

Methane Seep Contribution to Sedimentary Organic Matter in Puget Sound, Washington

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Abstract

Marine sediments are a critical carbon reservoir, locking both inorganic and organic carbon in sediments for thousands to millions of years. This carbon is released through the production of methane (CH_4) at methane seeps, places where methane gas or dissolved methane is emitted from the seafloor. This study quantified the amount of organic matter (OM) stored in Puget Sound sediments at a methane seep site and future publications will characterize source differences of OM and the amount of inorganic carbon stored in sediments. A multicorer collected sediment samples from the R/V Rachel Carson at two sites in December of 2023: the Alki Point methane vent field and a control site within the Main Basin of Puget Sound. Onboard, sediment cores were subsampled in 2-cm sections downcore and stored for later analysis. Analyses included physical parameters (grain size, percent loss on ignition (% LOI), and ^{210}Pb sediment dating) and geochemical parameters (Total Organic Carbon (TOC), Total Carbon (TC), $\delta^{13}C_{TOC}$, $\delta^{13}C_{TC}$). Presently, analyses for ^{210}Pb , TOC, TC, $\delta^{13}C_{TOC}$, and $\delta^{13}C_{TC}$ are still in the processing phase and data has not been received yet. Both sites were silt-dominated (mean grain size: Alki = 37 microns, Control = 30 microns), with a well-mixed layer of 15 cm thickness. Sediments had an average of 7.5% OM at the methane seep and an average of 6.9% at the control site, measured using the % LOI method. The methane seep core had both a larger mean grain size and a higher % OM above 15 cm, which is inconsistent with established literature that has proven that sediments with larger mean grain sizes typically have a lower amount of organic matter. Further analyses, including the analyses listed above, are needed to determine the cause of this anomaly. Given the amount of carbon they store and the potential for these reservoirs to be disturbed by bottom trawling, deep sea mining, and other invasive human activities, understanding how carbon is cycled through marine sediments is critical for preserving these reservoirs and adequately factoring their role in the carbon cycle into global climate models.

Plain-Language Summary

Marine sediments store large amounts of carbon for periods of thousands to millions of years, where it remains generally undisturbed and unable to return to the water column or atmosphere and influence processes like climate change and ocean acidification. Understanding how carbon is cycled through sediments in both organic (contains C-H bonds) and inorganic (carbonate) form is important for climate scientists to be able to adequately predict the effects that human activities such as bottom trawling and deep sea mining could have on that carbon. This study aimed to quantify the amount of carbon stored as organic matter in Puget Sound sediments at a methane vent site, defined as a location on the seafloor where methane gas is released from some sub-sediment reservoir deep beneath the sediment-water interface, along with how that organic matter ended up being stored in the sediment. This study found that organic matter was, on average, higher at the methane vent site, and that organic matter decreased in

abundance the deeper it was found in the sediment. Further analysis is needed in order to determine how the carbon that was measured in Puget Sound sediments ended up there.

Introduction

Methane (CH₄) from both terrestrial and marine sources is the second most abundant greenhouse gas in earth's atmosphere, accounting for 20% of global anthropogenic greenhouse gas (GHG) emissions, and is 25 times more potent at trapping heat in Earth's atmosphere than carbon dioxide (CO₂) (EPA.gov). Naturally-produced CH₄ emissions make up about 40% of the 576 Tg (5.76×10^{-1} Gt) CH₄ emitted to the atmosphere every year, and are sourced from a wide range of ecosystem processes, including wetlands, termites, and methane seeps on the ocean floor (Saunio et al., 2020). The seafloor of Puget Sound, a glacially carved deep fjord estuary, is home to 349 recently identified methane bubble plumes, whose source is yet to be determined (Fig 1.) (Johnson et al., 2021). Alki Point methane vent field, located in Puget Sound offshore of West Seattle, has presently been the subject of the majority of studies conducted on Puget Sound methane vents. Methane plumes in Puget Sound are estimated to emit 27 metric tons (2.7×10^{-6} Tg) of methane to the surrounding seawater every year, which raises estuary-wide concentrations of dissolved methane, feeds methanotrophic microbes, and contributes to global climate change by emitting methane to the atmosphere (Johnson & Liu, manuscript in preparation, 2023). Furthermore, methane seeps occur worldwide, indicating that this process may be important to understanding carbon cycling on a global scale. The amount of atmospheric emission of methane from submarine seeps globally is currently estimated at 7 Tg CH₄ yr⁻¹ (Etiope et al., 2019).

Marine sediments are a critically important carbon reservoir. Just the top 1m of global ocean sediments are estimated to store 2.3103×10^3 Tg carbon on a time scale of hundreds to thousands of years (Atwood et al., 2020), although the impacts of many different factors on sedimentary carbon storage, including methane venting, remain unknown. Therefore, quantifying the amount of carbon stored in different ecosystems and sedimentary environments is critically important to understanding the global carbon cycle and individual ecosystems' roles in buffering the effects of climate change. However, I know of no published studies in Puget Sound that quantify sedimentary carbon storage at methane vent sites.

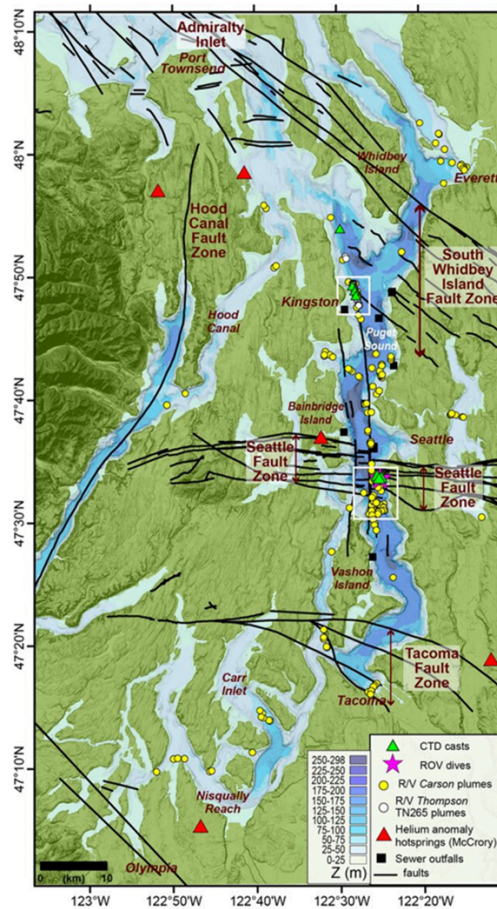


Figure 1. Map of all known methane plumes in Puget Sound (Johnson et al. 2021).

Methods

Coring

To measure differences in organic matter in Puget Sound sediments, an Ocean Instruments multi-corer sampled sediment at two sites in Puget Sound on December 2nd and 3rd, 2023 off of the R/V Rachel Carson: one on the Alki Point methane vent field (core BP2) and the other, our control site, in the main basin of Puget Sound (core R) (Figure 2a). Site R was chosen due to its location away from methane vents, known turbidite deposits, and tsunami deposits. To avoid grain size bias, we chose a location predicted to have a similar grain size based on grain size analysis conducted by Hoang et al., 2023 (Figure 2b). At the methane seep site, presence of methane plumes was confirmed through visualization using single-beam sonar. Similarly, a lack of methane plumes were observed on sonar at the control site. Once the multi-corer was brought onboard, cores were sliced into 2 cm subsections and stored in plastic bags for later analysis. All subsequent analyses were done with 2 cm binned resolution.

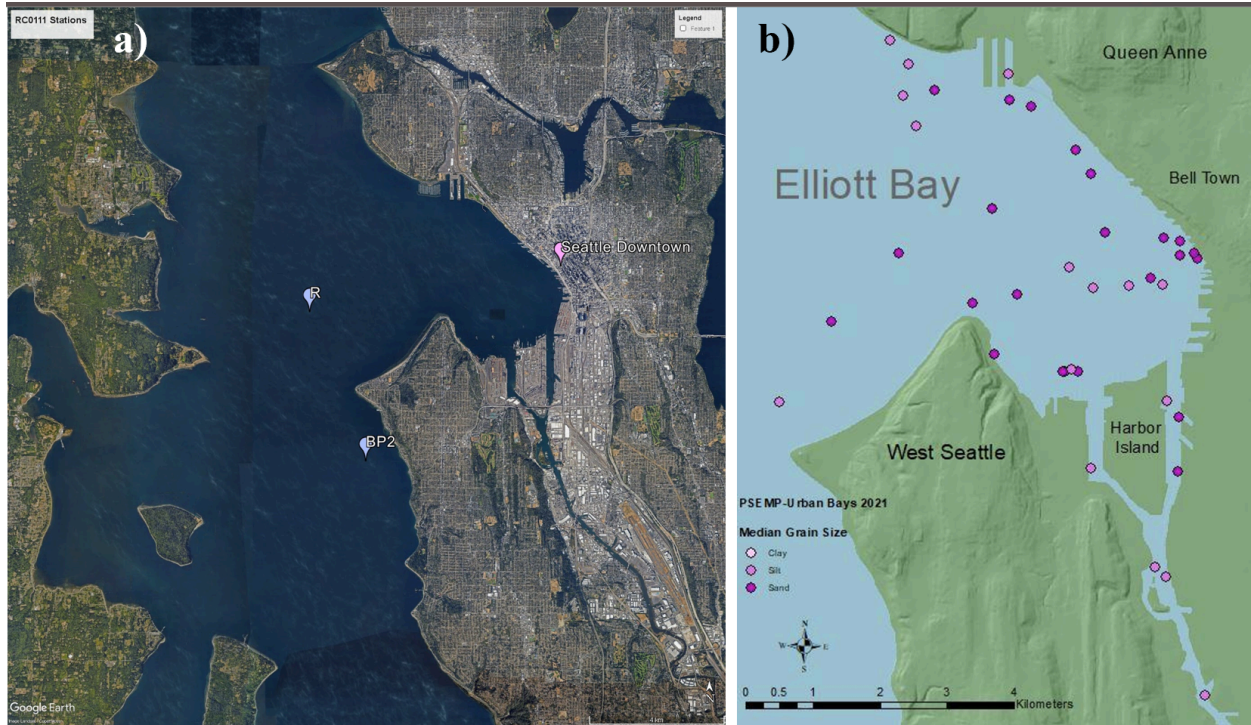


Figure 2. a) Map of two multi-core sites R and BP2, in reference to downtown Seattle. b) Sediment characterization by study site (Hoang et al., 2023).

Grain Size, % Loss on Ignition (% LOI)

Analysis of grain size and % LOI was done at the Sediment Dynamics Lab at the University of Washington. To analyze sediment for organic matter using the % LOI method, samples from each 2cm subcore were dried at 60°C until all moisture was removed and then ground to eliminate large chunks. Next, approximately 1 gram of sediment was added to a pre-weighed crucible and the precise mass was recorded prior to combustion. The samples were then combusted in a muffle furnace at 500°C for 4 hours and weighed again. The difference between the pre-combusted mass and post-combusted mass is the amount of organic matter present in the sample (Dean, 1974). % LOI was calculated using the following equation:

$$\% \text{ LOI} = \frac{(\text{Pre-combustion weight} - \text{Post-combustion weight})}{(\text{Pre-combustion weight} - \text{Crucible Weight})} \times 100$$

Grain size analysis was conducted using a LS13-320 Coulter Counter. 1-gram samples from each 2cm subcore were dissolved in dispersant and sonicated, and the DS50 mean for each sample was used for the plots below (Blott and Pye, 2001).

Results

Sites R and BP2 were both well-sorted and silt-dominated, with an average grain size at BP2 of 37 microns and an average of 30 microns at site R. Both sites have a well-mixed layer (the top section of a core where the grain size is internally constant) consisting of roughly the top 15 cm, but core BP2 decreased in grain size with depths deeper than 15 cm and core R increased in grain size with depths deeper than 13 cm (Figure 3a). Site BP2 had a range of 31.3 microns, and site R had a range of 27.4 microns.

Organic matter (% LOI) was higher at site BP2 than the core site by 0.6%. Site BP2 had an average of 7.5%, and site R had an average of 6.9%. The range of % LOI at BP2 was 1.1%, and the range at R was 1.5%. Organic matter generally decreases with depth at both sites, but the trend is not linear. There are a substantial amount of jumps in the data by 0.5% or more from datapoint to datapoint (Figure 3b). While site BP2 has a consistently higher % LOI above 15 cm, that trend dissipates below 15 cm, and % LOI values begin to overlap. Below 15 cm, control site R has a similar or greater % LOI value than BP2 at 4 depths.

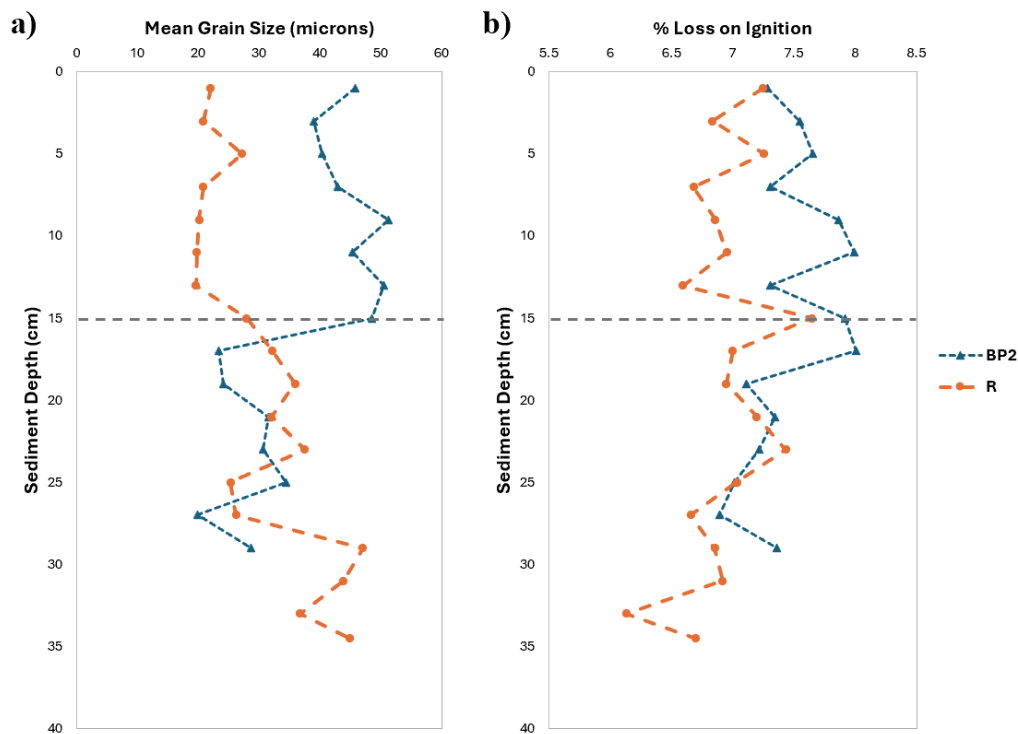


Figure 3. a) Sediment depth profile of mean grain size at sites BP2 and R. b) Sediment depth profile of % Loss on Ignition at site BP2 and R. The mixed-layer depth, roughly 15 cm, is marked with a dotted gray line.

Discussion

Data gathered from our cores is consistent with established literature stating that organic matter gradually breaks down in the sediment column due to early diagenetic processes (Henrichs, 1992), which is observed in our cores through the downward trend in % LOI as samples increase in sediment depth. The mixed-layer sediment depth is likely due to bioturbation, as biology such as worms and clams were observed at both sites.

The methane seep core had both a higher % LOI and a higher grain size above 15 cm, which is anomalous with established literature that has found that sediment grain size and organic matter content are inversely related. Sediments with larger grains tend to have a lower total surface area per unit volume, meaning that there is less surface area available for organic molecules to adsorb to. The cause of this anomaly is currently unknown, and further analyses are needed to determine whether the presence of methane venting at the BP2 site has a significant influence on the source of organic matter stored in sediments there. Two potential pathways for methane to affect the amount of organic matter stored in sediments at a seep site are a) adsorption of dissolved methane onto particle surfaces, and b) oxidation of methane by microbes on the surface of the seafloor, where it has been visually identified to form microbial mats (Fig. 4) that can contribute to sedimentary organic matter. Genetic sequencing may be undertaken in future studies to determine community composition of suspected bacterial mats and confirm whether those communities are being fed by the methane emitted from seeps.

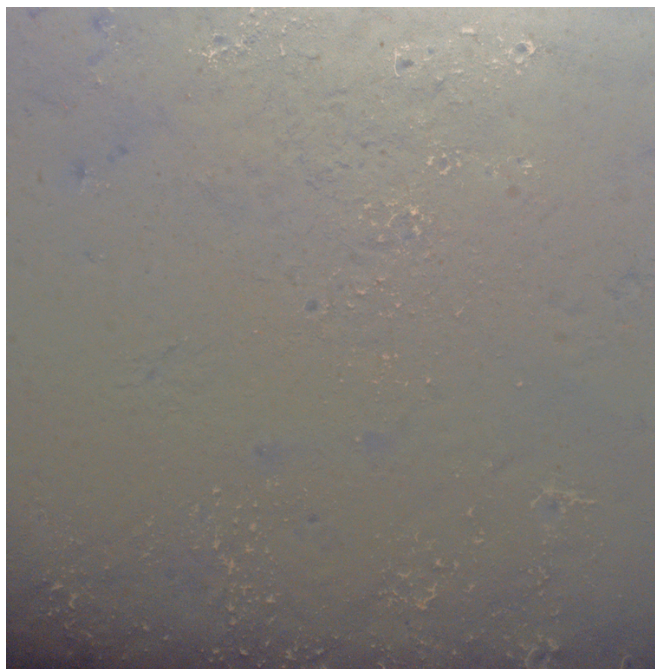


Figure 4. Suspected bacterial mats observed by ROV video at the Alki Point methane seep site.

Further analysis, including TOC, TC, and $\delta^{13}\text{C}$ are needed to determine the source of organic matter at the methane seep and our reference site. Replicates of % LOI measurements will also provide an additional degree of confidence in our assessments, and will also allow for the calculation of uncertainty. In addition to further chemical analyses, taking additional cores at the Alki vent field and at various control sites in Puget Sound would strengthen our ability to draw conclusions about the cause of observed differences in organic matter.

Conclusion

The results of this study align with previous literature describing trends of organic matter degradation with depth. Our methane seep site, BP2, showed trends of higher organic matter compared to our control site R. Further analysis, including replicates of % LOI and additional measures of organic matter, will determine if the observed differences in organic matter at site BP2 are statistically significant. Future iterations of this study will include measurements of $\delta^{13}\text{C}$ stable carbon isotope measurements, which will allow determination of whether the organic matter stored in sediments at site BP2 are depleted in ^{13}C . This would reflect that a significant amount of the organic material is at least partially sourced from the methane seep.

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