Goldschmidt 2026 Abstract
https://doi.org/10.46427/gold2026.36228

Methane and CO_2 dynamics in different cave environments: comparison of field flux measurements and controlled mesocosm experiments

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Cave environments represent substantial methane sinks, but their contribution to global biogeochemical cycles remains largely understudied. These ecosystems are often perceived as stable, humid, energy-limited environments with low nutrient availability and the absence of light; however, their environmental conditions can vary significantly, shaped by geological, microbial, hydrological, and climatic factors, complicating their estimation as carbon sinks or reservoirs on a global scale.

In this study, we present a comparison between in situ automated chamber monitoring results of greenhouse gas fluxes from cave sediments under natural conditions and closed mesocosm incubations containing homogenized cave sediments under controlled laboratory conditions. Sediment samples from three contrasting cave systems were studied: a gypsum cave in a semi-arid Mediterranean climate (Covadura), characterized by low rainfall and generally high temperatures; a volcanic cave in a semi-arid subtropical climate (La Corona); and a limestone cave under oceanic Atlantic conditions (Pindal).

Field measurements revealed a strong site-dependent variability in methane exchange, ranging from pronounced methane uptake in limestone sediments (up to −11.7 nmol m^{-2} s^{-1}) to moderate consumption in gypsum environments and weak gas emissions or nearly neutral behaviour in volcanic systems. Mesocosm incubations reproduced field observations, showing higher relative humidity (~95%) in Covadura and Pindal samples associated with stronger methane consumption, whereas La Corona mesocosms maintained lower humidity (~70%) and exhibited minimal methane consumption and CO_2 production, consistent with field measurements.

The progressive CO_2 accumulation observed in the mesocosms from Pindal and Covadura indicated active heterotrophic respiration. In addition, the high positive in situ CO_2 fluxes detected in the Covadura cave agree with the higher CO_2 accumulation measured in its mesocosms. Metagenomic analyses from Pindal cave revealed methane monooxygenase genes and carbohydrate-active enzymes, also supporting methanotrophic and heterotrophic metabolism.

Mesocosm experimental approaches can be used to test, under controlled conditions, how predicted changes in temperature and humidity under future climate scenarios can influence GHG dynamics and can be applied to improve global estimates of greenhouse gas fluxes in caves.