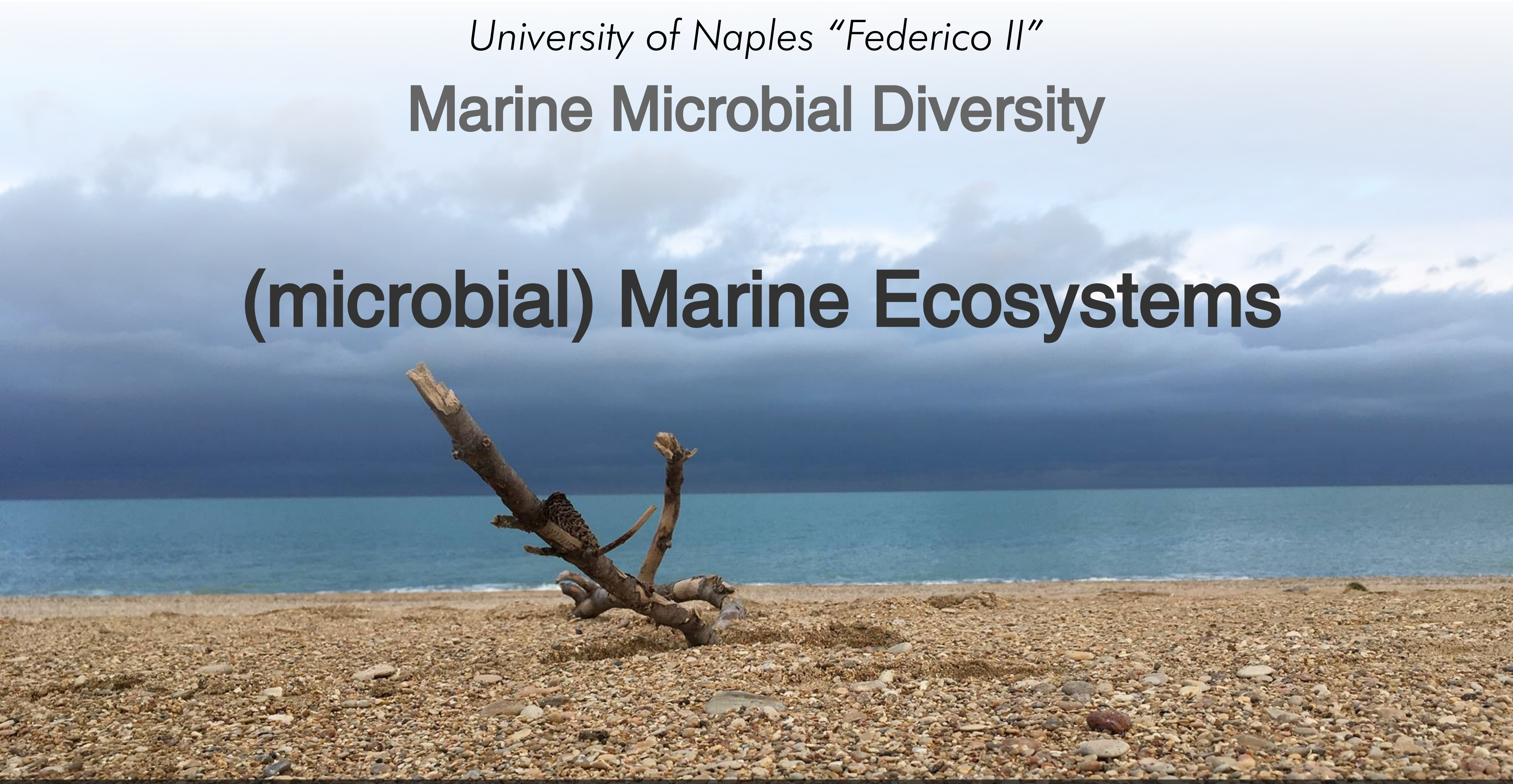
GIOVANNELLI LAB

University of Naples "Federico II"

Marine Microbial Diversity



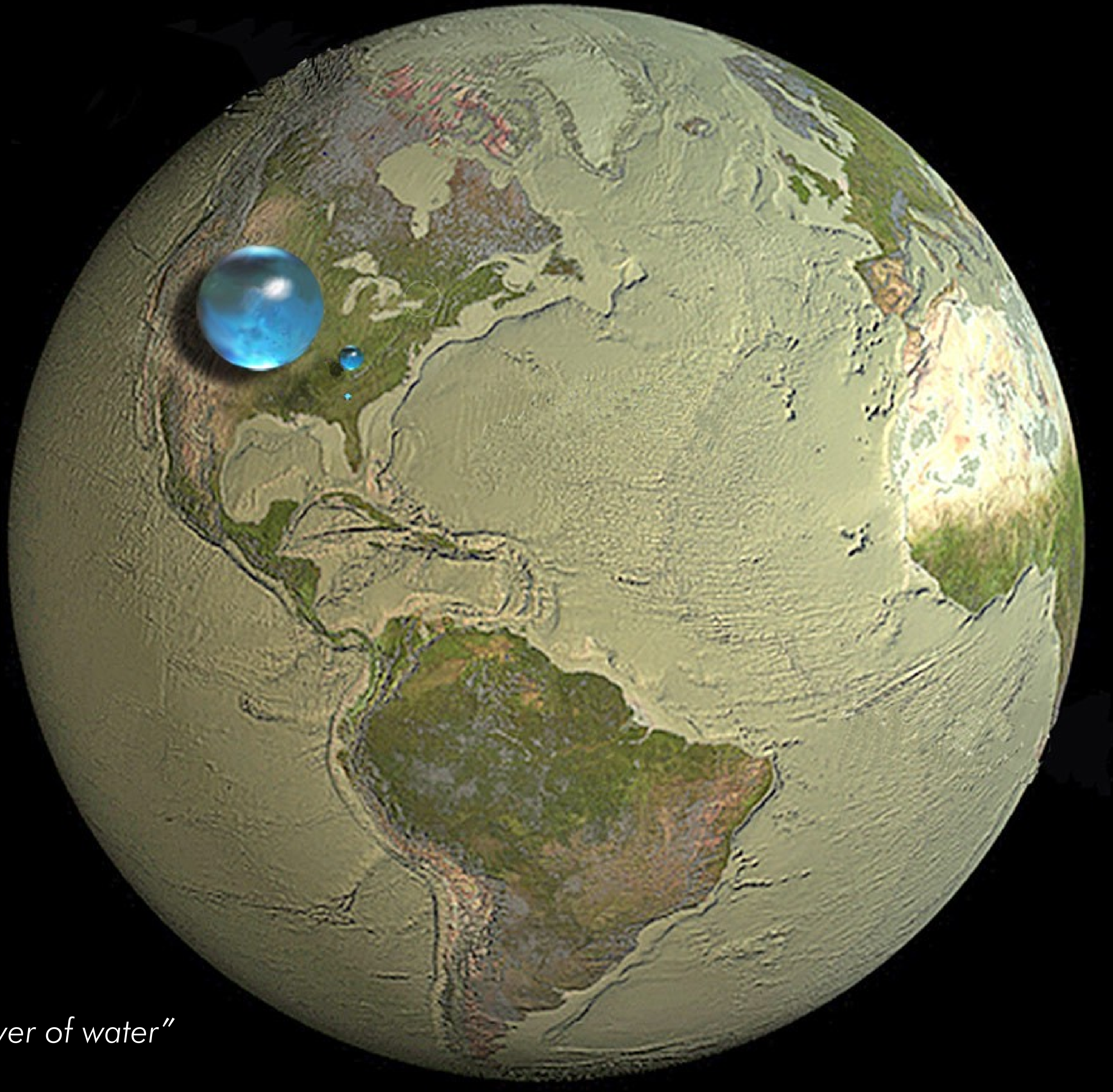
(microbial) Marine Ecosystems

donato.giovannelli@unina.it • @d_giovannelli • http://www.donatogiovannelli.com

NASA

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

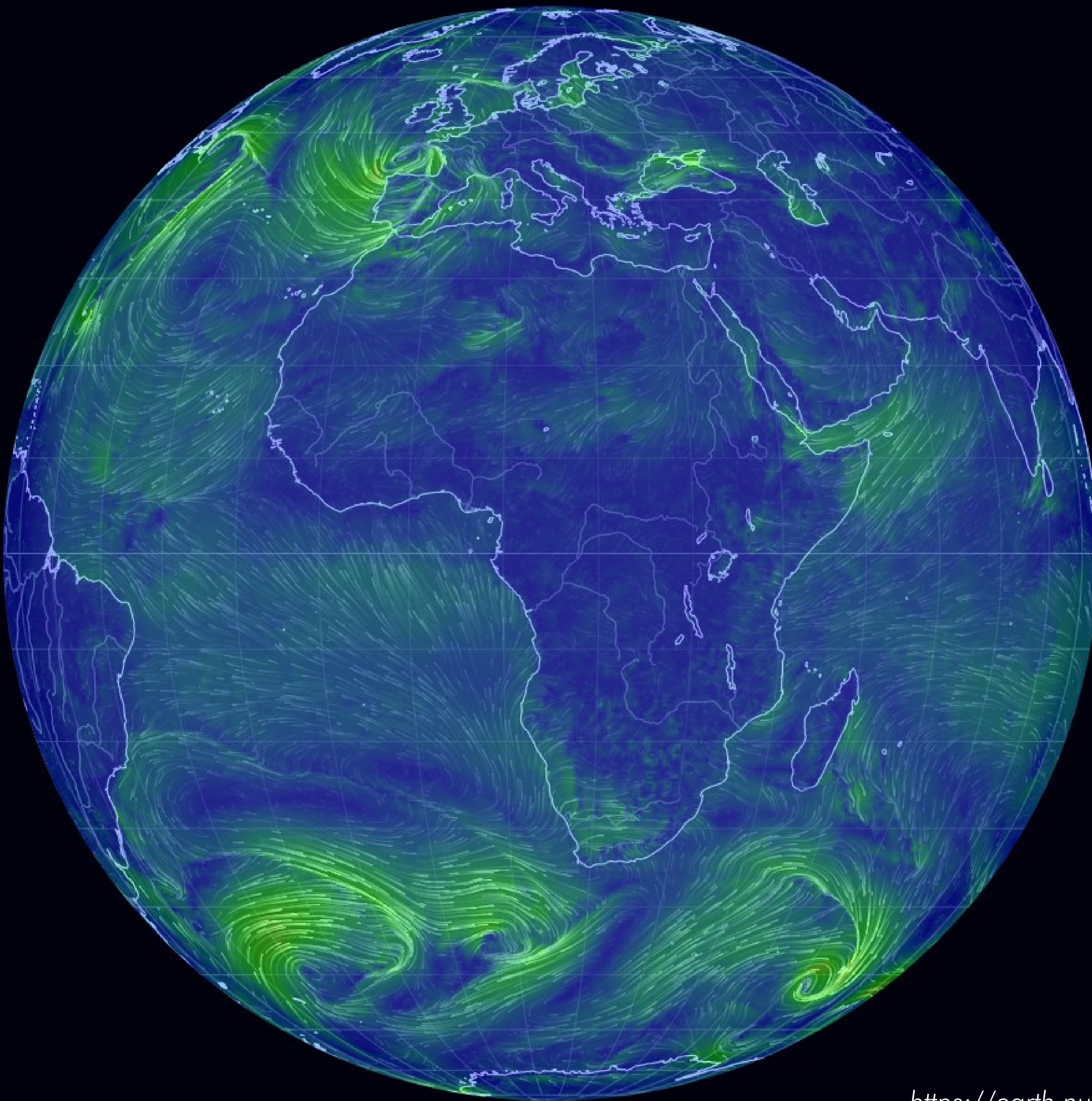


“A thin layer of water”

Seawater average composition

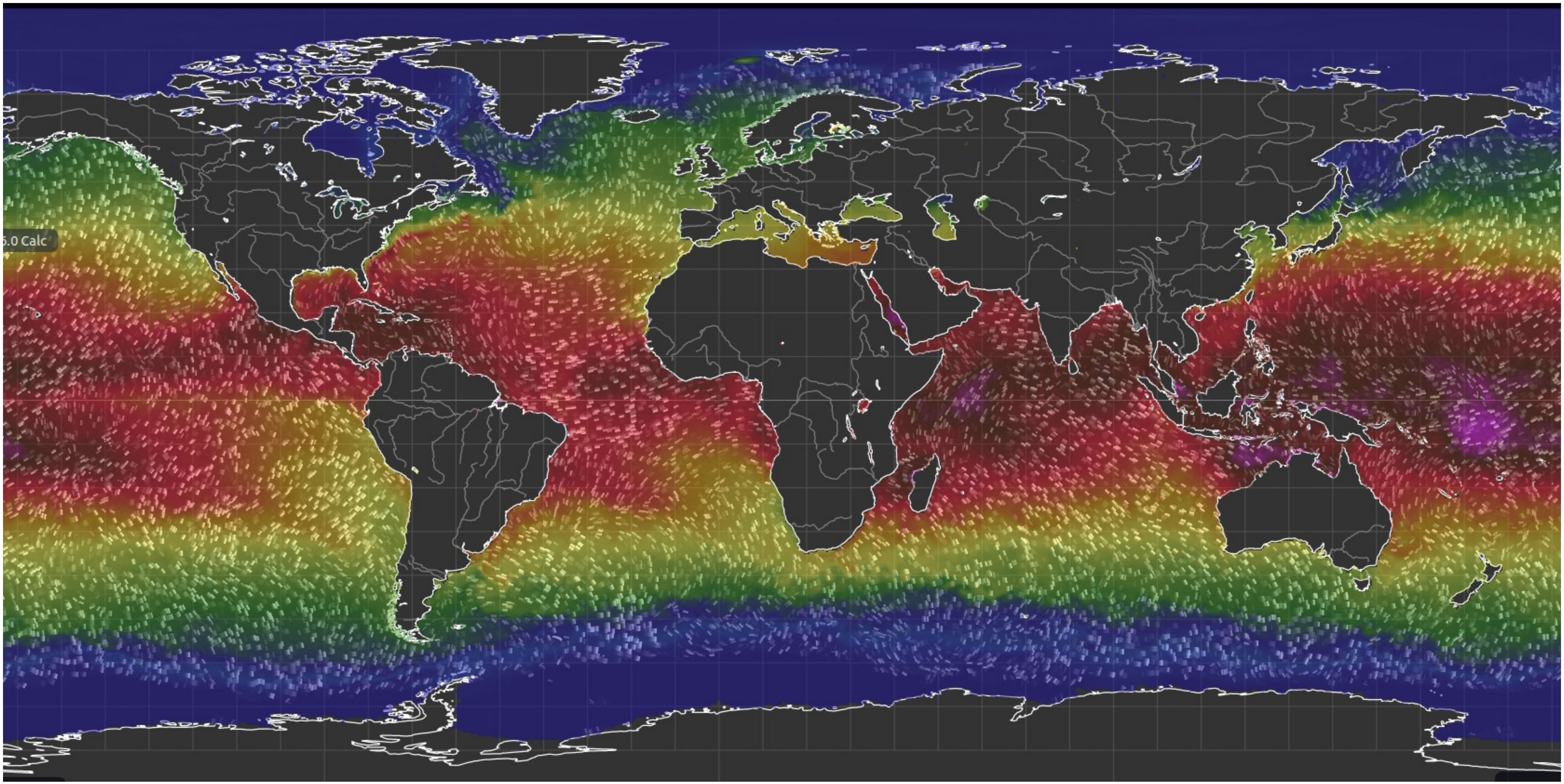
Table 9.2 The Major Dissolved Constituents of Seawater

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



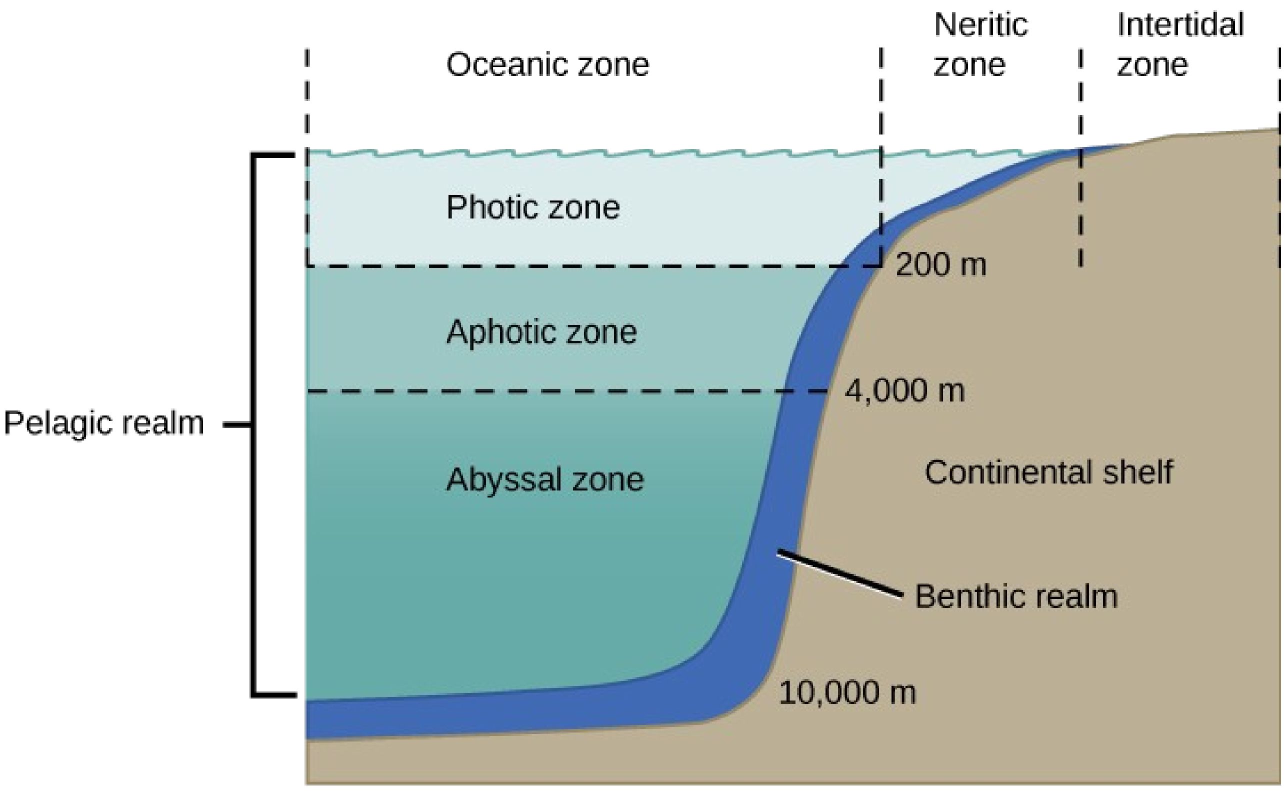
https://earth.nullschool.net/

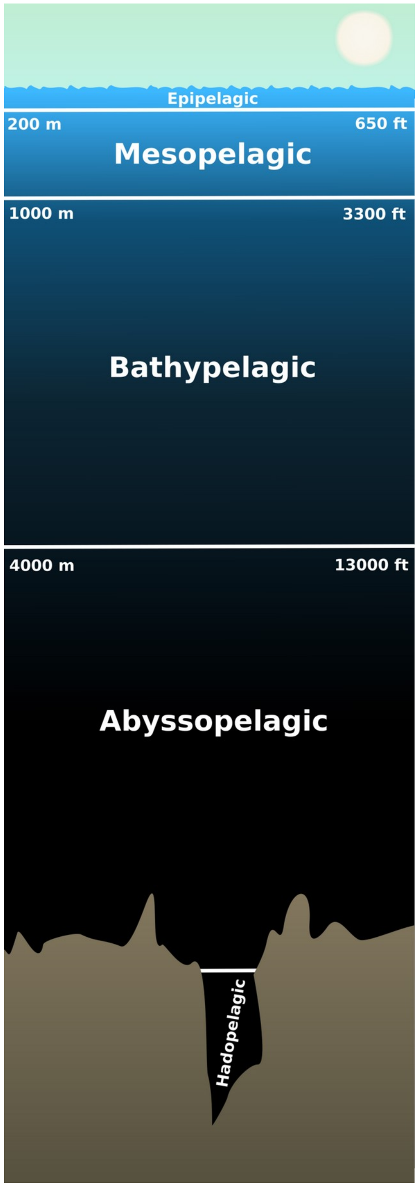
example: Sea Surface Temperature



Strong latitudinal gradients in physio-chemical variables

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

Subsurface: The subsurface is the ecological region below the seafloor. Although the actual starting depth is debated, it is currently set between 0.15 and 1 meters below sea floor (mbsf) and extends to high depths (several kilometers)

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).

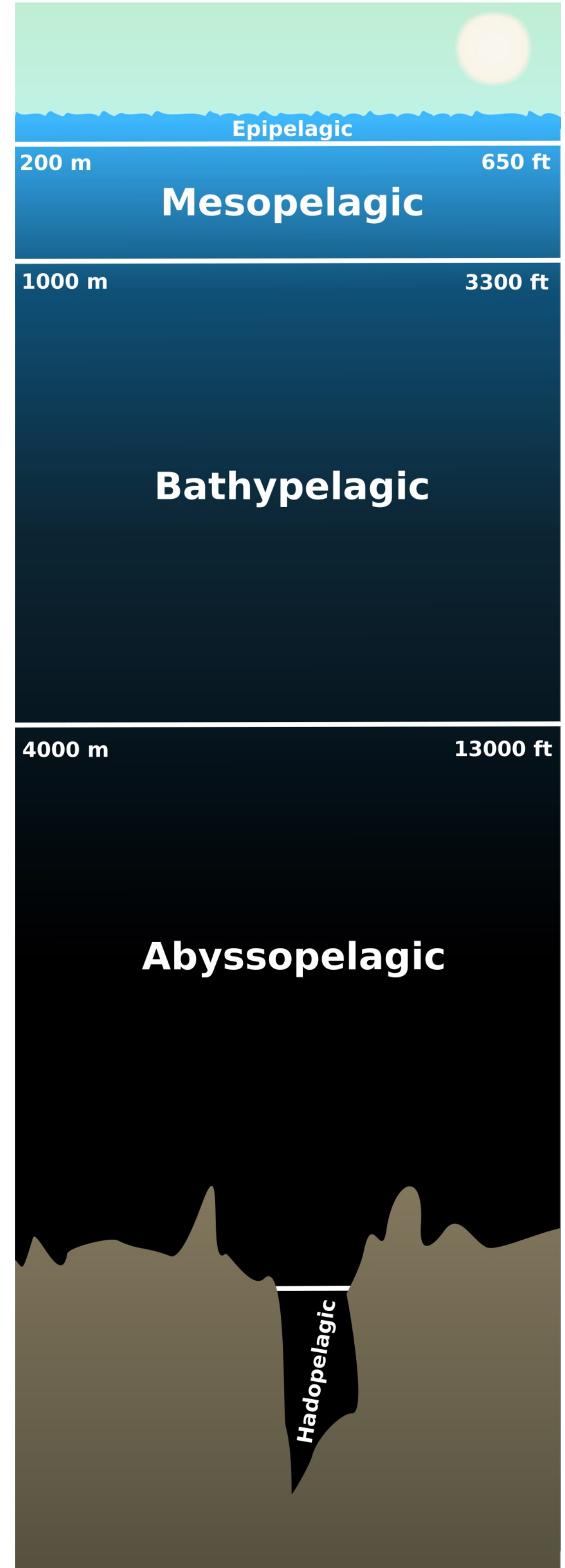
Epipelagic: up to 200 m depth, roughly corresponding to the euphotic zones and the depth at which the continental shelf breaks

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



(Surface) Primary Productivity

Primary production in the Marine Environment

Primary production (PP) is the synthesis of organic compounds from inorganic precursors, namely CO_2, HCO_3^- and CO. It occurs in the surface oceans and surface sediments within the photic zone through **photosynthesis. Chemosynthesis**, while also present in the photic zone in certain areas, is the primary production metabolism in the aphotic zone and subsurface. *Despite this, marine biologist commonly associate PP to photosynthesis only.*

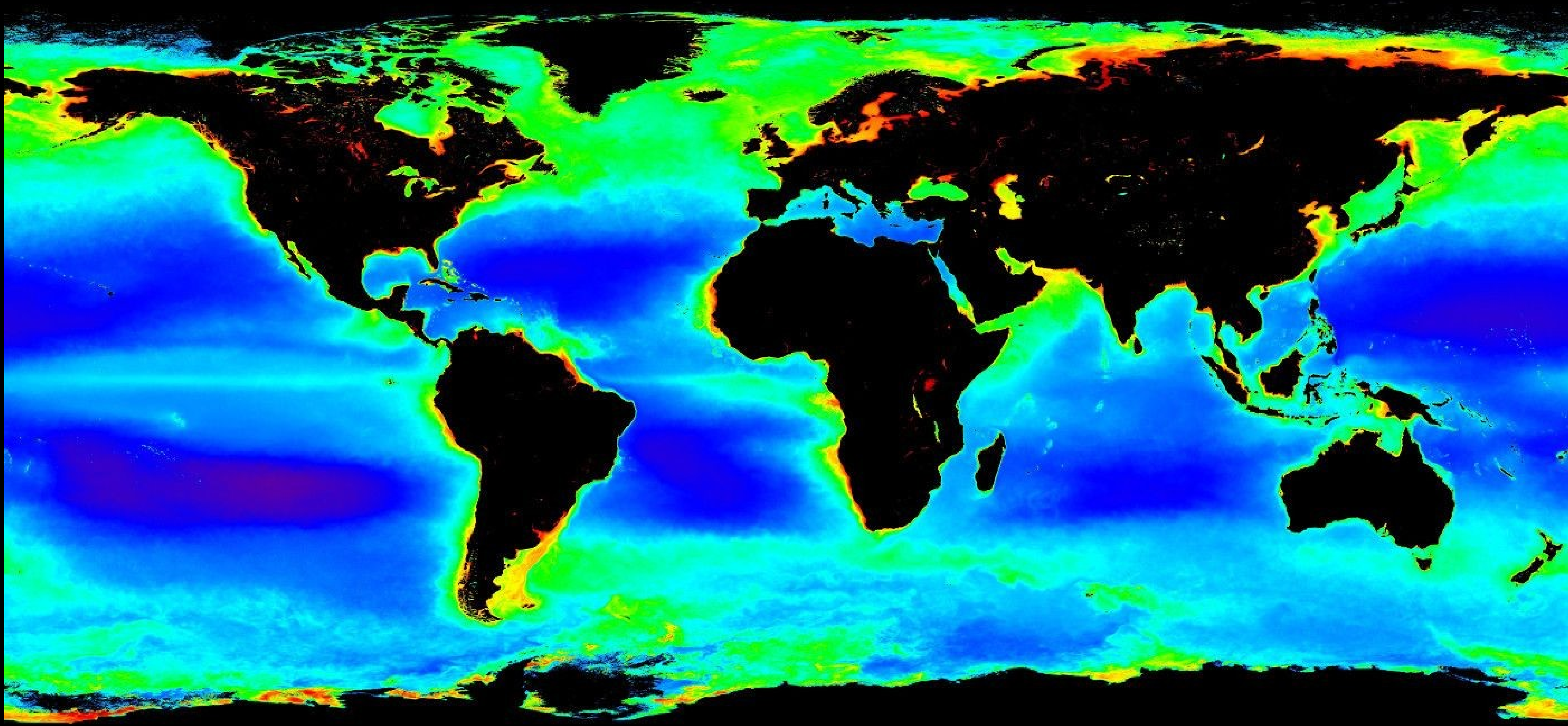
The organisms responsible for primary production are known as **primary producers** or **autotrophs**, and form the base of the food chain.

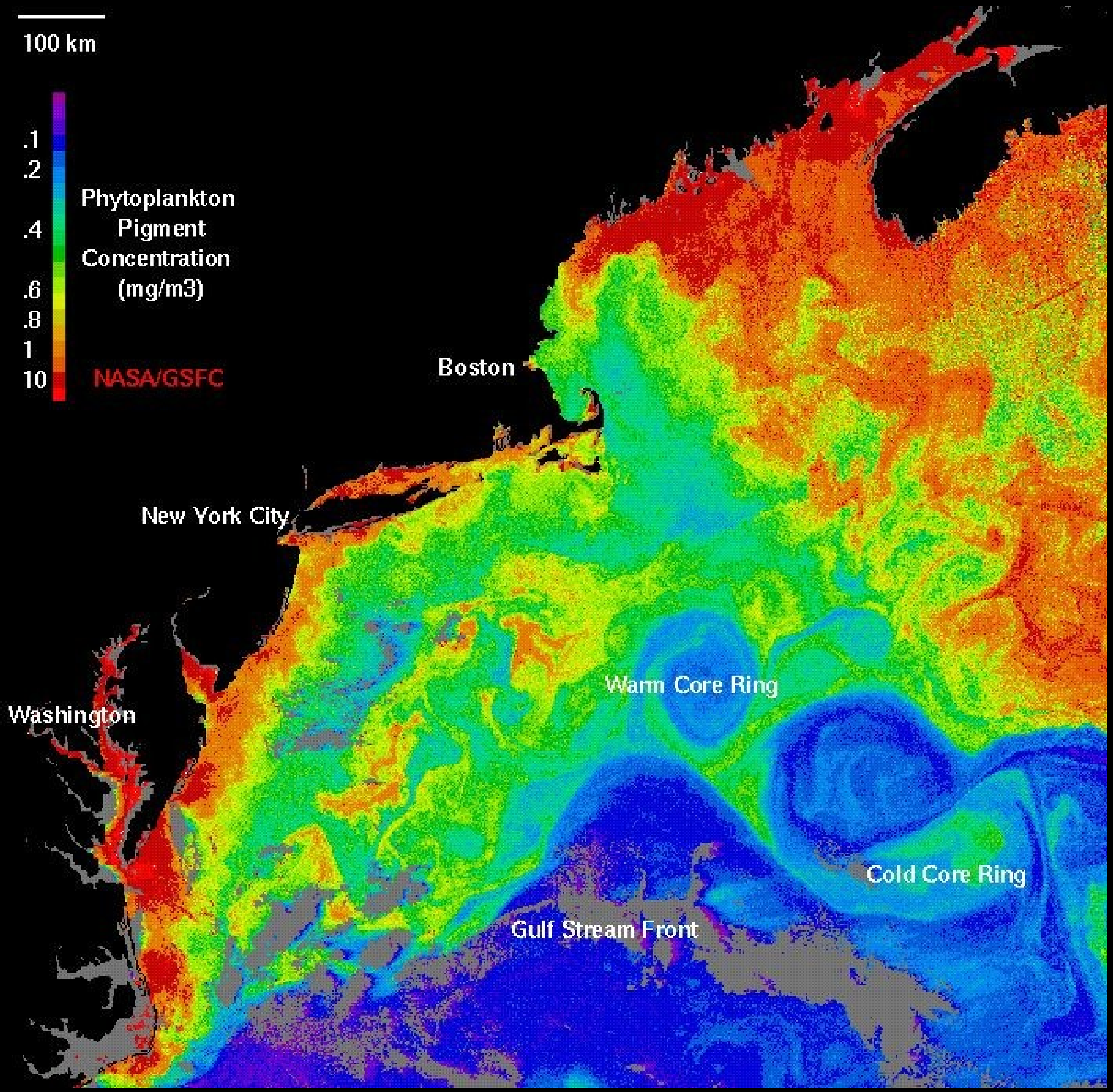
Gross *vs* Net Primary production

Gross primary production (GPP) is the amount of chemical energy as biomass that primary producers create in a given length of time. Some fraction of this fixed energy is used by primary producers for cellular respiration and maintenance of existing tissues (i.e., "growth respiration" and "maintenance respiration").

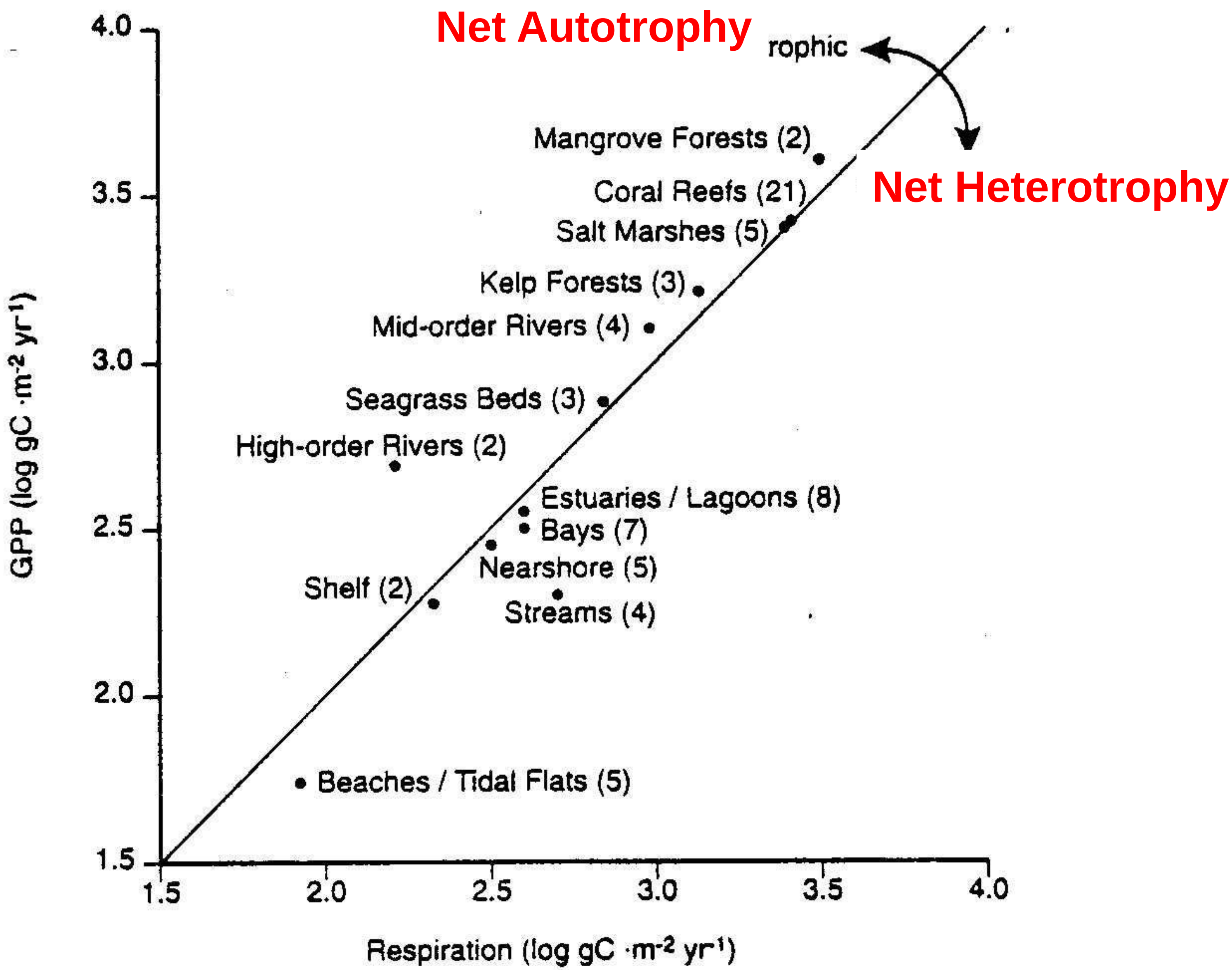
Net primary production (NPP) is the rate at which all the primary producers in an ecosystem produce net useful chemical energy. It is equal to the difference between the GPP and the rate at which they use some of that energy during respiration.

Surface Primary Production




100 km
.1
.2
.4
.6
.8
1
10
Phytoplankton
Pigment
Concentration
(mg/m3)
NASA/GSFC
Boston
New York City
Washington
Warm Core Ring
Cold Core Ring
Gulf Stream Front

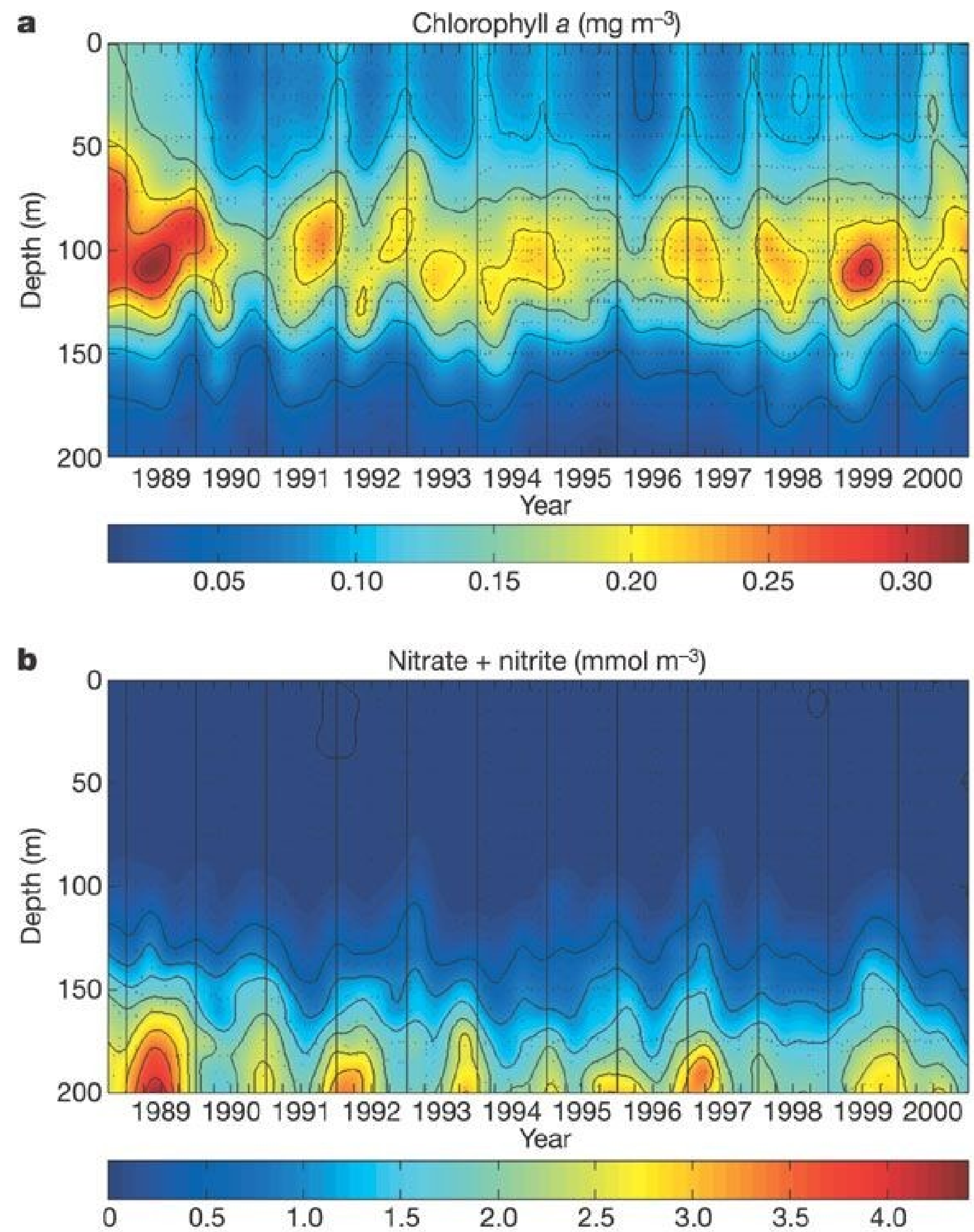
Primary production Vs Respiration



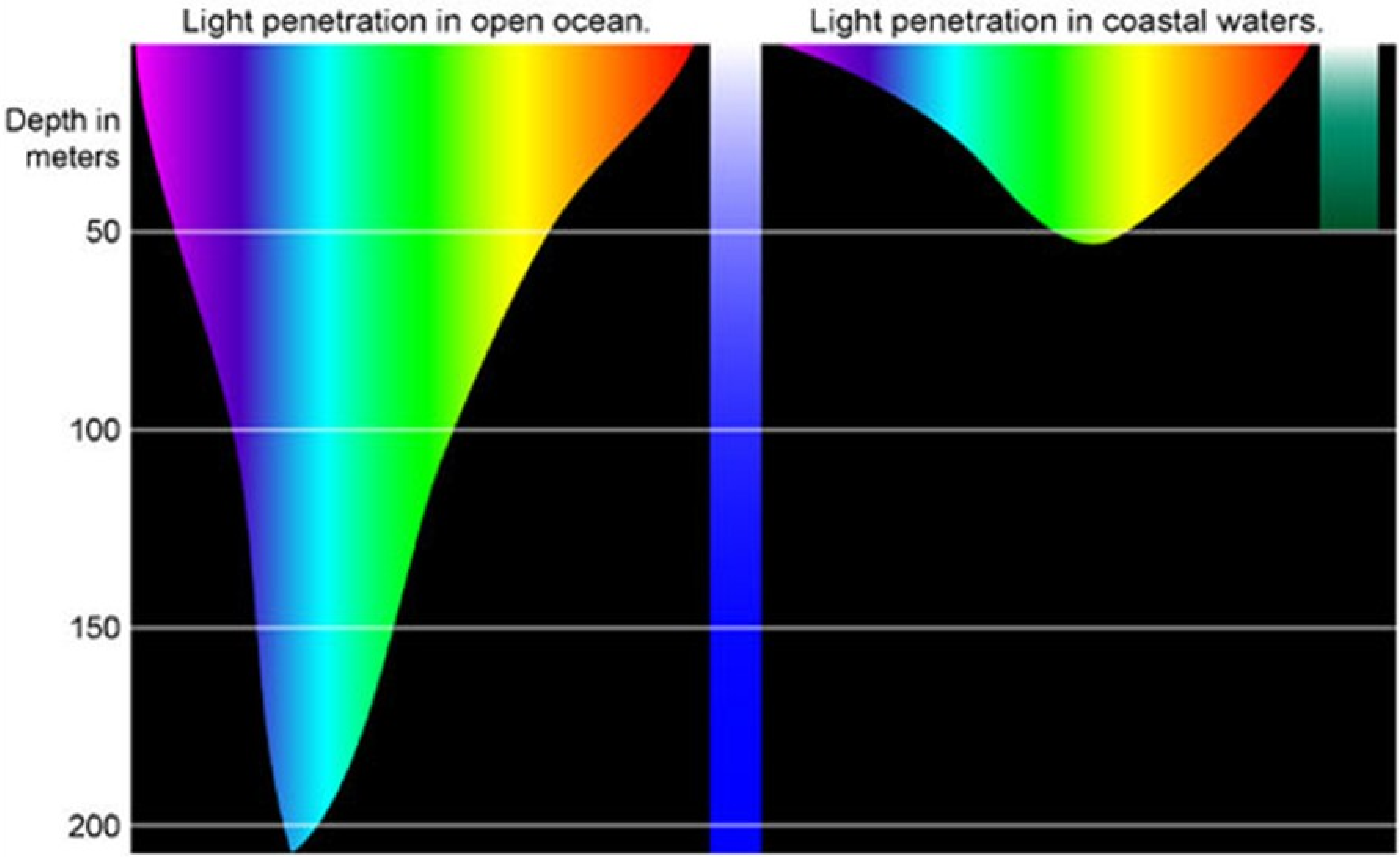
Factor limiting surface primary production

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

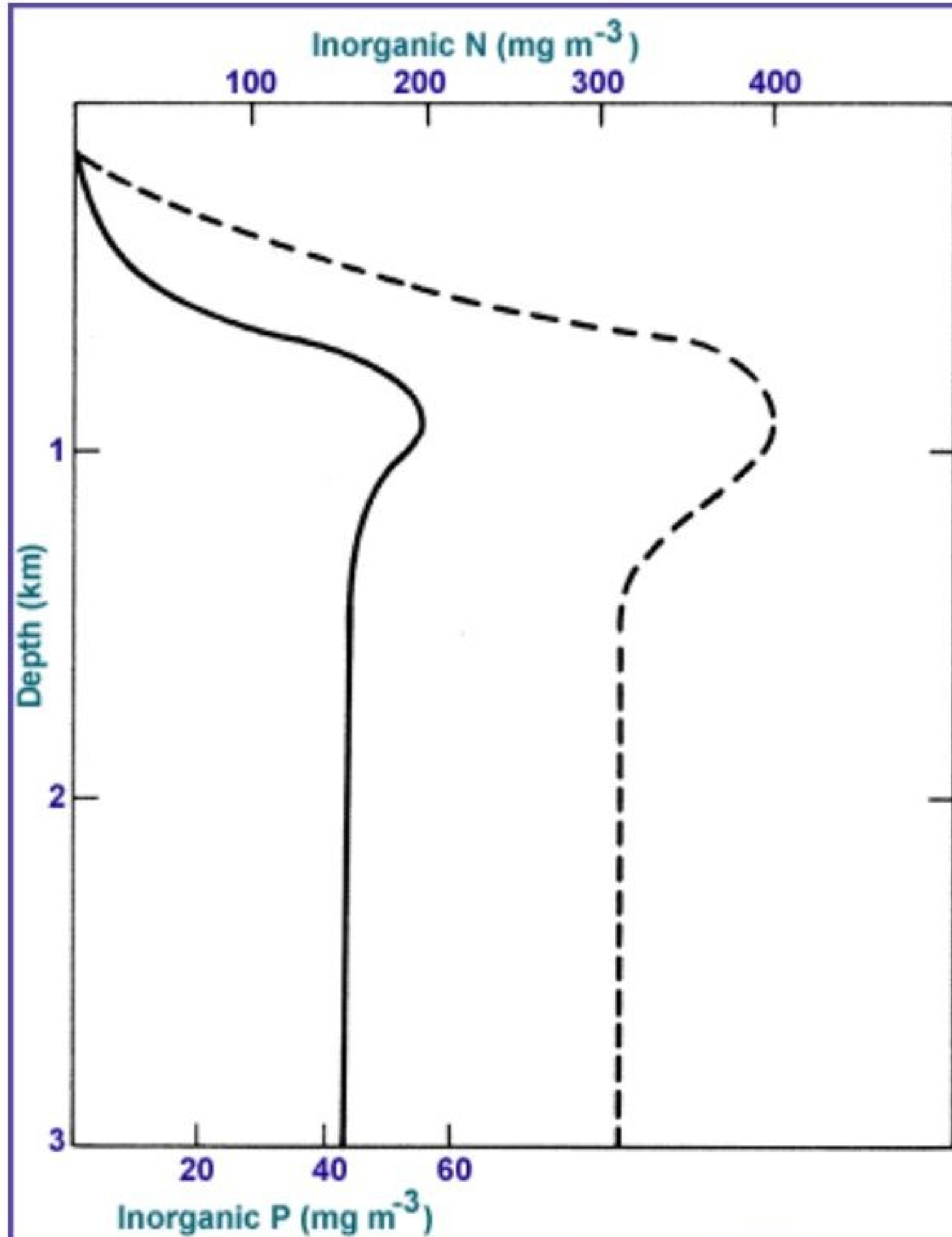


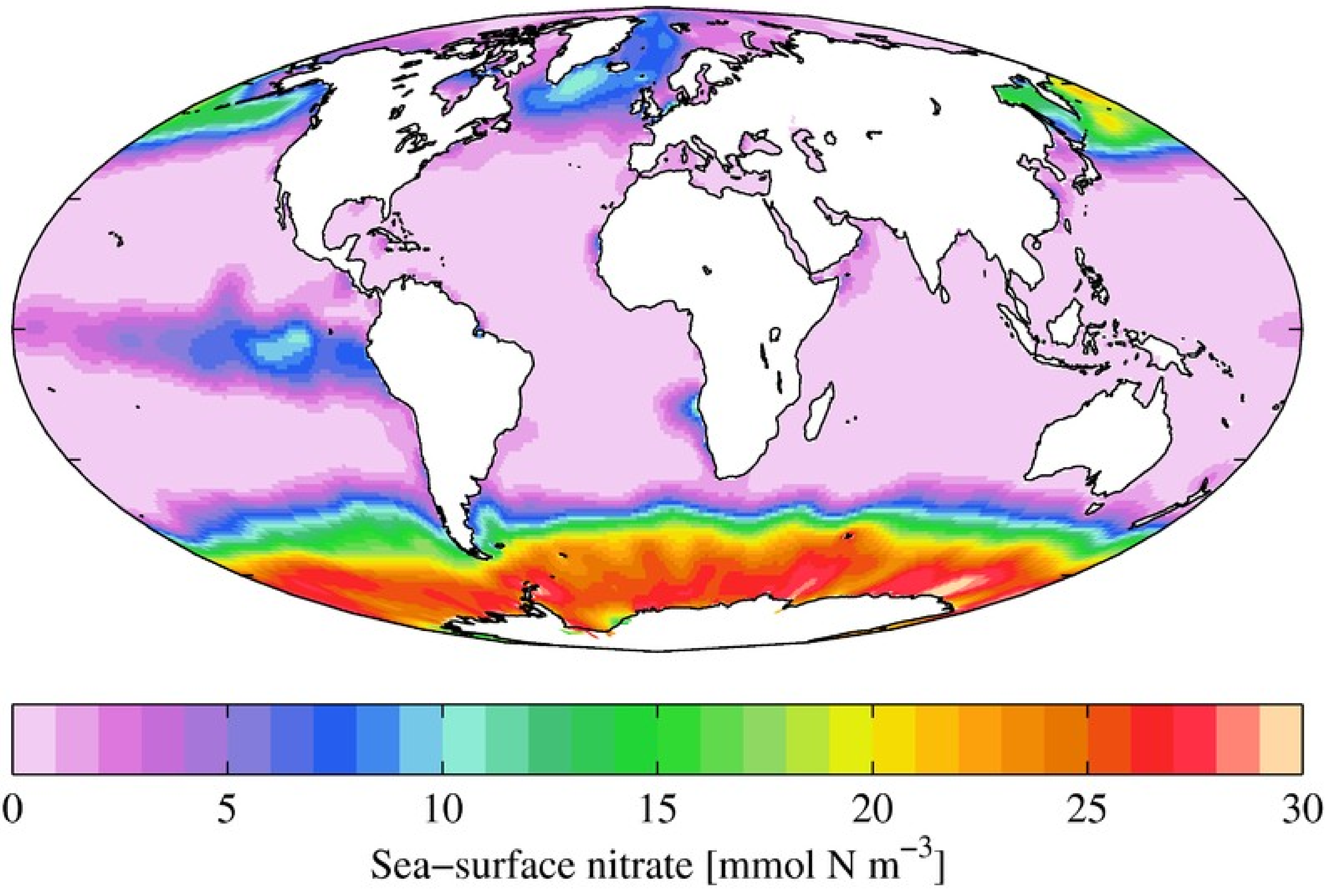
Limitation of PP

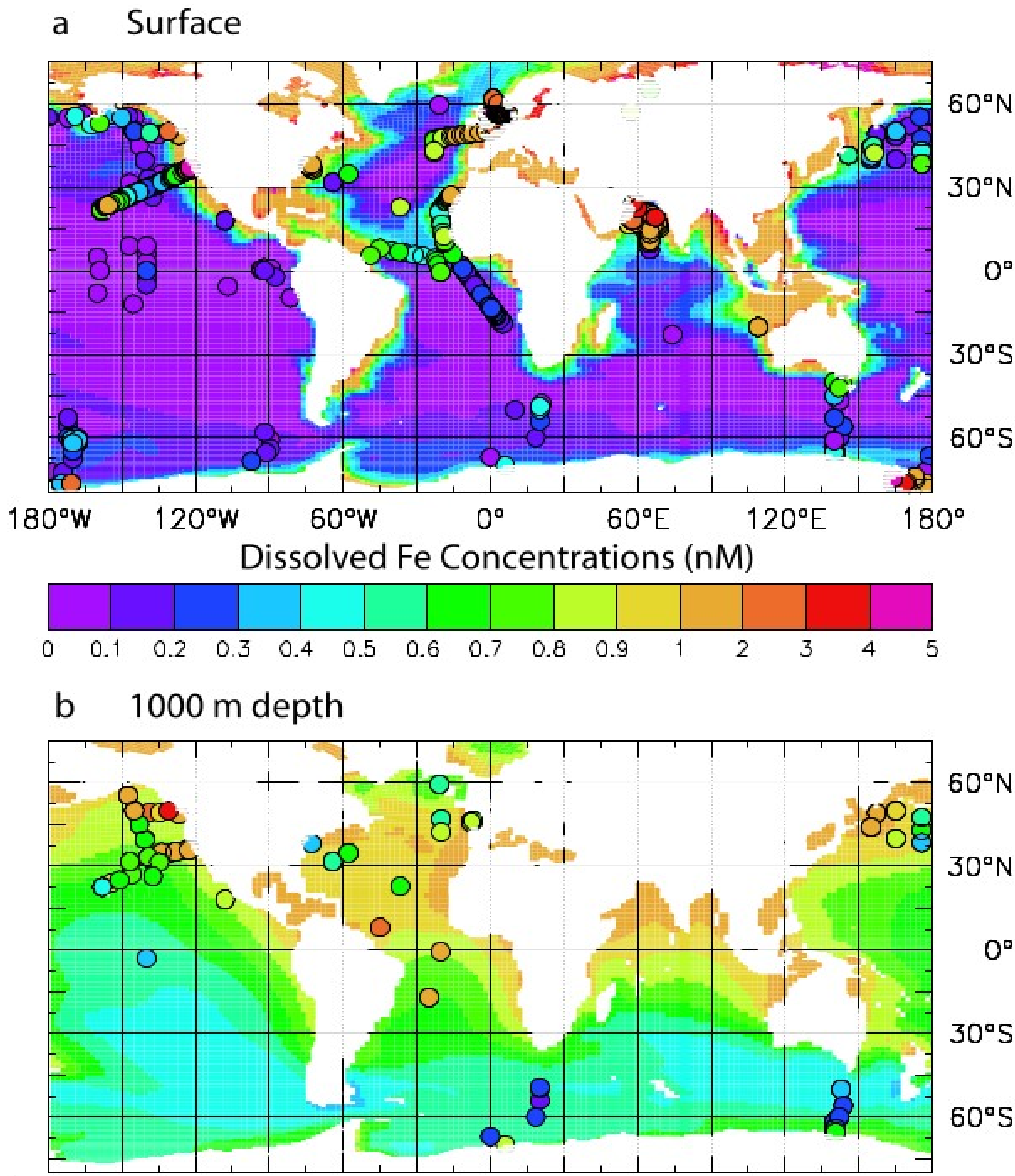
Different nutrient might limit different types of primary productivity.

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.

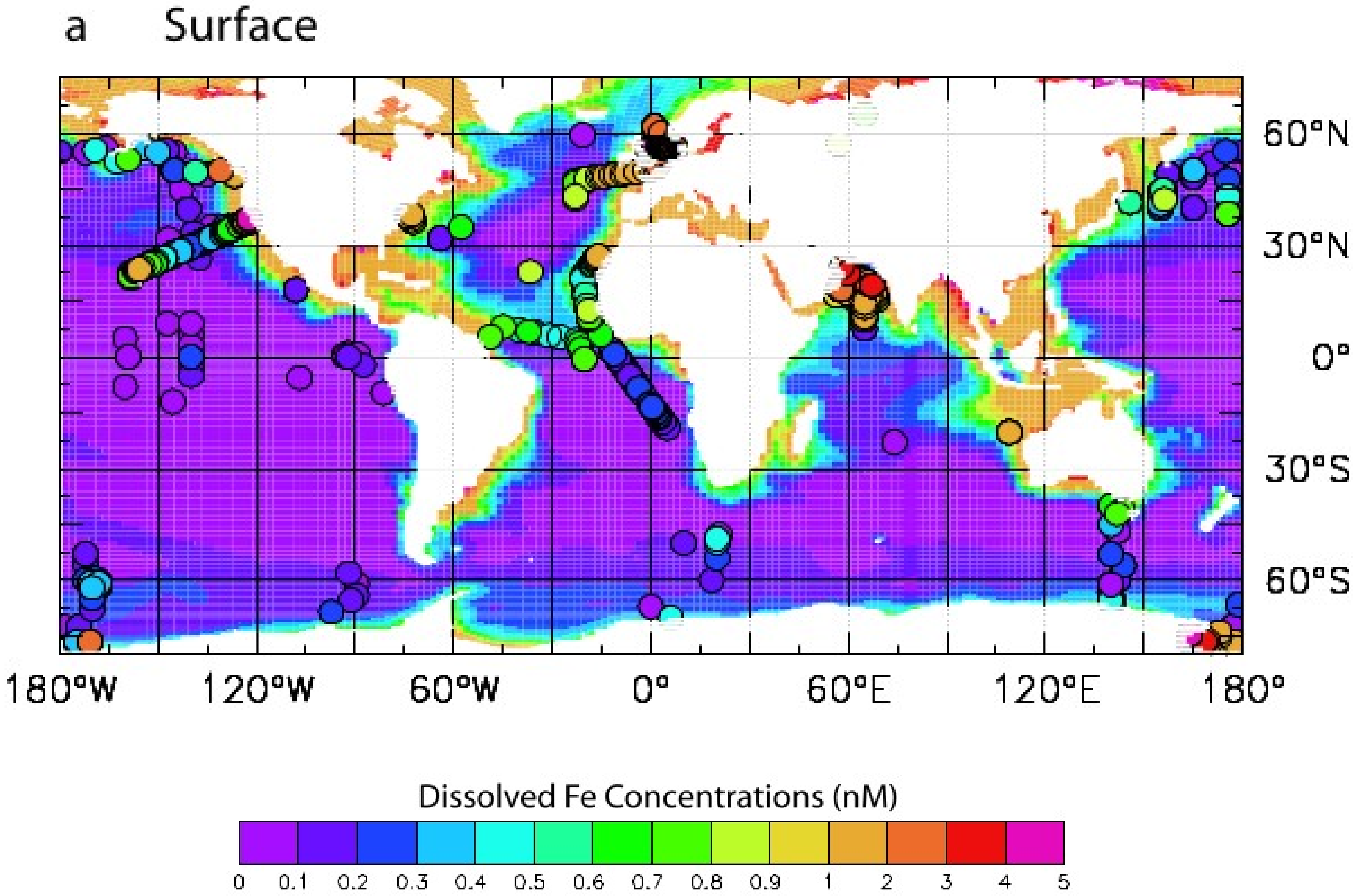
For example, nitrate limits photosynthetic PP in the temperate oceans, while iron limits photosynthetic PP at high-latitude during the summer. In the winter at those latitude light is the limiting factor. Dissolved silica might limit diatoms PP, while available NH_4^+ might limit Ammonia Oxidizers PP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

THE MOST IMPORTANT NUTRIENT IS THE LIMITING NUTRIENT

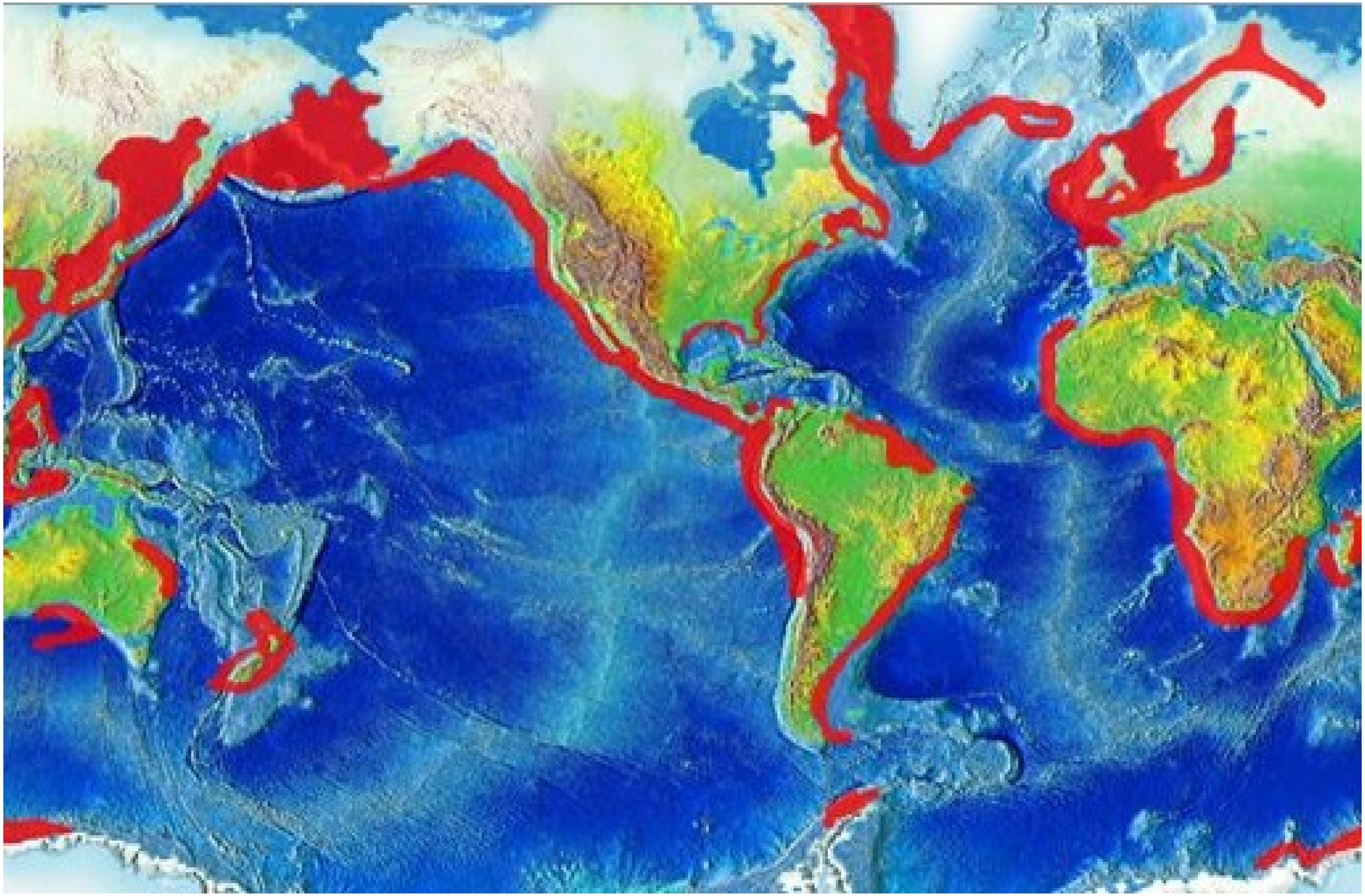
example: Iron limitation

Iron is an important cofactor in biological systems, and it is used by photosynthesizing microorganisms as a co-fatcor for nitrogen fixation and other important cellular functions.

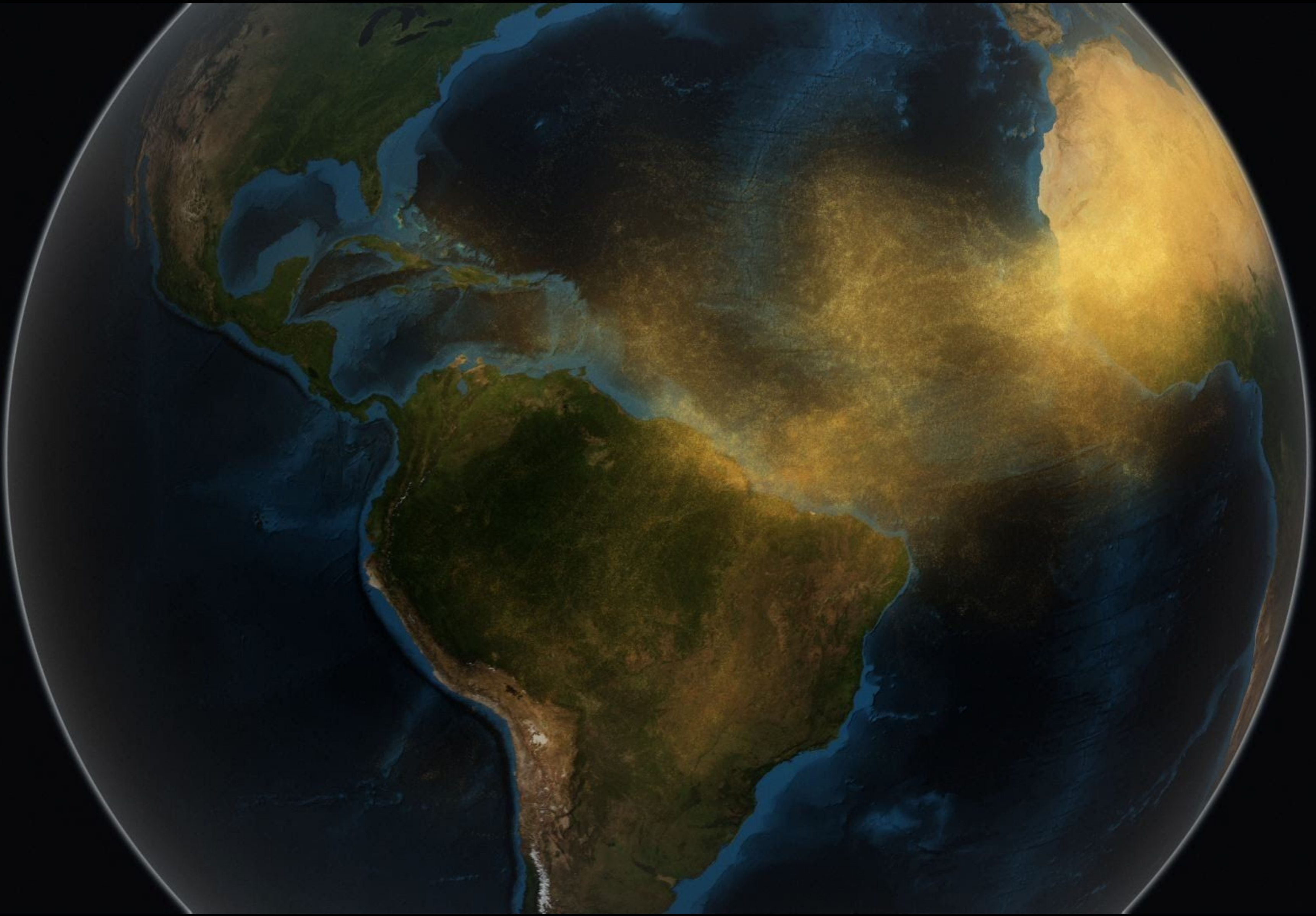
Iron is a scarce solute in seawater, and the abundance of dissolved oxygen in seawater means that what little iron is present in the ocean is typically oxidized iron, Fe^{3+}. This oxidized Fe forms inert iron oxides and hydroxides and is thus essentially not available to photosynthesizing organisms. Fe^{2+}, the reduced form of iron, is more soluble and thus more biological reactive – but it also oxidize very rapidly.


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

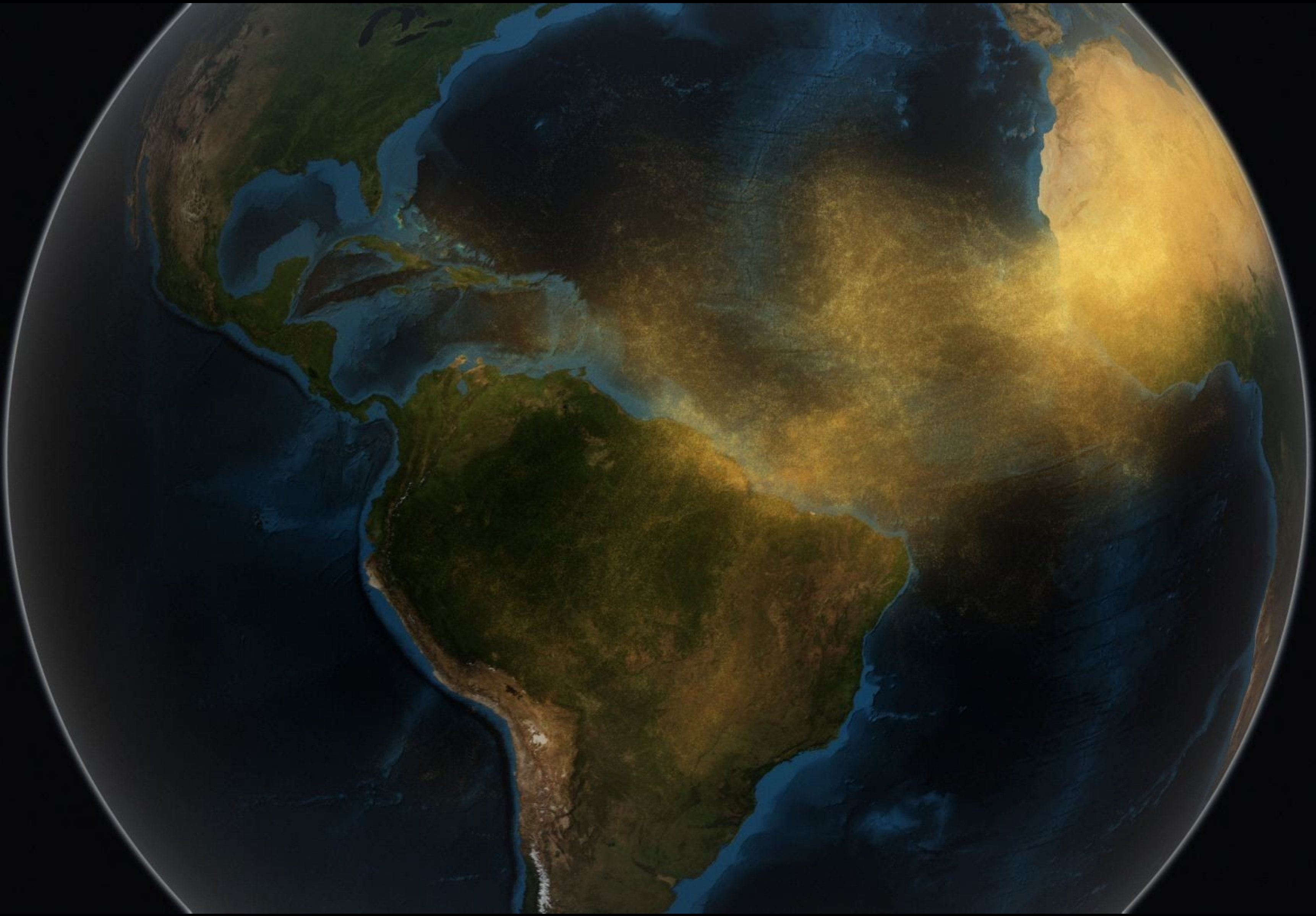
Upwelling zones

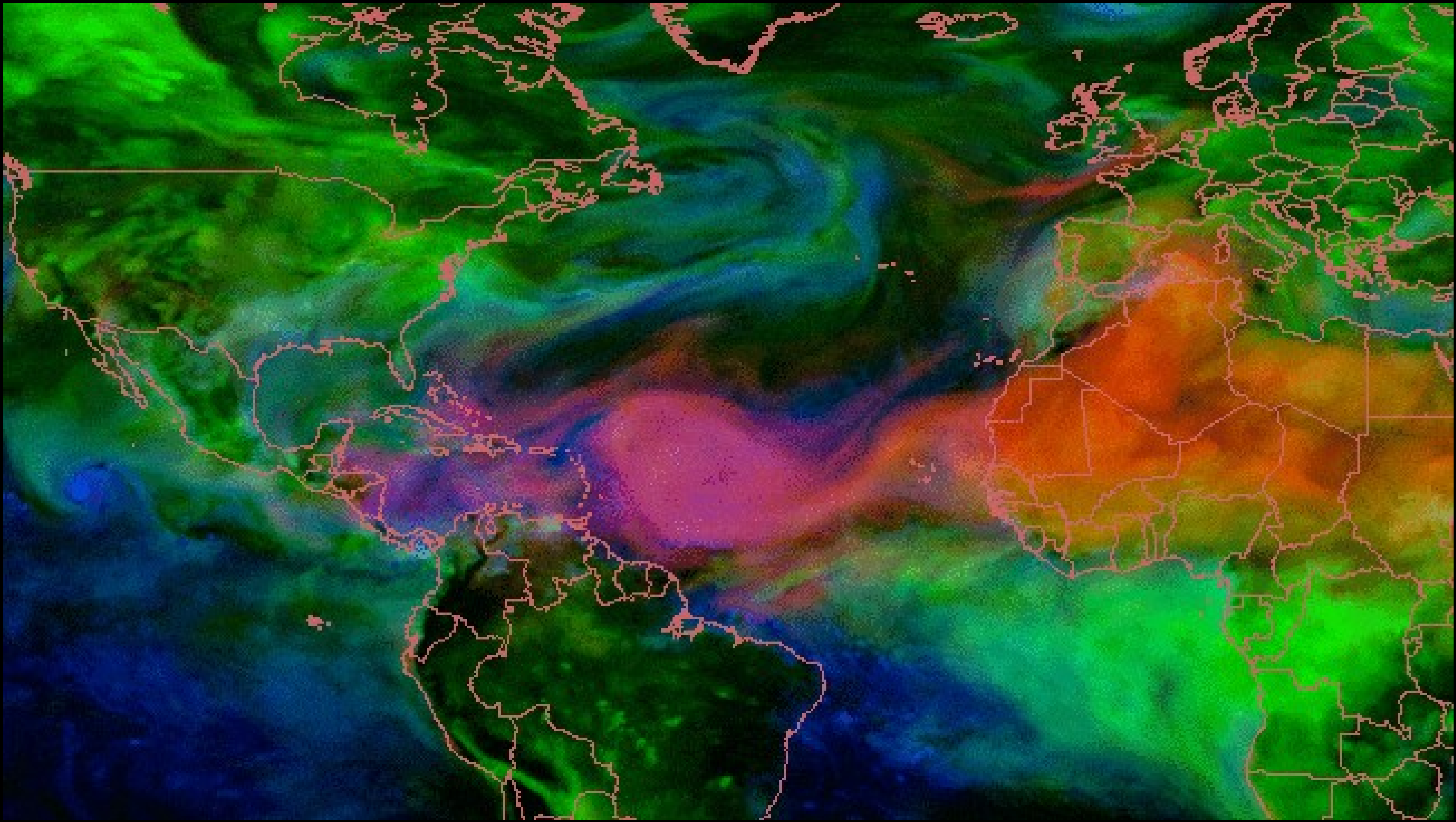


Upwelling zones cover ~5% of world oceans



Dust fertilizing the oceans





Exports to the seafloor

Primary production: POM and DOM

Primary production is not just accumulated in cell biomass. Phytoplankton contributes to total carbon fixed to the environment with the exudation and excretion of organics.

Both the exuded and excreted carbon, the carbon released during grazing and cell lysis (also virus induced) and the cell debris contribute to the Dissolved and Particulated Organic Matter pools (DOM and POM).

Each of the pool is constituted by the Carbon, Nitrogen and Phosporous fraction (for example DOC, DON and DOP for the dissolved fraction).

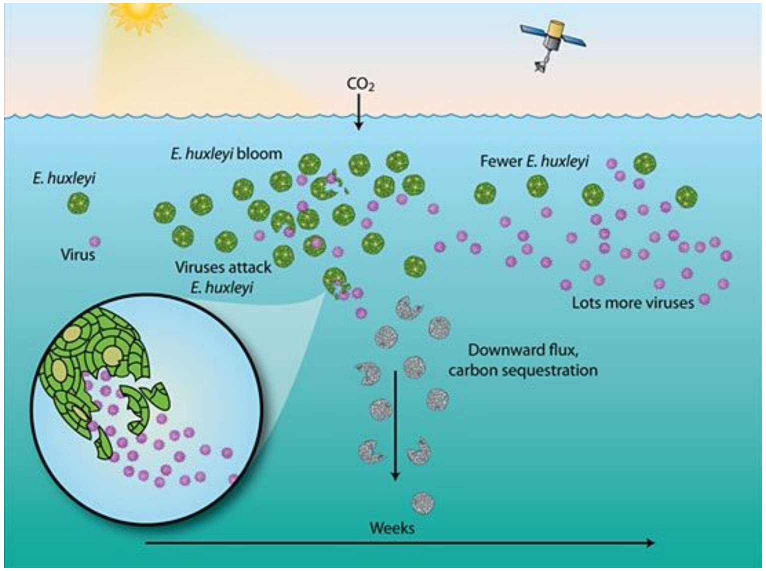
DOM and POM are an empirical division (with practical implications), based on a 0.45 μm filter cut-off.

DOM and POM

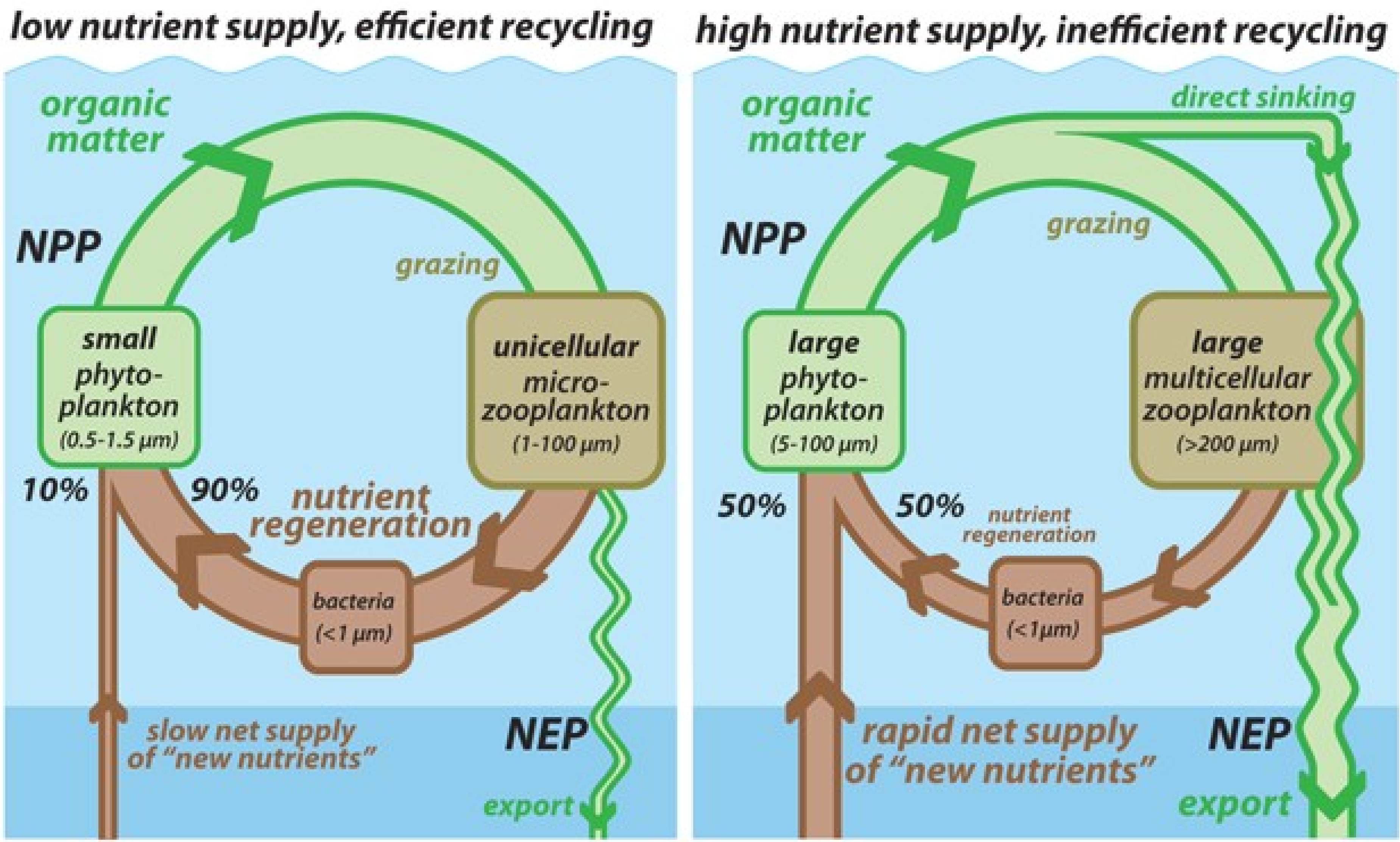
DOM and POM, while size partitioned, are a continuum in nature. The main (practical difference) resides in their sinking behavior.

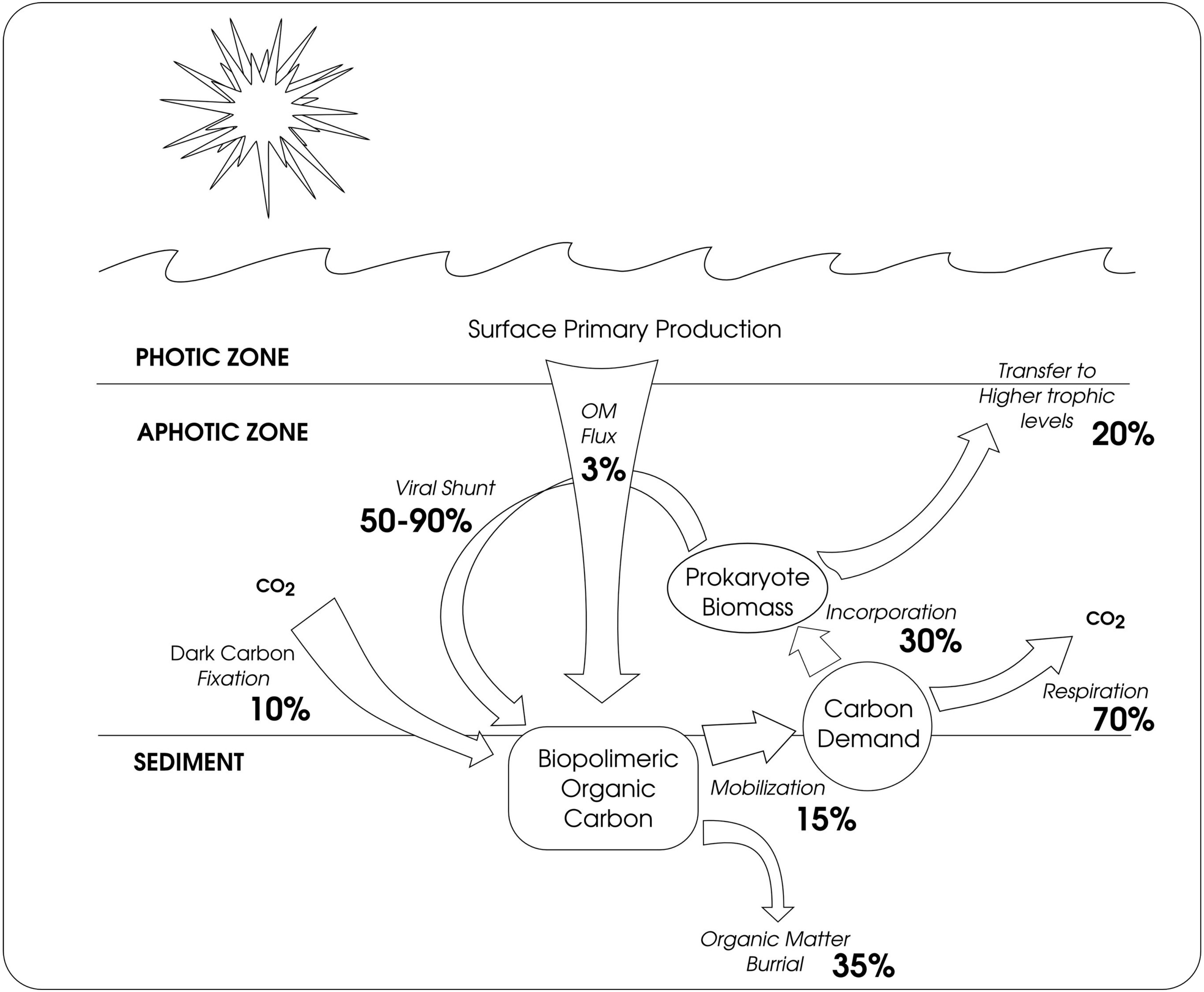
POM, constituted by cells, fecal pellets and cell debris, sinks efficiently, although different particles have different velocities. POM constitute one of the main export to the deep-sea floor.

DOM on the other hands, constituted by DNA and small soluble molecules, viruses and picoplankton, does not sink.



Export efficiency and the microbial loop

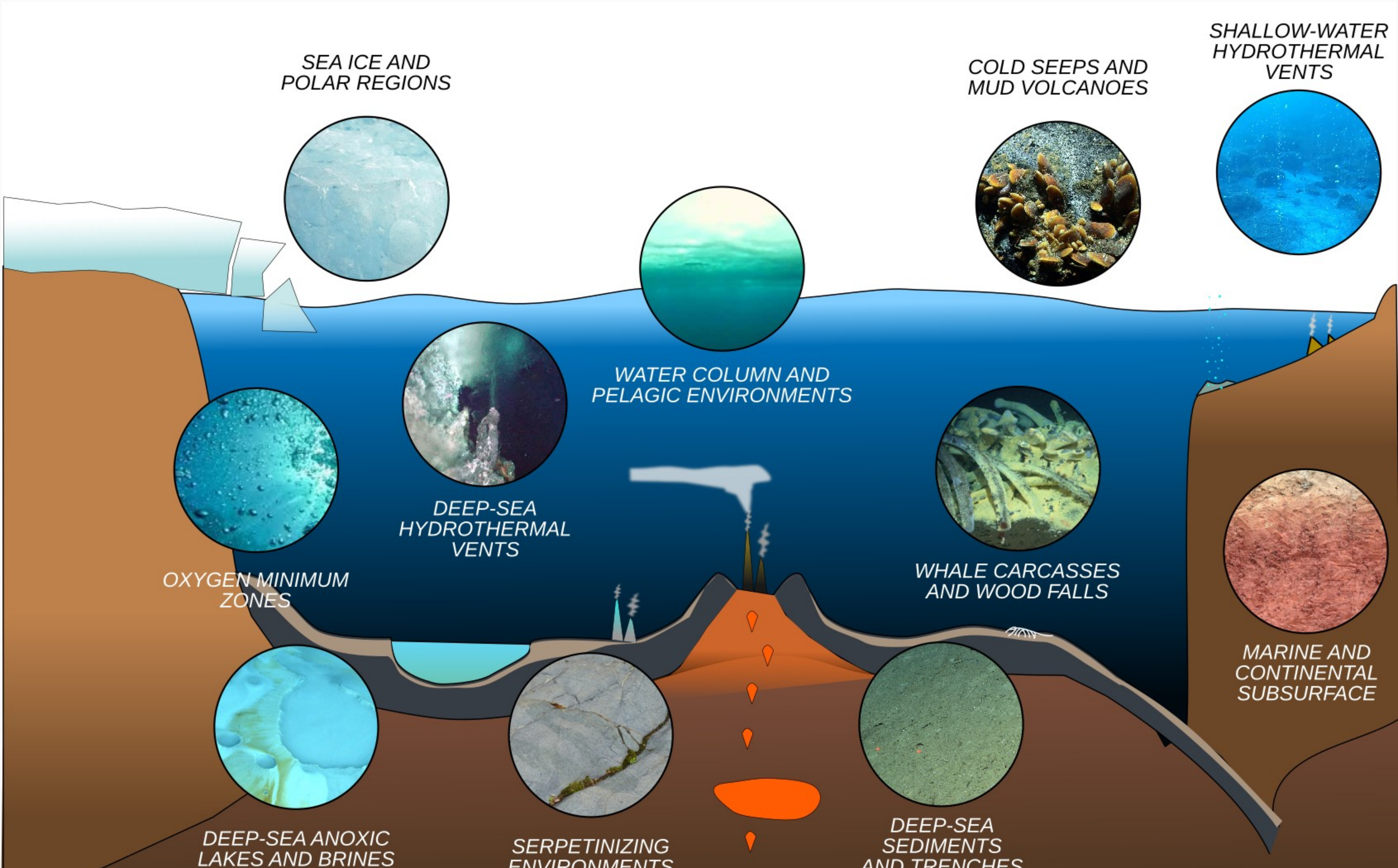




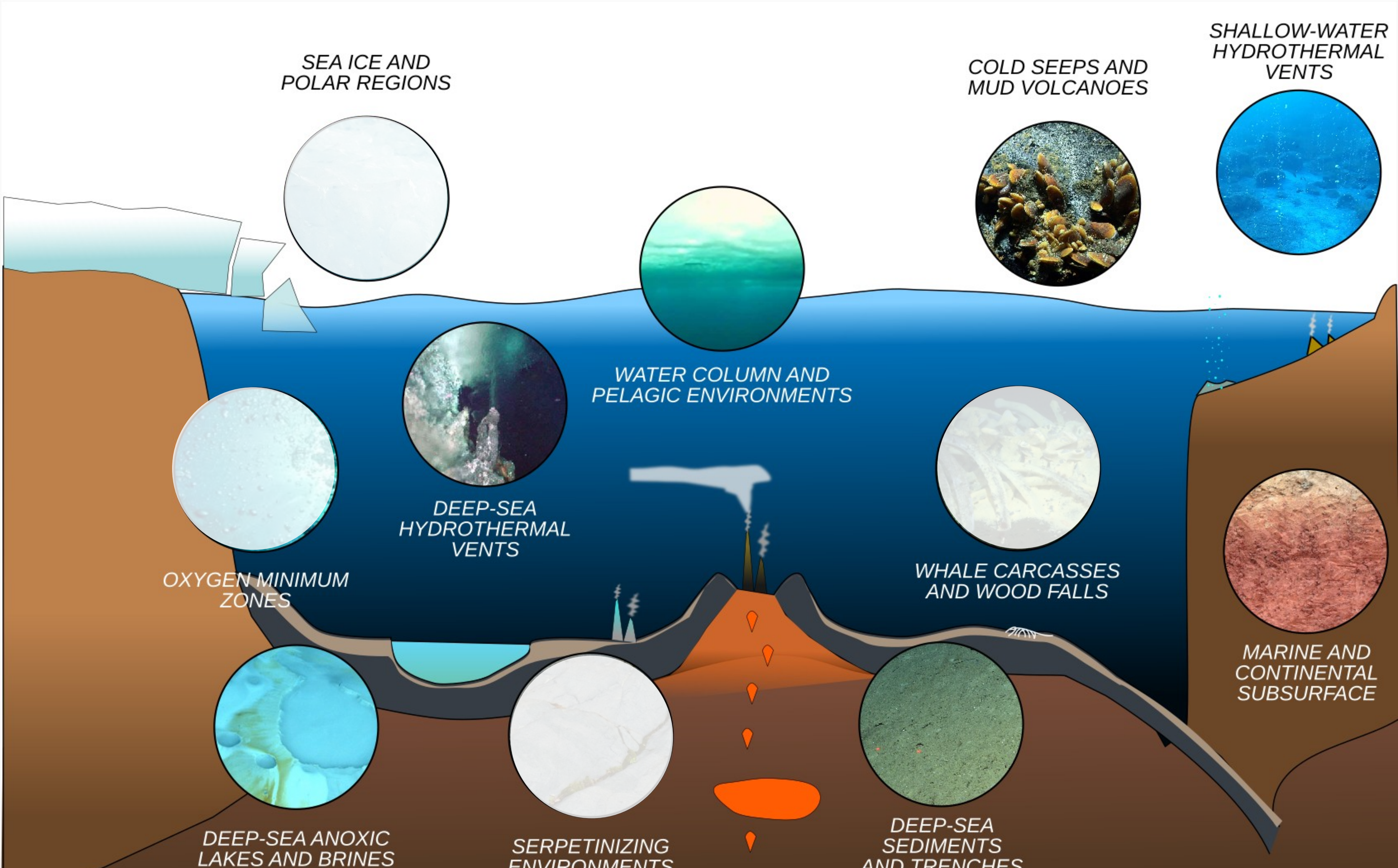
Export and biomass turnover for the deep Mediterranean Sea. *Giovannelli et al. unpublished*

Marine Ecosystems

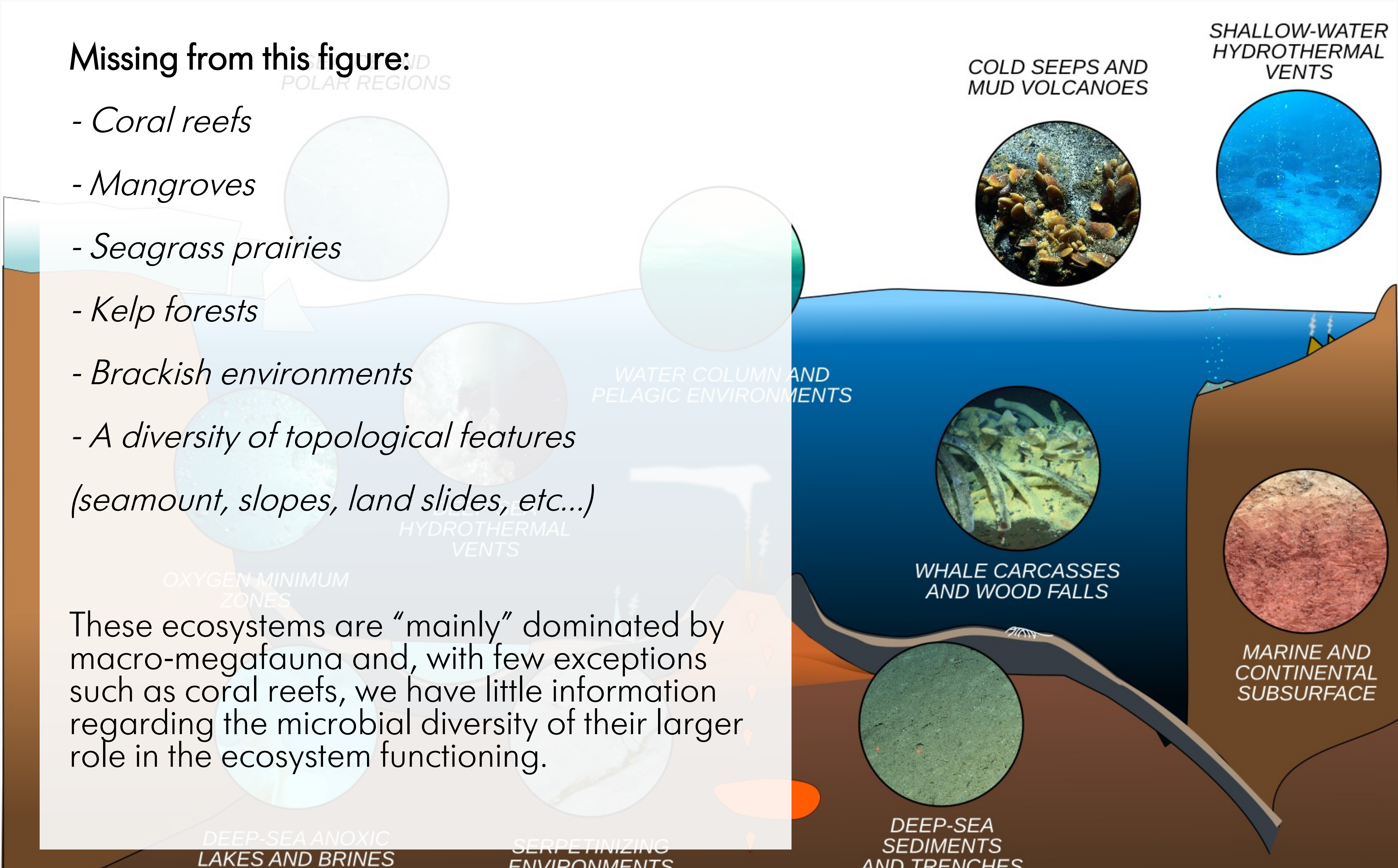
(some) marine ecosystems



(some) marine ecosystems



(some) marine ecosystems

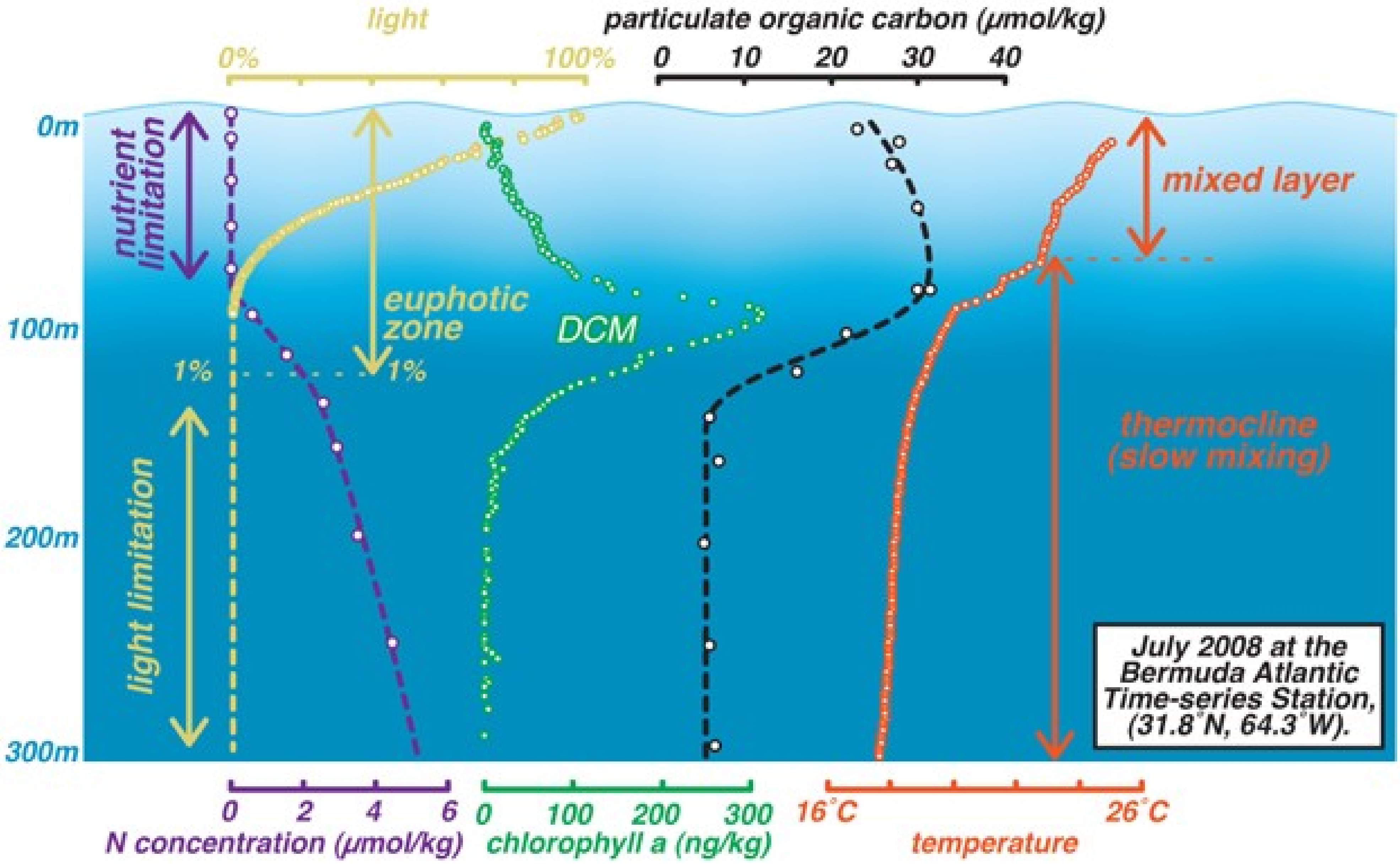


Missing from this figure:

- *Coral reefs*
- *Mangroves*
- *Seagrass prairies*
- *Kelp forests*
- *Brackish environments*
- *A diversity of topological features (seamount, slopes, land slides, etc...)*

These ecosystems are “mainly” dominated by macro-megafauna and, with few exceptions such as coral reefs, we have little information regarding the microbial diversity of their larger role in the ecosystem functioning.

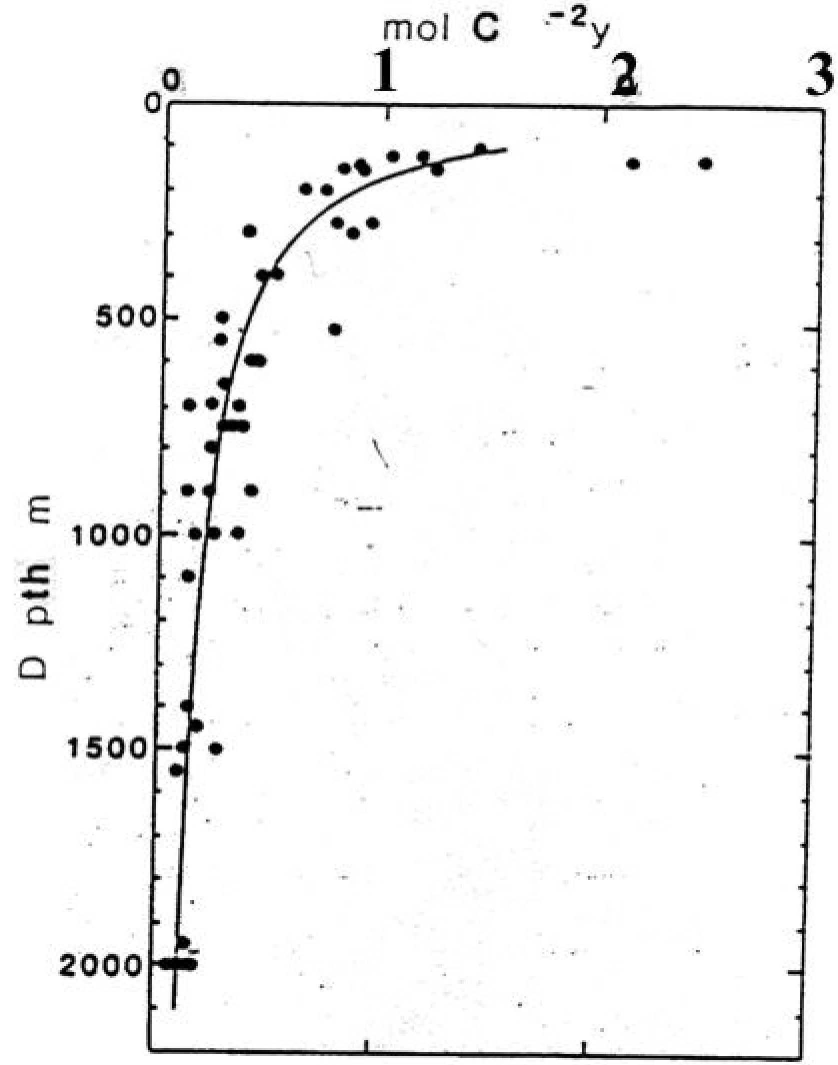
Water column diversity


light
0%
100%
particulate organic carbon (μmol/kg)
0 10 20 30 40
0m
100m
200m
300m
nutrient limitation
light limitation
euphotic zone
1%
1%
DCM
mixed layer
thermocline (slow mixing)
July 2008 at the Bermuda Atlantic Time-series Station, (31.8˚N, 64.3˚W).
0 2 4 6
N concentration (μmol/kg)
0 100 200 300
chlorophyll a (ng/kg)
16˚C
26˚C
temperature

Reduction in Vertical Flux over Depth

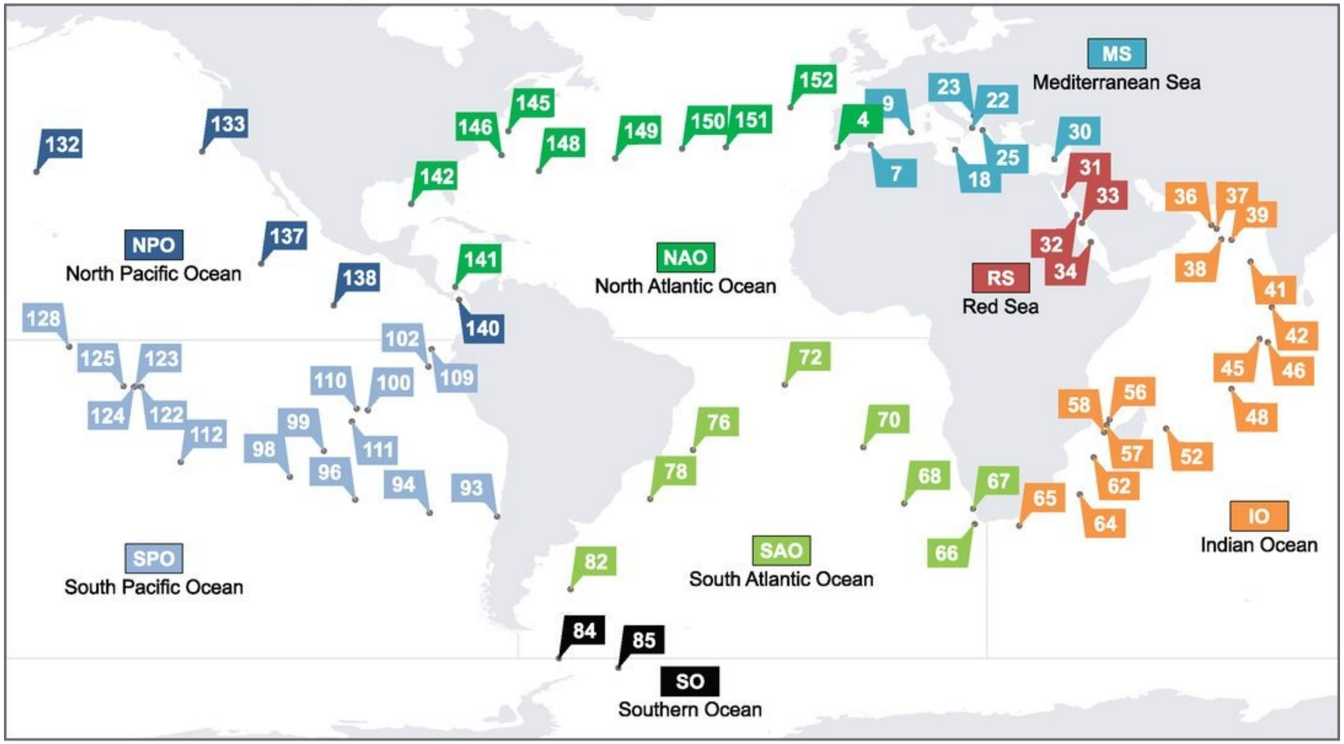
The Martin Curve

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

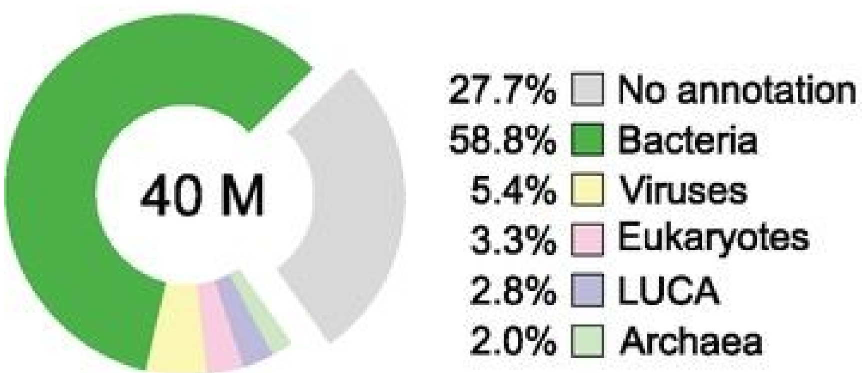


Martin and Knauer 1981

A *Tara* Oceans sampling stations

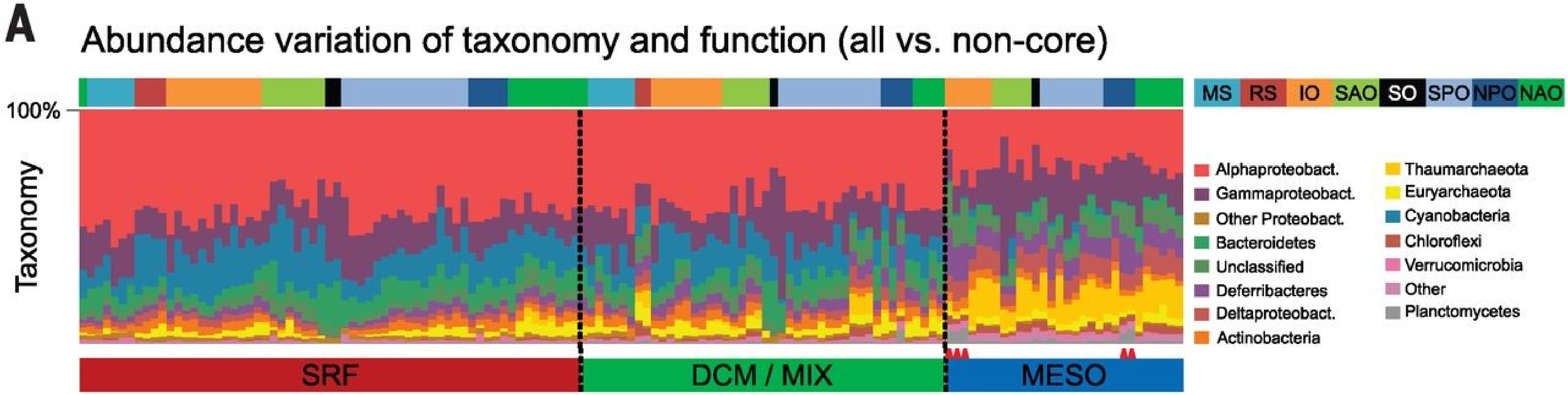


Taxonomic breakdown

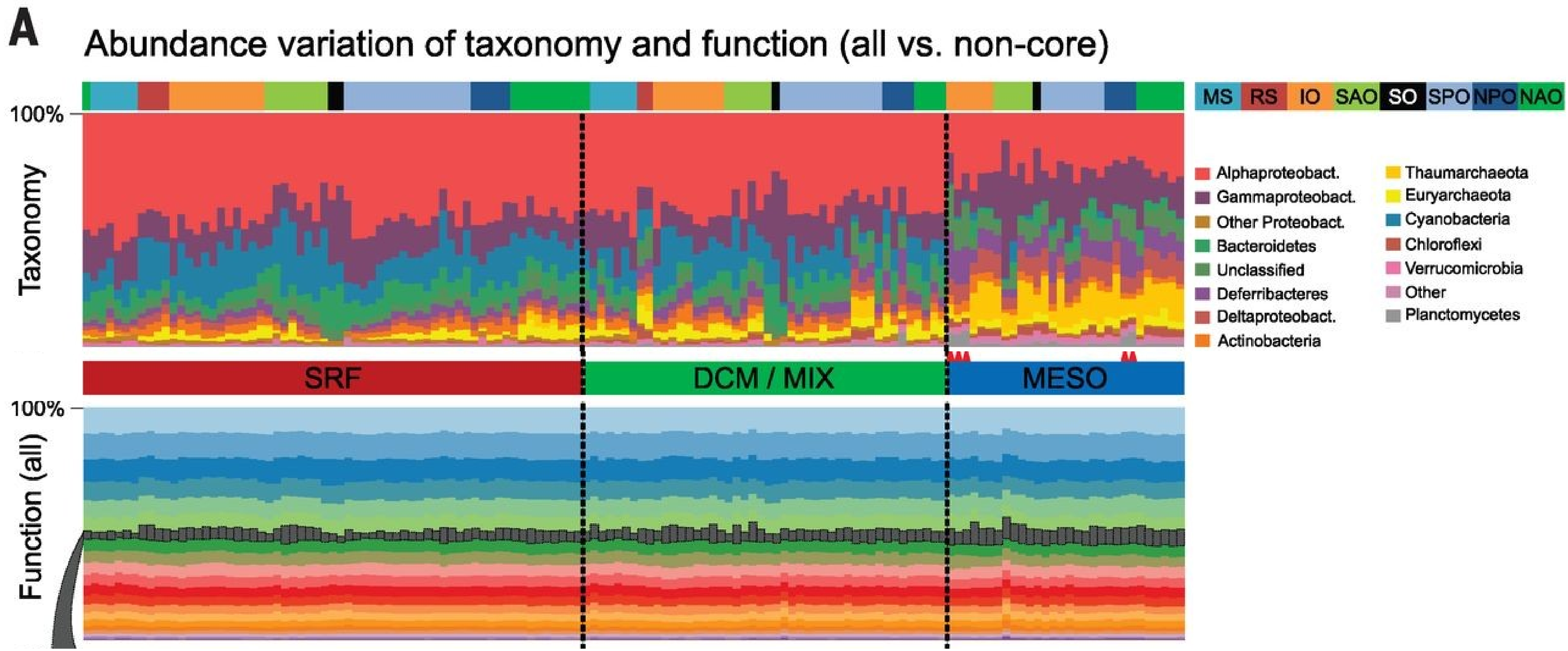


Sunagawa, S., Coelho, L. P., Chaffron, S., Kultima, J. R., Labadie, K., Salazar, G., … Bork, P. (2015). Structure and function of the global ocean microbiome. Science, 348(6237). https://doi.org/10.1126/science.1261359

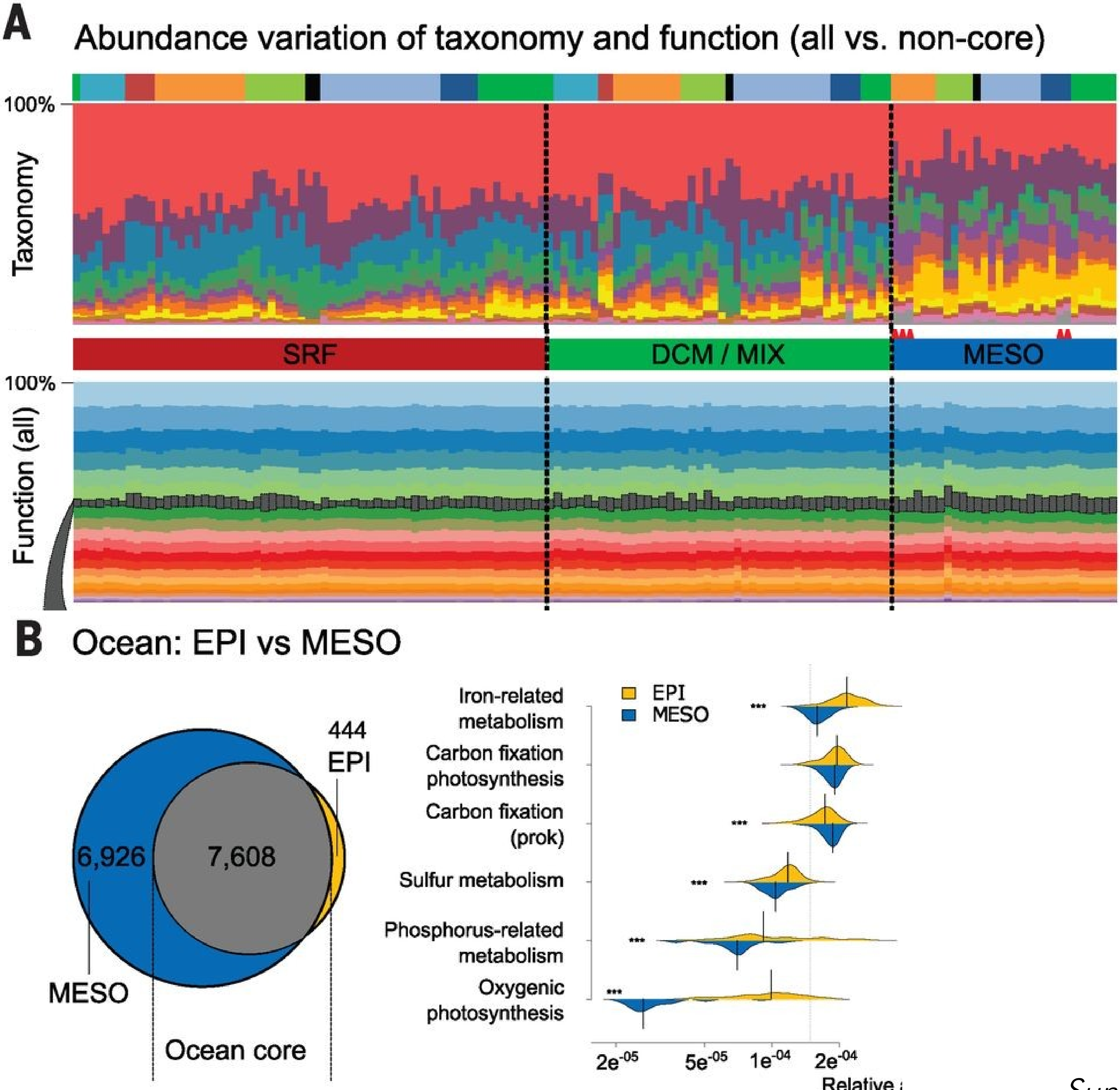
http://ocean-microbiome.embl.de/companion.html



Sunagawa et al. 2015 Science

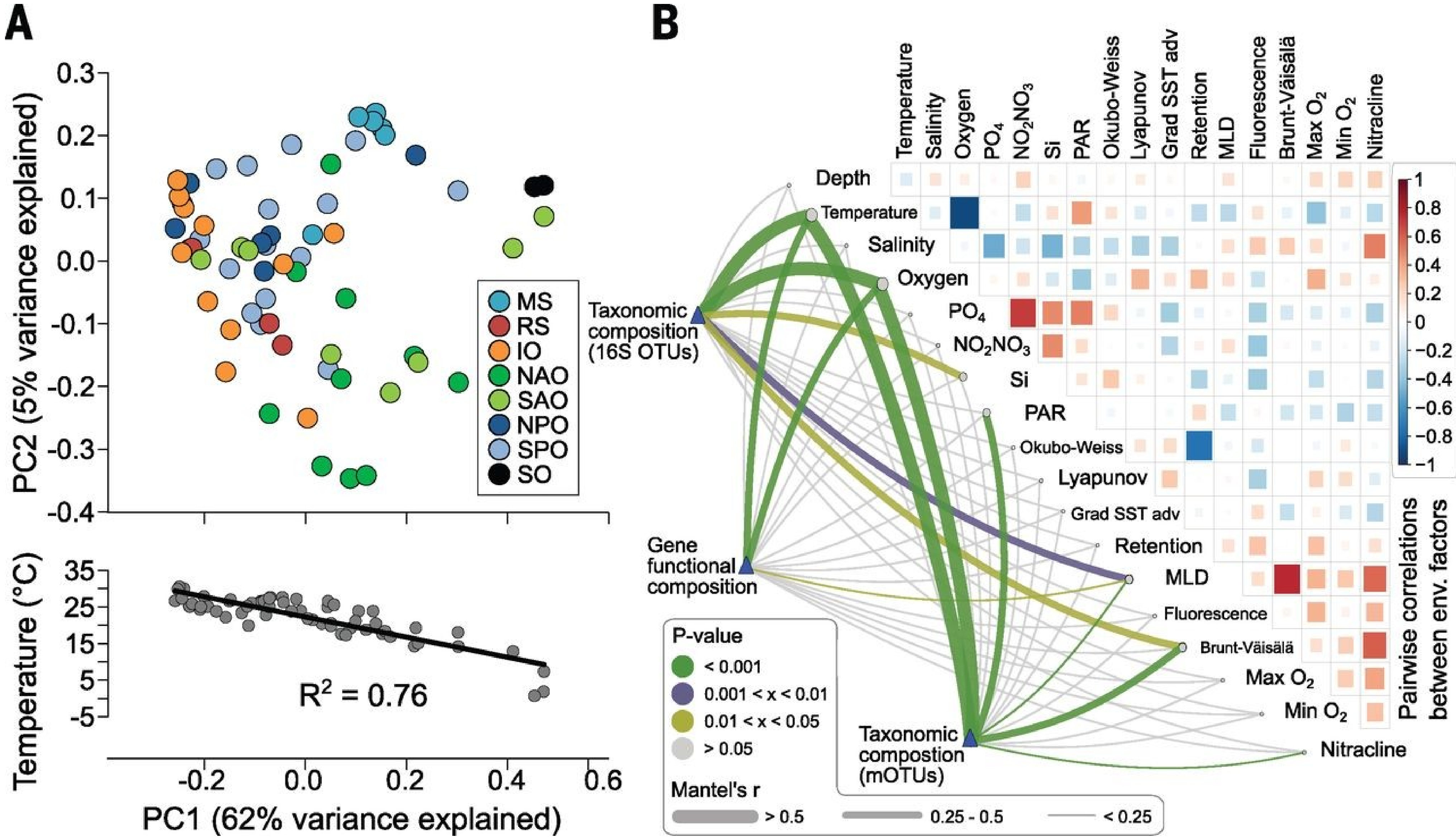


Sunagawa et al. 2015 Science



TARA OCEANS

Sunagawa et al. 2015 Science



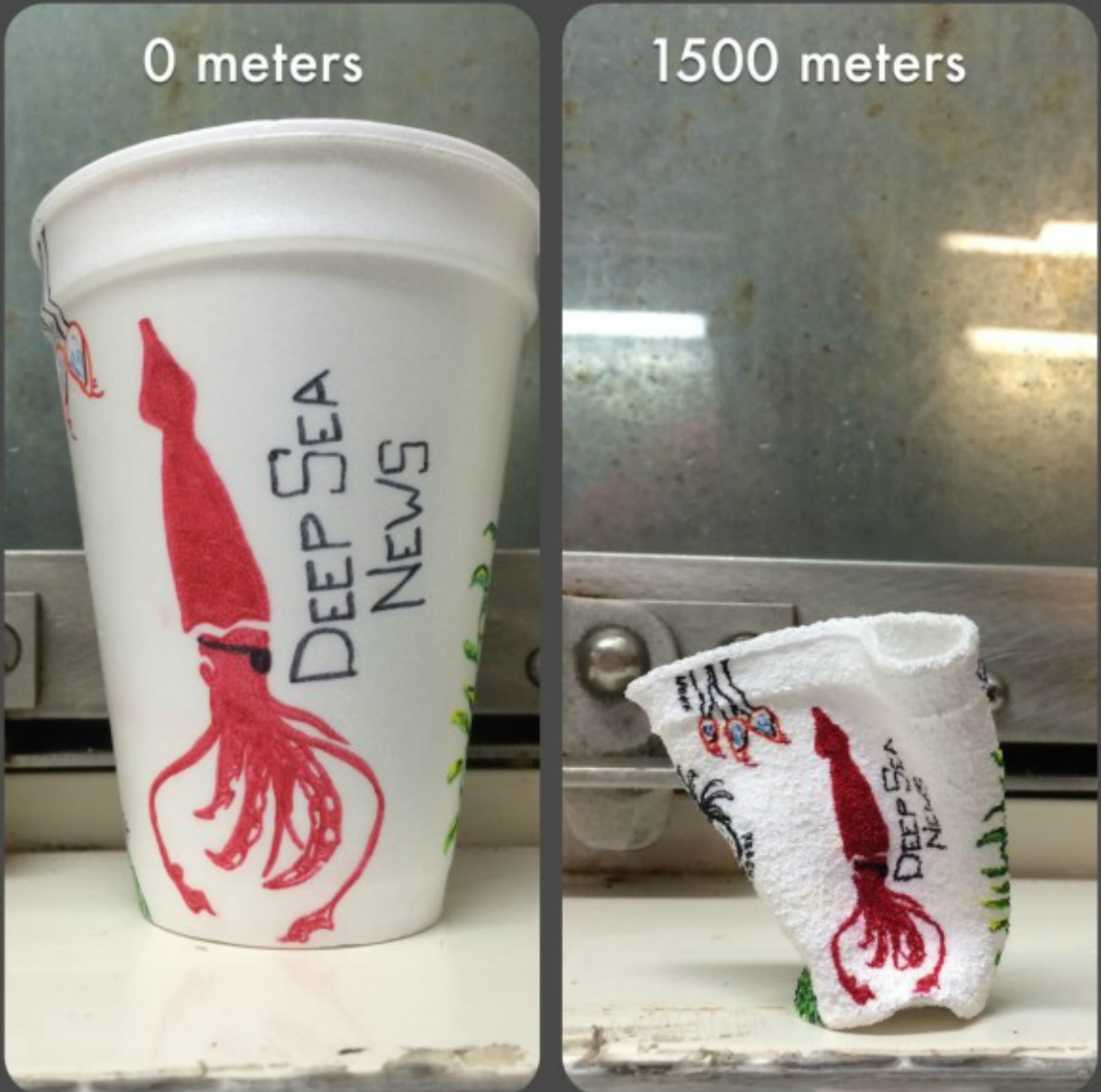
Sunagawa et al. 2015 Science

The Deep-Sea (floor)

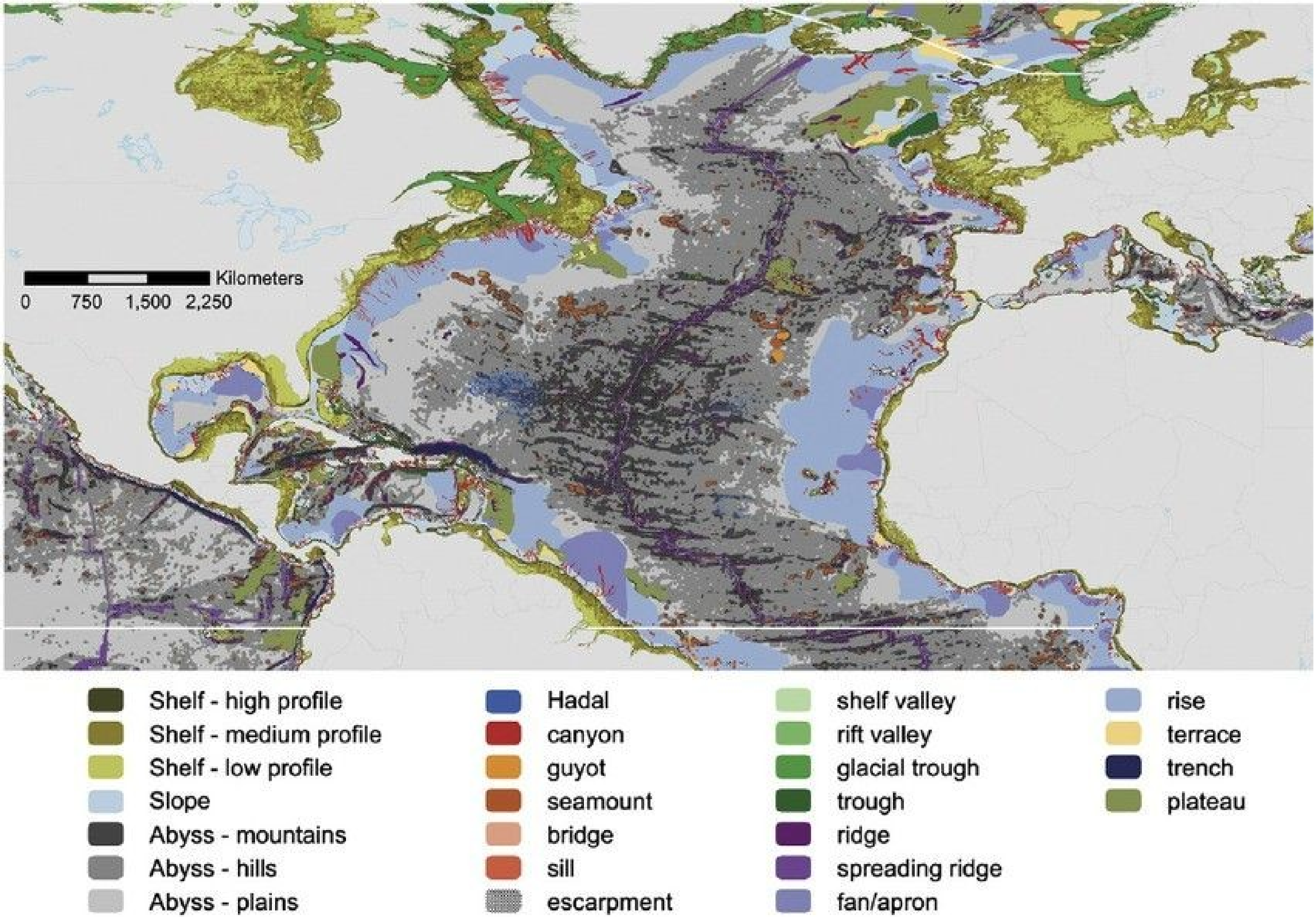
The deep-sea

The deep sea or deep layer is the lowest layer in the ocean. Different definitions are available:

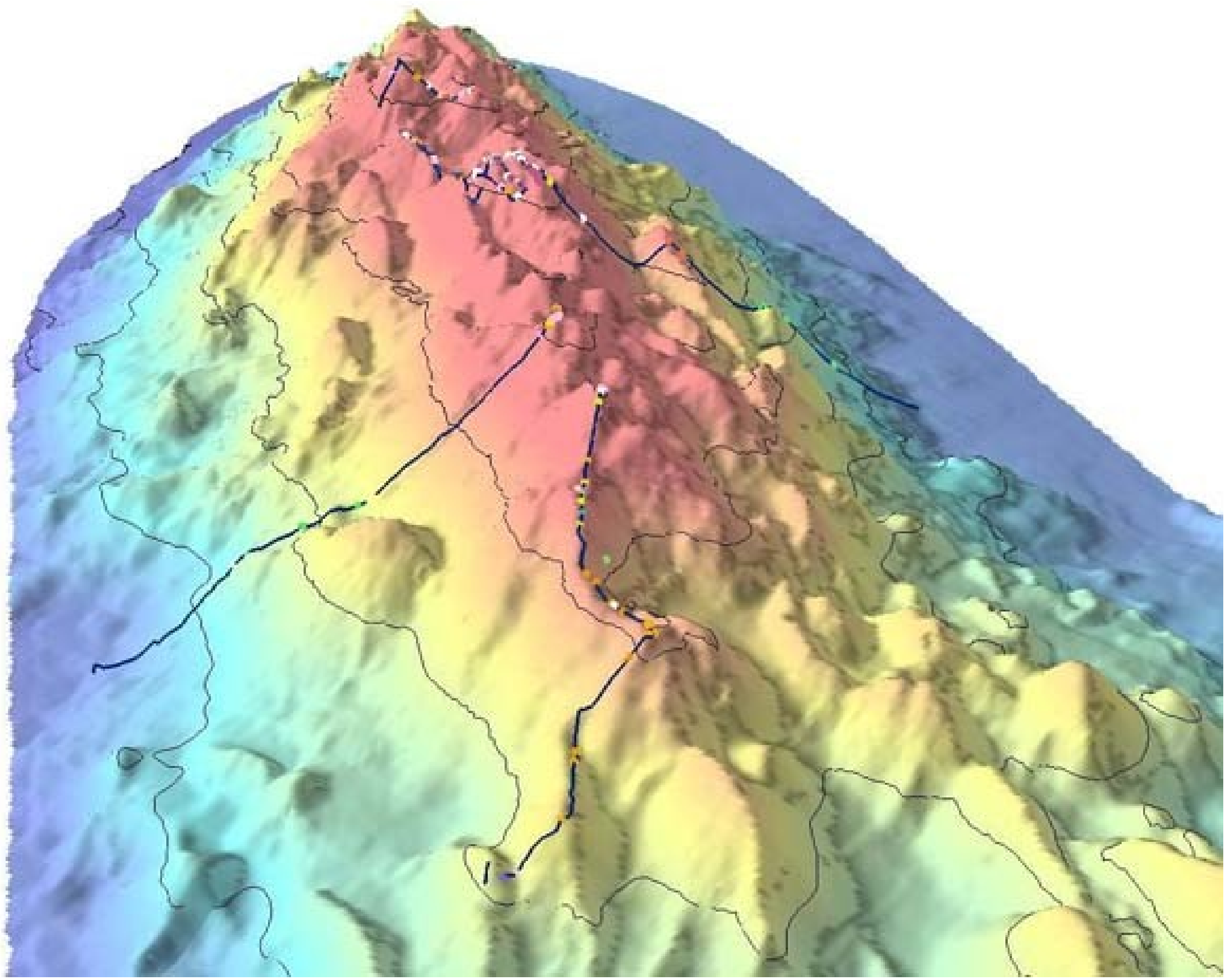
- Deeper than 200 m
- After the continental shelf break
- Deeper than 1,000 m


0 meters
1500 meters
DEEP SEA NEWS

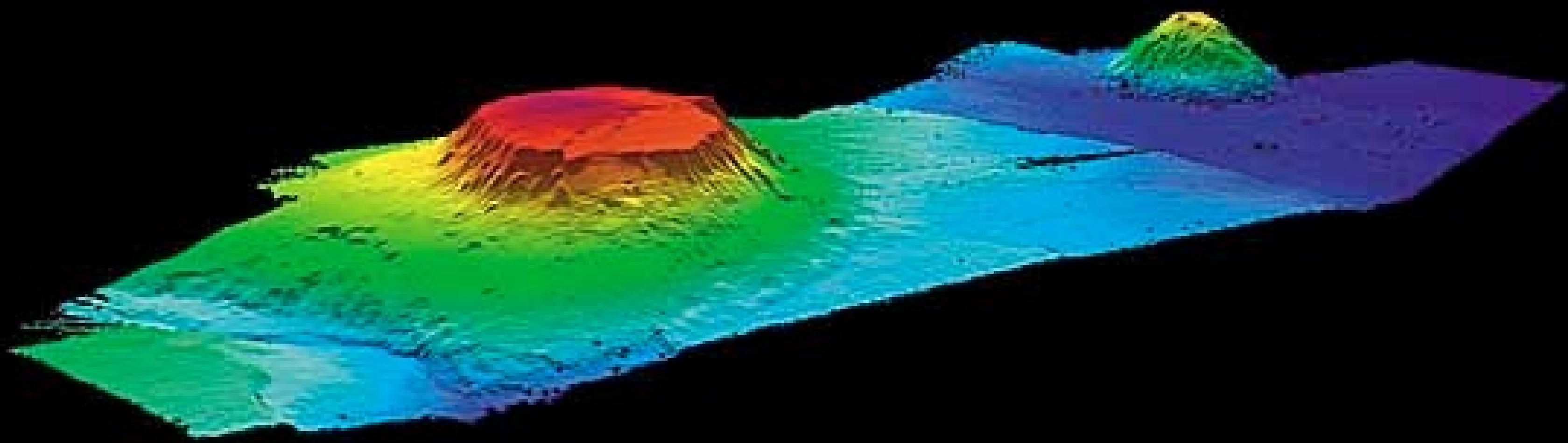
Seafloor geomorphology



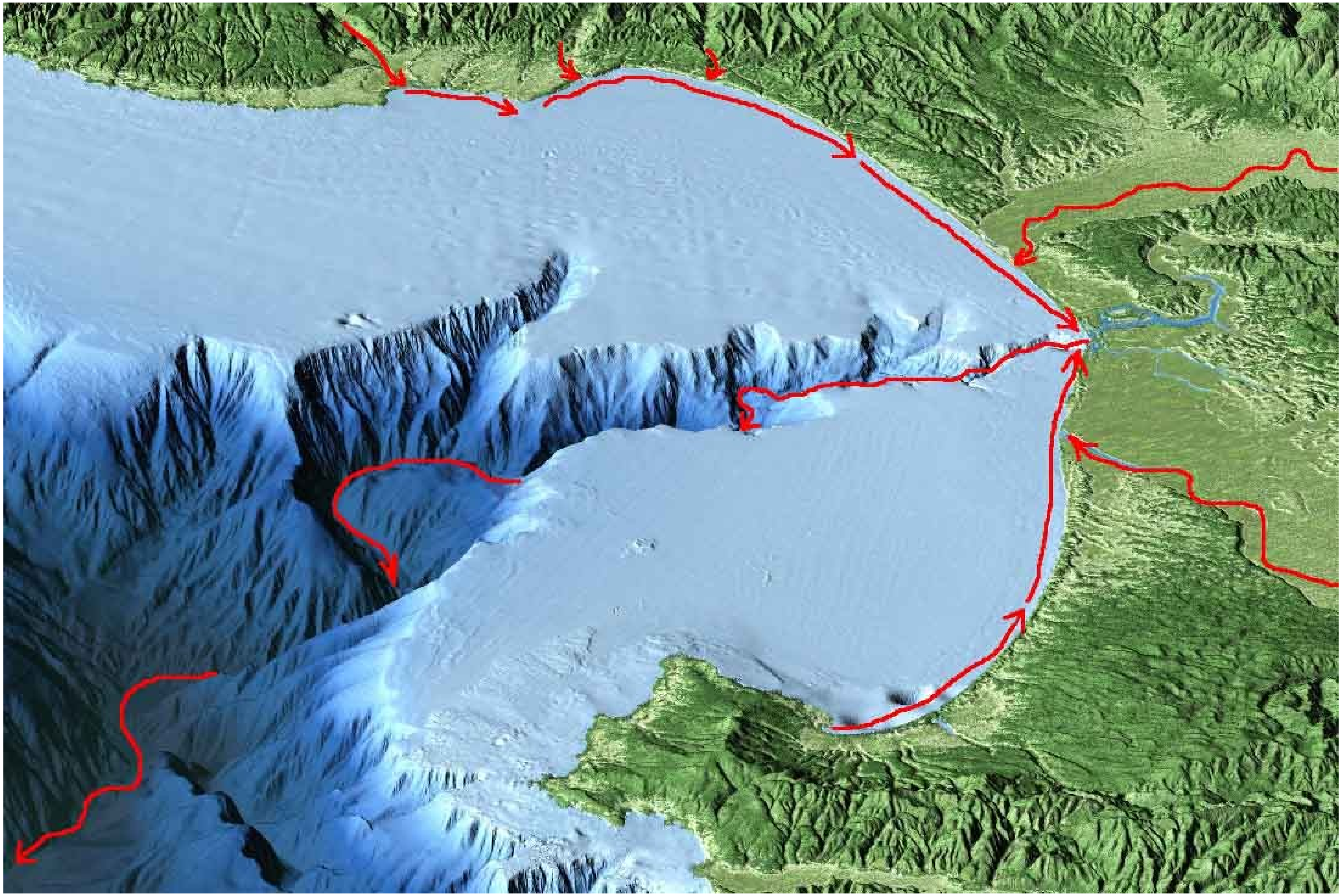
Seamounts



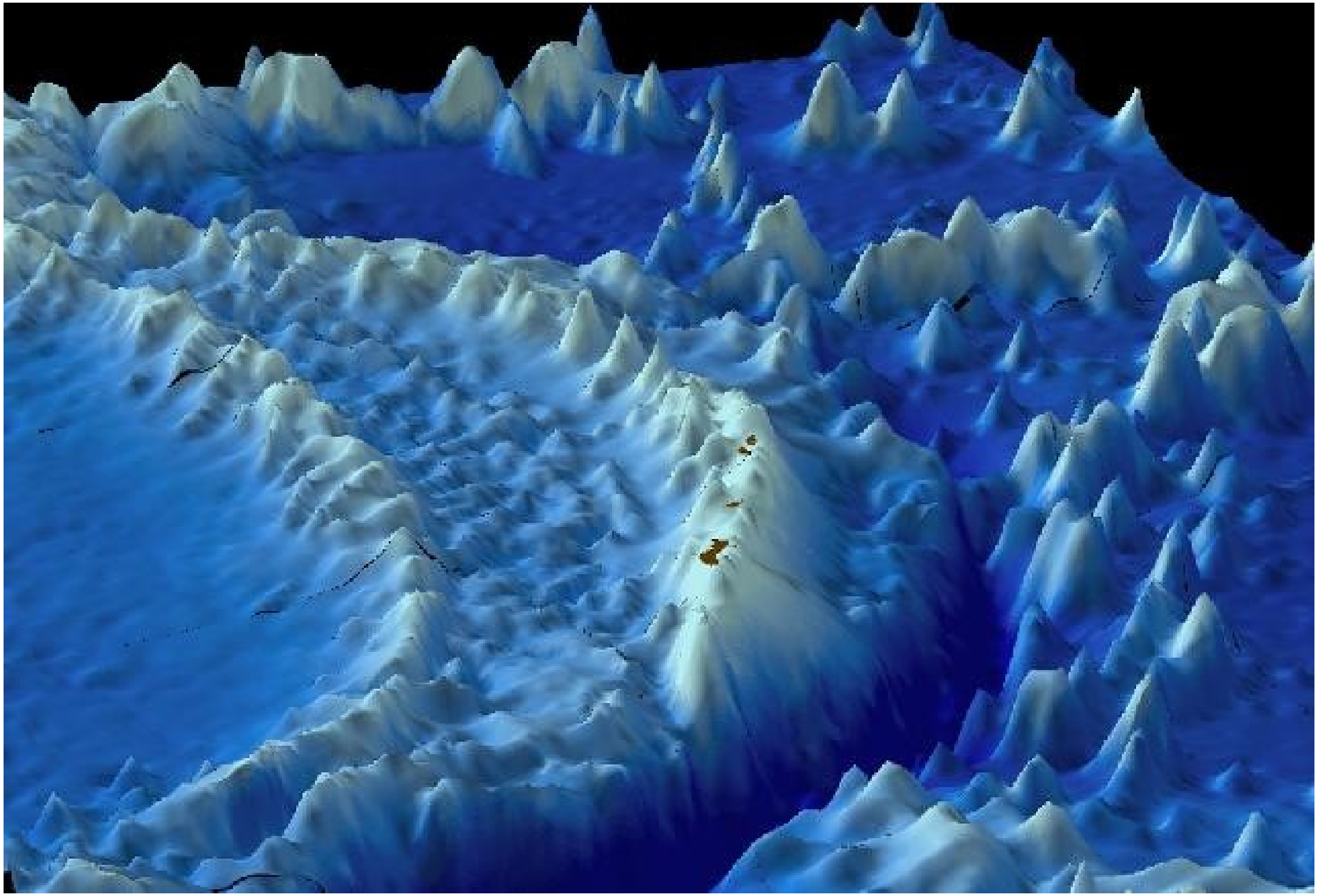
Guyont



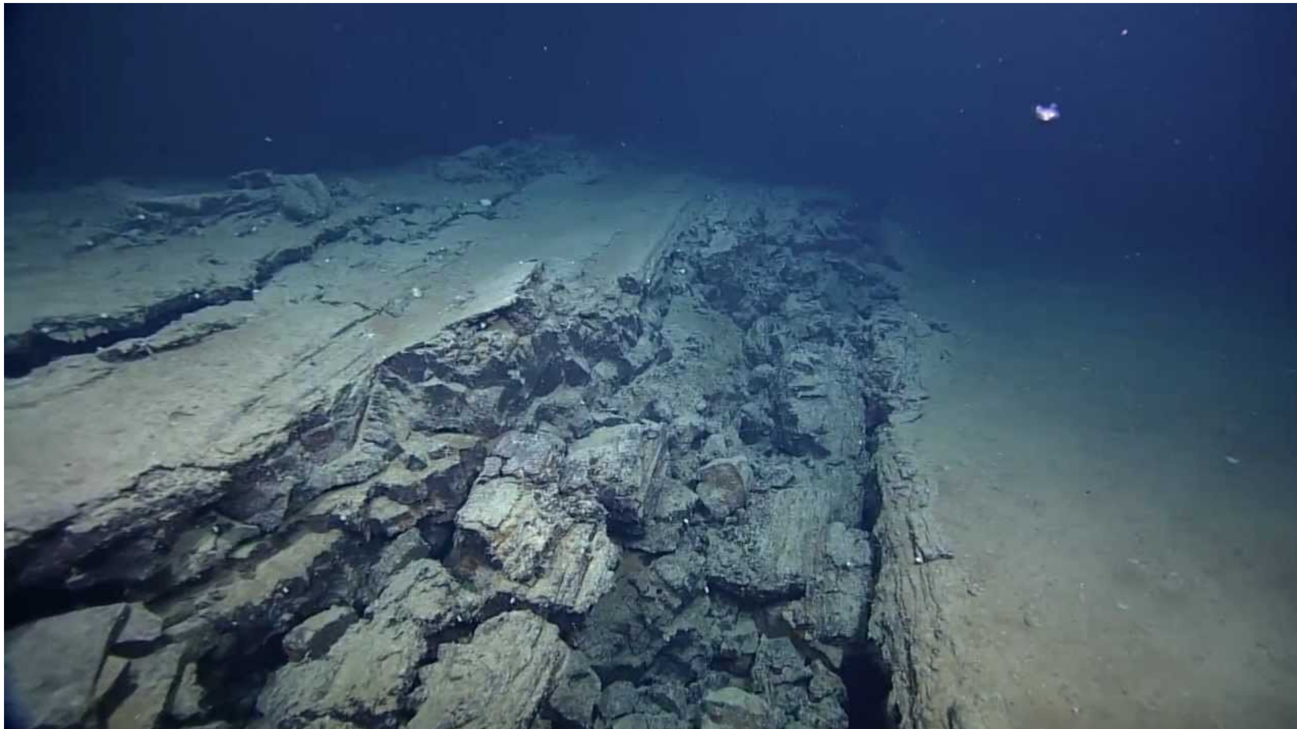
Canyons



Trenches



Ridges



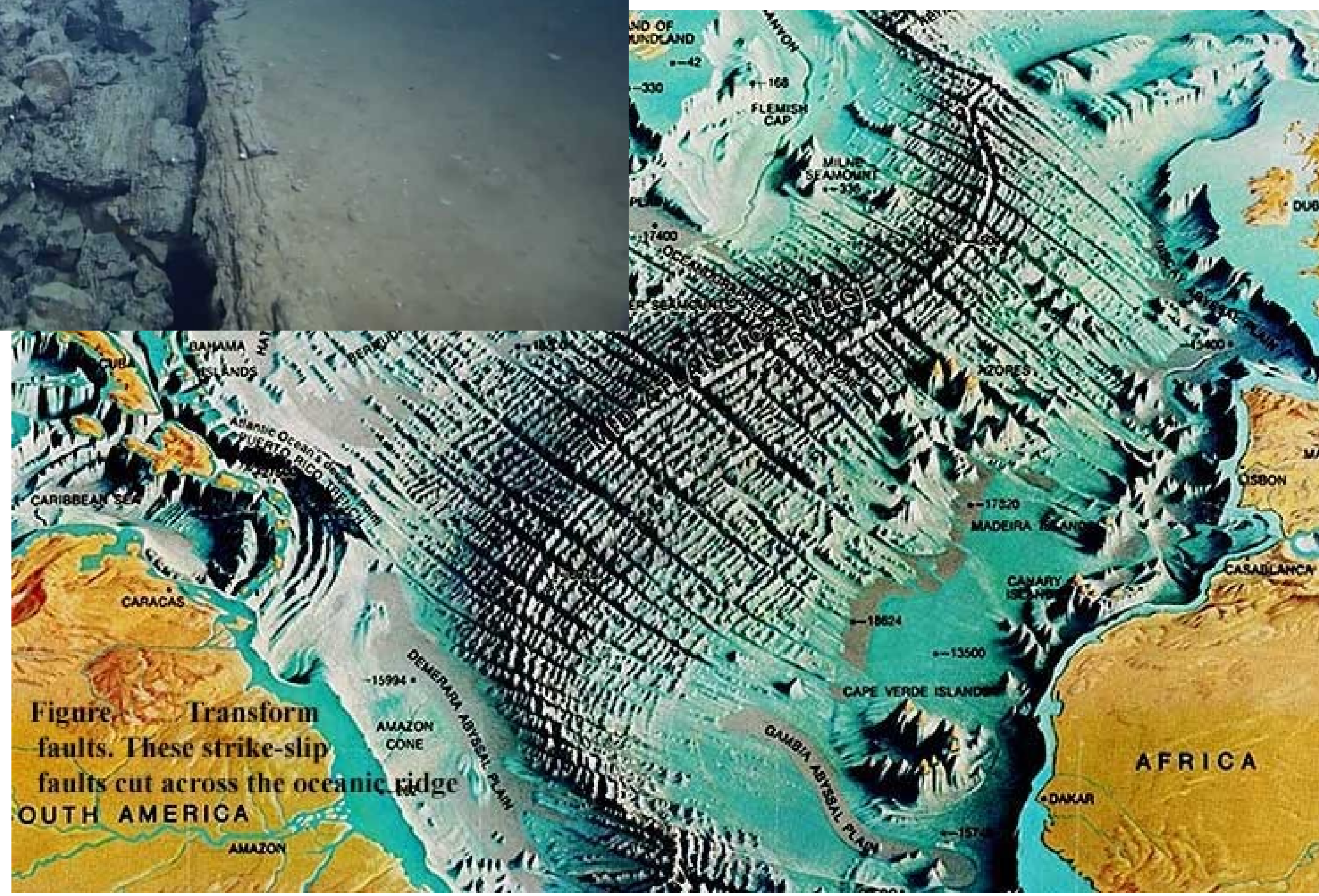
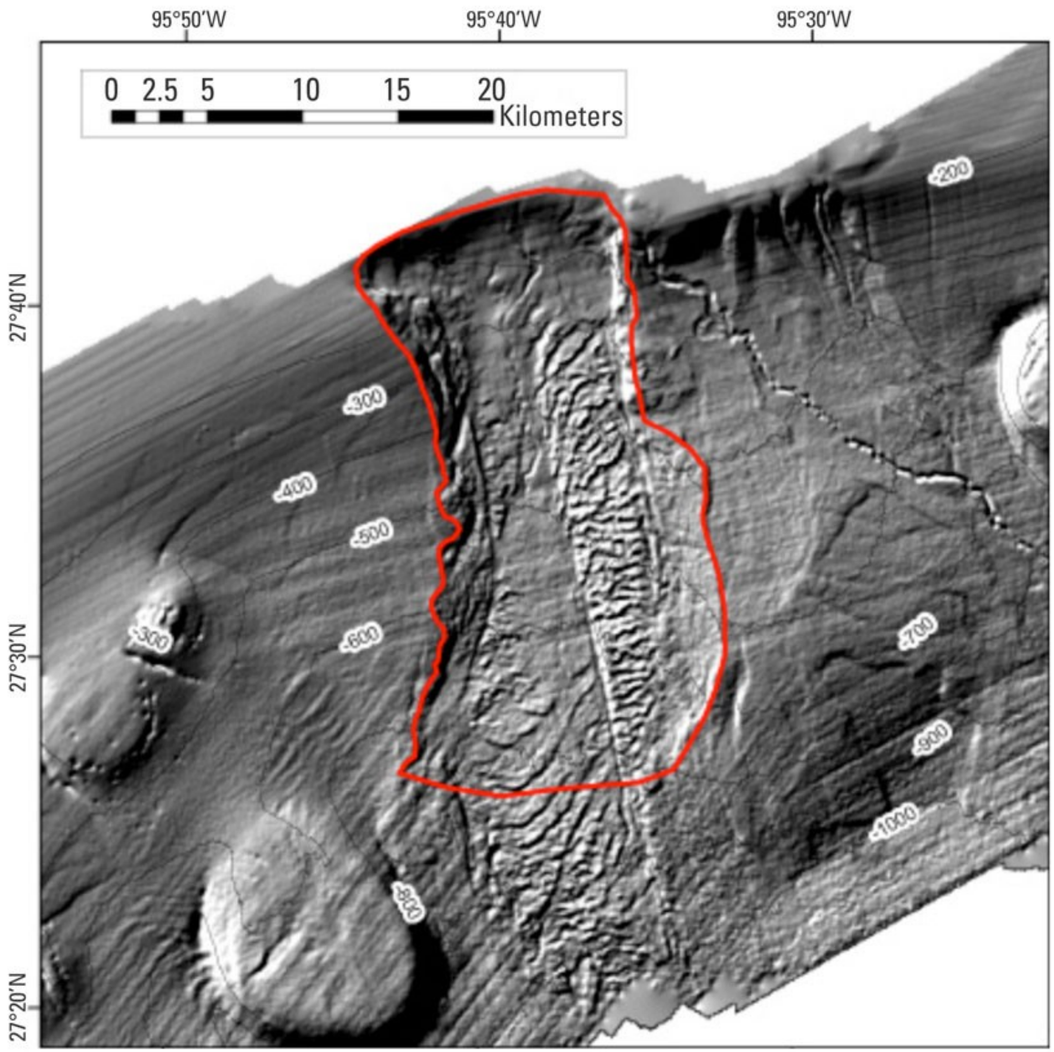


Figure. Transform faults. These strike-slip faults cut across the oceanic ridge

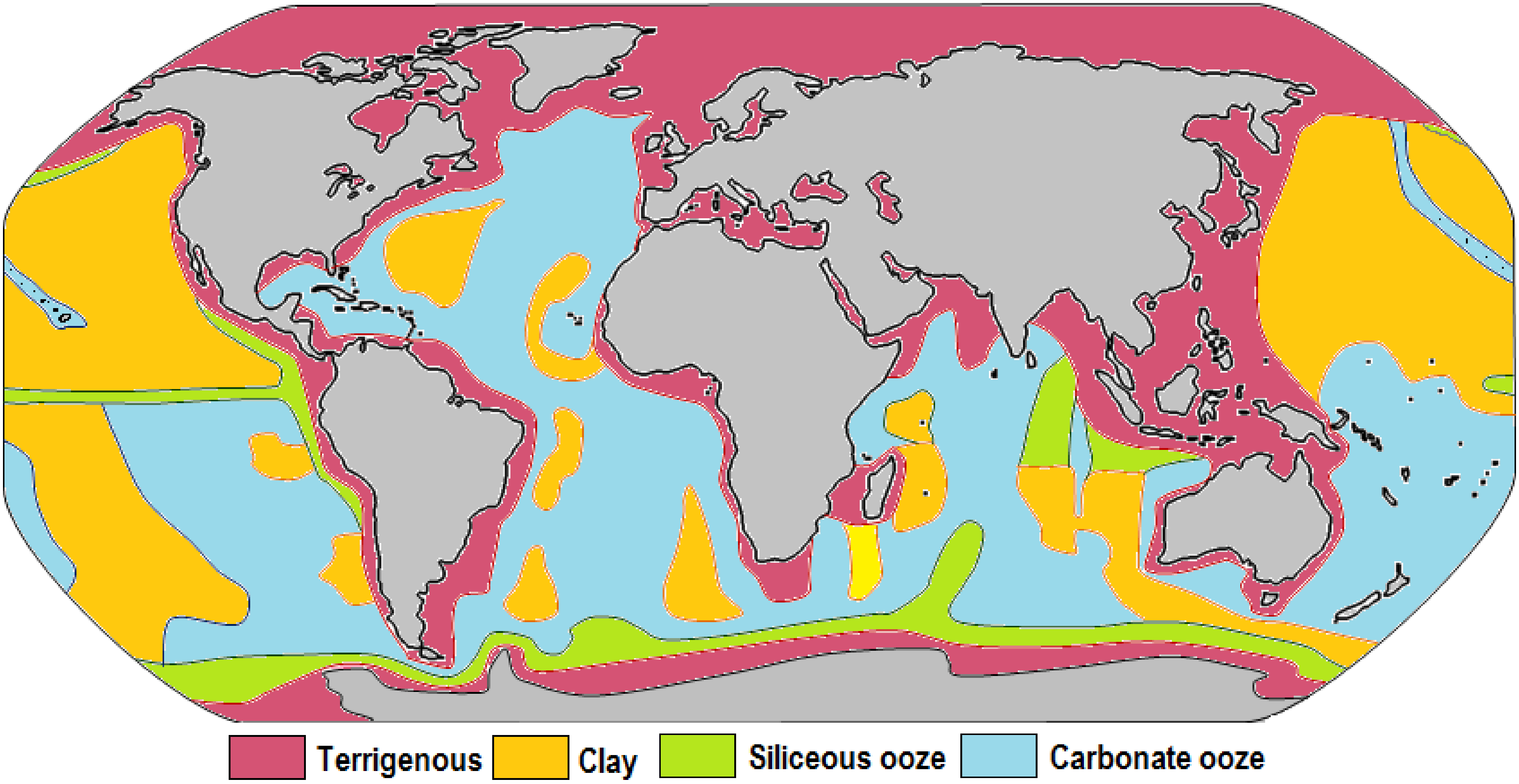
Landslides



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
-800
-900
-1000


GREENLAND
BAFFIN BAY
HUDSON BAY
NORTH AMERICA
SOUTH AMERICA
MATO GROSSO
AFRICA
SAHARA
EUROPA
ASIA
ARABIA
AUSTRALIA
ANTARCTICA
ARGENTINE RISE
BERING SEA
CHUKCHI SEA
WRANGEL ISLAND
BARENTS SEA
KARA SEA
NORTH SEA
SIBERIAN PLATEAU
WEDDELL ABYSSAL PLAIN
BELLINGSHAUSEN ABYSSAL PLAIN
ENDERBY ABYSSAL PLAIN
WILKES LAND

Seafloor Composition



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.

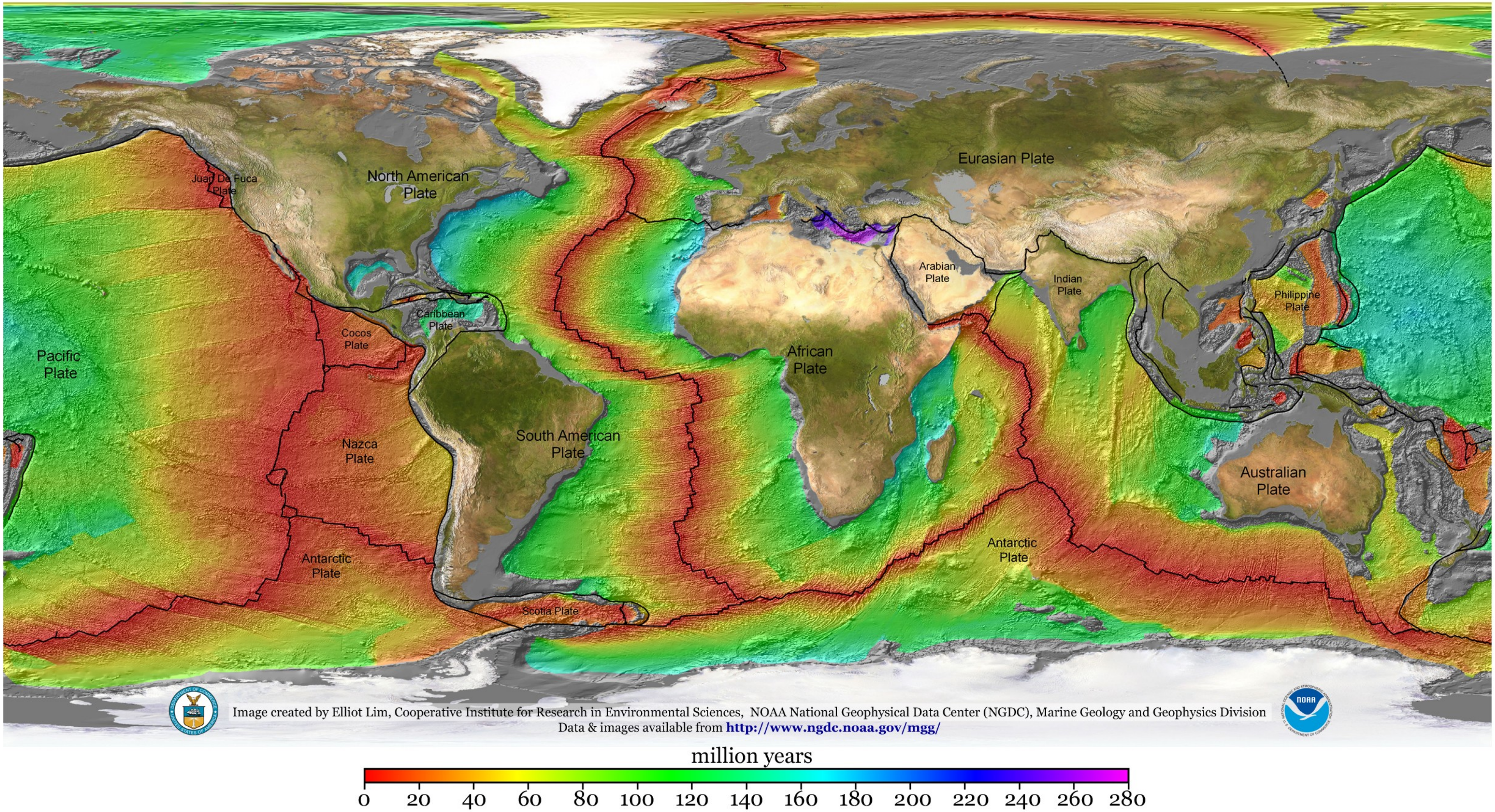


Plate Tectonic and the Seafloor

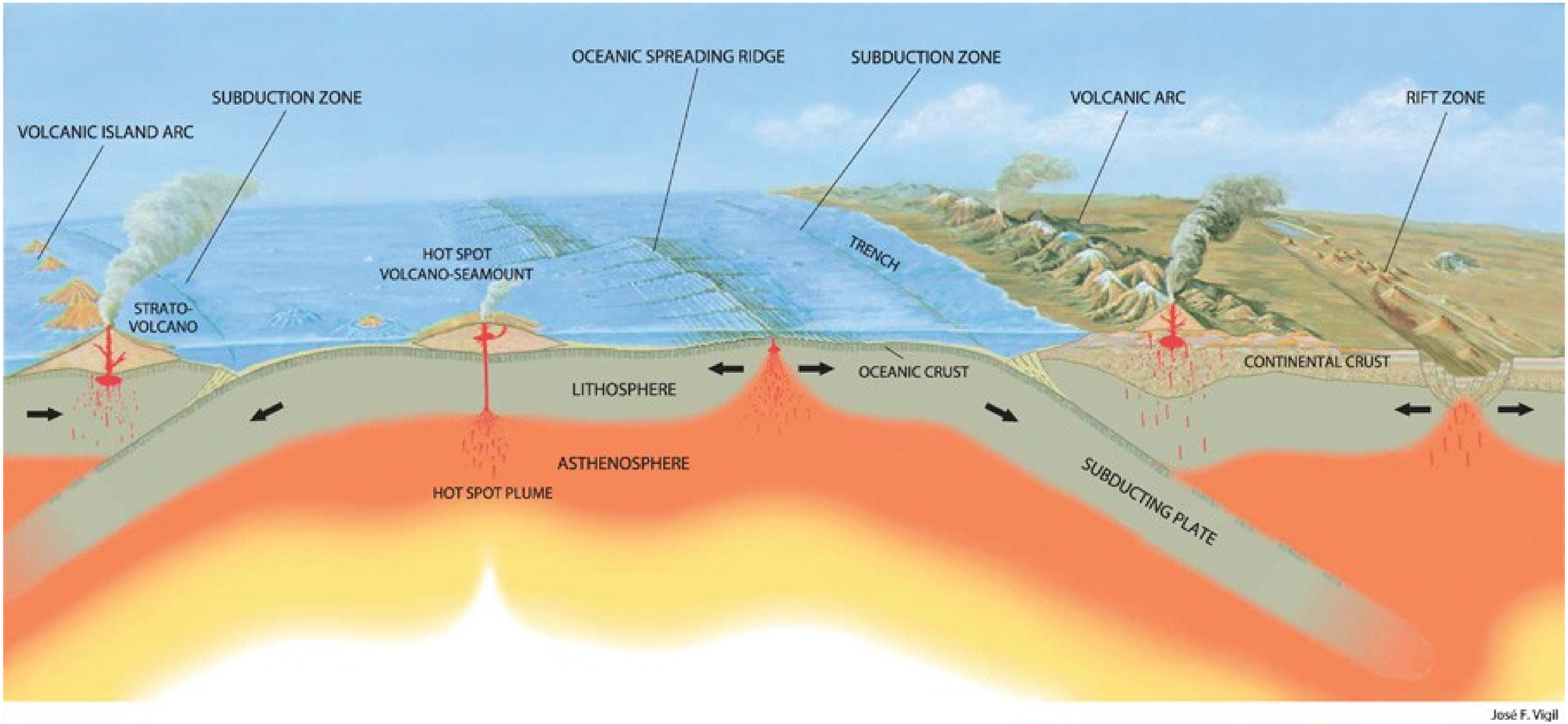
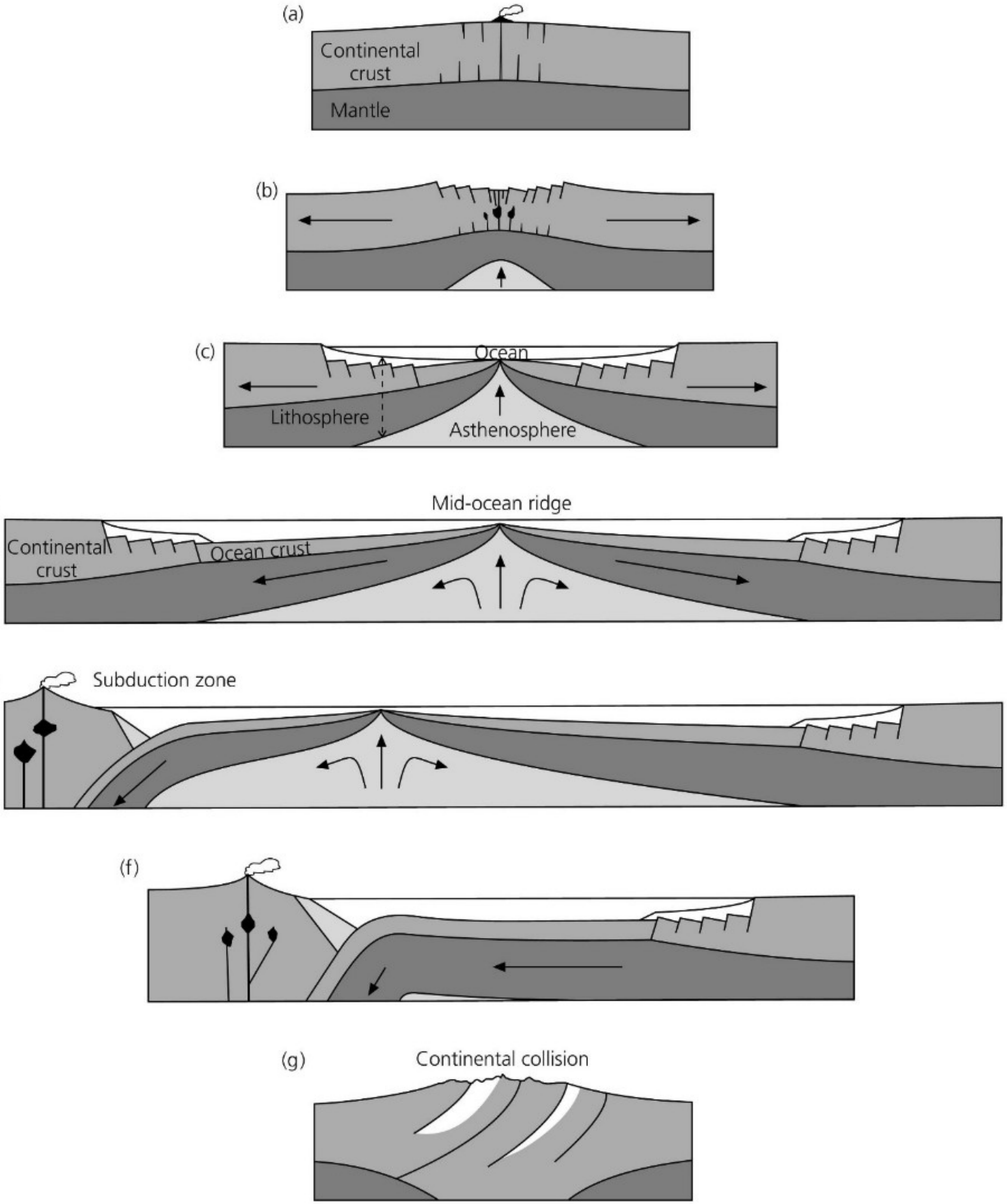


Figure 5.6-1: Schematic diagram of the Wilson cycle.

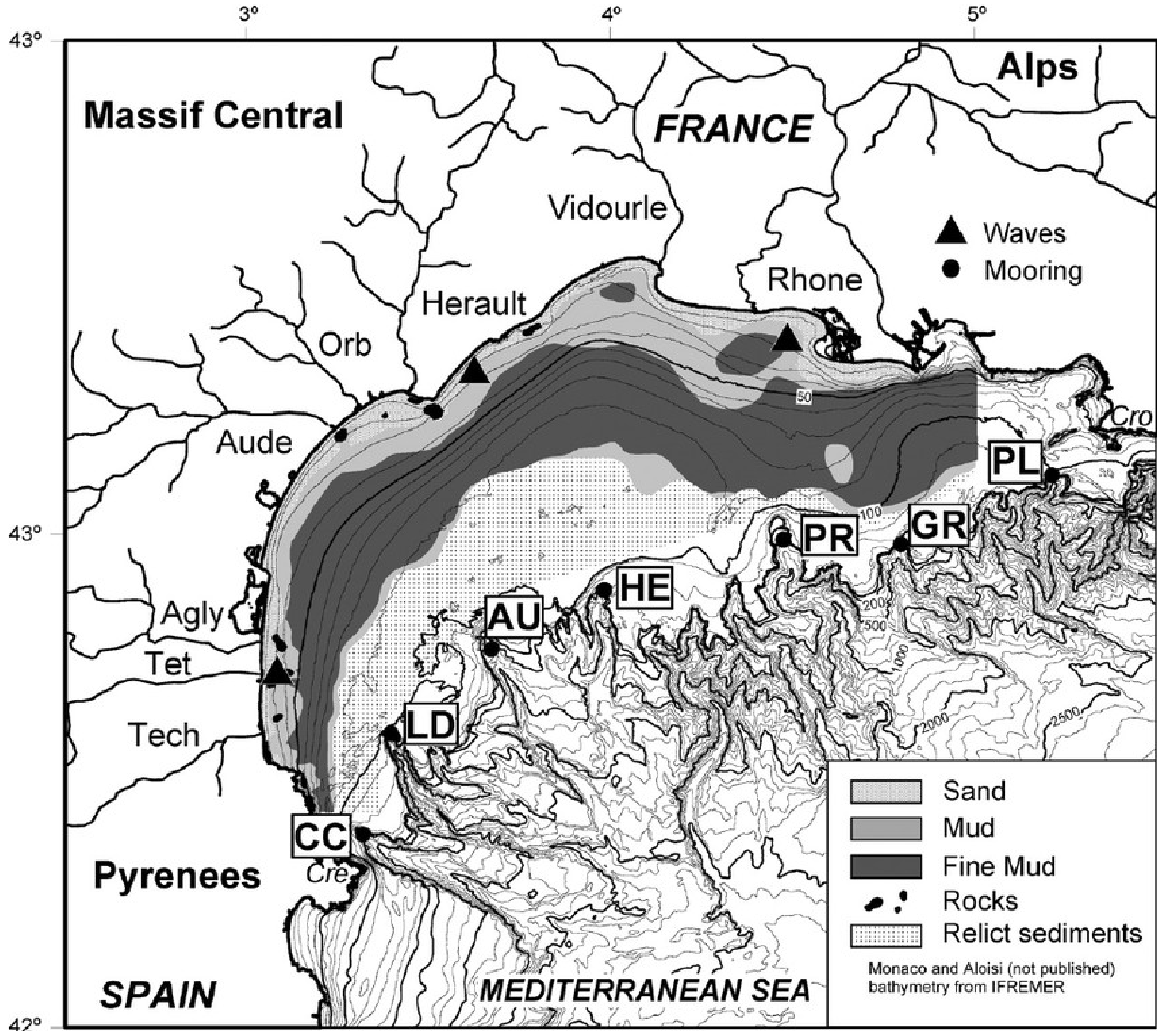


Case study: the Mediterranean Sea

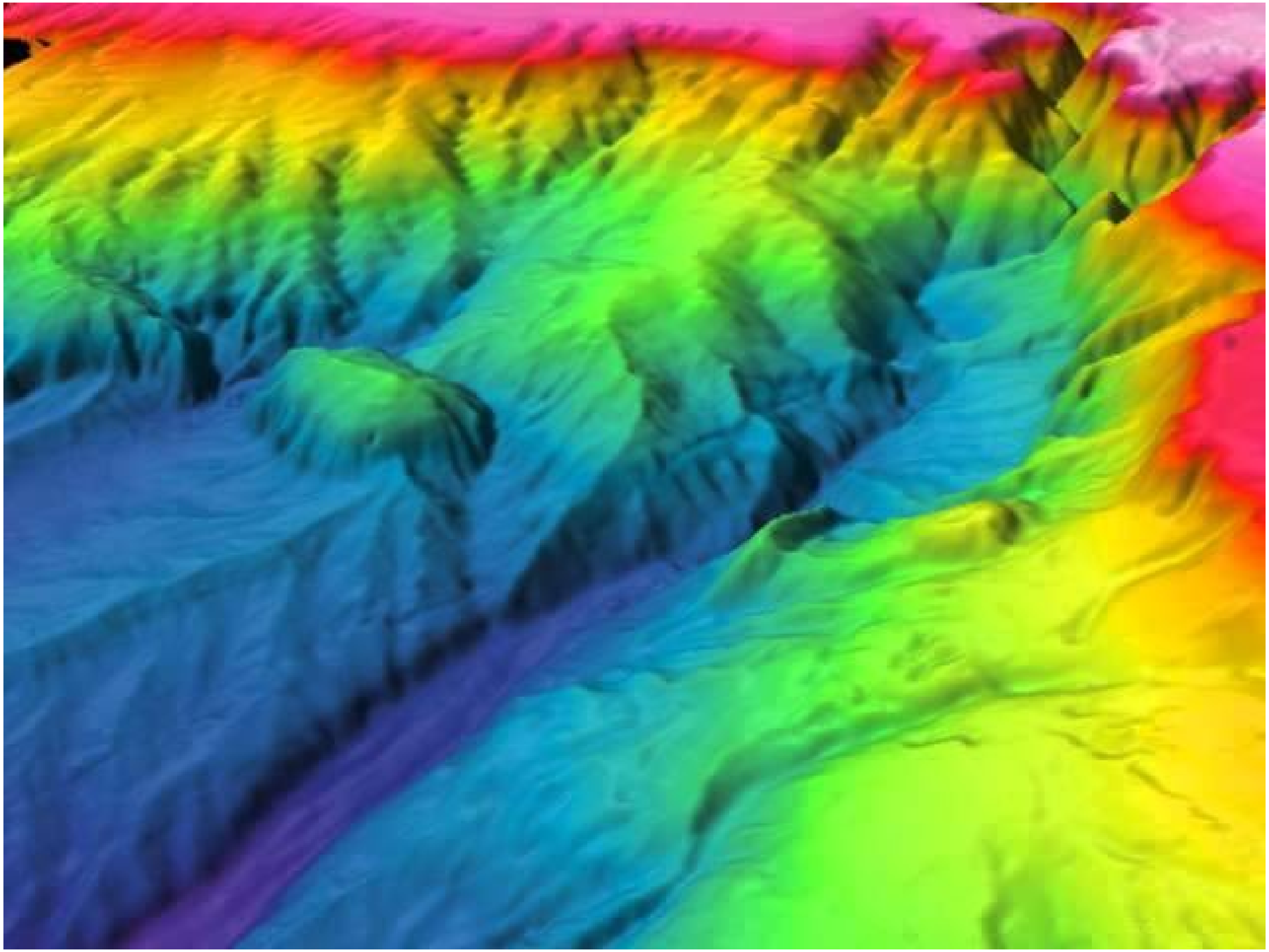
The Mediterranean Sea

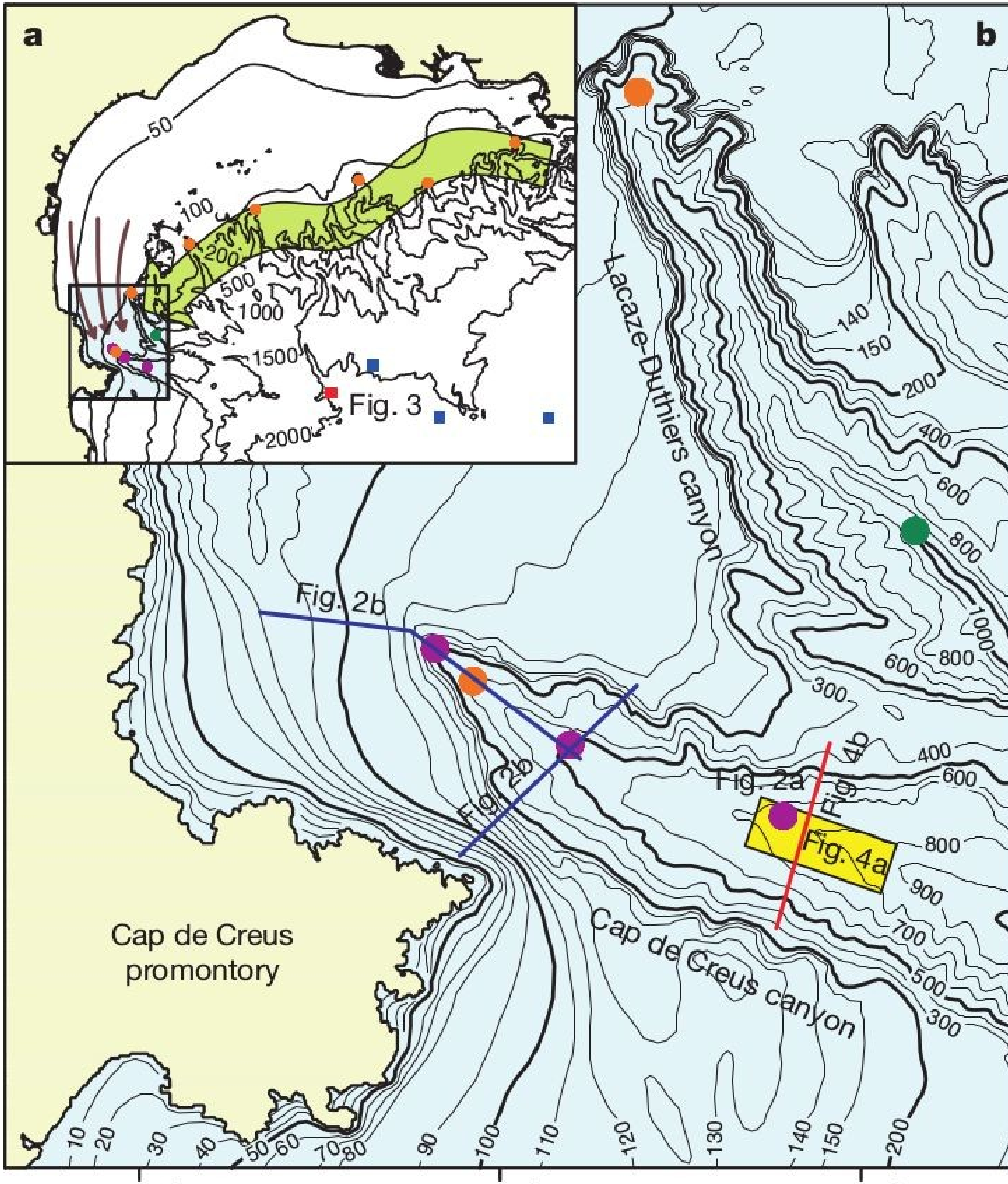
- Average depth of 1,500 m
- Deepest recorded point is 5,267 m
- Covers an approximate area of 2.5 million km^2
- Divided in three sector, Western, Central and Eastern Med
- The Strait of Gibraltar (connection with Atlantic) is only 14 km wide
- Evaporation greatly exceeds precipitation and river runoff
- 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



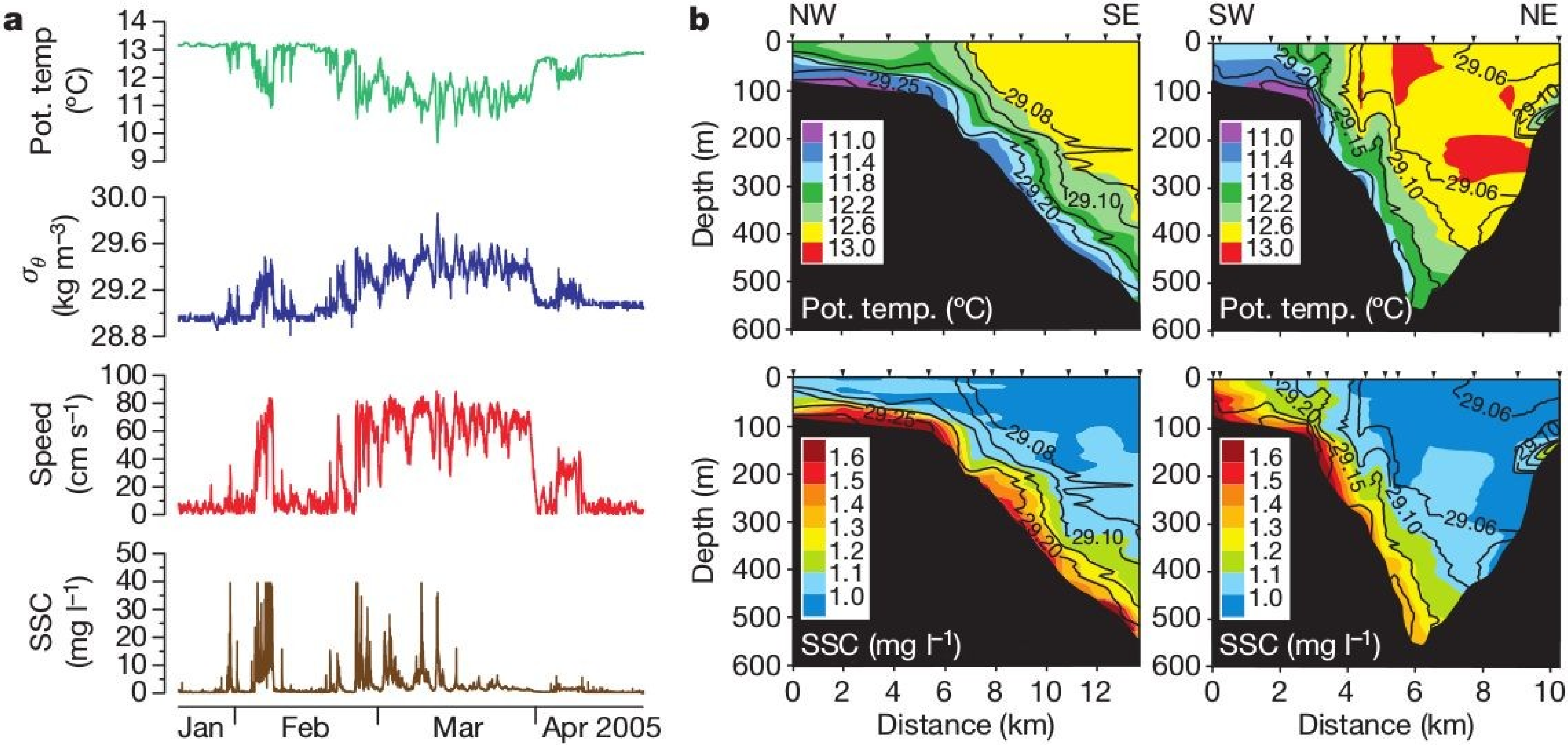
Mediterranean Canyons





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

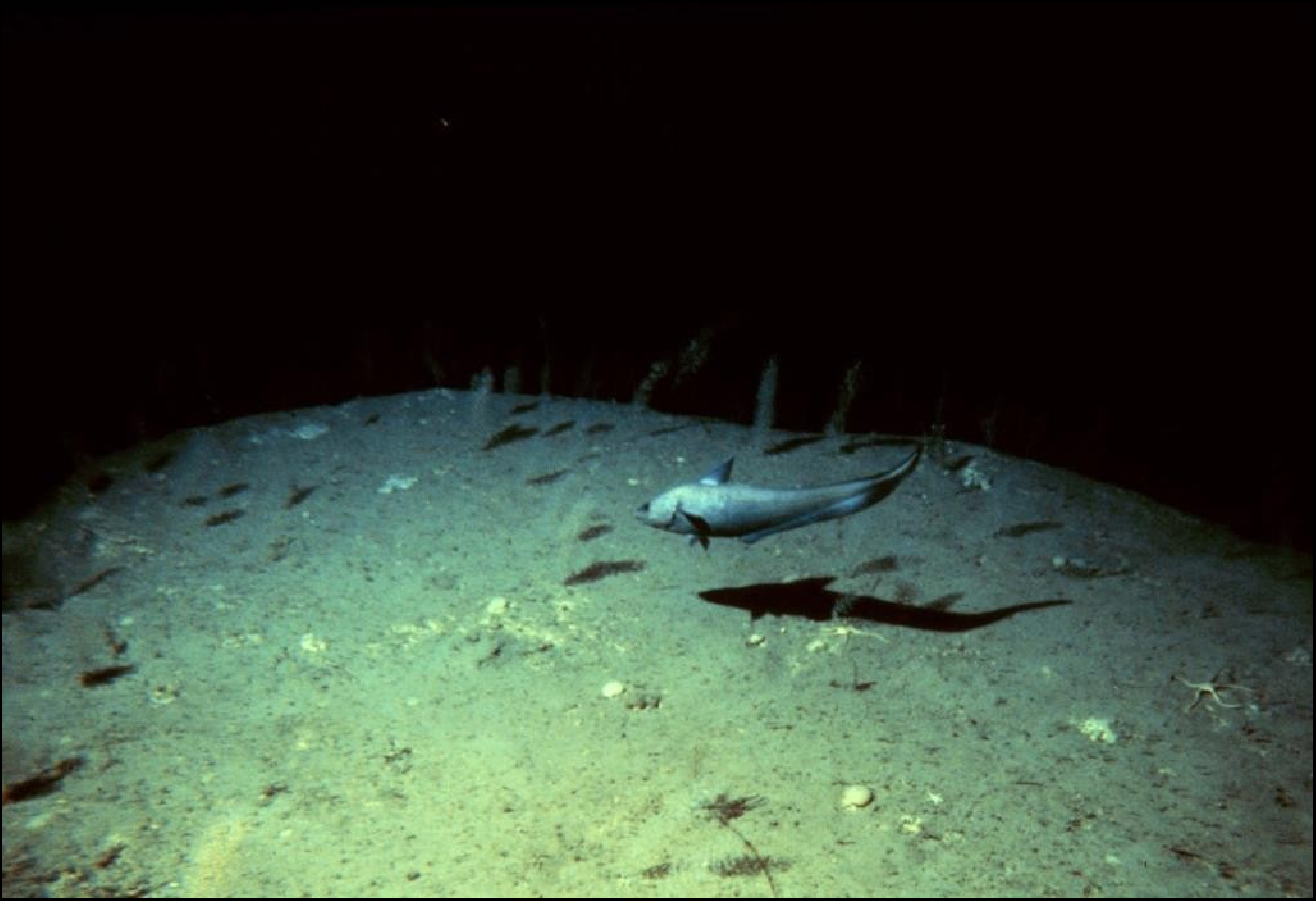
DSWC Events

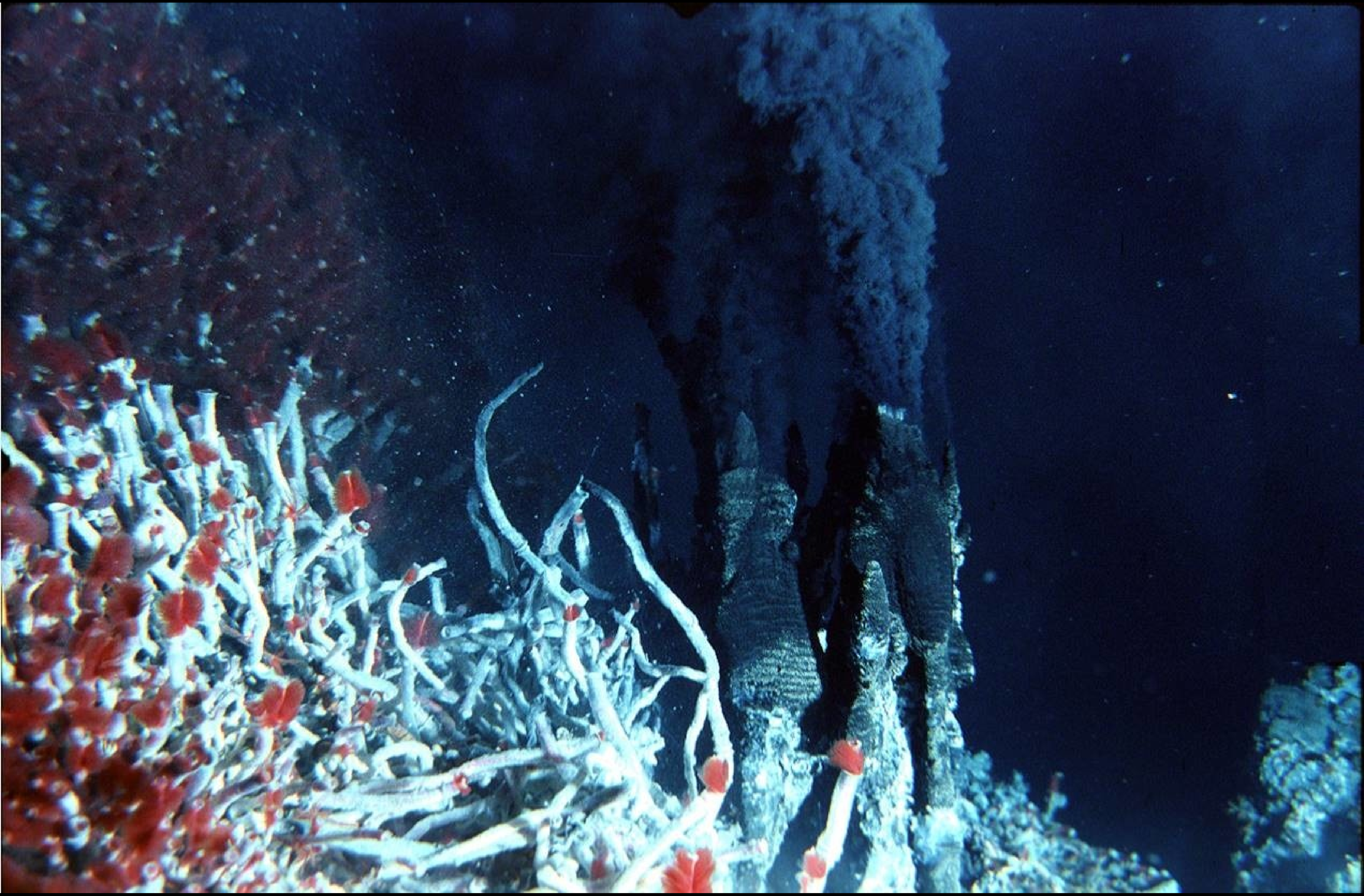

a
Pot. temp (°C)
σθ (kg m−3)
Speed (cm s−1)
SSC (mg l−1)
Jan
Feb
Mar
Apr 2005
b
NW
SE
SW
NE
Depth (m)
Distance (km)
Pot. temp. (°C)
SSC (mg l−1)
29.25
29.20
29.08
29.10
29.15
29.06

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*





(very) Brief history of Deep-Sea exploration

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

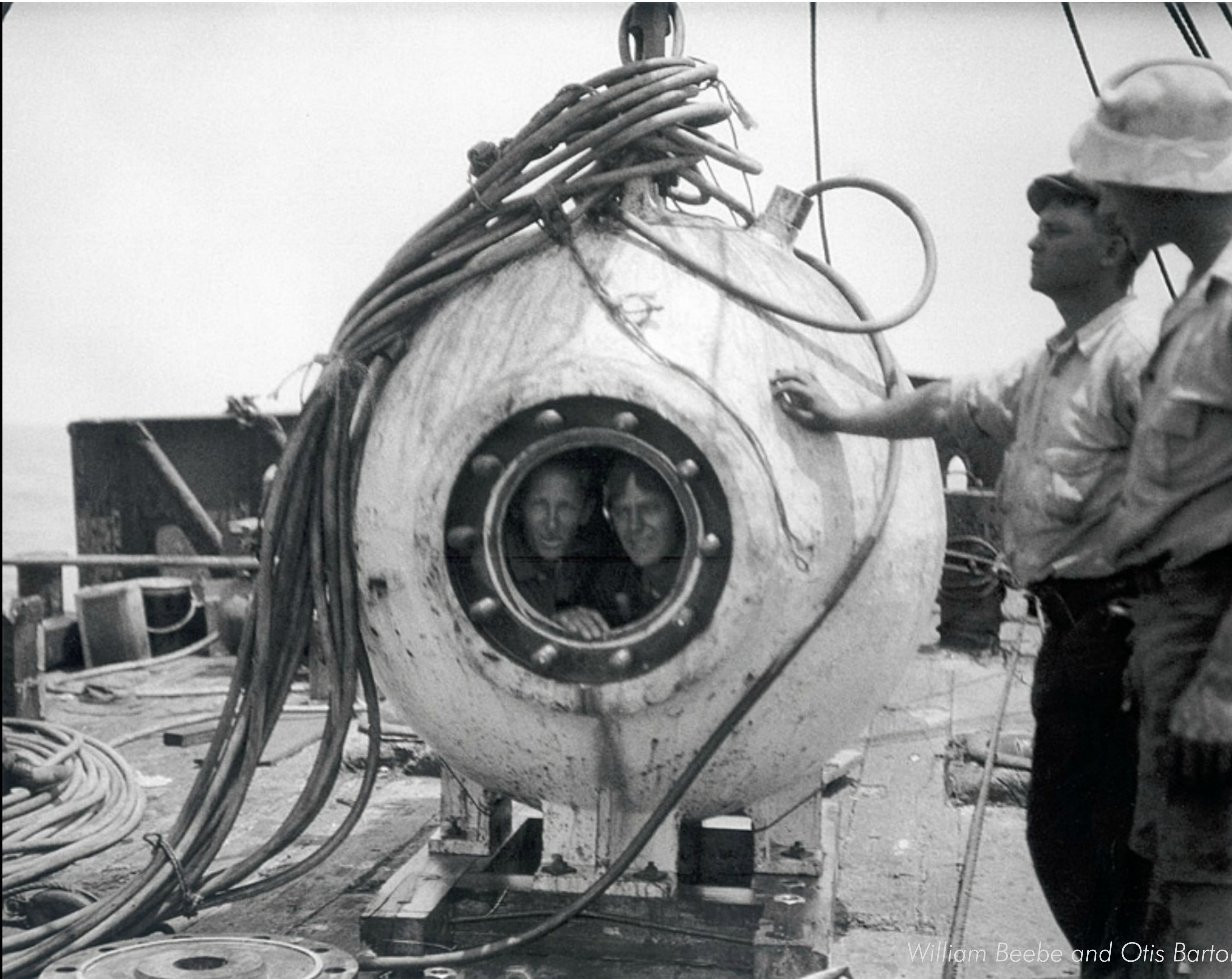
1867 - American naturalist Louis F. de Pourtales conducts dredging operations finding prolific life extending below 500 m.

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.

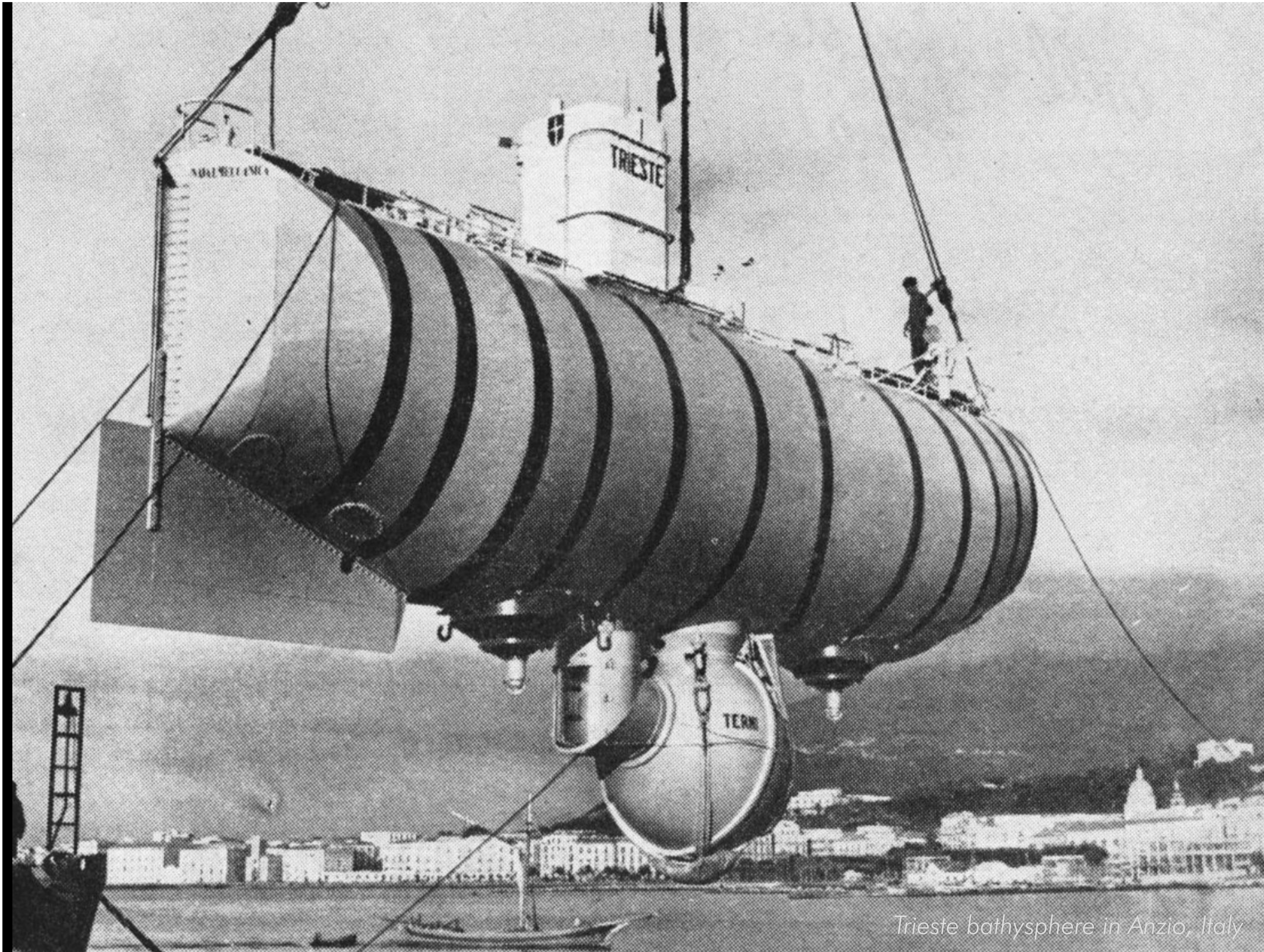
January 23, ***1960*** - Deepest Ocean Dive. Jacques Piccard and Dan Walsh descend into the Challenger deep with the bathyscaphe Trieste. The divers discover fish and other amazing deep-sea life at these tremendous depths.

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.

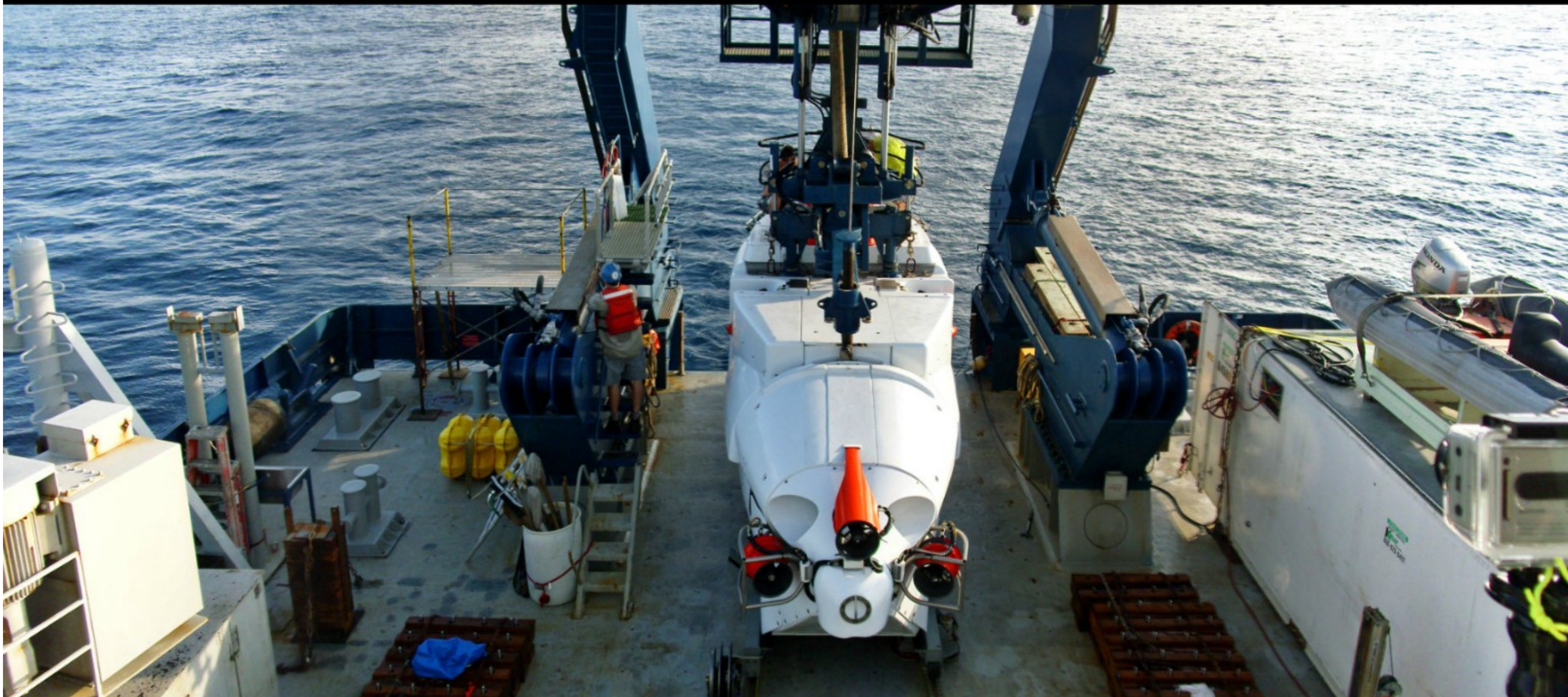


William Beebe and Otis Barton

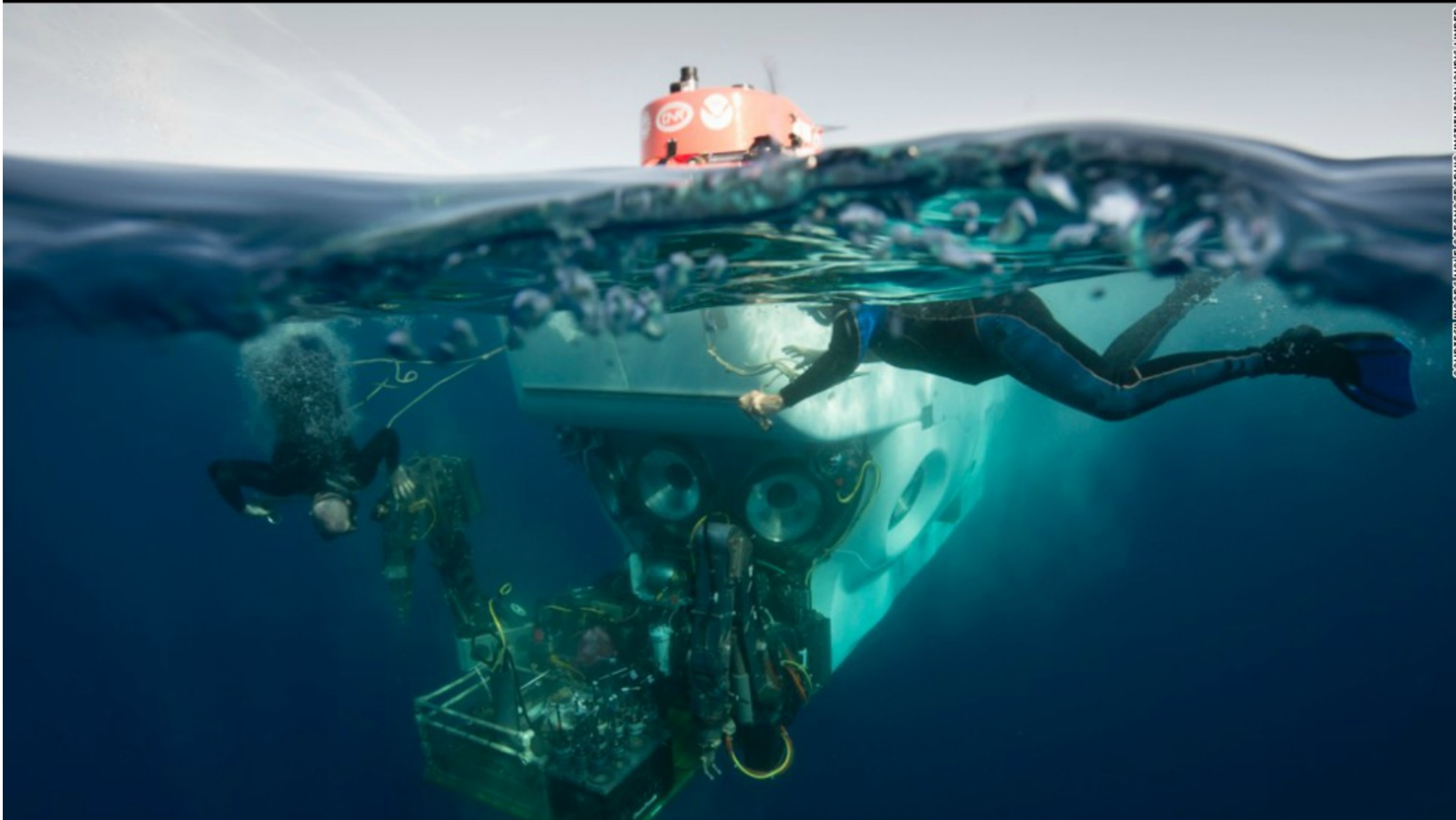
Jacques Piccard and Dan Walsh inside the Trieste



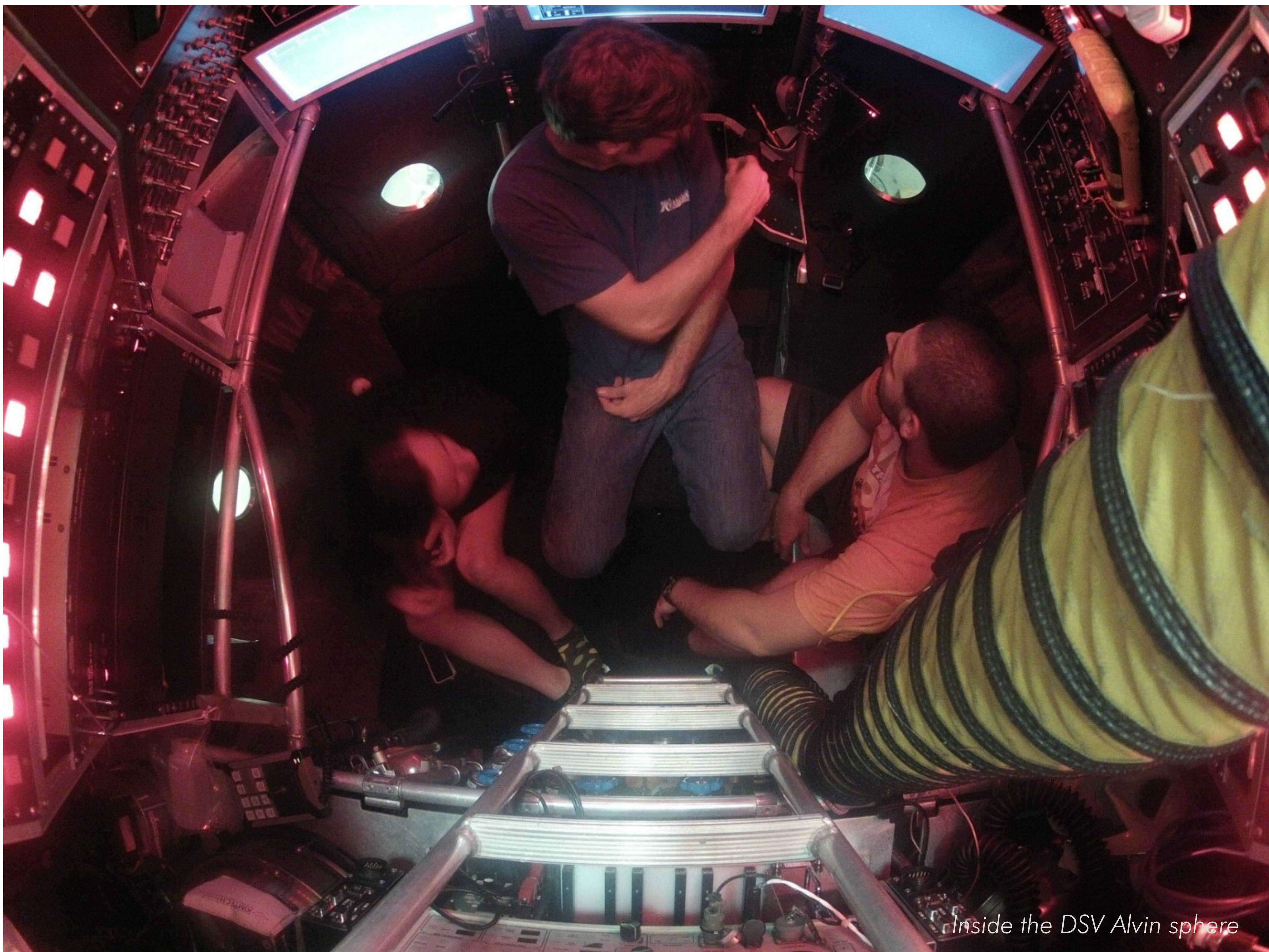
Trieste bathysphere in Anzio, Italy



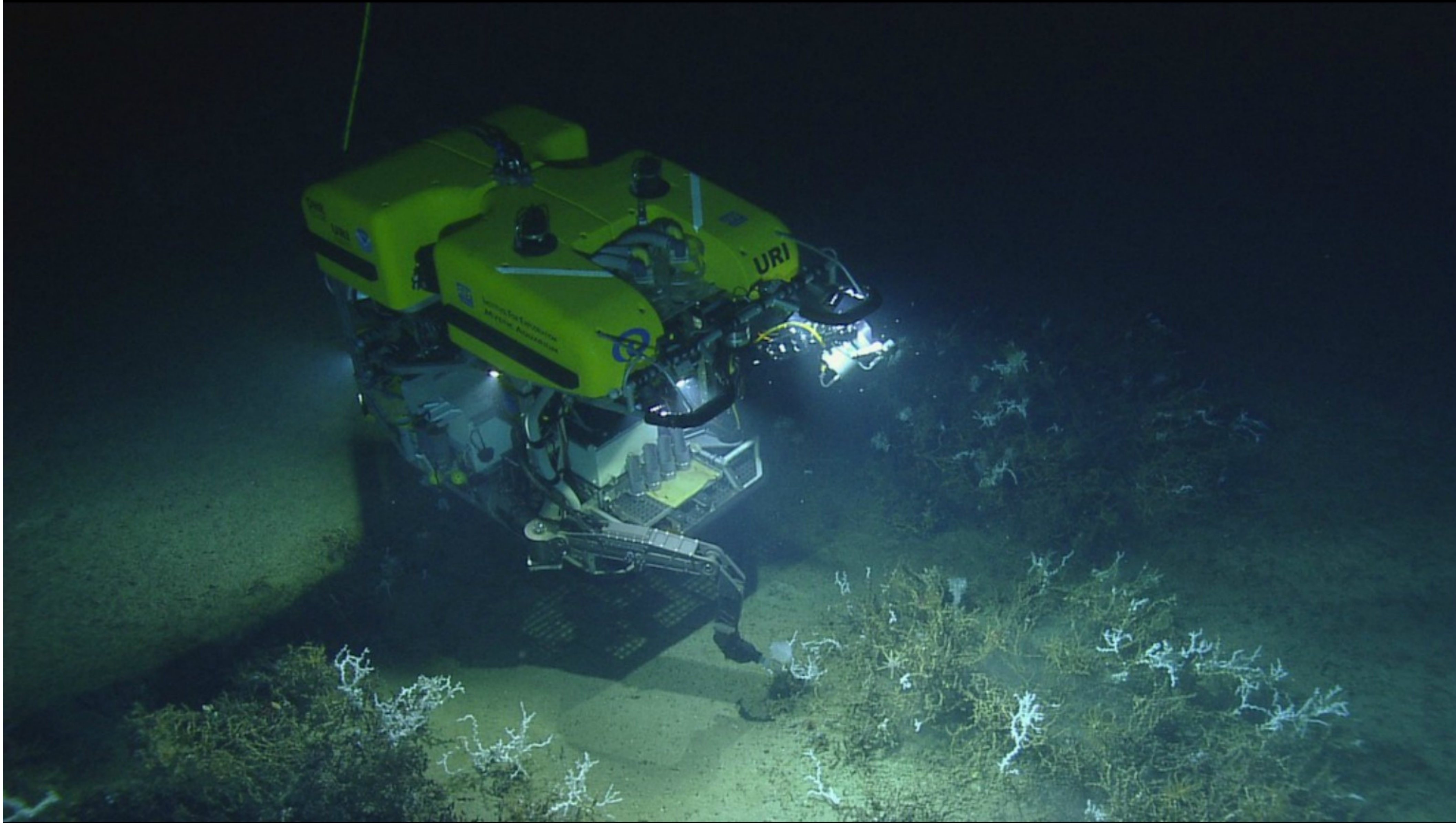
DSV Alvin on the deck of the R/V Atlantis, EPR



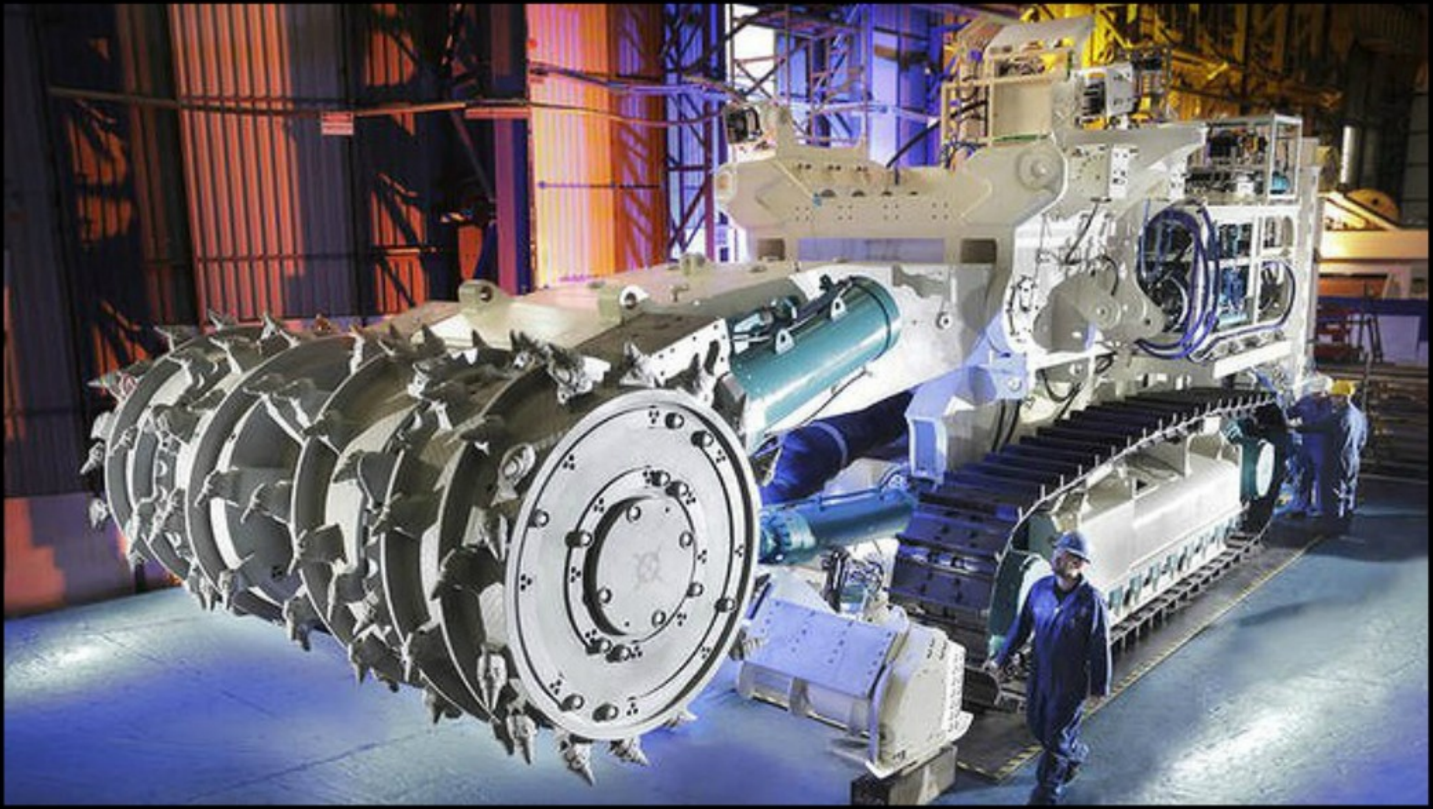
DSV Alvin in the water with the support divers



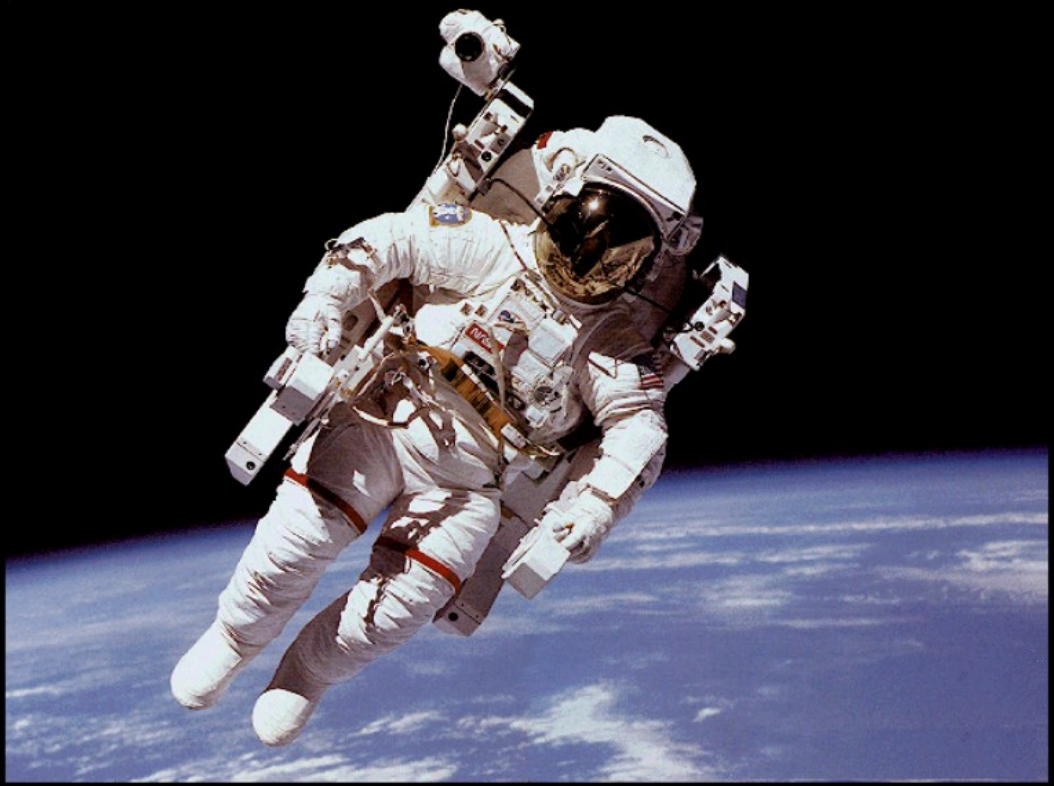
Inside the DSV Alvin sphere



The URI ROV Hercules on the seafloor



A deep sea mining ROV



NASA extravehicular mobility unit (EMU) and the US Navy ADS 2000

Carmagnolle ADS, 1882

This week read

Giovannelli D. 2016. Deep-Sea, Origin of Life and Astrobiology. IAS Institute Letter, Spring 2016 https://goo.gl/Tn8rM7

Sunagawa, S., Coelho, L. P., Chaffron, S., Kultima, J. R., Labadie, K., Salazar, G., ... Bork, P. 2015. Structure and function of the global ocean microbiome. Science, 348(6237). https://doi.org/10.1126/science.1261359

Thurber, A.R., Sweetman, A.K., Narayanaswamy, B.E., Jones, D.O.B., Ingels, J., Hansman, R.L., 2014. Ecosystem function and services provided by the deep sea. Biogeosciences 11, 3941–3963. https://doi.org/10.5194/bg-11-3941-2014