Effect of methane gas phase dynamics on the coupled methane-sulfur cycles in the subsurface

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Introduction

Ocean sediments represent the greatest CH4 reservoir on the planet. Nevertheless, their CH4 contribution is negligible towards the ocean-atmosphere system (fig. 1). This is due to the microbial process of anaerobic oxidation of methane (AOM), which acts as an efficient subsurface CH4 barrier and thus an important climate regulator. Our scope is to investigate the efficiency and behavior of AOM with respect to the dynamics of free methane gas (CH4(g)).

Comparison to field data - Profiles

Fig. 3 shows measured (Martens et al., 1998) and simulated CH4 (aq) and SO42- profiles for Eckernförde Bay sediments (Kiel Bight, Germany) at steady state. Supersaturation due to high MET rates leads to CH4(g) which is transported upwards and dissolves in undersaturated areas near the sulfate-methane transition zone (SMTZ). Gas results are compared to acoustic sounder profiles (fig. 3 left color column) collected by Wever et al., (2006).

Gas effects on AOM

Increasing POC fluxes lead to shallower SMTZs which amplify the zone of MET and thus the CH4(g) generated. Upward CH4(g) migration increases the diffusive flux and consequently the AOM intensity (fig. 5). In a system that ignores (implicit - fig. 5) the dynamics of CH4(g), the integrated AOM rate underestimation increases exponentially with higher POC fluxes, demonstrating the importance of CH4(g) feedbacks on AOM (Mogollón et al., 2008).

Predicting CH4 fluxes from MBD

The strong correlation between the MBD and CH4 fluxes to the SMTZ can lead to predictions of the CH4(g) turnover rates (integrated AOM rates) when CH4(g) escape from the sediment is negligible. Dale et al., (2008) developed MBD-CH4 flux curves for various CH4 saturations based on acoustic survey profiles (a standard mapping technique) and measured AOM rates. Our preliminary seasonal simulations show the same effect (fig. 7).

Conclusions

- CH4(g) produced in shallow sediments with high POC content has a greater propensity towards migration than dissolved methane. - CH4(g), transport effectively delivers CH4 to the SMTZ and leads to increased AOM rates. - AOM in Eckernförde Bay is strong enough to consume both dissolved and gaseous methane leading to negligible gas escape into the water column. - Understanding CH4(g) dynamics can lead to the development of cost-effective tools that can predict CH4 fluxes and integrated AOM rates.

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References:
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Conceptual model

Particulate organic carbon (POC) degradation coupled to SO42- reduction takes place in the upper parts of the sediment. Once SO42- is consumed, methanogenesis (MET) begins and generates CH4 (aq) in the deeper layers of the sediment. When CH4 (aq) exceeds the in situ solubility, CH4(g) forms. Buoyancy leads to upward gas flow, and dissolution takes place in the overlying undersaturated sediment layers where CH4 (aq) is consumed by AOM (fig. 2).

Comparison to field data - Rates

CH4 fluxes towards the SMTZ feed the microbial community performing AOM. In systems with high POC fluxes to the sediment-water interface (SWI), the transport and dissolution of CH4(g) in methane-depleted areas produces a steep CH4 gradient which maintains high CH4 diffusive fluxes. Thus, in systems where CH4(g) AOM rates are high and may even overshadow sulfate reduction rates (fig. 4).

Seasonal variations in CH4(g)

Variations in temperature at the SWI (fig. 6a) lead to heat diffusing into the sediments. The heat capacity of the sediment produces lag times reflected in both the temperature profiles (fig. 6b) and the monthly variations in the methane bubble depth (MBD) (fig. 6c). In the early winter, when the gas is shallowest, the propensity for CH4(g) escape increases.