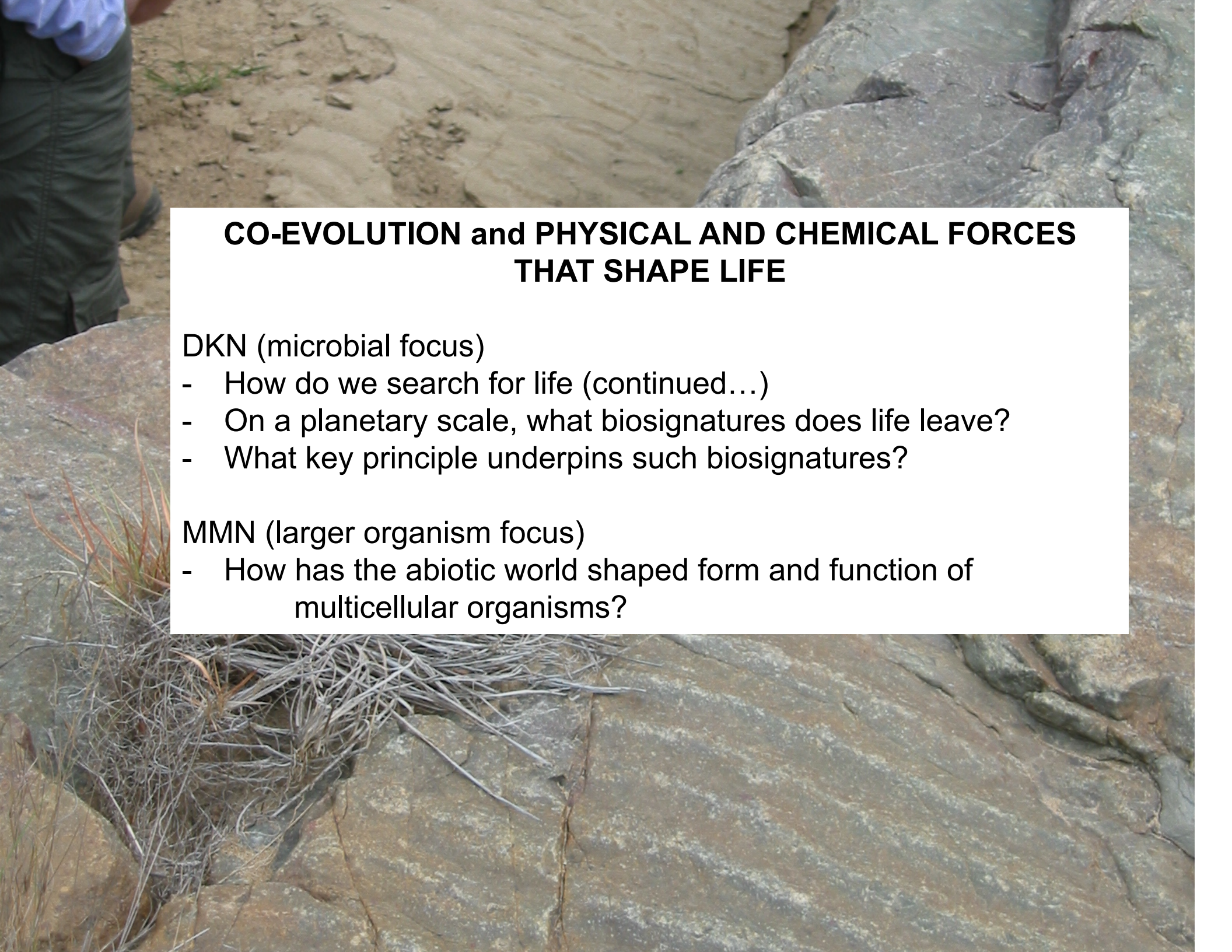




CO-EVOLUTION and PHYSICAL AND CHEMICAL FORCES THAT SHAPE LIFE

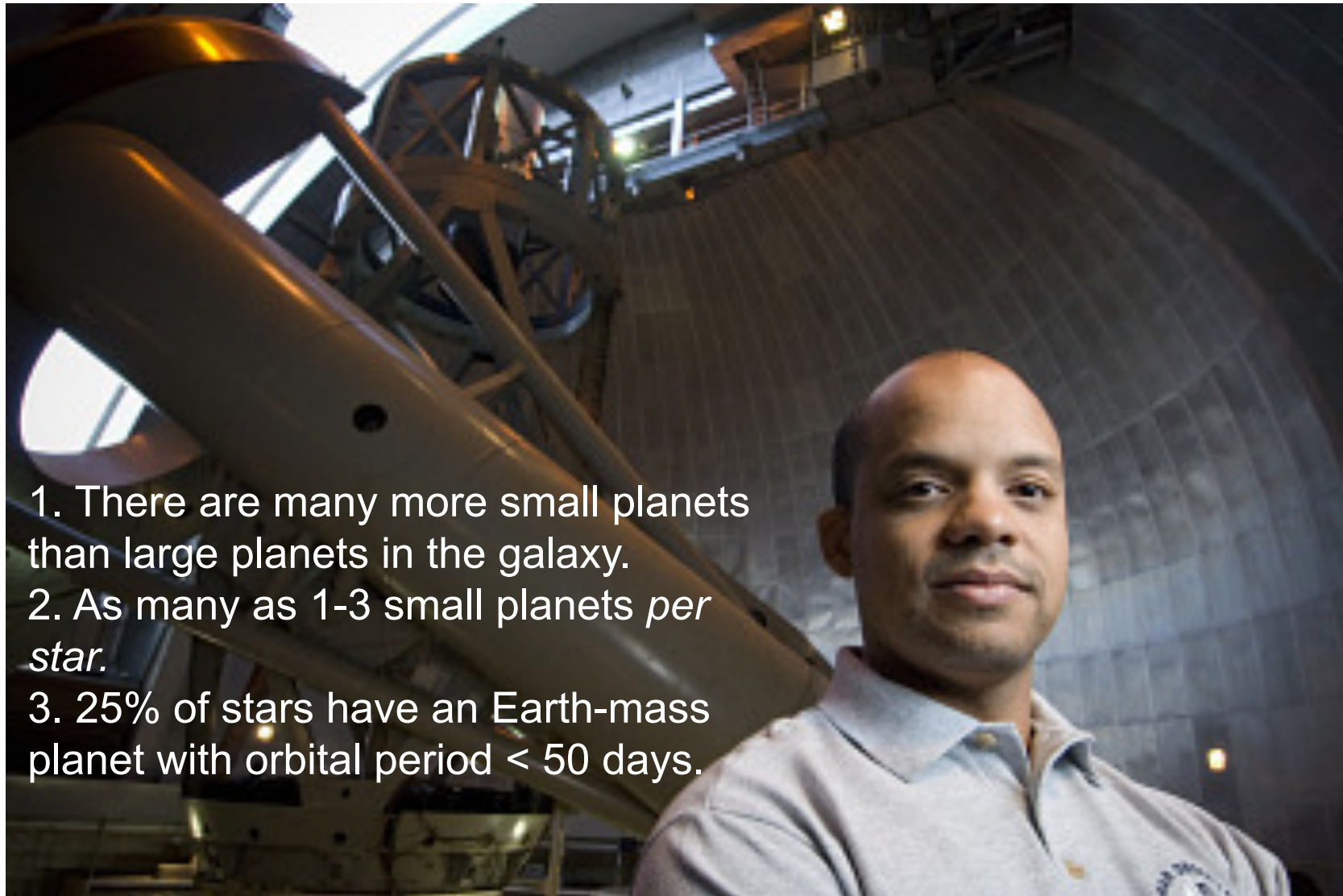
DKN (microbial focus)

- How do we search for life (continued...)
- On a planetary scale, what biosignatures does life leave?
- What key principle underpins such biosignatures?

MMN (larger organism focus)

- How has the abiotic world shaped form and function of multicellular organisms?

Prof. John Johnson is on the hunt for Exoplanets



1. There are many more small planets than large planets in the galaxy.
2. As many as 1-3 small planets *per star*.
3. 25% of stars have an Earth-mass planet with orbital period < 50 days.

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?

Water, O₂, magetosomes?

Mars Science Laboratory (MSL) “Curiosity” lands Aug. 5, 2012

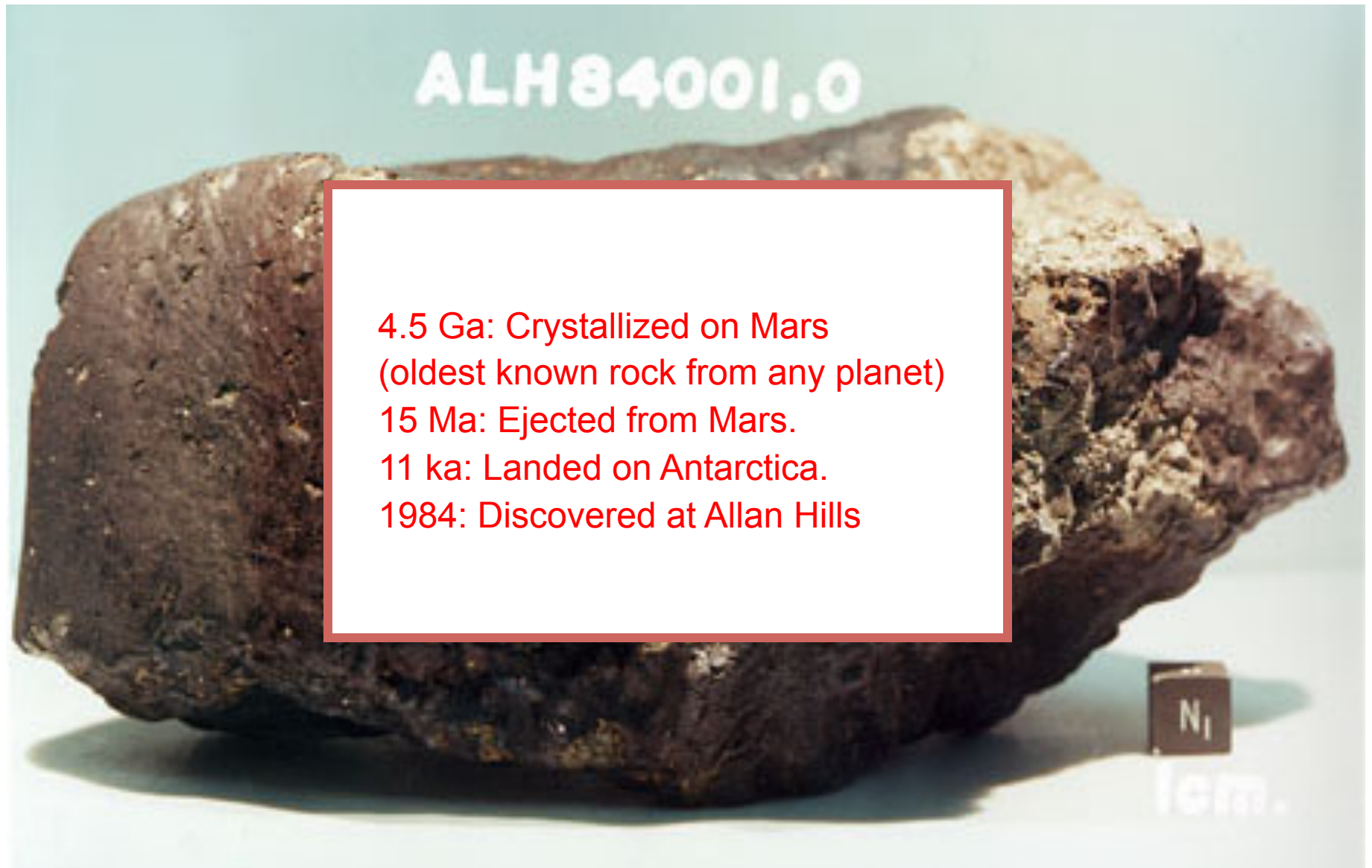


Prof. John Grotzinger

Sometimes Mars comes to us, so we have a head start...



Sometimes Mars comes to us, so we have a head start...



Fresh fracture surfaces of the martian meteorite ALH84001 contain abundant polycyclic aromatic hydrocarbons (PAHs). These fresh fracture surfaces also display carbonate globules. Contamination studies suggest that the PAHs are indigenous to the meteorite. High-resolution scanning and transmission electron microscopy study of surface textures and internal structures of selected carbonate globules show that the globules contain fine-grained, secondary phases of single-domain magnetite and Fe-sulfides. The carbonate globules are similar in texture and size to some terrestrial bacterially induced carbonate precipitates. Although inorganic formation is possible, formation of the globules by biogenic processes could explain many of the observed features, including the PAHs. The PAHs, the carbonate globules, and their associated secondary mineral phases and textures could thus be fossil remains of a past martian biota.

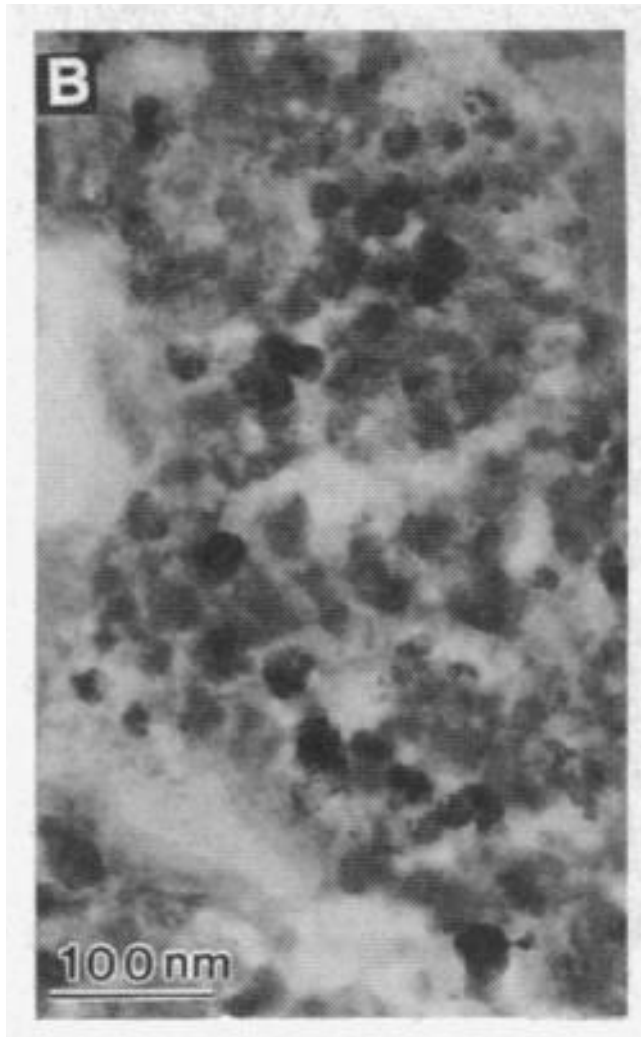
A long-standing debate over the possibility of present-day life on Mars was addressed by the Viking lander experiments in 1976. Although the results were generally interpreted to be negative for life in the tested surface soils, the possibility of life at other locations on Mars could not be ruled out (1). The Viking lander's mass spectrometry experiments failed to confirm the existence of organics for the martian surface samples analyzed. Furthermore, the Viking results

biomarkers on the basis of what we know about life on Earth. Therefore, if there is a martian biomarker, we may not be able to recognize it, unless it is similar to an earthly biomarker. Additionally, no information is available on the geologic context of this rock on Mars.

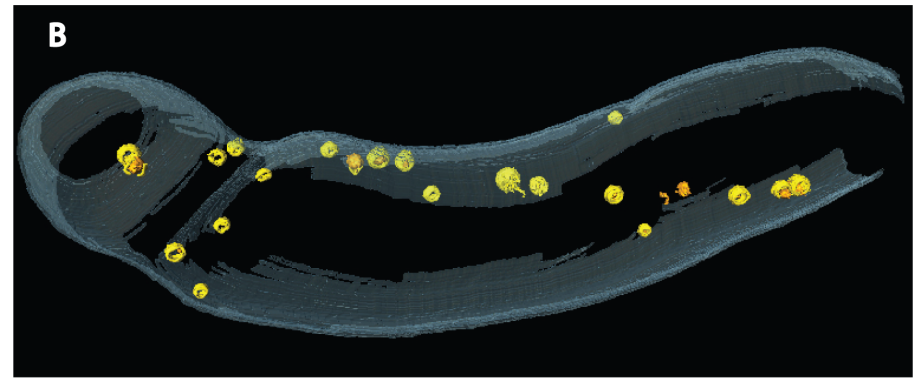
ALH84001 is an igneous orthopyroxenite consisting of coarse-grained orthopyroxene [(Mg,Fe)SiO₃] and minor maskelynite (NaAlSi₃O₈), olivine [(Mg,Fe)SiO₄], chro-

Science, 1996

What do you think?



==
?



Extra credit challenge (worth 2 correct iClicker questions)

What configuration of magnetite (chains or clumps) do you think is energetically preferred in the absence of life? (*i.e.* what would happen to the magnetite in *M. magneticum* if you dissolved its membranes and proteins?)

Based on what you have learned in Ph 1c, discuss qualitatively and/or quantitatively.

How does this affect your thinking about whether the magnetite in ALH8001 is a robust biosignature?

You can ask TAs for general guidance and collaborate with your fellow students, but what you turn in must be in your own hand.

Turn in at the beginning of class next Tuesday.

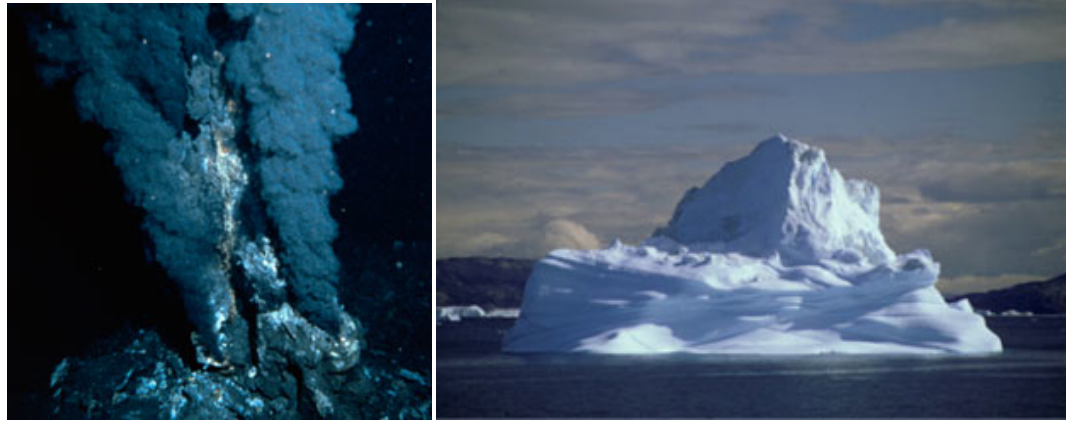
Life Detection: Let's ground-truth this discussion with the Earth

What features of Earth that are linked to life (i.e. necessary for it or a product of it) that you can see from space?



Water (in 3 phases),
oxygen

Why is water good for life?



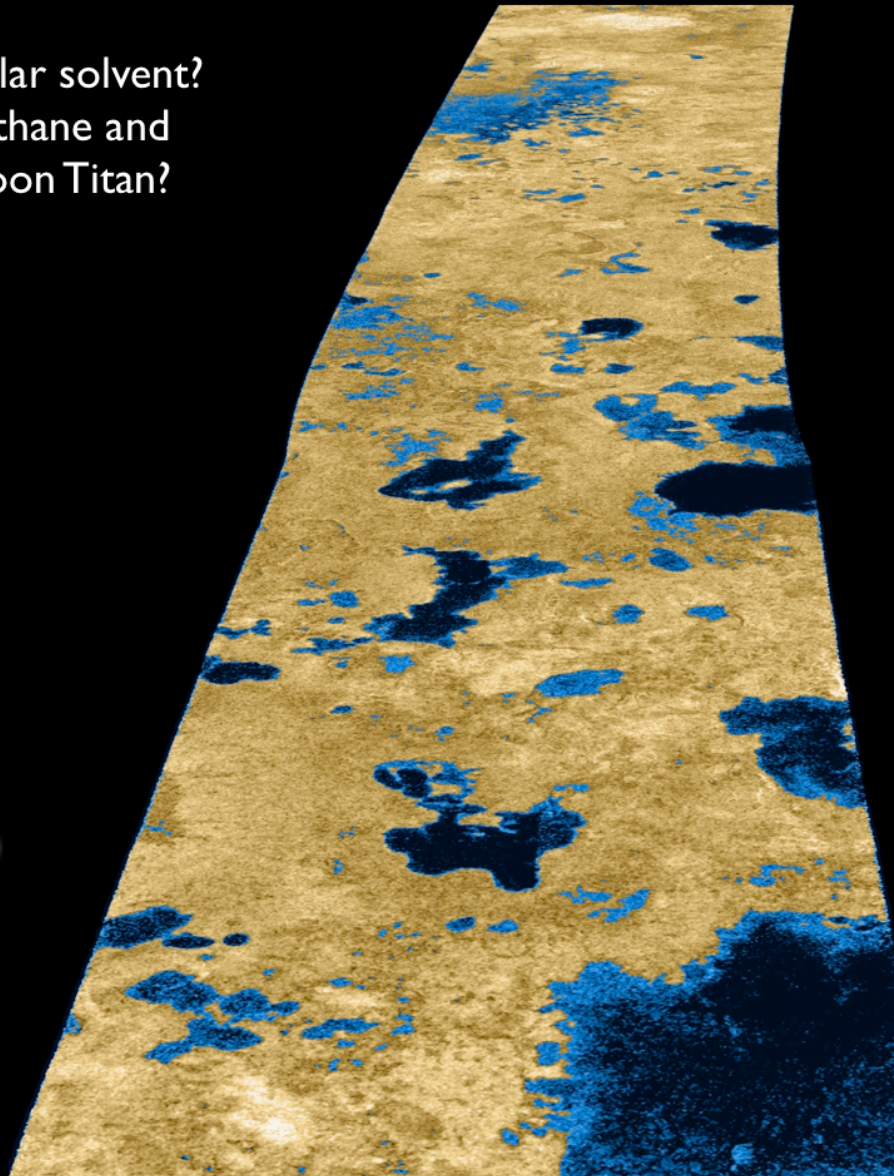
- Abundant in solar system
- Biochemical reactions need something to operate in; solvent permits a reasonable pace (solid too slow; gas too fast)
- Water dissolves most things
- Specifically, facilitates formation of covalent bonds and permits H bonds (C chemistry of life)
- At the temp/pressures of our planet, exists in three phases (solid, liquid, vapor) promoting hydrologic cycle
- Large liquid range (pure water freezes at 0 C, boils at 100C, add salt can lower freezing temperature raise pressure, increase the boiling temperature)
- High specific heat capacity (takes a lot of energy to raise its temp 1 degree)
- Latter 2 things allow Earth (2/3 liquid) to go through day/night cycle
- Fact that water expands when freezes makes life possible at the poles (underneath the frozen surface, liquid persists).

Prospects for 'Weird Life'?

Water = Polar solvent.

Could life 'work' in a non-polar solvent?
For instance, the liquid methane and
ethane lakes of Saturn's moon Titan?

← Titan



Huygens lander image of
what may have been a
methane river basin. The
rocks of water ice are ~10
cm across.

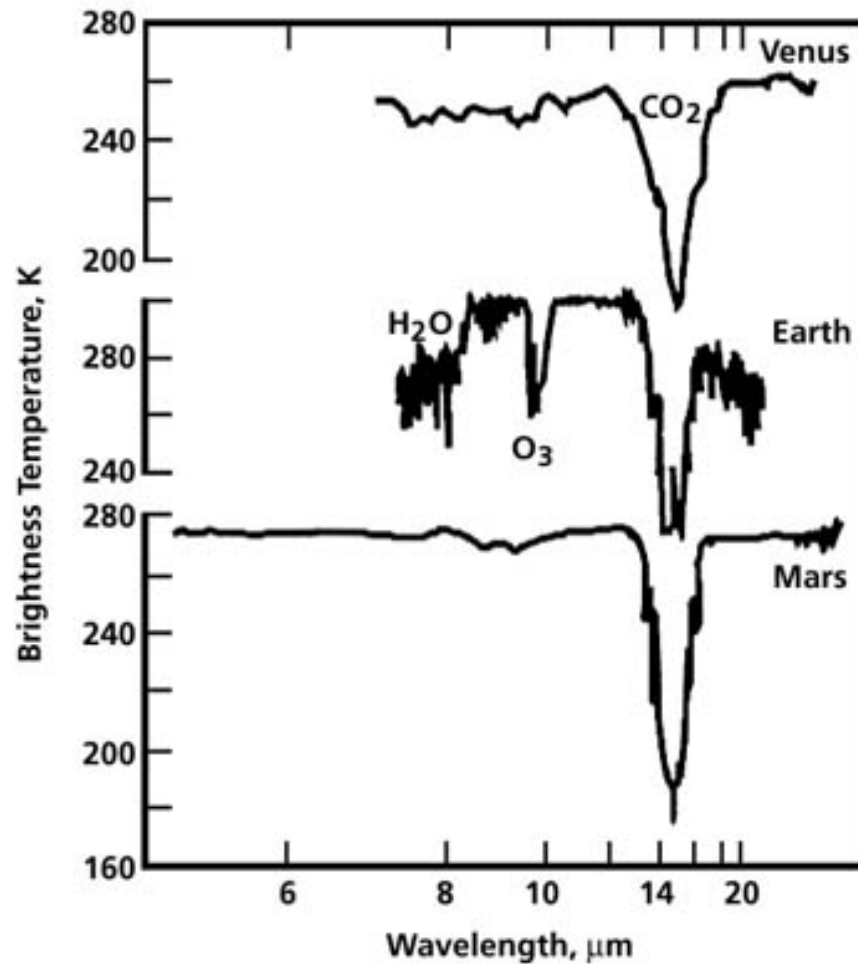
False color Radar image of
Titan's surface showing
methane/ethane lakes.

Images: NASA/JPL/ESA

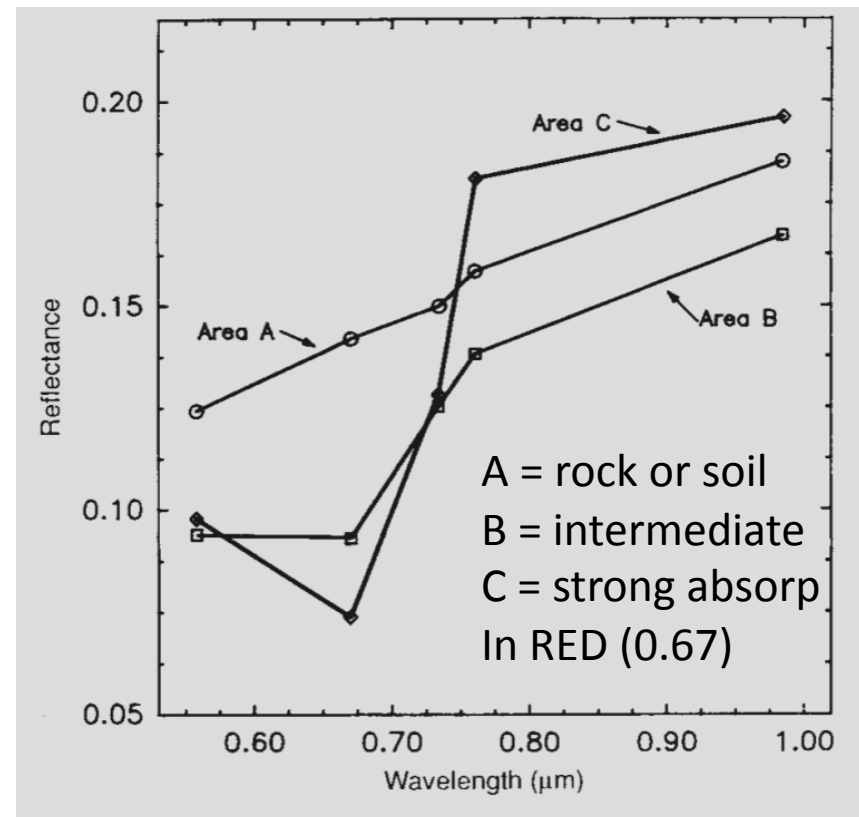
Life Detection: Let's ground-truth this discussion with the Earth



X Spectra of H₂O and O₂



Photosynthetic pigments



GEOFF BLAKE

Sagan, 1993

NASA SeaWiifs Movie (check out the chlorophyll!)

From NASA SeaWiifs satellites. is a composite compressed over three years time (with cloudy days taken out, of course). Chl is only from surface waters, one optical depth (~ upper 10 m), inferred from ocean color...

Is O₂ a Robust Biosignature?

i.e. If you *don't* detect O₂, does that mean there isn't life?

DISCUSS

0.) Write out equation of oxygenic photosynthesis, respiration

→ If in equilibrium, no net accumulation. So this can't be the only thing.

What sets the steady state level?

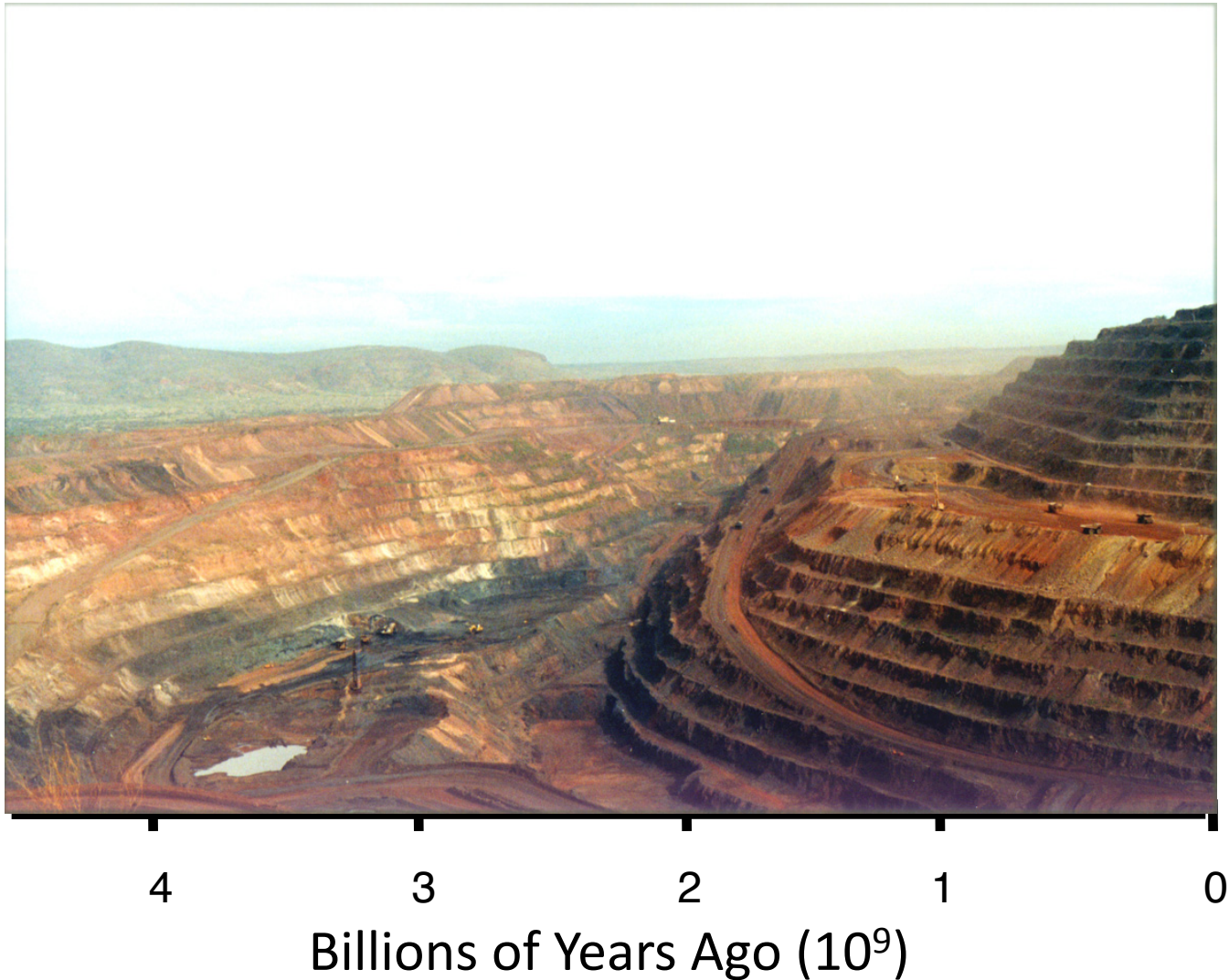
1.) Depends on planetary redox state (need to oxidize the Earth so O₂ can accumulate! Can do either by letting reductants escape to space (e.g. H₂; but gravity constrains this!) or burying them inside the Earth's interior (e.g. Carbon).

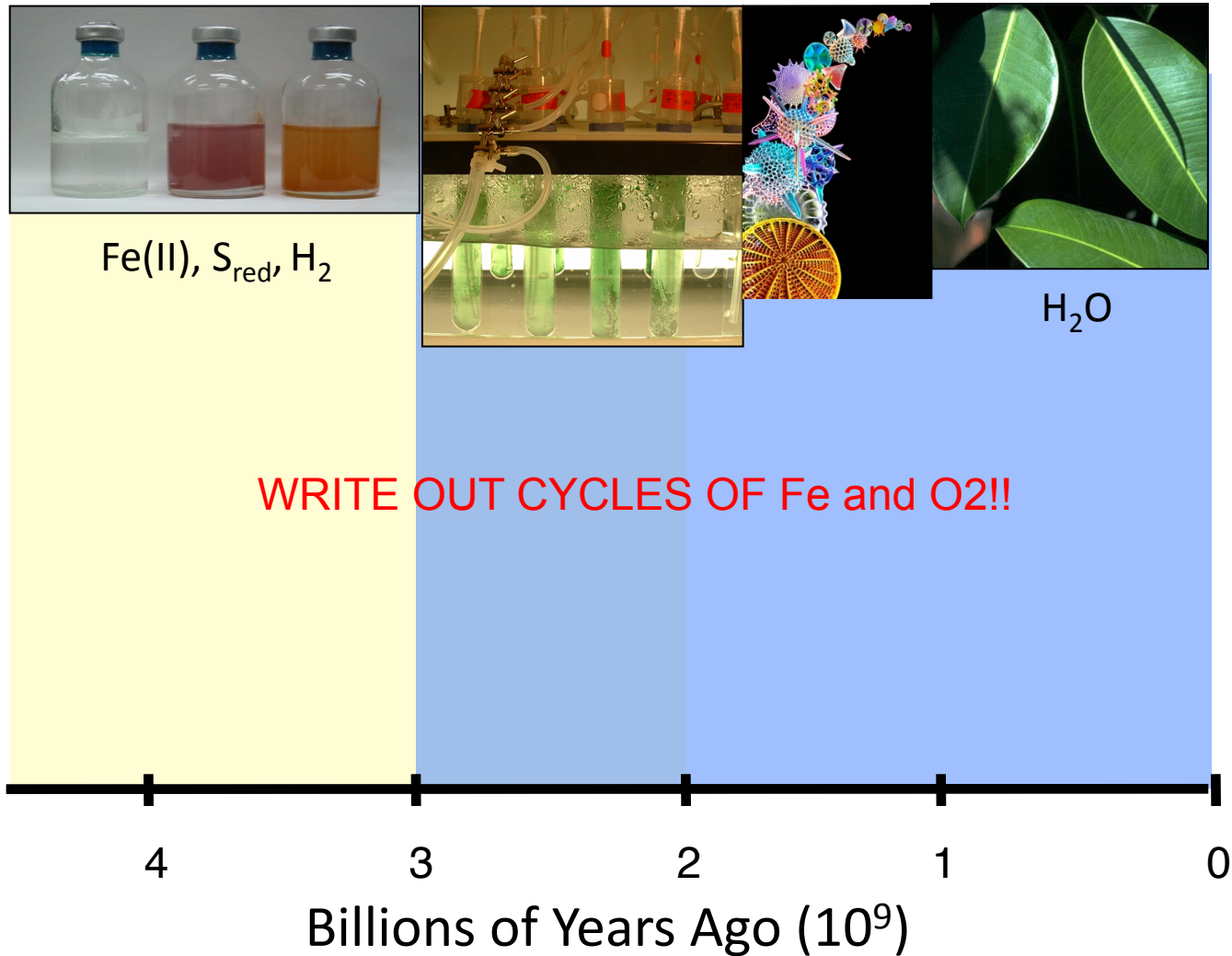
Maintenance of a steady state once Earth is oxidized is an example of CHEMICAL DISEQUILIBRIUM ON A PLANETARY SCALE!

2.) Depends on whether life is cycling water and O₂! Many other cycles (will discuss in week 5)... now will give one example...

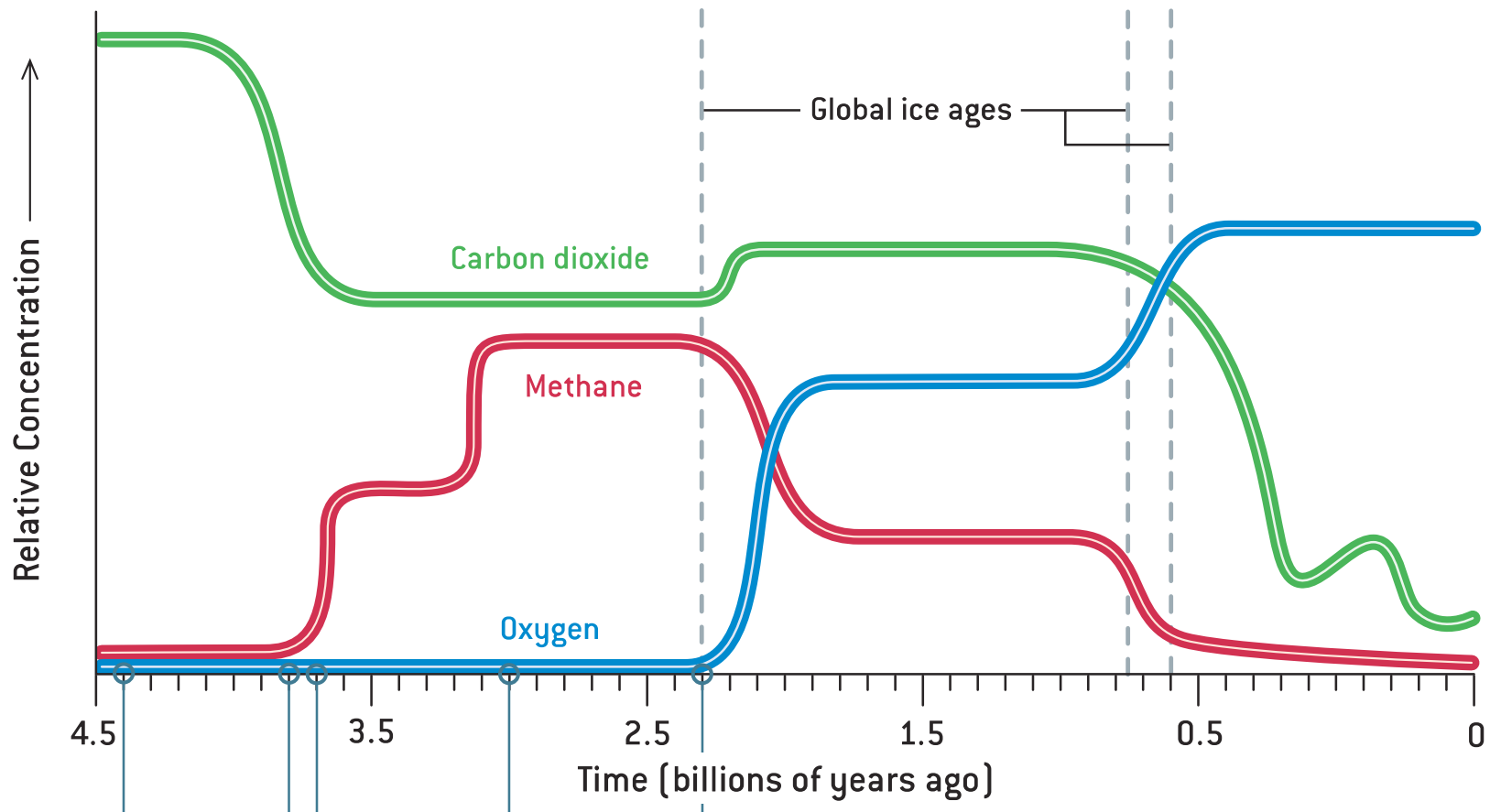
When did oxygenic photosynthesis evolve?

Based on what I said in last lecture, how might you look for it?
(Red beds, steroids require O₂ for biosynthesis; S, Fe isotope fractionations)



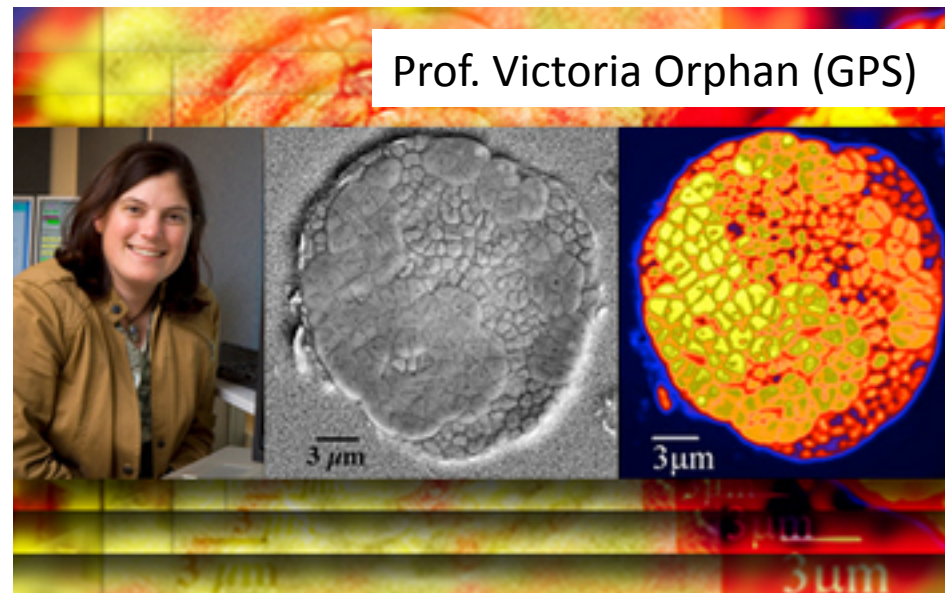
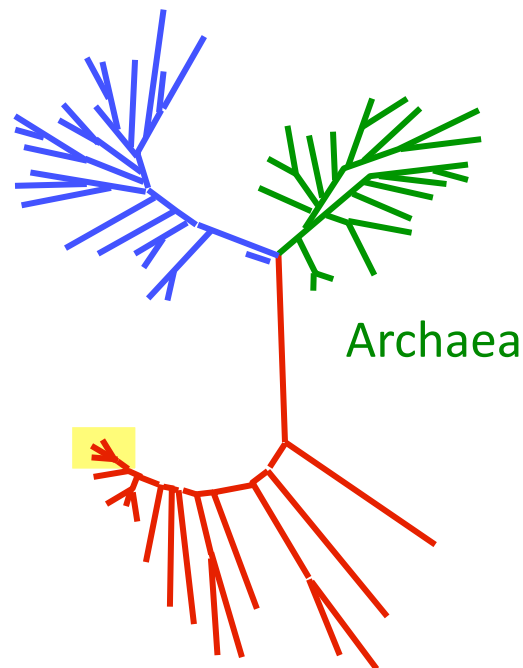


When did O_2 accumulate to the present atmospheric level (PAL)?
Was CH_4 an early Earth biosignature?



Kasting, Scientific American

Baxter Pond Volta Flame Movie

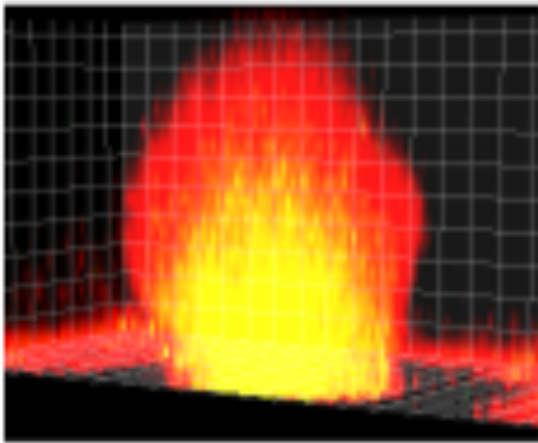


Talk about how methanogens (presumably ancient bugs) can create methane: $4\text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_4 + 2\text{H}_2\text{O}$ but something else removes it... oxygen is one thing, but Anaerobic organisms can consume it too... Week 8

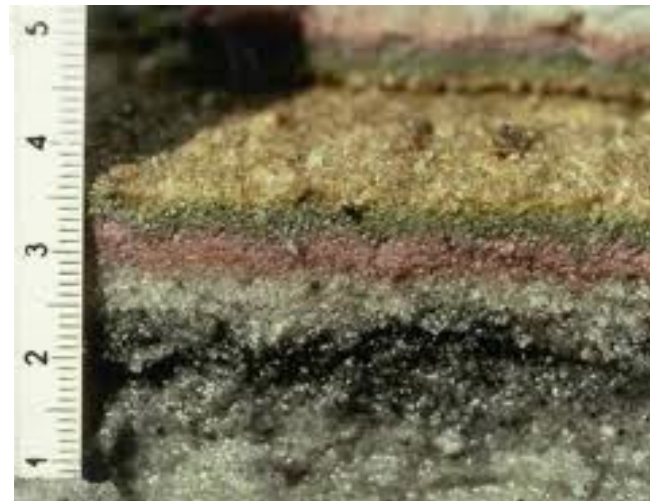
Concept of BIOGEOCHEMICAL DISEQUILIBRIUM: predictable layered sequence of metabolites

- Observation : layering dissipates if system poisoned or killed
- Conclusion: Such layers almost always biologically catalyzed
- Production/consumption of key metabolites outpaces diffusion

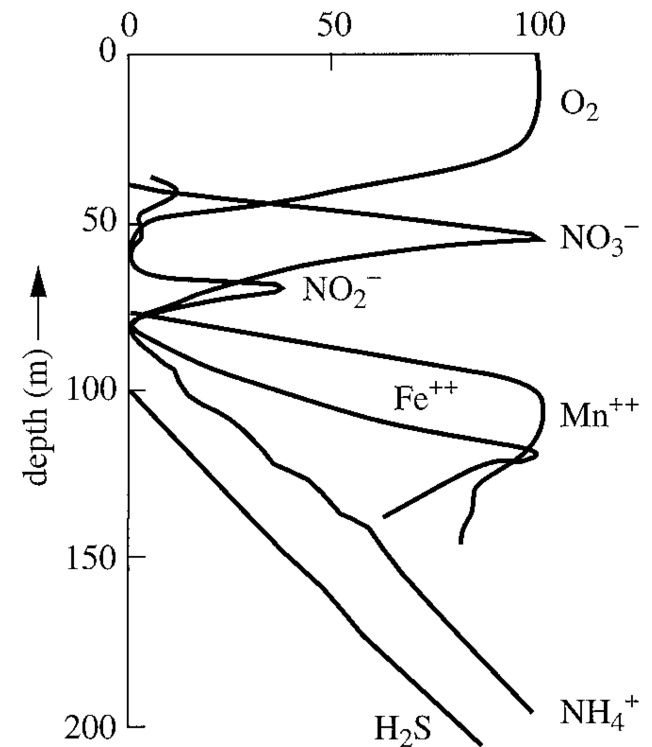
μ -meters



centimeters



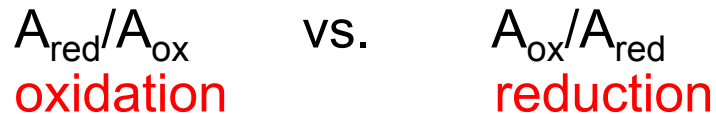
meters



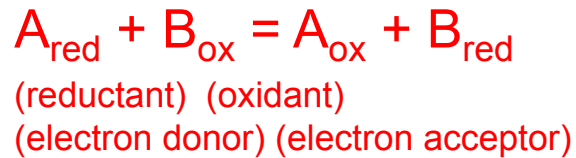
BIOGEOCHEMICAL DISEQUILIBRIUM

plays by thermodynamic rules

Redox couples:

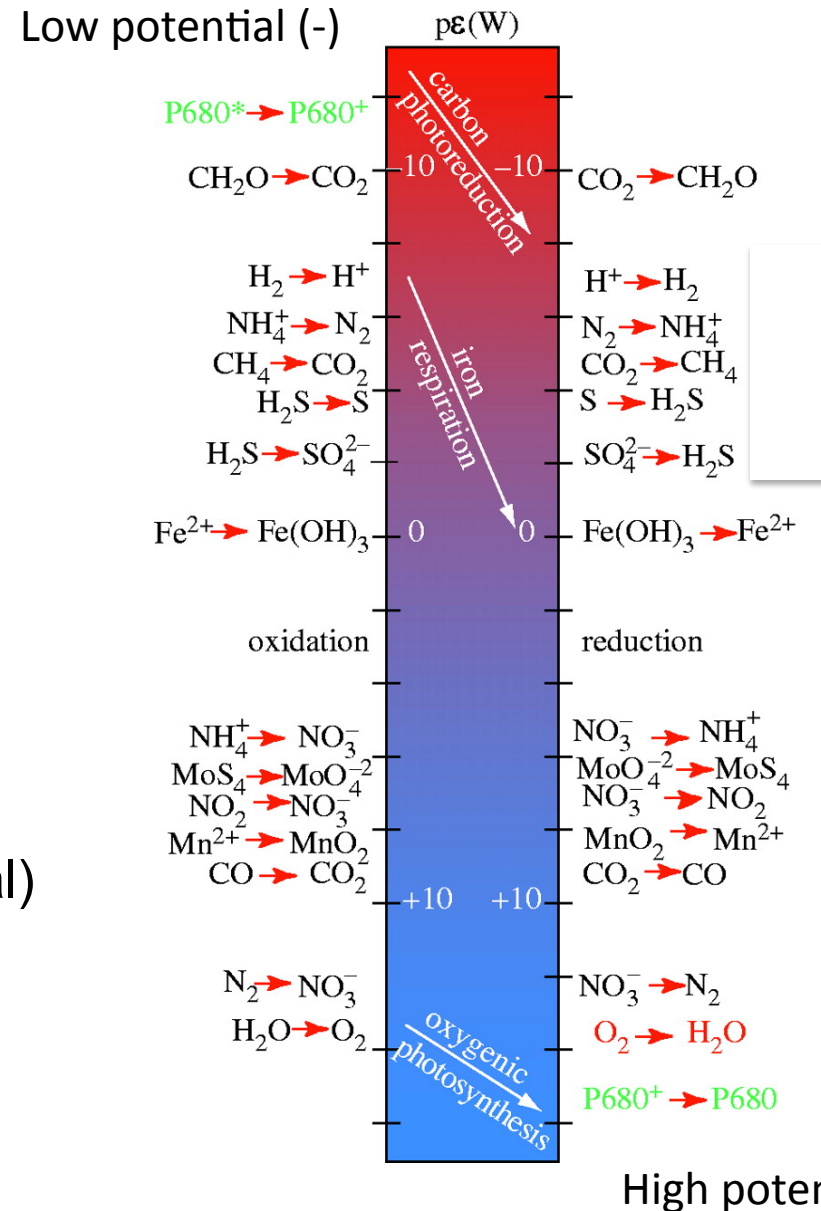


Redox reaction:



* Going downhill (low to high potential) generates energy

- Going uphill (high to low potential) requires energy



Thermodynamic underpinning:

From physics, recall:

energy change = electric charge × voltage difference

$$J = C \times V \text{ Joule} = \text{coulomb} \times \text{volt}$$

In biology, we can express this as:

Gibbs free energy $\Delta G = -n F \Delta E$

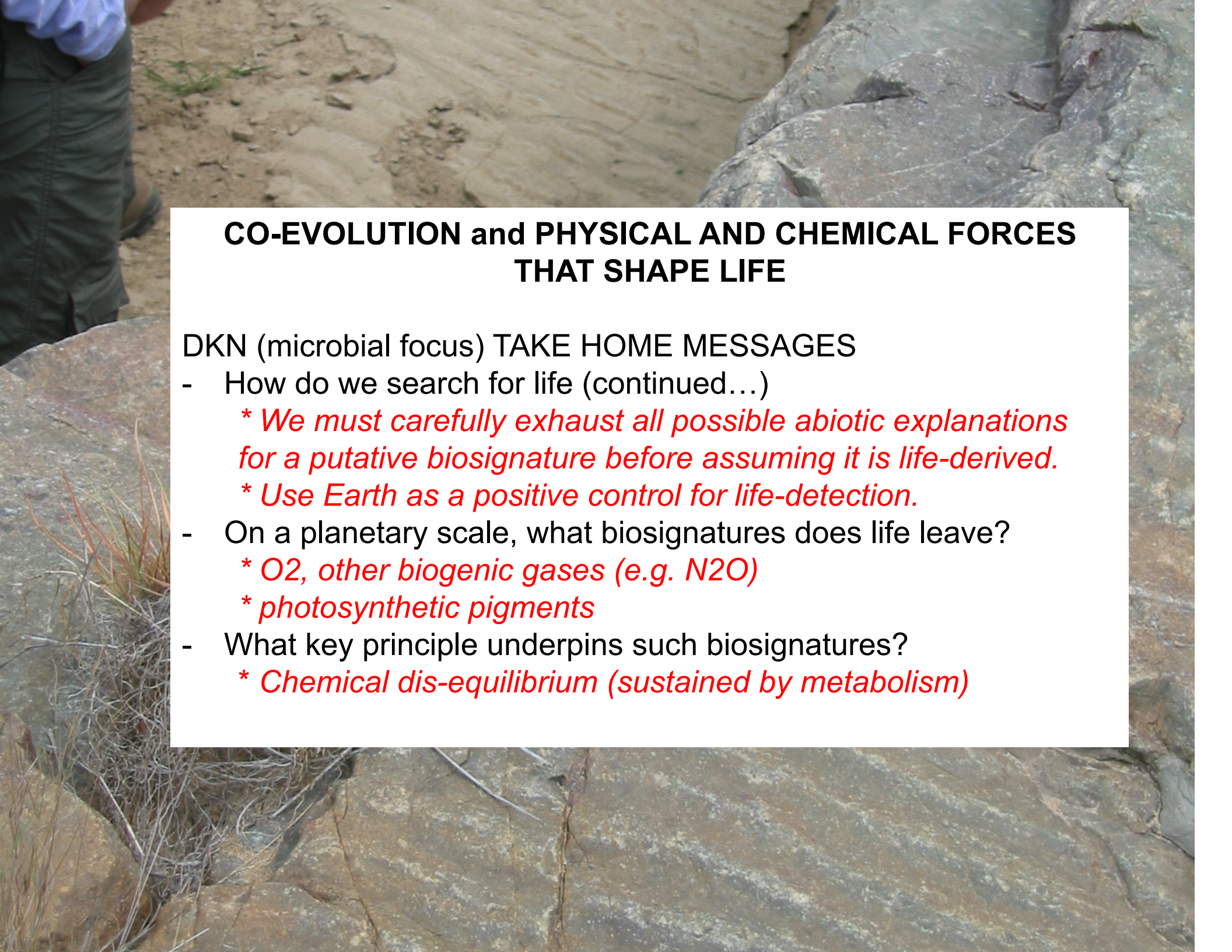
n = number of electrons transferred from reductant (e- donor) to
oxidant (e- acceptor)

F = Farady's constant (96,500 C × mol⁻¹)

ΔE = difference in potential between reductant and oxidant

RULE: the more negative ΔG, the greater the energy to be gained!

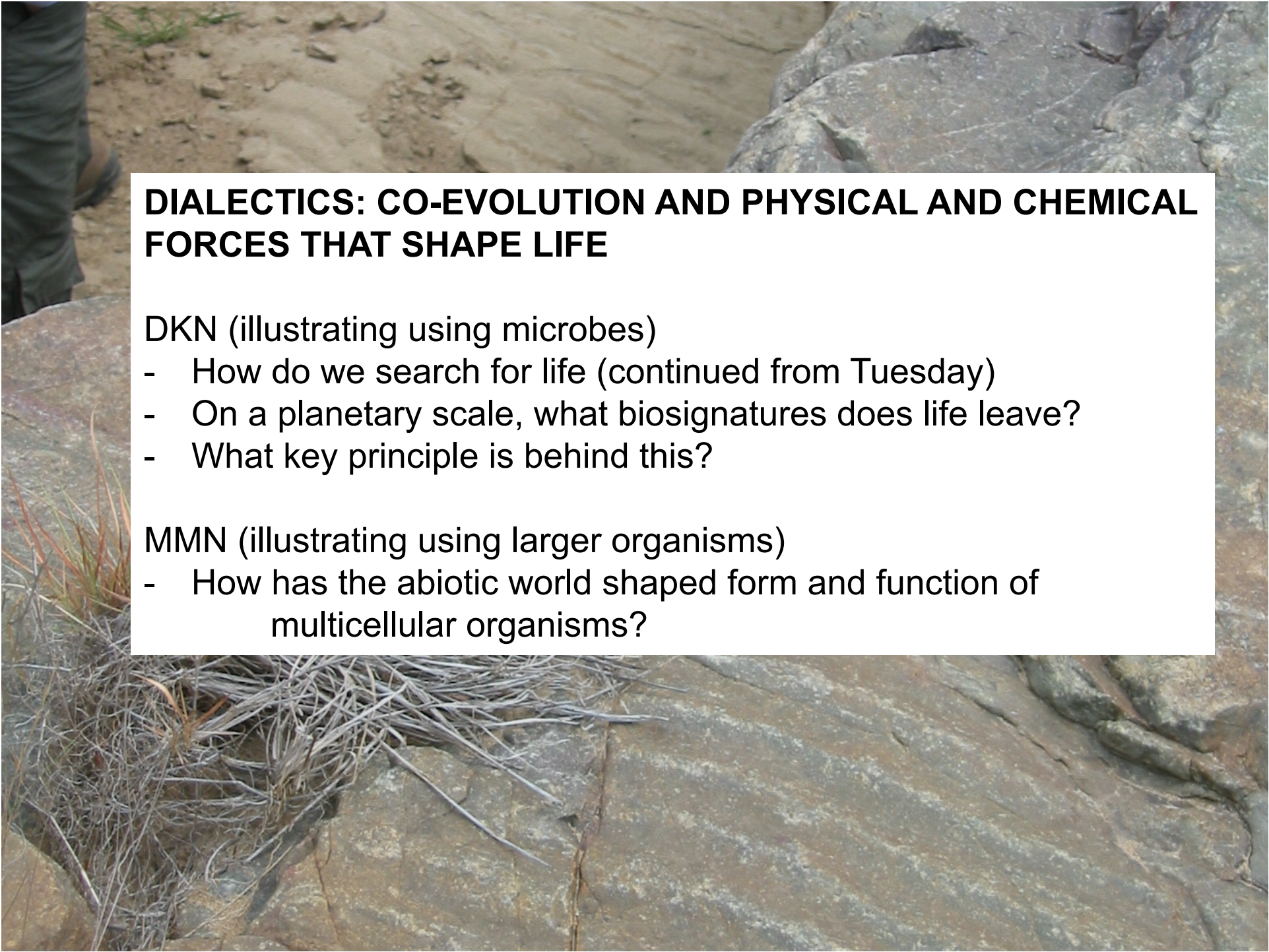
Will revisit this in detail in weeks 4, 5



CO-EVOLUTION and PHYSICAL AND CHEMICAL FORCES THAT SHAPE LIFE

DKN (microbial focus) TAKE HOME MESSAGES

- How do we search for life (continued...)
 - * *We must carefully exhaust all possible abiotic explanations for a putative biosignature before assuming it is life-derived.*
 - * *Use Earth as a positive control for life-detection.*
- On a planetary scale, what biosignatures does life leave?
 - * *O₂, other biogenic gases (e.g. N₂O)*
 - * *photosynthetic pigments*
- What key principle underpins such biosignatures?
 - * *Chemical dis-equilibrium (sustained by metabolism)*



DIALECTICS: CO-EVOLUTION AND PHYSICAL AND CHEMICAL FORCES THAT SHAPE LIFE

DKN (illustrating using microbes)

- How do we search for life (continued from Tuesday)
- On a planetary scale, what biosignatures does life leave?
- What key principle is behind this?

MMN (illustrating using larger organisms)

- How has the abiotic world shaped form and function of multicellular organisms?

Adaptations to aquatic vs. terrestrial (vs. aerial) existence:

- *Supporting the body

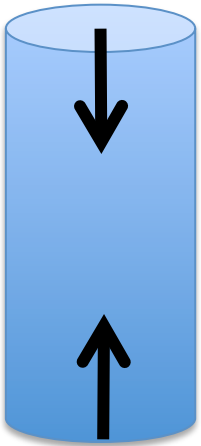
- Exchanging O₂ and CO₂

- *Reproducing

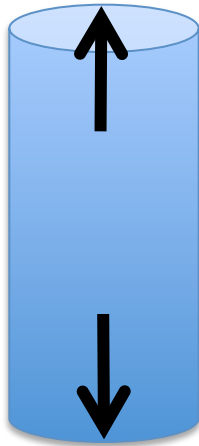
- Avoiding desiccation

Forces acting on biological systems:

compression



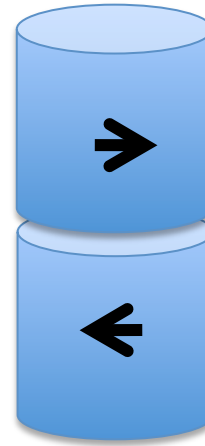
tension



bending



shear

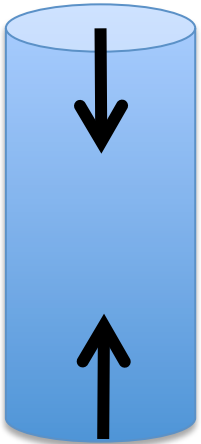


torsion

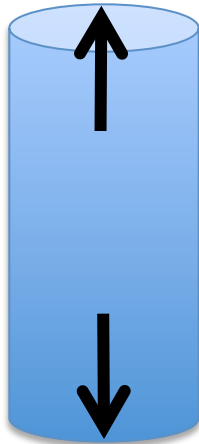


Forces that shape biological systems:

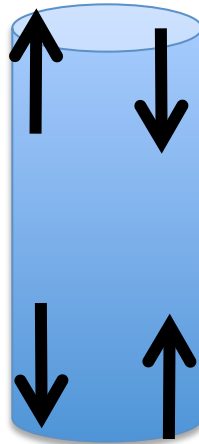
compression



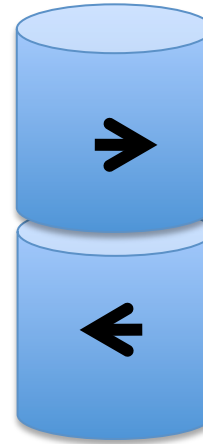
tension



bending



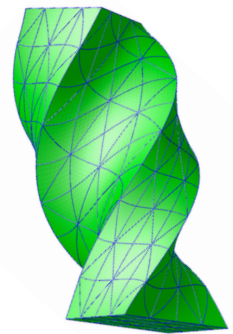
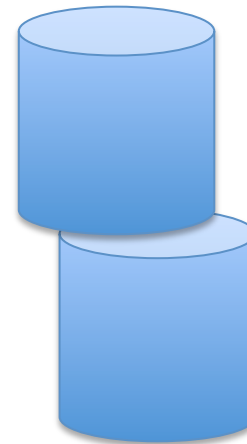
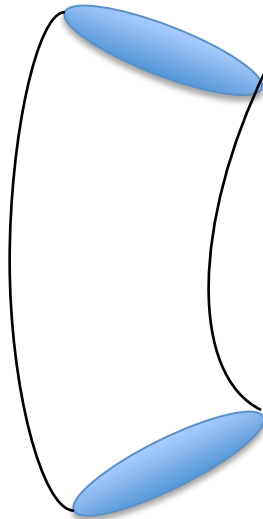
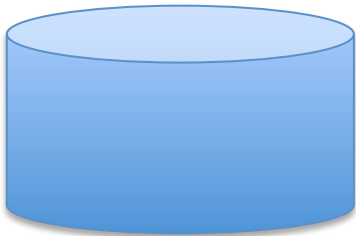
shear



torsion



stress (intensity of force) and **strain** (measurement of deformation)



Perhaps, the most striking difference between water and air?

DENSITY (ρ =mass/volume)

[at sea level, 20°C]

$$\left. \begin{array}{l} \text{H}_2\text{O}/\text{m}^3 = 1000 \text{ kg} \\ \text{Air}/\text{m}^3 = 1.2 \text{ kg} \end{array} \right\} 830\text{X}$$

Weight = mass X acceleration of gravity

or

$$\text{Weight} = (\rho - \rho_f)/Vg,$$

where ρ is the density,
 ρ_f is the density of the medium
 V is the object's volume
 g is the acceleration of gravity (9.81 m/sec²)

$(\rho - \rho_f)$ = effective density

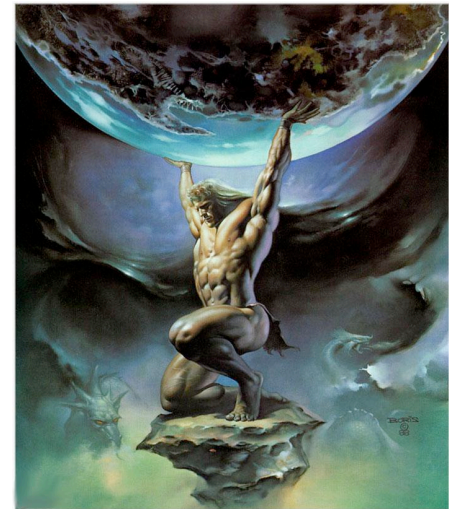
Most biological objects have a density of $\sim 1,100 \text{ kg/m}^3$

Therefore, effective density in air nearly same as their density (i.e., $\sim 1,100 \text{ kg/m}^3$)

in water $\sim 100 \text{ kg/m}^3$

Wood has a density less than water ($\sim 1000 \text{ kg/m}^3$) – floats

Some animals with CaCO_3 skeletons have densities of $2,000 \text{ kg/m}^3$, so have effective densities like animals on land



Because of low density of air, objects weigh more, so gravity more constaining in air

Compare a pine tree and kelp:

- 20-30 m in length
 - canopy of photosynthetic material near distal end
 - both $\sim 1,000 \text{ kg/m}^3$
-

Pine in air – maintain trunk diameter of 0.5 m

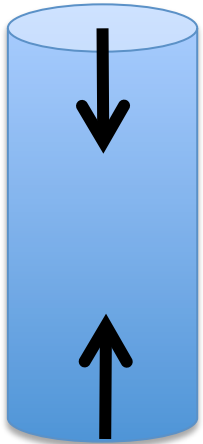
Kelp stipe – 0.05 cm

with about $\sim 1\%$ of investment in structural material

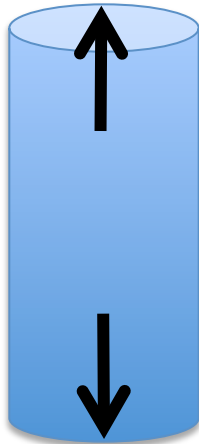


Forces acting on biological systems:

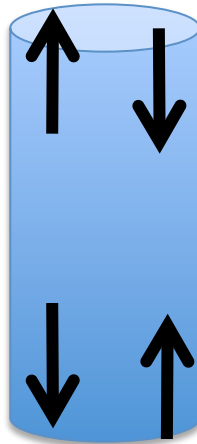
compression



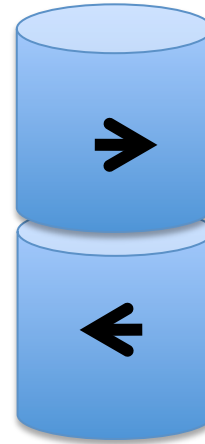
tension



bending



shear



torsion



Principal forces in air:

Principal forces in water:

A mixture

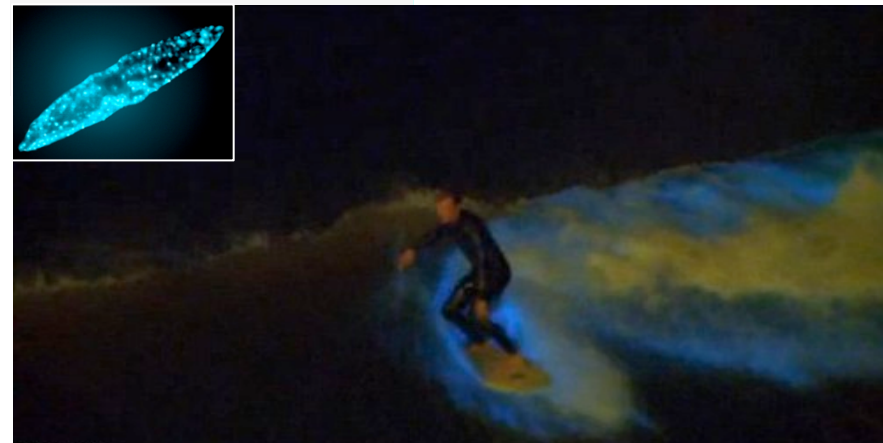
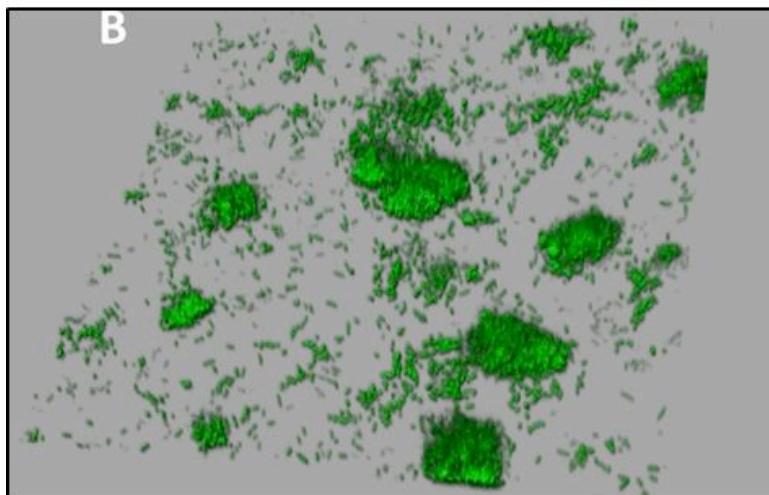
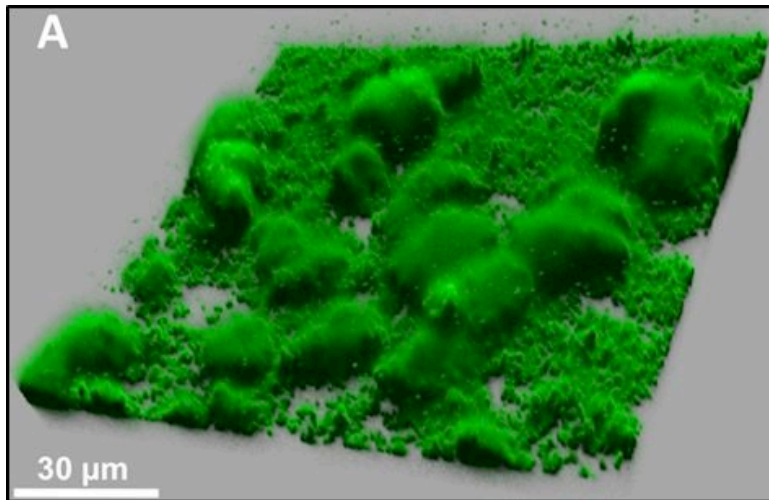
Structural members strained principally in:

1^o tension
(also shear)



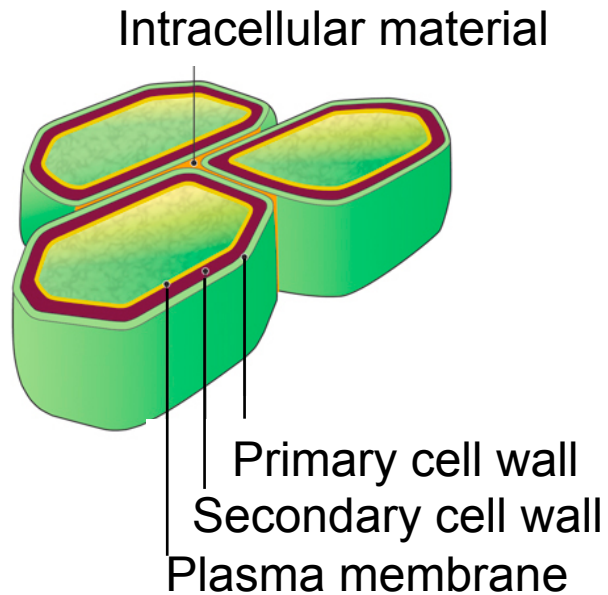
1^o compression
(also bending)



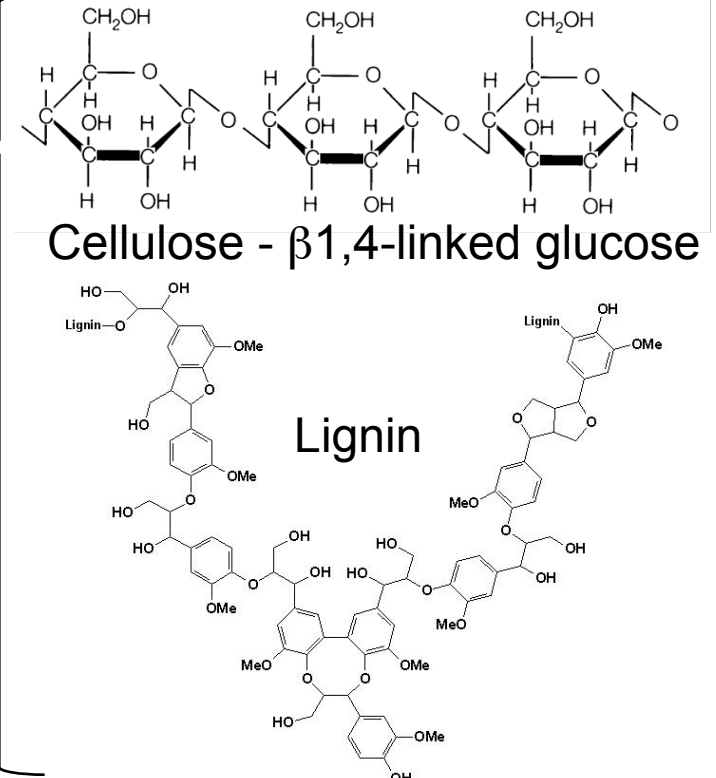


What is the principal force acting on these microbes?

Plants – investment in supportive materials

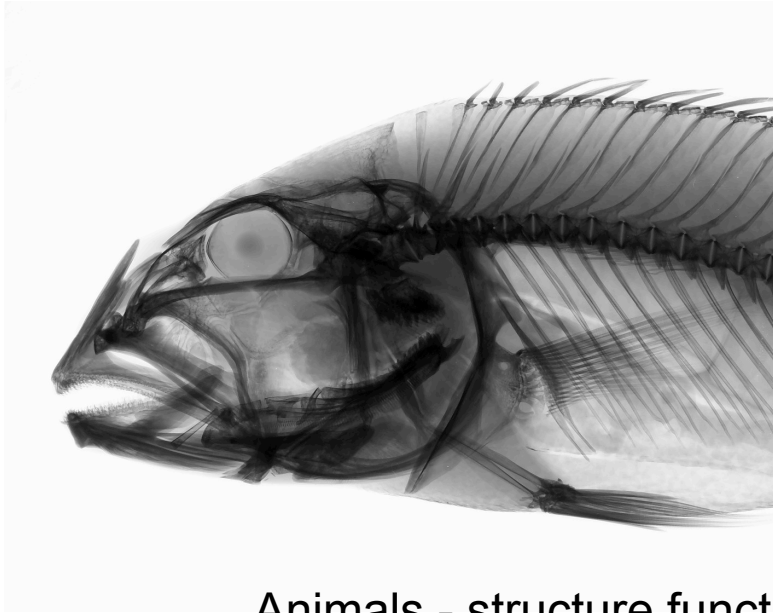


**Lignocellulose
(biofuels)**



Jared
Leadbetter





Animals - structure function of the skeleton in:

1. feeding

in water – relatively incompressible – highly kinetic skull
~30 bones, 50 muscles --**MOVIE**

in air – skull bones fuse/3 become inner ear bone, lower jaw,
only mobile element in feeding – tongue muscles



2. locomotion

in water – work against the medium

on land – work against the substrate **MOVIE**

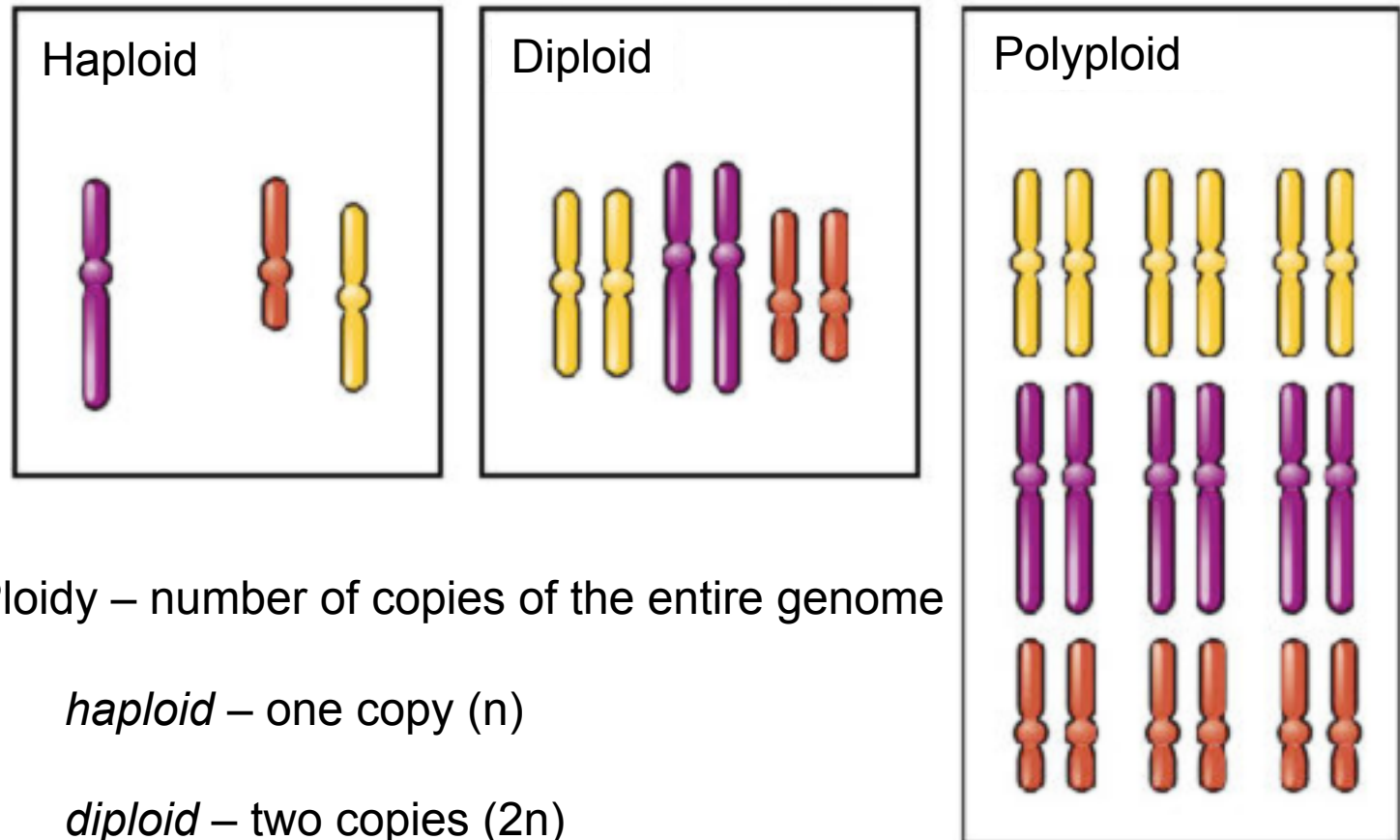
QUESTION—DIFFERENCES???

Adaptations to aquatic vs. terrestrial (vs. aerial) existence:

- *Supporting the body
- Exchanging O₂ and CO₂
- *Reproducing
- Avoiding desiccation

Reproductive 'Strategy'

'Ploidy'



Ploidy – number of copies of the entire genome

haploid – one copy (n)

diploid – two copies ($2n$)

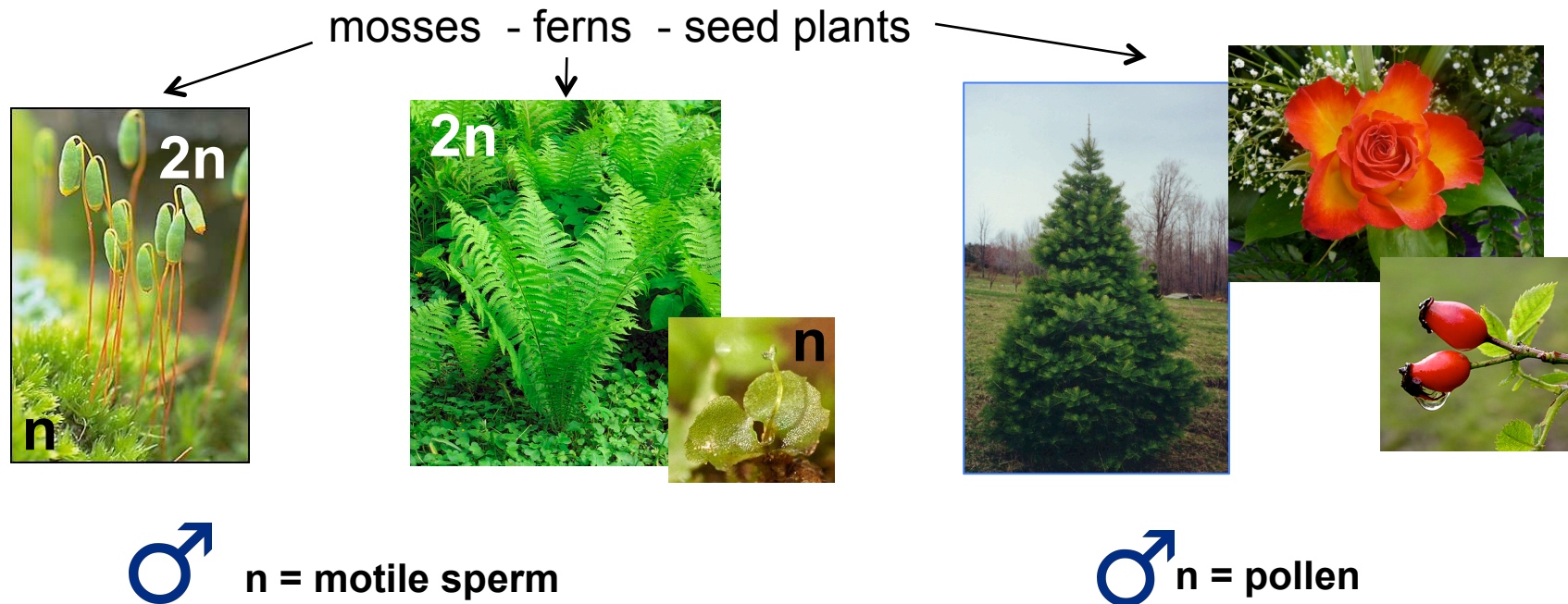
polyploid – many copies (xn)

Evolution in Reproductive 'Strategy' - Plants

In plant evolution:

Dominance of *haploid* ('n') → *diploid* (2n) generation

Increasing independence from water, motile sperm to pollen:



Animals – Reproductive Strategy

'broadcast' spawning



Animals – Reproductive Strategy

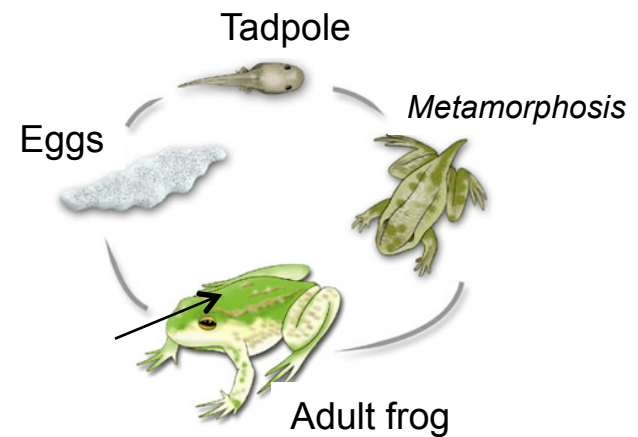


'broadcast' spawning

terrestrial – retain motile sperm throughout;

1. strategy – move to internal fertilization/
development out of water

Mate/develop in water



2.

shelled egg/
external development



3.

placenta/internal development



Take-home message:

The presence or absence of an aqueous environment has been a key driver of evolutionary selection pressure on the form and function of multicellular Eukarya.