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Hydrogenotrophic methanogens overwrite isotope signals of subsurface methane

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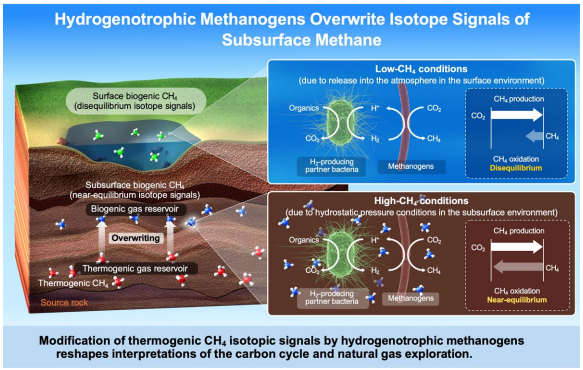

Modification of thermogenic CH_4 isotopic signals by hydrogenotrophic methanogens reshapes interpretations of the carbon cycle and natural gas exploration.

Vast quantities of methane are stored in the Earth's deep subsurface and, in the form of natural gas, constitute a substantial fraction of the global energy supply. Although the primary energy mix is increasingly shifting from fossil fuels toward renewable sources, methane continues to play a significant role as a major energy resource.

Understanding the origins of methane provides critical information for evaluating natural gas resources and guiding exploration strategies, as well as for elucidating the global carbon cycle. Methane is commonly classified into two types according to its origin: biogenic methane, produced by methanogenic archaea, and thermogenic methane, generated through the geothermal degradation of organic matter in deep subsurface environments. Stable isotope signals have long been used as key indicators for identifying the origin of methane. Biogenic methane from the subsurface is characterized by isotope signals that are close to isotopic equilibrium. However, such isotope signals have never been reproduced in laboratory cultures of methanogens, revealing a fundamental discrepancy between interpretations in isotope geochemistry and microbiology.

Here, we developed a high-pressure incubation system simulating subsurface conditions. By co-culturing a hydrogen-producing bacterium with a hydrogenotrophic methanogen, we successfully reproduced methane isotope signals with near-equilibrium. Furthermore, we demonstrated that under subsurface conditions, hydrogenotrophic methanogens can overwrite (re-equilibrate) the isotope signals of thermogenic methane, transforming them into signals consistent with biogenic methane. These findings highlight the need to re-evaluate current interpretations of the origin of natural gas reservoirs.