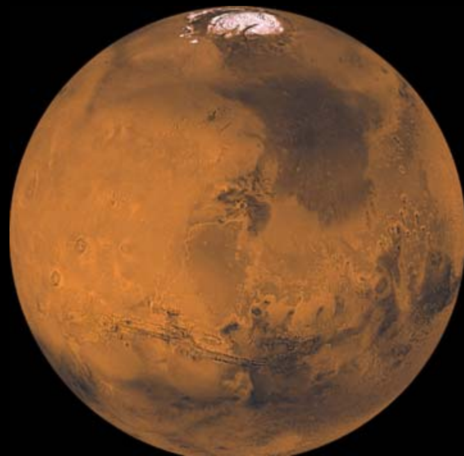
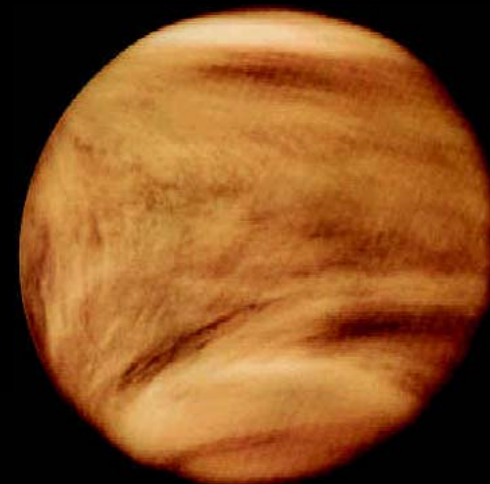
Origin and Early Evolution of an Equilibrium Earth Atmosphere

Mars is an equilibrium planet, and it is dead

Venus is an equilibrium planet, and it is dead

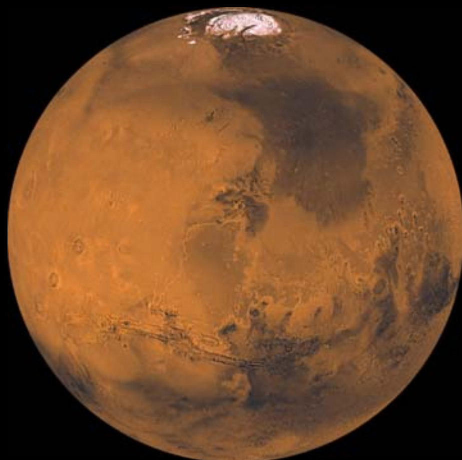


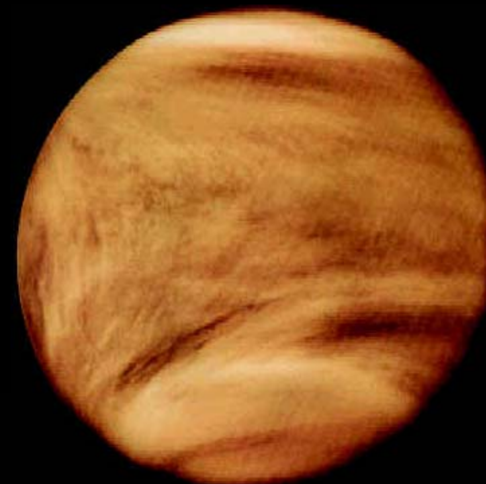


The Earth is a non-equilibrium planet, and it is alive.

Mars is an equilibrium planet, and it is dead

Venus is an equilibrium planet, and it is dead





But, it probably started off more like Venus, . . . or Mars.

Unique things about the Earth we need to explain

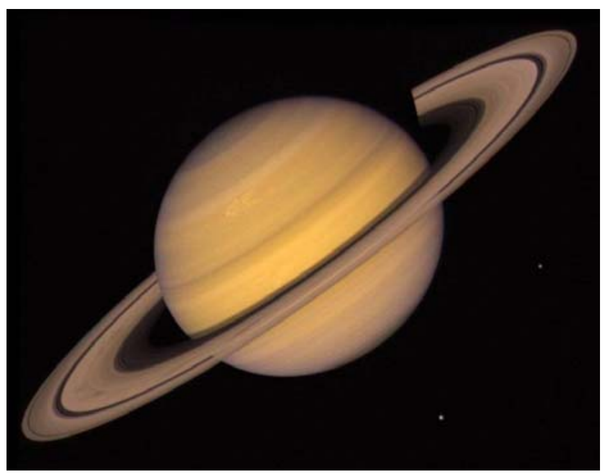
4. The atmosphere is oxygen rich even though oxygen is extremely chemically reactive. Left alone all oxygen would disappear in less than 1000 years. Something is actively maintaining an oxygen rich atmosphere.

Nitrogen	*79%*
Oxygen	*19%*
CO2	*0.03%*
Argon	*1.0%*
Water vapor	*variable*

Hydrogen	*75%*
Helium	*25%*
Methane (CH4)	*trace*
Ammonia (NH3)	*trace*
Water ice	*trace*

CO2	*95.3%*
Nitrogen	*2.7%*
Argon	*1.6%*
Oxygen	*0.15%*
Water vapor	*0.03%*

Earth



Saturn

Mars

Planetary Fractionation

Composition of the Jovian Planets

The gas planets have a composition very similar to that in the sun, meaning they have undergone almost no fractionation

Abundances of Elements in the Solar Spectrum

	Percent of atoms	Percent of mass
Hydrogen	91.2	71.0
Helium	8.7	27.1
Oxygen	0.078	0.97
Carbon	0.043	0.40
Nitrogen	0.0088	0.096
Silicon	0.0045	0.099
Magnesium	0.0038	0.076
Neon	0.0035	0.058
Iron	0.0030	0.14
Sulfur	0.0015	0.040

Abundances of Elements in Saturn

Hydrogen	75%
Helium	25%
Methane (CH_4)	trace
Ammonia (NH_3)	trace
Water ice	trace

At depth hydrogen becomes liquid hydrogen, then liquid metallic hydrogen. At the center is an iron and rock core.

Abundances of Elements in Jupiter

Hydrogen	~90%
Helium	~10%
Methane (CH_4)	trace
Ammonia (NH_3)	trace
Water ice	trace

In the center is a rocky core about 10-15 times the mass of the Earth, and at about 20,000 degrees centigrade (3x hotter than Earth's core).

Origin of Atmosphere and Oceans By Fractionation

But, even though the Earth has a markedly different atmosphere today than the other terrestrial planets . . . .

Comparison With Other Terrestrial Planets

Abundances of Gasses in Earth's Atmosphere

Nitrogen	79%
Oxygen	19%
CO_2	0.03%
Argon	trace
Water vapor	variable

Atmospheric Pressure
1.0

Temperature 13 C

Abundances of Gasses in Mar's Atmosphere

CO_2	95.3%
Nitrogen	2.7%
Argon	1.6%
Oxygen	0.15%
Water vapor	0.03%

Atmospheric Pressure
0.064

Temperature -23 C

Abundances of Gasses in Venus's Atmosphere

CO_2	96.5%
Nitrogen	3.5%
SO_2	150 ppm
Argon	70 ppm
Water vapor	20 ppm

Atmospheric Pressure
92
~1300 #/in^2

Temperature 462 C

Origin of Atmosphere and Oceans By Fractionation

It almost certainly began more like the other terrestrial planets, and has evolved to its present non-equilibrium state through history.

Comparison of Earth With Itself at 4 Billion Years Ago

Abundances of Gasses in Earth's Atmosphere

Nitrogen	79%
Oxygen	19%
CO_2	0.03%
Argon	1.0%
Water vapor	variable

Atmospheric Pressure
1.0

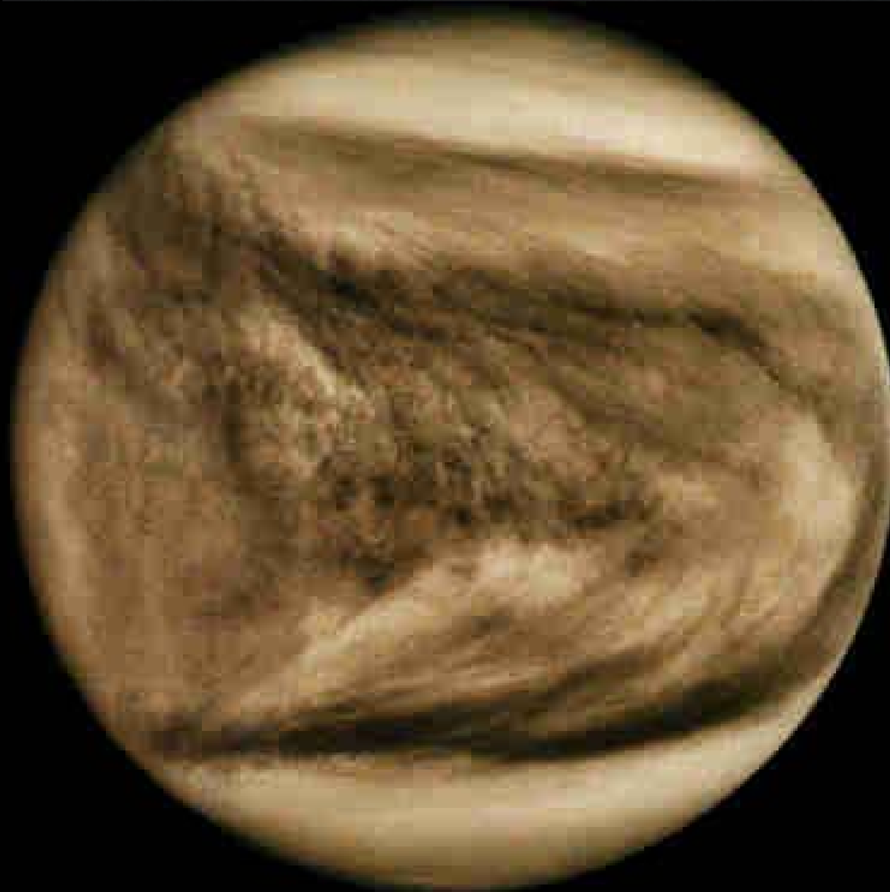
Original Composition of Earth's Atmosphere

CO_2	98.%
Nitrogen	1.9%
Oxygen	trace
Argon	0.1%

Atmospheric Pressure
60

From its early planetary state the Earth *could* have evolved in the direction of Venus

Fiery hot (477° C), a dense, choking atmosphere of acid, weighing about 90 times more than the Earth's atmosphere.

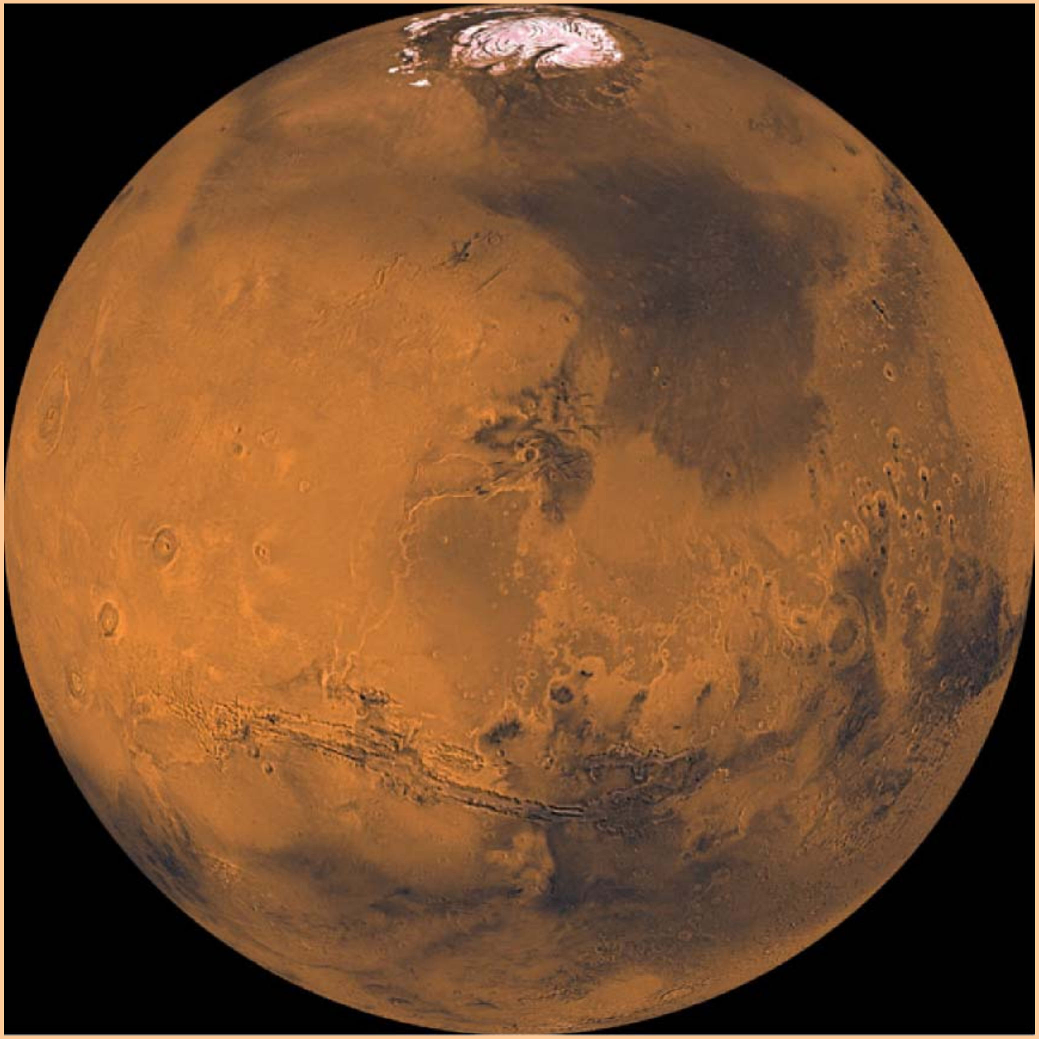


Radar image of Venus through the thick cloud cover that blocks view of the surface

Venus as seen with the naked eye covered by its thick atmosphere

Or, it *could* have evolved in the direction of Mars

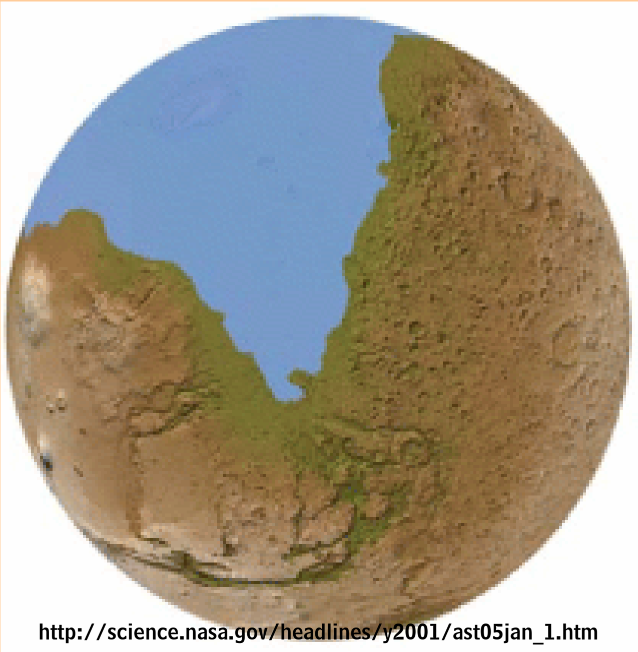
Bitter cold (-53º C), dry, with an atmosphere weighing only .06 times the Earth's.



Because Mars once had liquid water on its surface

http://www.lbl.gov/Science-Articles/Archive/SB-ESD-hunting-for-martians.html

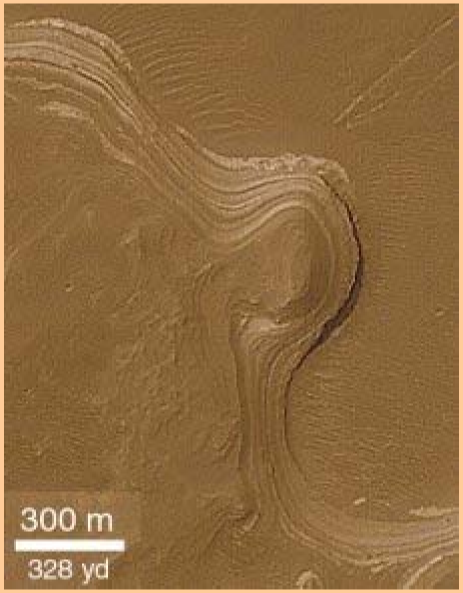
Millions of years ago, Mars may have hosted rivers and lakes like those depicted in this artist's rendition.



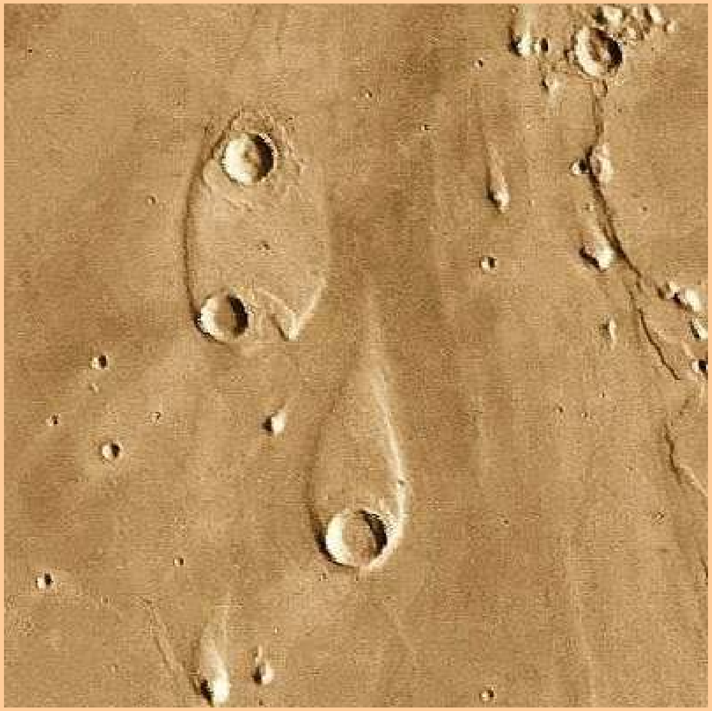
http://science.nasa.gov/headlines/y2001/ast05jan_1.htm

http://www.lcusd.net/rop/bb2000/1/mars.htm

The Case of the Missing Mars Water



http://science.nasa.gov/headlines/y2001/ast05jan_1.htm

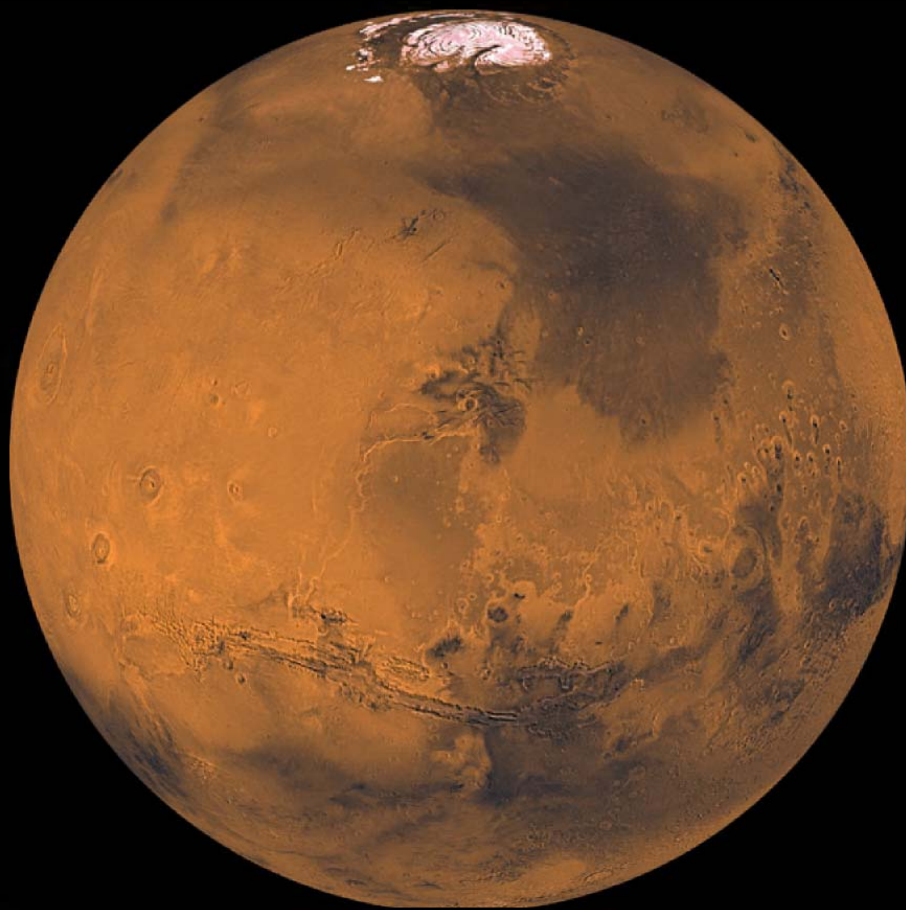


http://zebu.uoregon.edu/~imamura/121/lecture-11/lecture-11.html

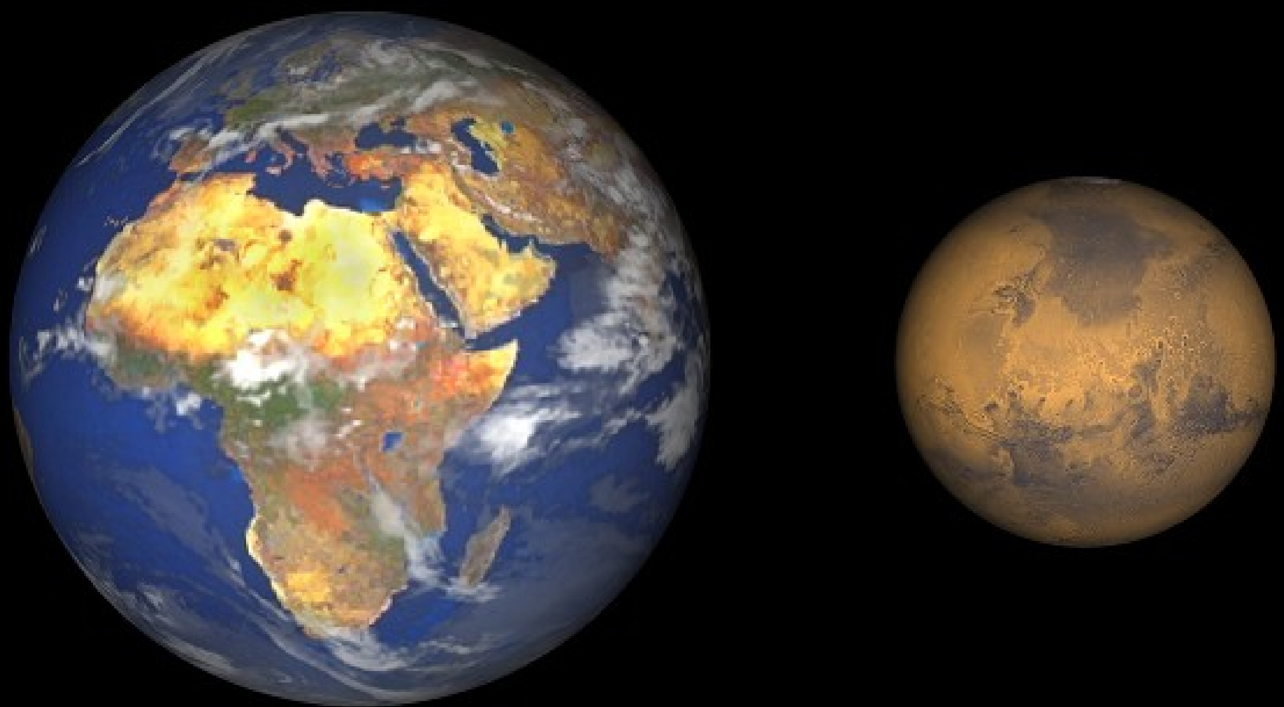
http://www.astro.virginia.edu/class/oconnell/astr121/marsImages.html

http://www.marsdaily.com/water.html

. . . even though Mars is cold and dry now.



Part of the Mars-Earth differences can be explained by their different sizes.

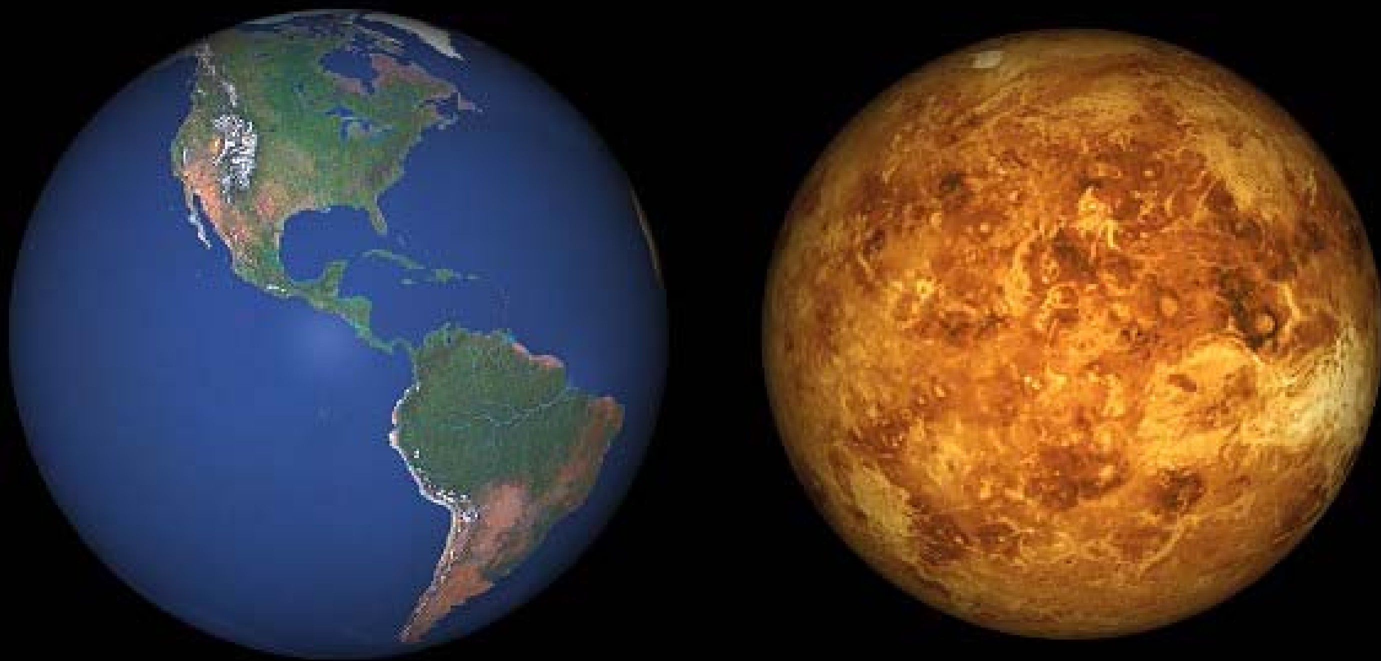


Earth and Mars compared

Mars' diameter is half that of the Earth's
It has ten percent the mass
If you weigh 180 pounds on Earth, you would weigh only 68 pounds on Mars
Mars is half again further from the Sun than the Earth

http://www.arcadiastreet.com/cgvistas/mars_002.htm

But, size differences cannot be used to explain the Venus-Earth differences.



Earth and Venus compared

Venus' diameter is 86% that of the Earth's
It has 82% the mass.
While Venus is roughly the same size and density as the Earth, it is otherwise a very different world. Earth's surface is a varied one, with liquid water covering three quarters of its surface. Those areas not under water have been highly modified by plate tectonics, weather, and life itself. Venus on the other hand is far too hot to host liquid water. Volcanoes, massive lava flows and the occasional impact crater characterize its surface.

http://www.arcadiastreet.com/cgvistas/mars_002.htm

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Temperature 13 C

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Atmospheric Pressure
92
~1300 #/in^2

Temperature 462 C

Mars is so cold now in part because it is far from the sun, and in part because its atmosphere is so thin there is no Greenhouse effect.

Venus is so hot now because it is closer to the sun, and its atmosphere is so thick with CO2 that the Greenhouse effect is powerful.

Origin of Atmosphere and Oceans By Fractionation

A Deductive Argument:

***IF**, . . .the Earth and other terrestrial planets lost whatever solar atmosphere they had early in the solar system's development,*

***AND, IF**, . . .the Earth had an initial atmosphere similar to those of Venus and Mars,*

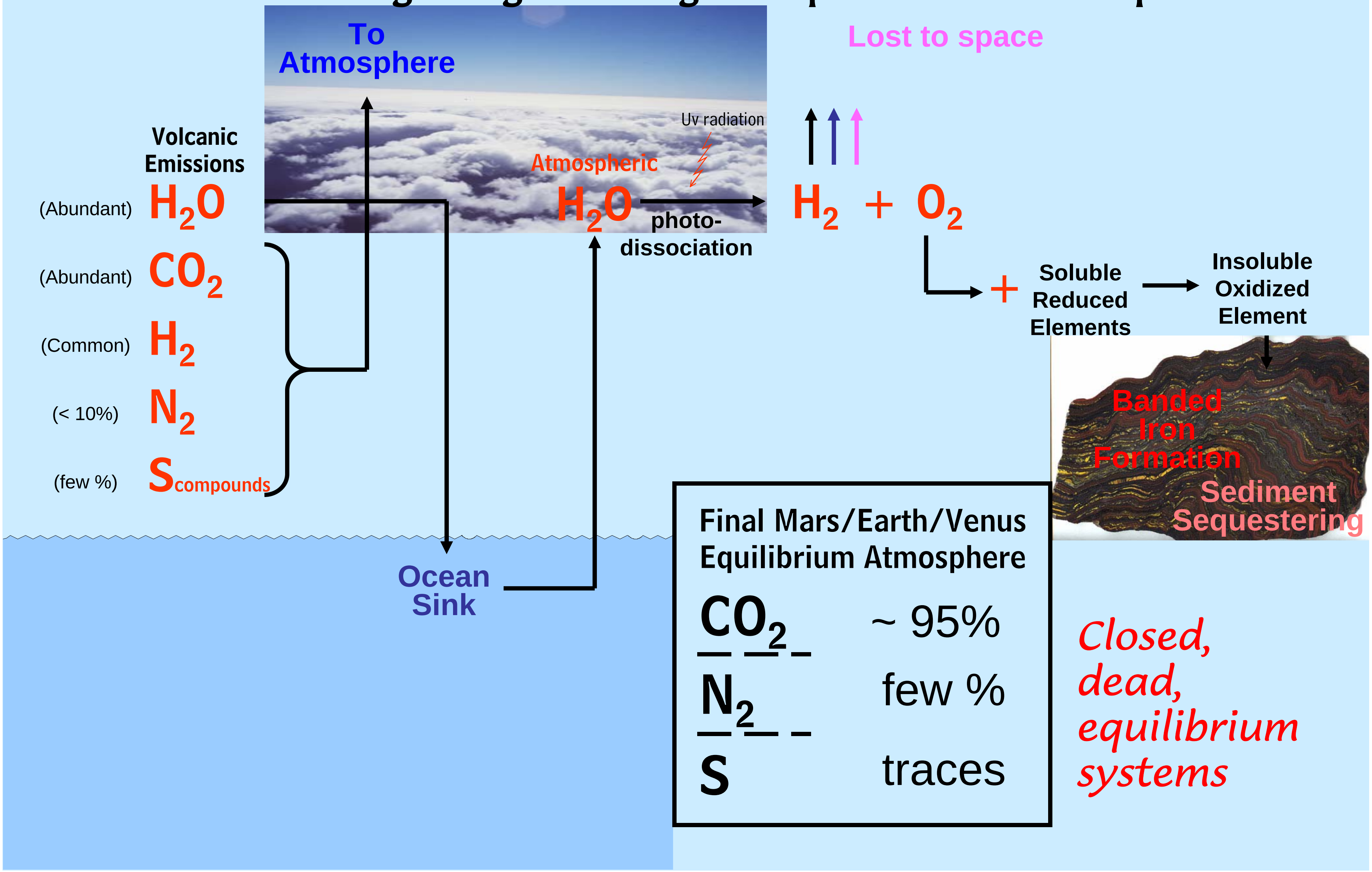
***THEN,** . . .the Earth's present atmosphere must be the result of some kind of evolutionary processes.*

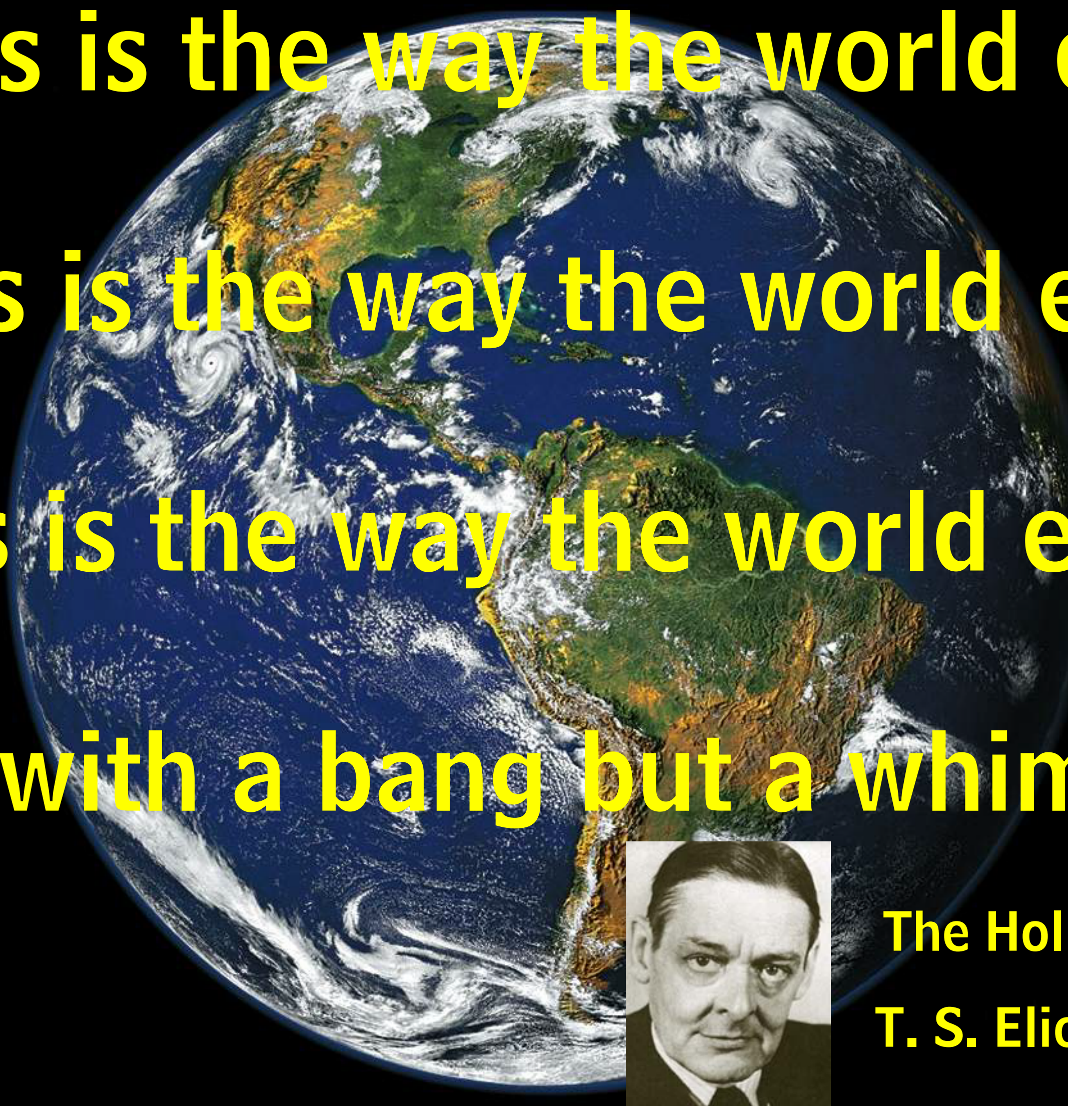
- **Nitrogen must increase from 1.9% to 79%**
- **Carbon dioxide must decrease from 98% to 0.03%**
- **Oxygen must increase from a trace to 19%**
- **Plus, there is a lot of sulfur in the atmosphere (like Venus)**
- **And, the pressure must reduce from 60 atmos. to 1 atmos.**

This is not a simple story . . . And it will take us some time to tell it.

Evolution of the Earliest Atmospheres of Mars and Earth

Volcanic Outgassing Evolving to Equilibrium Atmosphere





This is the way the world ends

This is the way the world ends

This is the way the world ends

Not with a bang but a whimper.

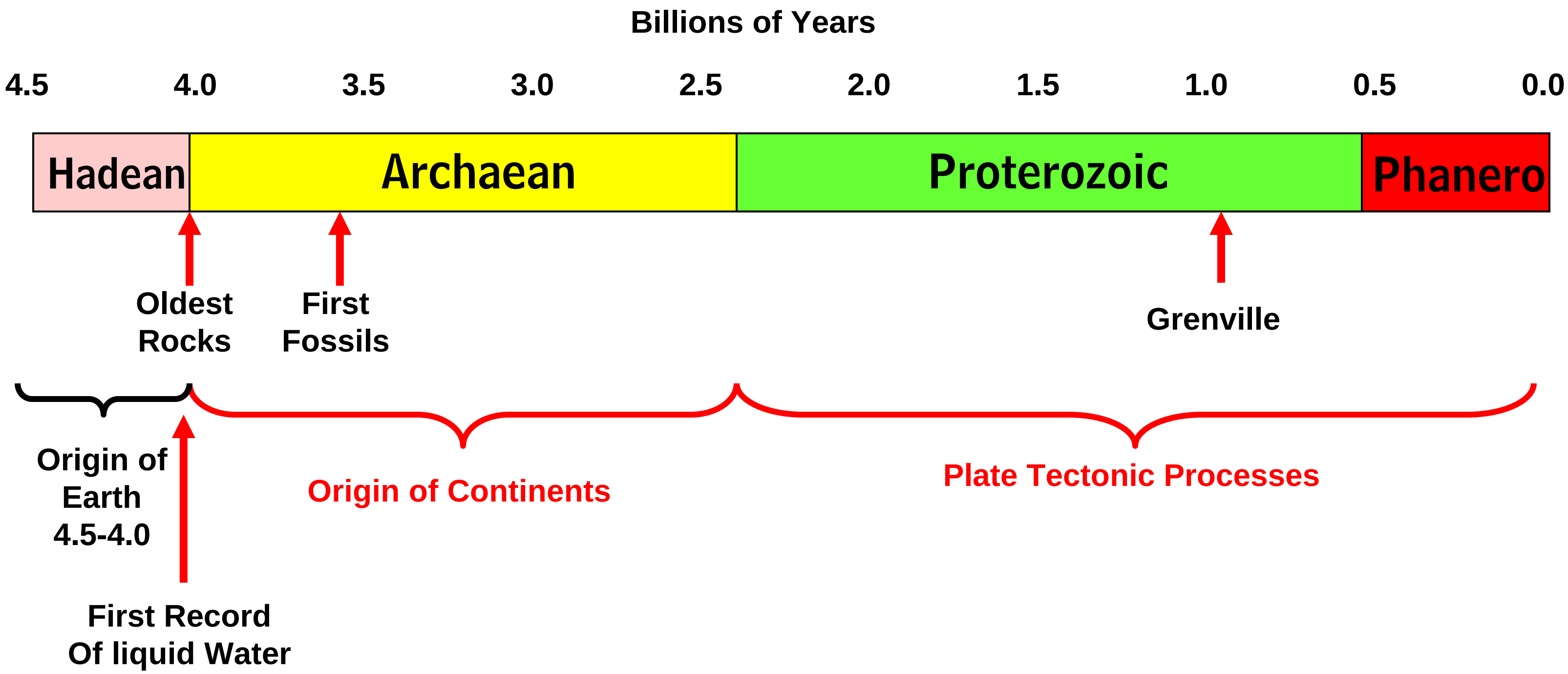
The Hollow Men

T. S. Eliot (1925)

But this is not what happened

The Influence of Life on the Earth

Just How Long is Earth History ? And When Did the Important Things Happen ?



With the addition of life we now add a new energy source to the Earth System.

Biological → *Organic chemistry, plus biological modifications of environments*

Life Energy

All life forms from the simplest known to the most complex use ATP as the mediator of biochemical reactions.

$$\mathbf{ATP} \longrightarrow \mathbf{e^-} + \mathbf{ADP} + \mathbf{P}$$

Adenosine Tri Phosphate

Adenosine Di Phosphate

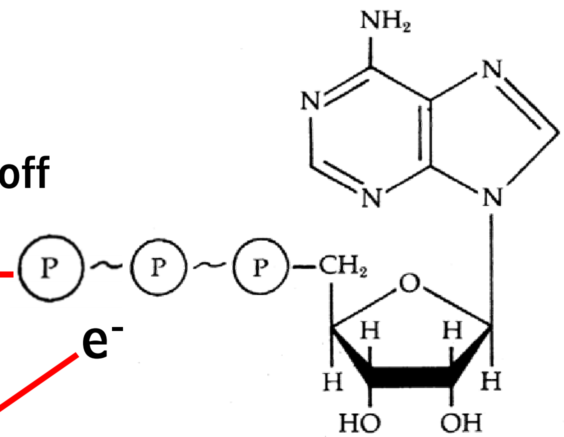
High energy electrons are used to break and make chemical bonds during biochemical reactions.

A major attractor of life, and the path's of its evolution, is about the procurement or manufacture of ATP.

Life as an Energy Dissipating System

The structure of Adenosine Tri Phosphate

3rd phosphate split off



e^-

Adenosine Tri Phosphate

ATP now becomes AdenosineDiPhosphate

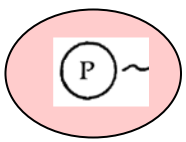
High energy electron released to mediate other chemical reactions.

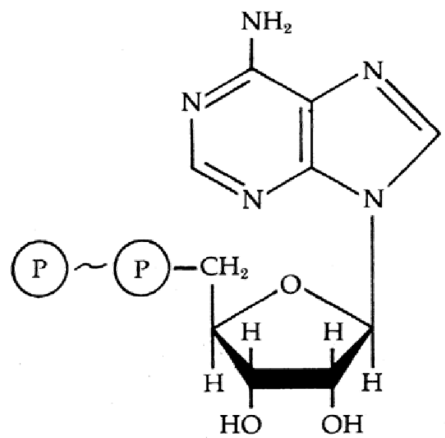
Life as an Energy Dissipating System

The structure of Adenosine Tri Phosphate

ADP does not have enough energy to split off another phosphate and release another high energy electron.

To reconstruct it as an energy source a high energy electron obtained from the environment or a food source is used to reconnect the third phosphate back on to the ADP.





ADP is now back to being ATP

e^-

High energy electron obtained from food source.

The issue is, . . . Where do the high energy electrons come from to reconstruct the ATP??

Life as an Energy Dissipating System

Life Energy has two modalities:

1. Environmental Energy – tectonic and/or solar.
2. Biochemical Energy - derived from or internal to life itself (i.e. some things eat other things).

Ultimately on Earth all energy is derived environmentally, meaning it comes down to either tectonic or solar energy.

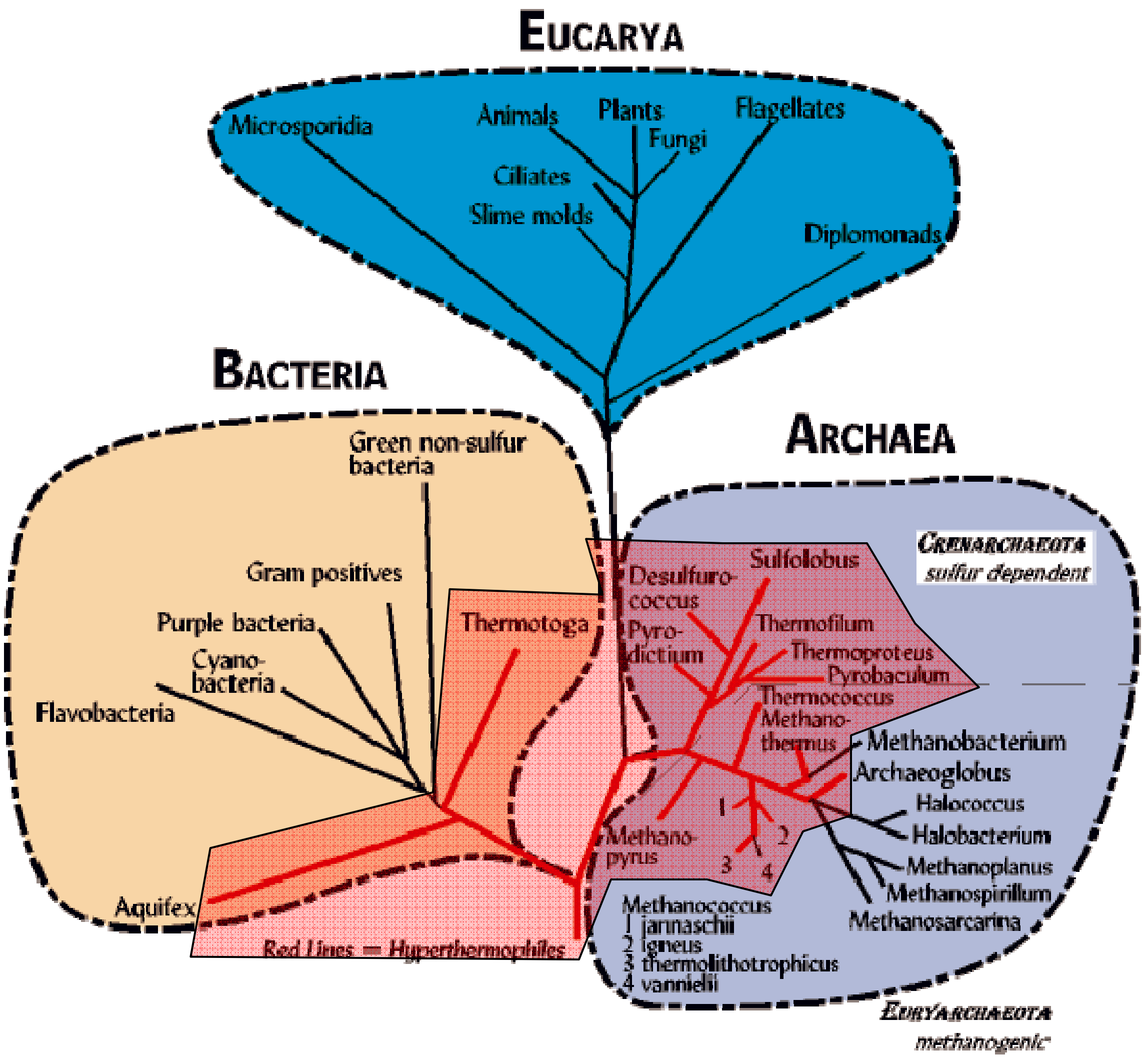
The story of the evolution of life is how it . .

- Extracts environmental energy, and . . .
- Mediates between these environmental and bioichemical energy sources.

And, how those mediations have influenced both the evolution of life itself and the Earth.

The Most Basic Forms of Life are . . . ?

Universal Tree of Life
And Earth's Earliest Life Forms

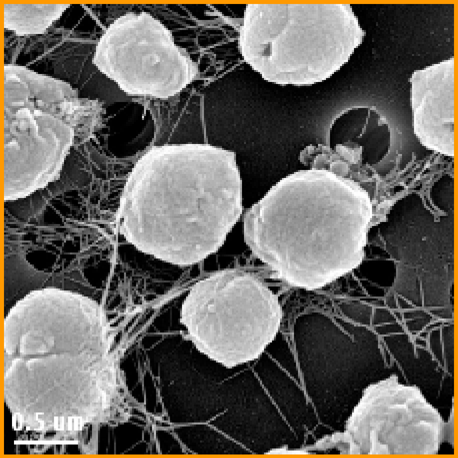


Archaebacteria - Archaea

Extremophiles

Extremophiles are the rule breakers of biology. These organisms live in the harshest environments on earth—boiling water holes in Italy, the ice of Antarctic seas, and hydrothermal vents at the bottom of the ocean. They not only survive but also thrive under conditions previously thought to prohibit all forms of life. In recent years, scientists have begun to mine the genomes of extremophiles for information that might lead to new technologies, such as heat-resistant molecules for commercial uses, and to breakthroughs in medicine and the environmental sciences.

The first extremophile to be sequenced was *Methanococcus jannaschii*, an organism straight out of science fiction. The single-celled microbe lives near hydrothermal vents 2,600 meters below sea level, where temperatures approach the boiling point of water and the pressure is sufficient to crush an ordinary submarine. There, *M. jannaschii* survives on carbon dioxide, hydrogen and a few mineral salts. It cannot tolerate oxygen and takes care of its energy needs by producing methane.

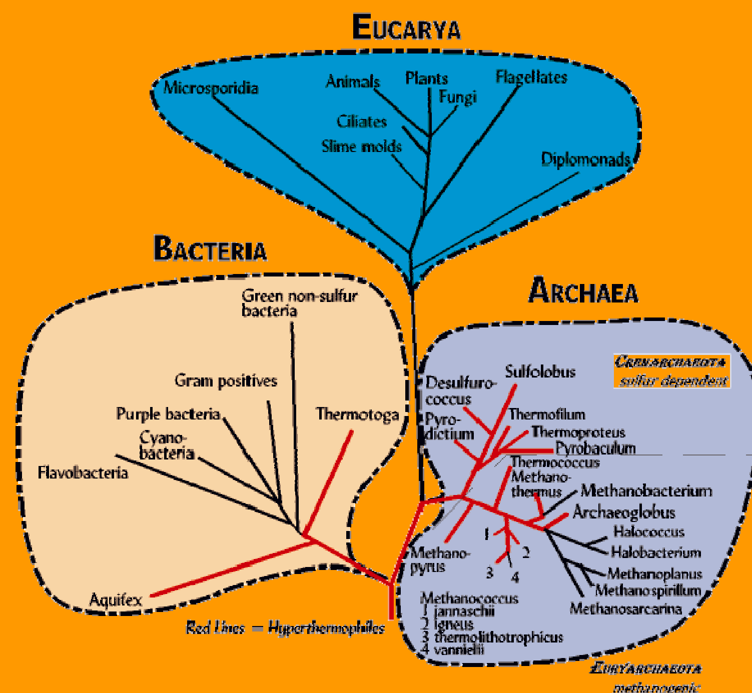


http://www.genomenewsnetwork.org/articles/02_02/extremo1.shtml

Archaebacteria - Extremophiles

1. Extreme Thermophiles - live in hot springs and black smokers.

Boiling hot springs in Yellowstone National Park are colored by colonies of thermophilic cyanobacteria, eubacteria and archaebacteria. <u>Thermus aquaticus</u> survives in temperatures too high for photosynthetic bacteria, up to 80 degrees Celsius (176 degrees F). <u>Thermus aquaticus</u> is heterotrophic and survives on minute amounts of organic matter in the water.



Archaebacteria - Extremophiles

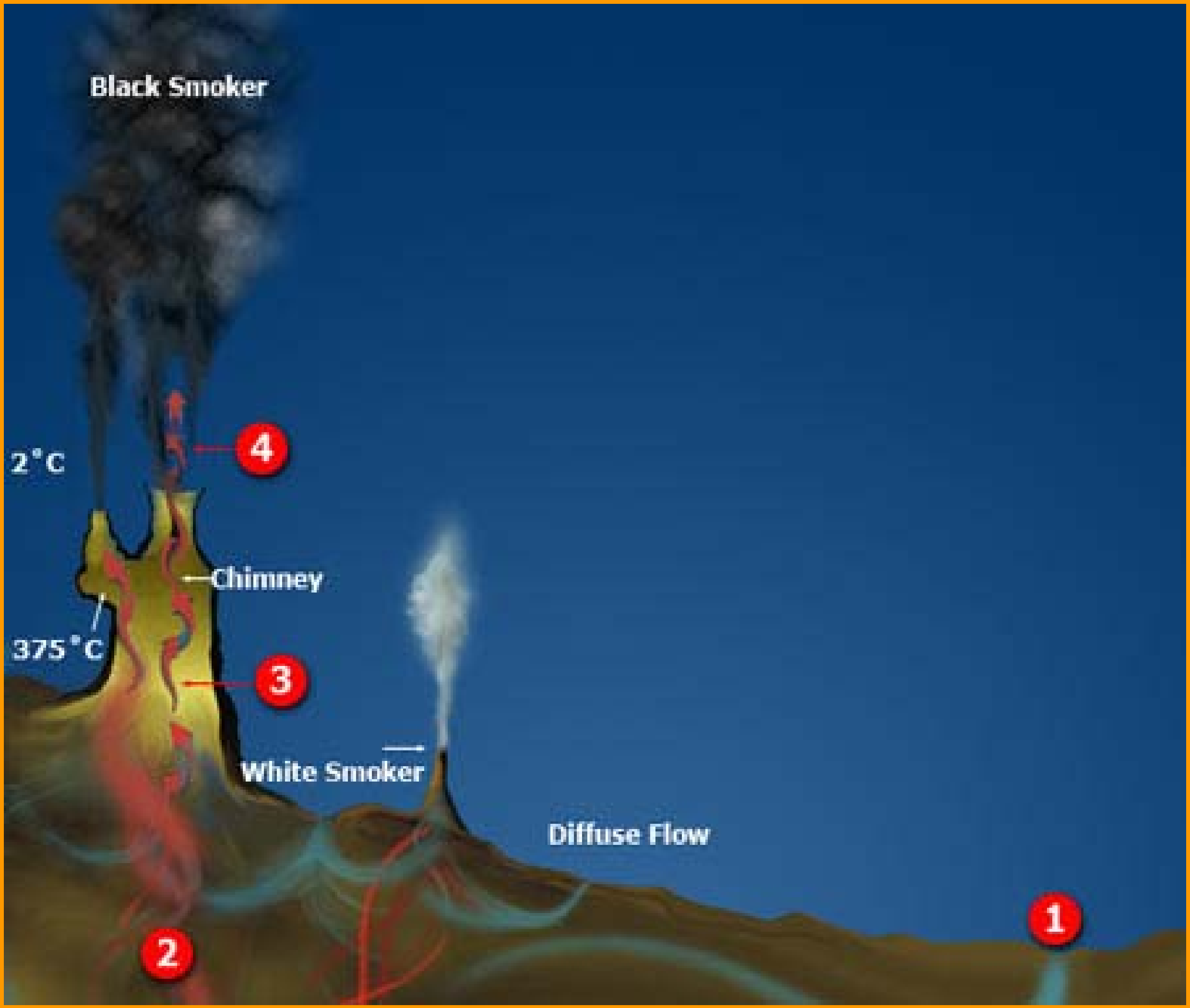
1. Extreme Thermophiles--live in hot springs and black smokers.

Links to videos of active smokers and vent environments

http://www.ocean.udel.edu/newscenter/VENT.jpg

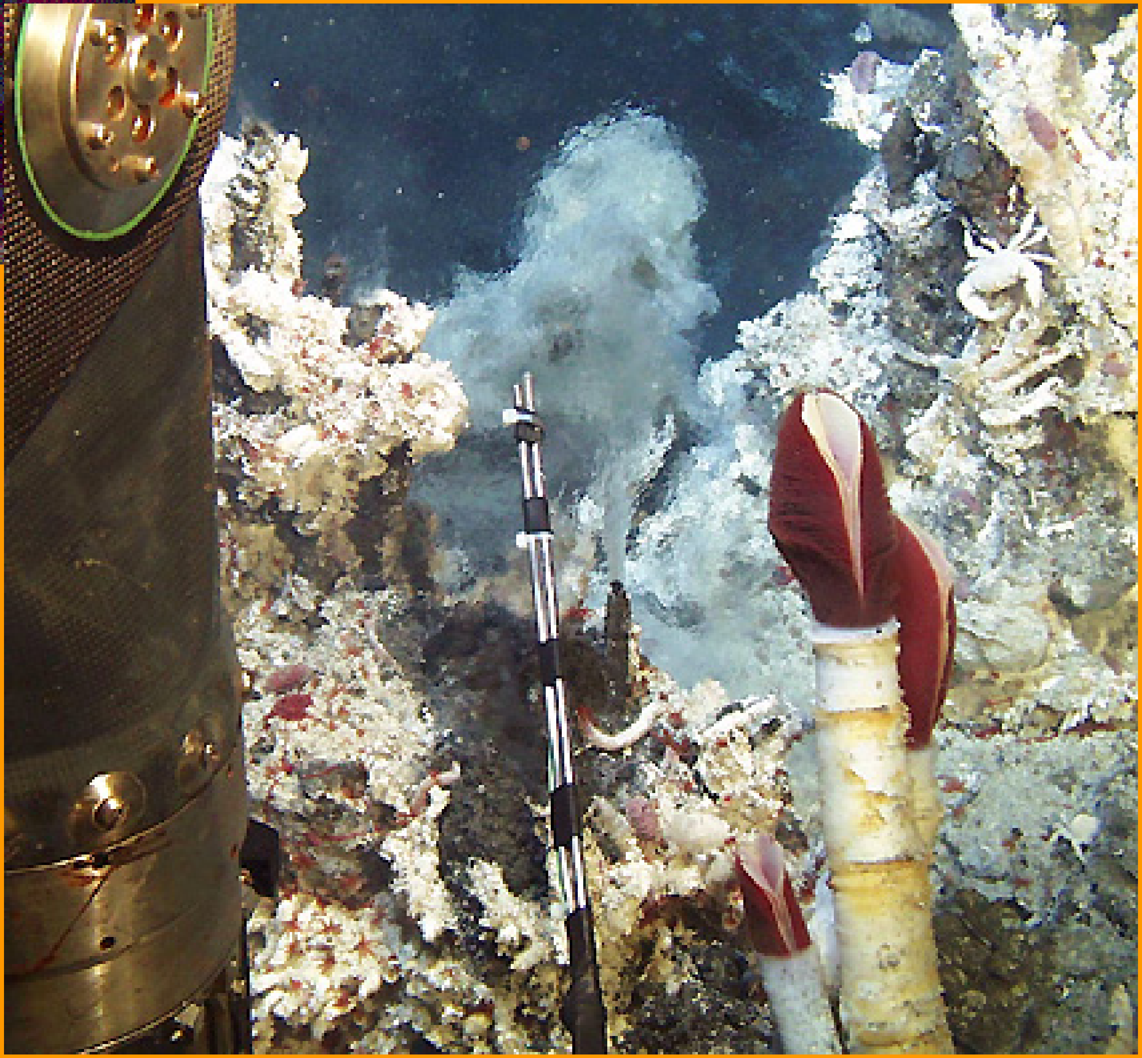
Archaebacteria - Extremophiles

1. Extreme Thermophiles--live in hot springs and black smokers.



http://www.care2.com/c2c/groups/disc.html?gpp=11767&pst=1028906&posts=3

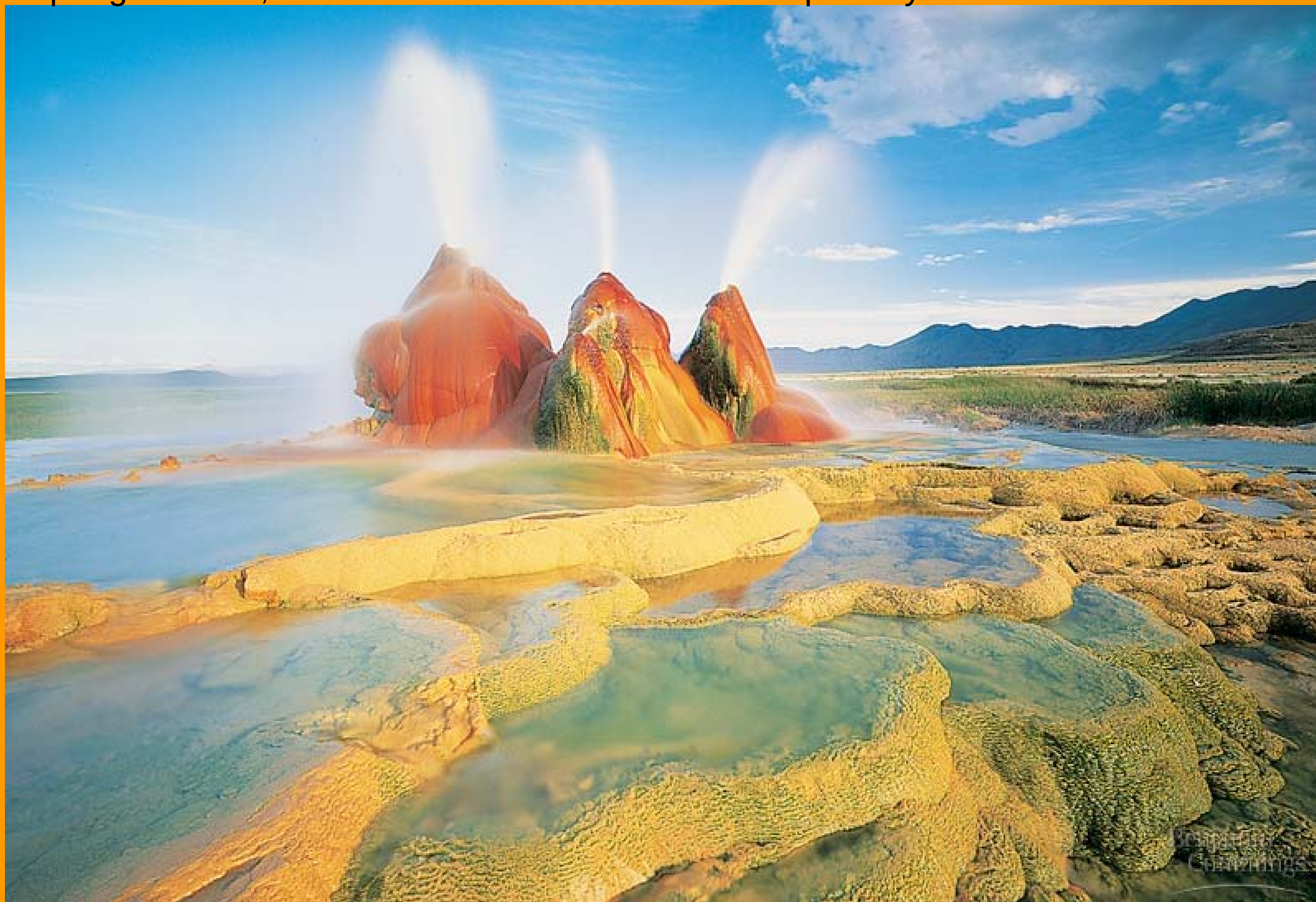
Giant tube worms living in the vent communities. These have no mouth or digestive system, but survive symbiotically on the bacteria that live in their bodies.



http://learning.mgccc.cc.ms.us/science/scienceppt/Hydrothermal%20Vents_files/v3_document.htm

http://www.ifremer.fr/2ishvb/images/o

These bacteria live in very hot, acid habitats of 60-80 Cº and pH 2-4, like the photo of a "Hot springs" below, the red stain on the rocks are the prokaryotic cells.



http://io.uwinnipeg.ca/~simmons/16cm05/1116/16monera.htm

Archaebacteria - Extremophiles

1. Extreme Thermophiles--live in hot springs and black smokers.

2. Extreme Halophiles – live in saturated brine and salt crust.

The bacteria thrive in saturated brine up to 30 percent salinity (9 times the salinity of sea water). They can also be found embedded in the thick, pinkish-red salt crust literally baking in the desert sun. In fact, they cannot survive if the salt concentration drops below 10 percent.

The vivid red brine (teaming with halophilic archaebacteria) of Owens Lake contrasts sharply with the gleaming white deposits of soda ash (sodium carbonate). The picturesque Inyo Range can be seen in the distance.

http://waynesword.palomar.edu/ploct97.htm

http://www.trekearth.com/gallery/Africa/Tunisia/South/photo78623.htm

Archaebacteria - Extremophiles

1. Extreme Thermophiles--live in hot springs and black smokers.

2. Extreme Halophiles--live in saturated brine and salt crust.

3. Extreme Acidophiles - live in waters with a pH below 7, and as low as 0.0.

Despite the extreme environment on the waste dump acid-loving algae/bacteria colonies live in puddles on the waste dumps where the pH can be extremely low. Some acidophiles thrive in water with a pH of 0.0.

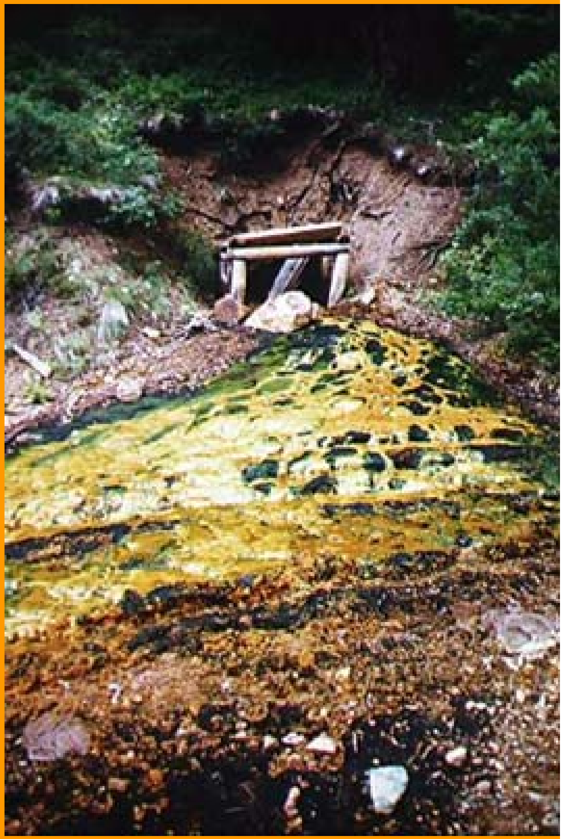
http://www.lagerstaetten.tu-berlin.de/staff/mfrei/sanyati.html

Archaebacteria - Extremophiles

1. Extreme Thermophiles--live in hot springs and black smokers.

2. Extreme Halophiles--live in saturated brine and salt crust.

3. Extreme Acidophiles
and acid mine drainage



Where and how did/do these extremophile organisms live on Earth?

Microbial Mat Communities

The modern mats to the right are much what an Archaean community was like. In fact, it is almost exactly what they were like – except for a few forms that will evolve during the Proterozoic.

Mat Community Cross-section of a microbial mat from Great Sippewissett Saltmarsh, Falmouth, MA

http://www-cyanosite.bio.purdue.edu/images/images.html

Microbial Mat Communities

Microbial Mats from a Hydrothermal System

Up close the mats look like tangled, chaotic, slimy messes.

But, they are a complex ecosystem of different species living symbiotically

http://www-eaps.mit.edu/geobiology/research/hydrothermal.html

Microbial Mat Communities

The Connection Between Teconic Energy and Biological Redox in Bacterial Mat Communities

Hot vent bacterial mat

These early extremophile bacteria obtained their energy by utilizing the oxidation-reduction chemical reactions driven by difference between the thermal highly reduced water and the less reduced Archaean sea water.

$$H_2S + FeS = FeS_2 + H_2 + e^-$$

Hydrogen sulfide

Pyrite

~ 3.6 Ga ~ 3.6 Ga ~ 3.6 Ga

Archaean Archaea Matt Communities

Stromatolites

http://www.spaceprime.com/early-earth.h

~ 3.6 Ga ~ 3.6 Ga ~ 3.6 Ga

Modern Bacterial Matt Communities

Stromatolites

http://www.spaceprime.com/early-earth.h

Early Biochemical Pathways for Obtaining Energy

ChemoLithoAutotrophy

- *Using or facilitating exothermic chemical reactions that release high energy electrons.*

$$H_2S + FeS = FeS_2 + H_2 \quad + e^-$$

Hydrogen sulfide

Pyrite

- *A common reaction in smokers and volcanic environments.*
- *Many similar reactions are known involving sulfur, sulfate, carbon dioxide, etc.*
- *Release high energy electrons captured by bacteria*

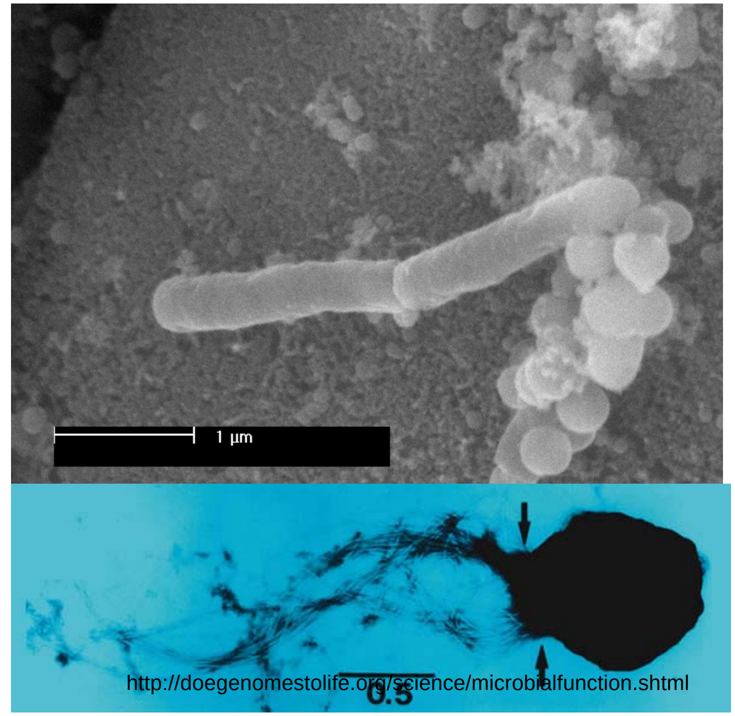
Archaebacteria - Extremophiles

1. Extreme Thermophiles--live in hot springs and black smokers.

http://www.ocean.udel.edu/newscenter/Extreme2002.html

Methanogenic Generating Archaea

<u>Methanococcus jannischiiwas</u> was originally isolated from a "white smoker" chimney at an oceanic depth of 2,600 meters. It can be grown in a mineral medium containing only H_2 and CO_2 as sources of energy and carbon for growth within a temperature range of 50 to 86 degrees centigrade.



"Methanococcus jannaschii, An Extremely Thermophilic Methanogen from a Submarine Hydrothermal Vent

To atmosphere

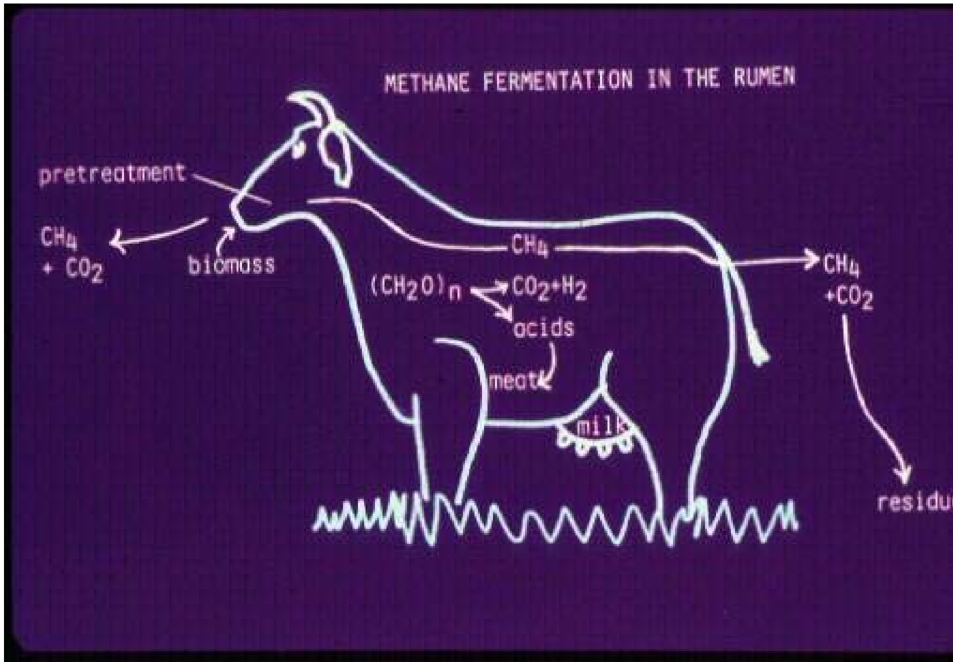
$$4H_2 + CO_2 = CH_4 + 2H_2O$$

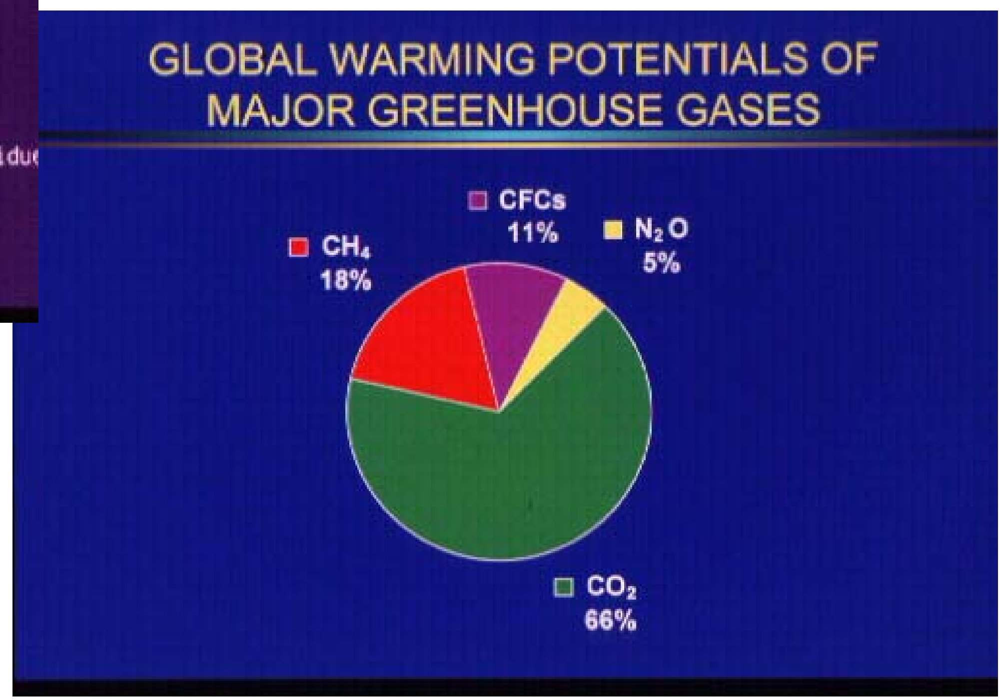
e^- Used to convert ADP to ATP

Today methanogens live in almost all anxoic environments on Earth.

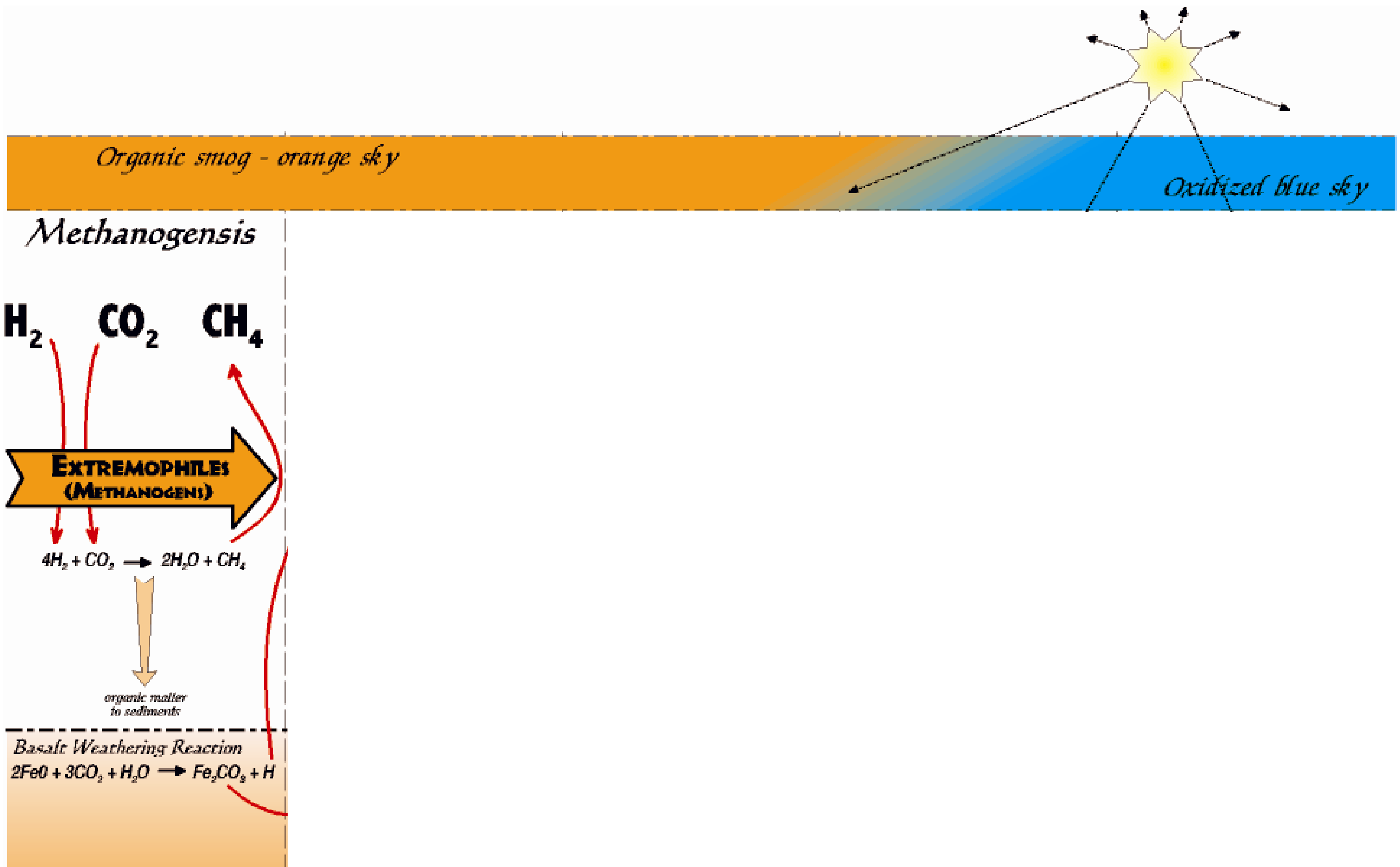
Methanogenesis

Methanogens (methane-producers)--responsible for swamp gas.





http://www.agen.ufl.edu/~chyn/age4660/lect/lect_08x/lect_08.htm



Suck hydrogen and carbon dioxide out of the atmosphere and put methane into the atmosphere. CO_2 (carbon) is sequestered in sediments as petroleum or natural gas.

Fermentation

- *Breaking a larger organic molecule into two smaller pieces releasing high energy electrons.*
- *Pyruvic fermentation is the best known.*

Sugar → 2 lactic acids

→ 2 e^- Used to convert ADP to ATP

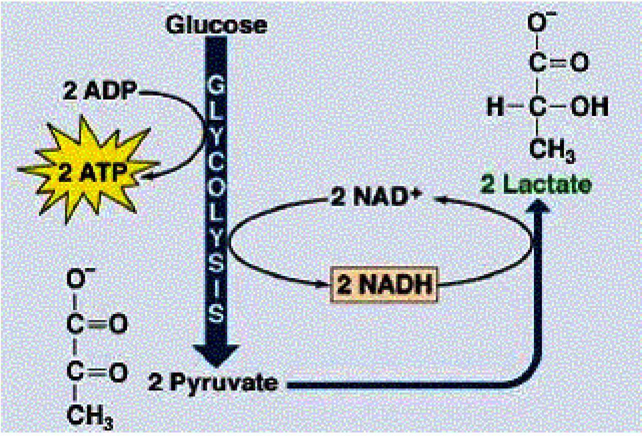
- *This takes place only in the absence of oxygen.*

Fermentation – like Yeast

Pyruvic fermentation is widespread today, but pretty inefficient – each fermentation results in only two ATP molecules, and a lot of energy remains in the remaining waste molecules.

It also does not provide a direct path to new sources of energy.

http://www.mr-damon.com/experiments/2sp/projects/



http://www.arches.uga.edu/~benm/

http://www.cc-charny.fr/focus/compostage.htm

Anaerobic Respiration and the Invention of Electron Transport Chains

VI – Desulfovibrios

Sulfur Reducing Bacteria

Respiration (in general)

Respiration using oxygen is fundamental to the life of higher plants and animals. Possibly, it is the only kind of respiration we are aware of.

$$\text{Lactic Acid} + O_2 \longrightarrow CO_2 + H_2O + ATP$$

- *Known as the Krebs or Citric Acid cycle.*
- *In plants and animals this is the only pathway of respiration.*

But, oxygen respiration is only one of dozens of respiration pathways, many of which are more important than oxygen respiration.

Anaerobic Respiration

Respiration: the process of breaking down food molecules where the electrons released are finally transferred to an inorganic molecule for neutralization.

- In oxygen respiration (aerobic respiration) oxygen is the final electron receptor.
- In anaerobic respiration the final electron receptor is an inorganic molecule other than oxygen.

$$SO_4^{2-} + e^- \longrightarrow H_2S$$

sulfate   sulfide

- Almost any reduced molecule can serve as the electron acceptor.

NO_3 NO_2 NO Fe^{+2} Mn^{+2} Etc. Etc. Etc.

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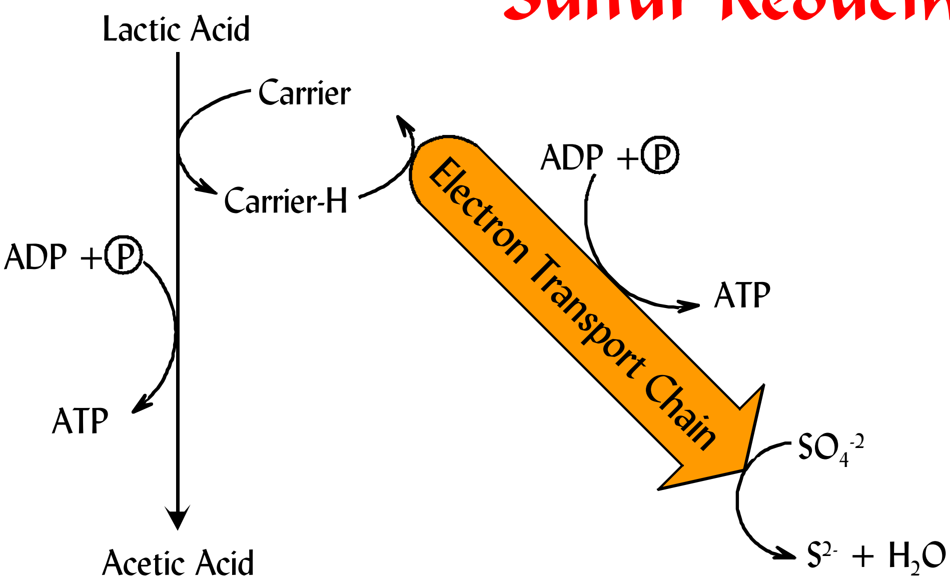
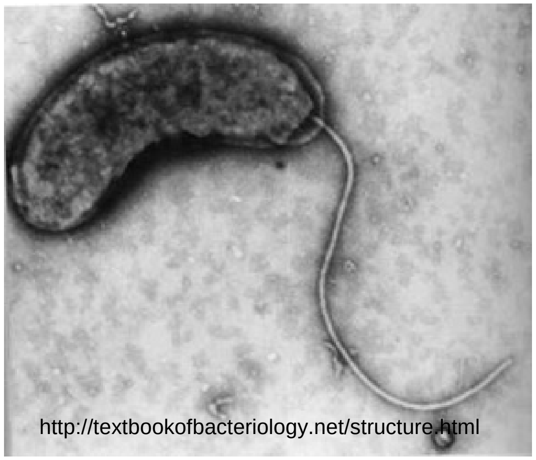
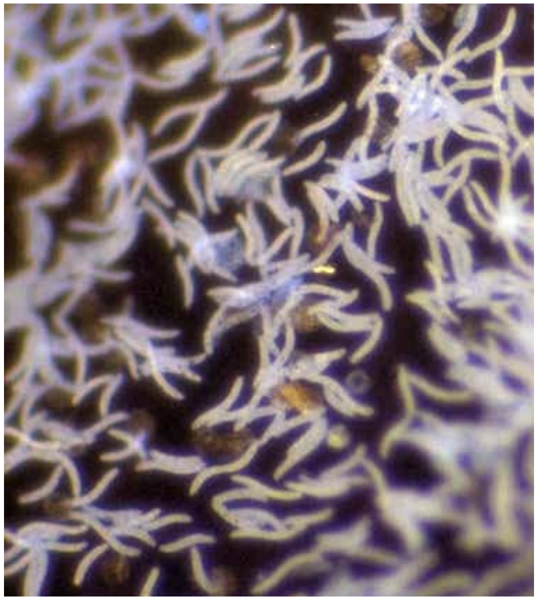


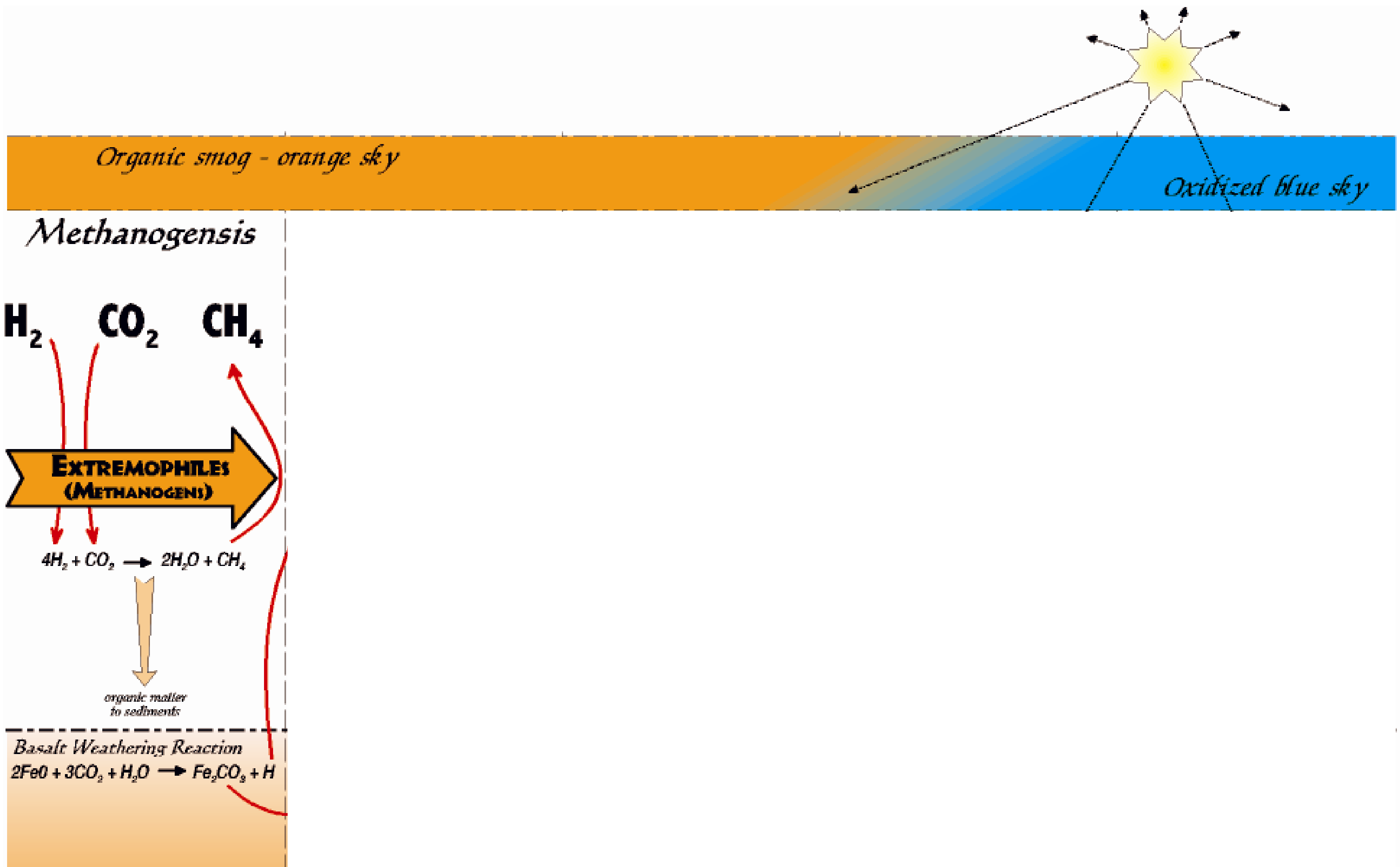




http://www.power-chemicals.com/bio/sulfate_reducing.htm

Desulfovibrios likely invented the electron transport chain very early in the Earth's history.

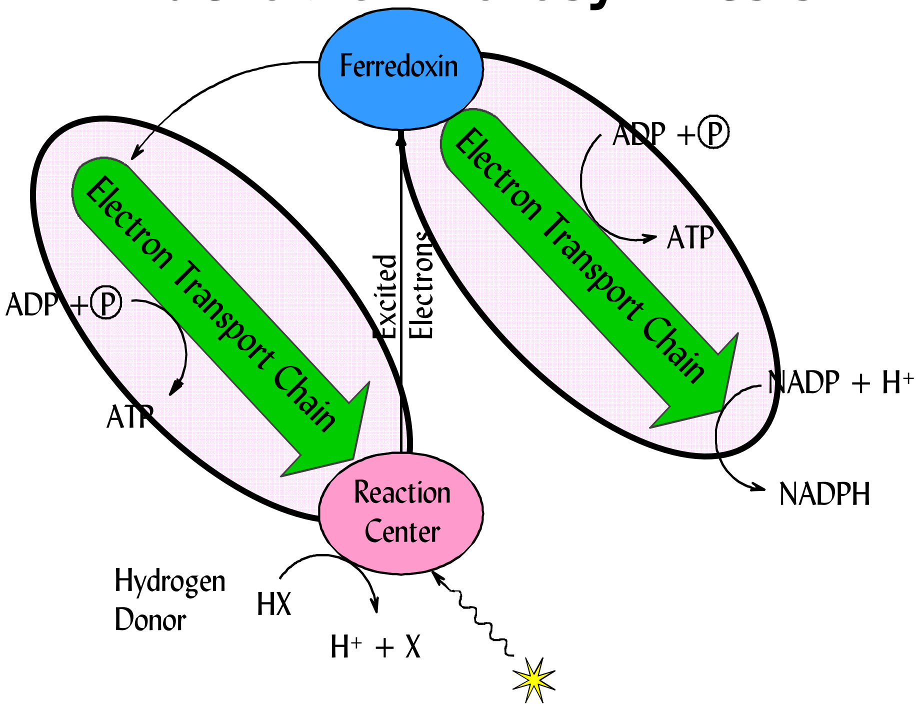
- *At the end of the chain the high energy electron is disposed of by passing it to a sulfate anion, reducing it to sulfide (S^{2-}), forming either H^2S, or some other smelly compound.*



Suck hydrogen and carbon dioxide out of the atmosphere and put methane into the atmosphere. CO_2 (carbon) is sequestered in sediments as petroleum or natural gas.

Green/Purple Sulfur Bacteria

Anaerobic Photosynthesis



(a)

A photogenic purple sulfur bacterial mat (Thiopedia)

bacteriochlorphyll

$$H_2S \rightarrow 2\,H^+ + S$$ **goes to S^{-2} (sulfide) like FeS_2 (pyrite)**

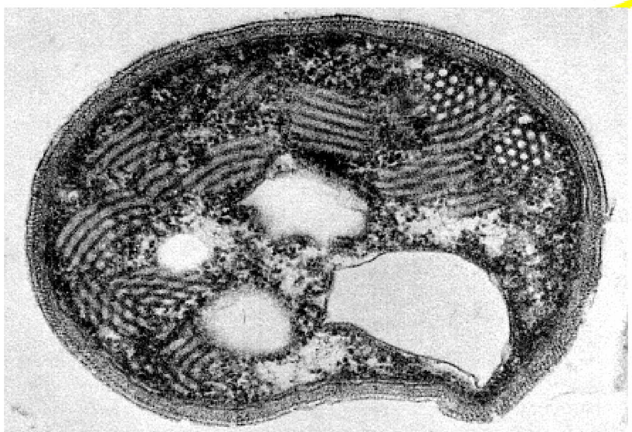
$$+ \; CO_2 \rightarrow \text{Sugar}$$

H reduces CO_2 **To form sugar**

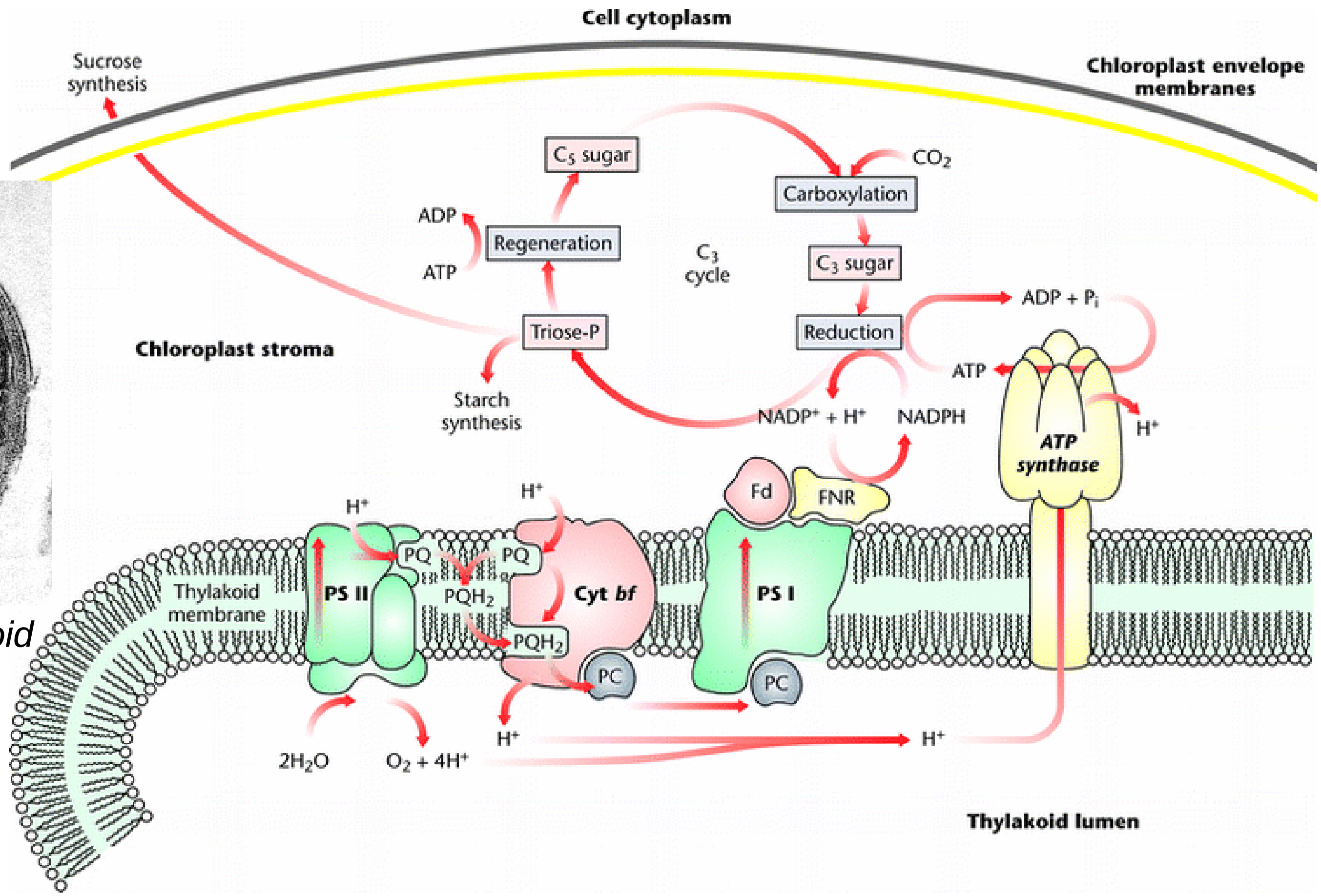
Green/Purple Sulfur Bacteria

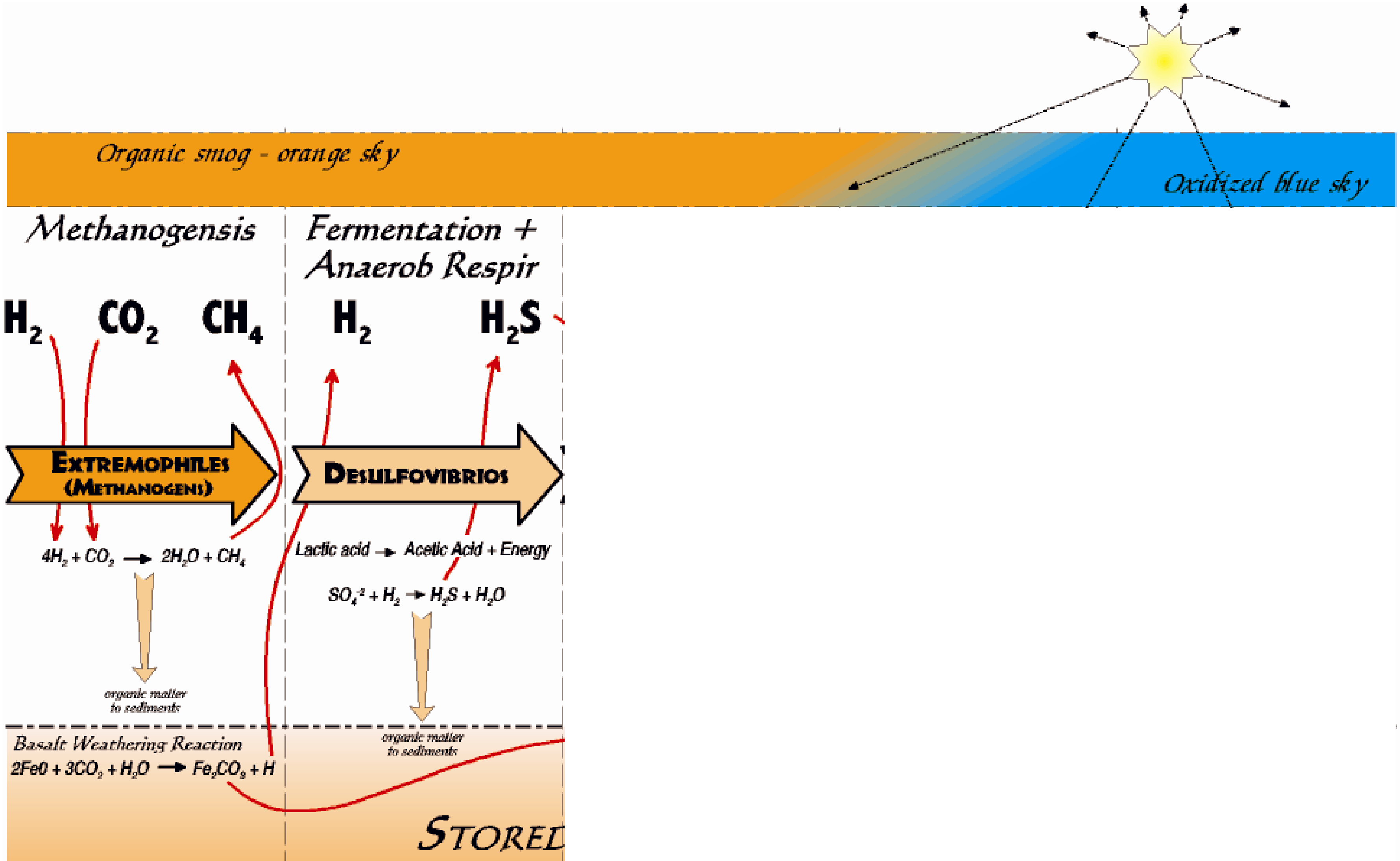
Anaerobic Photosynthesis

The two step sugar production, the first-hydrogen generation-along the thylacoid membranes, the second-CO^2 reduction-in the stroma space outside the thylacoids (Calvin-Benson Reaction). If the membranes are disturbed the reactions cease.



Purple sulfur bacteria with thylacoid membranes.





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Aerobic Photosynthesis

Precursor Blue Green Algae

Photosynthesis in General

- *The traditional photosynthetic equation most of us grew up with is*

$$6\ CO_2 + 6\ H_2O \longrightarrow C_6H_{12}O_6 \quad + O_2$$

- *In the history of the photosynthetic biochemical strategy atmospheric CO_2 has always been the source of carbon. The major problem has been finding a source of hydrogen.*

- *The preceding equation can be made more general by substituting "A" for the oxygen ("O") since what is essential here for photosynthesis is the reducing power of the hydrogen. The oxygen is just incidental.*

$$CO_2 \ + H_2A \longrightarrow C_6H_{12}O_6 \quad + 2A$$

Precursor Blue-Green Algae

Aerobic photosynthesis and Oxygen Sequestering

The Precursor Blue-Green algae initially solved the problem by taking advantage of an environmental convenience.

For the first two billion years of Earth history weathering released a lot of iron from igneous rock forming minerals like pyroxene and biotite. In these minerals most of the iron is in the ferrous state.

$$Fe^{+2}$$

On weathering, and in the absence of oxygen the ferrous iron combines with readily available anions.

$$2FeO + 3CO_2 + H_2O \longrightarrow Fe_2CO_3 + H_2$$

This is the basalt weathering reaction, likely one of the most common geological reactions on the early Earth, and results in iron carbonate as a product.

During the Archaean the oceans were supersaturated with this dissolved iron carbonate

BANDED IRON FORMATION

During the Archaean the oceans were likely supersaturated with this dissolved iron carbonate

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This is the basalt weathering reaction, likely one of the most common geological reactions on the early Earth, and results in iron carbonate as a product.

$$Fe_2CO_3 + O_2 \rightarrow Fe_3O_4$$

Magnetite

Banded Iron Formation – Peak abundance

2500 Ma

- **Peak development of Banded Iron formations world wide:**

http://www.eps.harvard.edu/people/faculty/hoffman/snowball_paper.html

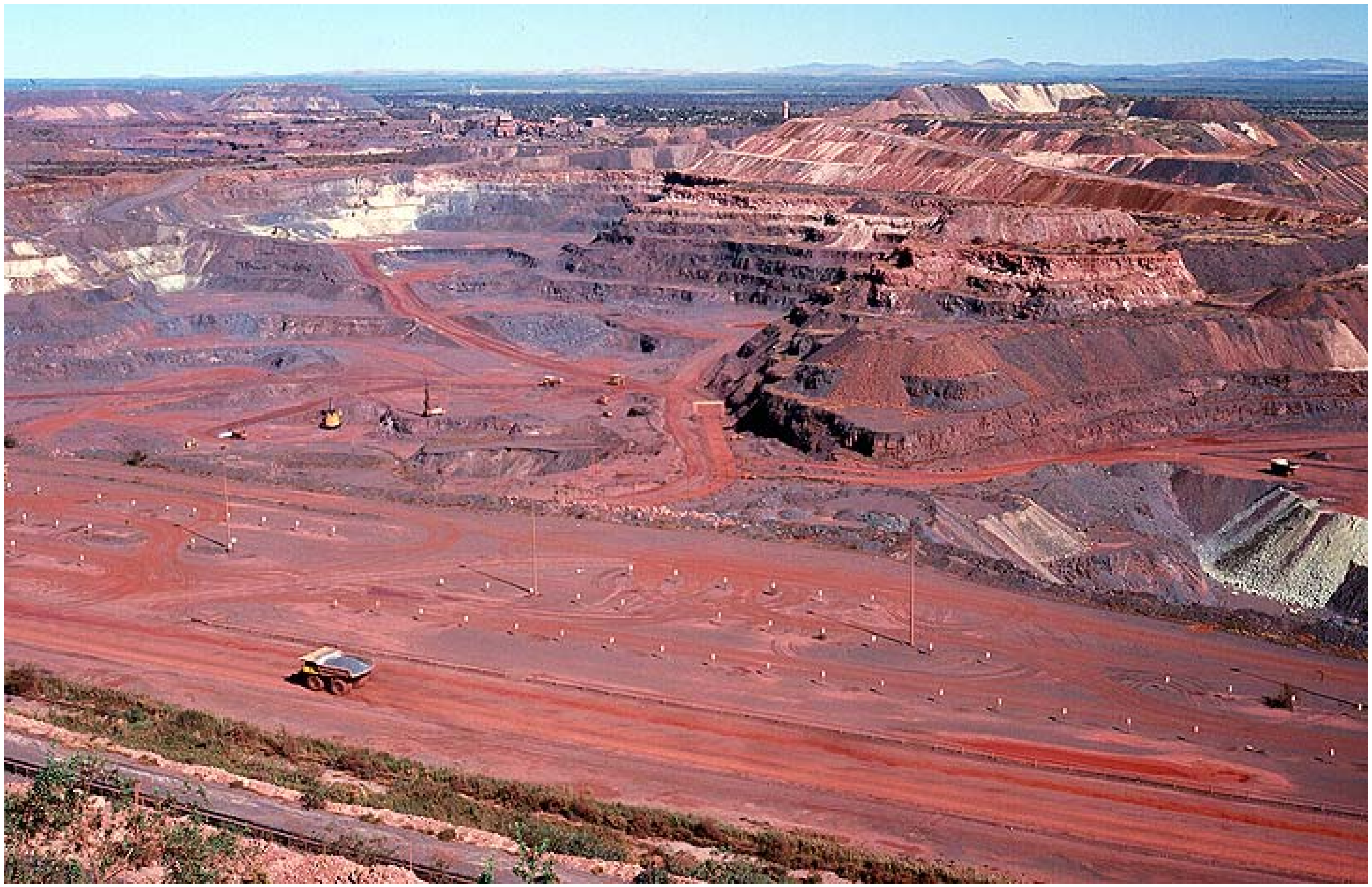
http://www.eps.harvard.edu/people/faculty/hoffman/snowball_paper.html

http://www.angelfire.com/rock3/michael/Interrocksmin.html

http://www.humboldt.edu/~natmus/lifeThroughTime/PreCam.web/

PreCambrian Record of Life And Associated Geologic Deposits

Banded Iron Formation – South Africa



http://web.uct.ac.za/depts/geolsci/dlr/hons1999/

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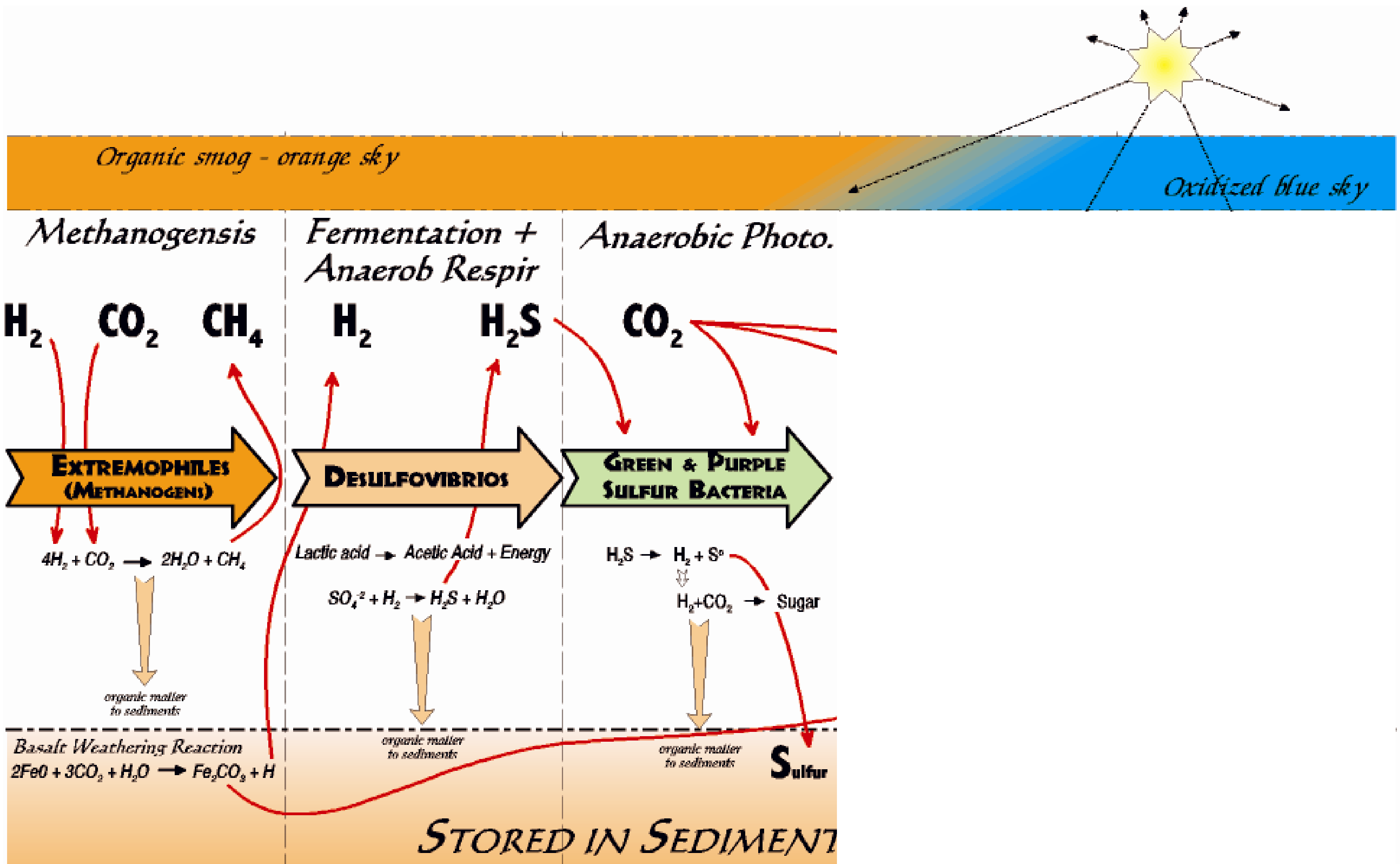

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Every advance leads to a limitation

Hydrogen (H_2S) shortage

As the population of green and purple sulfur bacteria increased across the world, and as they moved away from the hydrothermal vents, they soon ran up against a wall . . .

- **A shortage of hydrogen from H_2S to reduce CO_2 to produce sugar.**

Another energy strategy had to be invented.

Every limitation is an opportunity

Invention of Aerobic Photosynthesis

Precursor Blue Green Algae

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8 - Every limitation is an opportunity

Invention of Aerobic Photosynthesis

VIII – Precursor Blue Green Algae

Green/purple sulfur bacteria *photosynthetic reactions require hydrogen sulfide. In its absence these organisms wither and die from lack of energy.*

$$H_2S$$

There does exist, however, an unlimited supply of hydrogen, it is just that it is tightly bound up with other atoms. The key to the next step was finding a source of energy large enough to remove the hydrogen from . . .

$$H_2O$$

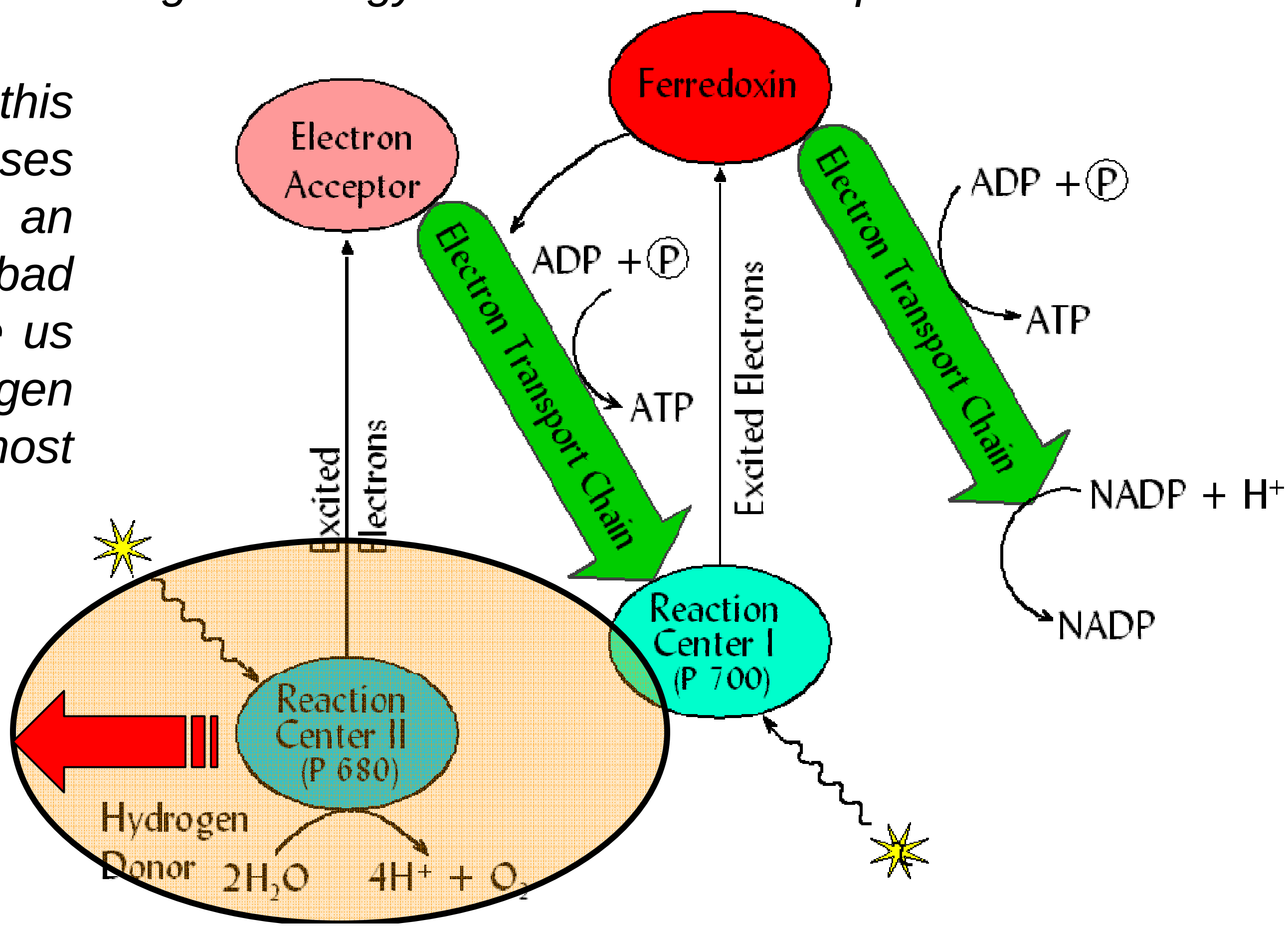
Precursor Blue-Green Algae

Aerobic Photosynthesis and Oxygen Sequestering

To access the hydrogen available in water the Precursor Blue-Green algae invented or incorporated from an earlier form a second form of chlorphyl and housed it in a new Reaction Center II. This chlorophyl absorbs a shorter wave length of light, that results in a more highly energized molecule, which results in a higher energy electron. This higher energy electron is used to split water.

The down side to this reaction is that it releases free oxygen, and in an anoxic world this is bad news. It would be like us breathing hydrogen cyanide gas – almost instant death.

OXYGEN GENERATION AND RELEASE



Every advance leads to a limitation and Sometimes unintended consequences

Oxygen Cataclysm

This spilling of toxic wastes into the environment precipitated one of the most severe environmental crises the Earth and the life on it experienced.

Life has three choices during such a crisis.

1. *Go extinct*
2. *Move to a safe environment*
3. *Adapt to new conditions*

Aerobic Photosynthesis

Blue Green Algae (Cyanophytes)

Blue-green algae are not true algae, but are more properly photosynthetic bacteria and can also be called cyanobacteria. They are commonly found in lakes, ponds, wetlands, and marine environments.

http://wlapwww.gov.bc.ca/wat/wq/brochures/bluegre.html

http://coris.noaa.gov/glossary/

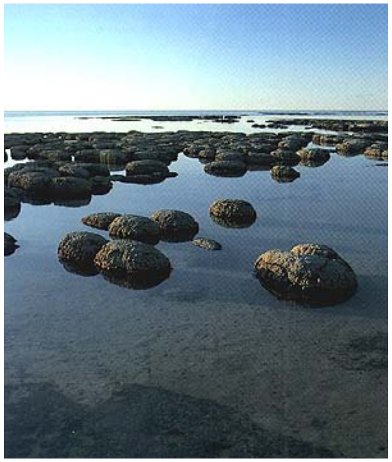
http://www.bioremediate.com/algae.htm

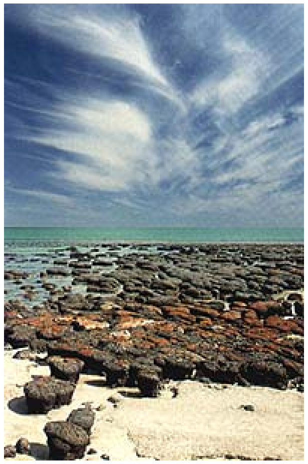
Stromatolites: Shark Bay, Australia

http://www-eaps.mit.edu/geobiology/biomarkers/whatis.html

http://www.nirgal.net/graphics/stromatolite_moderne.jpg

Stromatolites: Shark Bay, Australia



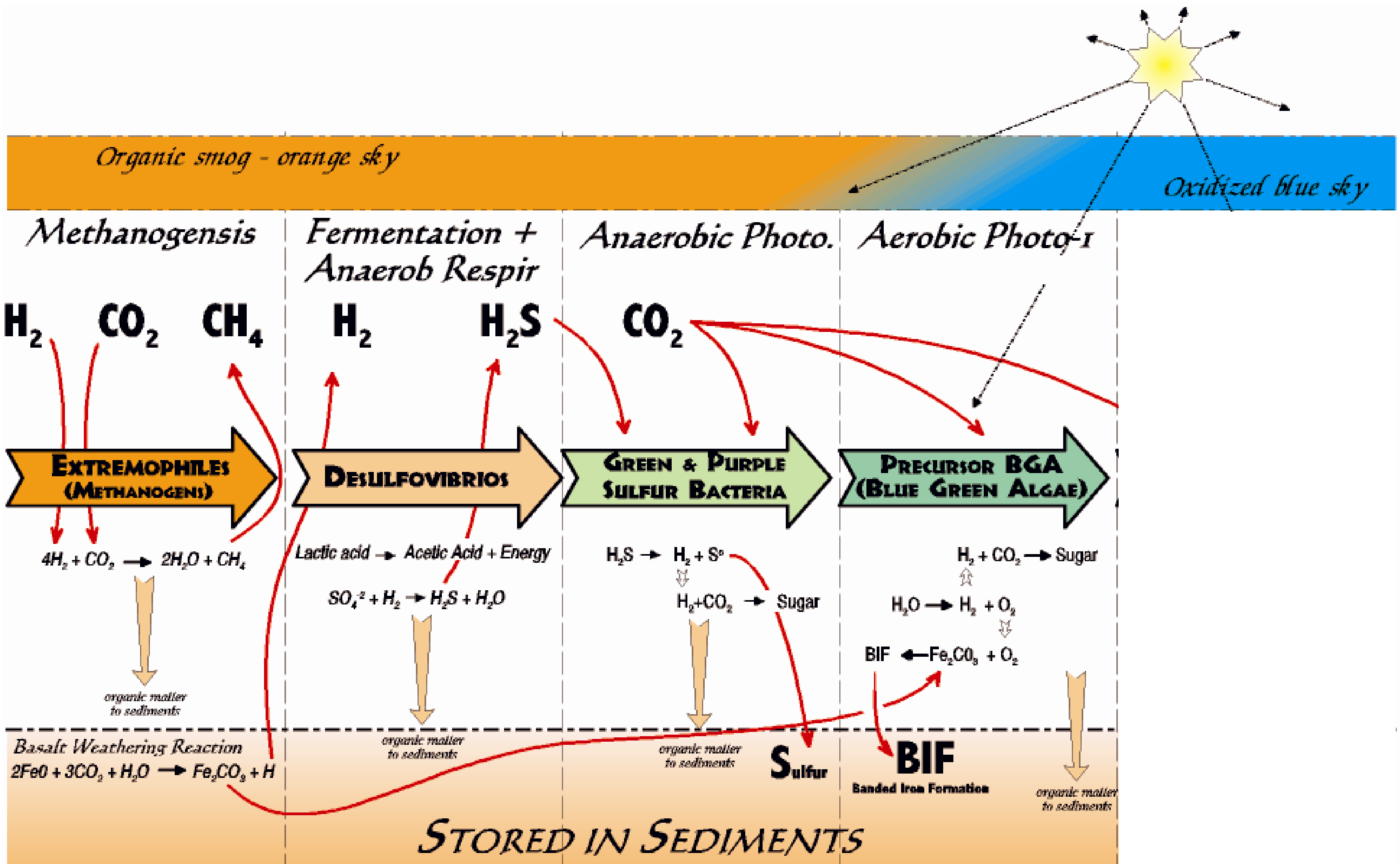


http://www.ucmp.berkeley.edu/bacteria/cyanofr.html

Stromatolite formation in Hamlin Pool, Shark Bay, western Australia. This is one of the few places in the world today where stromatolites form as commonly as they did on the proto-Atlantic DCM. Top picture is a close up of the stromatolite mounds; lower right intertidal region with tide in; lower left region with tide out. Good images of what Virginia looked like in the mid to late Cambrian.

Top picture from http://www.ea.gov.au/heritage/awh/worldheritage/sites/shark/index.html.

Bottom pictures from http://www.calm.wa.gov.au/national_parks/hamelin_pool_mnr.html



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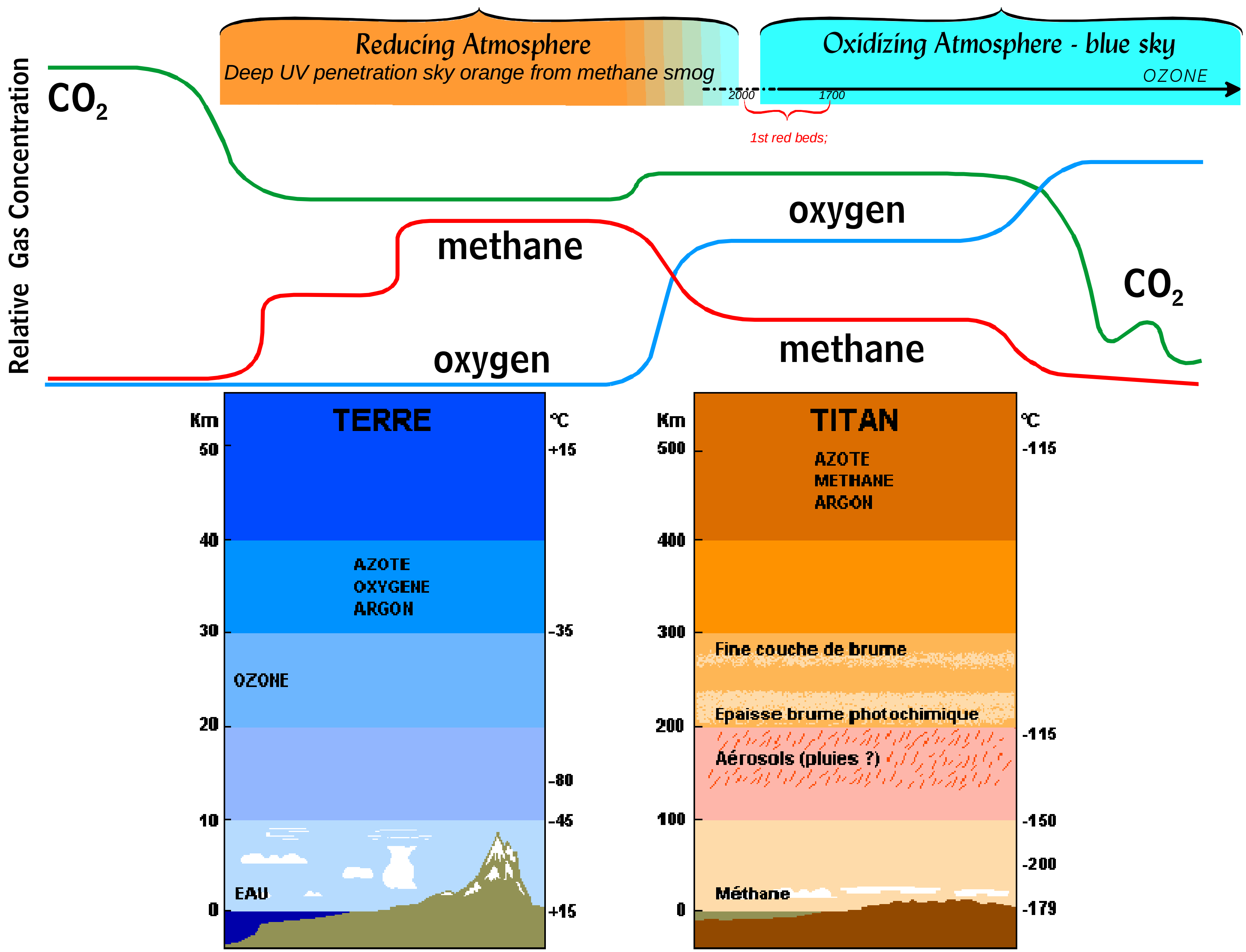
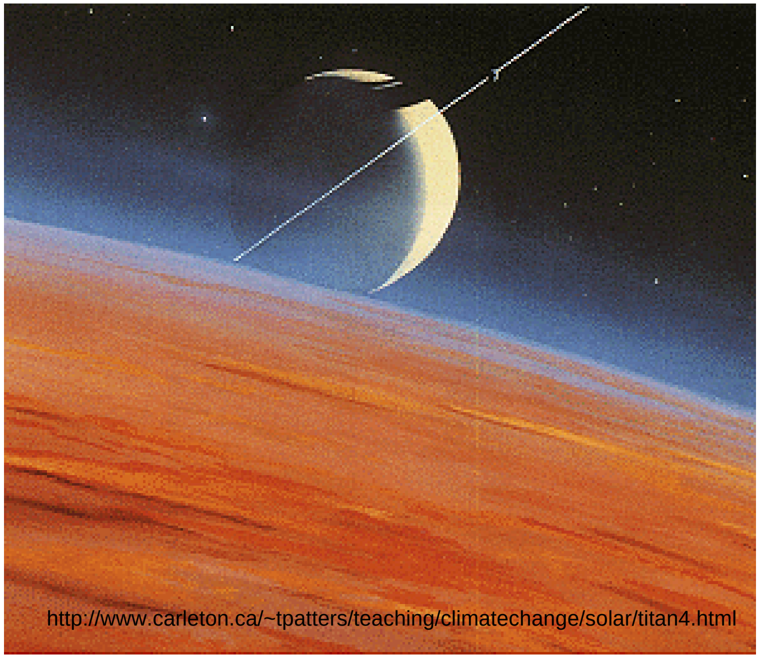
Proterozoic Cleansing of Methane Smog



http://www.astrosurf.com/lombry/sysol-saturne3.htm

The Cleansing of the Methane Smog

Saturn shimmers through the haze above the dense, orangish smog that obscures the surface of Titan. Above the clouds and haze, there may be a level in Titan's atmosphere where a blue sky color can be seen.

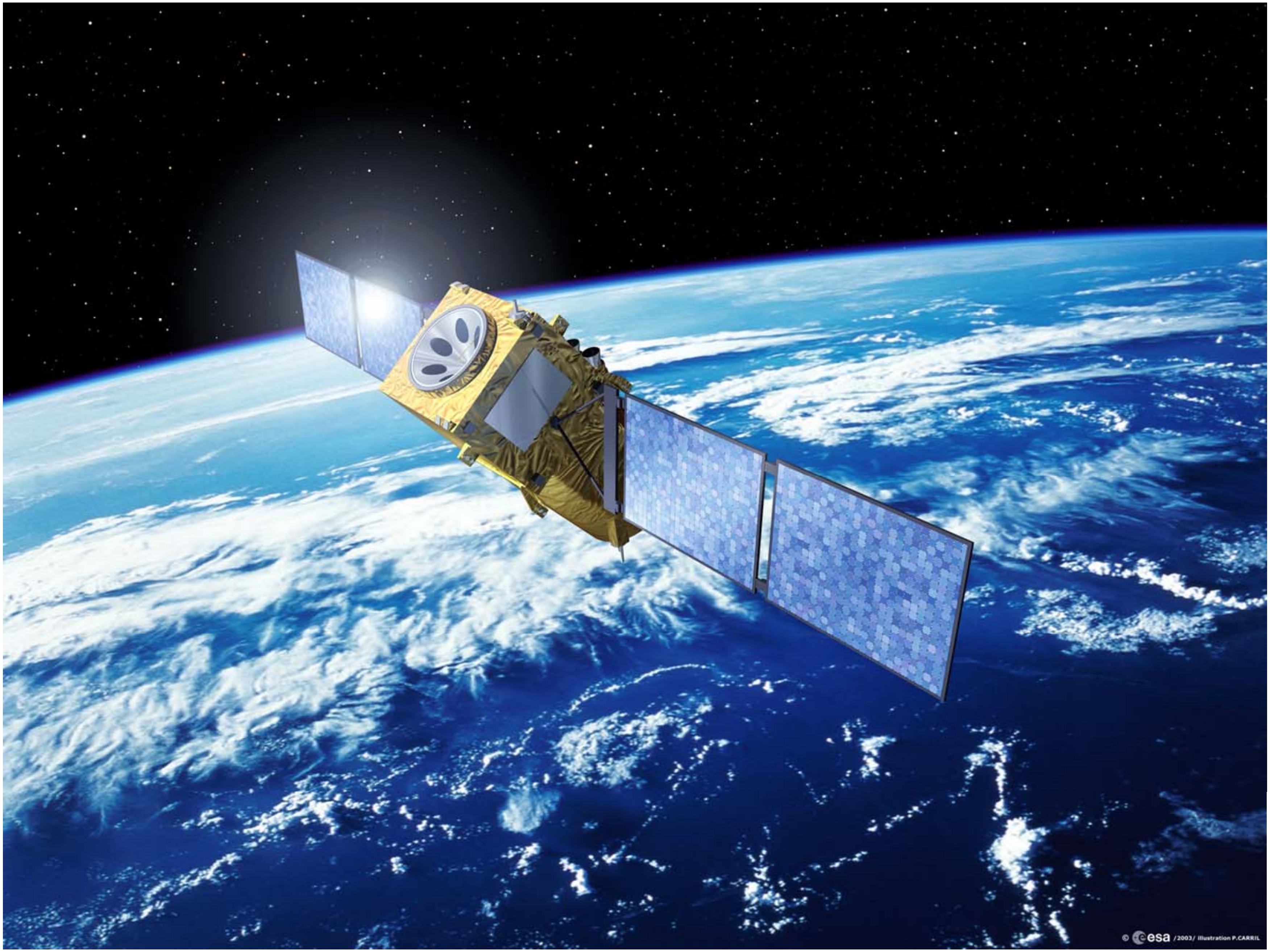


http://www.carleton.ca/~tpatters/teaching/climatechange/solar/titan4.html

The haze of an atmospheric layer on Saturn's moon, Titan. With an atmosphere thicker than Earth's, and composed of many biochemically interesting molecules (methane, hydrogen and carbon), Titan's rich chemistry will continue to interest astrobiologists as they look forward to landing a probe on its surface in 2004-5. Credit: Voyager Project, JPL, NASA

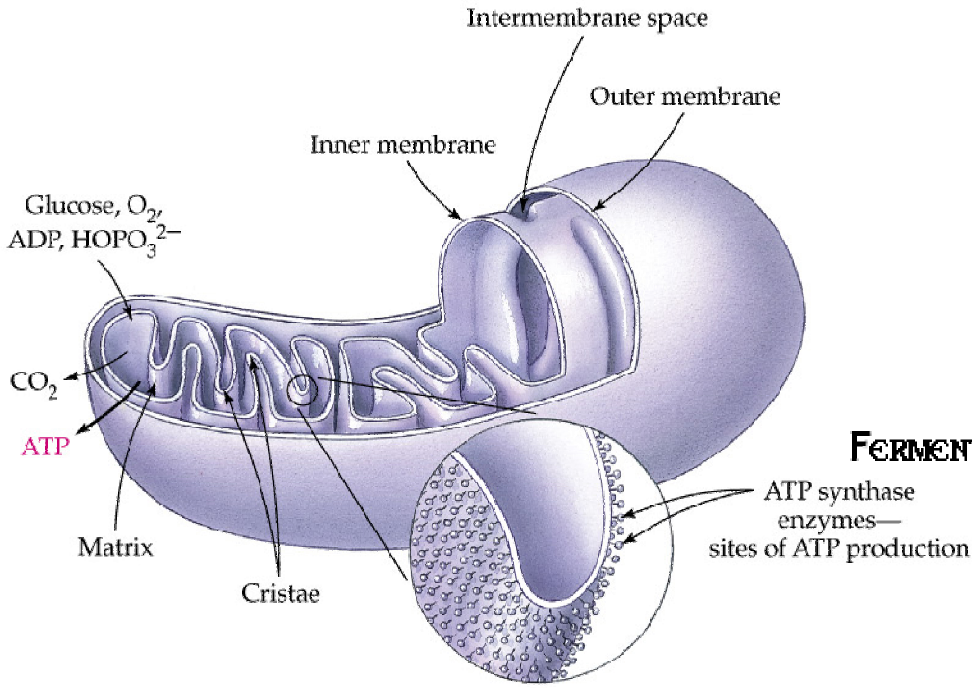
http://www.nasa.gov/mission_pages/cassini/whycassini/Saturns_Moon.html

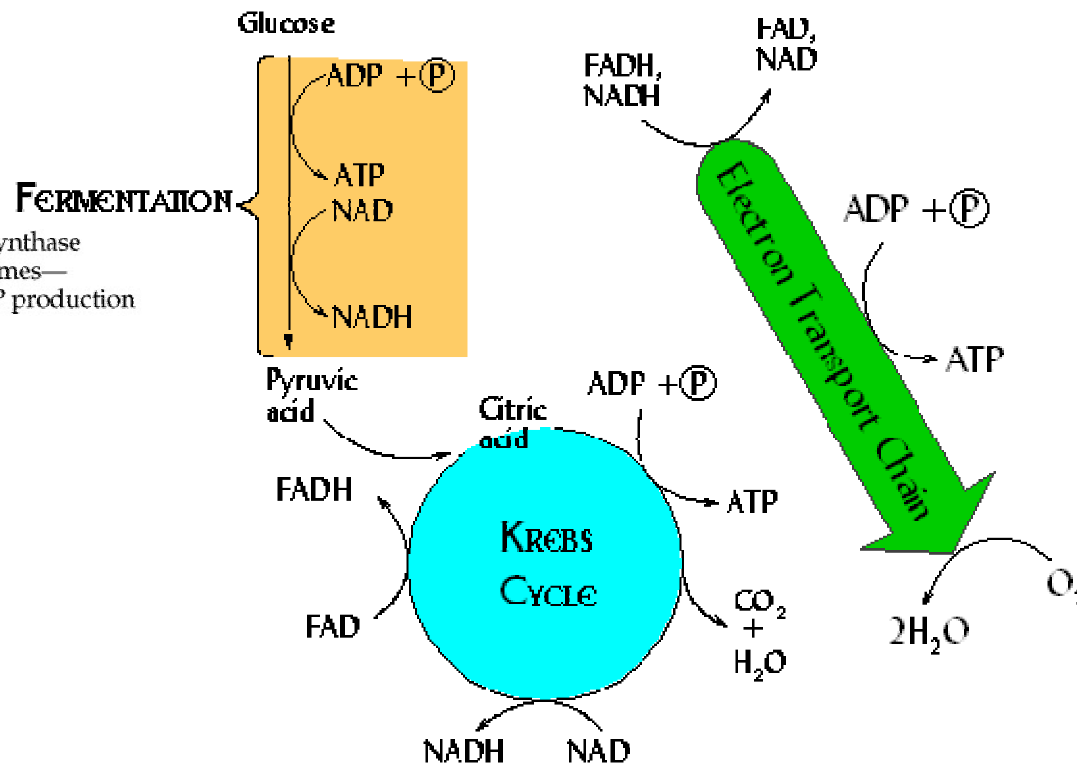
THE CLEANSING OF THE METHANE SMOG



Invention of Oxygenic Respiration

X – Mitochondria and the Krebs Cycle





http://cwx.prenhall.com/bookbind/pubbooks/mcmurrygob/medialib/media_portfolio/21.html

ATP Generating Biochemical Pathways

Organotrophy – energy is derived from organic processes rather than inorganic processes.

Aerobis; a.k.a. Respiration, or the Krebs cycle

- *This is the most efficient and abundant source of energy for living systems.*

$$2\ H_2O \longrightarrow 2\ H^+ + O_2$$

$$\hookrightarrow + \text{Lactic Acid} \longrightarrow H_2O + CO_2 + 36\ ATP$$

Methanogens – Suck hydrogen and carbon dioxide out of the atmosphere and put methane into the atmosphere. CO2 (carbon) is sequestered in sediments as petroleum or natural gas.

$$4H_2 + CO_2 = CH_4 + 2H_2O$$

Sulfur Reducing Bacteria (Desulfovibrius) – In fermenting food molecules use sulfate to neutralize a high energy electron, putting hydrogen sulfide and water into the atmosphere. Organic matter (C from CO2) sequestered in sediments.

$$SO_4^{-2} + H_2 \rightarrow H_2S + H_2O$$

Anaerobic Photosynthesis (Green/Purple Sulfur Bacteria) – Suck down hydrogen sulfide and CO2 from atmosphere to manufacture sugar. Sequester sulfur and carbon from organic matter in the sediments.

$$H_2S + CO_2 \longrightarrow \text{Sugar} + S$$

Aerobic Photosynthesis-1 (Precursor BGA) – Suck down CO2 from atmosphere and water from environment to manufacture sugar. Waste oxygen is combined with iron and sequestered as Banded Iron Formation. Organic matter to sediments.

$$\mathbf{CO_2 + H_20 \longrightarrow Sugar + {\color{red}O_2}}$$

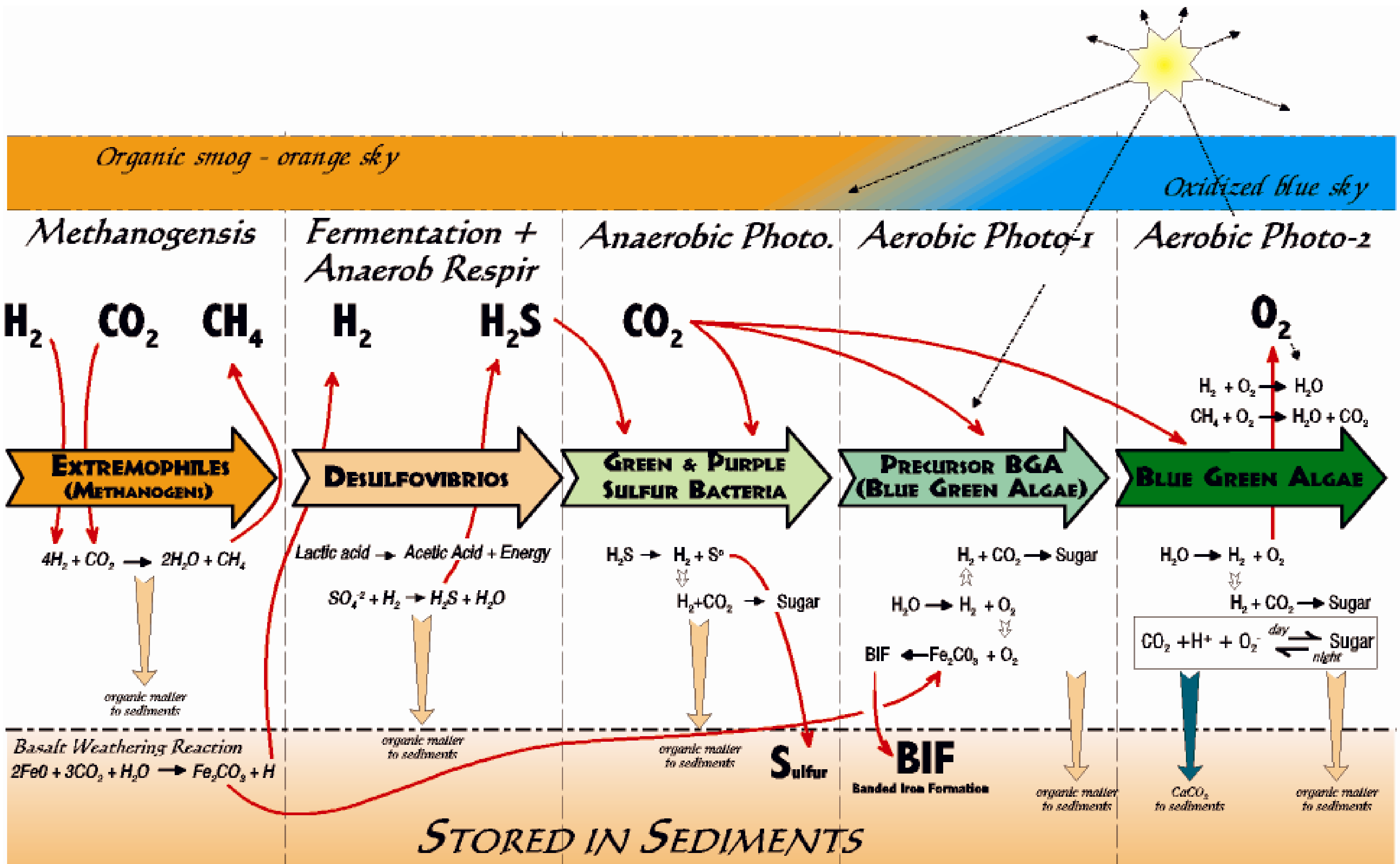
$$\downarrow$$

$$\mathbf{{\color{red}Fe_2CO_3} \quad {\color{red}\longrightarrow} \quad {\color{red}Fe_3O_4\ (BIF)}}$$

Aerobic Photosynthesis-2 (BGA) – Suck down CO2 from atmosphere and water from environment to manufacture sugar. Waste oxygen is released into the atmosphere. Organic matter to sediments.

To atmosphere

$$\mathbf{CO_2 + H_20 \longrightarrow Sugar + {\color{red}O_2}} \nearrow$$



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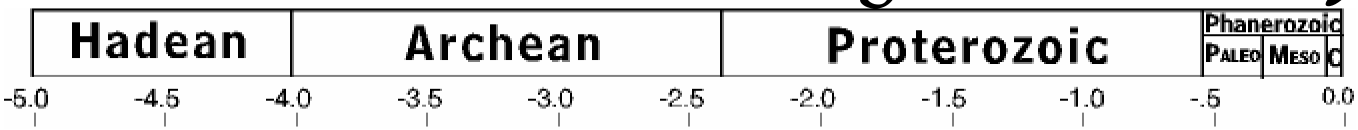
Stage Two Atmosphere – Archaean

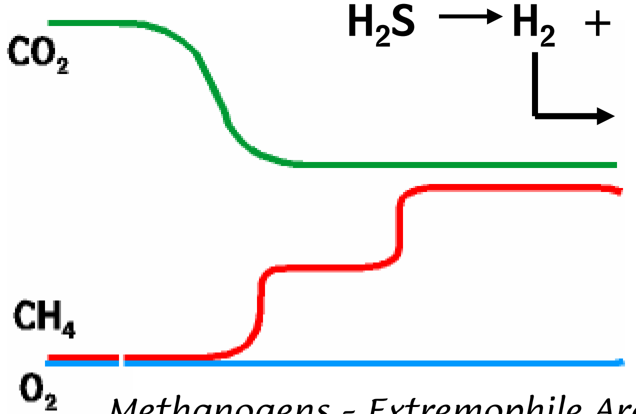
Initiation of Biogeochemical Cycling



Anaerobic Photosynthesis – Green/Purple Sulfur bacteria

$H_2S \longrightarrow H_2$ + sulfur

H_2 + $CO_2 \longrightarrow$ sugar



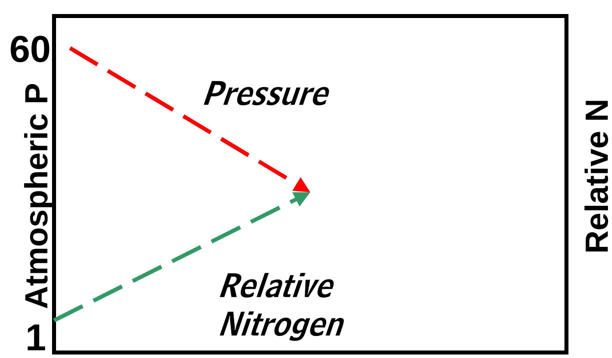
Fractionation (& sequestering)

1. To sediments (petroleum)
2. To carbonates (CO_2 to $CaCO_3$)
3. CO_2 to CH_4

Methanogens – Extremophile Archaebacteria

$$CO_2 + H_2 \longrightarrow CH_4 + H_2O$$

Cabon dioxide being sucked down and methane put into atmosphere

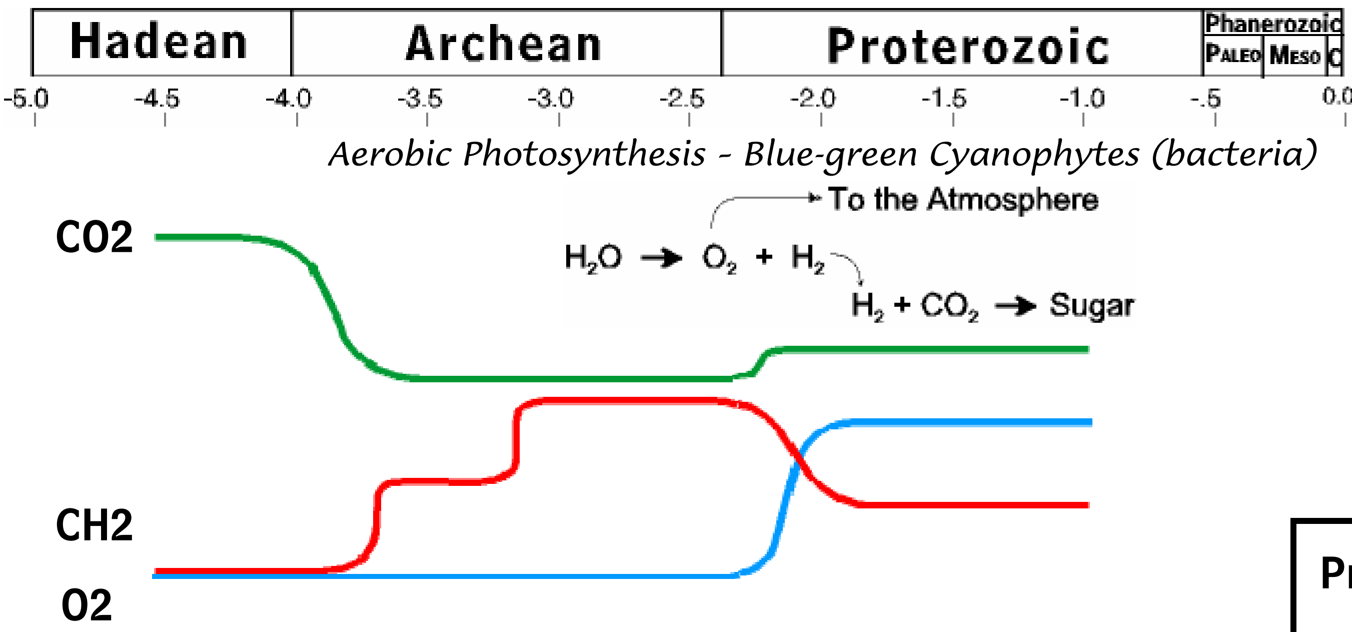


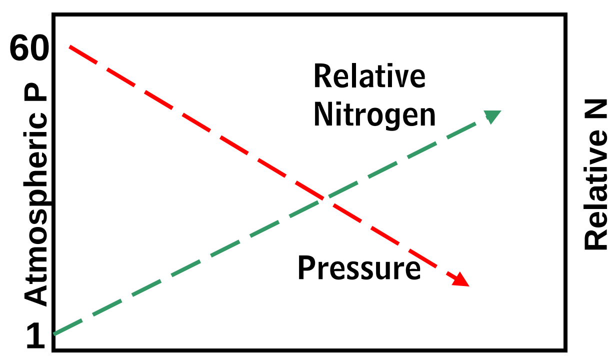
Archaean Atmosphere

CO_2	less
CH_4	more
N_2	rising

Stage Three Atmosphere – Proterozoic

The Great Switch





Proterozoic Atmosphere

CO_2 less

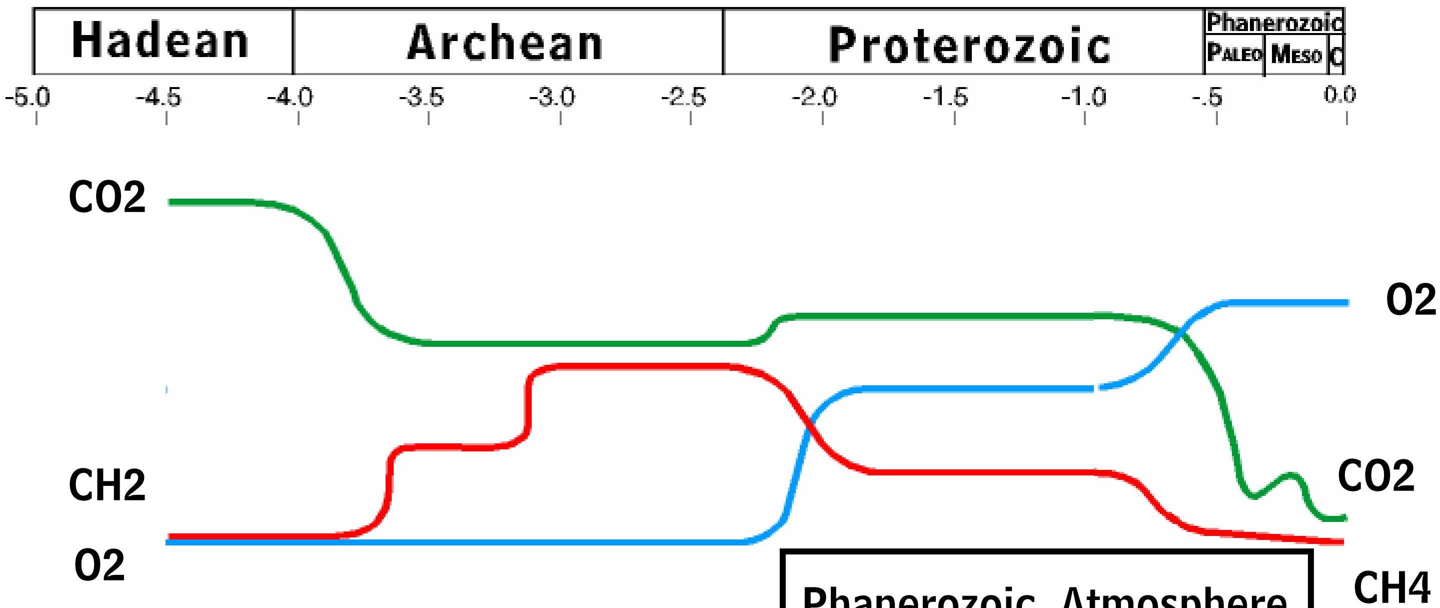
N_2 rising

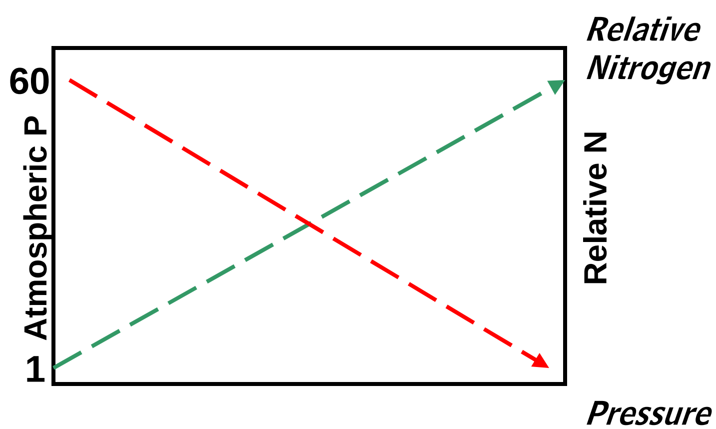
O_2 rising

CH_4 reduced

Stage Four Atmosphere – Phanerozoic

Settling in but still Fluctuating





Phanerozoic	Atmosphere
N_2	79%
O_2	19%
CO_2	0.03%
CH_4	trace