

SIMCO Experimental Results

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Cementitious Barriers Partnership



- Concrete mixture characterization
- Saltstone characterization
- Effect of damage on transport properties
- OPC pastes exposed to aggressive solutions
- SCM pastes exposed to aggressive solutions
- Saltstone/concrete samples



Concrete characterization

- 2 SRNL mixes
- Tested after 28d, 91d, 1yr, 2yrs of curing for porosity, diffusion coefficients, permeability
- Additional tests: moisture retention, chloride profiles, $f'c$, pore solution extraction
- Tests on 10 samples at 2 yrs

Vault 1/4 mix (425 kg/m³ binder)

Item	Value
Type I/II cement	255 kg/m ³ (60%)
GGBFS	169 kg/m ³ (40%)
Sand	692 kg/m ³
Coarse aggregates	1,095 kg/m ³
w/b	0.38
Air	6%

Vault 2 mix (405 kg/m³ binder)

Item	Value
Type V cement	121 kg/m ³ (30%)
GGBFS	162 kg/m ³ (40%)
Fly Ash F	95 kg/m ³ (23%)
Silica Fume	27 kg/m ³ (7%)
Sand	548 kg/m ³
Coarse aggregates	1,111 kg/m ³
w/b	0.38
Air	6%

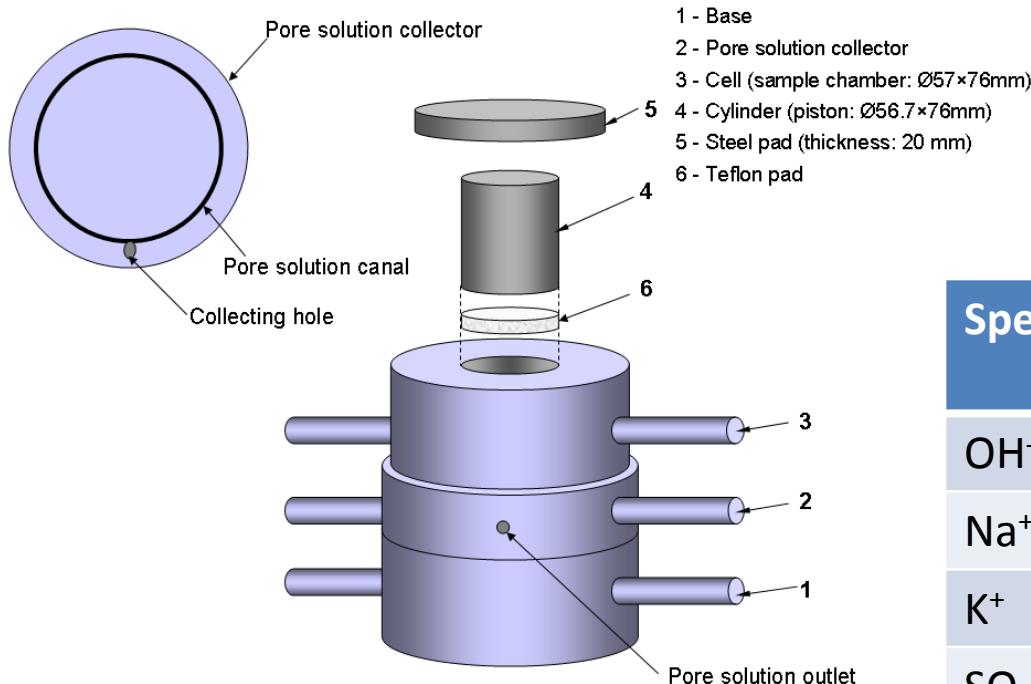
Mix preparation



Compressive strength at 28 days

Mix	Value (Mpa)
Vault 1/4	62.6
Vault 2	49.9

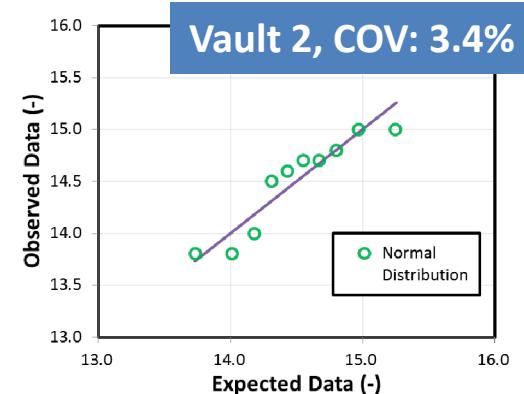
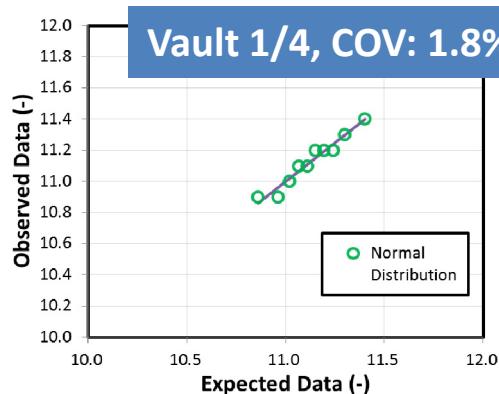
Pore solution at 28 days



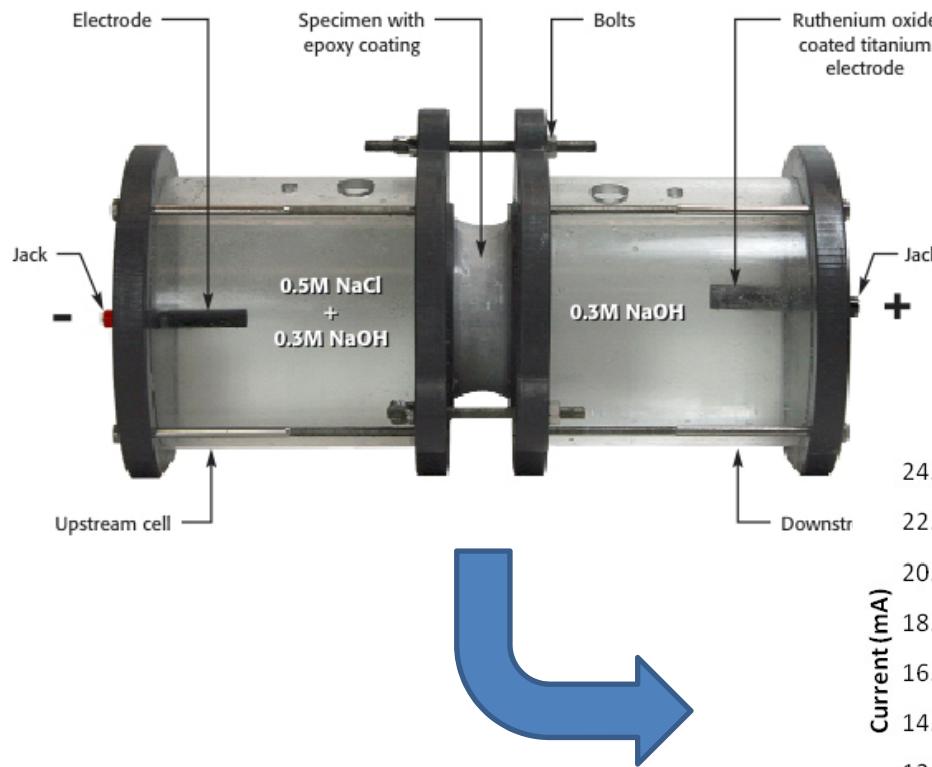
Species	Vault 1/4 (mmol/L)	Vault 2 (mmol/L)
OH^-	218.1	96.3
Na^+	84.1	36.4
K^+	135.4	59.6
SO_4^{2-}	< 0.1	< 0.1
Ca^{2+}	1.6	2.2
Cl^-	4.5	4.1

Porosity measurements (ASTM C642)

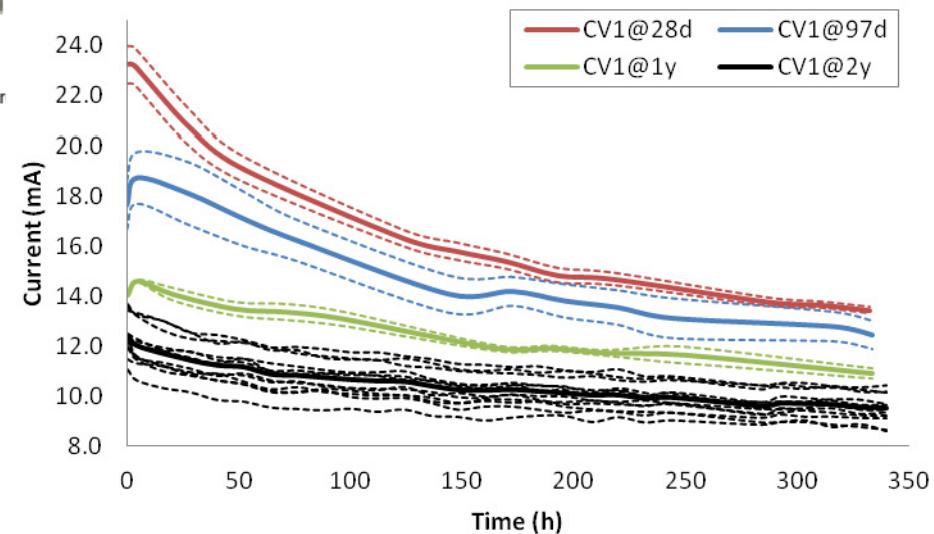
Age of samples	Vault 1/4 (%)	Vault 2 (%)
28 days	11.4	13.1
91 days	11.3	14.3
1 year	11.4	14.2
2 years	11.1	14.5



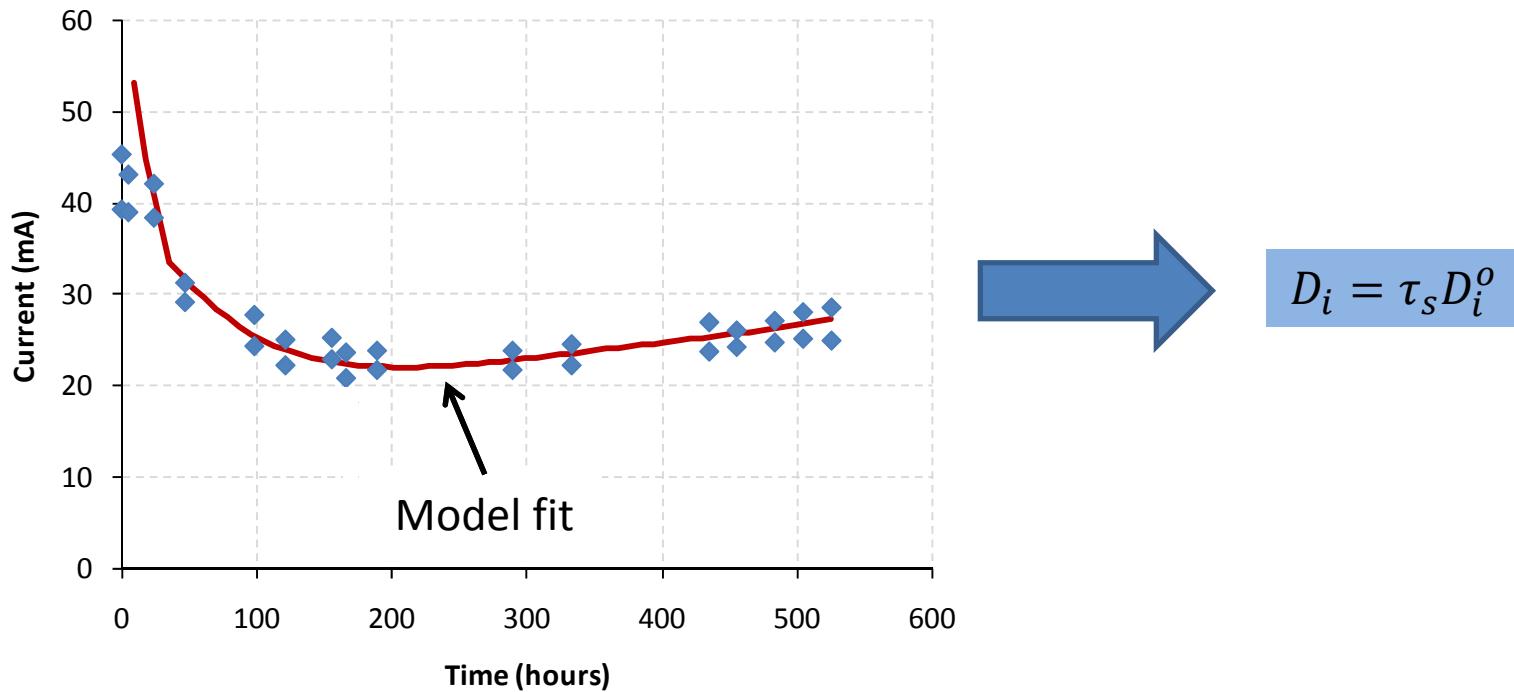
Diffusion coefficient measurements (migration test)



Vault 1/4



Diffusion coefficient measurements (migration test)

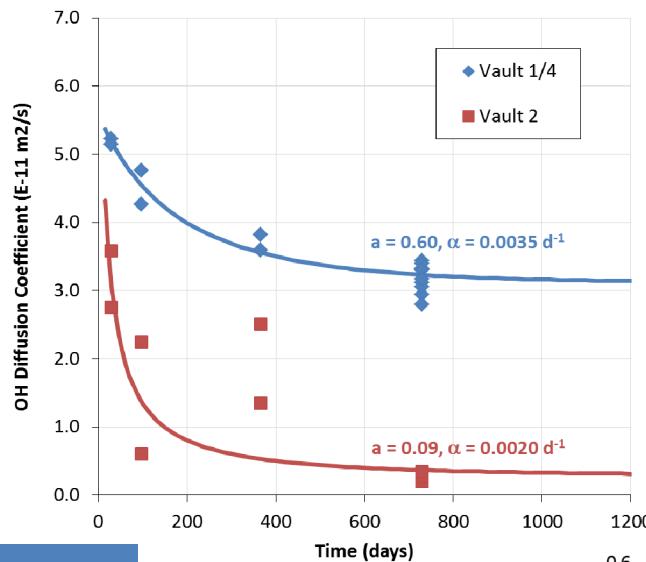


$$I = SF \sum_{i=1}^N z_i j_i$$



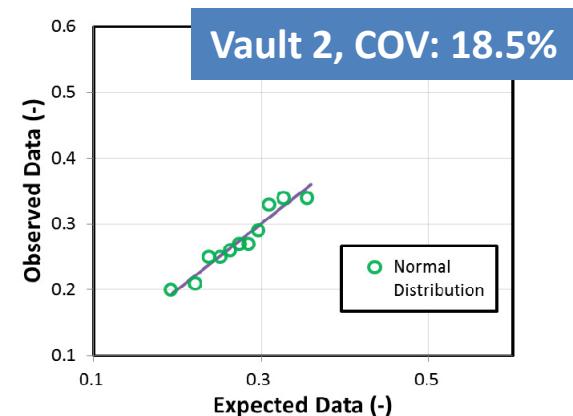
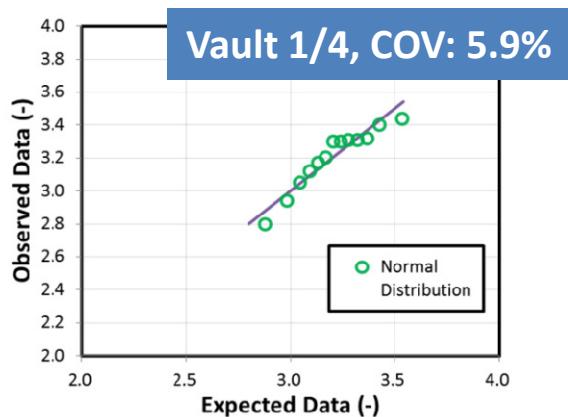
$$j_i = -D_i \phi \text{grad}(c_i) - \frac{D_i z_i F \phi}{RT} c_i \text{grad}(\psi) - D_i \phi c_i \text{grad}(\ln \gamma_i)$$

Diffusion coefficient measurements (migration test)



Avg. τ @ 2 yrs: 0.0061

Avg. τ @ 2 yrs: 0.0005

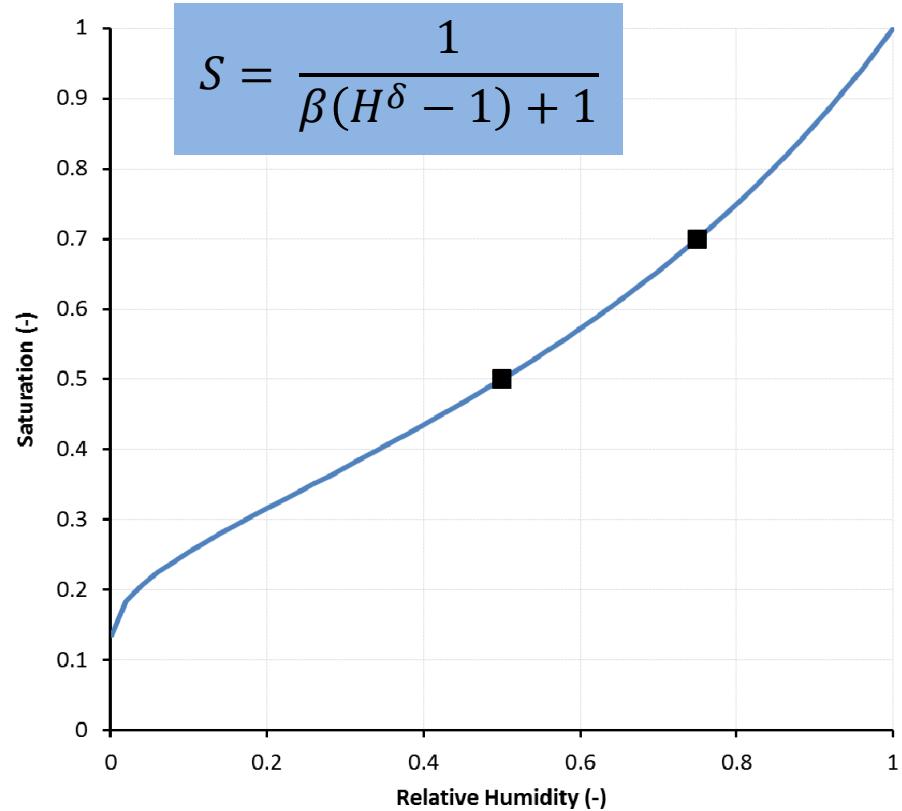


Drying of thin (1 cm) samples in controlled RH rooms until equilibrium:

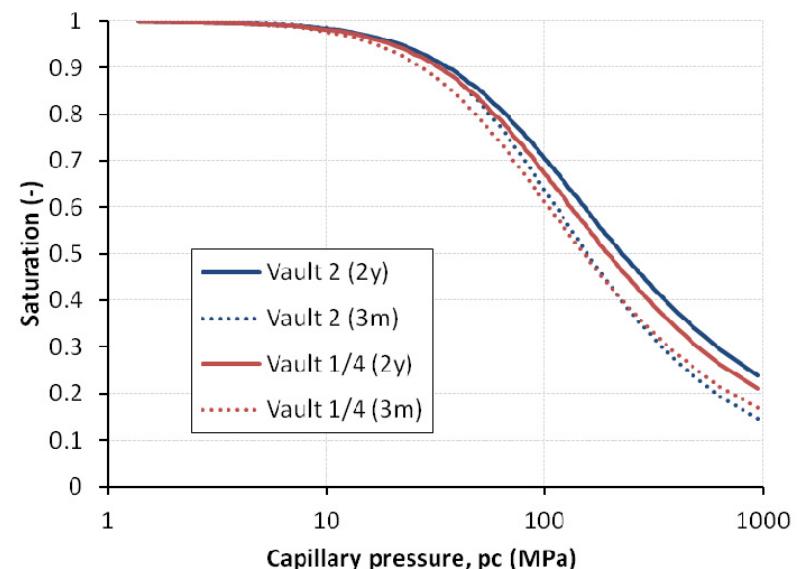
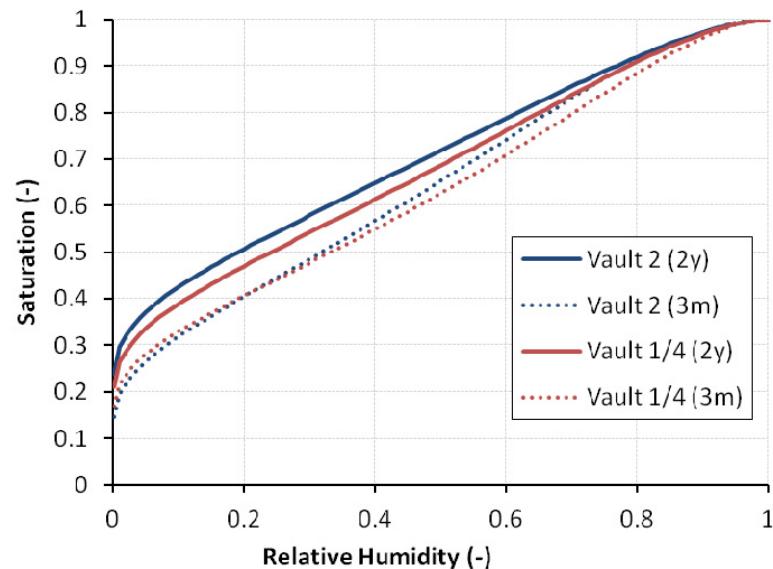
- 50% RH
- 75% RH



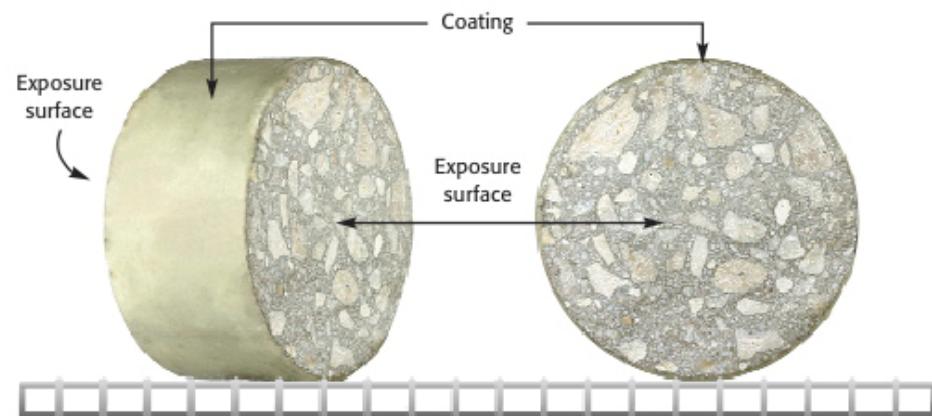
$$S = \frac{1}{\beta(H^\delta - 1) + 1}$$



Moisture retention curve



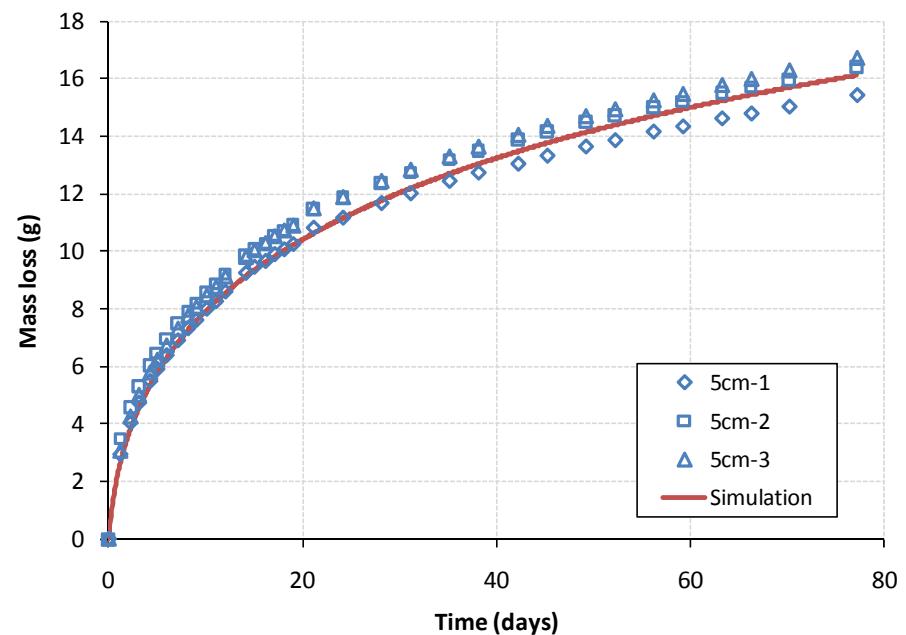
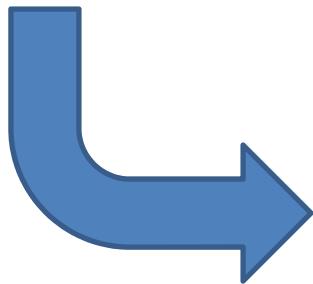
Permeability measurements (drying test)



Permeability measurements (drying test)

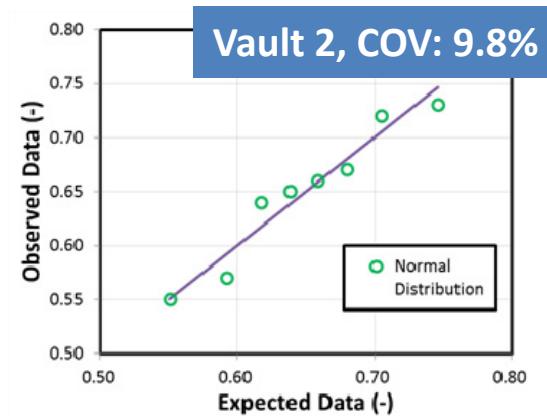
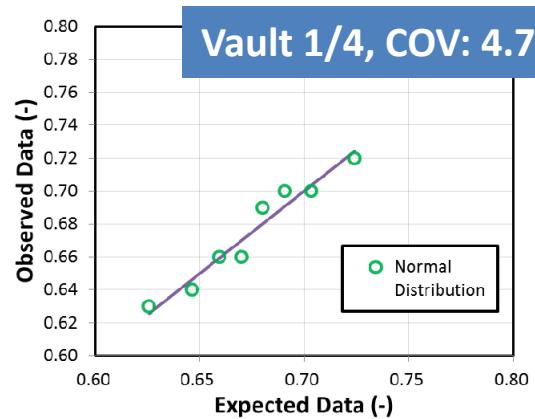
$$\frac{\partial w}{\partial H} \frac{\partial H}{\partial t} - \operatorname{div}(D_{mH} \operatorname{grad}(H)) = 0$$

$$D_{mH} = \frac{\kappa_s \epsilon_r^l \rho_l R}{\mu M_w} \frac{T}{H} + \frac{D_v^o \tau_s \tau_r^g M_w p_v^s}{\rho_l R} \frac{(\phi - w)}{T}$$



Permeability measurements (drying test)

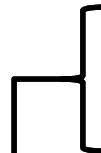
Age of samples	Vault 1/4 (E-22 m ²)	Vault 2 (E-22 m ²)
91 days	1.27	1.04
2 years	0.68	0.65



Saltstone characterization

Saltstone mixture

Item	Value
Type I/II cement	94 kg/m ³ (10%)
GGBFS	423 kg/m ³ (45%)
Fly Ash F	423 kg/m ³ (45%)
DI water	564 kg/m ³
Salt	232 kg/m ³
w/b	0.6



→ Premixed

Salt solution

Salt	Concentration (g/L of DI water)
NaOH	63.60
NaNO ₃	268.58
NaNO ₂	25.53
Na ₂ CO ₃	19.08
Na ₂ SO ₄	8.52
Al ₃ (NO ₃) ₃ .9H ₂ O	21.45
Na ₃ PO ₄ .12H ₂ O	3.8

Solution density: 1.22 g/cm³

Properties summary

Property	Value
Compressive strength (28d)	5.5 MPa
Porosity (1yr)	62.0 %
Tortuosity (1yr)	9.5e-5
Permeability (28d)	11.9e-21 m ²

Effect of damage on Transport properties

Objectives

- Find relationship between damage level and transport properties.
- Provide data to support model development.

Damage vs. transport properties

- Tests performed on 4 years old concrete OPC samples.
- Three mixtures tested.
- Use of F/T cycles to generate damage.
- Samples tested at different damage levels.
- Porosity and diffusion coefficient measurements.

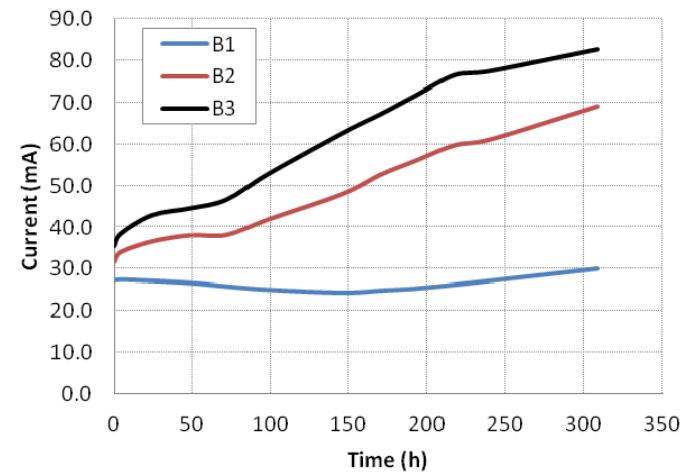
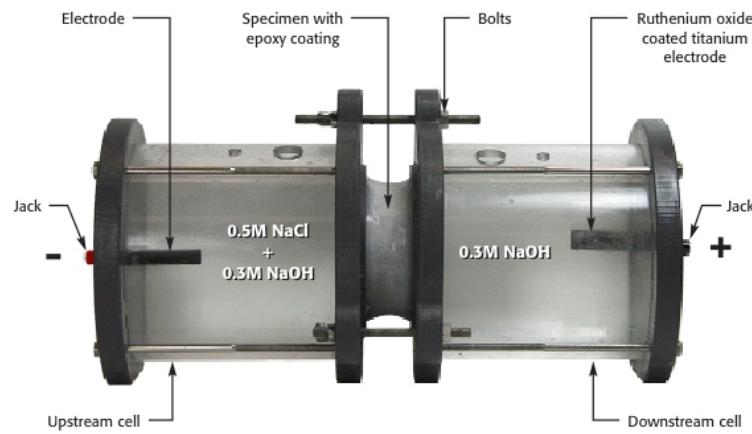
Damage vs. transport properties

Mixture characteristics

Item	Mix B1	Mix B2	Mix B3
Type I cement	380 kg/m ³	280 kg/m ³	250 kg/m ³
Water	190 kg/m ³	182 kg/m ³	188 kg/m ³
Sand	660 kg/m ³	735 kg/m ³	760 kg/m ³
Coarse aggregates	1,139 kg/m ³	1,171 kg/m ³	1,155 kg/m ³
w/c	0.50	0.65	0.75
Air	2%	2%	2%

No air-entraining agent

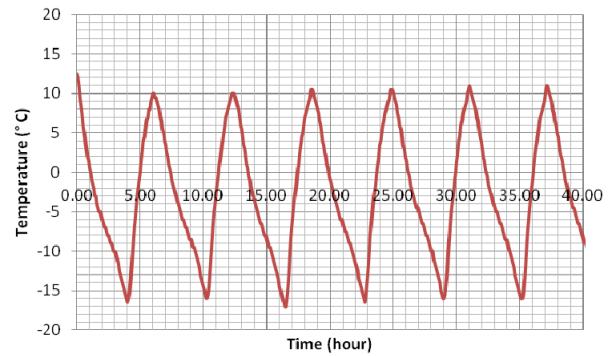
Characterization of undamaged samples



Material	Porosity [%]	D_{OH} [$\text{e}^{-11} \text{ m}^2/\text{s}$]	Tortuosity, $\tau_s [-]$
B1	14.1	11.63	0.0221
B2	14.4	18.43	0.0350
B3	15.0	20.07	0.0381

Damage vs. transport properties

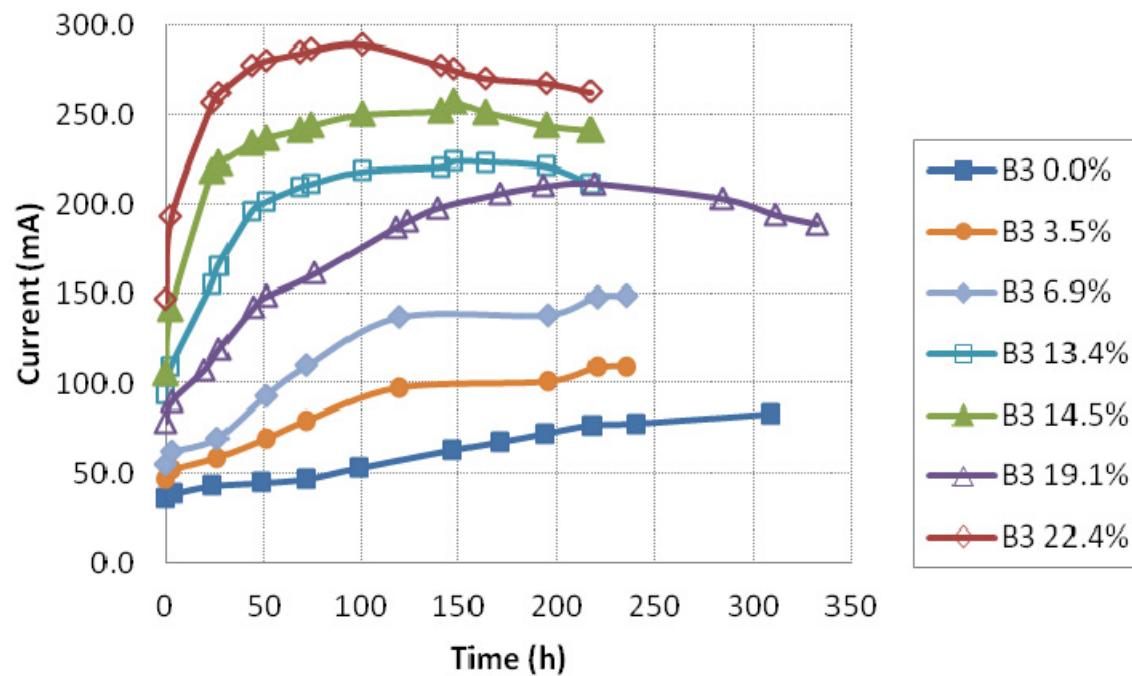
Inducing damage to samples



4 cycles / day

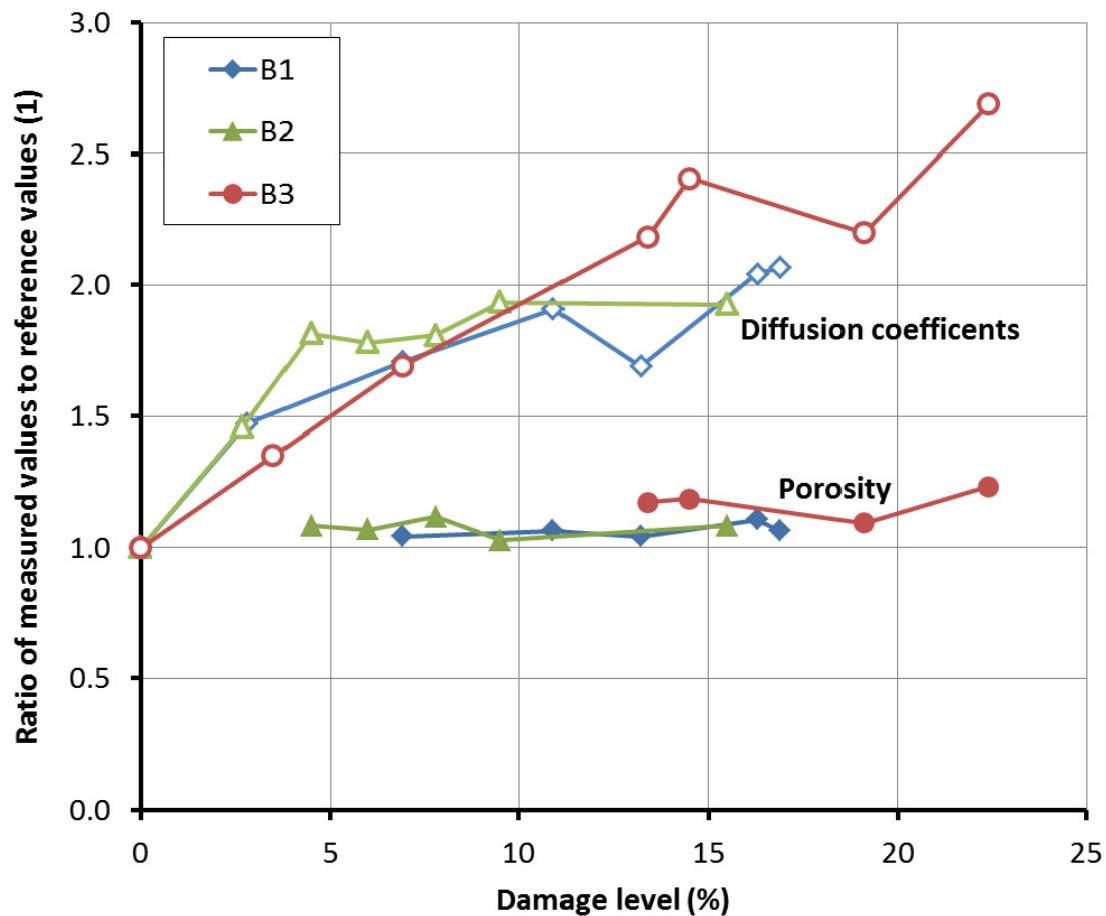
Damage vs. transport properties

Effect of damage on measured current



Damage vs. transport properties

Effect of damage on transport properties





OPC pastes exposed to aggressive solutions

OPC samples in solutions

- Tests performed on 4 years old OPC paste samples.
- Three mixtures tested.
- Two contact solutions: sodium sulfate solutions at pH = 7 and pH = 13.5.
- Solutions renewed once per week.
- Samples characterized after 3 months in solution.

Mixture characteristics

Item	Mix P1	Mix P2	Mix P3
Type I cement	380 kg/m ³	280 kg/m ³	250 kg/m ³
Water	190 kg/m ³	182 kg/m ³	188 kg/m ³
w/c	0.50	0.65	0.75
Air	2%	2%	2%

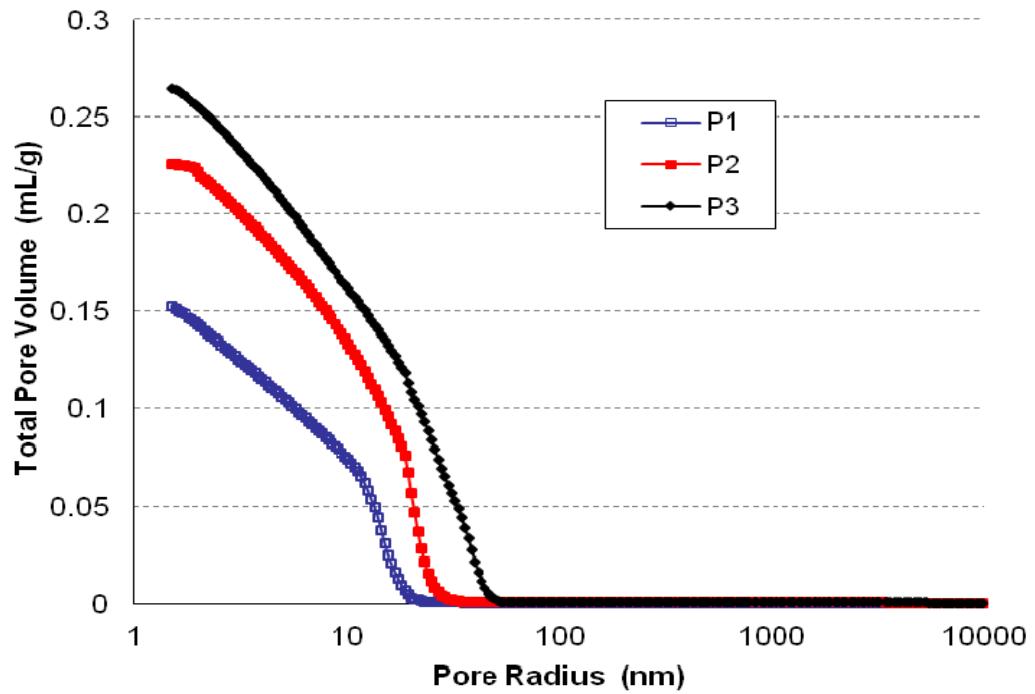
OPC samples in solutions

Contact solutions

Salts	Solution 1	Solution 2
Na ₂ SO ₄	150 mM	150 mM
NaOH	0 mM	500 mM

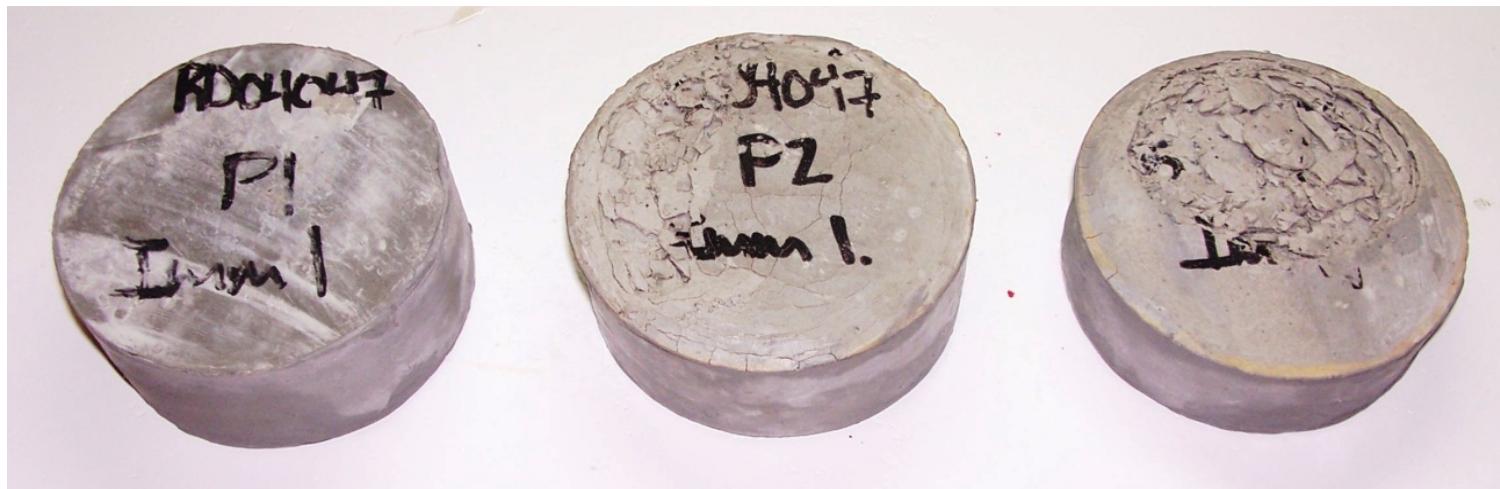
OPC samples in solutions

MIP measurements before exposure



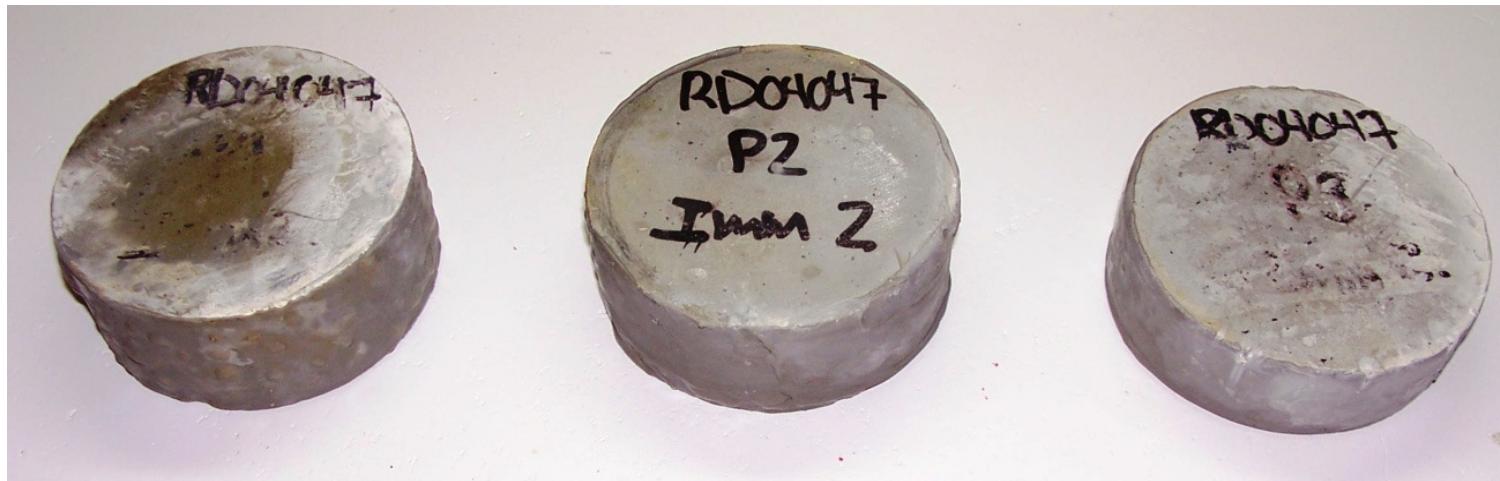
OPC samples in solutions

Paste samples after three months in pH-7 solution



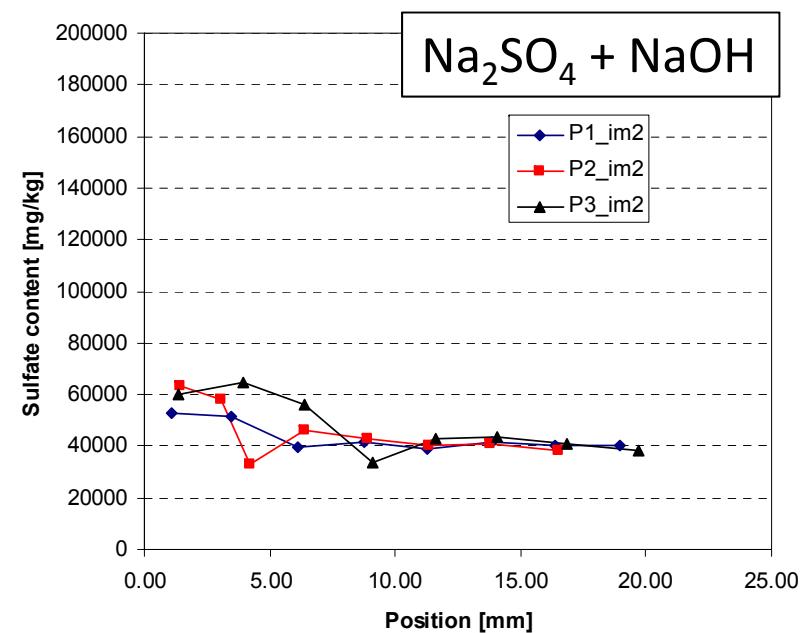
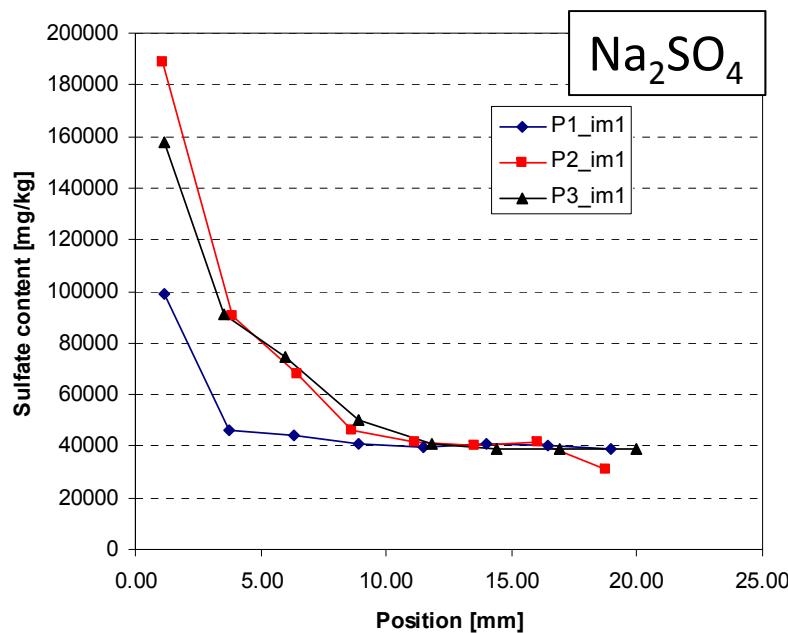
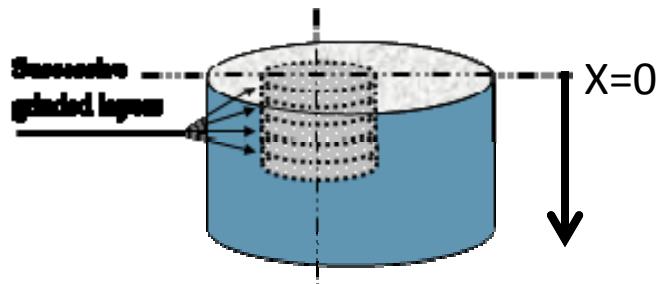
OPC samples in solutions

Paste samples after three months in pH-13.5 solution



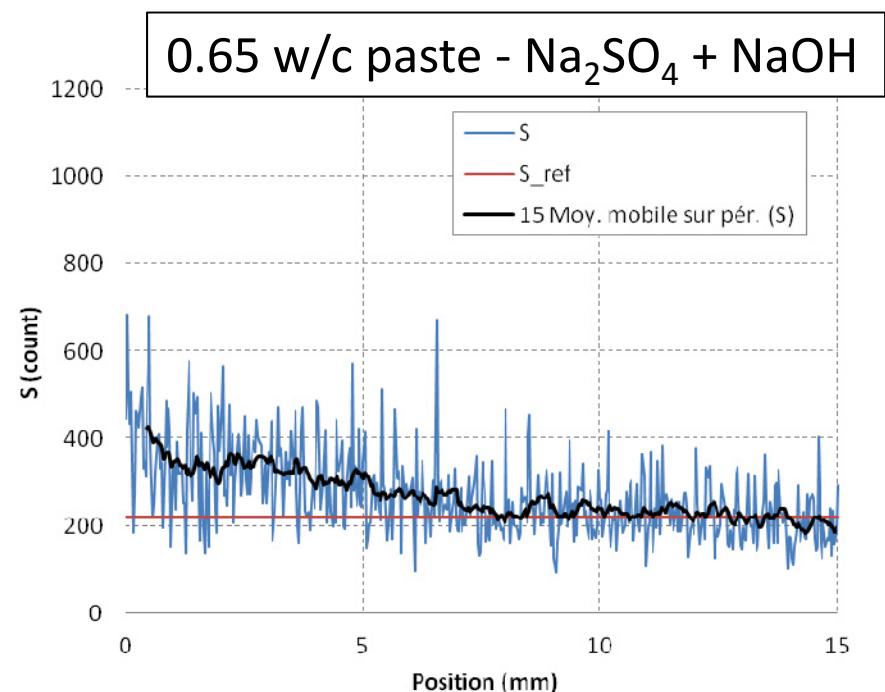
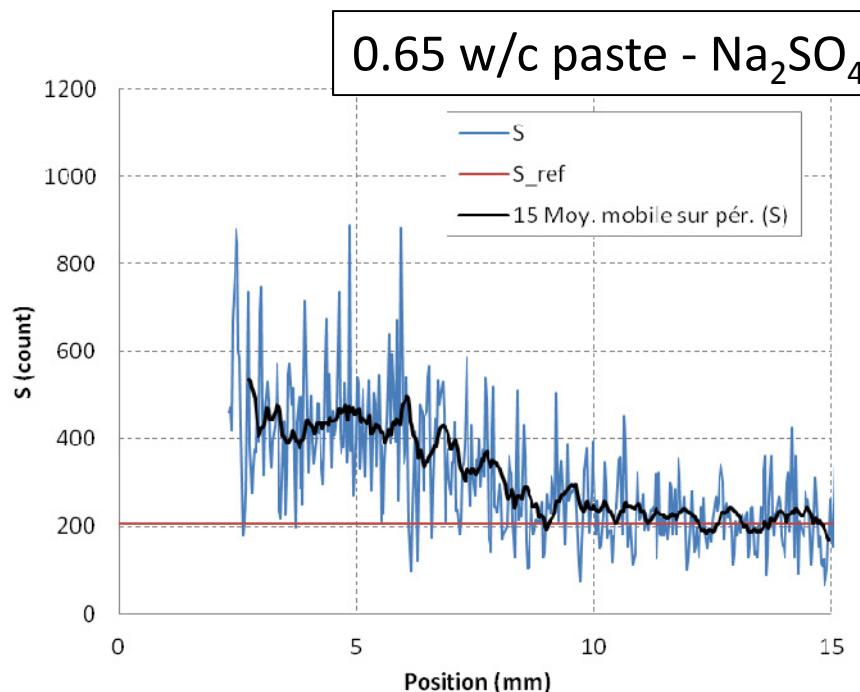
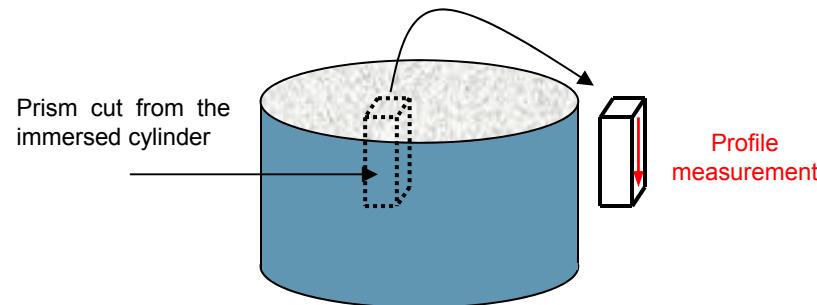
OPC samples in solutions

Sulfur profiles after three months – layer-by-layer chemical analysis



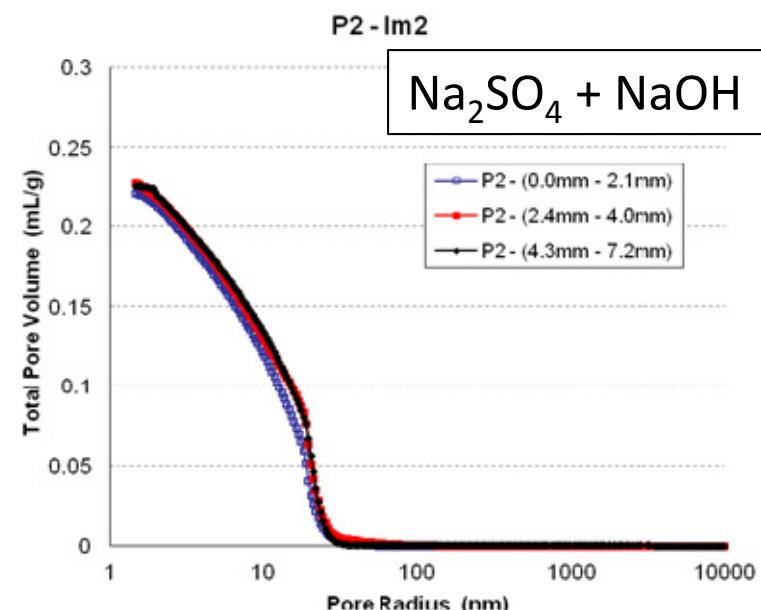
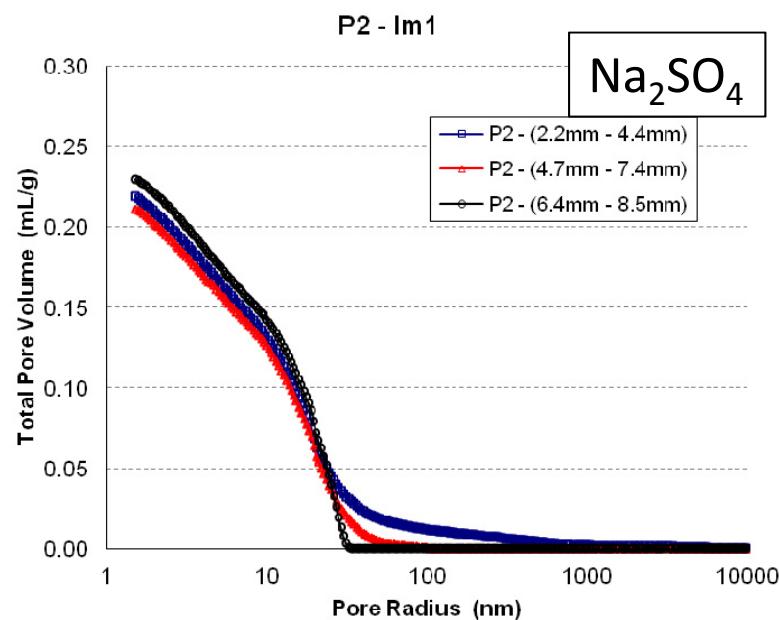
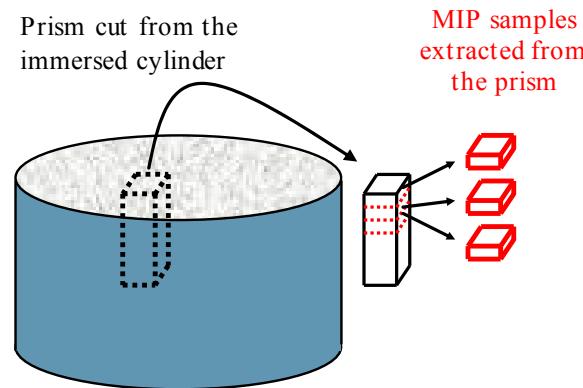
OPC samples in solutions

Sulfur profiles after three months – microprobe



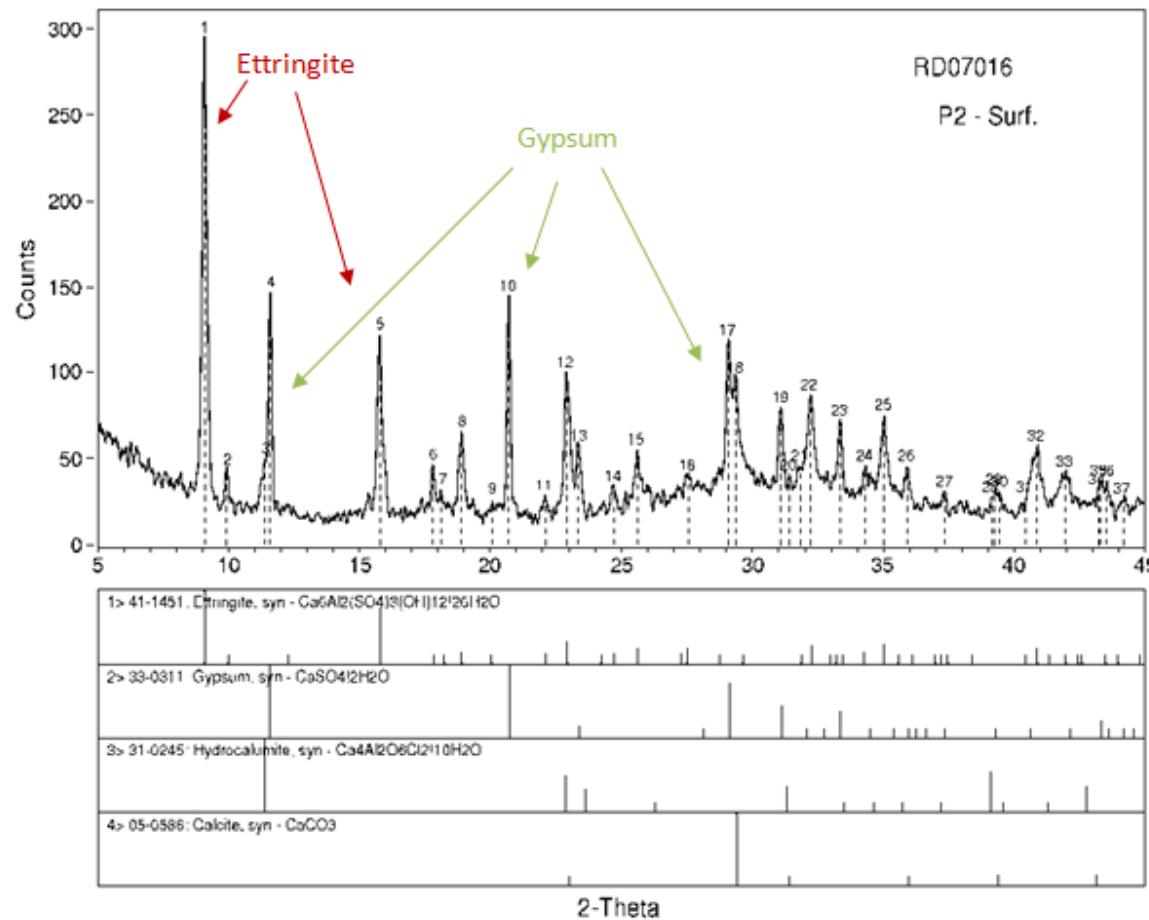
OPC samples in solutions

MIP pore size distribution after three months



OPC samples in solutions

XRD on sample exposed to Na_2SO_4





Vault pastes exposed to aggressive solutions

Vault pastes in solutions

- Tests performed on pastes cured 56 days replicating Vault 1/4 and 2.
- Paste samples at the same w/b but without SCM were also prepared.
- Five contact solutions were used.
- Solutions renewed once per week.
- Samples characterized after 3 and 8 months in solution.

Vault pastes in solutions

Contact solutions

Salts	Solution 1	Solution 2	Solution 3	Solution 4	Solution 5
Na ₂ SO ₄	150 mM				
NaOH	0 mM	500 mM	0 mM	500 mM	0 mM
NaNO ₃	0 mM	0 mM	3000 mM	3000 mM	0 mM
Na ₂ CO ₃	0 mM	0 mM	0 mM	0 mM	150 mM

Vault pastes in solutions

PV1b



PV2b



PV1

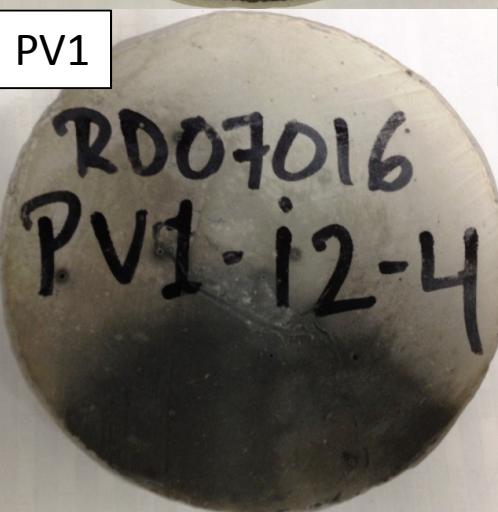


PV2



Salts	Solution 1
Na ₂ SO ₄	150 mM
NaOH	0 mM
NaNO ₃	0 mM
Na ₂ CO ₃	0 mM

Vault pastes in solutions



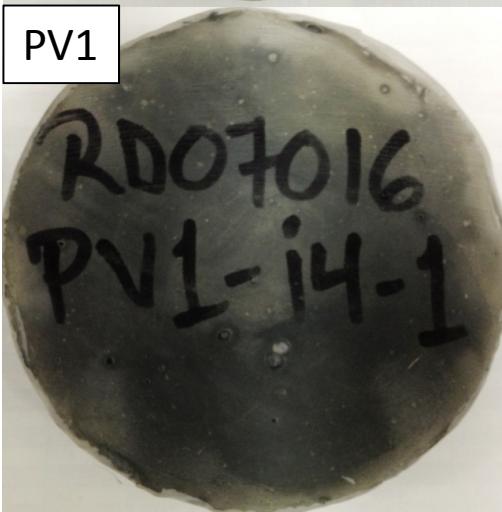
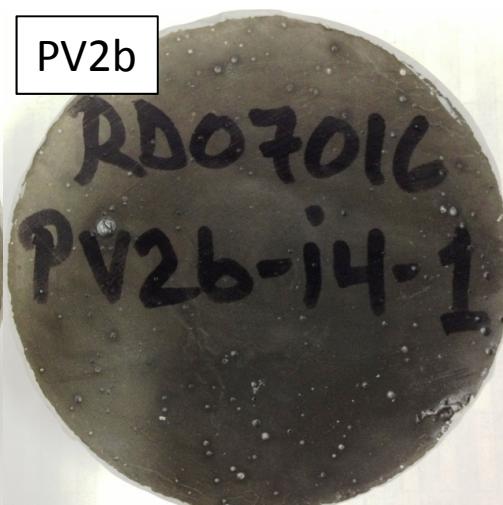
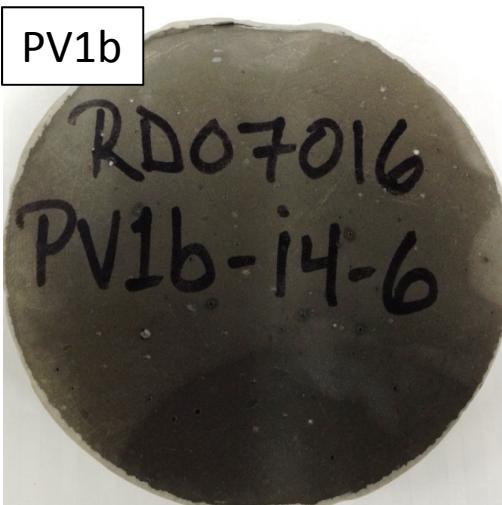
Salts	Solution 2
Na ₂ SO ₄	150 mM
NaOH	500 mM
NaNO ₃	0 mM
Na ₂ CO ₃	0 mM

Vault pastes in solutions



Salts	Solution 3
Na ₂ SO ₄	150 mM
NaOH	0 mM
NaNO ₃	3000 mM
Na ₂ CO ₃	0 mM

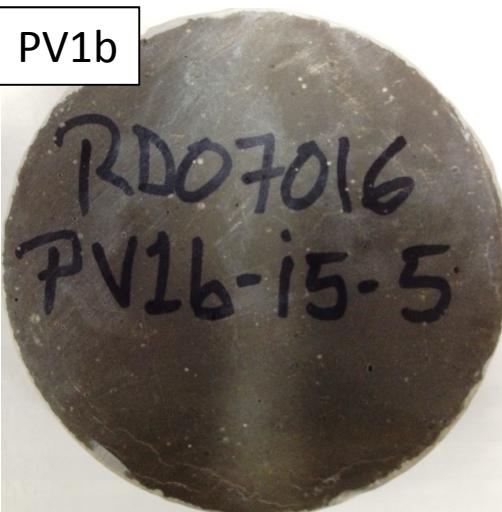
Vault pastes in solutions



Salts	Solution 4
Na ₂ SO ₄	150 mM
NaOH	500 mM
NaNO ₃	3000 mM
Na ₂ CO ₃	0 mM

Vault pastes in solutions

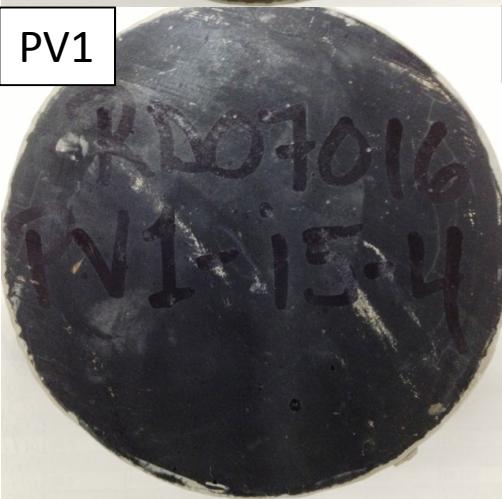
PV1b



PV2b



PV1



PV2

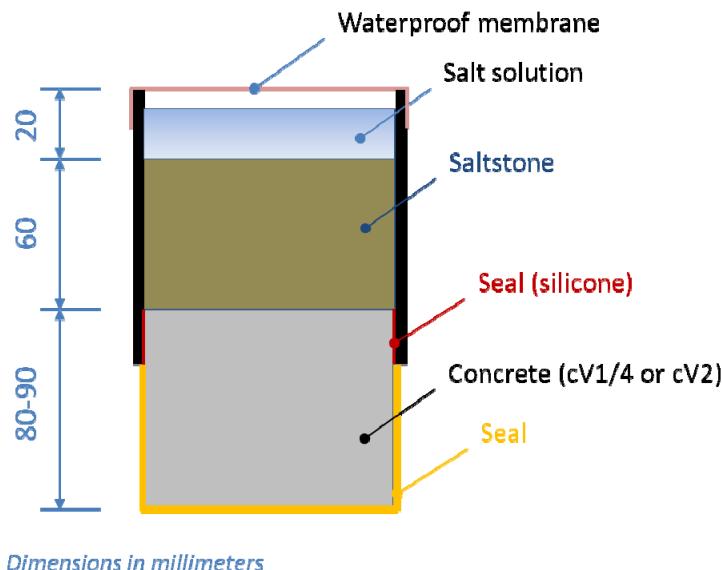


Salts	Solution 5
Na ₂ SO ₄	150 mM
NaOH	0 mM
NaNO ₃	0 mM
Na ₂ CO ₃	150 mM

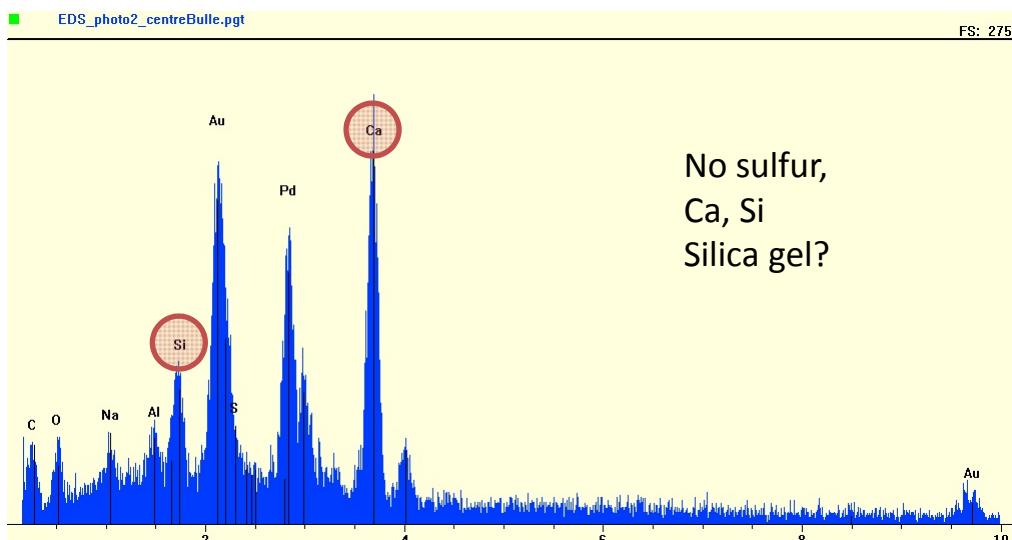
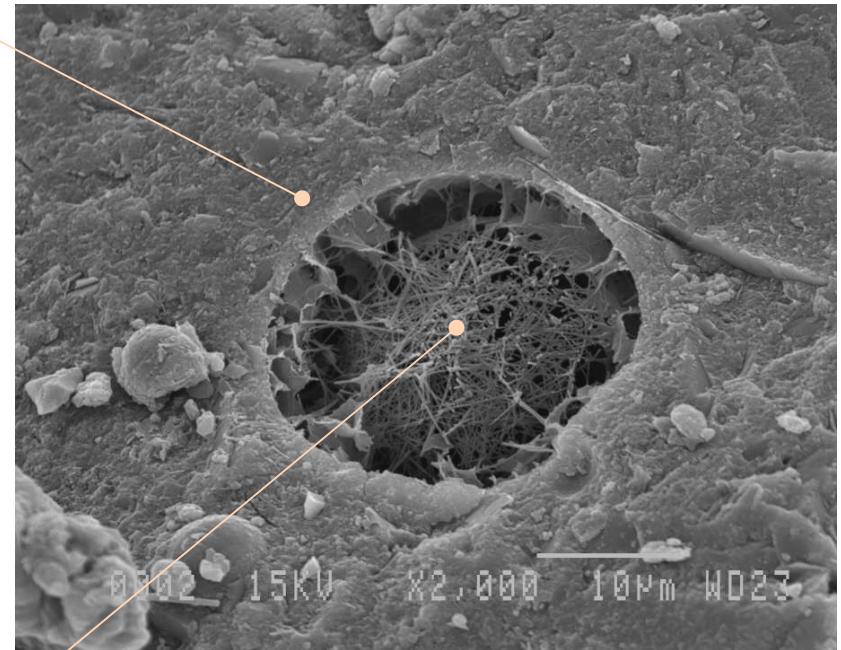
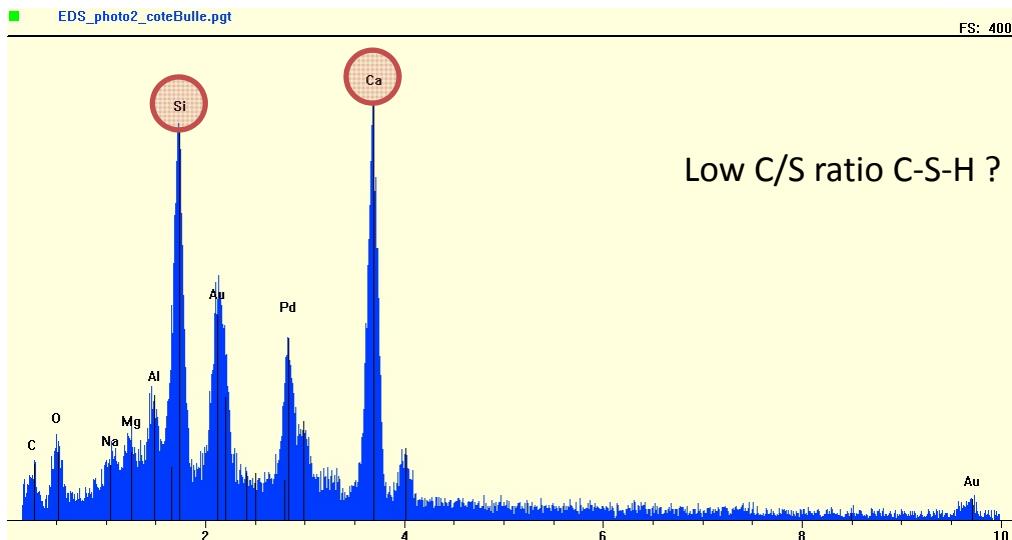
Saltstone/concrete samples

Saltstone/concrete samples

- Samples are 2 years old.
- Analysis in ongoing.

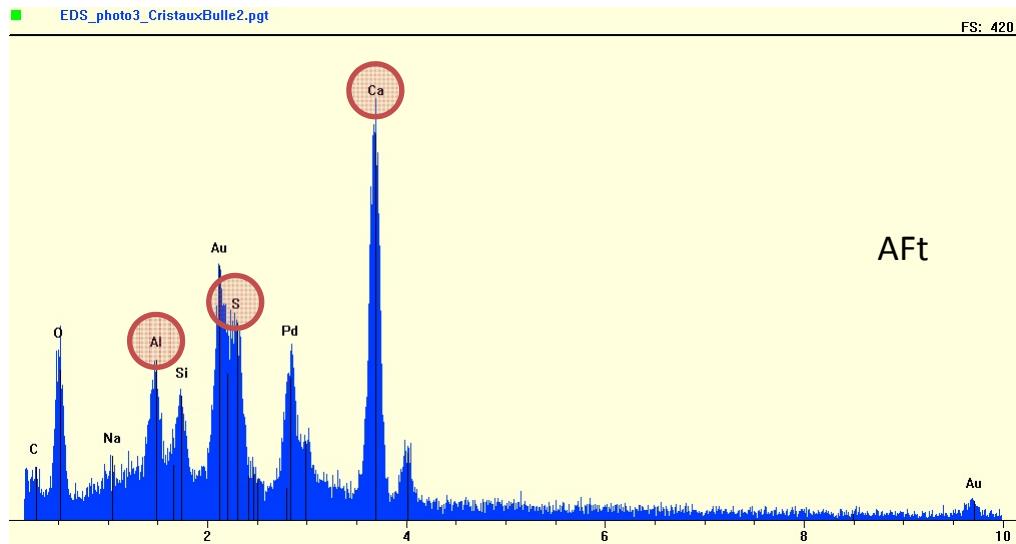


Saltstone/concrete samples



August 2014

Saltstone/concrete samples



AFT

