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Joint Polish-Norwegian research projects in the field of carbon capture and storage

Prof. dr hab. inż. Stanisław Nagy

Kraków, Febuary 2st 2024

Advanced Gas and Carbon Dioxide Storage in Aquifer

AGaStor

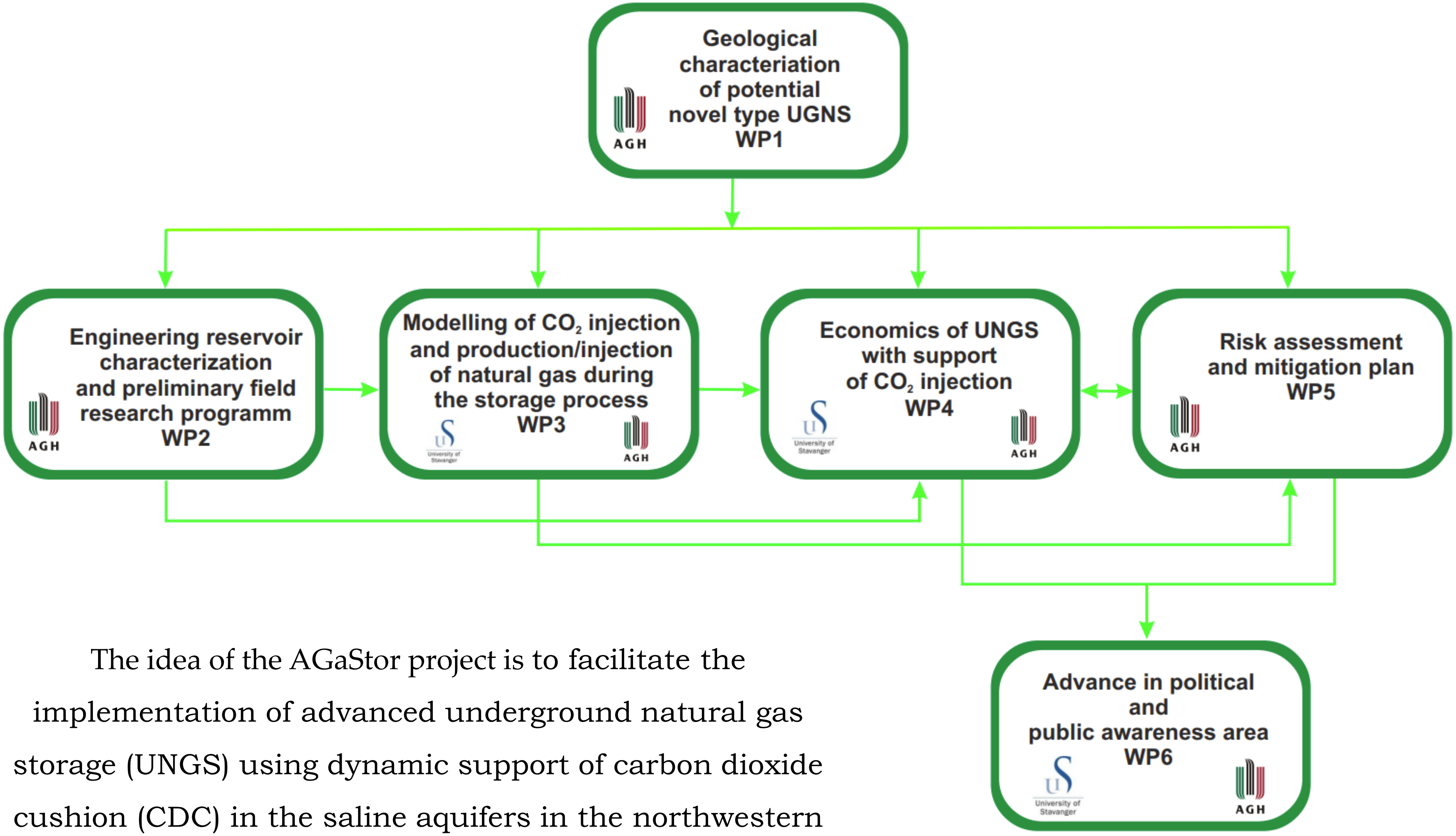
Project funded from the Norway Grants 2014–2021 under the Applied Research Programme
operated by the National Centre for Research and Development (NCBR)
Project no. NOR/POLNORCCS/AGaStor/0008/2019-00

Project leader:	AGH University of Krakow
Project partner:	University of Stavanger
Principal investigator:	Prof. Stanisław Nagy
Partner leader:	Prof. Mohsen Assadi
Project duration:	2020 - 2024

Project objectives

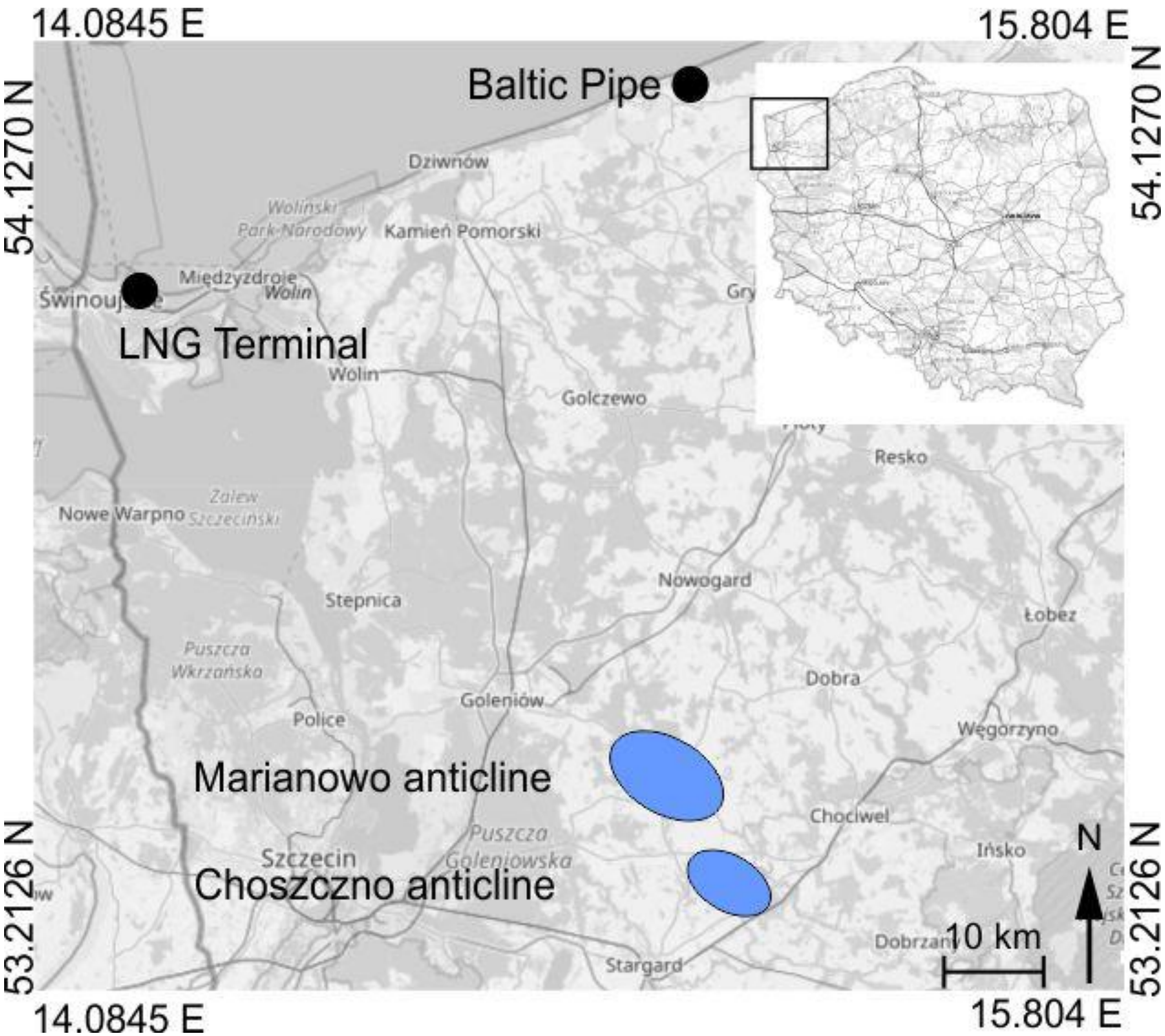
- Carbon geological storage is considered to be the most viable option for the storage of the large CO_2 quantities needed to reduce global warming and related climate change effectively.
- The innovative, guiding concept of the AGaStor project is based on synergy between natural gas storage and CO_2 storage process in a location near CO_2 emission source.
- The main objective of the project is to facilitate the implementation of advanced Underground Gas Storage (UGS) using dynamic support of Carbon Dioxide Cushion (CDC) in saline aquifers.
- A key innovation is development of new & safe technology for CO_2 storage as a cushion in energy gas storage build in aquifers. Combining CO_2 storage with UGS can bring economic and technological advantages to the industry and allow it to reduce the amount of anthropogenic emissions of CO_2 .
- A key issue of the AGaStor project is knowledge exchange and enhanced cooperation between the Polish & Norwegian partners to determine the best technologies & application in the energy systems of partner countries.
- **Guidelines and solutions for characterization of possible storage sites of UNGS with CDC (3D architecture of the storage complex, trapping mechanisms, reactive flow, CO_2/NG mixing process, risk assessment and sensitivity analysis)**

Workflow



The idea of the AGaStor project is to facilitate the implementation of advanced underground natural gas storage (UNGS) using dynamic support of carbon dioxide cushion (CDC) in the saline aquifers in the northwestern of Poland.

Structures' information



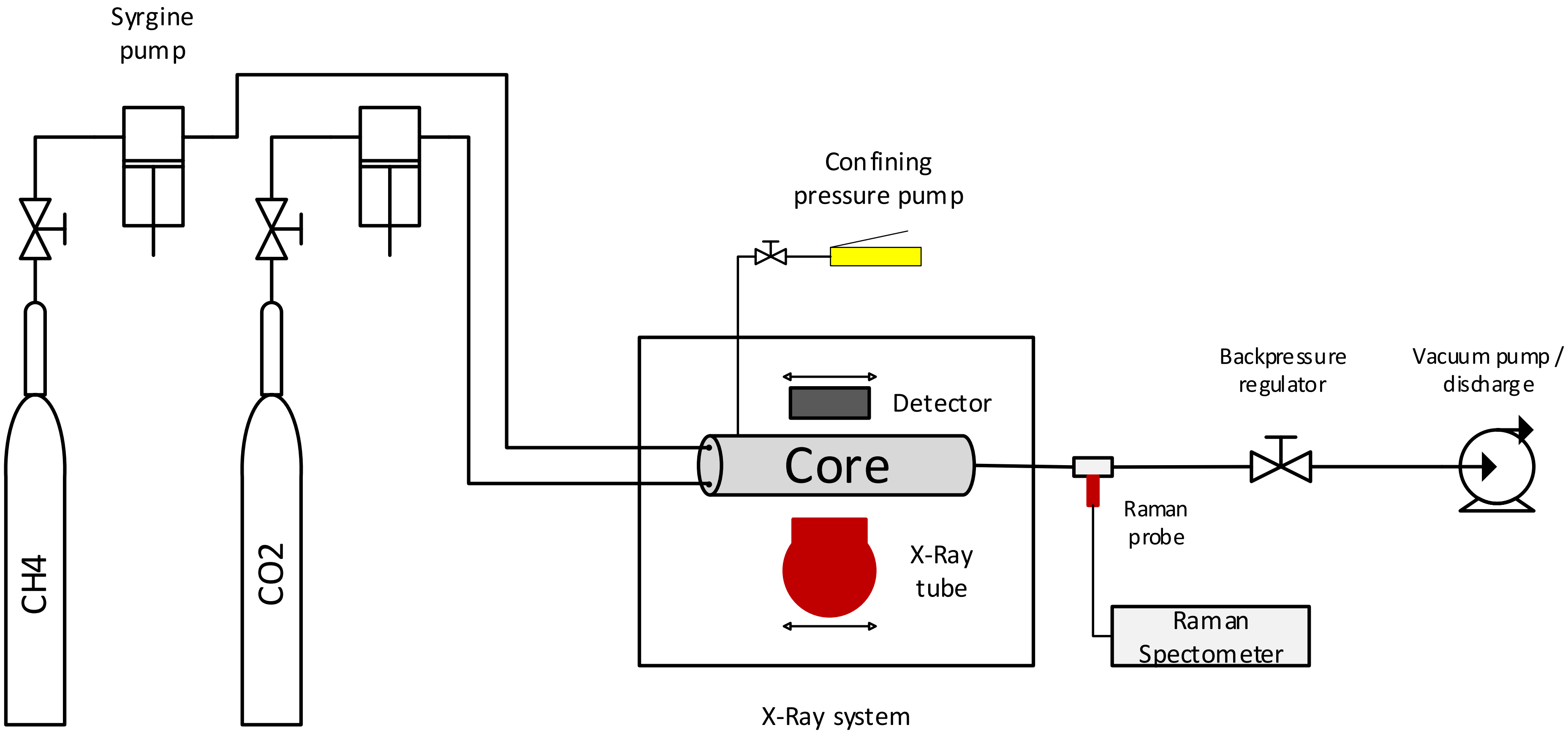
Area – 100 km^2

Thickness
60-100 m

Permeability
1750-3200 mD

Mineralization
100 g/dcm3

Laboratory research

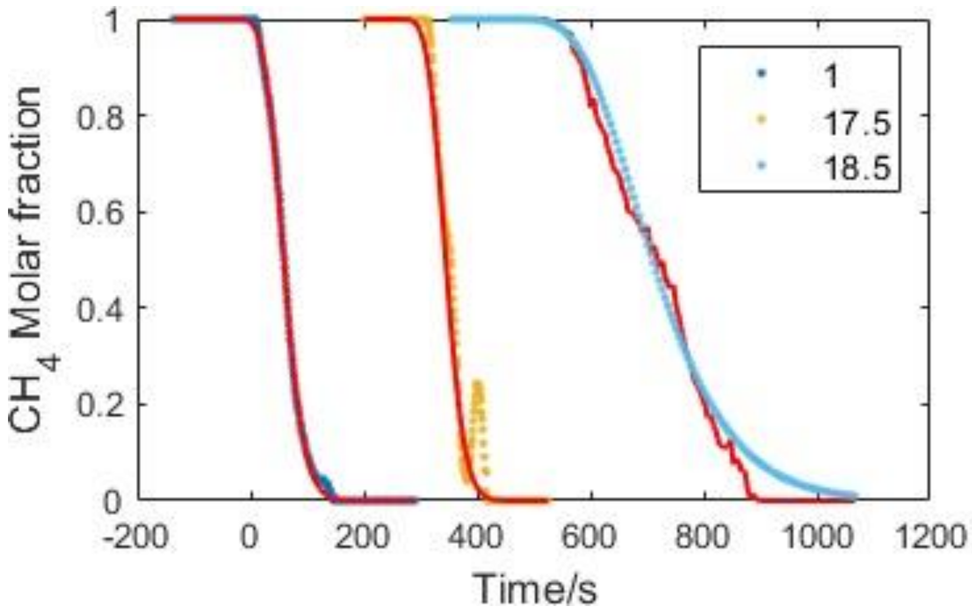


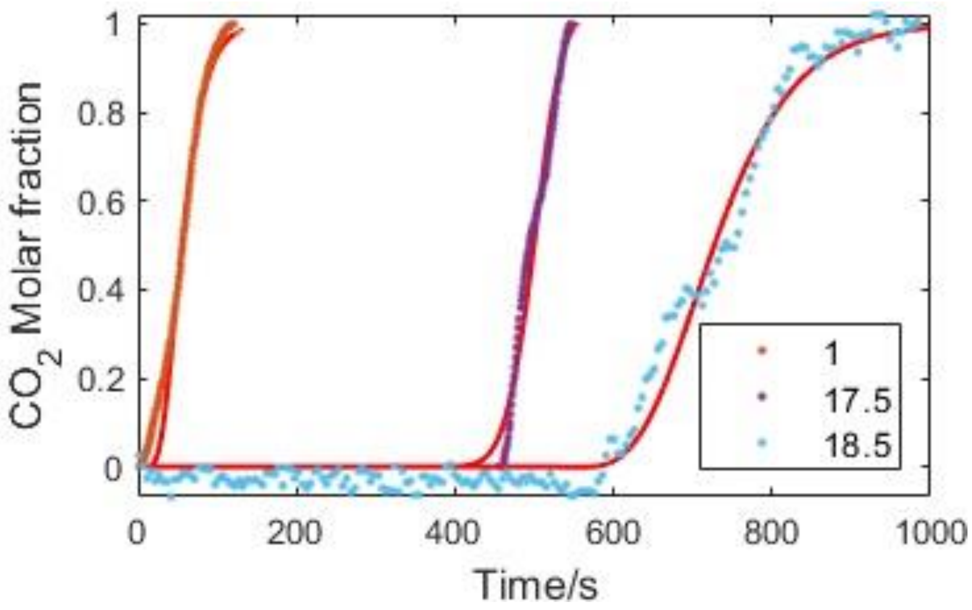
Laboratory experimental setup
equipped with X-ray system for rock cores & RS 785
for determination diffusion

Laboratory experimental setup

X-ray system for rock cores

Mixing coefficient



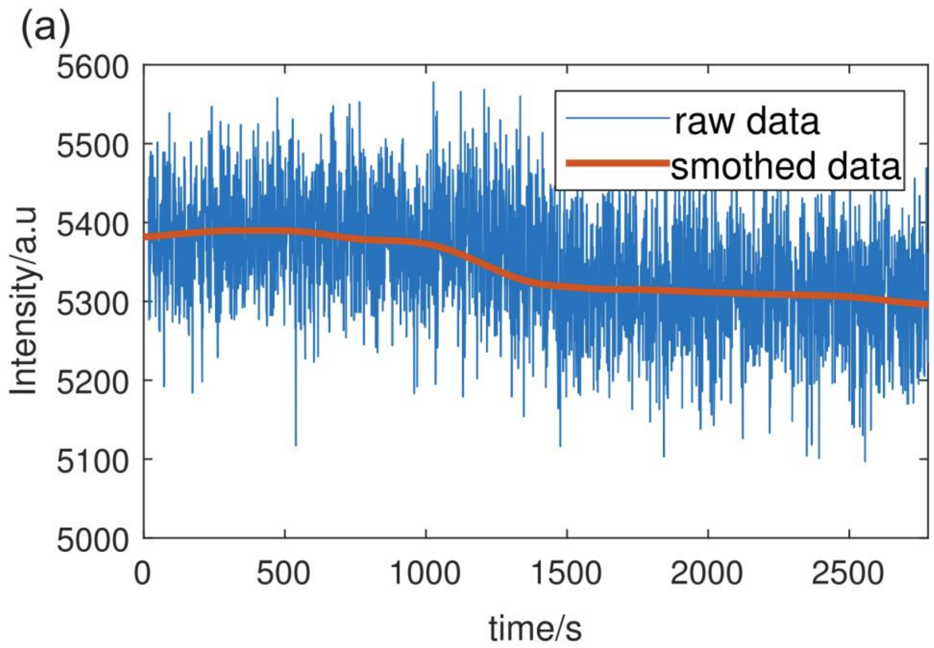


Concentration profiles for a rock core at three position inside a sample saturated with **CH_4 displaced by CO_2**

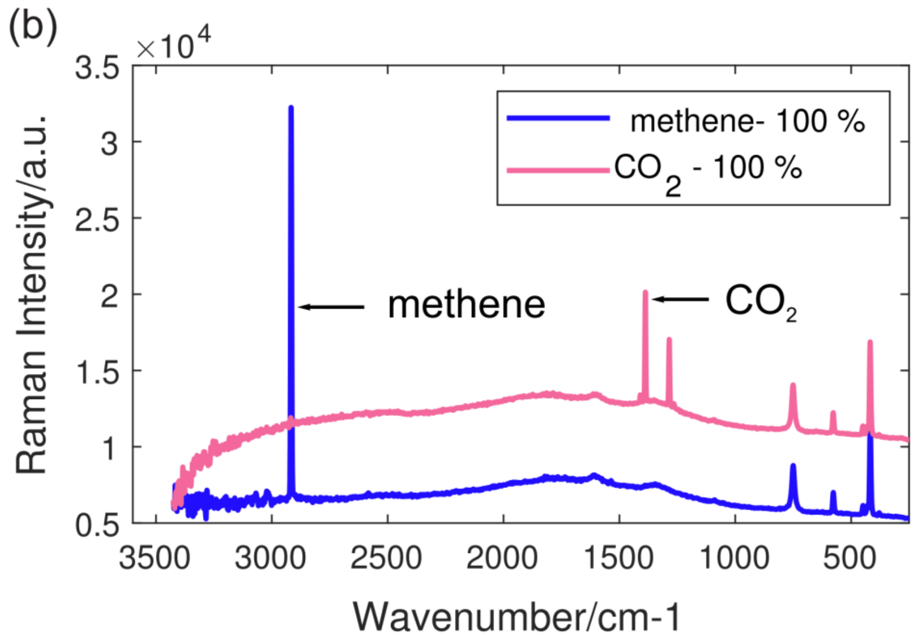
Concentration profiles for a rock core at three position inside a sample. **CO_2 displaced by CH_4.** P=12.5 MPa and T=50°C

X-Ray and Raman data

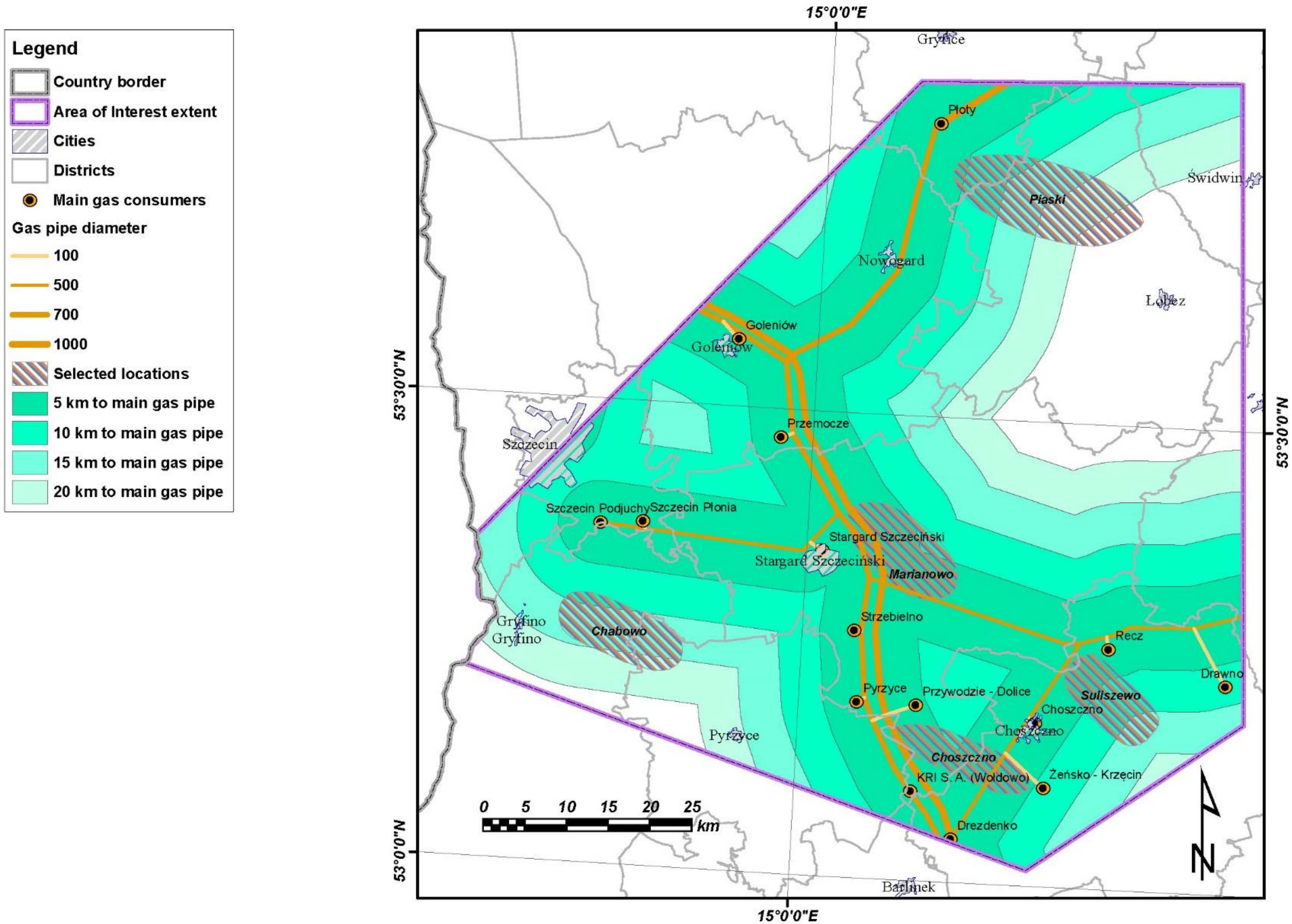
Change of the x-ray signal during displacement of CH4 by CO2



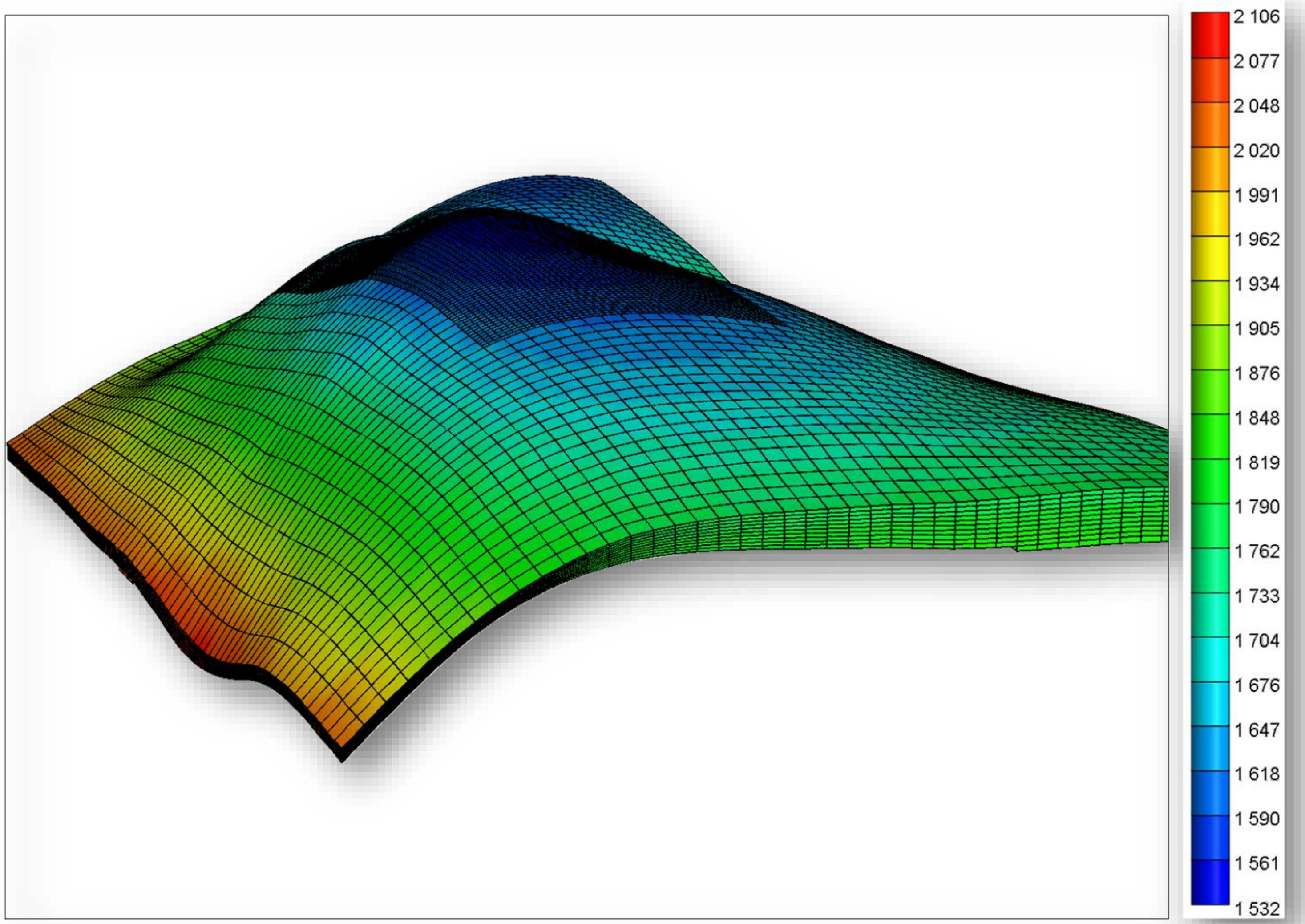
Raman intensity at the beginning of flow and at the end of the flow



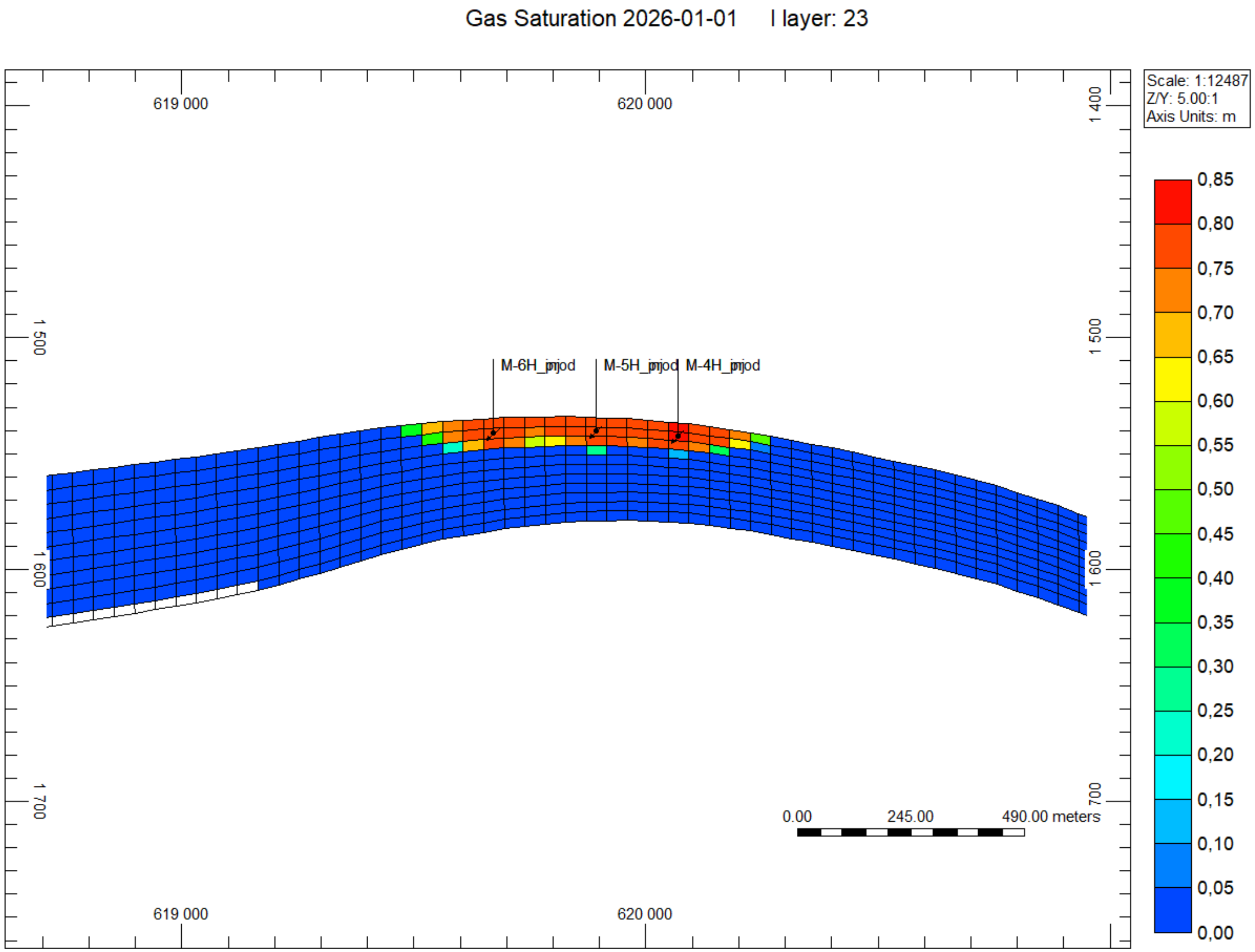
Analizowana lokalizacja



Static model



Example of gas saturation in UGS



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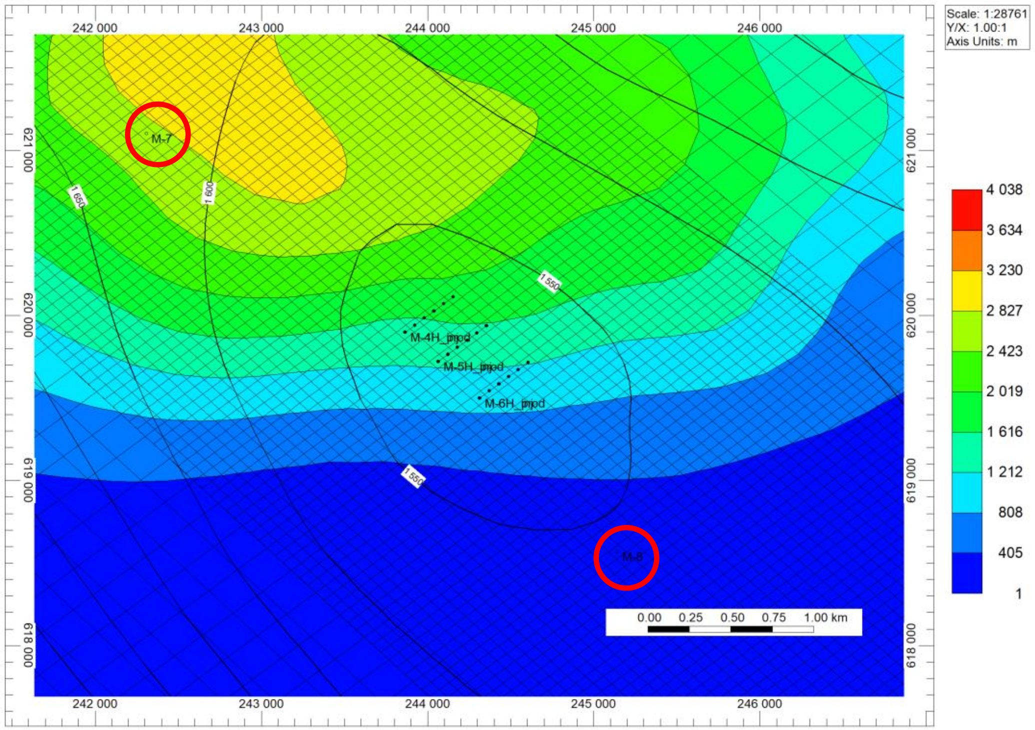
CO2 injection after CH4 injection

- » Injection of methane with three horizontal wells from May to September over four years;
- » carbon dioxide injection by two vertical wells (M-7 and M-8)with a capacity of 505630 Nm^3/d każdy (2 kt_{CO_2}/d, łącznie 730 kt_{CO_2})

Permeability I (md) 2040-04-01 K layer: 2



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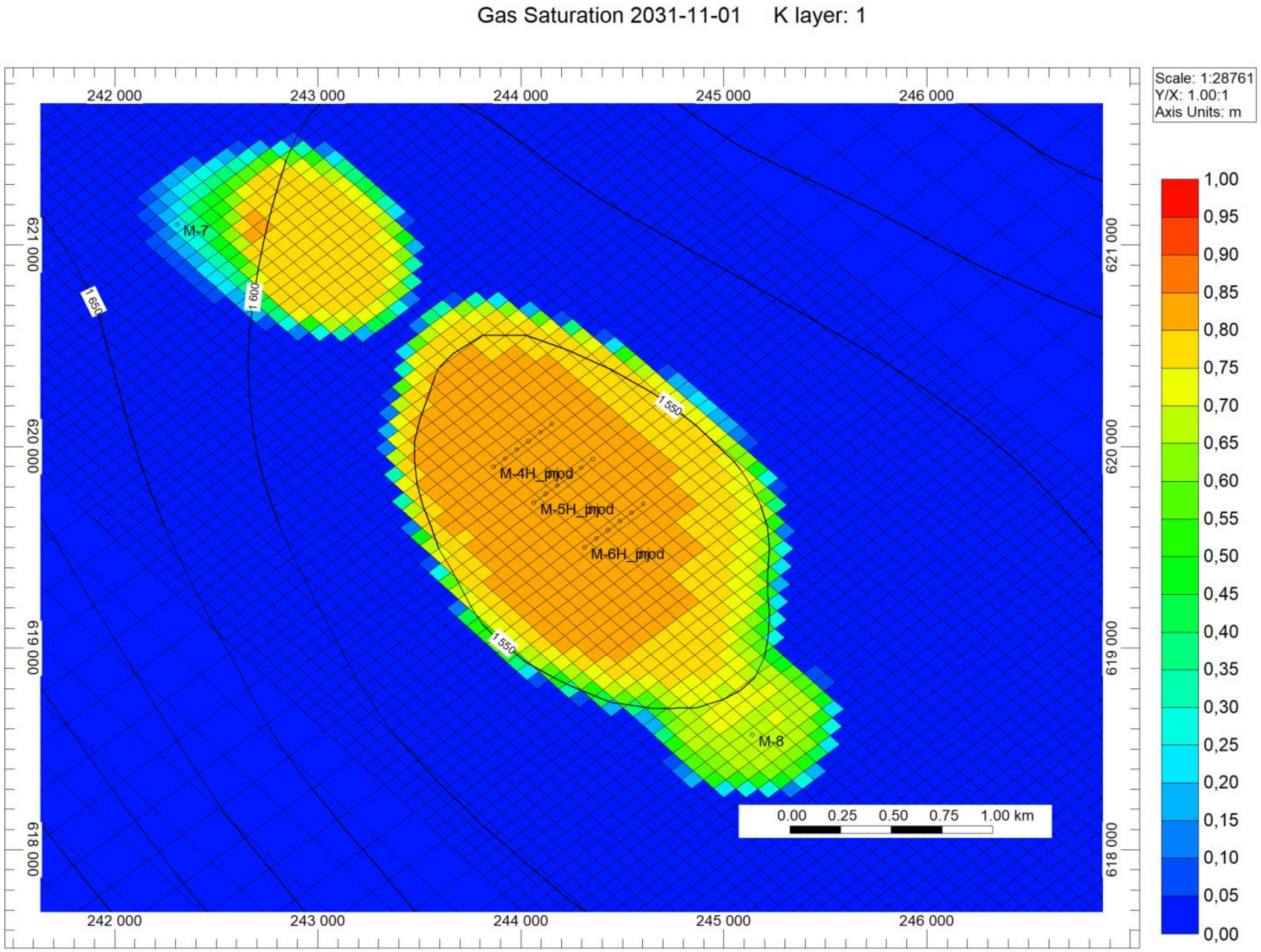
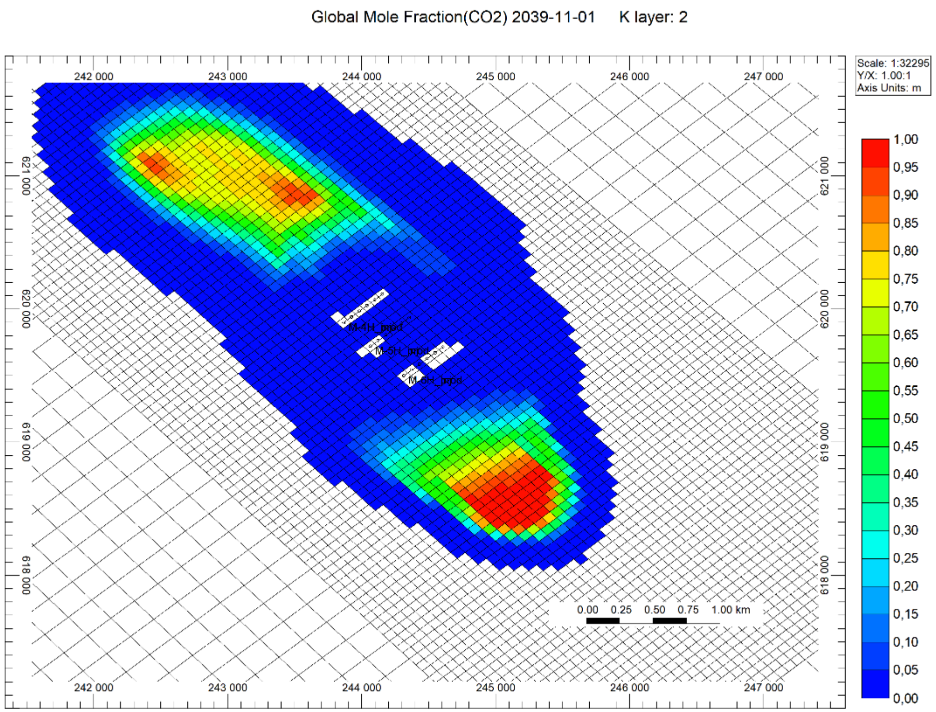
Wariant II

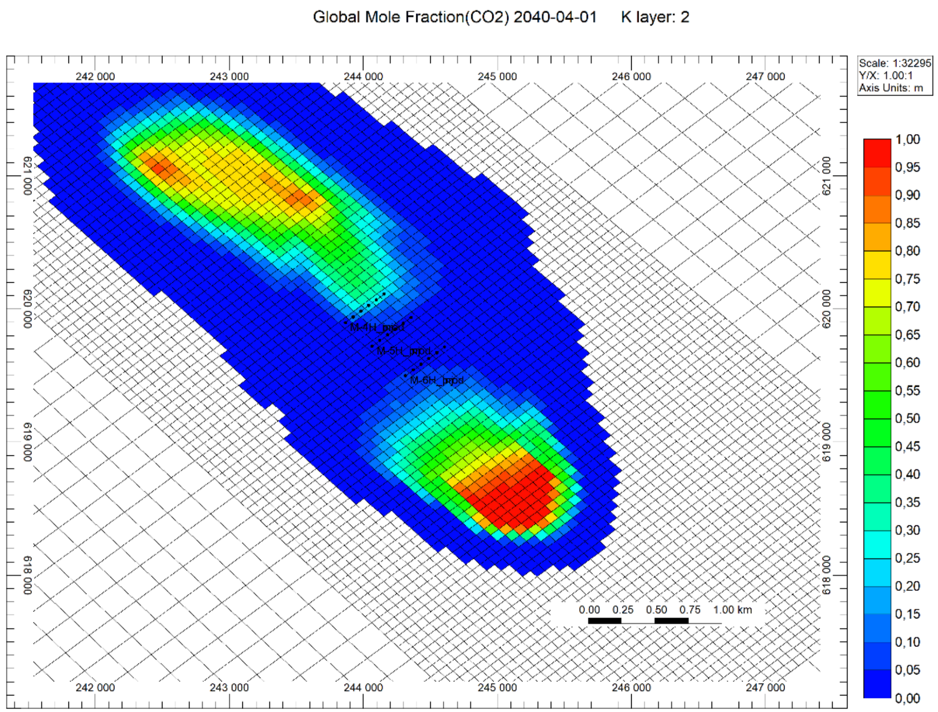
nasycenie gazem w stropie modelu po zakończeniu zatłaczania



The composition of co2 in the gas in the second layer of the model....

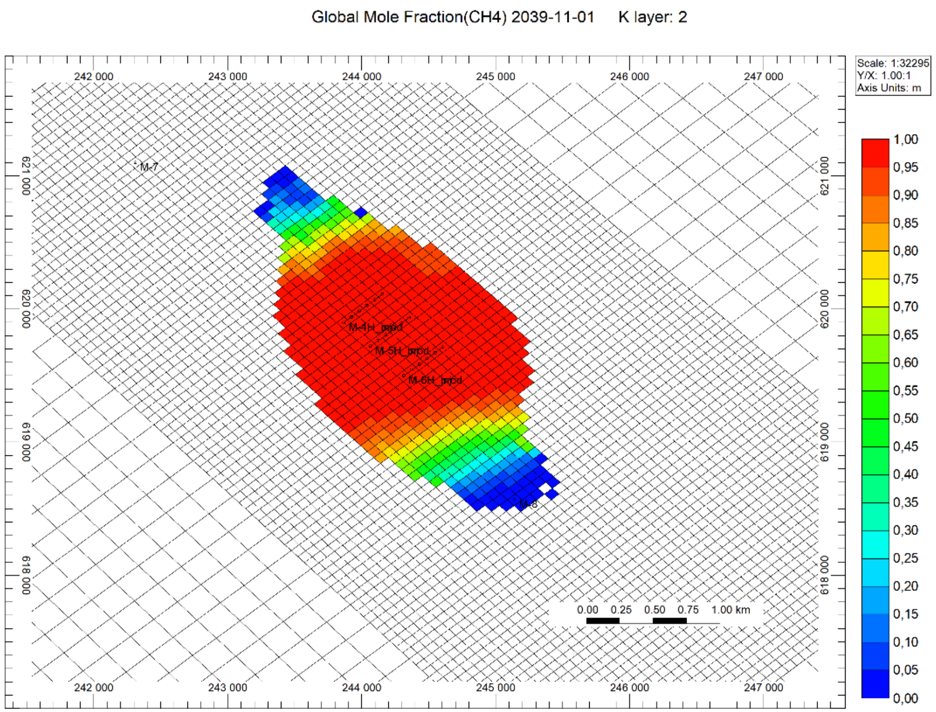


…przed 10-tym odbiorem gazu z PMG

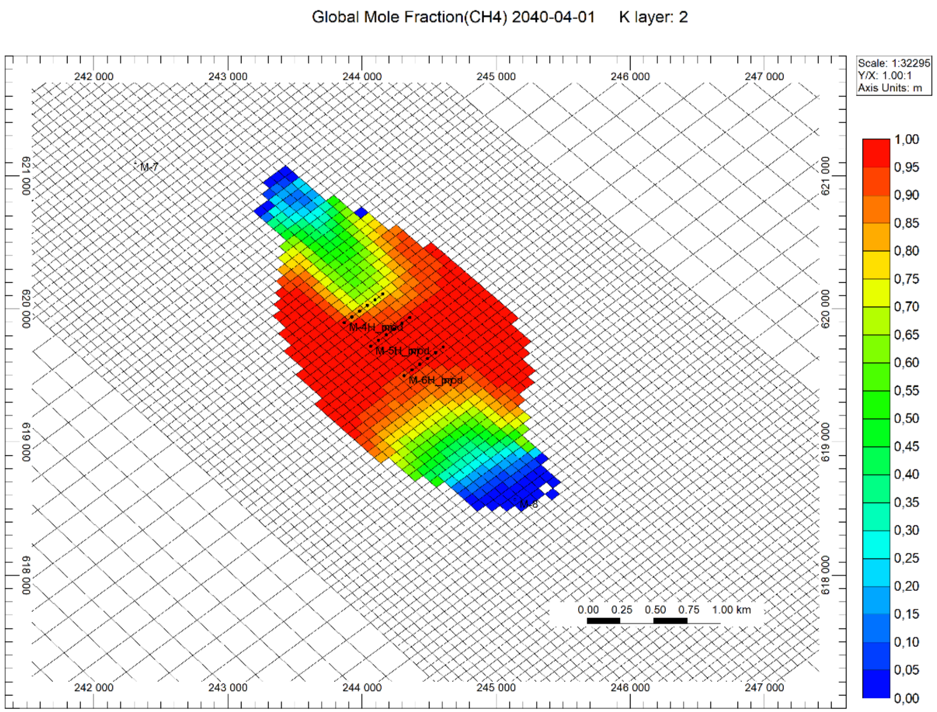


…po 10-tym odbiorze gazu z PMG

The composition of CH4 in the gas in the second layer of the model....

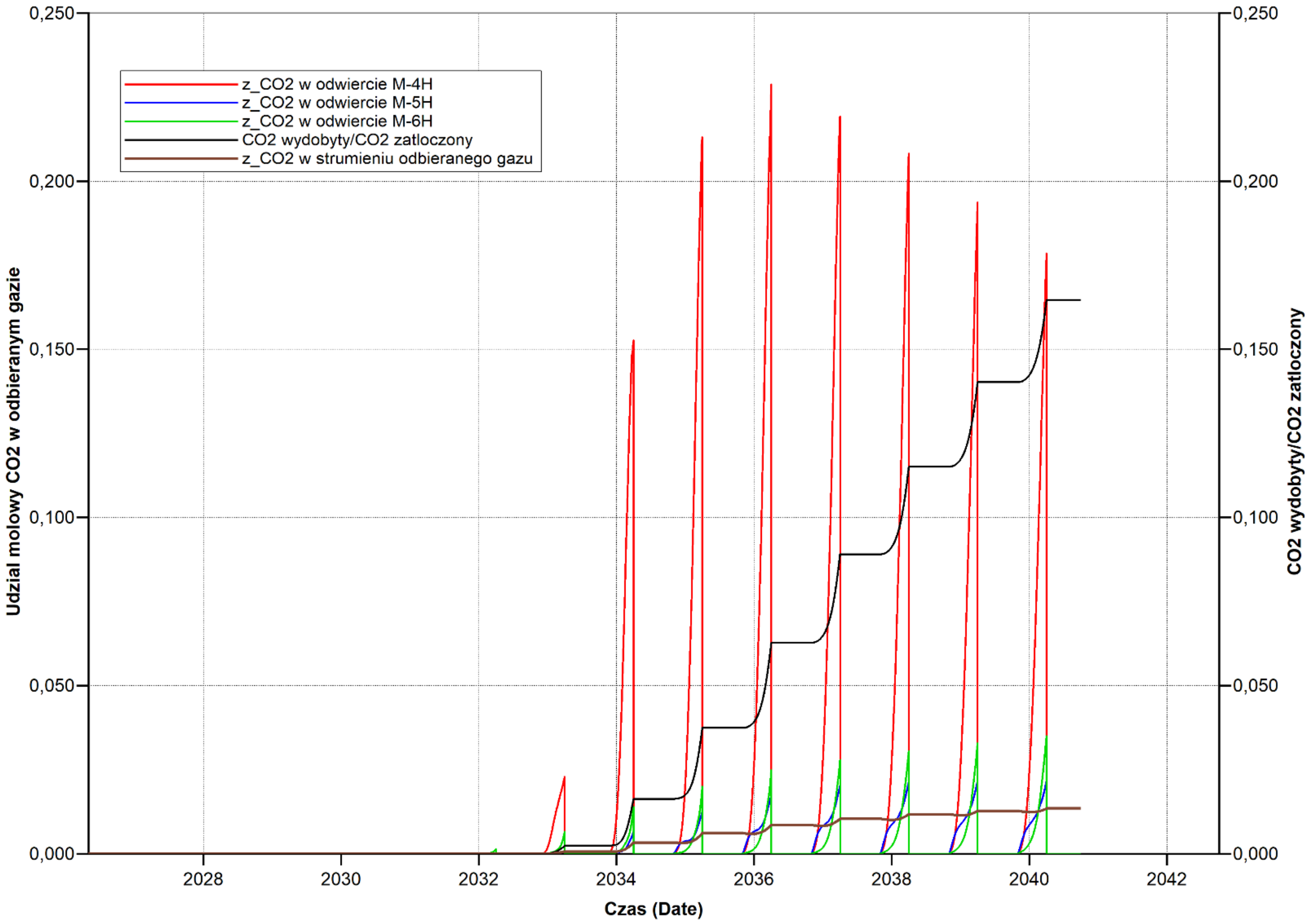


…przed 10-tym odbiorem gazu z PMG



…po 10-tym odbiorze gazu z PMG

The composition of CH4 in the gas from the UGS



Summary and further work

1. Experimental investigations have shown that the diffusion and dispersion processes of CO_2 are analogous to those of supercritical fluids, gases, and liquids. CO_2 as the working gas is withdrawn and the reservoir pressure decreases, the CO_2 cushion gas undergoes a substantial expansion due to the rapid decrease in density, resulting in increased volume.
2. This expansion, in turn, contributes to a more efficient gas drive mechanism within the reservoir, facilitating the extraction of stored gas with improved efficiency.
3. Presented outcomes of laboratory experiments conducted using a specialized setup that incorporates X-ray and Raman spectroscopy allows for a closer examination of the mixing zone within selected core samples. Under supercritical conditions, there are no unforeseen complications concerning these processes, reassuring researchers about the feasibility of this approach.
4. The research is ongoing and further analysis of the mixing characteristics can provide valuable insights into optimizing the use of CO_2 as a cushion gas in underground natural gas storage, particularly in saline aquifers.

Solid and Salt Precipitation Kinetics during CO2 Injection into Reservoir

SaltPreCO2

Project funded from the Norway Grants 2014–2021 operated by the Polish National Science Centre (NCN) in cooperation with the Research Council of Norway (NFR)

Project no. UMO-2019/34/H/ST10/00564

Project leader:	AGH University of Krakow
Project partner:	University of Oslo
Principal investigator:	Prof. Stanisław Nagy
Partner leader:	Prof. Helge Hellevang
Project duration:	2020 - 2024

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Norway grants

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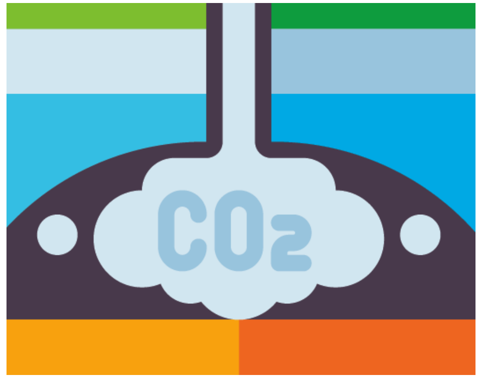
Project objectives



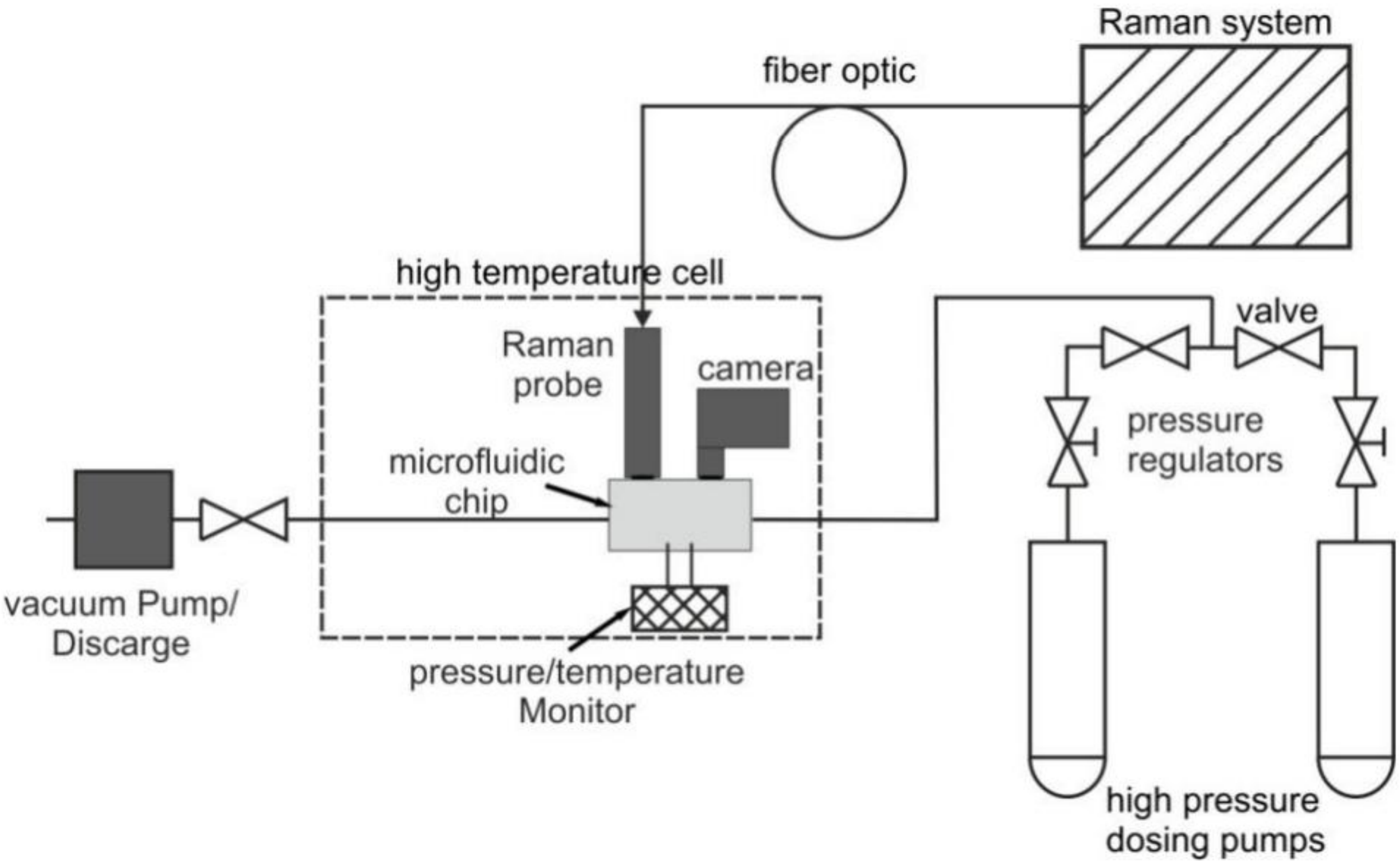
- The **main aim** of SaltPreCO2 is to predict optimal parameters such as pressure and volume flow during the injection of CO_2 into saline aquifers.

- **Salt Precipitation:** In simplified model increasing pressure of injected a CO_2 will result in a higher CO_2. As a result we are able to store more CO_2 in shorter time. However, higher pressure can lead to salt precitipation. Small salt crystals works like plugs which clog pores in rock and reduce or even prevent gas flow.

- **Scope of research:** Since this kind of studies (basic research) are not possible to perform directly underground we have to reproduce reservoir conditions in a laboratory. Since studies aquifers are at great depth rocks are under high pressure.

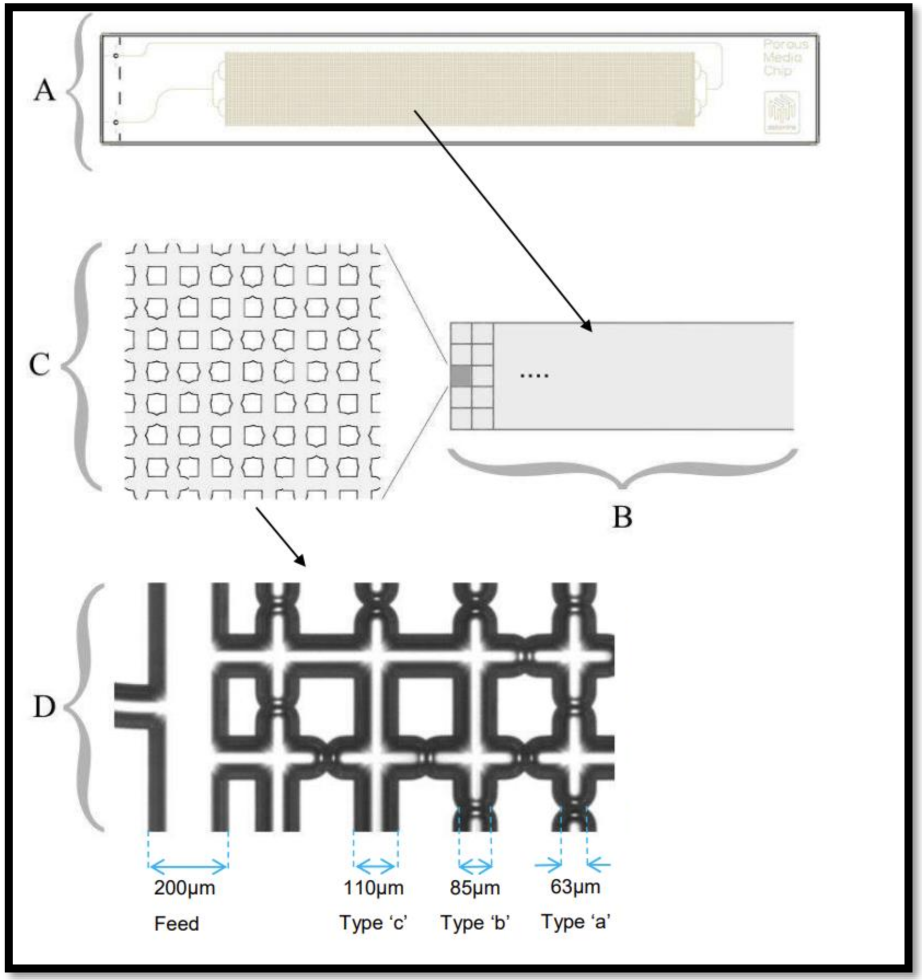
- **Effects:** The main effect is understanding a salt precipitation process under high pressure in rock formations. This led us to development of new accurate thermodynamic models which can be later used in the prediction optimization of CO_2/brine/rock interaction.

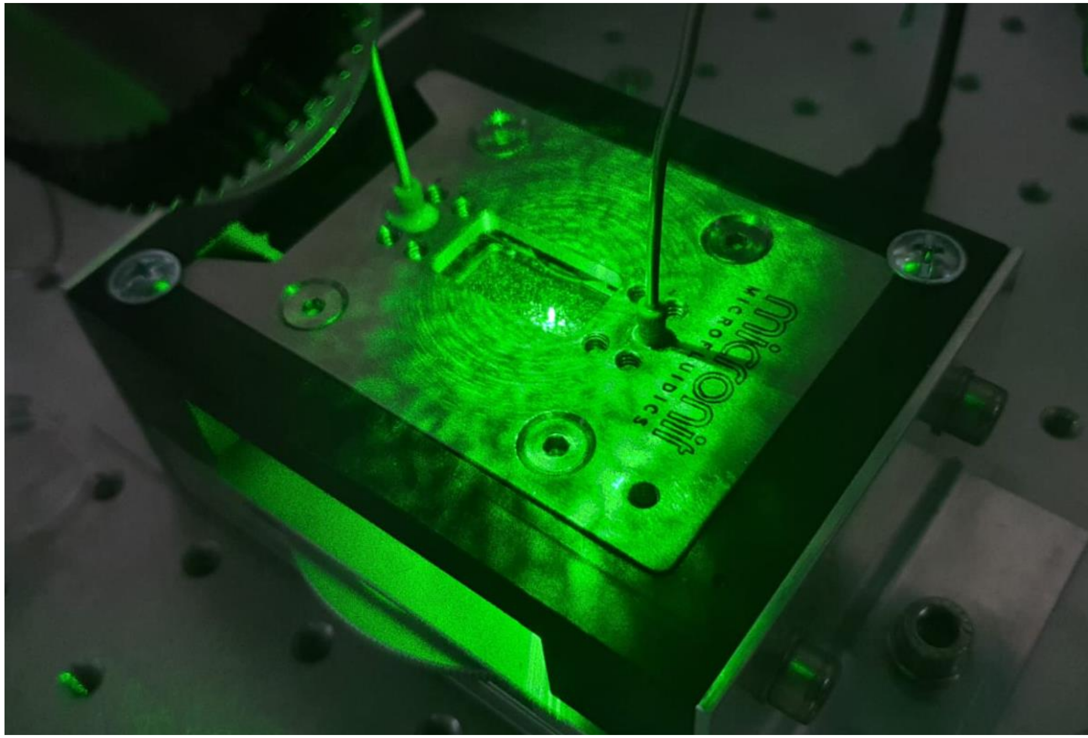
Laboratory research



Laboratory experimental setup
microfluidic & RS 532 for determination CO2 solubility in water and brine

Laboratory research
Lab-on-chip with Raman spectroscopy





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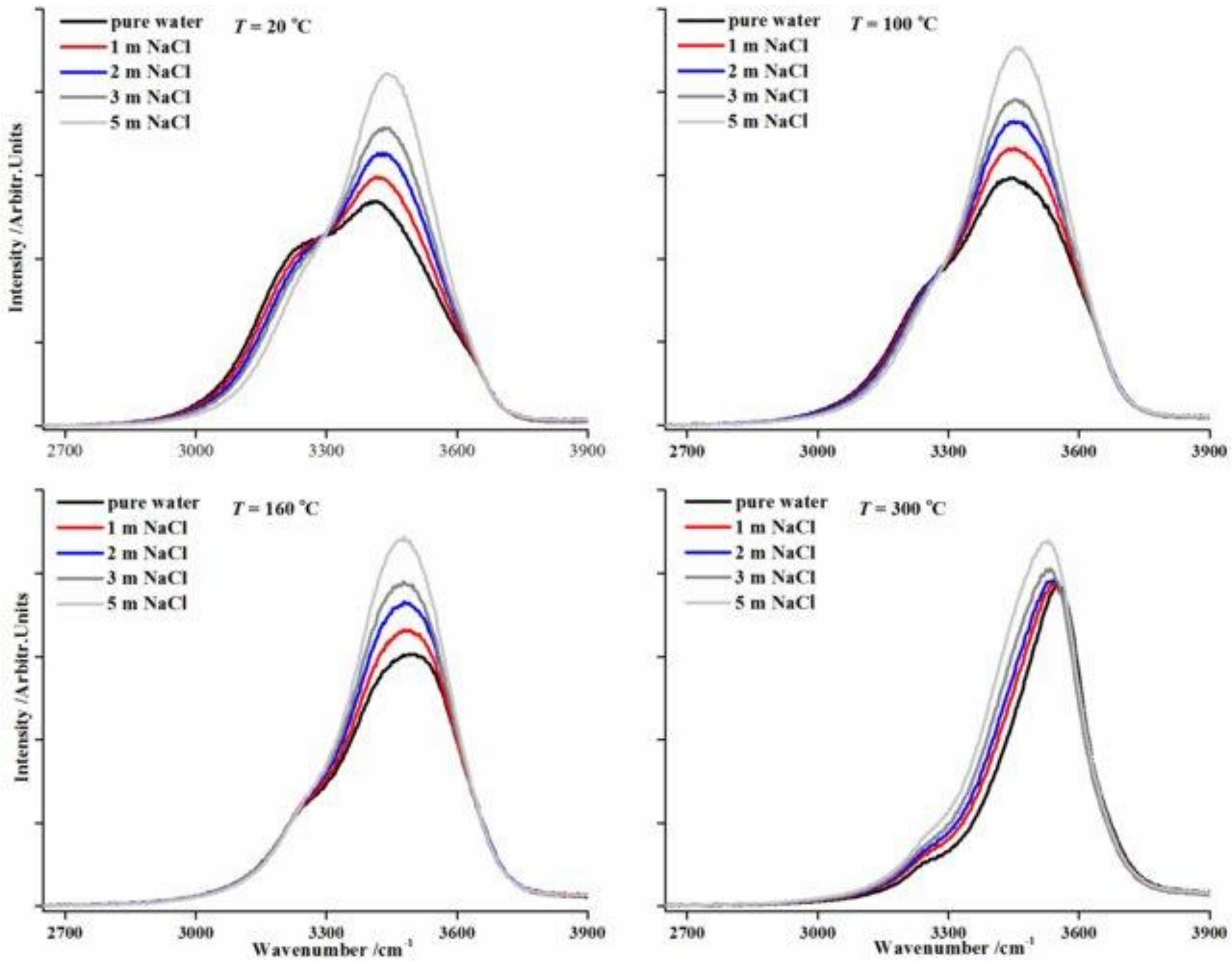
Laboratory experimental setup

Raman spectroscopy for water salinity monitoring

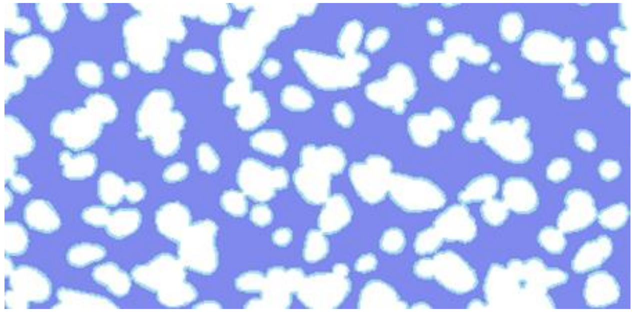
- Presence of NaCl in water, changed the frequency and shape of O-H stretching line
- The ratio of peak intensities - Peak2/Peak1 can be used to determine the NaCl content

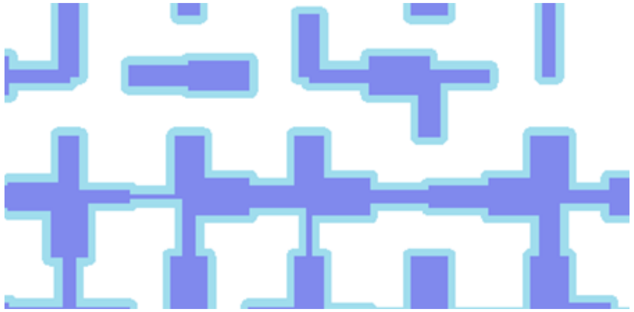


Comparison of the Raman spectra for different NaCl solutions at different temperatures (Wu, 2017)

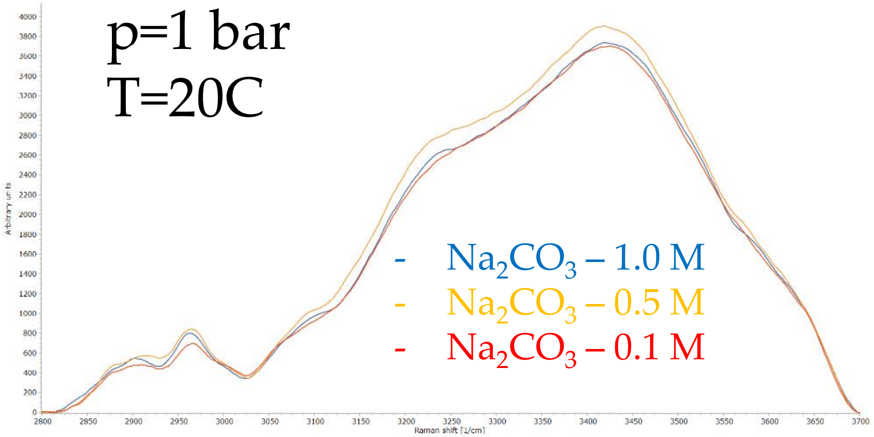
Investigated samples

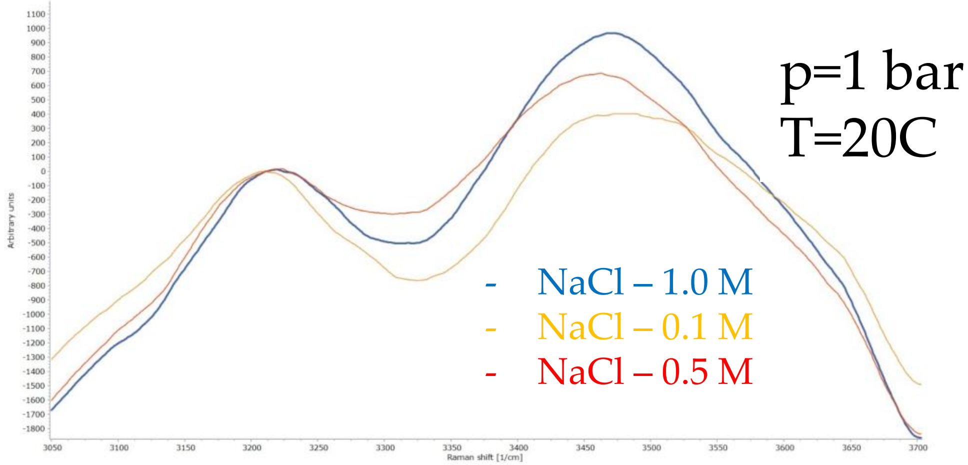
Subtrate	Substrate formula	Microchip		Water solution (beaker)
		Porous	Random	
Carbon dioxide	CO_2	+	+	-
Water	H_2O	+	+	-
Sodium Chloride solution (0.1; 0.5; 1 M)	NaCl	+	+	+
Potassium Chloride solution (0.1; 0.5; 1 M)	KCl	+	+	+
Sodium Carbonate solution (0.1; 0.5; 1 M)	Na_2CO_3	+	+	+
Sodium Sulfade solution (0.1; 0.5; 1 M)	Na_2SO_4	+	+	+

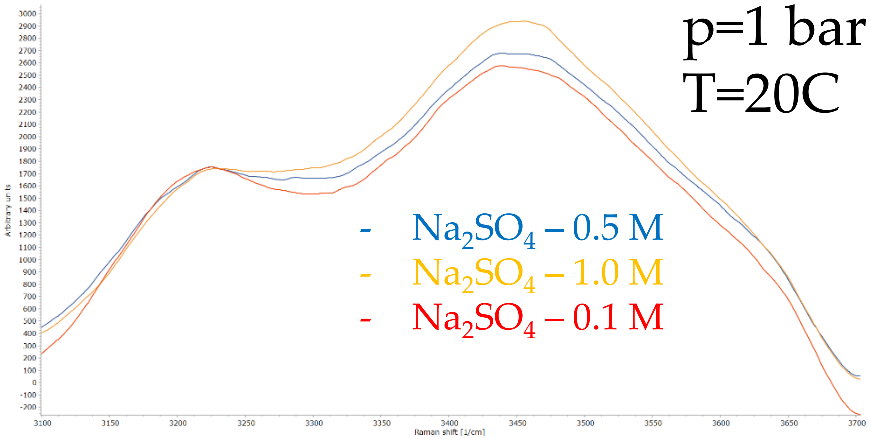


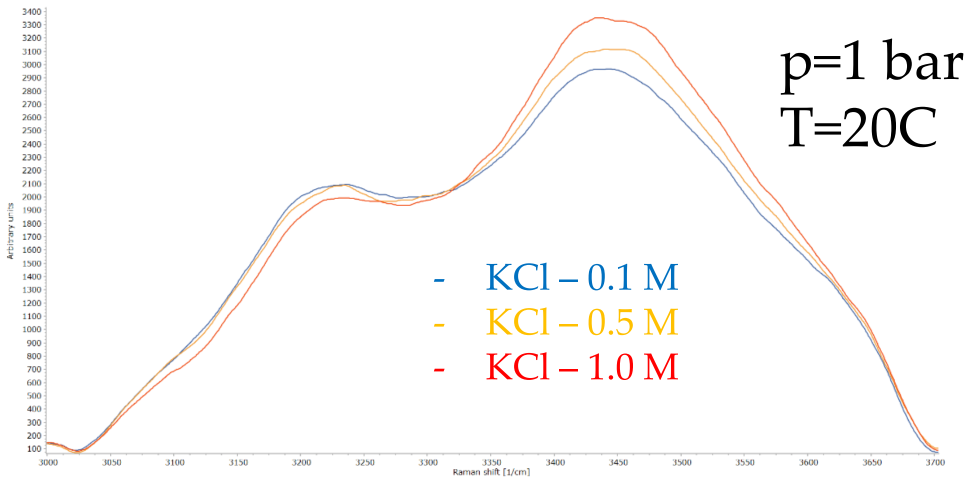


Different salts solutions (beaker)
Influence on H_2O band

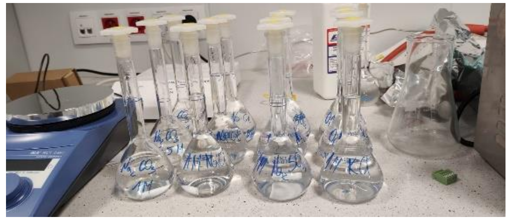


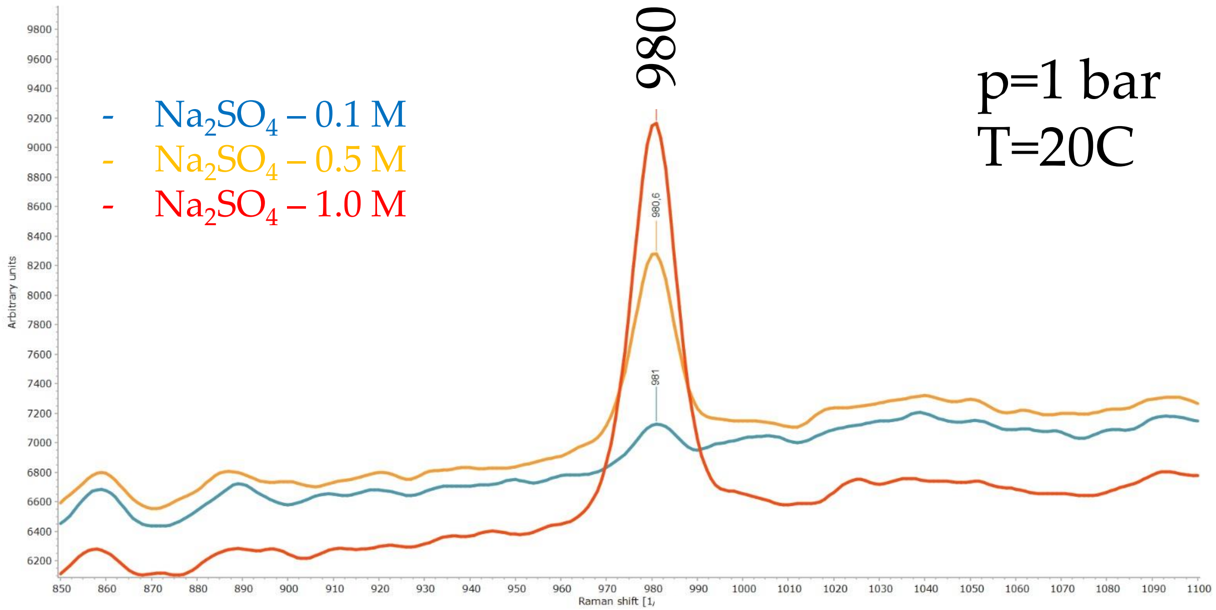




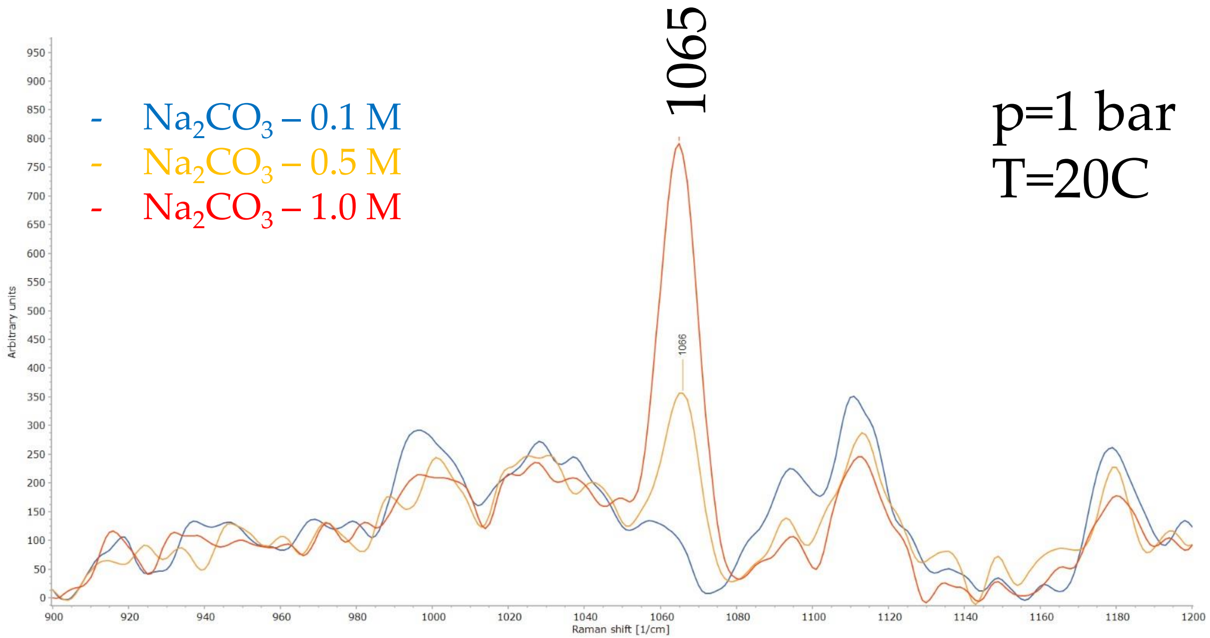


Different salts solutions (beaker)





sulfades



carbonates

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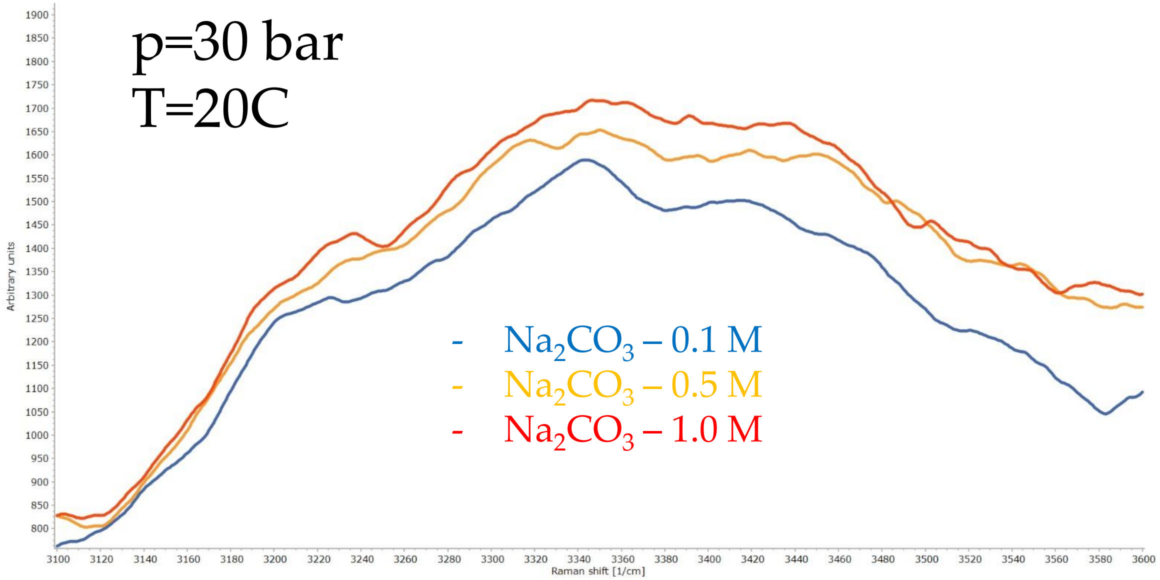
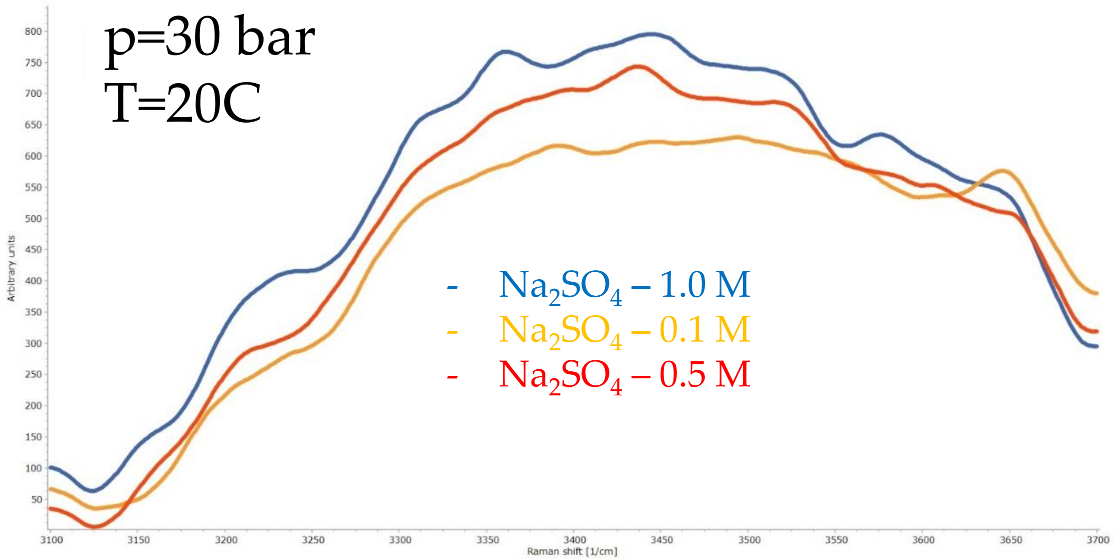
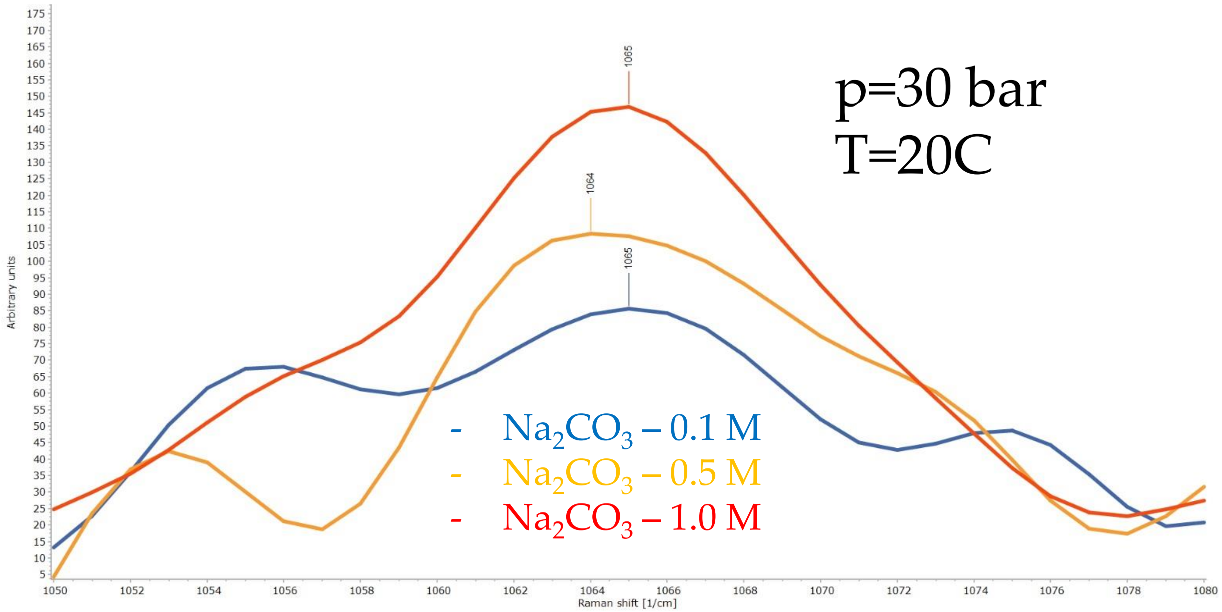
Different salts solutions (geochip) Influence on H_2O band

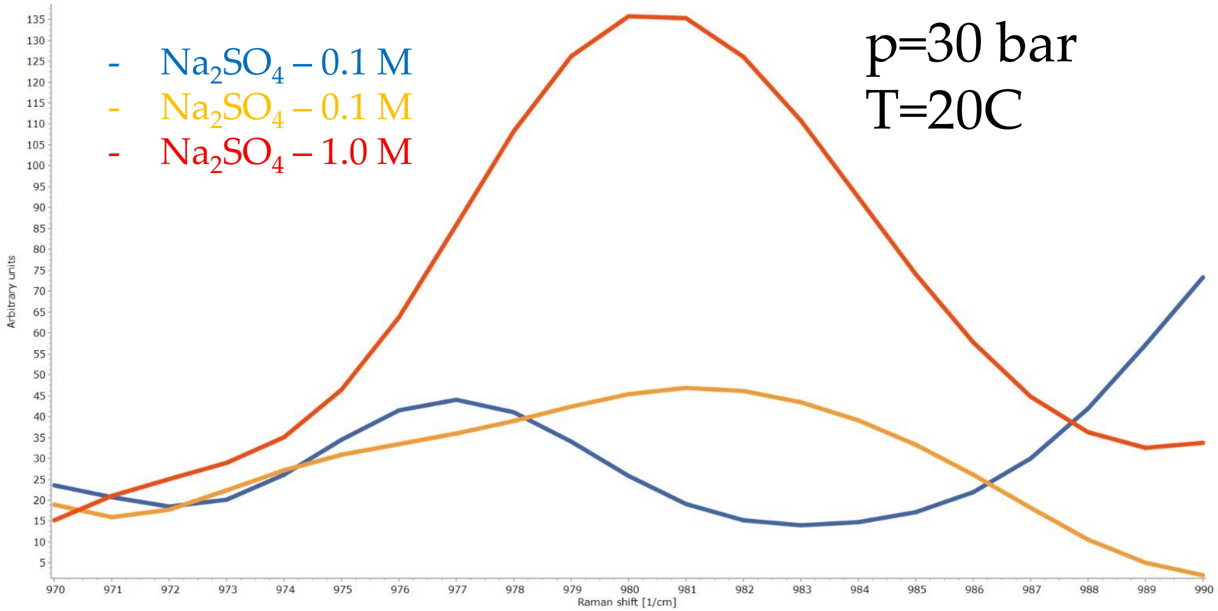




Different salts solutions (geochip)

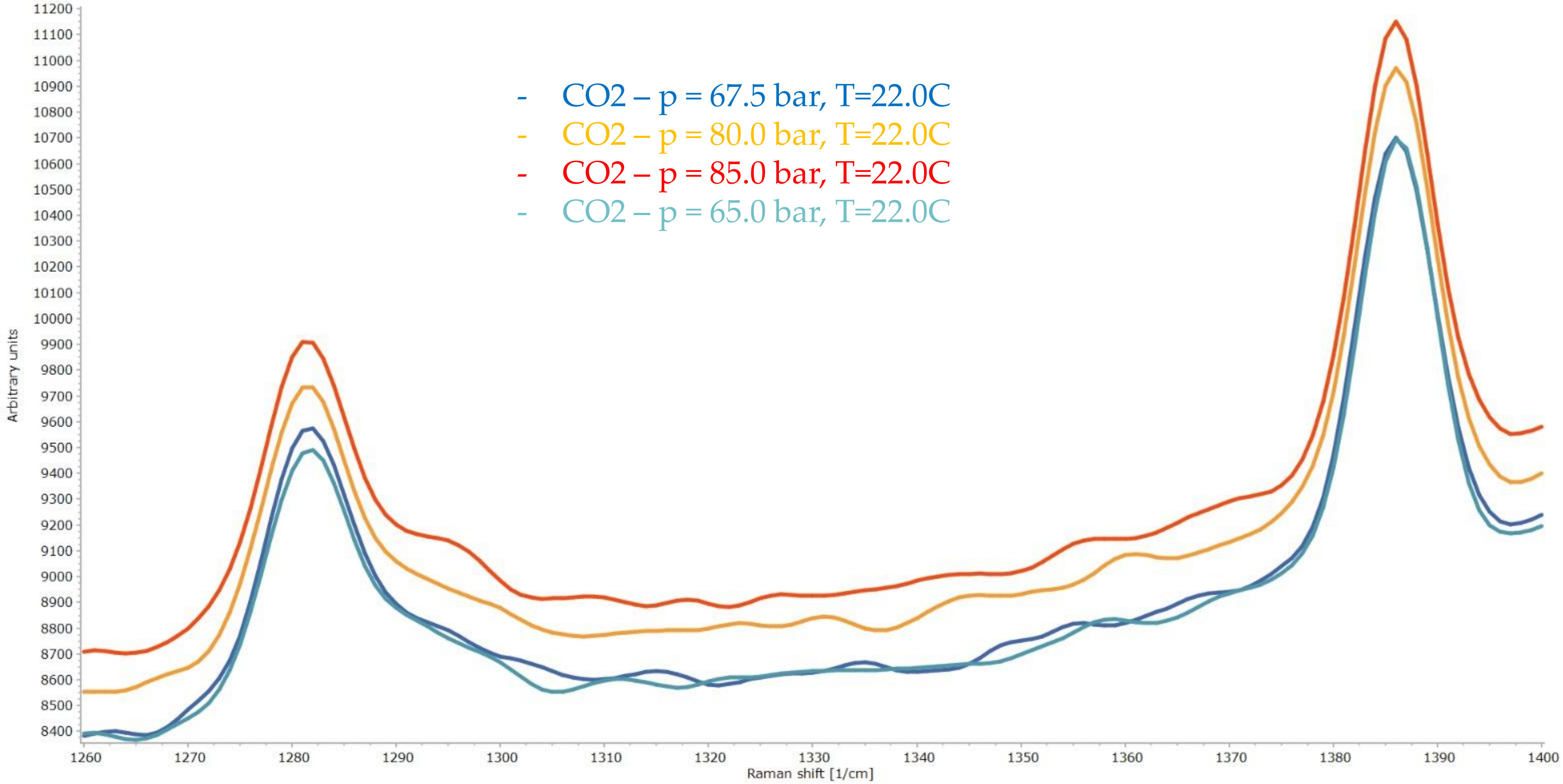


carbonates

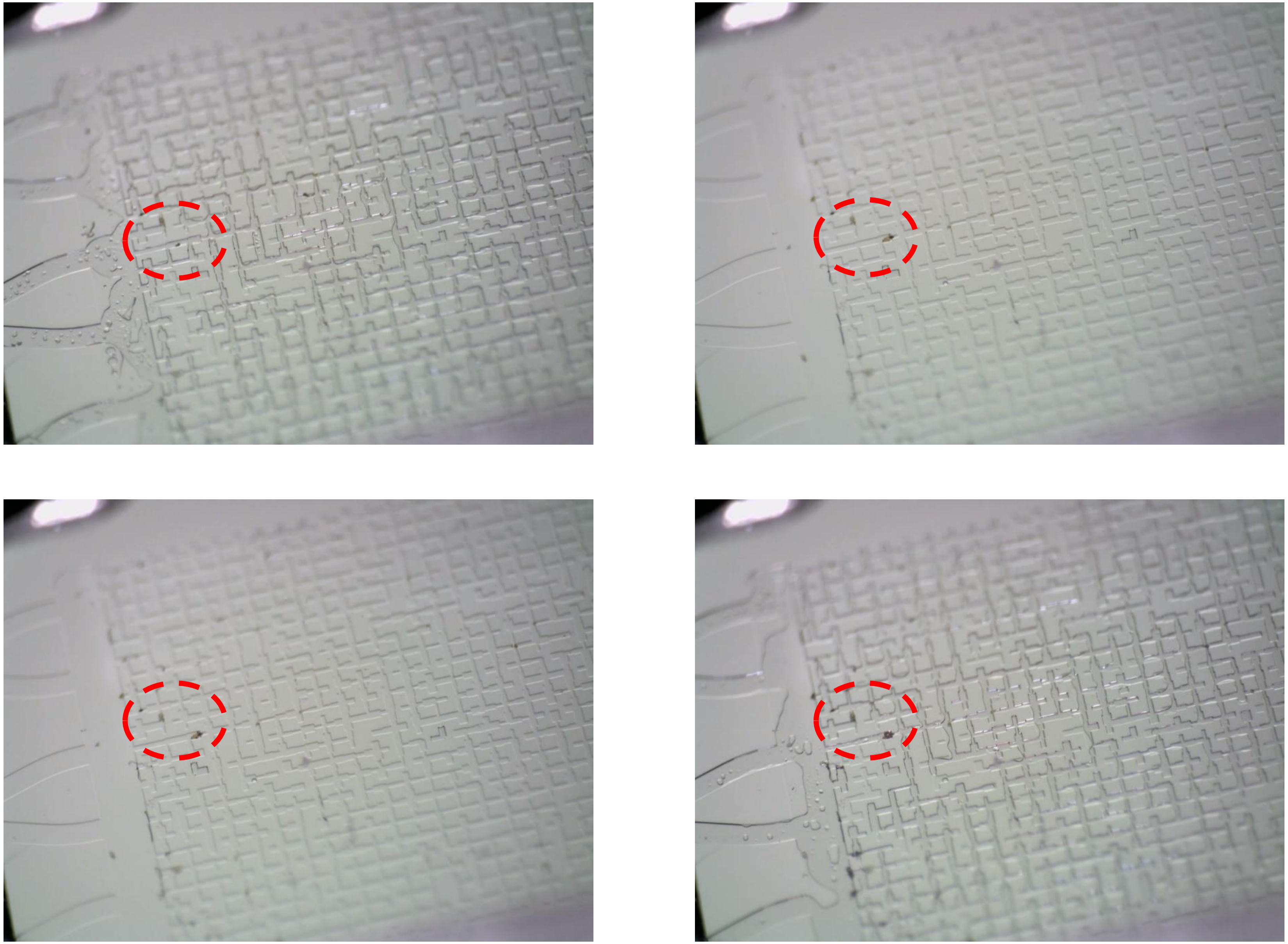


sulfades

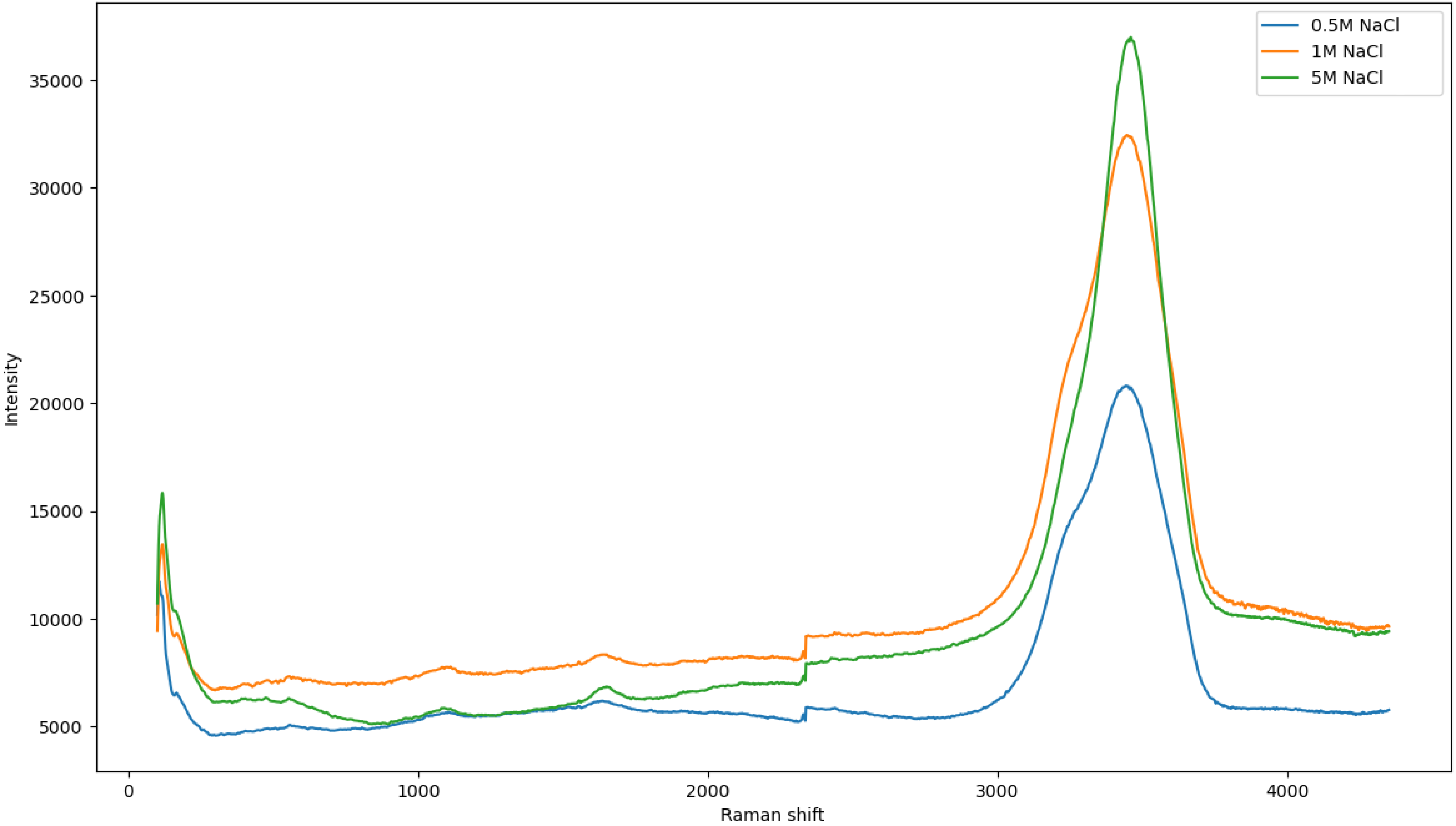
CO2 bands on geochip



Crystallization on random microchip
NaCl



Different salts solutions (geochip)
Influence on H_2O band (80° C, 80bar)



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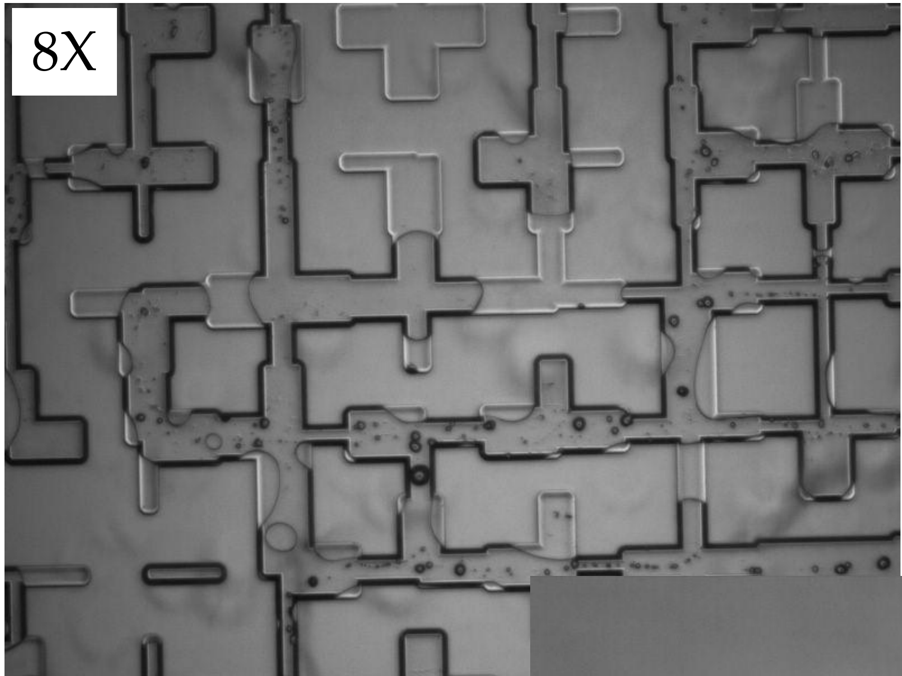
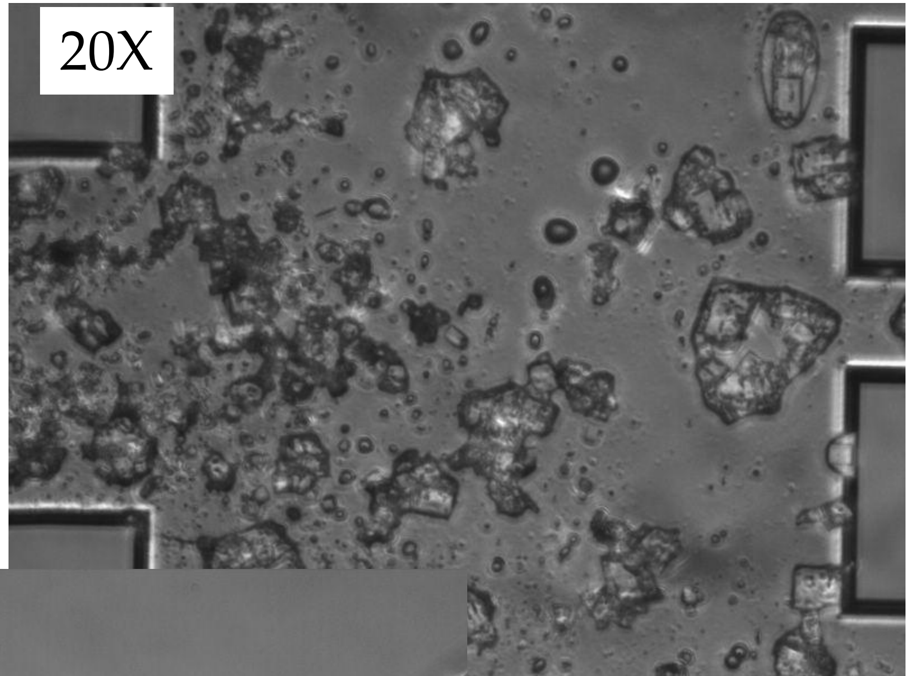
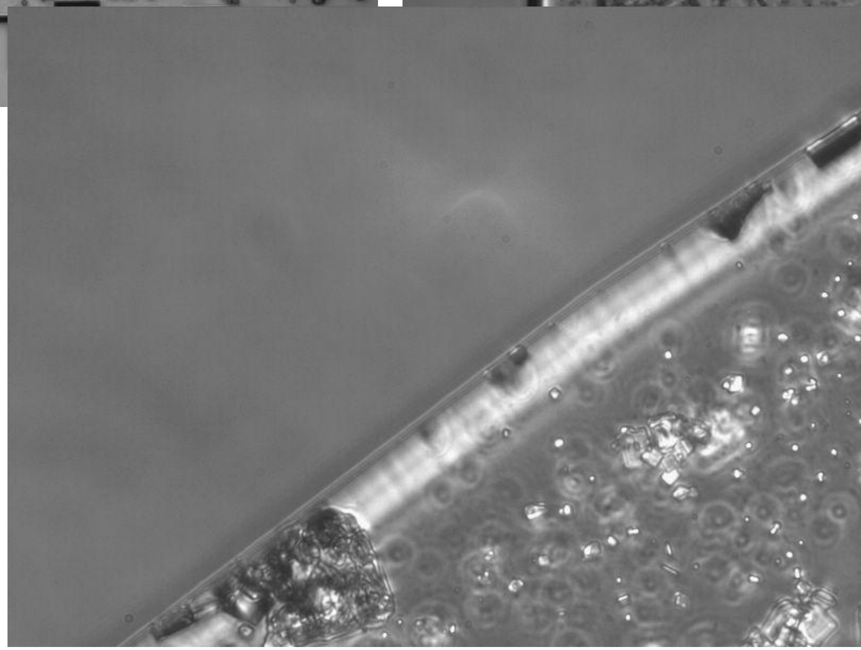
NaCl crystals precipitation during CO2 injection – hydrophilic microfluidic

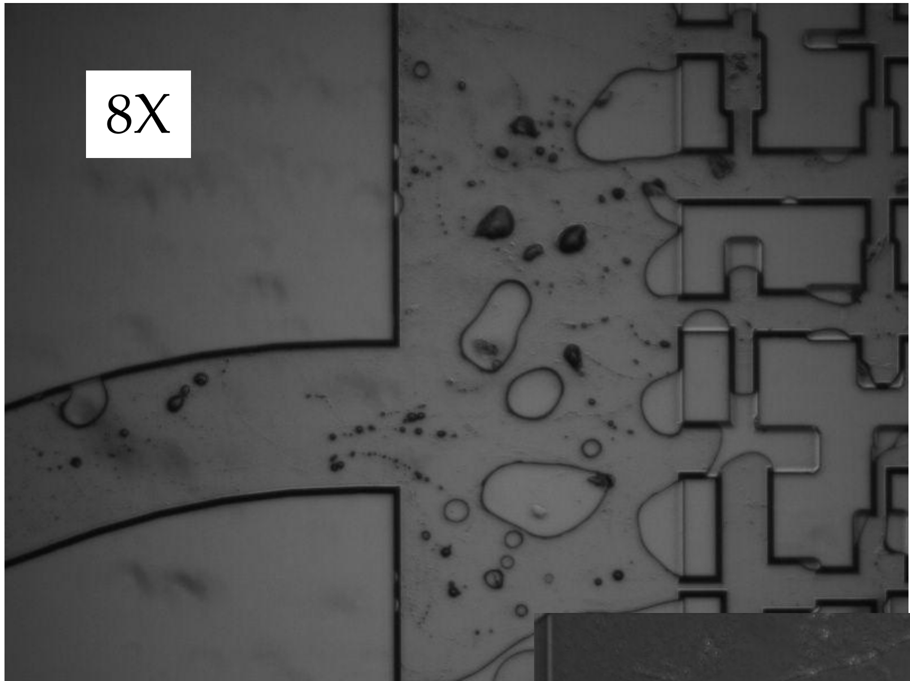


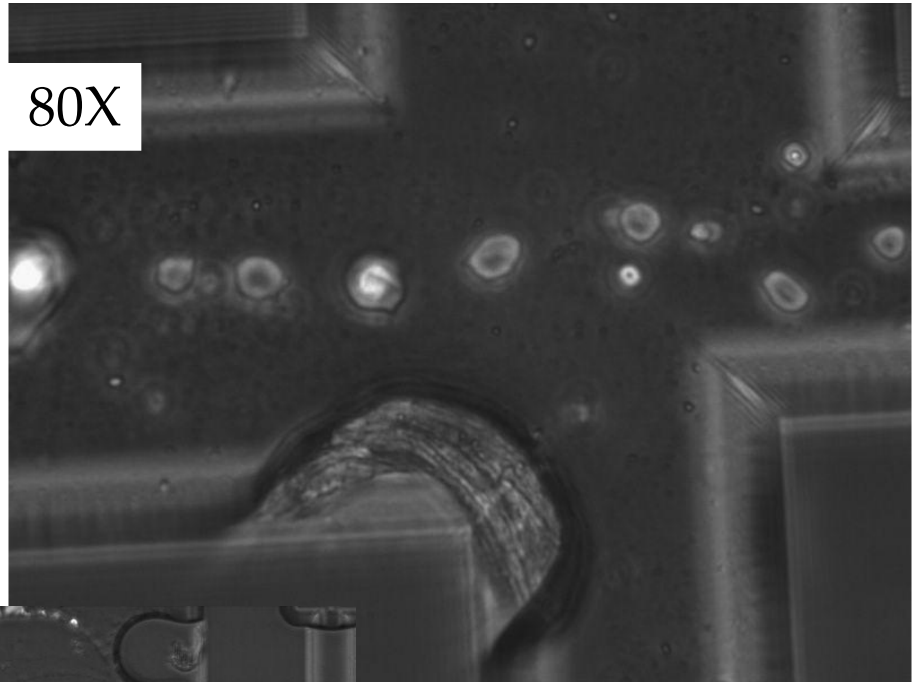


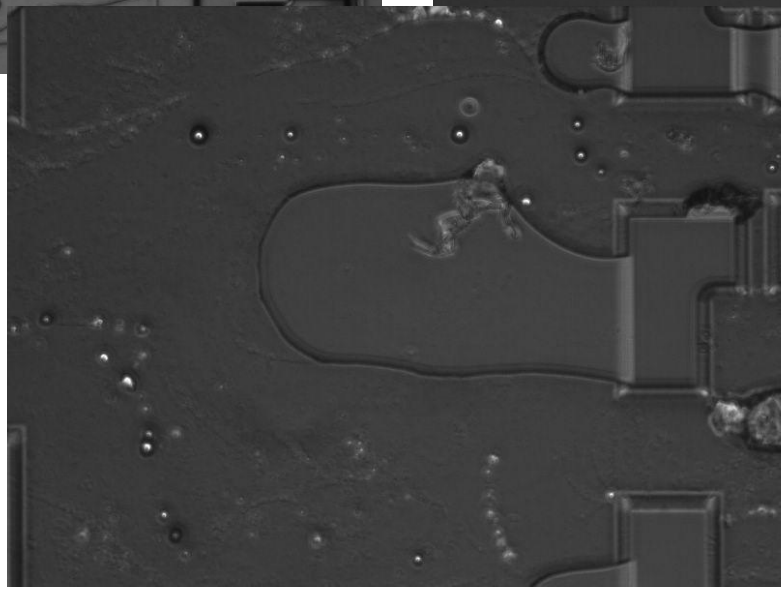


p=40 bar
T=25C
Q CO2 = 2ml/min
C NaCl = 5 M
t = 30 min

NaCl crystals precipitation during CO2 injection – hydrophobic microfluidic

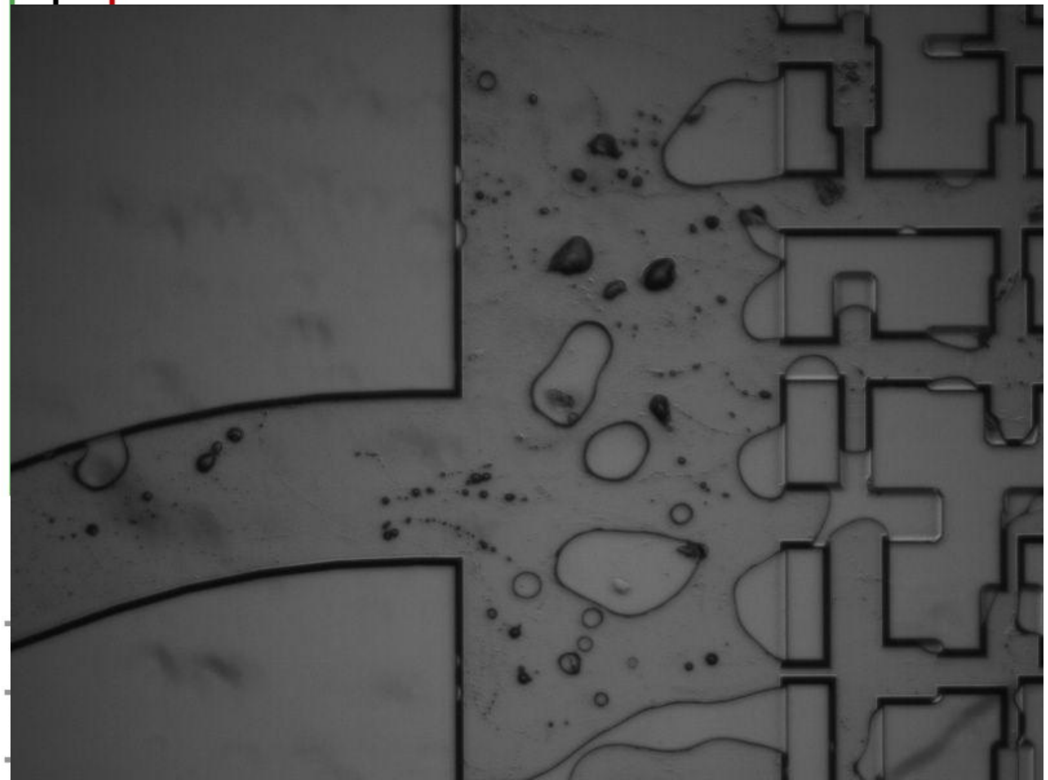




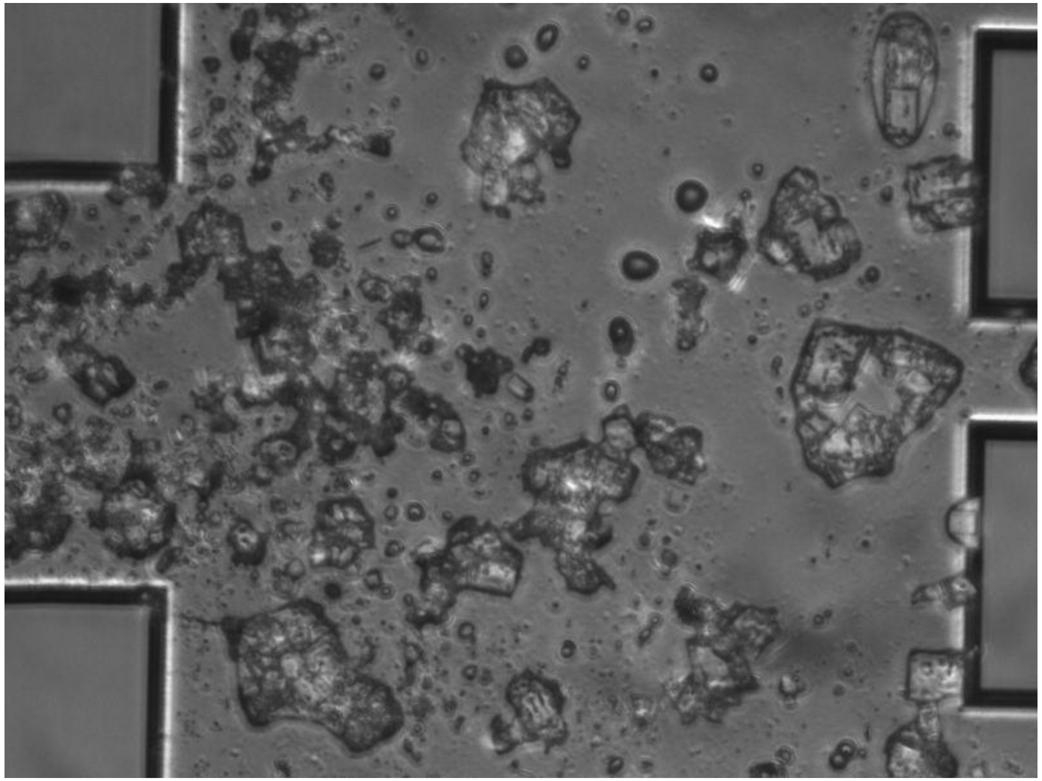


p=40 bar
T=25C
Q CO2 = 2ml/min
C NaCl = 5 M
T = 30 min

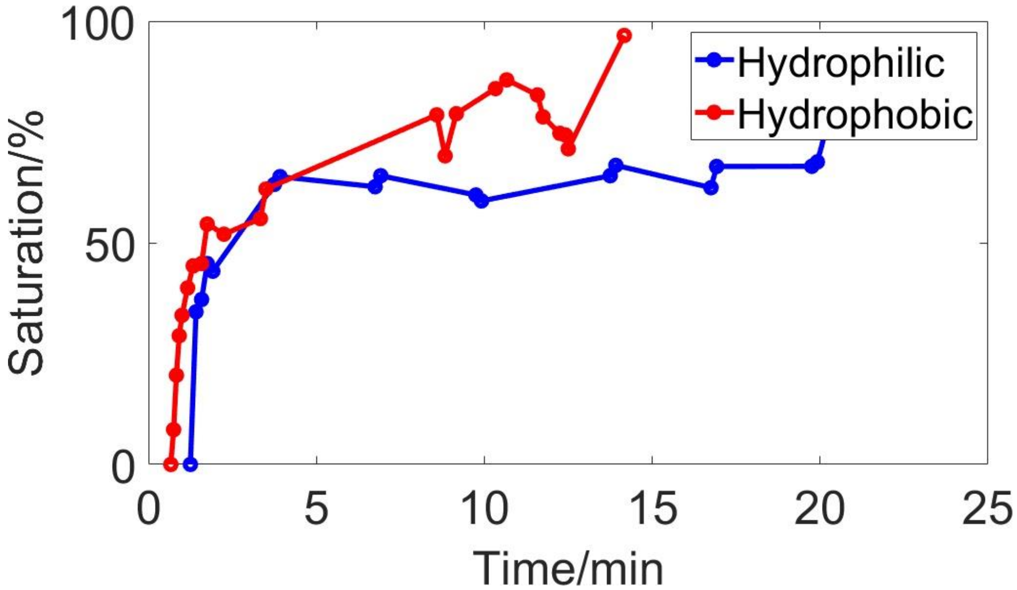
NaCl crystals precipitation during CO2 injection – comparison hydrophobic and hydrophilic microfluidic



Hydrophobic



Hydrophilic



Hydrophilic chip trappes capillary water

Salt precipitation due to dry out of that water

Additional possible capillary back flow

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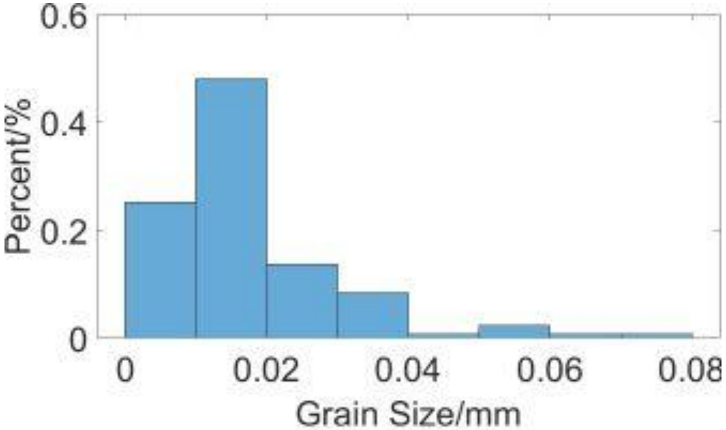

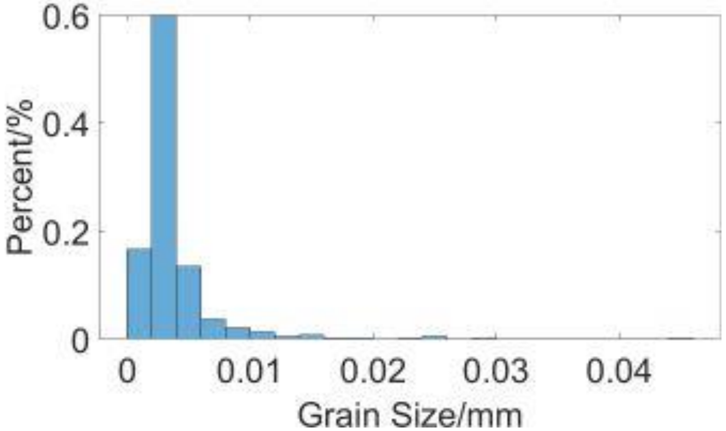

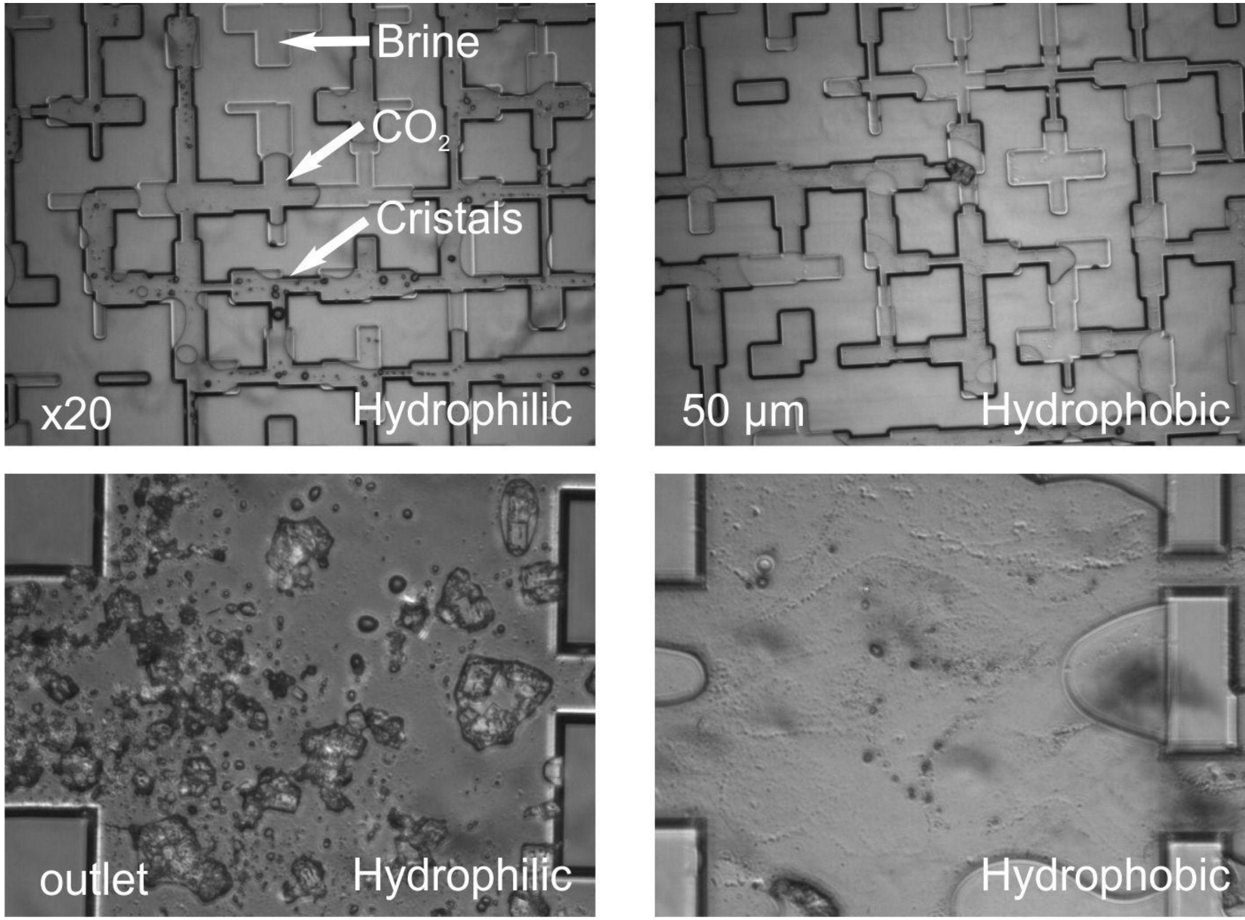

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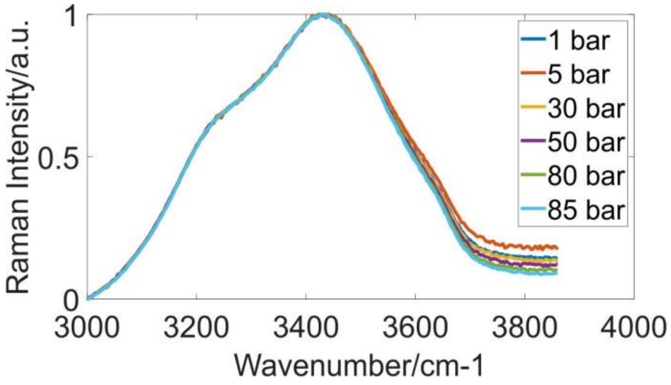
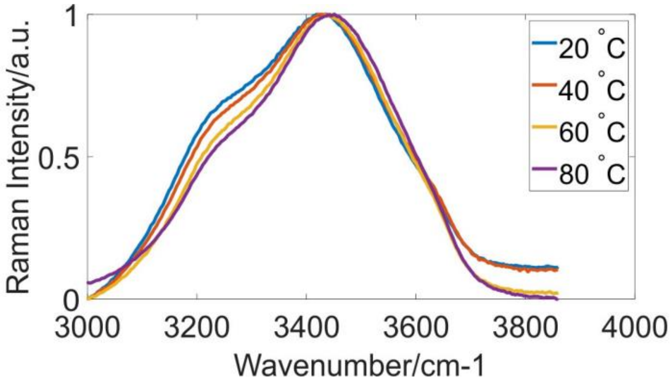
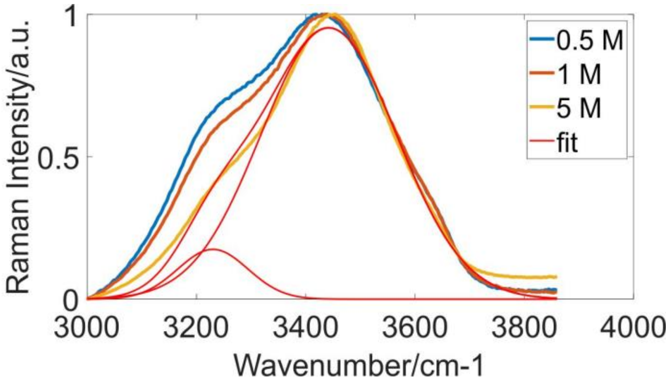
Raman spectra of NaCl solutions





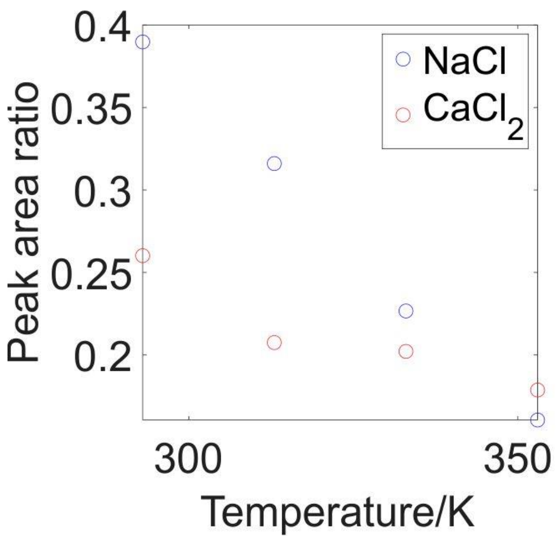


NaCl 0.5 M solution at 40 ^{o}C

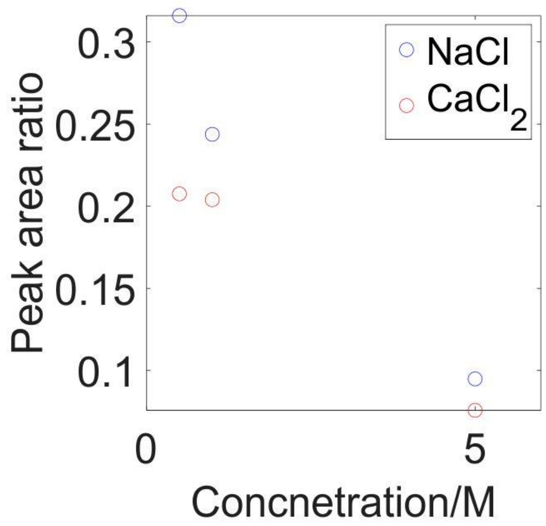
NaCl 0.5 M solution
at pressure 80 bar

NaCl solutions
80 bar and 40 ^{o}C

Raman spectra of NaCl solutions



Impact of temperature on peak area



Impact of concentration on peak area

- Peak area ratio give information about concentration
- Possible measurement of concentration gradient
- Evaluation of a capillary back flow

Summary and further work

1. Underground injection of large volumes of supercritical CO2 that is undersaturated with respect to water causes evaporation of formation water which increases concentration of dissolved salts in brine pores and salt crystals will form in the porous or fractured media;
2. The salt precipitation can severely reduce the reservoir permeability around the well, induce excess pressure build-up, and cause a decline in injectivity;
3. Further lab resesearch on geomaterial microfluidic system with Raman spectroscopy to real-time CO2 concentration determination ;
4. Measure thermodynamic properties of CO2/water, CO2/brine systems using an HPHT microfluidic;
5. Raman system such as minimal miscibility pressure, bubble/dew point and determine the phase equilibrium curve. Address nucleation, precipitation, and growth of salt crystals within the aqueous phase or on the interface of the gas stream and solid surface