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Methane formation in geothermal systems

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Methane is a potent greenhouse gas whose global budget remains underconstrained, particularly with respect to natural sources [1]. A particularly unconstrained source is volcanic and geothermal systems. Methane in these environments can be derived from multiple pathways, including microbial, thermogenic, and abiotic processes [2]. Resolving how methane is generated and the factors controlling it, is therefore essential for constraining natural methane fluxes and improving predictions of future climate change.

The diverse nature of the geothermal systems within Yellowstone National Park (YNP), along the Yellowstone Hotspot Track (YHT), and across the Italian Peninsula Volcanic Province make these locations ideal to understand potential methane sources within geothermal areas. Here, we compare data from three samples from the YNP, one sample from the YHT and four samples from Italy to investigate the different sources of methane across these distinct geothermal regions. We analyse clumped methane isotopologues ($^{13}CH_3D$ and $^{12}CH_2D_2$) together with bulk methane and noble gas isotopes, and microbial community sequencing to constrain methane's origin(s) and formation conditions.

Clumped methane isotopologue compositions provide constraints on the temperature and process(es) of methane formation, enabling discrimination between equilibrium and kinetic signatures associated with different genetic pathways. Using a Bayesian analysis of the bulk and clumped methane isotopes we find that methane in these systems is predominantly thermogenic and/or microbially derived.

By coupling methane isotopic systematics with noble gas tracers and microbial community composition, we assess the controls exerted by different processes and environmental conditions (including lithology, geothermal temperature, and subsurface biogeochemistry) on methane production between and across investigated sites. Our results indicate that methane generation in geothermal systems is governed by coupled geological and biological processes, providing new constraints on methane formation pathways in active geothermal environments. This integrated isotopic and microbiological framework offers a robust approach for resolving methane sources in complex natural systems.

[1] Saunois et al., 2020 https://doi.org/10.5194/essd-12-1561-2020
[2] Etiope et al., 2007 https://doi.org/10.1016/j.jvolgeores.2007.04.014