

Linking Earthquakes to Life Evolution: the Icelandic Laboratory

Coordinators: Laurent GEOFFROY (Geo-Ocean) & Karine ALAIN (BIOMEX-BEEP)

Partners:

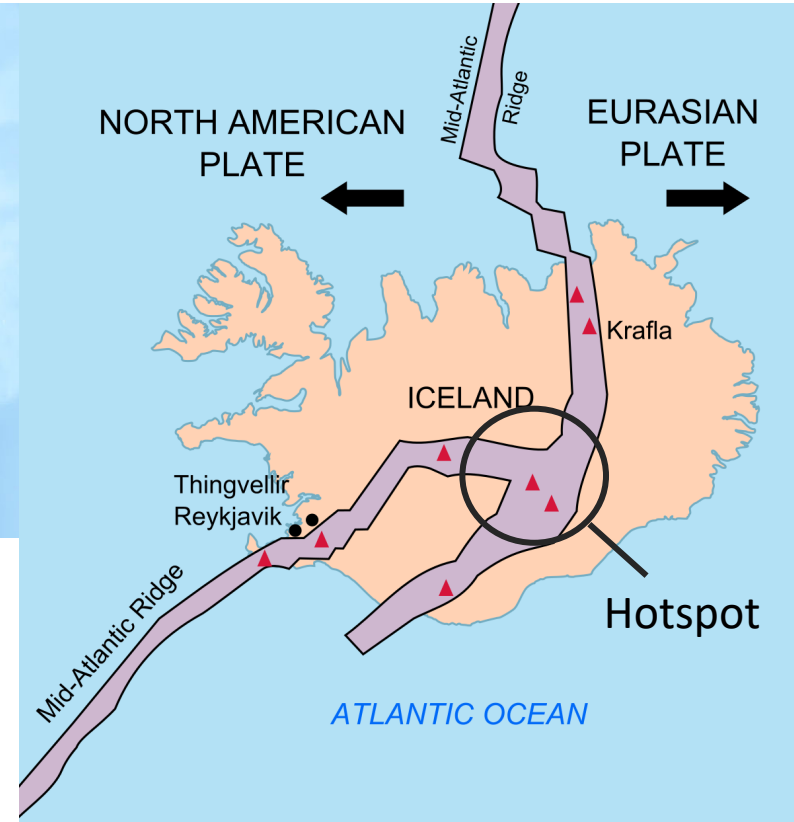


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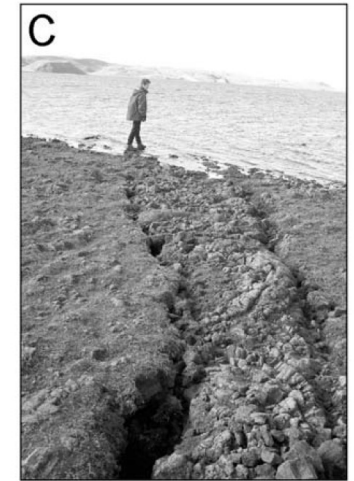
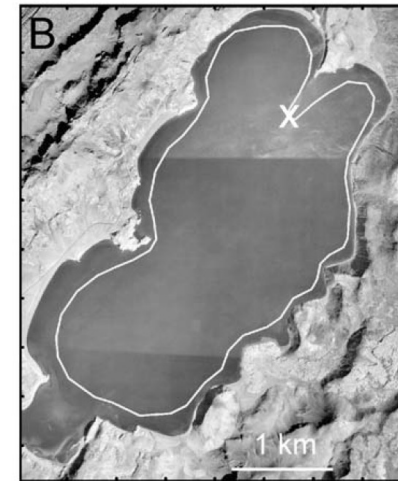
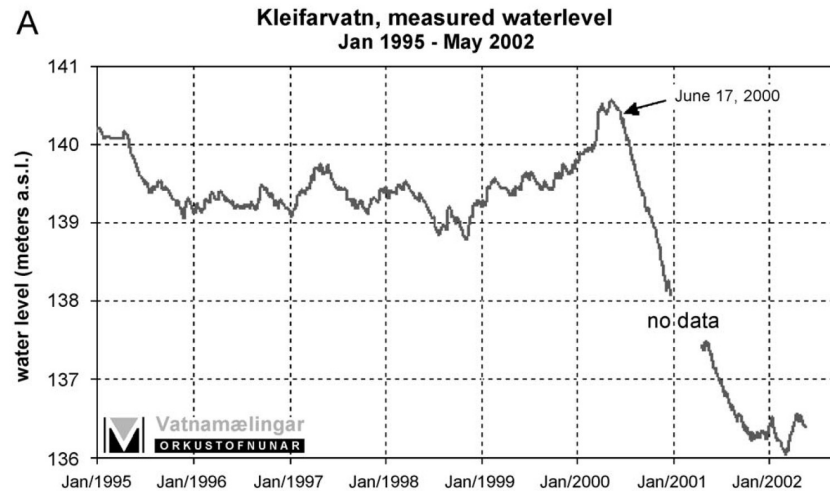
Study site : Reykjanes peninsula

- Emerged part of the Mid-Atlantic Ridge: rift
- Hotspot → **high volcanic and high hydrothermal activity**
- Iceland is **seismically very active**:
 - tectonic earthquakes (boundary between 2 plates)
 - volcanically induced earthquakes
 - (micro)earthquakes induced by fluid circulation in the crust
- **Several dikes intrusion events since 2020** occurred following an unrest of ~1,000 yr



There is a link between periodic tectonic earthquakes and fluid circulation in Iceland's basaltic crust.

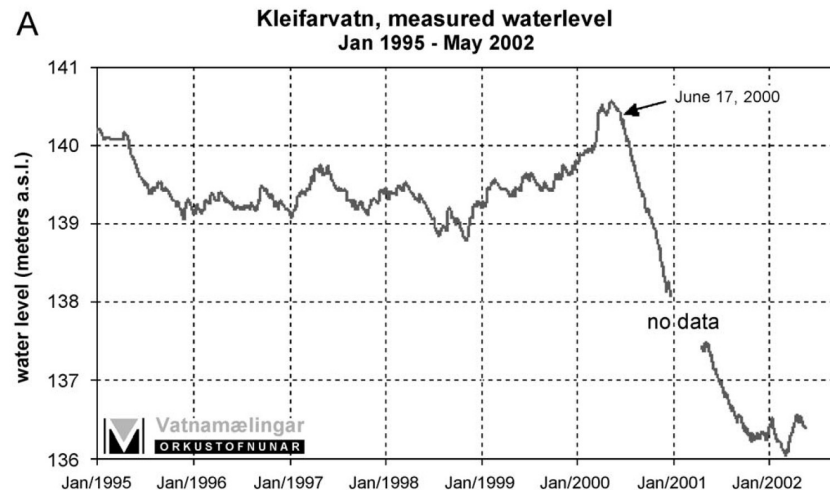
An earthquake ($M_w > 5$) on the Reykjanes peninsula partially emptied Lake Kleifarvatn for ~ 18 months (June 17, 2000 to December 2001).



Clifton et al., 2003

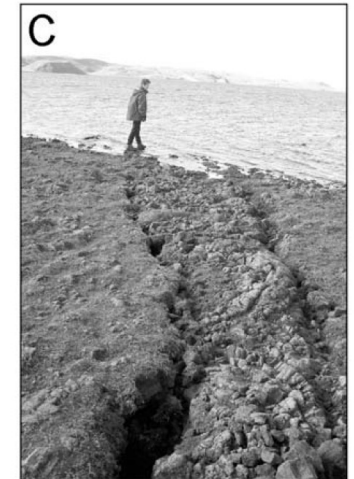
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An earthquake (Mw >5) on the Reykjanes peninsula partially emptied Lake Kleifarvatn for ~18 months (June 17, 2000 to December 2001).



Tectonic activity ⇒ Hydrothermal activity ⇒ Microbial life

Our hypothesis: **Time-dependent processes such like diking and faulting modulate the hydrothermal convection and thus exerts a significant indirect control over microbial abundance, diversity and microbial genetic responses/adaptations**



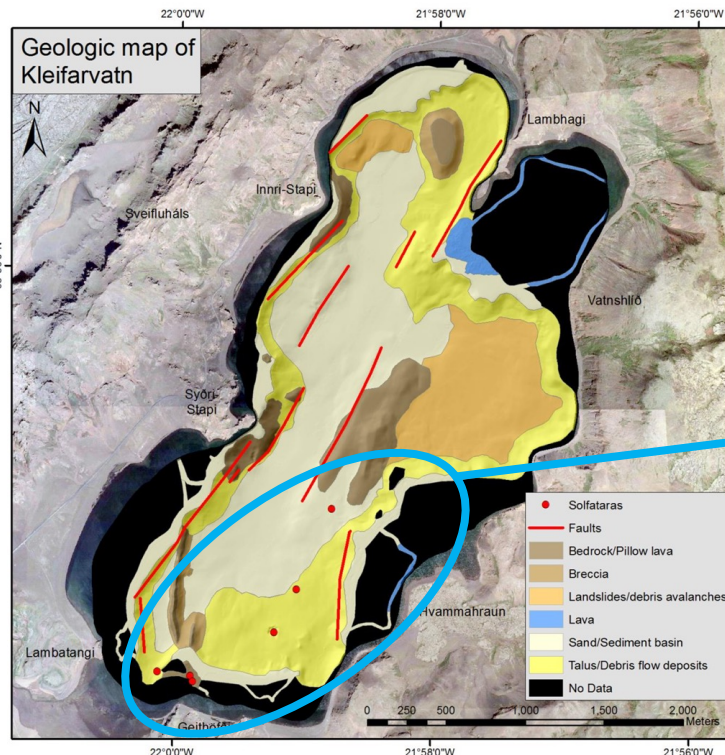
Clifton et al., 2003

An ideal study area : Kleifarvatn lake and its surrounding area

- Endorheic lake (mainly filled by water rainfall)
 - High temperature hydrothermal zone (above a magma chamber)
 - Surface: 9.7 km²
 - Mean depth : 29 m; Max. depth : 97m
 - ~139 m above sea-level
 - Very low salinity (0.055 g.L⁻¹)
 - Thermocline at 20-25m depth in warm periods



- Lake floor and banks host several hydrothermal vents.



Area with hydrothermal vents

(Fridriksson, 2014)

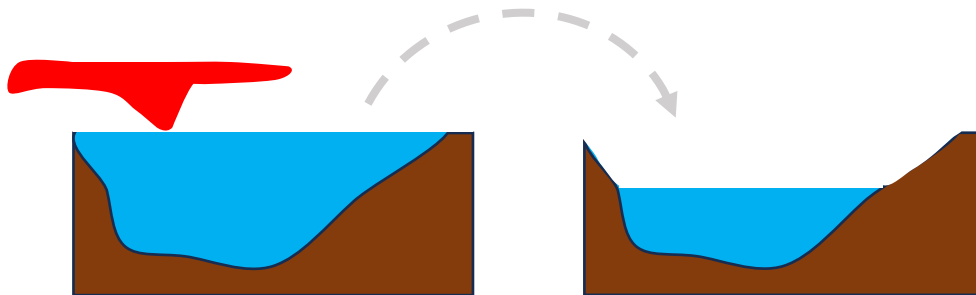


An ideal study area : Kleifarvatn lake and its surrounding area

- Close relationship between fault activation/tectonic activity, and variations in hydrothermal activity recorded over the last decade
- Manifestation : sudden variations in the lake level
- The sudden changes in lake level are linked to hydrothermal discharge and hydrothermal recharge



Plume +



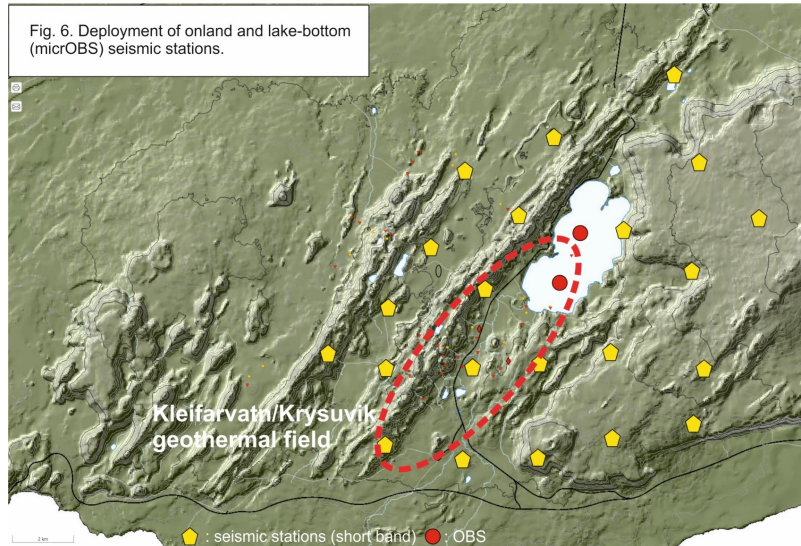
Tectonically controlled cyclic phenomenon of hydrothermal recharge and discharge at this lake?



Objectives & strategy

WP1: Present-day sensibility of hydrothermal fluxes and life to ongoing active tectonics and volcanic activity
(PI: L. Geoffroy Geo-Ocean)

PhD thesis : from Oct. 2025

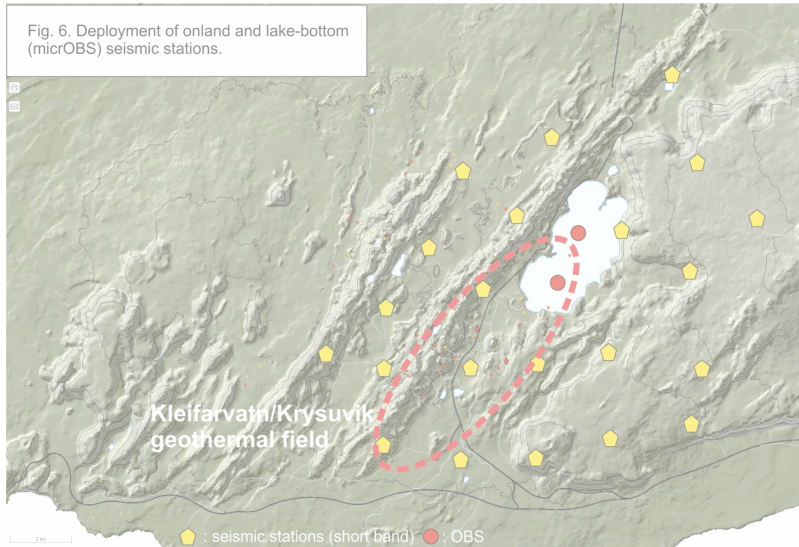


- Deployment of onland and lake bottom **seismometers** and **stress-meters** (May 2025)
- Study of the **chemical and thermal stratification of the lake in summer/ winter**
- **Monitoring of pressure, T° and fluid composition (CO₂, H₂S)** at the bottom of the lake in real time

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WP2: Exploring long-term (Holocene) cyclic relationship between (i) volcano-tectonic processes, (ii) hydrothermal activity and (iii) microbial life in Kleifarvatn lake sediments
(PI: K. Alain BEEP/BIOMEX)

PhD thesis: Mélanie LE MOIGNE



Coring of the lake at various points, to explore:

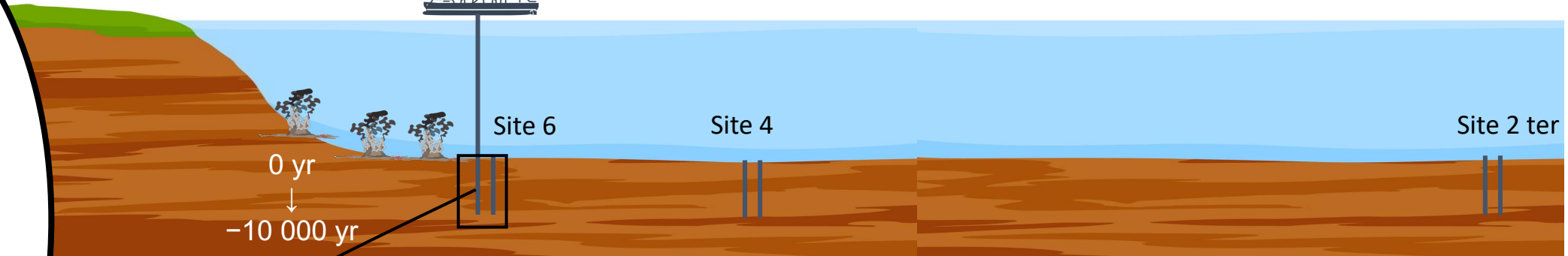
- the potential temporal relationships between **tectonic activity** (palaeoseismicity),
- **volcanic activity** (tephras, ...),
- **hydrothermal activity** (chemistry, temperature),
- and the distribution of microorganisms
 - **number of microbial cells,**
 - **microbial diversity,**
 - **genomic** **potential**
(functions/adaptations)

WP2: Strategy

No hydrothermal influence

Hydrothermal influence

Field trip:
May 2024



6 cores (104 to 121 cm)
50 to 60 sediment horizons (2 cm) / core

Geochemical, lithological and paleoenvironmental analyses

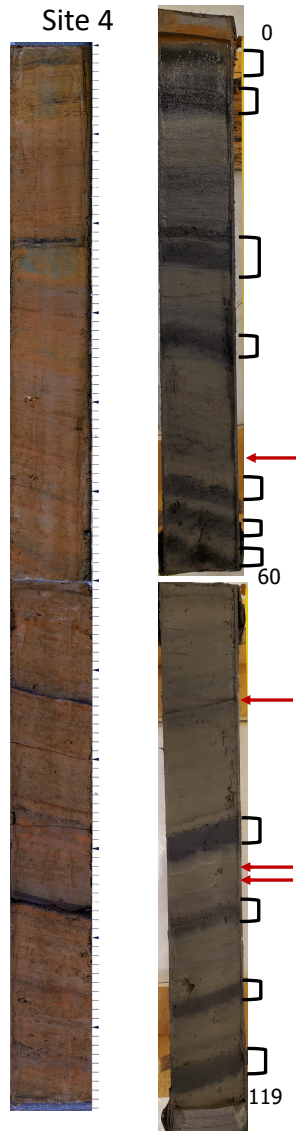
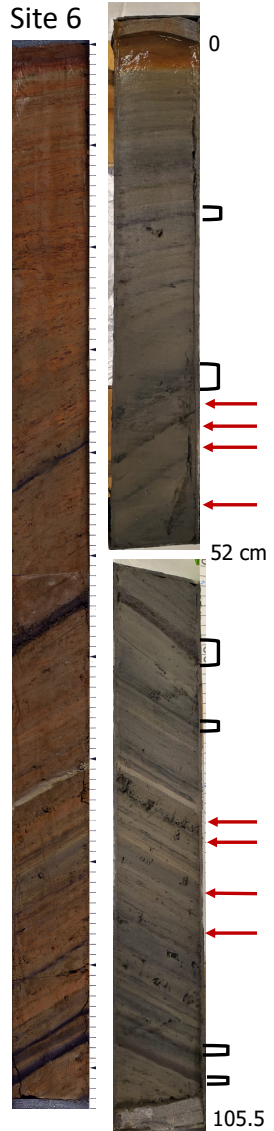
Microbiological and metagenomic analyses



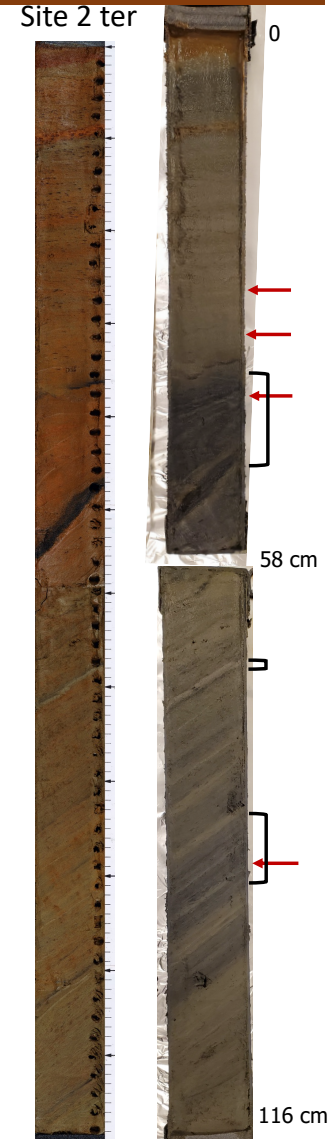
WP2: Preliminary results: Macroscopic observations of the cores



Hydrothermal influence



No hydrothermal influence



- **More tephras present in cores taken in the hydrothermally influenced zone** ⇒ characterization to come
- **No paleoseismites visible to the naked eye** ⇒ thin slides to come

Tephras:

- Volcanic ash
- Basalt fragments

Preliminary results: Pore water composition

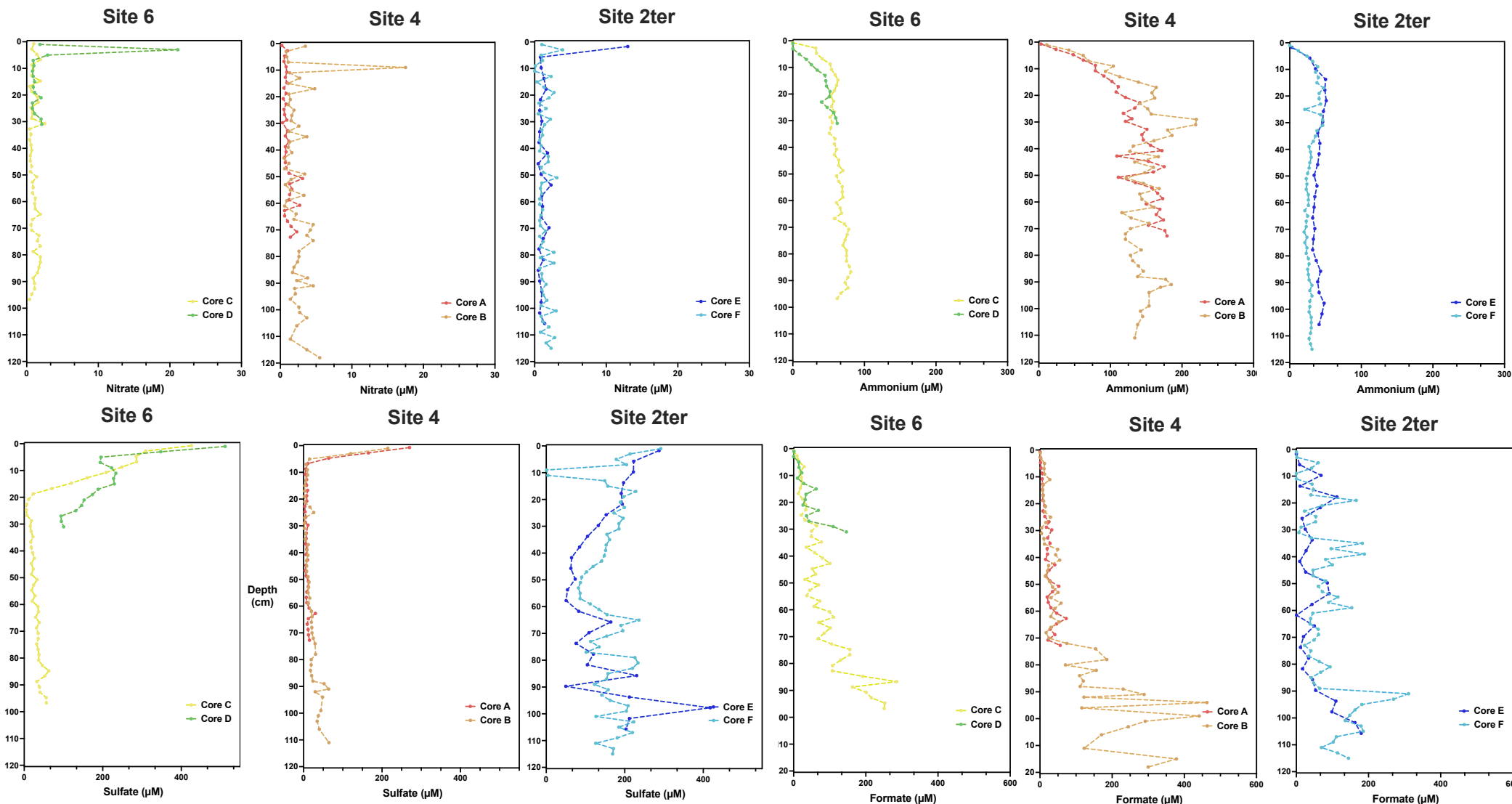


Hydrothermal influence

No hydrothermal influence

Hydrothermal influence

No hydrothermal influence



↘ nitrate and ↗ ammonium with depth

Presence of strong oxidative species (sulfate, nitrate) at depth

Presence of acetate (not shown) and formate: methanogenesis substrates

Preliminary results: gas composition



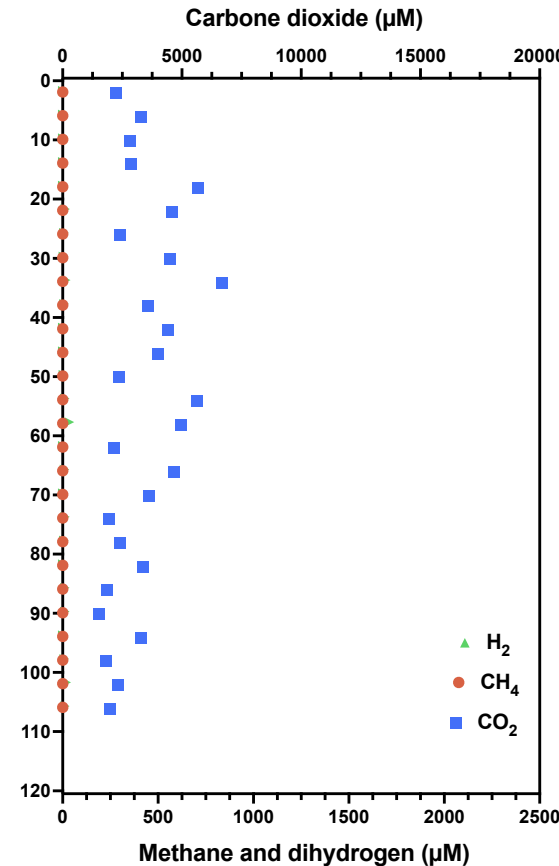
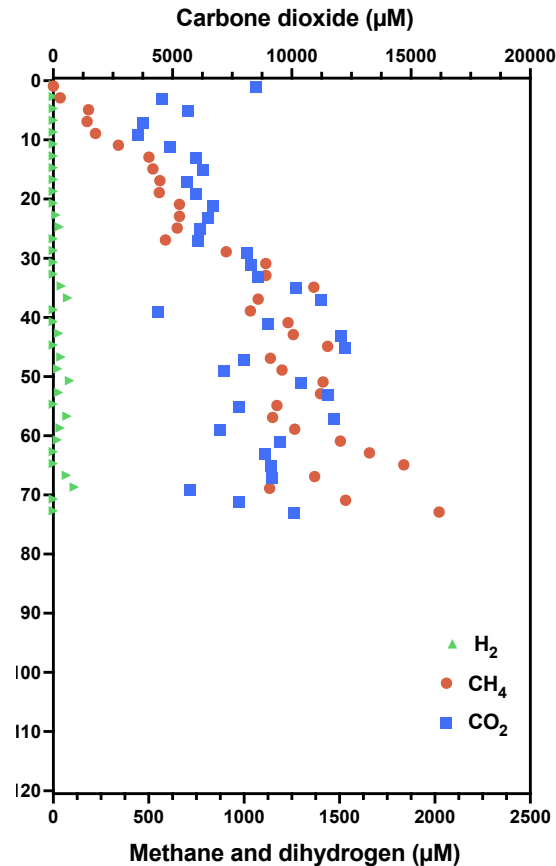
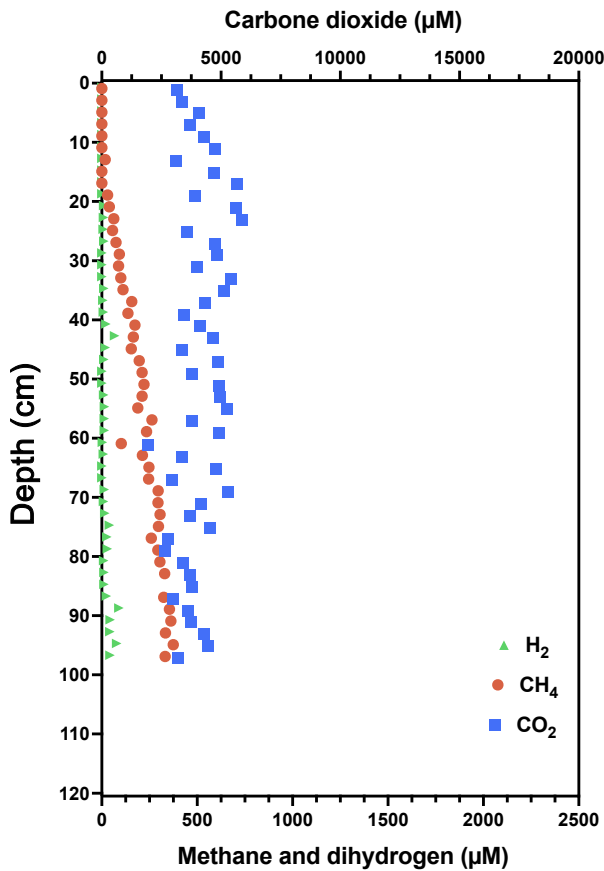
Hydrothermal influence

No hydrothermal influence

Site 6

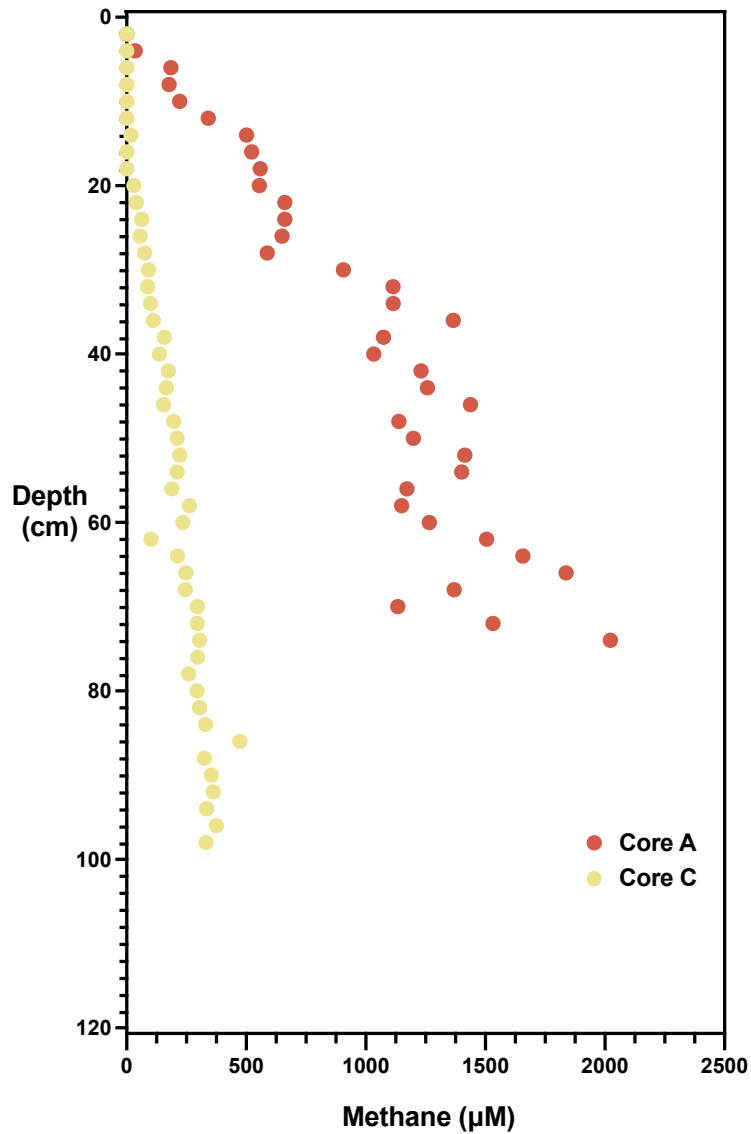
Site 4

Site 2ter



- CO_2 present in all 3 cores
- Methane and hydrogen only in the cores under hydrothermal influence
- Higher concentrations in CO_2 , H_2 , and CH_4 at site 4

Preliminary results: gas composition



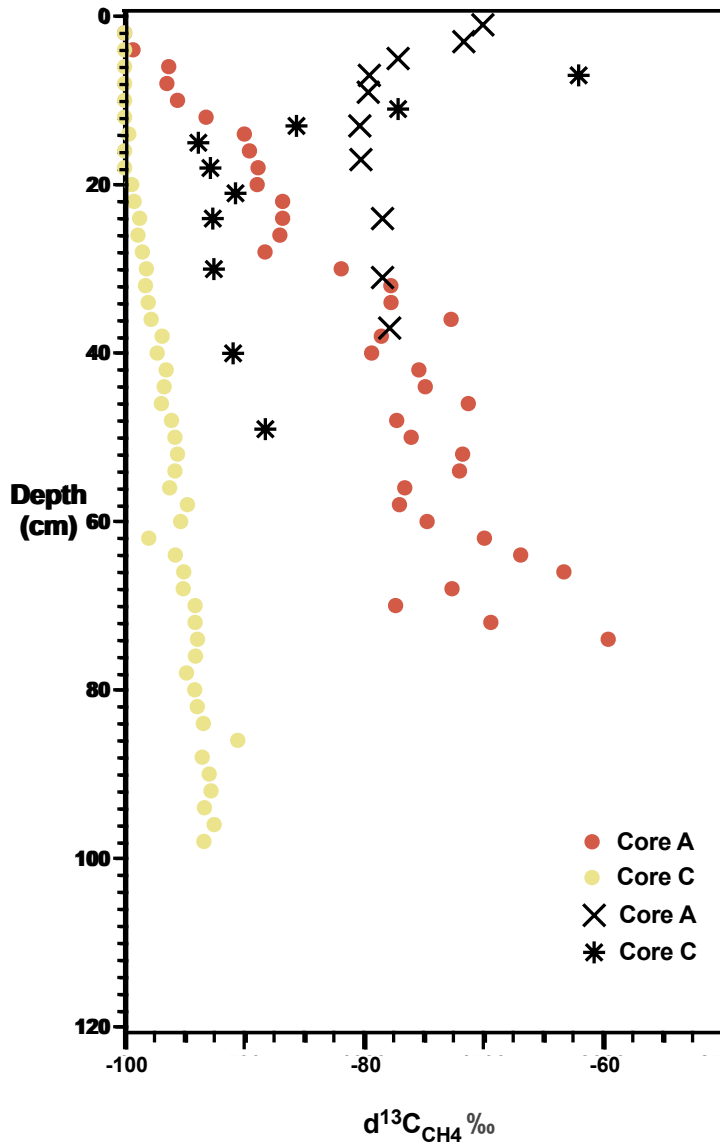
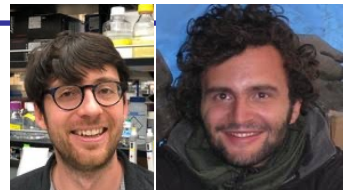
Hydrothermal influence

Methane core C (site 6) < core A (site 4)

No hydrothermal influence

No methane

Preliminary results: gas composition



Hydrothermal influence

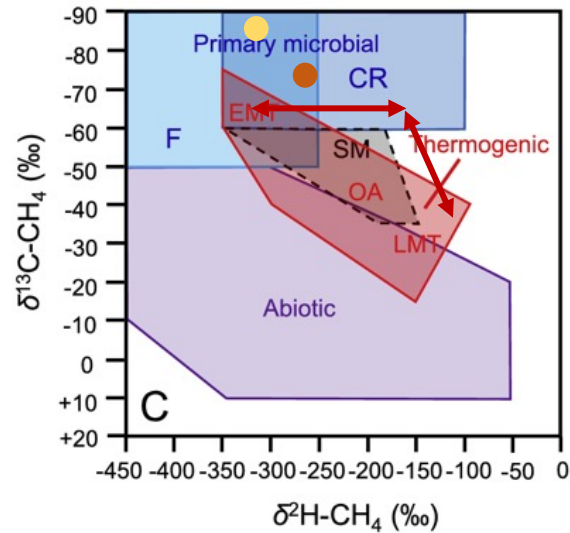
No hydrothermal influence

Methane core C (site 6) < core A (site 4)

No methane

→ **Not the same isotopic signature for the 2 cores**

Core A $\delta^{13}\text{C-CH}_4$ (up to -80 ‰) > **Core C** $\delta^{13}\text{C-CH}_4$ (up to -94 ‰)



Dominated by biogenic/microbial methane

Microbial methane : F: Fermentation; CR : CO_2 reduction

↔ Microbial-thermogenic transition/mixing

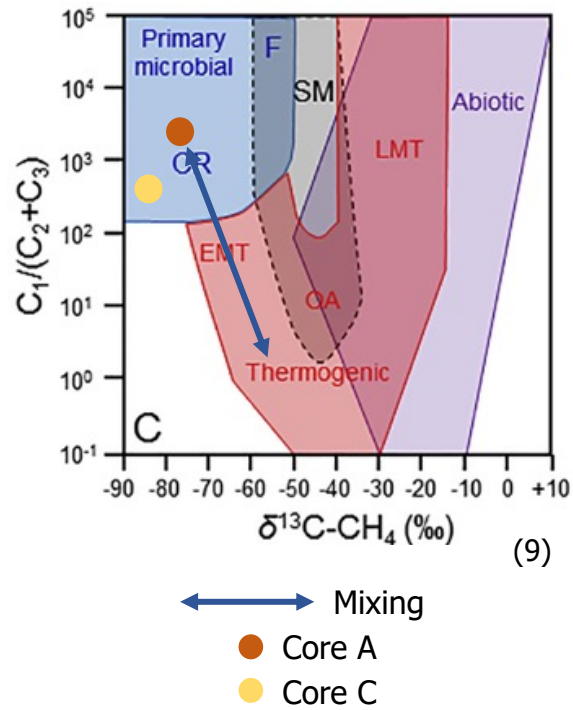
Preliminary results: gas composition



Complementary analyses (GC):

Measures of methane, ethane (C_2H_6), propane (C_3H_8) and N-butane (C_4H_{10}) on 4 horizons

Ratio $C_1 / (C_2 + C_3 + C_4)$: Higher in core 4



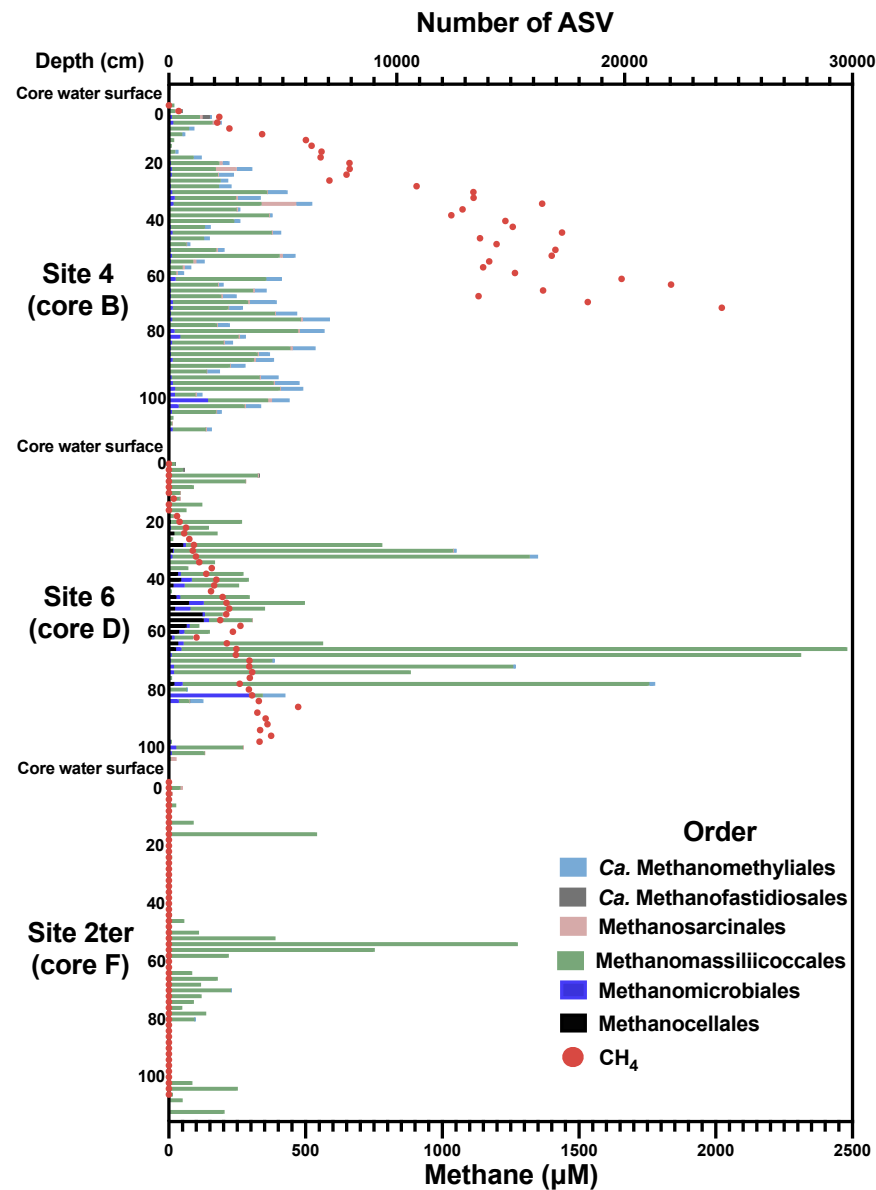
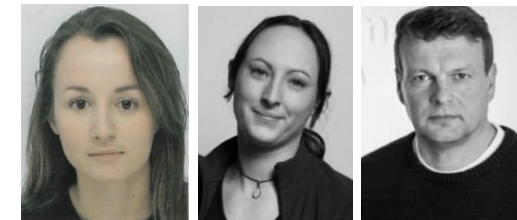
Not the same fluid for the 2 cores

Core C (site 6): Microbial/biogenic methane

Core A (site 4): Mixture microbial/biogenic and thermogenic methane

Hydrothermal influence

Preliminary results: microbial diversity (metabarcoding)

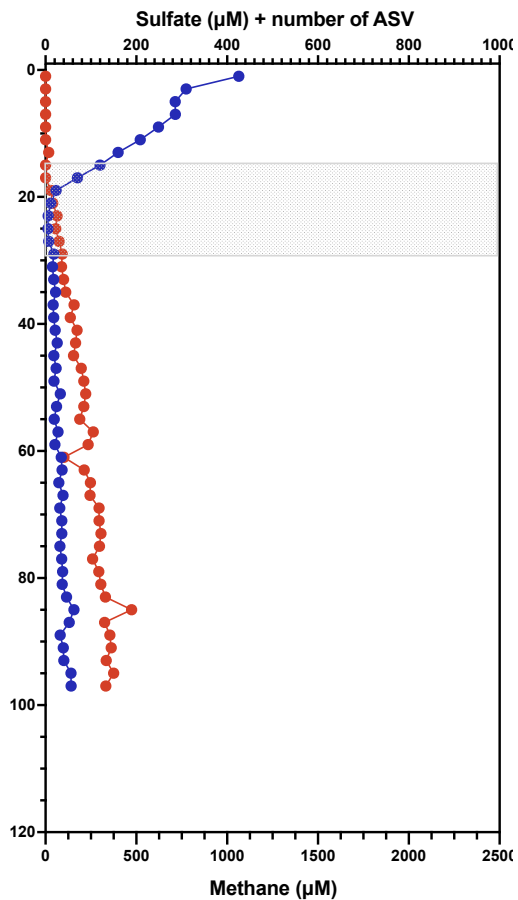


- **Methanogenic archaea in cores under hydrothermal influence**
- **Few methanogens in the reference zone, where no methane was detected**

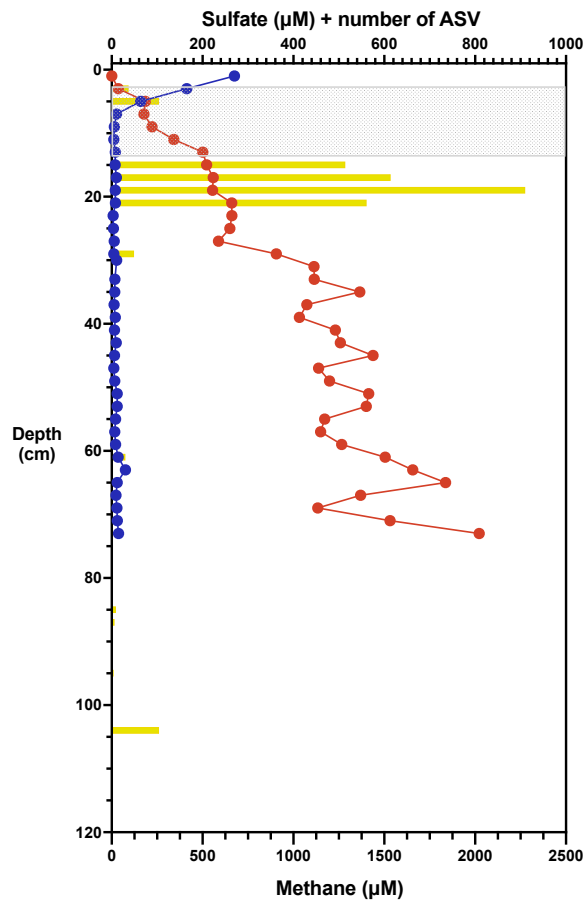
Preliminary results: microbial diversity (metabarcoding)

Hydrothermal influence

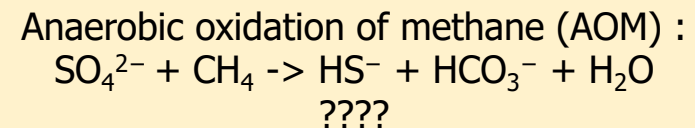
Site 6



Site 4



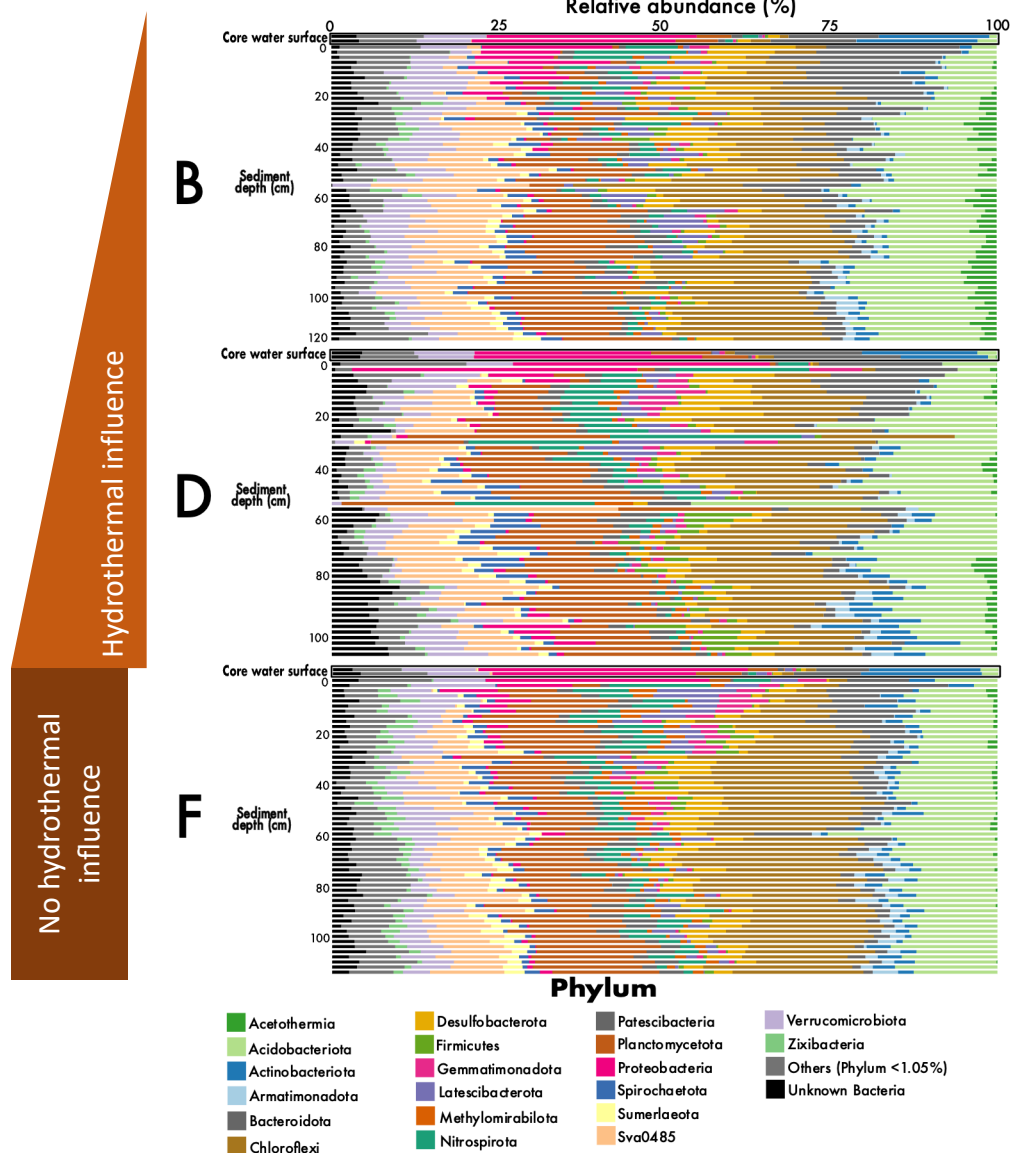
Sulfate Methane Transition Zone (SMTZ)



- Presence of archaea carrying out this reaction

● Sulfate ● Methane ■ SMTZ ■ ANME-2 *Methanoperedenaceae*

Preliminary results: microbial diversity (metabarcoding)



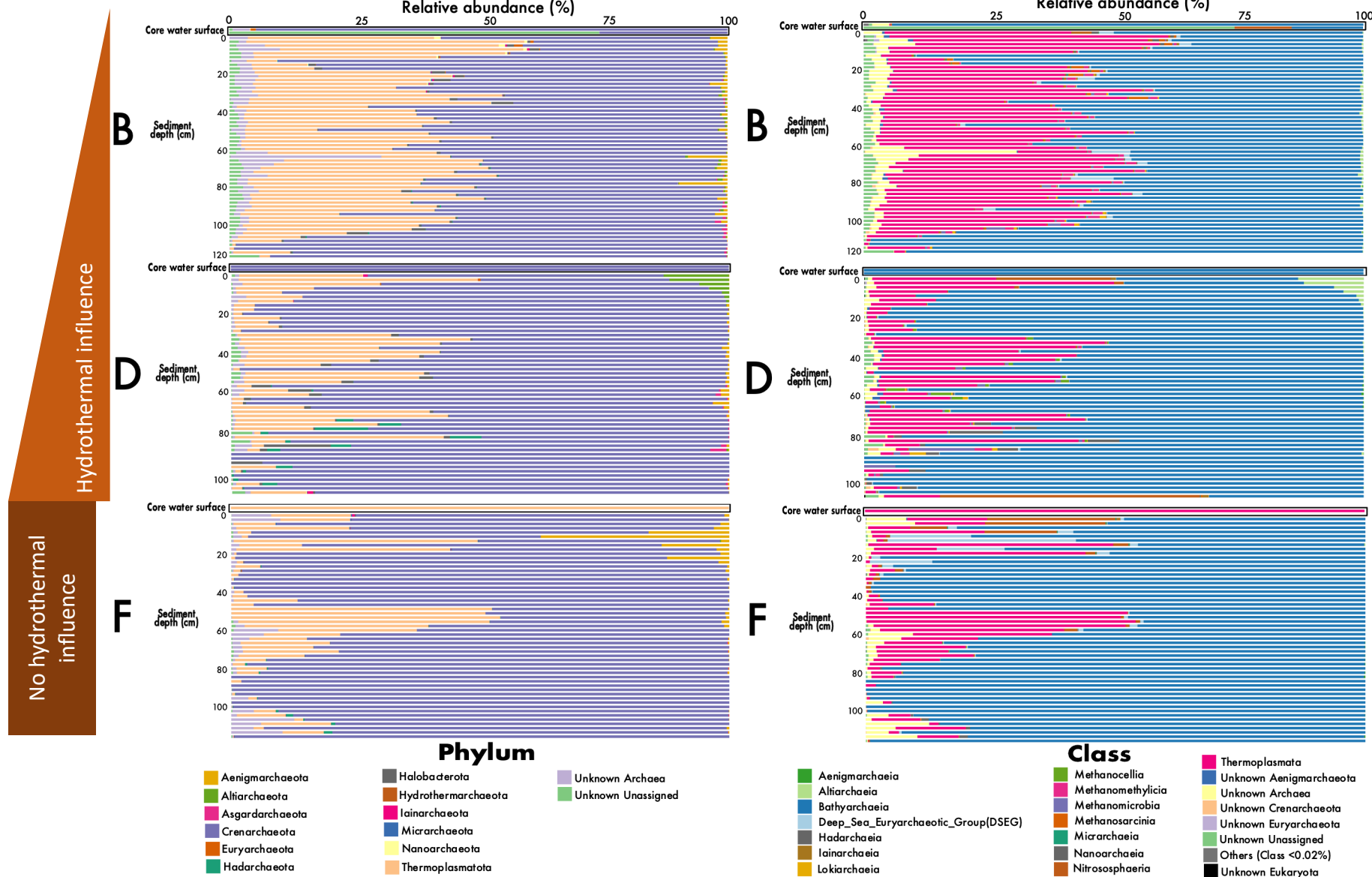
Microbial communities: Archaeal and bacterial lineages commonly found in sedimentary habitats and/or hydrothermal systems

The presence of certain thermophilic hydrothermal taxa coincides with S peaks detected by XRF

Bacteria involved in:

- **Nitrogen cycle** (anammox, comammox, nitrification, denitrification...)
- **Methane cycle** (methanogenesis, aerobic methanotrophy, AOM)
- **Sulfur cycle** (sulfate reduction, sulfur reduction)

Preliminary results: microbial diversity (metabarcoding)



Archaea:

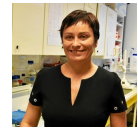
- Relative abundance increases with depth
- Large dominance of *Crenarchaeota* (of the class *Bathyarchaeia*)

WP2: Perspectives

- **Dating sedimentary horizons (^{14}C plant remains + organic matter)**
 - **Characterize tephras: nature + origin (→ to relate to recorded volcanic events)**
 - **Mineralogical analyses : XRD (→ to relate to hydrothermal activity)**
 - **Elementary analysis : notably TOC/ $\delta^{13}\text{C}$ et $\delta^{15}\text{N}$ (→ to characterize the organic matter)**
 - **Isotopic signature of the sulfate measured at the bottom of the cores (→ source of this sulfate)**
 - **Metagenomics : microbial genome reconstruction and analysis of encoded functions and adaptations**
 - **Finish cell counts (determined by microscopic counting after cell extraction and SYBR®Green staining)**
 - **Quantify *Bacteria*, *Archaea*, and a key gene of methanogenesis by quantitative PCR**
-
- **Determine if there are relationships between**
 - **(i) volcano-tectonic processes,**
 - **(ii) hydrothermal activity**
 - **and (iii) patterns of microbial diversity and microbial functions/adaptations**

Thank you for your attention

People involved in the WP2 d'ISLAB:



Karine
ALAIN



Mélanie Le
MOIGNE



Xavier
PHILIPPON



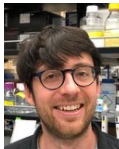
Françoise
LESONGEUR



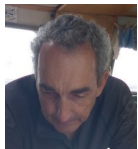
Pauline
VANNIER



Jérôme
GOSLIN



Antoine
CREMIERE



Laurent
GEOFFROY



Marina
RABINEAU



Thomas
GIUNTA



Thibaut
BARREYRE



Jean-Pierre
DONVAL

Léonie
DELALEAU
Sandrine
CHERON
Et alii.



Viggó Þór
MARTEINSSON



Alexandra
KLONOWSKI



Ármann
HOSKULDSSON



Steffen Leth
JØRGENSEN

People involved in the WP1 d'ISLAB (non-exhaustive list):



Laurent
GEOFFROY



Marina
RABINEAU



Thibaut
BARREYRE



Sara
BAZIN



Julie
PERROT



Christophe
PRUNIER



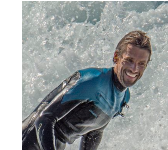
Pascal
PELLEAU



Hélène
PLANQUETTE



Corentin
BAUDET



Matthieu
WAELES



Peggy
RIMMELIN-MAURY



Ármann
HOSKULDSSON



Þorbjörg
Ágústsdóttir



Egill Árni
Guðnason