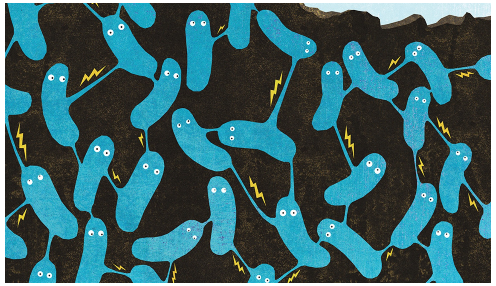
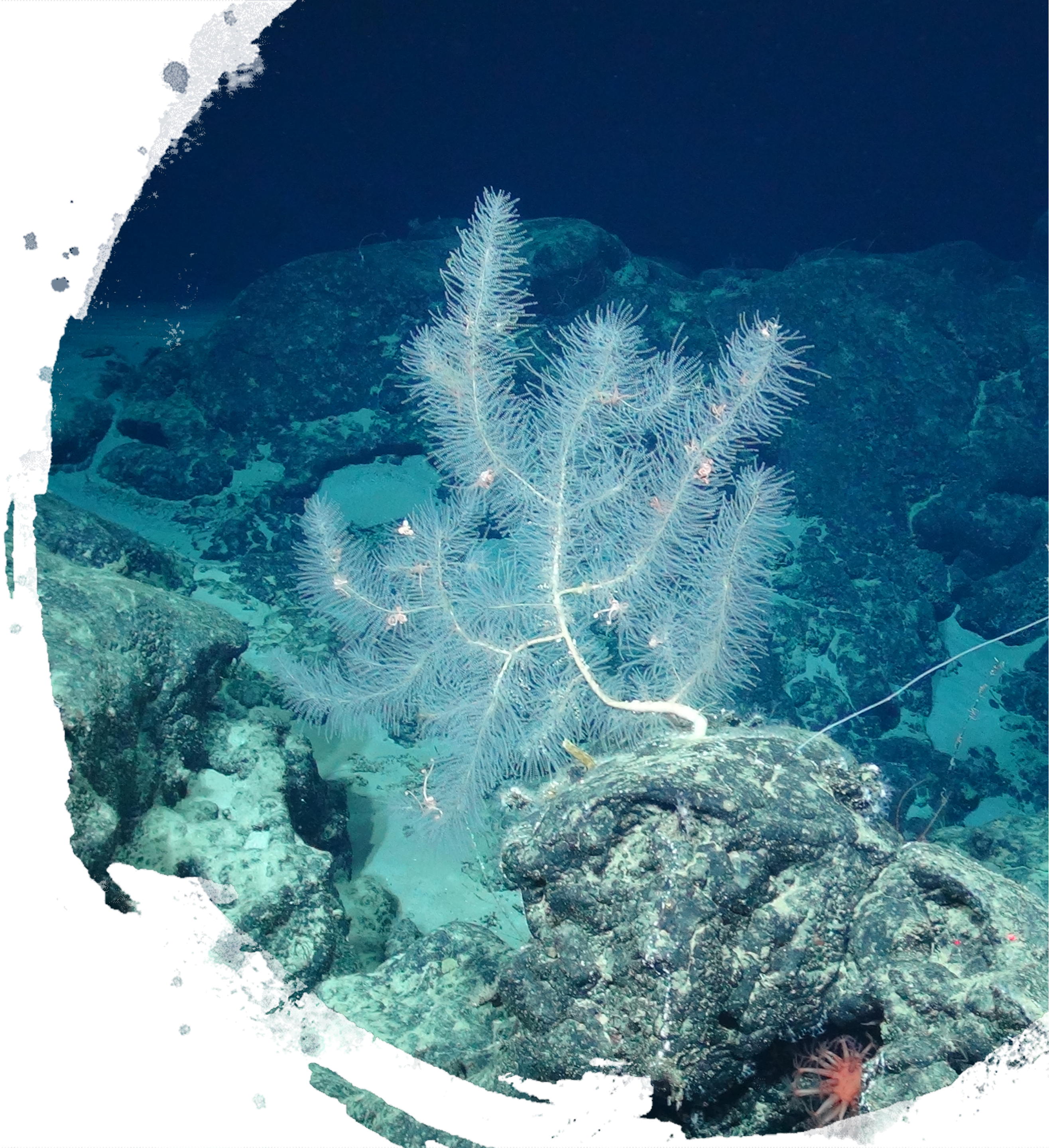
UNIVERSIDADE DE SÃO PAULO
IO
Instituto
Oceanográfico



Mar Profundo:
Vida e sub-superfície
Crostas e nódulos polimetálicos

Vivian Pellizari

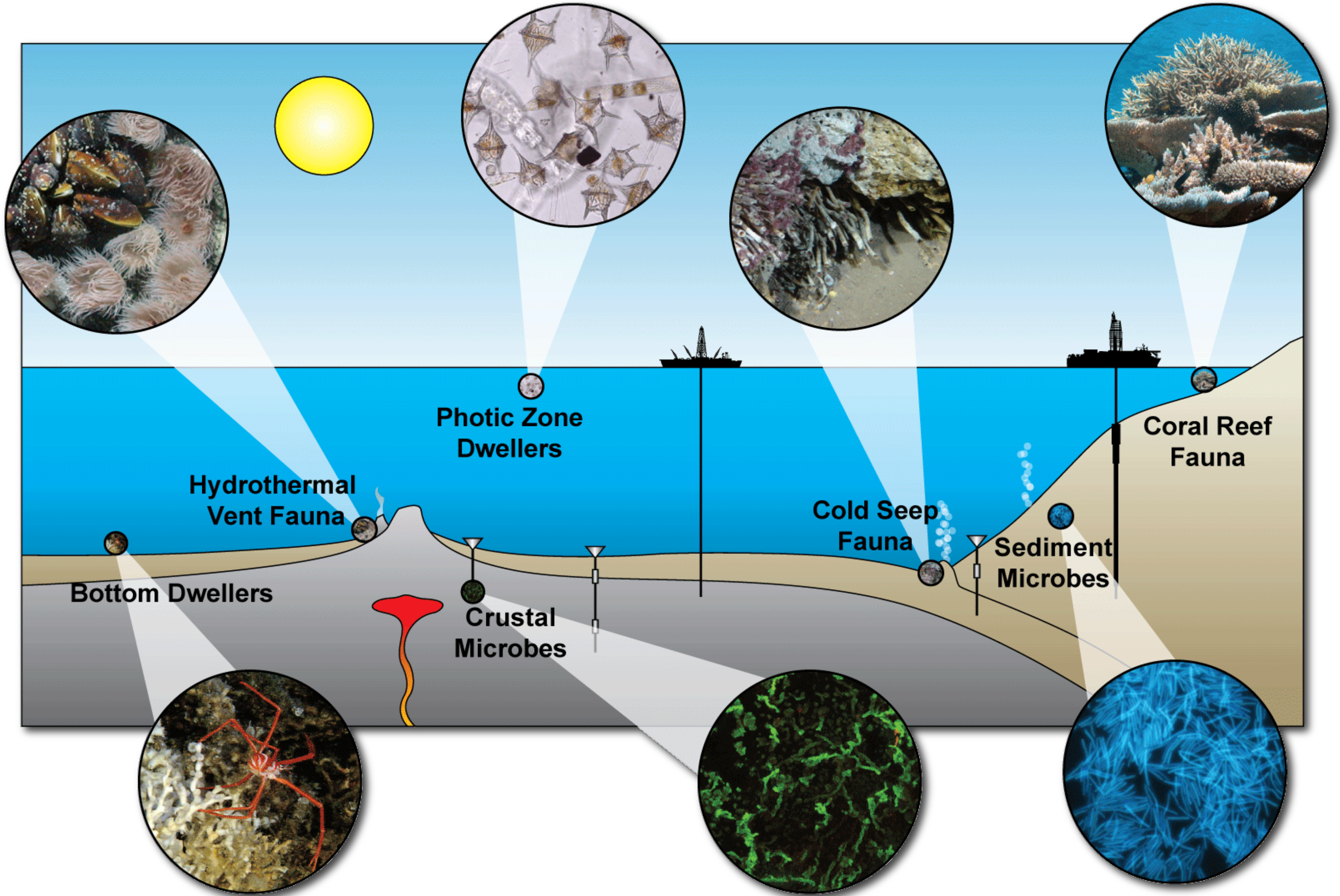
LECOM IOUSP
Laboratório de Ecologia Microbiana

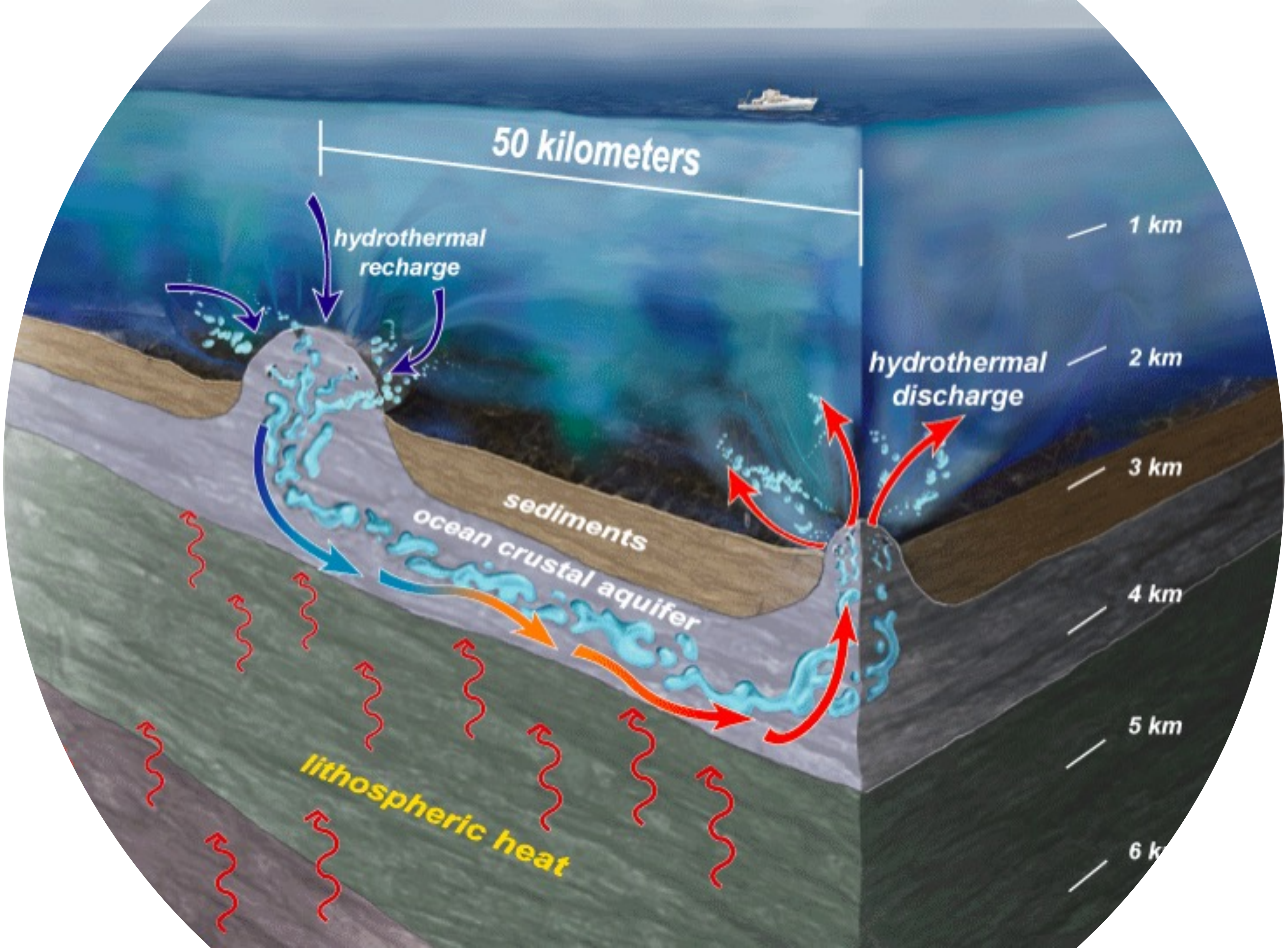


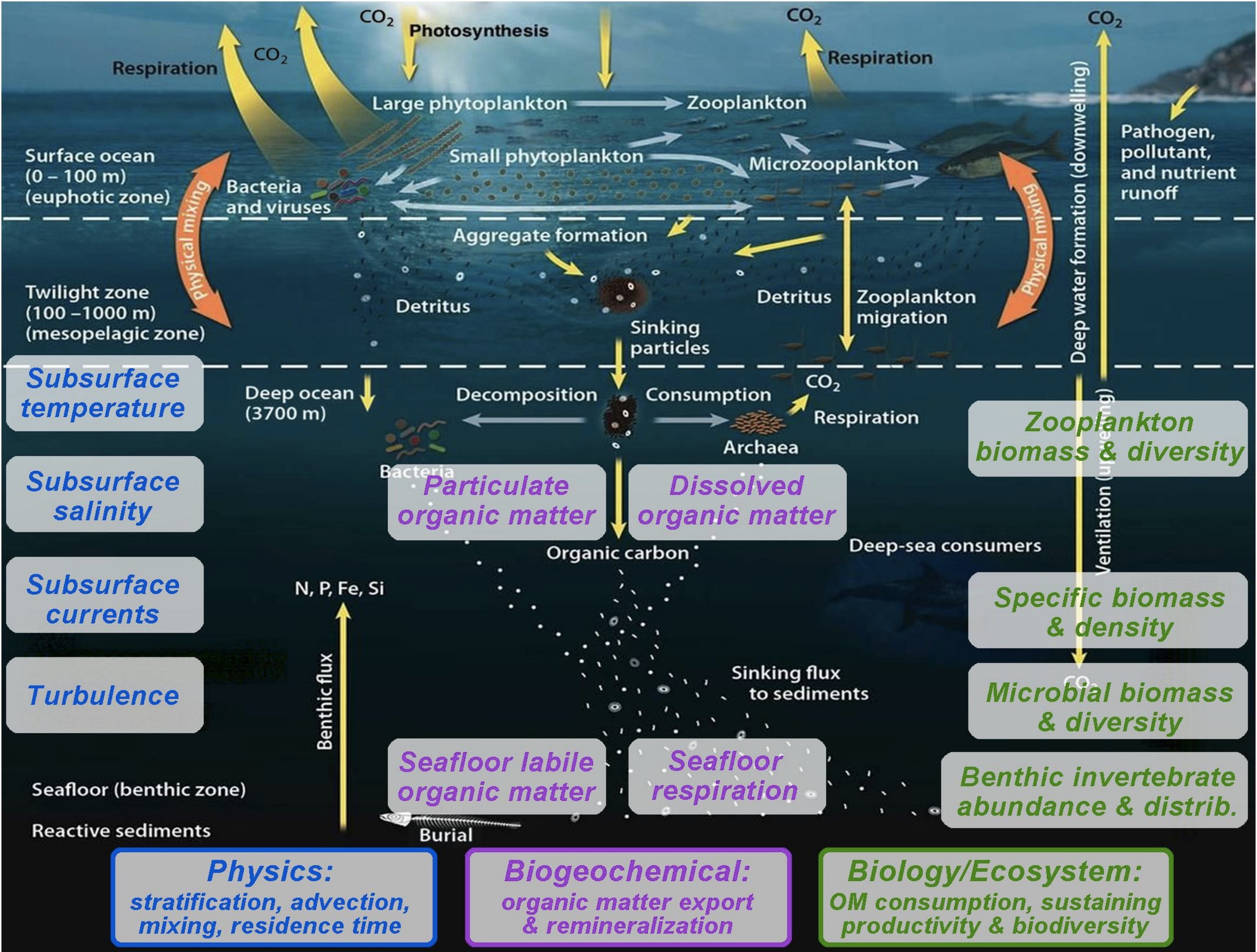
- Sedimento
- Sub-superfície e conexões
- Crosta e nódulo
- Resultados cold seep e organic fall
- Santos sedimento

Microrganismos no sedimento e em sub-superfície

- Drilling: revelou grande diversidade microbiana




50 kilometers
hydrothermal recharge
hydrothermal discharge
1 km
2 km
3 km
4 km
5 km
6 k
sediments
ocean crustal aquifer
lithospheric heat



Subsurface temperature

Subsurface salinity

Subsurface currents

Turbulence

Particulate organic matter

Dissolved organic matter

Seafloor labile organic matter

Seafloor respiration

Zooplankton biomass & diversity

Specific biomass & density

Microbial biomass & diversity

Benthic invertebrate abundance & distrib.

Physics:
stratification, advection, mixing, residence time

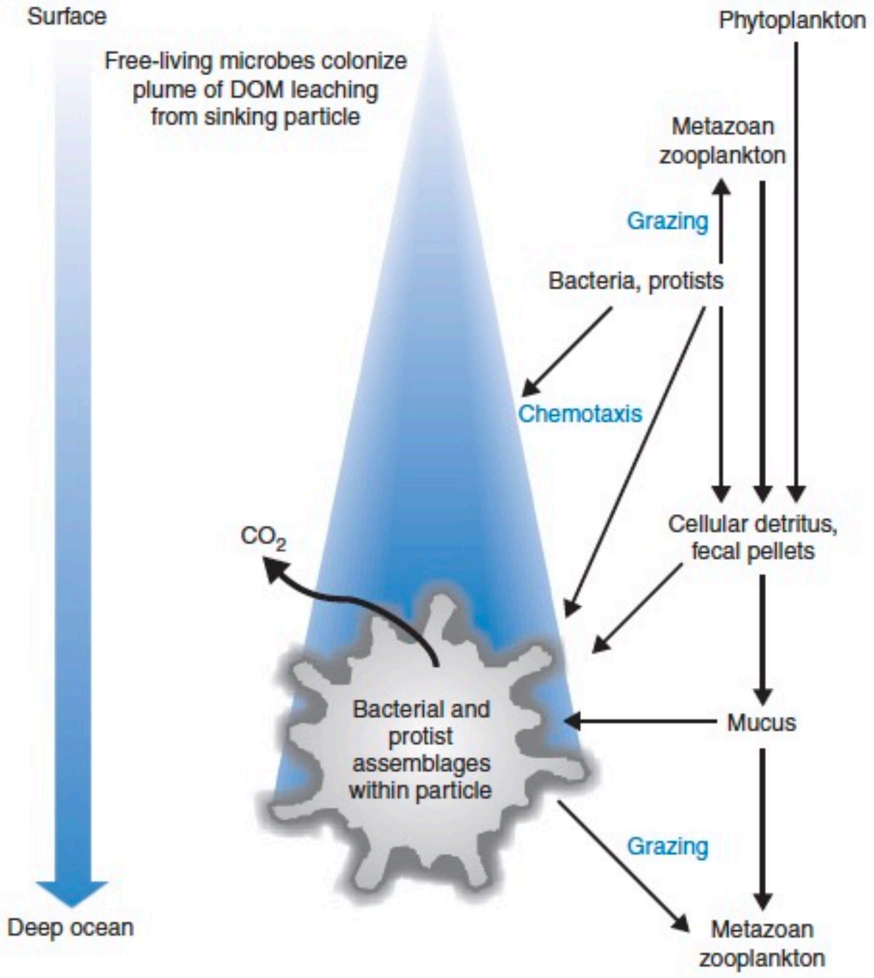
Biogeochemical:
organic matter export & remineralization

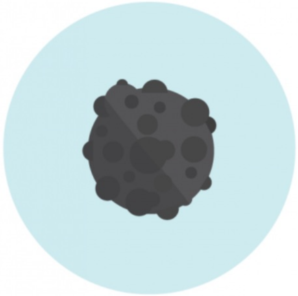
Biology/Ecosystem:
OM consumption, sustaining productivity & biodiversity

Deep EOVs related to the biological carbon pump

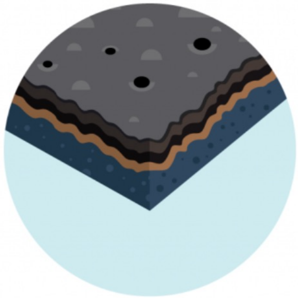
ttps://www.frontiersin.org/articles/10.3389/fmars.2019.00241/full

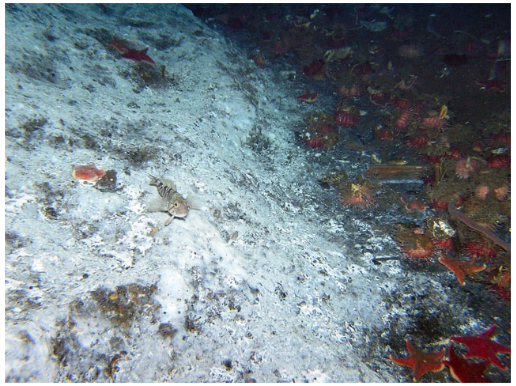
Cél na neve marinha: 10^8–10^9 mL−1,



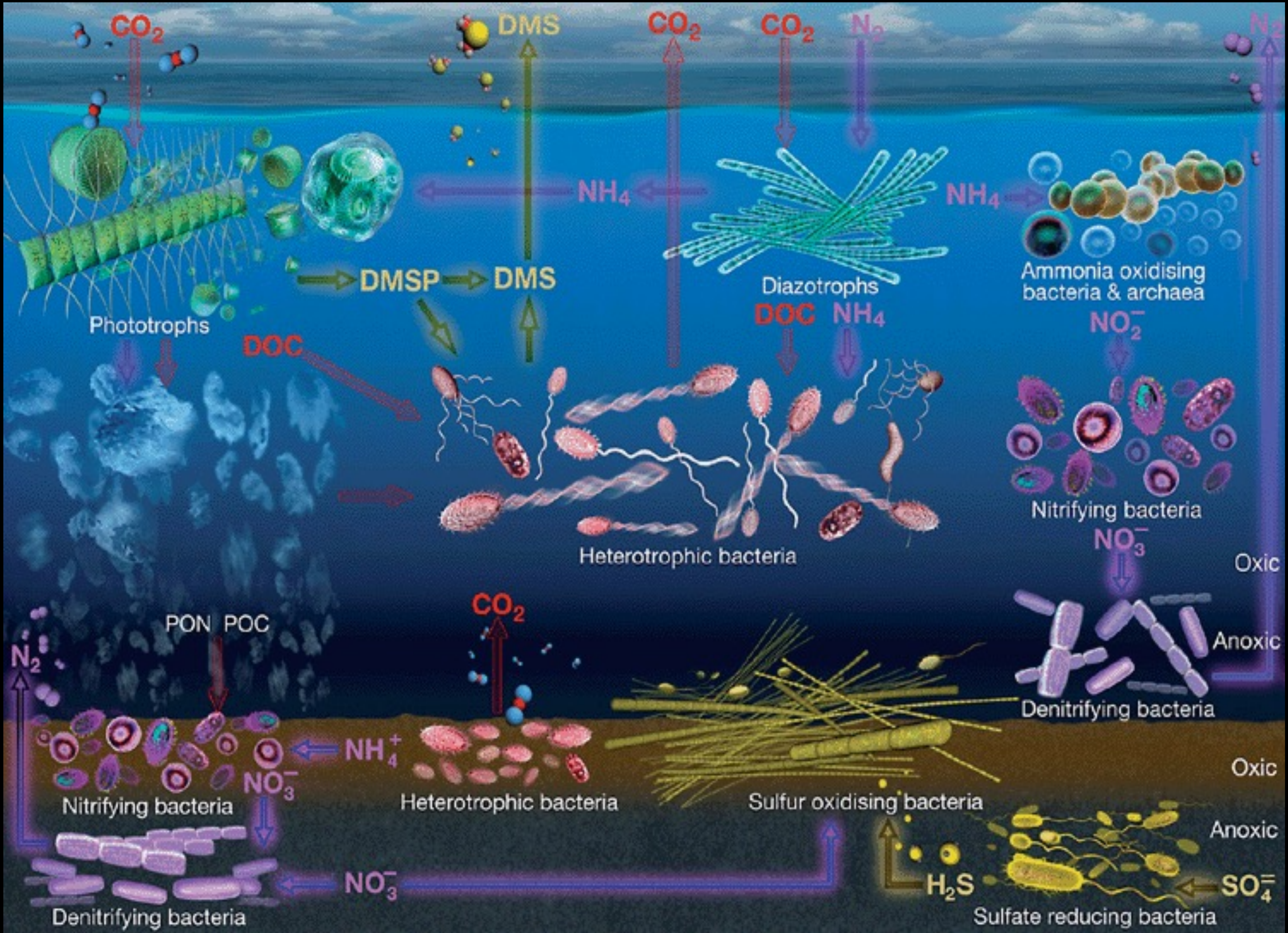

Nódulos de Fe-Mn


Maciços de sulfetos

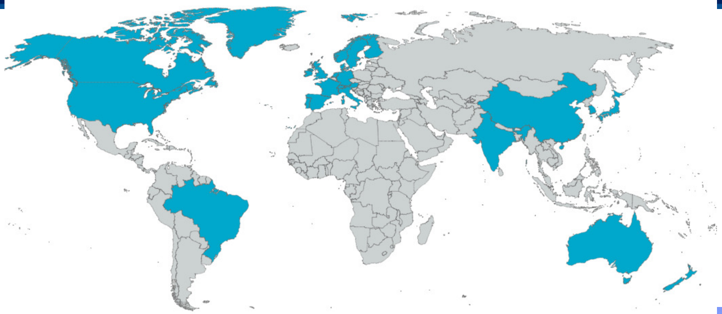

Crosta de Fe-Mn



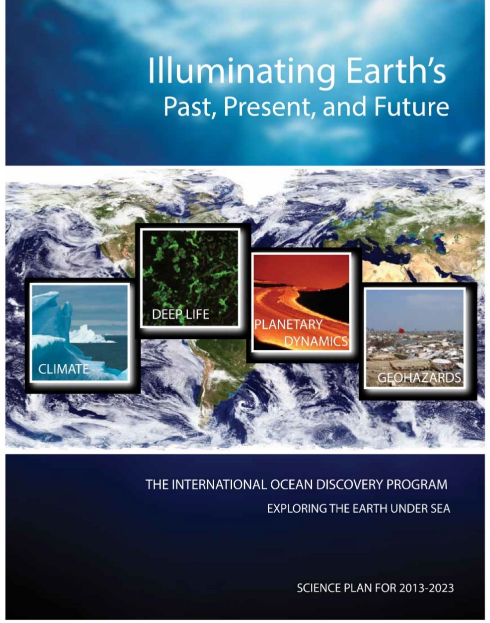
Biofilmes – Tapetes Microbianos


CO_2
DMS
CO_2
CO_2
N_2
N_2
NH_4
NH_4
DMSP
DMS
Phototrophs
Diazotrophs
Ammonia oxidising bacteria & archaea
DOC
DOC
NH_4
NO_2^-
Nitrifying bacteria
NO_3^-
Heterotrophic bacteria
Oxic
Anoxic
CO_2
PON
POC
N_2
Denitrifying bacteria
NH_4^+
NO_3^-
Nitrifying bacteria
Heterotrophic bacteria
Sulfur oxidising bacteria
Oxic
Anoxic
NO_3^-
H_2S
$SO_4^=$
Denitrifying bacteria
Sulfate reducing bacteria

PROGRAMA INTERNACIONAL DE PESQUISA EM OCEANOS - IODP



Programa IODP/CAPES-Brasil
BRASIL MEMBRO DO IODP 2012
(*International Ocean Discovery Program*)



Illuminating Earth's
Past, Present, and Future

THE INTERNATIONAL OCEAN DISCOVERY PROGRAM
EXPLORING THE EARTH UNDER SEA

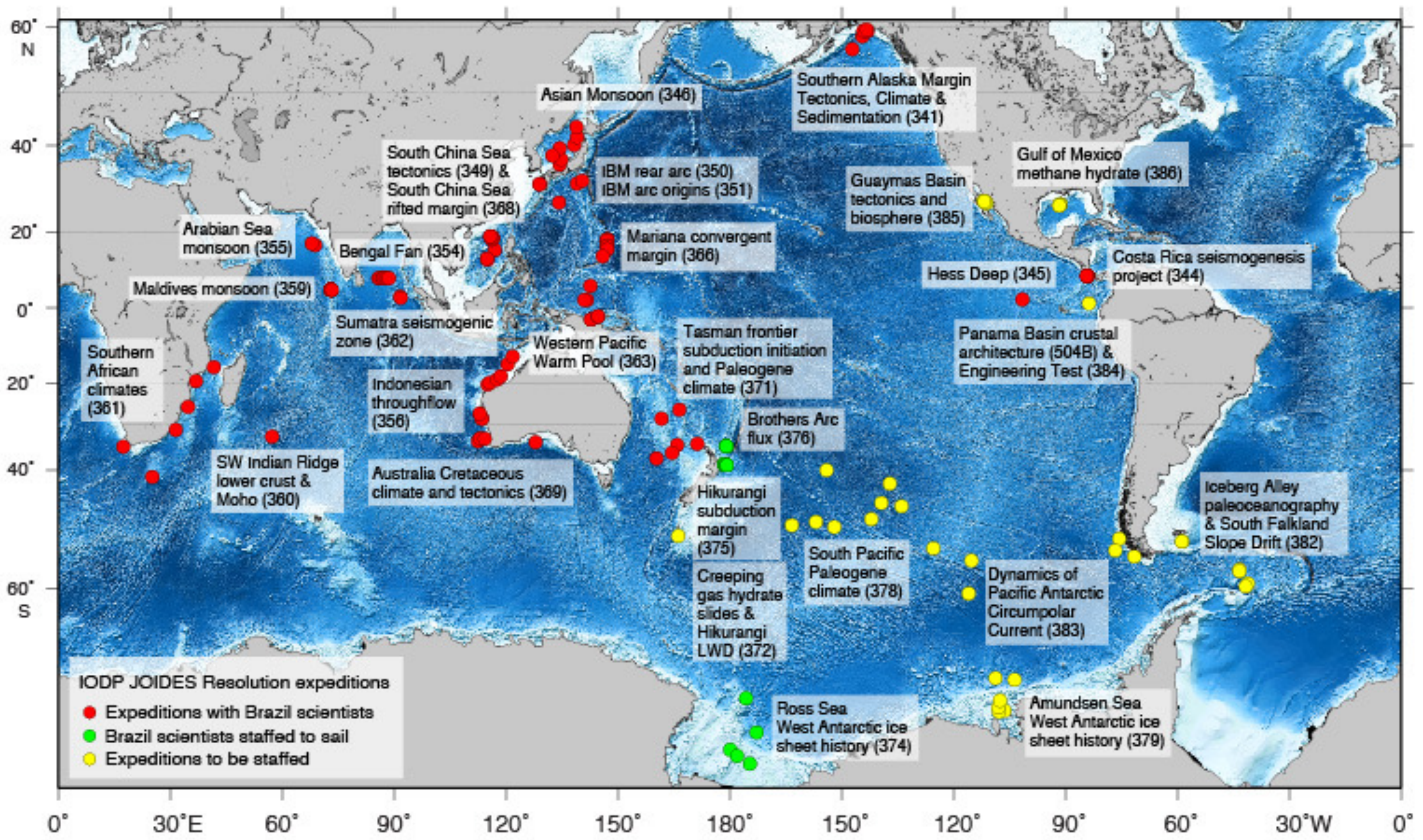
SCIENCE PLAN FOR 2013-2023

JOIDES RESOLUTION - JR

Benefícios:

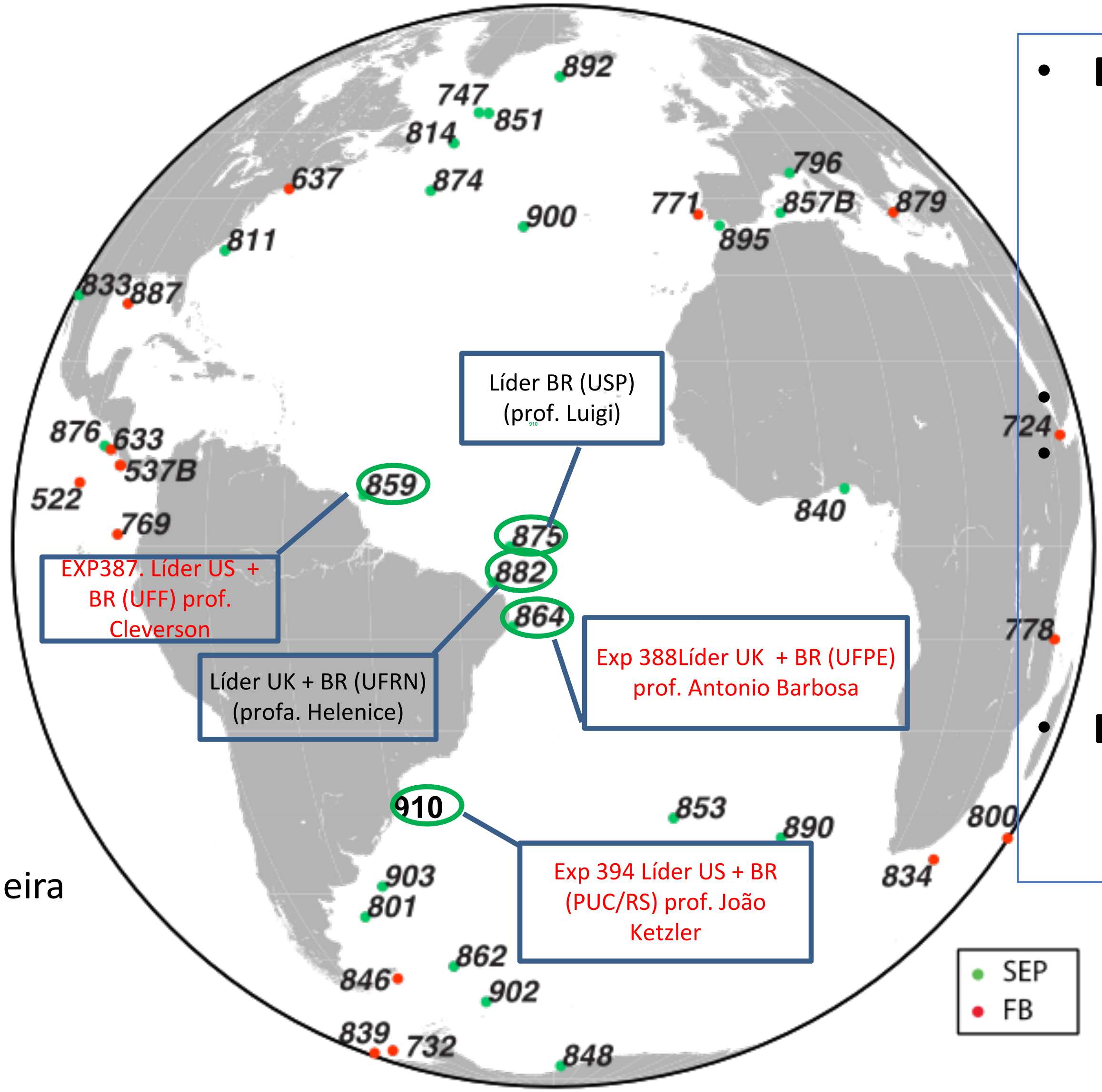
- Aumento do entendimento como o Clima da Terra e os Oceanos respondem às rápidas mudanças ambientais
- Melhor conhecimento sobre os processos de riscos geológicos (terremotos, tsunamis, etc) com vista à antecipação e melhor preparação destes eventos
- Quantificar o armanezamento e fluxo do carbono, fontes críticas de recursos da Terra
- Treinar a próxima geração de cientistas, engenheiros e educadores na estratégia Interdisciplinares e uso de ferramentas quantitativas
- Engajar da melhor maneira possível comunidades de educadores, estudantes e público em geral

Expedições com participações de Brasileiros (até Oct/17)



Propostas de sondagem por brasileiros

Expedições 2022/23



Líder BR (USP)
(prof. Luigi)

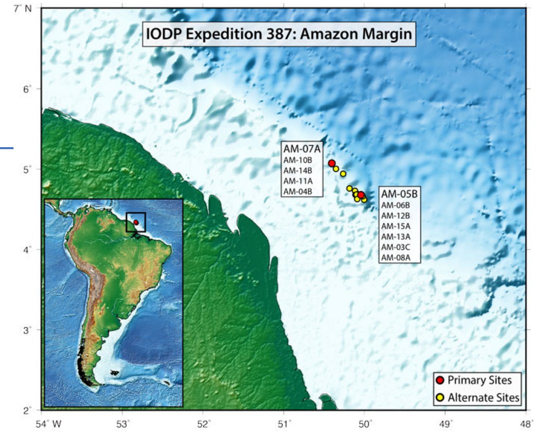
EXP387. Líder US + BR (UFF) prof. Cleverson

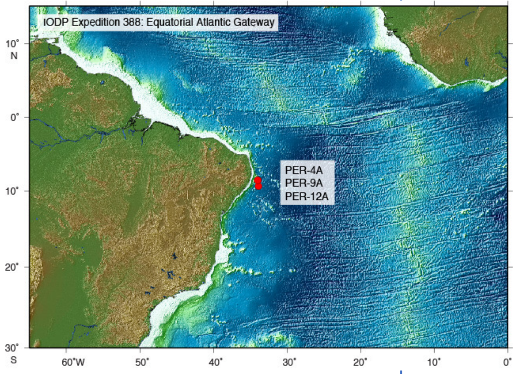
Líder UK + BR (UFRN)
(profa. Helenice)

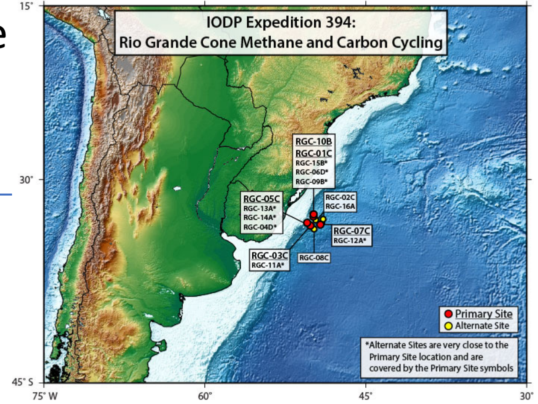
Exp 388Líder UK + BR (UFPE)
prof. Antonio Barbosa

Exp 394 Líder US + BR (PUC/RS) prof. João Ketzler

- **Exp387** Amazon Margin
- **Exp 388** Equatorial Atlantic gateway
- **Exp 394** Rio Grande Cone Methane and Carbon Cycling







Propostas com participação brasileira

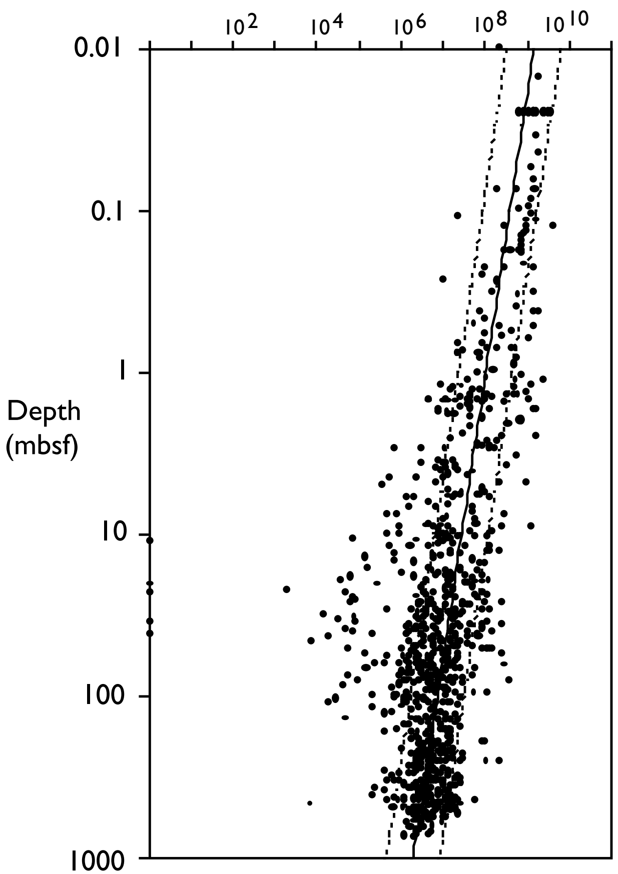


Figure 13. Bacterial abundances as a function of sub-bottom sediment depth as seen in ODP boreholes down to ~ 750 mbsf. Figure reprinted with permission from Parkes, R.J., B.A. Cragg and P. Wellsbury, Recent studies on bacterial populations and processes in subseafloor sediments: A review, Hydrogeol. Jour., 8, Figure 2b, p.15, copyright Springer-Verlag, 2000.

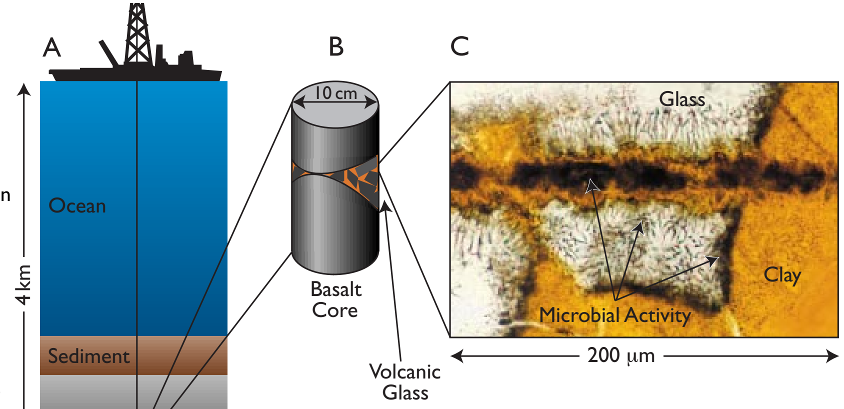


Figure 14. Photo at the right is of a section of basalt collected from about 290 meters below the seafloor, or about 54 meters into the volcanic basement, on DSDP Leg 82. The glass and clay in the photo are evident by their different colors. Wispy dark lines in the glass and dark areas in the clay and at the glass-clay margin are where iron oxides have formed in response to microbial activity. Ghosts of wispy lines can be seen in some areas of clay near the glass. ODP samples have established that this type of alteration exists throughout the

Sedimentos profundos e rochas de subsuperficie:

- 1.6 Km de prof. - porosidade .
- Abundância 3x 10^{29} cél procarióticas

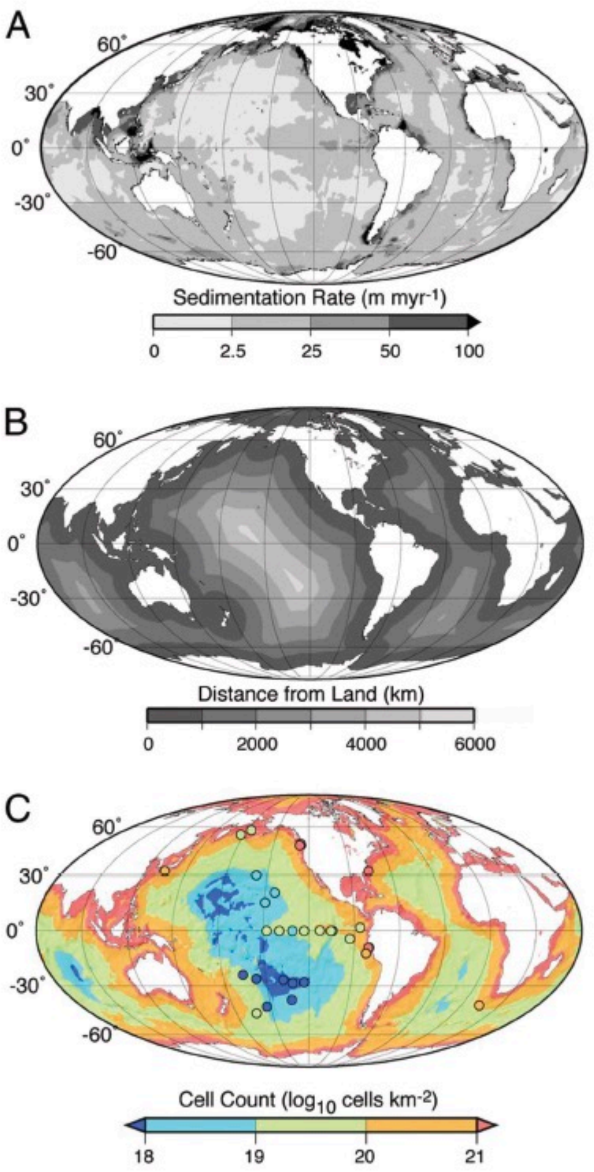


Figure 1.10 Global distribution of subseafloor sedimentary cell abundance. A. Sedimentation rate. B. Distance from shore. C. Integrated number of cells. Reprinted from Kallmeyer et al. (2012) with permission from National Academy of Sciences.

Deposição da matéria orgânica regiões muito oligotróficas:
poucos mm cada 1000 anos.
Baixa conc. O 2

Vida se sustenta por manter o mínimo de energia para "sobreviver" (Bradley et al 2019)
Respiração 100 vezes menor que na superfície do sedimento
Células : 100- 1000 células cm^{-3}

Jorgensen 2011 – células reproduzem uma vez apenas - período de mais de cem anos.

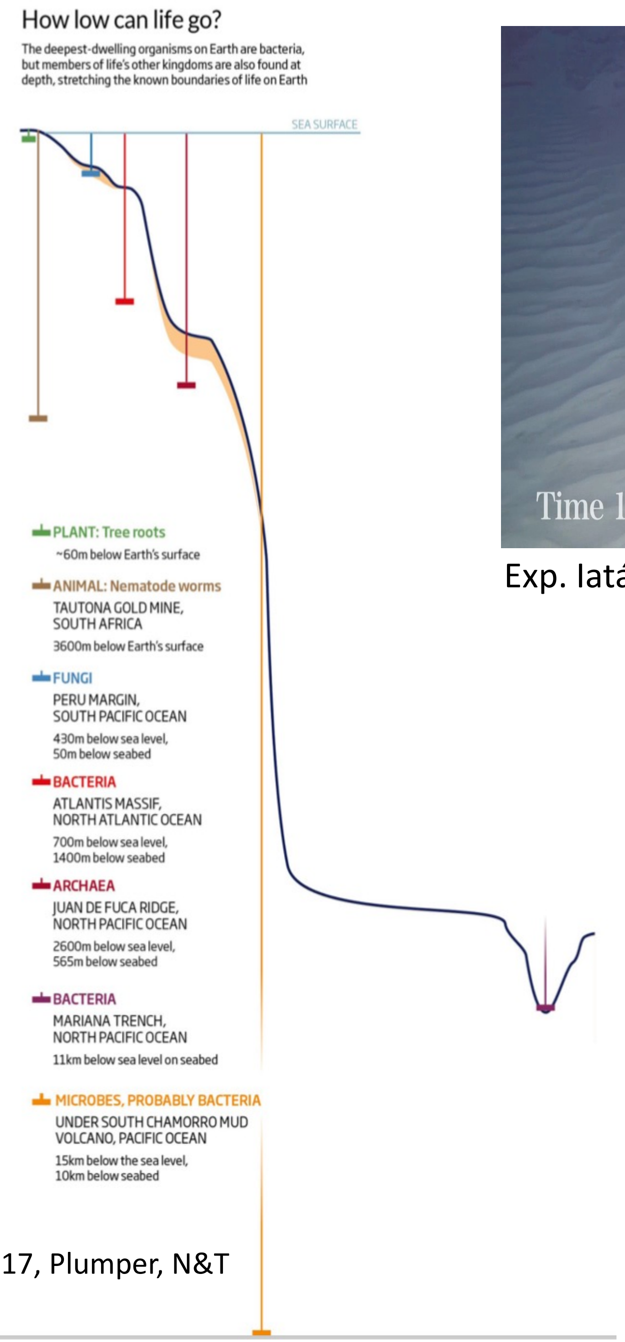
Proteção do ataque de vírus e protistas

Células foram reativada e o metabolismo aumentado até 1000 vezes (Morono et al 2011)

Material recuperado de 2,5 Km na costa do japão (10-100cm-3) a diversidade rRNA 16S era similar ao solo de floresta do que sedimentos marinhos (MO?)

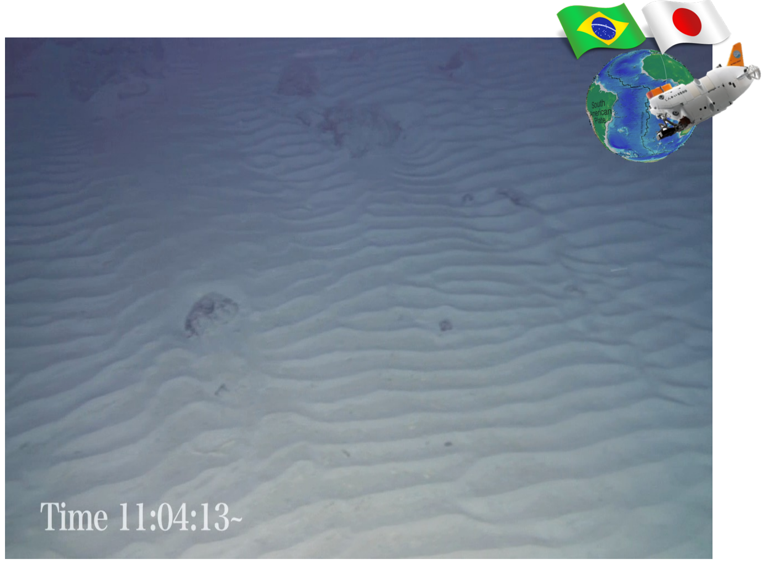
Arqueias tem maior biomassa do que as bactérias?

A VIDA EM MAR PROFUNDO E SUBSUPERFÍCIE


How low can life go?

The deepest-dwelling organisms on Earth are bacteria, but members of life's other kingdoms are also found at depth, stretching the known boundaries of life on Earth

2017, Plumper, N&T



Exp. Iatá-piuna 2013

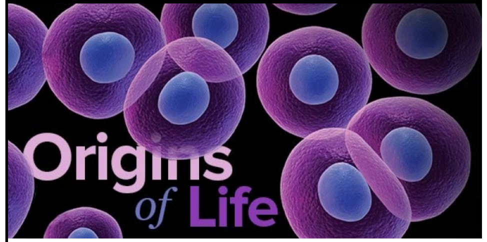
There are more microbes in the ocean, than stars in the galaxy

SUBSUPERFÍCIE 10^{29}

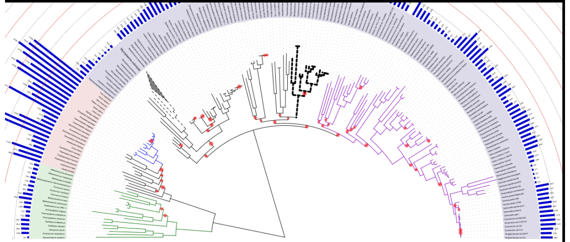
ESTRELAS NO UNIVERSO 10^{24}

Mar Profundo - Vida na Terra

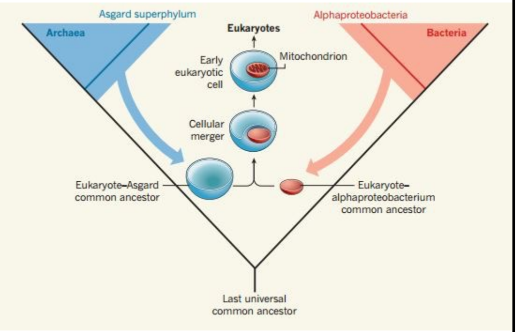
Origem da vida



Evolução da vida



Arqueias marinhas: origem dos eucariotos



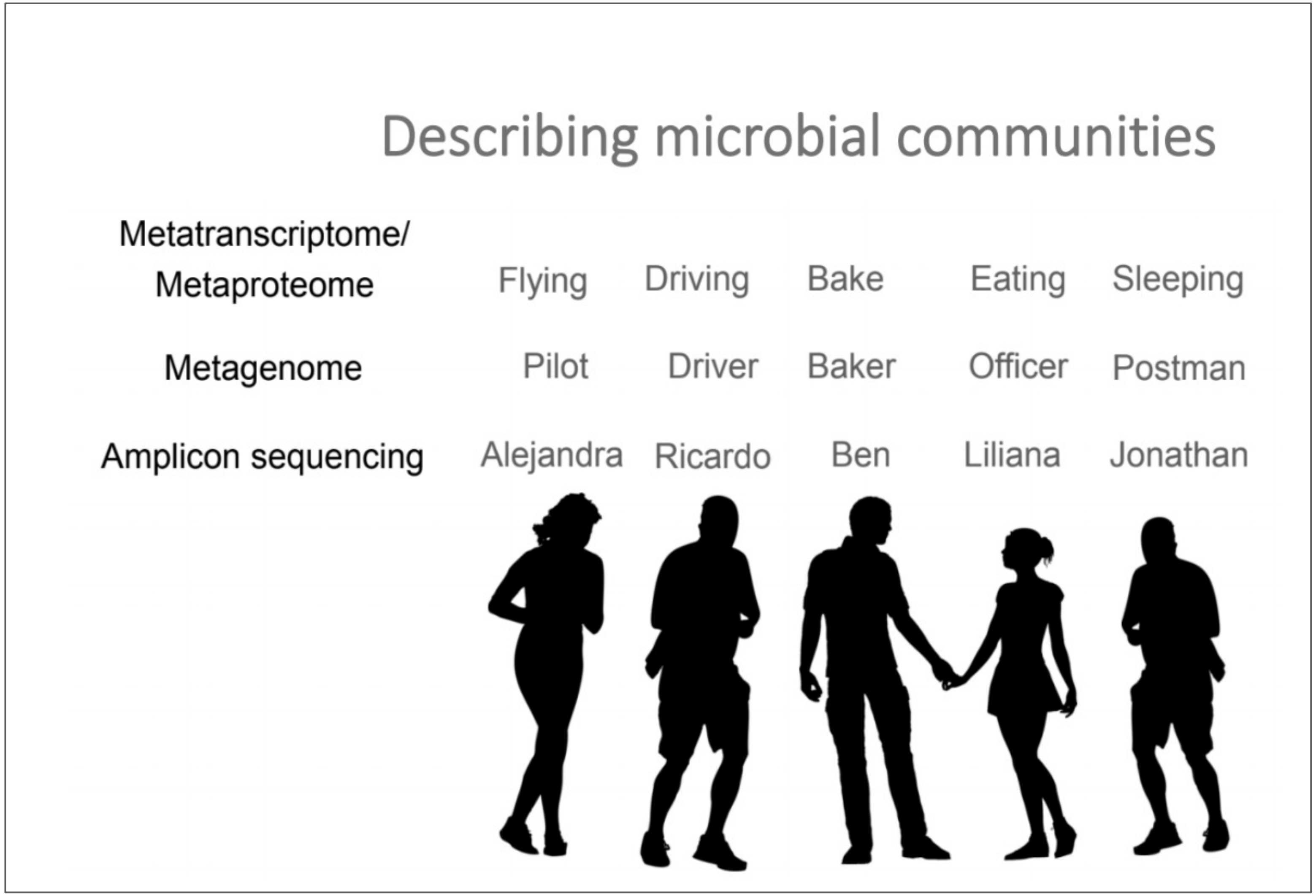
Limites da vida

Vida microbiana em temperaturas de 122ºC e altas pressões 125 MPa

Bactérias vivas em sedimentos de 100 milhões de anos

Merino et al. 2019. Front M Sc; Zaremba-Niedzwiedzka et al..2017. Nature.

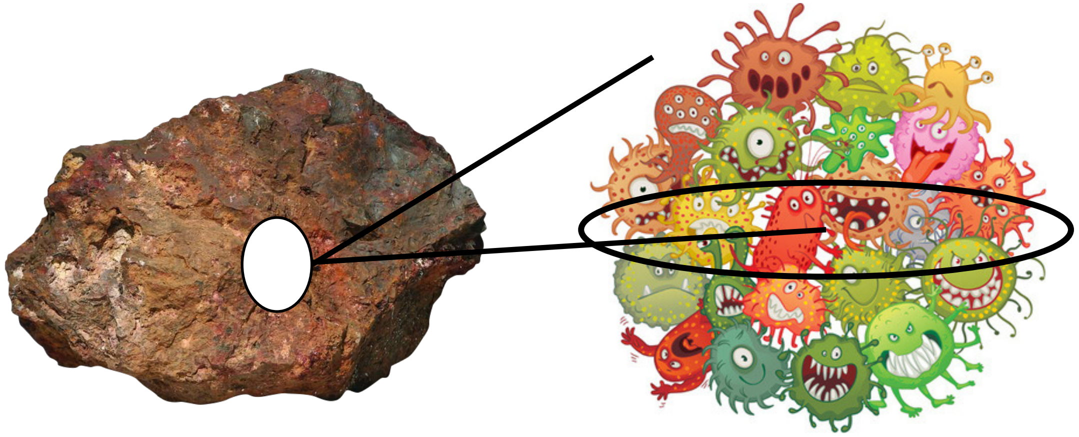
COMO ESTUDAR A DIVERSIDADE DE MICRO-ORGANISMOS SEM CULTIVAR?



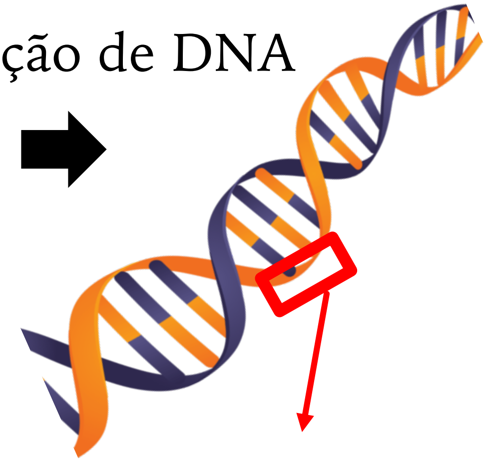
Describing microbial communities

Metatranscriptome/ Metaproteome	Flying	Driving	Bake	Eating	Sleeping
Metagenome	Pilot	Driver	Baker	Officer	Postman
Amplicon sequencing	Alejandra	Ricardo	Ben	Liliana	Jonathan

Como estudar a Diversidade de micro-organismos no ambiente?

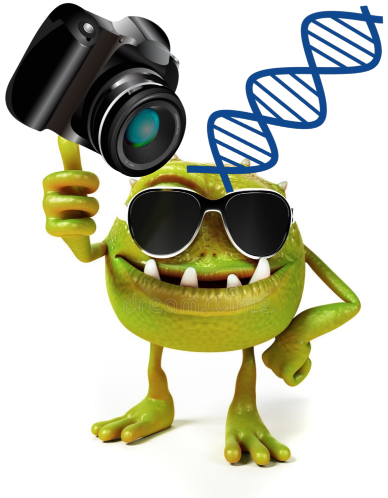


Extração de DNA



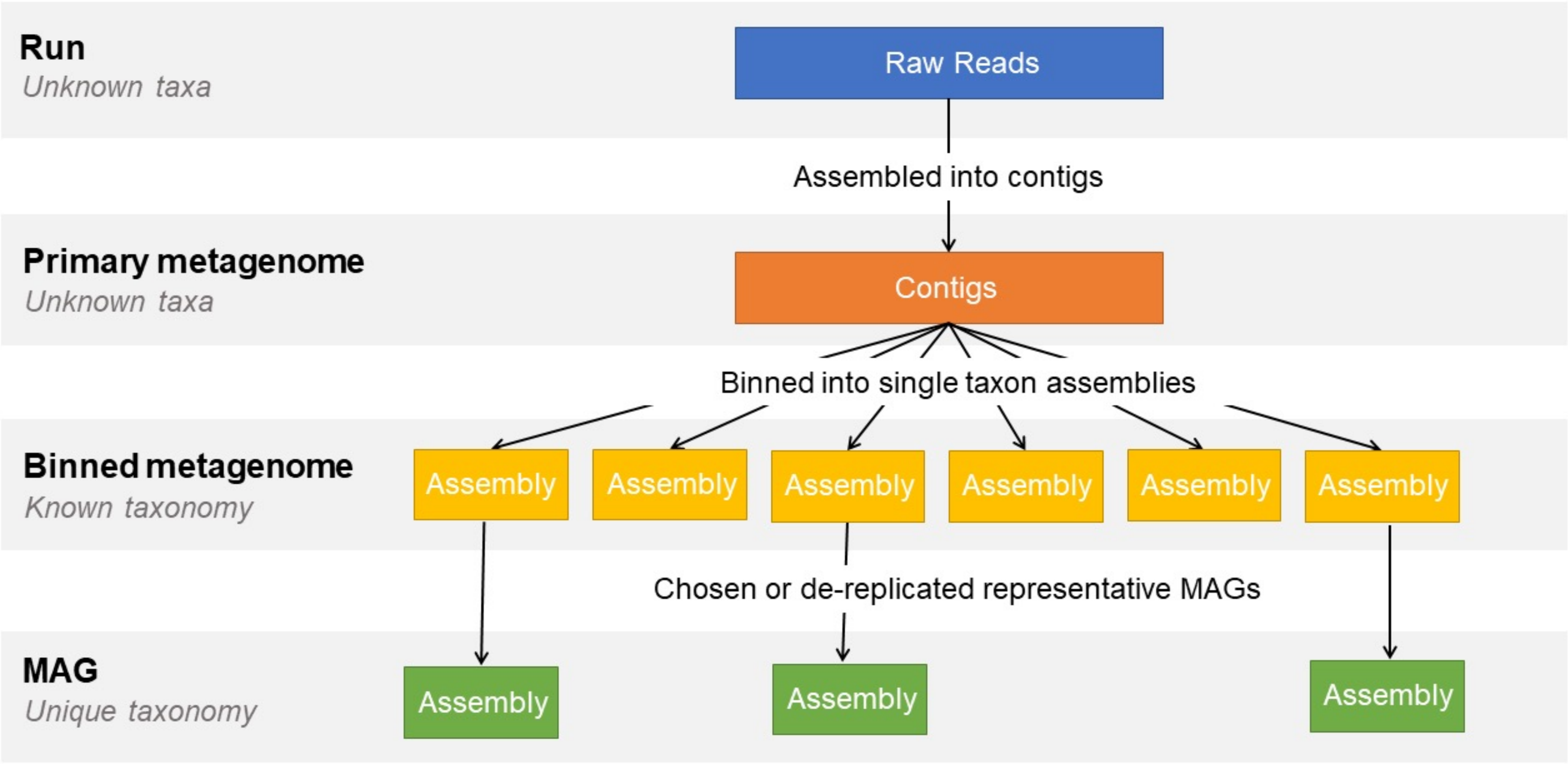
Sequenciamento de DNA
Gene do rRNA 16S

Bioinformática



Quem são?
Diversidade taxonômica

Reconstrução genoma a partir do metagenome (MAGs)



Run
Unknown taxa

Raw Reads

Assembled into contigs

Primary metagenome
Unknown taxa

Contigs

Binned into single taxon assemblies

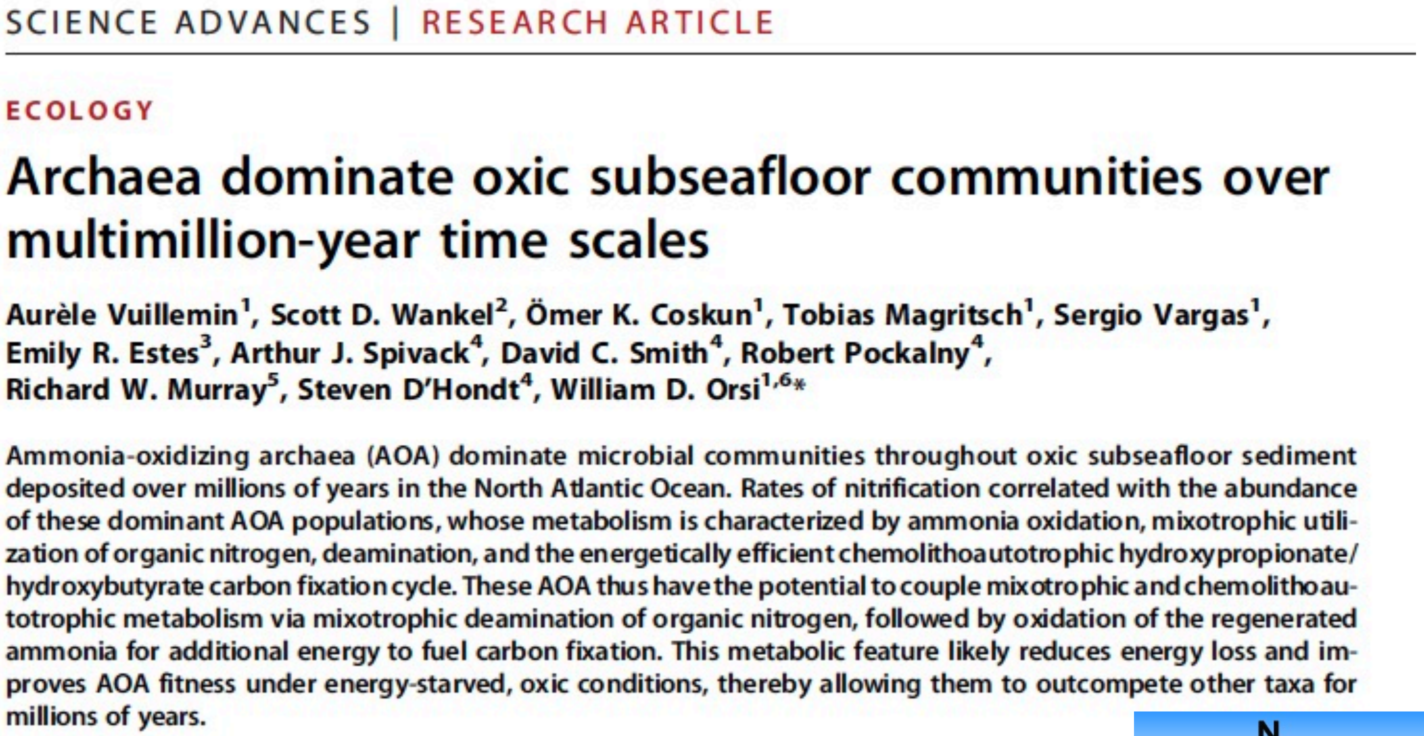
Binned metagenome
Known taxonomy

Assembly Assembly Assembly Assembly Assembly Assembly

Chosen or de-replicated representative MAGs

MAG
Unique taxonomy

Assembly Assembly Assembly



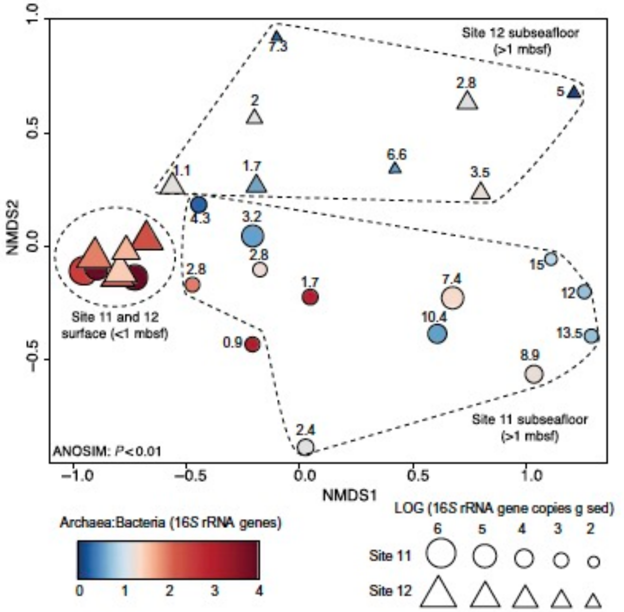
SCIENCE ADVANCES | RESEARCH ARTICLE

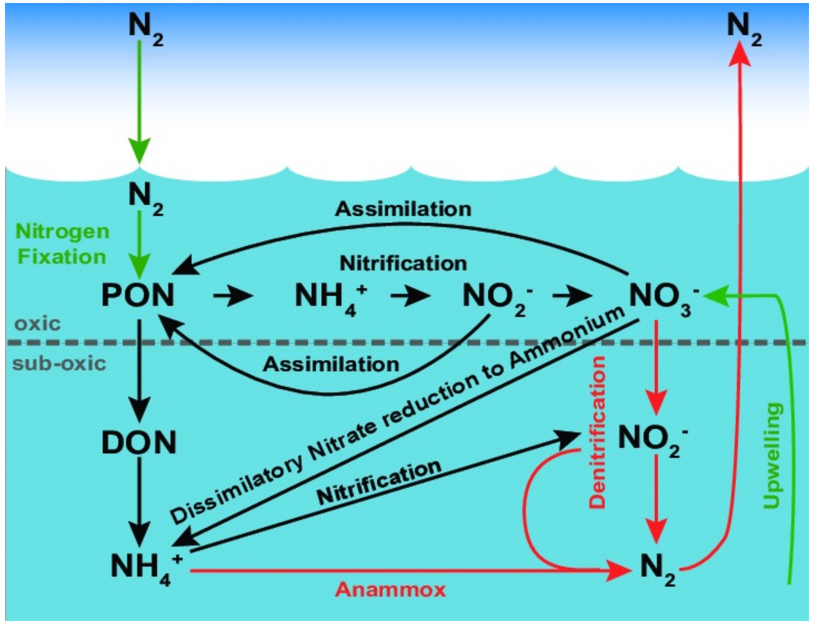
ECOLOGY

Archaea dominate oxic subseafloor communities over multimillion-year time scales

Aurèle Vuillemin[1], Scott D. Wankel[2], Ömer K. Coskun[1], Tobias Magritsch[1], Sergio Vargas[1], Emily R. Estes[3], Arthur J. Spivack[4], David C. Smith[4], Robert Pockalny[4], Richard W. Murray[5], Steven D'Hondt[4], William D. Orsi[1,6]*

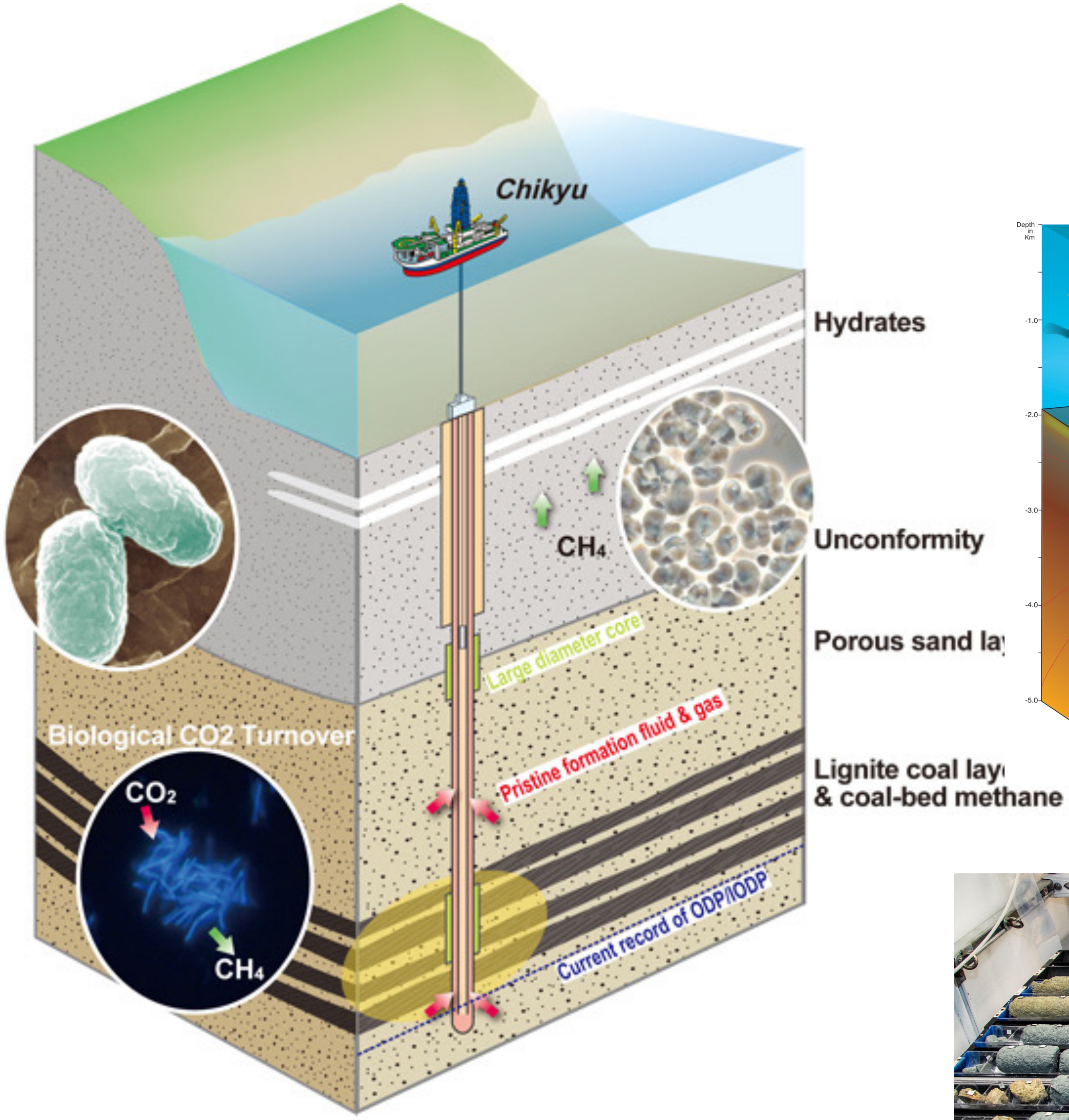
Ammonia-oxidizing archaea (AOA) dominate microbial communities throughout oxic subseafloor sediment deposited over millions of years in the North Atlantic Ocean. Rates of nitrification correlated with the abundance of these dominant AOA populations, whose metabolism is characterized by ammonia oxidation, mixotrophic utilization of organic nitrogen, deamination, and the energetically efficient chemolithoautotrophic hydroxypropionate/hydroxybutyrate carbon fixation cycle. These AOA thus have the potential to couple mixotrophic and chemolithoautotrophic metabolism via mixotrophic deamination of organic nitrogen, followed by oxidation of the regenerated ammonia for additional energy to fuel carbon fixation. This metabolic feature likely reduces energy loss and improves AOA fitness under energy-starved, oxic conditions, thereby allowing them to outcompete other taxa for millions of years.



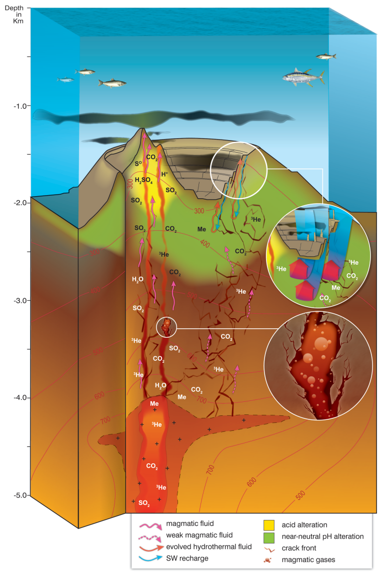


Ultra-oligotrófico
Sedimentação 1 m/ milhão de anos

Novo Desafio- Vida em Subsuperfíci



EXP 376 Brothers Volcano




nature COMMUNICATIONS

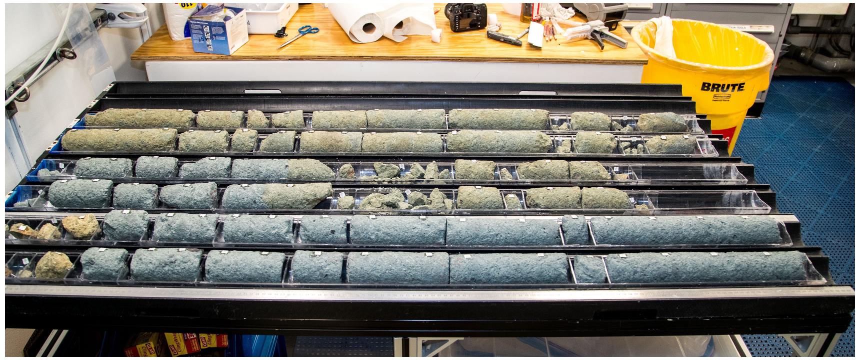
ARTICLE

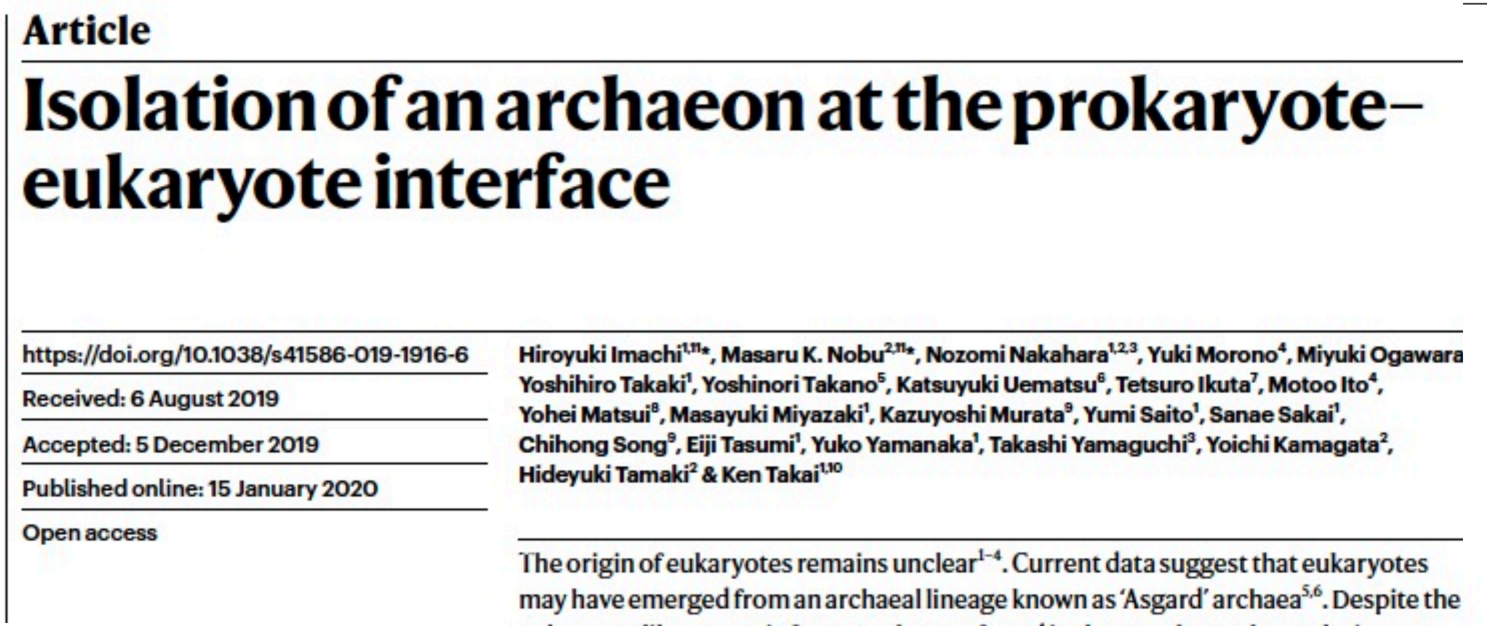
https://doi.org/10.1038/s41467-020-17330-1 OPEN

Aerobic microbial life persists in oxic marine sediment as old as 101.5 million years

Yuki Morono[1,2✉], Motoo Ito[1,2], Tatsuhiko Hoshino[1,2], Takeshi Terada[3], Tomoyuki Hori[4], Minoru Ikehara[5], Steven D'Hondt[6✉] & Fumio Inagaki[1,2,7,8✉]

Sparse microbial populations persist from seafloor to basement in the slowly accumulating oxic sediment of the oligotrophic South Pacific Gyre (SPG). The physiological status of these communities, including their substrate metabolism, is previously unconstrained. Here we show that diverse aerobic members of communities in SPG sediments (4.3–101.5 Ma) are capable of readily incorporating carbon and nitrogen substrates and dividing. Most of the 6986 individual cells analyzed with nanometer-scale secondary ion mass spectrometry (NanoSIMS) actively incorporated isotope-labeled substrates. Many cells responded rapidly to incubation conditions, increasing total numbers by 4 orders of magnitude and taking up labeled carbon and nitrogen within 68 days after incubation. The response was generally faster (on average, 3.09 times) for nitrogen incorporation than for carbon incorporation. In contrast, anaerobic microbes were only minimally revived from this oxic sediment. Our results suggest that microbial communities widely distributed in organic-poor abyssal sediment consist mainly of aerobes that retain their metabolic potential under extremely low-energy conditions for up to 101.5 Ma.





Article

Isolation of an archaeon at the prokaryote–eukaryote interface

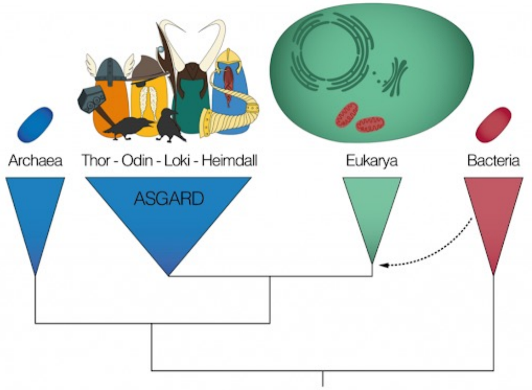
https://doi.org/10.1038/s41586-019-1916-6

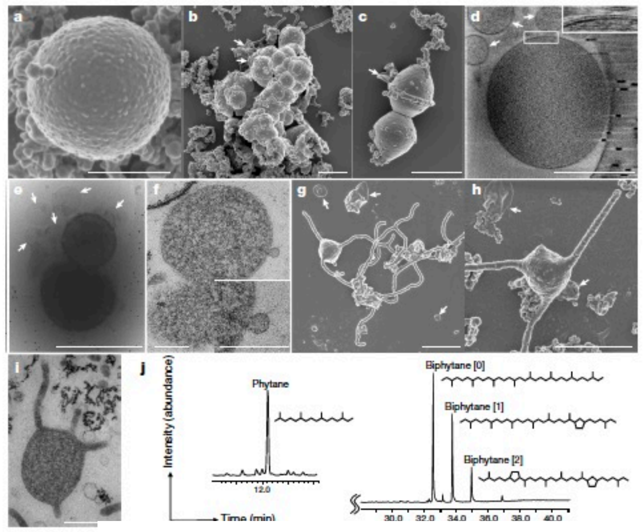
Received: 6 August 2019

Accepted: 5 December 2019

Hiroyuki Imachi[1,11]*, Masaru K. Nobu[2,11]*, Nozomi Nakahara[1,2,3], Yuki Morono[4], Miyuki Ogawara[1], Yoshihiro Takaki[1], Yoshinori Takano[5], Katsuyuki Uematsu[6], Tetsuro Ikuta[7], Motoo Ito[4], Yohei Matsui[8], Masayuki Miyazaki[1], Kazuyoshi Murata[9], Yumi Saito[1], Sanae Sakai[1], Chihong Song[9], Eiji Tasumi[1], Yuko Yamanaka[1], Takashi Yamaguchi[3], Yoichi Kamagata[2], Hideyuki Tamaki[2] & Ken Takai[1,10]

The origin of eukaryotes remains unclear[1–4]. Current data suggest that eukaryotes may have emerged from an archaeal lineage known as 'Asgard' archaea[5,6]. Despite the eukaryote-like genomic features that are found in these archaea, the evolutionary transition from archaea to eukaryotes remains unclear, owing to the lack of cultured representatives and corresponding physiological insights. Here we report the decade-long isolation of an Asgard archaeon related to Lokiarchaeota from deep marine sediment. The archaeon—'*Candidatus* Prometheoarchaeum syntrophicum' strain MK-D1—is an anaerobic, extremely slow-growing, small coccus (around 550 nm in diameter) that degrades amino acids through syntrophy. Although eukaryote-like intracellular complexes have been proposed for Asgard archaea[6], the isolate has no visible organelle-like structure. Instead, *Ca.* P. syntrophicum is morphologically complex and has unique protrusions that are long and often branching. On the basis of the available data obtained from cultivation and genomics, and reasoned interpretations of the existing literature, we propose a hypothetical model for eukaryogenesis, termed the entangle–engulf–endogenize (also known as E³) model.





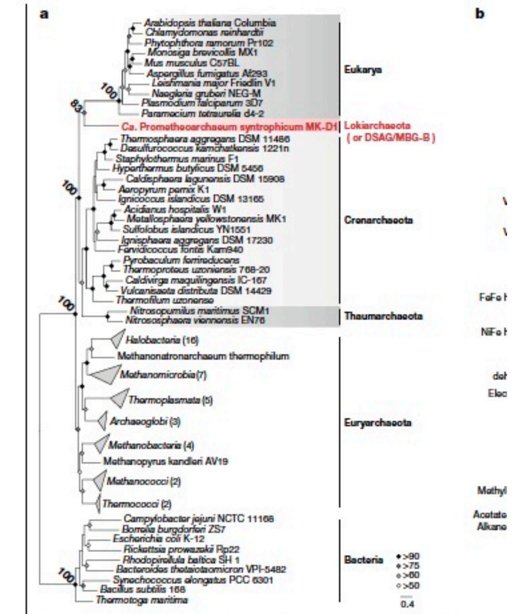
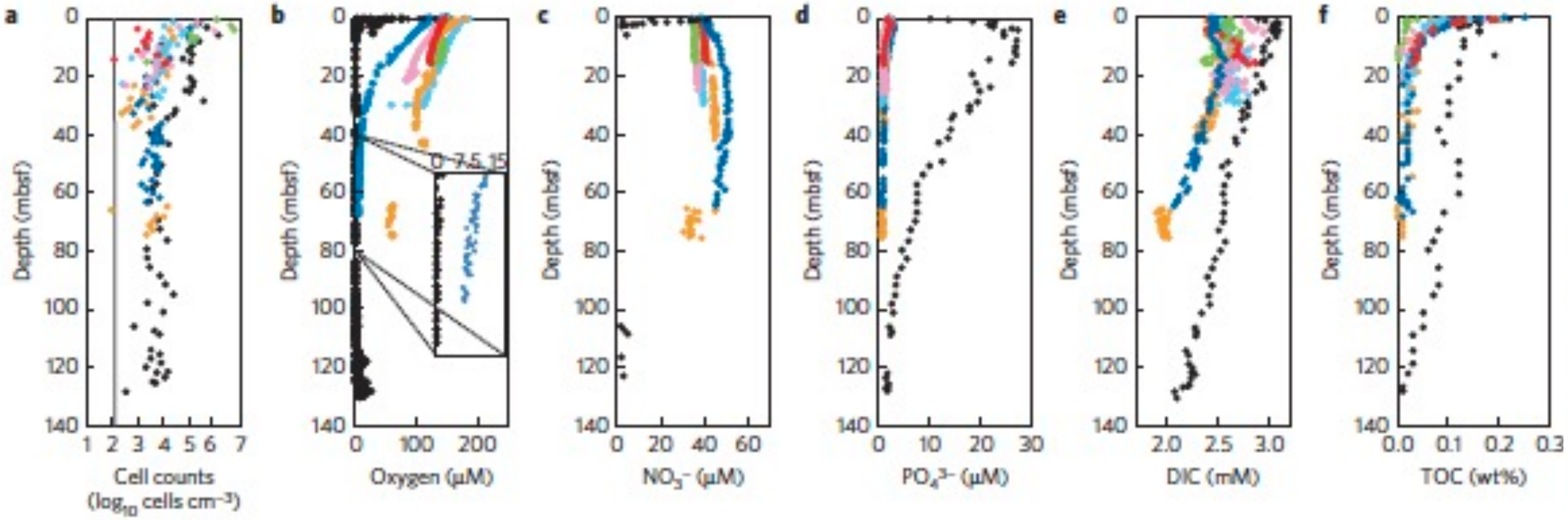


Fig. 4 | Phylogeny of MK-D1 and catabolic features of Asgard archaea. **a**, Maximum-likelihood tree (100 bootstrap replicates) of MK-D1 and select cultured archaea, eukaryotes and bacteria based on 31 ribosomal proteins that are conserved across the three domains (Supplementary Tables 7, 8). Bootstrap values around critical branching points are also shown. We used 14,024 sites of the alignment for tree construction. **b**, The presence or absence of amino acid degradation, electron metabolism, fermentation, C1 metabolism, sulfur metabolism and aerobic respiration in individual genomes are shown (complete pathway, full circle; mostly complete pathway, half circle). For aminc acid metabolism, pathways that are exclusively used for catabolism or

Bioreator aneróbio .
Sedimento aneróbio rico em metano.
Mantido por 2000 dias

Presence of oxygen and aerobic communities from sea floor to basement in deep-sea sediments

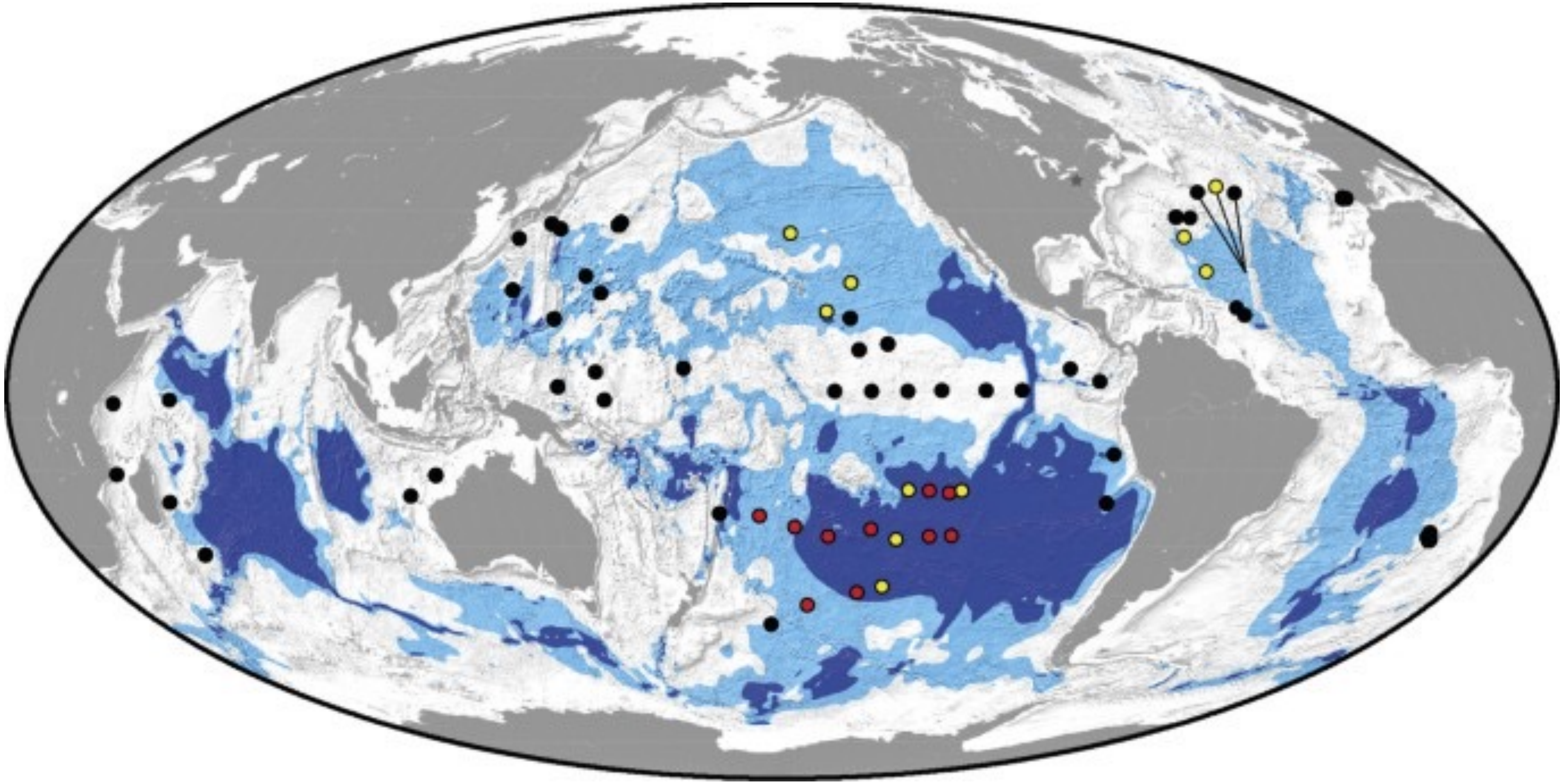


Comparison of our SPG results against other sites throughout the ocean indicates that dissolved O_2 penetrates the entire sediment column where mean sediment accumulation rate and total sediment thickness are both low (Fig. 4 and Supplementary Information). This result is consistent with the complexities outlined above. Organic flux to the sea floor broadly co-varies with sedimentation rate[14], and at very low sediment accumulation rates, most organic matter is consumed at or near the sea floor[10,24]. Dependence on sediment thickness is consistent with the exponential effect of distance on diffusive timescale; where sediment thickness is high, O_2 disappears faster than it can diffuse to the greatest depths.

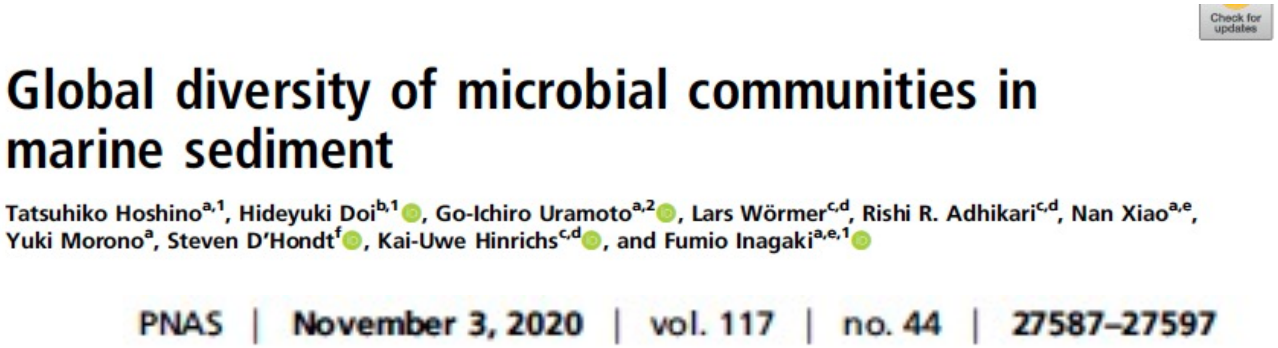
Figure 2 | Sedimentary profiles of cell abundance and chemical concentrations[11]. Data are keyed to site location colours in Fig. 1: **a**, cell concentration (logarithmic scales), **b**, dissolved O_2, **c**, dissolved NO_3^-, **d**, dissolved PO_4^-, **e**, dissolved inorganic carbon, **f**, total organic carbon. Profiles span the sediment column, from sea floor to basement. Vertical line in **a** marks the minimum quantification limit (MQL). Because optode-based O_2 measurements are less noisy than electrode-based measurements, O_2 profiles in **b** are limited to optode data except where sedimentary fabric prevented optode deployment (the lowermost portion of U1367, as well as most of U1368 and U1371).

O_2 em camadas mais profundas depende da taxa de sedimentação e espessura do sedimento

Regions where dissolved O_2 and aerobic activity may occur throughout the sediment.



- Red dots indicate sites where O_2 is known to occur throughout the sediment
- Black dots indicate sites where O_2 disappears centimetres to metres below the sea floor. Y
- Yellow dots indicate sites where O_2 penetrates many mbsf and may penetrate to basement but is not characterized throughout the sediment column
- Dissolved O_2 may be present in the basement over a greater area, due to seawater advection through the basement.



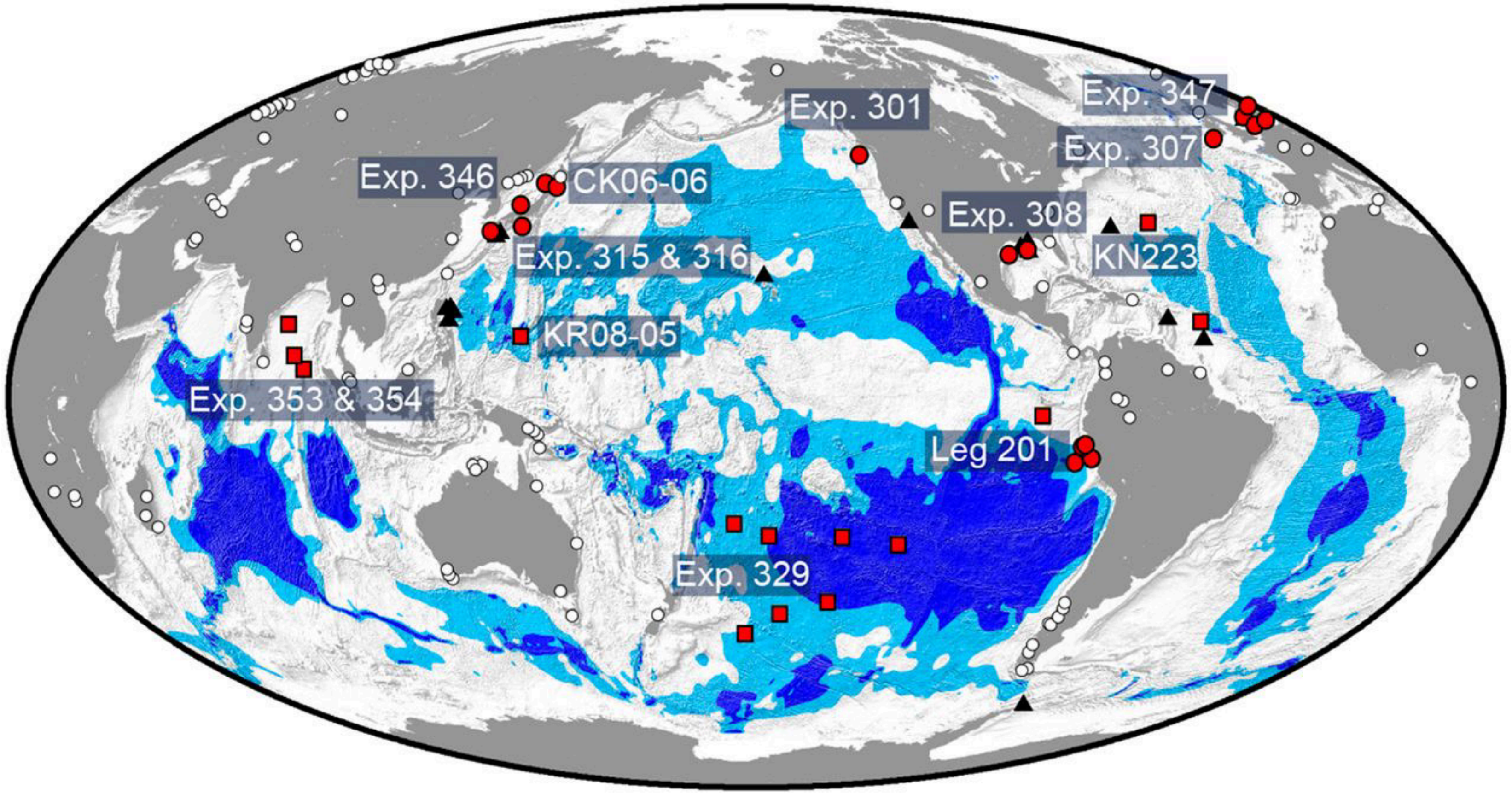
Global diversity of microbial communities in marine sediment

Tatsuhiko Hoshino[a,1], Hideyuki Doi[b,1], Go-Ichiro Uramoto[a,2], Lars Wörmer[c,d], Rishi R. Adhikari[c,d], Nan Xiao[a,e],
Yuki Morono[a], Steven D'Hondt[f], Kai-Uwe Hinrichs[c,d], and Fumio Inagaki[a,e,1]

PNAS | November 3, 2020 | vol. 117 | no. 44 | 27587–27597

- Sedimento: 2.9×10^{29} - 5.4×10^{29} cel., para 0.18% a 3.6% Biomassa total viva da Terra.
- Abundância diminui com a prof. e o aumento da idade do sedimento.
- O_2 e concentração de Carbono orgânico define a composição taxonômica e diversidade microbiana no sedimento.
- Estimativa Global: (Riqueza)
  - $7{,}85 \times 10^3$ - 6.10×10^5 Arqueias
  - $3{,}28 \times 10^6$ - $2{,}46 \times 10^8$ Bactéria
- Sedimento superficial (até 600m prof.) similar ao sistema pelágico

Location of sampling sites.



Tatsuhiko Hoshino et al. PNAS 2020;117:44:27587-27597

- Despite these limitations, studies of 16S ribosomal RNA (rRNA) gene sequences have demonstrated that
- 1) diverse bacterial and archaeal taxa are ubiquitous in organic-rich anoxic sediment,
- 2) microbial communities are stratified by sediment depth, and
- 3) geochemical and sedimentological properties influence microbial community composition
- In addition, single-cell genomic, metagenomic, and functional gene analyses have demonstrated that predominant bacterial and archaeal taxa (e.g., members of the *Atribacteria* and *Bathyarchaeota*) possess metabolic capabilities that can contribute to the heterotrophic subseafloor ecosystem, such as homoacetogenesis and the ability to degrade diverse organic compounds.

Comparison of the microbial community compositions of marine sediment, seawater, and topsoil

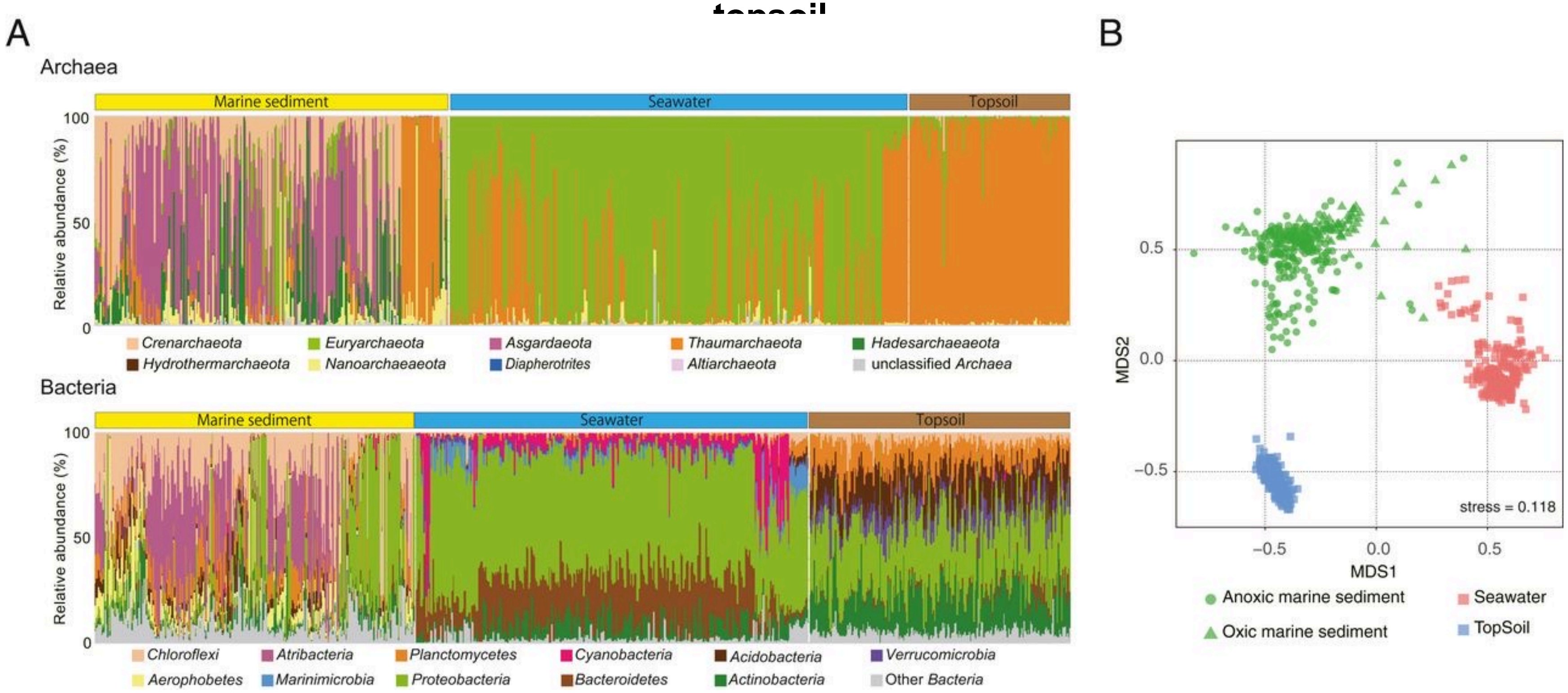
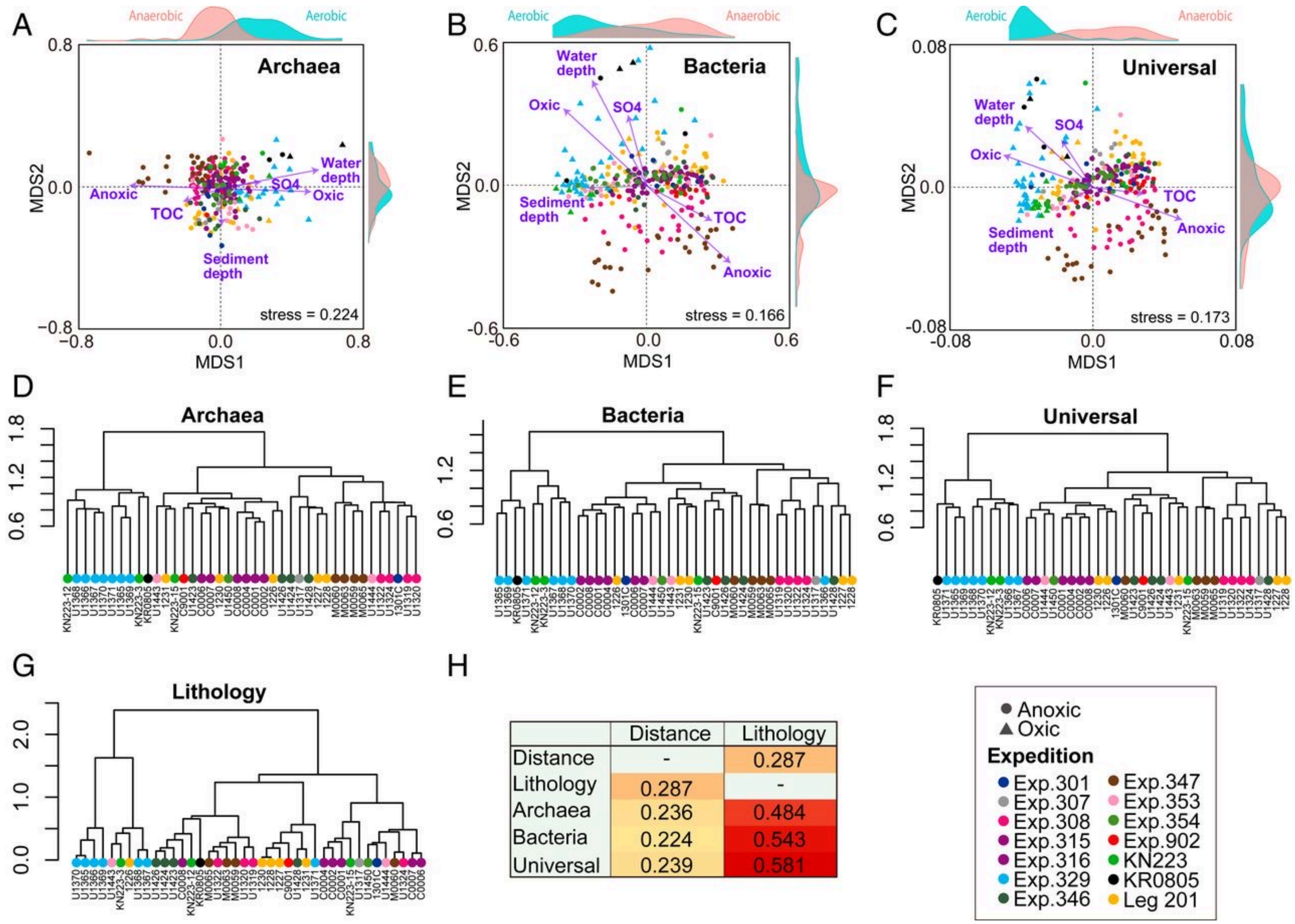


Fig. 3. Comparison of the microbial community compositions of marine sediment, seawater, and topsoil. (*A*) Archaeal and bacterial community compositions obtained by using the 16S rRNA universal primers. The gene sequences of seawater and topsoil samples were compiled from previous publications (19, 44, 46–49). (*B*) NMDS ordination plots generated using Jaccard similarity index values derived from the rarefied ASV populations.

Tatsuhiko Hoshino et al. PNAS 2020;117:44:27587-27597

Beta diversity of microbial communities in marine sediment.



	Distance	Lithology
Distance	-	0.287
Lithology	0.287	-
Archaea	0.236	0.484
Bacteria	0.224	0.543
Universal	0.239	0.581

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PNAS

Depth profiles of microbial richness in oxic marine sediment and anoxic marine sediment.

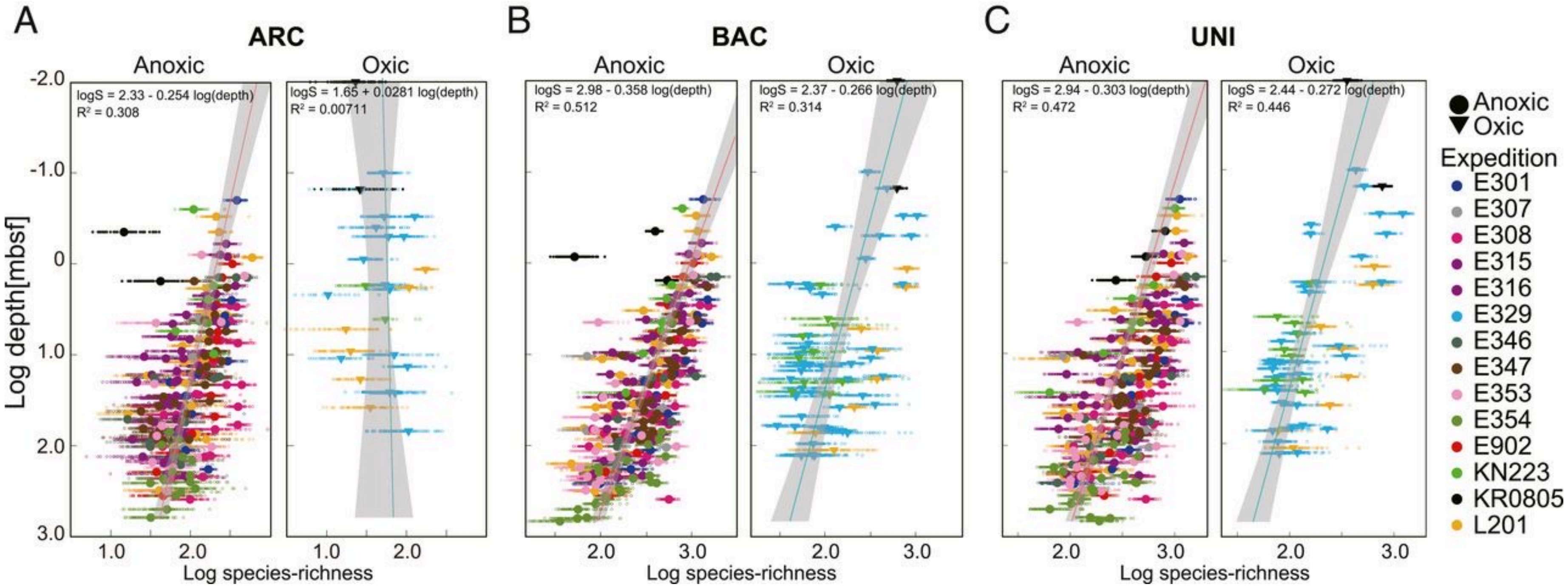


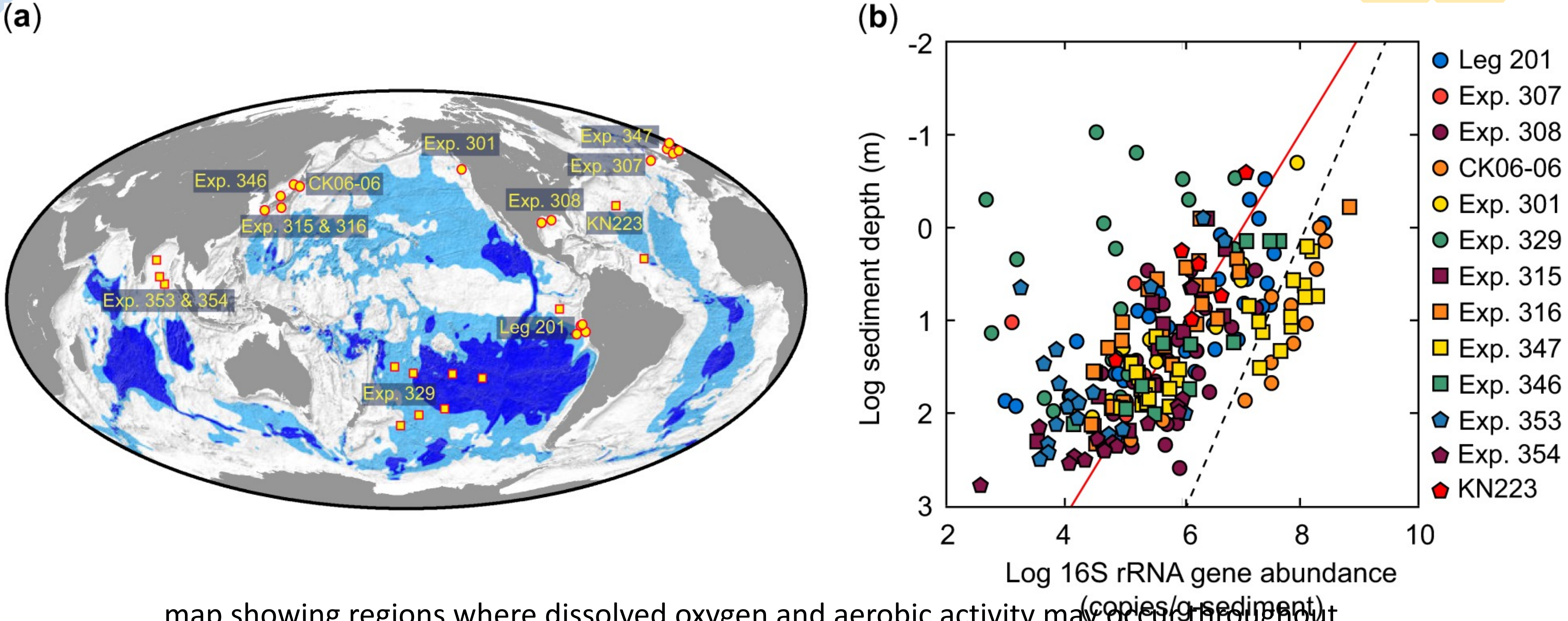
Fig. 6. Depth profiles of microbial richness in oxic marine sediment and anoxic marine sediment. (*A*–*C*) Archaeal (ARC), bacterial (BAC), and universal (UNI) ASV richness (Chao-1 estimator), calculated using data rarified to 1,000 reads per sample. Small, pale points represent the 100 resamplings per sample, and large points represent the mean values of the resamplings.

Tatsuhiko Hoshino et al. PNAS 2020;117:44:27587-27597

Conclusões

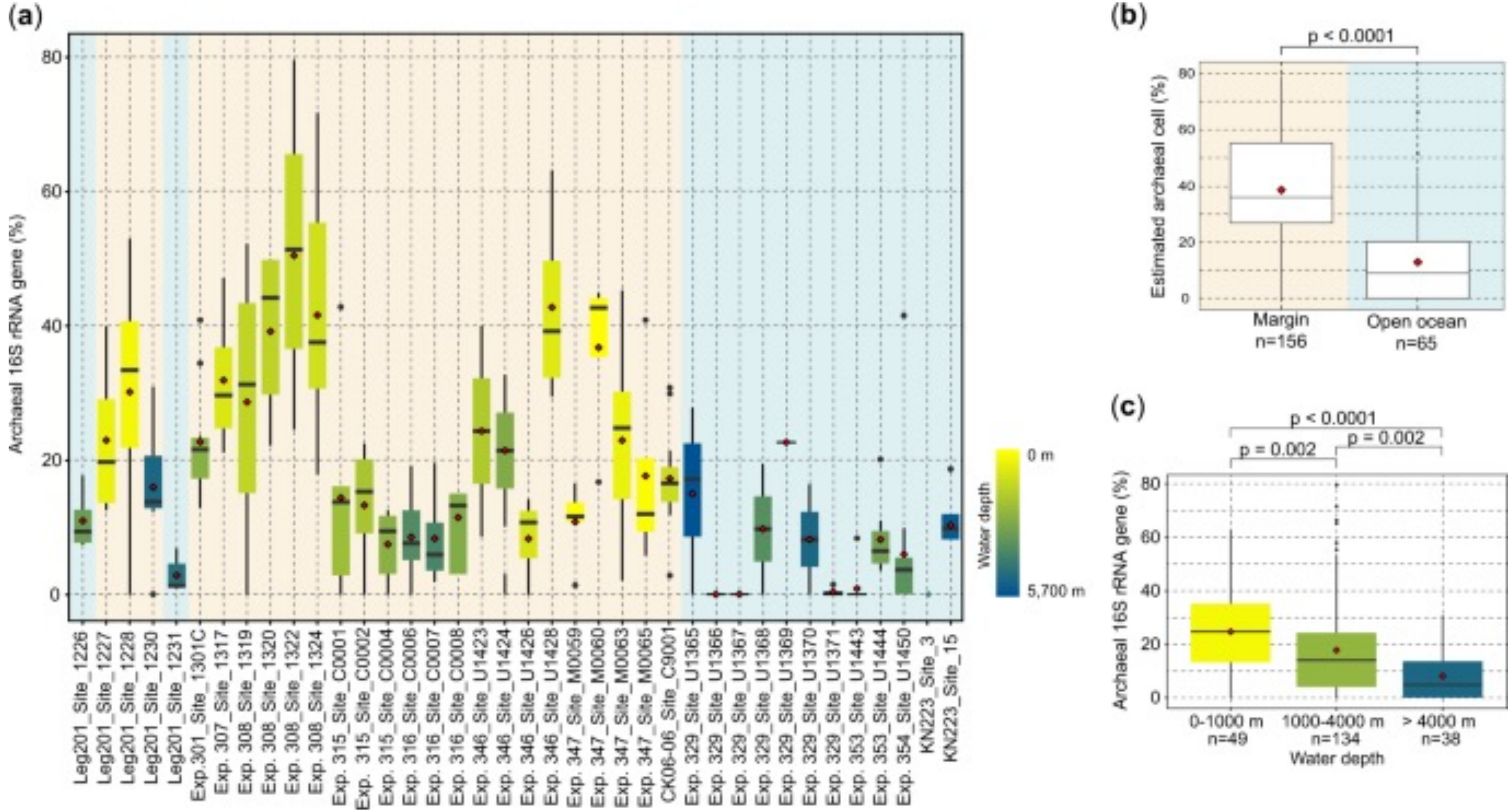
- 299 amostras sedimentos marinhos estudadas
- 2 grupos: aeróbio e anaeróbio
- Diversidade diminui com profundidade
  - Menor diminuição para arqueias
  - Diversidade bactéria é maior em diferentes profundidades
- Biomas distintos (solo, água do mar, sedimento)
- Riqueza com similaridades a nível global
- Bactéria mais diversa que as arqueias na biosfera em nível global

From: Abundance and distribution of Archaea in the subseafloor sedimentary biosphere. ISE J. 2019.



map showing regions where dissolved oxygen and aerobic activity may occur throughout
Circles and squares indicate marginal and open-ocean sites, respectively. Sediment samples were collected at different depths from the surface to 392 m below seafloor during 13 scientific drilling cruises from 38 drilling sites the sediment
logarithmically decreasing trend with increasing sediment depth

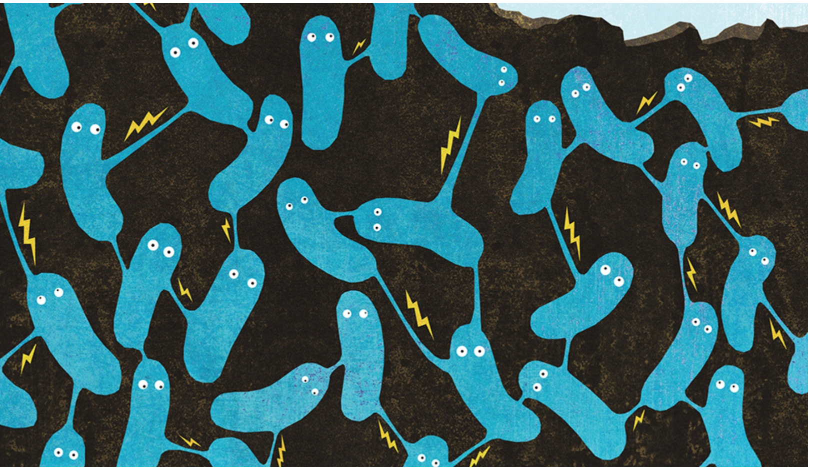
archaeal contribution to the anaerobic microbial ecosystem is more prominent than to the aerobic ecosystem



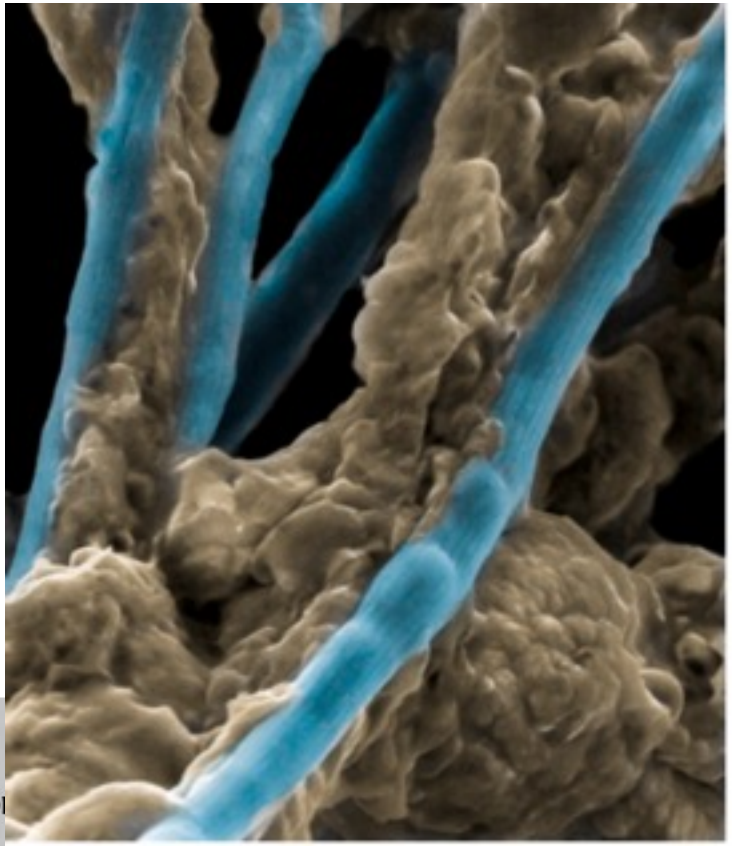
The highest archaeal abundance of up to 50.4% was observed at the Integrated Ocean Drilling Program Site 1322 in the Mars-Ursa salt-withdrawal basin on the north-eastern Gulf of Mexico continental slope (Fig. 2a, Supplementary Table S1), where nutrients and energy substrates were additionally supplied from the continent via the Mississippi River to the slope deposit

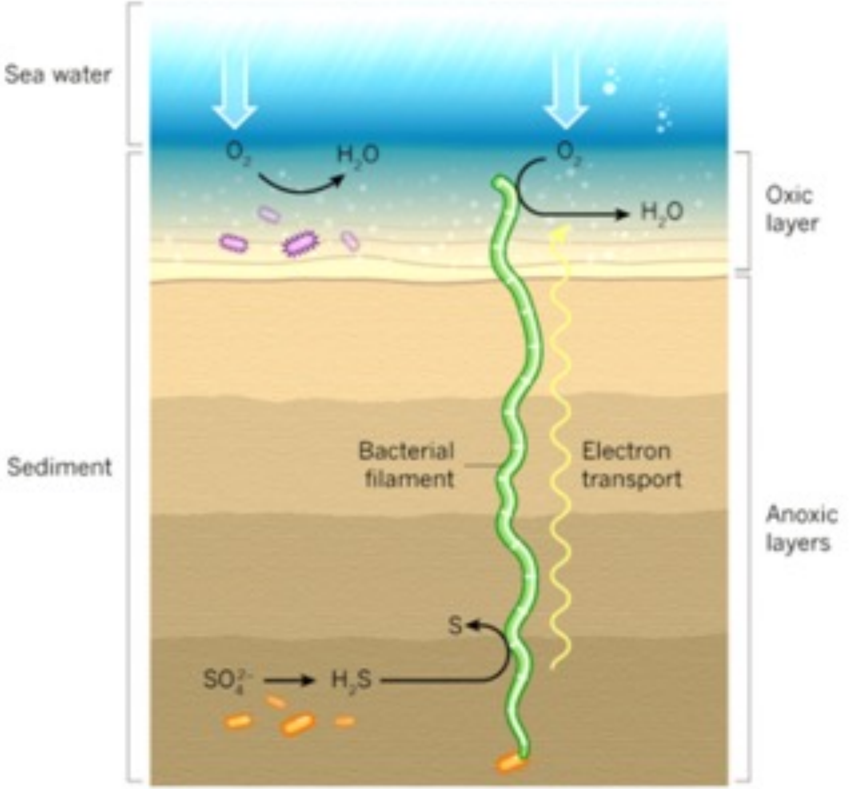
Conclusão/ Arqueias em subsuperfície 221 cores de sedimento - IODP

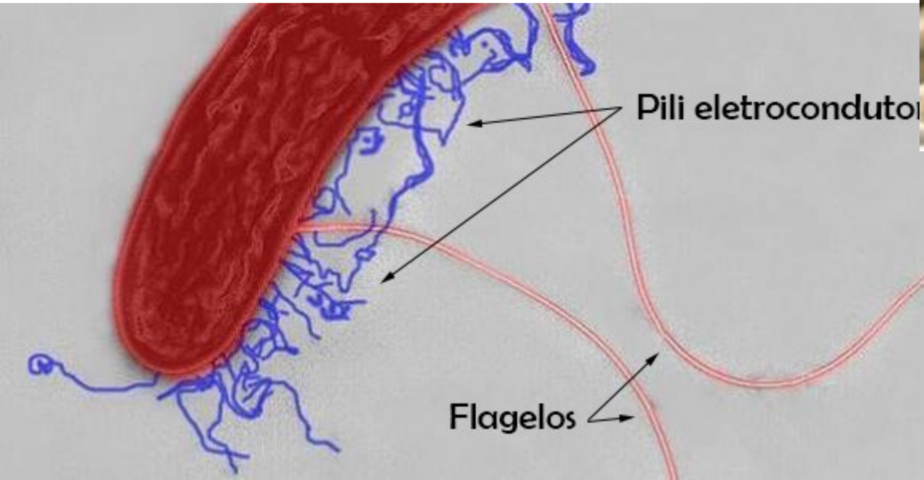
- Arqueias constituem 37,3% do total das células microbianas
- Correspondendo a 1,1 x10^{29} células na Terra
- 40% margens oceânicas e 12,8% áreas oceânicas
- Abundância relativa de genes 16SrRNA diminui com a profundidade da água nos ambientes estudados



CABLE BACTERIA





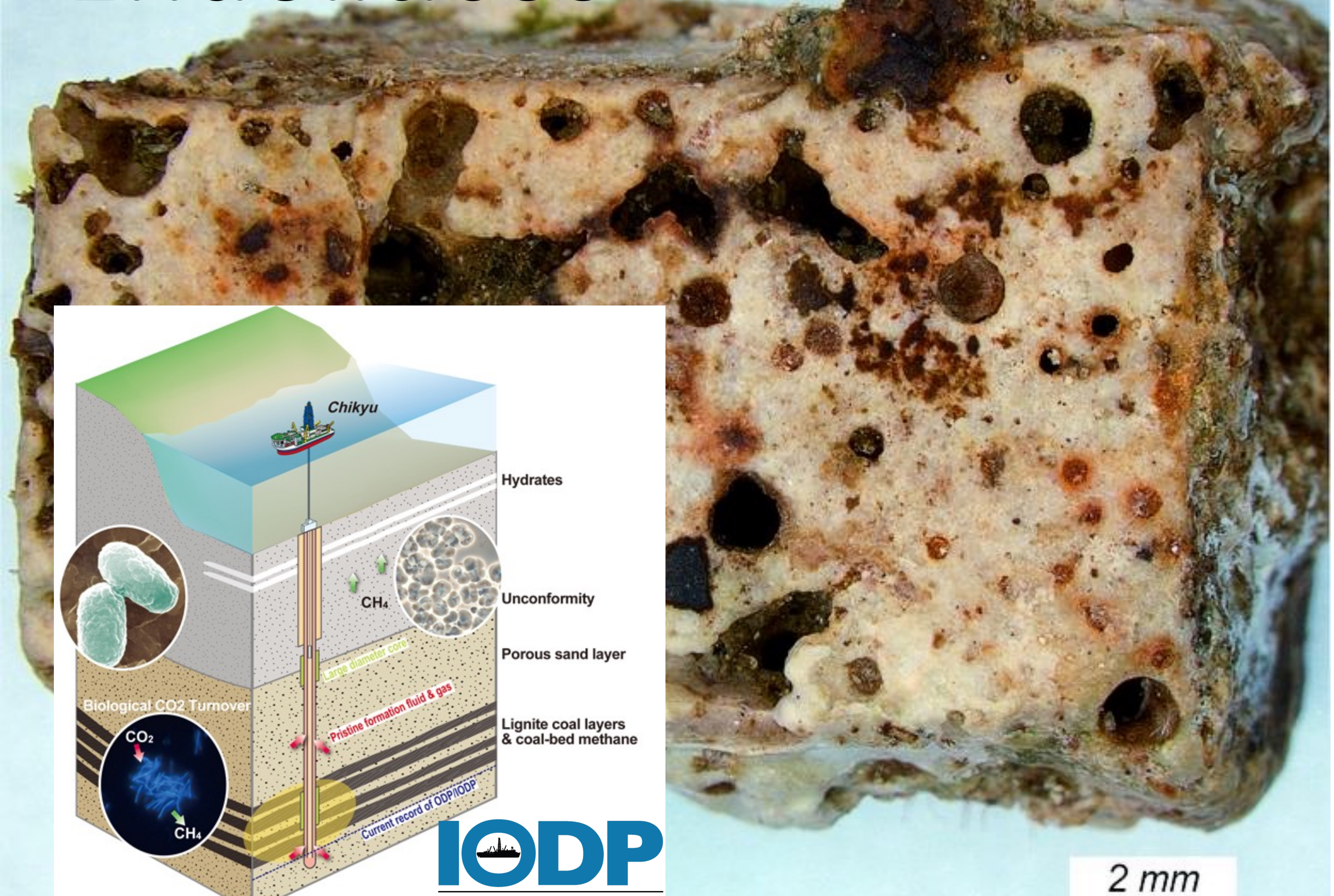


https://en-gb.facebook.com/TUDelft/videos/cable-bacteria-living-electrical-wires-with-record-conductivity/458808678048945/

Tópicos

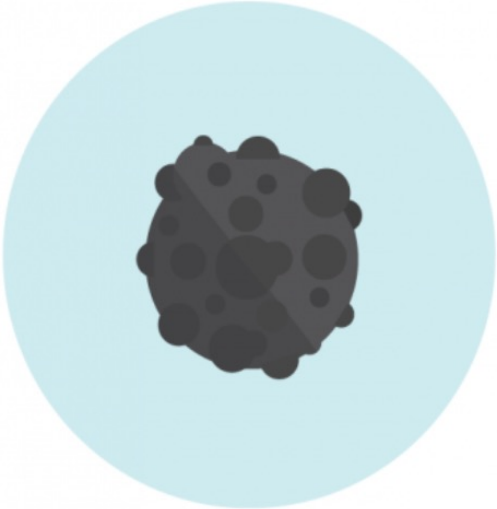
- Minerais marinhos de mar profundo
- Histórico
- Importância econômica
- Ciclo do Fe nos oceanos
- Estudo de caso

Endolíticos



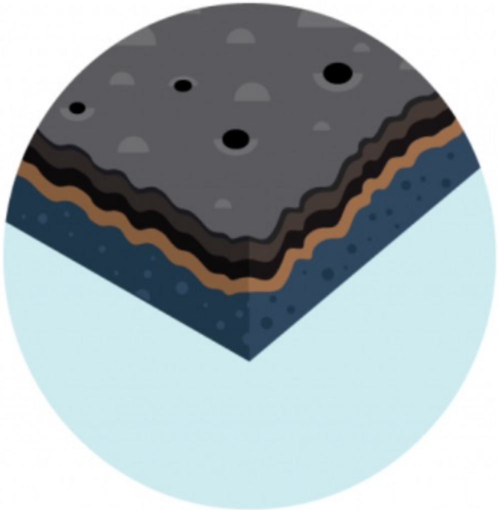
Minerais marinhos de mar profundo

Nódulos de Fe-Mn



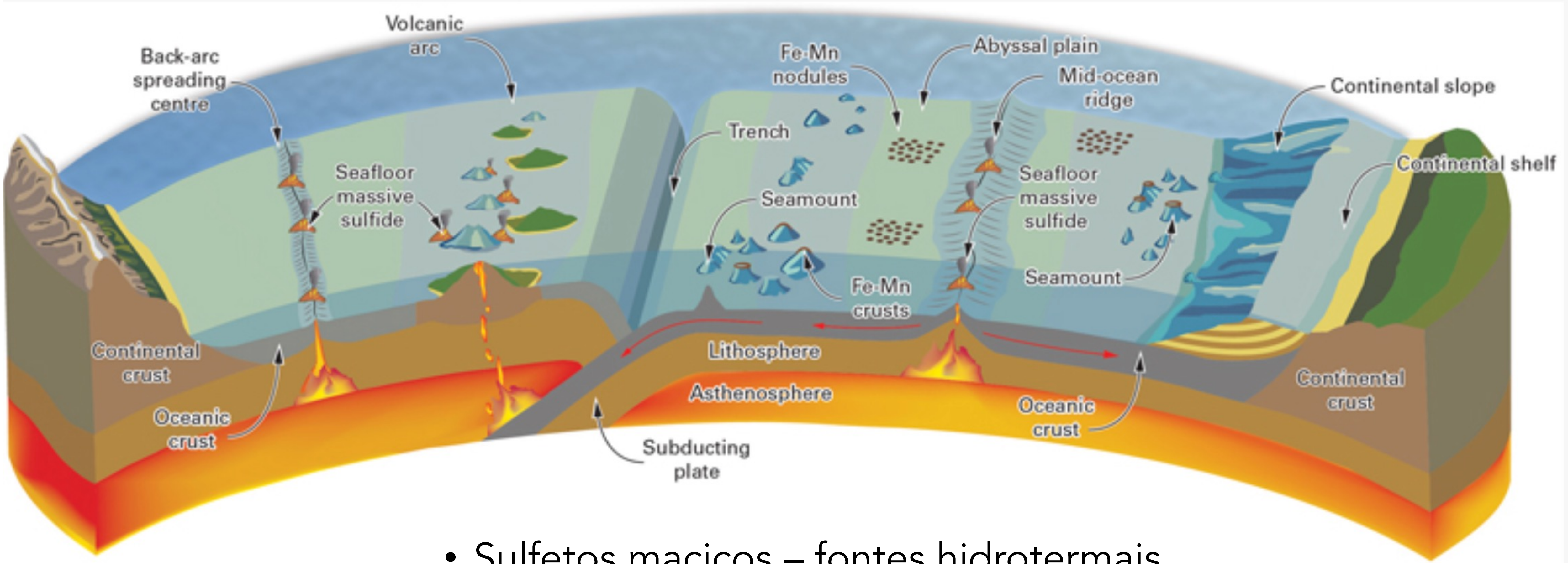
Maciços de sulfetos

Crosta de Fe-Mn



Fonte: Aldred, 2019

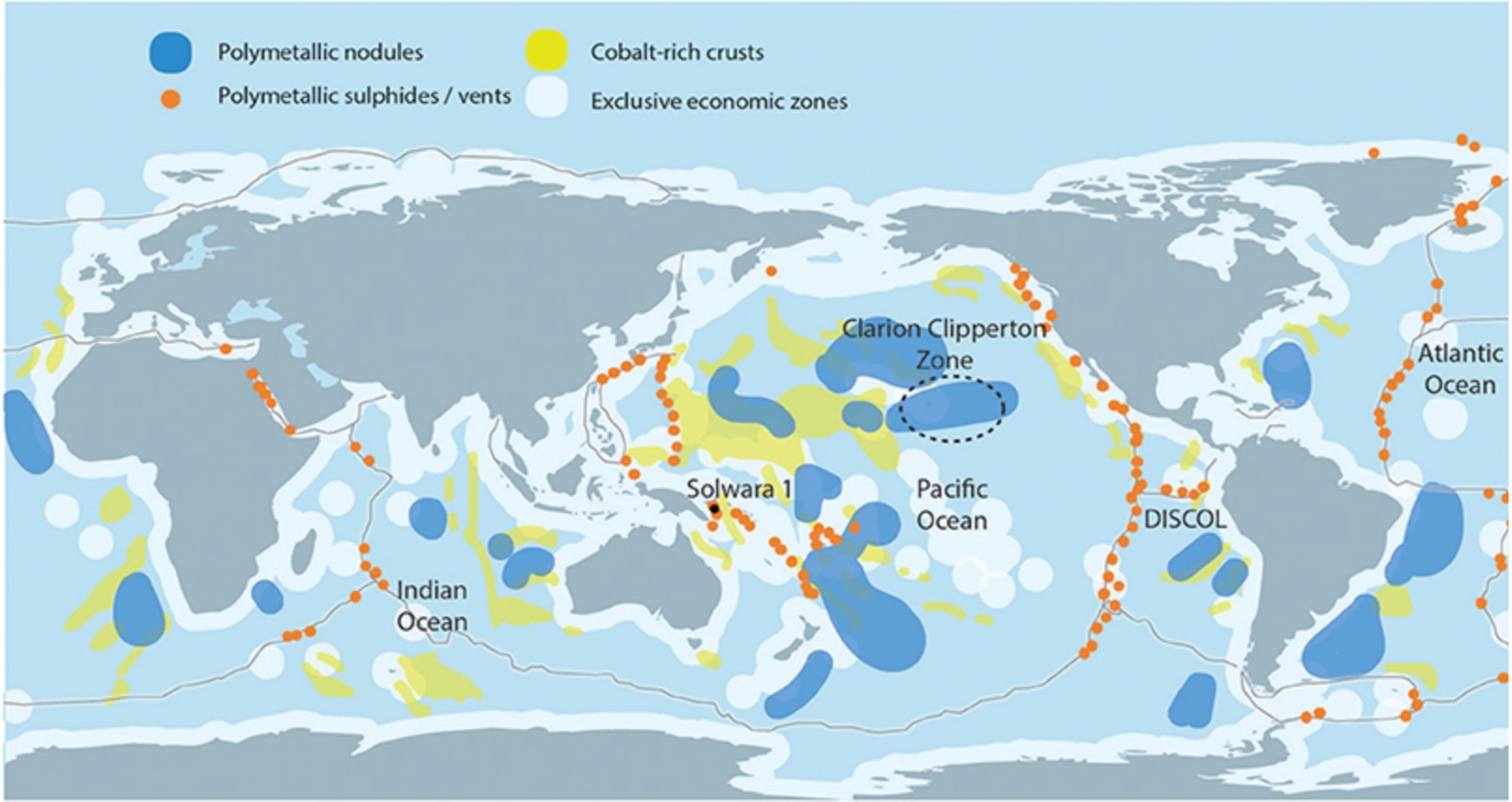
Minerais marinhos de mar profundo



- Sulfetos maciços – fontes hidrotermais
- Crostas de Fe-Mn
- Nódulos de Fe-Mn

Fonte: Copyright British Geological Survey © UKRI 2018

Distribuição nos oceanos



Fonte: Miller et al, 2018

Histórico

1870 I 20.000 Léguas Submarinas, Júlio Verne.

"Nas profundezas do oceano, existem minas de zinco, ferro, prata e ouro que seriam bastante fáceis de explorar." Capitão Nemo.

1872–1876 I Nódulos são descobertos na Expedição *Challenger*.

1965 I Oceanógrafo John L. Mero estimou enorme quantidade de nódulos no Oceano Pacífico e previu suprimento infinito de metais como Mn, Cu, Ni e Co.

1977 I Descoberta de 'fontes termais submarinas' com metais em Galápagos.

1979 I Sulfetos maciços no fundo do mar .

Imagem: Encyclopædia Britannica

Histórico

1982 | Convenção das Nações Unidas sobre o Direito do Mar, início da criação do código de mineração marinha

1994 | Autoridade Internacional dos Fundos Marinhos parte da ONU, 161 países

2000 | Regulamentos sobre Prospecção e Exploração de Nódulos.

2010 | Regulamentos sobre Prospecção e Exploração de Sulfetos.

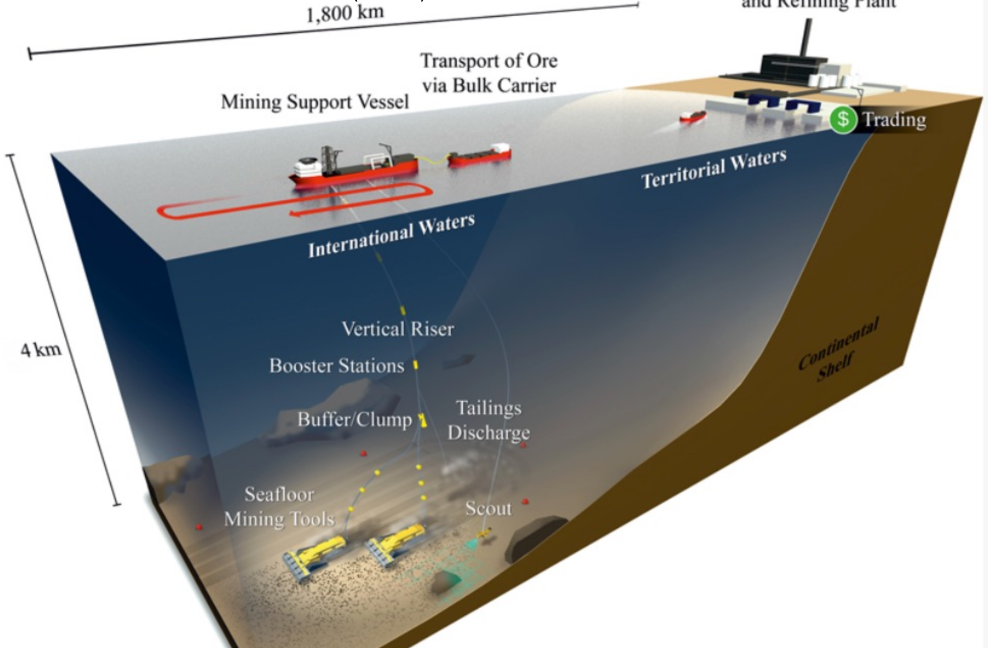
2012 | Regulamentos sobre Prospecção e Exploração de Crostas.

Fonte: INTERNATIONAL SEABED AUTHORITY

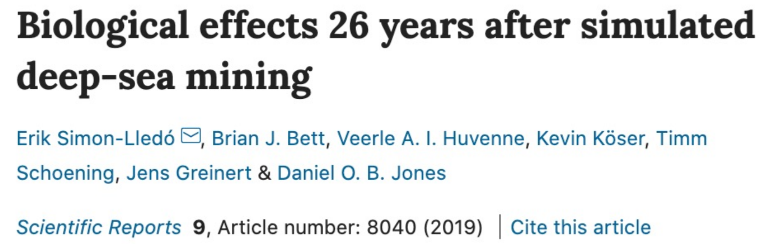
Histórico

2017 - hoje

Fonte: Volkmann and Lehnen (2017).



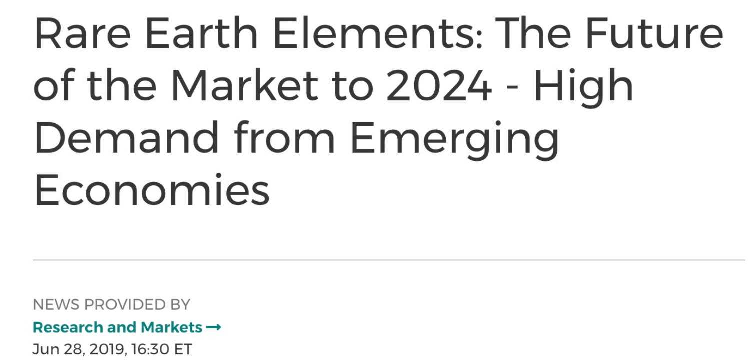
Fonte: Nautilus Minerals Inc



Biological effects 26 years after simulated deep-sea mining

Erik Simon-Lledó, Brian J. Bett, Veerle A. I. Huvenne, Kevin Köser, Timm Schoening, Jens Greinert & Daniel O. B. Jones

Scientific Reports **9**, Article number: 8040 (2019) | Cite this article



Rare Earth Elements: The Future of the Market to 2024 - High Demand from Emerging Economies

NEWS PROVIDED BY
Research and Markets →
Jun 28, 2019, 16:30 ET

Scientists fear impact of deep-sea mining on search for new medicines

@karenmcveigh1
Mon 20 May 2019
9.00 BST

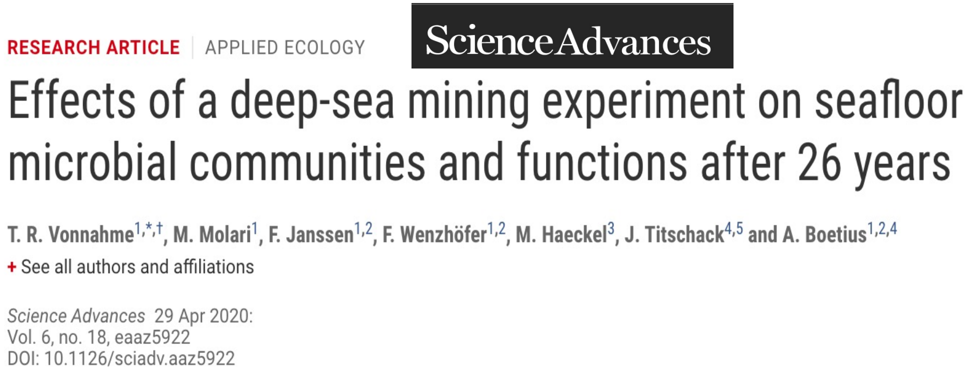
▲ Microbes from deep-sea sponges could be a breakthrough in the fight

NEWS FEATURE · 24 JULY 2019 · CORRECTION 16 AUGUST 2019

Seabed mining is coming — bringing mineral riches and fears of epic extinctions

Plans are advancing to harvest precious ores from the ocean floor, but scientists say that companies have not tested them enough to avoid devastating damage.

Olive Heffernan



RESEARCH ARTICLE | APPLIED ECOLOGY

Science Advances

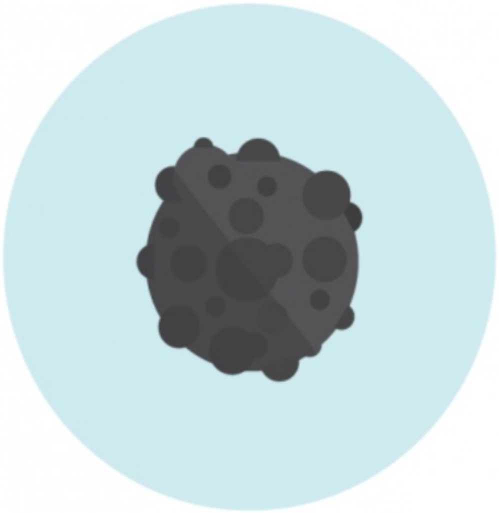
Effects of a deep-sea mining experiment on seafloor microbial communities and functions after 26 years

T. R. Vonnahme[1,*,†], M. Molari[1], F. Janssen[1,2], F. Wenzhöfer[1,2], M. Haeckel[3], J. Titschack[4,5] and A. Boetius[1,2,4]

+ See all authors and affiliations

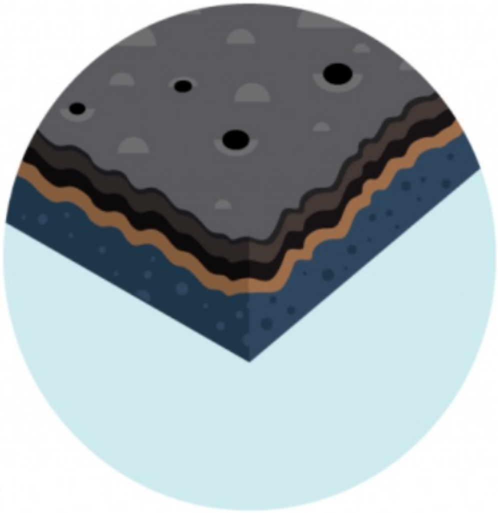
Science Advances 29 Apr 2020:
Vol. 6, no. 18, eaaz5922
DOI: 10.1126/sciadv.aaz5922

Minerais marinhos de mar profundo

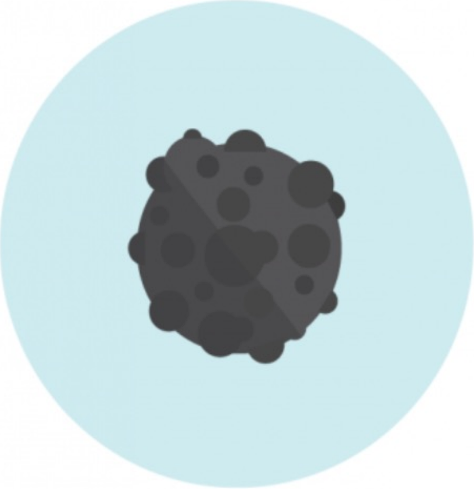


Nódulos de Fe-Mn

Sulfetos maciços



Crosta de Fe-Mn



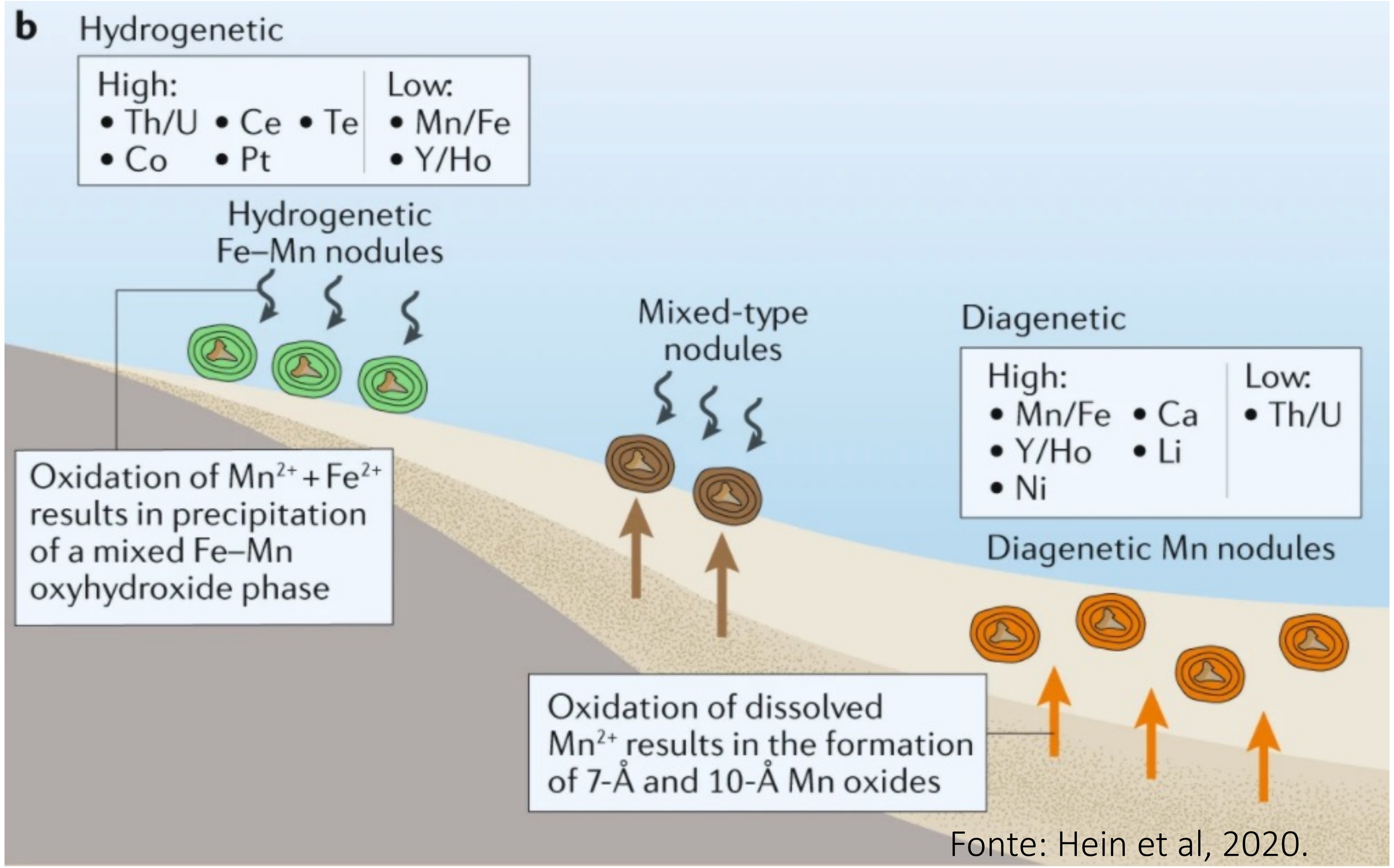
Nódulos de Fe-Mn

Composição: Níquel, cobalto,
cobre e manganês

Ocorrência: Bacias oceânicas,
3,500 –6,500 m

Produção: 1 mm a cada 1 milhão
de anos

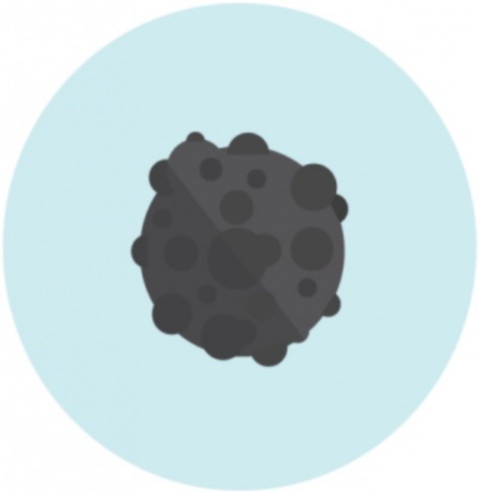
Gênese: Formam-se na superfície do sedimento do oceano, ou logo abaixo dele.



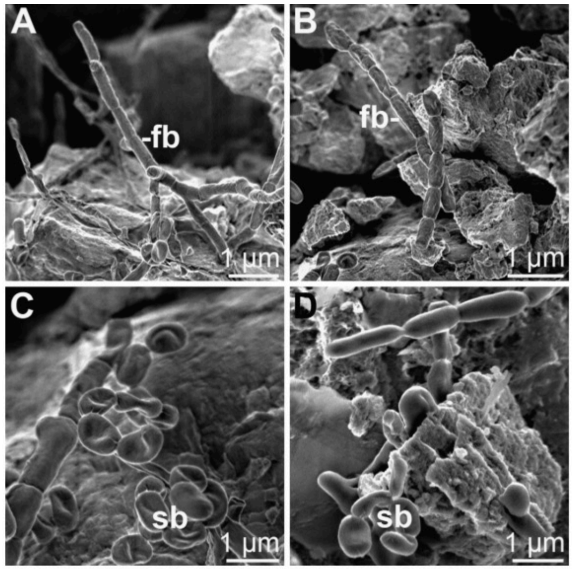
Oxidation of Mn^{2+} + Fe^{2+} results in precipitation of a mixed Fe–Mn oxyhydroxide phase

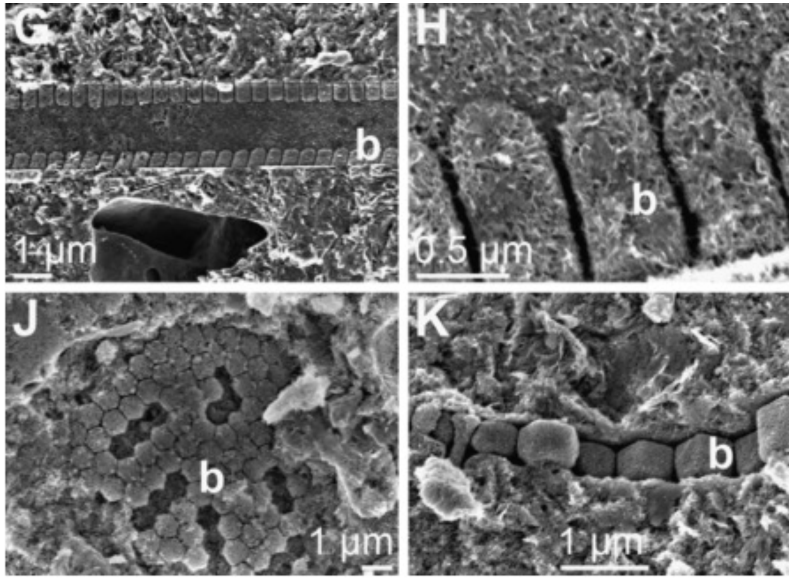
Oxidation of dissolved Mn^{2+} results in the formation of 7-Å and 10-Å Mn oxides

Fonte: Hein et al, 2020.



Nódulos de Fe-Mn

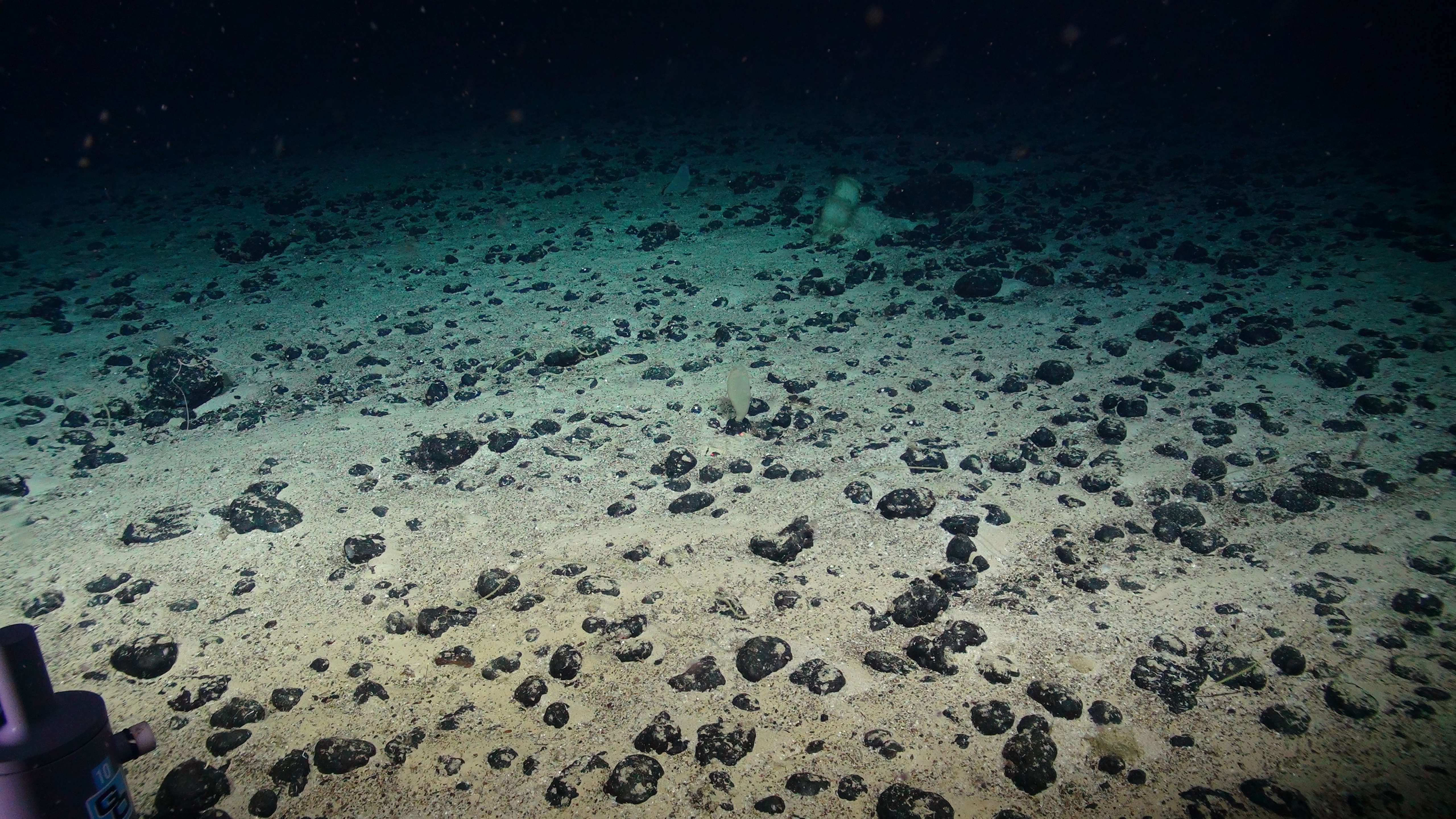


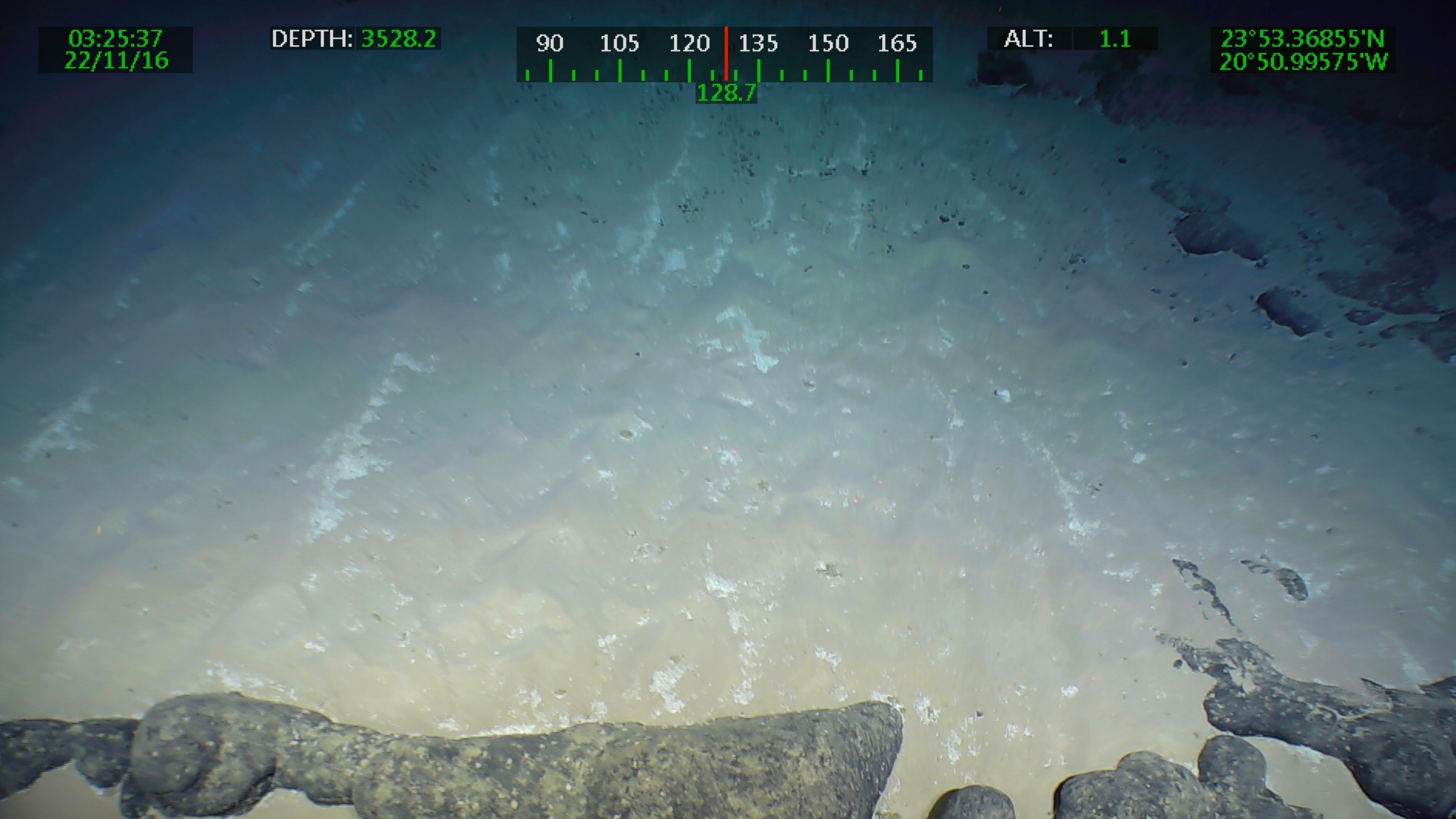


Ehrlich 2001, 2002; Wang & Müller, 2009.

<u>Biomineralização</u>: Oxidação dos cátions do nódulos como fonte de energia para os micro-organismos, seria um ecossistema fechado?

Blöthe et al., 2015




03:25:37
22/11/16
DEPTH: 3528.2
90
105
120
135
150
165
128.7
ALT: 1.1
23°53.36855'N
20°50.99575'W

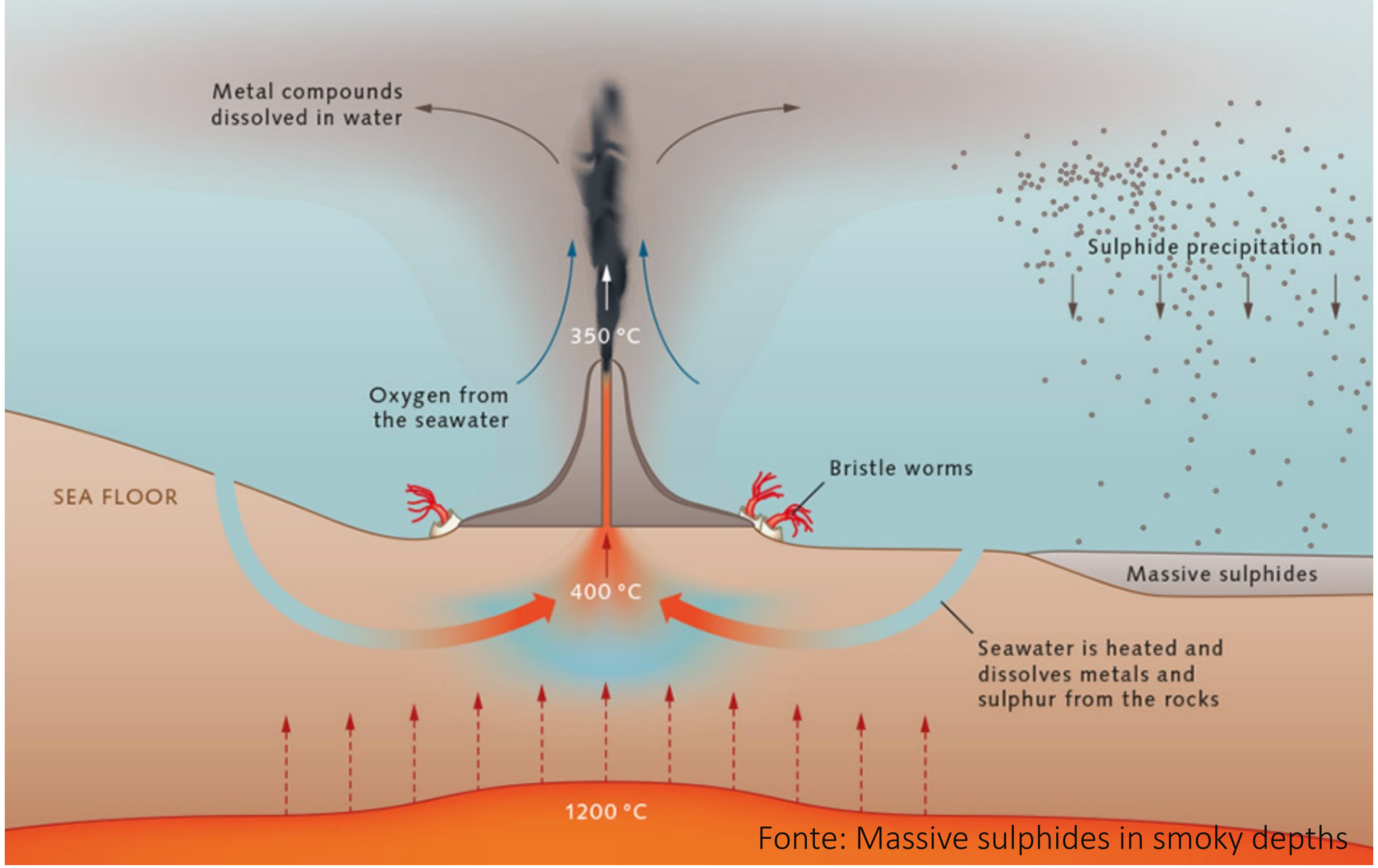
Sulfetos maciços

Composição: Cobre, chumbo, zinco, ouro e prata

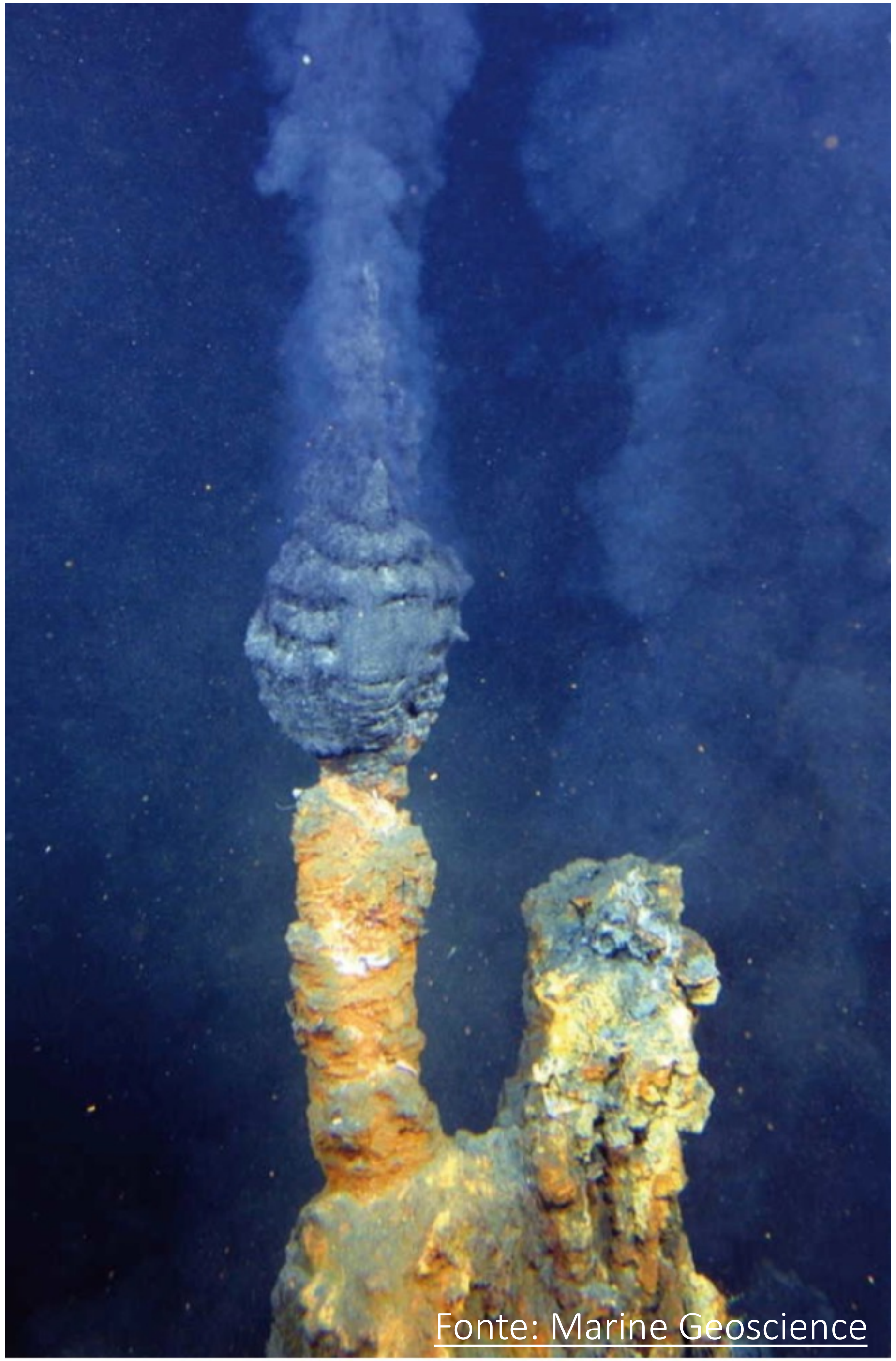
Ocorrência: Fontes hidrotermais, 1,000 –4, 000 m

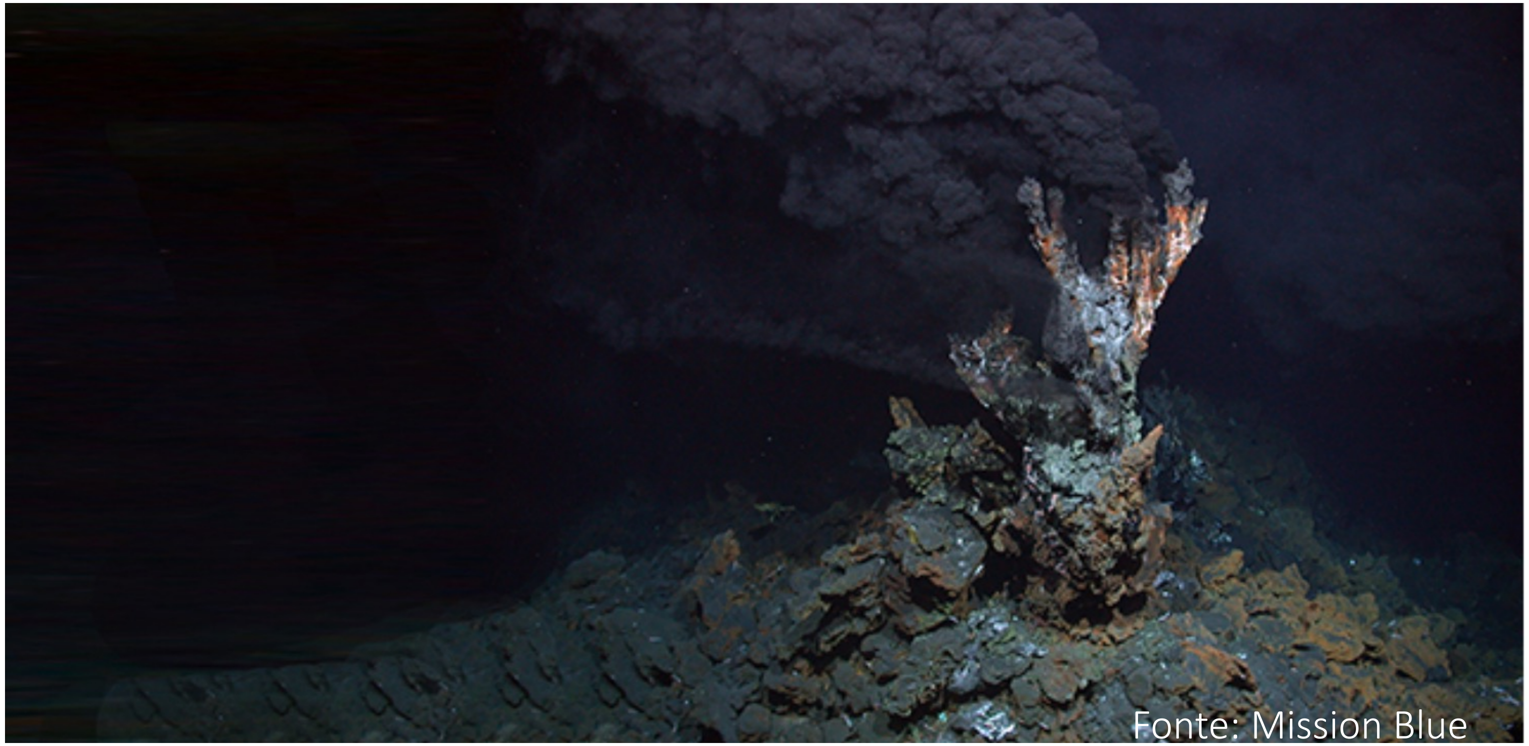
Produção: 1,5 milhões toneladas podem ser produzidas a cada cem anos

Gênese: A água do mar penetra nas fissuras no fundo do mar e é aquecida (400 C). A água aquecida é menos densa, por isso sobe rapidamente e volta ao mar. No oceano, a nuvem de água quente esfria rapidamente. Isso faz com que os metais dissolvidos se liguem em pequenas partículas de sulfeto e precipitam.

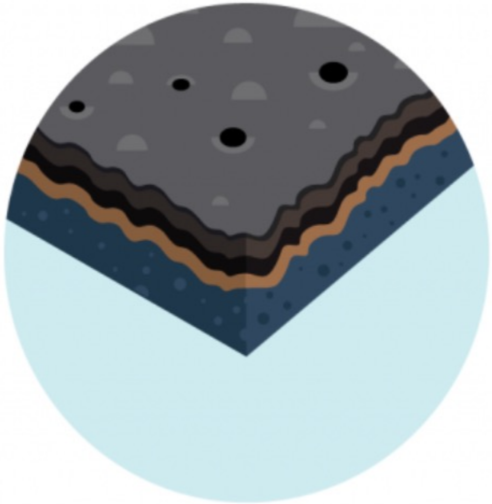


Fonte: Massive sulphides in smoky depths


Fonte: Marine Geoscience


Fonte: Mission Blue


Fonte: Woods Hole



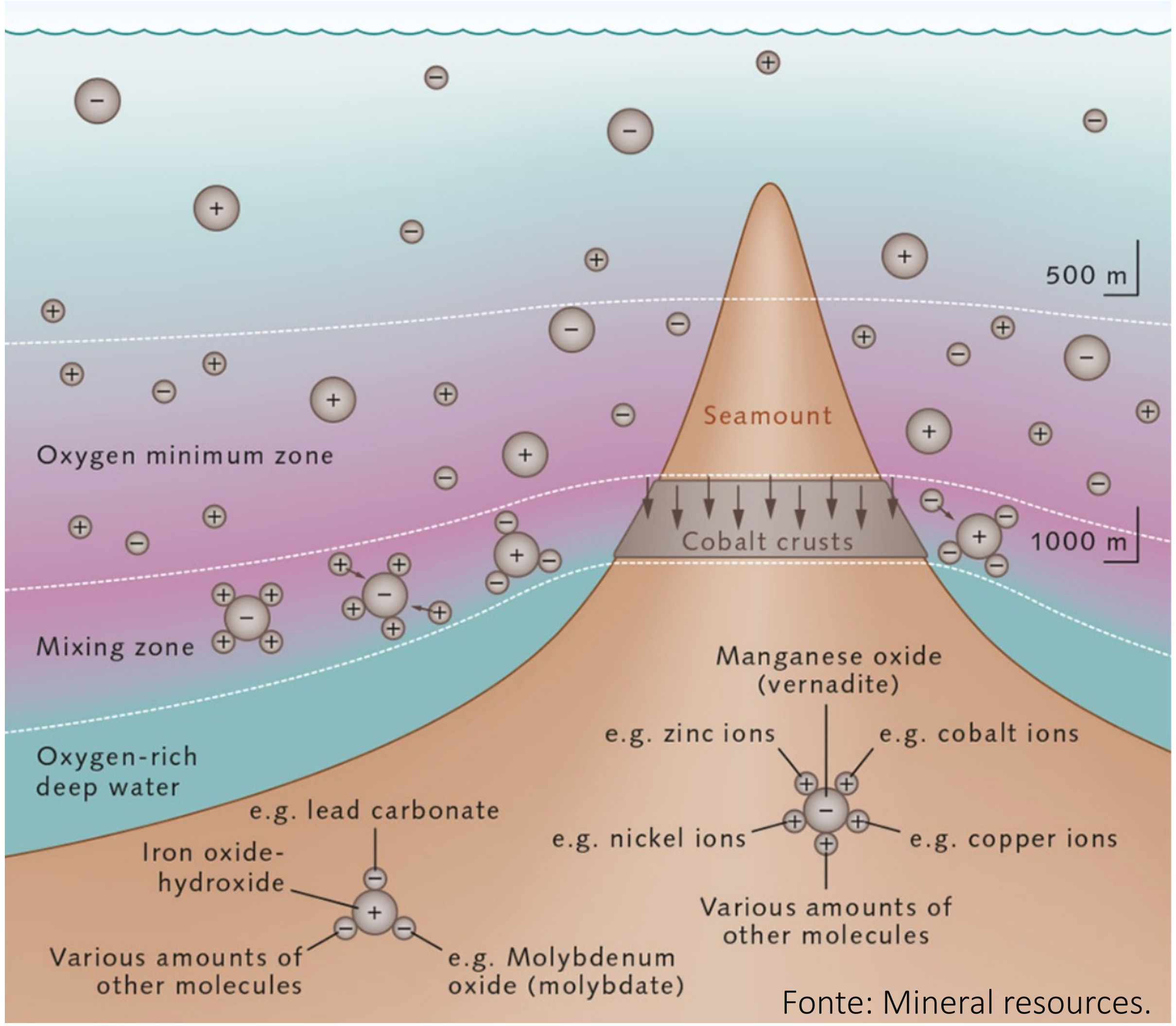
Crosta de Fe-Mn

Composição: Cobalto, vanádio, molibdênio, platina e telúrio.

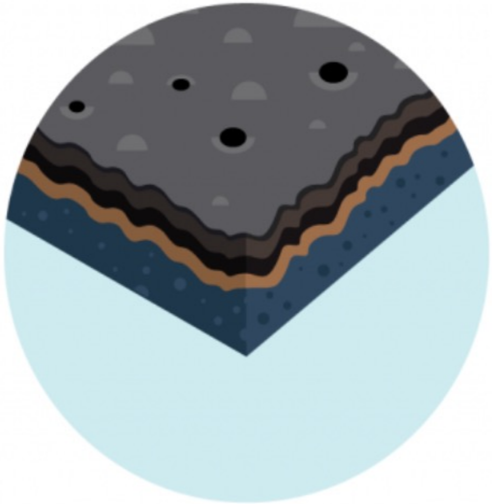
Ocorrência: Montes submarinos
e elevações,
400 –7,000 m

Produção: 1 -5 mm a cada 1
milhão de anos

Gênese: íons metálicos da água ligam–se à moléculas de ferro-hidróxido e óxidos de manganês e precipitam em superfícies duras dos montes submarinos.

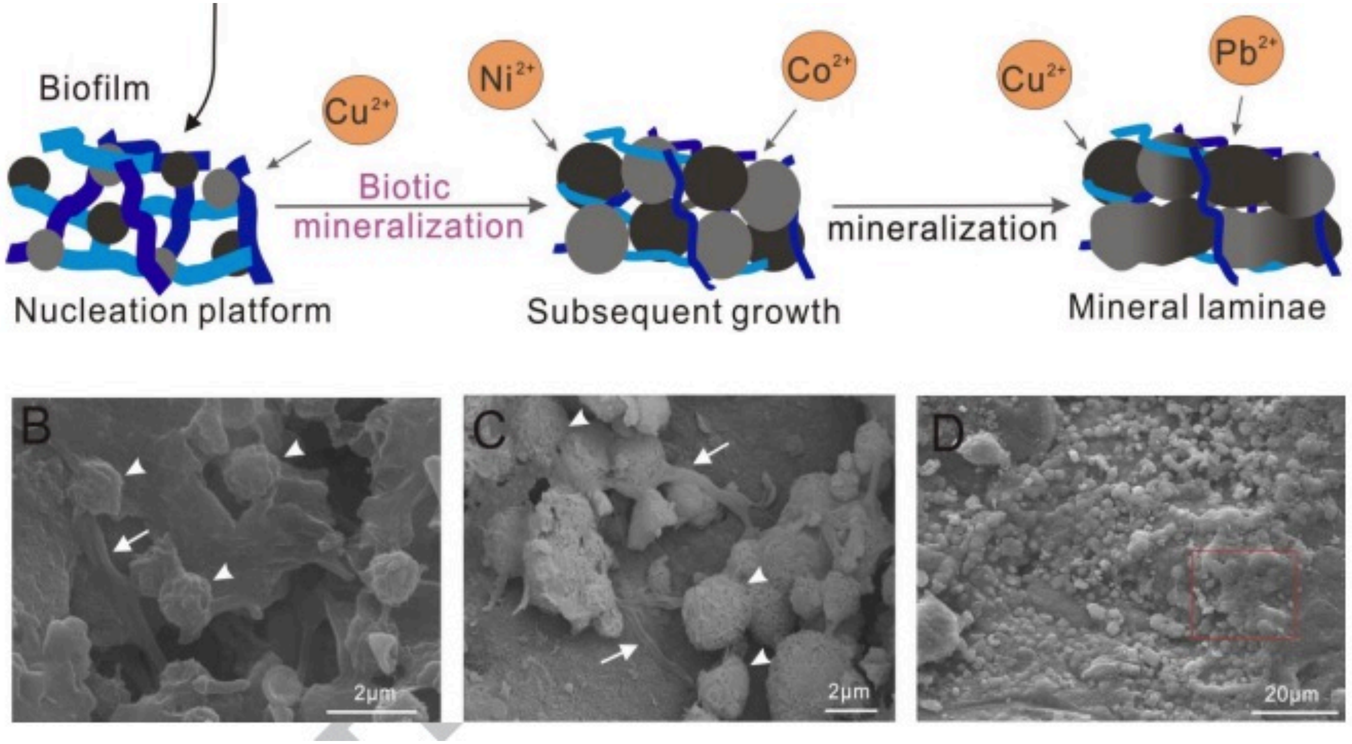


Fonte: Mineral resources.

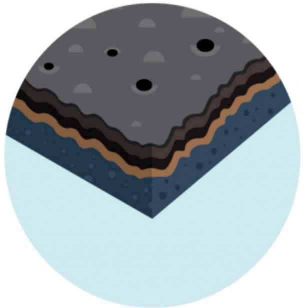


Crosta de Fe-Mn

<u>Biomineralização</u>: Agregados esféricos semelhantes aos estromatólitos
Bactérias oxidantes do Mn – Bacillus e Arthrobacter

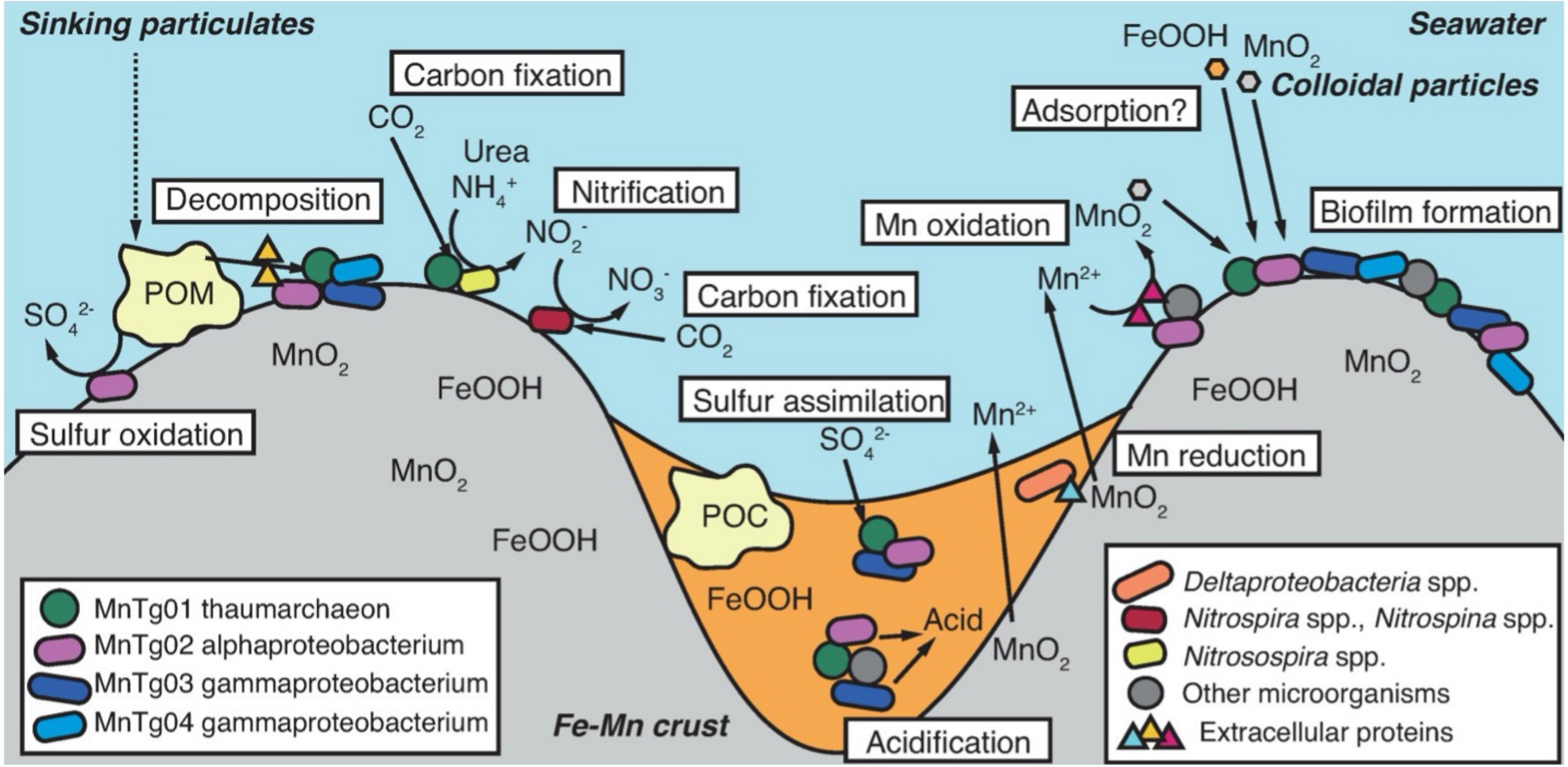


Xiao-Dong et al., 2017

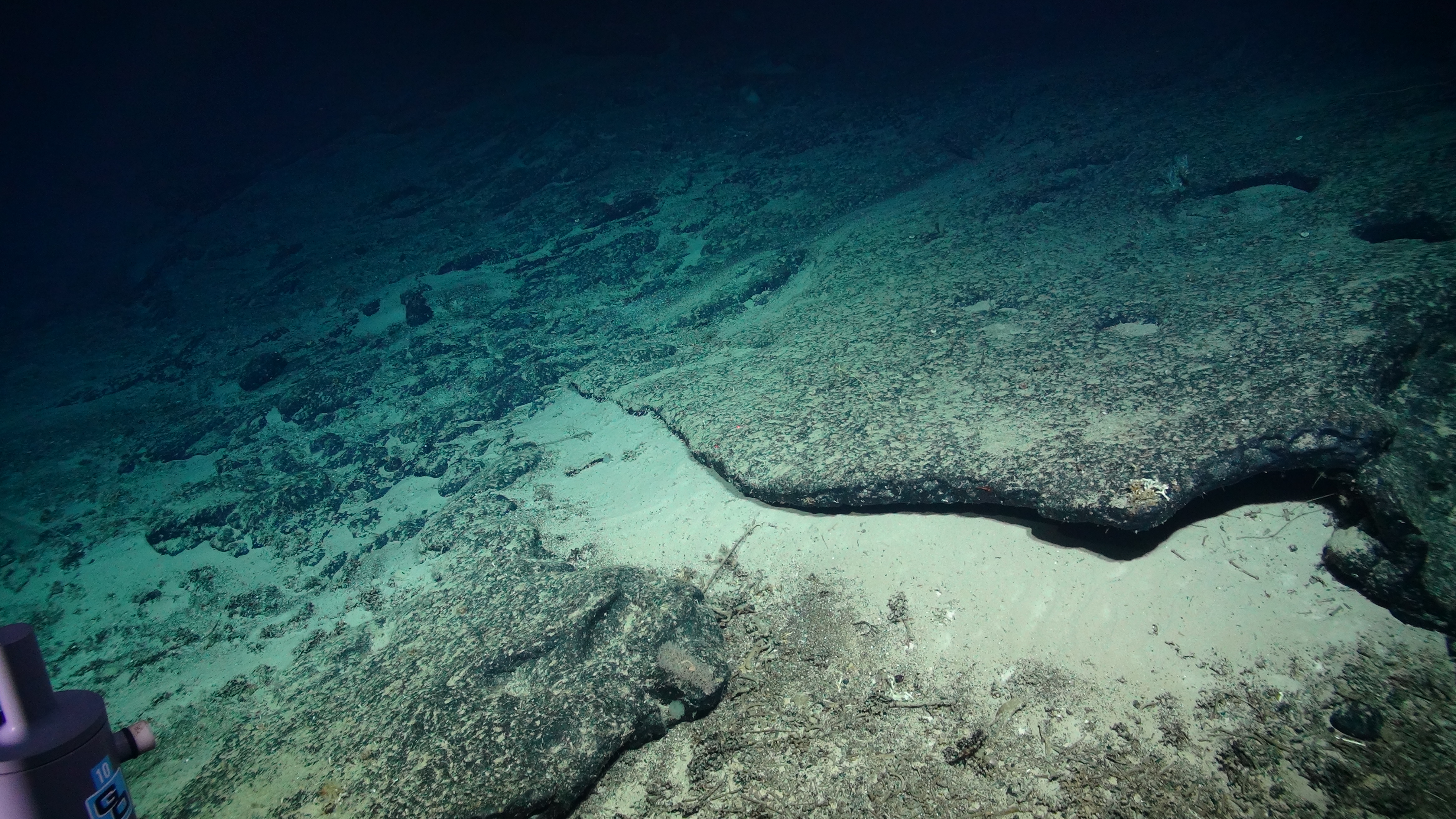


Crosta de Fe-Mn

Biomineralização: microbioma das crostas envolvido nos ciclos biogeoquímicos do C, N, S, Fe e Mn, e assim contribuindo para a formação das crostas.



Kato et al., 2019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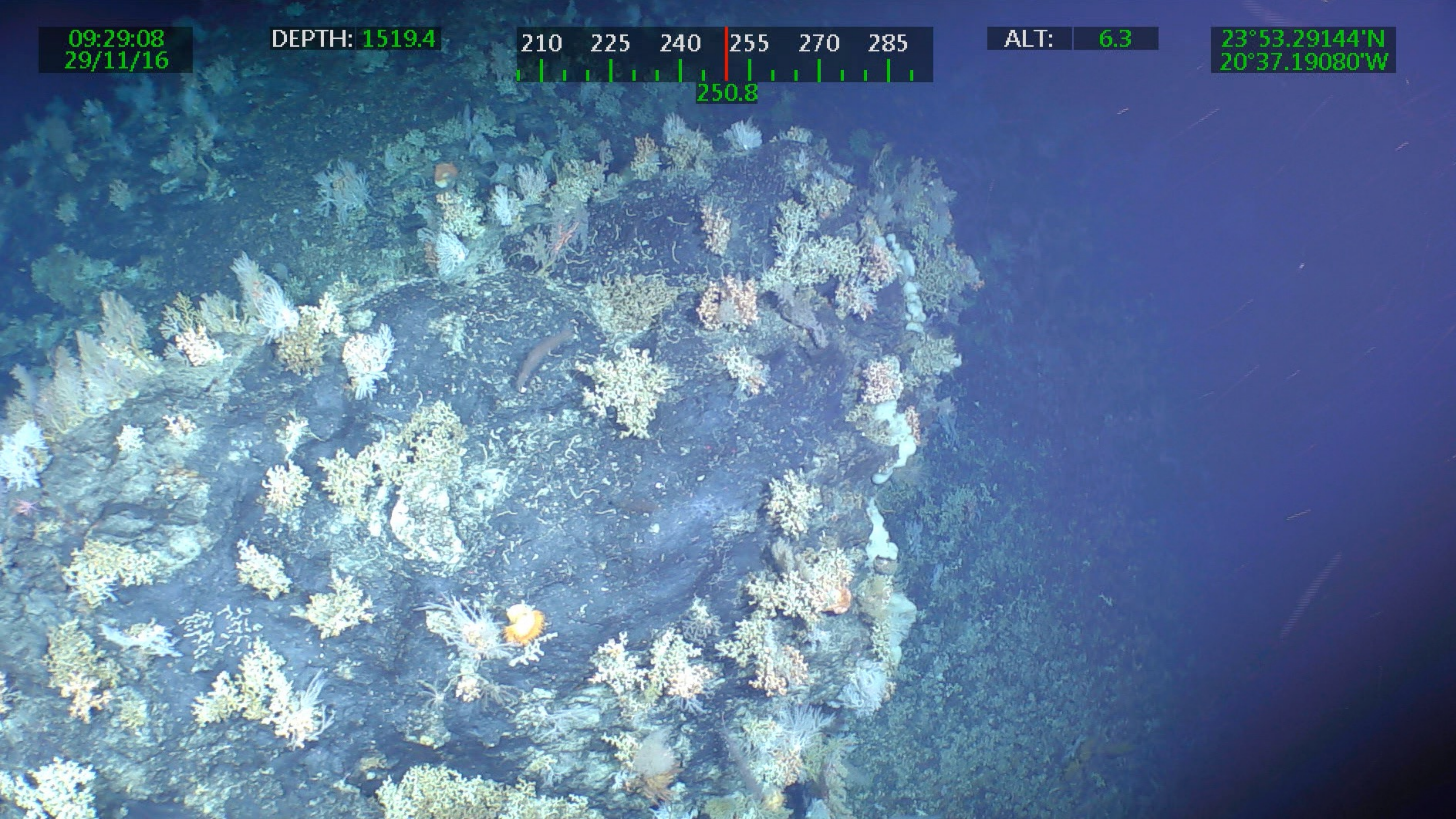
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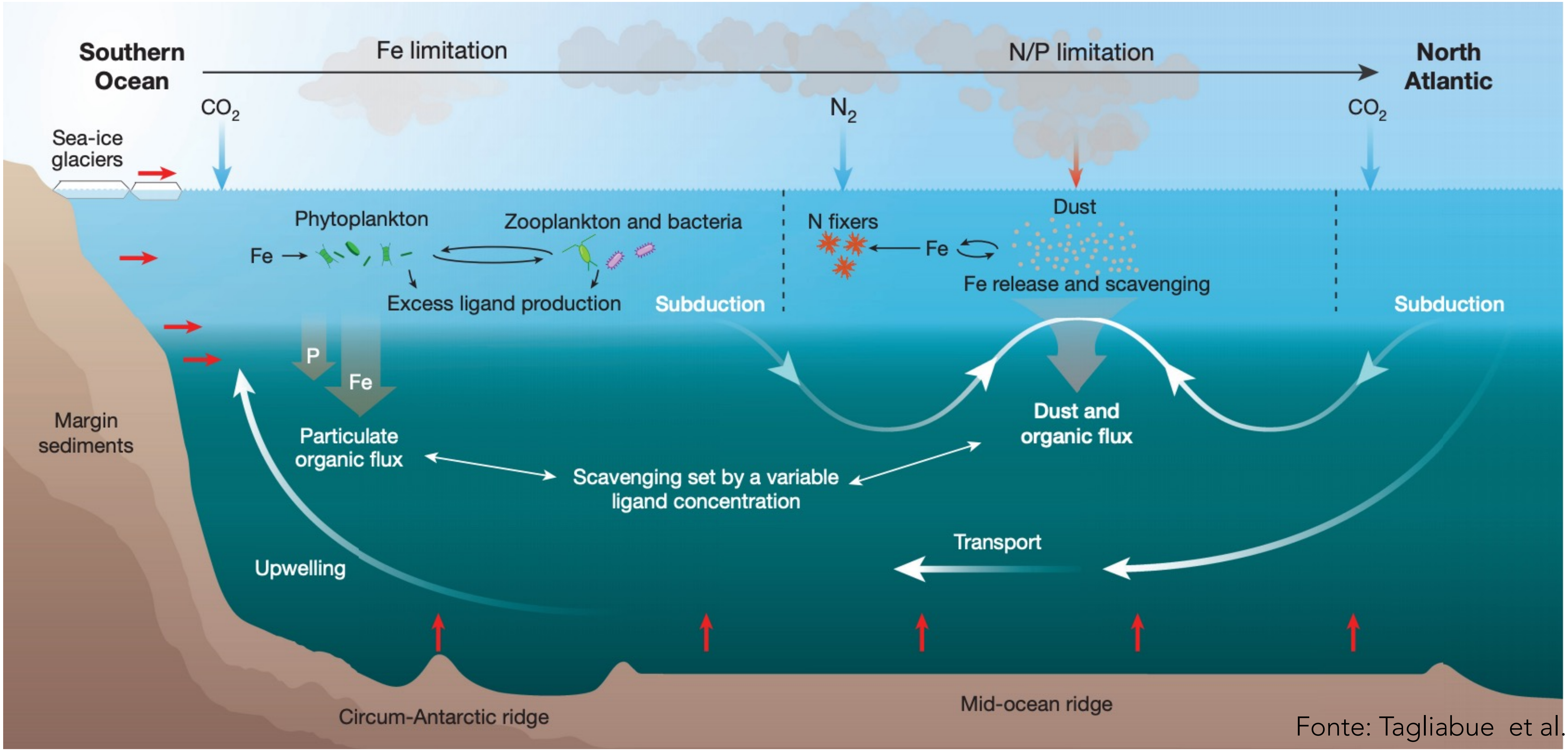
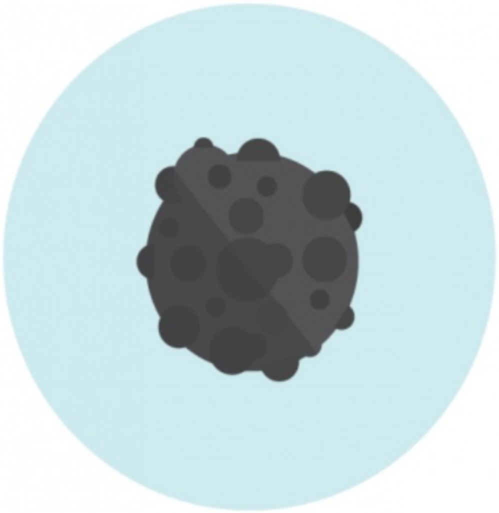
29/11/16
DEPTH: 1519.4
210 225 240 255 270 285
250.8
ALT: 6.3
23°53.29144'N
20°37.19080'W

Ciclo do Fe no oceano Atlântico



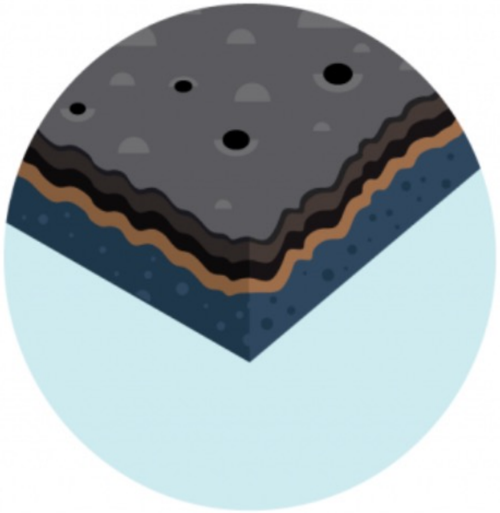
Fonte: Tagliabue et al.

Importância econômica



Nódulos de Fe-Mn

Maciços de sulfetos



Crosta de Fe-Mn

Importância econômica

Demandas Globais

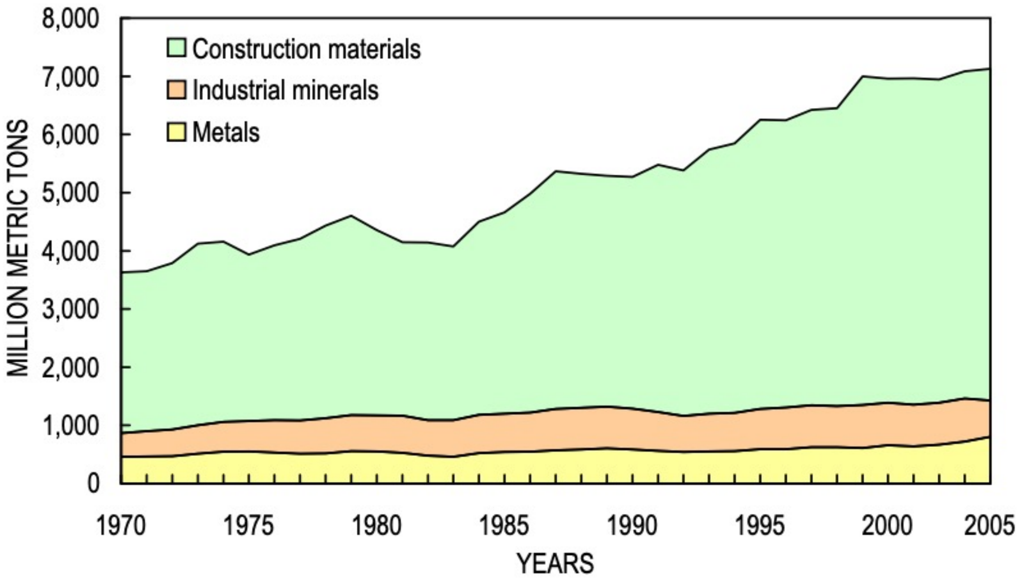


Figure 2. Global metals and minerals extraction.

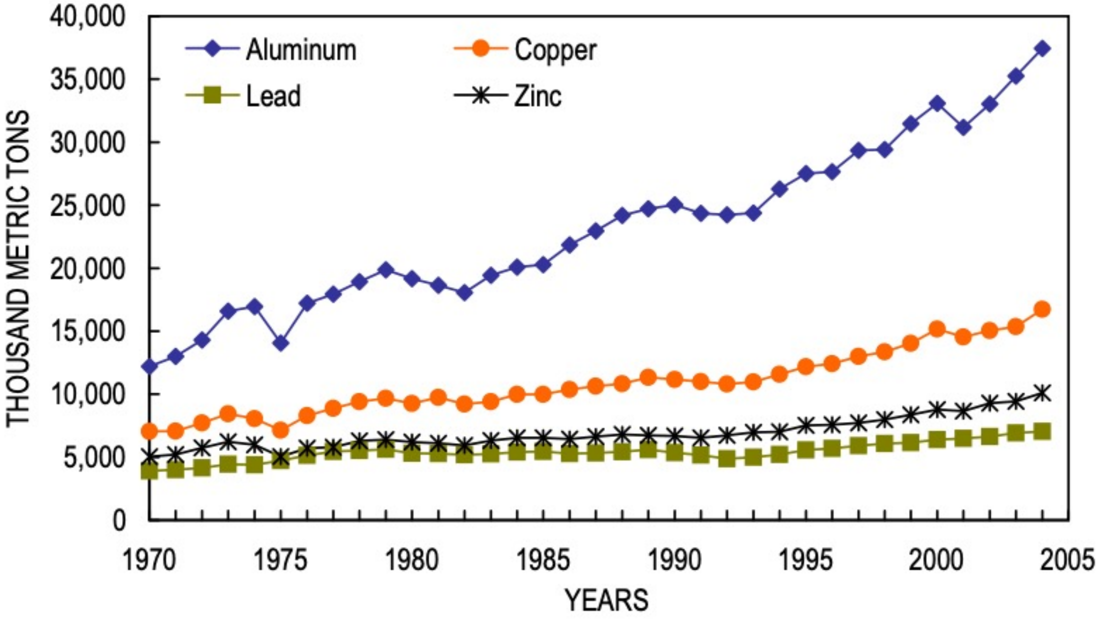


Figure 3. Global aluminum, copper, lead, and zinc consumption.

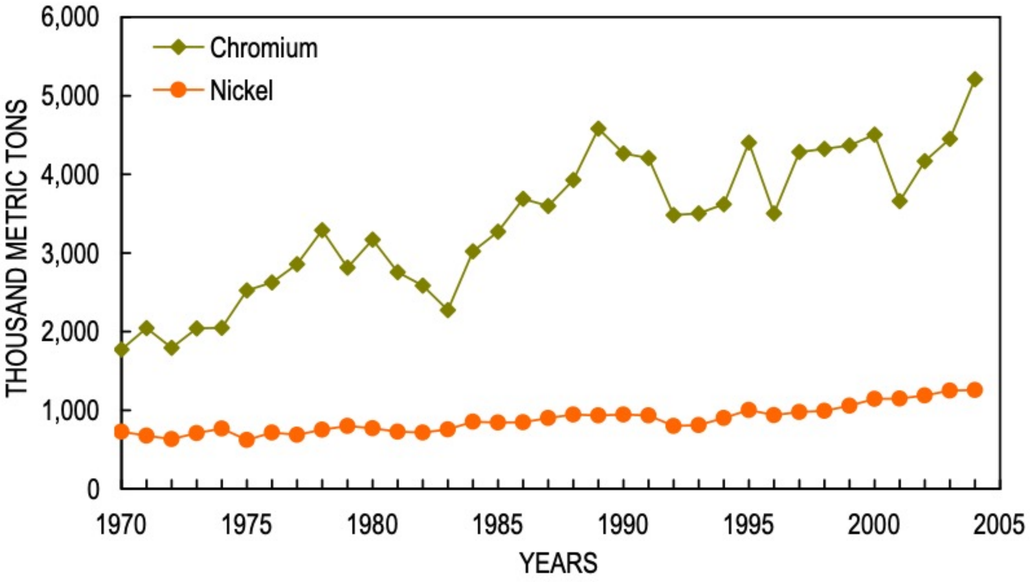
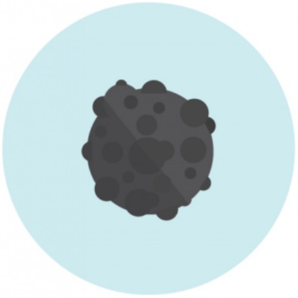


Figure 5. Global chromium and nickel consumption.

Fonte: Rogich et al.

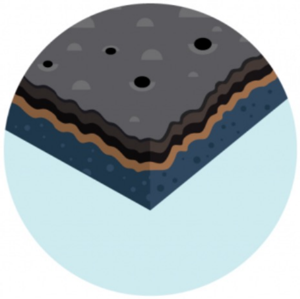
Importância econômica

Aplicações



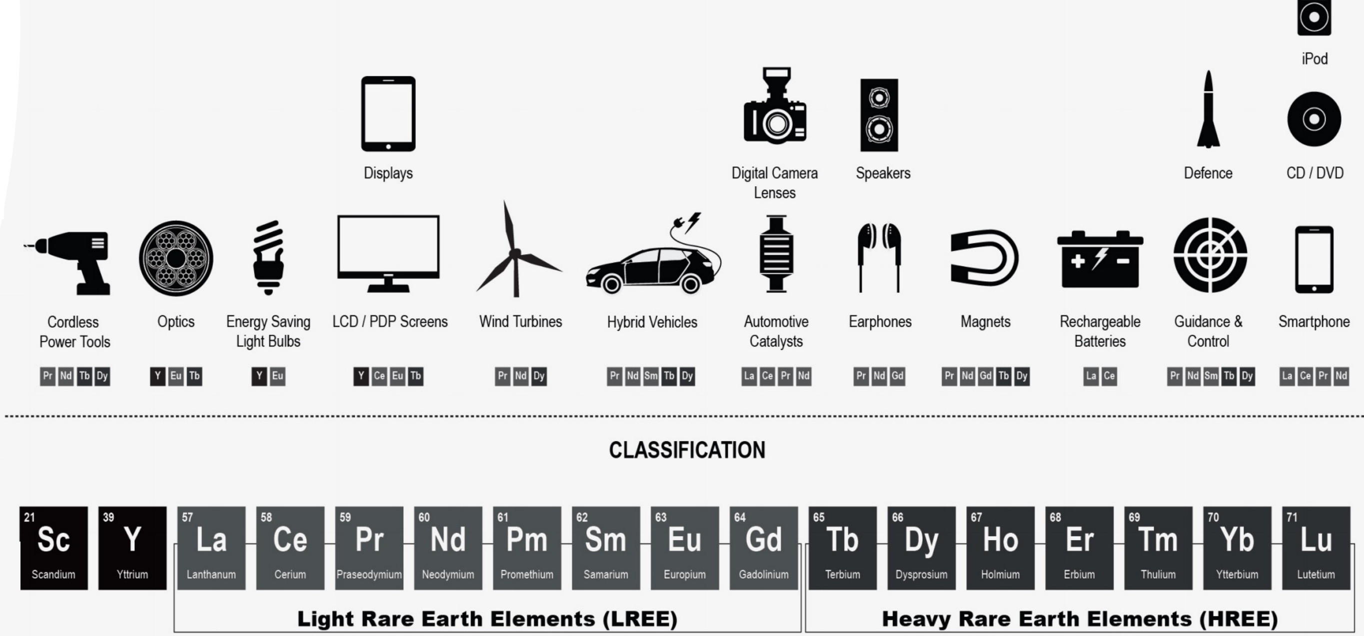
Nódulos de Fe-Mn

Maciços de sulfetos



Crosta de Fe-Mn

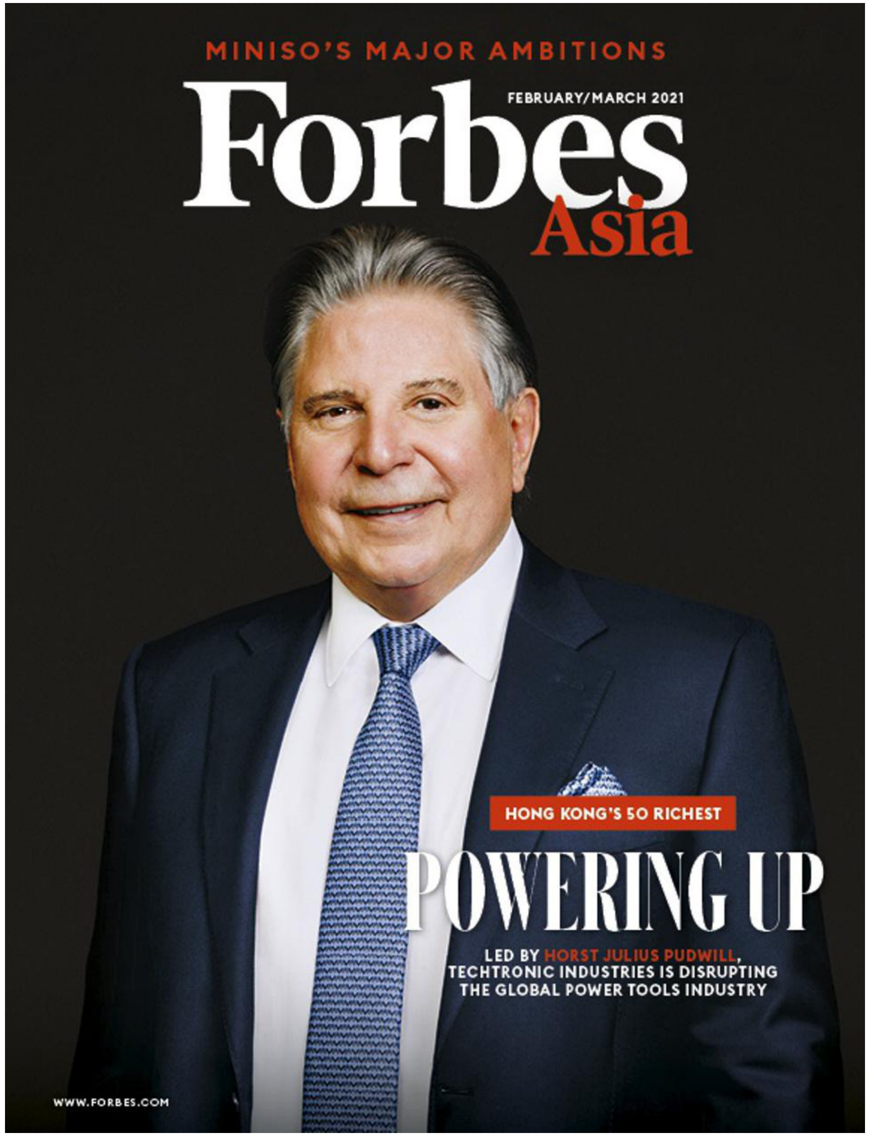
Fonte: China Water Risk

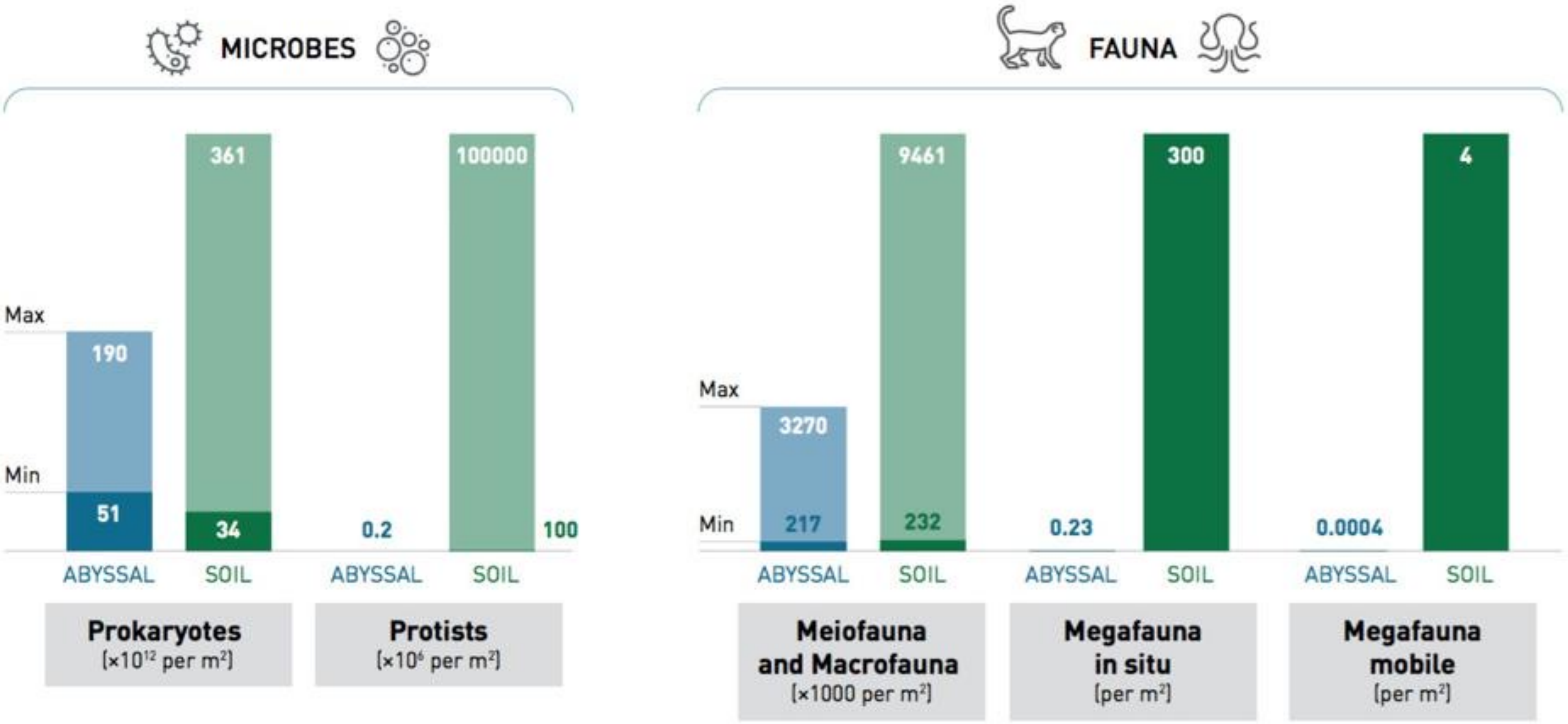



The Economist
FILMS

Feb 24, 2021

Is Mining The Ocean Bottom For Metals Really Better Than Mining On Land?





Organisms per Square Meter: Land Ores versus Nodules.
PAULIKAS ET AL.

Demand scenario:

Passenger electric vehicle (EV) fleet globally reaches 1 billion by 2047

75KWh battery with NMC811 cathode chemistry + copper wire harness

*Sample metal requirements for a single passenger EV

Supply scenario #1

Conventional land ores

Mining
↓
Processing
↓
Refining

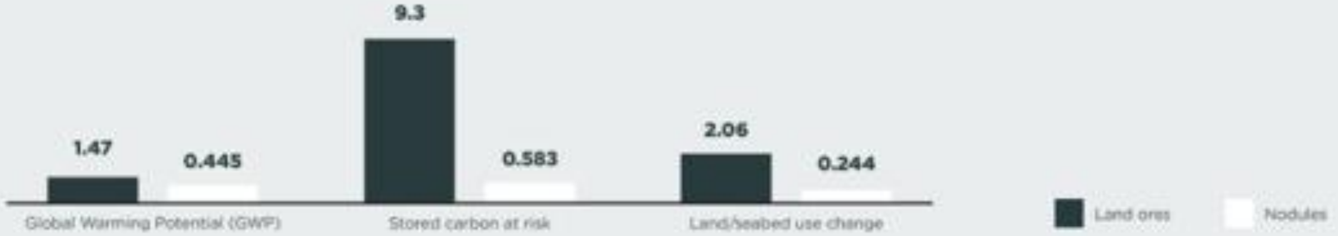
Supply scenario #2

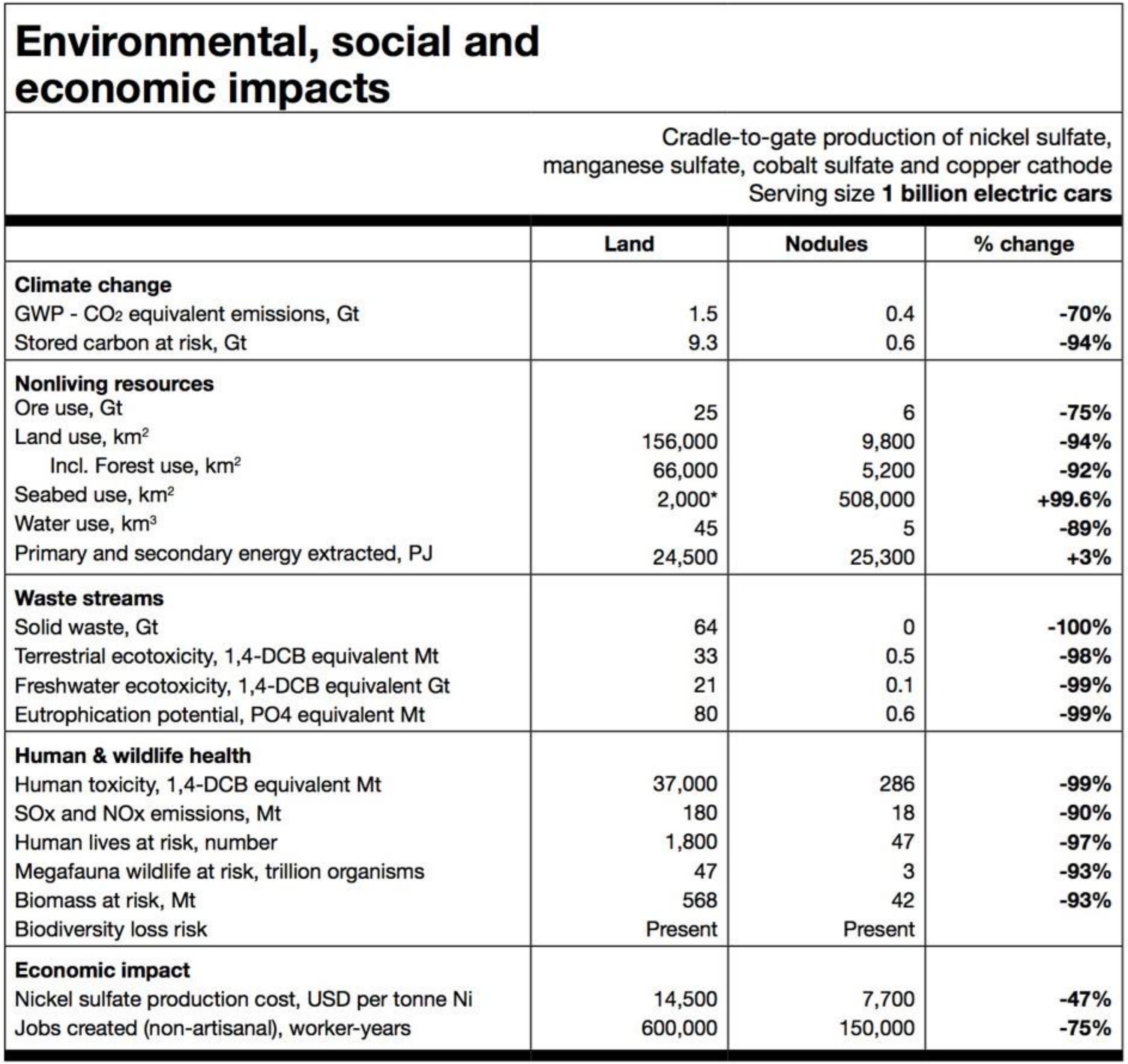
Deep-sea polymetallic nodules

Collection
↓
Processing
↓
Refining

Climate change impacts of metal production of two supply scenarios

Cradle-to-gate life cycle impacts, gigatonnes of CO2 equivalent





Environmental, social and economic impacts

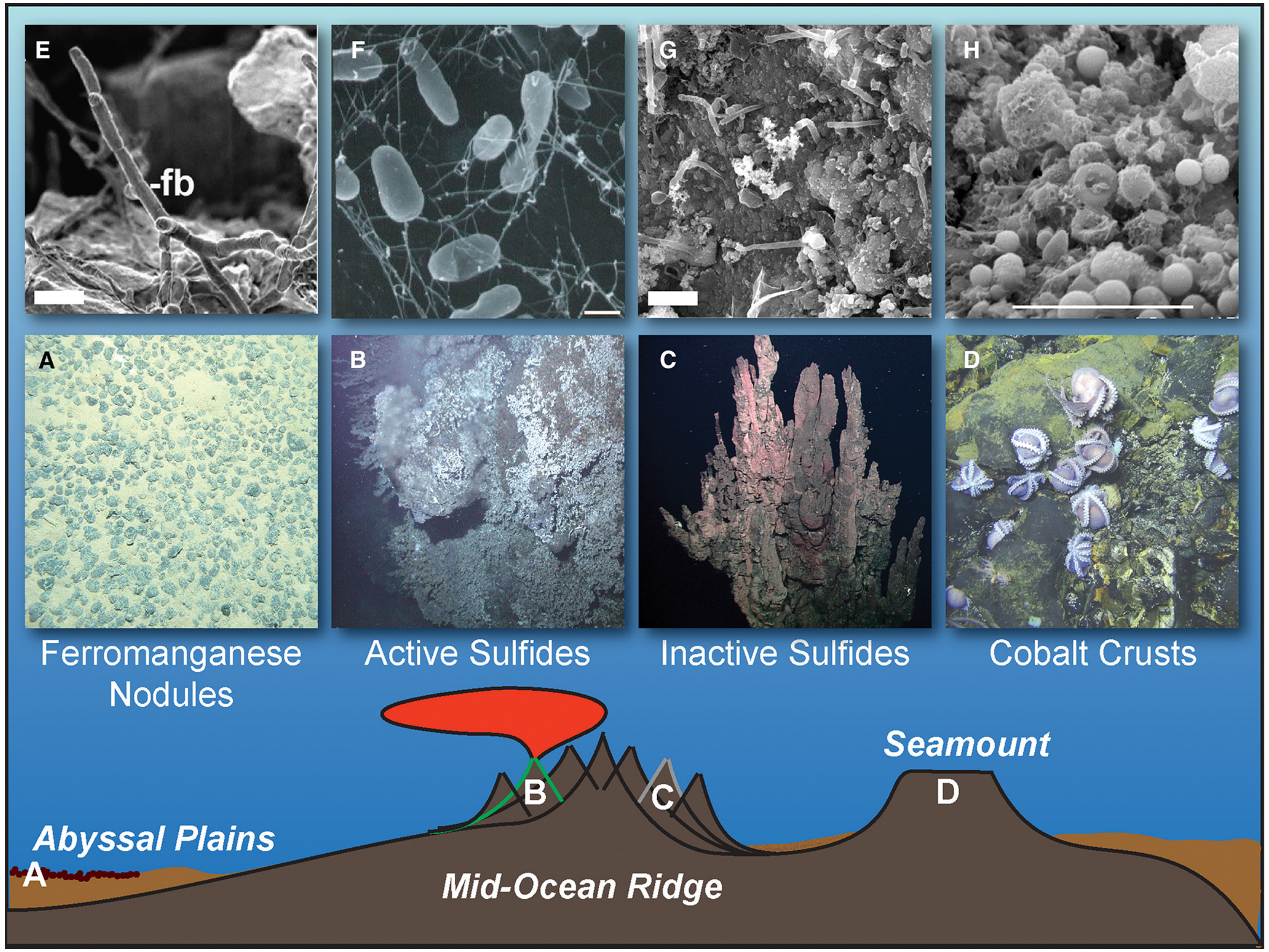
Cradle-to-gate production of nickel sulfate,
manganese sulfate, cobalt sulfate and copper cathode
Serving size **1 billion electric cars**

	Land	Nodules	% change
Climate change			
GWP - CO_2 equivalent emissions, Gt	1.5	0.4	**-70%**
Stored carbon at risk, Gt	9.3	0.6	**-94%**
Nonliving resources			
Ore use, Gt	25	6	**-75%**
Land use, km^2	156,000	9,800	**-94%**
Incl. Forest use, km^2	66,000	5,200	**-92%**
Seabed use, km^2	2,000*	508,000	**+99.6%**
Water use, km^3	45	5	**-89%**
Primary and secondary energy extracted, PJ	24,500	25,300	**+3%**
Waste streams			
Solid waste, Gt	64	0	**-100%**
Terrestrial ecotoxicity, 1,4-DCB equivalent Mt	33	0.5	**-98%**
Freshwater ecotoxicity, 1,4-DCB equivalent Gt	21	0.1	**-99%**
Eutrophication potential, PO4 equivalent Mt	80	0.6	**-99%**
Human & wildlife health			
Human toxicity, 1,4-DCB equivalent Mt	37,000	286	**-99%**
SOx and NOx emissions, Mt	180	18	**-90%**
Human lives at risk, number	1,800	47	**-97%**
Megafauna wildlife at risk, trillion organisms	47	3	**-93%**
Biomass at risk, Mt	568	42	**-93%**
Biodiversity loss risk	Present	Present	
Economic impact			
Nickel sulfate production cost, USD per tonne Ni	14,500	7,700	**-47%**
Jobs created (non-artisanal), worker-years	600,000	150,000	**-75%**

Ecosystem Impacts of Metal Production. Seabed mining operations are far and away better and safer from any standpoint, except habitat effects. This is where we need to be very careful and come up with innovative solutions.

PAULIKAS ET AL.

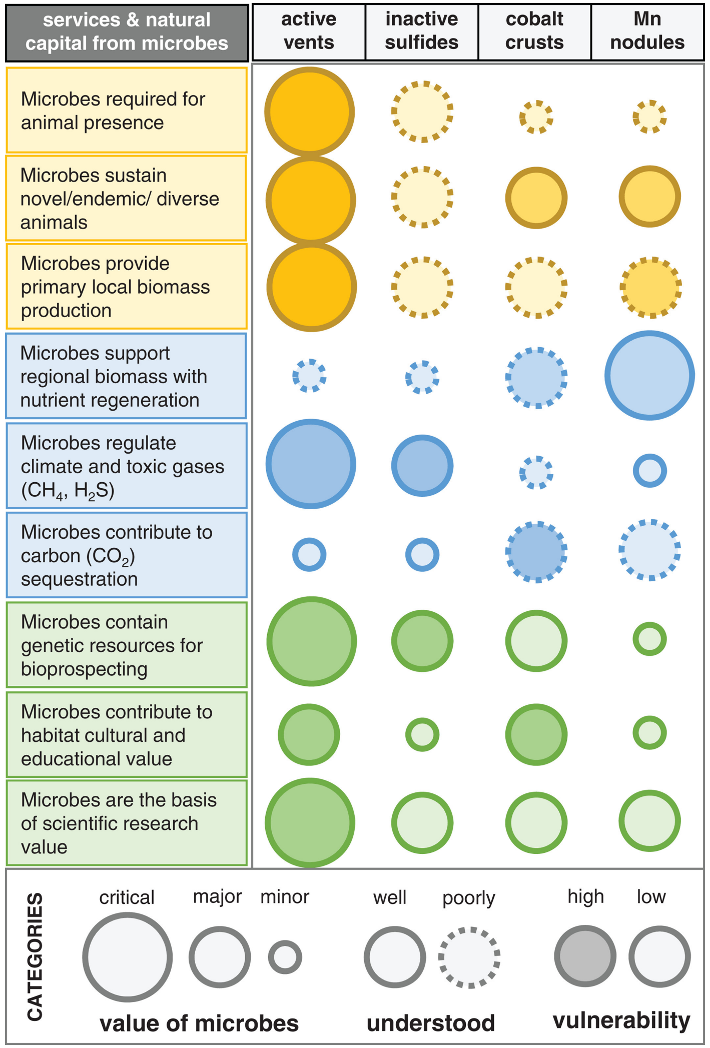
Impacts of deep-sea mining on microbial ecosystem services



F: Desulfurobacterium

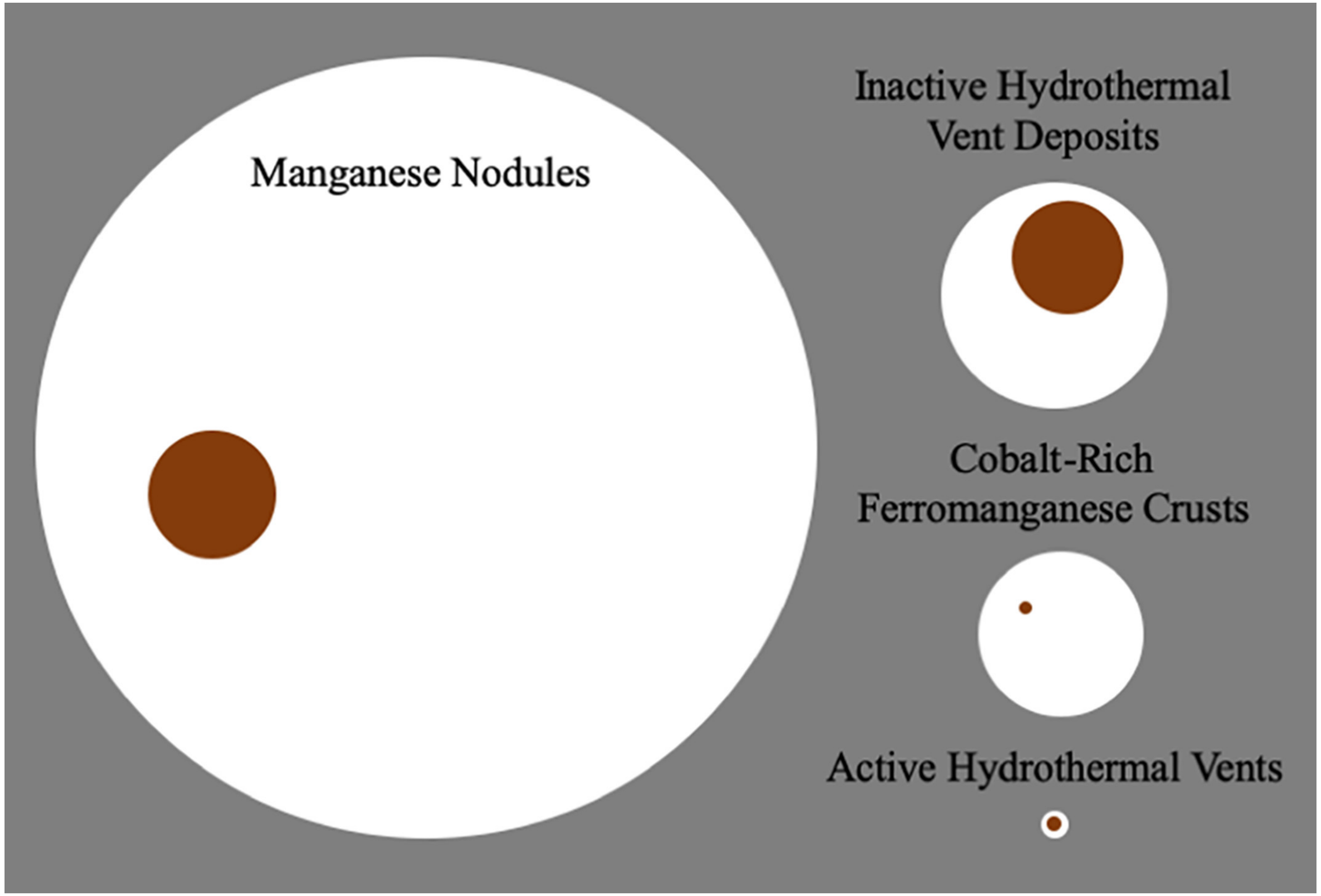
Limnology and Oceanography, Volume: 65, Issue: 7, Pages: 1489-1510, First published: 13 January 2020, DOI: (10.1002/lno.11403)

Impacts of deep-sea mining on microbial ecosystem services



Limnology and Oceanography, Volume: 65, Issue: 7, Pages: 1489-1510, First published: 13 January 2020, DOI: (10.1002/lno.11403)

Impacts of deep-sea mining on microbial ecosystem services



Limnology and Oceanography, Volume: 65, Issue: 7, Pages: 1489-1510, First published: 13 January 2020, DOI: (10.1002/lno.11403)

Sci Adv
. 2020 Apr 29;6(18):eaaz5922.
doi: 10.1126/sciadv.aaz5922. eCollection 2020 May.

Effects of a deep-sea mining experiment on seafloor microbial communities and functions after 26 years

T R Vonnahme[1], M Molari[1], F Janssen[1,2], F Wenzhöfer[1,2], M Haeckel[3], J Titschack[4,5], A Boetius[1,2,4]

- DOI: 10.1126/sciadv.aaz5922

Abstract

Future supplies of rare minerals for global industries with high-tech products may depend on deep-sea mining. However, environmental standards for seafloor integrity and recovery from environmental impacts are missing. We revisited the only midsize deep-sea disturbance and recolonization experiment carried out in 1989 in the Peru Basin nodule field to compare habitat integrity, remineralization rates, and carbon flow with undisturbed sites. Plough tracks were still visible, indicating sites where sediment was either removed or compacted. Locally, microbial activity was reduced up to fourfold in the affected areas. Microbial cell numbers were reduced by ~50% in fresh "tracks" and by <30% in the old tracks. Growth estimates suggest that microbially mediated biogeochemical functions need over 50 years to return to undisturbed levels. This study contributes to developing environmental standards for deep-sea mining while addressing limits to maintaining and recovering ecological integrity during large-scale nodule mining.

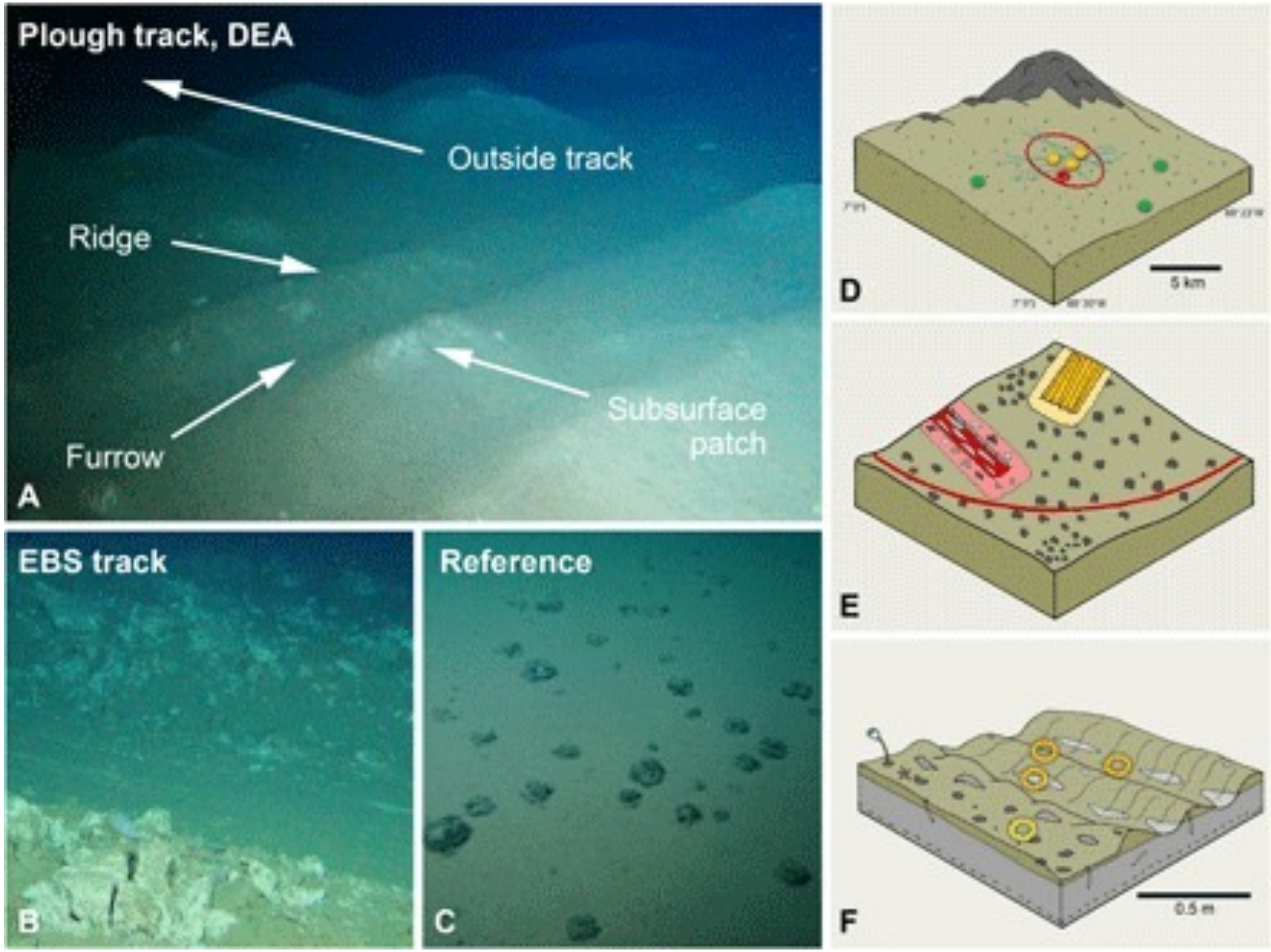
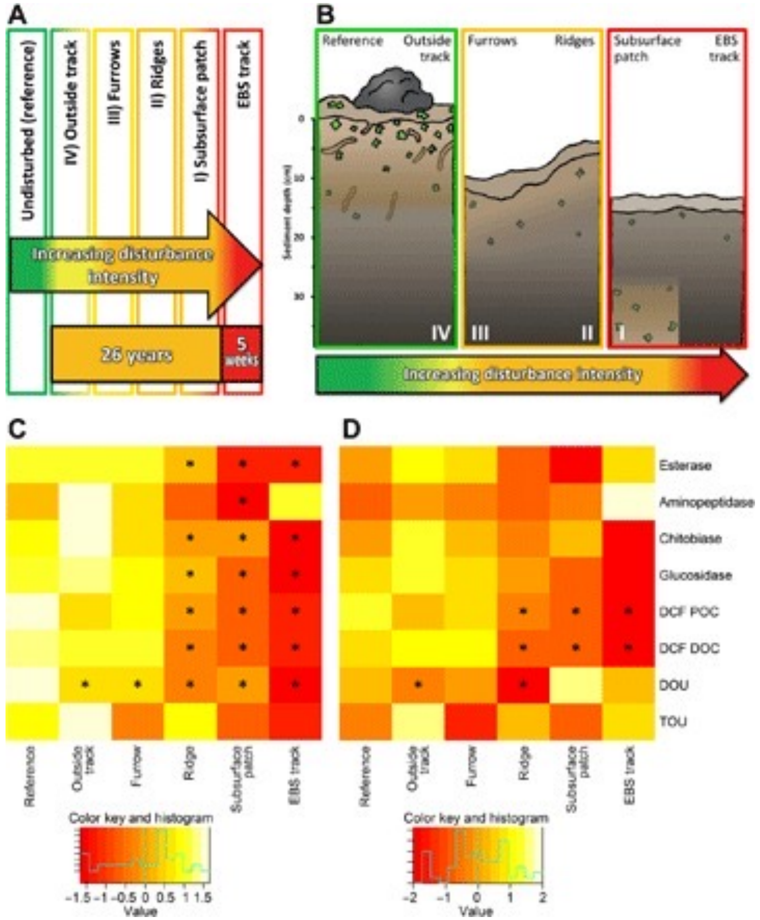


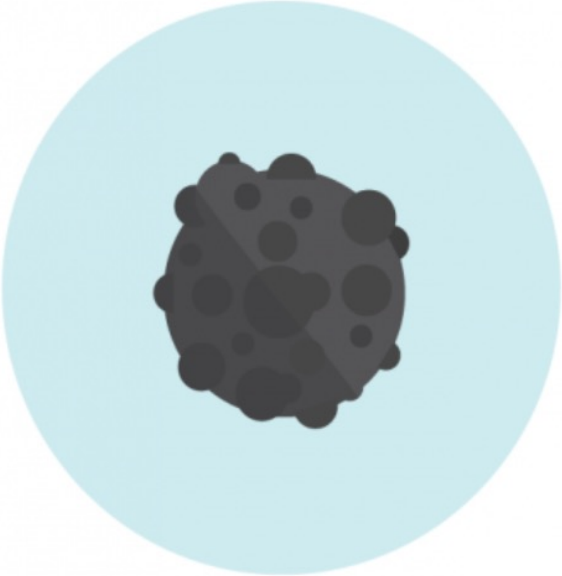
Fig. 1. Photographs of the sampling sites. (**A**) DEA plough track (photo credit: ROV Kiel 6000 Team, GEOMAR), showing the different microhabitat samples; (**B**) EBS track [photo credit: Ocean Floor Observation System (OFOS), Alfred-Wegener Institute (AWI)]; and (**C**) the Reference (photo credit: ROV Kiel 6000 Team, GEOMAR). (**D** to **F**) Schematic representation of the sampling design (A) and different microhabitats observed (photo credit: Autun Purser)



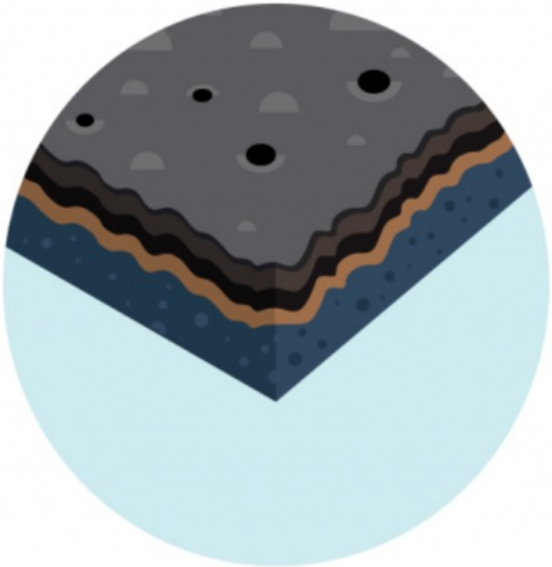
. Synthesis of the observed disturbance gradient. (**A**) Schematic representation of increasing degree of impact from left to right, i.e., green to red color. (**B**) Schematic summary of the differences between the different disturbance levels. (**C** and **D**) Overview of biogeochemical activity per area (C) and per cell numbers (D). Light yellow fields indicate more activity, while orange and red colors represent less activity. The distribution of relatively more and less activity can be seen in the color key histogram on top. The activity is summarized as the median of the z-scaled values (mean = 0, standard deviation = 1). Asterisks indicate significant differences from the reference sites (Kruskal-Wallis, $P < 0.05$; table S1).

Estudo de caso

Micro-organismos em Crostas e Nódulos de Fe-Mn:
Estudo Comparativo entre o Oceano Atlântico Norte e Sul



Nódulos de Fe-Mn



Crosta de Fe-Mn

Estudo de caso

Micro-organismos em Crostas e Nódulos de Fe-Mn:
Estudo Comparativo entre o Oceano Atlântico Norte e Sul

Perguntas

Quem são os micro-organismos dos depósitos Fe-Mn no Oceano Atlântico ?

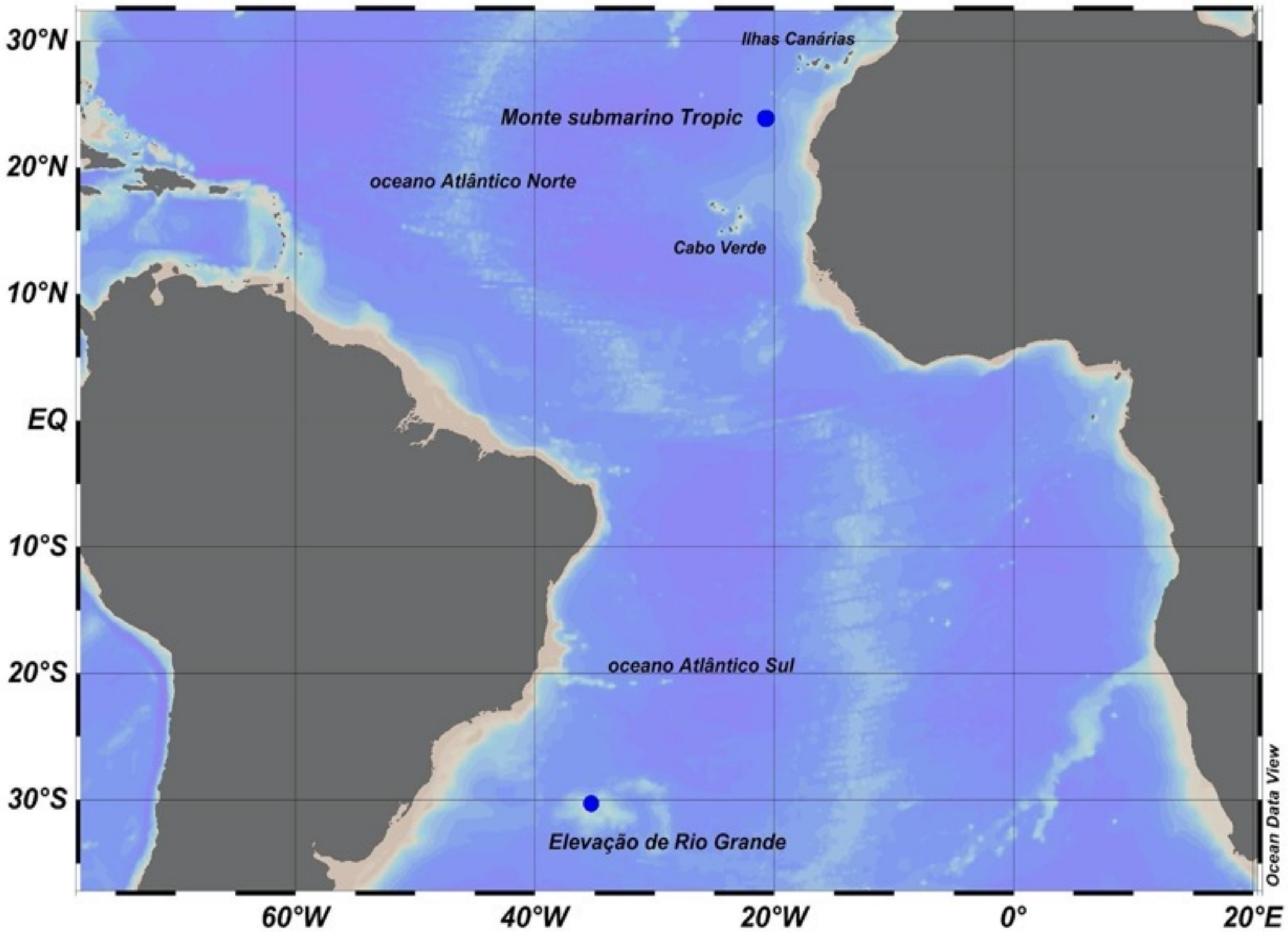
Existem diferenças na diversidade de depósitos de Fe-Mn nos Oceanos Atlântico e Pacifico?

Existem diferenças na diversidade de depósitos de Fe-Mn entre o monte submarino Tropic (Oceano Atlântico Norte) e a Elevação de Rio Grande (Oceano Atlântico Sul)?

Existe diferença na diversidade entre substratos de Fe-Mn?

Quem são os micro-organismos redutores de Fe e oxidantes de Mn depósitos Fe-Mn no Oceano Atlântico ?

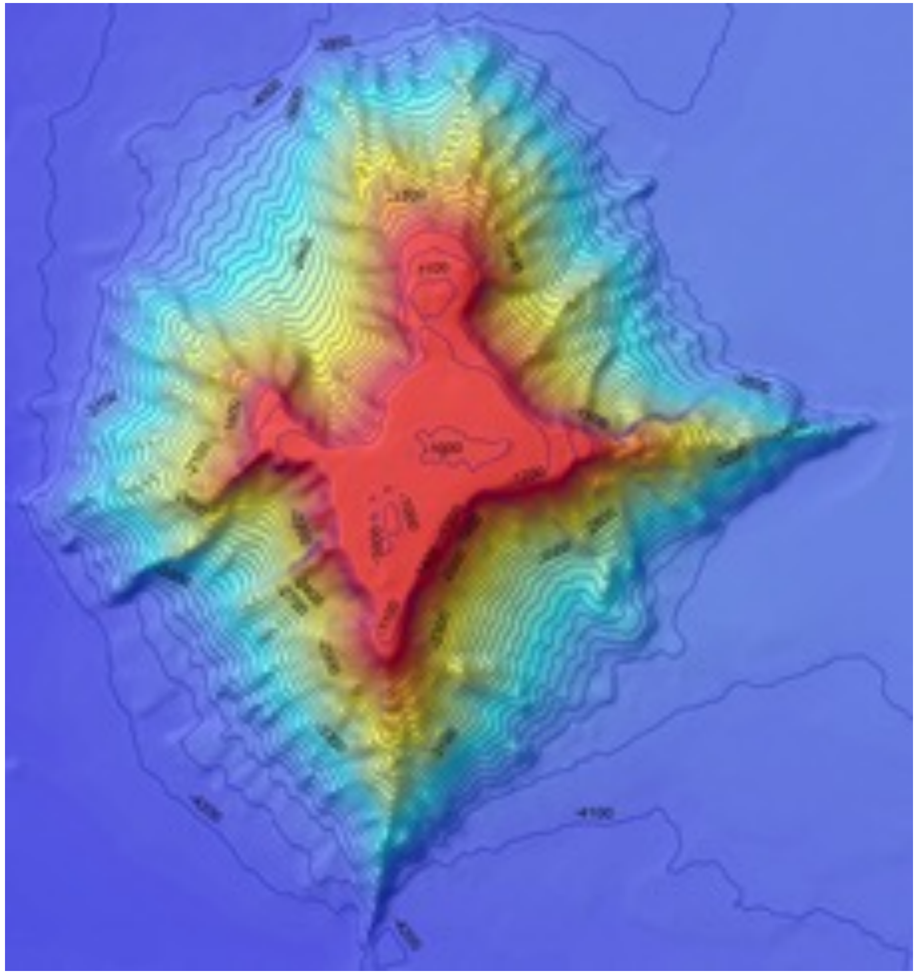
Áreas de Estudo



Áreas de Estudo

Monte submarino *Tropic*

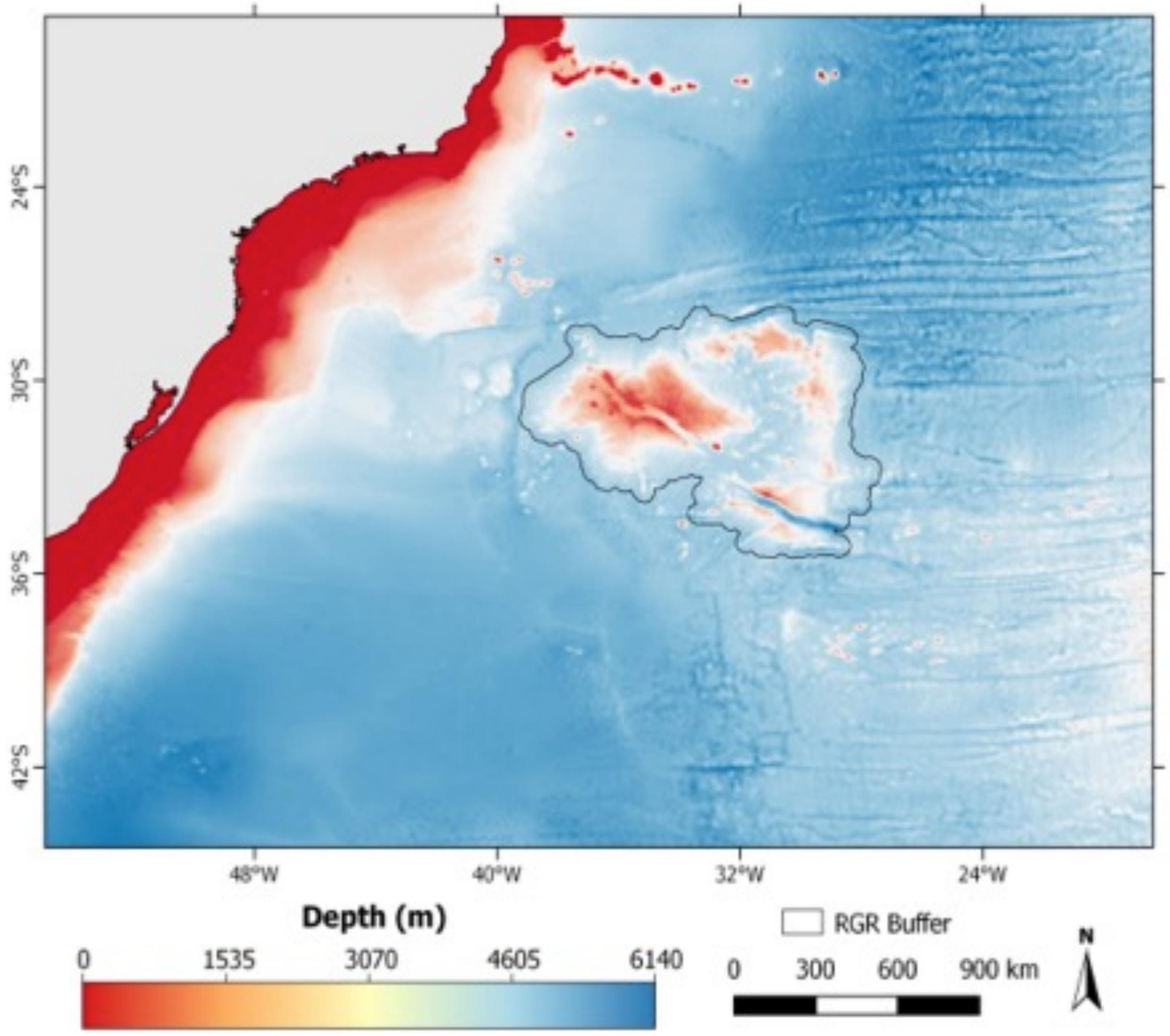
- Ilha vulcânica
- 120 Ma.
- Guyot



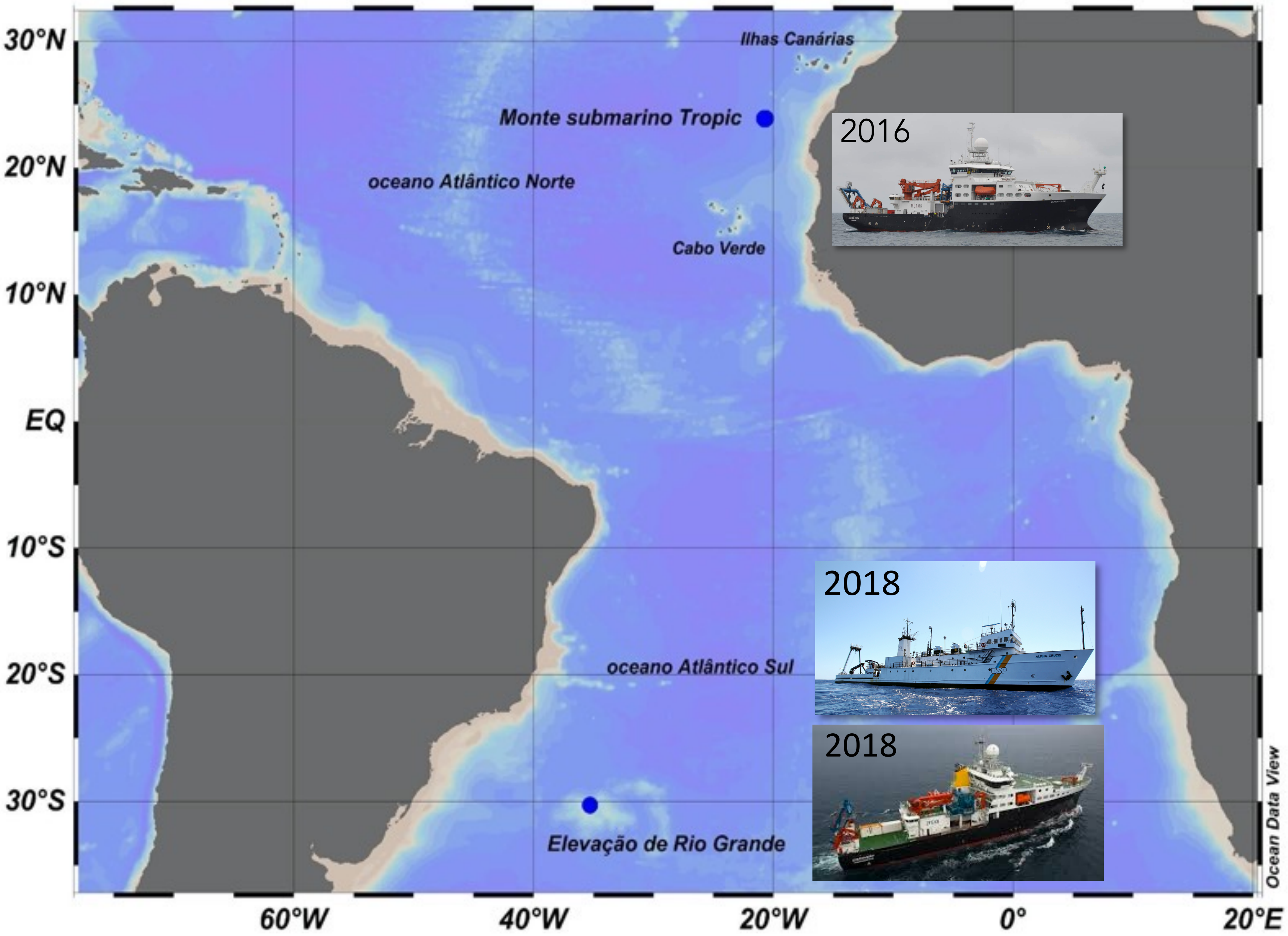
Áreas de Estudo

Elevação de Rio Grande

- Bacia oceânica do Brasil e da Argentina
- 1300 km
- Elevação

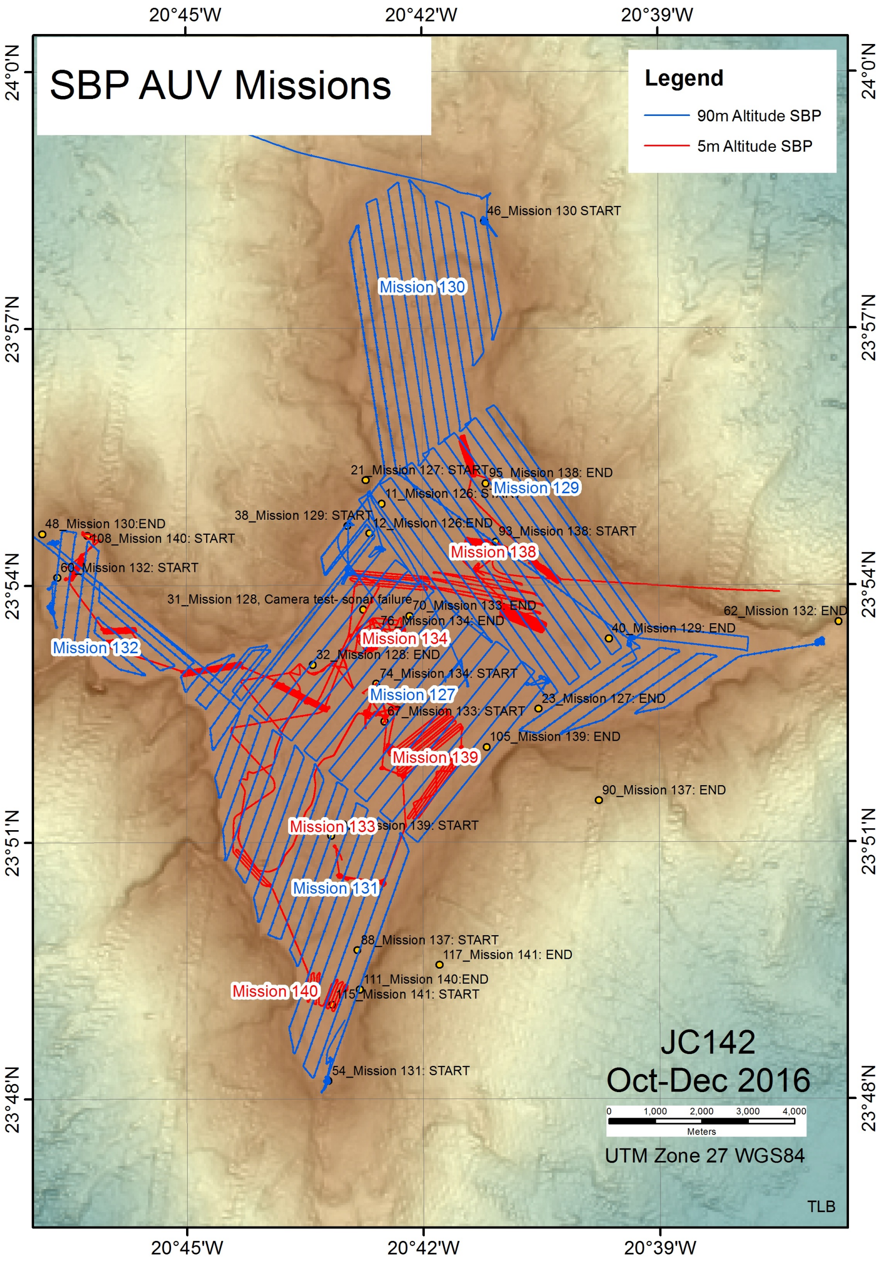


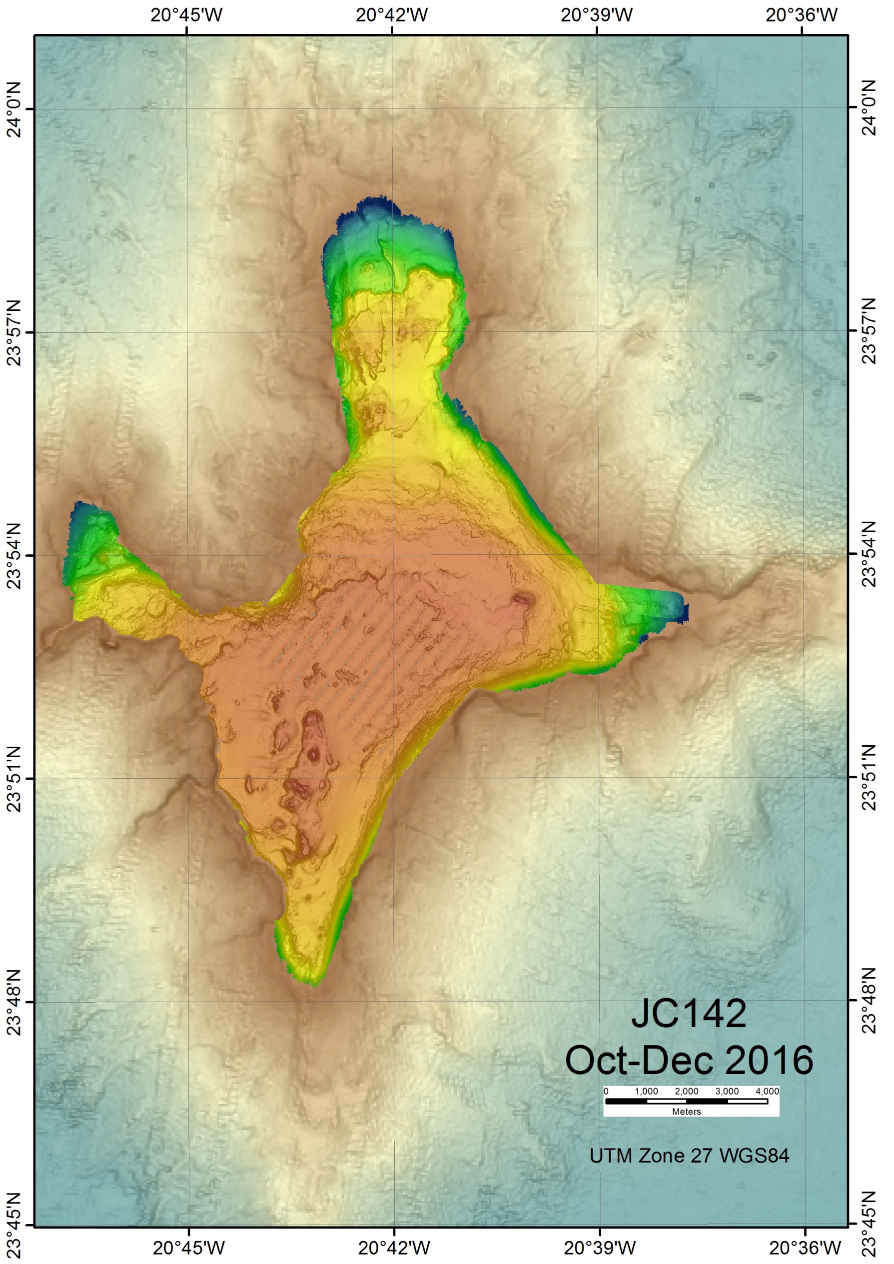
Coletas | Expedições Oceanográficas



Coletas | Expedição Oceanográfica JC142 – RRS James Cook - Tropic

Expedição Oceanográfica RGR1 – RRS James Cook - Tropic



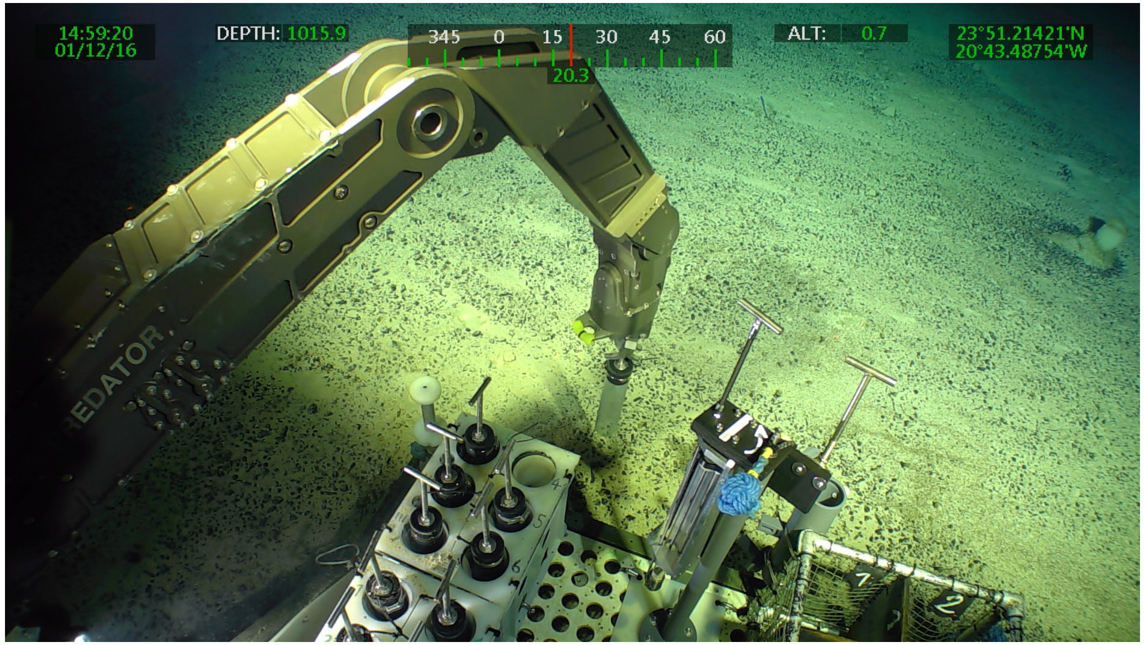


Coletas | Expedição Oceanográfica JC42 – RRS James Cook - Tropic

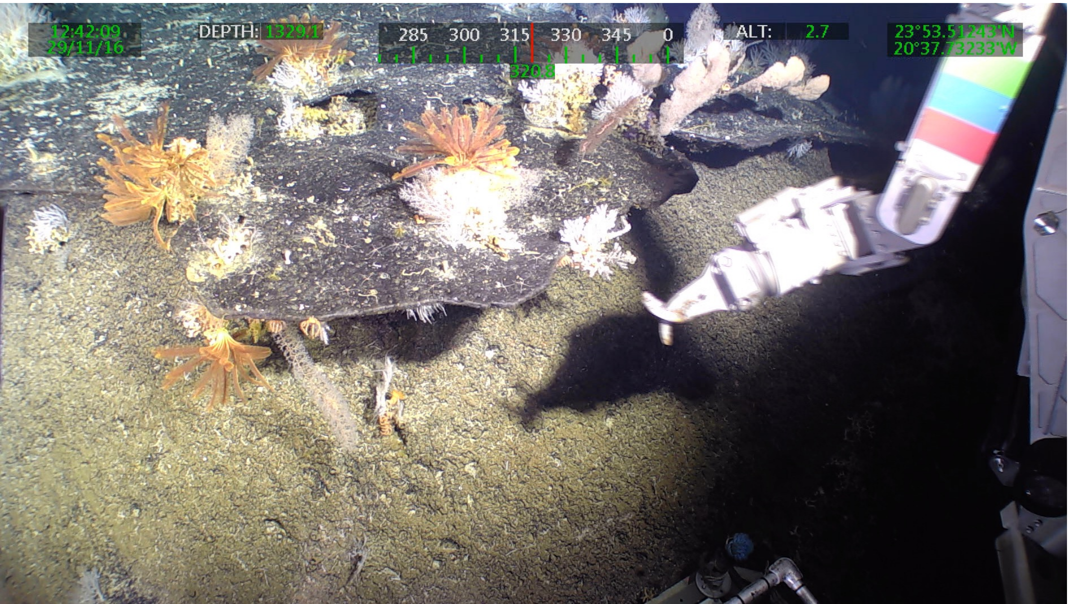
ROV Isis

Coletas

Expedição Oceanográfica JC142 – RRS James Cook - Tropic



Crosta
Sedimento
Nódulo



Coletas

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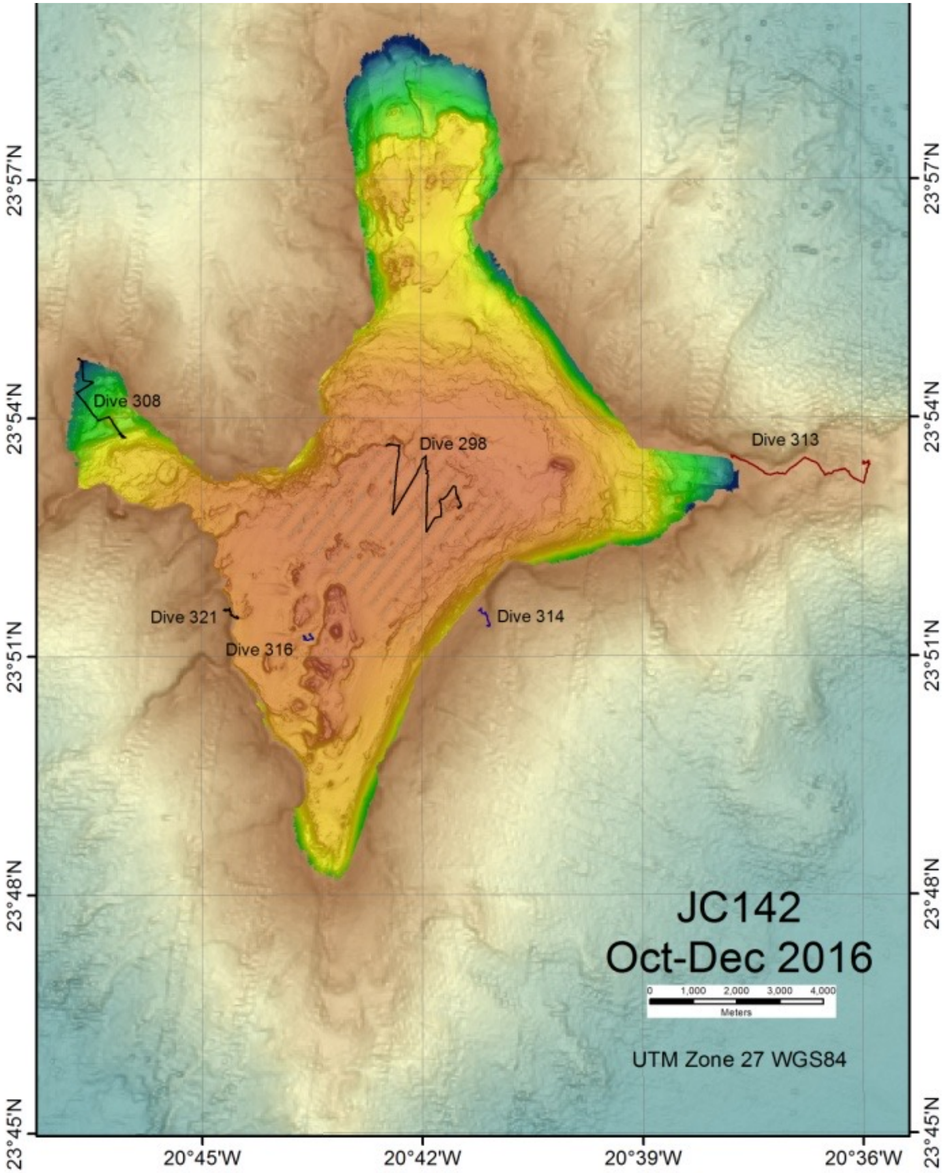
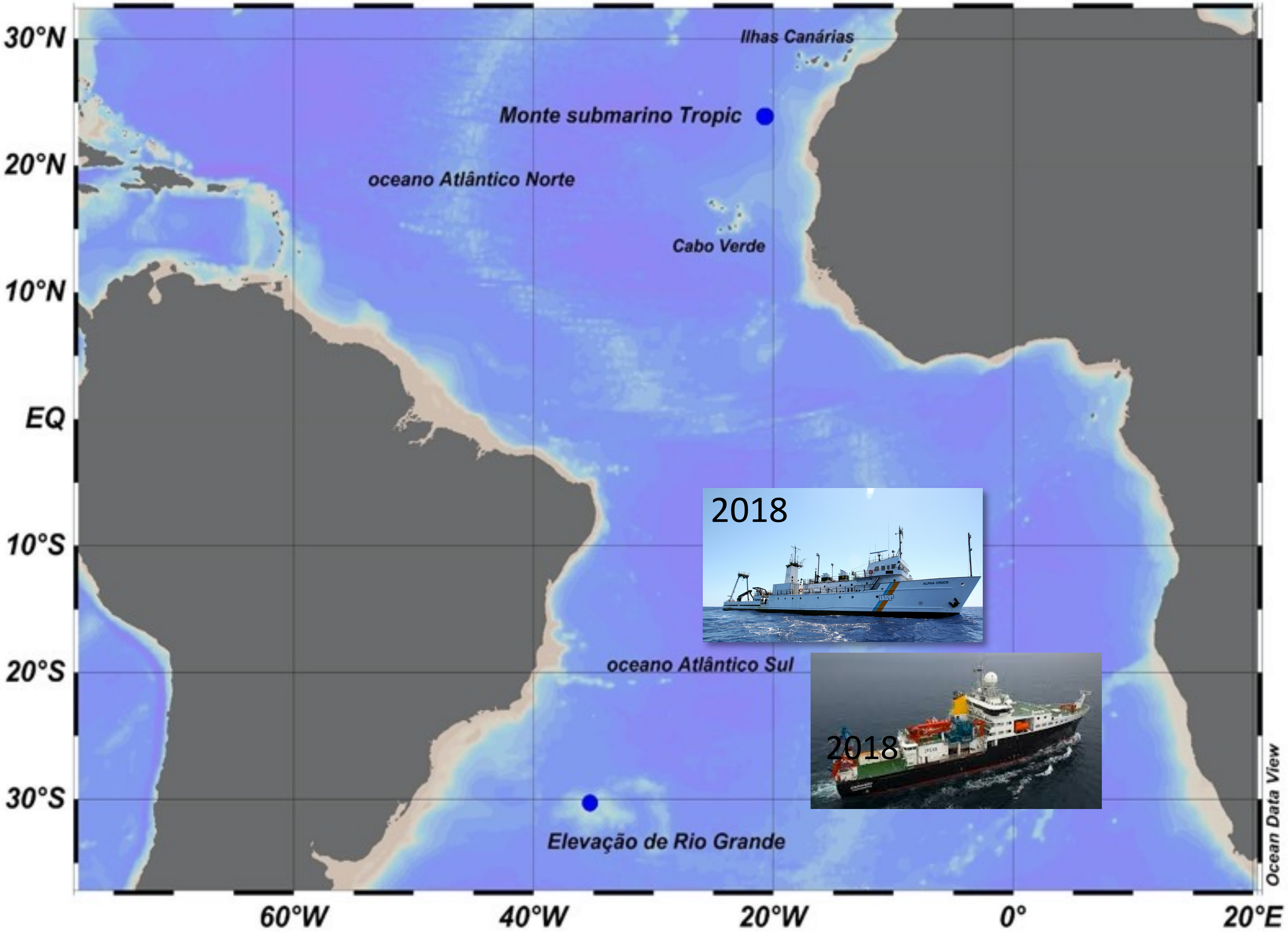


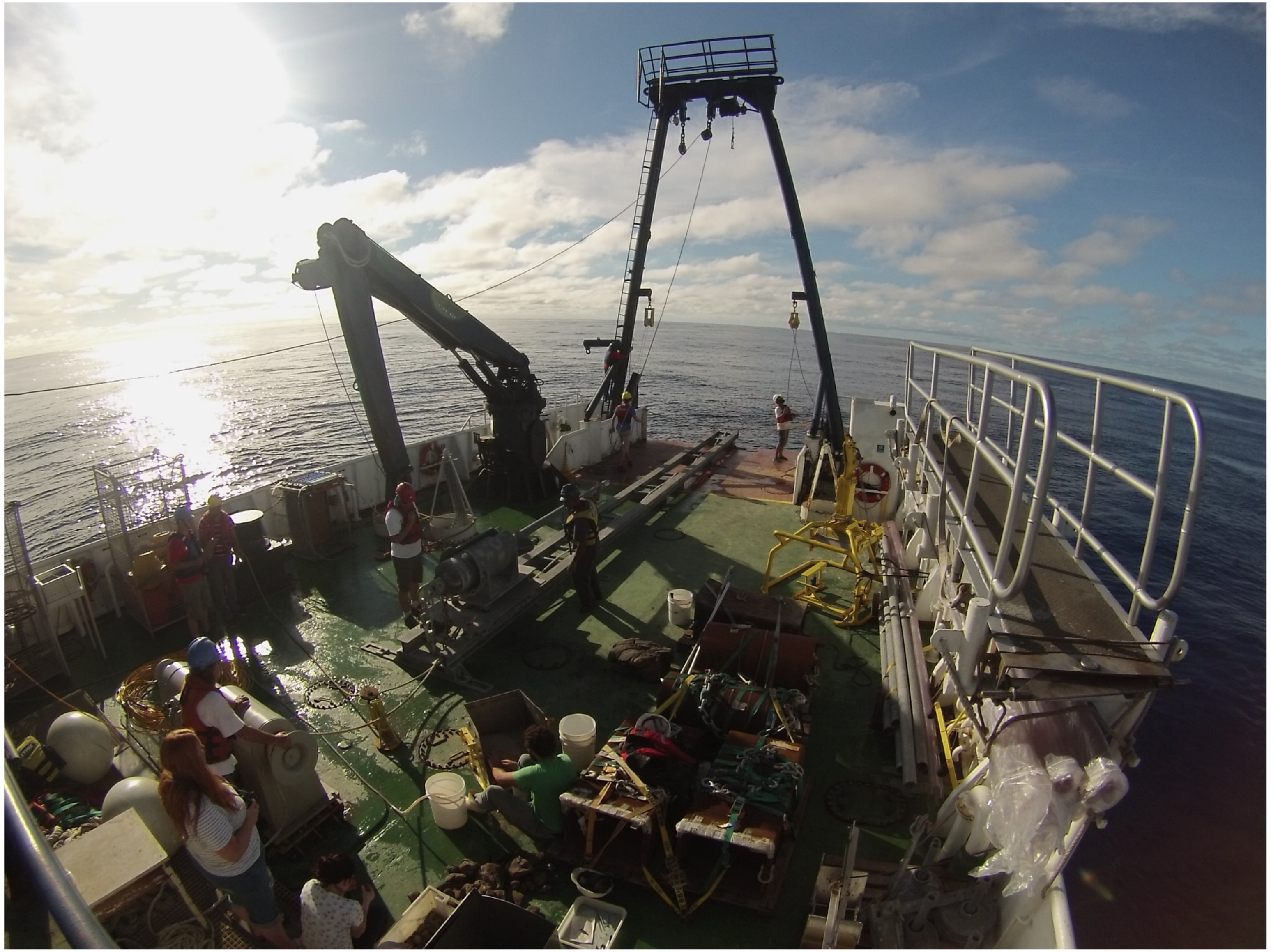
Expedições Oceanográficas na Elevação de Rio Grande



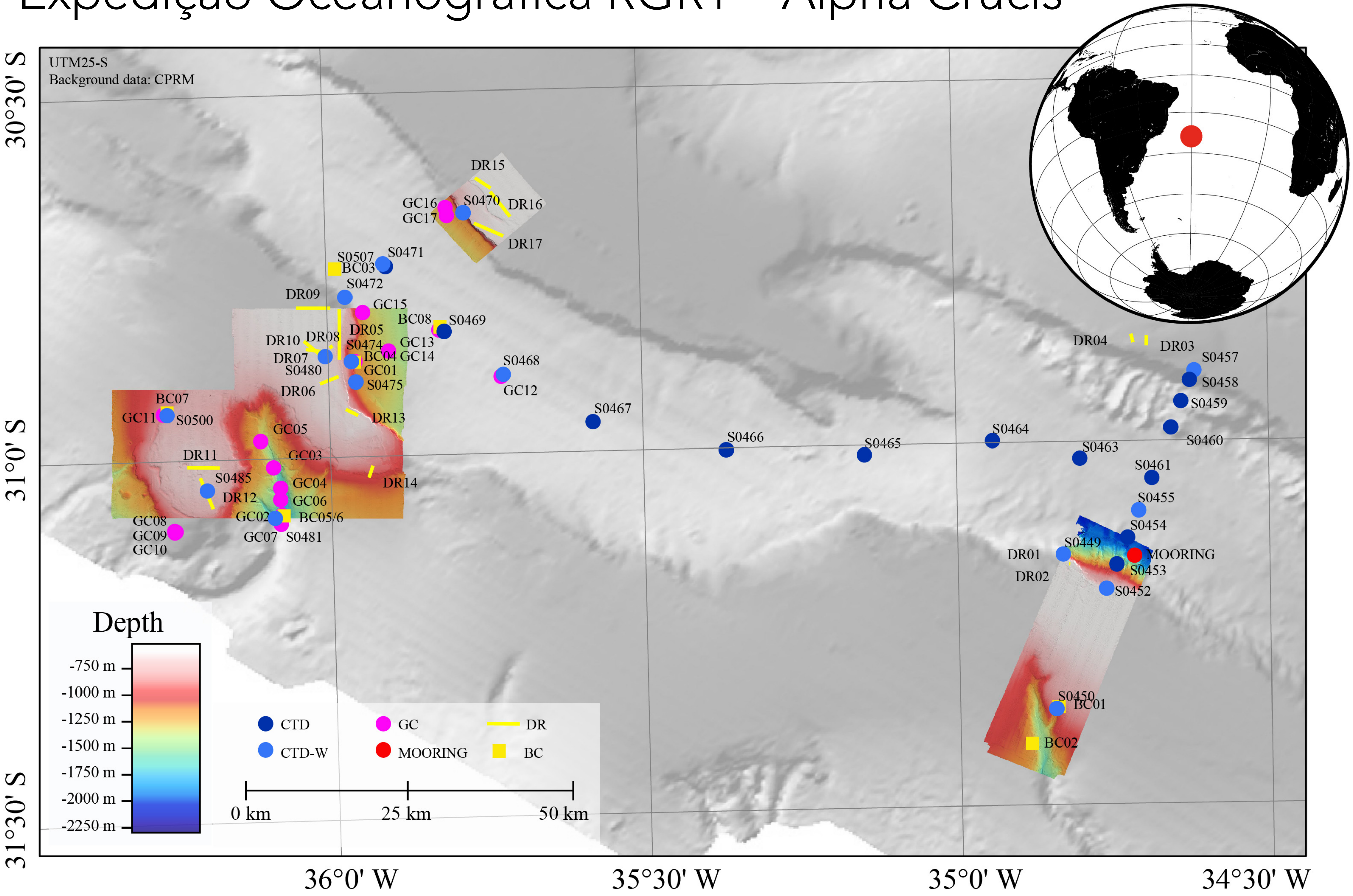
Coletas

Expedição Oceanográfica RGR1 – Alpha Crucis

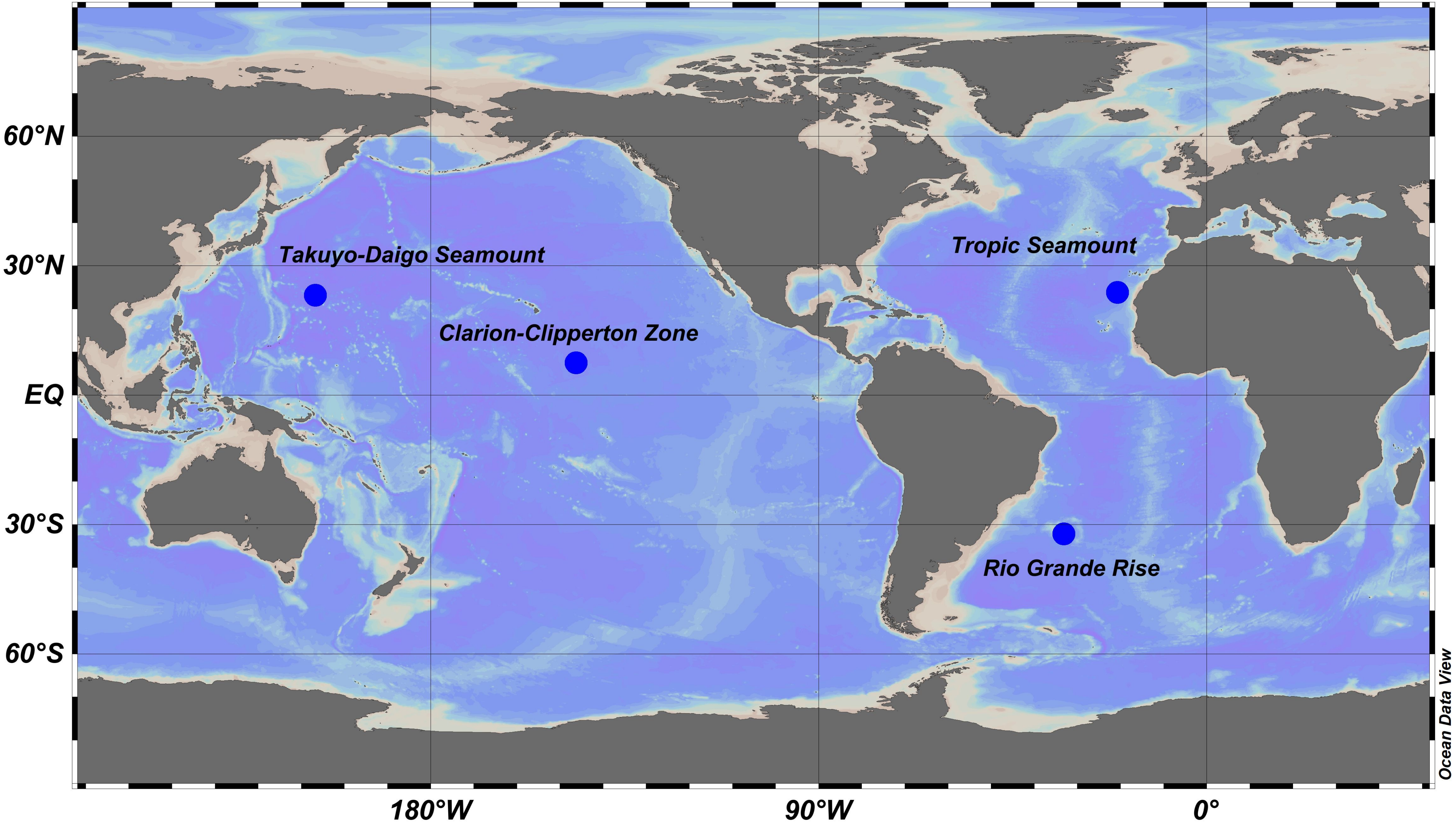
Sedimento
Crosta



Expedição Oceanográfica RGR1 – Alpha Crucis

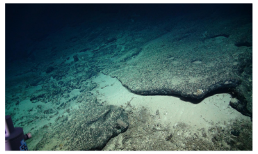


Amostras do Oceano Pacifico - bancos de dados

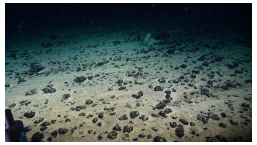


Extração de DNA, sequenciamento e processamento dos dados

1.Extração de DNA



Crosta
Tropic
RGR



Nódulos
Tropic

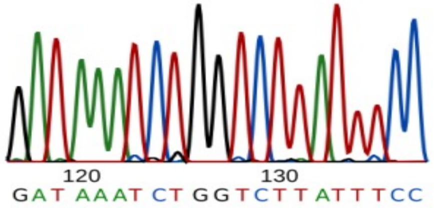
Sedimentos
Tropic
RGR

10 g

2. Amplificação e sequenciamento

illumina Miseq
16S rRNA
515F – 926R

earth microbiome project

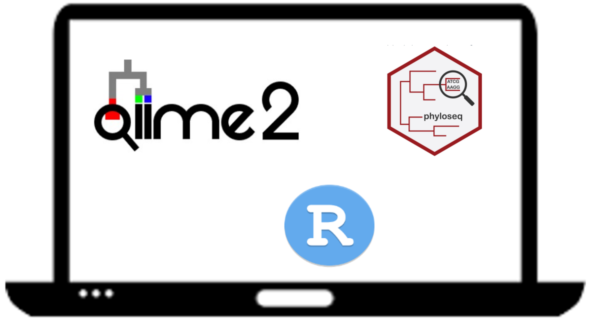


3. Dados de banco de dados

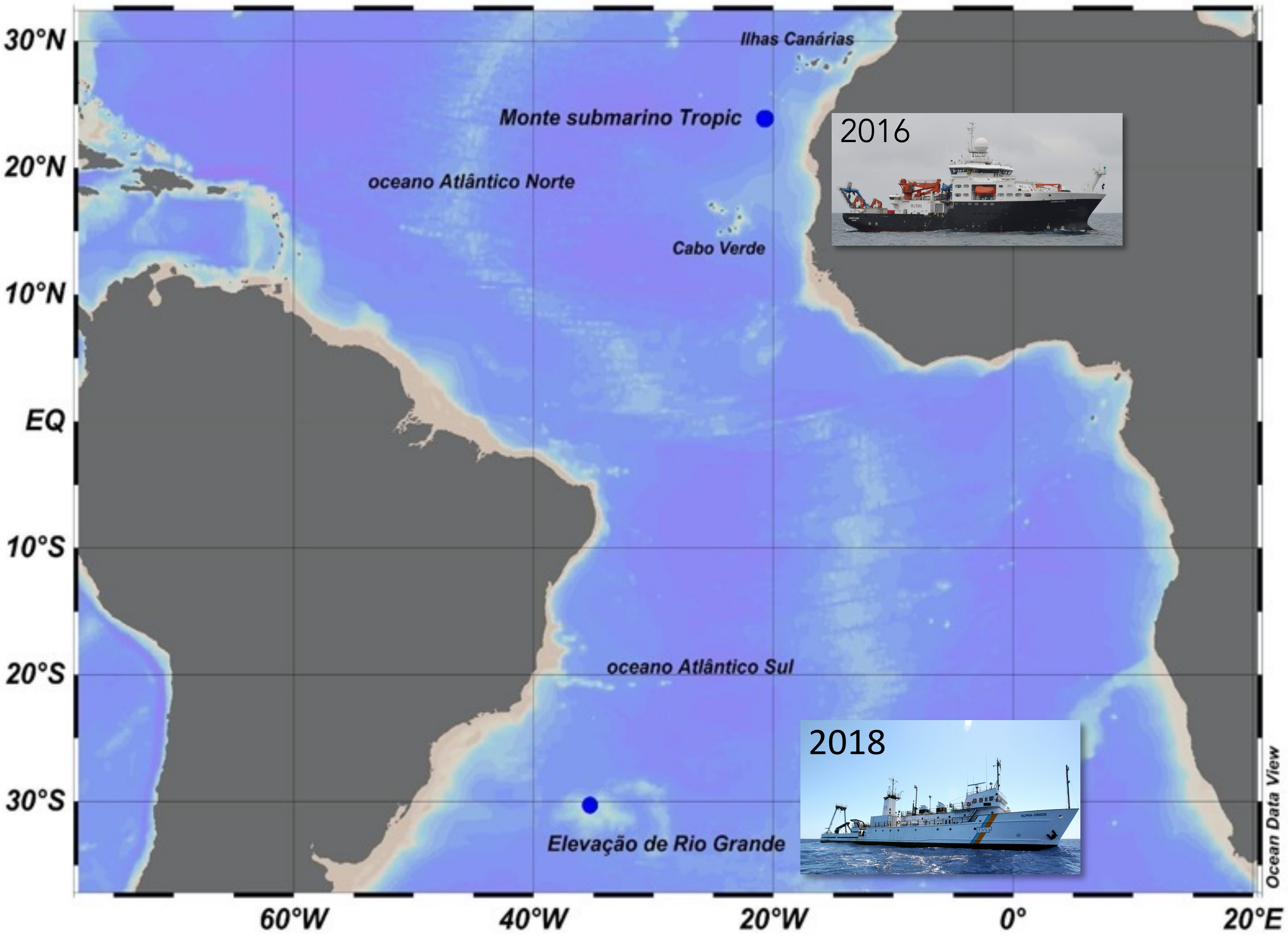
NCBI Clarion-Clipperton Zone | Nódulos
Sedimentos

DDBJ DNA Data Bank of Japan Takuyo-Daigo Seamount | Crosta
Sedimentos

4. Bioinformática



Expedições Oceanográficas – JC142 e RGR1



Conclusões

Estrutura e composição da comunidade microbiana são semelhantes em crostas, nódulos e sedimentos do mesmo Oceano (montes submarinos do Atlântico ou Pacífico), mas diferentes em escala local, uma vez que estão altamente associados às variáveis ambientais e de profundidade

Por outro lado, padrões heterogêneos locais provavelmente enfatizam a importância de características como conteúdo de metal nos substratos de Fe-Mn, profundidades da água, local de amostragem, disponibilidade de nutrientes e dinâmica física na formação de nichos microbianos.

Beta diversidade mostrou uma nítida separação entre sedimentos, e crostas e nódulos, indicando micro habitats diferentes para a vida na RGR e no Trópico.

Crostas e nódulos apresentaram maior abundancia de micro-organismos potencialmente envolvidos nos ciclo dos metais (Pseudomonas, Burkholderiaceae, Colwelliaceae, Alteromonadaceae).

Rio Grande Rise
FAPESP - NERC

LECOM IOUSP
Laboratório de Ecologia Microbiana

CAPES

National Oceanography Centre
NATURAL ENVIRONMENT RESEARCH COUNCIL

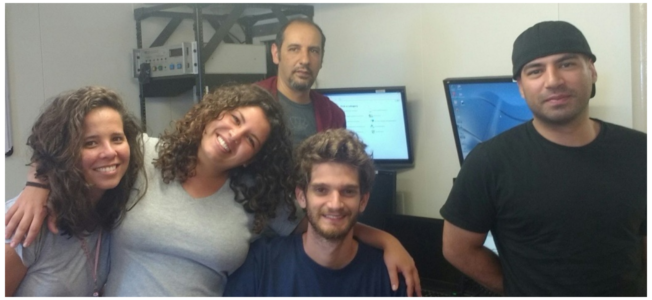
CORE

LABMAR
Laboratório de Biogeoquímica Marinha - IO - USP

FAPESP

UNIVERSIDADE DE SÃO PAULO
IO
Instituto Oceanográfico

Agradecimentos !



Referencias

- An Overview of Seabed Mining Including the Current State of Development, Environmental Impacts, and Knowledge Gaps. doi: 10.3389/fmars.2017.00418
- Global Ocean Mineral Resources - https://www.usgs.gov/centers/pcmsc/science/global-ocean-mineral-resources?qt-science_center_objects=0#qt-science_center_objects
- Deep-Ocean Mineral Deposits: Metal Resources and Windows into Earth Processes - http://elementsmagazine.org/2018/10/01/deep-ocean-mineral-deposits-metal-resources-windows-earth-processes/
- Challenger Expedition - https://www.britannica.com/event/Challenger-Expedition
- The Mining Code - https://www.isa.org.jm/mining-code
- Production key figures for planning the mining of manganese nodules - doi: 10.1080/1064119X.2017.1319448
- https://chinadialogue.net/article/9209-The-bottleneck-of-a-low-carbon-future
- China Water Risk - http://www.chinawaterrisk.org/wp-content/uploads/2016/08/China-Water-Risk-Report-Rare-Earths-Shades-Of-Grey-2016-Eng.pdf
- Hein et al, Deep-ocean polymetallic nodules as a resource for critical materials, 2020. doi: 10.1038/s43017-020-0027-0
- Massive sulphides in smoky depths. https://worldoceanreview.com/en/wor-3/mineral-resources/massive-sulphides/
- Marine Geoscience - https://wwz.ifremer.fr/gm_eng/Understanding/Public-authorities-support/Deep-Sea-Mineral-Resources/Sulfides
- Mission Blue - https://mission-blue.org/2013/07/deep-sea-mining-%E2%88%92-the-pacific-experiment/
- Woods Hole - https://www.whoi.edu/oceanus/feature/vent-shrimp-symbiosis/
- Mineral resources - https://worldoceanreview.com/en/wor-3/mineral-resources/cobalt-crusts/
- Tagliabue et al. The integral role of iron in ocean biogeochemistry. Doi: 10.1038/nature21058
- Rogich et al. The Global Flows of Metals and Minerals. https://pubs.usgs.gov/of/2008/1355/pdf/ofr2008-1355.pdf
- Kato et al,. Microbial metabolisms in an abyssal ferromanganese crust from the Takuyo-Daigo Seamount as revealed by metagenomics. Doi: 10.1371/ journal.pone.0224888
- Jessica Aldred, The future of deep seabed mining. https://chinadialogueocean.net/6682-future-deep-seabed-mining/