C And H Sources To Methane Production Associated With Permafrost Degradation

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Introduction
Methane production in Siberian thaw lakes is estimated to be 3.8 Tg CH$_4$ yr$^{-1}$. When entered into global models, this estimate increases northern wetland CH$_4$ emissions (~6-40 Tg CH$_4$ yr$^{-1}$) by 10-63%. Methane release of this magnitude from Siberian and other northern lakes, such as those in Alaska, may be linked to the rich carbon resources available to sediment-dwelling methanogens. Researchers posit that methanogens in upper-latitude thermokarst lakes utilize high-quality carbon (C) stocks made available by thaw of permafrost beneath and around the margins of lakes. The potential for enhanced availability of this C as a result of projected climate warming and associated permafrost thaw makes C source contributions to methane production important to understand. Based on the $^{14}$C radiocarbon ages and stable isotope composition of emitted CH$_4$, we suggest that thawed permafrost, made recently bioavailable through the deepening of taliks and/or by thermokarst erosion and deposition of shoreline, supplies labile organic C to anaerobic sediments and drives CH$_4$ production in some interior Alaska thermokarst lakes. We further propose that methanogens utilizing permafrost C also utilize pore water derived from melted permafrost ice as a hydrogen (H) source.

Experimental
The NHMFL stable isotope facility was used for analysis of $\delta$D of CH$_4$. Samples were injected onto the Carlo Erba gas chromatograph which is coupled to a Thermo-Finnigan Isotope Ratio Mass Spectrometer.

Results and Discussion
The $\delta$D signature of CH$_4$ corrected by a microbial fractionation of 165‰ for production via CO$_2$ reduction (evidenced directly by $\delta$C calculations) is consistent with $\delta$D of permafrost H$_2$O (ice) ($\delta$D = -186‰) for bubbling sources near Goldstream Lake’s thermokarst margin (Figure 1). This contribution appears to decrease with distance from the thermokarst margin as methanogens transition toward use of H from modern surface H$_2$O ($\delta$D = -134‰). $^{14}$C dating of CH$_4$ additionally evidences strong C contributions from ancient permafrost sources near the thermokarst margin, and weak contributions near the opposite shore. Radiocarbon ages of CH$_4$ emitted from bubbling sources radiating away from Goldstream’s thermokarst margin also evidence a gradient of incorporation of old permafrost C from high to low. In contrast, Killarney Lake exhibits homogenous bubbling of CH$_4$ produced from a mixture of permafrost and modern organic C sources. Killarney, is a more mature lake (>290 yrs old) with a well-developed talik and a thick modern organic sediment package. The fact that less CH$_4$, and CH$_4$ of a younger radiocarbon age is produced and emitted from Killarney Lake suggests depletion of the labile C fraction of permafrost thawed beneath the lake.

Conclusions
Based on observations of CH$_4$ emissions and $^{14}$CH$_4$ ages in two thermokarst lakes differing in their age, sediment structure and talik development, we can conclude that organic C quality, and particularly the availability of labile permafrost C released immediately upon thaw, is an important control over the CH$_4$ production capacity of lakes. Stable isotope analysis of CH$_4$ emitted from a lake thermokarsting actively along one margin also reveals H contributions to CH$_4$ production from permafrost H$_2$O/ice which are greatest near the margin and that decline with distance from the margin.

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