

# Geoelectrical monitoring of dissolution and precipitation reactions in a saturated calcareous porous medium

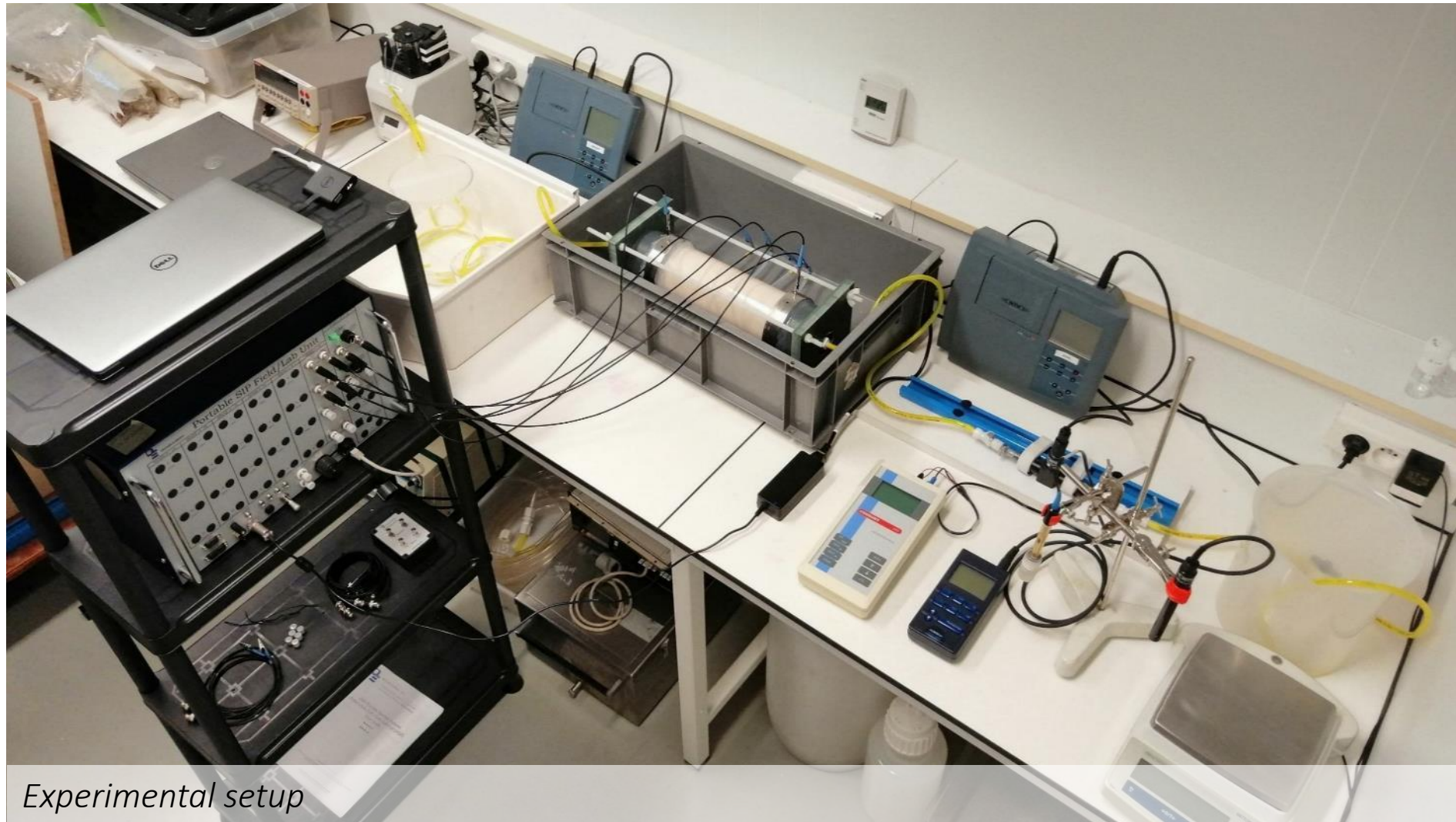
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Linda LUQUOT

Pierpaolo ZUDDAS

Roger GUÉRIN



*Experimental setup*



# Geoelectrical monitoring of dissolution and precipitation reactions in a saturated calcareous porous medium



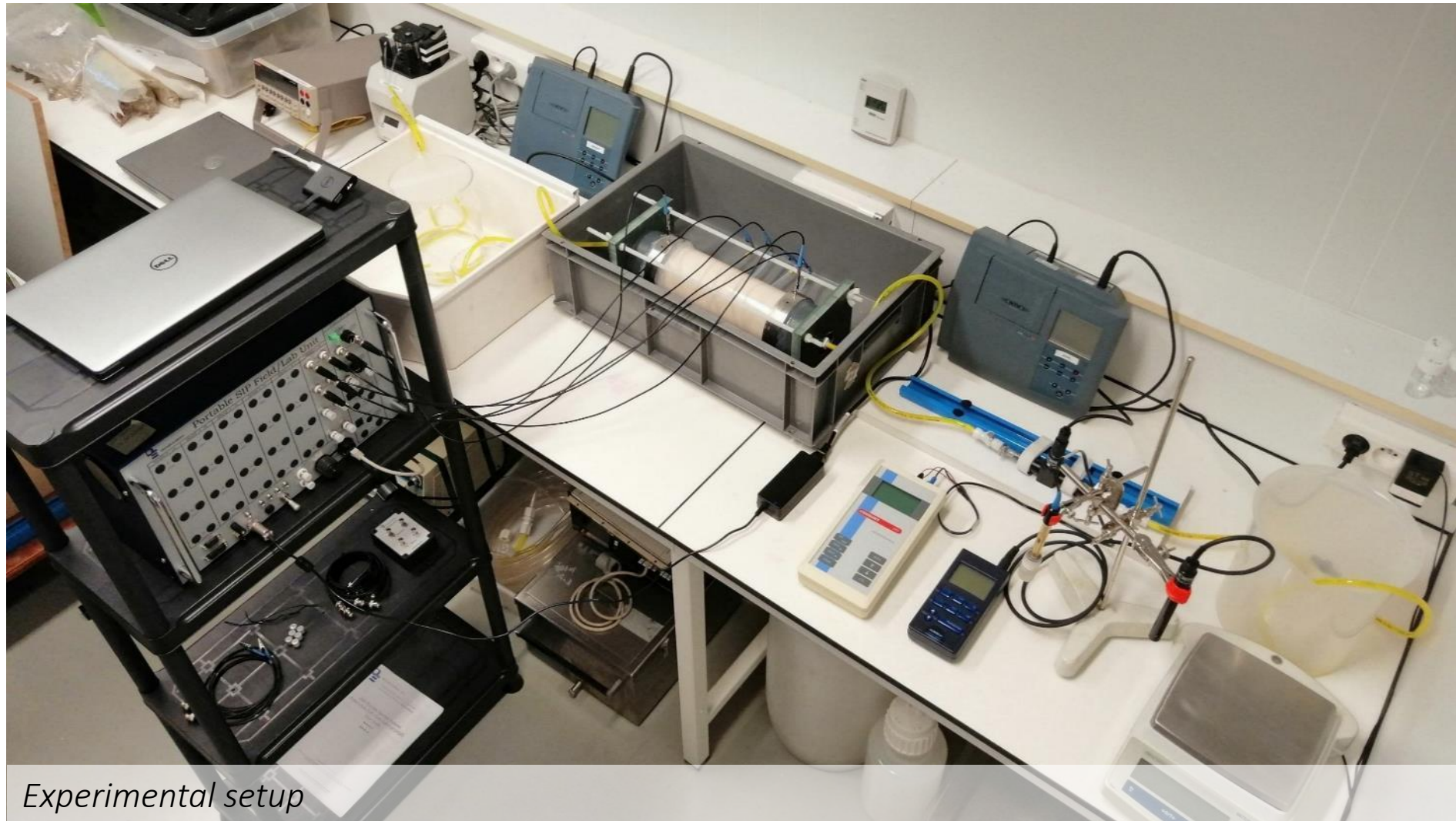
Background



Experimental results



Conclusions

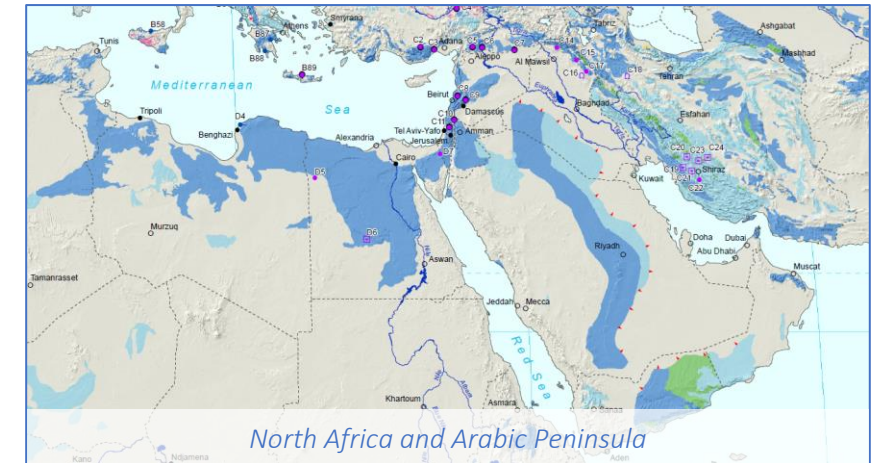
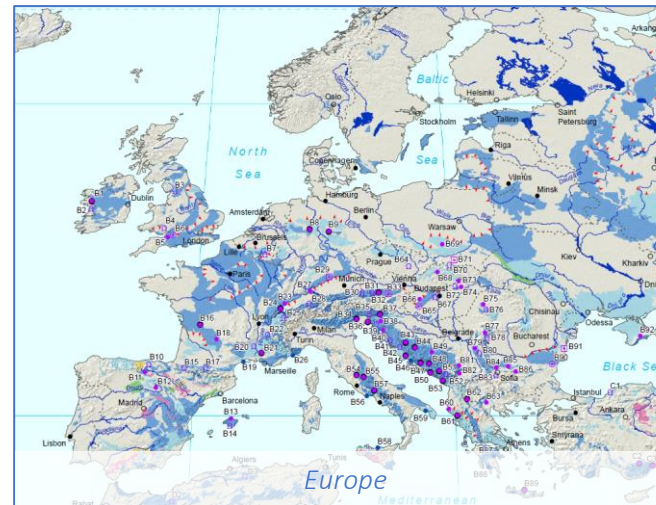
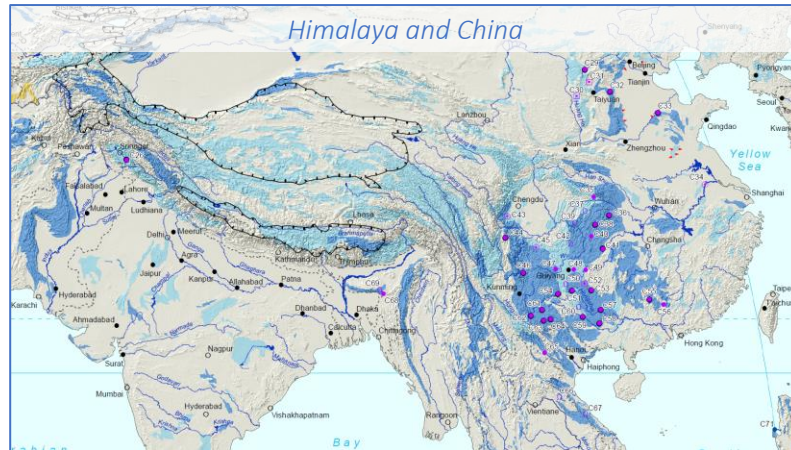








# Carbonate reservoirs are **essentials**

📍 They are worldwide distributed



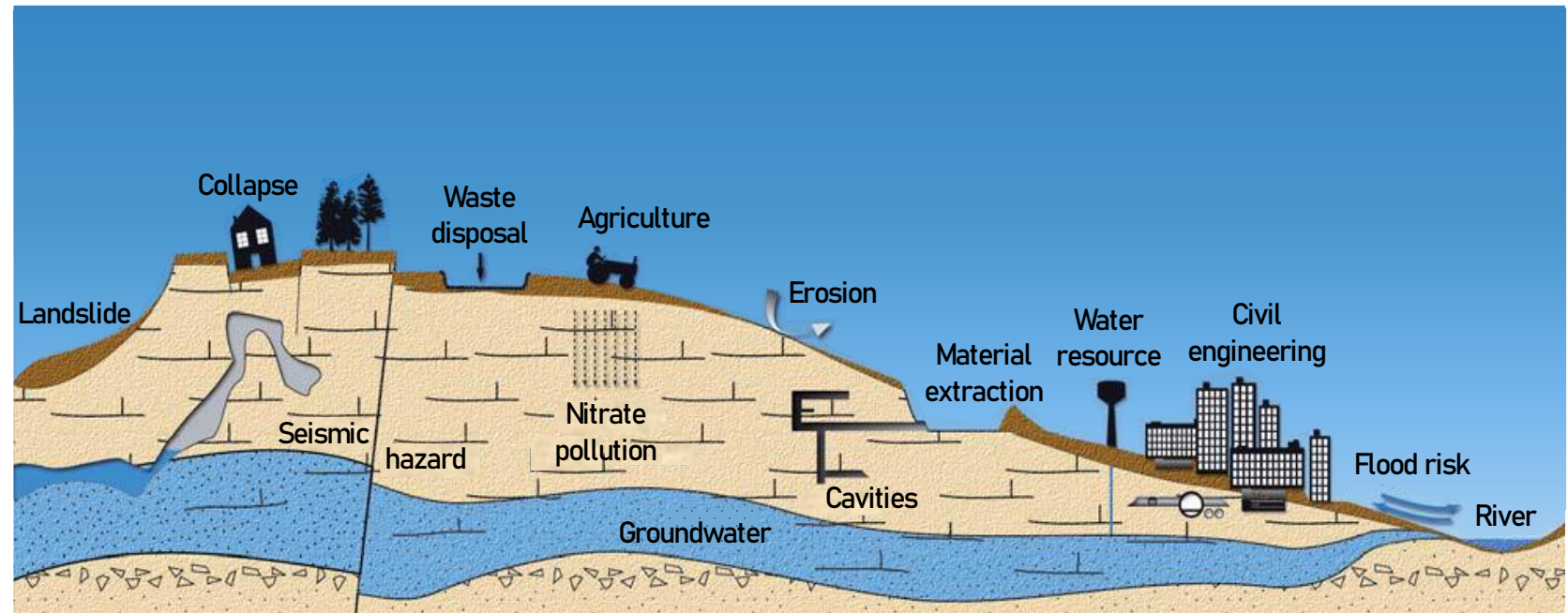
*Karst Aquifer Maps  
from Chen et al. (2017)*

-  Carbonate rocks continuous / discontinuous
-  Large freshwater lake



## Carbonate reservoirs are **essentials**

- 📍 They are worldwide distributed
- ⚙️ They cover many needs and are related to many problematics



*Carbonate issues (from the French Geological Survey, BRGM, 2009)*

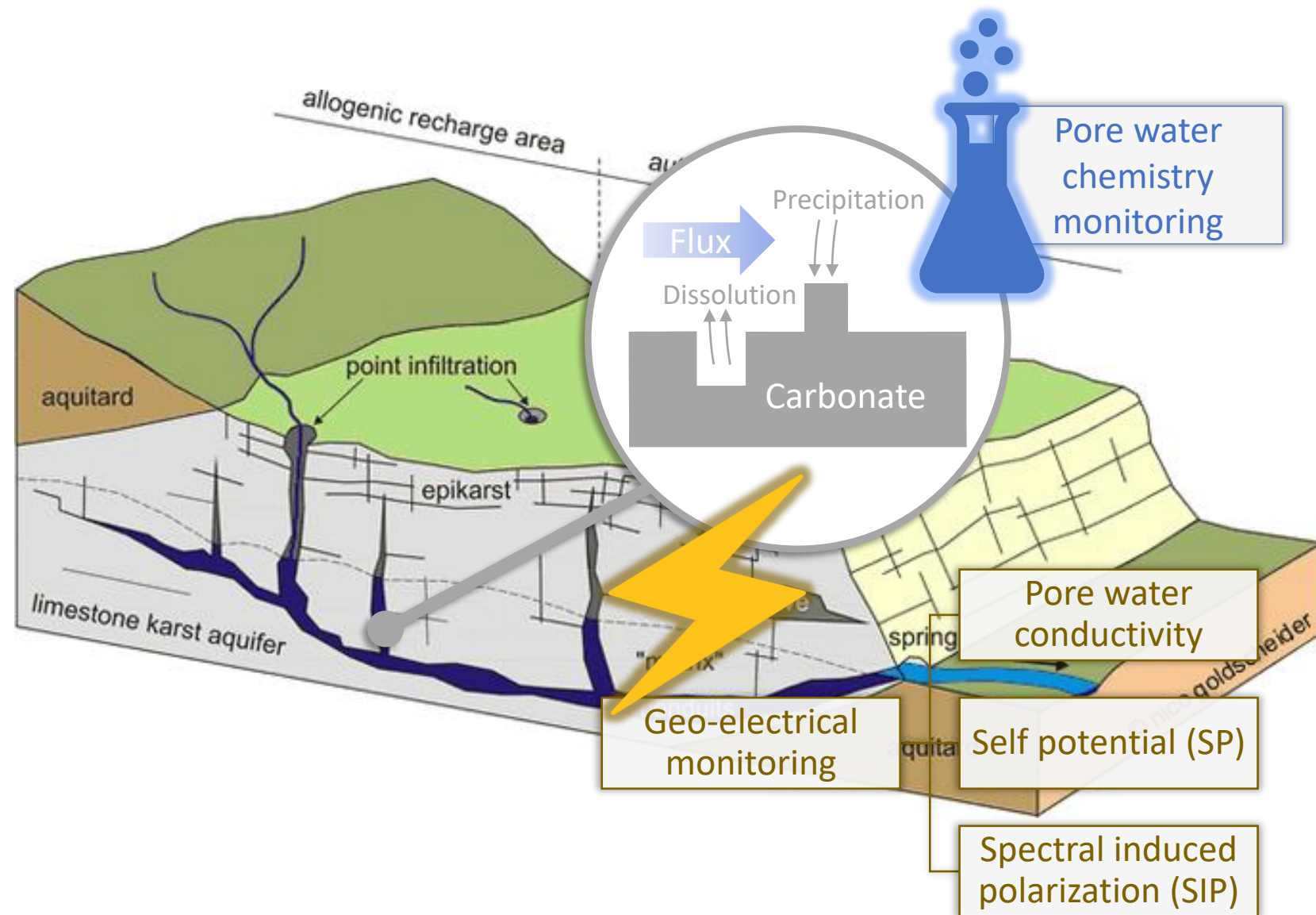




In a near-surface context carbonate reservoirs form complex karst-systems.

This karstic shape is driven by chemical reactions caused by the water flux.

Which methods should we use to study dissolution and precipitation processes?



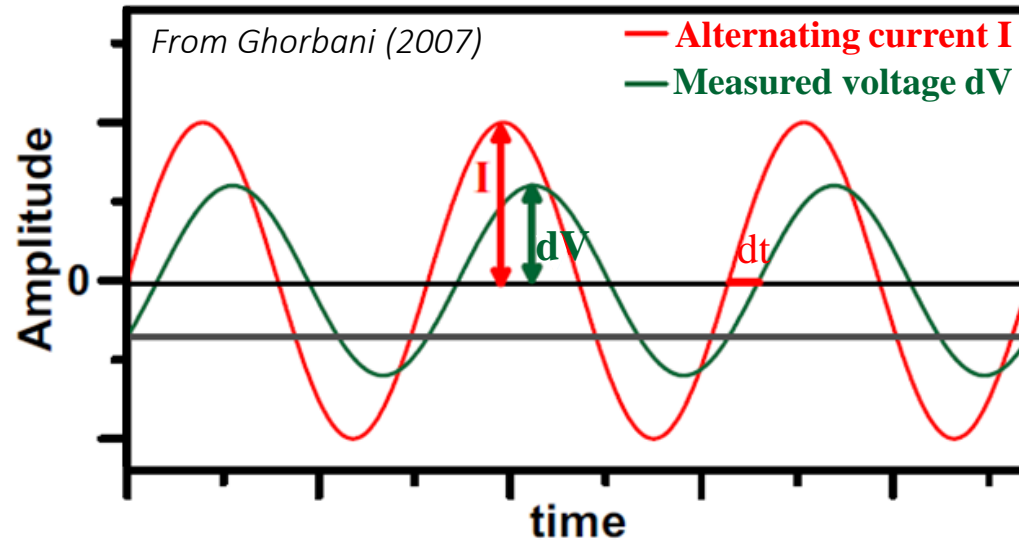
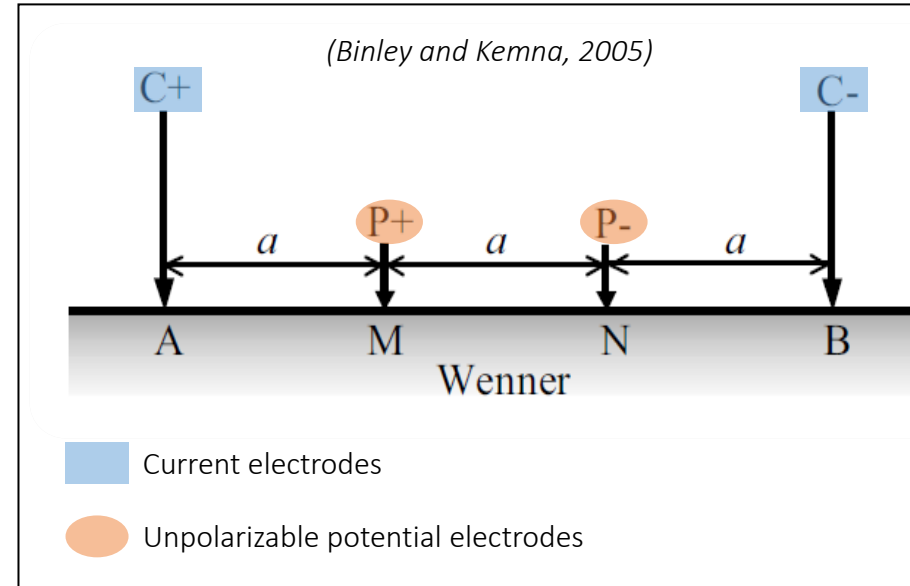
## Spectral induced polarization

This electrical method is conducted through the injection of an electrical current and the measure of the resulting voltage with unpolarizable electrodes.

The alternating current is injected at several frequencies.

The measured voltage is sinusoidal: it oscillates at the same frequency but is temporally shifted.

The resulting resistivity is a complex number which possesses an amplitude and a phase.



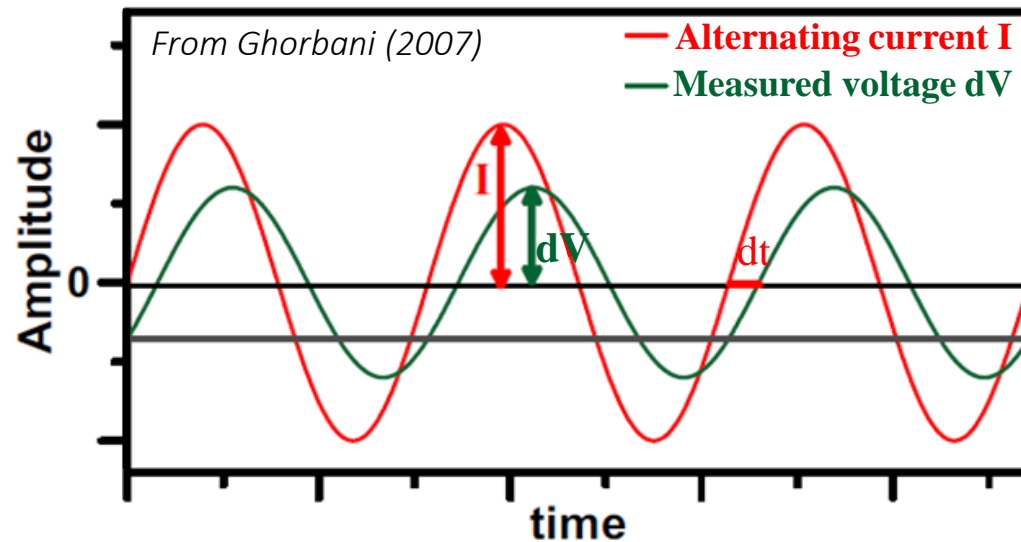
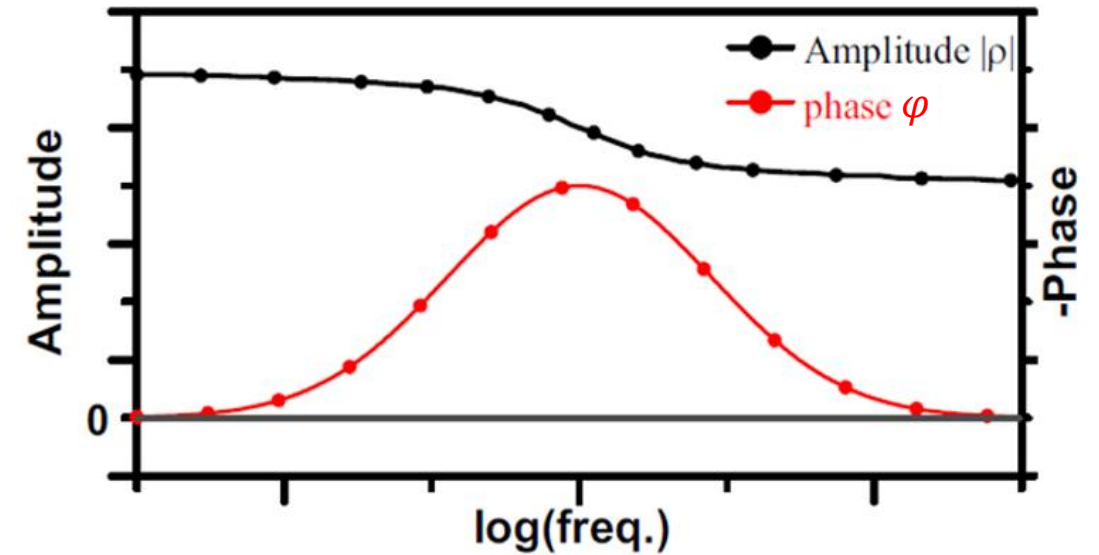
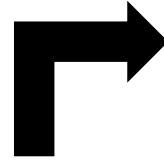
$$\frac{dV(\omega)}{I(\omega)} \propto \rho^*(\omega) = |\rho(\omega)| \cdot e^{i\varphi(\omega)}$$

## Spectral induced polarization

The SIP method allows to get the spectra of these two values over the explored frequency range.

While the amplitude is linked to the microstructure of the porous medium, the phase gives also insights about the mineral surface state.

This information is crucial for the study of rock-water chemical processes.



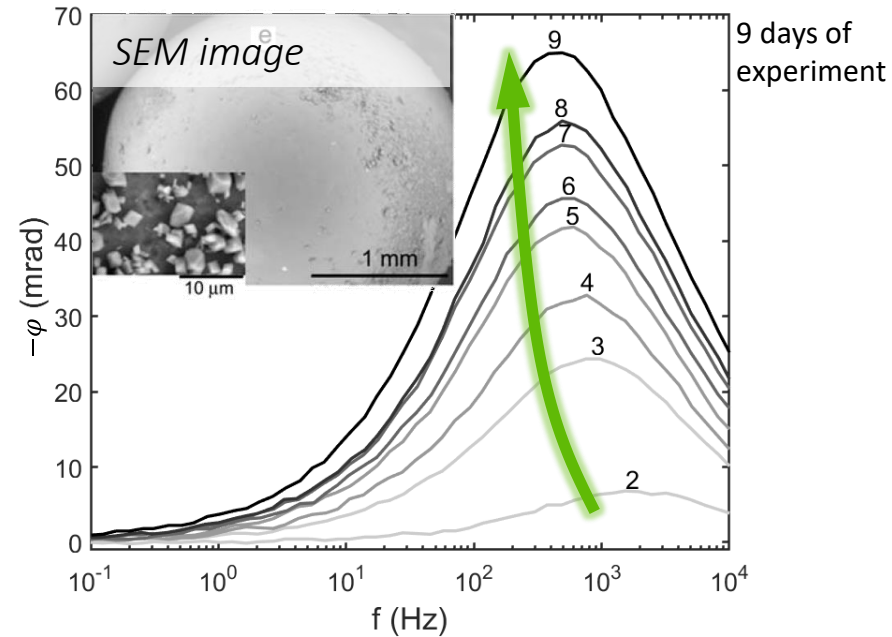
$$\frac{dV(\omega)}{I(\omega)} \propto \rho^*(\omega) = |\rho(\omega)| \cdot e^{i\varphi(\omega)}$$

## Spectral induced polarization

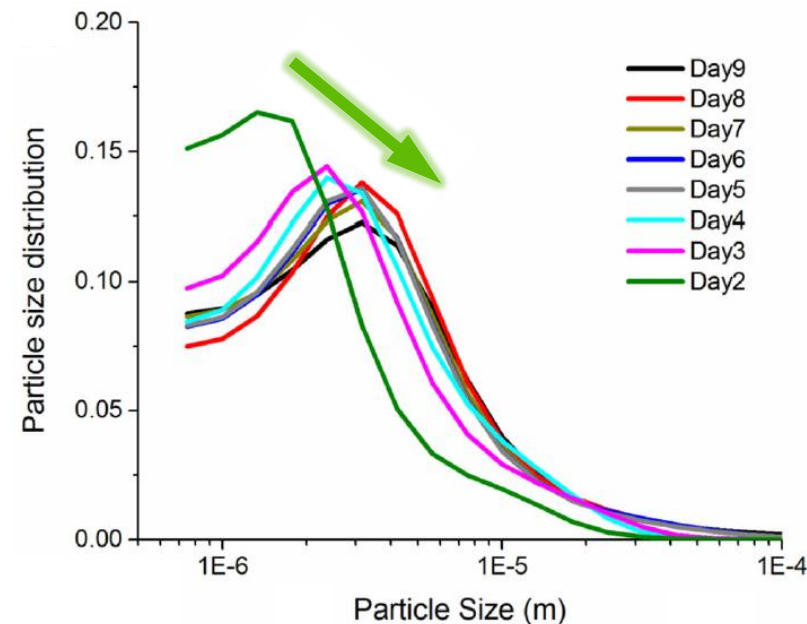
The study of Wu et al. (2010) highlights that during precipitation of calcite grains in a glass beads packed cell:

- The phase peak grows
- And is shifted towards low frequencies.

Leroy et al. (2017) developed a mechanistic model to interpret this evolution as the growth of the grains' size during the experiment.



Wu et al. (2010)



Leroy et al. (2017)



## Self potential

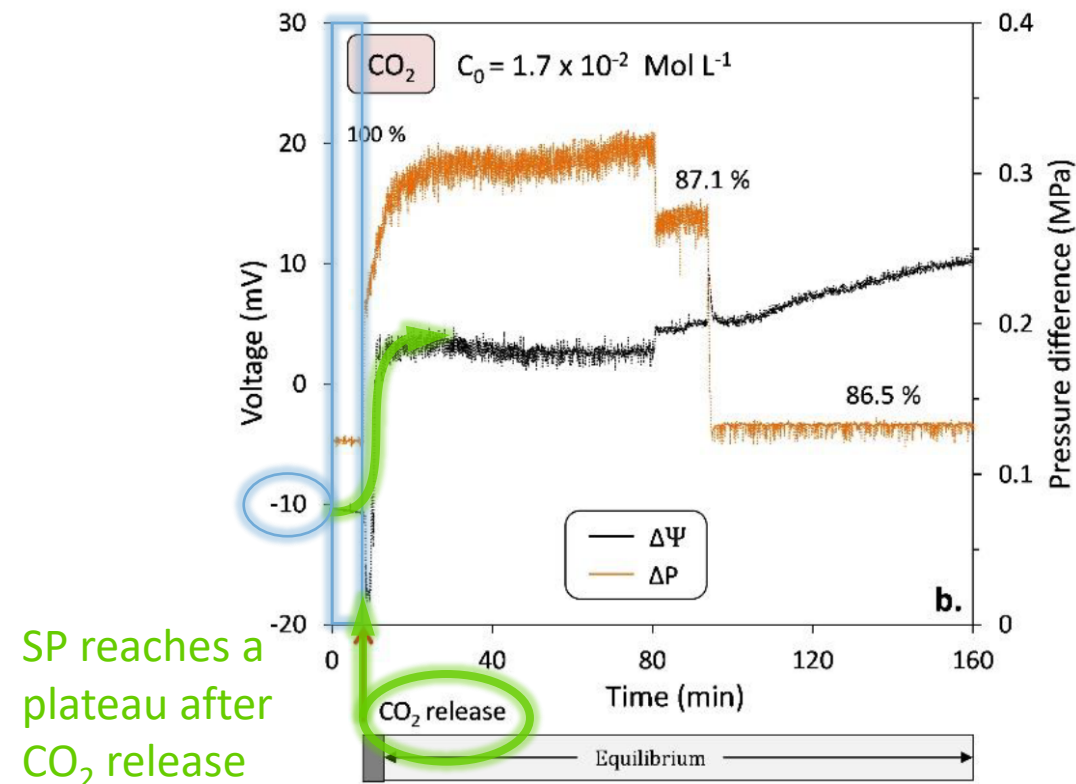
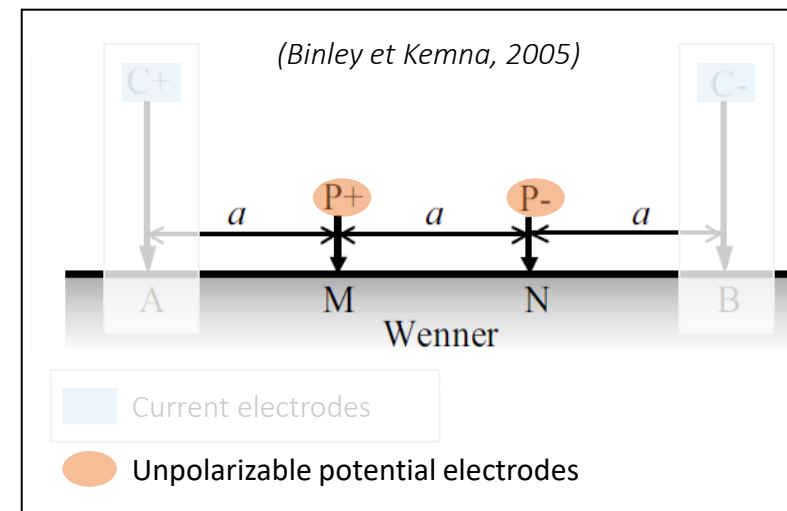
This passive method measures the electrical current generated by natural sources.

These sources can be:

- Electrokinetic
- Electrochemical

Cherubini et al. (2019) measured SP signal of brine flowing through limestone.

- The electrokinetic source is observed at the beginning of the experiment
- Then the electrochemical source is added with the injection of  $\text{CO}_2$  with the brine.



Cherubini et al. (2019)



## Experimental setup



Calcite grains  
 $125\ \mu\text{m} < d < 250\ \mu\text{m}$



Pore water  
chemistry  
monitoring

Alkalinity

Concentrations

pH

Saturation state

$$\Omega = \frac{\text{ion activity product}}{\text{Solubility constant}}$$

Tightening  
structure

Column

P<sub>1</sub>

P<sub>2</sub>

P<sub>3</sub>

P<sub>4</sub>

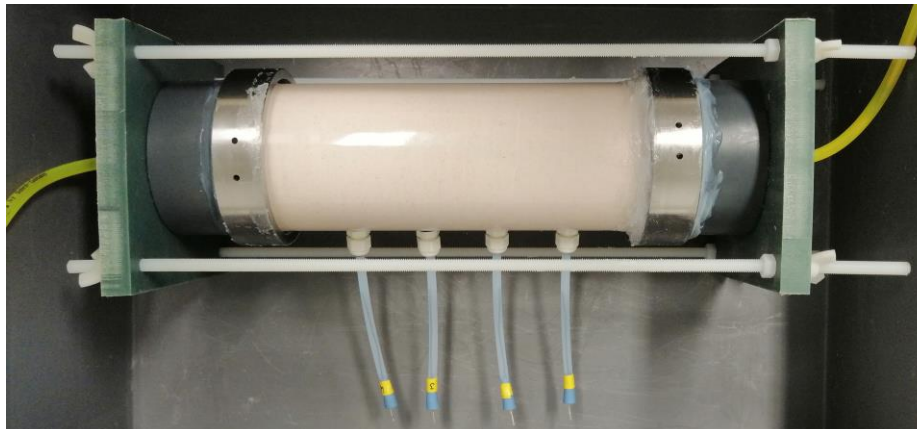
25 cm

Sampling

Downstream  
solution

Pump

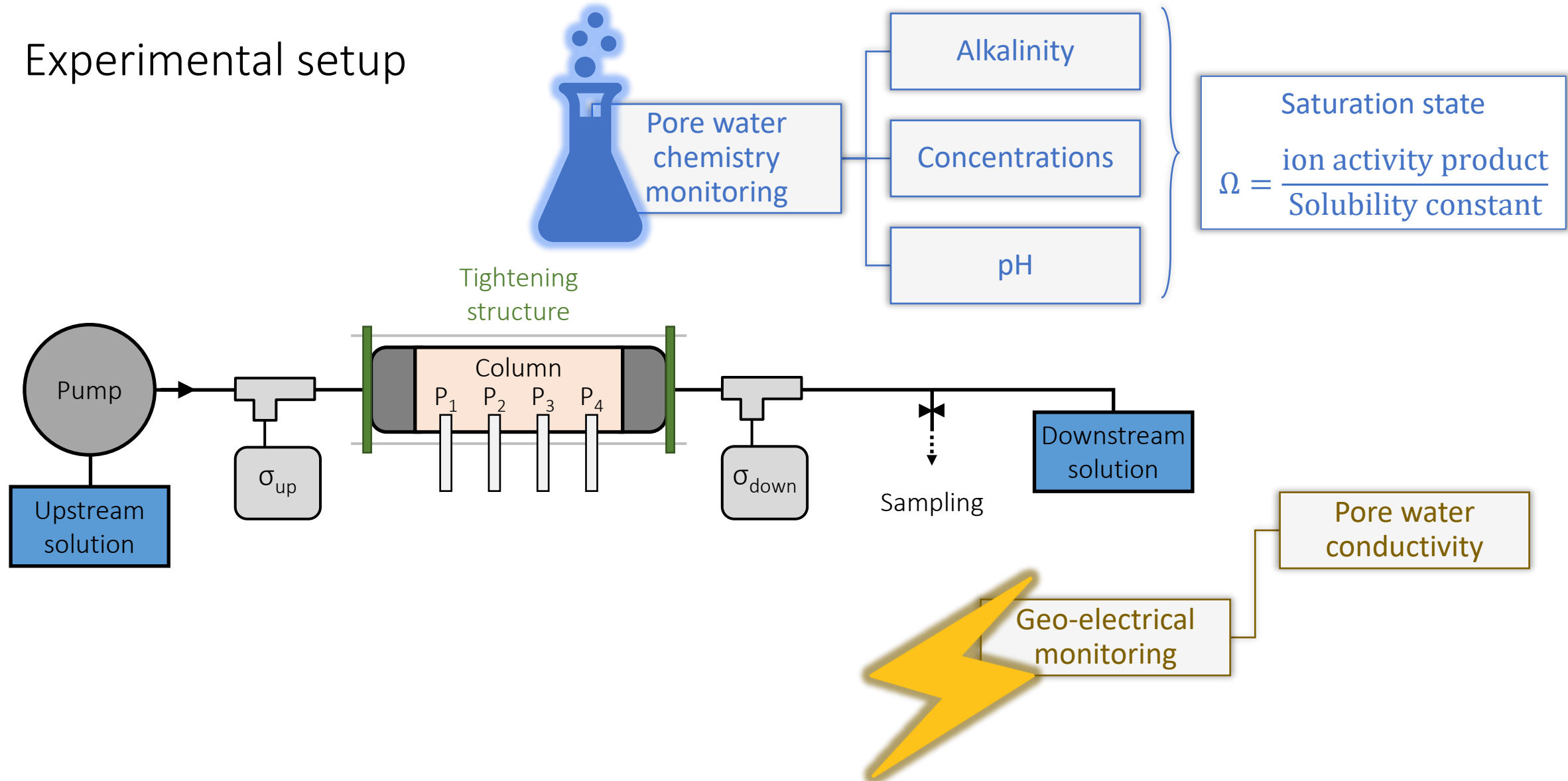
Upstream  
solution



Air-conditioned room  
 $T = 21,8 \pm 1,3\ ^\circ\text{C}$



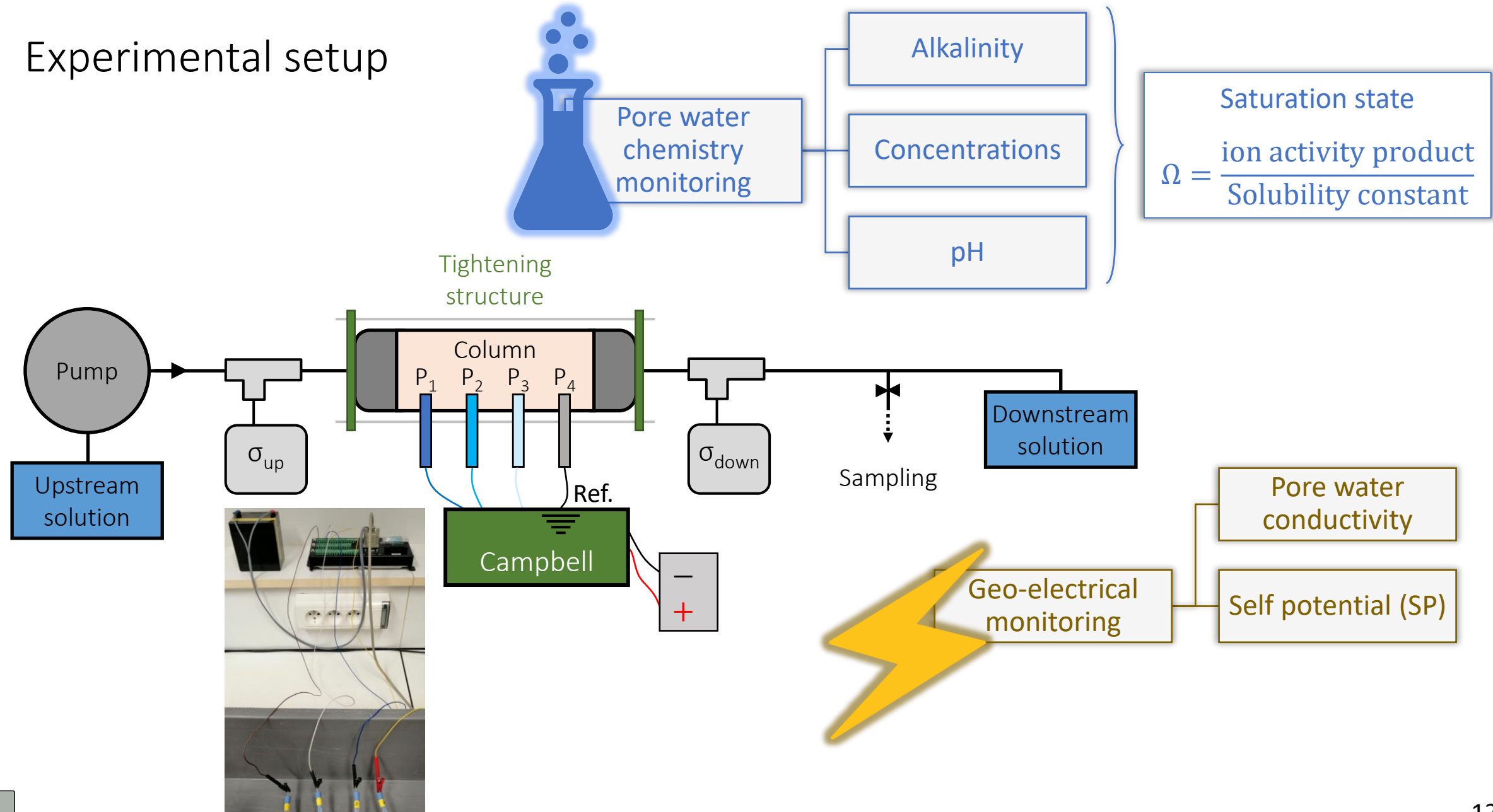
## Experimental setup





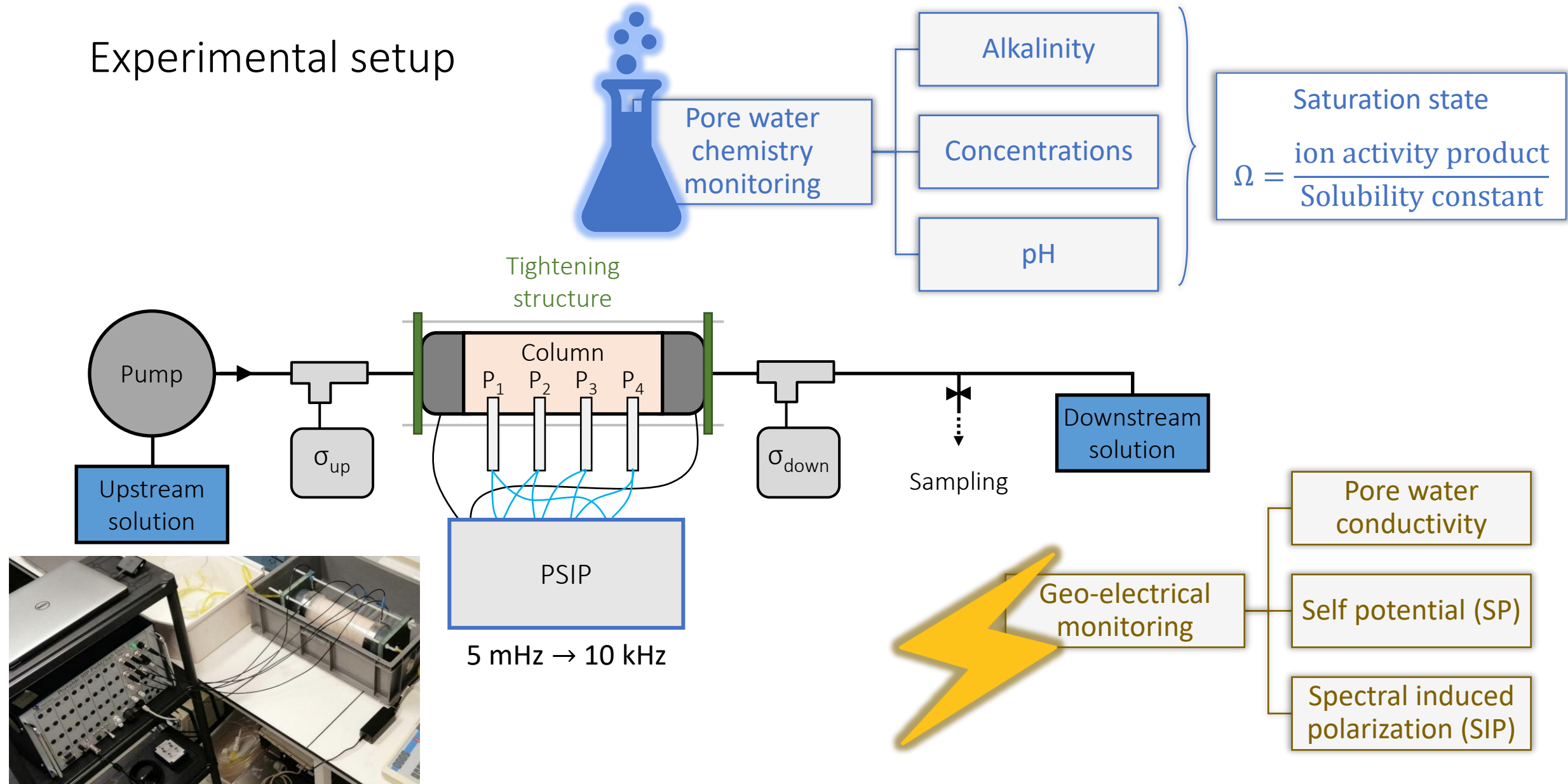


## Experimental setup



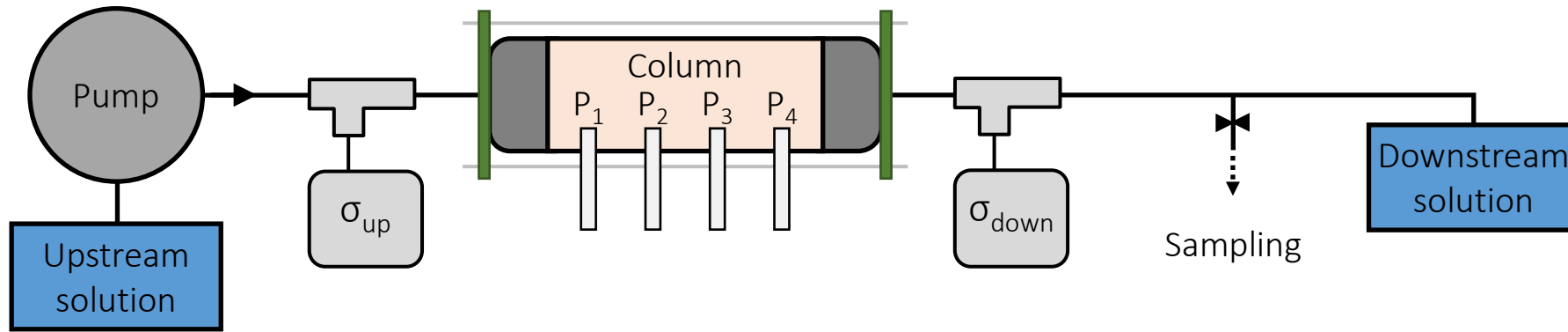
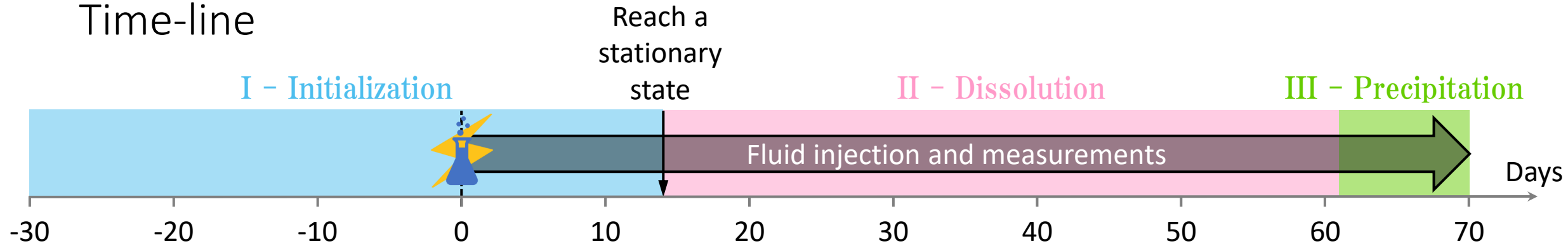


## Experimental setup





## Time-line

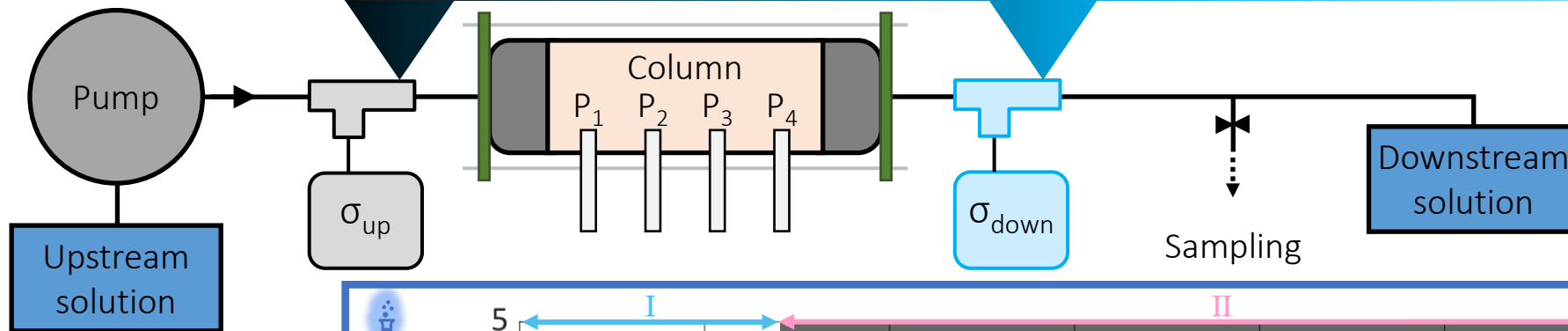
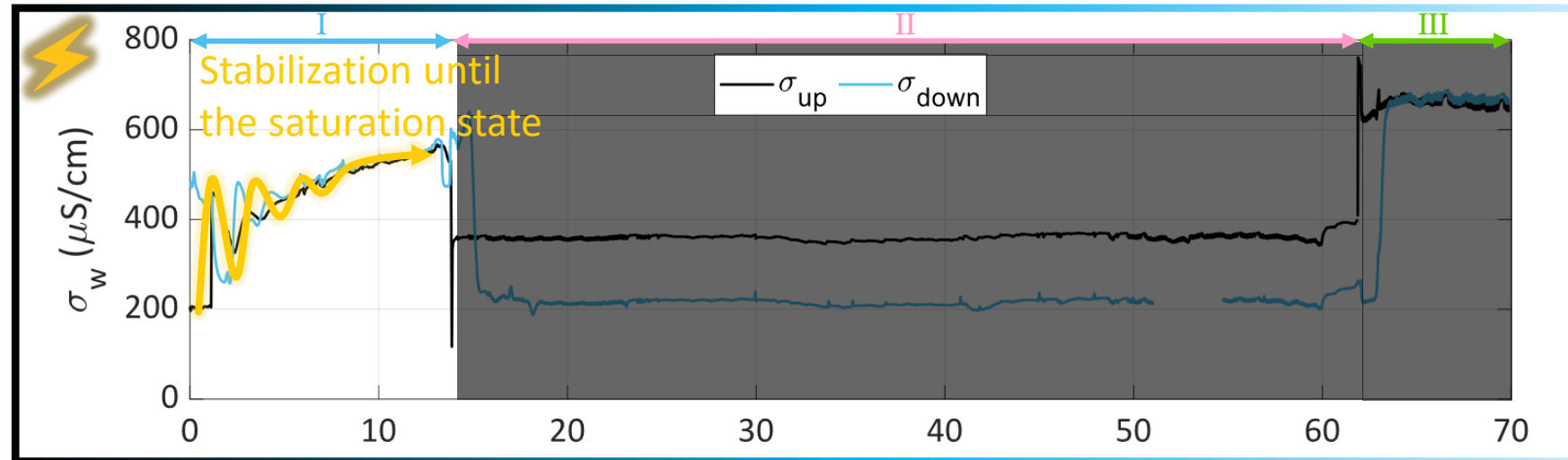




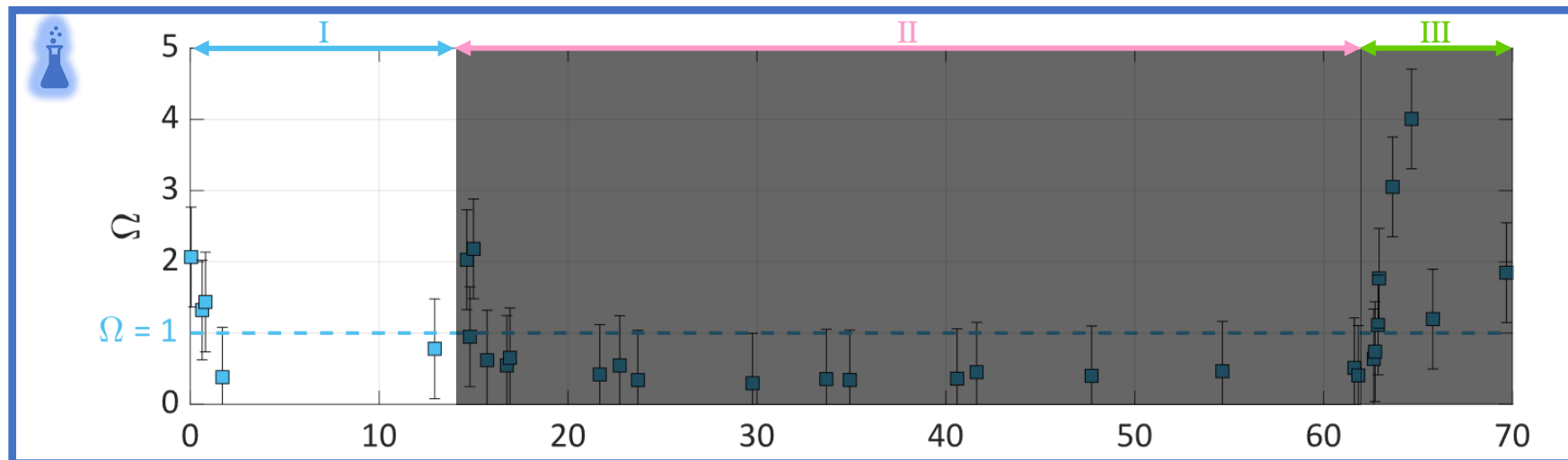


## Pore water monitoring

*Upstream and  
downstream pore  
water electrical  
conductivity*



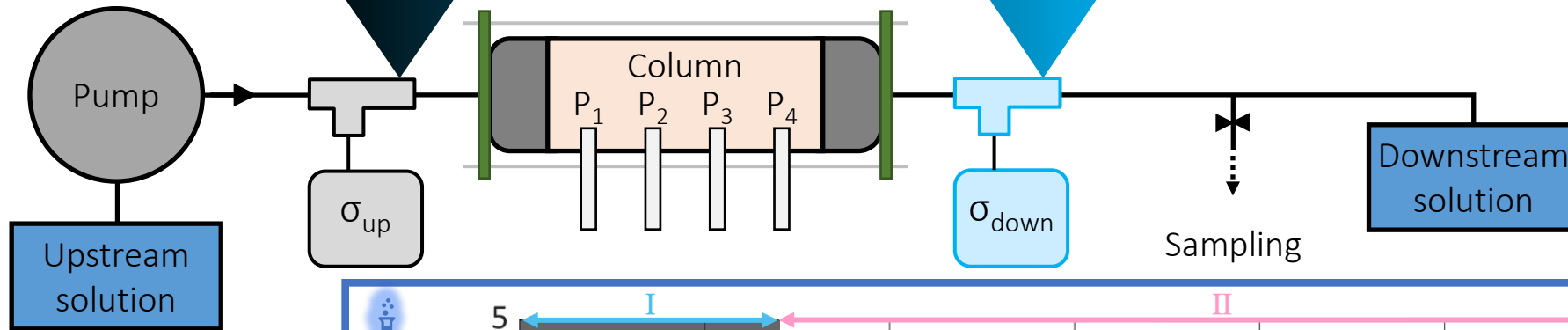
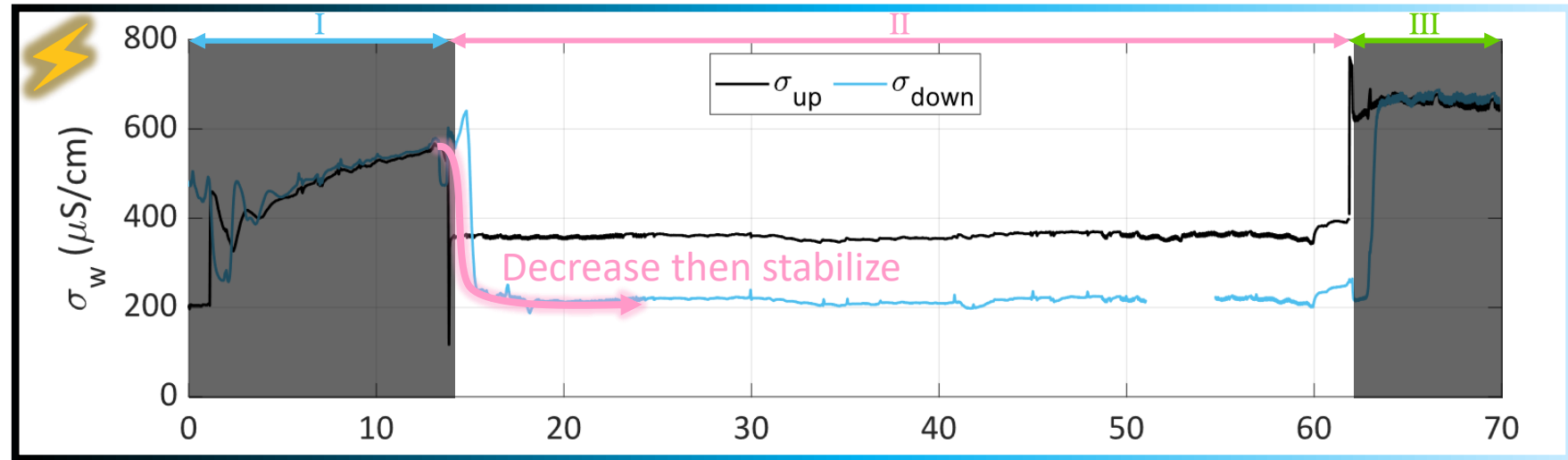
*Saturation state  
calculated from the  
measurements of  
water samples  
collected downstream*



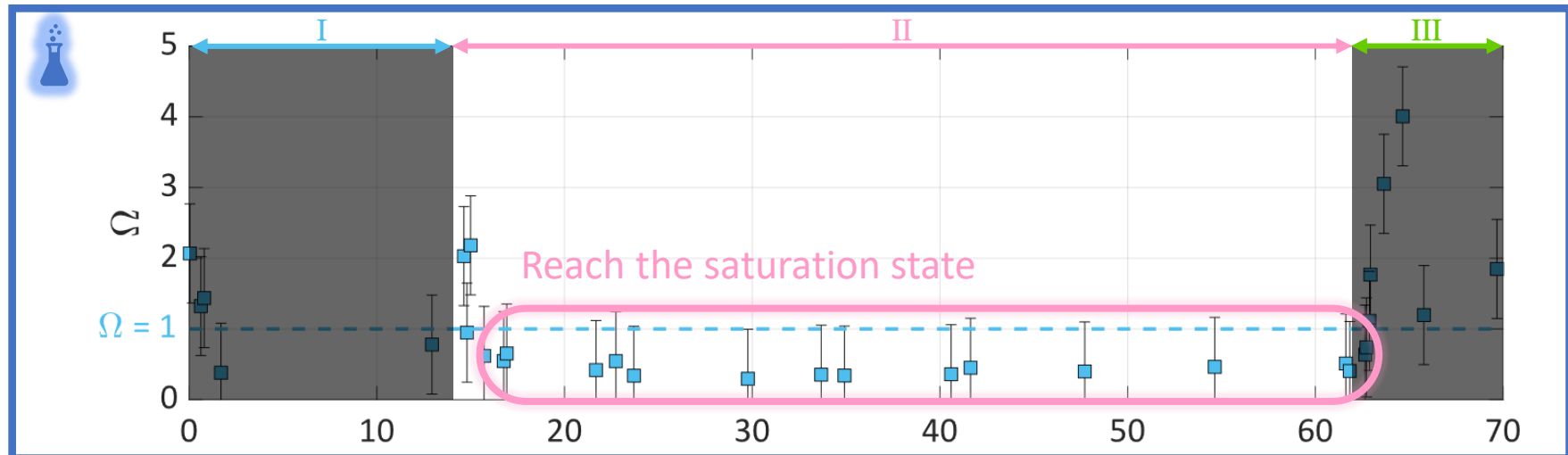


## Pore water monitoring

*Upstream and  
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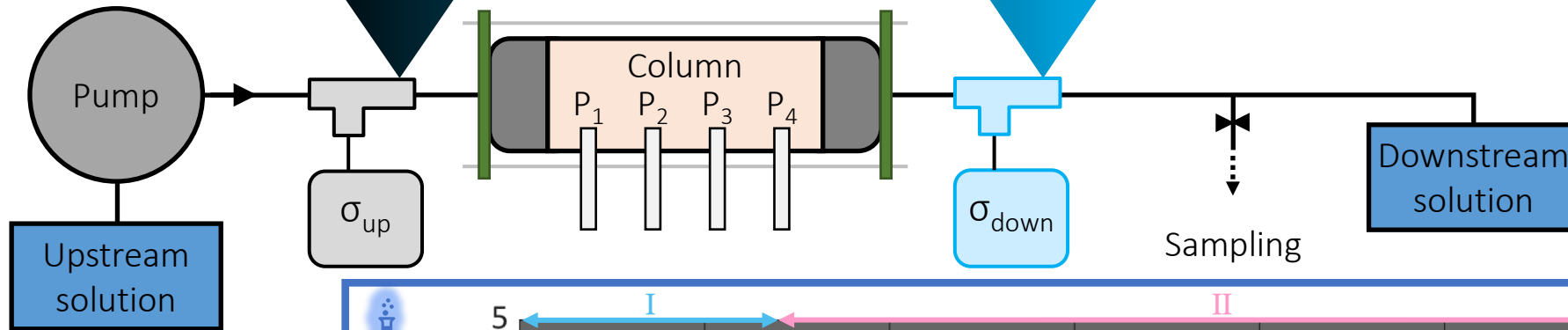
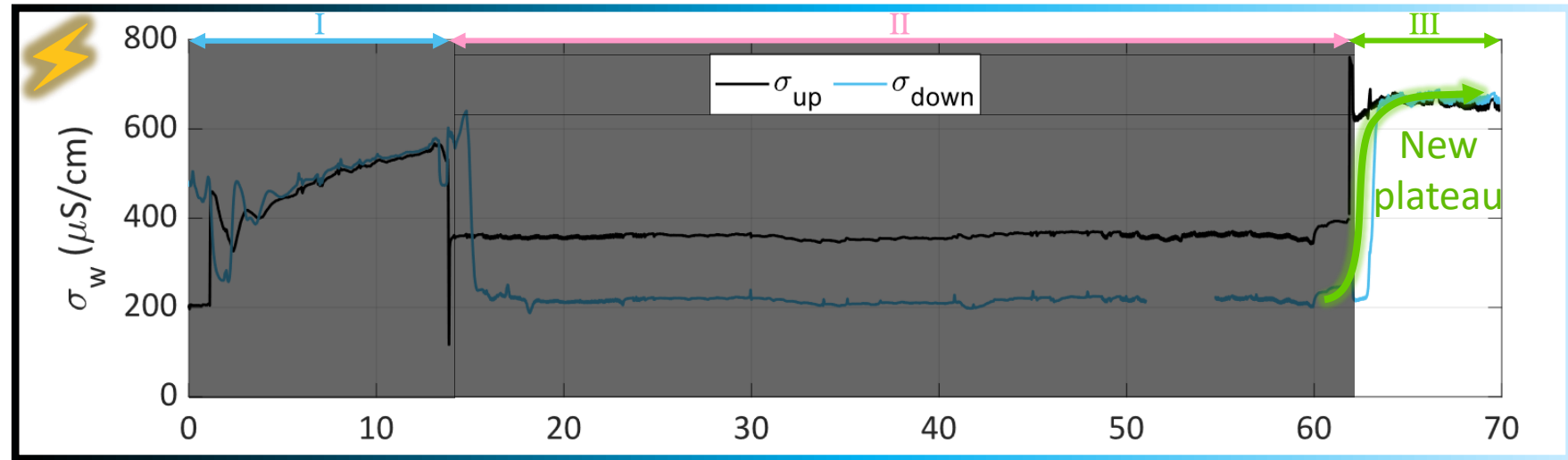
*Saturation state  
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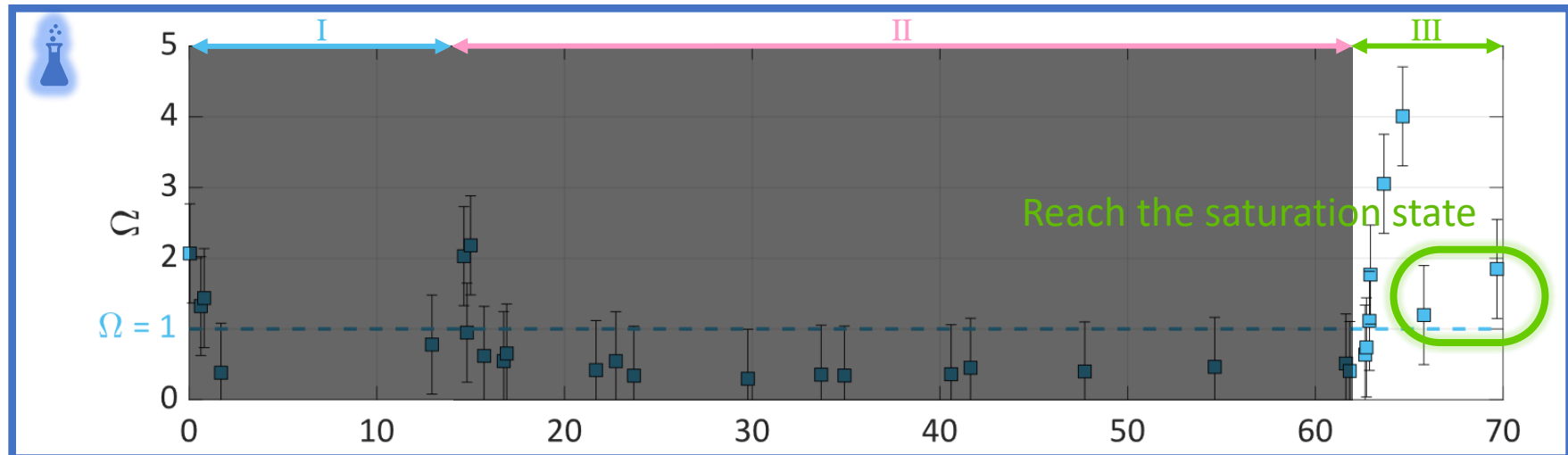


## Pore water monitoring

*Upstream and  
downstream pore  
water electrical  
conductivity*



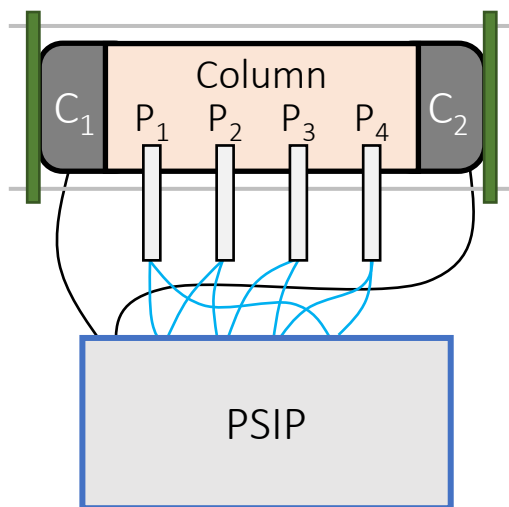
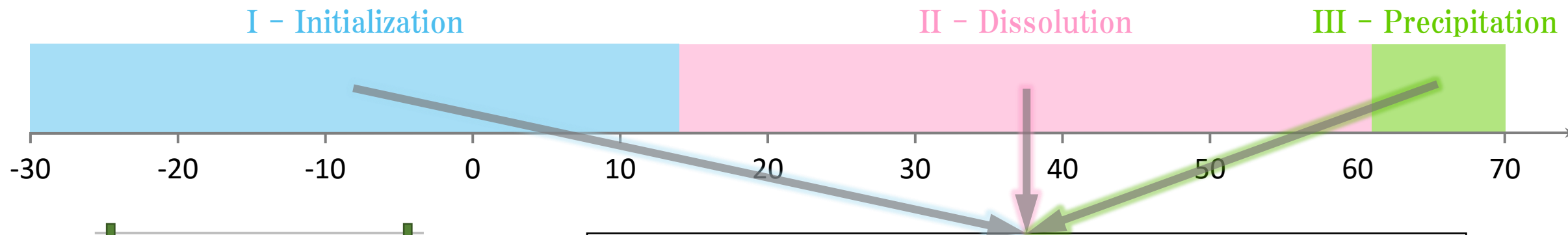
*Saturation state  
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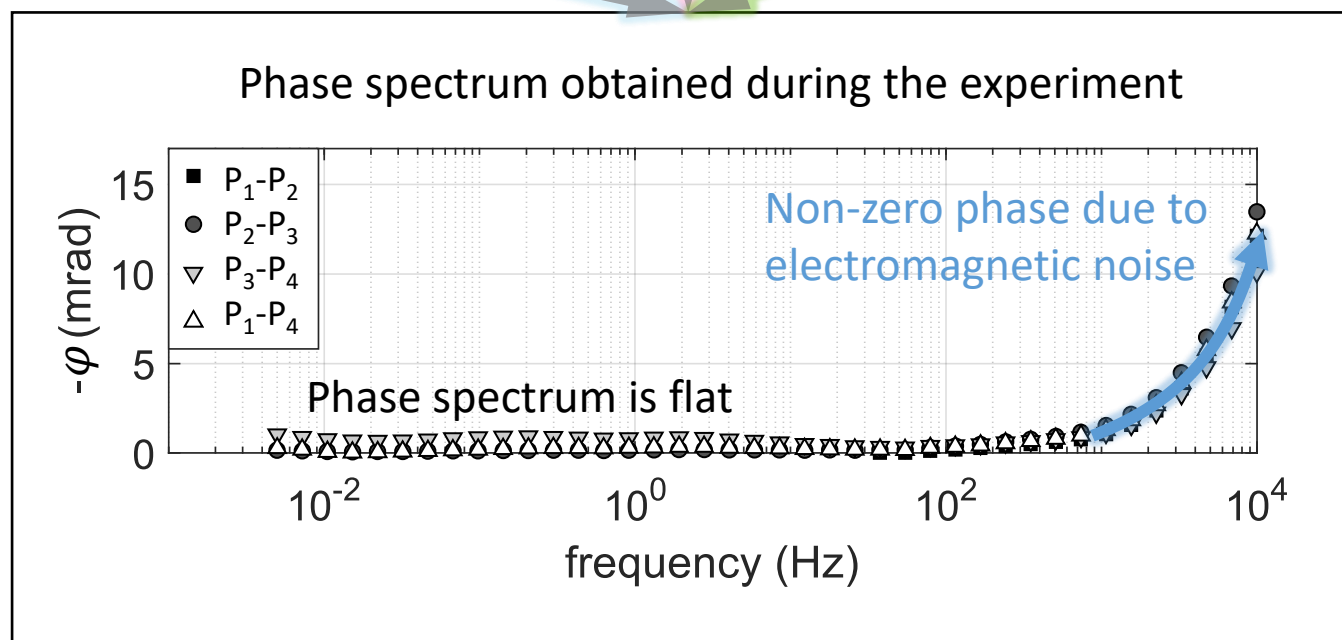




## Spectral induced polarization results



During all the experiment, we  
observed no polarization.  
**Why?**



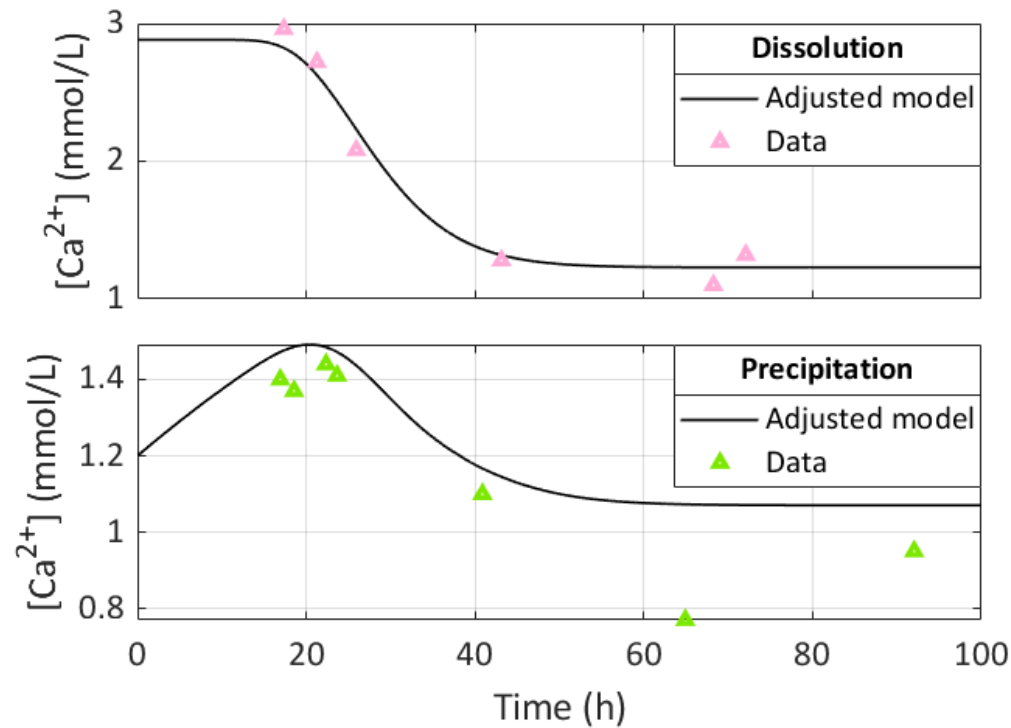


# 1D reactive transport modeling with CrunchFlow

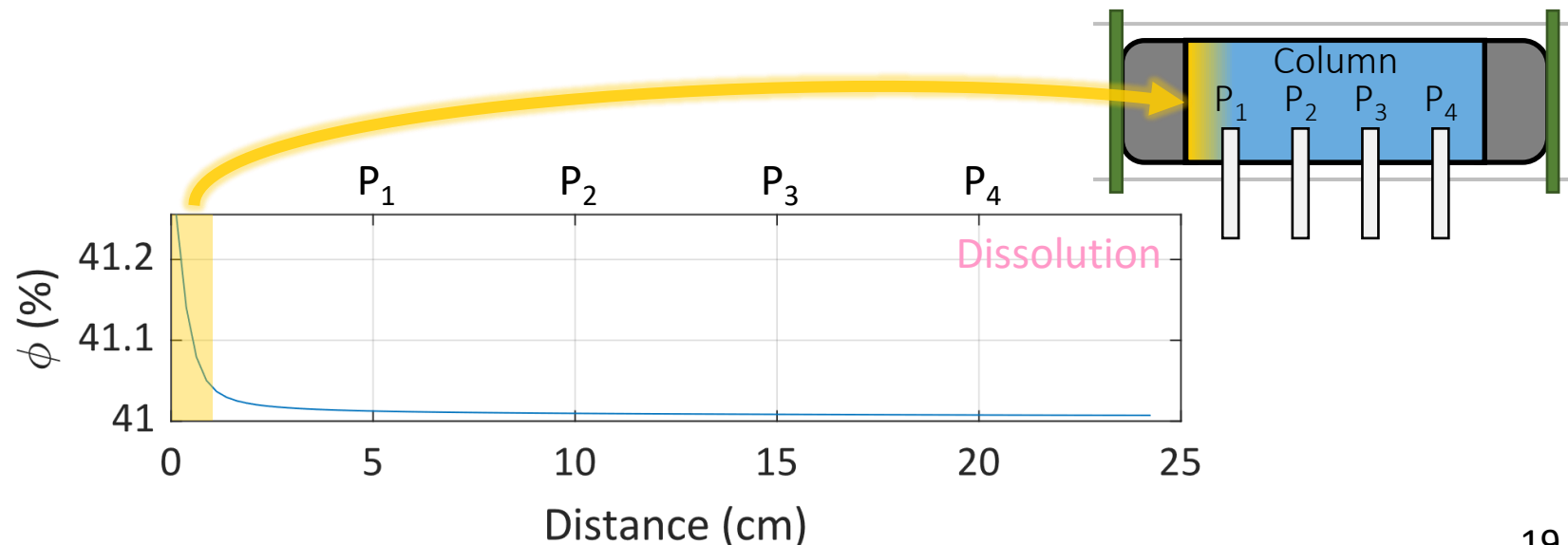
We succeed to predict  $[\text{Ca}^{2+}]$  with  
this 1D approach during both  
dissolution and precipitation.

The adjusted models show that  
the porosity change due to  
chemical processes on the  
sample is small and occurs at the  
entrance of the column.

Dissolution and precipitation  
occur in the first centimeter of  
the sample, which generates no  
SIP signal



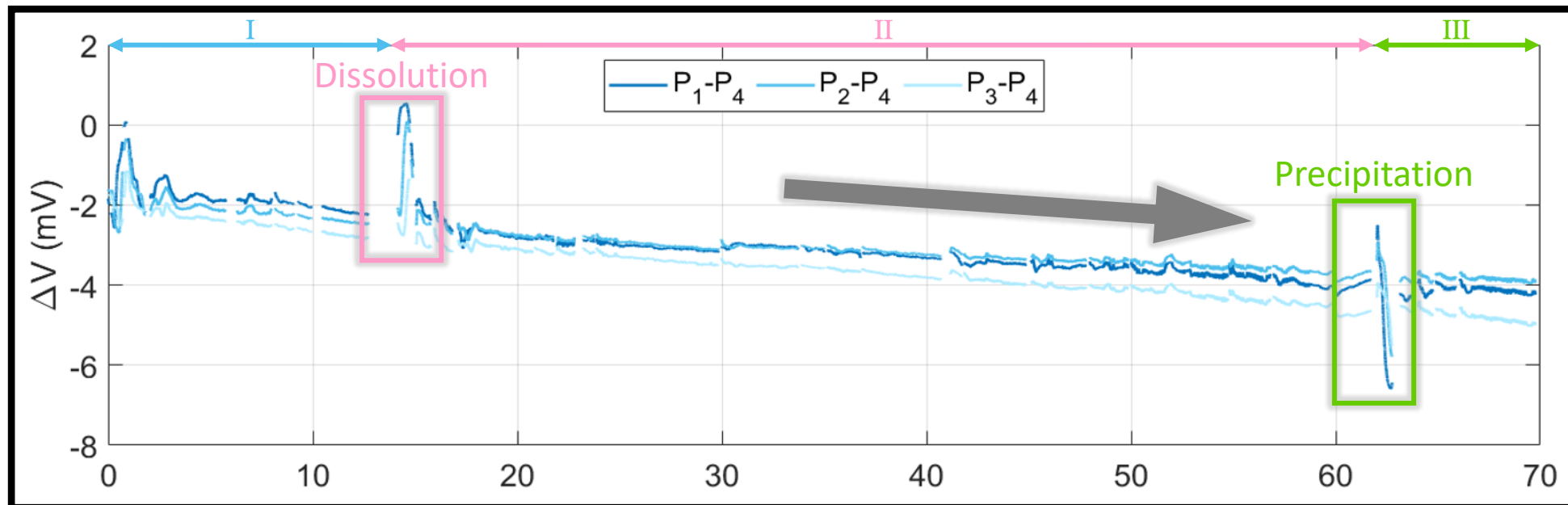
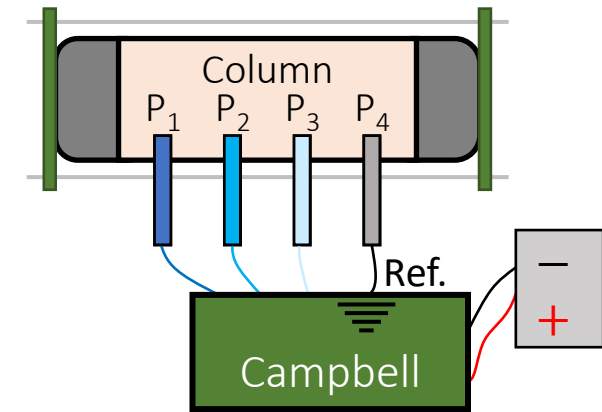
*Calcium concentration  
measurements from  
water samples  
collected at the outlet  
of the column.*





## Self potential results

- Evolution of the intrinsic potential of the electrodes
- Transient variations after the injection of a new fluid

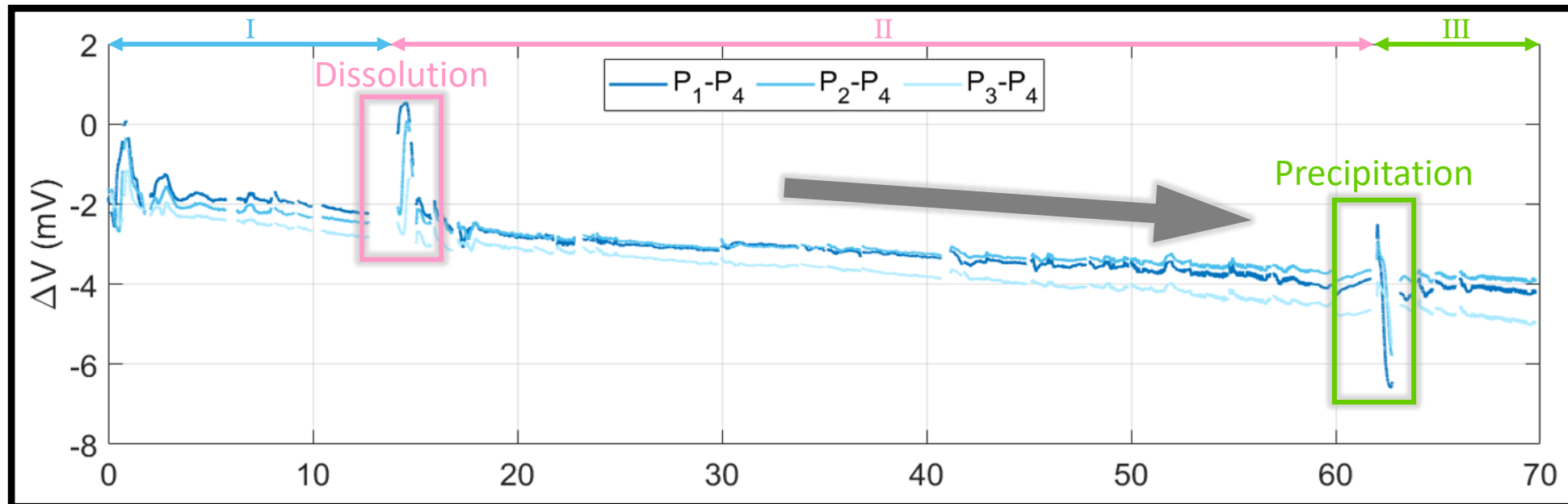
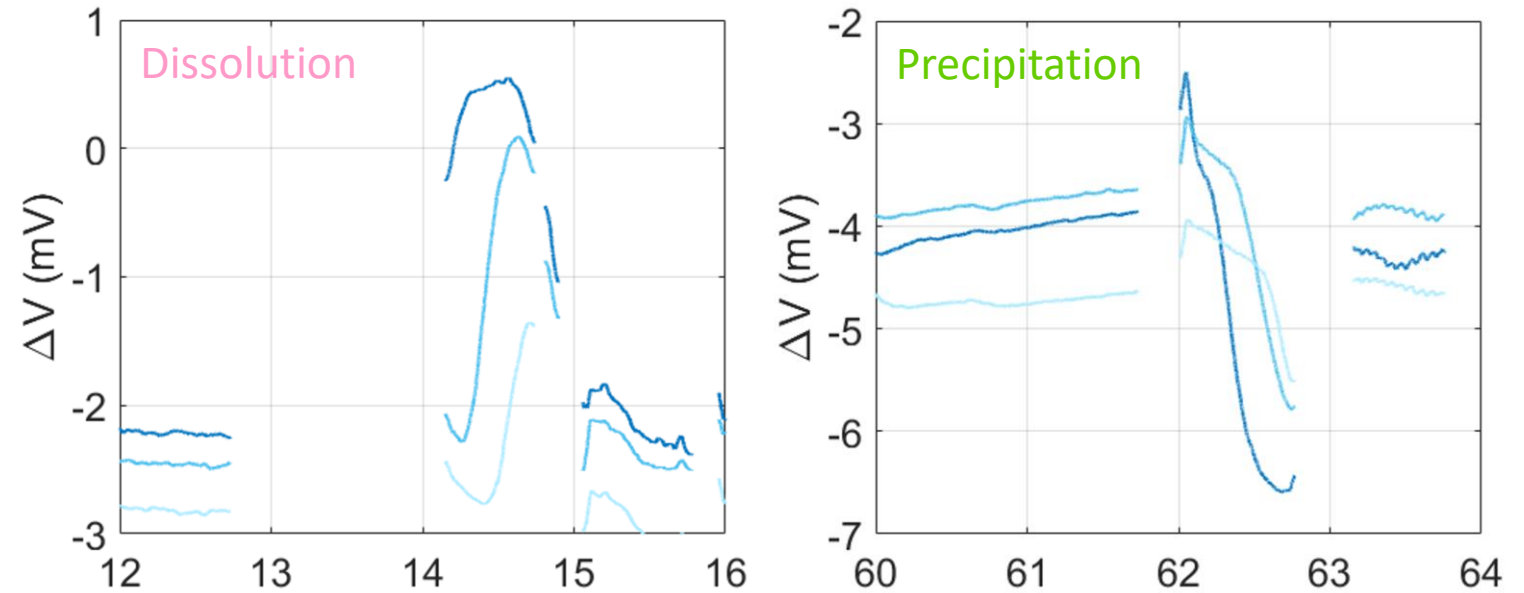




## Self potential results

- Evolution of the intrinsic potential of the electrodes
- Transient variations after the injection of a new fluid

*Variations begin staggered in time and end simultaneously.*

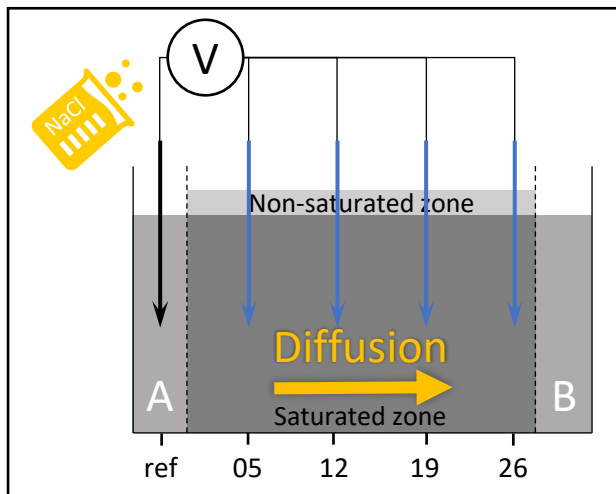




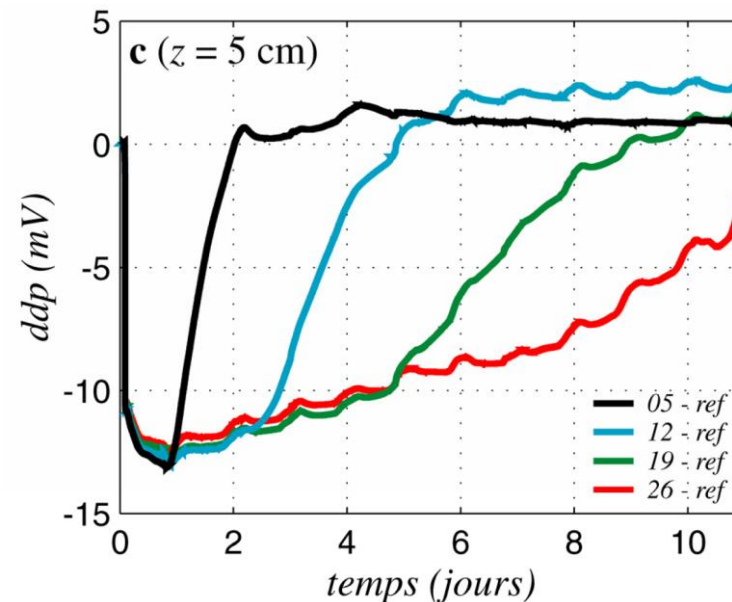
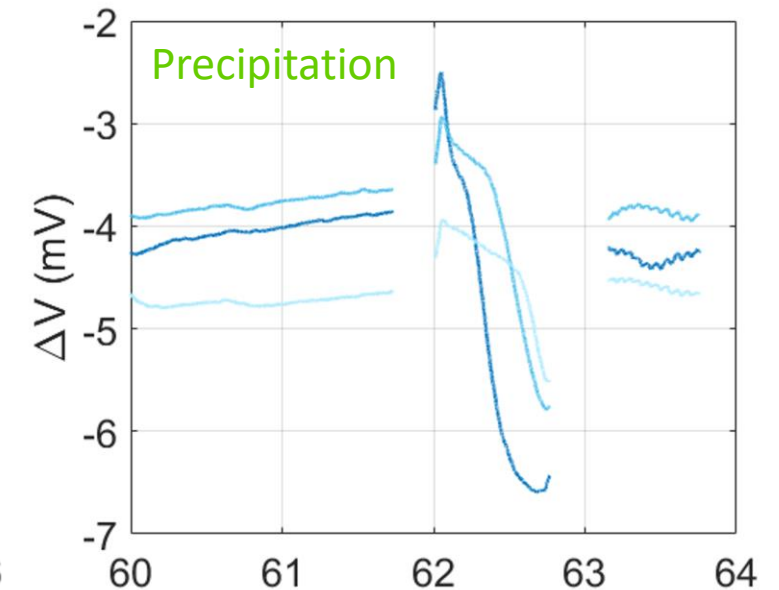
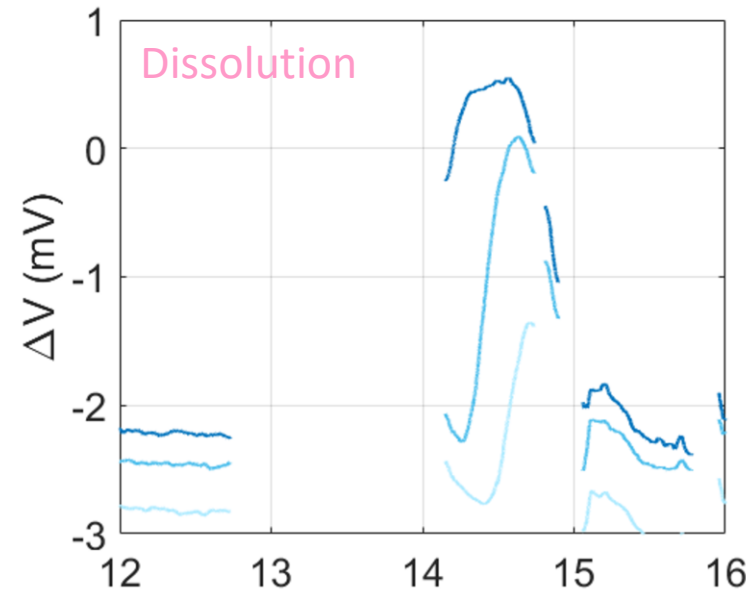


## Self potential results

- Evolution of the intrinsic potential of the electrodes
- Transient variations after the injection of a new fluid
- These SP signals come from an electrochemical coupling due to ionic concentration gradients



*Variations begin staggered in time and end simultaneously.*



Experiment of **NaCl diffusion** in a sand matrix from Maineult (2004) with SP monitoring on 4 channels:

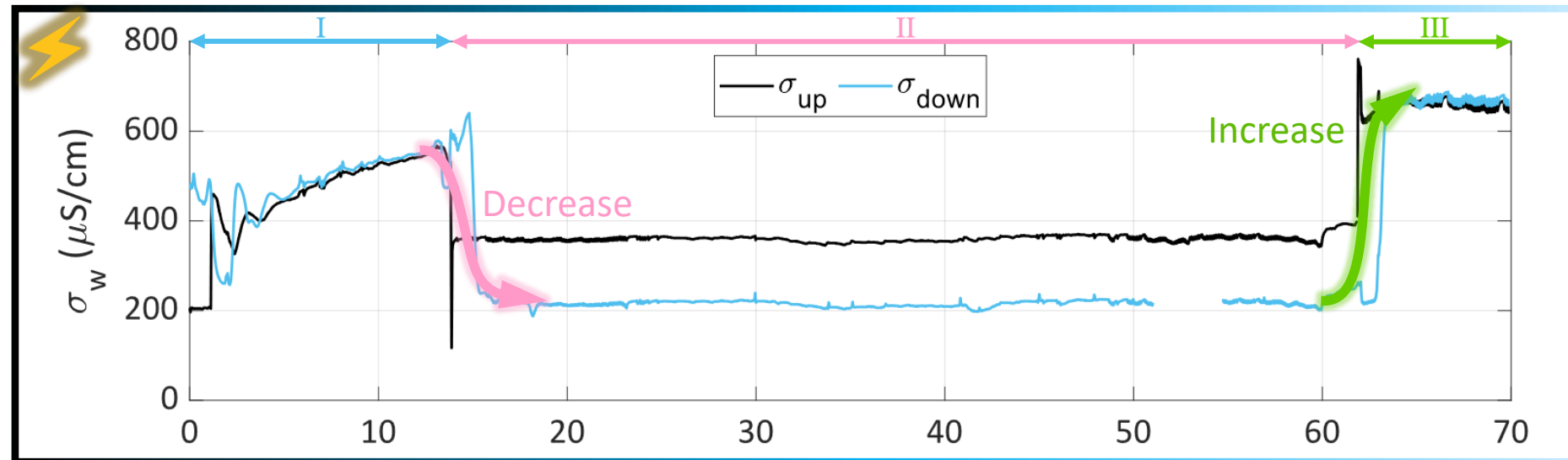
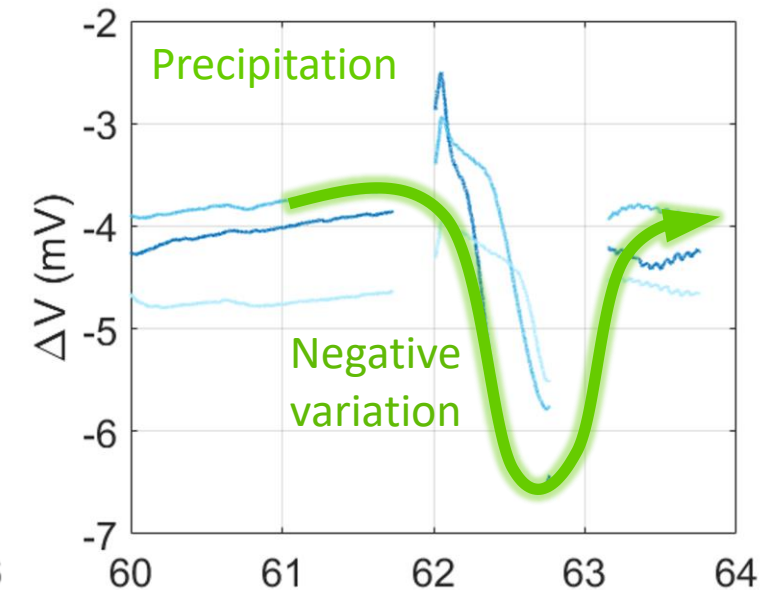
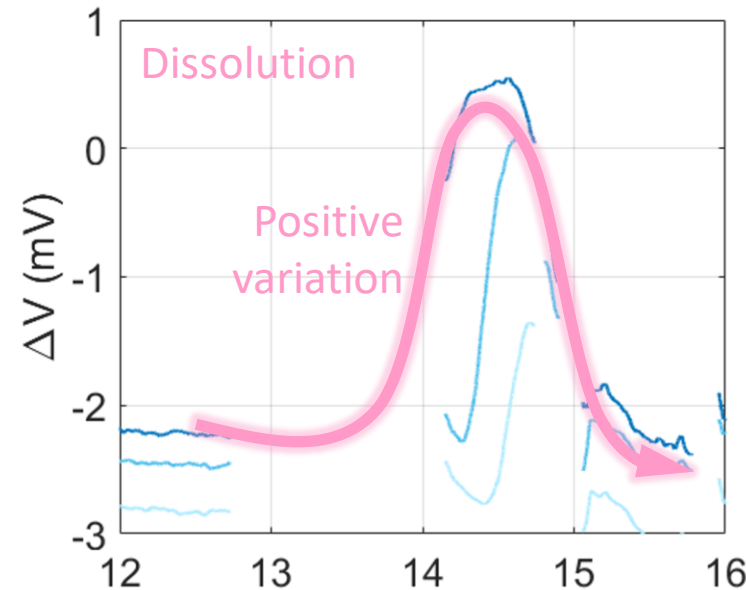
- Variations are related to NaCl diffusion
- The solute front speed can be quantified



## Self potential results

- Evolution of the intrinsic potential of the electrodes
- Transient variations after the injection of a new fluid
- These SP signals come from an electrochemical coupling due to ionic concentration gradients
- There is a good correlation between  $\sigma_w$  and SP variations

*Variations begin staggered in time and end simultaneously.*





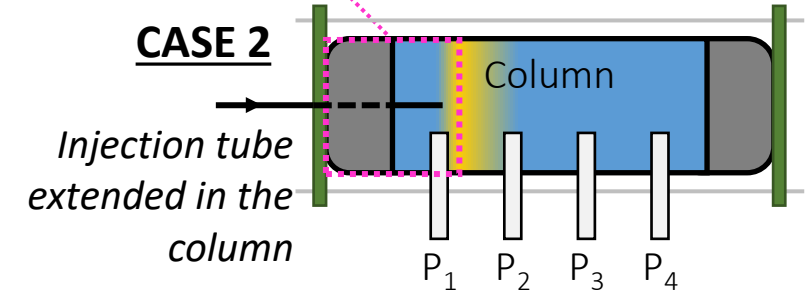
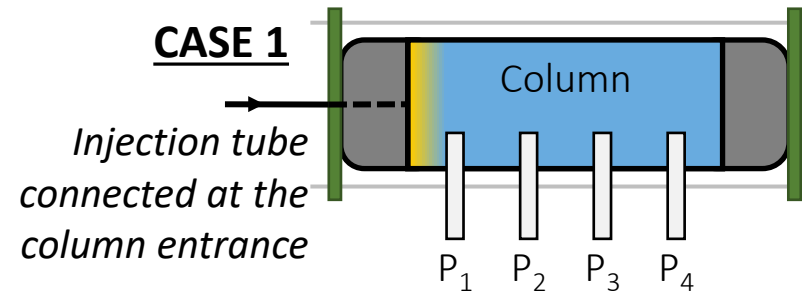
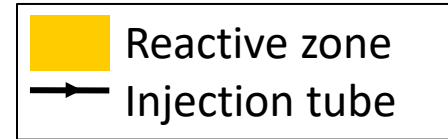
## Experimental setup improvement

In a new dissolution experiment, acid injection was **shifted** to locate the **reactive zone** between electrodes  $P_1$  and  $P_2$ .

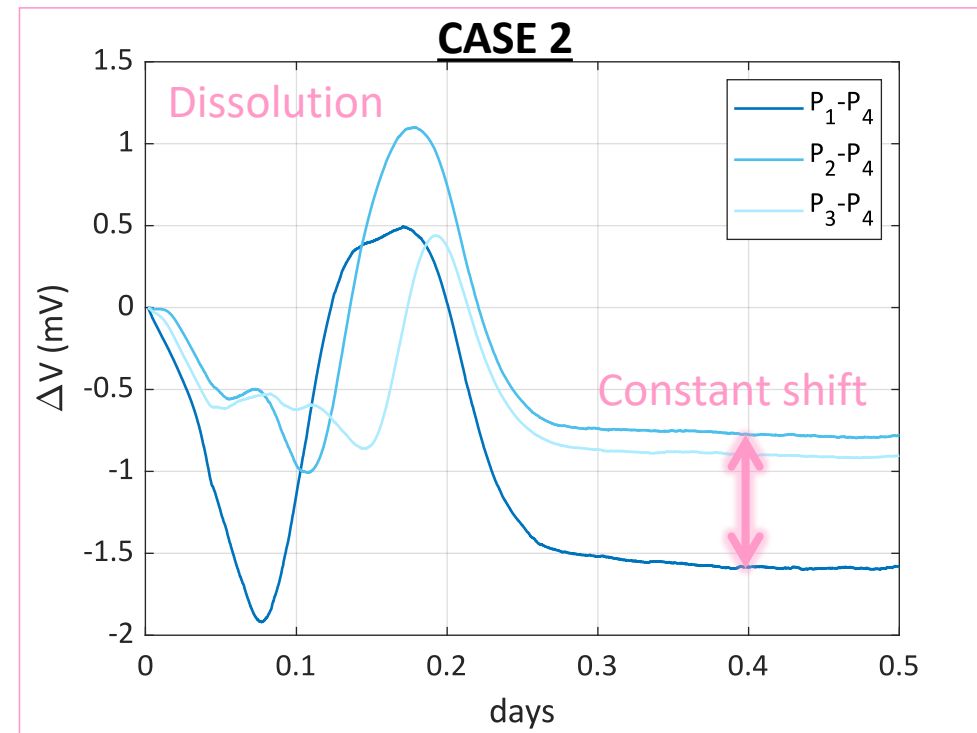
We observe that the measured voltage for channel  $P_1$ - $P_4$  is different from the others because of dissolution process.  
⇒ The injection shift allows to identify the reactive zone.

However, the phase spectrum obtained with SIP remained flat.

⇒ Dissolution generates no phase signal



Picture of the injection tube shifted in the column filled with brine





## Conclusions

- Successful monitoring of dissolution and precipitation processes with the self potential method
- No SIP response in dissolution
- Good agreement and complementarity between geoelectrical methods and geochemical monitoring and modeling

## Next steps

- Quantitative interpretation of self potential measure using the junction potential theory
- New acquisition during precipitation process with a better control of the injection location



Thank you for watching.  
I look forward for your questions.

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