MICROBIOLOGY OF EXTREME ENVIRONMENTS

Extreme environments 1

Donato Giovannelli

donato.giovannelli@unina.it

www.donatogiovannelli.com

@d_giovannelli

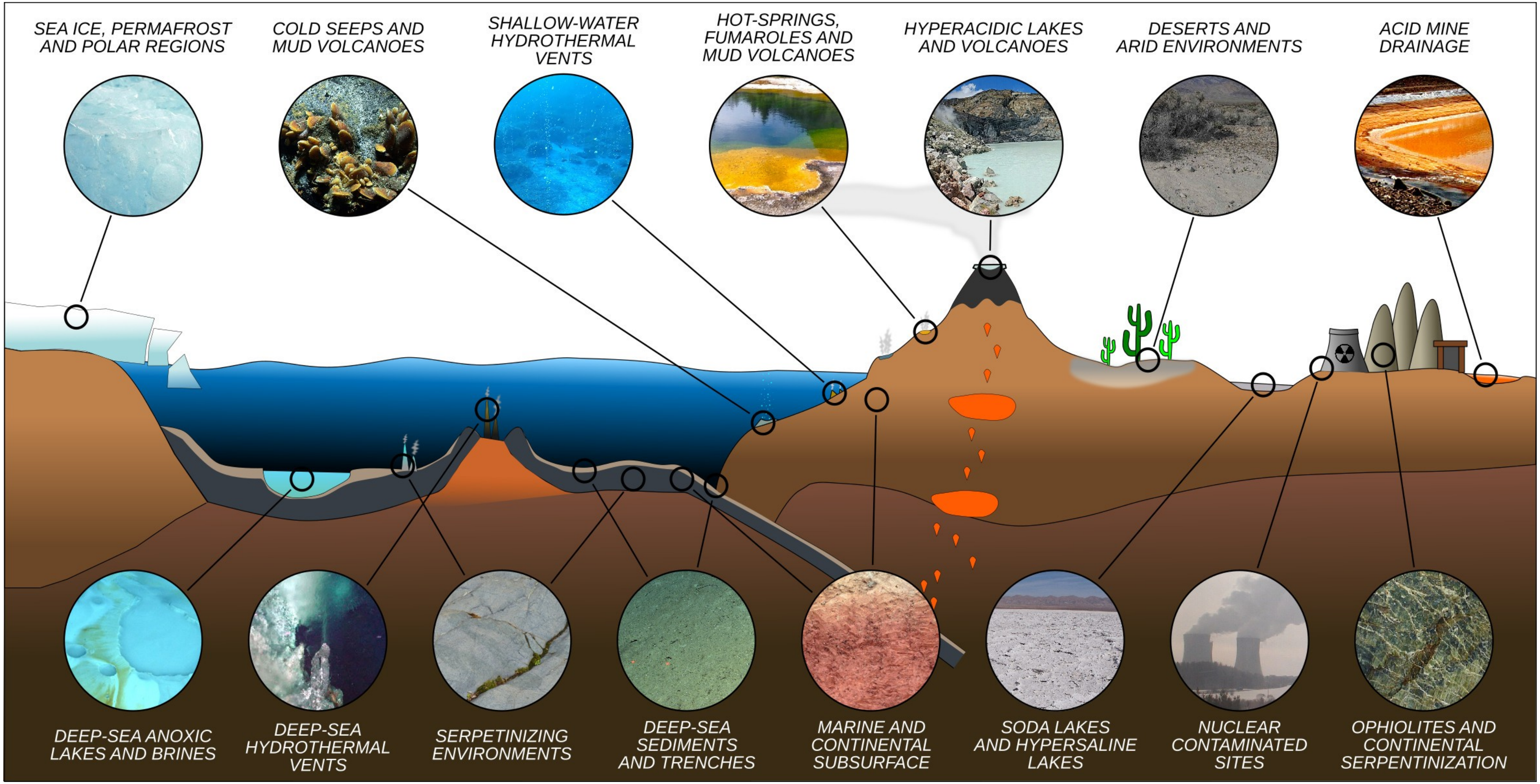
@donatogiovannelli

GIOVANNELLI LAB

BIOLOGY OF EXTREME ENVIRONMENTS

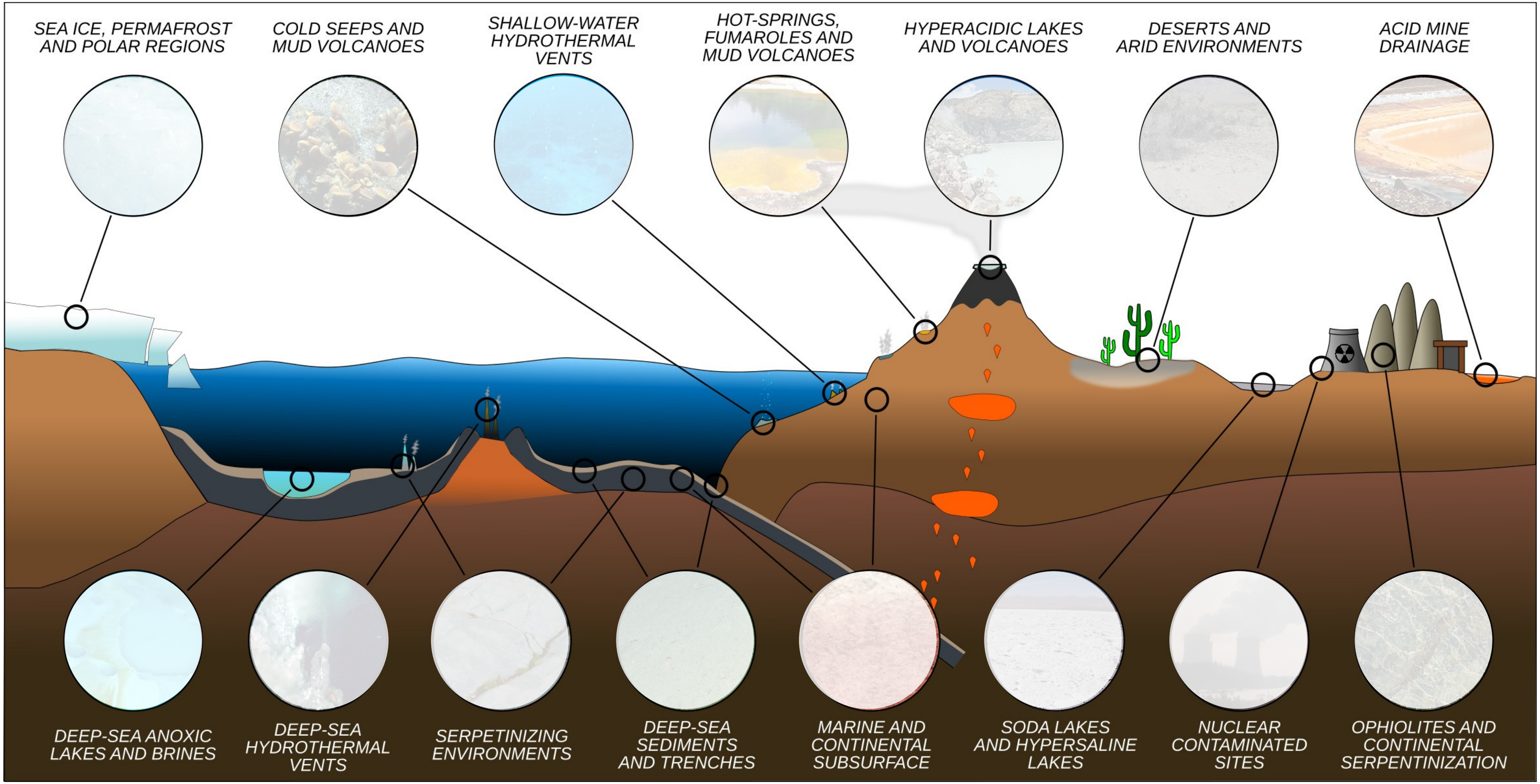
DIPARTIMENTO DI BIOLOGIA

Earth's Extreme Environments



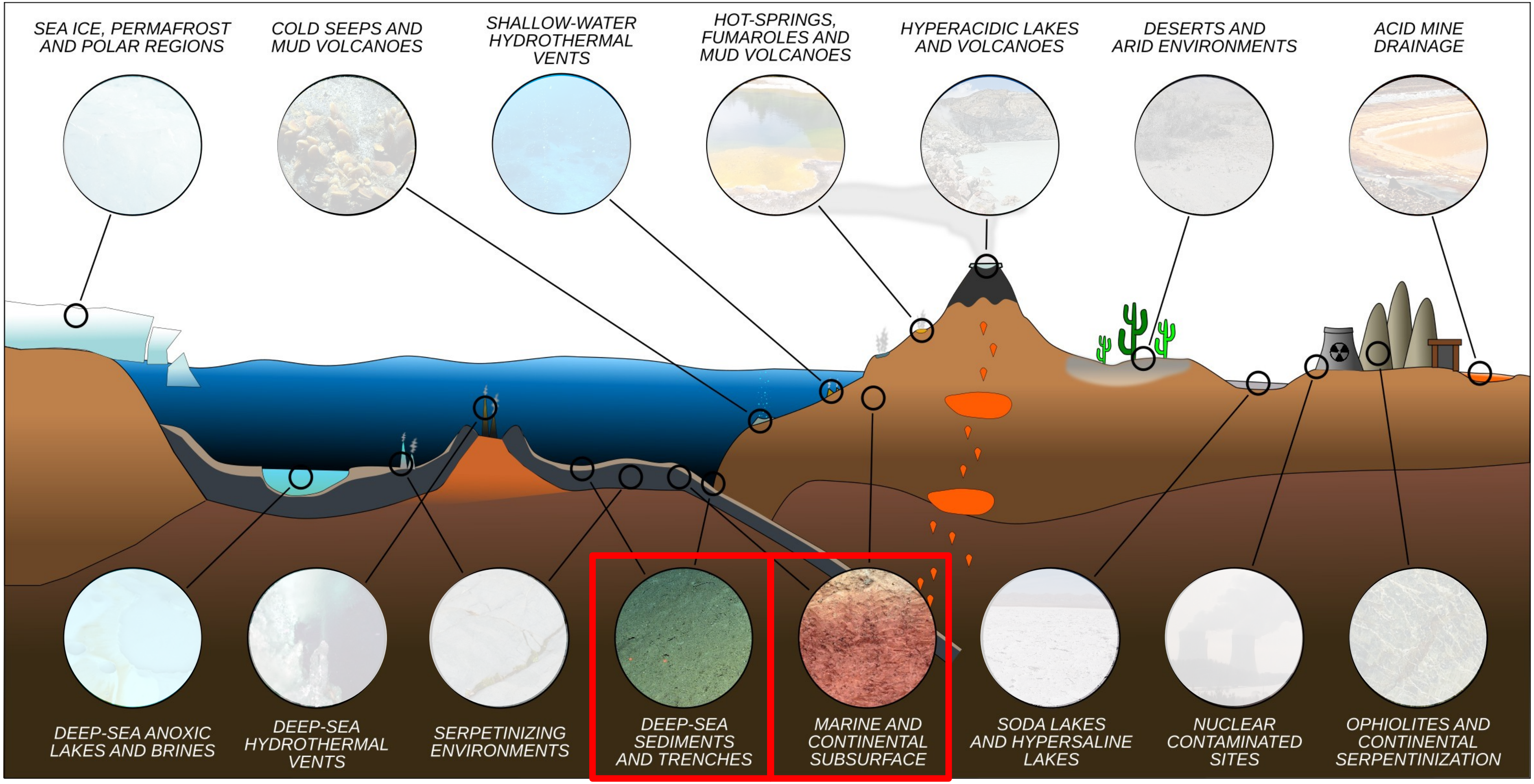
Merino et al 2019 Front Microbiol

Earth's Extreme Environments



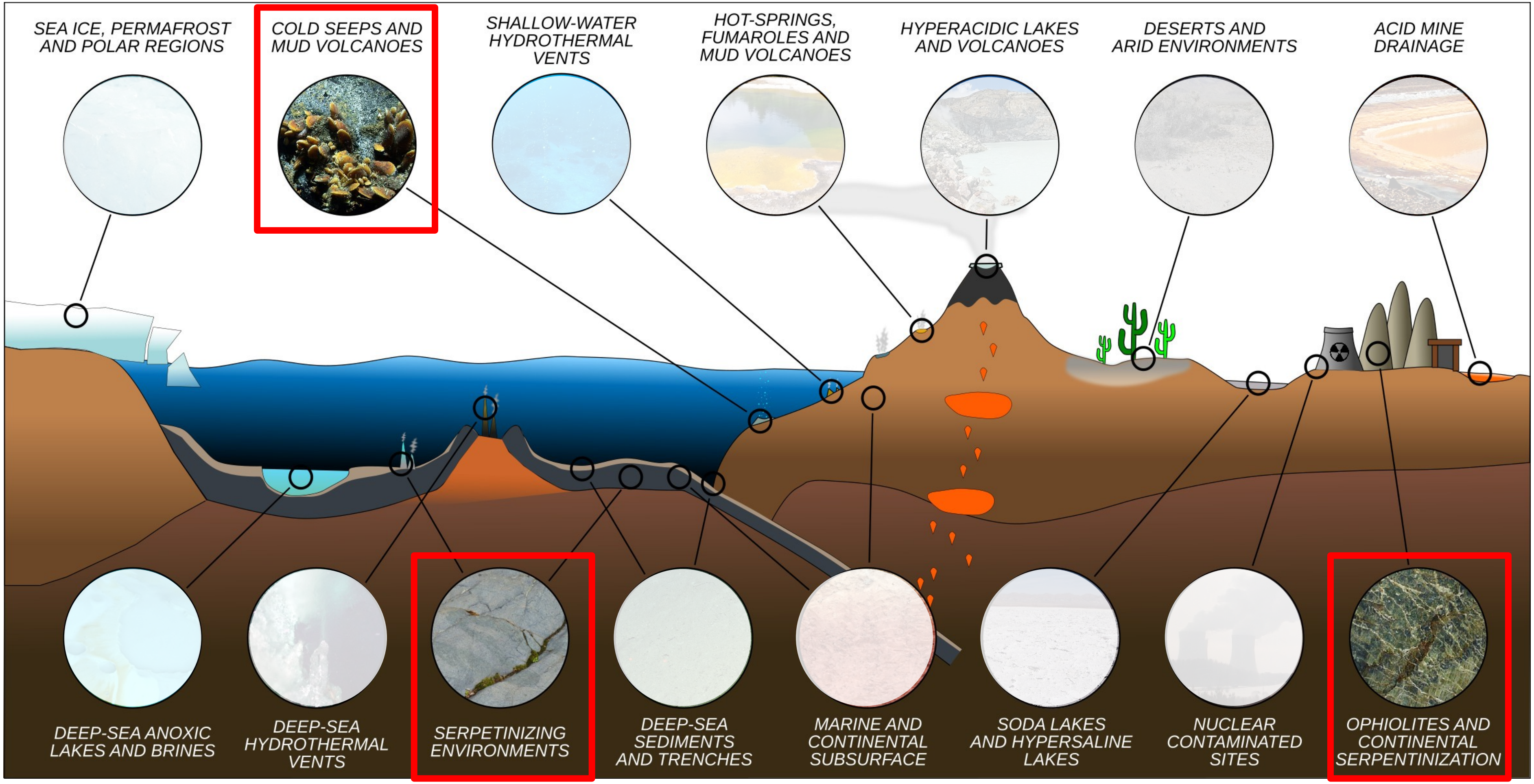
Merino et al 2019 Front Microbiol

Earth's Extreme Environments



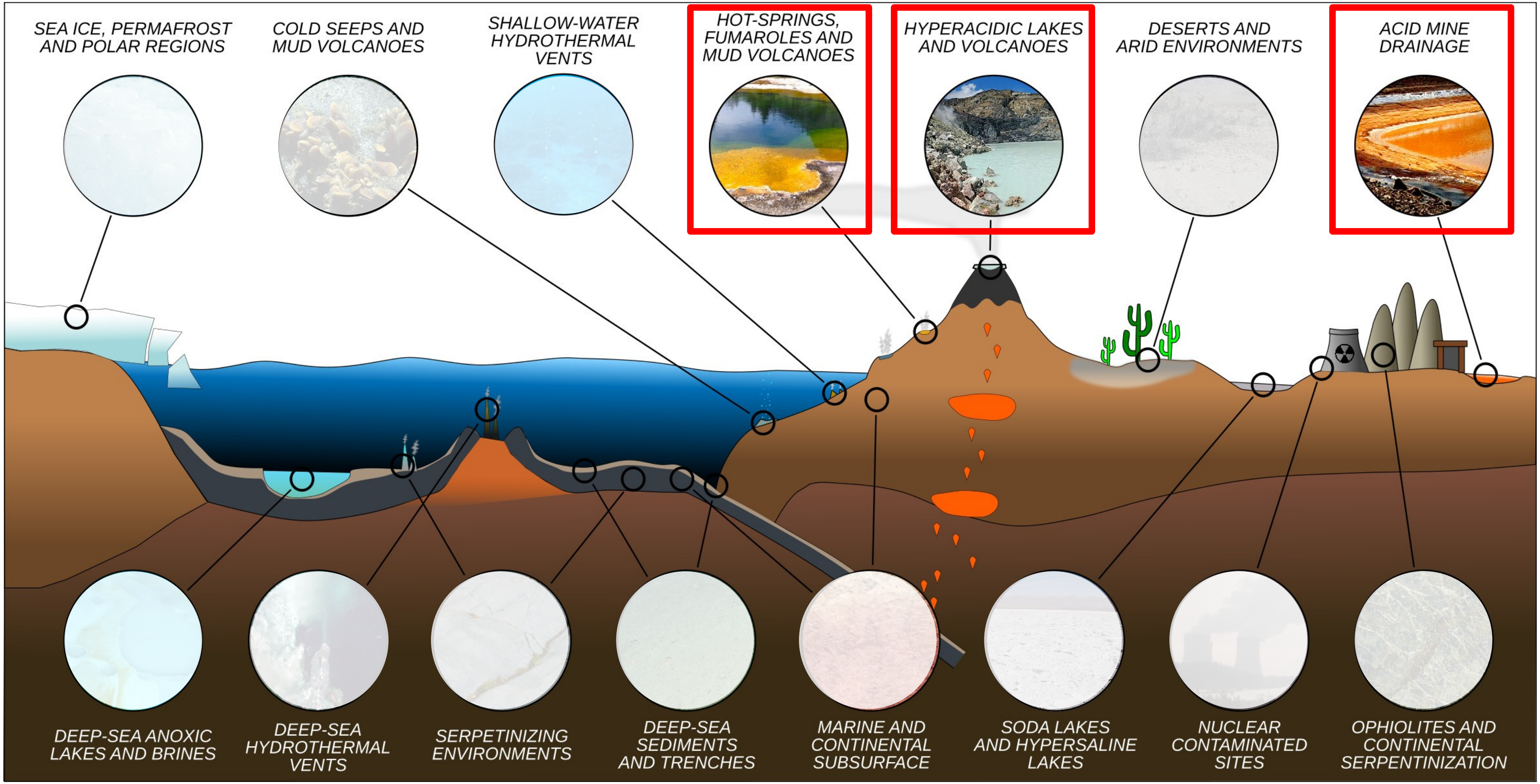
Merino et al 2019 Front Microbiol

Earth's Extreme Environments



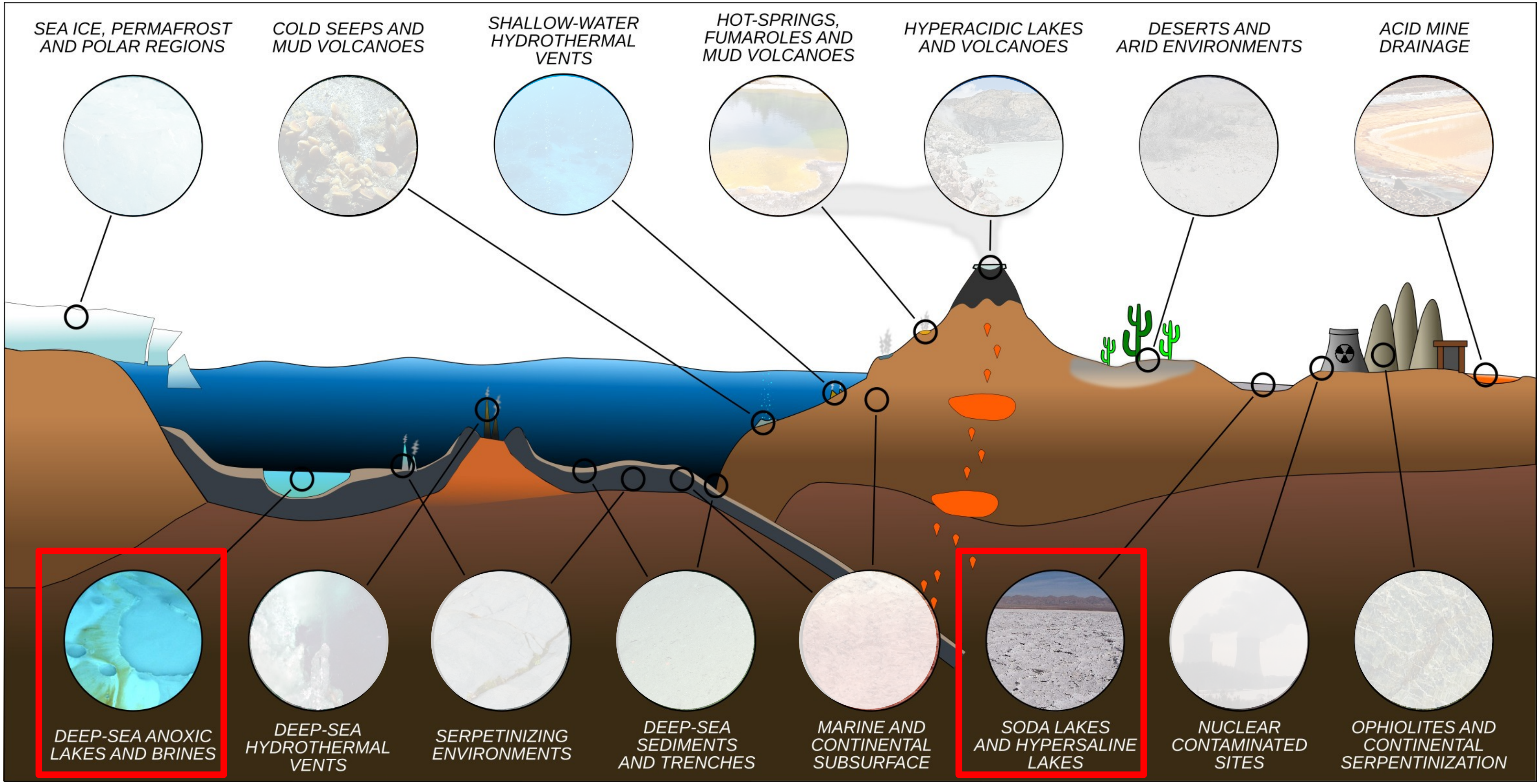
Merino et al 2019 Front Microbiol

Earth's Extreme Environments



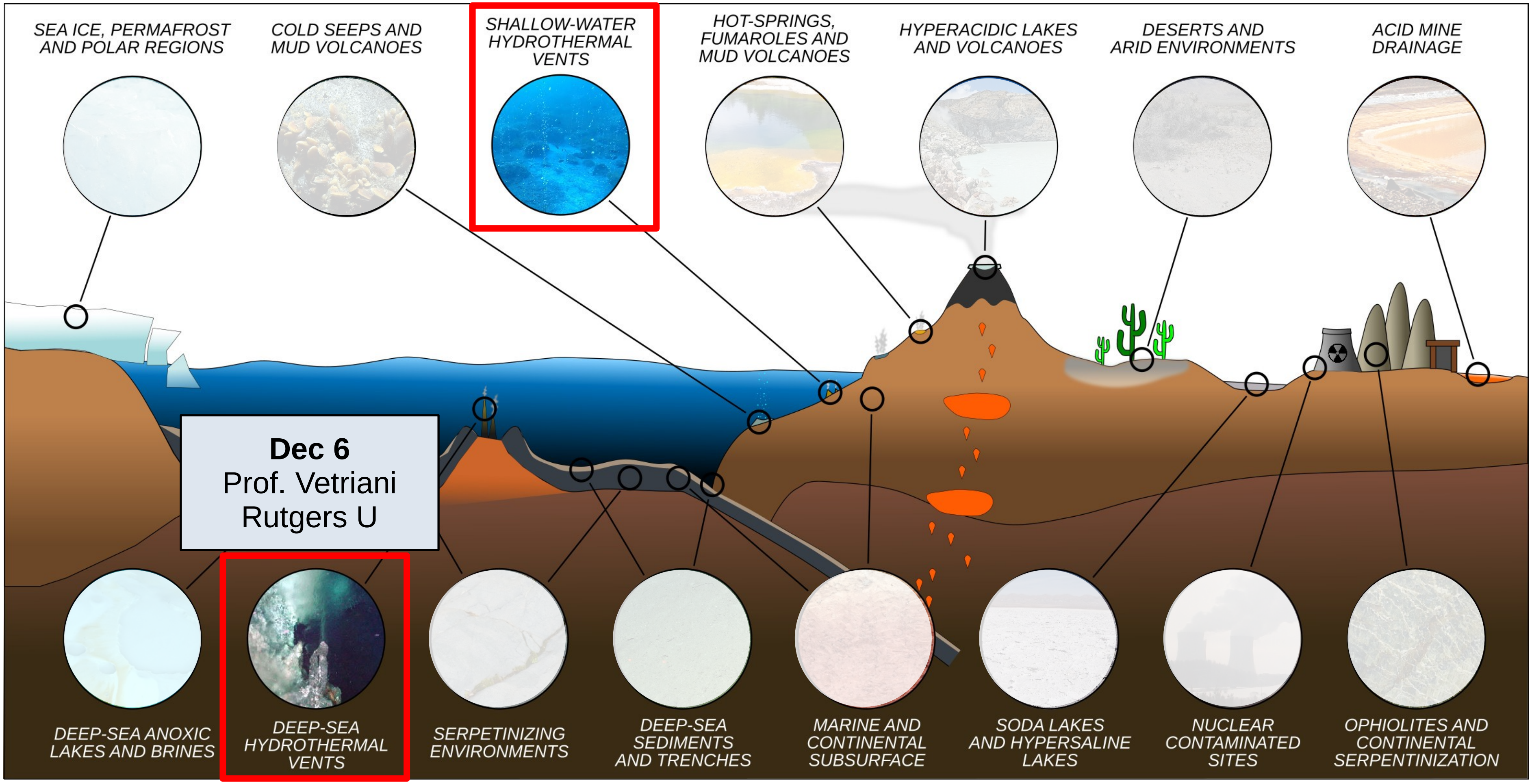
Merino et al 2019 Front Microbiol

Earth's Extreme Environments



Merino et al 2019 Front Microbiol

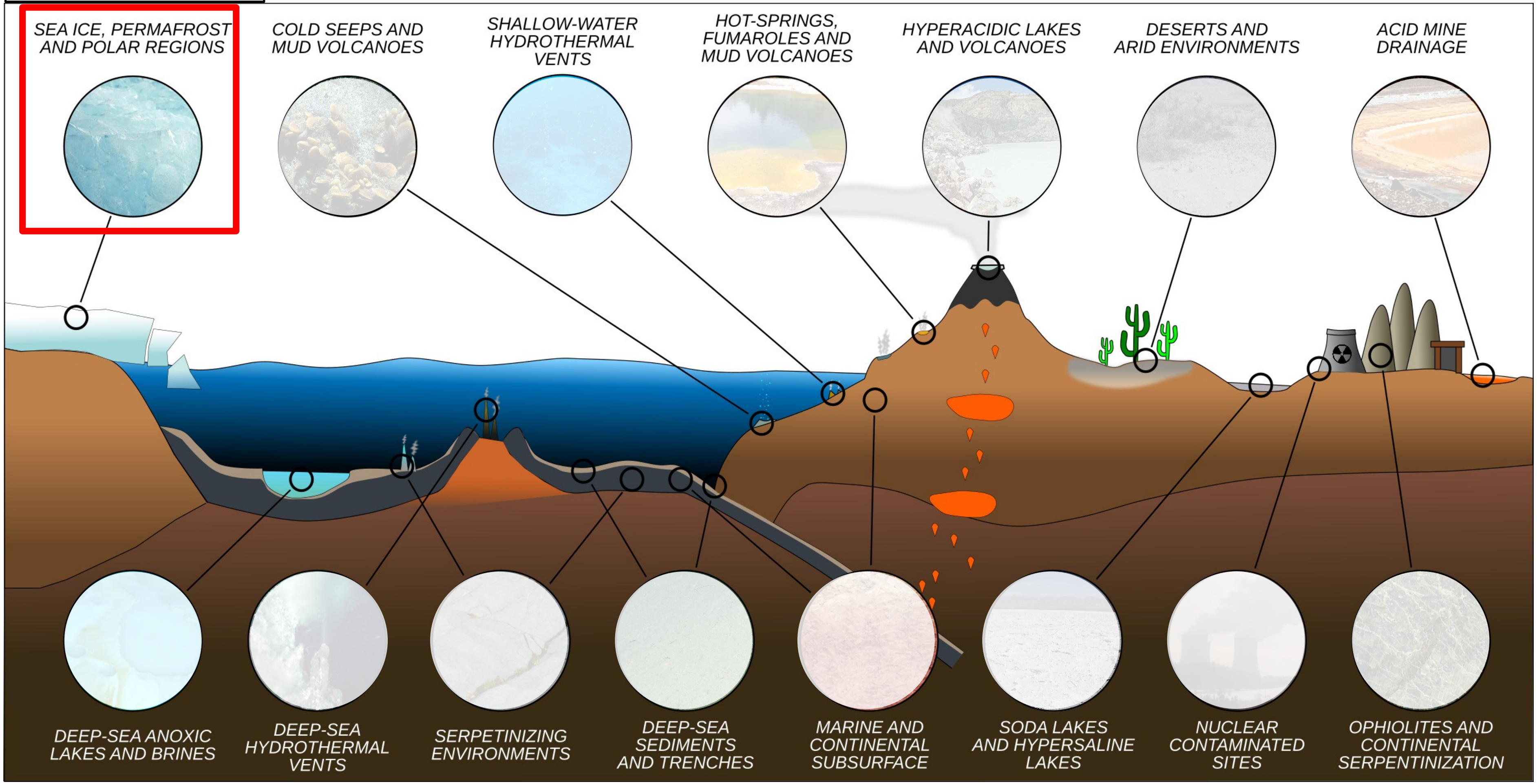
Earth's Extreme Environments



Merino et al 2019 Front Microbiol

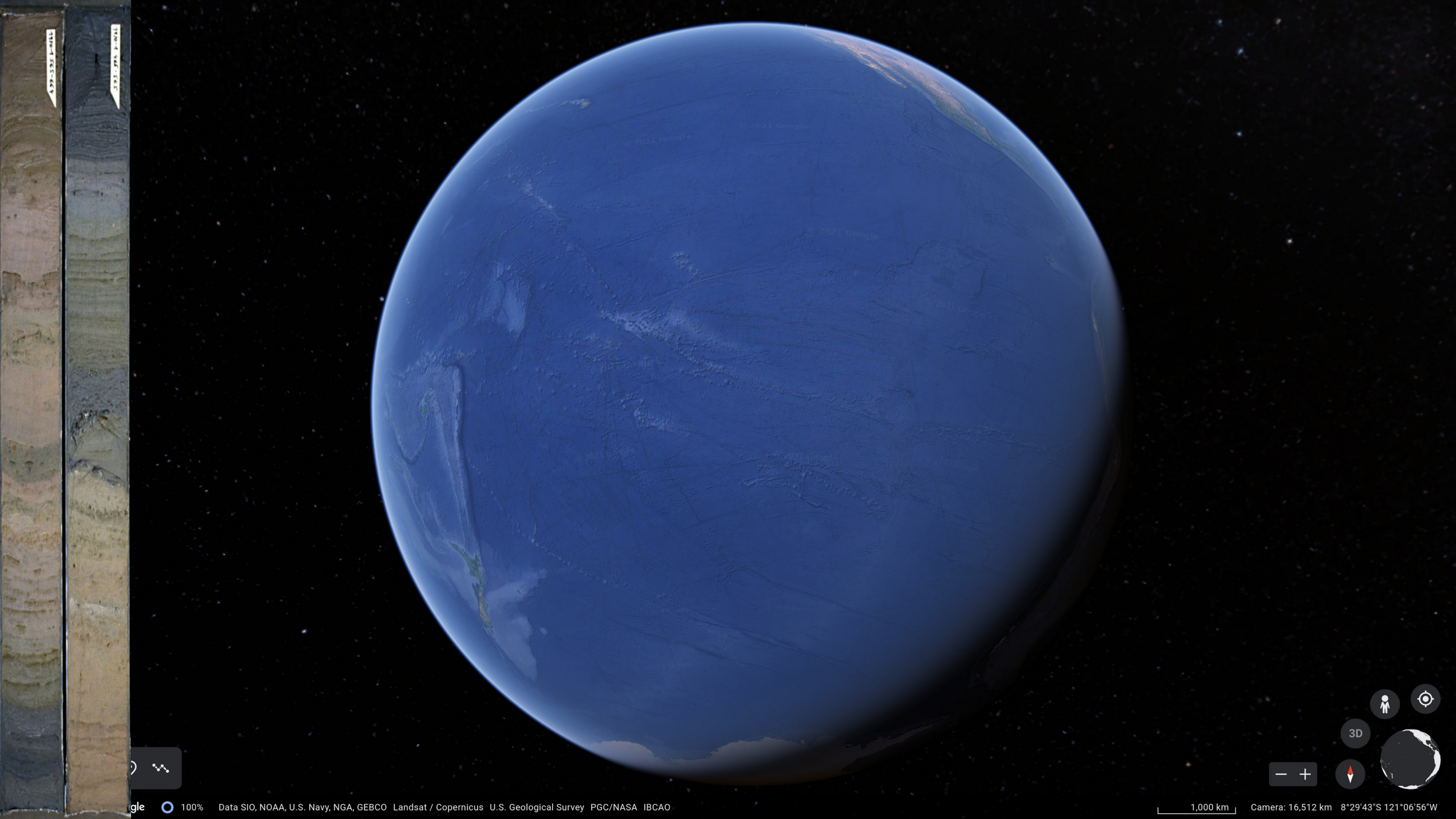
Dec 2
Prof. Franzetti
UNIMIB

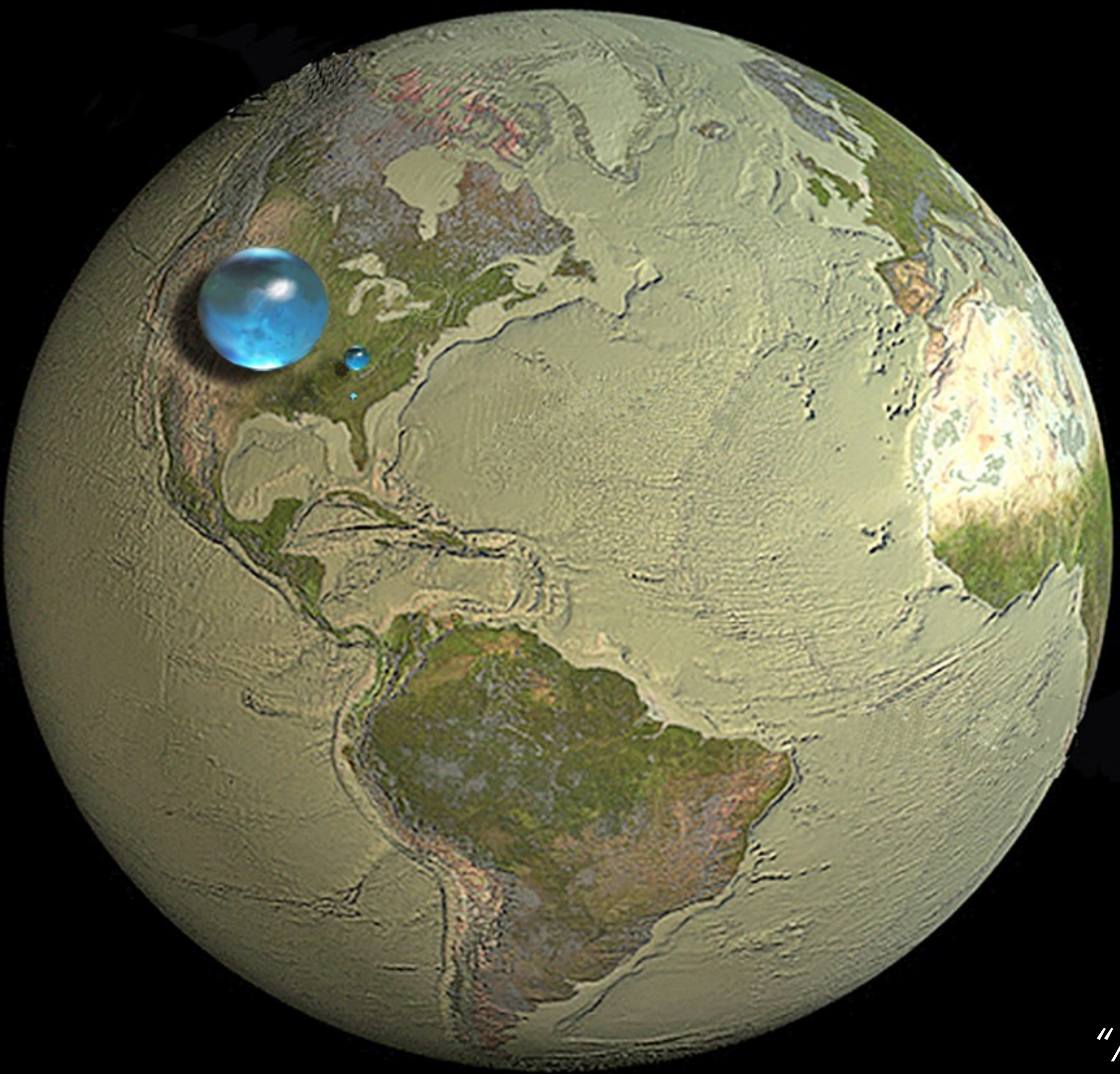
Earth's Extreme Environments



Merino et al 2019 Front Microbiol

DEEP SEA WATER COLUMN


3D
gle
100%
Data SIO, NOAA, U.S. Navy, NGA, GEBCO Landsat / Copernicus U.S. Geological Survey PGC/NASA IBCAO
1,000 km
Camera: 16,512 km 8°29'43"S 121°06'56"W



“A thin layer of water”

The Ocean(s) in Numbers

Seawater covers approximately 71% of Earth's surface and 90% of the Earth's (surface) biosphere

The ocean contains 97% of Earth's (surface) water

The total volume is approximately 1.35 billion cubic kilometers

Average depth of more about 4,000 meters

Average salinity is around 34.7‰

Average temperature of Ocean’s surface waters is about 17 °C, deep-sea temperature is within the 0-3 °C range (13.3 °C in the Mediterranean deep-sea)

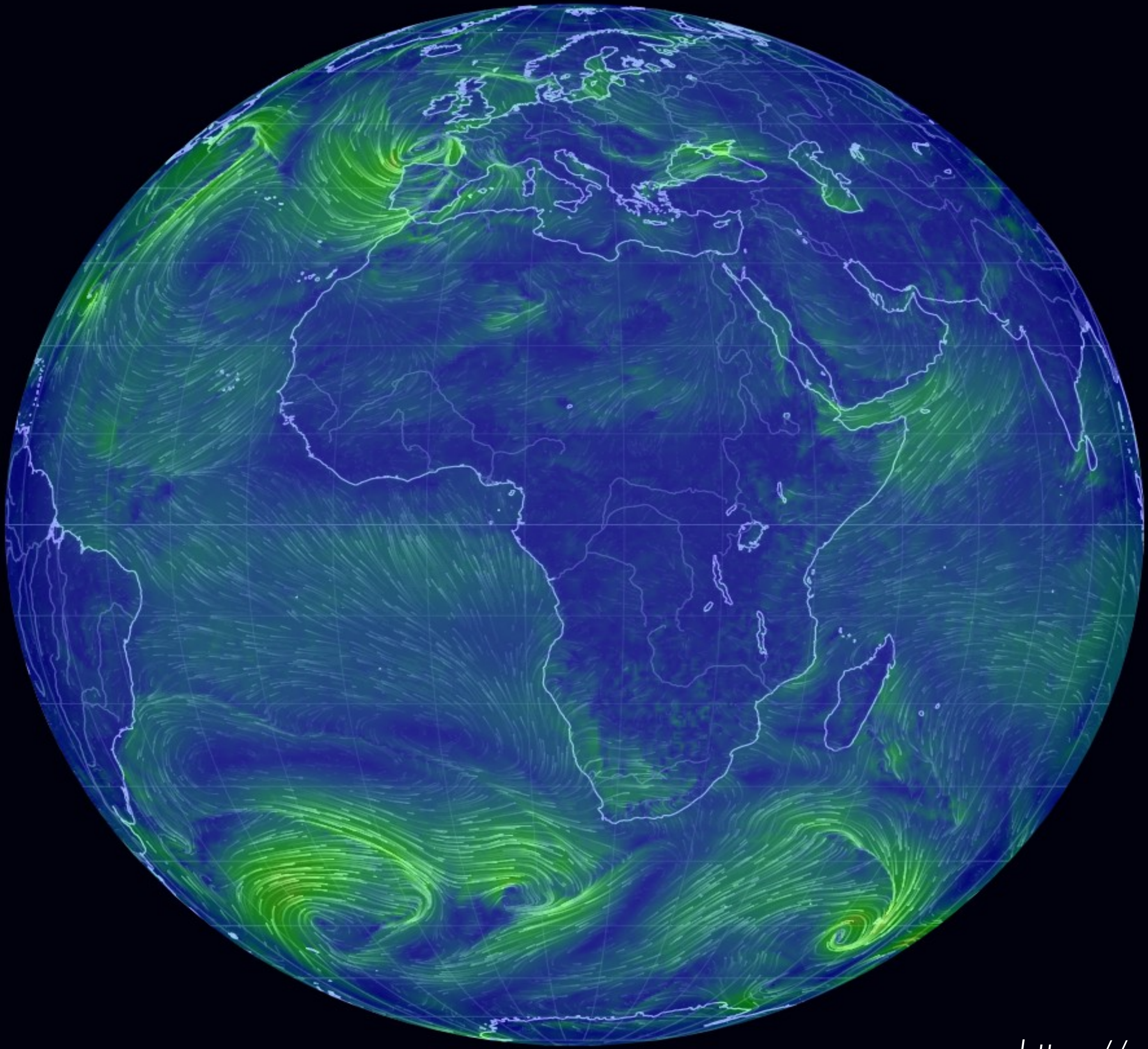
Seawater freezes at around −1.9 °C at atmospheric pressure

Less than 5% of the World Ocean has been explored in any details, and even less of marine sediments and subsurface

Seawater average composition

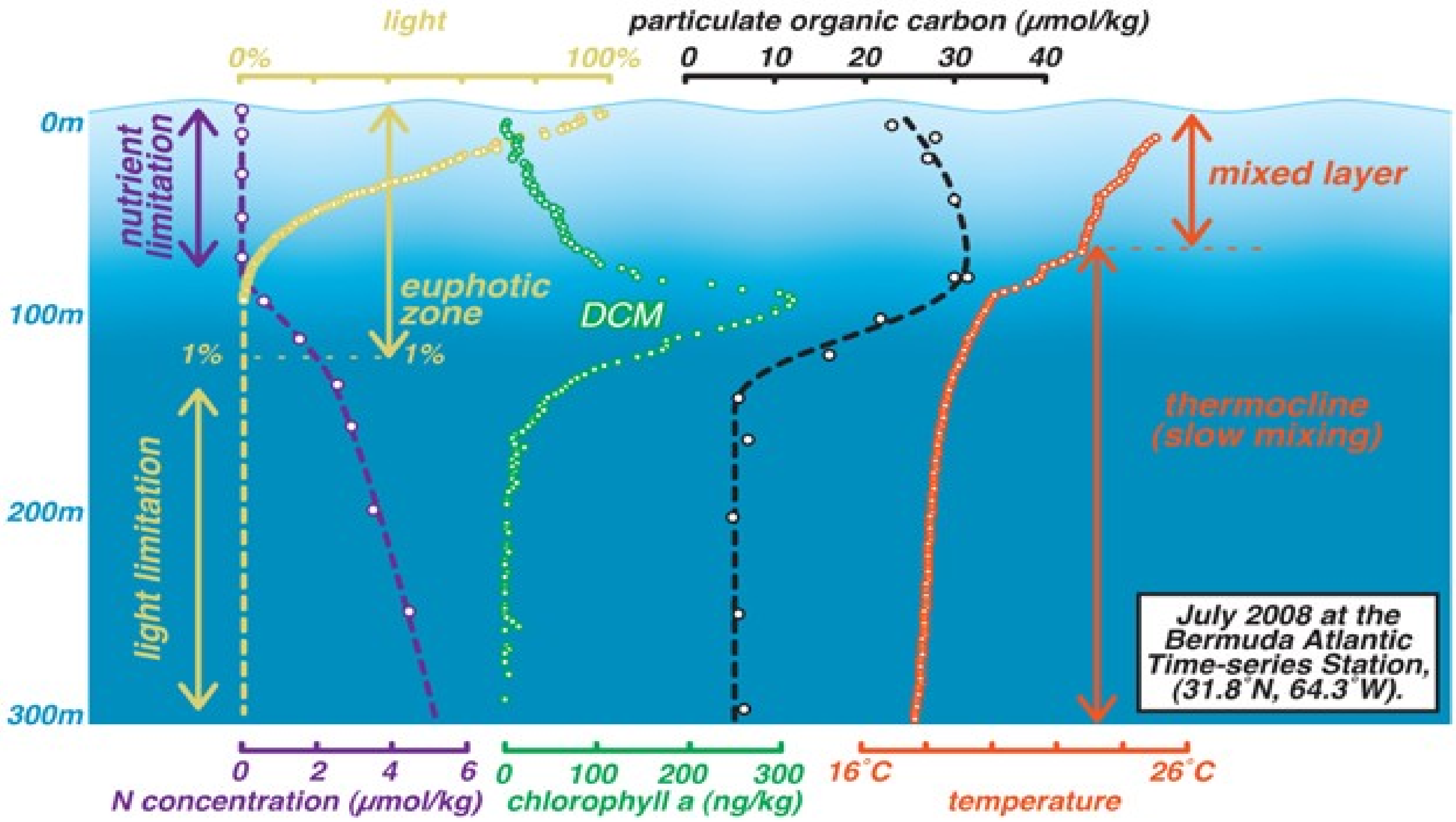
Table 9.2 The Major Dissolved Constituents of Seawater

Ion	Cl = 19‰	Percent
Cl	18.980	55.05
Br	0.065	0.19
SO_4	2.649	7.68
HCO_3	0.140	0.41
F	0.001	0.00
H_3BO_3	0.026	0.07
Mg	1.272	3.69
Ca	0.400	1.16
Sr	0.008	0.03
K	0.380	1.10
Na	10.556	30.61
Total	34.477	99.99

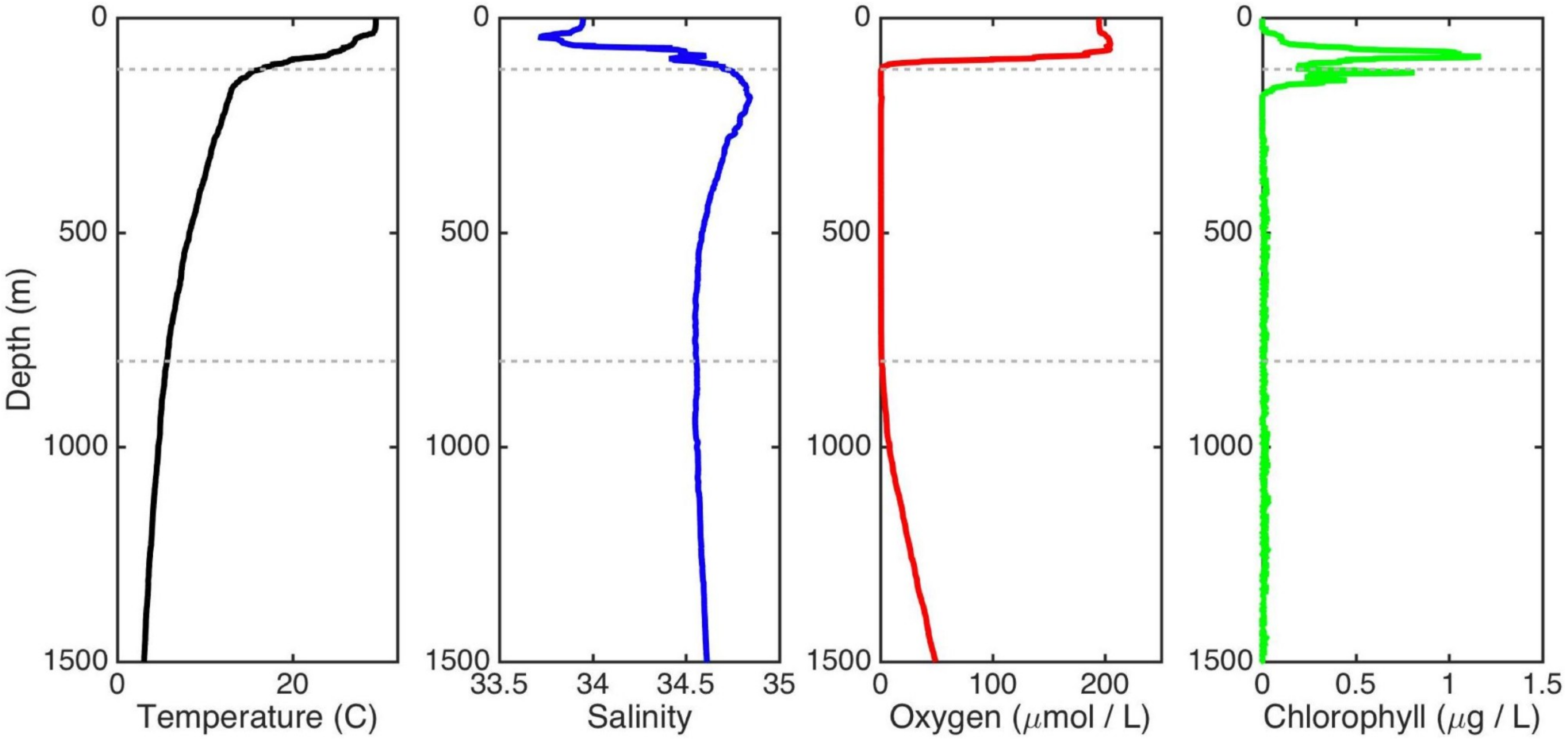


https://earth.nullschool.net/

Depth profiles

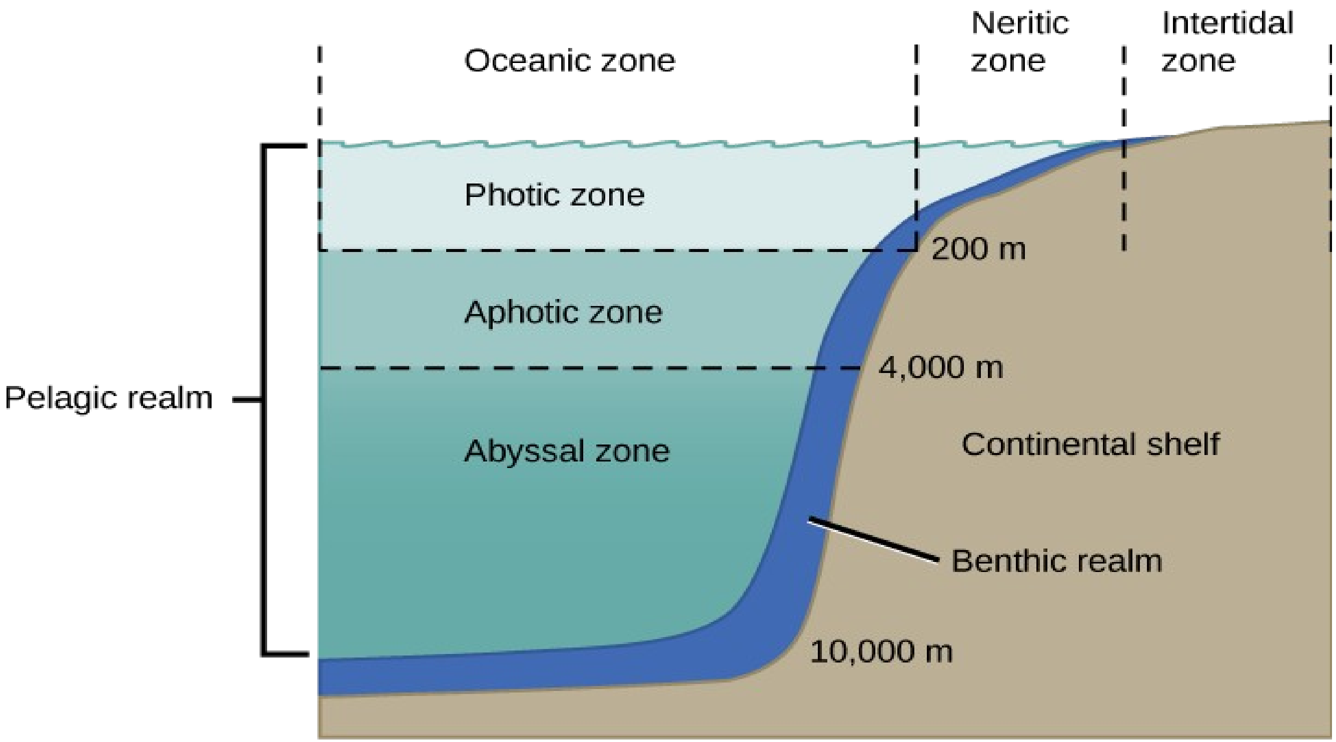


Depth profiles



https://web.whoi.edu/darklife/first-science-of-the-cruise/

Slicing the pie: by light or by depth?



Benthic vs Pelagic

Pelagic: *Any water in a sea or lake that is neither close to the bottom nor near the shore can be said to be in the pelagic zone. The pelagic zone can be thought of in terms of an imaginary cylinder or water column that goes from the surface of the sea almost to the bottom*

Demersal: *The demersal zone is the part of the sea or ocean comprising the water column that is near to (and is significantly affected by) the seabed and the benthos. The demersal zone is just above the benthic zone*

Benthic: *The benthic zone is the ecological region at the lowest level of a body of water such as an ocean or a lake, including the sediment surface and some sub-surface layers. The superficial layer of the soil lining the given body of water, the benthic boundary layer, is an integral part of the benthic zone, as it greatly influences the biological activity that takes place there*

Photic and Aphotic zones

*The **photic zone,** or the portion of ocean receiving sunlight, also called the euphotic zone is defined up to the depth of water receiving up to 1% of the PAR, were photosynthesis is supported. Typical euphotic depths vary from only a few centimeters in highly turbid eutrophic lakes, to around 200 metres in the open ocean*

*The **aphotic zone** is the portion of a lake or ocean where there is little or no sunlight. It is formally defined as the depths beyond which less than 1% of sunlight penetrates. Often the aphotic zone is further divided in a **twilight zone** (or disphotic zone, between 1 and 0.1% of sunlight) and the true aphotic or **abyssal zone** (less than 0.1% of sunlight)*

Epipelagic: up to 200 m depth, roughly corresponding to the euphotic zones and the depth at which the continental shelf breaks

Mesopelagic: from 200 m to 1,000 m; temperature varies less than the epipelagic (between 20 and 4°C; is the location of the thermocline

Bathypelagic: from 1,000 m to 4,000 m; also known as midnight zone; average temperature hovers at about 4 °C; majority of the ocean depth is in this zone

Abyssopelagic: from 4,000 m to 6,000 m; temperatures around 2 °C to 3 °C

Hadopelagic: below 6,000 m; also known as the hadal zone and trench zone

Primary production in the Marine Environment

Primary production *(PP) in surface oceans and surface sediments within the photic zone happens through* ***photosynthesis***

Chemosynthesis*, while also present in the photic zone in certain areas, is responsible for primary productivity in the aphotic portions of the oceans. This includes the water column, marine sediments and a number of chemosythetic based ecosystems*

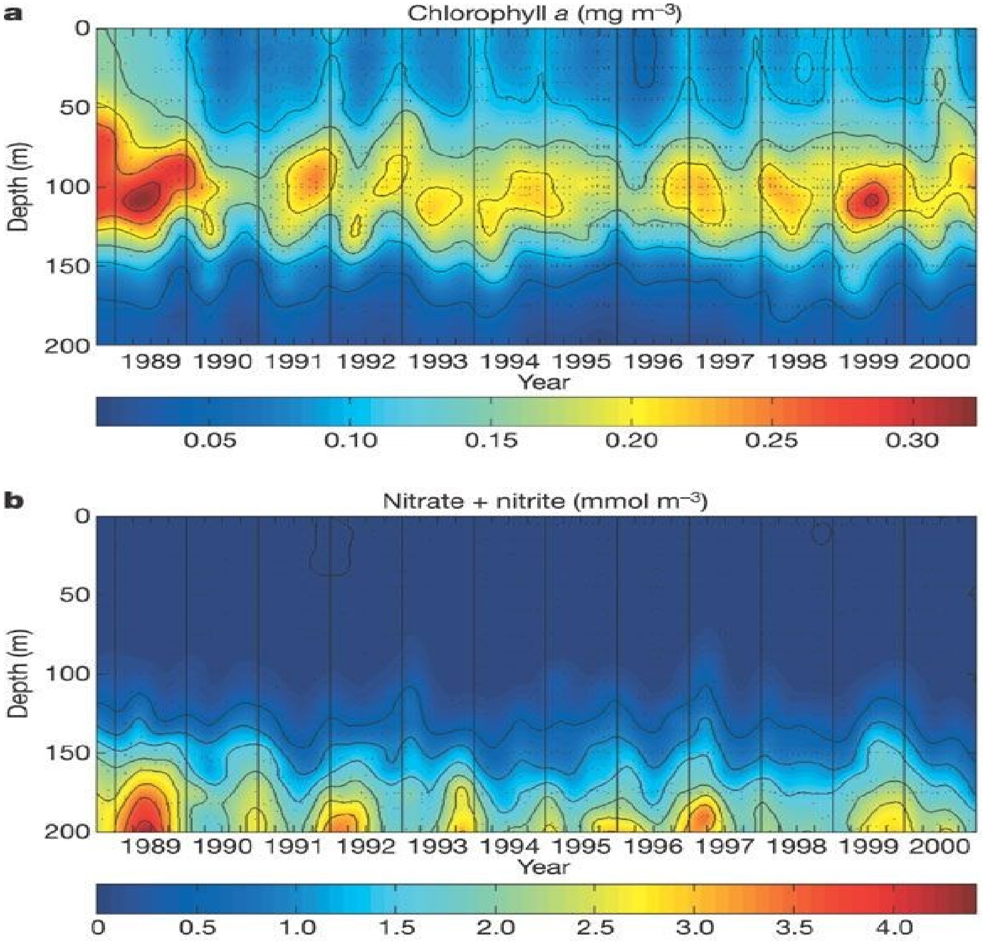
Despite this, a large fraction of the organic carbon sustaining the food chain in the deep sea is derived from the surface primary productivity

Exports to the seafloor strongly influence life in the water column, in the marine sediments and in the subsurface, controlling not only the amount of available caron but also the distribution fo electron acceptors

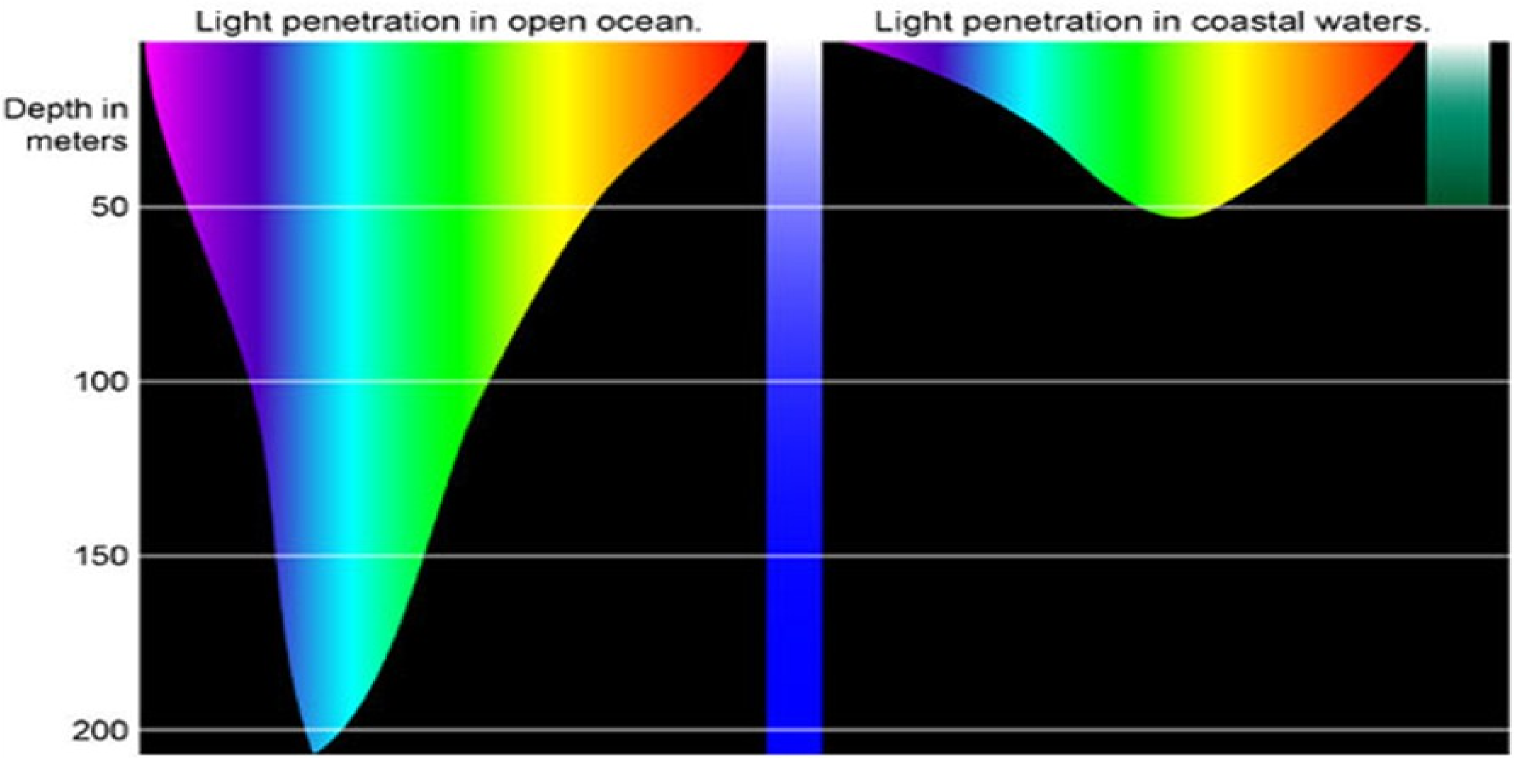
Factor limiting surface primary production

The major factor controlling primary production in the marine environment are:

- *Availability of light (PAR)*
- *Available nutrients (N and P)*
- *Availability of trace elements (e.g. iron, cobalt)*



Penetration of light

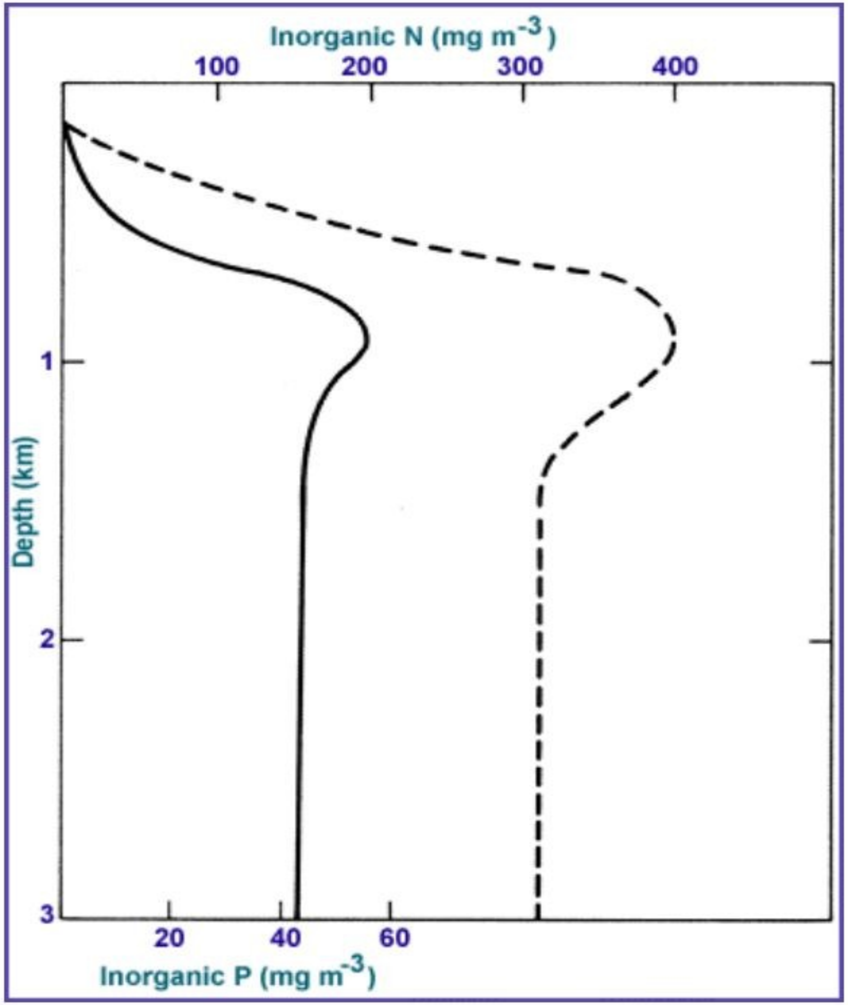


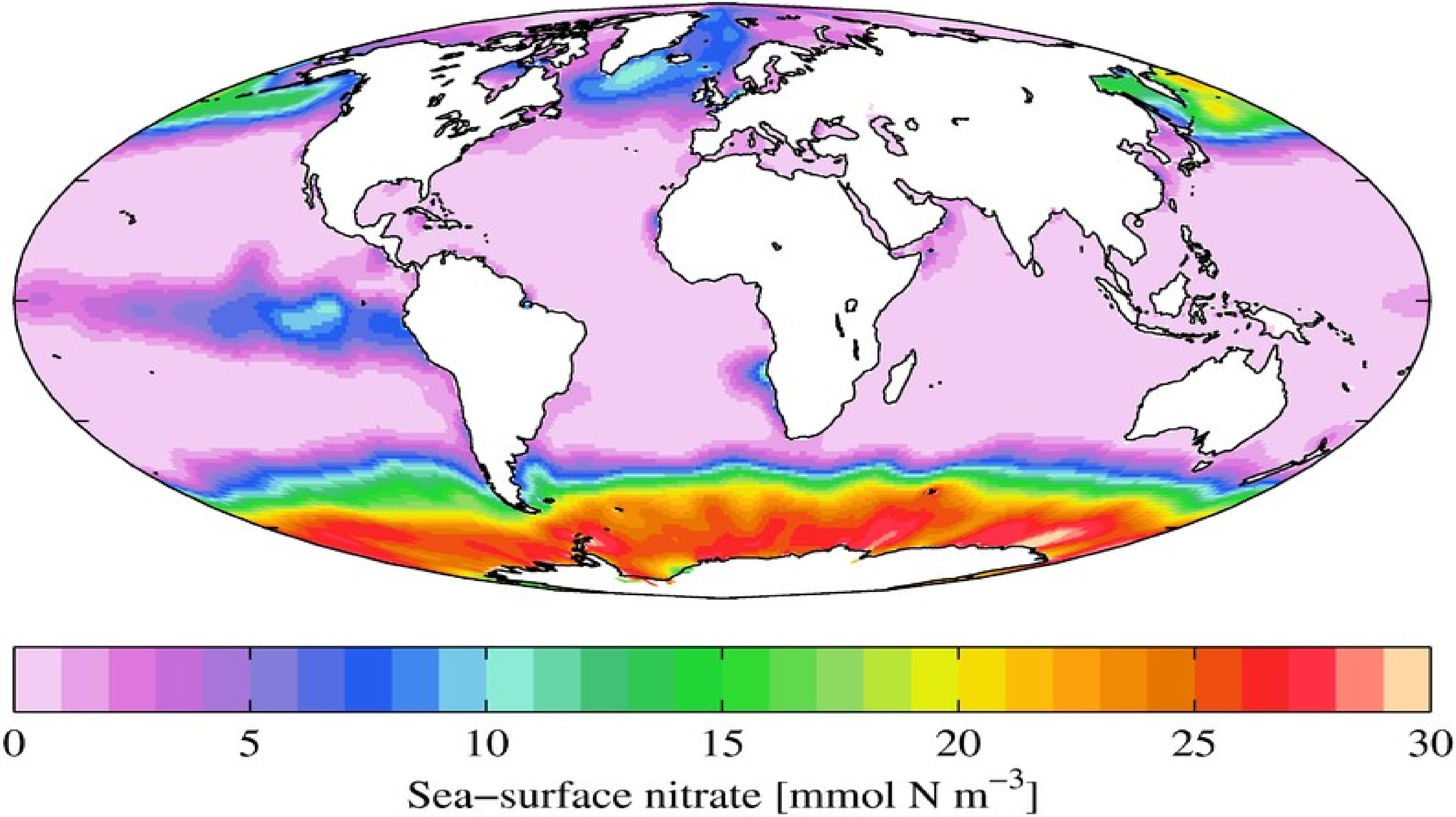
Limitation of PP

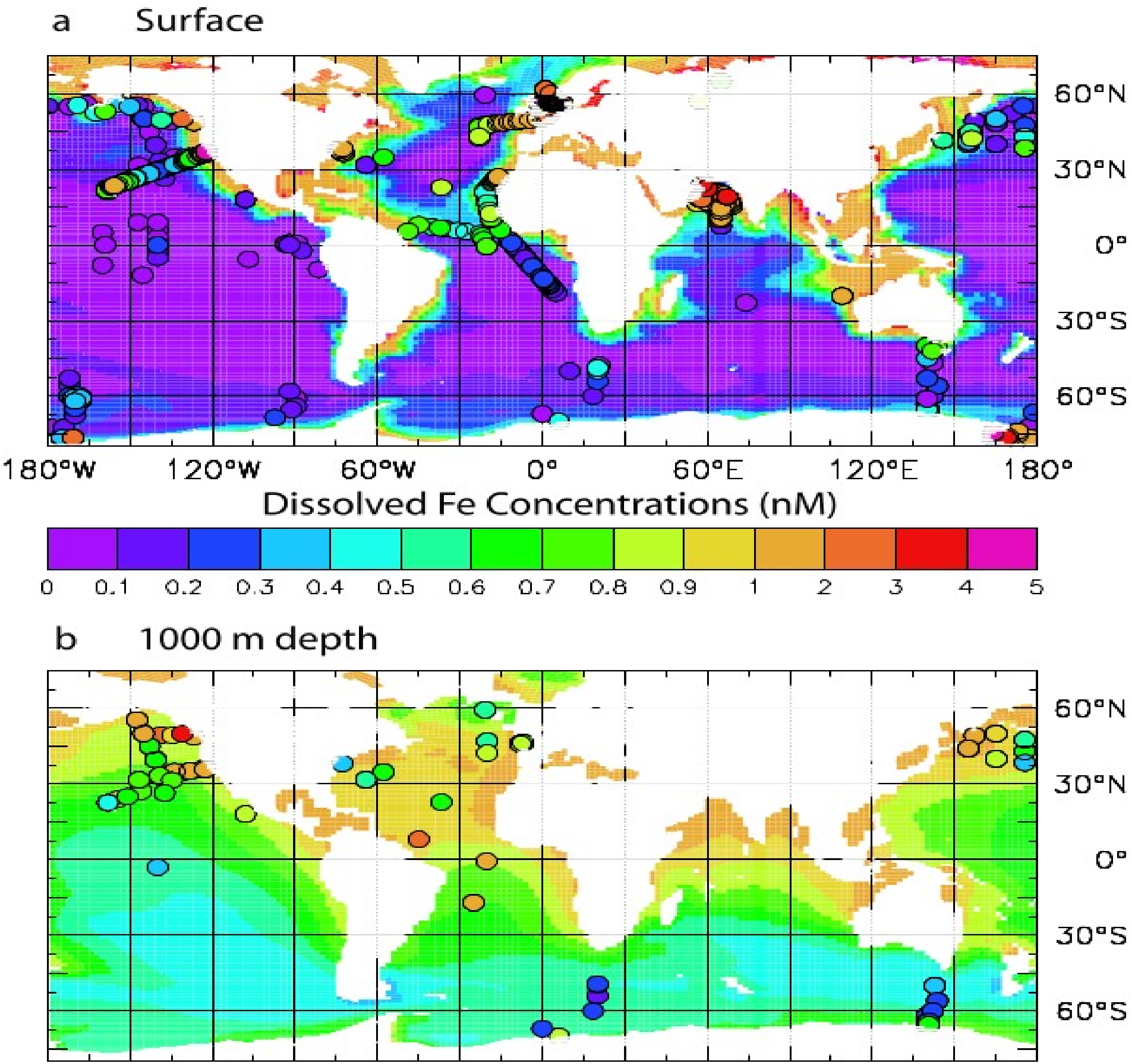
Different nutrient might limit different types of primary productivity

Photosynthesis is limited by the supply of essential nutrients in the sun light photic zone, and by light in the lower, dark, aphotic zone, within which nutrients are instead abundant

Chemosynthesis is instead limited by the availability of suitable electron acceptor or donor, and or by the direct competition with phototrophs in the photic zone




0
5
10
15
20
25
30
Sea–surface nitrate [mmol N m^{-3}]


a Surface
60°N
30°N
0°
30°S
60°S
180°W
120°W
60°W
0°
60°E
120°E
180°
Dissolved Fe Concentrations (nM)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
2
3
4
5
b 1000 m depth
60°N
30°N
0°
30°S
60°S

What is the most important nutrient for PP?

Depends on the PP we are referring to, the ecosystem and where we are on the planet. It furthers depends on the organism in question

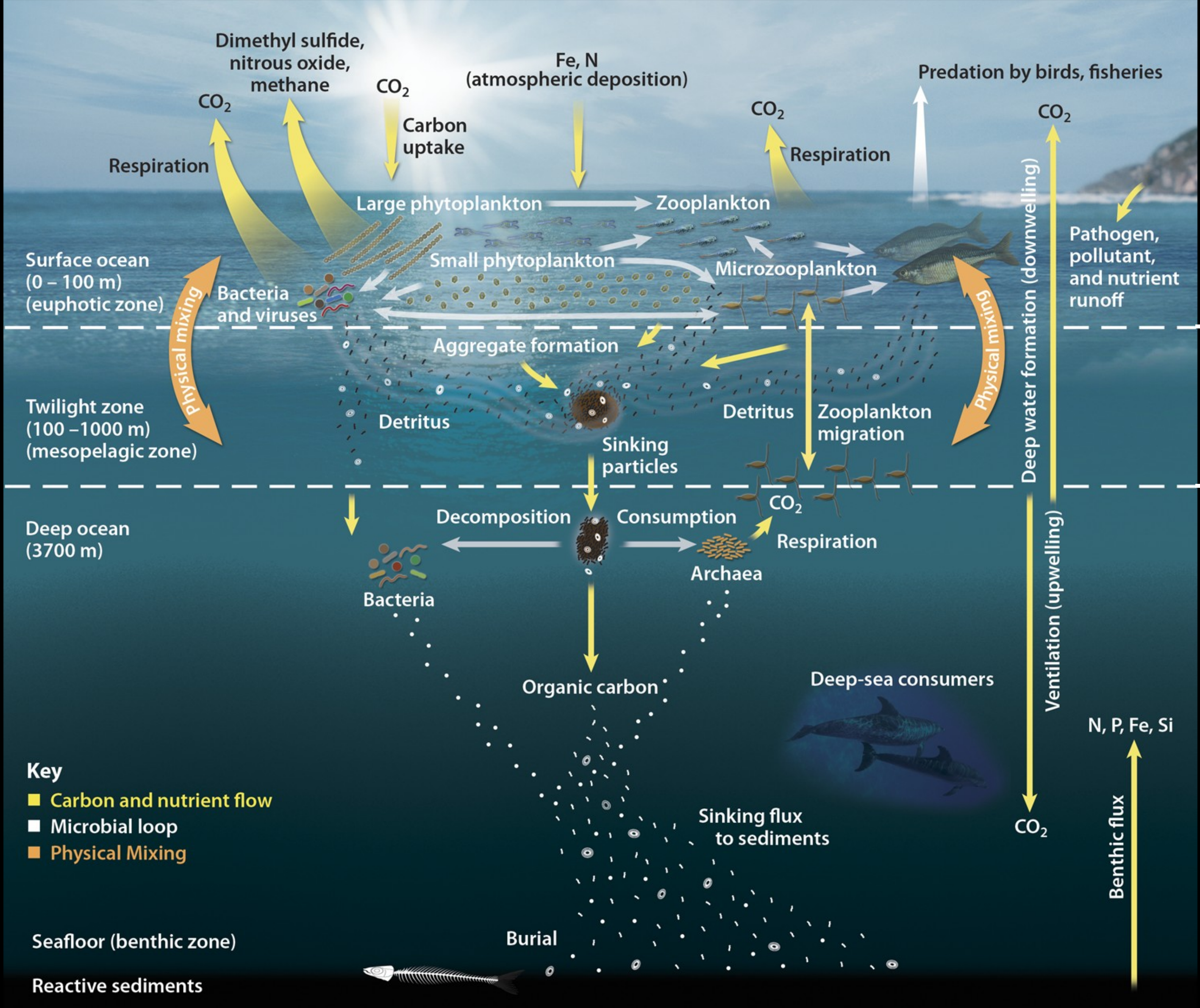
For example, nitrate limits photosynthetic PP in the temperate oceans, while iron limits photosynthetic PP at high-latitude during the summer. In the winter at those latitude light is the limiting factor. Dissolved silica might limit diatoms PP, while available NH_4^+ might limit Ammonia Oxidizers PP in the bathypelagic zones

What is the most important nutrient for PP?

Depends on the PP we are referring to, the ecosystem and where we are on the planet. It furthers depends on the organism in question.

For example, nitrate limits photosynthetic PP in the temperate oceans, while iron limits photosynthetic PP at high-latitude during the summer. In the winter at those latitude light is the limiting factor. Dissolved silica might limit diatoms PP, while available NH4+ might limit Ammonia Oxidizers PP in the bathypelagic zones

THE MOST IMPORTANT NUTRIENT IS THE LIMITING NUTRIENT



Sunlight

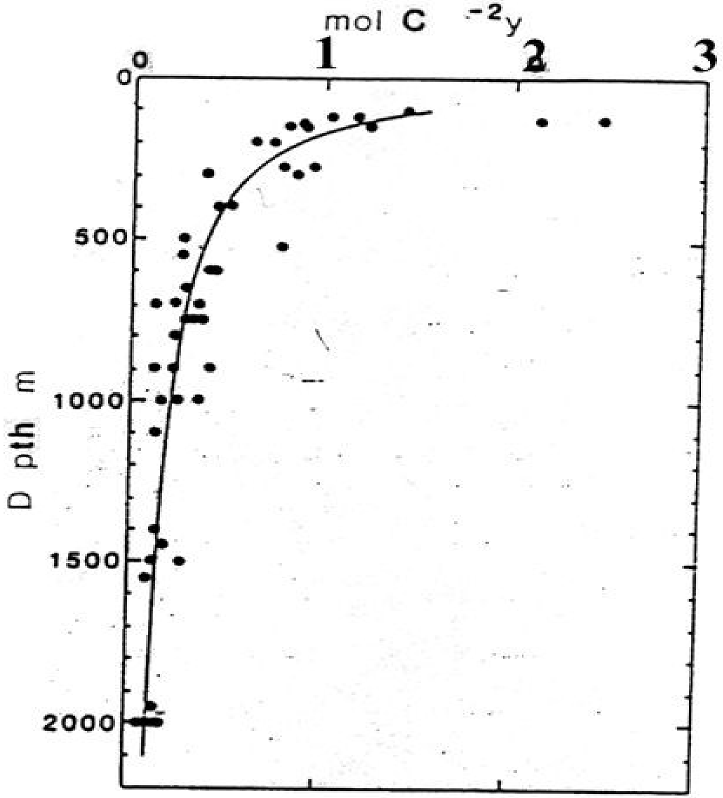
Twilight

Permanently
dark

Reduction in Vertical Flux over Depth

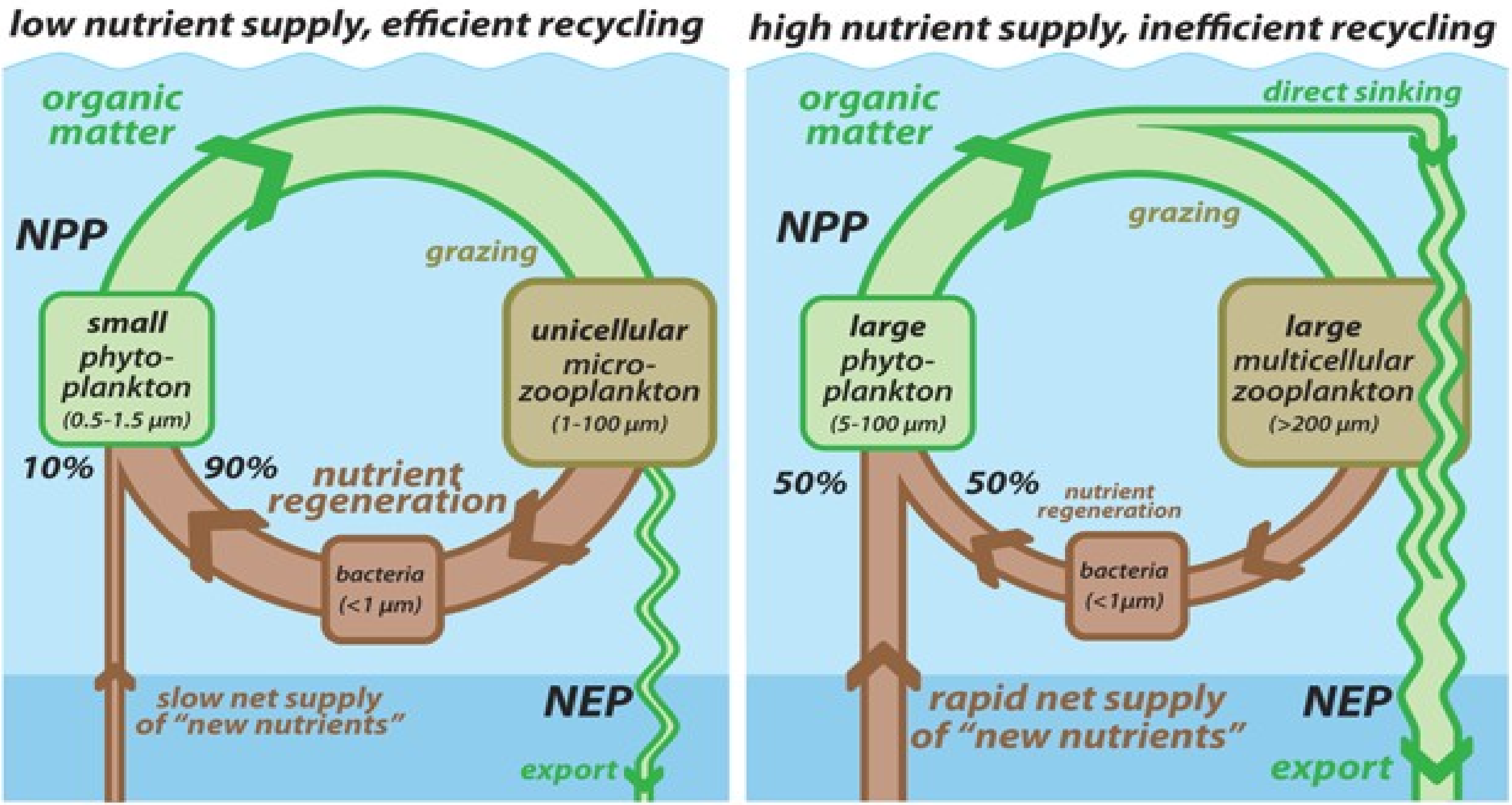
The Martin Curve

50% losses by 300 m
75% losses by 500 m
90% losses by 1500 m



Martin and Knauer 1981

Export efficiency and the microbial loop



Dominant microbial groups in the water column

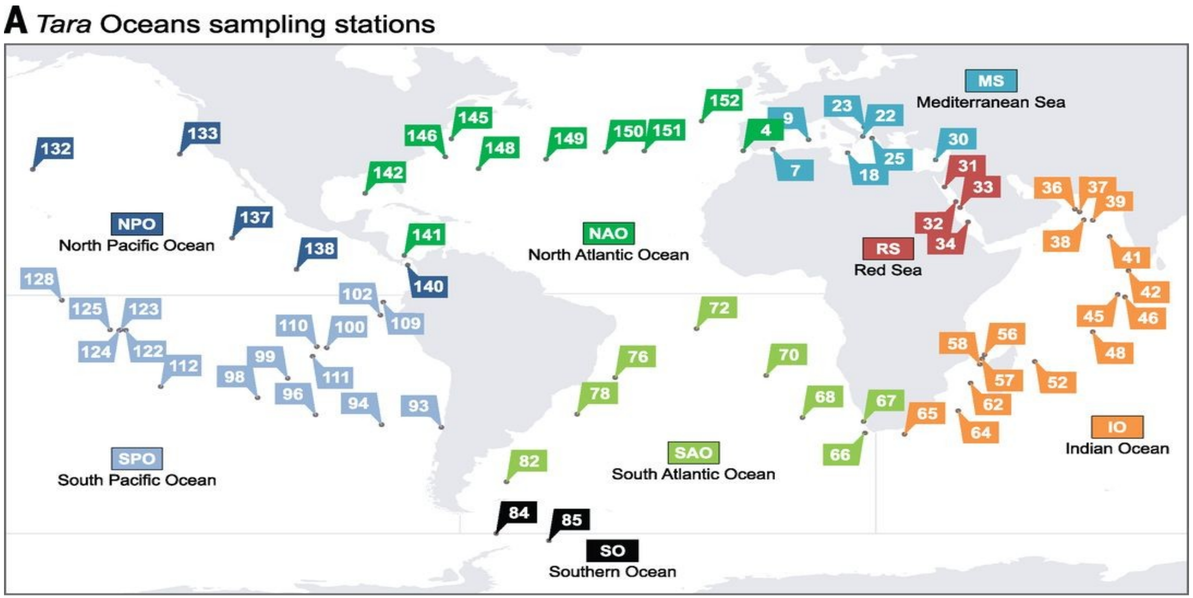
Members of the Alphaproteobacteria, Gammaproteobacteria and Bacteroidetes dominate free living microbial communities in the water column

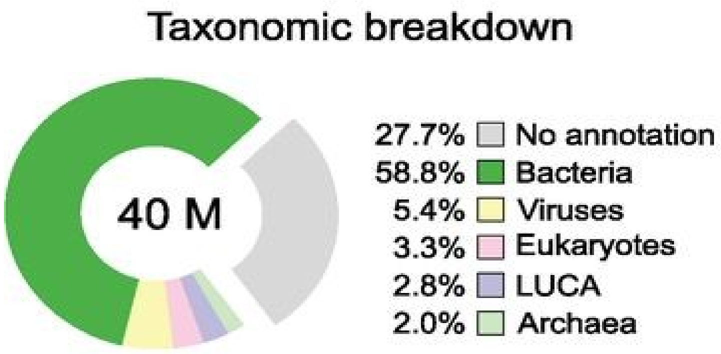
The large majority of these microbes are either heterotrophs or oligotrophs, mostly using oxygen as terminal electron acceptor

One of the most abundant bacterioum is the Alphaproteobacterium Pelagibacter ubique (of the clade SAR11) estimated to be one of the most abundant lifeform on the planet

In deep waters, ammonia oxidizing Thaumarchaeota, can be abundant, and dominate primary productivity through chemolithoutotrophy

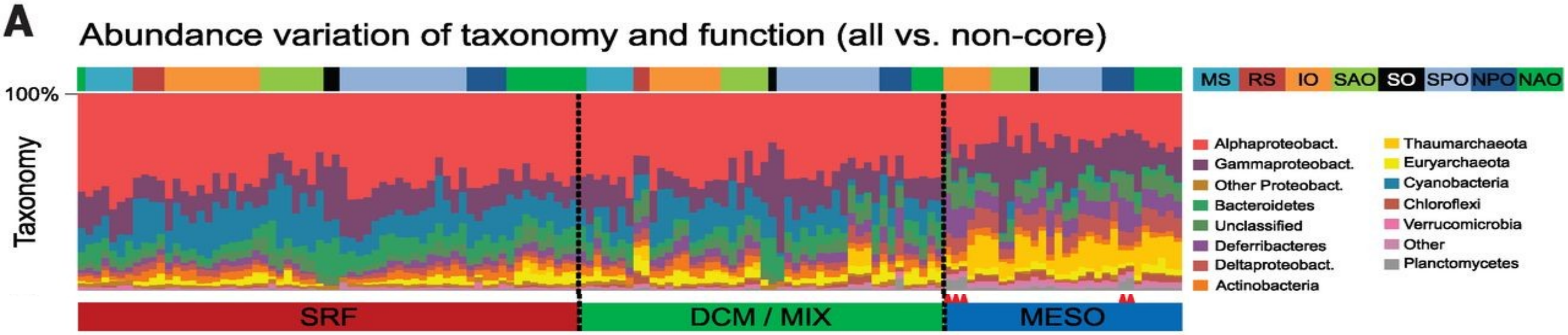
A significant fraction of microbial diversity in the deep sea water column is particle attached, and is more diverse than free living microorganisms due to anaerobic pockets that allow for a more diverse set of electron donors to be used





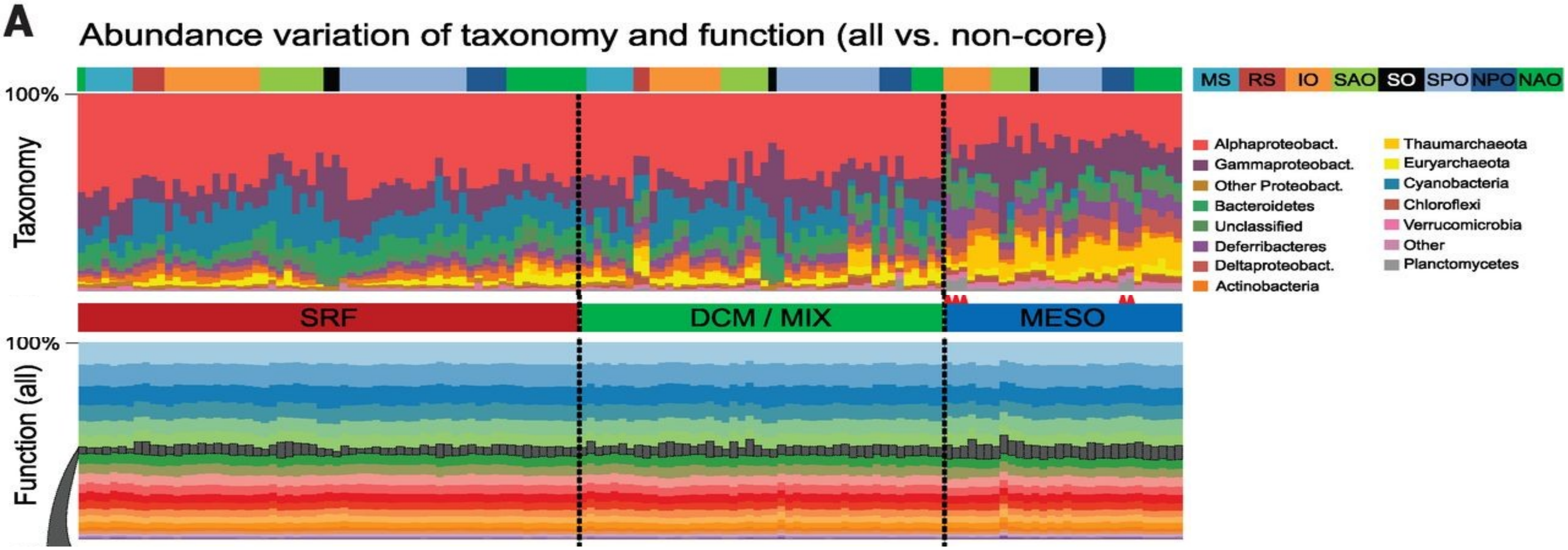
Sunagawa, et al. (2015). Structure and function of the global ocean microbiome. Science, 348(6237). https://doi.org/10.1126/science.1261359

http://ocean-microbiome.embl.de/companion.html



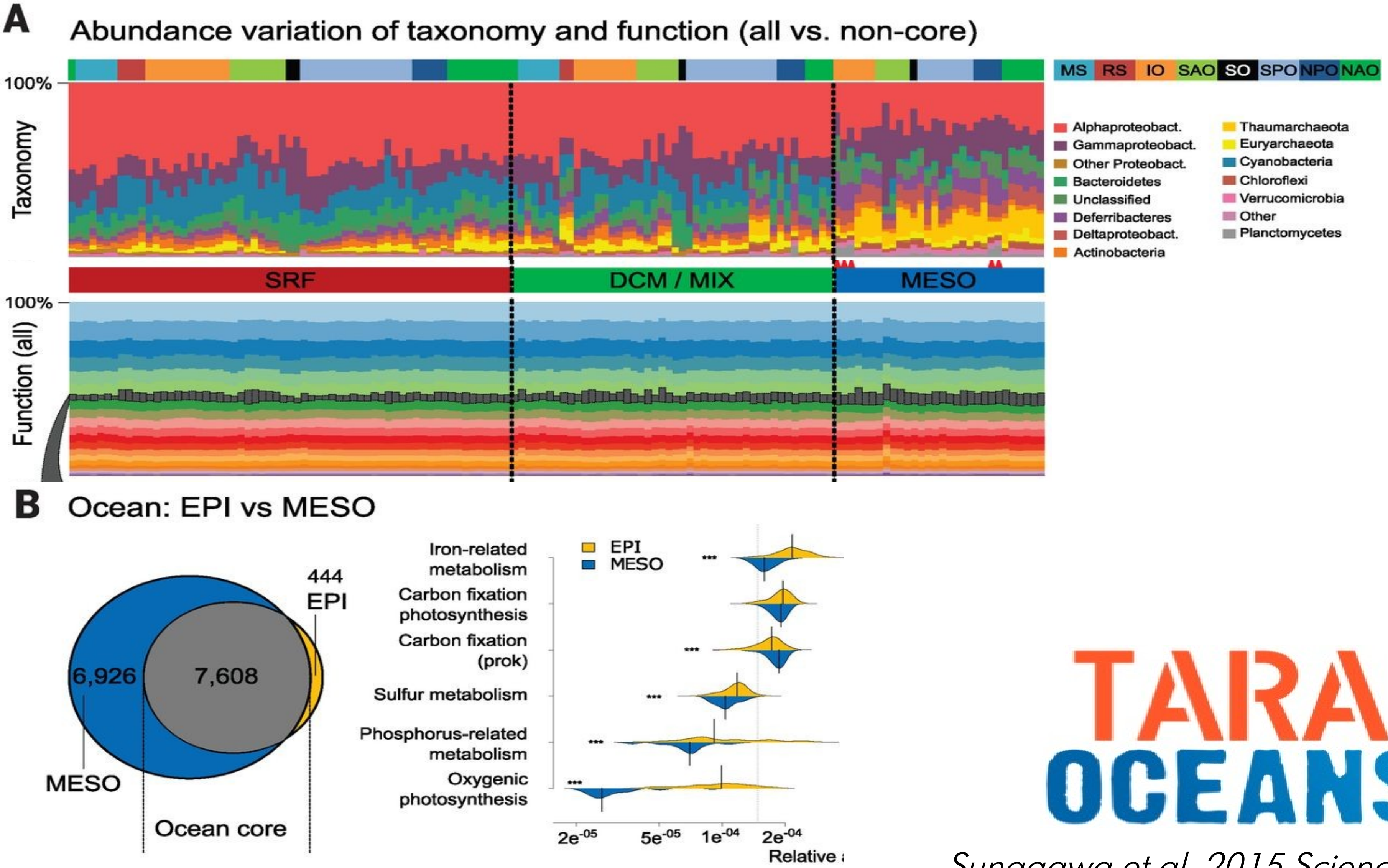
TARA OCEANS

Sunagawa et al. 2015 Science



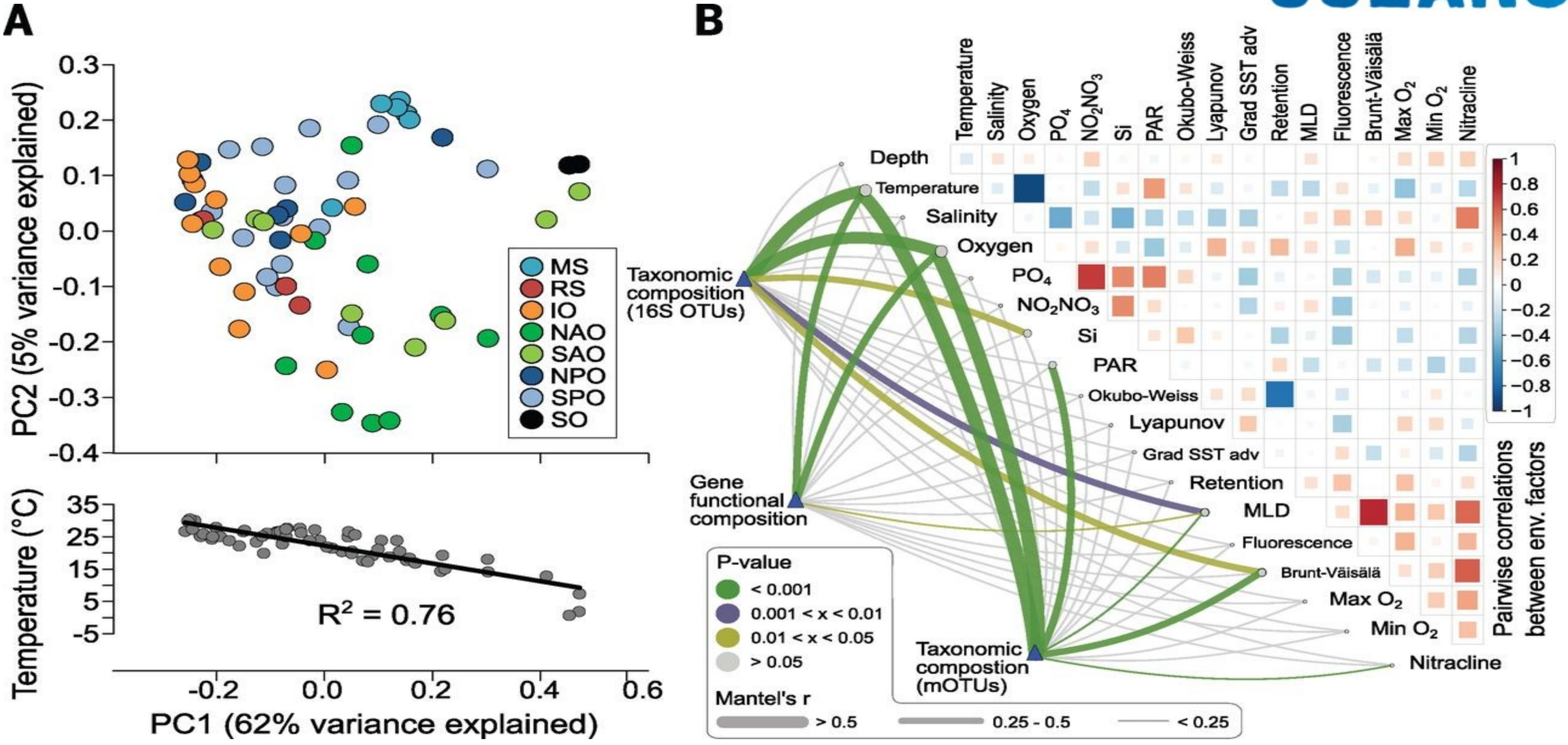
TARA OCEANS

Sunagawa et al. 2015 Science



TARA OCEANS

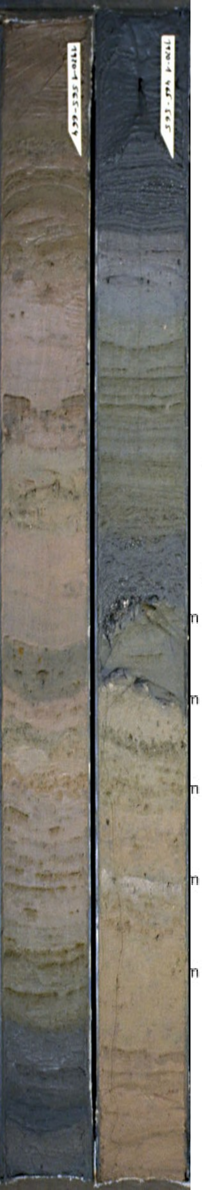
Sunagawa et al. 2015 Science

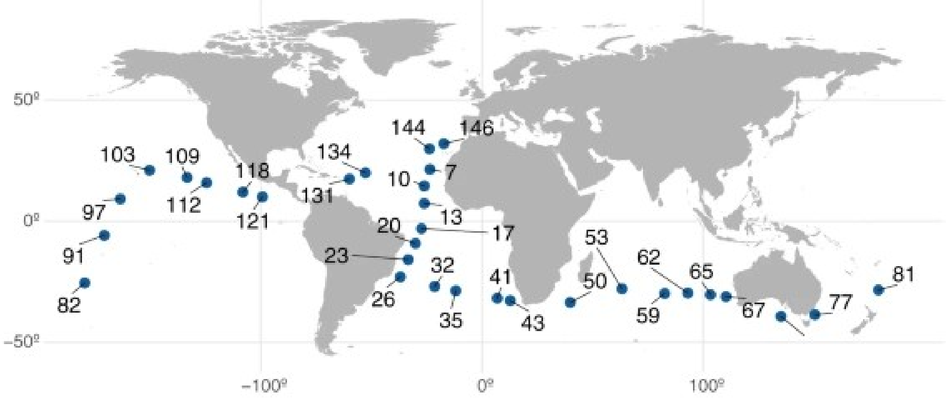


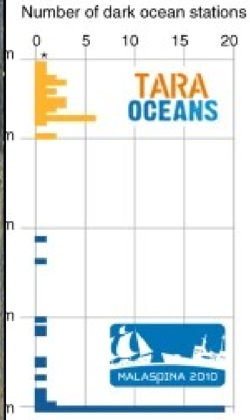
TARA OCEANS

Sunagawa et al. 2015 Science

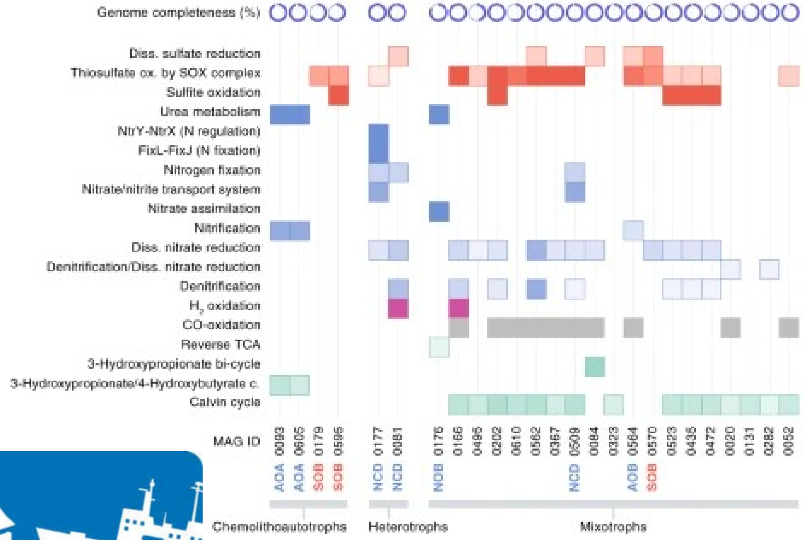
Metabolism in the deep sea

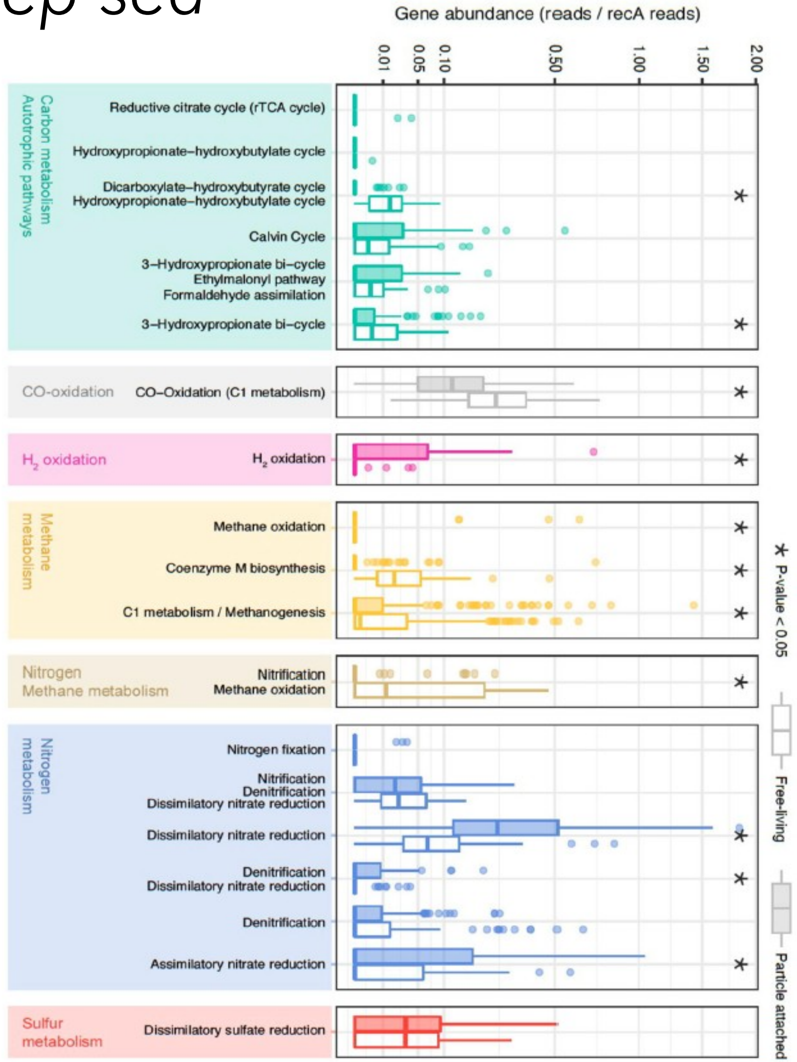






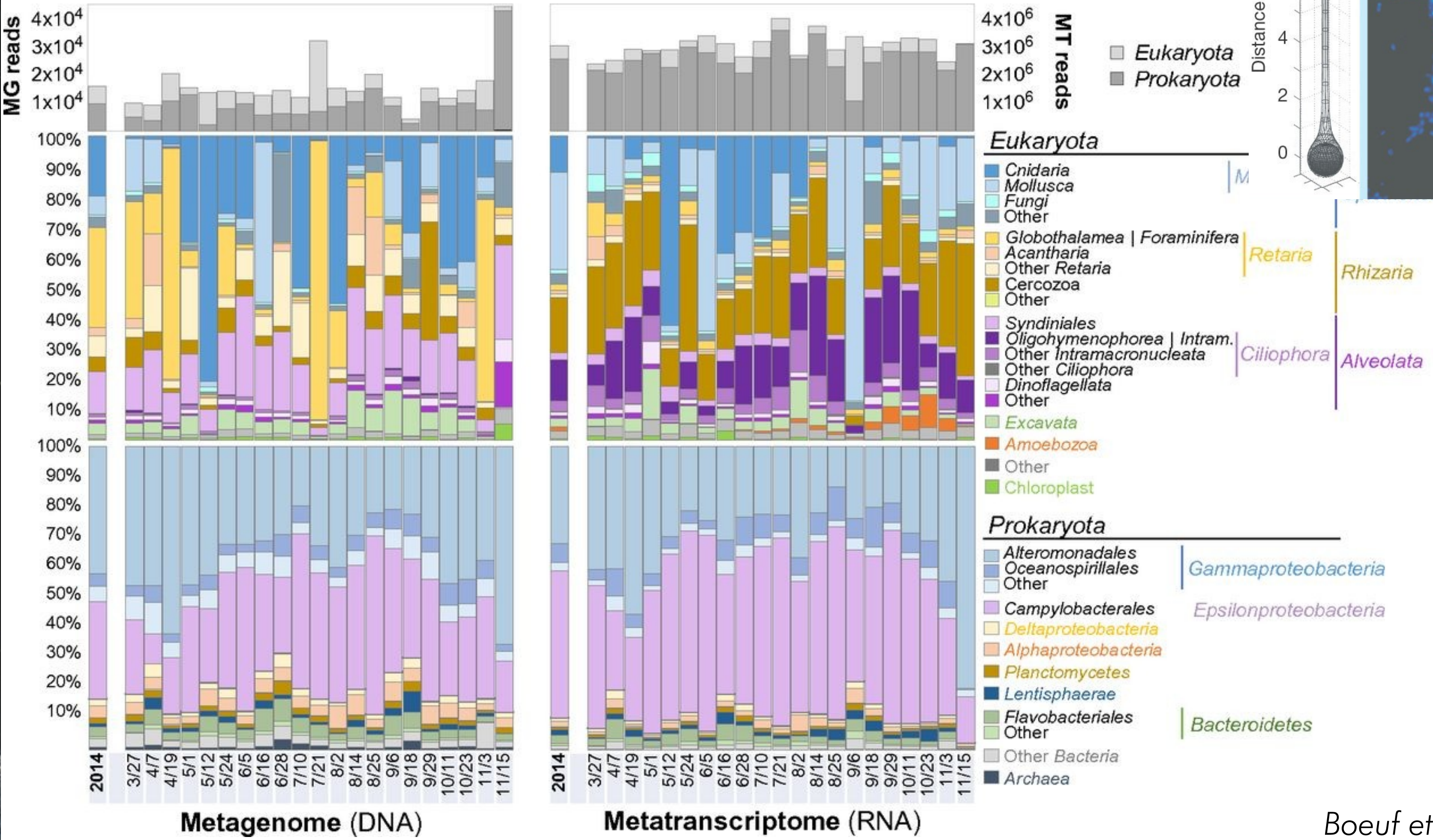
MALASPINA 2010

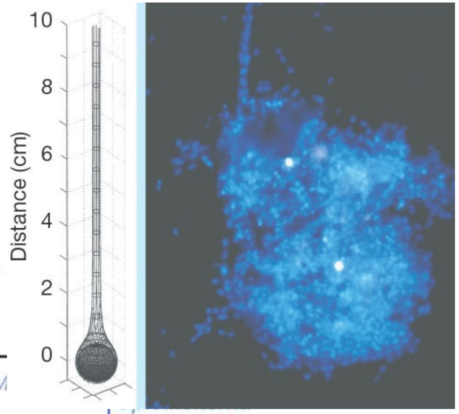




Acinas et al. 2021 Nat Comm

Microbial diversity in marine snow





Boeuf et al. 2019 PNAS

OXYGEN MINIMUM ZONES

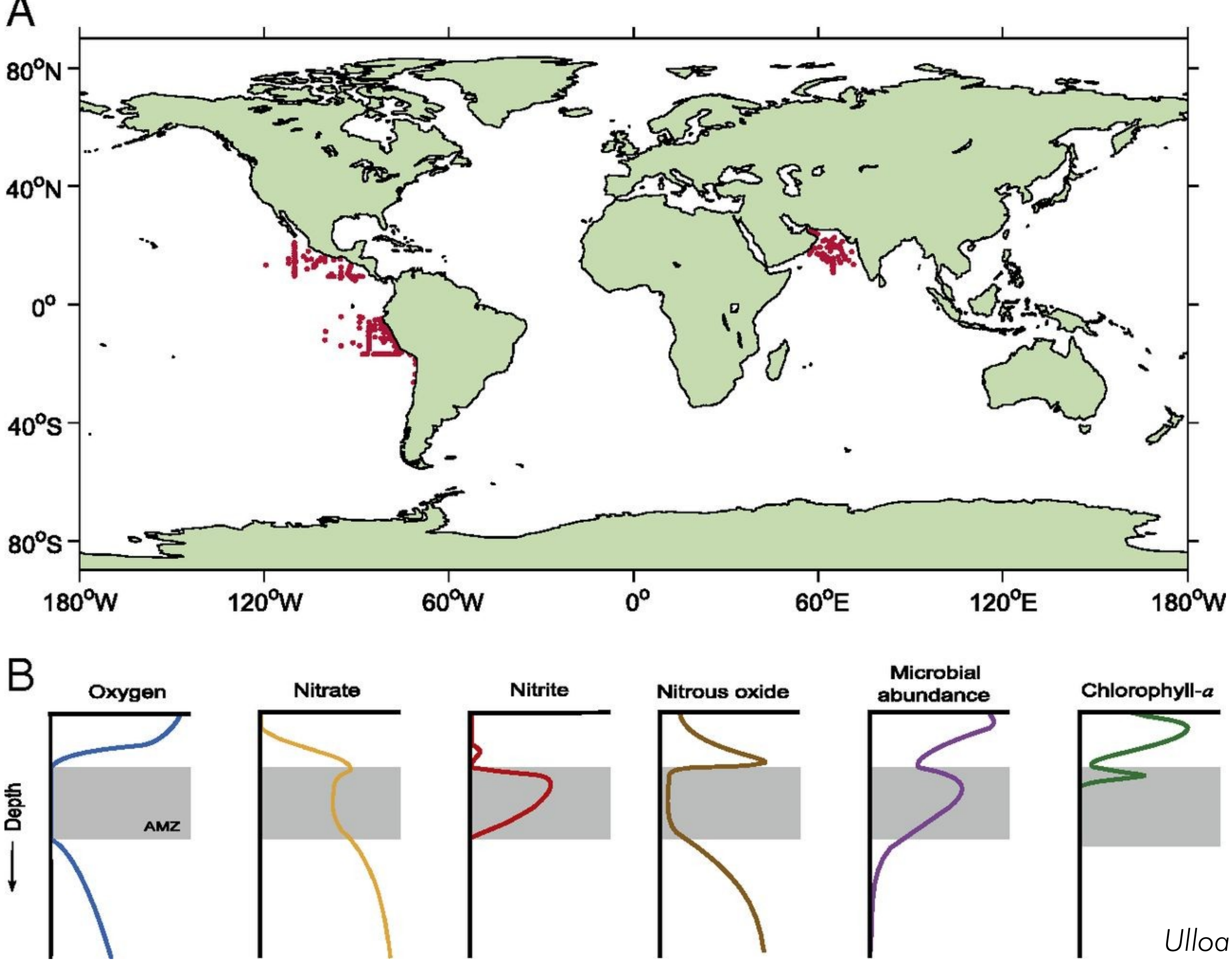
Oxygen minimum zones

Oxygen minimum zones (OMZs) are oxygen-starved regions of the ocean that are currently expanding owing to the warming of the water column that is induced by global climate change

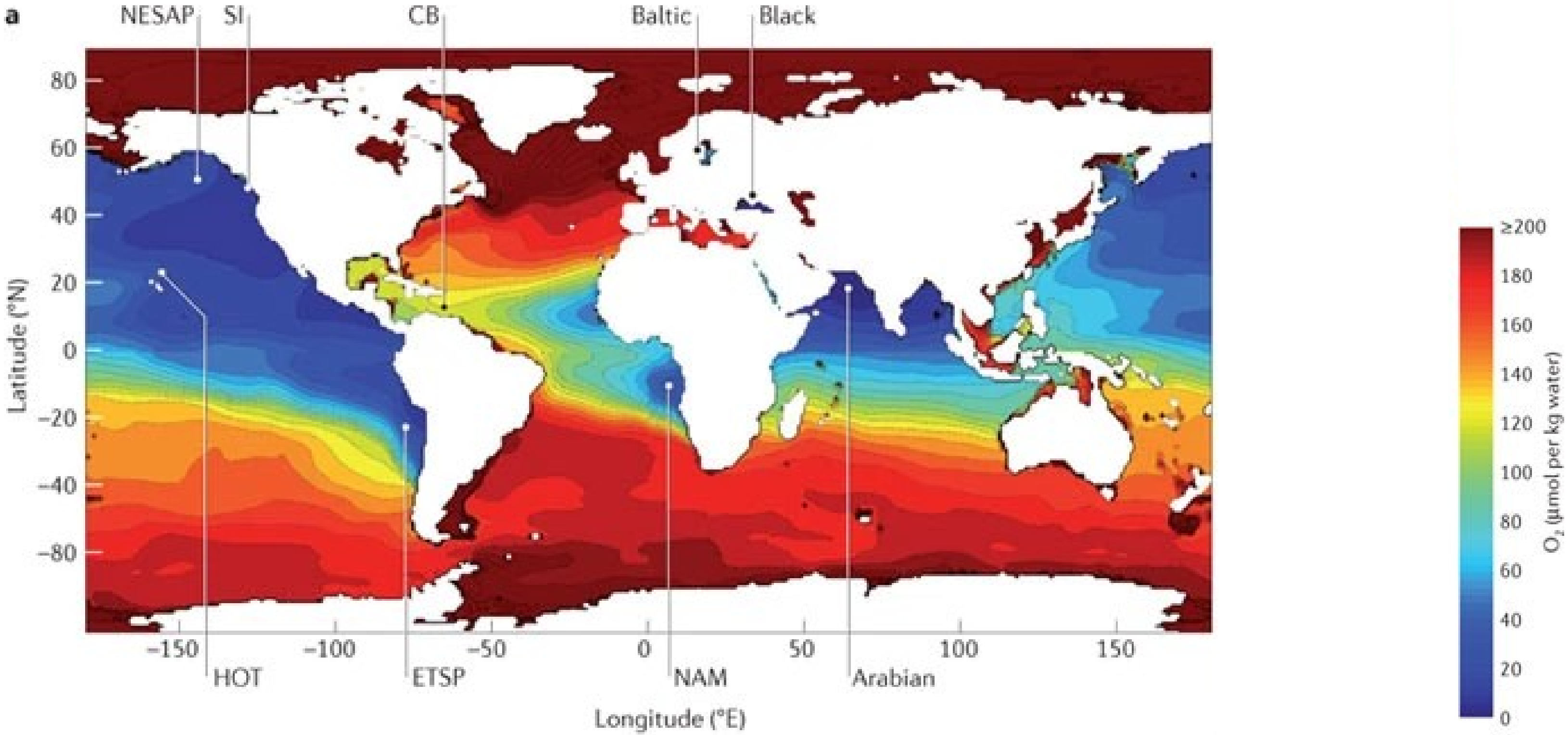
Although OMZs are inhospitable to aerobically respiring organisms, these regions support thriving microbial communities, the metabolic activities of which have a profound impact on marine productivity and climate balance

open-ocean OMZs has identified conserved patterns of microbial community structure and function, and uncovered novel modes of metabolic integration coupling carbon, nitrogen and sulphur cycles

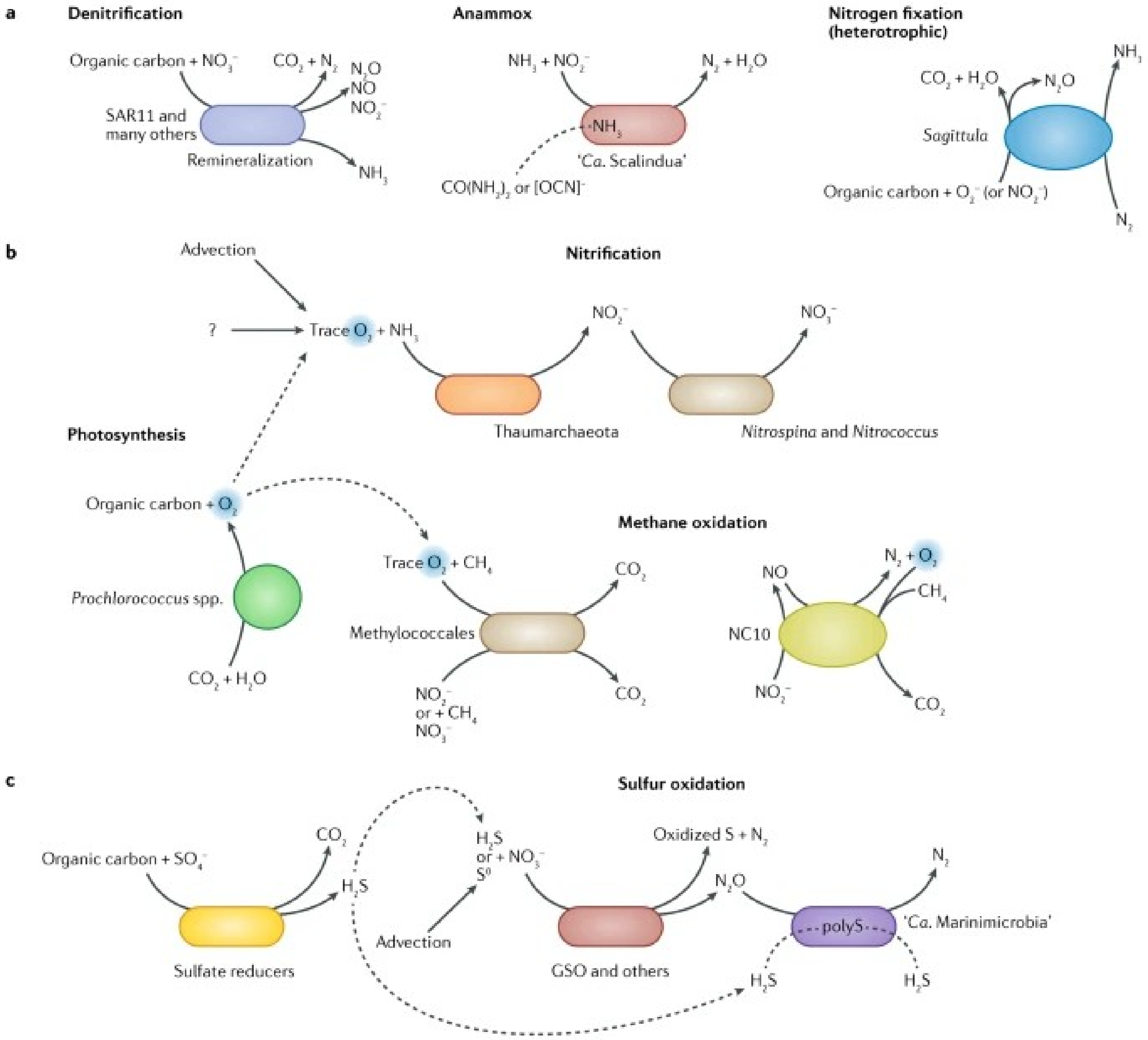
A cryptic sulfur cycle (sulfate reduction and sulfide oxidation), methane oxidation, methylotrophy and denitrification dominate metabolic processes



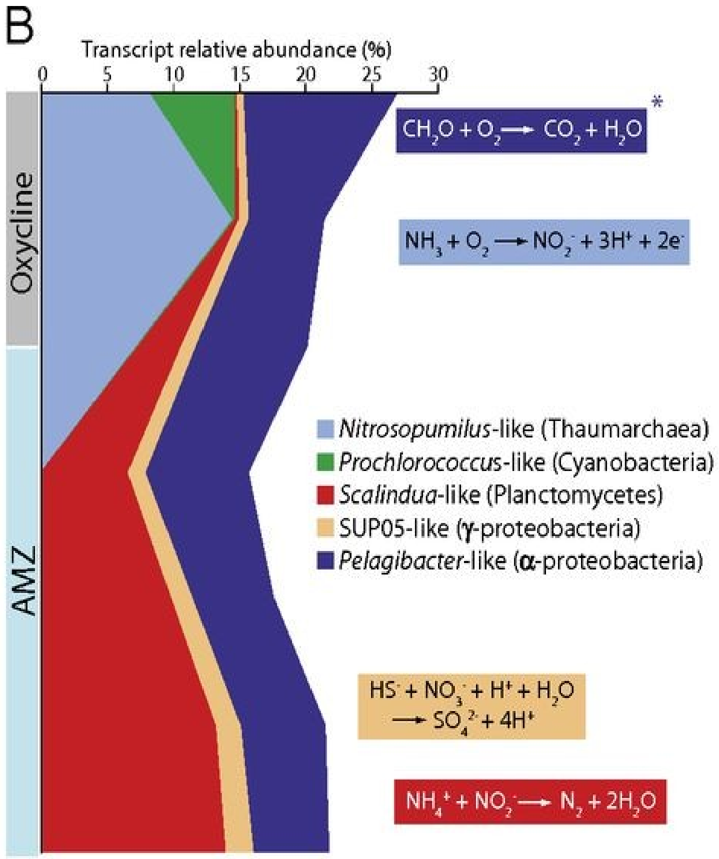
Ulloa et al 2012 PNAS



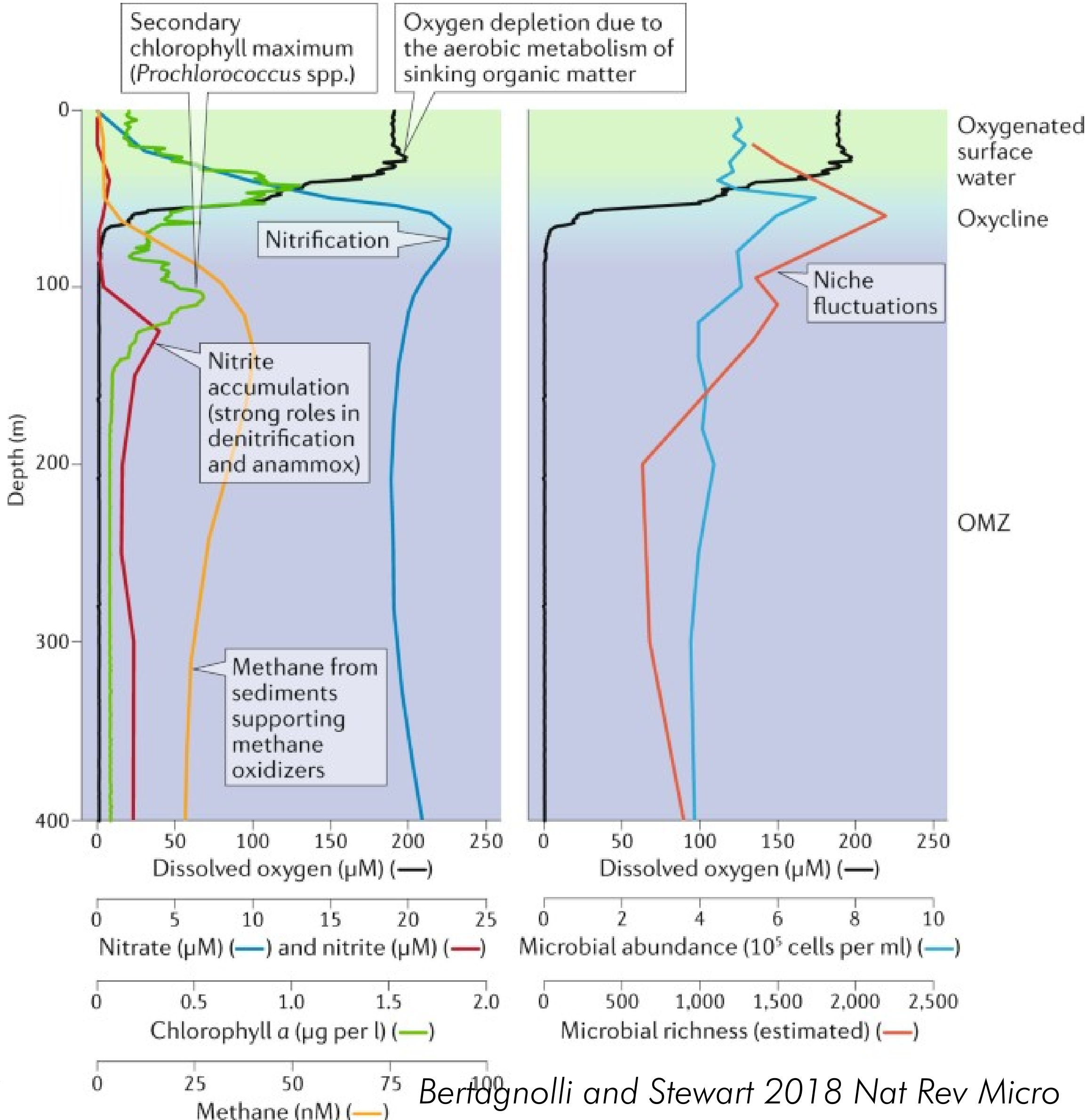
Ulloa et al 2012 PNAS



Ulloa et al 2012 PNAS



Ulloa et al 2012 PNAS



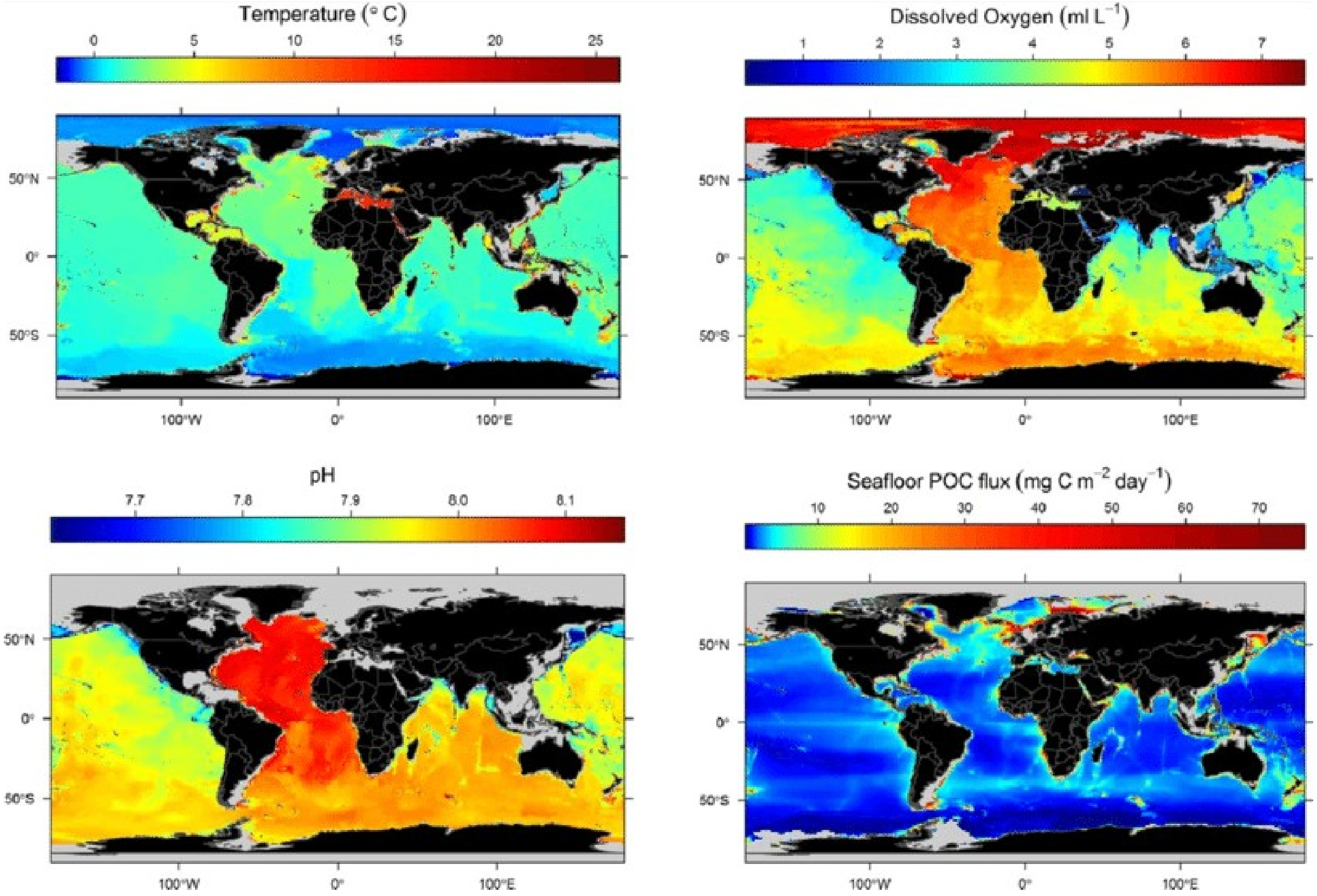
Bertagnolli and Stewart 2018 Nat Rev Micro

SURFACE MARINE SEDIMENTS

Deep Sea Exploration

"From the time of Pliny until the late nineteenth century...humans believed there was no life in the deep. It took a historic expedition in the ship Challenger between 1872 and 1876 to prove Pliny wrong; its deep-sea dredges and trawls brought up living things from all depths that could be reached. Yet even in the twentieth century scientists continued to imagine that life at great depth was insubstantial, or somehow inconsequential. The eternal dark, the almost inconceivable pressure, and the extreme cold that exist below one thousand meters were, they thought, so forbidding as to have all but extinguished life. The reverse is in fact true....(below 200 meters) lies the largest habitat on Earth."

Tim Flannery, ***Where Wonders Await Us****, New York Review of Books*
December 2007


Temperature (° C)
0 5 10 15 20 25
50°N
0°
50°S
100°W 0° 100°E
Dissolved Oxygen (ml L^{-1})
1 2 3 4 5 6 7
50°N
0°
50°S
100°W 0° 100°E
pH
7.7 7.8 7.9 8.0 8.1
50°N
0°
50°S
100°W 0° 100°E
Seafloor POC flux (mg C m^{-2} day^{-1})
10 20 30 40 50 60 70
50°N
0°
50°S
100°W 0° 100°E

Deep sea surface sediments

Deep sea surface sediments represent a large reservoir of microbial diversity. For a very long time they have been considered a biological desert

Despite this available information represent a small subset of global distribution of sediments

Different definitions of deep sea surface sediments are available. The first concerns the definition of "deep sea" the second of "surface sediments"

The **deep sea** is defined either as the portion of the Ocean deeper than 200 m (the nominal depth of the photic zone), the depth of the actual photic zone, the portion of the ocean deeper than 1,000 m or the depths of the oceans after the continental shelf break

Surface sediments are defined as going from the benthic boundary layer (the interface between sediments and water) and either a depth of 30 cm or 1 meter

Biology is sustained by exports from the photic zone, lateral input of organic matter or in situ production by chemolithoautotrophy

(very) Brief history of Deep-Sea exploration

1843 - British naturalist Edward Forbes states that life cannot exist below 500 m, the azoic zone.

1867 - American naturalist Louis F. de Pourtales conducts dredging operations finding prolific life extending below 500 m.

1872 - Voyage of the H.M.S. Challenger. Four year cruise around the world testing the salinity, temperature and density of the seawater and life. This research forms the basis of modern oceanography.

1951 - The British ship Challenger II bounces sound waves off the ocean bottom and locates what appears to be the sea's deepest point. The Challenger Deep located off the coast of the Marianas Islands in the Pacific Ocean.

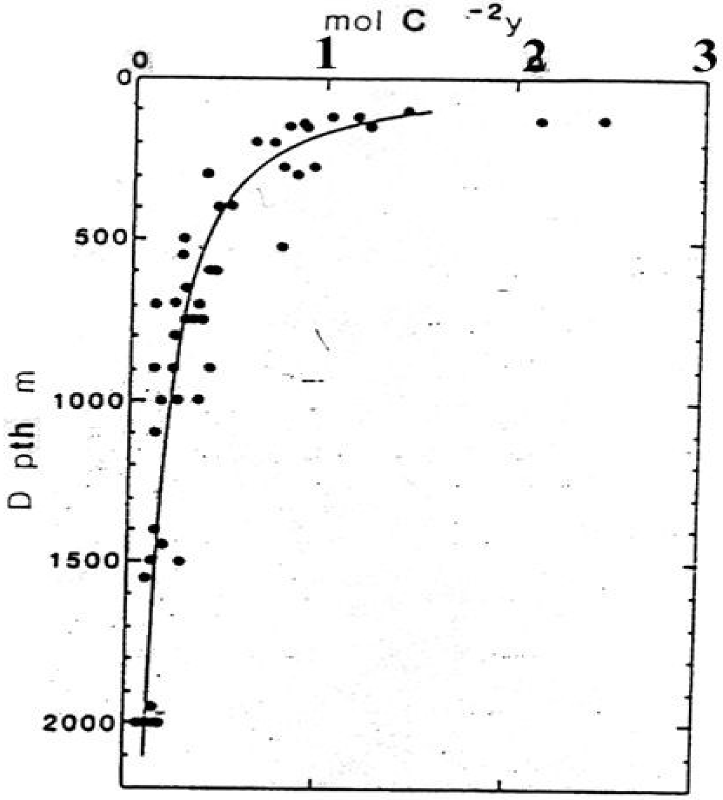
January 23, 1960 - Deepest Ocean Dive. Jacques Piccard and Dan Walsh descend into the Challenger deep with the bathyscaphe Trieste. The divers discover fish and other amazing deep-sea life at these tremendous depths.

February 17, 1977 - Hydrothermal Vents Discovered. Scientists aboard the deep sea submersible, Alvin, discover and document incredible deep sea hydrothermal vents in the eastern Pacific ocean. This discovery rocks the scientific community because, for the first time, an ecosystem has been found that thrives without the energy of the Sun.

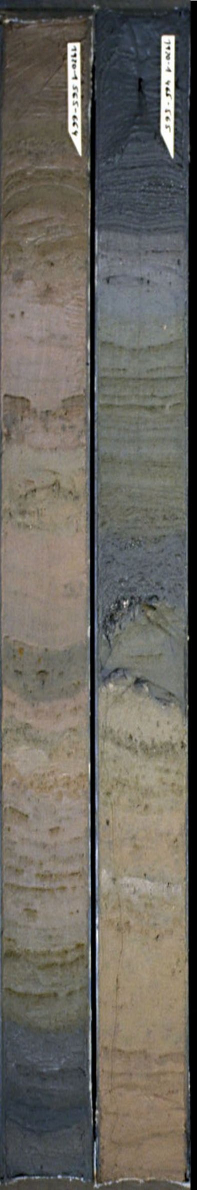
Reduction in Vertical Flux over Depth

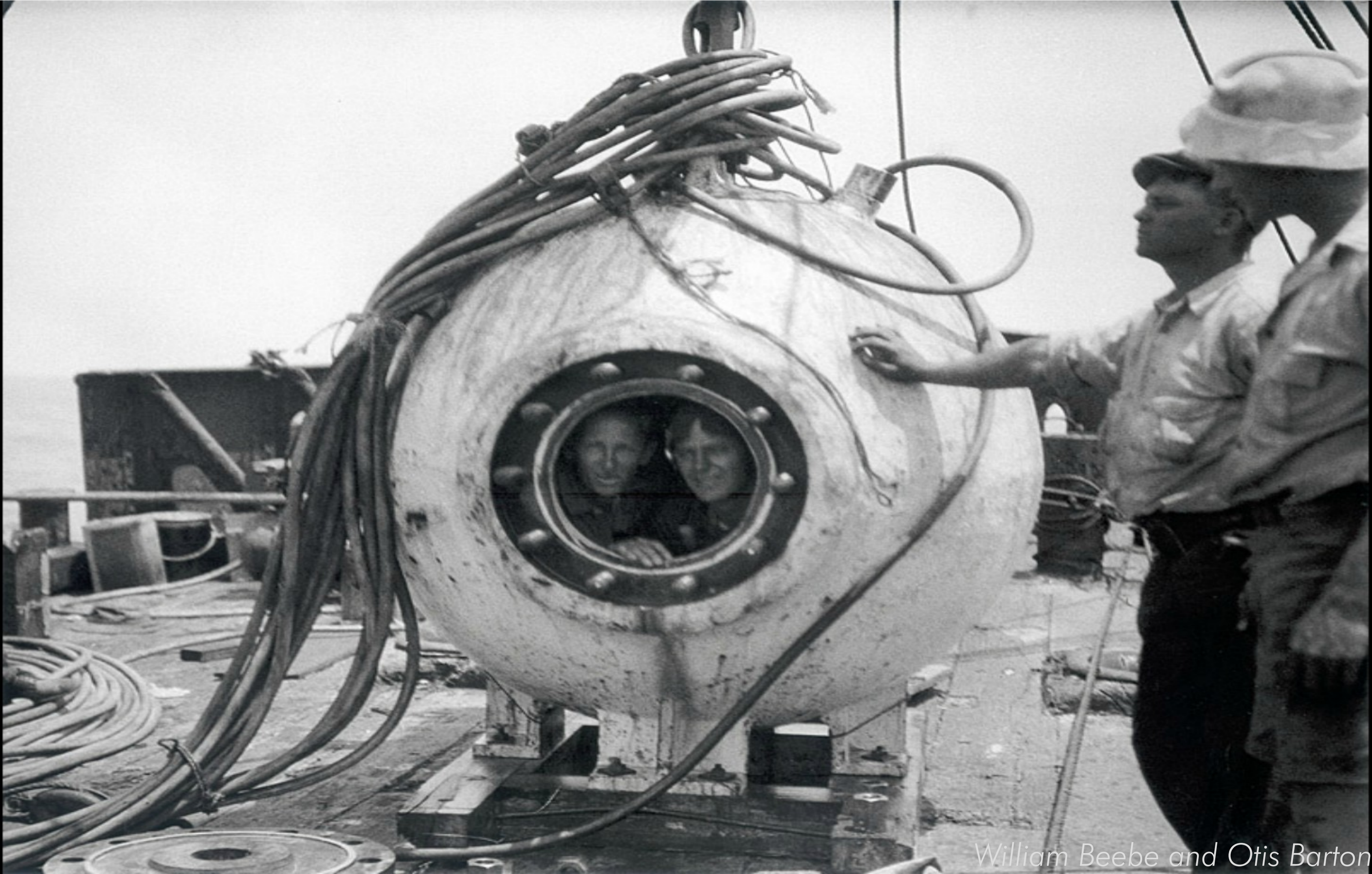
The Martin Curve

50% losses by 300 m
75% losses by 500 m
90% losses by 1500 m

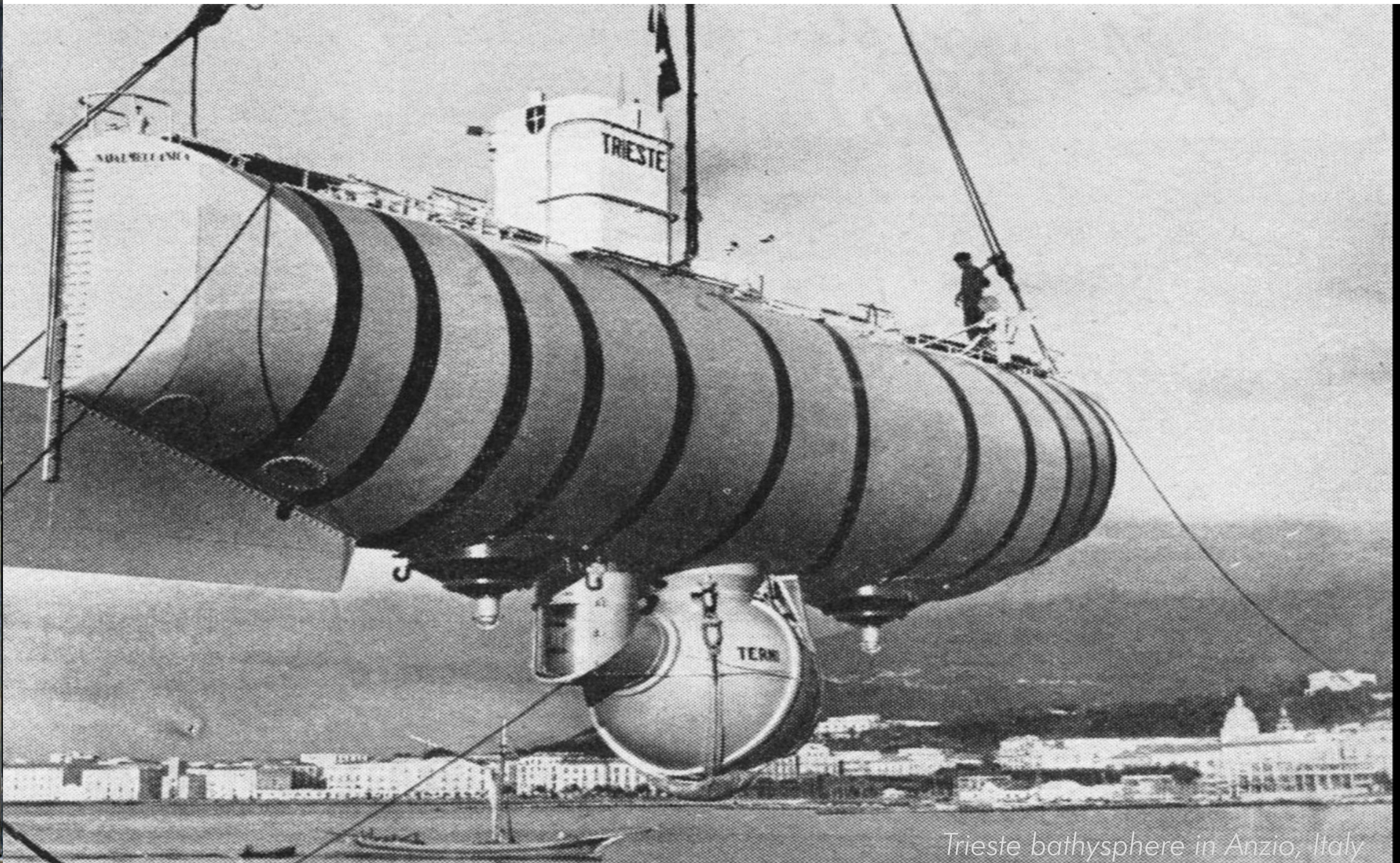


Martin and Knauer 1981





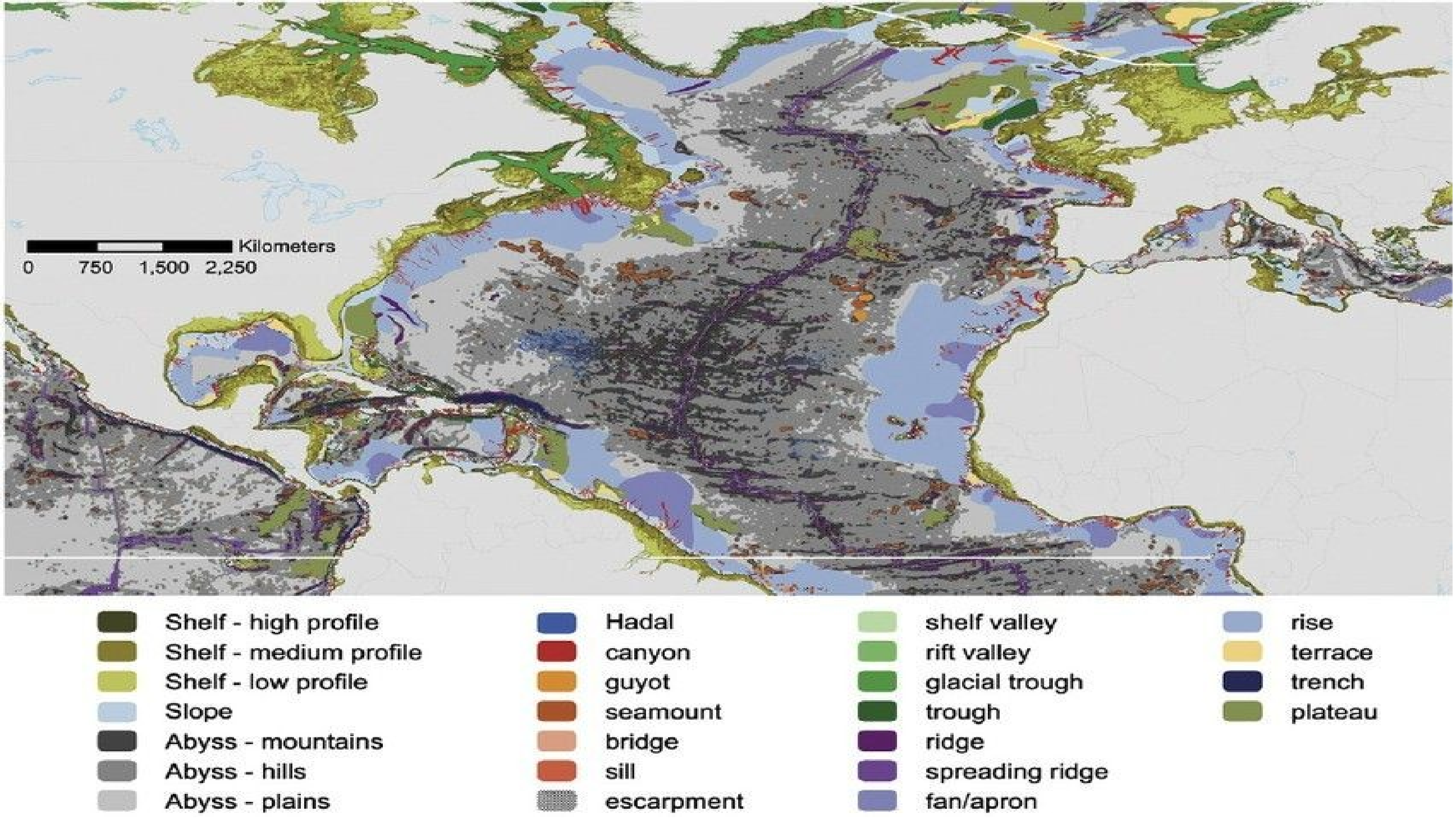
William Beebe and Otis Barton



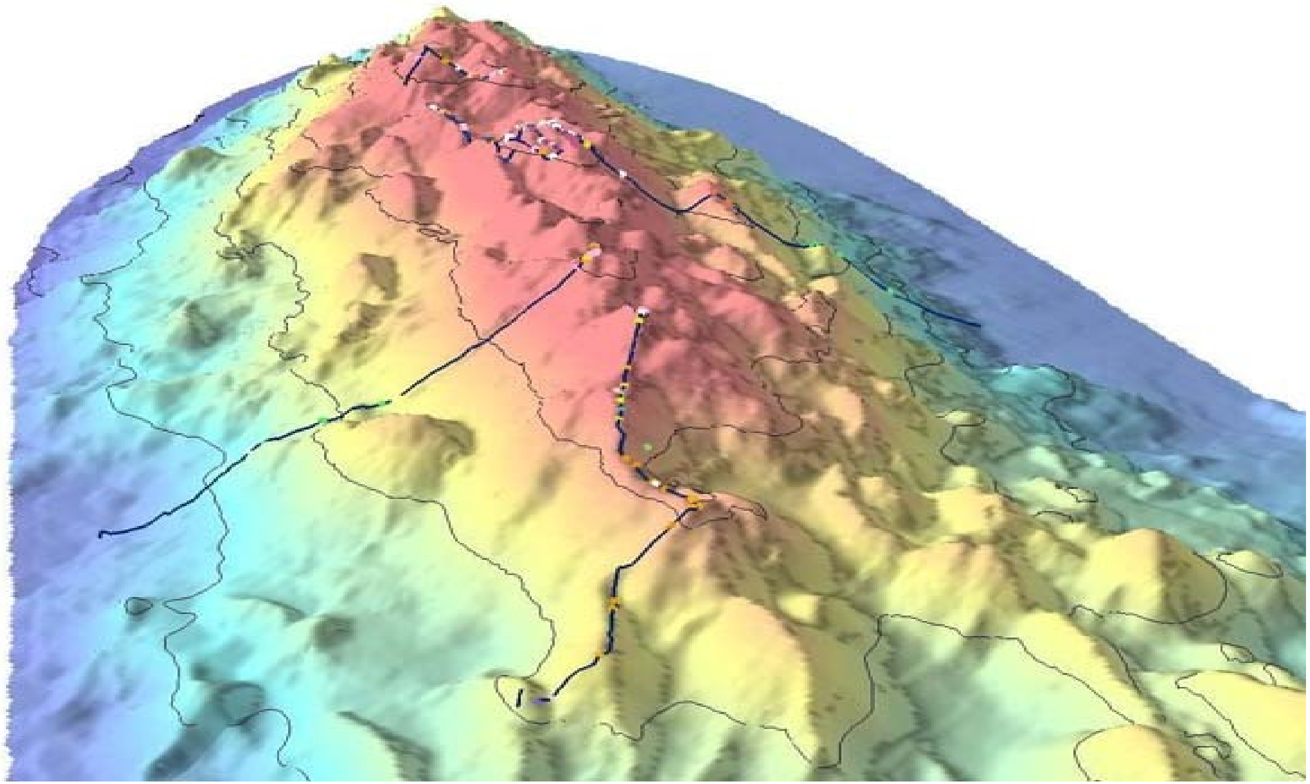
Trieste bathysphere in Anzio, Italy

Jacques Piccard and Dan Walsh inside the Trieste

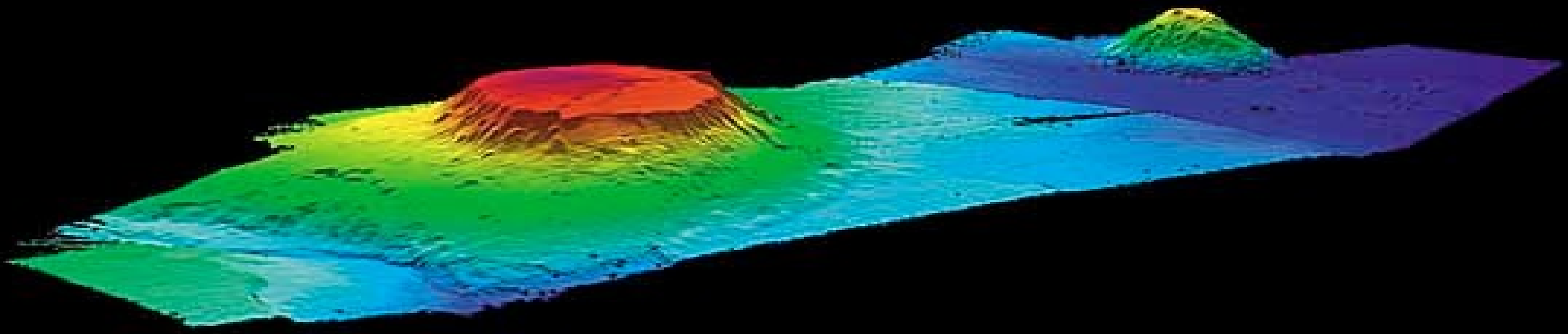
Seafloor geomorphology



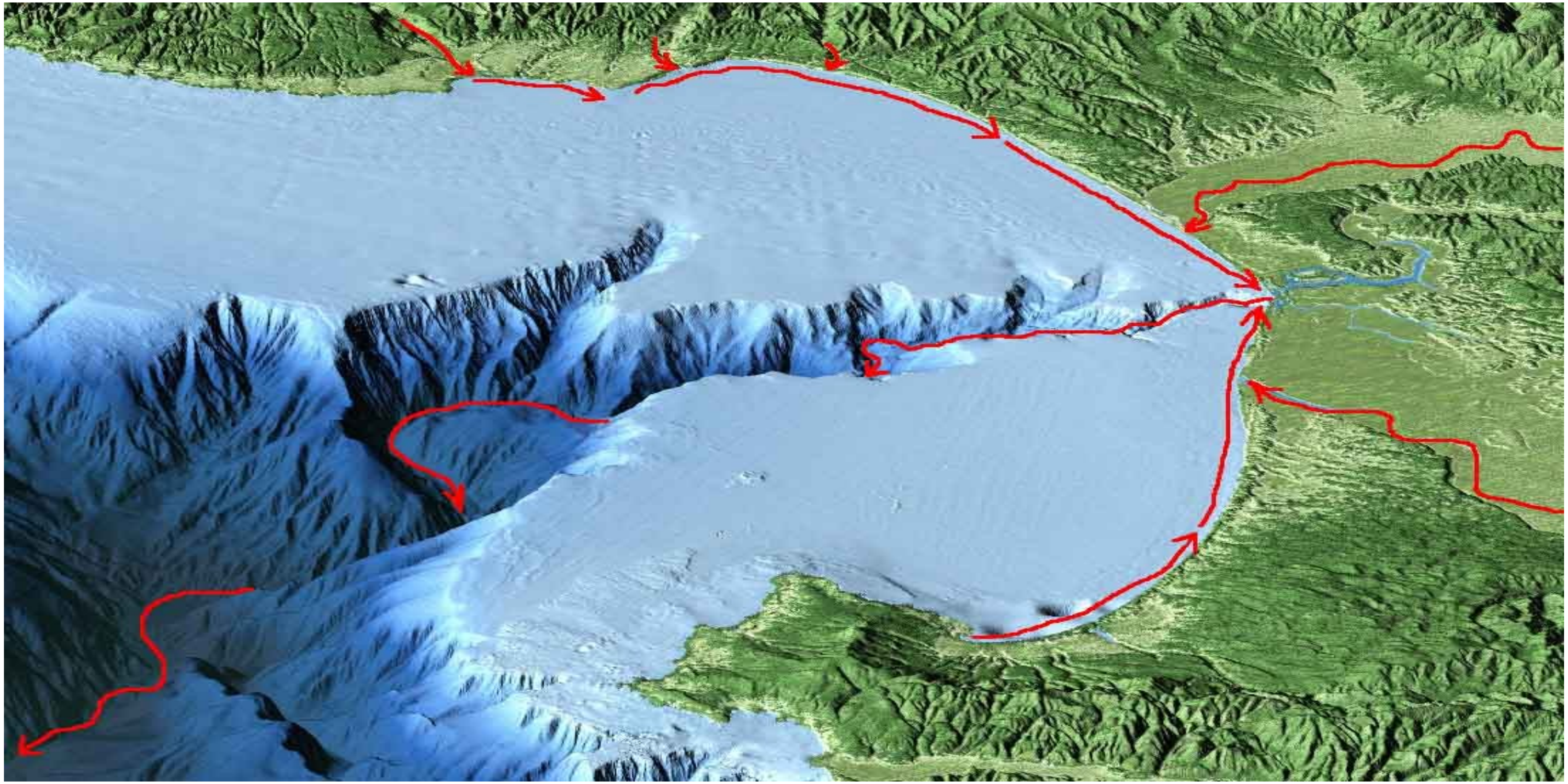
Seamounts



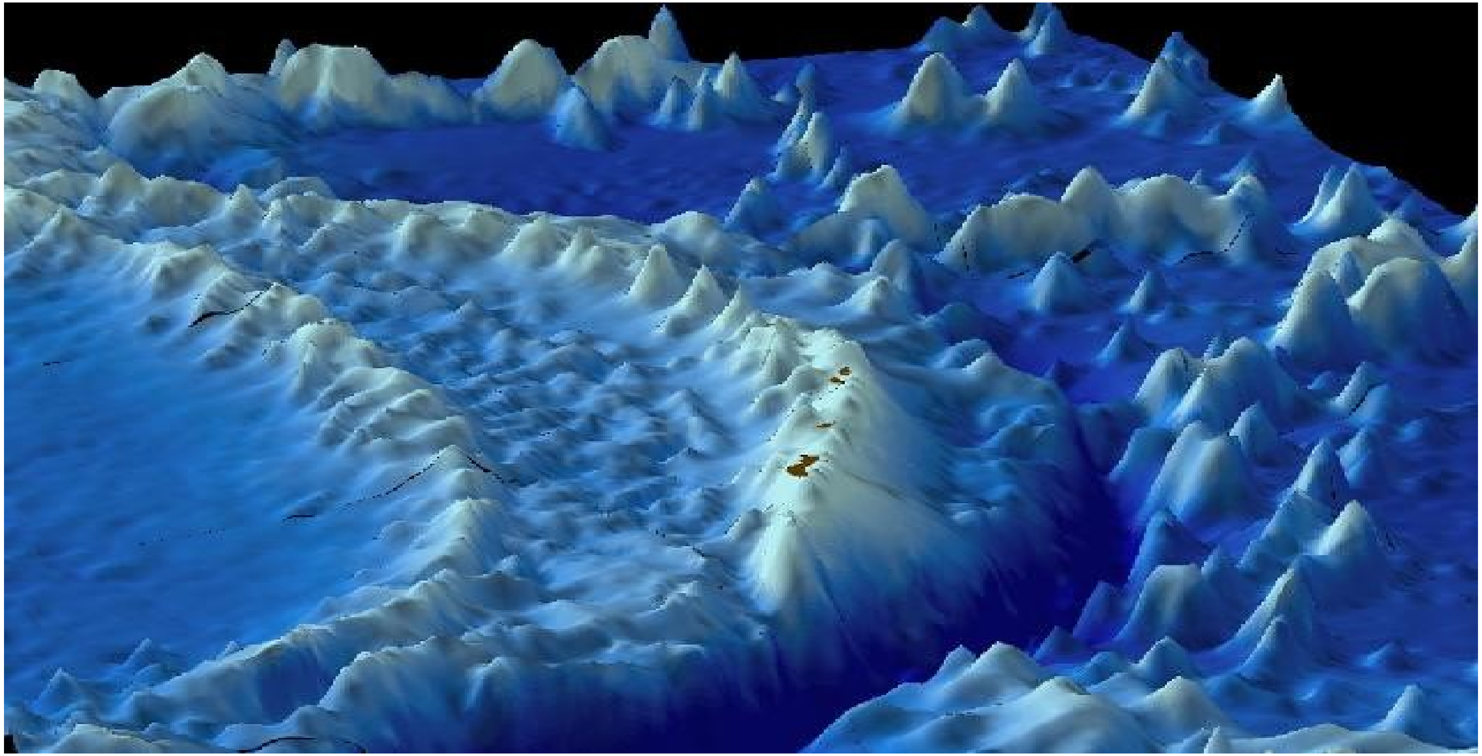
Guyont



Canyons



Trenches



Ridges

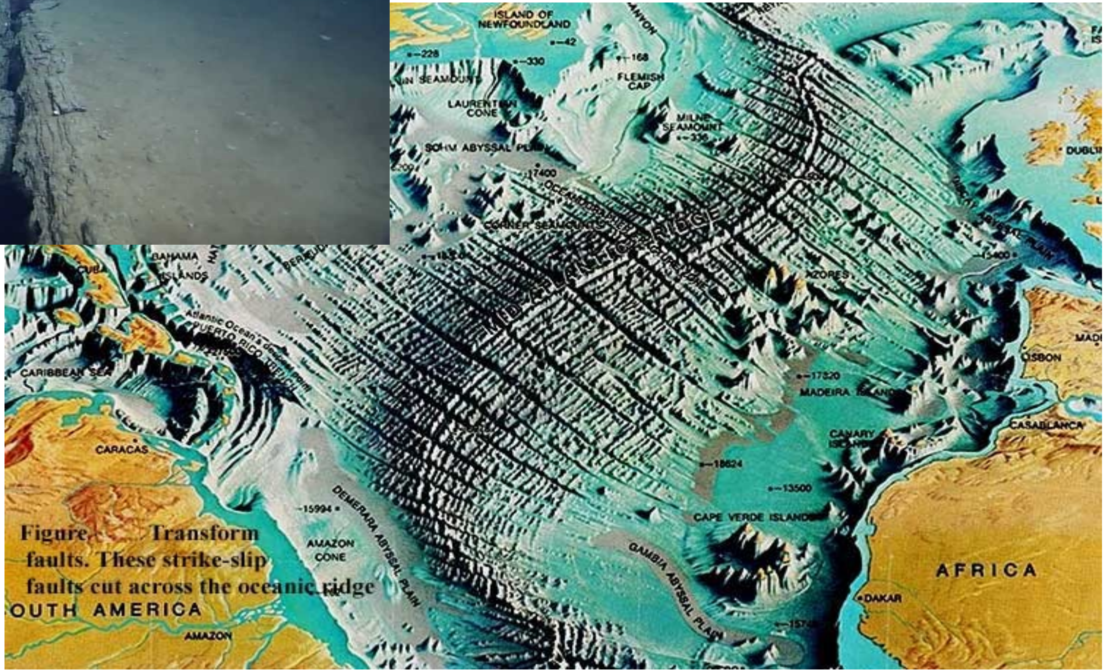
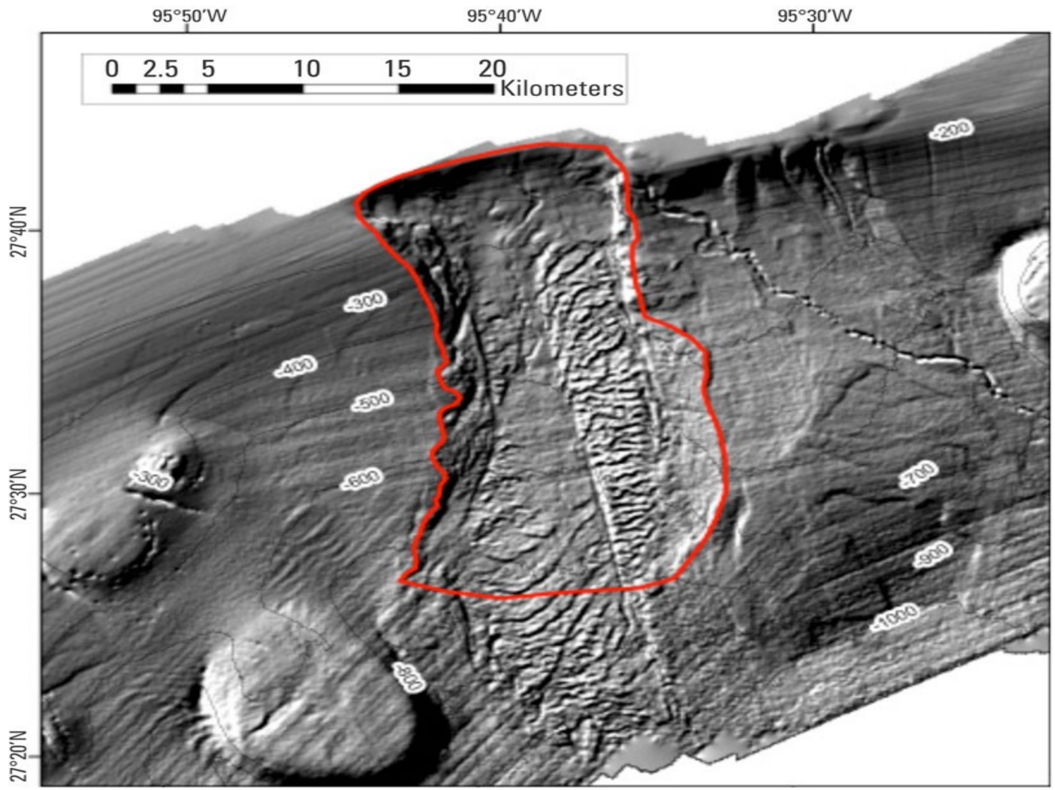
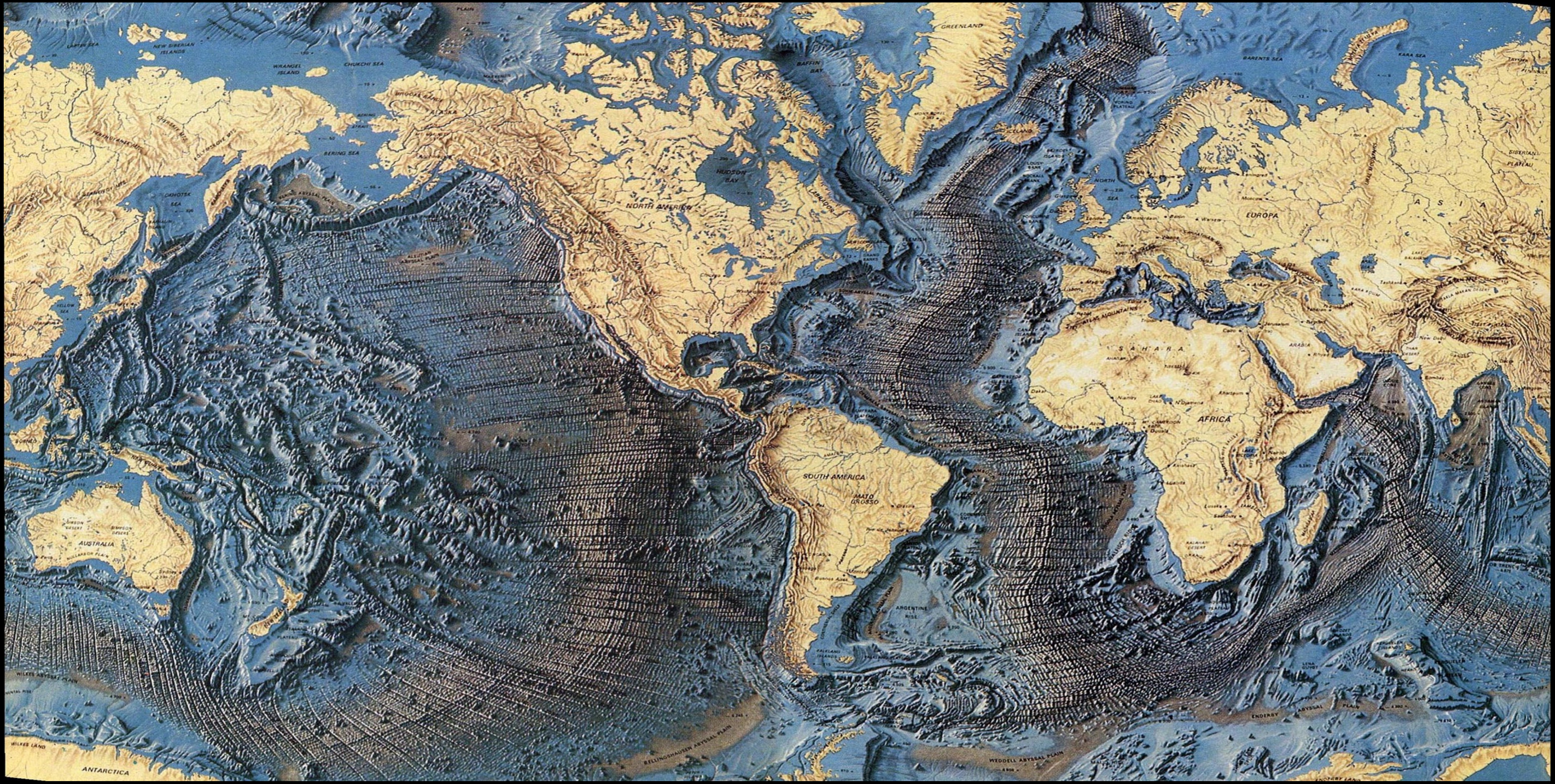


Figure Transform faults. These strike-slip faults cut across the oceanic ridge

Landslides

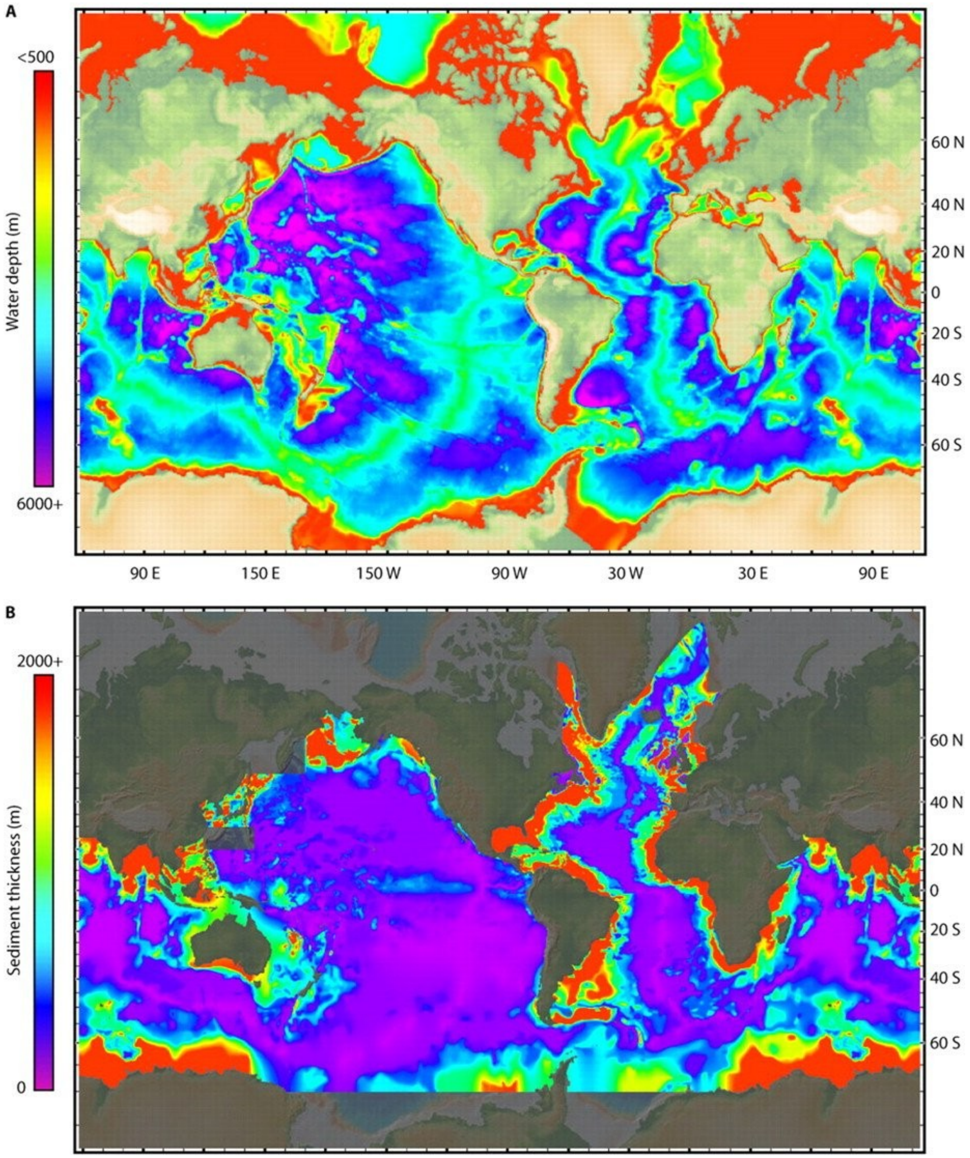

95°50'W
95°40'W
95°30'W
27°40'N
27°30'N
27°20'N
0 2.5 5 10 15 20
Kilometers
-200
-300
-400
-500
-600
-300
-700
-900
-1000
-800

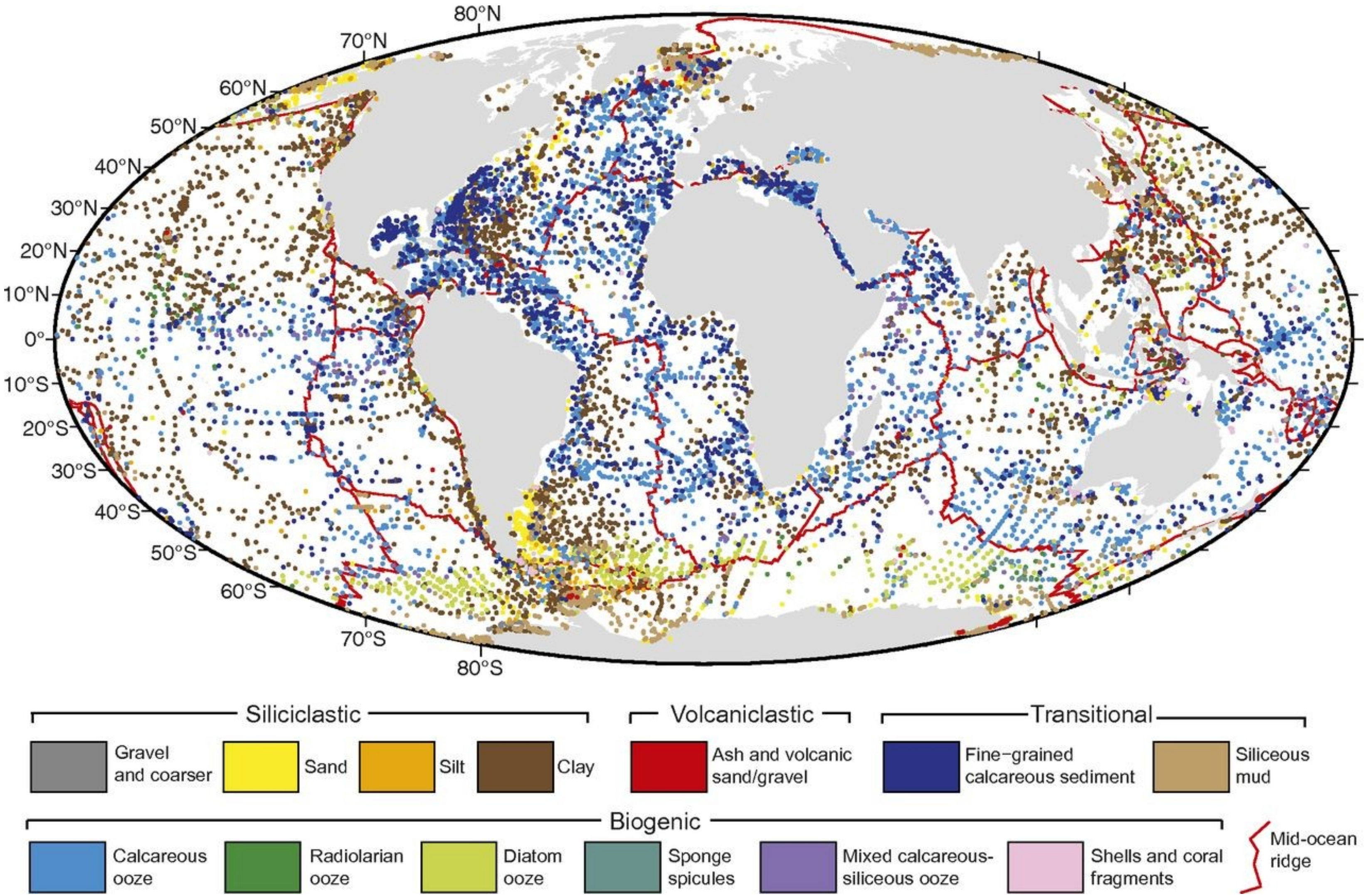


Heezen and Tharp, 1977

Water depth (m)

Sediment thickness (m)




80°N
70°N
60°N
50°N
40°N
30°N
20°N
10°N
0°
10°S
20°S
30°S
40°S
50°S
60°S
70°S
80°S
Siliciclastic
Gravel and coarser
Sand
Silt
Clay
Volcaniclastic
Ash and volcanic sand/gravel
Transitional
Fine−grained calcareous sediment
Siliceous mud
Biogenic
Calcareous ooze
Radiolarian ooze
Diatom ooze
Sponge spicules
Mixed calcareous-siliceous ooze
Shells and coral fragments
Mid-ocean ridge

Age of Oceanic Lithosphere (m.y.)

Data source:

Muller, R.D., M. Sdrolias, C. Gaina, and W.R. Roest 2008. Age, spreading rates and spreading symmetry of the world's ocean crust,Geochem. Geophys. Geosyst., 9, Q04006, doi:10.1029/2007GC001743.

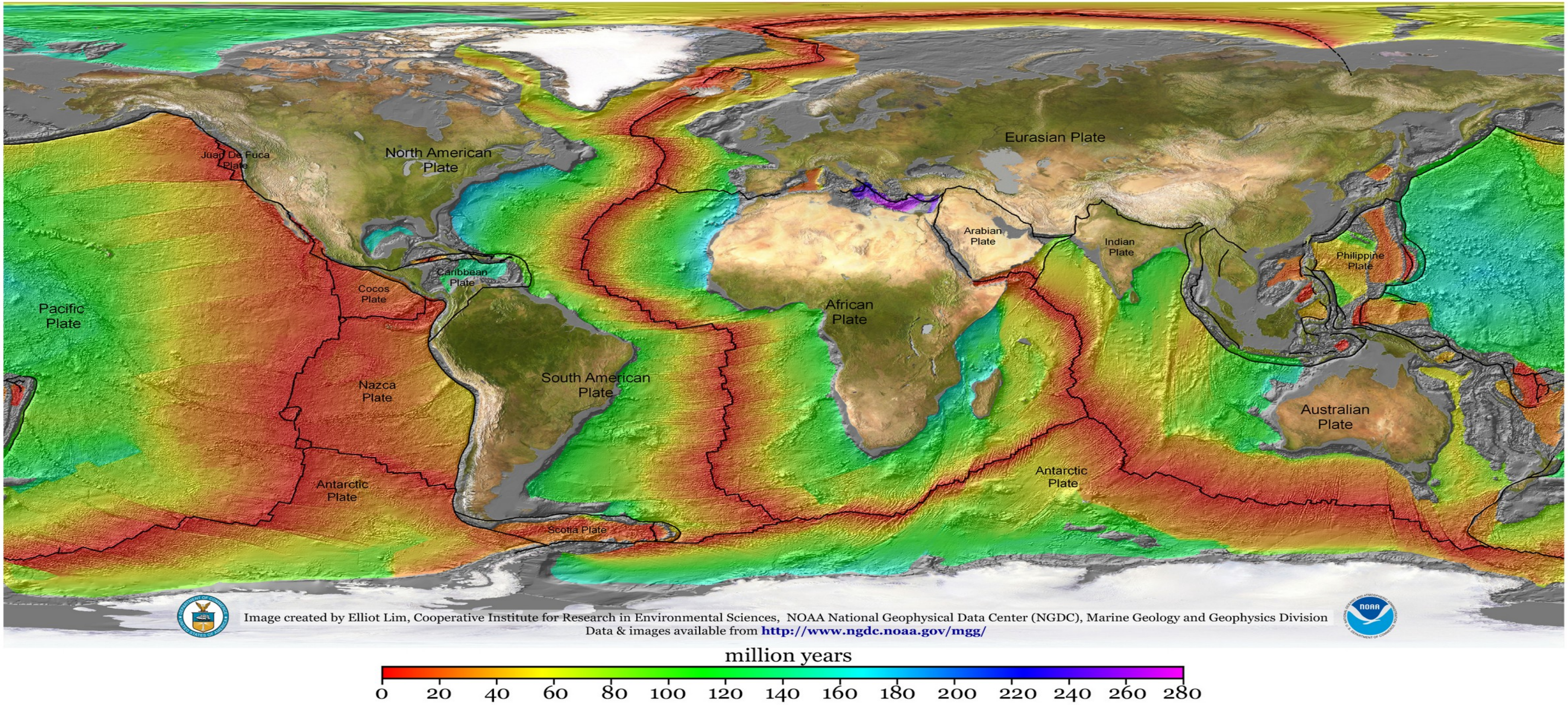


Plate Tectonic and the Seafloor

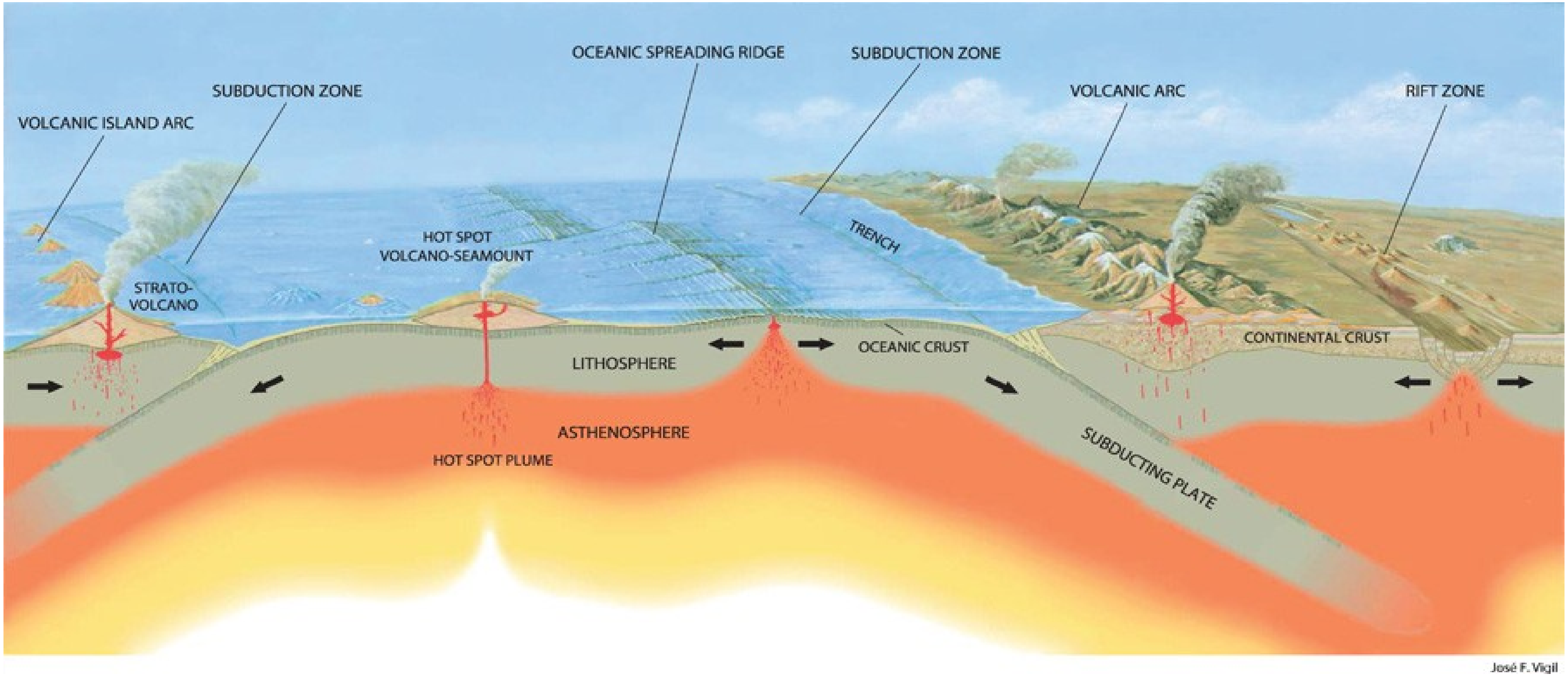
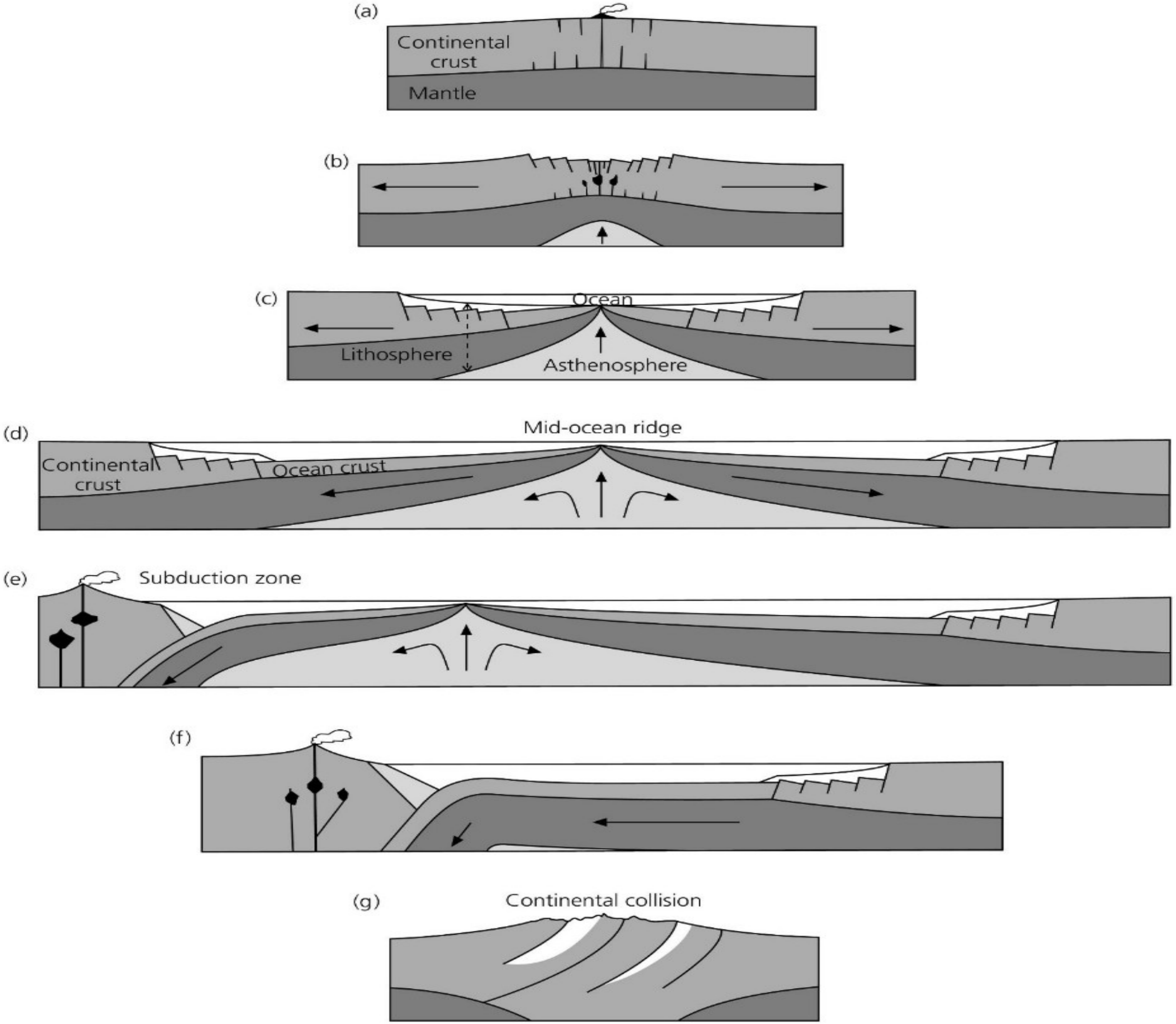
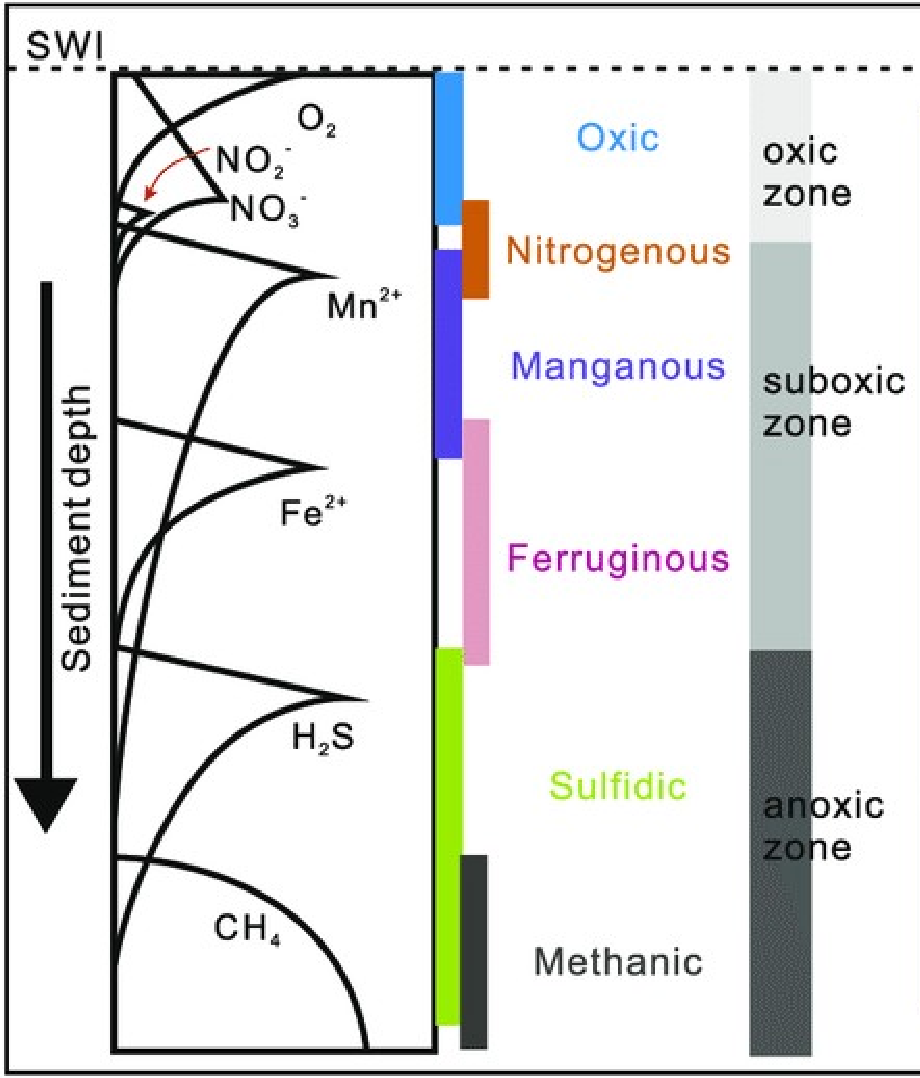


Figure 5.6-1: Schematic diagram of the Wilson cycle.





Respiration reactions in marine sediment pore-waters at 25°C and pH = 7:

Oxic respiration:

$$2O_2 + C_2H_3O_2^- \rightarrow 2HCO_3^- + H^+$$

Denitrification:

$$8NO_3^- + 3H^+ + 5C_2H_3O_2^- \rightarrow 4N_2 + 10HCO_3^- + 4H_2O$$

Mn reduction:

$$7H^+ + 4MnO_2 + C_2H_3O_2^- \rightarrow 4Mn^{2+} + 2HCO_3^- + 4H_2O$$

Fe reduction:

$$15H^+ + 8FeOOH + C_2H_3O_2^- \rightarrow 8Fe^{2+} + 2HCO_3^- + 12H_2O$$

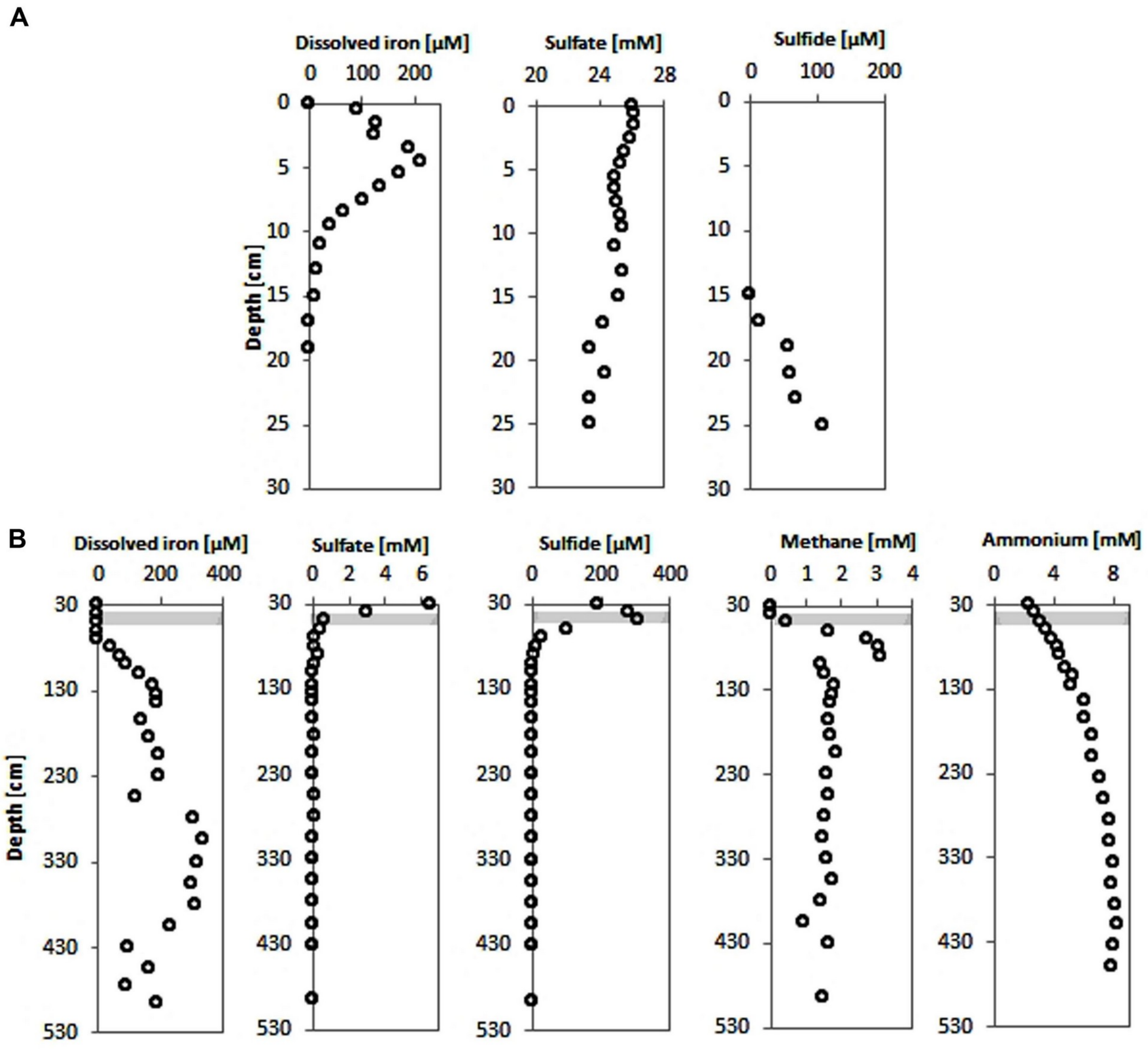
Sulfate reduction:

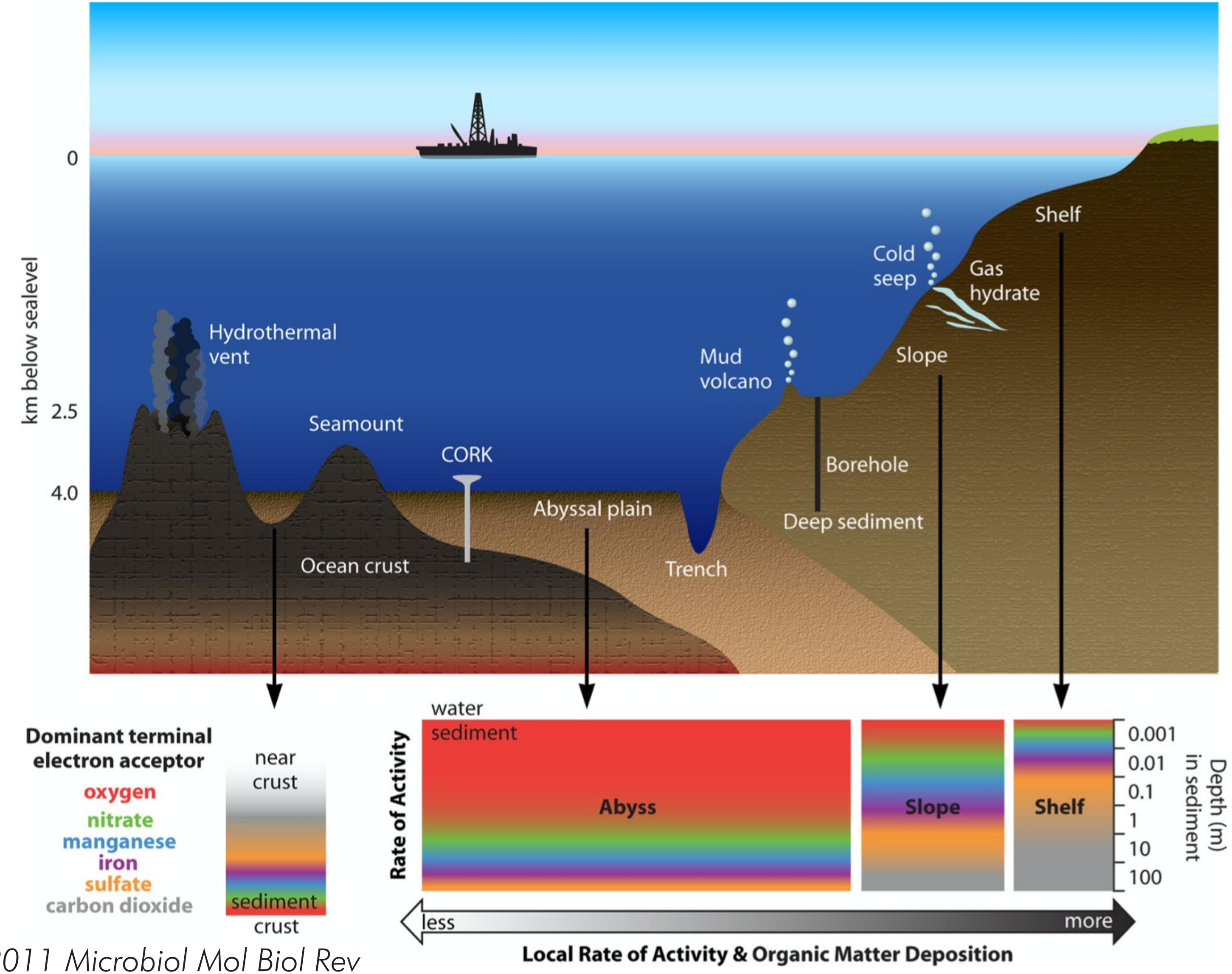
$$H^+ + SO_4^{2-} + C_2H_3O_2^- \rightarrow H_2S + 2HCO_3^-$$

Methanogenesis:

$$H_2O + C_2H_3O_2^- \rightarrow CH_4 + HCO_3^-$$

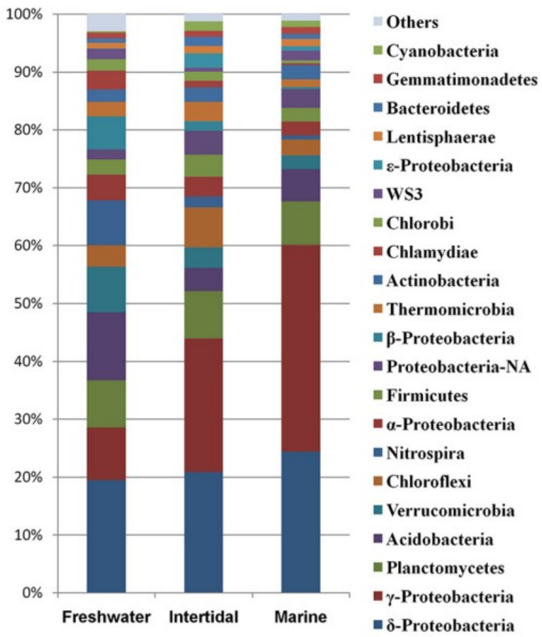
Algeo et al. 2015 PNAS

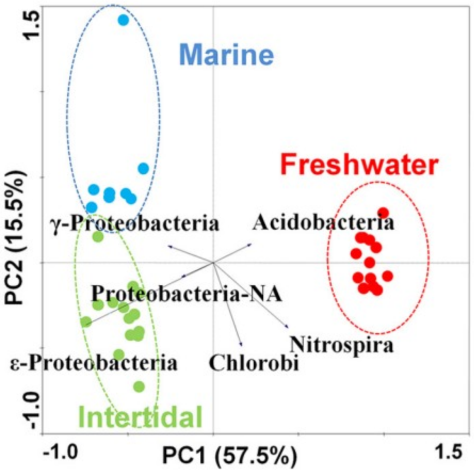

A
Dissolved iron [µM]
Sulfate [mM]
Sulfide [µM]
Depth [cm]
B
Dissolved iron [µM]
Sulfate [mM]
Sulfide [µM]
Methane [mM]
Ammonium [mM]
Depth [cm]

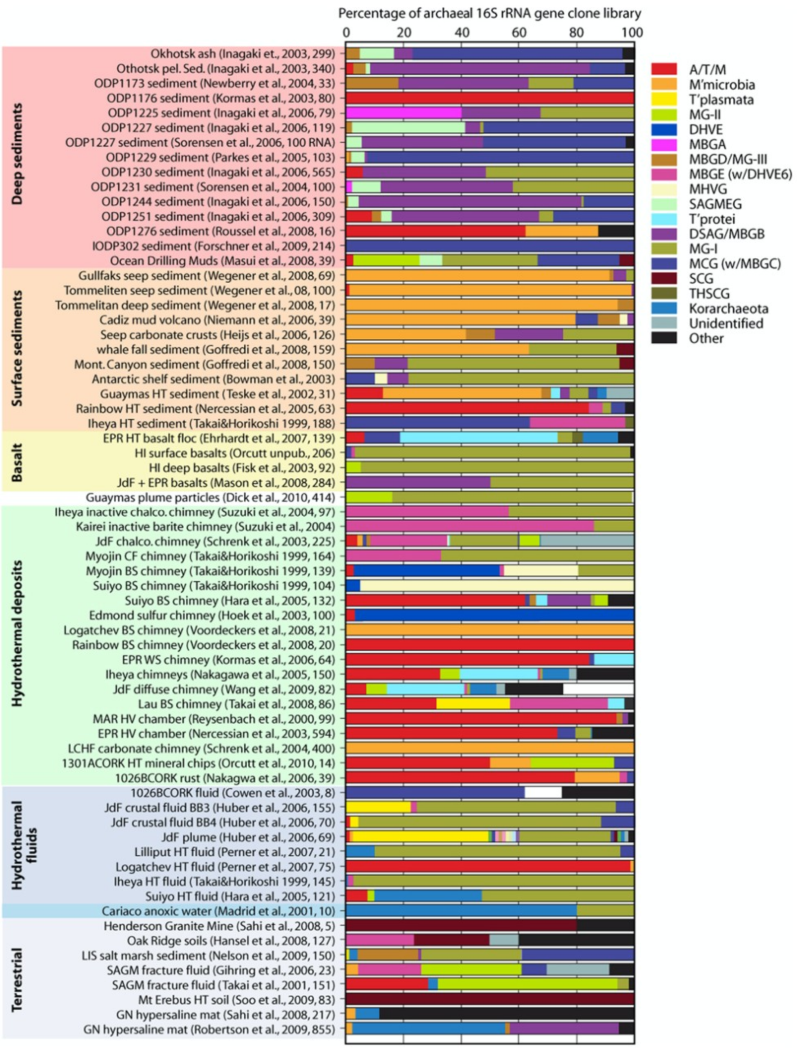


Orcutt et al 2011 Microbiol Mol Biol Rev

Marine Sediments Diversity

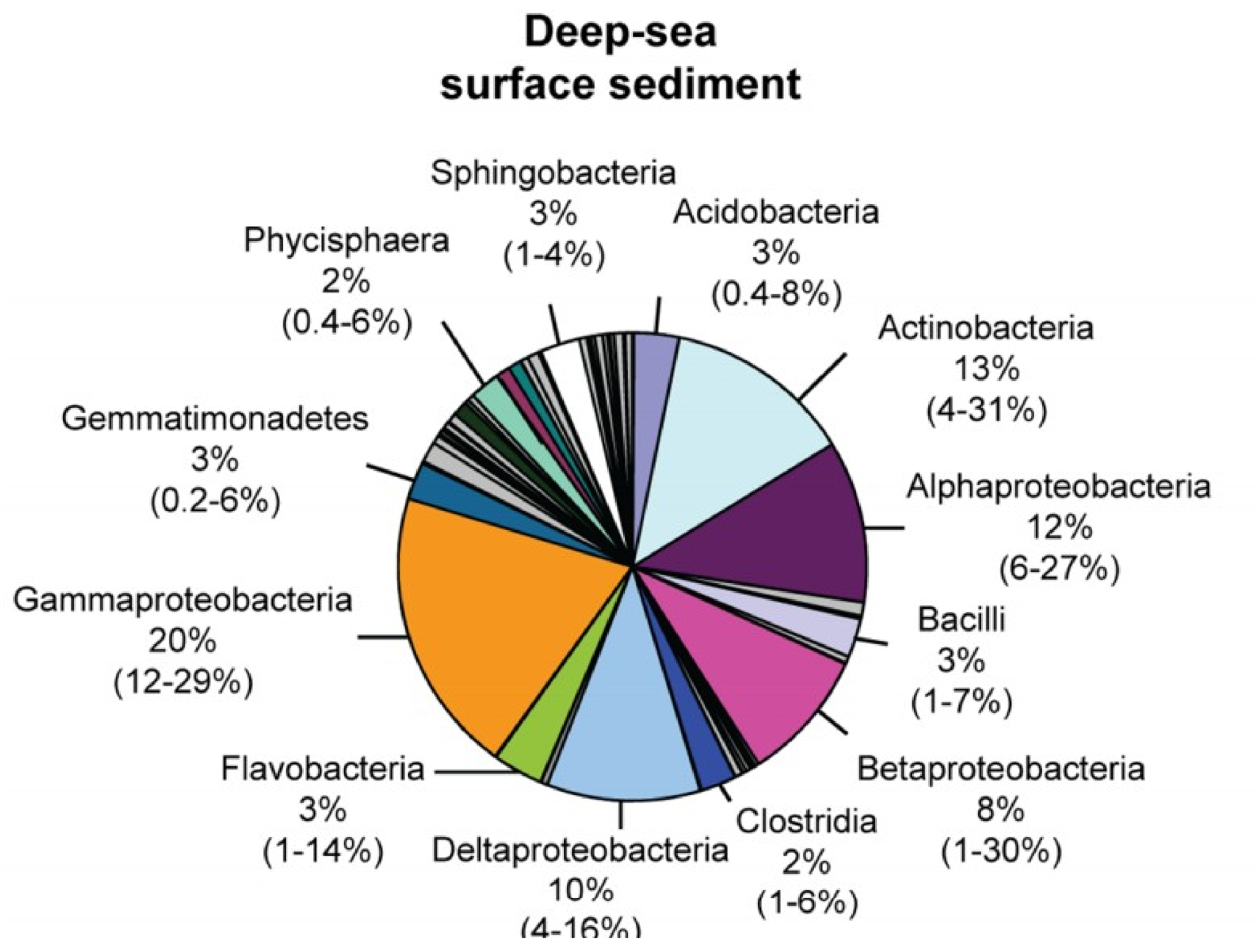




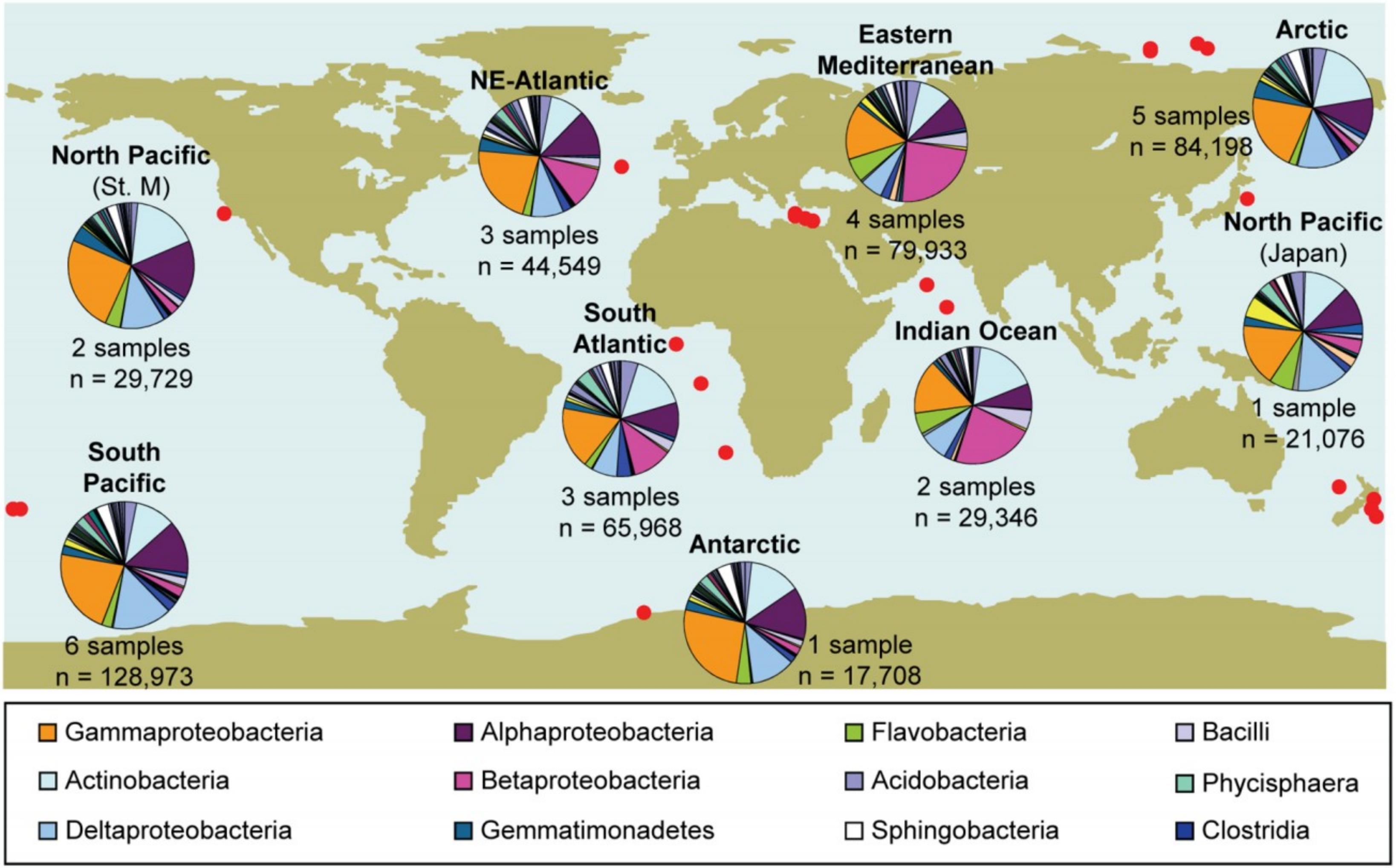


Wang et al. 2012 Appl Env Microbiol

Orcutt et al. 2011 Microbiol Mol Biol Rev



Bienhold et al. 2016 Plos ONE



Bacterial community composition in deep-sea sediments at water depths >1000 m

Bienhold et al. 2016 Plos ONE

Case study: the Mediterranean Sea

The Mediterranean Sea

Average depth of 1,500 m

Deepest recorded point is 5,267 m

Covers an approximate area of 2.5 million km^2

Divided in three sector, Western, Central and Eastern Med

The Strait of Gibraltar (connection with Atlantic) is only 14 km wide

Evaporation greatly exceeds precipitation and river runoff

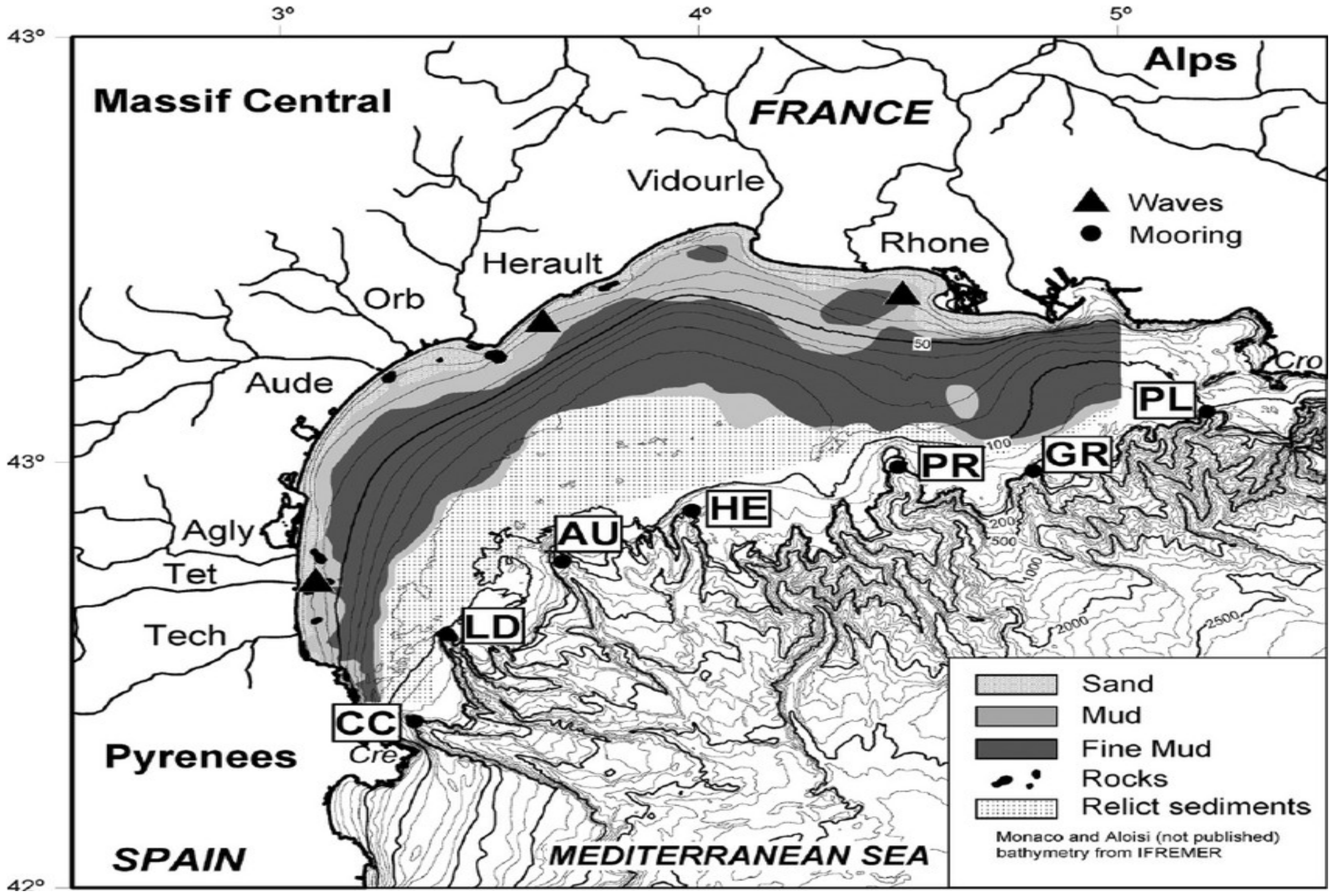
Evaporation is especially high in its eastern half, causing the water level to decrease and salinity to increase eastward

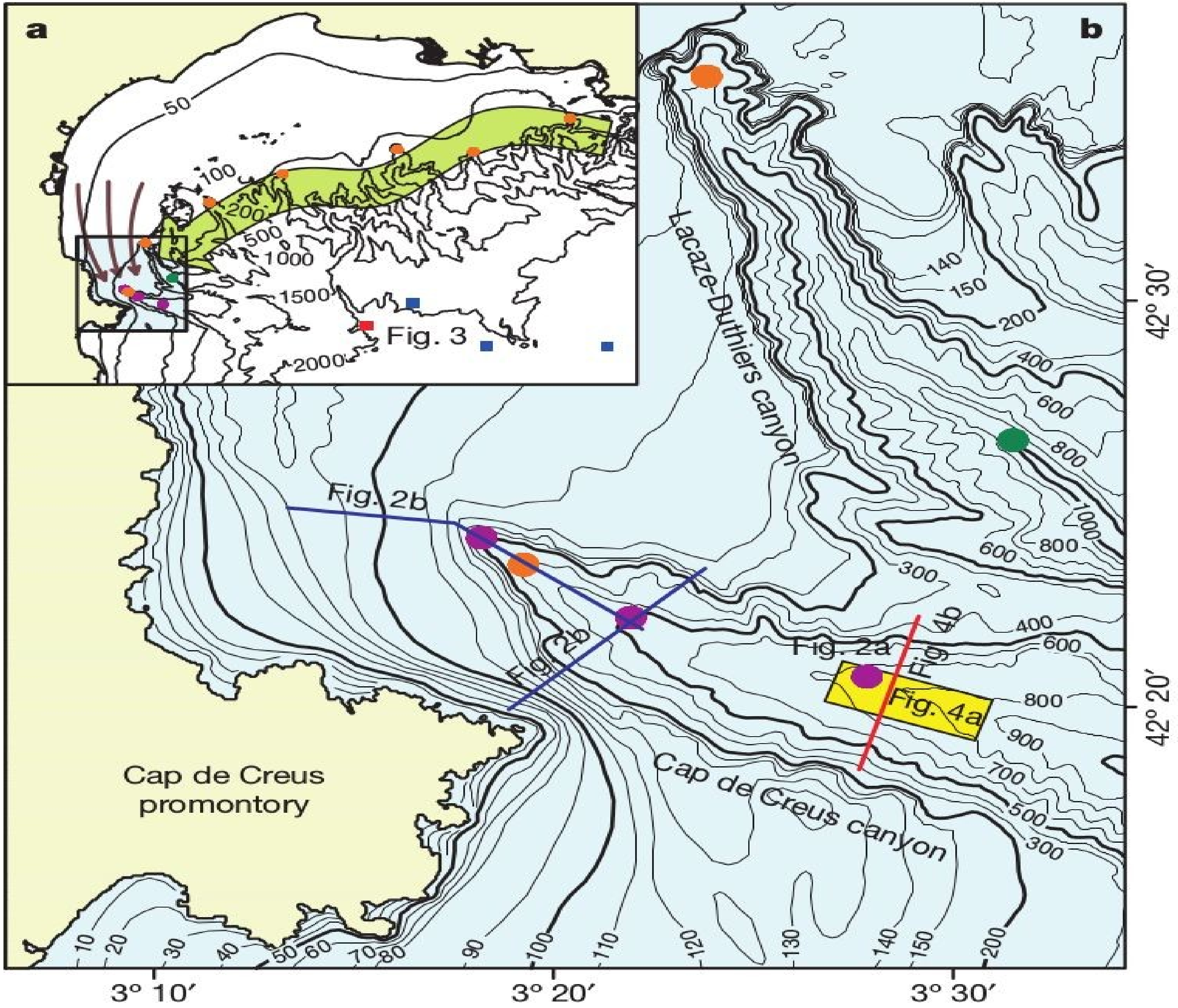
The salinity at 5 m depth is 3.8%

Deep-sea temperature are constant at 13.8°C

Heavily populated since ancient times

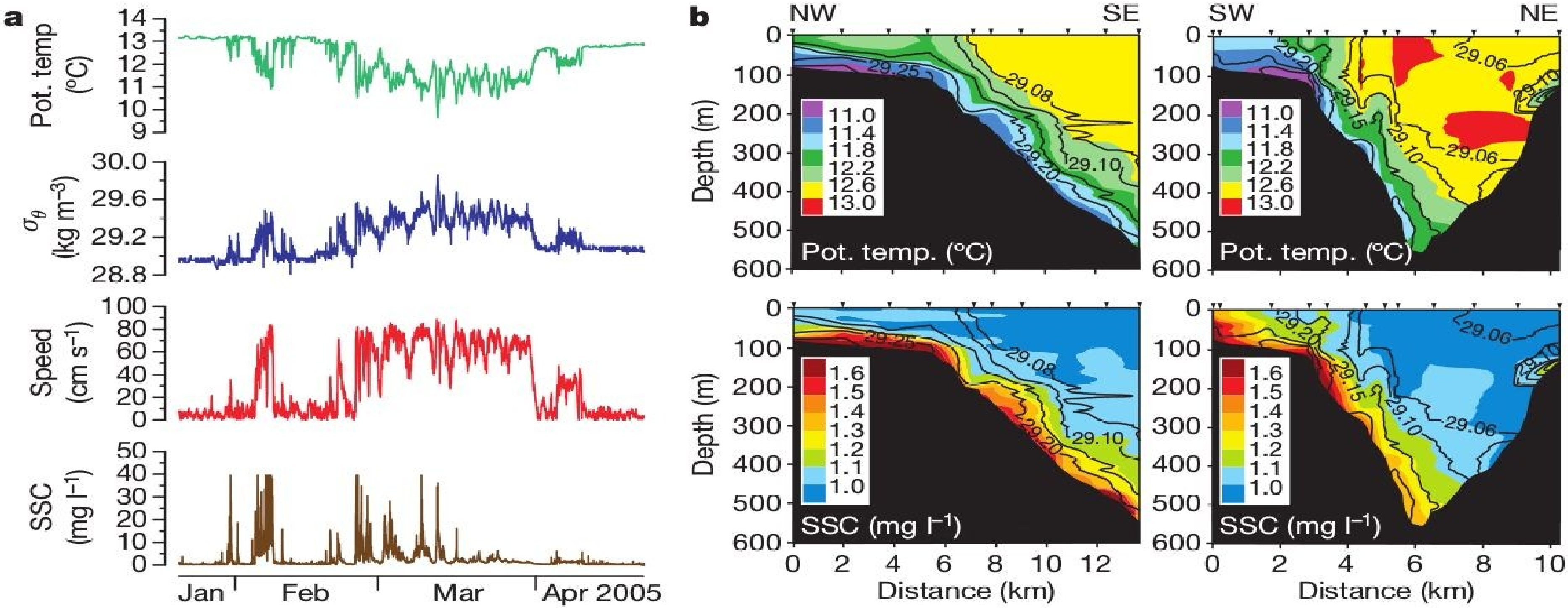
Mediterranean Canyons and lateral inputs of OM





a
b
50
100
200
500
1000
1500
2000
Fig. 3
Lacaze-Duthiers canyon
140
150
200
400
600
800
1000
800
600
300
400
600
Fig. 2b
Fig. 2b
Fig. 2a
Fig. 4b
Fig. 4a
800
900
700
500
300
Cap de Creus canyon
Cap de Creus promontory
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
200
3° 10′
3° 20′
3° 30′
42° 30′
42° 20′

Dense Waters Cascading Events



Readings

Sunagawa, S., Coelho, L. P., Chaffron, S., Kultima, J. R., Labadie, K., Salazar, G., et al. (2015). Structure and function of the global ocean microbiome. Science 348. doi:10.1126/science.1261359.

Bertagnolli, A. D., and Stewart, F. J. (2018). Microbial niches in marine oxygen minimum zones. Nat Rev Microbiol 16, 723–729. doi:10.1038/s41579-018-0087-z.

Bienhold, C., Zinger, L., Boetius, A., and Ramette, A. (2016). Diversity and Biogeography of Bathyal and Abyssal Seafloor Bacteria. PLOS ONE 11, e0148016. doi:10.1371/journal.pone.0148016.

SUBSURFACE ENVIRONMENTS

Marine Subsurface Environments

The **subsurface biosphere** is loosely defined as the habitable region beneath the soil and sediments where the limits of habitability are typically defined by some physical process

Current estimates of the habitable volume of the subsurface range from ~2.0 to 2.3 10^9 km^3 , or roughly twice the volume of our oceans

This large biosphere is estimated to hold ~70% of all bacterial and archaeal cells and potentially over 80% all bacterial and archaeal species

Average estimates for subsurface biosphere are 2.9 x 10^{29} Cells(10^{22}-10^{24} stars in the universe by comparison)

Earliest investigations into the deep subsurface biosphere were performed in oil fields and coal beds within the continental subsurface in the mid-1920s

Current investigations spans the marine and terrestrial subsurface, often involving drilling or access through existing caves and mines

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.

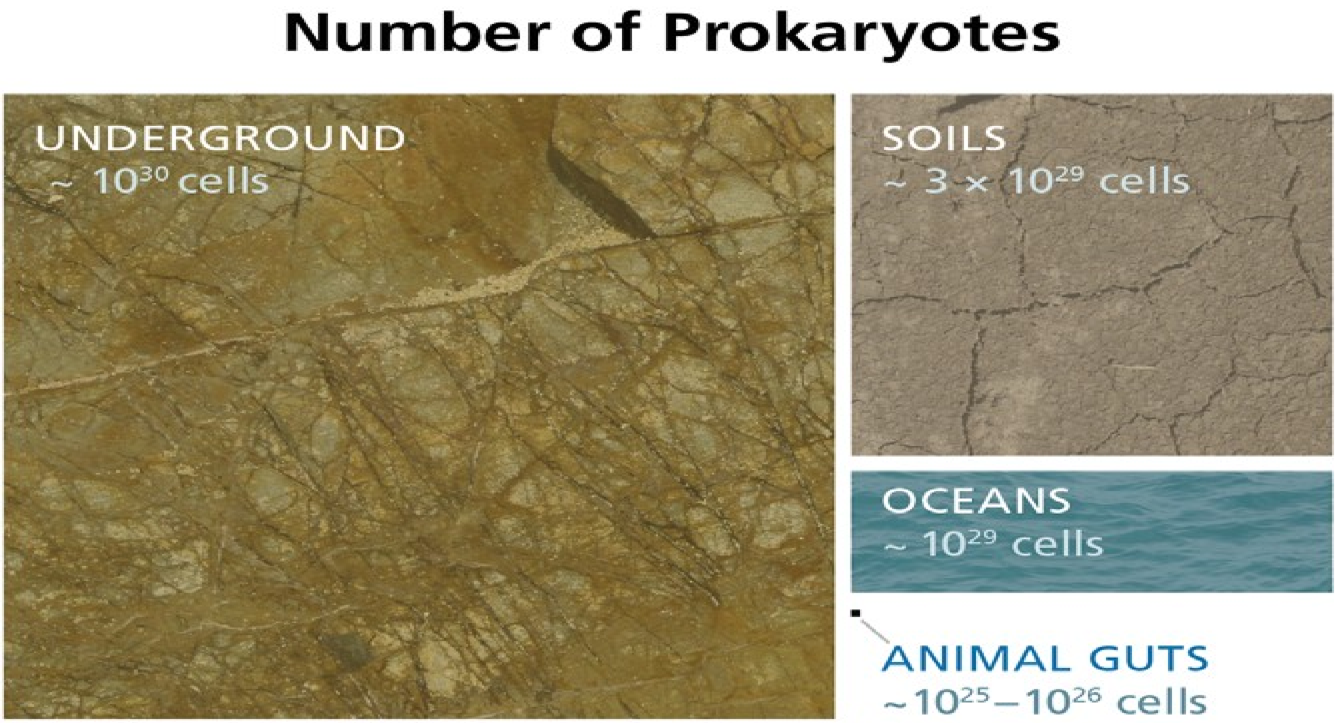
Where such liquids or gases stream up to higher levels into different chemical surroundings, they will continue to represent a chemical disequilibrium and therefore a potential energy source. There will often be circumstances where chemical reactions with surrounding materials might be possible and would 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

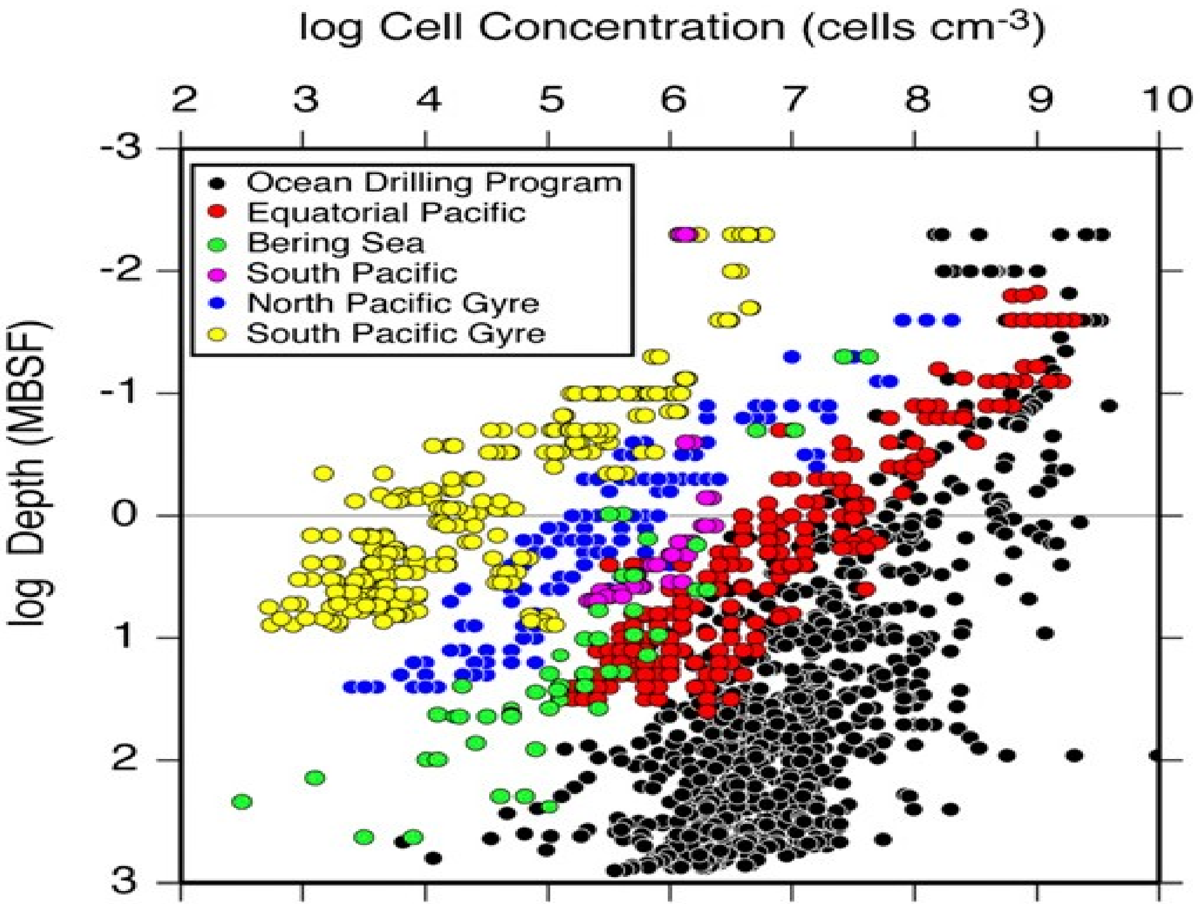

NSF International Ocean Discovery Program
Joides Resolution
NSF International Ocean Discovery Program

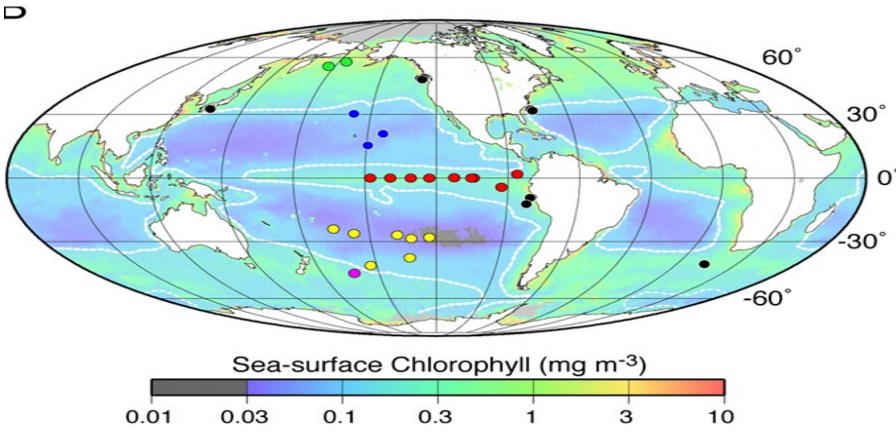
ICDP Oman Drilling Site – Deep Carbon Observatory

2.4 km Deep Canadian Mine – Deep Carbon Observatory

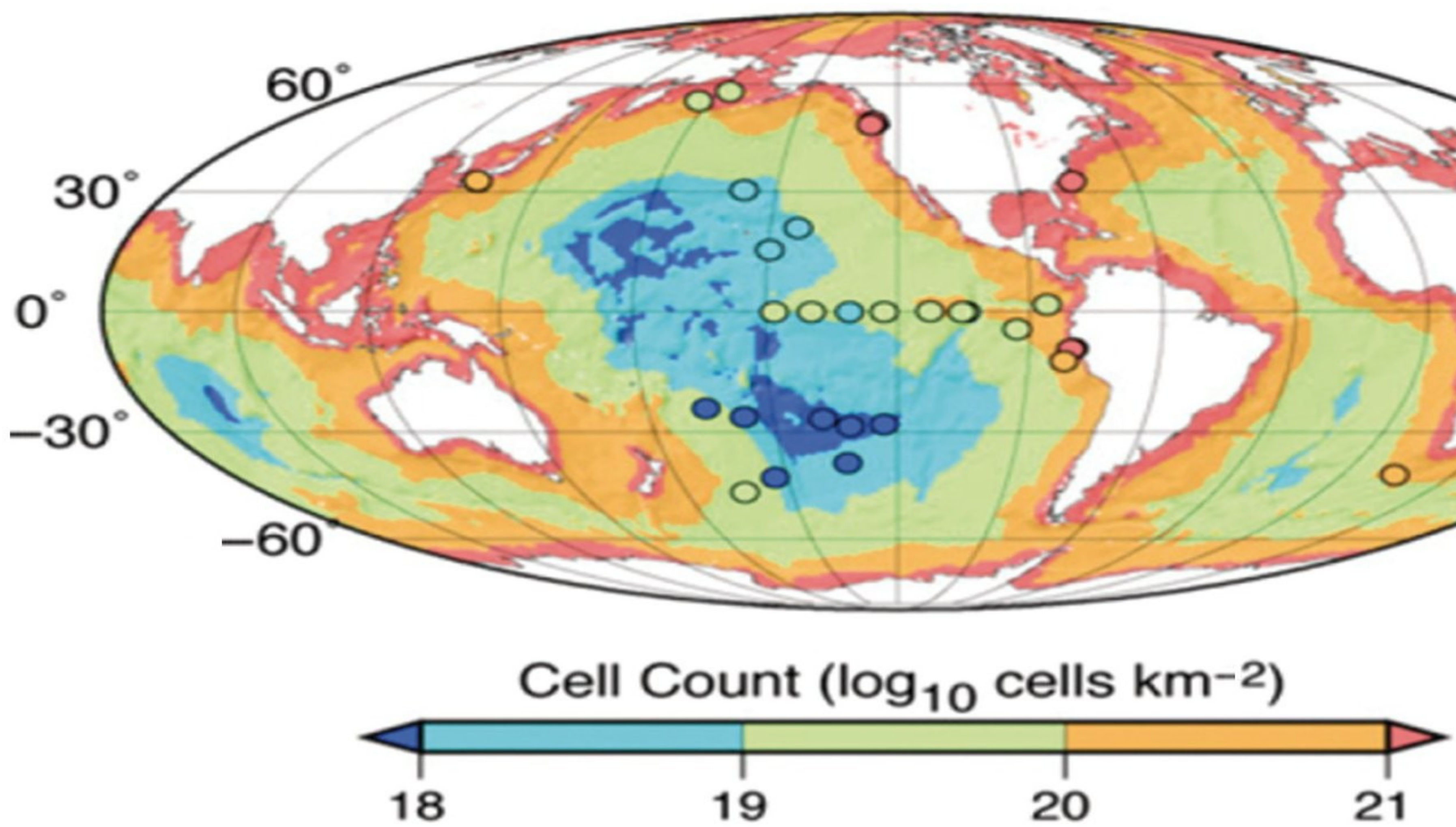


Magnabosco et al. 2019 in Deep Carbon Past to Present





Kallmeyer et al. 2012 PNAS



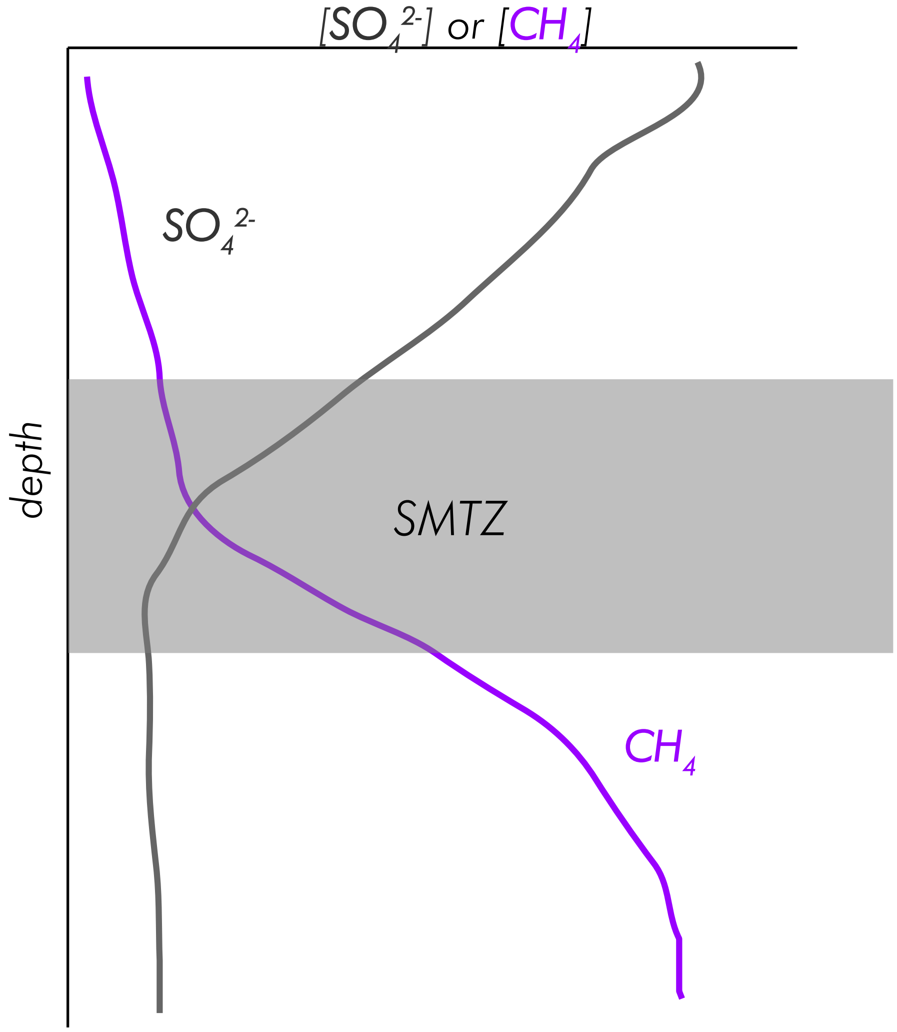
Kallmeyer et al. 2012 PNAS

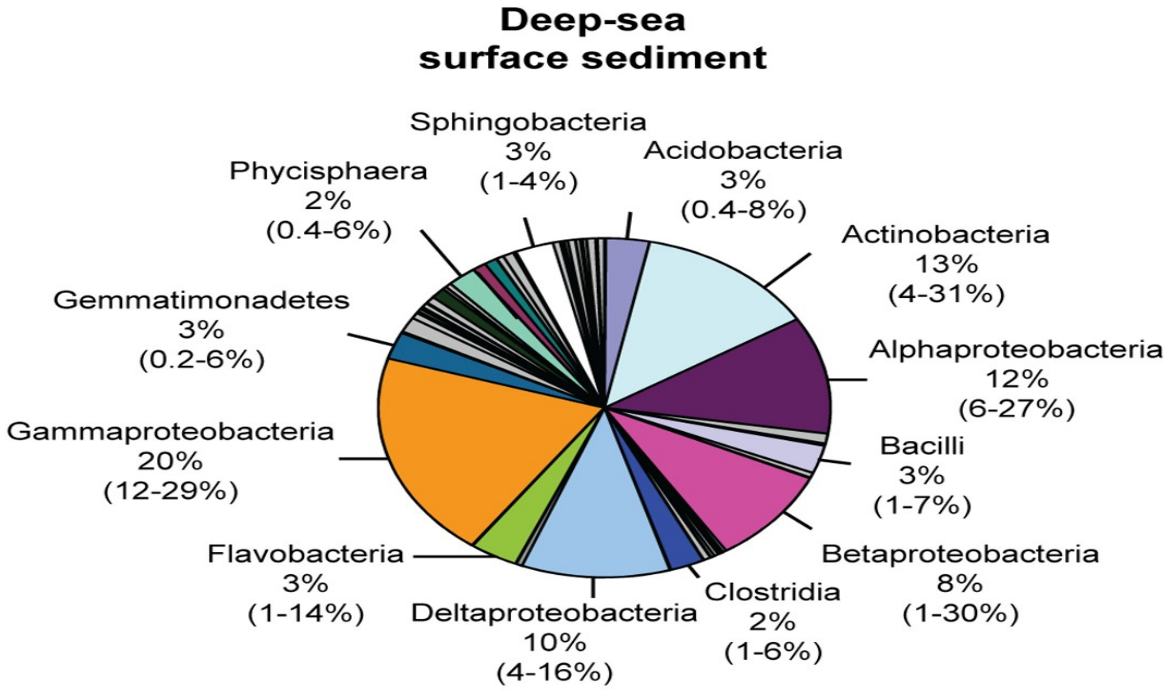
The **Sulfate-Methane Transition Zone** (SMTZ) is one of the most important zone in marine subsurface sediments together with the oxic-anoxic interface

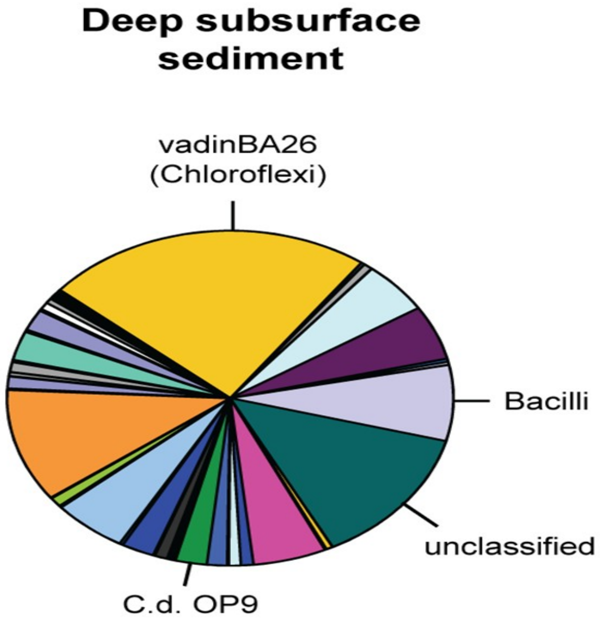
It is a geochemically defined zone in marine sediments between the minima of sulfate and the maxima of methane concentrations.

The SMTZ is an area of intense metabolic activity, where anaerobic methane oxidizers (ANME) is believed to play a key role in removing methane in partnership with sulfate reducing bacteria (SRB)

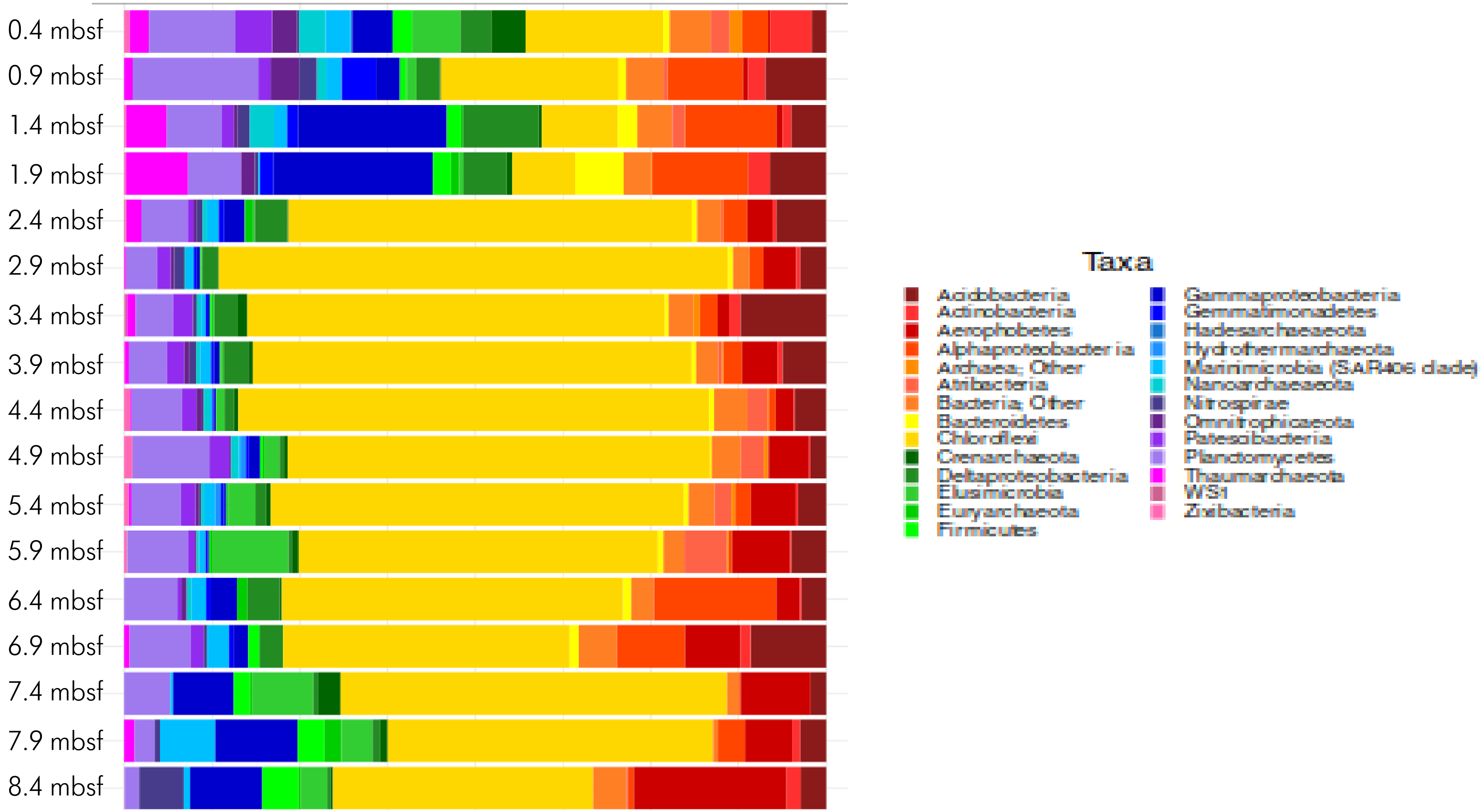
The SMTZ has a variable depth globally, and it is dependent upon sediment lithology, productivity of the overlaying water column



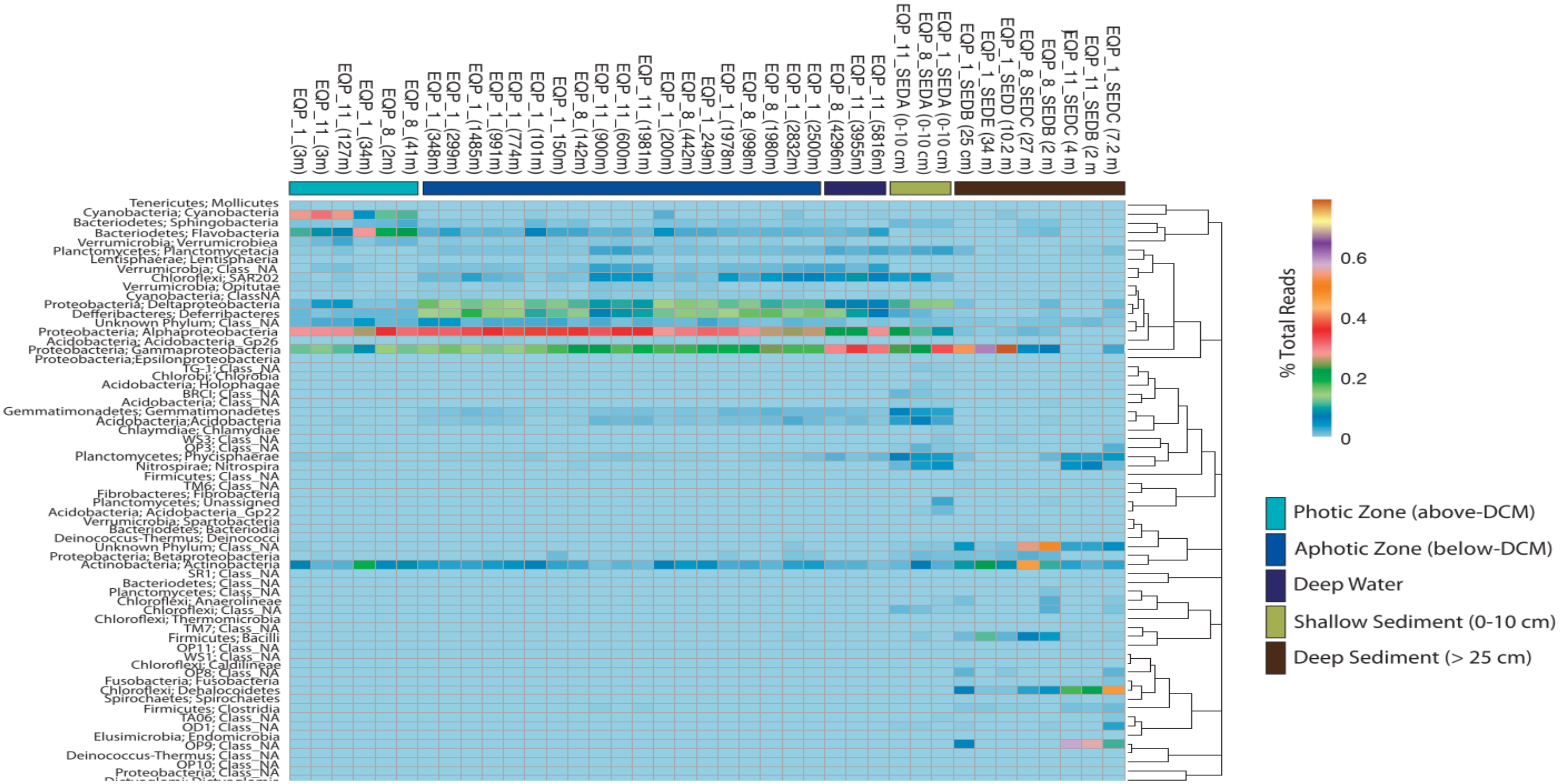




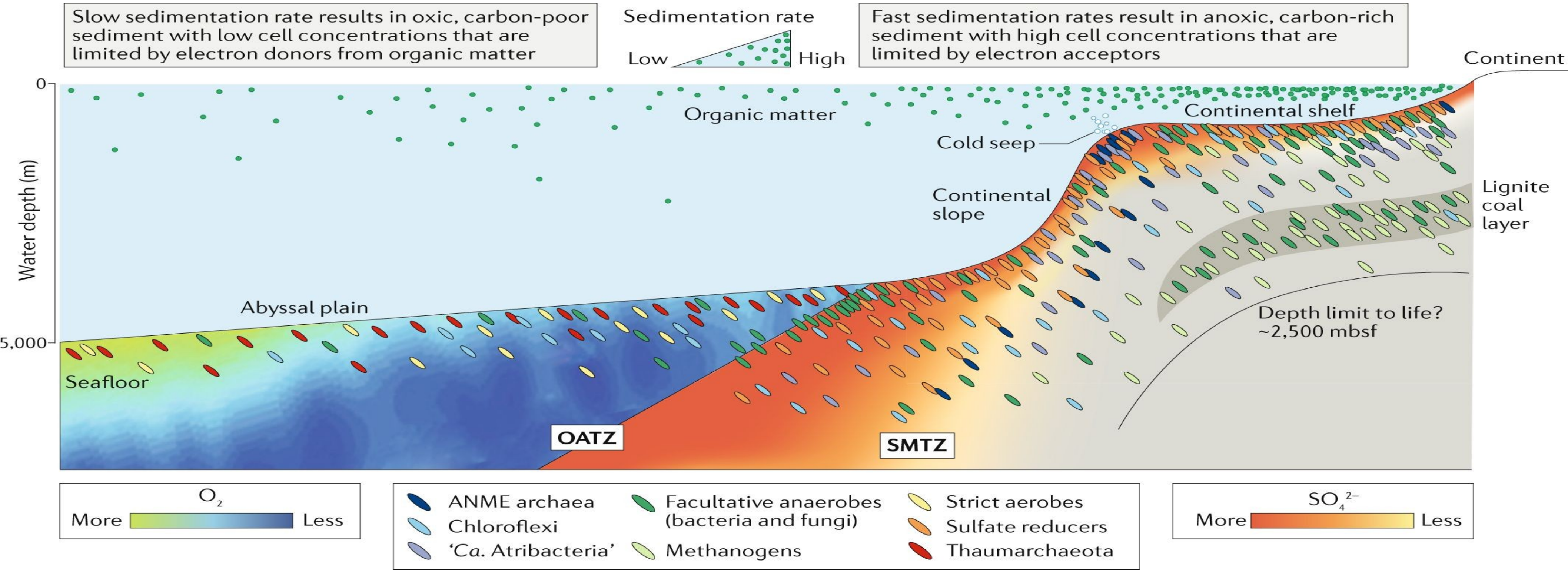
Bienhold et al. 2016 PlosONE



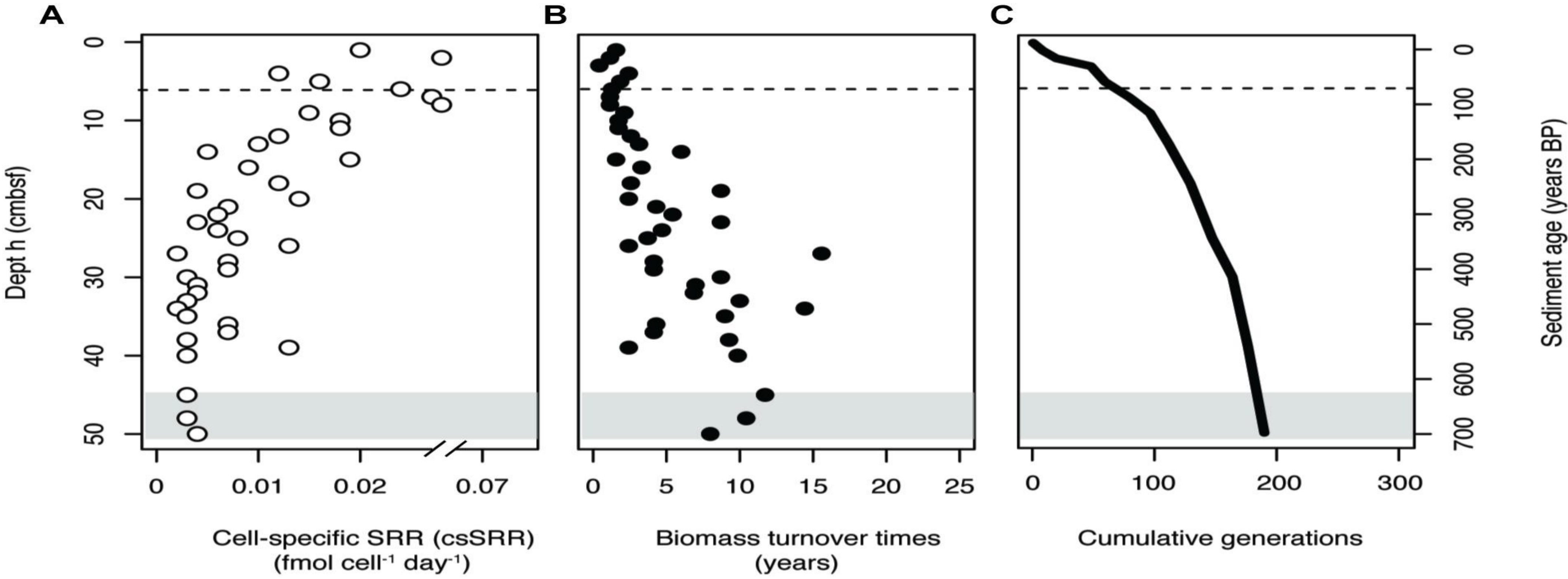
Biddle, Ash and Giovannelli, unpublished



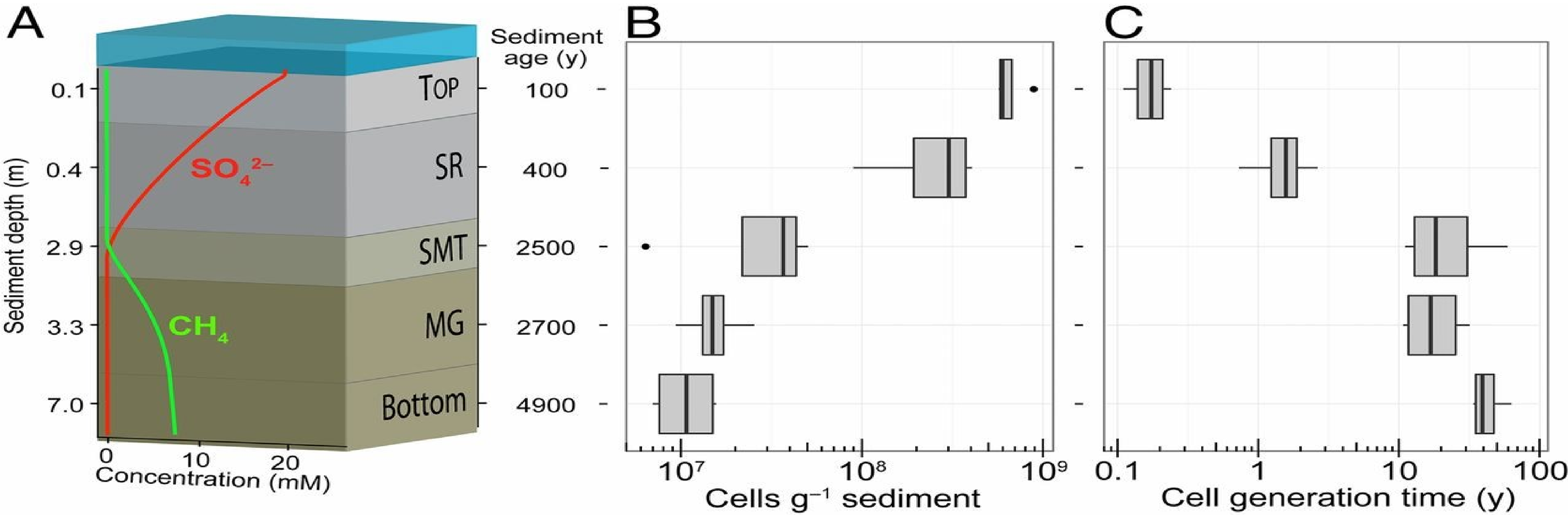
Walsh et al. 2016 ISMEJ



Orsi et al 2018



Petro et al., 2019 Front in Microbiol



Starnawski et al. 2017 PNAS

Habitable Zone

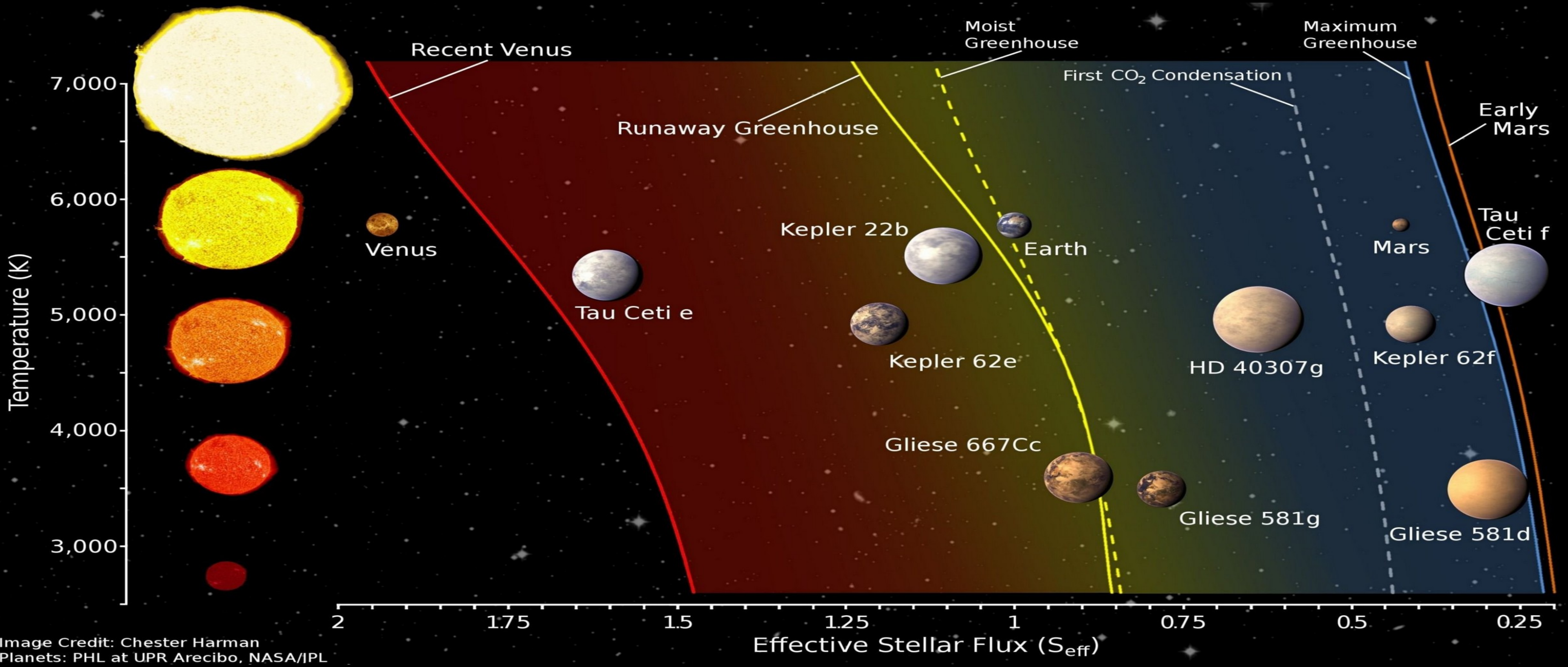
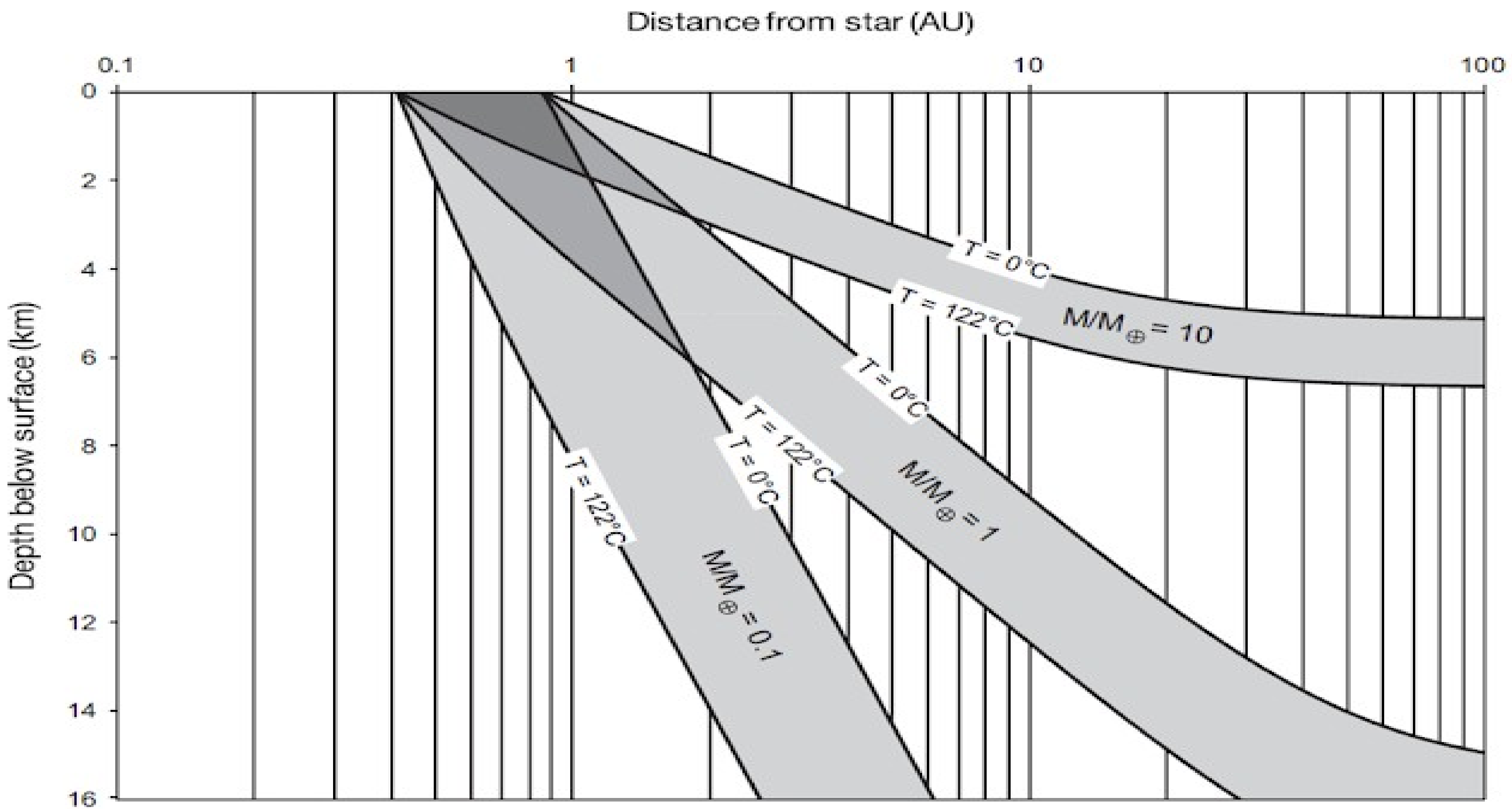


Image Credit: Chester Harman
Planets: PHL at UPR Arecibo, NASA/JPL



McMahon et al. 2013 Planet Space Sci

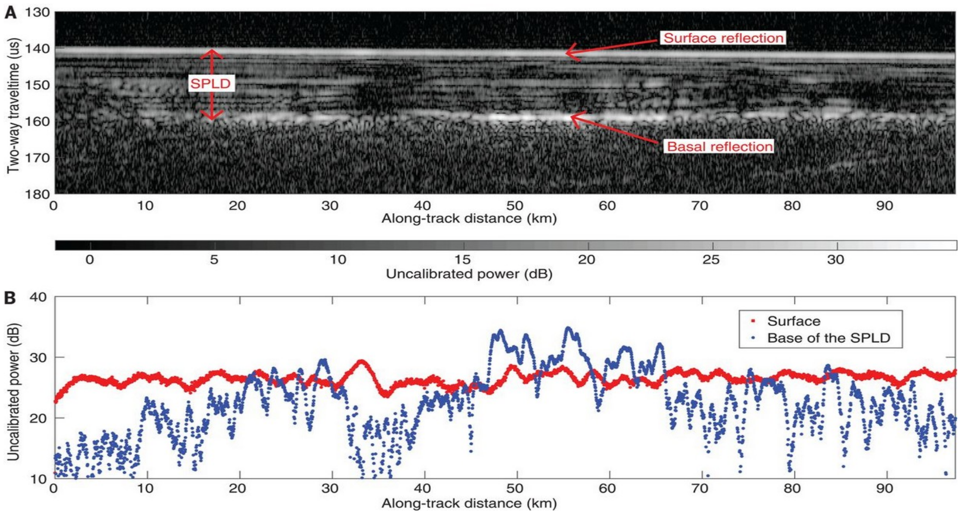
SHARE

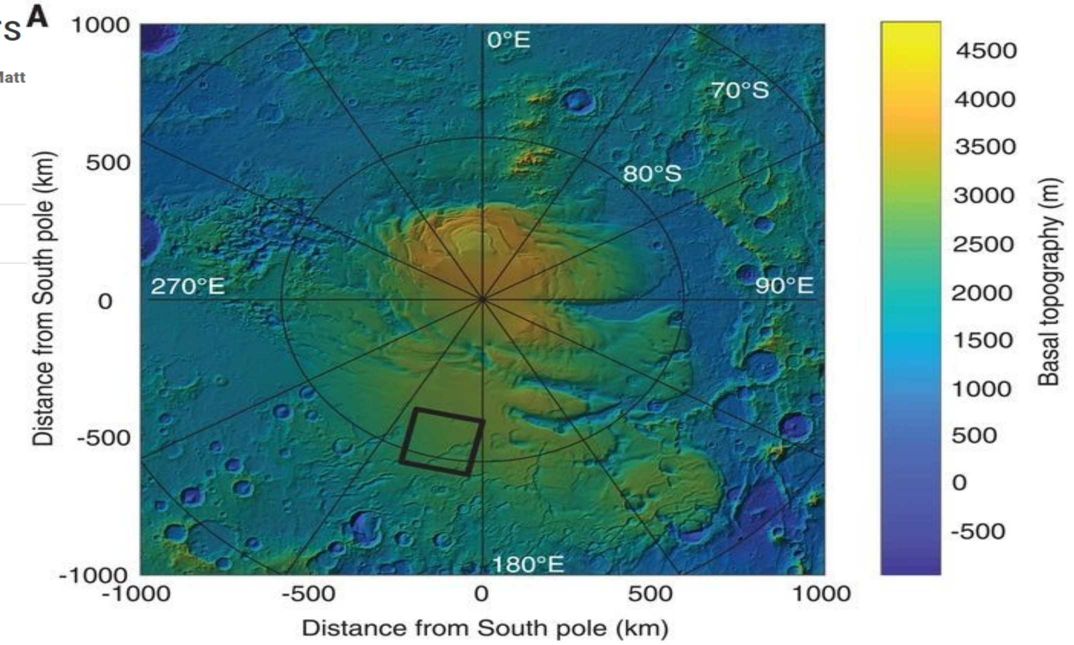
REPORT

Radar evidence of subglacial liquid water on Mars

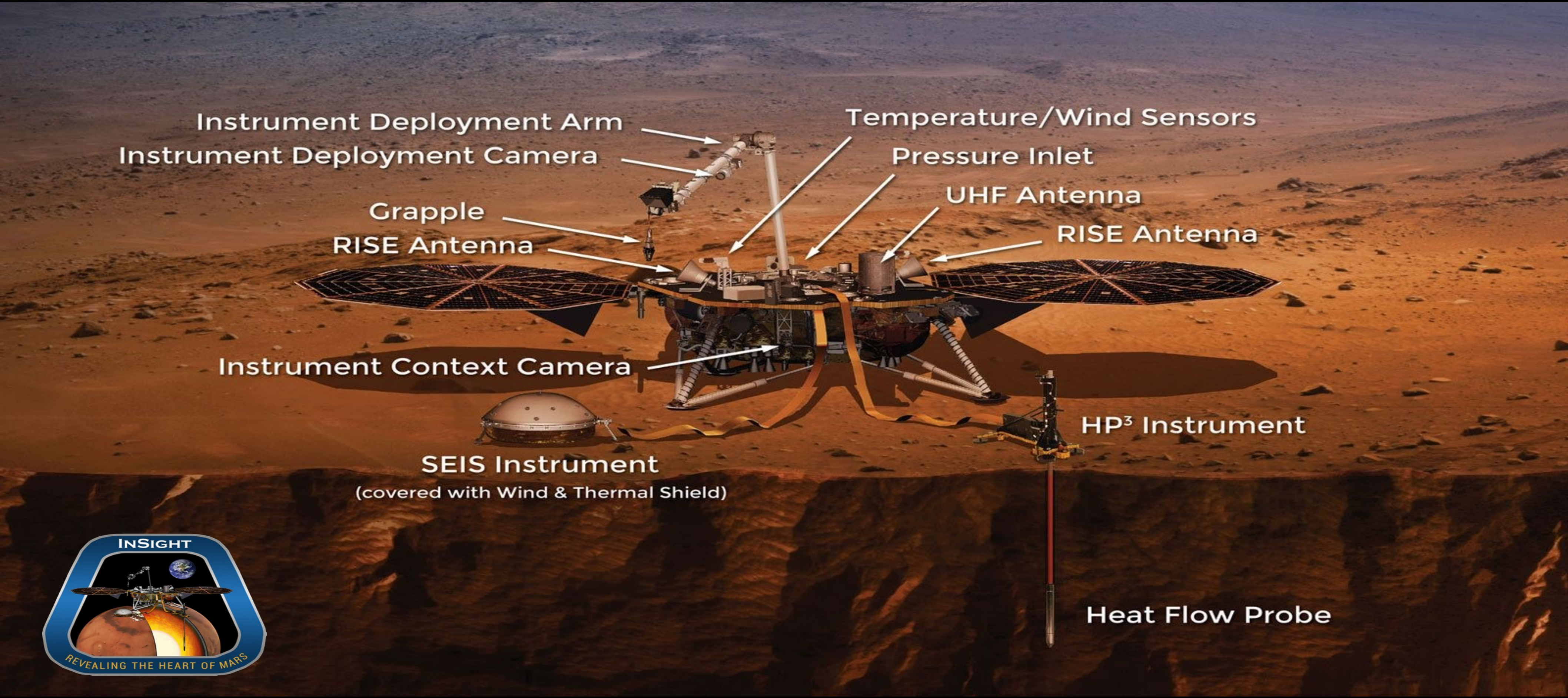
R. Orosei[1,*], S. E. Lauro[2], E. Pettinelli[2], A. Cicchetti[3], M. Coradini[4], B. Cosciotti[2], F. Di Paolo[1], E. Flamini[4], E. Matt
+ See all authors and affiliations

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





Orosei et al. 2018 Science



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

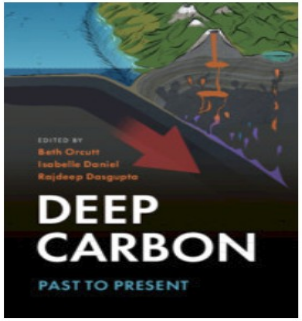
Deep Carbon
Past to Present

Search in this book

Export citation

Buy the print book

Open full book PDF



Access   Open access

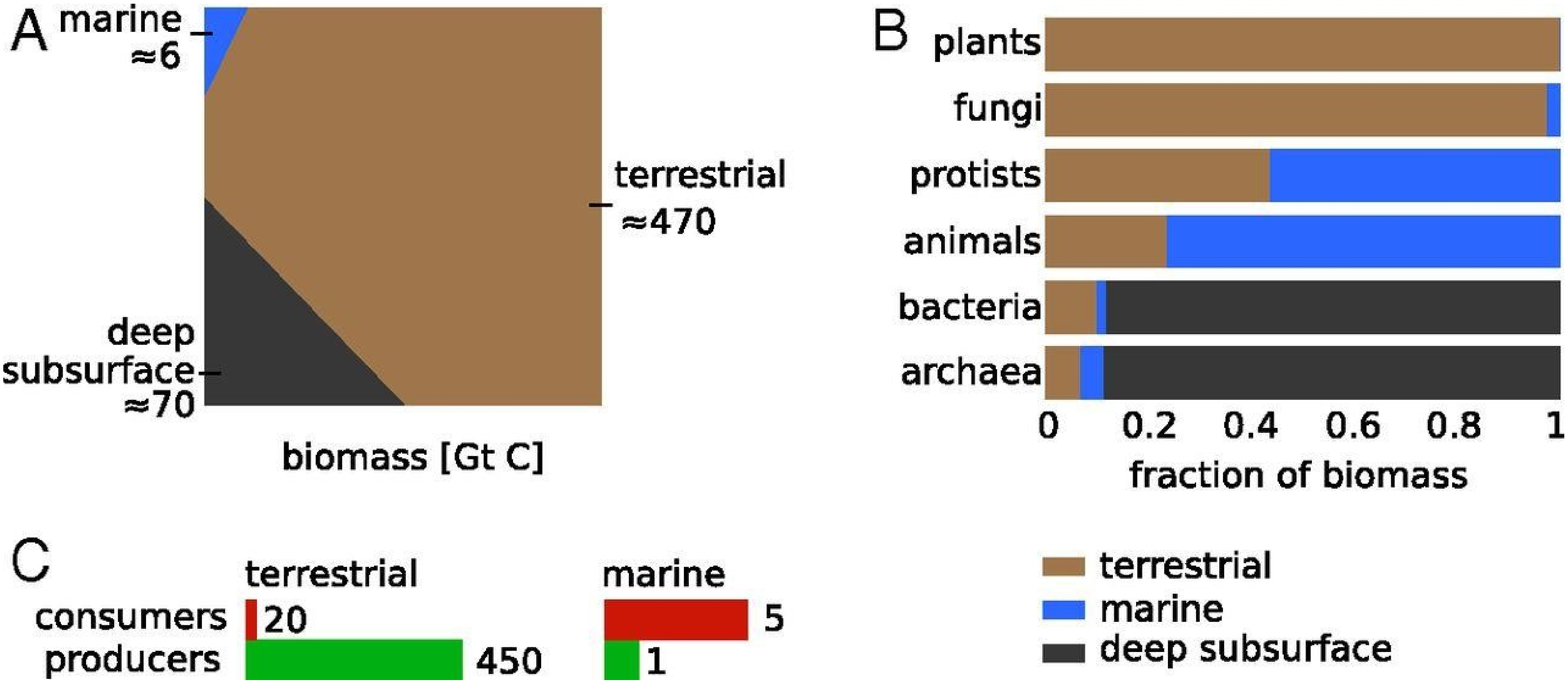
Edited by Beth N. Orcutt, *Bigelow Laboratory for Ocean Sciences, Maine* , Isabelle Daniel, *Université Claude-Bernard Lyon I* , Rajdeep Dasgupta, *Rice University, Houston*

Publisher: Cambridge University Press
Online publication date: October 2019
Print publication year: 2019
Online ISBN: 9781108677950
DOI: https://doi.org/10.1017/9781108677950

Subjects: Earth and Environmental Sciences, Geochemistry and Environmental Chemistry, Mineralogy, Petrology and Volcanology

Orcutt, B.N., Daniel, I., Dasgupta, R. (Eds.), 2019. Deep Carbon: Past to Present, 1st ed. Cambridge University Press. https://doi.org/10.1017/9781108677950

Deep Subsurface Environments



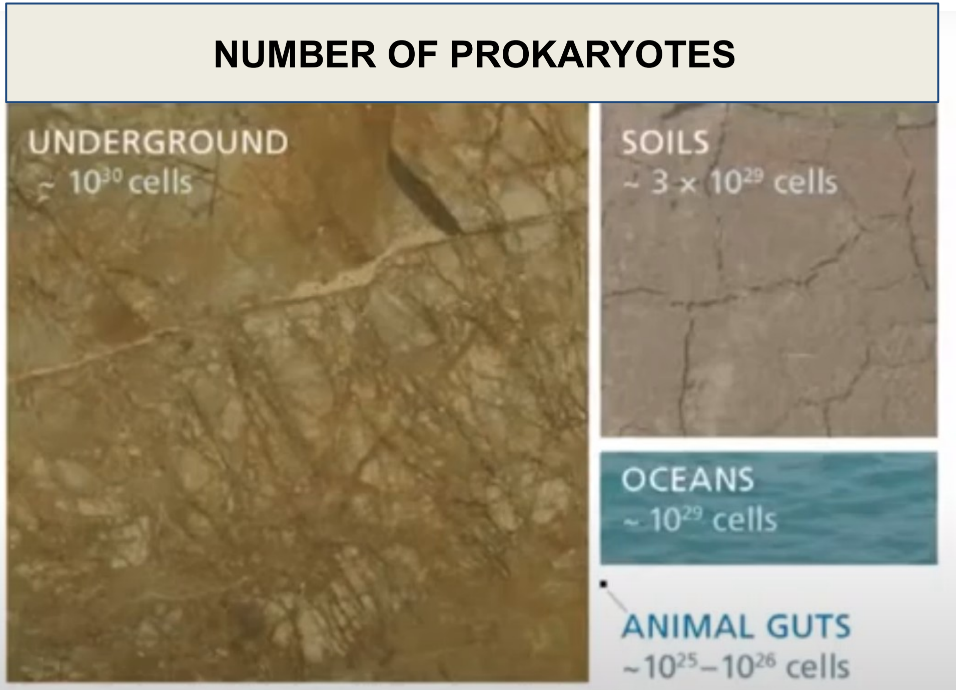
Bar-On, Y. M., Phillips, R., & Milo, R. (2018). The biomass distribution on Earth. *Proceedings of the National Academy of Sciences*, *115*(25), 6506-6511.

Deep Subsurface Environments

Table 1 | Summary of prokaryotic biomass estimates for various biomes

Host environment	Biomass (cells)	fgC per cell	Biomass (PgC)	Depth interval	Method and assumptions
Continental subsurface (Gold[1])	*5×10^{33}*	*21*	**110,000**	0–5,000 m	Pore space occupancy model; 3% porosity, 1% occupancy of pore space
Continental subsurface (Whitman et al.[2])	**2.5×10^{29}**	86	22	8–4,000 m	Arithmetic averages versus depth to 600 m; power fit with depth from 600 m to 4 km; DNA-stain counts as a function of depth
Continental subsurface (Whitman et al.[2])	**2.2×10^{30}**	86	189	8–4,000 m	Pore space occupancy model; 3% porosity, 0.016% occupancy of pore space
Continental subsurface (Whitman et al.[2])	**2.5×10^{30}**	86	215	8–4,000 m	Groundwater-based model; 9.5×10^{21} cm^3 groundwater volume, correction factor = 1,723
Continental subsurface (Onstott et al.[8])	**5.4×10^{29}**	100	54	1–4,000 m	Power fit with depth; DNA-stain counts as a function of depth
Continental subsurface (McMahon and Parnell[12])	**5.2×10^{29}** **5.2×10^{30}**	26	13.5 135	Up to 2,000 m depth	Groundwater-based model; 10^{22} cm^3 groundwater volume, correction factor = 100–1,000
Continental subsurface (Bar-On et al.[13])	**2.4×10^{30}**	26	62	Up to 2,000 m depth	Groundwater-based model; 2.3×10^{25} cm^3 groundwater volume, correction factor = 300
Sub-seafloor sediments (Parkes et al.[11])	**8.7×10^{29}**	65	56	Up to 500 mbsf	Power fit with depth; DNA-stain counts as a function of depth
Sub-seafloor sediments (Whitman et al.[2])	**3.6×10^{30}**	86	305	0.1–2,000 m	Arithmetic averages versus depth to 600 m; power fit with depth from 600 m–2 km; DNA-stain counts as a function of depth
Sub-seafloor sediments (Lipp et al.[15])	5×10^{30}	18	**90**	Seafloor sediment volume	Power fit relating total organic carbon to intact polar lipids; 1.93×10^{23} cm^3 of sediment
Sub-seafloor sediments (Kallmeyer et al.[7])	**2.9×10^{29}**	14	4	0.1 m to basement or 4,000 m	Regionally aware power fit with depth; *A* and *B* of power law function were estimated for 1° × 1° grid of ocean as a function of sedimentation rate and distance from land
Sub-seafloor sediments (Parkes et al.[10])	**5.4×10^{29}**	*14*	*7.6*	Up to 500 mbsf	Power fit with depth; DNA-stain counts as a function of depth
Sub-seafloor sediments (Bar-On et al.[13])	**4×10^{29}**	24	10	All seafloor sediments below 0.1 m depth	Geometric mean of Kallmeyer et al.[7] and Parkes et al.[10]
Oceanic crust (Heberling et al.[14])	*1×10^{31}*	*21*	**210**	0 m to 120 °C isotherm	Pore space occupancy model; 5%, 2% and 1% porosities, 0.016%, 0.0016% and 0.00016% pore occupancies for pillow lavas, dikes, and gabbros, respectively
Oceanic crust (Bar-On et al.[13])	**2×10^{28}** **2×10^{29}**	25	0.55.2	0–5,000 m	Groundwater (basement fluid)-based model; 2×10^{22} cm^3 fluid volume, 10^4 cells cm^{-3}, correction factor = 100–1,000
Aquatic habitats (Whitman et al.[2])	1.2×10^{29}	10 (sedimentary) 20 (planktonic)	2.2	N.A.	Regionally aware estimate
Aquatic habitats (Bar-On et al.[13])	1.2×10^{29}	11	**1.3**	N.A.	Binned cell concentrations with depth; based on refs [81–84]
Soil (Whitman et al.[2])	**2.6×10^{29}**	100	26	0–8 m	Regionally aware function with depth; DNA-stain counts as a function of depth
Soil (Bar-On et al.[13])	*3.8×10^{29}* *2.6×10^{29}*	*21* *31*	**8**	N.A.	Soil biomass - fungal biomass; based on refs [85–87]
Animal hosts (Kieft and Simmons[88])	$2.1–2.3\times10^{25}$	*100*	*0.002*	N.A.	Allometric model; DNA-stain counts versus animal mass

Numbers in bold are the reported basis of the biomass estimate. Numbers in italic were not reported in the cited publication but are used in this table for comparison purposes. mbsf, metres below seafloor; N.A., not applicable.



Magnabosco, C., Lin, L. H., Dong, H., Bomberg, M., Ghiorse, W., Stan-Lotter, H., ... & Onstott, T. C. (2018). The biomass and biodiversity of the continental subsurface. *Nature Geoscience*, *11*(10), 707-717.

Deep Subsurface Environments

Deep Subsurface

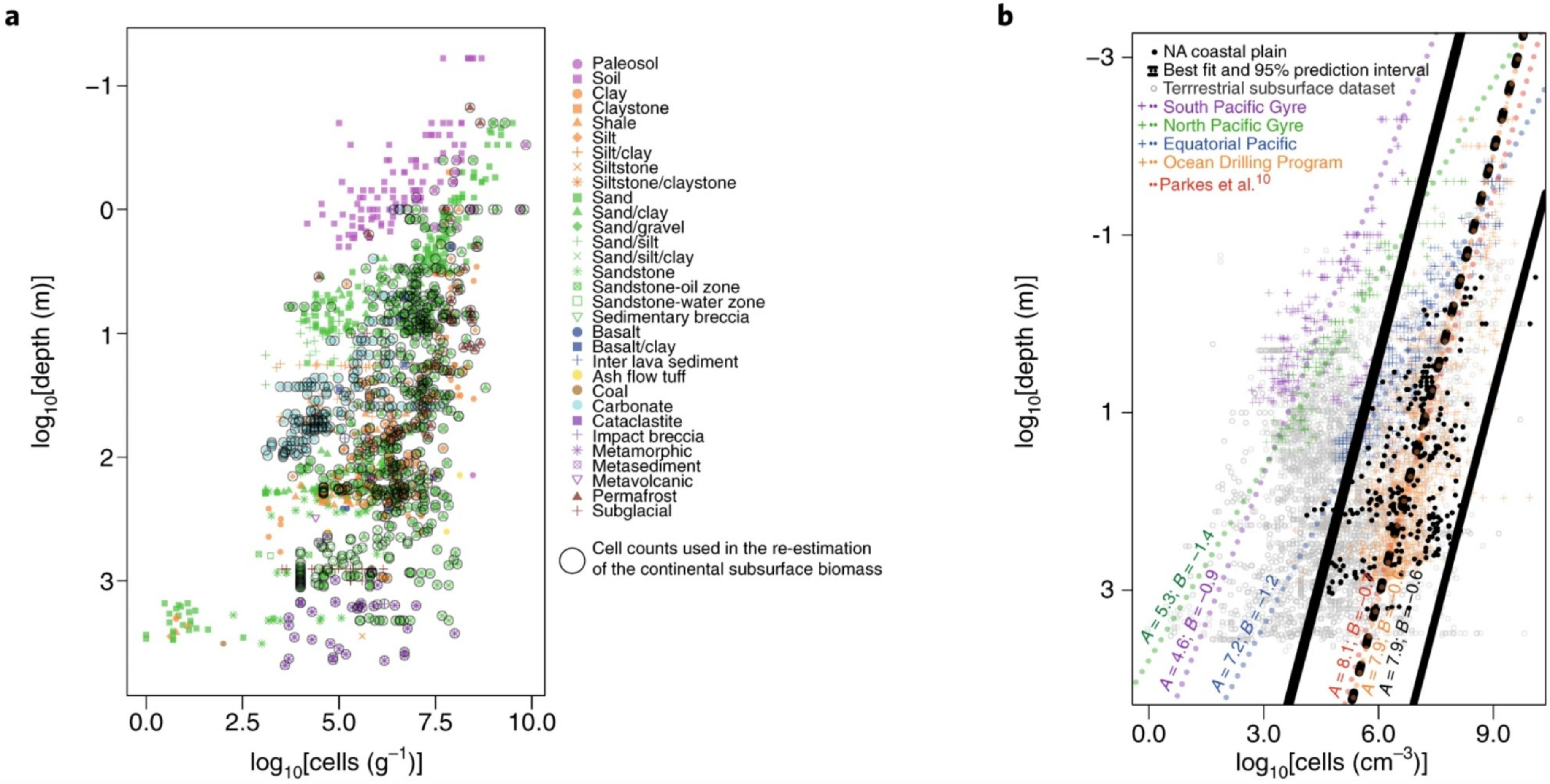
Marine Environment

the region that is not bioturbated by animals

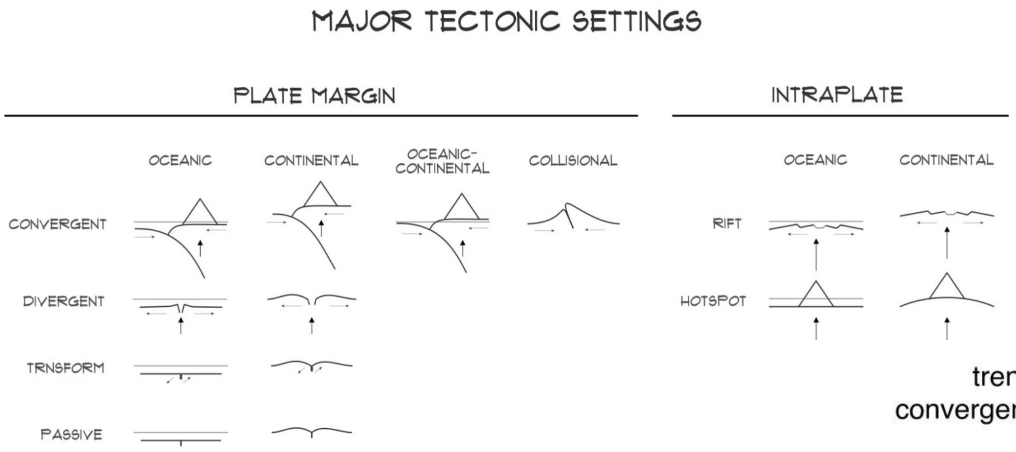
Continental Environment

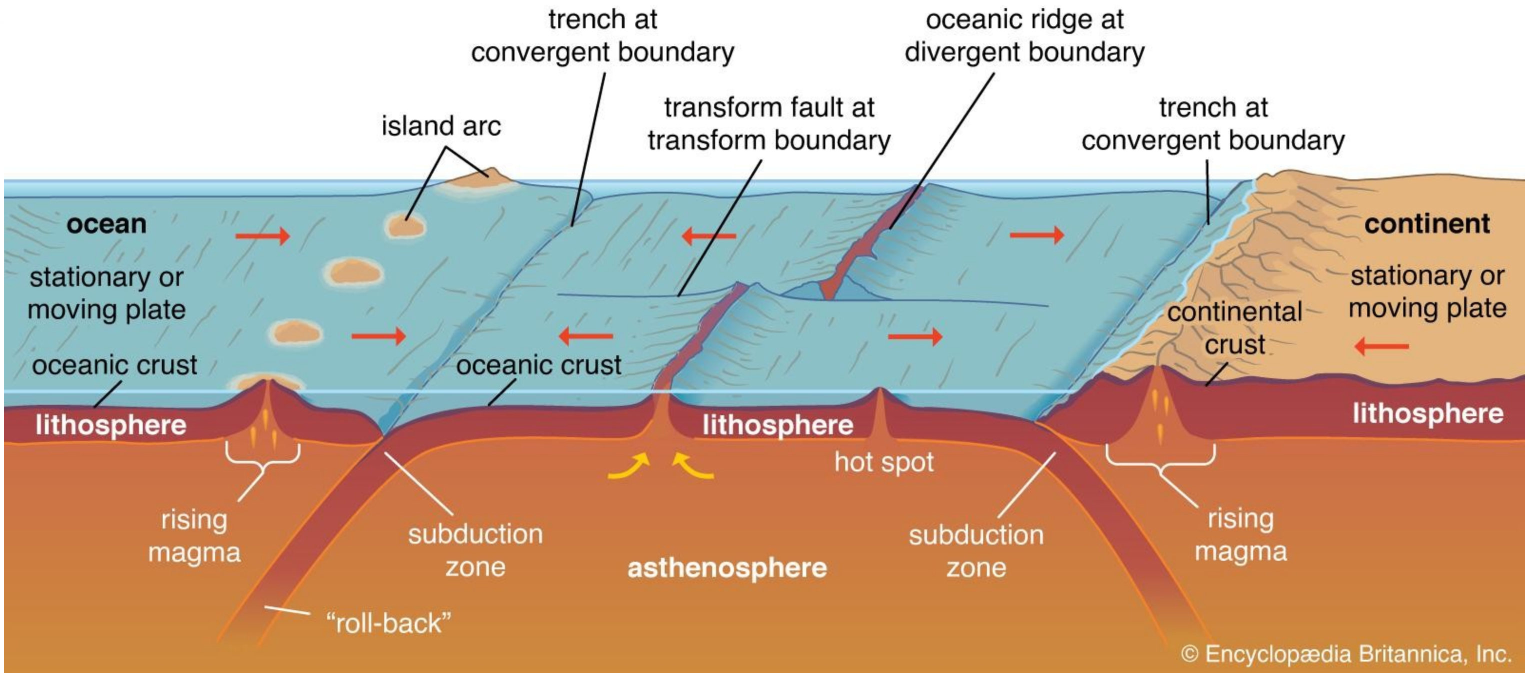
it is below a few meters, not including soils

Deep Subsurface Environments



Deep Subsurface Environments



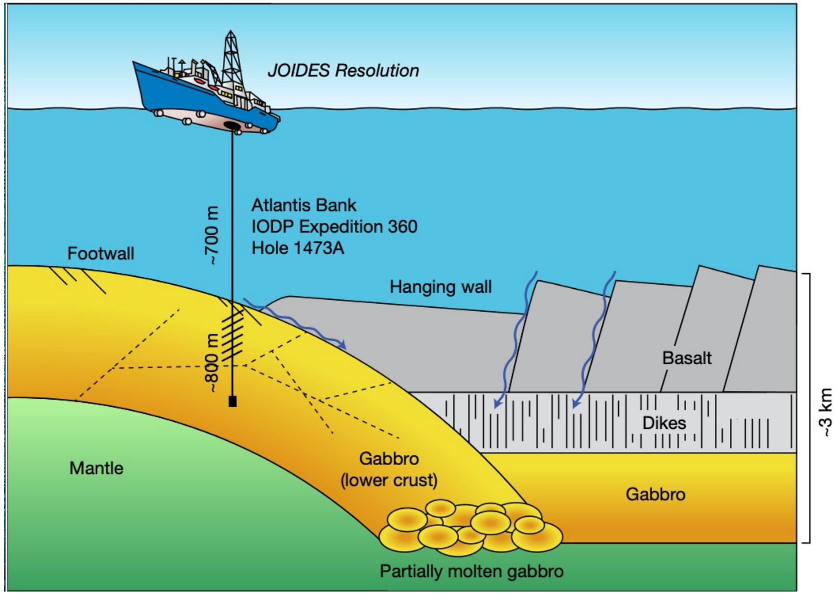


Marine Subsurface Environments: Oceanic Crust

Oceanic crust is about 6 km thick, composed of several layers and doesn’t include the overlying sediment. It comprises the largest aquifer system on Earth, with an estimated fluid volume of roughly 2% of the total ocean.

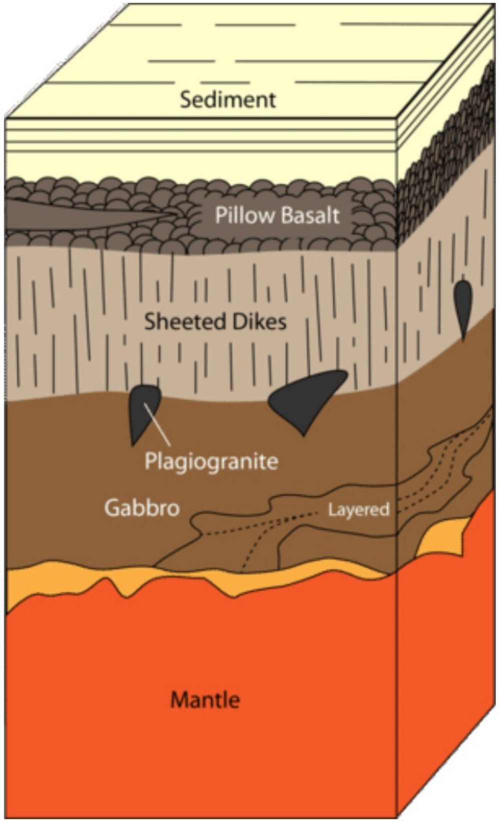
Oceanic crust differs from [continental crust]() in several ways: it is thinner, denser, younger, and has a different chemical composition.

Nearly 70% of the ocean seafloor is exposed or shallowly buried (100 m of sediment) oceanic crust.



IODP
INTERNATIONAL OCEAN
DISCOVERY PROGRAM

Oceanic Crust



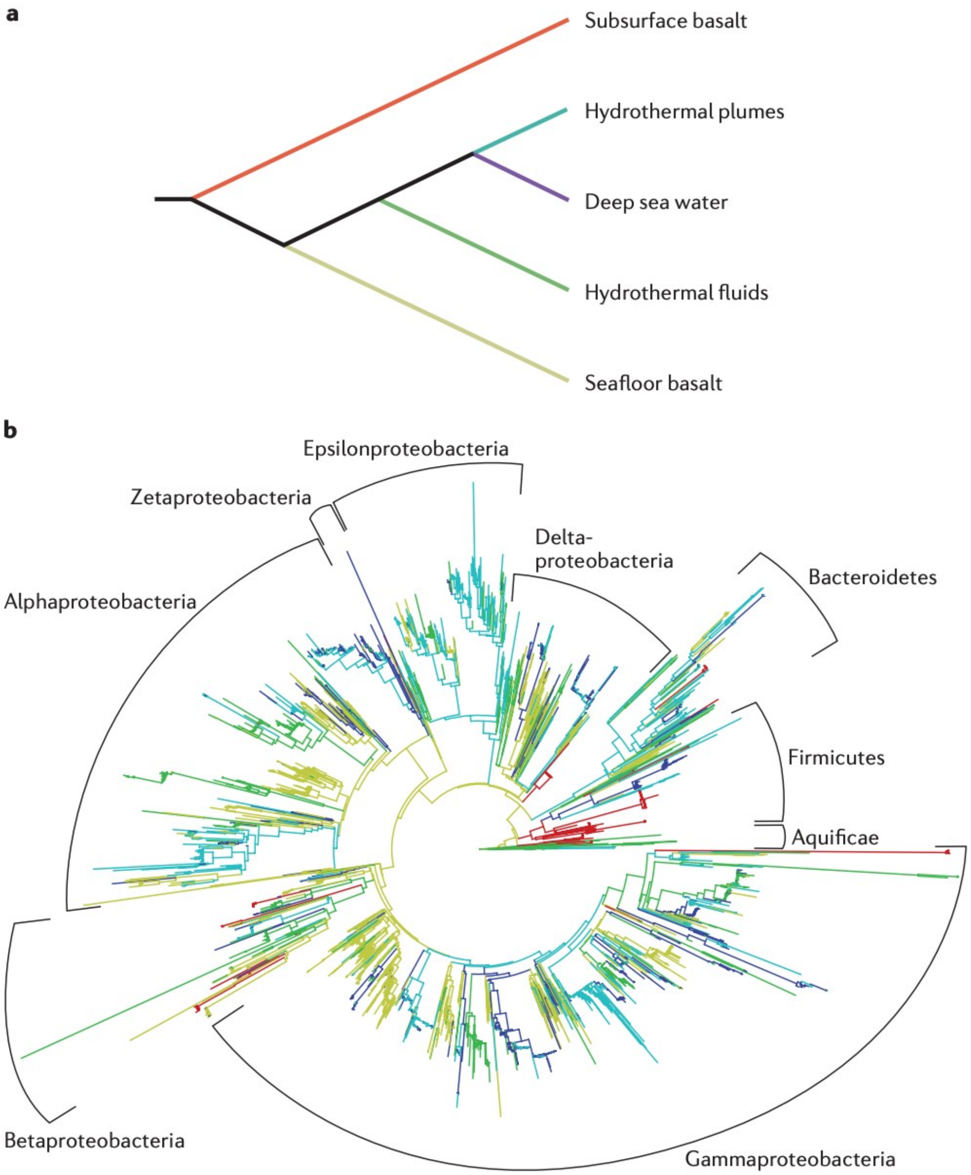
It has three layers:

- few hundred meters of extrusive and intrusive basalts, characterized by extensive fracturing, roughly 10% porosity;
- a middle layer down to roughly 1.5 km below seafloor of sheeted dike complexes;
- a deeper layer to roughly 4-km depth of igneous crystalline gabbroic rock.

The basalt porosity tends to decrease with age of the ocean crust as fractures are filled in by compression or mineral precipitation, although there are exceptions.

Marine subsurface Environments

Bacterial communities on seafloor basalts are often dominated by the phyla *Proteobacteria* (in particular, the classes *Alphaproteobacteria* and *Gammaproteobacteria*), *Actinobacteria, Bacteriodetes, Chloroflexi, Firmicutes* and *Planctomycetes*.



Edwards, K. J., Wheat, C. G., & Sylvan, J. B. (2011). Under the sea: microbial life in volcanic oceanic crust. *Nature Reviews Microbiology*, *9*(10), 703-712.

Marine subsurface Environments

Basalt:

- roughly 9% FeO [Fe(II)]
- 0.1% each MnO and S

Metabolic reactions involving these compounds are likely candidates for supporting lithotrophic activity in oceanic crust

Marine subsurface Environments

Basalt:

- roughly 9% FeO [Fe(II)]
- 0.1% each MnO and S

Metabolic reactions involving these compounds are likely candidates for supporting lithotrophic activity in oceanic crust

- **Fe oxidation:** *alpha* (including *Hyphomonas* species)-, *gamma* (including *Marinobacter* species)- and *zetaproteobacteria* are potential candidates for mediating this proces;

Marine subsurface Environments

Basalt:

- roughly 9% FeO [Fe(II)]
- 0.1% each MnO and S

Metabolic reactions involving these compounds are likely candidates for supporting lithotrophic activity in oceanic crust

- **Fe oxidation:** *alpha* (including *Hyphomonas* species)-, *gamma* (including *Marinobacter* species)- and *zetaproteobacteria* are potential candidates for mediating this proces;
- **Fe(III)-reduction:** microorganisms, including *Shewanella frigimarina* and *Shewanella loihica*

Marine subsurface Environments

Basalt:

- roughly 9% FeO [Fe(II)]
- 0.1% each MnO and S

Metabolic reactions involving these compounds are likely candidates for supporting lithotrophic activity in oceanic crust

- **Fe oxidation:** *alpha* (including *Hyphomonas* species)-, *gamma* (including *Marinobacter* species)- and *zetaproteobacteria* are potential candidates for mediating this proces;
- **Fe(III)-reduction:** microorganisms, including *Shewanella frigimarina* and *Shewanella loihica*
- **Mn(II) oxidation:** The Bacillus genus (*Firmicutes*) is frequently identified Mn-oxidizing group. Other Mn oxidizers recovered from basalts include the genera *Marinobacter* and *Pseudoalteromonas* and the alphaproteobacterial genus *Sulfitobacter*, as well as *Actinobacteria* and some Gram-positive bacteria.

Marine subsurface Environments

Basalt:

- roughly 9% FeO [$Fe(II)$]
- 0.1% each MnO and S

Metabolic reactions involving these compounds are likely candidates for supporting lithotrophic activity in oceanic crust

- **Fe oxidation:** *alpha* (including *Hyphomonas* species)-, *gamma* (including *Marinobacter* species)- and *zetaproteobacteria* are potential candidates for mediating this proces;
- **Fe(III)-reduction:** microorganisms, including *Shewanella frigimarina* and *Shewanella loihica*
- **Mn(II) oxidation:** The Bacillus genus (*Firmicutes*) is frequently identified Mn-oxidizing group. Other Mn oxidizers recovered from basalts include the genera *Marinobacter* and *Pseudoalteromonas* and the alphaproteobacterial genus *Sulfitobacter*, as well as *Actinobacteria* and some Gram-positive bacteria.
- Species distantly related to **sulfate reducing** bacteria of the *Deltaproteobacteria* have been documented in basalt communities, but it is unclear if these species are sulfate reducers. Members of the *Epsilonproteobacteria*, commonly found in S-oxidizing environments, are detected infrequently in basalt microbial communities.

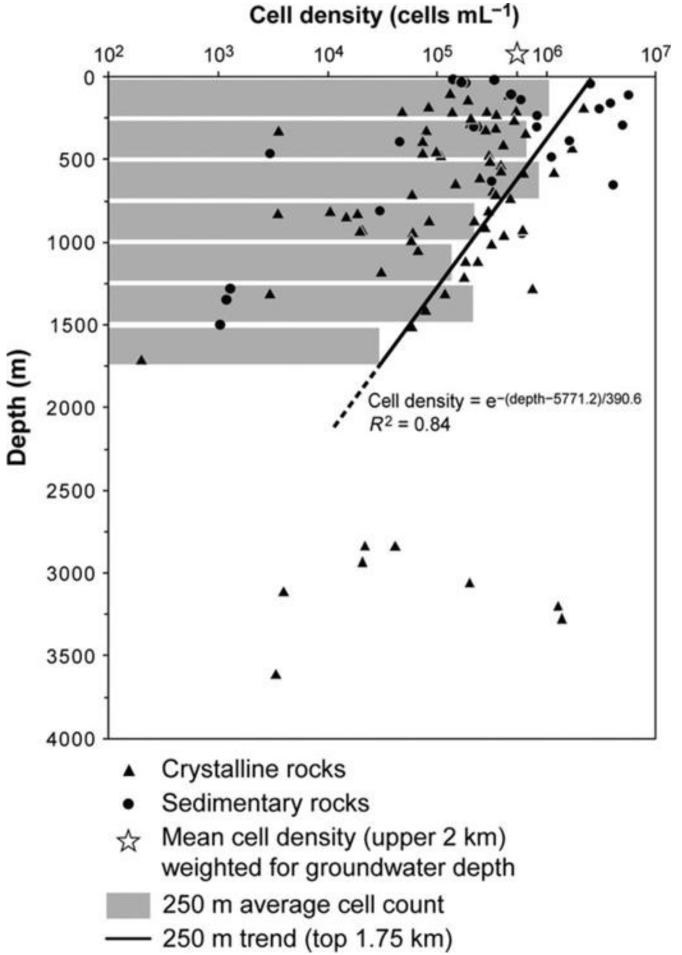
Continental subsurface Environments: Continental Crust

Continental crust is broadly granitic in composition and is somewhat lighter than oceanic crust , which is basaltic. Continental crust is typically 40 km thick, while oceanic crust is much thinner, averaging about 6 km in thickness.

Continental crust in much more heterogeneous than the oceanic one!

Continental subsurface Environments

Continental subsurface Environments

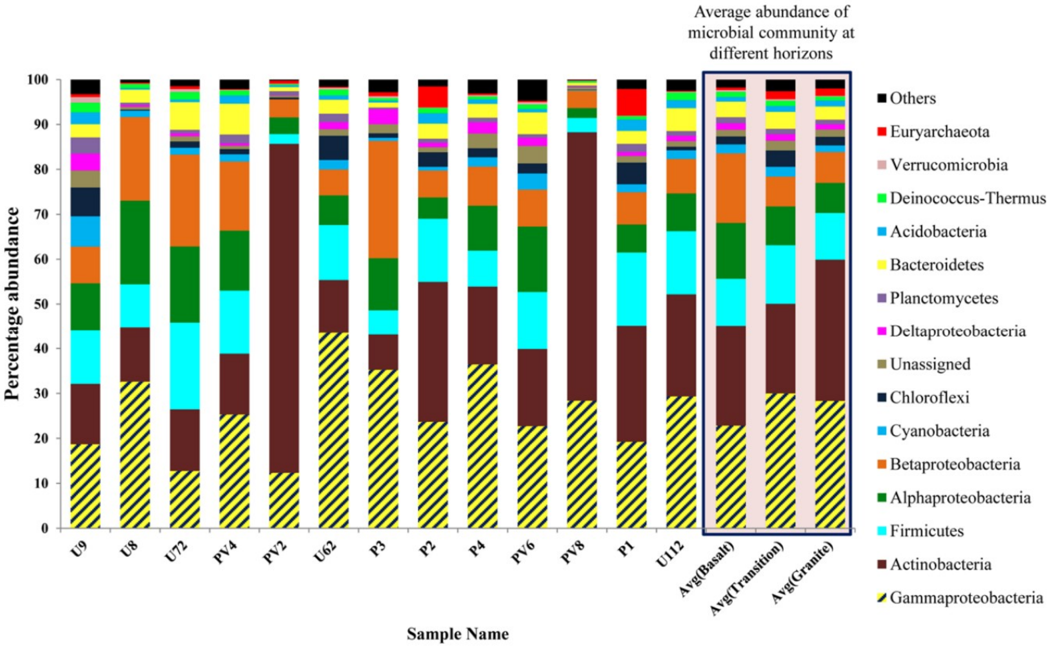


- Number and diversity of microorganisms decrease with depth.
- The abundance of Bacteria is superior to Archaea

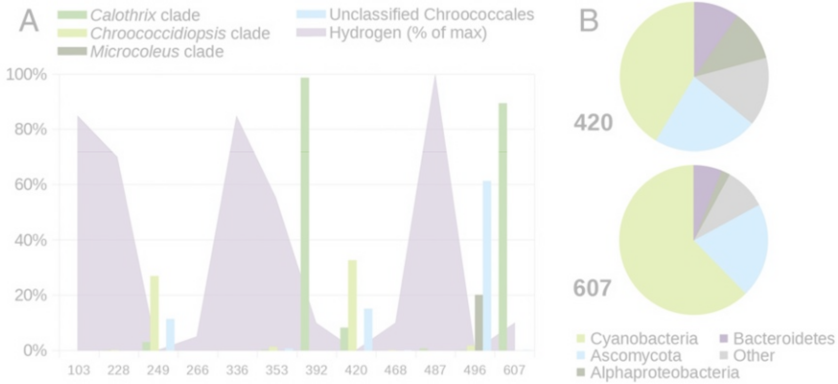
The microbial populations that have been described in different subsurface locations vary widely, even at different depths of the same borehole, which might be due to the geological and physicochemical heterogeneity of the studied systems as well as the origin of the water. This variability, together with the scarcity of studied sites and the different methodologies used, makes it difficult to compare existing geomicrobiological data to extract general rules for subsurface ecosystems.

McMahon, S., & Parnell, J. (2014). Weighing the deep continental biosphere. *FEMS Microbiology Ecology*, *87*(1), 113-120.

Continental subsurface Environments



Within Bacteria, the most commonly detected phyla correspond to *Proteobacteria, Actinobacteria, Bacteroidetes, and Firmicutes.* Within Archaea, methanogens are recurrently detected in most analyzed subsurface samples.

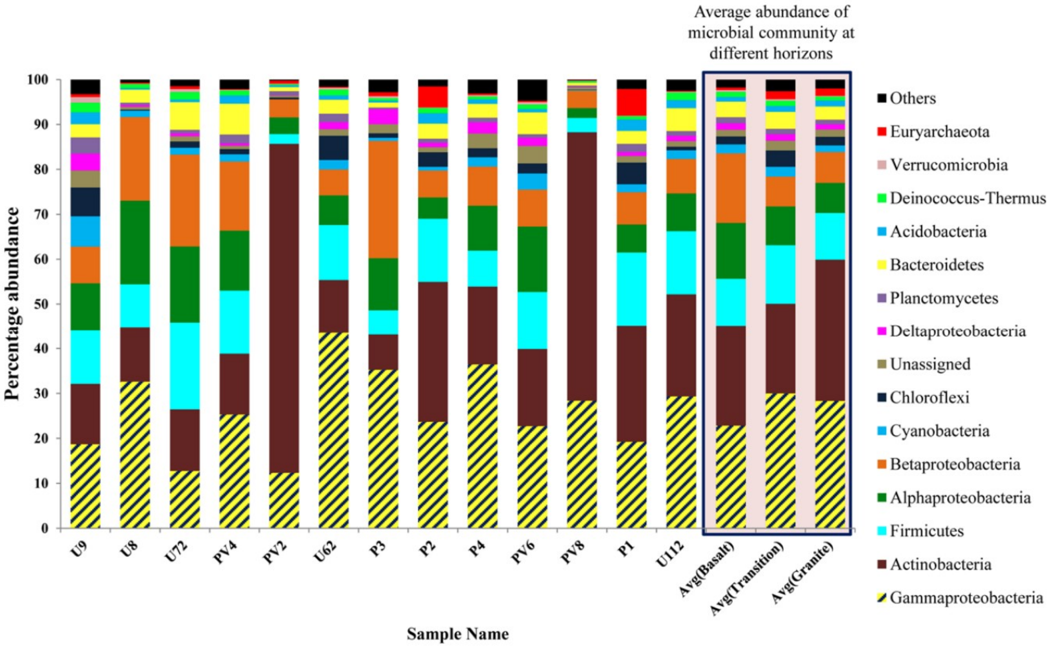


One of the great surprises has been the frequent appearance of sequences belonging to members of the phylum Cyanobacteria.

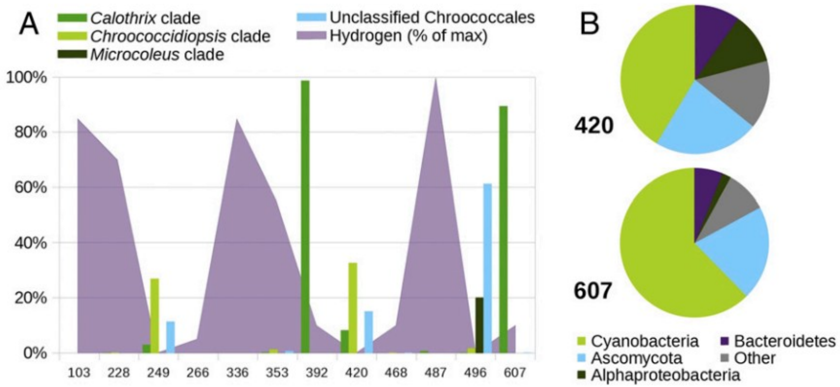
Dutta, A., Gupta, S. D., Gupta, A., Sarkar, J., Roy, S., Mukherjee, A., & Sar, P. (2018). *Scientific reports*, *8*(1), 1-16.

Puente-Sánchez, F., Arce-Rodríguez, A., Oggerin, M., García-Villadangos, M., Moreno-Paz, M., Blanco, Y., ... & Parro, V. (2018). *Proceedings of the National Academy of Sciences*, *115*(42), 10702-10707.

Continental subsurface Environments



Within Bacteria, the most commonly detected phyla correspond to *Proteobacteria, Actinobacteria, Bacteroidetes, and Firmicutes.* Within Archaea, methanogens are recurrently detected in most analyzed subsurface samples.



One of the great surprises has been the frequent appearance of sequences belonging to members of the phylum Cyanobacteria.

Dutta, A., Gupta, S. D., Gupta, A., Sarkar, J., Roy, S., Mukherjee, A., & Sar, P. (2018). *Scientific reports*, *8*(1), 1-16.

Puente-Sánchez, F., Arce-Rodríguez, A., Oggerin, M., García-Villadangos, M., Moreno-Paz, M., Blanco, Y., ... & Parro, V. (2018). *Proceedings of the National Academy of Sciences*, *115*(42), 10702-10707.

Continental subsurface Environments

Minerals are virtually the main source of substrates, either because they are biologically dissolved or because energy is released by abiotic processes. Thus, the available electron donors and acceptors are determined by the geological composition of the underground location.

H2 is one of the most commonly used molecules by chemolithoautotrophic microorganisms. Among these are the oxidation of reduced sulfur compounds, iron and nitrogen. In addition, other less common metabolisms have also been detected such as the oxidation of arsenic, manganese, or methane

Suggested reads

Merino et al 2019 Front Microbiol