Chytridiomycota
Blastocladiomycota
Neocallimastigomycota

About 1000 species in six (+) orders:

- Blastocladiales
- Chytridiales
- Monoblepharidales
- Neocallimastigales
- Spizellomyceteales
- Rhizophydiales

All have motile <u>zoospores</u> with posterior whiplash flagellae

most are monoflagellate, a few spp are polyflagellate

flagellae are always the <u>whiplash</u> type

Only group of true fungi that has a motile cell stage (zoospores and gametes)

most primitive group of true fungi

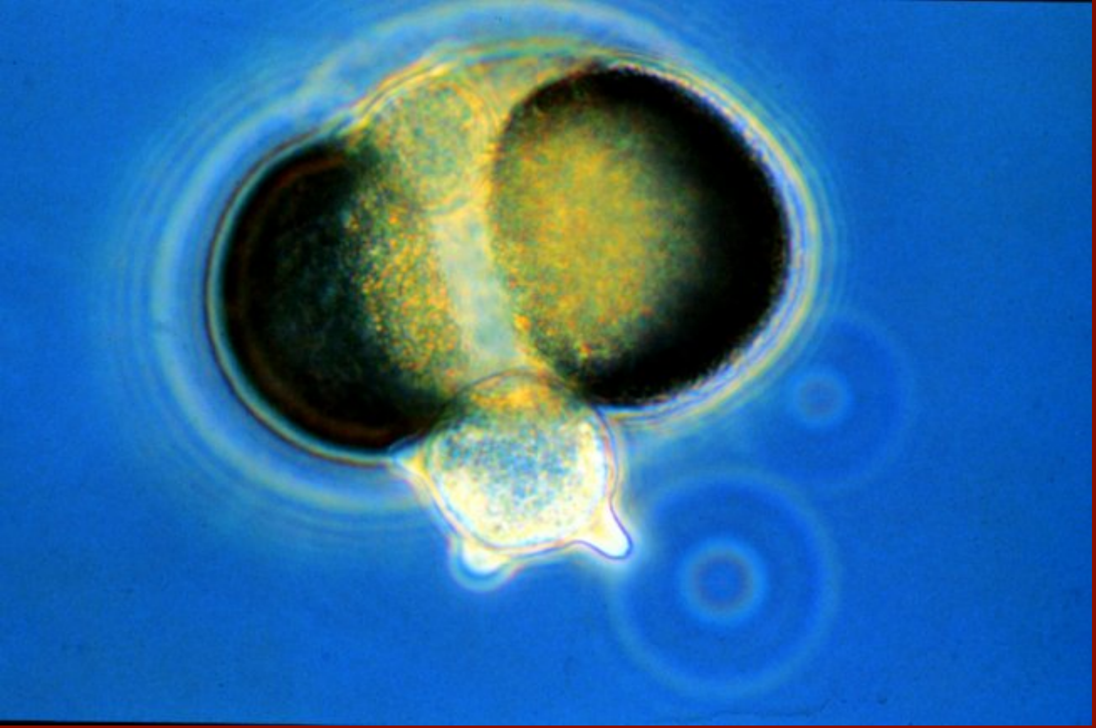
Ecology

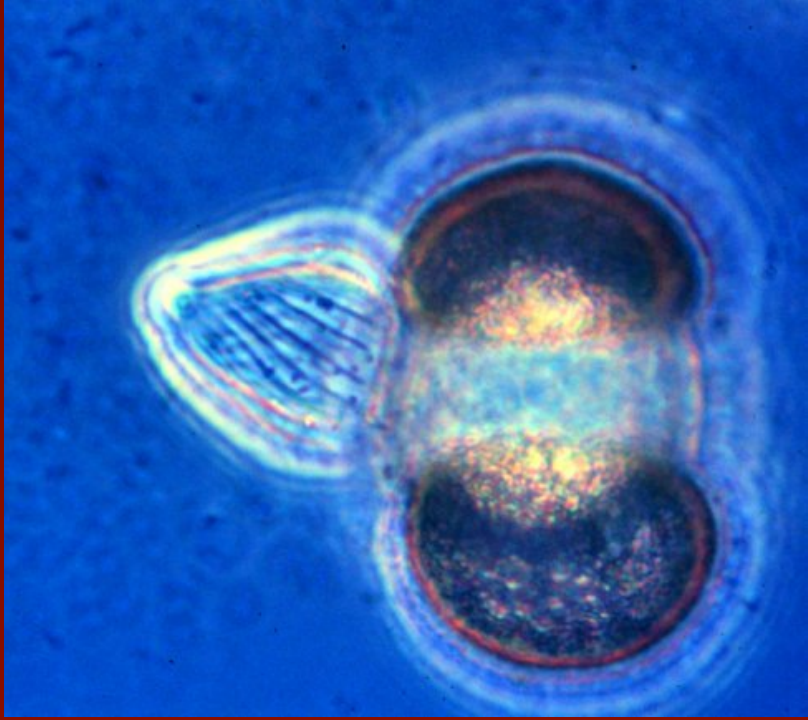
Most chytrid species are saprobes in aquatic habitats and soils, grow on decaying plant matter, pollen
A few marine spp

A few are pathogens of plants, animals, and fungi:
e.g. chytridiomycosis of amphibians
parasites/pathogens of vascular plants, mosses algae and phytoplankton
fungal parasites of vesicular-arbuscular mycorrhizal fungi, basidiomycetes, and other chytrids
animal parasites of nematodes, rotifers, tardigrades, and insects

Only true anaerobes, Neocallimasticales, live in rumen of herbivores, contribute to animal nutrition

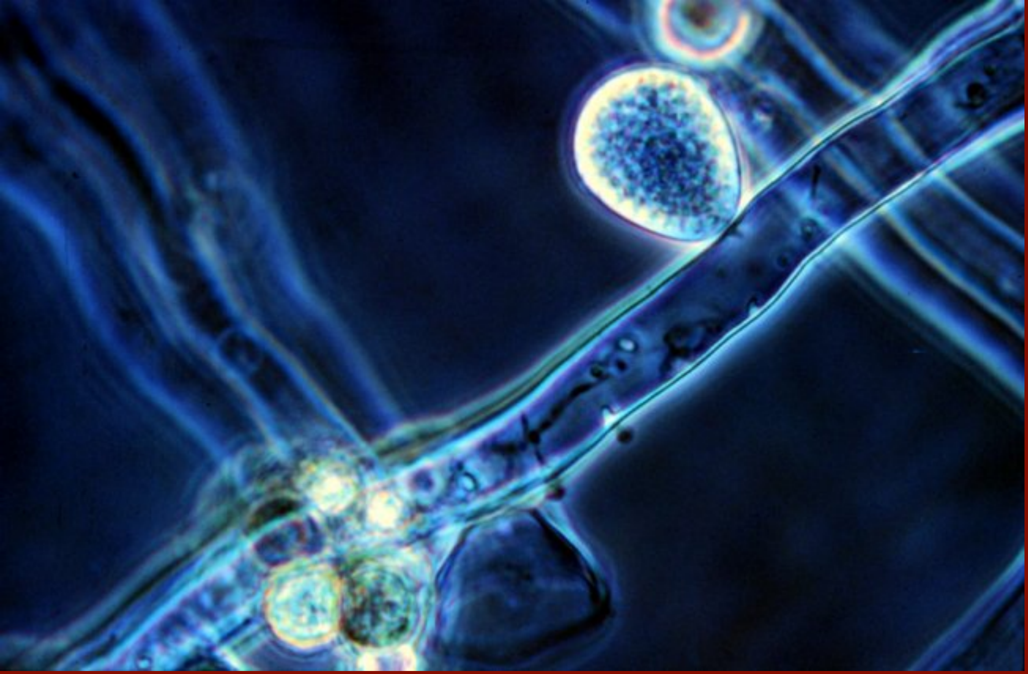
Pollen, a primary substrate used by aquatic chytrids

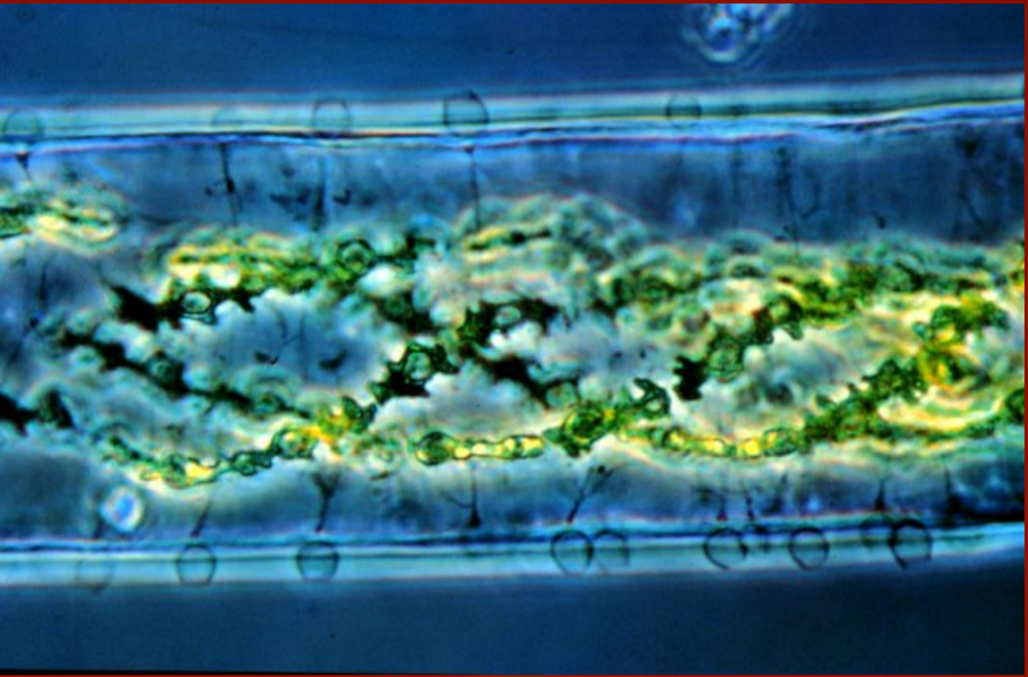




Chytrids growing on pollen grains

Chytrids growing on algae





Chytridiomycetes are true fungi, Eumycota

Based on rDNA sequences a part of the same lineage that includes zygomycetes, ascomycetes and basidiomycetes

The only true Fungi with flagellated stage, zoospores

Cell walls contain chitin and glucan (cellulose, however, has been detected recently in one species)

mitochodrial cristae are flat (vs. tubular type in oomycetes)

nuclear condition is predominantly haploid, like other true Fungi

Endobiotic forms: most simple thallus structure
live entirely within the cells of their hosts

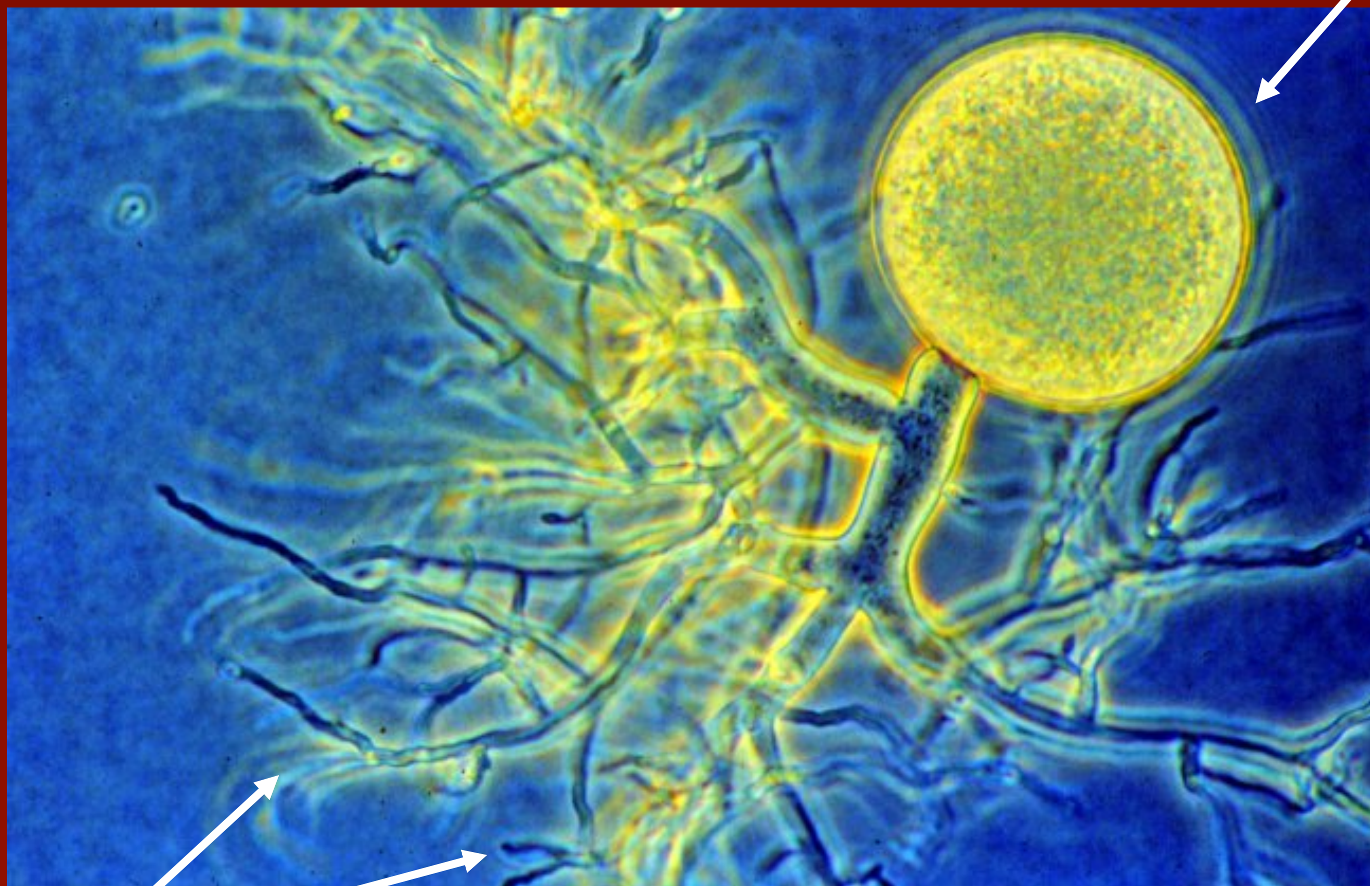
Epibiotic forms: produce reproductive structures on either the surface of the living host or organic matter, absorptive hyphae are immersed in the substrate

Holocarpic: The entire thallus is converted into one or more reproductive structures (sporangia, gametangia)

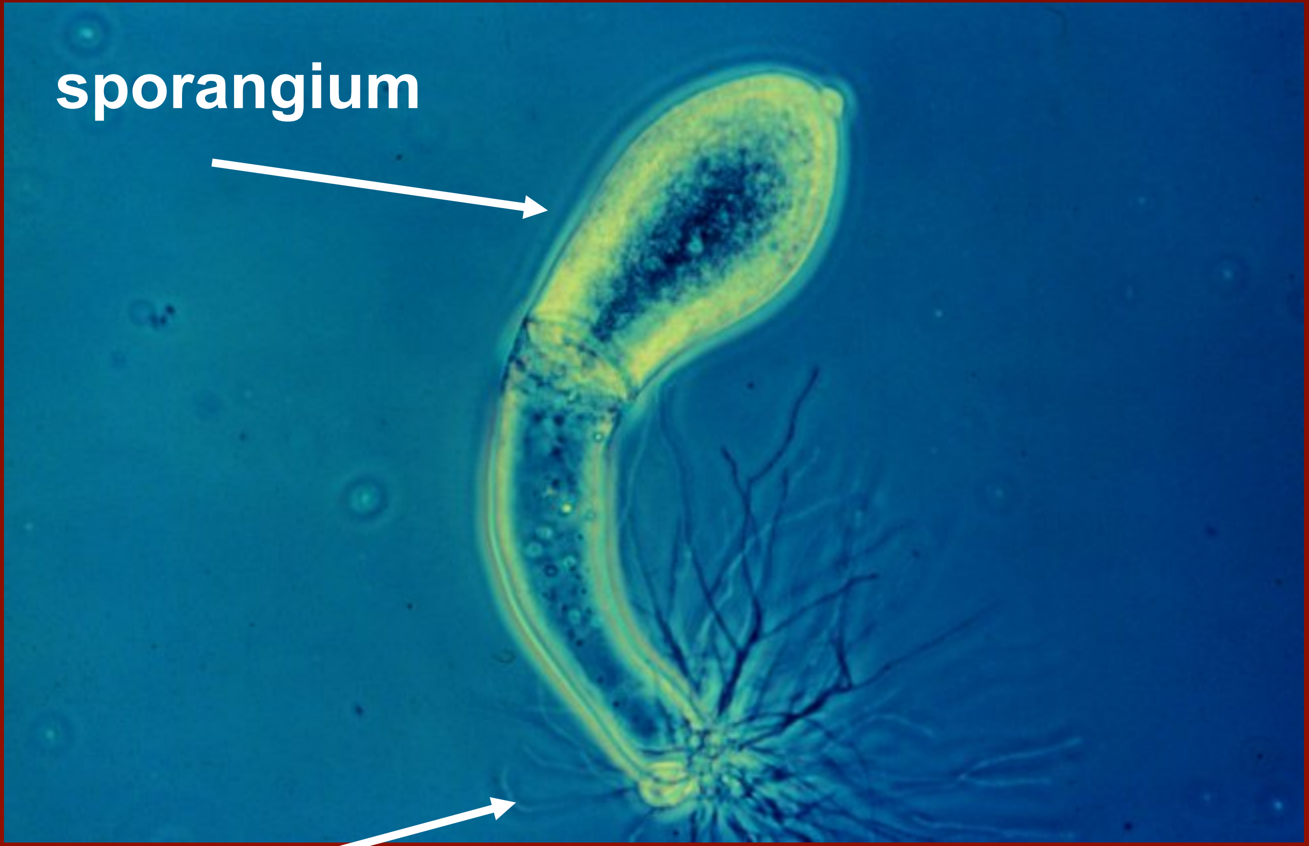
Eucarpic: The reproductive structures arise from only a part of the thallus, the rhizoids are not incorporated.

Rhizoids of eucarpic chytrids are fine hyphae that contain cytoplasm but no nuclei

A Eucarpic Chytrid



Another Eucarpic Chytrid



holocarpic: thallus reduced, no vegetative structures, entire thallus consists of reproductive structures (sporangia, gametangia). *Olpidium, Synchytrium*

eucarpic: thallus has both vegetative (rhizoids, rhizomycelium) and reproductive structures *Physoderma*

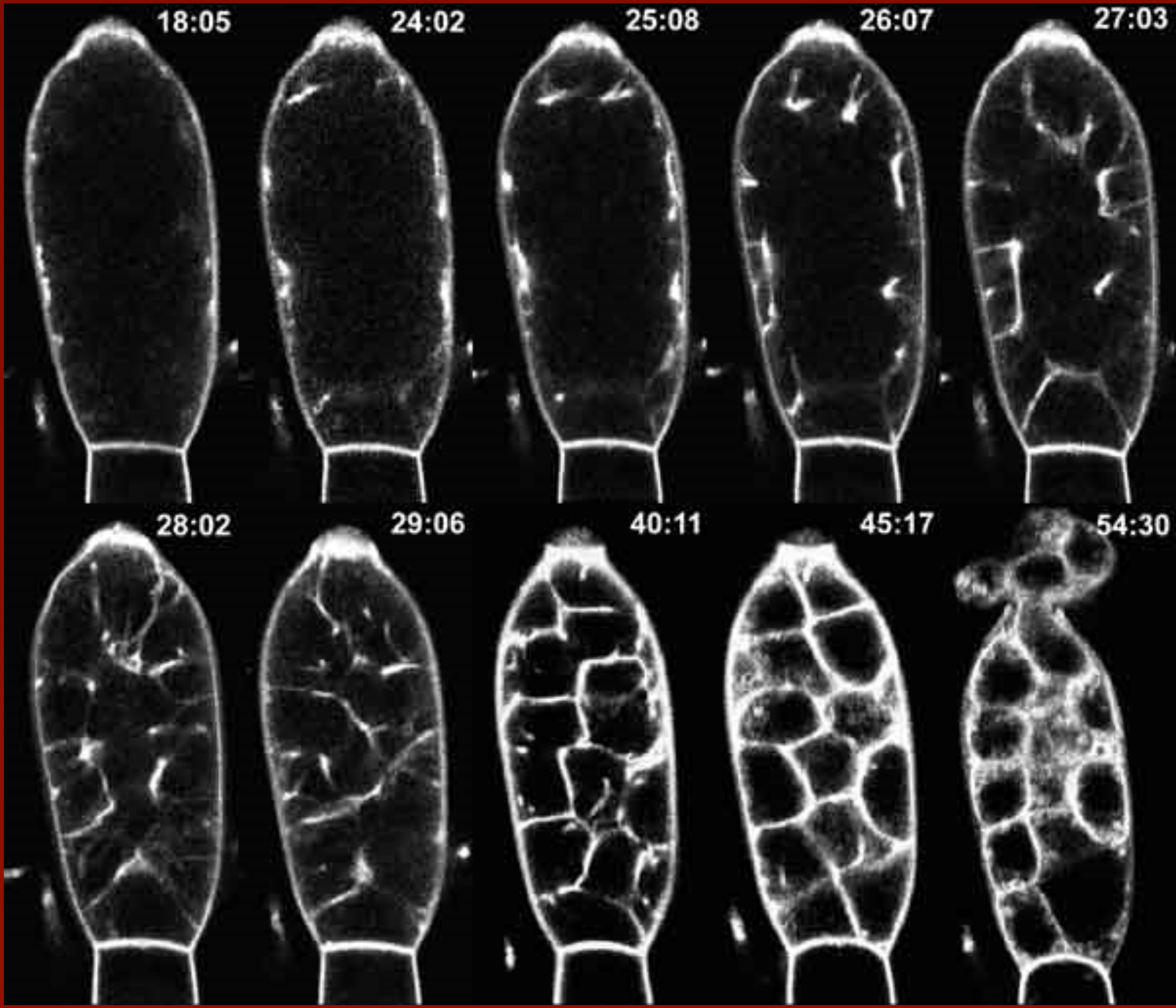
endobiotic: entire thallus within host tissue. Olpidium, Synchytrium

epibiotic: reproductive structures produced on the surface of host plant. Physoderma.

Reproduction

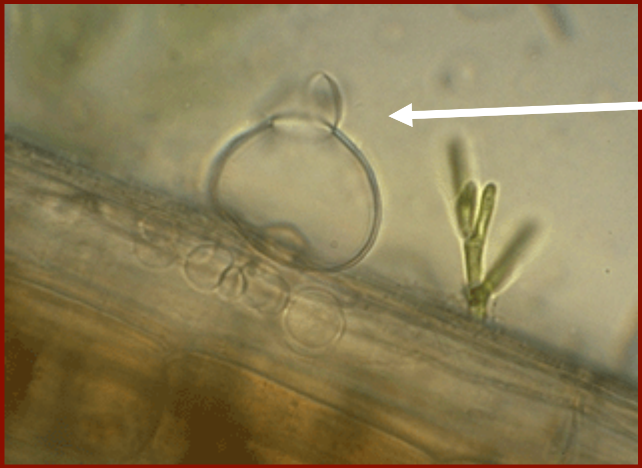
Asexual reproduction by motile <u>zoospores</u> produced in <u>sporangia</u>

zoosporangia initially contain multinucleate cytoplasm that undergoes cleavage into numerous uninucleate sections that develop into posteriorly flagellated zoospores



When the sporangium matures one or multiple a discharge papillae form in the sporangium wall

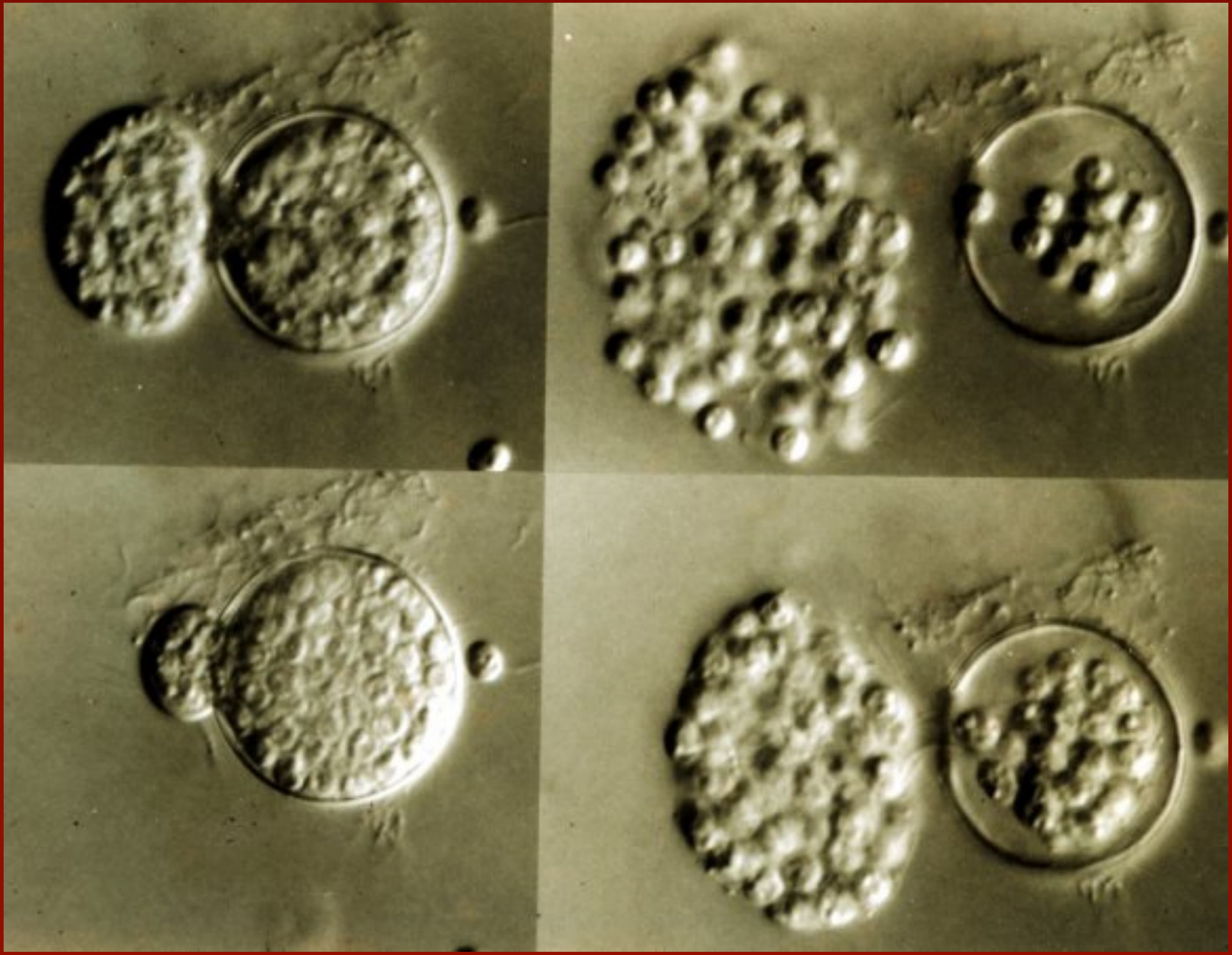
Papillae may be operculate or inoperculate



operculum

After emergence, zoospores swim to find a suitable substrate, forms a cyst, germinates

Zoospore release



Zoospore structure

Zoospores contain a single nucleus, its position and shape vary according to Chytrid Order

There are two **kinetosomes** associated with the flagella but only one is functional

Non functional kinetosome is called a **basal body**

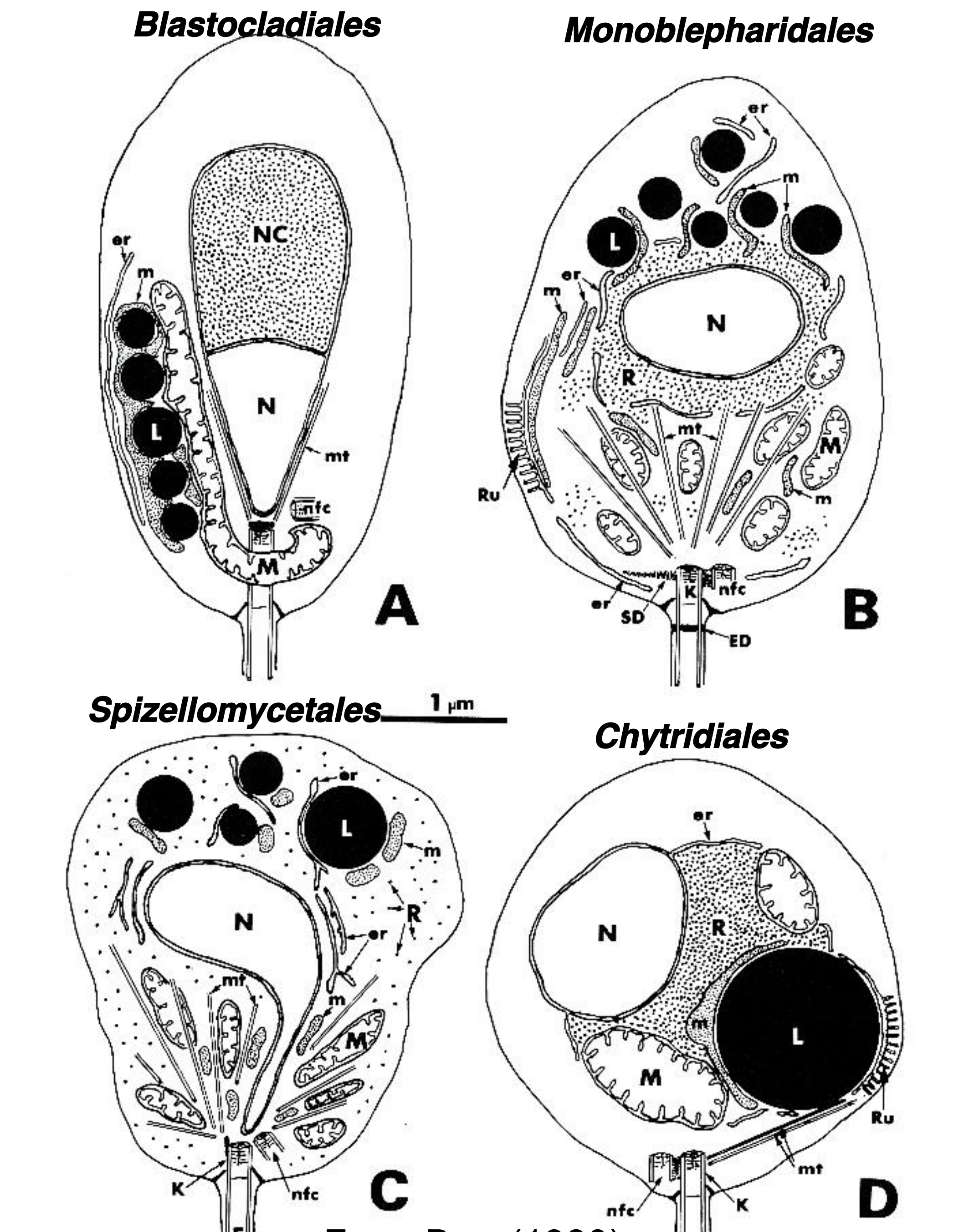
At least one mitochondrion, microbodies, strands of ER, lipid bodies

Microbodies and lipid bodies closely associated in the microbody-lipid globule complex (**MLC**)

Ribosomes either dispersed in cytoplasm (Spizellomyces type) or clustered in a ribosomal aggregation or **nuclear cap** (Blastocladiales)

Current ordinal taxonomy of the Chytridiomycota is based on zoospore ultrastructure.

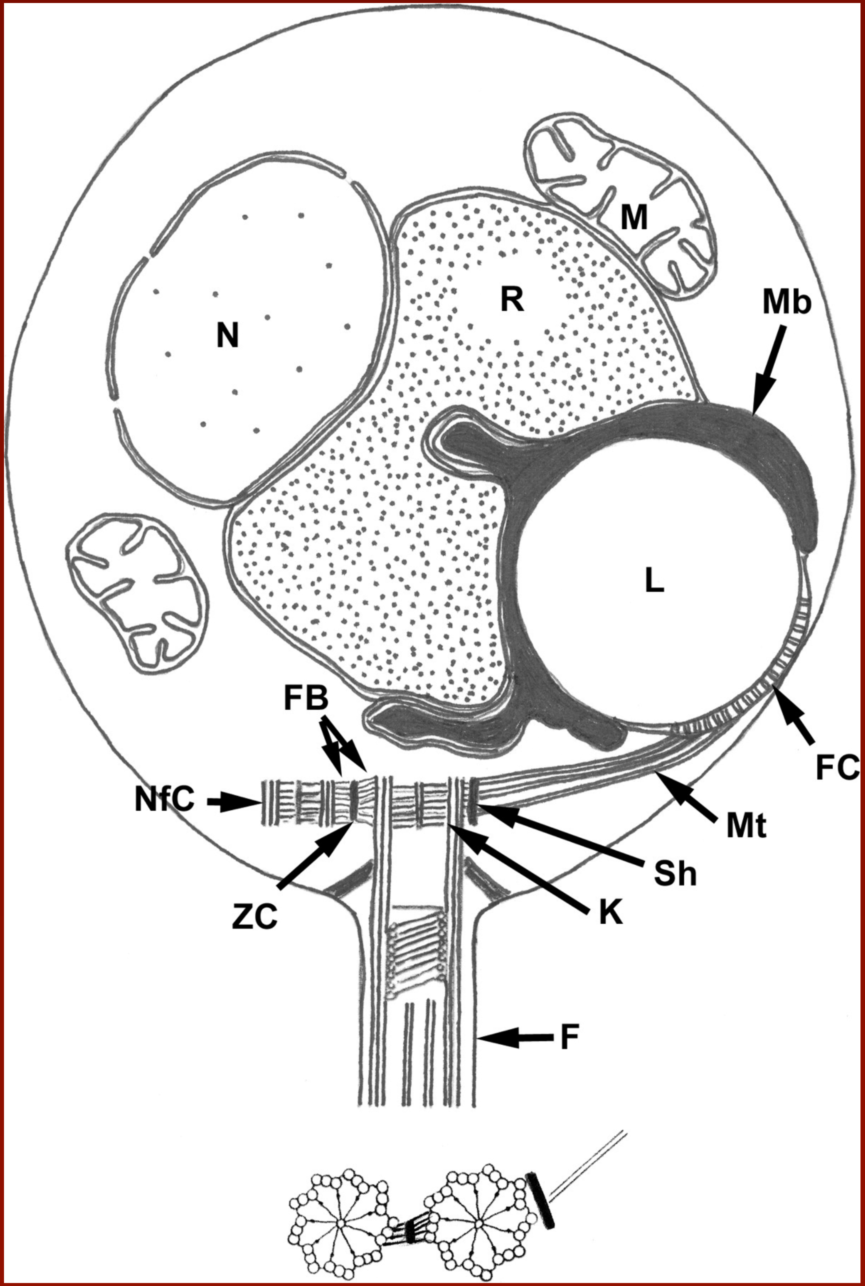
The more diffuse organization of the Spizellomycetales appears to have been derived more than once.

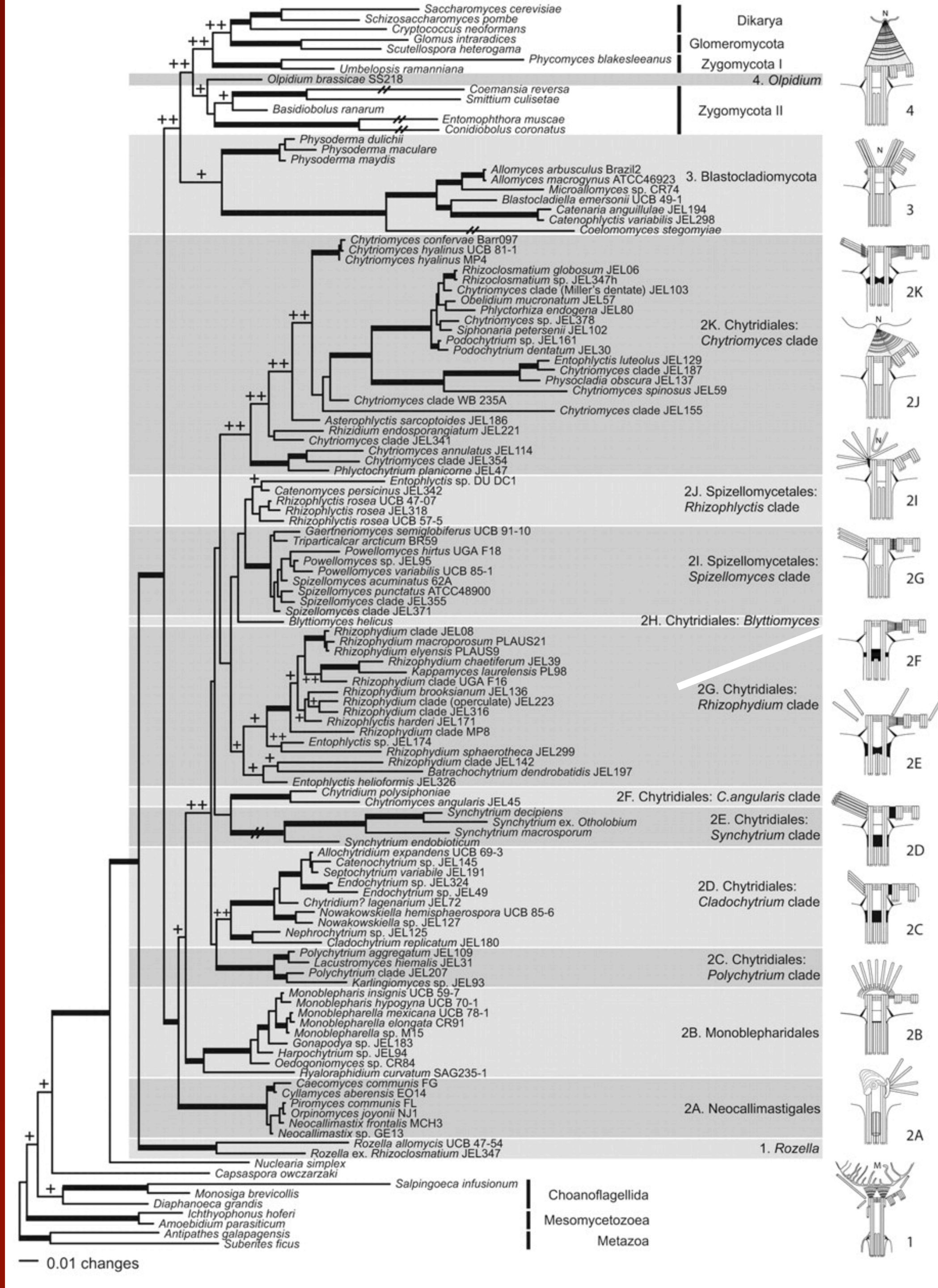


From Barr (1980)

A new order, Rhizophydiales was introduced in 2006.

This order now includes the amphibian pathogen Batrachochytrium dendrobatidis





Blastocladiomycota

Chytridiales is polyphyletic

Rhizophydiales

Chytridiomycota

structure of the kinetosome has been used as a character for classifying chytrid fungi

Sexual reproduction

Sexual reproduction is unknown in several chytrid genera, but is well documented in others

1. **Planogametic copulation**
   a. isogametic conjugation; two swimming gametes similar, fuse to form a motile zygote
   b. anisogamous conjugation: one gamete is much larger, gametes fuse to form a motile zygote
   c. nonmotile egg fertilized by motile male gamete (antherozoid): motile male gametes swim to female gametangia (oogonia) with one female gamete (egg). Male zoospore enters the oogonium and unites with the egg.

2. **Gametangial copulation:** contents of one gametangium transferred to the other
3. **Somatogamy:** fusion of rhizoids precedes formation of a resting spore

Gametes, gametic fusion

Gametes and gametic fusion vary in the different Chytrid groups:

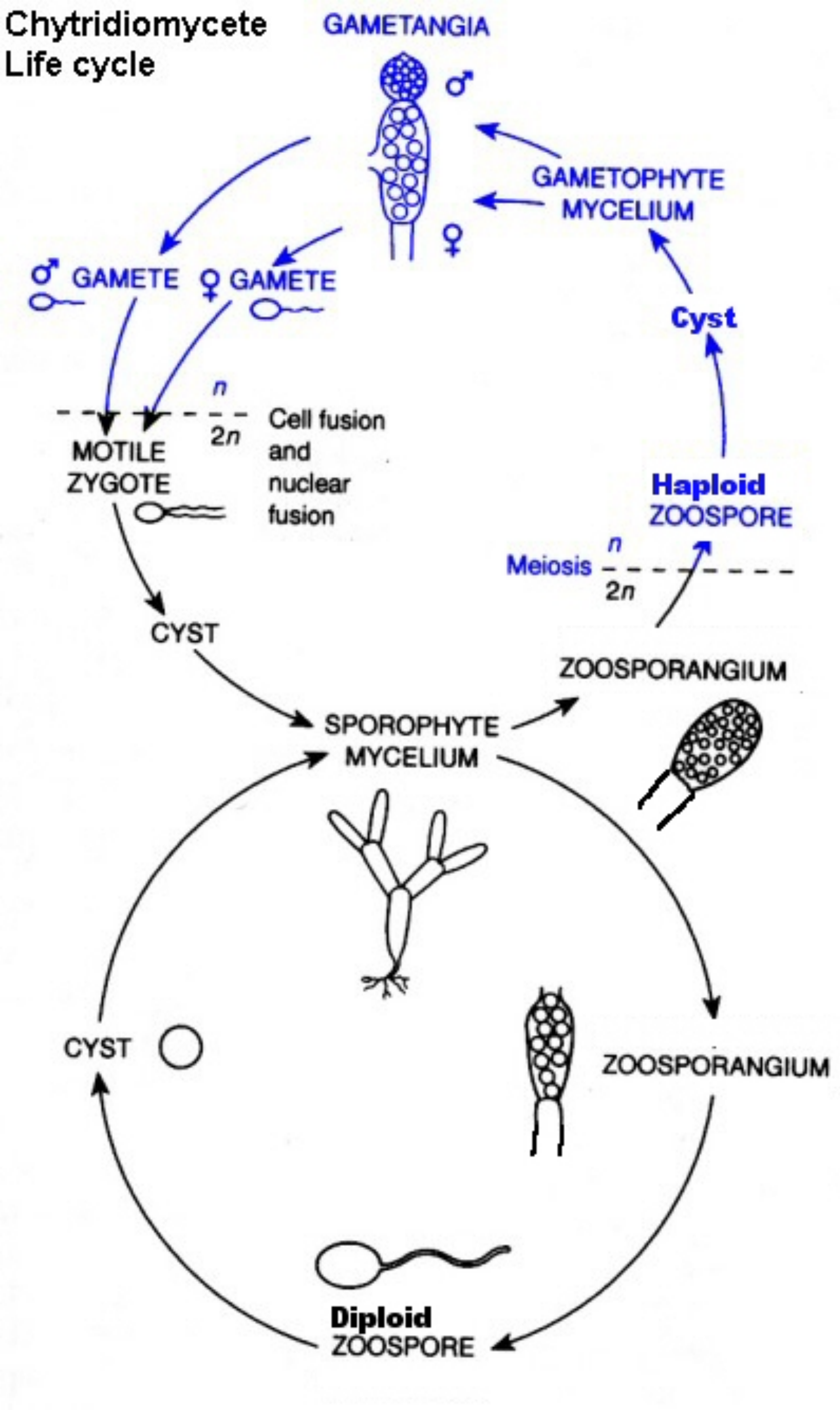
Isogamous gametes, i.e. of similar size and appearance,
Fusion of the two flagellate gametes results in a biflagellate zygote

Anisogamous gametes

fusion results in a biflagellate zygote
or one may be nonmotile (designated female by convention) and remains in the female gametangium (oogonium), swimming male gametes fuse with the female gametes in the female gametangium (Monoblepharis)

Taxis of male gametes to female gametes and gametangia is directed by a pheromone, sirenin

A second pheromone attractive to female gametes, parisin



Alternation of generations:

Alternation of haploid and diploid generations in *Allomyces*

Haploid thalli produce <u>gametes</u> in differentiated <u>gametangia</u>

Gametes fuse (conjugate) to produce a <u>zygote</u> that gives rise to the diploid thallus (plasmogamy + karyogamy),

sporangia produce diploid zoospores

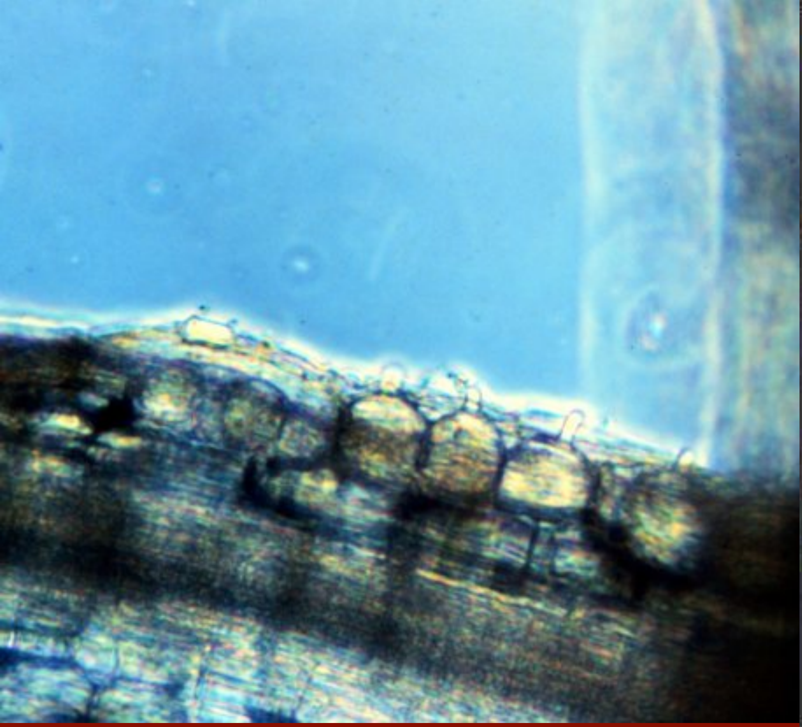
Classification

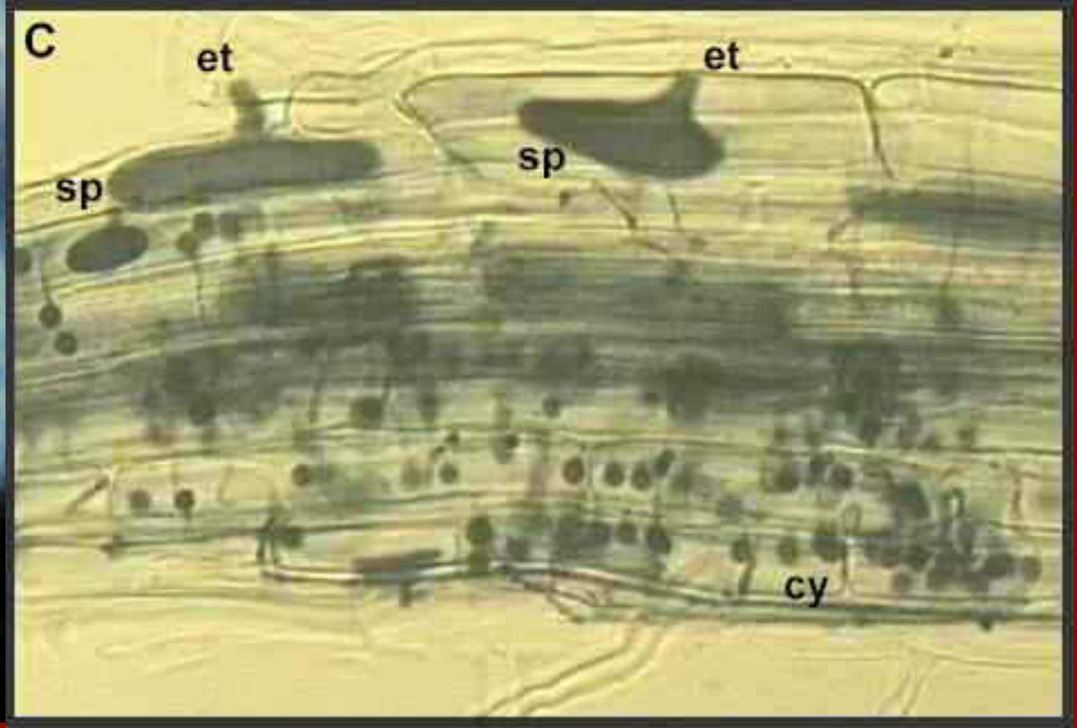
Spizellomycetales

Order recognized based on zoospore structure, appears to be polyphyletic based on molecular evidence
Ribosomes in zoospore are dispersed
scattered lipid droplets with associated microbodies
nucleus near kinetosome
sexual reproduction unknown in the entire Order

Parasites of other fungi, including the chytrid genus Allomyces
Plant pathogens: *Urophlyctis alfalfae*, crown wart disease of alfalfa

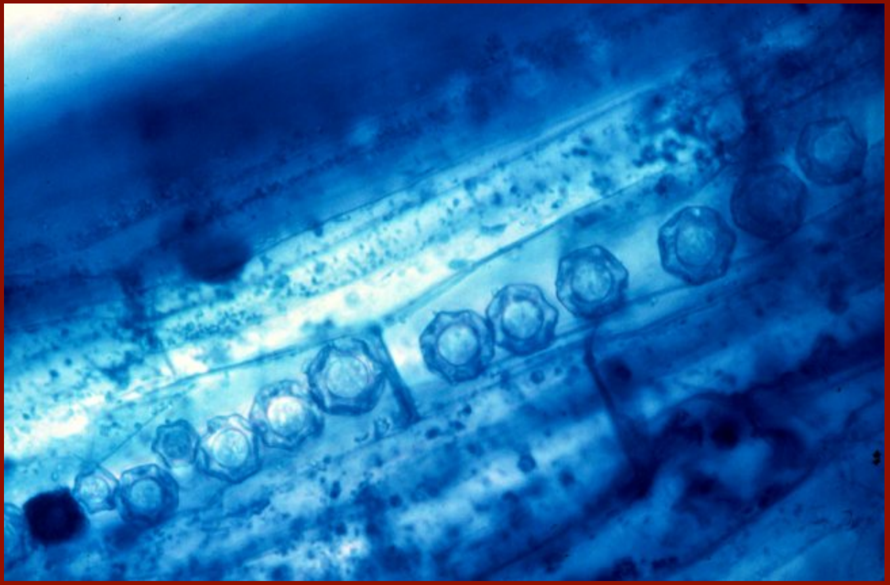
Olpidium 35 spp
Olpidium brassicae
O. trifolii
Inconsequential, except as vectors of plant viruses

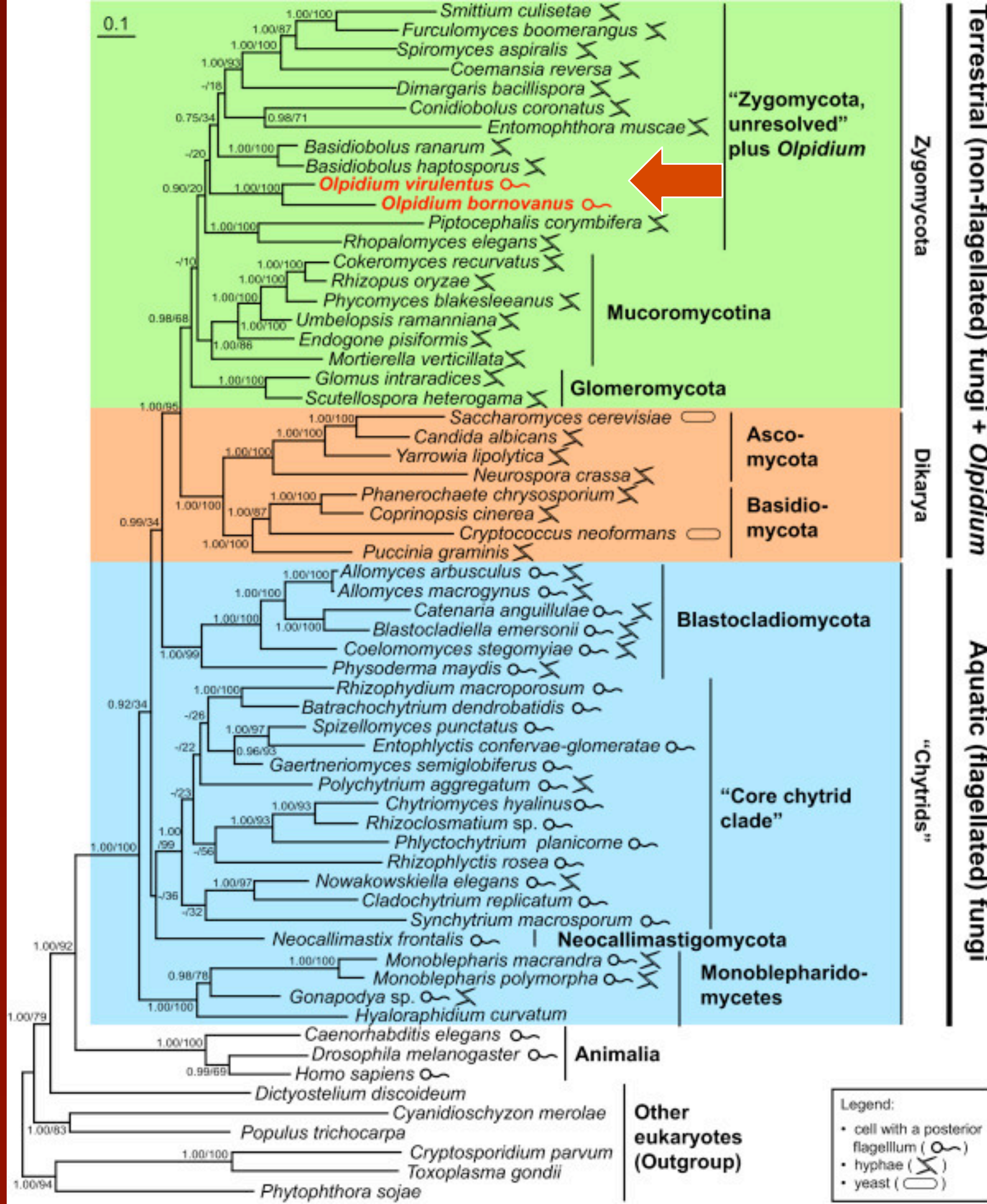




Olpidium

whoops! Olpidium now groups in the Zygomycota!





Olpidium

This study provides strong support for Olpidium as the closest living flagellated relative of the terrestrial fungi. Appearing nested among hyphal fungi, Olpidium's unicellular thallus may have been derived from ancestral hyphae. Early in their evolution, terrestrial hyphal fungi may have reproduced with zoospores.

Symptoms of lettuce big vein virus, vectored by Olpidium brassicae

Neocallimastigomycota, Neocallimastigales

All anaerobic, inhabit the rumen and caecum of herbivores
The only known obligately anaerobic fungi
Degrade cellulose but have fermentative matabolism
Some polyflagellate (10+ flagella)) species
Zoospores lack mitochondria

Able to break down cellulosic plant material in the rumen and contribute to animal nutrition

Break down material that would otherwise pass through digestive tract

Neocallimastix

Order Chytridiales

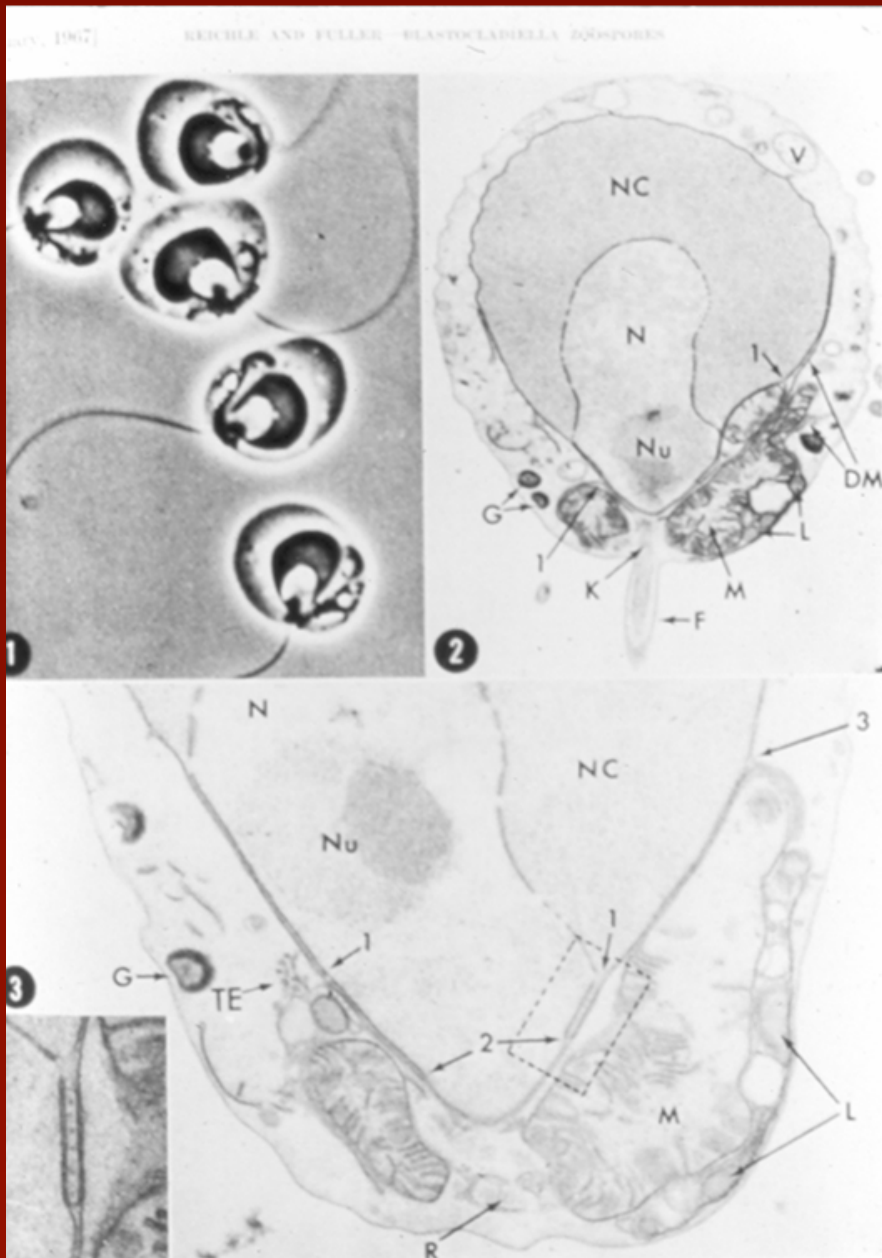
Based on zoospore structure
One or several mitochondria associated with MLC
Ribosomes aggregated and separated from cytoplasm by membrane

Water or soil inhabiting, parasitic on algae, water molds, parasites of microscopic eggs of nematodes and protozoa

Rhizophydiales (new order in Chytridiomycota)

Batrachochytrium dendrobatidis cause of worldwide amphibian decline

Blastocladiales zoospore



Chytridiales zoospore

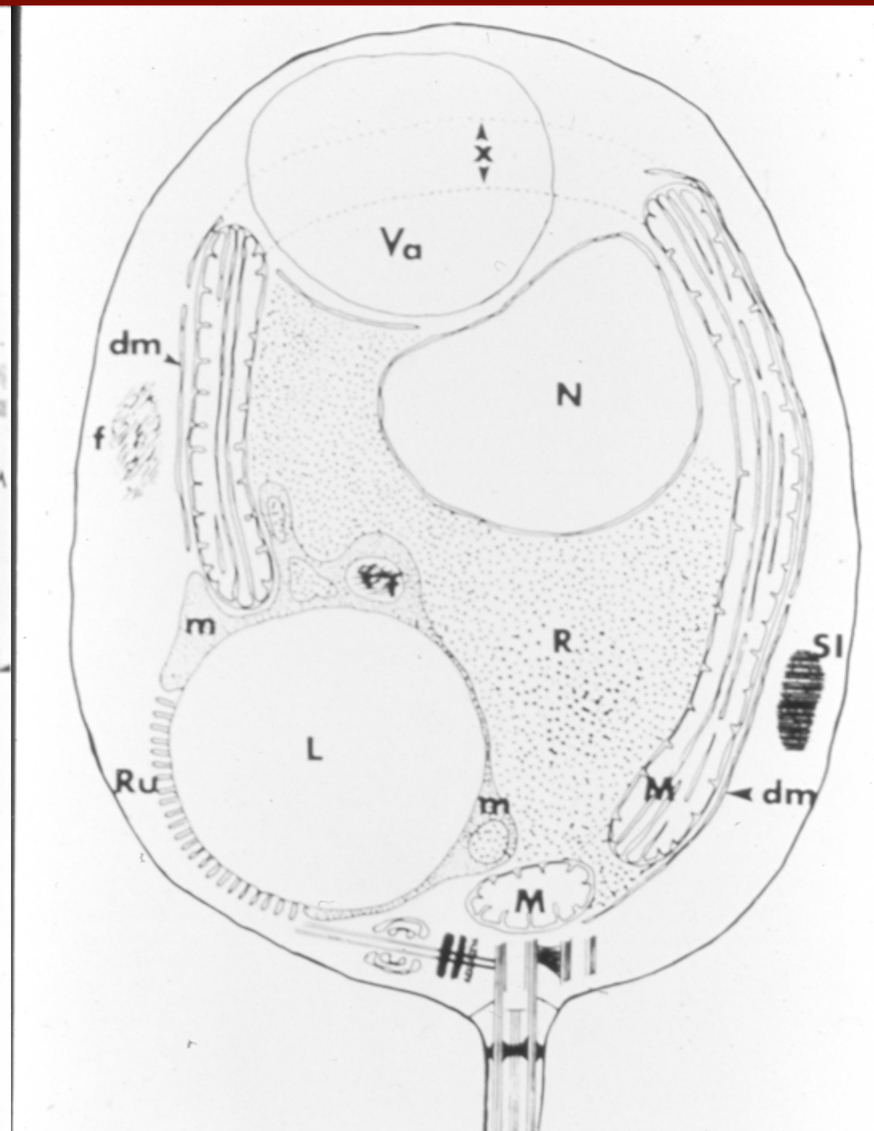


FIG. 4. Schematic drawing of *Rhizoclosmatium globosum* zoospores in longitudinal section. Continuity of the mitochondrion is shown by the dotted lines at X.

Chytridiales, various plant pathogens

Synchytrium 120 spp

Synchytrium aureum: galls of various hosts (~200 host spp.)

S. desmodii: wart disease or false rust of Desmodium ovalifolium (Fabaceae)

S. decipiens: false rust of Amphicarpaea (Fabaceae)

S. endobioticum: potato wart

long life cycle

S. lagenarieae: galls of cucurbits, Luffa

S. macrosporum: galls of various hosts, mainly ornamentals

short life cycle, resting spores but no summer sporangia

S. phaseoli: pustules on leaves, pods of Phaseolus

short life cycle, summer sporangia no resting spores

S. phaseoli-radiati: galls on stems and leaves of Phaseolus

short life cycle, resting spores, no summer sporangia

S. psophocarpi: false rust of winged bean

short cycle, summer sporangia, no resting spores

Synchytrium endobioticum life cycle

Holoarpic, endobiotic
motile cells functions as either zoospores or gametes
depends on the availability of water during development
early season more zoospores produced

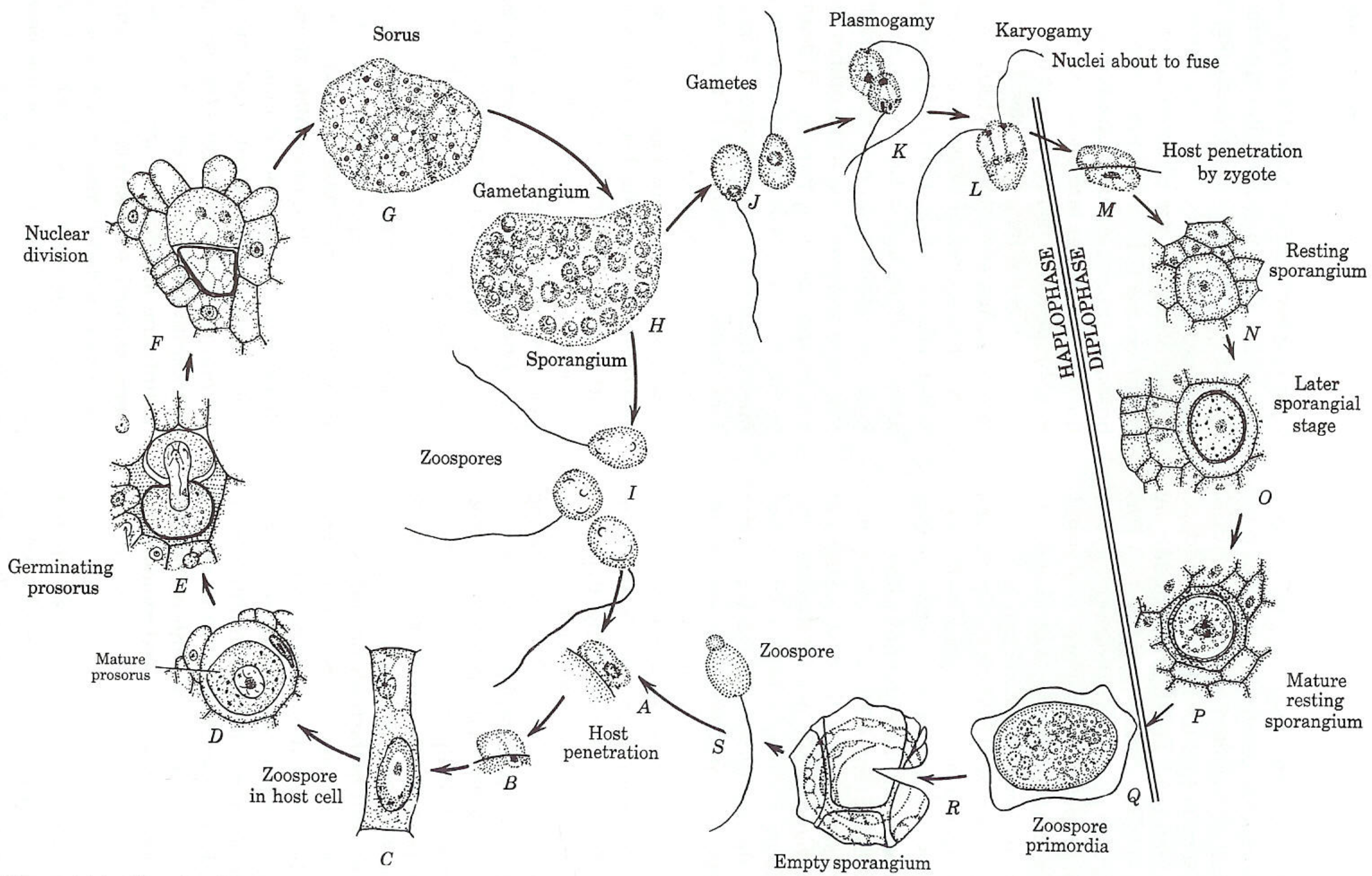


Figure 4-11 Life cycle of *Synchytrium endobioticum*. [Redrawn from Curtis (1921). By permission of the Royal Society of London.]

Potato wart disease
Synchytrium endobioticum

Resting spores of S. endobioticum can persist in soil for >40 years

Origin of potato wart disease

widespread in South America, particularly Peru and thought to be endemic there

also found on wild potatoes in Mexico, but unknown whether native or introduced there, however, others have concluded that the pathogen is native to Europe (England or Russia)

May have been introduced to Europe from S America during genetic improvement projects following the potato late blight epidemics of 1840-50. This timing agrees with the first detections of the disease in the UK, 1876.

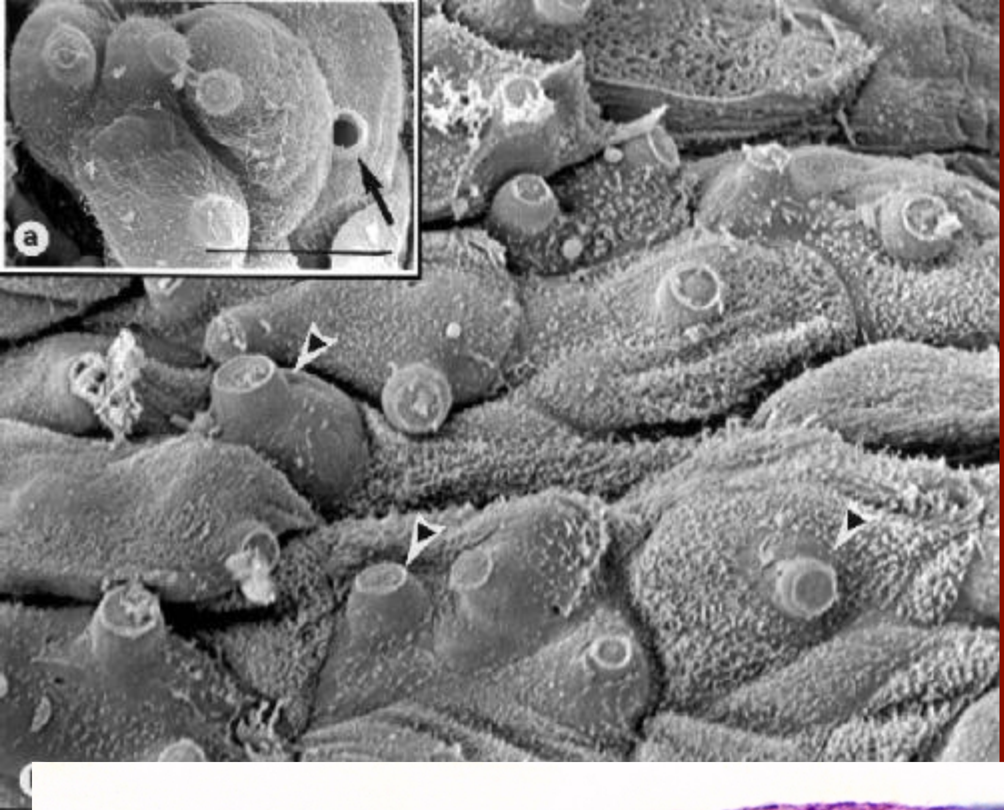
Disease was established in Newfoundland by 1908, believed to have been introduced from the UK

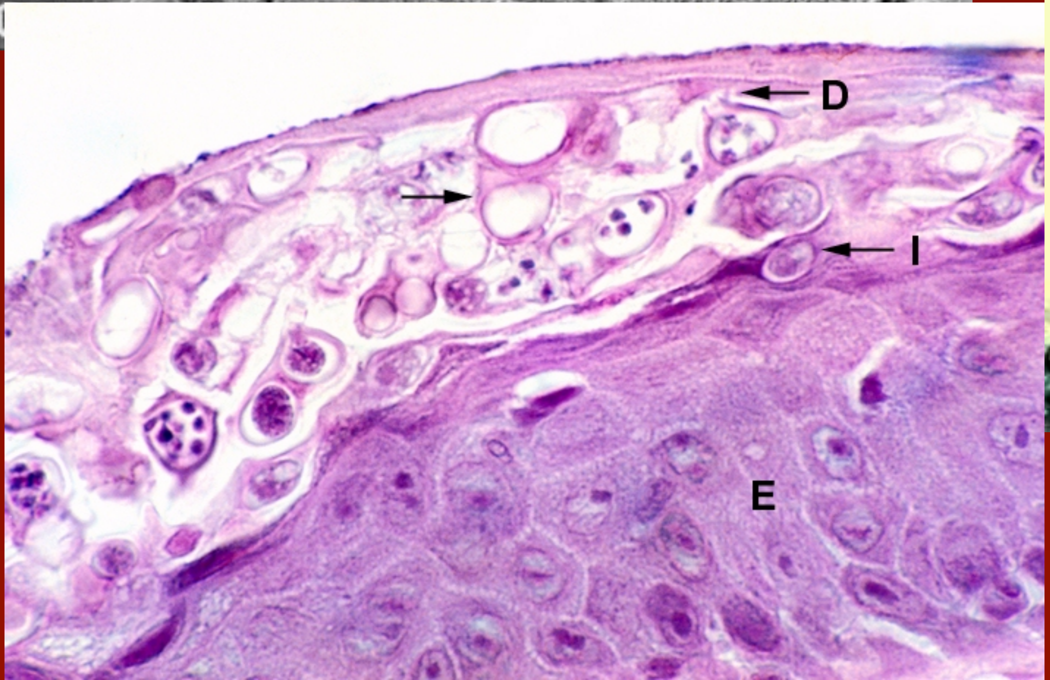
Chytridiomycota, Rhizophyidiales

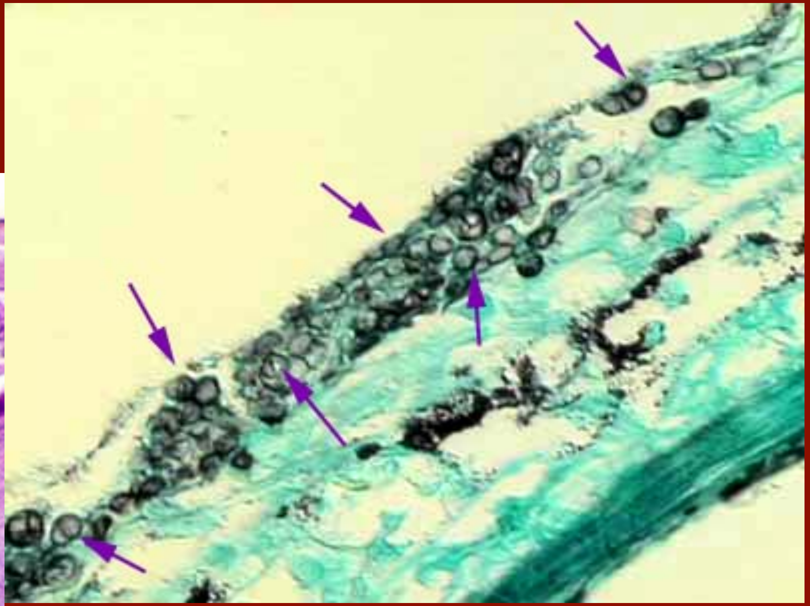
Amphibian decline caused by *Batrachochytrium dendrobatidis* was first reported in 1998. Found in Australia, Panama, now found affecting Amphibians world wide.

B. dendrobatiditis affects the skin of amphibians, impairs their exchange with the atmosphere and electrolytes

Affects keratinized portions of amphibian skin



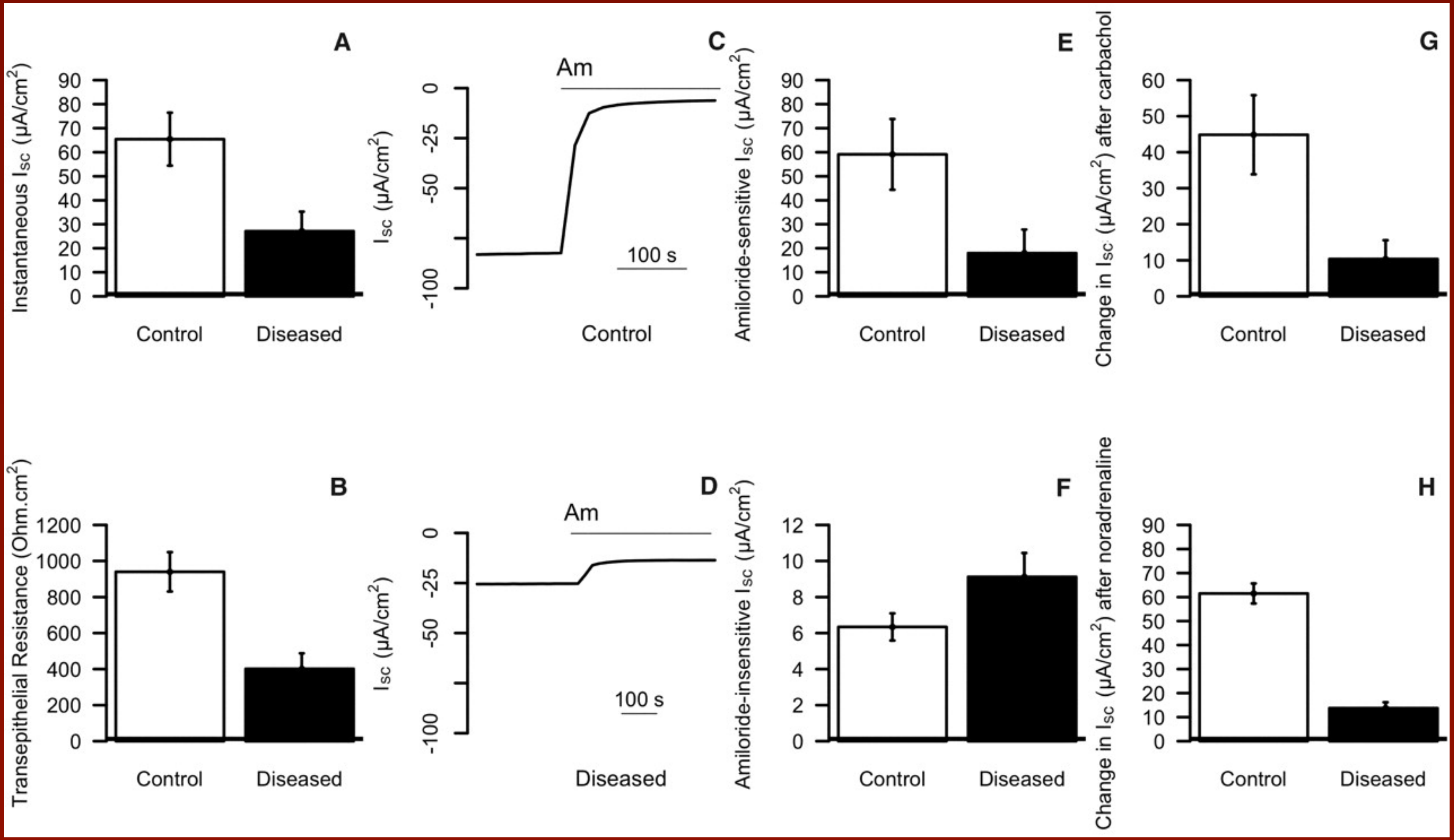




Early effects of chytridiomycosis appear on keratinized tadpole mouthparts

Bd infection inhibits Na absorption, disrupts electrolyte transport

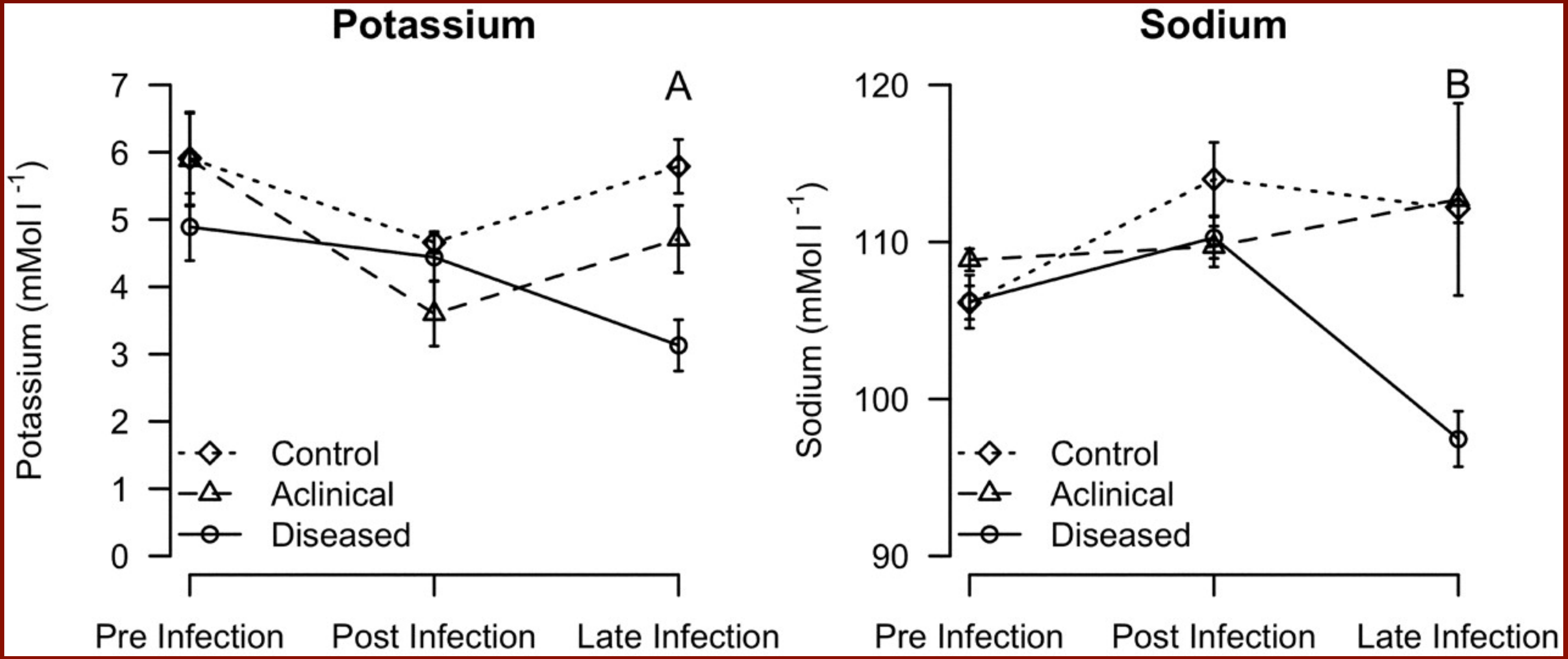
Fig. 2 Electrophysiological measurements of electrolyte transport across ventral skin samples from L. caerulea infected with B. dendrobatidis.



J Voyles et al. Science 2009;326:582-585

Published by AAAS

Fig. 3 Blood plasma potassium and sodium concentrations in L. caerulea.



Blood plasma potassium and sodium concentrations in L. caerulea. Blood samples were collected from infected L. caerulea (aclinical, N = 7; clinically diseased, N = 11; uninfected control, N = 7) on three sample occasions: 20 days before exposure (Pre Infection), 30 days after exposure (Post Infection), and 60 to 123 days after exposure when clinical signs of disease were obvious (Late Infection). (A and B) Data show mean (±SEM) concentrations of plasma potassium and plasma sodium.

J Voyles et al. Science 2009;326:582-585

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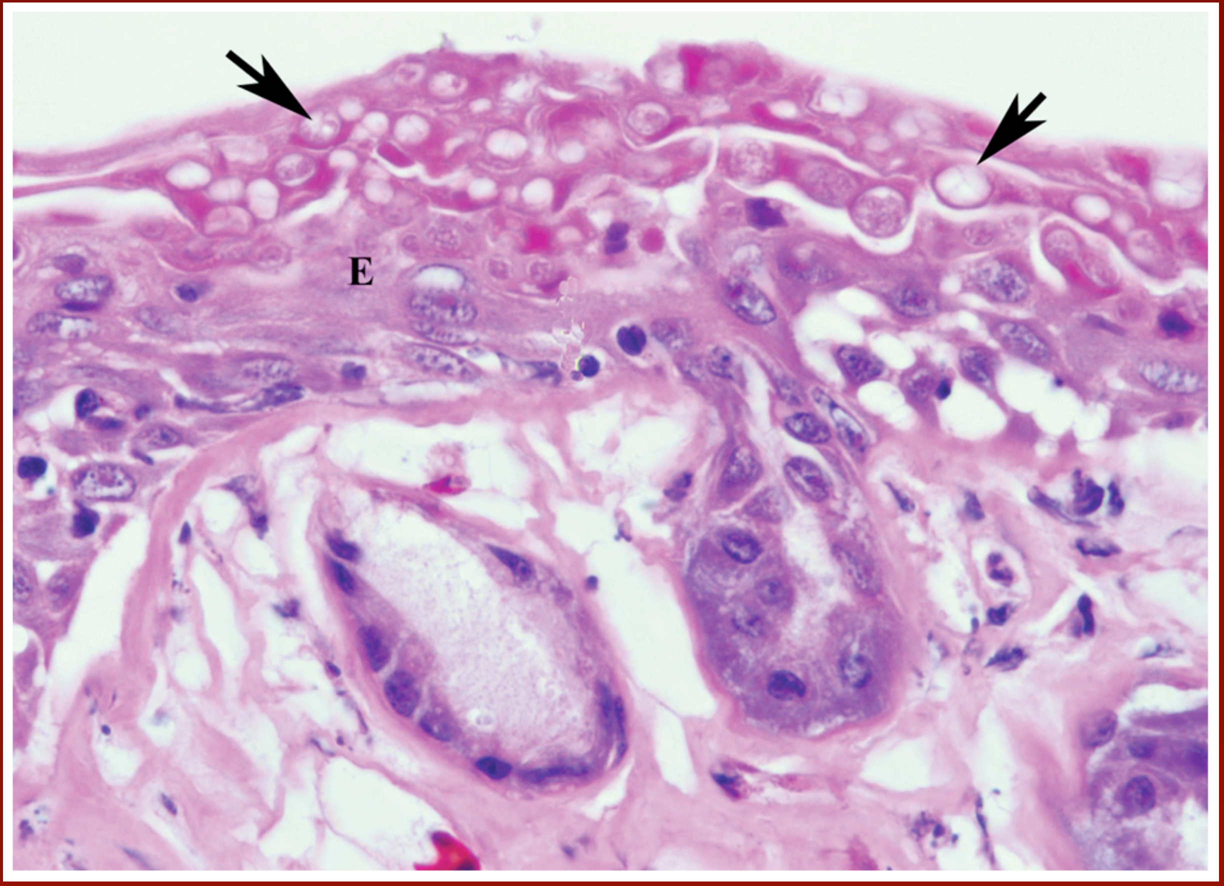
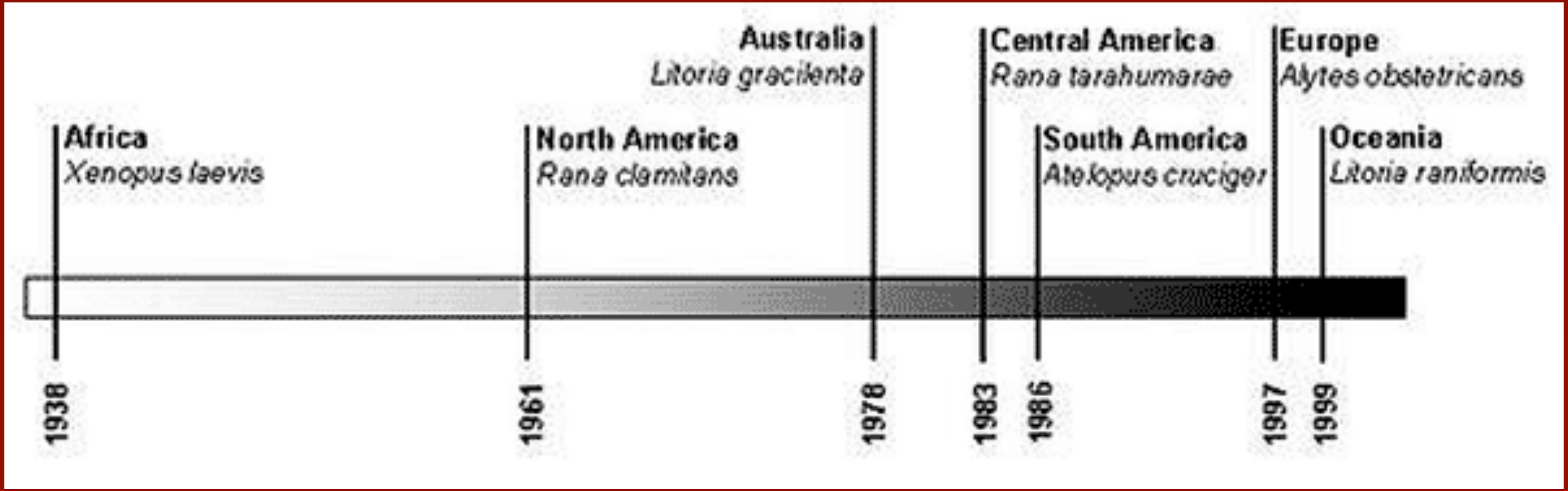
“Our results support the epidermal dysfunction hypothesis, which suggests that Bd disrupts cutaneous osmoregulatory function, leading to electrolyte imbalance and death. The ability of Bd to compromise the epidermis explains how a superficial skin fungus can be fatal to many species of amphibians; their existence depends on the physiological interactions of the skin with the external environment”



Oldest *B. dendrobatidis* found in preserved *Xeopus laevis* in South Africa

Thought to have been spread worldwide by use of *X. laevis* in pregnancy testing

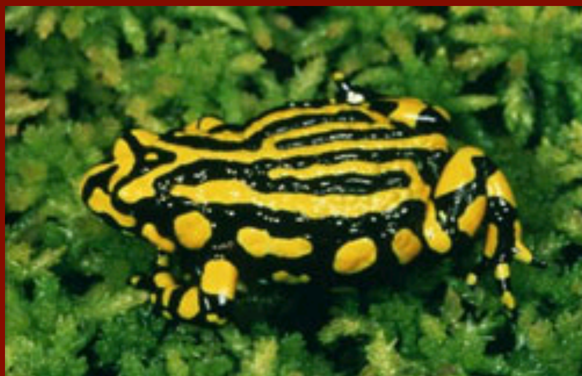
Amphibian declines caused by this fungus have been reported from the Boreal toad in Colorado, the Wyoming toad in Wyoming, the mountain yellow leg frog in the Sierra of California and numerous additional species in Central America.



Amphibians in six continents, Africa, South America, Central America, North America, Europe, Australia, and Oceania have been reported as infected by the amphibian chytrid. The earliest record is from North America in *Rana pipiens* collected in 1974.

Currently a total of 2 amphibian orders (Anura and Caudata), 14 families and 93 species have been diagnosed infected with *Batrachochytrium dendrobatidis*. Australia has the most species infected (46) of any country. All of the records from Germany, except for a report in one species in the wild, are in imported amphibians or amphibians in the pet trade, illustrating the importance of the global movement of amphibians in disseminating chytridiomycosis.

Various amphibians worldwide are now threatened with extinction due to Batrachochytrium



Southern corroboree frog, Australia

Litoria raniformis, New Zealand

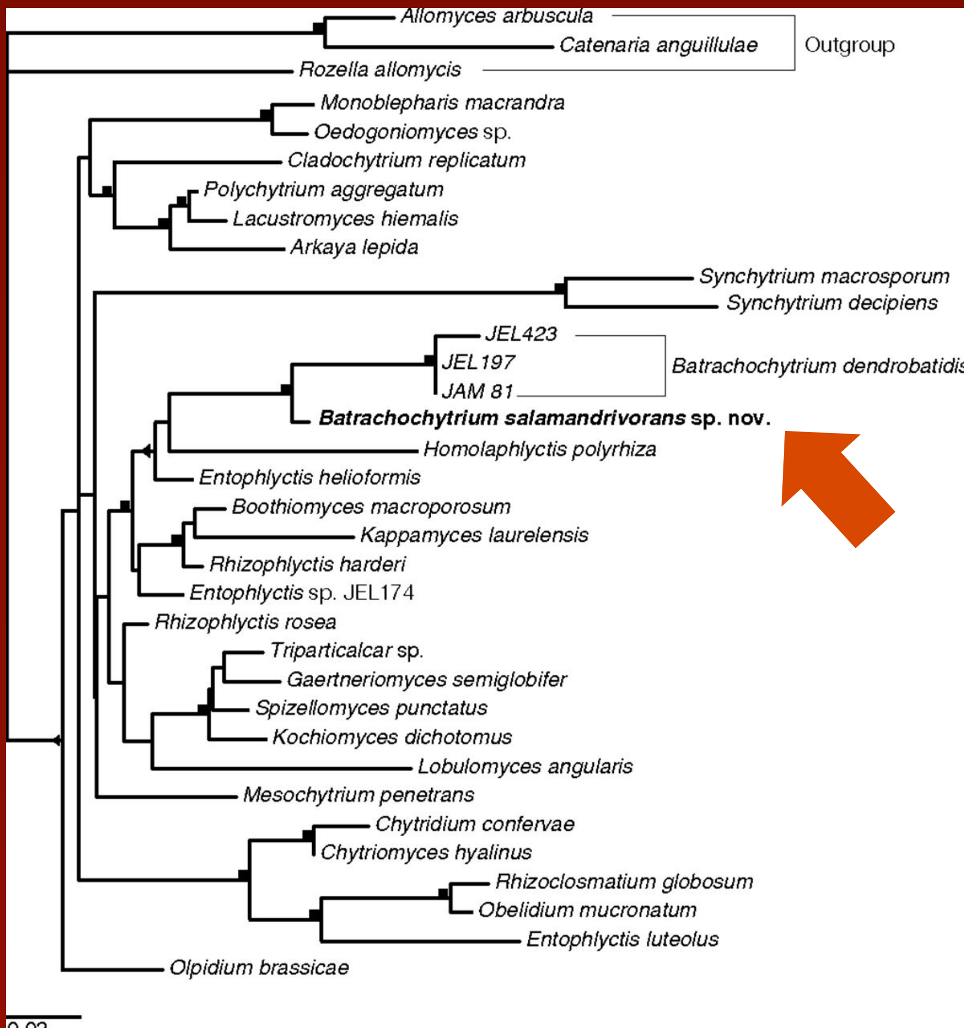
And now another species of Batrachochytrium

Endangered populations of fire salamanders in Europe have succumbed to a new fungus.

E Stokstad Science 2014;346:530-531

Published by AAAS

Maximum likelihood tree (−Ln L = 9,562.04266) for the analysis of a 1,513-bp data matrix of partial 18S + 28S rRNA genes.



First described from diseased fire salamanders in the Netherlands.

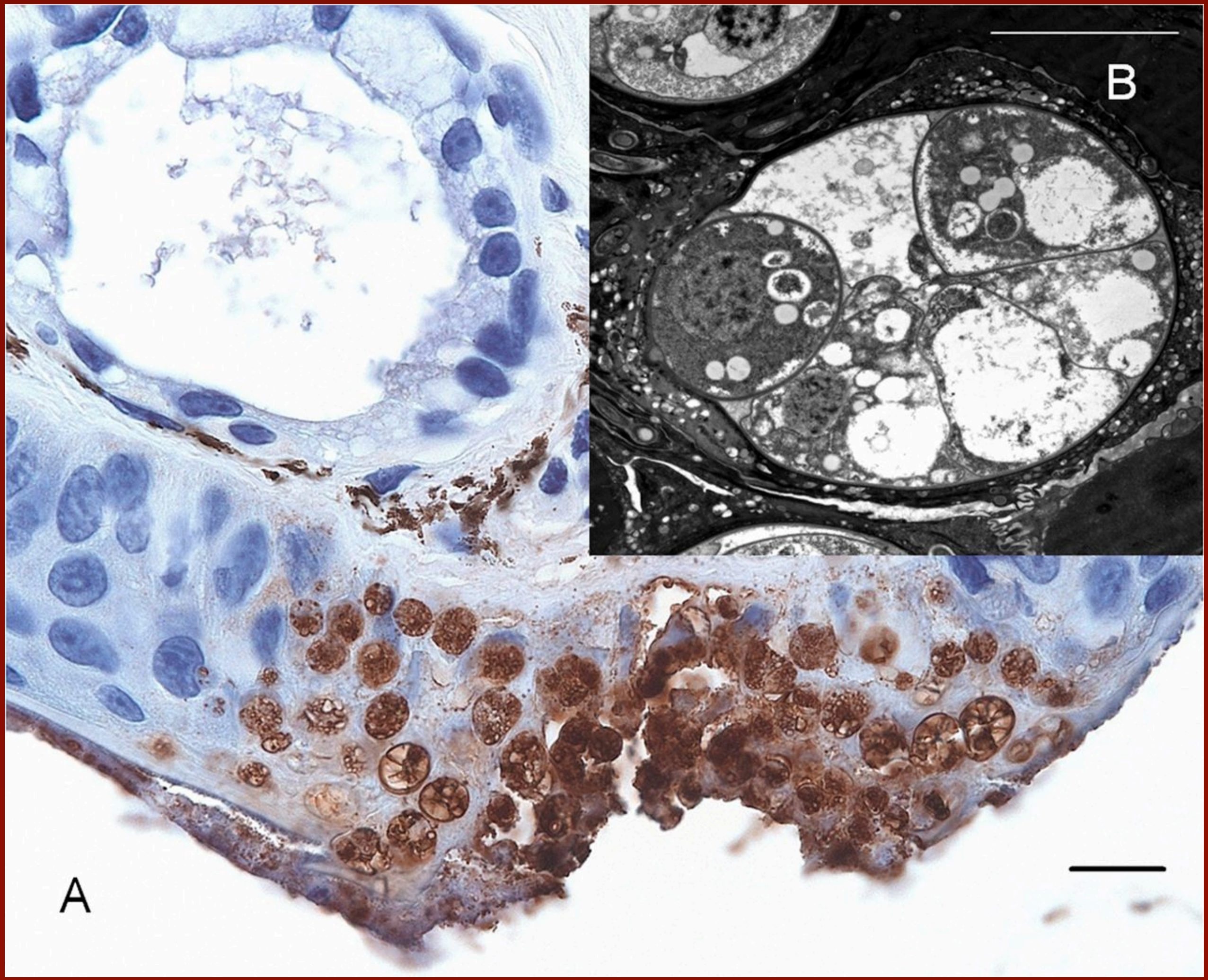
Probably native to South Asia, lethal to most European and North American salamanders

“Chytridiomycosis in amphibians can no longer be attributed to a single species of chytrid, but can be caused by either B. dendrobatidis or B. salamandrivorans.”

Martel A et al. PNAS 2013;110:15325-15329

PNAS

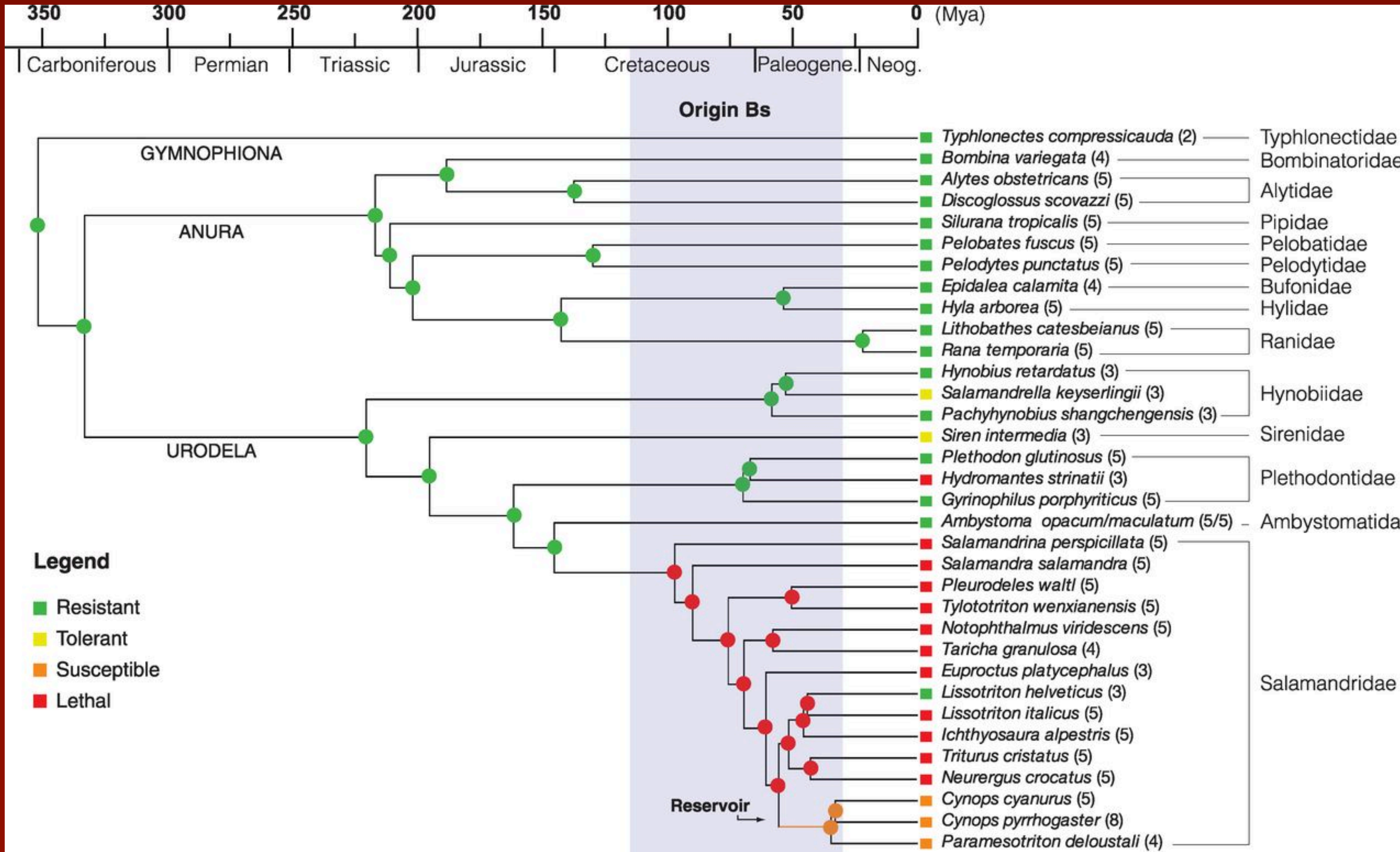
Microscopy of the skin of a fire salamander that died due to infection with B. salamandrivorans.



Martel A et al. PNAS 2013;110:15325-15329

PNAS

Fig. 1 Amphibian susceptibility to Batrachochytrium salamandrivorans (Bs) through time. Molecular time scale (millions of years ago) for 34 species; rectangles indicate the species category based on the experimental infection tests.



A Martel et al. Science 2014;346:630-631

Published by AAAS

Species loss and rediscovery in Costa Rica.The fungal pathogen Batrachochytrium dendrobatidis (Bd) has been linked to the decline and extinction of amphibians worldwide.

Amphibian populations in Costa Rica experienced substantial declines, with 20 of the 199 species feared extinct, after Bd moved through the country from the mid-1980s to the early 1990s. However, 11 of the 23 species have been rediscovered. Holdridge's toad (*Incilus holdridgei*), a species endemic to a single volcano, vanished during the declines and was declared extinct in 2007 but was rediscovered in 2008. Today, relict populations persist in areas where Bd once contributed to their demise.

B A Minteer et al. Science 2014;344:260-261

Order Blastocladiales Now in phylum Blastocladiomycota

Mainly soil and water inhabitants
Form thick-walled resting sporangia
Zoospores have prominent nuclear cap, ribosomes
Allomyces, Physoderma, Catenaria, Coelomomyces

Allomyces hormones: females make Sirenin, males make parisin
Mechanism of sexual differentiation is unknown

Chytrid plant pathogens

Blastocladiales

Physoderma ~ 50 spp.
Physoderma alfalfae: crown wart of alfalfa
P. citri: citrus blight
P. leproides: galls of sugar beet
P. maydis: brown spot of maize
P. pulposum: galls of Chenopodiaceae

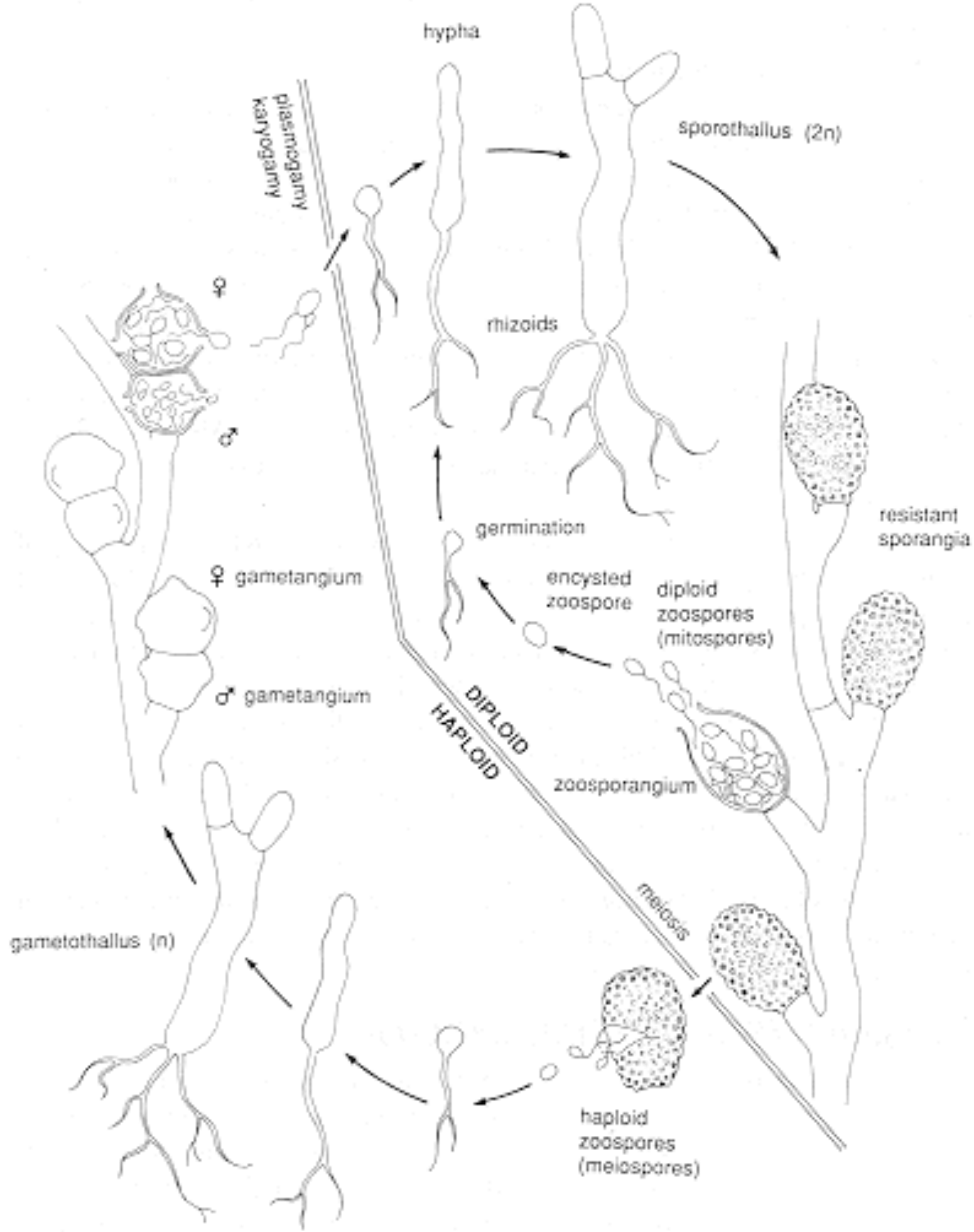
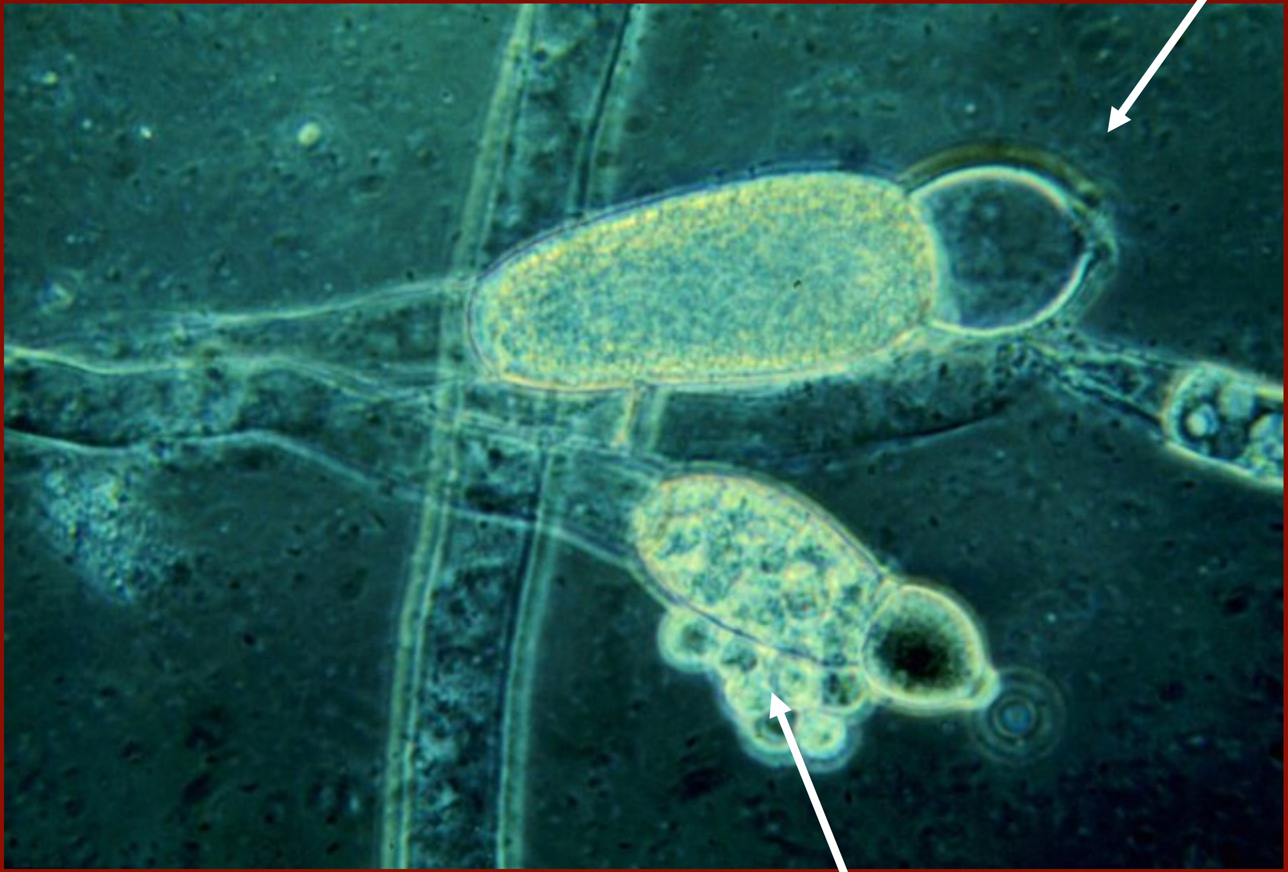


Fig. 2.7 Blastocladiales: life cycle of ***Allomyces arbusculus***.

Allomyces

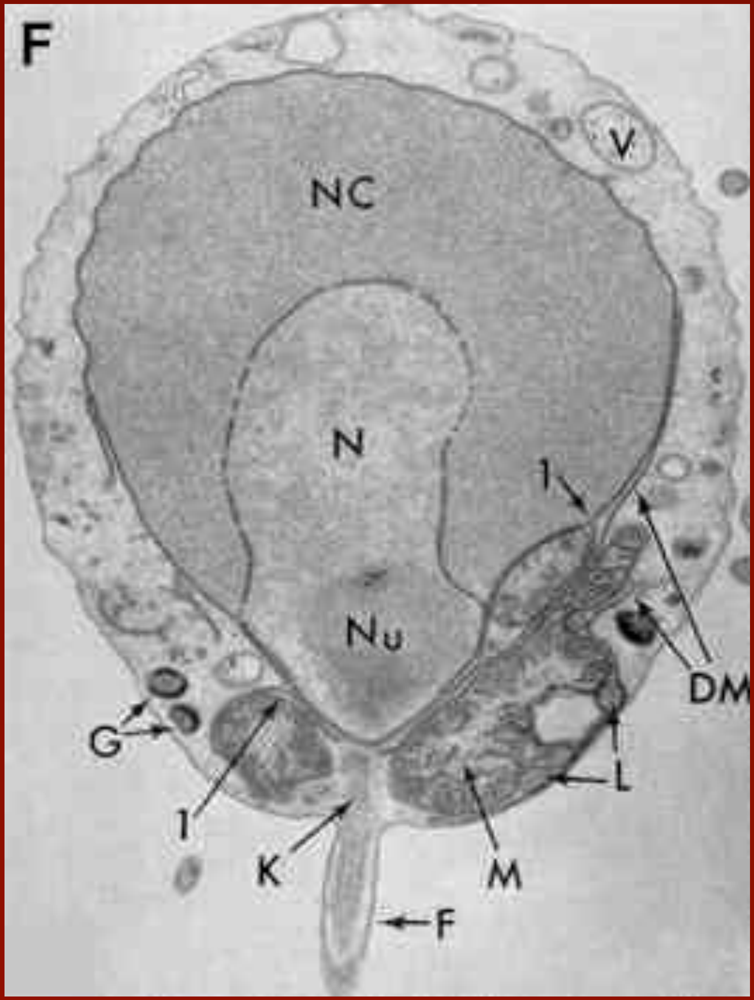
male gametangium



female gametangium

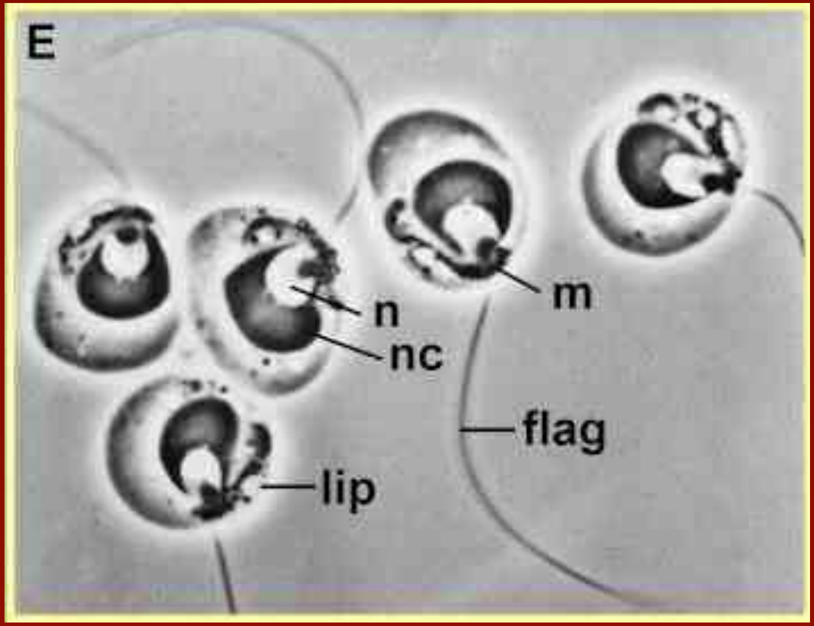
Allomyces sporangia (diploid)

Zoospores of Blastocladiales

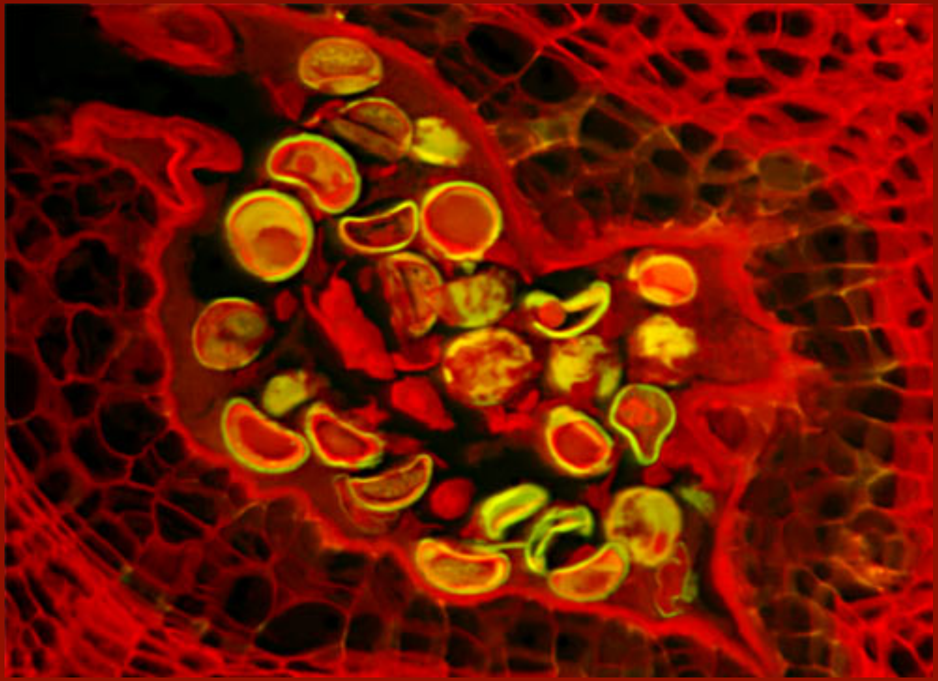


Have a distinct nuclear cap:

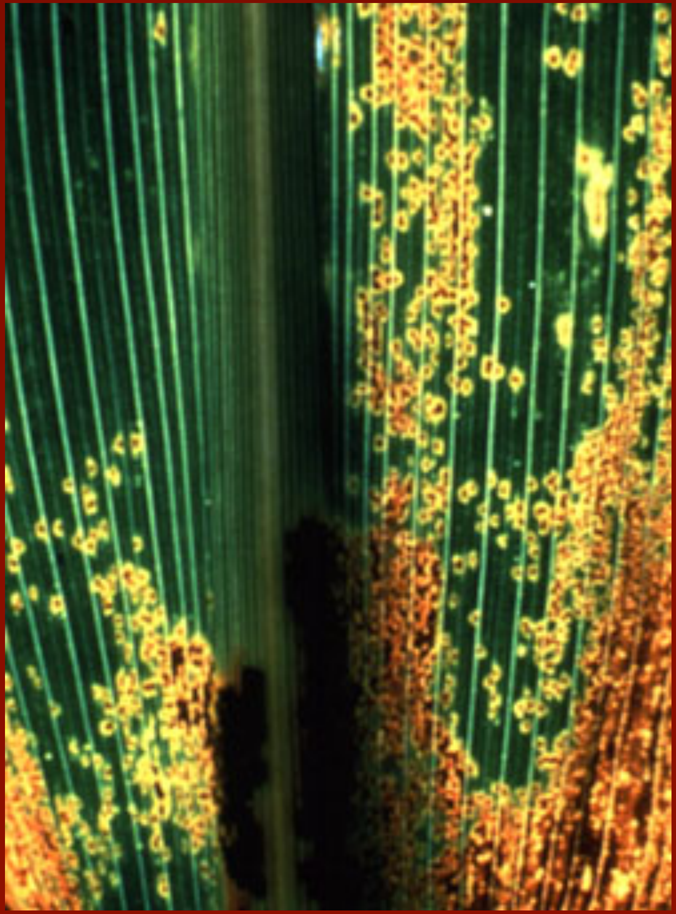
ribosomes aggregated near nucleus, not dispersed

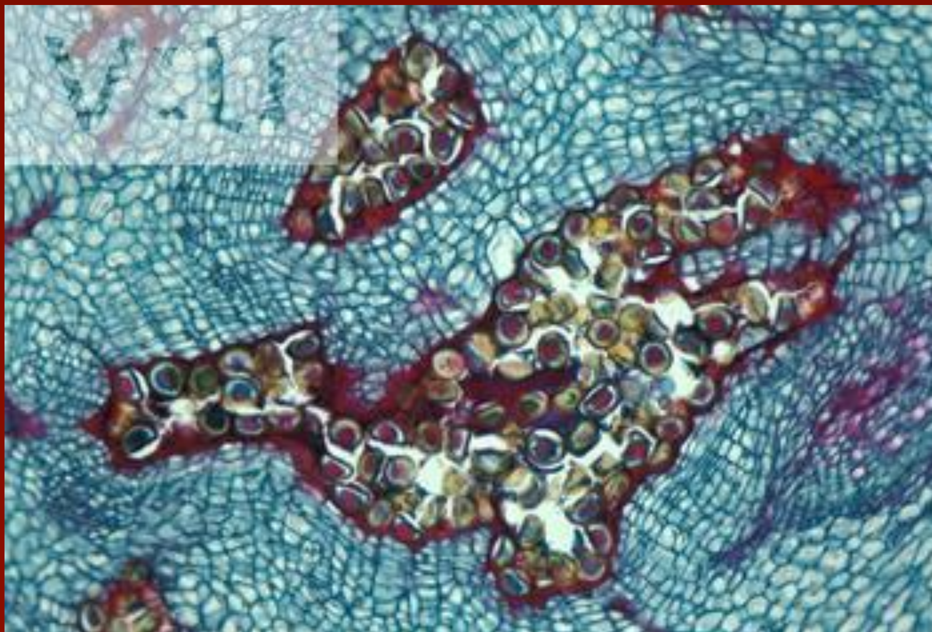


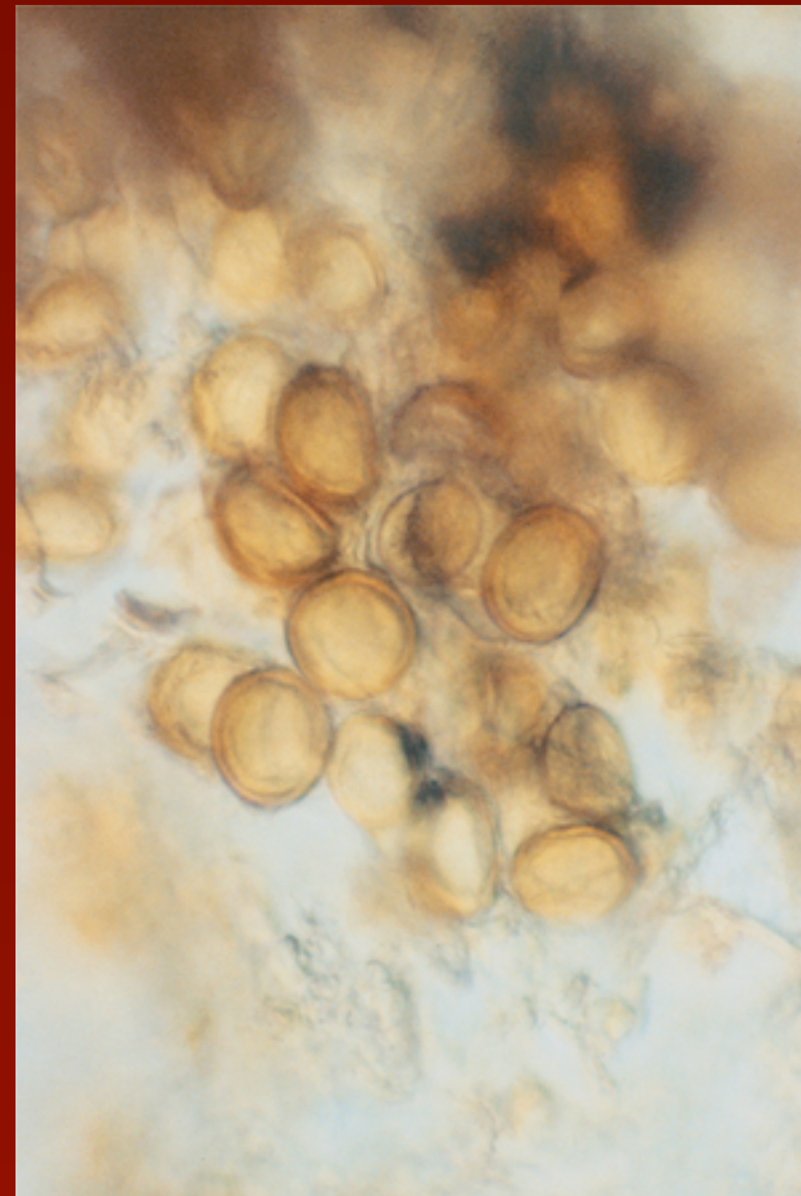
Crown wart of alfalfa caused by Physoderma alfalfae



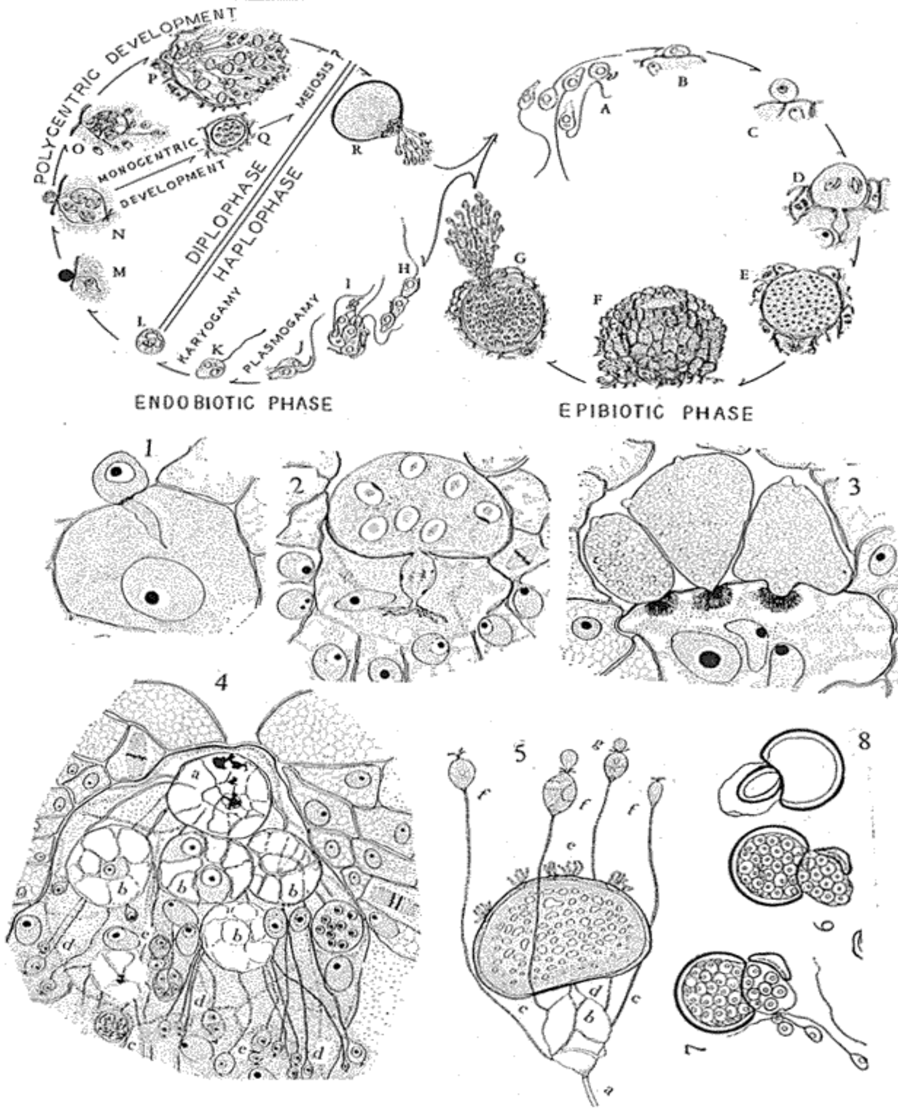
Physoderma maydis brown spot symptoms





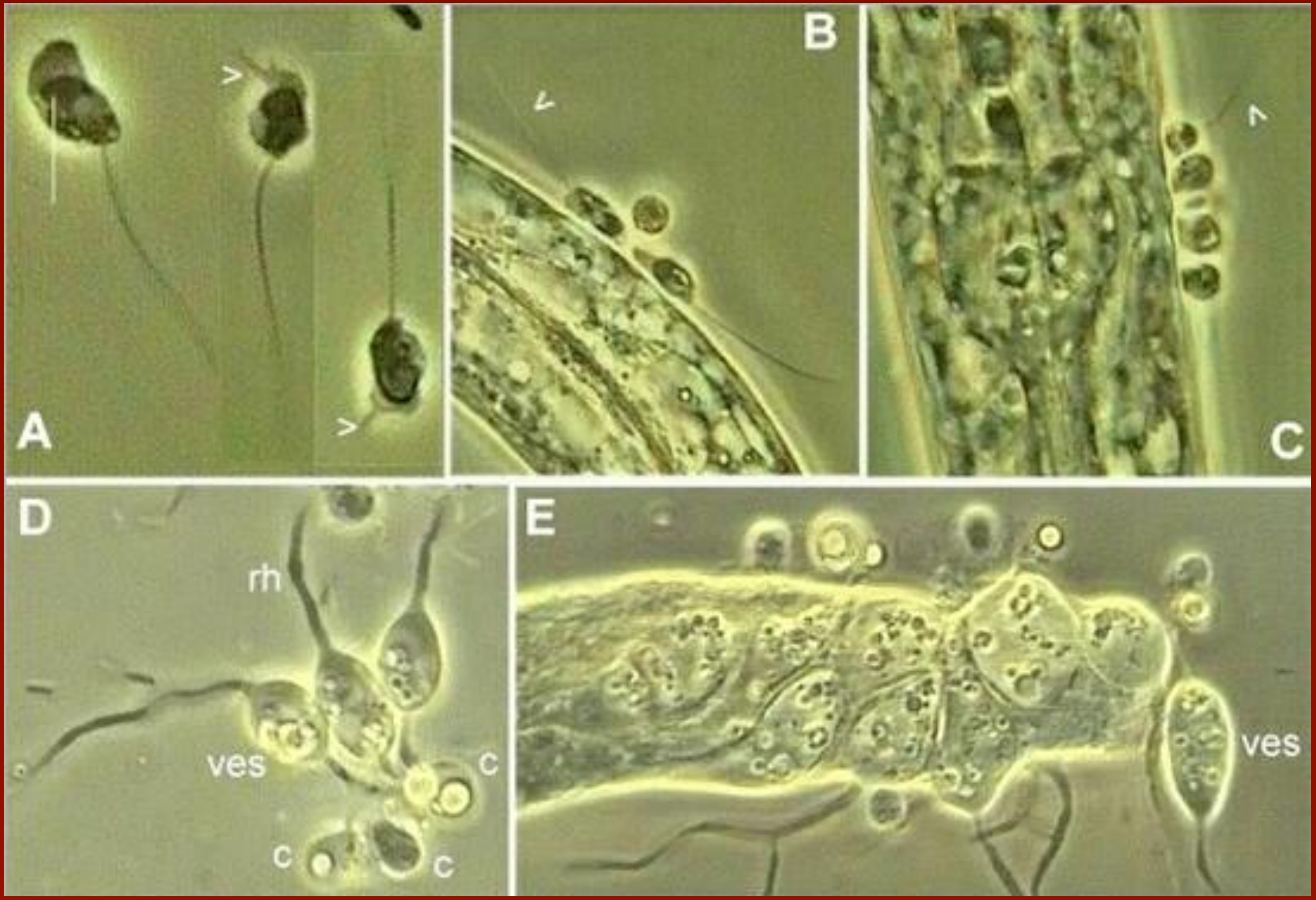


Physoderma
endobiotic resting sporangia



Physoderma pulposum (Walr.)Karling on ***Chenopodium album*** L. Life-cycle. **Fig.A-G**. Stages in the development of Epibiotic phase .**Fig.A.** Planospores (zoospores, gametes). **B.** Attachment of a planospore to an epidermal cell. **C.** An early stage of infection. **D.** Incipient epibiotic sporangium. **E-F.** It's maturation and germination. **G-L.** Some zoospores functioning as gametes, copulate, & result in zygote. **M-N.** Zygotes Infect the host cell. **O**-P. Development of the rhyzomycelium (Endobiotic phase). **R.** Germinating Resting sporangium. 1. Infection of an epidermal cell by a planospore. 2. An early stage in the development of epibiotic sporangium. 3. Three mature epibiotic sporangia developing on an epidermal host cell. 4. Eight days-old rhizomycelium ; with empty, primary (a), secondary (b), & tertiary ©, turbinate organs. (Fig.5). 6 &7. Stages in germination of resting sporangia of **P. corcori,** Lingappa. Notice the difference between germination processes between **Fig.** R & 6-7. **Fig.** 8. Empty resting sporangium.

Catenaria, an endobiotic parasite of nematodes and nematode eggs



Catenaria

Coelomomyces

About 70 species
parasites of aquatic insects (Diptera), mosquito larvae

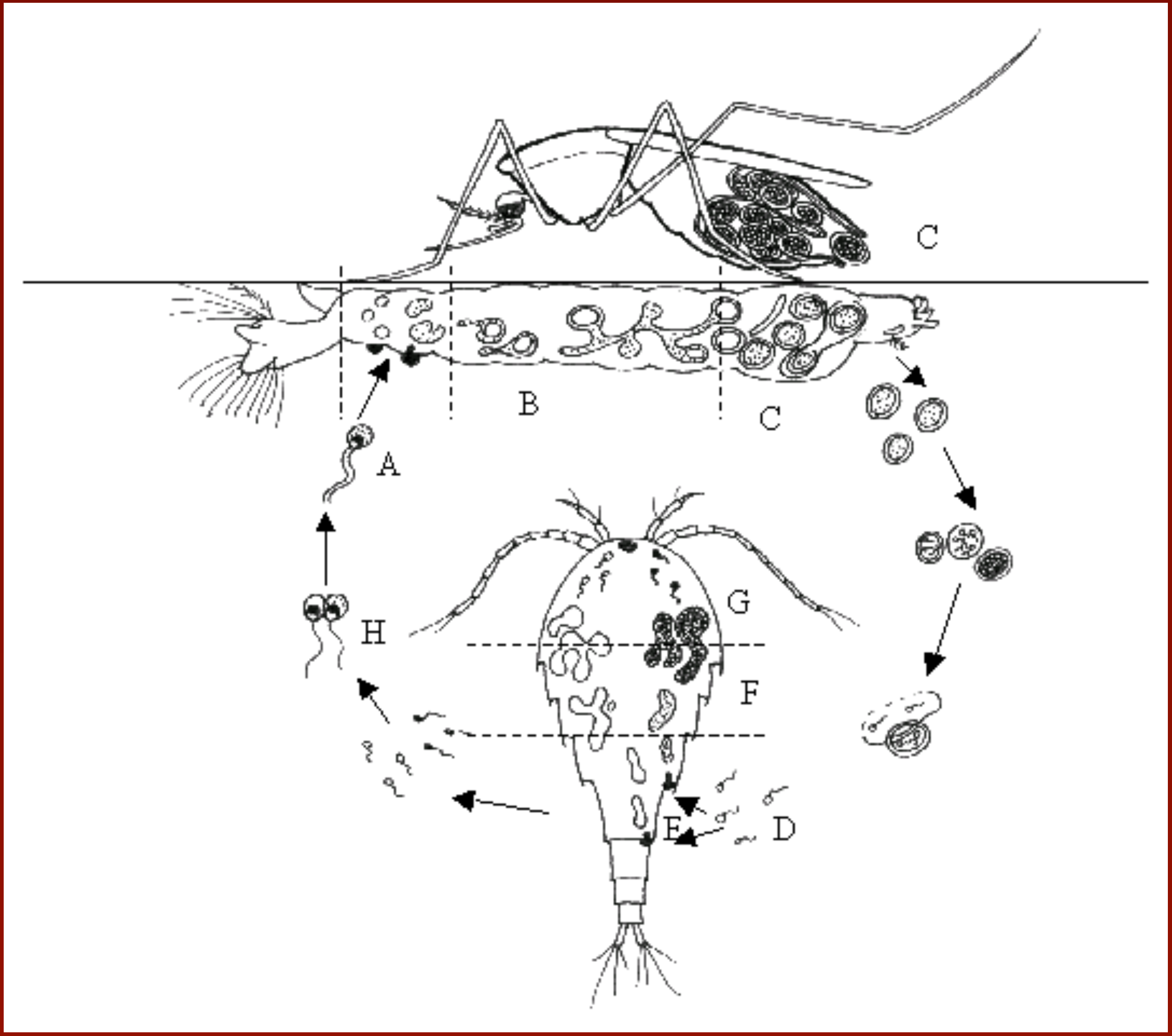
proposed as biocontrol by Couch (the *Septobasidium* guy)

Actually a heteroecious fungus, the only non-rust heteroecious fungus known

Alternation of generations, gametophyte (haploid) stage produced on Copepods (Crustacea)
Sporophyte (diploid) produced on mosquito larvae

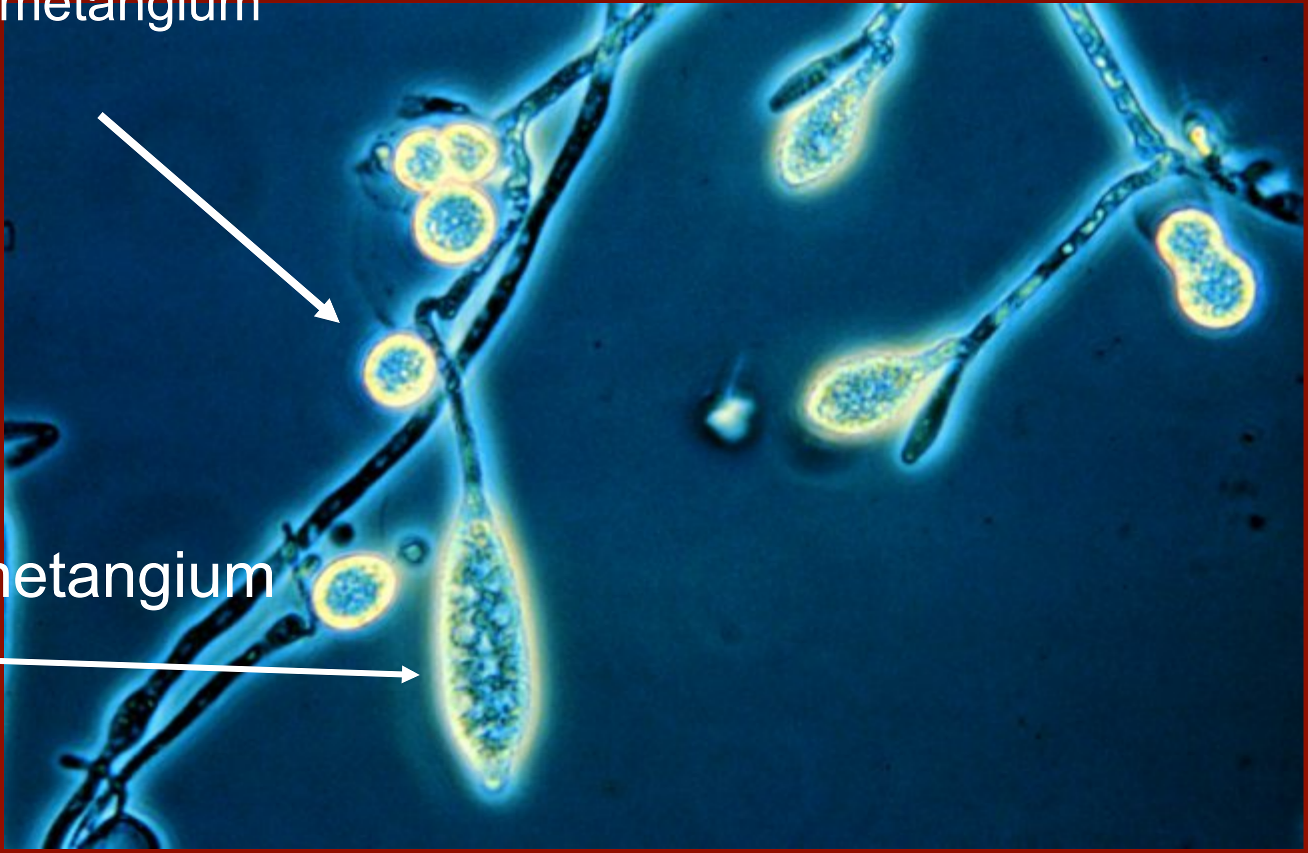
Used as a biocontrol agent for mosquito control
effective but difficult to mass produce

Life cycle of Coelomomyces, alternation between mosquito larva and copepod



Monoblepharidales (now Monoblepharidomycetes)

Reproduction by fertilization of nonmotile female gamete by a motile male gamete



Saprobes in freshwater environments