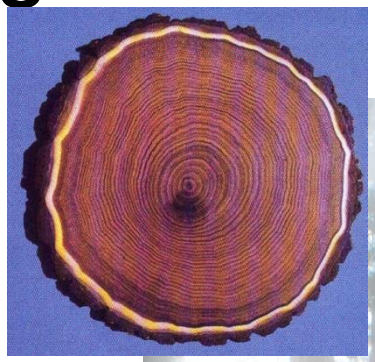
NOVIDADES EVOLUTIVAS DAS ESPERMATÓFITAS com ênfase na reprodução

PLANTAS COM SEMENTES
Espermatófitas ou fanerógamas

Plantas com sementes pertencem à linhagem das LIGNÓFITAS

Solanum



Rhododendron

Sequoiadendron

LIGNÓFITAS ou Plantas Lenhosas

ESPERMATÓFITAS ou Plantas com sementes

Gimnospermas

Cicadófitas Ginkgófitas Pinófitas Gnetófitas

ANGIOPERMAS

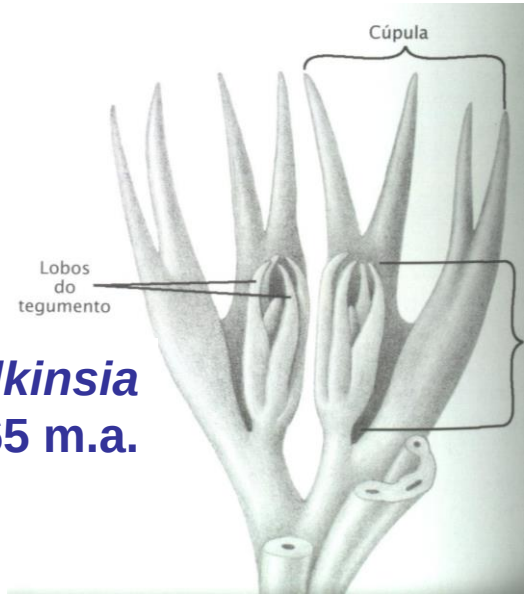
Plantas com flores e frutos

Archaeopteris*

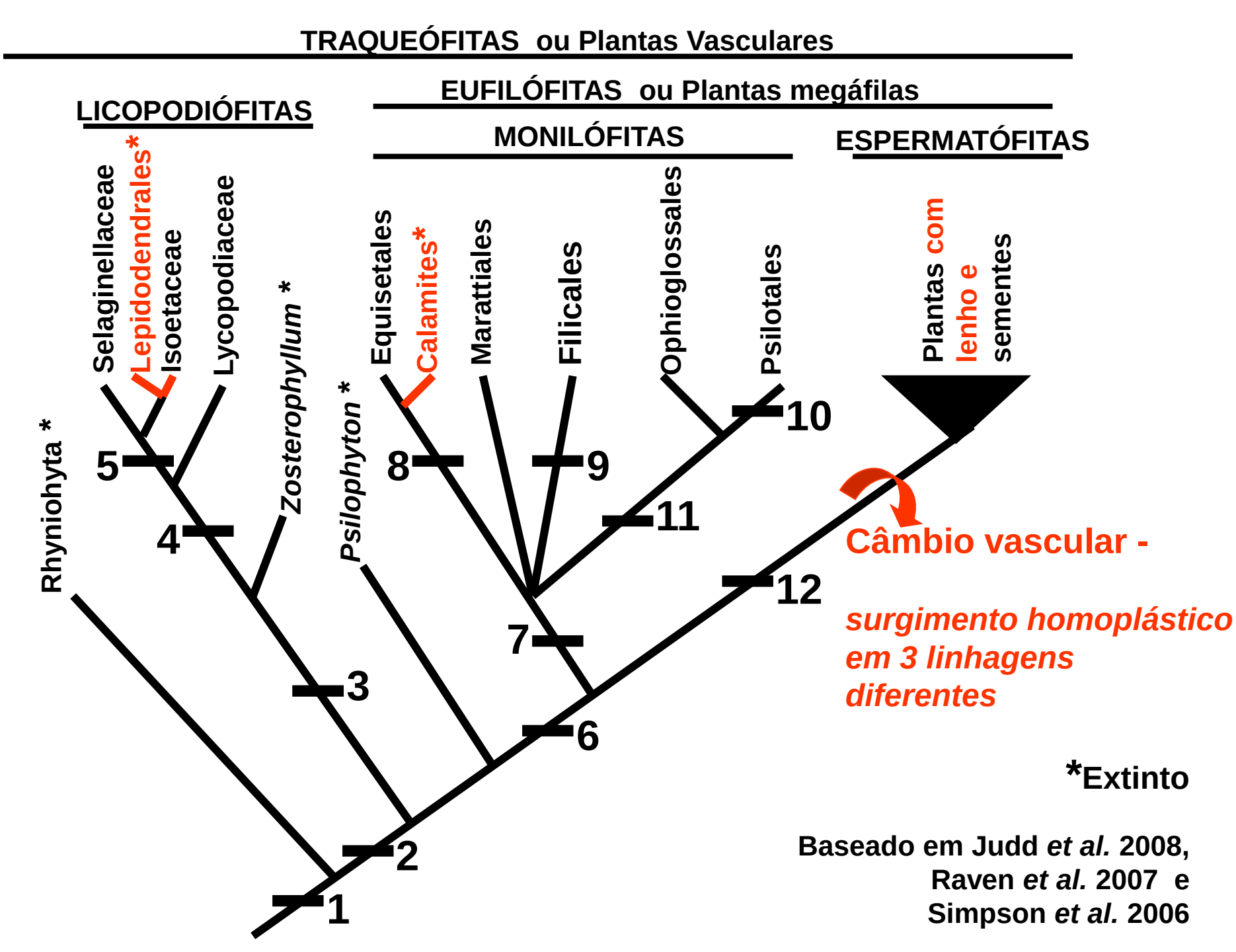
Aneurófitas*

SEMENTE

CÂMBIO **c. 380 m.a.**



Elkinsia
c. 365 m.a.


TRAQUEÓFITAS ou Plantas Vasculares
LICOPODIÓFITAS
EUFILÓFITAS ou Plantas megáfilas
MONILÓFITAS
ESPERMATÓFITAS
Selaginellaceae
Lepidodendrales*
Isoetaceae
Lycopodiaceae
Zosterophyllum *
Rhyniohyta *
Psilophyton *
Equisetales
Calamites*
Marattiales
Filicales
Ophioglossales
Psilotales
Plantas com lenho e sementes
1
2
3
4
5
6
7
8
9
10
11
12
Câmbio vascular -
surgimento homoplástico em 3 linhagens diferentes
*Extinto
Baseado em Judd et al. 2008,
Raven et al. 2007 e
Simpson et al. 2006

Licopodiófitas Progimnospermas Equisetales

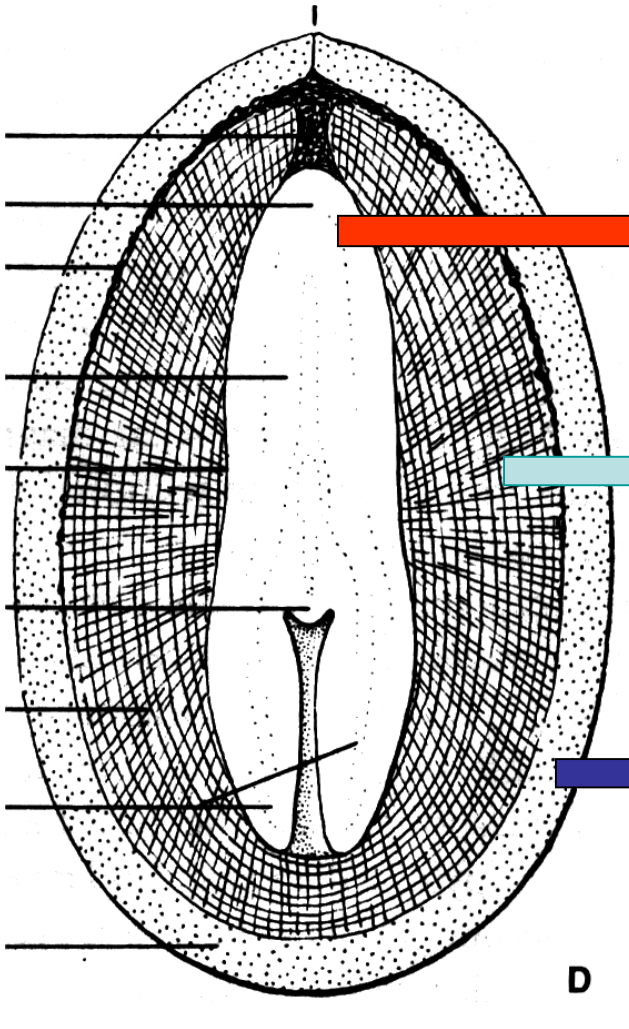
Floresta do Carbonífero (360-295 m.a.)

Giffortd & Foster 1989

Plantas com câmbio eram Licopodiófitas, Equisetales e Lignófitas com ou sem sementes

Lignófitas que sobreviveram no Mesozóico foram as espermatófitas

Lignófitas espermatófitas: SEMENTE

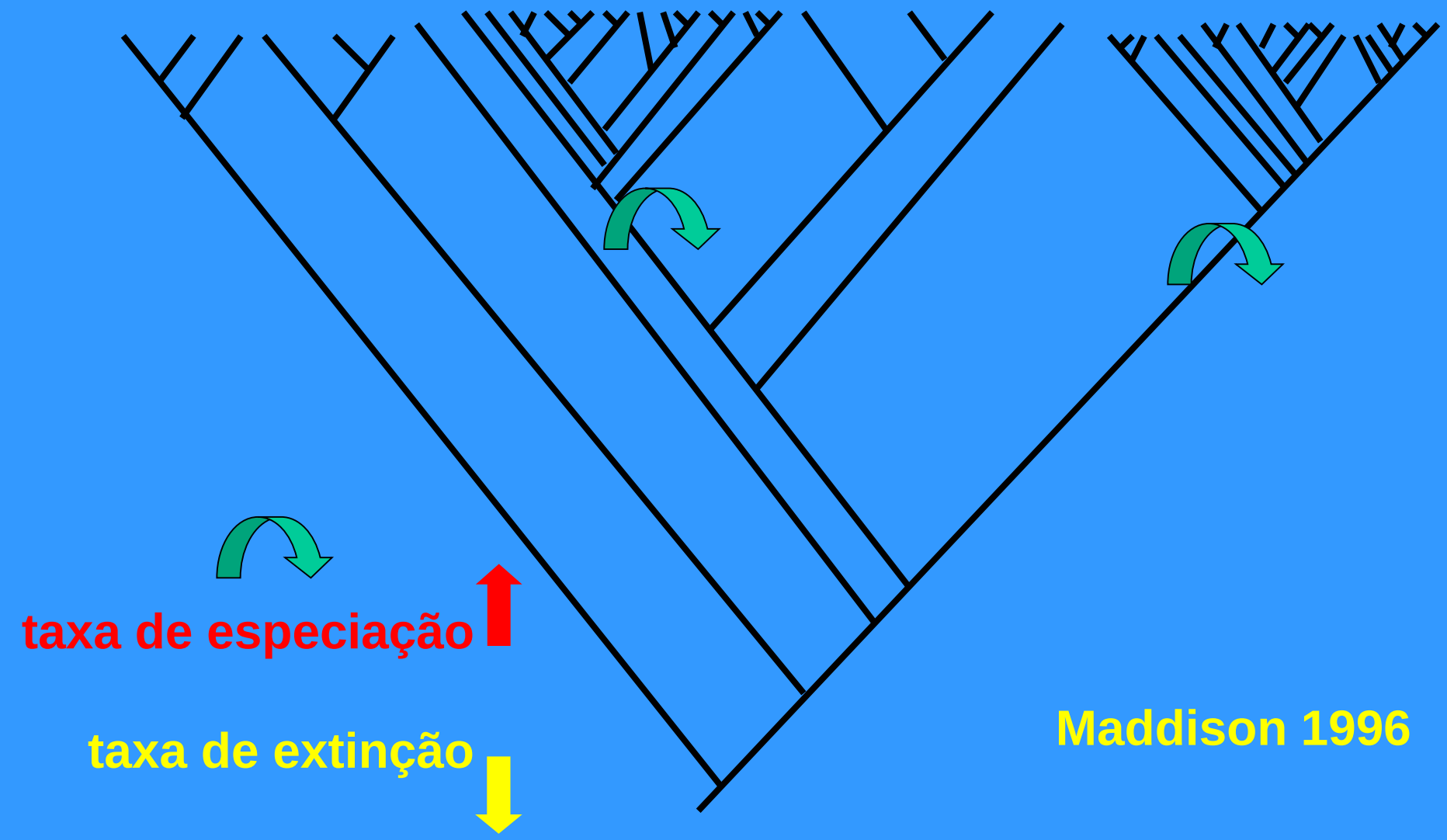


Embrião

Tecido nutritivo

Tegumento protetor

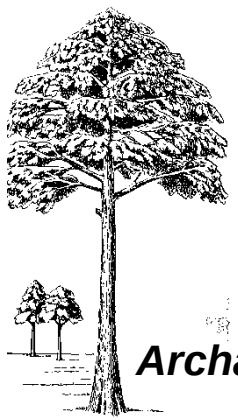
Inovações-chave



Maddison 1996

LIGNÓFITAS ou Plantas Lenhosas

ESPERMATÓFITAS ou Plantas com sementes



*Archaeopteris**

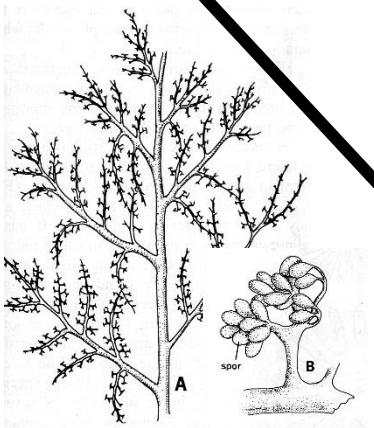
“Gimnospermas”

ANGIOPERMAS

Cicadófitas Ginkgófitas Pinófitas Gnetófitas

Plantas com flores e frutos

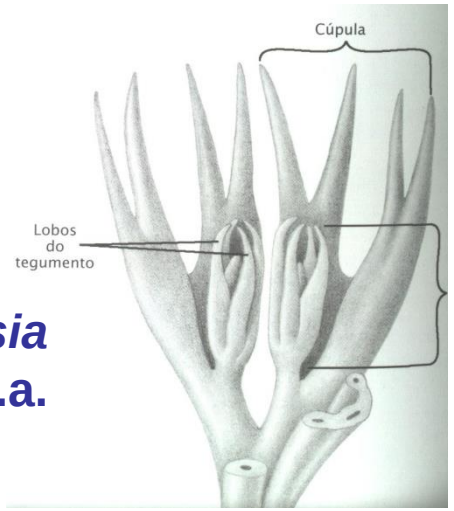
Aneurófitas*



Aneurophyton

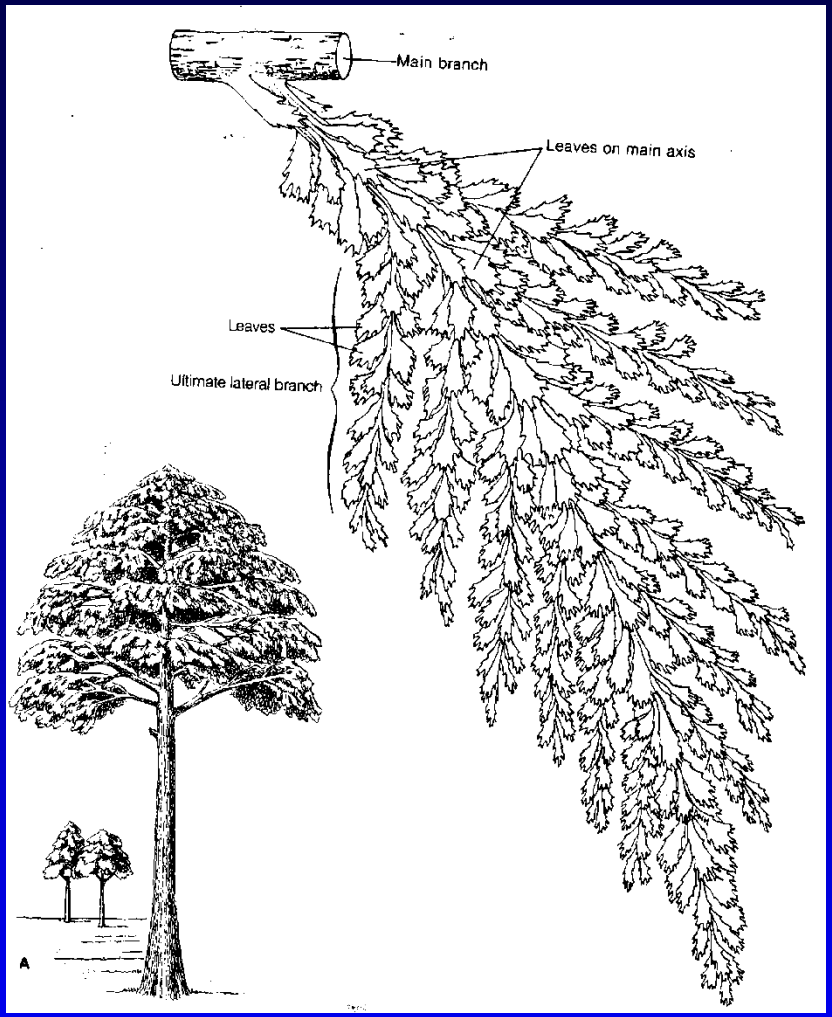
SEMENTE ***Elkinsia***

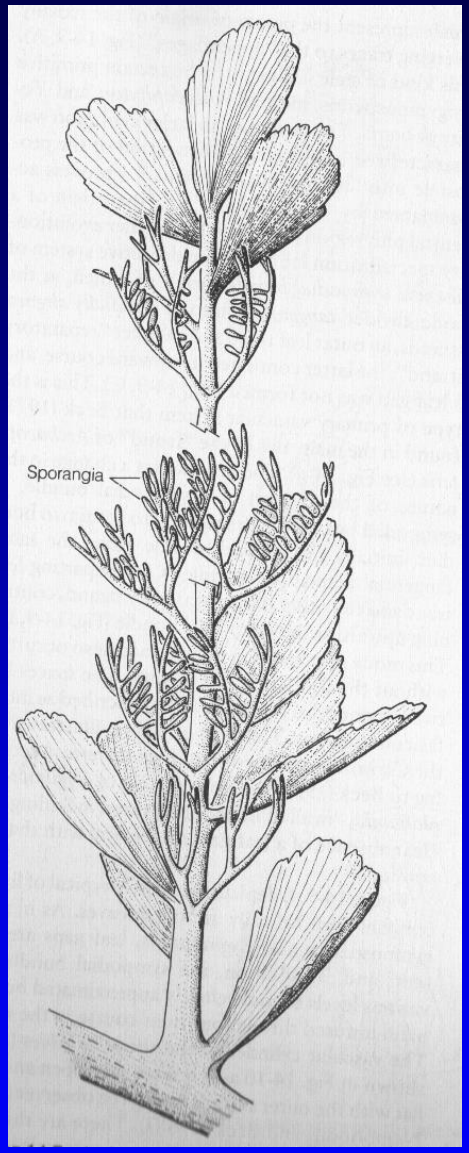
c. 365 m.a.

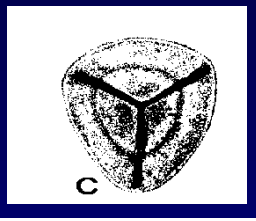


?

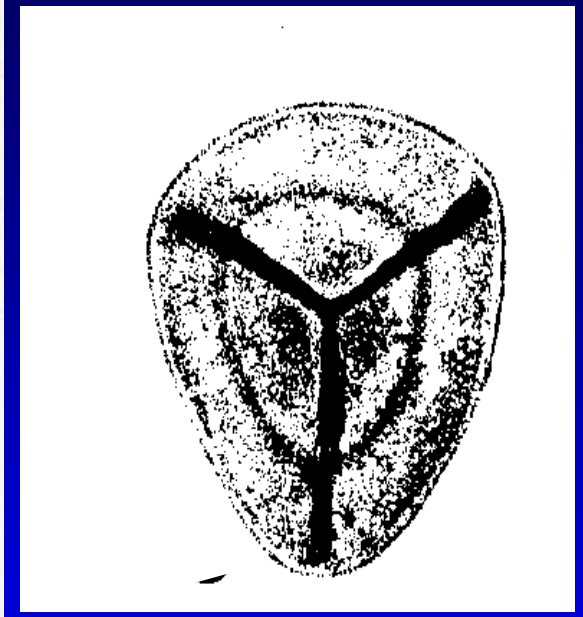
CÂMBIO **c. 380 m.a. (Devoniano)**







micrósporo



megásporo

Heterosporia

Archaeopteris

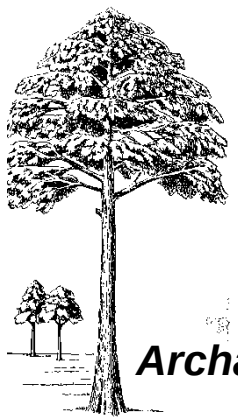
Progymnospermophyta

Devoniano Superior

Gifford & Foster 1988

LIGNÓFITAS ou Plantas Lenhosas

ESPERMATÓFITAS ou Plantas com sementes



*Archaeopteris**

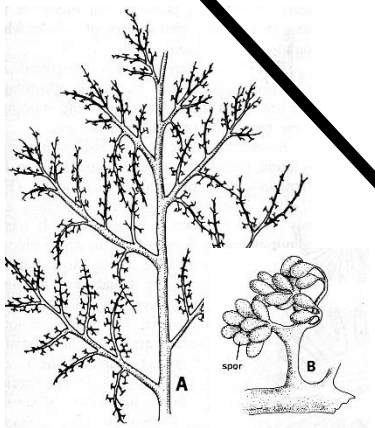
Gimnospermas

ANGIOPERMAS

Cicadófitas Ginkgófitas Pinófitas Gnetófitas

Plantas com flores e frutos

Aneurófitas*



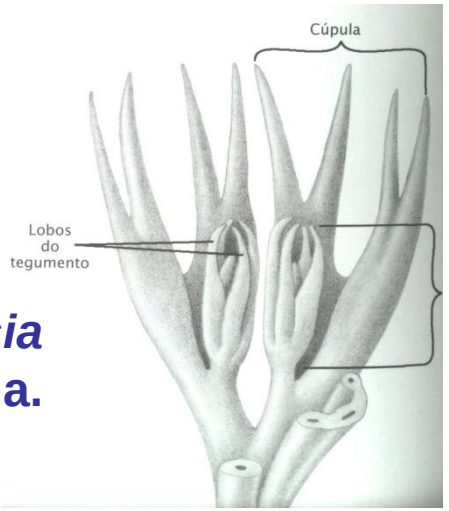
Aneurophyton

SEMENTE ***Elkinsia***

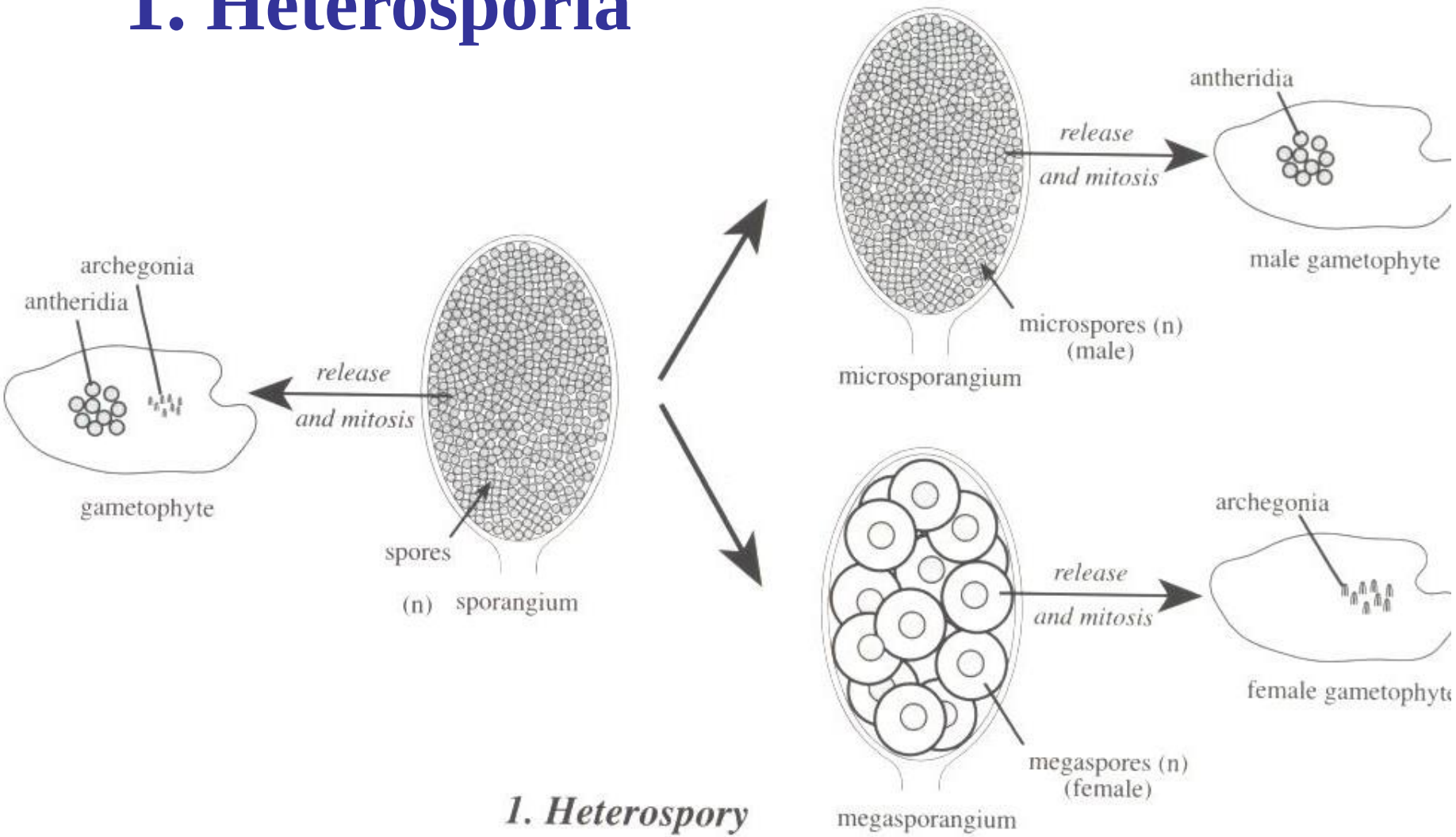
c. 365 m.a.

Heterosporia

CÂMBIO **c. 380 m.a. (Devoniano)**



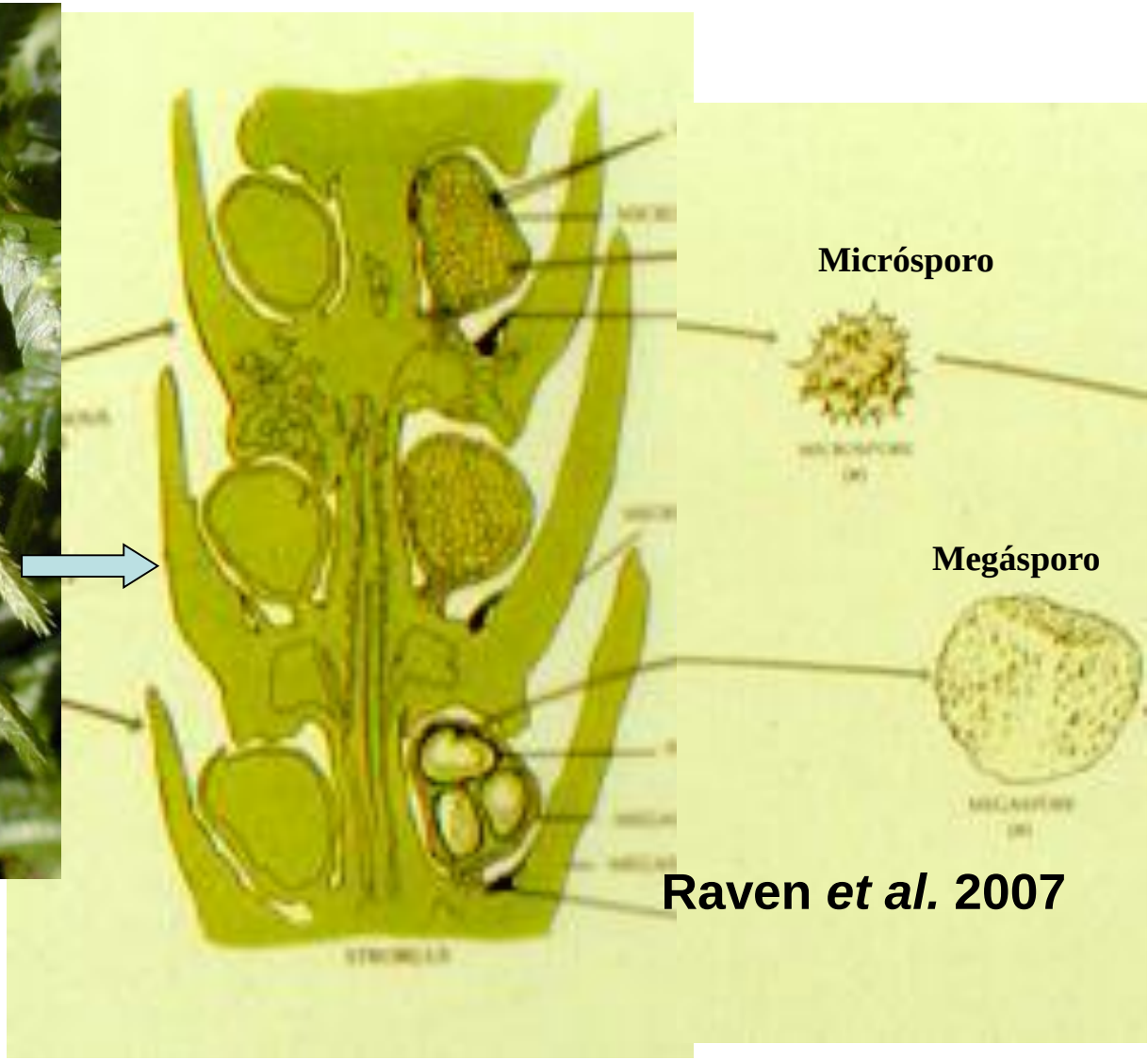
1. Heterosporia



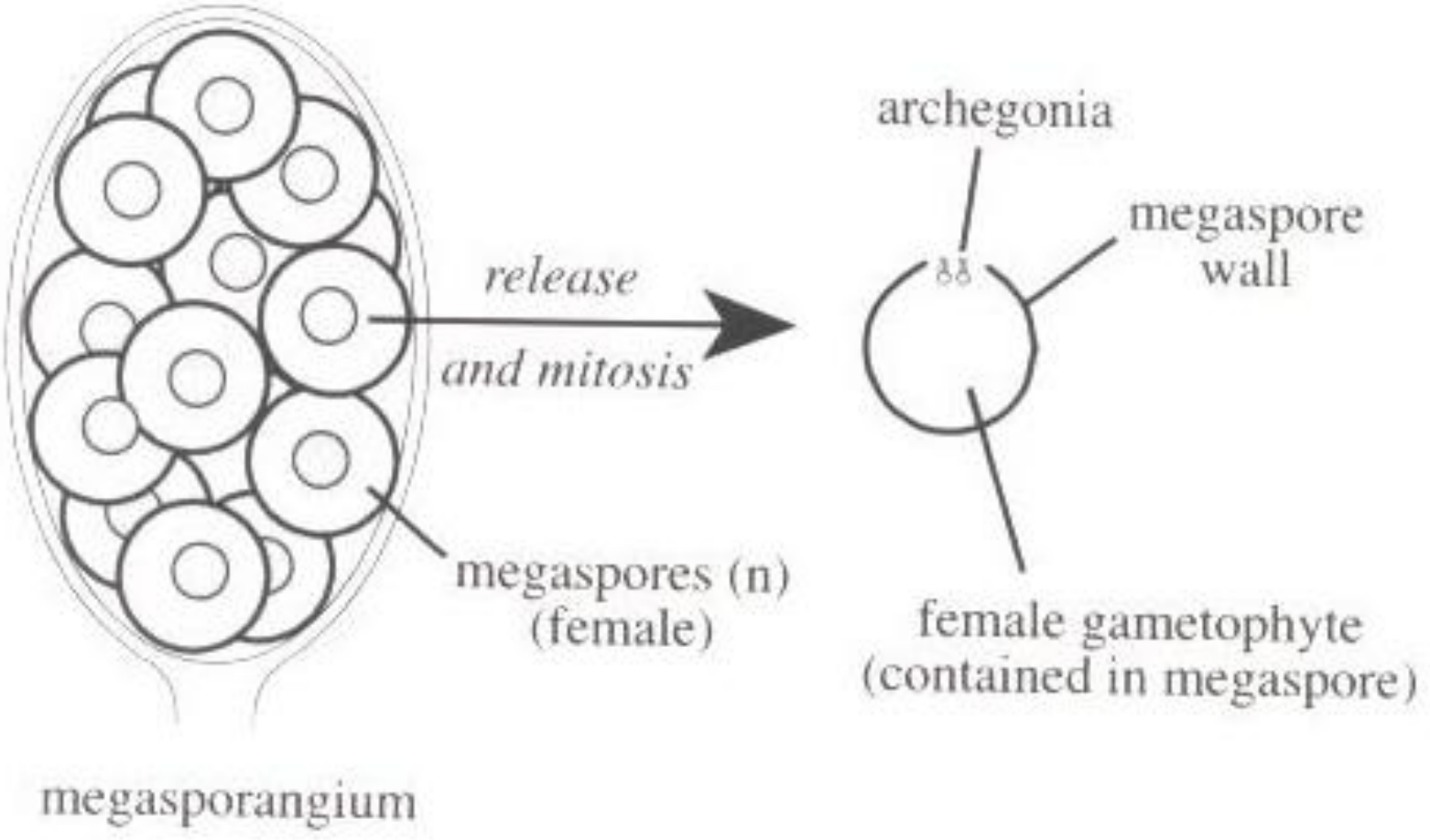
1. Heterospory

Simpson 2006

Heterosporia em Selaginellaceae
(linhagem das Licopodiófitas)



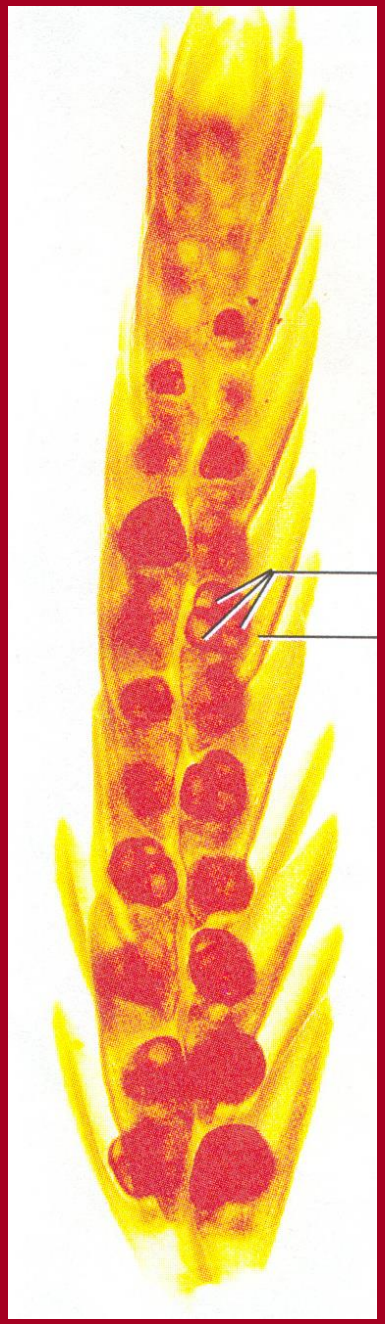
2. ENDOSPORIA

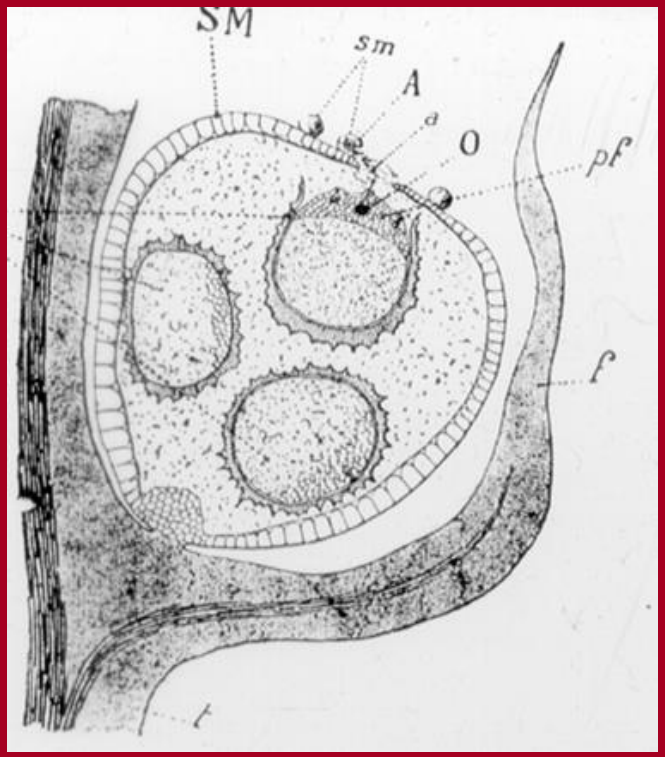


Simpson 2006

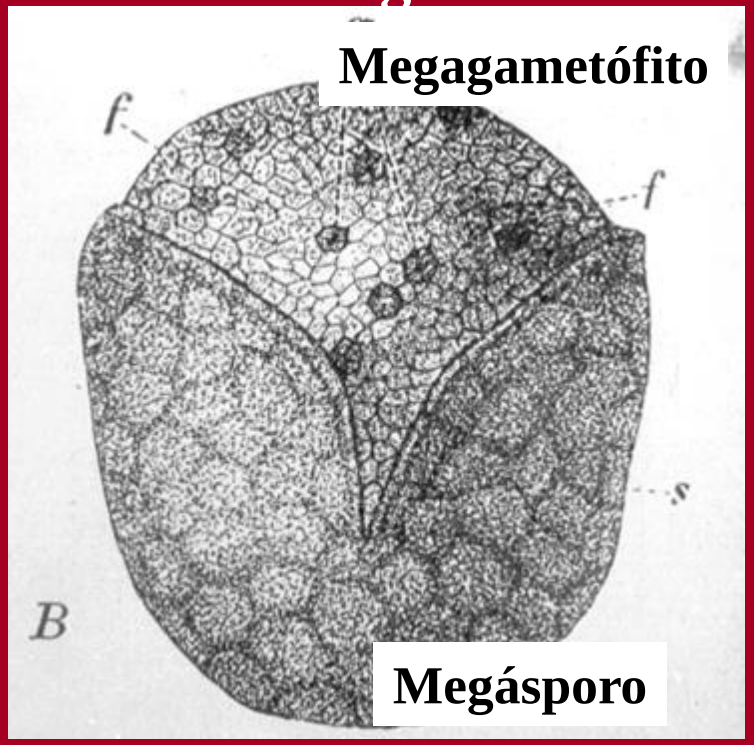
2. ENDOSPORIA

***Selaginella*, Sellaginelaceae**

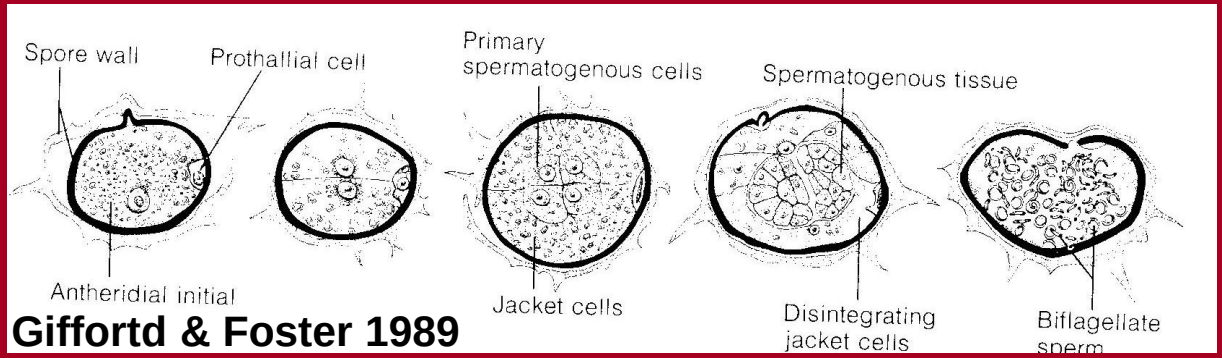




Deiscência do megasporângio libera os megásporos ao solo

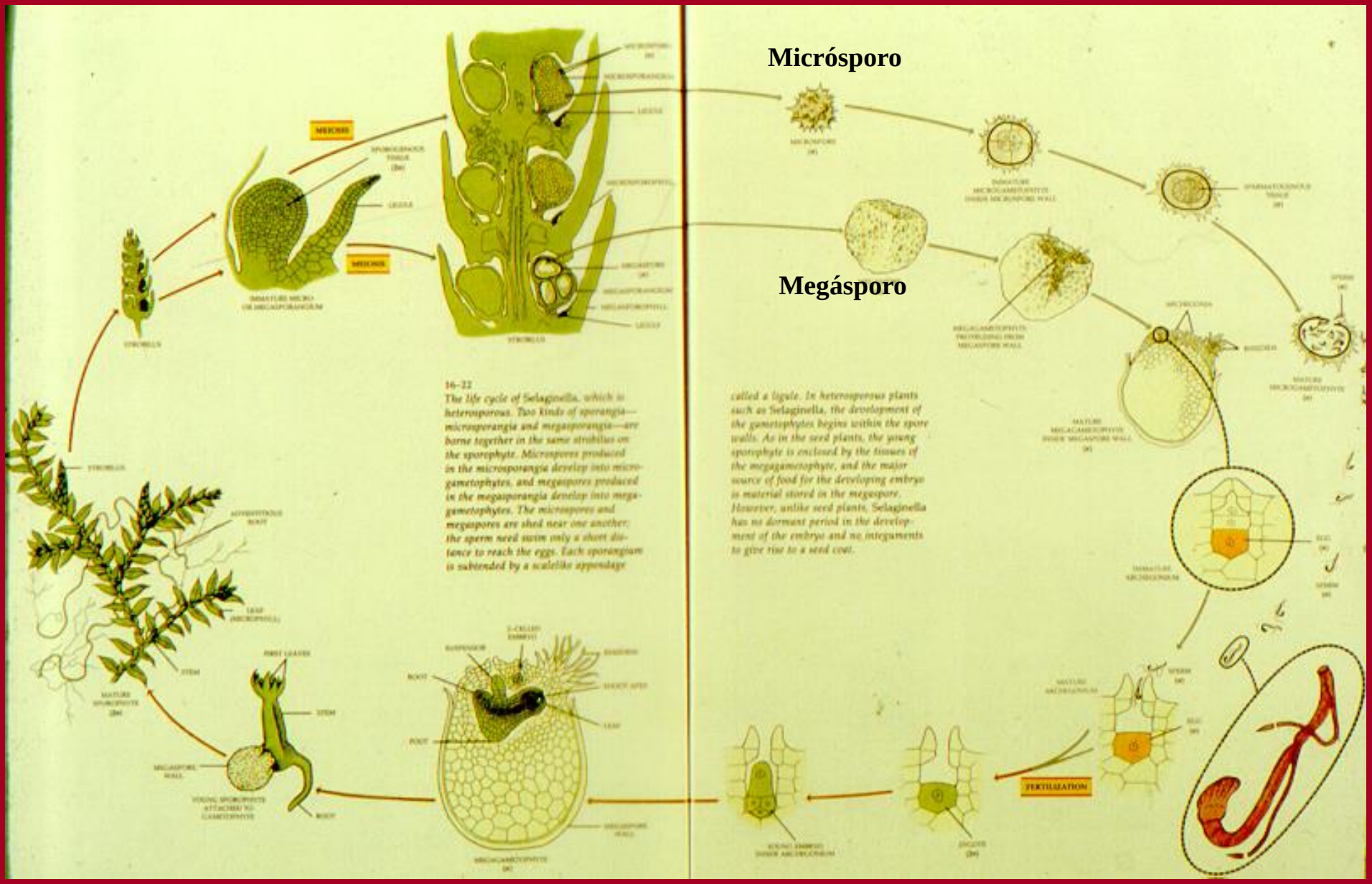


Megagametófito formado no interior do megásporo



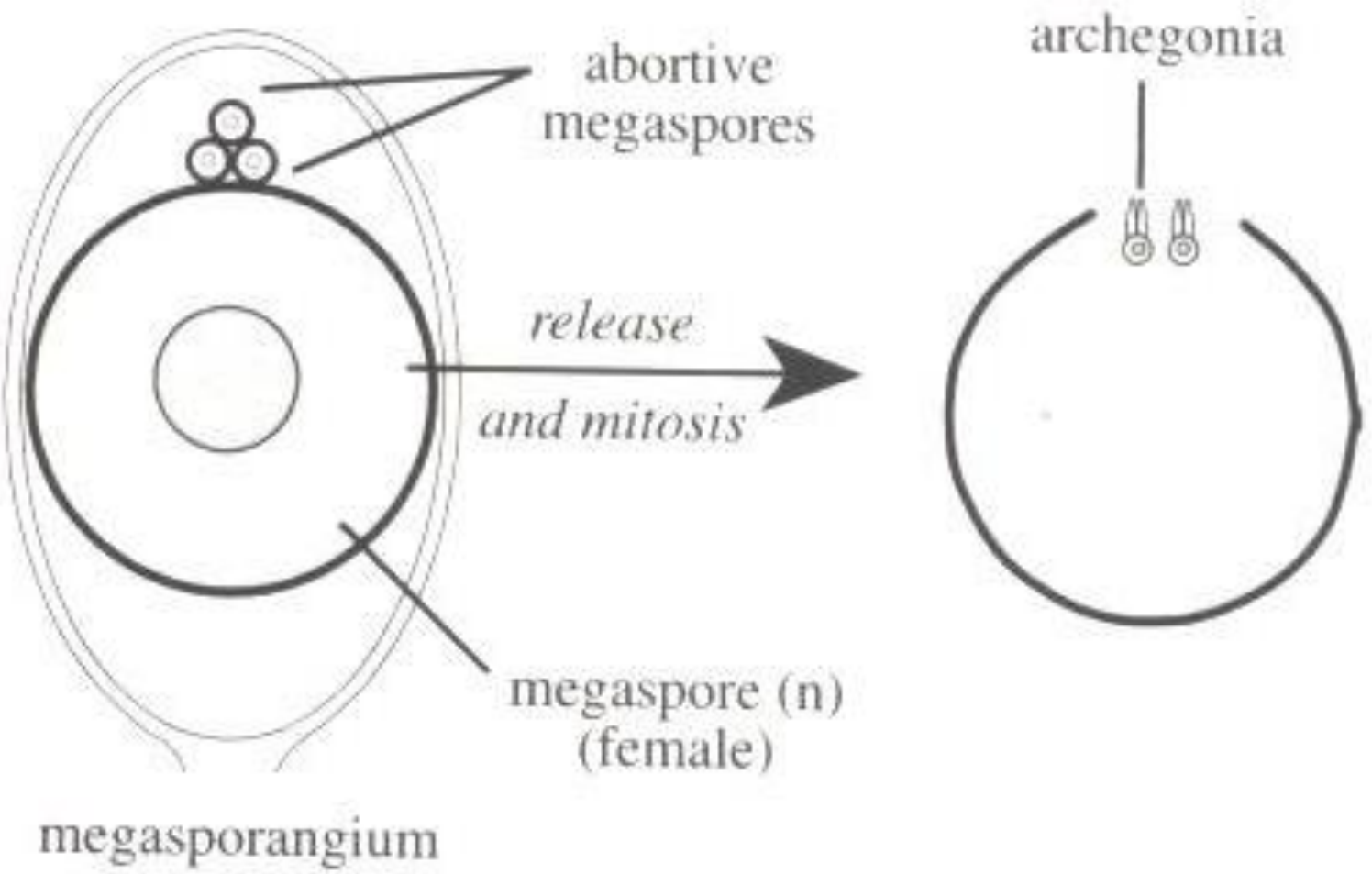
Giffortd & Foster 1989

Heterosporia e endoporia em Selaginellaceae



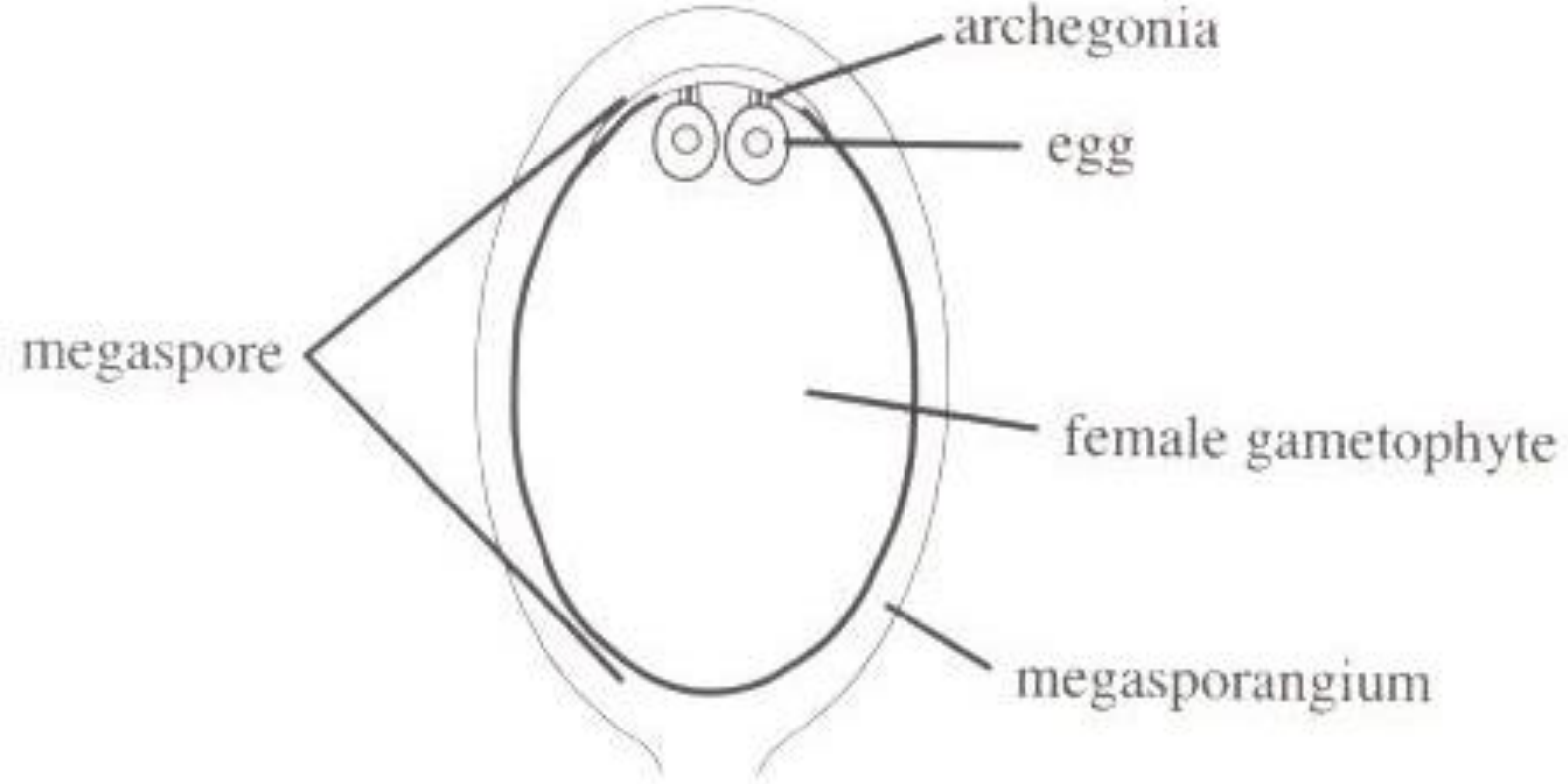
Raven *et al.* 2007

3. Redução a apenas 1 MEGÁSPORO



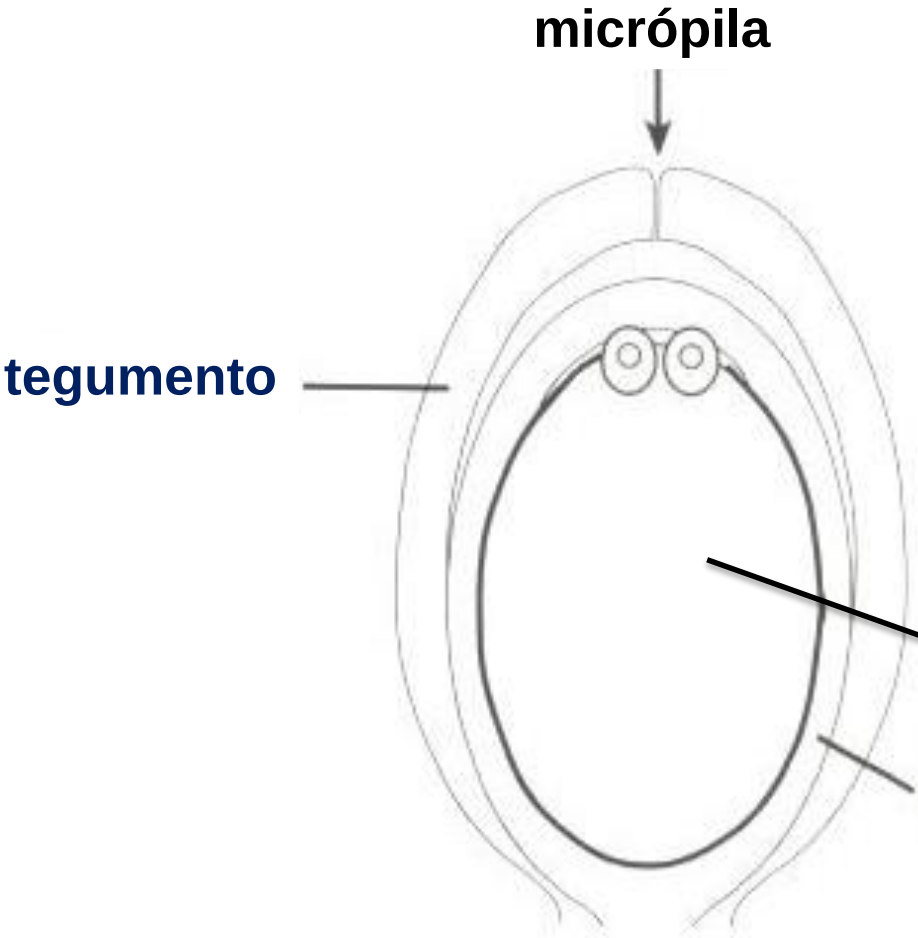
Simpson 2006

4. Retenção do MEGÁSPORO dentro do esporângio



Simpson 2006

5. Evolução do TEGUMENTO



surgimento do óvulo

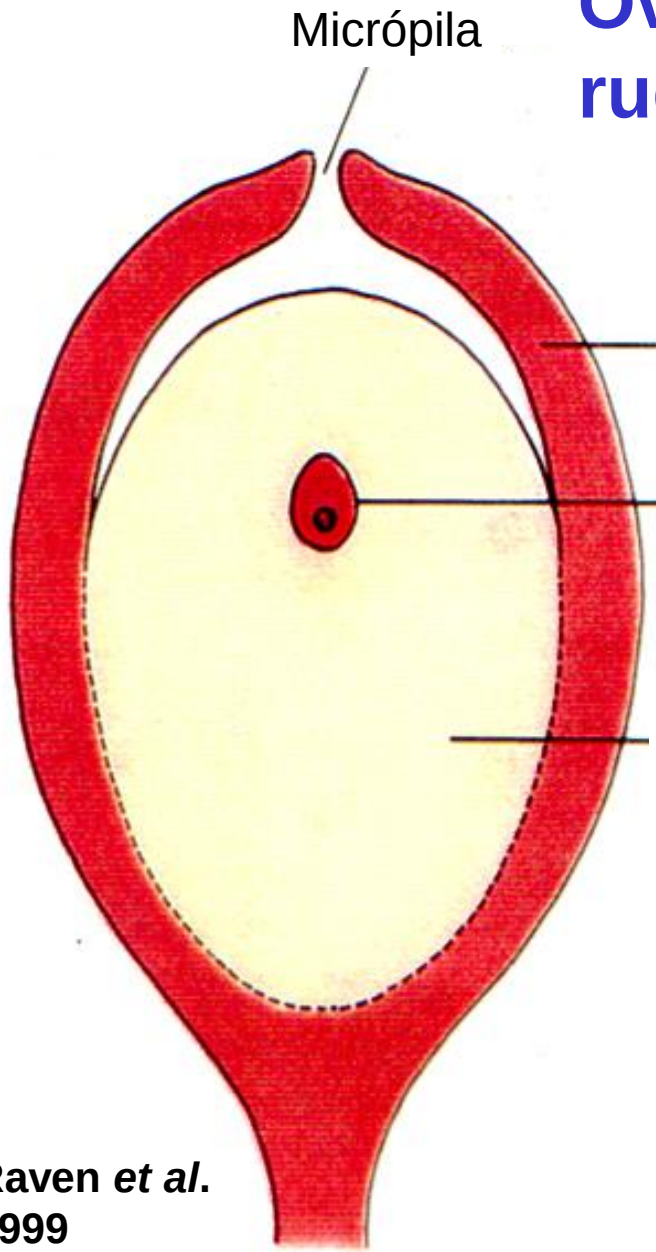
Simpson 2006

Óvulo =

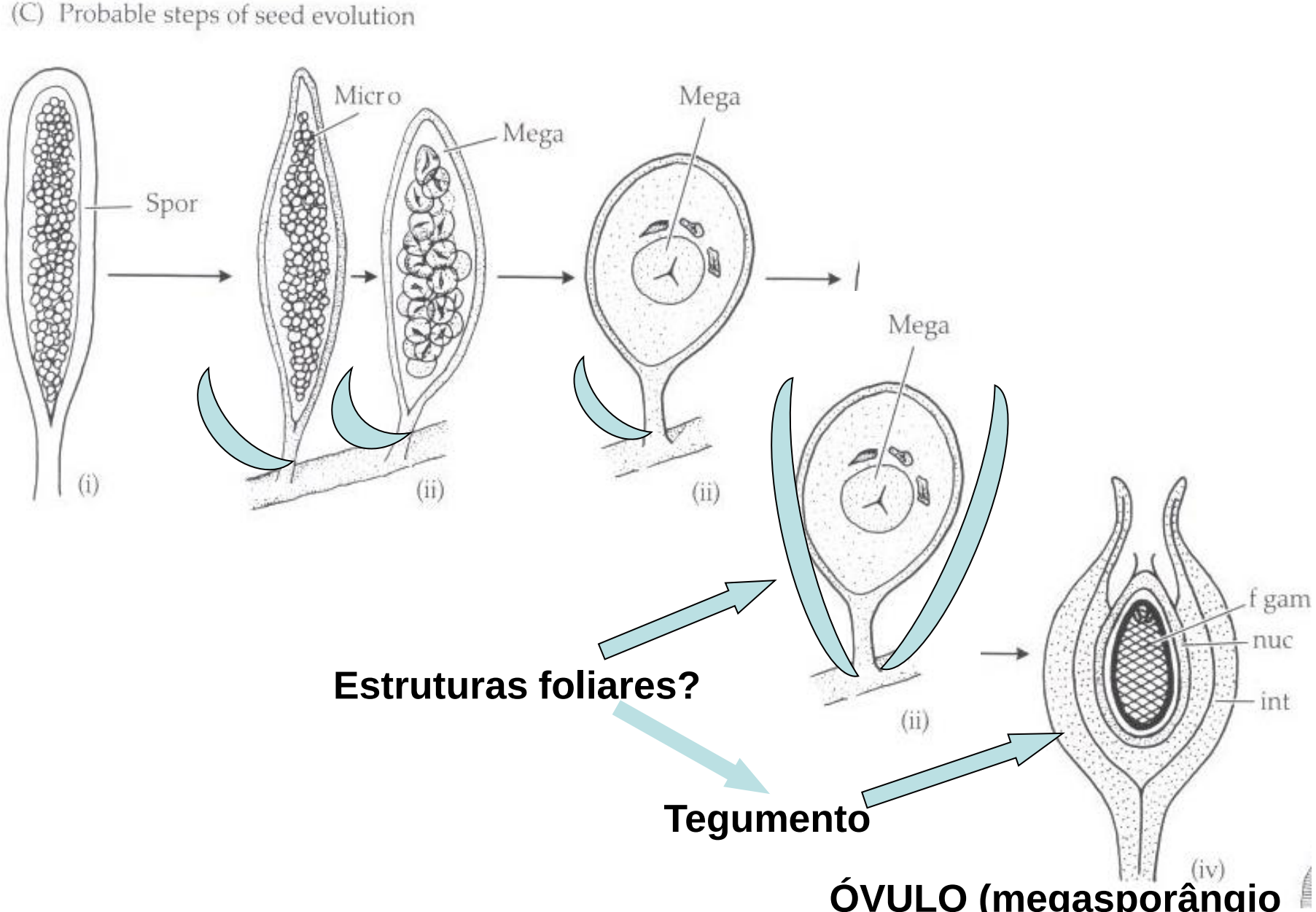
Megasporângio
+
Tegumento

Precursor ontogenético da semente

Óvulo = rudimento seminal



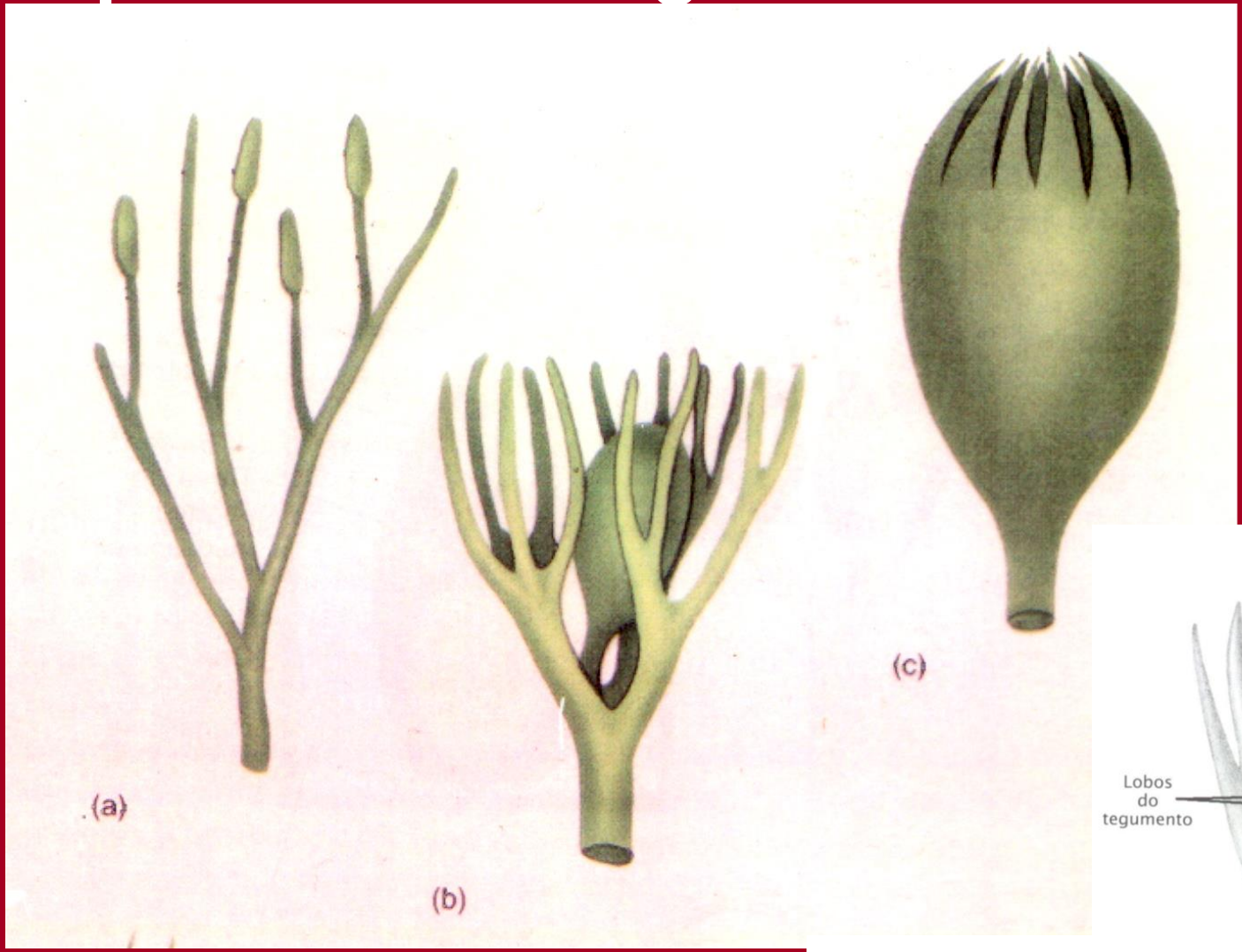
Raven *et al*. 1999



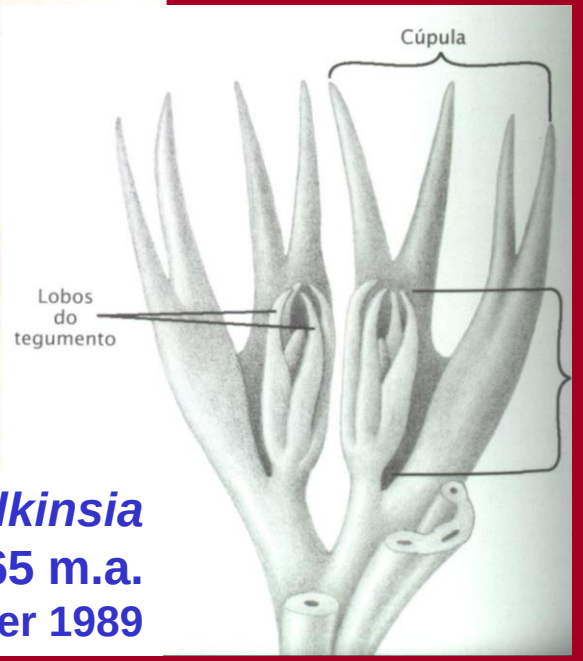
Judd *et al.* 2008

ÓVULO (megasporângio + tegumento)

Hipótese do surgimento do óvulo

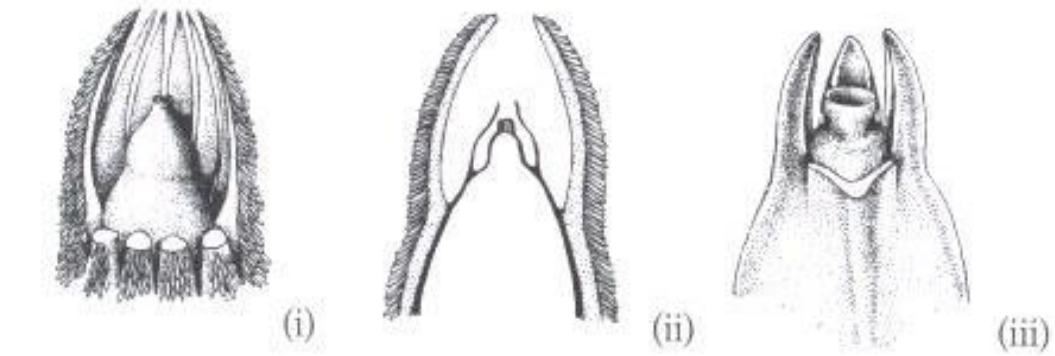


Mauseth 2003



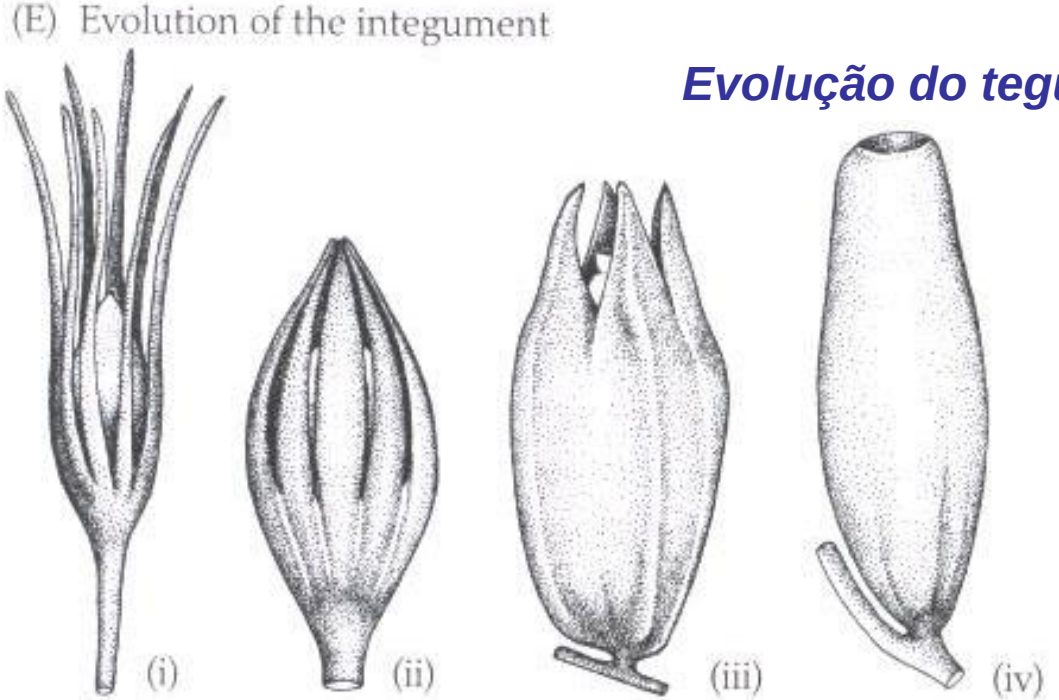
Elkinsia
c. 365 m.a.
Gifford & Foster 1989

Evolução da micrópila



Judd *et al.* 2008

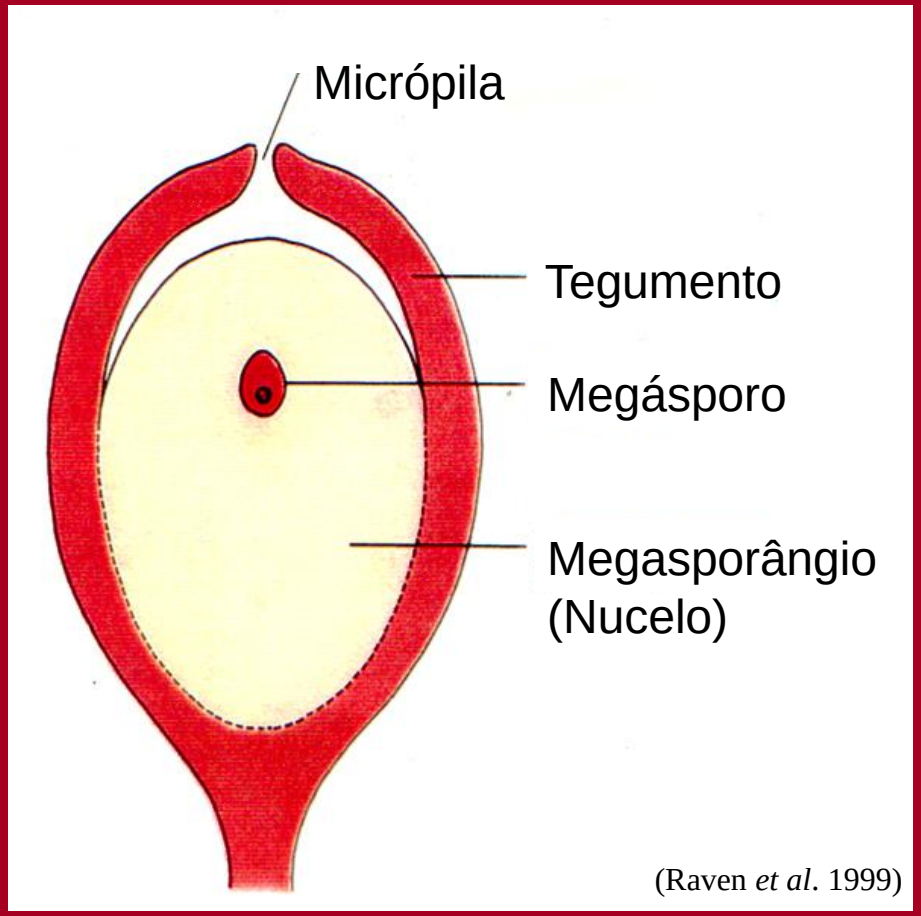
Evolução do tegumento



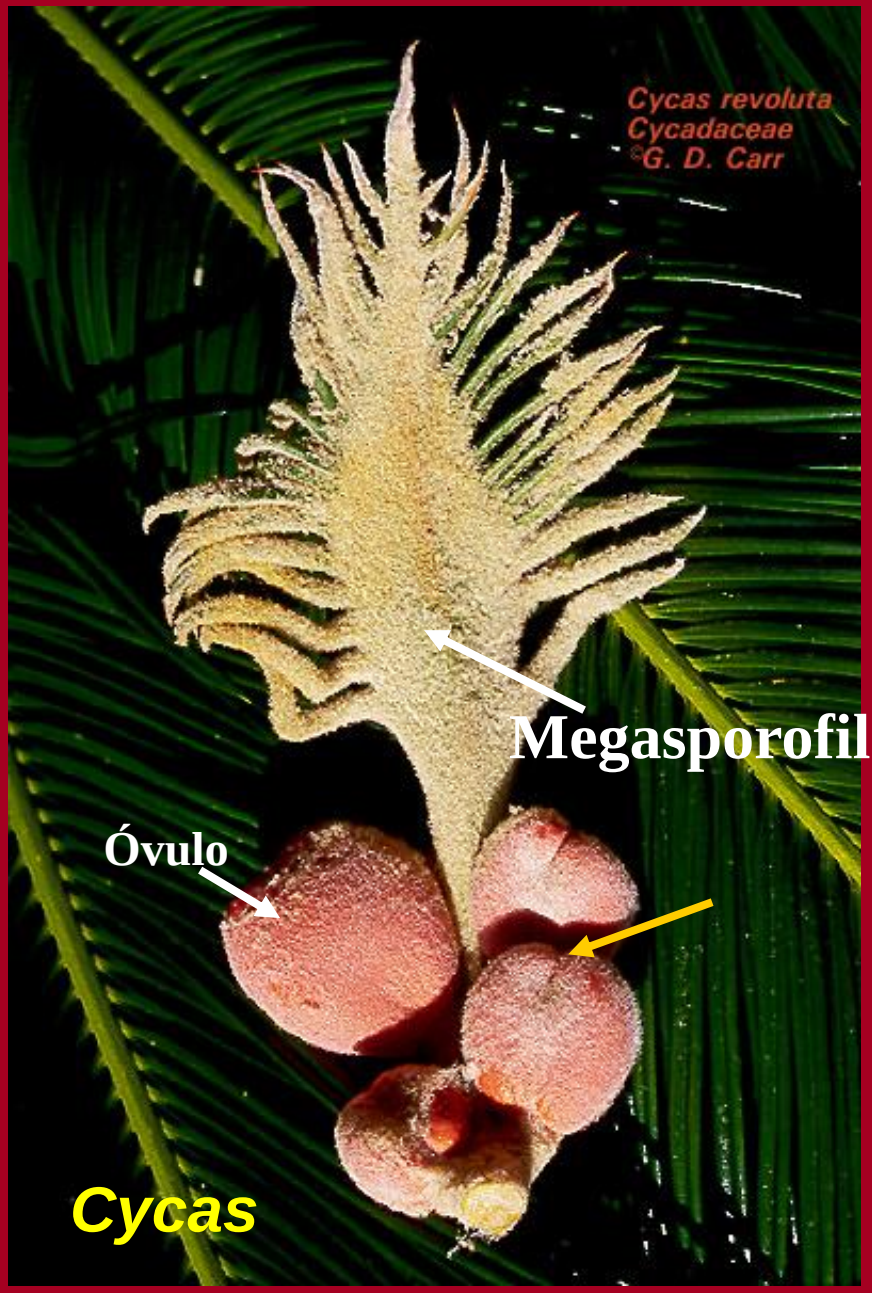
Gifford & Foster 1988

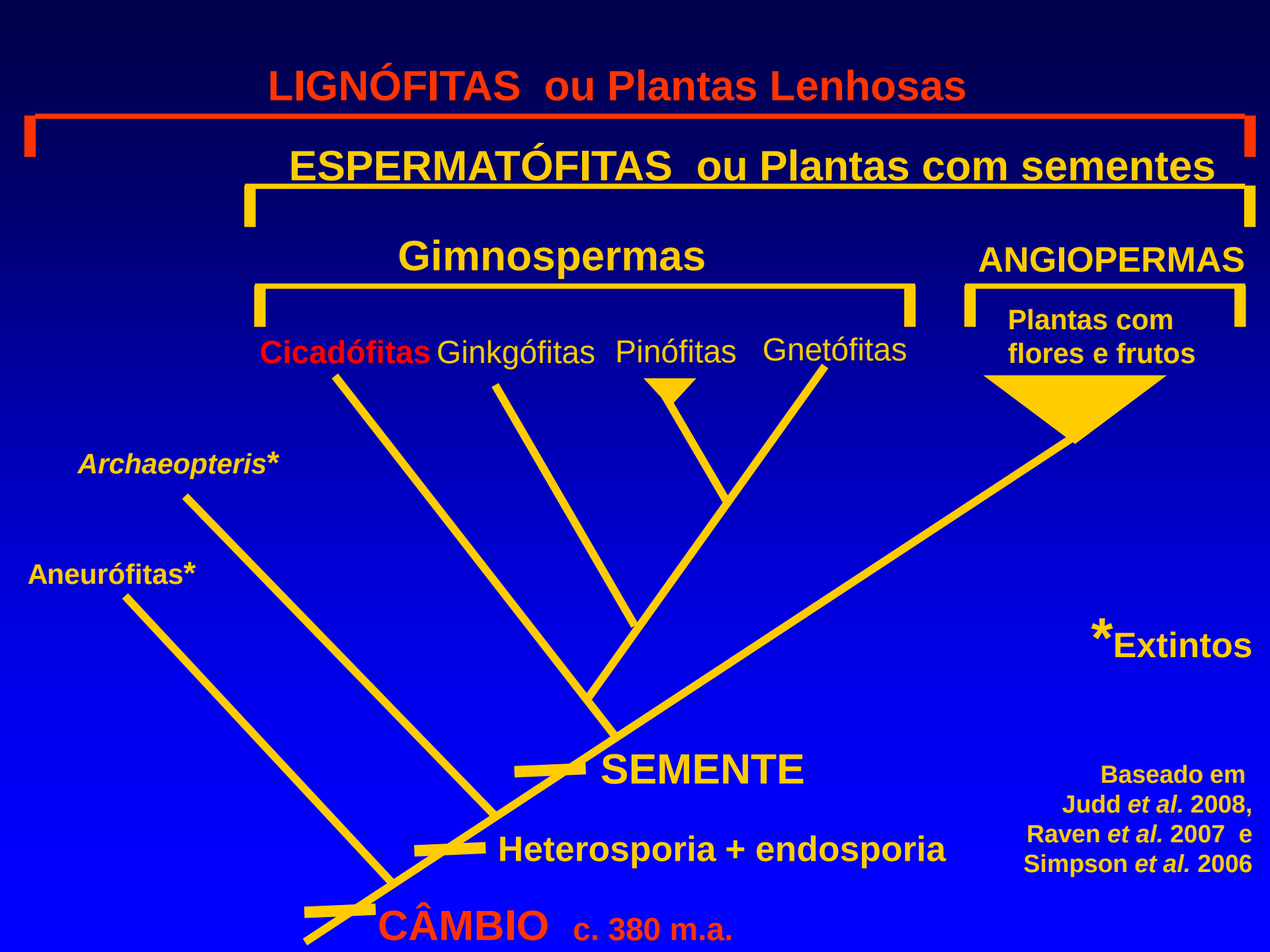
Genomosperma ***Eurystoma*** ***Stamnostoma***

Óvulo



(Raven *et al*. 1999)

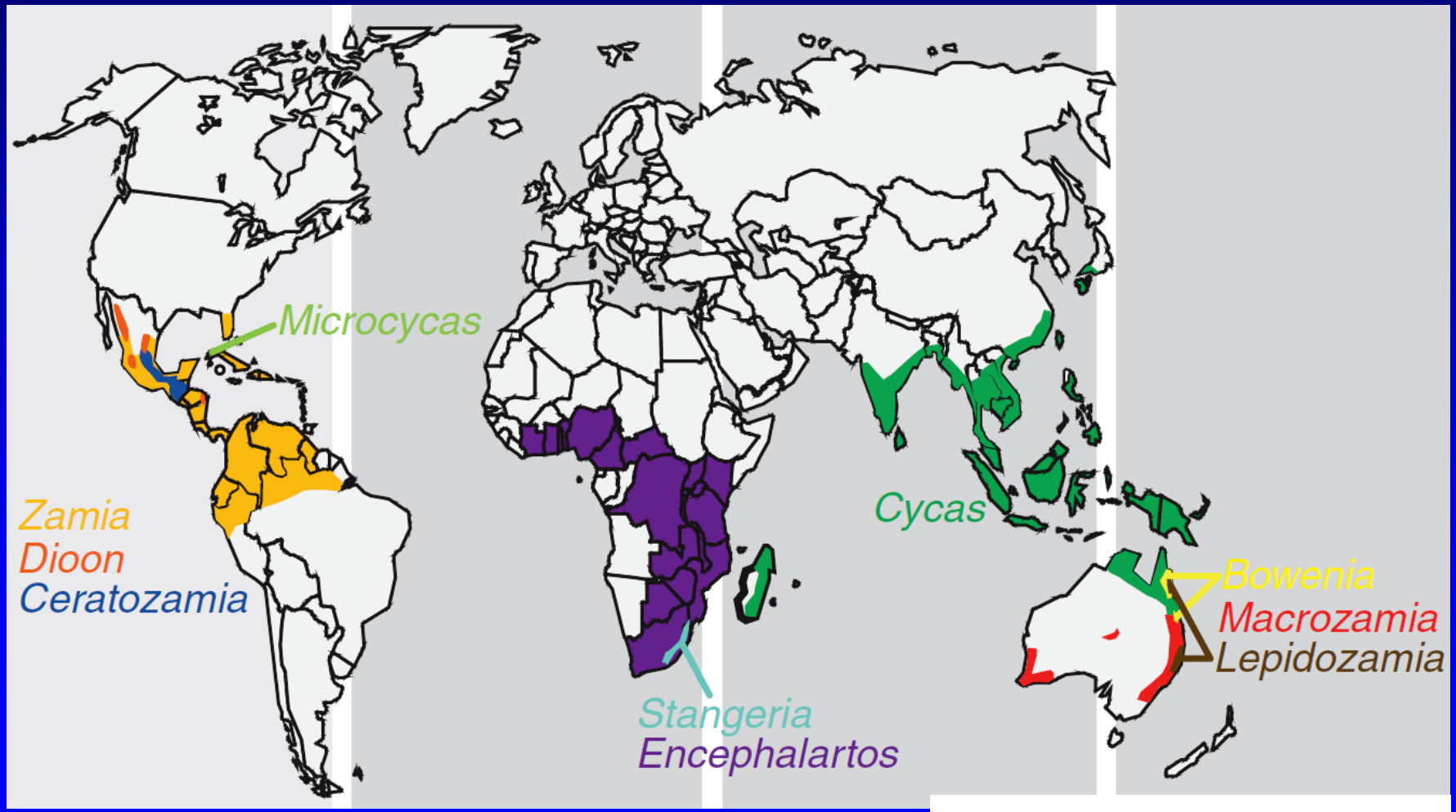



LIGNÓFITAS ou Plantas Lenhosas
ESPERMATÓFITAS ou Plantas com sementes
Gimnospermas
ANGIOPERMAS
Plantas com flores e frutos
Cicadófitas
Ginkgófitas
Pinófitas
Gnetófitas
Archaeopteris*
Aneurófitas*
*Extintos
SEMENTE
Heterosporia + endosporia
CÂMBIO c. 380 m.a.
Baseado em Judd et al. 2008, Raven et al. 2007 e Simpson et al. 2006

CYCADOPHYTA

- surgimento no Permiano, com apogeu no Jurássico

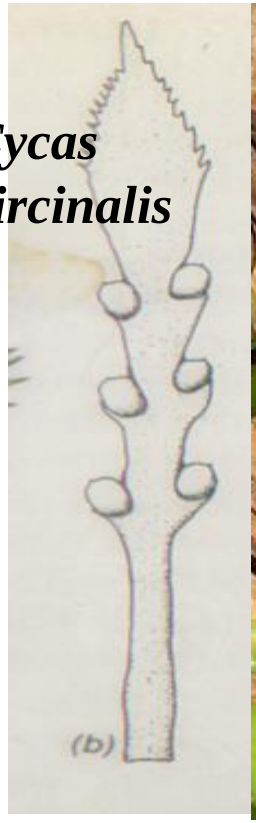
- distribuição atual PANTROPICAL – 2 famílias, 10 gêneros, 140 espécies



Nagalingum *et al.* 2011

Cycadophyta

Cycas circinalis



Cycas revoluta

Encephalartos

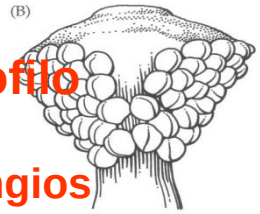
Zamiaceae

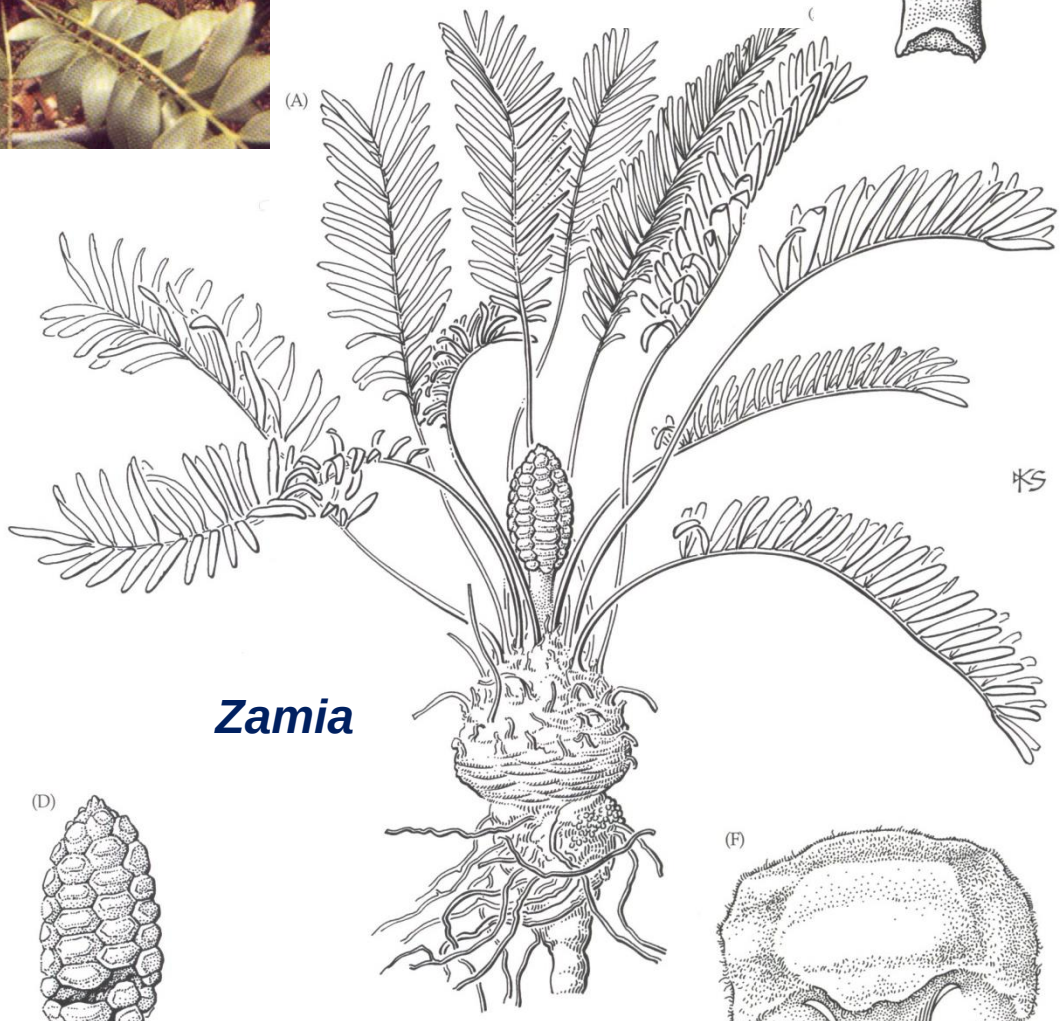
Cycadophyta

Encephalartos ferox

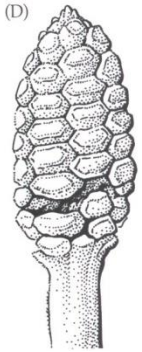
óvulo → semente

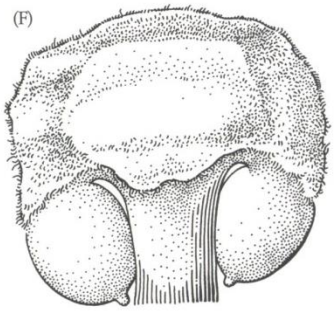
Microsporofilo
com muitos
microsporângios





Zamia





CYCADOPHYTA:

todas dióicas, com estróbilos simples

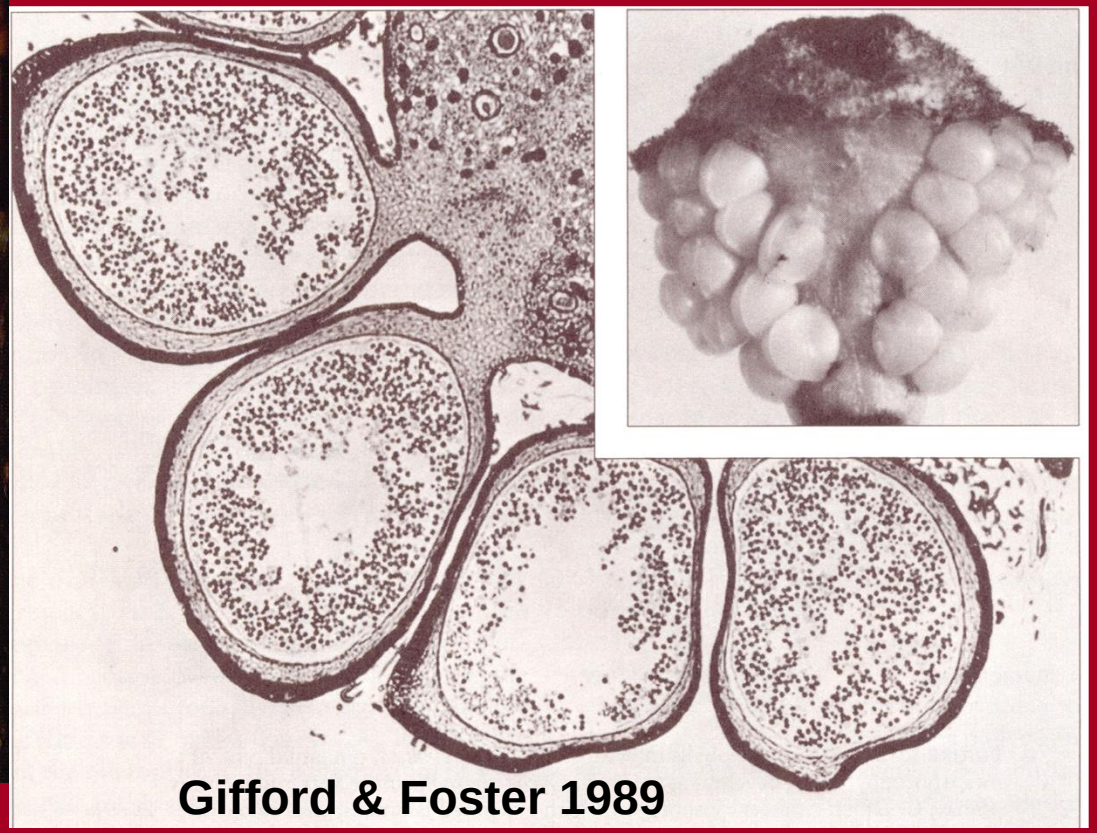
Megasporofilo
com 2 óvulos

Stevenson 1991

CYCADOPHYTA

Heibloem 1999

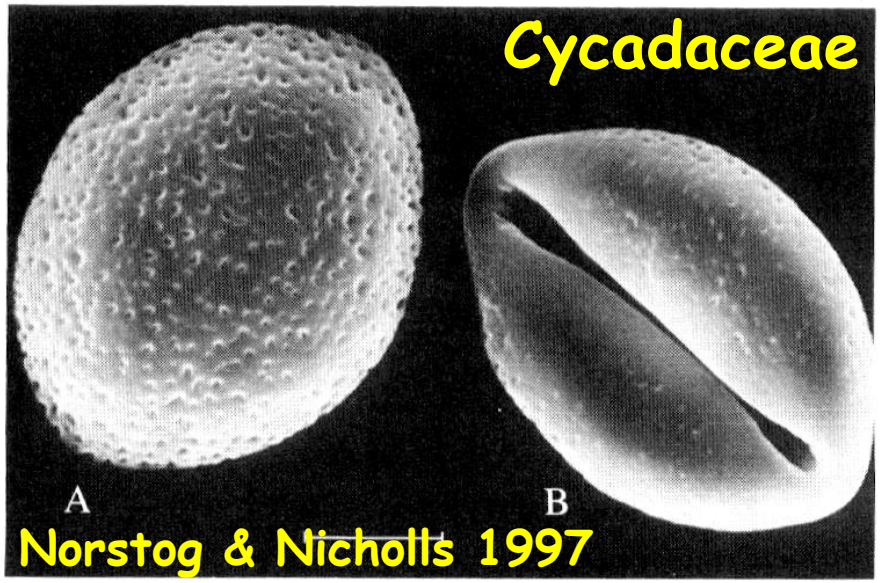
Wettstein 1957

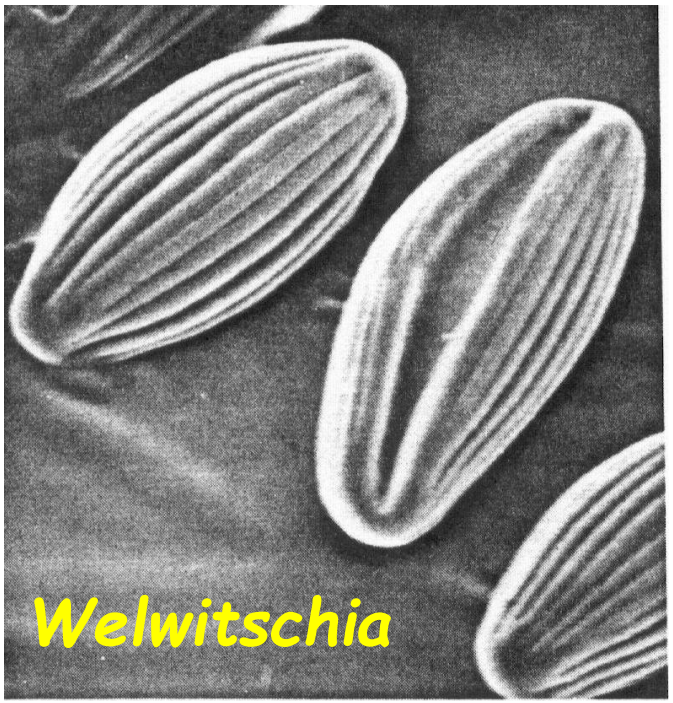


Gifford & Foster 1989

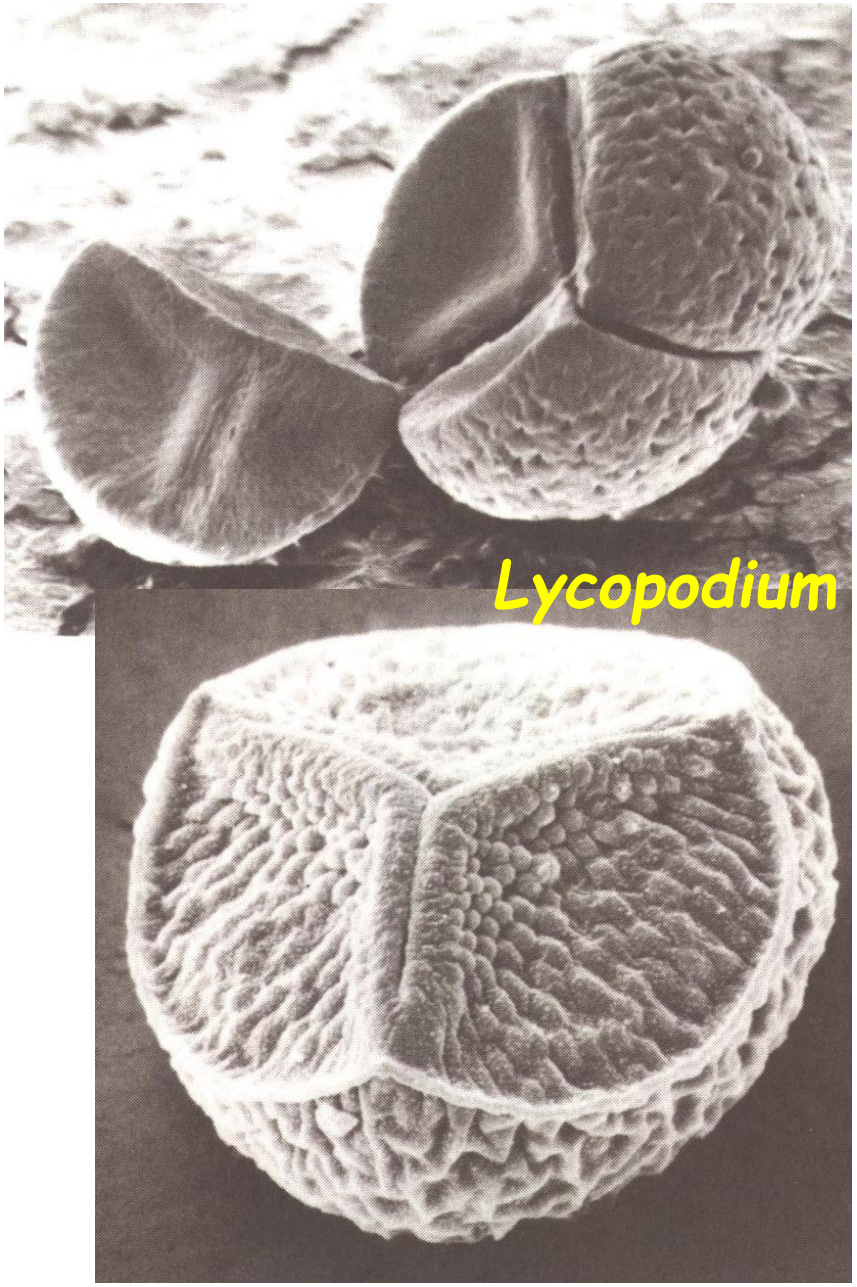
Microstróbilo simples

♦ **PÓLEN** monossulcado



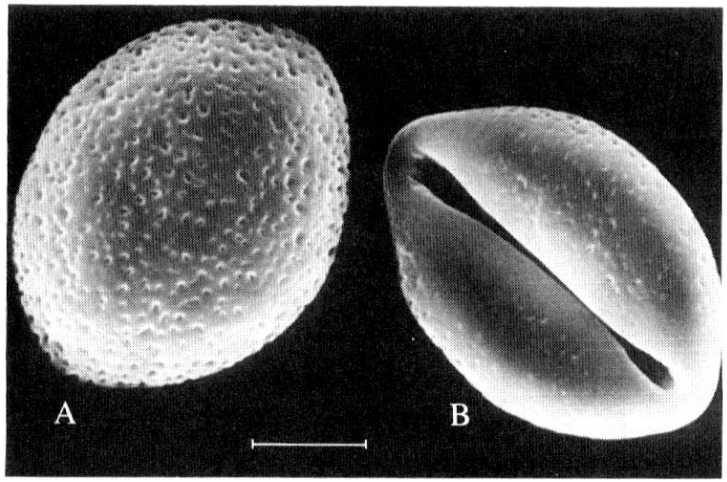


♦ **ESPORO**



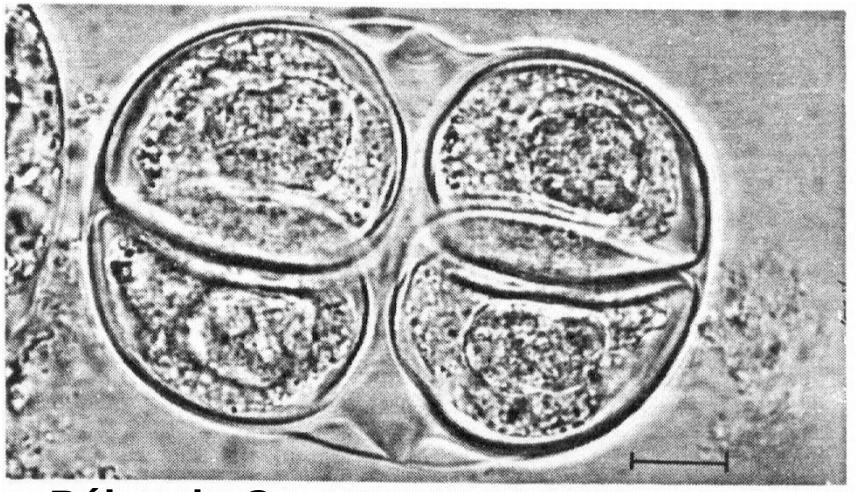
- **PÓLEN**

monossulcado

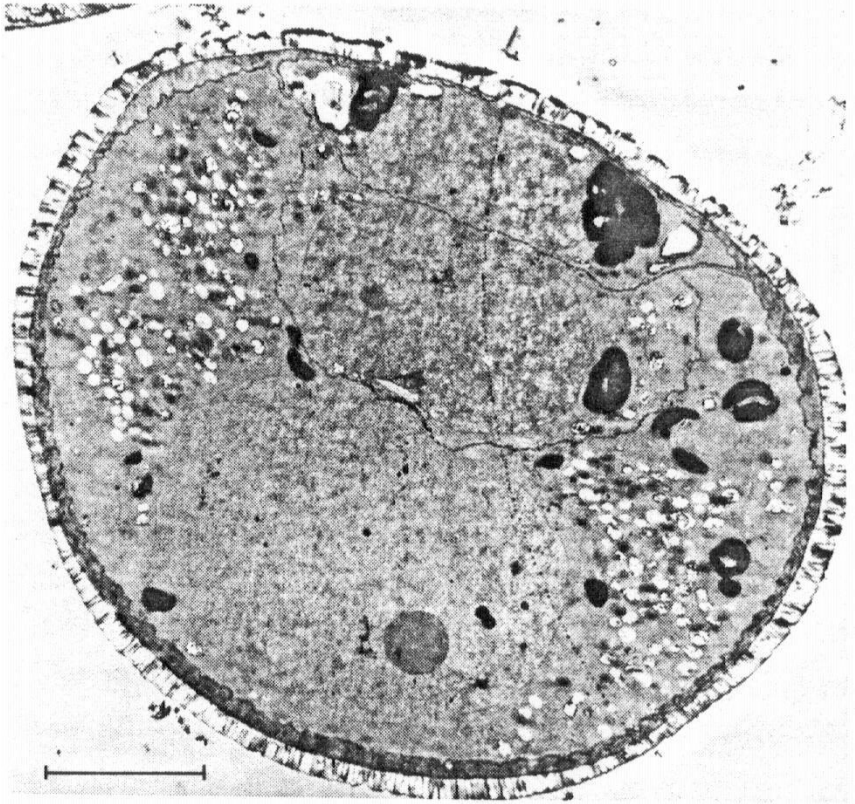


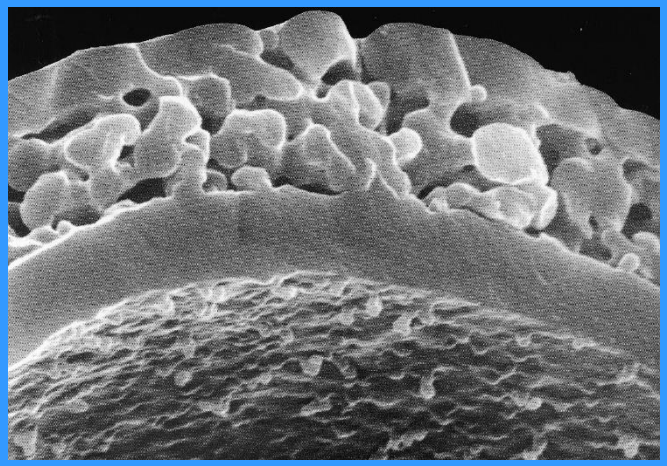
Pólen monossulcado de Cycadaceae

Norstog & Nicholls 1997

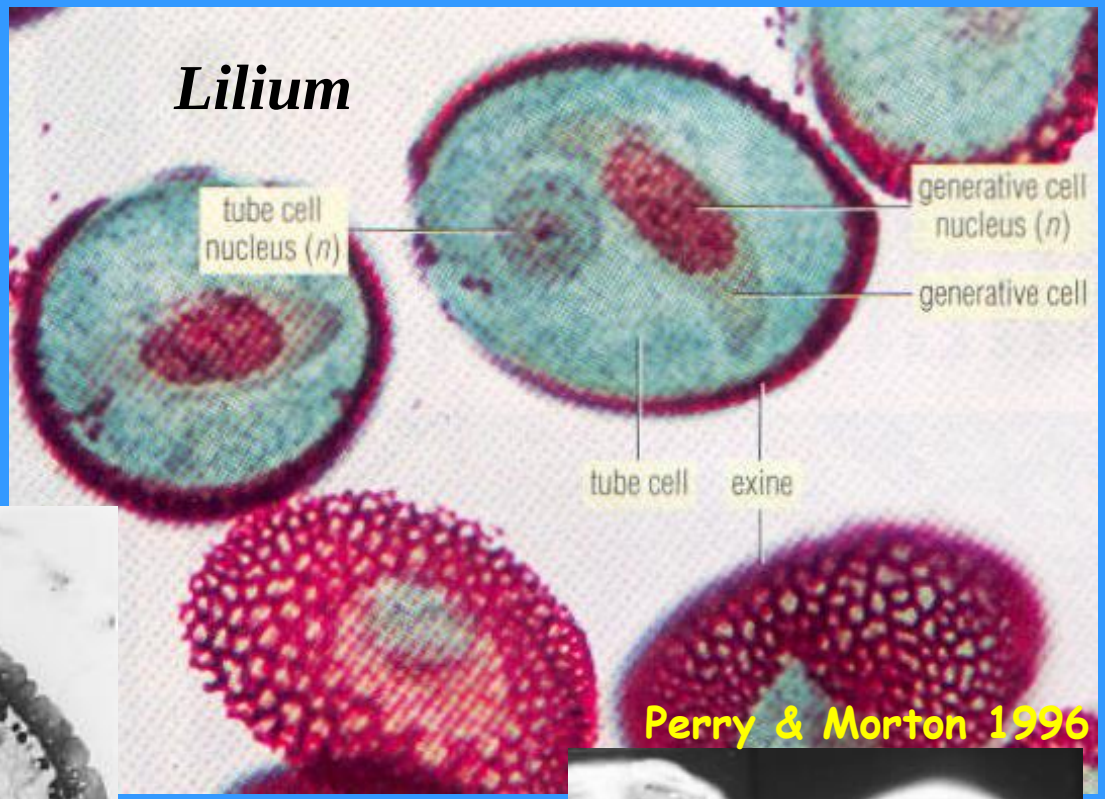


Pólen de *Cycas* Gifford & Foster 1989



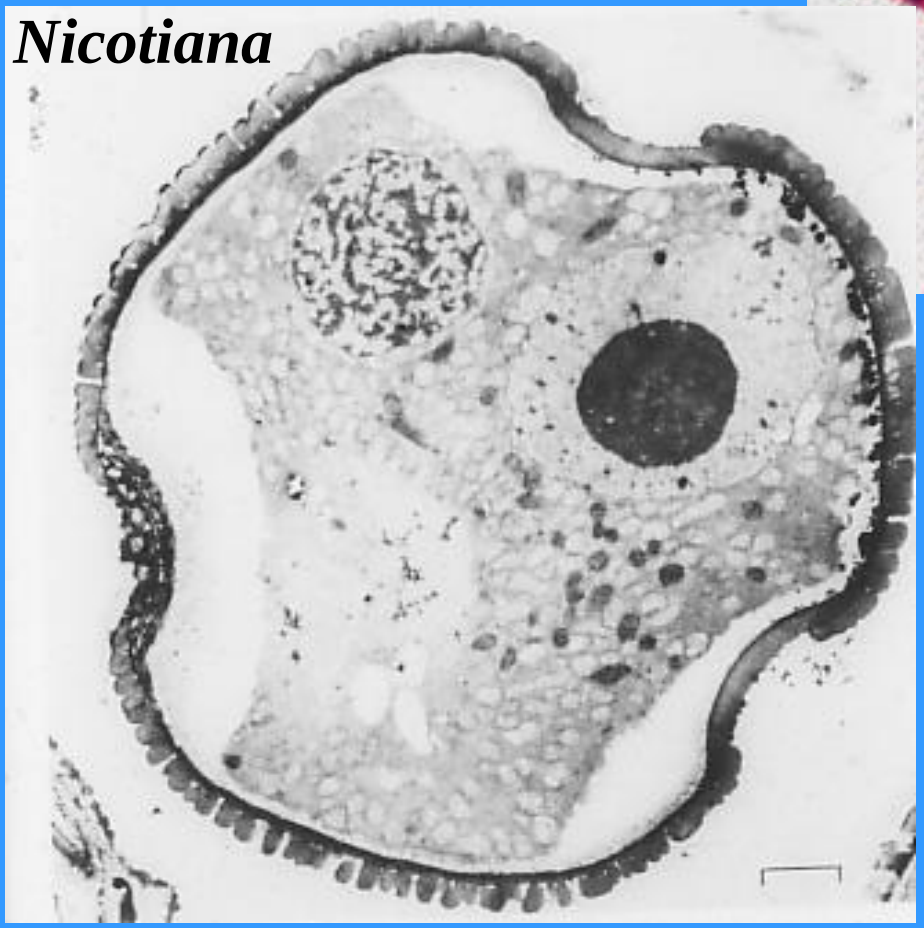


Lilium



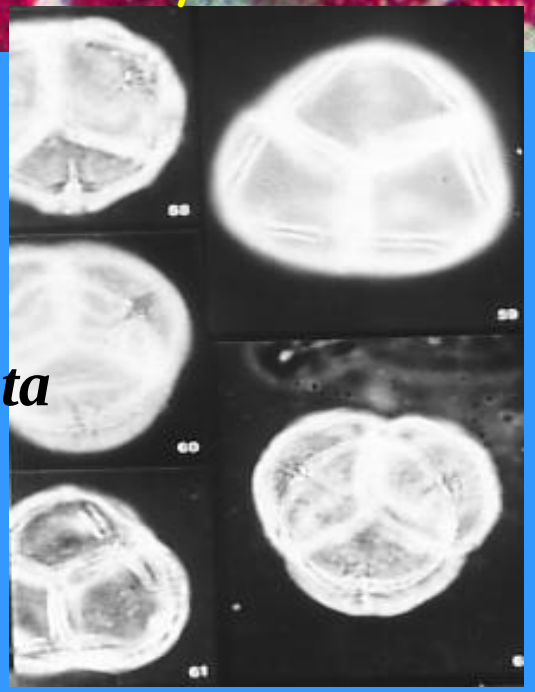
Perry & Morton 1996

Nicotiana

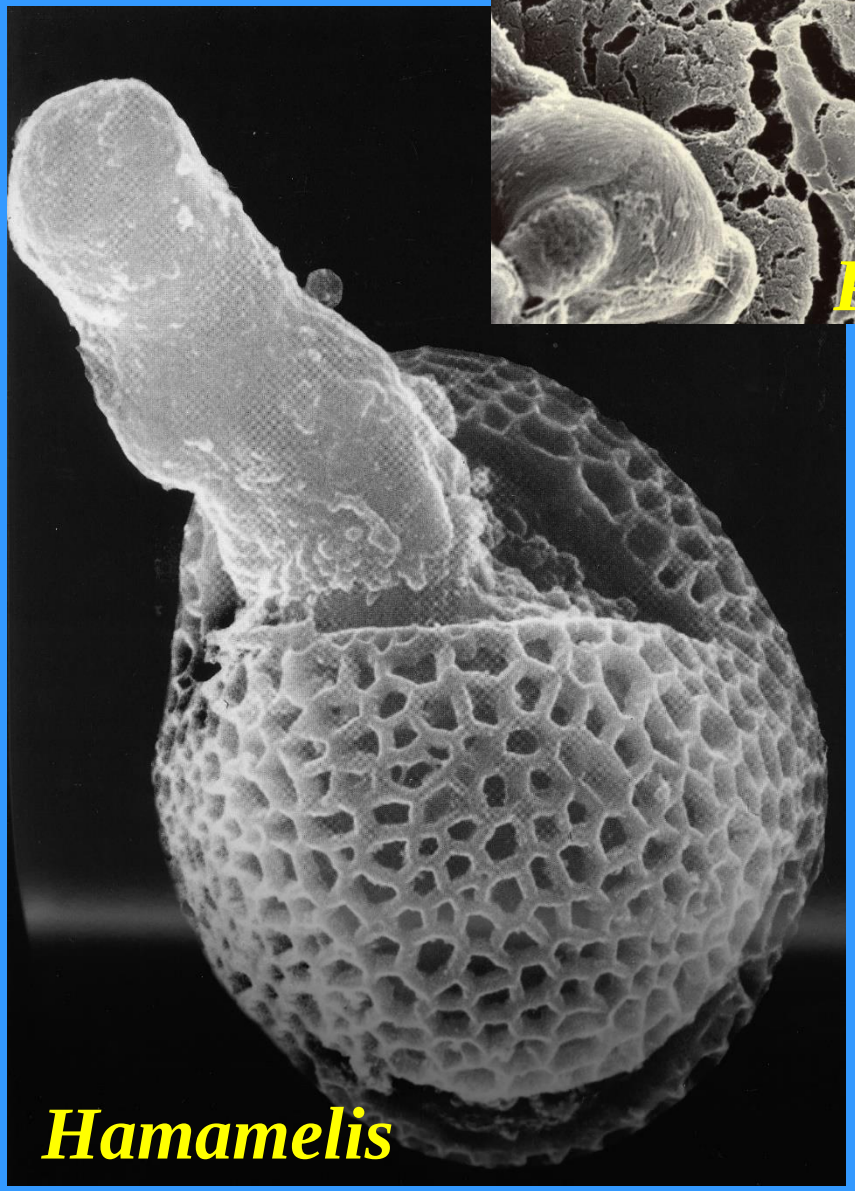


Pólen

Agarista

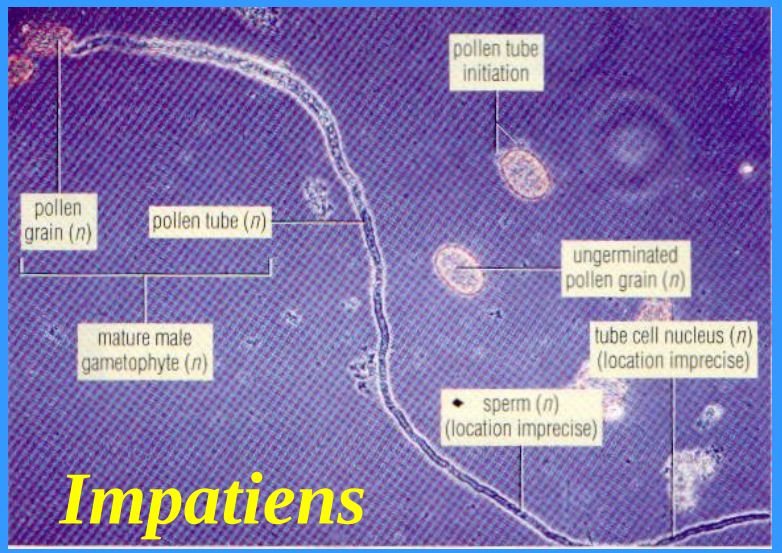


Tubo polínico



Hamamelis

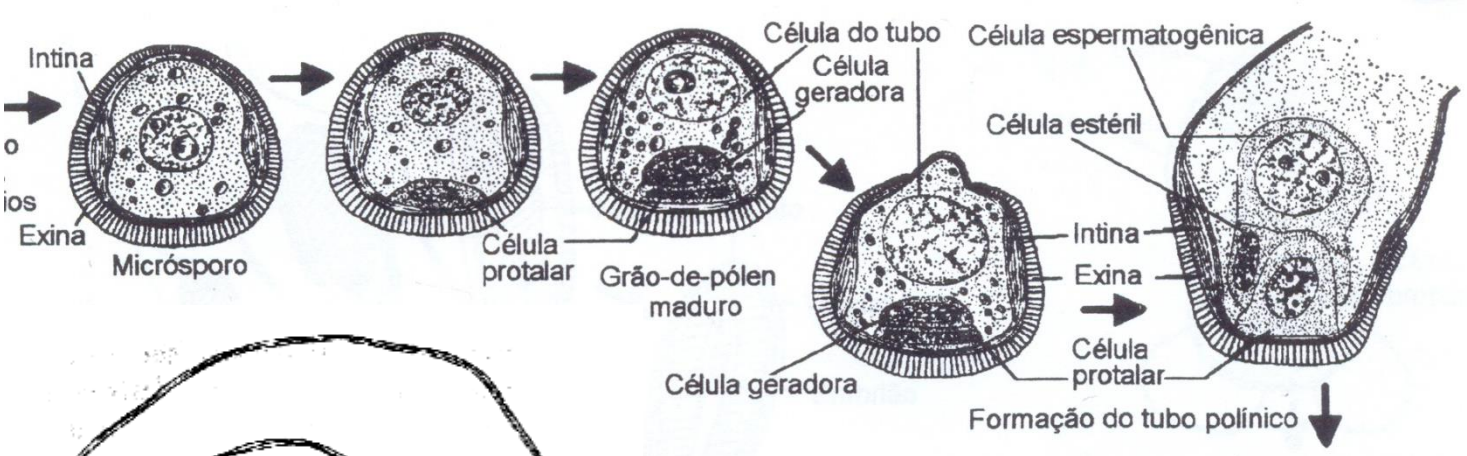
Prunus

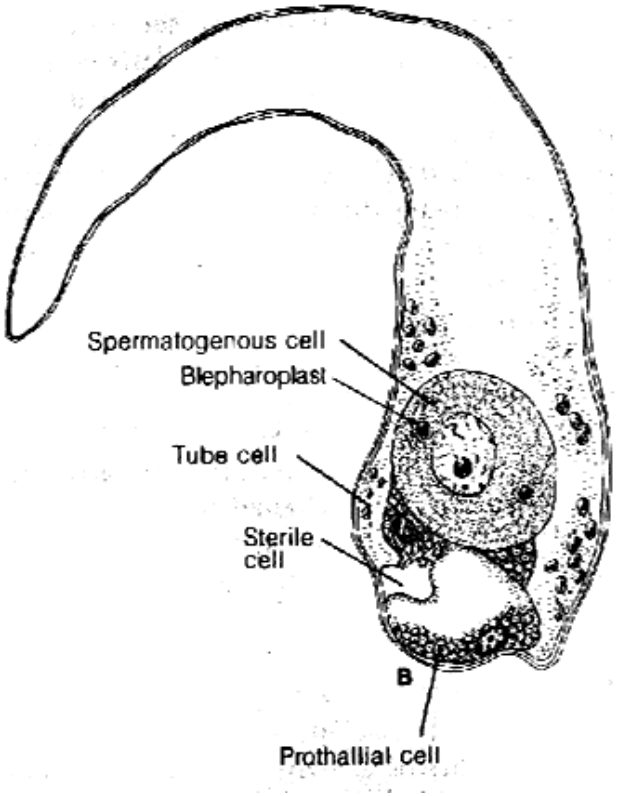


Impatiens

Perry & Morton 1996

Grão de pólen = micrósporo contendo o gametófito masculino imaturo

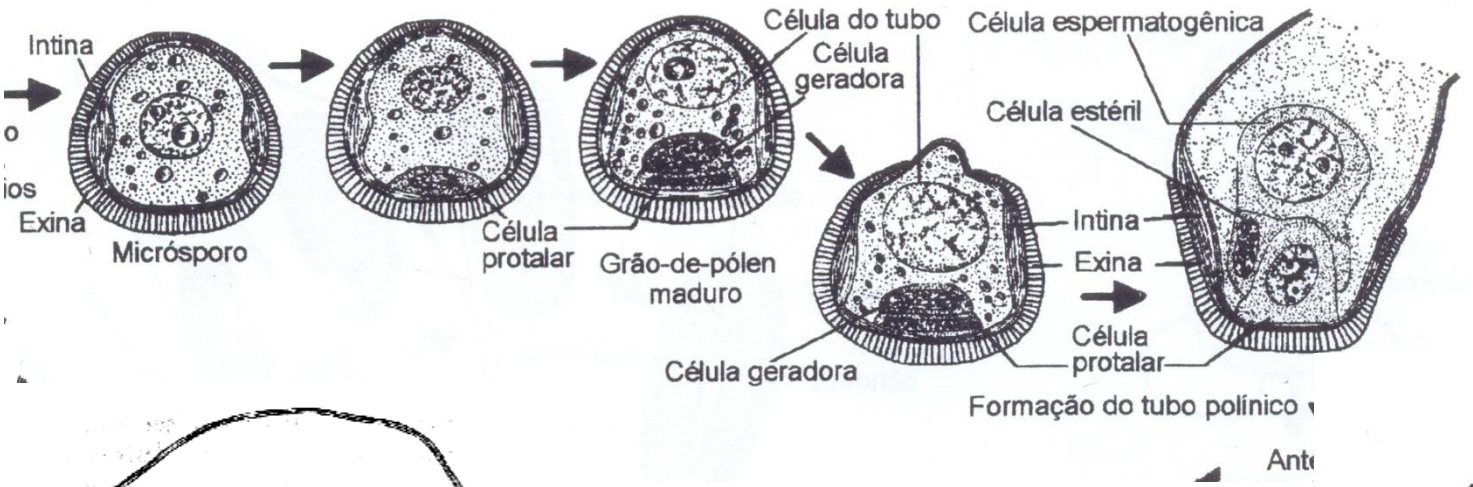


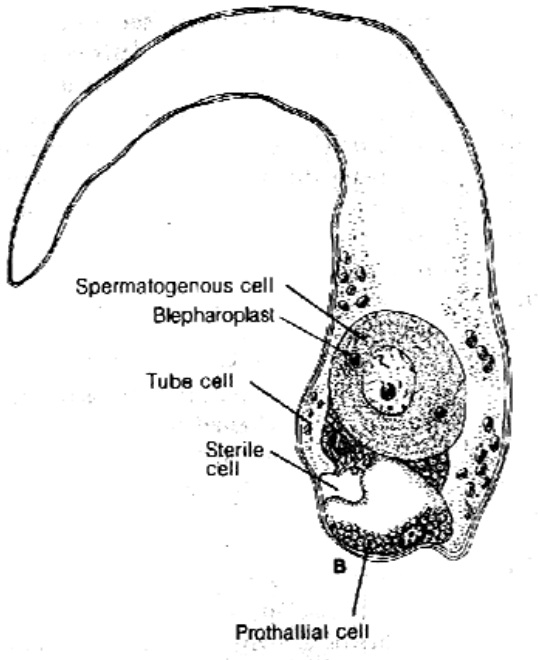


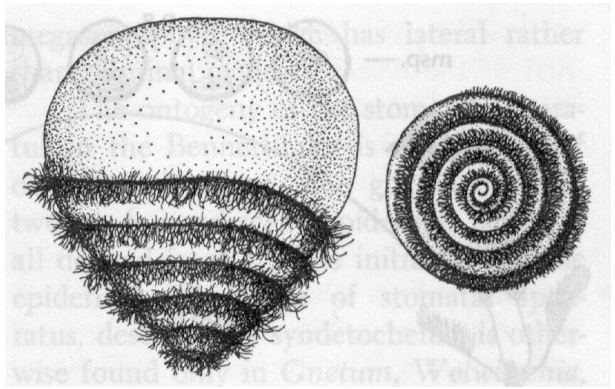
Cycadophyta

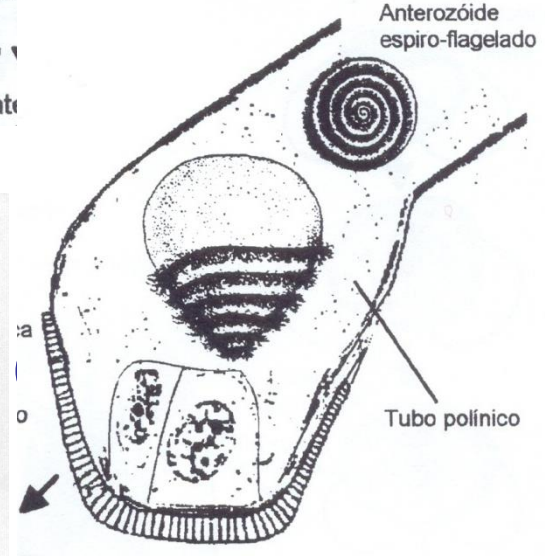
Tubo polínico em *Cycas* (Gifford & Foster 1989)

pólen - microgametófito forma um tubo com 2 gametas (supressão do anterídeo)



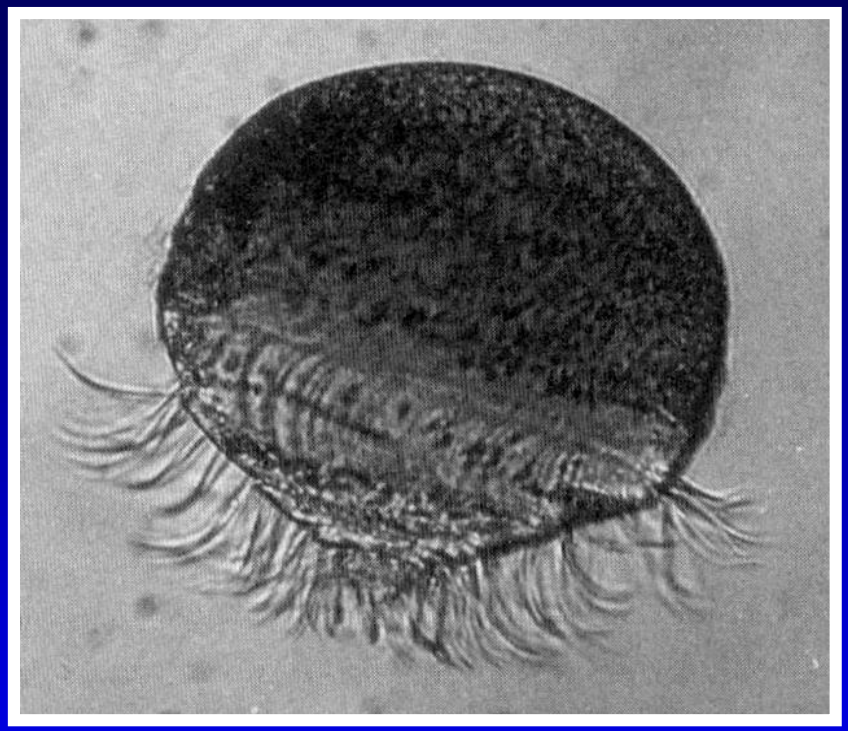






Tubo polínico e gametas em Cycadófitas (Gifford & Foster 1989)

- anterozóide multiflagelado (gameta masculino)



Zamia integrifolia

Gifford & Foster 1989

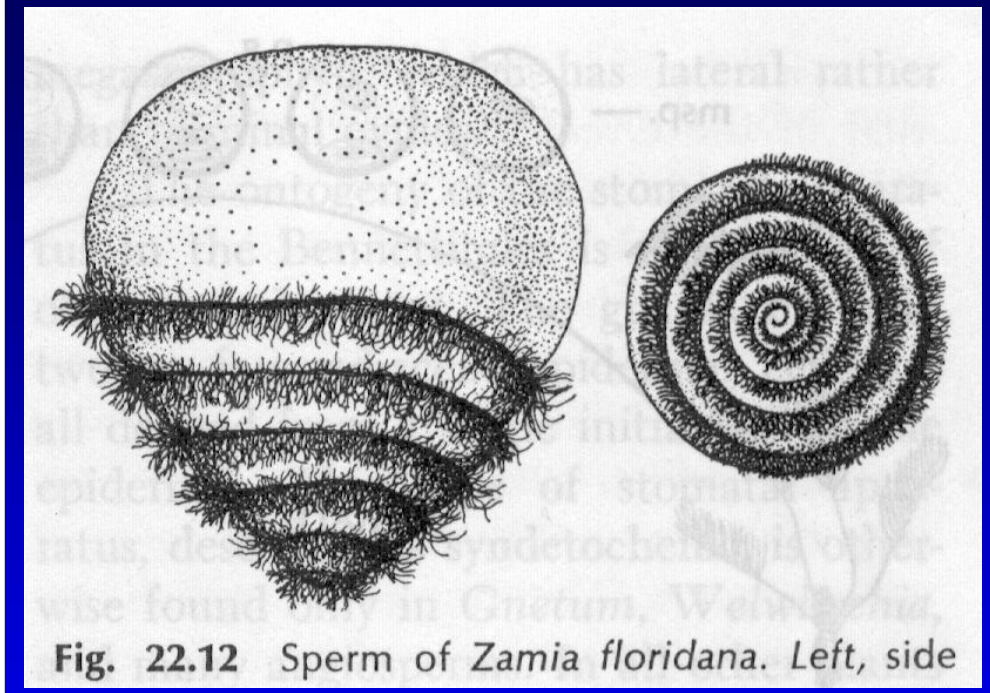
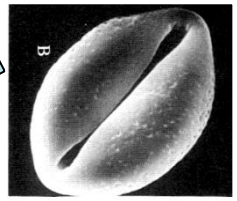
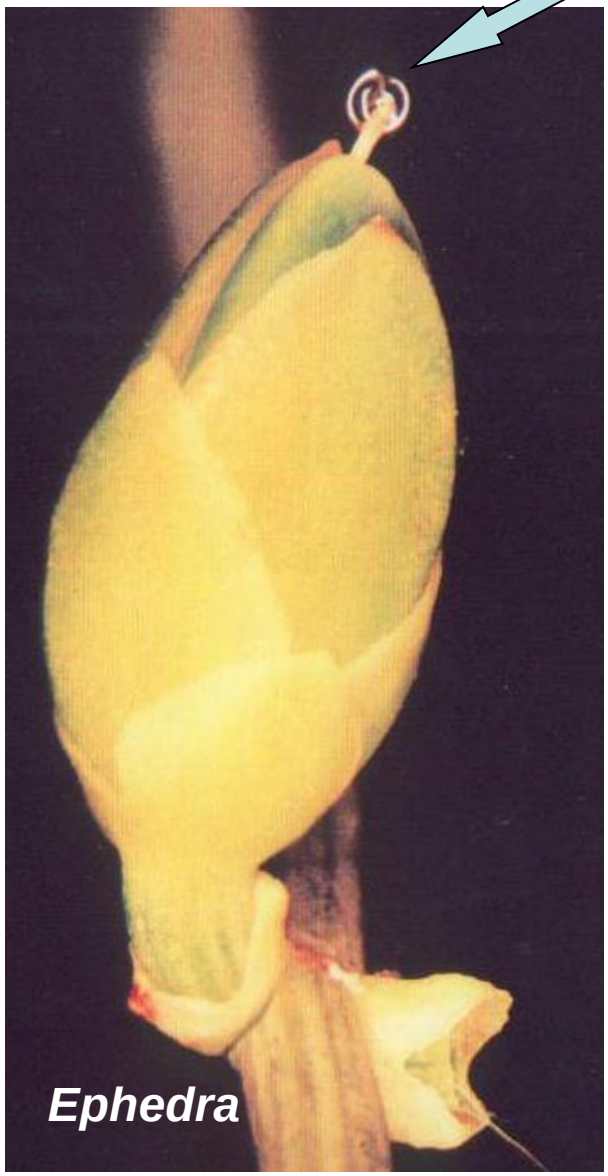


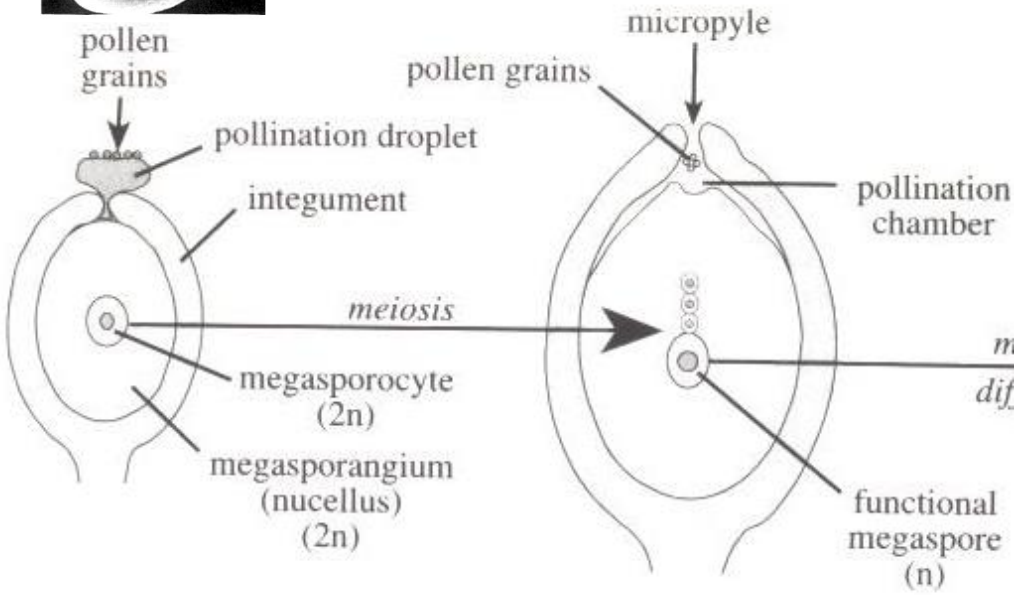
Fig. 22.12 Sperm of *Zamia floridana*. Left, side

Cronquist 1971

Como o pólen chega na micrópila de um óvulo? E onde nadam os gametas?







Gnetophyta

Cycadophyta

CICADÓFITAS

2 famílias principais

CYCADACEAE:

Micrópilas orientadas distalmente – polinização ?

9. Release of pollen from a cone o

10. The 500 cc of pollen typically released from a male cone of *Cycas rumphii*.

Norstog & Nichols 1997

Cycas sp.
Melanésia

CICADÓFITAS

2 famílias principais

CYCADACEAE:

Micrópilas orientadas distalmente – polinização pelo vento

9. Release of pollen from a cone o

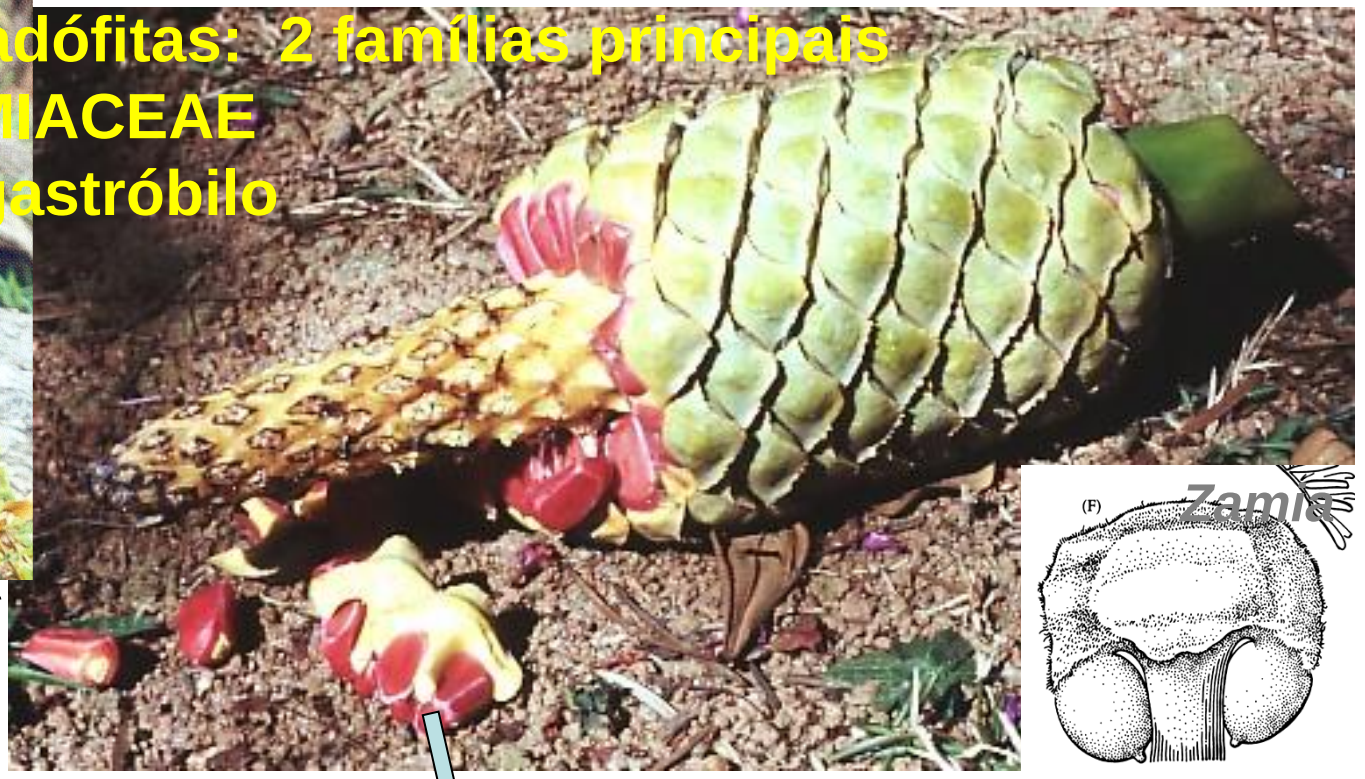
10. The 500 cc of pollen typically released from a male cone of *Cycas rumphii*.

Norstog & Nichols 1997

Cycas sp.
Melanésia

Cicadófitas: 2 famílias principais
ZAMIACEAE
megastróbilo

Encephalartos
Zamiaceae

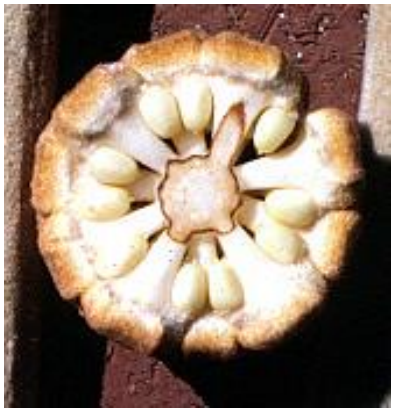


Micrópilas orientadas proximalmente

2 óvulos ➡ sementes

Zamia

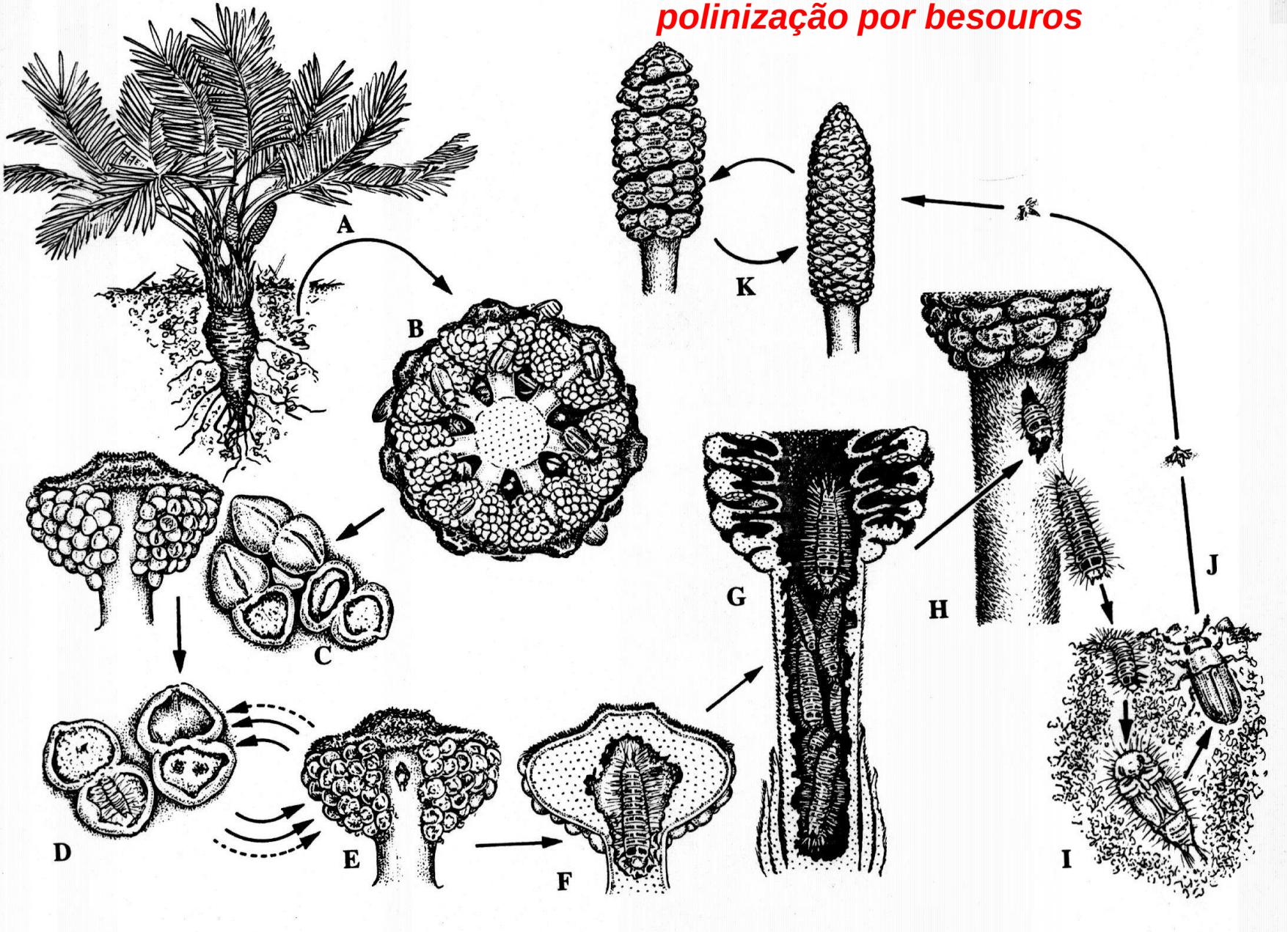
www.huh.harvard.edu



www.plantsystematics.org

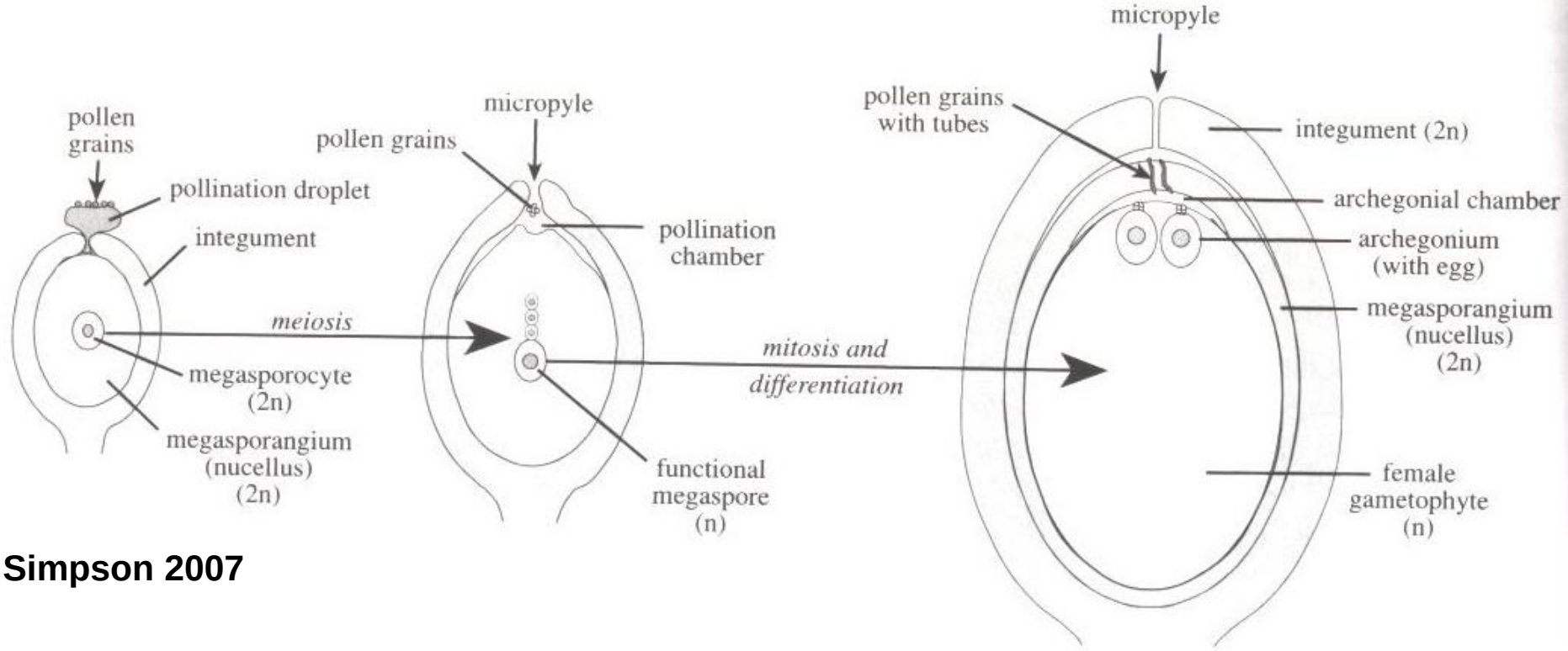
CICADÓFITAS – Zamiaceae

Micrópilas orientadas proximalmente – polinização por besouros



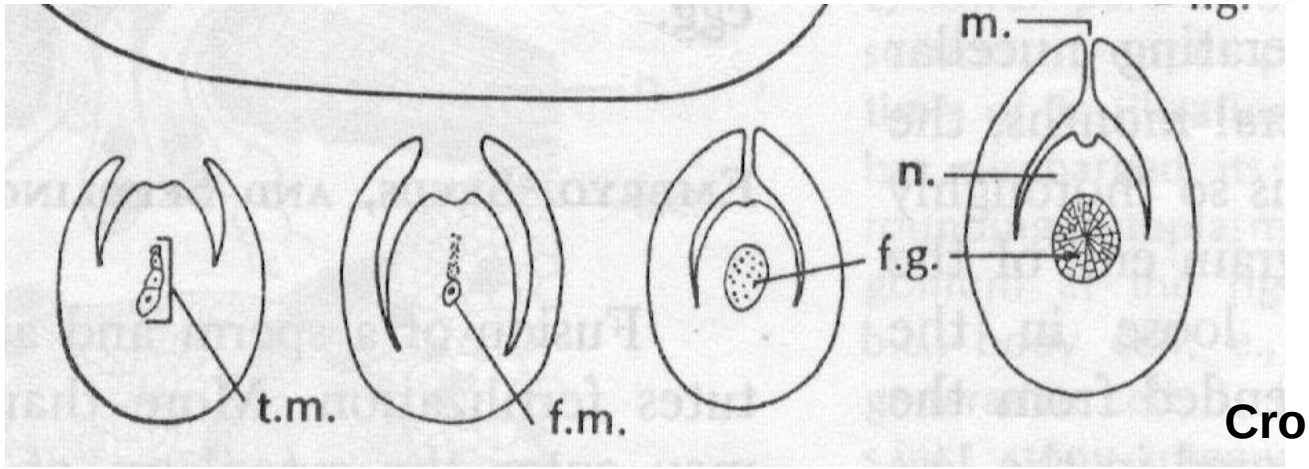
Ciclo reprodutivo de *Pharaxonotha zamiae* em *Zamia integrifolia*

Polinização e fecundação em Cycadophyta



Simpson 2007

FIGURE 5.11 Ovule development in the in the nonflowering Spermatophytes.



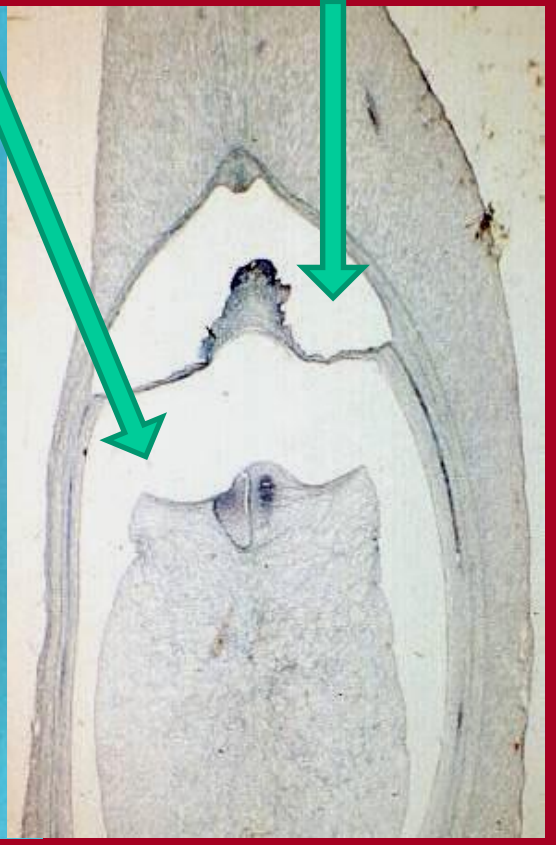
Cronquist 1971

Óvulo em Cycadophyta

Cycas, Cycadaceae

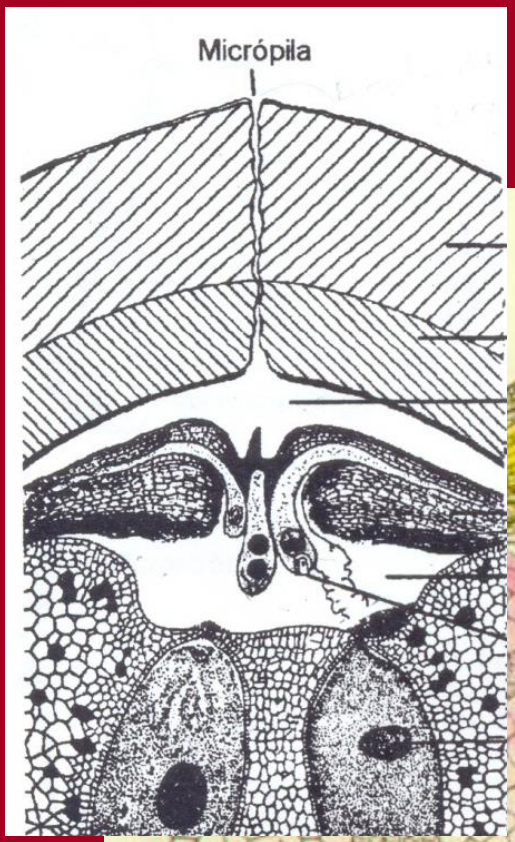
Câmara arquegonial

Câmara polínica



Encephalartos, Zamiaceae

CYCADOPHYTA



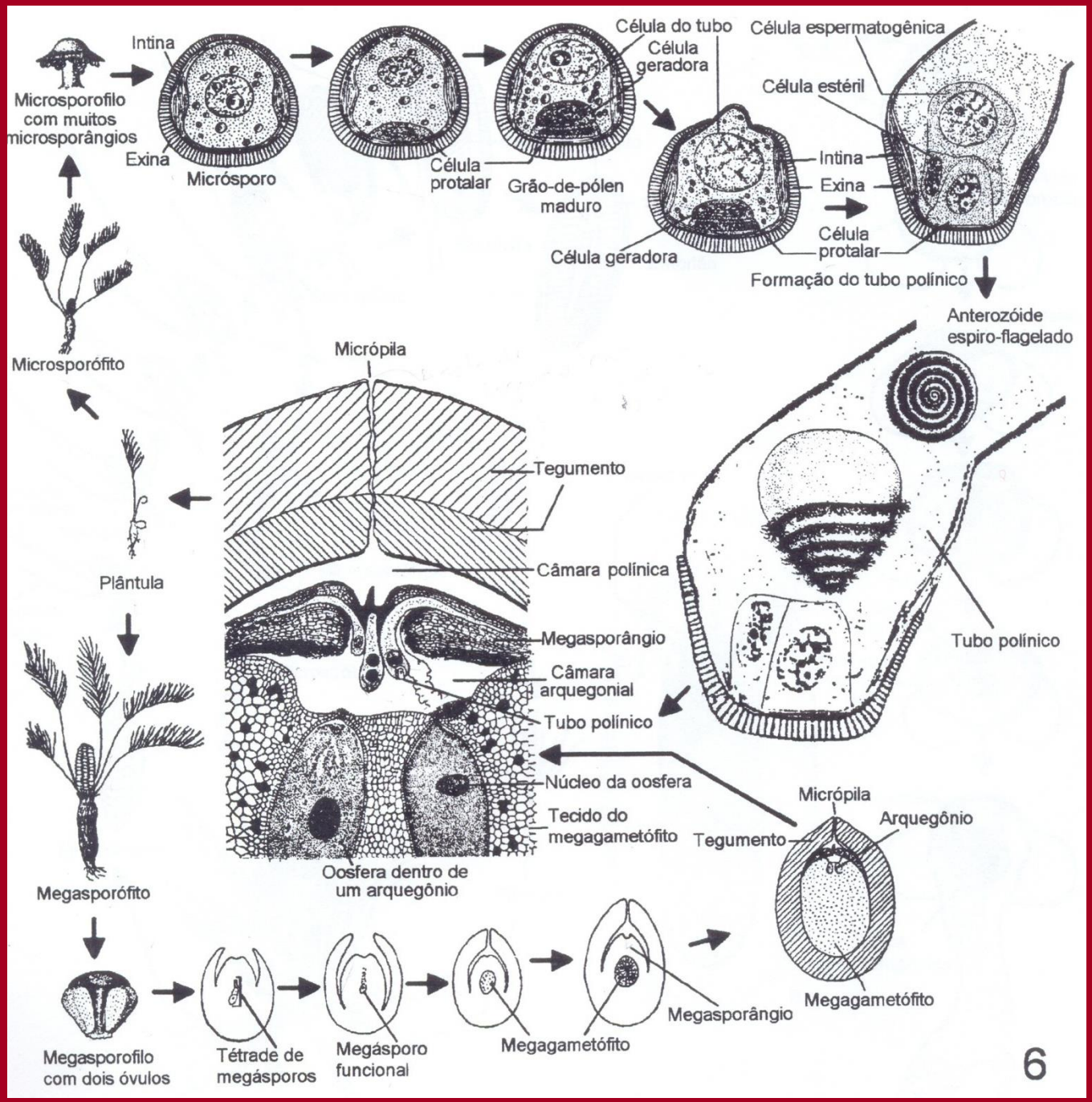
câmara polínica

câmara arquegonial

Chamberlain 1935

Fecundação

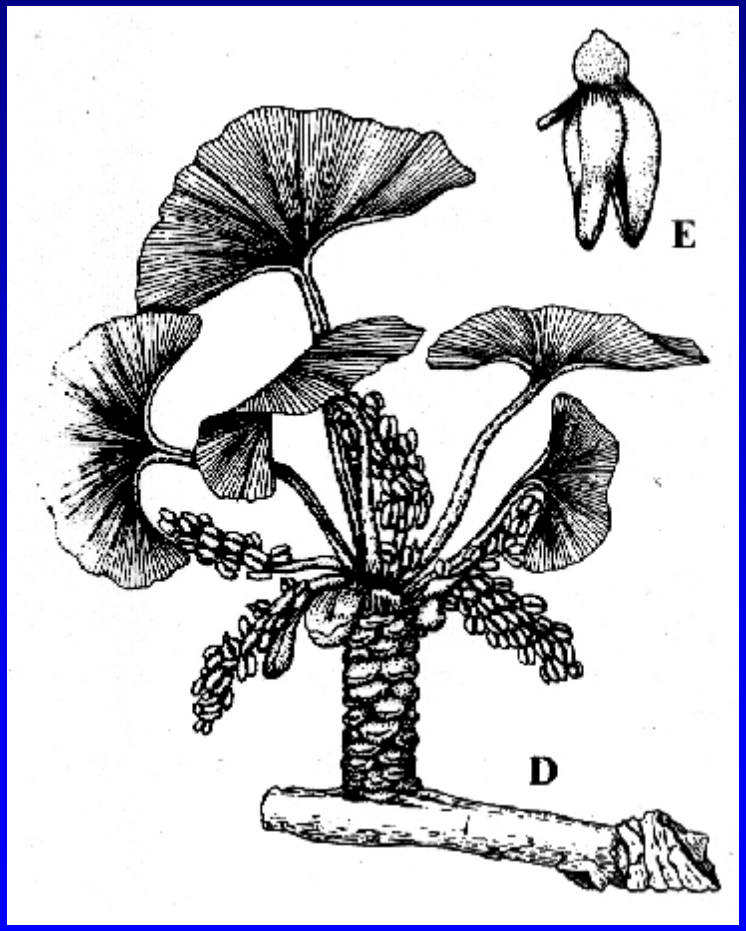
CYCADOPHYTA



Cronquist 1971

GINKGOPHYTA

Ginkgo biloba



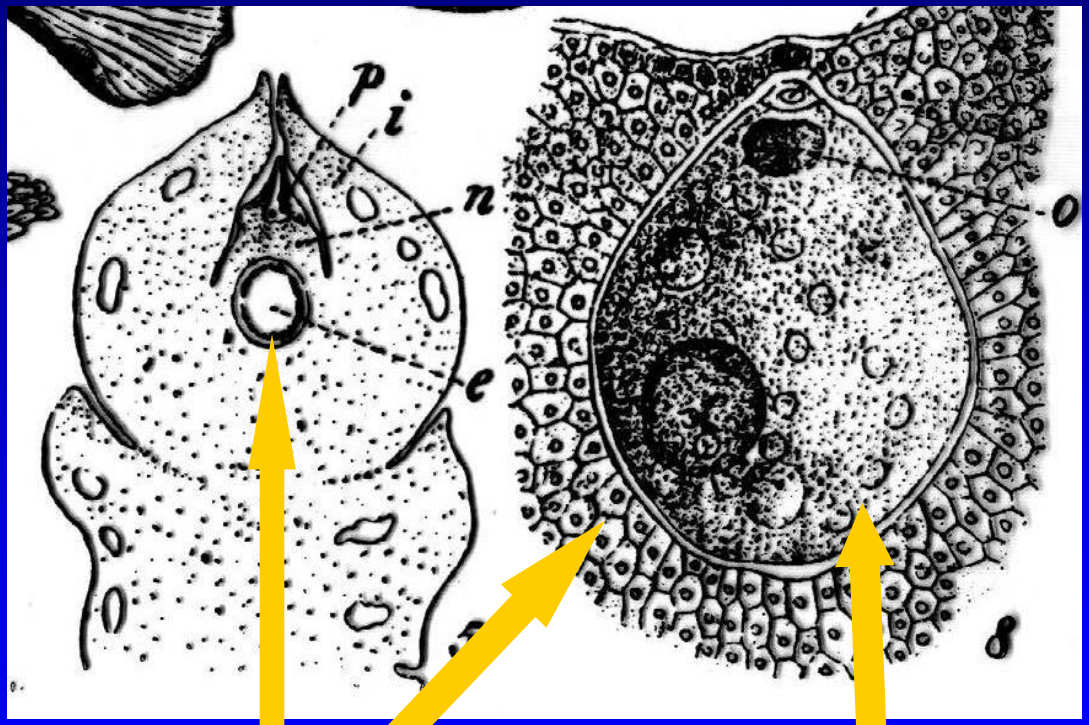
Kubitzki 1990

Óvulo

GINKGOPHYTA

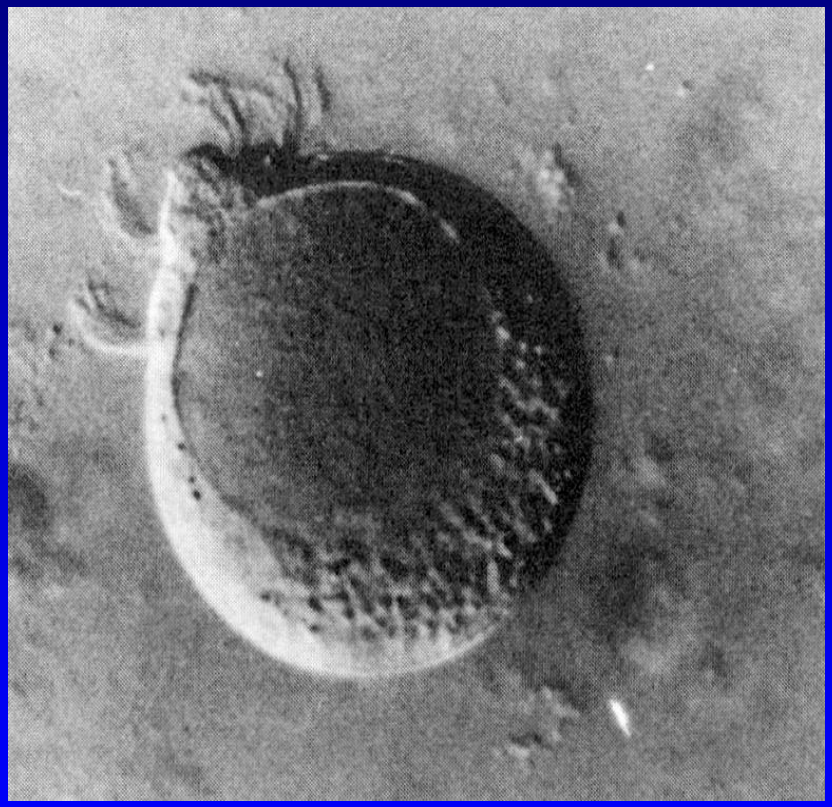
Câmaras polínica e arquegonial

gametas masculinos flagelados



Arquegônio com oosfera

Gametófito feminino



Gifford & Foster 1989

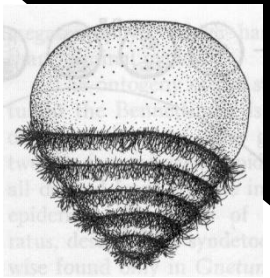
TRAQUEÓFITAS ou Plantas Vasculares

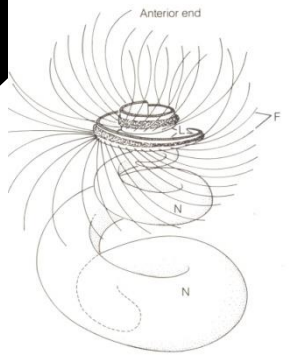
EUFILÓFITAS

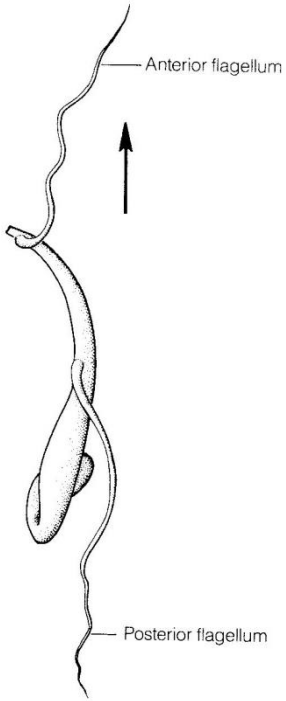
LICOPODIÓFITAS

ESPERMATÓFITAS

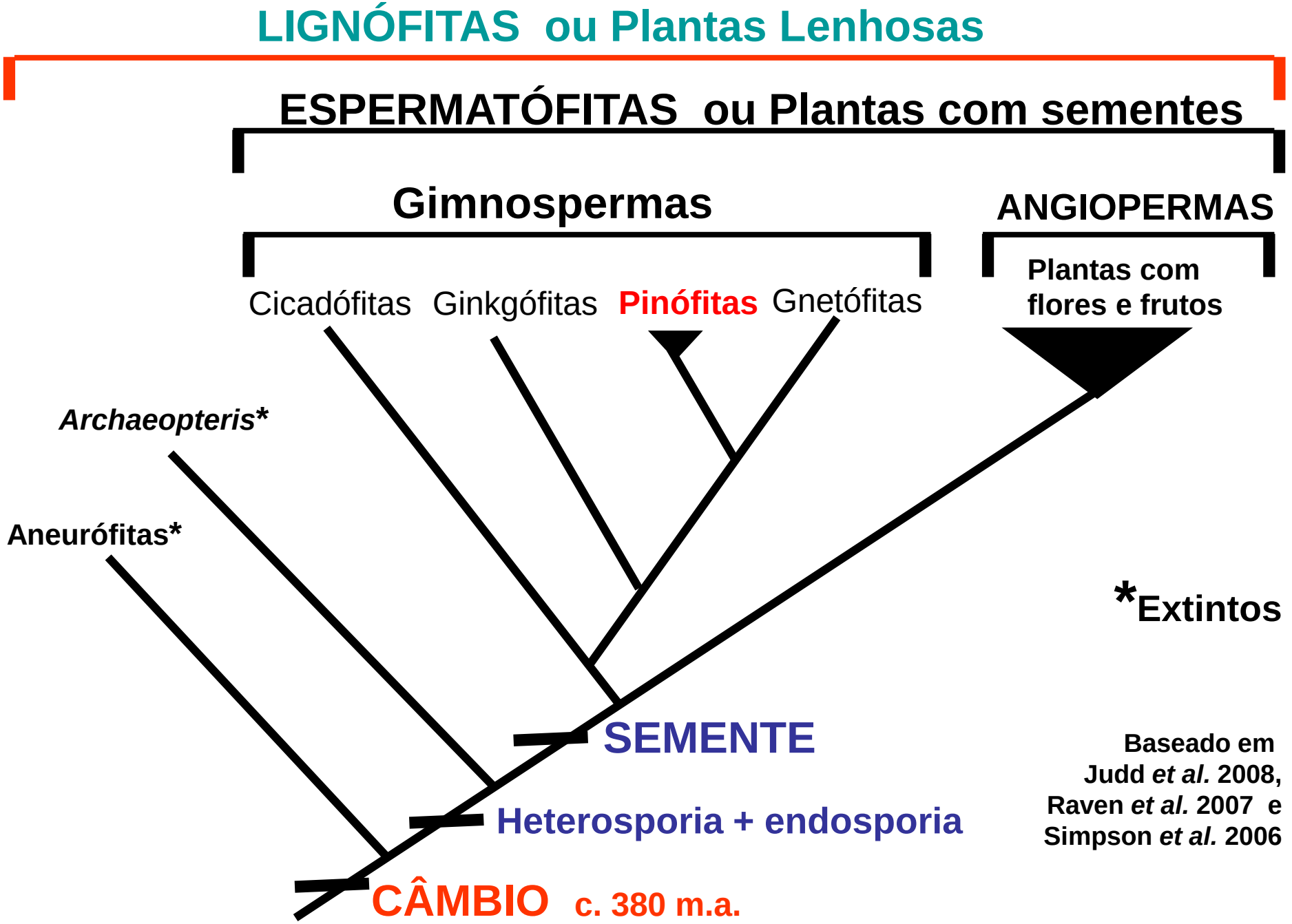
MONILÓFITAS





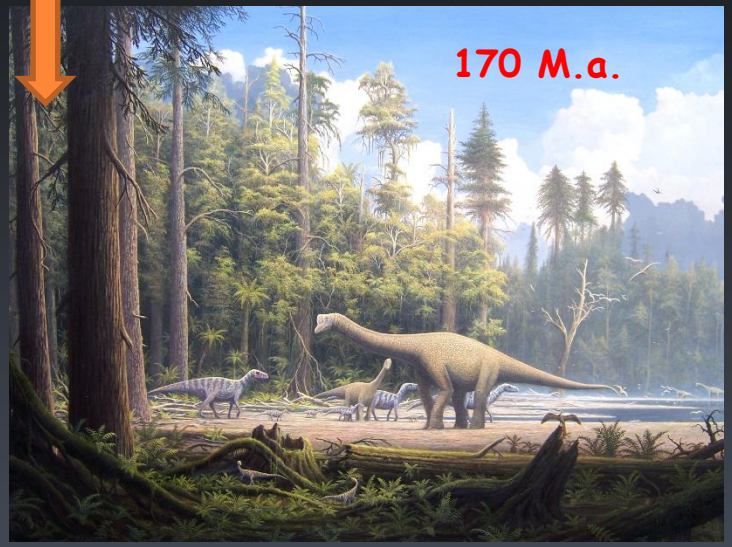


megafilos,
anterozóides multiflagelados

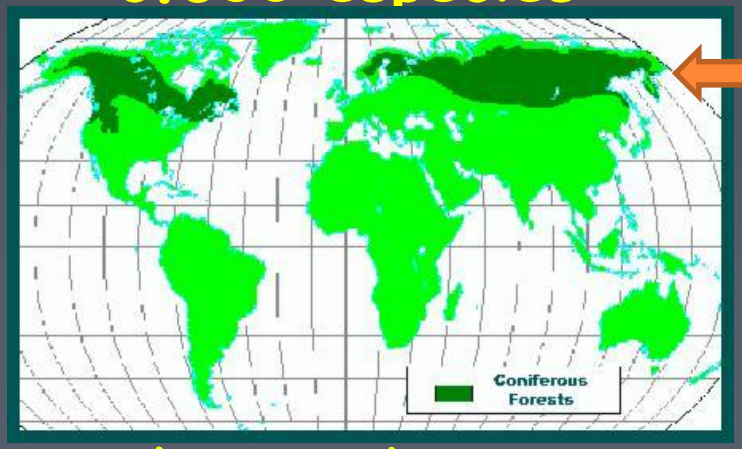

LIGNÓFITAS ou Plantas Lenhosas
ESPERMATÓFITAS ou Plantas com sementes
Gimnospermas
ANGIOPERMAS
Plantas com flores e frutos
Cicadófitas
Ginkgófitas
Pinófitas
Gnetófitas
Archaeopteris*
Aneurófitas*
*Extintos
SEMENTE
Heterosporia + endosporia
CÂMBIO c. 380 m.a.
Baseado em Judd et al. 2008, Raven et al. 2007 e Simpson et al. 2006

PINÓFITAS (ou Coníferas): surgiram no Permiano (Paleozoico superior)

Dominantes no Triássico e Jurássico (Mesozoico inferior e médio)



viventes: 7 famílias
c.630 espécies



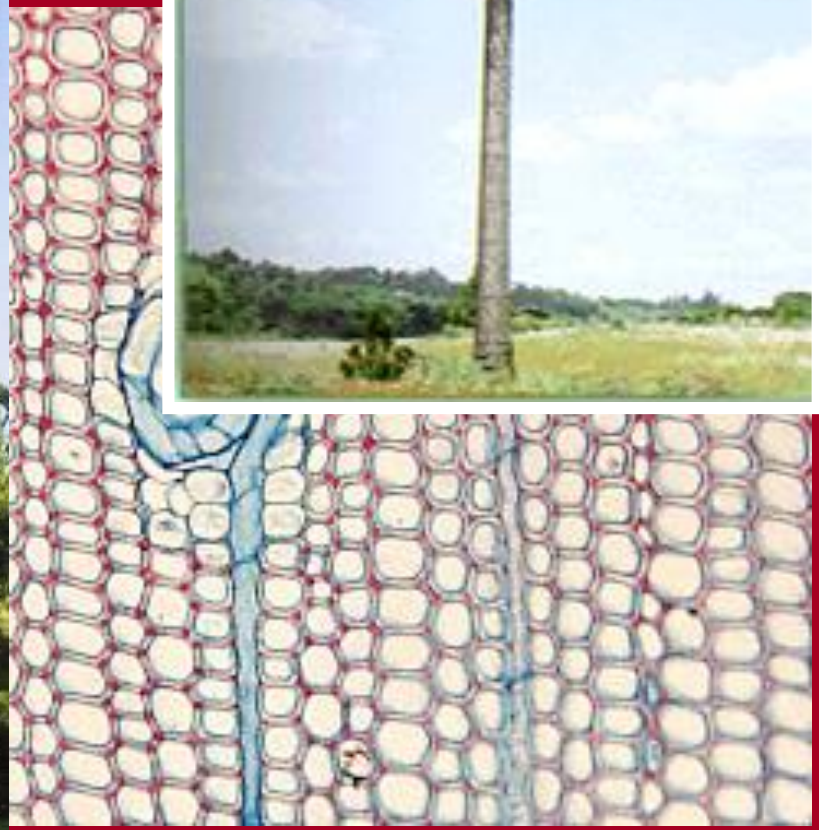
Atualmente: dominantes na Floresta Boreal (Taiga)

PINOPHYTA (coníferas)

Pinus

Araucaria

Cupressus



Contraste da copa ramificada com o hábito das Cicadófitas

Cordaitales

extintas

Cordaites angulostriatus

www.ucmp.berkeley.edu

Ginkgófitas

Ginkgo biloba

Pinófitas

Araucaria angustifolia

Cupressus sempervirens

Cicadófitas

Dioon spinulosum

Cycas ophiolitica

Contraste da copa ramificada com o hábito das Cicadófitas

Cordaitales

extintas

Cordaites angulostriatus

www.ucmp.berkeley.edu

Ginkgófitas

♦gemas axilares e folhas simples

Ginkgo biloba

Pinófitas

Araucaria angustifolia

Cupressus sempervirens

Cicadófitas

(folhas compostas sem gemas laterais)

Dioon spinulosum

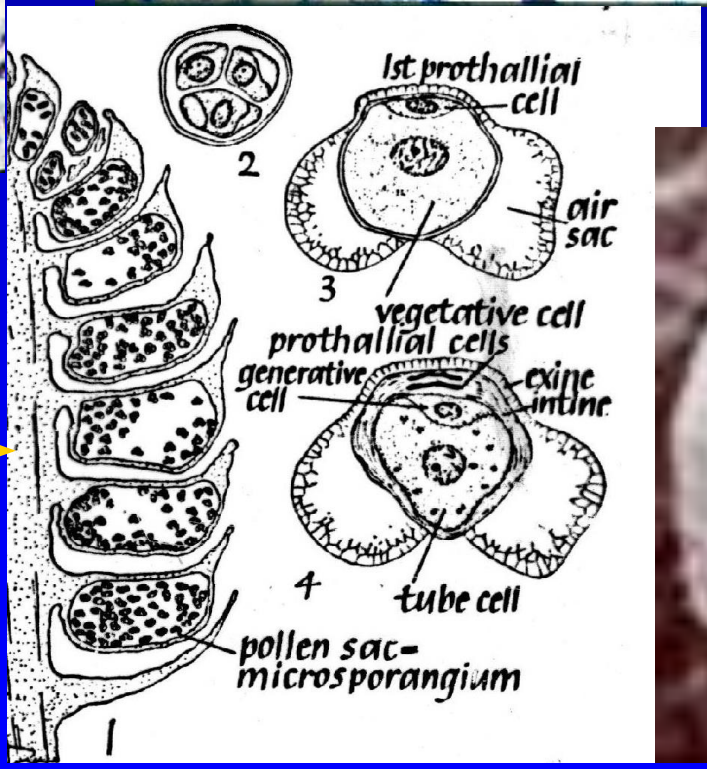
Cycas ophiolitica

Pinus

PINOPHYTA
(coníferas)

PINACEAE

microsporofilos com
2 microsporângios

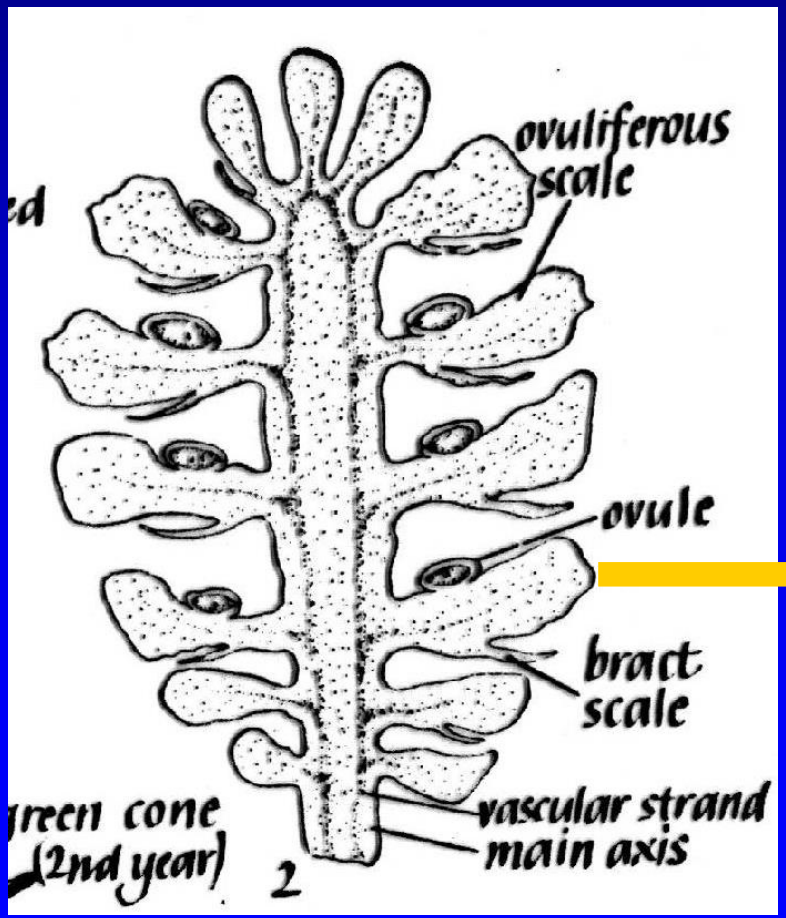


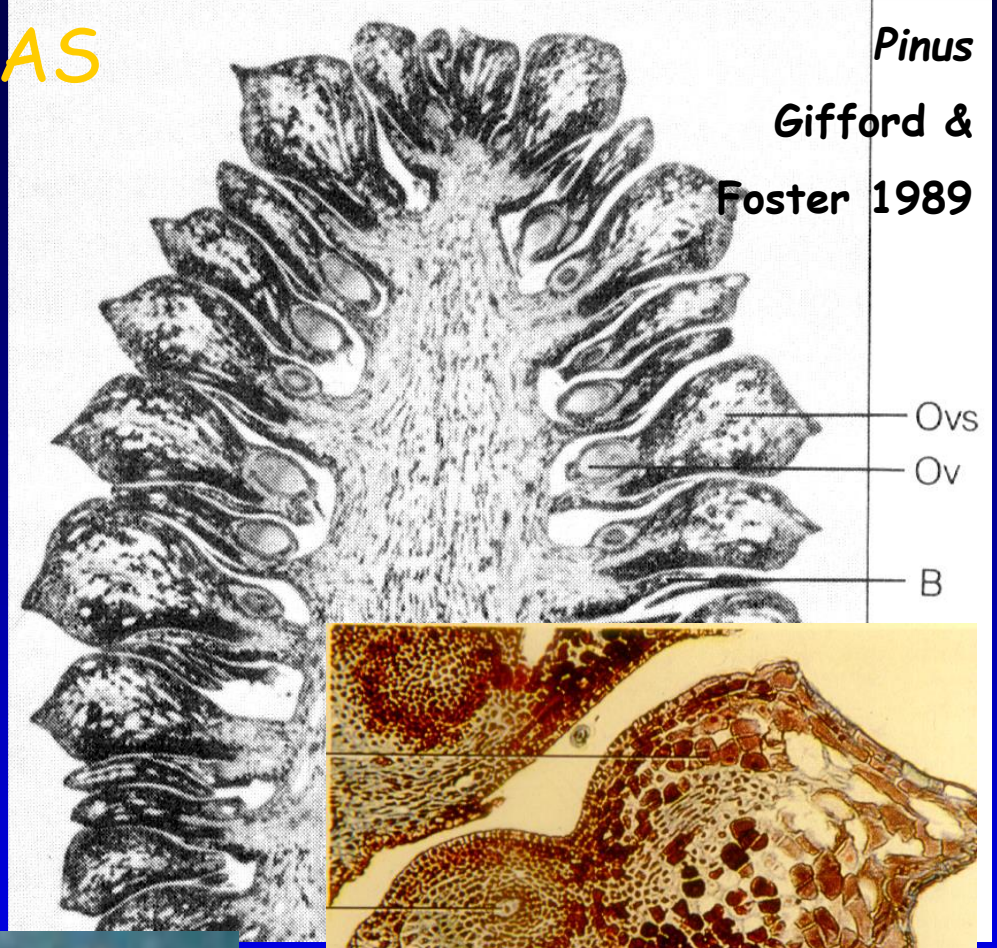
pólen com
2 sacos aéreos

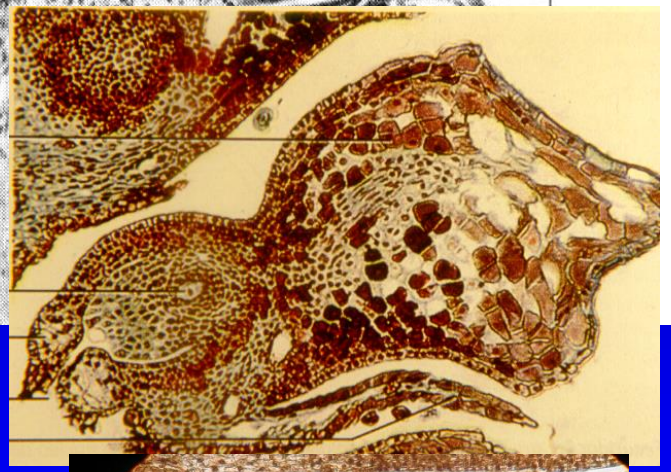
NOVIDADES EVOLUTIVAS

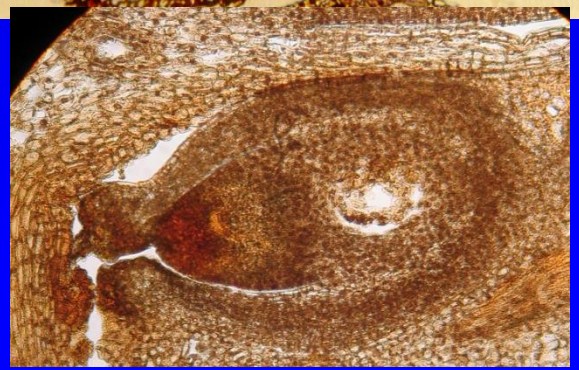
- megastróbilo composto = CONE

(eixo com escamas ovulíferas e bracteais)







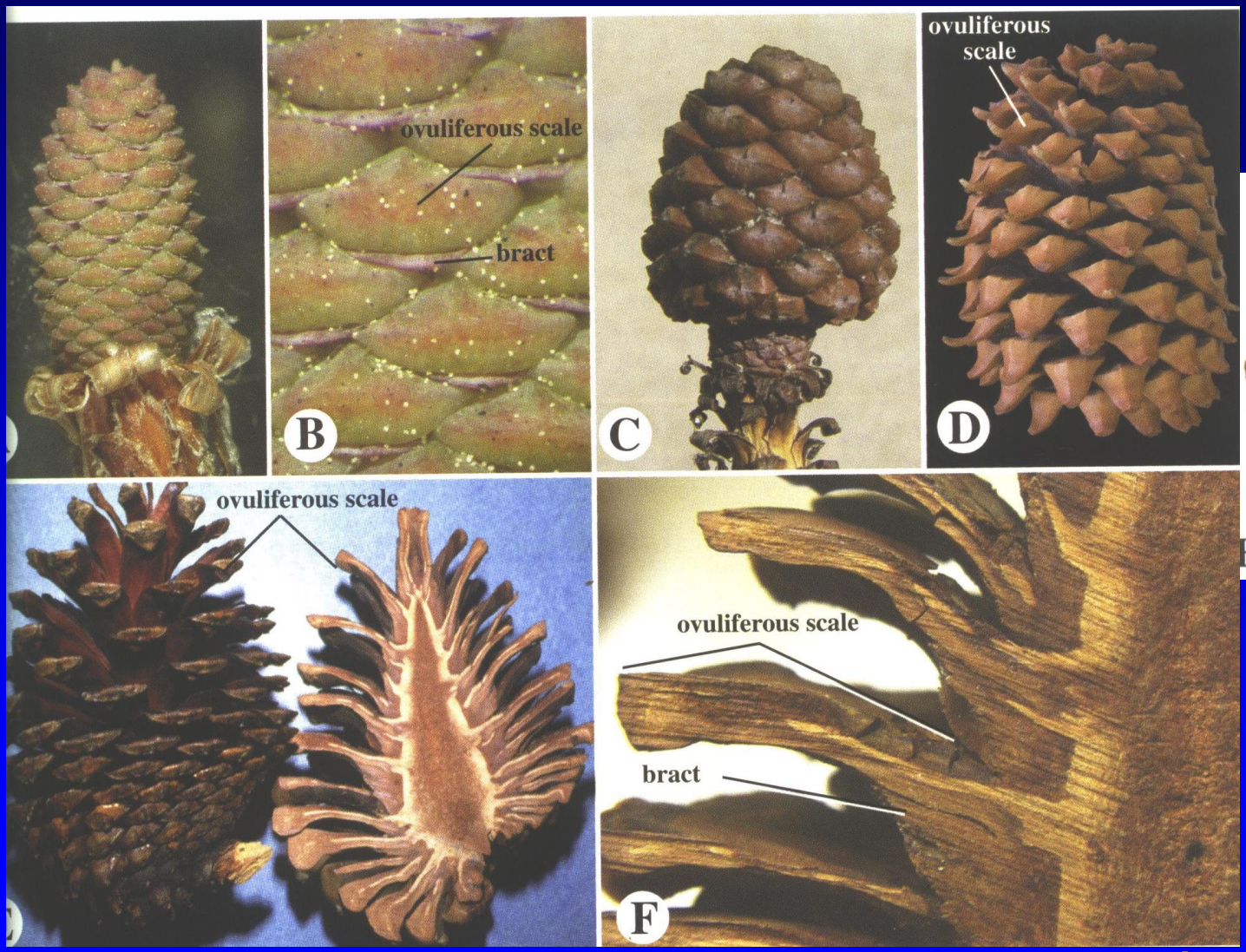


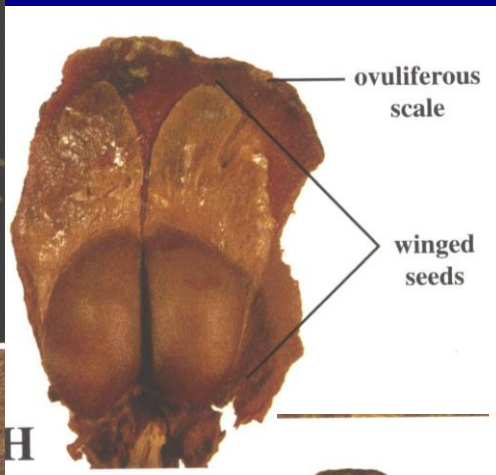
NOVIDADES EVOLUTIVAS

- megastróbilo composto = CONE (eixo com escamas ovulíferas e bracteais)

Pinus

Pinophyta

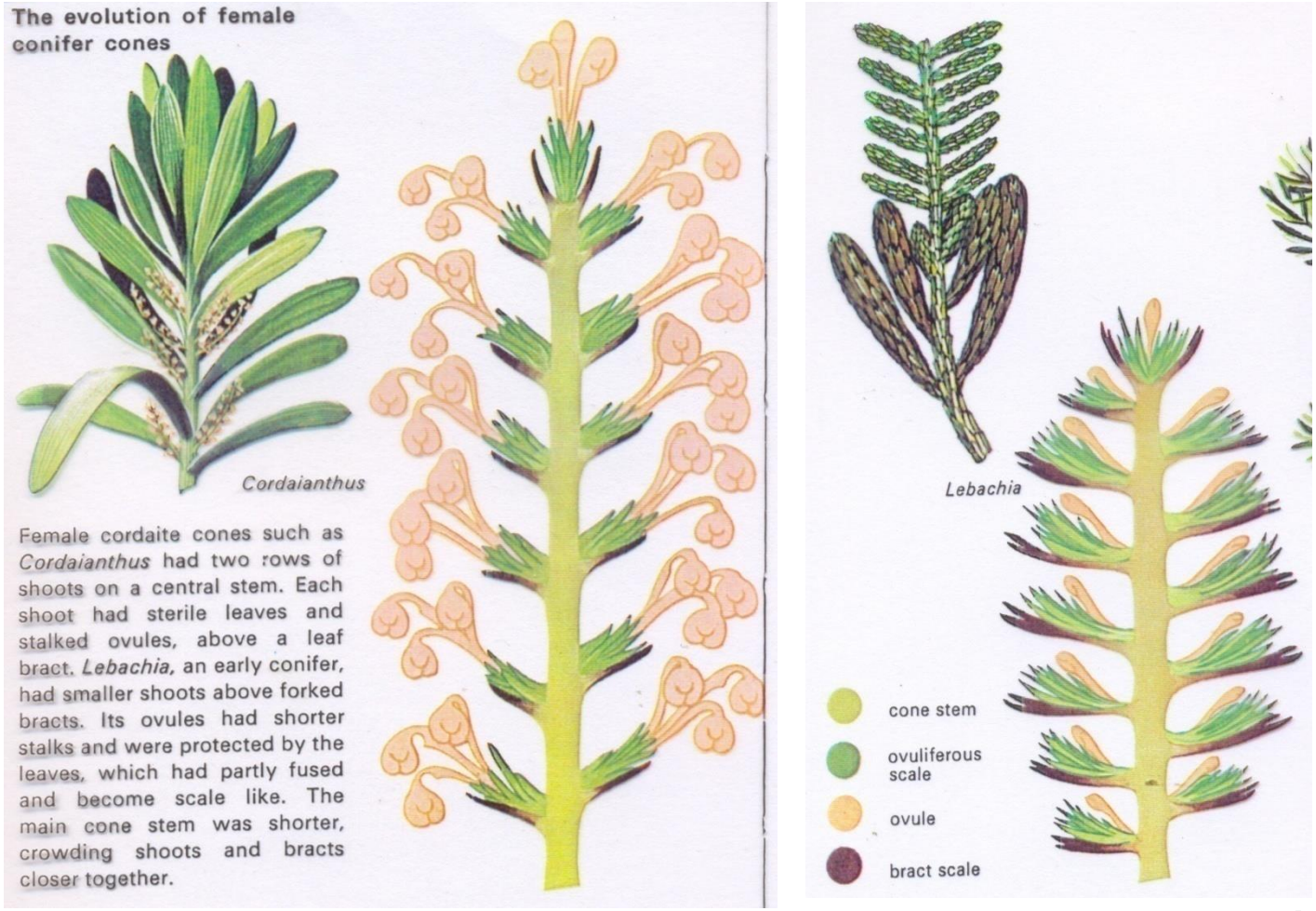




semente

Simpson 2007

Megastróbilo composto (CONE): origem



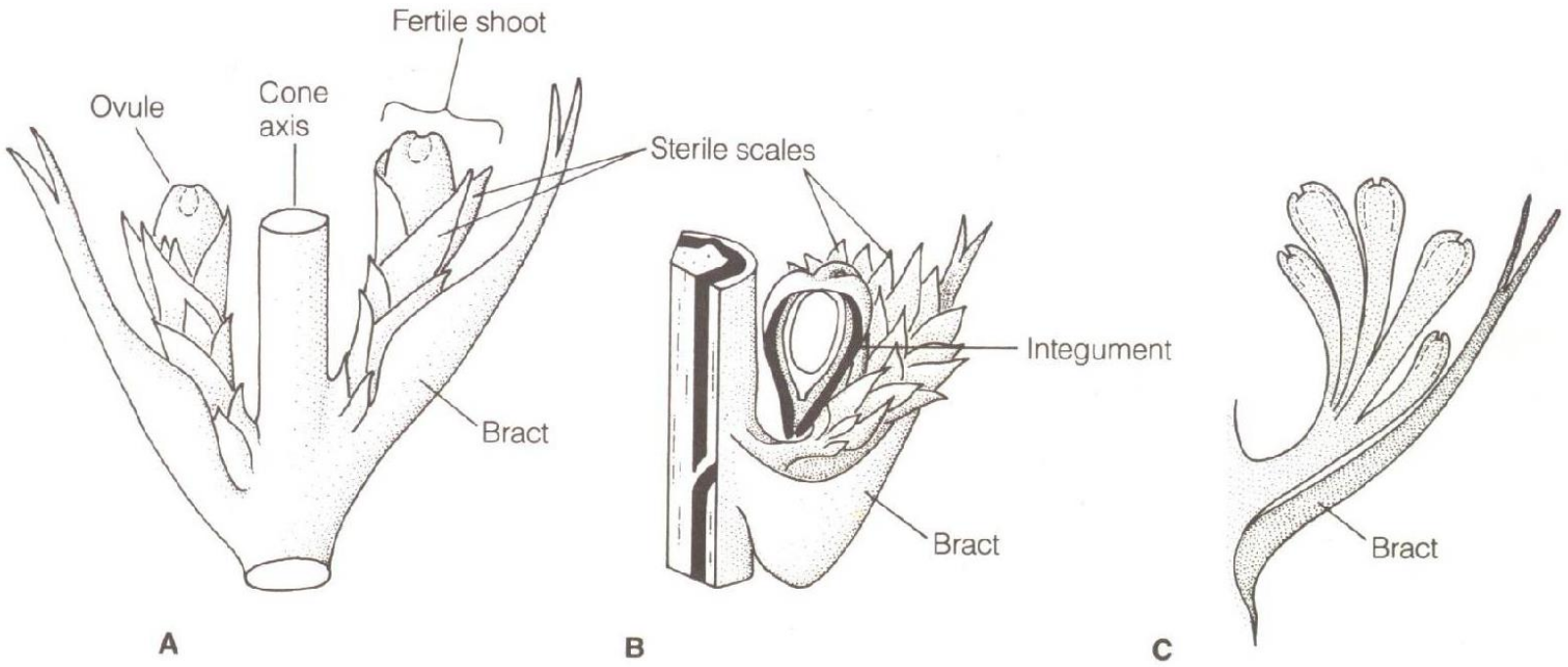
Cordaitales - fósseis

Mauseth 1989

Escama bracteal = folha modificada

Escama ovulífera = ramo fértil reduzido

Megastróbilo composto (CONE): origem



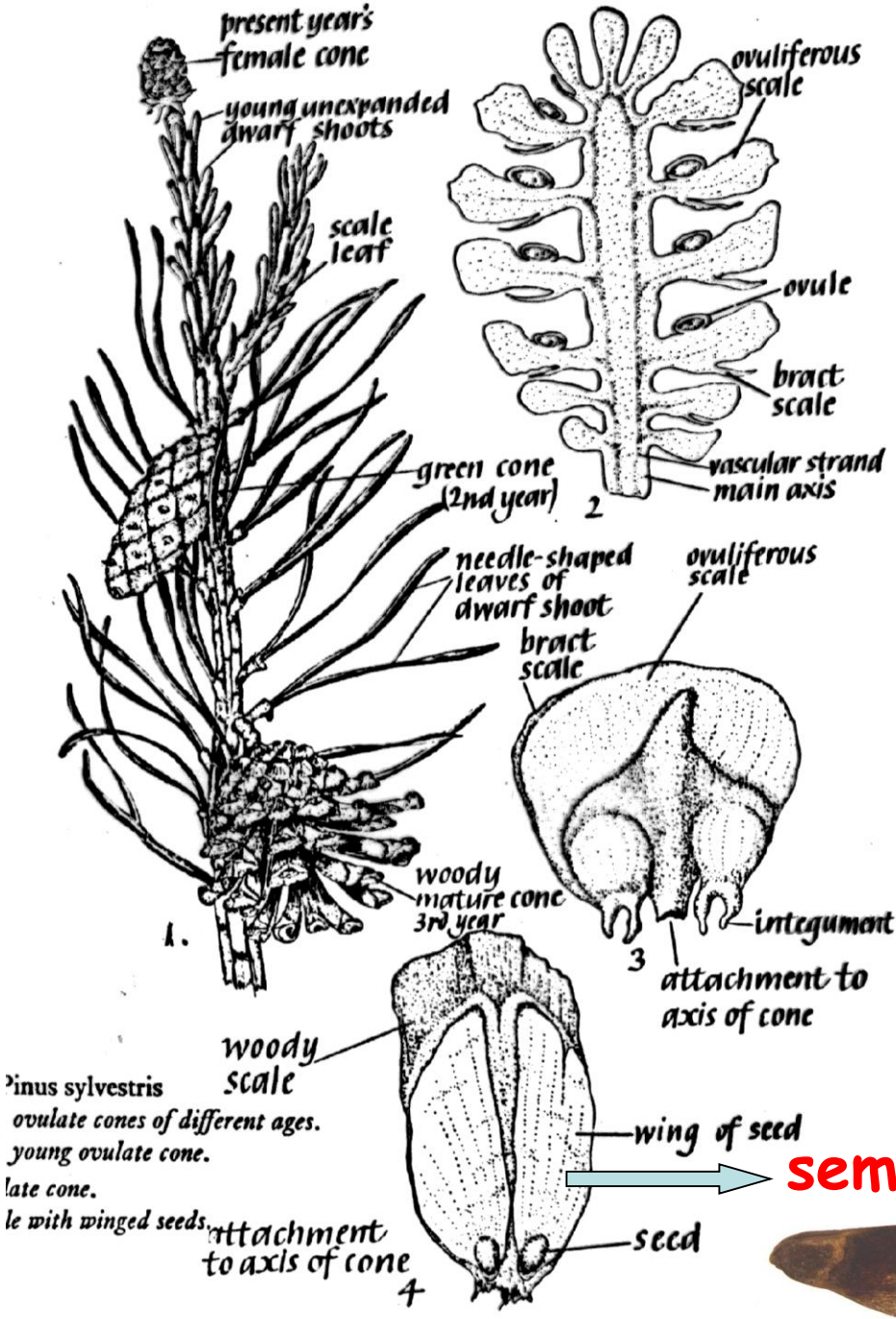
A, B. *Lebachia* **C. *Ernestiodendron***

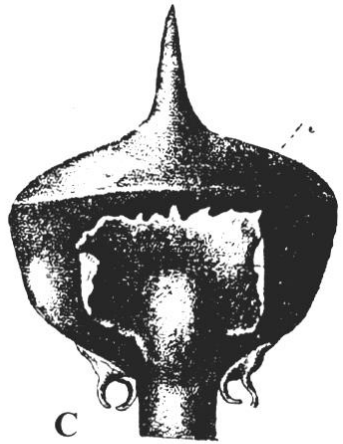
Gifford & Foster 1989

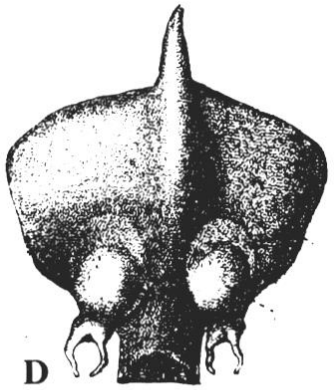
Voltziales, Pinophyta

PINÓFITAS

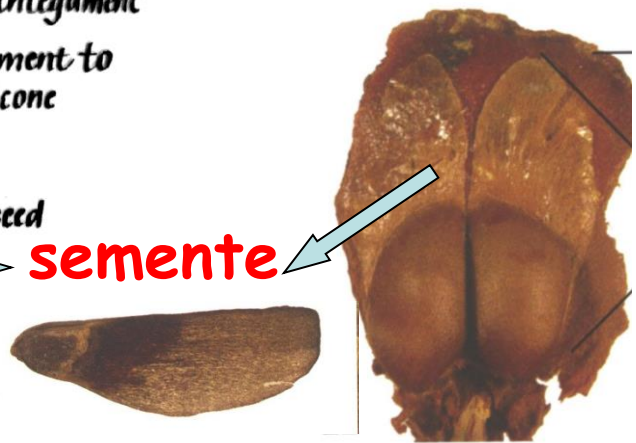
- escama ovulífera é um ramo curto com 1, 2 ou + óvulos, na axila da escama bracteal







semente



PINÓFITAS

Pseudotsuga

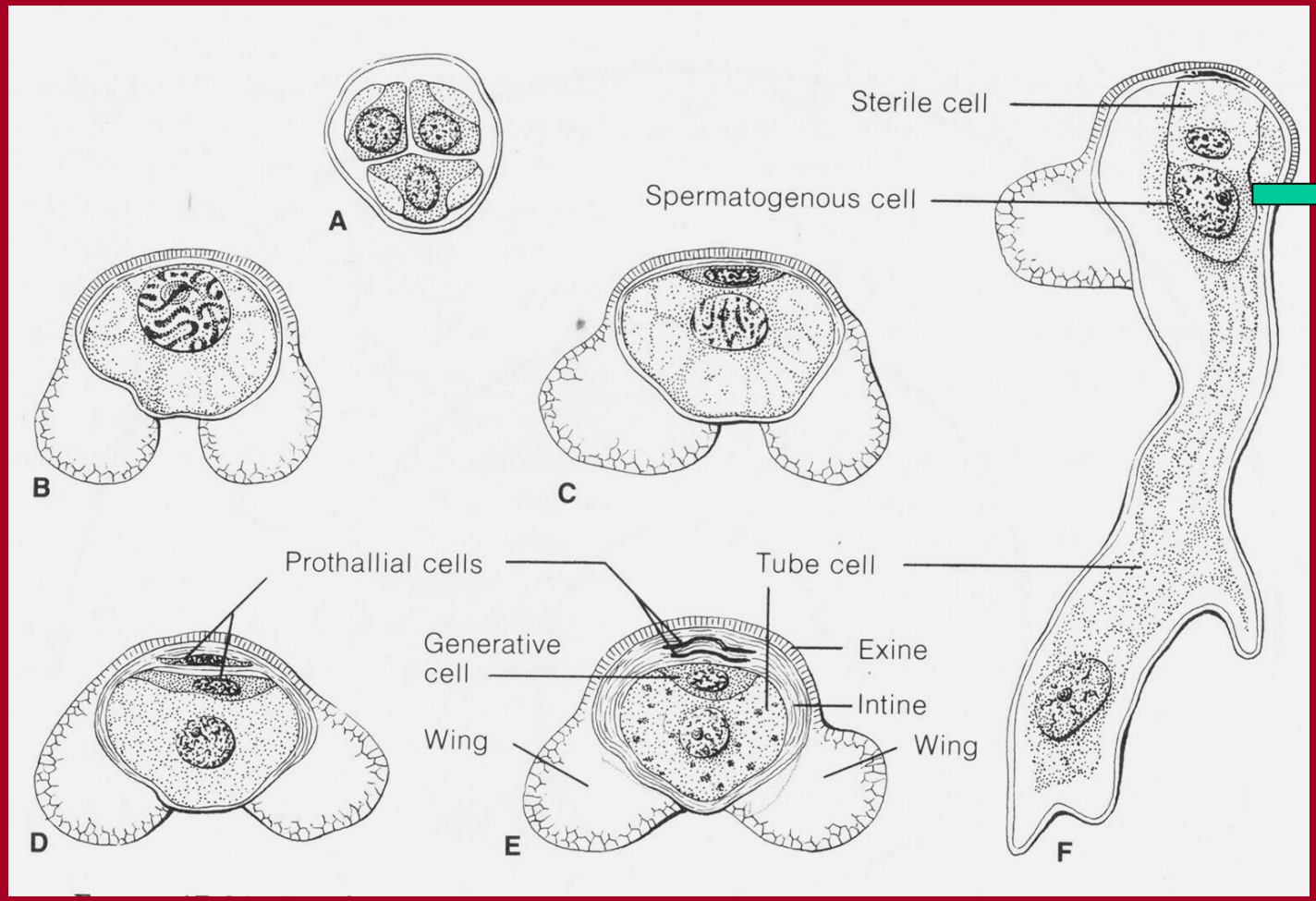
CONE

escama ovulífera

escama bracteal

NOVIDADES EVOLUTIVAS

Pinófitas:
o tubo polínico leva os gametas masculinos até os arquegônios = sifonogamia

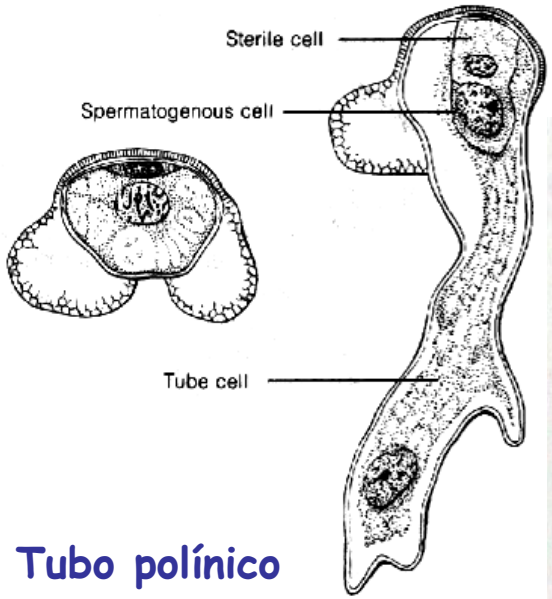


Esta célula origina 2 gametas sem flagelos

Gifford & Foster 1989

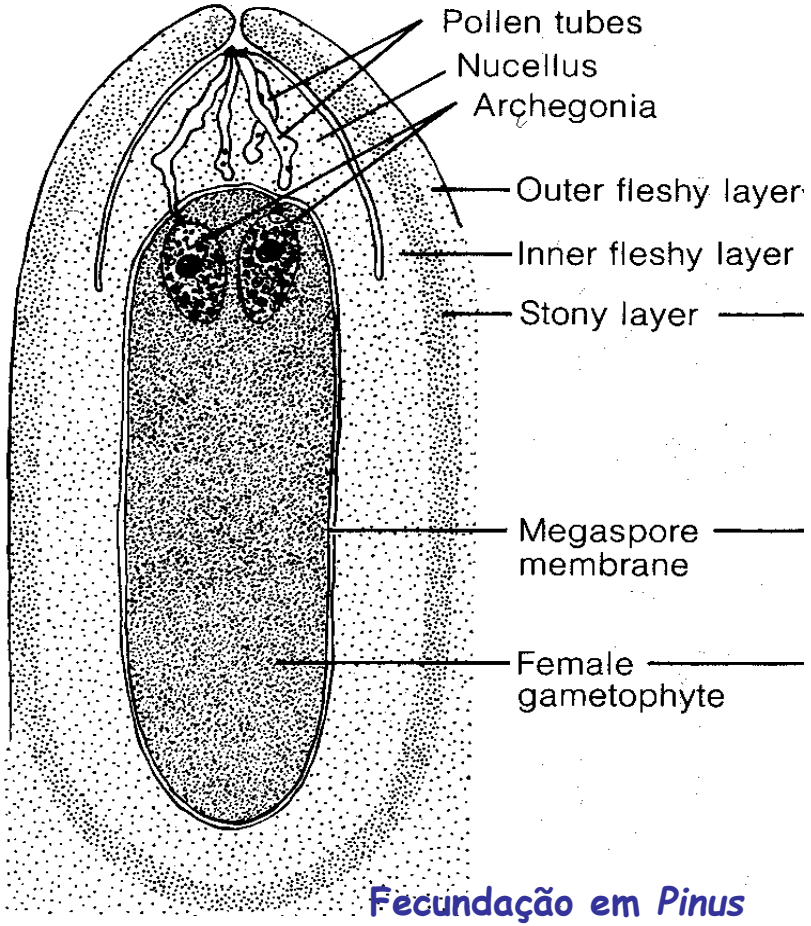
NOVIDADES EVOLUTIVAS
de (PINOPHYTA + GNETOPHYTA)
e surgimento independente nas ANTHOPHYTA

- **sifonogamia**
- **gametas masculinos não flagelados (células espermáticas)**



Tubo polínico em *Pinus*

Gifford & Foster 1989

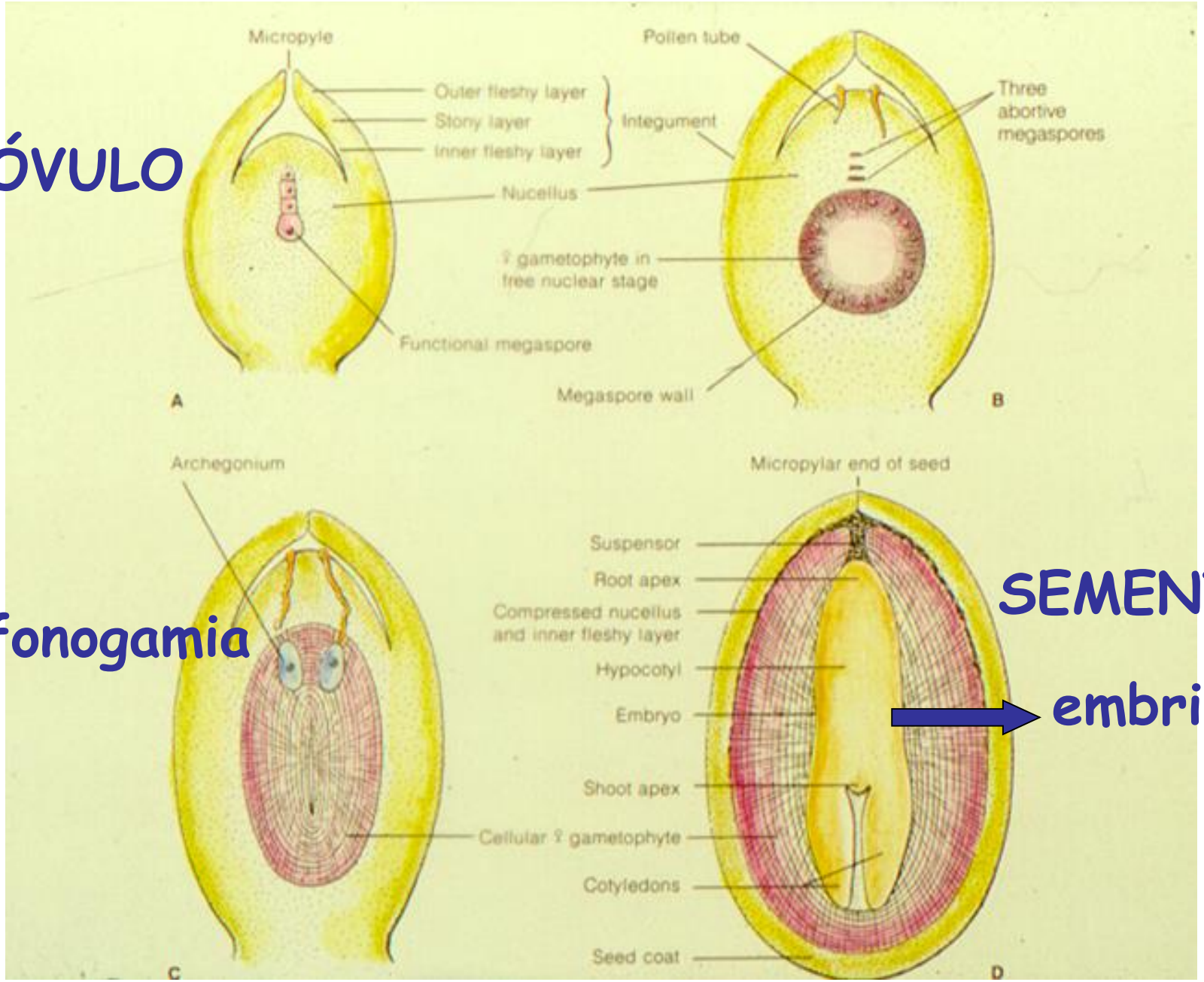


Fecundação em *Pinus*

Gifford & Foster 1989

Do óvulo à semente: megasporogênese, gametogênese, embriogênese.

ÓVULO

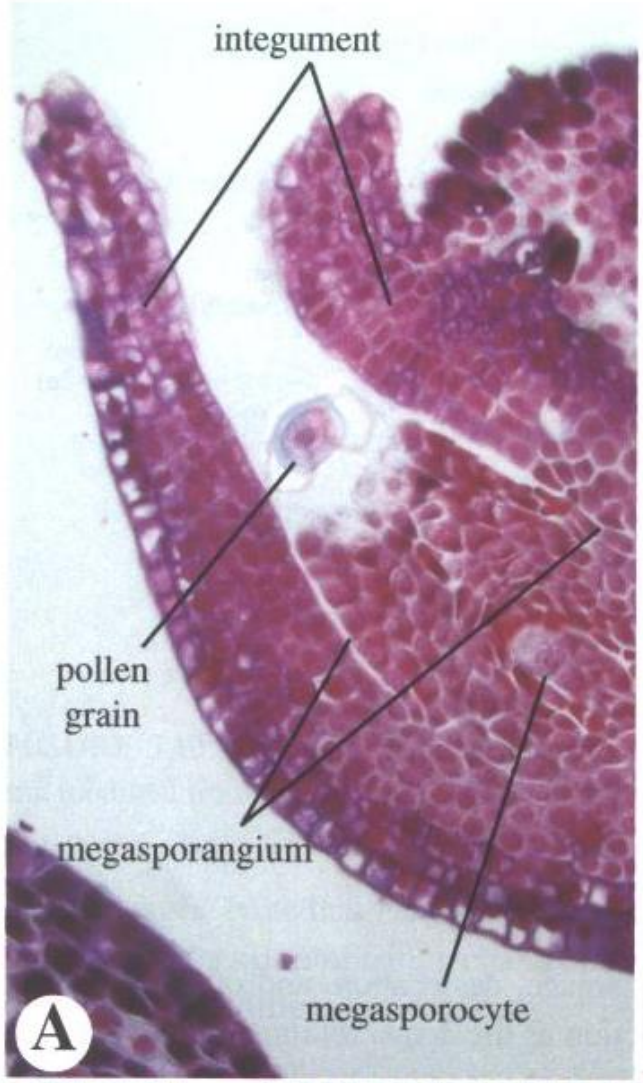


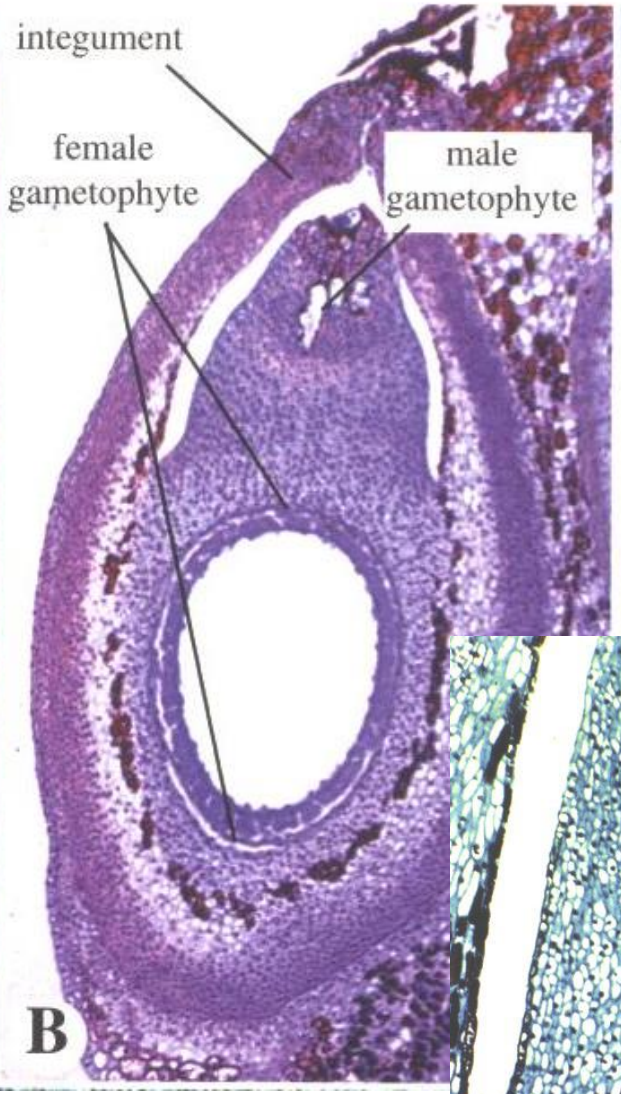
sifonogamia

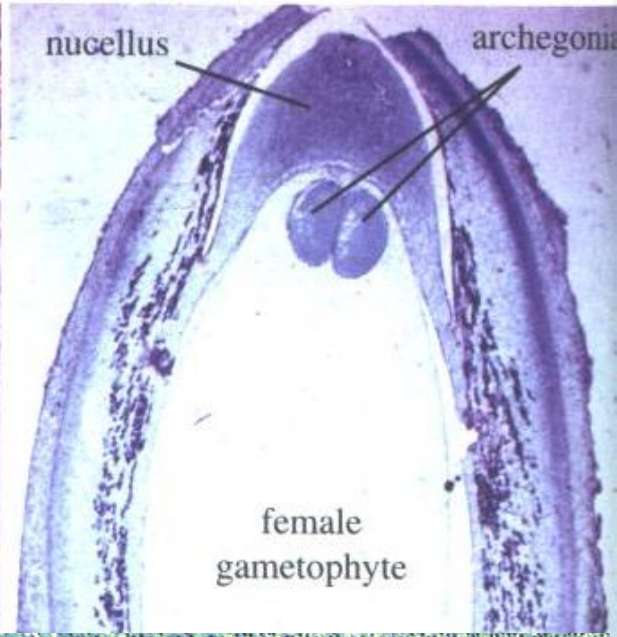
SEMENTE

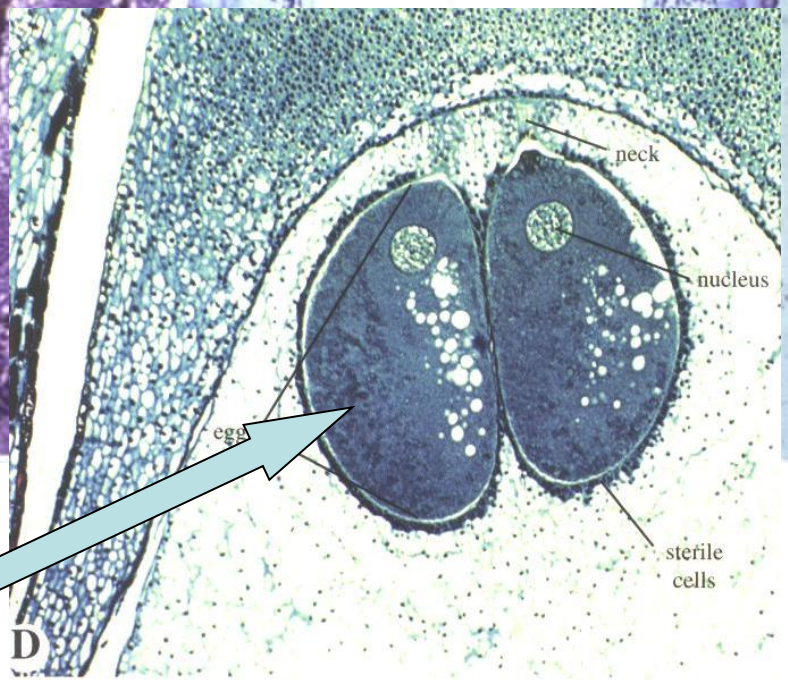
embrião

PINACEAE *Pinus*









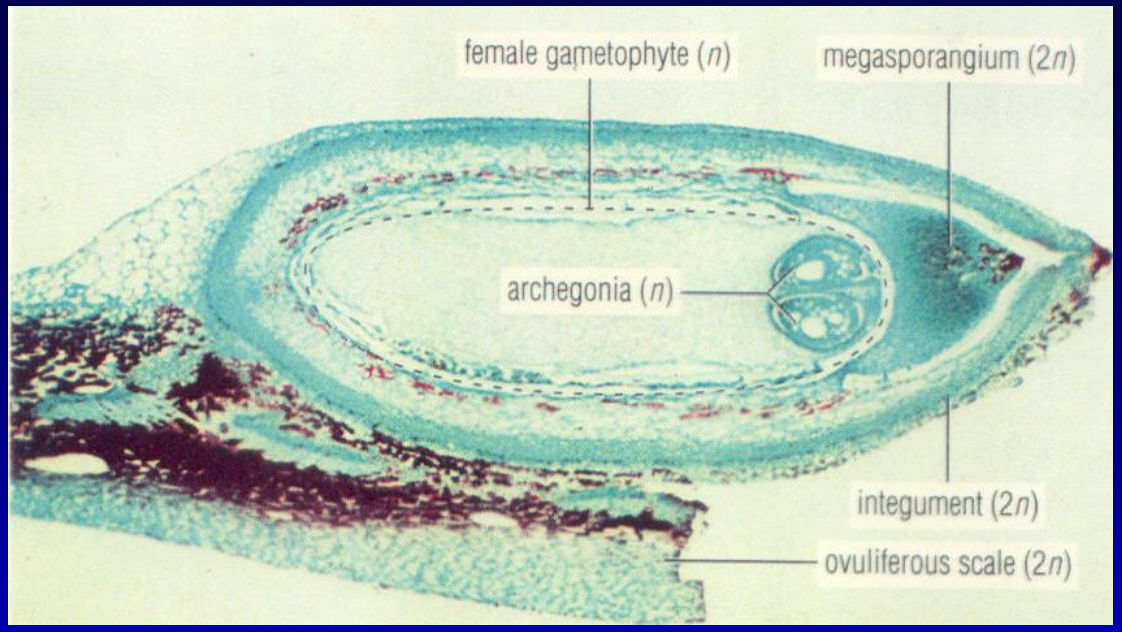
oosfera

Simpson 2006

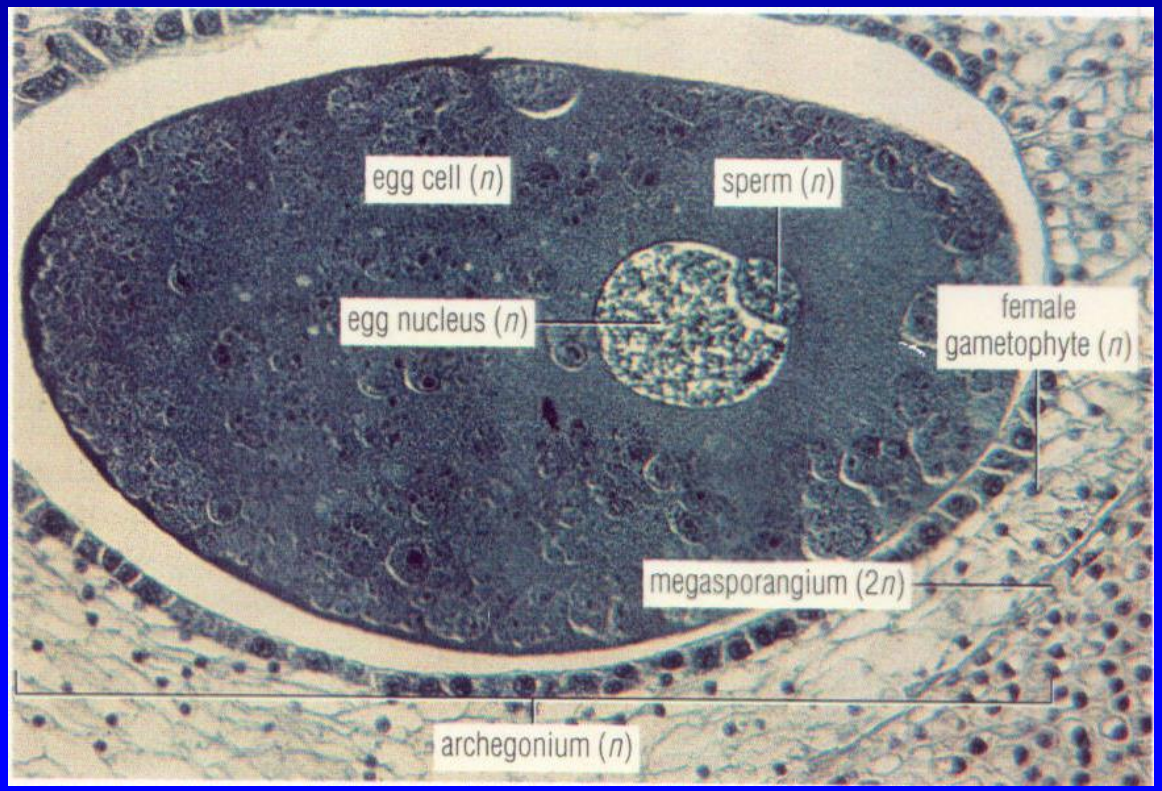
PINACEAE

Pinus

óvulo



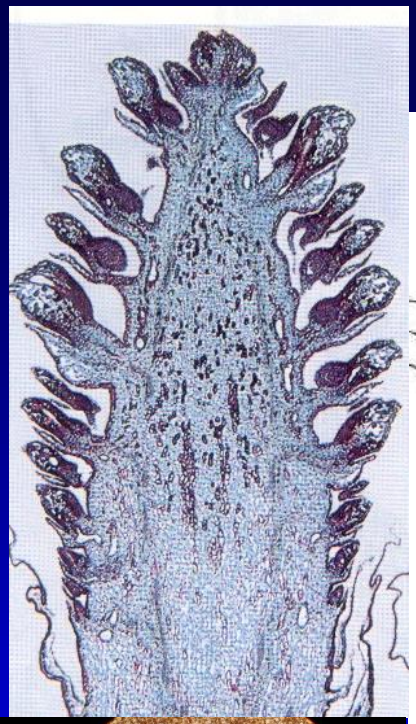
fecundação da oosfera

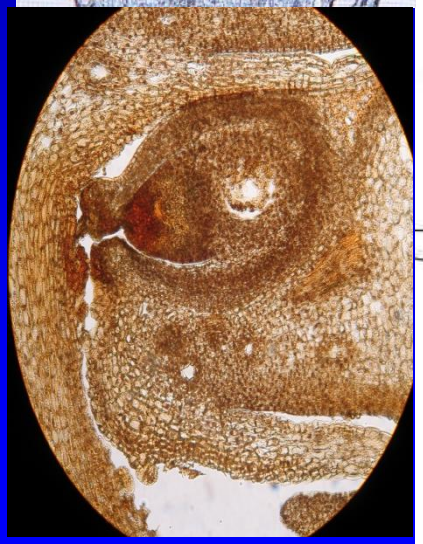


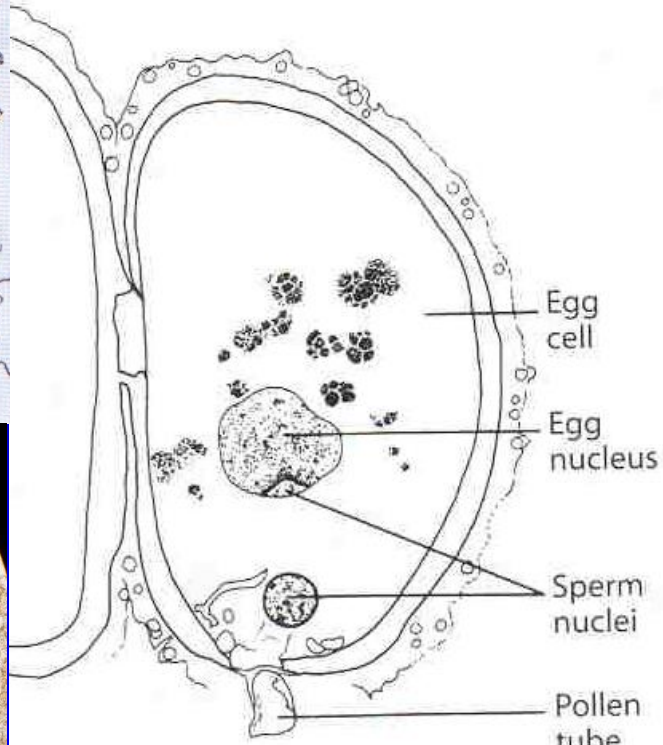
Perry & Morton 1996

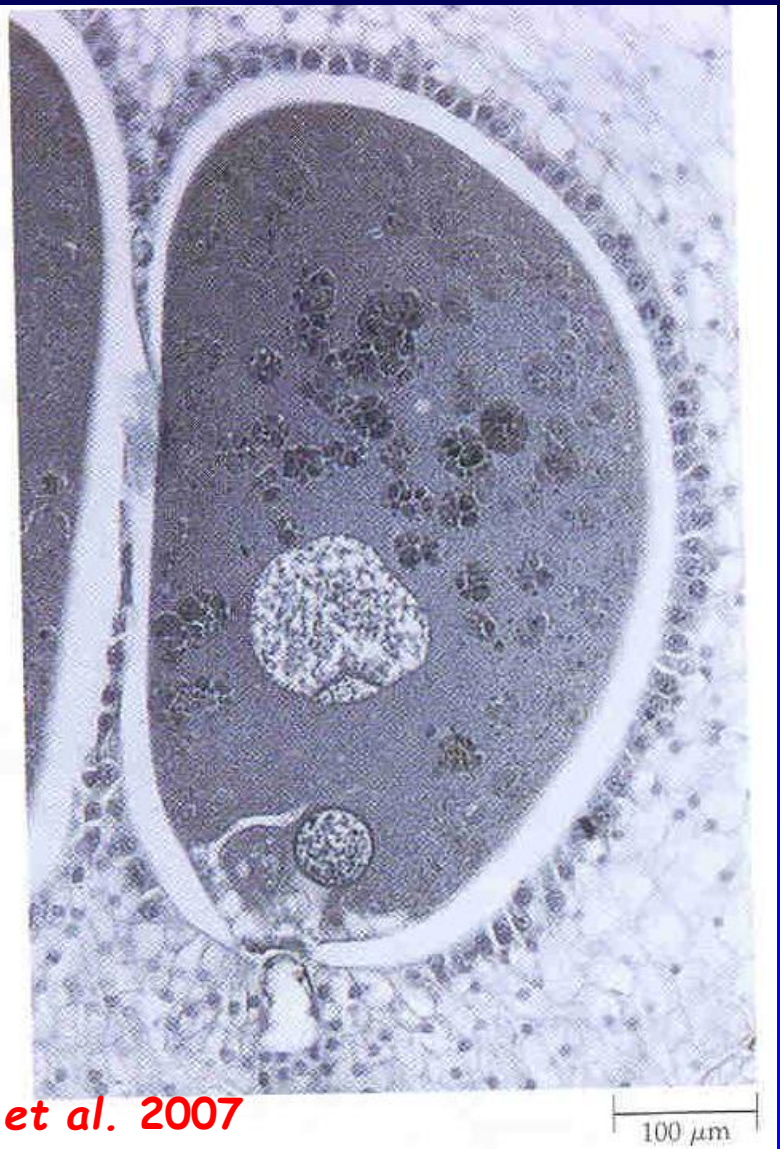
A fecundação

Pinus **Pinaceae**









Raven et al. 2007

Pinus. *Fertilization: union of a sperm nucleus with the egg nucleus. The second sperm nucleus (below) is nonfunctional; it will eventually disintegrate.*

Desenvolvimento do Megastróbilo

Pinus

PINOPHYTA (coníferas)

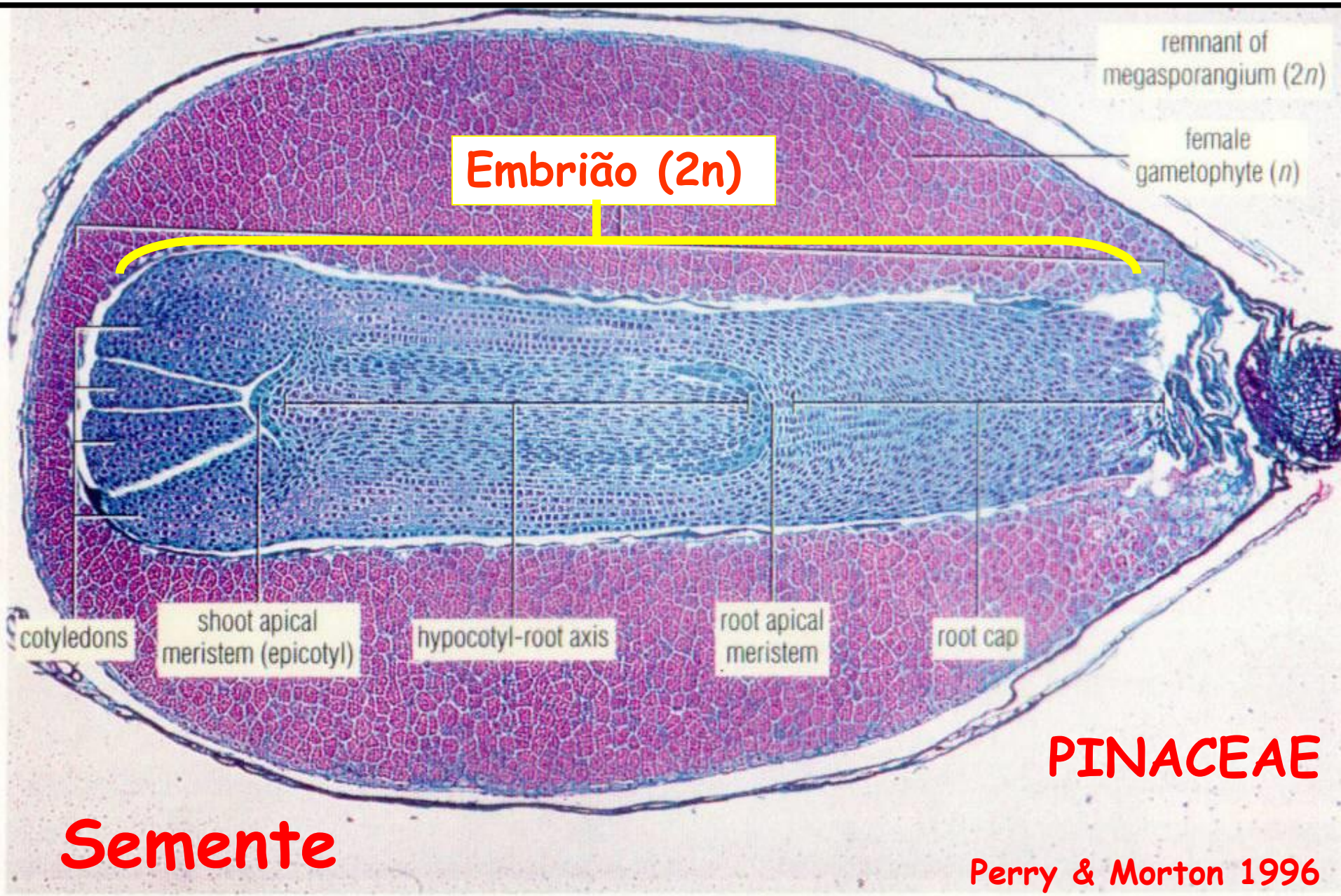


Figure 57d ***Pinus*, seed** containing **embryo**. The hard seed coat was removed during slide preparation (prep. slide, l.s., 30×). (Photo courtesy Biodisc, Inc.)

PINOPHYTA

ARAUCARIA

semente = pinhão

Araucaria angustifolia

Araucaria bidwillii

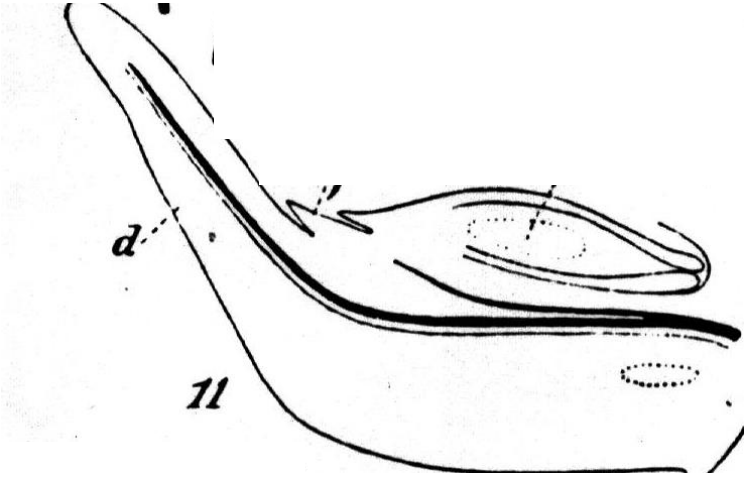
PINOPHYTA

ARAUCARIA

PINOPHYTA

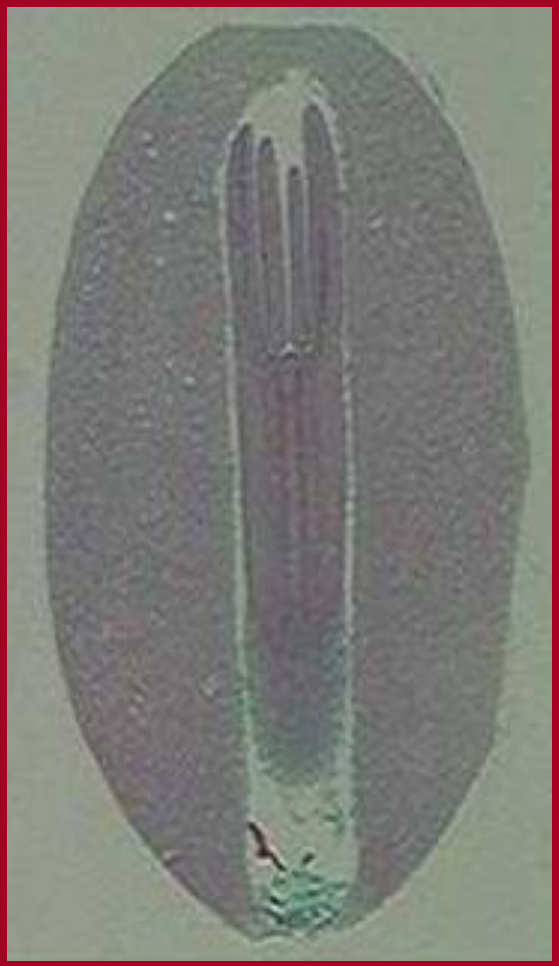
ARAUCARIA

escamas ovulíferas e bracteais soldadas, recobrindo o óvulo e formando o "pinhão"



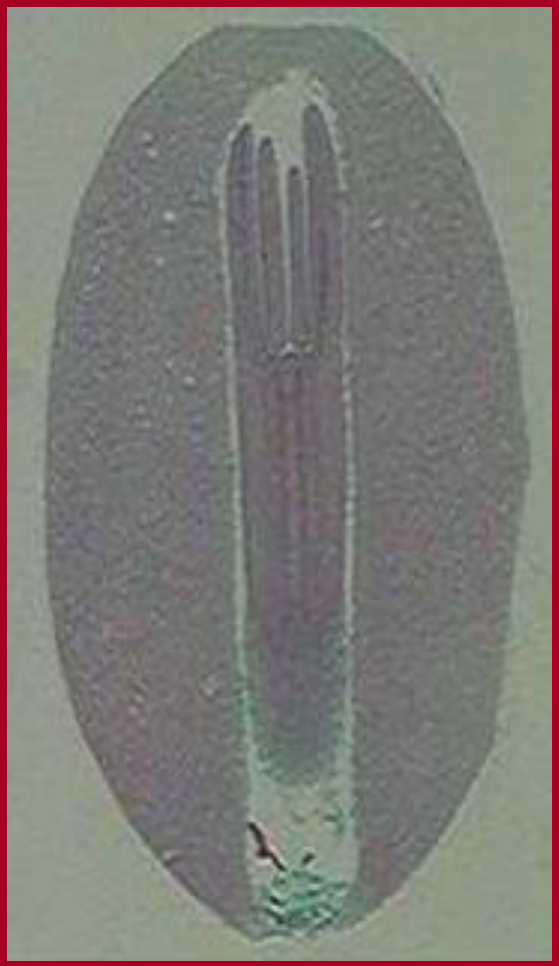
Araucaria angustifolia

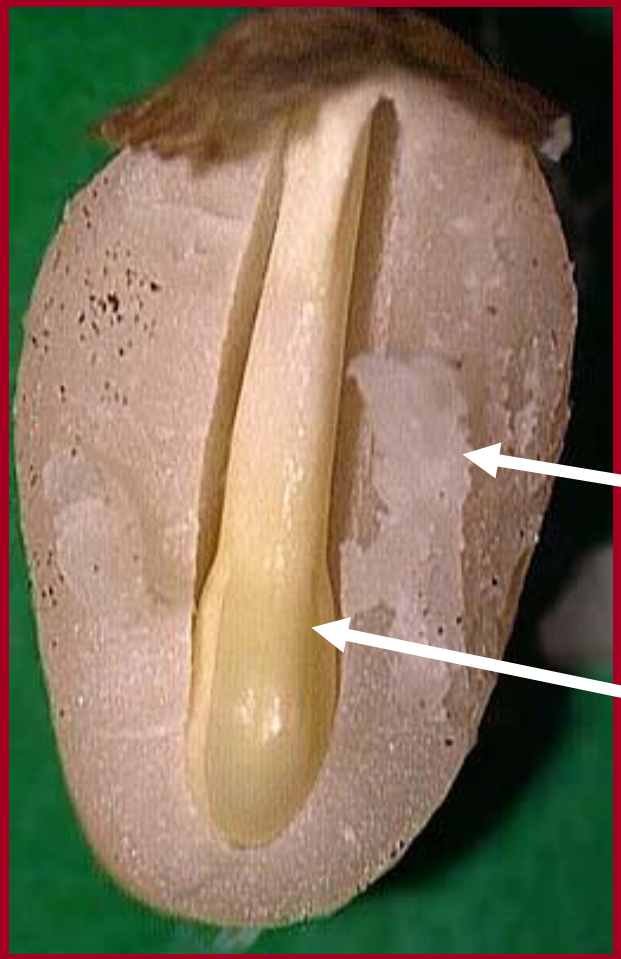
→ **pinhão = semente**



A porção comestível corresponde a quais estruturas?

→ **pinhão = semente**





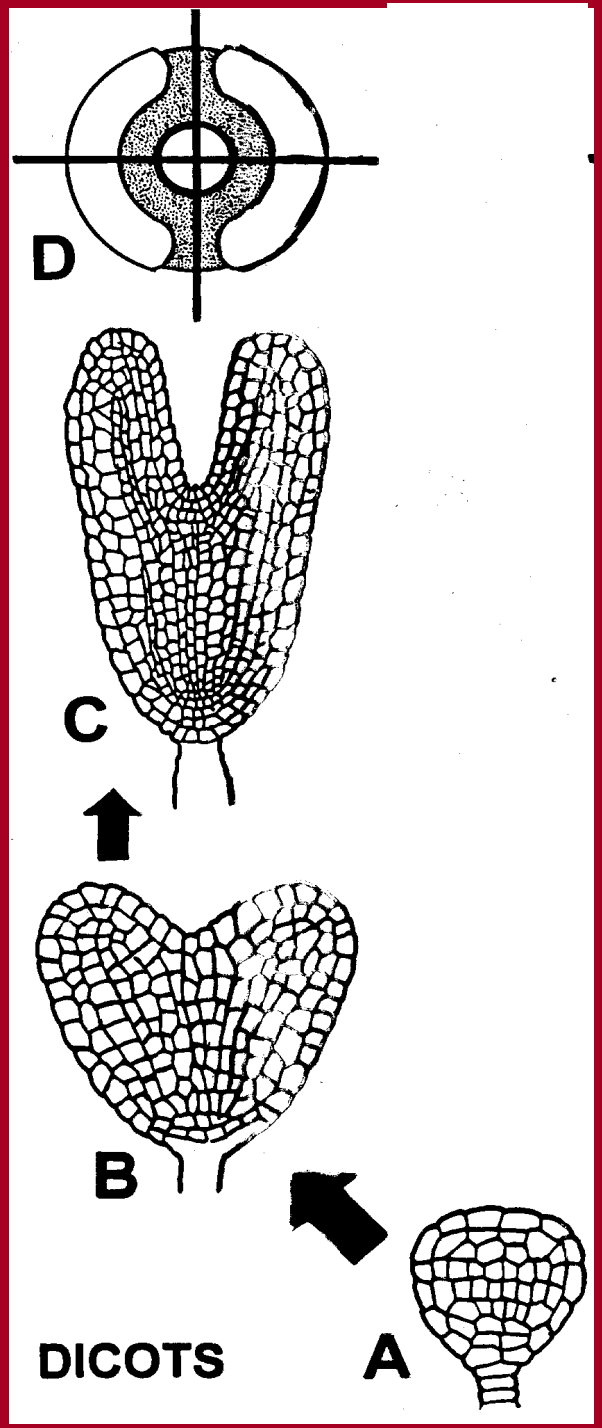
A porção comestível corresponde a quais estruturas?

Gametófito feminino

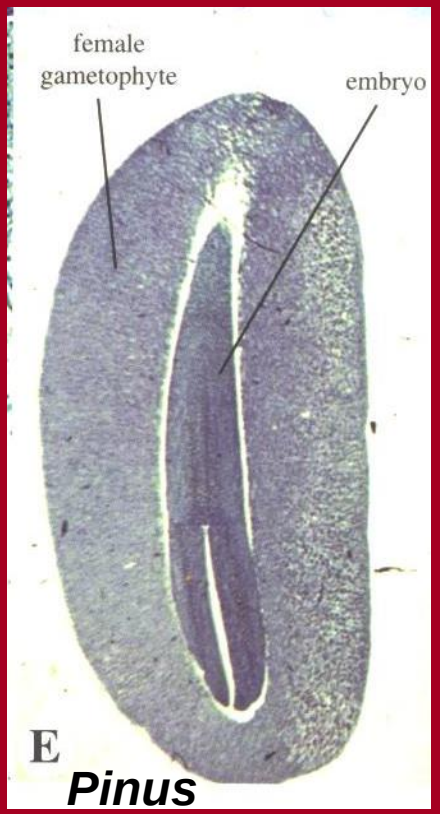
e embrião

(com 2 cotilédones)

Embrião nas espermatófitas



Gifford & Foster 1988,
Yamashita 1976

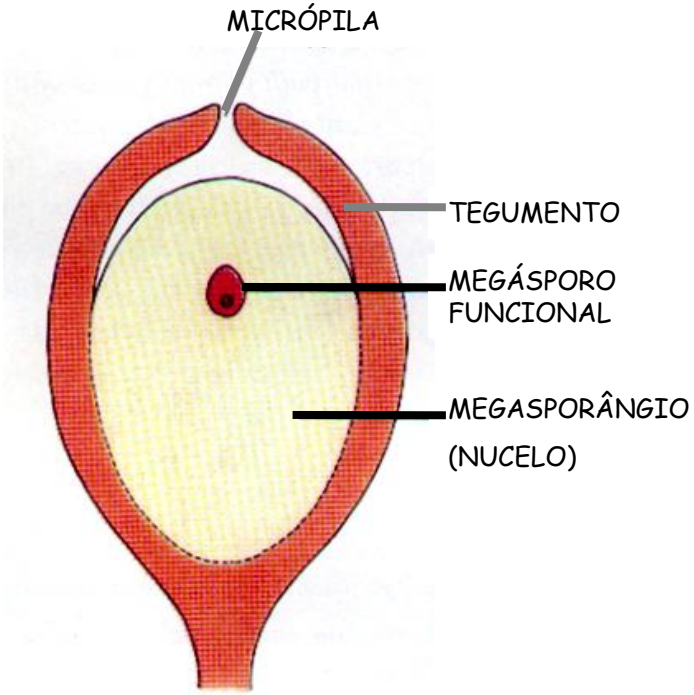


Pinus
Simpson 2006

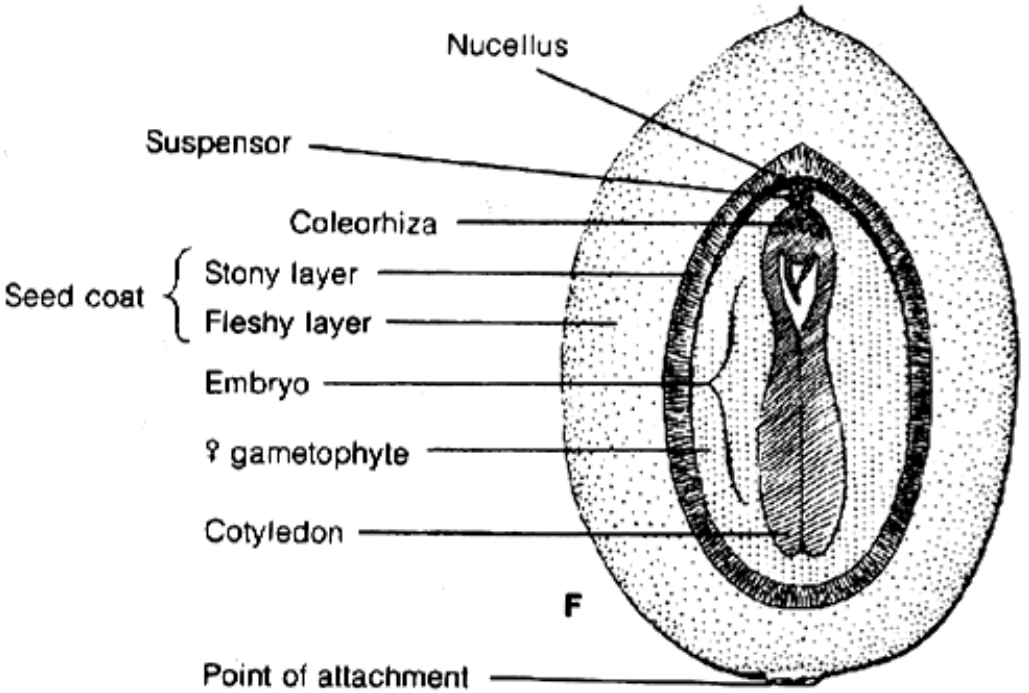
EMBRIÃO, GERMINAÇÃO e PLÂNTULA

NOVIDADES EVOLUTIVAS REPRODUTIVAS
(sinapomorfias de ESPERMATÓFITAS)

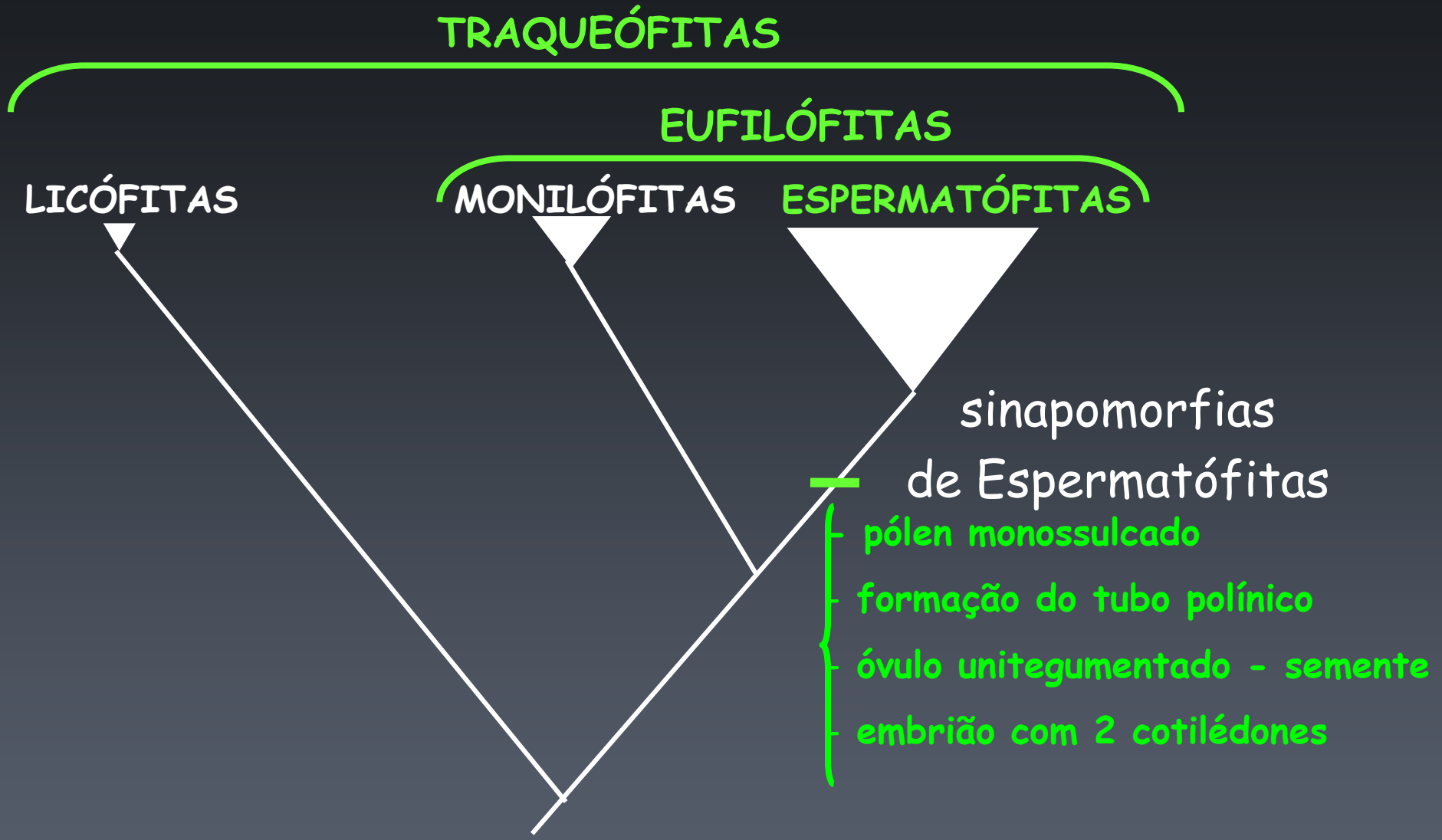
- **óvulo unitegumentado => formação da SEMENTE**

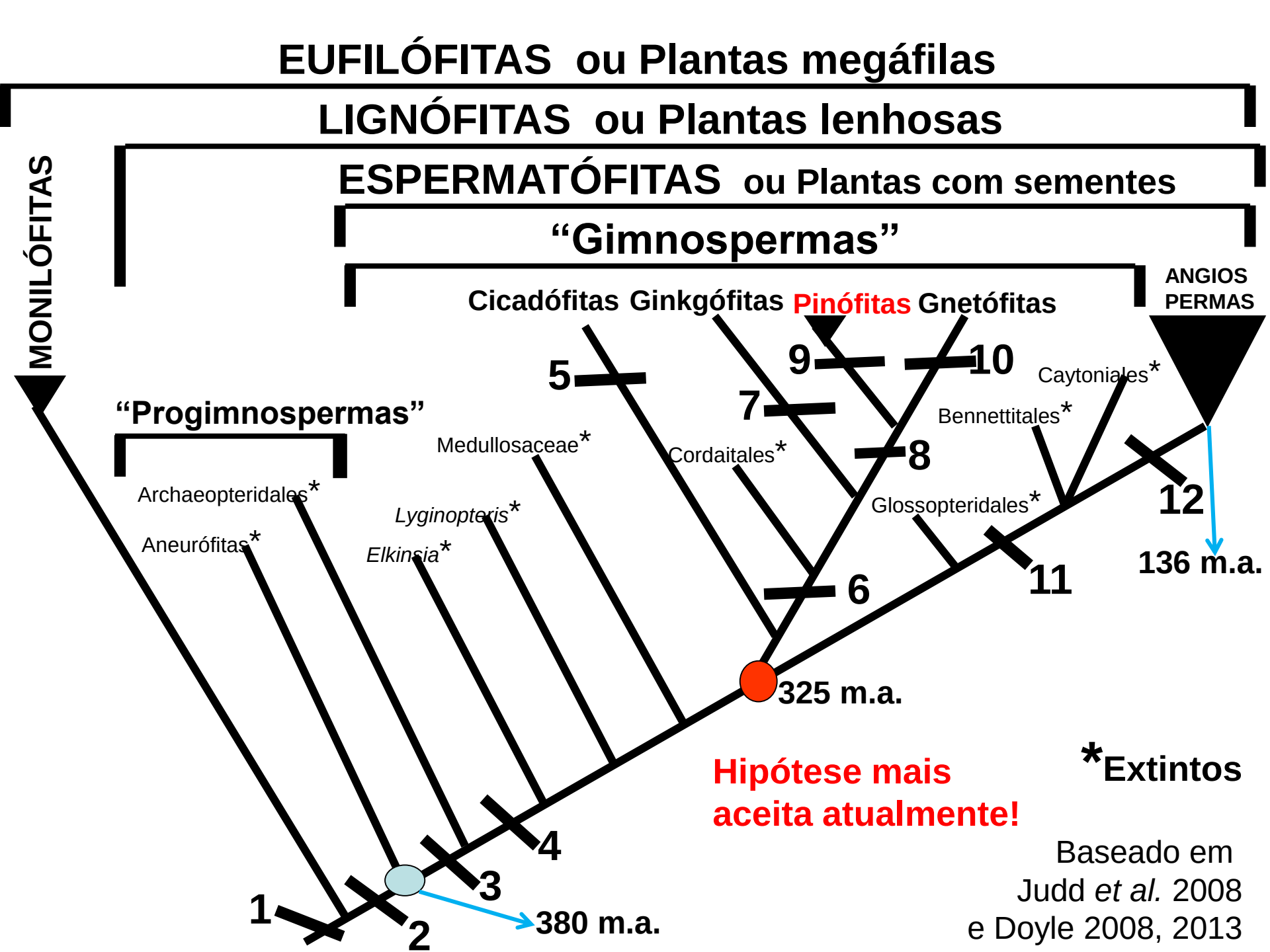


Raven *et al.* 1999



Corte longitudinal da semente de *Zamia pumila* (Gifford & Foster 1989)


TRAQUEÓFITAS
EUFILÓFITAS
LICÓFITAS
MONILÓFITAS
ESPERMATÓFITAS
sinapomorfias
de Espermatófitas
pólen monossulcado
formação do tubo polínico
óvulo unitegumentado - semente
embrião com 2 cotilédones


EUFILÓFITAS ou Plantas megáfilas
LIGNÓFITAS ou Plantas lenhosas
ESPERMATÓFITAS ou Plantas com sementes
"Gimnospermas"
MONILÓFITAS
ANGIOS PERMAS
Cicadófitas
Ginkgófitas
Pinófitas
Gnetófitas
"Progimnospermas"
Archaeopteridales*
Aneurófitas*
Lyginopteris*
Elkinsia*
Medullosaceae*
Cordaitales*
Caytoniales*
Bennettitales*
Glossopteridales*
1
2
3
4
5
6
7
8
9
10
11
12
380 m.a.
325 m.a.
136 m.a.
Hipótese mais aceita atualmente!
*Extintos
Baseado em Judd et al. 2008 e Doyle 2008, 2013