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Deep Thermogenic Hydrocarbon Migration in Antarctic Permafrost: Evidence from Molecular and Isotopic Signatures in the McMurdo Dry Valleys

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Permafrost is commonly regarded as a biogeochemical barrier that limits vertical fluid exchange. However, its role in modulating deep subsurface inputs under a warming climate remains poorly constrained. Here we present molecular and isotopic data from gases recovered from permafrost samples (via controlled laboratory thawing) and complementary in situ soil-gas samples collected in Wright and Taylor Valleys (McMurdo Dry Valleys, Antarctica).

Methane concentrations range from trace levels to several ppmv and are systematically associated with elevated C_2–C_4 hydrocarbons, yielding low $C_1/(C_2+C_3)$ ratios (<10) indicative of wet thermogenic gas. Carbon isotopic compositions ($\delta^{13}C$-CH_4 between –36‰ and –46‰ VPDB) highlight a typical thermogenic domain, excluding dominant microbial origin within the active layer. The enrichment in higher hydrocarbons, including locally elevated C_3 relative to C_1, indicates migration from mature organic matter hosted in deeper sedimentary units.

Compositional contrasts between Wright Valley (hydrocarbon-richer and isotopically lighter) and Taylor Valley (comparatively drier and isotopically heavier) suggest structurally controlled subsurface inputs from compositionally distinct deep sources. These results demonstrate that Antarctic permafrost preserves a geochemical record of deep crustal fluid circulation and functions as a cryogenic seal over thermogenic reservoirs.

In a warming climate, progressive thawing and permeability changes could enhance vertical connectivity, facilitating episodic release of stored deep carbon. Our findings highlight that permafrost systems are not solely governed by surface biogeochemical processes but may integrate, and potentially mobilize, deep geogenic carbon pools as subsurface dynamics evolve.