Geophysics, Geomechanics and Geochemistry of CO_2 Geological Store

Marcelo Ketzer

CEPAC – Centre of Excellence in Research and Innovation in Petroleum, Mineral Resources, and Carbon Storage (www.pucrs.br/cepac)

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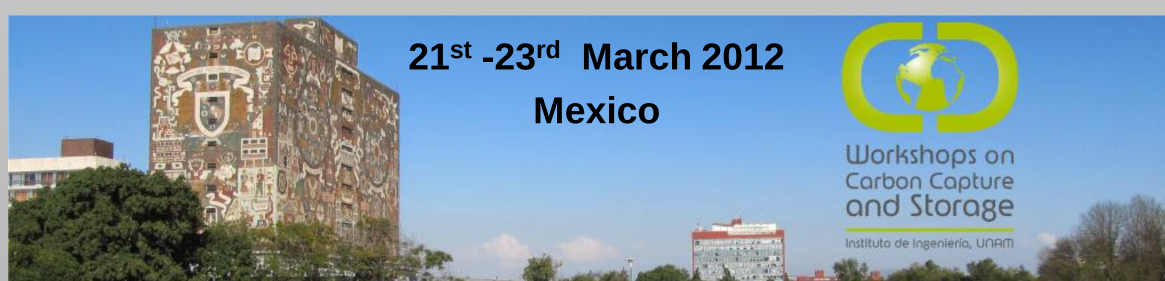

Agenda

1. Introduction.
2. Types of reservoirs for CO_2 storage.
3. The fate of stored CO_2: trapping mechanisms.
4. Applied geophysics: site selection and monitoring.
5. Applied geomechanics: site selection (and monitoring).
6. Applied geochemistry: site selection and monitoring.

    5.1 Changes in the geochemical system,

    5.2 Forms of investigations (experiments and modelling),

    5.3 Rock integrity (mineral dissolution and precipitation):

    A case study in Brazil.

7. Final remarks.

AD VERVM DVCIT

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Creation of CEPAC / October 2007
(Joint initiative PUCRS-PETROBRAS)

Center of Excellence in Research and Innovation in Petroleum, Mineral Resources, and Carbon Storage.

BR PETROBRAS

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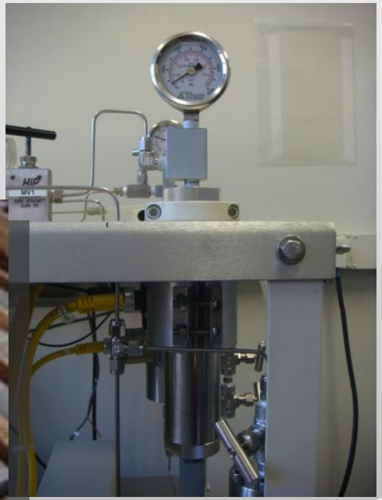
AREAS OF RESEARCH AND DEVELOPMENT

CEPAC

CO_2
Geological Storage

Exploration and Production of
Gas Hydrates in the continental margin

Geochemistry of giant pre-salt
reservoirs (CCS)



Reservoir characterization
(E&P)

Other projects (cooperation):
Palaeogeography and Palaeoclimatology applied to petroleum exploration.
Genomic Stratigraphy.
Non-destructive imaging of sedimentological experiments.
CO_2 capture with ionic liquids.

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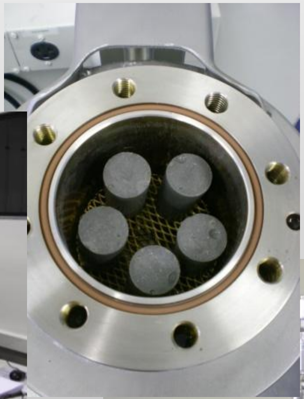
Infrastructure

Building with 1100 m^2 (3800 m^2 in 2013)

in the Technological Park of PUCRS: TECNOPUC

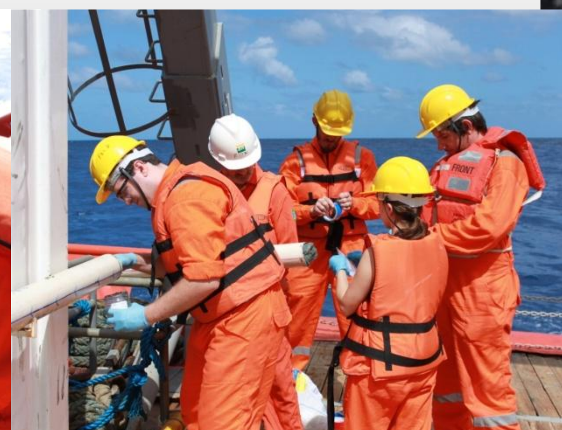
Loboratories

- High-pressure CO_2 lab
- Coal characterization lab
- Reservoir characterization lab
- Well bore integrity lab
- Numerical modelling lab
- X-ray difractometry lab
- Isotopic geochemistry lab
- Water analyses lab
- Gas analyses lab
- Gas hydrate lab

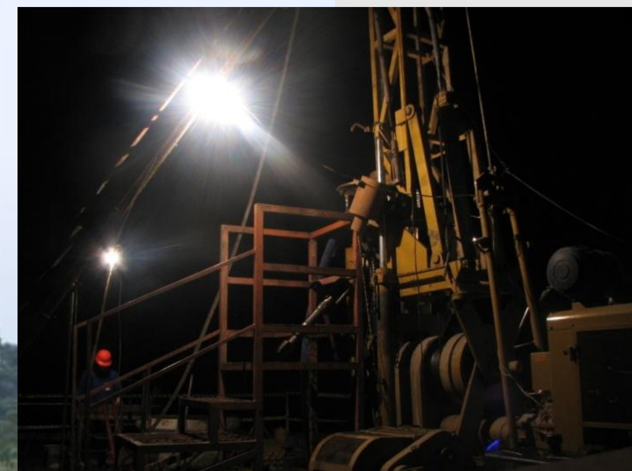


Human Resources

- 10 Professors at PUCRS
- 14 researchers
- 18 graduate students
- 14 undergraduate students



Porto Batista CCS Pilot Site (coal)



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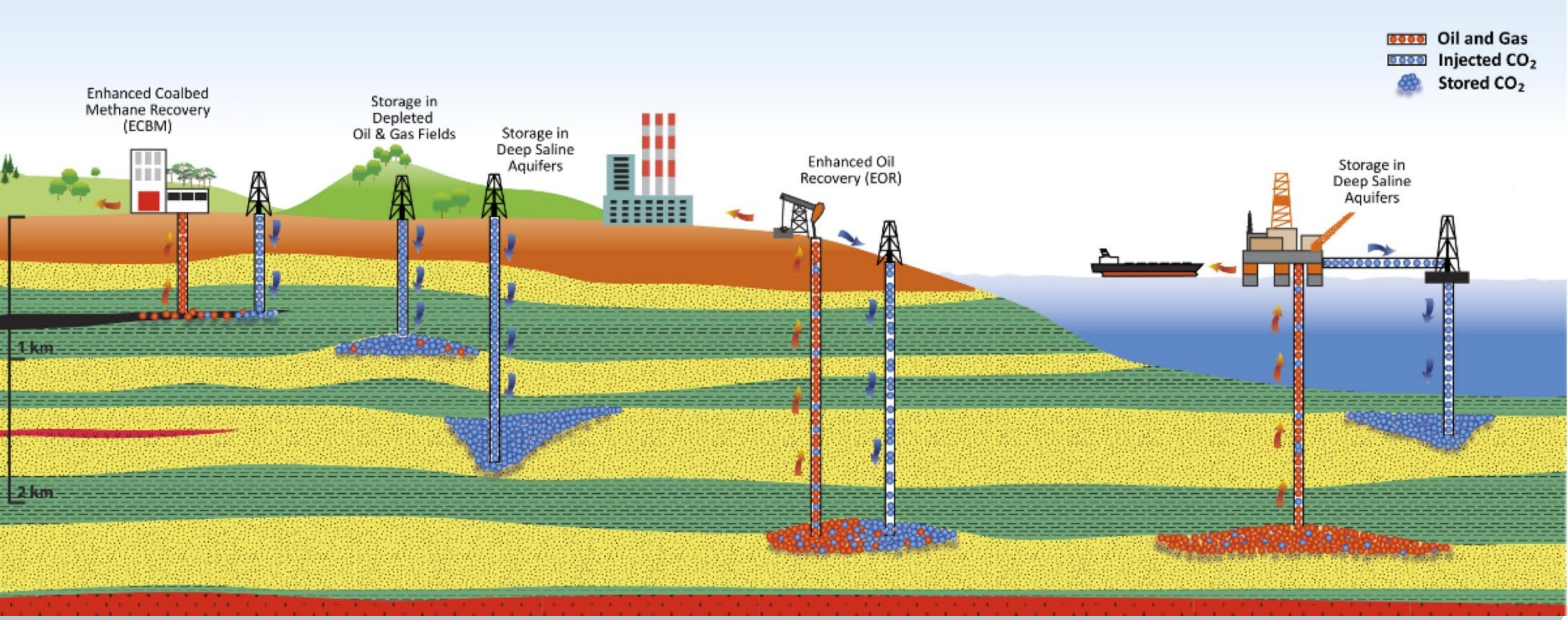
Porto Batista CCS Pilot Site (coal)

CONEGAS Project (gas hydrate exploration)

Types of geological reservoirs for CO_2 storage: petroleum fields, saline aquifers, and coal seam.



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The fate of stored CO_2 storage: Trapping mechanisms.

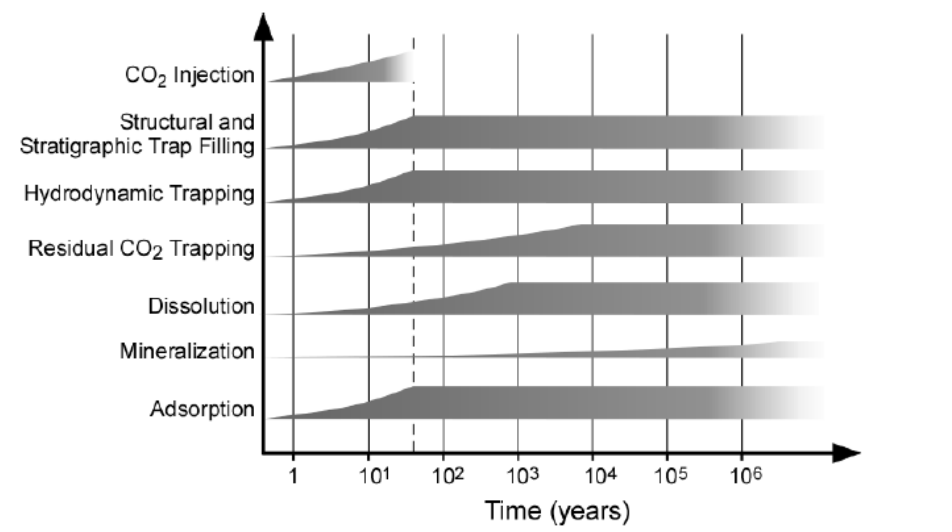
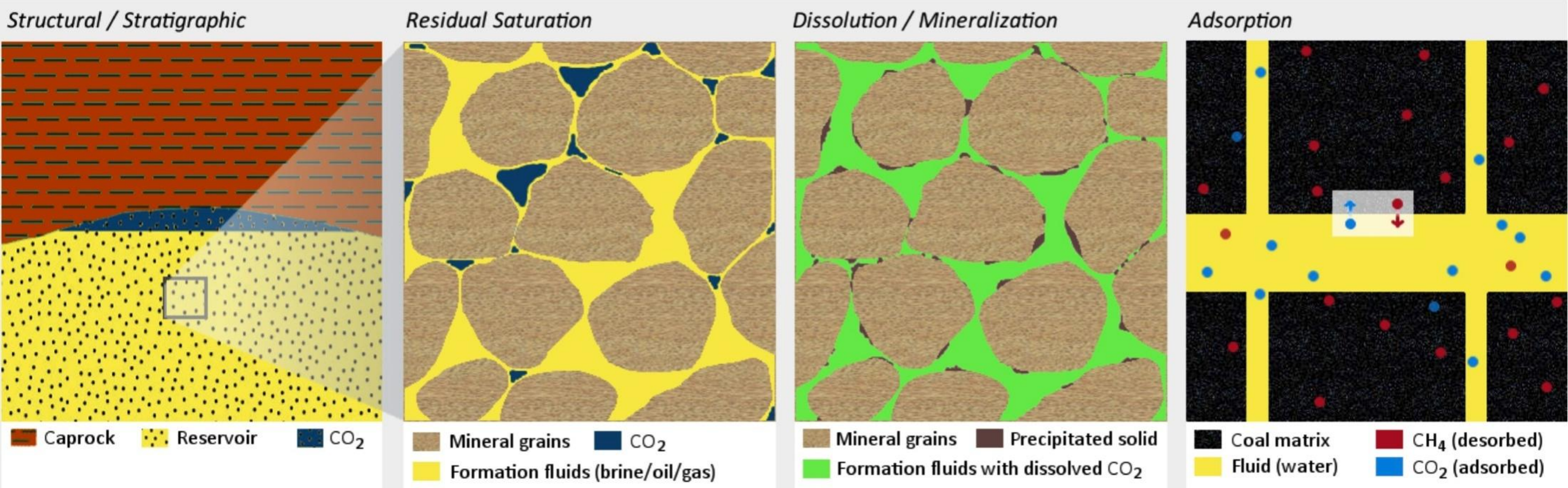
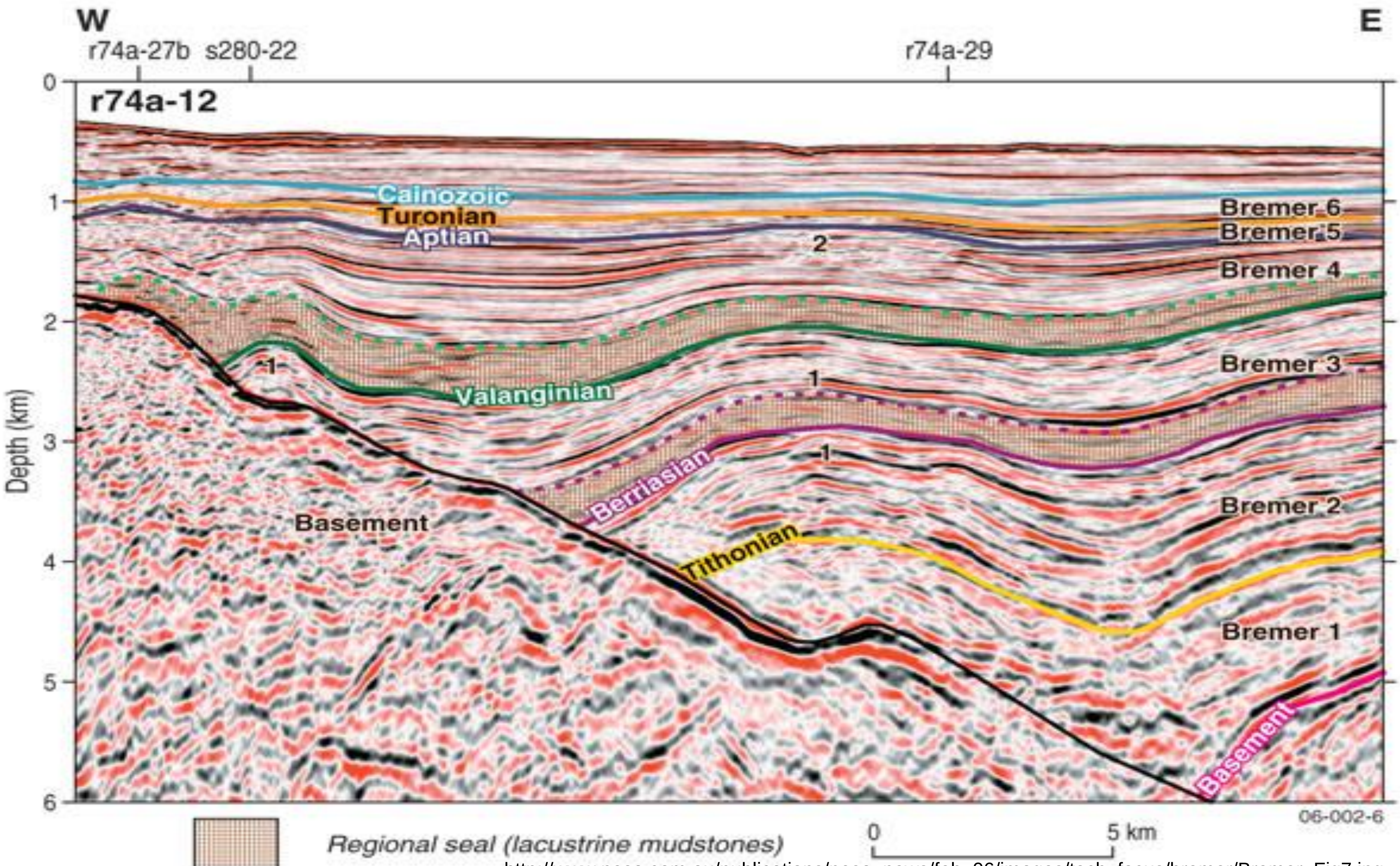


Figure 1. Operating time frame of various CO_2 geological-storage mechanisms (modified from IPCC, 2005).



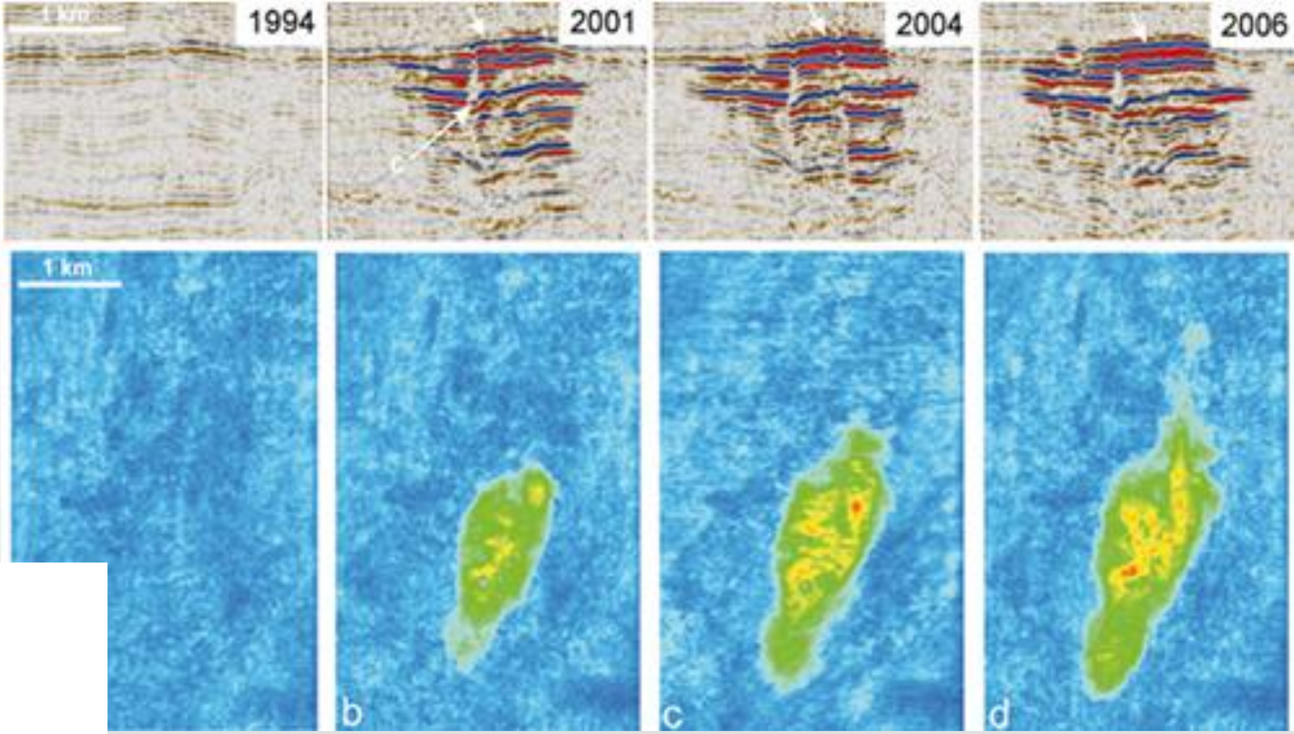
Applied geophysics: Site selection and monitoring.

- Seismic (depth and type of trap, volume, type and migration of fluids).
- Others: Well logs, electromagnetic survey, gravimetric survey, etc.

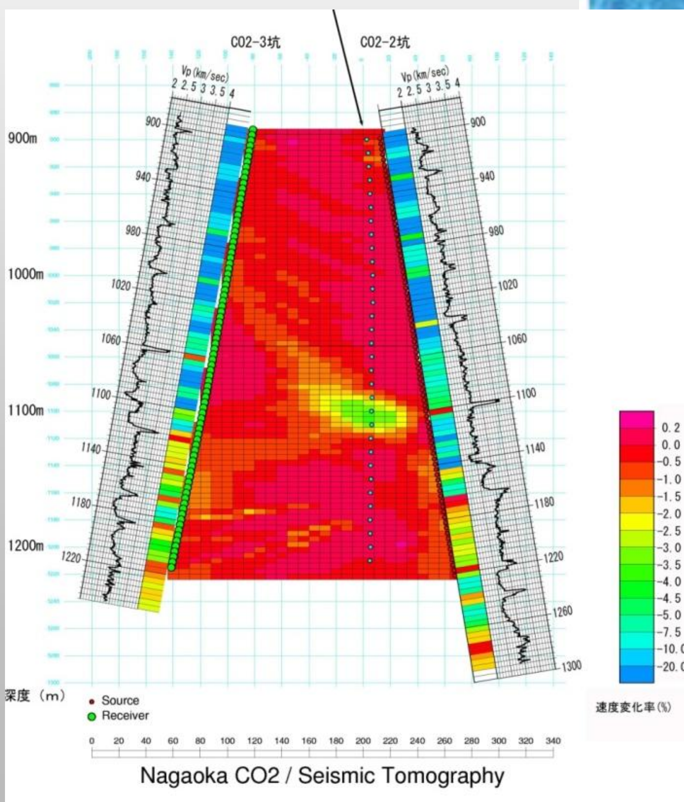


http://www.pesa.com.au/publications/pesa_news/feb_06/images/tech_focus/bremer/Bremer_Fig7.jpg

4D seismic monitoring (Sleipner Project, Norway)



http://noc.ac.uk/f/content/science-technology/marine-resources/carbon-capture-img3.png



www.rite.or.jp/English/lab/.../ccsws2007/6_xue.pdf

Cross-well seismic tomography (Nagaoka Project, Japan)

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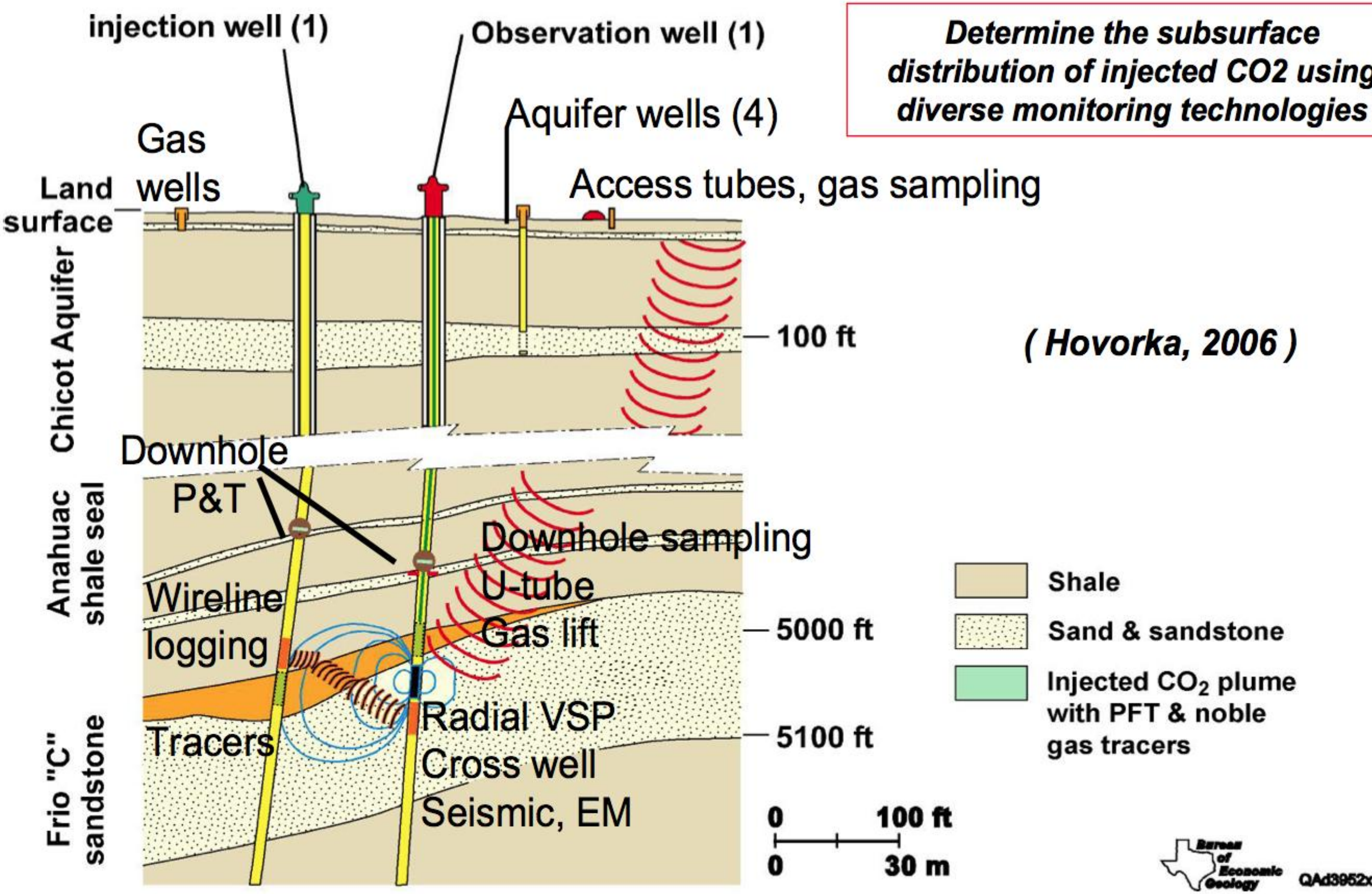
Monitoring at Frio Pilot

Determine the subsurface distribution of injected CO2 using diverse monitoring technologies

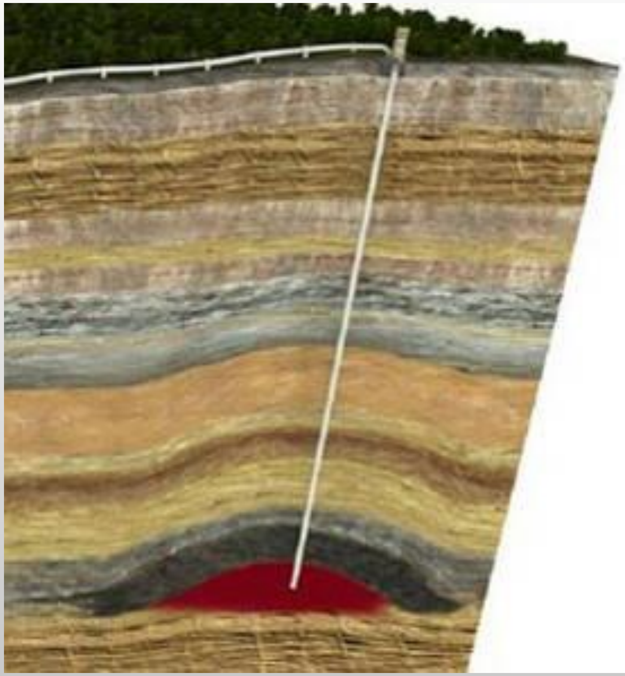
(Hovorka, 2006)



Applied geomechanics: Site selection (and monitoring).

- **Hydraulic fracturing threshold for reservoir and caprock (site selection).**
- **Pressure threshold for fault activity (site selection).**
- **Use of tiltmeters, microseismographs, etc (monitoring).**

http://www.geology.wisc.edu/courses/g112/Images/salv_faults.jpg



http://bellona.org/ccs/typo3temp/pics/b5712e213f.jpg

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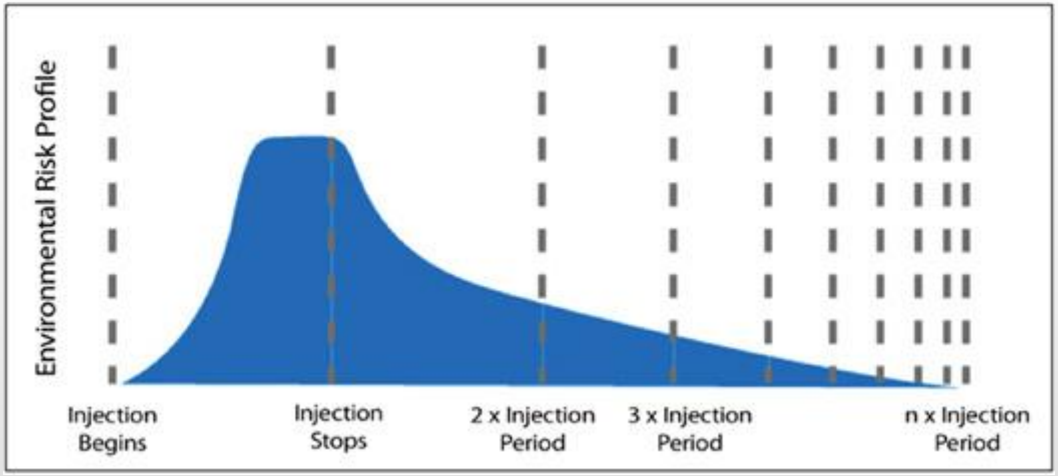
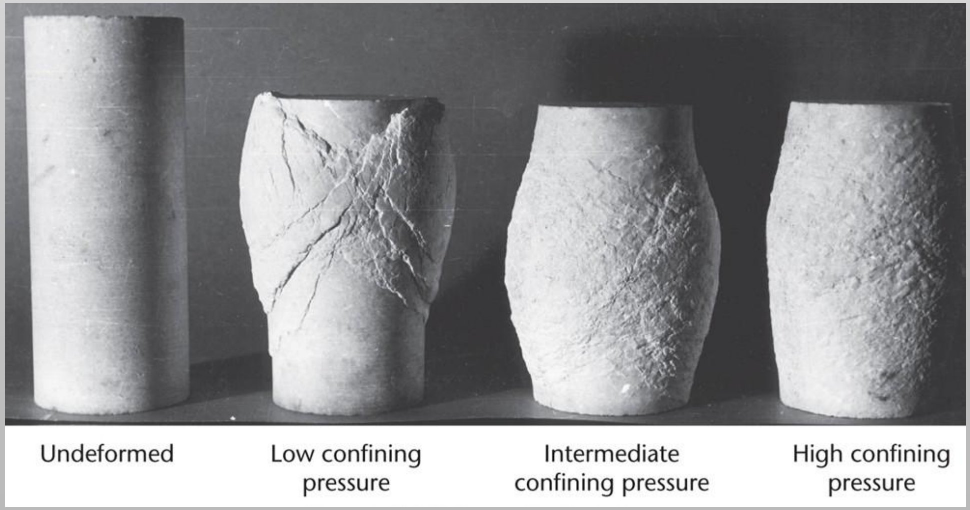
Applied geomechanics: Site selection (and monitoring).



http://www.netl.doe.gov/technologies/carbon_seq/corerd/images/simulation_1.jpg



http://geophysics.ou.edu/geol1114/notes/structure/confining%20pressure%20lab.jpg

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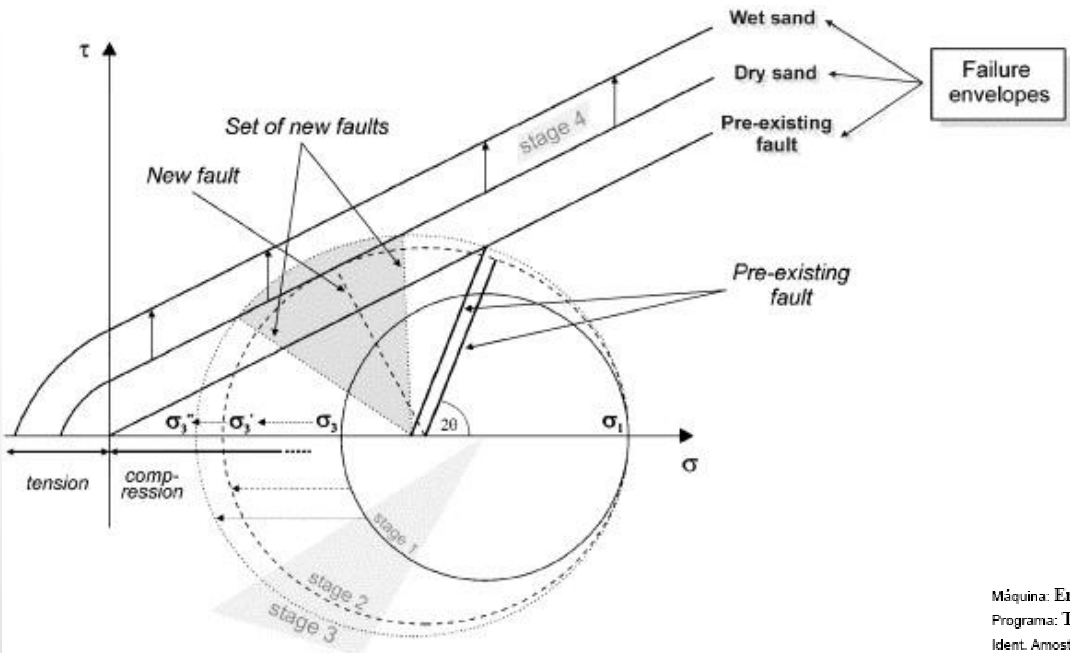


Windhoffer et al. (2005)

Mohr-diagram showing failure envelopes for a pre-existing fracture, and for wet and dry sand.

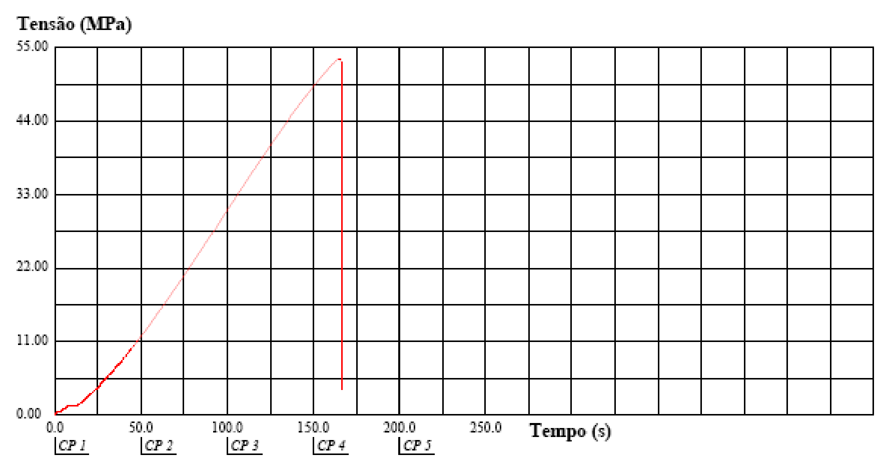
Relatório de Ensaio

Máquina: Emic PC200 Célula: Trd 29 Extensômetro: - Data: 17/12/2009 Hora: 16:47:07 Trabalho nº 0978

Programa: Tesc versão 1.13 Método de Ensaio: ROCHA

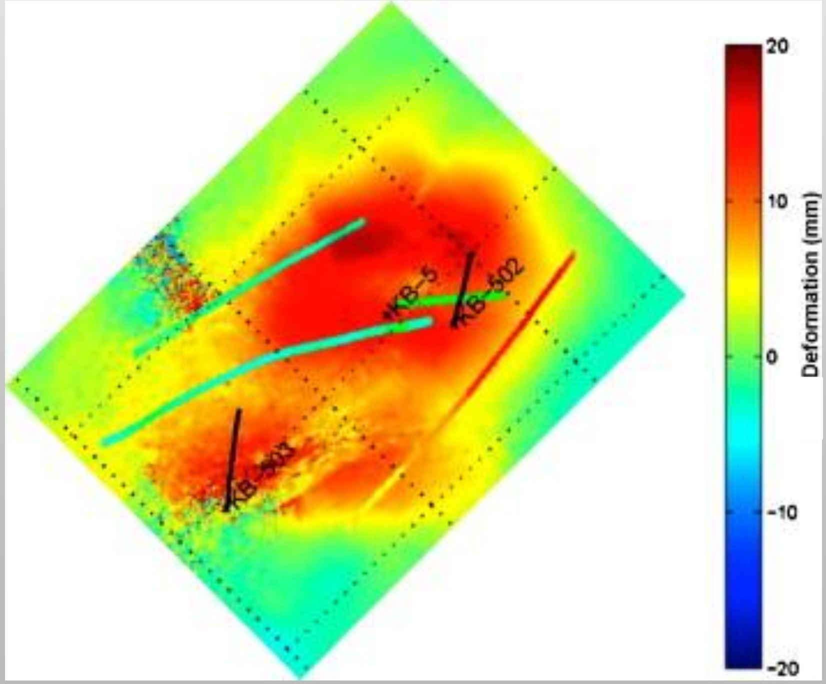
Ident. Amostra: >>> SELO MB CLARO:

Corpo de Prova	Área (cm2)	Força Máxima (kgf)	Tensão Máxima (MPa)
CP 1	38.5	20963	53.42
Número CPs	1	1	1
Média	38.48	20960	53.42
Mediana	38.48	20960	53.42
Desv.Padrão	*	*	*
Coef.Var.(%)	*	*	*
Mínimo	38.48	20960	53.42
Máximo	38.48	20960	53.42



Uniaxial/Triaxial rock experiments →

In Salah Project (Algeria)



Surface displacement observed by InSAR (Interferometric Synthetic Aperture Radar)

Morris et al. (2011)

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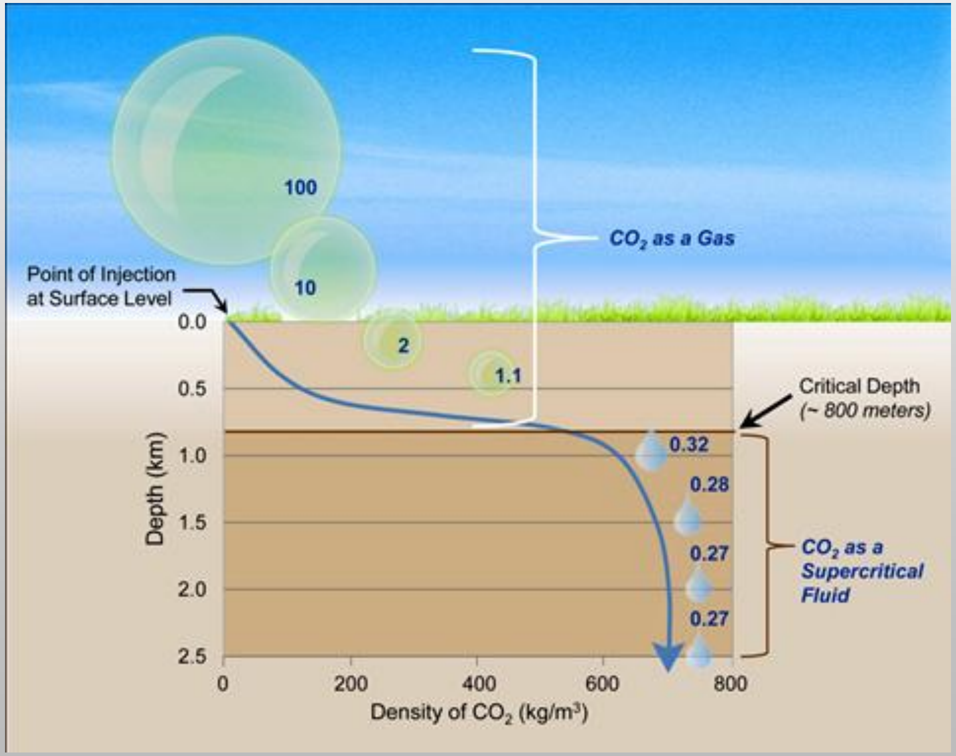
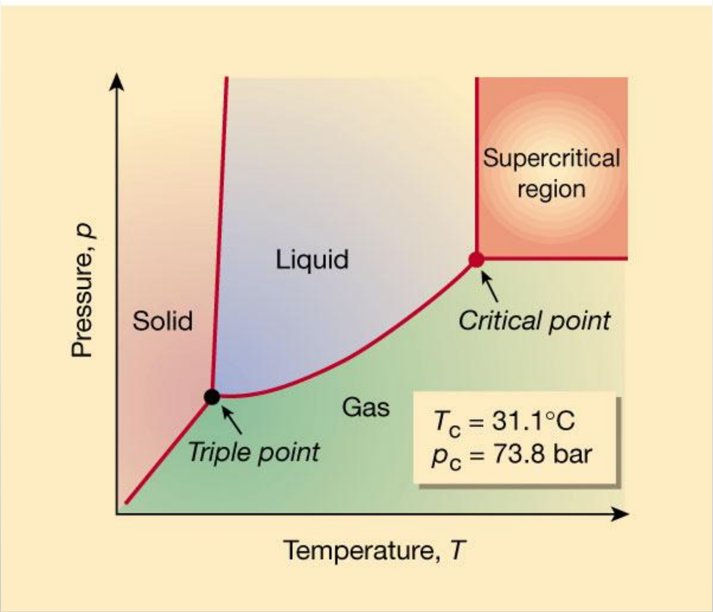
Applied Geochemistry:
changes in the geochemical system.

CO_2 as a supercritical fluid…



http://www.netl.doe.gov/technologies/carbon_seq/FAQs/images/capture_6.jpg



http://netsains.com/wp-content/uploads/2011/02/purba-co23.jpg

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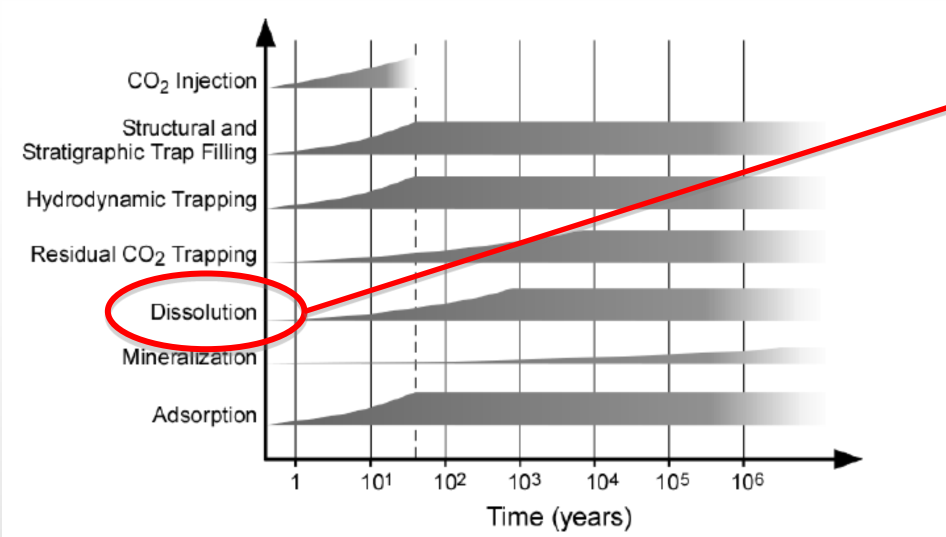
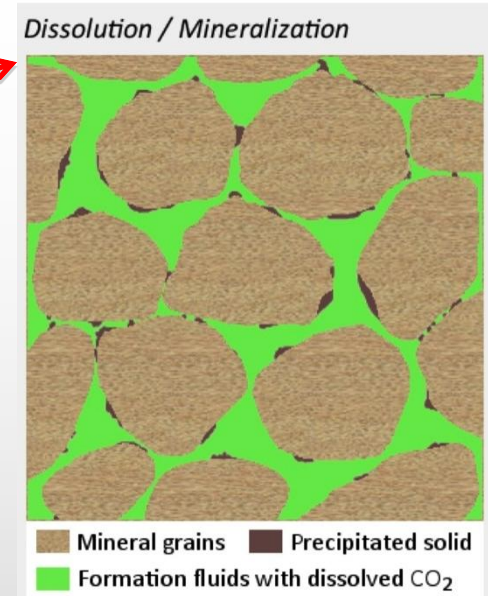


Figure 1. Operating time frame of various CO_2 geological-storage mechanisms (modified from IPCC, 2005).



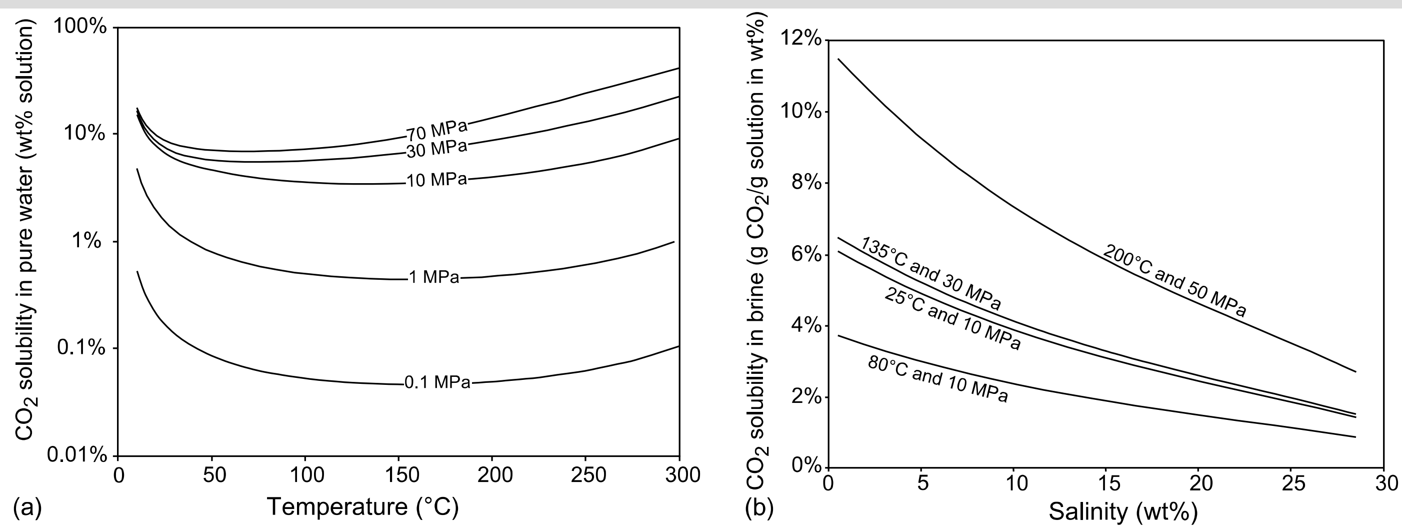


Fig. 1. Variation of CO_2 solubility in water: (a) with temperature and pressure; and (b) with salinity, for various conditions representative of sedimentary basins.

Bachu & Adams (2003)

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Acidification of the formation water…

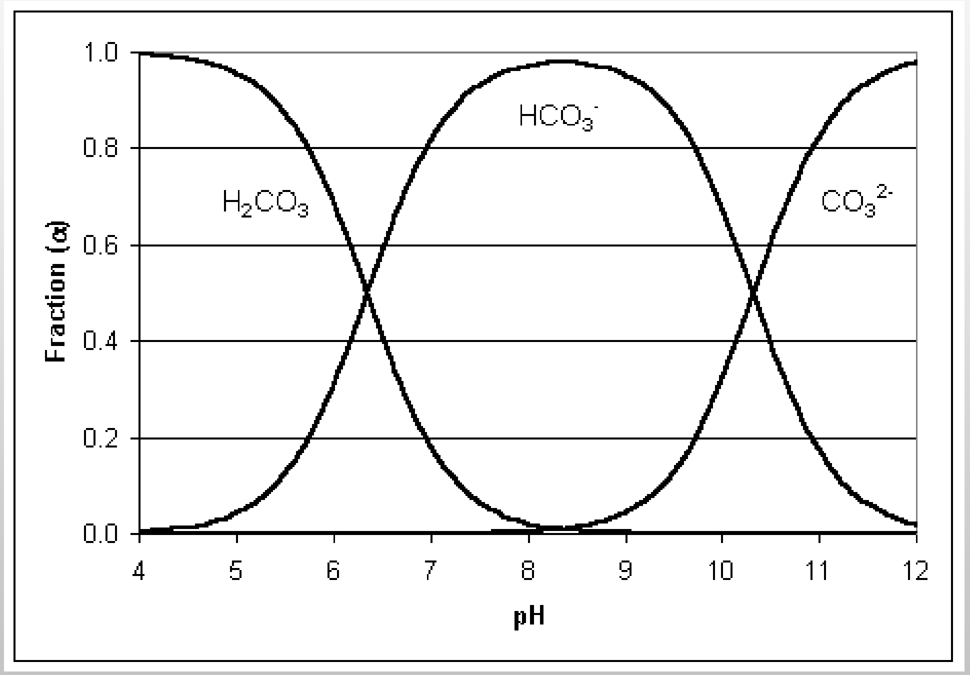
Reactions of CO_2 in water:

$CO_{2\ (g)} \leftrightarrow CO_{2\ (aq)}$

$CO_{2\ (aq)} + H_2O \leftrightarrow H_2CO_{3\ (aq)}$

$H_2CO_3 \leftrightarrow H^+_{\ (aq)} + HCO^{3-}_{\ (aq)}$

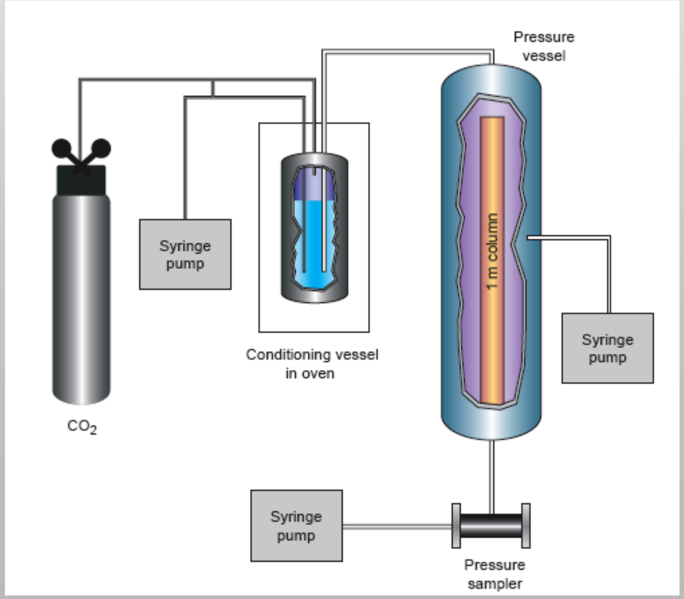
$HCO^{3-}_{(aq)} \leftrightarrow H^+_{(aq)} + CO_3^{-2}{}_{\ (aq)}$



Experiments to simulate CO_2-water-rock interactions

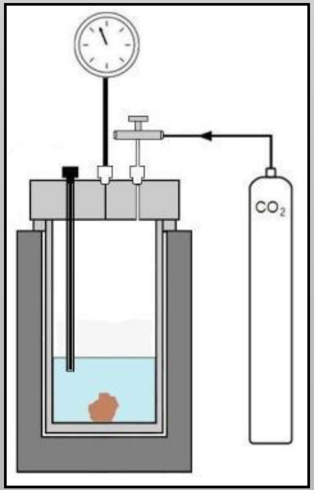
“Batch experiments”

“Flow experiments”

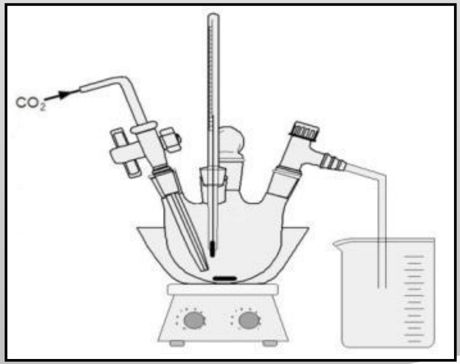


Bateman et al. (2005)

High pressure (autoclaves)



Atmospheric pressure



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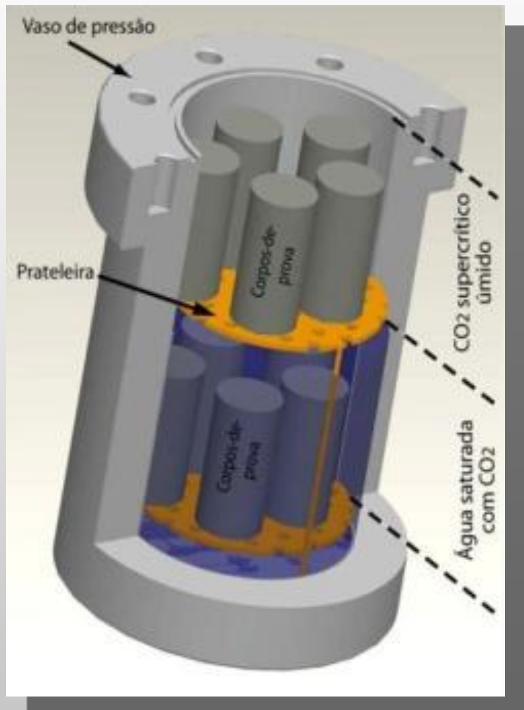
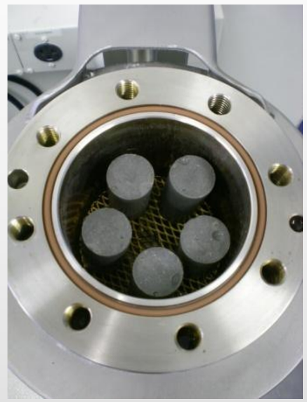
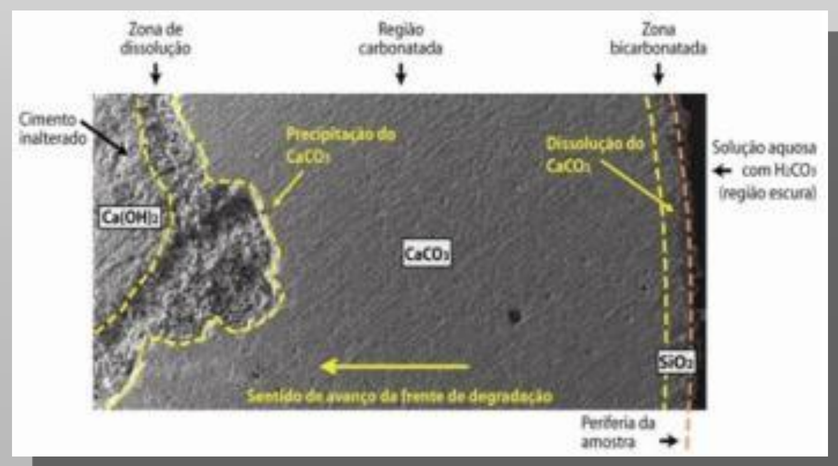
Experiments to simulate CO_2-water-cement (materials) interactions







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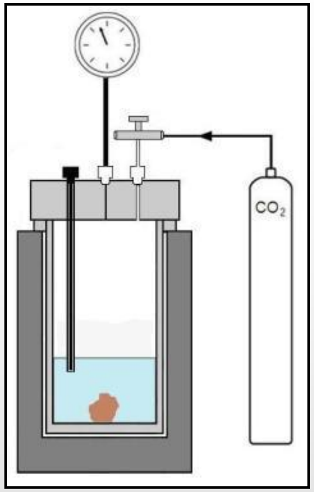
“Batch experiment workflow”

Rock sample (powder or cut/chunk)

Reactants (solution)

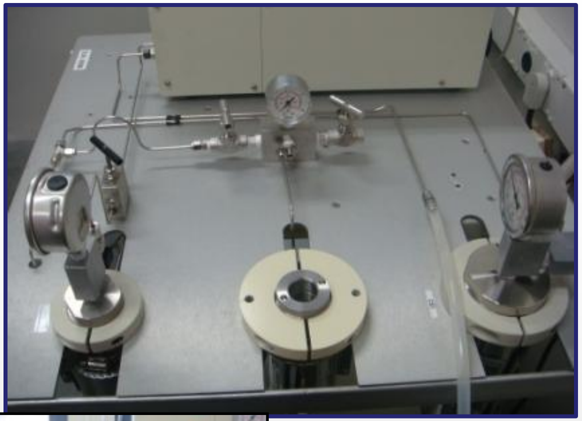
Carbon dioxide

Experiment preparation
(assembly, P+T set)



System is locked from hours to months…

“Flow experiment”

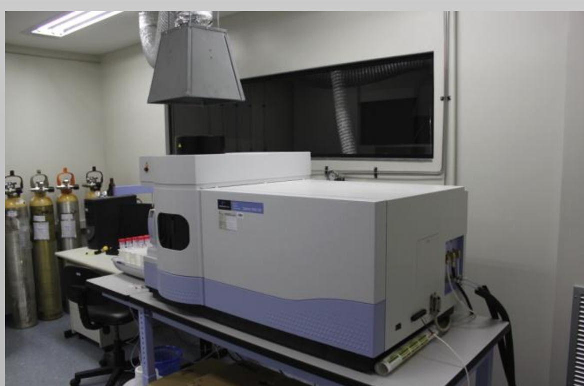


Characterization before and after experiments:

WATER

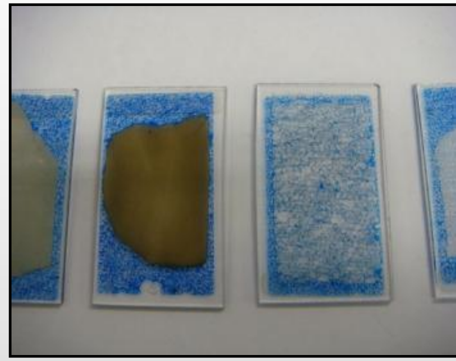
pH, resistivity, alkalinity

Major and trace elements (ICP-EOS)

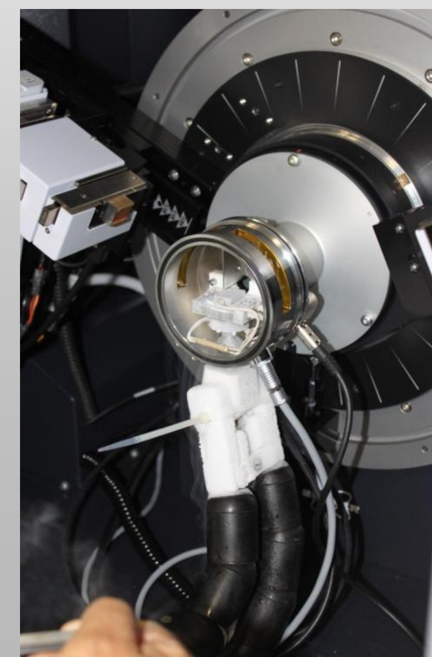


ROCK

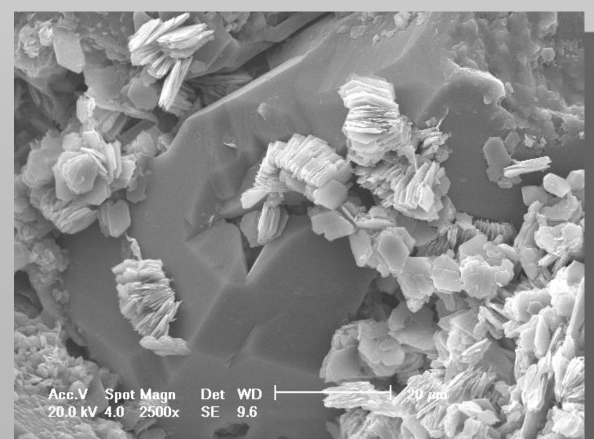
Optical petrography



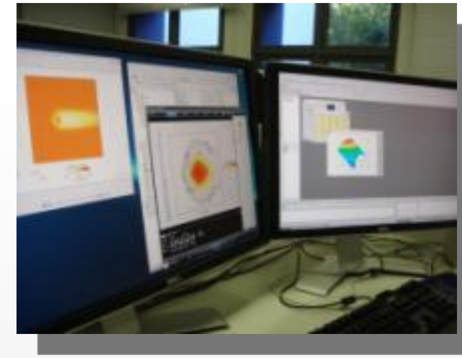
X-ray diffractometry



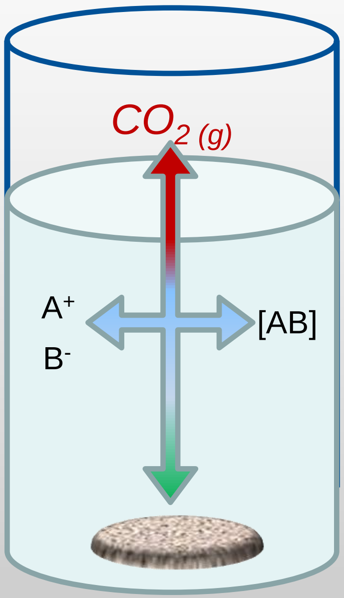
Scanning Electron Microscopy

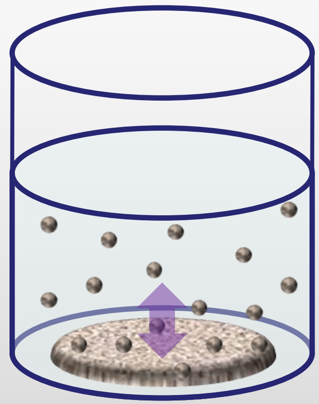


Numerical modelling to simulate CO_2-water-rock interactions



"Batch" geochemical models

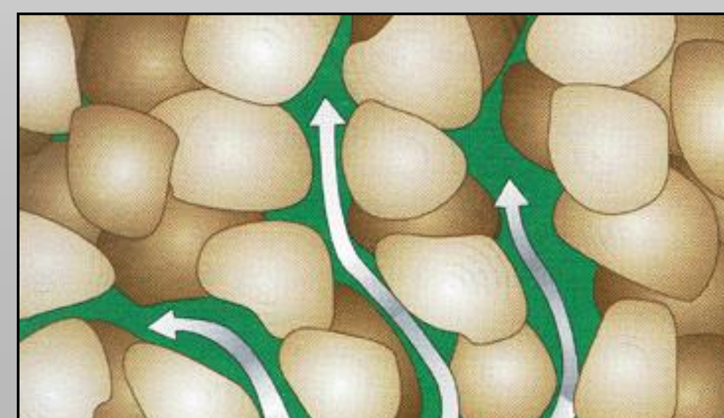




Kinetics, evolution of quantities of minerals and species in water

Equilibrium among phases, dissolution, precipitation, solubility of CO_2

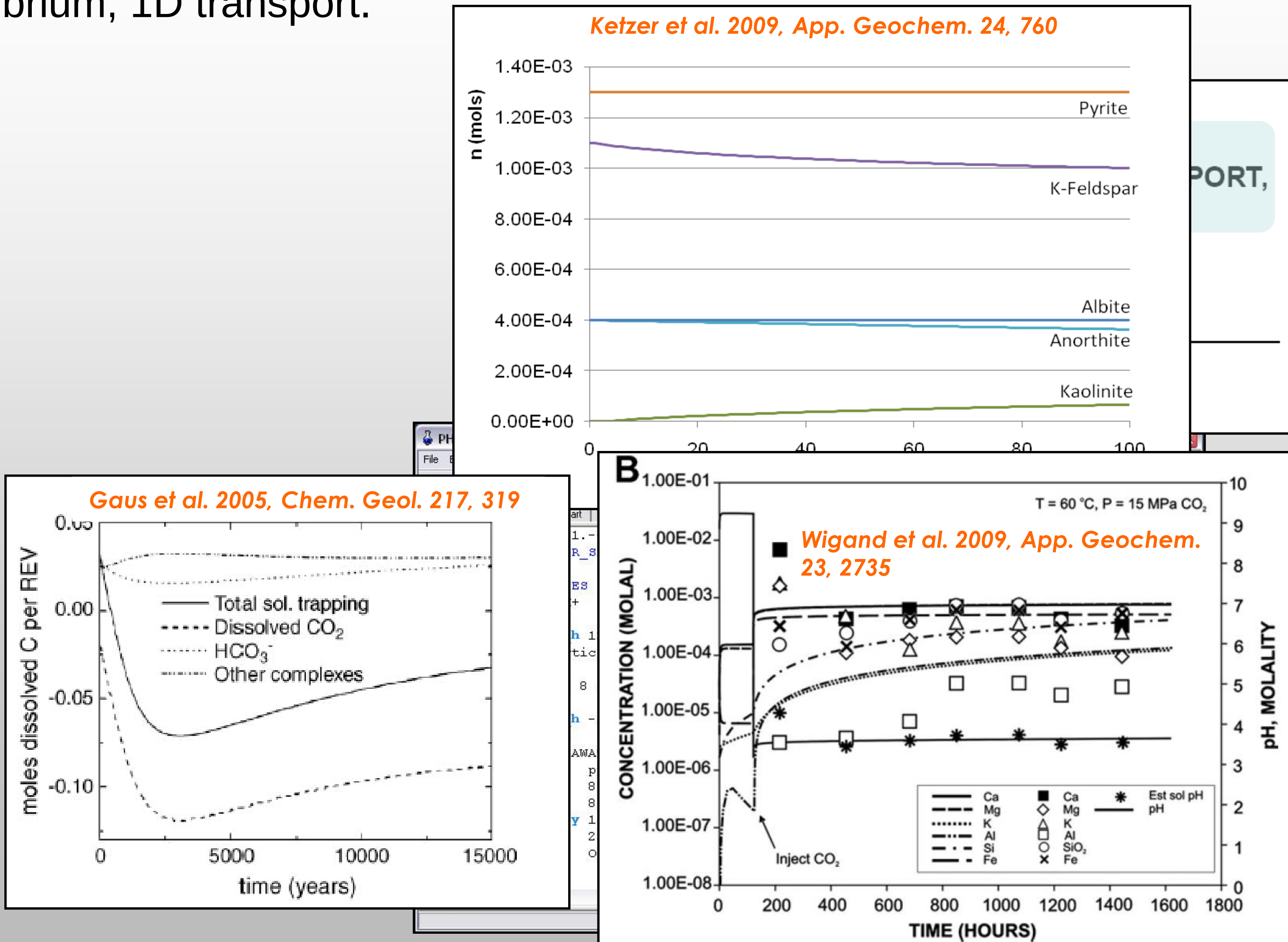
Reactive transport models



Multiphase flow and reactive transport in porous/fractured media

PHREEQC v2 (USGS)

- Chemical species, equilibrium, 1D transport.



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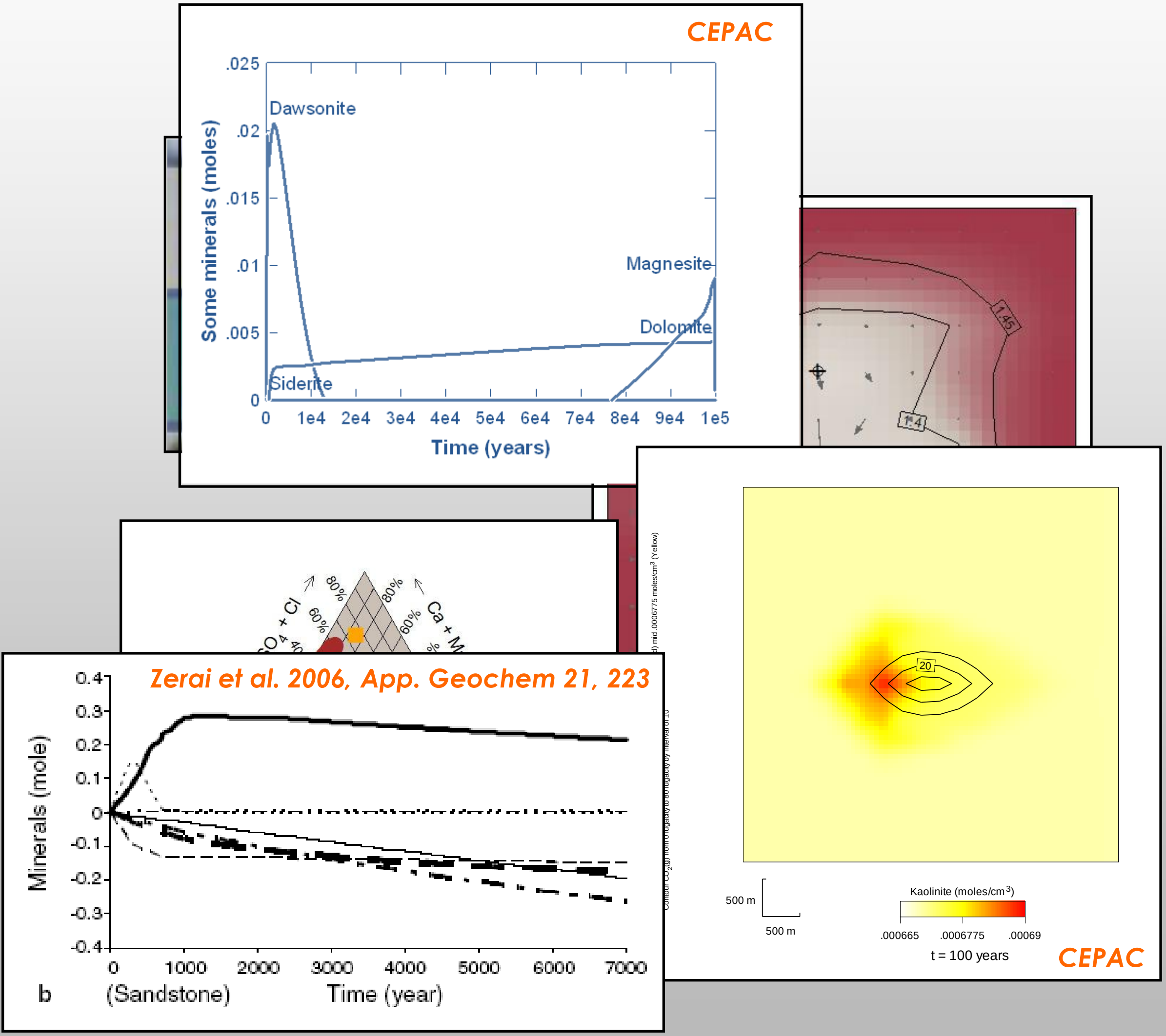
The Geochemist's Workbench 7.0 (GWB) (Rockware, Inc.)

- Chemical species, equilibrium, kinetics of dissolution and precipitation, 2D single phase transport reactions.

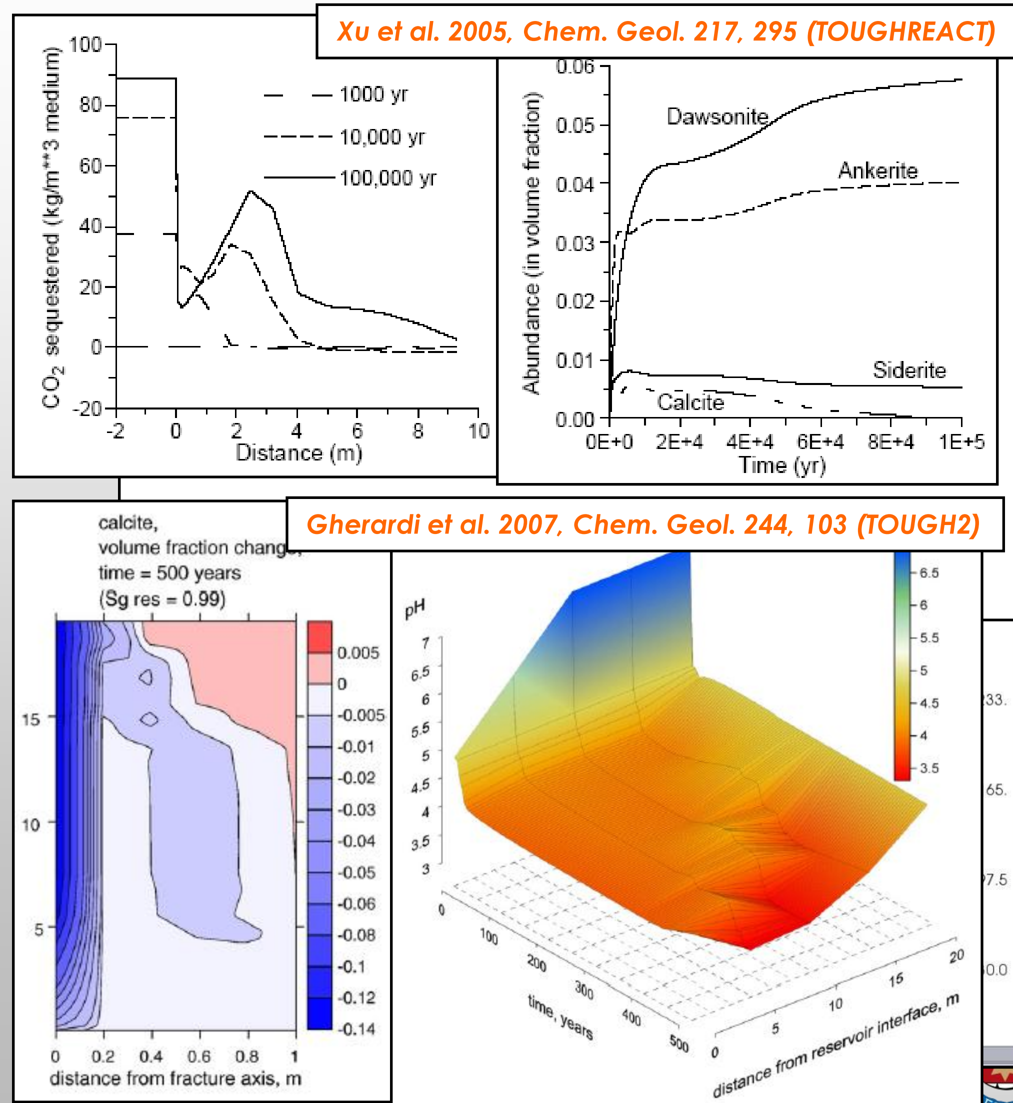


TOUGH2 (LBNL)

- 3D Multiphase and multicomponente flow in porous/fractured media.

TOUGHREACT (LBNL)

- Inclusion of reactive models inTOUGH2.



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Rock integrity (mineral dissolution and precipitation): A case study in Brazil for reservoir rock

Applied Geochemistry 24 (2009) 760–767

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journal homepage: www.elsevier.com/locate/apgeochem

Water–rock–CO_2 interactions in saline aquifers aimed for carbon dioxide storage: Experimental and numerical modeling studies of the Rio Bonito Formation (Permian), southern Brazil

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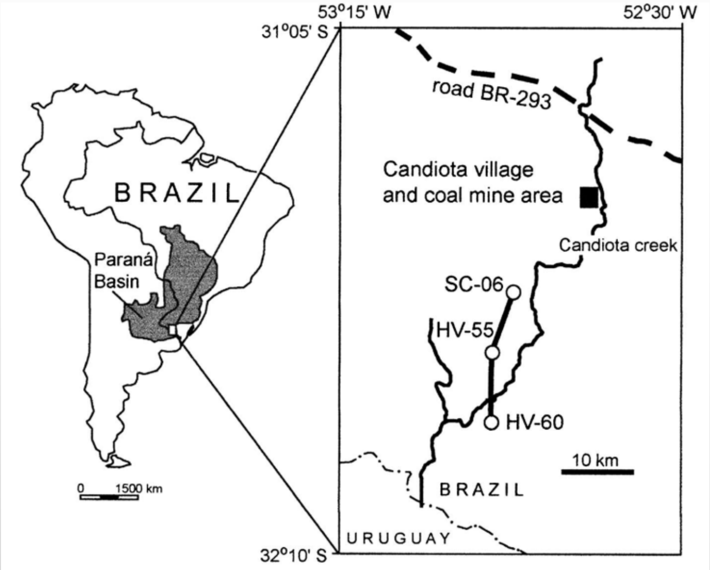
Editorial handing by R. Fuge

ABSTRACT

Mineral trapping is one of the safest ways to store CO_2 underground as C will be immobilized in a solid phase. Carbon dioxide will be, therefore, sequestered for geological periods of time, helping to diminish greenhouse gas emissions and mitigate global warming. Although mineral trapping is considered a fairly long process, owing to the existence of kinetic barriers for mineral precipitation, it has been demonstrated both experimentally and by numerical modeling. Here the results of experimental and numerical modeling studies performed in sandstones of the saline aquifer of the Rio Bonito Formation, Paraná Basin, are presented. The Rio Bonito Formation consists of paralic sandstones deposited in the intracratonic Paraná Basin, southern Brazil, during the Permian (Artinskian–Kungurian). These rocks have the largest potential for CO_2 storage because of their appropriated reservoir quality, depth and proximity to the most important stationary CO_2 sources in Brazil. Here it is suggested that CO_2 can be permanently stored as carbonates as CO_2 reacts with rocks of the Rio Bonito Formation and forms $CaCO_3$ at temperatures and pressures similar to those encountered for CO_2 storage in geological formations. Results of this work will be useful for studies of partitioning mechanisms for C trapping in CO_2 storage programs.

Numerical modeling and experiments to "test" sandstones of the Rio Bonito Formation (saline aquifer in the Paraná Basin)



Sandstone composition:

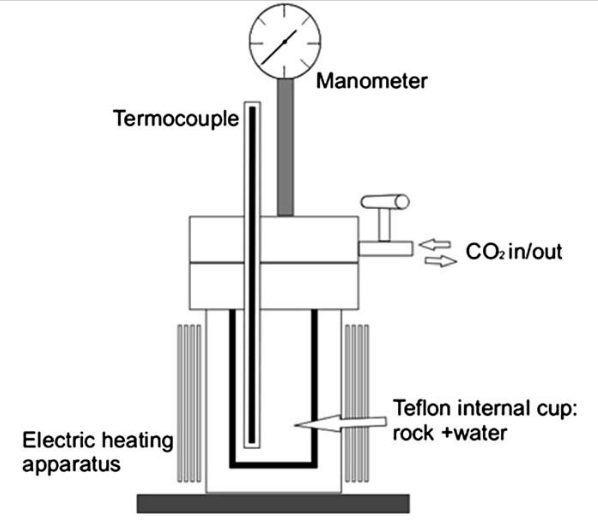
Sample composition (vol %)[a].

Sample 1		Sample 2		Sample 3	
Quartz	67.66	Quartz	66.66	Quartz	67.00
Kaolinite	6.66	Calcite	13.66	Kaolinite	6.66
Calcite	4.66	K-feldspars	5.00	Dolomite	5.33
K-feldspars	4.00	Pyrite	1.33	K-feldspars	4.66
Albite	1.33	Plagioclase	0.33	Albite	1.33
other	0.66	other	1.33	Pyrite	0.33
Porosity	15	Porosity	11.66	Porosity	14.66

[a] Minerals determined by modal analysis of thin sections, counting 300 points per section.

Batch experiments:

Rock mass ca. 5 g
Temperature 200 ° C
Pressure 10-15 Mpa
Time: 100 h



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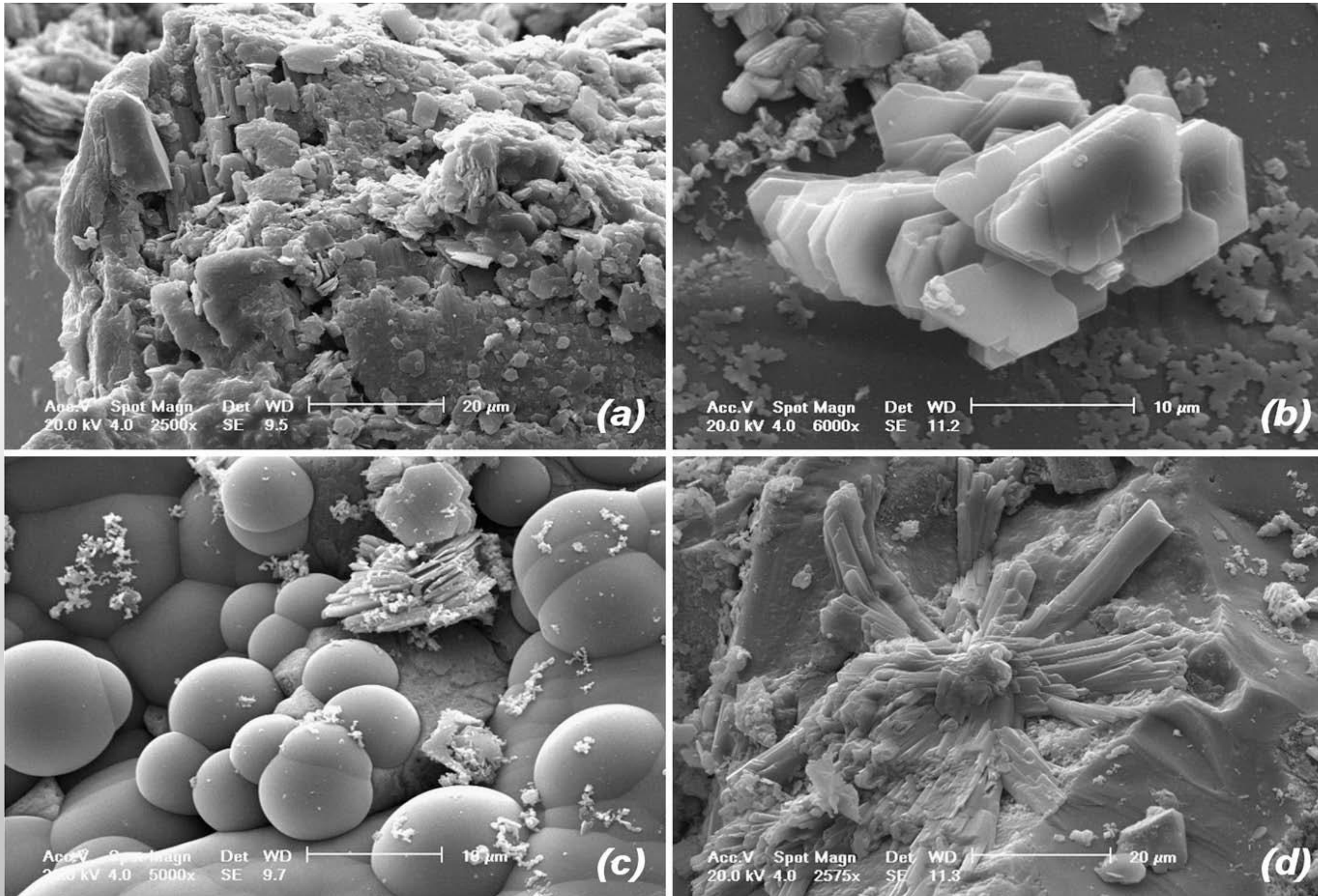
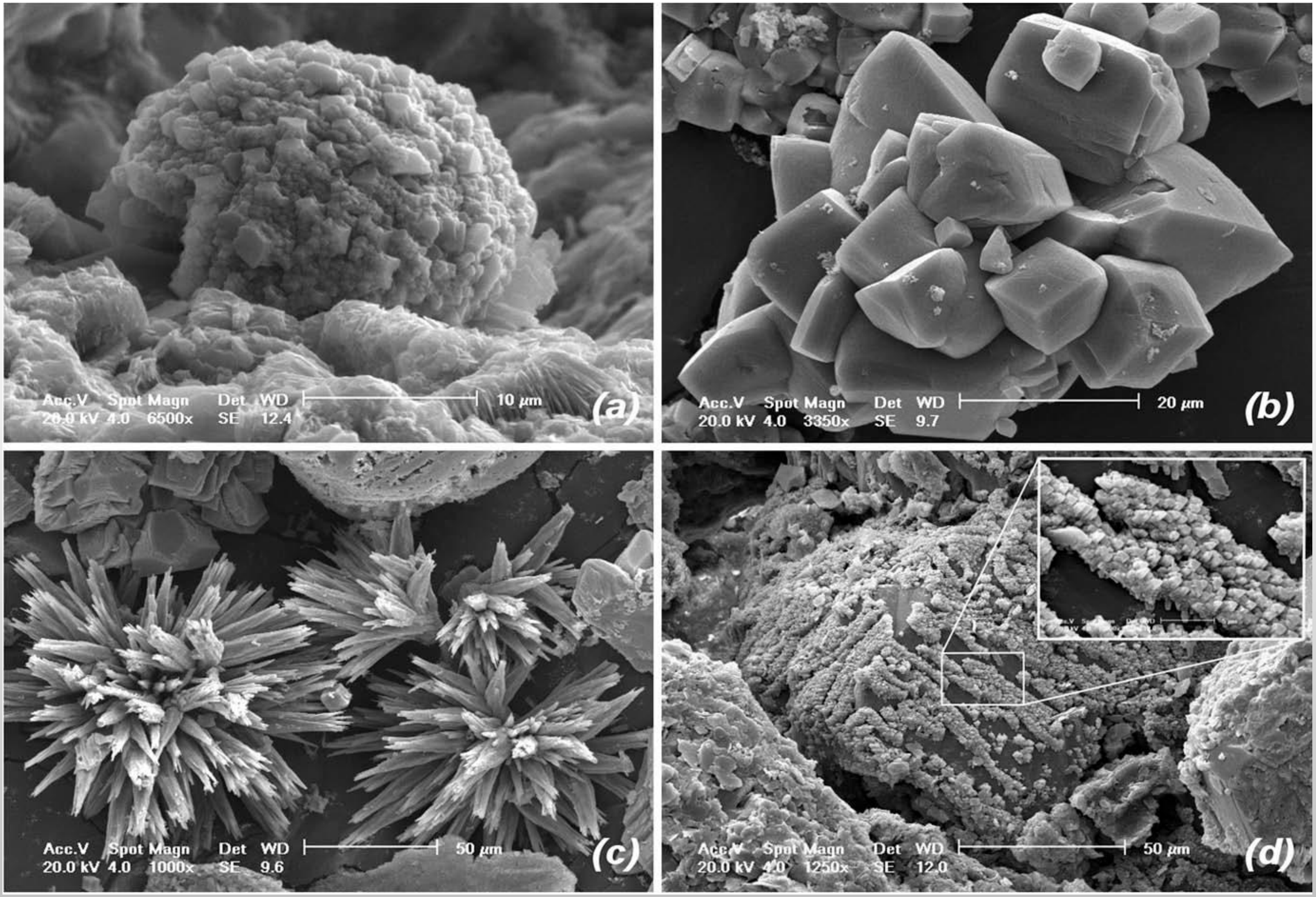


(a) Dissolution of detrital grains (K-feldspar)
(b) Precipitation of ordered kaolinite/disordered dickite
(c) Precipitation of opal (botrioidal texture)
(d) Precipitation of gypsite



Different forms of carbonates (calcite) precipitated in the reactor:
(a) framboidal aggregates
(b) blocky crystals
(c) acicular
(d) microcrystalline

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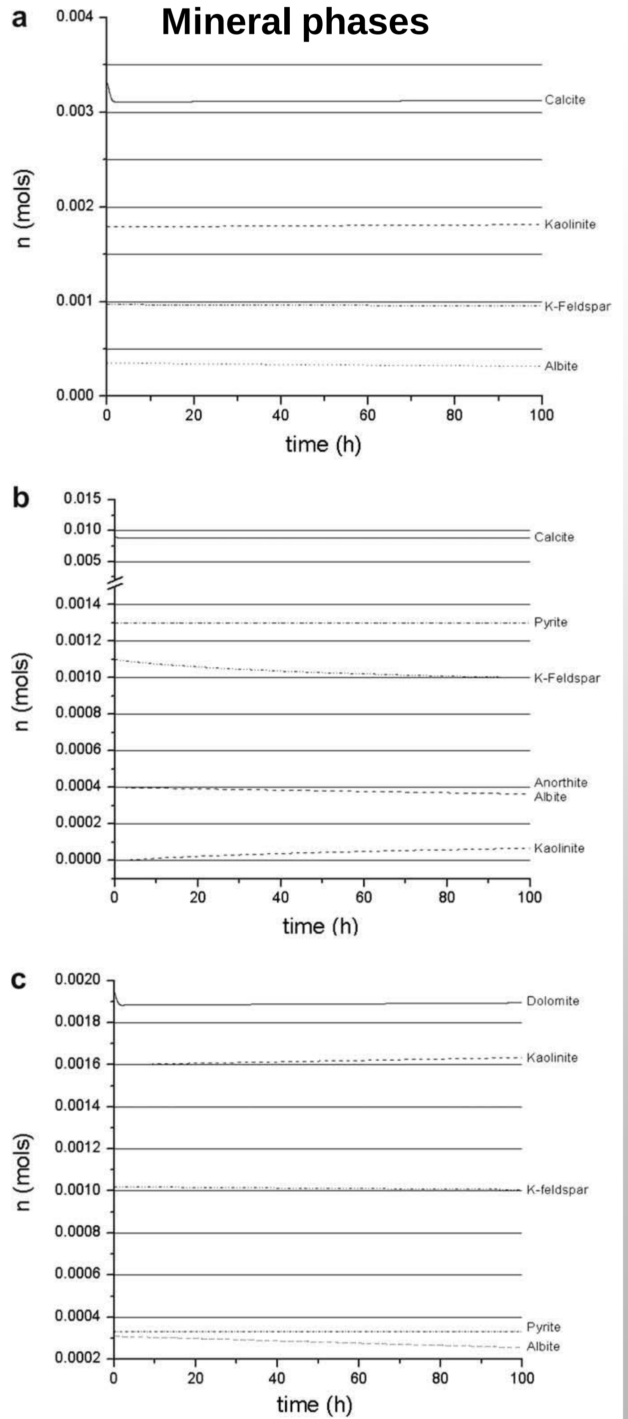
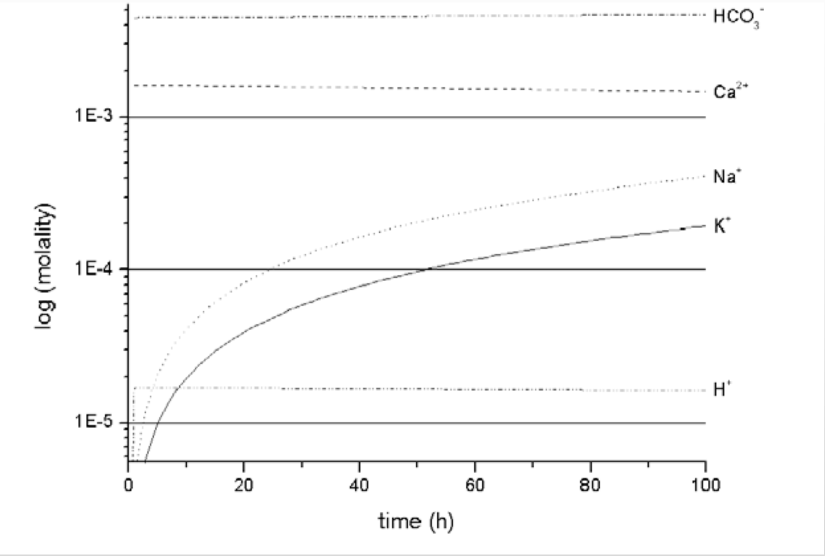
Numerical models using PHREEQC v2

Mineral phases



Dissolved species



Example of dissolution/precipitation reaction

$$\underbrace{2KAlSi_3O_8}_{k\text{-}feldspar} + \underbrace{2NaAlSi_3O_8}_{albite} + Ca^{2+} + CO_2 + 4H_2O$$

$$\rightarrow \underbrace{2CaCO_3}_{calcite} + \underbrace{2\,Al_2Si_2O_5(OH)_4}_{kaolinite} + 2Na^+ + 2K^+ + \underbrace{8SiO_2}_{quartz}$$

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CO_2 Geological Storage in Saline Aquifers: Paraná Basin Caprock and Reservoir Chemical Reactivity

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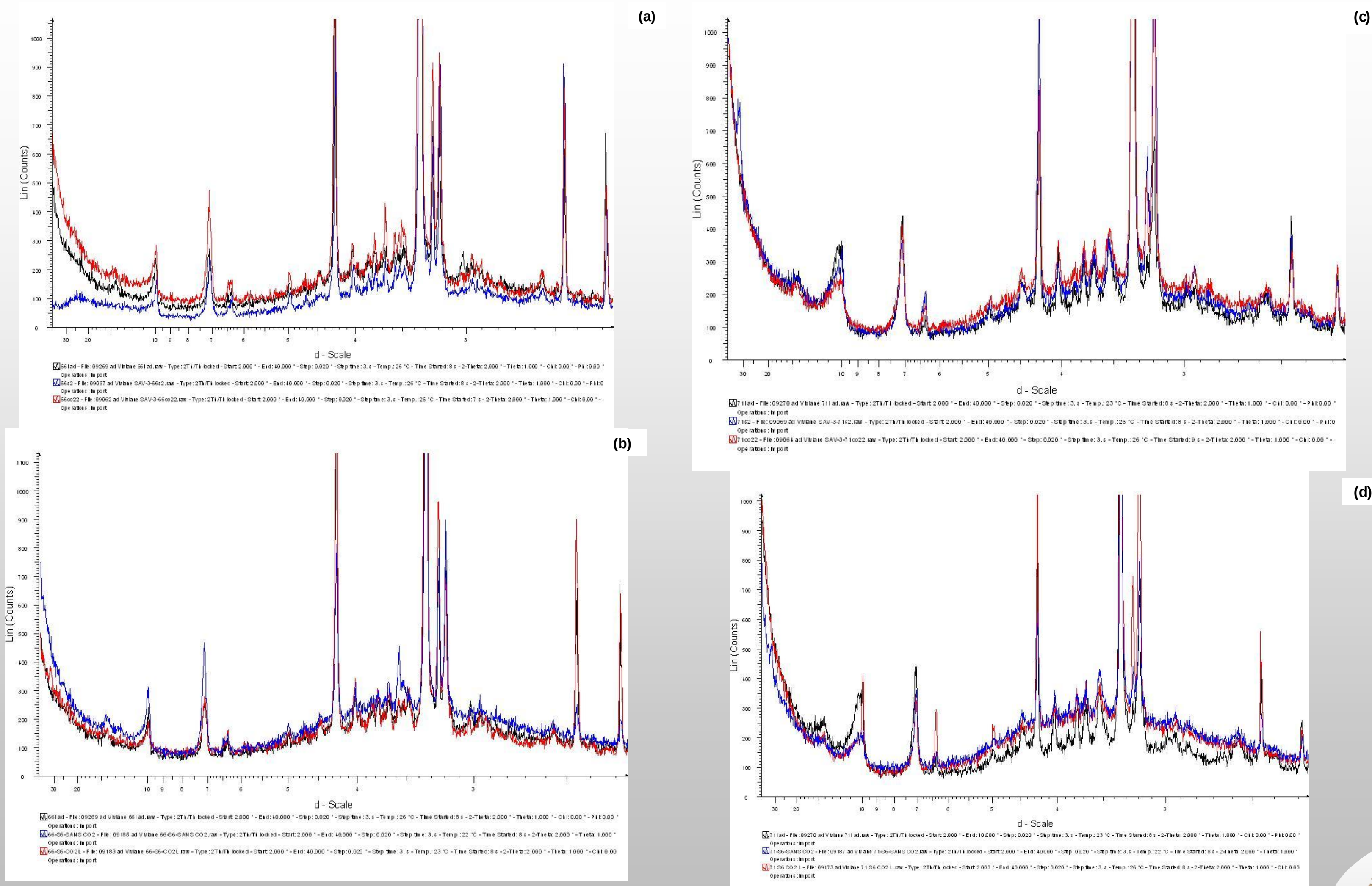
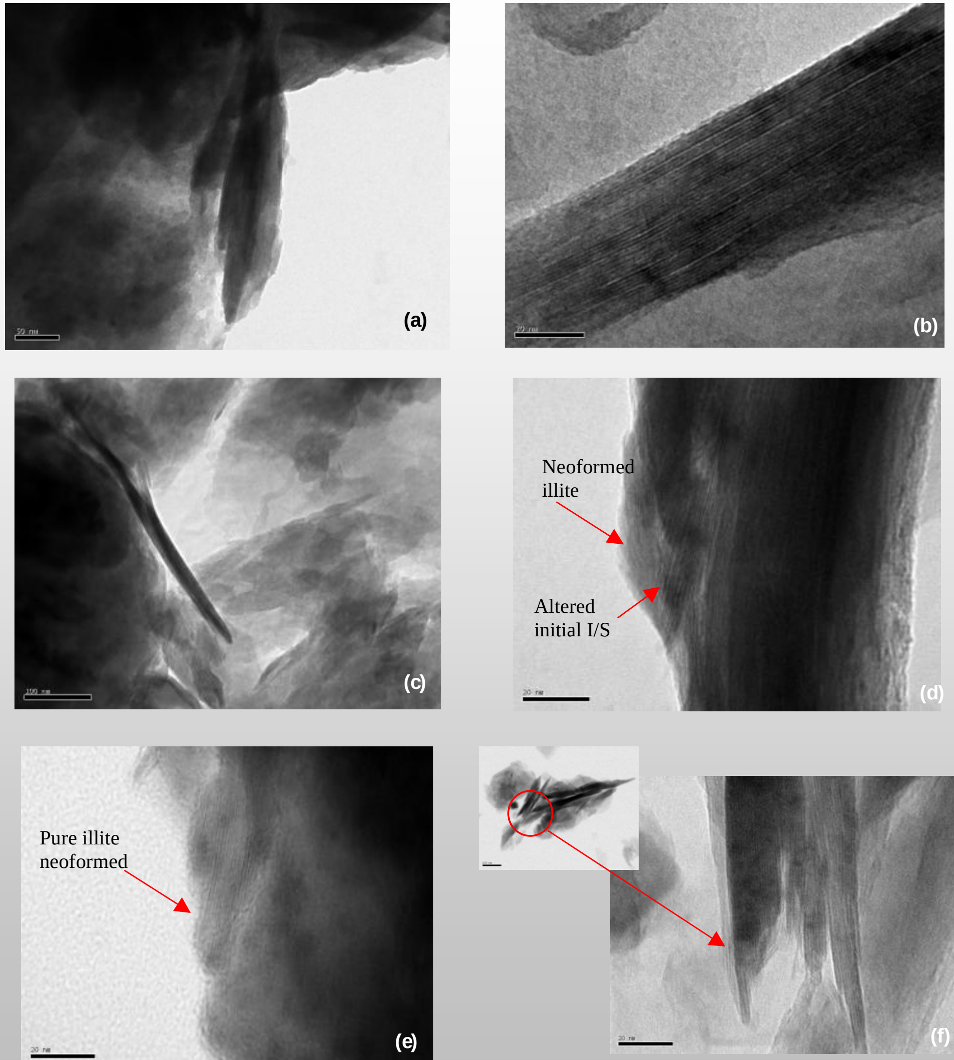
Results of low pressure experiments



Initial - without CO_2 - with CO_2

XRD spectrums: (a) *RB1* sample after 3 months, (b) *RB1* sample after 6 months, (c), PAL sample after 3 months, (d) PAL sample after 6 months



Example of dissolution/precipitation reaction:

$$\text{Na-smectite} + K^{+} + Al^{3+} \rightarrow \text{illite} + Si^{4+}$$

Figure 2: TEM analyses of PAL sample: (a) and (b) illite crystals and/or interstratified I/S in initial sample; c) neoformed illite, (d) altered I/S and neoformed illite, (e) pure illite neoformed, (f) illite crystals (detail) and I/S after 6 months of reaction in CO_2 presence.

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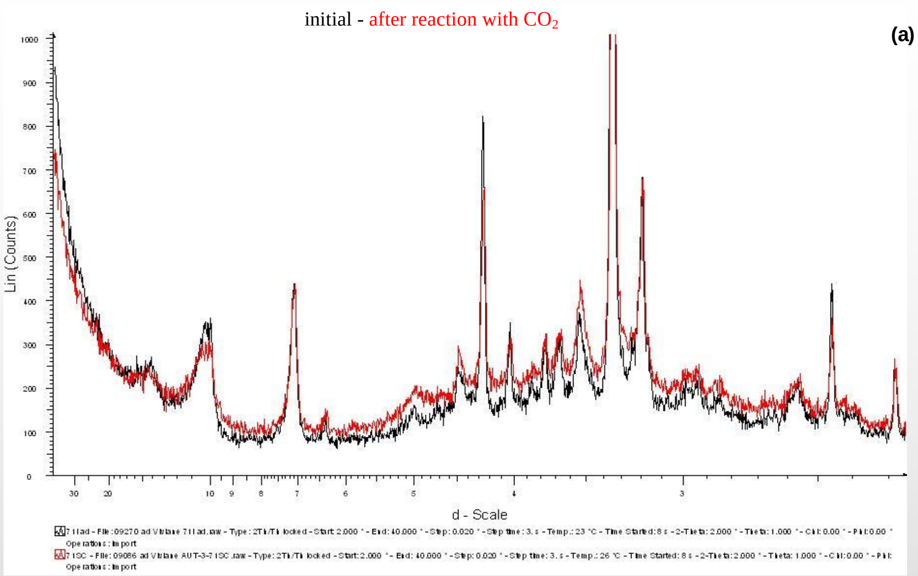
Results of high pressure experiments



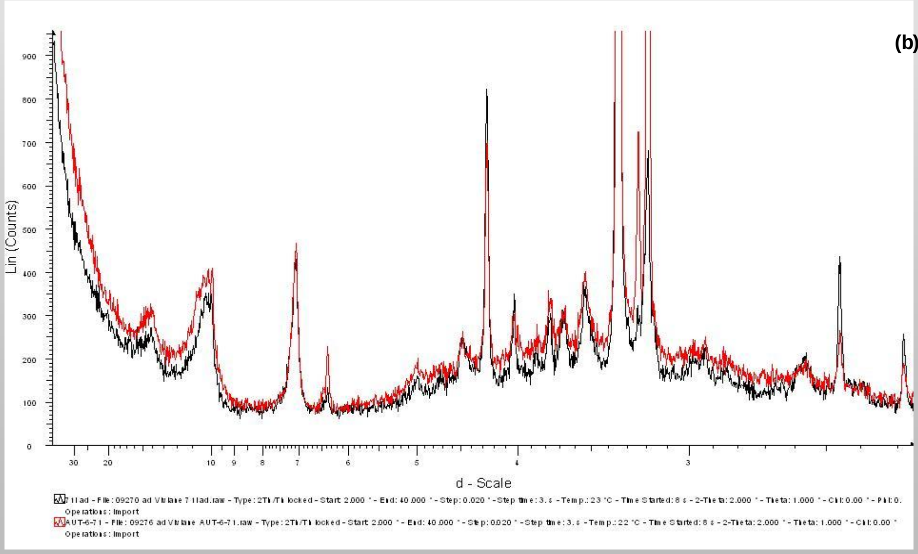


Figure 3: XRD spectrums of *PAL* sample submitted to high pressure: (a) after 3 months, (b) after 6 months.

Final remarks

Geophysics is very important for site selection of CCS projects and monitoring stored CO_2, particularly seismics.

Geomechanical properties are key for site selection, notably those related to fracturing of reservoirs and caprocks, and reactivation of existing faults.

Changes in geochemical properties related to massive injection of CO2 in reservoirs can be constrained by numerical modelling and experiments.

Minerals in the reservoir and caprock interact with stored CO_2 and formation water, changing trapping mechanisms with time.

Reactivity of minerals is an important factor to consider during site selection of CCS projects as they affect reservoir and caprock integrity .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