Evolution of Biospheres on Planets

(or, 30 minutes of fun and speculation!!)

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Evolution of Biospheres?

After yesterday, I prefer some other questions !!

What are the ”ingredients” that any planetary body needs to encourage life?

How does life alter the planet so it (the planet) is recognizable as “alive” ?

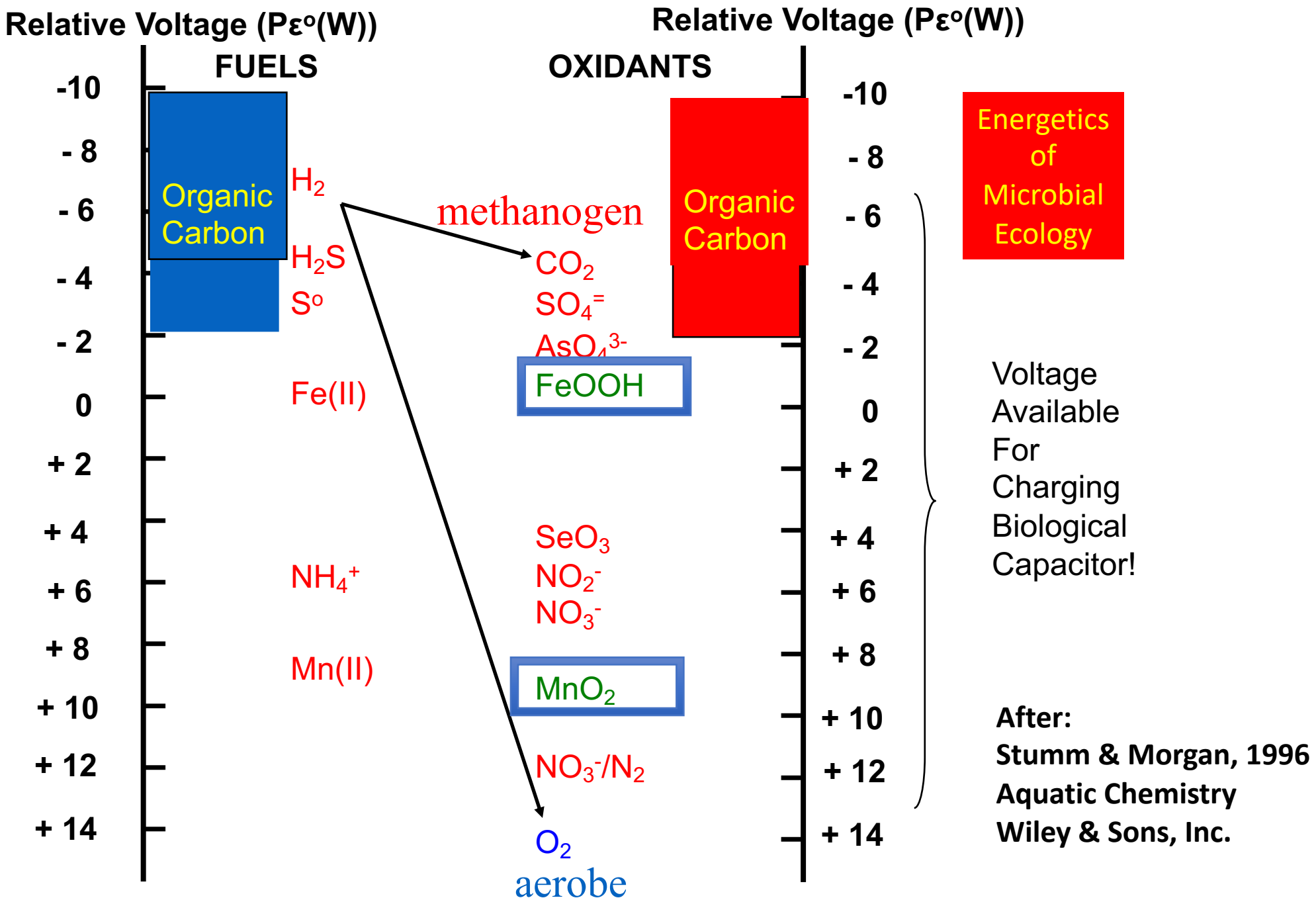
How do the “spheres” – Atmo- Litho- & Bio- co-evolve?

What are the ”ingredients” that any planetary body needs to encourage life?

1. **Energy:**
    - Radiant – “nearby” sun
        - Essence of the habitable zone idea
        - Zone where liquid water is possible
    - Geothermal – hot core
        - Constant thermal reduction to produce Fe^{2+}, H_2S, etc.
        - Plate tectonics, heat flow, etc.

The geological environment Is rich in many of the oxidants and reductants that life can utilize !!

Some of these EAs are insoluble and thus were thought to not be "available" to life.



After:
Stumm & Morgan, 1996
Aquatic Chemistry
Wiley & Sons, Inc.

What about other forms of energy?

1. Radiant (other wavelengths)
2. Magnetic
3. Kinetic (wind, water)
4. Thermal
5. Electric

Electric Bacteria: Now we know that we have bacteria that:

Convert organic carbon to electricity:

Myers & Nealson, 1988, Science

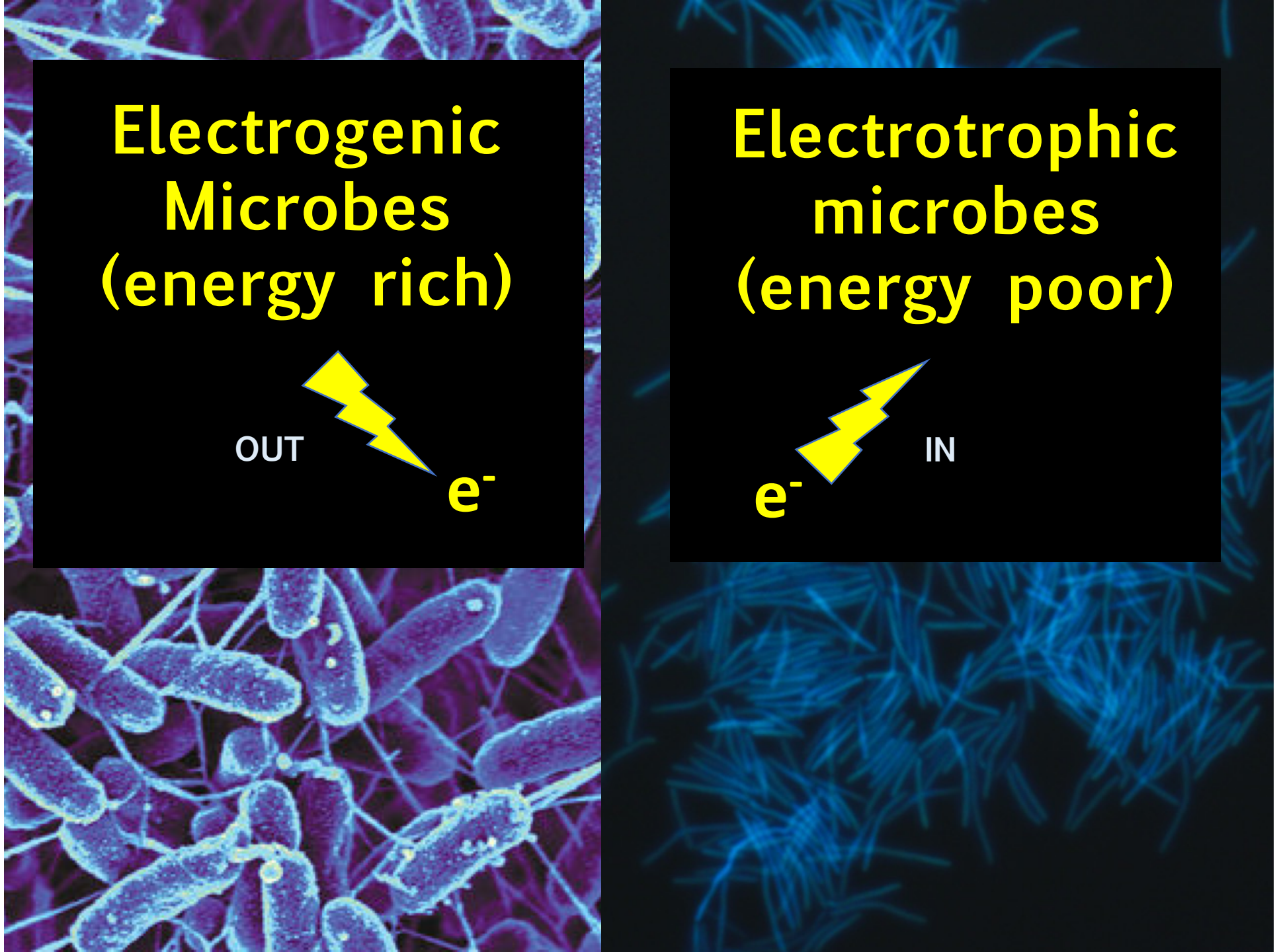
Lovley & Phillips, 1988, Appl. Envir. Micro.

Convert electricity to organic carbon:

Rowe et al.,

Chang et al.,

And many, many, other references !!


Electrogenic
Microbes
(energy rich)
OUT
e-
Electrotrophic
microbes
(energy poor)
e-
IN

What are the ”ingredients” that any planetary body needs to encourage life?

1. **Energy:**
   - Radiant – “nearby” sun
   - Geothermal – hot core
   - Others ?

2. **Liquid of some kind (doesn’t have to be water !)**
   - Hard to do solid state chemistry
   - Life works by changing the rates of reactions (catalyst inventions)
   - Not clear how to do this in the solid state – maybe ??

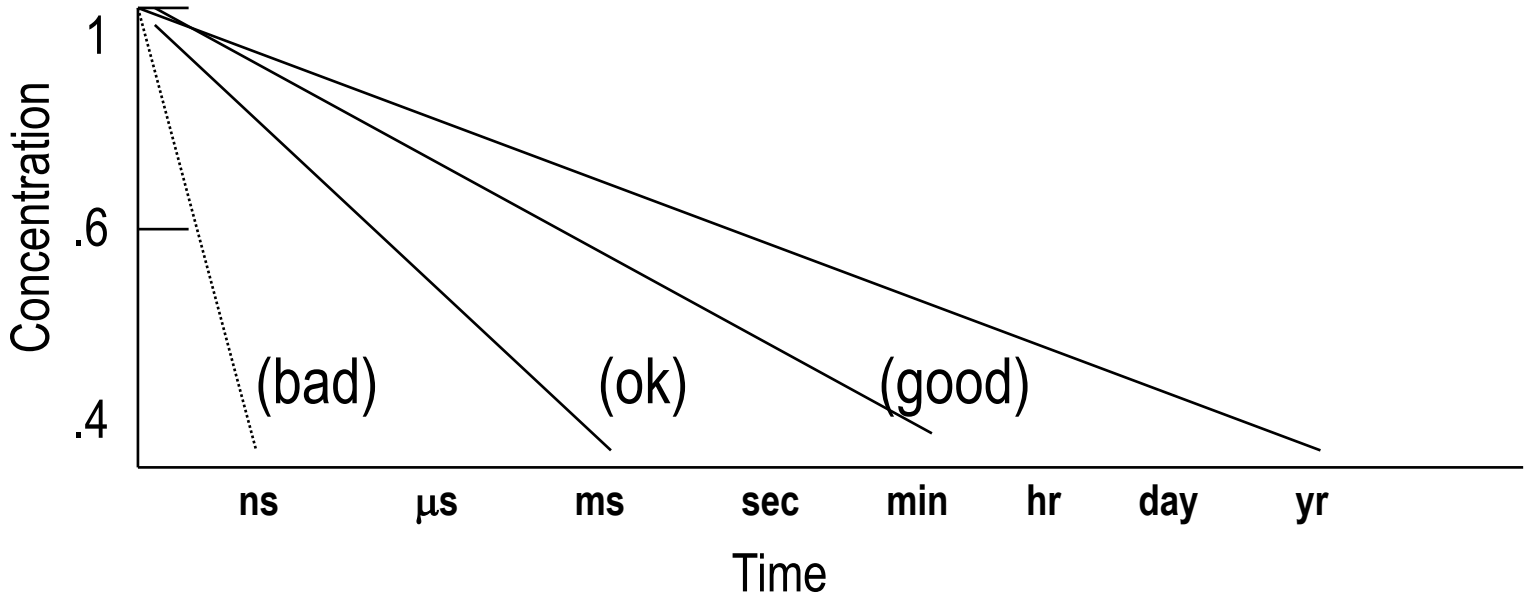
Kinetics and Life

Slow chemistry is "good" for life

- Especially high activation energies are good (sulfate reduction !)
- Life can harvest energy easily above the background

Fast chemistry is "bad" for life (hard to exploit reactions for energy)

- Difficult to compete with natural chemical systems



Kinetics

Should be energy sources (and conditions) that favor slow kinetics

Life will invent ways to speed up the reactions

Life will also invent ways to store energy that is stable

Organic carbon is one of those inventions

In some cases (Fe^{3+} in the ocean) life has invented organics

that bind Fe^{3+} and stabilize it (siderophores) !

Alters kinetics by slowing it down!!

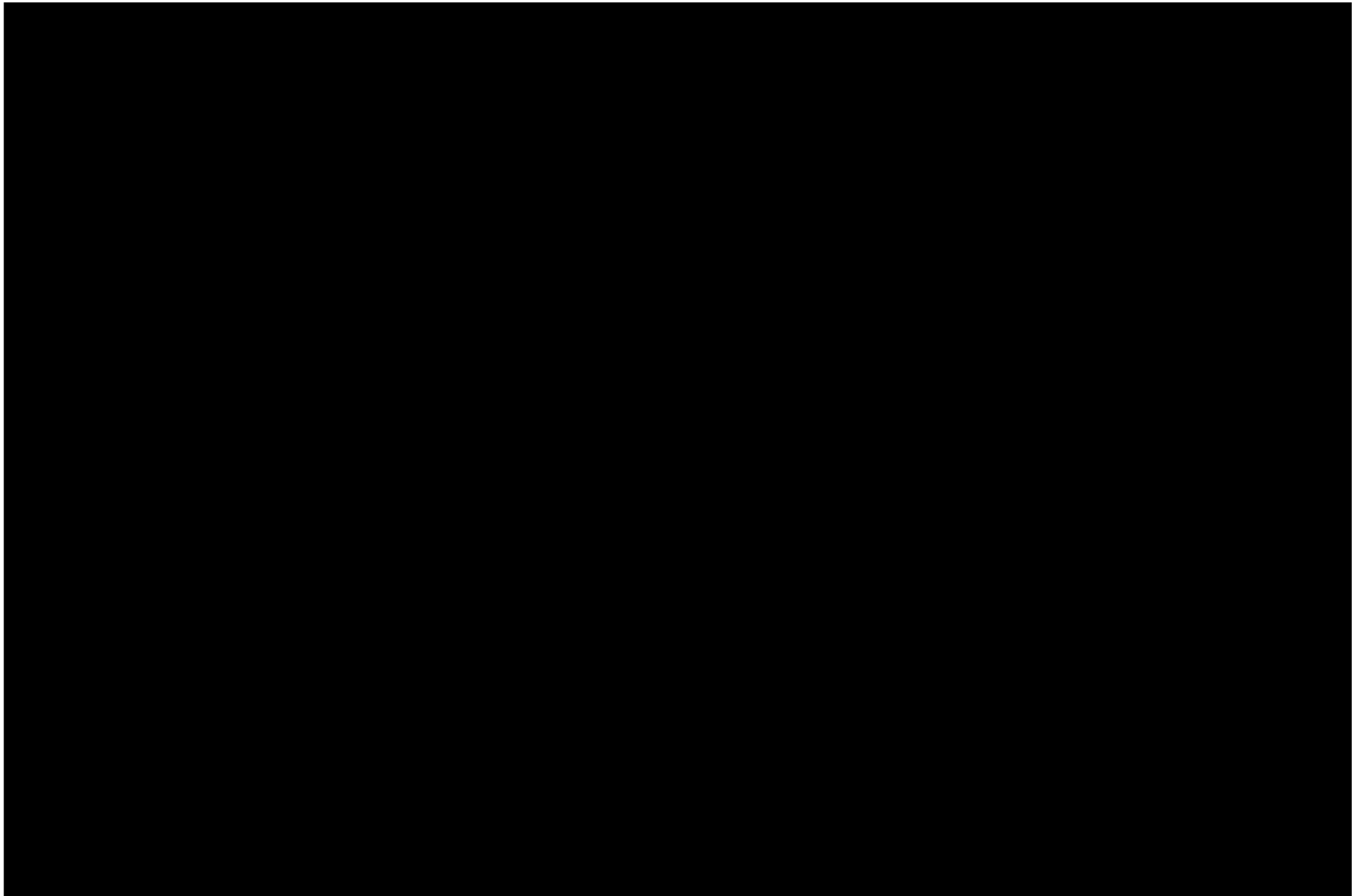
Many important biological processes have been "discovered"
by geochemists who reported reactions that were proceeding
far faster than the rates predicted by the chemistry of the environment:

1. Anaerobic methane oxidation (ANME)

2. Anaerobic ammonia oxidation (ANAMMOX)

3. Reduction of metal oxides and other solids (EET)
   (Extracellular Electron Transfer)

Metal dissolution by *Shewanella oneidensis*



How does life alter the planet so it is recognizable from a non-living planet?

Uses available Energy Sources (electron donors)

Early Earth: light, Fe^{2+}, H_2, H_2S, CO, organics?, minerals?

Uses available electron acceptors

Early Earth: CO_2, CO, organics?

Examples: methanogens, acetogens, PS bacteria (H_2, H_2S, Fe^{2+})

Major Impact: organics begin to accumulate (acetate, methane, dead organisms)
oxidized S and Fe compounds (minerals) accumulate

Notable Events:

1. Iron adopted as major electron carrier (1st metallo-organic?)
2. Electron transport "invented" for respiration
3. Other electron transporters "invented" (NAD, Flavins, quinones)

4. Biosphere Evolution Really Began:
    a. Waste of one bug became the substrate for another, etc.
    b. Concept of microbial communities began to emerge
    c. Still see this today in anaerobic world (Winogradsky !)
    d. Communities based on collaboration, NOT competition
        i. "No" bacterial or archaeal predators (of each other)
        ii. No need for fast growth – balanced by metabolism
        iii. No need for motility – metabolism slower than diffusion??

Invention of oxygenic photosynthesis and rise of oxygen

Major event for life on Earth

Oxygen and its products are nasty toxins: singlet oxygen, superoxide, peroxides, etc.
- Probably widespread death of anaerobes
- Slow but steady removal of iron from the ocean (BIFs)

Invention of oxygen respiration (cytochrome oxidase – oxygen reduction without toxins!)

A much more energetic metabolism – in prokaryotes
- Respiratory diversity in prokaryotes as other EA's enabled by oxygen!

Rise of primitive eukaryotes -- great endosymbiosis event

Ability of 3-D life on land – gaseous electron acceptor – enables technology development

Rise of Predation and Beginning of "Modern Biospheres"

Predator/Prey begins to drive evolution

1. Phagocytosis – ability to consume other organisms (amoebae)
   Prokaryotes have rigid cell walls – no phagocytosis
2. Protective hard parts
   Prokaryotes make minerals, but not as part of the cell structure
3. Evolution of motility and "predation structures" (teeth, bones, etc.)
   Prokaryotes are often motile and are chemotactic
3. Bacteria needed to "learn" to grow rapidly, or live where predators are NOT
   Luckily, most eukaryotes utilize only oxygen for respiration !!

TAKE HOME LESSONS:

1. Prokaryotes are chemists – small cells; high S/V; diverse chemistry; “no” predation
   Activities leave their catalytic signatures everywhere

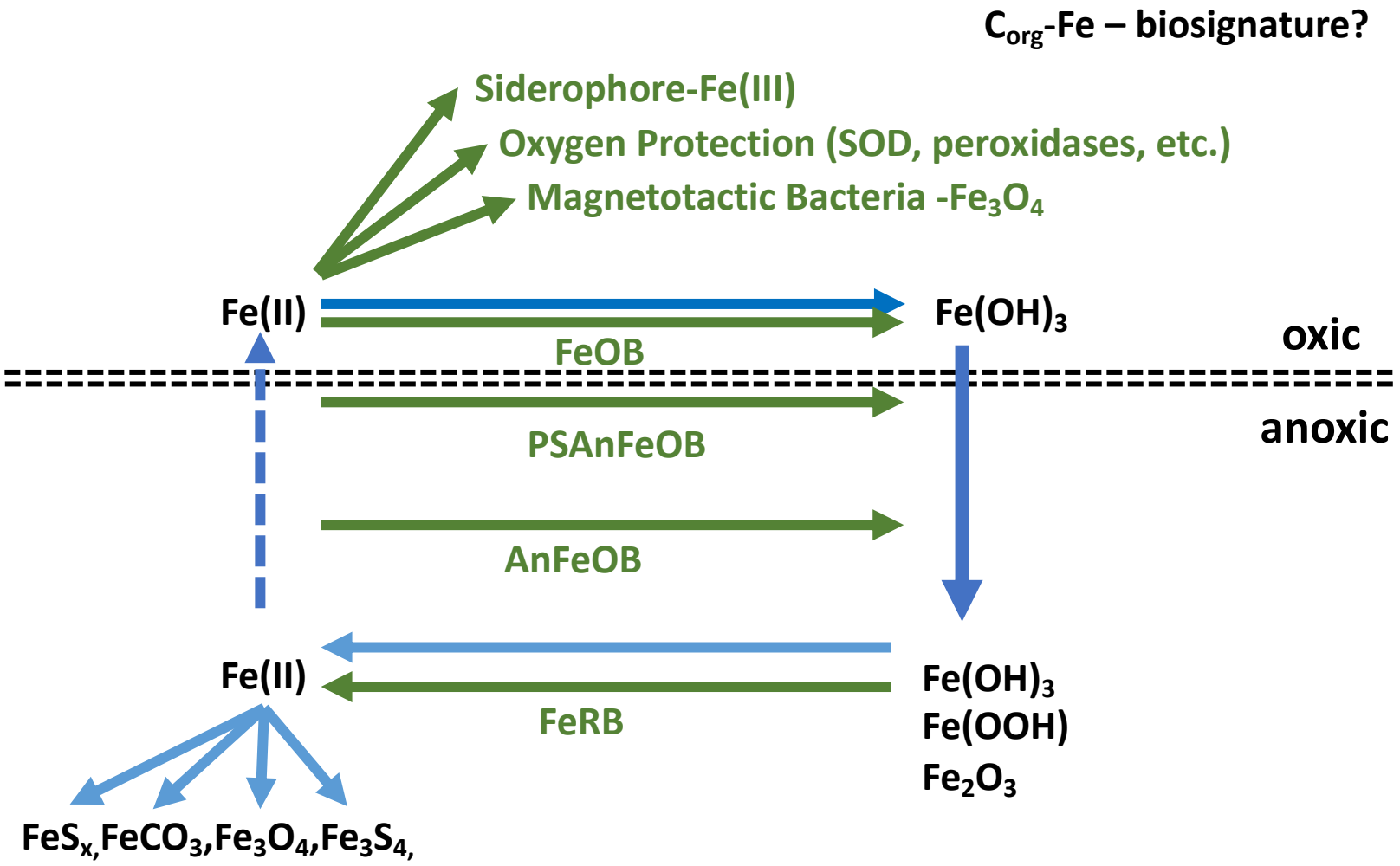
1. Eukaryotes are biologists – predator/prey; low S/V; ”simple” chemistry/ complex behaviour

2. Early life was anoxic, prokaryotic, slow growing, non-motile, communal

3. Oxygen changed everything

4. Prokaryotic life leaves its fingerprints everywhere – we just need to recognize them!

Life's "fingerprint" on the iron cycle:



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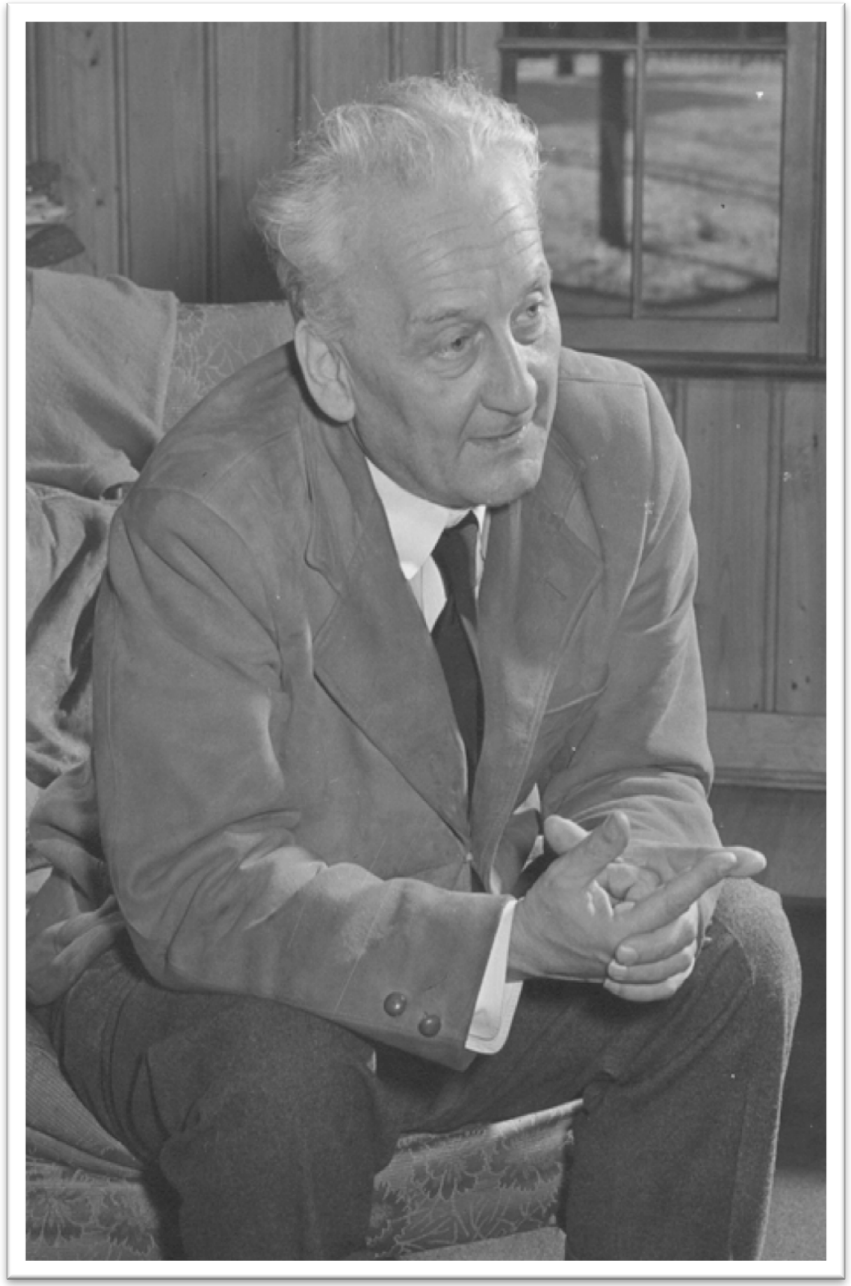
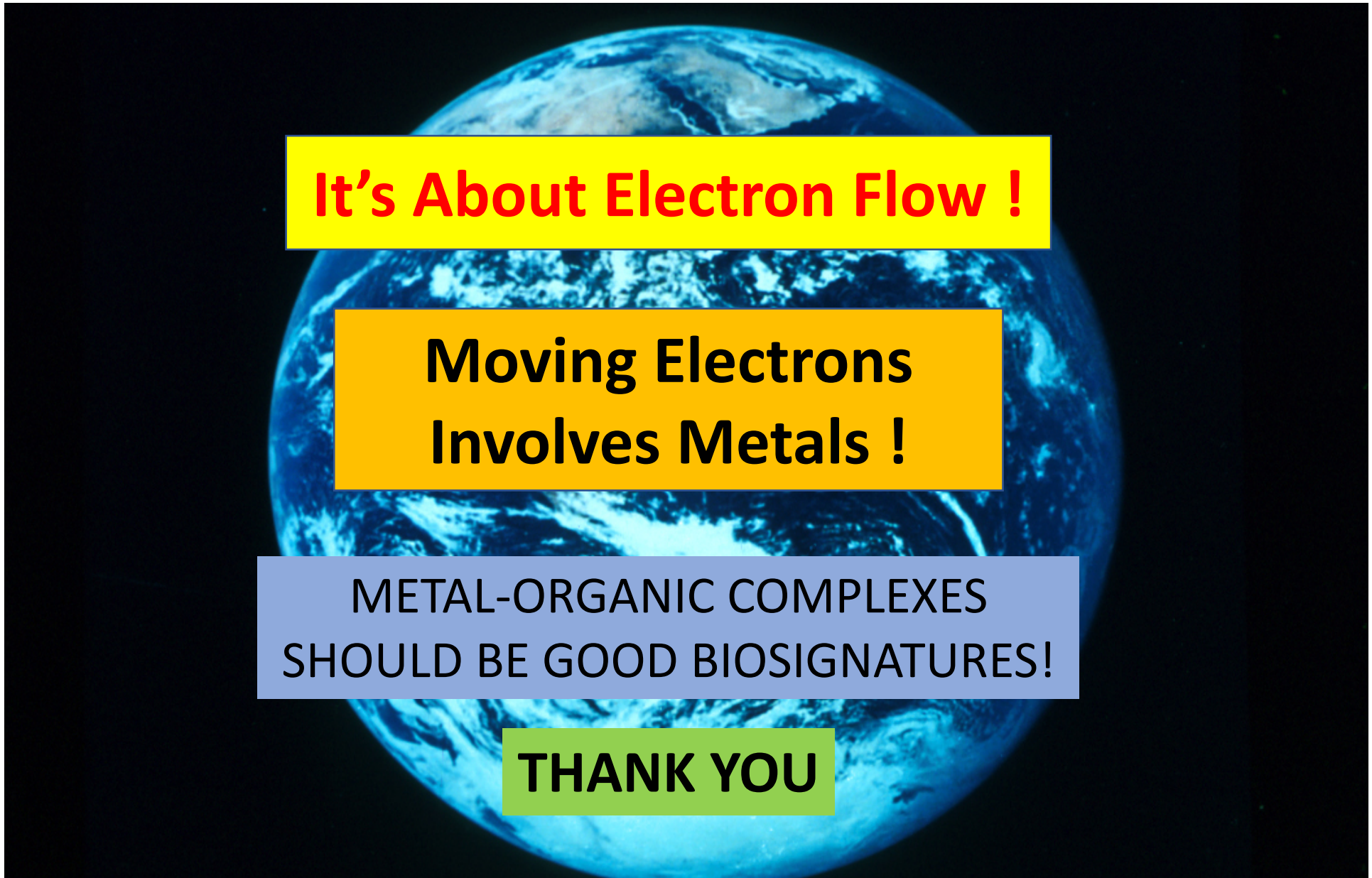
One can do this for every elemental cycle on Earth !!

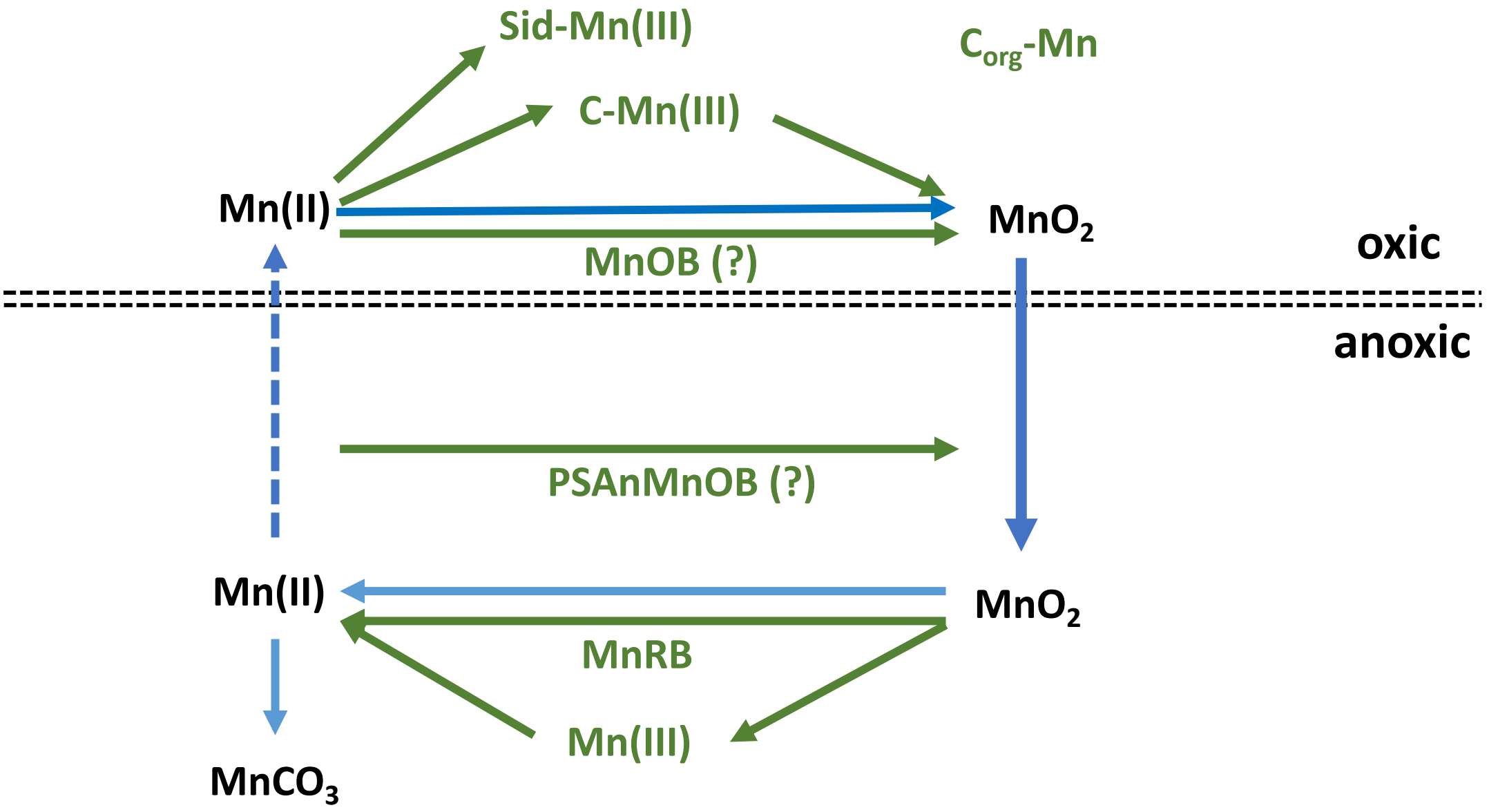


“Life is nothing but an electron looking for a place to land.”

Albert Szent Gyorgi

1937 Nobel Prize in Physiology


It's About Electron Flow !
Moving Electrons
Involves Metals !
METAL-ORGANIC COMPLEXES
SHOULD BE GOOD BIOSIGNATURES!
THANK YOU


Sid-Mn(III)
C_{org}-Mn
C-Mn(III)
Mn(II)
MnO_2
oxic
MnOB (?)
anoxic
PSAnMnOB (?)
Mn(II)
MnO_2
MnRB
Mn(III)
$MnCO_3$