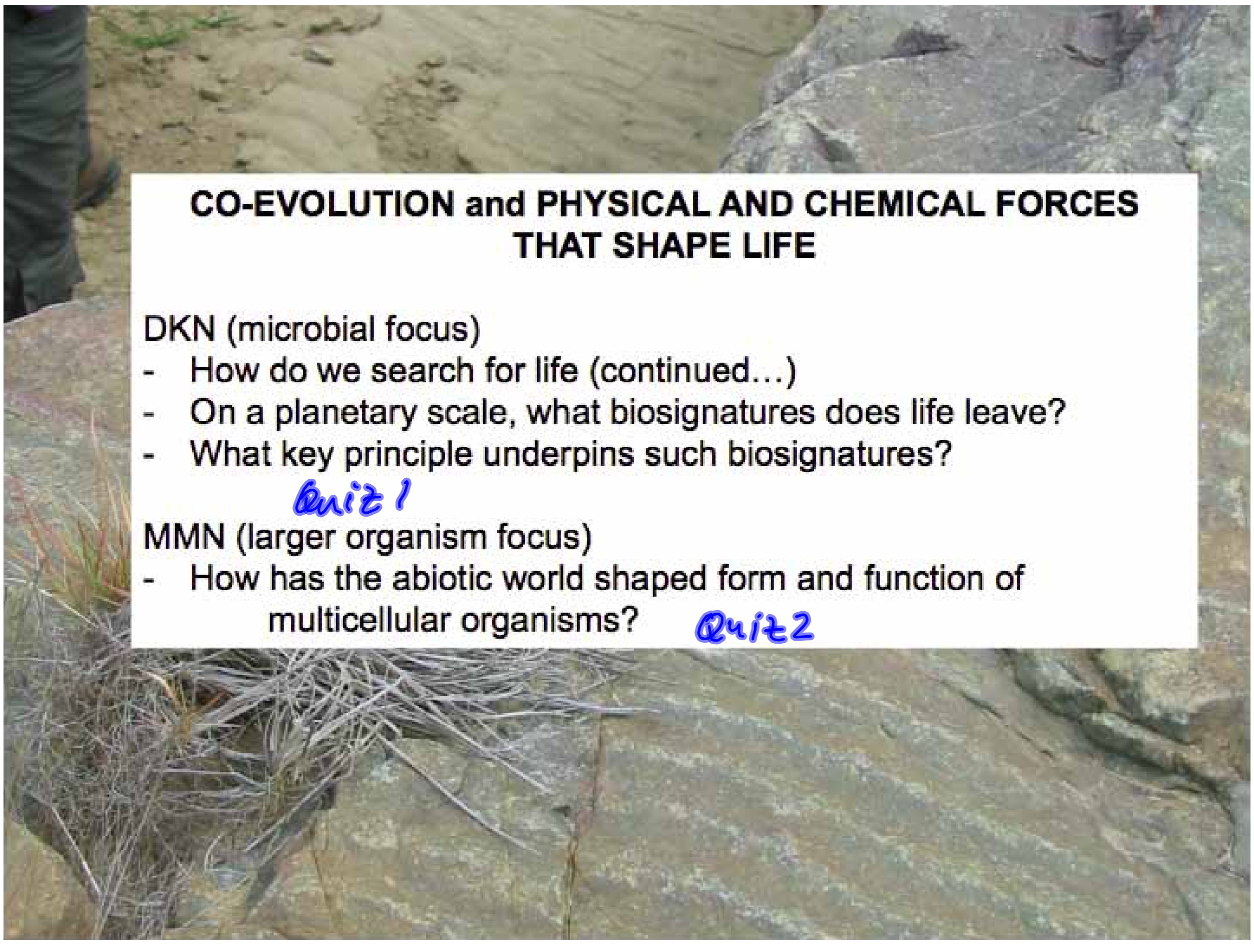
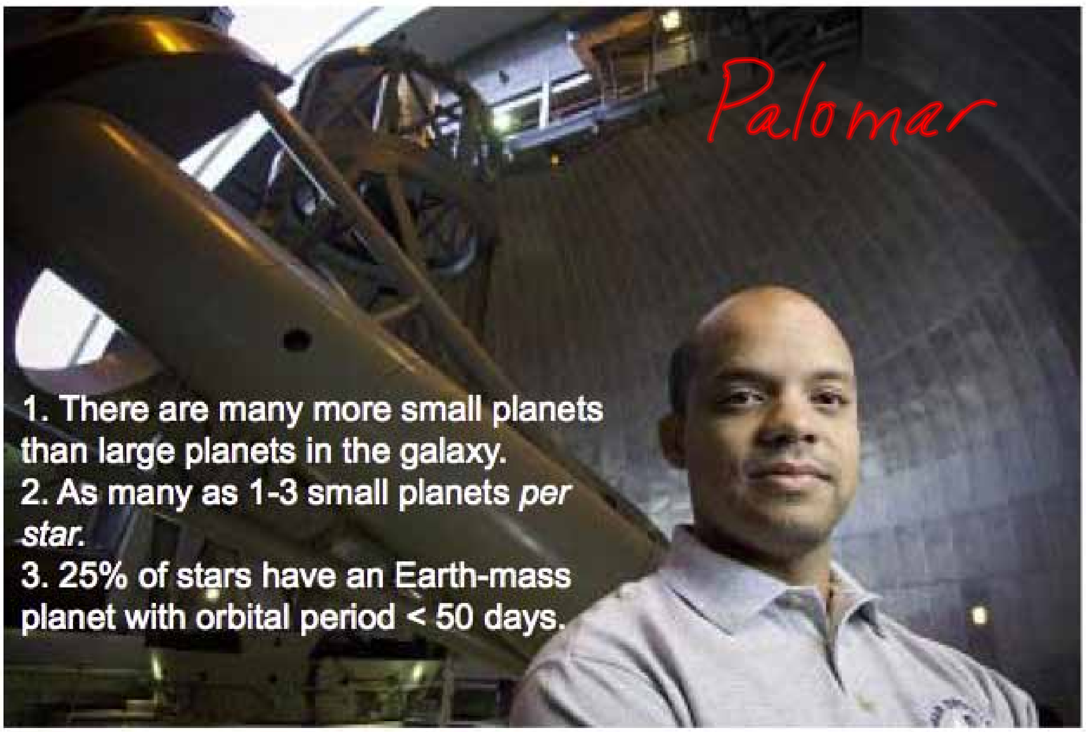

CO-EVOLUTION and PHYSICAL AND CHEMICAL FORCES THAT SHAPE LIFE
DKN (microbial focus)
- How do we search for life (continued…)
- On a planetary scale, what biosignatures does life leave?
- What key principle underpins such biosignatures?
Quiz 1
MMN (larger organism focus)
- How has the abiotic world shaped form and function of multicellular organisms? Quiz2

Prof. John Johnson is on the hunt for Exoplanets

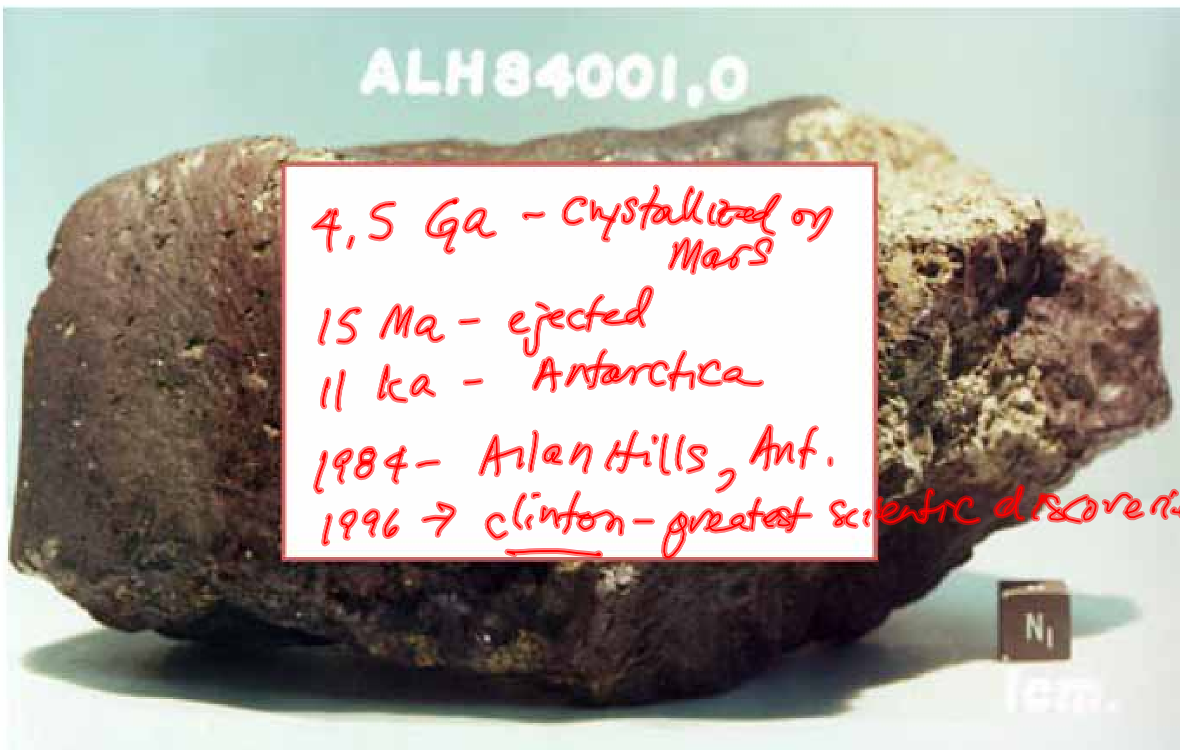


Can we define generic "biosignatures" that could help us search for life on other planets? What would you look for if you were the chief scientist?

nucleic acids, structured mineral deposits, H_2O

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

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



4,5 Ga - crystallized on Mars

15 Ma - ejected

11 ka - Antarctica

1984 - Allan Hills, Ant.

1996 → clinton - greatest scientific discoveries

April 12, 2012

Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001

David S. McKay, Everett K. Gibson Jr., Kathie L. Thomas-Keprta, Hojatollah Vali, Christopher S. Romanek, Simon J. Clemett, Xavier D. F. Chillier, Claude R. Maechling, Richard N. Zare

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.

Science, 1996

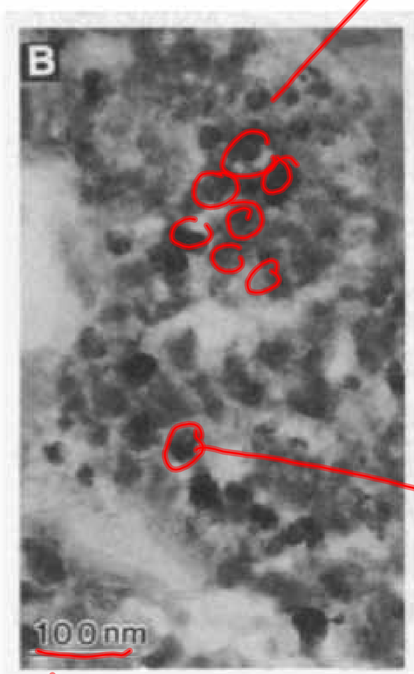
?

- Abiotic processes?

What do you think?

clamp

chain



100nm

= ?

50nm single domain

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?

H_2O] → pre-req.

2/3

- Green] chlorophyll

- O_2

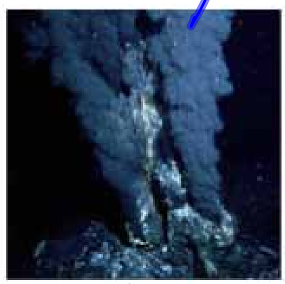
biogenic trace

→ N_2O] abiotic can make
CH_4

→ concentration

liquid hydrothermal → FeS

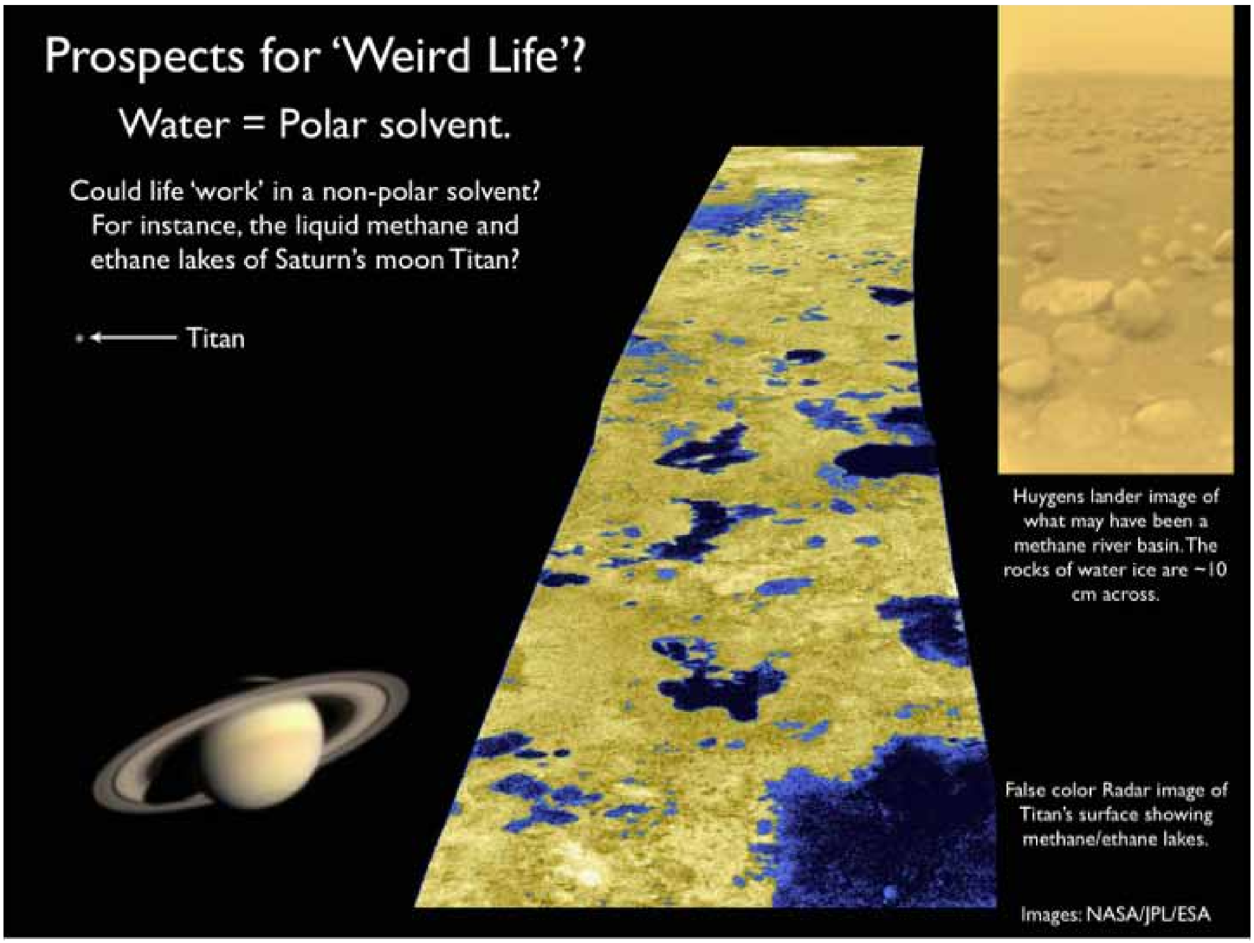
Why is water good for life?



- Dissolves most things
- Solvent/liquid?
  → app. rates for biochemistry

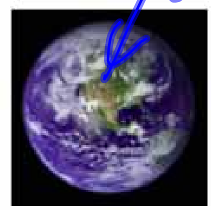
  C-life: covalent bond formation
  H-bonds

- Floats when freezes → expands
- High heat capacity → regulates T
  compatible seasons, diurnal
- Large liq. range (pure H_2O 0°C - 100°C
  +salt ↓ freezing T
  ↑ pressure ↑ boiling T


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

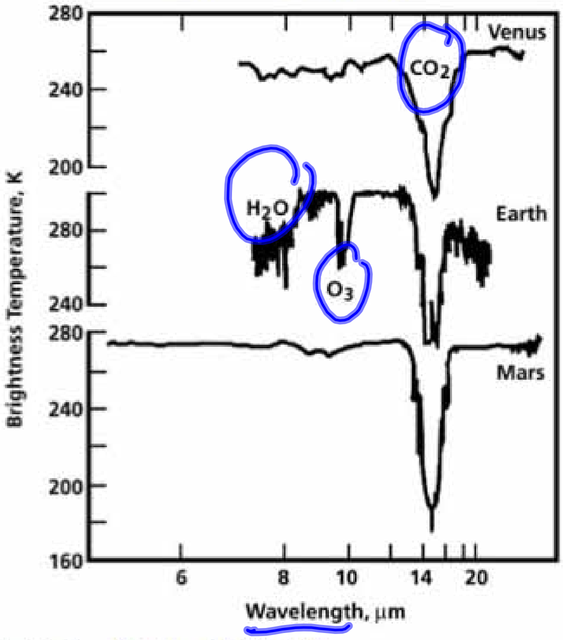
April 12, 2012

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

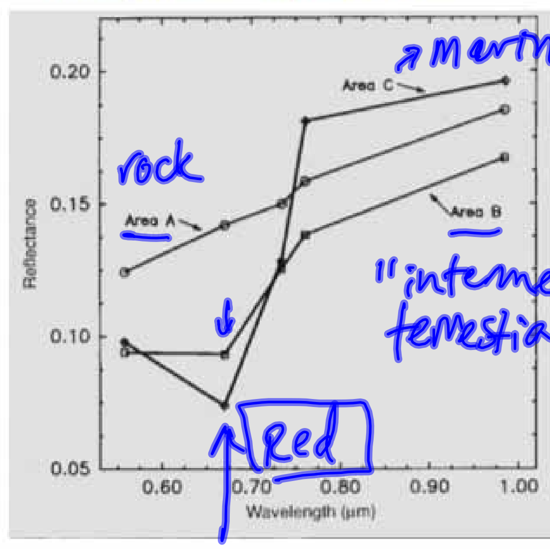


green

Planetary spectra



Chlorophyll absorption in red



marine

rock

"intermed." terrestial

Red

Prof. Geoff Blake (CCE,GPS)

Sagan 1993

NASA SeaWiffs Movie

Is O_2 a Robust Biosignature?

i.e. If you *don't* detect O_2, does that mean there isn't life?

- anaerobic metabolism
- below detection limit

$$CO_2 + H_2O \underset{\text{oxy. pho.}}{\xrightarrow{h\nu}} \text{"}CH_2O\text{"} + O_2$$

$\xleftarrow[\text{respiration}]{\text{aerobic}}$

equib. → no net accum. of O_2

What sets the steady state level?

Fe^{2+}] "Reductant"

- until abiotic reductants are scavenged

H_2 – escape to space ✓ limited → gravity

"CH_2O" – buried (coal)

organic

Complex combination of physical, chemical and biological processes set the planetary redox state. This can (and has!) changed through time.

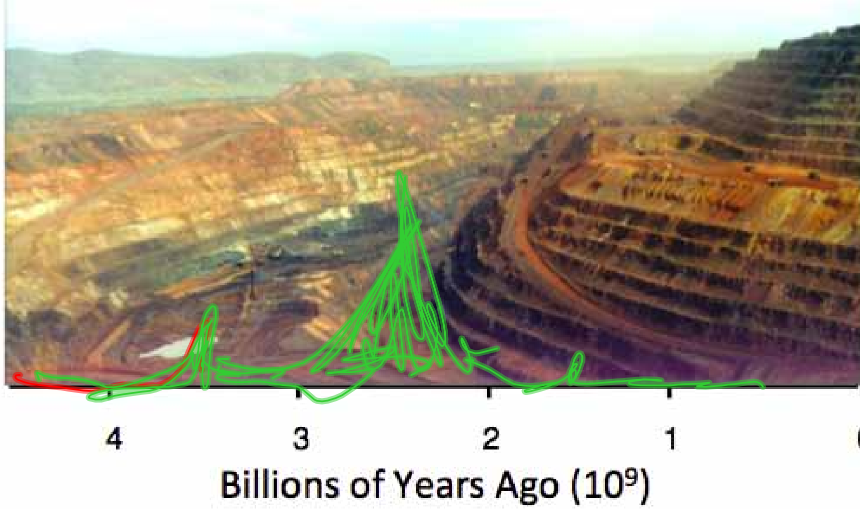
sea surface

When did oxygenic photosynthesis evolve?

Fe^{2+}

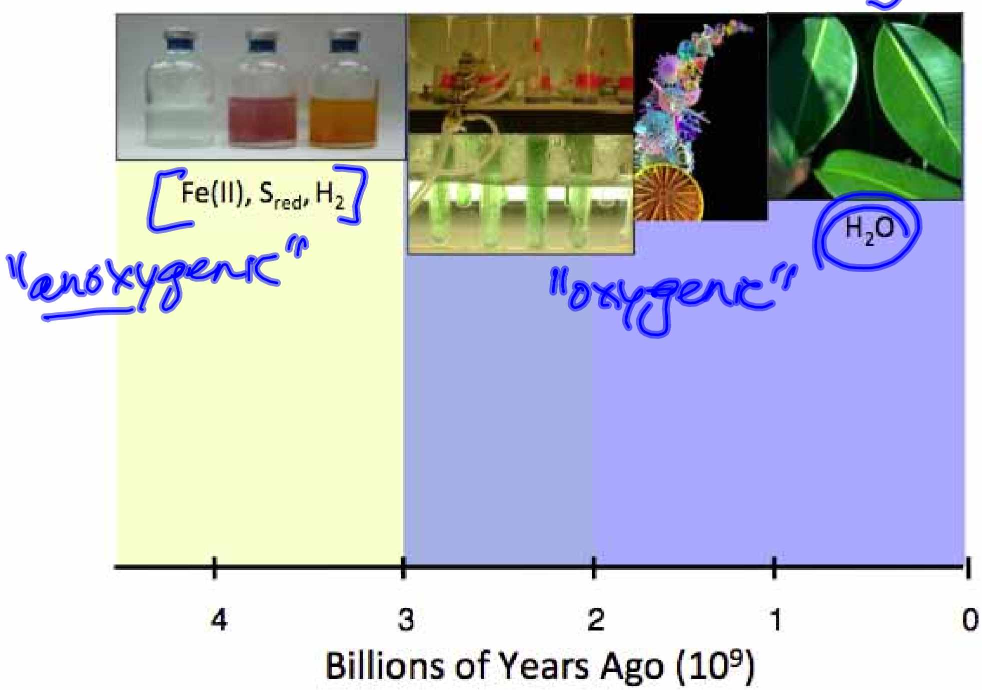
Fe^{3+}

$\searrow Fe(OH)_3\,(s) \rightarrow$ Banded Iron Formation

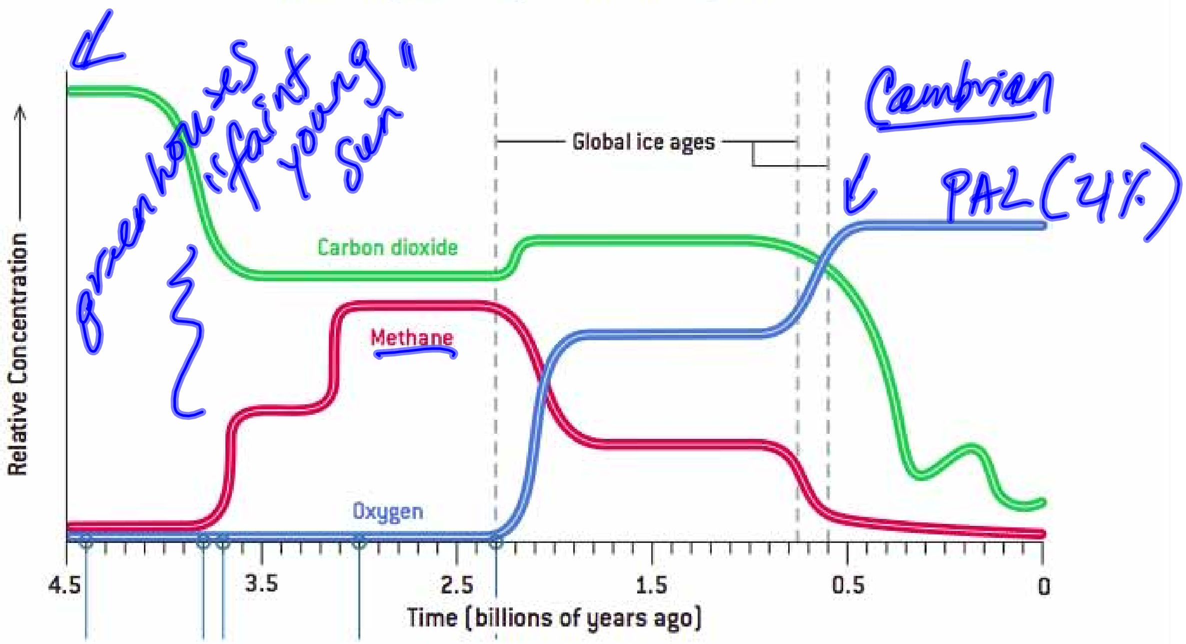


Generic Rxn: $\overset{e^-\text{ donor}}{A_{red}} + \overset{e^-\text{ acceptor}}{CO_2} \rightarrow A_{ox} + \overset{\text{biomass}}{CH_2O}$

$A_{red} = H_2, S_{red}, Fe(II), H_2Os$



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



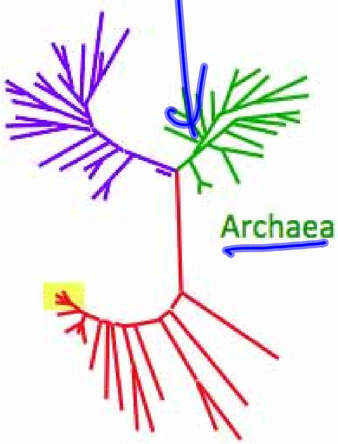
Kasting, Scientific American

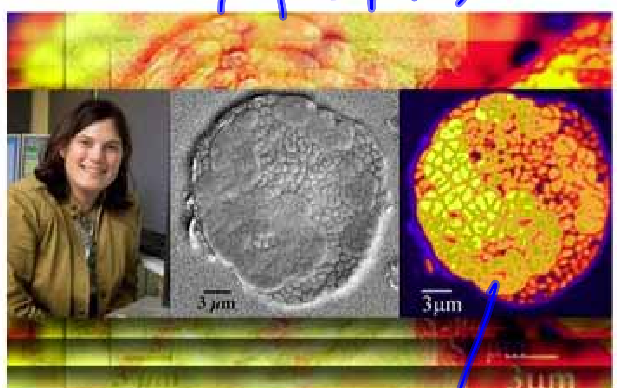
$4H_2 + CO_2 \rightleftarrows CH_4 + 2H_2O$

methanogenic archaea

Baxter Pond Volta Flame Movie

Prof. Orphan





week 8

symbiotic other bacteria

Concept of BIOGEOCHEMICAL DISQUILIBRIUM: predictable layered sequence of metabolites

→ kill/poison → layers disappear

→ ∴ biological consump/production of metabolites outpaces diffusion

→ Kinetic fingerprint

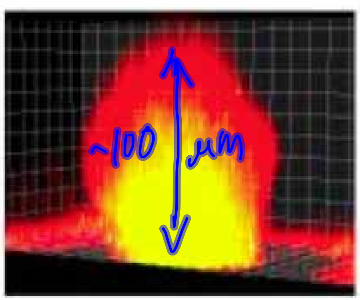
μ-meters

→ centimeters

diatoms

Black Sea

meters

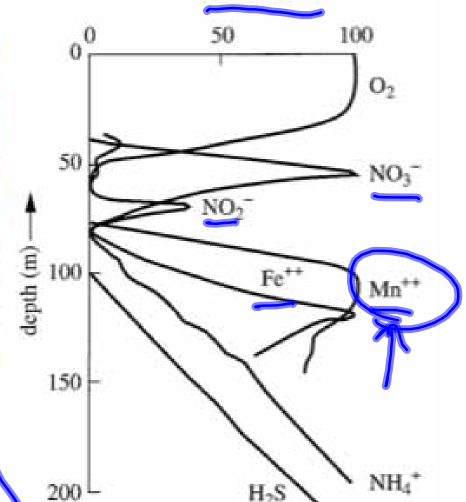


microbial mat

cyano

purple bacteria → anoxy. pho

Sulfate-red



Nealson and Conrad (

Electron tower

BIOGEOCHEMICAL DISEQUILIBRIUM
plays by thermodynamic rules

→ Redox couples:

A_{red}/A_{ox} vs. A_{ox}/A_{red}

oxidation (lose e-)   reduction (gain e-)

Redox reaction:

$A_{red} + B_{ox} = A_{ox} + B_{red}$

e- donor, reductant   e- acceptor, oxidant

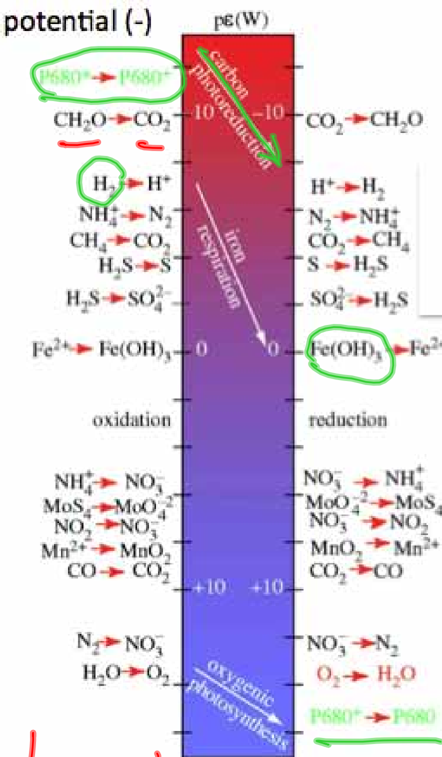
→ Going downhill (low to high potential) *generates* energy

→ Going uphill (high to low potential) *requires* energy

Kirschvink and Kopf, Royal Society Trans.

e- donors

chlor



Ared/Aox

e- accep.

Aox/Ared

Thermodynamic underpinning:

From physics, recall:
energy change = electric charge × voltage difference

$J = C \times V$

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, more − ΔG, ↑ energy

Week 4,5

CO-EVOLUTION and PHYSICAL AND CHEMICAL FORCES THAT SHAPE LIFE

DKN TAKE HOME MESSAGES

- How do we search for life (continued…)

• Exhaust all possible abiotic alternative

• "Geobiology" → Earth ⊕ control

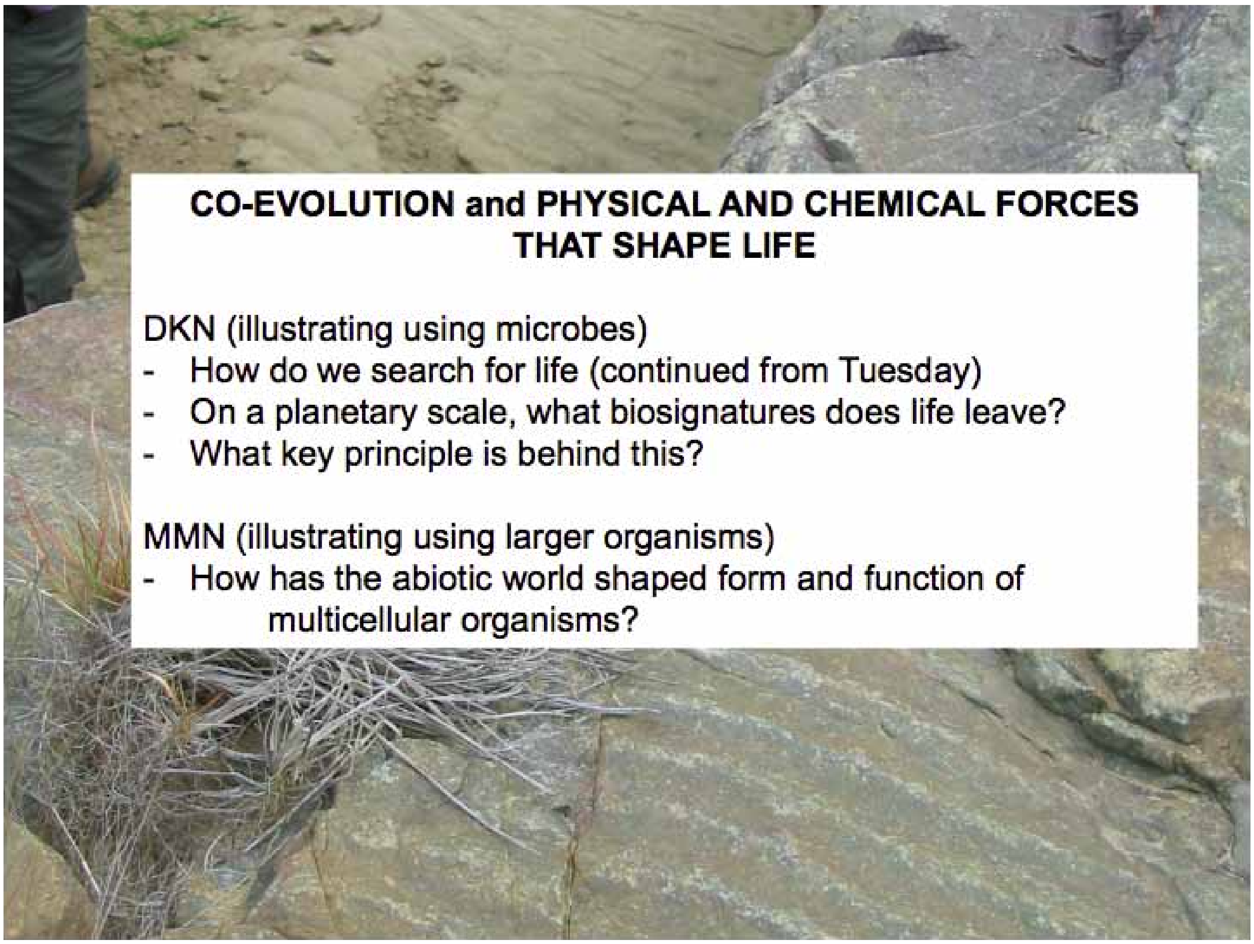
- On a planetary scale, what biosignatures does life leave?

$-O_2$, N_2O ....

- photosyn.-pigments

- What key principle underpins such biosignatures?

→ chemical disequilibria driven by microbial metabolism → incredible variety of solutions


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:

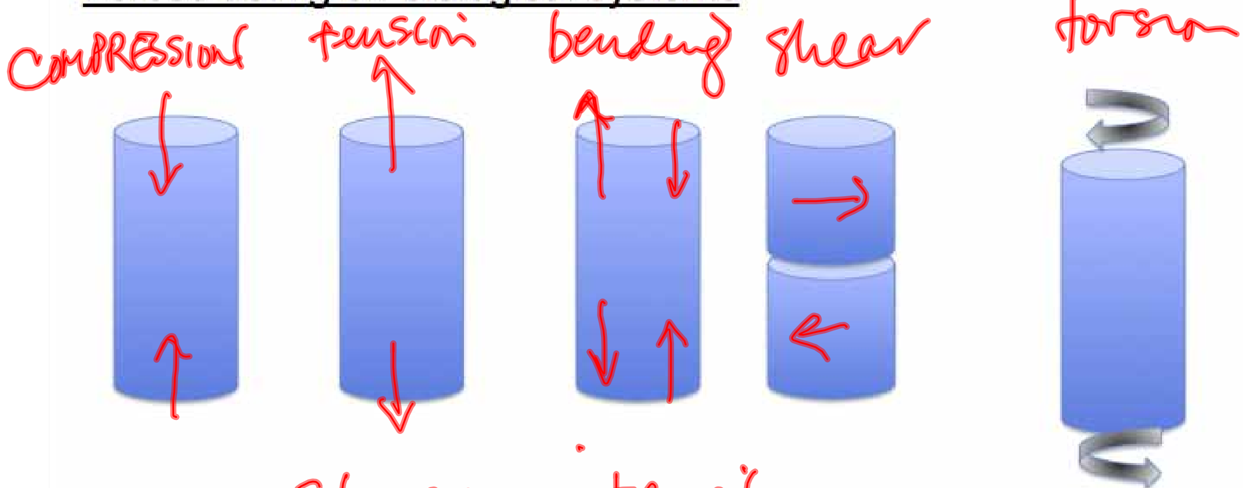
* Supporting the body

Exchanging O_2 and CO_2

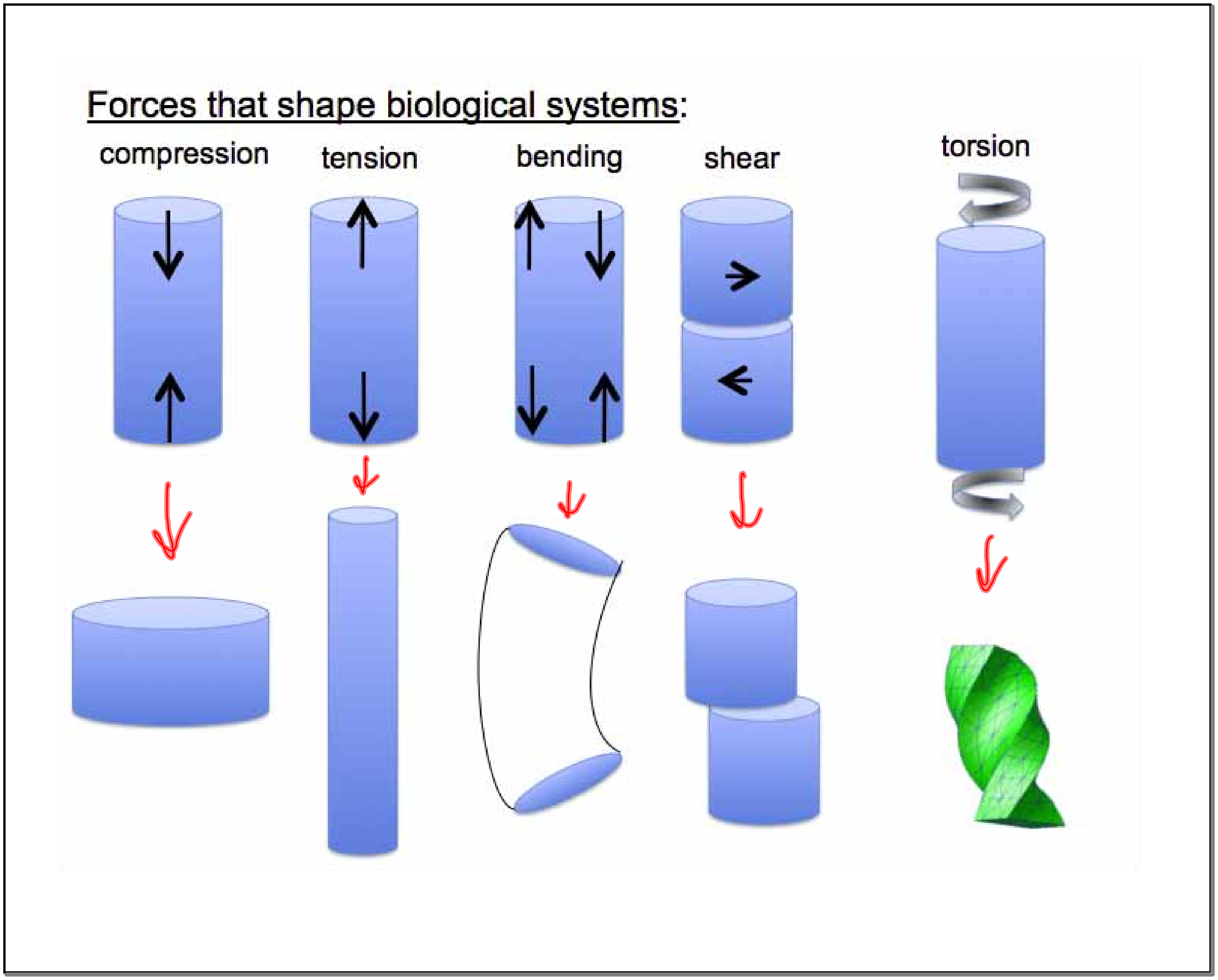
* Reproducing

Avoiding desiccation

Forces acting on biological systems:



Stress - intensity
Strain (measurement of deformation


Forces that shape biological systems:
compression
tension
bending
shear
torsion

Perhaps, the most striking difference between water and air?

Density (ρ = mass / volume)

[at sea level, 20°C]

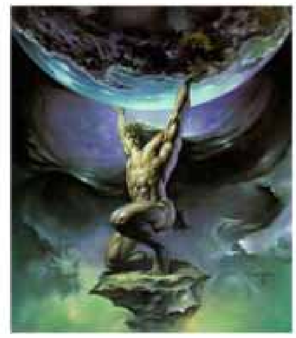
$$\left.\begin{aligned} H_2O/m^3 &= 1000\ kg \\ {*}Air/m^3 &= 1.2\ kg \end{aligned}\right\} 830\times$$

Weight = m $\cdot$ g

$\rho - \rho_f$

ρ = density

ρ_f = density of medium



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

Most biological forms density ~ 1100 kg/m^3

~~kg/m~~ 100 kg/m^3

1000 kg/m^3

↓

floats

Compare a pine tree and kelp:

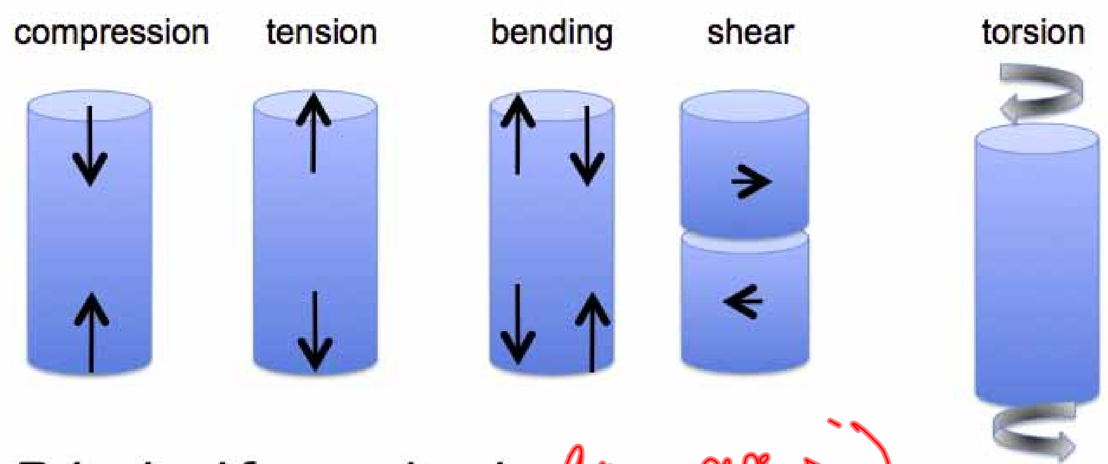
20 - 30 m length
- canopy for photosynthesis w/ distal ~~de~~ ends
- both 1,000 kg/m^3

Pine - trunk diameter 0.5 m

kelp stipe 0.05 m

1/10

Forces acting on biological systems:



Principal forces in air: compression (bending)

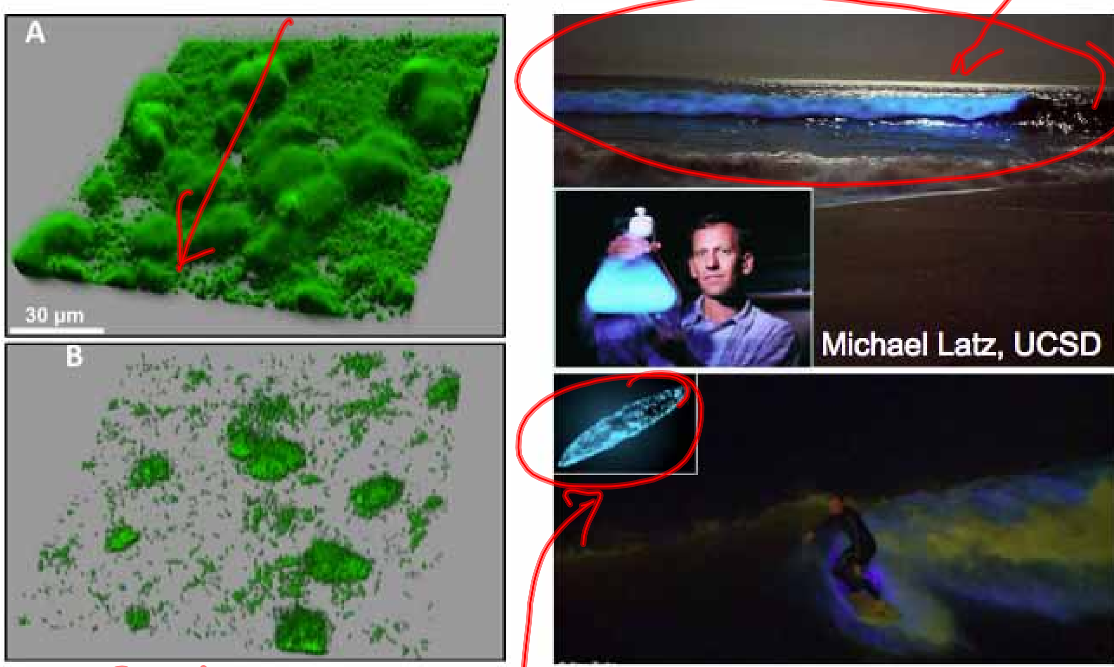
Principal forces in water: tension (shear)

[rupture]

Structural members strained principally in:

1° tension

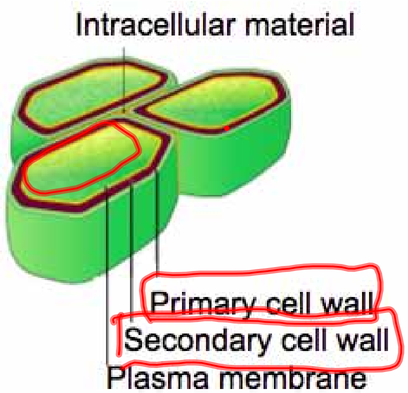
1° compression



Biofilm
shear

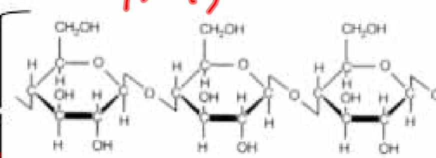
dinoflagellates
shear

Plants – investment in supportive materials

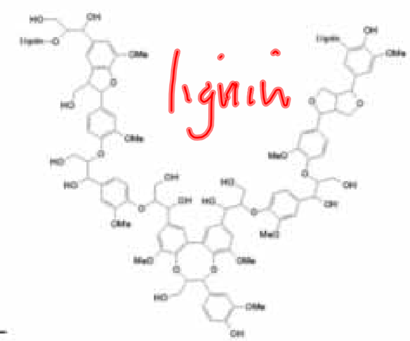


lignocellulose
(biofuels)

cellulose
β 1,4-linked glucose



lignin

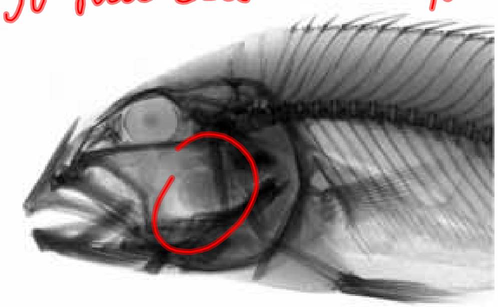


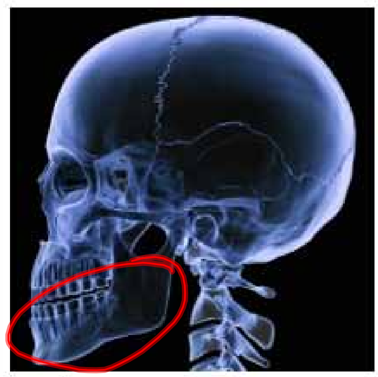
*

Jared
Leadbetter

30 independent bones
50 muscles

40%





~17%

Animals – structure/function of the skeleton in:

1. feeding
   in water – INCOMPRESSIBLE
   in air – COMPRESSIBLE (tongue muscles)

2. locomotion
   in water – working against medium
   on land – working against substrate (gravity)

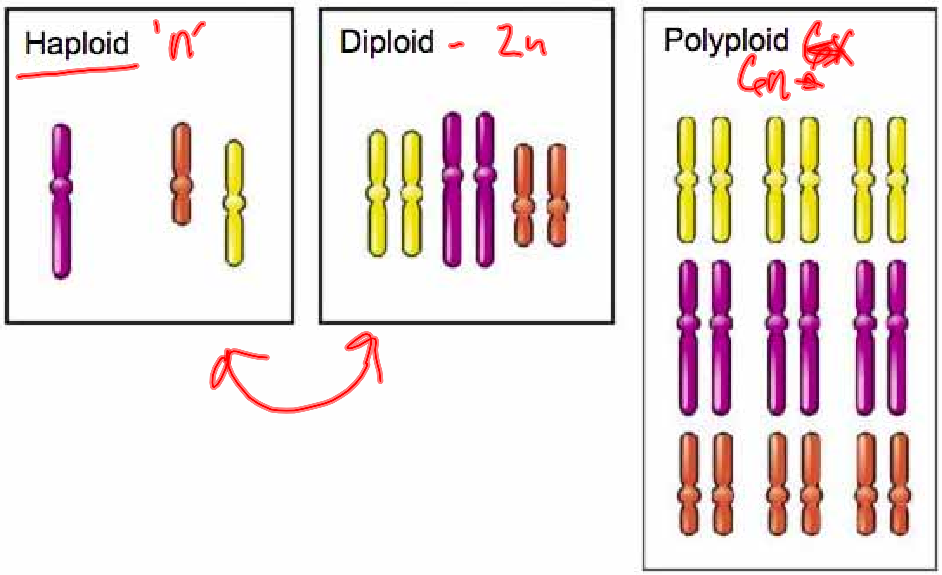
	km/h	body-lengths/sec
Cheetah	112	25
House cat	48	29
Human (Michael Johnson)	45	7
Tiger beetle	1.9	125
[Sailfish	112	25]

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

*Supporting the body
Exchanging O_2 and CO_2
*Reproducing
Avoiding desiccation

Reproductive 'Strategy

PLOIDY = # OF CHROMOSOME SETS



Evolution in Reproductive 'Stategy' - Plants

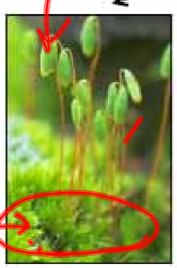
In plant evolution:

DOMINANCE 'n' → 2n

seeds

mosses - ferns - seed plants

2n



n

moss

2n

n

motile sperm

2n

pollen

Animals – Reproductive Strategy

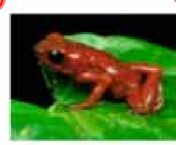
broadcast

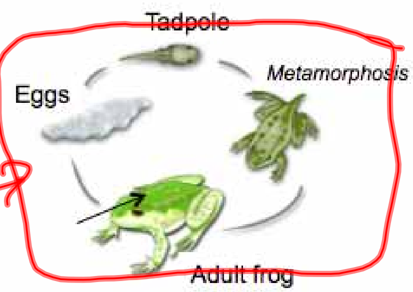
Animals – Reproductive Strategy

'broadcast' spawning

terrestrial – motile sperm

1. internal fertilization
dev. out of H_2O





2.

Shelled EGGS/ EXTERNAL DEV.

3.

Placental mammals
internal develop

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.