CICLI BIOGEOCHIMICI ED
EVOLUZIONE DEL PIANETA

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GIOVANNELLI LAB

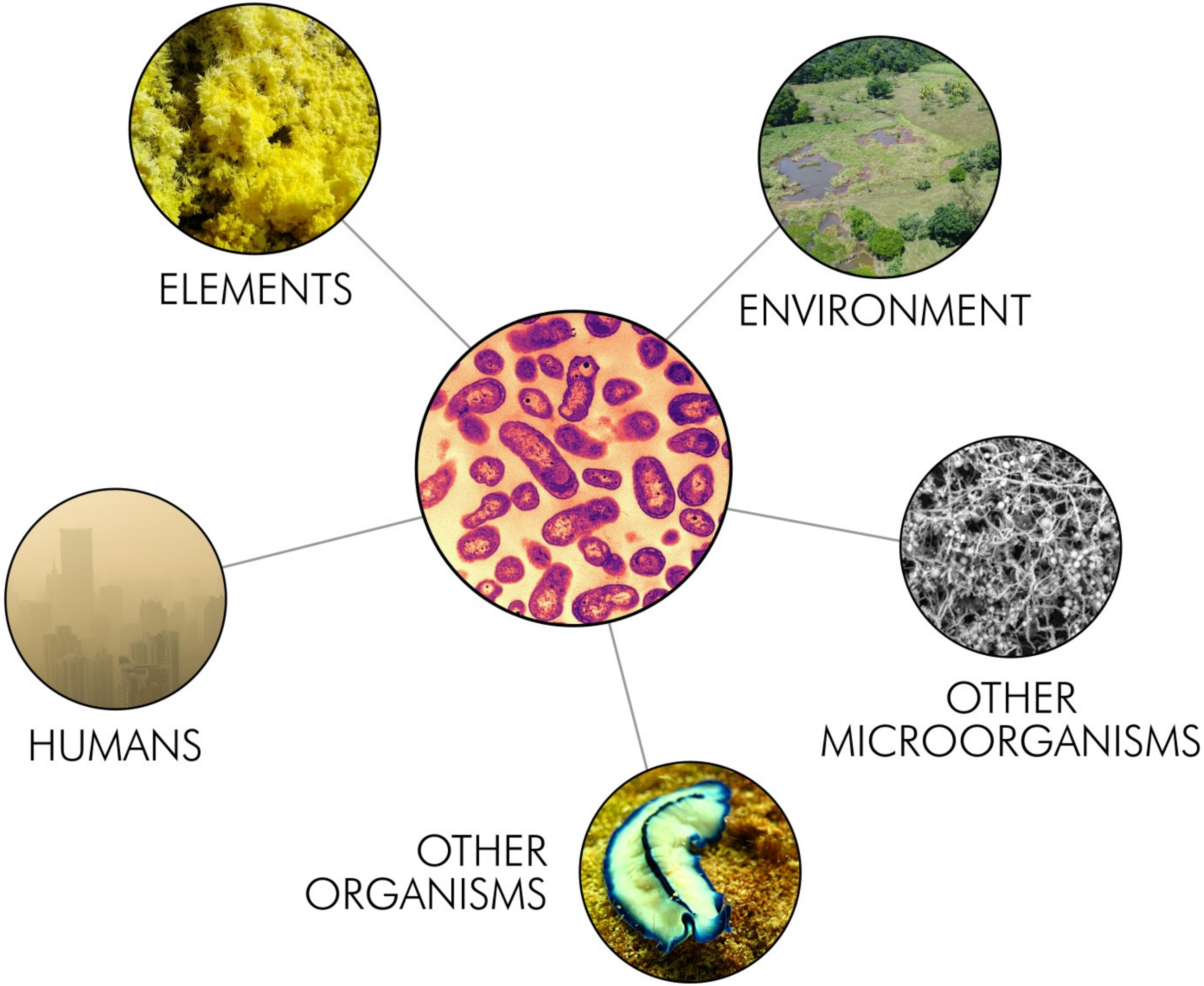
DIPARTIMENTO DI BIOLOGIA

CNR IRBIM
ISTITUTO PER LE RISORSE BIOLOGICHE E LE BIOTECNOLOGIE MARINE

RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

ELSI
EARTH - LIFE SCIENCE INSTITUTE

WOODS HOLE OCEANOGRAPHIC INSTITUTION
1930



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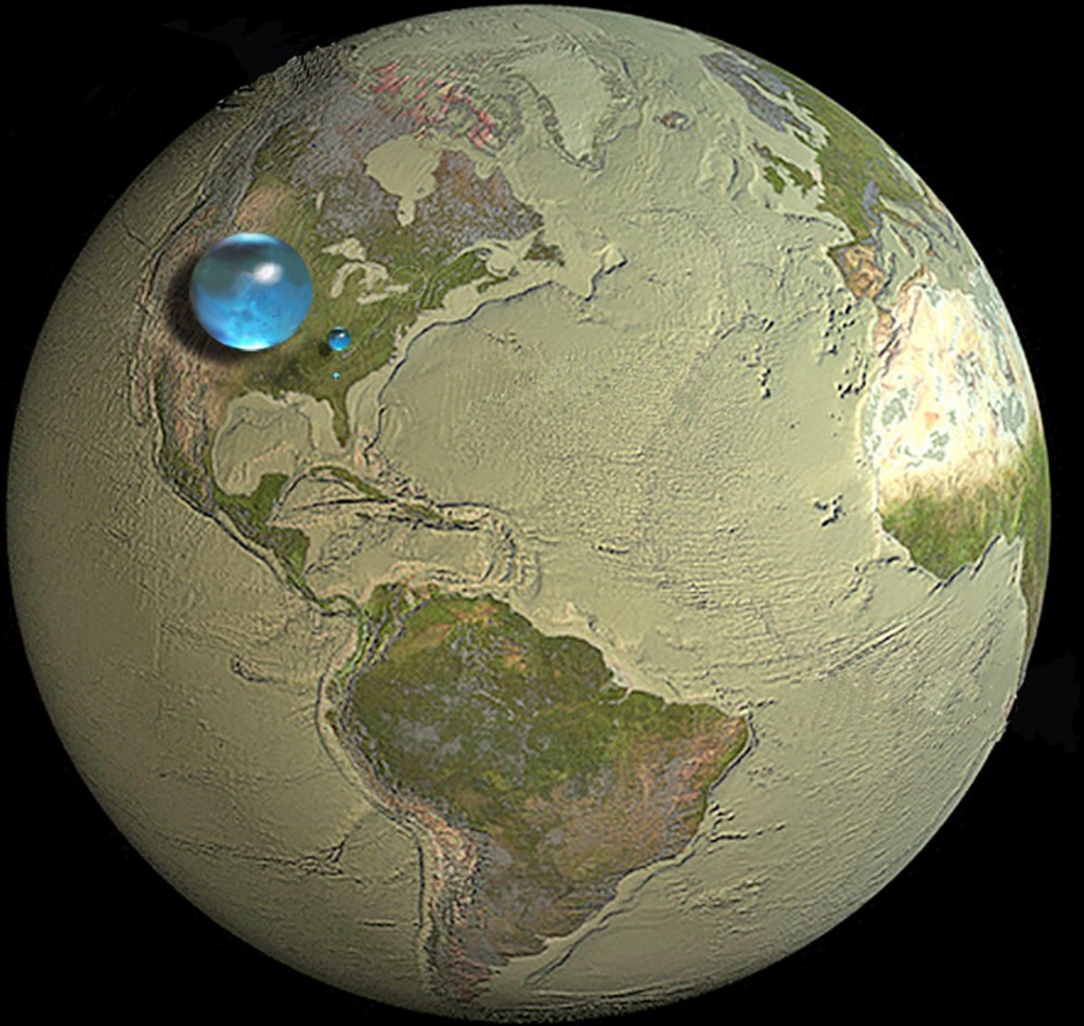
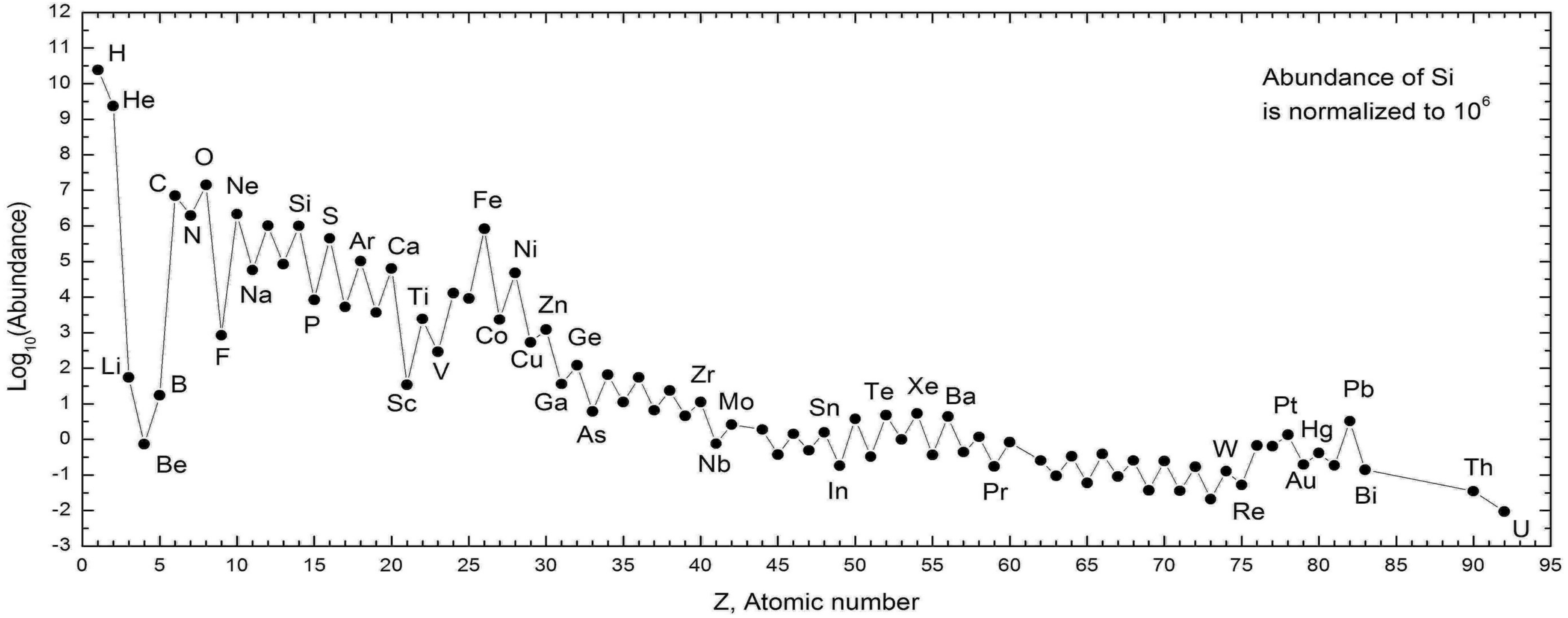
from NASA




SETI

Is it its composition?



The cosmic abundances of the elements were estimated by Goldschmidt (1937) from a study of terrestrial and meteoritic abundances and a comparison of these with Russell's data on the sun.

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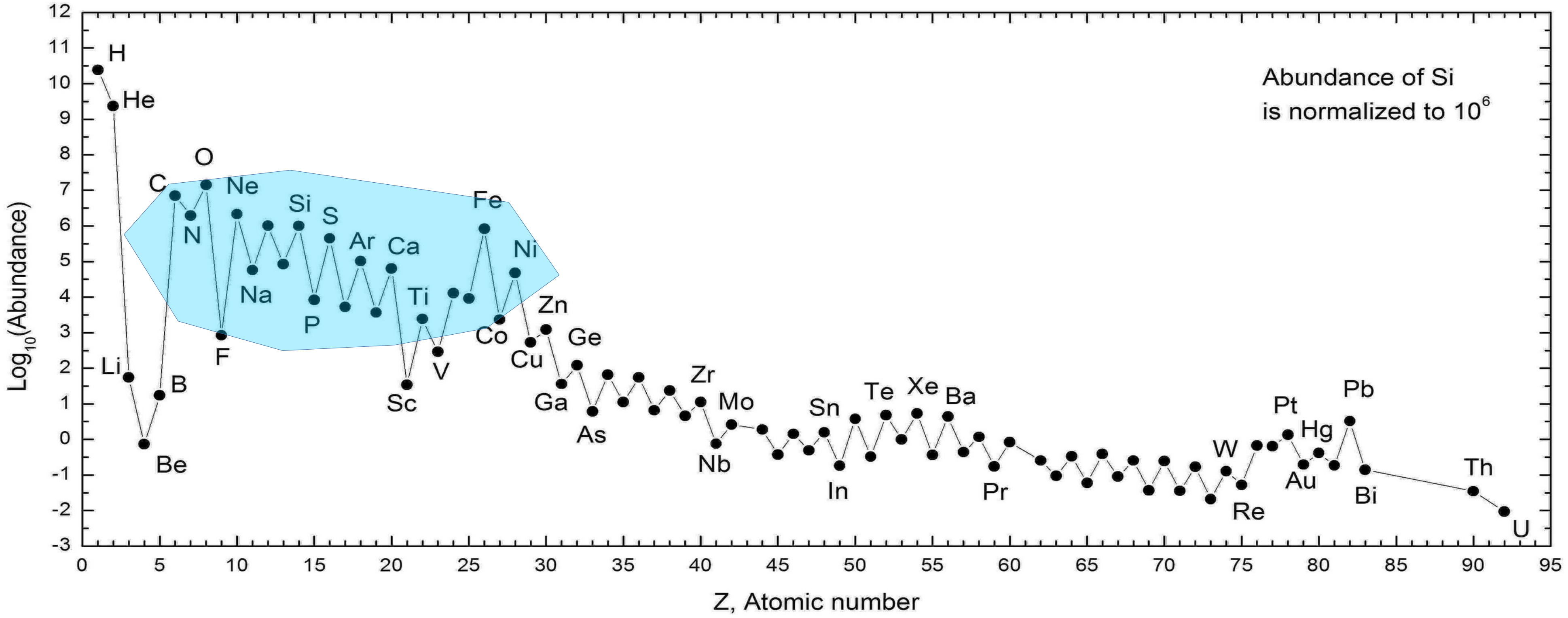

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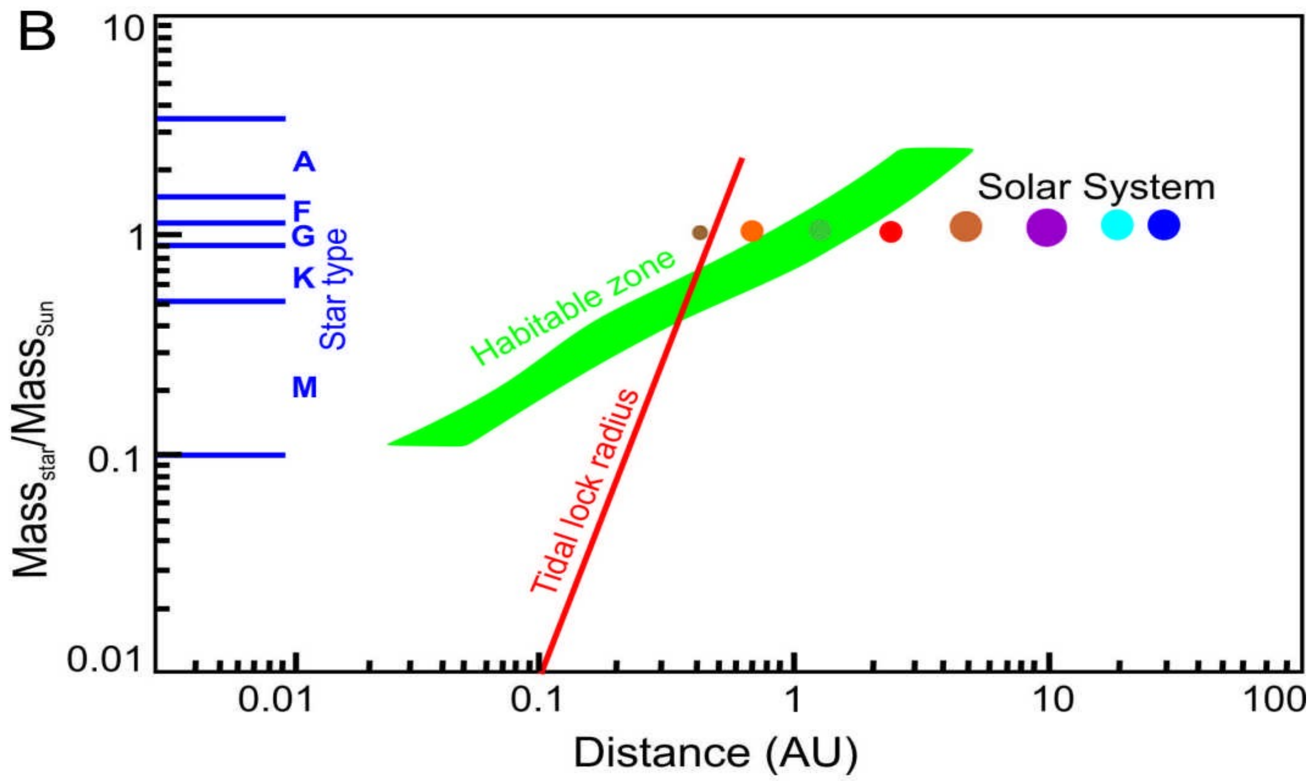
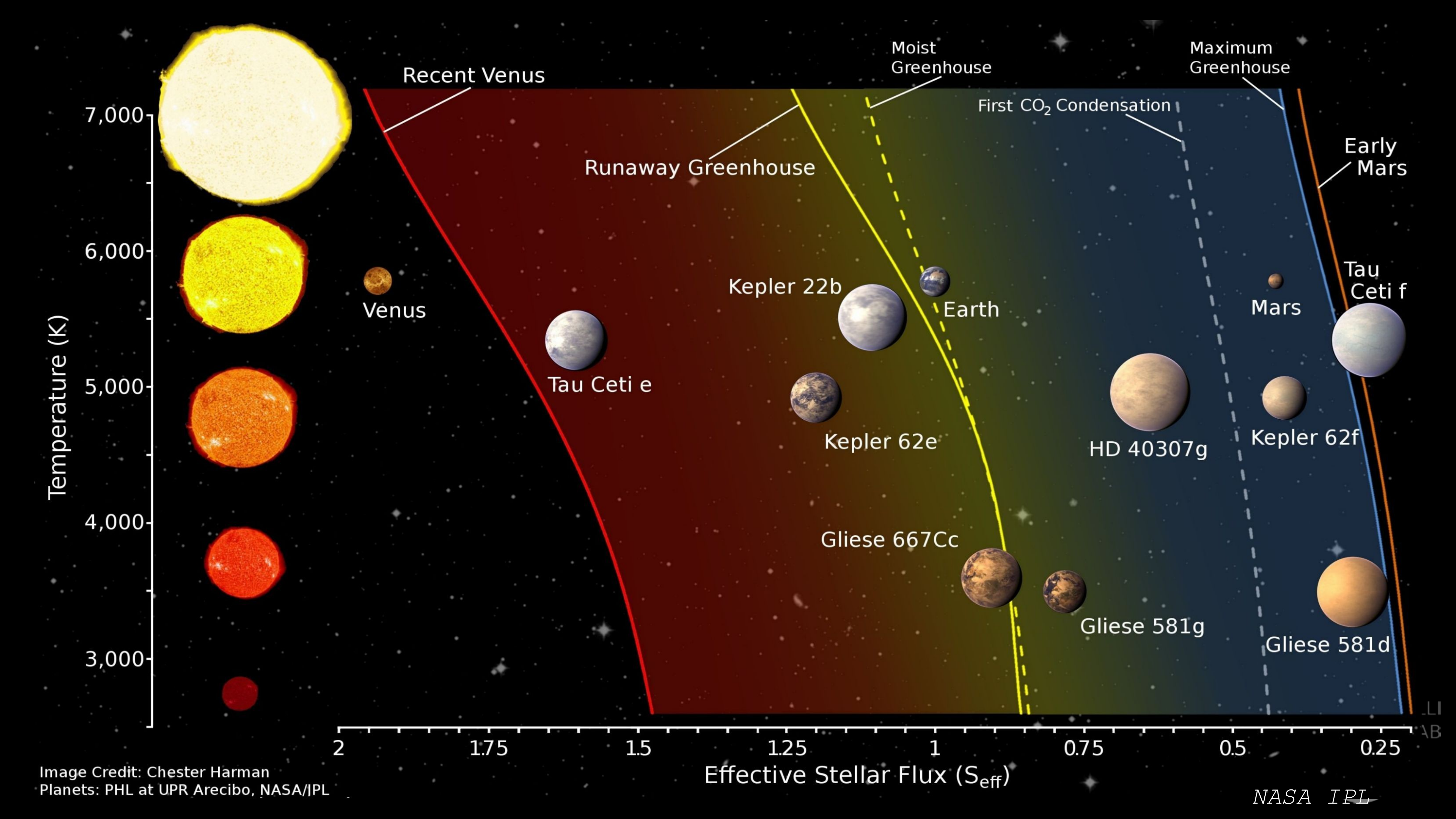
Is it its position?

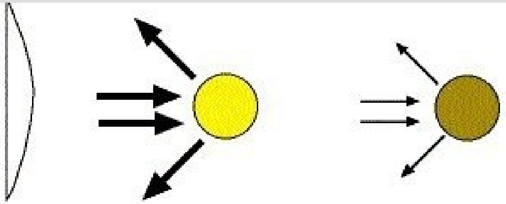


***Encyclopedia Britannica:** Habitable zone, the orbital region around a star in which an Earth-like planet can possess liquid water on its surface and possibly support life. Liquid water is essential to all life on Earth, and so the definition of a habitable zone is based on the hypothesis that extraterrestrial life would share this requirement*

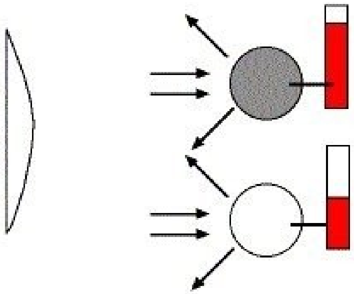


Recent Venus
Runaway Greenhouse
Moist Greenhouse
First CO_2 Condensation
Maximum Greenhouse
Early Mars
7,000
6,000
5,000
4,000
3,000
Temperature (K)
Venus
Tau Ceti e
Kepler 22b
Earth
Kepler 62e
Gliese 667Cc
Gliese 581g
HD 40307g
Mars
Kepler 62f
Tau Ceti f
Gliese 581d
2
1.75
1.5
1.25
1
0.75
0.5
0.25
Effective Stellar Flux (S_{eff})
Image Credit: Chester Harman
Planets: PHL at UPR Arecibo, NASA/JPL
NASA JPL

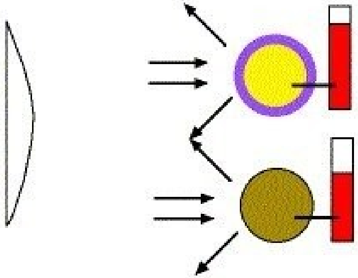
Is it a <u>combination of both</u>?



Distance from the Sun: closer => hotter

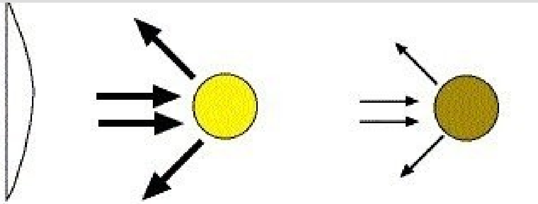


Surface reflectivity (albedo): greater reflectivity (albedo closer to 1) => cooler



Planet's atmosphere (greenhouse effect): more greenhouse => hotter

Is it a combination of both?



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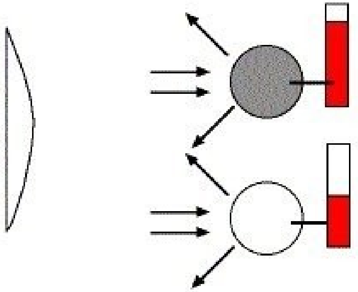

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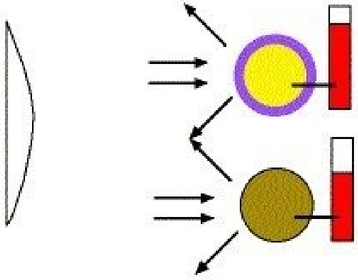

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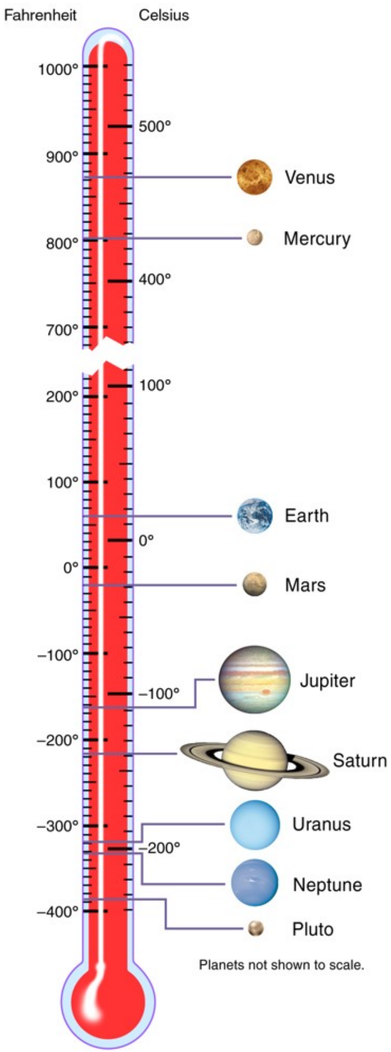

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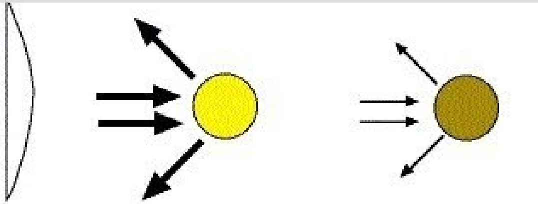

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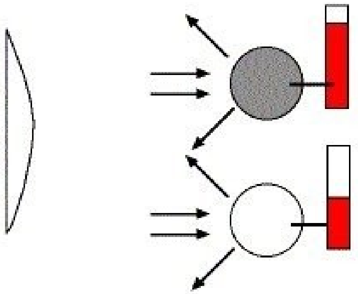

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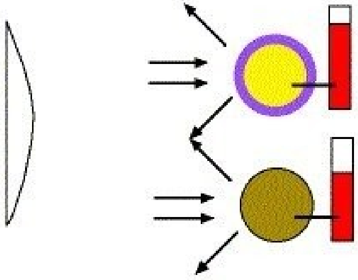

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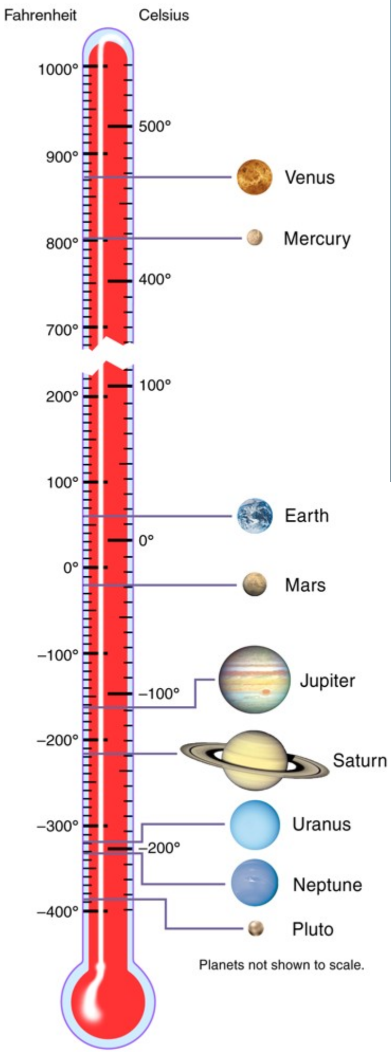

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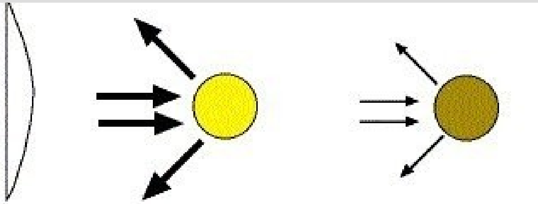

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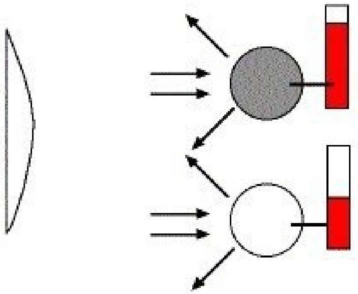

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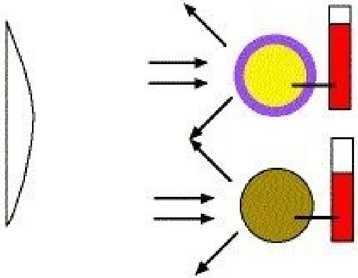

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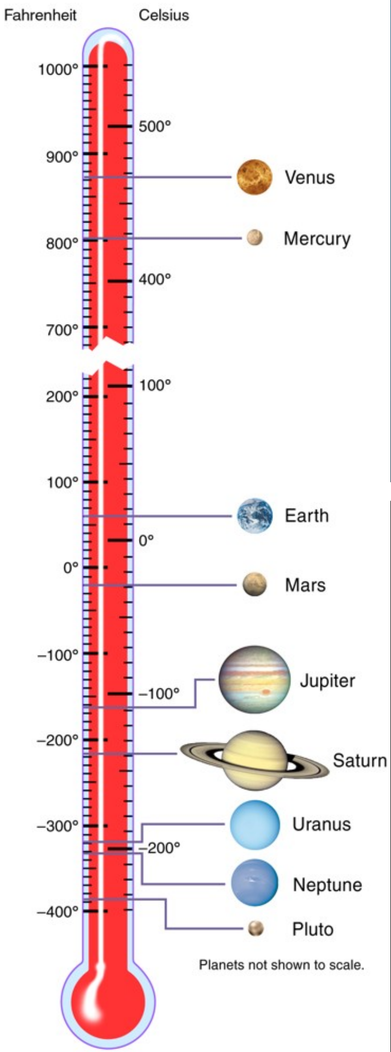
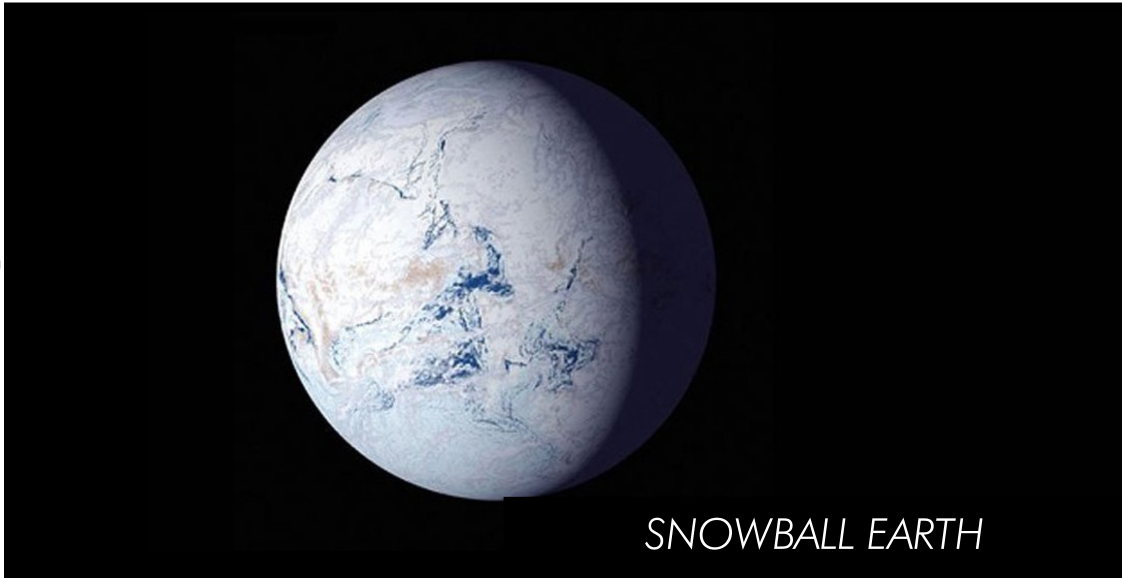
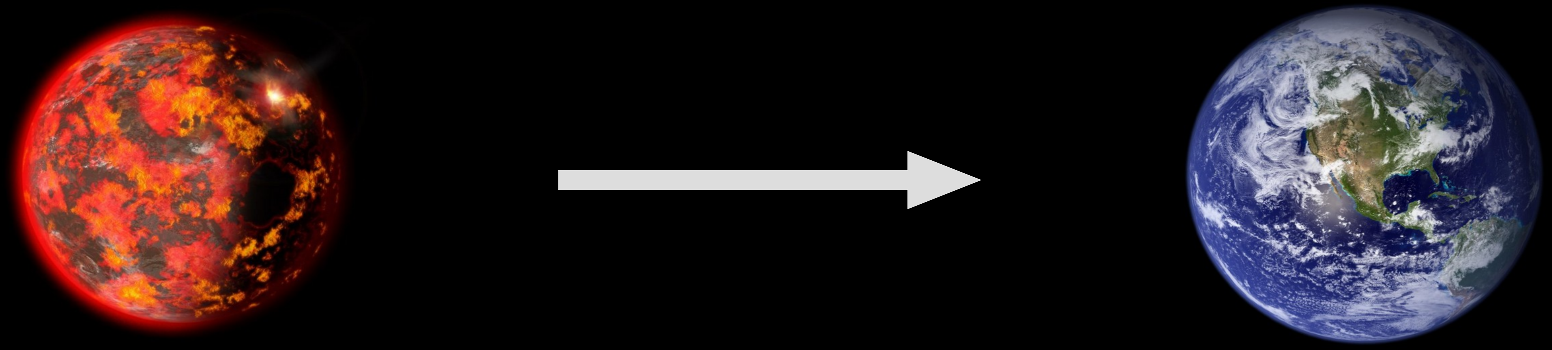
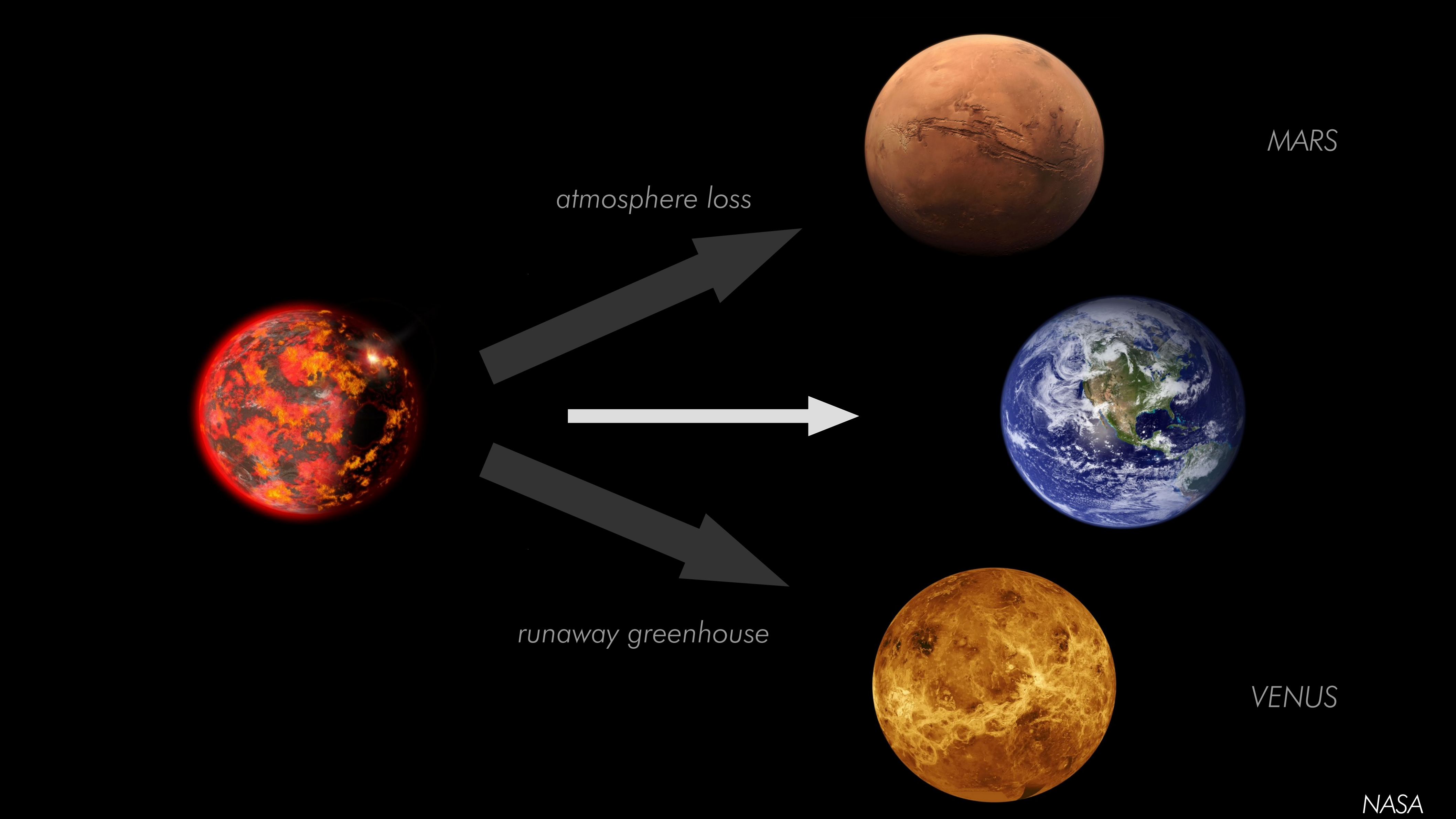






NASA


atmosphere loss
runaway greenhouse
MARS
VENUS
NASA

Could it be Life itself to make our planet unique?

Could it be Life itself to make our planet unique?

What is the job, after all, that required Life emergence?

Available online at www.sciencedirect.com

ScienceDirect

Physics of Life Reviews 7 (2010) 424–460

PHYSICS of LIFE reviews

www.elsevier.com/locate/plrev

Review

Life, hierarchy, and the thermodynamic machinery of planet Earth

Axel Kleidon

Max-Planck-Institut für Biogeochemie, Hans-Knöll-Str. 10, 07745 Jena, Germany

"This perspective allows us to view life as being the means to transform many aspects of planet Earth to states even further away from thermodynamic equilibrium than is possible by purely abiotic means. In this perspective pockets of low-entropy life emerge from the overall trend of the Earth system to increase the entropy of the universe at the fastest possible rate."

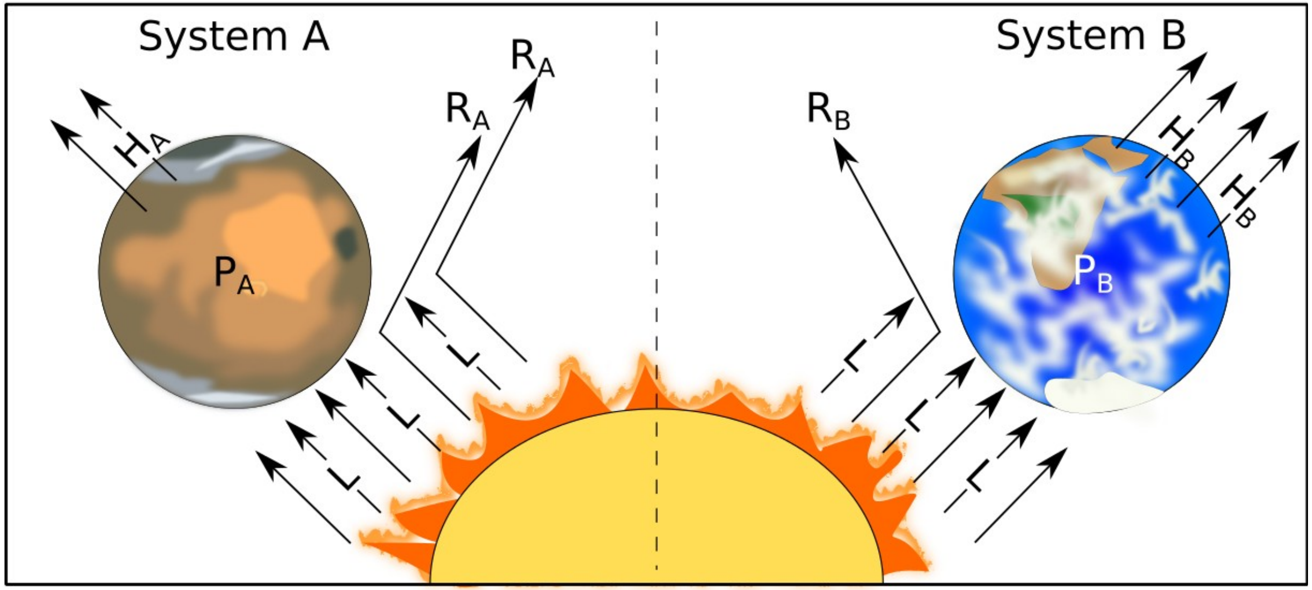
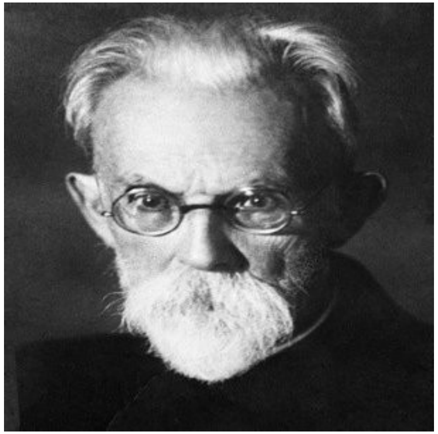
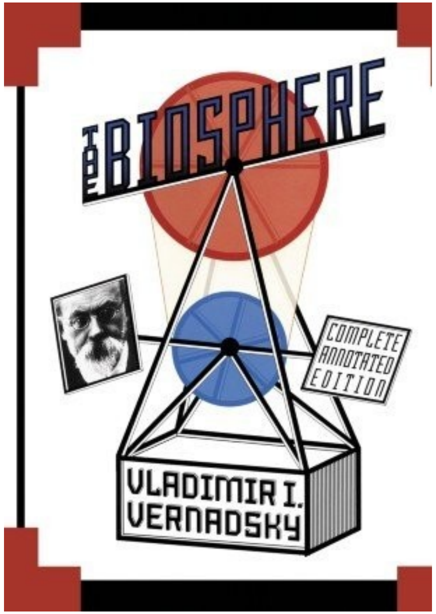
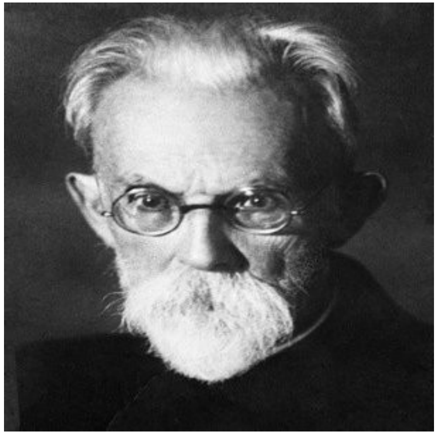


Figure representing the relationship between life and the second law of thermodynamic on a planetary scale. Planet A represent a dead planet (devoid of life). Planet B represent a situation identical to planet A but with the presence of life (in particular photosynthesis). Both planets are caracterized by the presence of an atmosphere and active tectonic. The presence of life changes entrophy states such as that total entropy of System B is greater than System A ($S_B>S_A$), while planetary local entropy of Planet B is lower than Planet A ($PS_B<PS_A$). Abbreviations: L - Light from the sun reachine the planets; P - Energy absorbed by the planet; R - Reflected light; H - Heat released to outer space. The presence of life (lower local entrophy) is permitted because $P_B > P_A$, $R_A > R_B$ and $H_B > H_A$.



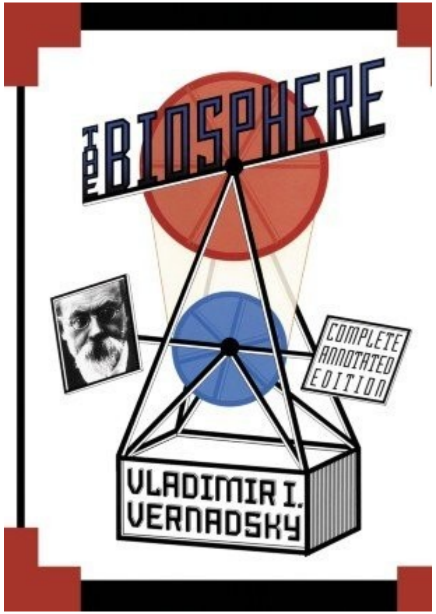
Vladimir Vernadskij, 1926

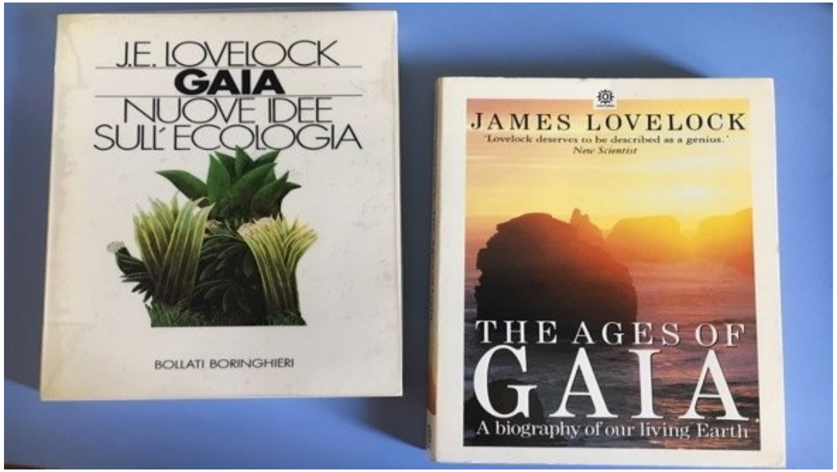




Vladimir Vernadskij, 1926

Lynn Margulis and James Lovelock, 1979





"Life emerges as a planetary response"

Shock and Boyd, 2015

Lynn Margulis and James Lovelock, 1979

RESEARCH ARTICLE | DECEMBER 01, 2015

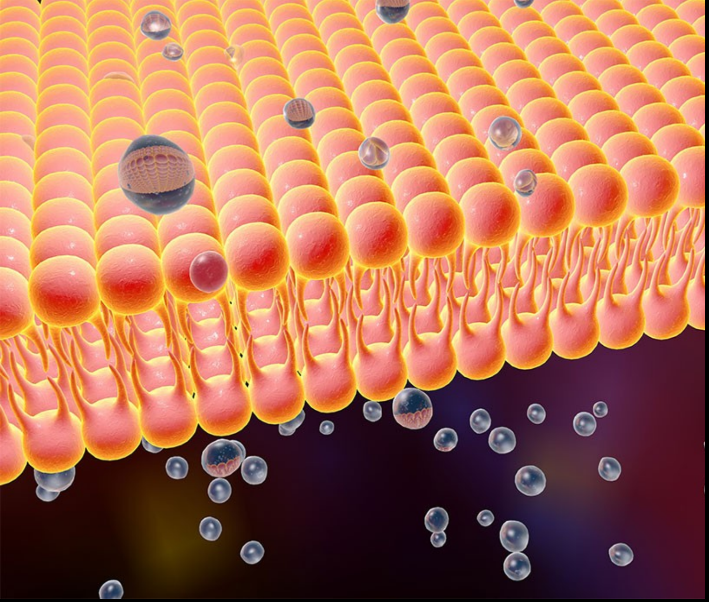
Principles of Geobiochemistry

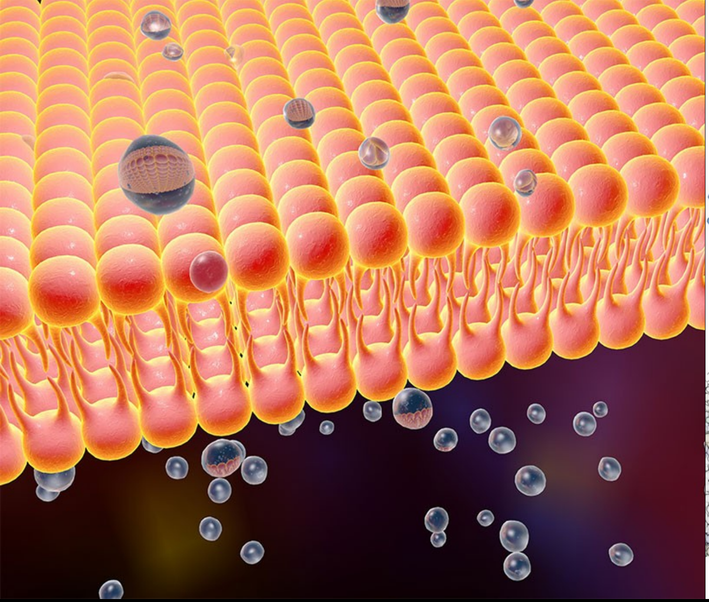
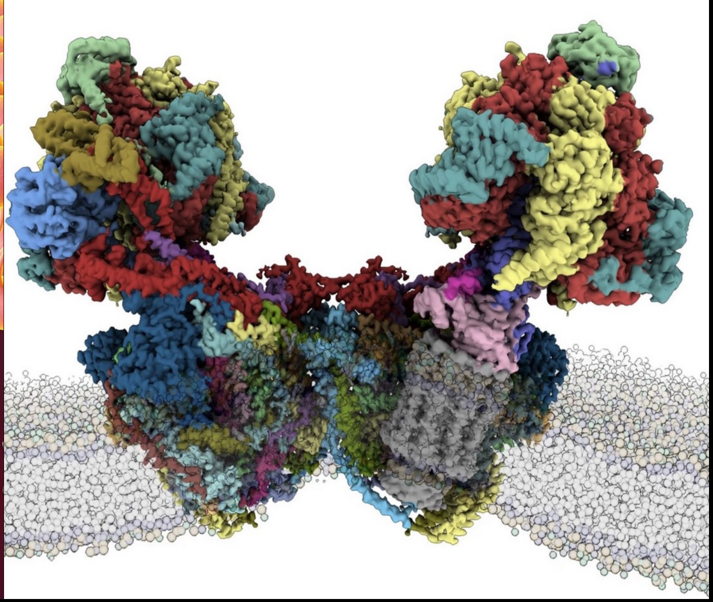
Everett L. Shock; Eric S. Boyd

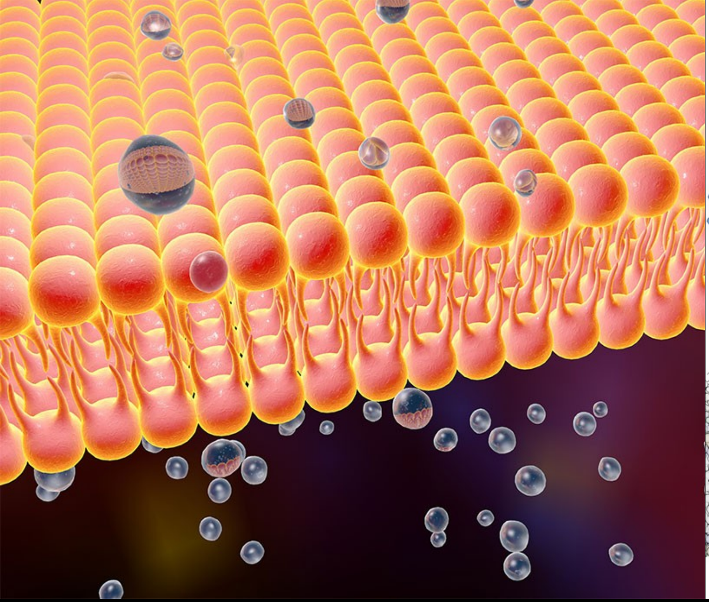
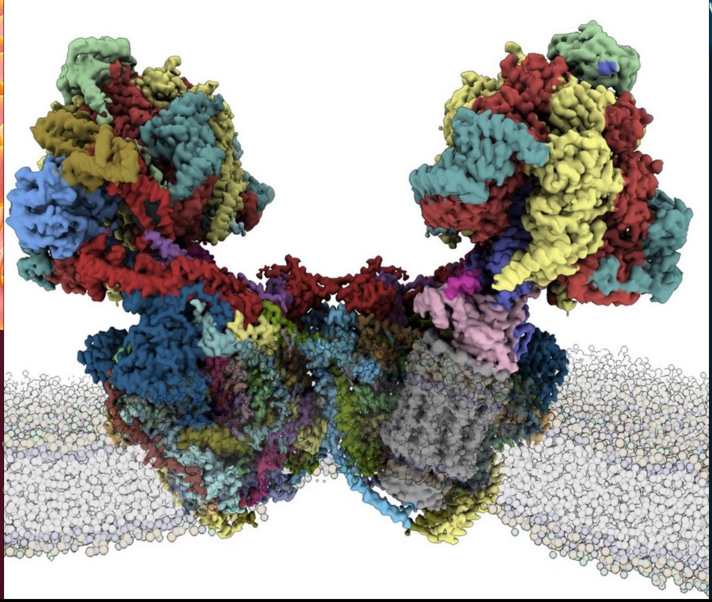
Elements (2015) 11 (6): 395–401.

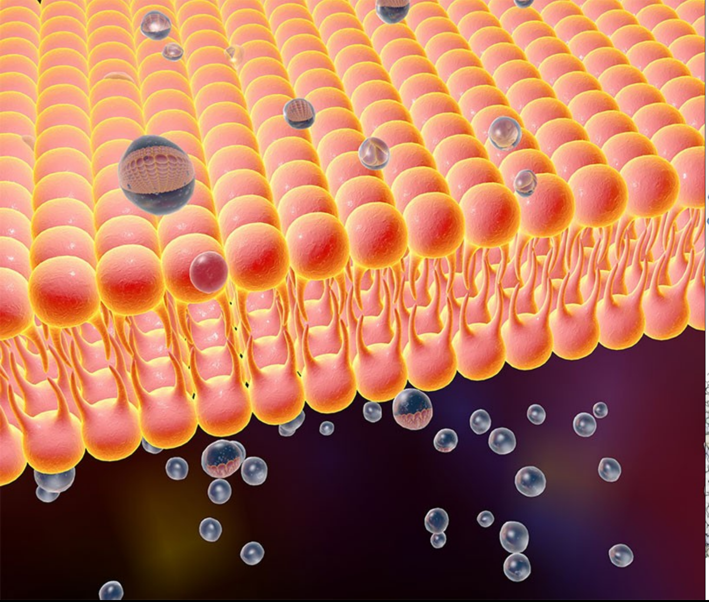
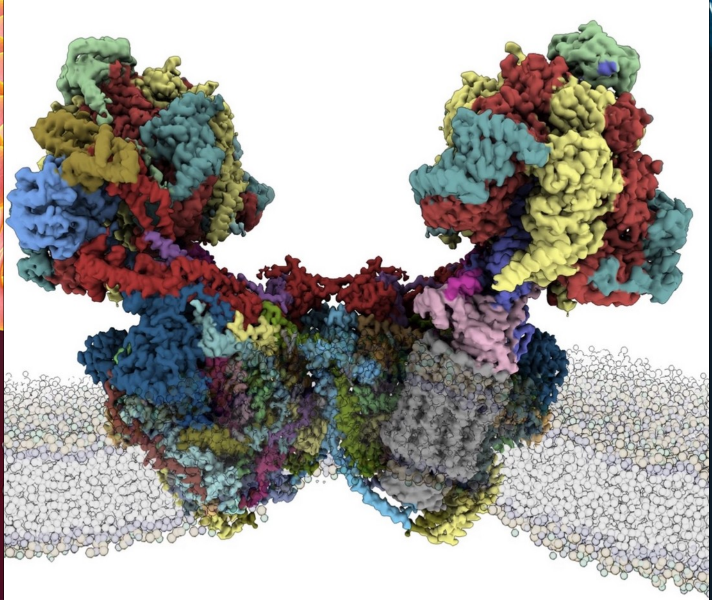
https://doi.org/10.2113/gselements.11.6.395 Article history

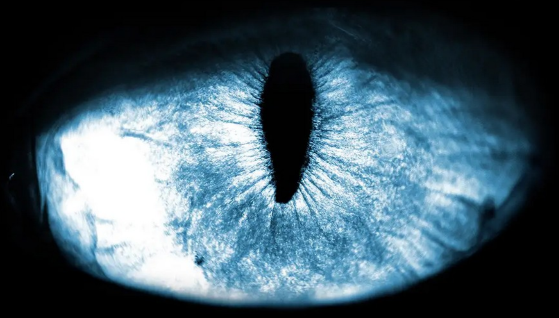
What is Life greatest invention?

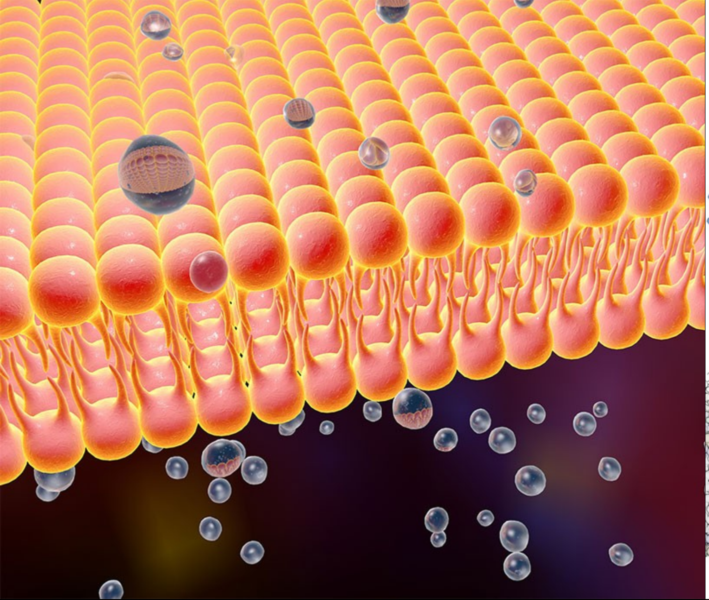
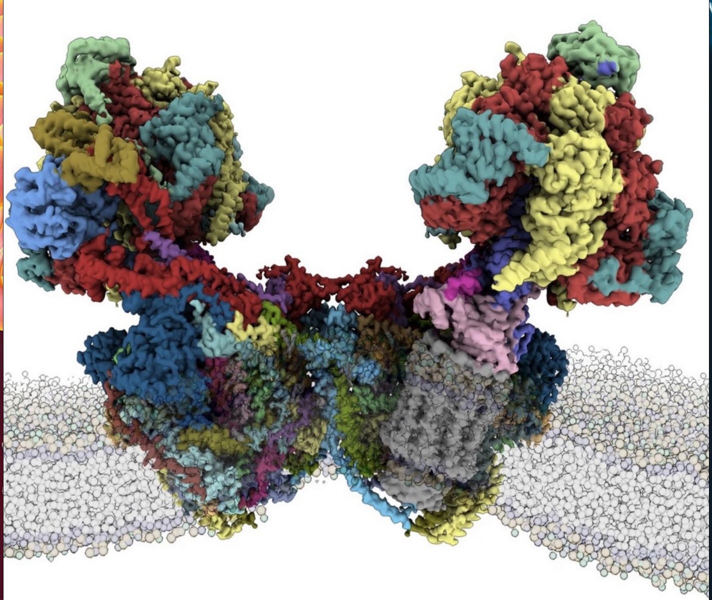


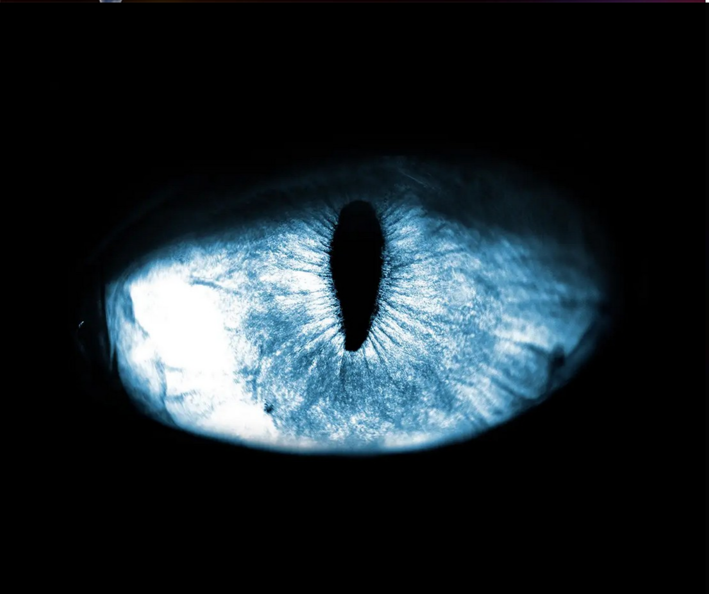



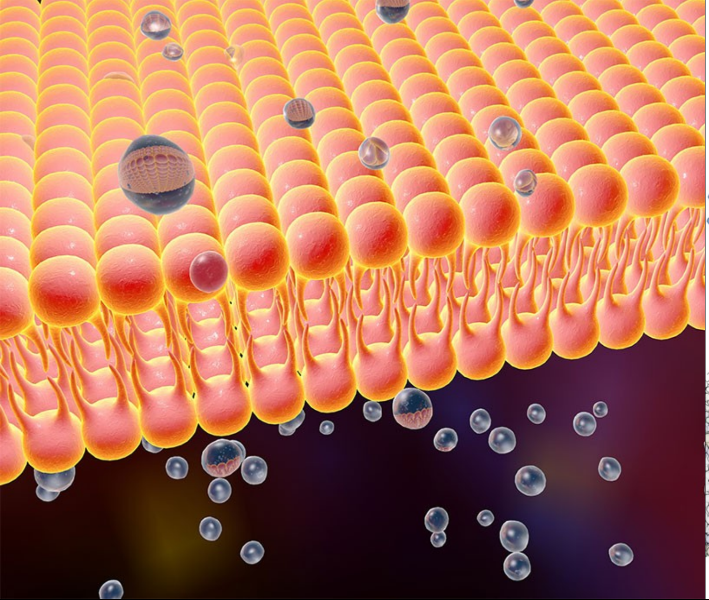
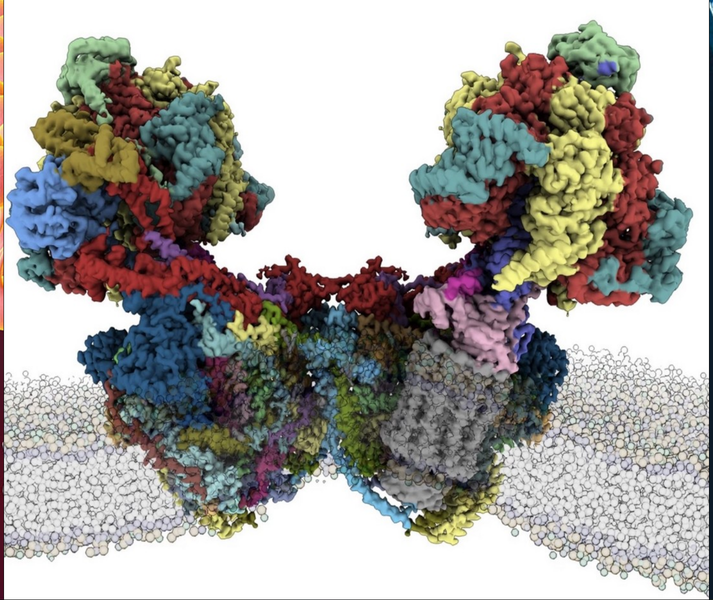



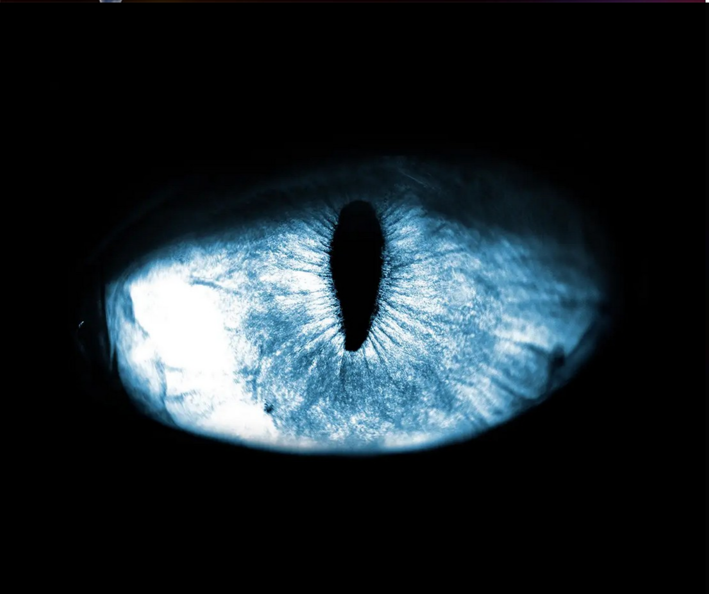






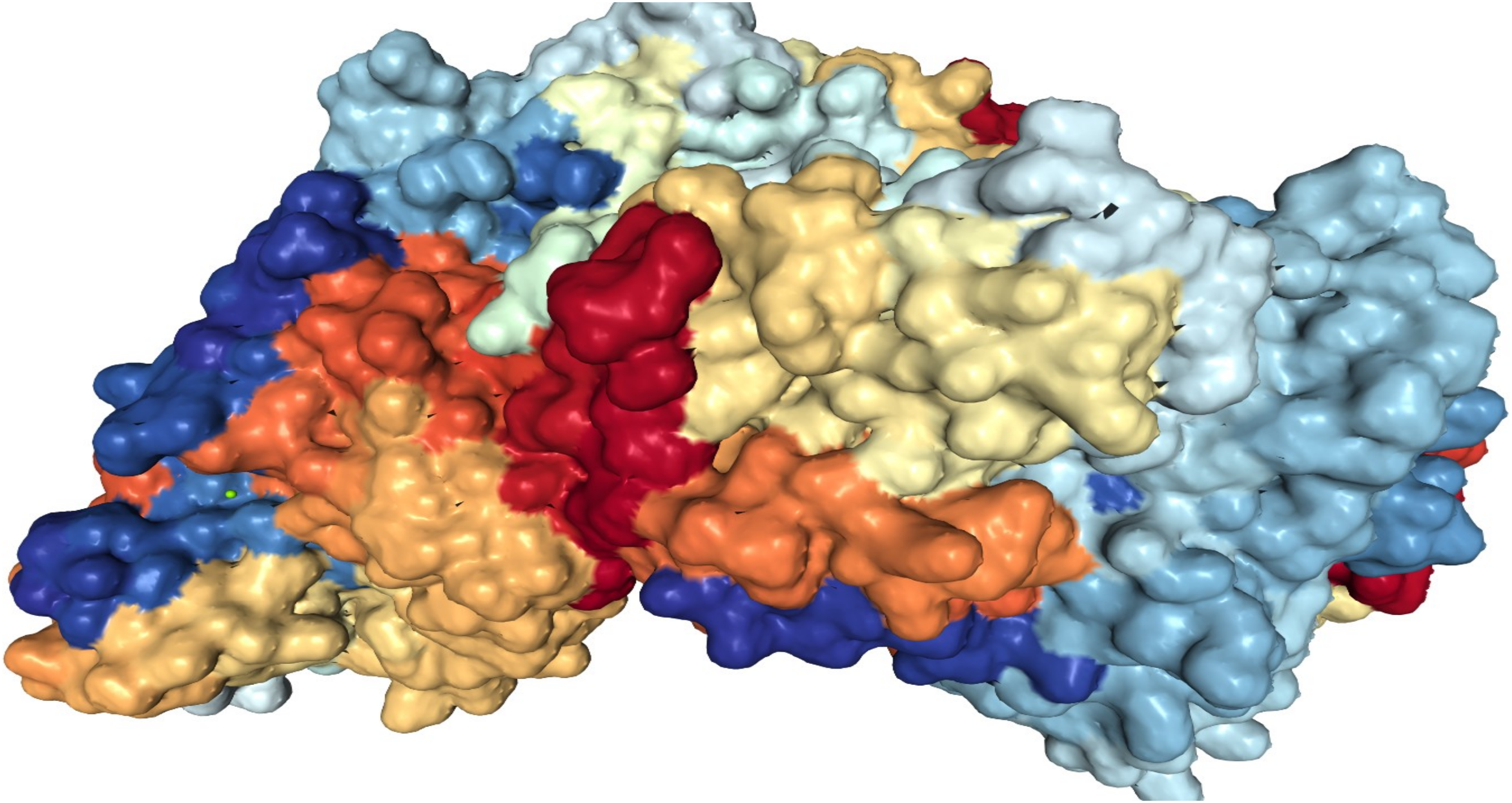



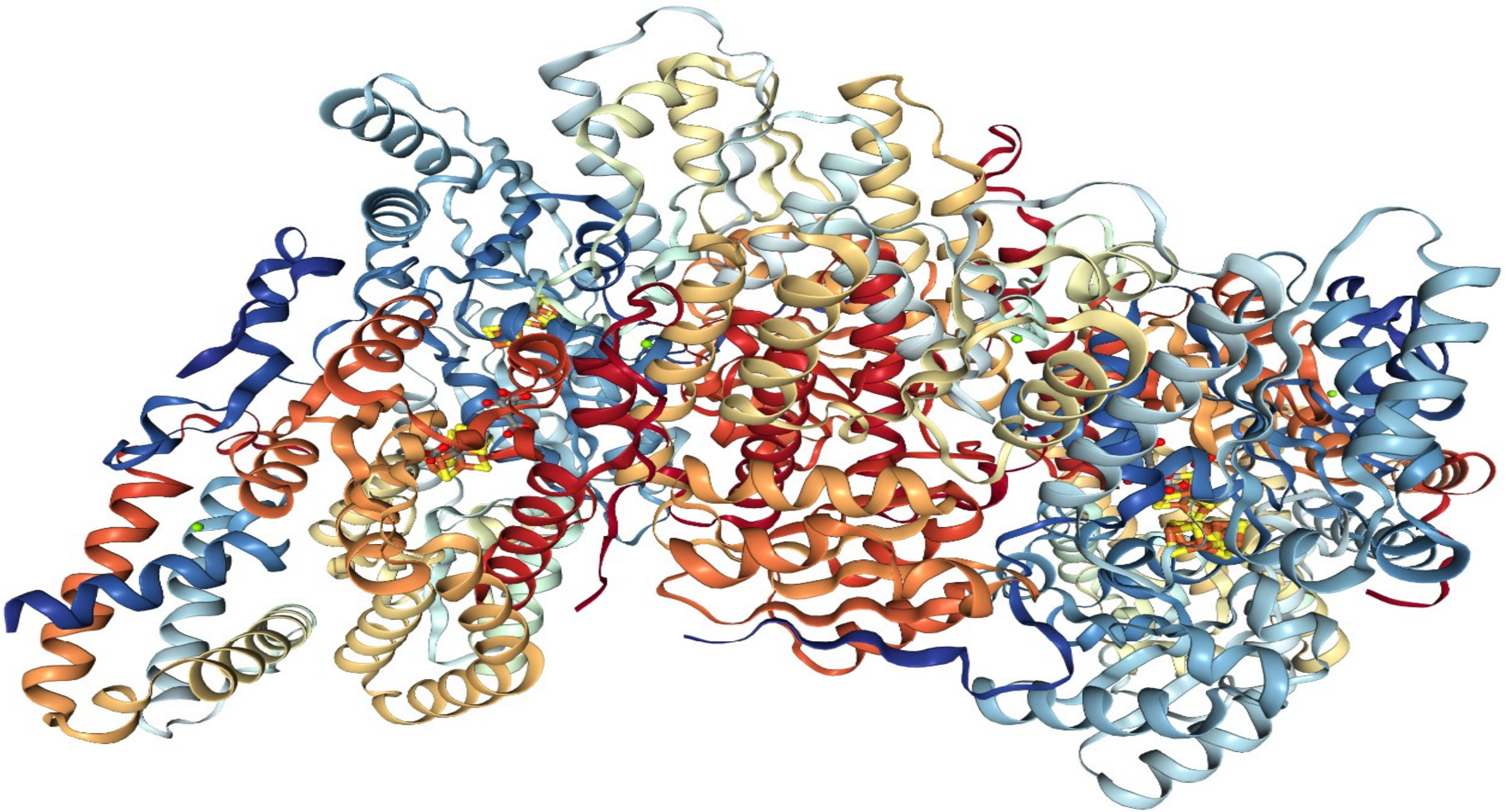




*Life is **electric**. Literally.*





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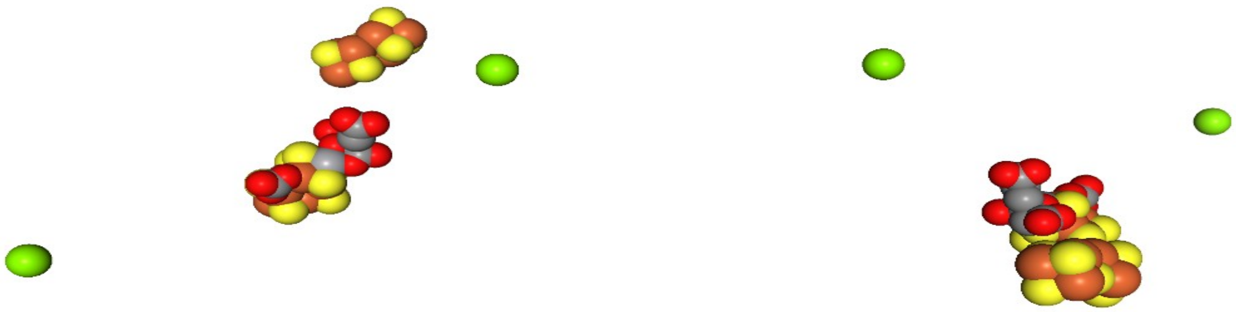
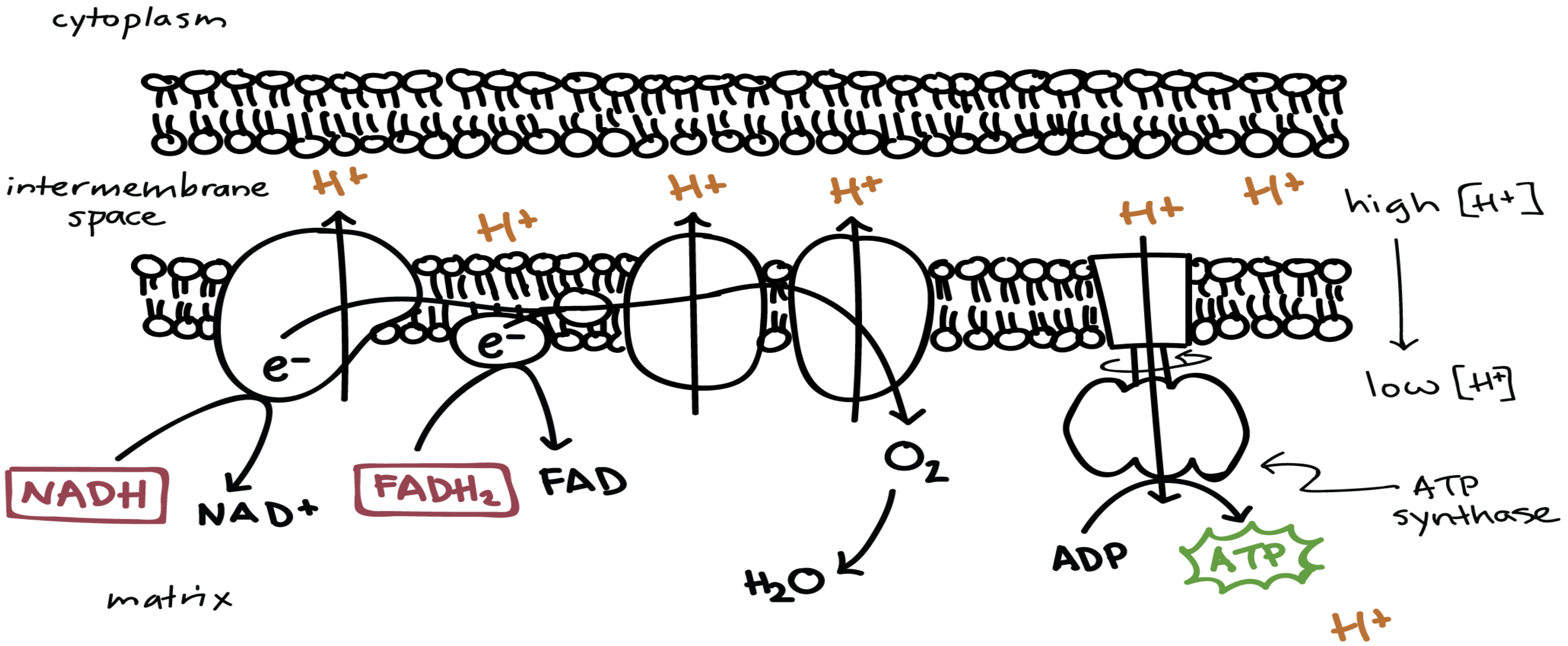
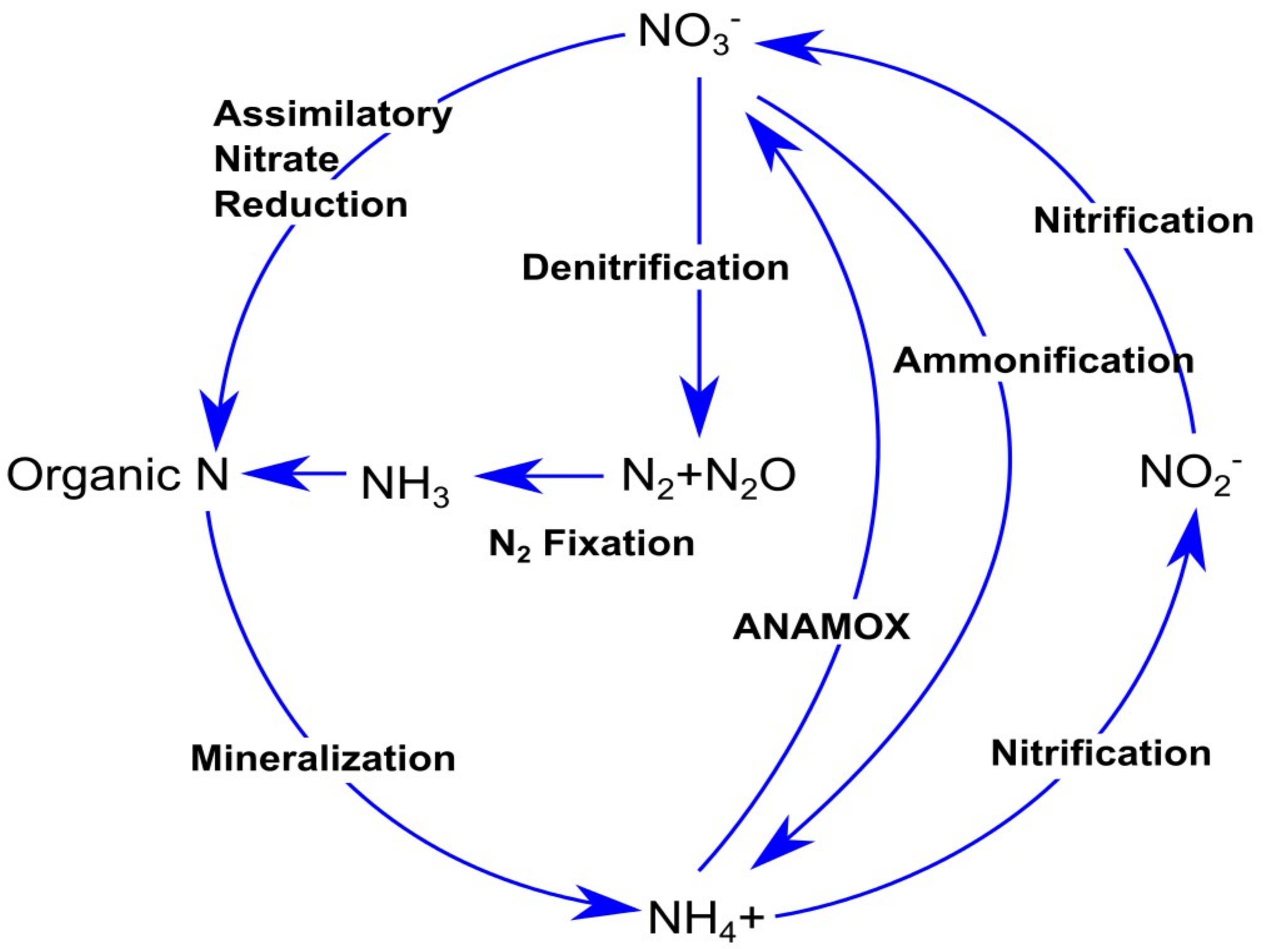
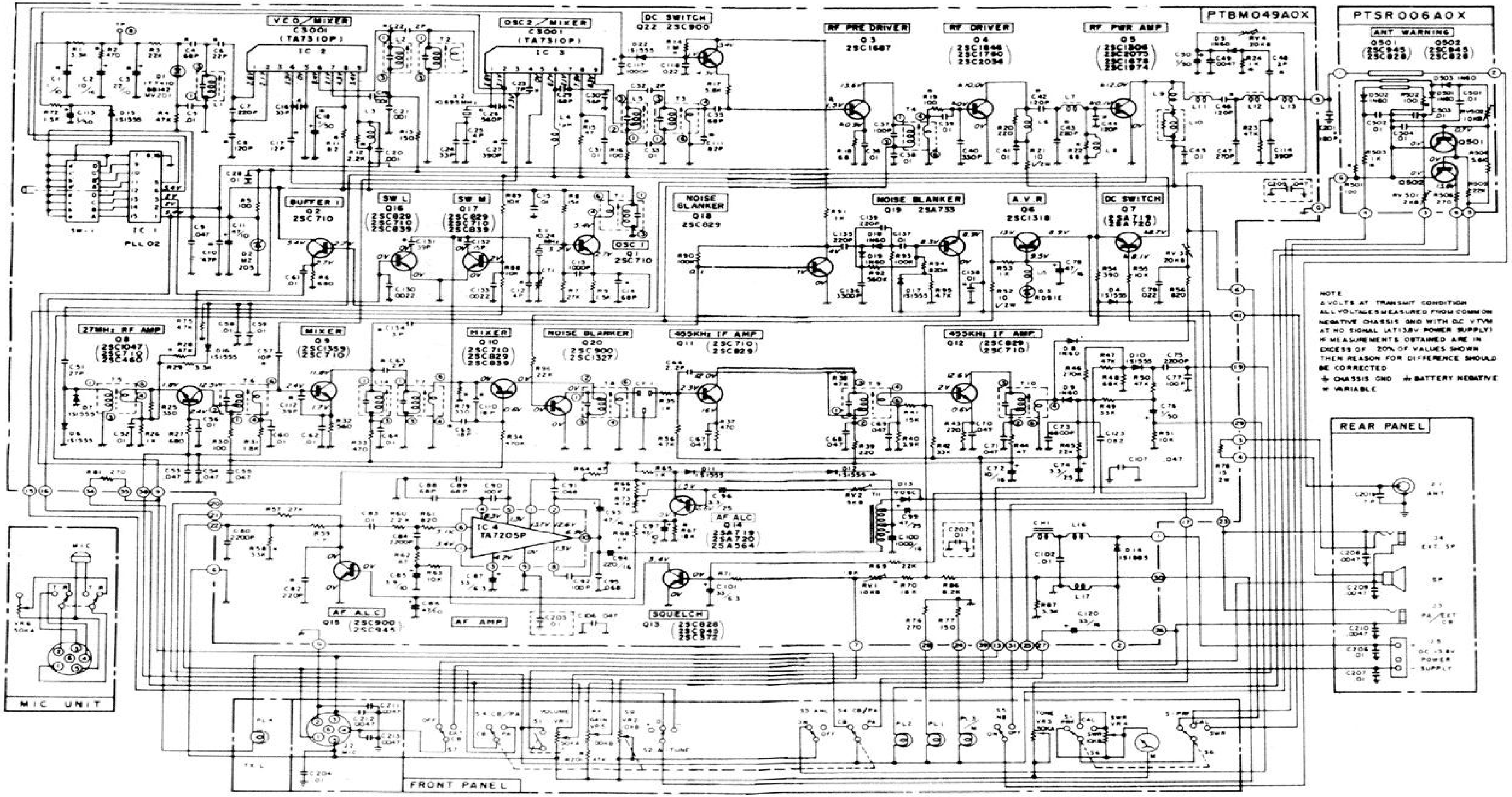


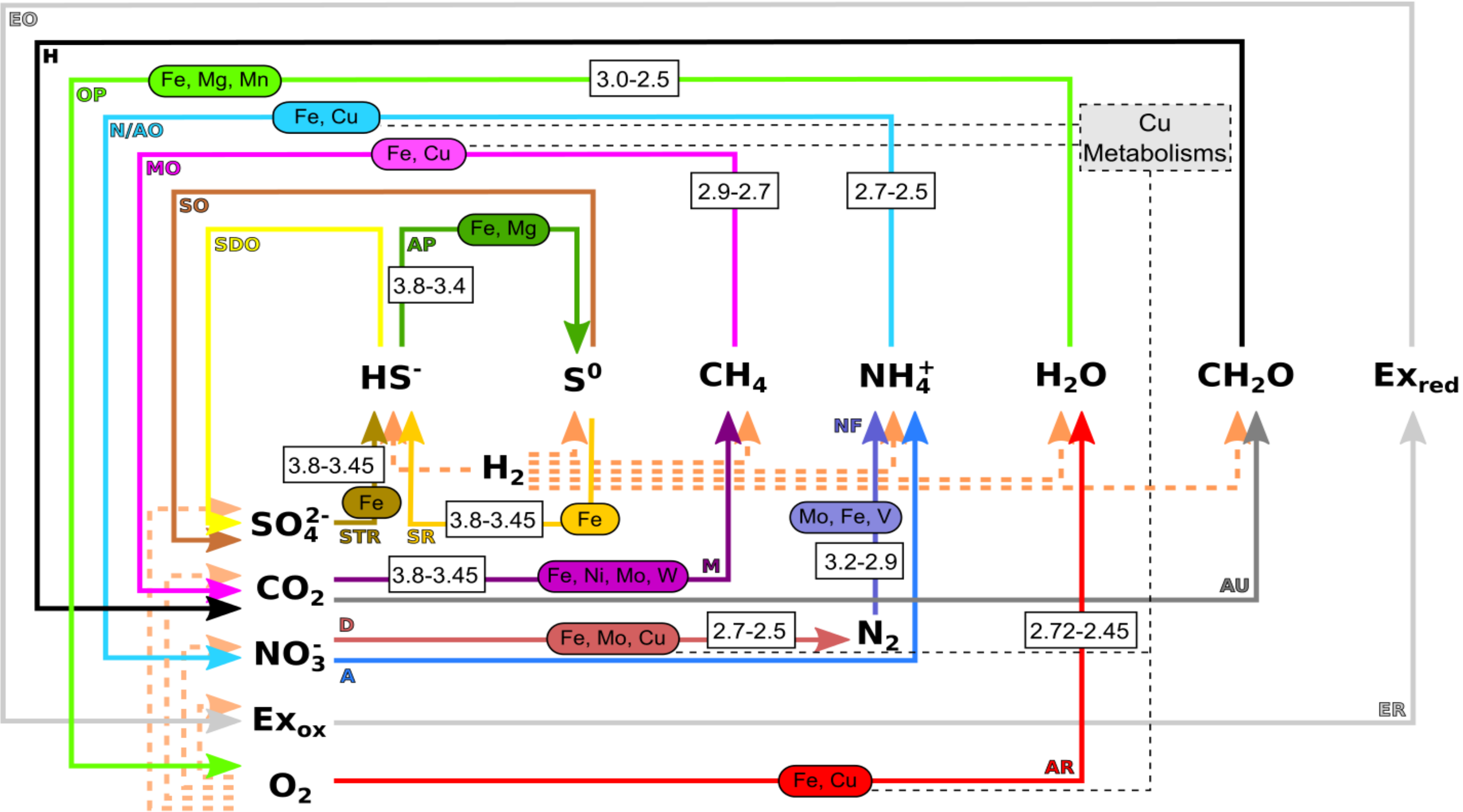
Life greatest invention: **scalar to vector**




NO_3^-
Assimilatory
Nitrate
Reduction
Denitrification
Nitrification
Ammonification
Organic N
NH_3
N_2+N_2O
NO_2^-
N_2 Fixation
ANAMOX
Mineralization
Nitrification
NH_4+



PTBM049A0X
PTSR006A0X
VCO/MIXER
C3001 (TA7310P)
IC 2
OSC2/MIXER
C3001 (TA7310P)
IC 3
DC SWITCH
Q22 2SC900
RF PRE DRIVER
Q3 2SC1687
RF DRIVER
Q4 2SC1846 2SC1760 2SC2036
RF PWR AMP
Q5
ANT WARNING
Q501 2SC945 2SC828
Q502 2SC945 2SC828
SW-1
IC 1
PLL02
BUFFER I
Q2 2SC710
SW L
Q16 2SC829 2SC710 2SC839
SW M
Q17 2SC829 2SC710 2SC839
OSC I
Q1 2SC710
NOISE BLANKER
Q18 2SC829
NOISE BLANKER
Q19 2SA733
A.V.R
Q6 2SC1318
DC SWITCH
Q7 2SA719 2SA720
27MHz RF AMP
Q8 2SC1047 2SC710 2SC460
MIXER
Q9 2SC1359 2SC710
MIXER
Q10 2SC710 2SC829 2SC839
NOISE BLANKER
Q20 2SC900 2SC1327
455KHz IF AMP
Q11 2SC710 2SC829
455KHz IF AMP
Q12 2SC829 2SC710
IC 4
TA7205P
AF ALC
Q14 2SA719 2SA720 2SA564
AF ALC
Q15 2SC900 2SC945
AF AMP
SQUELCH
Q13 2SC828 2SC945 2SC372
MIC
MIC UNIT
FRONT PANEL
REAR PANEL
ANT
EXT SP
SP
PA/EXT CB
DC 13.8V POWER SUPPLY
NOTE
△ VOLTS AT TRANSMIT CONDITION
ALL VOLTAGES MEASURED FROM COMMON NEGATIVE CHASSIS GND WITH DC VTVM AT NO SIGNAL (AT 13.8V POWER SUPPLY)
IF MEASUREMENTS OBTAINED ARE IN EXCESS OF 20% OF VALUES SHOWN THEN REASON FOR DIFFERENCE SHOULD BE CORRECTED
CHASSIS GND
BATTERY NEGATIVE
* VARIABLE

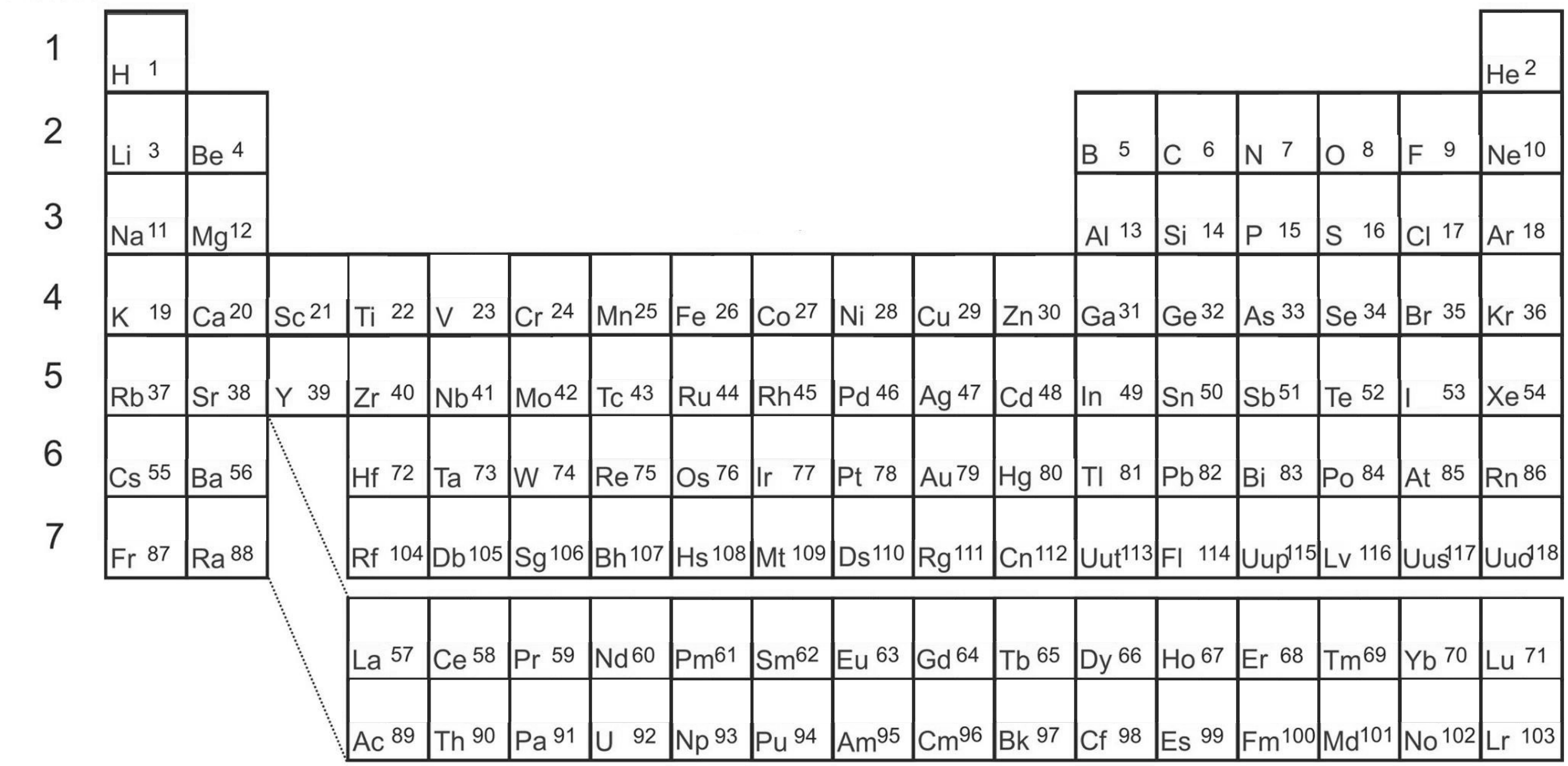


Moore et al 2017 Nature Geosciences

The periodic table as Life's playground

microbes interact with elements a lot

(more than you think)



Biological data from Wackett, L.P., Dodge, A.G., Ellis, L.B.M. (2004) *Applied and Environmental Microbiology* **70,** 647-655.

Cockell 2015

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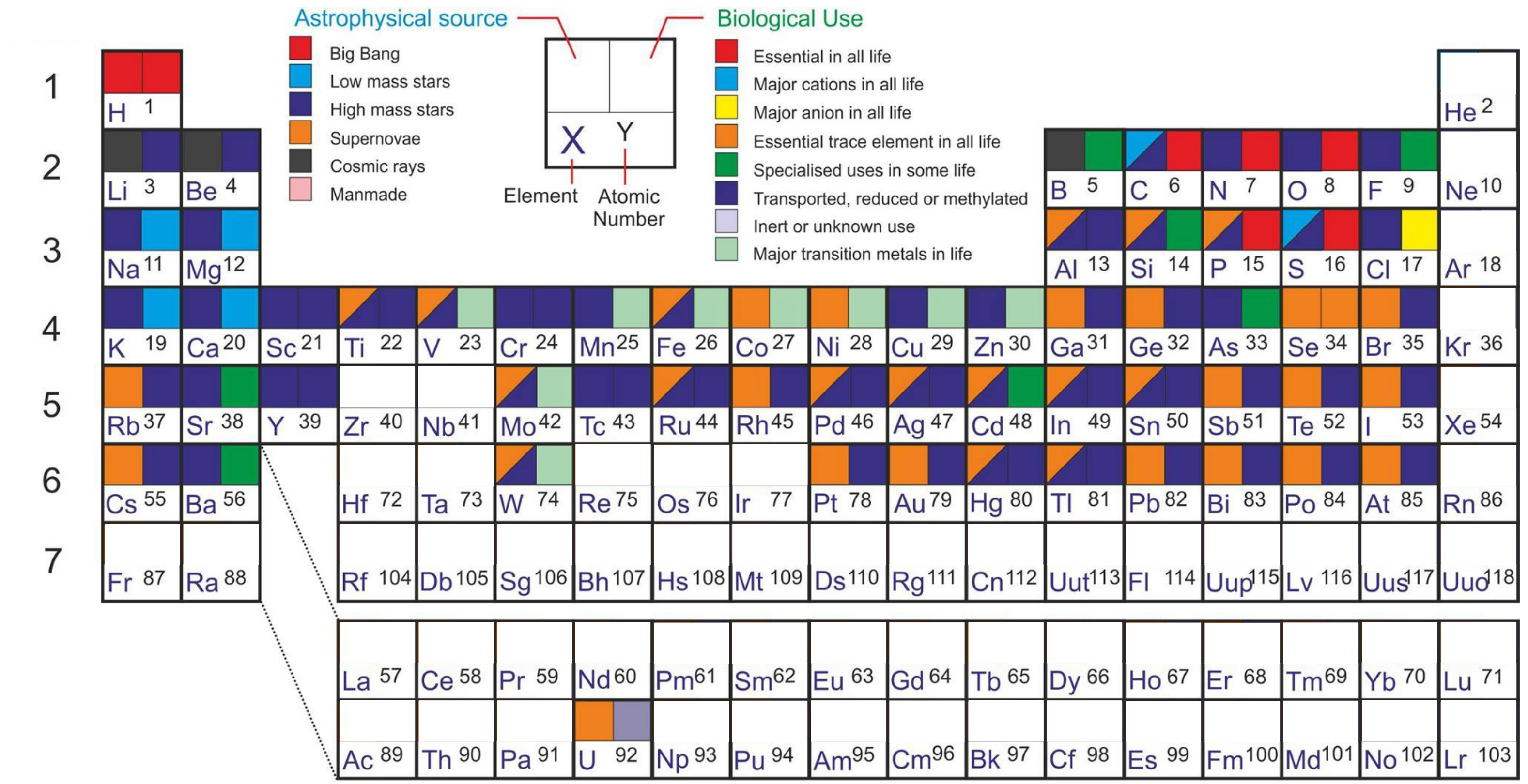
(more than you think)



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Cockell 2015

Chemical Geology
November 2020, Volume 555, Pages 119832 (13p.)
https://doi.org/10.1016/j.chemgeo.2020.119832
https://archimer.ifremer.fr/doc/00643/75496/

Microbial utilization of rare earth elements at cold seeps related to aerobic methane oxidation

Bayon Germain [1,*], Lemaitre Nolwenn [2], Barrat Jean-Alix [3], Wang Xudong [1,4], Feng Dong [4], Duperron Sebastien [5,6]

PLOS ONE

OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

A Catalytic Role of XoxF1 as La^{3+}-Dependent Methanol Dehydrogenase in *Methylobacterium extorquens* Strain AM1

Tomoyuki Nakagawa, Ryoji Mitsui, Akio Tani, Kentaro Sasa, Shinya Tashiro, Tomonori Iwama, Takashi Hayakawa, Keiichi Kawai

Published: November 27, 2012 • https://doi.org/10.1371/journal.pone.0050480

environmental microbiology

sfam society for applied microbiology

Research article

Rare earth metals are essential for methanotrophic life in volcanic mudpots

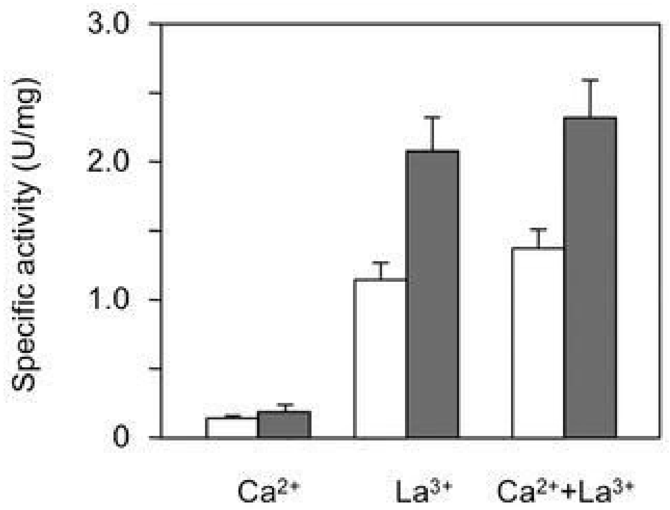
Arjan Pol, Thomas R. M. Barends, Andreas Dietl, Ahmad F. Khadem, Jelle Eygensteyn, Mike S. M. Jetten, Huub J. M. Op den Camp

First published: 18 August 2013 | https://doi.org/10.1111/1462-2920.12249 | Citations: 215

Chemical Geology
November 2020, Volume 555, Pages 119832 (13p.)
https://doi.org/10.1016/j.chemgeo.2020.119832
https://archimer.ifremer.fr/doc/00643/75496/

Microbial utilization of rare earth elements at cold seeps related to aerobic methane oxidation

Bayon Germain [1,*], Lemaitre Nolwenn [2], Barrat Jean-Alix [3], Wang Xudong [1,4], Feng Dong [4], Duperron Sebastien [5,6]



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RESEARCH ARTICLE

A Catalytic Role of XoxF1 as La^{3+}-Dependent Methanol Dehydrogenase in *Methylobacterium extorquens* Strain AM1

Tomoyuki Nakagawa, Ryoji Mitsui, Akio Tani, Kentaro Sasa, Shinya Tashiro, Tomonori Iwama, Takashi Hayakawa, Keiichi Kawai

Published: November 27, 2012 • https://doi.org/10.1371/journal.pone.0050480

environmental microbiology

sfam society for applied microbiology

Research article

Rare earth metals are essential for methanotrophic life in volcanic mudpots

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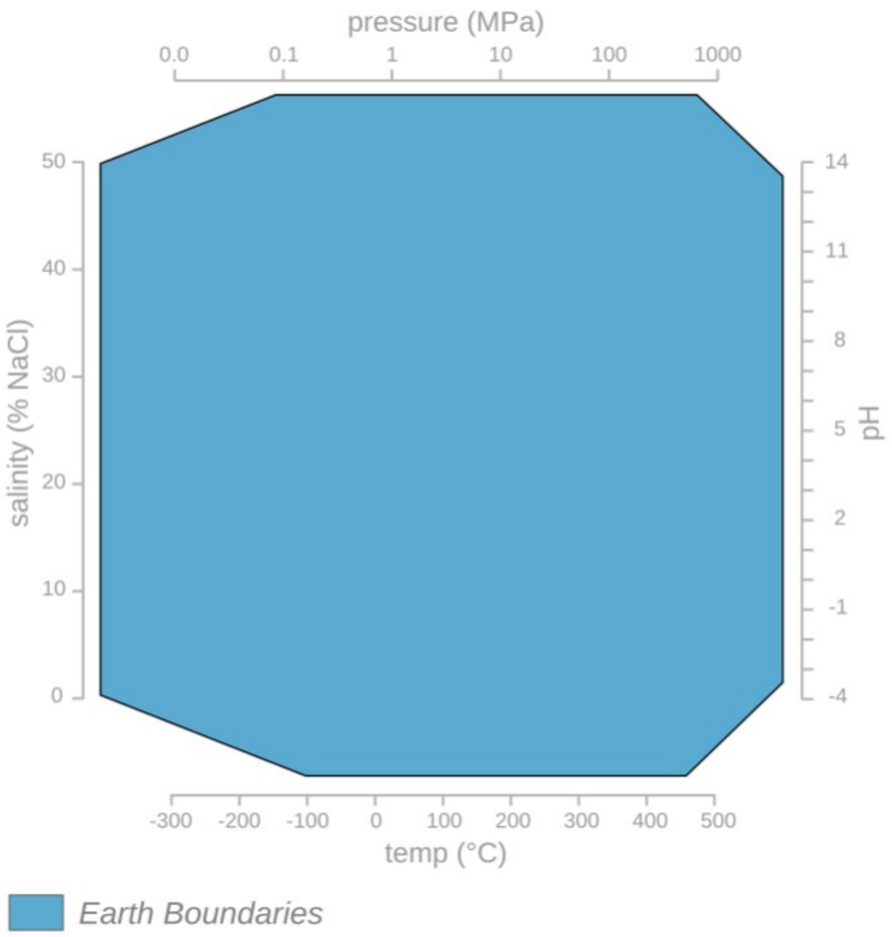
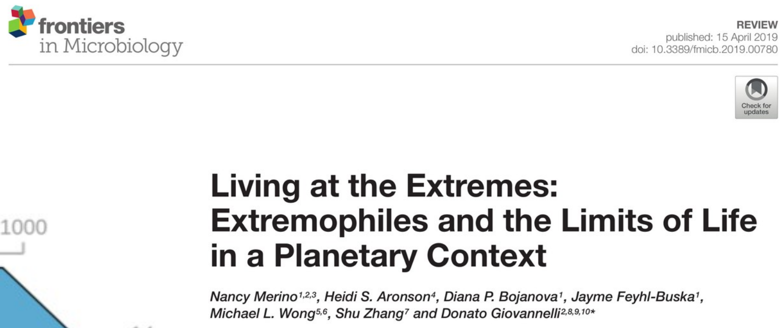
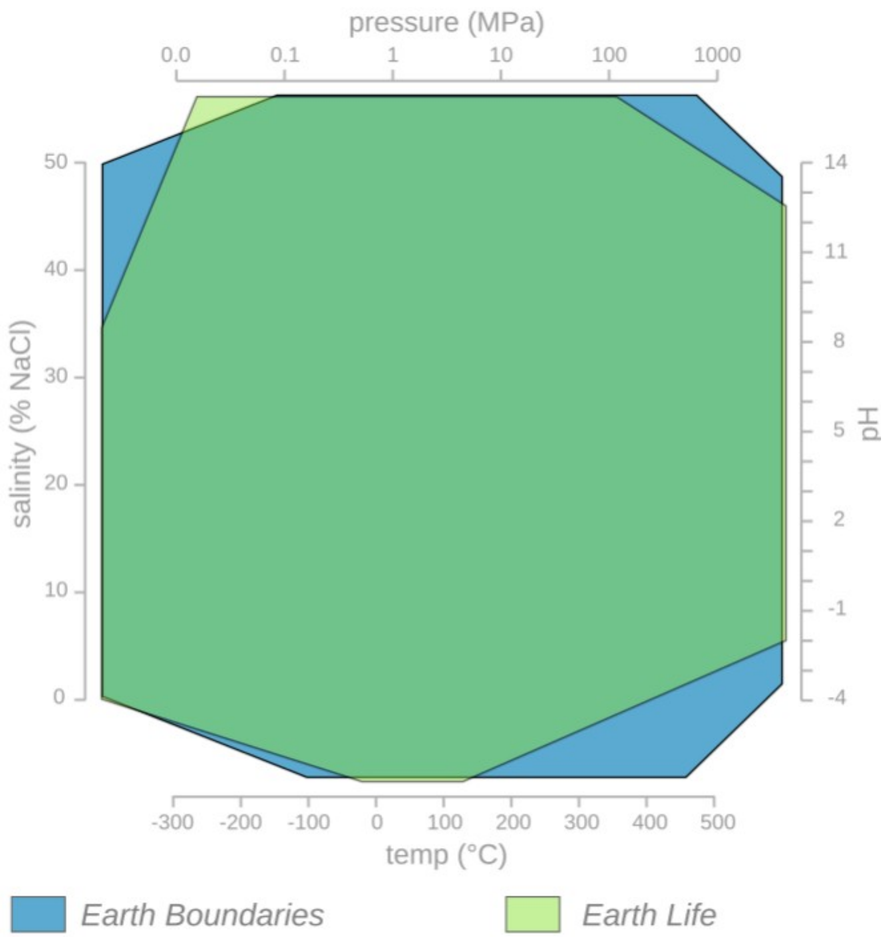
Life thrives in all available niches





Merino et al 2019 Front Microbiol

Life thrives in all available niches



frontiers in Microbiology
REVIEW
published: 15 April 2019
doi: 10.3389/fmicb.2019.00780

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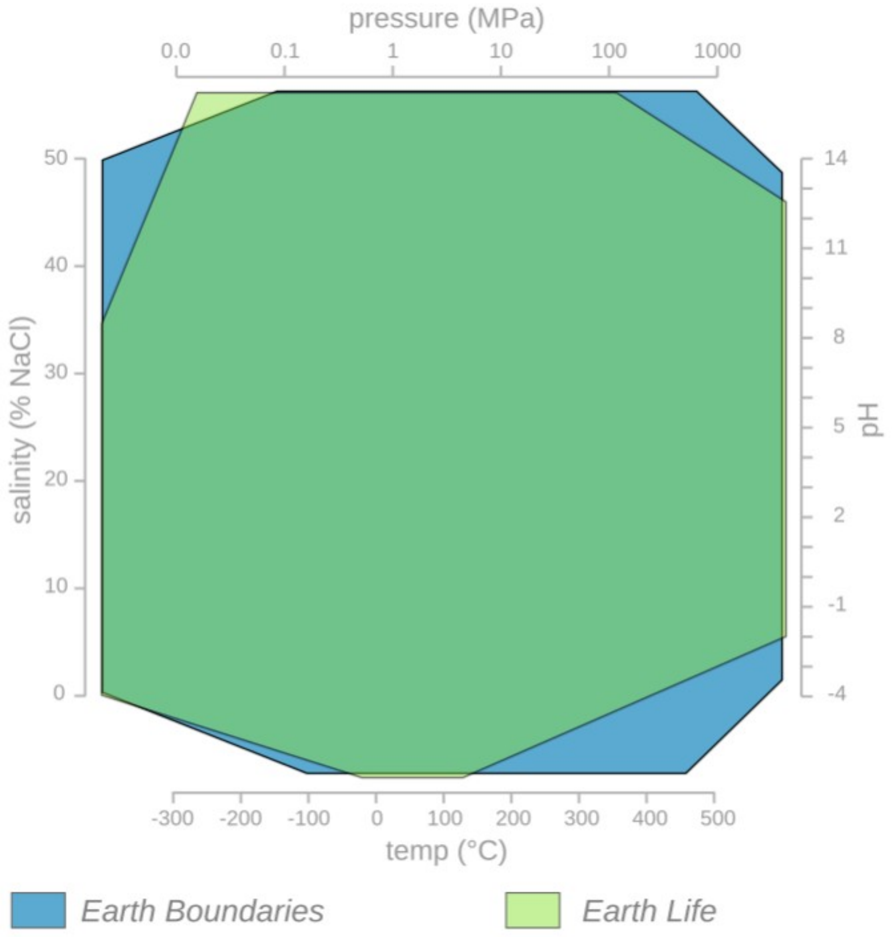
Living at the Extremes: Extremophiles and the Limits of Life in a Planetary Context

Nancy Merino[1,2,3], Heidi S. Aronson[4], Diana P. Bojanova[1], Jayme Feyhl-Buska[1], Michael L. Wong[5,6], Shu Zhang[7] and Donato Giovannelli[2,8,9,10]*

Merino et al 2019 Front Microbiol

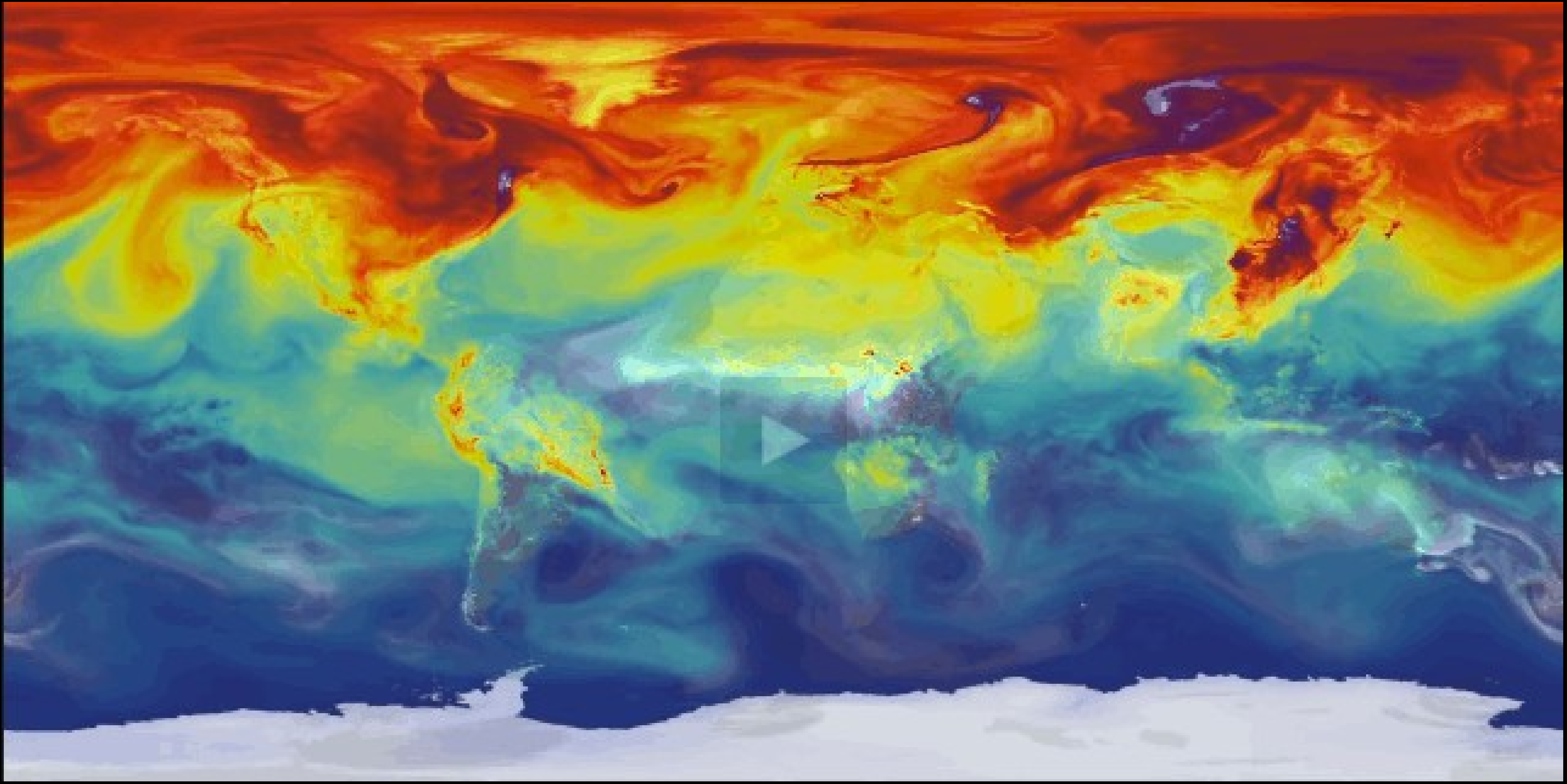
Life thrives in all available niches



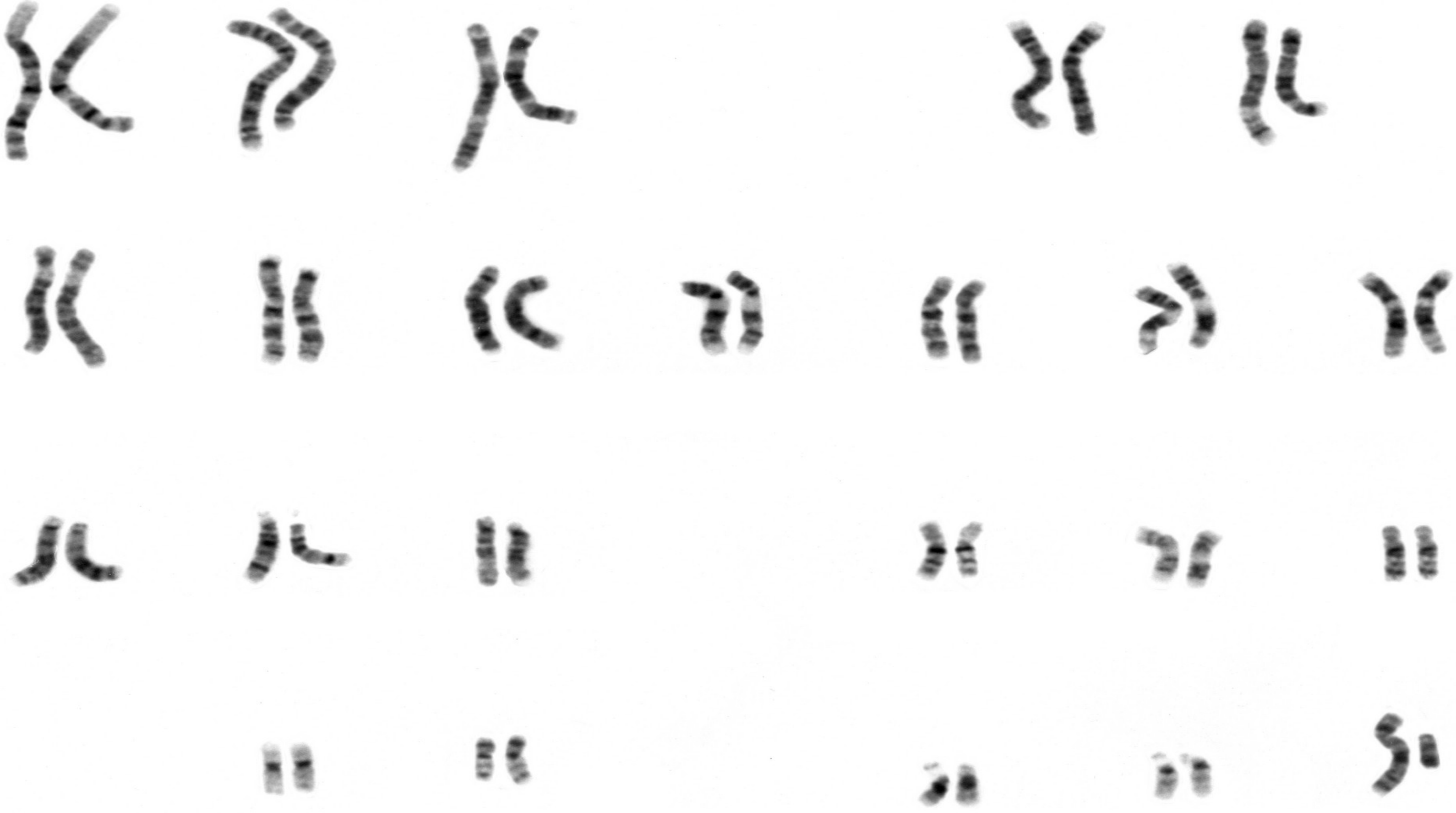
Strain	Temperature (°C)	pH	Pressure (Mpa)	Salinity (%)
Picrophilus oshimae KAW 2/2	47–65 (60)[a]	**–0.06–**1.8 (0.7)	nr	0–20
Serpentinomonas sp. B1	18–37 (30)	9–**12.5** (11)	nr	0–0.5 (0)
Methanopyrus kandleri 116	90–**122** (105)	(6.3–6.6)	0.4–40	0.5–4.5 (3.0)
Planococcus halocryophilus Or	**–18–37** (25)	nr (7–8)	nr	0–19 (2)
Halarsenatibacter silvermanii SLAS-	28–55 (44)	8.7–9.8 (9.4)	nr	20–35 (**35**)
Thermococcus piezophilus CDGS	60–95 (75)	5.5–9 (6)	0.1–**125** (50)	2–6 (3)
Haloarchaeal strains GN-2 and GN-5	nr	nr	nr	nr

[a] *Data presented ablication. Current limits are highlighted in bold.*

Merino et al 2019 Front Microbiol



CO_2 concentration, NASA Earth Observatory



EXTENDED PHENOTYPE AND ECOLOGICAL NICHE

Human Karyotype

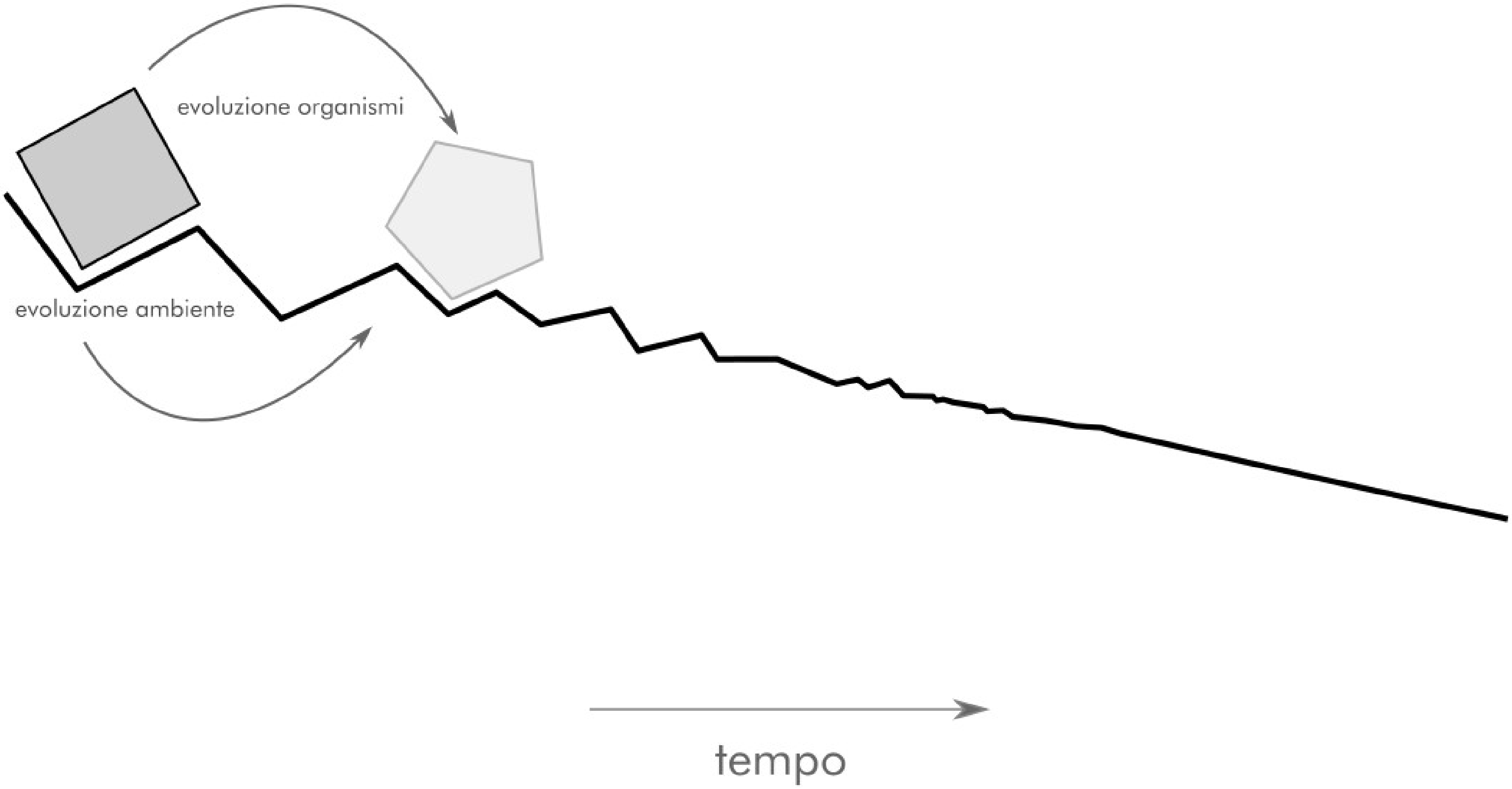
NICHE CONSTRUCTION: Niche construction is the process whereby organisms, through their activities and choices, modify their own and each other's niches. By transforming natural selection pressures, niche construction generates feedback in evolution, on a scale hitherto underestimated, and in a manner that alters the evolutionary dynamic.

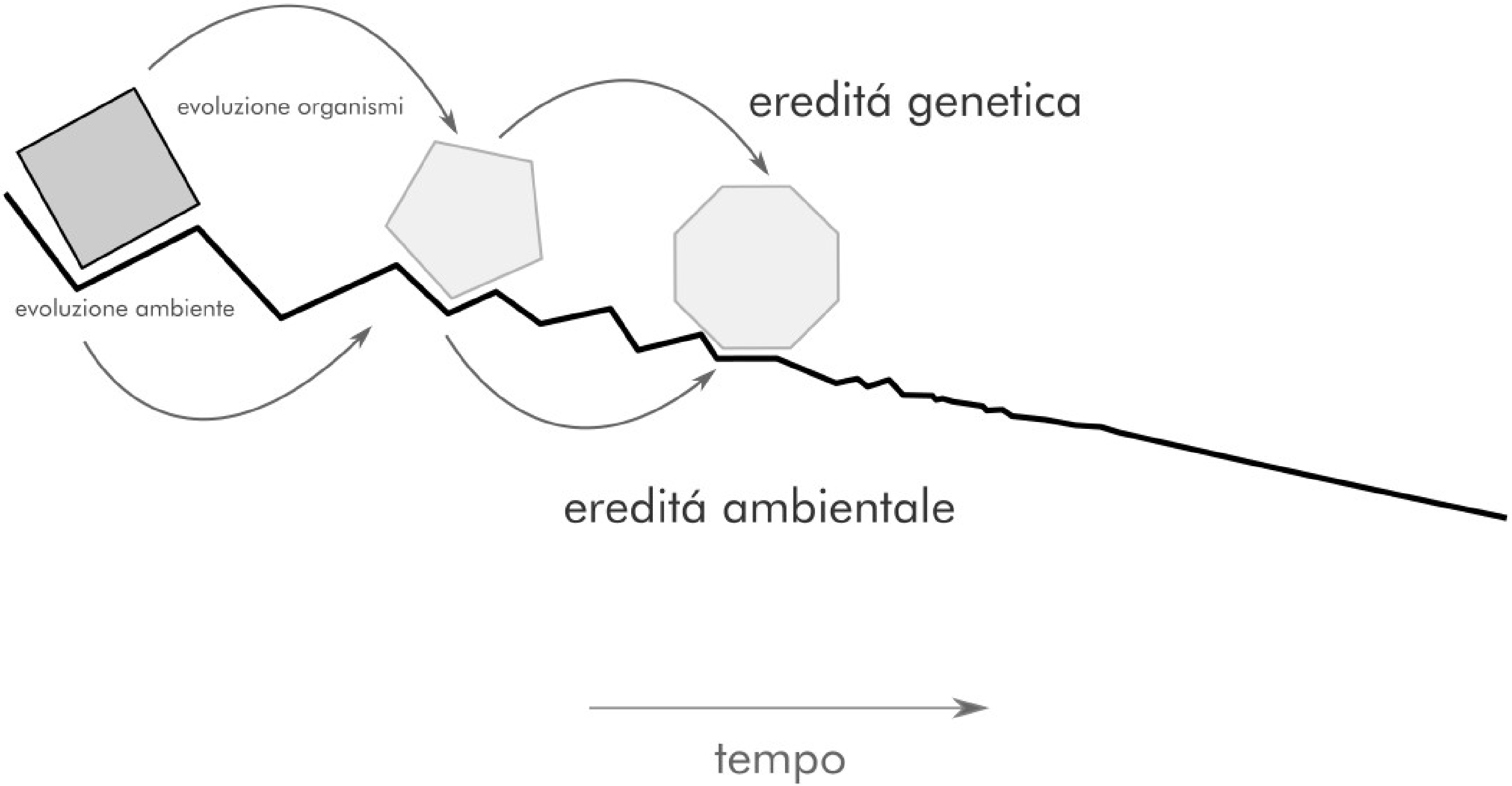
ECOLOGICAL INHERITANCE: The set of environmental modifications produced by organisms that may persist for longer than the individual constructors, and may continue to modulate the impact of these effects on subsequent generations of the same or other populations, even driving macroevolution over geological timescales.

https://synergy.st-andrews.ac.uk/niche/

termite mounds


VITA
AMBIENTE


evoluzione organismi
evoluzione ambiente
tempo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evoluzione ambiente
ereditá ambientale
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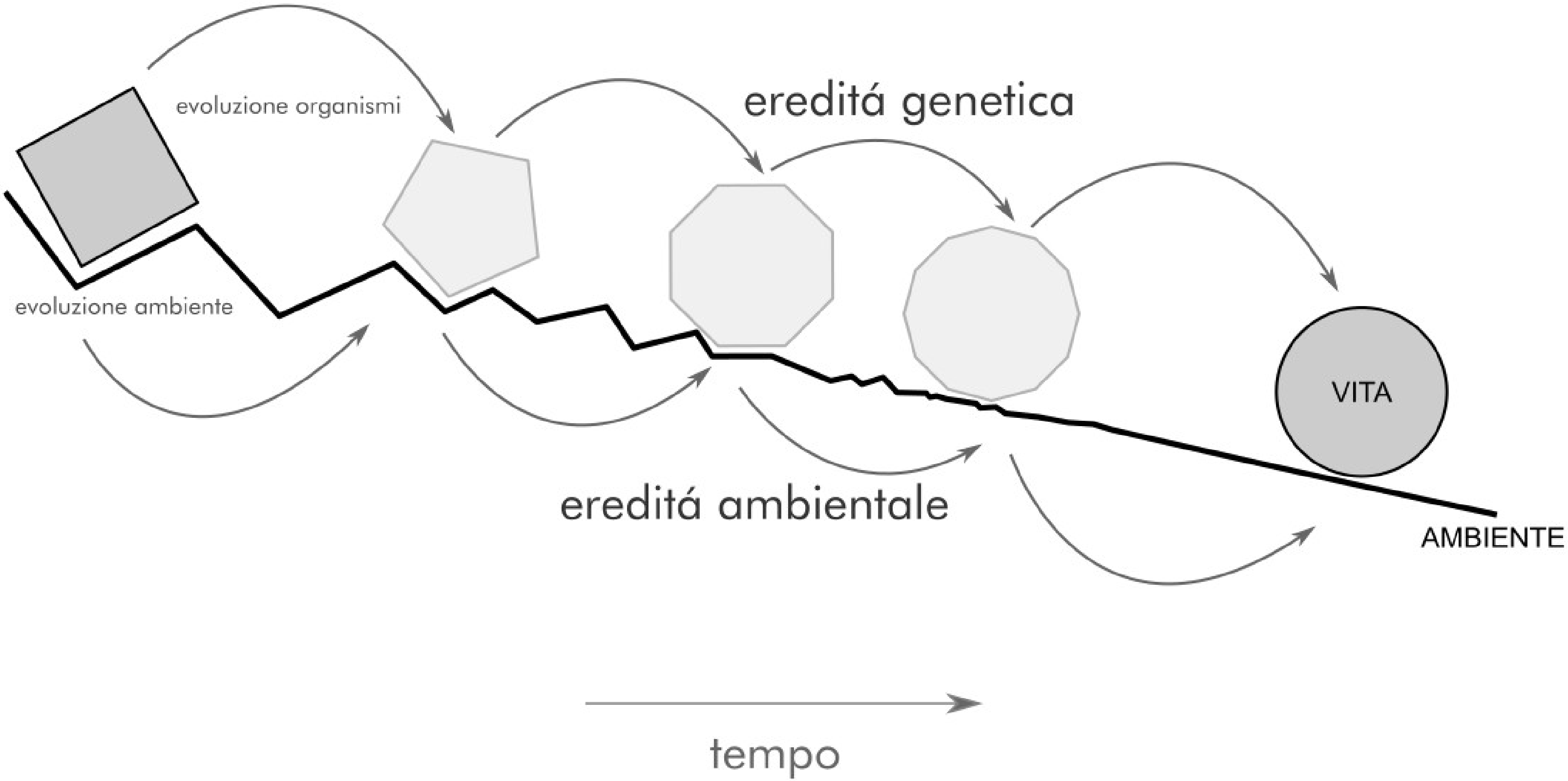
evoluzione organismi
eredità genetica
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VITA
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AMBIENTE
tempo

So exactly, how much has biology influenced planetary evolution through time?

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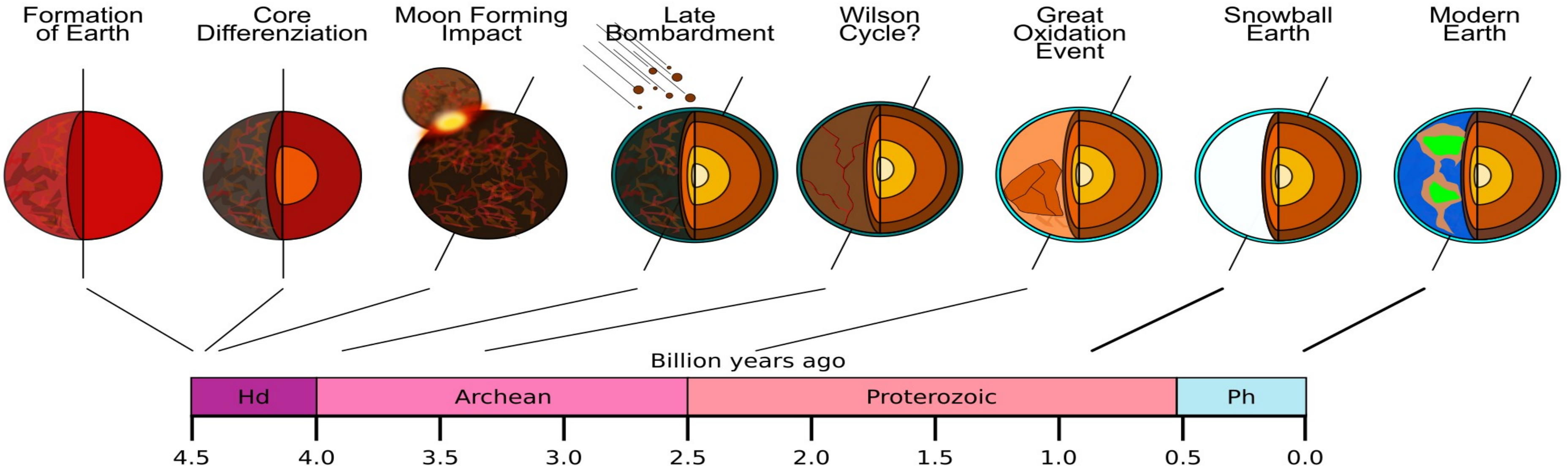
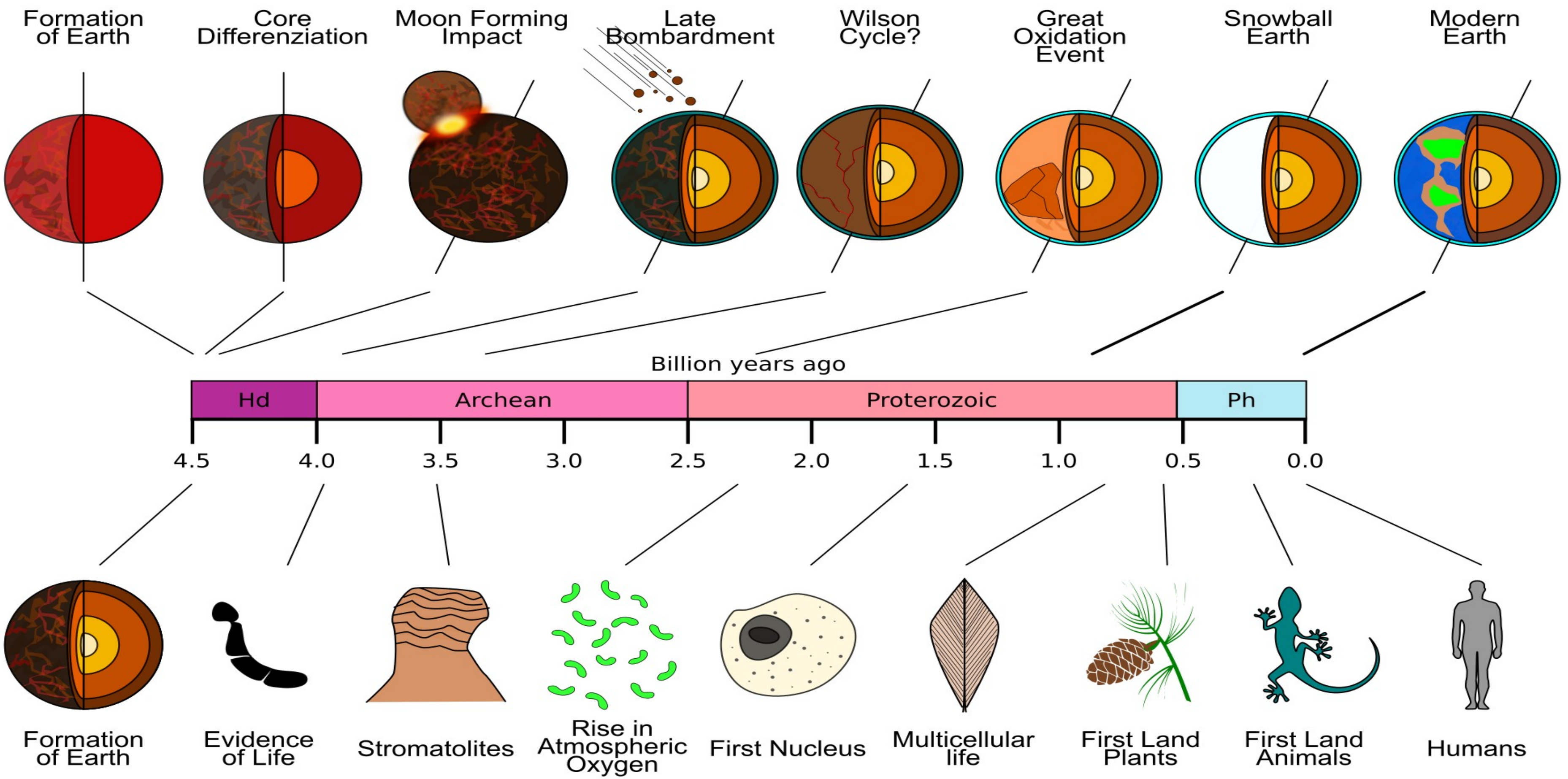
And more specifically, what is the role of life in sustaining life? And on its own emergence?

Earth's transitions

Timeline of Earth History: a Geologist View

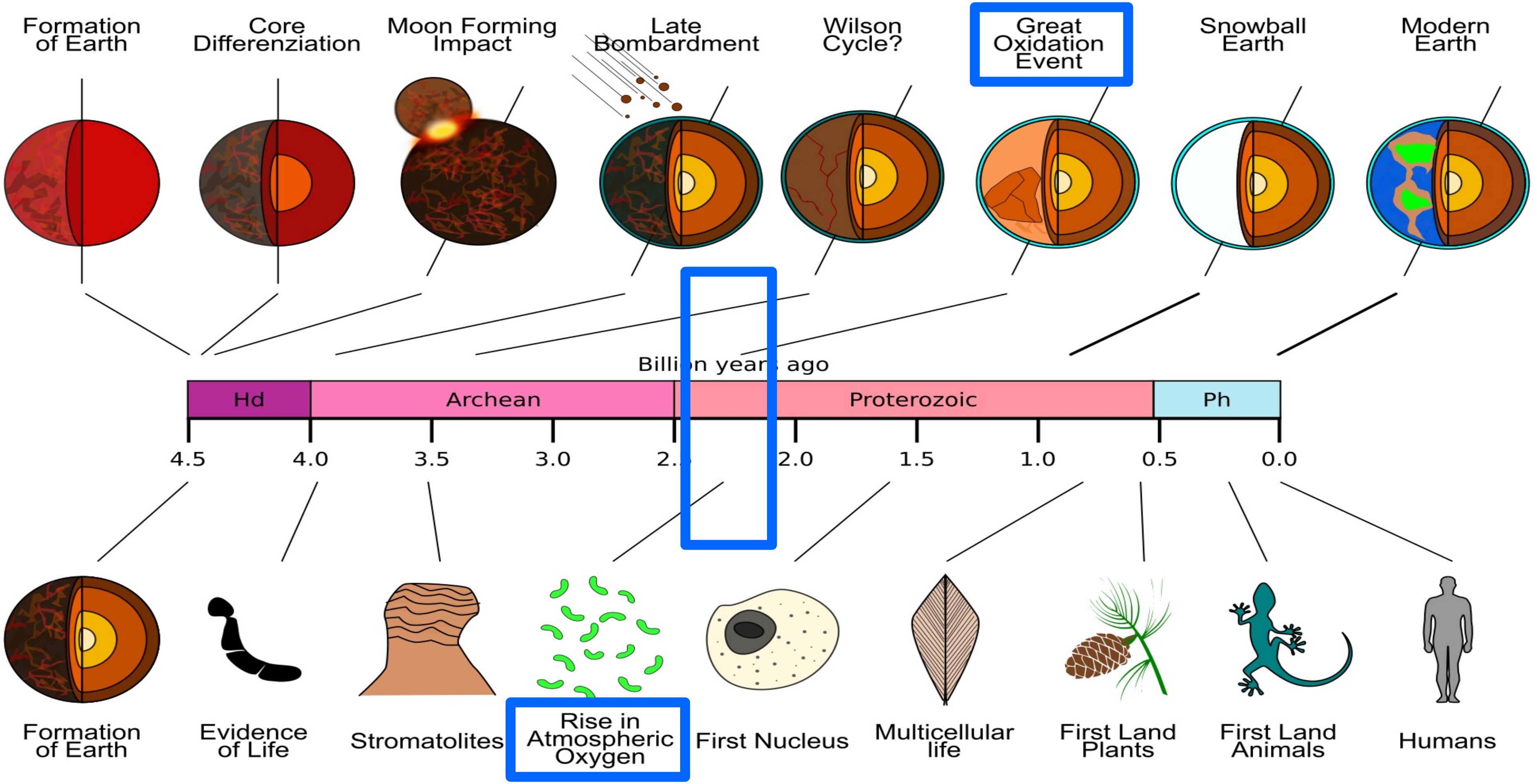


Timeline of Earth History: a Geologist View

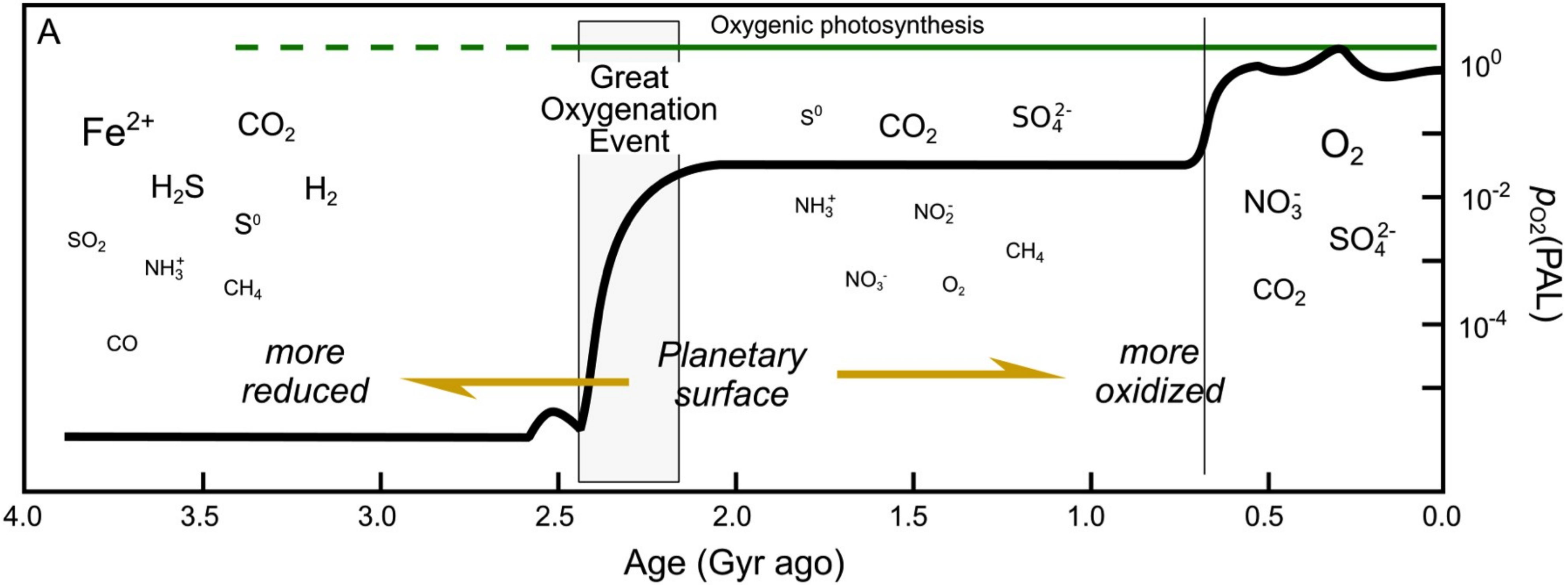


Timeline of Earth History: a Biologist View

Timeline of Earth History: a Geologist View



Timeline of Earth History: a Biologist View

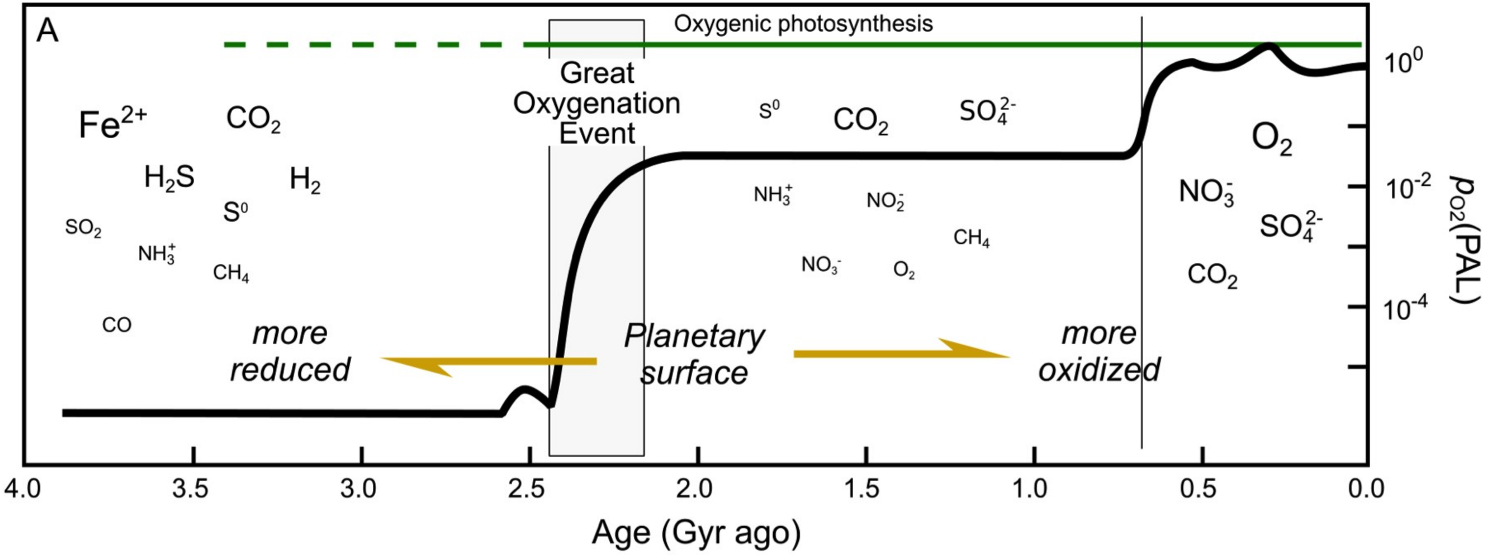


Jelen et al 2016 Ann Rev Microbiol

Oxidation of Earth surface

Banded iron formations


Iron pit



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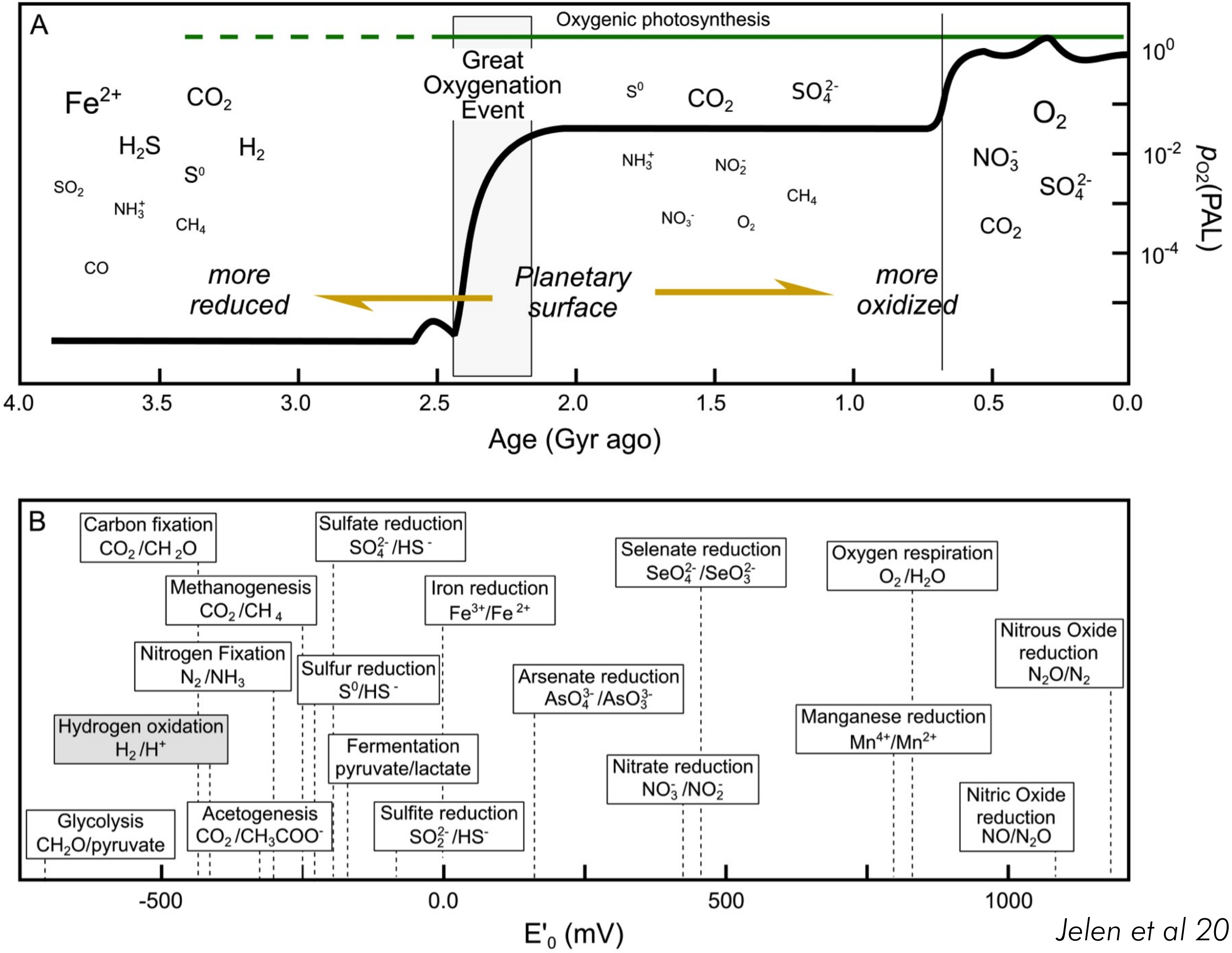

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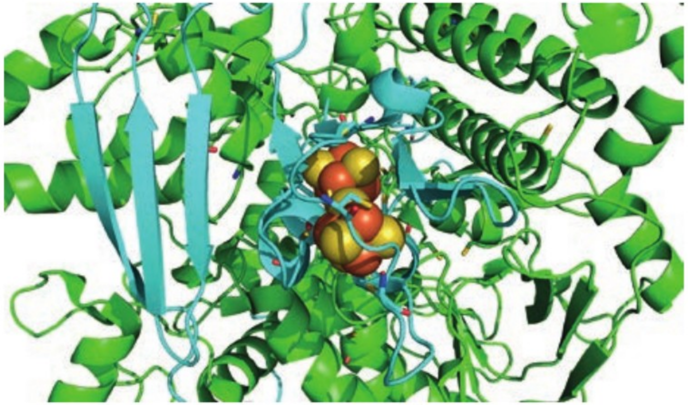
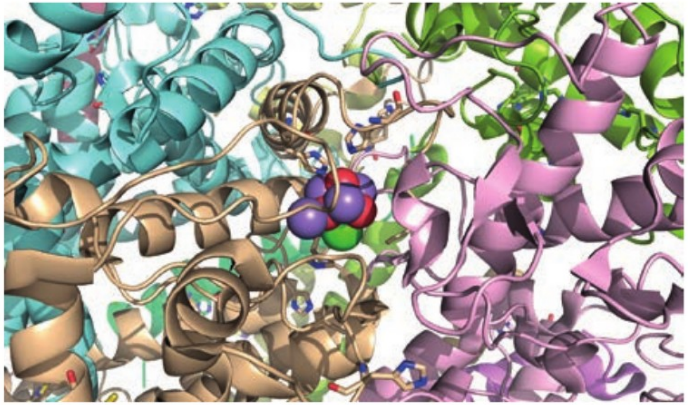
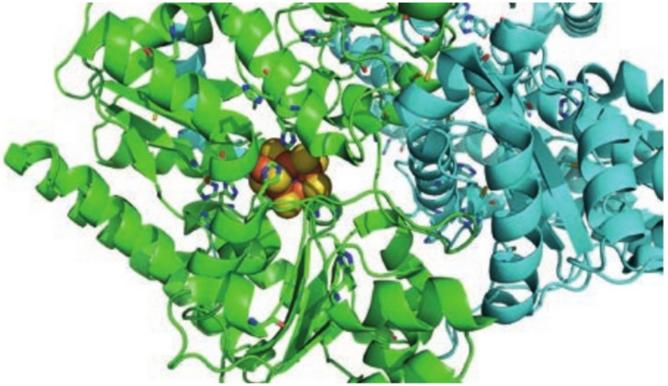
Adenylyl sulfate reductase



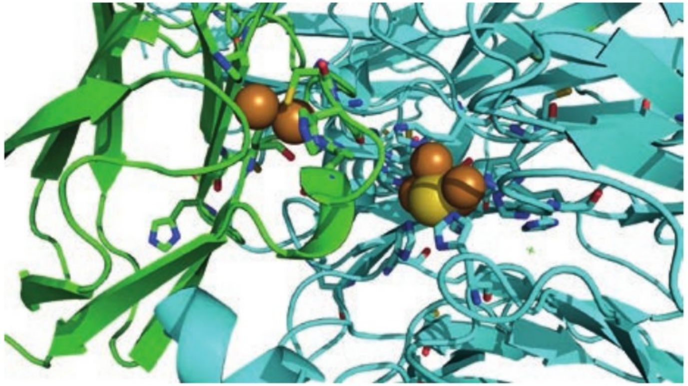
PSII oxygen-evolving complex



Nitrogenase



Nitrous oxide reductase



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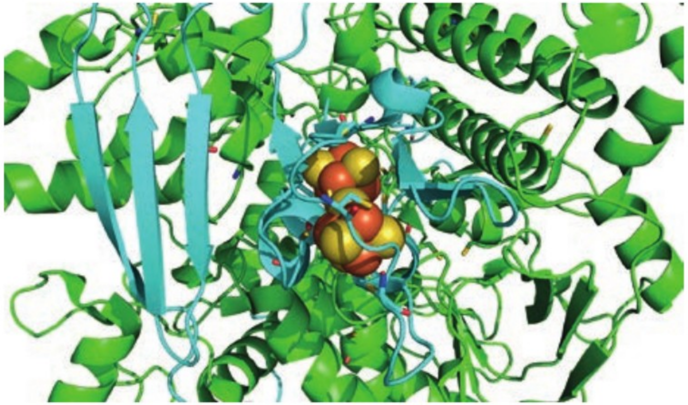
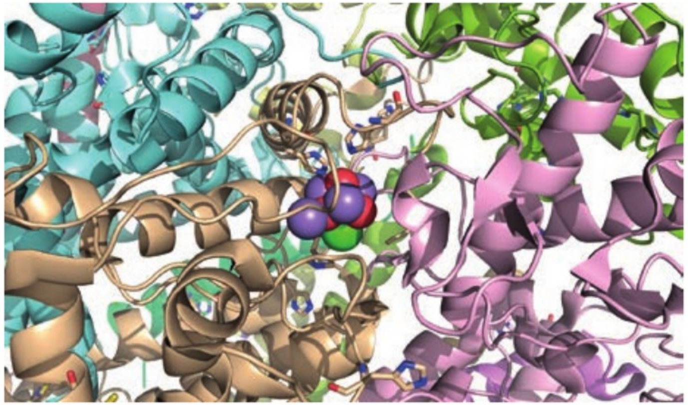
Adenylyl sulfate reductase



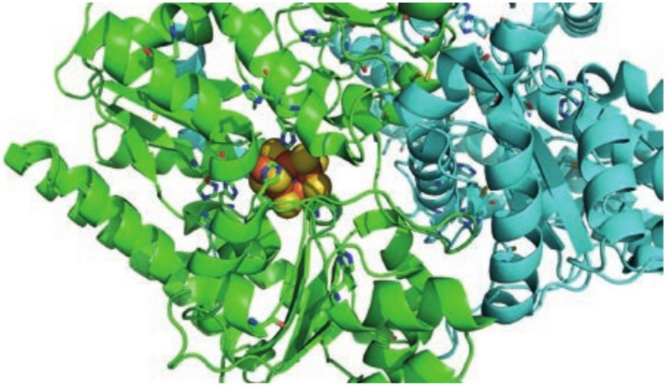
$Fe_4S_4 - Fe_4S_4$

PSII oxygen-evolving complex



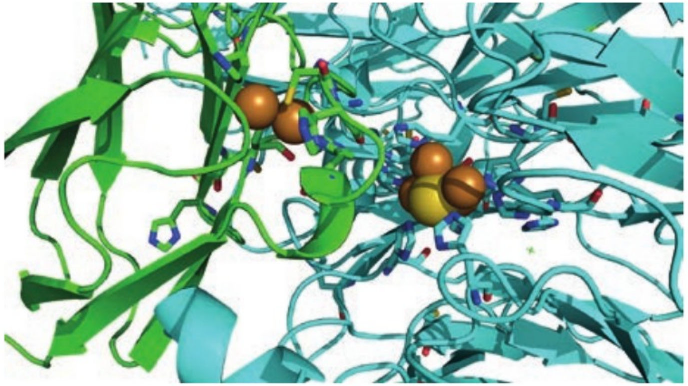
$CaMn_4O_4$

Nitrogenase



$MoFe_7S_8C$

Nitrous oxide reductase



Cu_4S

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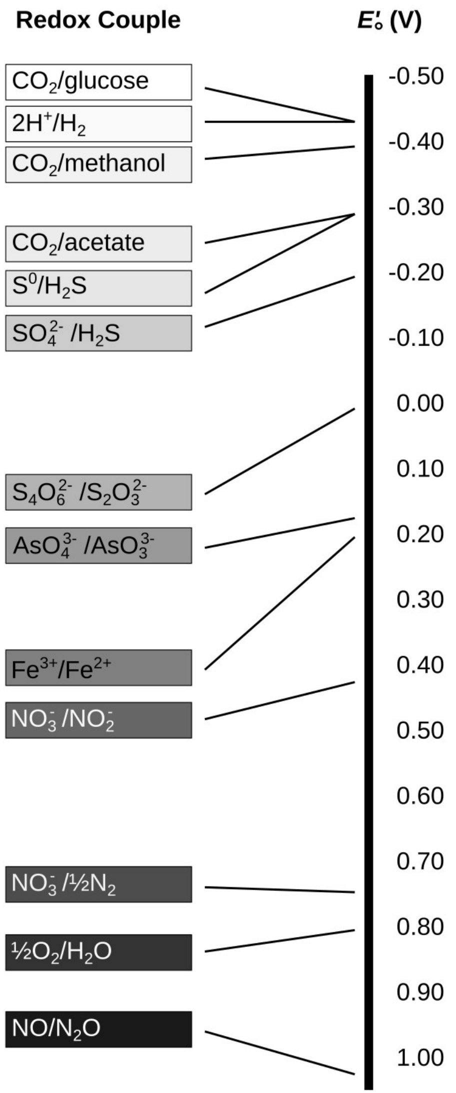

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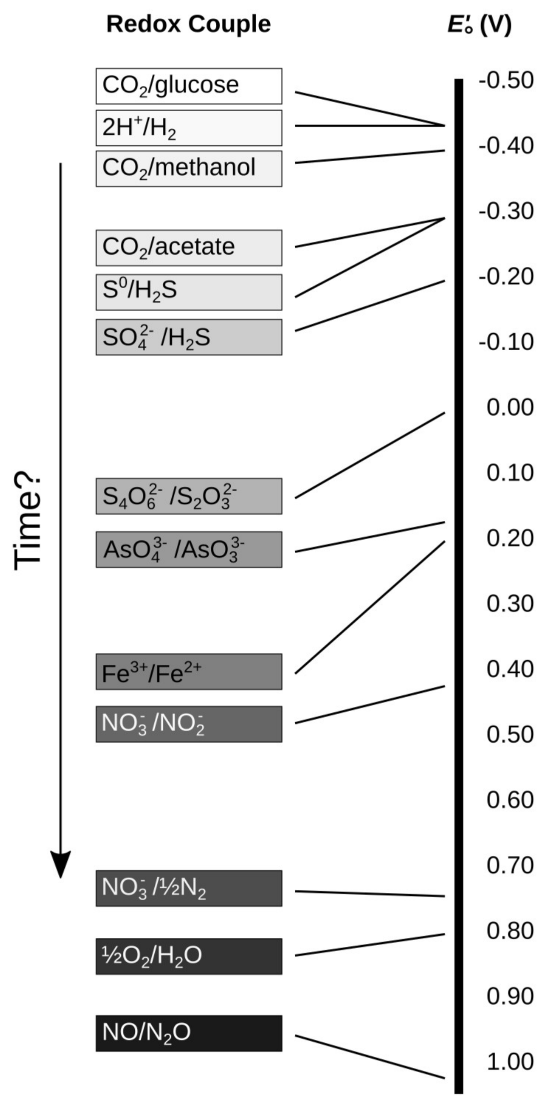

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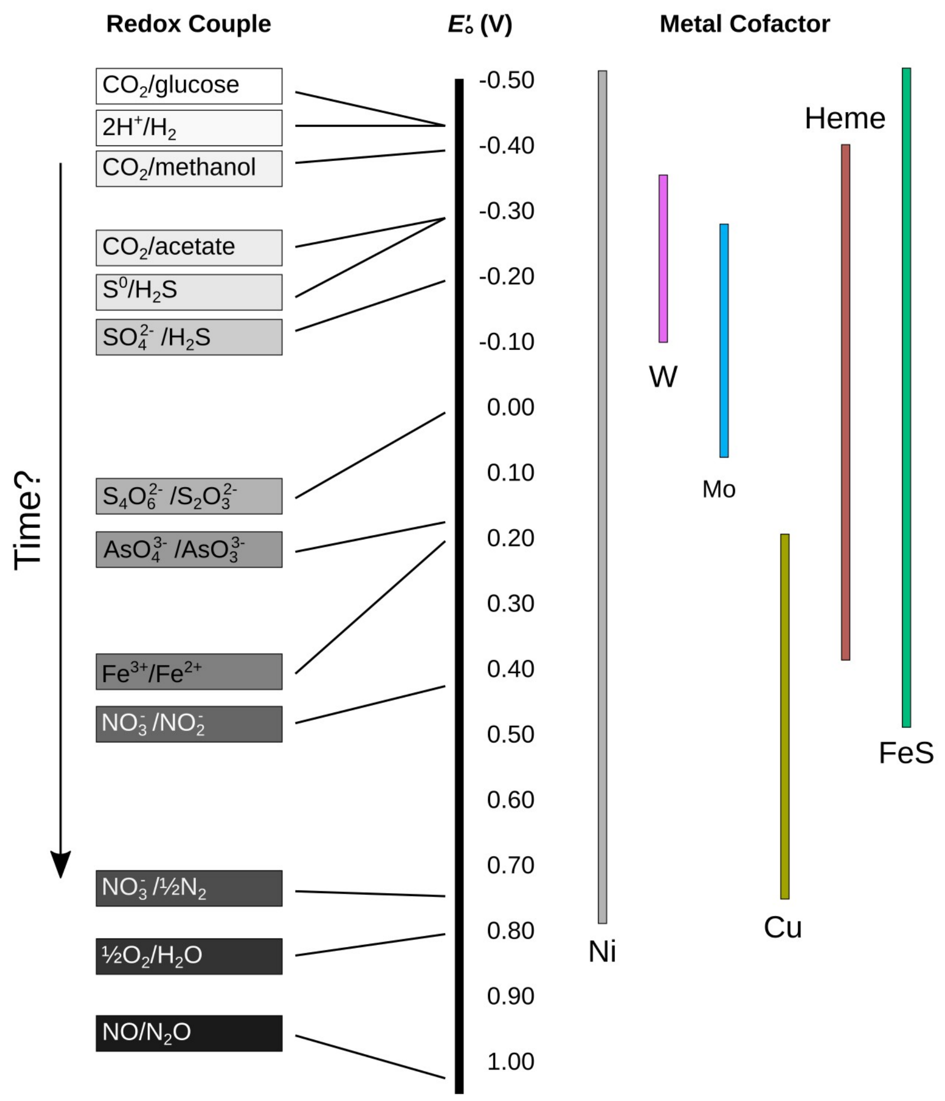

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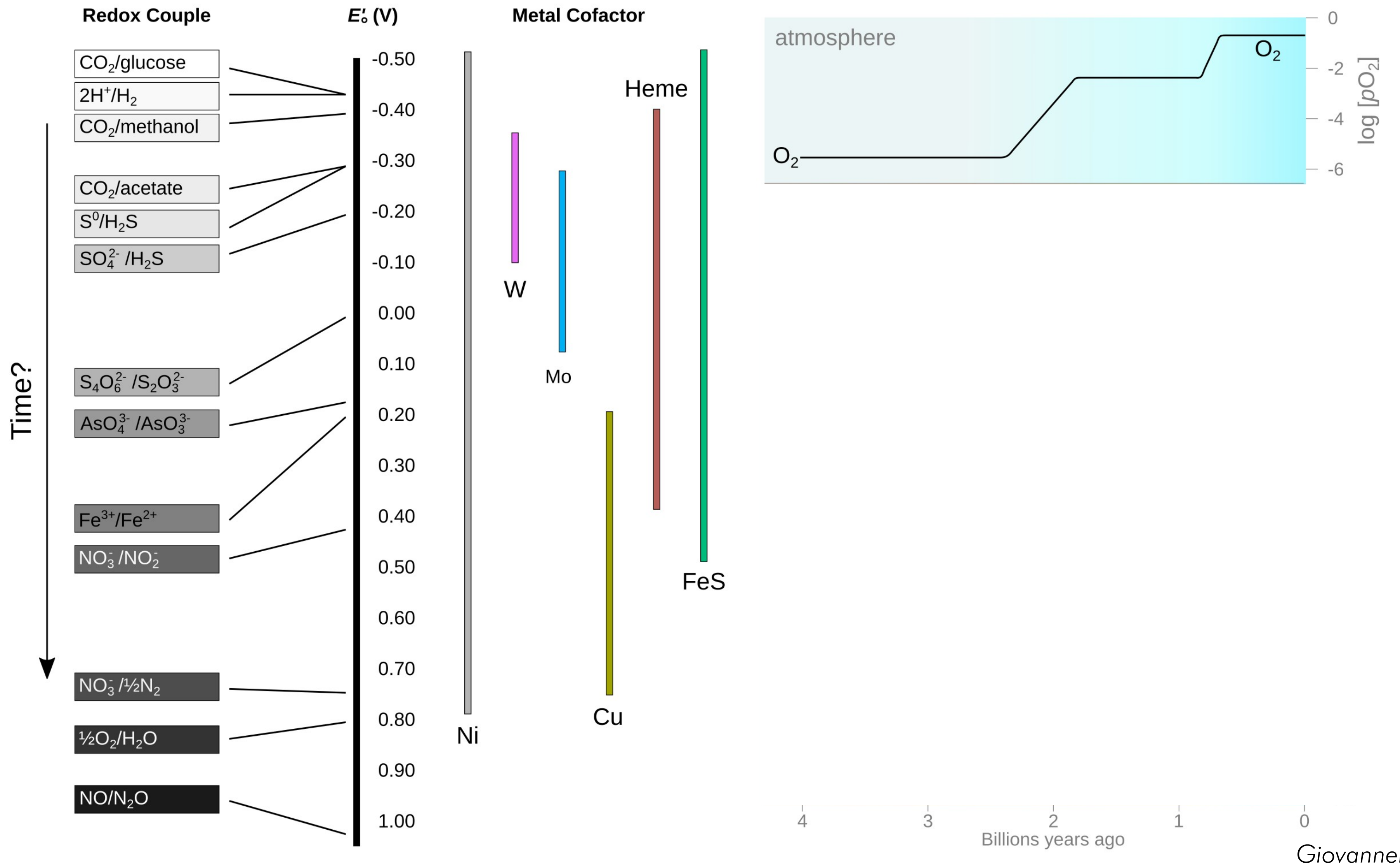

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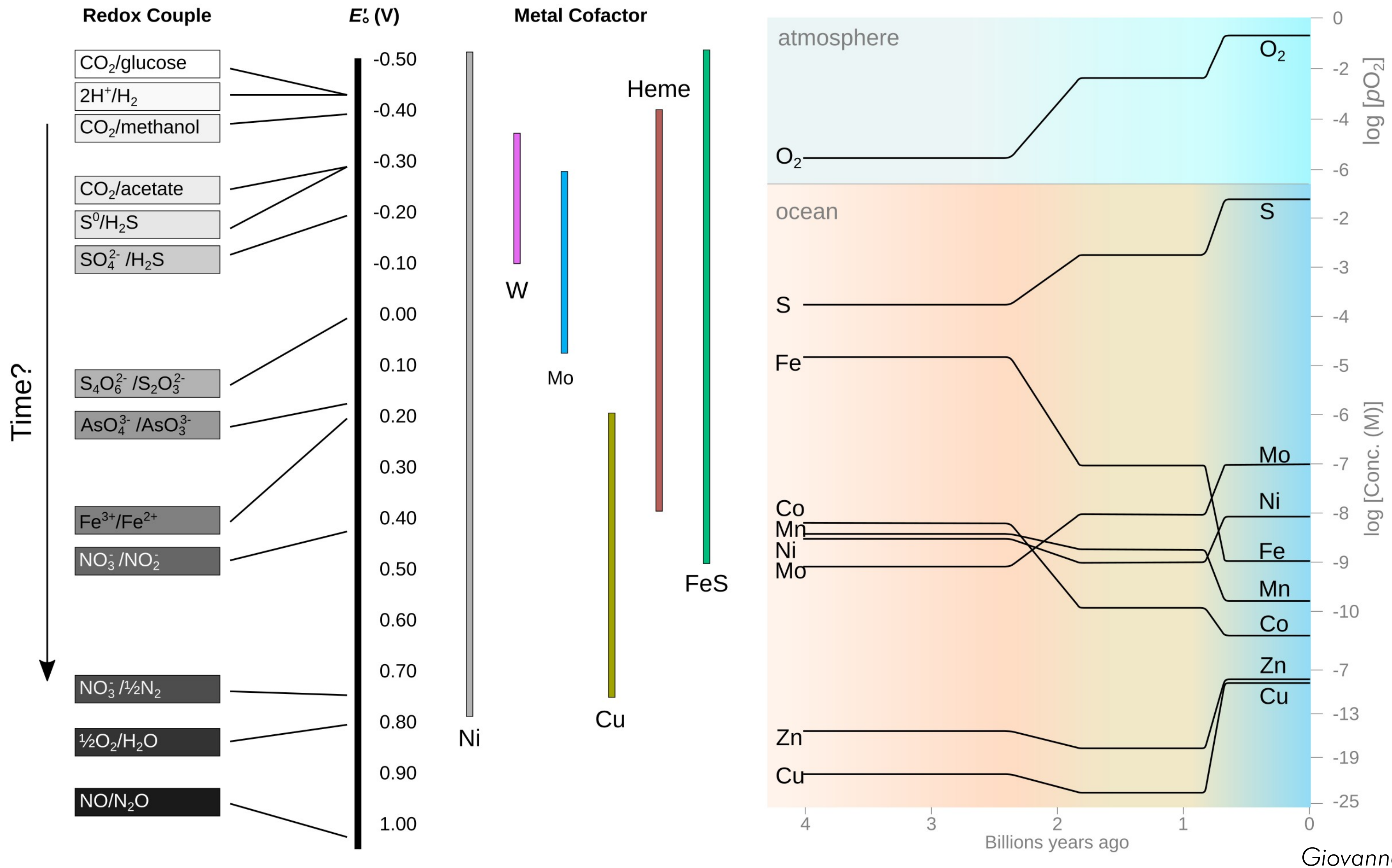

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Published: 28 January 1988

Iron deficiency limits phytoplankton growth in the north-east Pacific subarctic

John H. Martin & Steve E. Fitzwater

Nature **331**, 341–343(1988) | Cite this article

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Limnology and Oceanography / Volume 40, Issue 8

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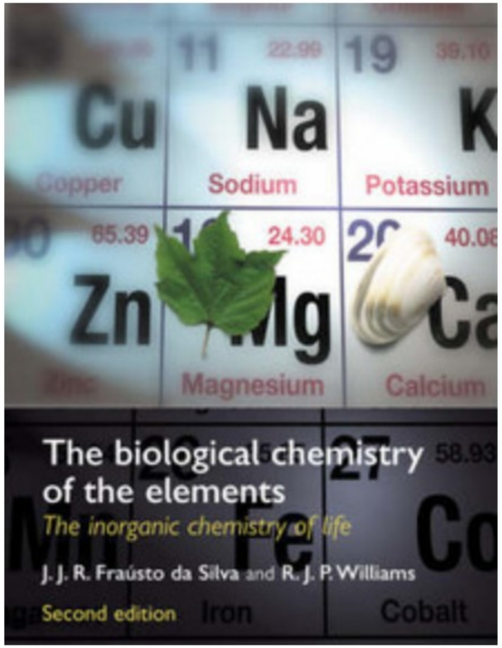
Cobalt and zinc interreplacement in marine phytoplankton: Biological and geochemical implications

William G. Sunda, Susan A. Huntsman

First published: December 1995
https://doi.org/10.4319/lo.1995.40.8.1404



The Biological Chemistry of the Elements: The Inorganic Chemistry of Life

di J. J. R. Frausto da Silva, R. J. P. Williams

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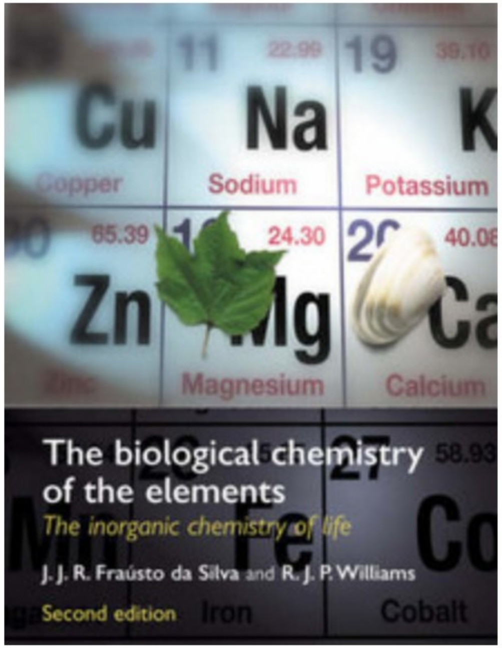

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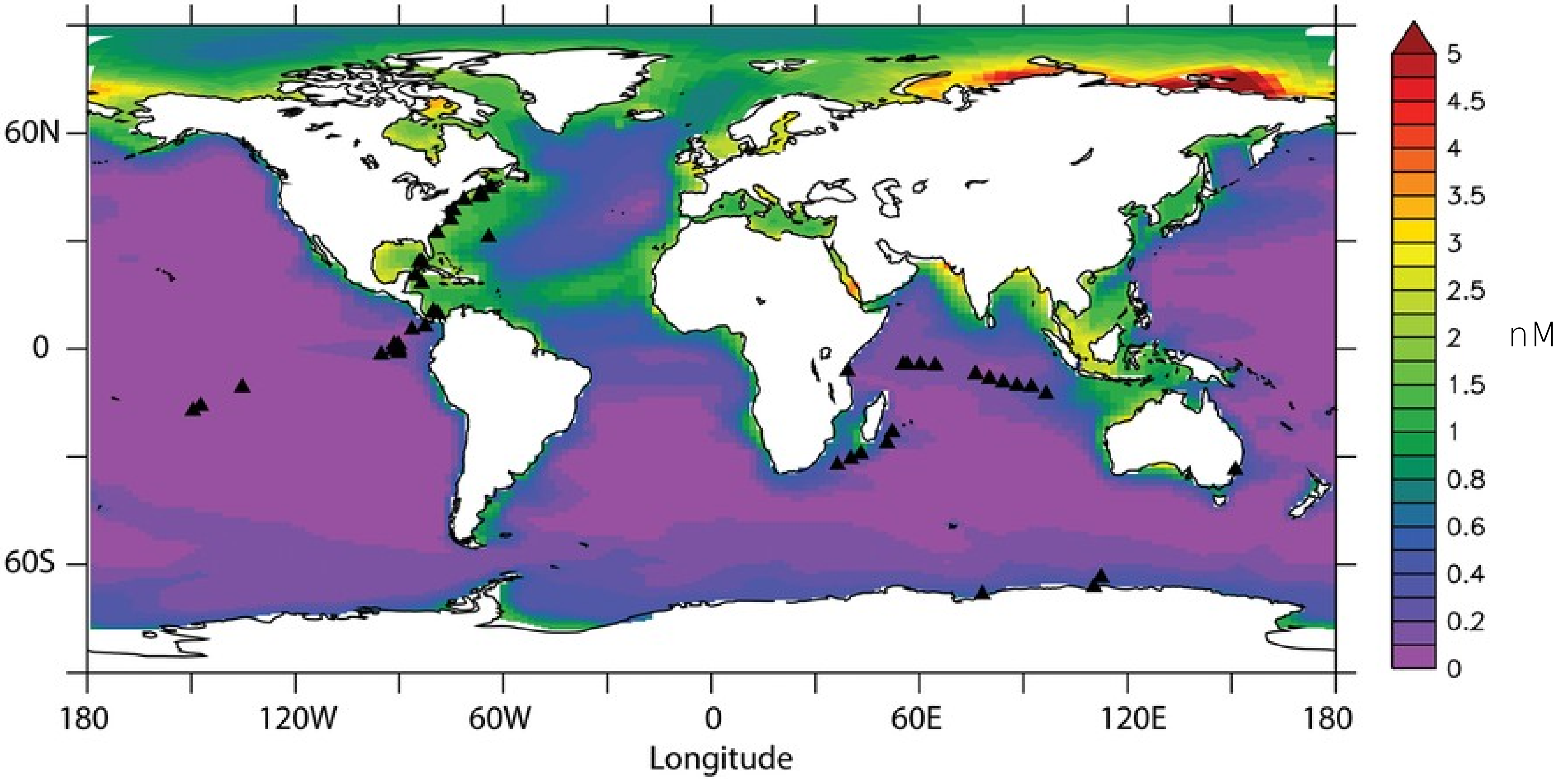
"[...] cell's trace element inventory was directly related to the conditions under which the host organism evolved [...]



60N
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Longitude
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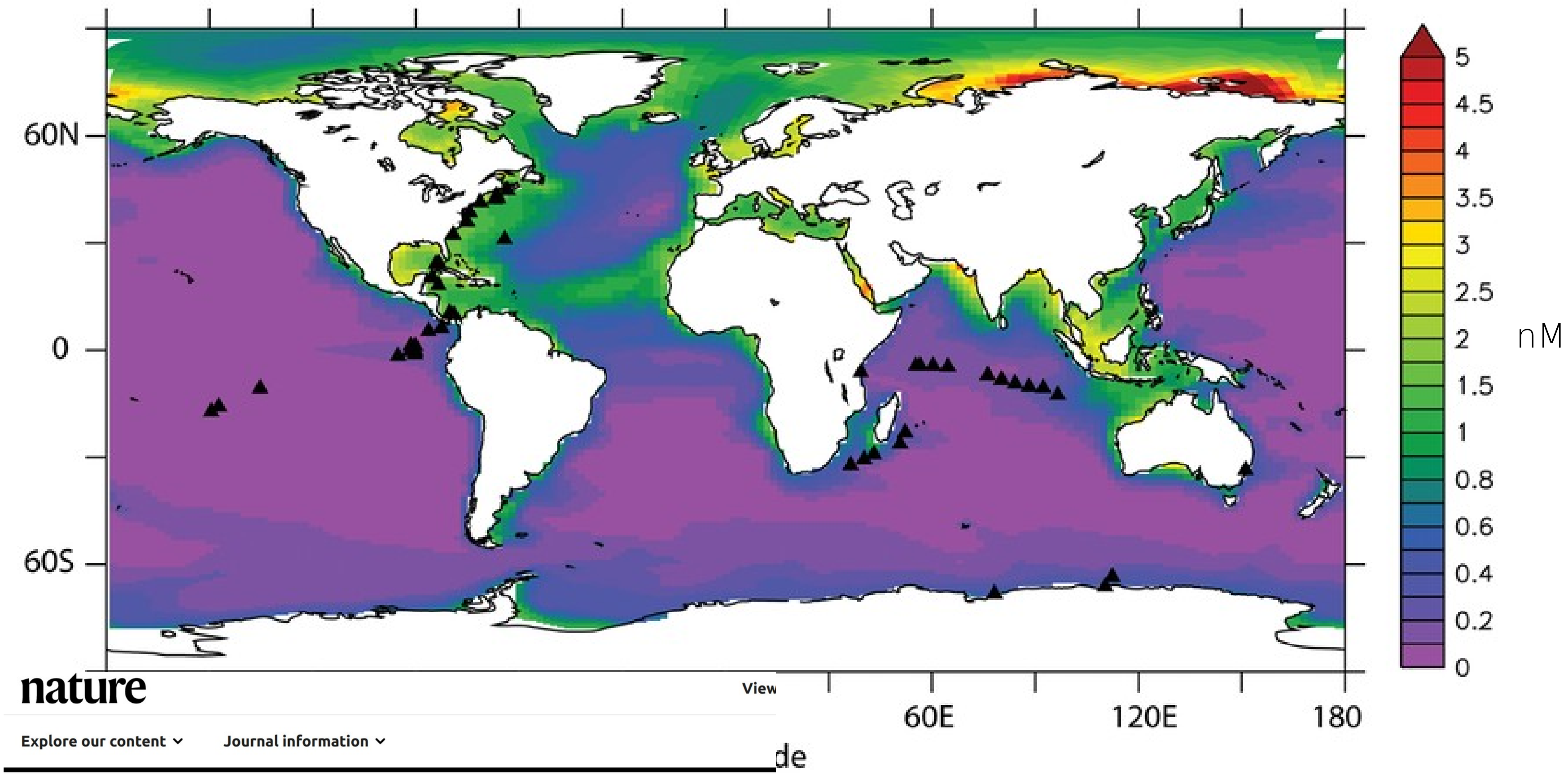
nM



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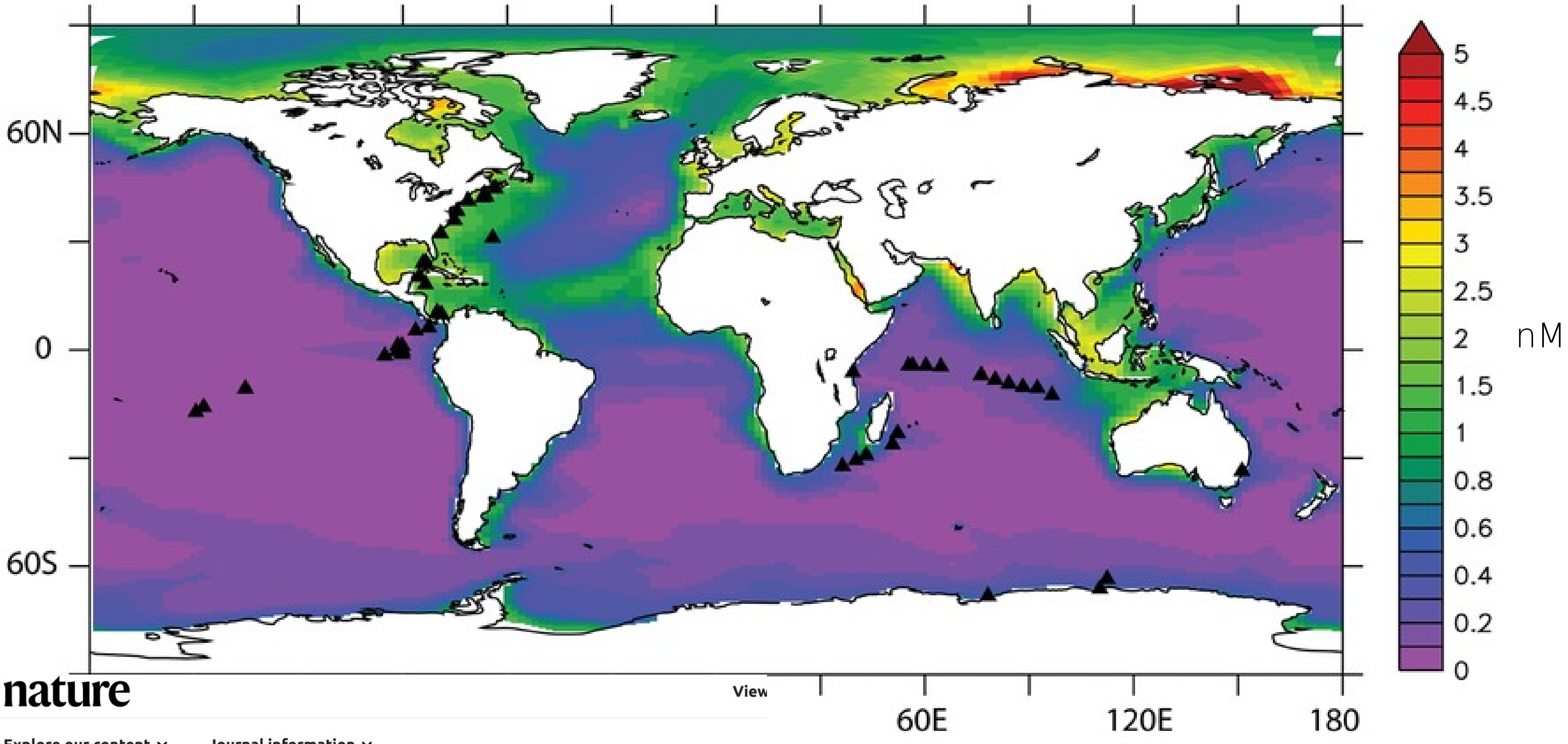
The integral role of iron in ocean biogeochemistry

Alessandro Tagliabue ✉, Andrew R. Bowie, Philip W. Boyd, Kristen N. Buck, Kenneth S. Johnson & Mak A. Saito



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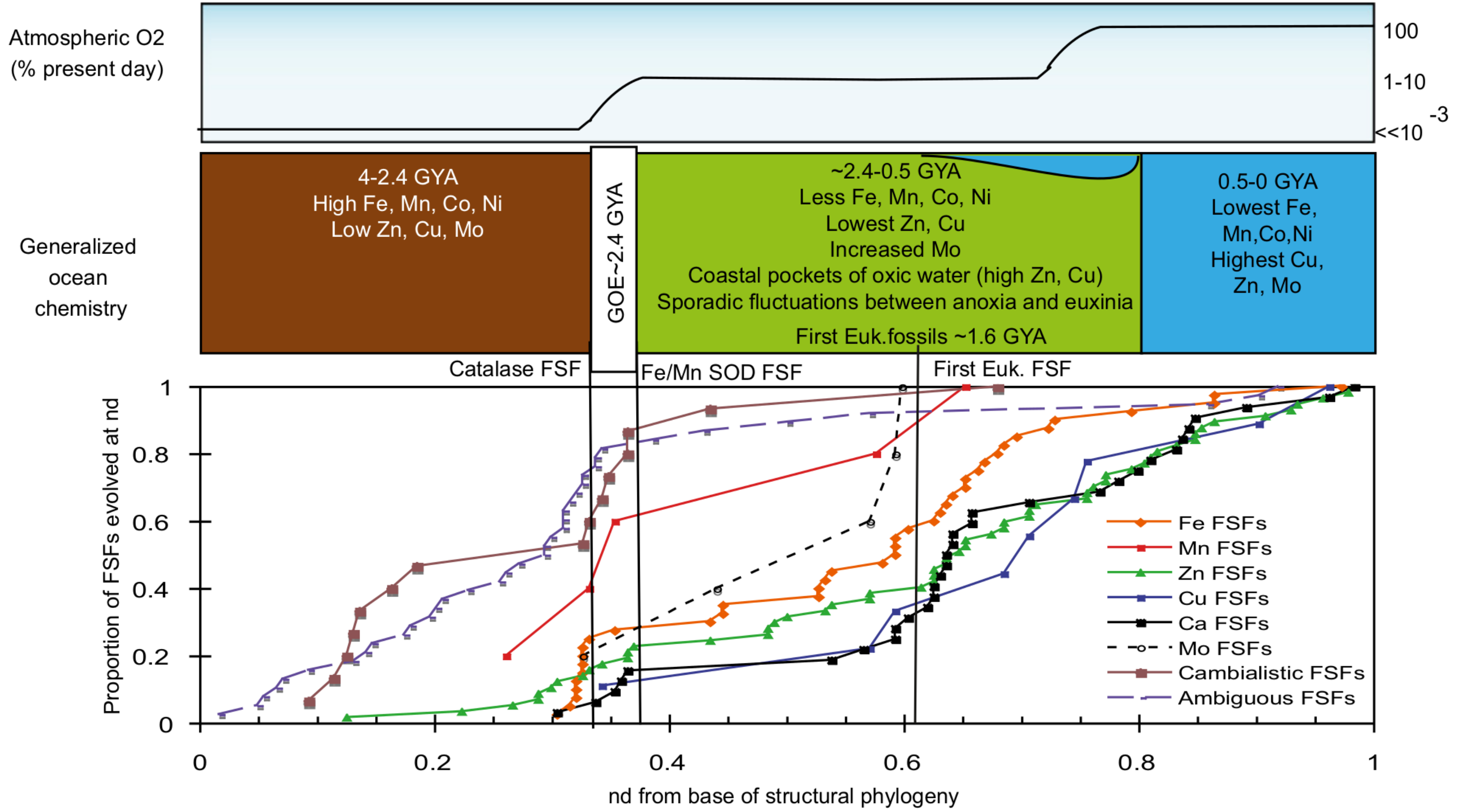
"Iron requirement as an evolutionary relict"

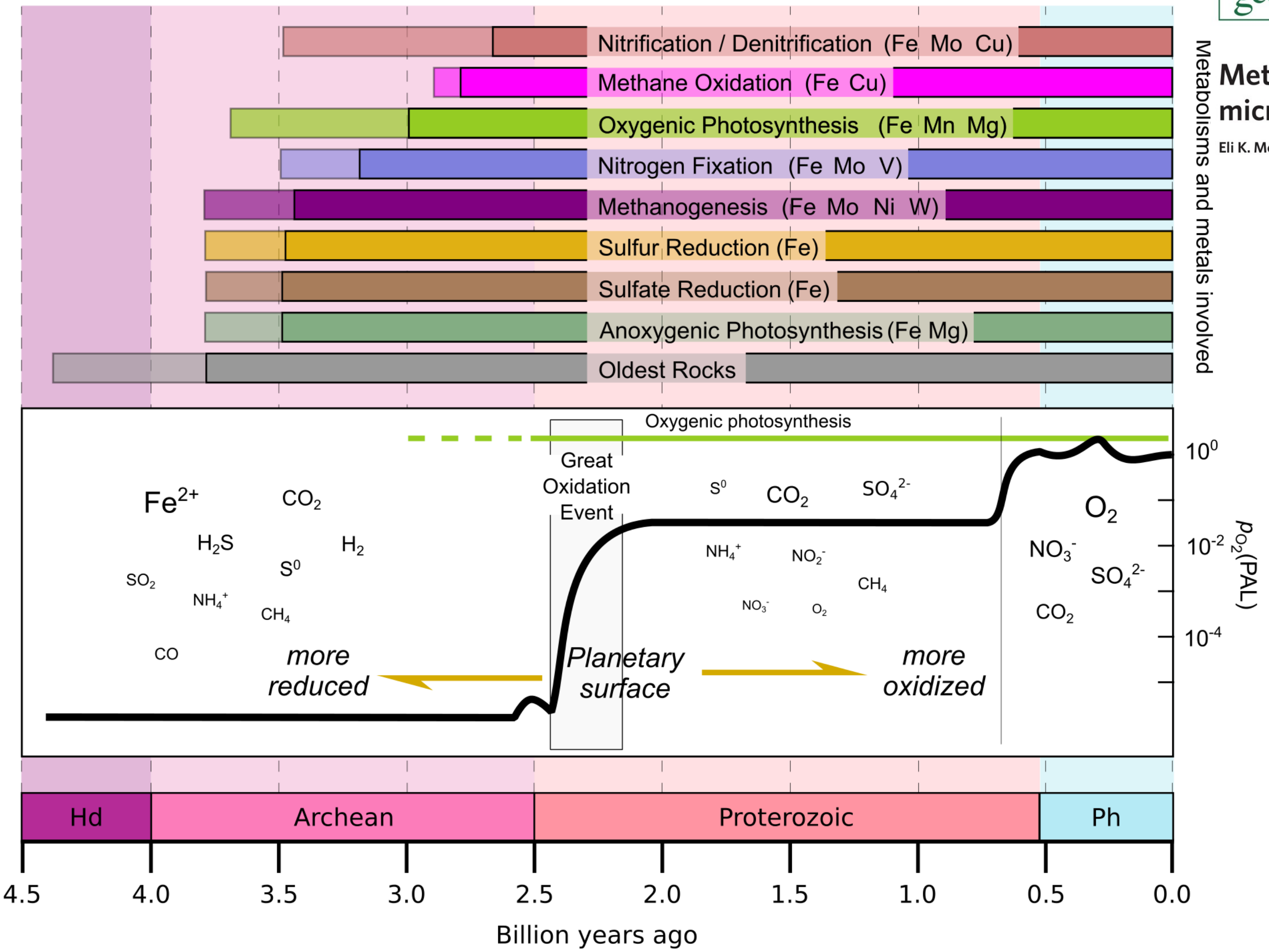
PNAS

History of biological metal utilization inferred through phylogenomic analysis of protein structures

Christopher L. Dupont[a,1], Andrew Butcher[b], Ruben E. Valas[c], Philip E. Bourne[d], and Gustavo Caetano-Anollés[e,1]

[a]Microbial and Environmental Genomics Group, J. Craig Venter Institute, La Jolla, CA 92121; [b]Department of Biology, University of York, York YO10 5YW, United Kingdom; [c]Bioinformatics Program and [d]Skaggs School of Pharmacy and Pharmaceutical Sciences, University of California, La Jolla, CA 92064; and [e]Evolutionary Bioinformatics Laboratory, Department of Crop Sciences, University of Illinois, Urbana–Champaign, IL 61801



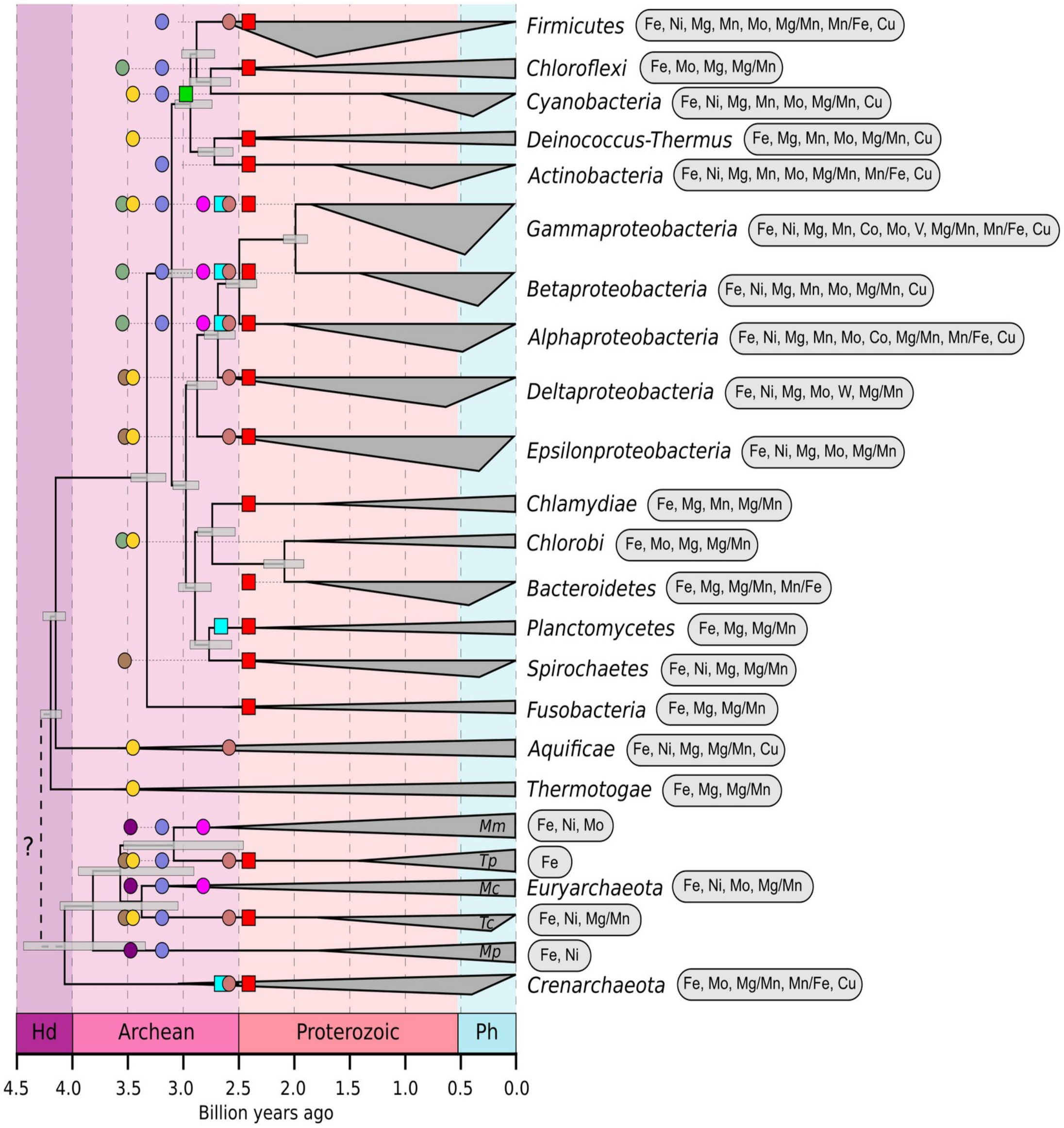


nature geoscience REVIEW ARTICLE
PUBLISHED ONLINE: 28 AUGUST 2017 | DOI: 10.1038/NGEO3006

Metal availability and the expanding network of microbial metabolisms in the Archaean eon

Eli K. Moore[1], Benjamin I. Jelen[1], Donato Giovannelli[1,2,3], Hagai Raanan[1] and Paul G. Falkowski[1,4*]

Moore et al 2017 Nature Geoscience



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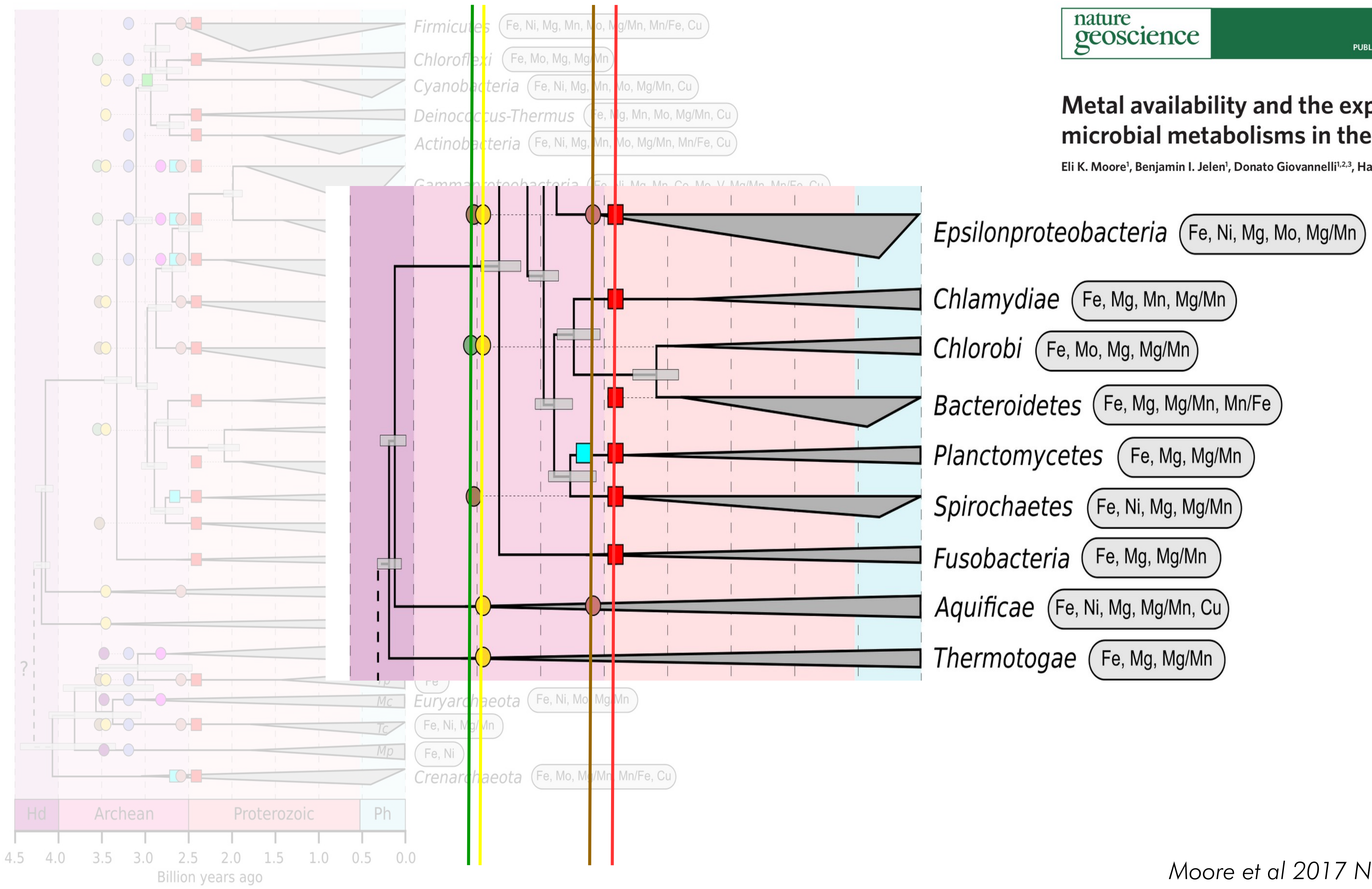

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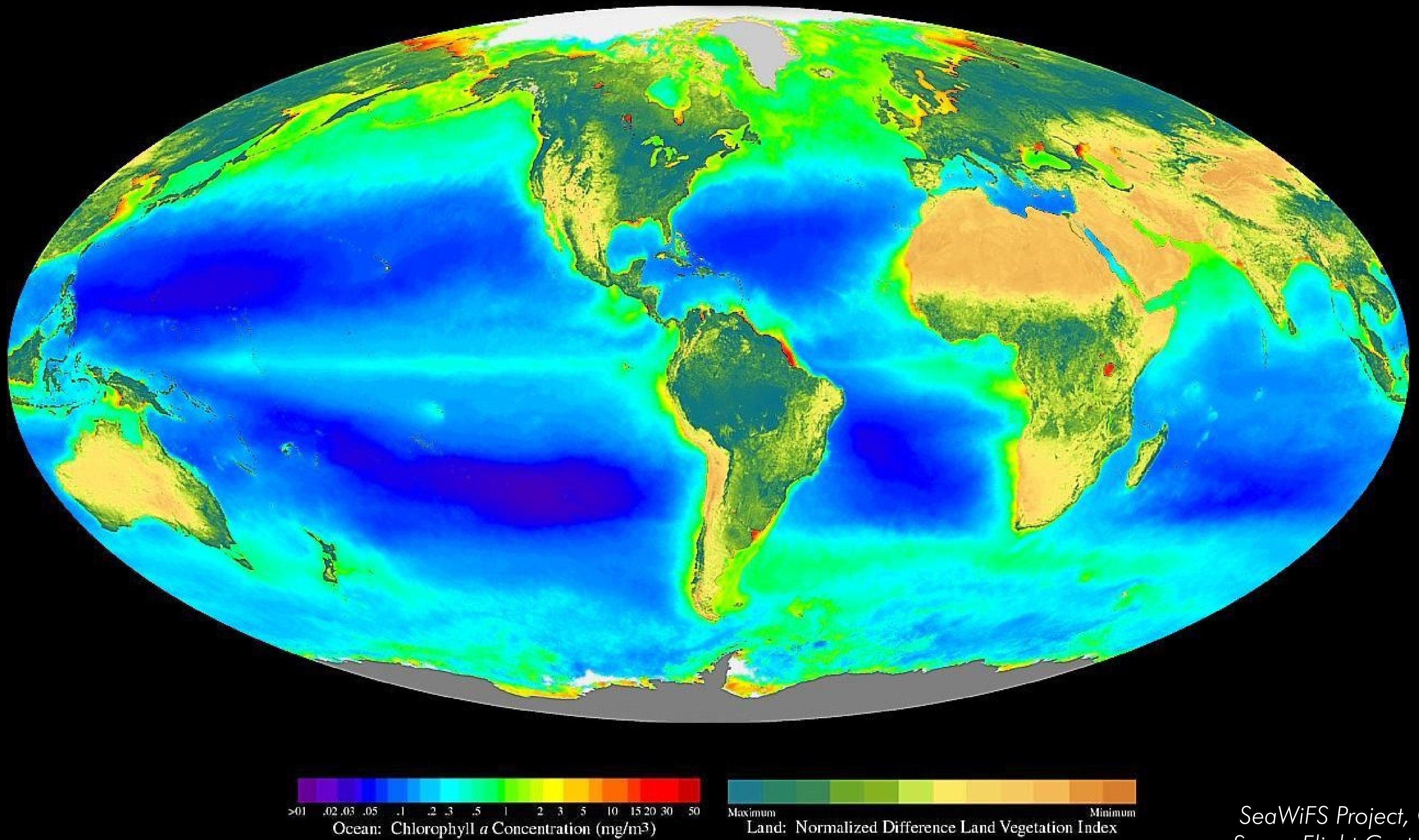
Life, Earth and Oxygen



SeaWiFS Project, Goddard Space Flight Center

$$CO_2 + H_2O \xrightarrow{h\nu} [CH_2O] + O_2$$

$$CO_2 + H_2O \xrightarrow{h\nu} [CH_2O] + O_2$$

$$[CH_2O] + O_2 \rightarrow CO_2 + H_2O$$

Photosynthesis

$$CO_2 + H_2O \xrightarrow{h\nu} [CH_2O] + O_2$$

Respiration

$$[CH_2O] + O_2 \rightarrow CO_2 + H_2O$$

Photosynthesis

$$CO_2 + H_2O \xrightarrow{h\nu} [CH_2O] + O_2$$

Respiration

$$[CH_2O] + O_2 \rightarrow CO_2 + H_2O$$

Photosynthesis

$$CO_2 + H_2O \xrightarrow{h\nu} [CH_2O] + O_2$$

Respiration

$$[CH_2O] + O_2 \rightarrow CO_2 + H_2O$$

Photosynthesis

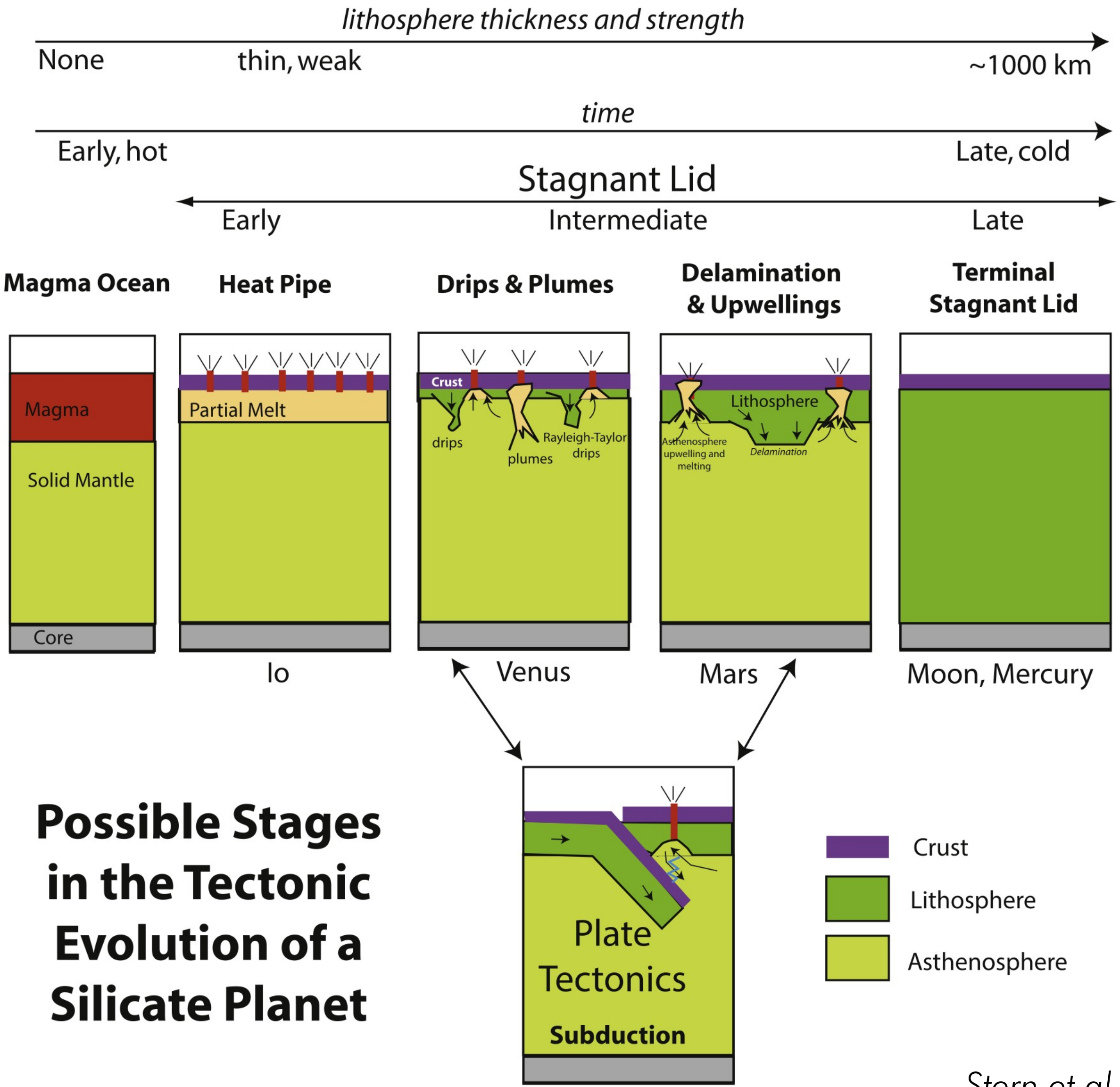
$$CO_2 + H_2O \xrightarrow{h\nu} [CH_2O] + O_2$$

Respiration

$$[CH_2O] + O_2 \rightarrow CO_2 + H_2O$$

The Biosphere (through photosynthesis) and the Geosphere (through organic matter burrial and subduction) have contributed to the net accumulation of oxygen in our atmosphere, decoupling photosynthesis and respiration in space and time

Possible Stages in the Tectonic Evolution of a Silicate Planet



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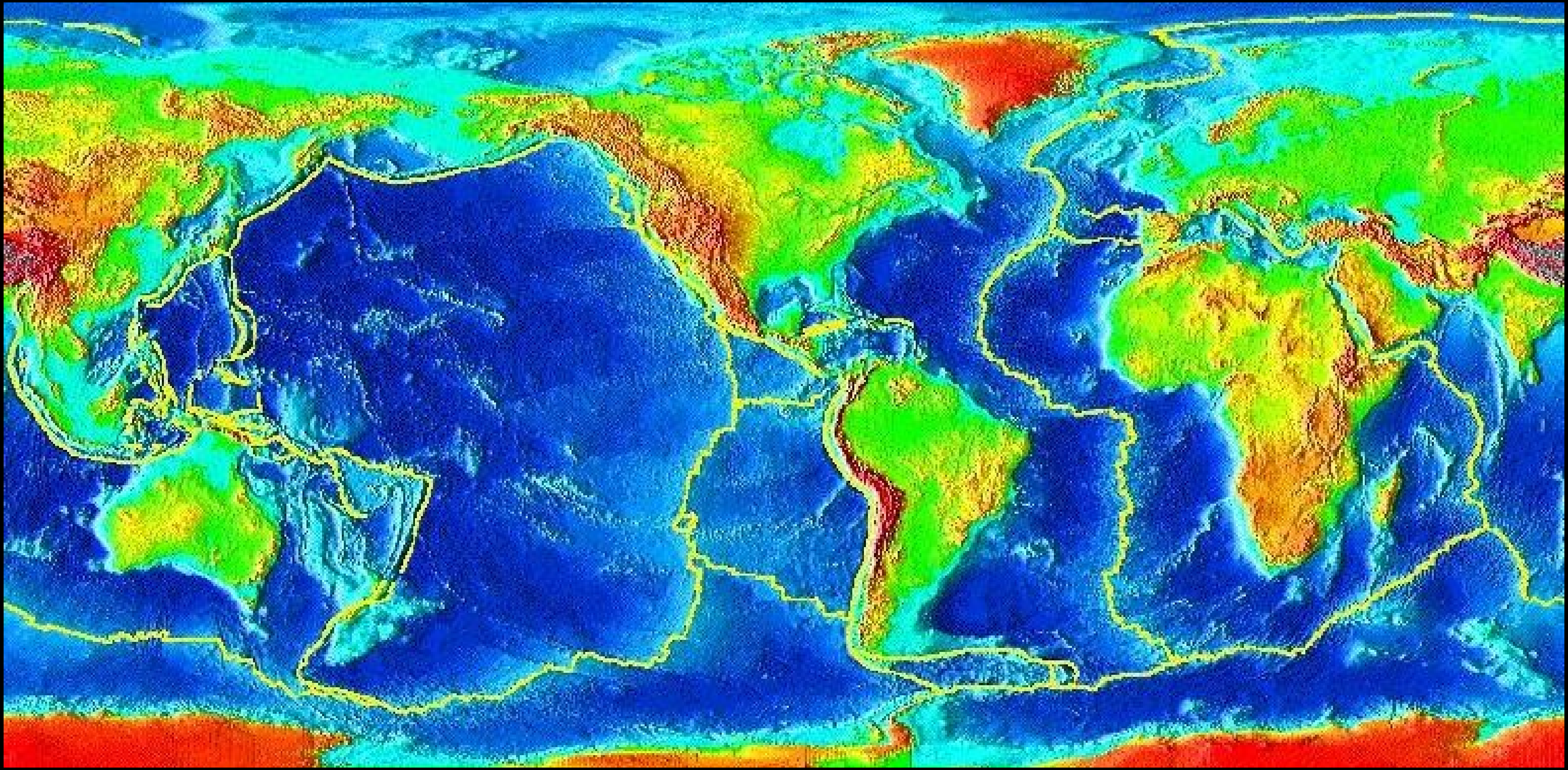
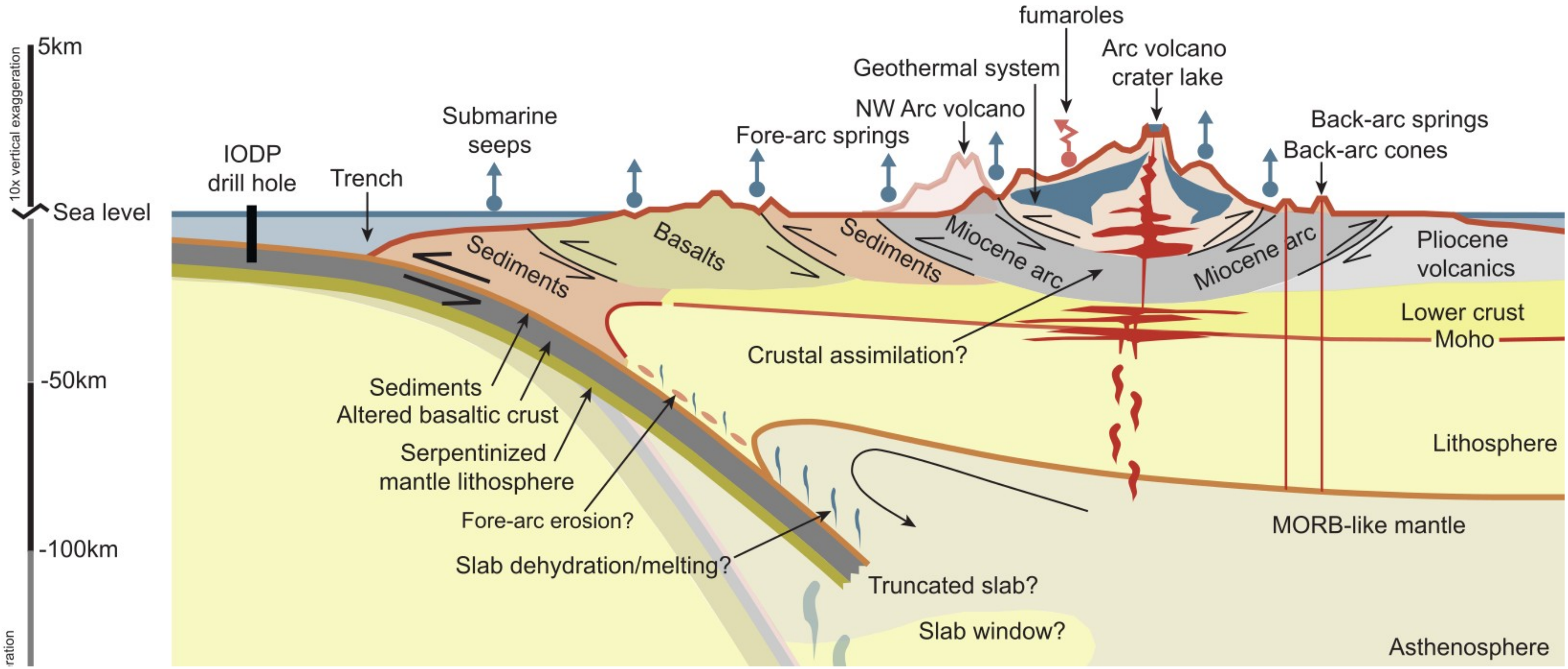


Gplate reconstruction



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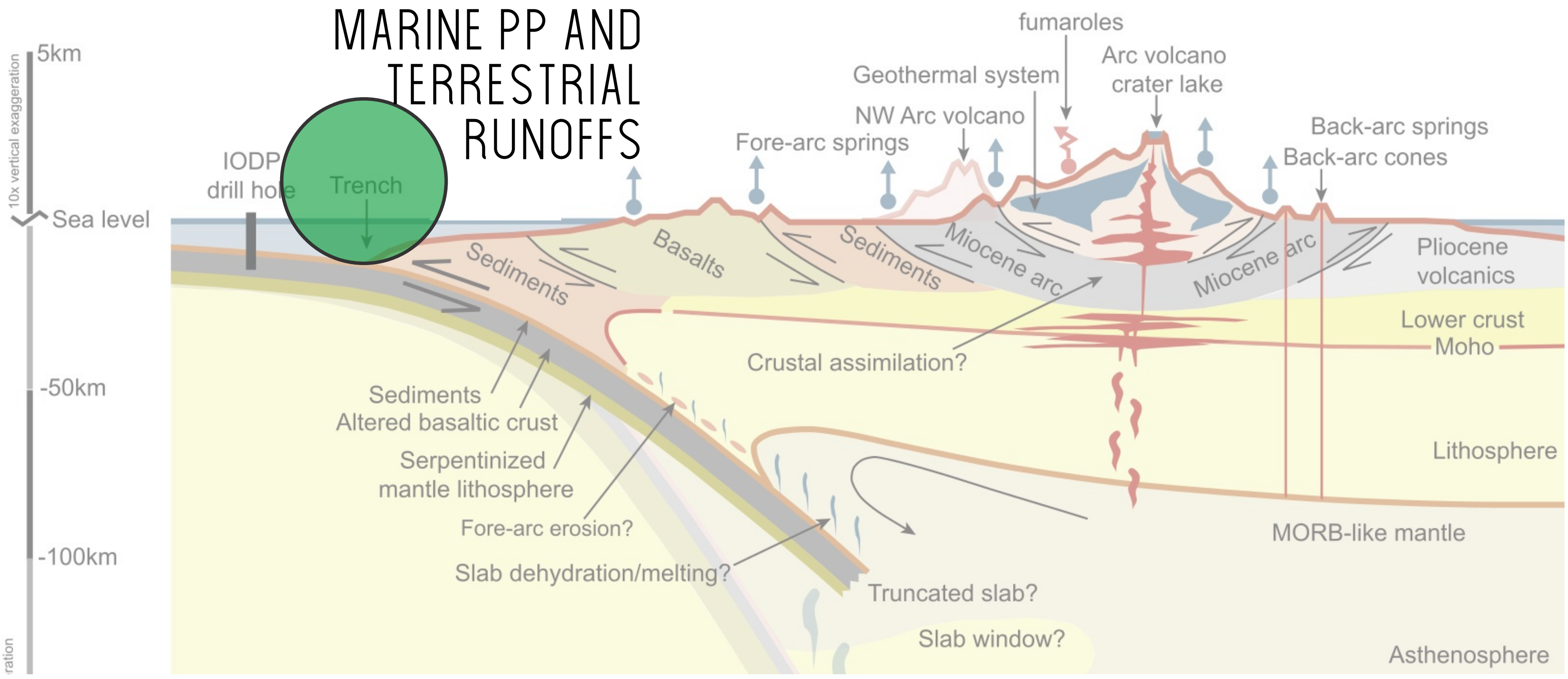
THE FATE OF MARINE CARBON



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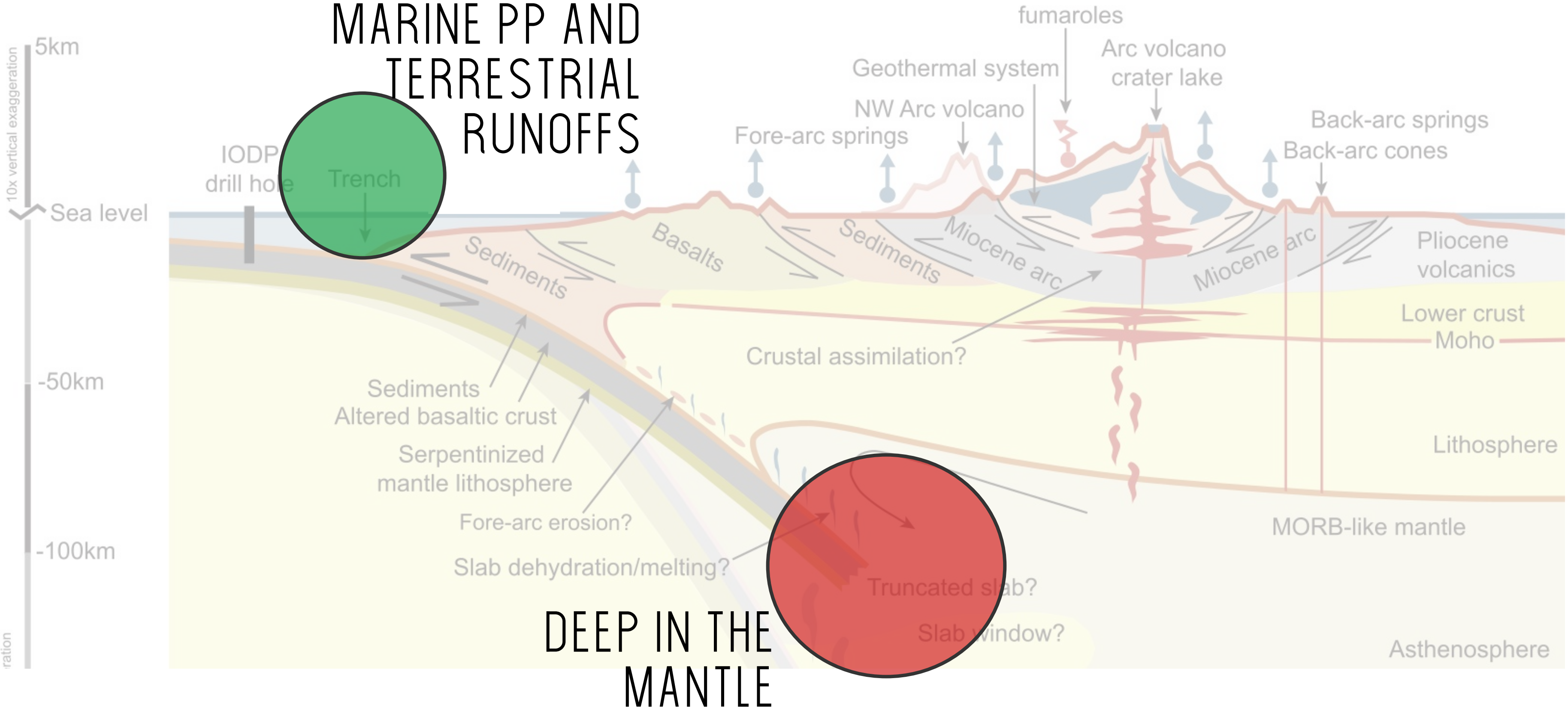
THE FATE OF MARINE CARBON



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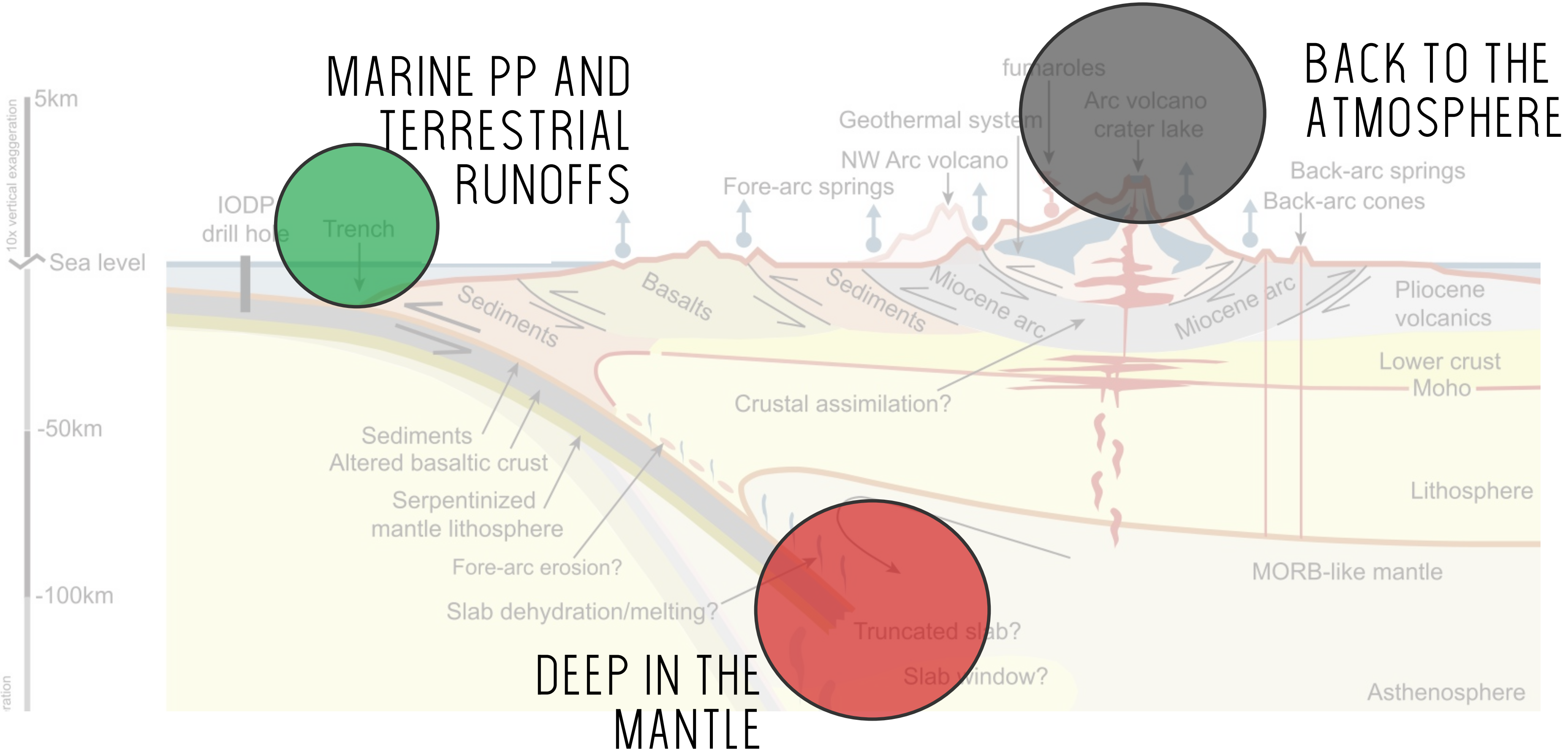
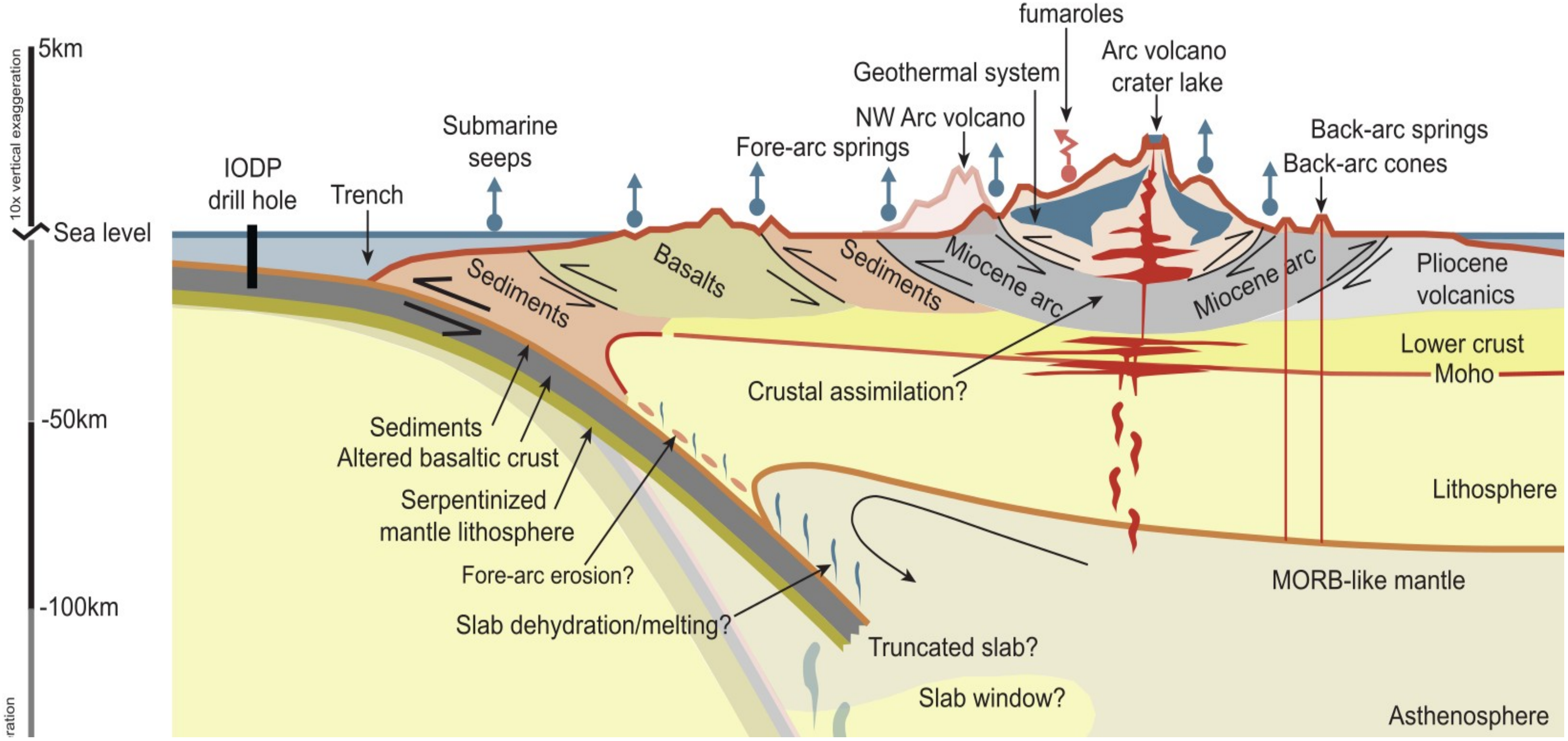


Giovannelli et al 2020 Eos

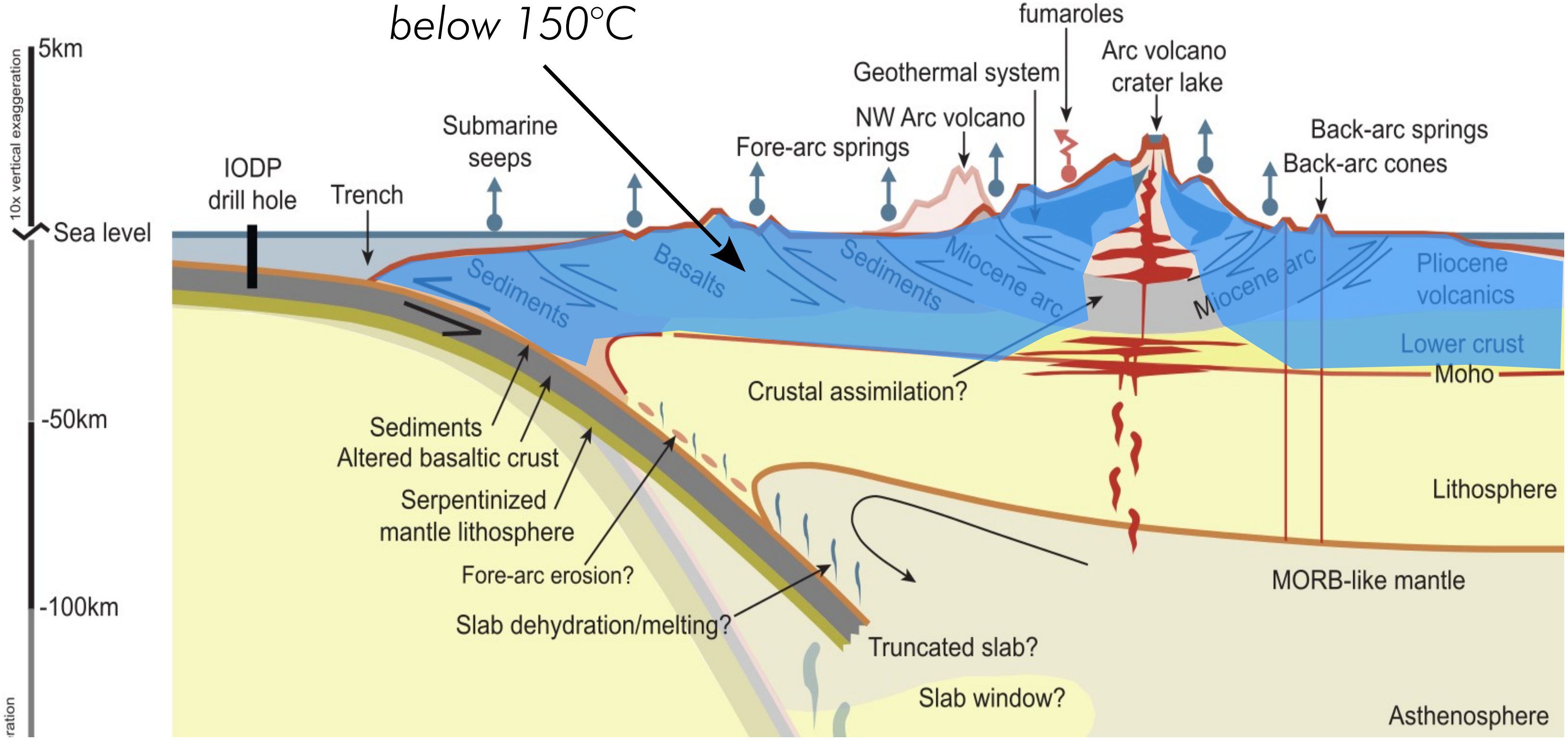

Schmidt Ocean Institute

credits: C Vetriani (Rutgers U)



Giovannelli et al 2020 Eos

potentially below 150°C



Giovannelli et al 2020 Eos

There is a pervasive Subsurface Biosphere

Proc. Natl. Acad. Sci. USA
Vol. 89, pp. 6045–6049, July 1992
Microbiology

The deep, hot biosphere

(geochemistry/planetology)

THOMAS GOLD
Cornell University, Ithaca, NY 14853

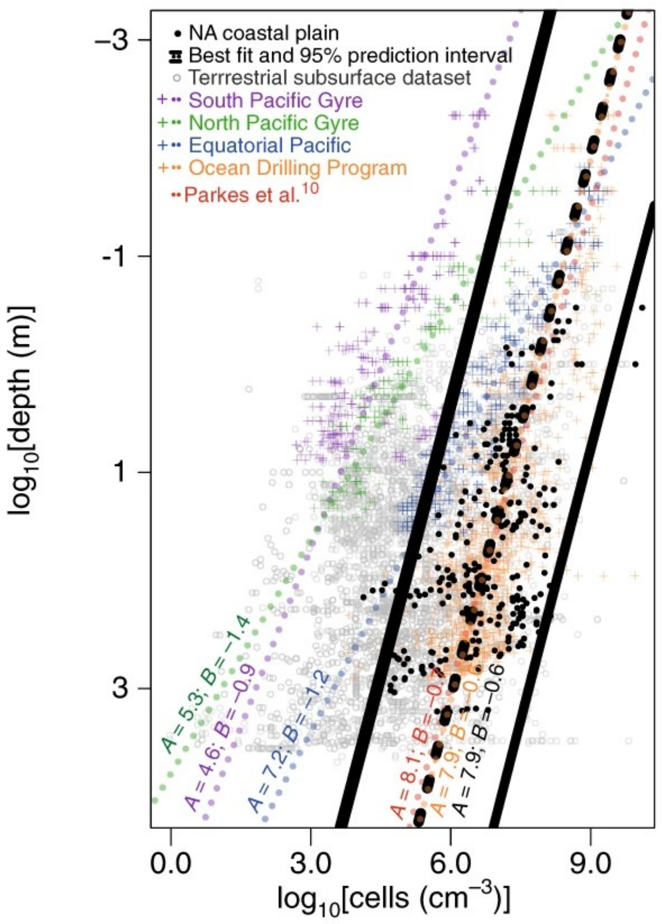
Contributed by Thomas Gold, March 13, 1992

ABSTRACT There are strong indications that microbial life is widespread at depth in the crust of the Earth, just as such life has been identified in numerous ocean vents. This life is not dependent on solar energy and photosynthesis for its primary energy supply, and it is essentially independent of the surface circumstances. Its energy supply comes from chemical sources, due to fluids that migrate upward from deeper levels in the Earth. In mass and volume it may be comparable with all surface life. Such microbial life may account for the presence of biological molecules in all carbonaceous materials in the outer crust, and the inference that these materials must have derived from biological deposits accumulated at the surface is therefore not necessarily valid. Subsurface life may be widespread among the planetary bodies of our solar system, since many of them have equally suitable conditions below, while having totally inhospitable surfaces. One may even speculate that such life may be widely disseminated in the universe, since planetary type bodies with similar subsurface conditions may be common as solitary objects in space, as well as in other solar-type systems.

We are familiar with two domains of life on the Earth: the surface of the land and the body of the oceans. Both domains

gasification. As liquids, gases, and solids make new contacts, chemical processes can take place that represent, in general, an approach to a lower chemical energy condition. Some of the energy so liberated will increase the heating of the locality, and this in turn will liberate more fluids there and so accelerate the processes that release more heat. Hot regions will become hotter, and chemical activity will be further stimulated there. This may contribute to, or account for, the active and hot regions in the Earth's crust that are so sharply defined.

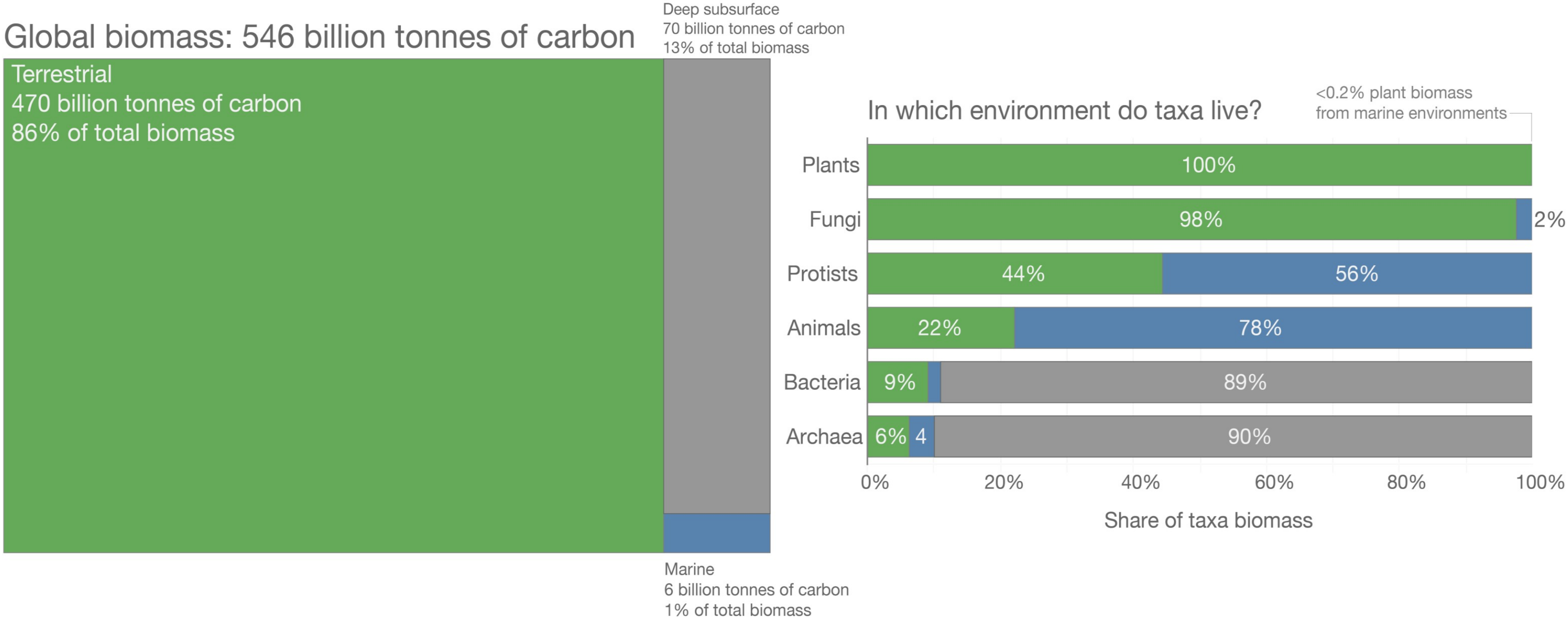
Where such liquids or gases stream up to higher levels into different chemical surroundings, they will continue to represent a chemical disequilibrium and therefore a potential energy source. There will often be circumstances where chemical reactions with surrounding materials might be possible and would release energy, but where the temperature is too low for the activation of the reactions. This is just the circumstance where biology can successfully draw on chemical energy. The life in the ocean vents is one example of this. There it is bacterial life that provides the first stage in the process of drawing on this form of chemical energy; for example, methane and hydrogen are oxidized to CO_2 and water, with oxygen available from local sulfates and metal



Gold 1992 PNAS
Magnabosco et al 2018 Nature Geoscience

Where do we find life on Earth?

Global distribution of Earth's biomass by the environment in which its found (**terrestrial**, **marine**, or **deep subsurface**).
This is shown as the aggregate global biomass (left) and the breakdown of specific taxa by the environment in which its found (right).
Biomass is measured in tonnes of carbon.



Source: Based on data from Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences.*
This is a visualization from OurWorldinData.org, where you find data and research on how the world is changing.

https://ourworldindata.org/

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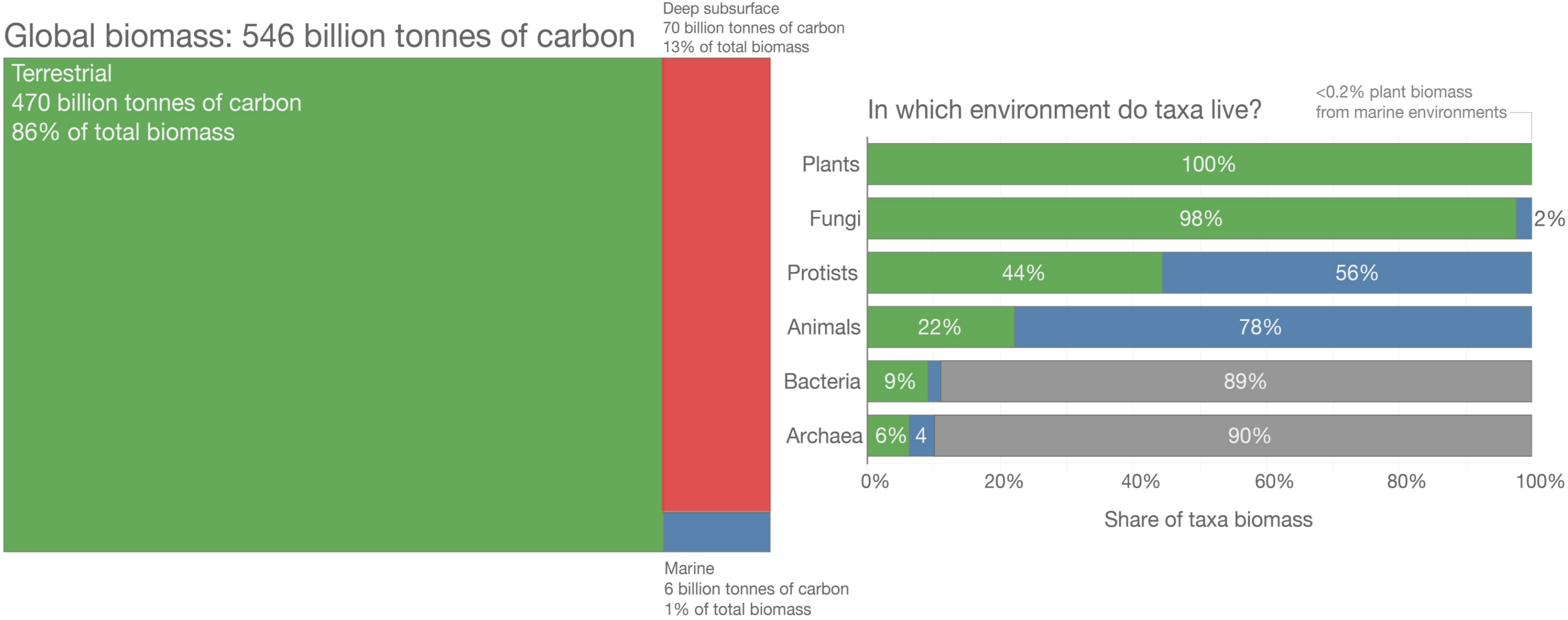

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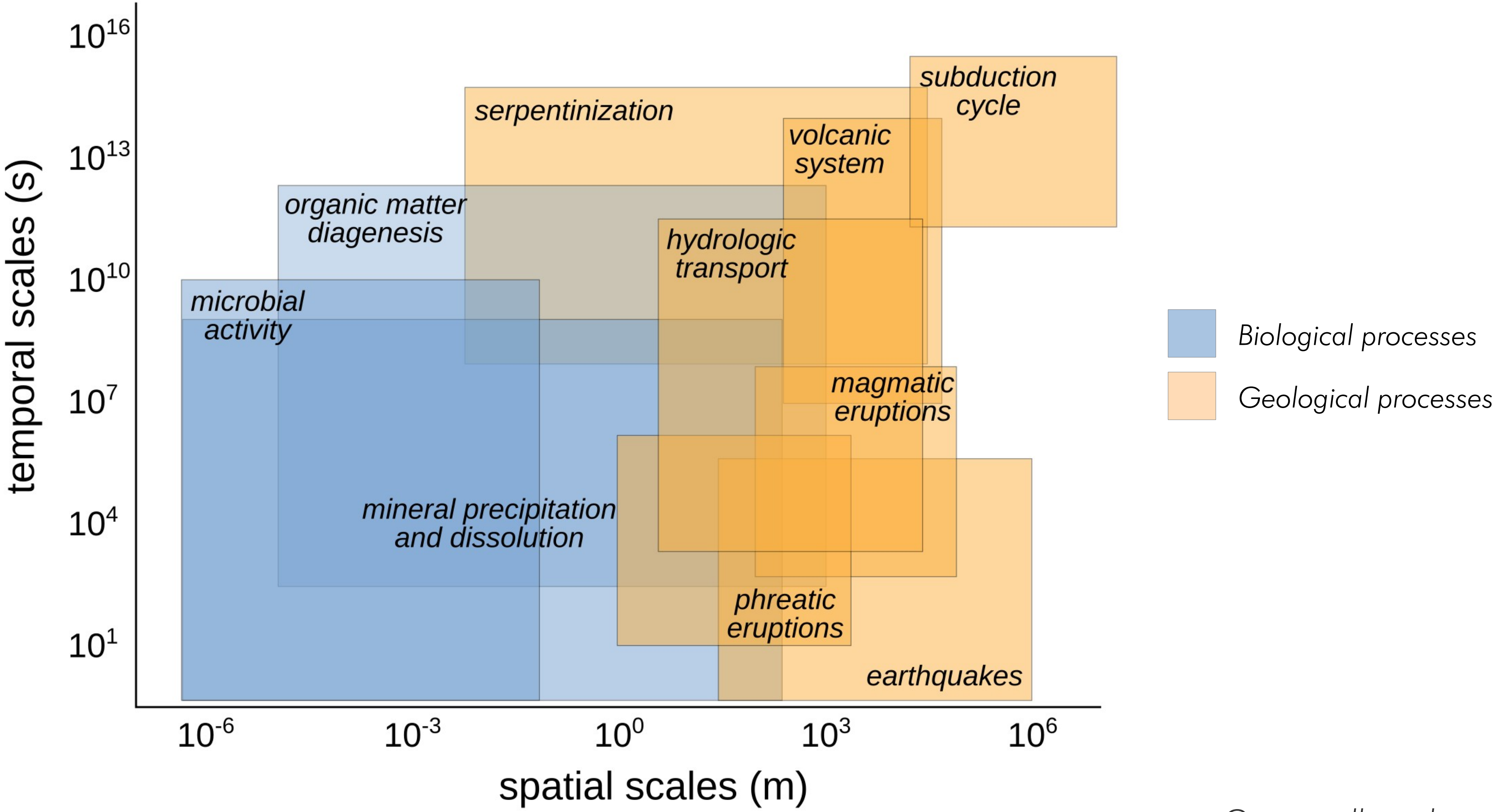
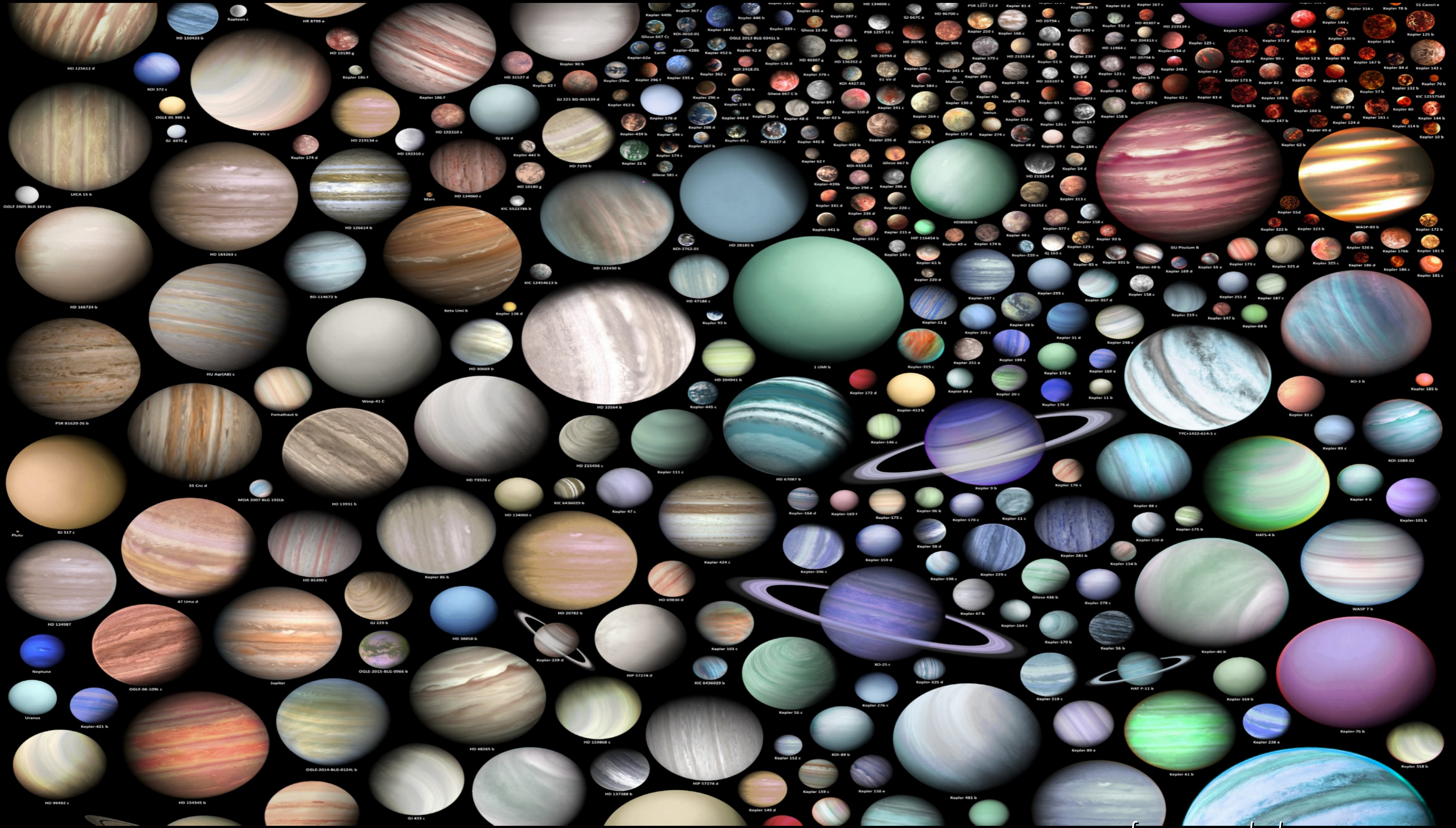
Geology and Biology are potentially on the same scales



Giovannelli et al in prep



from www.halcyonmaps.com

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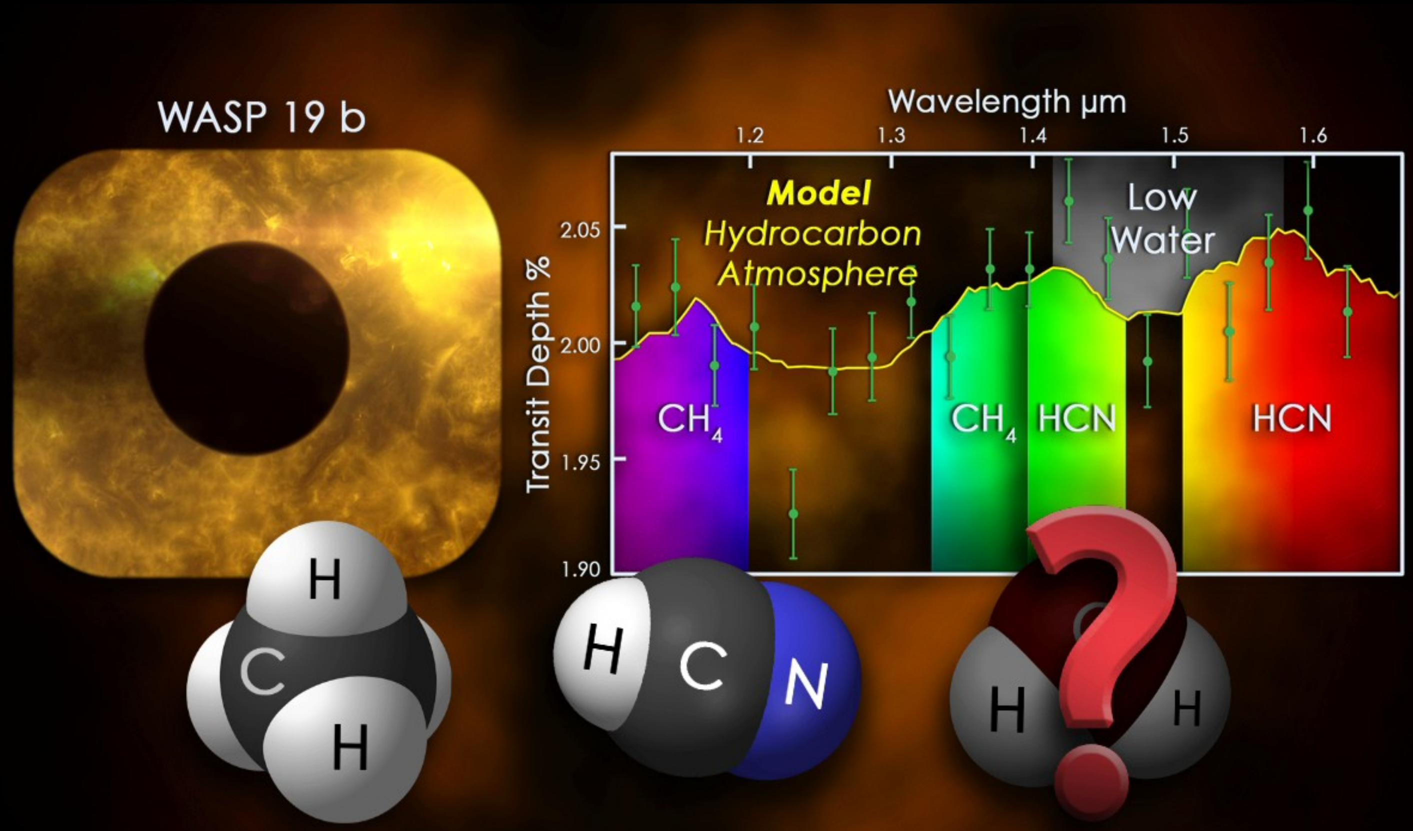
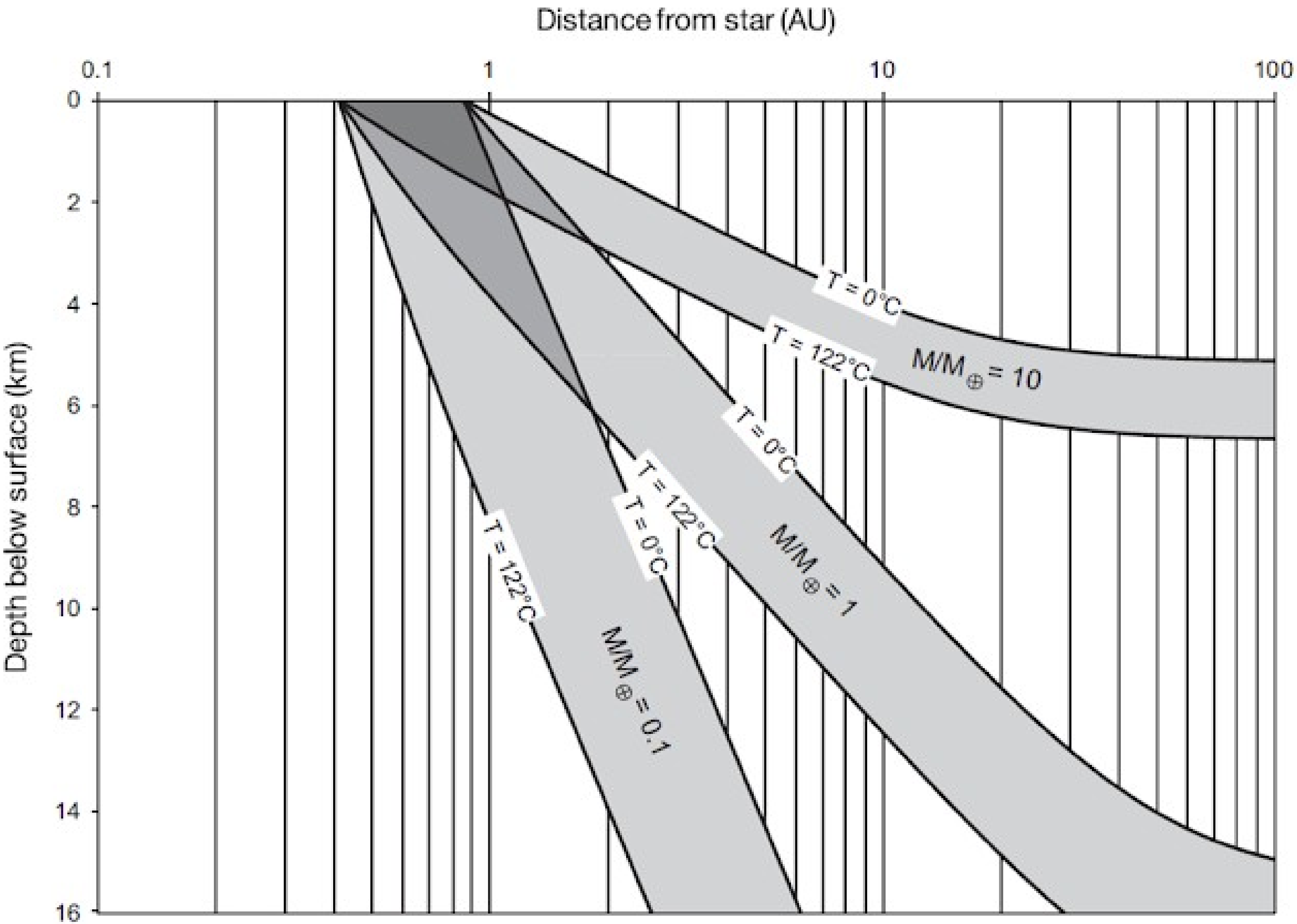


from NASA svs.gsfc.nasa.gov/11428



McMahon et al. 2013 Planet Space Sci

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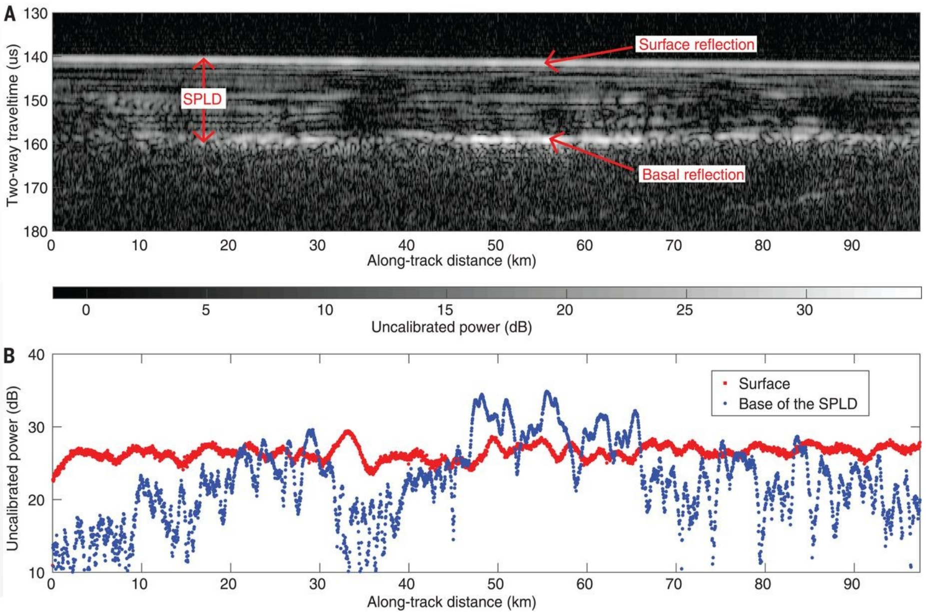
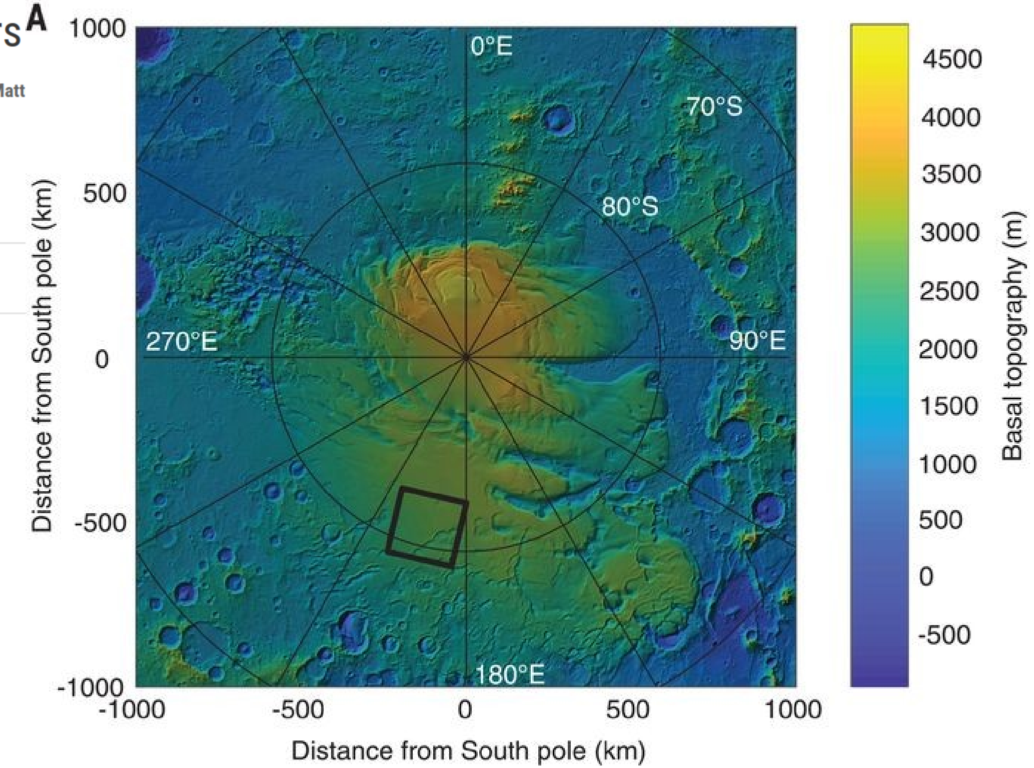
REPORT

Radar evidence of subglacial liquid water on Mars

R. Orosei[1,*], S. E. Lauro[2], E. Pettinelli[2], A. Cicchetti[3], M. Coradini[4], B. Cosciotti[2], F. Di Paolo[1], E. Flamini[4], E. Matt
+ See all authors and affiliations

Science 03 Aug 2018:
Vol. 361, Issue 6401, pp. 490-493
DOI: 10.1126/science.aar7268

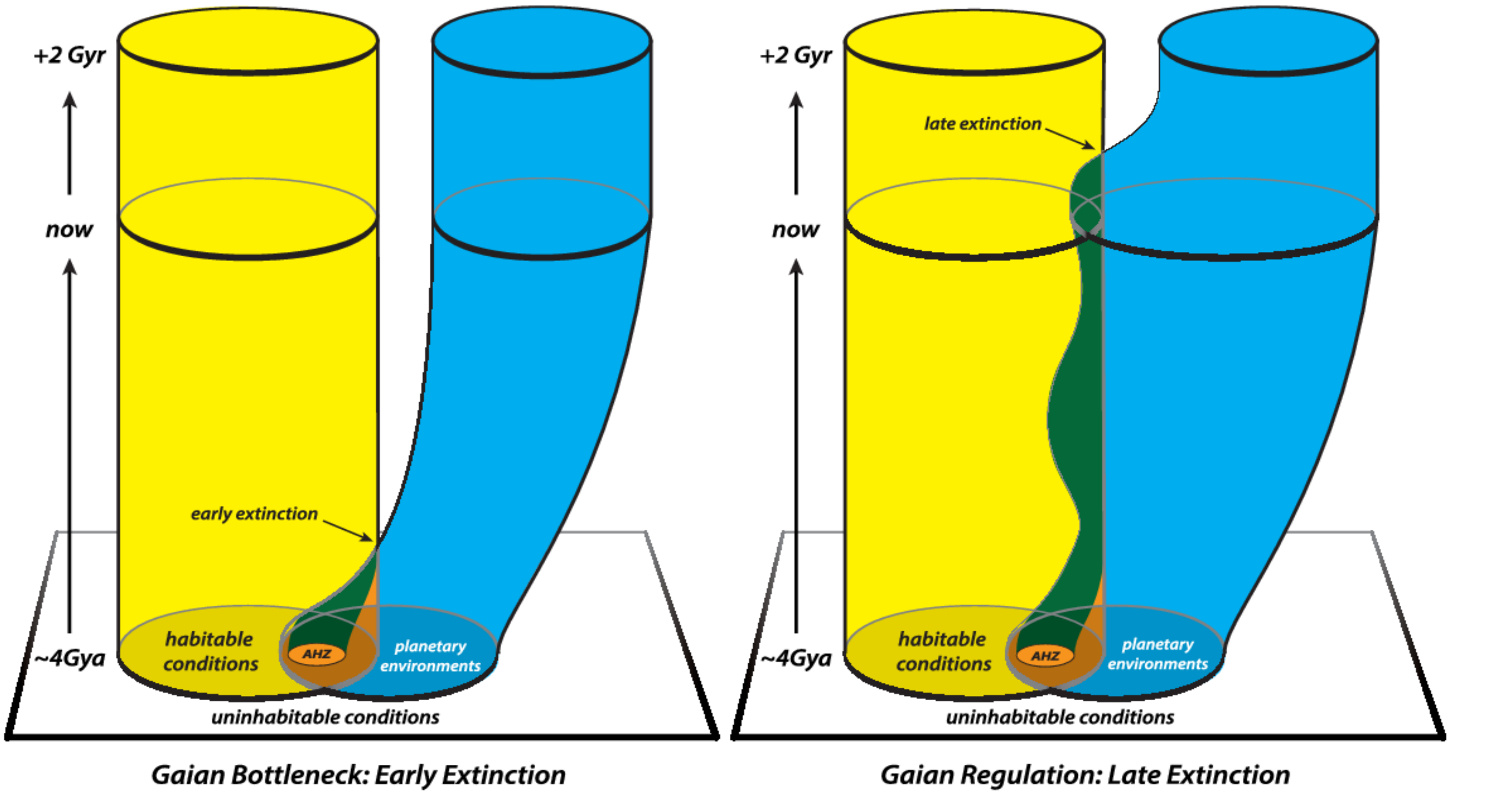




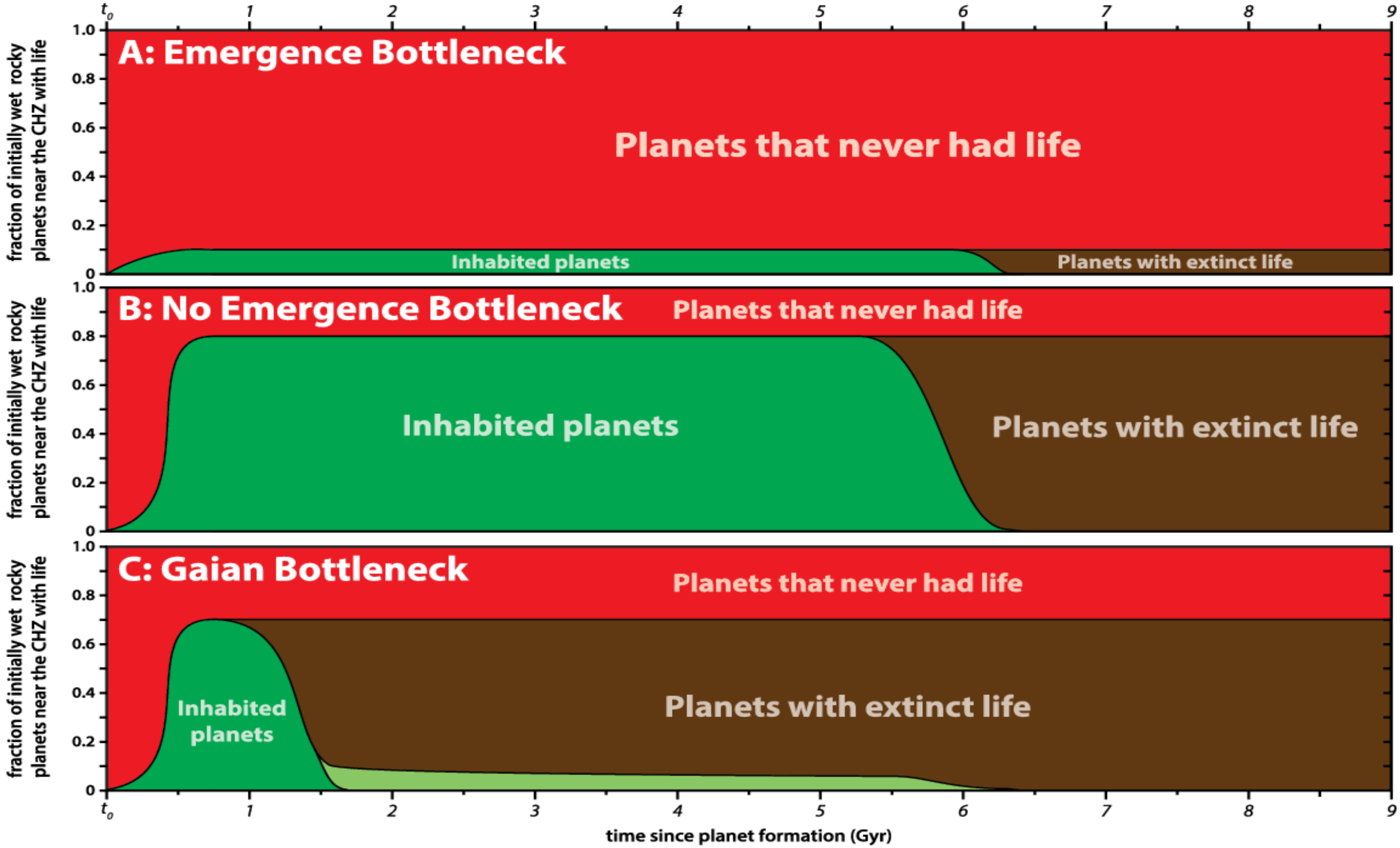
GIOVANNELLI LAB

Orosei et al. 2018 Science

No Emergence Bottleneck



Chopra and Lineweaver 2016 Astrobiology



Chopra and Lineweaver 2016 Astrobiology

Take home messages

- *Geosphere and Biosphere have co-evolved through time*
- *Prokaryotes are responsible for the bio in biogeochemistry both at the ecosystem level and through time*
- *Genes (oxydoredutases) might hold the key to unserdtand metabolism emergence*
- *The extent of co-evolution has been thus far greatly underestimated*
- *Niche construction is widespread, and a modified environment is part of Life's ecological inheritance*
- *The habitability of our planet is determined in part by the presence of life itself*
- *The (lack of) early feedback mechanisms between life and a planet may explain the presence (and absence) of life elsewhere*

Suggested readings

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