Earthquake-induced redistribution and reburial of microbes in the hadal trenches

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GRAPHICAL ABSTRACT

PUBLIC SUMMARY

- Earthquake-triggered turbidites bring allochthonous microbes into the hadal trenches.
- Evidences of vertical microbial redistribution are observed in the trench sediments.
- Earthquake introduce large amount of microbial biomass carbon into the subduction zones.
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INTRODUCTION

Microorganisms residing in the deep biosphere account for more than 50% of the total biomass on Earth and play vital roles in the global carbon cycles. The hadal trenches harbor a thriving microbial population that serves as a critical link between the Earth’s surface and deep biosphere. These microbes are engaged in various deep-sea geosphere-biosphere interactions with unique metabolic pathways and consequently, regulate the carbon dynamics on plate convergent margins. Tectonic processes have been shown to impact the evolution of the deep biosphere over geological timescales. The occurrence of frequent earthquakes due to plate convergence movements, such as unstable sliding at the plate interface, episodic stress release and seismic slip in the hadal trenches, can potentially stimulate microbial activity and abundance in subsurface sediments. Our discovery highlights the impacts of tectonic processes on carbon dynamics and deep biosphere in the hadal trenches, where sedimentary OC, including microbe-mediated OC, may be transported into the subduction zone.

RESULTS AND DISCUSSION

Distinct archaean communities in the event deposits indicative of turbidite sources

Emerging research suggests that material input, transport, and deposition in the hadal trenches are significantly driven by earthquakes. Remobilized microorganisms brought into the JT can be identified through their distinct community structures. Cores GeoB16431 (water depth 7542 m) and GeoB21804 (water depth 8025 m) from the central and south JT, respectively, were demonstrated the impact of earthquake-triggered turbidites on the microbial redistribution in the hadal area, and emphasized the amount of microbial biomass carbon reburial caused by earthquakes. Our discovery highlights the impacts of tectonic processes on carbon dynamics and deep biosphere in the hadal trenches, where sedimentary OC, including microbe-mediated OC, may be transported into the subduction zone.
**Candidatus Nitrosopumilus** in T1 and T3 turbidites of GeoB16431 (Figure 1B) indicates that these turbidites are composed of mostly remobilized oxic surficial sediments at the sea floor instead of deep subsurface sediments. Comparing to T1 and T3 turbidites, higher proportion of the anaerobic Lokiarchaeia in T2 turbidite implies a turbidite flow sourced from subsurface anoxic sediments. These observations suggest the potential of using variations of microbial community structures, together with lithological characteristics, short-lived radioisotopes and organic geochemical parameters as indicators for sediment provenances of the earthquake-triggered turbidites. The analysis of the microbial community signals preserved in the sediments can provide new insights into the redistribution of microorganisms and sedimentary OC within the hadal zone.

The abundances and metabolic potentials of bacteria and archaea in deep-sea environment has been under debate. While bacteria constitute most of the microbial biomass carbon (MBC) in marine sediments, researches have shown that archaea may have more significant contribution to deep subsurface sediments. In contrast to the archaean communities, the bacterial communities in the JT seem to be less regulated by the event turbidites (see Figure S1). On the other hand, the bacterial species richness in the background deposits decreases with increasing depth, whereas the archaean species richness in the background deposits, albeit low, decreases at a much lower rate (Figure S2). The observation that the composition of the archaean community changes in response to earthquake disturbances, but does not exhibit significant loss in species richness in the subsurface sediments, implies that archaea in the trench sediments have better adaptability and less-inhibited metabolic activity under irregular disturbance (i.e., event turbidites).

**Vertical archaean community redistribution relevant to OC characteristics**

The microbial composition and function change along with food availability and nutrient conditions in marine sediments. In the hadal trenches, trench locations and water depths are inferred to regulate the distribution of microorganisms in the sediments through determining the amount and characteristics of sedimentary OC. Indeed, the redundancy analysis suggests that the archaean community compositions are strongly coupled with sedimentary OC characteristics inside the turbidite deposits. However, the distribution of microbial communities in trench sediments may not resemble the natural succession of microbial communities under a relatively stable environment, where the microbial distribution is regulated by sedimentary redox conditions. Instead, the source heterogeneity of turbidites is a more powerful regulator on the microbial distribution in a frequently-disturbed hadal environment like JT.

Variations of archaean communities in JT sediments suggest that the OC characteristics determined by turbidite sources may exhibit small spatial scale influences on the microbial communities. The Bray-Curtis Dissimilarity is sensitive to the abundance difference between microbial species, and has been widely used to quantify the microbial compositional dissimilarity in geological and ecological studies. In the Bray-Curtis Dissimilarity matrix of core GeoB16431 (Figure 3), the microbial communities within each turbidite deposit exhibited similar community structures as indicated by relatively small Bray-Curtis Dissimilarity values. Conversely, the archaean communities in the background deposits were less similar to those in the adjacent sediments. Interestingly, similar community structures (indicated by small Bray-Curtis Dissimilarity values) were observed between T1 turbidite and the background deposits below (within ~20 cm), as well as...
between T2 turbidite and the background deposits above (within ~90 cm) and below (within ~100 cm) in GeoB16431 (Figure 3).

The observed similarities in archaeal communities between turbidite and background deposits cannot be simply attributed to sediment mixing caused by ground-shaking or bioturbation, as such similarity is not observed among the bacterial communities (Figure S3). Instead, they suggest archaeal lineage redistribution between the turbidite and background deposits in the JT sediments. After turbidite deposition, sediment compression results in porewater flowing into adjacent sediments, providing opportunities for microbial redistribution via upward seepage. Motility of some microbial lineages also aid in microbial redistribution between different depth horizons. Additionally, some lineages may be dormant or take up only minor proportions in background sediments, but increase their population under transient nutrient pulses stimulated by turbidite deposition. These proposed mechanisms for the observed microbial redistribution are potentially driven by changing OC characteristics between turbidite and background deposits. For instance, the low total organic carbon (TOC) content, high C/N values and old δ13C ages in T2 turbidite (Figure 2A) indicate the recalcitrance of the earthquake-remobilized OC. In contrast, OC in the background hemipelagic deposits is mainly derived from phytoplankton and has higher bioavailability. Microbes in T2 turbidite with tolerance to low nutrient level may colonize the adjacent background deposits in response to the high nutrient concentrations. Redistribution in an opposite direction may also occur, as microbial preference for the terrestrial, refractory OC is observed in trench environments. In the meantime, distinct characteristics of sedimentary OC in turbidites may hinder microbial migration (e.g., limited redistribution in T3 turbidite, Figure 3).

Variations of earthquake-induced MBC reburial in the trenches

Our study discovers the redistribution of unique microbial communities caused by earthquake-triggered turbidites in the JT, and demonstrates the role of episodic events in efficiently transplanting microorganisms into the hadal trenches. However, the amount of earthquake-induced MBC burial in the trenches remains uninvestigated. Our estimated amounts of MBC in T1, T2 and T3 turbidites of GeoB16431 are 4 (+0.5/−0.5), 18 (+9.8/−8.2) and 13 (+7.5/−6.5) t, respectively (Table S1, see Method for calculation). Differences between the MBC burial by each earthquake at certain location are regulated by the thickness of the turbidites and OC composition of the source sediments, which are controlled by modes of earthquakes and sediment transport processes (e.g., surficial remobilization and seismic strengthening). On the other hand, the event sequences in GeoB16431 and GeoB21804 provide a sharp contrast regarding the spatial differences of earthquake-induced MBC burial in the JT. Compared with GeoB16431, GeoB21804 received approximately 70 times greater volume of sediments remobilized by the AD 2011 earthquake. The spatial difference of turbidite volume along the JT is caused by variations of canyon connection, proximity to the megathrust displacement area, earthquake occurrence and sedimentation rate of the source (i.e., slope) area. The thickest AD 2011 turbidite deposit was observed at GeoB21804 in southern JT (Figure S4). As a consequence,

Figure 2. Comparisons of archaeal β-diversity and OC characteristics between the turbidite and background deposits. (A) Box plot of archaeal species richness (indicated by Chao1 Index), diversity (indicated by Shannon Index) on OTU level, and organic geochemistry parameters of sedimentary OC in cores GeoB16431 and GeoB21804 (from this study and refs. [7,19]). The center line denotes the median value and the center dot denotes the average value. The box contains 3/4 of dataset, with the whiskers mark the 5th and 95th percentiles. Values beyond these upper and lower bounds are marked with dots. (B) Results of redundancy analyses on OTU level. The microbial communities within each turbidite are correlated with different characteristics of the sedimentary OC (e.g., TOC of T1 turbidite and δ13C of T2 turbidite in core GeoB16431), indicating regulation of sedimentary OC on the microbial distribution in the turbidite deposits.

Figure 3. Result of archaeal Bray-Curtis Dissimilarity analysis on OTU level of GeoB16431. The turbidite deposits are indicated by color and background deposits by gray. Smaller Bray-Curtis Dissimilarity values, indicative of high community structure similarities, are observed within each turbidite deposit, between T1 and the background deposit below, and between T2 with adjacent background deposits. Microbial redistributions across these boundaries are indicated by arrows.
the MBC reburial caused by the AD 2011 earthquake reaches remarkable 409 (+110/−76) t in the southern JT (Table S1). These contrasts suggest that turbidite source and TOC content are potentially crucial regulators of the MBC reburial in the JT.

Estimation of earthquake-induced MBC burial in the Circum-Pacific seismic belt area during the past century exhibits further spatial diversities (Figure 4). The Pacific subduction zones have buried ~5.1 Pg (S140 t, Table S2) of earthquake-induced MBC since 1900, with 66% delivered into the north and west Pacific subduction zones. The global variation of earthquake-induced MBC reburial indicates that both high earthquake frequency (e.g., Kermadec and Japan Trenches) and high TOC content of the event turbidites (e.g., Chile Trench) can result in high MBC input into the trenches. The east Pacific trenches receive large amount of MBC due to the high TOC content of the remobilized sediments, despite that the earthquake frequency in this region is relatively low (Figure 4). On the contrary, the high earthquake frequency at the Kuril, Kamchatka and New Britain Trenches contributes to the high earthquake-induced MBC reburial (Figure 4). The Aleutian Trench represents those that receive OC-rich sediments at high frequencies, thereby receive moderately high MBC. Notably, most trenches in the north-west Pacific (e.g., Izu-Bonin, Marianas, Yap Trenches) have minor earthquake-induced MBC. These trenches generally receive less OC due to their remote distance from land[16,19] and have low earthquake frequencies, rendering the JT the most prominent location of earthquake-induced MBC reburial in the west Pacific.

Our preliminary estimations, albeit complicated by large uncertainties, emphasize the magnitude and variation of the MBC reburial in the global trenches driven by tectonic events. The compositions of the OC and microbial communities transported by event turbidites are largely controlled by the varying depositional settings of the global trenches (proximity to land, surface primary production, geomorphology, etc.). The tectonic events at plate boundaries, on the other hand, determine the magnitude and frequency of earthquakes and thus sediment remobilization. Open questions remains whether earthquake magnitude or frequency regulates the earthquake-induced MBC burial in the trenches. The elusive pattern of giant earthquake-driven MBC. These trenches generally receive less OC due to their remote distance from land[16,19] and have low earthquake frequencies, rendering the JT the most prominent location of earthquake-induced MBC reburial in the west Pacific.

REFERENCES
REPORT

Geophys.  **55**  97–125.


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AUTHOR CONTRIBUTIONS

R.B. designed the study and provided funding. R.B. and M.C. conducted the main analysis, wrote the manuscript and drew figures. A.K. and M.S. helped in sample acquisition and manuscript improvement. J.L. and H.L. helped with data interpretation. N.W. and C.X. provided technical support. All authors contributed to manuscript revision.

DECLARATION OF INTERESTS

The authors declare no competing interests.

DATA AND MATERIALS AVAILABILITY

See Supplemental Information for details.

DATA AND CODE AVAILABILITY

Sequencing data used in this study have been uploaded to NCBI (PRJNA898593).

SUPPLEMENTAL INFORMATION

It can be found online at https://doi.org/10.5971/jxim-geo.2023.100027

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