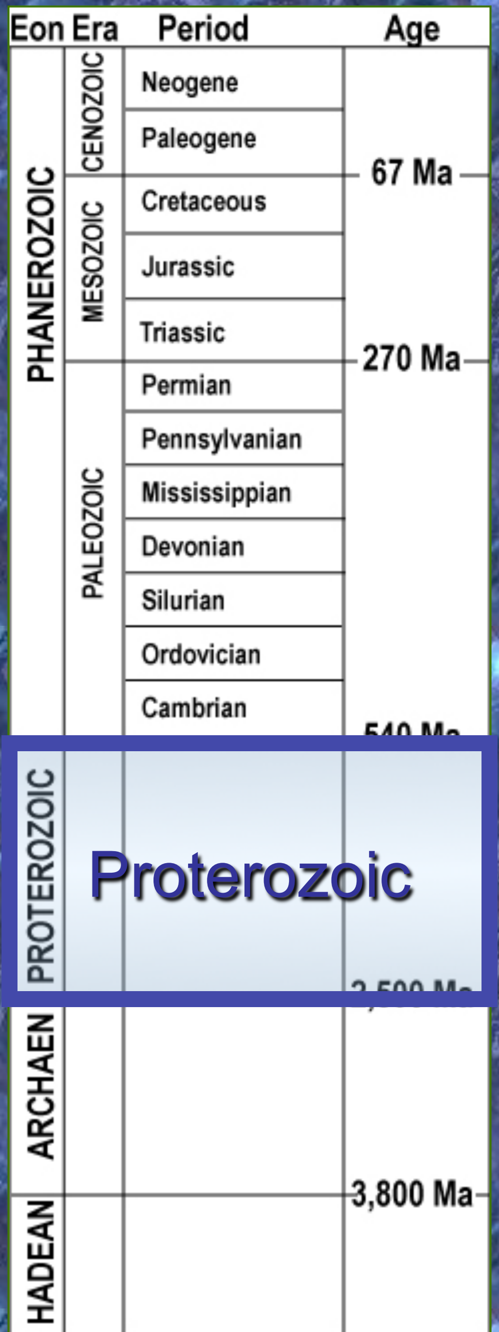


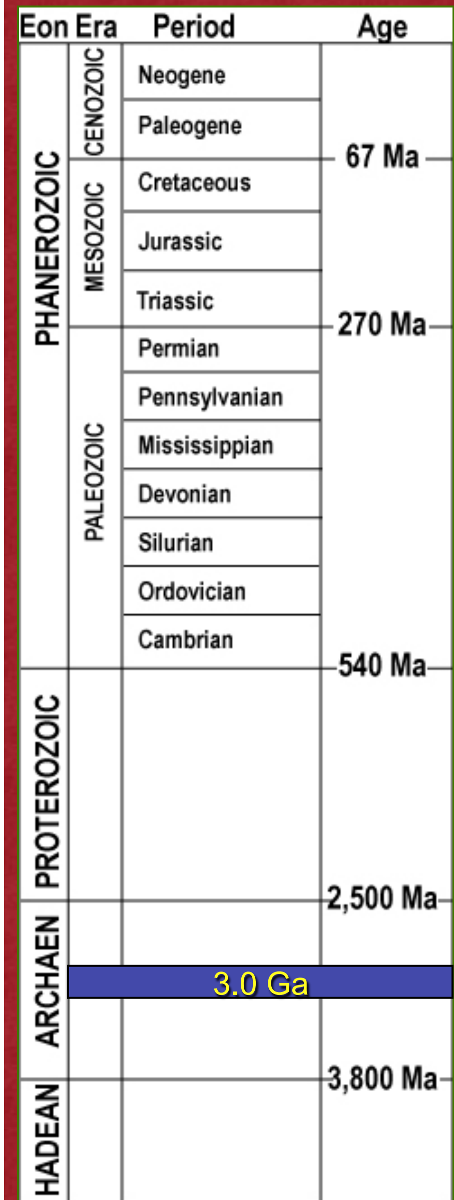
The Proterozoic

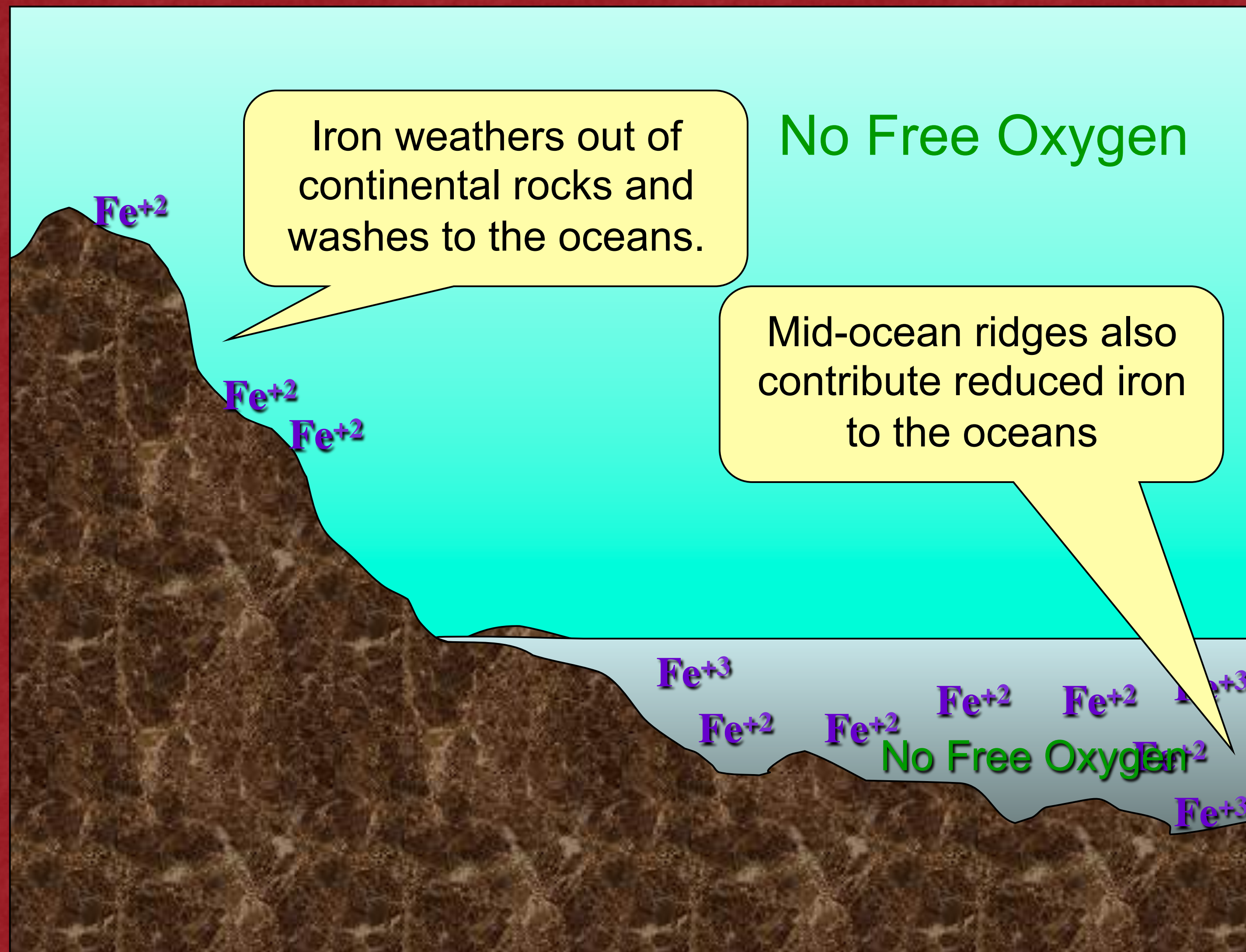
~2,500,000,000 – 540,000,000 years ago

(2.5 – 0.54 Ga)

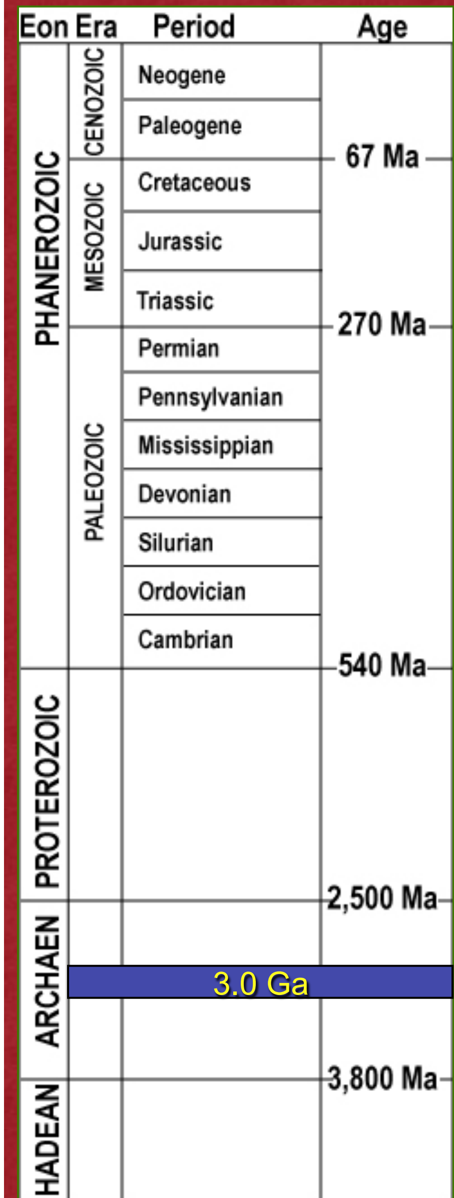
- Free oxygen builds up in shallow oceans, then atmosphere
- Massive banded iron deposited (2.5-1.8 Ga)
- First good body fossils of complex, multicellular animals (Vendian, 650-540 Ma)
- Probable ancestors of some animal phyla identified

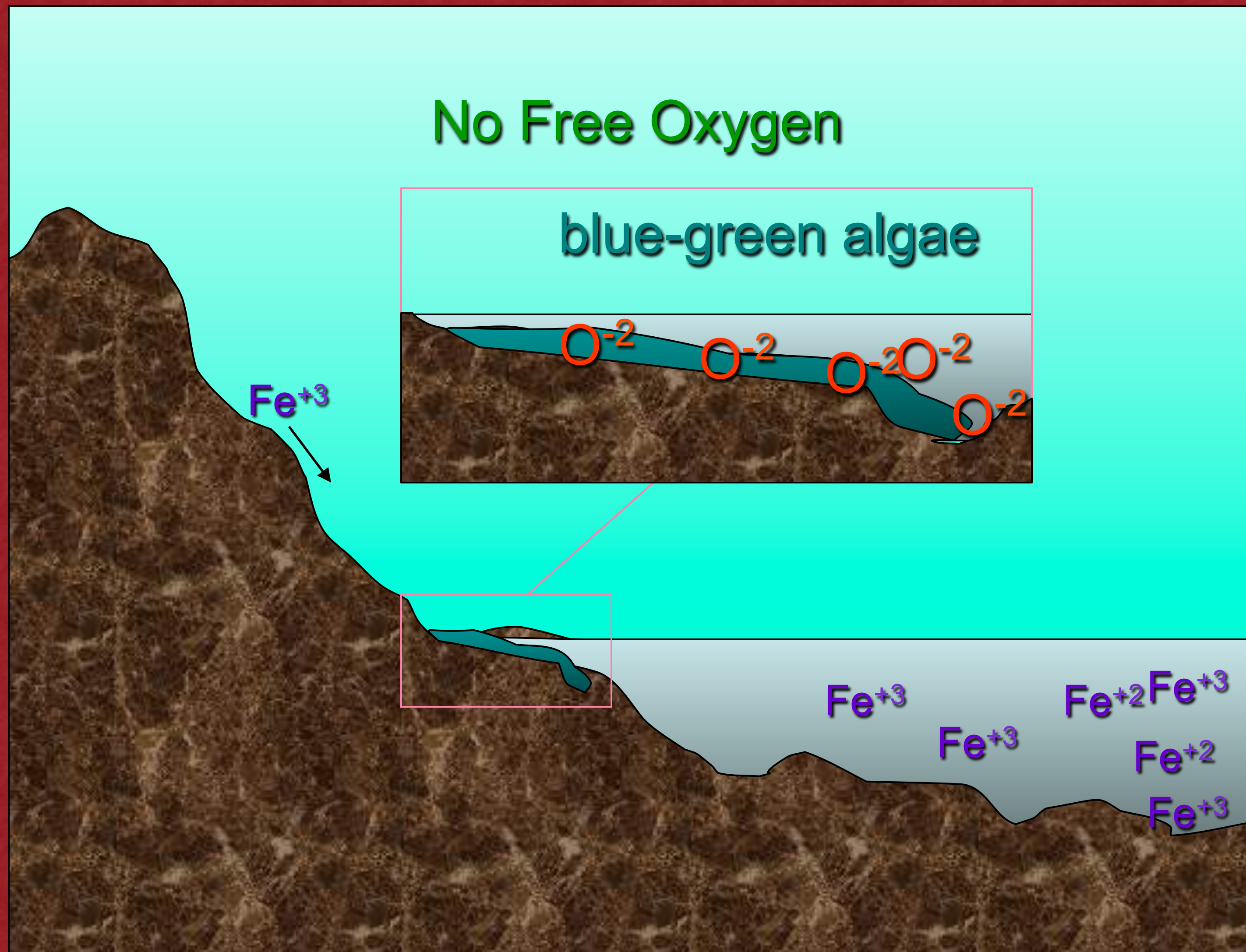
3,000,000,000 Years Ago
(three billion years ago)

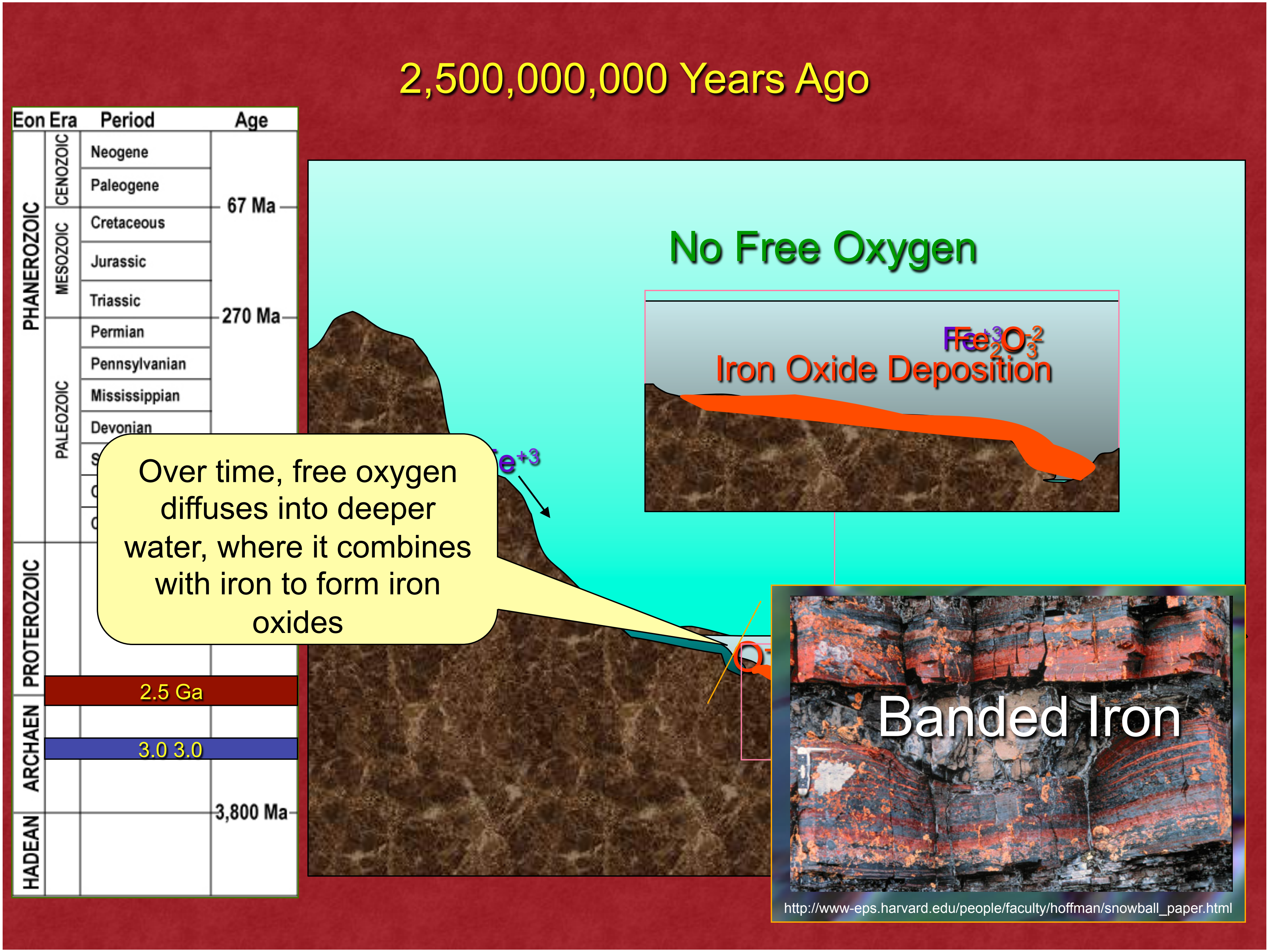




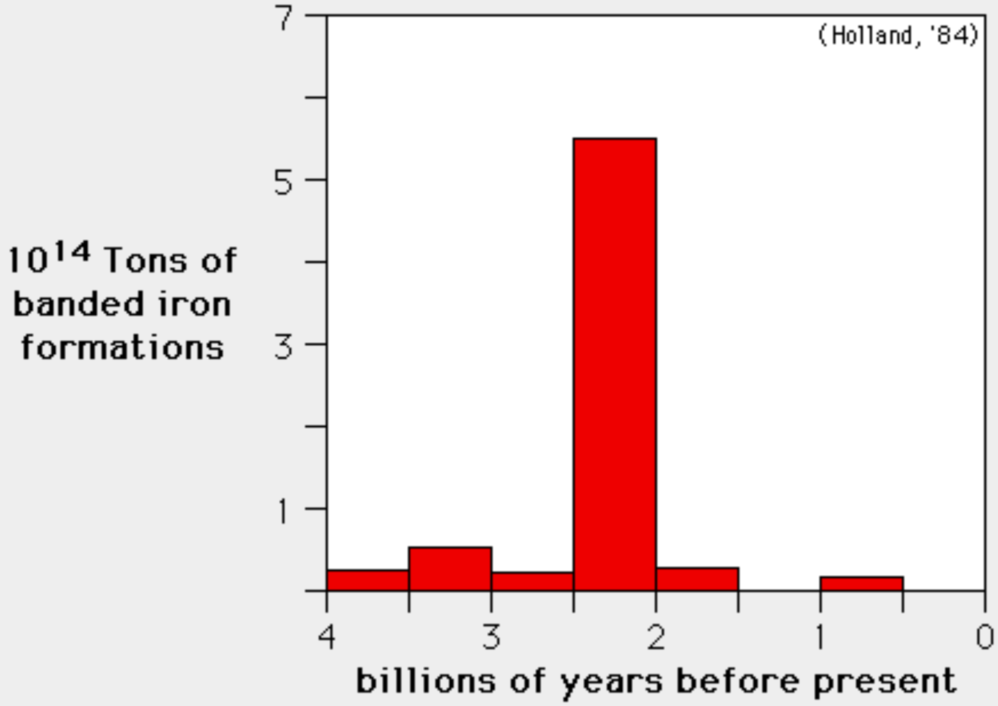
3,000,000,000 Years Ago
(three billion years ago)






2,500,000,000 Years Ago
Eon Era Period Age
PHANEROZOIC
CENOZOIC
MESOZOIC
PALEOZOIC
Neogene
Paleogene
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
67 Ma
270 Ma
PROTEROZOIC
2.5 Ga
ARCHAEN
3.0 3.0
3,800 Ma
HADEAN
No Free Oxygen
Fe+3
Fe2O3
Iron Oxide Deposition
Over time, free oxygen diffuses into deeper water, where it combines with iron to form iron oxides
Banded Iron
http://www-eps.harvard.edu/people/faculty/hoffman/snowball_paper.html

Banded Iron Formations (very low O_2 in atm)

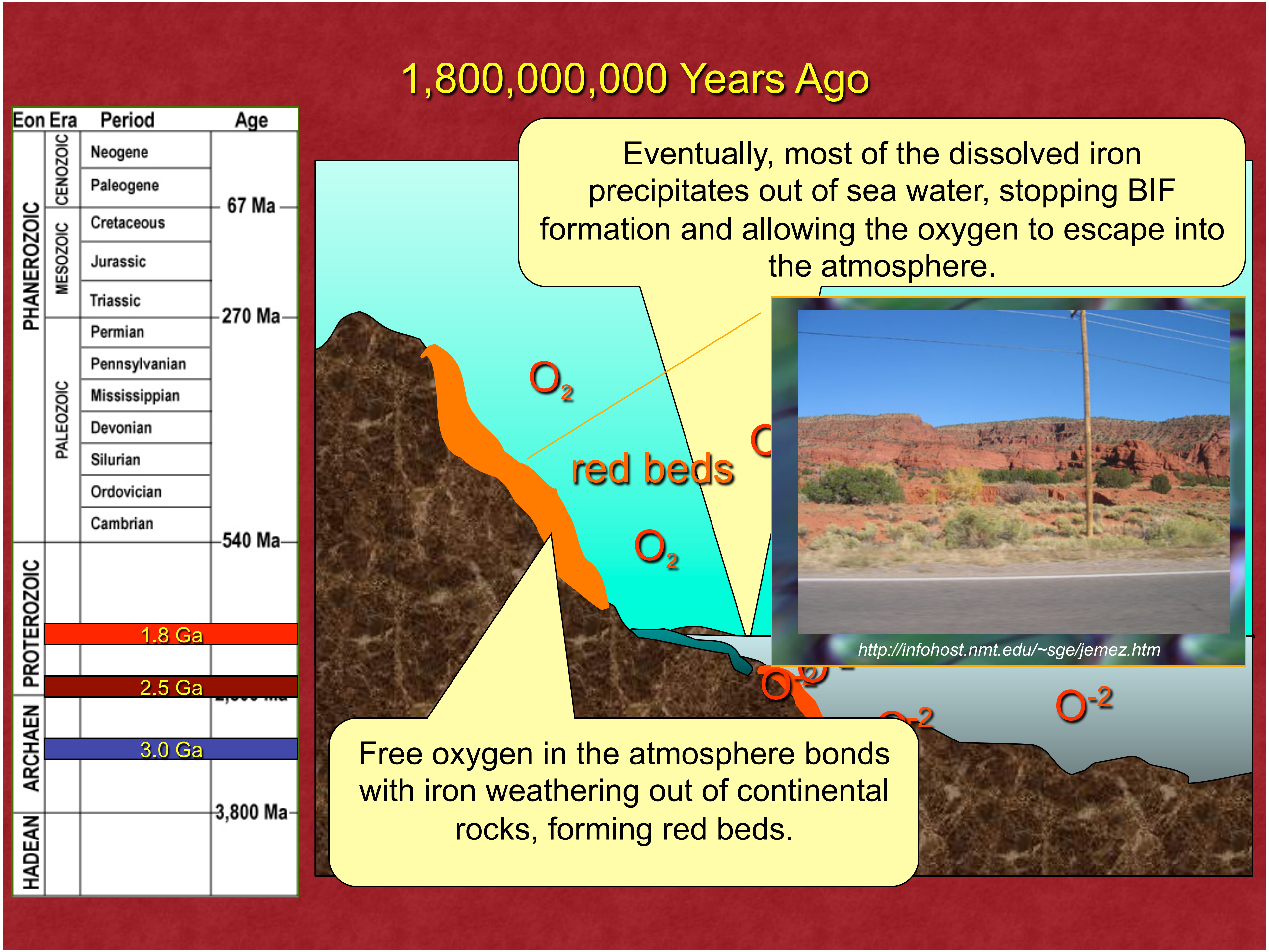


Very Large Fe Deposits

Continent	Area	Age (10^6 yrs)
Africa	Transvaal, S.A.	2100-2600
Australia	Hamersley Range	2400-2700
Eurasia	Krivoi Rog, Ukraine	1900-2600
North America	Labrador Trough, Canada	1900-2500
South America	Minas Gerais, Brazil	2000-2700

HJS/LP

http://rainbow.ldeo.columbia.edu/ees/SIPA/Lectures/Lecture_1.html


1,800,000,000 Years Ago
Eon Era Period Age
PHANEROZOIC
CENOZOIC
MESOZOIC
PALEOZOIC
Neogene
Paleogene
Cretaceous
Jurassic
Triassic
Permian
Pennsylvanian
Mississippian
Devonian
Silurian
Ordovician
Cambrian
67 Ma
270 Ma
540 Ma
PROTEROZOIC
1.8 Ga
2.5 Ga
ARCHAEN
3.0 Ga
3,800 Ma
HADEAN
Eventually, most of the dissolved iron precipitates out of sea water, stopping BIF formation and allowing the oxygen to escape into the atmosphere.
O2
red beds
O2
http://infohost.nmt.edu/~sge/jemez.htm
O-2
O-2
Free oxygen in the atmosphere bonds with iron weathering out of continental rocks, forming red beds.

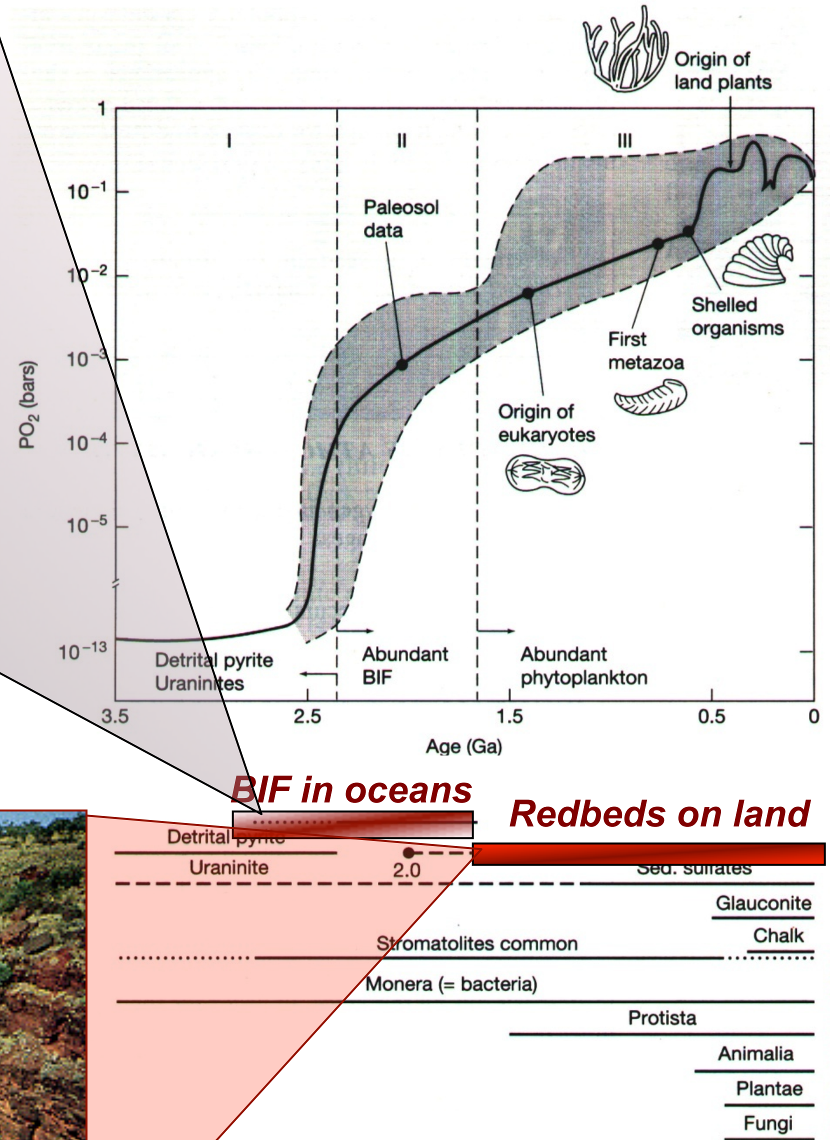


FIGURE 5.10
Model for the growth of oxygen in Earth's atmosphere. I, II, and III are stages in atmosphere evolution. Also shown are the time relationships of various oxygen-recording sediments and organisms as discussed in the text.

http://earth.usc.edu/~geol150/evolution/precambrian2.html

Global Increase in Oxygen

The increase in atmospheric oxygen caused a major turning point in Earth's history.

- Once the reduced iron sink was consumed, oxygen became one of the most abundant gases in the atmosphere. Surface and oceanic chemistry changed dramatically from primarily reducing to predominantly oxidizing.
- The effect on life can not be underestimated - the dominant mode of metabolism on Earth changed from anaerobic to aerobic. Oxygen is a highly efficient oxidizer of organic matter, and the switch in metabolism may be responsible for the great diversification of macroscopic life that would follow. It was a disaster for the dominant life forms of the time.

The Earth would never be the same as it was

Global Increase in Oxygen

As the amount of atmospheric oxygen increased through the Proterozoic, new living systems evolved.

- Eukaryotic organisms became more diverse and abundant. There was also an increase in eukaryote body size, with large (>1m) eukaryotes becoming abundant in the late Proterozoic.
- Eukaryotes diversified into both new and pre-existing ecologic niches, and created brand new kinds of ecosystems.
- By the end of the Proterozoic, the ancestral taxa of several major animal groups became recognizable.

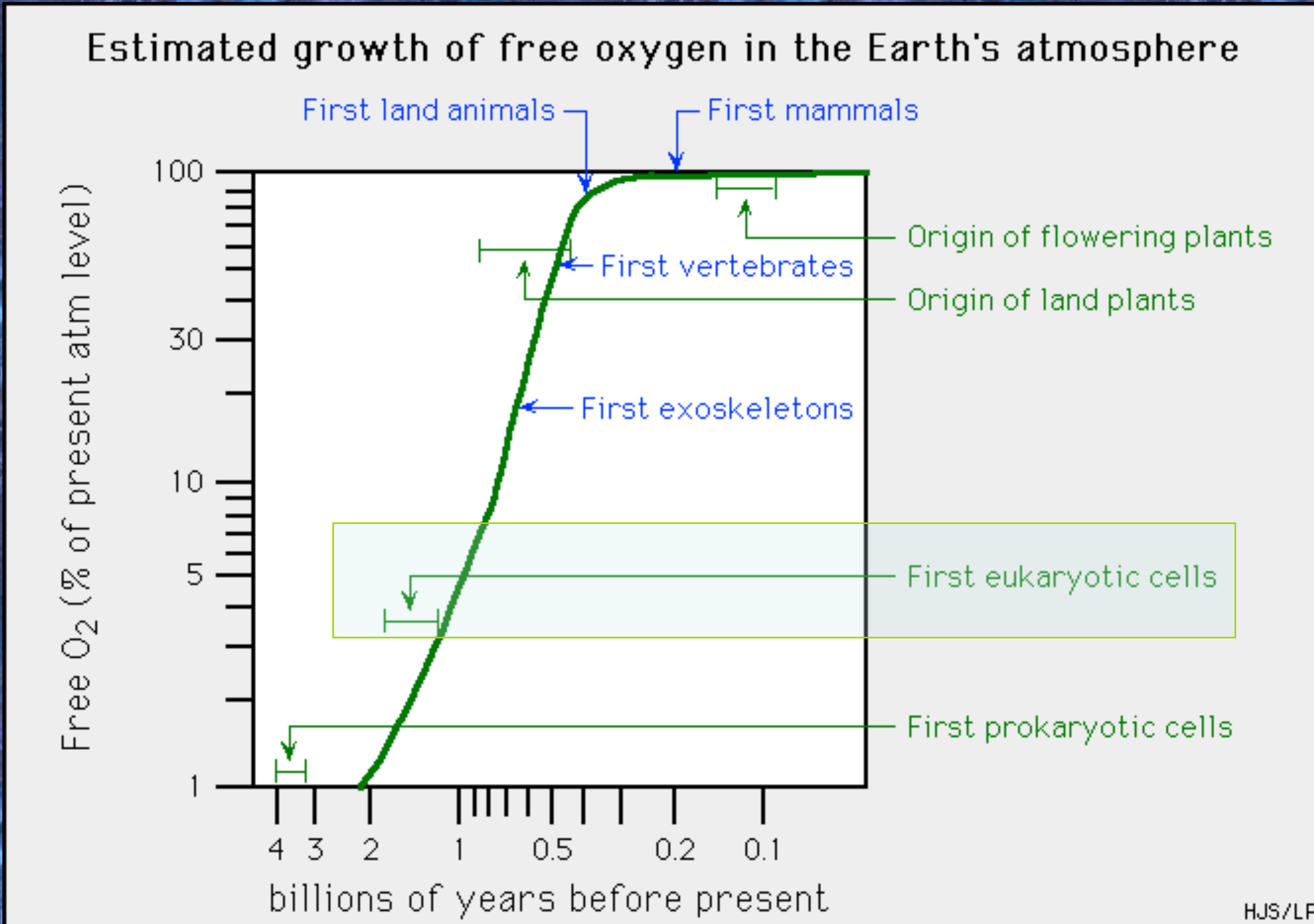
What would Earth be like without life?

Venus does not have Earth-like life. We can infer what Earth would be like without life by comparing Earth's atmospheric composition to Venus's.

Gas	Venus	Earth w/life	Earth w/o life
CO_2	95%	0.03%	98%
N_2	-	78%	1.9%
O_2	-	21%	trace

Estimated surface temperature: 290°C

http://csmres.jmu.edu/geollab/Fichter/GeoBio350

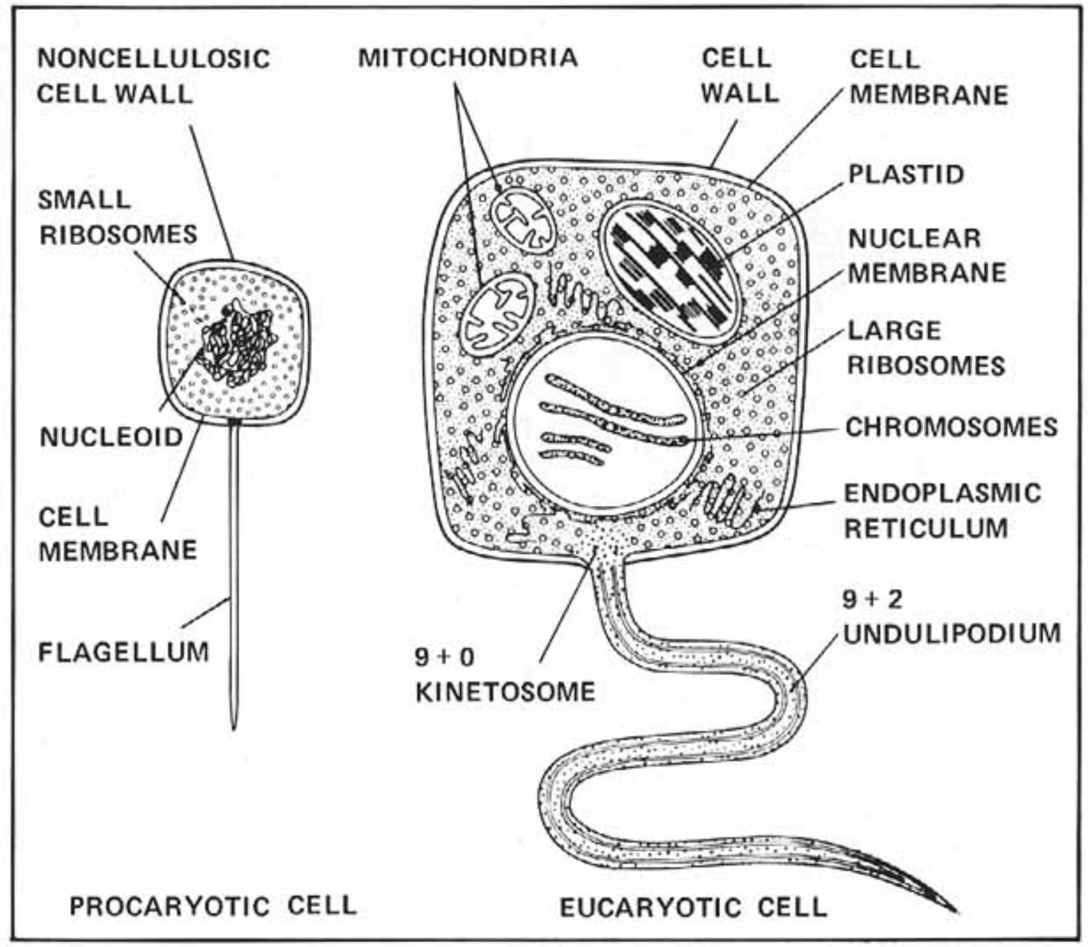


http://rainbow.ldeo.columbia.edu/ees/SIPA/Lectures/Lecture_1.html

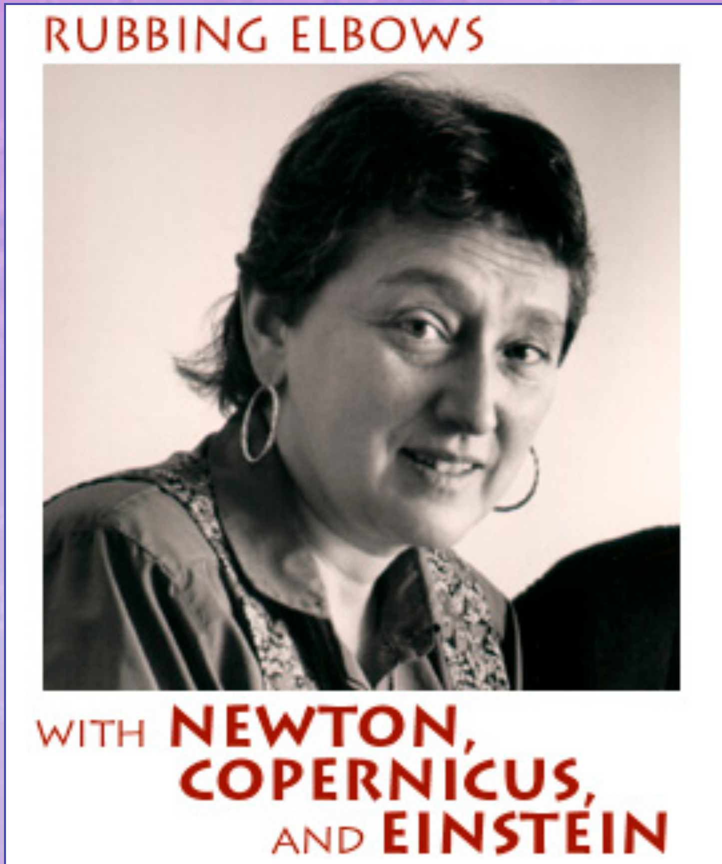
Complex life forms on Earth have complex cell structures including specialized structures called organelles.

Most organelles contain their own genetic code, and reproduce independently of the cell.

The leading theory on how these came about is Lynn Margulis's endosymbiotic theory.



http://history.nasa.gov/



http://www.umass.edu/synergy

Basic idea: The organelles used to be free living single celled organisms, but over time were incorporated into larger single celled organisms, and symbiosis co-evolved.

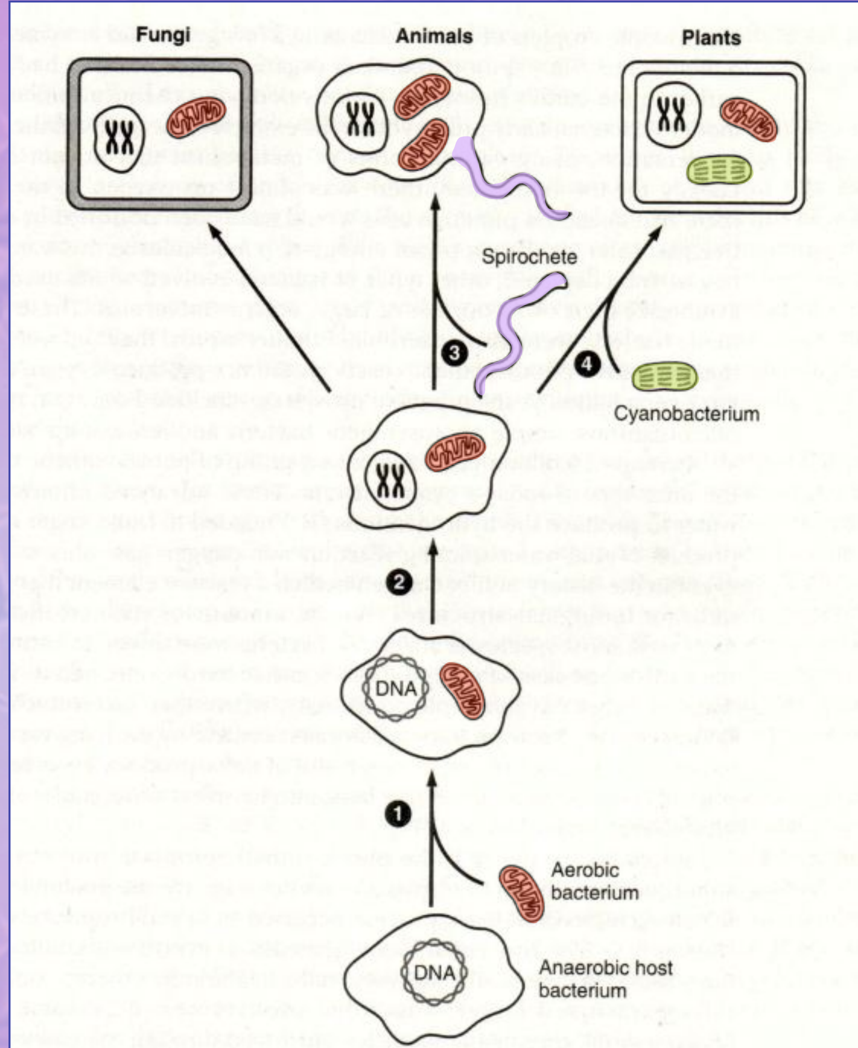
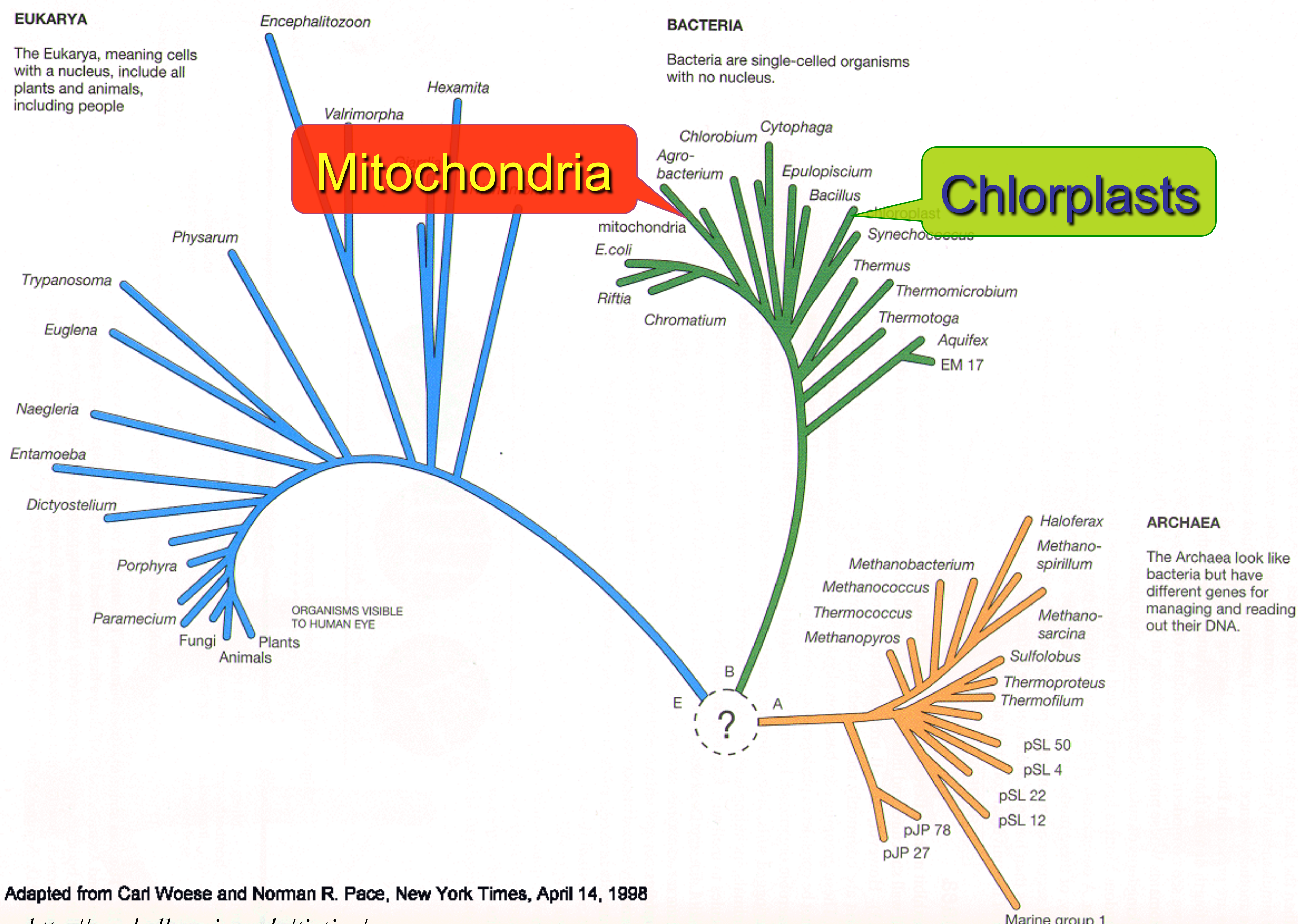


FIGURE 3.3 Evolution of eukaryotic cells by a series of endosymbiotic events: (1) mitochondria evolve from small, free-living, respiring bacteria; (2) the nucleus evolves from the simpler prokaryotic DNA molecule; (3) flagella (undulipodia) evolve from symbiotic spirochetes; (4) chloroplasts arise from free-living cyanobacteria. Cell walls in plants and fungi, which are structurally quite different, evolve independently.

http://www.msu.edu/course/lbs/



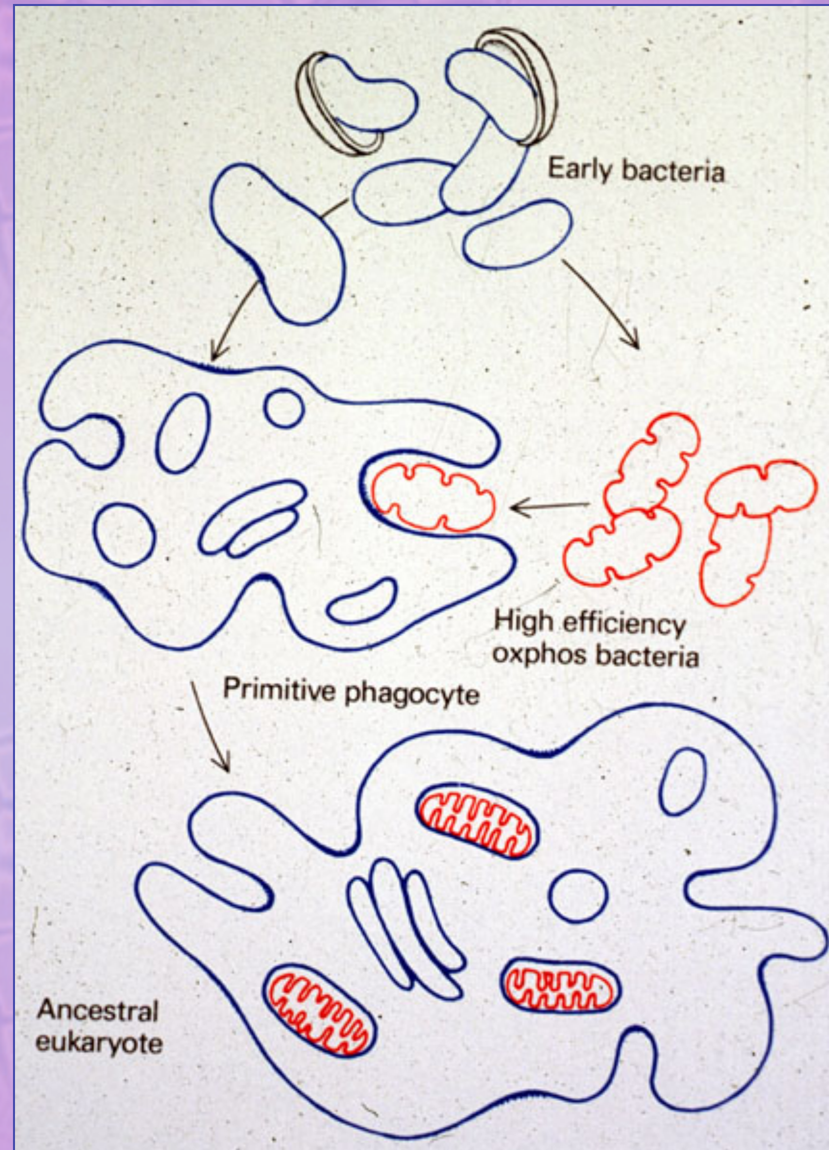
Adapted from Carl Woese and Norman R. Pace, New York Times, April 14, 1998

http://cas.bellarmine.edu/tietjen/

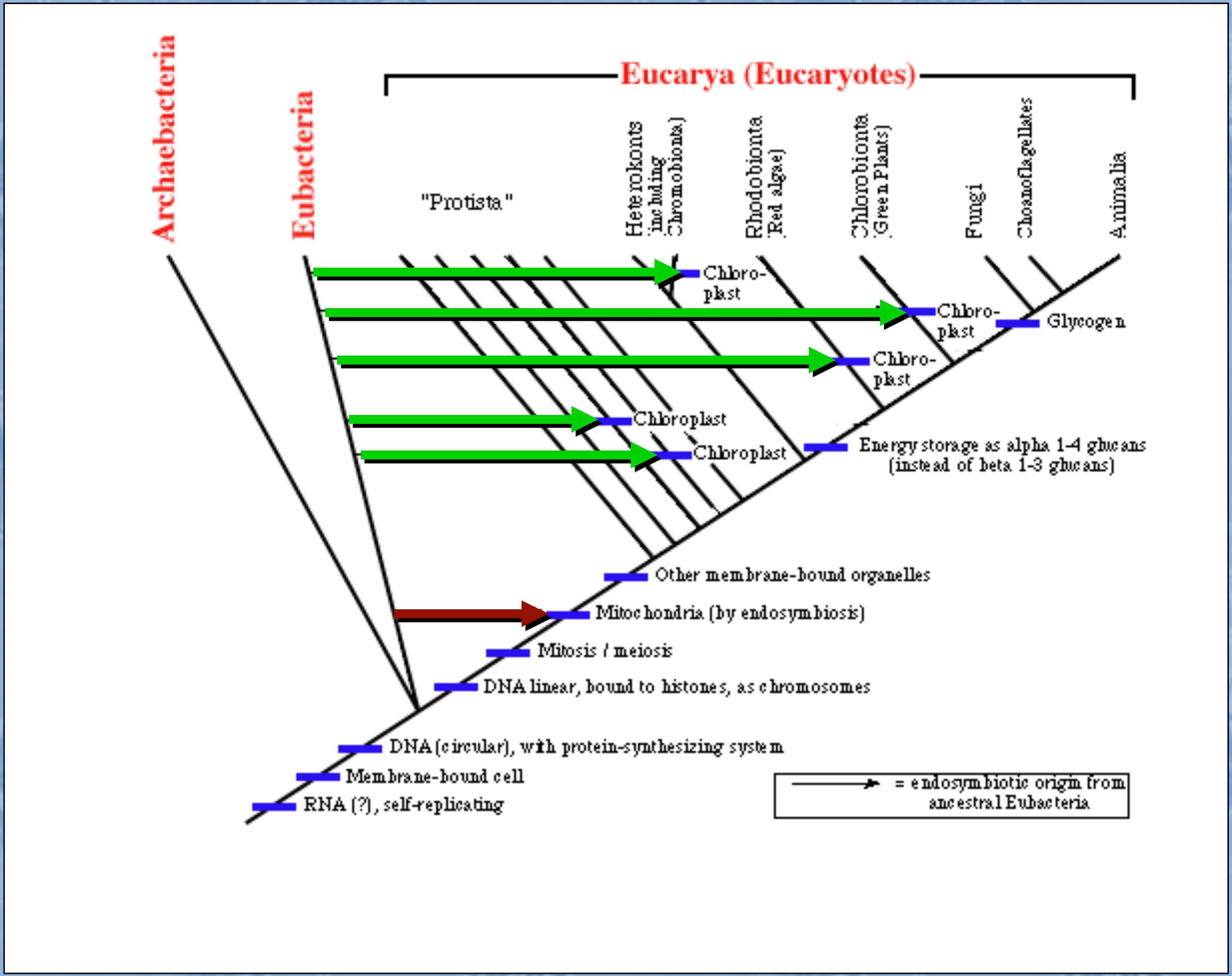
The incorporated bacteria all have a "skill" (e.g., efficient protein production, photosynthesis, or locomotion] that would be of benefit to a potential phagocyte (cell-eater).

By incorporating the foreign cells instead of digesting them, the cell gains these skills.

Natural selection should tend to favor the evolution of efficient working relationships through co-evolution of host and guest.



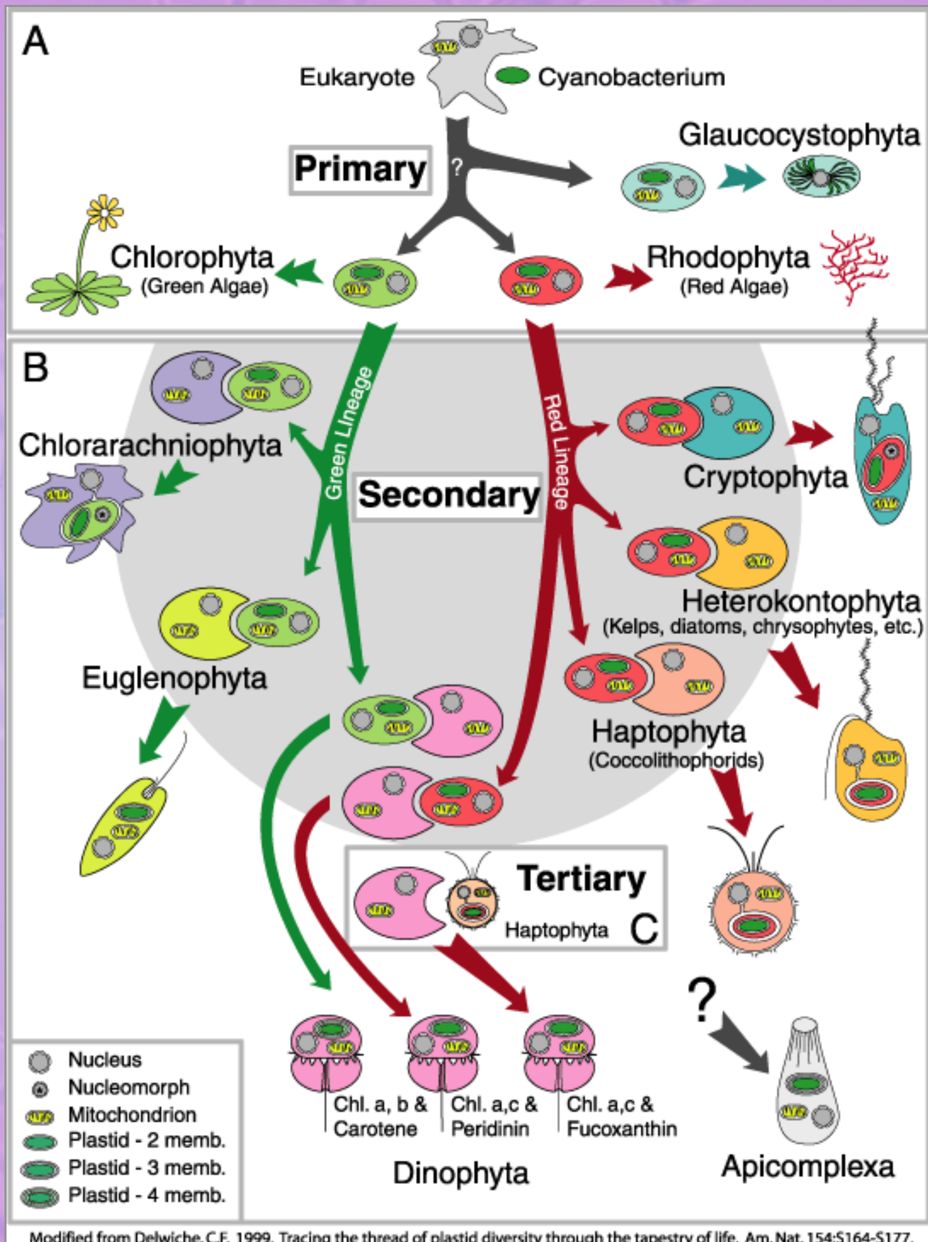
http://www.lib.byu.edu/~imaging/brad/frame1.html

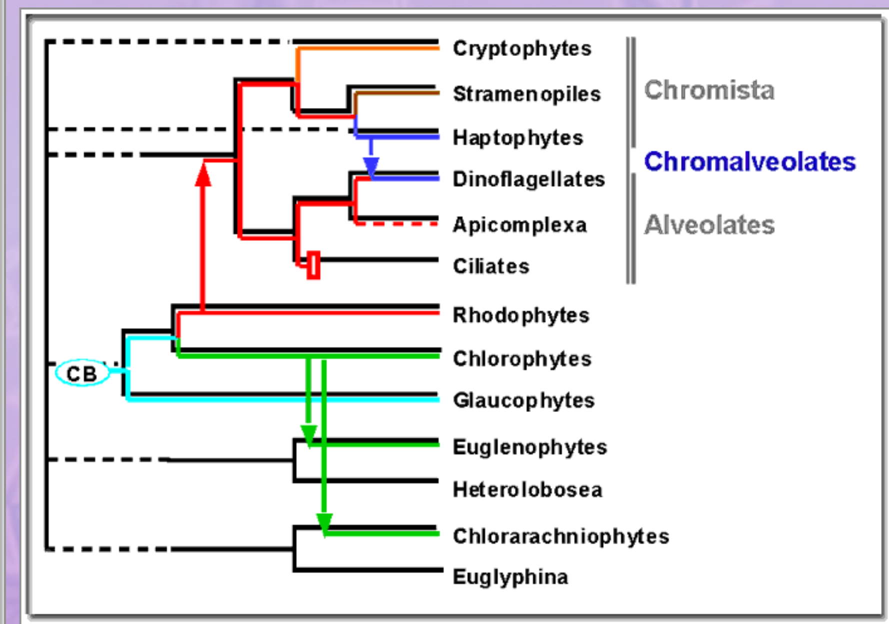


http://www.scibridge.sdsu.edu/

Secondary Endosymbiosis

(eukaryotes absorbing other eukaryotes!)





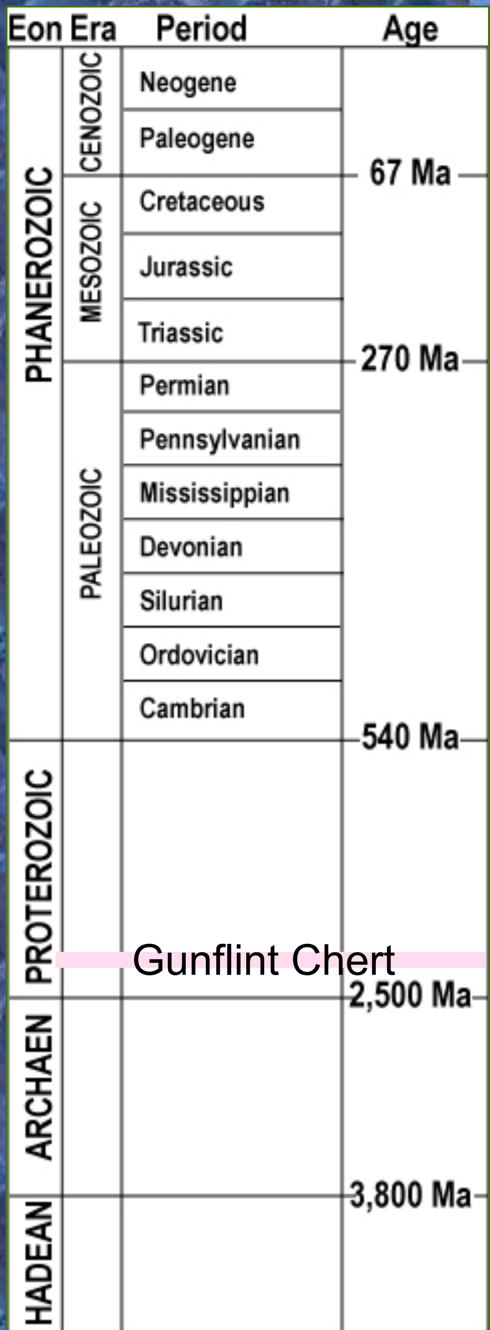
http://www.life.umd.edu/labs/delwiche/pubs/endosymbiosis.gif

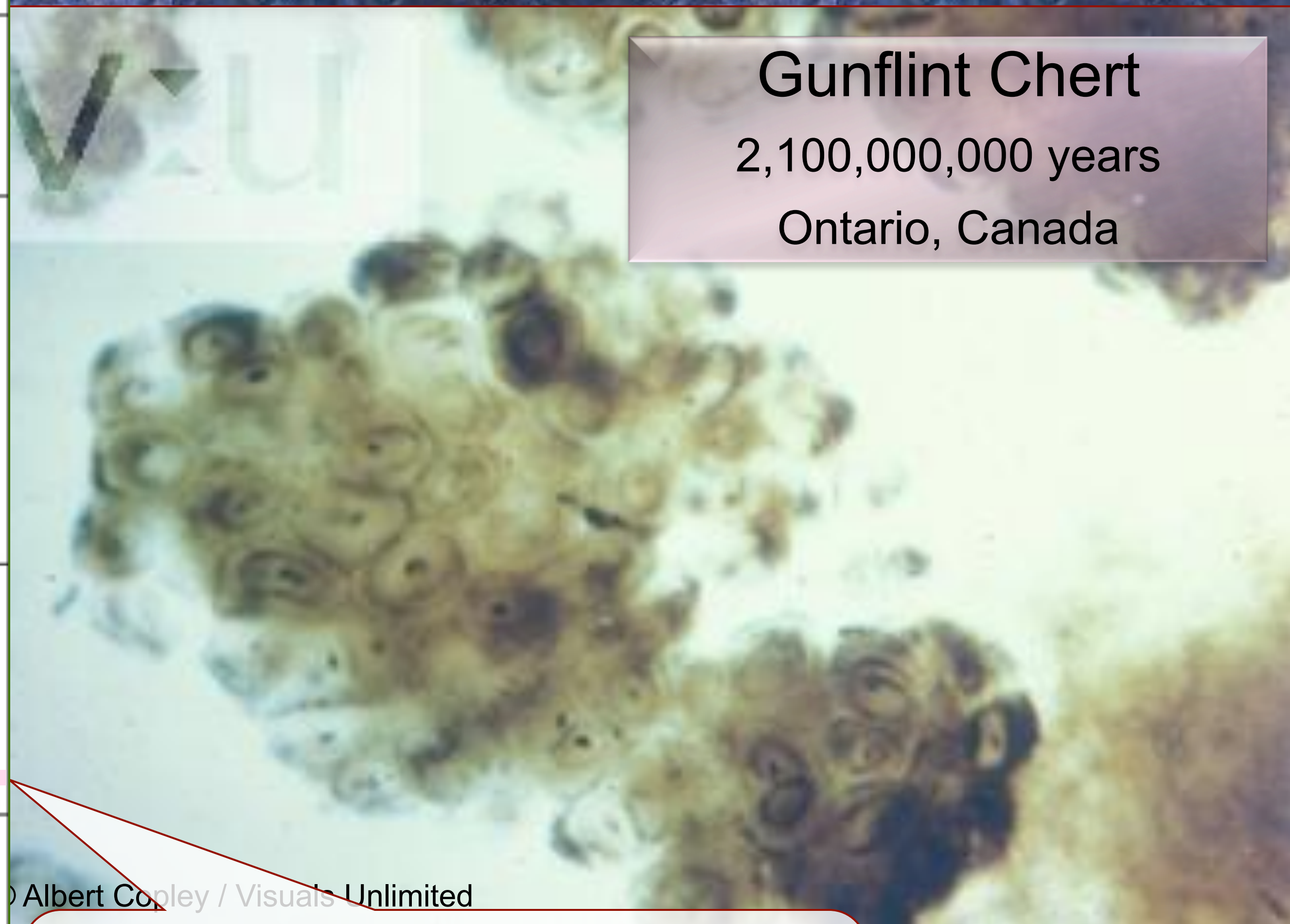
http://www.biology.uiowa.edu/debweb/images1/MdChrEvol.gif

Lynn Margulis accepting National Medal of Science (1998)

http://www.asee.org/nstmf/html/photos2.htm

Prokaryotes

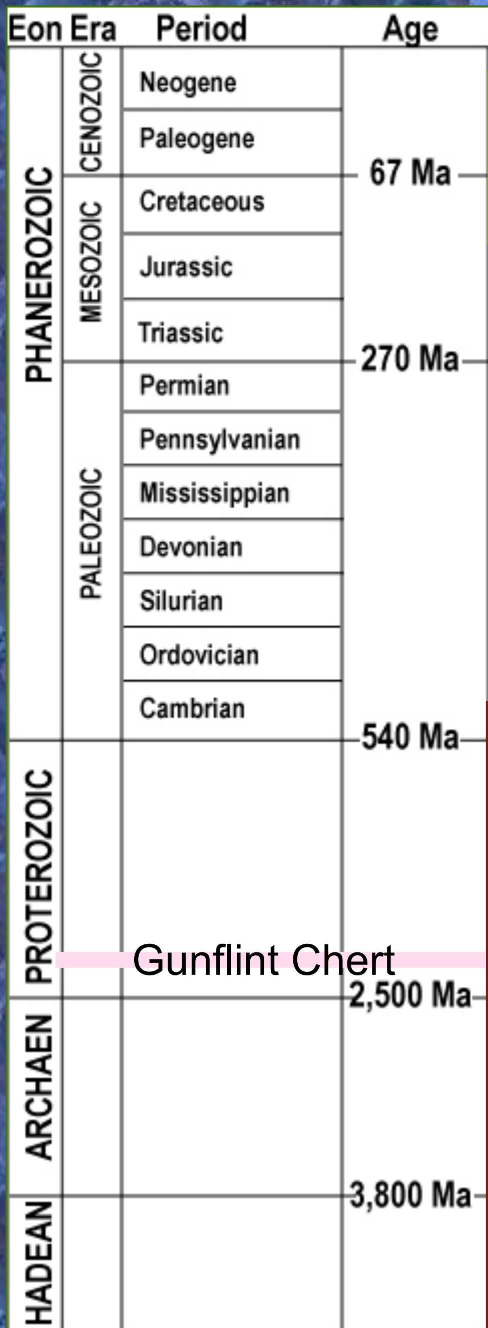




Contains high diversity of **prokaryote fossils**, very few **eukaryotes**

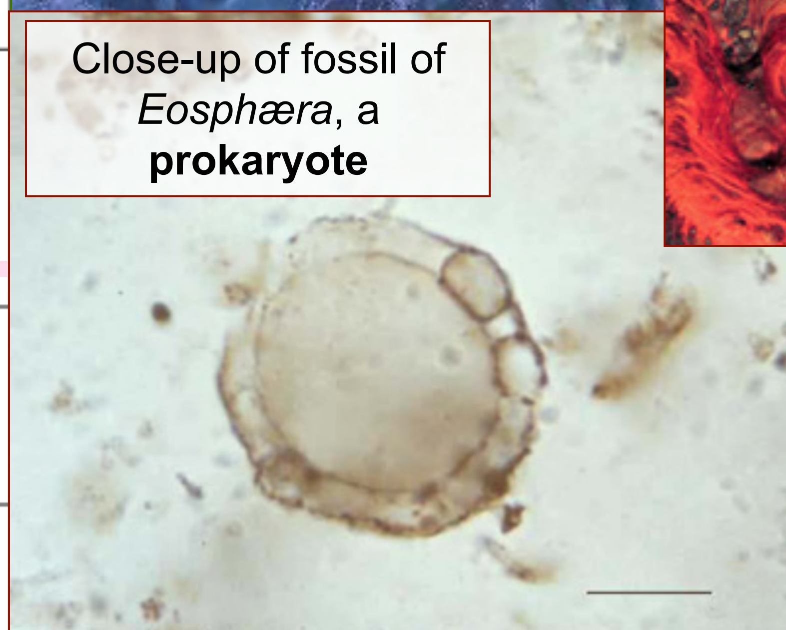
http://www.visualsunlimited.com/

Prokaryotes



Gunflint Chert Stromatolites

Close-up of fossil of *Eosphæra*, a **prokaryote**



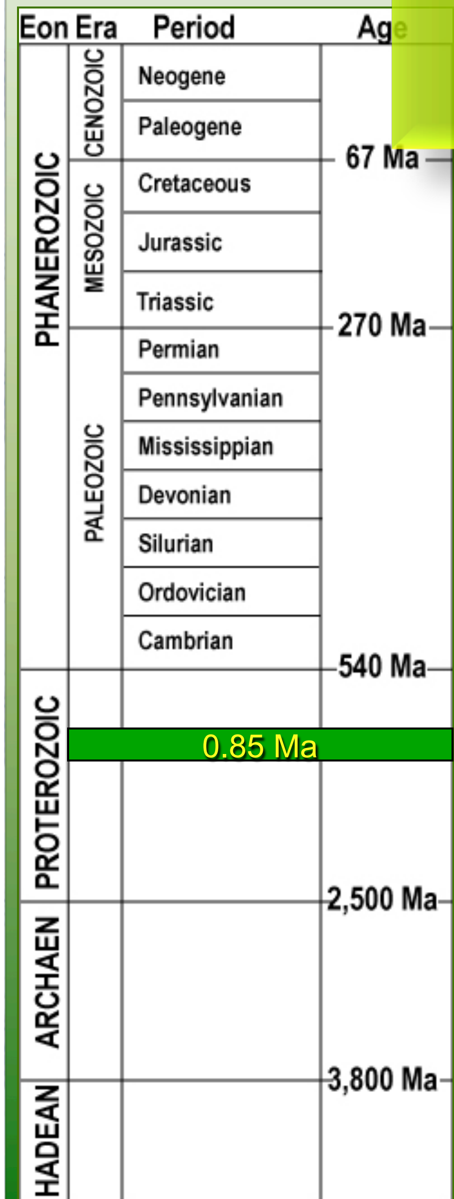
Gunflint Chert

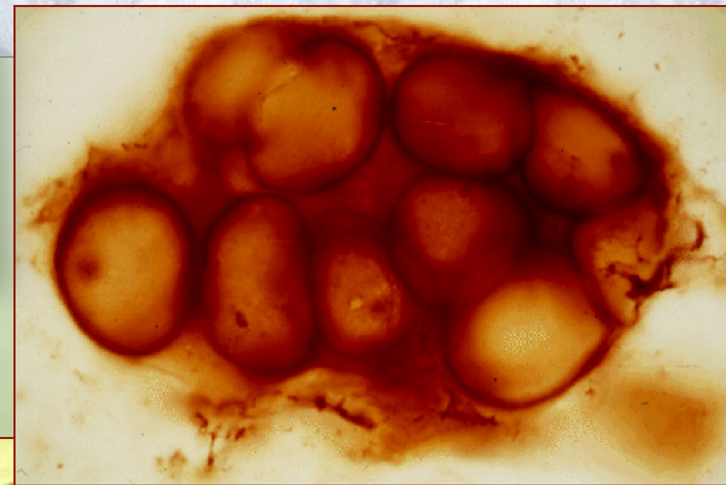
2,100,000,000 years

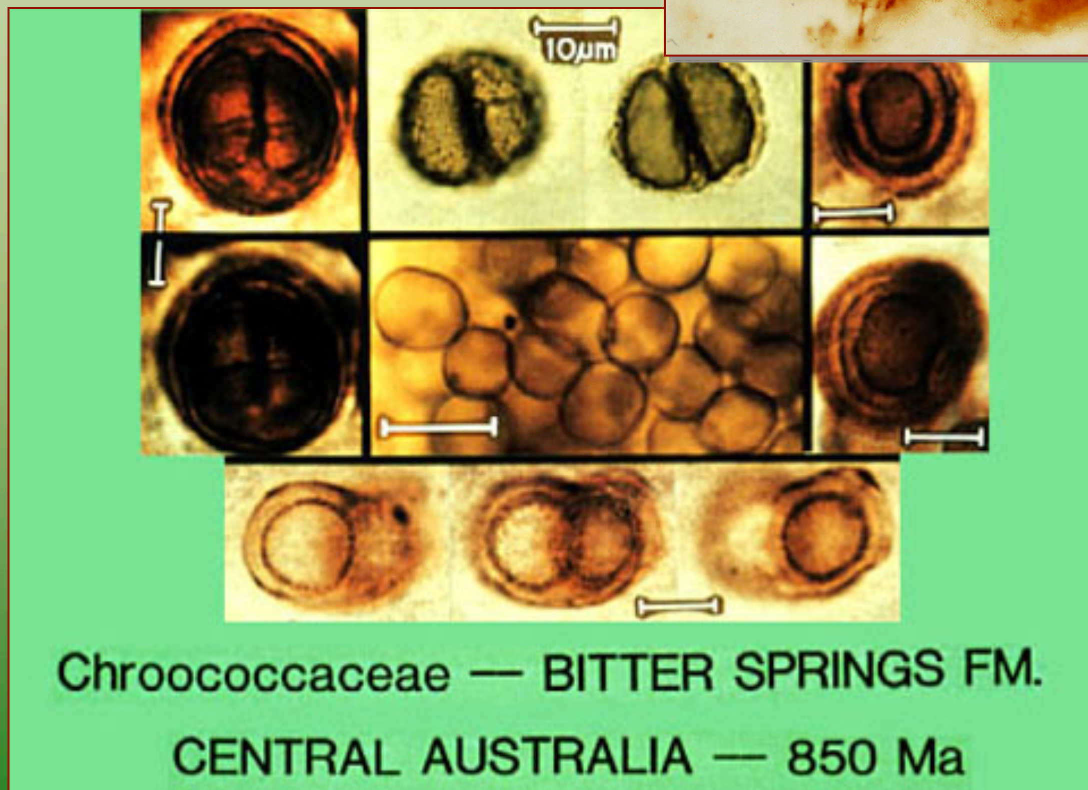
Ontario, Canada

http://www.nrcan.gc.ca/gsc/calgary/canpal/pastlives/05_f.html

Prokaryote
Eubacteria







Cyanobacteria, Bitter Springs Chert, Australia (~ 850 Ma)

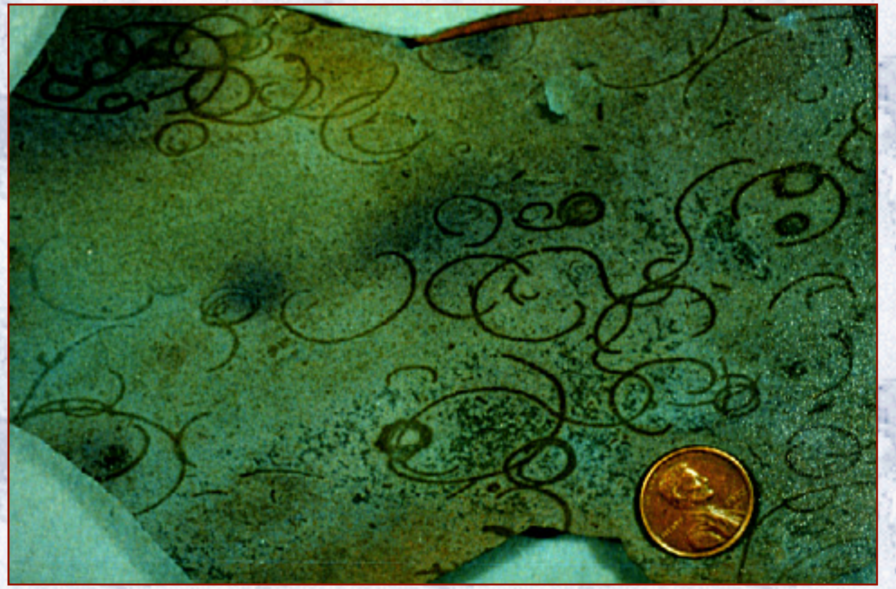
http://www.ucmp.berkeley.edu/

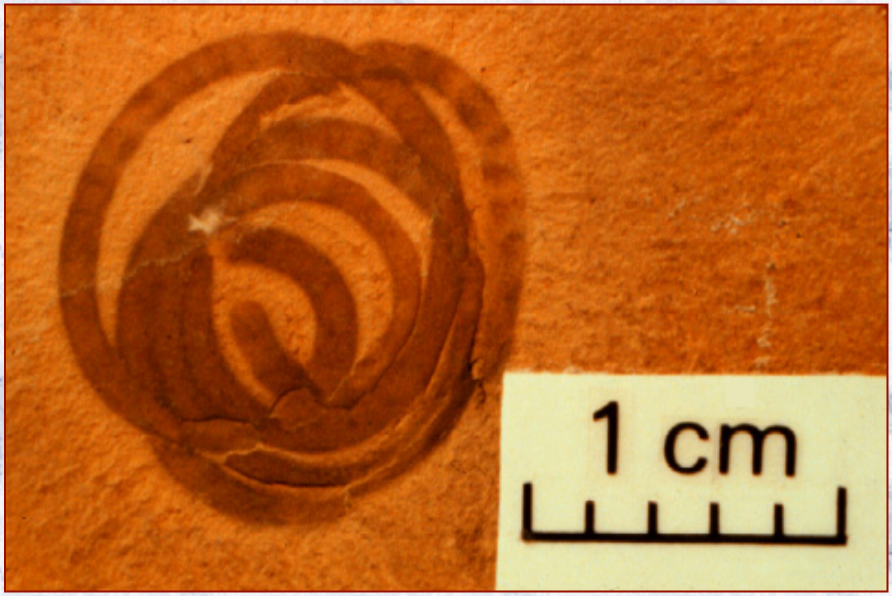
Prokaryote - Eubacteria

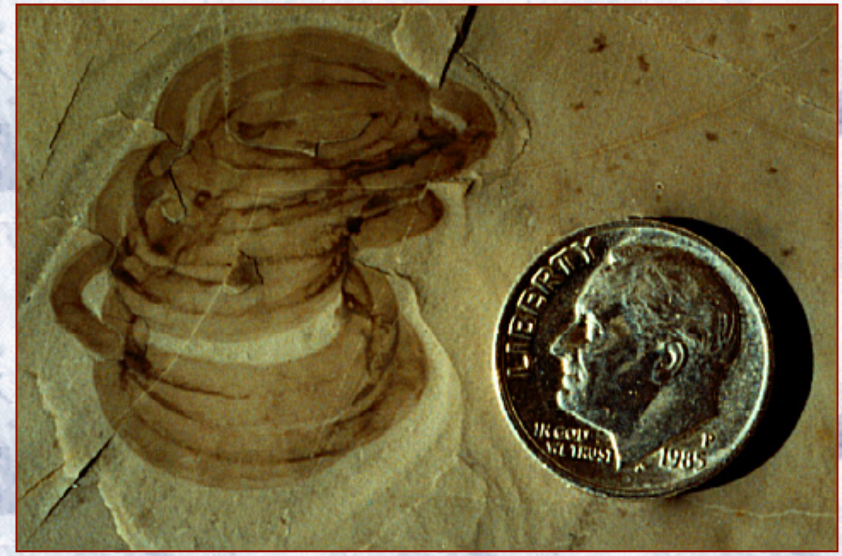
Cyanobacteria, Bitter Springs Chert, Australia (~ 850 Ma)

http://www.ucmp.berkeley.edu/

Eukaryotes





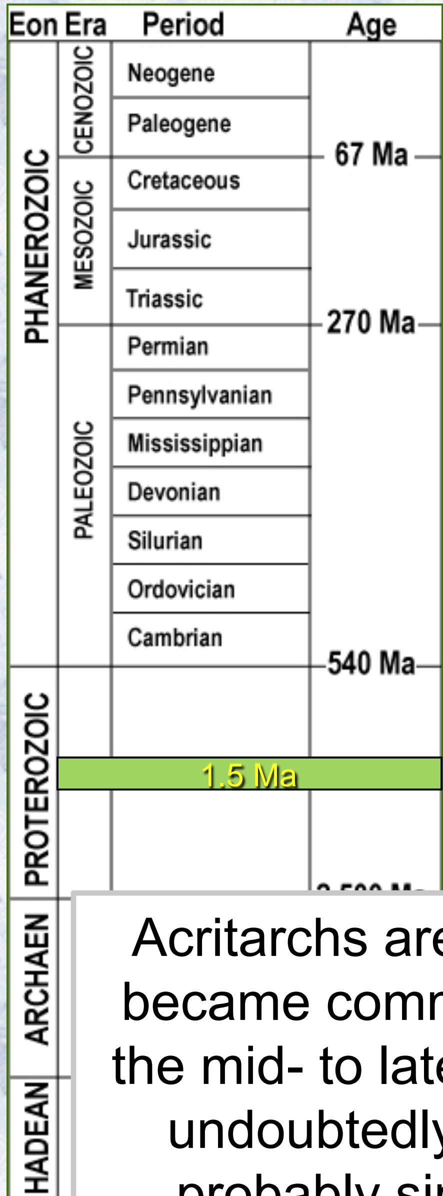


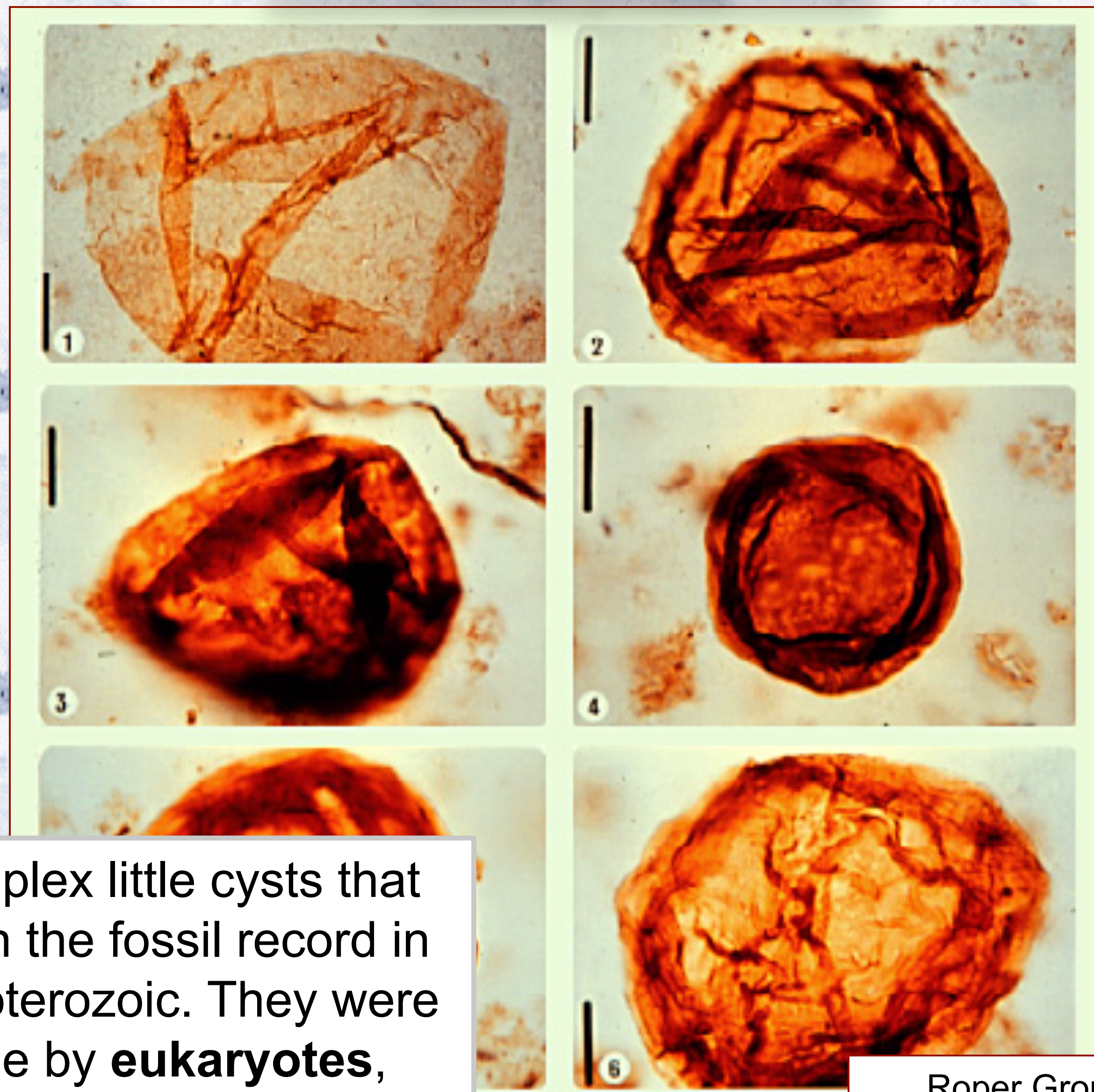
Problematic fossils like *Grypania*, appear approximately 1.8 Ga, worldwide distribution in Proterozoic.

Best guess is that this is the remains of a green alga, a **macroscopic eukaryote**.

http://astrobiology.ucla.edu/

Eukaryotes



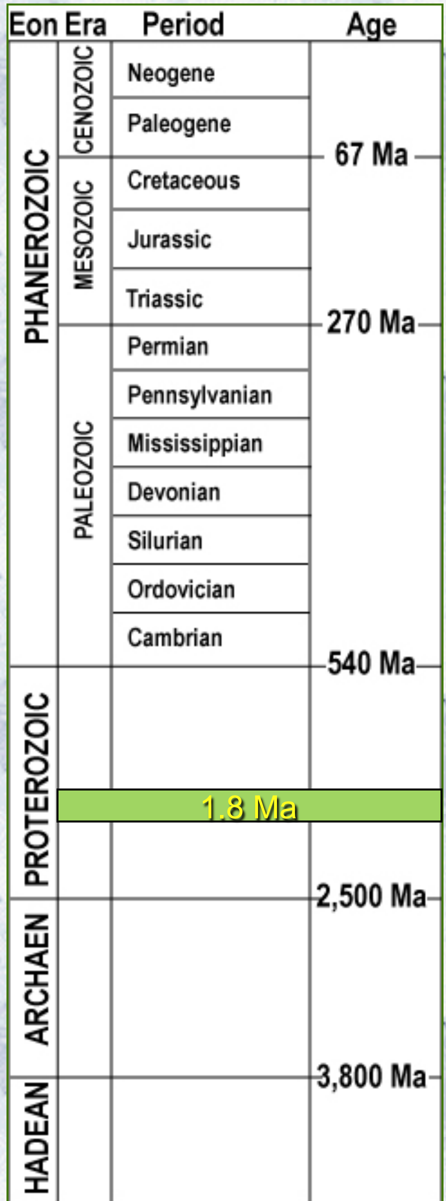


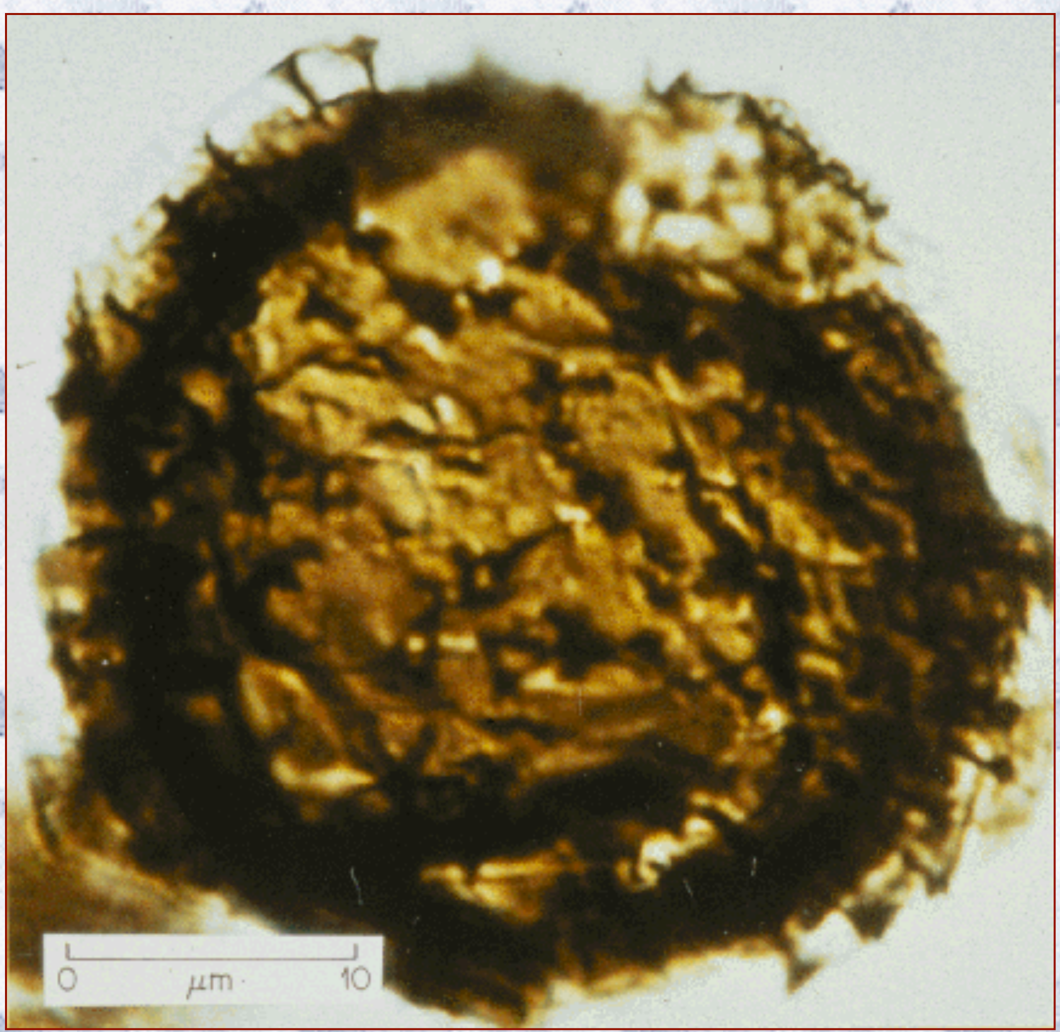
Acritarchs are complex little cysts that became common in the fossil record in the mid- to late- Proterozoic. They were undoubtedly made by **eukaryotes**, probably similar to dinoflagellates.

Roper Group, Australia

http://astrobiology.ucla.edu/

Eukaryotes





Acritarch, Bitter Springs Chert, Australia (~ 850 Ma)

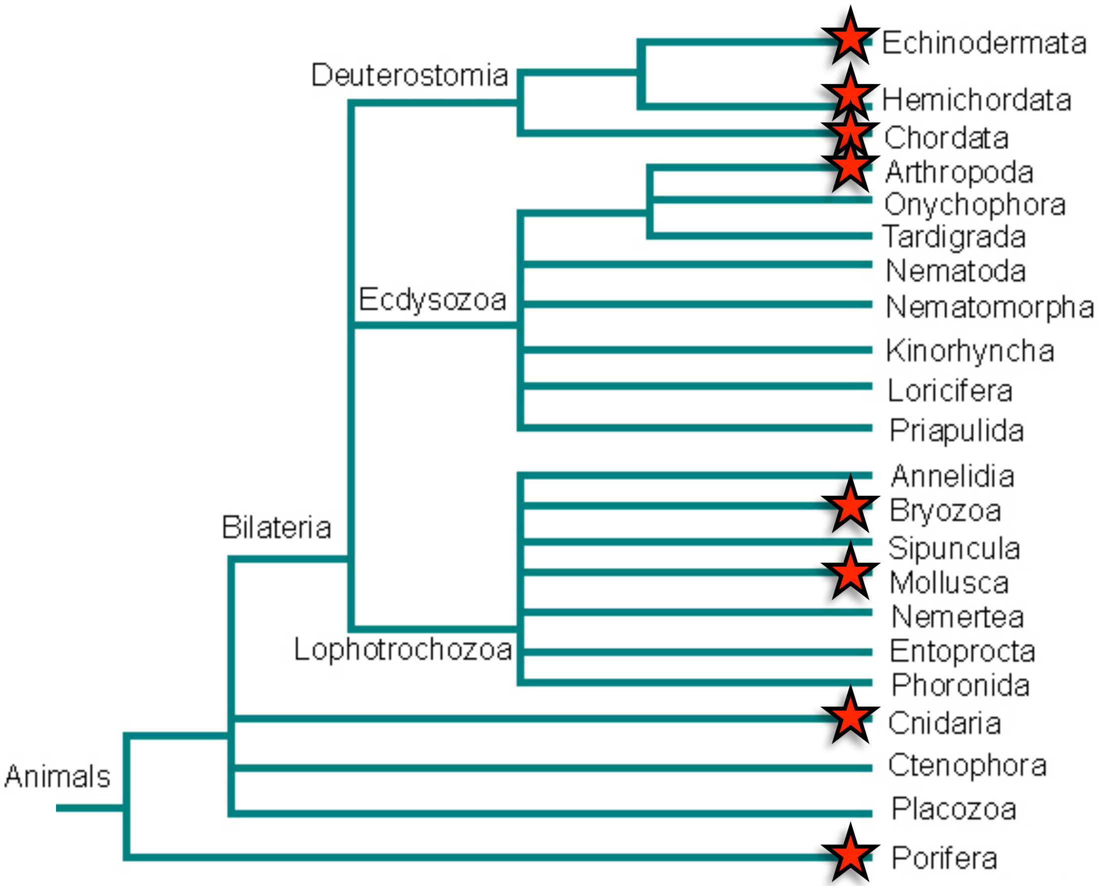
http://cushforams.niu.edu/Acritarch.htm

Metazoans

Includes all animals, including sponges (Philippe et al 2009)

All phyla except sponges have organized tissues and a nerve cells.

Among other traits, “advanced” metazoans are distinguished by their embryonic development.



Most metazoan phyla consist of worms, which are rarely preserved as fossils.

http://www.animalcognition.net/pages/phylogeny.html

★ *Metazoans with good fossil records*

Metazoan Embryonic Development

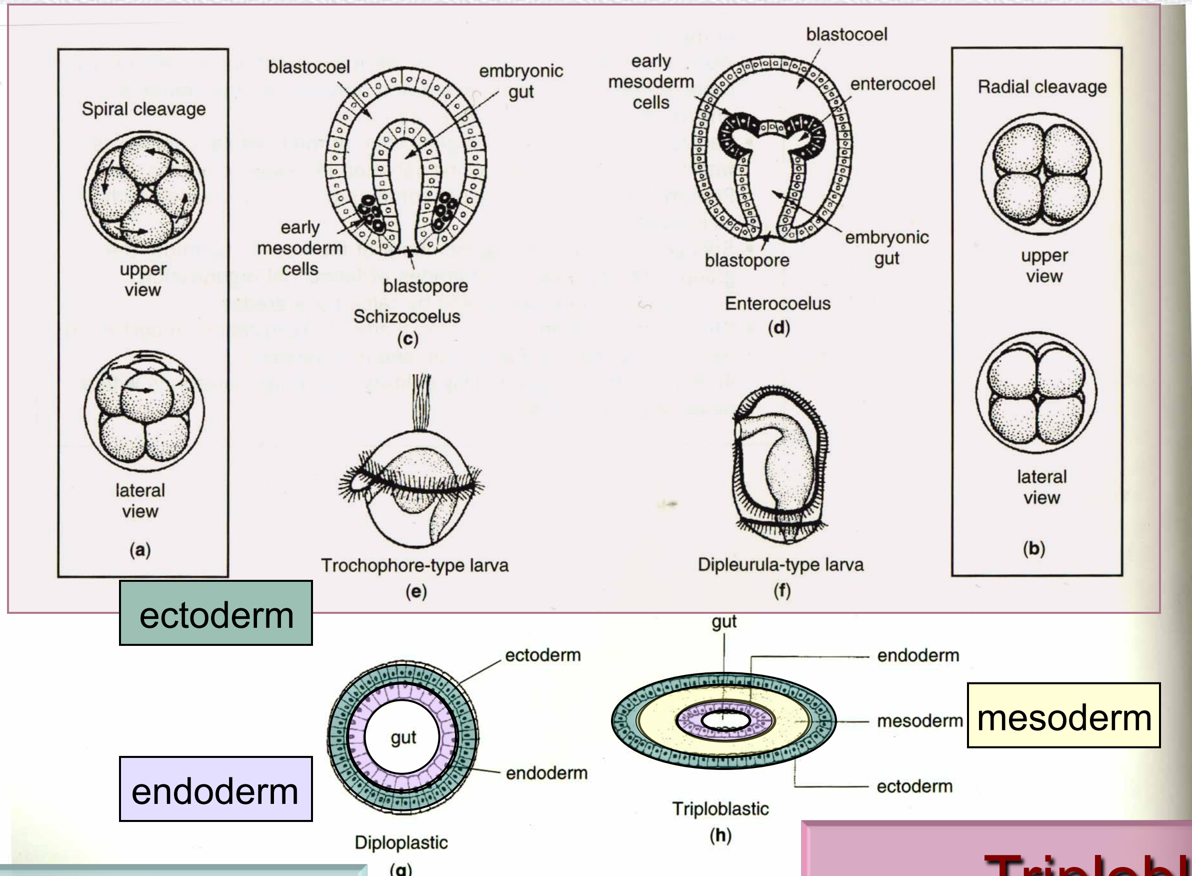


Fig 5.1 Main invertebrate body p[illegible]ans and larvae: upper and lateral views of sp[illegible]ral (a) and radial (b) patterns [illegible] [illegible]ment of the mesoderm in the spiralians (c) and radialians (d), dip[illegible]loblastic (g) and triploblastic (h) body [illegible] the trochophore- (e) and dipleurula- (f) type larvae.

Diploblastic

Two embryonic cell layers:

- ectoderm
- endoderm

Triploblastic

Three embryonic cell layers:

- ectoderm
- mesoderm
- endoderm

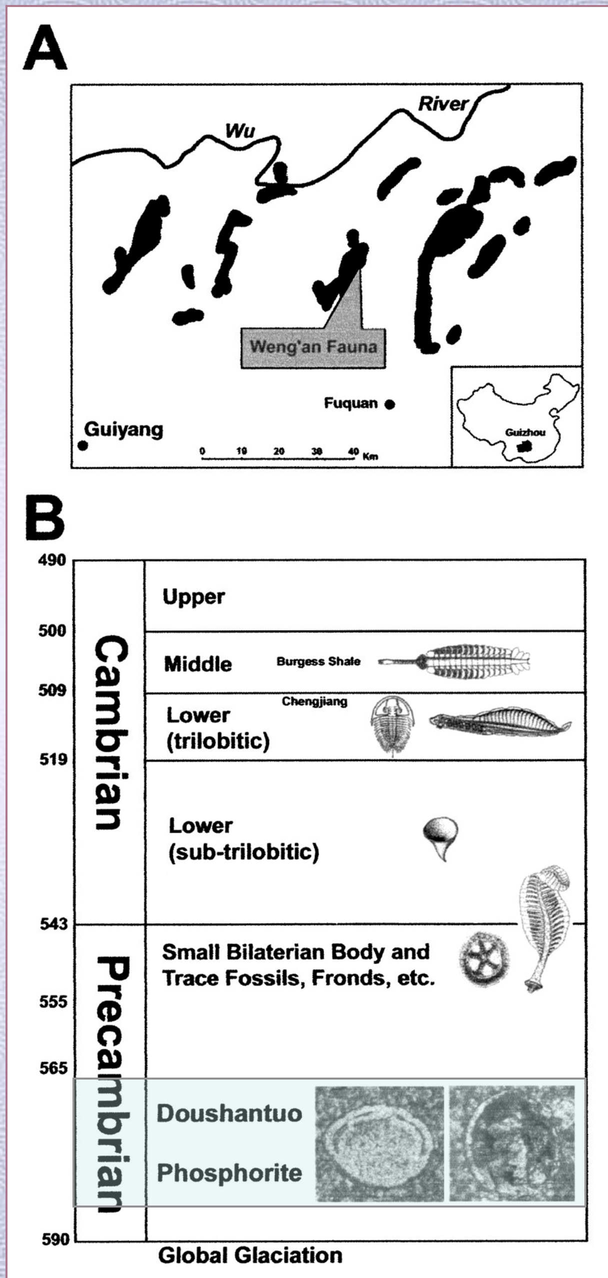
http://www.cyber.vt.edu/geol3604/l8.htm

Shuhai Zhao

Education: University of Beijing, Harvard University

Current Position: Virginia Tech

Discovered fossil embryos (and other fossils) in the Precambrian strata of China - specifically in the **Doushantuo Formation** (~575 Ma).



A. Doushantuo Formation localities in Guizhou Province, China.

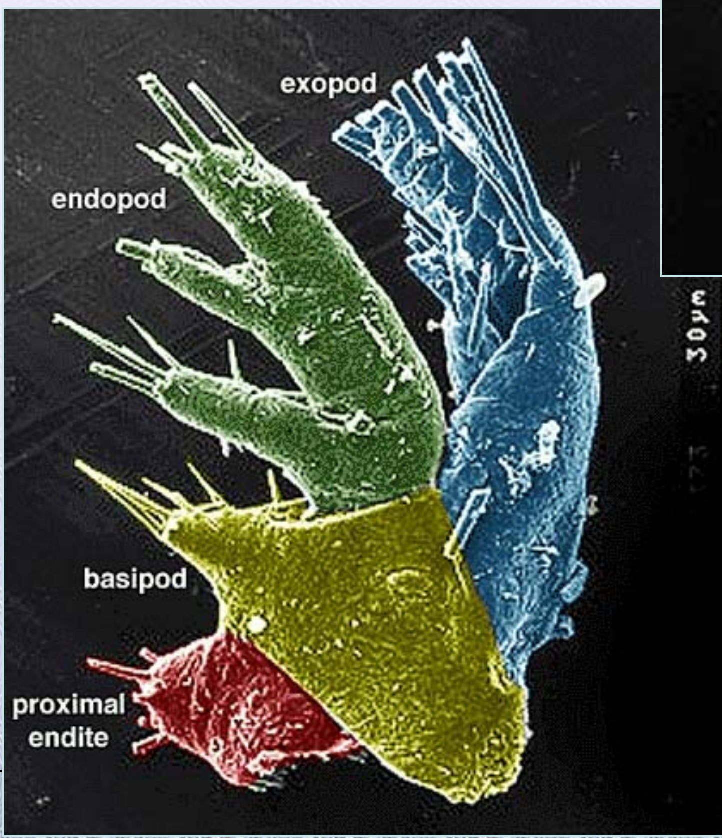
B. Age of Doushantuo Formation relative to other important early fossil assemblages.

Chen et al., 2000

http://www.pnas.org/cgi/content/full/97/9/4457/F1

Phosphatization -
replacement of organic matter by calcium phosphate.

Can preserved exceedingly fine detail of organic matter…

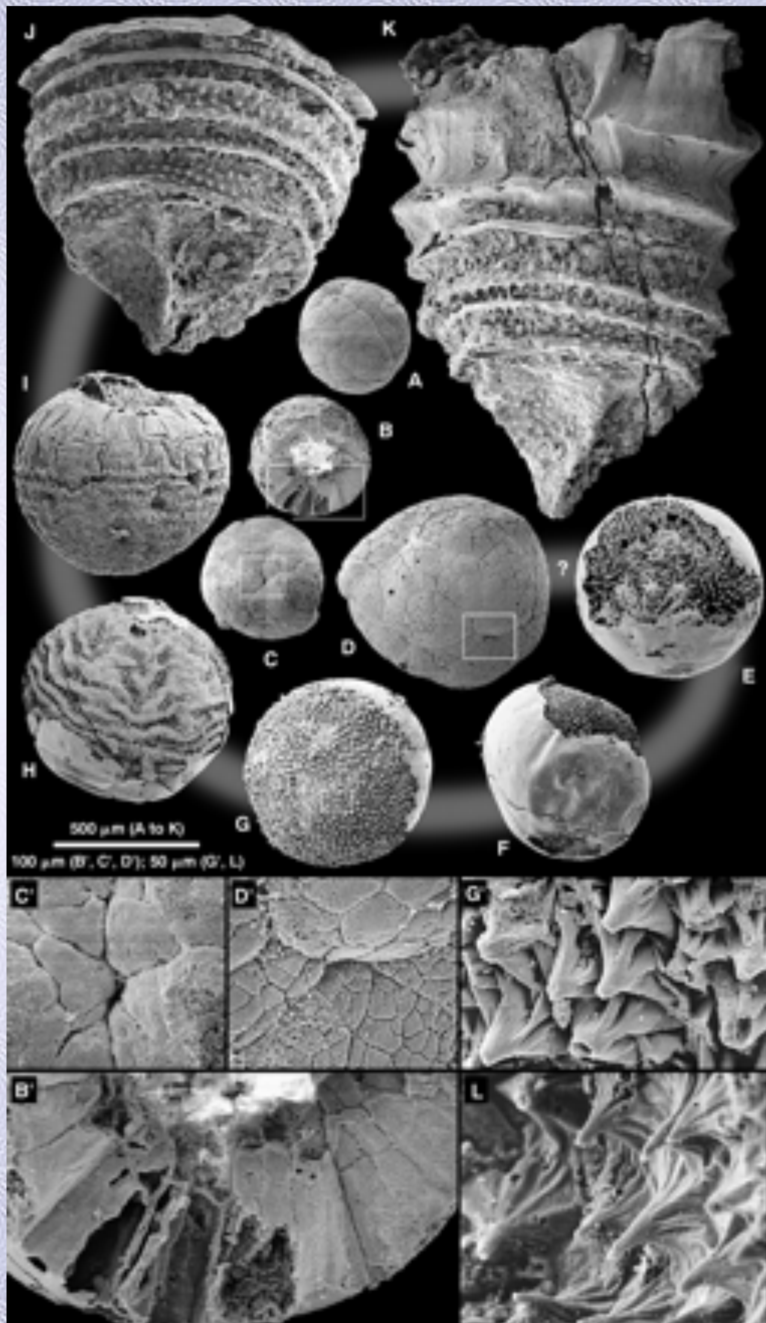


SEMs of a phosphatized Cambrian ostracode

Above: Specimen showing exquisite preservation of legs and antennae. Specimen ~ 1mm across

Left: Leg attachment structure from same species. Color added.

http://biosys-serv.biologie.uni-ulm.de/sektion/dieter/stemline/phosphatos.html



Doushantuo Formation

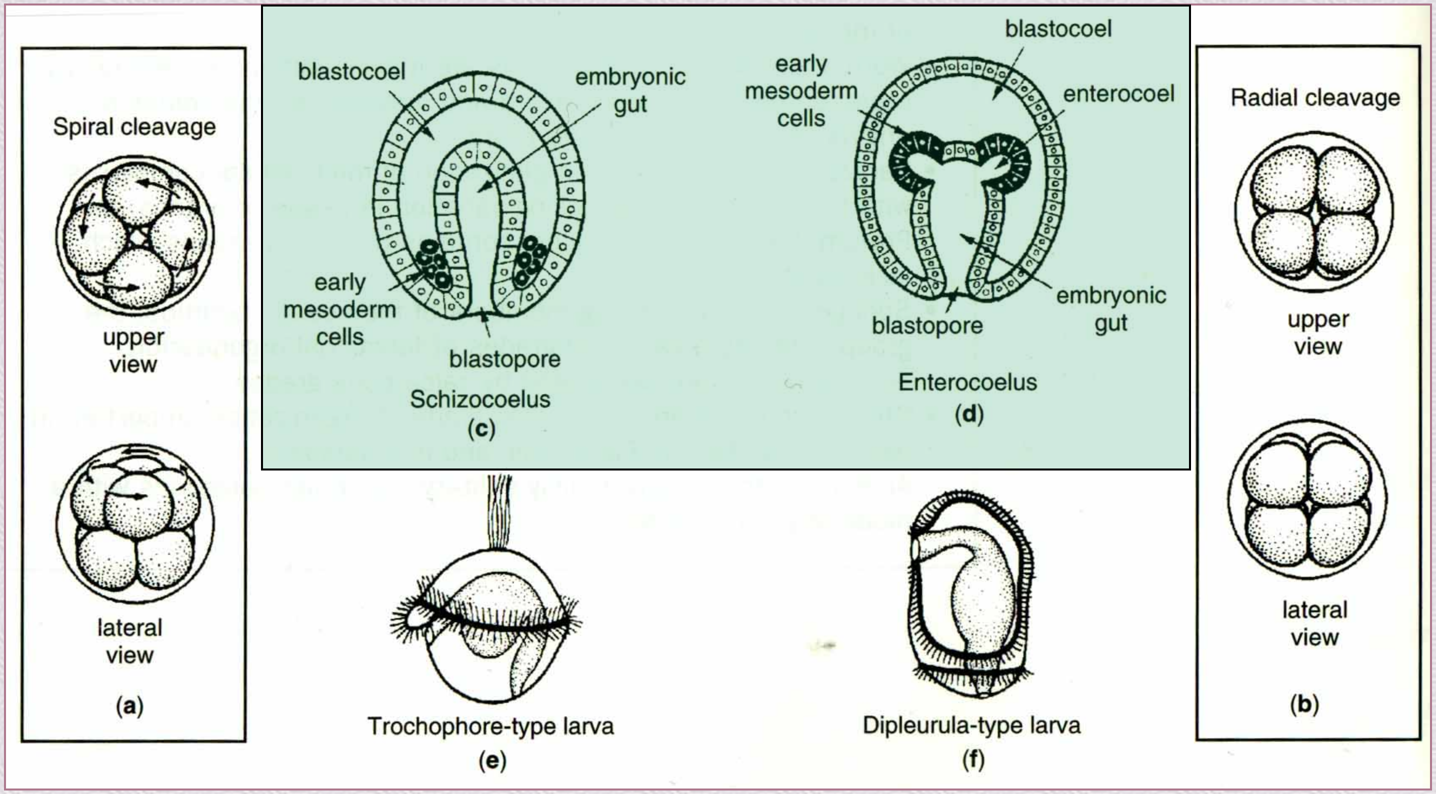
Metazoan embryo at different stages of development

These fossils form a growth series from several hundred cell ball to a several thousand cell embryo with a distinct spiral structure.

Bengston and Zhao 1997

http://www.sciencemag.org/cgi/content/full/277/5332/1645/F1

Gastrula - stage of development in which embryo folds back on itself, making an internal opening



http://www.cyber.vt.edu/geol3604/l8.htm

Possible Fossil Gastrulae – Doushantou Fm.

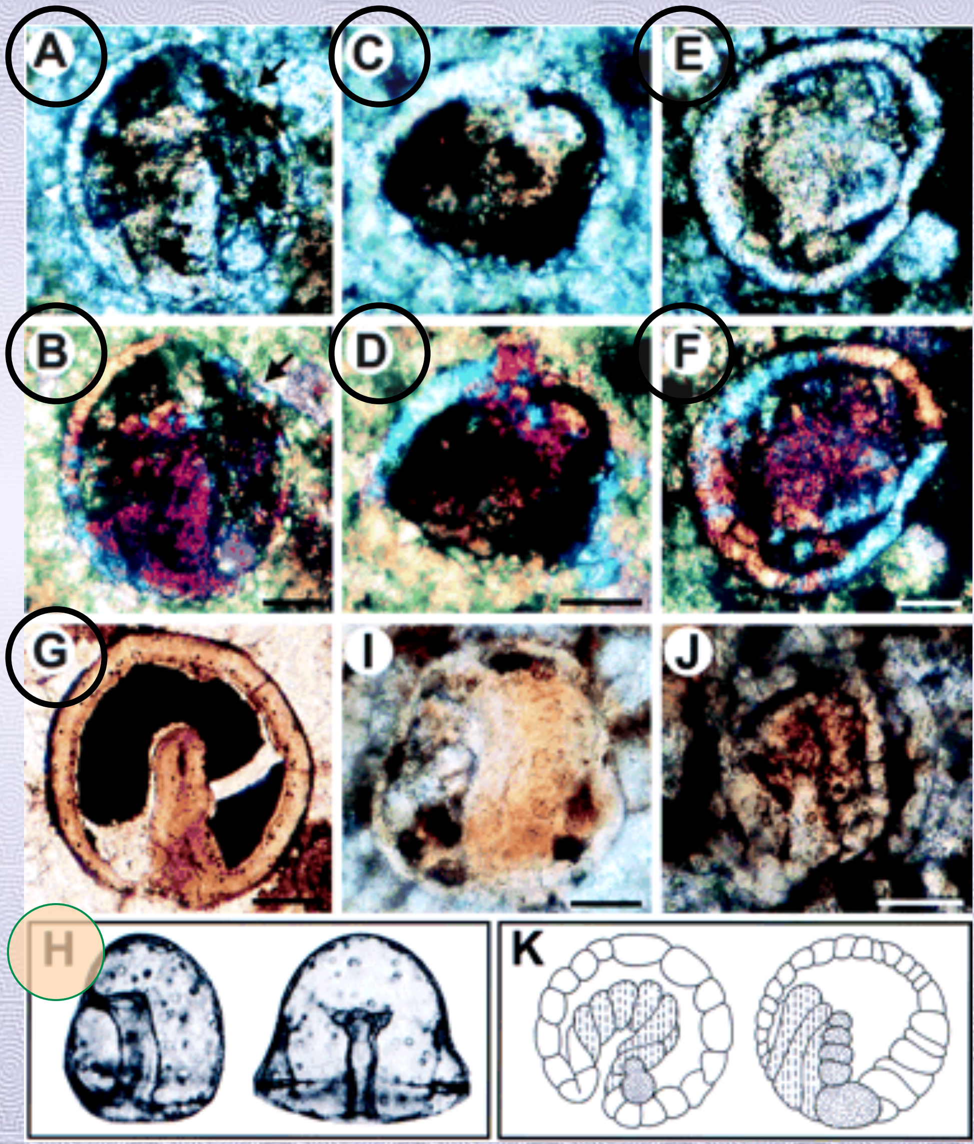
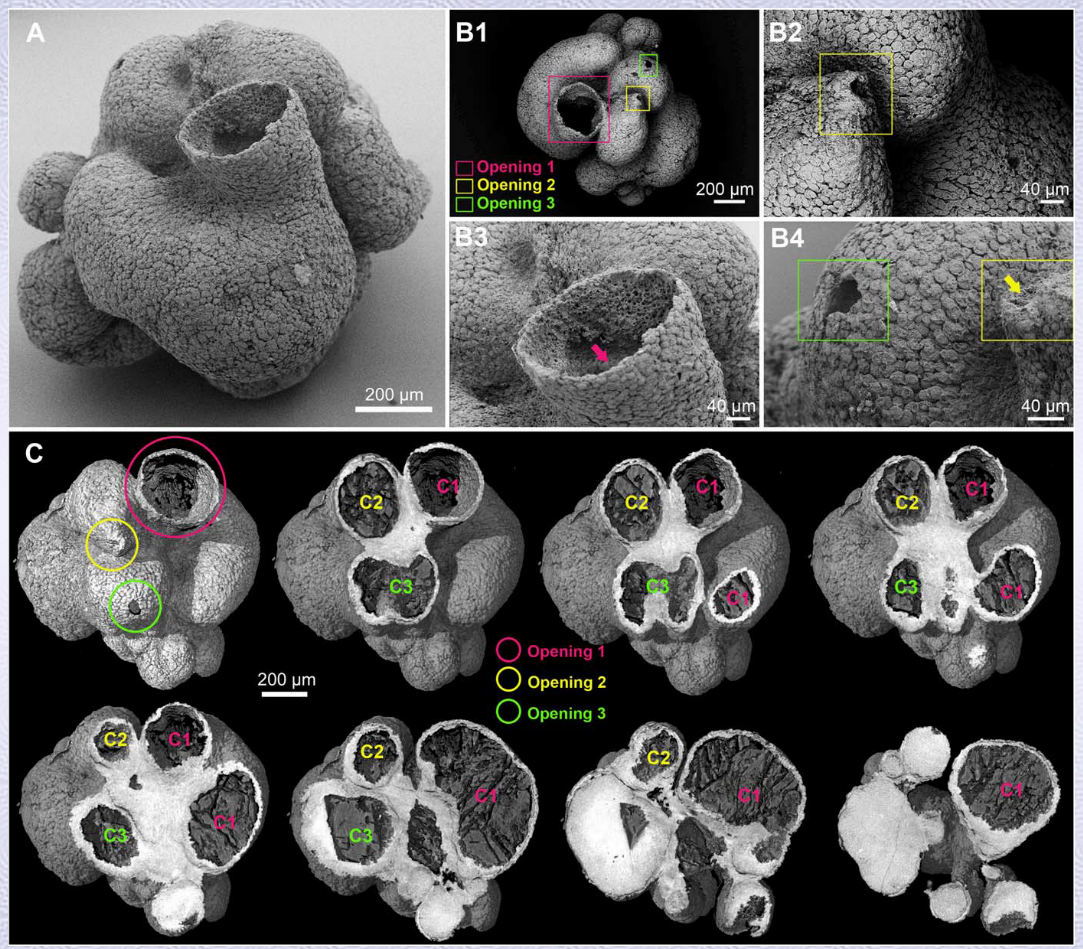


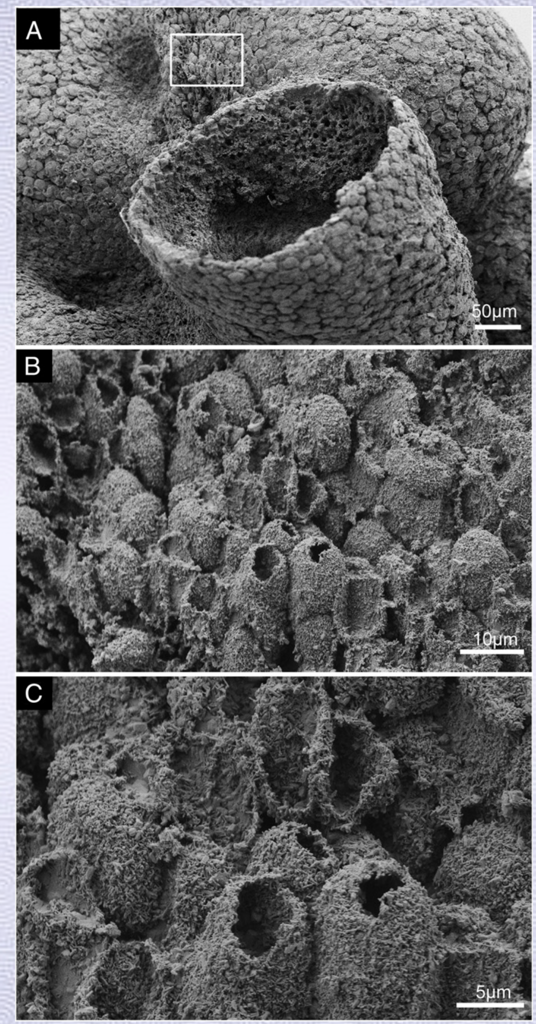
Fig. 3. Putative fossil embryos that resemble bilaterian gastrulae. (*A-G*) Fossils resembling deuterostome embryos; (*H*) Modern example (gastrulae of the sea urchin *Mespilia globulus*, ref. 49) In *A*, *C*, and *E*, the archenteron is bent to one side, and in *A* and *C* displays bilobed outpocketings

Chen et al., 2000

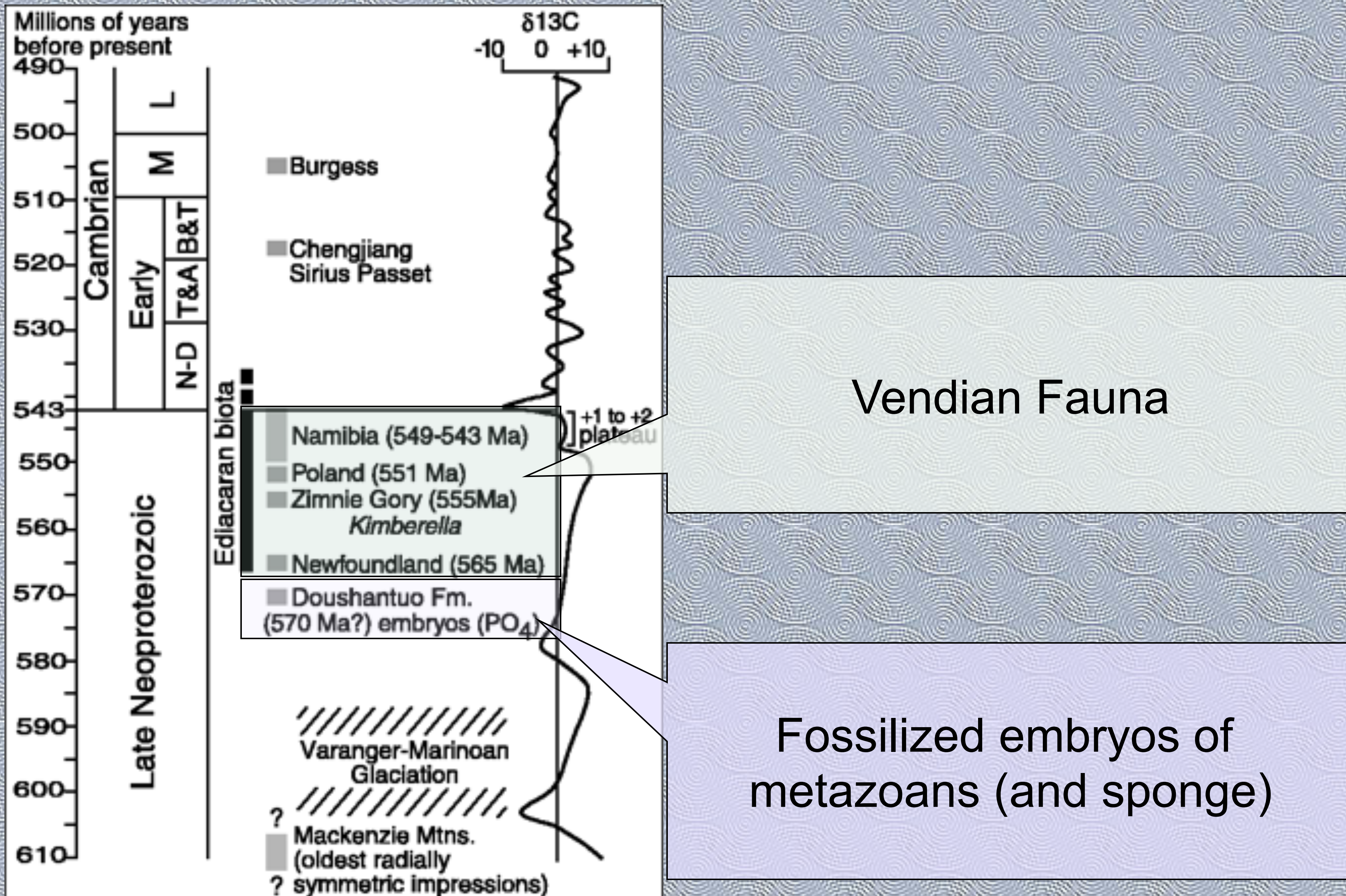
http://www.pnas.org/cgi/content/full/97/9/4457/F1

Earliest Fossil Sponge – Doushantou Fm.





Yin, Z., M. Zhu, E.H. Davidson, D.J. Bottjer, F. Zhao and p. Tafforeau. 2015. Sponge grade body fossil with cellular resolution dating 60 Myr before the Cambrian. Proceedings of the National Academy of Science (Early Edition). doi: 10.1073.



http://www.sciencemag.org/cgi/content/full/288/5467/841/F1

The Vendian

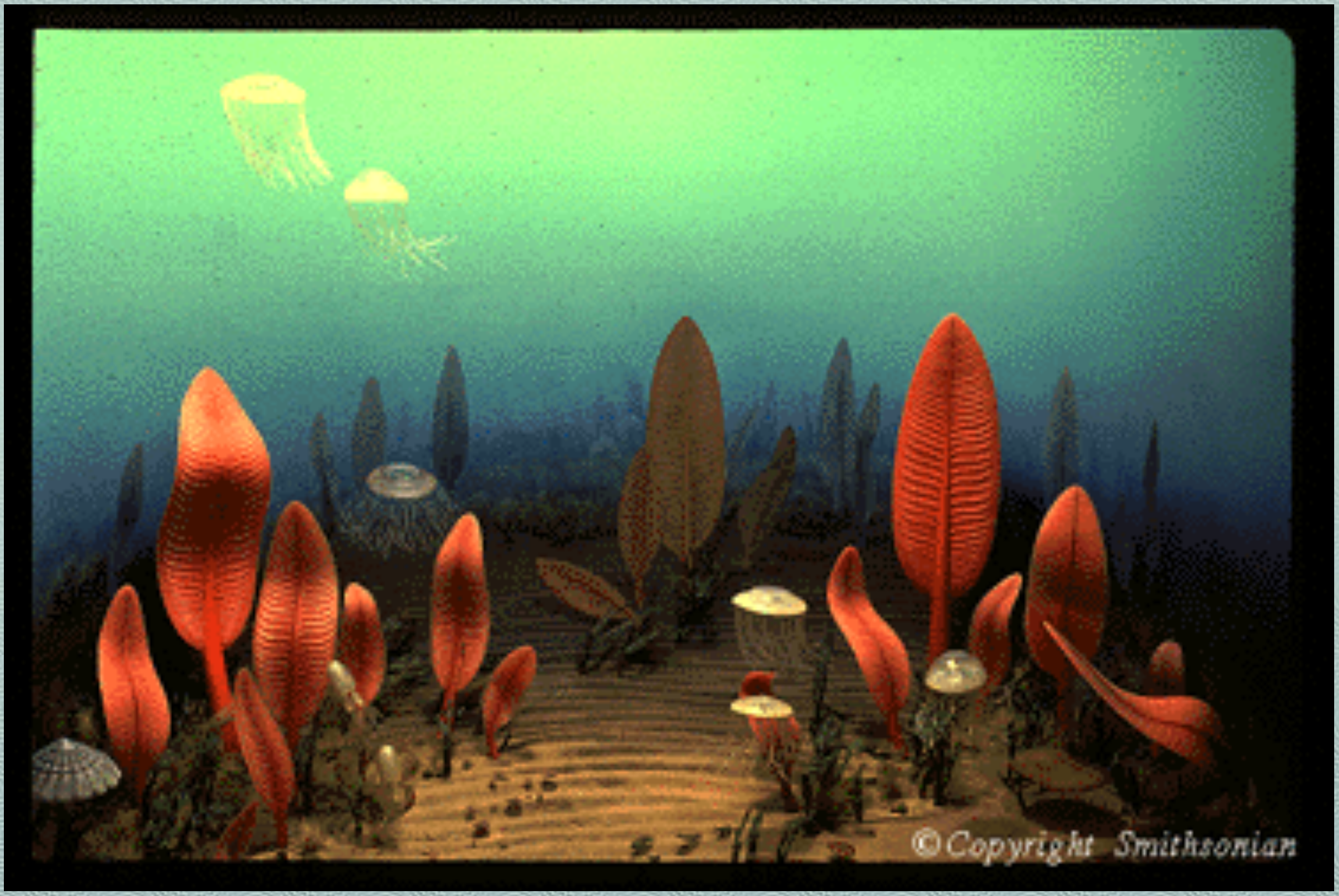
Worldwide distribution

The Vendian is the last time period before the Cambrian. It is characterized by the Vendian (or Ediacaran) Fauna.

http://www.mnh.si.edu/museum/

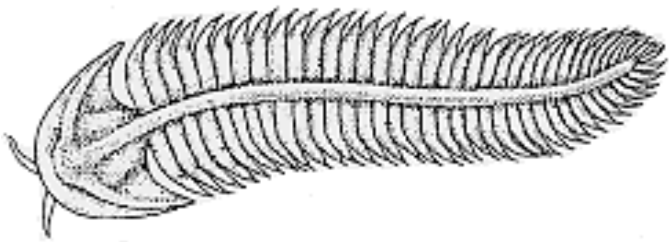
Vendian/Ediacaran Fauna

Late Proterozoic fossil impressions
of soft-bodied animals



http://www.mnh.si.edu/museum/

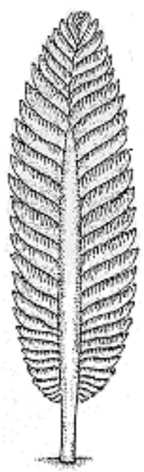
Vendian/Ediacaran Fauna



Forme vue comme un **arthropode** nu (sans squelette) ou une annélide

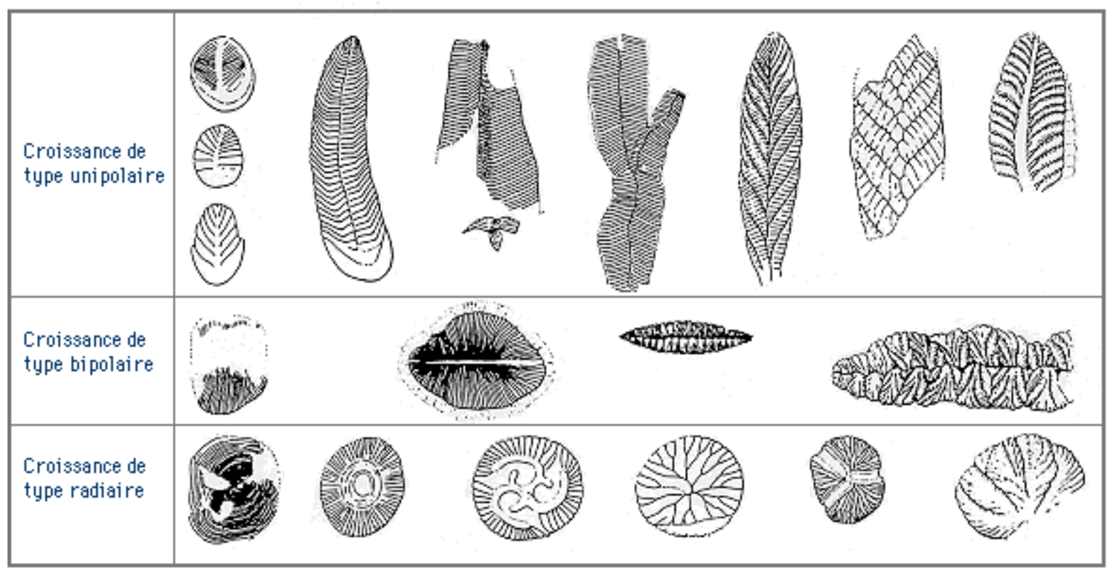
Forme interprétée comme une **méduse**, pouvant atteindre 1 mètre de diamètre

Formes discoïdes ne ressemblant à aucun animal connu.



Forme interprétée comme s'apparentant aux **coraux mous** (embranchement des Cnidaires), pouvant atteindre près de 1 mètre.

LES VENDOBIONTS *



* Nom dérivé du Vendien, dernier intervalle de temps du Protérozoïque où a vécu cette faune.
Source : A. Seilacher (1984), rapporté dans Gould, S.J. (1991), La vie est belle, Editions du Seuil.

http://nte-serveur.univ-lyon1.fr/nte/geosciences/biosphere/Liens/Lien%20Ediacara/Lien%20Ediacara.htm

Vendian
Fauna

Namibia

Swartpuntia germsi, fossil and a reconstruction of the youngest Ediacaran fossils from a recent find in Namibia.

http://geol.queensu.ca/people/narbonne/index.html

Vendian Fauna

http://www.accessexcellence.org/bioforum/bf02/lipps/bf02c2.html

http://perso.club-internet.fr/ciavatti/

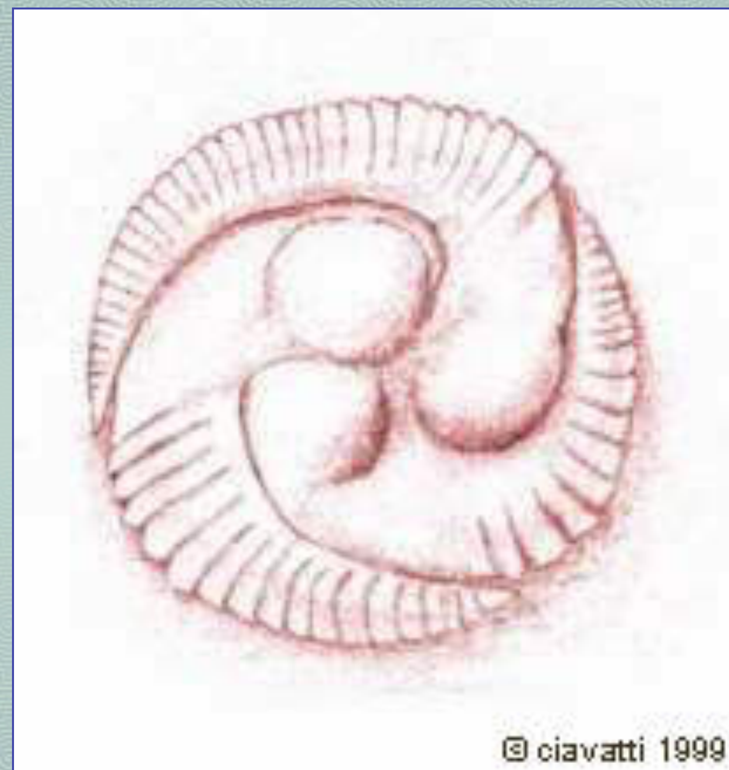
Vendian Fauna

http://www.ucmp.berkeley.edu/vendian/vendianlife.html

http://userpage.fu-berlin.de/~amadeusm/Erdgeschichte/ediacara.html

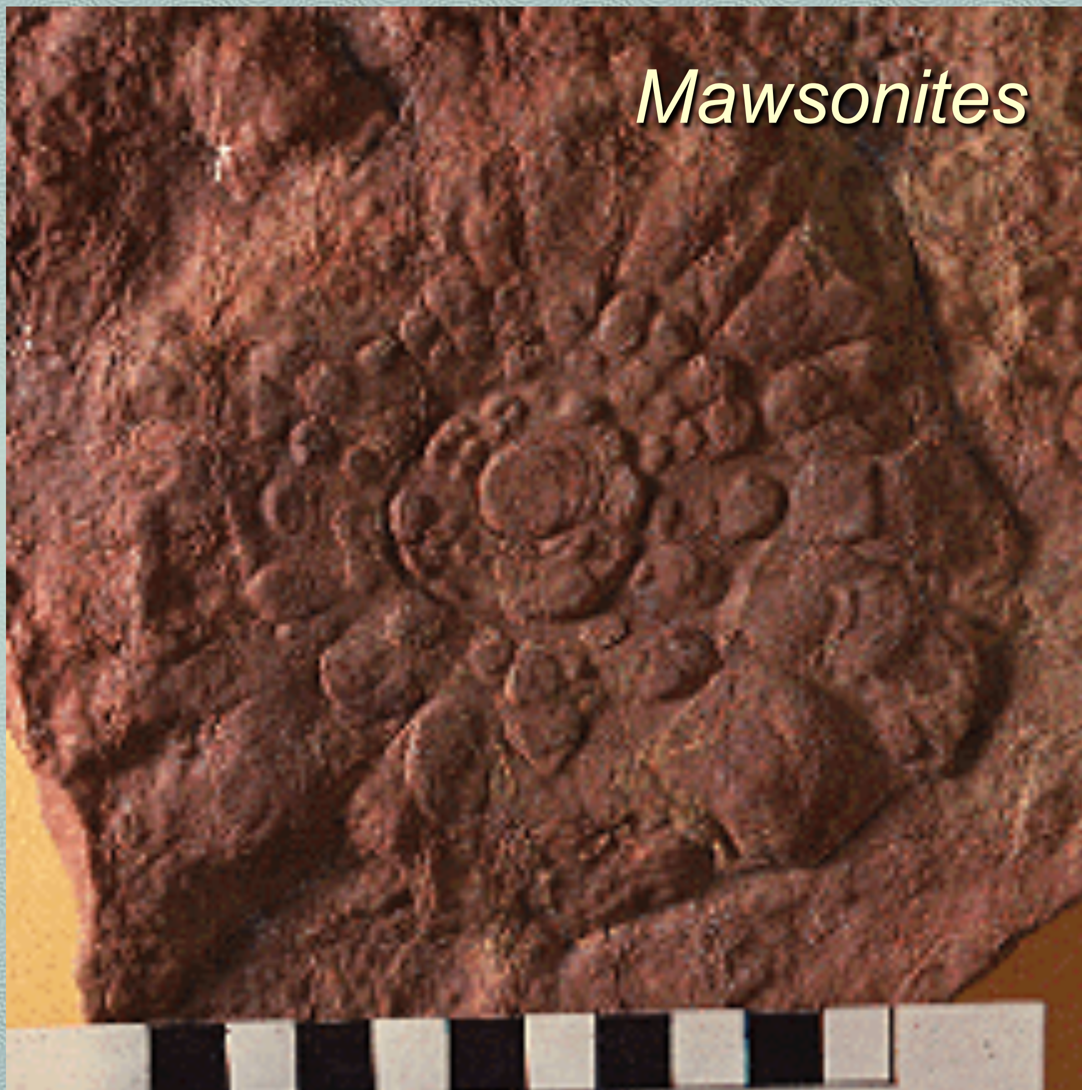
Vendian Fauna

http://www.ucmp.berkeley.edu/vendian/vendianlife.html



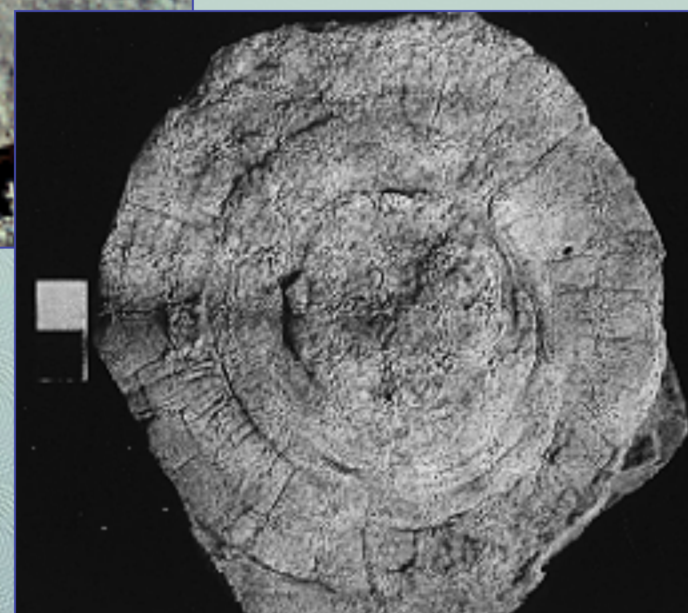
http://perso.club-internet.fr/ciavatti/

Vendian Fauna



http://members.tripod.com/~Cambrian/IntrotoEdiacaran

Vendian Fauna



Australia

http://members.tripod.com/~Cambrian/IntrotoEdiacaran

Vendian Fauna

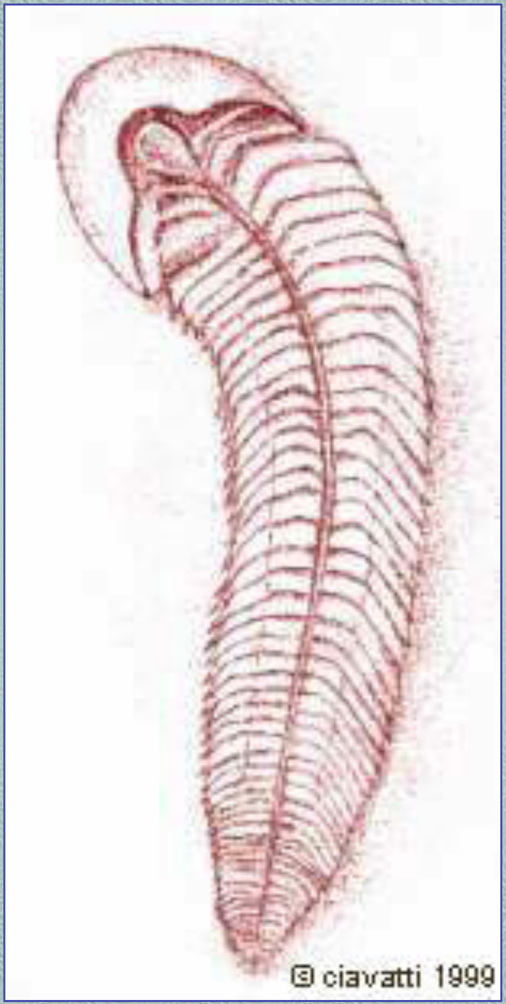
Parvancorina minchami Sprigg

Precambrian, Pound Quartzite. Flaggy beds, 100200 ft below top, Ediacara, South Australia. Collector: Glaessner, M.F.

Australia

http://www.yale.edu/ypmip/

Vendian Fauna

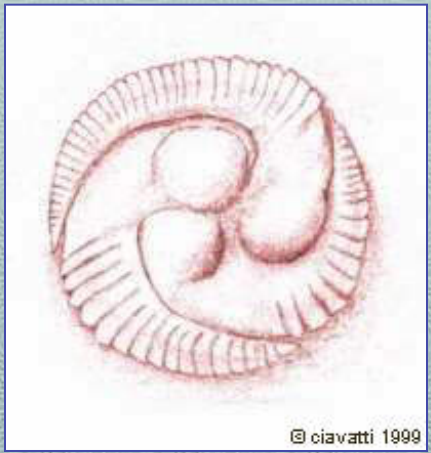


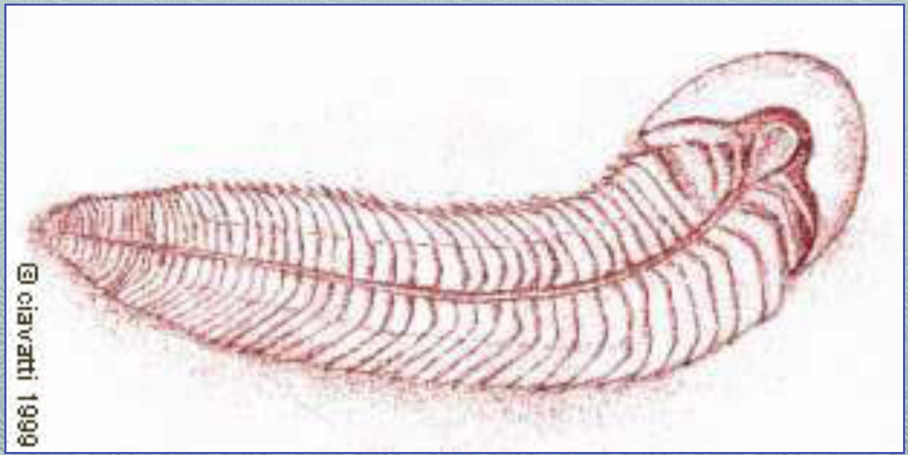
http://www.ucmp.berkeley.edu/vendian/vendianlife.html *http://perso.club-internet.fr/ciavatti/*

Vendian/Ediacaran Fauna

So what *were* these things?

- The most popular view is that these were the first large metazoans, and that at least some are ancestral to animal phyla.
- A now discredited hypothesis is that they were early fungi.
- A minority view is the "Garden of Ediacara" theory.





http://perso.club-internet.fr/ciavatti/