Cryptic oxygen control on methane oxidation and production – more than just one methane paradox?

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The standing paradigm is that methane (CH_4) production through methanogenesis occurs exclusively under anoxic conditions, and that at least in freshwater environments most of the biogenic CH_4 is oxidized by aerobic methanotrophic bacteria (MOB) under oxic conditions. However, subsurface CH_4 accumulation in oxic waters, a phenomenon referred to as the "CH_4 paradox", has been observed both in the ocean and in lakes. Analogously, MOB seem to thrive also under micro-oxic conditions, i.e., they may be responsible for significant CH_4 turnover at extremely low, or "hidden", O_2 concentrations.

Here we provide multiple lines of evidence for apparent "methanogenesis" in well-oxygenated waters and discuss the potential mechanisms that lead to CH_4 accumulation in the oxic epilimnia of two south-alpine lakes. On the other end, we present data from a deep meromictic lake, which indicate aerobic CH_4 oxidation (MOx) at O_2 concentrations below the detection limit of common O_2 sensors. A strong MOx potential throughout the anoxic hyplimnion of the studied lake implies that the MOB community is able to survive prolonged periods of O_2 starvation and can rapidly resume MOx upon introduction of low levels of O_2. This observation is qualitatively consistent with field data from a coastal shelf environment, where we observed maximum MOx rates during the summer stratification period when O_2 concentrations were lowest, implying that in both environments MOx bacteria are adapted to trace levels of O_2. Indeed, laboratory experiments suggest a nanomolar O_2 optimum for MOx in both environments. The very low O_2 requirements may reflect the adaption of water column MOB at the organismic level to O_2-limited conditions, with several ecological advantages: it allows them to escape grazing pressure and to avoid the detrimental effects of oxidative stress and/or CH_4 starvation in more oxygenated waters.