Basidiomycota: (31,500)

- septate mycelium
- clamp connections
- complex dolipore septa
- dikaryotic, haploid mycelium
- sexual spores are (basidiospores) on a basidium
- production of complex sporocarps

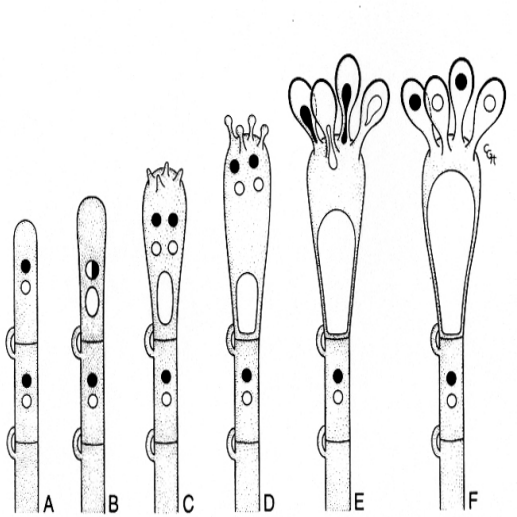


Figure 16-6 Successive stages in development of a basidium and basidiospores. (A) Binucleate hyphal tip. (B) Uninucleate, diploid basidium following karyogamy. (C) Postmeiotic basidium with four haploid nuclei. Sterigmata have begun to develop. (D) Basidiospore initials on sterigmata and nuclei preparing to migrate into the spore initials. (E) Migration of nuclei into basidiospore initials. (F) Highly vacuolate, maturing basidium bearing four young uninucleate basidiospores. (Drawing by Carol Gubbins Hahn.)

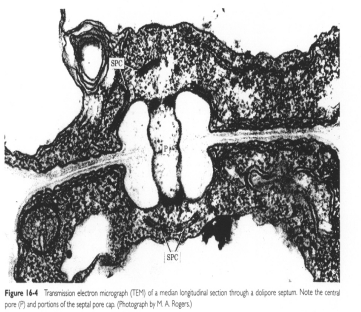
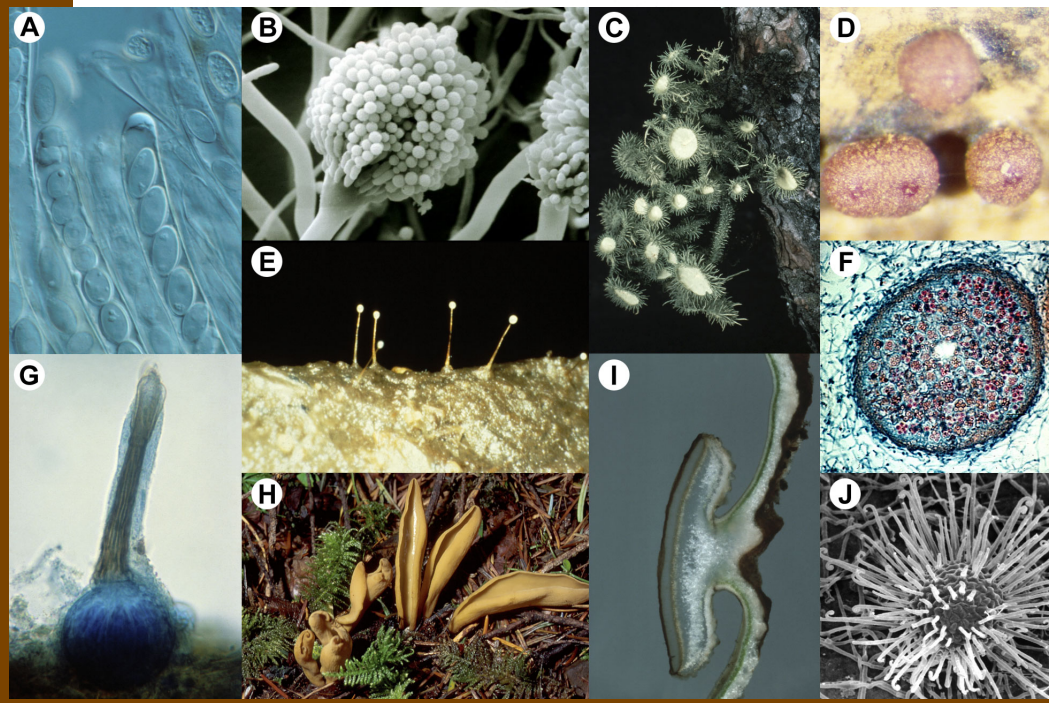


Figure 16-4 Transmission electron micrograph (TEM) of a median longitudinal section through a dolipore septum. Note the central pore (P) and portions of the septal pore cap. (Photograph by M. A. Rogers.)

Ascomycota: (64,200)

- septate mycelium
- simple septa, Woronin bodies
- monokaryotic, haploid mycelium
- dikaryotic phase brief, in ascocarp primordia
- sexual spores (ascospores) in an ascus
- production of complex sporocarps
- often dominant asexual reproduction



Fungal life cycles

The somatic (vegetative) thallus predominates in the life cycles of fungi

The thallus may be monokaryotic haploid (1n), dikaryotic haploid (n_a+n_b) or diploid (2n) in different groups of fungi

Ploidy of thallus is determined by the timing of these events in the life cycle:

Plasmogamy, somatogamy: fusion of gamete cytoplasm

Dikaryophase: period following fusion of haploid cells during which resulting hyphae contain two different types of haploid nuclei which divide simultaneously (dikaryon, heterokaryon)

Karyogamy: fusion of haploid nuclei

Meiosis: divison of diploid nuclei resulting in haploid nuclei

Chytridiomycota, Blastocladiomycota

- Form motile spores called zoospores
- Zoospores function as gametes (sexual) or propagules (asexual)
- Meiosis occurs in a resting sporangium
- Alternating gametic (n) and sporophyte (2n) thallus types

Zygomycota

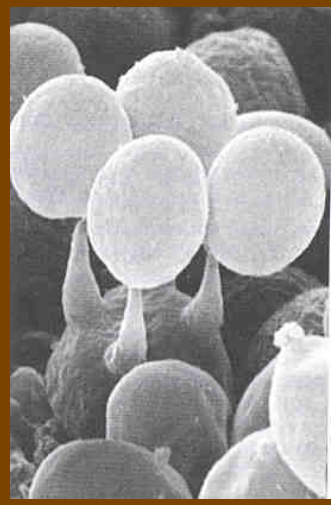
- Form asexual spores called sporangiospores
- Differentiated hyphae (gametangia) function as gametes
- Plasmogamy is quickly followed by karyogamy
- Meiosis occurs in zygospore

Ascomycota

- Form asexual spores (conidia)
- Diferentiated hyphae or conidia function as gametes
- Dikaryotic phase follows plasmogamy
- Meiosis occurs in ascus
- Sexual spores are haploid ascospores

Basidiomycota

- Asexual conidia formed by several spp.
- Undifferentiated hyphae function as gametes
- Prolonged dikaryotic phase
- Meiosis occurs in basidium
- Sexual spores are haploid basidiospores



Fungal reproduction

Anamorph = asexually reproducing forms

Mitospore = spore formed via asexual reproduction (mitosis), commonly called a conidium (pl. conidia) or sporangiospore

Teleomorph = sexual reproductive stage

Meiospore = spore formed via sexual reproduction (e.g., resulting from meiosis), type of spore, terminology, varies by phylum

Holomorph = the whole fungus, all life cycle stages

The holomorph concept

Fungi may reproduce through asexual and/or sexual processes.

Asexual and sexual reproductive forms may be very different for the same species.

Multiple asexual reproductive forms can occur in the same species, but only one sexual form.

Asexual and sexual reproduction, and reproductive structures, may be separated in time and space, or different ecological conditions.

Connecting the asexual and sexual forms of the same organism can be very difficult.

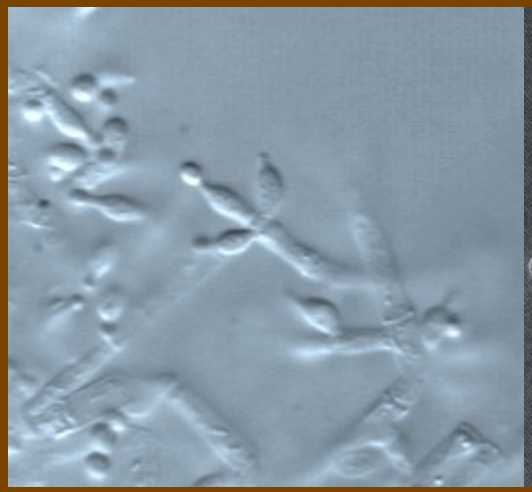
Different latin binomials can be introduced for naming the sexual reproductive state and all other asexual reproductive states (for ascomycetes and basidiomycetes).

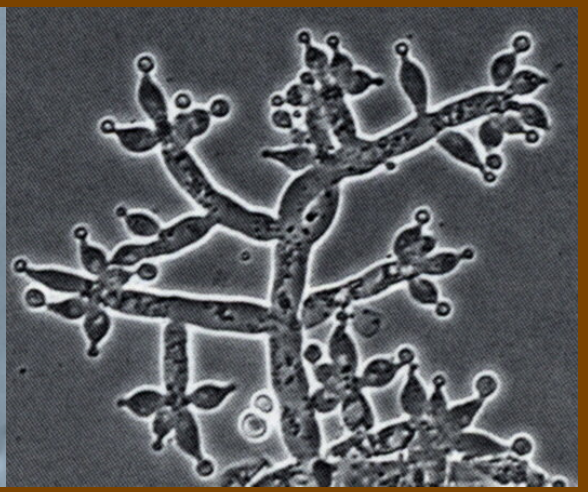
The holomorph is the entire fungus—including asexual and sexual stages if both are formed.

The holomorph name is the same as the name applied to the sexual reproductive state (teleomorph).

Holomorph/teleomorph:
Hypocrea jecorina

Anamorph: *Trichoderma reesei*





Multiple anamorphs: synanamorphs

Holomorph/teleomorph: *Ophiostoma ulmi*

Synanamorph:
Sporothrix schenkii

Synanamorph: *Pesotum ulmi*

Nomenclature: what's in a name?

➡ Information and an hypothesis

Amanita muscaria (L.) Hook.

Kingdom – Fungi
Phylum – Basidiomycota
Subphylum – Basidiomycotina
Class – Agaricomycetes
Order – Agaricales
Family – Amanitaceae
Genus - *Amanita*
Species - *A. muscaria*

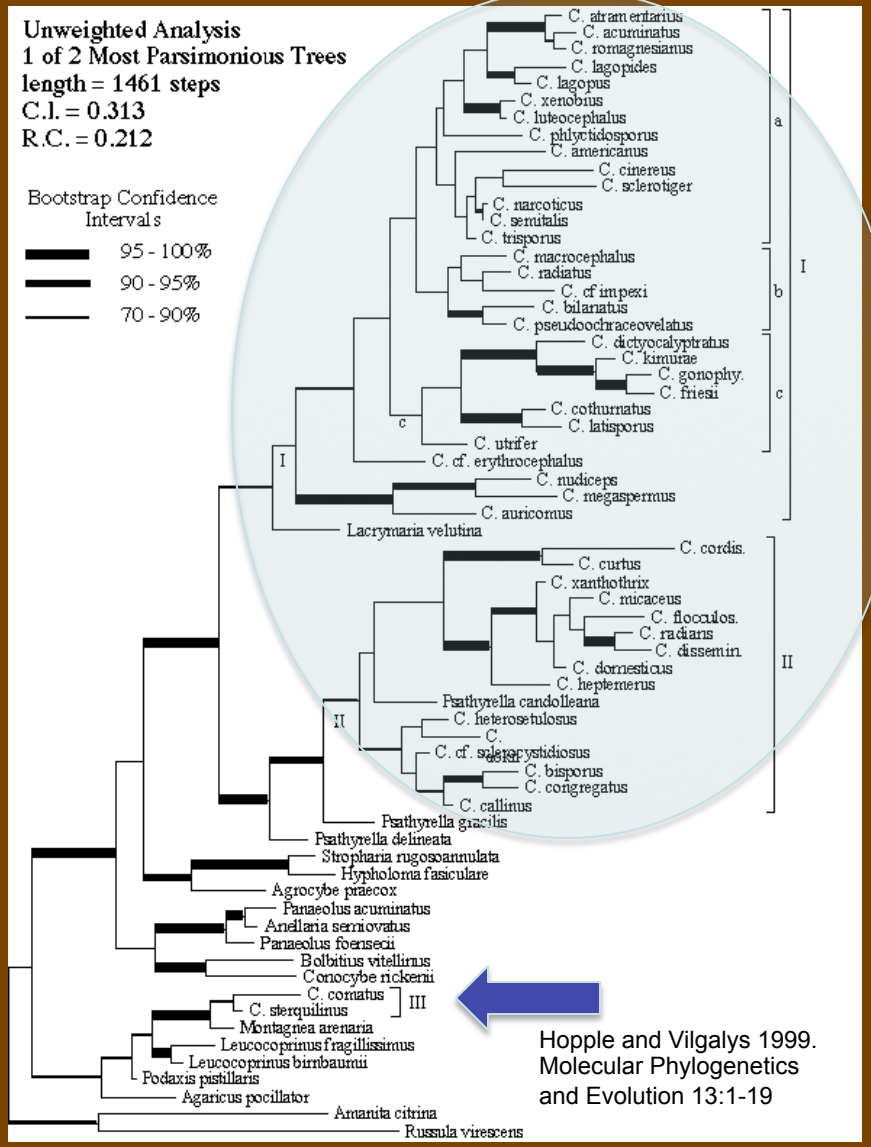
The species was first named by Linneaus (L.) as *Agaricus muscarius* in 1753

Hooker (Hook.) later (1797) transferred the species to the genus *Amanita*.

The latin binomial for a species is a shorthand form for the phylogenetic position of the species. If the hypothesis is disproved, e.g. by molecular phylogenetic analysis, the name must be changed.

Example: *Coprinus*

Coprinus comatus, the type species for the genus is not closely related to the majority of species (formerly) classified in *Coprinus*.



Hopple and Vilgalys 1999. Molecular Phylogenetics and Evolution 13:1-19

Because *C. comatus* is the type species for *Coprinus,* other species formerly classified in *Coprinus* were transferred to other genera. New genera had to be created to accomodate these species.

Coprinus atramentarius
Coprinopsis atramentaria (Psathyrellaceae)

Coprinus cinereus
Coprinopsis cinerea (Psathyrellaceae)

Coprinus micaeus
Coprinellus truncorum (Agaricaceae)

Names to know in this class

Kingdoms: Fungi, Chromista (Stramenopila), Protozoa/Amoebozoa
Phyla: Ascomycota, Basidiomycota, Blastocladiomycota, Chytridiomycota, Glomeromycota, Zygomycota

Several orders will be covered in detail, e.g. Agaricales, Pucciniales

Some genera will be emphasized in connection with specific groups of fungi, or organisms with important & interesting biology or ecology.

Examples: *Aspergillus, Fusarium, Neurospora, Phytophthora, Pilobolus, Saccaromyces*

A few species with biological, ecological or economic importance will be considered in detail.

Examples: *Aspergillus flavus*, *Ustilago maydis*

Fungi in the fossil record

Fungi first appear in the fossil record 460 MYA
Early chytrids and zygomycetes divergence estimated at about 630 MYA
Glomeromycota diverged about 600 MYA
Ascomycota, Basidiomycota diverged about 500 MYA

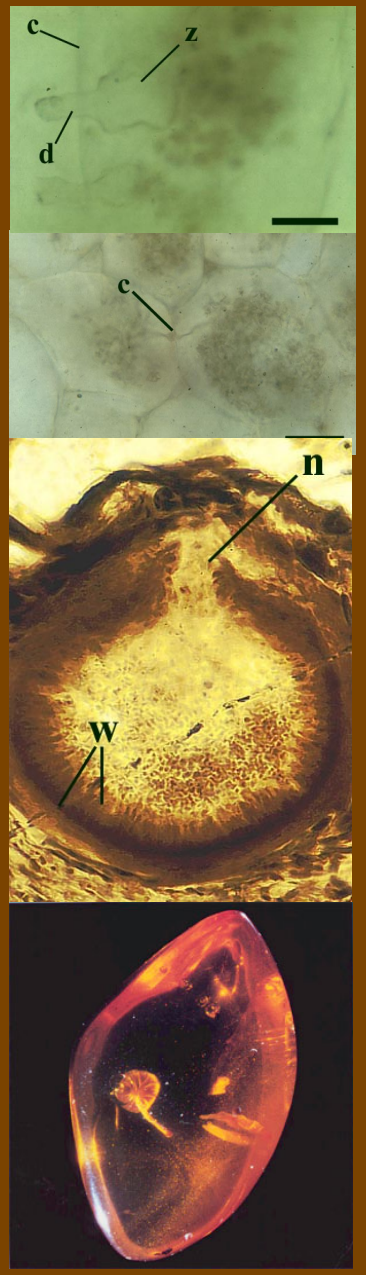
Ordovician (450 – 460 MYA) fossil fungi are associated with land plants, resemble contemporary glomeromycetes

Silurian (410 – 440 MYA) fossil fungi are associated with land plants, resemble contemporary ascomycetes

Representatives of all modern fungal groups were present by the Pennsylvanian epoch (320 MYA)

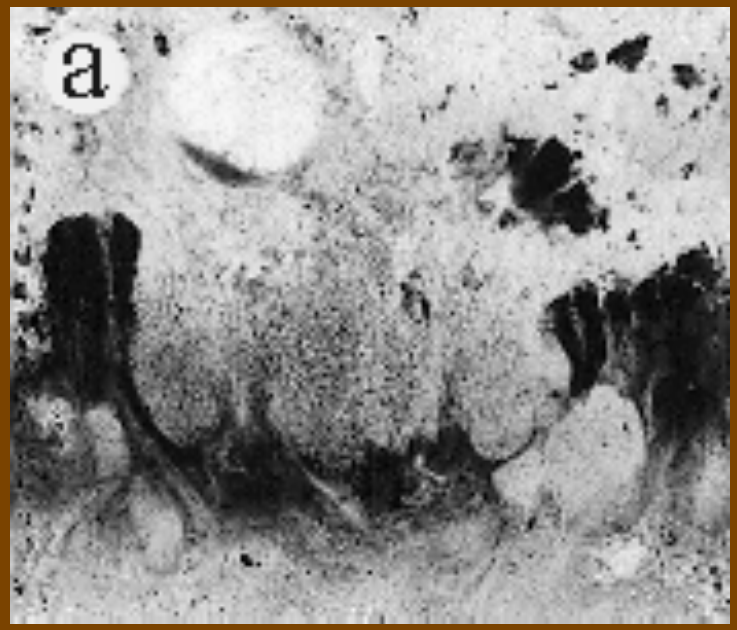
Fossil Record of Kingdom Fungi - How old are fungi?

Ediacaran	650	oldest multicellular plants and animal fossils	
Ordovician	460	hyphae, spores	Glomeromycota
Silurian	440	hyphae, spores	?Ascomycota
Devonian	410	*Paleopyrenomycetes*	Pezizomycotina
		wood decay	Basidiomycota
		mycorrhizae	Glomeromycota
		lichens	
		zoosporangia	Chytridiomycota
Carboniferous	360	zygospores	Zygomycota
		clamp connections	Basidiomycota
		?fruit bodies	
Permian	286	white rot	Basidiomycota
Triassic	245	wood decay	Basidiomycota
		mycorrhizae	Glomeromycota
Jurassic	208	shelf fungus	Basidiomycota
Cretaceous	144	rusts	Basidiomycota
		polypores	
		conidia	Ascomycota
Tertiary	65	extant morphologies	



The oldest fossil fungi?

Glomalean (?) fungus from Ordovician, 460 MYA
Madison, WI
Redecker et al (2000). Science 289: 1920-21



Fossil lichen(?) from Devonian
Rhynie chert, 440 MYA

modern Glomus spore

Symbiosis, “living together” is an ancient life history trait in the fungi.

symbiosis: mutualism + / +
antagonism + / -
commensalism + / neutral

Symbiosis has helped drive fungal evolution, speciation

Earliest fossils are fungi closely associated with plants and arthropods, the two groups that today support the greatest diversity of fungal species

Mycorrhiza-like structures in early land plants suggest that fungal symbionts enabled land colonization by plants

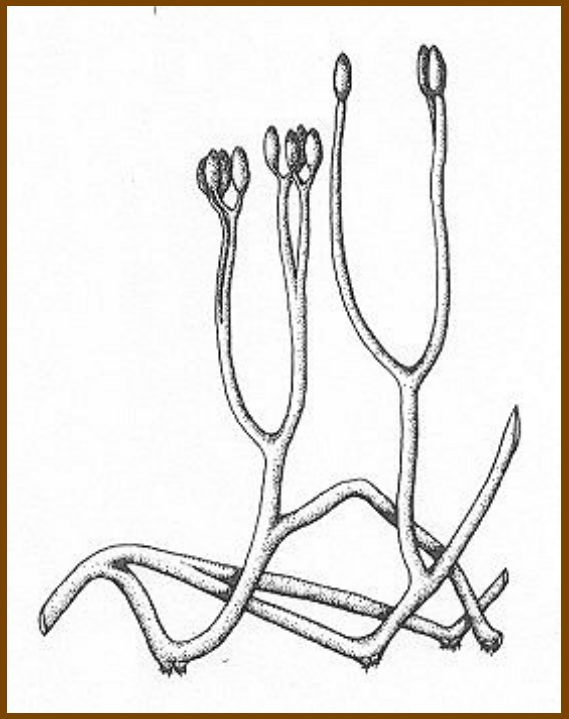
Plants and fungi conquered land together.

The Rhynie Chert Fossils

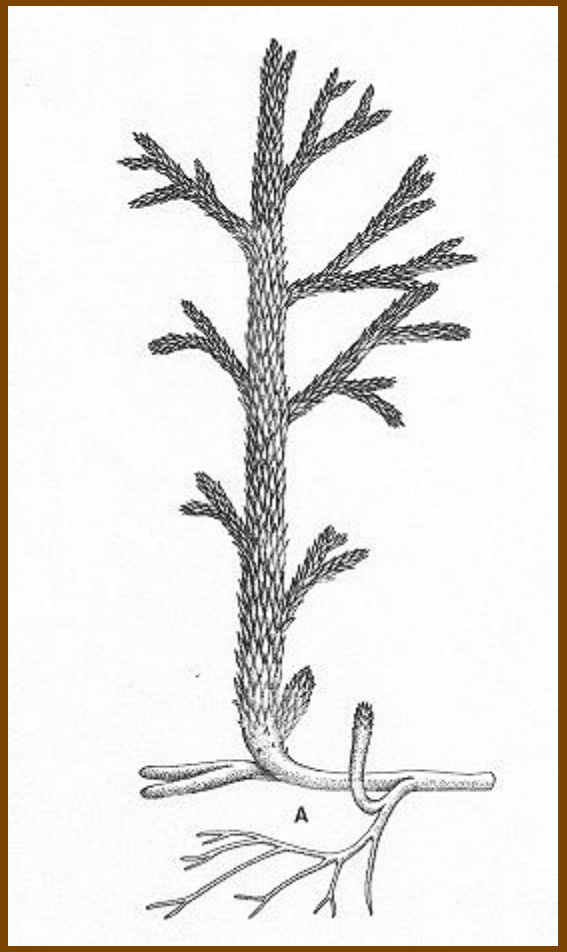
Rhynie -- a village near Aberdeen, Scotland
Chert -- a silica-rich rock formed from deposition of silica deposited from hot springs and geysers.
Age: Early Devonian, ~ 412-400 million years ago
In early Devonian, Rhynie was at about 28 ° S latitude

http://www.abdn.ac.uk/rhynie/intro.htm

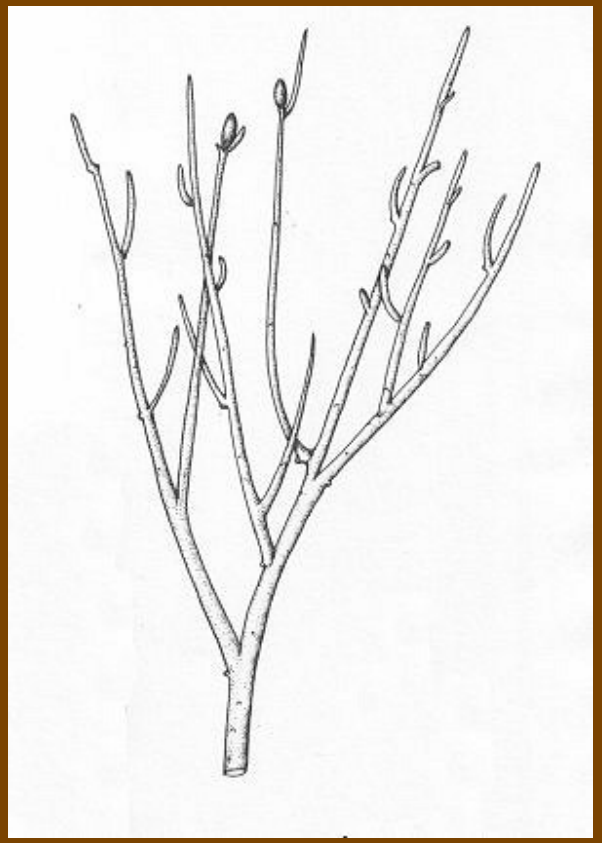
Fossil plants of the Rhynie Chert



Agalophyton major

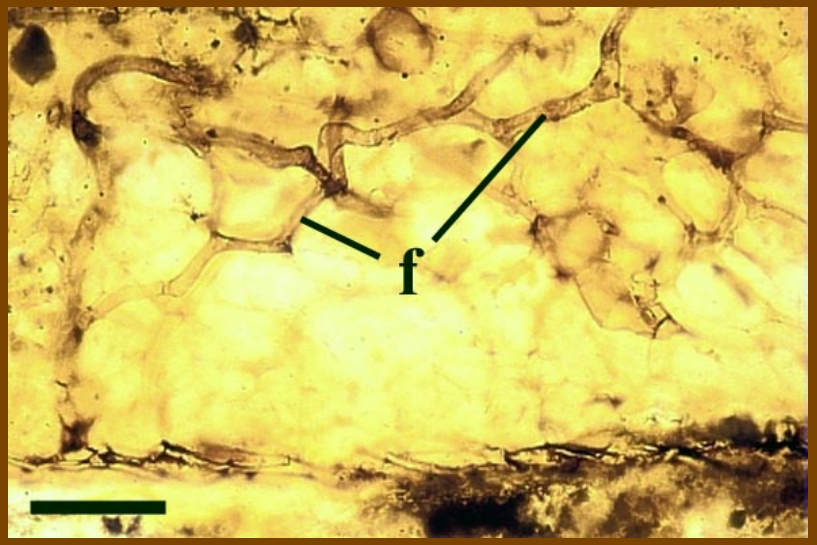


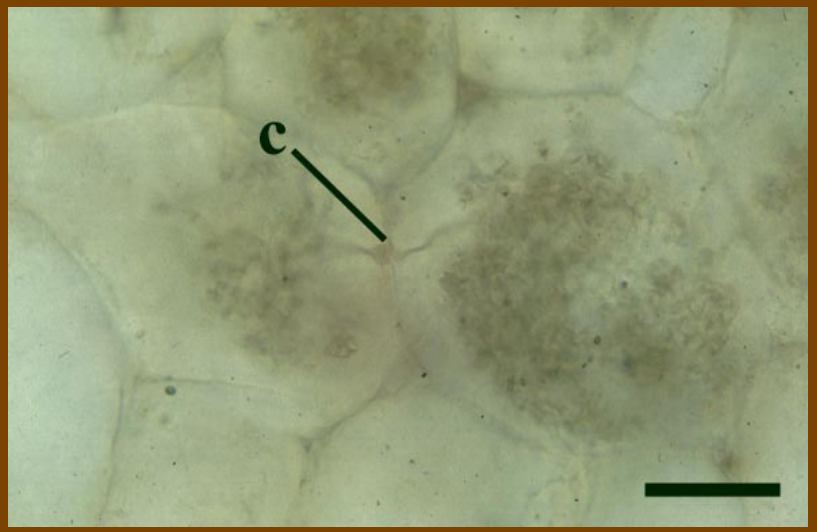
Asteroxylon mackei



Rhynia gwynne-vaughanii

Glomites rhyniensis from Agalophyton

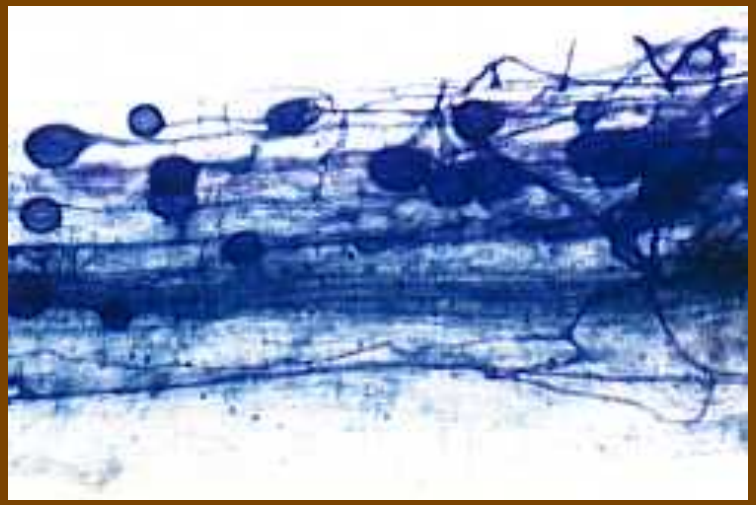




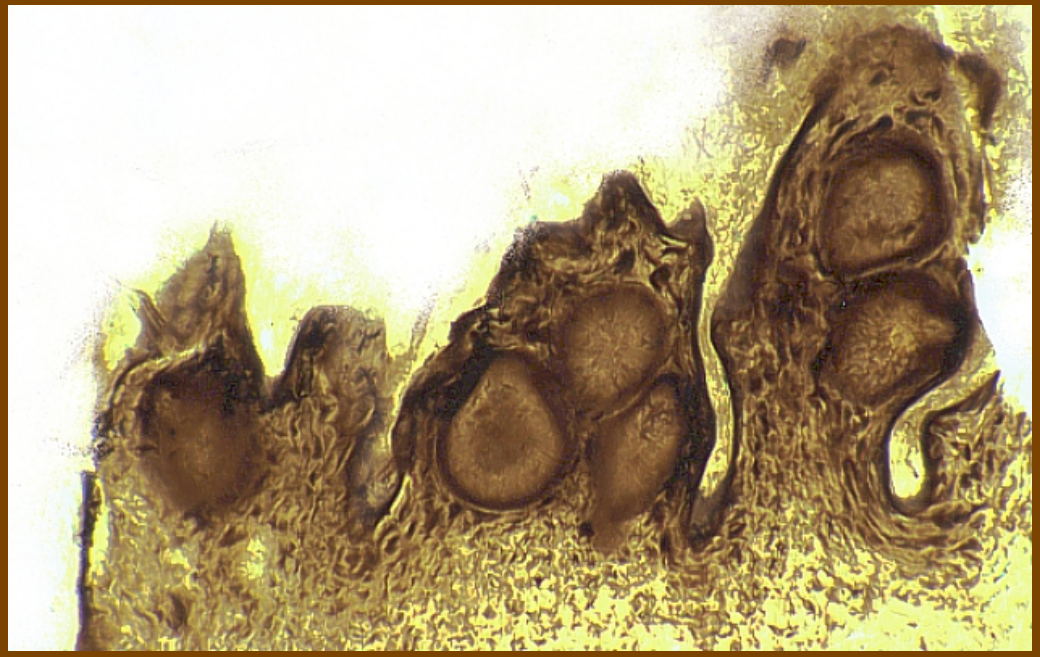
Fungal hyphae (f) and arbuscules penetrating the outer cortex of an *Aglaophyton major* stem (scale bar = 100μm)

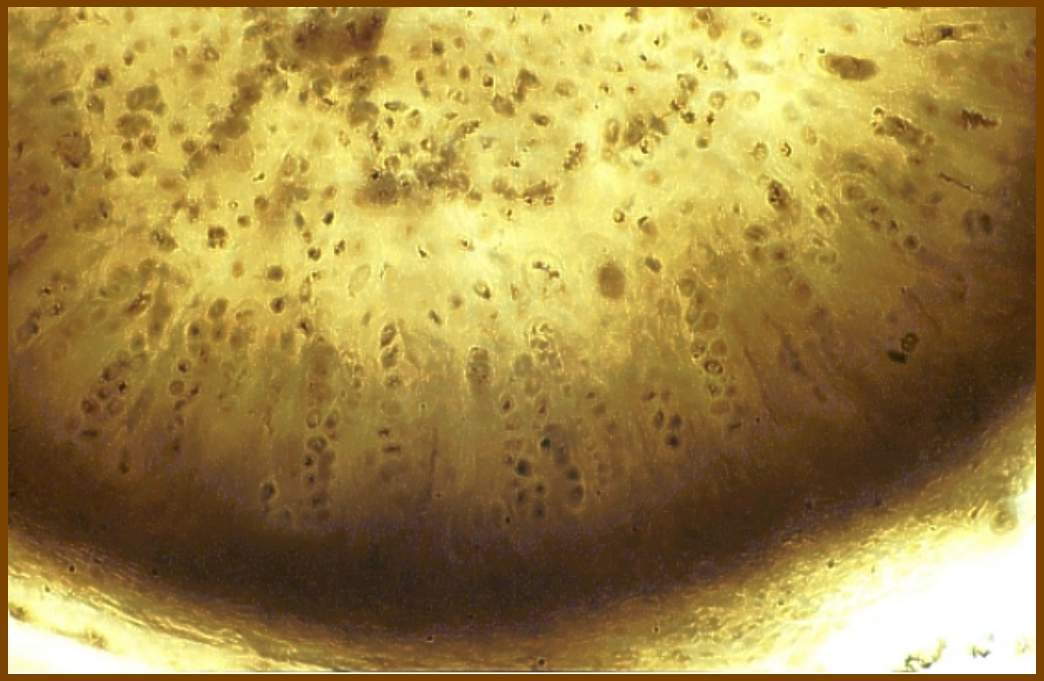
Arbuscules of modern AM (Glomeromycotan) fungi

Glomites, which was symbiotic with *Aglaophyton*, *Rhynia* and *Nothia*. Believed to be related to *Glomus*.



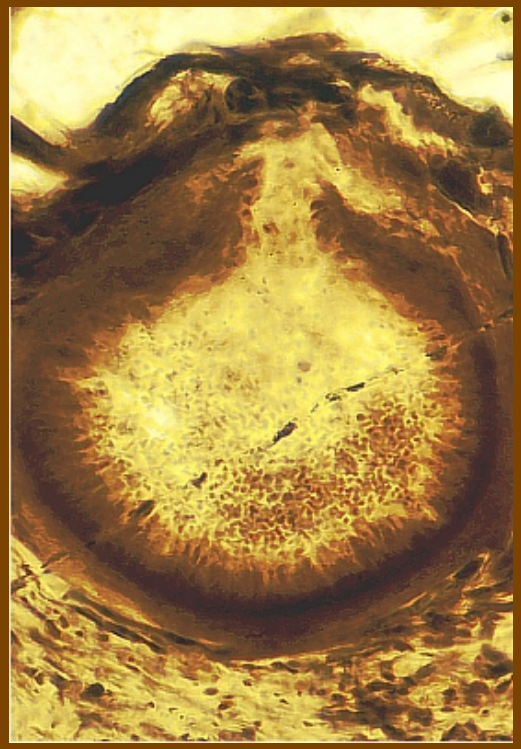
Modern Glomus

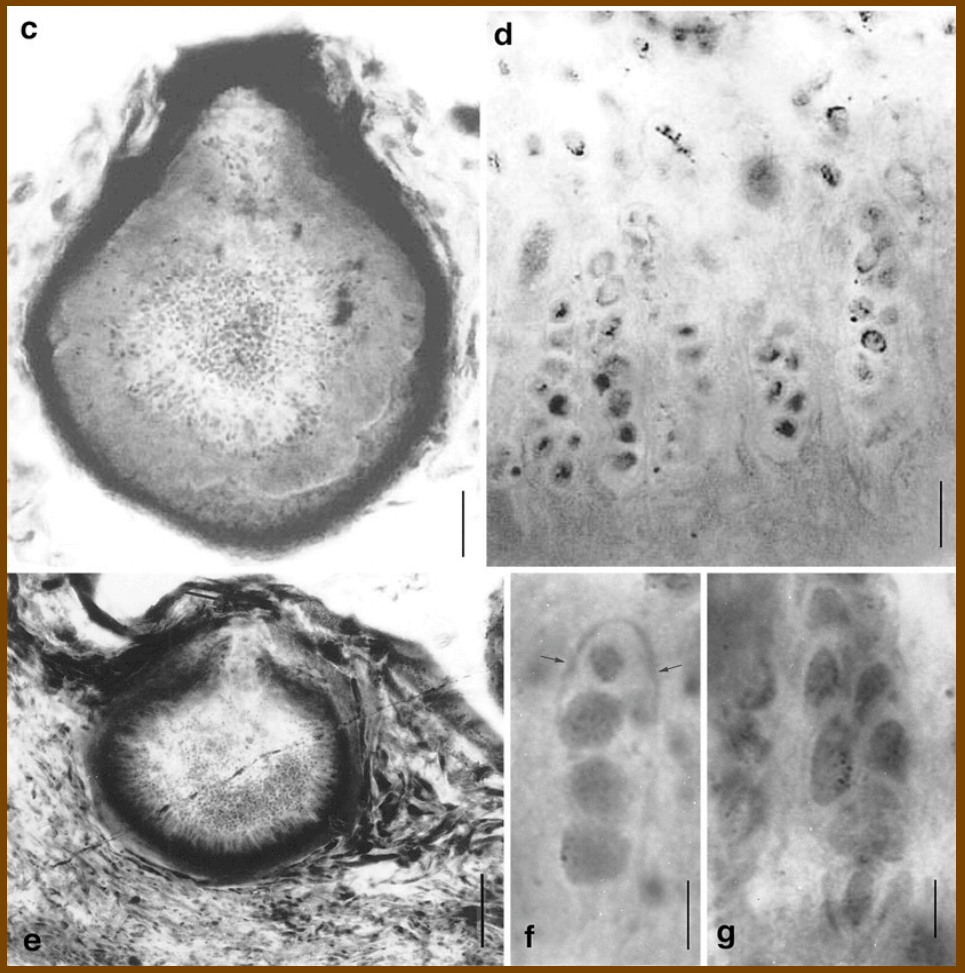




Paleopyrenomycites devonicus
on *Asteroxylon* from 400 MY old Rhynie chert, similar to modern ascomycetes

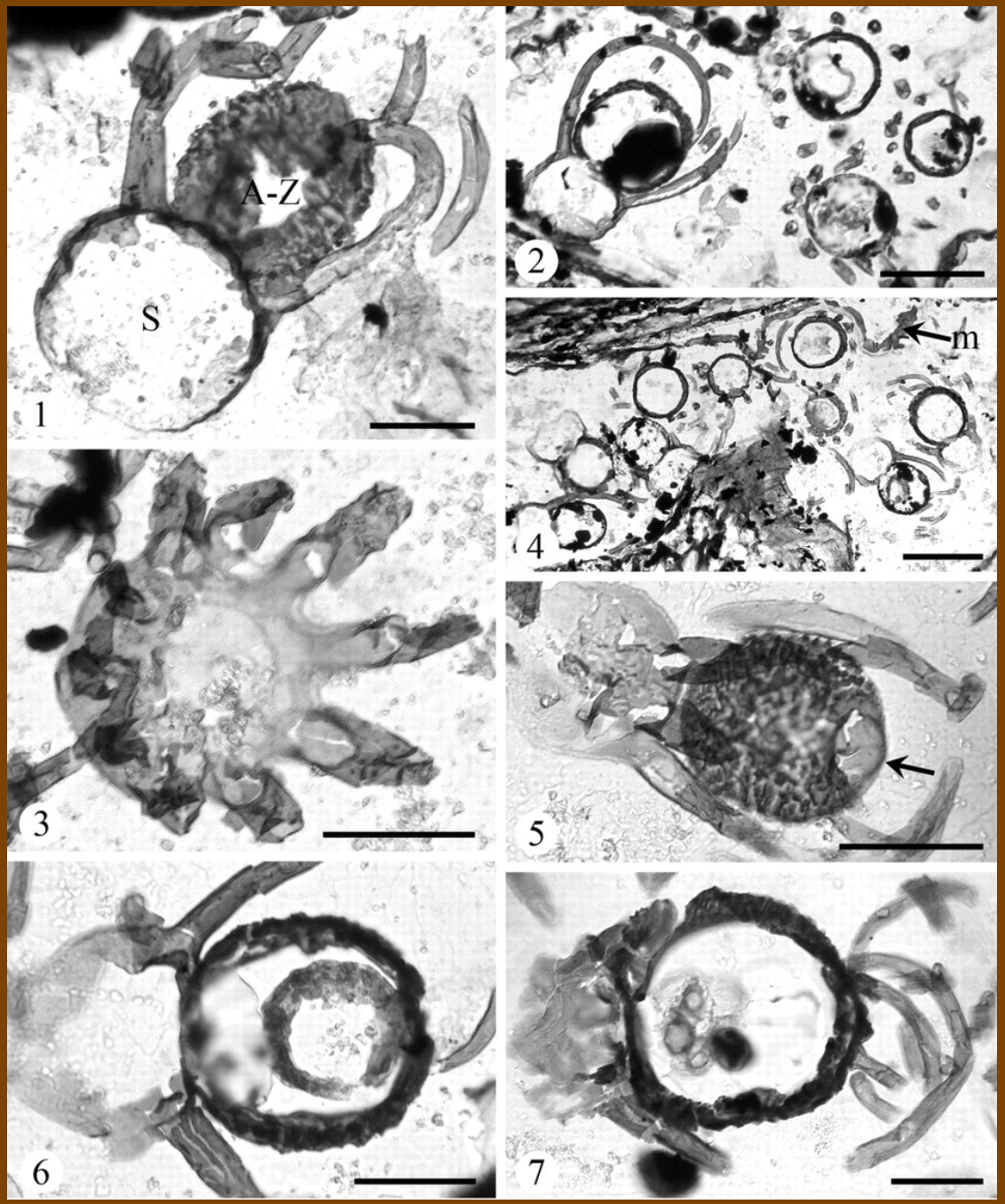
A key fossil for dating age of fungal lineages



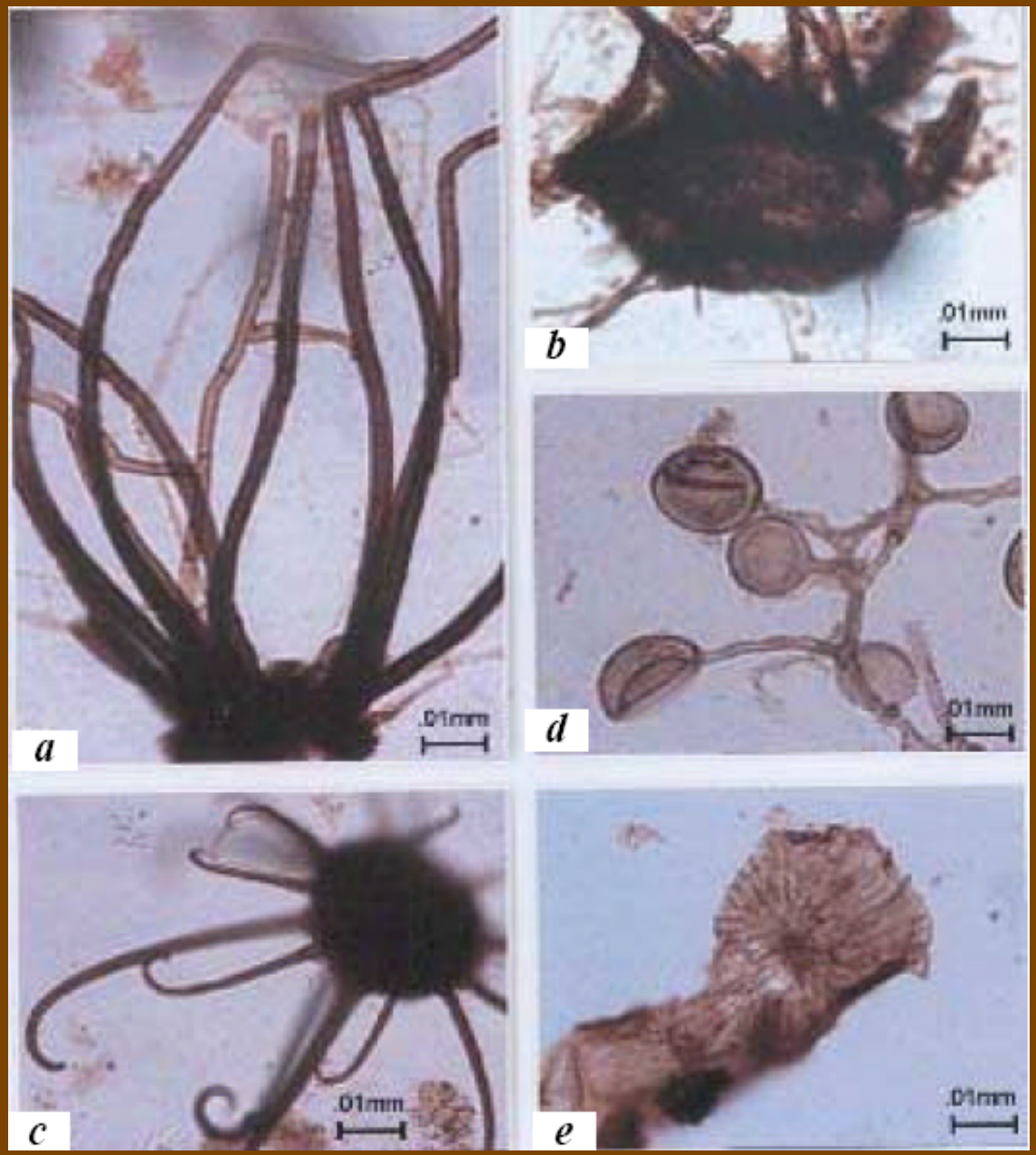


Paleopyrenomycites devonicus

Sordaria fimicola
a contemporary species



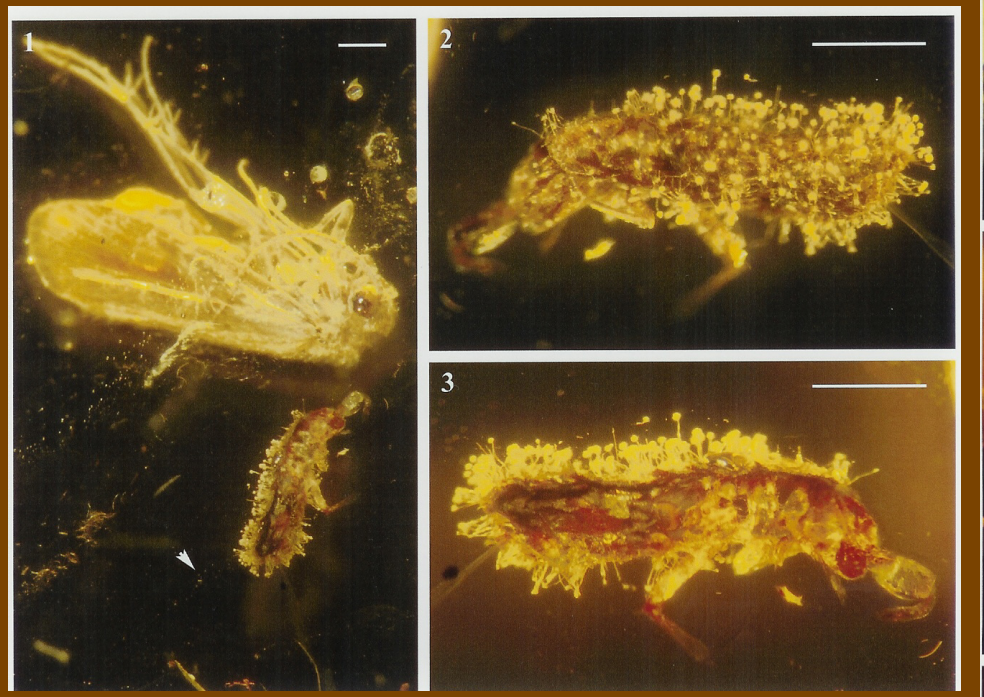
Protoascon missouriensis
a fossil zygomycete
(Mucorales) from the
Carboniferous, 354-290 MYA



Fungi from fossil dinosaur dung resemble contemporary fungi that are parasites on foliage—were ingested with the leaves consumed by herbivorous dinousaurs

70 – 65 MYA

Some more recent fossil fungi



Aspergillus - like fungus on Collembolan
Baltic amber, Tertiary, Eocene, 35-50 MYA

Protomycena from Dominican amber, 15-30 MYA

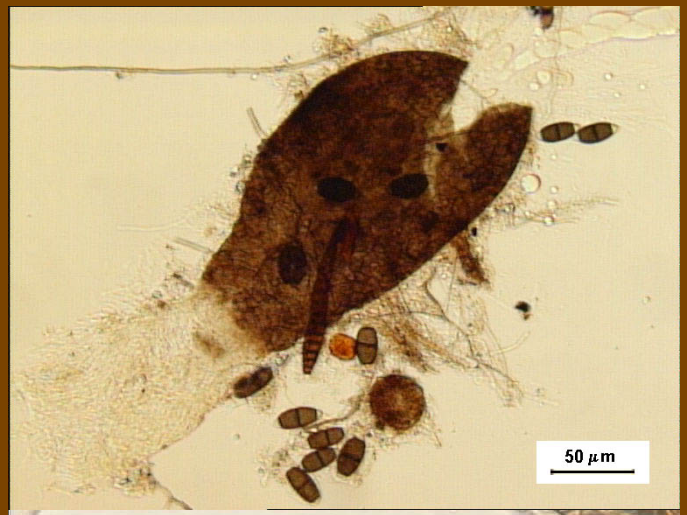
Hibbett et al. 1997 Amer. J. Botany 84: 981-991

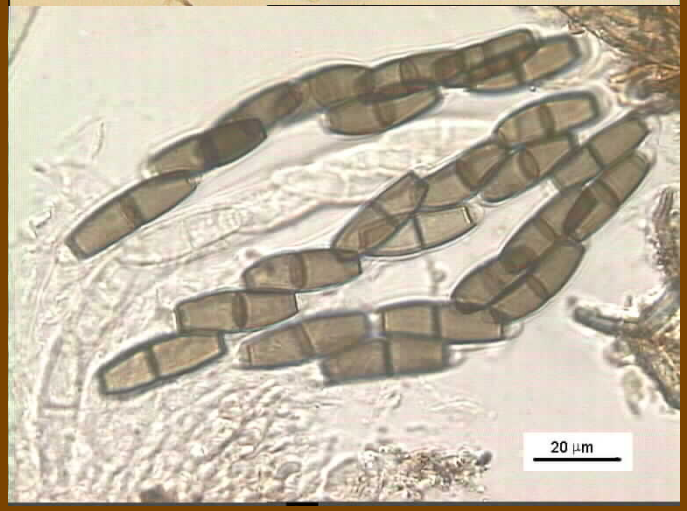
Archaeomycena from mid-Cretaceous, 90-94 MYA, New Jersey

Hibbett et al. 1997 Amer. J. Bot. 84: 981-991

Perithecium from Miocene 24 to 5 MYA preserved in chert (Nevada, USA)

resembles the modern genus *Savoryella*





How many species of fungi are there?

97,330 10th edition Dictionary of the Fungi (2008)

47,000 - 69,000 species listed in Dictionary of Fungi 1983

Saccardo's *Sylloge Fungorum* (Saccardo 1882-1931) had 120,000 names of fungi described by 1931

Other estimates based on cross referencing species lists suggests as many as 300,000 species named, but many have not been critically reassessed since their first description

How many undiscovered fungi?

Would you believe one billion?

Kingdom Fungi, Kingdom Eumycota

6 Phyla:

Ascomycota

15 classes, 68 orders, 327 families, 6355 genera, 64,163 species

Basidiomycota

16 classes, 52 orders, 177 families, 1353 genera, 31,515 species

Chytridiomycota

2 classes, 4 orders, 14 families, 105 genera, 706 species

Blastocladiomycota

1 class, 1 order, 5 families, 14 genera, 179 species

Glomeromycota (formerly Glomales, Zygomycetes)

4 orders, 9 families, 12 genera, 169 species

Zygomycota

4 subphyla, 10 orders, 27 families, 168 genera, 1065 species

Σ [AS] + [BA] + [CH] + [GL] + [BL] + [ZY] = 97,797 species

(Dictionary of the Fungi, 10th Ed, 2008)

Estimates of fungal diversity

The number of fungus species on earth has been estimated indirectly based on ratios of fungi to vascular plants

Hawksworth, D. L. (1991). The fungal dimension of biodiversity: magnitude, significance, and conservation. Mycological Research 95: 641-655

Hawksworth, D.L. (2001) The magnitude of fungal diversity: the 1.5 million species estimate revisited. Mycological Research 105 (12): 1422-1432.

David Hawksworth

For the British Isles:

Flowering plant species = 2,000

Fungus species = 12,000

So ~6 times as many fungi as plants

Worldwide:

Total number of plant species = ~250,000

6 x 250,000 = 1.5 million species of fungi?

$98 \times 10^3 / 1.5 \times 10^6 = 0.065$ or 6.5%

93.5% of fungi remain to be discovered?

Schmit and Mueller (2006) estimated the minimum number of fungi worldwide to be 712,000

To obtain this figure they also used ratios of plants to fungi, but tried to account for regional variation in numbers of plant species, levels of endemism, and derived estimates for several different ecological groups of fungi: macrofungi, lichens, aquatic fungi, plant- and arthropod-associated fungi, and soil fungi.

So where are all these undiscovered fungi?

?

The *Helvella lacunosa* species complex in western North America: cryptic species, misapplied names and parasites

Nhu H. Nguyen[1]

Department of Plant and Microbial Biology, University of California at Berkeley, Berkeley, California 94720

Fidel Landeros

Departamento de Botánica y Zoología, Universidad de Guadalajara, Mexico

Roberto Garibay-Orijel

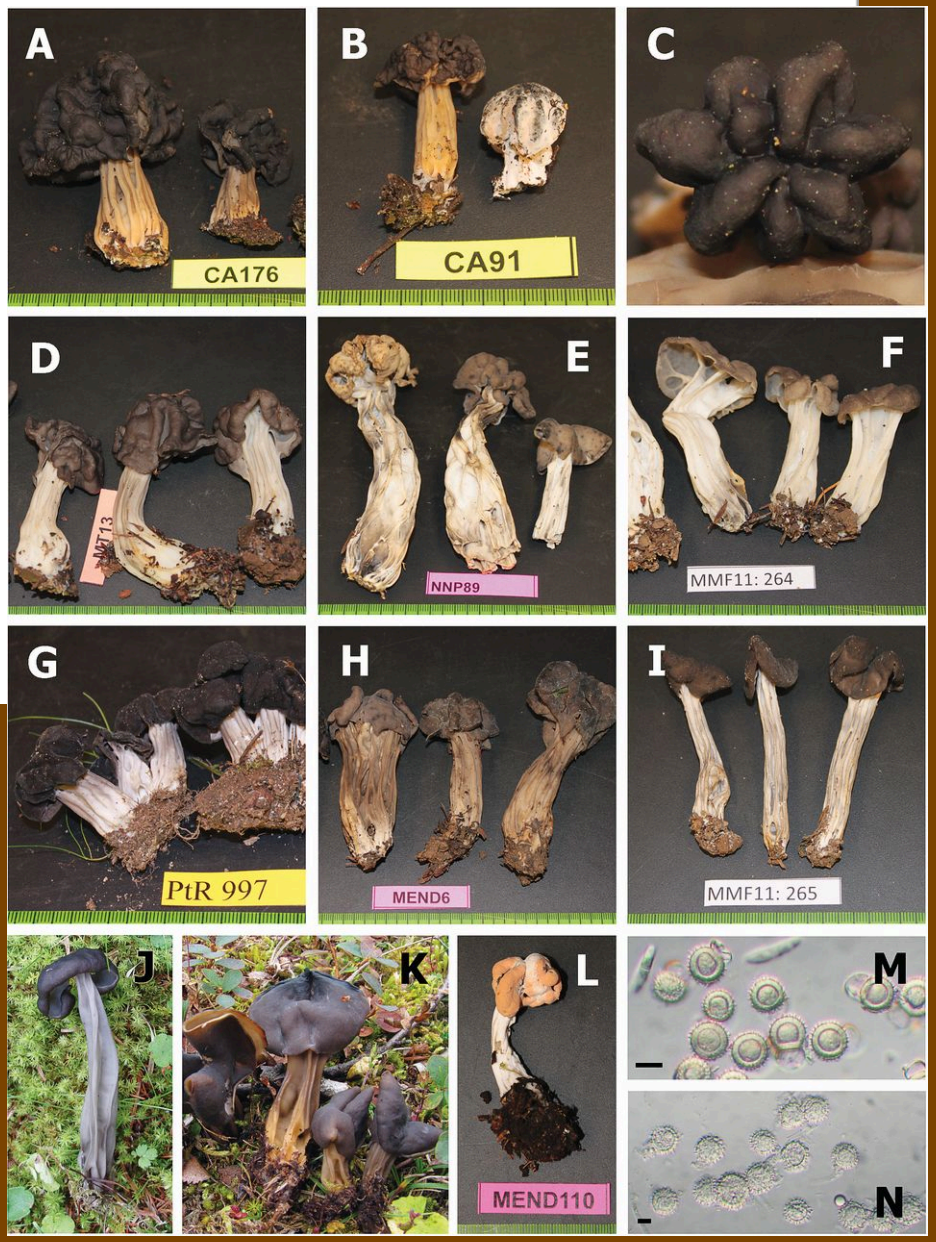
Instituto de Biología, Universidad Nacional Autónoma de México, Mexico

Karen Hansen

Swedish Museum of Natural History, Department of Cryptogamic Botany, P.O. Box 50007, SE-104 05 Stockholm, Sweden

Else C. Vellinga

Department of Plant and Microbial Biology, University of California at Berkeley, Berkeley, California 94720



Comparisons of ITS and LSU rDNA sequences from ectomycorrhizal root tips and ascomata of specimens identified as *Helvella lacunosa* from North America, Europe and Asia revealed that the taxa from western North America and Mexico formed a well supported clade different from the eastern North American, European and Asian taxa. Within this western North American clade there are at least four taxa. Here we describe two of these western taxa as new species: *Helvella vespertina* and *Helvella dryophila*.

Sept 16 2014

AUDIO | New mushroom species discovered in London grocery store

DNA barcoding tests 15 pieces in a package of porcini mushrooms

CBC News Posted: Sep 22, 2014 2:40 PM ET | Last Updated: Sep 23, 2014 8:23 AM ET

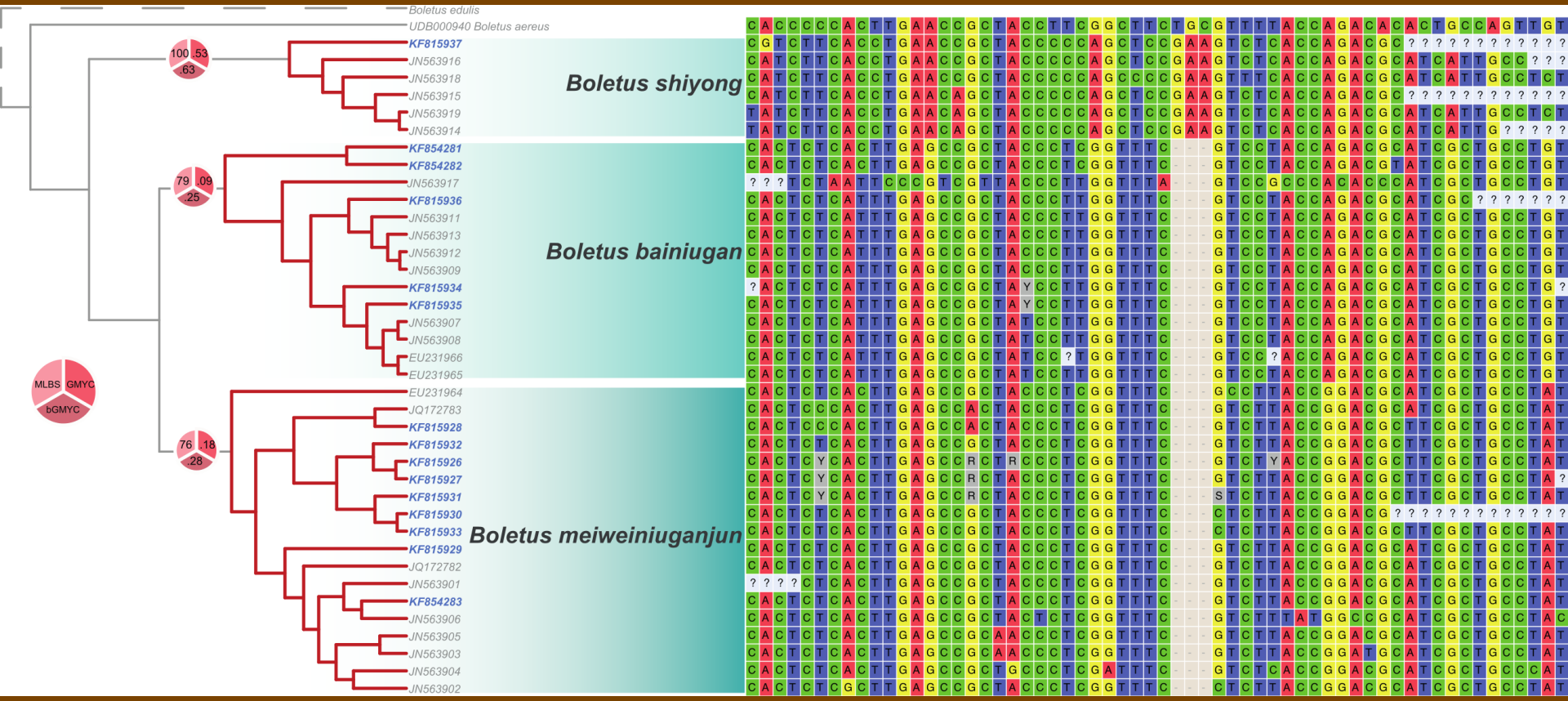
Samples of the new mushroom species are shown in the original packet, purchased at a grocery store in southwest greater London. (Bryn Dentinger/Royal Botanical Gardens, Kew)

What's a good place to look for undiscovered species? Remote

Top News Headlines

- 'We shot it down': Benjamin Netanyahu stands by downing of Syrian fighter jet
- Surrey mayor outraged over 2013 release of suspect in Serena Vermeersch death
- N.B. Liberals win election, as chief electoral officer affirms vote results
- Canada's 1st home? Archeologists make intriguing find off B.C. coast
- Netflix: We will not hand over subscriber data to CRTC

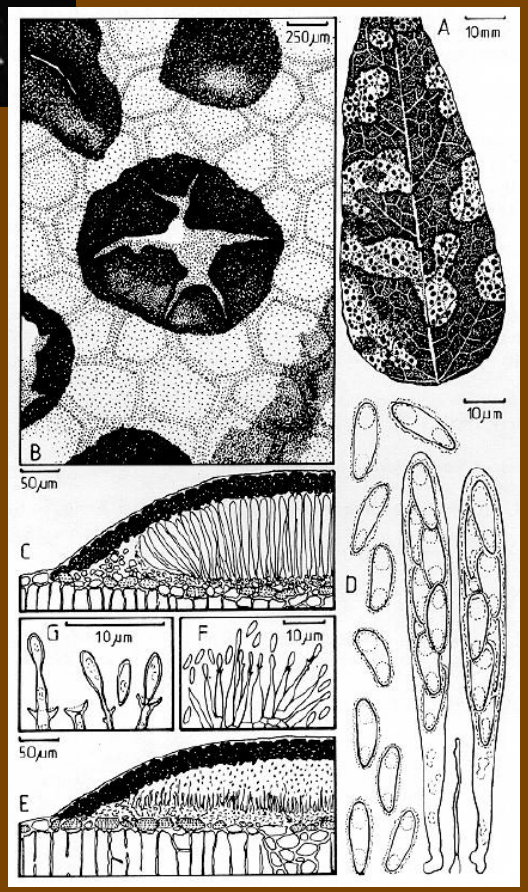
DNA sequence alignment and phylogenetic tree for three novel species of Boletus from a commercial package of dried mushrooms



Yes, there is a fungus named for Homer Simpson

Also Count Dracula...

Vladracula annuliformis



Valsonectria simpsonii, "for H. J. Simpson, in honour of his contributions to the safety of nuclear power."