

Fading of a sulfate-methane transition in deep and hot subseafloor sediments from the Nankai Trough

SPP527 Project 388260220 (2017-2022): Examining the role of biotic iron reduction as a life-sustaining process at the potential temperature limit of the deep subseafloor biosphere (IODP Expedition 370) (RESPIRE)

Background

Microorganisms in subseafloor sediments face extreme energy limitation and increasing temperatures with ongoing burial^{1,2}. To study the effect of increasing temperature on microbial communities, International Ocean Discovery Program (IODP) Expedition 370 drilled Site C0023 down to 1,180 mbsf in the Nankai Trough off Japan³. A key feature is an inverse sulfate-methane transition (SMT) with high methane concentrations above 700 mbsf and increasing sulfate concentrations at greater depths⁴. Here, we used reactive transport modeling^{5,6} to reconstruct the evolution of biogeochemical processes, particularly the deep inverse SMT, along the tectonically induced migration and the ongoing burial and heating of the sediments.

Results

Evolution of biogeochemical processes in the past

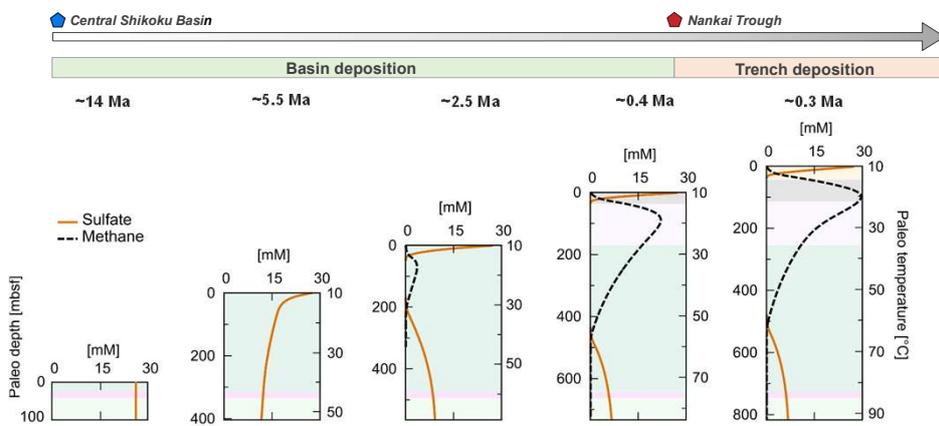


Fig. 3: Snapshots of simulated depth-profiles of sulfate and methane derived from the reactive transport model^{11,12}

- Low organic carbon burial prevents complete sulfate consumption; sulfate is preserved
- Increase in carbon burial and onset of biogenic methanogenesis (MG) and anaerobic oxidation of methane (AOM)
- Formation of shallow and deep inverse SMT
- Enhanced biogenic MG due to elevated carbon burial and increase in temperature
- Up- and downward migration of shallow and inverse SMT

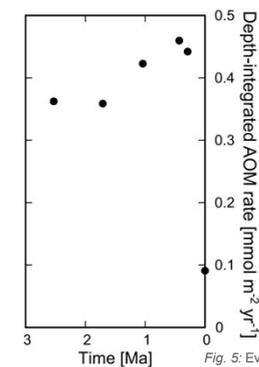


Fig. 5: Evolution of depth-integrated AOM rate at the deep inverse SMT since the onset of AOM at ~2.5 Ma¹¹

- Decrease in depth-integrated AOM rate (Σ AOM) since the beginning of trench deposition and the associated rapid heating
- Microbial activity of AOM-performing communities has already started to cease and the SMT gradually disappears

Study Site

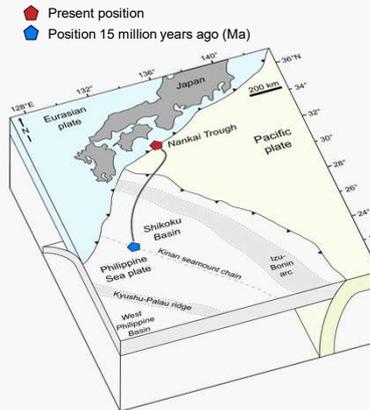


Fig. 1: Relative movement of Site C0023 over the past 15 Ma (modified after^{3,8,9}). The Nankai Trough offshore Japan marks the subduction boundary between the Philippine Sea plate and the Eurasian plate

- Site C0023 moved ~750 km from the central Shikoku Basin to the Nankai Trough due to tectonic motion⁷

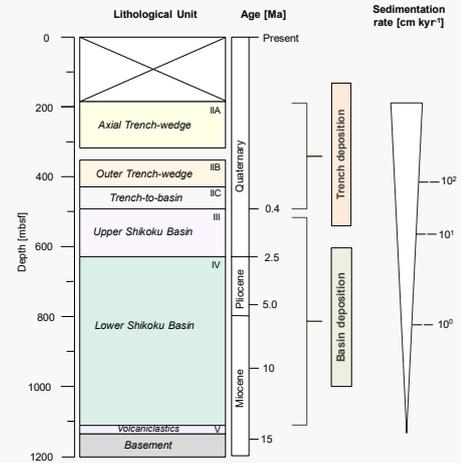


Fig. 2: Lithological units³ and associated sedimentation rate of Site C0023¹⁰

- Shift from basin to trench deposition led to increase in sedimentation rate¹⁰ and temperature⁴
- Geothermal gradient: 110°C km⁻¹

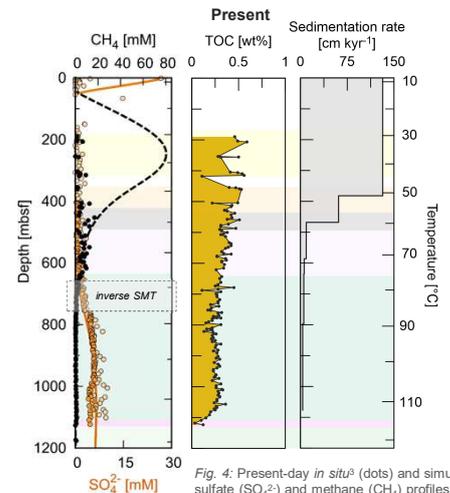


Fig. 4: Present-day *in situ* (dots) and simulated¹¹ (lines) sulfate (SO_4^{2-}) and methane (CH_4) profiles, total organic carbon (TOC) contents³ and sedimentation rates¹⁰

- Broad sulfate-methane overlap zone of ~100 m suggests inefficient AOM at the deep inverse SMT at present
- Depth interval corresponds to a temperature of 80° to 85°C, coinciding with the known thermal limit of AOM-performing microorganisms^{13,14}

Conclusion

Our study demonstrates that sediment temperature strongly controls the rates of biogeochemical processes and microbial activity, especially in deposits of subduction zones (e.g., Nankai Trough) that are characterized by a high geothermal gradient. We therefore recommend considering changes in temperature and their impact on rate constants as a consequence of the local burial history of such sediments to improve the reconstruction of pore-water and sedimentary records.

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