GIOVANNELLI LAB

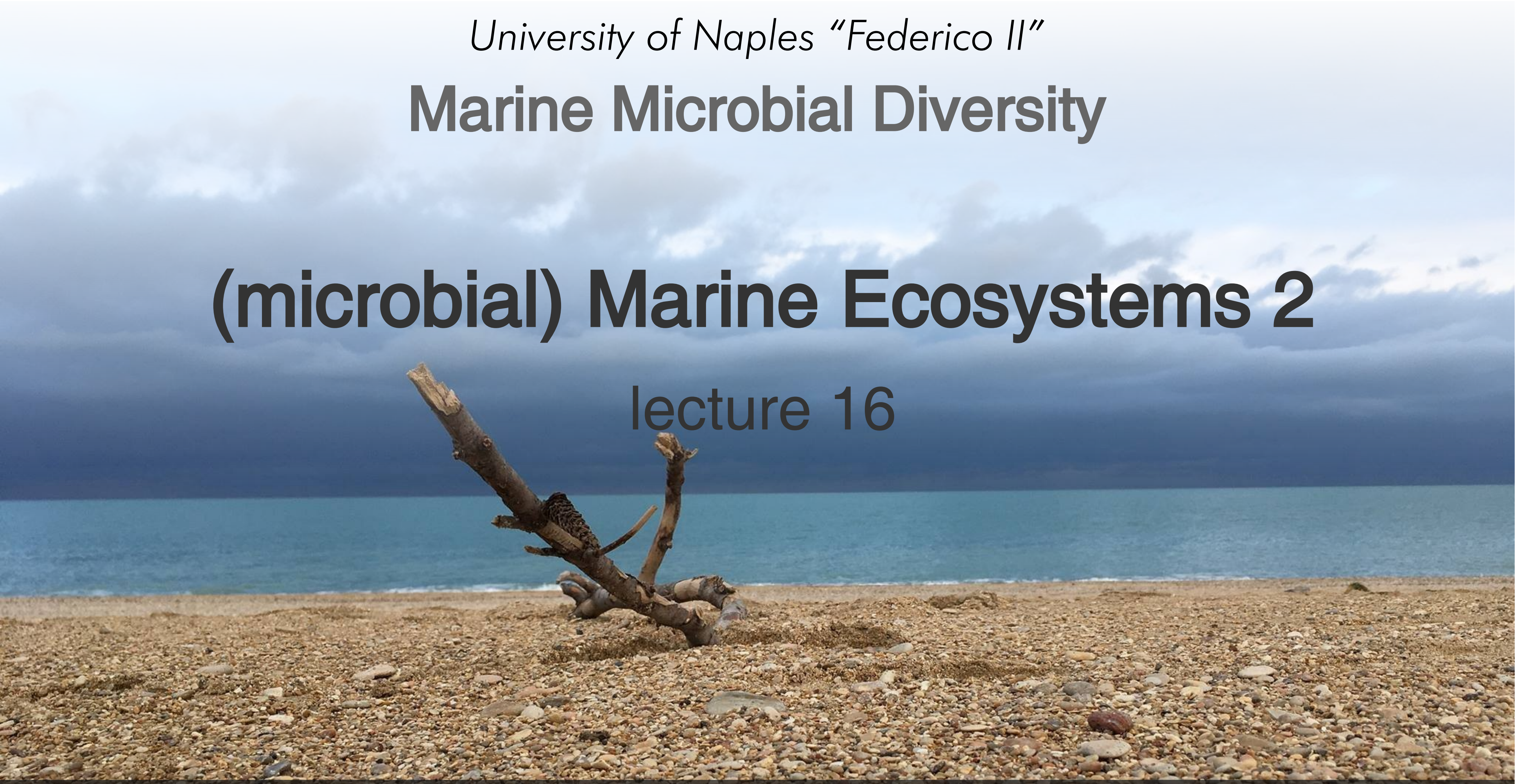
DIPARTIMENTO DI BIOLOGIA

University of Naples "Federico II"

Marine Microbial Diversity

(microbial) Marine Ecosystems 2

lecture 16



donato.giovannelli@unina.it • @d_giovannelli • http://dgiovannelli.github.io

Marine Sediments

Marine Sediments

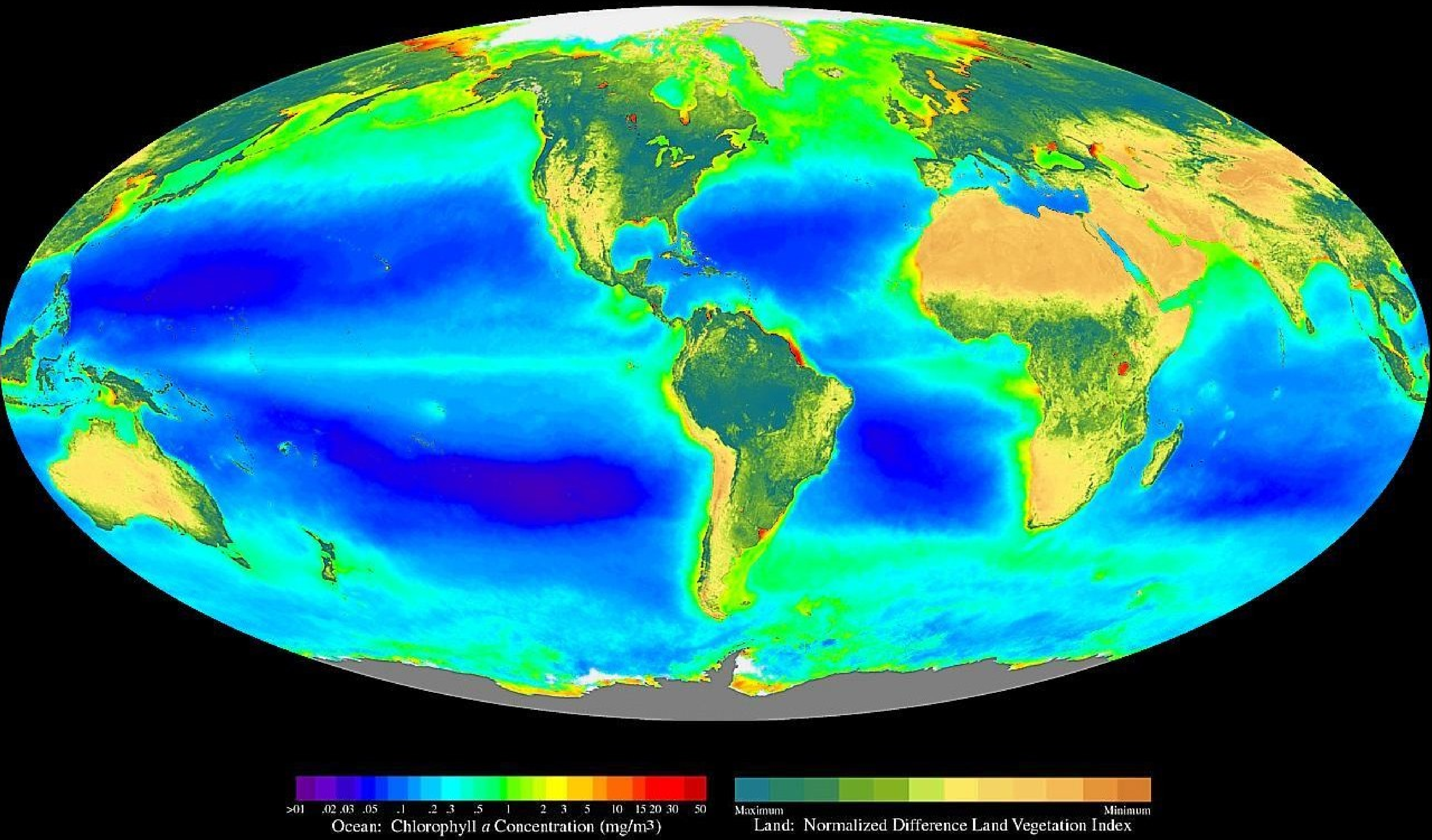
Marine sediments are the **largest oceanic biome** of our planet. They are an **integrated record** of the water column processes, the **interact with the water column** acting as a bioreactor through benthic boundary layer fluxes and act as the ultimate sink for nutrients and elements.

Surface sediments are defined from the benthic boundary layer to a depth of ca.15 cm.

The penetration of oxygen is influenced by the quantity of organic carbon, the microbial activity and the lithology (composition and grain size). All this influences the distribution across the surface sediments

The diversity of microorganism in surface marine sediment is higher than the water column and the average abundance is about 10 times higher (10^7 - 10^8 cells/g of sediment).

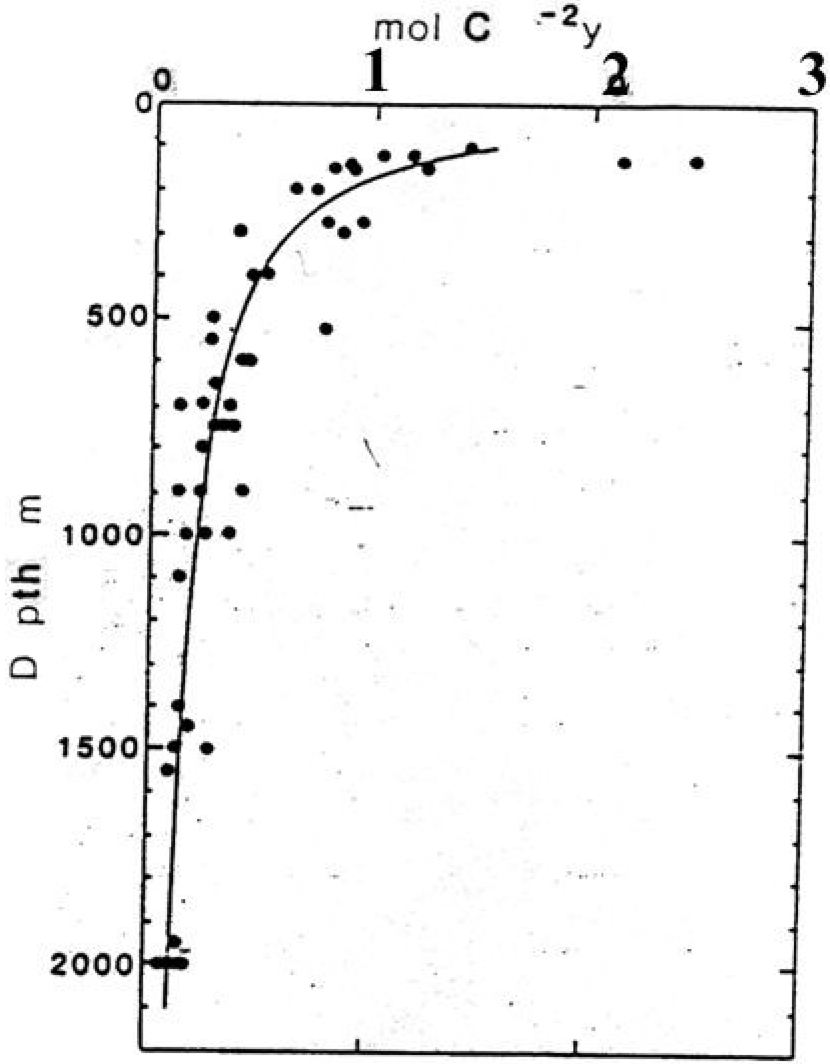
The majority of the community is involved in organic carbon cycling, both aerobic (in the surface) and anaerobic, with other major processes (nitrate reduction, ammonia oxidation, iron and methane cycling) happening at or below the surface.


>01 .02 .03 .05 .1 .2 .3 .5 1 2 3 5 10 15 20 30 50
Ocean: Chlorophyll a Concentration (mg/m3)
Maximum
Minimum
Land: Normalized Difference Land Vegetation Index

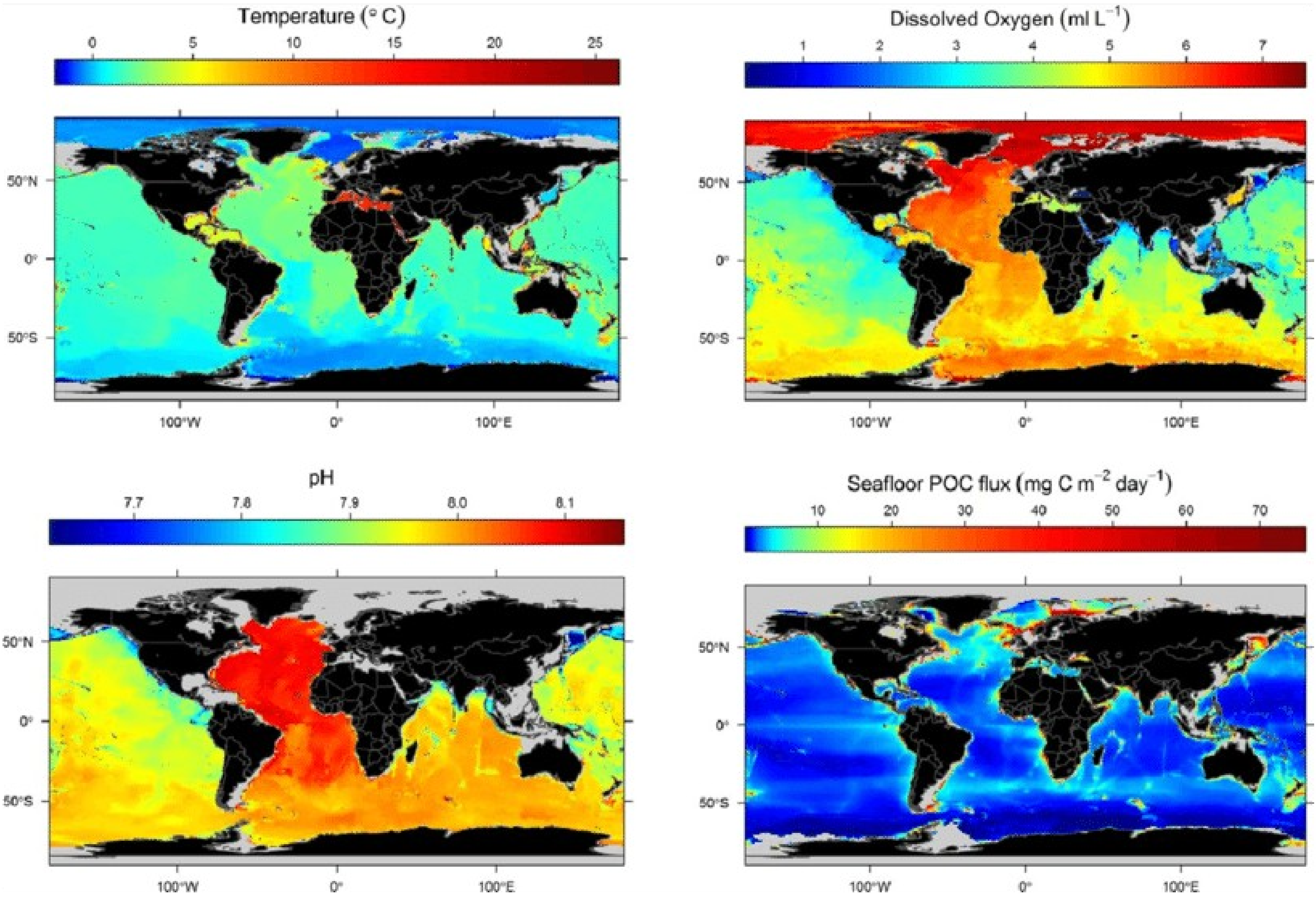
Reduction in Vertical Flux over Depth

The Martin Curve

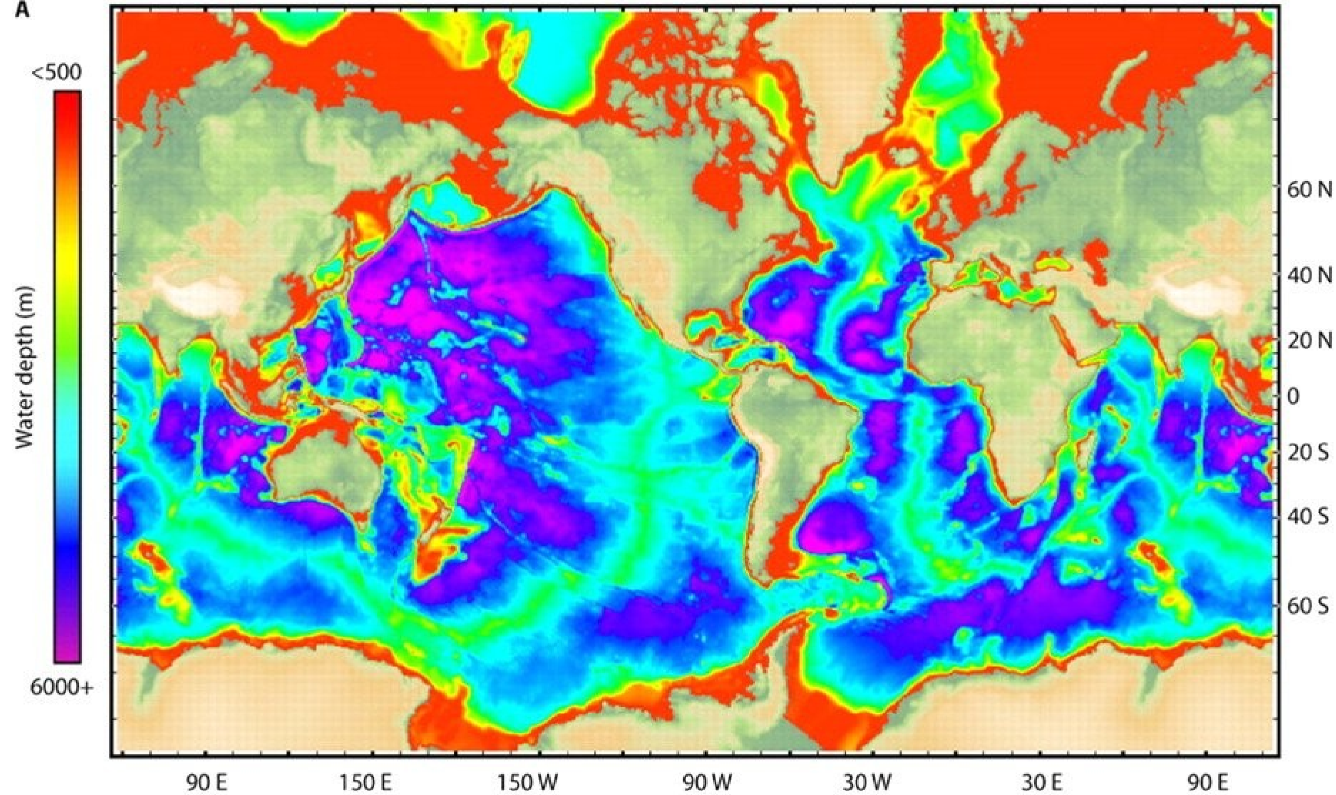
50% losses by 300 m
75% losses by 500 m
90% losses by 1500 m



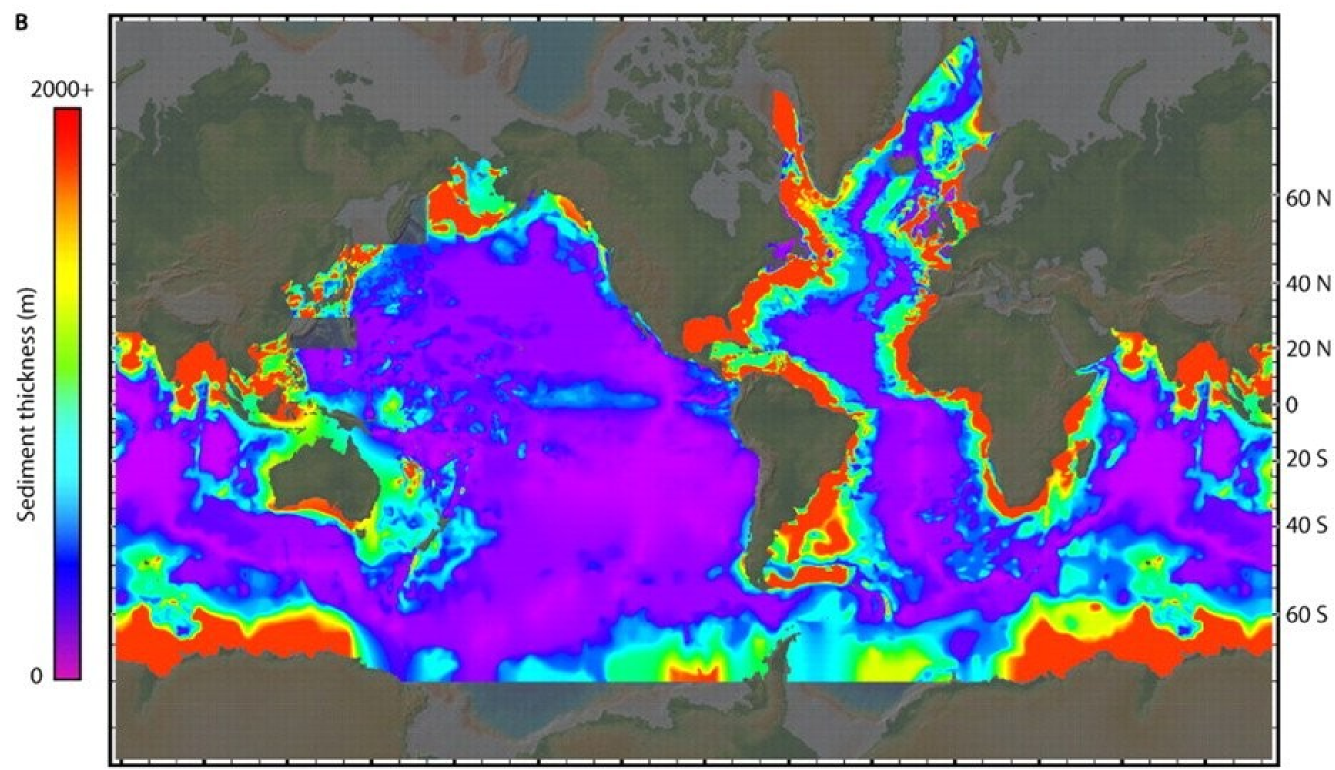
Martin and Knauer 1981

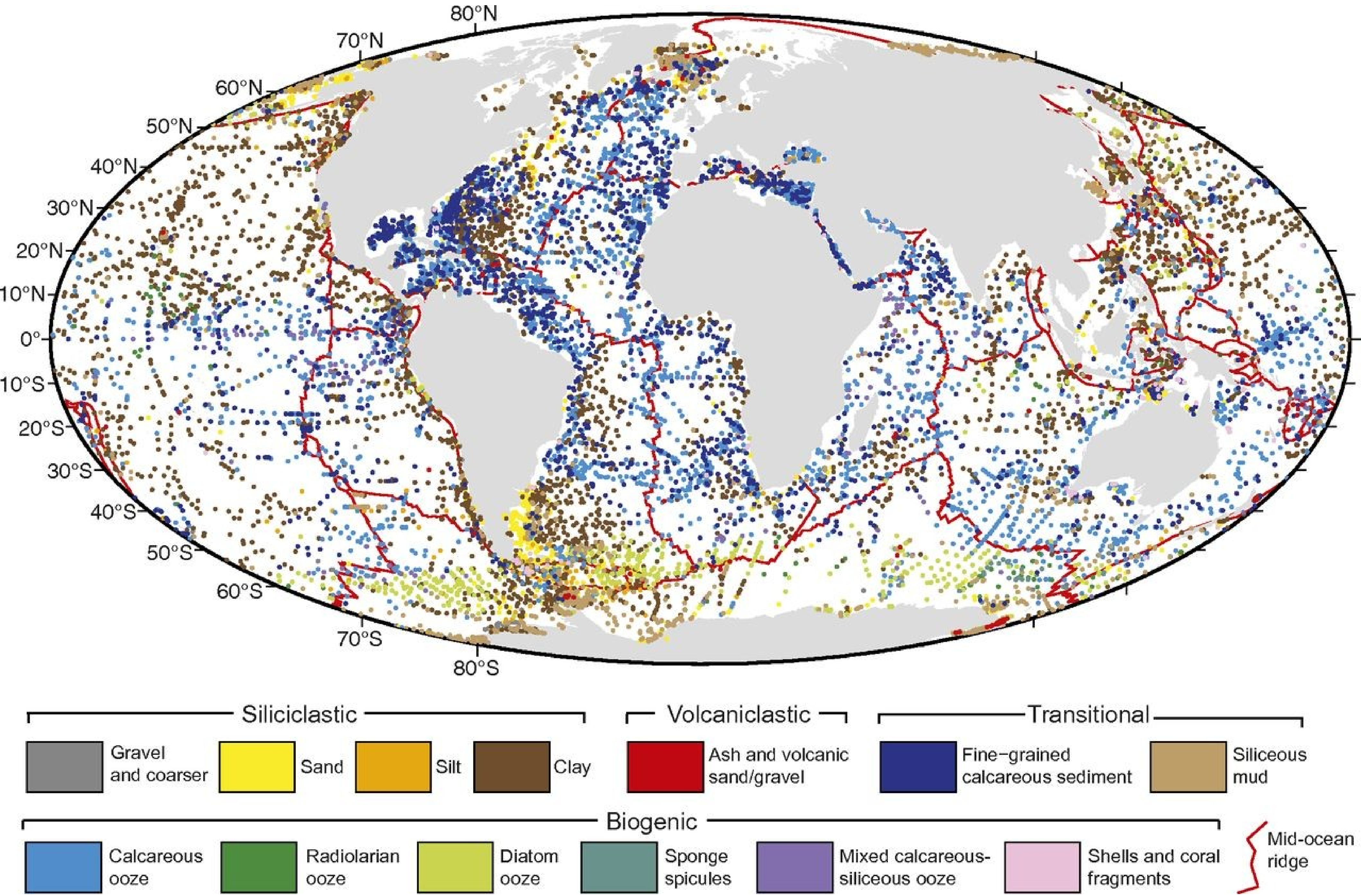

Temperature (° C)
0
5
10
15
20
25
Dissolved Oxygen (ml L^{-1})
1
2
3
4
5
6
7
pH
7.7
7.8
7.9
8.0
8.1
Seafloor POC flux (mg C m^{-2} day^{-1})
10
20
30
40
50
60
70
50°N
0°
50°S
100°W
0°
100°E

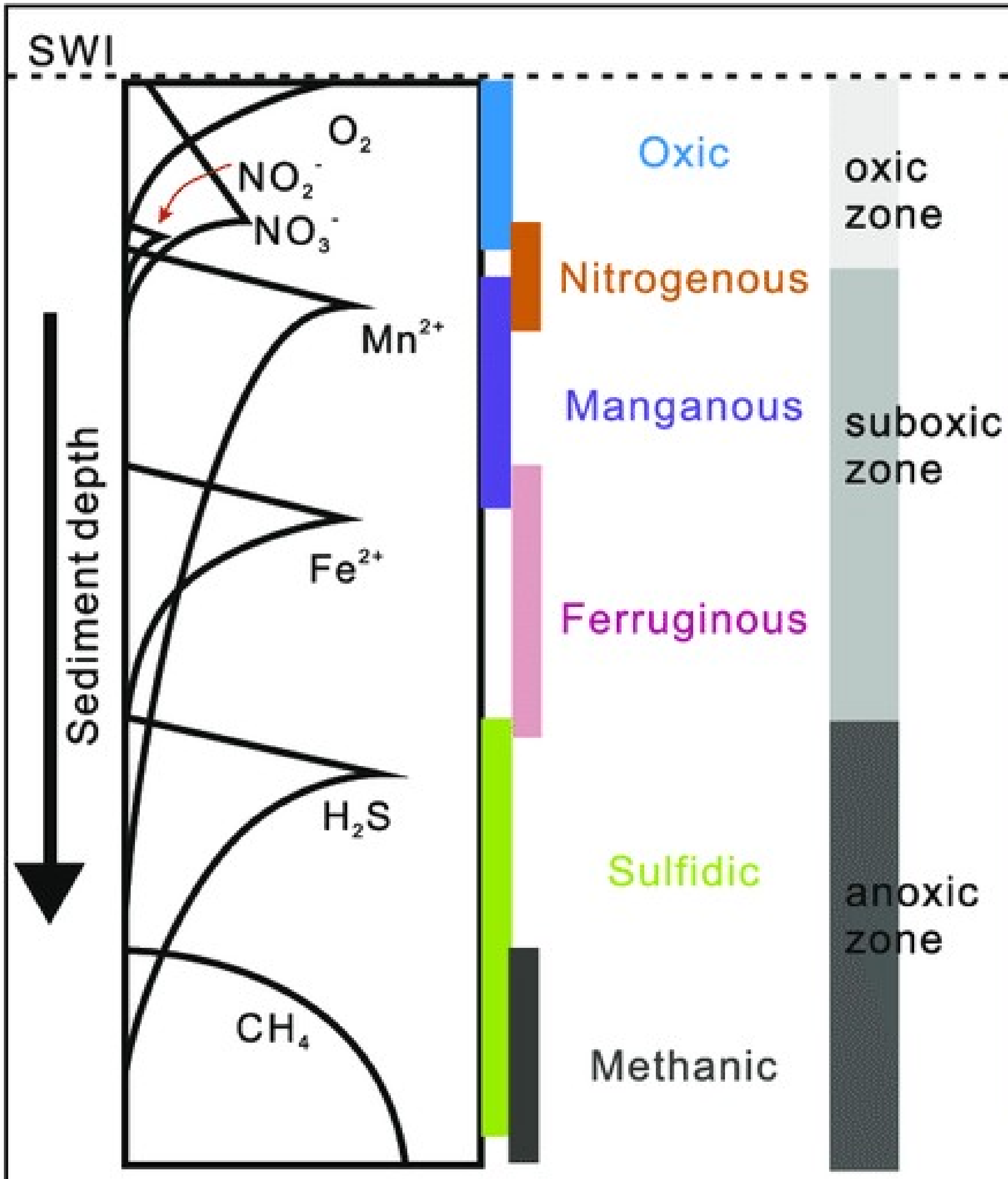
Water depth (m)



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



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:

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

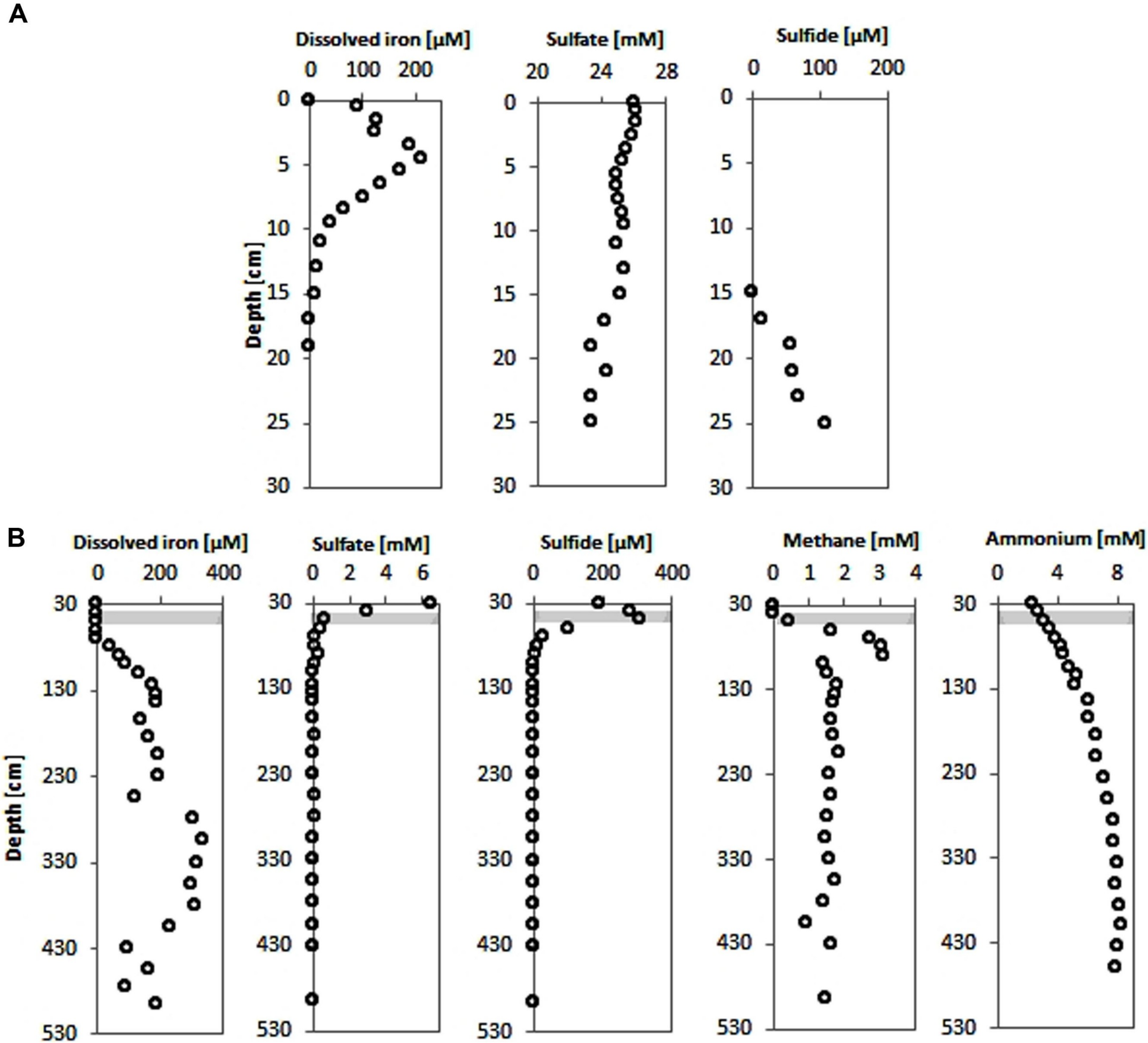
Sulfate reduction:

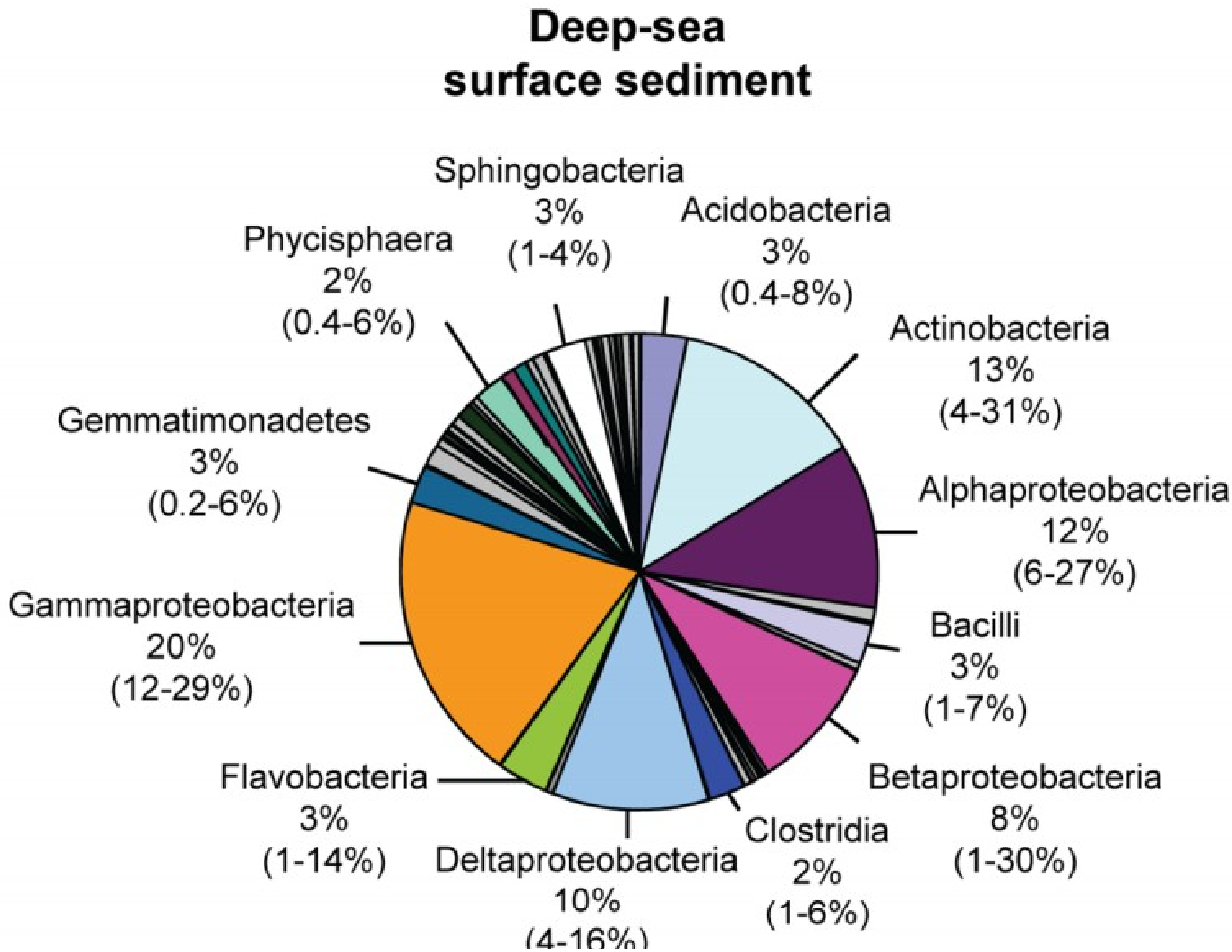
$$H^+ + SO_4^{2-} + C_2H_3O_2^- \rightarrow H_2S + 2HCO_3^-$$

Methanogenesis:

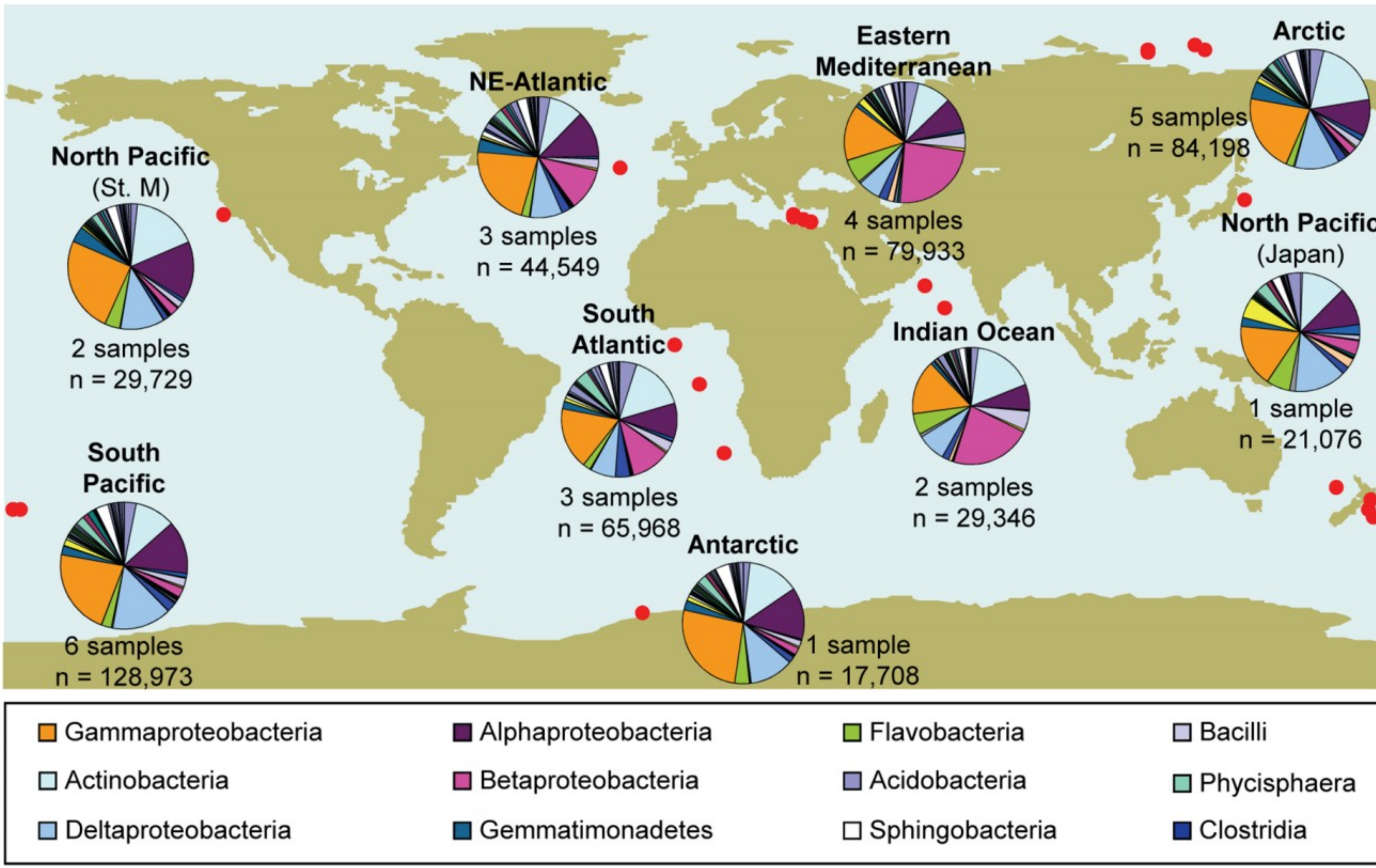
$$H_2O + C_2H_3O_2^- \rightarrow CH_4 + HCO_3^-$$

Algeo et al. 2015 PNAS


A
Dissolved iron [µM]
0 100 200
Sulfate [mM]
20 24 28
Sulfide [µM]
0 100 200
Depth [cm]
0 5 10 15 20 25 30
B
Dissolved iron [µM]
0 200 400
Sulfate [mM]
0 2 4 6
Sulfide [µM]
0 200 400
Methane [mM]
0 1 2 3 4
Ammonium [mM]
0 4 8
Depth [cm]
30 130 230 330 430 530



Bienhold et al. 2016 Plos ONE



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

Bienhold et al. 2016 Plos ONE

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

The marine subsurface environments appear to be less diverse in term of habitat diversity compared to the terrestrial subsurface, and it is mainly divide in sedimentary habitats and crustal environments

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

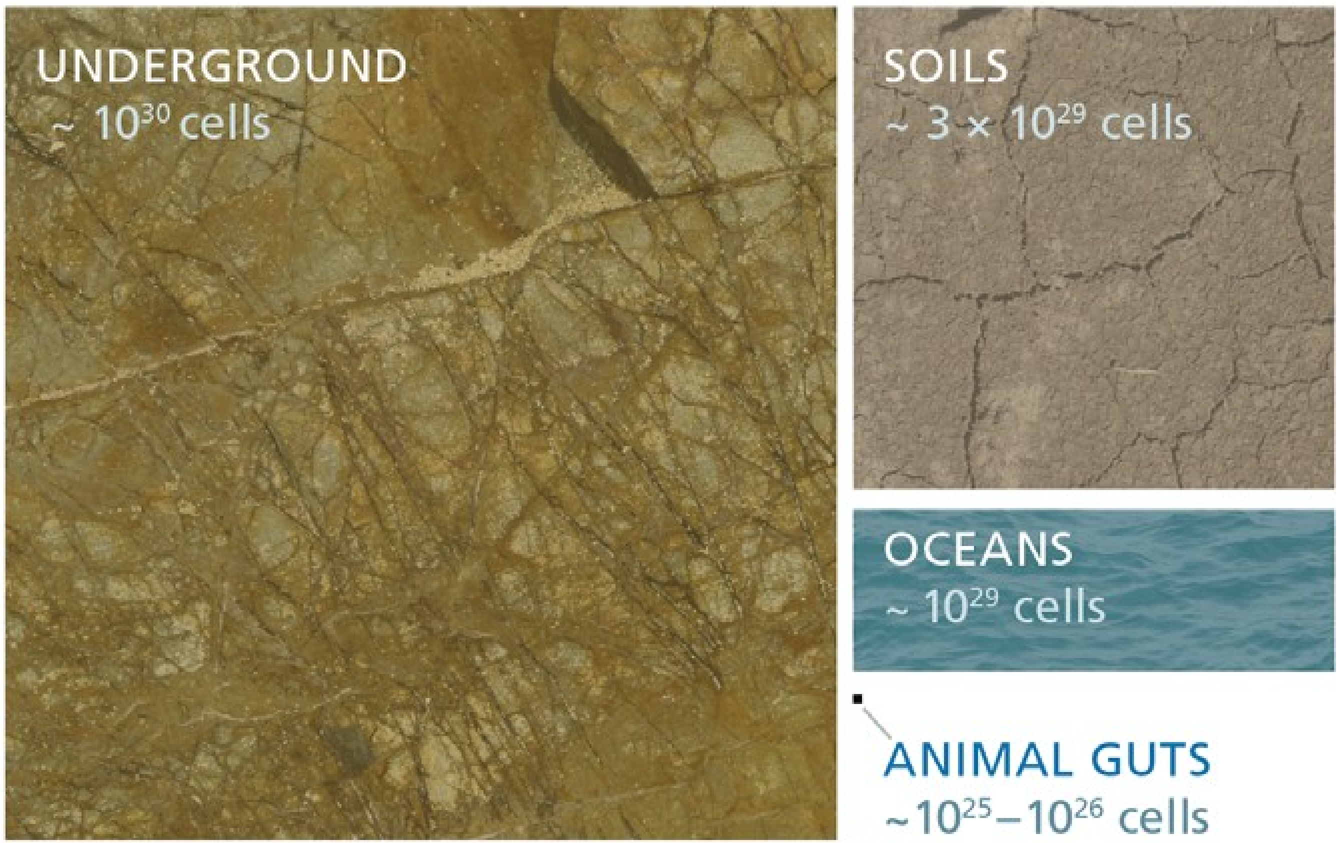
Gold, 1992 PNAS


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

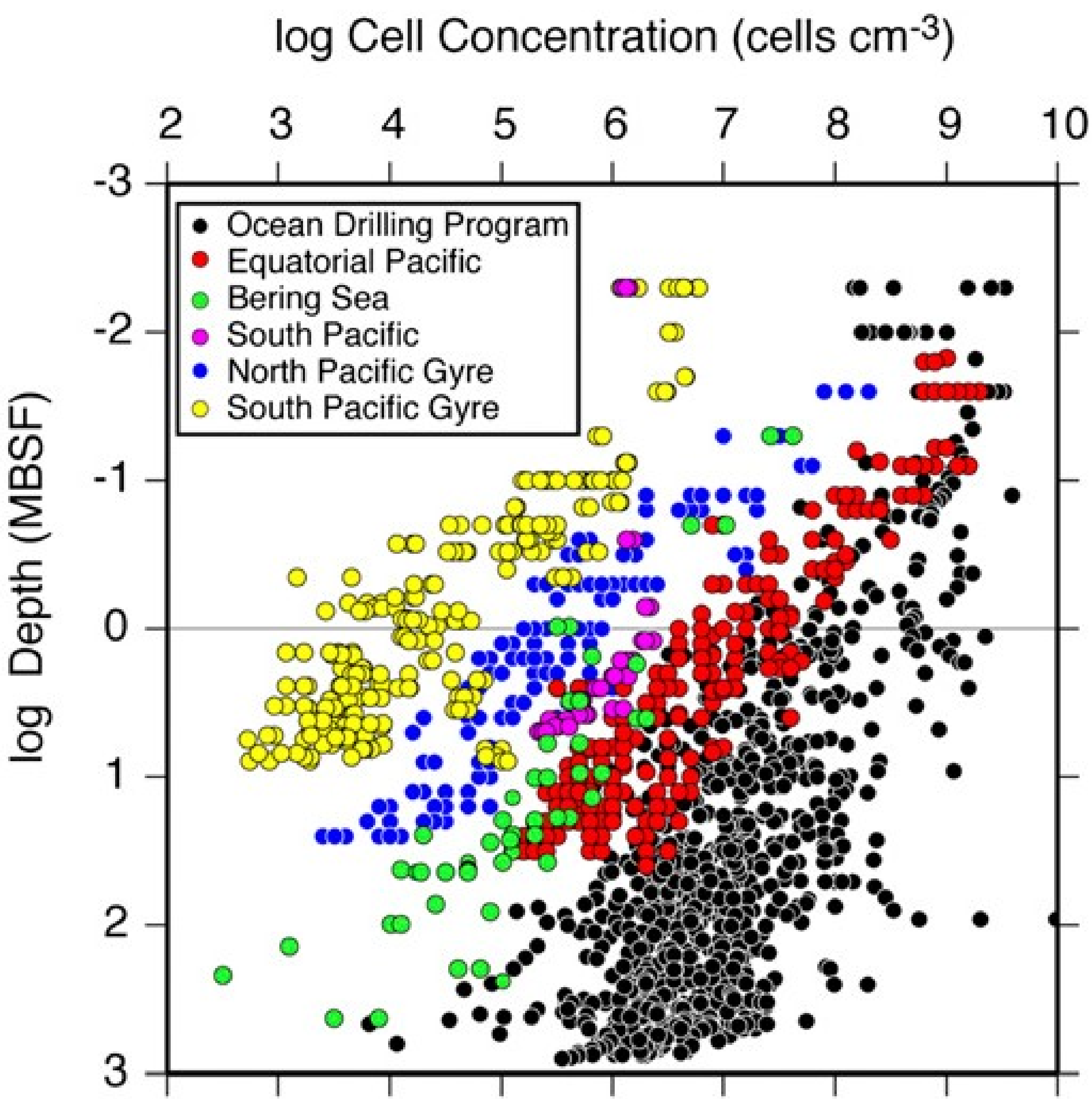
ICDP Oman Drilling Site – Deep Carbon Observatory

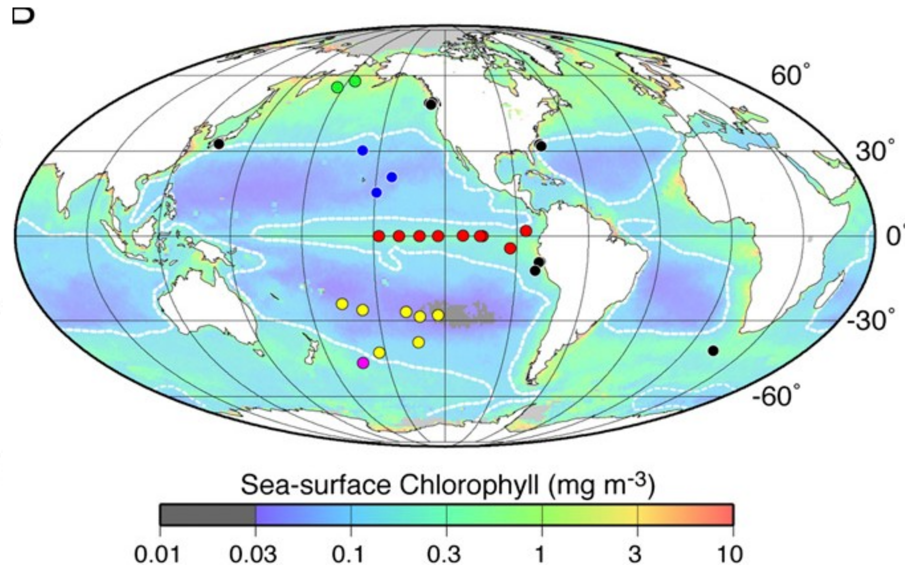

2.4 km Deep Canadian Mine – Deep Carbon Observatory

Number of Prokaryotes

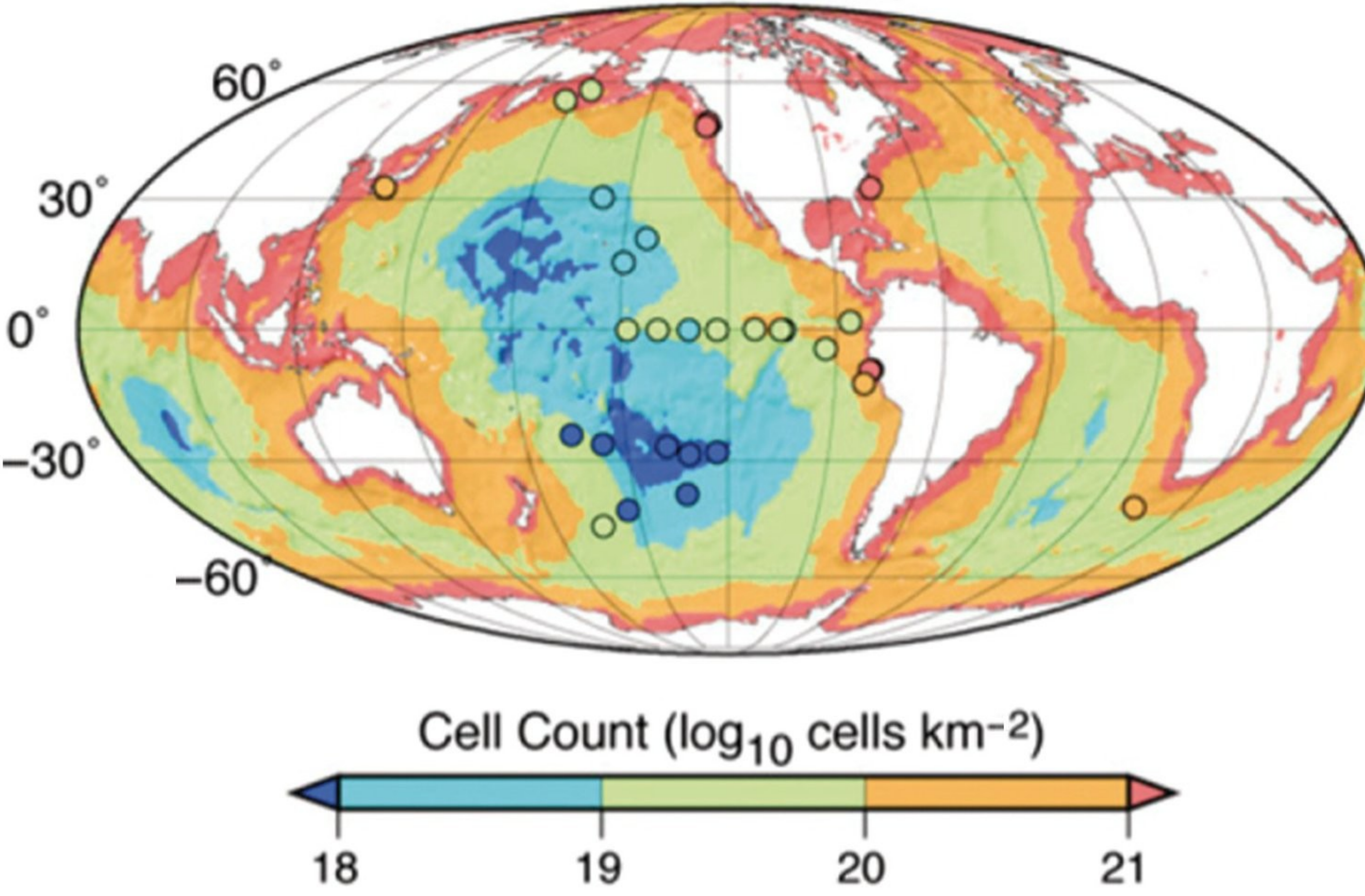


Magnabosco et al. 2019 in Deep Carbon Past to Present





Kallmeyer et al. 2012 PNAS



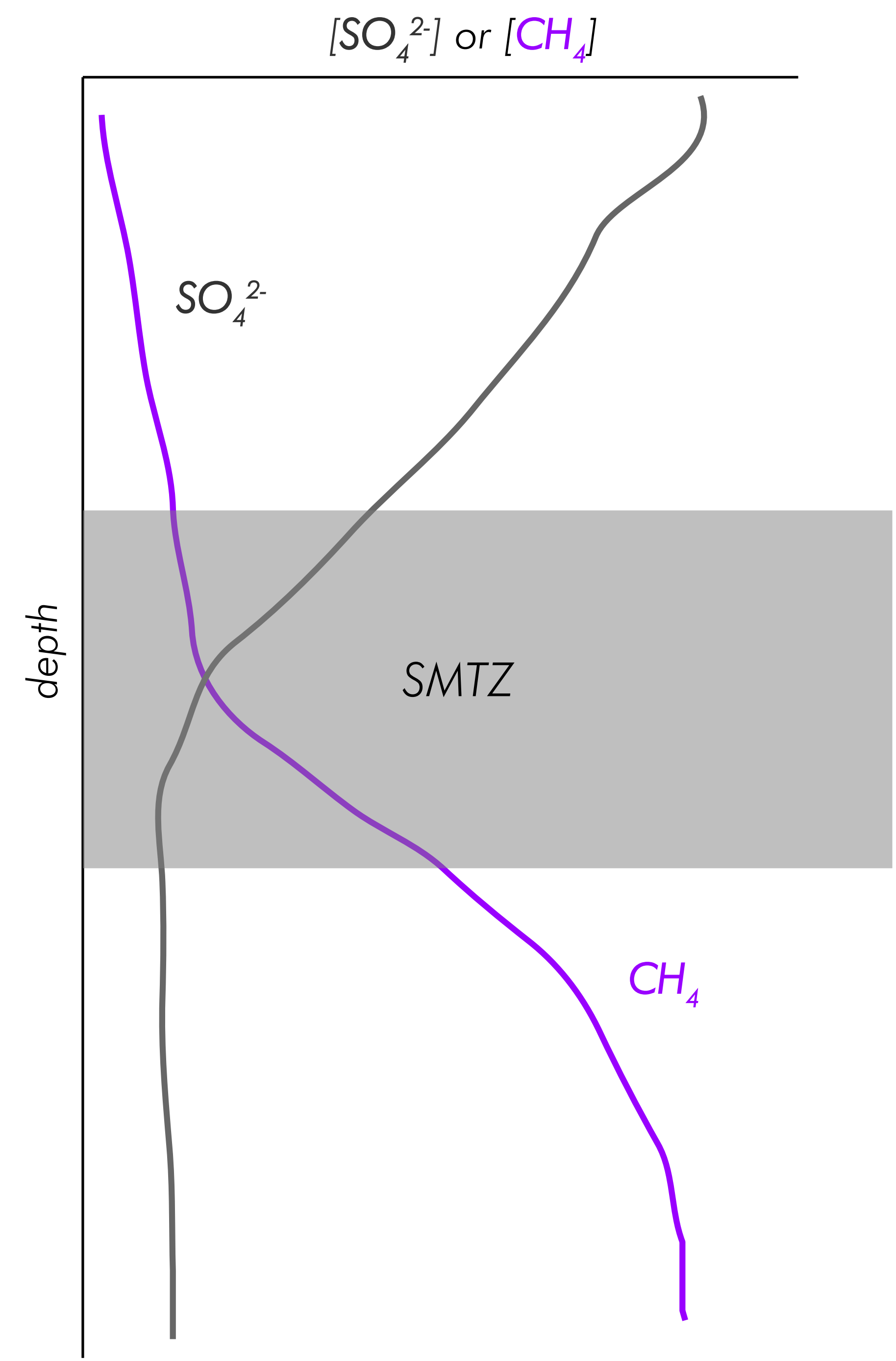
Kallmeyer et al. 2012 PNAS

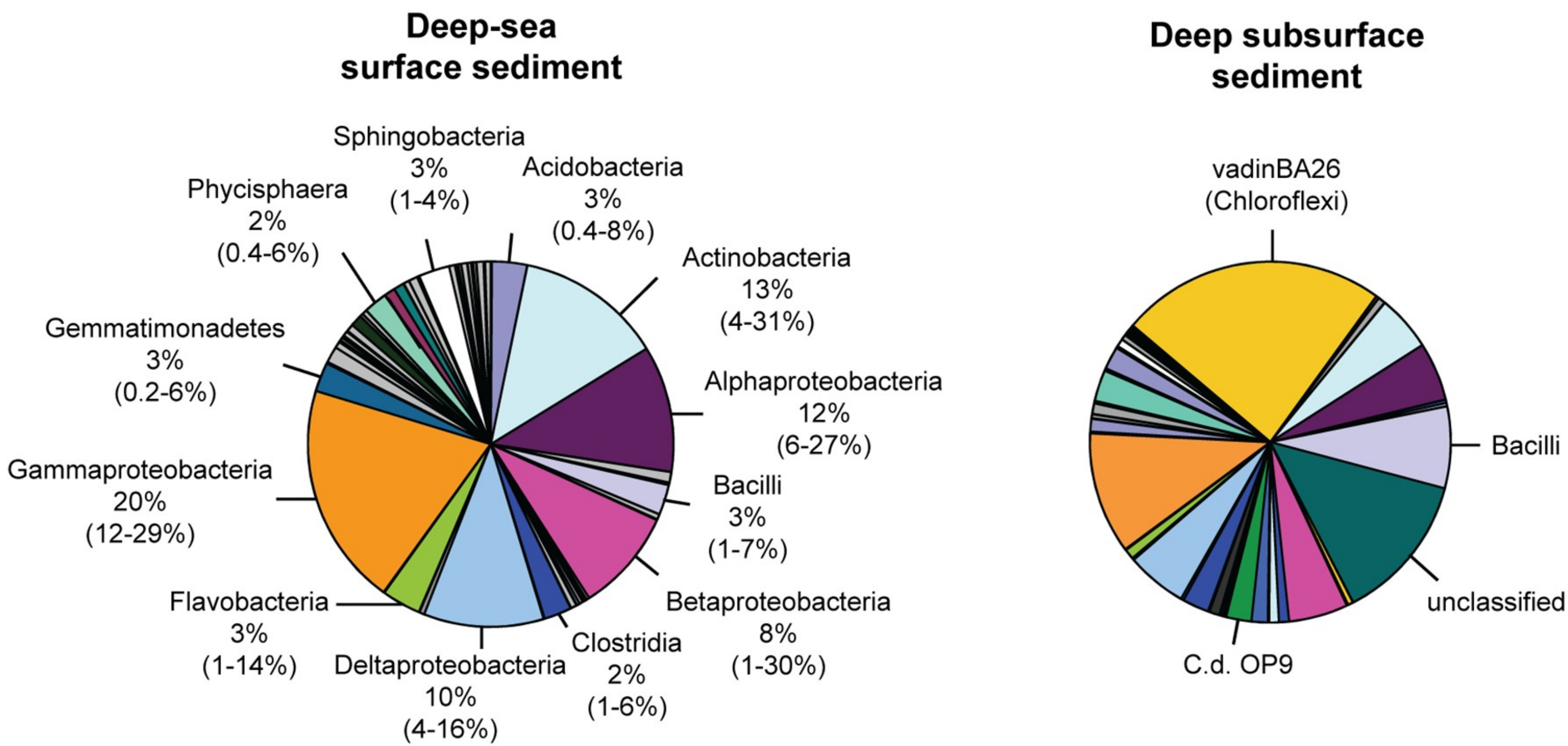
The **Sulfate-Methane Transition Zone** (SMTZ) is one of the most important zone in marine subsurface sediments together with the oxic-anoxic interface

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

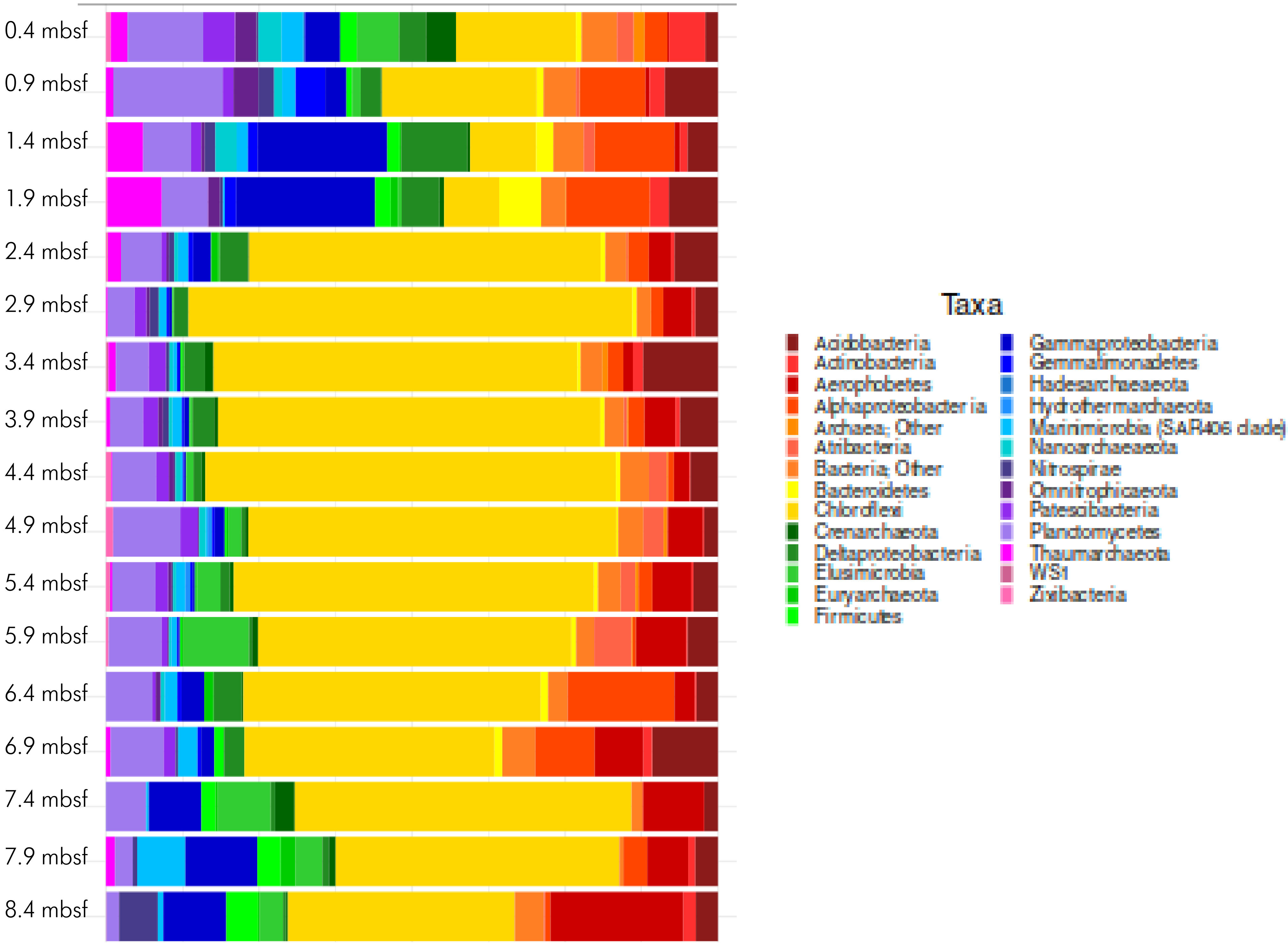
The SMTZ is an area of intense metabolic activity, where anaerobic methane oxidizers (ANME) is believed to play a key role in removing methane in partnership with sulfate reducing bacteria (SRB)

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

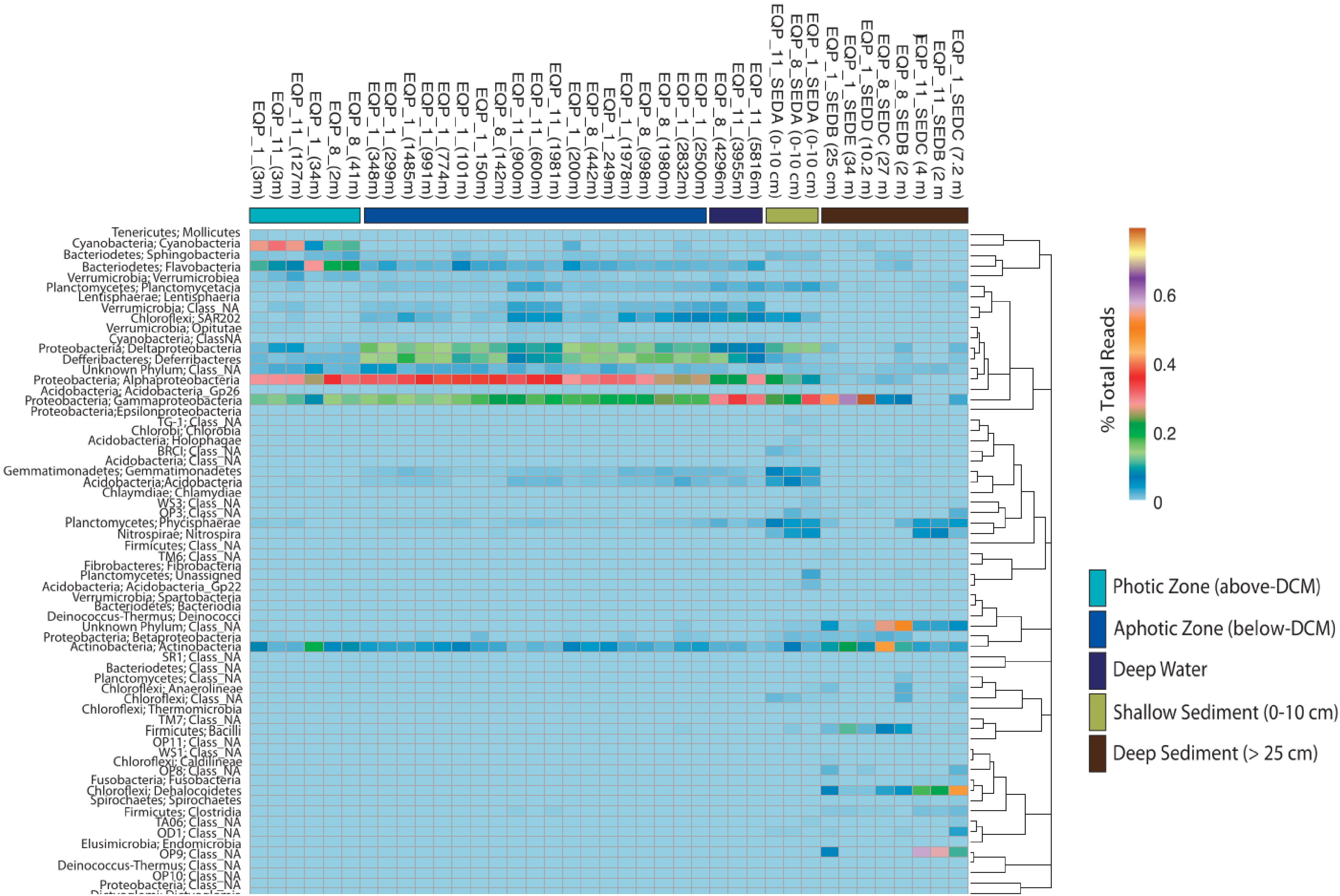




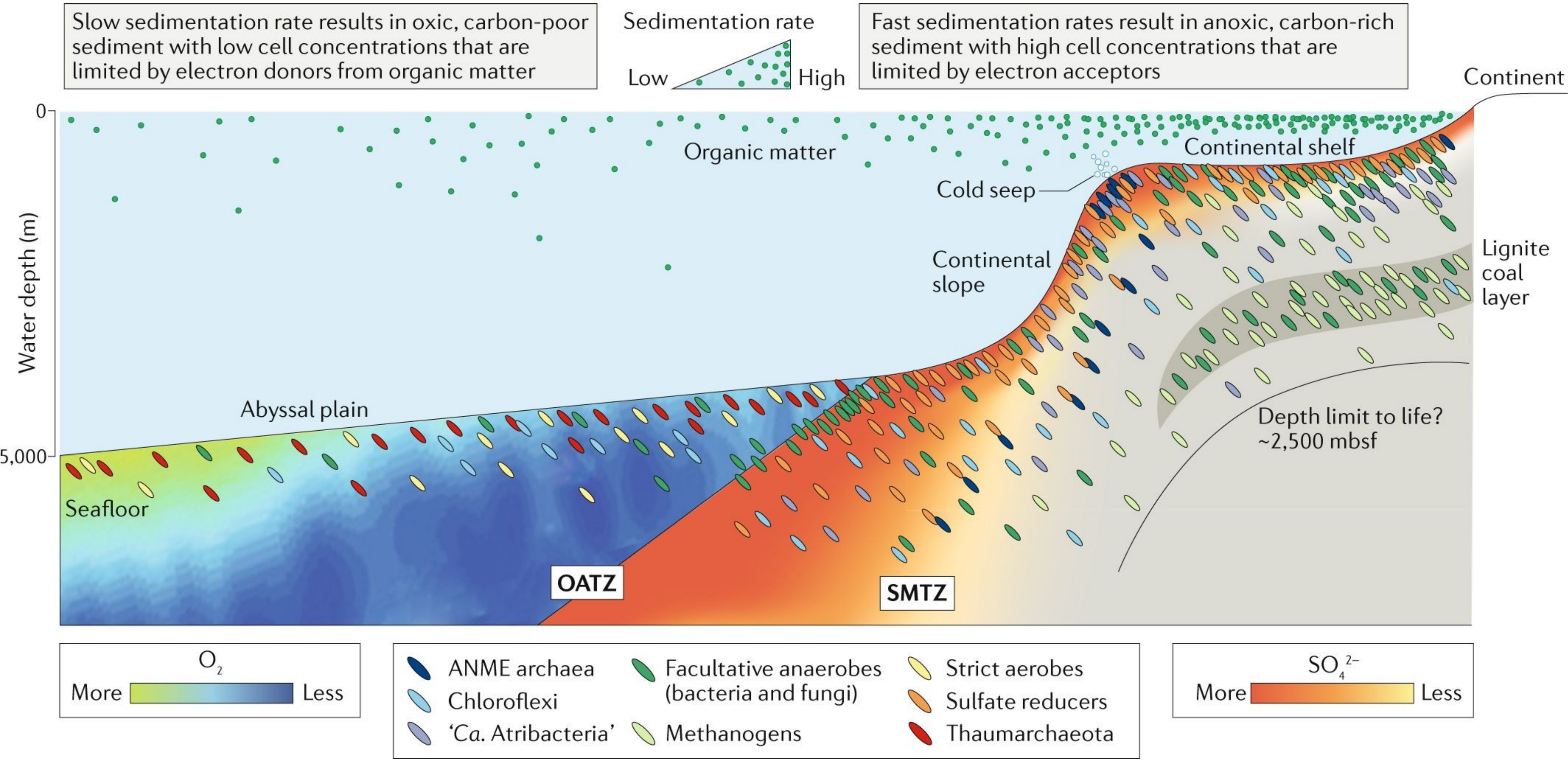
Bienhold et al. 2016 PlosONE



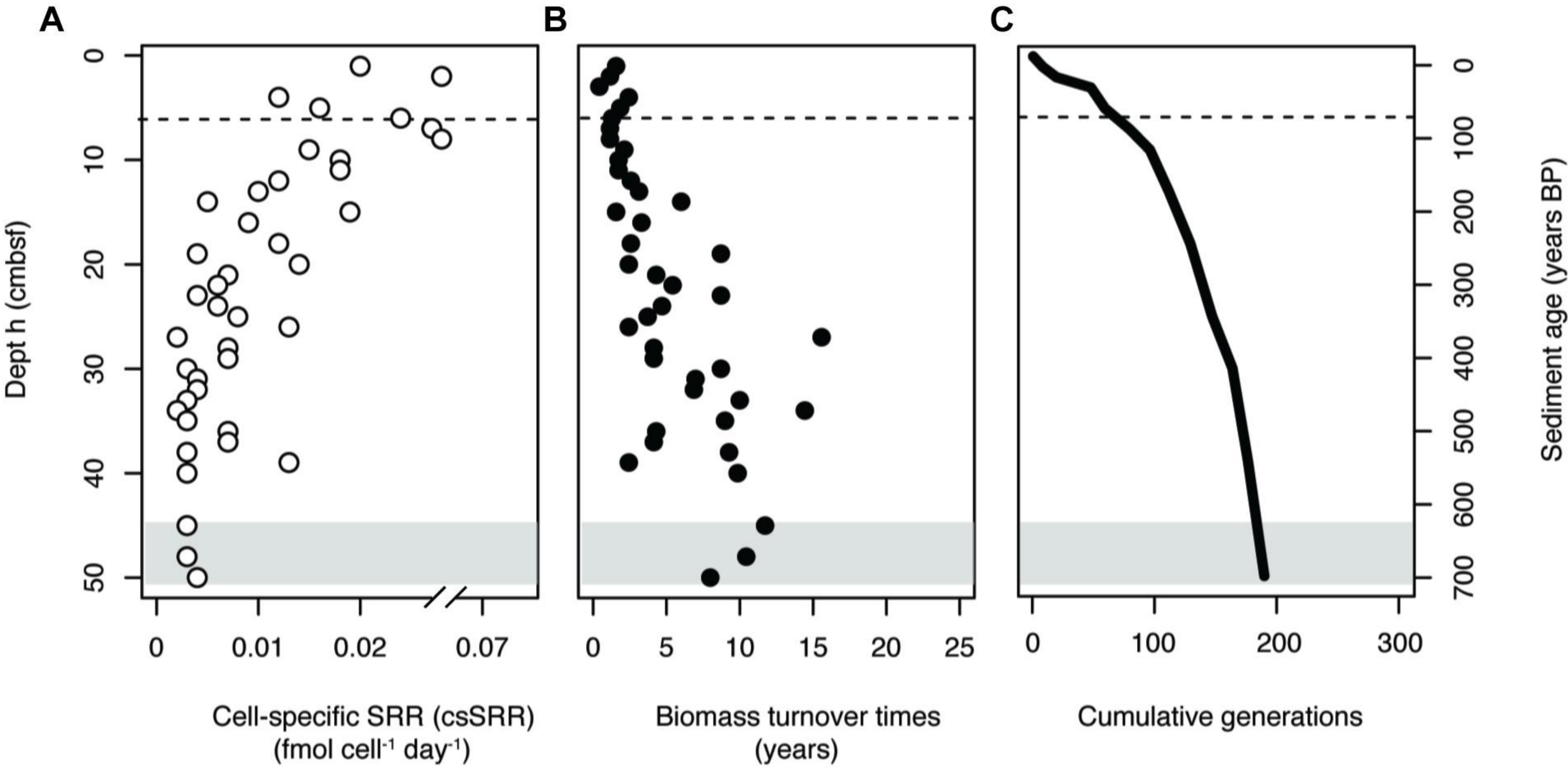
Biddle, Ash and Giovannelli, unpublished



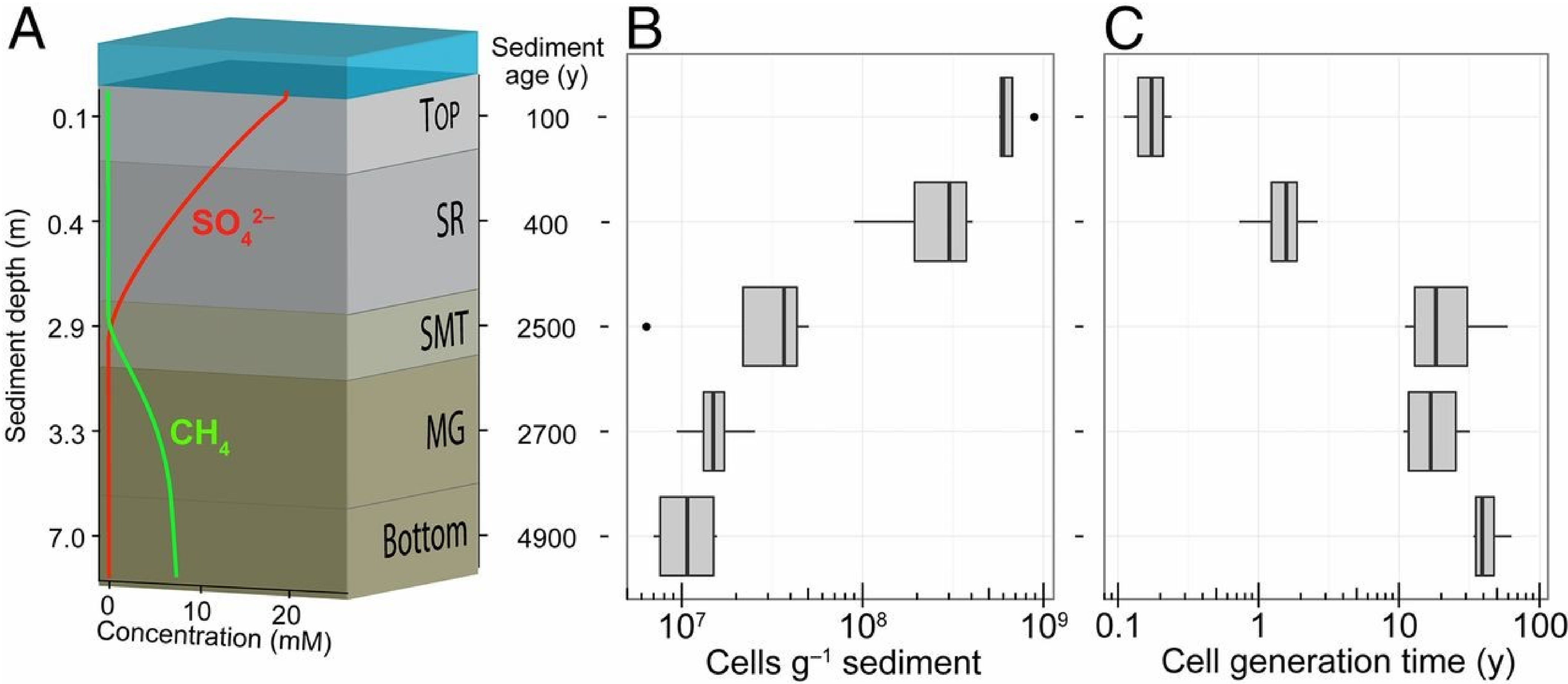
Walsh et al. 2016 ISMEJ



Orsi et al 2018



Petro et al., 2019 Front in Microbiol



Starnawski et al. 2017 PNAS

Habitable Zone

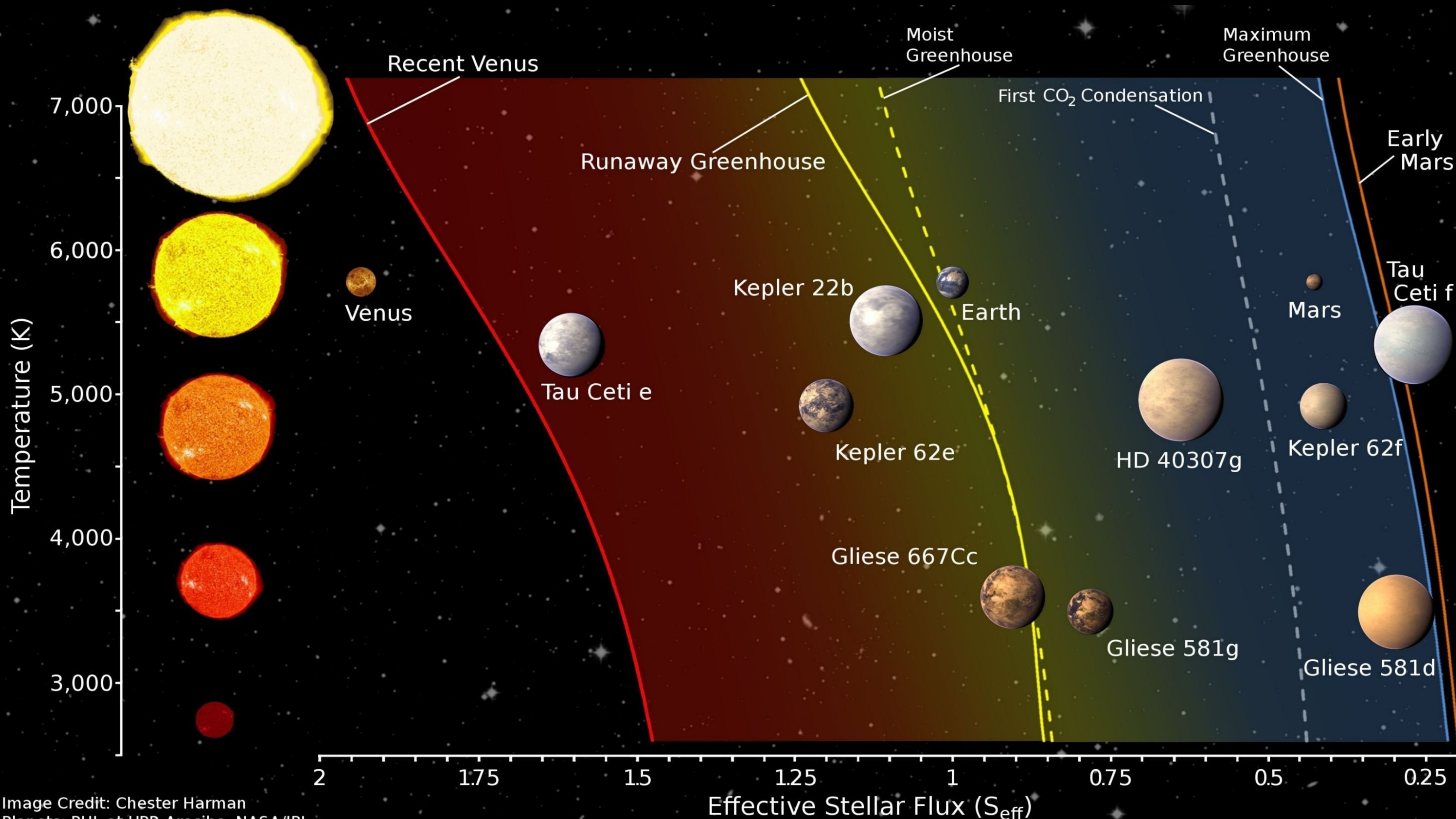
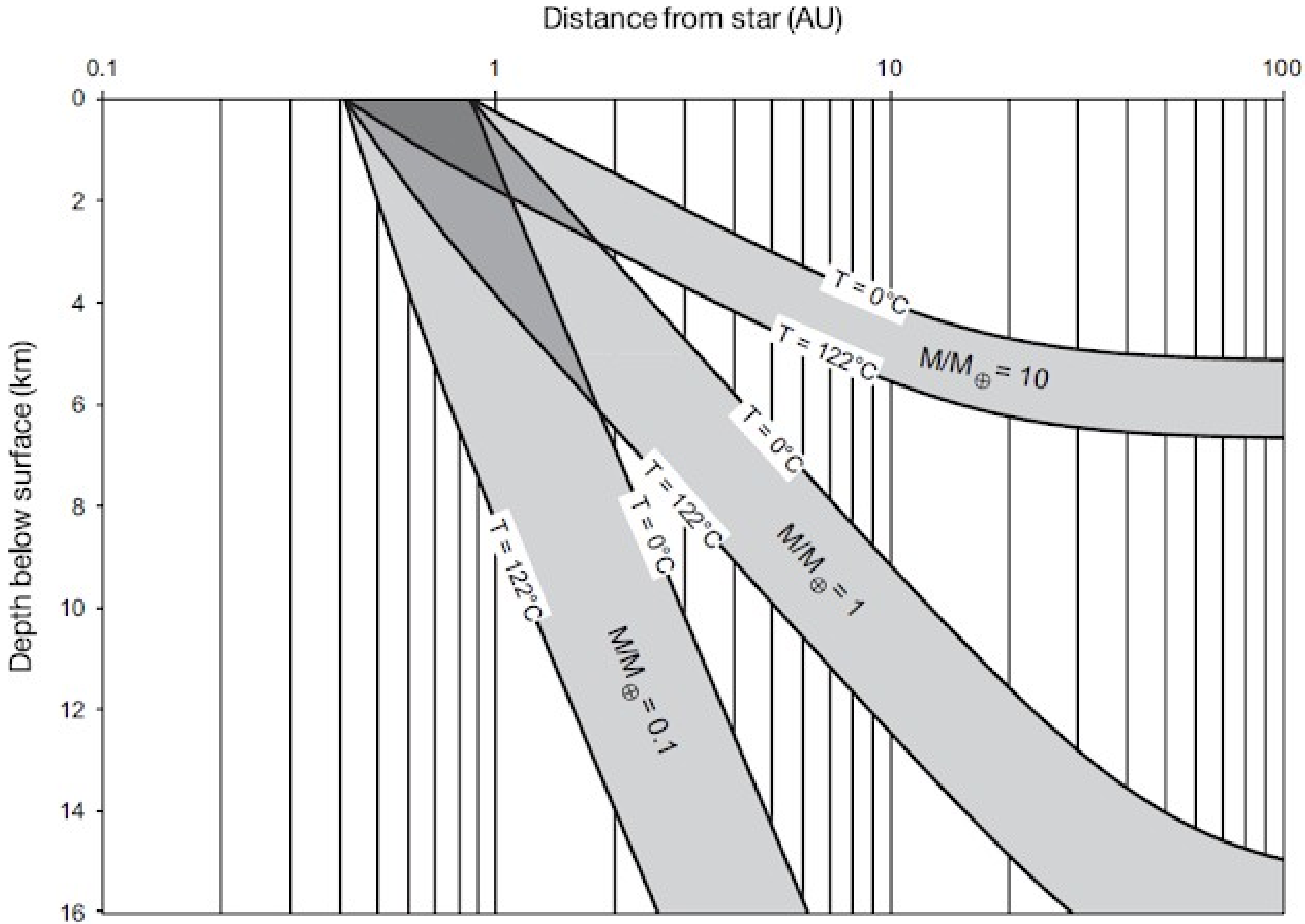


Image Credit: Chester Harman
Planets: PHL at UPR Arecibo, NASA/JPL



McMahon et al. 2013 Planet Space Sci

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REPORT

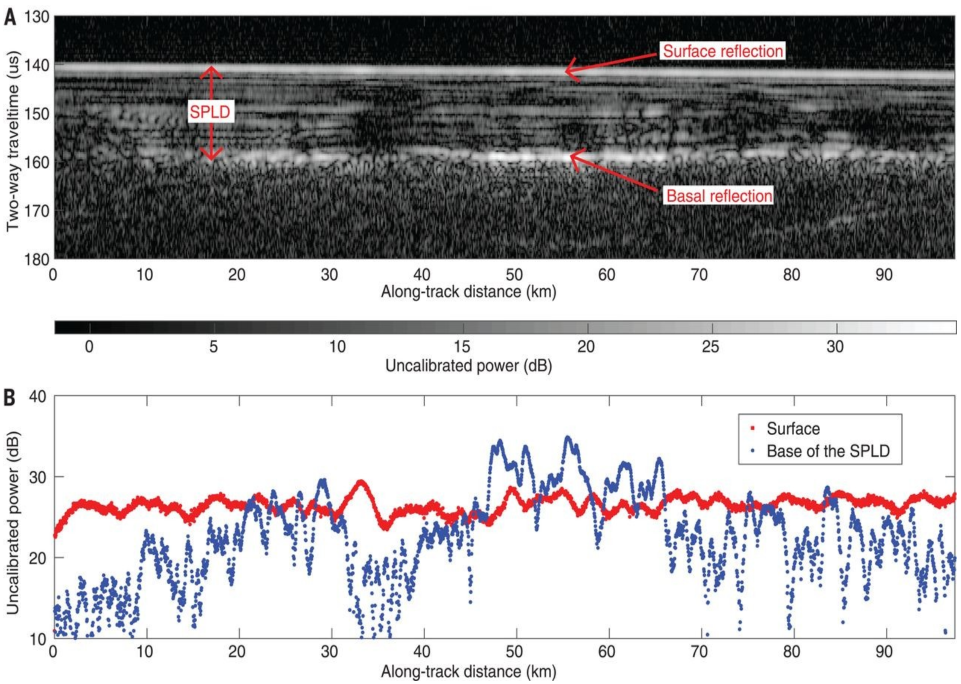
Radar evidence of subglacial liquid water on Mars

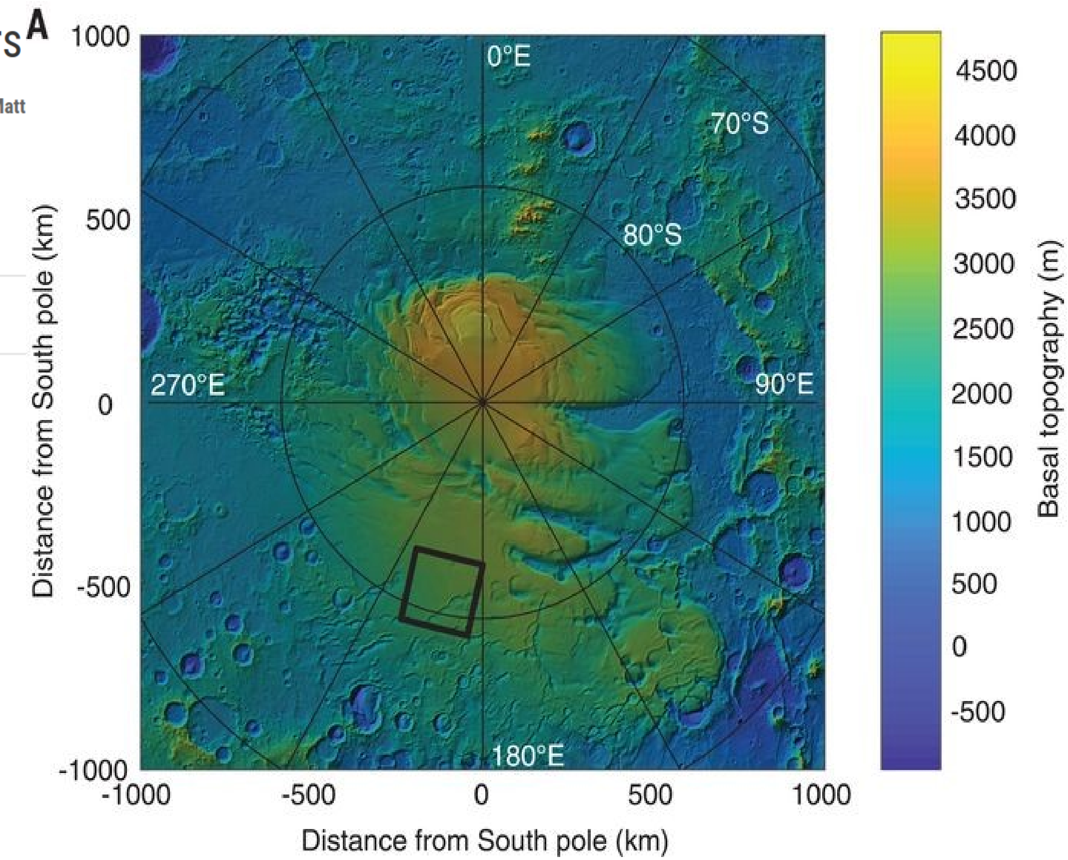
R. Orosei[1,*], S. E. Lauro[2], E. Pettinelli[2], A. Cicchetti[3], M. Coradini[4], B. Cosciotti[2], F. Di Paolo[1], E. Flamini[4], E. Matt

+ See all authors and affiliations

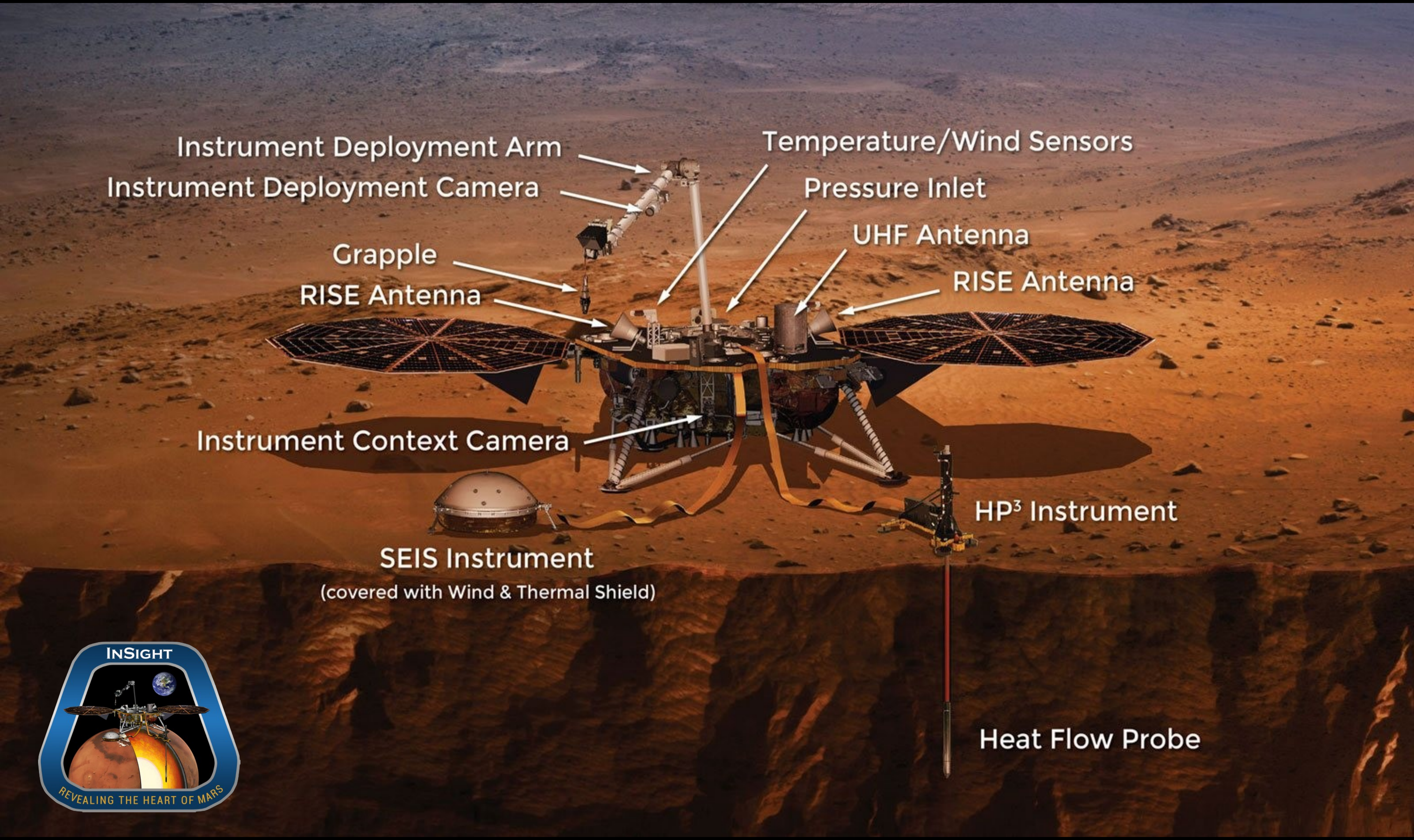
Science 03 Aug 2018:
Vol. 361, Issue 6401, pp. 490-493
DOI: 10.1126/science.aar7268

Article | Figures & Data | Info & Metrics | eLetters





Orosei et al. 2018 Science



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

Deep Carbon

Past to Present

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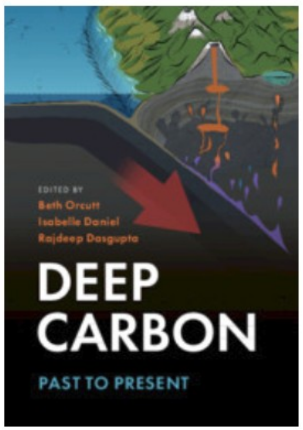

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Orcutt, B.N., Daniel, I., Dasgupta, R. (Eds.), 2019. Deep Carbon: Past to Present, 1st ed. Cambridge University Press. https://doi.org/10.1017/9781108677950

Cold-Seeps

Cold seeps

A **cold seep** (sometimes called a cold vent) is an area of the ocean floor where *hydrogen sulfide*, *methane* and other *hydrocarbon-rich* fluid seepage occurs, often in the form of a brine pool

Cold does not mean that the temperature of the seepage is lower than that of the surrounding sea water. On the contrary, its temperature is often slightly higher (15-45°C)

Cold seeps were discovered in 1983 by Dr. Charles Paull on the Florida Escarpment in the Gulf of Mexico at a depth of 3,200 meters

They are globally abundant and usually found at variable water depth in the continental shelf and the continental slope

Cold seeps are believed to be major contributor to global methane cycle

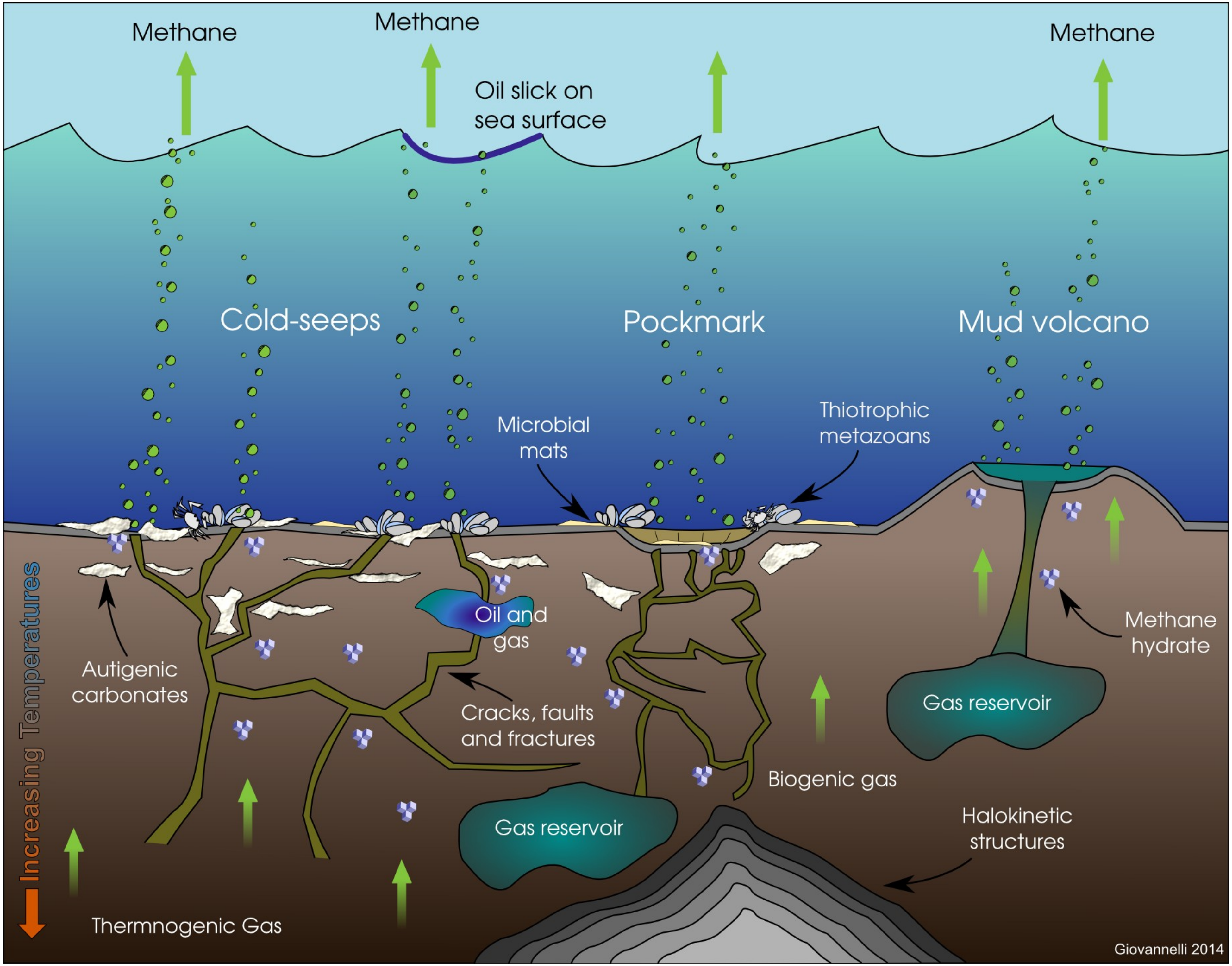
The anaerbic methane oxidation operated by the uncultured archea ANME group is a major metabolism in cold seep environments

Numerous symbiosis are present at these locations, both in bivalvs and tubeworms

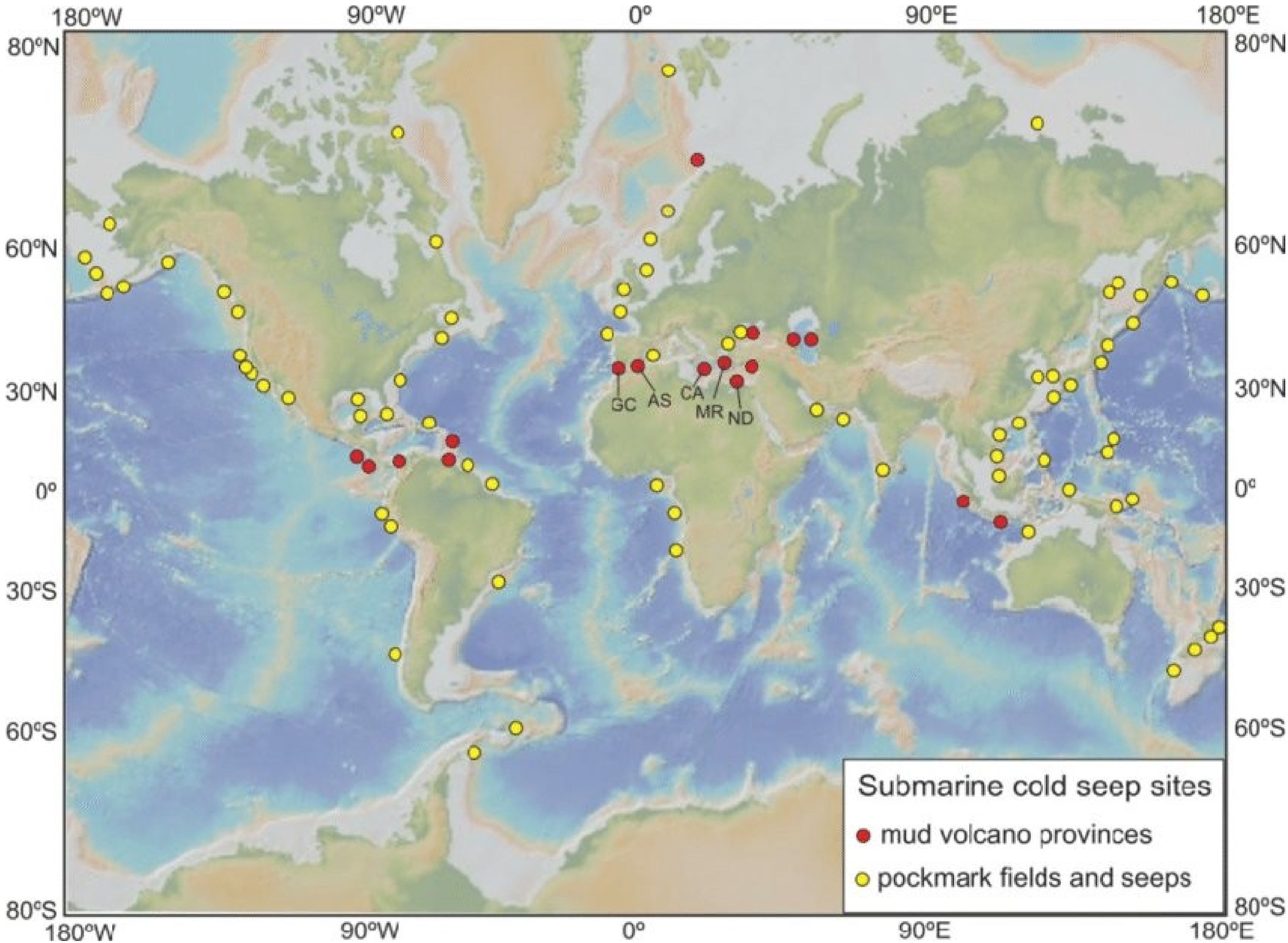
Cold seeps

Types of cold seeps distinguished according to the depth, as shallow cold seeps and deep cold seeps, and classified as:

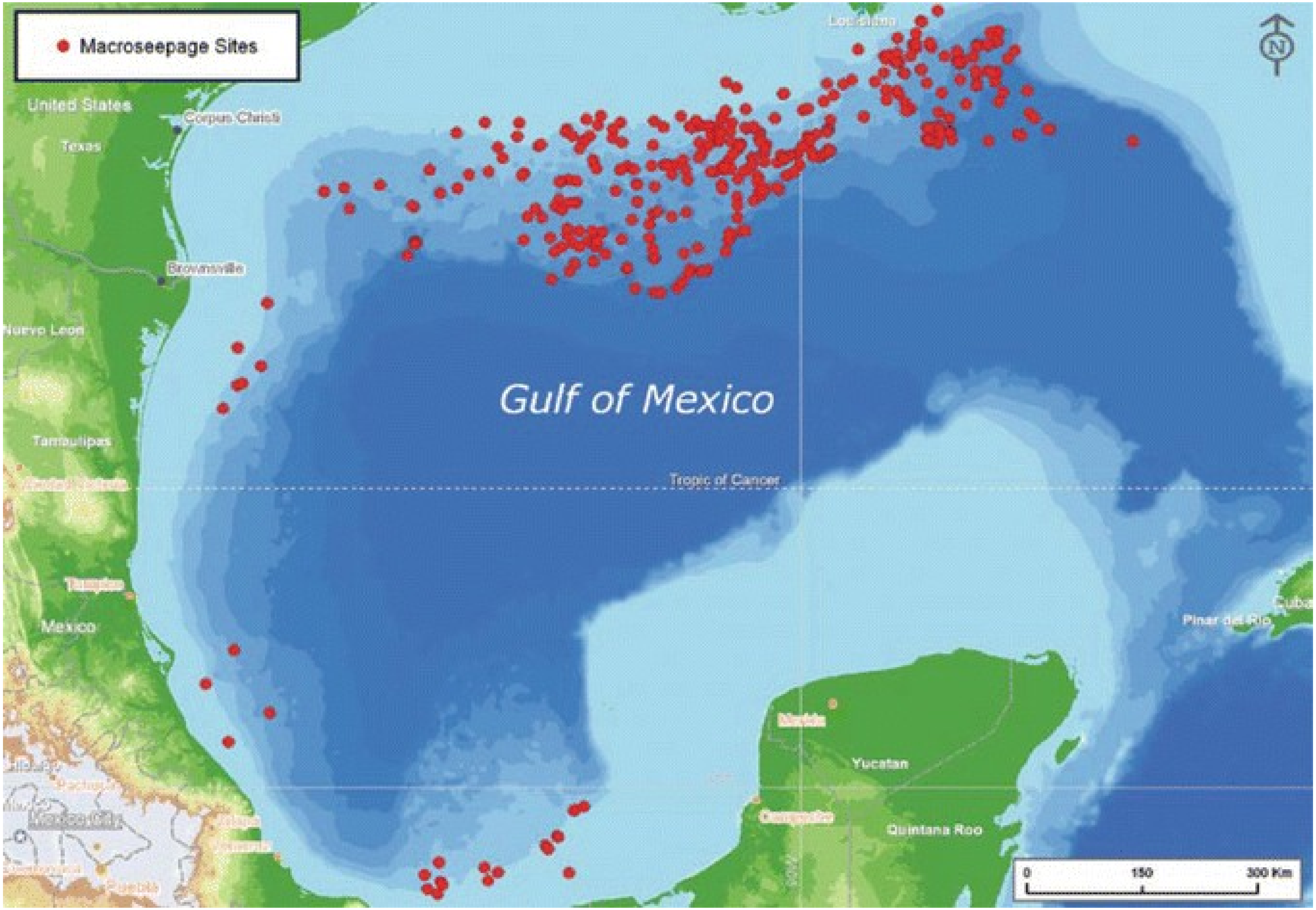
- oil/gas seeps
- gas seeps: methane seeps
- gas hydrate seeps
- pockmarks
- mud volcanoes
- brine seeps (brine pools)

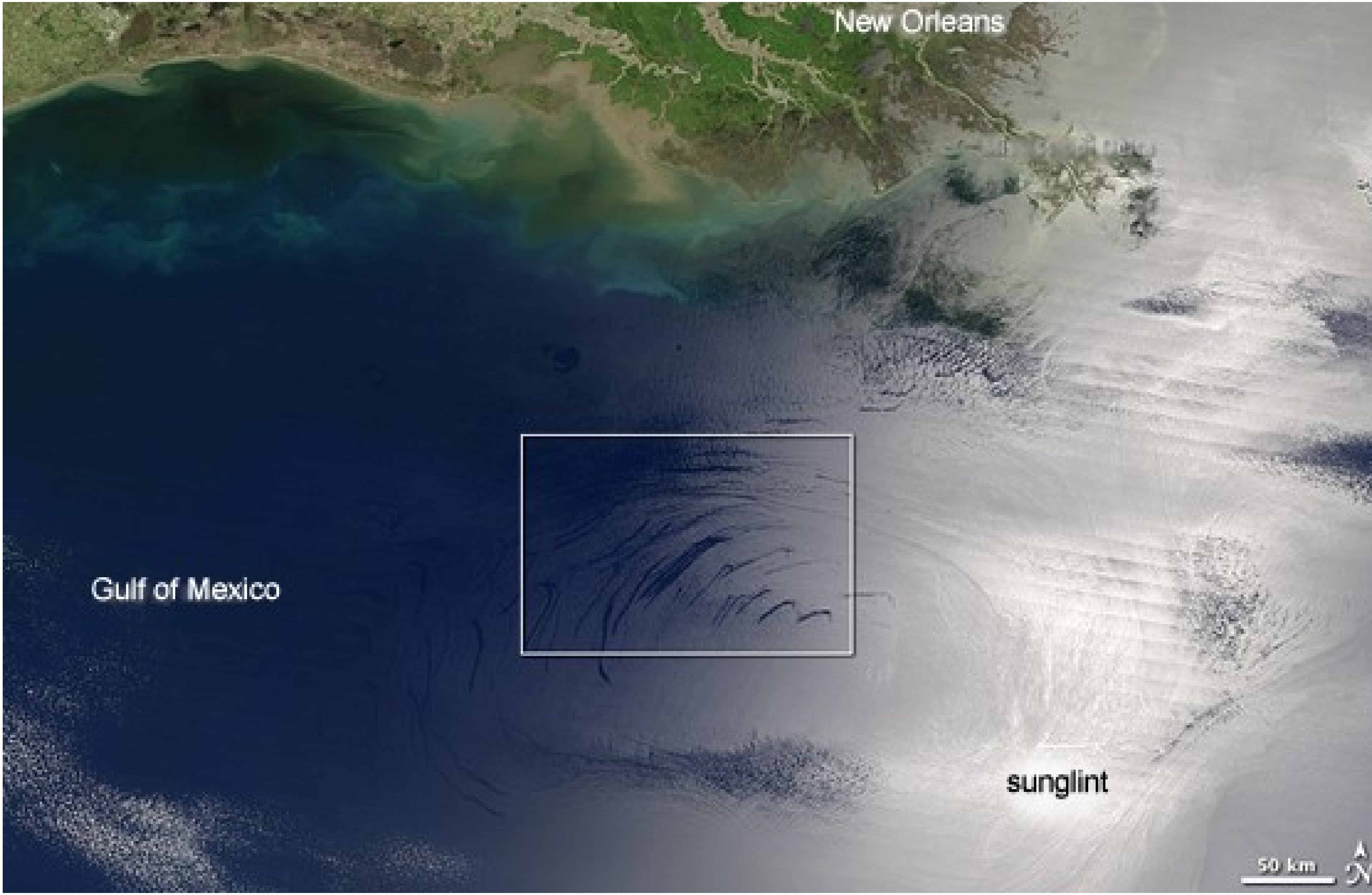


Methane
Methane
Methane
Oil slick on sea surface
Cold-seeps
Pockmark
Mud volcano
Microbial mats
Thiotrophic metazoans
Autigenic carbonates
Oil and gas
Methane hydrate
Cracks, faults and fractures
Gas reservoir
Biogenic gas
Gas reservoir
Halokinetic structures
Increasing Temperatures
Thermnogenic Gas
Giovannelli 2014

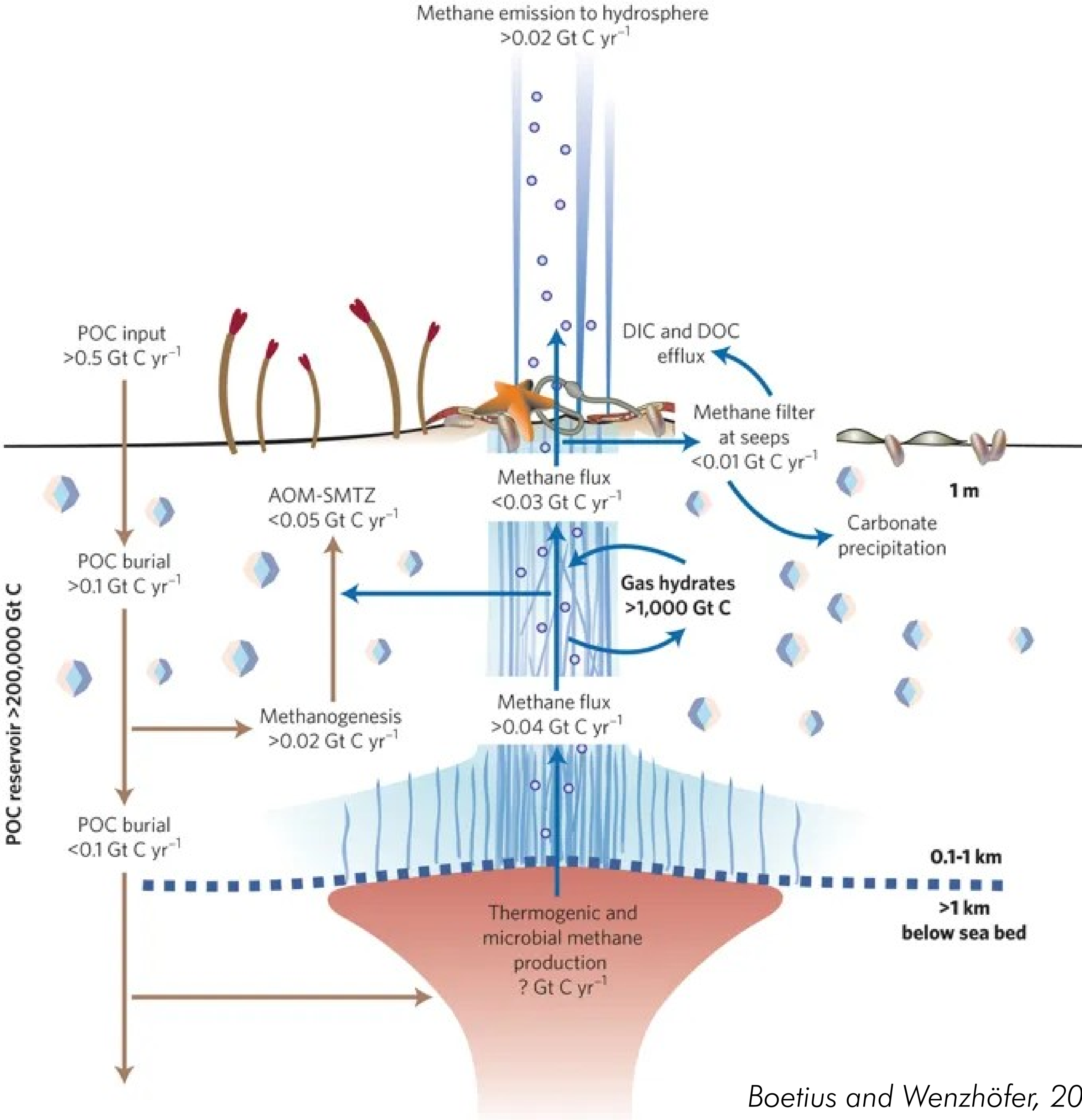


Ceramicola et al. 2018


Macroseepage Sites
United States
Corpus Christi
Texas
Brownsville
Nuevo Leon
Gulf of Mexico
Tamaulipas
Tropic of Cancer
Mexico
Pinar del Rio
Cuba
Yucatan
Quintana Roo
0
150
300 Km
N



Oil sheen seen from satellite in the Gulf of Mexico



Boetius and Wenzhöfer, 2013 Nat Geosci

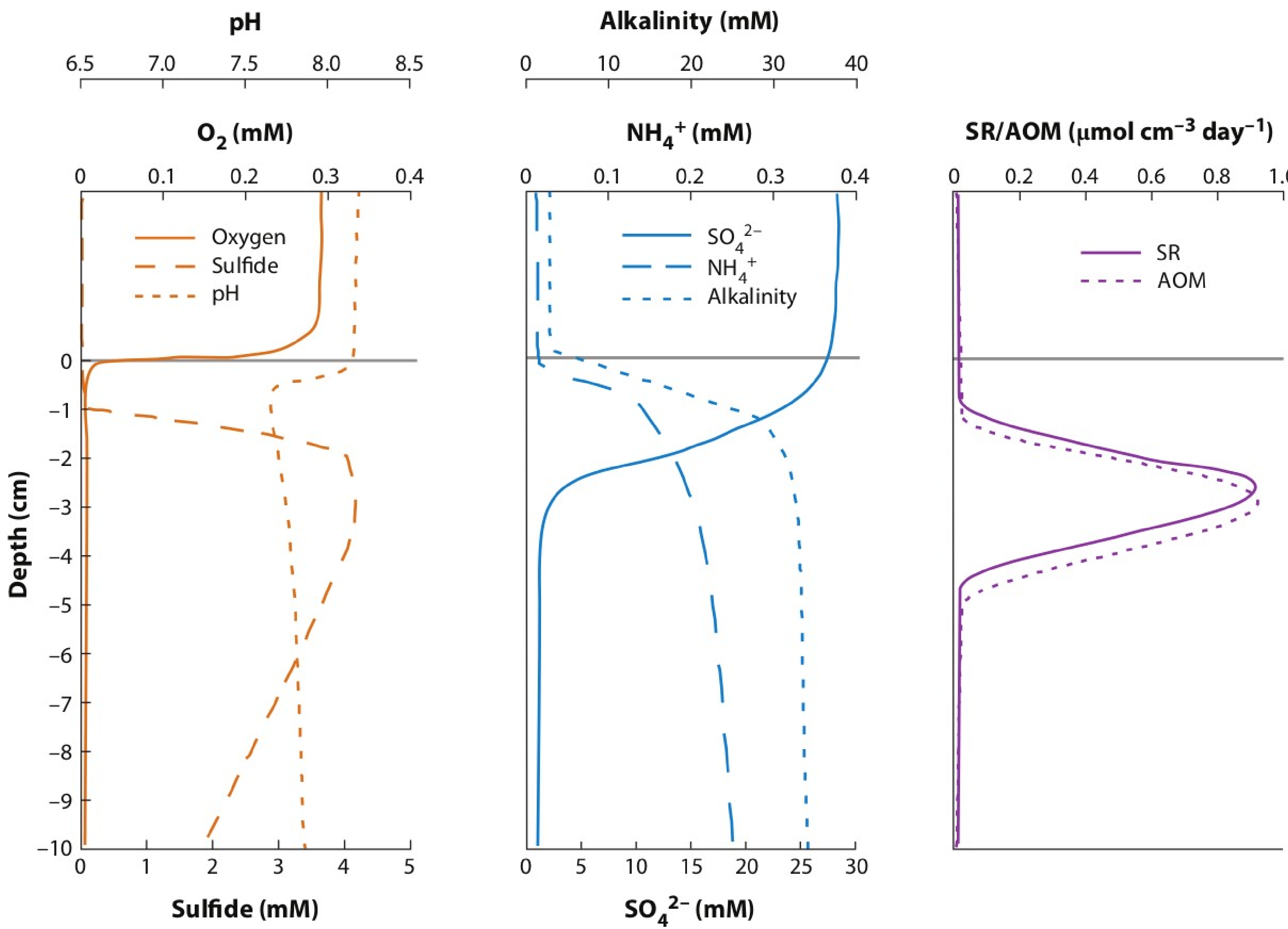
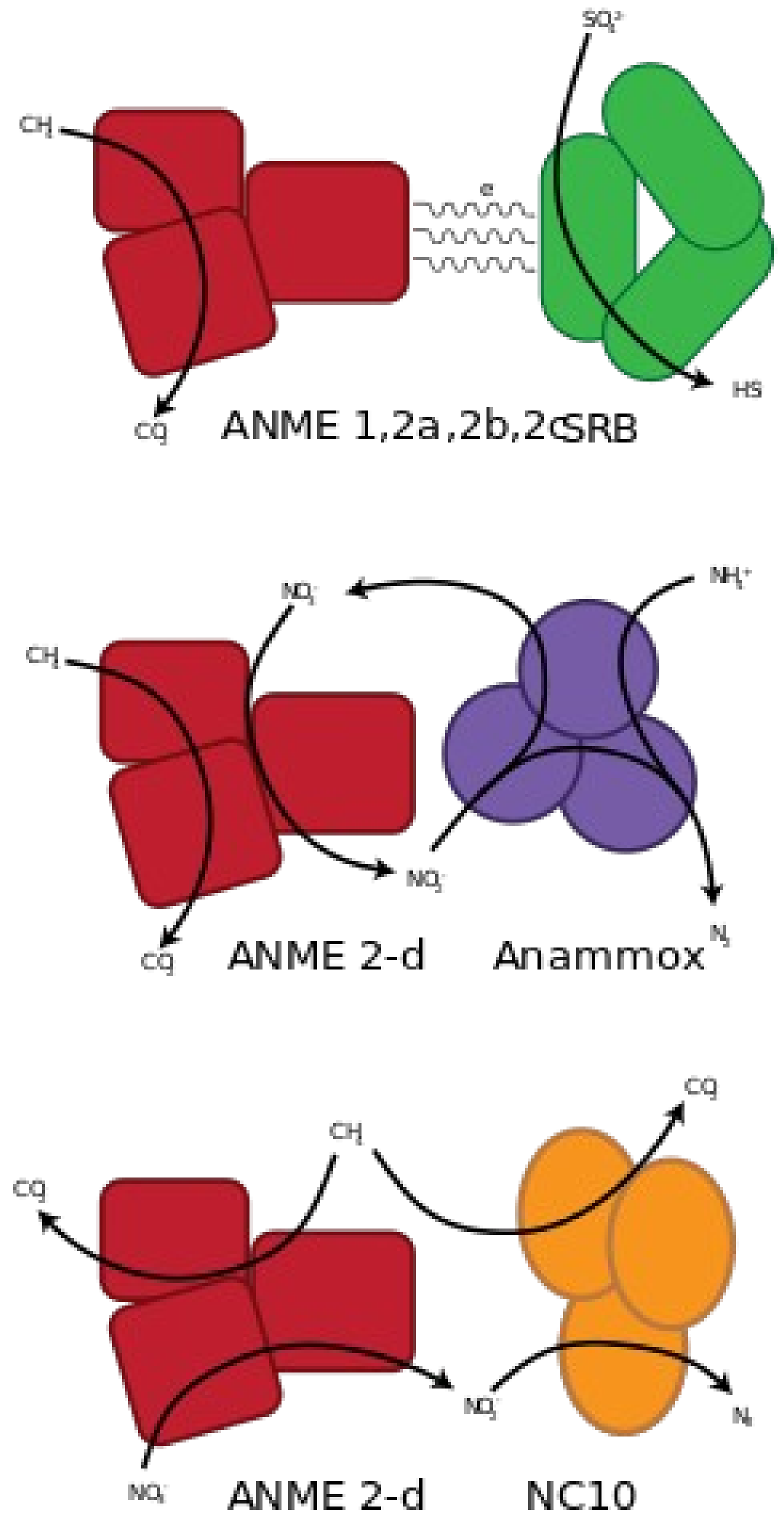


Figure 1

Scheme of biogeochemical gradients in the AOM zone above hydrates (modified after Reference 9). AOM, anaerobic oxidation of methane; SR, sulfate reduction.

Knittel and Boetius, 2009 Ann Rev Microbiol



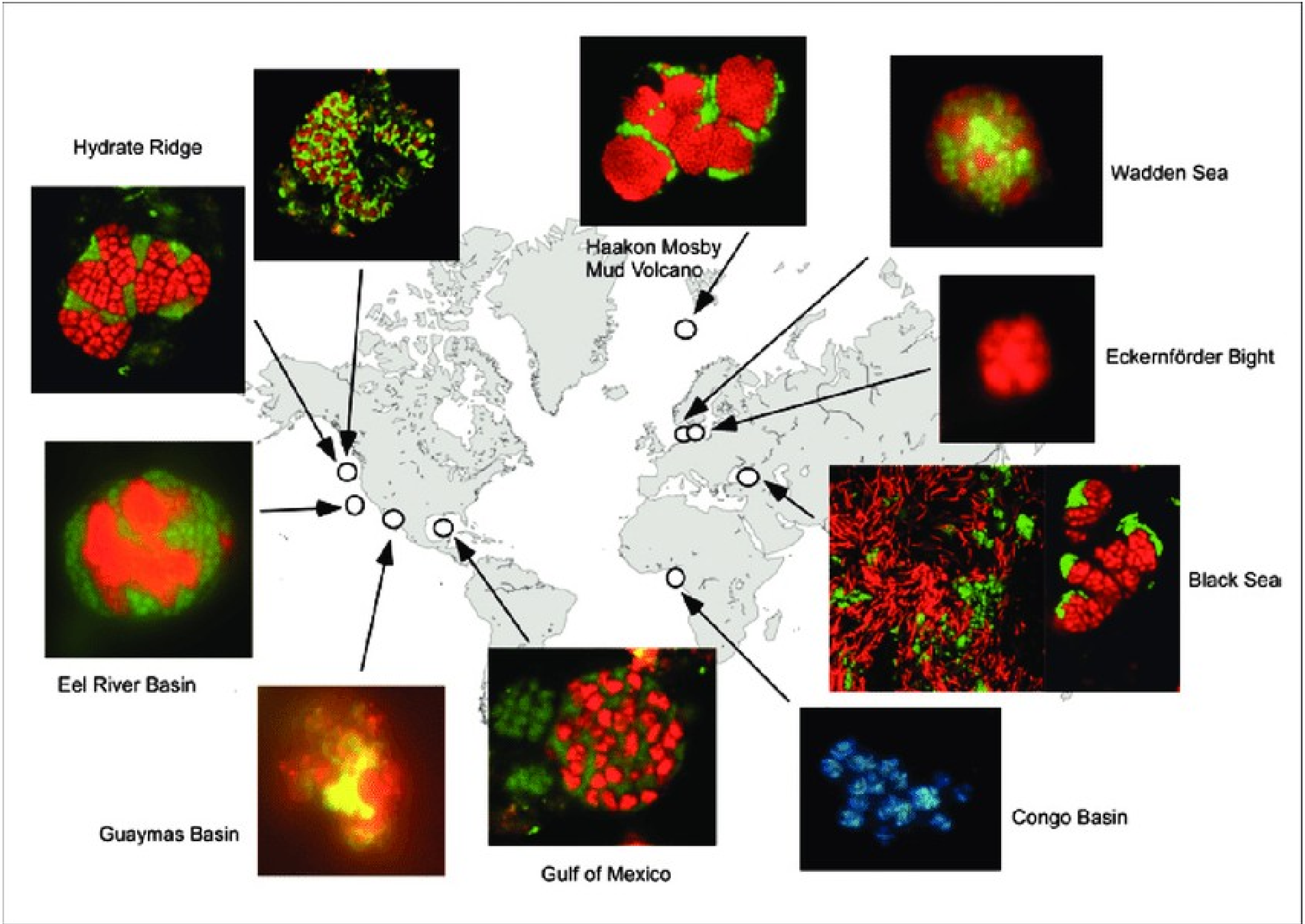
Anaerobic Methane Oxidation

Anaerobic Methane Oxidation is capable of removing globally the majority of the methane produced in marine sediments. Possible partnership in the AMO:

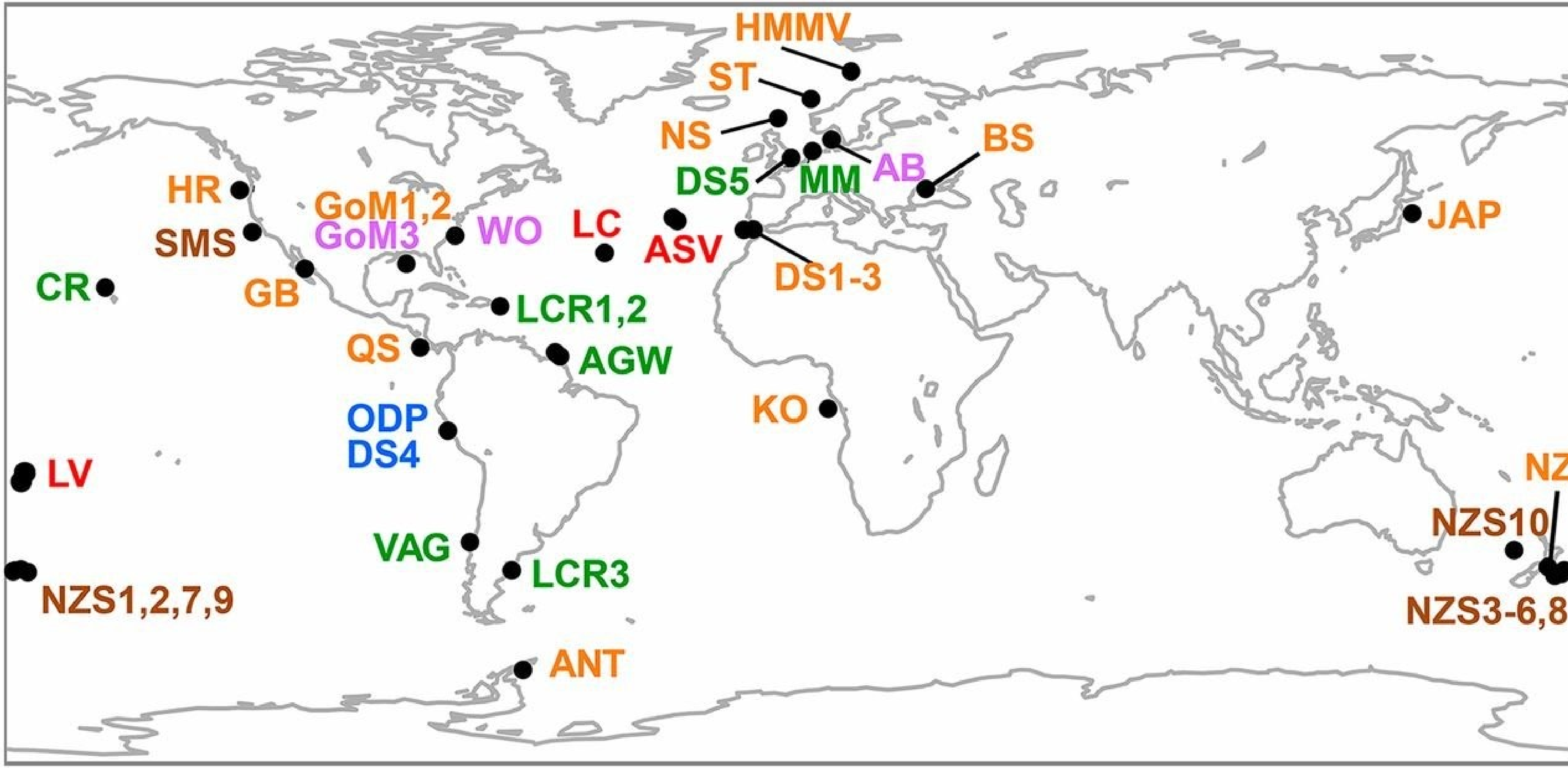
- ANME 1, 2a, 2b, 2c (Archaea) with Sulfate Reducing Bacteria (Deltaproteobacteria)

- ANME 2-d with Anammox (Planctomycetes)

- ANME 2-d with NC10 (Bacteria)



Hydrate Ridge
Haakon Mosby
Mud Volcano
Wadden Sea
Eckernförder Bight
Eel River Basin
Black Sea
Guaymas Basin
Gulf of Mexico
Congo Basin



PNAS

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Global dispersion and local diversification of the methane seep microbiome

S. Emil Ruff[a,b,1], Jennifer F. Biddle[c], Andreas P. Teske[d], Katrin Knittel[b], Antje Boetius[a,e,f], and Alban Ramette[a,2]

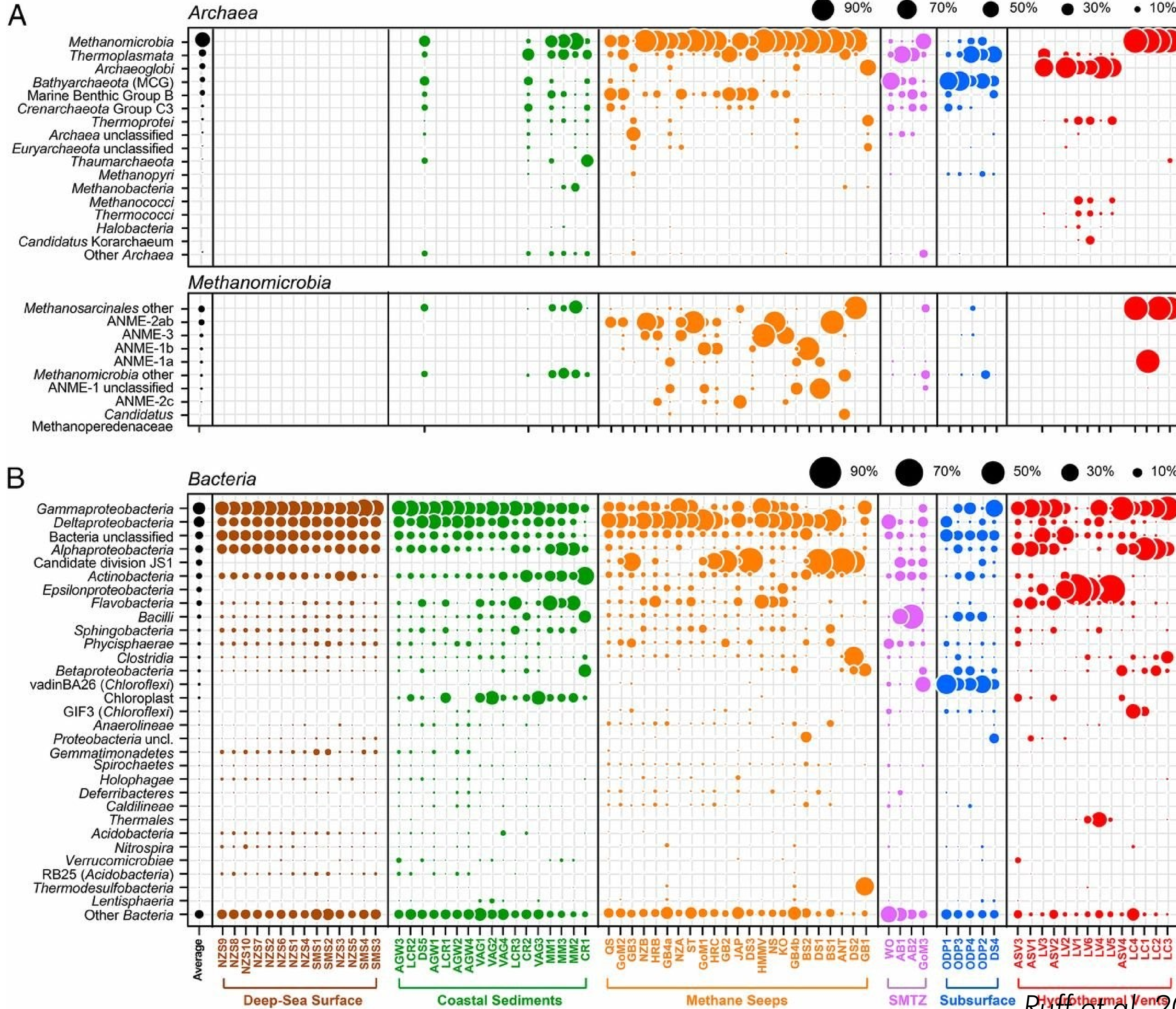
[a]HGF MPG Group for Deep Sea Ecology and Technology and [b]Department of Molecular Ecology, Max Planck Institute for Marine Microbiology, D-28359 Bremen, Germany; [c]College of Earth, Ocean and Environment, University of Delaware, Lewes, DE 19958; [d]Department of Marine Sciences, University of North Carolina, Chapel Hill, NC 27599-3300; [e]Alfred Wegener Institute, Helmholtz Center for Polar and Marine Research, D-27570 Bremerhaven, Germany; and [f]Center for Marine Environmental Sciences, University of Bremen, D-28359 Bremen, Germany

Edited by Mary E. Lidstrom, University of Washington, Seattle, WA, and approved February 6, 2015 (received for review November 17, 2014)

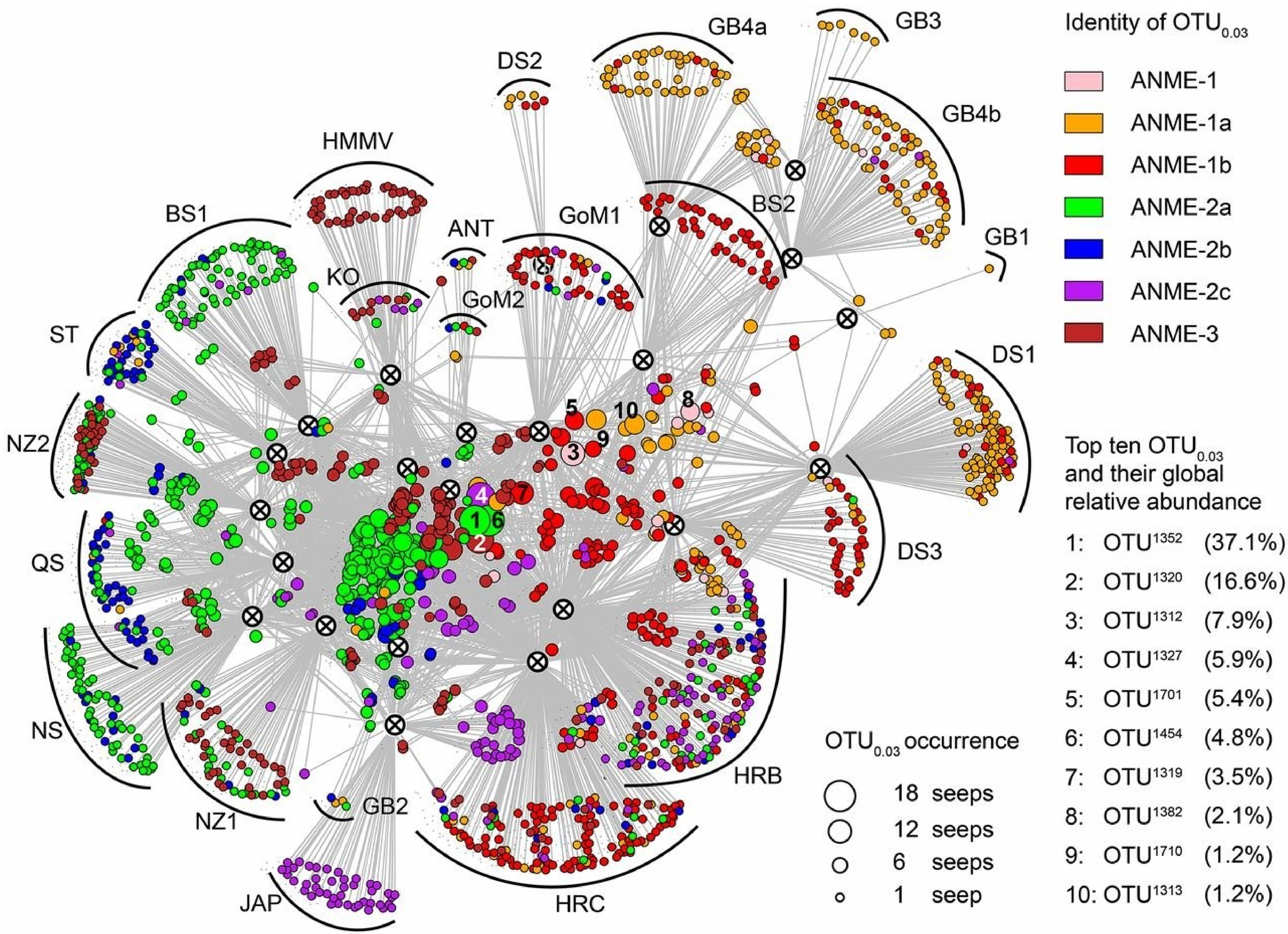
Methane seeps are widespread seafloor ecosystems shaped by the emission of gas from seabed reservoirs. The microorganisms inhabiting methane seeps transform the chemical energy in methane to products that sustain rich benthic communities around the gas leaks. Despite the biogeochemical relevance of microbial

impacted by water depth (11, 12), sediment depth (13, 14), and by energy availability in the form of deposited organic matter (12, 15, 16). Marine sediments are known to host communities as diverse as those found in soils, with pronounced community turnover on small (decimeter to kilometer), intermediate (hun-

Ruff et al. 2015 PNAS



Ruff et al. 2015 PNAS



Ruff et al. 2015 PNAS

Shallow-water hydrothermal vents

Shallow-water hydrothermal vents

Shallow-water hydrothermal vents (also known as shallow vents, or shallow- water gaseous vent, SWHV) are globally distributed environments associated with volcanism. Gas discharge is often conspicuous, contrarily to their deep-sea counterparts

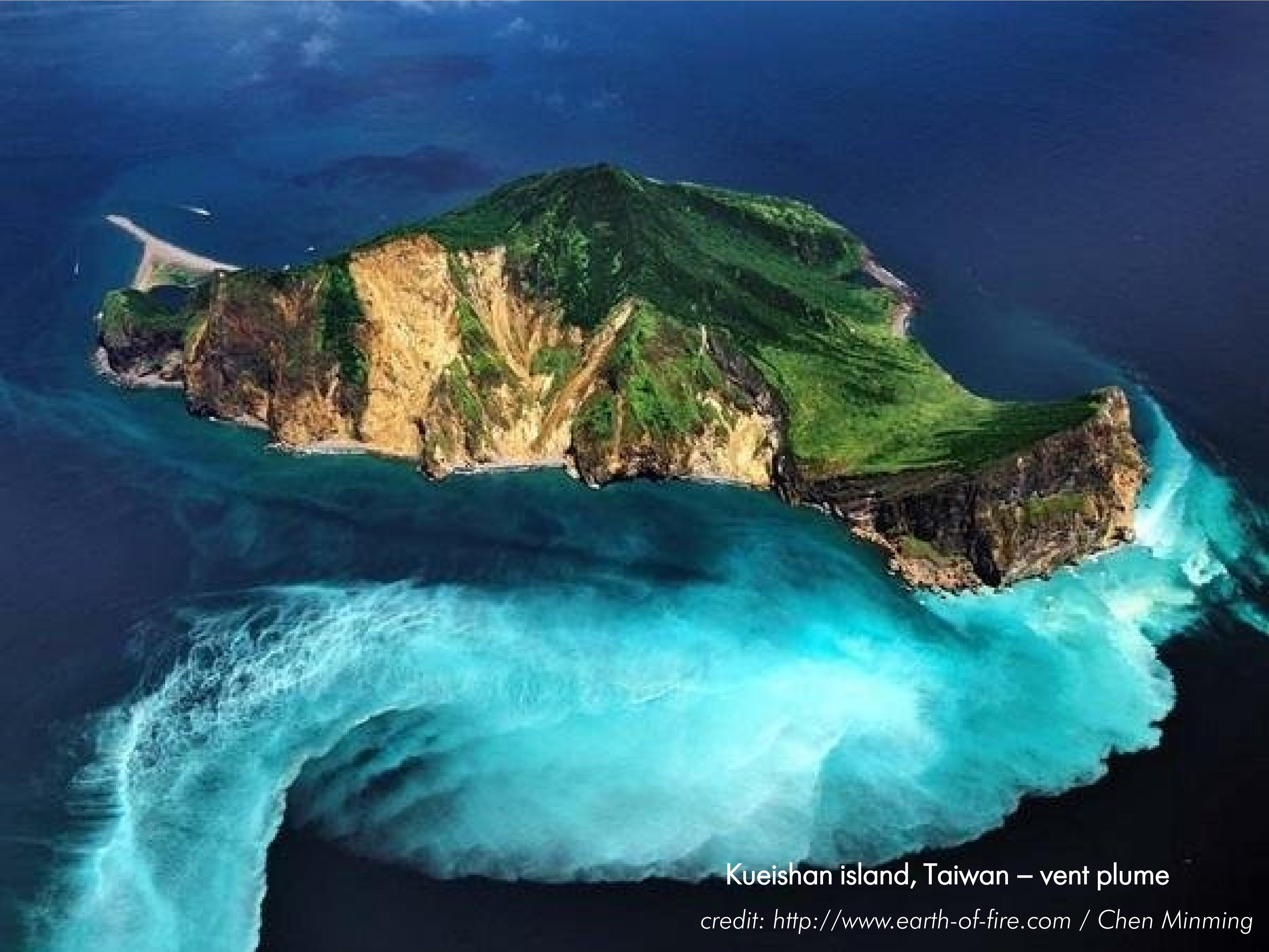
They are characterized by reduced fluid and gas emission sometimes associated with a temperature anomaly (but not necessarily)

SWHV are high energy environments where photoautotrophy and chemolithoautotrophy coexist within very narrow geochemical and thermla gradients

Microbial diversity in these ecosystem is highly diverse and dependent on the fluid geochemistry

Four major classes of SWHV have been proposed, depending on the temperature/geochemical regime

The chemolithoautotrophic community is generally dominated either by sulfur oxidizers, iron reducers or hydrogen/methane oxidizers depending on the vent class



Kueishan island, Taiwan – vent plume

credit: http://www.earth-of-fire.com / Chen Minming

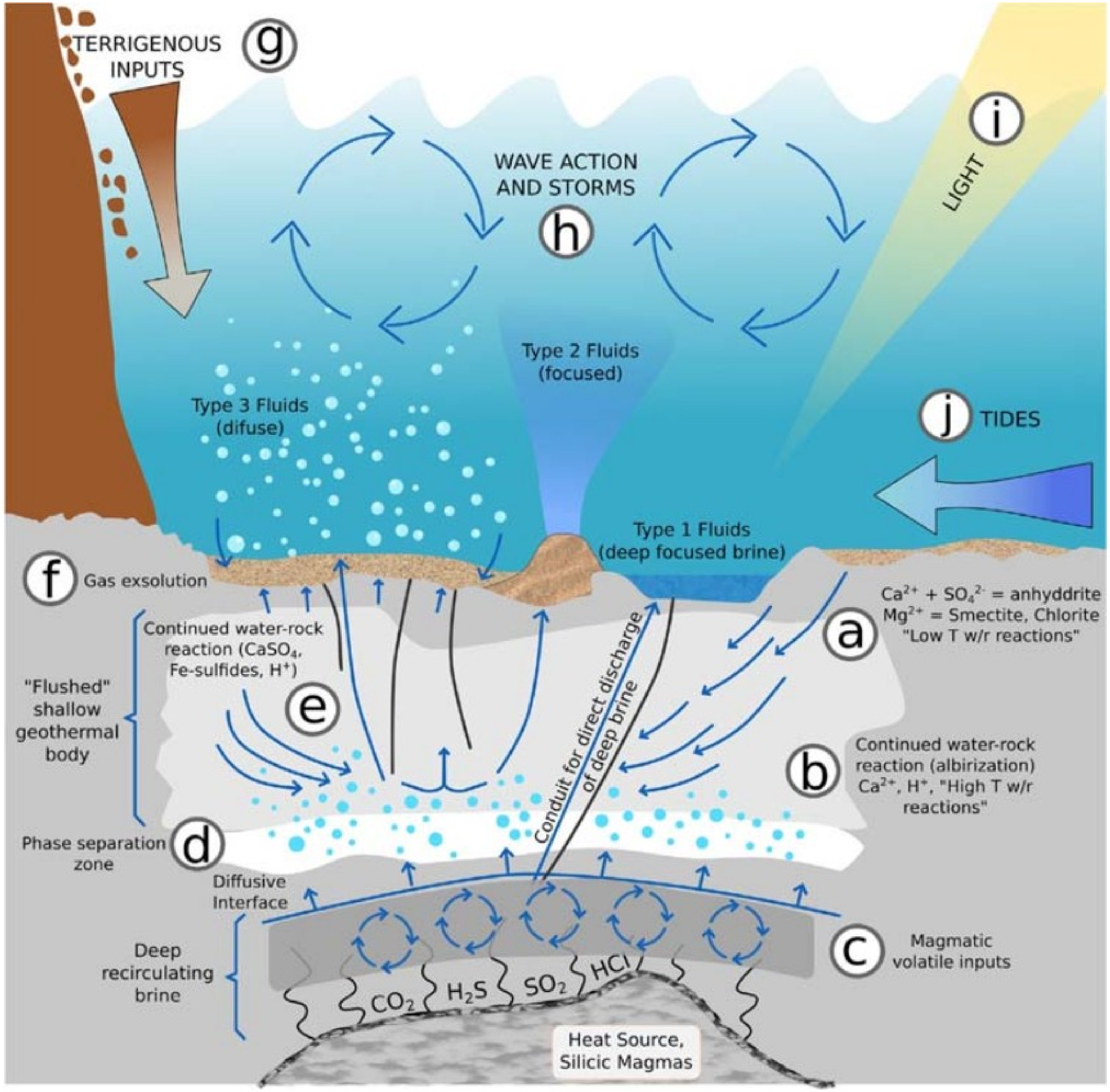
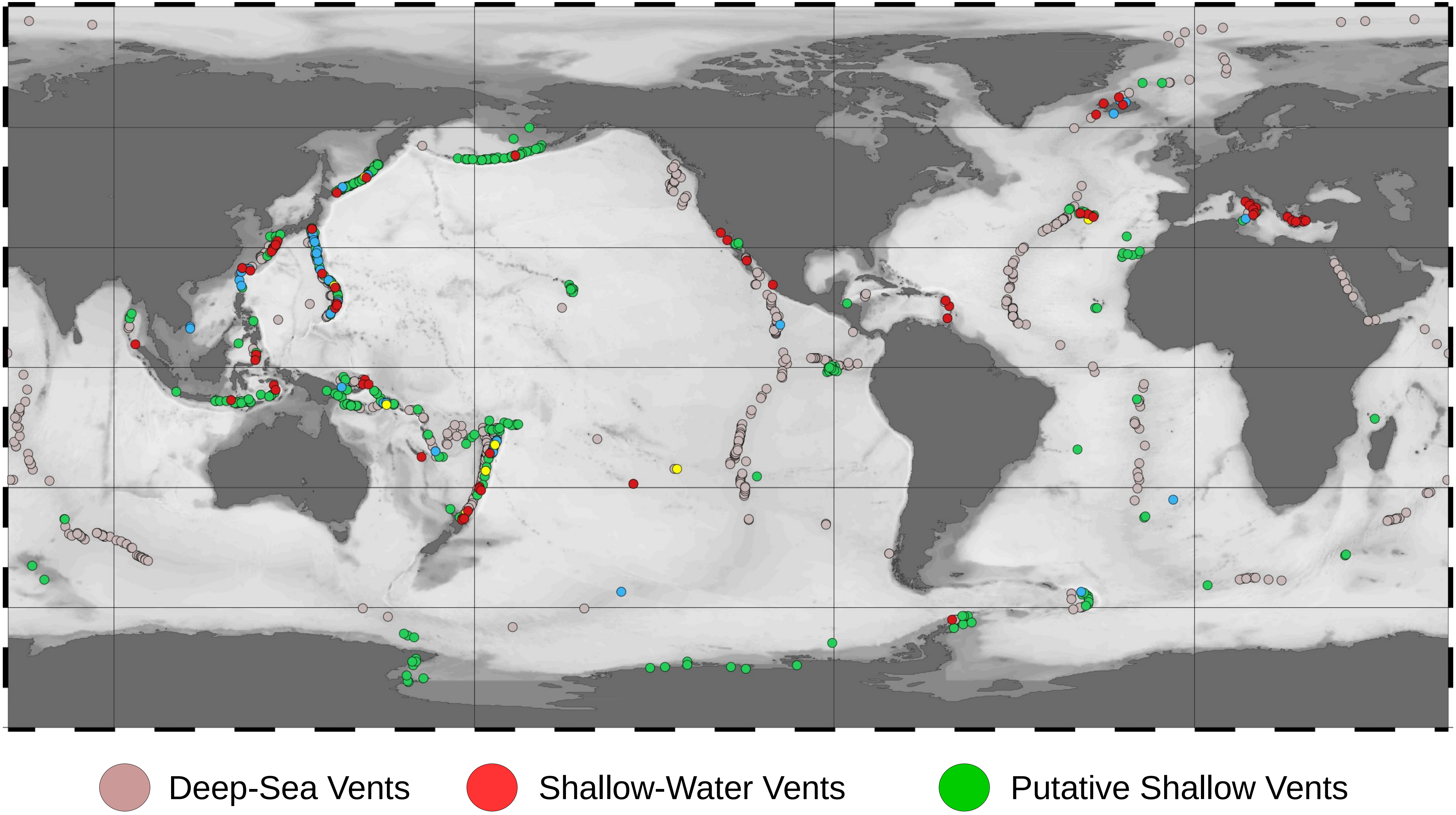


Fig. 3 Schematic of the hydrothermal processes at shallow-water hydrothermal vents and the additional dynamic drivers characteristic of their depth range distribution. (A) Low temperature water–rock reactions, (B) high temperature water–rock reactions, (C) magmatic volatile inputs, (D) phase separation, (E) continued water–rock reactions, and (F) degassing of dissolved volatiles, (G) terrigenous input of labile organic matter and phytodetritus, (H) wave action and storms, (I) penetration of light, and (J) tidal cycles.

Price and Giovannelli, 2017 ESSC

487 Putative shallow vent sites

(estimated)



Price and Giovannelli, 2017 ESSC

Milos (Greece) shallow vent, credits: Vetriani (Rutgers U)

Tor Caldara Biofilm, credit: Vetriani (Rutgers U)

Azores shallow vent, credits: Jorge Fontes

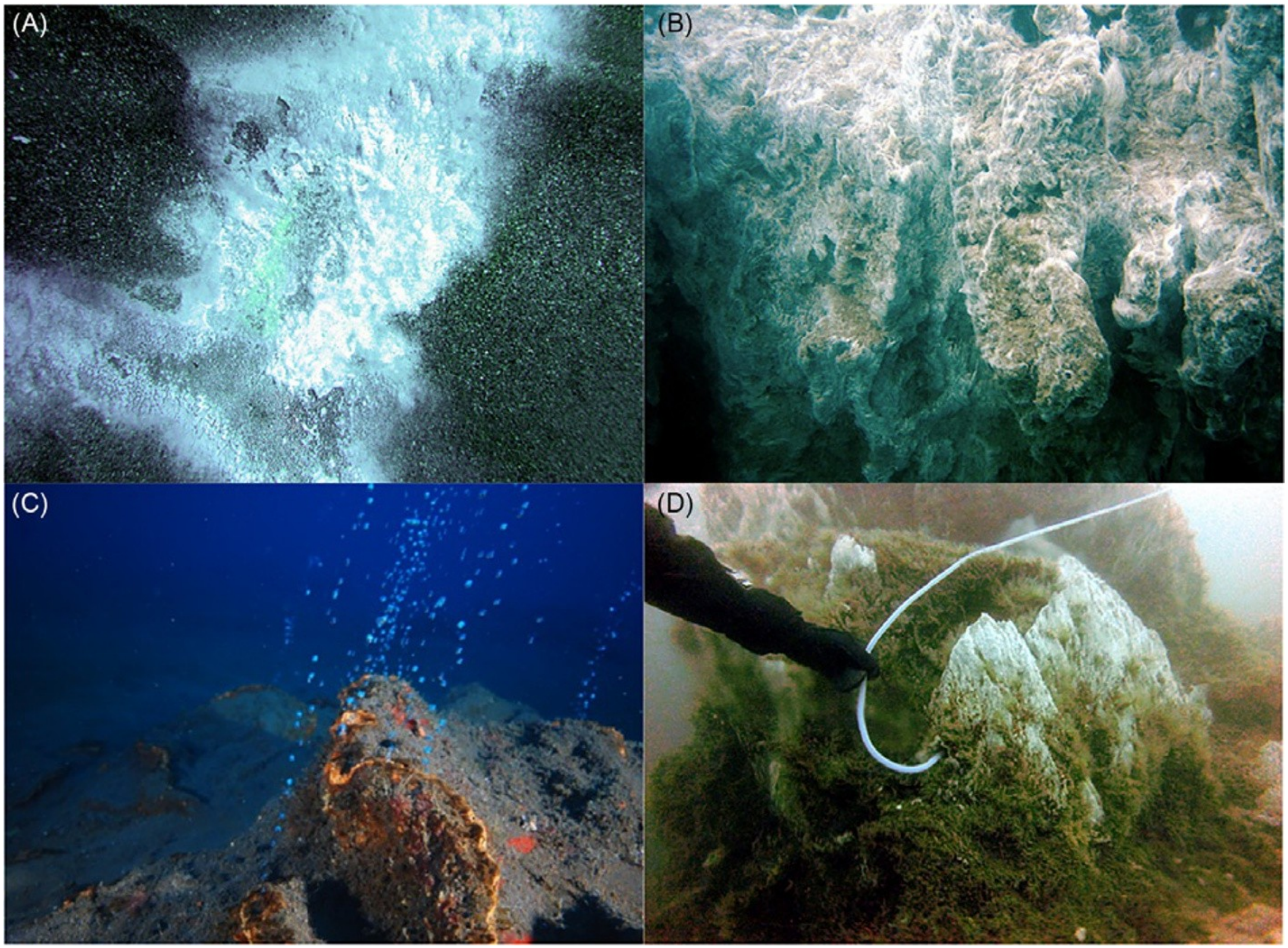

Iceland alkaline vents, credit: https://www.dive.is/

Panarea Island shallow vents, credits Giulia Bernardi/Giovannelli Lab

Types of shallow vents

high T
high S

low T
high S

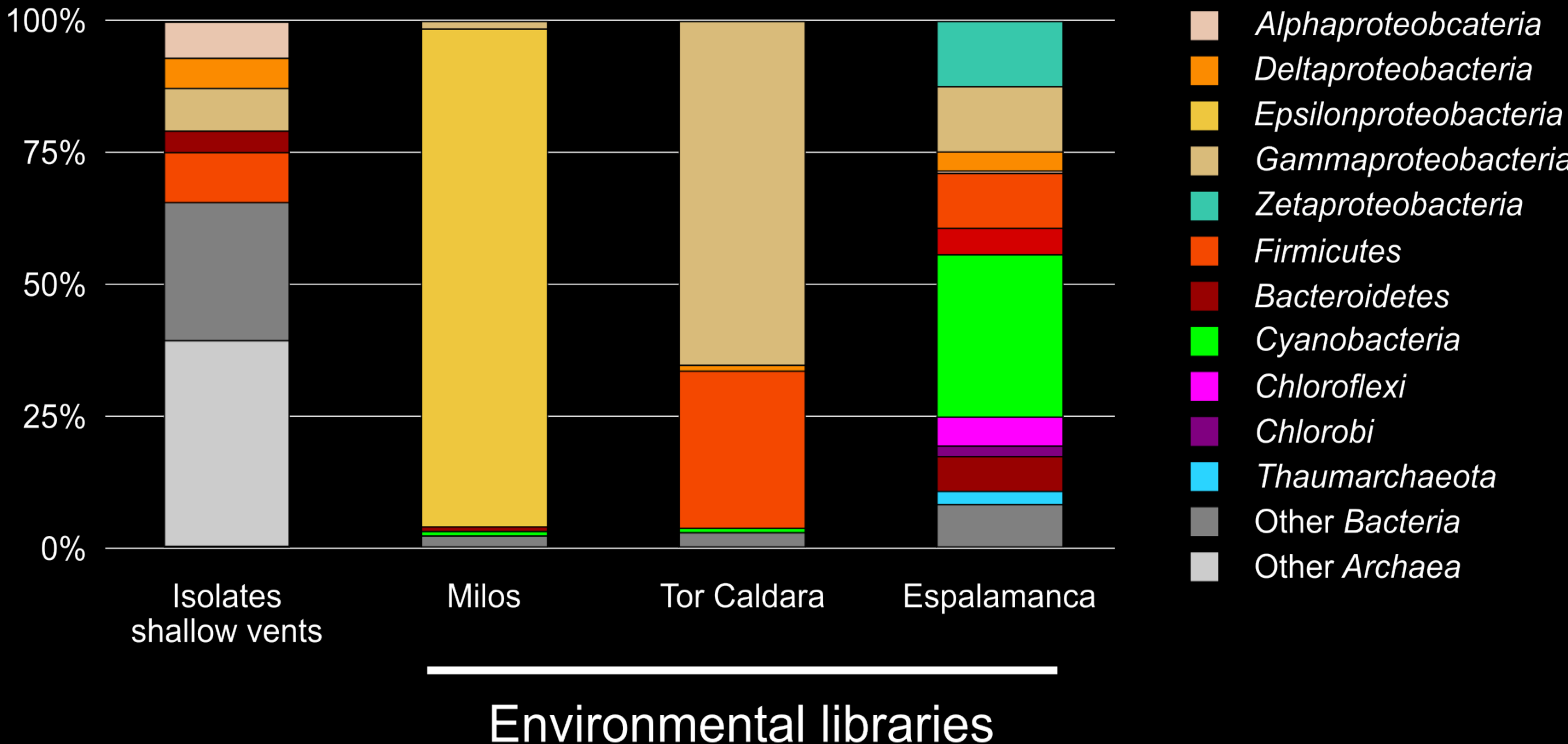


low S
high Fe

high pH

Giovannelli and Price, 2018 Enc. Ocean. Sci

Shallow vent diversity



Giovannelli et al, unpublished

This week reads

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