

Determining the magnitude, controls, and mediators of microbial activity in shelf to abyssal marine sediments and implications for deep time

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Marine sediment microorganisms comprise up to a third of the Earth's total living biomass [1] and influence atmospheric O₂ and CO₂ concentrations on geologic timescales. Despite considerable recent advances, significant questions regarding the magnitude, physicochemical controls, and mediators of benthic microbial activity remain unresolved, particularly in deep-sea sediments. Here, we combined 16S rRNA sequencing with nearly 300 ¹⁵N- and ¹³C- tracer experiments to determine the rates and controls of total microbial anabolic activity, heterotrophy, autotrophy, and nitrogen fixation in sediments from 100–4500 m water depth in the northeastern Pacific and northwestern Atlantic Oceans, and modeled global anabolic activity rates from the Devonian to the present. We show that ammonium assimilation rates – a proxy of total anabolic activity – range from 0 to 0.20 nmol N ml⁻¹ y⁻¹, and correlate with distance from shore, chlorophyll a concentrations in the overlying water column, and depth in sediment. Although benthic nitrogen fixation was previously detected at deep-sea sites of anomalous carbon loading (e.g. in oxygen minimum zones, methane seeps, and whale fall sites [2, 3]), ¹⁵N₂ assimilation was undetected in all samples, even with the addition of glucose. Generally, 10–20% of the microbial community's carbon assimilation was due to autotrophy. These nitrogen fixation and autotrophy data, as well as the results from experimental additions, are consistent with a benthic microbial community that is limited by carbon and/or energy availability, not by bioavailable nitrogen. The microbial communities are dominated by the activity of Deltaproteobacteria, particularly from the Desulfobacterales and Desulfurellales orders. Although these orders are associated with sulfate reducing bacteria, no sulfate reduction was detected in any samples, suggesting they use alternative metabolisms such as fermentation. We modeled the global distribution of microbial activity today (Figure 1) and extrapolated to the geologic past, and find that the magnitude of global benthic microbial activity is sensitive to supercontinental cycles, with implications for marine sediment organic carbon burial through deep time.

[1] Lipp et al. (2008), *Nature* 454, 991–994.

[2] Dekas et al. (2018), *Environmental Microbiology* 20, 4281–4296.

[3] Gier et al. (2016), *Biogeosciences* 13, 40654080.

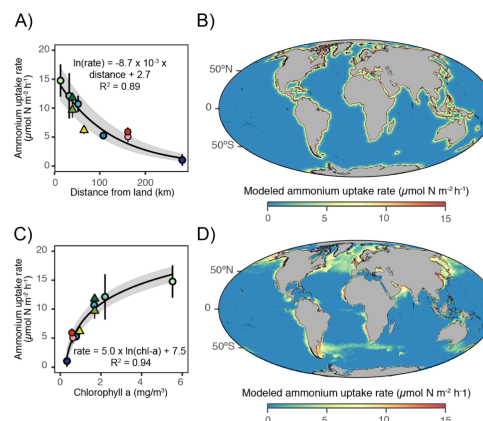


Figure 1: Global estimates of marine sediment microbial anabolic activity. A) Regression of distance from land and depth-integrated ammonium assimilation rates for the top 15 cm below the seafloor. Regression equation and R² are indicated. Error bars = 1 SD of the biological replicates. The grey ribbon represents the model's 95% confidence interval. B) Map of extrapolated, global ammonium assimilation rates using the regression in A. Total ammonium assimilation rate is 54 Tg N per year [42, 70 Tg N y⁻¹; 95% confidence interval]. C) Regression of satellite MODIS chlorophyll-a concentrations and integrated ammonium assimilation rate. Data are the same as in panel A. D) Map of extrapolated, global ammonium assimilation rates using the regression in C. Total ammonium assimilation rate is 39 Tg N per year [30, 51 Tg N y⁻¹].