THE INFLUENCE OF TEMPERATURE AND MINERALOGY ON MICROBIAL COMPETITION FOR HYDROGEN CONSUMPTION: IMPLICATIONS FOR UNDERGROUND HYDROGEN STORAGE (UHS)

GDR HYDROGEMM

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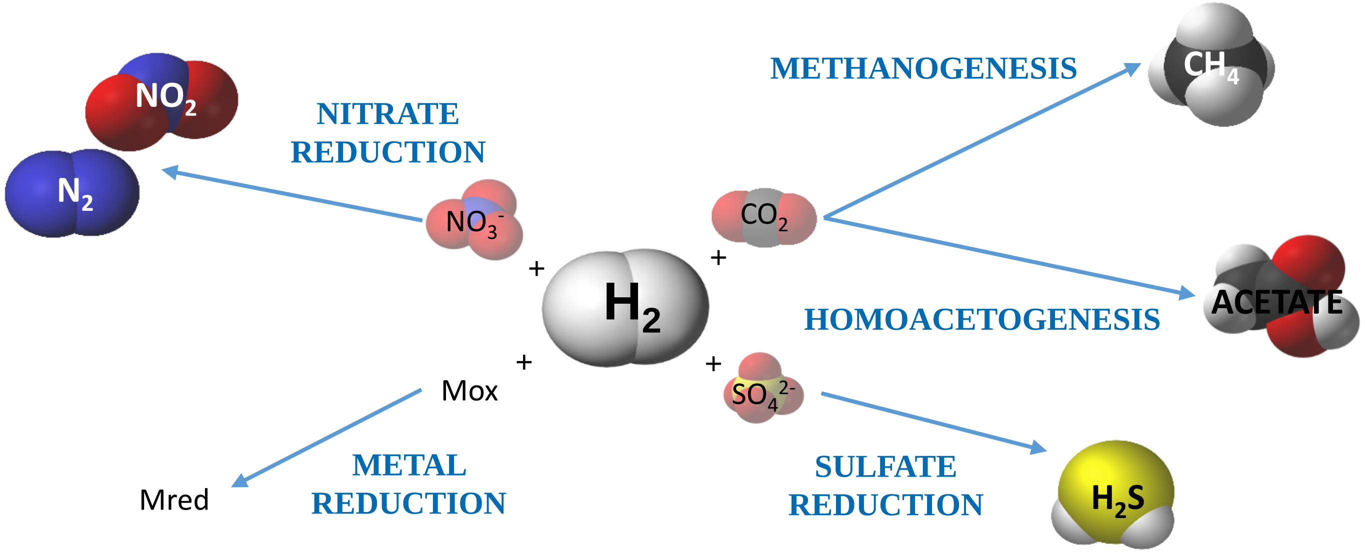
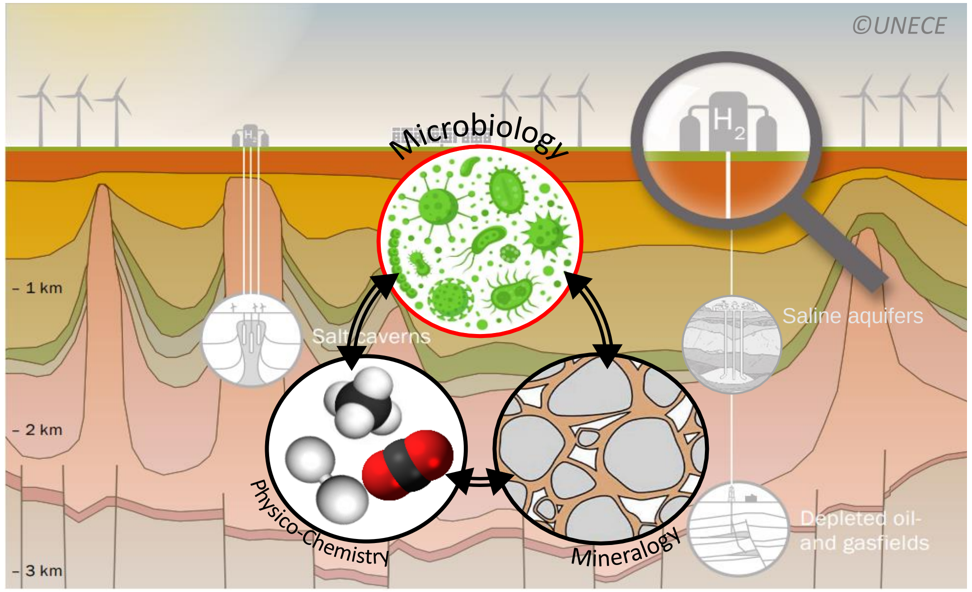
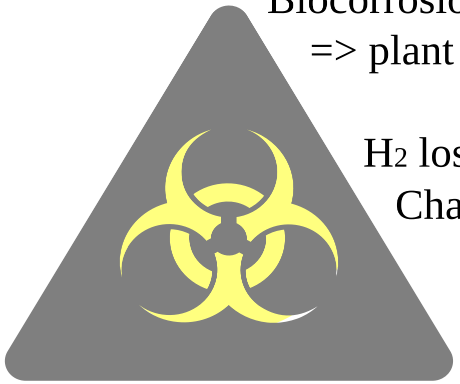
MICROBIAL RISKS IN UNDERGROUND H_2 STORAGE







Biocorrosion & souring
=> plant damages

H_2 loss
Changes in gas composition

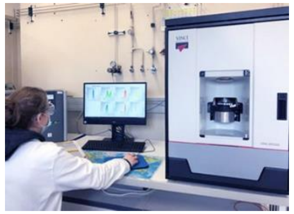
Reservoir alteration
=> clogging, weakening

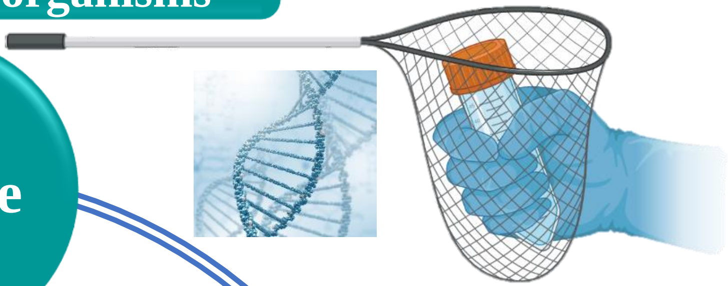
More experience from field-specific tests and laboratory experiments is needed to predict and manage microbial effects.

For more details:
Hemme et al., 2017
Heinemann et al., 2021
Dopffel et al., 2023
Dohrmann & Krüger, 2023
Khajooie et al., 2024
Ranchou-Peyruse et al., 2024
Mura et al., 2024

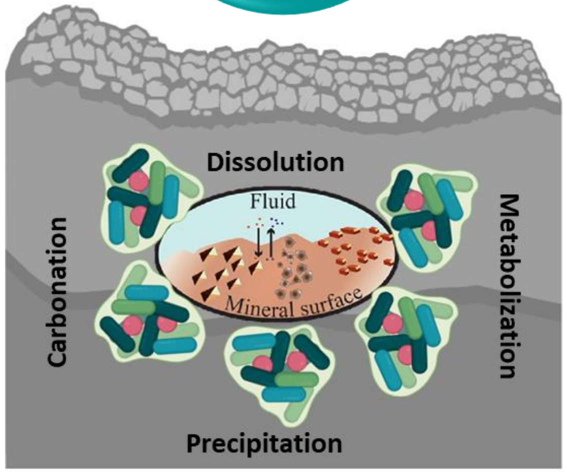
IFPEN SCIENTIFIC WORKFLOW

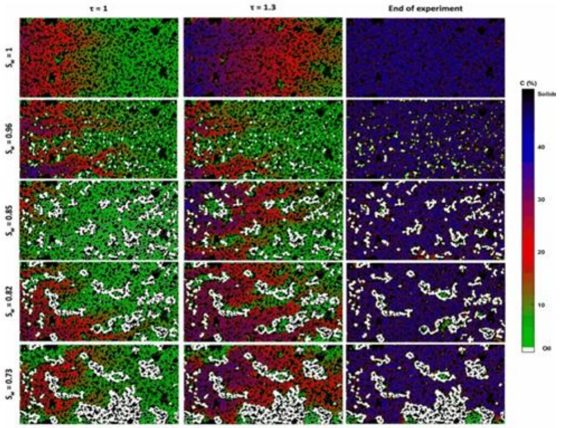
Characterize the reactions and identify the microorganisms





Explore

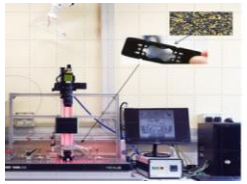




Model

in situ
Biogeochemical cycles

Monitor

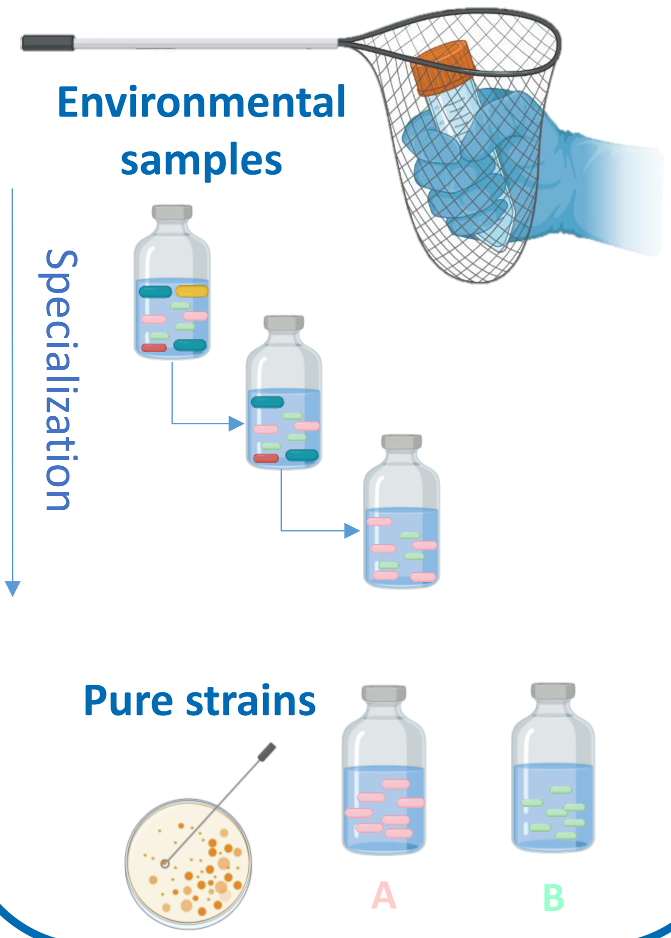


Predict and drive the biological reactions

Reproduce and monitor the reactivity in representative conditions

EXPERIMENTAL & ANALYTICAL APPROACH

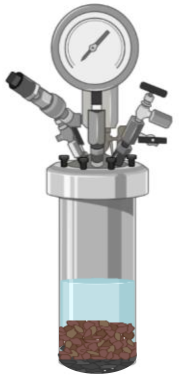
Biological material



Experimental settings

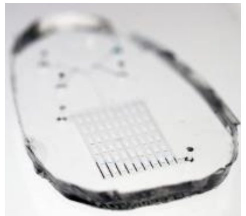
Batch

Vials



HP reactor

Flow



Micromodels

Coreflood

Analytical methods

DNA/RNA extraction/sequencing

Multi-omics

Cytometer

qPCR

Cellular quantif.

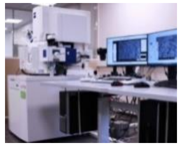
HPLC/ICS

µGC

Geochemical reactivity

XRD

SEM



Substrate alteration

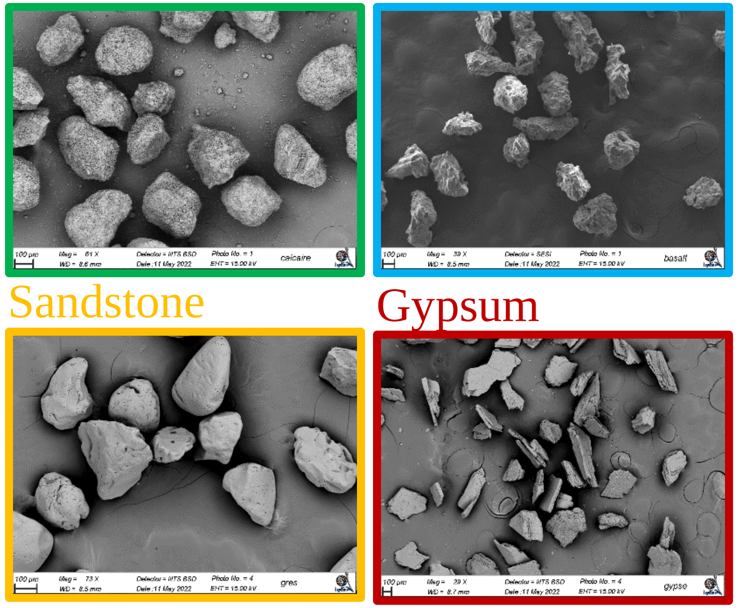
Key environmental parameters

25°C

34°C

40°C

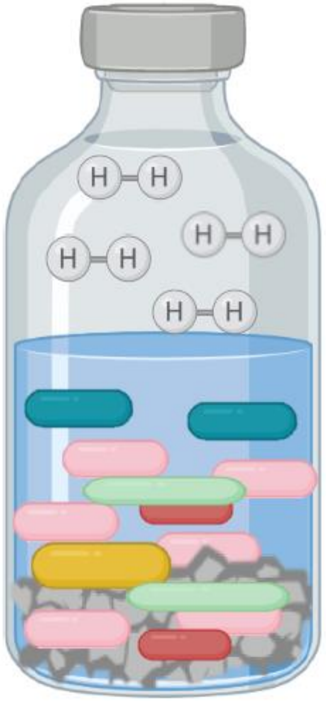
Calcite Basalt



Grain size: 100-200µm

+ Ø

Kinetics of H_2 consumption



Methanogenous Archaea

Sulfate reducing bacteria

Homoacetogenous bacteria

Incubation

- 150ml vials
- Agitation at 110 rpm
- DSMZ medium

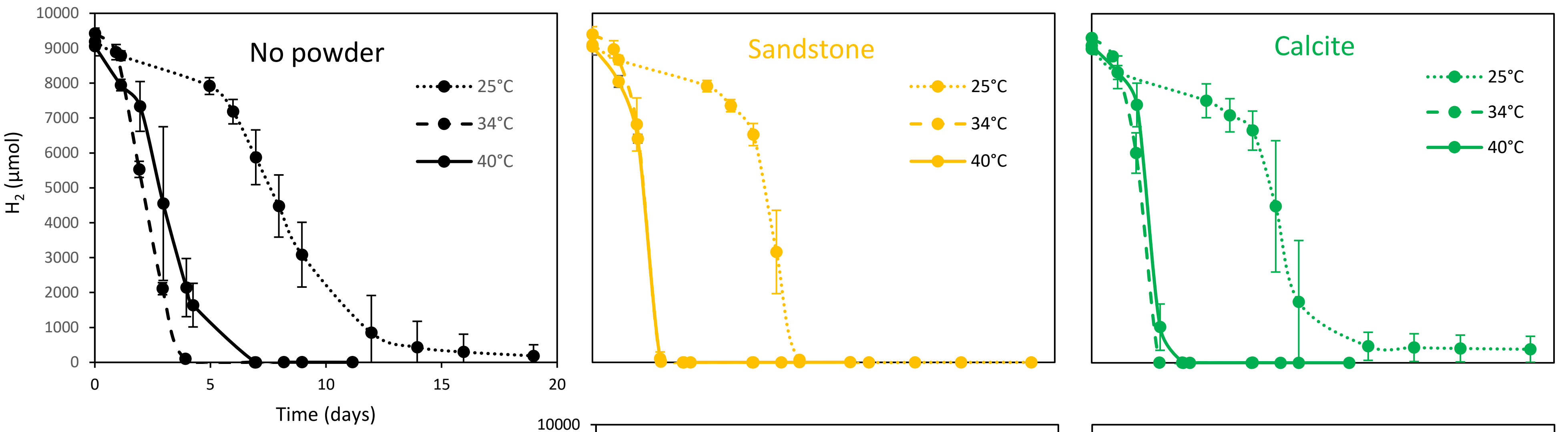
Inoculum

- Environmental consortium
- Specialized under H_2/CO_2 (80:20) 2 bars

Monitoring

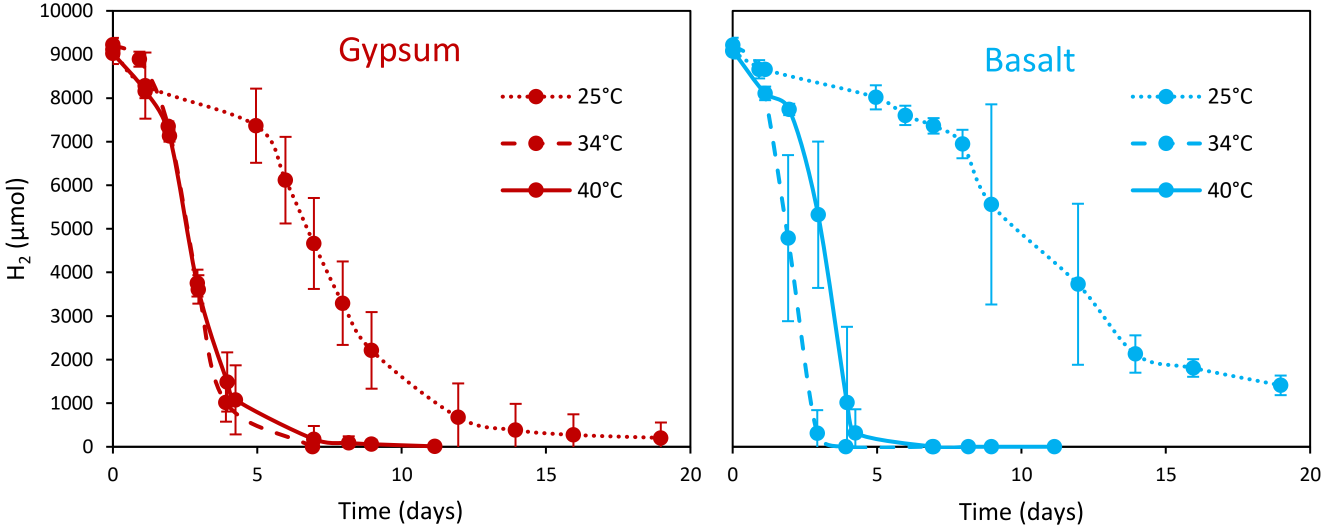
- Gas composition
- Dissolved S species, VOA
- ADN 16S sequencing

RESULTS. *Temperature affects H2 consumption kinetics*

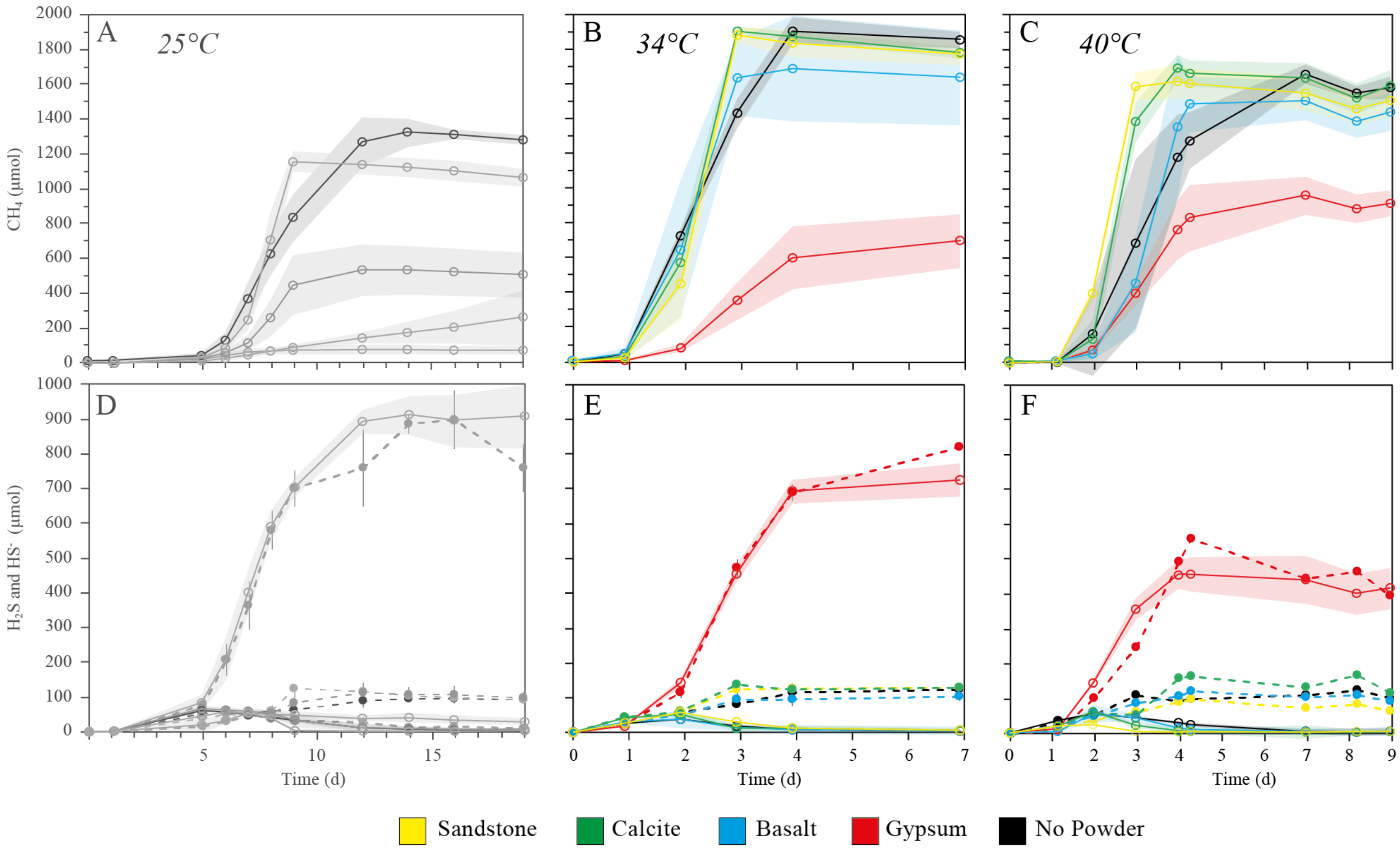


- At 25°C, H_2 consumption slows down

- The presence of a subtrate increases the consumption kinetics at 34 and 40°C



RESULTS. *Mineralogy drives H2 conversion pathways*



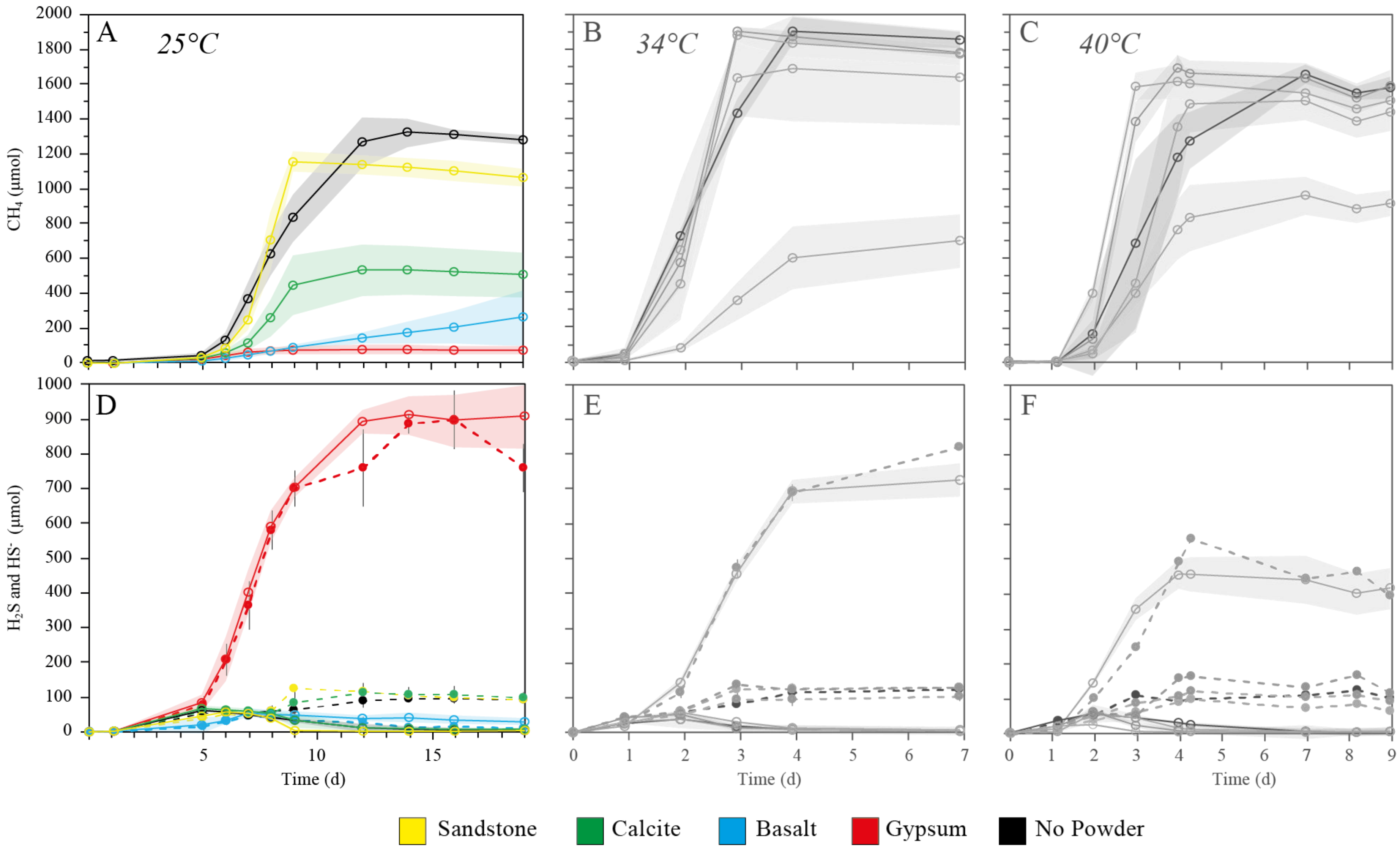
H2 convertion into CH4 (by methanogenesis) with calcite, basalt, sandstone and control

$$4H_2 + HCO_3^- + 2H^+ \rightarrow CH_4 + 2H_2O$$

Major production of H2S by sulfate reduction with gypsum

$$4H_2 + SO_4^{2-} + 2H^+ \rightarrow H_2S + 4H_2O$$

RESULTS. *Mineralogy drives H_2 conversion pathways*



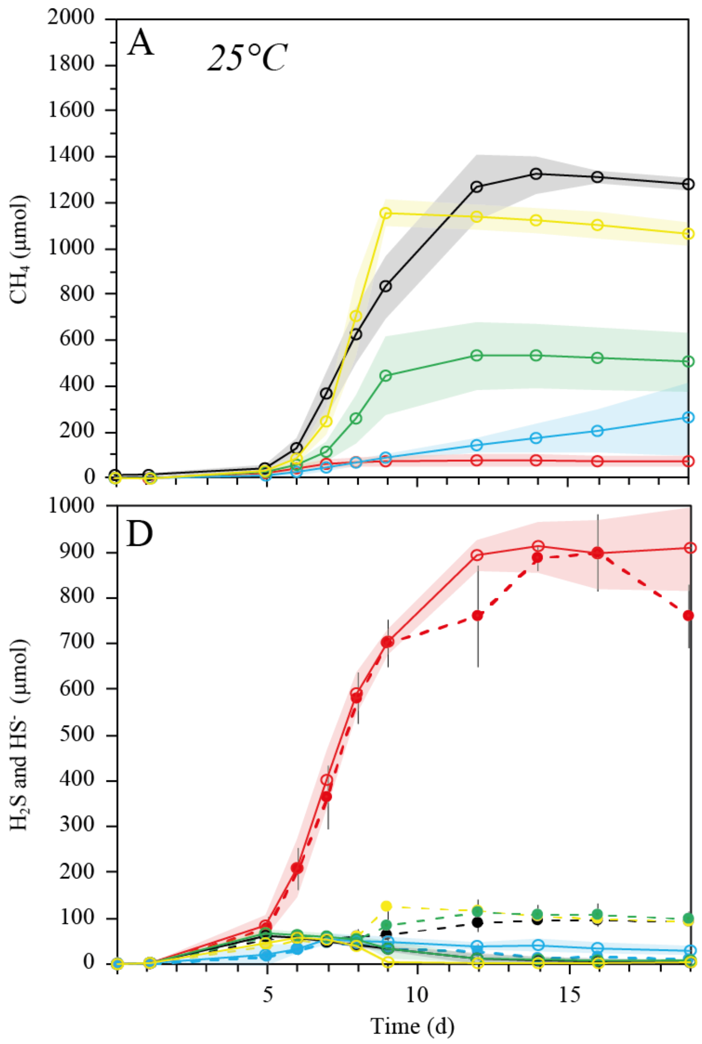
Lower and variable H_2 convertion into CH_4 (by methanogenesis) with calcite, basalt, sandstone and control

$$4H_2 + HCO_3^- + 2H^+ \rightarrow CH_4 + 2H_2O$$

Major production of H_2S by sulfate reduction with gypsum

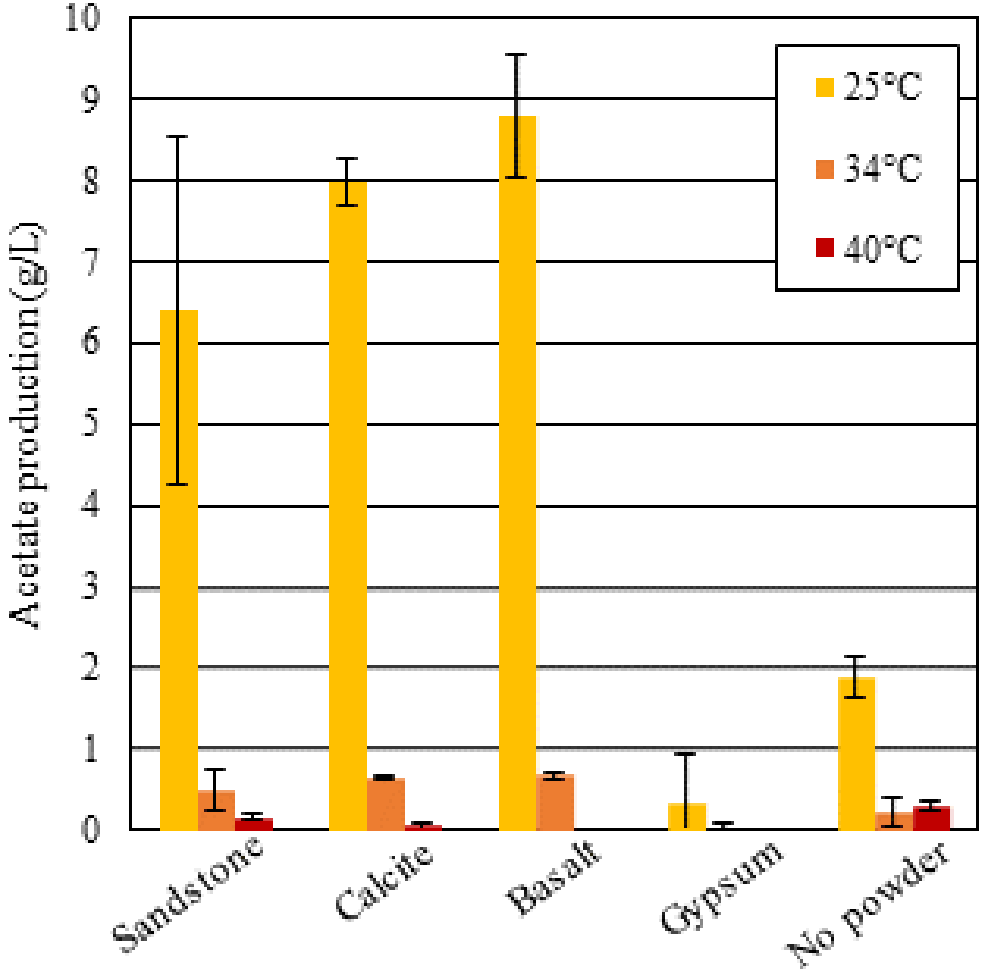
$$4H_2 + SO_4^{2-} + 2H^+ \rightarrow H_2S + 4H_2O$$

RESULTS. *Mineralogy drives H_2 conversion pathways*

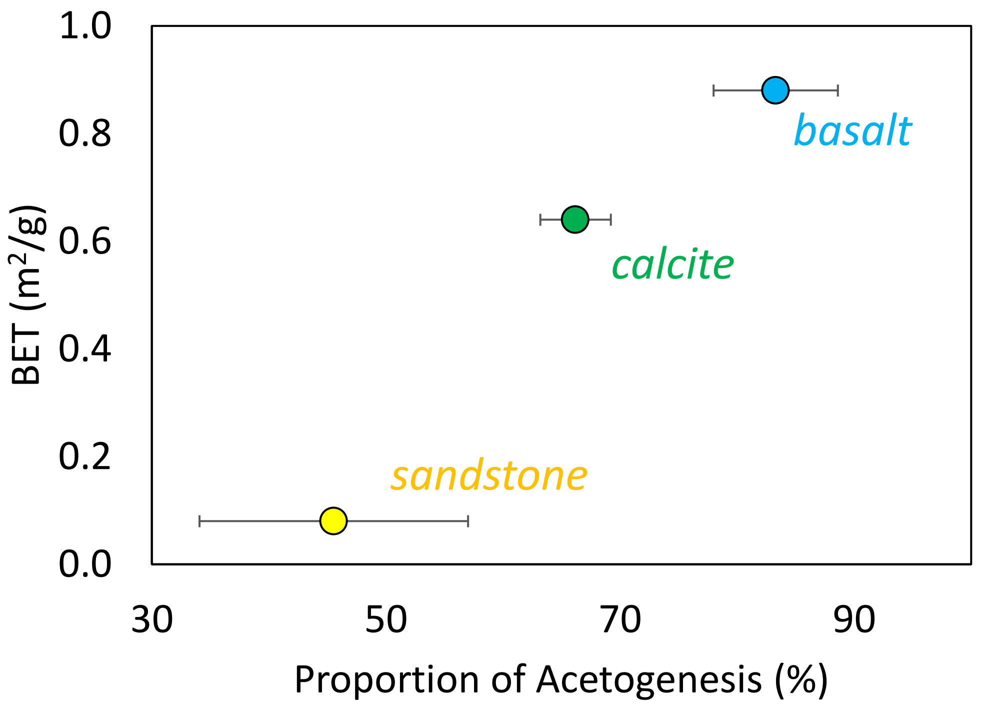


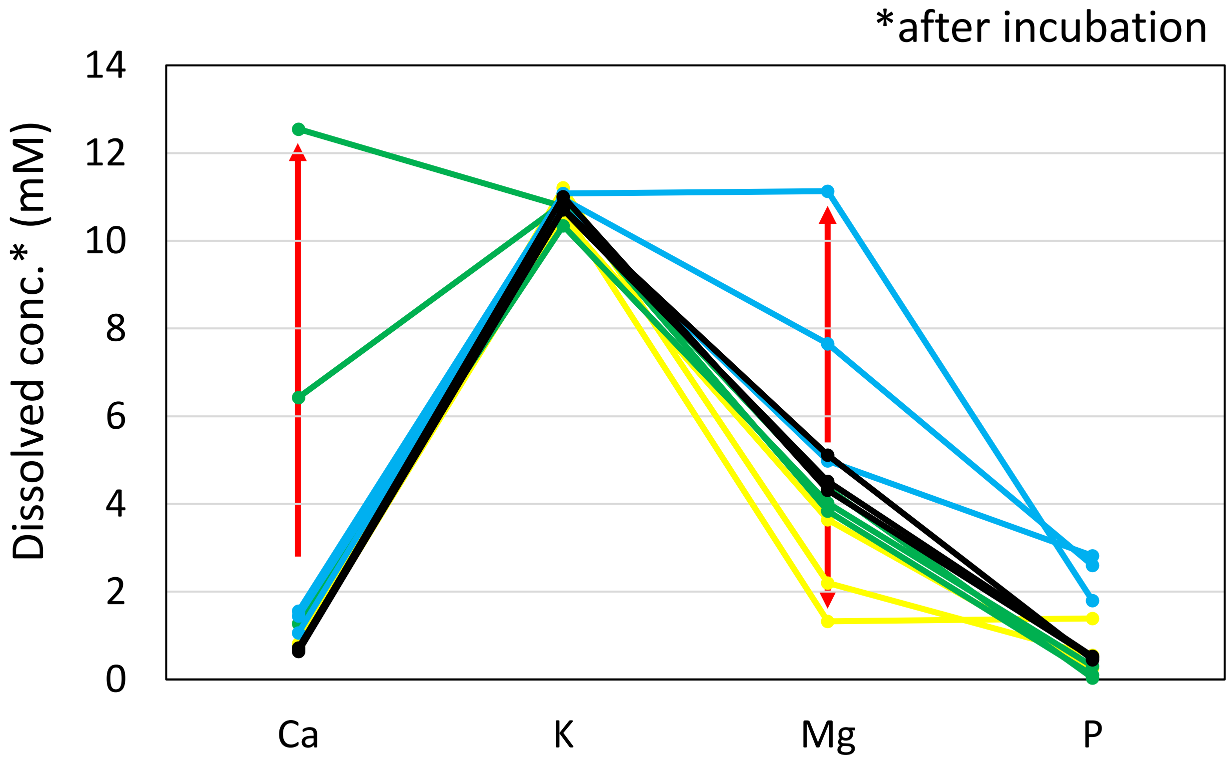
- Low temperature favors homoacetogenesis over methanogenesis
- Variable H_2 convertion into acetate (by homoacetogenesis) with calcite, basalt, sandstone versus control
- No homoacetogenesis with gypsum

$$4H_2 + 2HCO_3^- + 2H^+ \rightarrow C_2H_4O_2 + 2H_2O$$



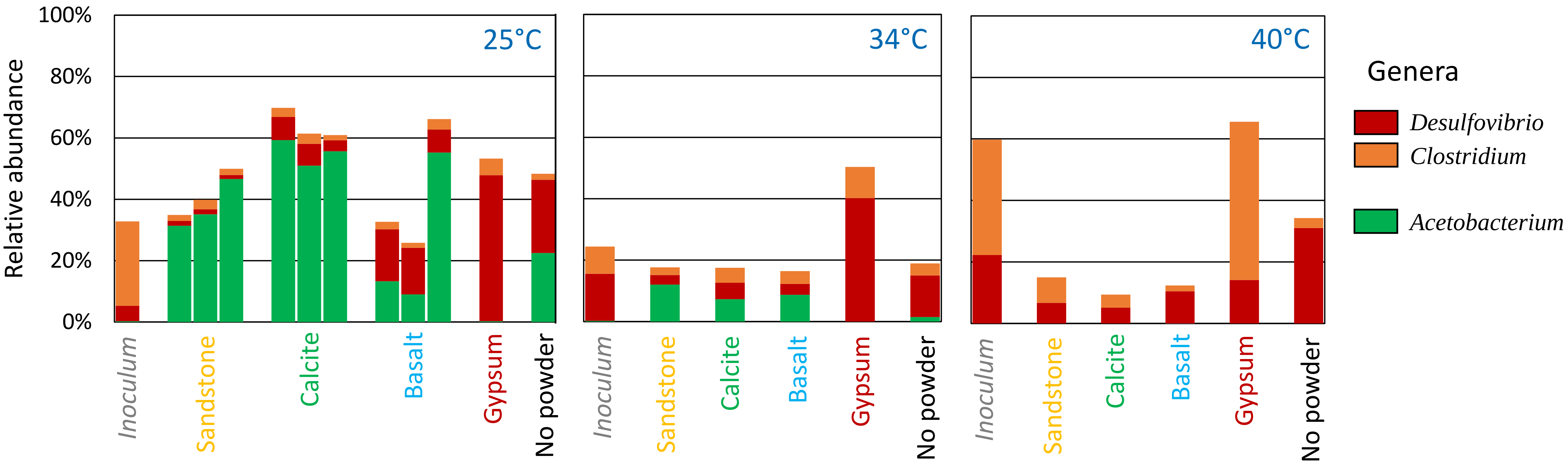
RESULTS. *Influence of the mineral substrate*





- Hyp: the presence of a mineral substrate to form biofilms may influences the competition for H_2
- Hyp: the microbial activity in biofilms may alter the substrate

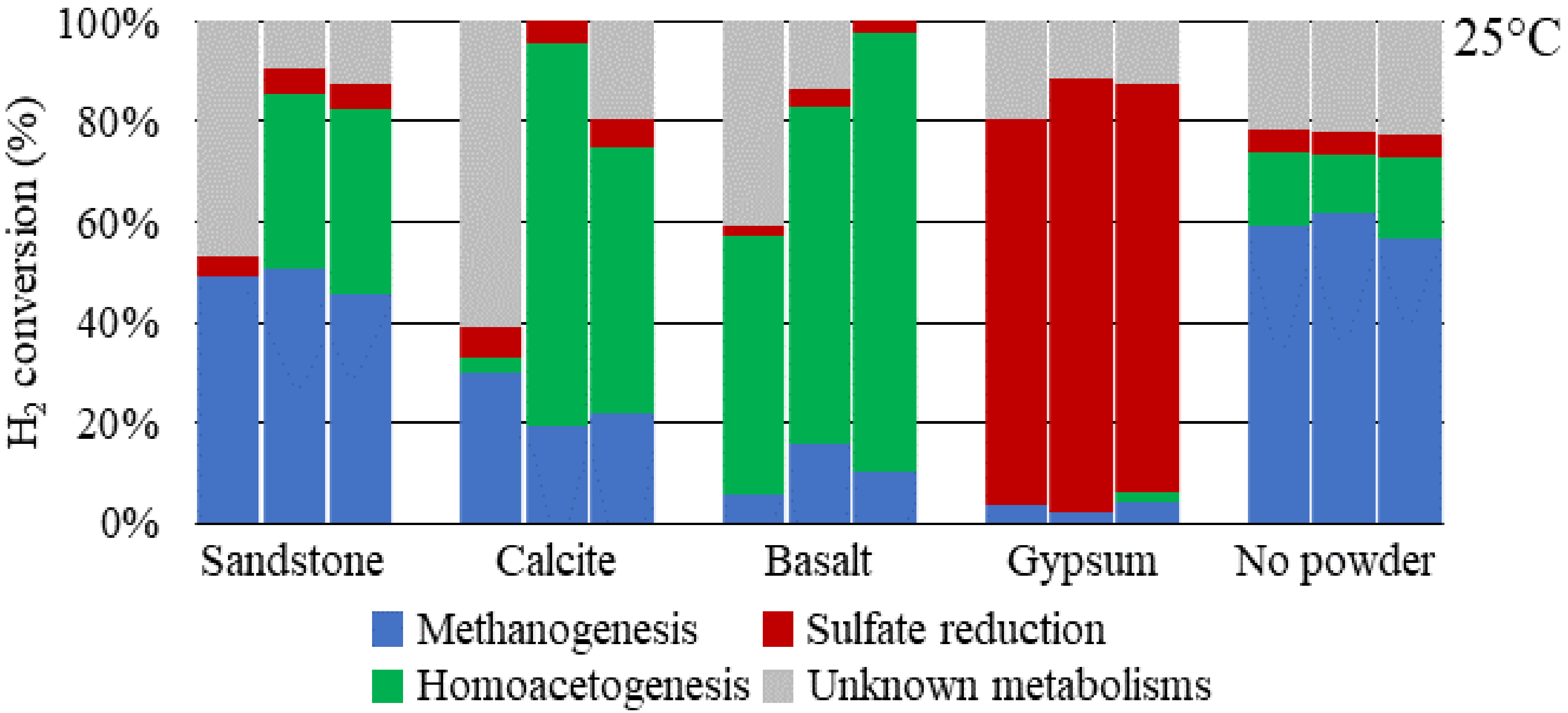
RESULTS. *Evolution of the hydrogenotroph populations of the consortium*



- Confirms the ecological response of microbial populations to variations in operating conditions
- Homoacetogenesis ensured by *Acetobacterium* genus
- Sulfate reduction ensured by a *Desulfovibrio* species at 25 and 34°C
- At 40°C, mesophilic *Clostridium* species involved in the H_2S production

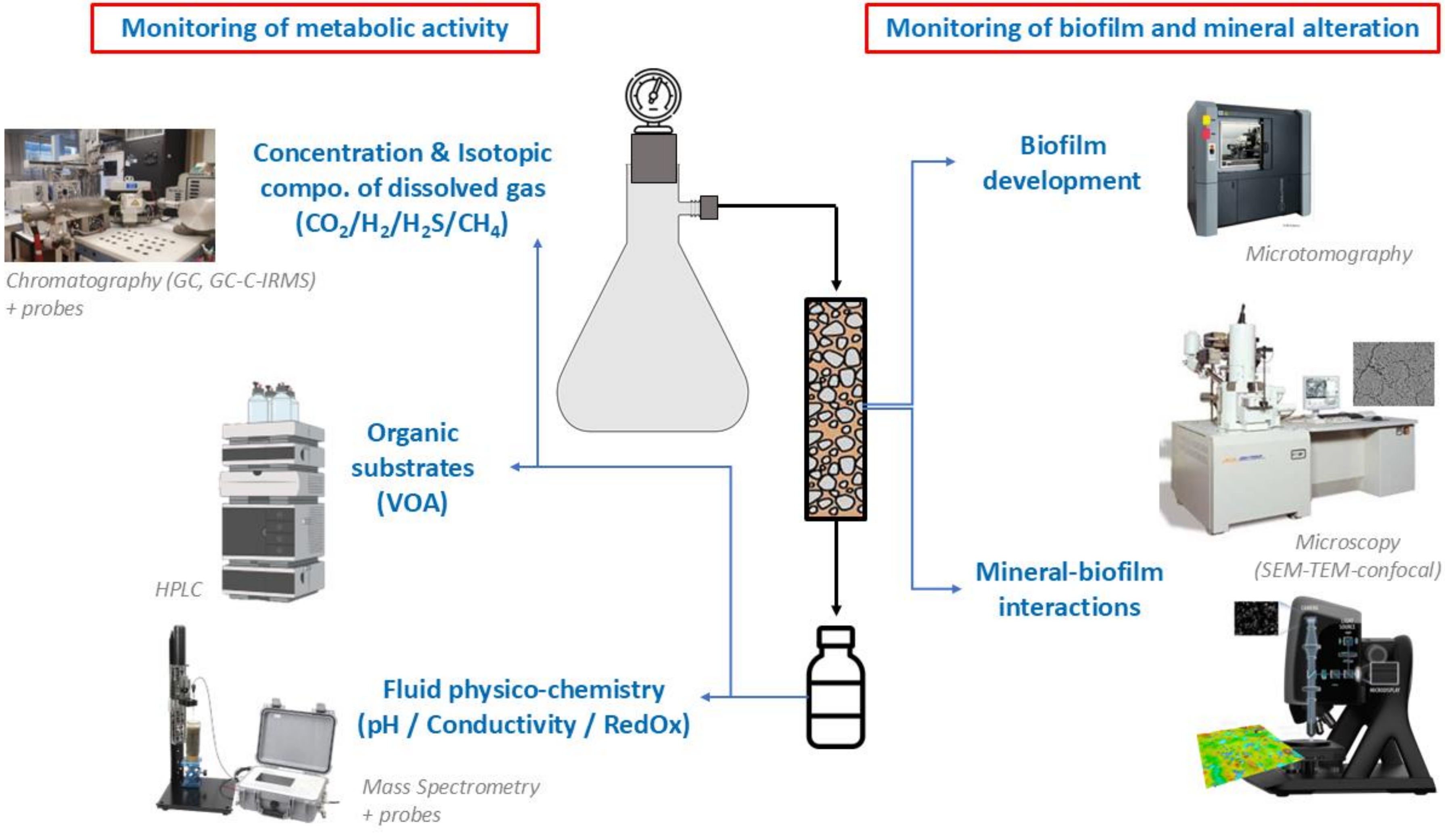
CONCLUSIONS

- **Functional plasticity** of the consortium (homoacetogenesis, methanogenesis and sulfate reduction)
- Temperature and mineralogy are key factors influencing the kinetic parameters and pathways of H_2 utilization by microorganisms.
- Preferential adhesion of some communities to mineral substrates?



NEXT STEPS IN PROGRESS

1. Improve models of microbial reaction kinetics
2. Set up more relevant experimental systems



BIOFILM MONITORING IN POROUS MEDIA… PHD OF ALEXIS VINDRET

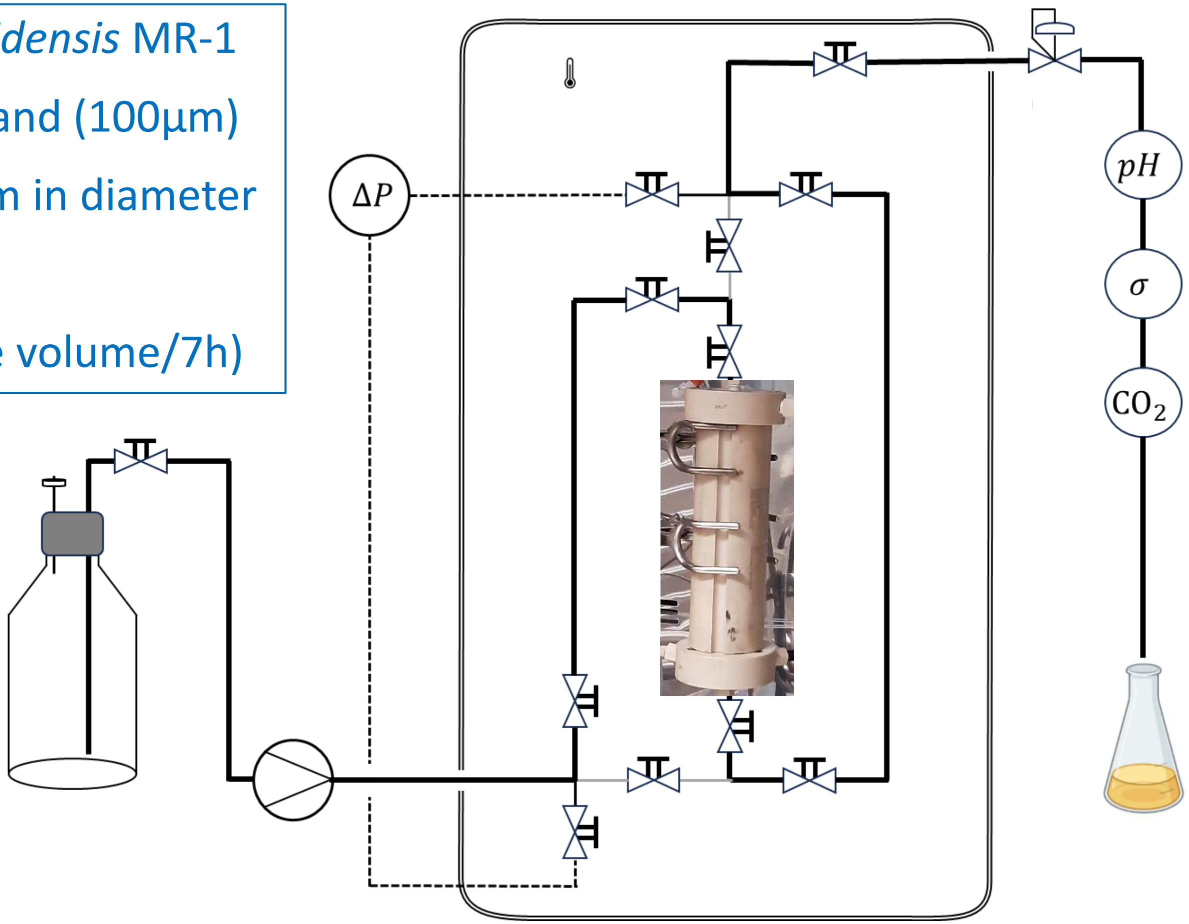
Strain: *Shewanella oneidensis* MR-1

Porous medium: SiO_2 sand (100µm)

Size: 13 cm long by 3 cm in diameter

T/P: 30°C / 5 bar

$Q_{injection}$: 5 mL/h (1 pore volume/7h)



1. Porous media characterization
Porosity & permeability measurement (t_0;t_f)

2. ΔP measurement
(proxy of clogging)

3. pCO_2 measurement
(proxy of bacterial activity)

4. Effluent analyses
   - Absorbance (OD_{600})/Plating
   - pH
   - Metabolites

(proxy of bacterial activity)

Géosciences

Modélisation

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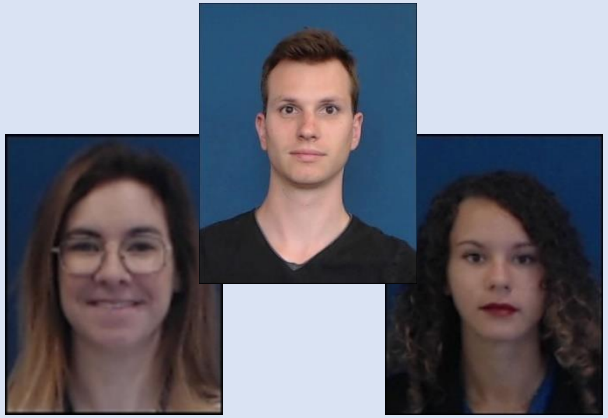
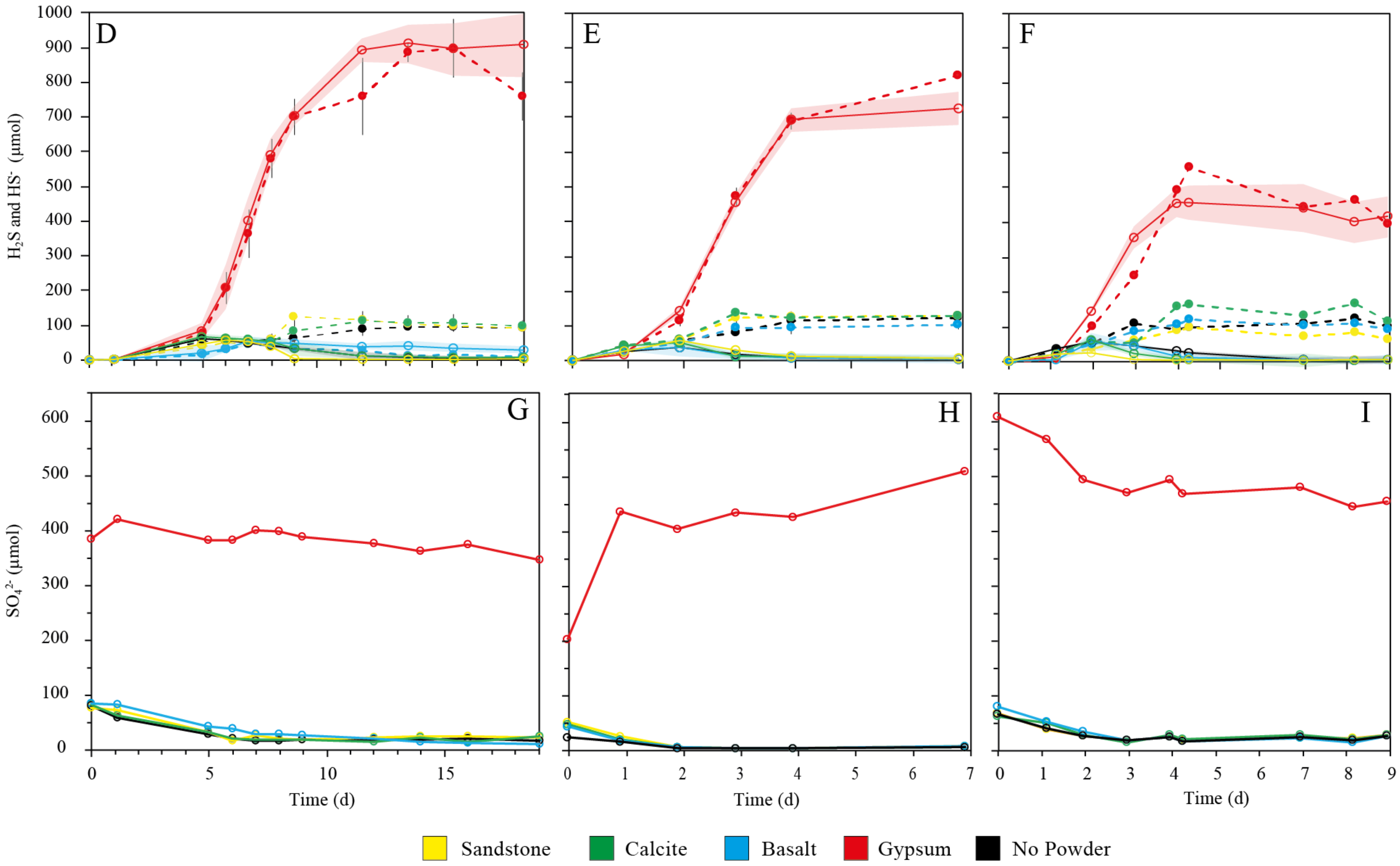
Merci aux équipes IFPEN impliquées !

Contact : elodie.muller@ifpen.fr



Microbiologie

RESULTS. *Mineralogy drives the H_2 conversion pathways*



Abiotic dissolution of gypsum powder provides "unlimited quantities of sulfate"
⇒ Competitive advantage for sulfate-reducing populations

This advantage is reduced at 40°C

BIODIVERSITY