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Paleoclimate Inferred from Concentration of Greenhouse Gas and Ratios of O₂/Ar and N₂/Ar in Ice Wedges in Northeastern Siberia and Northern Alaska

Nayeon Ko¹, Ji-Woong Yang², Go Iwahana³, Alexandre Fedorov⁴, Andrei G. Shepelev⁴, Thomas Opel⁵, Sebastian Wetterich⁵, and Jinho Ahn¹

¹Seoul National University, Seoul, Korea

²Laboratoire des Science du Climat et de l'Environnement, French

³International Arctic Research Center, Fairbanks, USA

⁴Melnikov Permafrost Institute Siberian Branch RAS, Yakutsk, Russia

⁵Alfred Wegener Institute Helmholtz Centre for Polar and Marine Research, Bremerhaven, Germany

Global warming is drawing keen attention to people all over the world. Especially, the history of climate in permafrost area is of great interest to better understand greenhouse gas emission due to the thaw of permafrost in the future. In this context, formation of ice wedges and greenhouse gas was studied based on gas chemistry in permafrost ice wedges. The study areas are Batagay and Zyryanka in northeastern Siberia, and North Slope in Alaska. The gas was extracted using a dry extraction method that physically breaks down ice, and cryogenically collects gas in a stainless steel tube. The gas mixing ratios were analyzed by gas chromatography. N₂ and Ar occluded in the air bubbles in the ice are relatively unaffected by microbial activity, but if liquid water contacted atmospheric air and froze, the N₂/Ar ratio in the ice will differ from the atmospheric value due to difference in the gas solubility in water. On the other hand, if O₂ was consumed by microorganisms in the ice, the concentration of O₂ will decrease and consequently the O₂/Ar ratio will also decrease. Our results show that the $\delta(\text{O}_2/\text{Ar})$ and $\delta(\text{N}_2/\text{Ar})$ of the ice wedges in Zyryanka and North Slope areas range from -86.5% to -12.2% and from -16.0% to 5.5%, respectively with regard to modern air. The ¹⁴C ages of Zyryanka and North Slope samples are 810±30 BP and 1920±30 BP, respectively, corresponding to the late Holocene. Because the late Holocene was a relatively warm period, it may be interpreted that the ice wedges formed predominantly from snow melt water, resulting in the negative values of $\delta(\text{N}_2/\text{Ar})$. This is in contrast with our earlier study on ice wedges in Central Yakutia region (Syrdakh, Cyuie, and Churapcha) (Kim et al., 2019). The Central Yakutian ice wedges formed during the Last Glacial Maximum (LGM) and the $\delta(\text{N}_2/\text{Ar})$ values of ~0% indicates that the ice did not form from snow melting. The $\delta(\text{O}_2/\text{Ar})$ of the Zyryanka and North Slope is much less depleted than that of Central Yakutian (close to -100%). Oxygen consumption by microorganisms in the Central Yakutian ice is more completed probably by the longer time period for the biogeochemical reaction compared to the Zyryanka and North Slope ice (>20,000 years vs. < 2,000 years). The ages of Batagay ice wedges range to earlier part of the Late Pleistocene, and may allow us to study longer biogeochemical reactions in ice. The concentrations

of CO₂, N₂O and CH₄ in the Batagay ice range 260-71,000 ppm, 0.11-68 ppm and 4.7-130 ppm, respectively. Further geochemical analyses are in progress. Future study will include scrutinizing correlations among the three greenhouse gas concentrations. Our study shows that the gas mixing ratios in ice wedges may help us better understand the biogeochemical reactions in the ice and climate conditions when the permafrost formed.