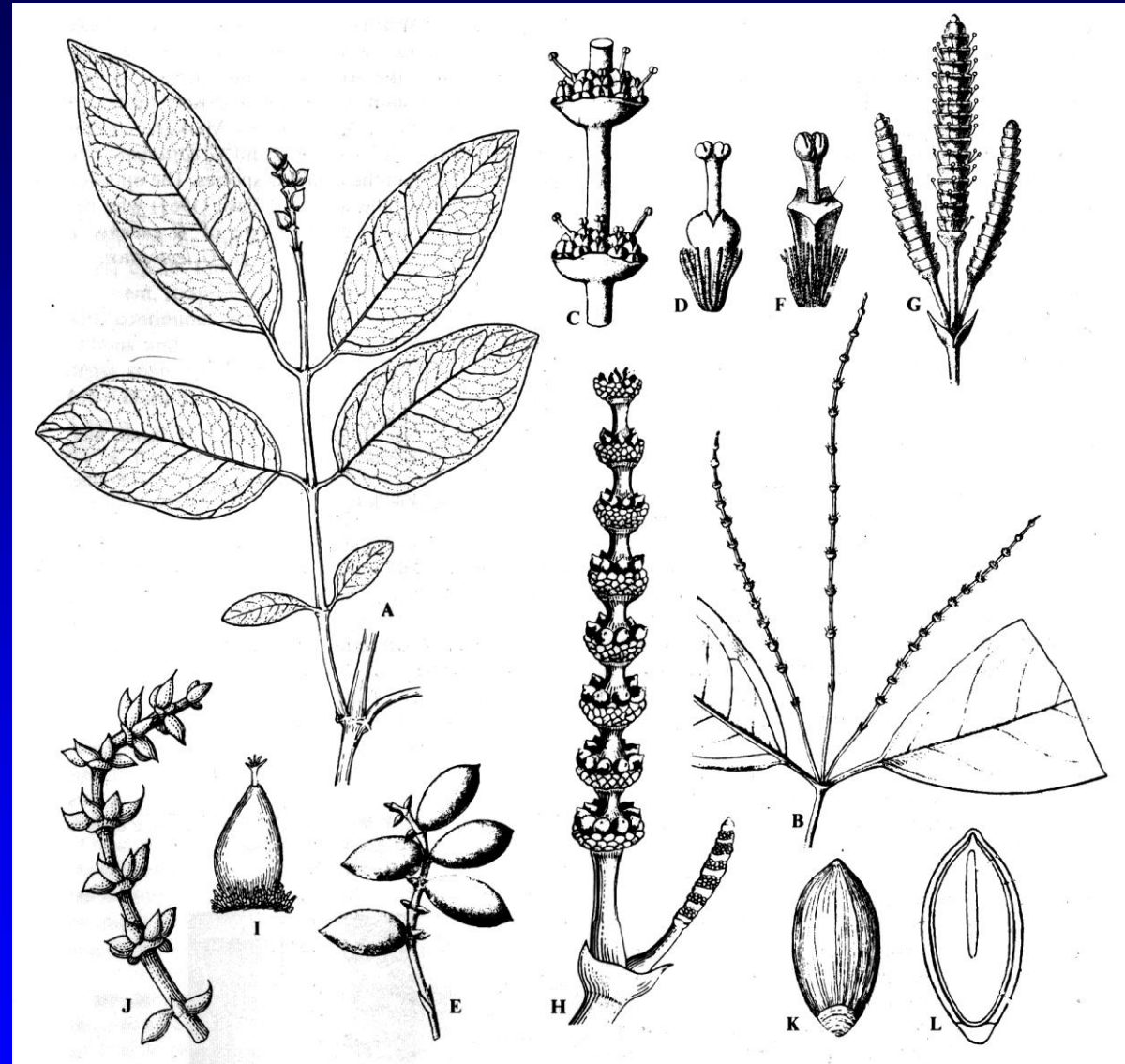
Gnetum (40 spp.)

CARACTERES DIAGNÓSTICOS

lianas lenhosas,
raramente árvores
(*Gnetum gnemon*)
ou arbustos

- folhas simples,
largas e opostas;
com nervação
reticulada

- plantas dióicas



Gnetum: A. *G. indicum*; B -E. *G. africanum*; F, *G. G. latifolium*; H-L. *G. gnemon* (Kubitzki 1990)

Microstróbilo



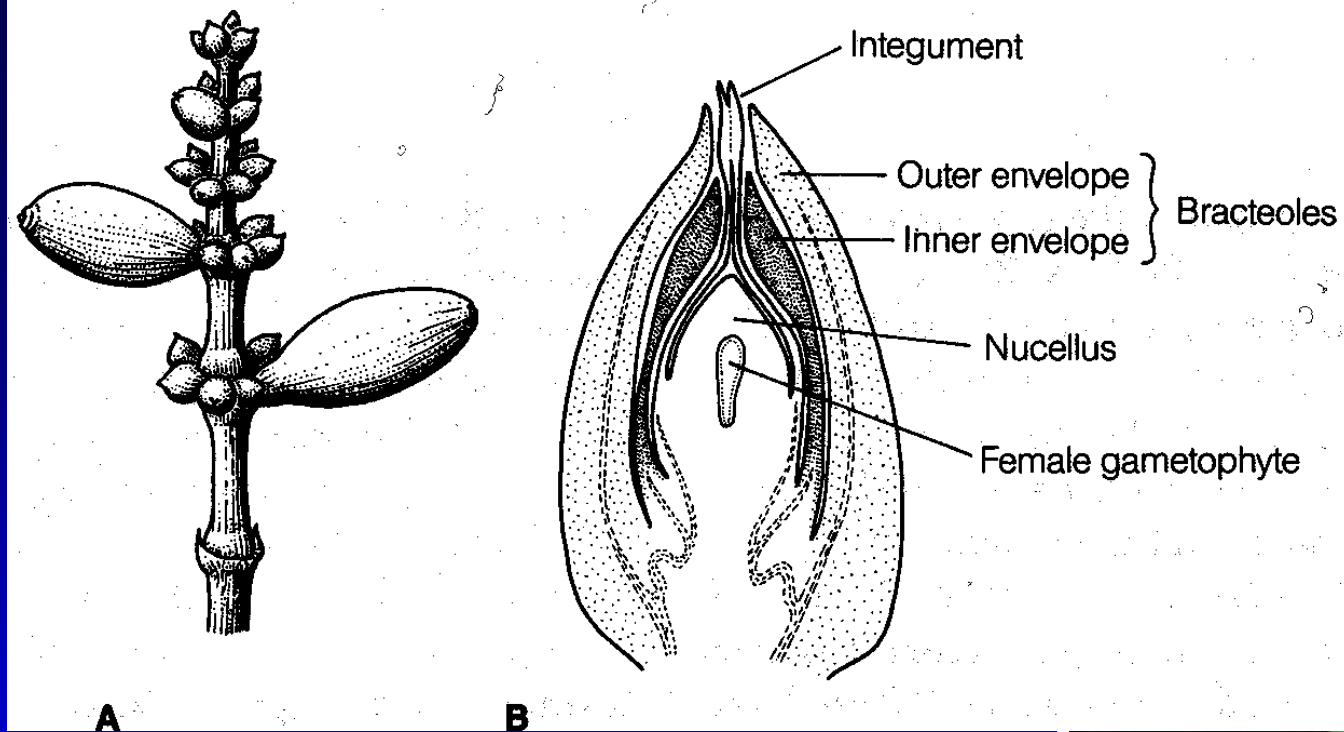
GNETÓFITAS
GNETACEAE
Gnetum 40 spp.

Lianas de
florestas
úmidas



GNETACEAE

Gnetum



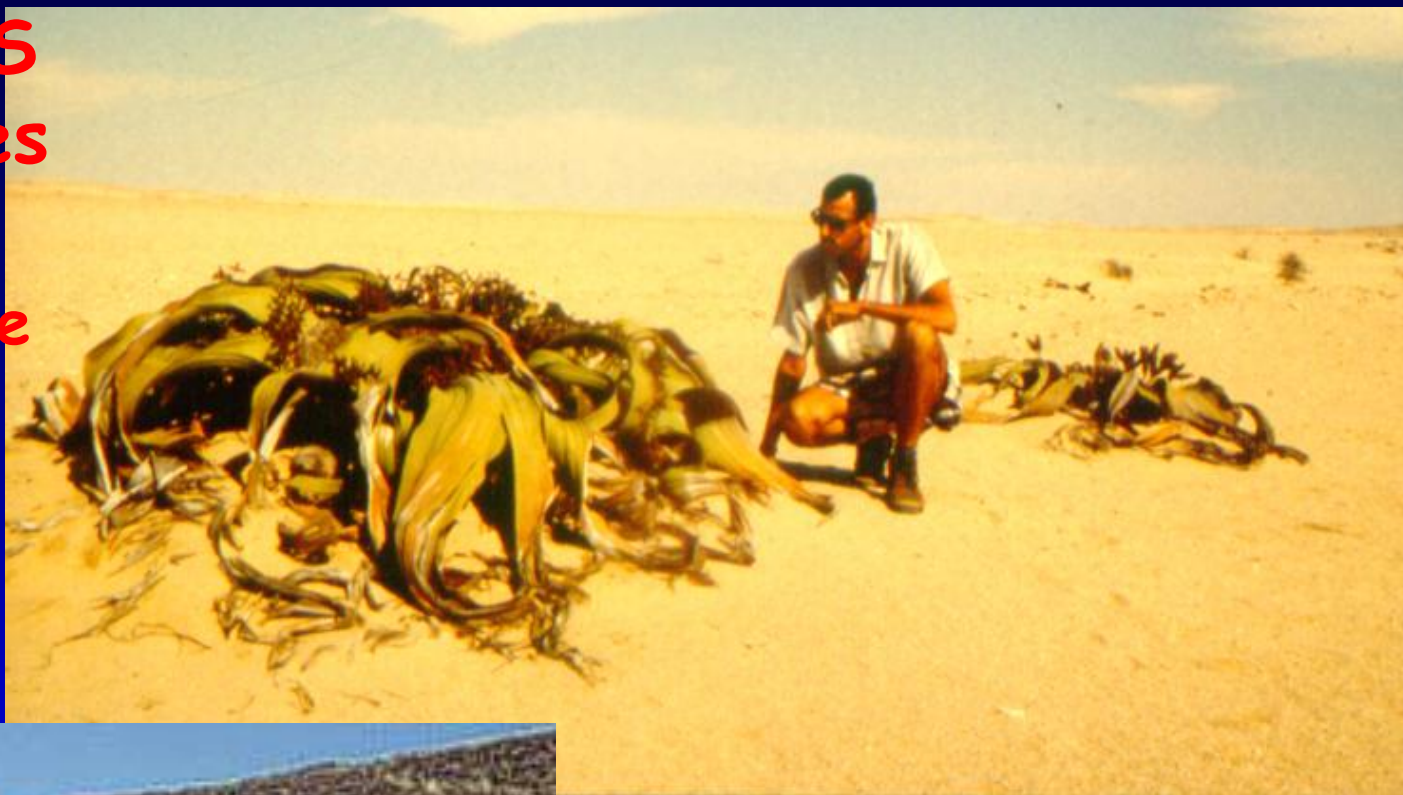
megastróbito com sementes carnosas

GNETÓFITAS

Welwitschiales

Welwitschiaceae

Welwitschia mirabilis



WELWITSCHIALES

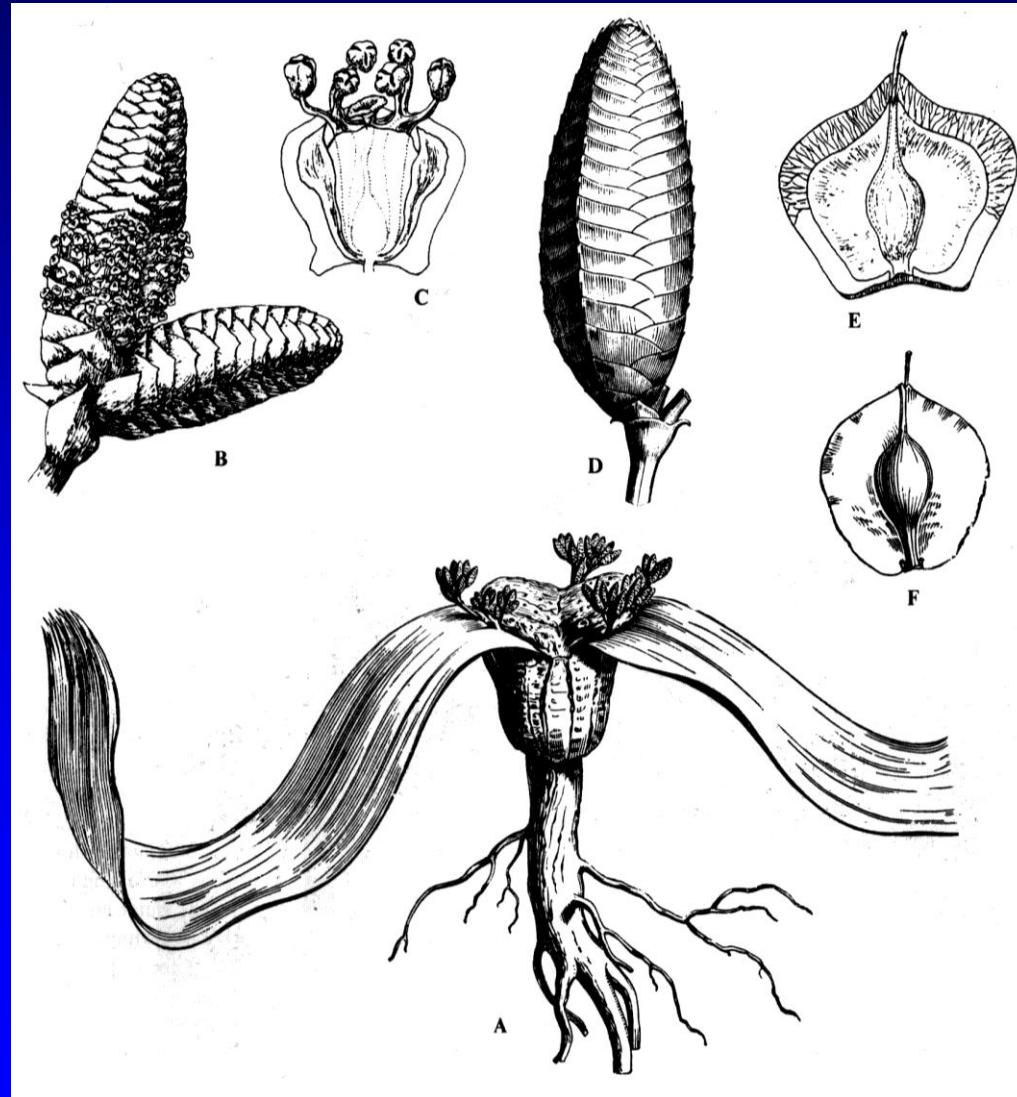
GNETÓFITAS

WELWITSCHIACEAE - *Welwitschia mirabilis*

CARACTERES DIAGNÓSTICOS

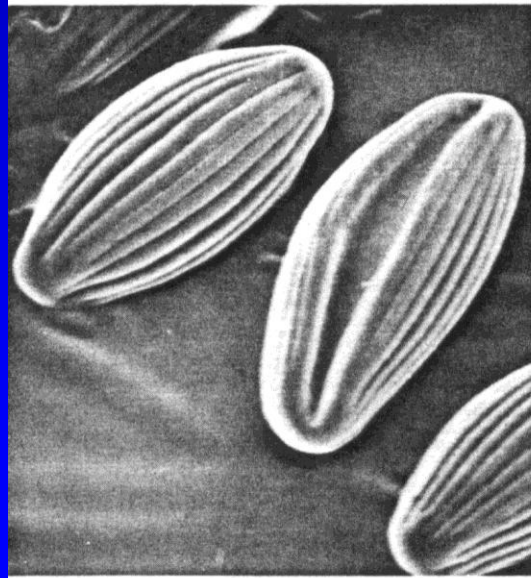
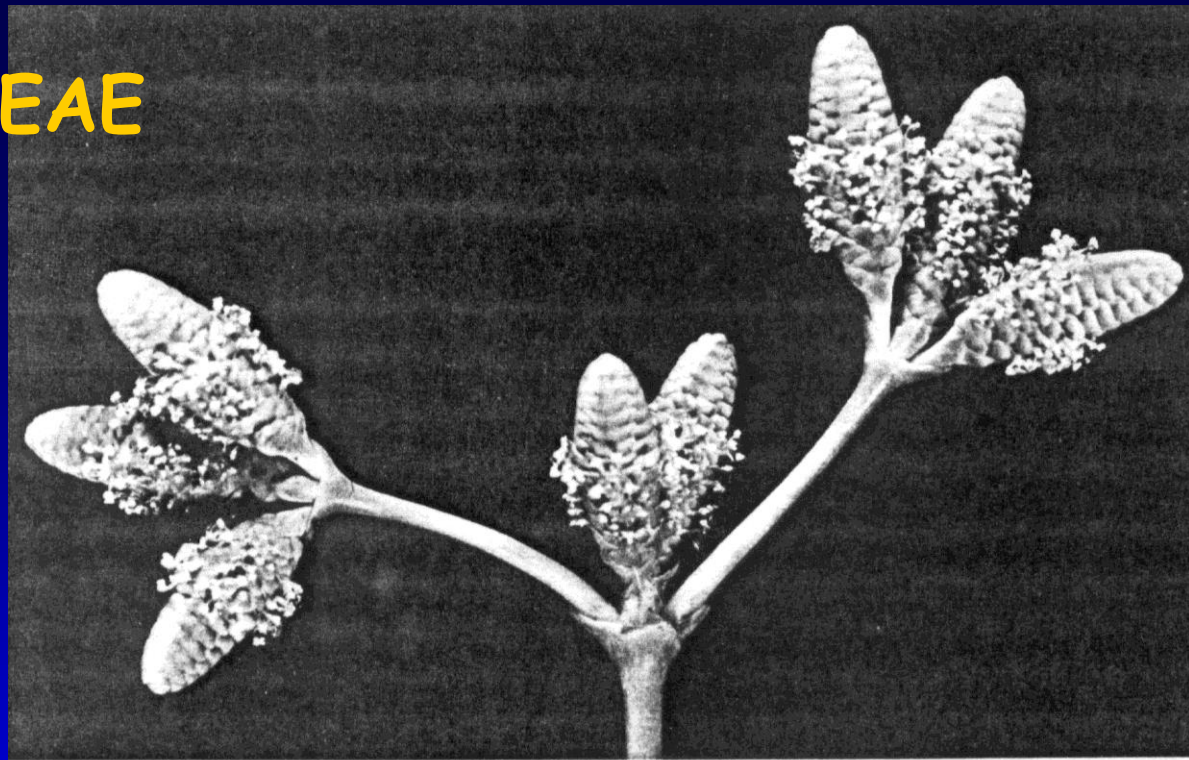
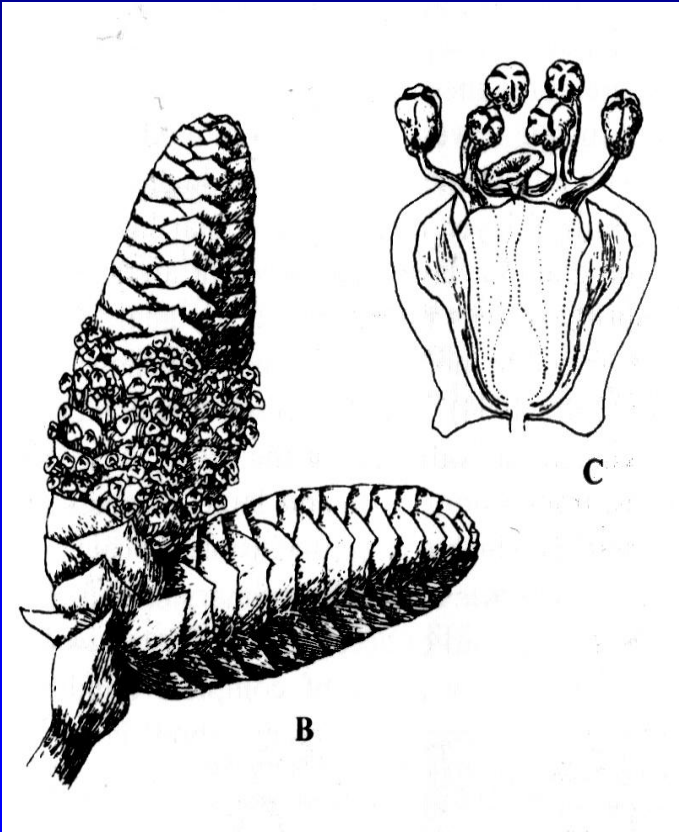
- caule curto, muito lenhoso e não ramificado
- 2 enormes folhas em forma de fita
- nervuras paralelas
- planta dióica
- óvulo envolto por brácteas

Kubitzki 1990



WELWITSCHIACEAE

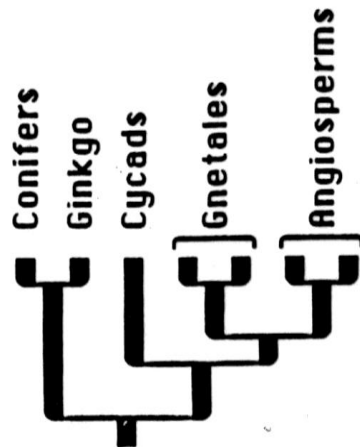
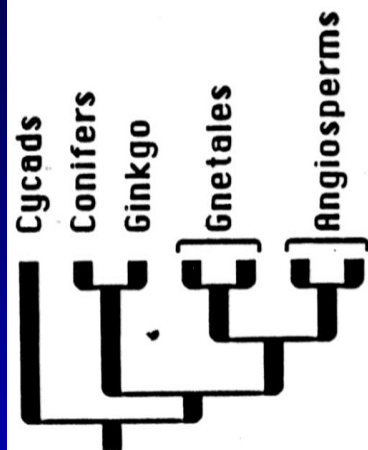
Welwitschia



Welwitschia

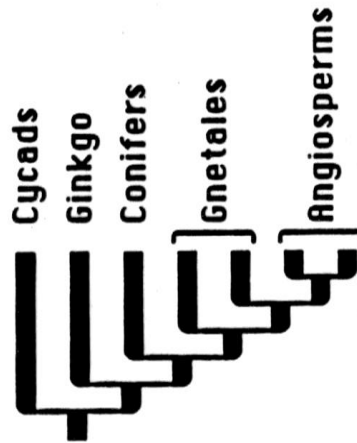
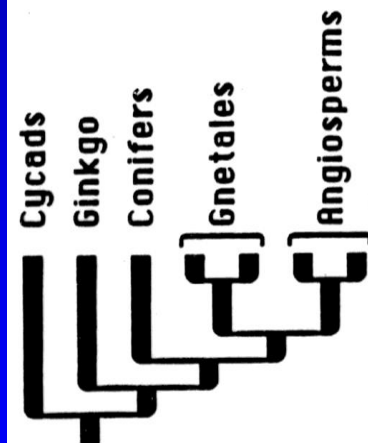
FIGURE 18-22 *Welwitschia mirabilis*. A, portion of a microsporangiate shoot system showing strobili, bract and protruding microsporangiophores; B, pollen grain note median longitudinal furrow (sulcus) ($\times 700$). [A courtesy of Dr. D. W. Stevenson.]

Morphology



Crane 1985
Doyle & Donoghue 1986, 1992
Doyle 1996

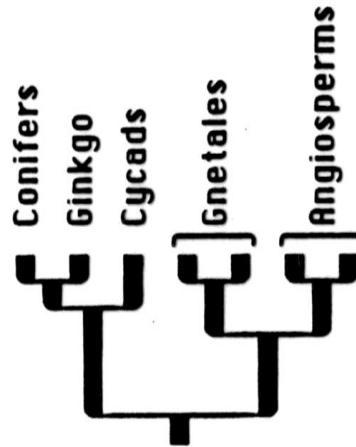
Doyle & Donoghue 1986, 1992
Doyle 1996



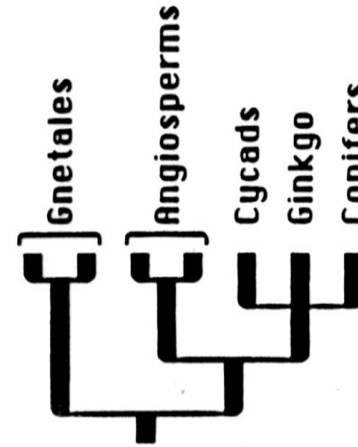
Nixon et al. 1994

Loconte & Stevenson 1990
Doyle & Donoghue 1992 (R)

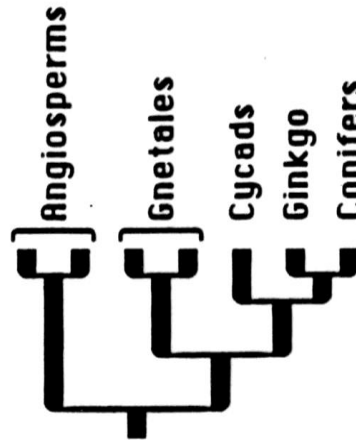
Molecular data



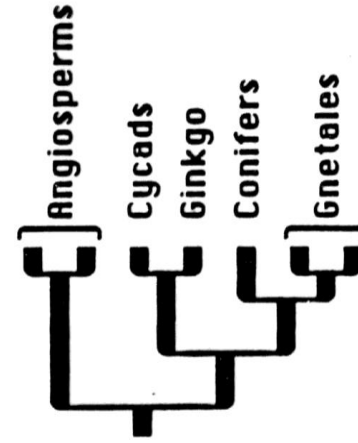
rRNA, Hamby & Zimmer 1992



rRNA, Hamby & Zimmer 1992
rbcL, Albert et al. 1994



rbcL, Hasebe et al. 1992
28S, Stefanovic 1996



cpITS, Goremykin et al. 1996
18S, Chaw et al. 1997
coxI, Bowe & DePamphilis 1997

Figure 3 Relationships among living groups of seed plants found in different analyses of morphological and molecular data

Chaw *et al.* 2000

rbcl

mt SSU rDNA

nu SSU rDNA

Evidências moleculares
de ancestralidade comum
das Gnetófitas
com a família Pinaceae!

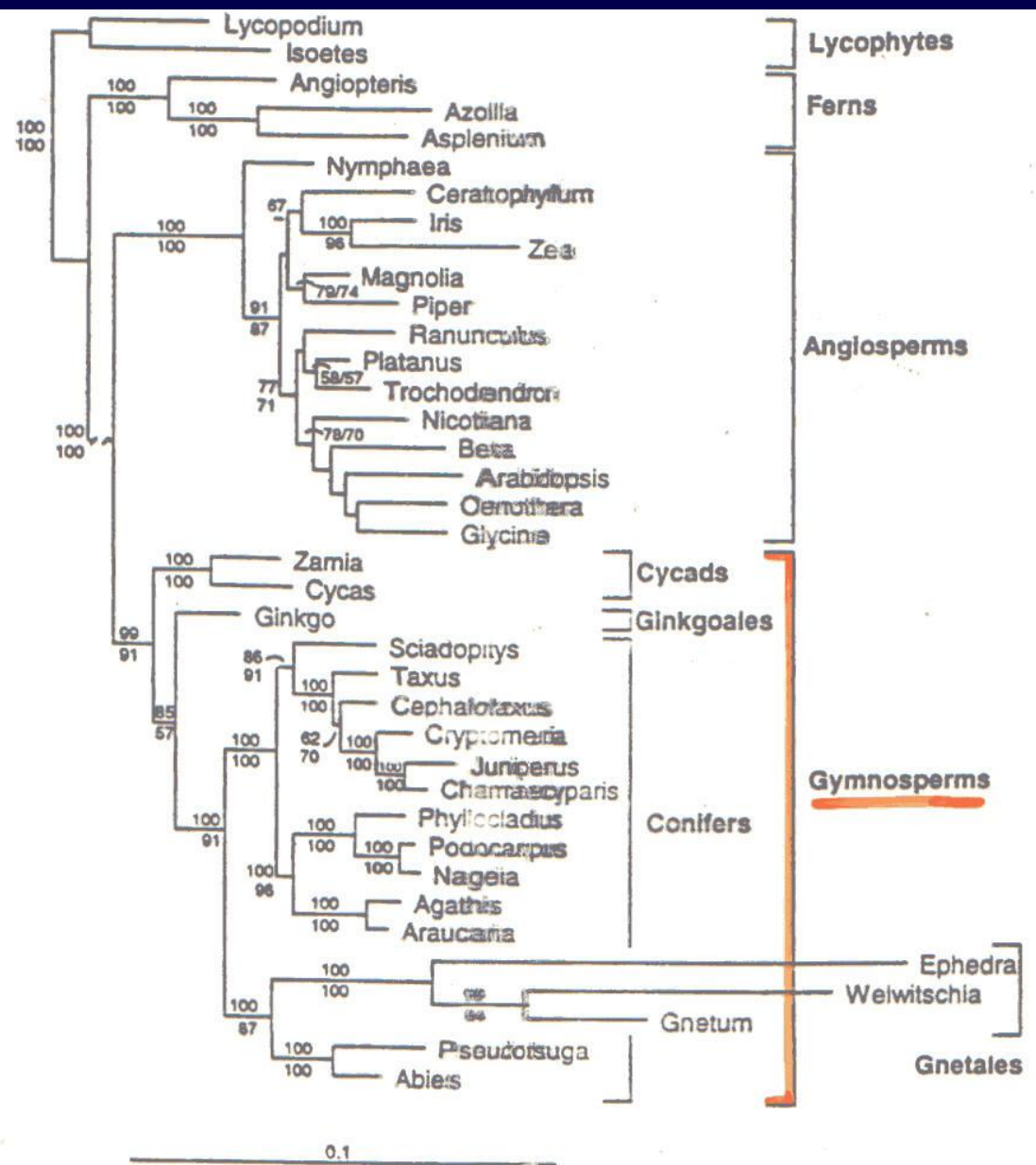
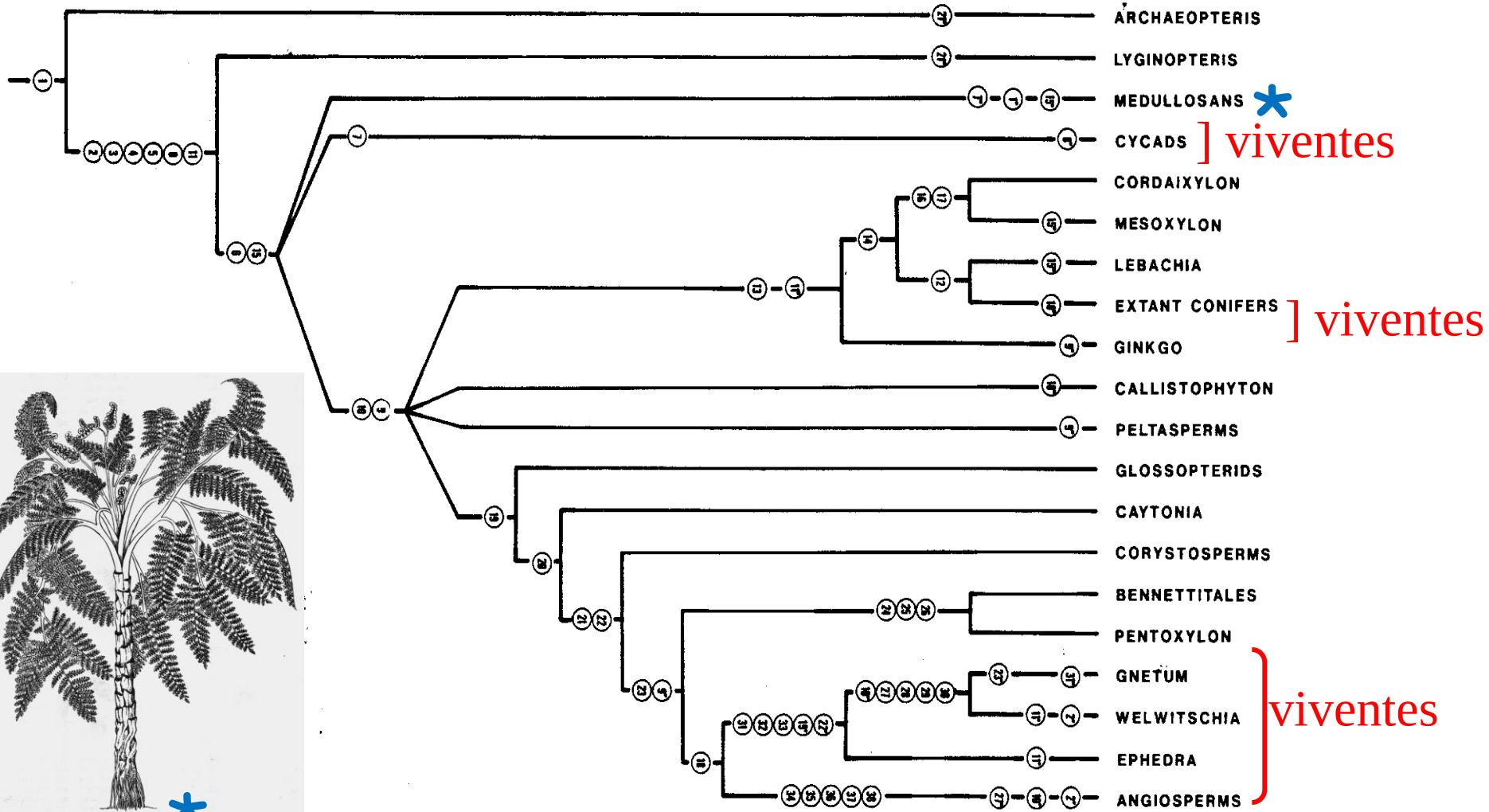


Fig. 4. Analysis of a combined dataset of all three genes. The ML tree shown has a log likelihood = -35,774.90 and was estimated by using a ti/tv ratio = 2.1. All BS values >50% are shown above (ML no-rates) and below (MP) nodes.

Acesso à informação paleontológica (campo praticamente exclusivo da morfologia)



Medullosa

Crane 1985

Specht & Bartlett
2009

baseado em Doyle
2008

e Soltis et al. 2008

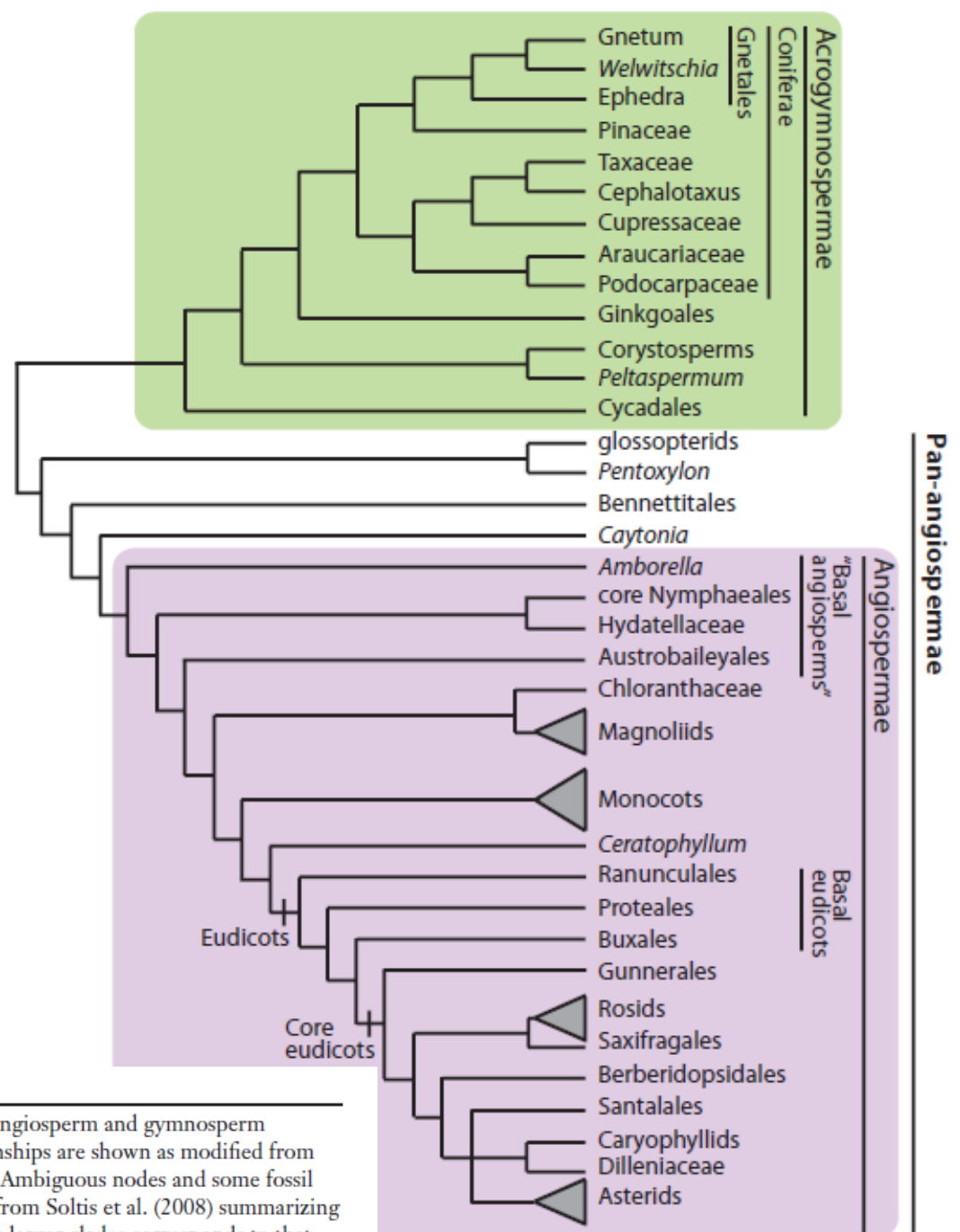


Figure 1

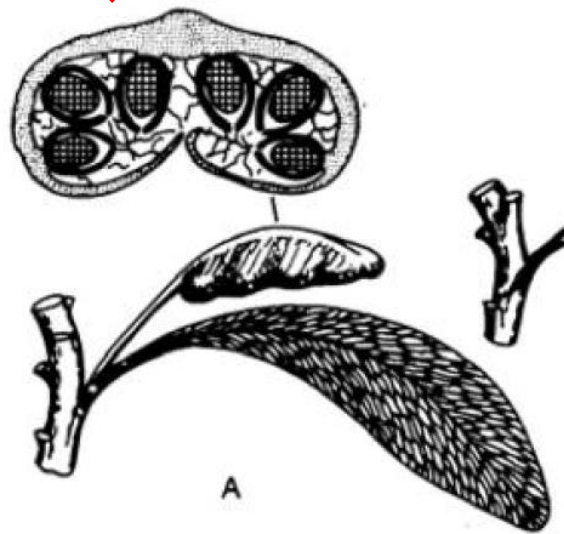
Summary topology of current views and recent advances in deep-level angiosperm and gymnosperm relationships. Acrogymnospermae and stem lineage angiosperm relationships are shown as modified from Doyle's (2008) analysis including fossil taxa with a molecular backbone. Ambiguous nodes and some fossil taxa are excluded if not discussed in text. Angiosperm relationships are from Soltis et al. (2008) summarizing Jansen et al. (2007) and Moore et al. (2007). Terminology used to define larger clades corresponds to that used throughout the text.

Grupos fósseis com sementes que compoariam o clado
Pan-angiospermas segundo **Specht & Bartlett 2009**

Pentoxylum; CAYTONIALES - Permiano ao Triássico;

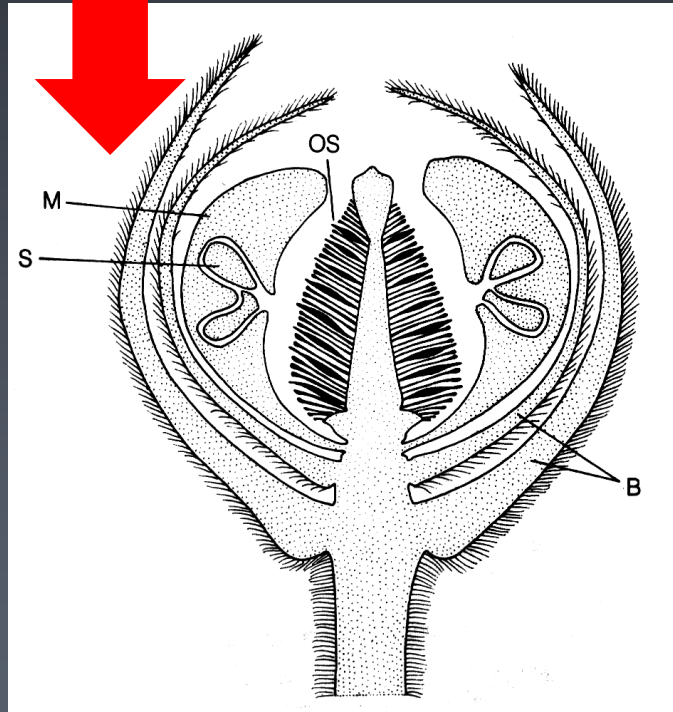
GLOSSOPTERIDALES - Triássico ao Cretáceo;

BENNETTITALES - Triássico ao Cretáceo



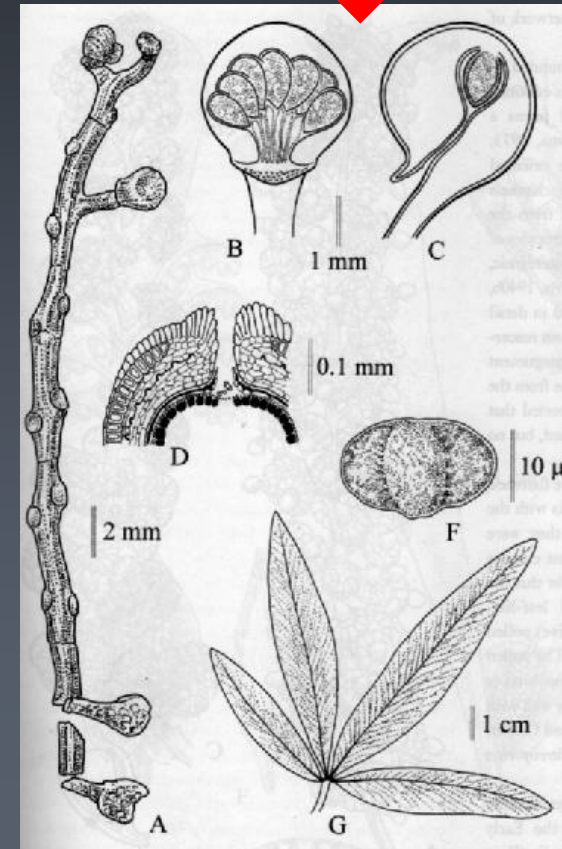
Glossopterid

Doyle 2008 apud
Retallack & Dilcher 1981



Williamsoniella

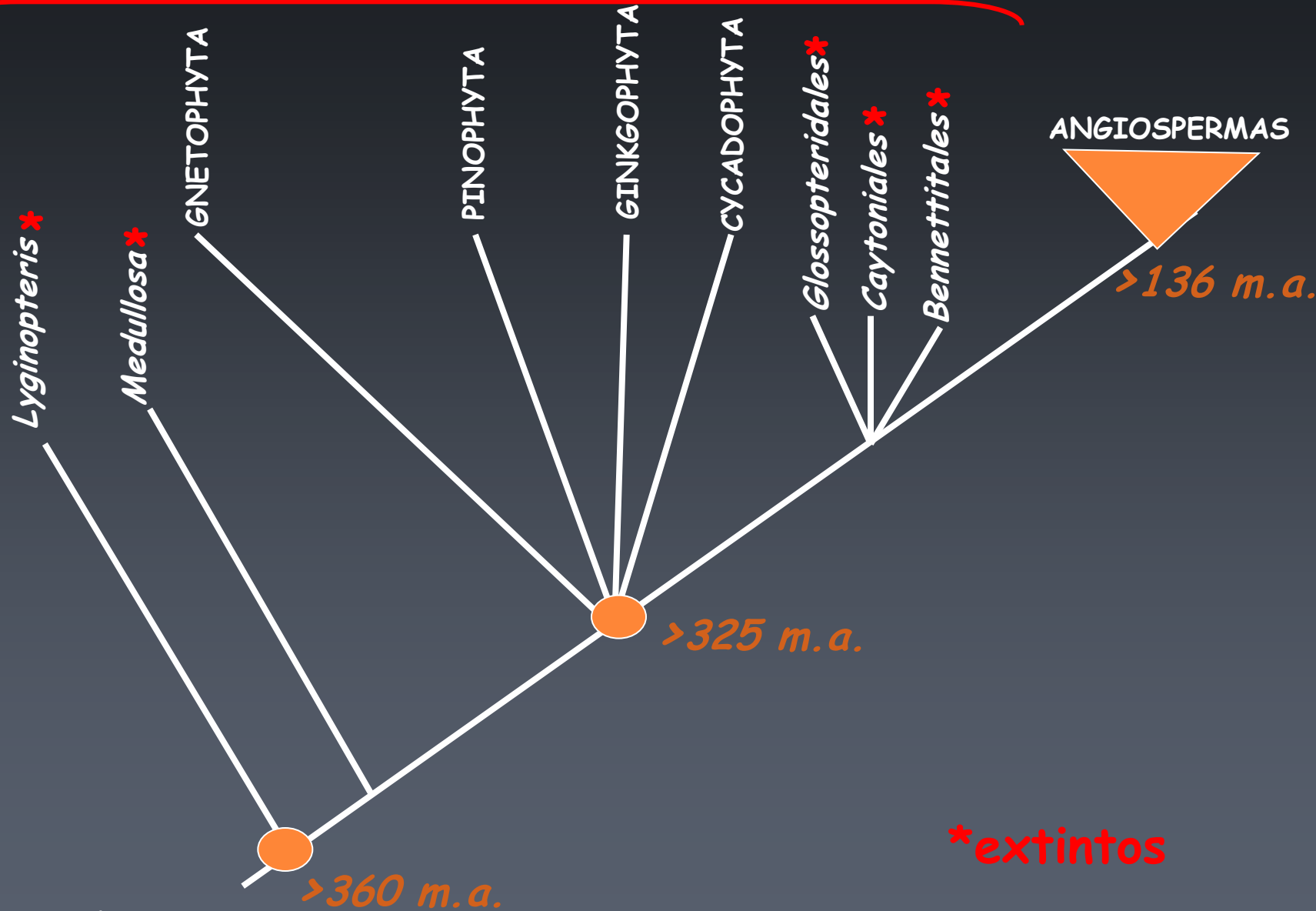
Gifford & Foster 1989



Caytonia, Friis et al. 2011

ESPERMATÓFITAS

"GIMNOSPERMAS"



***extintos**

