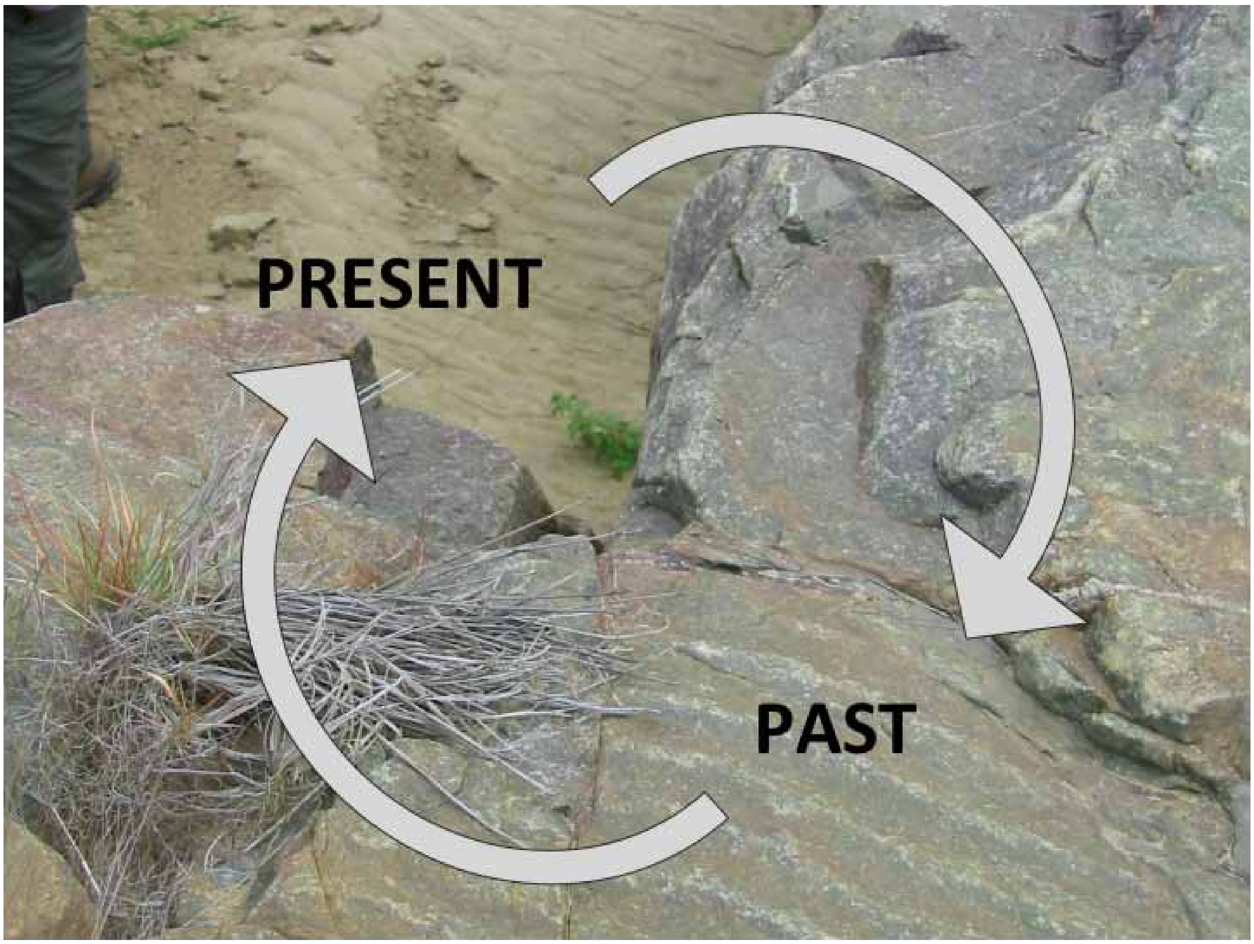
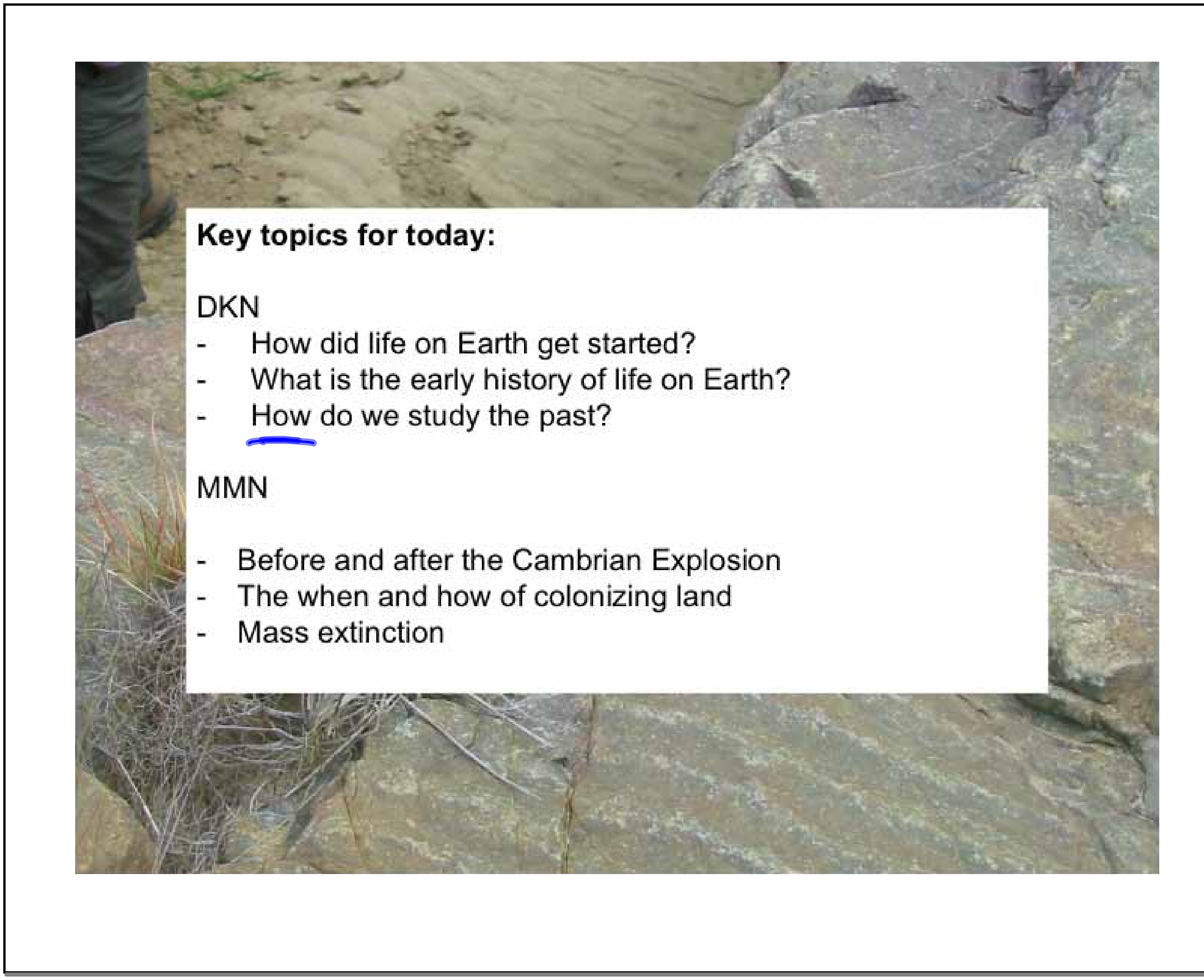
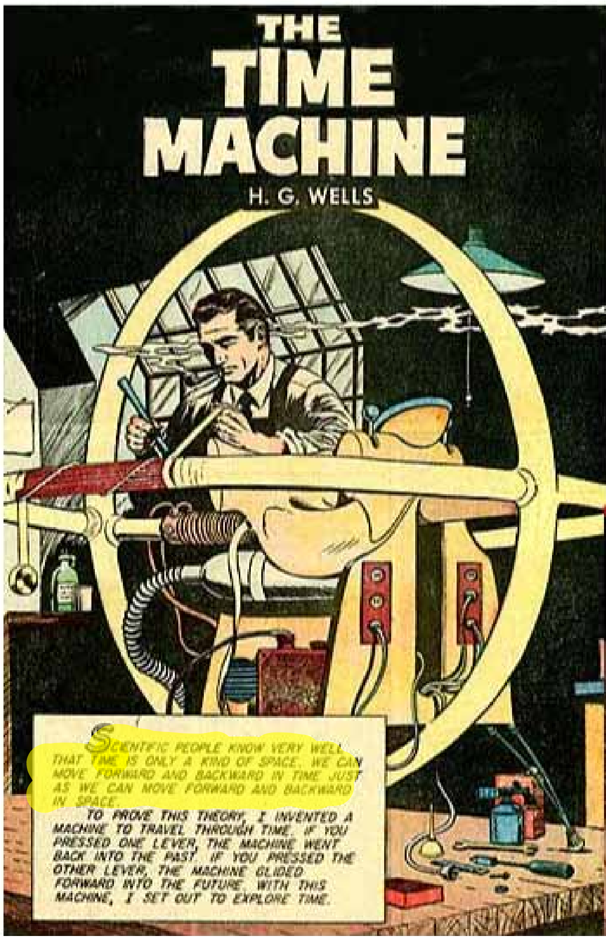

PRESENT
PAST


Key topics for today:
DKN
- How did life on Earth get started?
- What is the early history of life on Earth?
- How do we study the past?
MMN
- Before and after the Cambrian Explosion
- The when and how of colonizing land
- Mass extinction



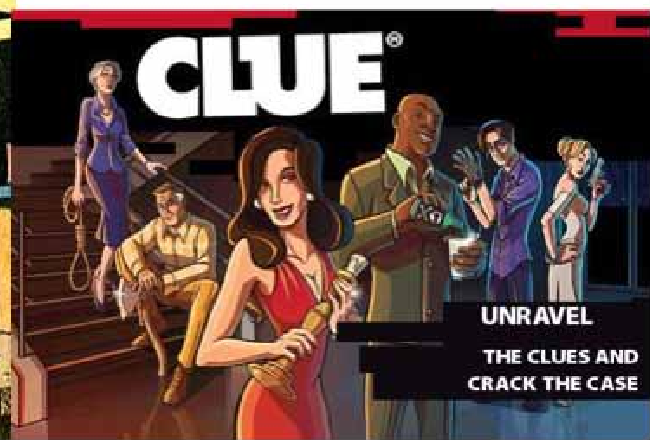
Who dunnit?

When?

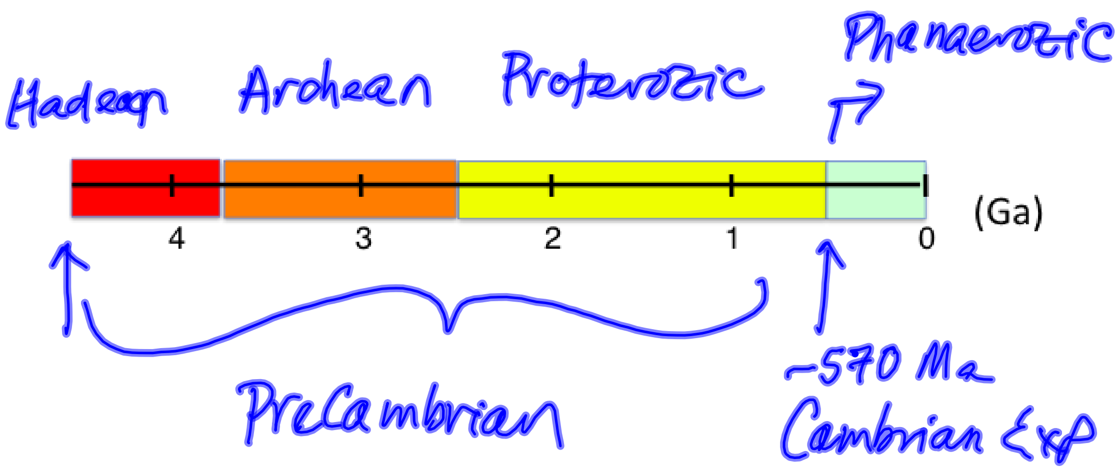
How

CHALLENGE

- Earth Exp 1
- Art/Science of Int.



Let's frame the problem:



Setting the boundary condition: Age of the Earth
Prof. Clair Patterson (Caltech, GPS)

1956 – determined age of Earth to be 4.55 ± 0.07 billion years

lead

^{204}Pb (primordial), ^{206}Pb, ^{207}Pb (decay products of ^{238}U, ^{235}U) but also primordial

$$\frac{R_{1a} - R_{1b}}{R_{2a} - R_{2b}} = \frac{(e^{\lambda_1 T} - 1)}{k(e^{\lambda_2 T} - 1)}$$

Canyon Diablo meteroite

a, b = different meteorites
$R_1 = Pb^{207}/Pb^{204}$, $R_2 = Pb^{206}/Pb^{204}$
$k = U^{238}/U^{235}$ today (137.8)
$\lambda_1 = U^{235}$ decay constant ($9.72 * 10^{-10}$ yr^{-1})
$\lambda_2 = U^{238}$ decay constant ($1.537 * 10^{-10}$ yr^{-1})

C. Patterson (1956) *Geochim. Cosmochim. Acta*

T: Age of Earth

Prof. Claire Patterson

How did life first emerge? (EXIST)

→ Need building blocks:

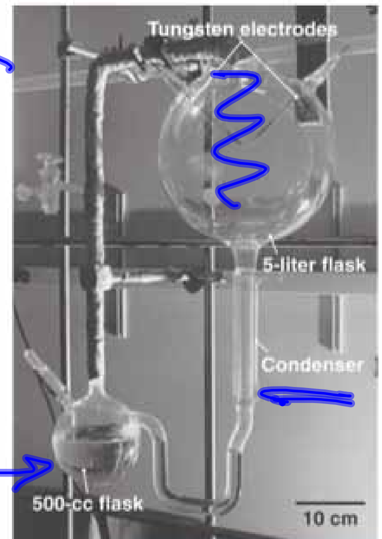
Pre-biotic soup

1953 Miller-Urey (U. of C)

Sim early Earth

(CH_4, NH_3, H_2, H_2O)

→ amino acid, nucleotides

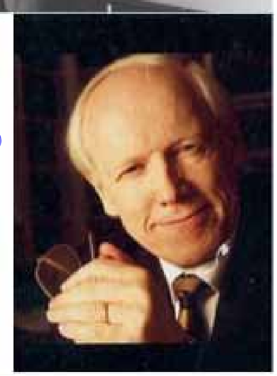


Mineral surface catalysis

1980s Günter Wächtershäuser (with Claudia Huber)

→ black smokers → pyrite FeS →

→ lipids, aa, nucleotides



http://exploringorigins.org

How did life first emerge? $\boxed{\text{(PERSIST)}}$

→ Need to be able to replicate ~~DNA~~ → RNA

Ribosomes

catalysis

DNA → RNA → Protein

Ribosome rRNA 50% protein 50%

T. Cech and S. Altman found evidence in 1980s (Nobel Prize) for:

Ribozyme : 1.) Stores genetic info

2.) Catalyzes making copies

http://exploringorigins.org

How did life first emerge? (EXIST & PERSIST EFFICIENTLY)

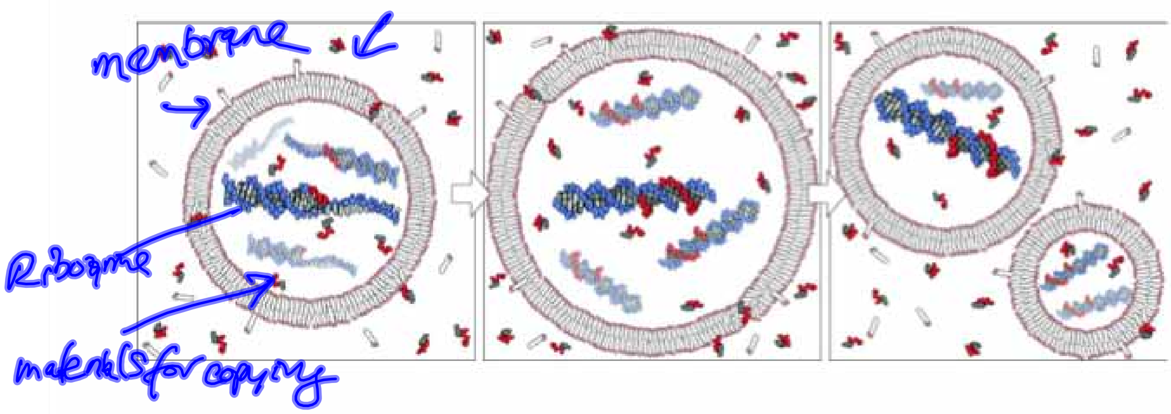
→ Solving the problem of separating self from rest: membranes

- Why is compartmentalization useful?

How did life first emerge? (EXIST & PERSIST EFFICIENTLY)

Solving the problem of separating self from rest: membranes

- Why is compartmentalization useful?



- How do vesicles grow? *J. Szostak (Harvard)*

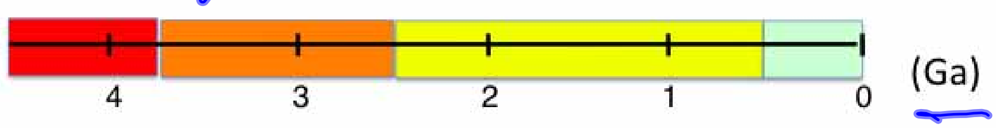
http://exploringorigins.org

Once the first life forms arose, then what happened/when?

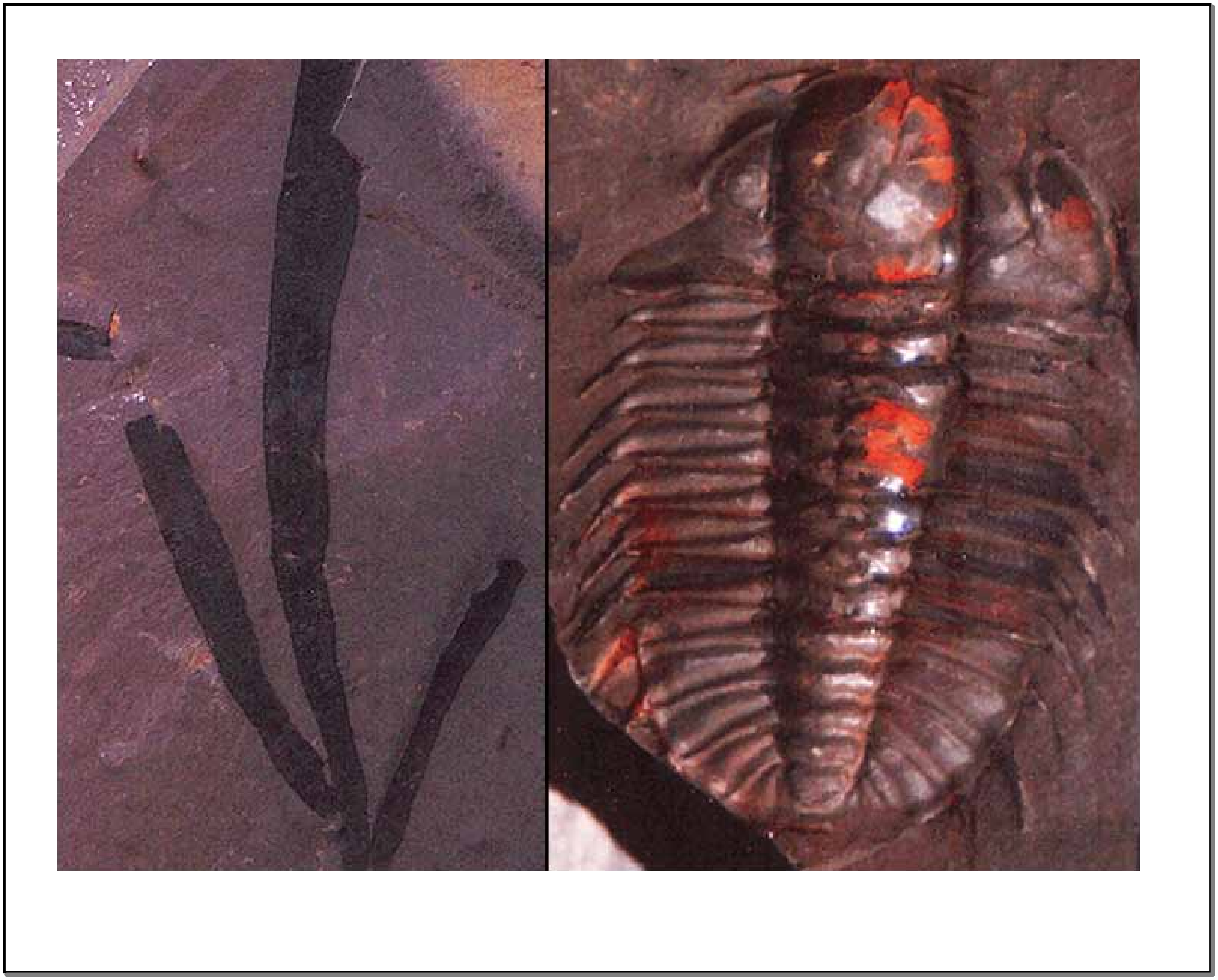
How do we know?

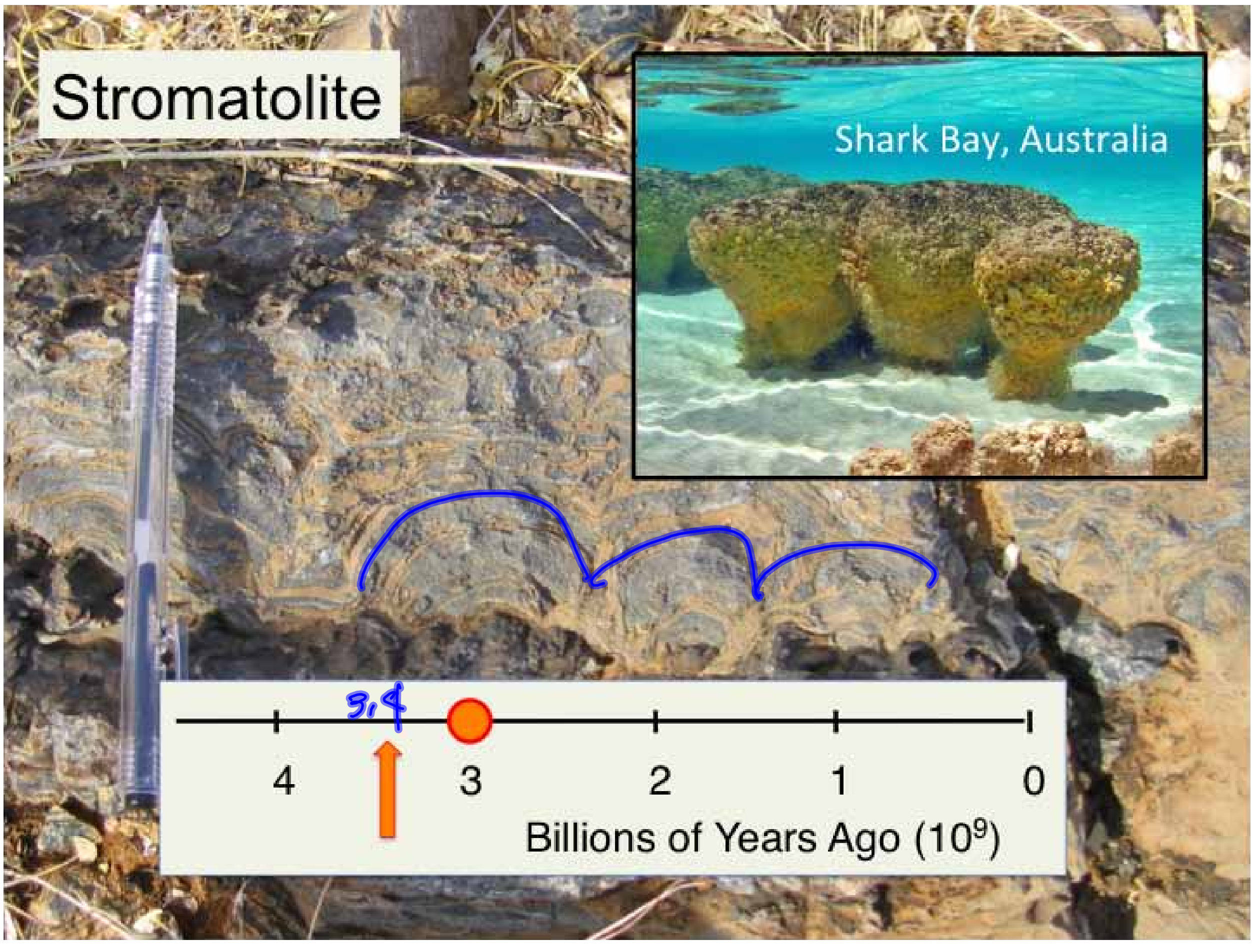
$\boxed{3.8}$

$\delta^{13}C$



Billions of Years

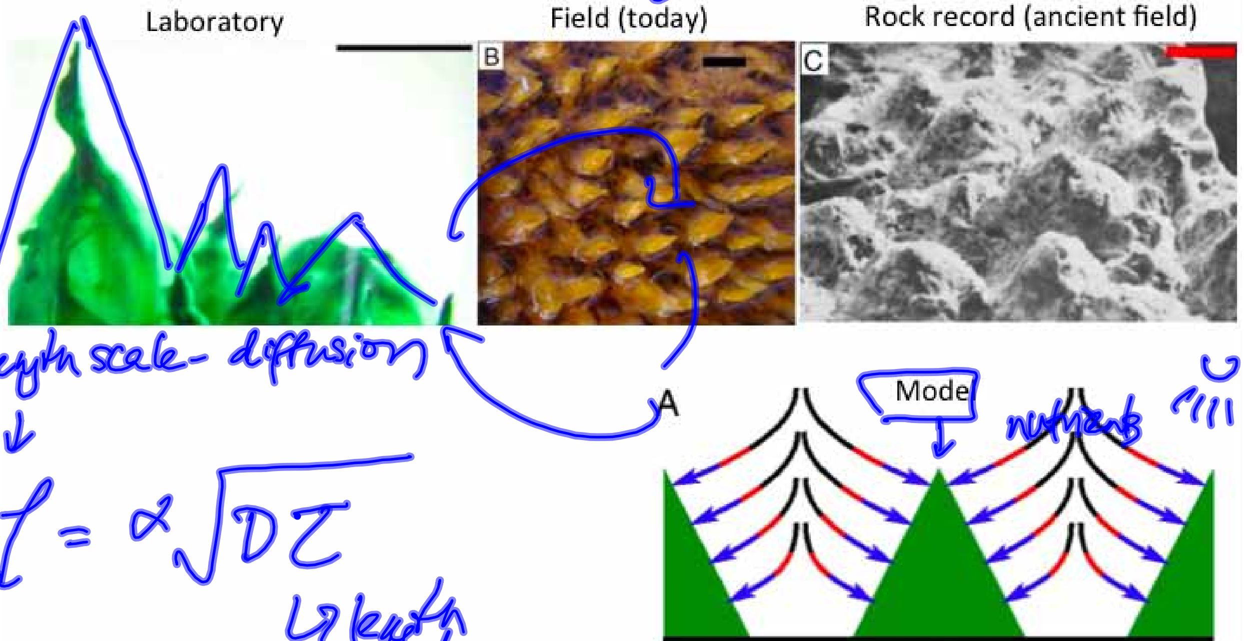



Stromatolite
Shark Bay, Australia
3.4
4
3
2
1
0
Billions of Years Ago (10^9)

Conical stromatolites

Iterations between Lab – Field - Modeling

Yellowstone



nutrients

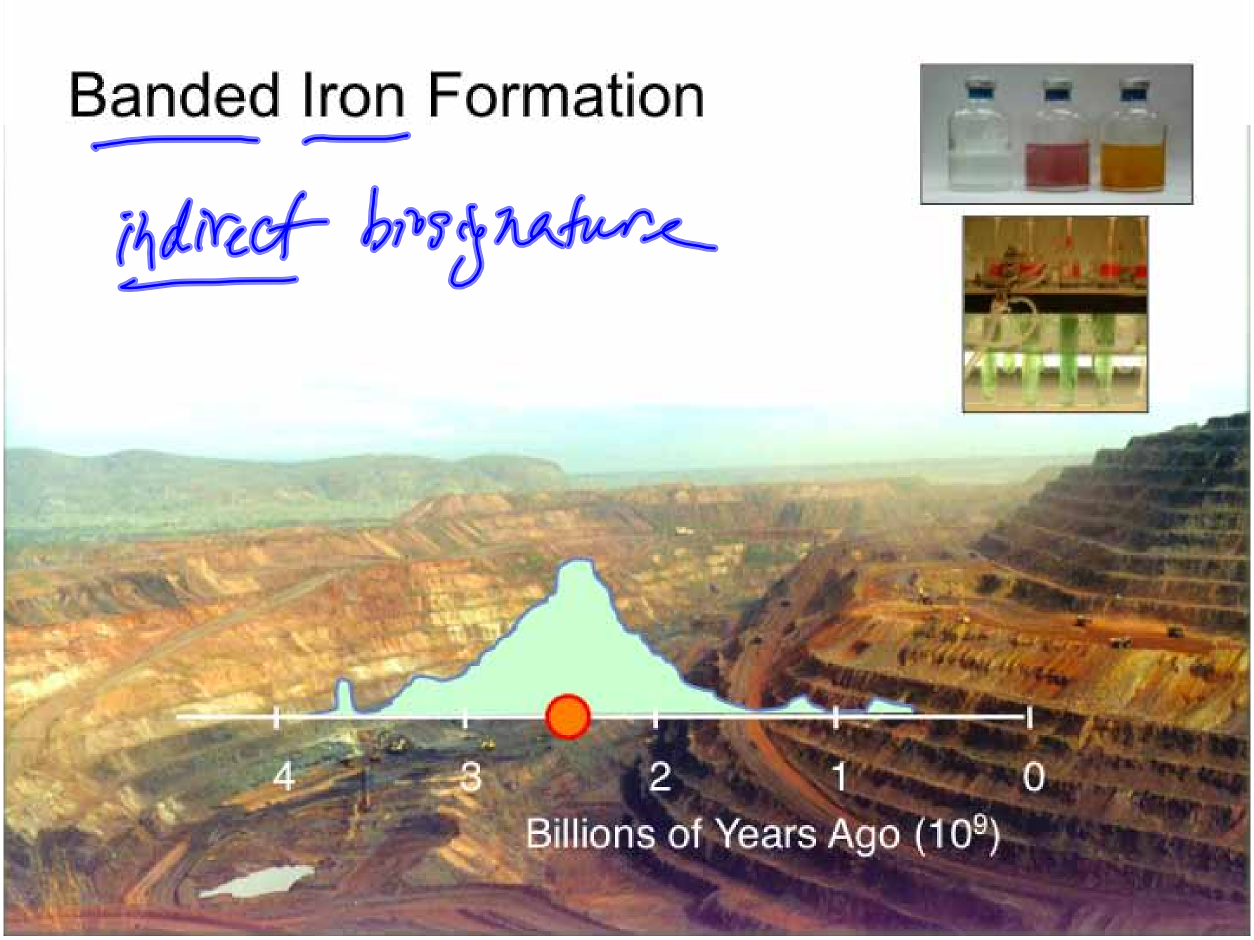
length scale - diffusion

$$\ell = \alpha\sqrt{D\tau}$$

↳ length day

photosynthesis

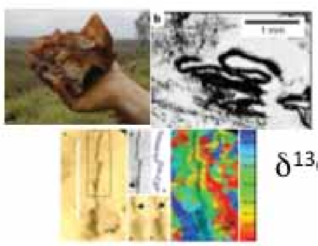
Petroff et al. (2010) Biophysical basis for the geometry of conical stromatolites PNAS 107:9956-9961


Banded Iron Formation
indirect biosignature
4
3
2
1
0
Billions of Years Ago (10^9)

What types of clues do we have to work with?

biosignatures

Morphological



Molecular

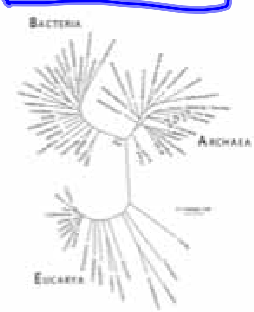
organic

$\delta^{13}C$ ‰, $\delta^{34}S$ ‰, $\delta^{56}Fe$ ‰

isotopic

constrain time → Rock record

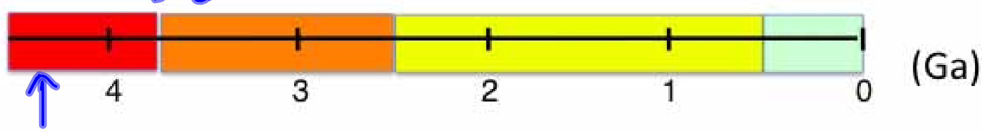
$\boxed{\text{Genomic}}$



phylogenetic → relative order

Some important early dates

Rise of O_2 atm



$\boxed{4.4}$ $\delta^{18}O$ content of zircons points to existence of water

Valley et al, A Cool Early Earth, (2002) Geology. 30: 351-354.

3.85 $\delta^{13}C$ content of graphite inclusions from Akilia, Greenland

Mojzsis et al (1996) Nature 384

3.46? Cyanobacterial fossils? [morphological fossils]

3.4 Stromatolite platforms in western Australia

Mojzsis et al (1996) Nature 384

Photosynthetic microbial mats

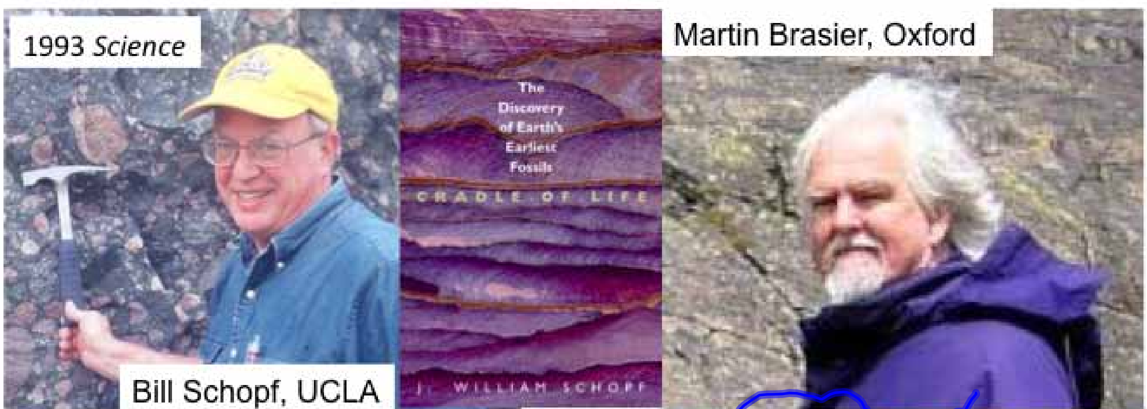
Tice and Lowe (2004) Nature 431:549

2.7? Sterols, first eukaryotes? [molecular fossils]

2.4 MIF $\delta^{33}S$, ^{34}S, ^{36}S reveals atmospheric oxygen

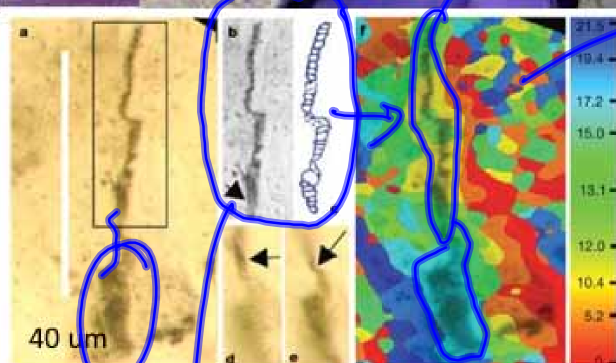
Farquar et al (2000) Science 289:756

The Archean Cyanobacterial Microfossil Debate



Apex Chert → Nat. Hist. Mus. London

- $\boxed{3D}$ optical microscopy
  e^-
- Raman spectroscopy
  - μ-scale composition



Schopf (1993) *Science*, Brasier et al (2002) *Nature*

The Molecular Fossil (a.k.a. “Biomarker”) Brawl

Prof. Roger Summons, MIT

Archean Molecular Fossils and the Early Rise of Eukaryotes

Jochen J. Brocks,[1,2]* Graham A. Logan,[2] Roger Buick,[1]
Roger E. Summons[2]

Molecular fossils of biological lipids are preserved in 2700-million-year-old shales from the Pilbara Craton, Australia. Sequential extraction of adjacent samples shows that these hydrocarbon biomarkers are indigenous and syngenetic to the Archean shales, greatly extending the known geological range of such molecules. The presence of abundant 2α-methylhopanes, which are characteristic of cyanobacteria, indicates that oxygenic photosynthesis evolved well before the atmosphere became oxidizing. The presence of steranes, particularly cholestane and its 28- to 30-carbon analogs, provides persuasive evidence for the existence of eukaryotes 500 million to 1 billion years before the extant fossil record indicates that the lineage arose.

Science (2000)

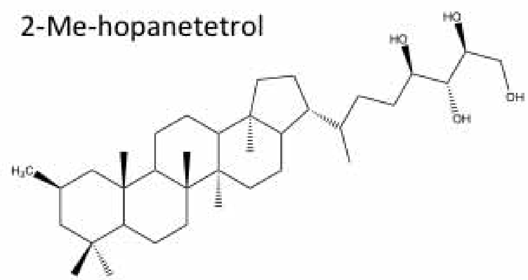
Top 10!!

Let's take a look at some of the key assumptions here…

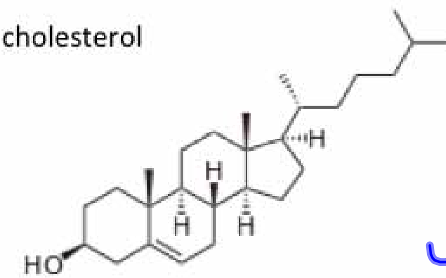
1.) cyanobacteria
2.) Because → O_2
∴

1.) only euks.

2-Me-hopanetetrol

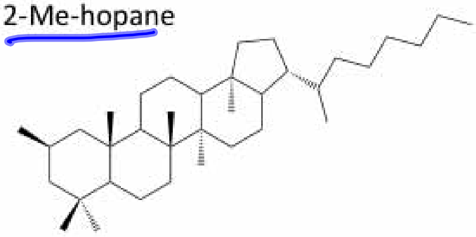


cholesterol

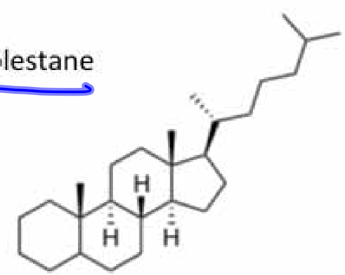


modern lipids

2-Me-hopane



cholestane



fossils

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Reassessing the first appearance of eukaryotes and cyanobacteria

Nature (2008)

Birger Rasmussen[1], Ian R. Fletcher[1], Jochen J. Brocks[2,3] & Matt R. Kilburn[4]

→ pushed back date
1st Euks → 1.78–1.68

What happened? What went wrong?

Time X living cell

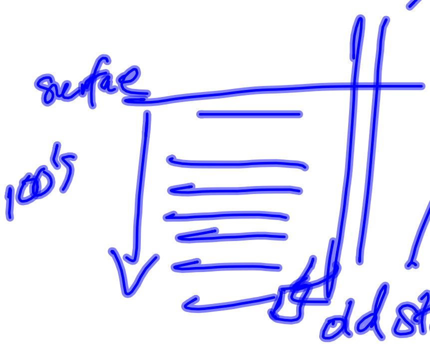
molecules (hopanes, steranes)

diagenesis / burial

Rock

1.) contaminated.

2.) oil inclusions was not "syngenetic"



organic geochemist

identify biomarkers

Technological advance behind the change in interpretation?

Chief Engineers will talk tomorrow April 11th
Kubota Auditorium → Guggenheim Building!

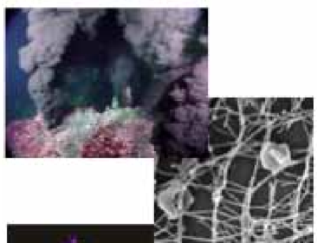
Topic for Thursday: Can we define generic "biosignatures" that could help us search for life on other planets? What would you look for if you were the chief scientist?

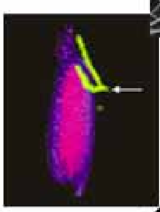
Key concepts for today – Part 2:

1. Before and after the Cambrian Explosion
2. The when and how of colonizing land
3. Mass extinction

Multicellular Archaea

Pyrodictium occulatum

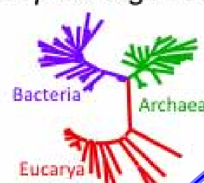




MEASURING RELATEDNESS THROUGH SEQUENCE

rRNA

Slowly changing deep divergences



Do all mitochondrial genes have the same sequence? NO!

QUICKLY EVOLVING

1) MODERN HUMANS - 167,000 yr

2) SPECIATION?

Hawaiian squid

[3-4 million years old]

Have populations evolving on opposite sides of Oahu diverged into two species?

2 species

Today's lecture:

Key concepts for today – Part 2:

1. Before and after the Cambrian Explosion
2. The when and how of colonizing land
3. Mass extinction

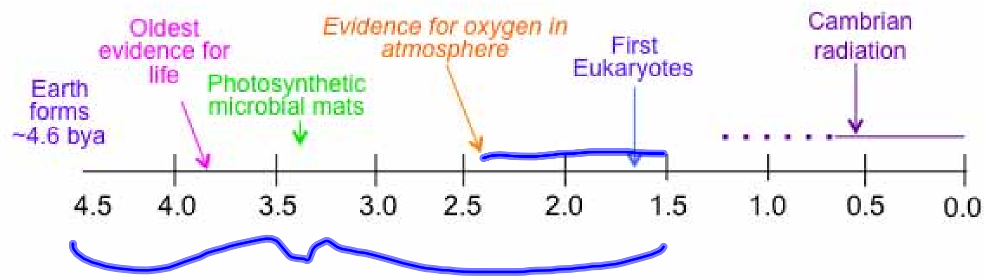
Animal & Plant Diversification

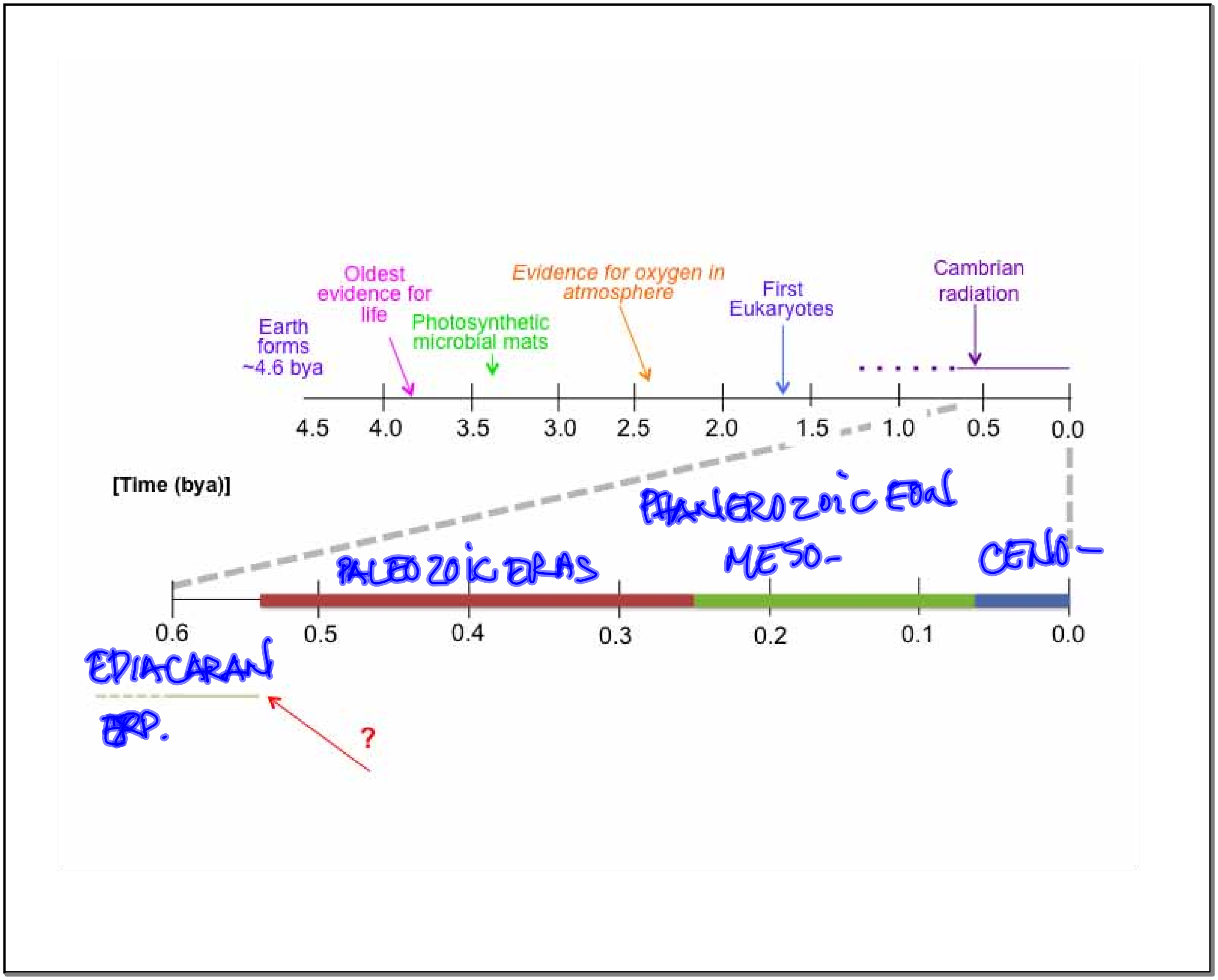
<u>*Actually – two questions*</u>:

1. when 1st appeared?
2. when radiate?

Evidence:

1. FOSSILS - MODERN FORMS
2. SEQUENCE DATA - INFERENCE


Oldest evidence for life
Evidence for oxygen in atmosphere
First Eukaryotes
Cambrian radiation
Earth forms ~4.6 bya
Photosynthetic microbial mats
4.5 4.0 3.5 3.0 2.5 2.0 1.5 1.0 0.5 0.0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Photosynthetic microbial mats
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
[Time (bya)]
PHANEROZOIC EON
PALEOZOIC ERAS
MESO-
CENO-
0.6
0.5
0.4
0.3
0.2
0.1
0.0
EDIACARAN
?

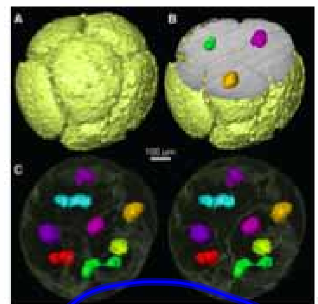
Ediacaran - oldest definite multicellular life

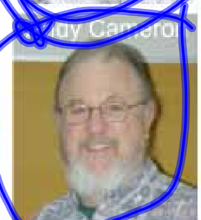
Evidence:

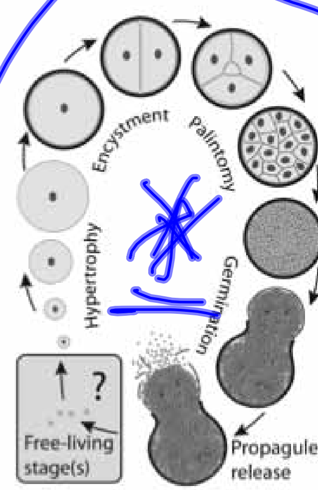
1. fossils
2. modern forms - EXTANT PROTIST LEAVE THE SAME PATTERNS

Ediacaran Doushantou Formation, China

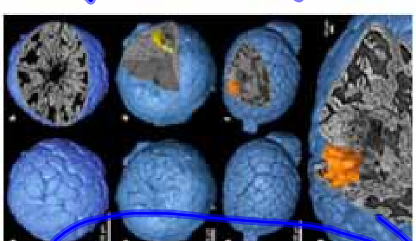
XRAY TOMOGRAPHIC MICROSCOPY
MEGABACTERIA, EMBRYOS, PROTISTS
~570 mya



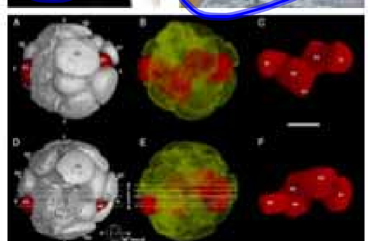




embryos



Donoghue et al., 2006



Chen et al., 2009

Huldtgren et al., 2011

PROTISTS

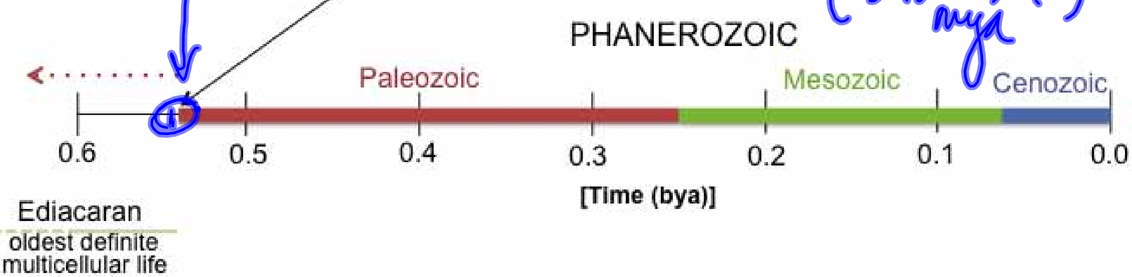
Animals - Ediacaran

Evidence – Gene Sequences

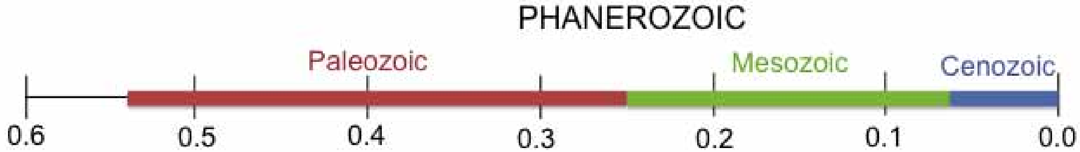
'molecular clock' -
gene sequence - 1.2 - 1.0 bya

620

CAMBRIAN EXPLOSION - FOSSILS
(~570 - 540) mya



What was the Cambrian Explosion (or radiation)?



NEARLY ALL ~35 ANIMAL BODY PLANS AROSE 20-30 my

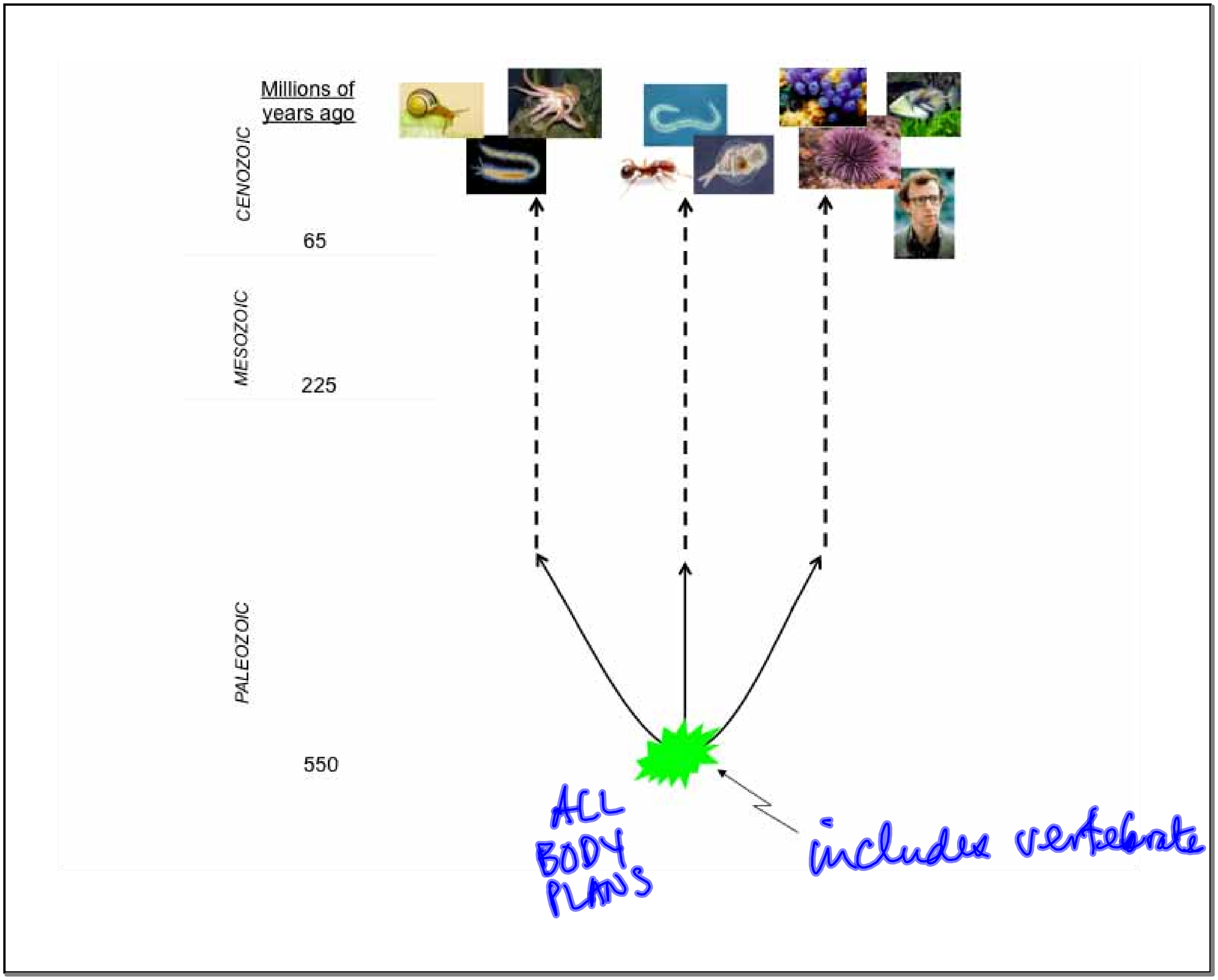
BODY PLAN - DIFFERENT SOLNS

WHY ONLY 35? - "morphospace"

\# cells, cell type, symmetry, # appendages

WHY ALL AT ONE TIME?

punctuated equilibrium


Millions of years ago
CENOZOIC
65
MESOZOIC
225
PALEOZOIC
550
ALL BODY PLANS
includes vertebrate

Why all at one time? ?

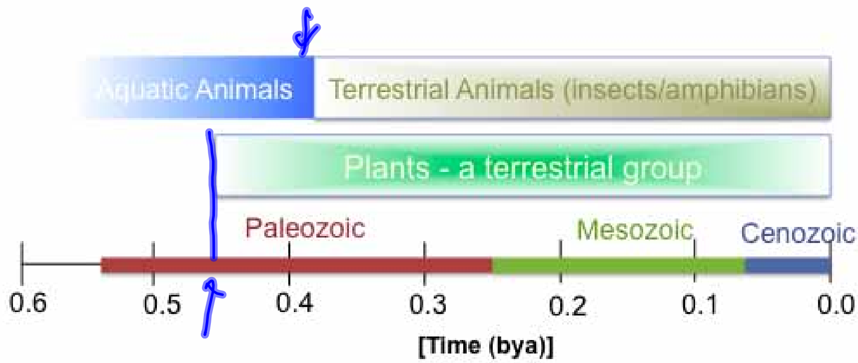
ΔO_2
critical position of continents
↑ Ca^{++} in seawater

Evolution of gene clusters –
'hox genes' – developmental regulation

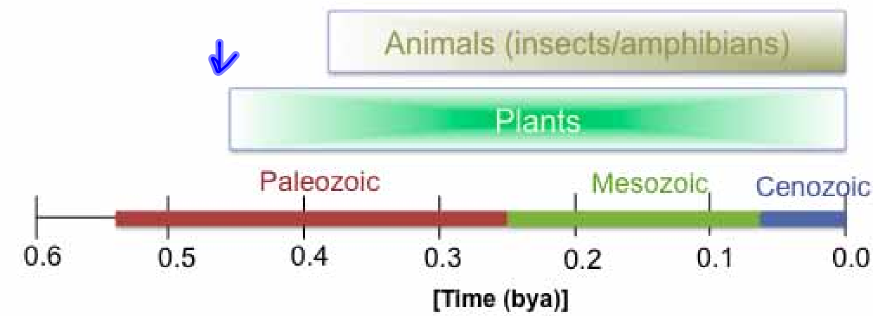
ALL

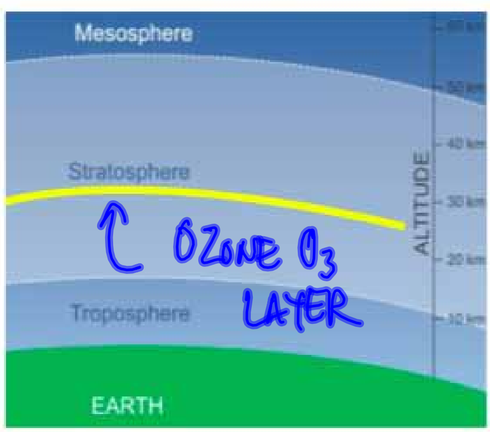
Plants?

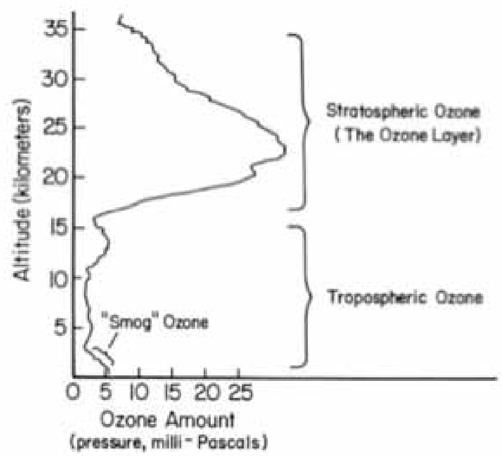
The Water-to-Land Transition



The Water-to-Land Transition







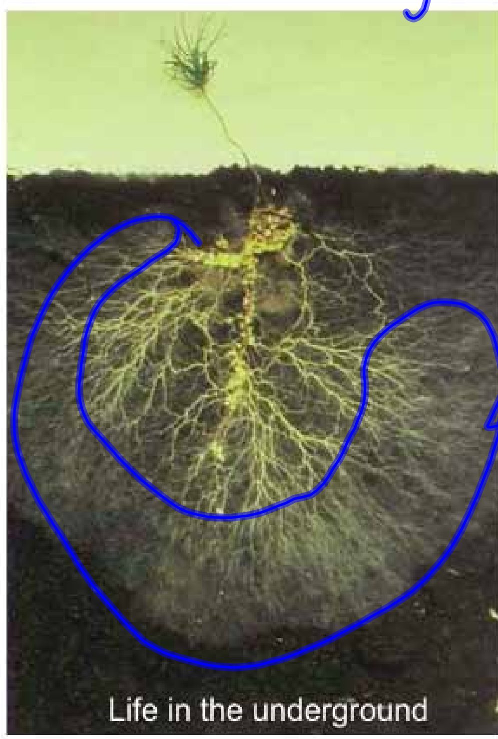
Plants on land
symbiosis ← mycorrhizae

mobilize P in soil

>80%

when absent → lost

Arabidopsis

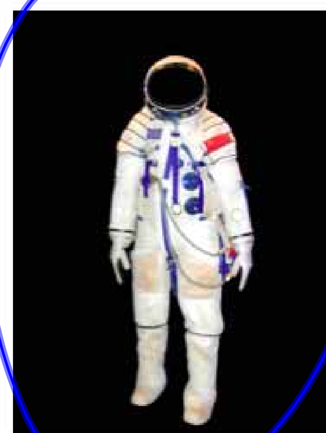


fungus

Key aspects that drive selection in the terrestrial environment –

The medium is:

- non- ~~sp~~' ~~sy~~ supportive
- dry



Both plants and animals must:

- support
- gas exchange
- reproduce
- avoid desiccation

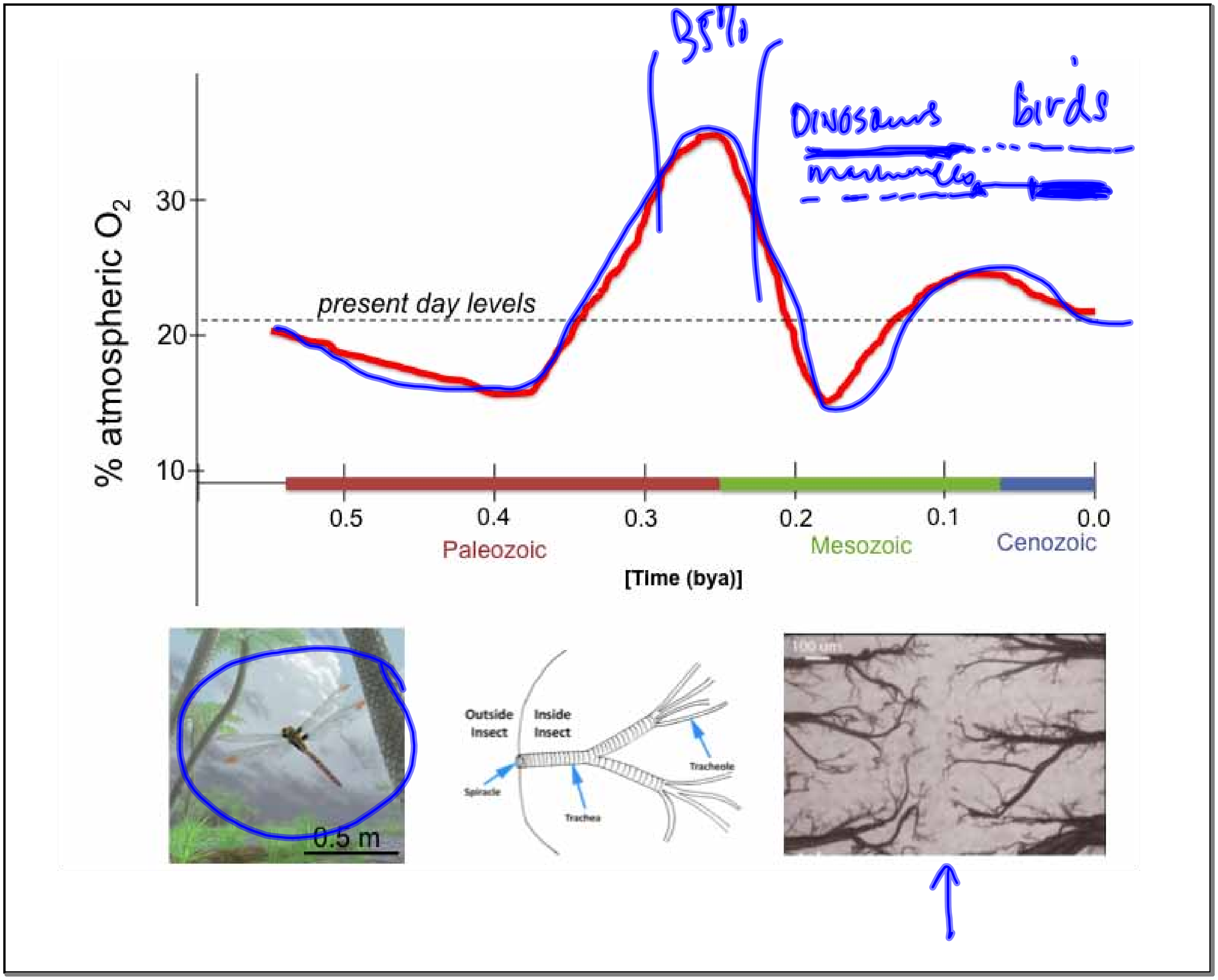
Animals 'fishes'

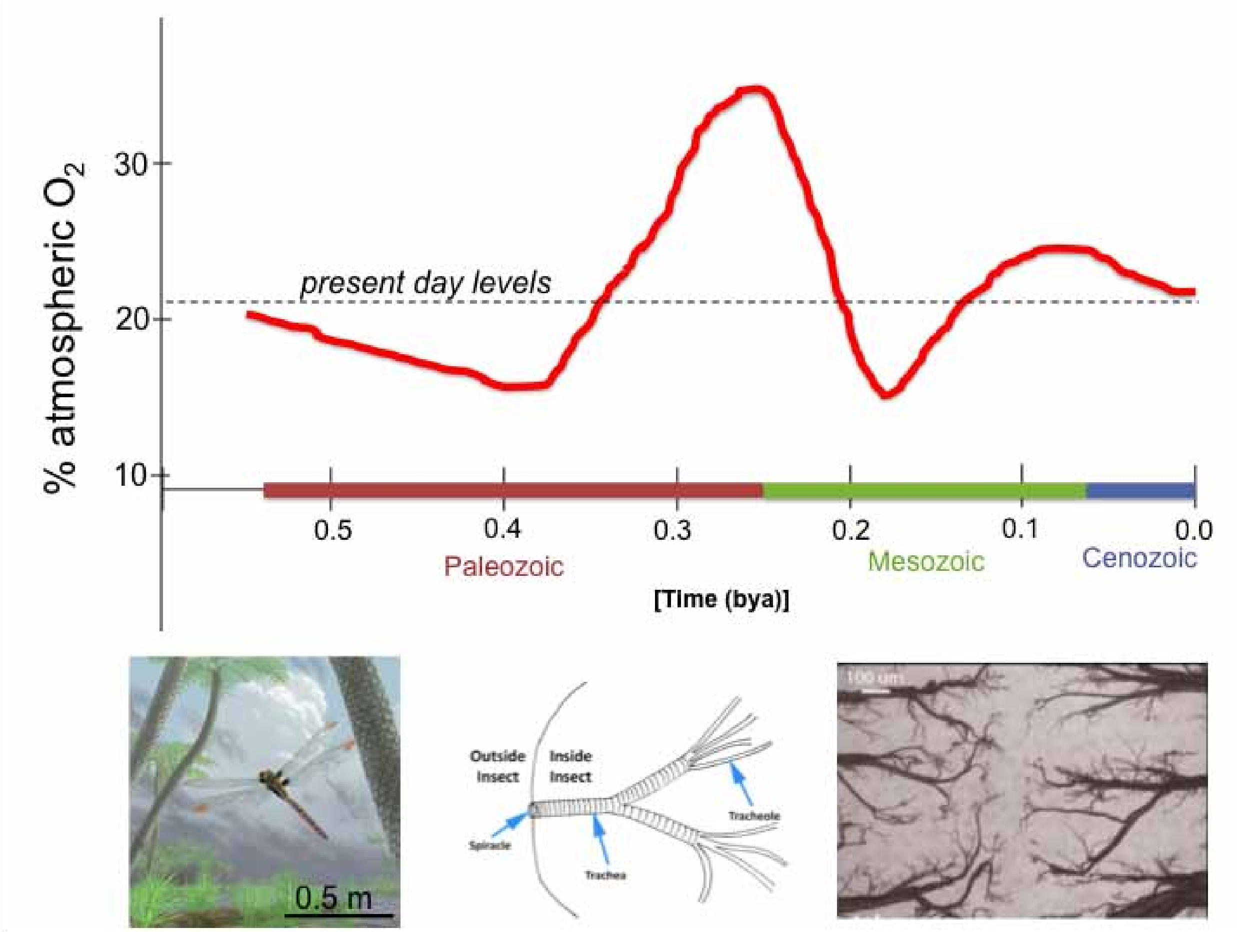
Next lecture – some detail about how they do this?

At the end of the day - extant forms

Animals > 90% in oceans
> 96% invertebrates

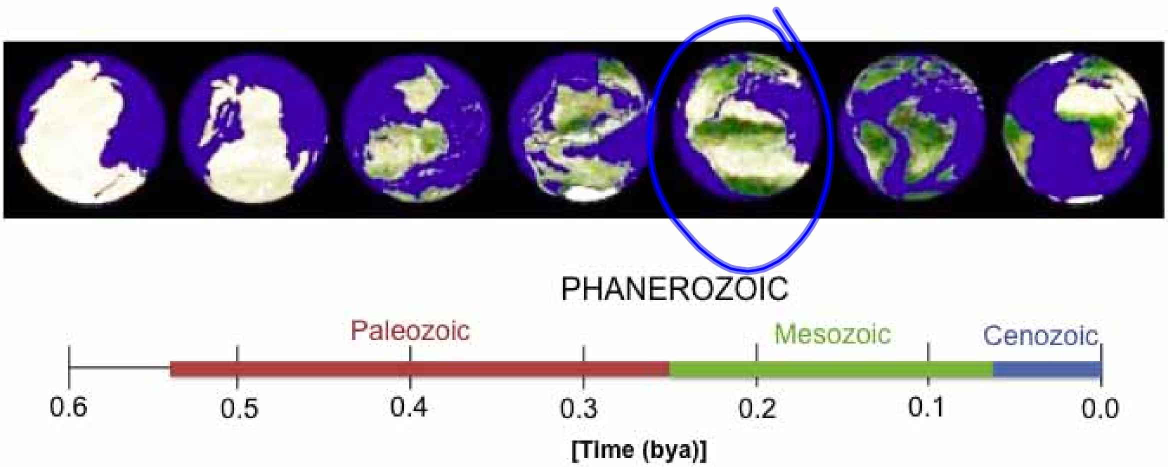
Plants > 90% terrestrial


35%
Dinosaurs
birds
mammals
% atmospheric O_2
30
20
10
present day levels
0.5
0.4
0.3
0.2
0.1
0.0
Paleozoic
Mesozoic
Cenozoic
[Time (bya)]
0.5 m
Outside Insect
Inside Insect
Spiracle
Trachea
Tracheole
100 um

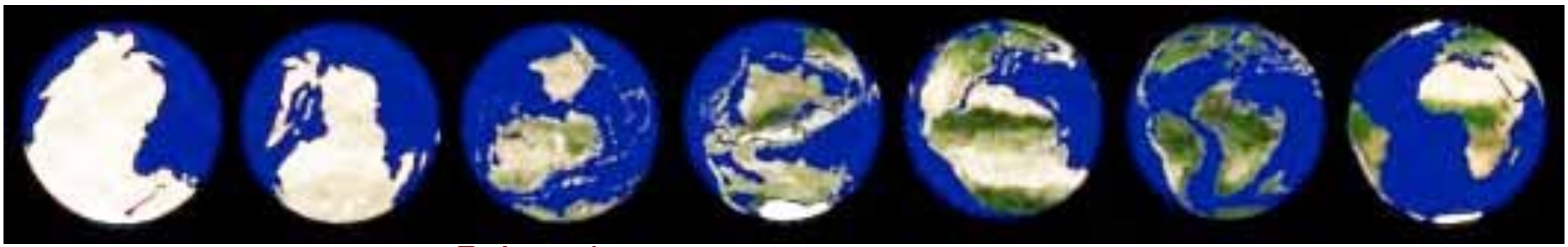

% atmospheric O_2
30
20
10
present day levels
0.5
0.4
0.3
0.2
0.1
0.0
Paleozoic
Mesozoic
Cenozoic
[Time (bya)]
0.5 m
Outside Insect
Inside Insect
Spiracle
Trachea
Tracheole

Movie of continental drift

Plate tectonics and continental drift



Prevalent theories – causes of Phanerozoic extinctions



Paleozoic Mesozoic Cenozoic

0.6 0.5 0.4 0.3 0.2 0.1 0.0

Drop in sea level
due to plate tectonics
~ 50% extinction
of animals & plants

Drop in sea level
due to glaciation
~ 50% extinction

Volcanic activity,
formation of the supercontinent
70 – 90% extinction

Central Atlantic magmatic
activity, global warming,
atmospheric CO2
extinction

Anthropogenic

Asteroid-induced,
supercontinent breakup
70-90% extinction

Golden toad
Central America
Once abundant, not seen since 1980

>32% threatened

>43% in decline

Climate Δ – imbalance with microbes

~~eg~~ chytrid fungi

iridoviruses

protection in skin – bacteria

PROF LUNCH WITH OMBUDSMEN
EACH WEEK

→ GIVE THEM YOUR IDEAS

ABOUT Bi1