Greenhouse gases (CO$_2$, CH$_4$, and N$_2$O) entrapped in Alaskan and Siberian ice wedges: a direct evidence of the microbial activity within ground ice

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Ice wedge are one of the dominant components of massive ground ice in terrestrial permafrost. Due to repetitive thermal cracking and the downward infiltration of snowmelt and soil pore waters, ice wedge contains organic and inorganic compounds and microbes. Previous culture-based microbial sequencing assays discovered microorganisms the ice wedges, however, these studies did not address whether the microorganisms are active within ice matrix in subfreezing temperatures. Here we present preliminary results of greenhouse gas (GHG) measurements in gas enclosed in Pleistocene-aged ice wedges from central Siberia (Cyuie, Churapcha, and Syrdakh) and Alaska (Fox Permafrost Tunnel). Our results show the GHG mole fractions ranging from 0.5 ∼ 18% CO$_2$, 70 ∼ 13284 ppm CH$_4$, 7.4 ∼ 40451 ppb N$_2$O in the Fox tunnel, Alaska. We measured 8.2 ∼ 13.8% CO$_2$, 1.3 ∼ 22.5 ppm CH$_4$, 1959 ∼ 80988 ppb N$_2$O in Churapcha, 7.4 ∼ 13.2% CO$_2$, 11.0 ∼ 91.2 ppm CH$_4$, 74 ∼ 5539 ppb N$_2$O in Cyuie, and 5.1 ∼ 10.7% CO$_2$, 3.3 ∼ 9.1 ppm CH$_4$, 405 ∼ 13987 ppm N$_2$O in the Syrdakh ice wedge. We found no clear evidence that the observed GHGs were produced by abiotic processes. Molar ratios of δ(N2/Ar) of the enclosed air and bubble shapes the ice wedges studied in this study were created mainly by snow (and/or hoar) compaction without melting. Stable carbon isotope ratios of CO$_2$ (δ$^{13}$C-CO$_2$) from the four ice wedges indicate a biogenic origin of the CO$_2$. Geologic CH$_4$ production is unlikely due to low temperature condition. Inverse relationship between CH$_4$ and N$_2$O mixing ratios is observed in all sites, providing further evidence of microbial methanogenesis due to the inhibitory effect of N-oxides on methanogens. Further study is needed to determine whether microbial nitrification and denitrification existed in the past. Our results demonstrate that aerobic and anaerobic respiration occurred within the ground ice.