

Fig. 1.1. Bryophytes sensu lato have a life cycle dominated by the gametophyte; all other extant plants have a life cycle dominated by the sporophyte. Plants with isomorphic phase are not known among living plants but may have occurred 420 mya!

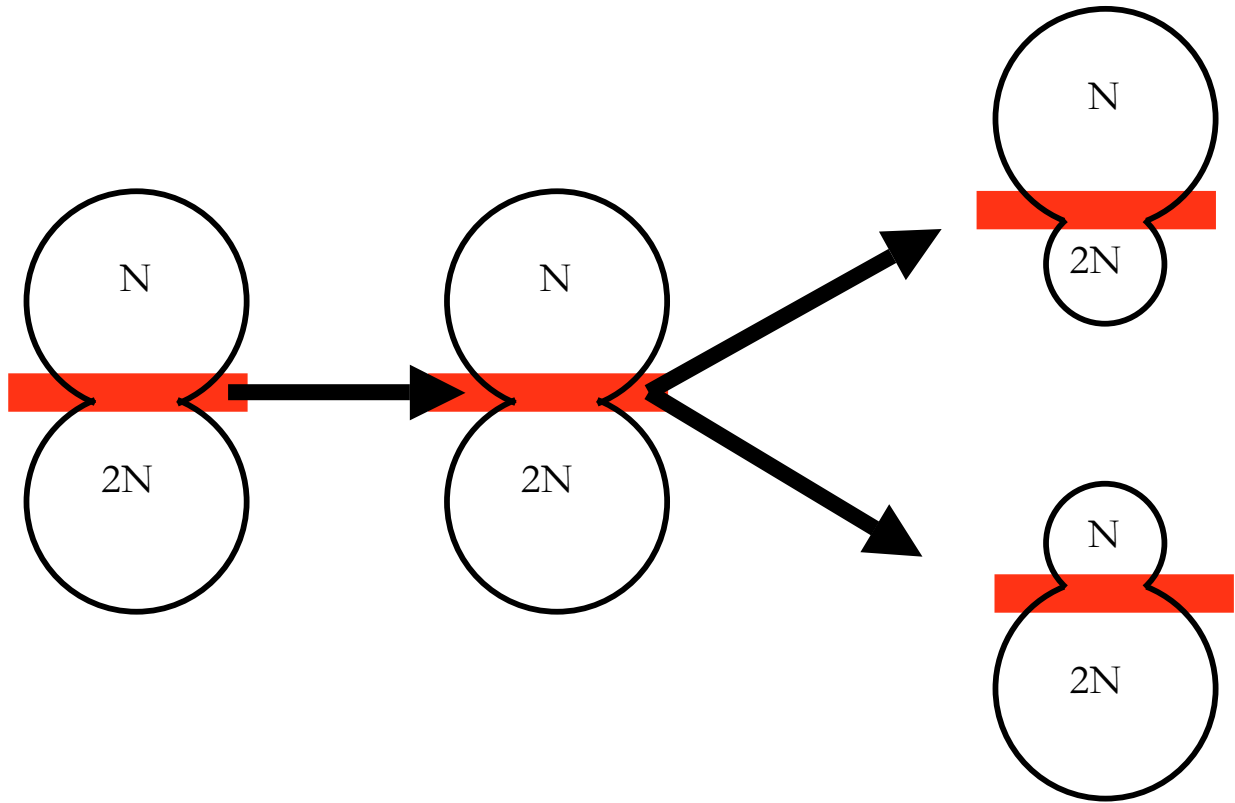
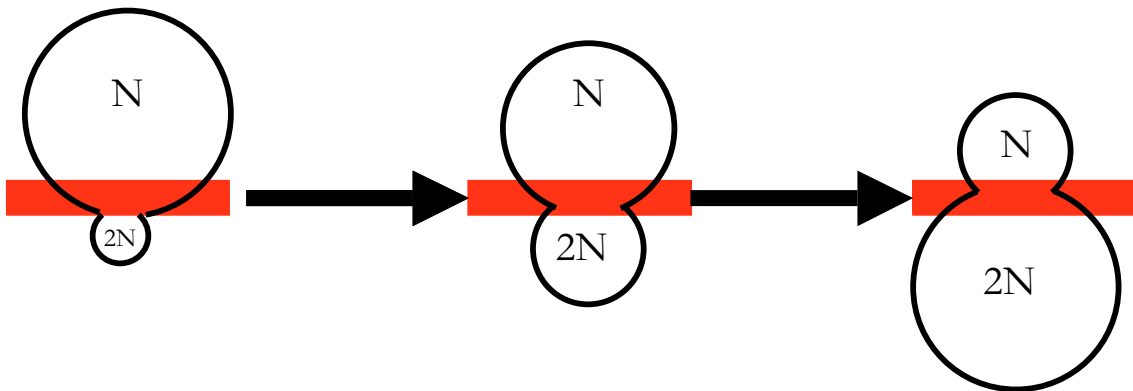


Fig. 1.2. Under the hypothesis of homologous generations (Pringsheim 1878) the two alternative dominances diverged



Hypothesis of antithetic generations (by Celakosky and Bower): Algal ancestor has \pm heteromorphic generations (zygote was unicellular), first land plants (and bryophytes) had heteromorphic generations, with simple multicellular sporophyte, and ultimately land plants adopted a life cycle with a dominant sporophyte.

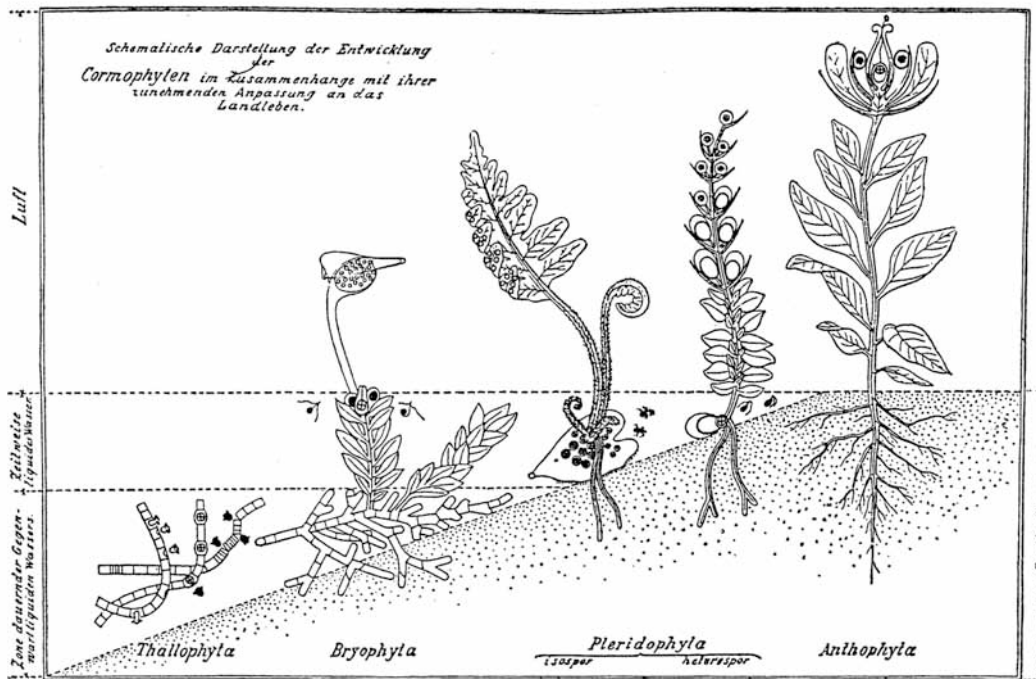


Fig. 1.3. Transition to land and evolutionary trends in land plants; the two dotted lines mark zones of constant (below) and temporary (upper) aquatic conditions. Based on Zimmerman

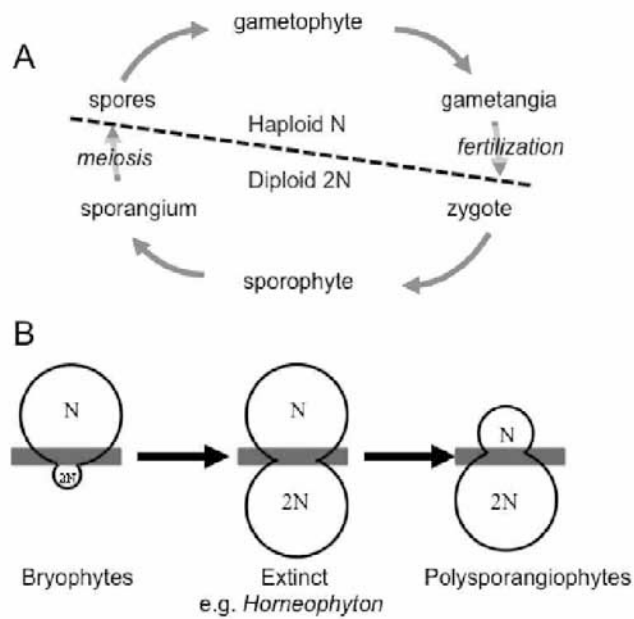


Fig. 1.4. Schematic representation of the evolution of life cycle in land plants (Vanderpoorten and Goffinet 2009)

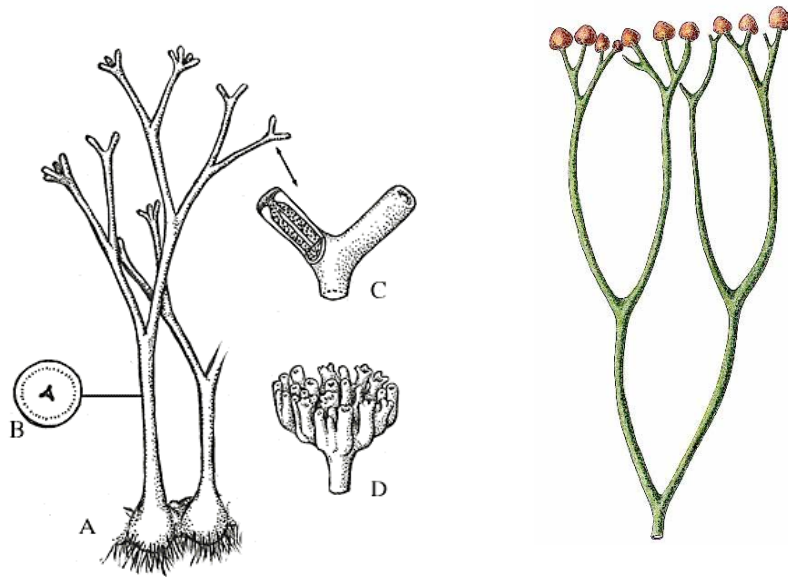


Fig. 1.5: Two Devonian and thus now extinct plants that may compose the intermediates between the bryophytes and the ancestors to the modern polysporangiophytes, which are all vascularized. Left: *Horneophyton lignieri*. (A) Whole plant reconstruction; (B) schematic protostele; (C) sporangia. (D) *Langiophyton mackiei*, the suggested gametophyte of *Horneophyton*. Note the dichotomously branching axes (sporophyte). (<http://www.ucmp.berkeley.edu/IB181/VPL/Elp/Elp2.html>). Right: *Cooksonia caledonica*. Sporophyte is dominant, and in fact the gametophyte is thought to be a thalloid plant. (<http://www.palaeos.com/Plants/Rhyniophytes/Cooksonia.html>)



Fig. 1.6. Life history of *Aglaophyton major* / *Lyonophyton rhytiensis* showing stages in the development of the **dimorphic gametophytes**. Taylor et al., 2005 T.N. Taylor, H. Kerp and H. Hass, Life history biology of early land plants: deciphering the gametophyte phase, Proc. Natl. Acad. Sci. U. S. A. 102 (2005), pp. 5892–5897.

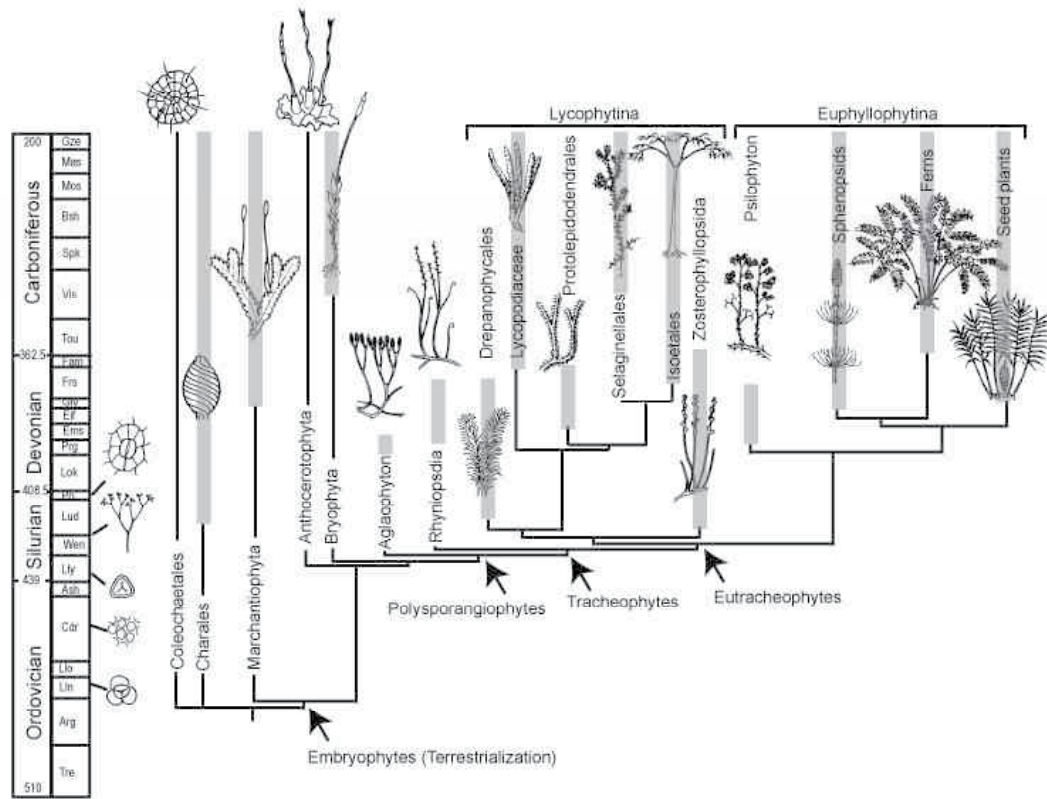


Fig. 1.7 Phylogenetic relationships among major lineages of extinct and extant land plants based on inferences from morphological characters. Grey bars indicate minimum origin of lineage based on megafossil record. Also illustrated along the time scale are minimum age estimates for the appearance of certain important land plant features (from the bottom: spore tetrads, cuticle, trilete marks on spores, megafossils and stomata). Redrawn from Kenrick and Crane (Nature 1997, 389: 33-39) and adapted based on VanAller Hernick et al. Review of Palaeobotany & Palynology 148:154-162.

Question: Can you explain why the branches of the tree point further down that the grey bars? What does it mean?

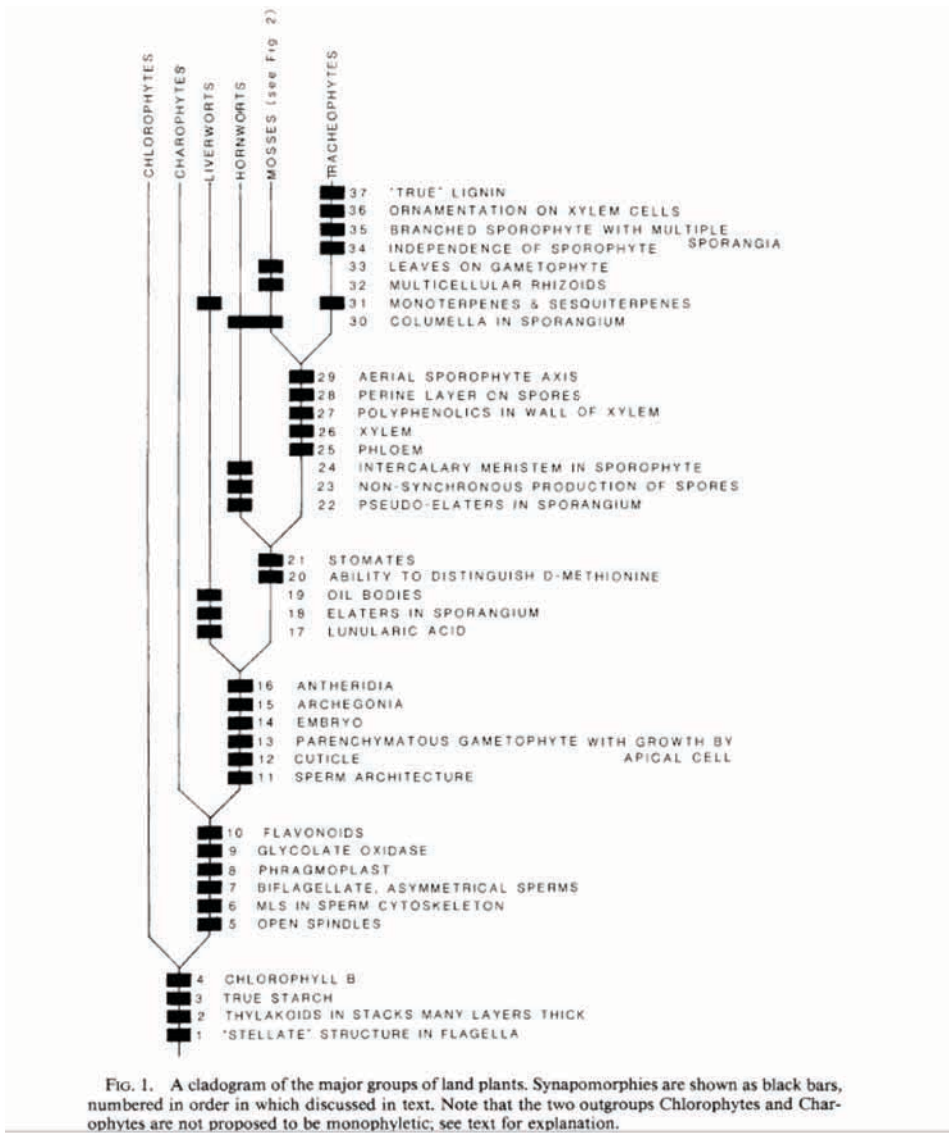
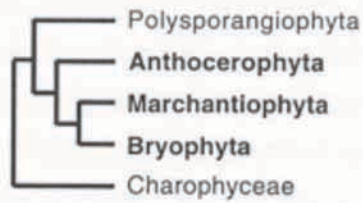
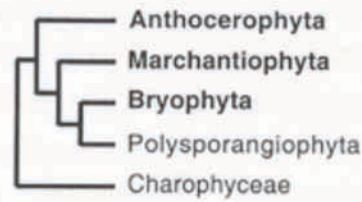


Fig. 1. 8. A phylogenetic hypothesis for major lineages of extant land plants based on morphological/chemical but not molecular characters. Characters diagnosing lineages and shared ancestry are shown and defined.



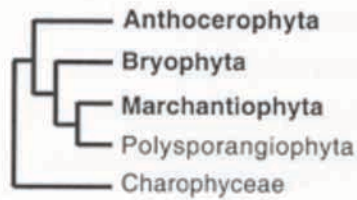
A. Hori *et al.* (1985; 5S)
 Garbary *et al.* (1993; sperm ultrastructure)
 Maden *et al.* (1997; sperm ultrastructure)
 Renzaglia *et al.* (2000; sperm ultrastructure)



B. Mishler *et al.* (1994;
 morphology + 18S)



C. Lewis *et al.* (1997; *rbcL*)



D. Garbary & Renzaglia (1998;
 sporophyte only)
 Mishler *et al.* (1994; 18S)
 Malek *et al.* (1996; *cox3*)



E. Mishler & Churchill (1984; morphology),
 Bremer (1985; morphology)
 Mishler *et al.* (1994;
 morphology 26S & 18S)
 Kenrick & Crane (1997b; morphology)



F. Hedderson *et al.* (1996 & 1998; 18S)
 Crowe *et al.* (1997; *psbA*)
 Garbary & Renzaglia (1998; morphology)
 Nishiyama & Kato (1999; 18S+*rbcL*
psaA, *psaB*, *psbD*, *rpoC2*)
 Duff & Nickrent (1999; 19S)
 Renzaglia *et al.* (2000; morphology and
 ontogeny)

Fig. 1. 8. Phylogenetic hypotheses for land plants derived from various sources of data (Goffinet 2000; Bryophyte Biology, 1st edition).

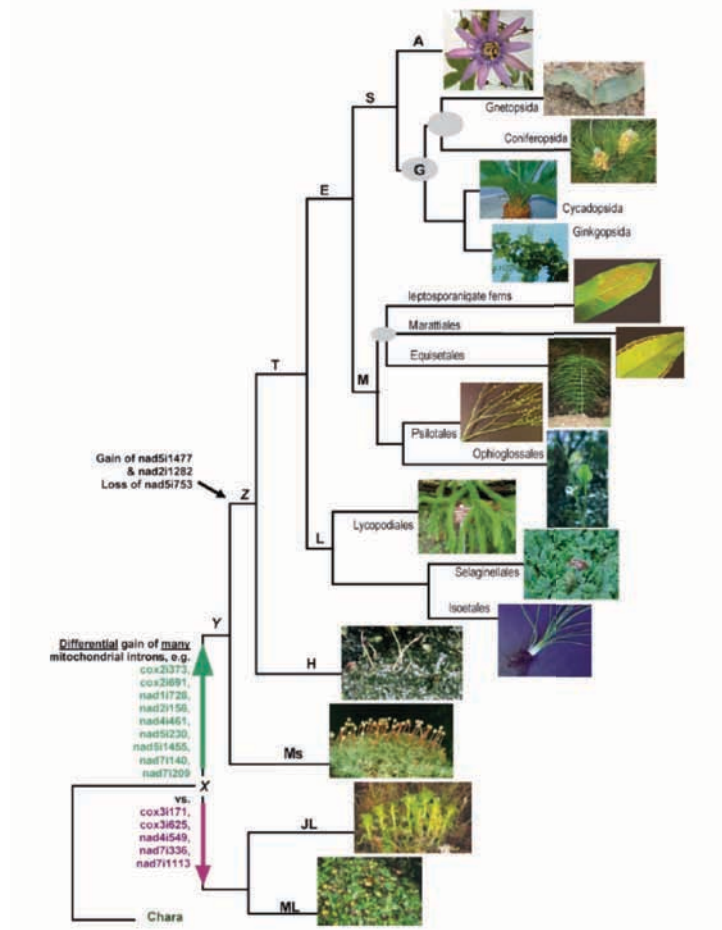


Fig. 1.9. Phylogeny of land plants inferred from mitochondrial markers (Knoop Current genetics 2004).

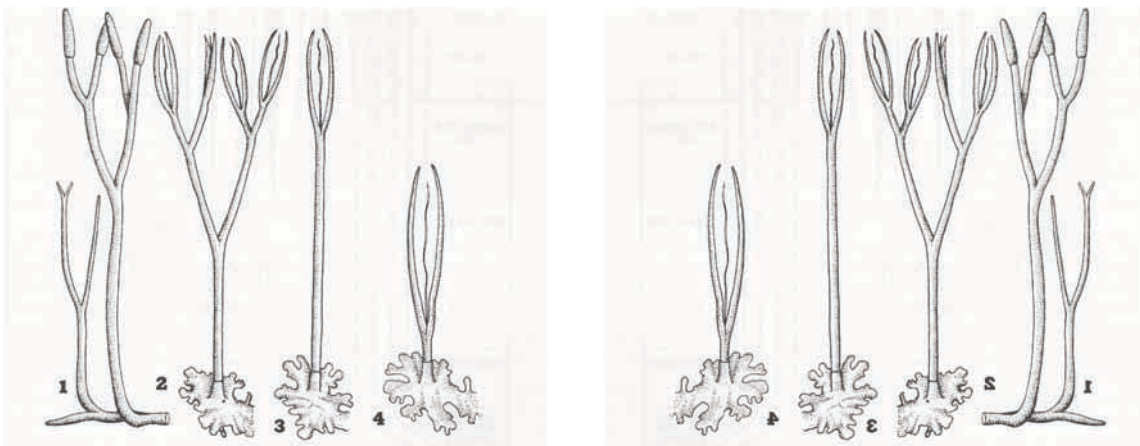


Fig. 1.10. Alternative interpretation of the origin of bryophytes (mirror images of the fig. by Schuster 1966). Can we reject the hypothesis of bryophytes (or here hornworts) being reduced polysporangiate plants?

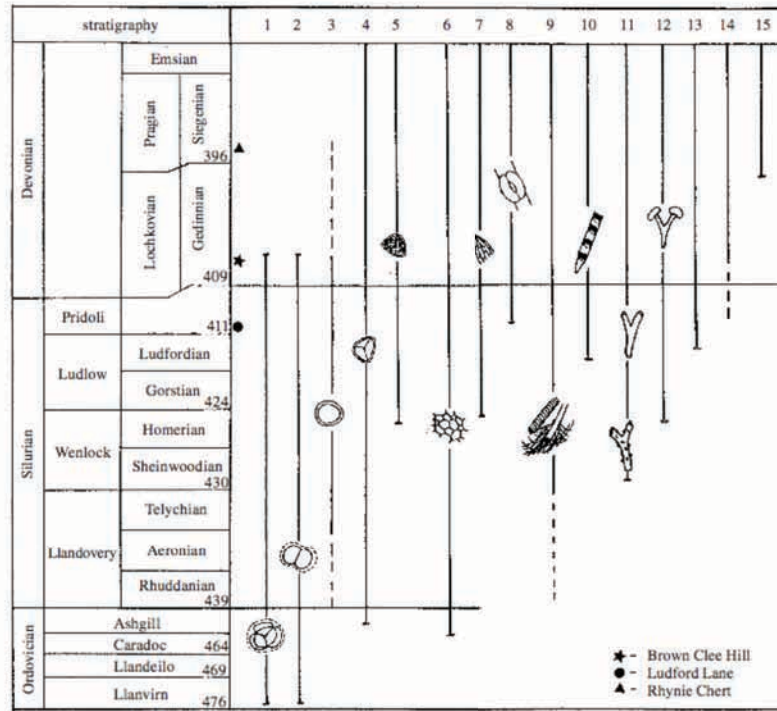


Figure 1. Stratigraphic ranges of fossils mentioned in text. 1, permanent (obligate) tetrads \pm envelope; 2, permanent dyads \pm envelope; 3, hilate monads; 4, trilete laevigate monads; 5, ornamented trilete monads; 6, cuticular sheets (cf. *Nematothallus*); 7, sporangial cuticles; 8, stomata; 9, associations of tubes, solid line only indicates presence of banded tubes; 10, tracheids; 11, bifurcating axes of ?tracheophyte type; 12, *Cooksonia*/Rhyniopsida; 13, Lycophytina sensu lato; 14, zosterophylls; 15, Trimerophytina.

Fig. 1.11. What microfossils tell about the timing of the origin of land plants and major lineages thereof. (Edwards Phil Trans. R. Soc. London 2000; 355: 733-755.

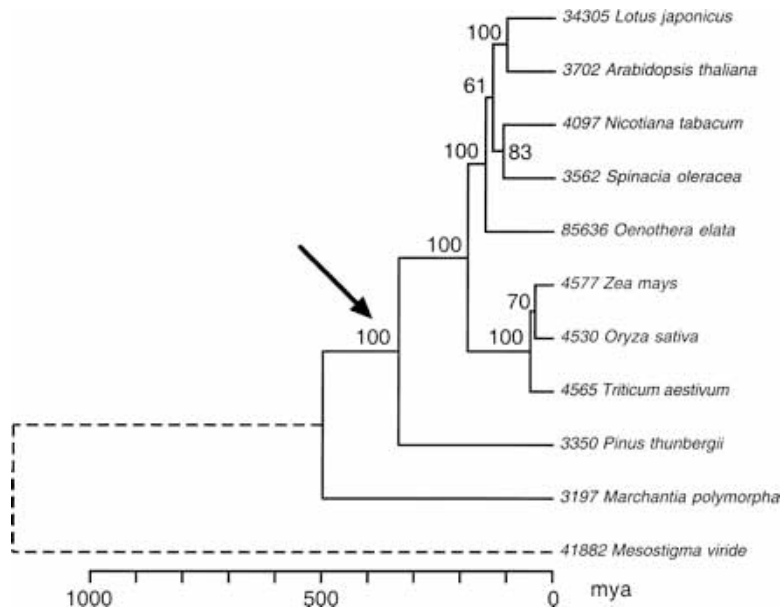


Fig. 1.12. Inferring the timing of cladogenetic events using molecular data. Here inferences from chloroplast DNA sequences. Sanderson 2003. *Ame. J. Bot.* 90: 954-956.

Table 1. Divergence time estimates.

Comparison	Number of proteins		Total amino acids ^c		Divergence time estimates (Ma)				
					Multigene		Average distance		Mean [†] (±SE)
					All	Constant	All	Constant	
Neocallimastix (chytrids) vs. other groups	5	2	1,976	497	1,497	1,457	1,513	1,459	1,458 ± 70
Mucorales/Blastocladales vs. Basidiomycota/Ascomycota	27	17	8,821	5,492	1,215	1,128	1,184	1,085	1,107 ± 56
Basidiomycota vs. Ascomycota	52	37	19,800	11,987	1,269 [‡]	1,244 [‡]	1,206	1,172	1,208 ± 108
Ustilaginomycetes vs. Hymenomycetes	8	4	2,948	1,301	951	982	950	950	966 ± 86
Archiascomycetes vs. other Ascomycota	88	70	37,500	27,261	1,166 [‡]	1,139 [‡]	1,151	1,149	1,144 ± 77
Hemiascomycetes vs. filamentous Ascomycota	68	48	26,921	17,412	1,058 [‡]	1,050 [‡]	1,112	1,120	1,085 ± 81
<i>Candida albicans</i> vs. <i>Saccharomyces cerevisiae</i>	35	26	15,258	10,763	815	837	823	844	841 ± 62
Plectomycetes vs. Pyrenomycetes	40	28	18,174	12,221	667	642	654	698	670 ± 71
Chlorophyтан green algae vs. higher plants	48	41	13,996	11,541	1,099 [‡]	1,111 [‡]	1,010	1,010	1,061 ± 109
Mosses vs. vascular plants	54	50	5,526	5,131	708 [‡]	715 [‡]	680	690	703 ± 45

^c Aligned, with gaps, missing data, and ambiguities removed.
[†] Mean (multigene, constant rate; average distance, constant rate) ± SE (multigene, constant rate).
[‡] Mode used here.

Fig. 1.13. Divergence time estimates for major lineages leading to plants. Inferences from nuclear data. Heckman et al. 2001. *Science* 293: 1129-1132

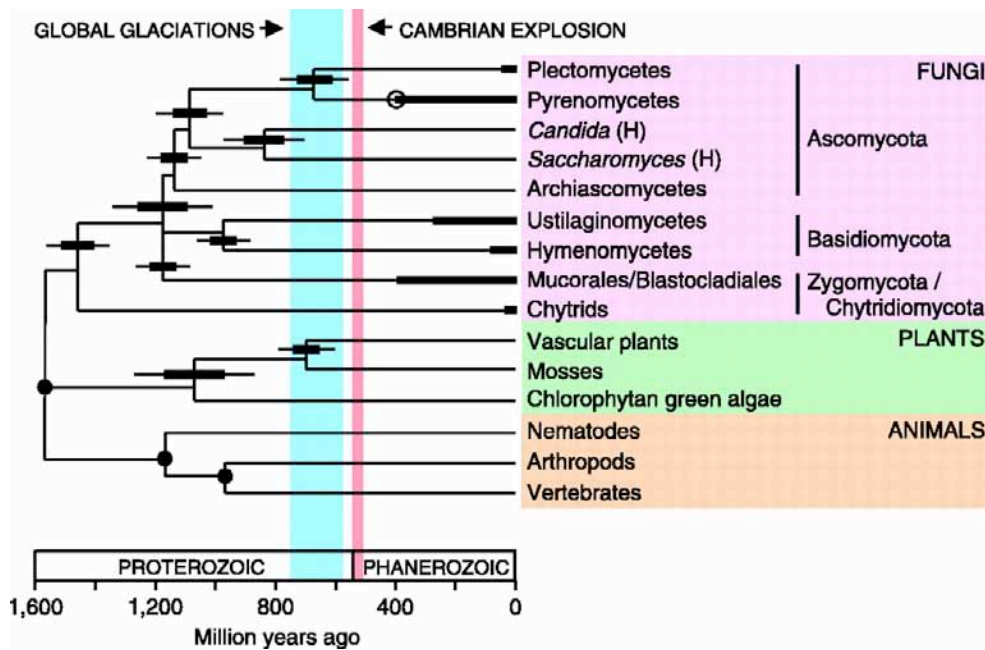


Fig. 1.14. Phylogenetic view of these estimates. Same source. **Compare this tree with fig. 11 and 12.**

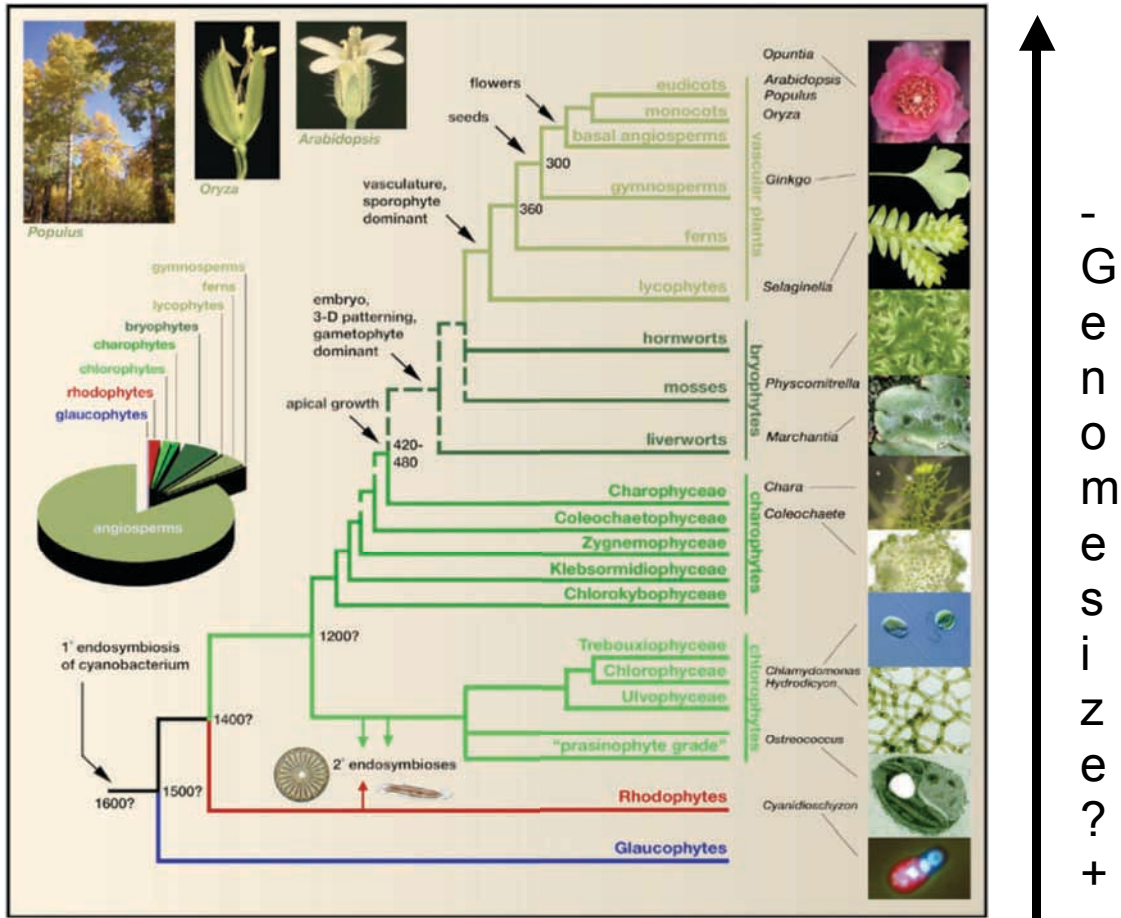


Fig. 1.15. Phylogenetic relationships among plants and their algal ancestors. One could superimpose onto this phylogeny a gradient of increasing complexity. Where is the complexity coming from? More genes and hence larger genomes? Bowman et al. 2007; Cell 129: 234.

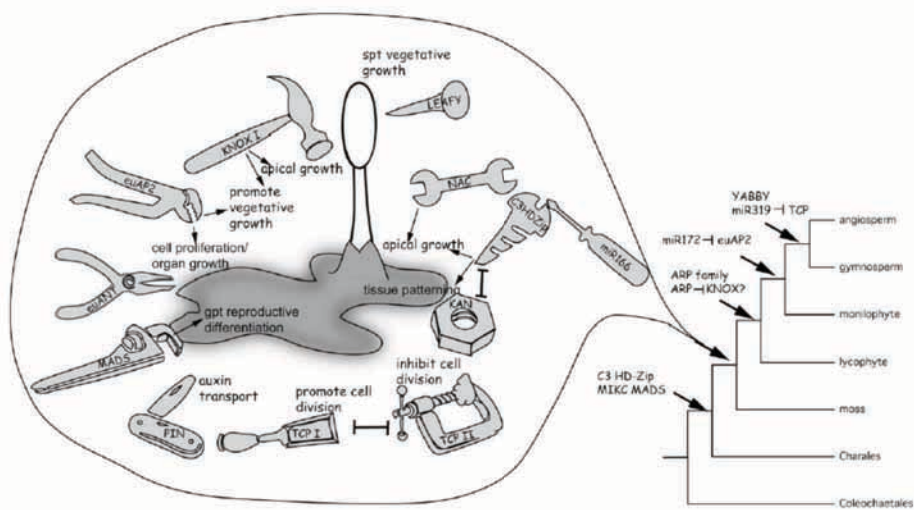


Fig. 12 Ancestral tool kit of land plants. A hypothetical ancestral land plant is depicted with haploid gametophyte and dependent diploid sporophyte. Most of the gene families discussed in the article are depicted as tools and associated with possible developmental roles. These genes are known to date back to the common ancestor of mosses and tracheophytes as mapped on the basic land plant phylogeny. We also map the earlier origin of the Class III HD-Zip gene and the later origins of ARP and YABBY genes as well as regulation by miRNA172 and miRNA319.

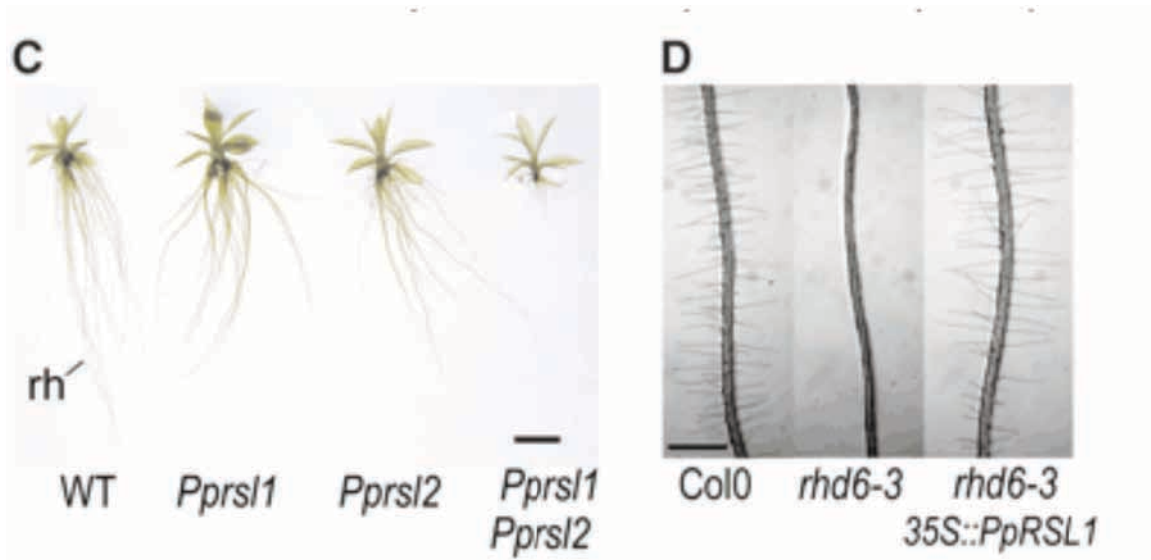


Fig. 1. 17. One example of evolution in gene function. The gene responsible for rhizoid development in bryophytes (here mosses) triggers or restores root-hair development in a vascular plant. (Identifying the genes involved in rhizoid development in *Physcomitrella* and transferring them to a mutant of *Arabidopsis* for which the root hair development genes are turned off, resulted in root hairs being developed!

The genes in *Physcomitrella* and *Arabidopsis* are homologues!

Are rhizoids and roots homologous?