DEEP LIFE, VOLATILES AND THE SEARCH FOR EXTRATERRESTRIAL LIFE

Donato Giovannelli

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GIOVANNELLI LAB

DIPARTIMENTO DI BIOLOGIA

IRBIM
Istituto per le Risorse Biologiche e le Biotecnologie Marine

RUTGERS
THE STATE UNIVERSITY OF NEW JERSEY

EBSI
EARTH - LIFE SCIENCE INSTITUTE

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NASA

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Mars

modern Earth

Venus

early Earth

NASA

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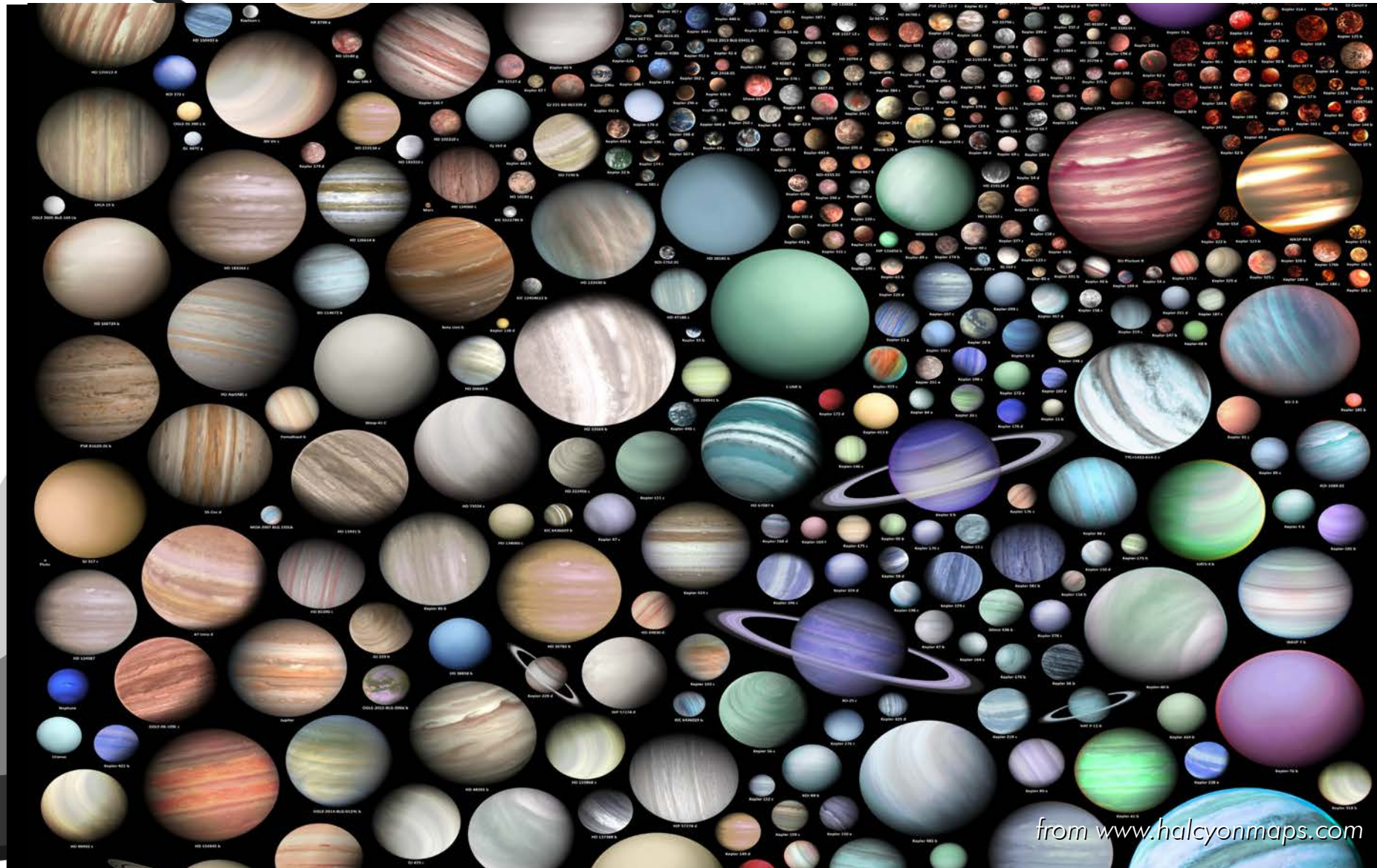

from www.halcyonmaps.com

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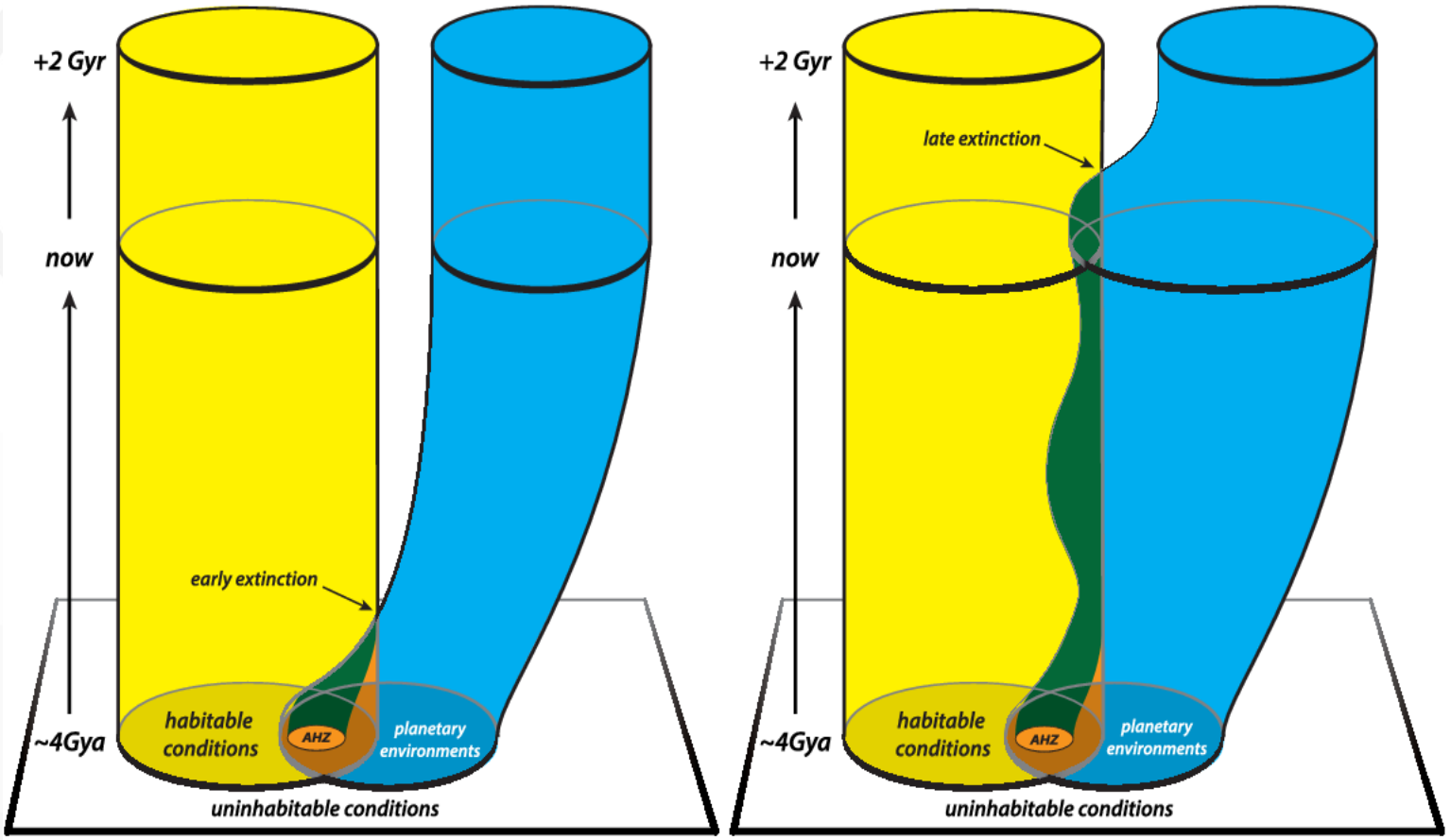
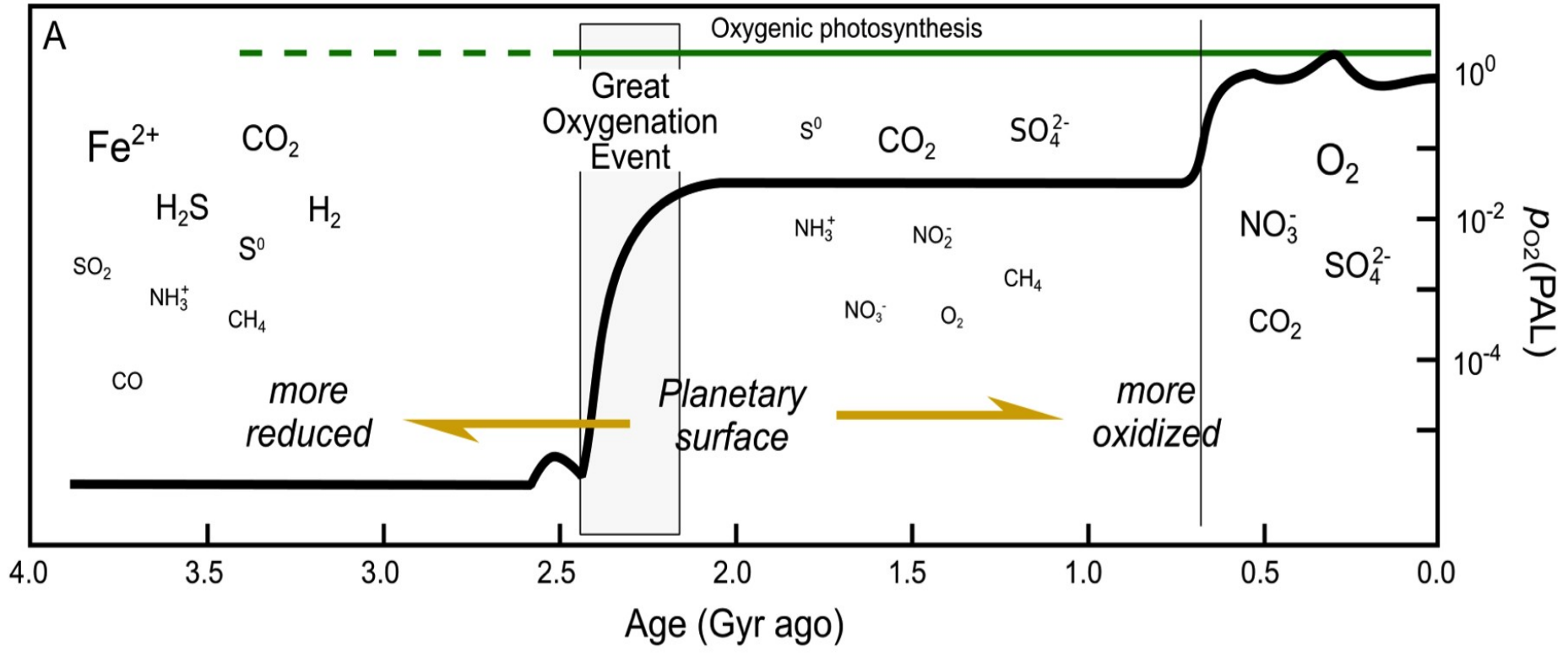
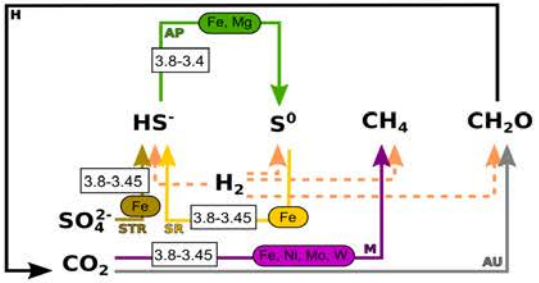
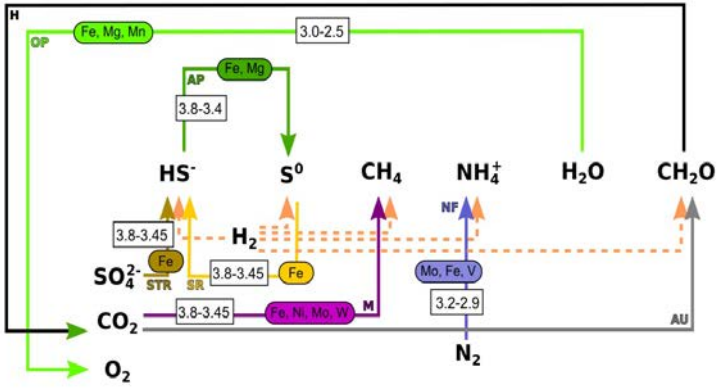


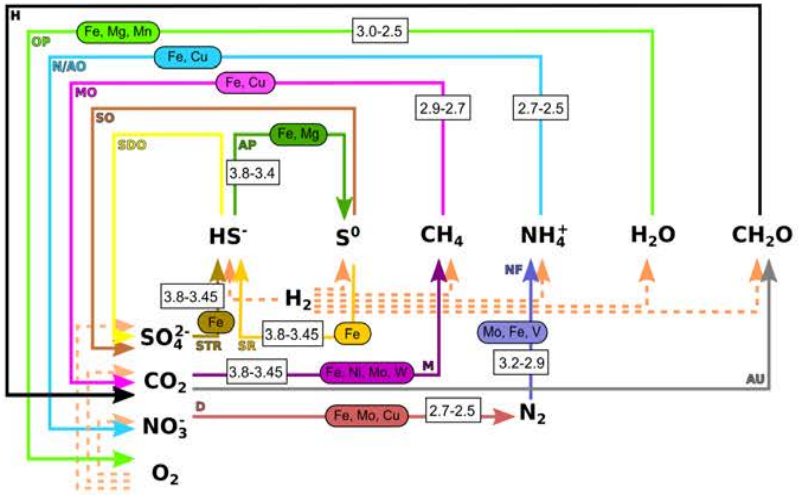
Chopra and Lineweaver, 2016 Astrobiology

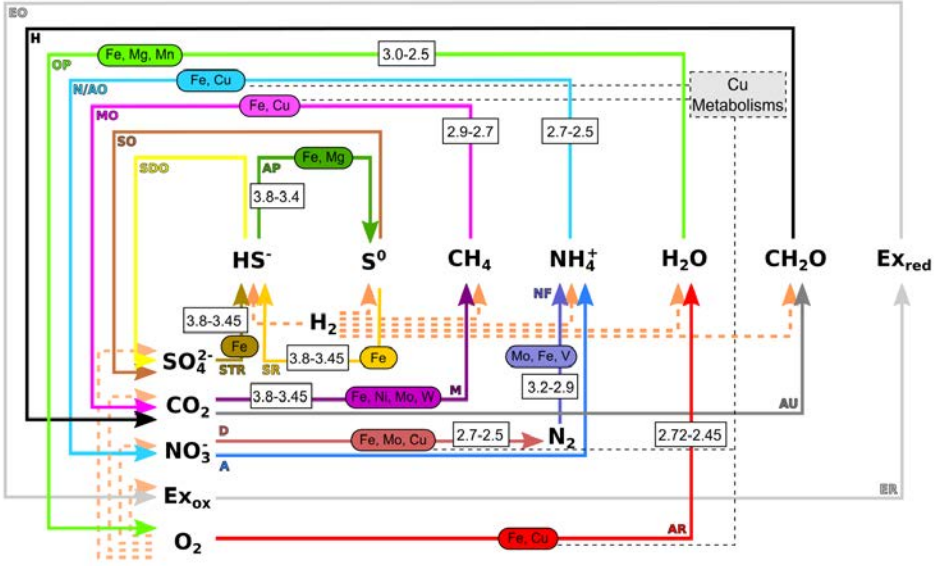


Jelen et al, 2016. Ann. Rev. Microbiol.

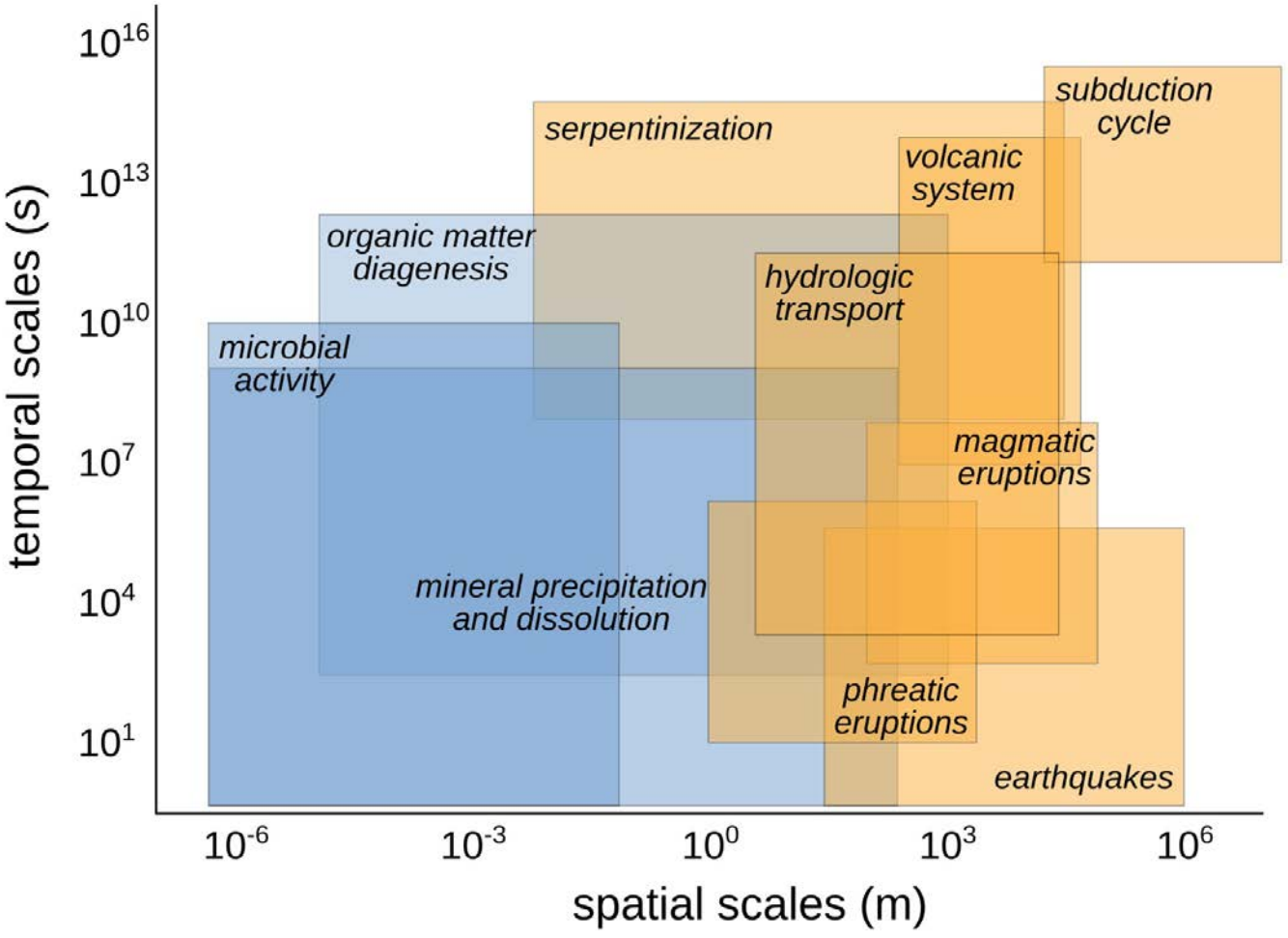








Moore et al. 2017 Nature Geosci.



Giovannelli, Barry, Lloyd, de Moor, Schrenk, unpublished

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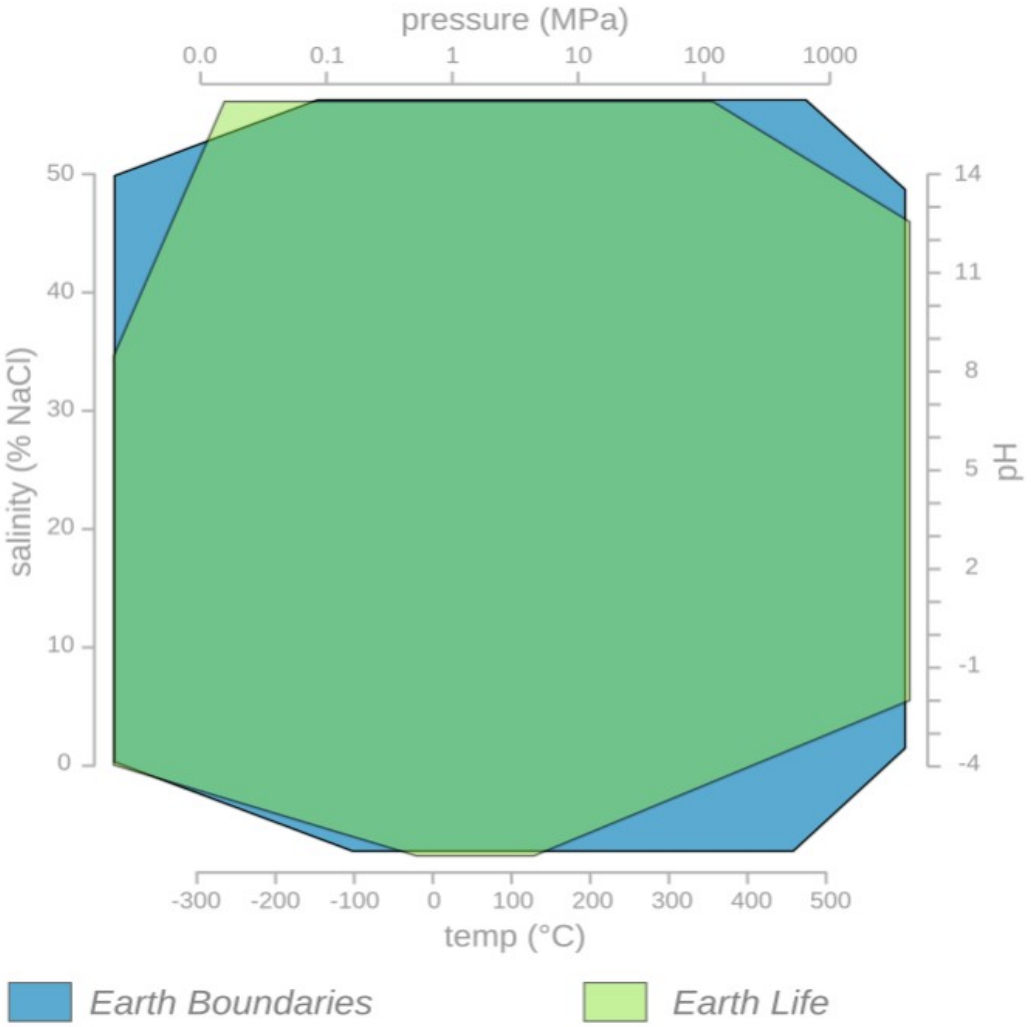

Merino et al, 2019 Front Microbiol
Giovannelli et al. in prep

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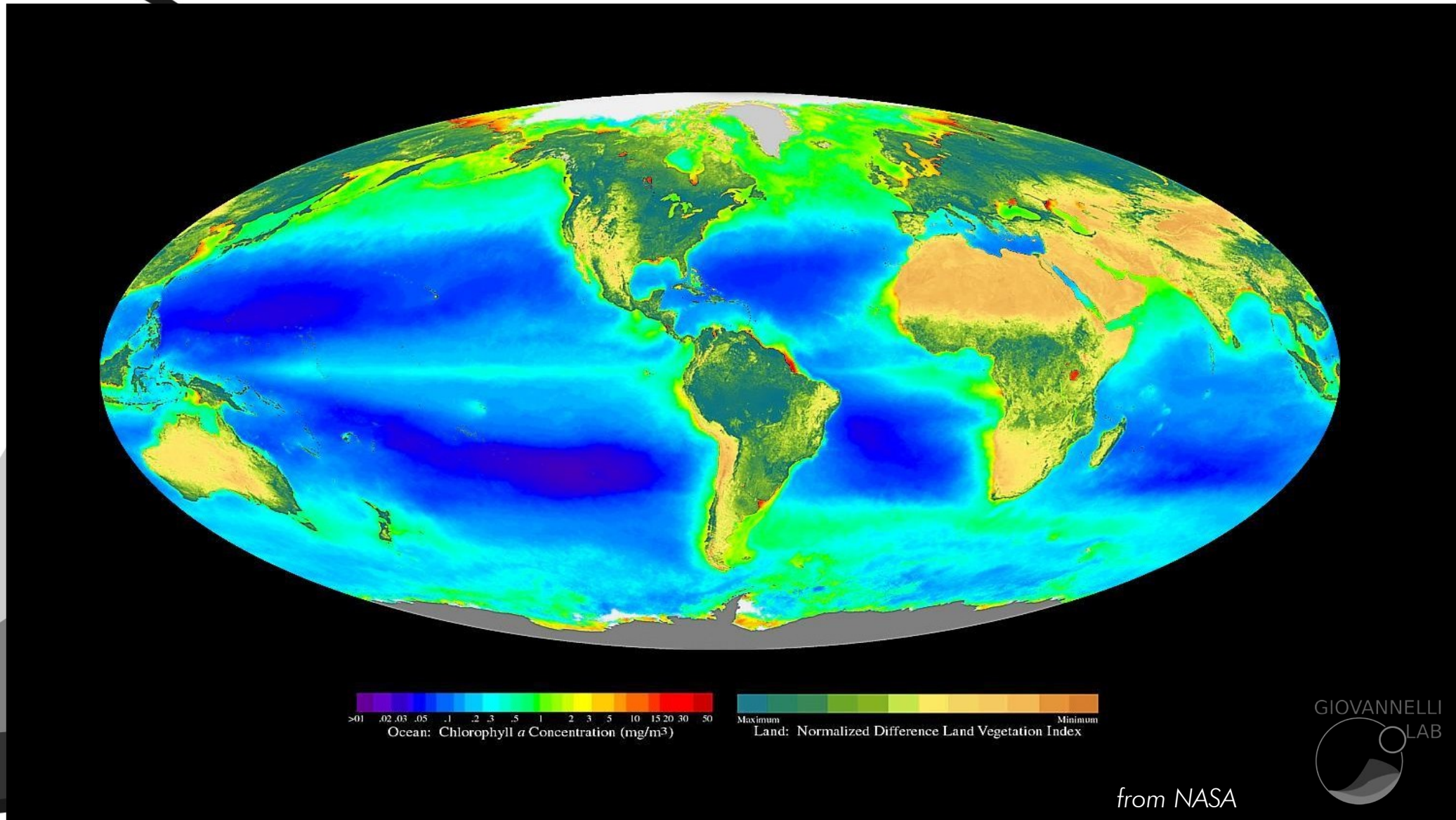

from NASA

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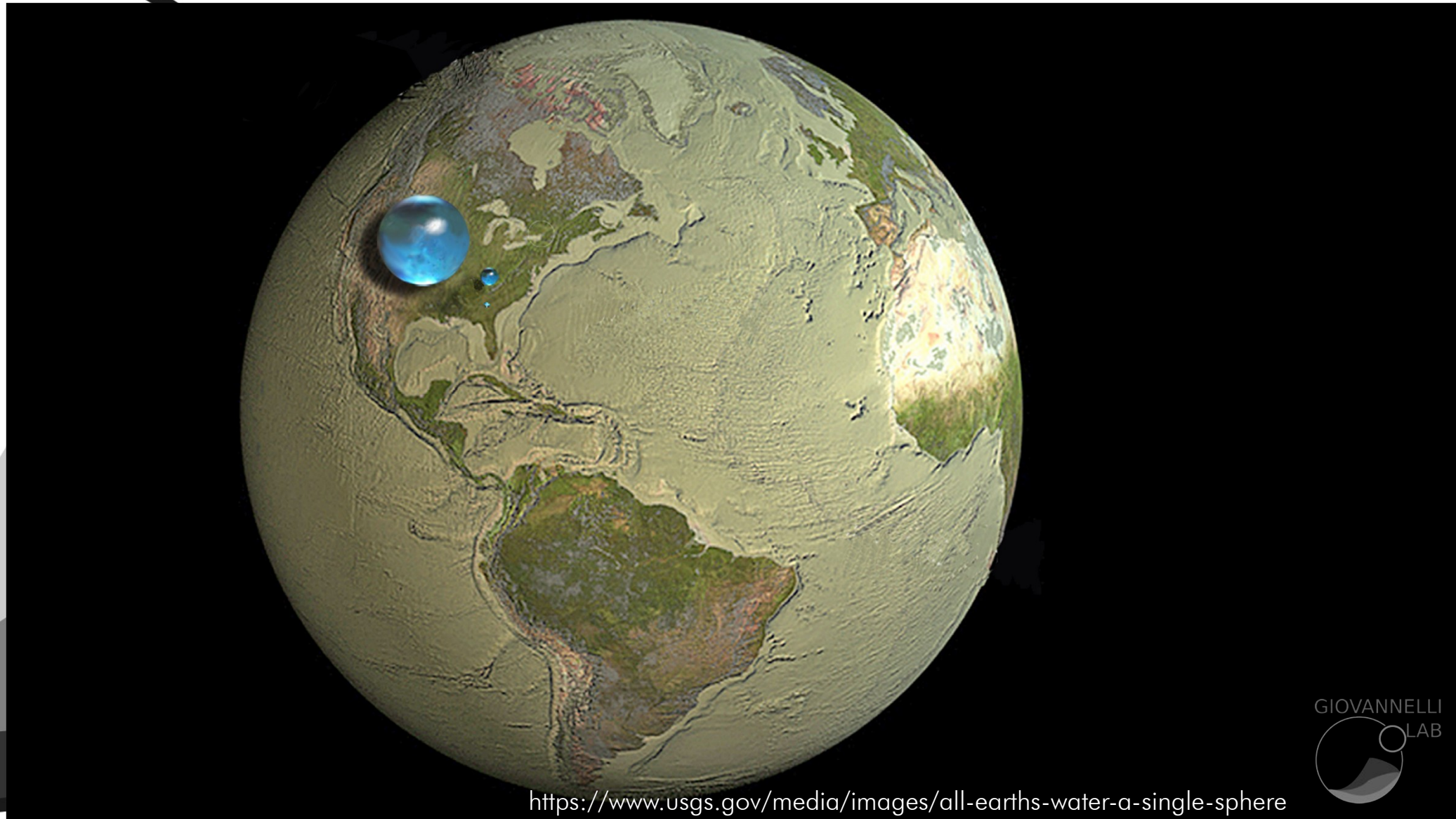

https://www.usgs.gov/media/images/all-earths-water-a-single-sphere

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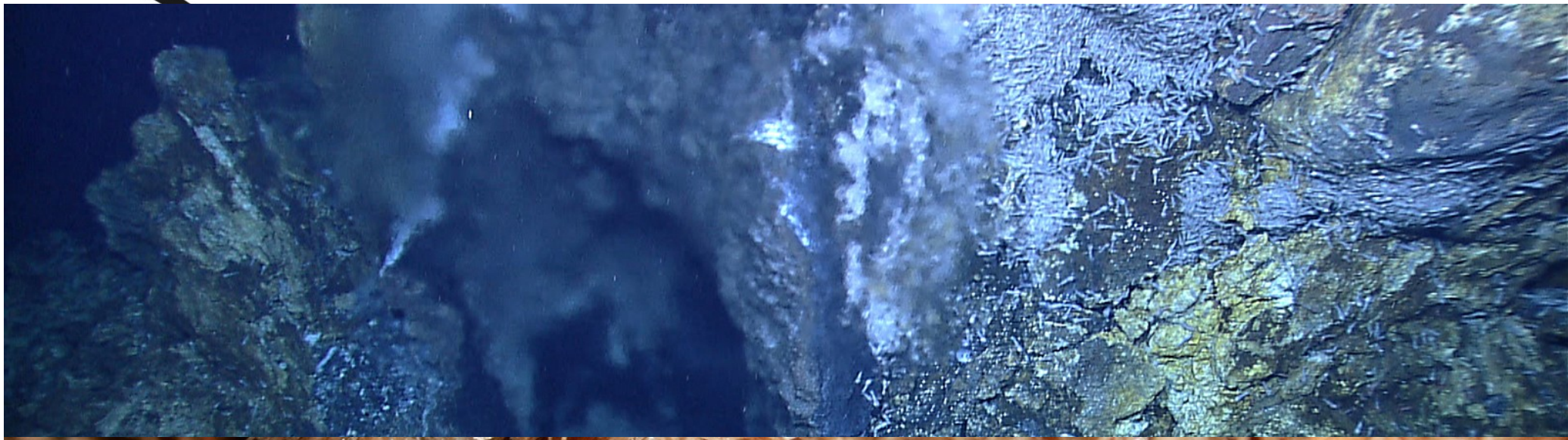


Proc. Natl. Acad. Sci. USA
Vol. 89, pp. 6045–6049, July 1992
Microbiology

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

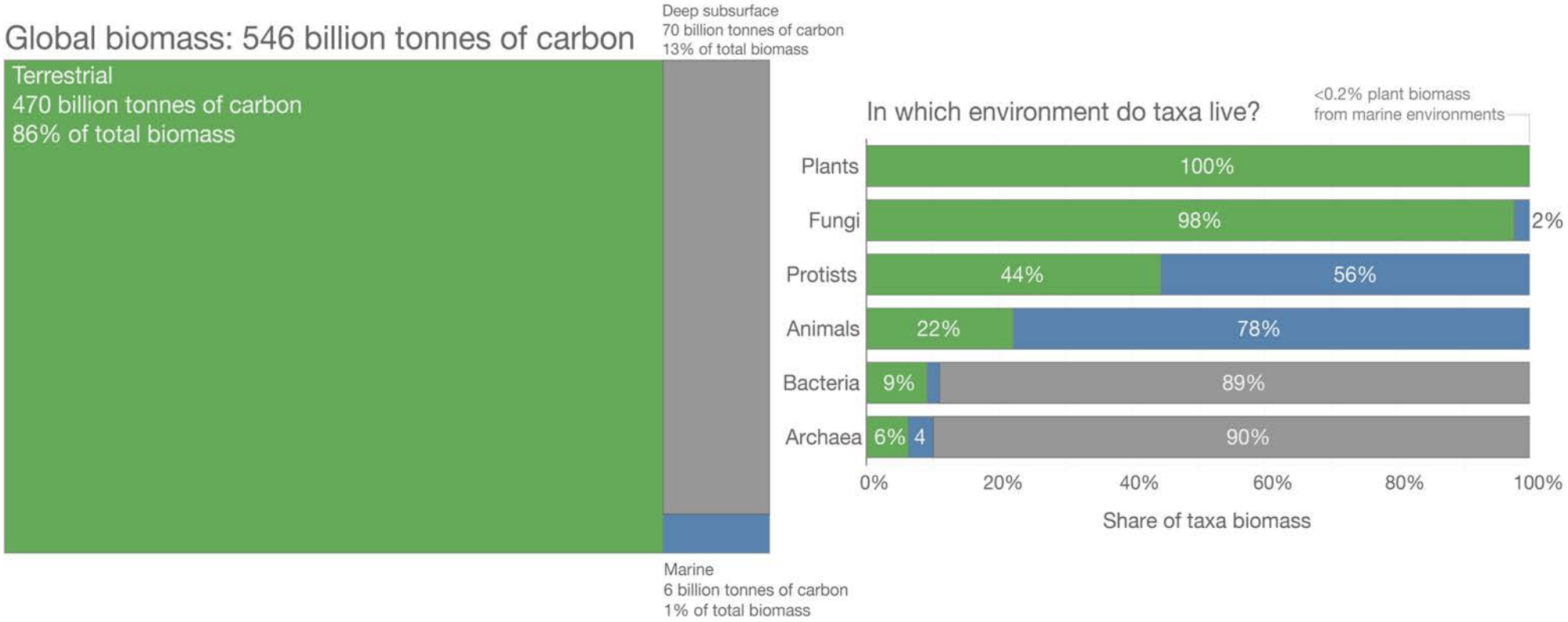
gasification. As liquids, gases, and solids make new contacts, chemical processes can take place that represent, in general, an approach to a lower chemical energy condition. Some of the energy so liberated will increase the heating of the locality, and this in turn will liberate more fluids there and 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

Where do we find life on Earth?

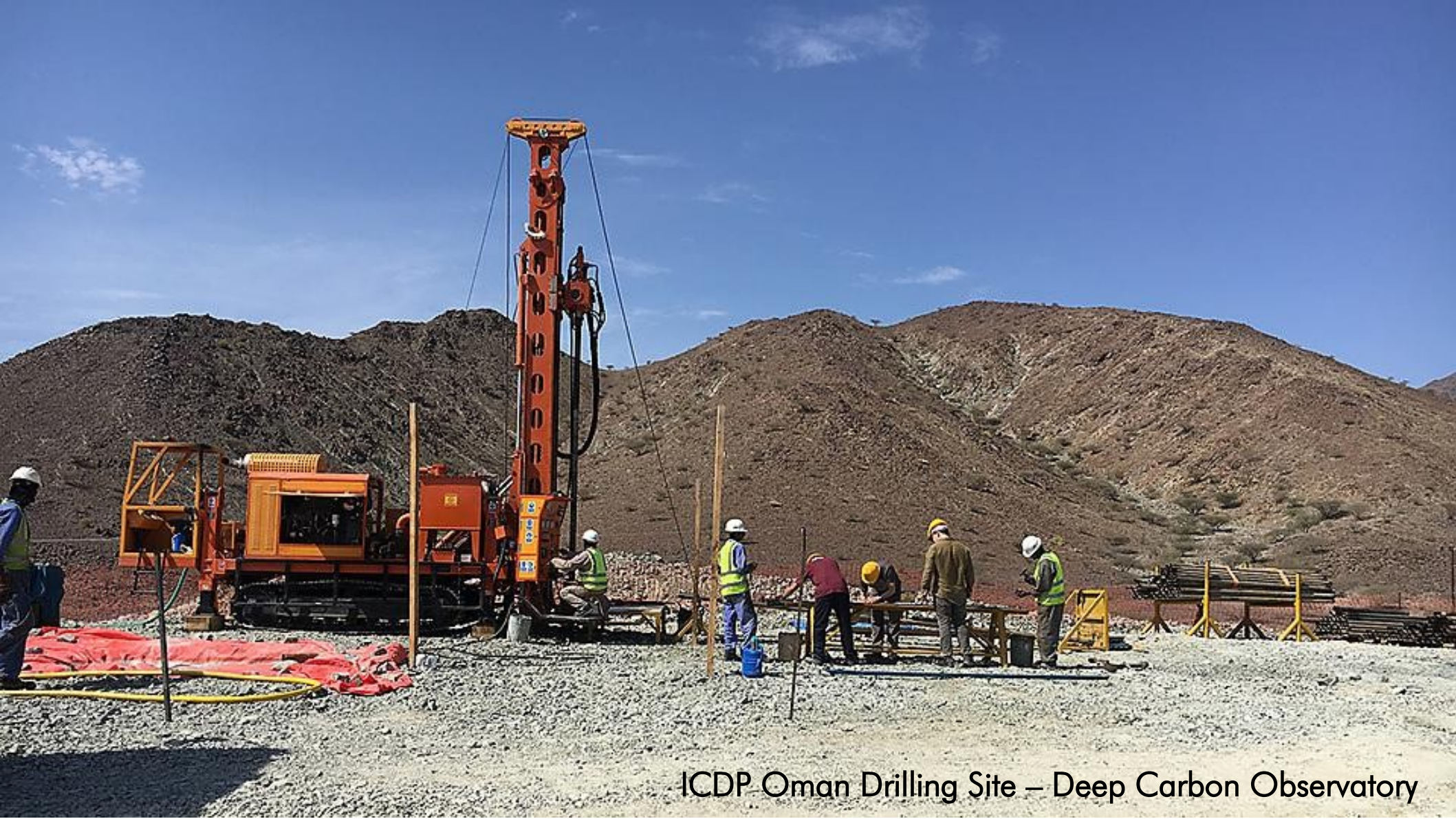
Our World in Data

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.



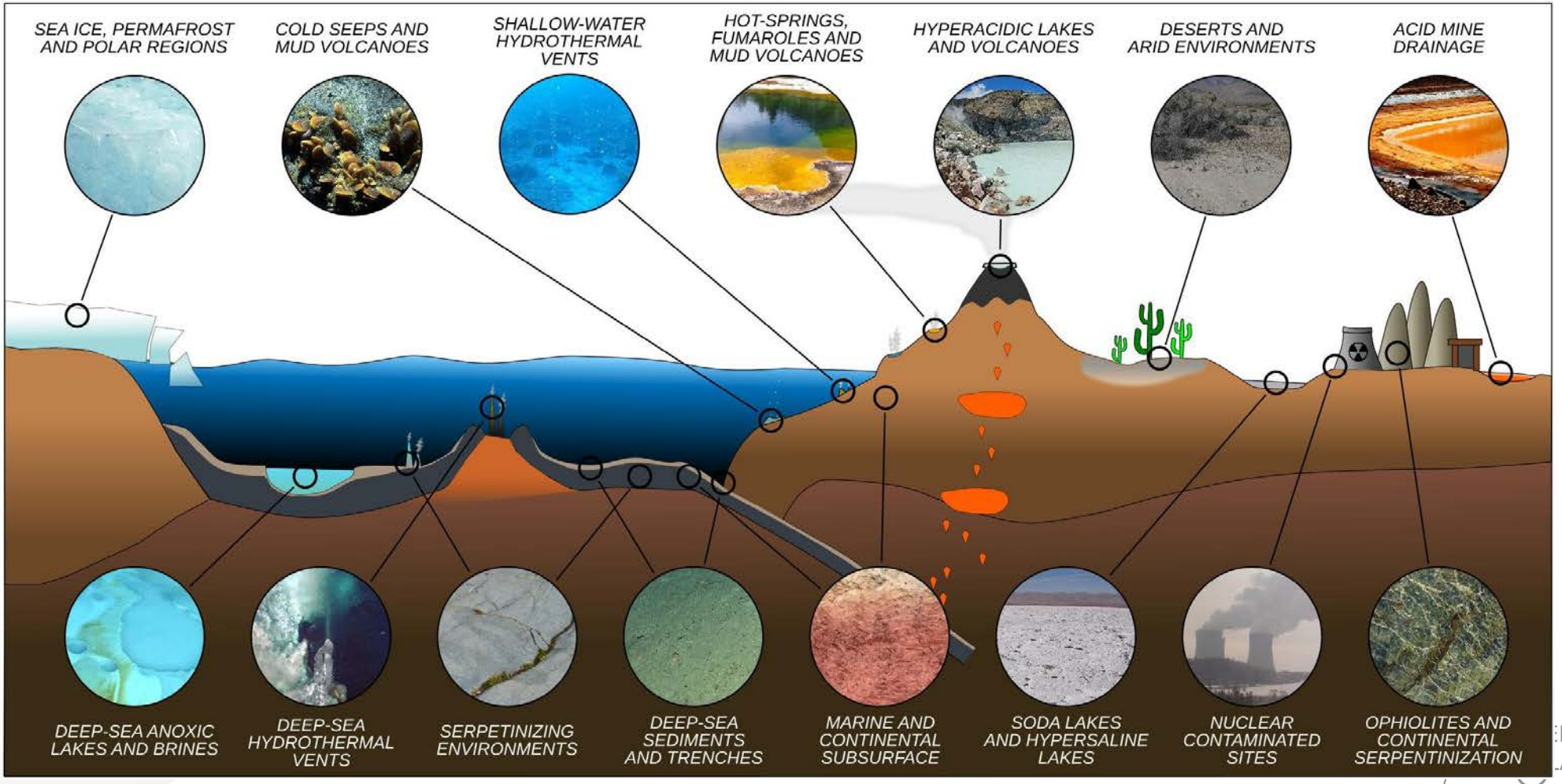
Source: Based on data from Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences.*
This is a visualization from OurWorldinData.org, where you find data and research on how the world is changing.

Joides Resolution
NSF International Ocean Discovery Program

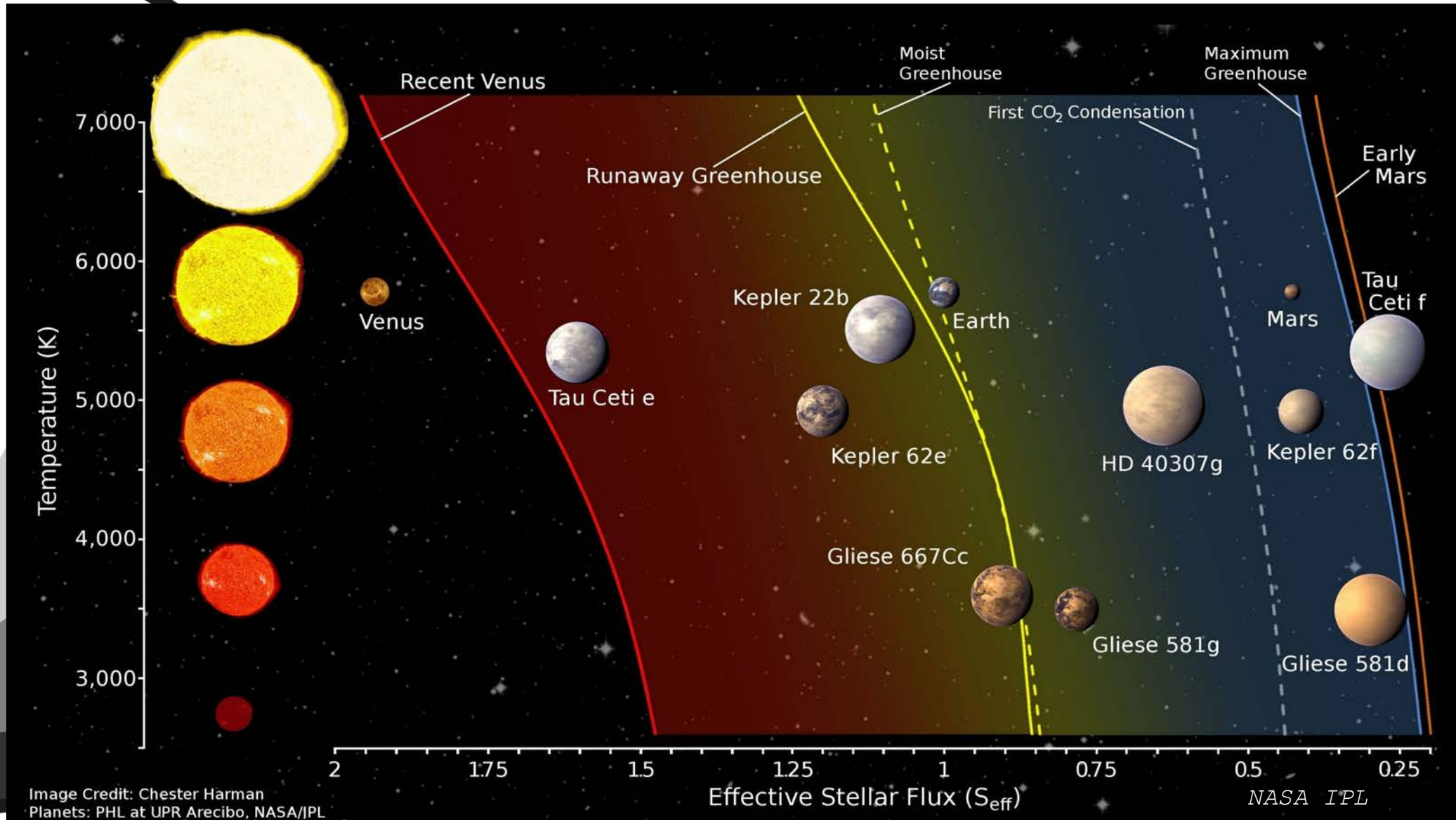


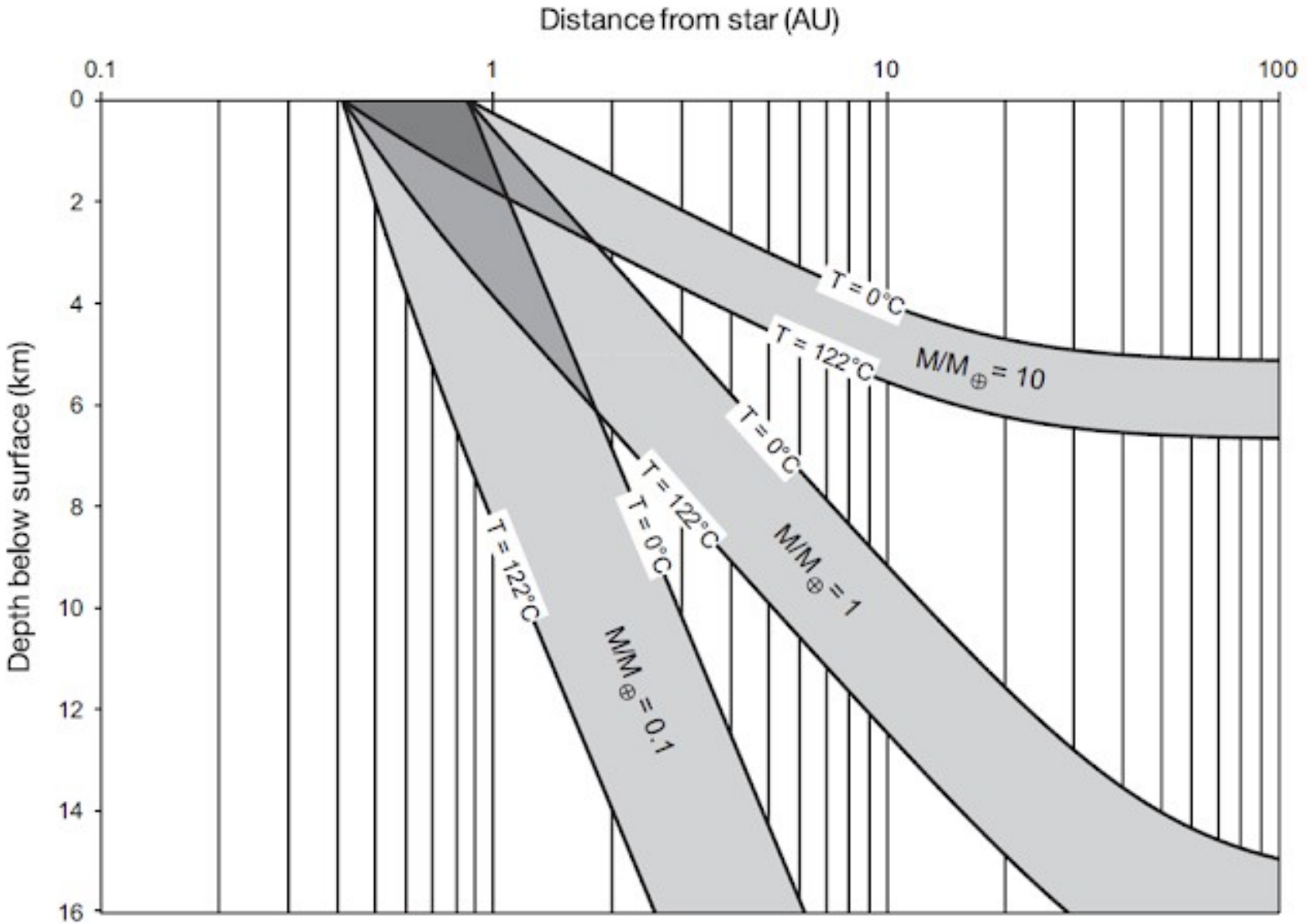
ICDP Oman Drilling Site – Deep Carbon Observatory

2.4 km Deep Canadian Mine – Deep Carbon Observatory



Merino et al. 2019 Front Microbiol


Recent Venus
Moist Greenhouse
Maximum Greenhouse
First CO_2 Condensation
Runaway Greenhouse
Early Mars
Venus
Kepler 22b
Earth
Mars
Tau Ceti f
Tau Ceti e
Kepler 62e
HD 40307g
Kepler 62f
Gliese 667Cc
Gliese 581g
Gliese 581d
Temperature (K)
7,000
6,000
5,000
4,000
3,000
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/IPL
NASA IPL



McMahon et al. 2013 Planet Space Sci

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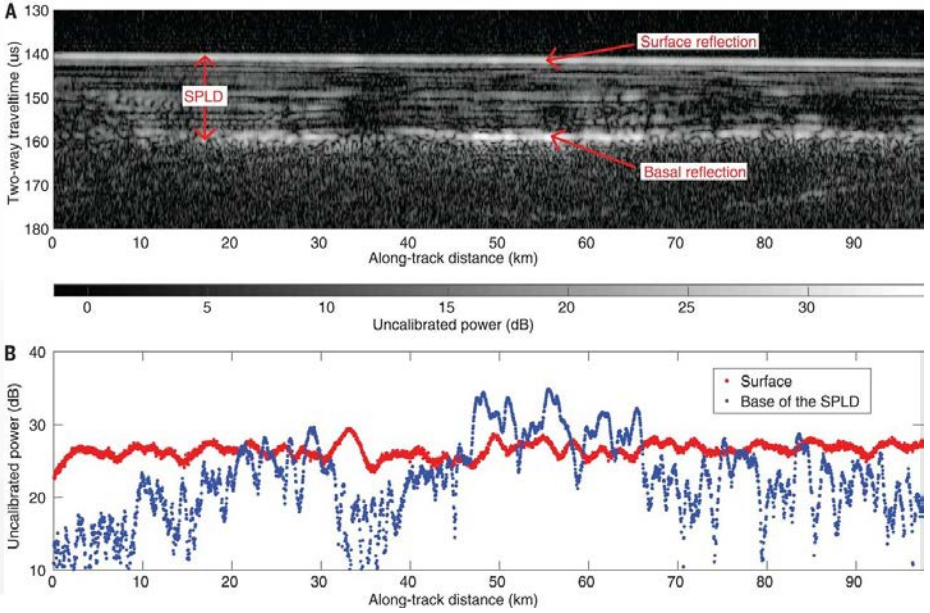
REPORT

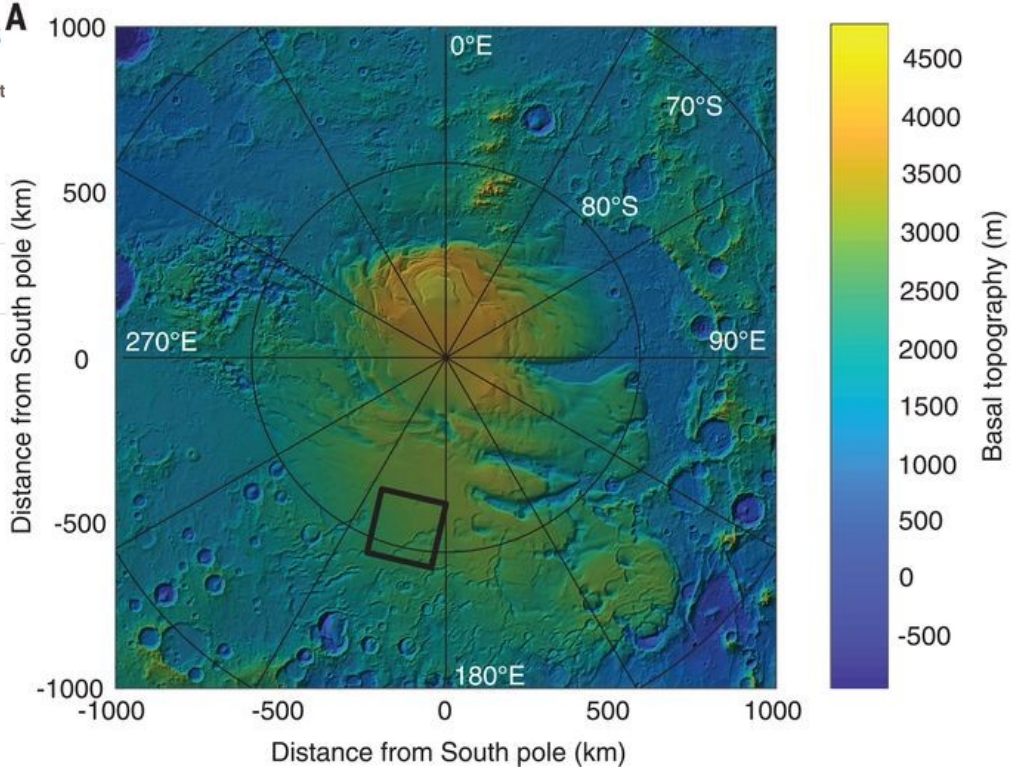
Radar evidence of subglacial liquid water on Mars

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

Article Figures & Data Info & Metrics eLetters





Orosei et al. 2018 Science

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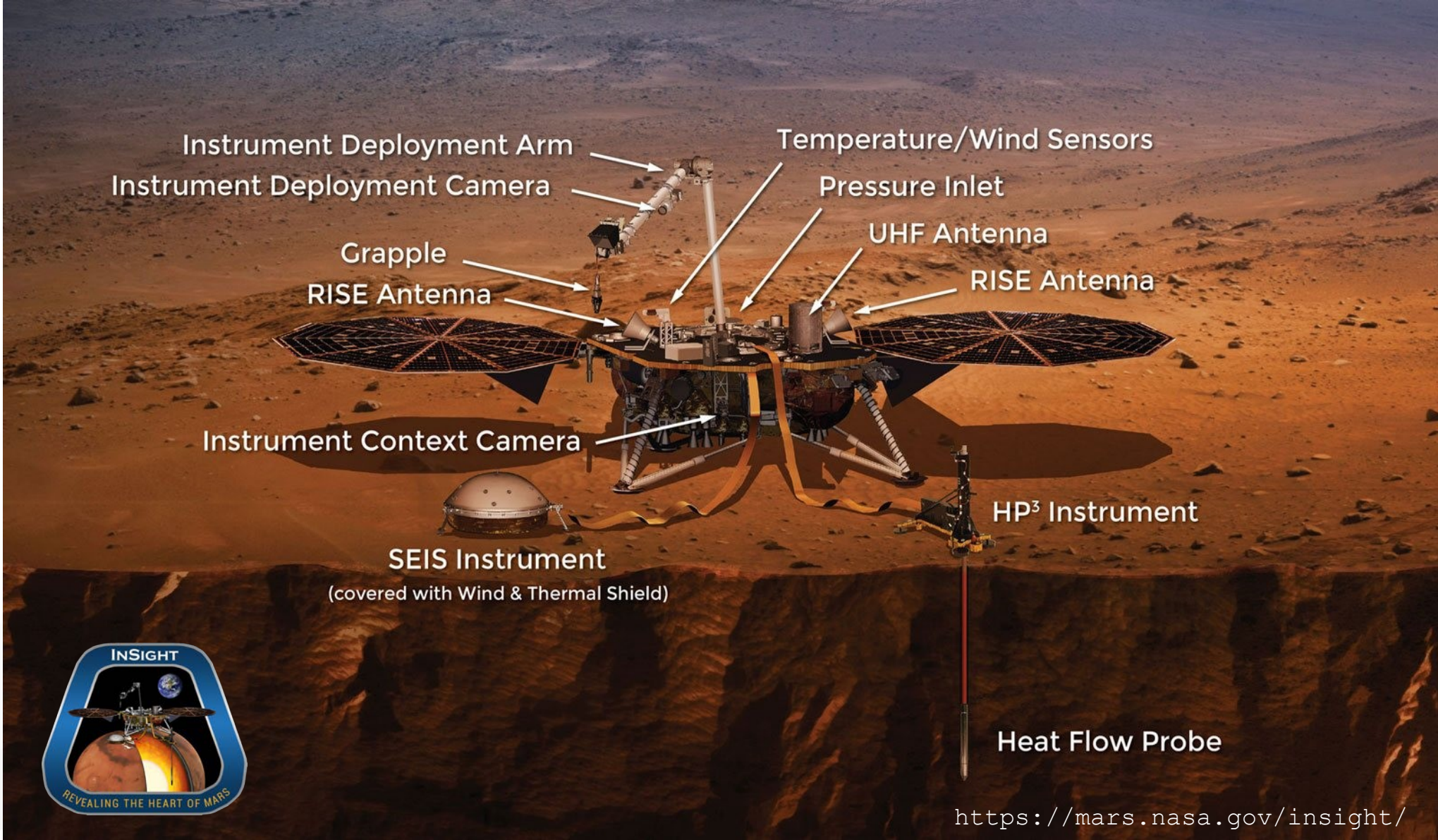
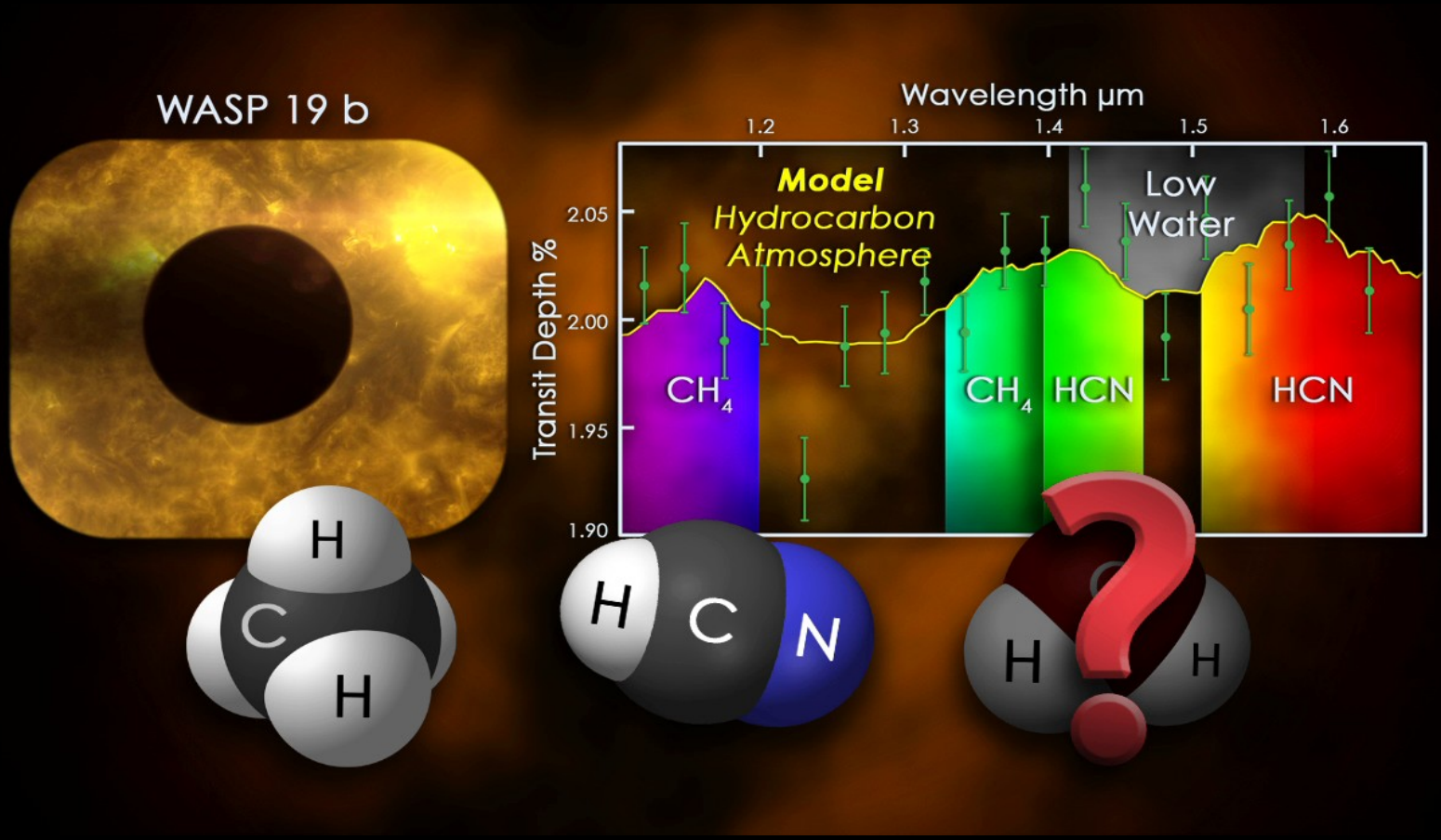


https://mars.nasa.gov/insight/



from NASA svs.gsfc.nasa.gov/11428

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"It's not a biome, it's a **die-ome**."

-Jordan Bird, in his first year PhD student in Lloyd's Lab (UTK, USA)

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Photosynthesis

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

Photosynthesis

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

Respiration

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

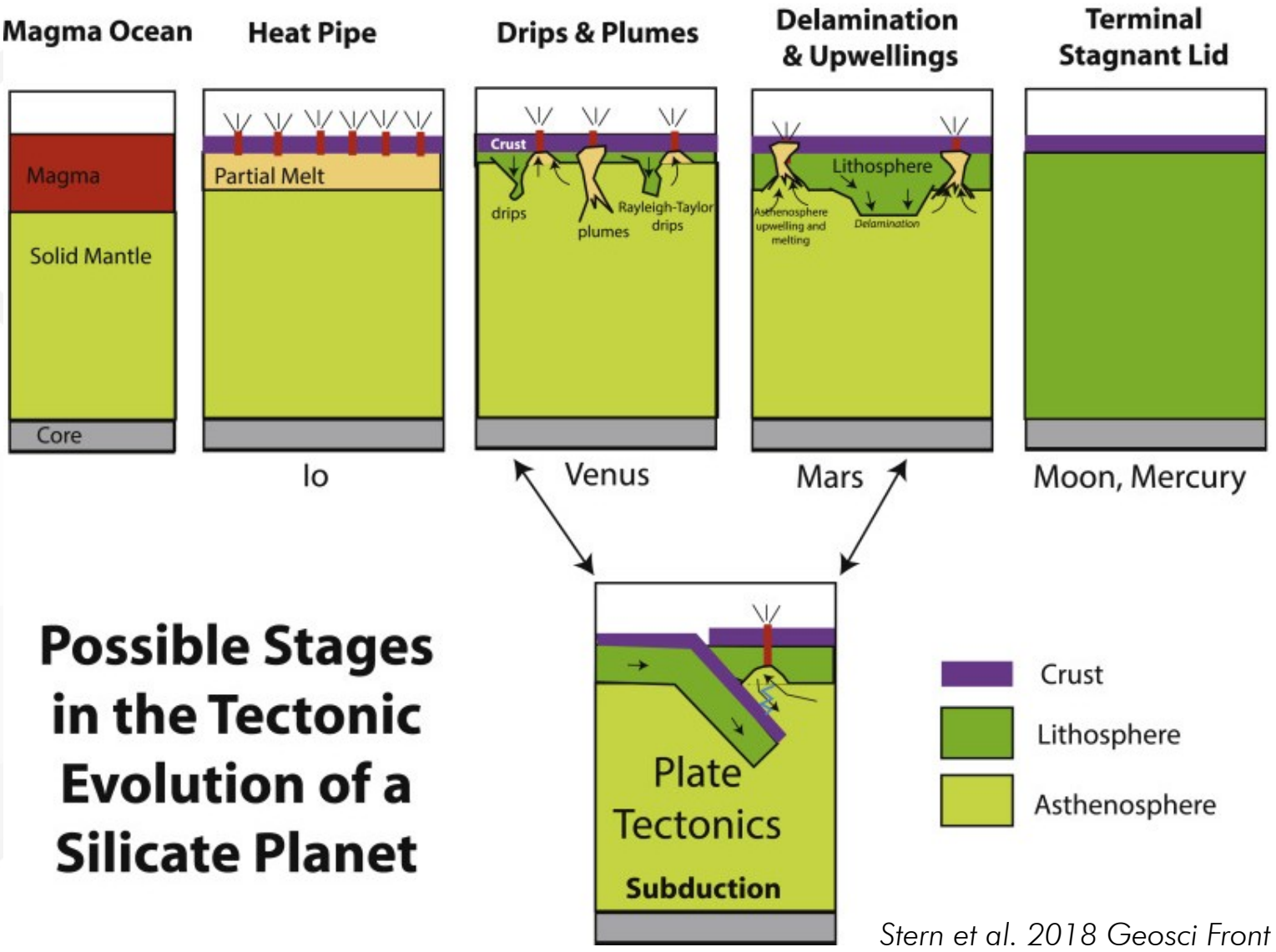
Photosynthesis

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

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

Stern et al. 2018 Geosci Front

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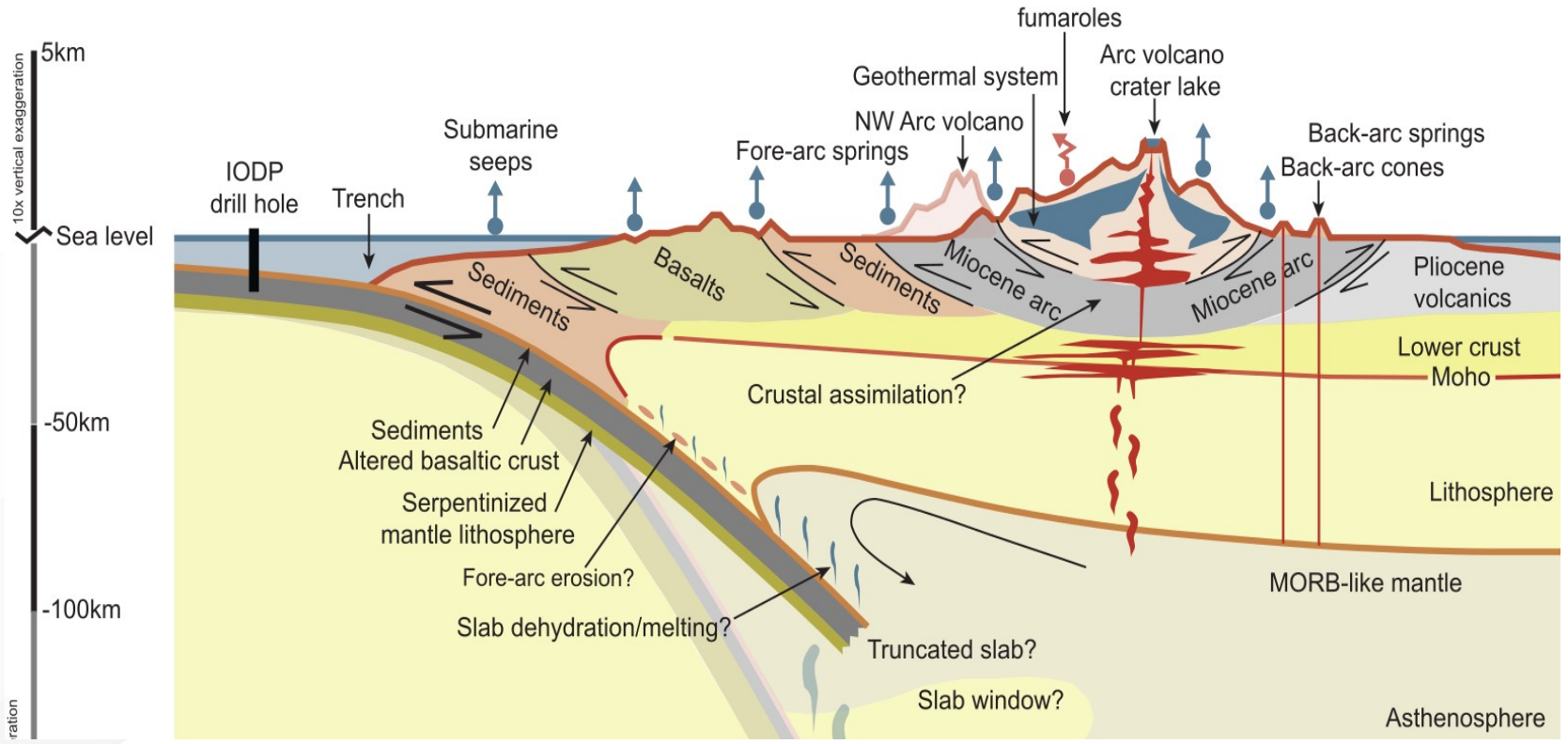

Giovannelli et al., EOS, accepted

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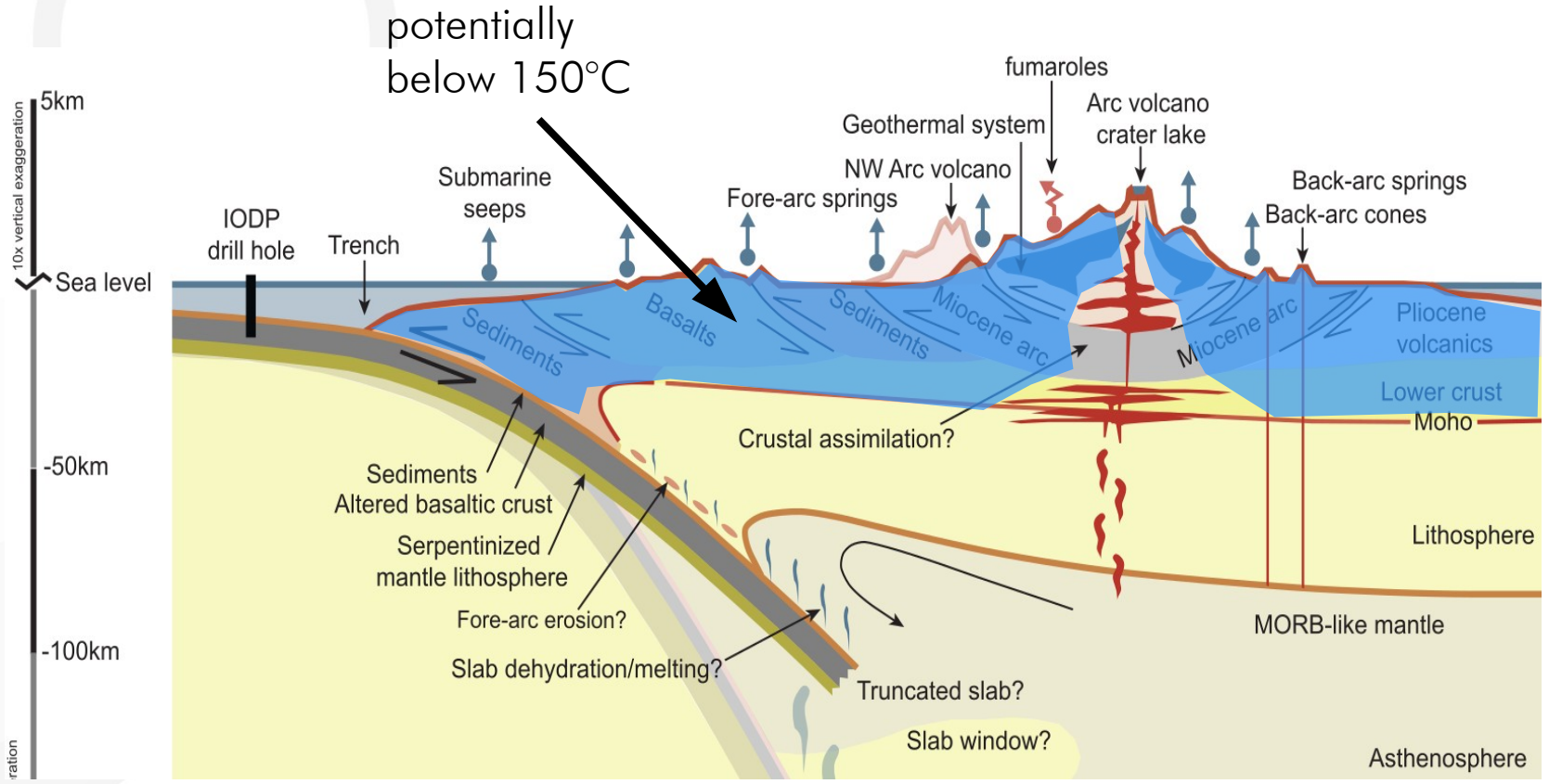
A ROLE FOR SUBSURFACE MICROBES?



Giovannelli et al., EOS, accepted

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"BIOLOGY MEETS SUBDUCTION"

Funding

DEEP CARBON OBSERVATORY

Alfred P. Sloan FOUNDATION

Institutions

CNR-IRBIM (Italy) • Oxford U (UK) • ELSI (Japan) • U Tennessee (USA) • U Alaska (USA) • OVSICORI (Costa Rica) • UNIVPM (Italy) • METU (Turkey) • U Rodhe Island (USA) • ASU (USA) • Michigan State U (USA) • Rutgers U (USA) • Carnegie (USA) • among others

People

46 Researchers
9 Nationalities
19 Institutions

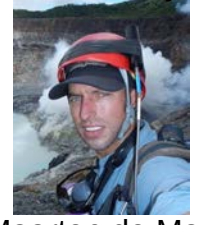
Disciplines

Microbiology • Volcanology • Geochemistry • Gas Geochemistry • Isotope • Geochemistry • Geology • Mineralogy • Petrology • Science Communication


Karen Lloyd


Peter Barry


Matt Schrenk


Maarten de Moor

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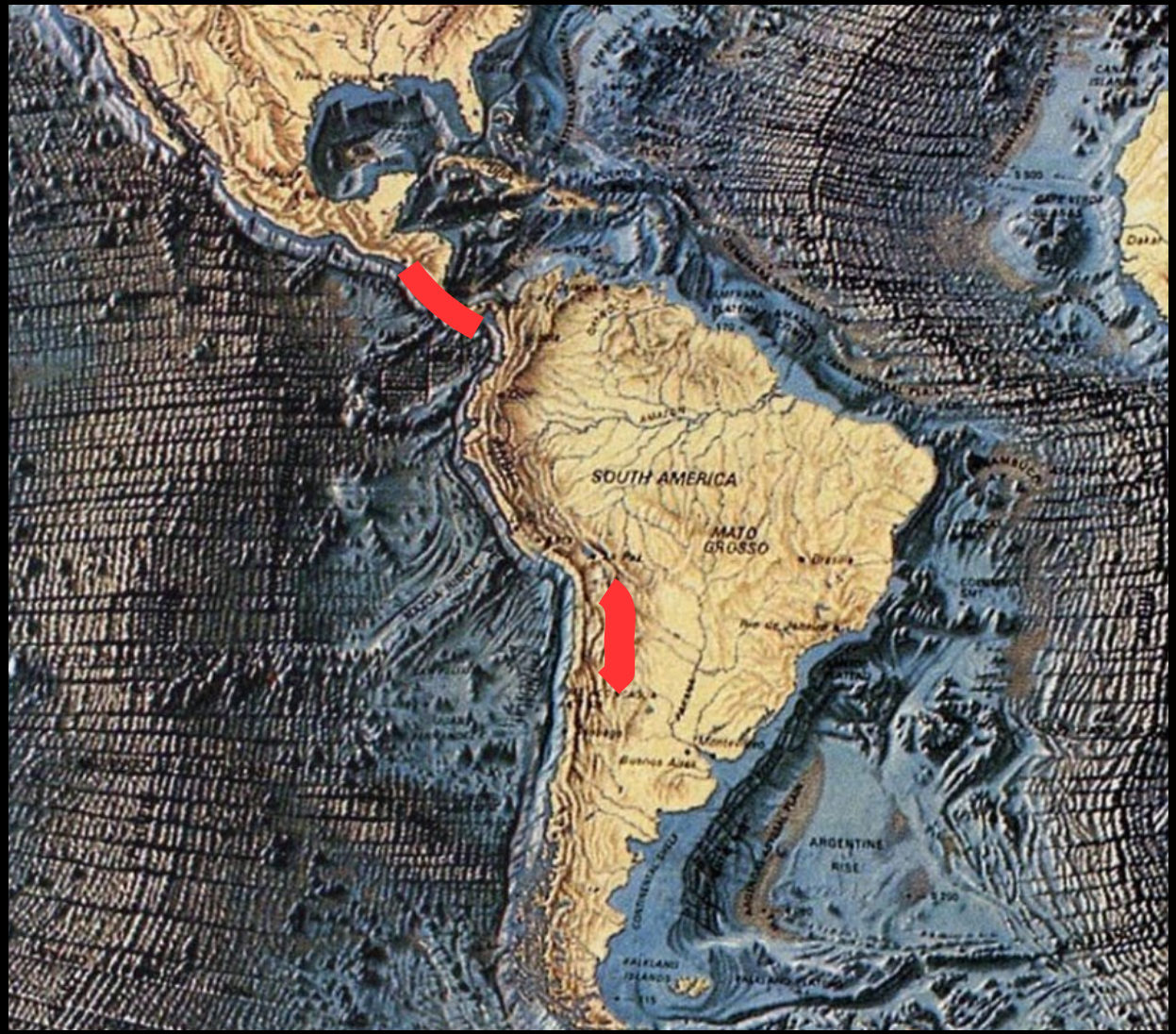

~900 km of convergent margin
>75 sites sampled
>1,000 samples collected

Microbiology
Gas geochemistry
Aqueous geochemistry
Organic geochemistry
Mineralogy

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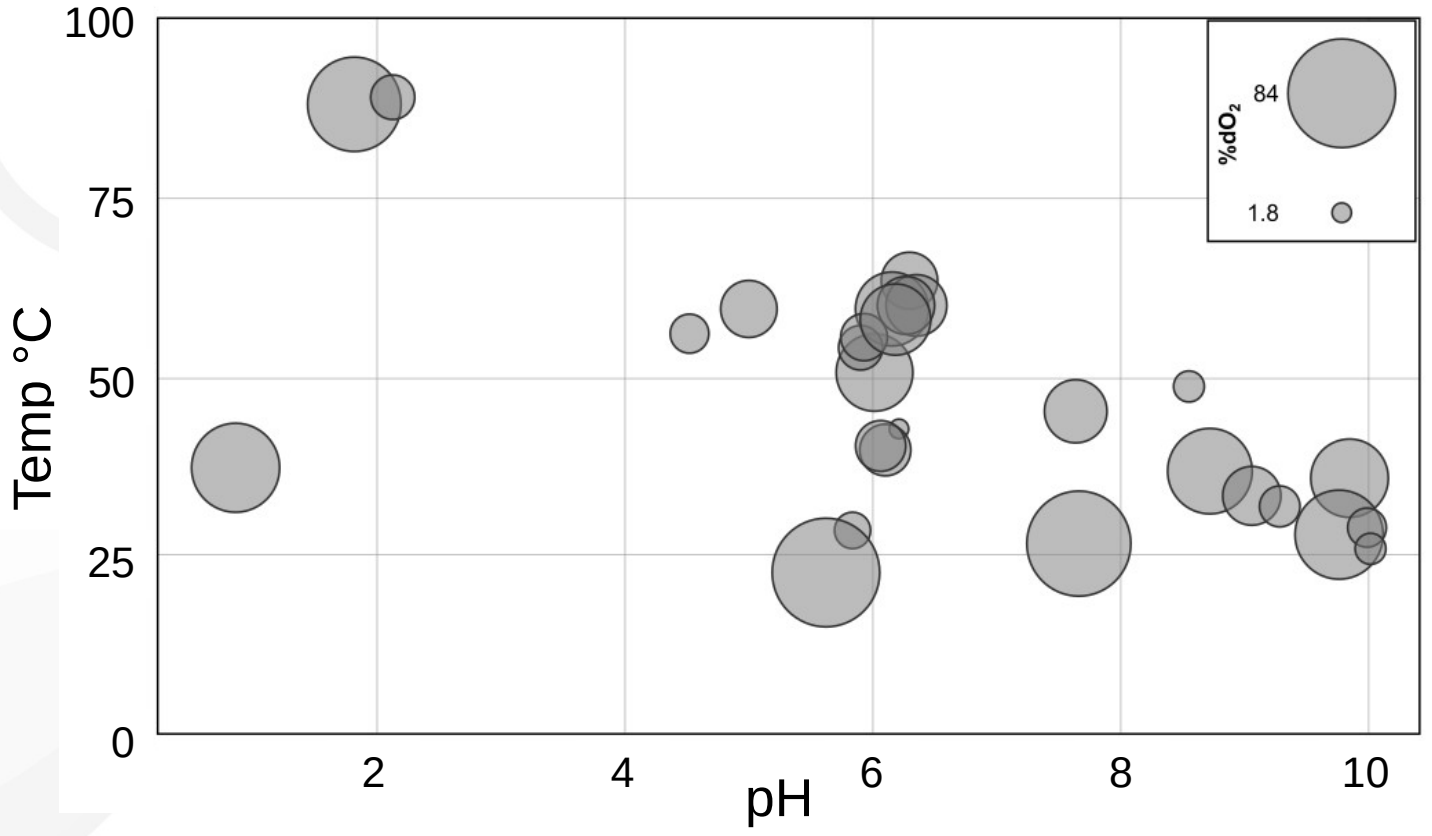
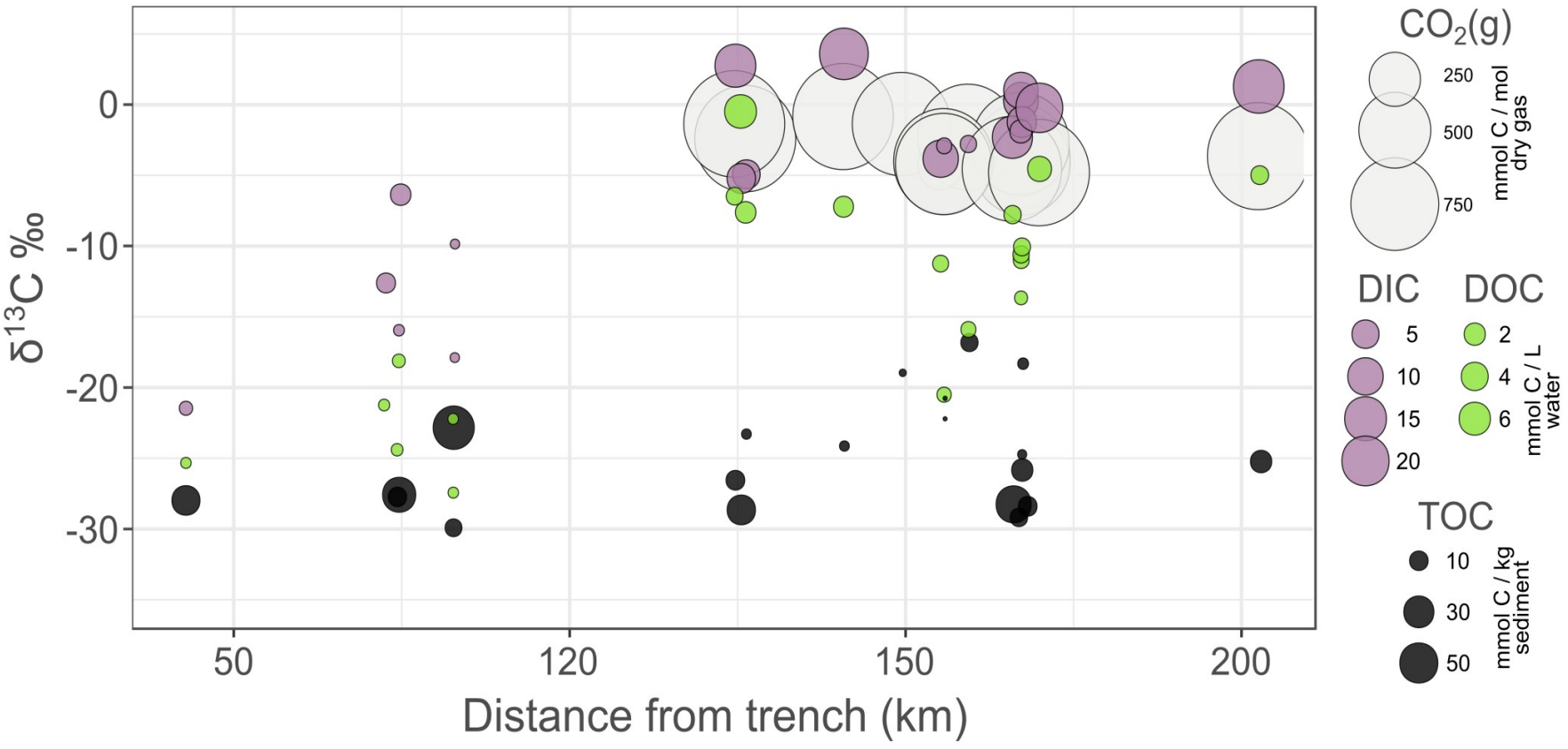
Biology Meets Subduction



Barry et al, 2019 Nature



Barry et al, 2019 Nature

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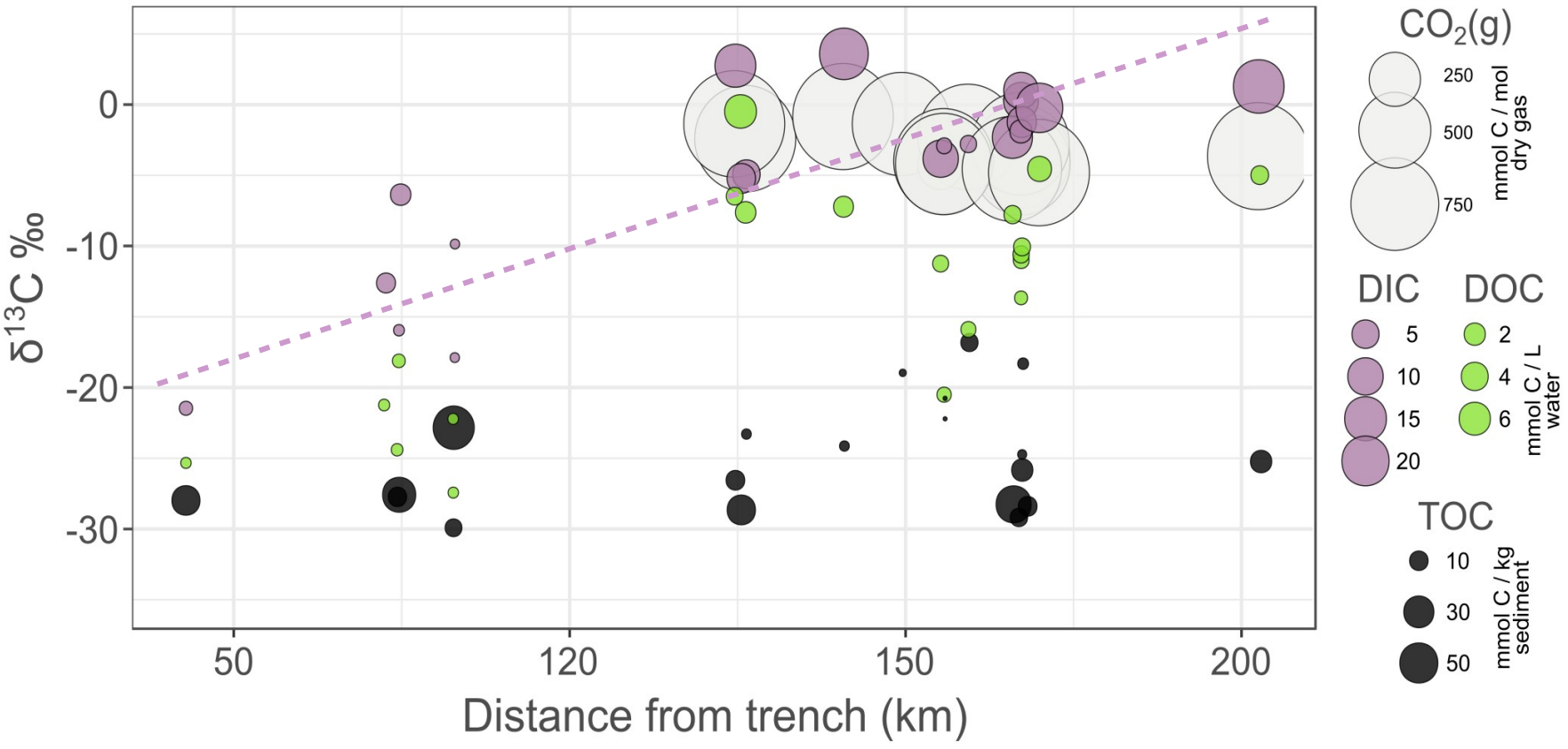

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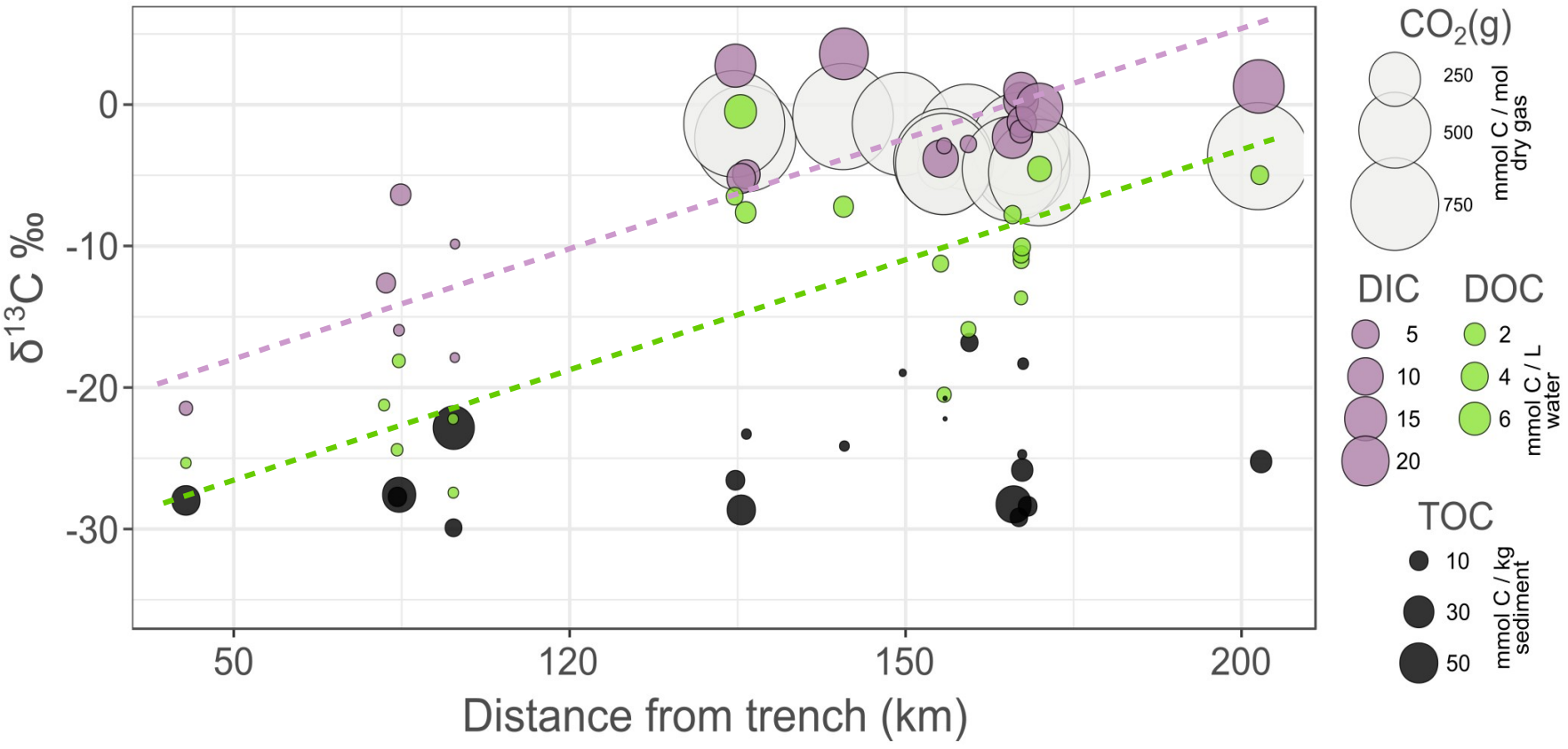

Barry et al, 2019 Nature

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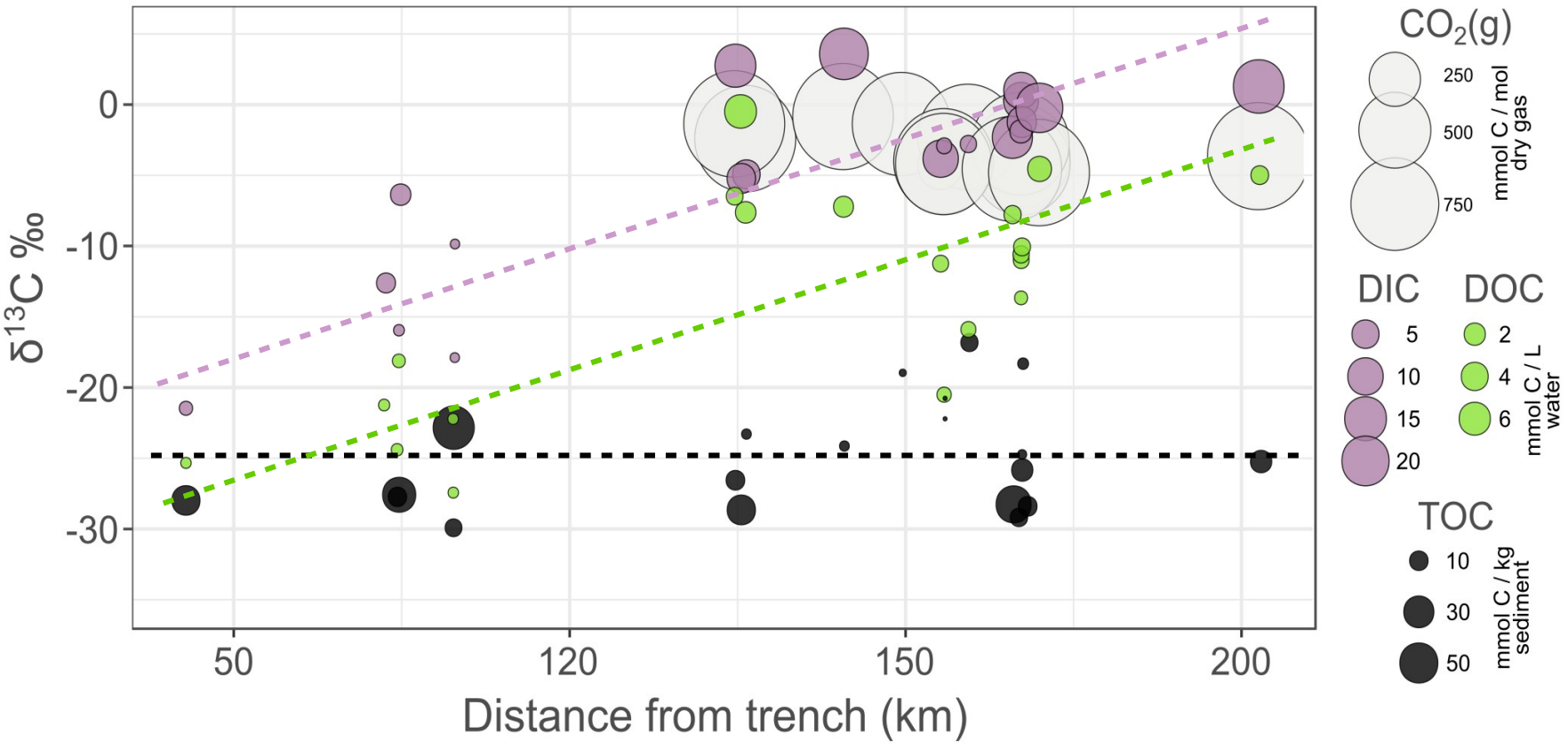

Barry et al, 2019 Nature

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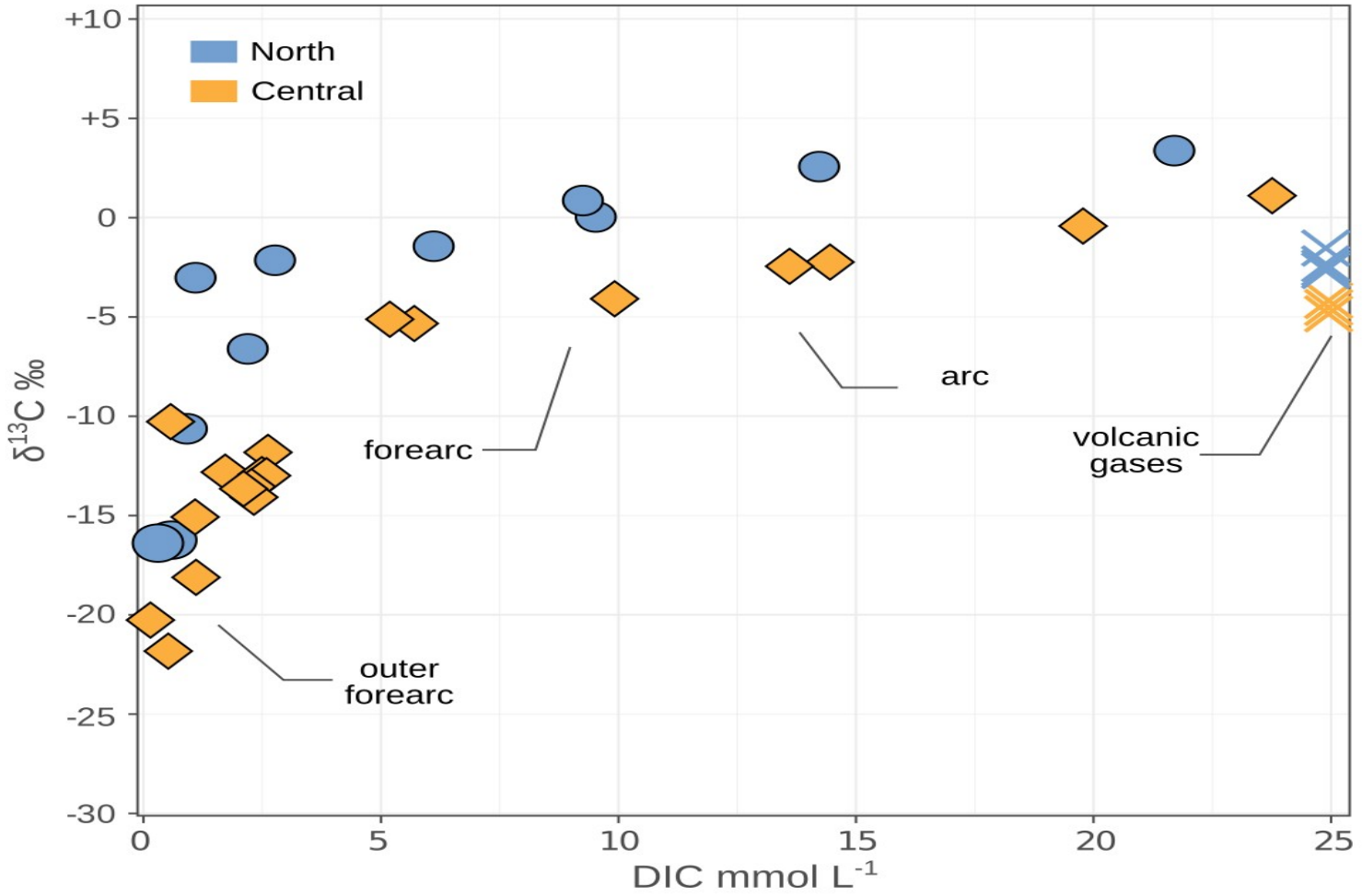

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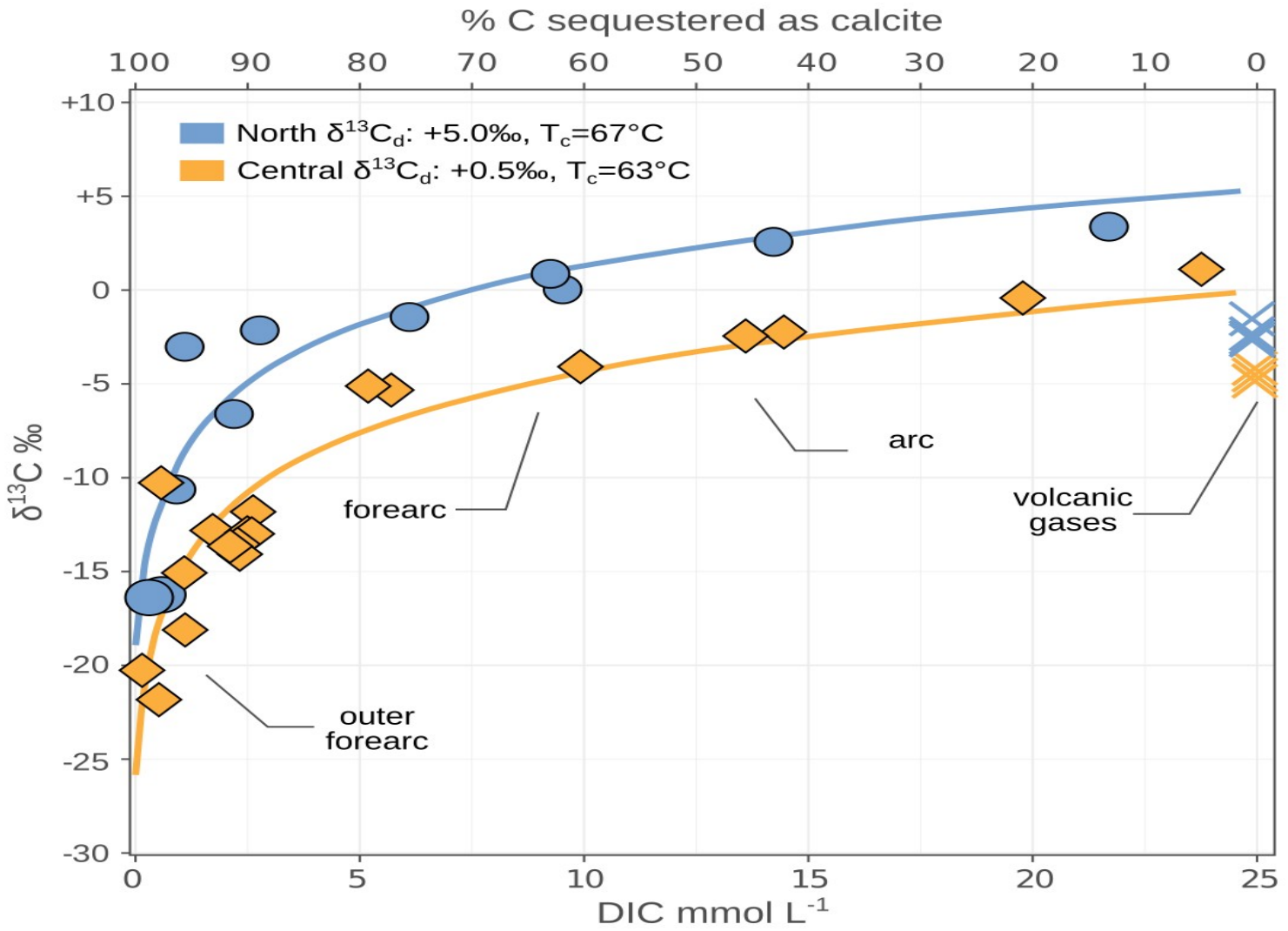

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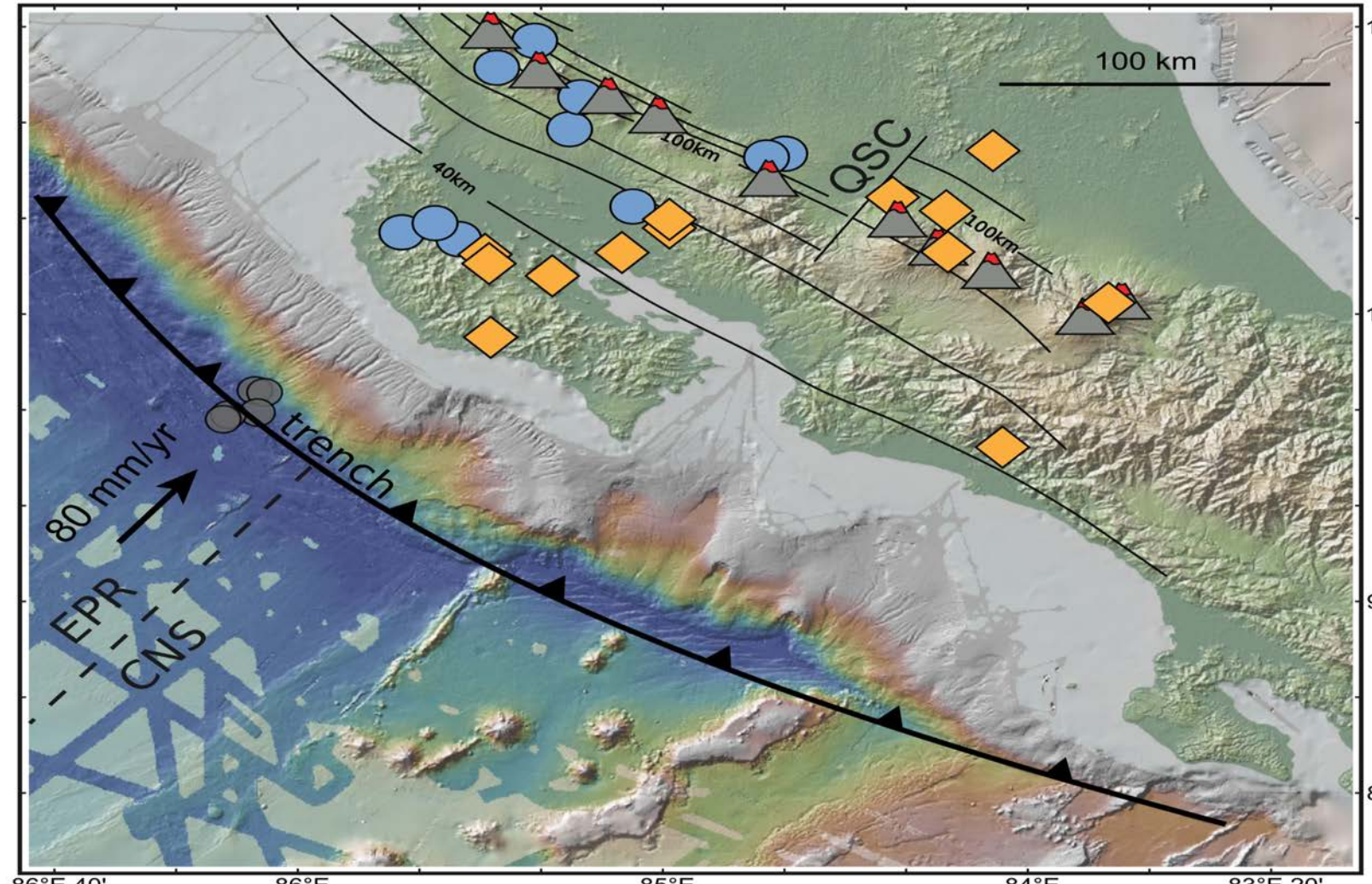
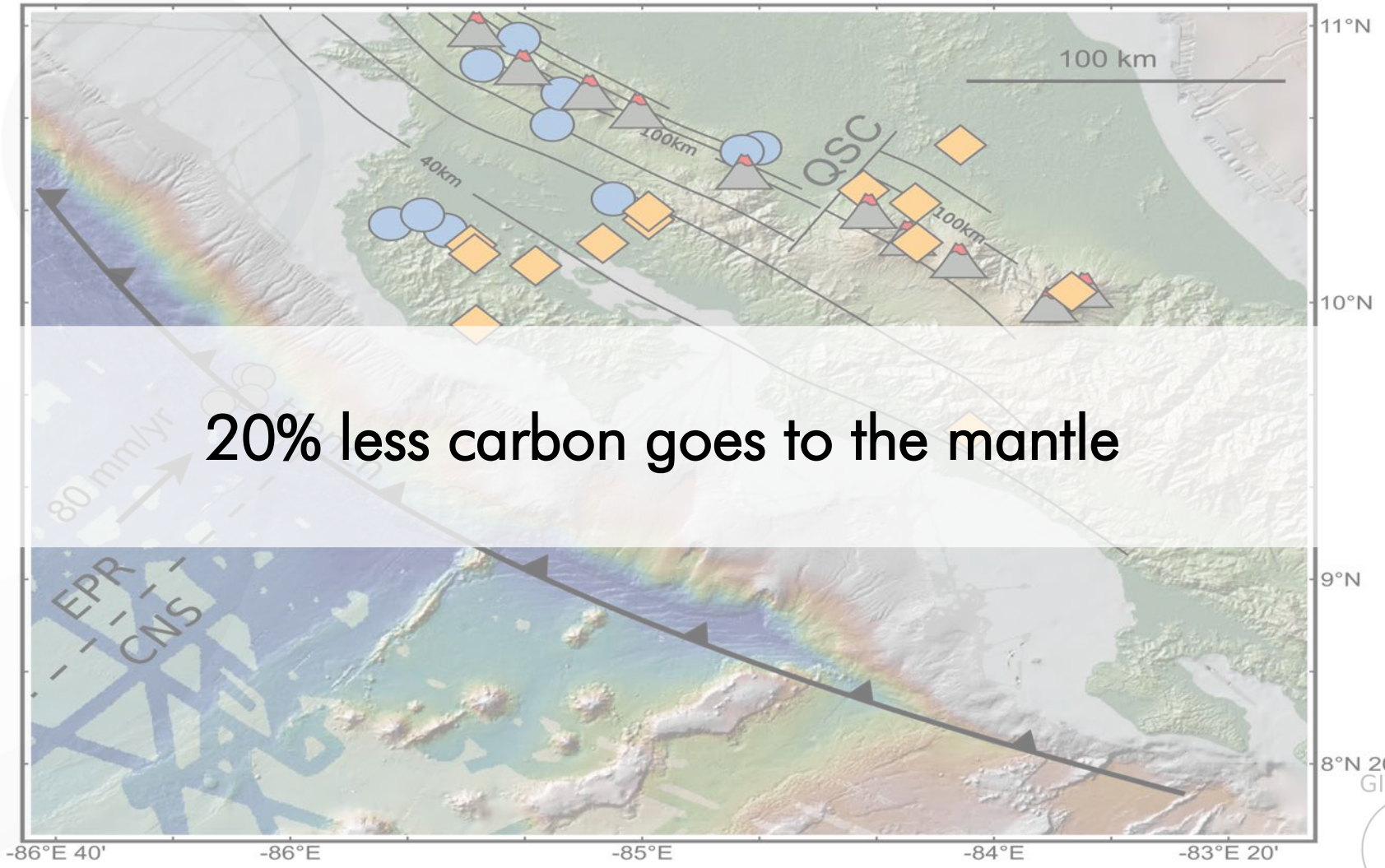
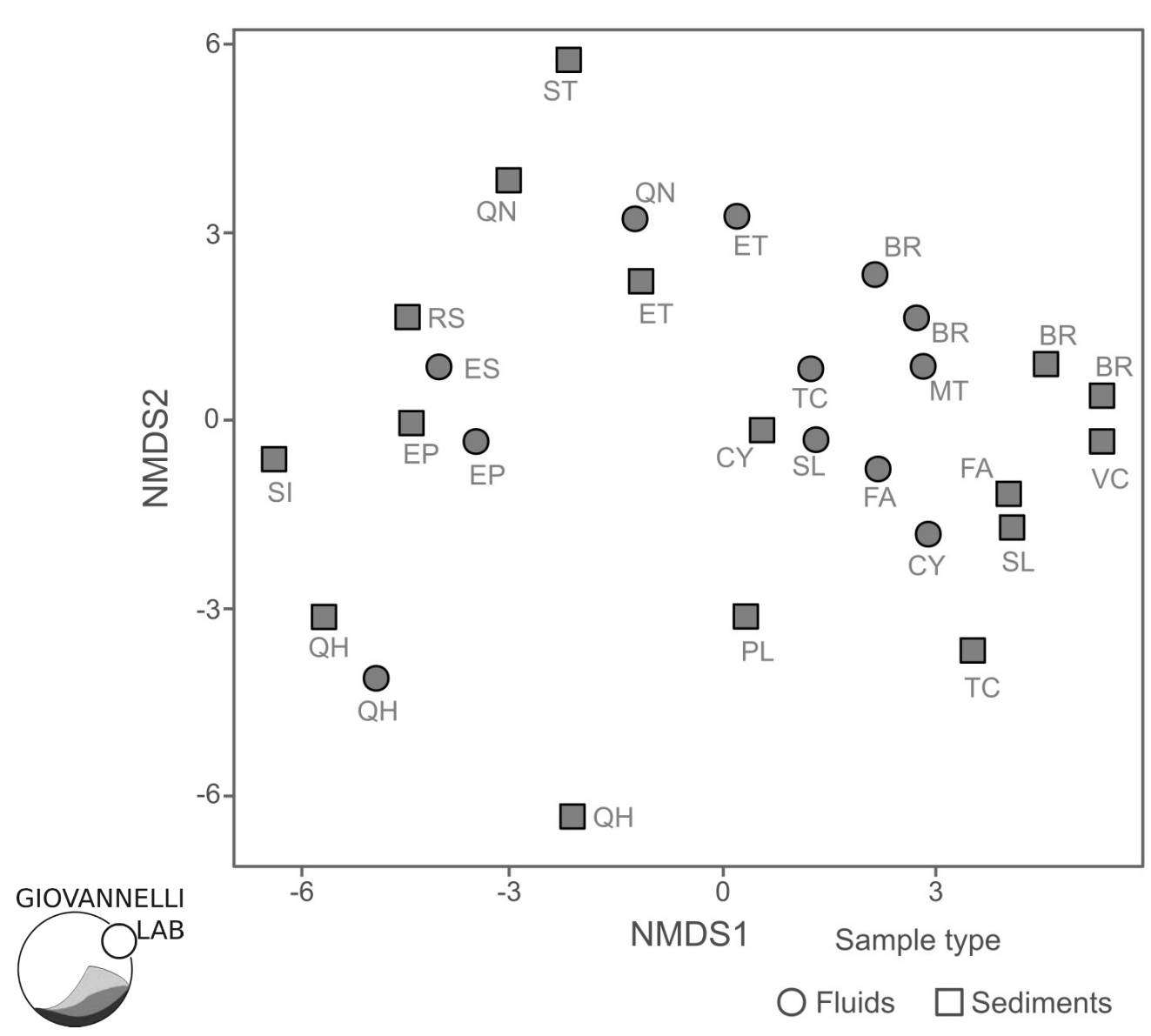


Barry et al, 2019 Nature



20% less carbon goes to the mantle

Barry et al, 2019 Nature



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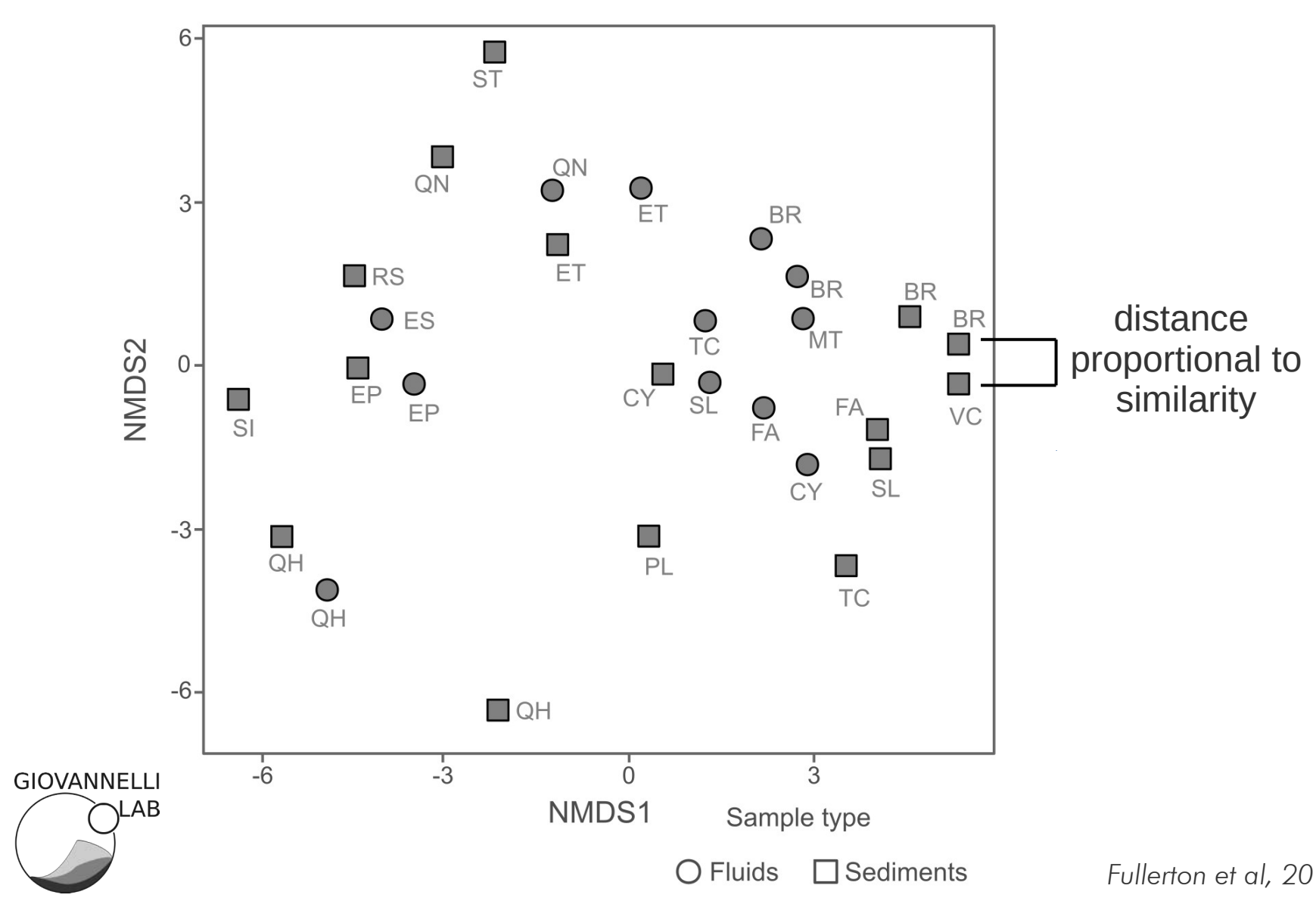
Fullerton et al, 2019 EarthArXiv preprint



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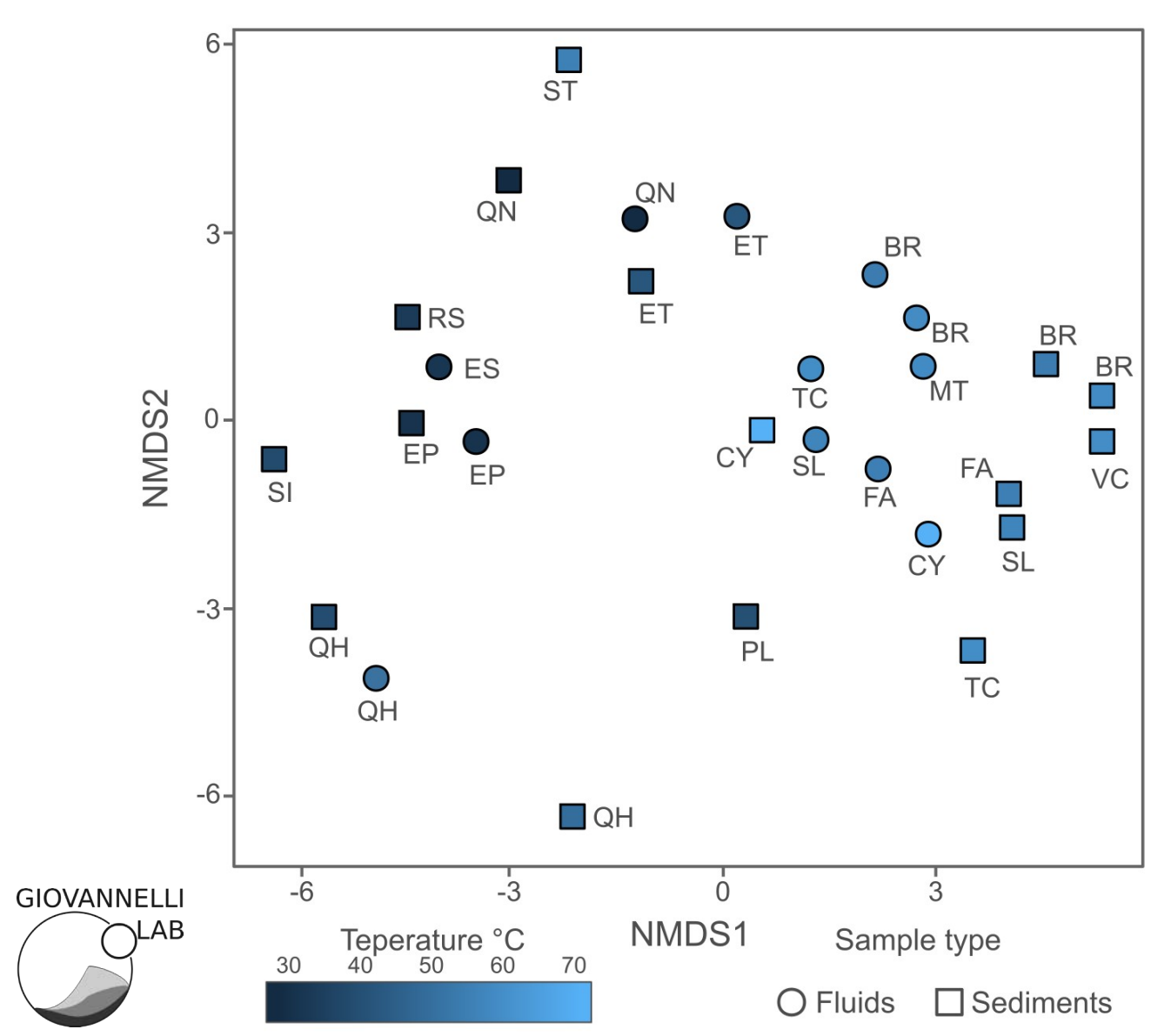

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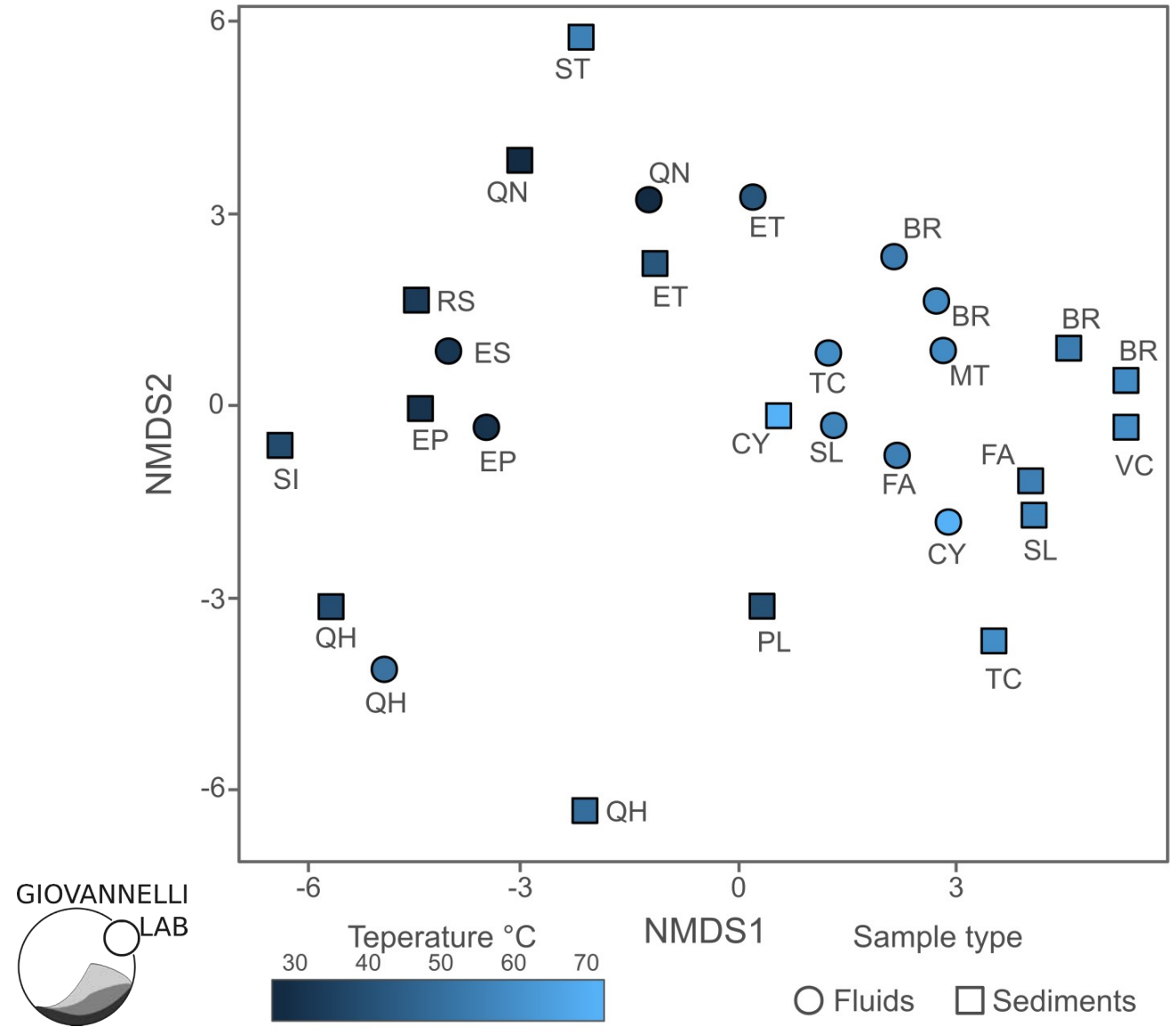

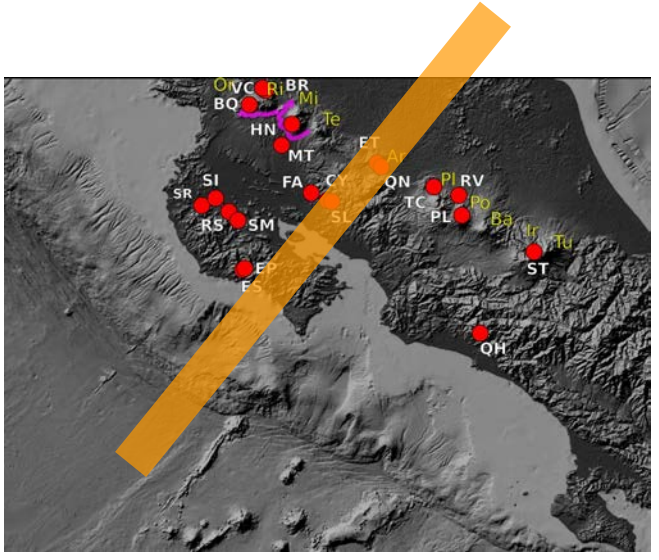

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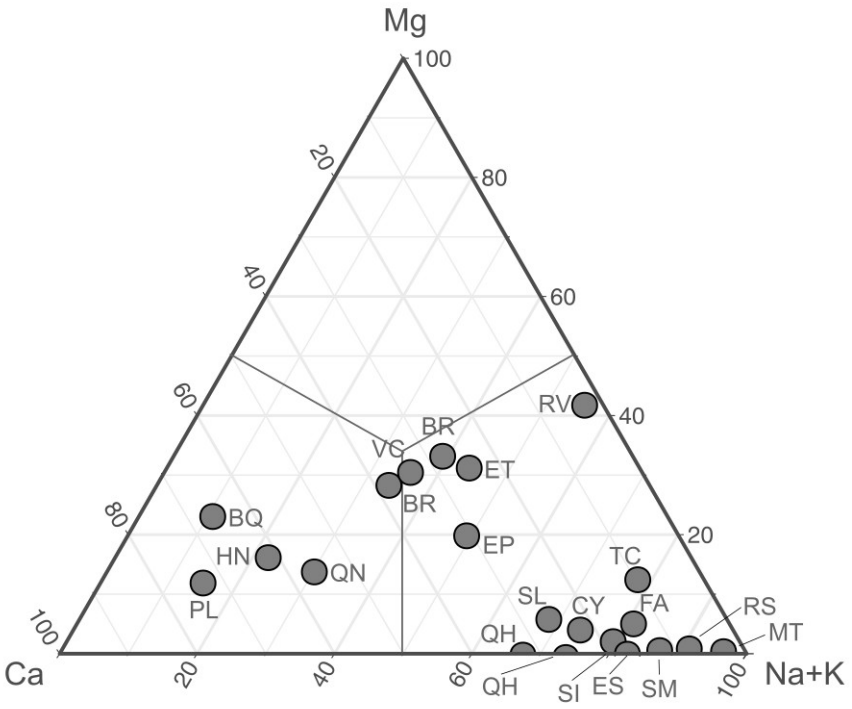

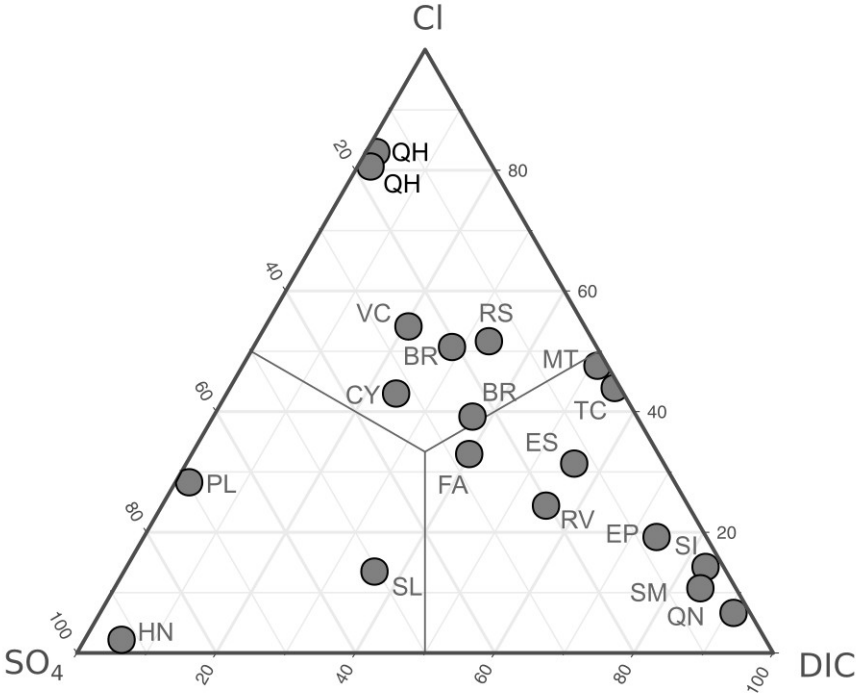

Fullerton et al, 2019 EarthArXiv preprint

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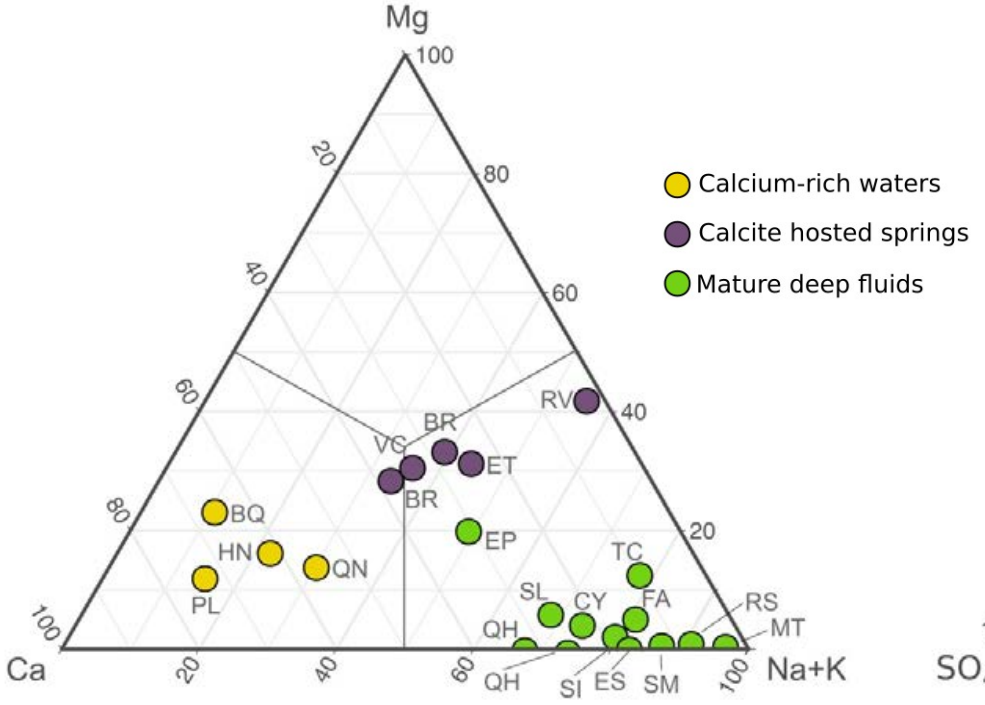

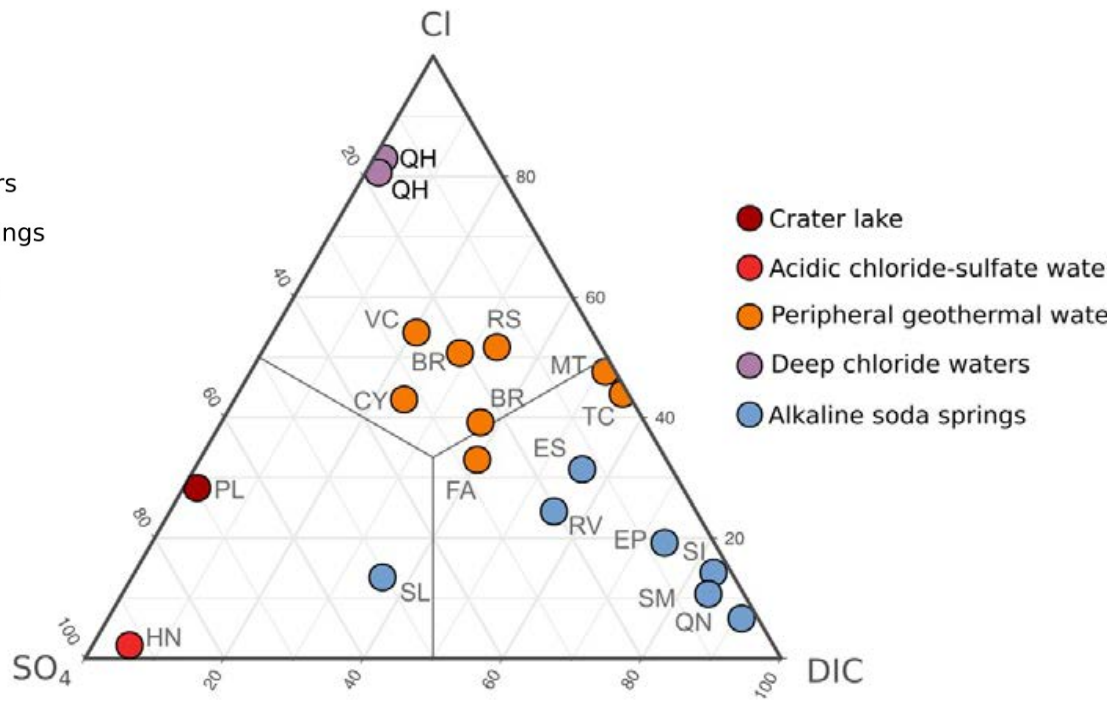

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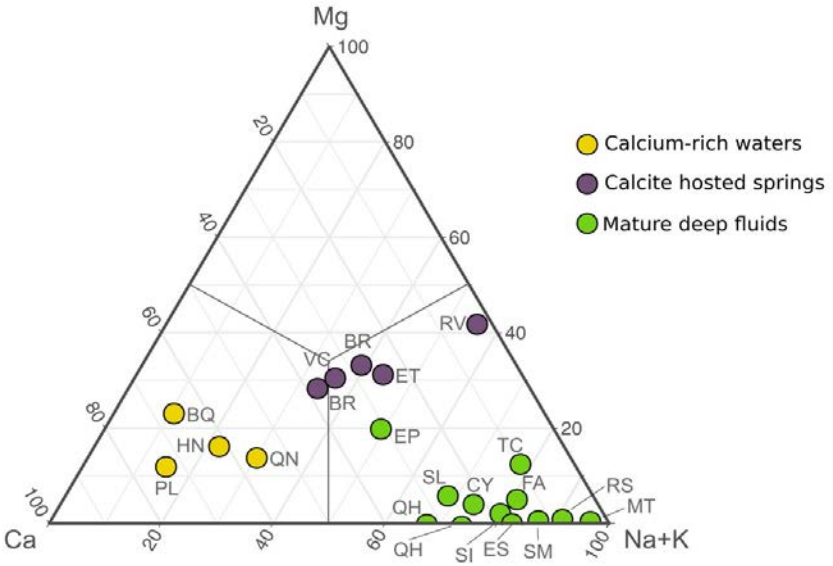

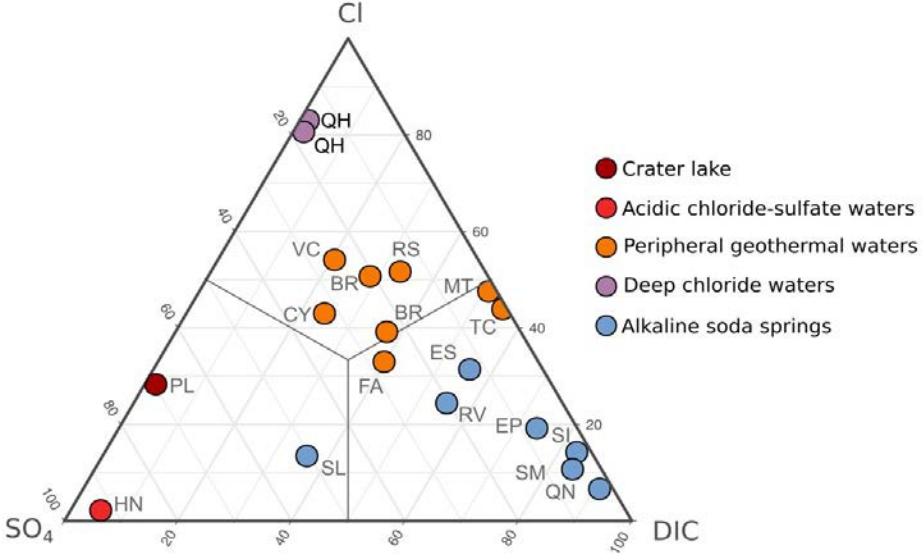

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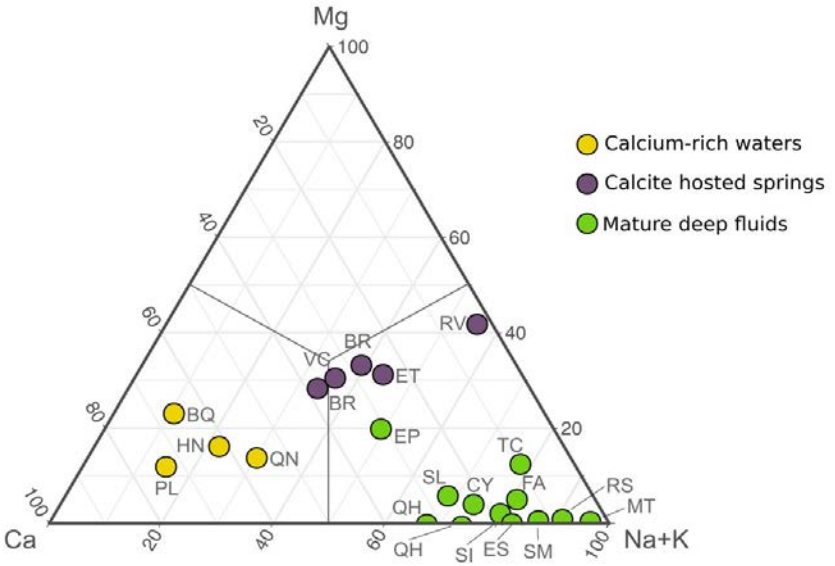

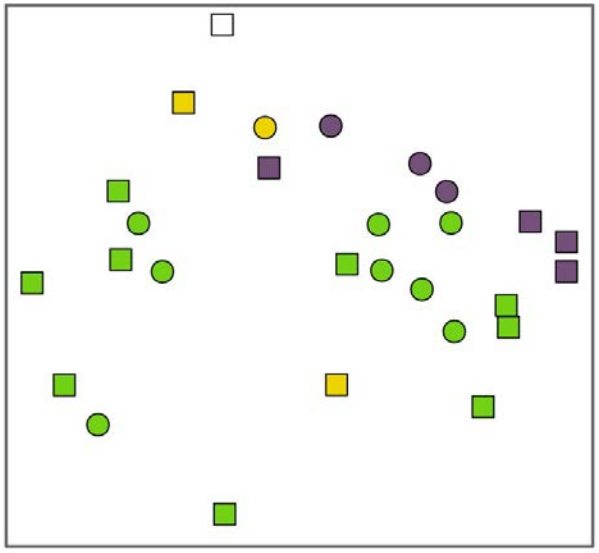

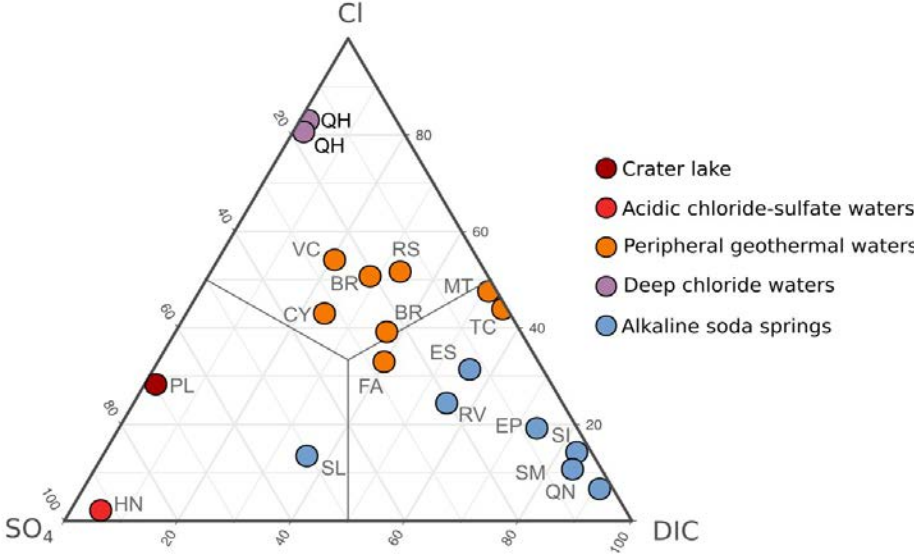

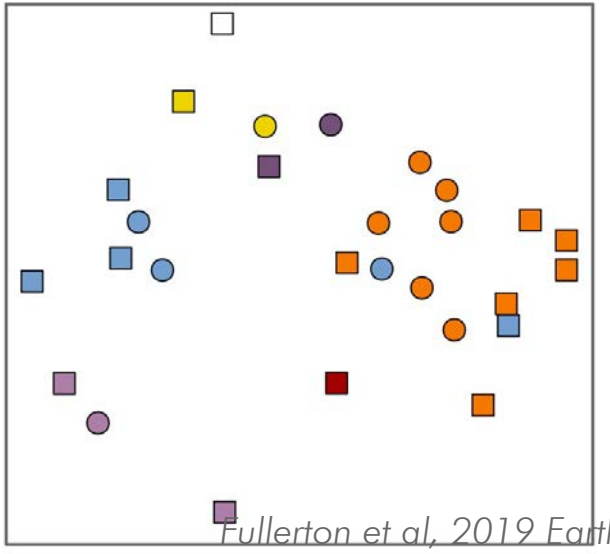

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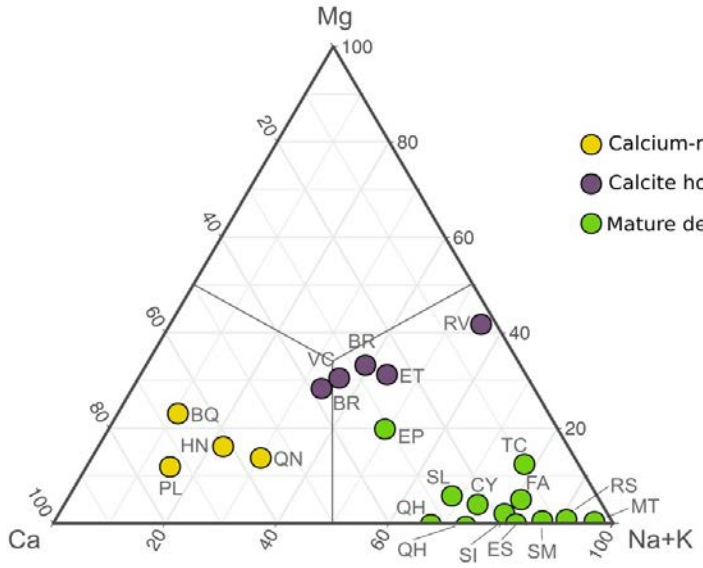

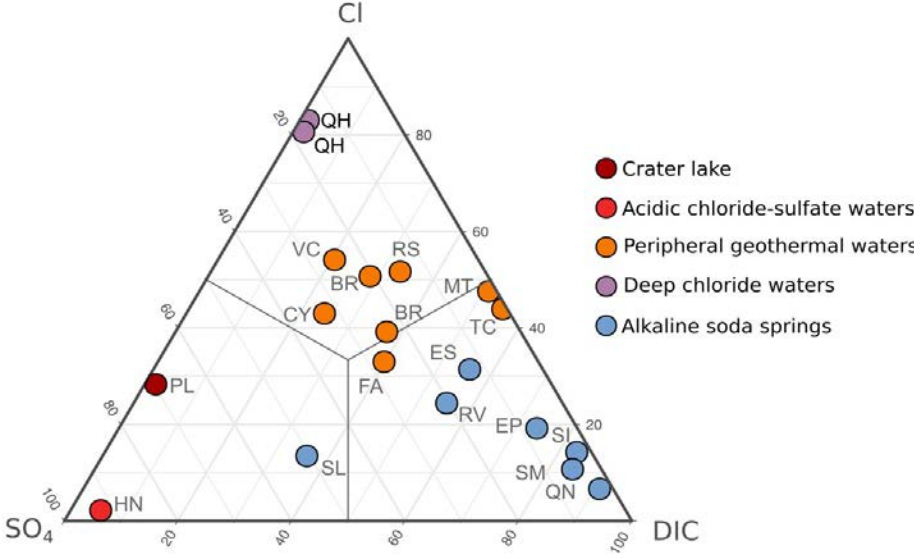

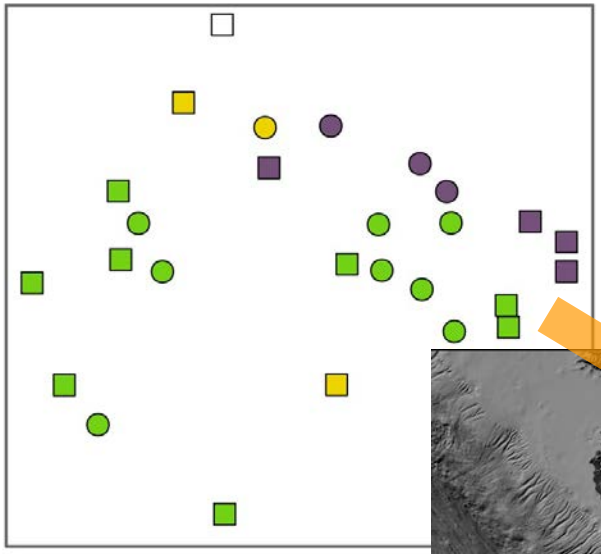

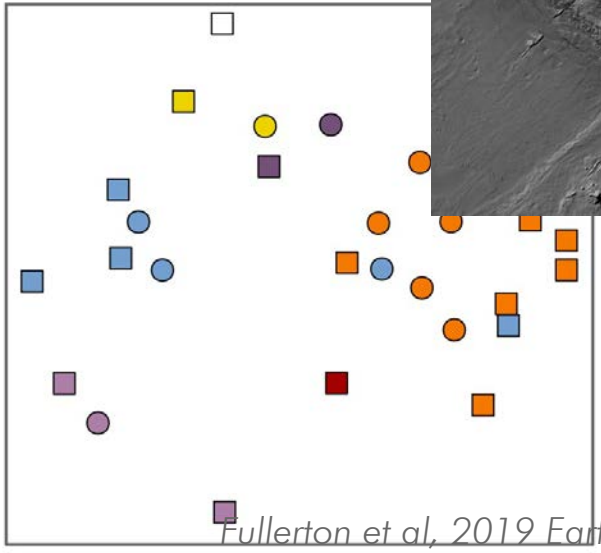

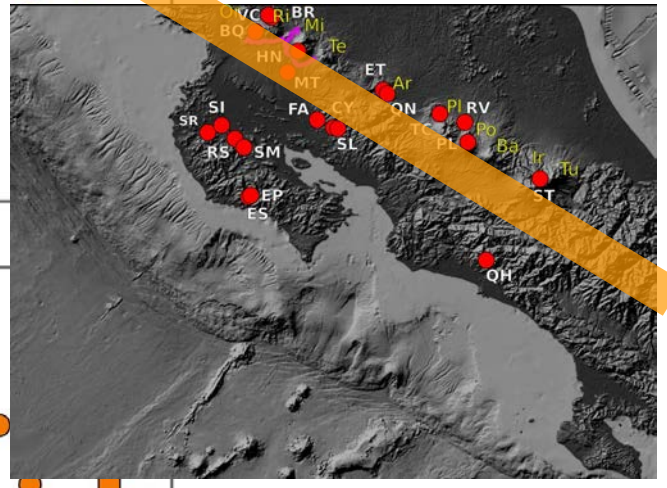

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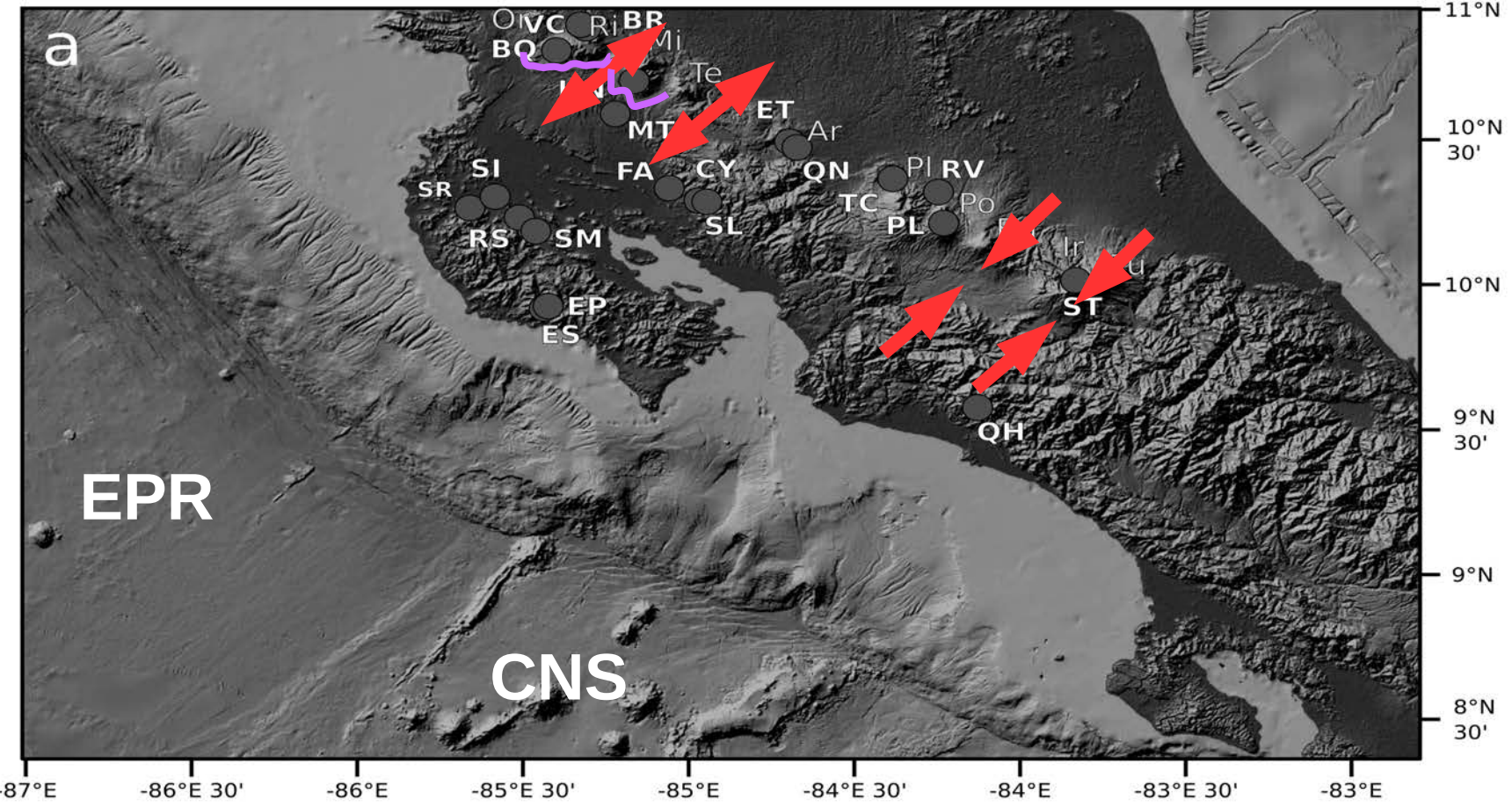

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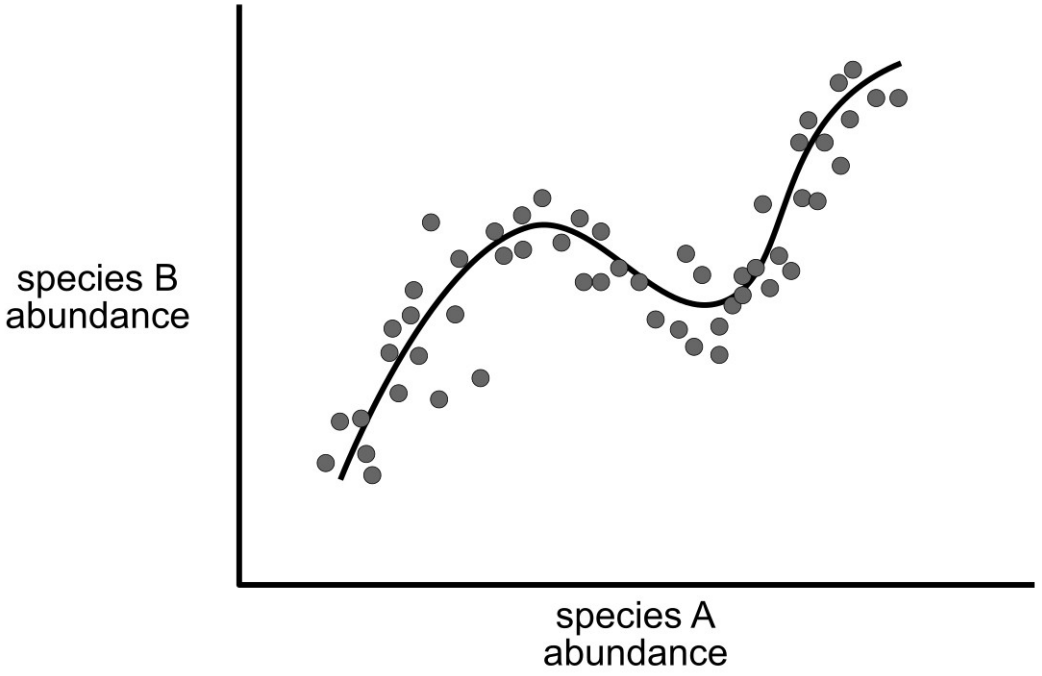
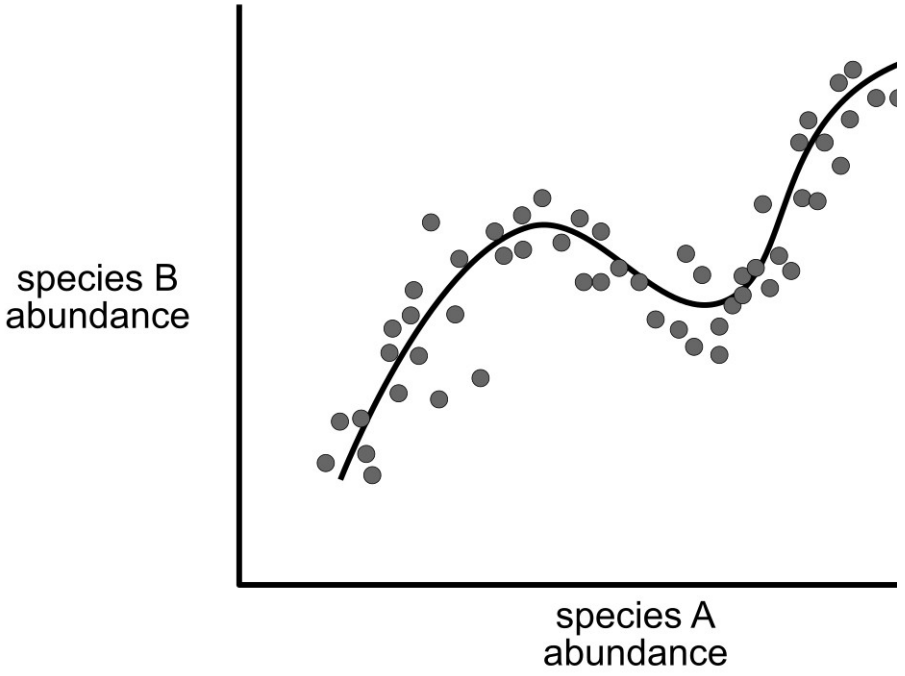
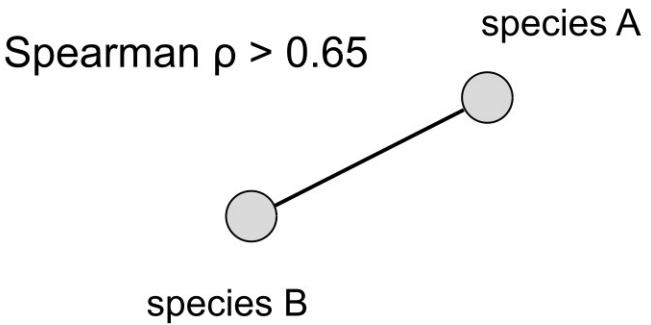
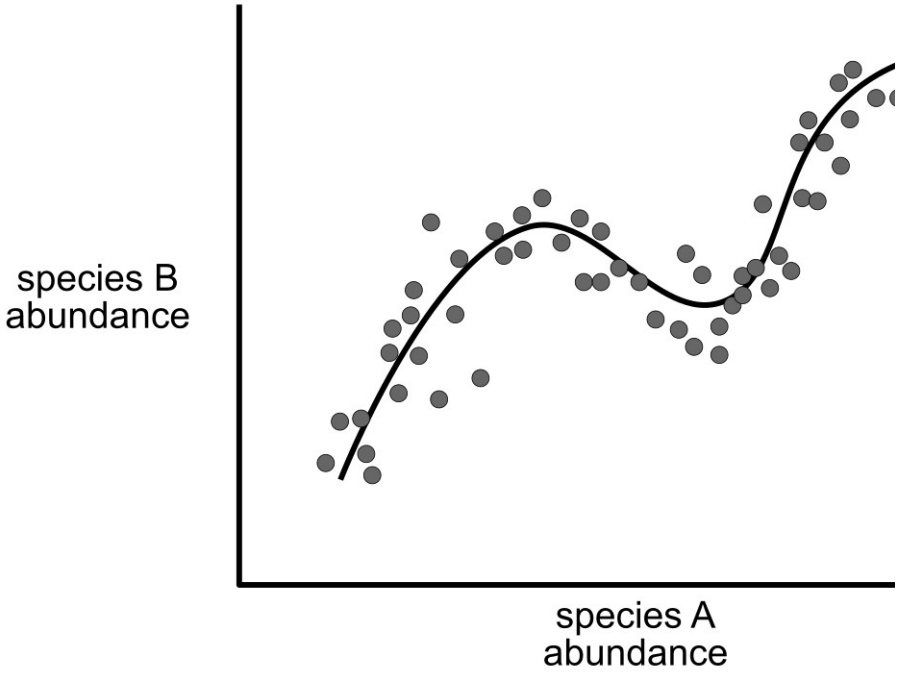
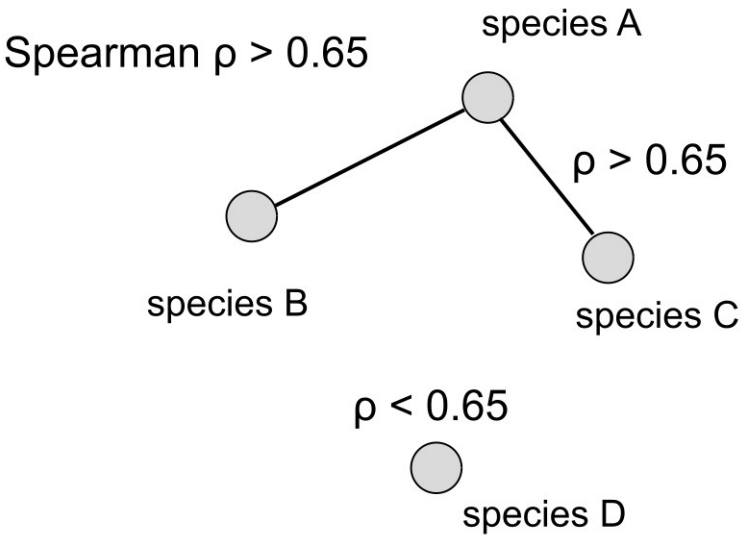
VEGAN OR CARNIVORE?


species B
abundance
species A
abundance


species B
abundance
species A
abundance


Spearman ρ > 0.65
species A
species B


species B
abundance
species A
abundance


Spearman ρ > 0.65
species A
ρ > 0.65
species B
species C
ρ < 0.65
species D

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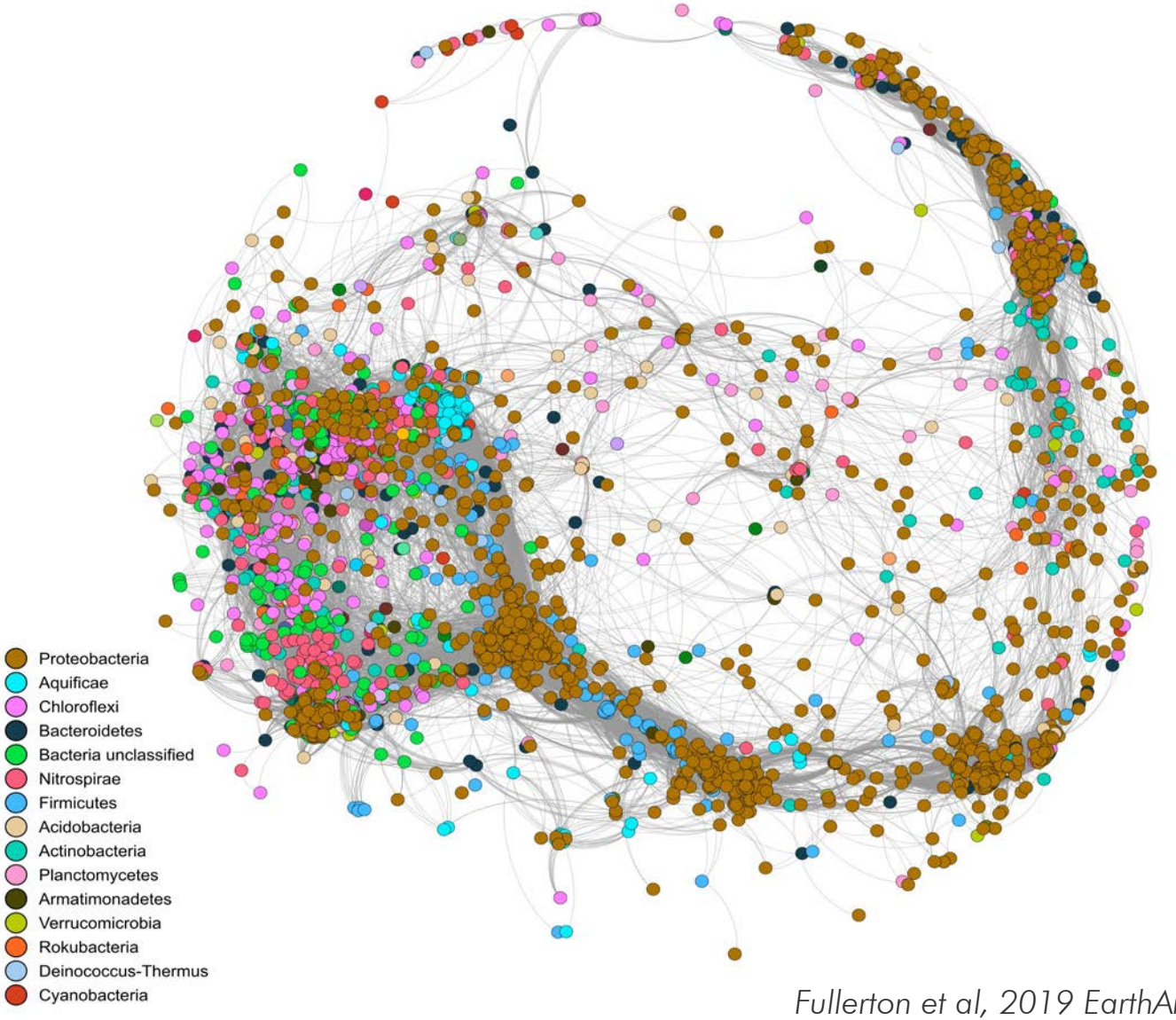

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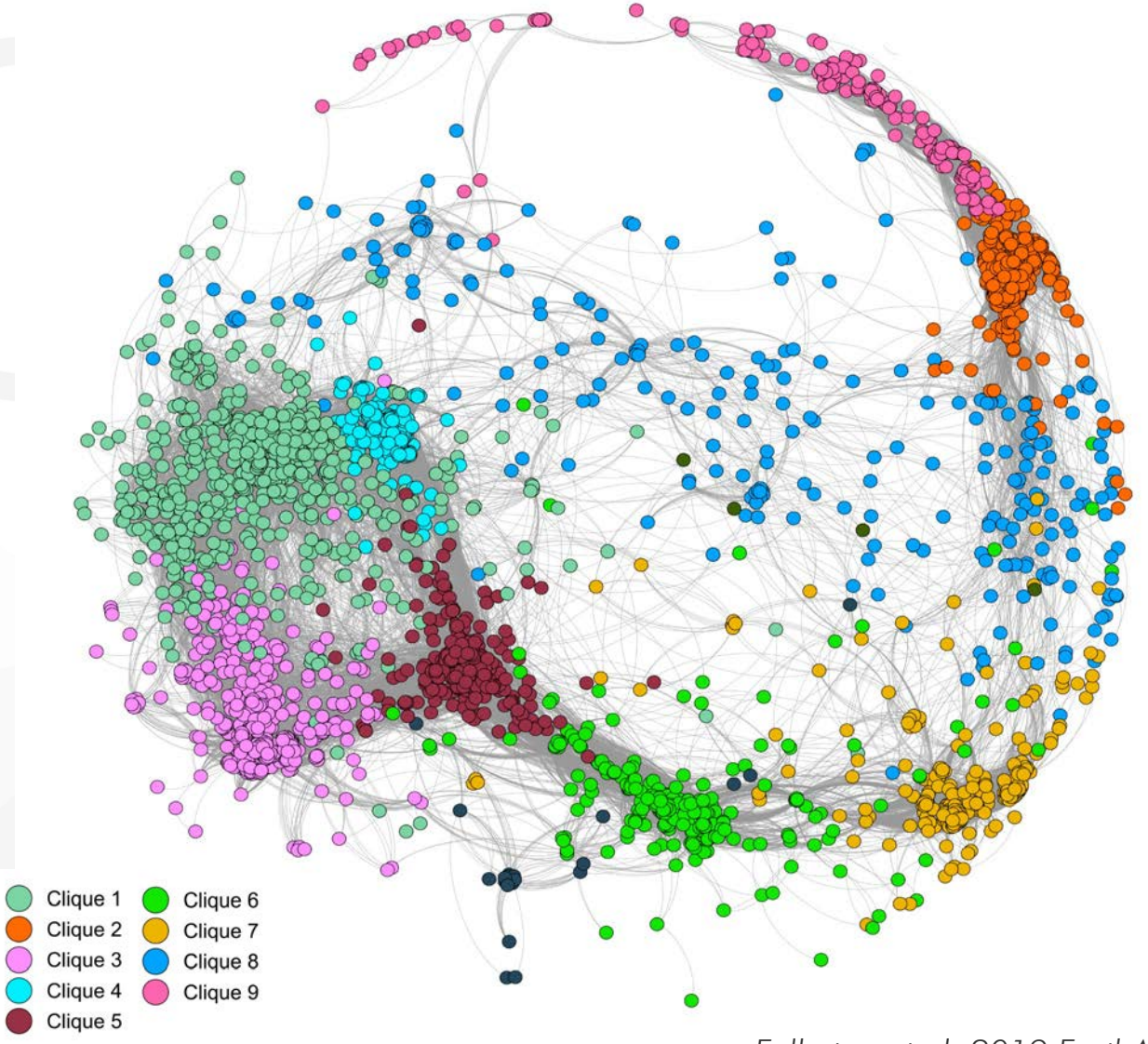

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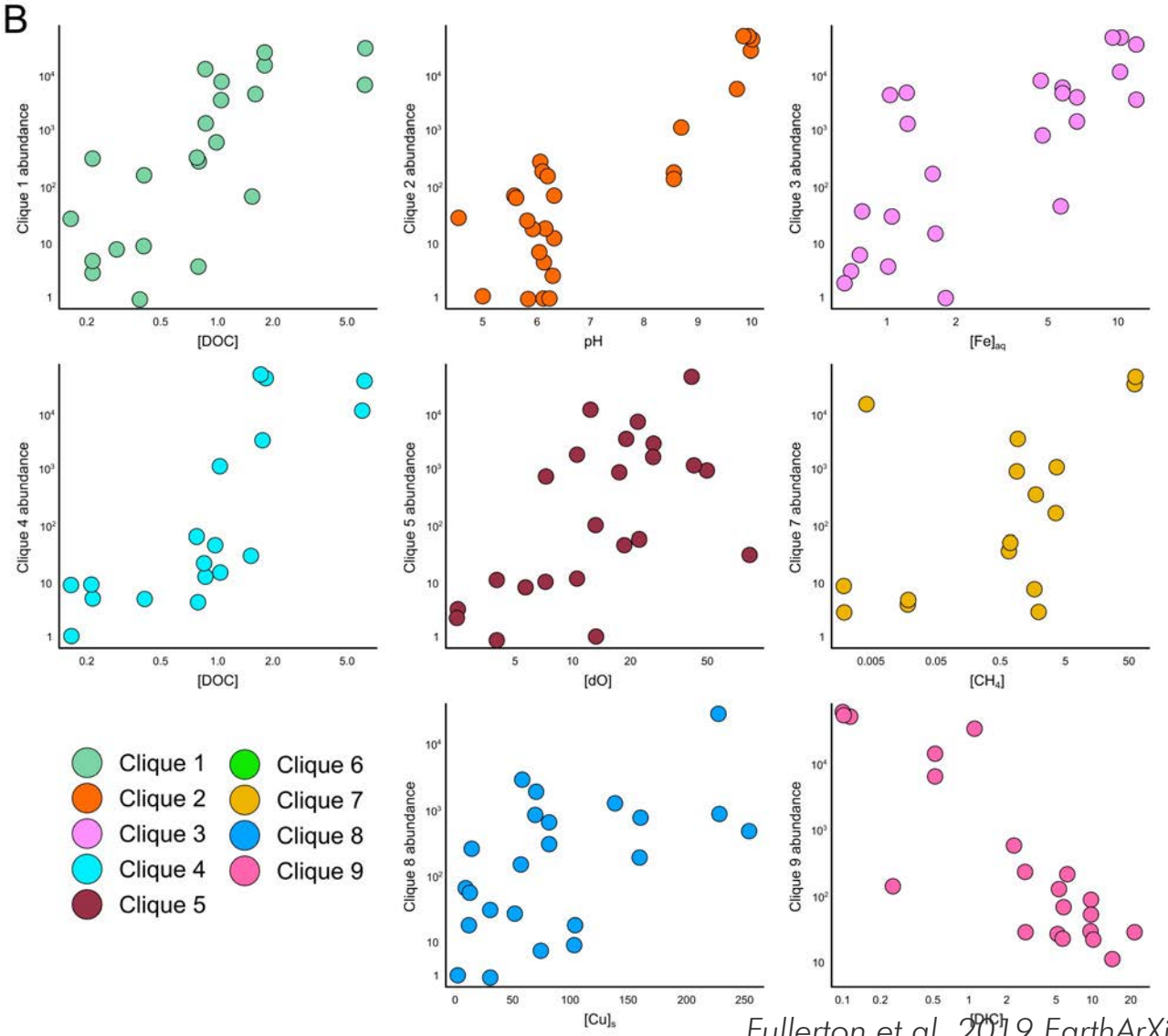

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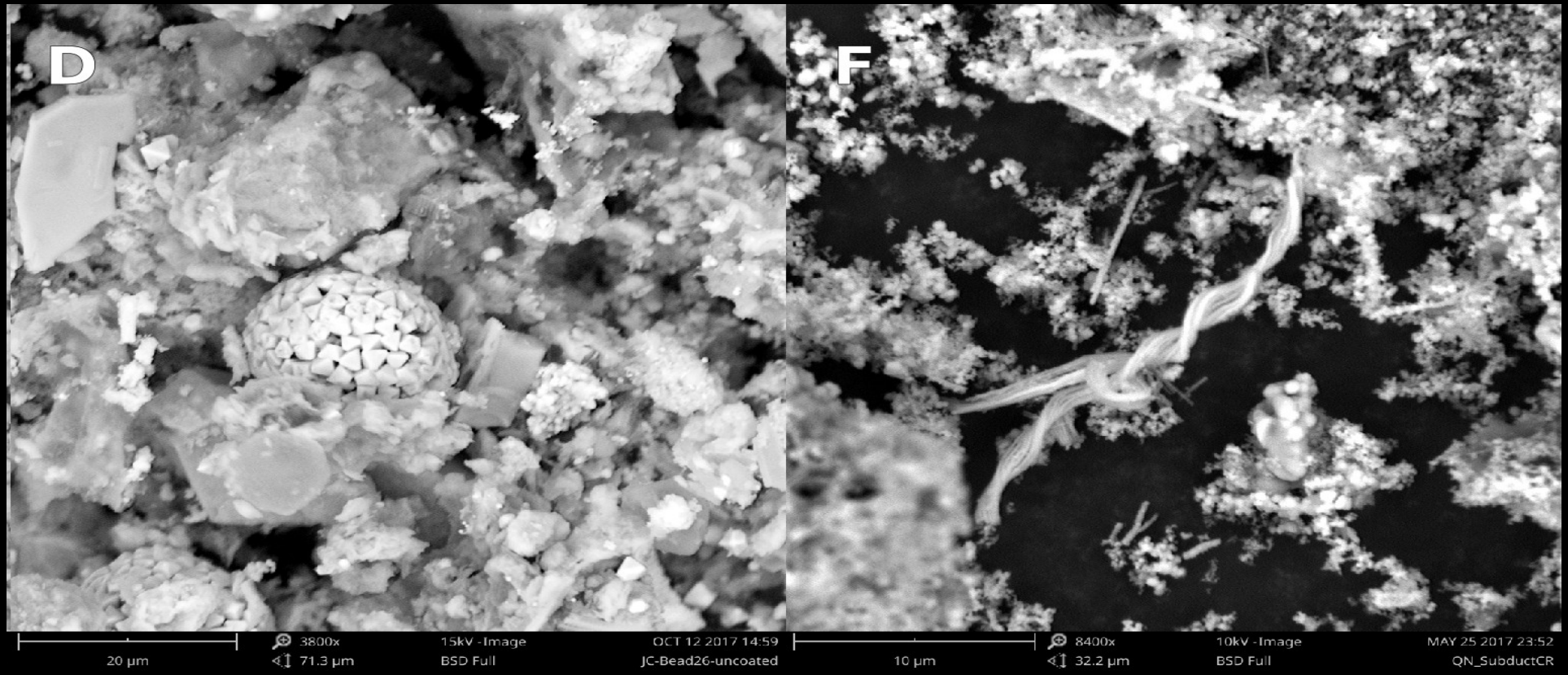

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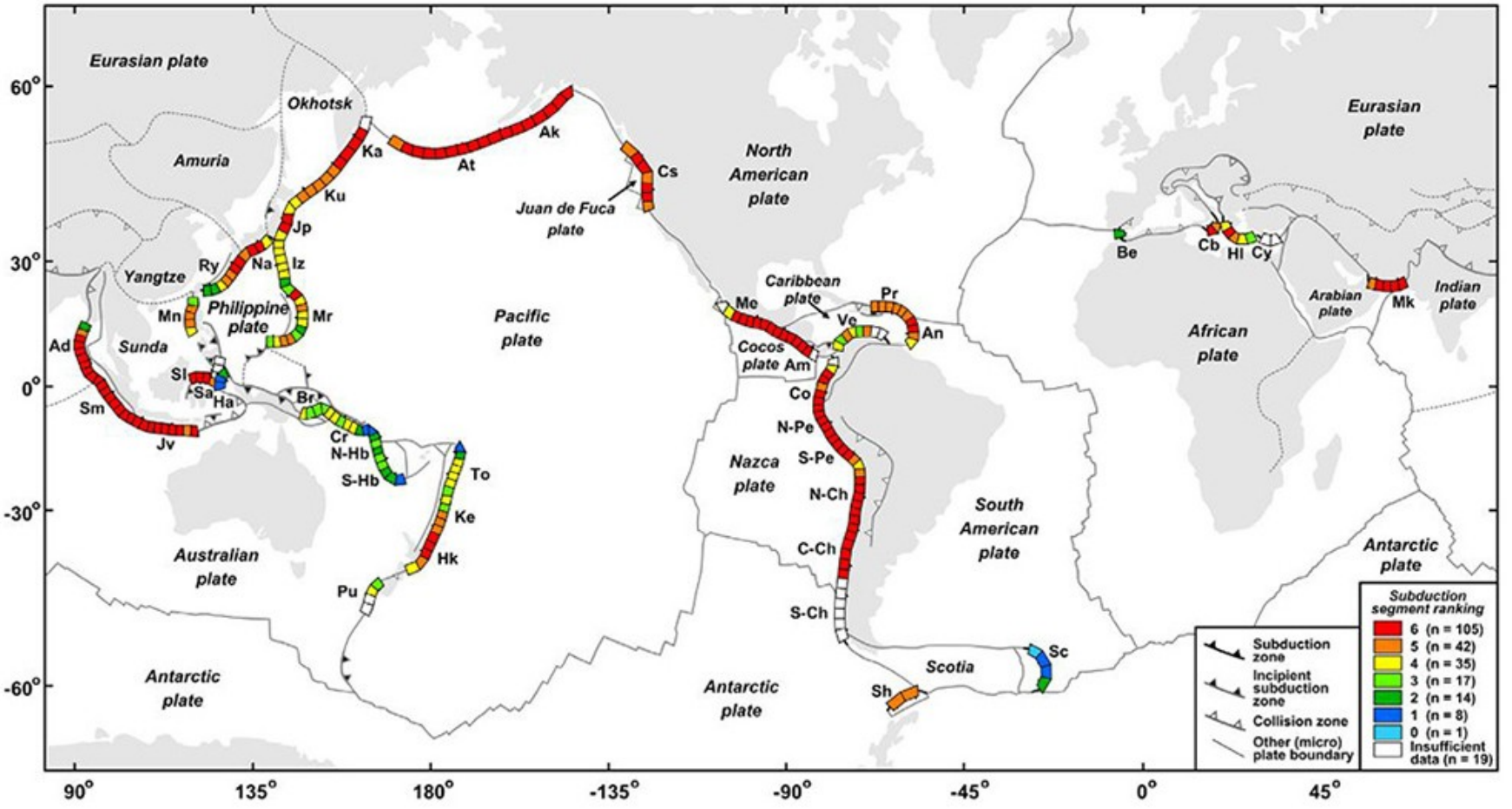

Schellart and Rawlinson, 2013 Phys Earth Planet Int

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Subsurface Life responds cohesively to deep plate processes

Subsurface Life can significantly alter the composition and flux of volatiles

Our best bet to find extraterrestrial Life is to look for an extraterrestrial subsurface biosphere

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Carly C. Blair, Steven D'Hondt, Arthur J. Spivack, and Richard H. Kingsley

Published Online: 28 Dec 2007 | https://doi.org/10.1089/ast.2007.0150

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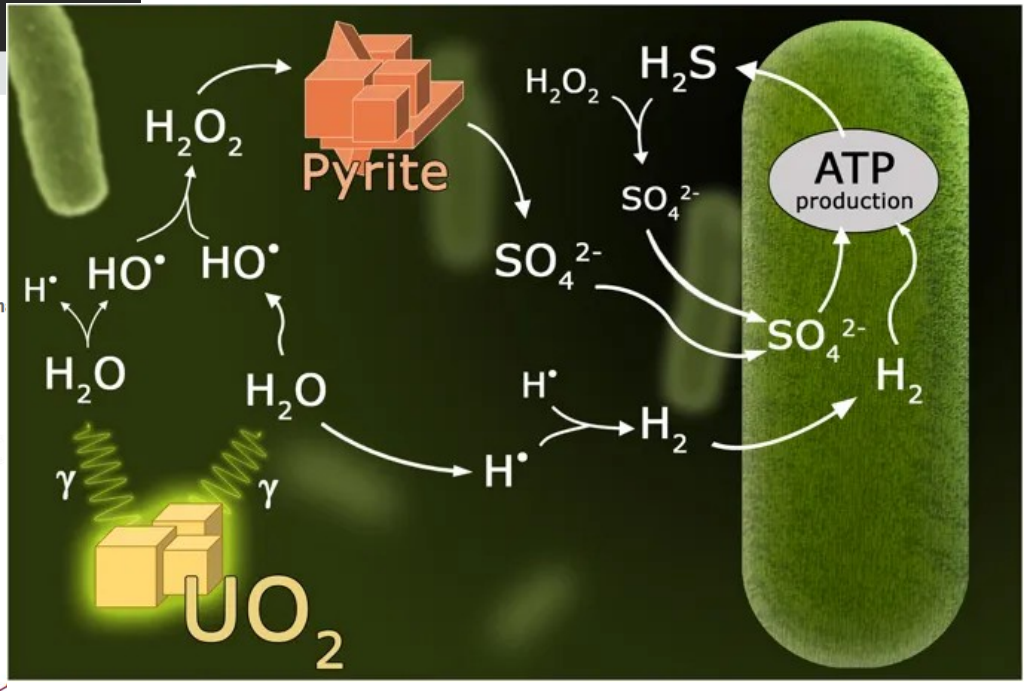
Steven D'Hondt, Arthur J. Spivack, Robert Pockalny, Timothy G. Ferdelman, Jan P. Fischer, Jens Kallmeyer, Lewis J. Abrams, David C. Smith, Dennis Graham, Franciszek Hasiuk, Heather Schrum, and Andrea M. Stancin

PNAS July 14, 2009 106 (28) 11651-11656; https://doi.org/10.1073/pnas.0811793106

Edited by Edward F. DeLong, Massachusetts Institute of Technology, Cambridge, MA, and approved May 6, 2009 (received for review November 23, 2008)



Ca. *Desulforudis audaxviator*'s pathway for obtaining energy from the decay of uranium, Mponeng gold mine in South Africa.
Chivian et al. 2008 Science

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Astrobiology, Vol. 18, No. 9 | Research Articles

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Mary Dzaugis ✉, Arthur J. Spivack, and Steven D'Hondt

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Dimitra Atri

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Earth and Planetary Science Letters
Volume 502, 15 November 2018, Pages 133-145

Radiolytic H_2 production on Noachian Mars: Implications for habitability and atmospheric warming

J.D. Tarnas [a] ✉, J.F. Mustard [a], B. Sherwood Lollar [b], M.S. Bramble [a], K.M. Cannon [c], A.M. Palumbo [a], A.-C. Plesa [d]

South Africa Gold Mines

The average activity concentrations in $Bq \cdot kg^{-1}$ for Uranium-238, Thorium-232, and Potassium-40 from the mine tailings were found to be 785, 44 and 427, respectively.
Kamunda et al. 2018 Int J Environ Res Public Health

INFN Gran Sasso Underground Laboratory

Activity concentrations in $Bq \cdot kg^{-1}$ for Uranium-238, Thorium-232, and Potassium-40 *are clearly below the levels observed for typical carbonate rocks and limestone concrete, with values of 1.7, 1.4, and 26 respectively.*
Malczewski et al. 2013 J Radioanal Nucl Chem

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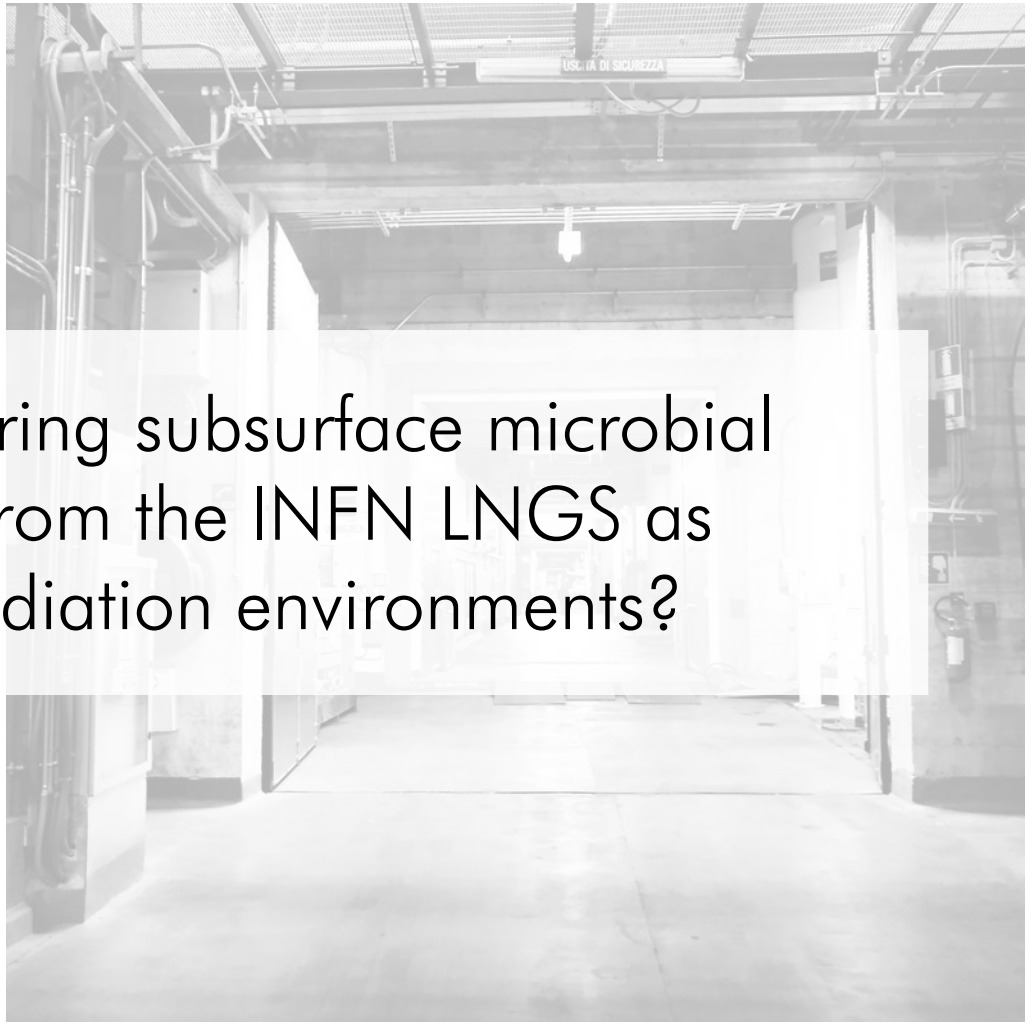

Can we use natural occurring subsurface microbial communities accessed from the INFN LNGS as endmember for low radiation environments?

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