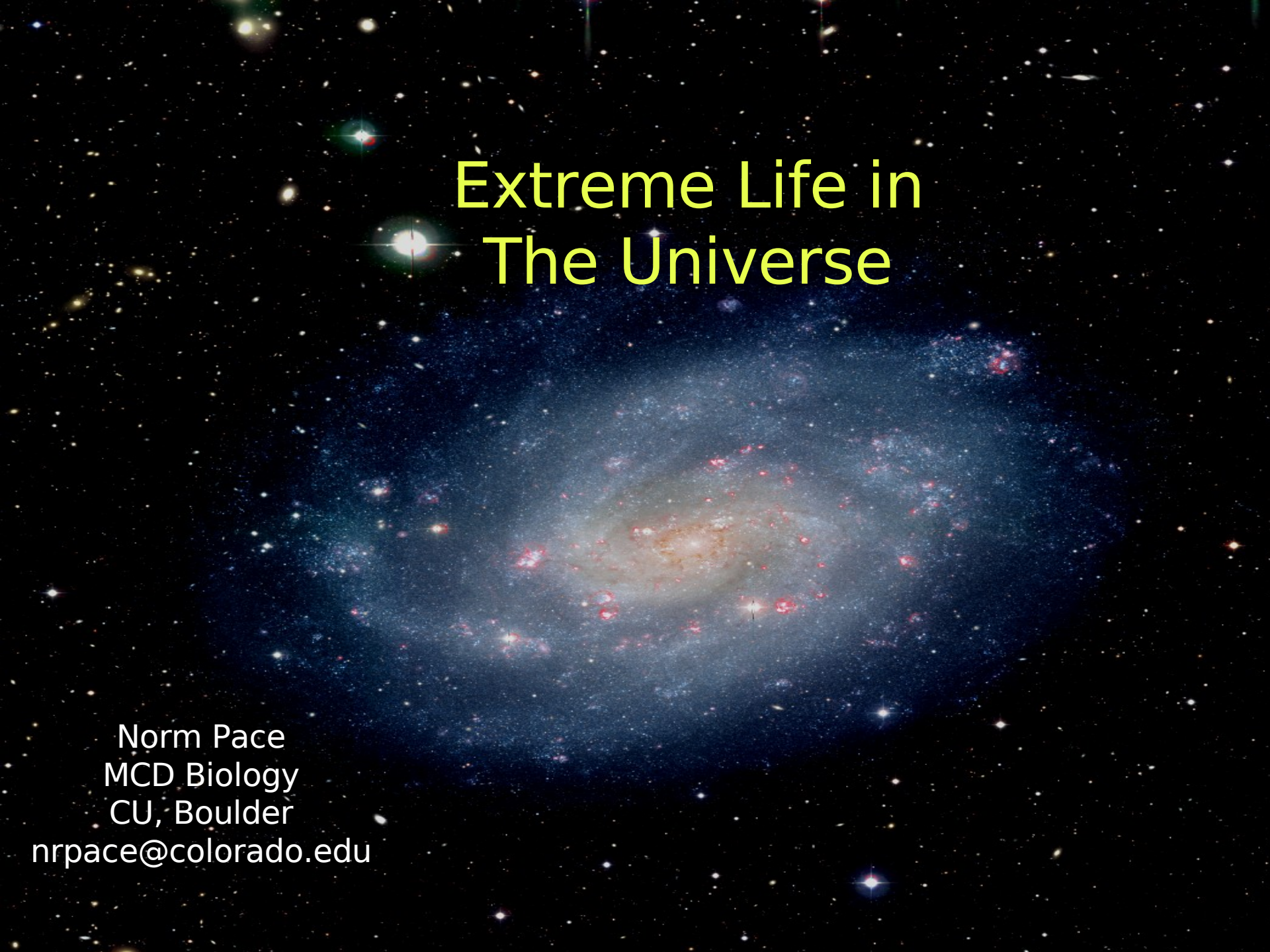
Extreme Life in The Universe



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Outline

- Current perspective on the history of life

- Molecular phylogeny: Key to understand biological diversity - and to map the course of evolution

- When did the modern kind of eukaryotic cell come to be?

-bang

What is Life?

What is Life?

NP's definition: Life is self-replicating, evolving, organic chemistry.

Three records of life's history

1. **Astronomica**l - How stars and planets form

2. **Geological** - The record of fossils and isotopes

3. **Biological** - The record of organism relationships written in the genes - "phylogenetics"

Times for Early Events

~4.5 gy ago -- Planet Earth in-place

~4.4 gy ago -- Global magma ocean - no life

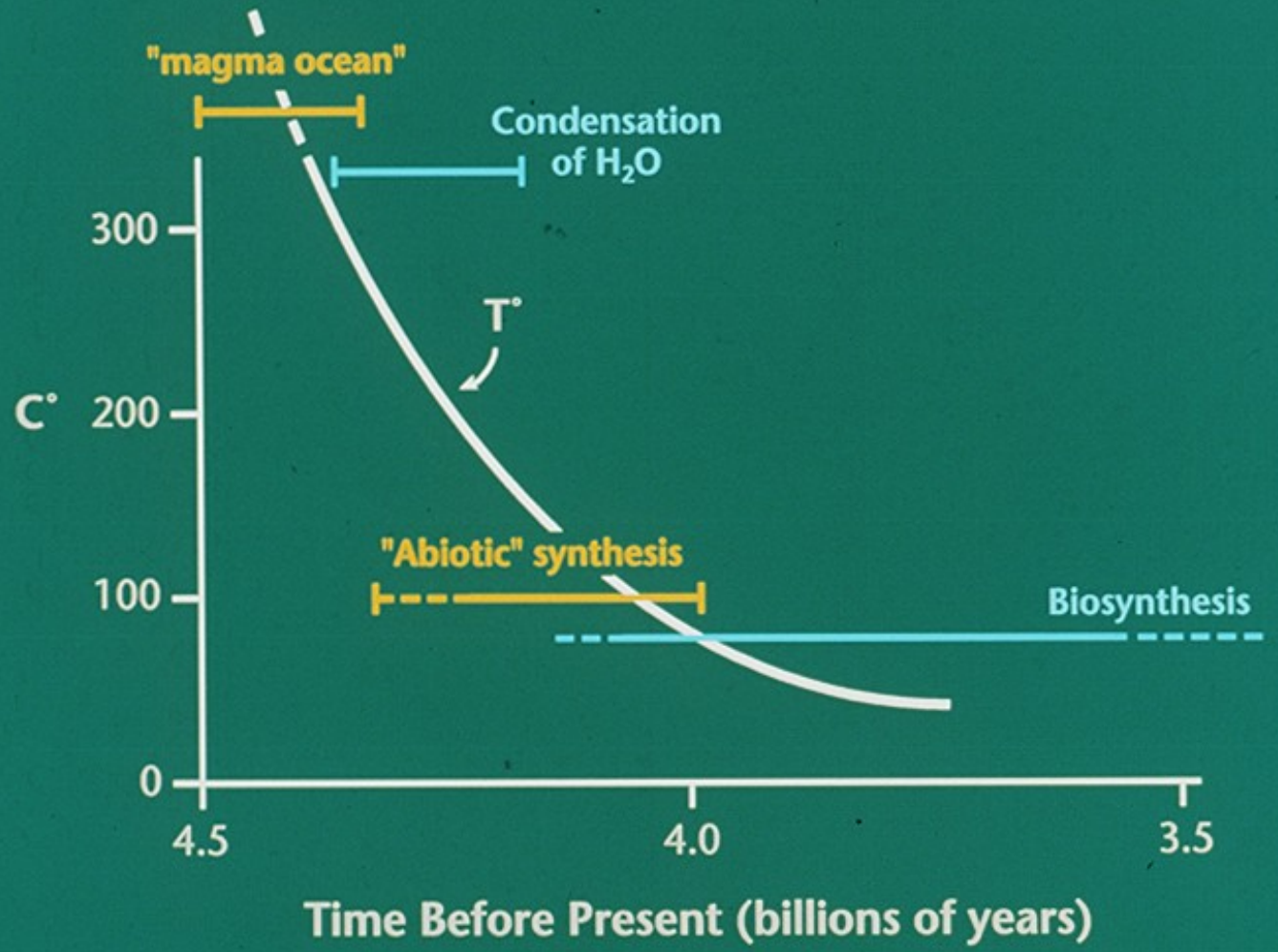
~4.2 gy ago -- abundant water, a prerequisite for life

If Assume Temperature of 500°C at surface:

Compound	Pressure (Atm)
H_2O	488
H_2	10
CO_2	39
CO	0.3
CH_4	0.9 (CH_4 <CO/CO_2 regardless of model)
N_2	1.5
NH_3	0.03
H_2S	? (potential early foodstuff)

From S. Chang *et al*.

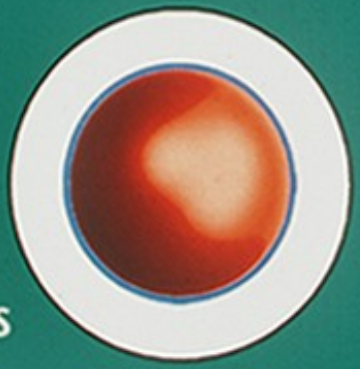
Life came to be at "high" temperatures (80°-150°C?)



Life came to be in geothermal environments

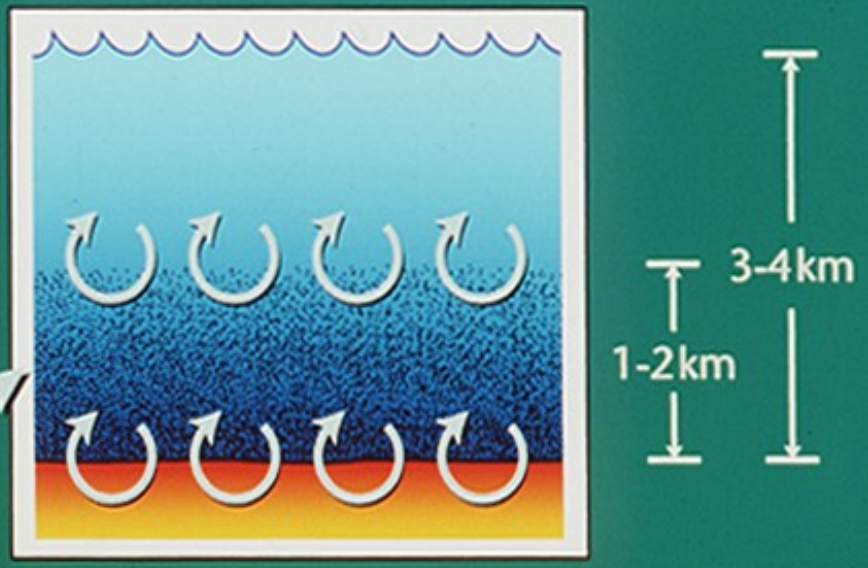
A. Early Earth

- a molten ball with thin film of H_2O
- not much, if anything, sticking above waves

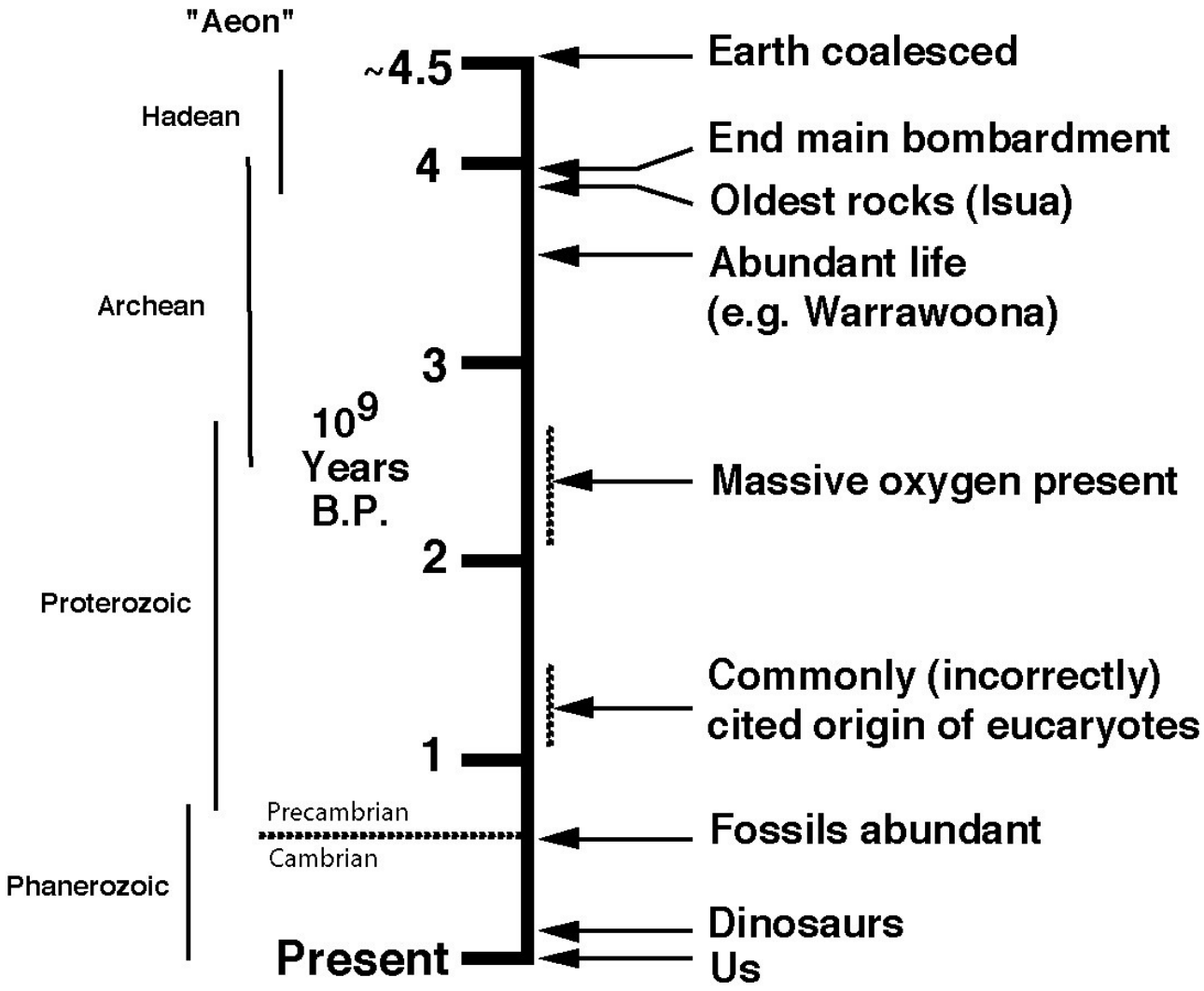


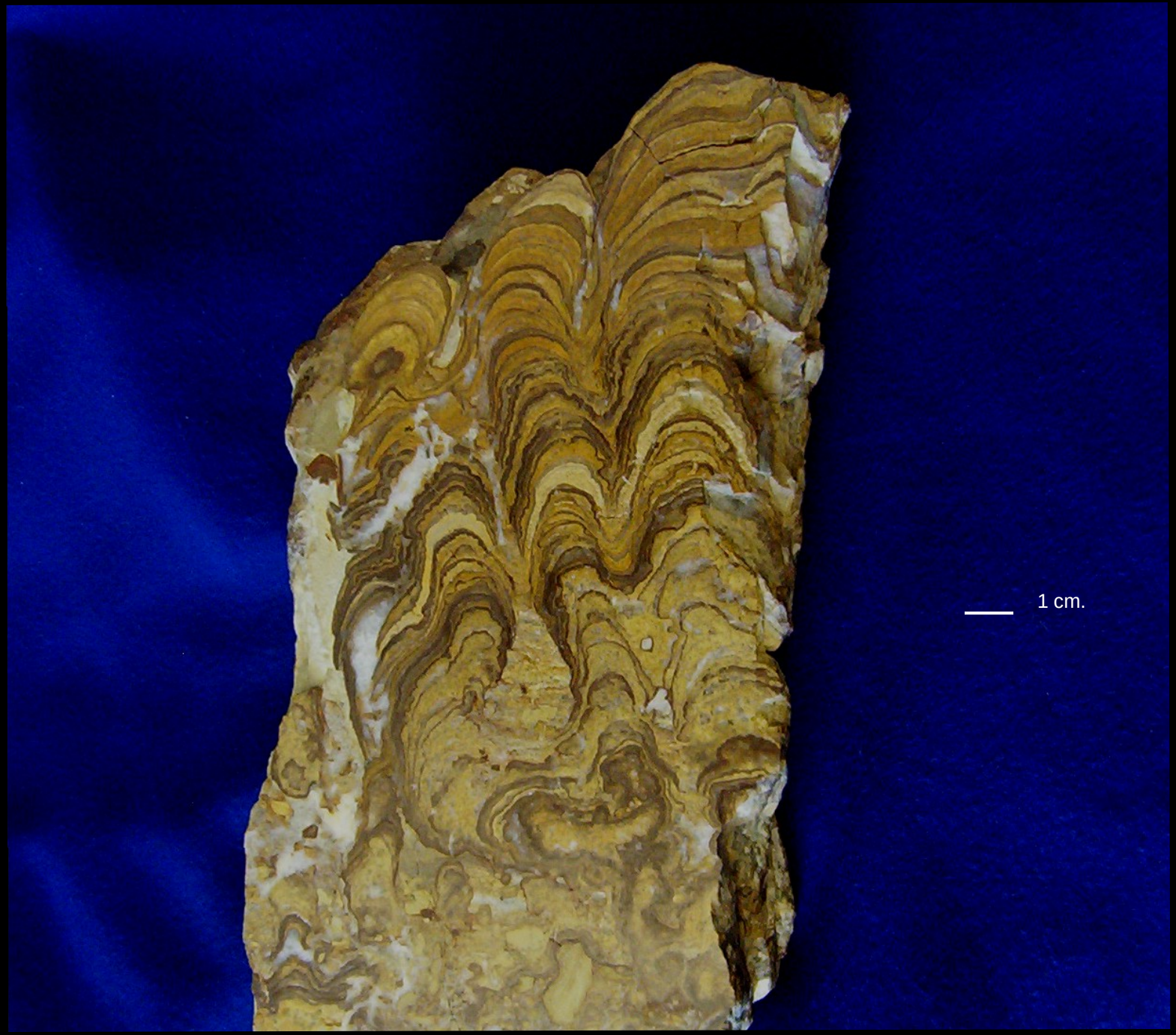
B. Eden was a harsh place

Organics & H_2S-rich, pyrite/basalt-glass sludge stirred by convective circulation



Timeline - Life on Earth




1 cm.

1 cm.

Isotopic Fractionation

- Stable isotopes of carbon include ^{12}C and ^{13}C.

- Biological processes select for the **light** isotope, ^{12}C.

- Enrichment for $^{12}C/^{13}C$ in rocks implies some biological process (although there are other explanations).

- Carbon extracted from 3.8 gy rocks is light!

Life was abundant by 3.5 gy ago, possibly by 3.8 gy ago.

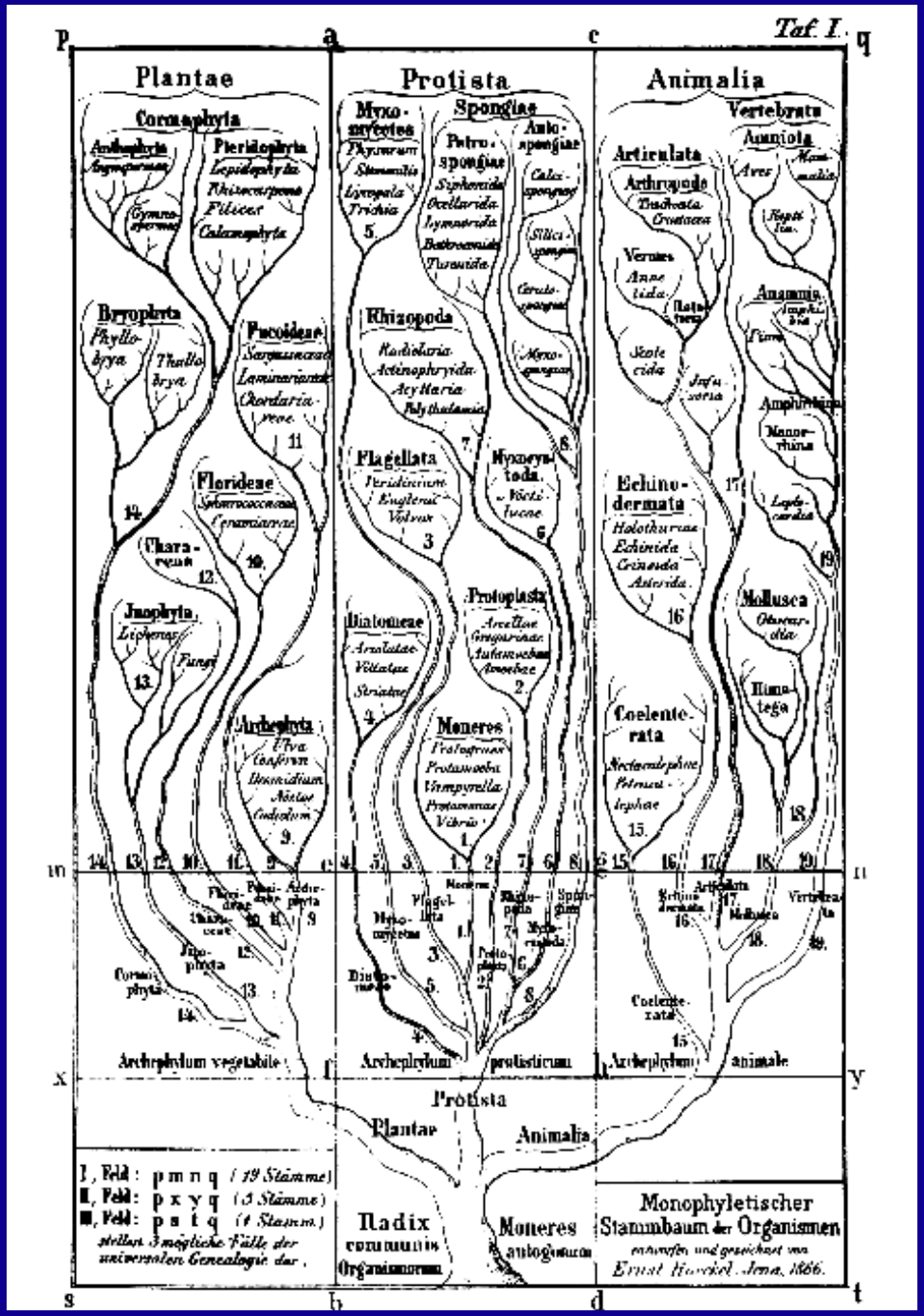
What happened? How? When?

“How” is still speculative;

“What Happened” is emerging from studies in “molecular phylogeny”

“When” needs geological context to date.

Molecular Phylogeny - Mapping the Tree of Life



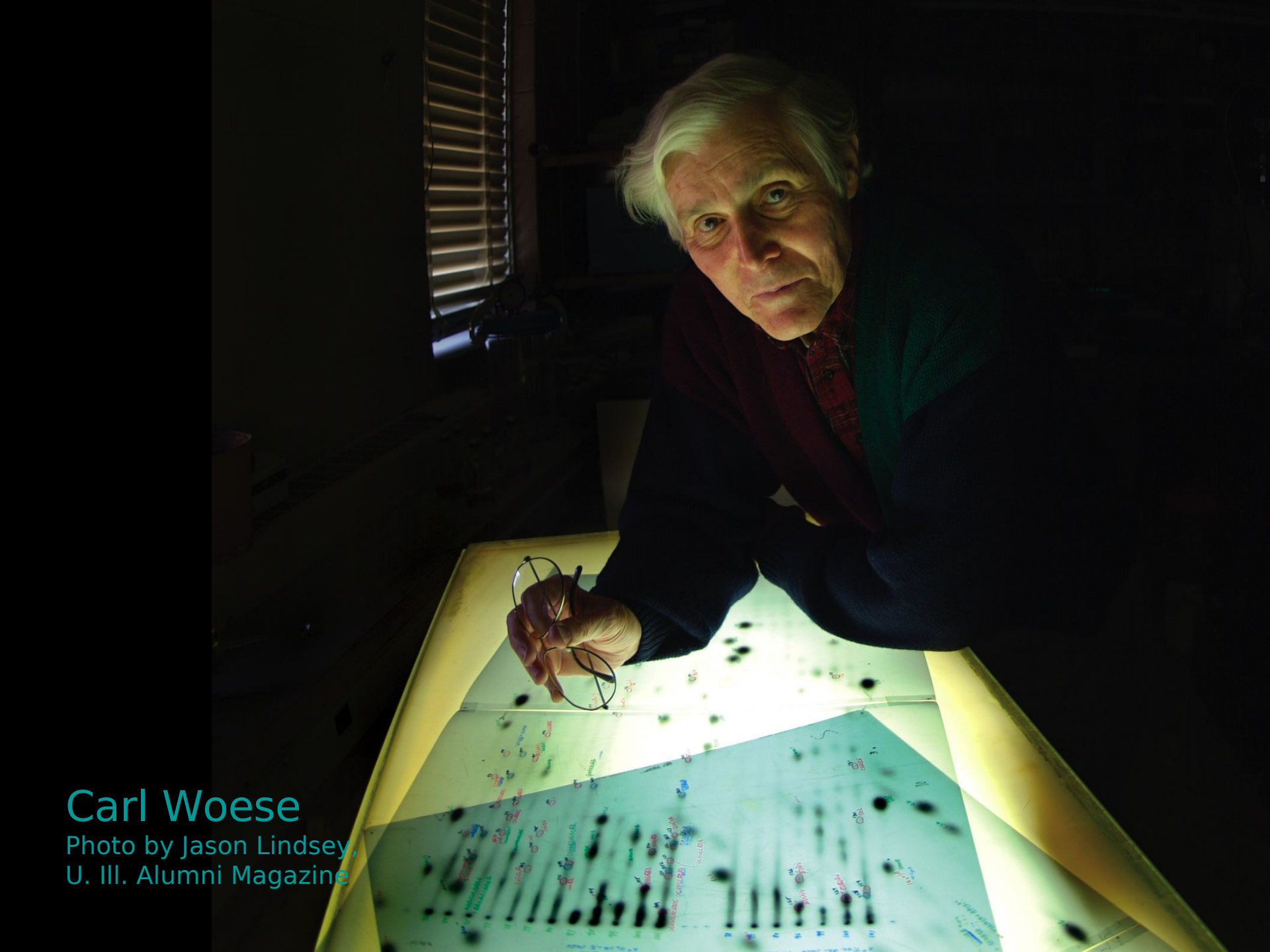
Haeckel, 1866

Molecular Phylogeny: relating organisms by gene sequences

1. **Align** “homologous” sequences so that homologous residues are juxtaposed.

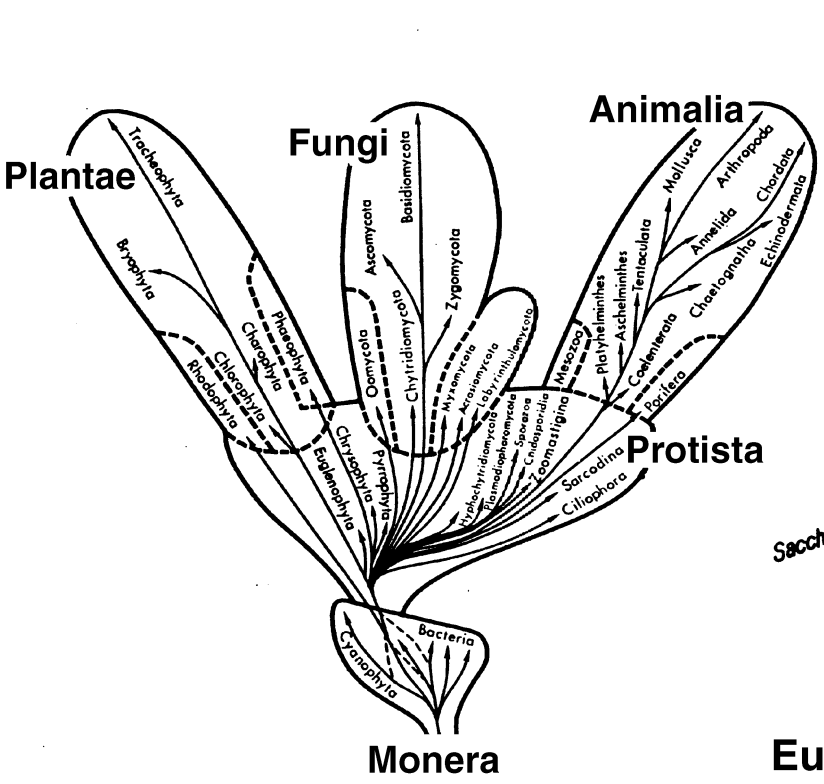
2. **Count the number of differences** between pairs of
   sequences; this is some measure of “evolutionary distance” between the organisms

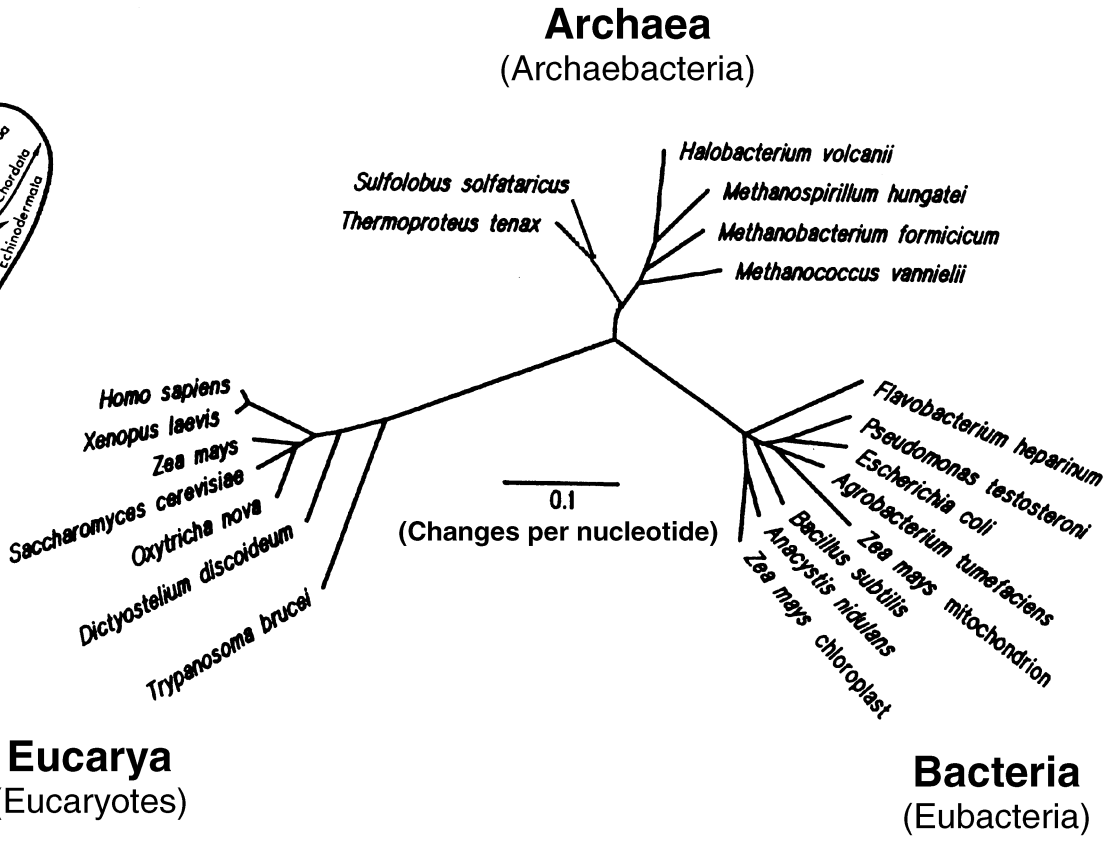
3. **Calculate the “tree”,** the relatedness map, that most accurately represents all the pairwise differences

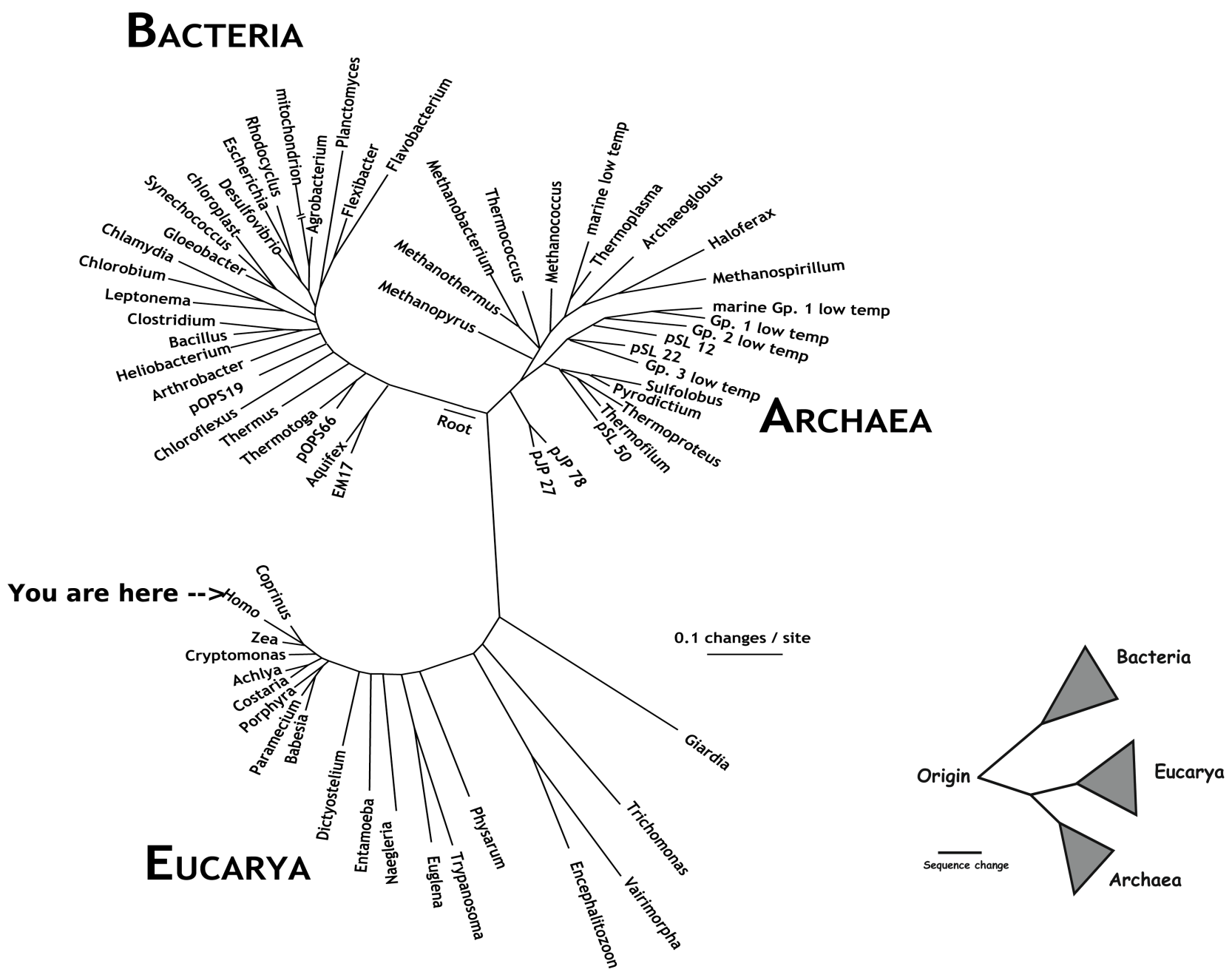


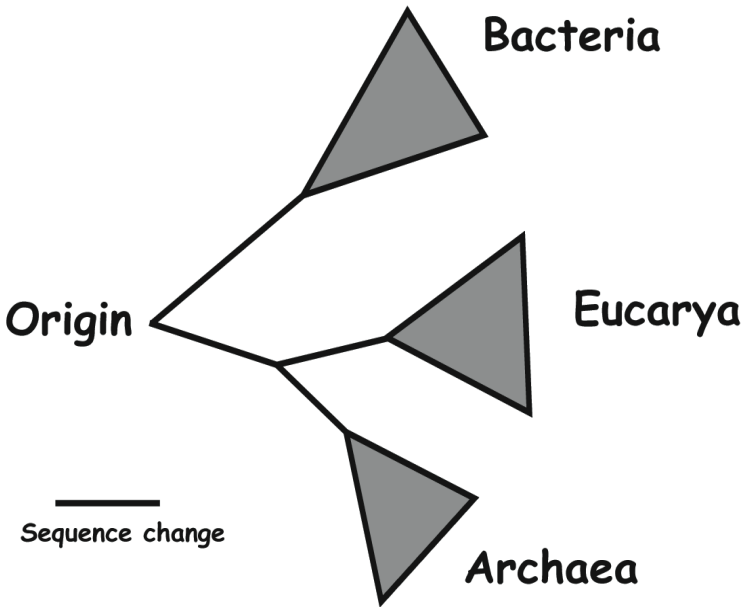
Carl Woese

Photo by Jason Lindsey,
U. Ill. Alumni Magazine


Plantae
Fungi
Animalia
Protista
Monera
Tracheophyta
Bryophyta
Phaeophyta
Charophyta
Chlorophyta
Rhodophyta
Chrysophyta
Euglenophyta
Pyrrophyta
Ascomycota
Basidiomycota
Oomycota
Chytridiomycota
Zygomycota
Myxomycota
Acrasiomycota
Labyrinthulomycota
Plasmodiophoromycota
Sporozoa
Cnidosporidia
Foraminifera
Mastigina
Sarcodina
Ciliophora
Mesozoa
Platyhelminthes
Aschelminthes
Tentaculata
Coelenterata
Porifera
Mollusca
Arthropoda
Annelida
Chaetognatha
Chordata
Echinodermata
Cyanophyta
Bacteria


Archaea
(Archaebacteria)
Sulfolobus solfataricus
Thermoproteus tenax
Halobacterium volcanii
Methanospirillum hungatei
Methanobacterium formicicum
Methanococcus vannielii
Homo sapiens
Xenopus laevis
Zea mays
Saccharomyces cerevisiae
Oxytricha nova
Dictyostelium discoideum
Tryanosoma brucei
0.1
(Changes per nucleotide)
Flavobacterium heparinum
Pseudomonas testosteroni
Escherichia coli
Agrobacterium tumefaciens
Zea mays mitochondrion
Bacillus subtilis
Anacystis nidulans
Zea mays chloroplast
Eucarya
(Eucaryotes)
Bacteria
(Eubacteria)


BACTERIA
mitochondrion
Planctomyces
Flavobacterium
Rhodocyclus
Escherichia
Agrobacterium
Flexibacter
Synechococcus
chloroplast
Desulfovibrio
Gloeobacter
Chlamydia
Chlorobium
Leptonema
Clostridium
Bacillus
Heliobacterium
Arthrobacter
pOPS19
Chloroflexus
Thermus
Thermotoga
pOPS66
Aquifex
EM17
Root
Methanobacterium
Thermococcus
Methanococcus
marine low temp
Thermoplasma
Archaeoglobus
Haloferax
Methanothermus
Methanospirillum
Methanopyrus
marine Gp. 1 low temp
Gp. 1 low temp
Gp. 2 low temp
pSL 12
pSL 22
Gp. 3 low temp
Sulfolobus
Pyrodictium
Thermoproteus
Thermofilum
pSL 50
pJP 78
pJP 27
ARCHAEA
You are here -->
Homo
Coprinus
Zea
Cryptomonas
Achlya
Costaria
Porphyra
Paramecium
Babesia
Dictyostelium
Entamoeba
Naegleria
Euglena
Trypanosoma
Physarum
Encephalitozoon
Vairimorpha
Trichomonas
Giardia
EUCARYA
0.1 changes / site
Bacteria
Origin
Eucarya
Sequence change
Archaea



Some Lessons from the Big Tree:

- Three main relatedness groups, Eucarya, Bacteria, Archaea.

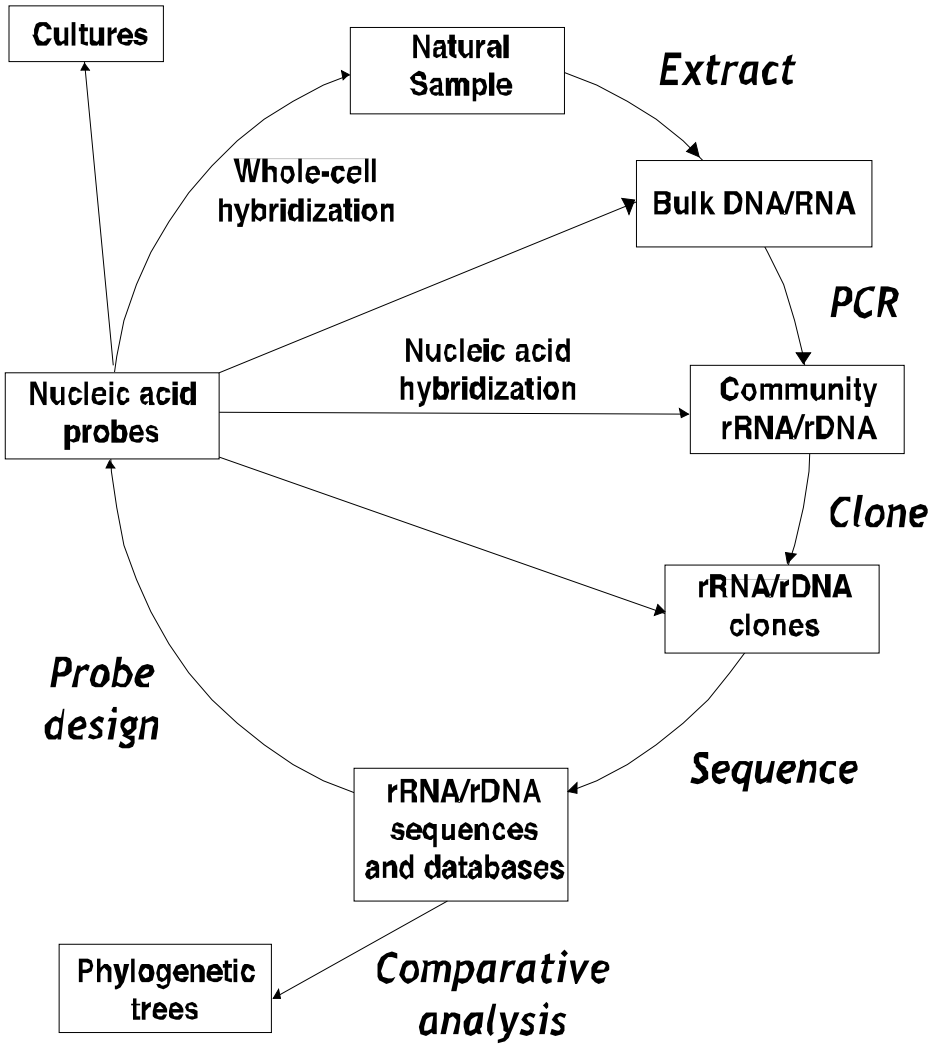
- Origin is on the bacterial line of descent: Eucarya and Archaea are related to the exclusion of Bacteria.

- Chloroplasts and mitochondria are of bacterial origin.

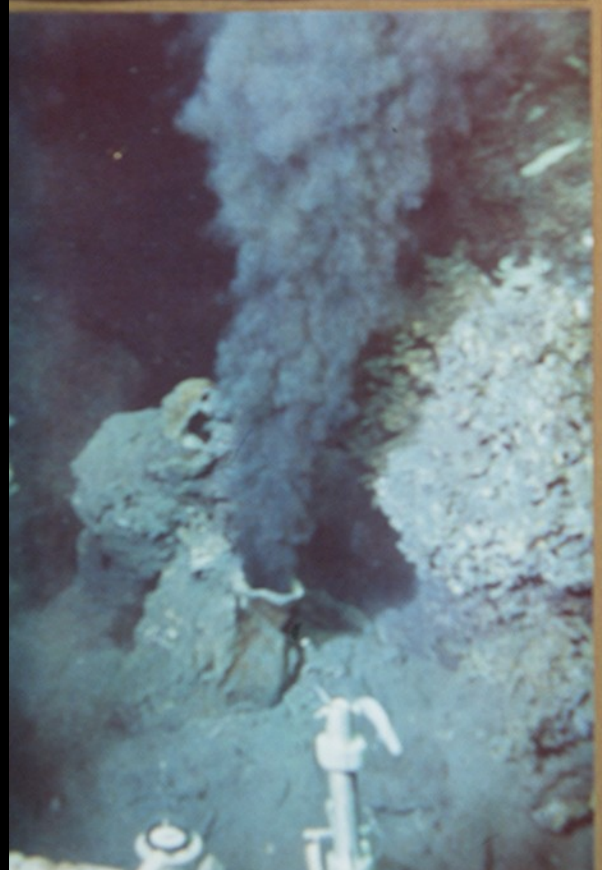
- The eucaryal **nuclear** line is as old as the archaeal line; the prokaryote-eukaryote model for biological organization was wrong.

- Sequences are identifiers of organisms - you don't need to culture to identify!!

Molecular Method

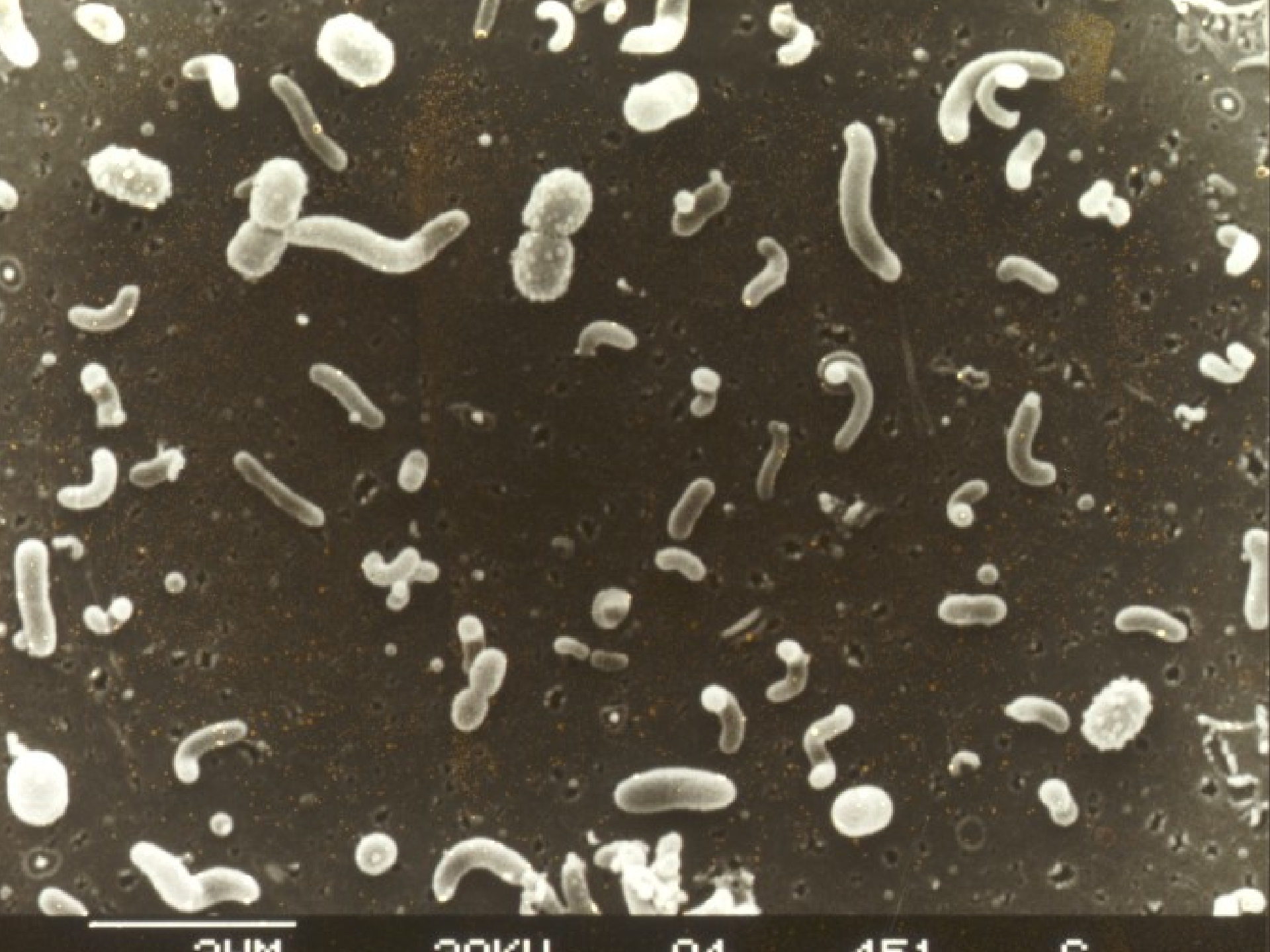


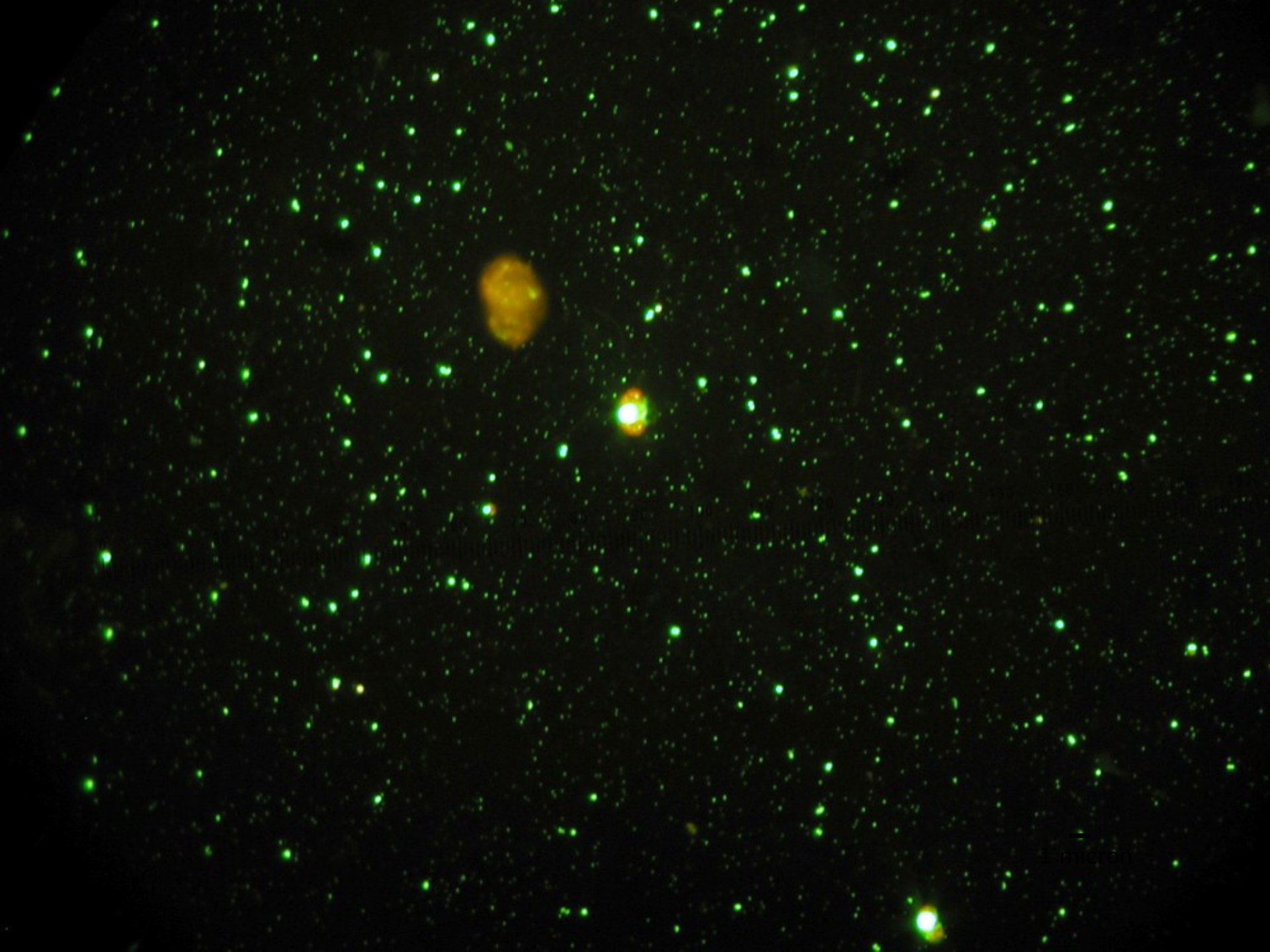
ALVIN



6.4
00

a
5 μm
b
5 μm
c
5 μm


2UM
20KV
84
451
S



Guerrero Negro halite-gypsum-life

Photo by John Spear

Endolithic Community in Sandstone

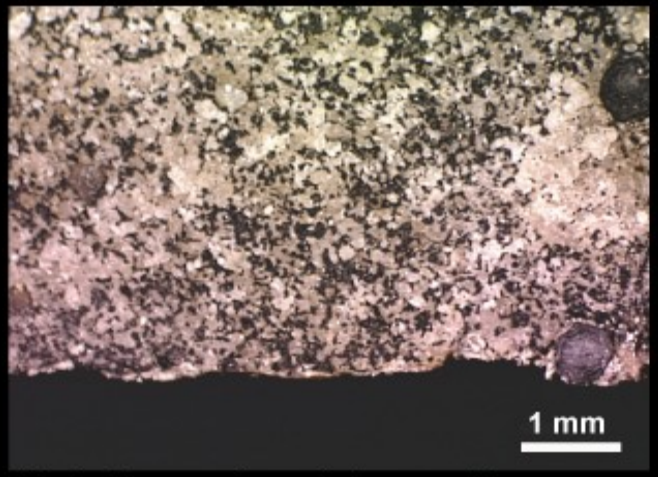


Fig 1. Exposed sandstone surface

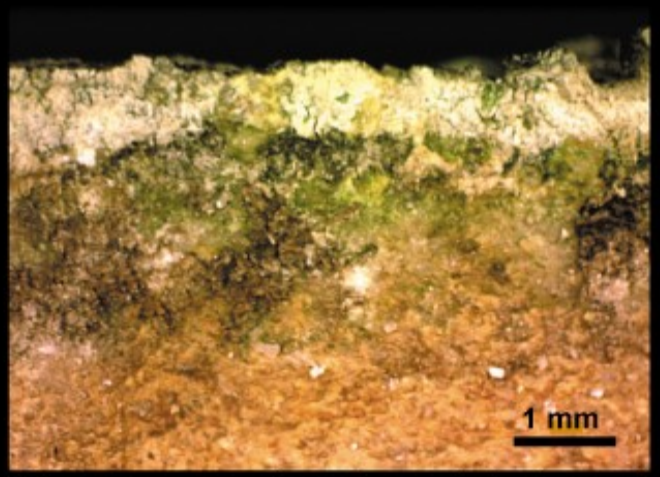
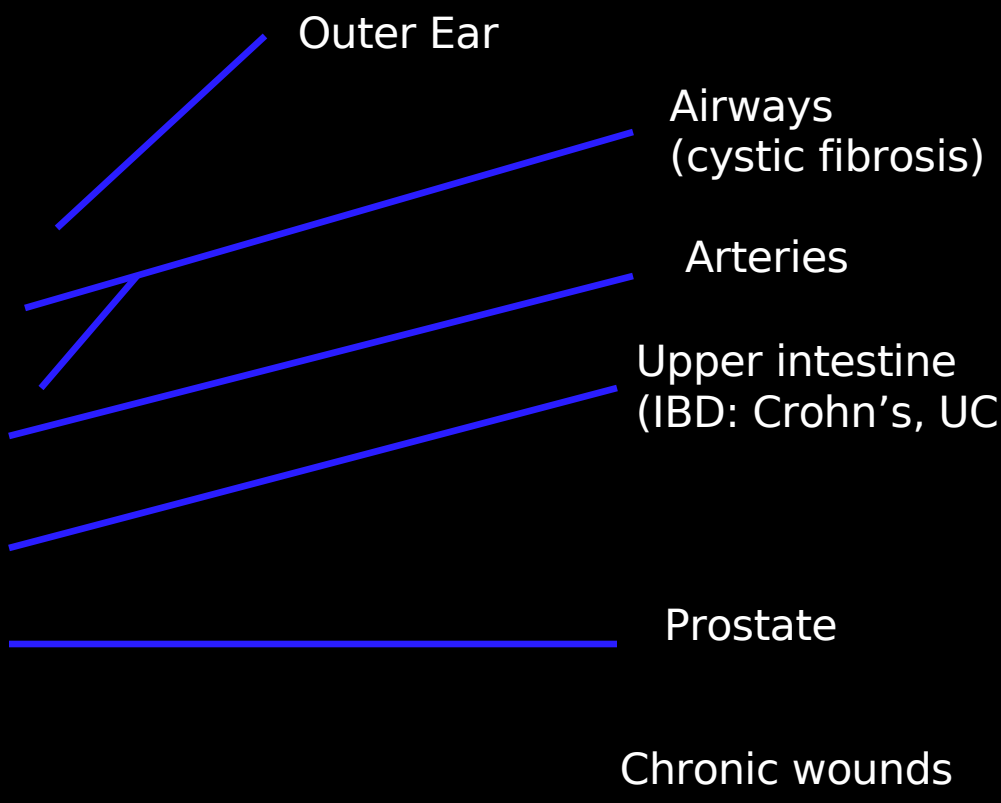
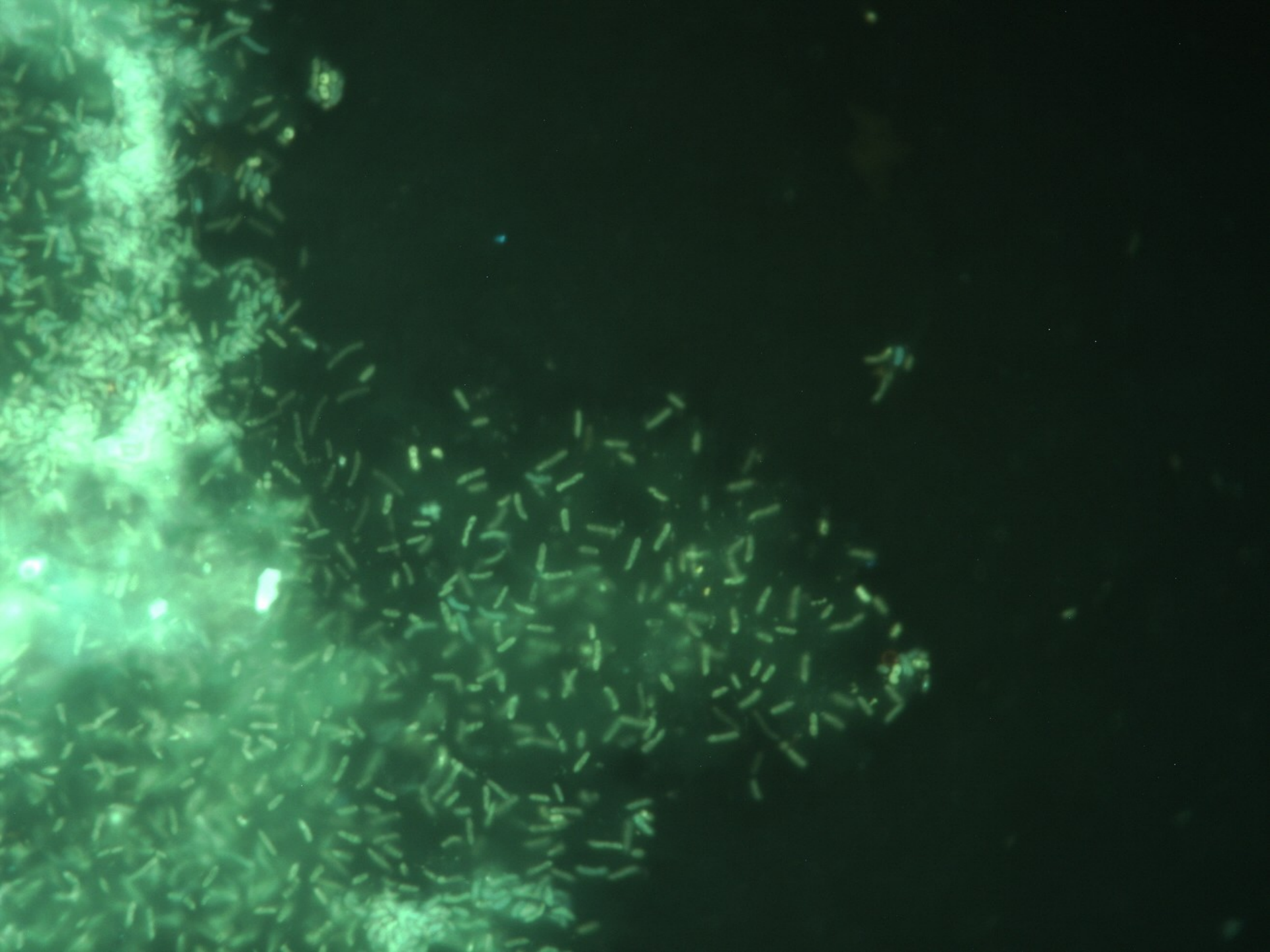


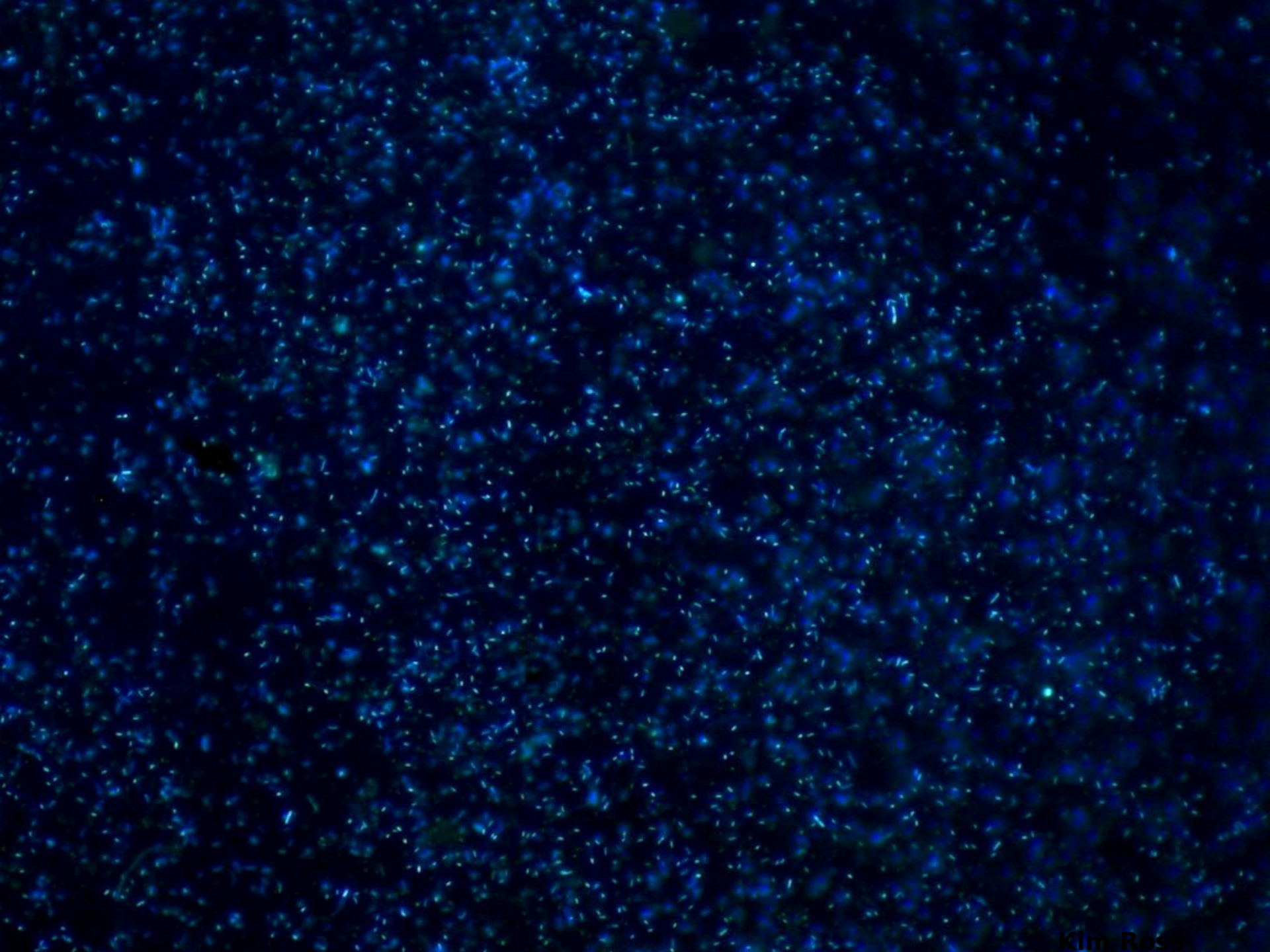
Fig 2. Cross section of sample in figure 1

Fig 3. 3D view

Fig 4. Same as figure 2, illuminated with fiber-optic light from the surface

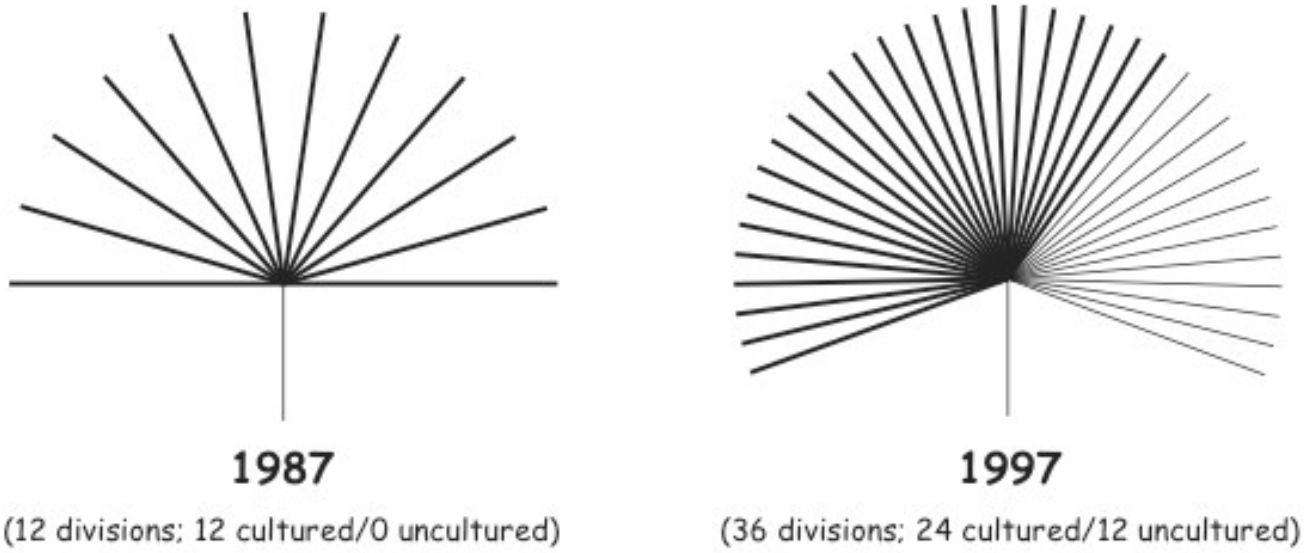

Outer Ear
Airways
(cystic fibrosis)
Arteries
Upper intestine
(IBD: Crohn’s, UC
Prostate
Chronic wounds

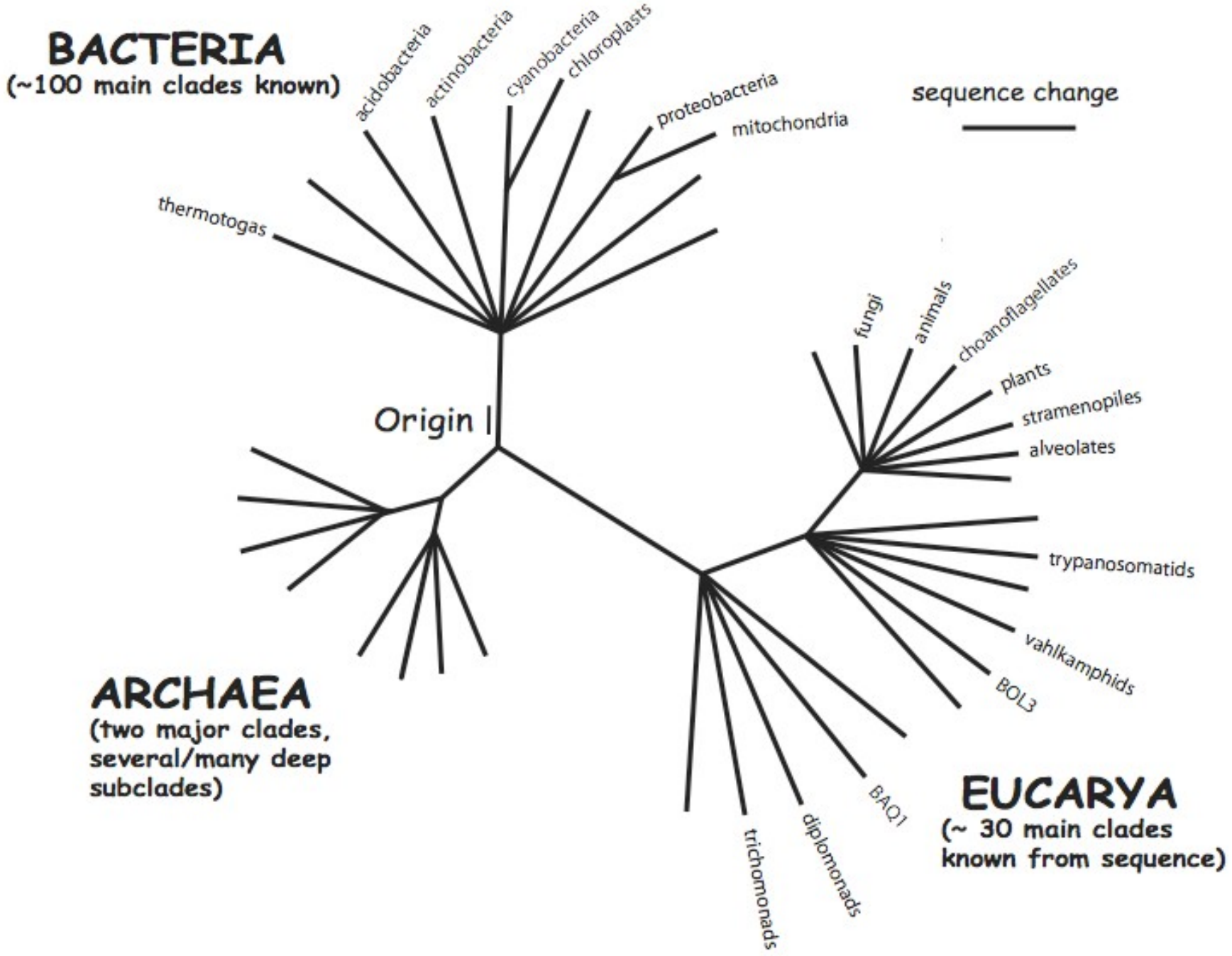


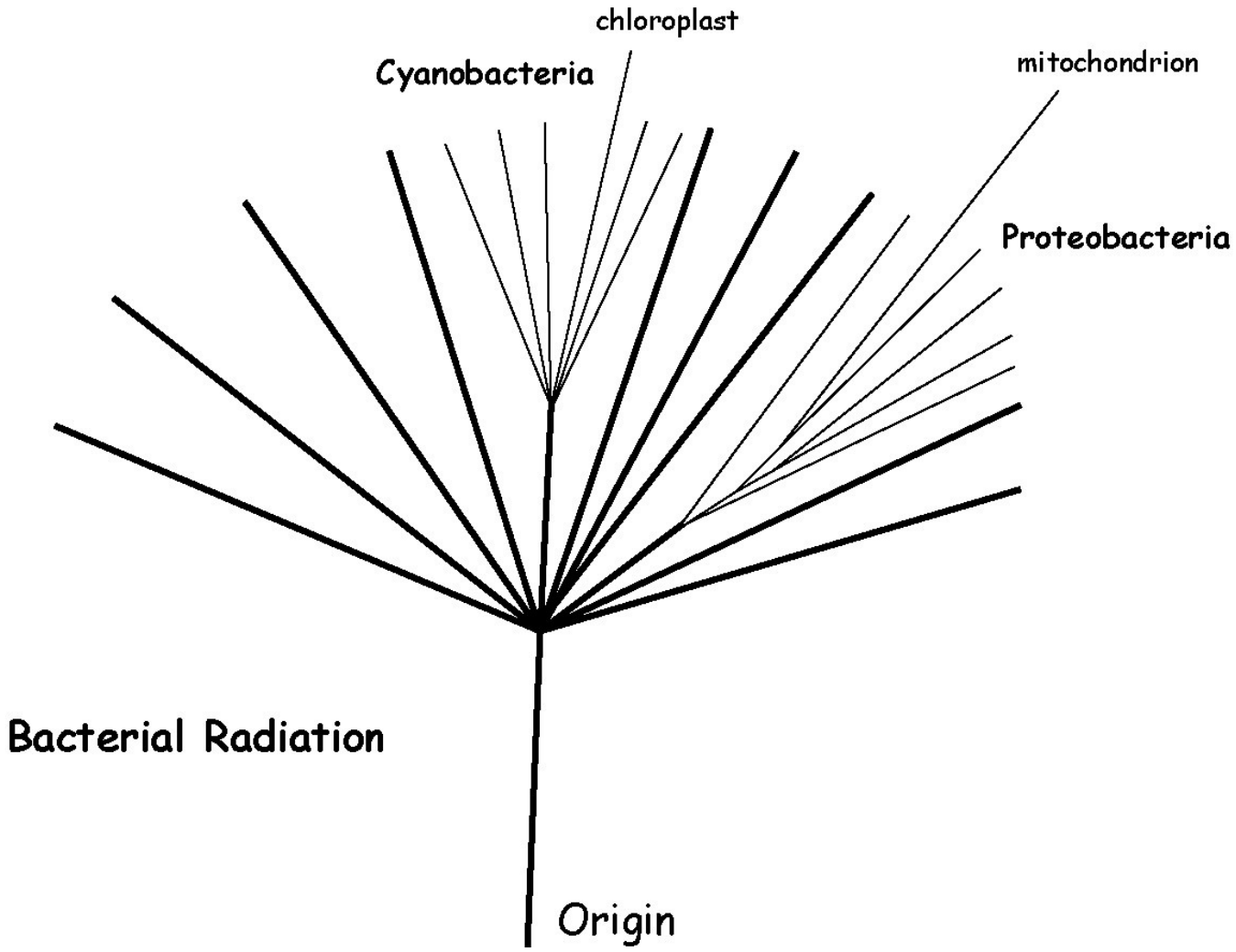

Kim Ros

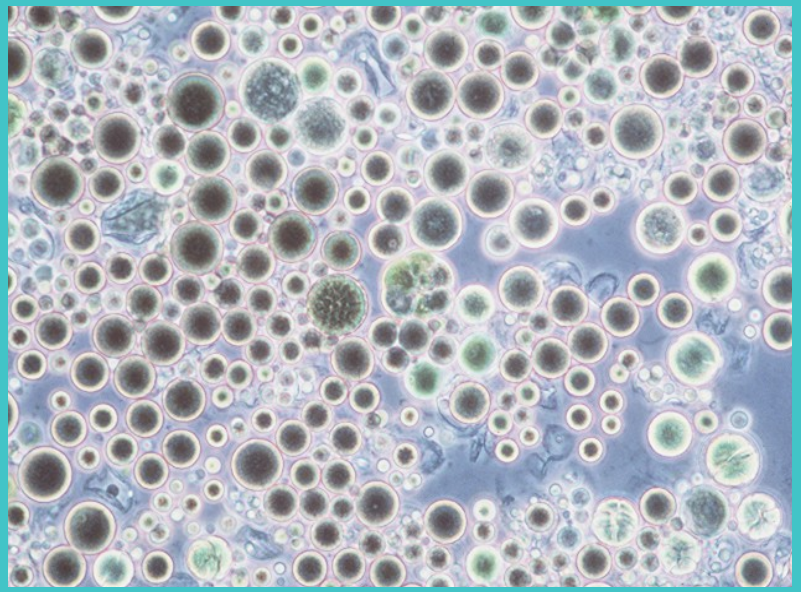
We are embedded in a microbial world !

Known Bacterial Phylogenetic Divisions




BACTERIA
(~100 main clades known)
acidobacteria
actinobacteria
cyanobacteria
chloroplasts
proteobacteria
mitochondria
thermotogas
sequence change
Origin
fungi
animals
choanoflagellates
plants
stramenopiles
alveolates
trypanosomatids
vahlkamphids
BOL3
BAQ1
diplomonads
trichomonads
ARCHAEA
(two major clades, several/many deep subclades)
EUCARYA
(~ 30 main clades known from sequence)


chloroplast
Cyanobacteria
mitochondrion
Proteobacteria
Bacterial Radiation
Origin



W. Australia
1.7 gy

Akilia Island
3.83 gy

The modern kind of eucaryotic cell,
complete with chloroplast and mitochondrion, probably was in-place by 3.5, possibly 3.8 billion years ago !!

WHAT?? Is this reasonable??

Yes.

The End –
It’s a microbial world
(Micrograph: Guerrero Negro hypersaline microbial mat. Photo by Ruth Ley)
Thanks! to NIH, NSF, DOE, ONR, NASA for $upport over The years.