Progress of the Heletz pilot injection project

Auli Niemi, Uppsala University, Sweden
Jac Bensabat, EWRE, Israel

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CO_2QUEST

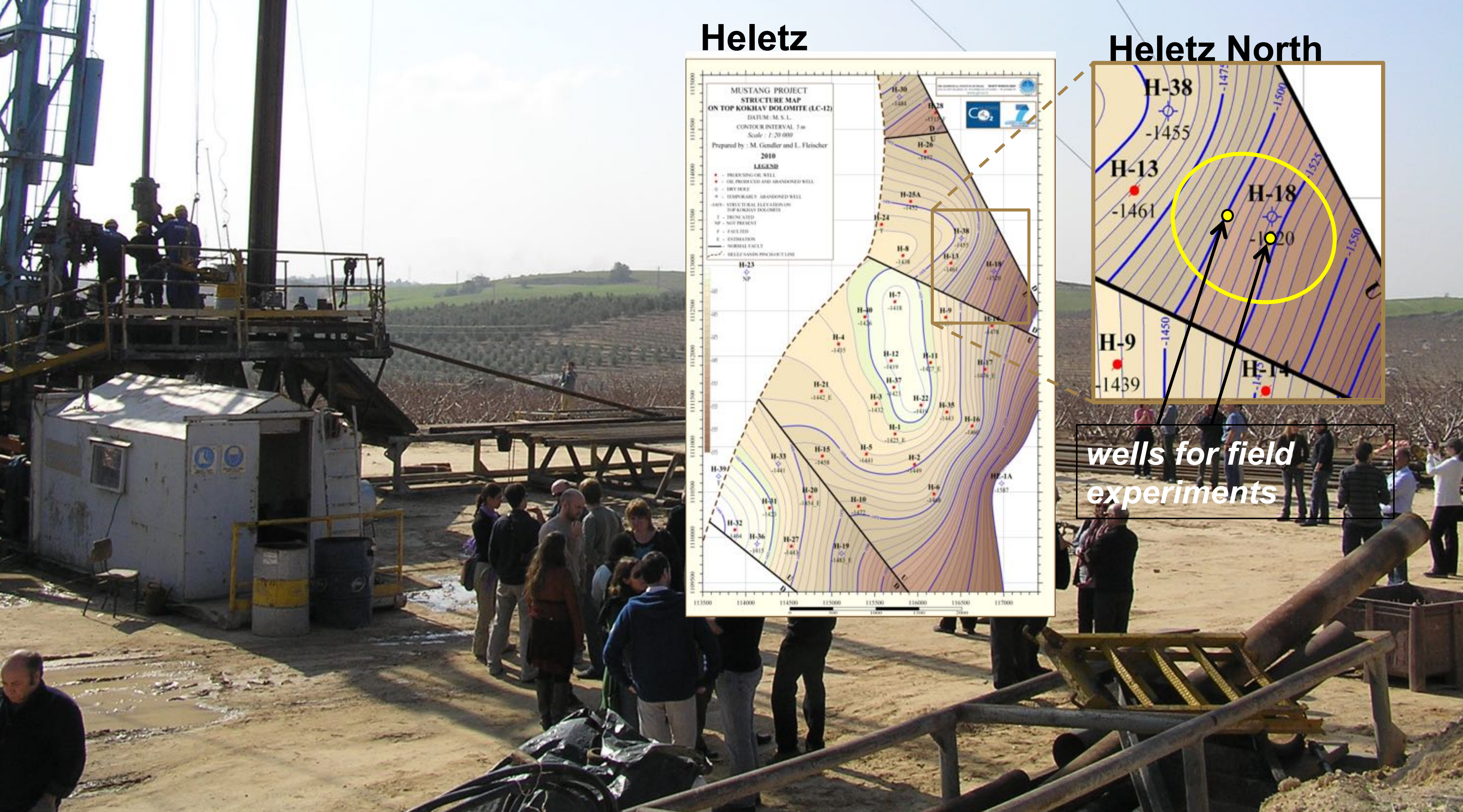
Outline

- Background on the Heletz pilot injection project
- Objectives of the test program
- Status and results so far

CO_2QUEST

Heletz deep CO_2 injection experiment site

Scientifically motivated CO2 injection experiment site of scCO2 injection to a reservoir layer at 1600 m depth, with monitoring and sampling



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The site has been developed within EU funded R&D projects

MUSTANG – large-scale integrating project for quantifying Saline Aquifers for CO2 Geological Storage (2009-2014)
(led by Uppsala University) http://www.co2mustang.eu

Panacea – project focusing **on long term effects** of CO2 Geological Storage (2012-2014) (led by EWRE, Israel) http://panacea-co2.org/

TRUST – project continuing and **expanding the field experiment** of MUSTANG (Nov. 2012-Nov 2017) (led by EWRE, Israel) http://trust-co2.org/

CO2QUEST – project focusing on **effect of impurities** of CO2 stream (March 2013- Feb 2016) (led by UCL, England) http://www.co2quest.eu/

MUSTANG CO_2 TRUST CO_2QUEST

Objectives of the experimental program

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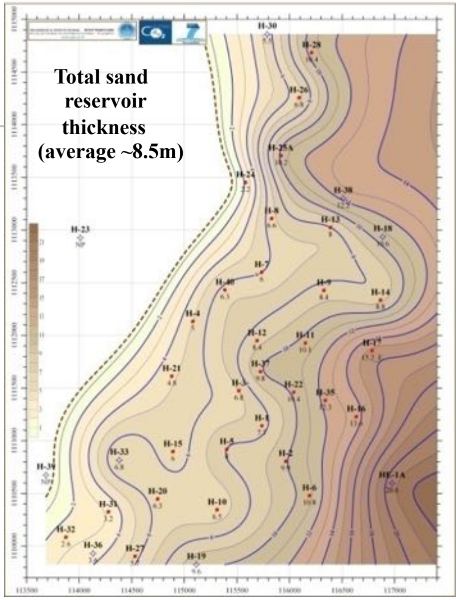
- To gain understanding and develop methods to determine the two key trapping mechanisms of CO2 - ***residual trapping and dissolution trapping*** - at field scale, evaluate the impact of heterogeneity
(MUSTANG)

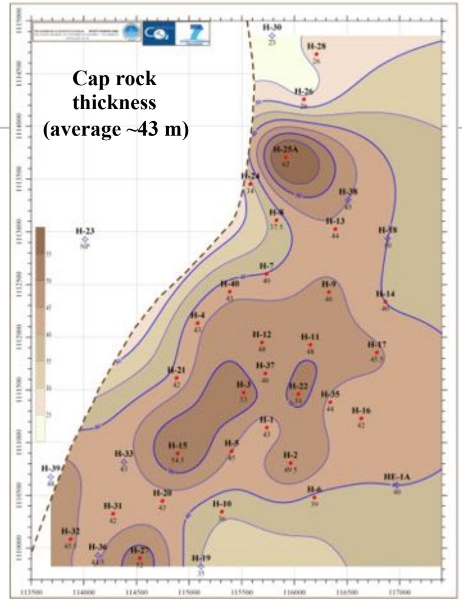
- Estimate ***how to enhance trapping*** by different modes of injection (TRUST)

- ***Effect of impurity gases*** in CO2 stream (CO2QUEST)

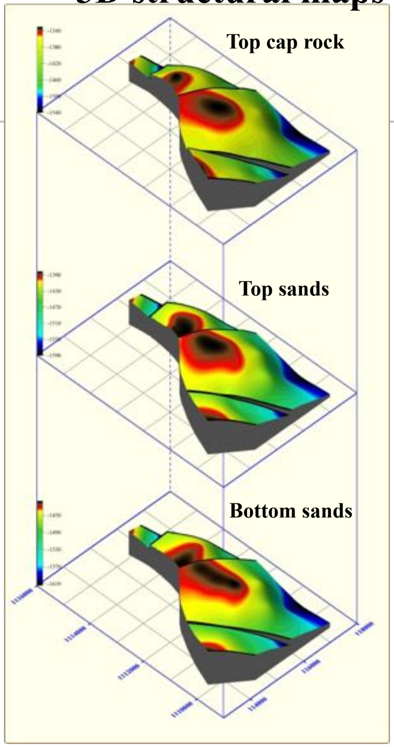
CO_2QUEST

HELETZ SITE - STRUCTURAL MODEL

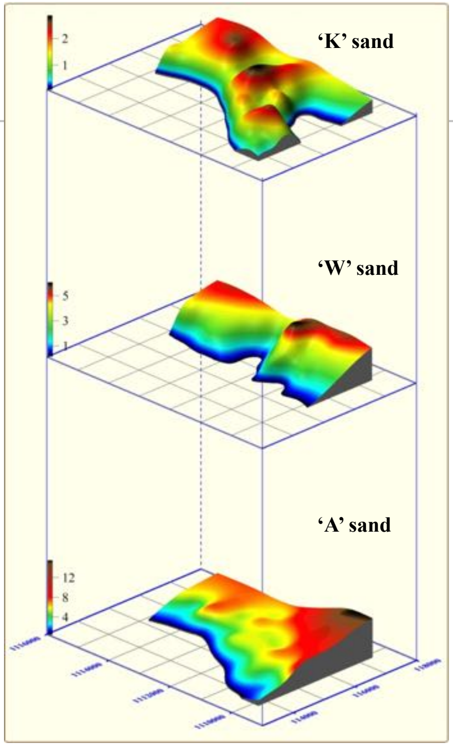


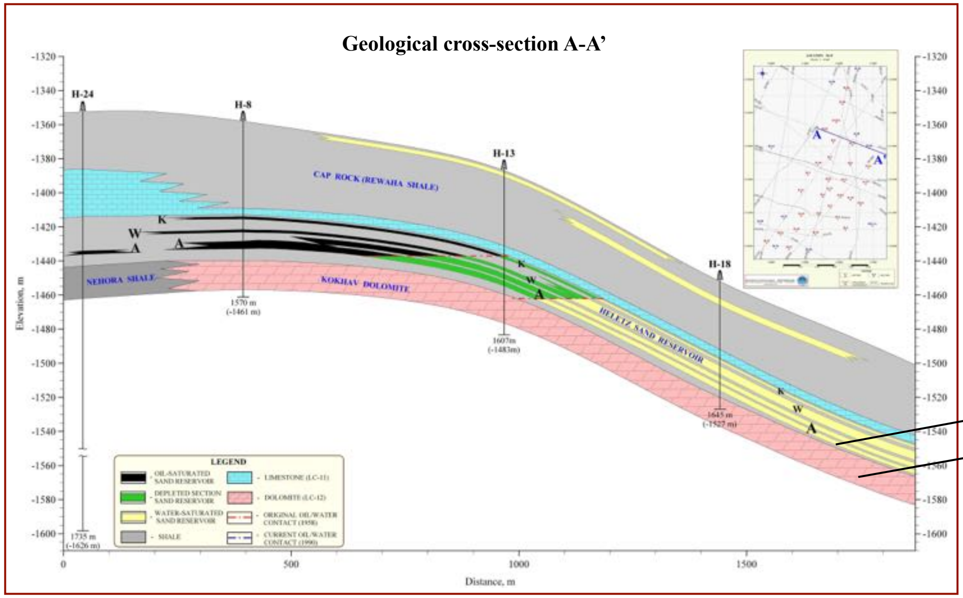


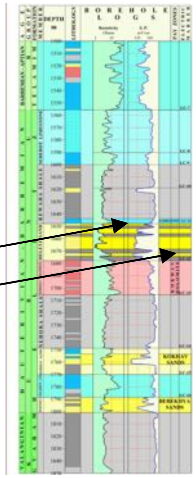
3D structural maps



3D isopach maps







Niemi, A. et al (2016) Heletz experimental site overview, characterization and data analysis for CO2 injection and geological storage *<u>Int. J. of Greenhouse Gas Control</u>. In press, available online.*

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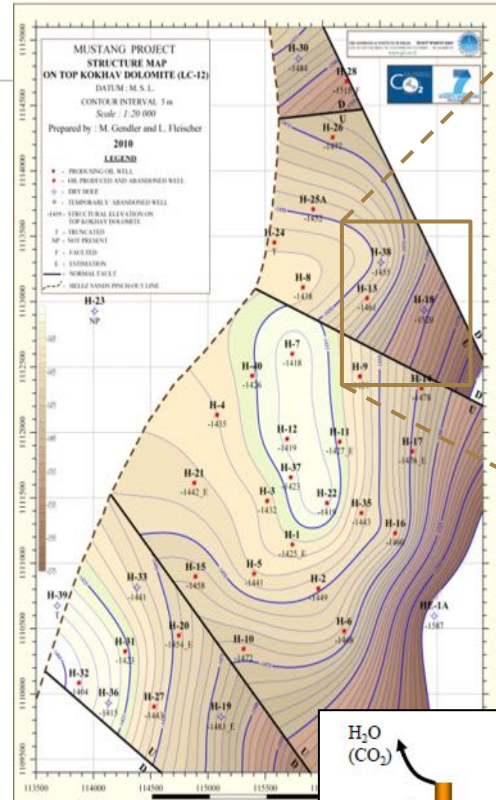
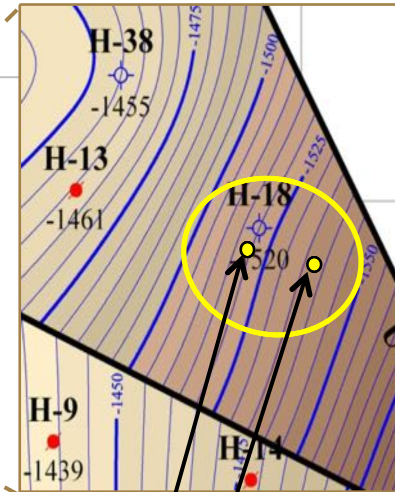
Site setup for the experiments

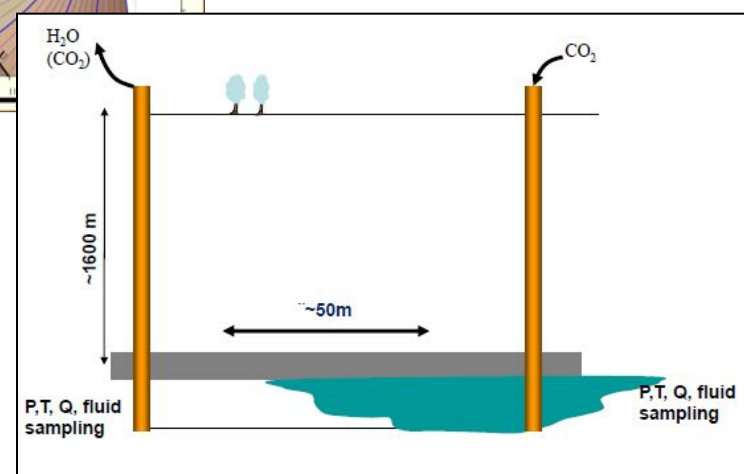
Location of monitoring well

Injection well





wells for field experiments



Well instrumentation

fluid injection/withdrawal, P/T sensors,

U-tube fluid sampling, optical fibre

Injection system



Site Characterization- structural model

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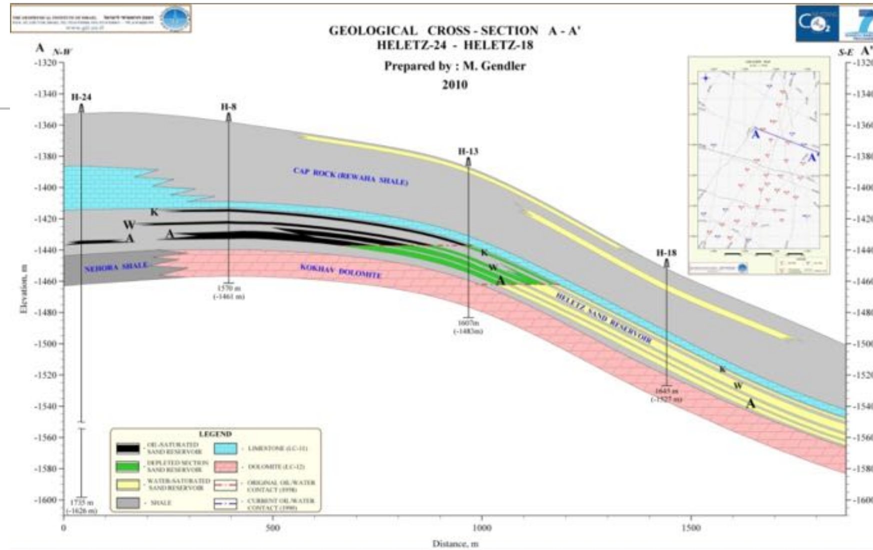
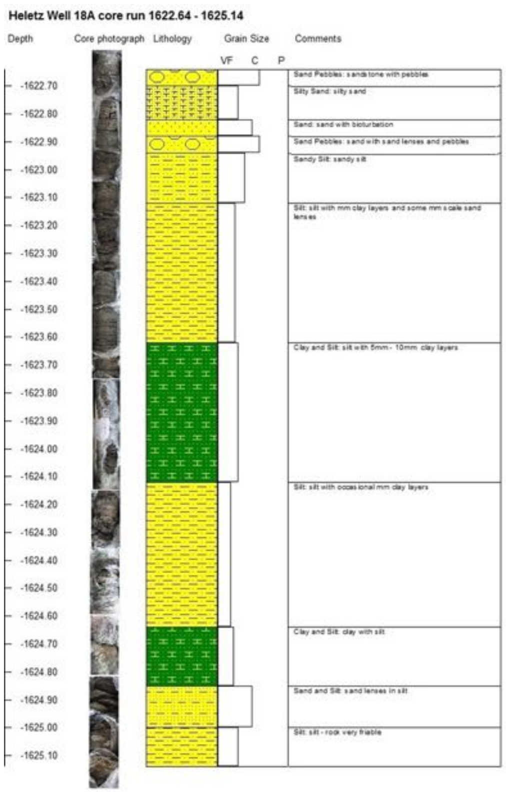
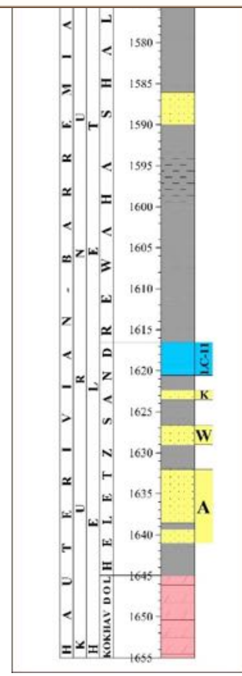
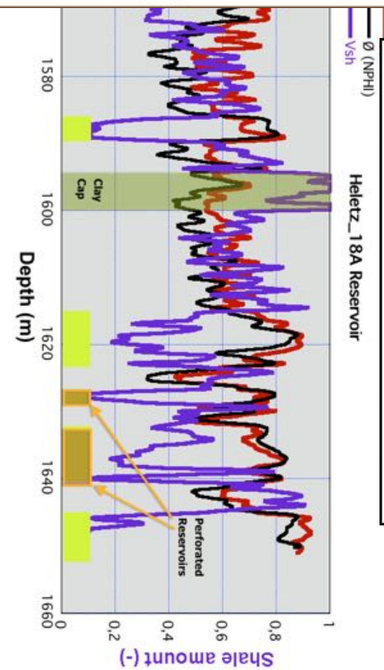
Data from old oil wells for the entire region gave a good basis, locally refined based on data from the new wells



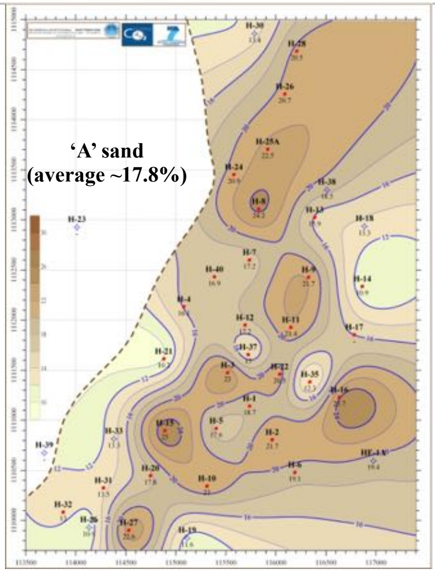


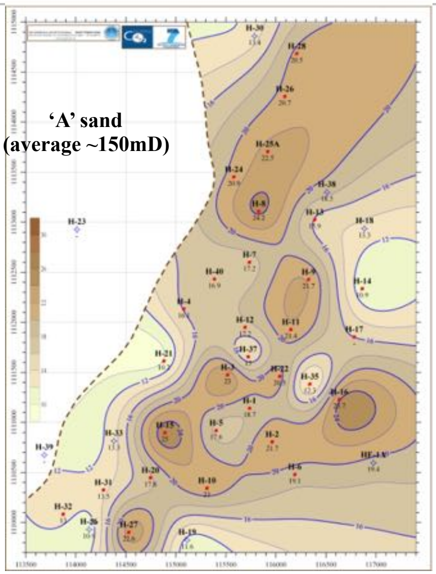


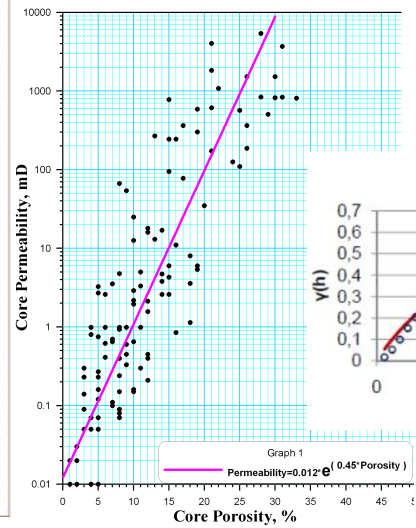


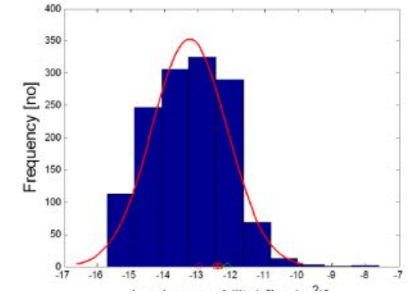
Niemi, A. et al (2016) *Int. J. of Greenhouse Gas Control*. In press, available online

Site Characterization- conductivity and porosity









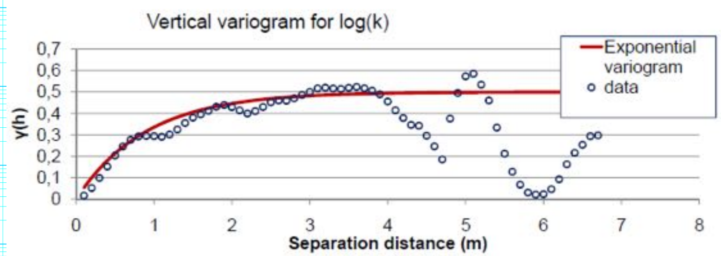
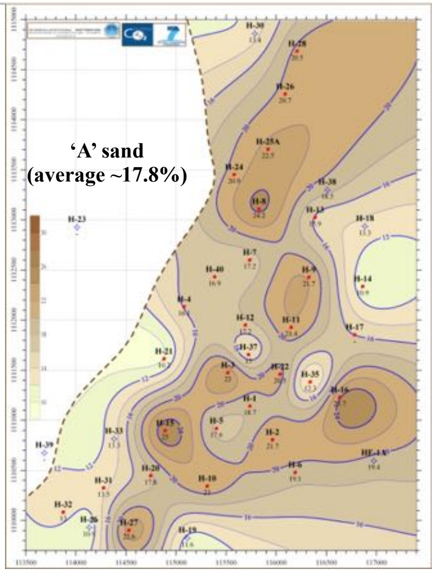


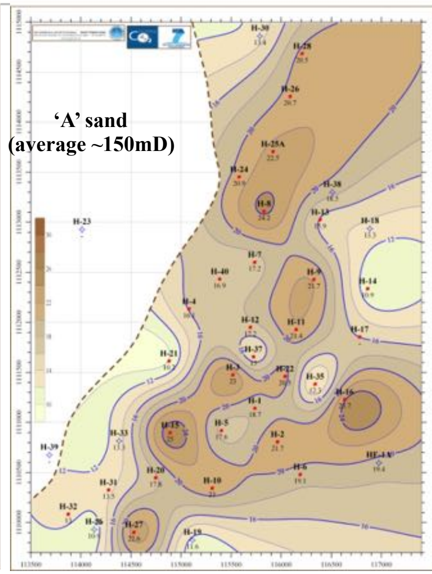
Table 10: Statistical data for Heletz sand layer permeabilities

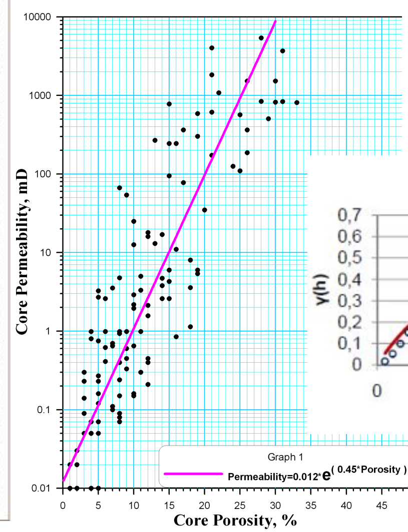
Parameter	Values	Layer	Data base
Data from entire Heletz formation			
μ, σ (m² and mD) (1 of model to log-converted data (2	-13.25, 1.1 (log m²) 2.1, 1.1 (log mD)	A	borehole porosity logs
-‘’-	-12.9, 1.1 (log(m²): 1.7, 1.1 (log mD)	W	-‘’-
Data from old wells in the vicinity of experimental area			
m, s (mD) from log-converted data (3	1.43, 0.725	Layers A,W, K	Borehole porosity logs, wells H-13, H-18 and H-38 only
Parameters for exponential model fitted to variogram data (4 a, nugget (C_0), sill (ω)	All layers 0.9,0, 0.526	-‘’-	-‘’-
Data from the new drilled wells			
Range of values (mD) (5 Range of values (log transformed, m²)	100-410 ~-13-12.4	Layer A	Core samples, only tests with in-situ P/T conditions included
Horizontal/ Vertical permeability (mD)	735/135	Layers A, W	In-situ well test, provides an ‘upscaled’ value for the entire layer

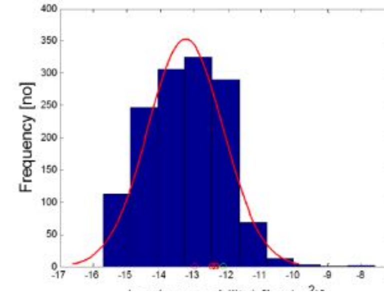
Niemi, A. et al (2016) Int. J. of Greenhouse Gas Control. In press, available online

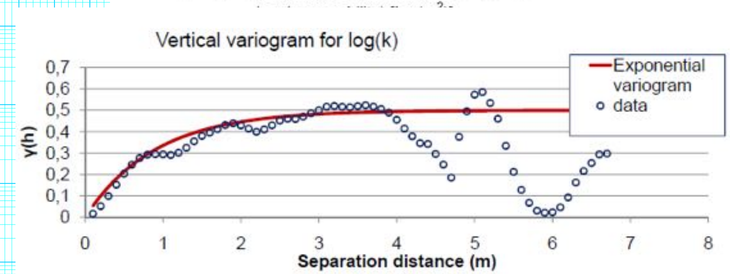
Site Characterization- conductivity and porosity











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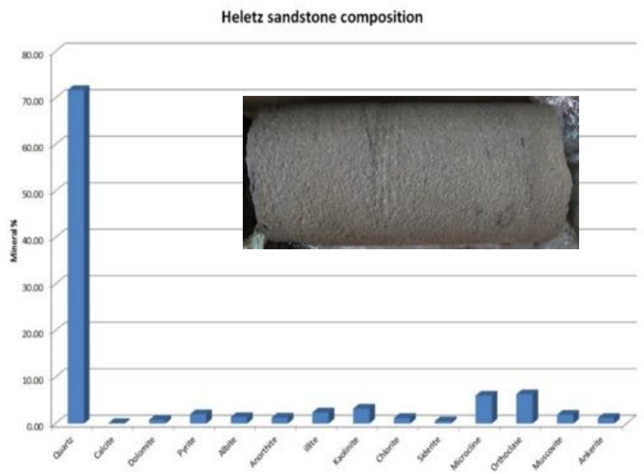
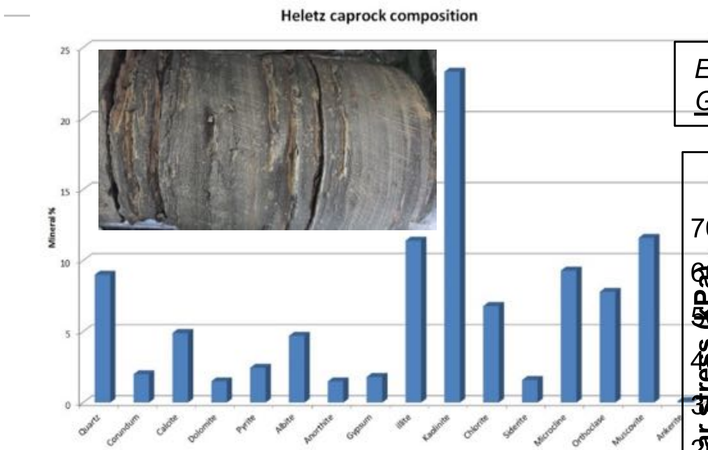
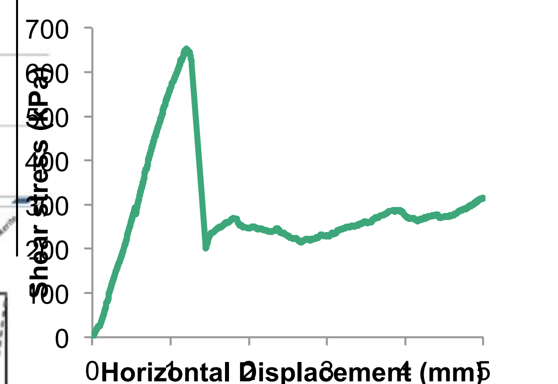
Niemi, A. et al (2016) Int. J. of Greenhouse Gas Control. In press, available online

Site Characterization- selected lab results

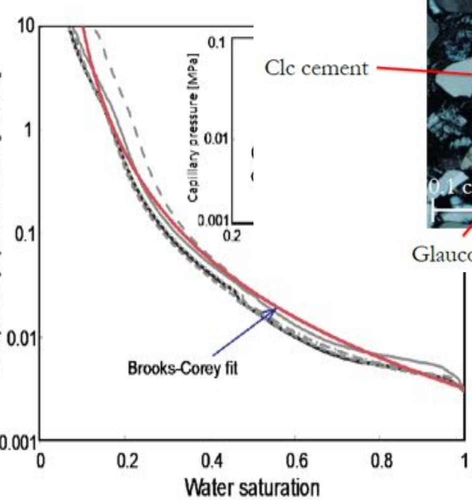


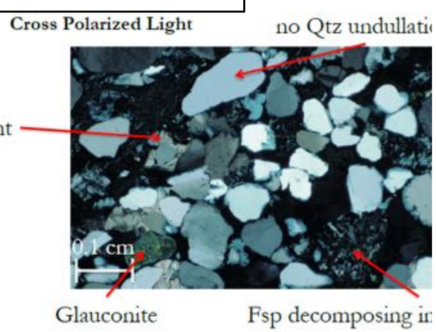


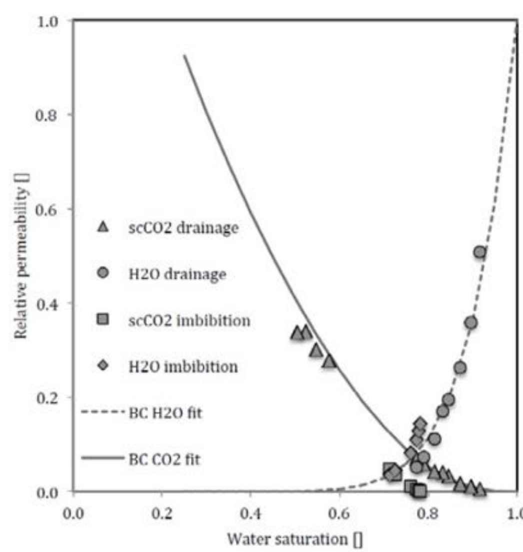
Elhmai et al (2016) Int. J. of Greenhouse Gas Control. In press, available online



Edlmann. et al (2016) Int. J. of Greenhouse Gas Control. In press, available online







Hingerl. et al (2016) Int. J. of Greenhouse Gas Control. In press, available online

Changes to rock properties when in contact with CO2

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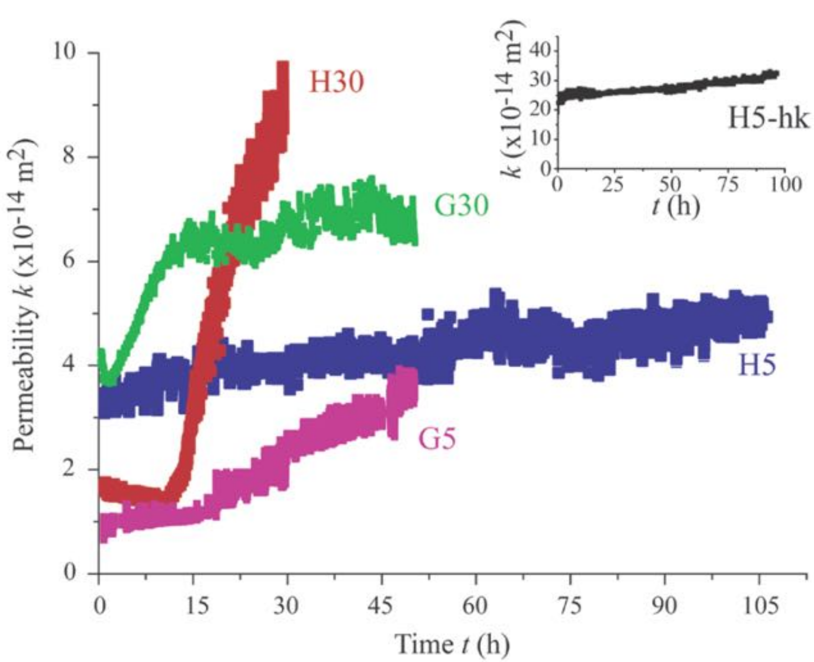
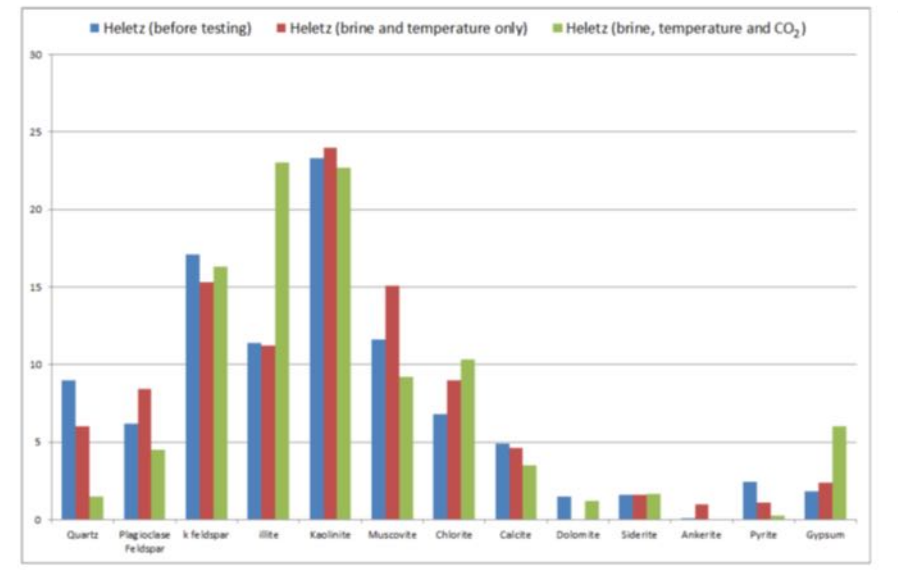


	Q (ml/min)	Brine
H5-hk	0,05	Heletz Brine (H-Type)
H5	0,05	Heletz Brine (H-Type)
H30	0,30	Heletz Brine (H-Type)
G30	0,30	Heletz Brine eq, Gypsum (G-Type)
G5	0,05	Heletz Brine eq, Gypsum (G-Type)

Reservoir permeability change when exposed to brine/CO2

Luguot et al (2016) <u>Int. J. of Greenhouse Gas Control</u>. In press, available online



Caprock mineralogy before and after exposure to brine/CO2

Edlmann. et al (2016) <u>Int. J. of Greenhouse Gas Control</u>. In press, available online

Site characterization and site properties - summary

- A summary of the characterization work is publisehd in a Mustang/Heletz ***Special Edition of International Journal of Greenhouse Gas Control*** Niemi, Gouze, Bensabat (eds.); 2016 (in Press, available online) ***Characterization of formation properties for geological storage of CO_2 – Experiences from the Heletz CO_2 injection site and other example sites from the EU FP7 project MUSTANG***

- ***Overview article*** summarizing the site properties is given in

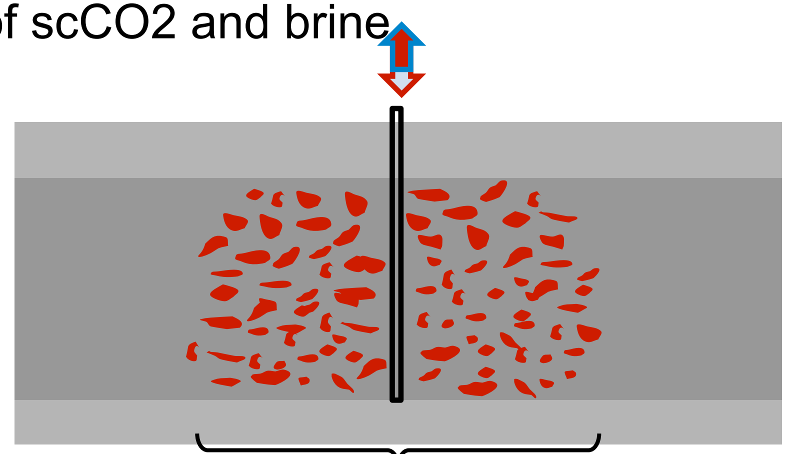
Niemi, A. Bensabat, J, Shtivelman, V, Edlmann, K, Gouze, P., Luquot, L., Hingerl,F, Benson, S.M., Pezard, P.A, Rasmusson, K., Liang,T., Fagerlund, F., Gendler, M., Goldberg,I, Tatomir,A., Lange, T., Sauter, M., and Freifeld, B. (2016) ***Heletz experimental site overview, characterization and data analysis for CO2 injection and geological storage*** *Int. J. of Greenhouse Gas Control*. In press.
http://dx.doi.org/10.1016/j.ijggc.2015.12.030

Special Edition of International Journal of Greenhouse Gas Control (Niemi, Gouze, Bensabat (eds.); 2016)

Pezard et al.	Time-lapse downhole electrical resistivity monitoring of subsurface CO2 storage at the Maguelone shallow experimental site (Languedoc, France).
McDermott et al.	Experimental investigation and hybrid numerical analytical hydraulic mechanical simulation of supercritical CO2 flowing through a natural fracture in caprock.
Elhami et al.	Physical- and geomechanical properties of a drill core sample from 1.6 km depth at the Heletz site in Israel: some implications for reservoir rock and CO2 storage
Edlmann et al.	Mineralogical investigation of the caprock of the field scale experimental CO2 injection site, Heletz, and its reactivity to scCO2 injection
Tatomir et al.	An integrated core-based analysis for the characterization of flow, transport and mineralogical parameters of the Heletz pilot CO2 storage site reservoir
Soler-Sagarra et al.	Simulation of chemical reaction localization using a multi-porosity reactive transport approach
Hingerl et al.	Characterization of Heterogeneity in the Heletz Sandstone from Core to Pore Scale and Quantification of its Impact on Multi-Phase Flow
Niemi et al.	Heletz experimental site overview, characterization and data analysis for CO2 injection and geological storage
Abdoulghafouri et al.	Characterization and modeling of the alteration of fractured class-G Portland cement flowed by CO2-rich brine
Davila et al.	Efficiency of magnesium hydroxide as engineering seal in the geological sequestration of CO2
Davila et al.	Interaction between a fractured marl caprock and CO2-rich sulfate solution under supercritical CO2 conditions
Zhang et al.	A feasibility and efficiency study of seismic waveform inversion for time-lapse monitoring of onshore CO2 geological storage sites using reflection seismic acquisition geometries
Luquot et al.	CO2-rich brine percolation experiments through Heletz reservoir rock samples (Israel): Role of the flow rate and brine composition

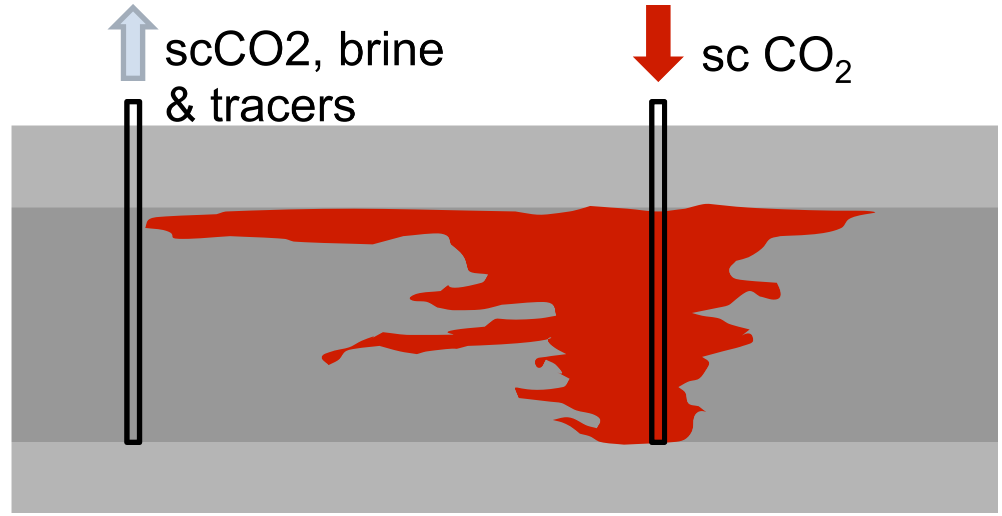
Testing program (1/4)
Determine in-situ residual and dissolution trapping parameters

1. push-pull



- Reduced influence of formation heterogeneity

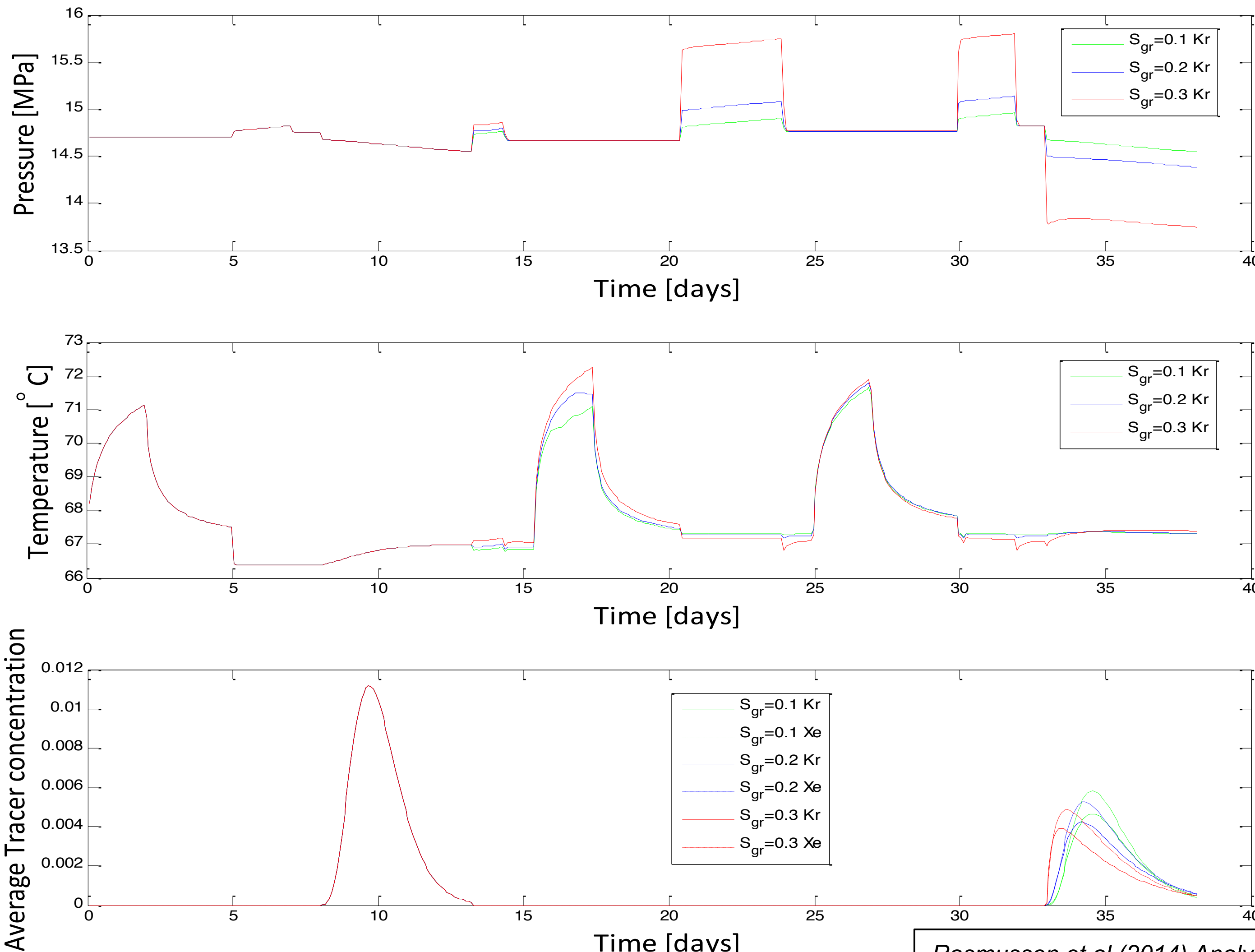
2. dipole



- Heterogeneity affects migration and trapping

Hydraulic tests	⇨	residual trapping
Thermal tests	⇨	residual trapping
Tracer tests	⇨	residual & dissolution trapping, (& interfacial area)

Push-pull test: expected pressure, temperature and tracer responses to determine residual trapping of CO2



- P, T & tracer responses depend on the amount of residually trapped CO2 (S_{gr})

Rasmusson et al (2014) Analysis of alternative designs for push –pull …Int. J. of Greenhouse Gas Control. Vol 27, pp 155-168

Testing program (2/4)
Determine in-situ residual and dissolution trapping parameters

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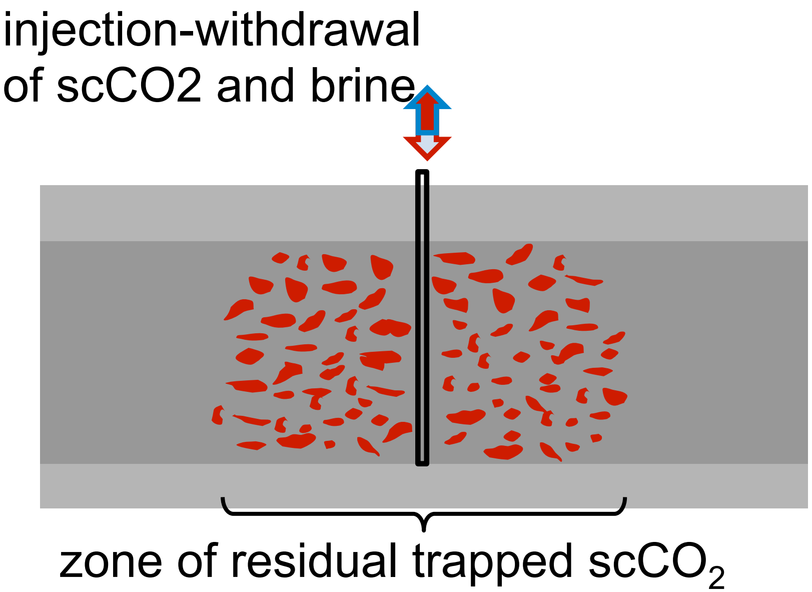
1. push-pull



- ❑ Reduced influence of formation heterogeneity

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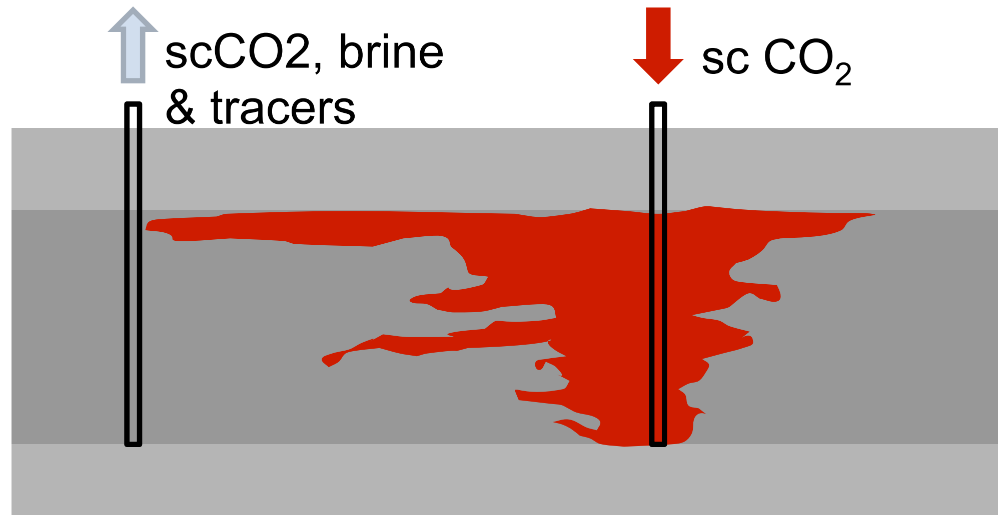
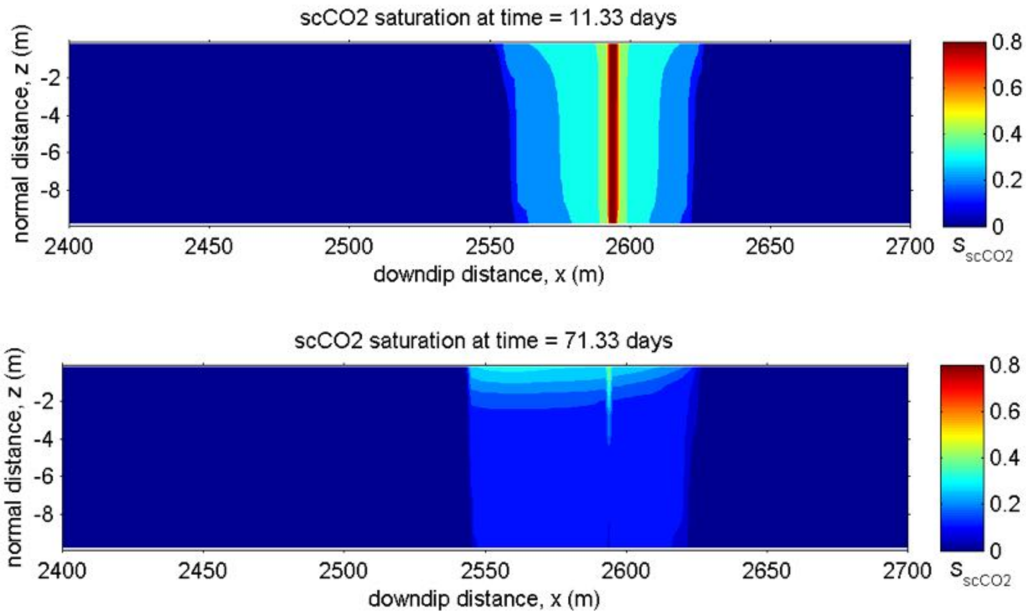


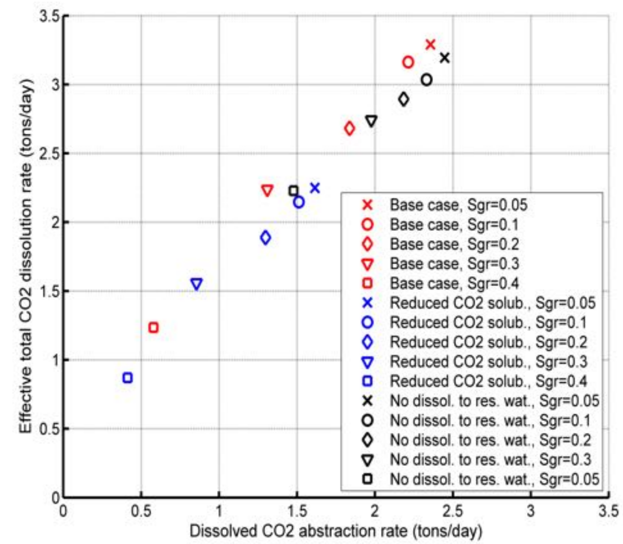
- ❑ Heterogeneity affects migration and trapping

MUSTANG CO_2

- ❑ Hydraulic tests → residual trapping
- ❑ Thermal tests → residual trapping
- ❑ Tracer tests → residual & dissolution trapping, (& interfacial area)

Testing program (2/4)
Determine in-situ dissolution trapping parameters



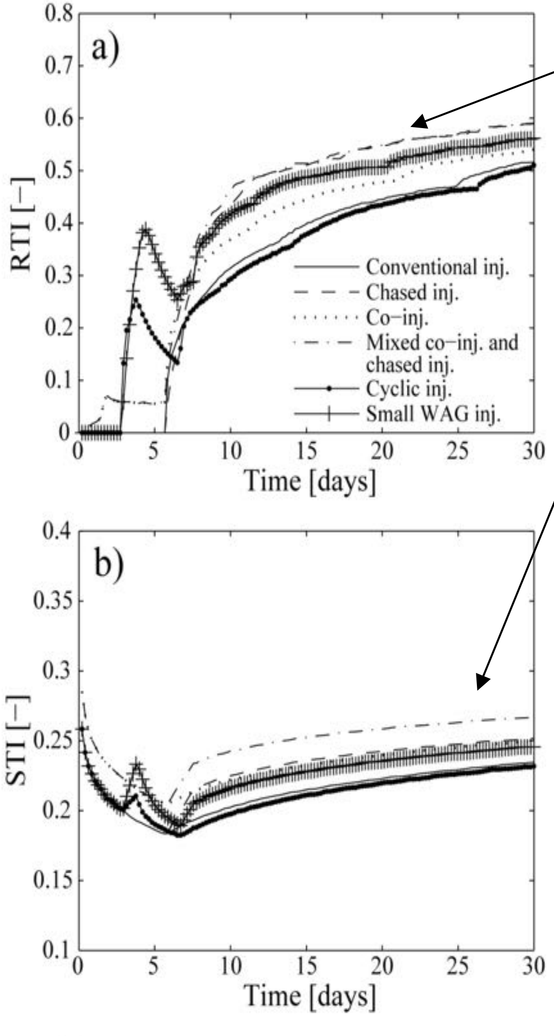


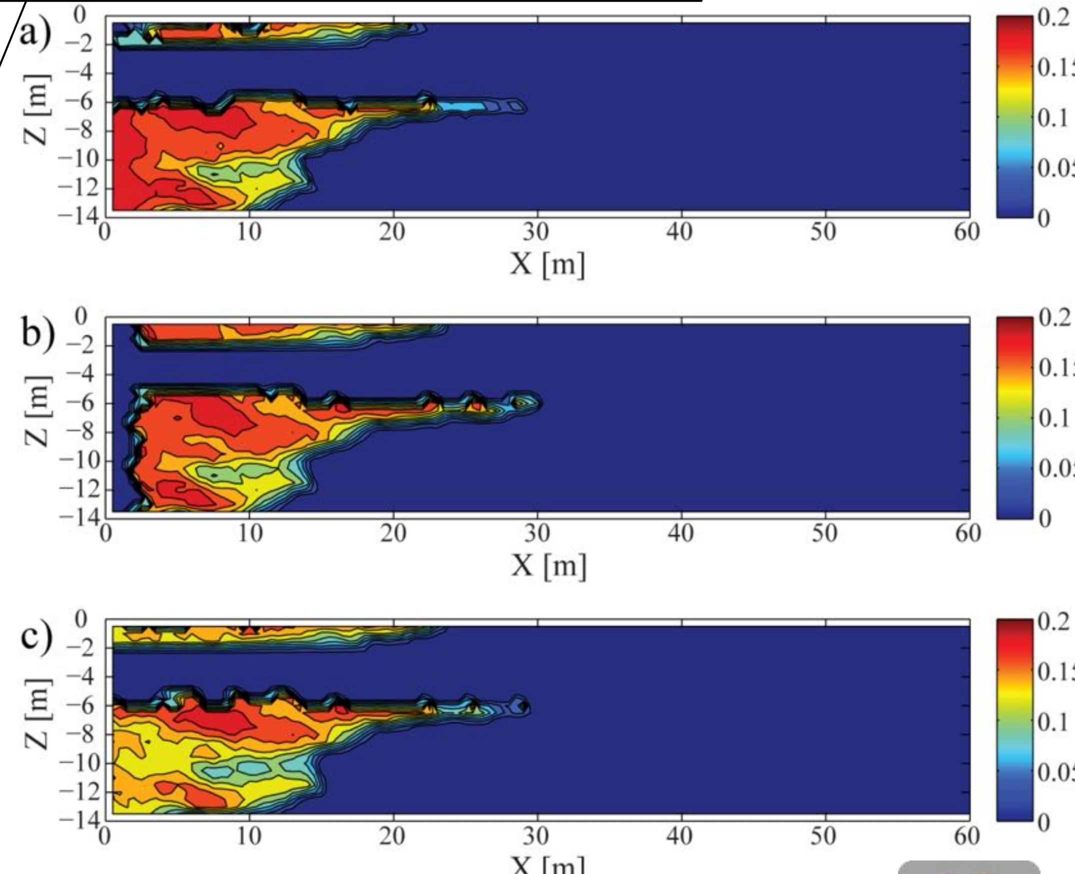
- ❑ **During stable flow-field conditions, the abstracted dissolved CO2 directly reflects the total rate of CO2 dissolution**

Fagerlund et al (2013) Design of two-well field test …Int. J. of Greenhouse Gas Control. 19 (2013) 642–651

Testing program (3/4)
Determine enhanced trapping when altering CO2 and water injection schemes

Injection schemes where water is added improve the trapping





Rasmusson et al. (2016) "A simulation study of the effect of trapping model, geological heterogeneity and injection strategies on CO2 trapping *Int. J. of Greenhouse Gas Control.* Accept. with minor rev.

Testing program (4/4)
Effect of impurity gases is CO2 stream

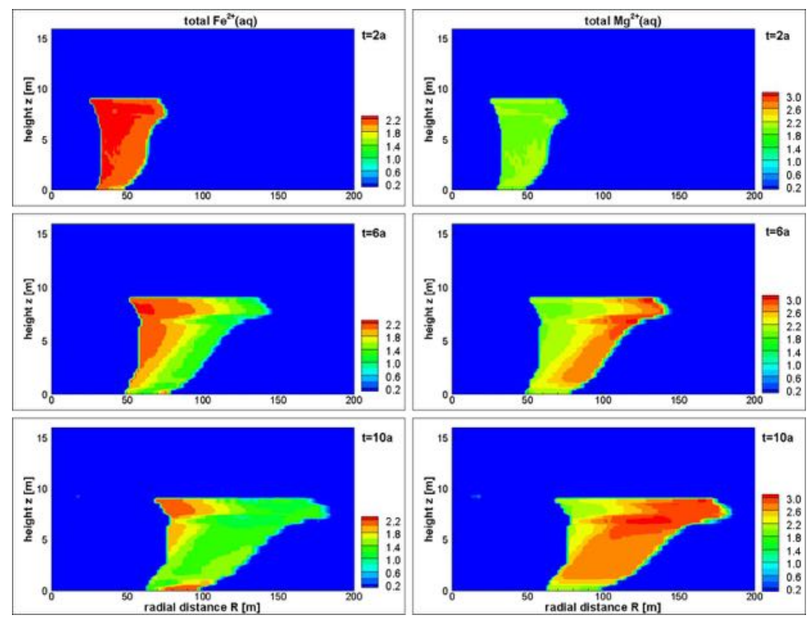
Use SO_2 and N_2 as impurity gases

- SO2 effects will be chemical,

N2 physical

- For comparison, laboratory experiments

on rock cores are being carried out by CanMet, Canada

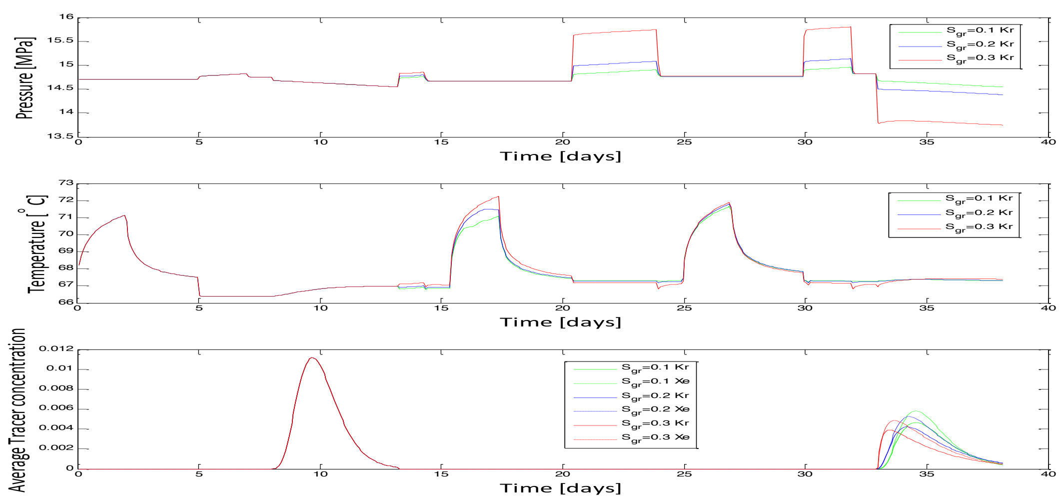


Wolff et al. (2016) Manuscript

CO_2QUEST

Status - where are we now

- Sequece 1/4 was started in Nov 2015
- U-tube sampling system could not maintain the formation pressure (serious leaks in the tubing) -> the high pressure fluid samples would not have been representative -> replacement of the tubing required
- New U-tubes are now being constructed and installed in end of May, after which the experiments will be resumed



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Especially acknowledged co-workers

Jac Bensabat, EWRE
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Lennart Wolff, BGR
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Linda Luguot, CSIC
Philippe Gouze, CNRS
Philippe Pezard, CNRS
Katriona Edlmann, UEDIN
Fritjof Fagerlund, Uppsala
Kristina Rasmusson, Uppsala
Sally Benson, Stanford University
Ferdinand Hingerl, Stanford University
Maria Ask, LTH
Andrew Wigston, CanMet, Canada

MUSTANG CO_2

TRUST C_2

CO_2QUEST

and all MUSTANG, TRUST and CO2QUEST partners

Thank you for your attention!

CO_2QUEST