The ocean, the hadal zone and the climate

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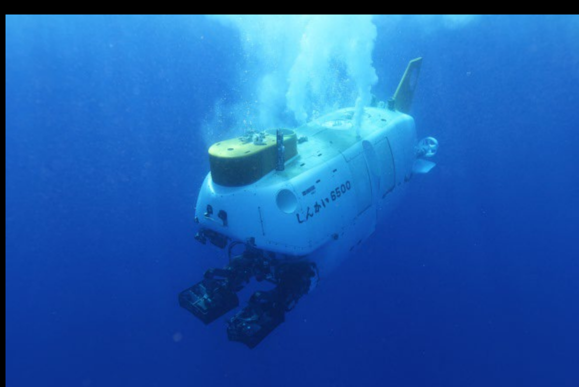
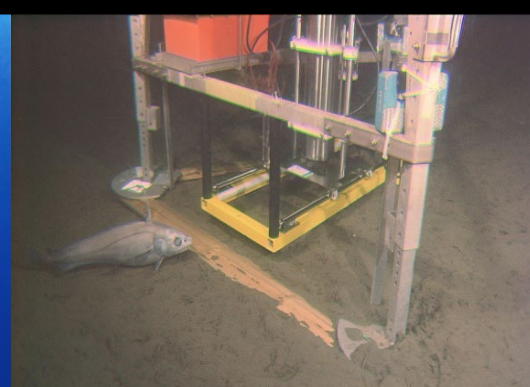
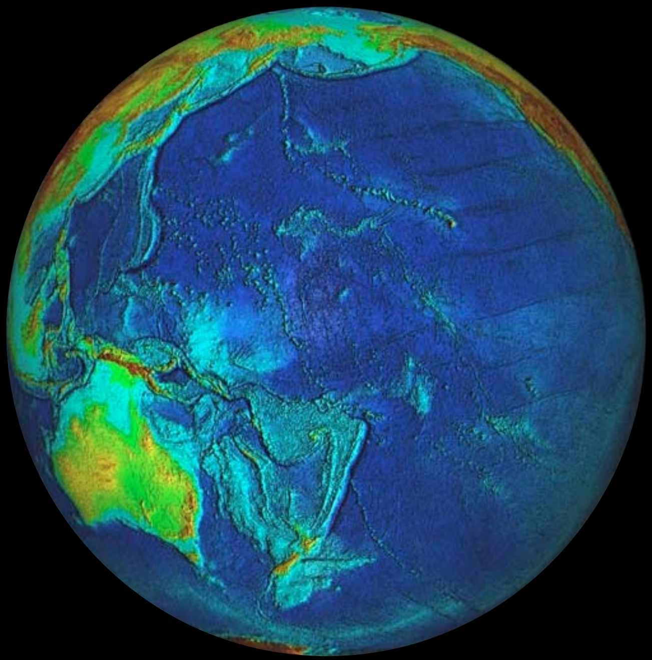
Danish Center for Hadal Research

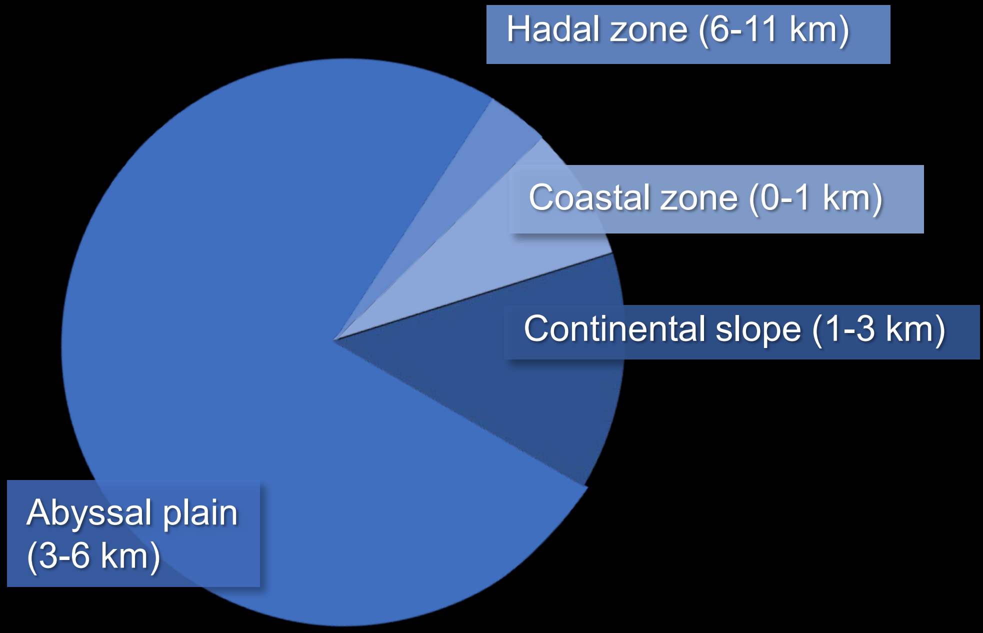
Mission: *Define the biogeochemical and the biological function, importance and diversity of the hadal realm, adding these unique high-pressure environments to current understanding of the global ocean.*





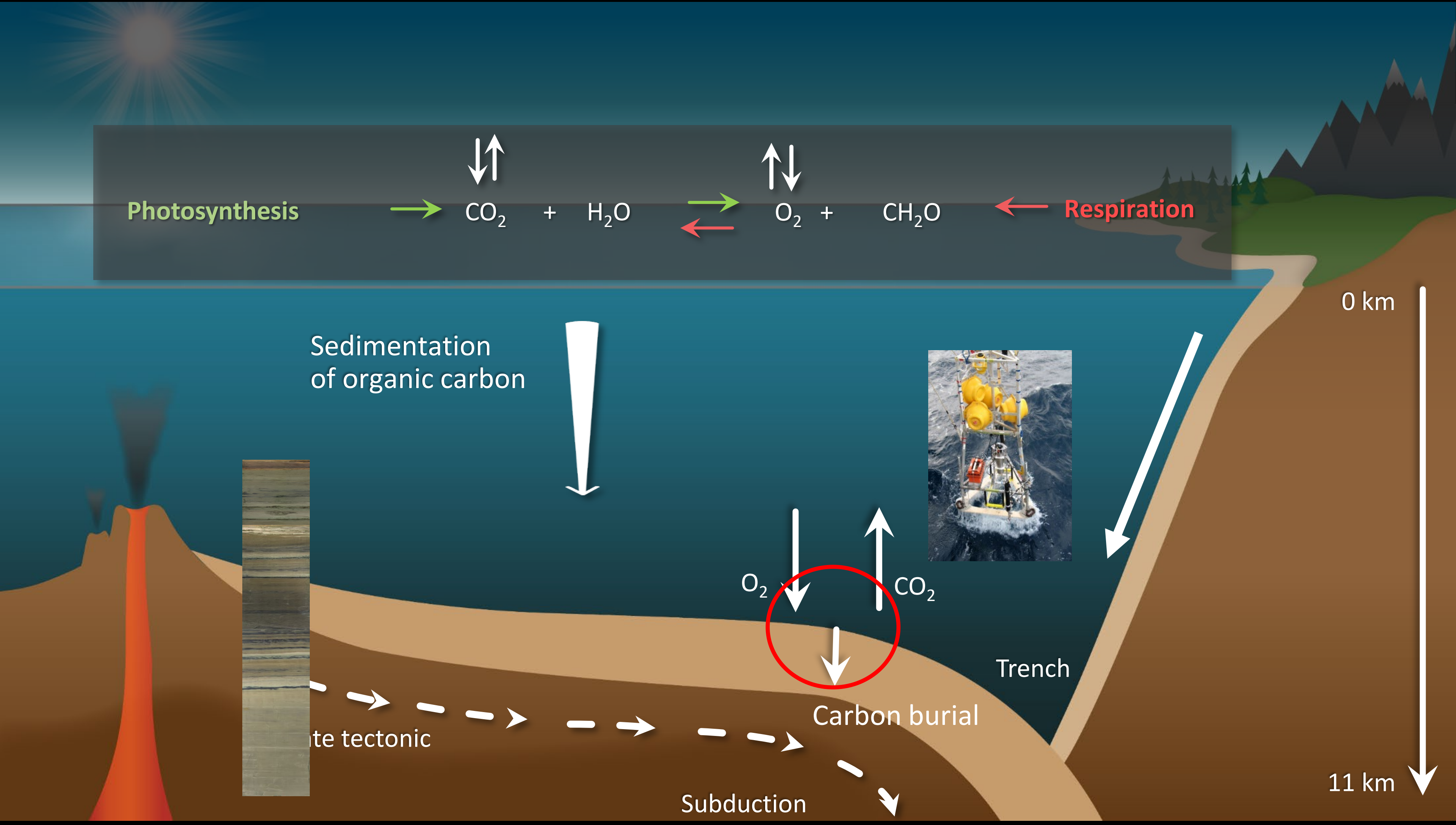
The deep ocean covers most of planet Earth



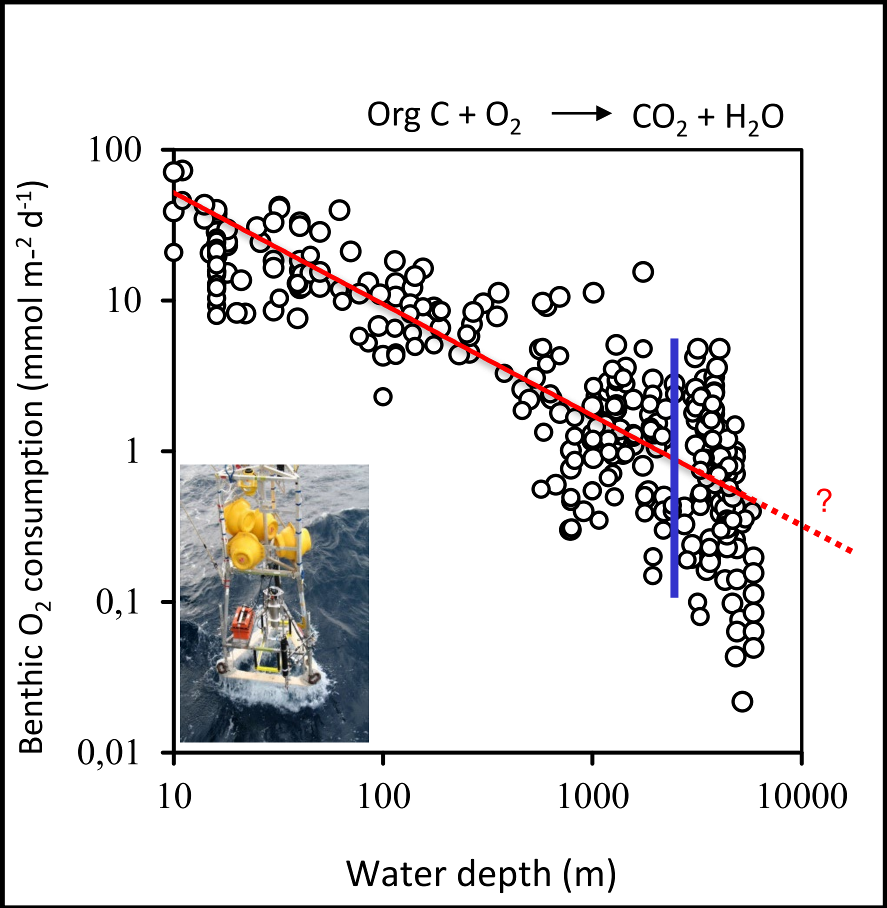


The average ocean depth is 3.8 km

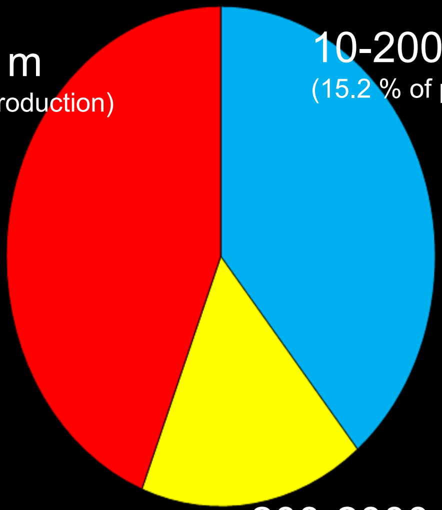
Bathymetry and material deposition in the deep ocean



Large scale gradients and global data base



Total 1.52 Gt C yr^{-1}



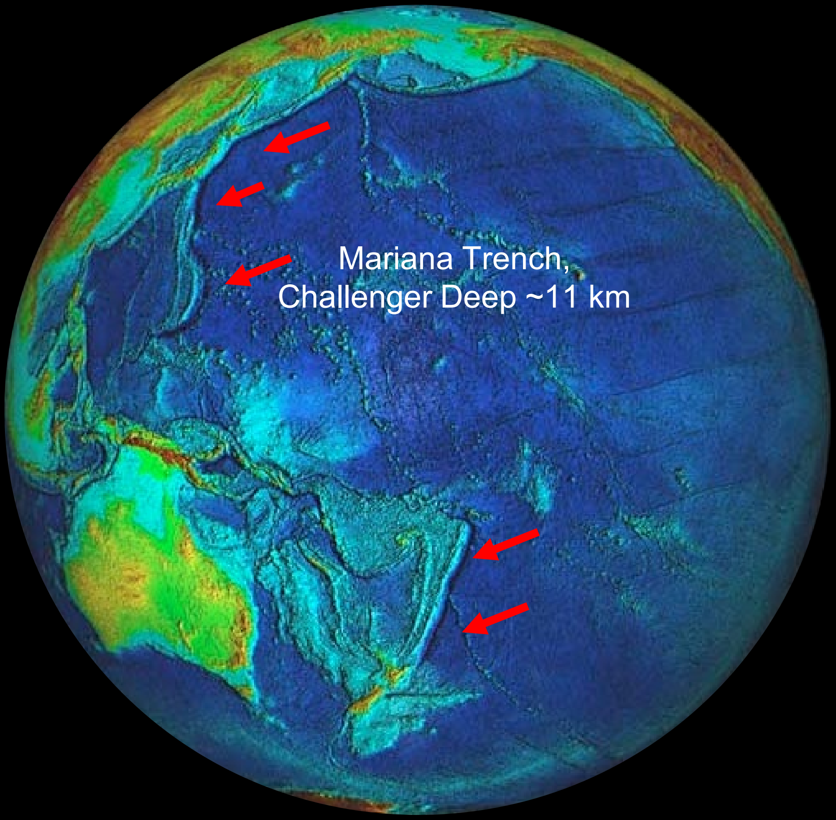
Global benthic mineralization 1.52 Gt C yr^{-1}

3.3% of global pelagic primary production

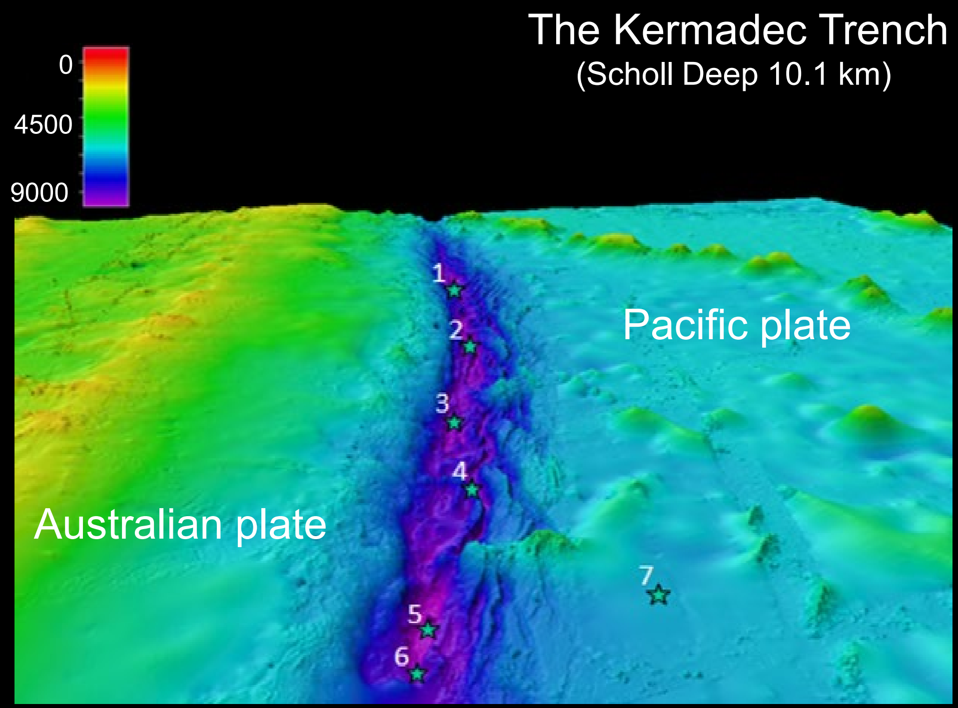
(ca 12% of global emission)

Glud (2008)

Large scale “sea-scape” effects - Seamounts & Hadal trenches



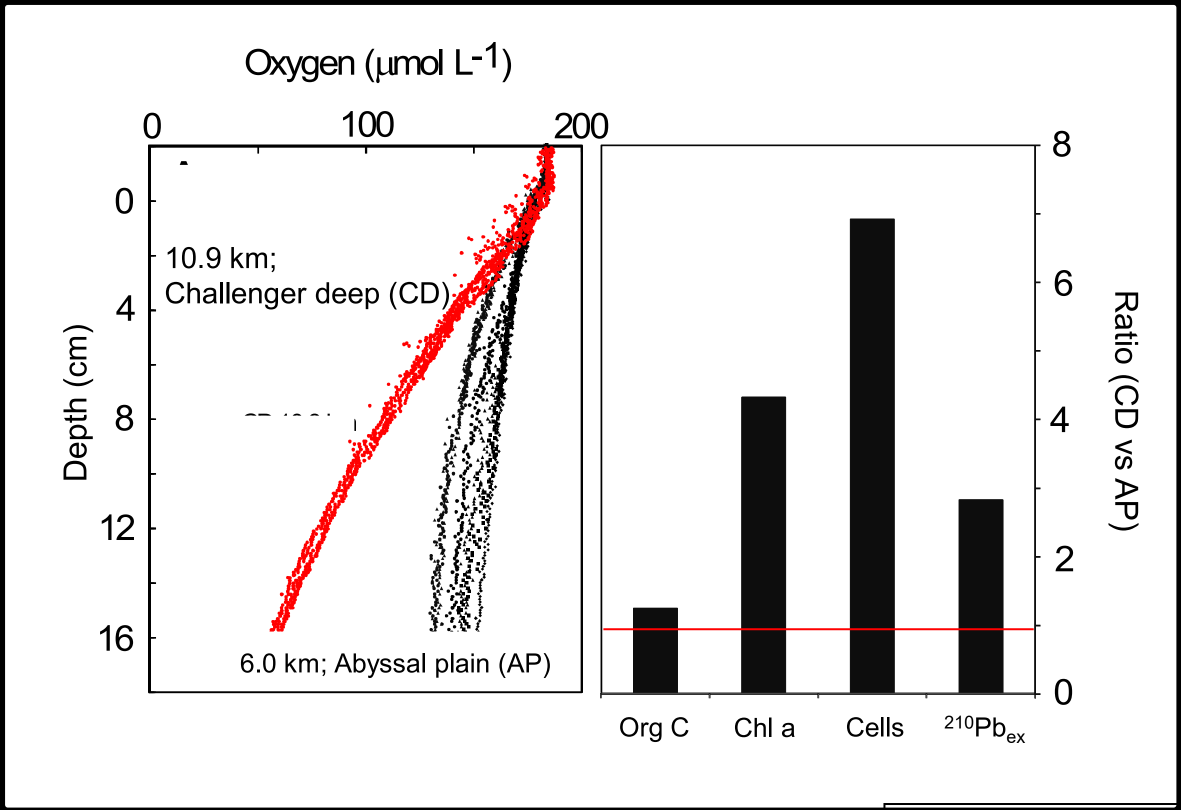
Hadal trenches



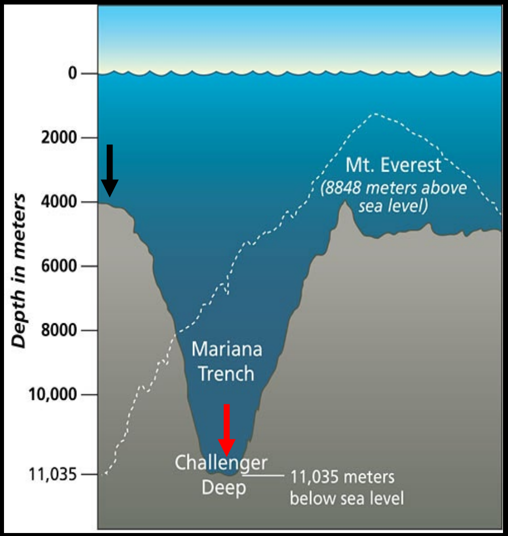
Hadal realm cover 3.800.000 km^2 and is dominated by 37 large trenches

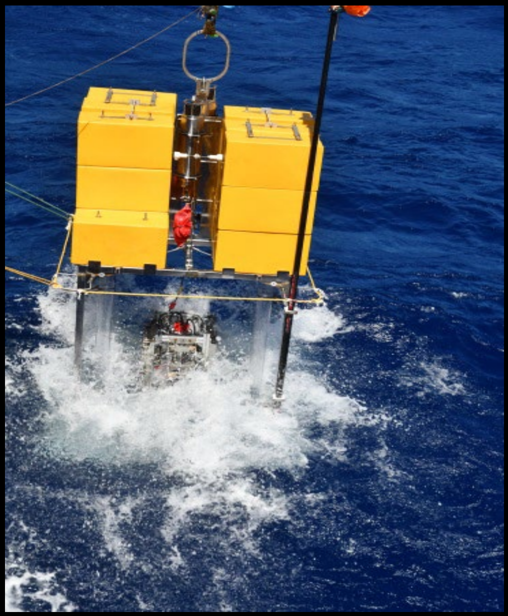
Once believed to be deprived of life….. but act as depoenters and hot spots for biological activity and element cycling mediated by life that flourish at extreme hydrostatic pressure

Hadal trenches; hot spots for deposition and mineralization of organic material?



Glud et al (2013)

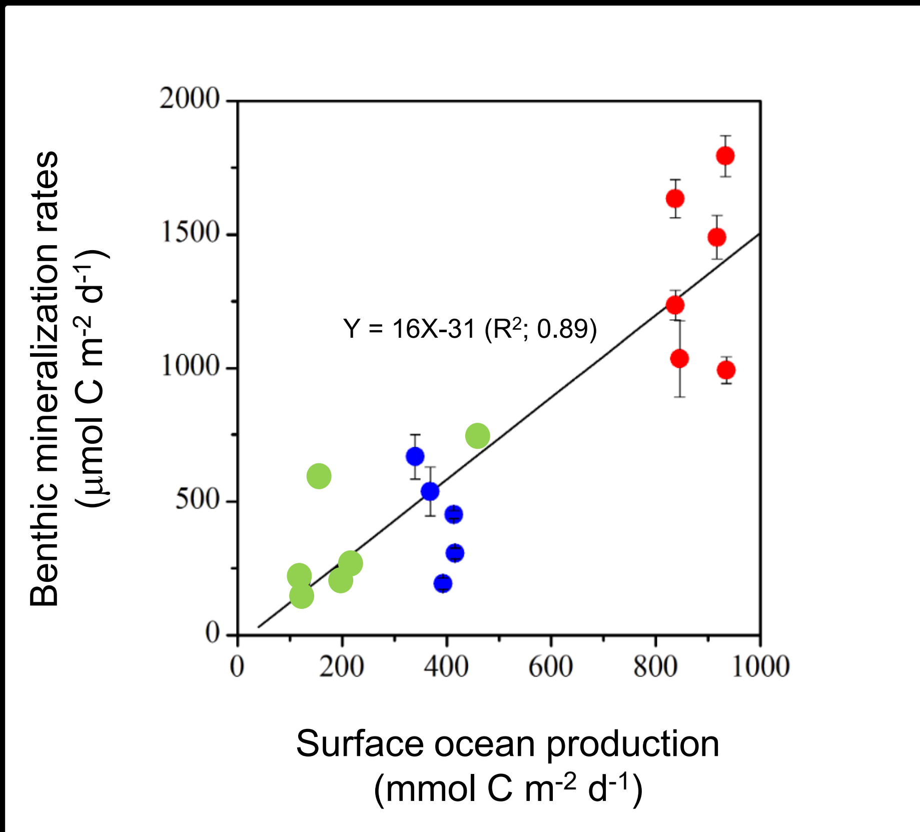


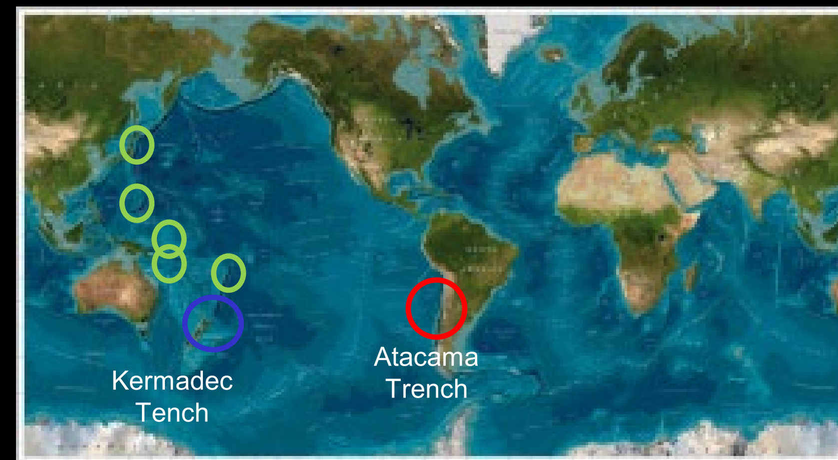


Hadal trench sediments have **2 – 8** times higher biological activities than adjacent abyssal sites

(Mariana, Tonga, Kermadec, Atacama, Puysegur Trench)

Benthic mineraization rates in hadal trenches





Surface production affect life and element cycling at the greatest depths

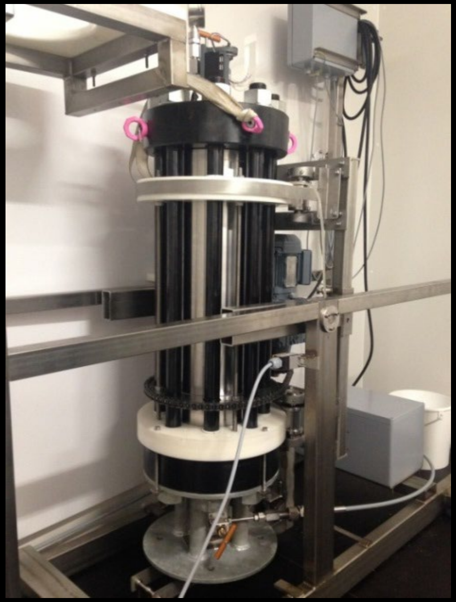
Large spatial variation within trenches

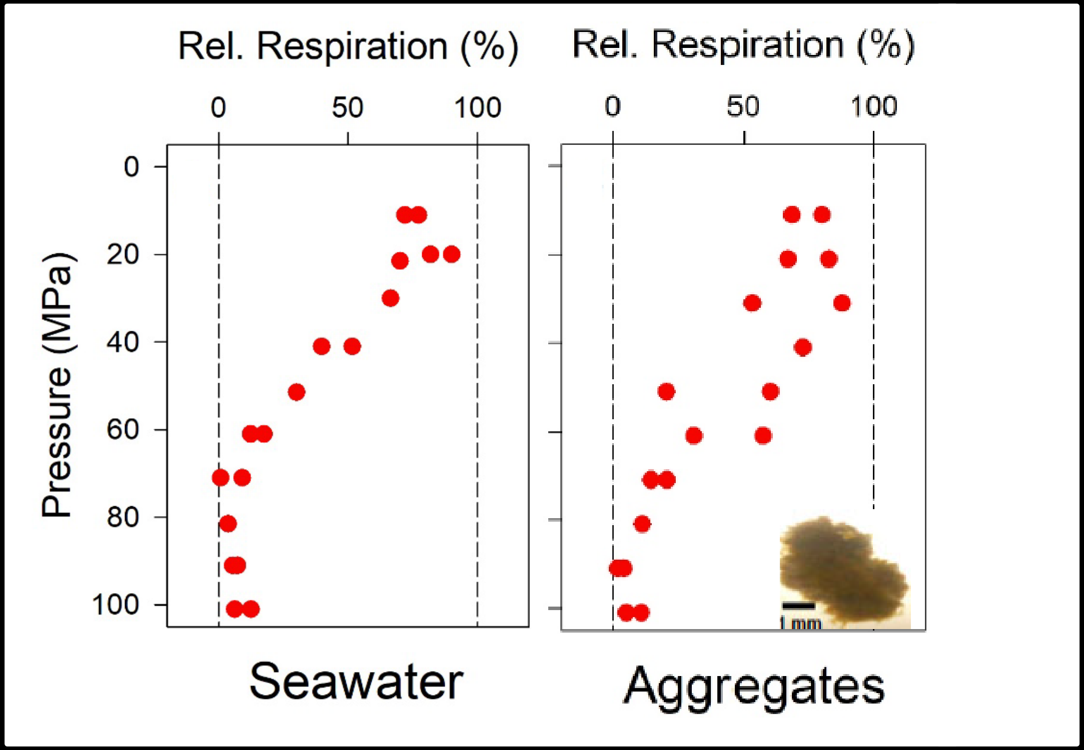
High deposition rates !

Wenzöfer et al 2016, Luo et al 2017

, Glud et al 2021

Sinking marine snow and hydrostatic pressure



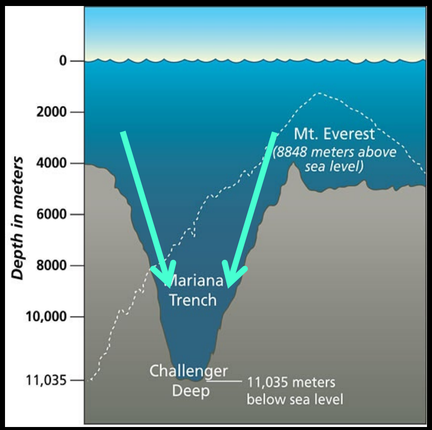


Stief et al 2021

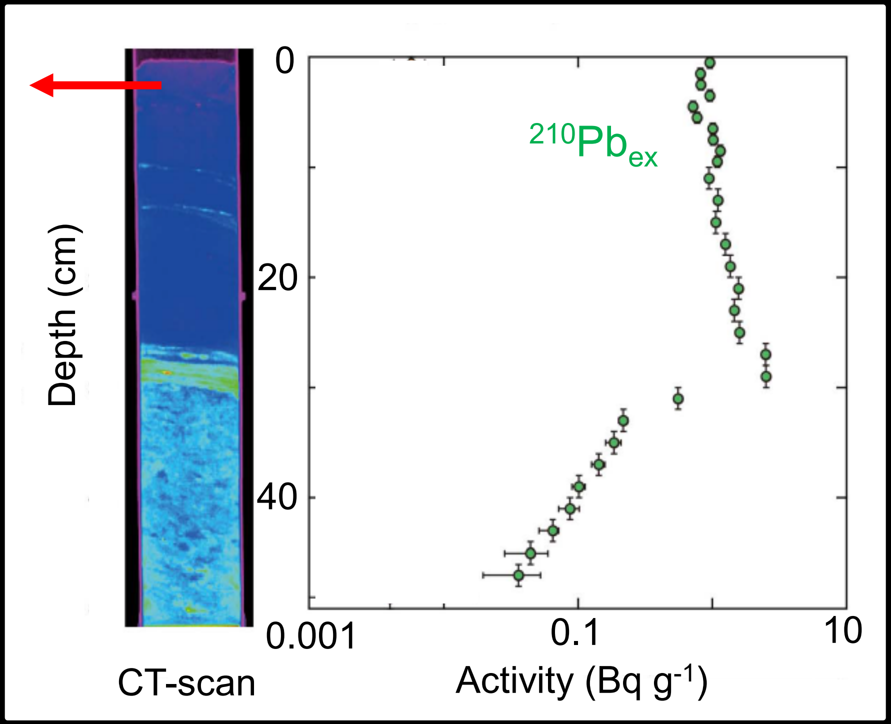
Zooplankton carcasses, fecal pellets and long-term sinking experiments provide similar results

Stief et al 2023
Cisterna et al 2024

Mass wasting events in trench systems (Tohoku-Oki earthquake 2011)

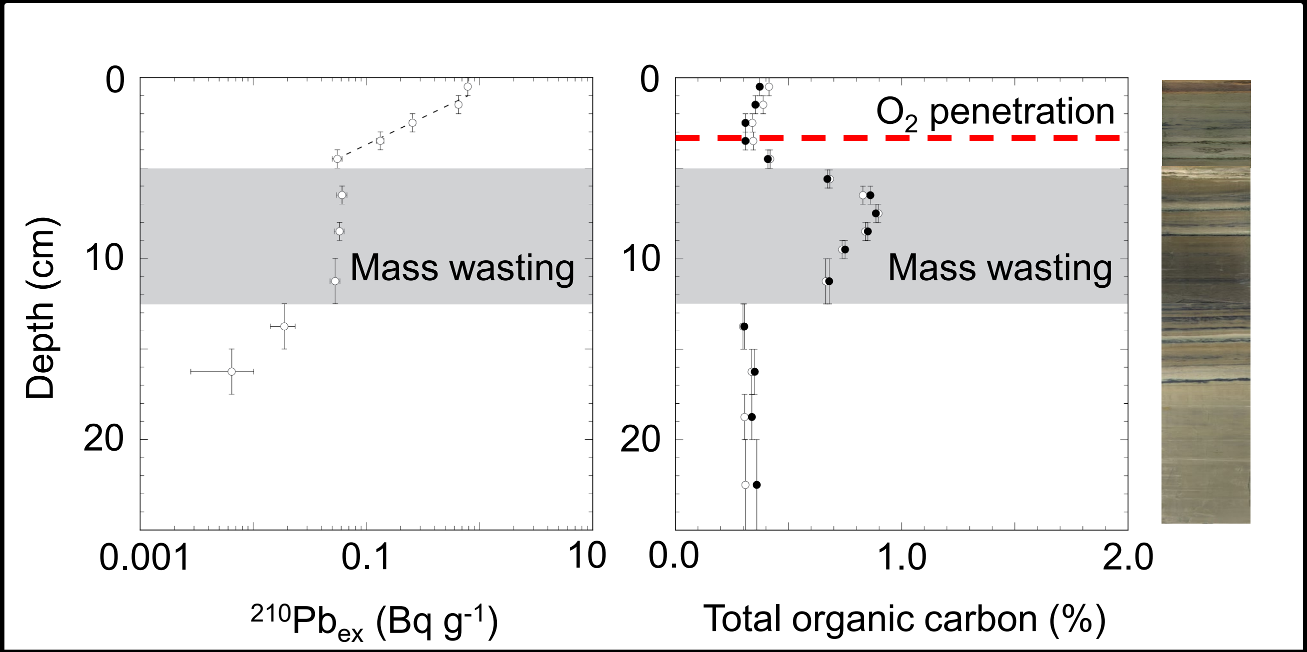


Carbon enriched sediment



Oguri et al 2013

Mass wasting events in trenches – Atacama Trench



Oguri et al 2022

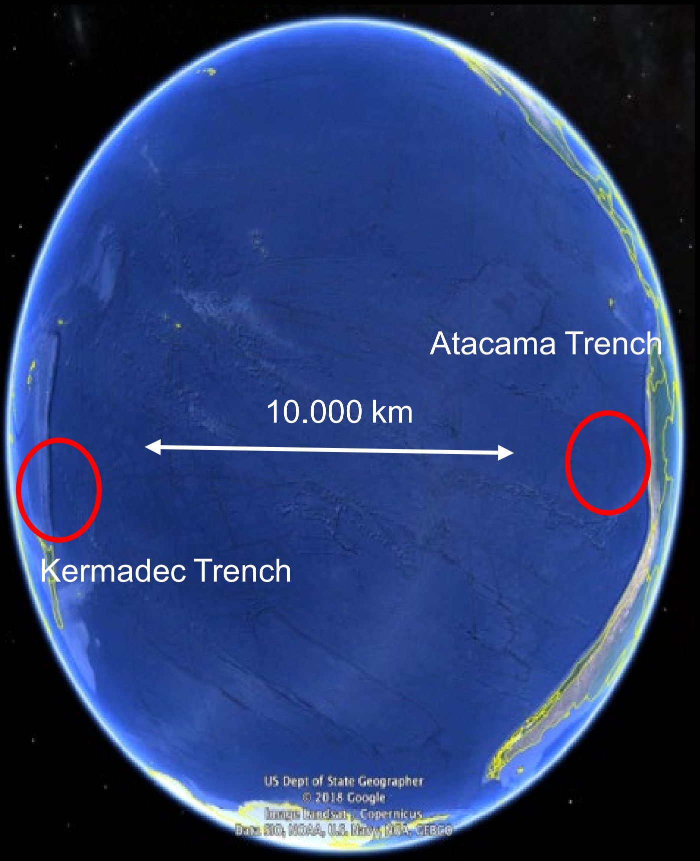
Sediment accumulation 1929 -2018; 0.35 mm yr^{-1} (1.3 gC m^{-2} yr^{-1})

Earthquake induced, mass wasting 1929; 8 cm (296 gC m^{-2})

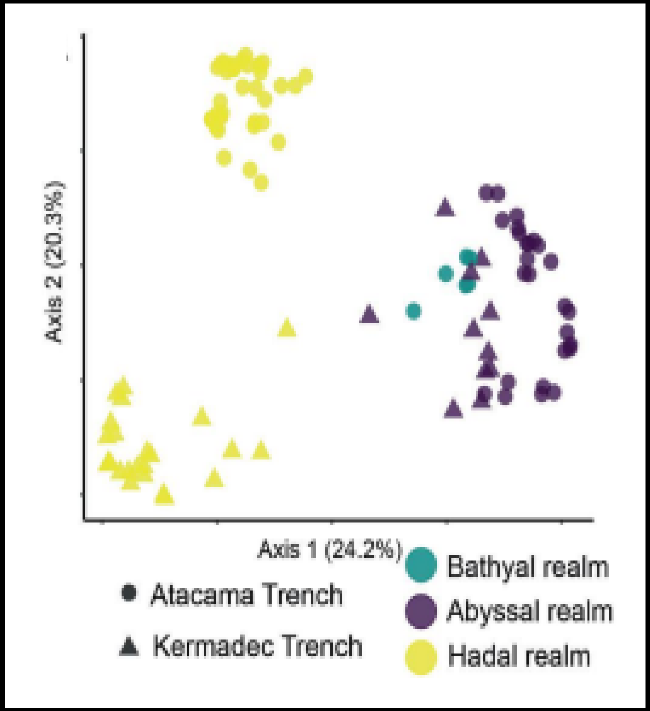
Average carbon burial rate along trench axes ~70X that of the deep sea average – per m^2

(Atacama, Kermadec, Mariana, Kuril-Kamchatka)

Are hadal microbes distinct from abyssal microbes – between trenches?



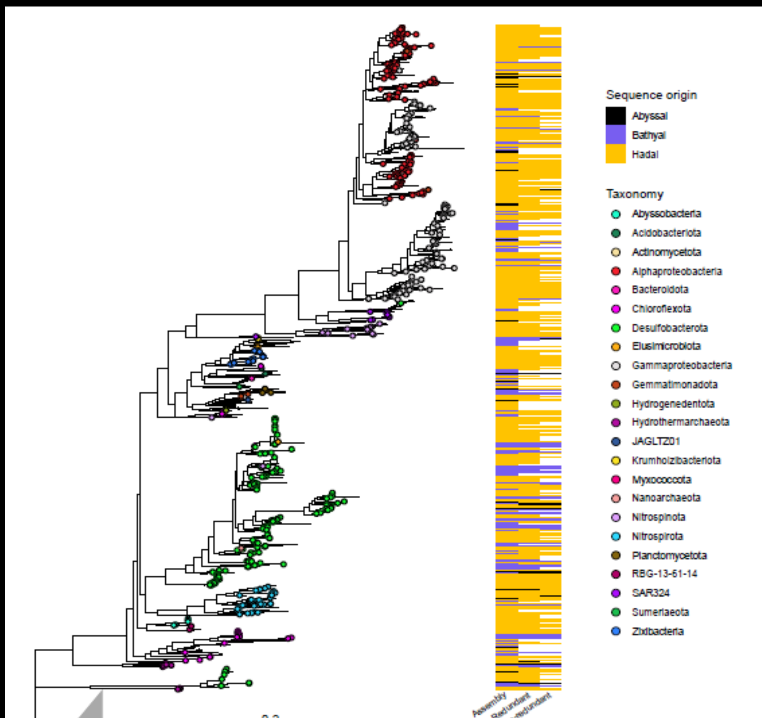
PCoA's of 16S rRNA genes -Oxic zone only



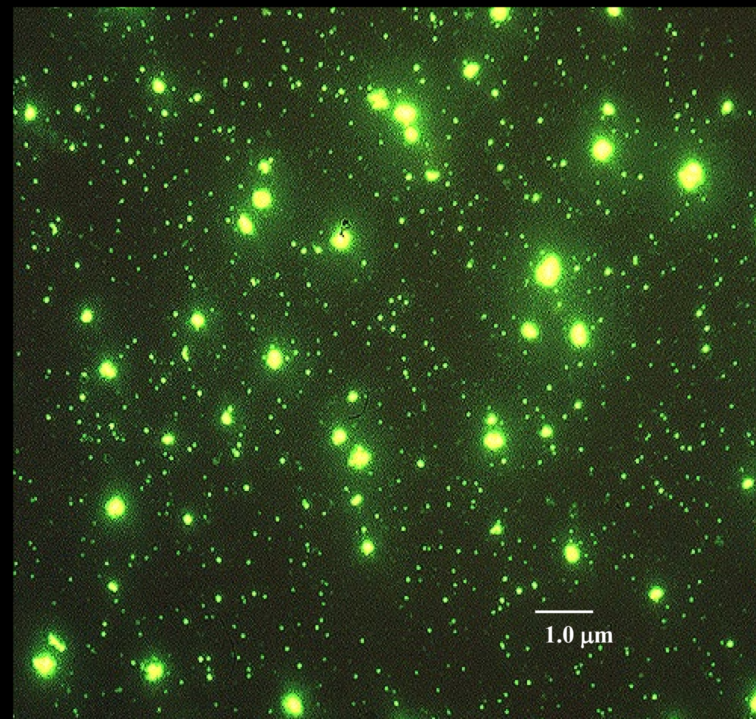
Schauberger et al 2021a, 2021b, 2024

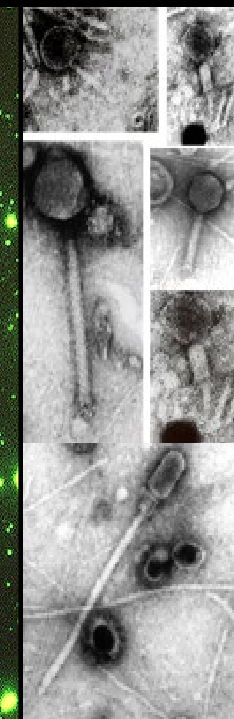
Who are the hadal microbes ?

IQTree of dsr B sequences in Atacama– hadal hits are indicated



Yen-Ting et al in review





Middelboe et al 2025
Traving et al in Prog

Macro and megafauna in the Atacama trench

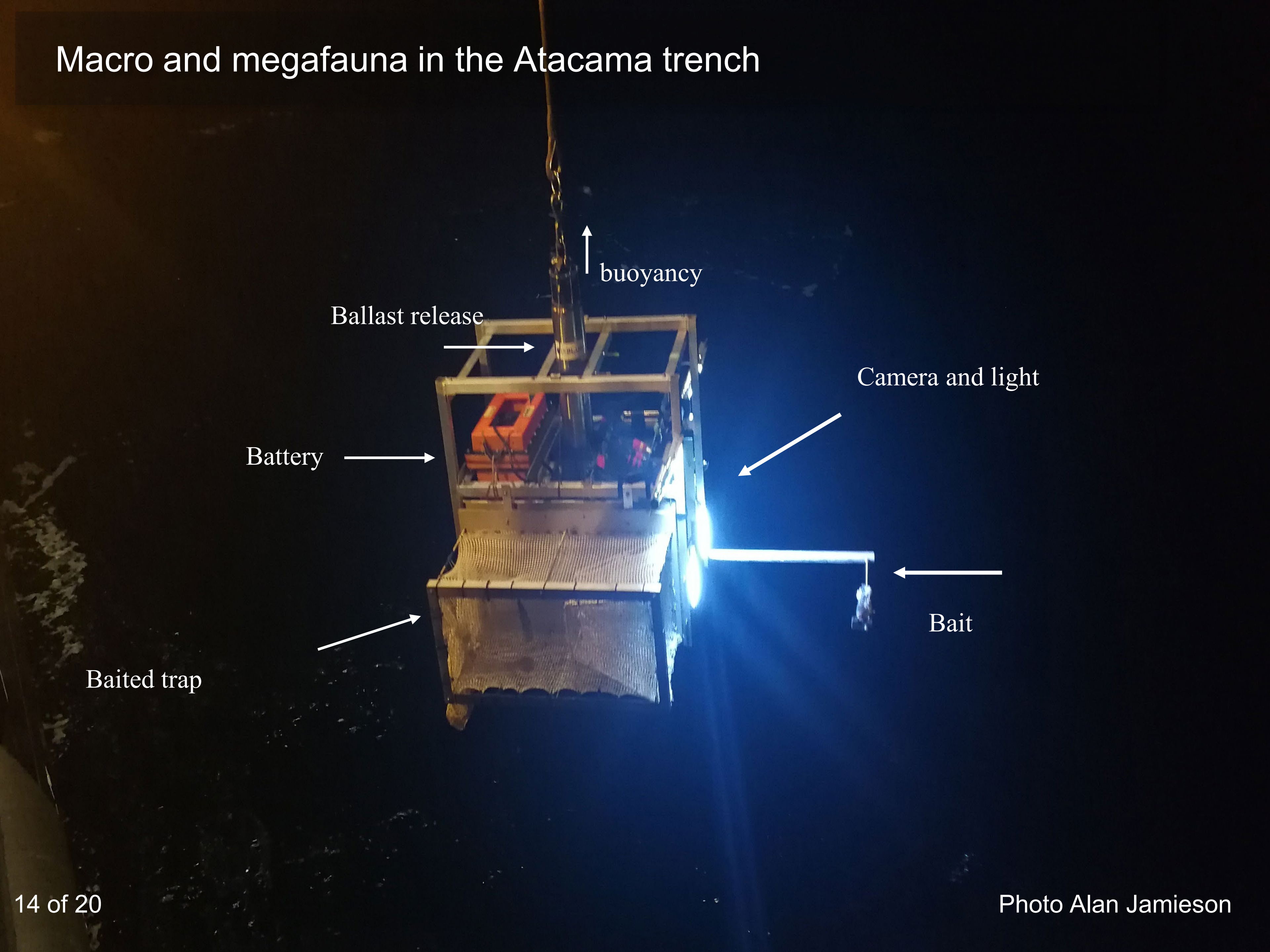
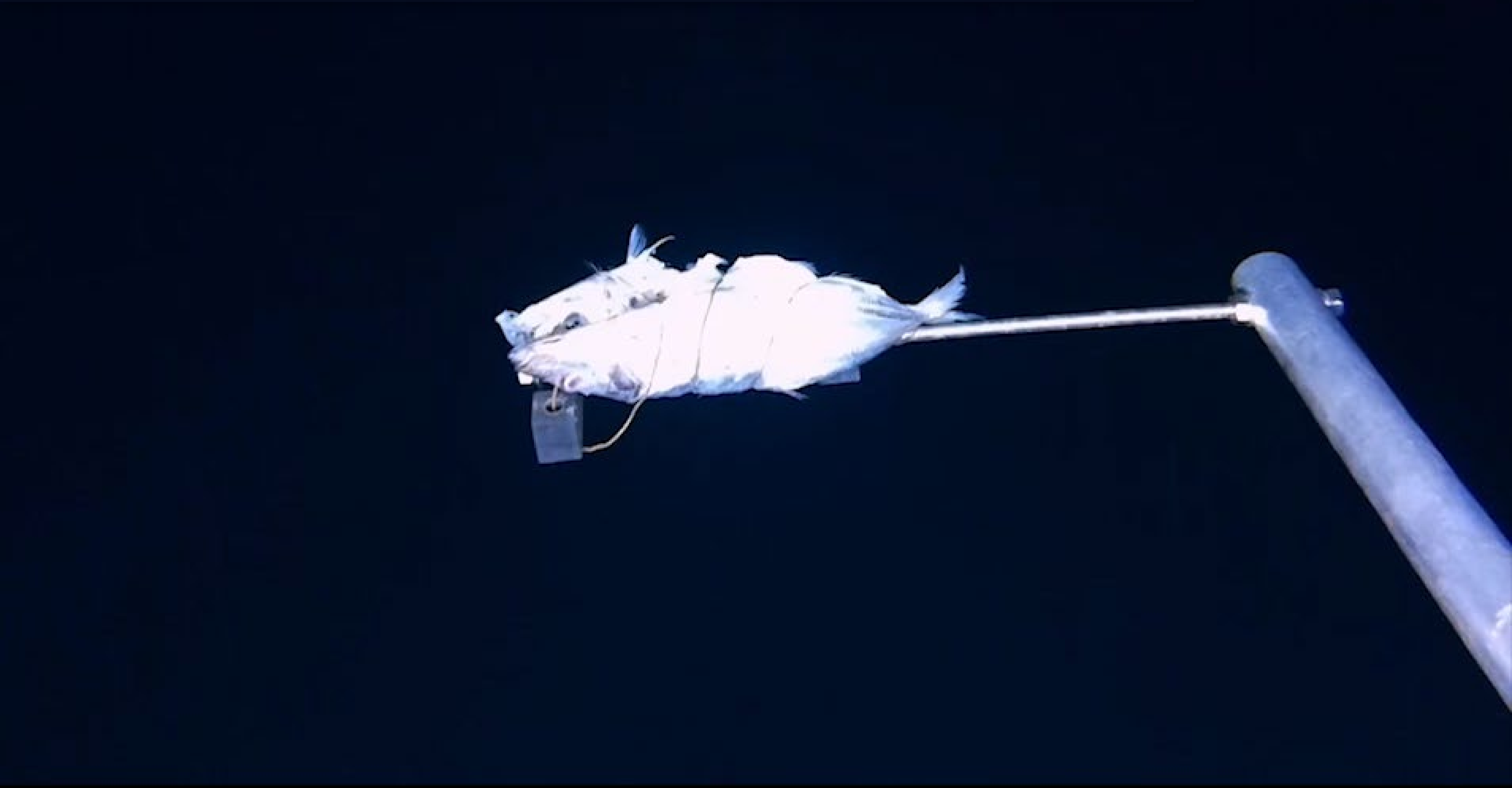
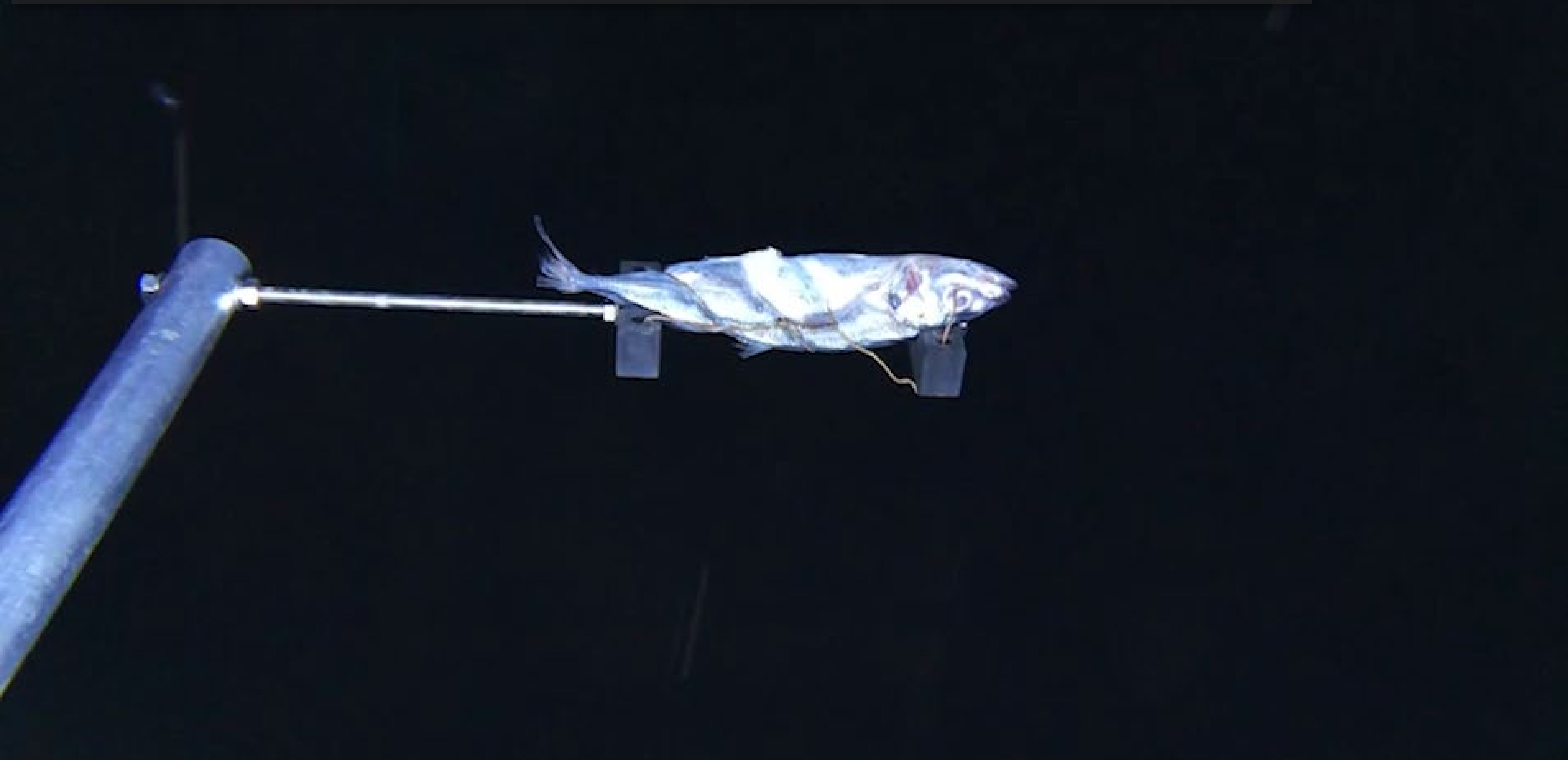


Photo Alan Jamieson

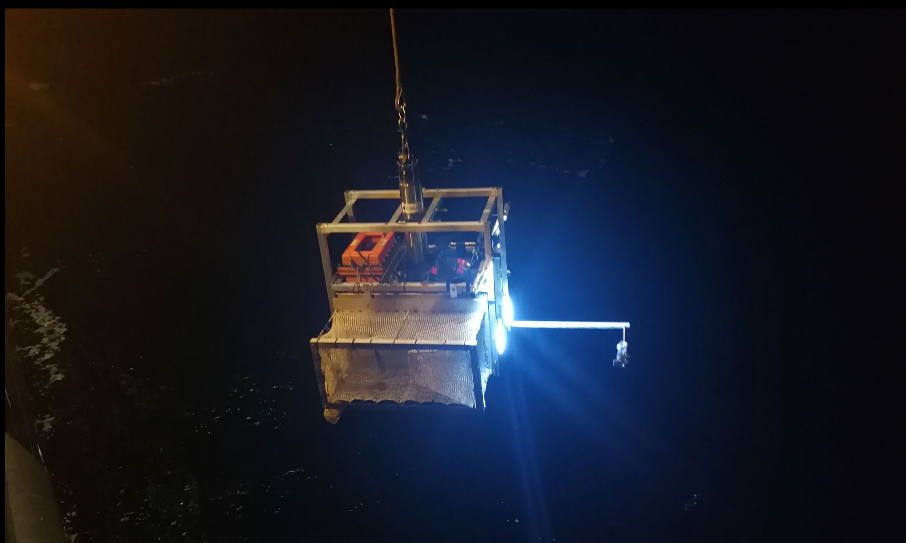
Abyssal plain adjecent to the Atacama Trench: 4.053 m
12 h timelab (Linley & Jamieson)



Atacama Trench: 6.980 m
12 h timelab (Linley & Jamieson)



Amphipods a conspicuous element of hadal trenches



Photos Alan Jamieson & Ashley A Rowden

Hadal trenches depo centers for pollutants

nature ecology & evolution

BRIEF COMMUNICATION

PUBLISHED: 13 FEBRUARY 2017 | VOLUME: 1 | ARTICLE NUMBER: 0051

Bioaccumulation of persistent organic pollutants in the deepest ocean fauna

Alan J. Jamieson[1*†], Tamas Malkocs[2], Stuart B. Piertney[2], Toyonobu Fujii[1] and Zulin Zhang[3]

Jamieson et al 2017

scientific reports

Check for updates

OPEN **High mercury accumulation in deep-ocean hadal sediments**

Hamed Sanei[1], Peter M. Outridge[1,2,3], Kazumasa Oguri[4,5], Gary A. Stern[3], Bo Thamdrup[5], Frank Wenzhöfer[5,6,7], Feiyue Wang[3] & Ronnie N. Glud[5,8,9]

Sanei et al 2021

20-50 times higher Hg-enrichment in hadal sediments as compared to the average of deep sea sediments

Environmental Science & Technology LETTERS

pubs.acs.org/journal/estlcu Letter

Methylmercury Bioaccumulation in Deepest Ocean Fauna: Implications for Ocean Mercury Biotransport through Food Webs

Maodian Liu,[⊥] Wenjie Xiao,[⊥] Qianru Zhang, Linlin Shi, Xuejun Wang,* and Yunping Xu*

Cite This: https://dx.doi.org/10.1021/acs.estlett.0c00299 Read Online

Liu et al 2020

nature communications

Article https://doi.org/10.1038/s41467-023-37718-z

Organic matter degradation causes enrichment of organic pollutants in hadal sediments

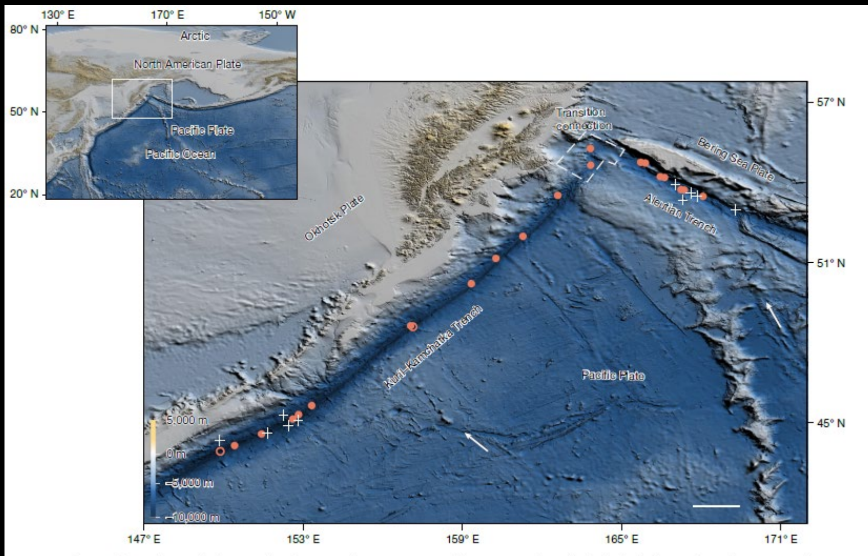
Received: 17 November 2022

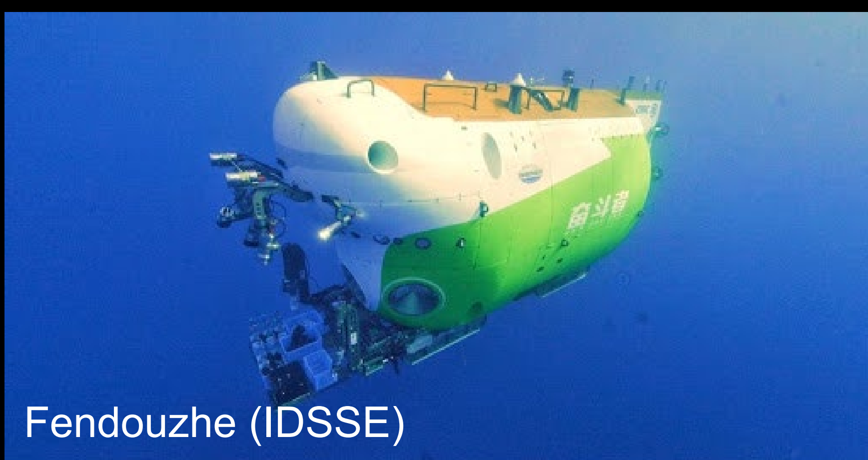
Accepted: 28 March 2023

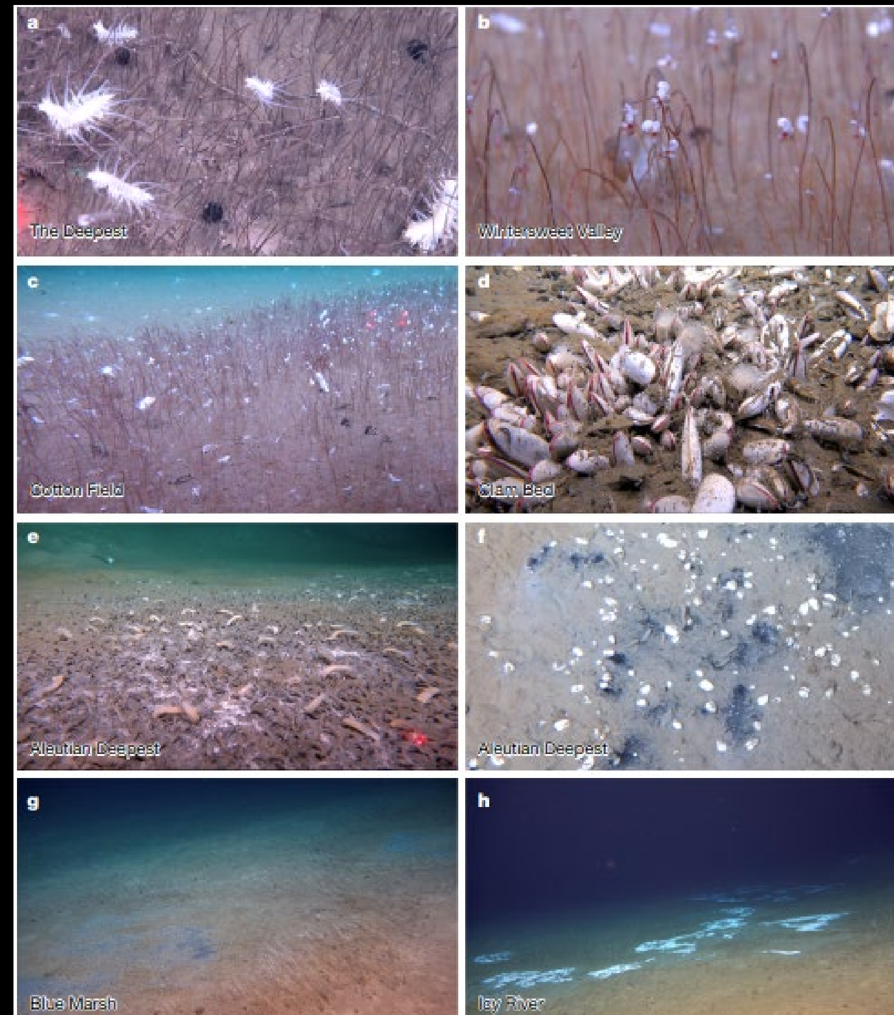
Anna Sobek[1], Sebastian Abel[1], Hamed Sanei[2], Stefano Bonaglia[3], Zhe Li[1], Gisela Horlitz[1], Arka Rudra[2], Kazumasa Oguri[4,5] & Ronnie N. Glud[4,6,7]

Søbek et al 2023

New chemosynthetic communities – thriving at 9.5 km depth !







Peng et al 2025

Take home messages: Trenches are different

1) **Hadal trenches act as depocenters with high sediment accumulation, carbon sequstration – and inventories of pollutants**

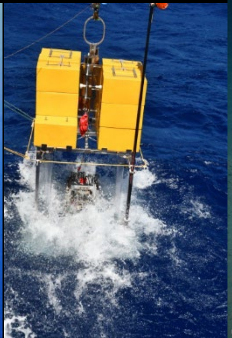
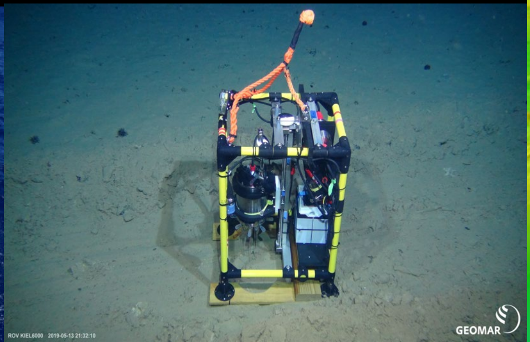
But at the same time…

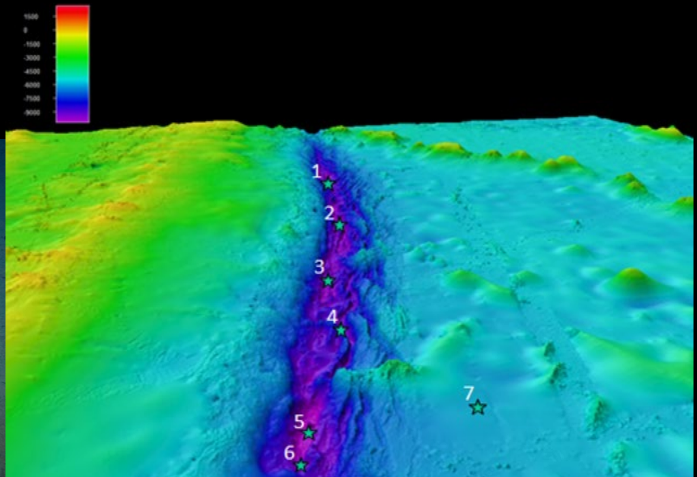
2) **Hadal trenches act as dynamic deep-sea hotspots with intensified biological activity & high microbial diversity (functionally and taxonomic)**

3) **Hadal sediments express a high degree of spatio-temporal variability – within and between trenches**

4) **Hadal trenches are an important for global element cycling, biodiversity and climate interaction**

5) **Still many unresolve fundamental questions and discoveries to be made.**



Thanks to the very many great collaborators, and the HADAL-team

HADAL Team

HADAL
Danish Center for Hadal Research

and the funding agencies:

Danmarks Grundforskningsfond
Danish National Research Foundation

Japan Society for the Promotion of Science
Founded 1932

DANMARKS FRIE FORSKNINGSFOND

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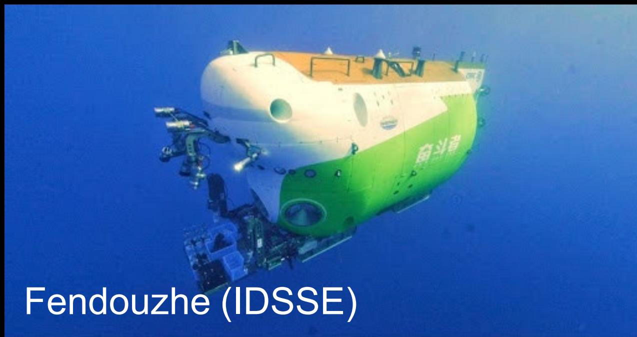
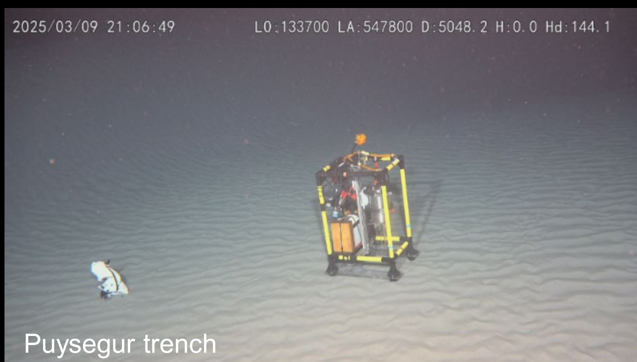
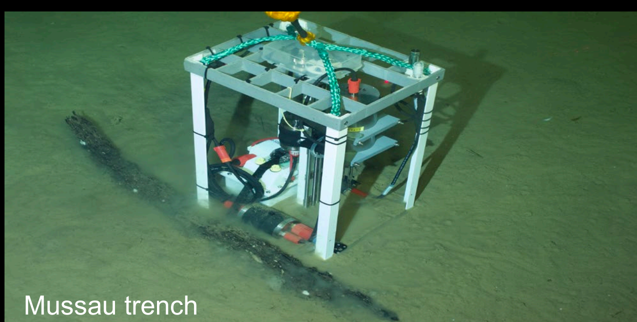
Below – selected slides for potential questions

Revelations at hadal depth encountered by submersible


Fendouzhe (IDSSE)



Puysegur trench

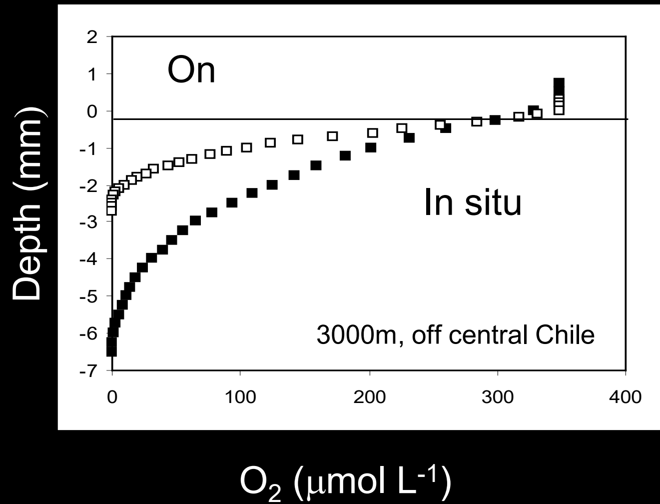

Mussau trench

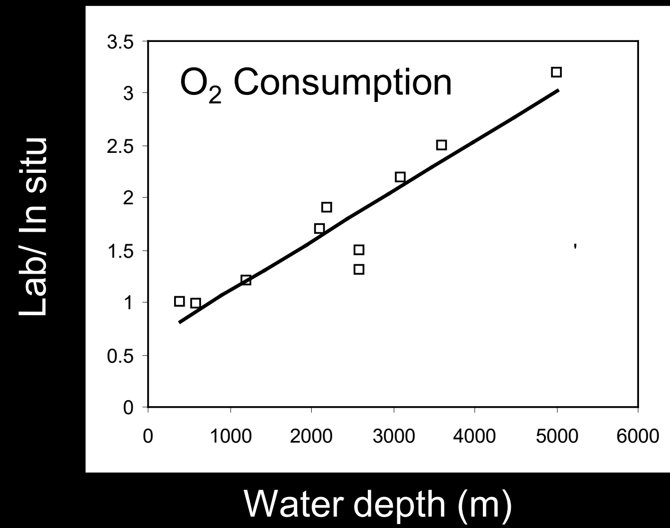
The unexplored hadal realm

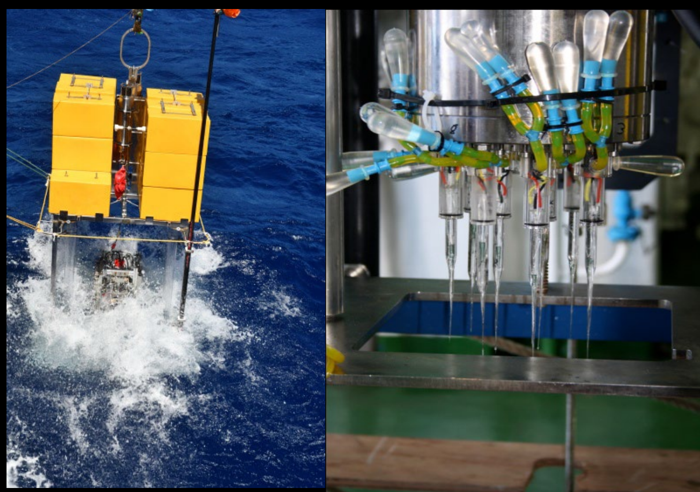
Photos from 6520-6714 depth in the Atacama trench

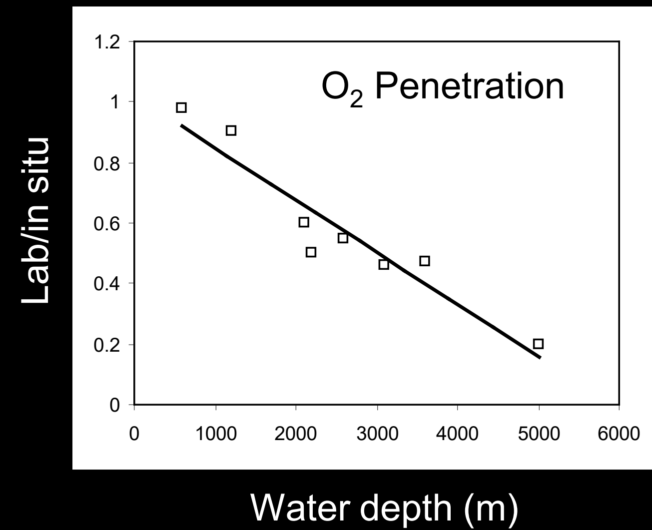
Linley et al 2022

In situ measurements of benthic O_2 uptake



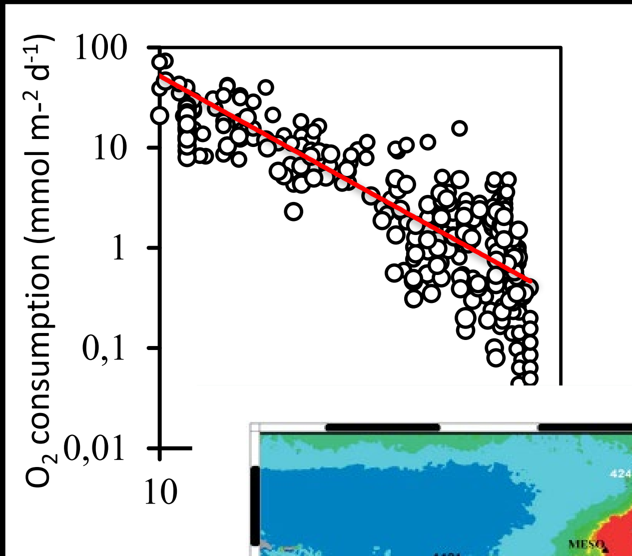






Glud et al (1994)
Glud et al (1999)

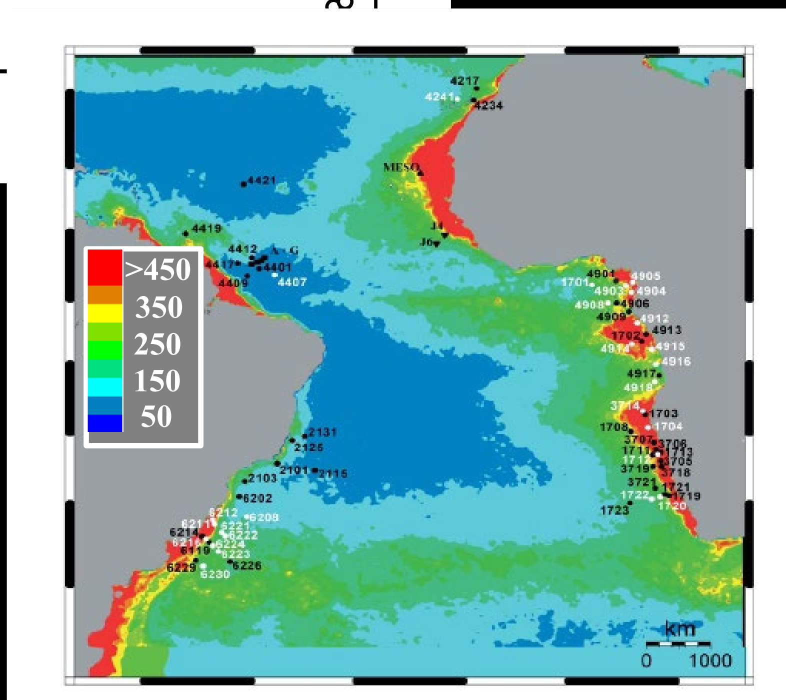
Measurements in the South Atlantic



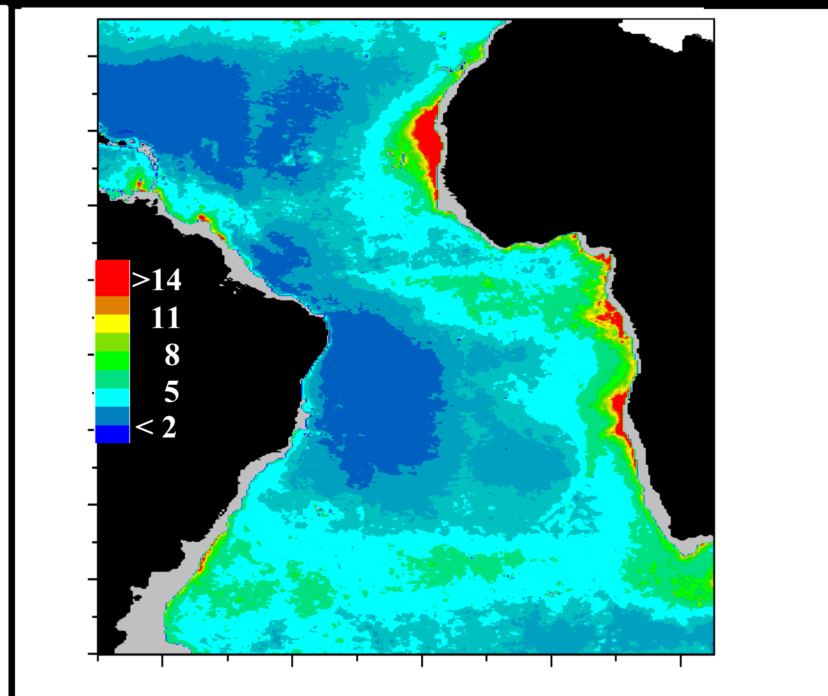
$$O_2 \text{ consumption} = PP^{0.74}\ Z^{-0.33}$$

PP = primary production
Z = water depth

The integrated value remain the same (1.52 Gt C yr^{-1})



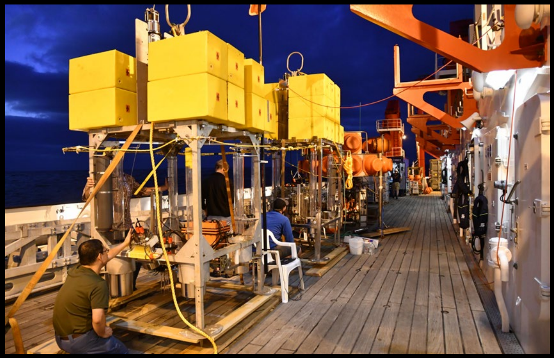
Algae production (PP)
(g C m^{-2} yr^{-1})

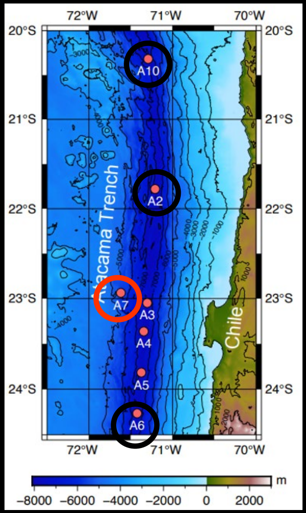


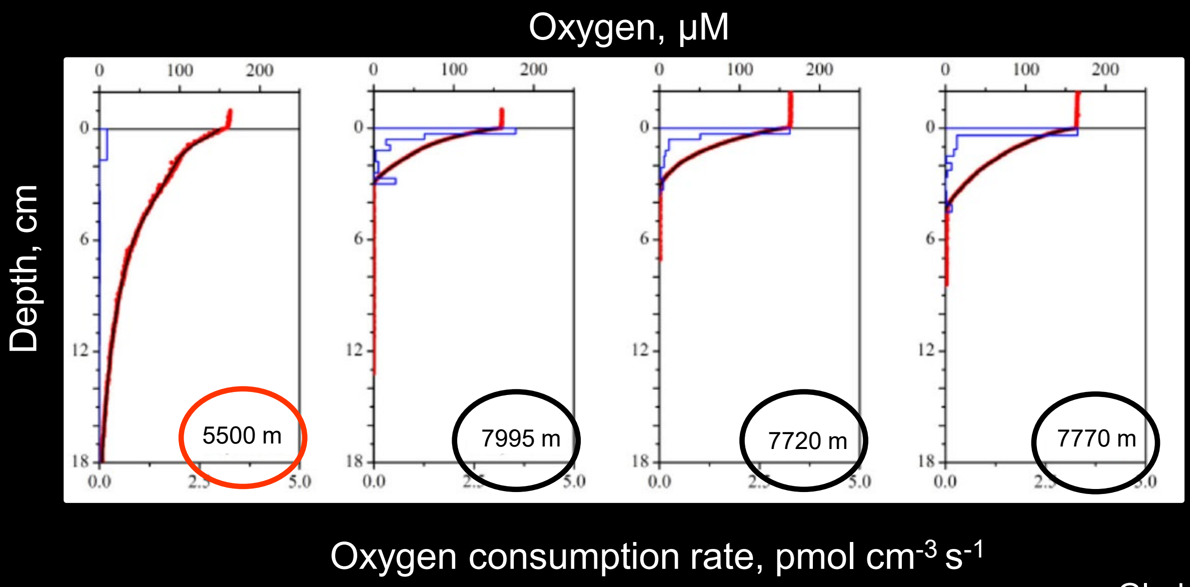
Benthic O_2 consumption
(g C m^{-2} yr^{-1})

Wenzhoefer and Glud, 2002

Variable diagenetic activity along trench axes



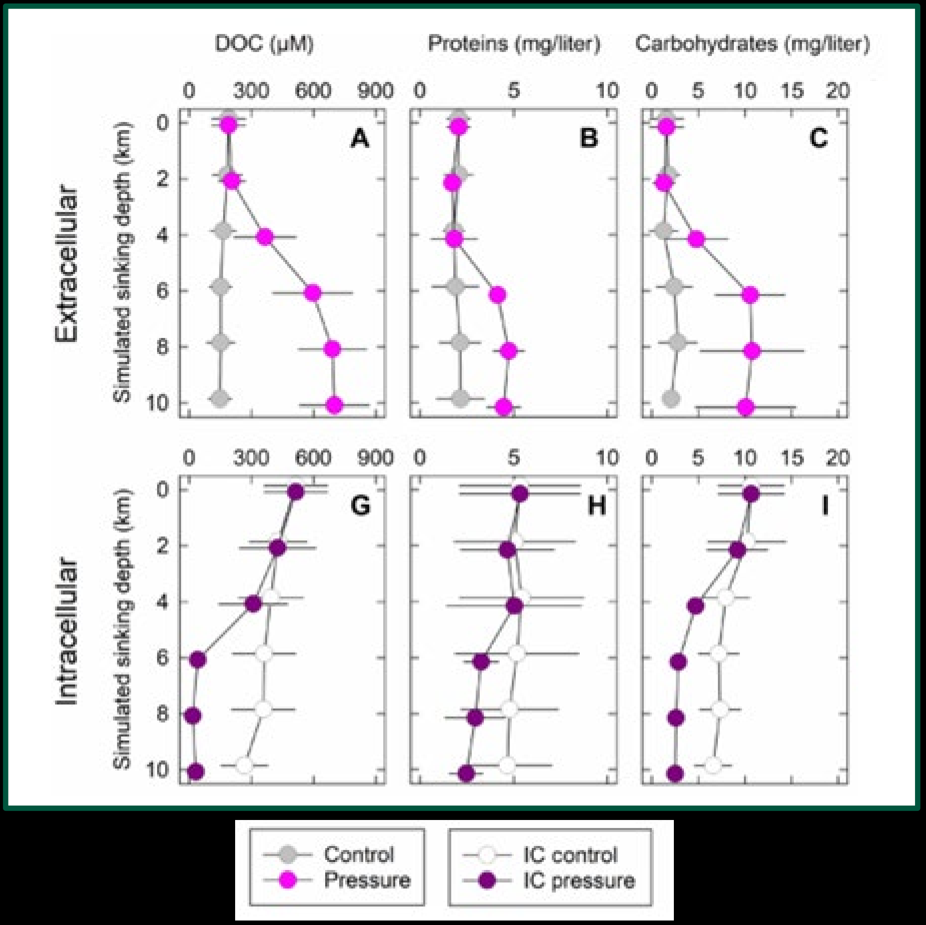


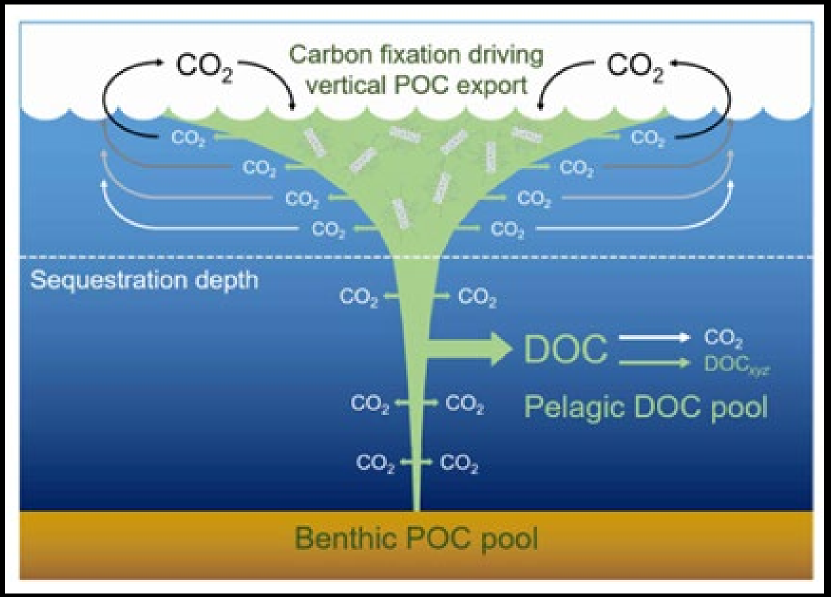


Glud et al (2021)

Hadal trench sediments have **2 – 8** times higher activities than adjacent abyssal sites
(Mariana, Tonga, Kermadec, Atacama, Puysegur Trench)

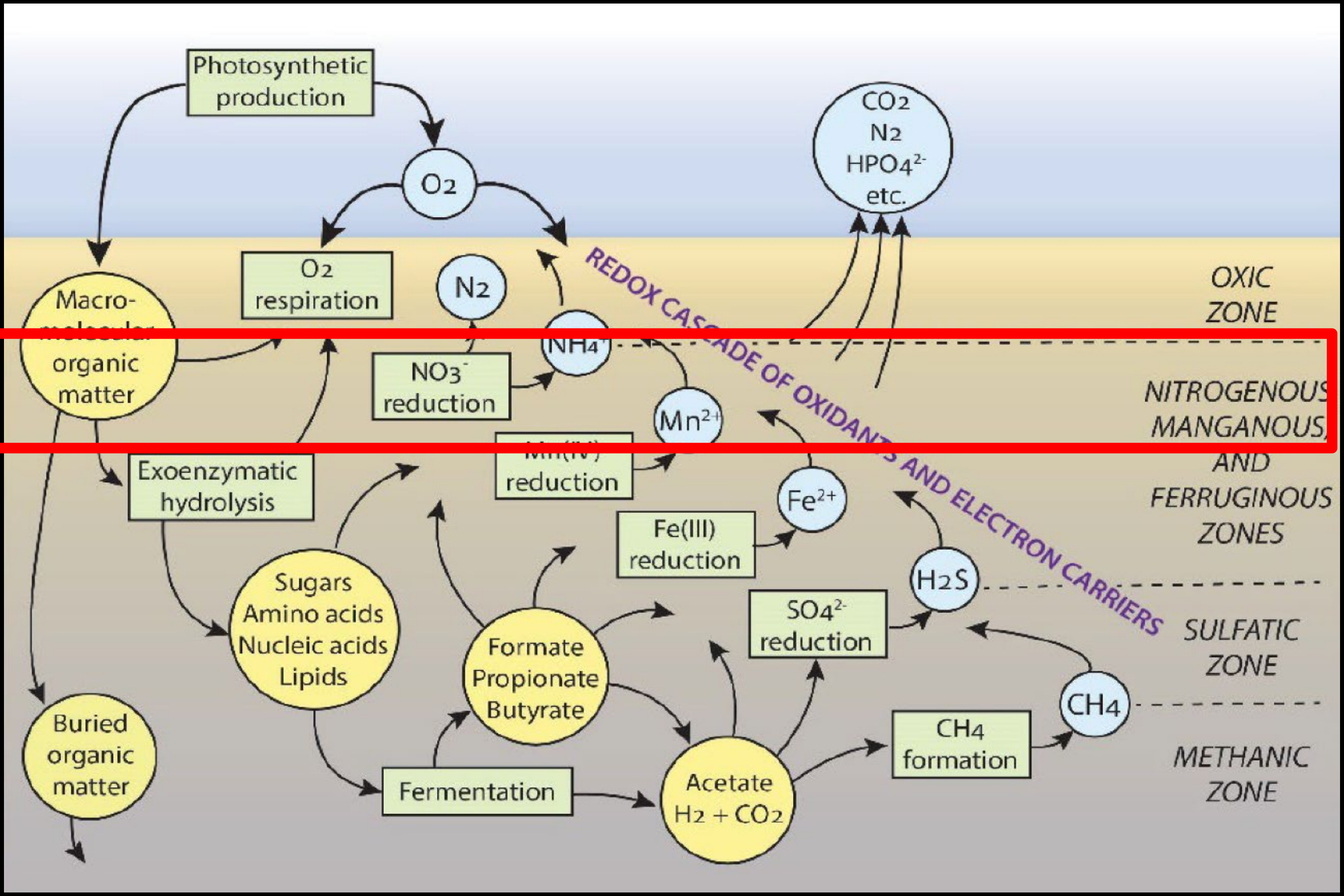
Sinking marine snow and hydrostatic pressure





Stief et al 2026

Benthic redox zonations



Jørgensen et al 2022

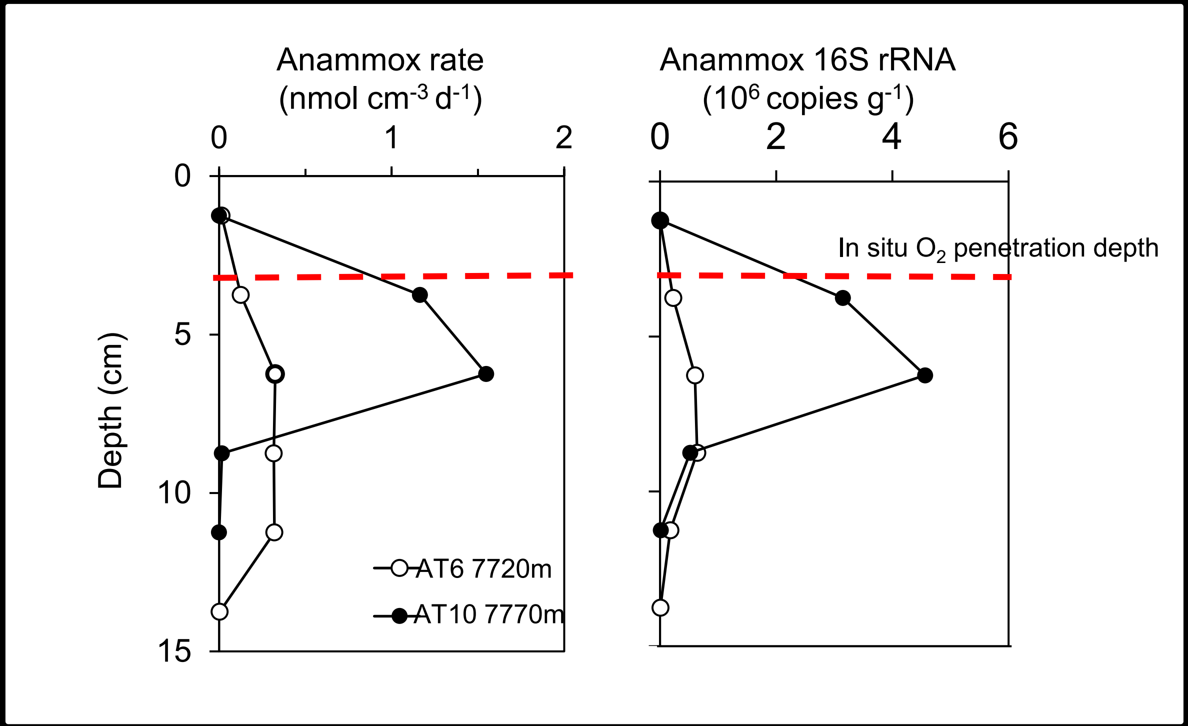
Are hadal sediments sinks for fixed N ?

Anammox
(Anaerobic ammonium oxidation)

$NH_4^+ + NO_2^- \rightarrow N_2 + 2H_2O$

Denitrification

$NO_3^- + \text{Org C} \rightarrow N_2 + CO_2$

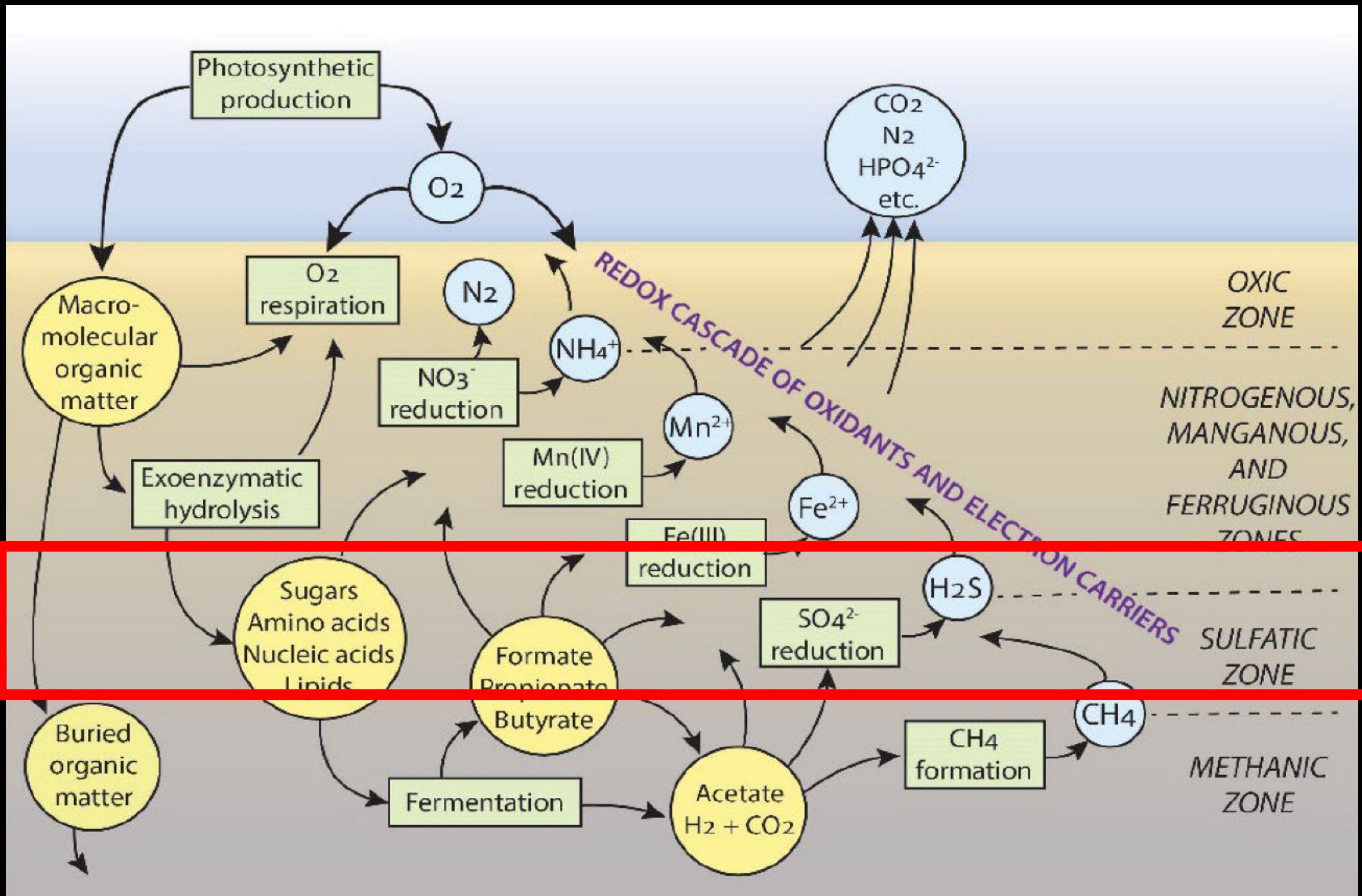


	Atacama		Kermadec
N_2 Production (umol N m^{-2} d^{-1})	45 ± 12	(n=6)	21 ± 8 (n=2)
Anammox (%)	67 ± 13		91 – 98

In contract to Abyssal sediments Hadal sediment act as a sink for fixed nitrogen

Thamdrup et al 2021

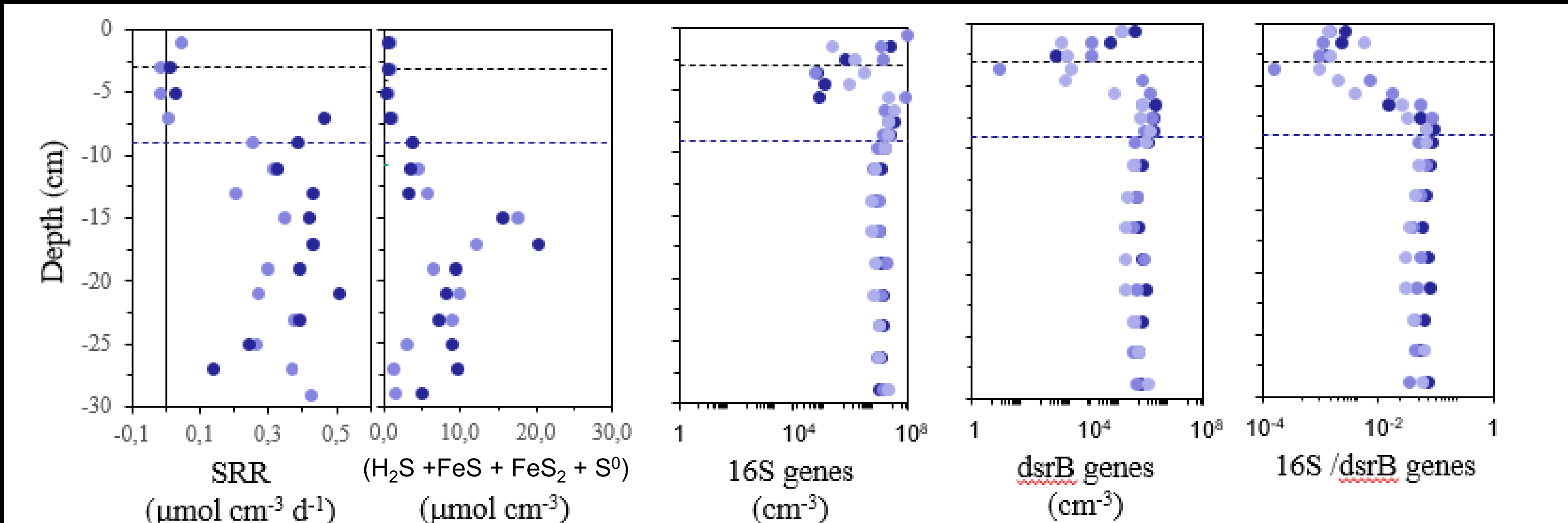
Benthic redox zonations



Jørgensen et al 2022

Anaerob carbon mineralization – Sulfate reduction Atacama Trench (7.8 km)

SRR: Org C + ½SO_4^{2-} $\longrightarrow$ CO_2 + ½H_2S qPCR gene copy numbers



O_2 depth

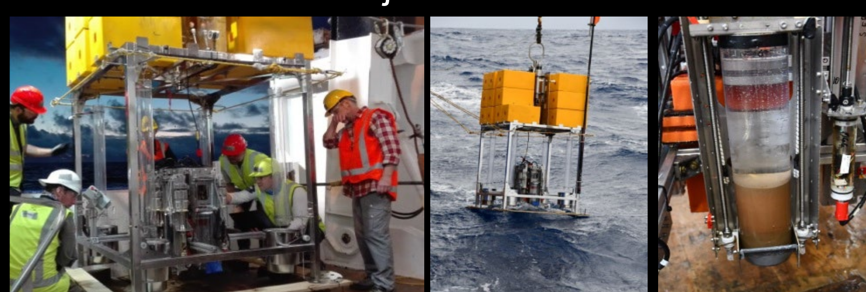
NO_3^- depth

Yen-Ting et al in review

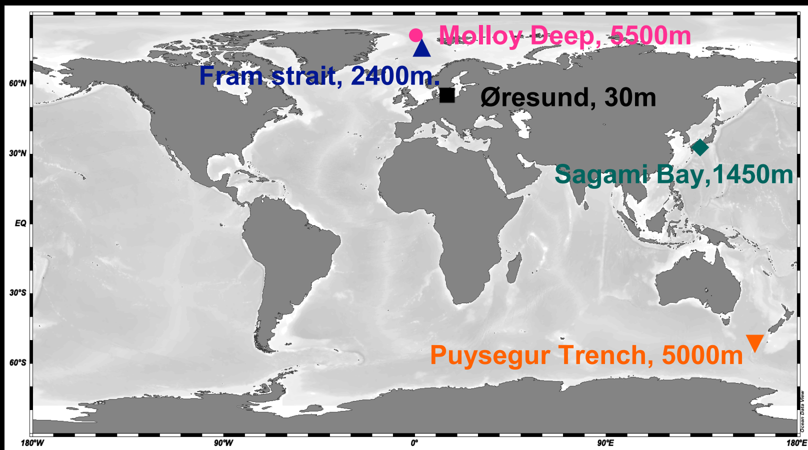
i) The redox processes know from shallow settings re-appear at hadal depth – now operating at extreme pressure

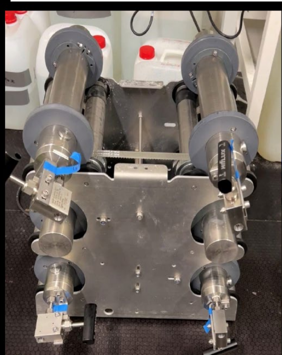
ii) Anaerobic mineralization contribute by 15 -20% of benthic carbon mineralization (Atacama Trench)

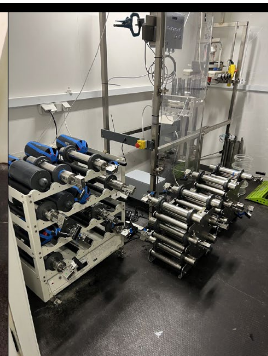
Sediment incubation-injection lander

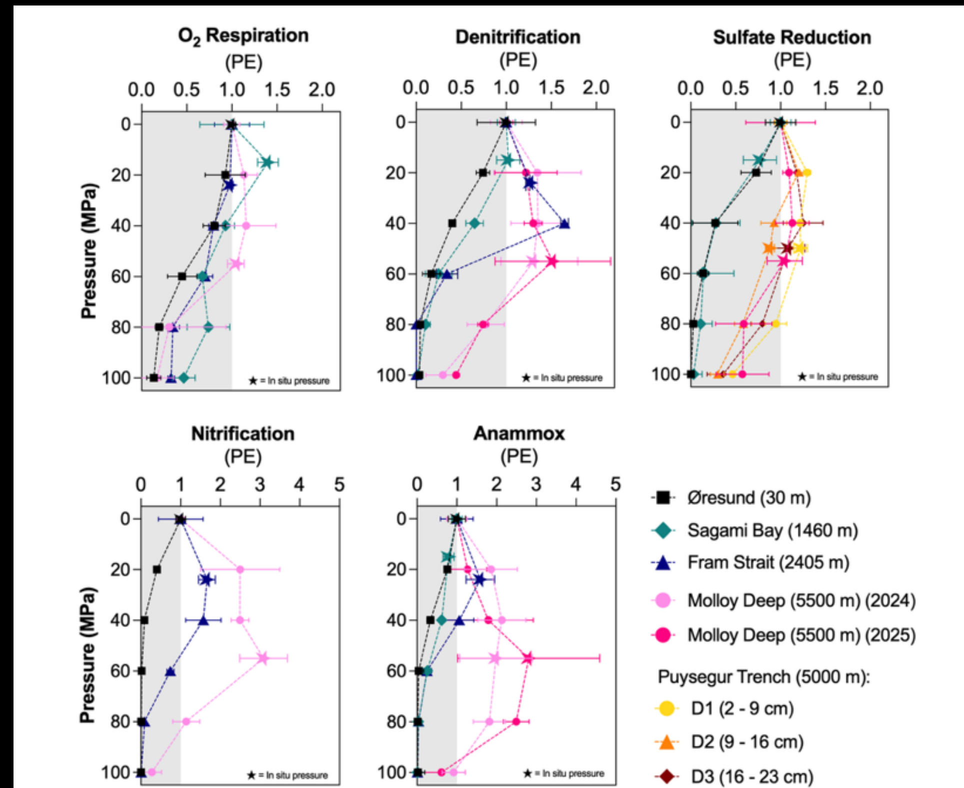


Hydrostatic pressure and benthic microbial activity









Sørensen et al in prog

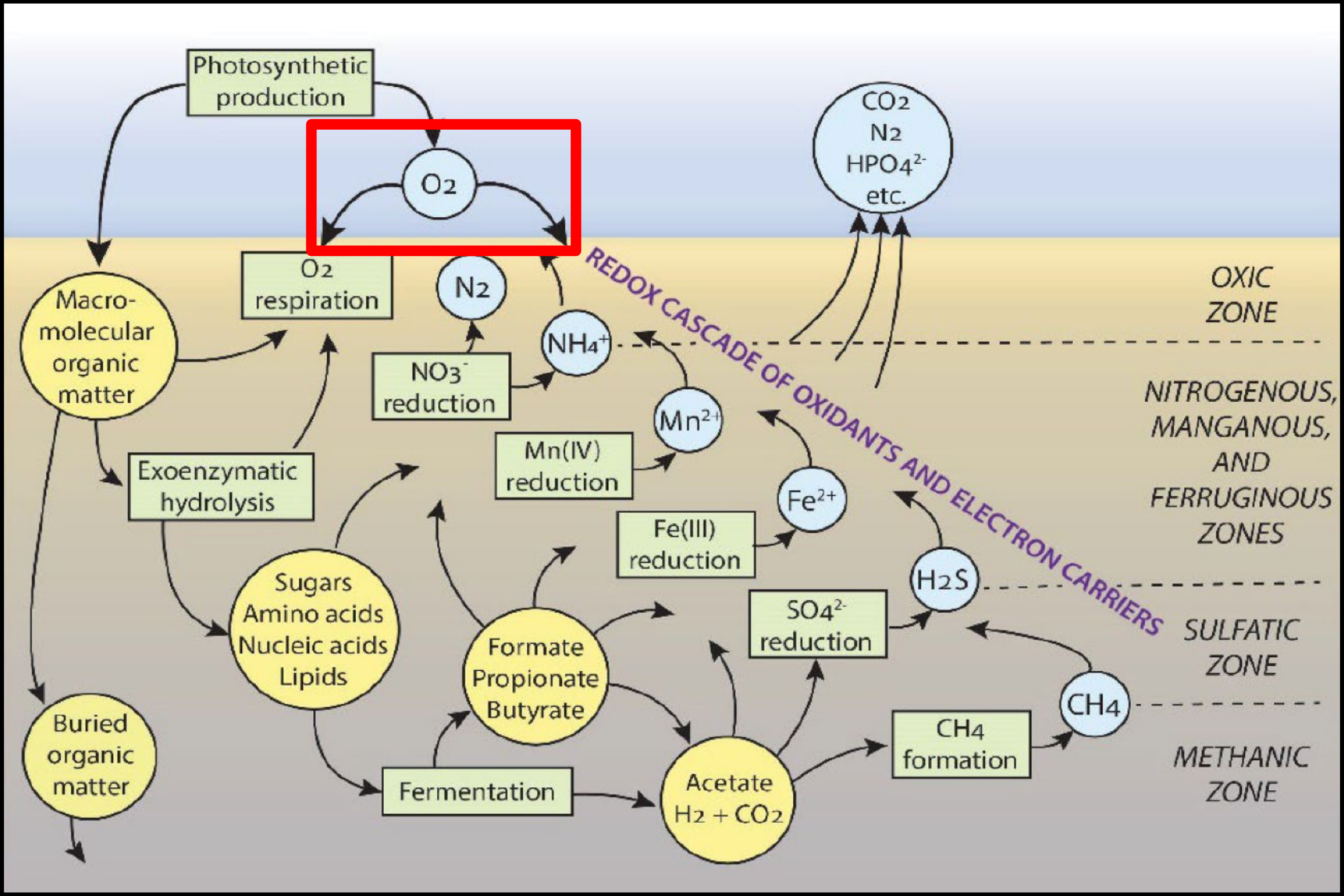
i) Benthic microbial communities adapted to in situ pressure

ii) Diaganetic process rates express different degree of pressure sensitivity

iii) Distinct communities responsible for a given process express similar pressure respons

Organic matter mineralization in marine sediment

– oxygen uptake a proxy for benthic carbon mineralization



Jørgensen et al 2022

In situ measurements of benthic O_2 consumption