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Key Points:
- Total oxygen uptakes were measured for the first time in hadal trenches using in situ benthic chamber incubations
- Data compilation from hadal trenches suggests that rates of benthic carbon mineralization reflect the surface ocean productivity
- However, factors governing the diagenetic activity in hadal trenches apparently include supply of terrestrial organic material

Supporting Information:
- Supporting Information S1

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Benthic Carbon Mineralization in Hadal Trenches: Insights From In Situ Determination of Benthic Oxygen Consumption

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Abstract Hadal trenches have been proposed as depocenters of organic material and hot spots for organic matter mineralization. In this study, we for the first time quantified the total benthic O_2 uptake in hadal trenches using in situ chamber incubations. Three trenches in the tropical Pacific were targeted and exhibited relatively high diagenetic activity given the great water depths, that is, the Mariana Trench (2.0×10^2 μmol O_2 m^{-2} d^{-1}, 10,853 m), the Mussau Trench ($2.7 \pm 0.1 \times 10^2$ μmol O_2 m^{-2} d^{-1}, 7,011 m), and the New Britain Trench ($6.0 \pm 0.1 \times 10^2$ μmol O_2 m^{-2} d^{-1}, 8,225 m). Combined with the analyses of total organic carbon and $\delta^{13}C$ of total organic carbon in the sediments and previously published in situ O_2 microprofiles from hadal settings, we suggest that hadal benthic carbon mineralization partly is governed by the surface production and also is linked to the distance from land. Therefore, we highlight that terrestrial organic matter can be of importance in sustaining benthic communities in some hadal settings.

Plain Language Summary Hadal trenches that refer to seafloor areas covered by a water column with depths >6,000 m have been proposed as depocenters of organic material and hot spots for organic matter mineralization. We applied in situ benthic chamber incubation techniques within three trenches in the tropical Pacific Ocean (the Mariana Trench, the Mussau Trench, and the New Britain Trench) and thereby reported the first benthic total O_2 uptake rates measured in hadal settings. The benthic carbon mineralization rates generally show a positive correlation with the net primary production in respective provinces and the sedimentary total organic carbon (TOC) level. Analyses of TOC contents and $\delta^{13}C$ of TOC indicated a downslope transport of sediment containing a large amount of terrestrial organic matter, possibly via mass-wasting events to the axis of New Britain Trench off the New Britain Island. Therefore, we speculate that both surface production regimes and the distance from land are closely connected with the benthic carbon mineralization rate at the trench axes. The elevated organic carbon turnover rate may in part result from preferential concentration of relatively labile organic matter in the surface sediments of trench axes or efficient utilization of refractory terrestrial material under extreme pressure.

1. Introduction

Hadal trenches refer to areas of the ocean formed by seafloor subduction that are among the least explored habitats on Earth because of their extreme depths (>6,000 m) (Jamieson et al., 2010; Watling et al., 2013). Contrary to the general perception that the rates of organic matter deposition and benthic mineralization decline with increasing water depth (Glud, 2008) and that food scarcity and a dearth of benthic biomass prevail in the deep seabed, hadal trenches have been considered to act as deep ocean depocenters for organic material sustaining the unique trench-associated benthic communities that are adapted to the extreme hydrostatic pressure (Boetius et al., 1996; Danovaro et al., 2002; Ichino et al., 2015; Kitahashi et al., 2013; Leduc et al., 2016). However, it remains to be explored if the elevated deposition is accompanied by higher benthic carbon mineralization rate or if the materials transported into the hadal trenches are too refractory to sustain elevated diagenetic activity.

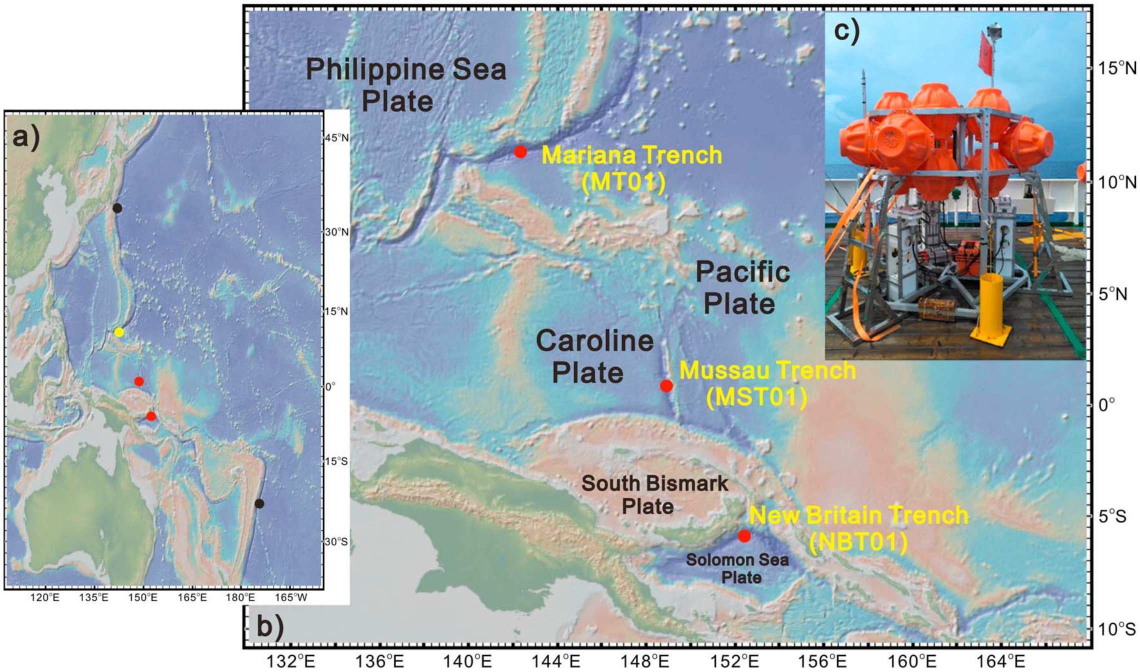

Figure 1. (a) Locations of available in situ benthic O_2 flux data from hadal settings. The black dots represent the sites reported in Wenzhöfer et al. (2016). The red dots are the lander deployment sites of this study. The yellow dot represents the overlapped site of this study and Glud et al. (2013). (b) Overview of the study area and locations of lander deployment sites reported in this study (red dots). (c) Picture of the lander (Lander-II) prior to deployment.

Benthic O_2 uptake rates are widely used as a robust proxy for the total turnover of organic material (Canfield et al., 1993; Glud, 2008). It has been realized that at great water depths, artifacts associated with sediment recovery require that the benthic O_2 consumption rates are determined in situ (Glud et al., 1994; Hall et al., 2007). However, conducting in situ measurements in hadal trenches is challenging and requires specialized instrumentation. Only three successful in situ measurements have been performed in hadal trenches, including the Mariana Trench, the Izu-Bonin Trench, and the Tonga Trench (Glud et al., 2013; Wenzhöfer et al., 2016) (Figure 1a). These studies demonstrated, on the basis of in situ microprofile measurements, that the benthic O_2 consumption rates and thereby the microbial carbon turnover at the trench axes were intensified in comparison to adjacent abyssal sites (Glud et al., 2013; Wenzhöfer et al., 2016). This supports the hypothesis that hadal trenches host elevated diagenetic activity. Nevertheless, do trenches in general maintain relatively high diagenetic activity? If so, what are the sources of organic material sustaining such activity?

In this study, we apply a new benthic chamber lander and provide the first in situ total O_2 uptake (TOU) in hadal settings by targeting three hadal trenches in the tropical Pacific Ocean. We hereby double the number of in situ O_2 consumption measurements obtained in hadal settings, and from the compiled database we evaluate the importance of regional productivity and potential terrestrial organic material for the diagenetic activity in hadal trenches. Furthermore, the combined data set is used to discuss the drivers and sources of organic carbon sustaining benthic microbial activity in such settings.

2. Materials and Methods

2.1. Study Sites

The three targeted hadal trenches, the Mariana Trench, the Mussau Trench, and the New Britain Trench, are all located in the tropical Pacific Ocean and were visited by the MV *Zhangjian* in December 2016/January 2017. The Mariana Trench was formed by the subduction of the Pacific Plate beneath the Philippine Sea Plate (Fryer, 1996) (Figure 1b). The deepest point on the Earth's surface, the Challenger Deep (~11,000 m), is situated in the southern section of Mariana Trench where it trends nearly E-W in contrast to the N-S orientation of the northern section (Fujioka et al., 2002). The Mariana Trench is overlain by oligotrophic surface waters, resulting in low primary productivity and corresponding low vertical deposition of organic material (Jamieson et al., 2009).

Table 1
Characteristics of Lander Deployment Stations

Location		Water depth (m)	Bottom water temperature (°C)	Bottom water salinity	Surface sediment porosity (0–2 cm)	Distance to the nearest island (km)
Mariana Trench						
MT01	11°24.22′N 142°21.78′E	10,853	2.1	34.6	0.84	355
Mussau Trench						
MST01	0°53.84′N 148°53.35′E	7,011	2.4	34.7	0.81	255
New Britain Trench						
NBT01	5°53.08′S 152°24.67′E	8,225	2.2	34.8	0.84	55

The Mussau Trench is located along the eastern boundary of the Caroline Plate (Figure 1b). The trench has maximum depth of 7,000–7,200 m and can be followed over a distance of 380 km (Ablaev et al., 1992). The surface waters overlying the Mussau Trench are characterized by excess nutrients yet low concentrations of chlorophyll, and the primary productivity is considered to be limited by iron (Behrenfeld et al., 1996; Coale et al., 1996; Gordon et al., 1997).

The New Britain Trench is ~840 km long curved trench formed by the subduction of Solomon Sea Plate beneath the South Bismark Plate and the Pacific Plate (Cooper & Taylor, 1987) (Figure 1b). Its maximum depth is 9,140 m at the Planet Deep (Davies et al., 1986). The surface waters overlying the New Britain Trench are generally more productive than that of the Mariana Trench (Gallo et al., 2015). Characteristics of the deployment sites are listed in Table 1.

2.2. In Situ Benthic Chamber Incubations

In situ benthic O_2 fluxes were determined using three benthic chambers mounted in a newly built autonomous lander (Lander-II). In brief, Lander-II contains cuboid benthic chambers with a base area of 400 cm^2 and a chamber height of 25 cm (Figure 1c). During the present study, 2 h after the lander reached the seafloor, the chambers were slowly driven into the sediments to a targeted depth of 21 cm below the sediment-water interface before a lid sealed the chambers. In order to detect the decline of O_2 in the chamber water during a relatively short incubation time, the height of the enclosed water column was kept to only ~4 cm as confirmed by measuring the height of the retrieved sediment column. During the incubation the enclosed water was continuously mixed by a rotating central stirrer, while changes in O_2 concentration were determined by optodes customized for 11,000 m (Oxygen Optope 5331, Aanderaa, Norway) that recorded oxygen concentrations at an interval of 10 min over an incubation period of 10 h. A two-point calibration of the O_2 sensor was realized by onboard anoxic readings and O_2 signals in ambient bottom water. The bottom water was recovered by a separate lander (Lander-I) designed for collecting bottom water (up to 40 L) and videotaping. Its concentration was analyzed by Winkler titration (Grasshoff, 1983). The TOU was calculated from the slope of the linear regression fitted to the O_2 concentration variation versus time in the enclosed overlying water. The uncertainty in resolved flux is mainly introduced by the product of the uncertainty in the linear fit to the O_2 concentration and the uncertainty in estimating the height of enclosed water column. This gives an uncertainty of 3.2% for the Mariana Trench, 5.5% for the Mussau Trench, and 8.8% for the New Britain Trench.

2.3. Measurements of Porosity, Total Organic Carbon, and $\delta^{13}C$ of TOC

Porosity was determined from the weight loss before and after freeze-drying of the wet sediments. The volume fraction of pore water was calculated assuming a dry sediment density of 1.45 g cm^{-3} that is the average of the available density measurements in hadal trenches (Glud et al., 2013; Wenzhöfer et al., 2016) and a density of the pore water of 1.023 g cm^{-3}.

Weight percent (wt %) and carbon isotopic composition of total organic carbon (TOC) were determined by high temperature combustion on a Vario Pyro Cube Elemental Analyzer connected to an Isoprime 100 continuous flow isotope ratio mass spectrometer. For the analysis, ~150 mg of freeze-dried, ground sediment powder was digested in 8 mL 10% HCl for 12 h to remove inorganic carbon. The residues were analyzed for

Table 2
Summary of Benthic O_2 Uptake Rates, Depth-Integrated TOC Content, $\delta^{13}C$ Values of TOC at the Seafloor, and Estimated Primary Production From Hadal Trenches

Location	O_2 uptake (μmol m^{-2} d^{-1})	Depth-integrated TOC (g m^{-2})[a]	TOC at the seafloor (wt %)	$\delta^{13}C$ of TOC at the seafloor (‰)	Net primary production (g C m^{-2} yr^{-1})	Water depth (m)
Izu-Bonin Trench						
W01[b]	$7.5 \pm 1 \times 10^2$	$1.8 \pm 0.1 \times 10^3$	1.11	N.A.	200[b]	9,200
Mariana Trench						
G01[c]	$1.5 \pm 0.5 \times 10^2$	6.2×10^2	0.40	N.A.	50[c]	10,813
MT01	2.0×10^2	9.2×10^2	0.57	−21.7	50	10,853
Mussau Trench						
MST01	$2.7 \pm 0.1 \times 10^2$	1.2×10^3	0.83	−22	79	7,011
New Britain Trench						
NBT01	$6.0 \pm 0.1 \times 10^2$	1.8×10^3	0.97	−25.3	108	8225
Tonga Trench						
W02[b]	$2.3 \pm 0.5 \times 10^2$	$2.3 \pm 0.5 \times 10^3$ [d]	2.19[d]	N.A.	106[b]	10,800

Note. The uncertainties indicate the standard deviations for O_2 uptake and TOC content. TOC = total organic carbon. N.A. = not available.
[a]Depth-integrated values of upper 13 cm. [b]According to Wenzhöfer et al. (2016). [c]According to Glud et al. (2013). [d]The TOC value was derived from loss on ignition assuming a carbon content of organic material of 45%, and samples were not acidified before analysis and could thus be compromised by the contribution of inorganic carbon.

the carbon contents and isotopes. Stable isotope results were reported using the per mil notation (δ, ‰) relative to the Vienna Peedee belemnite standard. The average standard deviation of replicate measurements for the contents and $\delta^{13}C$ values of TOC were ± 0.03 wt % and ± 0.2‰, respectively.

2.4. Estimation of Annual Average Net Primary Production

Estimates of an average of net primary production (NPP) over each of the three targeted trenches were calculated using the standard Vertically Generalized Production Model (Behrenfeld & Falkowski, 1997) and 1998–2007 remote sensing data (Sea-viewing Wide Field-of-view Sensor, https://doi.org/10.5067/ORBVIEW-2/SEAWIFS_OC.2014.0) (Wenzhöfer et al., 2016).

3. Results and Discussion

3.1. Benthic Carbon Mineralization in the Mariana Trench, the Mussau Trench, and the New Britain Trench

The TOU in the Mariana Trench was 198 μmol m^{-2} d^{-1} (Table 2), which is similar to the diffusive O_2 uptake (DOU, 154 ± 48 μmol m^{-2} d^{-1}) previously derived from in situ microprofile measurement at the same location (Glud et al., 2013). The DOU solely represents the diffusive mediated benthic O_2 uptake, while the TOU also includes any potential contribution from macrofauna. The difference between TOU and DOU is frequently used as a measure of the benthic fauna-mediated O_2 uptake (Archer & Devol, 1992; Graf et al., 1982). In coastal settings, bioirrigation, bioturbation, and fauna respiration can contribute as much as 50% to the TOU (Aller, 1994; Wenzhöfer & Glud, 2004). However, compilation of a large database of parallel measurements has shown that TOU and DOU converge with increasing water depth as macrofaunal biomass attenuates and the importance of irrigation decreases with increasing oxygenation of the sediments. The ratio of TOU and DOU thus becomes close to unity in deep-sea settings (Glud, 2008). In fact, by careful visible inspection, no conspicuous macrofauna were observed in any of the recovered sediment cores from the chambers. Therefore, the very similar (within uncertainty) rates of TOU and DOU in the Mariana Trench are to be expected and provide confidence of the two independent approaches for quantifying the benthic O_2 consumption rate. The central stirring and the shallow water height of the chambers could potentially have induced internal resuspension during the incubations. However, due to the deep O_2 penetration of >16 cm (Glud et al., 2013) and the well-oxygenated surface sediment, the internal hydrodynamics of the chamber or a slight resuspension of the surface will have little or no impact on the derived TOU values (Glud et al., 1995; Tengberg et al., 1995).

The average benthic O_2 fluxes of two simultaneous measurements in the Mussau Trench and in the New Britain Trench were 266 μmol m^{-2} d^{-1} and 604 μmol m^{-2} d^{-1}, respectively (Figure 2 and Table 2). Although DOUs were not determined in these trenches, the conclusion from the Mariana Trench and the fact that no conspicuous macrofauna was found in any sediments recovered by the chambers make it reasonable to assume that the rates of DOU and TOU also are similar in these settings and that microbial carbon

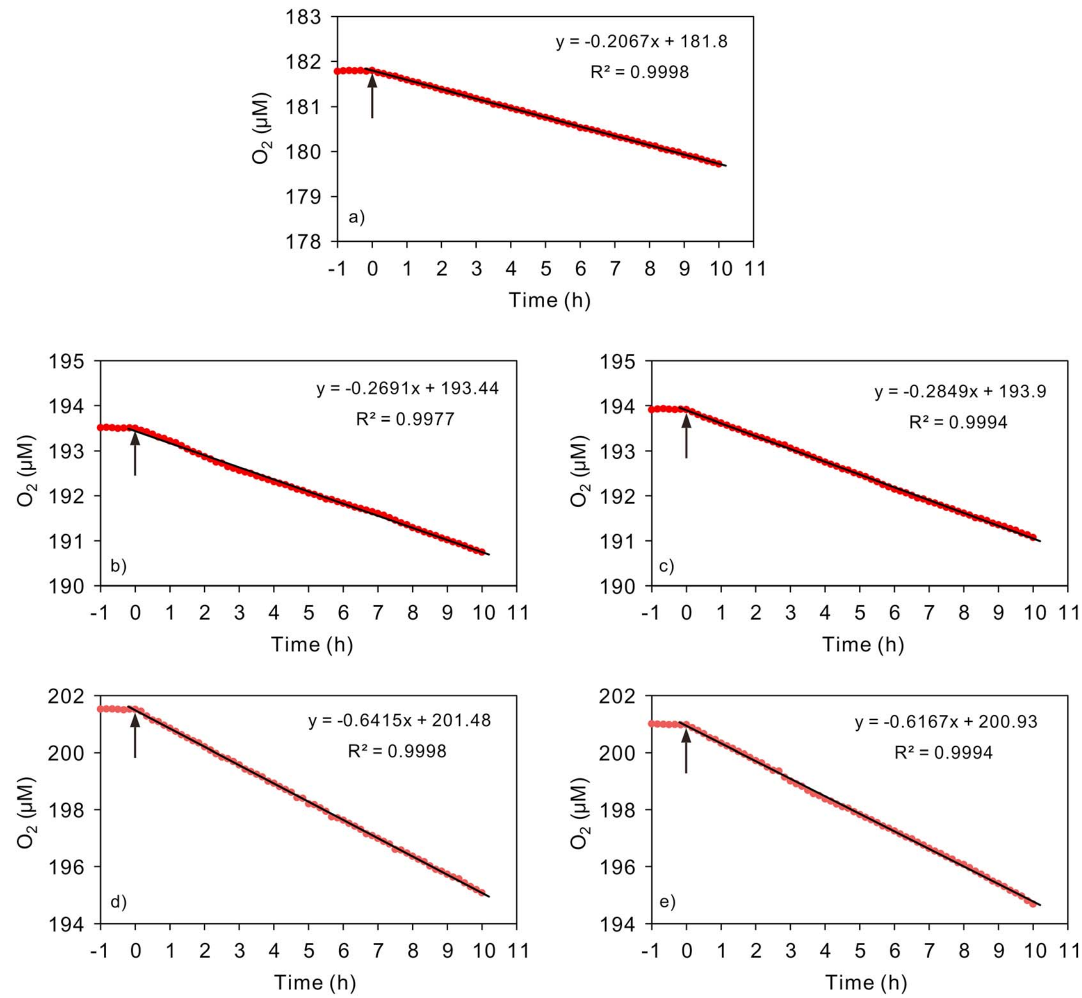

Figure 2. O_2 concentrations measured during chamber deployments at the trench axes of the (a) Mariana Trench, (b and c) the Mussau Trench, and the (d and e) New Britain Trench. The arrows indicate the time when the lids were closed and incubations started. Straight lines represent the linear regression fits to the measured O_2 concentrations. Due to malfunctioning of the newly customized optodes, we only successfully obtained one set of O_2 data from the Mariana Trench and two sets of O_2 data from the Mussau Trench and the New Britain Trench, respectively. Data were provided by one oxygen optode in each chamber.

mineralization dominates the benthic O_2 consumption in the Mussau and New Britain Trenches. However, the benthic O_2 consumption in the three trenches varies by approximately threefold with highest rate in the New Britain Trench and lowest rate in the Mariana Trench, presumably reflecting the differences in the supply of degradable organic material.

3.2. Factors Controlling the Rates of Benthic Carbon Mineralization Within Different Trenches

It is commonly accepted that the rate of benthic carbon mineralization declines with increasing water depth, as the pelagic mineralization becomes more important with increasing water depth and the phytoplankton productivity in coastal and slope settings is elevated compared to the open ocean (Eglinton & Repeta, 2003; Wenzhöfer & Glud, 2002). However, available in situ data of O_2 consumption at abyssal settings (4–6 km) vary by ~2 orders of magnitude and exhibit no direct relationship with water depths (Glud, 2008). This partly reflects the spatial difference in primary production, but presumably also variations in downslope transport and focusing of organic matter governed by complex interactions of hydrography and seabed topography (de Leo et al., 2010; de Stigter et al., 2007; Hwang et al., 2010; Jahnke et al., 1990). For the three trenches targeted here, the benthic O_2 consumption rates increased in the order of the Mariana Trench, the Mussau Trench, and the New Britain Trench, which is in line with the increasing estimated NPP of the respective provinces with 50 g C m^{-2} yr^{-1} in the Mariana Trench, 79 g C m^{-2} yr^{-1} in the Mussau Trench, and 108 g C m^{-2} yr^{-1} in the New Britain Trench (Figure 3a and Table 2). This is in agreement with Wenzhöfer

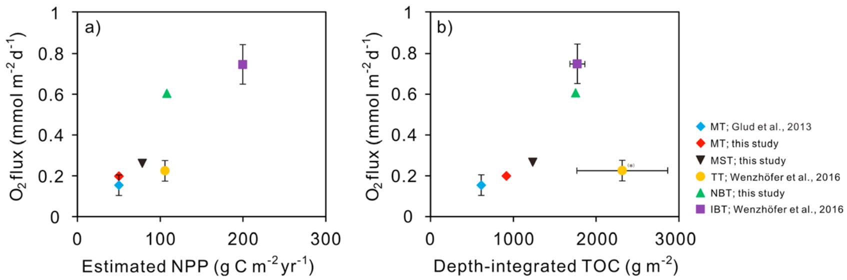

Figure 3. (a) The benthic O_2 consumption rates versus estimated net primary production (NPP) in different trenches. (b) The benthic O_2 consumption rates versus depth-integrated TOC contents of the upper 13 cm of the respective trenches. The TOC value represented by the yellow circle (asterisk) was derived from loss on ignition assuming a carbon content of organic material of 45%, and samples were not acidified before analysis and could thus be compromised by an inorganic carbon contribution. Error bars indicate the standard deviation of duplicate measurements. TOC = total organic carbon.

et al. (2016) who also observed a sequential increase in benthic carbon mineralization rates from the Mariana Trench ($1.5 \pm 0.5 \times 10^2$ μmol O_2 m^{-2} d^{-1}), the Tonga Trench ($2.3 \pm 0.5 \times 10^2$ μmol O_2 m^{-2} d^{-1}), and to the Izu-Bonin Trench ($7.5 \pm 1 \times 10^2$ μmol O_2 m^{-2} d^{-1}), mirroring the estimated NPP of provinces overlying the corresponding trenches (Figure 3a). This clearly suggests a linkage between the regional primary production and benthic diagenesis encountered at the trench axis.

However, although the NPP in the New Britain Trench region is only ~50% of that in the Izu-Bonin Trench region, the sedimentary TOC content and the benthic carbon mineralization rates at the two trench axes are quite similar. It is thus conceivable that additional factors might be also important for the supply of organic material to the central part of the trenches such as the distance to land and the inclination of trench slopes. Overall, the sedimentary TOC contents correlate well with the benthic O_2 uptake, especially if ignoring values from the Tonga Trench that might have been compromised (Figure 3b and Table 2). Notably, the New Britain Trench and the Izu-Bonin Trench are both close to land and the sedimentary TOC in both trenches is among the highest of available hadal data set and comparable to those on the continental margins (Burdige, 2007). The funnel-like shape and fluid dynamics within the hadal trenches have been proposed to facilitate the lateral and downslope transport of sediment particles toward the trench bottom (Turnewitsch et al., 2014). The New Britain Island is characterized by a very narrow shelf and steep slope, and the trench axis that is parallel to the coastline lies around 55 km off the coast in the eastern section of New Britain Trench (Davies et al., 1987). Furthermore, the landward trench slope is uniformly steep with an average gradient of ~8° (Tiffin et al., 1987). Consequently, a wealth of fluvial sediments may have bypassed the shelf and been channeled to the deep sea and the trench axis via gravity flow and/or nepheloid layers. The carbon isotopic composition of TOC (−25.3‰) on the seafloor of New Britain Trench is indicative of a major input of terrestrial organic material, in contrast to the less negative $\delta^{13}C$ values of TOC in the Mariana Trench (−21.7‰) and Mussau Trench (−22‰) that are typical of marine-sourced organic matter (Meyers, 1994). Indeed, submersible video footage has documented the presence of terrestrial debris even on the axis of the New Britain Trench (8,233 m) (Gallo et al., 2015). Therefore, proximity to the land and resulting enhanced input of allochthonous terrestrial organic material appear to have contributed to the relatively high benthic carbon mineralization rate in the New Britain Trench. Direct quantitative assessments of the relative importance of potential sources of organic material sustaining the intensified benthic oxygen uptake at the trench axes remain a future challenge. It should be addressed through deploying long-term sediment traps and carrying out continuous hydrographic observations from shallower upper slope all the way to the trench axis combined with detailed geochemical characterization of the trap material and sediments of the region.

Most of the sedimentary organic matter at the trench axis is presumably of refractory nature, and a relatively small fraction of labile material may be unproportionally important for the intensified diagenetic activity at the trench bottom. Mass-wasting events triggered by recurrent earthquakes along subduction zones and fast-sinking organic materials are hypothesized to play a role in trapping organic matter within the central parts of trenches (Itou et al., 2000; Nozaki & Ohta, 1993; Oguri et al., 2013; Robison et al., 2005; Wilson et al., 2013). Comparison of the depth profiles of $^{210}Pb_{ex}$ and TOC contents between the trench axis site and abyssal site in the Mariana Trench and Tonga Trench pointed to recent mass-wasting depositions at both trench axes (Glud et al., 2013; Wenzhöfer et al., 2016). It has been speculated that fresher, more labile organic matter is concentrated at the trench bottom, leading to enhanced diagenetic activity (Glud et al., 2013; Wenzhöfer et al., 2016). This could be facilitated by focusing of nekton carcasses or delayed settling of lighter, fresher detrital material at the surface of trench axis sediments following mass-wasting events. However, such mechanisms remain unsubstantiated by direct observation but are consistent with the relatively high content of phytodetrital material in trench axis sediments exceeding values from abyssal sites.

The New Britain subduction zone is extremely seismically active and has experienced 22 earthquakes with magnitudes equal to or larger than 7.5 since 1990 Common Era according to U.S. Geological Survey (http://earthquake.usgs.gov/earthquakes/search/). Surprisingly, the sediment retrieved by the benthic chamber contained a great amount of calcium carbonate (up to 50%, unpublished data), which is unexpected at depths below the carbonate compensation depth of the western Pacific. This is unequivocal evidence for the sudden and rapid movement of material from shallow water via mass-wasting transport possibly triggered by the frequent earthquakes in the New Britain Trench area. It is thus plausible to infer that the relatively high diagenetic activity on the bottom of New Britain Trench is not only associated with the primary production but also pertinent to the input of terrestrial organic matter from nearby land. It is commonly accepted that the major source of terrestrial organic matter is vascular plants that generally contain high concentrations of recalcitrant biomacromolecules (Hedges et al., 1997). We thus speculate that the intensified benthic carbon turnover at the trench axis might be due to (i) relatively efficient utilization of “refractory” organic matter by microorganisms under extreme pressure or, alternatively, (ii) rapid transportation of labile terrestrial organic matter to the New Britain Trench. The potential enzyme-driven metabolism degrading refractory organic matter in hadal settings and the mechanism for an apparent elevated deposition of labile organic matter and inorganic carbon at the trench axes are yet to be investigated.

4. Conclusion

We applied in situ benthic chamber incubation techniques within three trenches in the tropical Pacific Ocean (the Mariana Trench, the Mussau Trench, and the New Britain Trench) and thereby reported the first benthic TOU rates measured in hadal settings. Our aims were to explore variation in diagenetic activity among the respective trenches and to investigate the underlying factors governing the variations in the benthic carbon mineralization rates and the drivers for intensified microbial carbon turnover at the trench axes. The benthic carbon mineralization rates generally show a positive correlation with the NPP in respective provinces and the sedimentary TOC level. Analyses of TOC contents and δ^{13}C of TOC indicated a downslope transport of sediment containing a large amount of terrestrial organic matter, possibly via mass-wasting events to the axis of New Britain Trench off the New Britain Island. Therefore, we speculate that both surface production regimes and the distance from land are closely connected with the benthic carbon mineralization rate at the trench axes. The elevated organic carbon turnover rate may in part result from preferential concentration of relatively labile organic matter in the surface sediments of trench axes or efficient utilization of refractory terrestrial material under extreme pressure.

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References

Ablaev, A. G., Khudik, V. D., Biryulina, M. G., Pletnev, S. P., & Ashurov, A. A. (1992). Biostratigraphy of the Mussau Trench (Caroline Basin). *Geo-Marine Letters*, *12*(4), 236–239. https://doi.org/10.1007/BF02091845

Aller, R. C. (1994). Bioturbation and remineralization of sedimentary organic matter: Effects of redox oscillation. *Chemical Geology*, *114*(3-4), 331–345. https://doi.org/10.1016/0009-2541(94)90062-0

Archer, D., & Devol, A. (1992). Benthic oxygen fluxes on the Washington shelf and slope: A comparison of in situ microelectrode and chamber flux measurements. *Limnology and Oceanography*, *37*(3), 614–629. https://doi.org/10.4319/lo.1992.37.3.0614

Behrenfeld, M. J., Bale, A. J., Kolber, Z. S., Aiken, J., & Falkowski, P. G. (1996). Confirmation of iron limitation of phytoplankton photosynthesis in the equatorial Pacific Ocean. *Nature*, *383*(6600), 508–511. https://doi.org/10.1038/383508a0

Behrenfeld, M. J., & Falkowski, P. G. (1997). Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnology and Oceanography*, *42*(1), 1–20. https://doi.org/10.4319/lo.1997.42.1.0001

Boetius, A., Scheibej, S., Tselepides, A., & Thiel, H. (1996). Microbial biomass and activities in deep-sea sediments of the eastern Mediterranean: Trenches are benthic hotspots. *Deep Sea Research Part I: Oceanographic Research Papers*, *43*(9), 1439–1460. https://doi.org/10.1016/S0967-0637(96)00053-2

Burdige, D. J. (2007). Preservation of organic matter in marine sediments: Controls, mechanisms, and an imbalance in sediment organic carbon budgets? *Chemical Reviews*, *107*(2), 467–485. https://doi.org/10.1021/cr050347q

Canfield, D. E., Jørgensen, B. B., Fossing, H., Glud, R., Gundersen, J., Ramsing, N. B., et al. (1993). Pathways of organic carbon oxidation in three continental margin sediments. *Marine Geology*, *113*(1-2), 27–40. https://doi.org/10.1016/0025-3227(93)90147-N

Coale, K. H., Fitzwater, S. E., Gordon, R. M., Johnson, K. S., & Barber, R. T. (1996). Control of community growth and export production by upwelled iron in the equatorial Pacific Ocean. *Nature*, *379*(6566), 621–624. https://doi.org/10.1038/379621a0

Cooper, P., & Taylor, B. (1987). Seismotectonics of New Guinea: A model for arc reversal following arc-continent collision. *Tectonics*, *6*(1), 53–67. https://doi.org/10.1029/TC006i001p00053

Danovaro, R., Gambi, C., & Della Croce, N. (2002). Meiofauna hotspot in the Atacama Trench, eastern South Pacific Ocean. *Deep Sea Research Part I: Oceanographic Research Papers*, *49*(5), 843–857. https://doi.org/10.1016/S0967-0637(01)00084-X

Davies, H. L., Honza, E., Tiffin, D. L., Lock, J., Okuda, Y., Keene, J. B., et al. (1987). Regional setting and structure of the western Solomon Sea. *Geo-Marine Letters*, *7*(3), 153–160. https://doi.org/10.1007/BF02238045

Davies, H. L., Keene, J., Hashimoto, K., Joshima, M., Stuart, J., & Tiffin, D. (1986). Bathymetry and canyons of the western Solomon Sea. *Geo-Marine Letters*, *6*(4), 181–191. https://doi.org/10.1007/BF02239579

de Leo, F. C., Smith, C. R., Rowden, A. A., Bowden, D. A., & Clark, M. R. (2010). Submarine canyons: Hotspots of benthic biomass and productivity in the deep sea. *Proceedings of the Royal Society B: Biological Sciences*, *277*(1695), 2783–2792. https://doi.org/10.1098/rspb.2010.0462

de Stigter, H. C., Boer, W., de Jesus Mendes, P. A., Jesus, C. C., Thomsen, L., van den Bergh, G. D., & van Weering, T. C. E. (2007). Recent sediment transport and deposition in the Nazaré canyon, Portuguese continental margin. *Marine Geology*, *246*(2–4), 144–164. https://doi.org/10.1016/j.margeo.2007.04.011

Eglinton, T. I., & Repeta, D. J. (2003). Organic matter in the contemporary ocean. In H. Elderfield (Ed.), *Treatise on geochemistry* (Vol. 6, pp. 151–158). Amsterdam: Elsevier. https://doi.org/10.1016/B0-08-043751-6/06155-7

Fryer, P. (1996). Evolution of the Mariana convergent plate margin system. *Reviews of Geophysics*, *34*(1), 89–125. https://doi.org/10.1029/95RG03476

Fujioka, K., Okino, K., Kanamatsu, T., & Ohara, Y. (2002). Morphology and origin of the Challenger Deep in the Southern Mariana Trench. *Geophysical Research Letters*, *29*(10), 1372. https://doi.org/10.1029/2001GL013595

Gallo, N. D., Cameron, J., Hardy, K., Fryer, P., Bartlett, D. H., & Levin, L. A. (2015). Submersible-and lander-observed community patterns in the Mariana and New Britain Trenches: Influence of productivity and depth on epibenthic and scavenging communities. *Deep Sea Research Part I: Oceanographic Research Papers*, *99*, 119–133. https://doi.org/10.1016/j.dsr.2014.12.012

Glud, R. N. (2008). Oxygen dynamics of marine sediments. *Marine Biology Research*, *4*(4), 243–289. https://doi.org/10.1080/17451000801888726

Glud, R. N., Gundersen, J. K., Jørgensen, B. B., Revsbech, N. P., & Schulz, H. D. (1994). Diffusive and total oxygen uptake of deep-sea sediments in the eastern South Atlantic Ocean: In situ and laboratory measurements. *Deep Sea Research Part I: Oceanographic Research Papers*, *41*(11–12), 1767–1788. https://doi.org/10.1016/0967-0637(94)90072-8

Glud, R. N., Gundersen, J. K., Revsbech, N. P., Bo, B. J., & Hüttel, M. (1995). Calibration and performance of the stirred flux chamber from the benthic lander Elinor. *Deep Sea Research Part I: Oceanographic Research Papers*, *42*(6), 1029–1042. https://doi.org/10.1016/0967-0637(95)00023-Y

Glud, R. N., Wenzhöfer, F., Middelboe, M., Oguri, K., Turnewitsch, R., Canfield, D. E., & Kitazato, H. (2013). High rates of microbial carbon turnover in sediments in the deepest oceanic trench on Earth. *Nature Geoscience*, *6*(4), 284–288. https://doi.org/10.1038/ngeo1773

Gordon, R. M., Coale, K. H., & Johnson, K. S. (1997). Iron distributions in the equatorial Pacific: Implications for new production. *Limnology and Oceanography*, *42*(3), 419–431. https://doi.org/10.4319/lo.1997.42.3.0419

Graf, G., Bengtsson, W., Diesner, U., Schulz, R., & Theede, H. (1982). Benthic response to sedimentation of a spring phytoplankton bloom: Process and budget. *Marine Biology*, *67*(2), 201–208. https://doi.org/10.1007/BF00401286

Grasshoff, K. (1983). Determination of oxygen. In K. Grasshoff, M. Ehrhardt, & K. Kremling (Eds.), *Methods of seawater analysis* (pp. 61–72). Weinheim: Verlag Chemie GmbH.

Hall, P. O. J., Brunnegård, J., Hulthe, G., Martin, W. R., Stahl, H., & Tengberg, A. (2007). Dissolved organic matter in abyssal sediments: Core recovery artifacts. *Limnology and Oceanography*, *52*(1), 19–31. https://doi.org/10.4319/lo.2007.52.1.0019

Hedges, J. I., Keil, R. G., & Benner, R. (1997). What happens to terrestrial organic matter in the ocean? *Organic Geochemistry*, *27*(5–6), 195–212. https://doi.org/10.1016/S0146-6380(97)00066-1

Hwang, J., Druffel, E. R. M., & Eglinton, T. I. (2010). Widespread influence of resuspended sediments on oceanic particulate organic carbon: Insights from radiocarbon and aluminum contents in sinking particles. *Global Biogeochemical Cycles*, *24*, GB4016. https://doi.org/10.1029/2010GB003802

Ichino, M. C., Clark, M. R., Drazen, J. C., Jamieson, A., Jones, D. O., Martin, A. P., et al. (2015). The distribution of benthic biomass in hadal trenches: A modelling approach to investigate the effect of vertical and lateral organic matter transport to the seafloor. *Deep Sea Research Part I: Oceanographic Research Papers*, *100*, 21–33. https://doi.org/10.1016/j.dsr.2015.01.010

Itou, M., Matsumura, I., & Noriki, S. (2000). A large flux of particulate matter in the deep Japan Trench observed just after the 1994 Sanriku-Oki earthquake. *Deep Sea Research Part I: Oceanographic Research Papers*, *47*(10), 1987–1998. https://doi.org/10.1016/S0967-0637(00)00012-1

Jahnke, R. A., Reimers, C. E., & Craven, D. B. (1990). Intensification of recycling of organic matter at the sea floor near ocean margins. *Nature*, *348*(6296), 50–54. https://doi.org/10.1038/348050a0

Jamieson, A., Fujii, T., Mayor, D. J., Solan, M., & Priede, I. G. (2010). Hadal trenches: The ecology of the deepest places on Earth. *Trends in Ecology & Evolution*, *25*(3), 190–197. https://doi.org/10.1016/j.tree.2009.09.009

Jamieson, A., Fujii, T., Solan, M., Matsumoto, A. K., Bagley, P. M., & Priede, I. G. (2009). Liparid and macrourid fishes of the hadal zone: In situ observations of activity and feeding behaviour. *Proceedings of the Royal Society B: Biological Sciences*, *276*(1659), 1037–1045. https://doi.org/10.1098/rspb.2008.1670

Kitahashi, T., Kawamura, K., Kojima, S., & Shimanaga, M. (2013). Assemblages gradually change from bathyal to hadal depth: A case study on harpacticoid copepods around the Kuril Trench (north-west Pacific Ocean). *Deep Sea Research Part I: Oceanographic Research Papers*, *74*, 39–47. https://doi.org/10.1016/j.dsr.2012.12.010

Leduc, D., Rowden, A. A., Glud, R. N., Wenzhöfer, F., Kitazato, H., & Clark, M. R. (2016). Comparison between infaunal communities of the deep floor and edge of the Tonga Trench: Possible effects of differences in organic matter supply. *Deep Sea Research Part I: Oceanographic Research Papers*, *116*, 264–275. https://doi.org/10.1016/j.dsr.2015.11.003

Meyers, P. A. (1994). Preservation of elemental and isotopic source identification of sedimentary organic matter. *Chemical Geology*, *114*(3-4), 289–302. https://doi.org/10.1016/0009-2541(94)90059-0

Nozaki, Y., & Ohta, Y. (1993). Rapid and frequent turbidite accumulation in the bottom of Izu-Ogasawara Trench: Chemical and radiochemical evidence. *Earth and Planetary Science Letters*, *120*(3–4), 345–360. https://doi.org/10.1016/0012-821X(93)90249-9

Oguri, K., Kawamura, K., Sakaguchi, A., Toyofuku, T., Kasaya, T., Murayama, M., et al. (2013). Hadal disturbance in the Japan Trench induced by the 2011 Tohoku–Oki earthquake. *Scientific Reports*, *3*(1), 1915. https://doi.org/10.1038/srep01915

Robison, B. H., Reisenbichler, K. R., & Sherlock, R. E. (2005). Giant larvacean houses: Rapid carbon transport to the deep sea floor. *Science*, *308*(5728), 1609–1611. https://doi.org/10.1126/science.1109104

Tengberg, A., Bovee, F. D., Hall, P., Berelson, W., Chadwick, D., Ciceri, G., et al. (1995). Benthic chamber and profiling landers in oceanography—A review of design, technical solutions and functioning. *Progress in Oceanography*, *35*(3), 253–294. https://doi.org/10.1016/0079-6611(95)00009-6

Tiffin, D. L., Davies, H. L., Honza, E., Lock, J., & Okuda, Y. (1987). The New Britain Trench and 149° embayment, western Solomon Sea. *Geo-Marine Letters*, *7*(3), 135–142. https://doi.org/10.1007/BF02238043

Turnewitsch, R., Falahat, S., Stehlikova, J., Oguri, K., Glud, R. N., Middelboe, M., et al. (2014). Recent sediment dynamics in hadal trenches: Evidence for the influence of higher-frequency (tidal, near-inertial) fluid dynamics. *Deep Sea Research Part I: Oceanographic Research Papers*, *90*, 125–138. https://doi.org/10.1016/j.dsr.2014.05.005

Watling, L., Guinotte, J., Clark, M. R., & Smith, C. R. (2013). A proposed biogeography of the deep ocean floor. *Progress in Oceanography*, *111*, 91–112. https://doi.org/10.1016/j.pocean.2012.11.003

Wenzhöfer, F., & Glud, R. N. (2002). Benthic carbon mineralization in the Atlantic: A synthesis based on in situ data from the last decade. *Deep Sea Research Part I: Oceanographic Research Papers*, *49*(7), 1255–1279. https://doi.org/10.1016/S0967-0637(02)00025-0

Wenzhöfer, F., & Glud, R. N. (2004). Small-scale spatial and temporal variability in coastal benthic O_2 dynamics: Effects of fauna activity. *Limnology and Oceanography*, *49*(5), 1471–1481. https://doi.org/10.4319/lo.2004.49.5.1471

Wenzhöfer, F., Oguri, K., Middelboe, M., Turnewitsch, R., Toyofuku, T., Kitazato, H., & Glud, R. N. (2016). Benthic carbon mineralization in hadal trenches: Assessment by in situ O_2 microprofile measurements. *Deep Sea Research Part I: Oceanographic Research Papers*, *116*, 276–286. https://doi.org/10.1016/j.dsr.2016.08.013

Wilson, S. E., Ruhl, H. A., & Smith, K. L. (2013). Zooplankton fecal pellet flux in the abyssal northeast Pacific: A 15 year time-series study. *Limnology and Oceanography*, *58*(3), 881–892. https://doi.org/10.4319/lo.2013.58.3.0881