



IFSTTAR

FRENCH INSTITUTE OF SCIENCE
AND TECHNOLOGY FOR TRANSPORT,
DEVELOPMENT AND NETWORK



IMN

INSTITUT DES MATÉRIAUX
JEAN ROUXEL



UNIVERSITÉ DE NANTES

Microstructural investigations and chemo-hydro-mechanical couplings in soil stabilisation

D. Deneele

GNMEBA – Nantes 07.06.16



FRENCH INSTITUTE OF SCIENCE
AND TECHNOLOGY FOR TRANSPORT,
DEVELOPMENT AND NETWORK

IFSTTAR is a major player in the European research on the city and the territories, transportation and civil engineering.

The French Institute of Science and Technology for Transport, Development and Networks, born on January 1st 2011, from the merger of INRETS and LCPC, is a Public Institution of a Scientific and Technical Nature, under the joint supervision of the Ministry of Environment, Energy and the Sea and the ministry of higher education and research.

MAST - Materials and Structures

GERS - Geotechnical engineering, Environment,
Natural hazards and Earth sciences

COSYS - Components and systems

TS2 - Transport, health, safety

AME - Planning, Mobilities and Environment



Use of natural soils in earthworks

Road network and industrial platforms



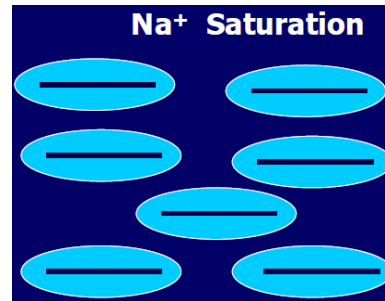
→ Soil stabilisation with binders

Stabilisation with binders

□ Binder adding

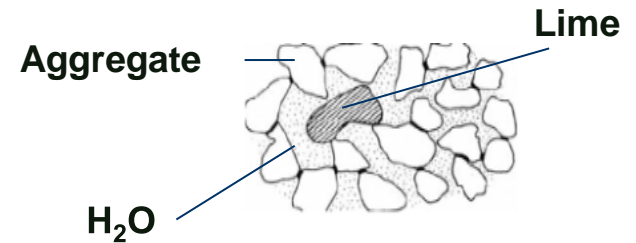


□ Short-term effects

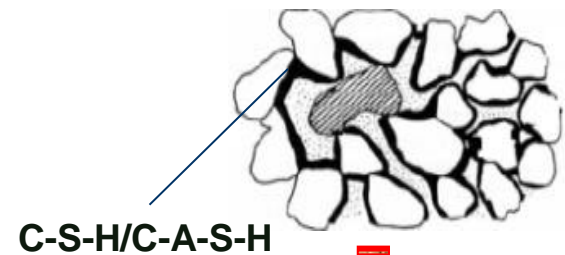


Decrease of soil plasticity and swelling potential

□ Long-term effects



- ✓ pH > 12
- ✓ Dissolution
- ✓ Si, Al, ... Ca



Increase of soil resistance

Stabilisation failure

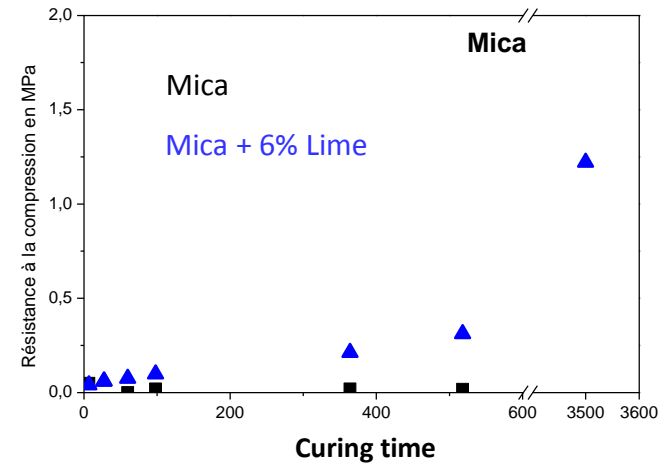
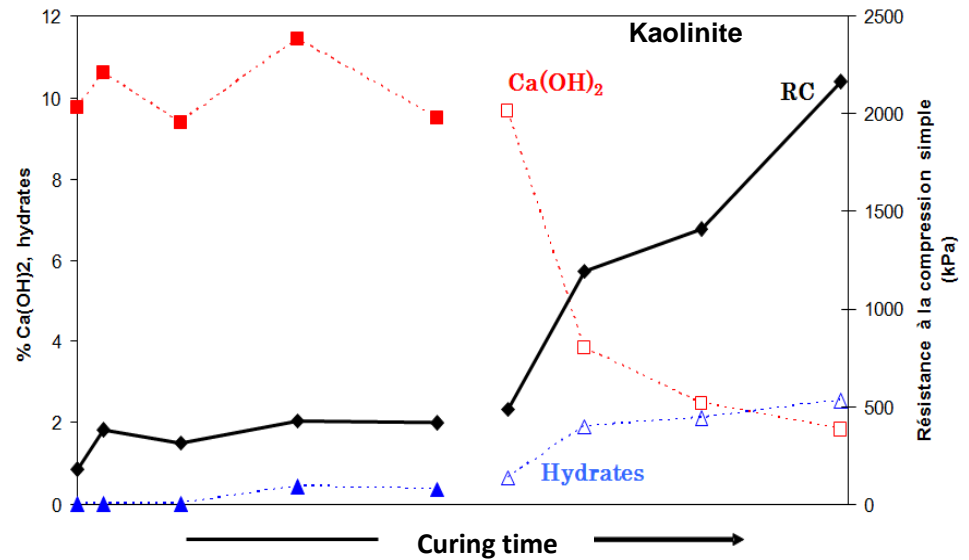
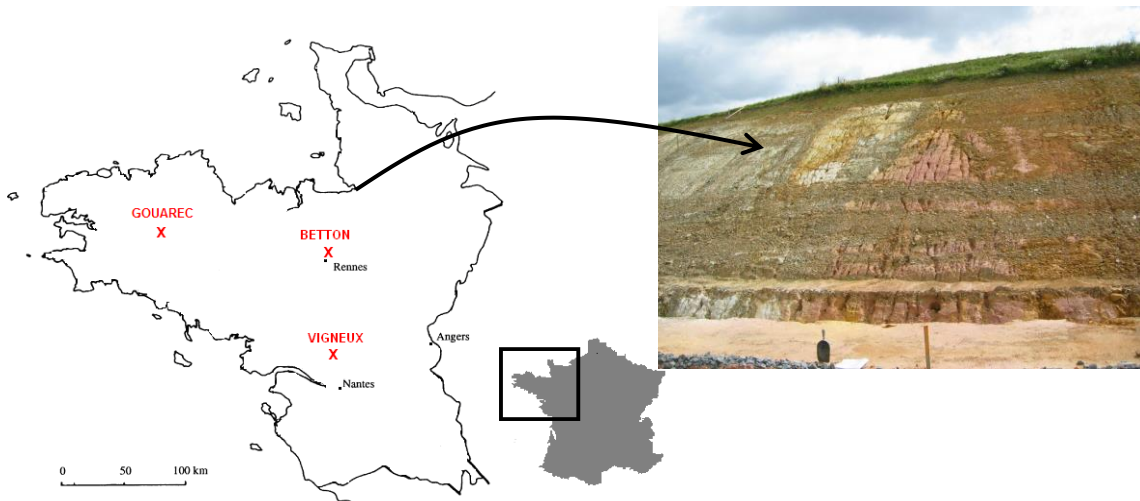
⇒ Low pozzolanic activity

Maubec PhD thesis (2010)

⇒ Short-Term modification ?

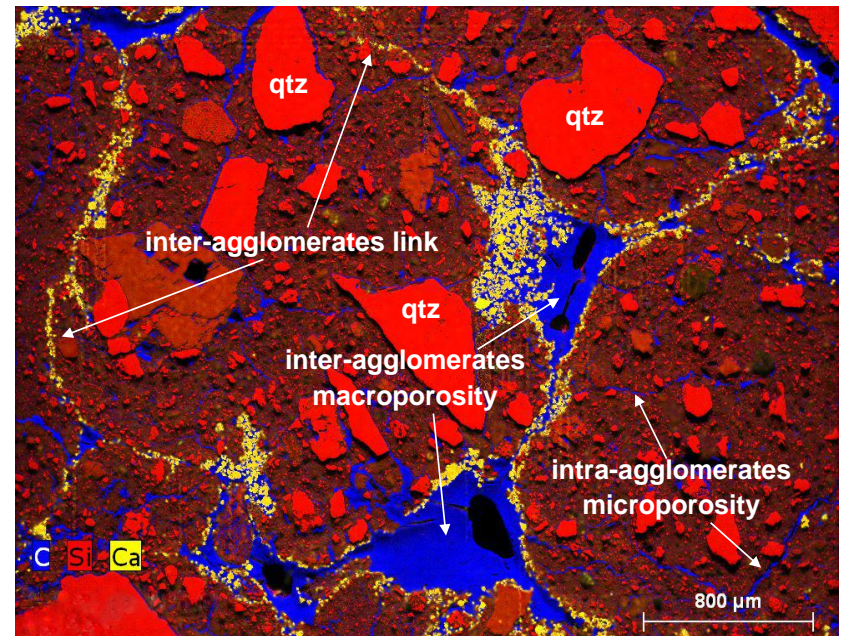
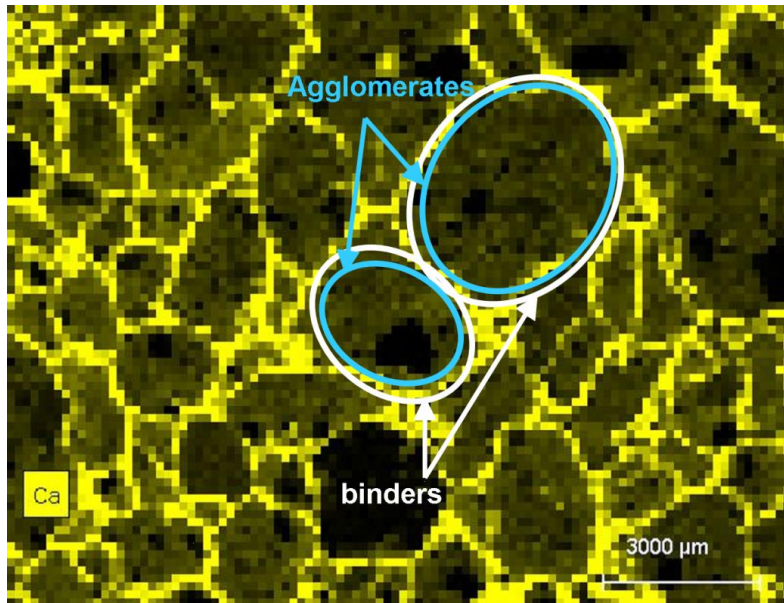
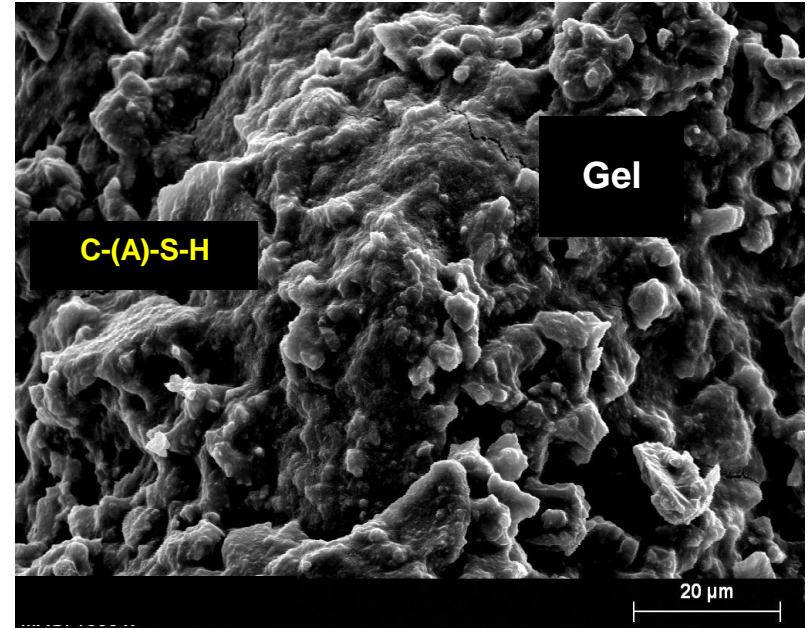
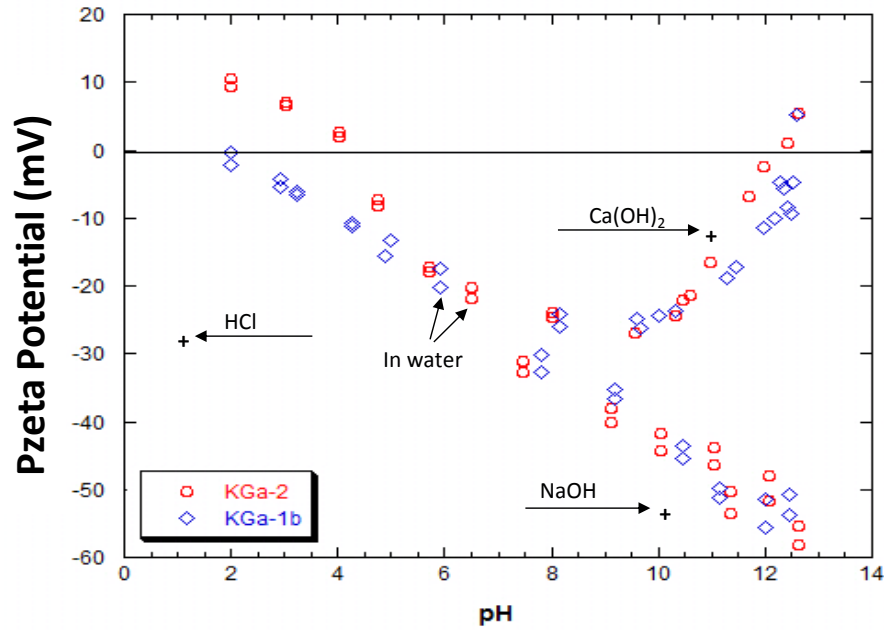
⇒ Soils rich in micas

Delavernhe (2011)



⇒ Short-term modification ?

Understanding from the particles organisation to compacted structure

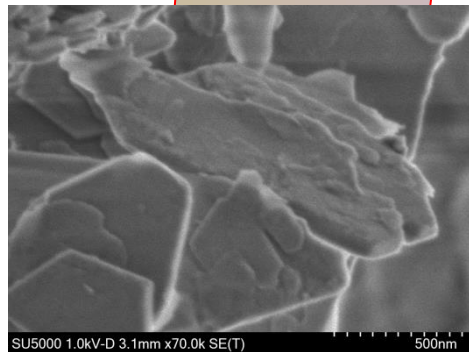


What about the imaging of soil microstructure ?

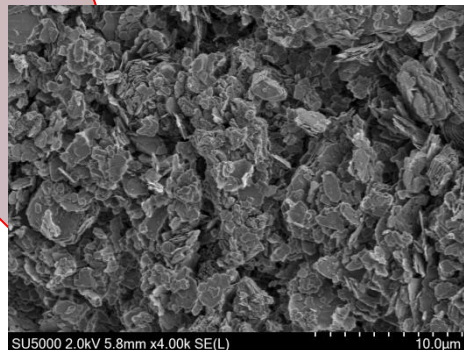
In geotechnical applications, the understanding of the mechanical behaviour or macroscopic properties of soils goes through the elementary analysis of soil components and their arrangement



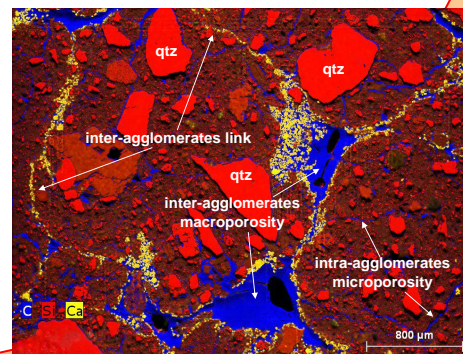
Different techniques and different levels in the soil organization



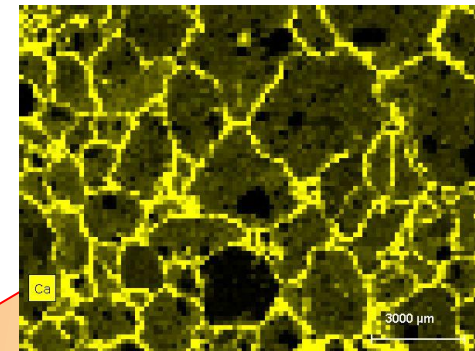
1,5 μm



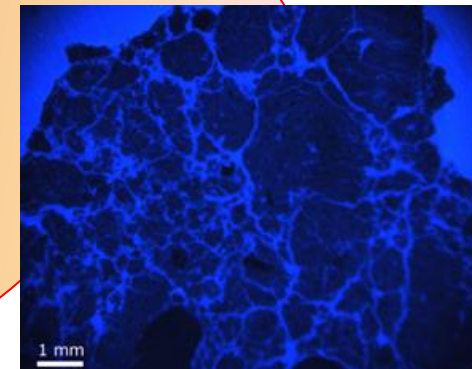
30 μm



1,5 mm

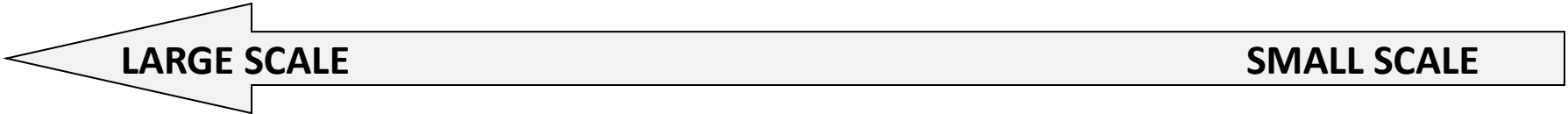
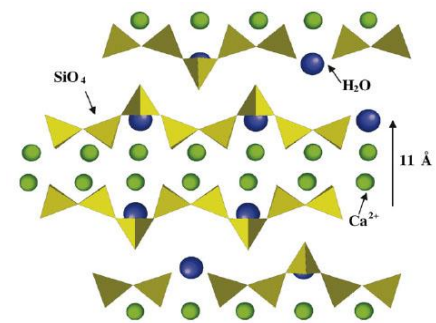
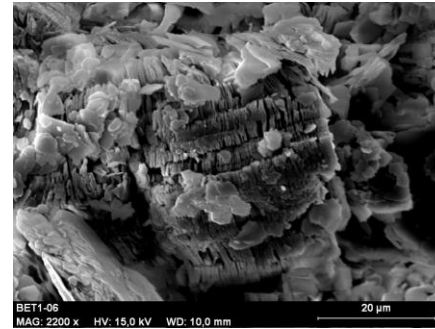


15 mm



Multi-disciplinary and multi-scale approach

Chemo-hydro-mechanical approach in soils stabilisation



Thermal Analysis

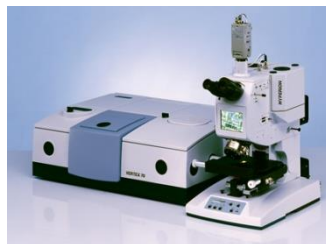


XRD



SEM, TEM

FTIR



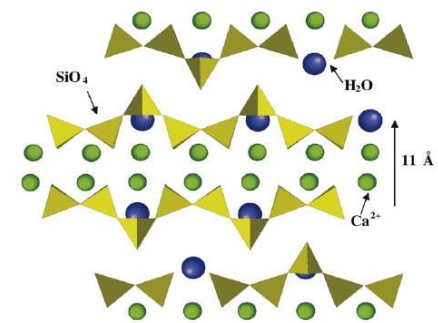
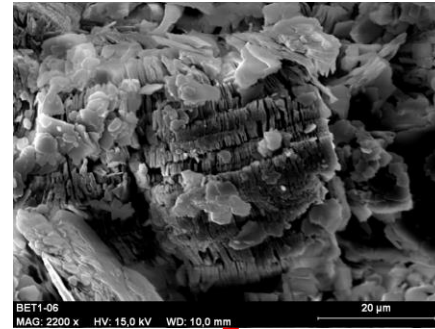
Zetameter

Solid state NMR



Multi-disciplinary and multi-scale approach

Chemo-hydro-mechanical approach in soils stabilisation



Use of Scanning Electron Microscope (SEM)



To assess the soil microstructure:

- 1) For two compaction methods and water contents
- 2) After the lime addition, role of the pozzolanic reaction

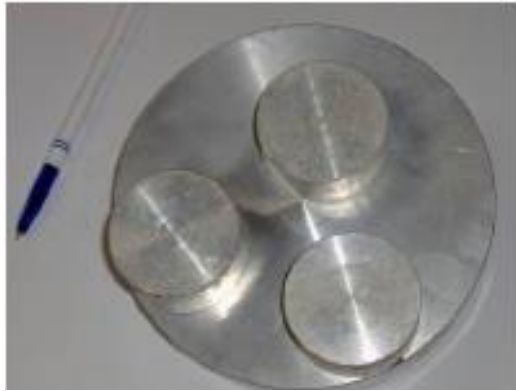
SEM - Preparation of the samples

- Conventional SEM – HITACHI S570 – LaB6 Tip
- Soil pieces were :
 - quickly frozen with liquid nitrogen and then placed in a freeze-drier for 72h for the sublimation of the water.
 - coated with gold
 - SEM → equipped with an energy dispersive X-ray spectrometer (Quantax 200) coupled with a Bruker detector SDD X-Flash.
 - The microscope was operated at an accelerating voltage of 15 kV, under high vacuum !

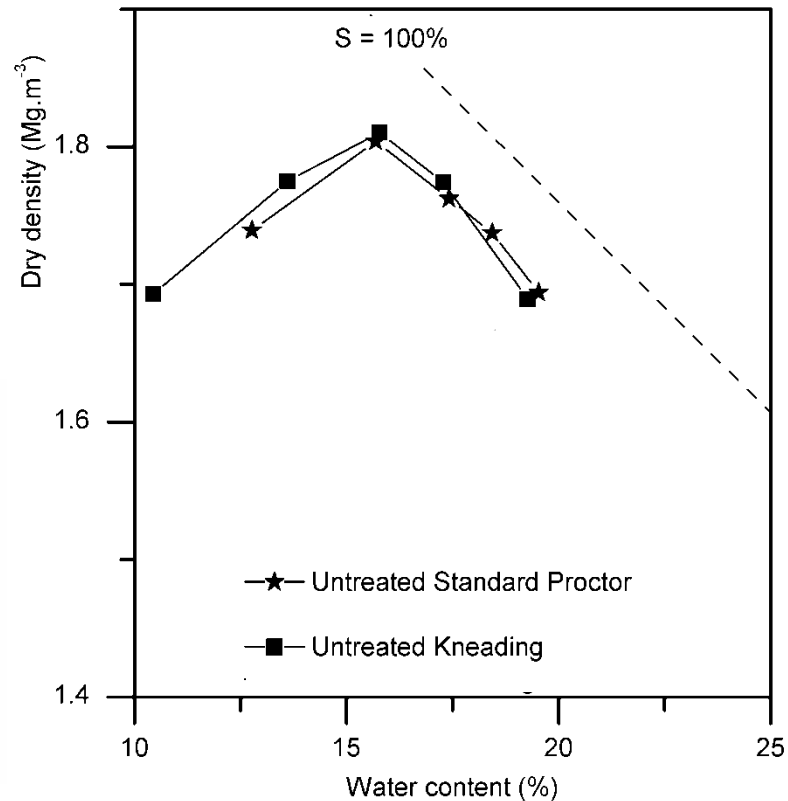
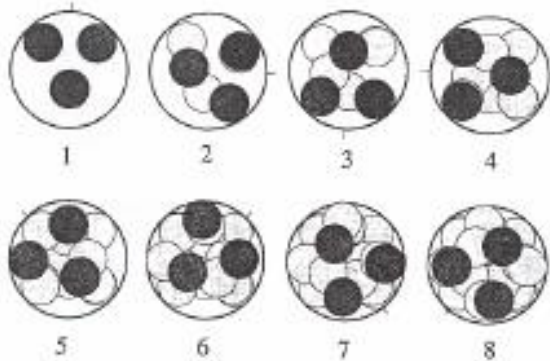
→ to explain MIP data and hydraulic conductivity ?

*Microstructure and hydraulic conductivity of a compacted lime-treated soil –
Cuisinier et al., 2011, Engineering Geology 123.*

Effect of the mode of compaction ?



KNEADING



PROCTOR

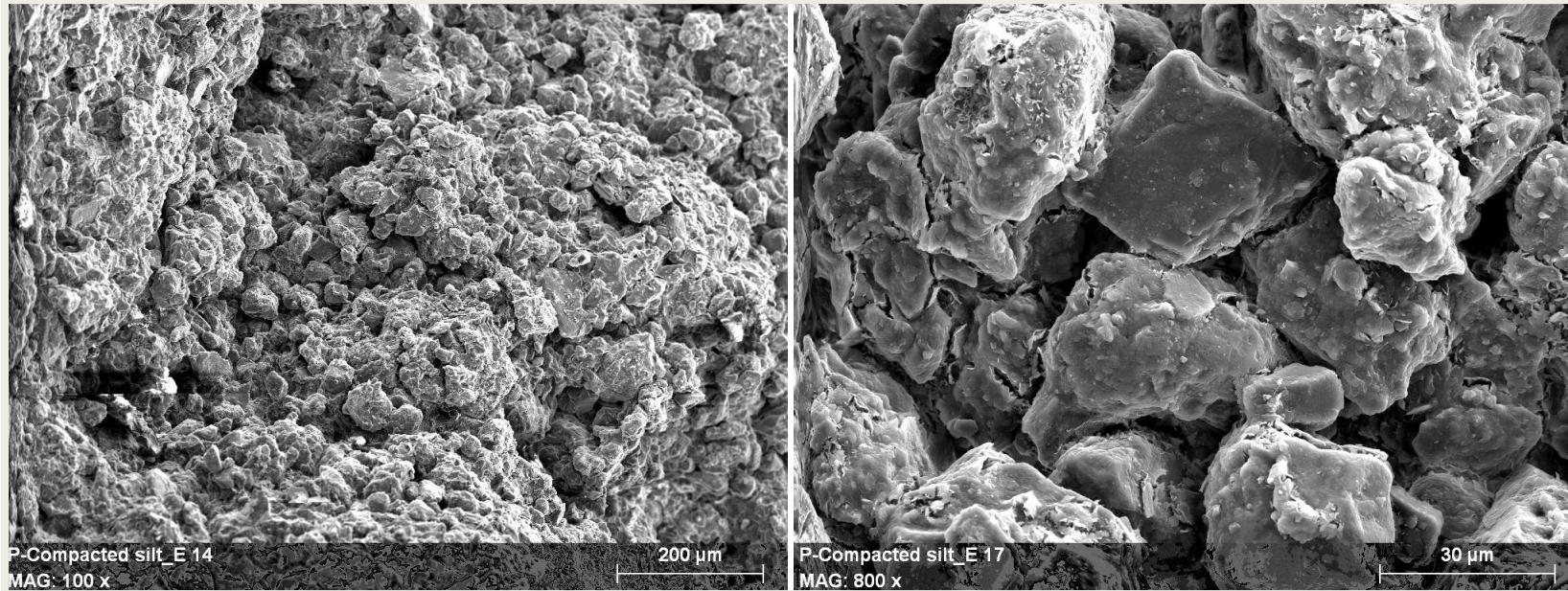


Same compaction curve !

SEM Analysis

OMC

PROCTOR

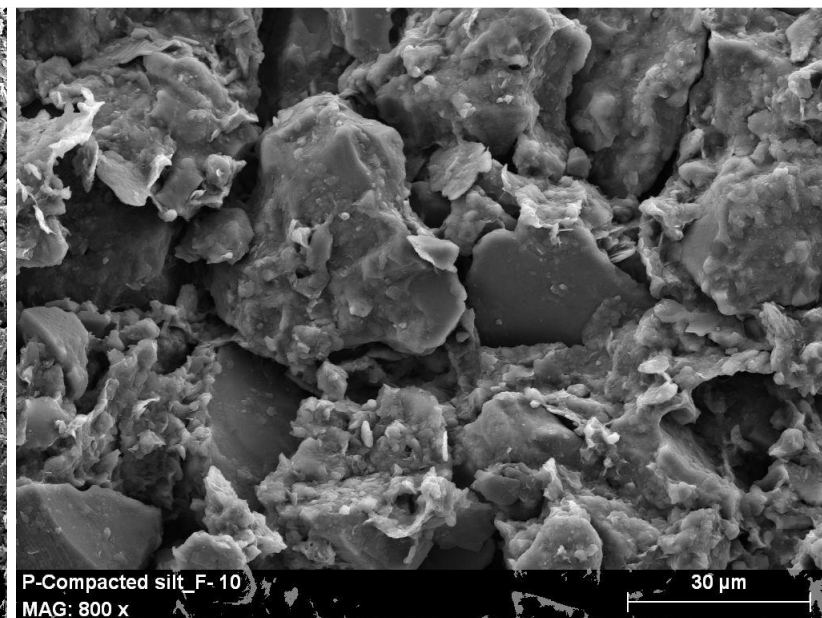
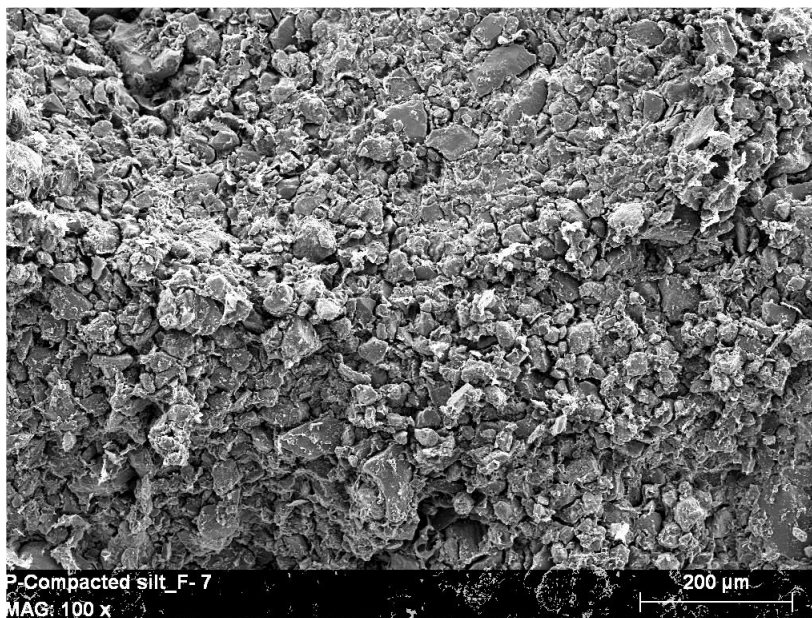
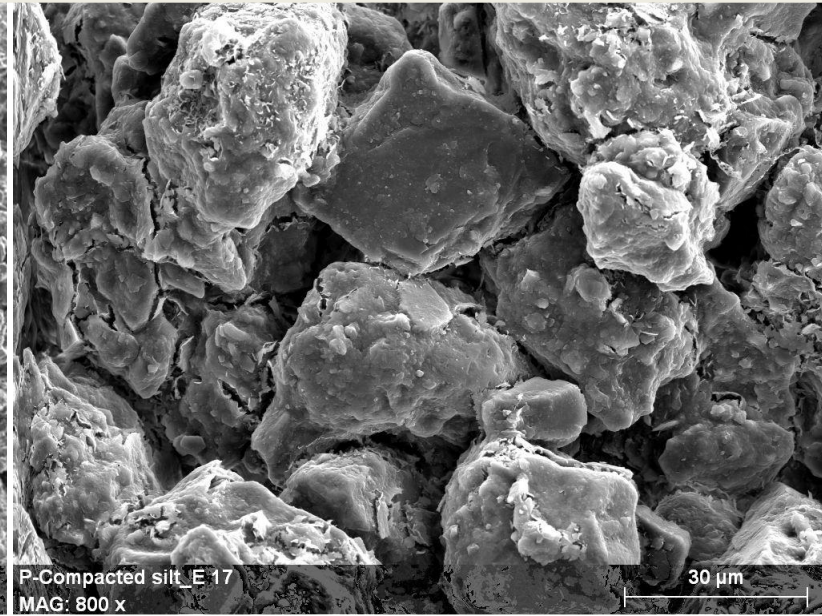
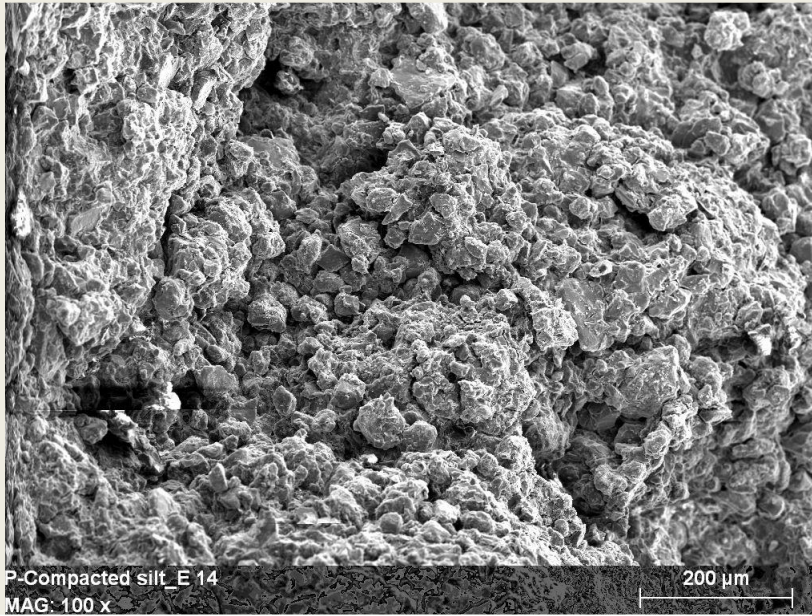


Grains (Quartz & Feldspars) covered by the clayey fraction leaving macropores and micropores

Effect of the water content ?

OMC

PROCTOR

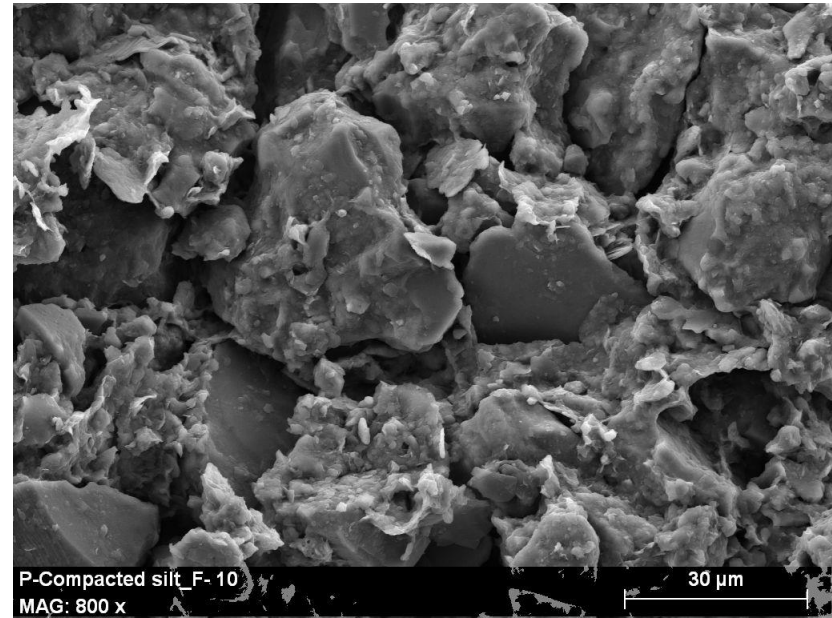
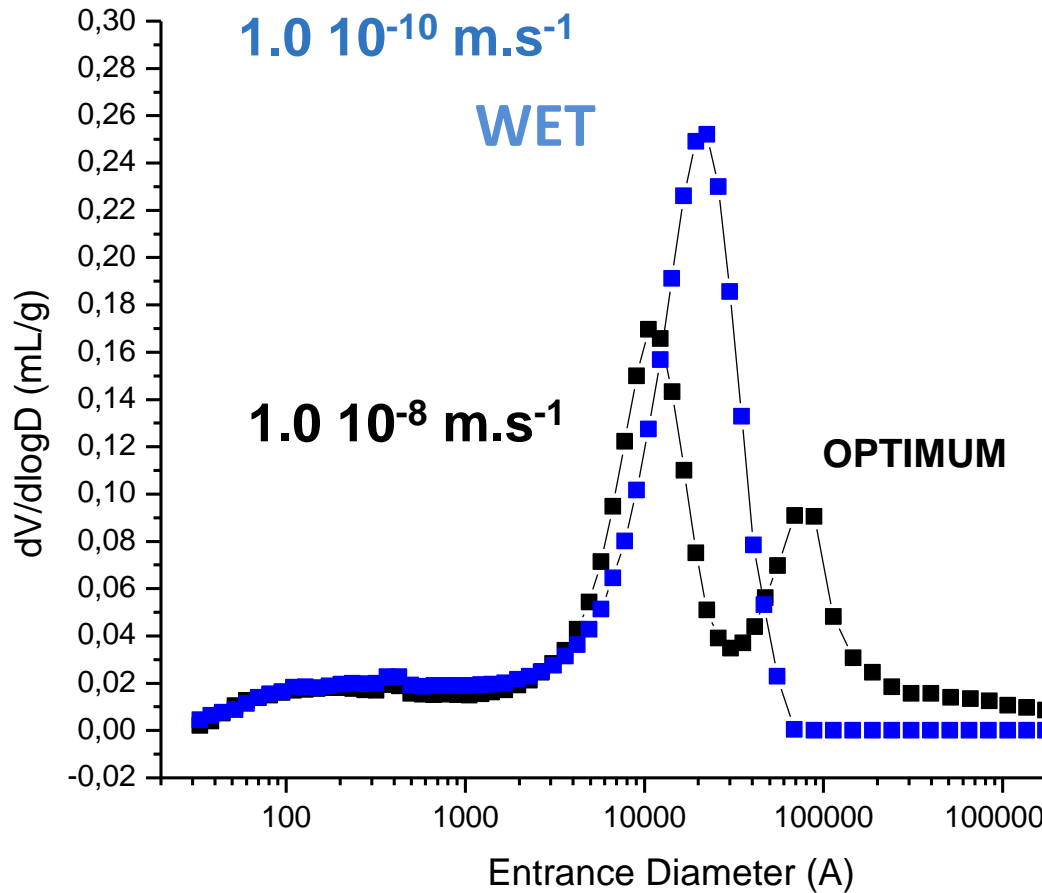


WMC

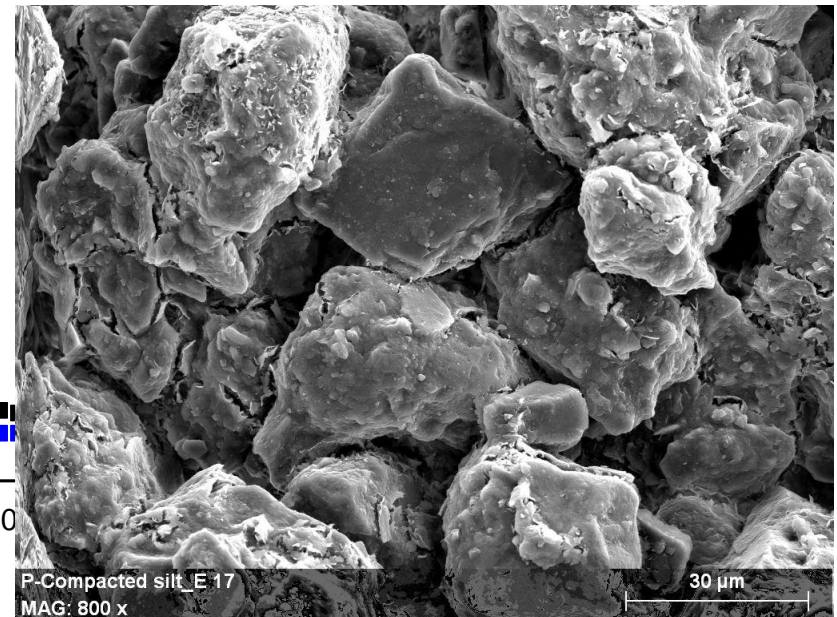
1.2x OMC

PROCTOR COMPACTION

Wet vs. optimum →
dispersion of the clayey
fraction



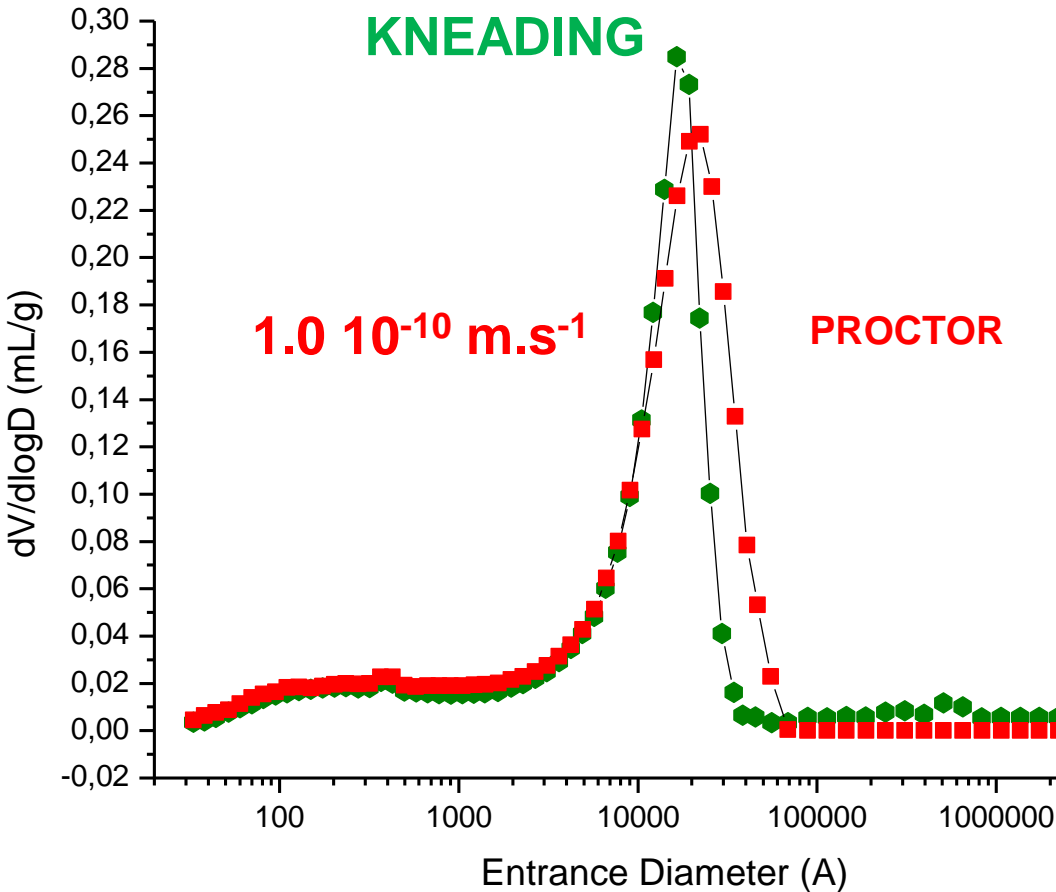
OPTIMUM



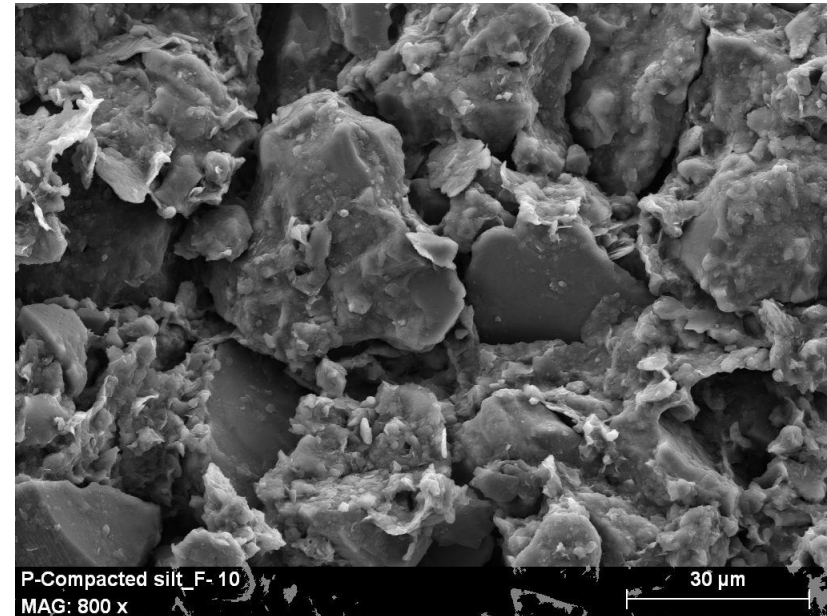
WET CONDITIONS

→ more water =
increase of the dispersion of clays

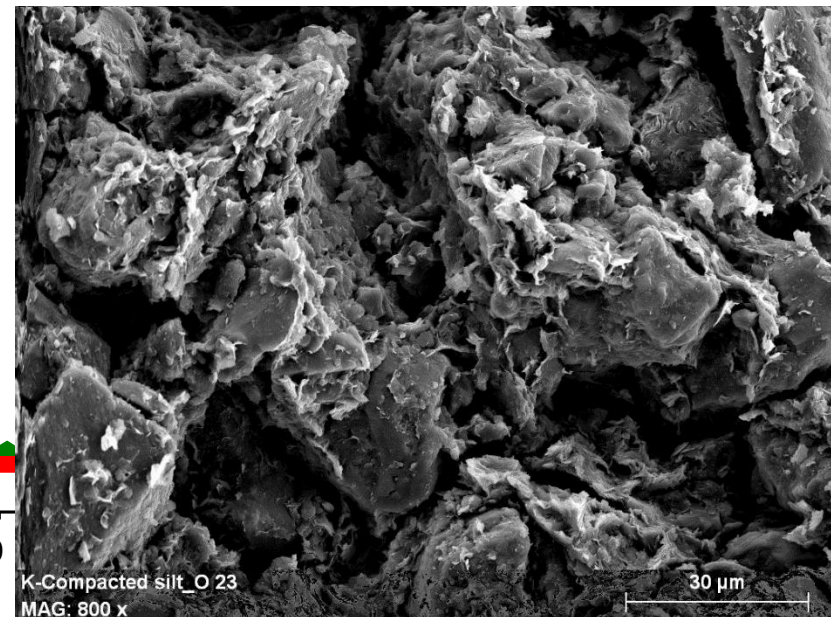
$4.3 \cdot 10^{-11} \text{ m.s}^{-1}$
KNEADING



PROCTOR



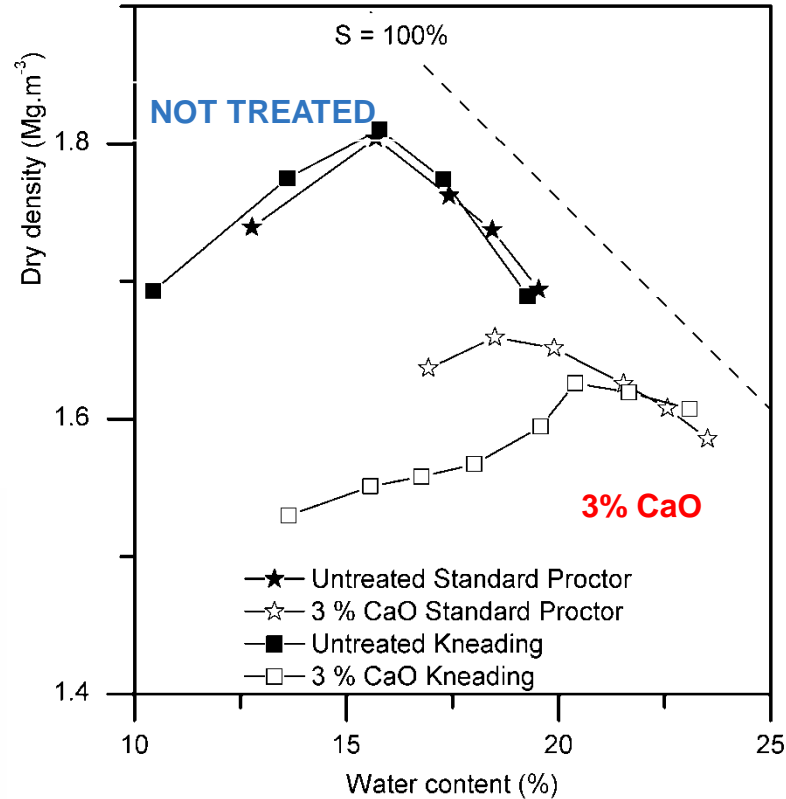
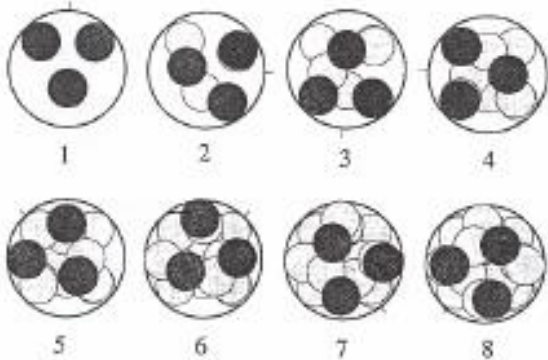
KNEADING



Effect of the lime addition ?



KNEADING



PROCTOR

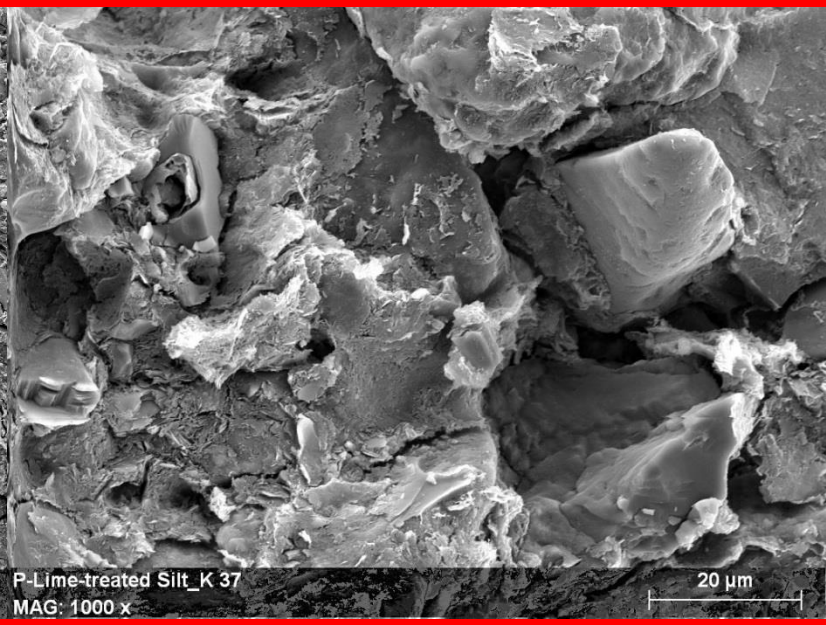
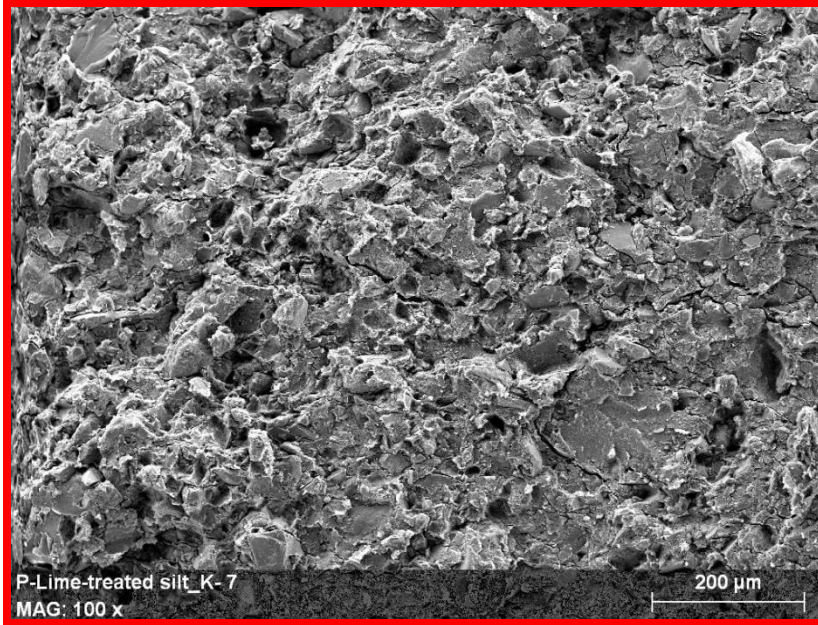


Lime treated 3%CaO

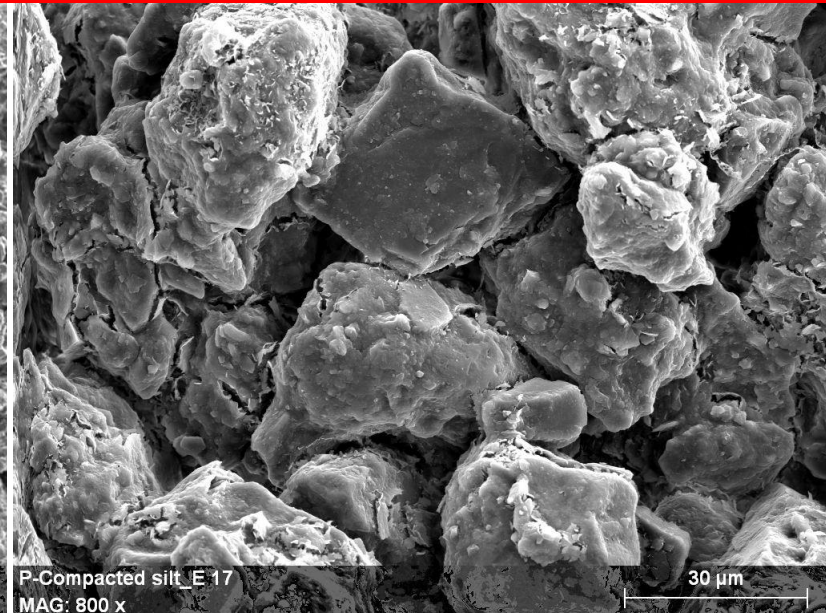
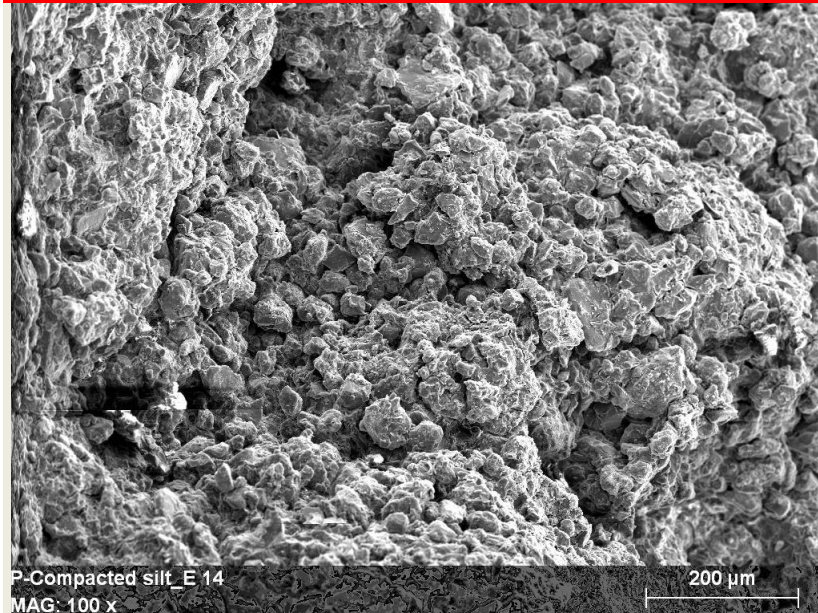
→ Flocculation of the clays and pozzolanic reaction

SEM observations - 3% CaO – Proctor compaction

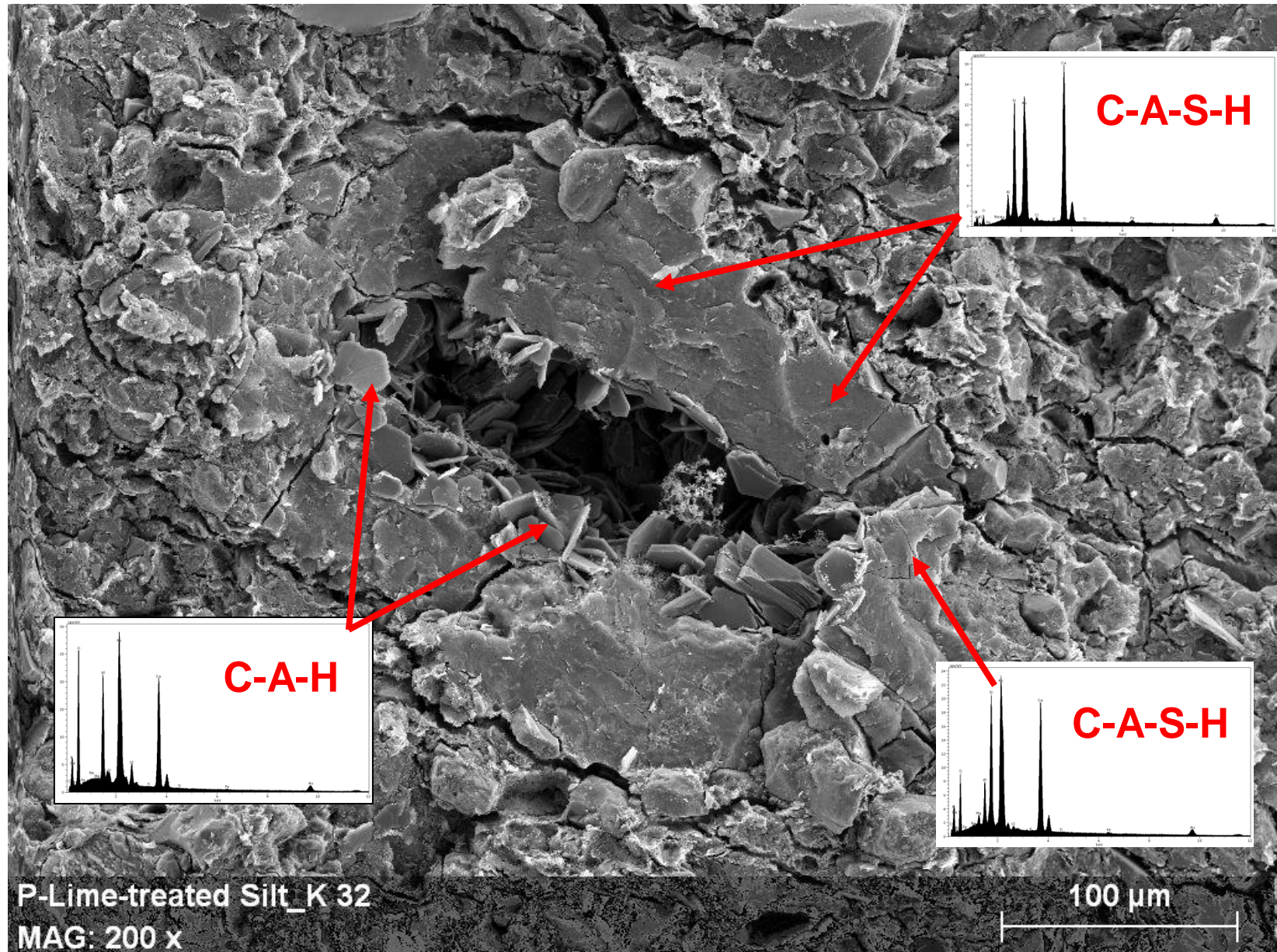
3%CaO – 28d
of curing



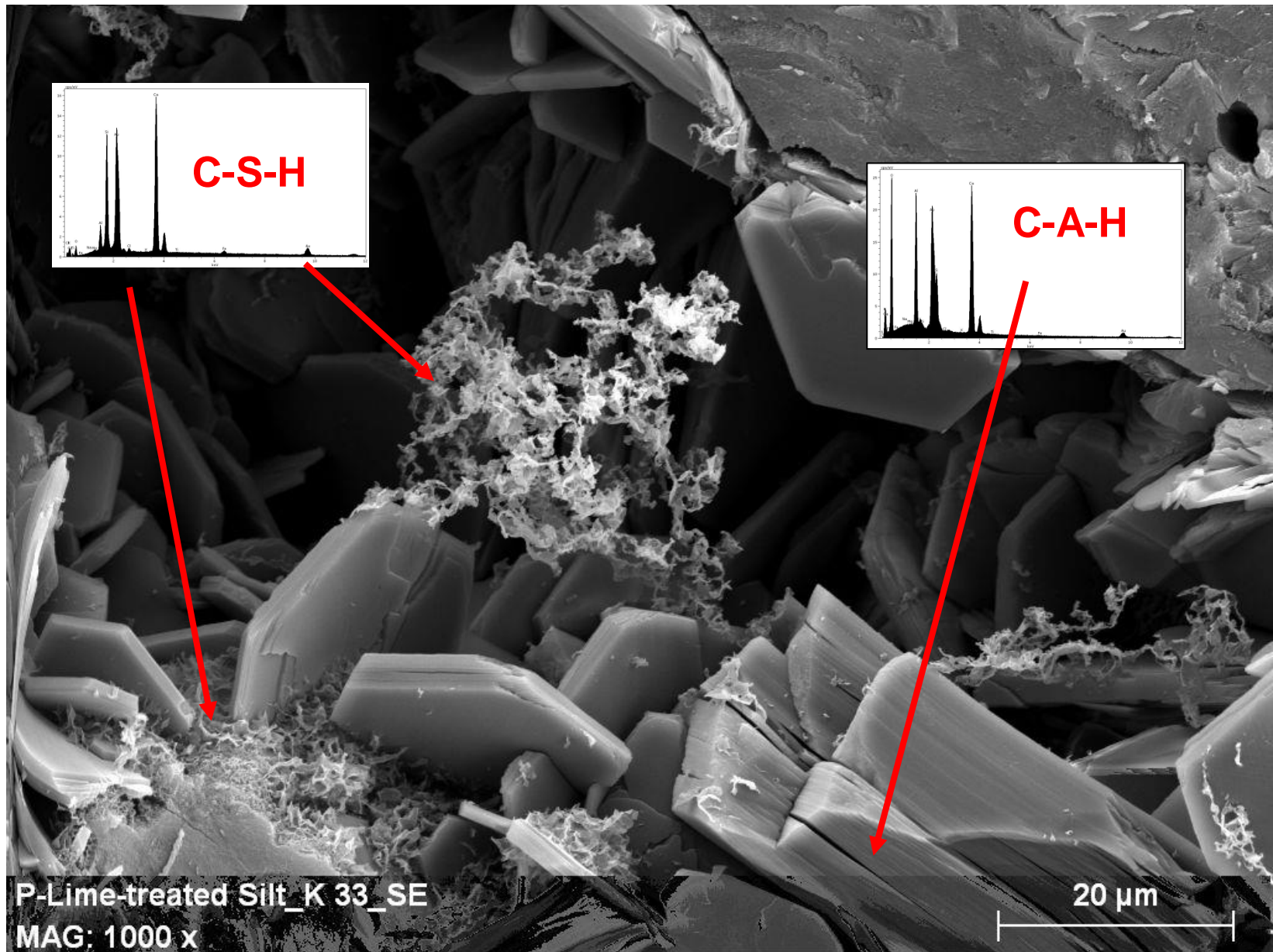
Raw silt



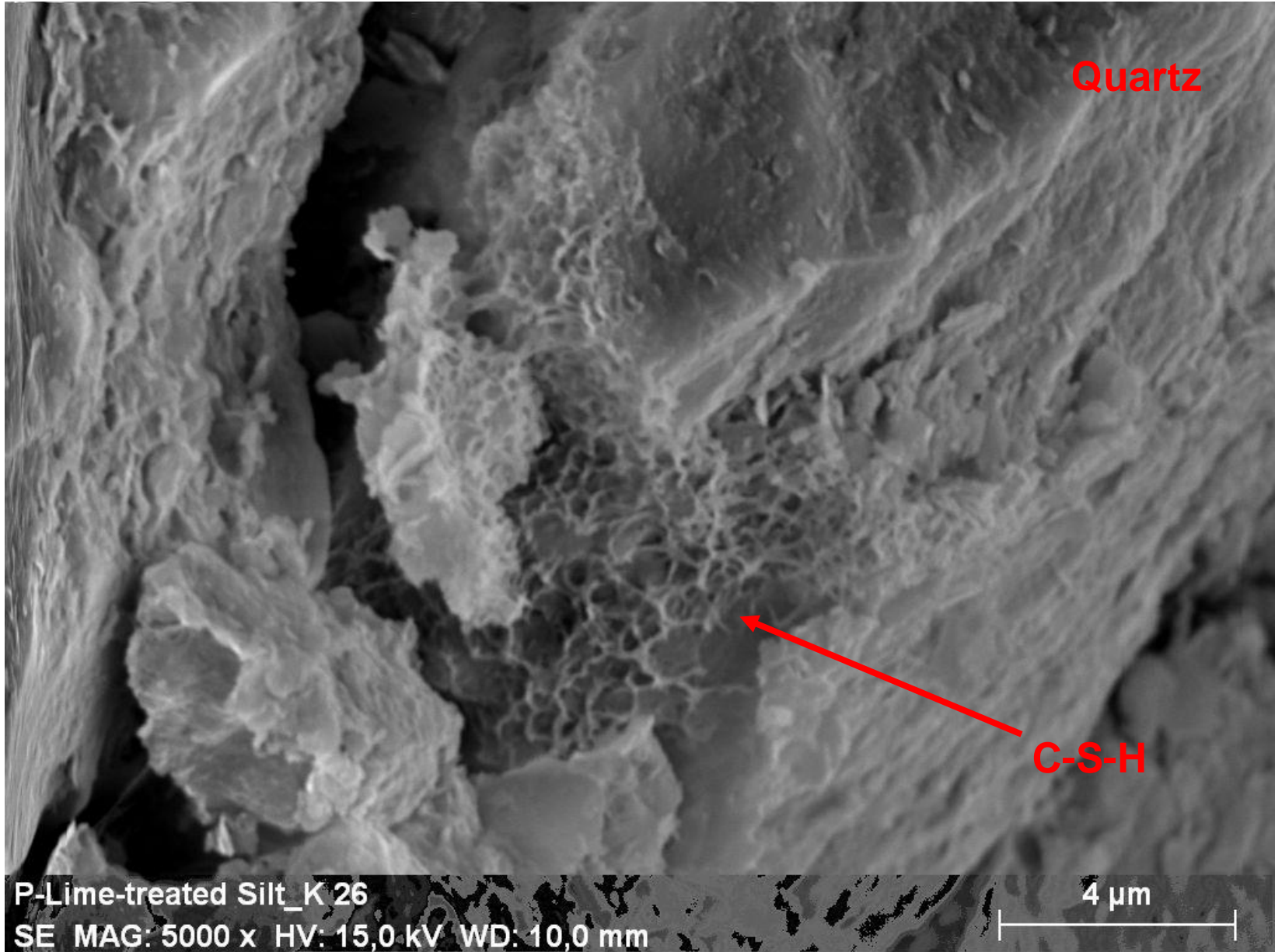
SEM observations - 3% CaO – Proctor compaction



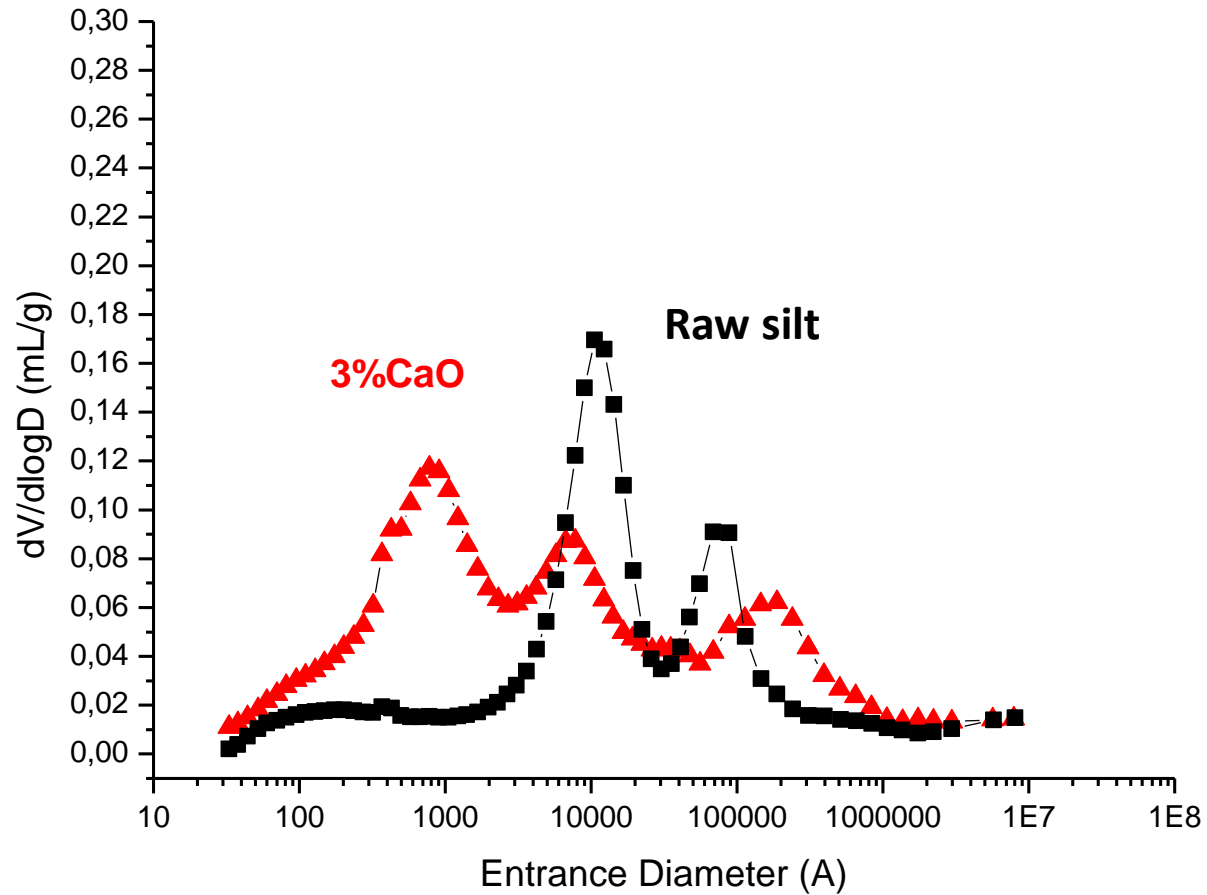
SEM observations - 3% CaO – Proctor compaction



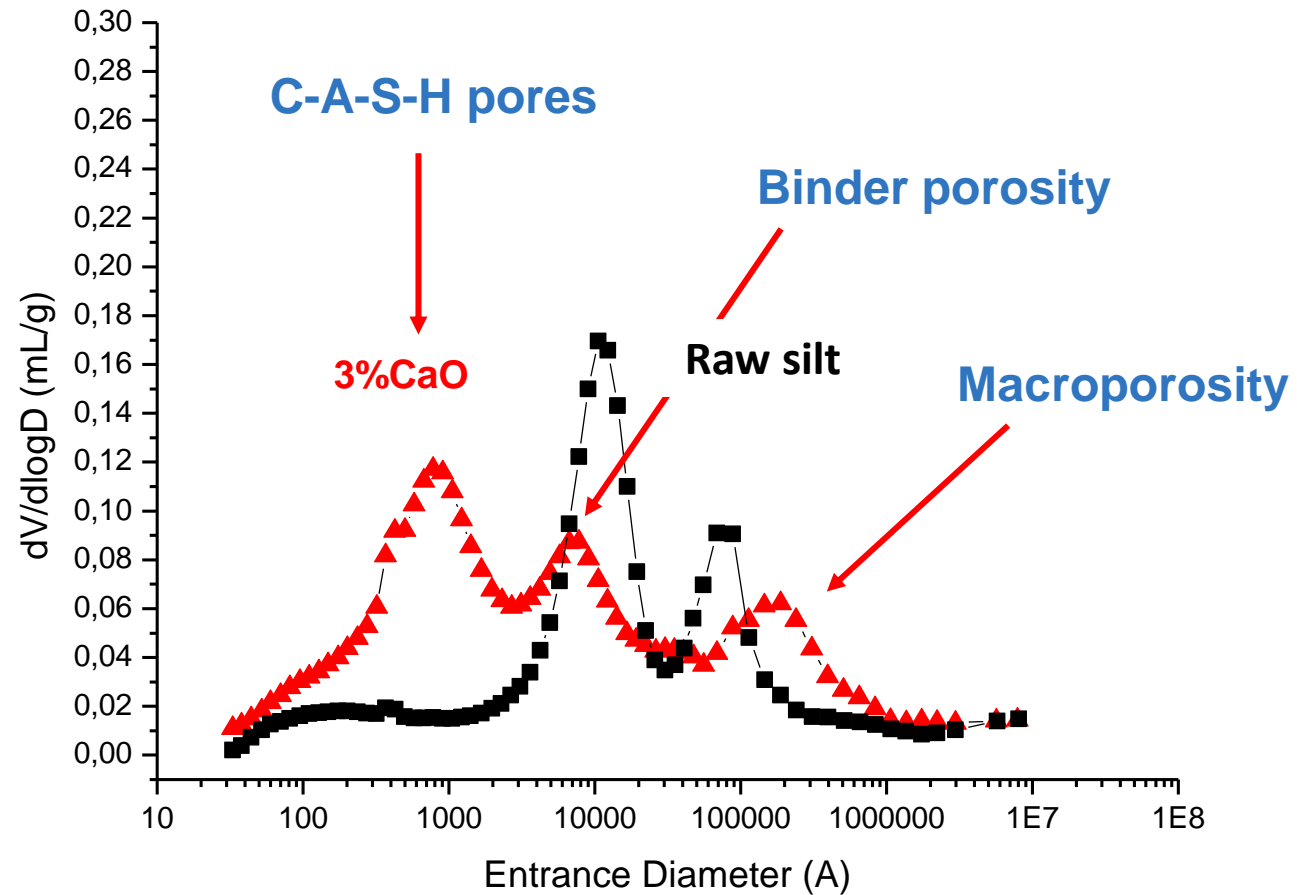
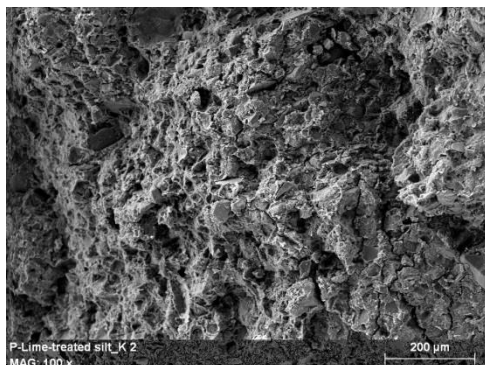
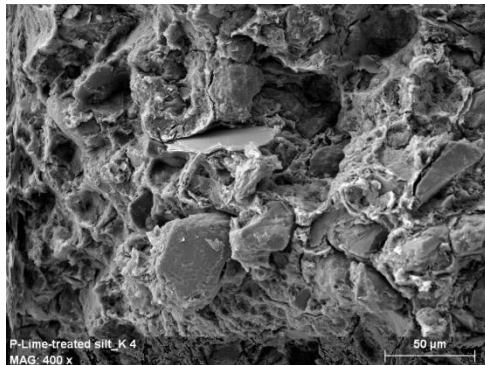
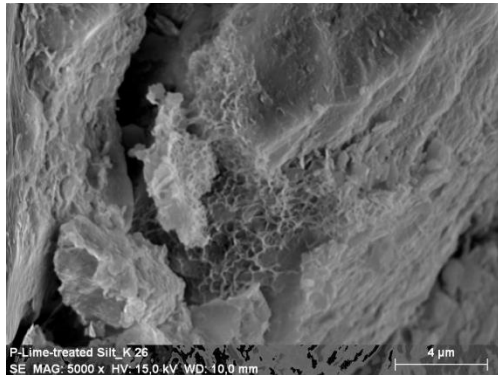
SEM observations - 3% CaO – Proctor compaction



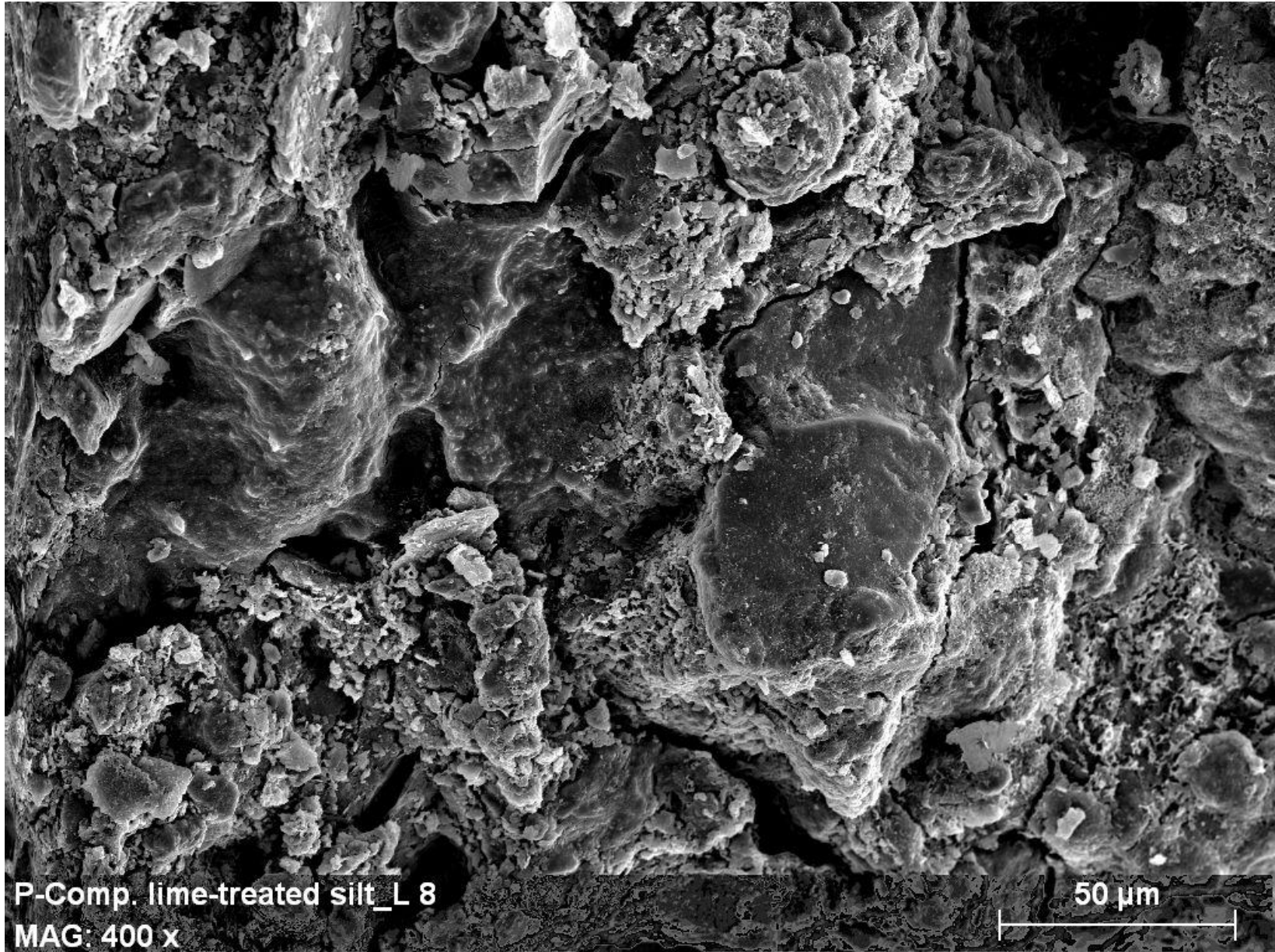
SEM vs. MIP data - Interest



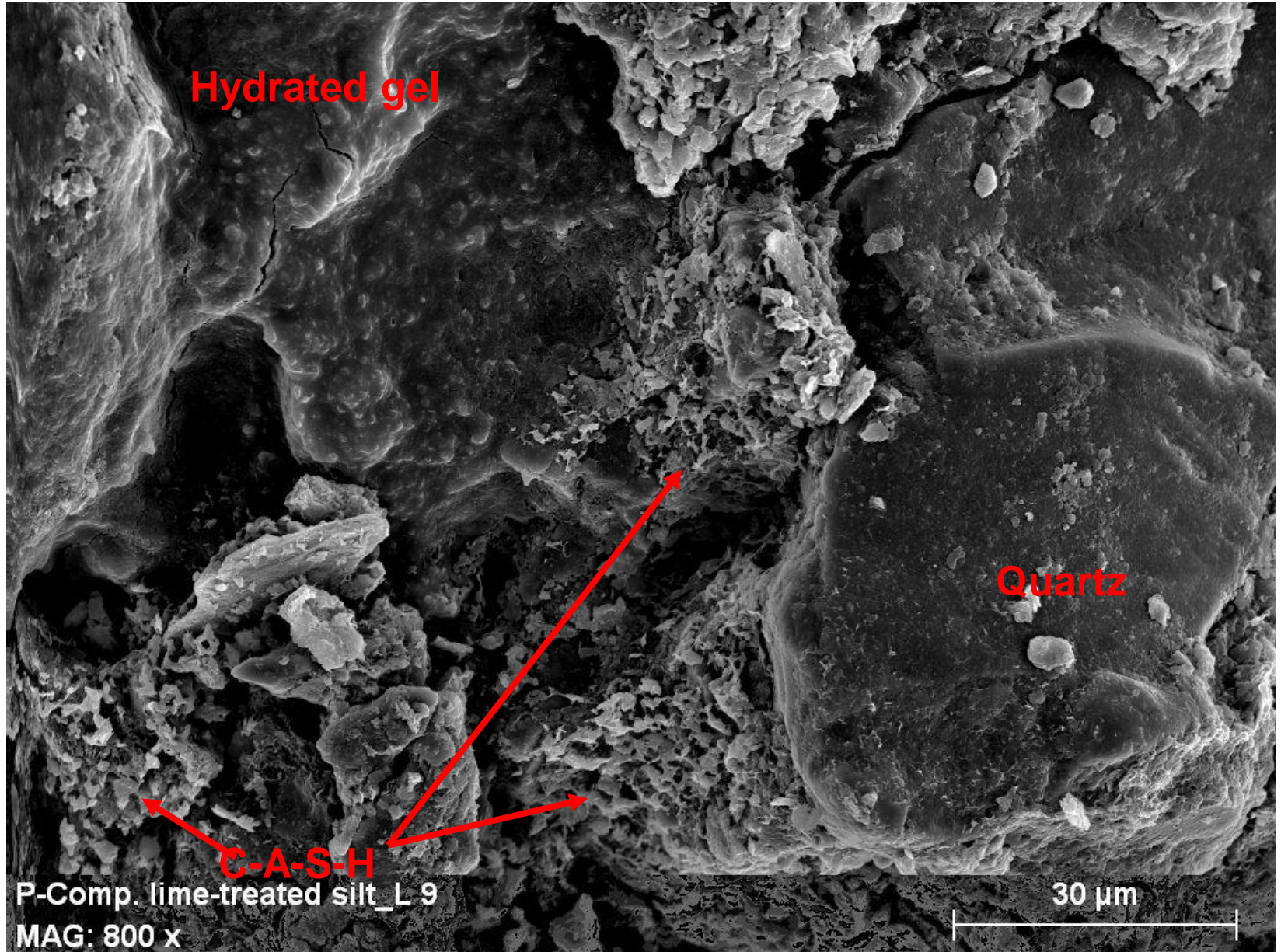
SEM vs. MIP data - Interest



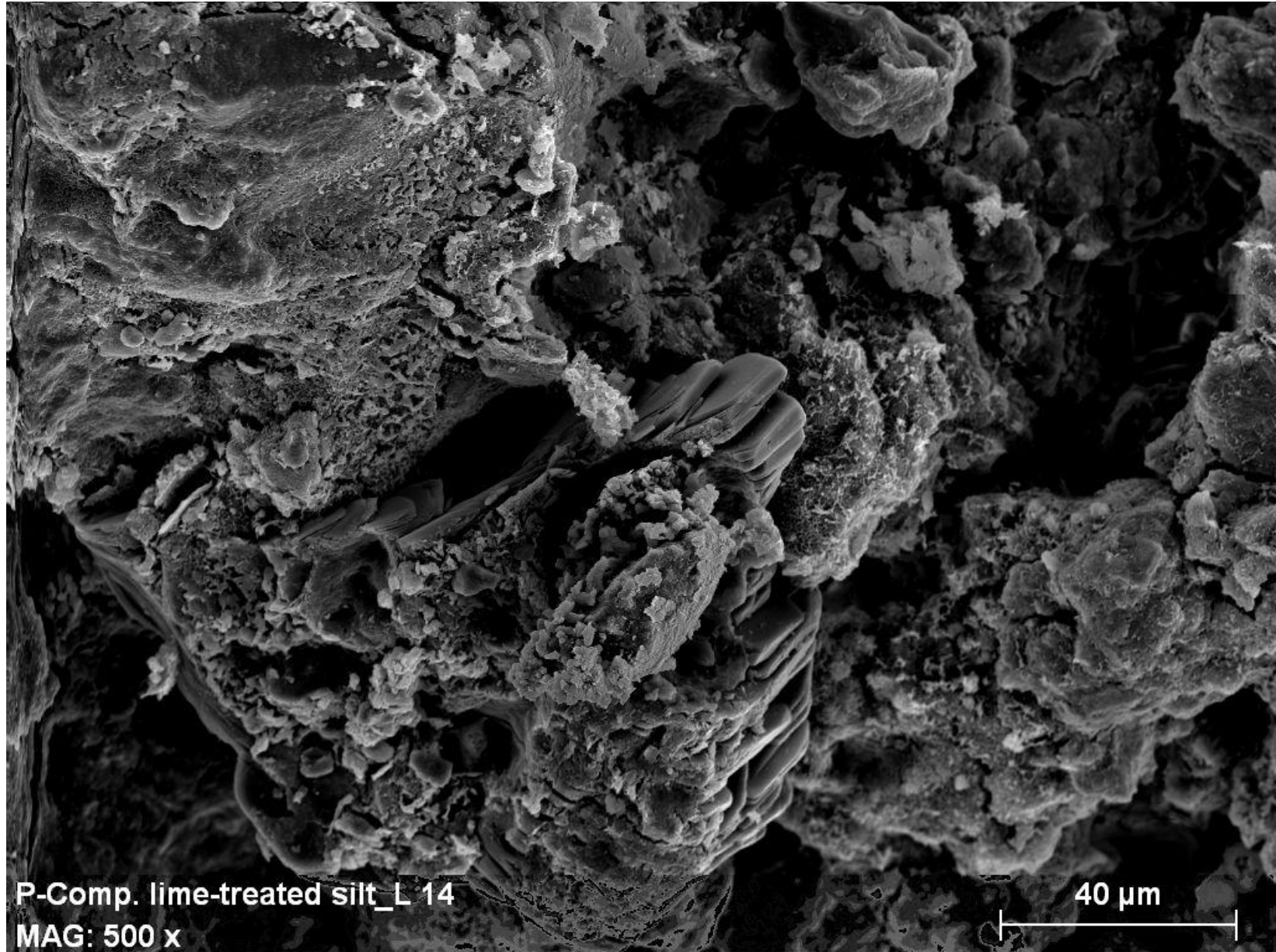
Effect of water amount– 3%CaO WMC



Effect of water amount– 3%CaO WMC



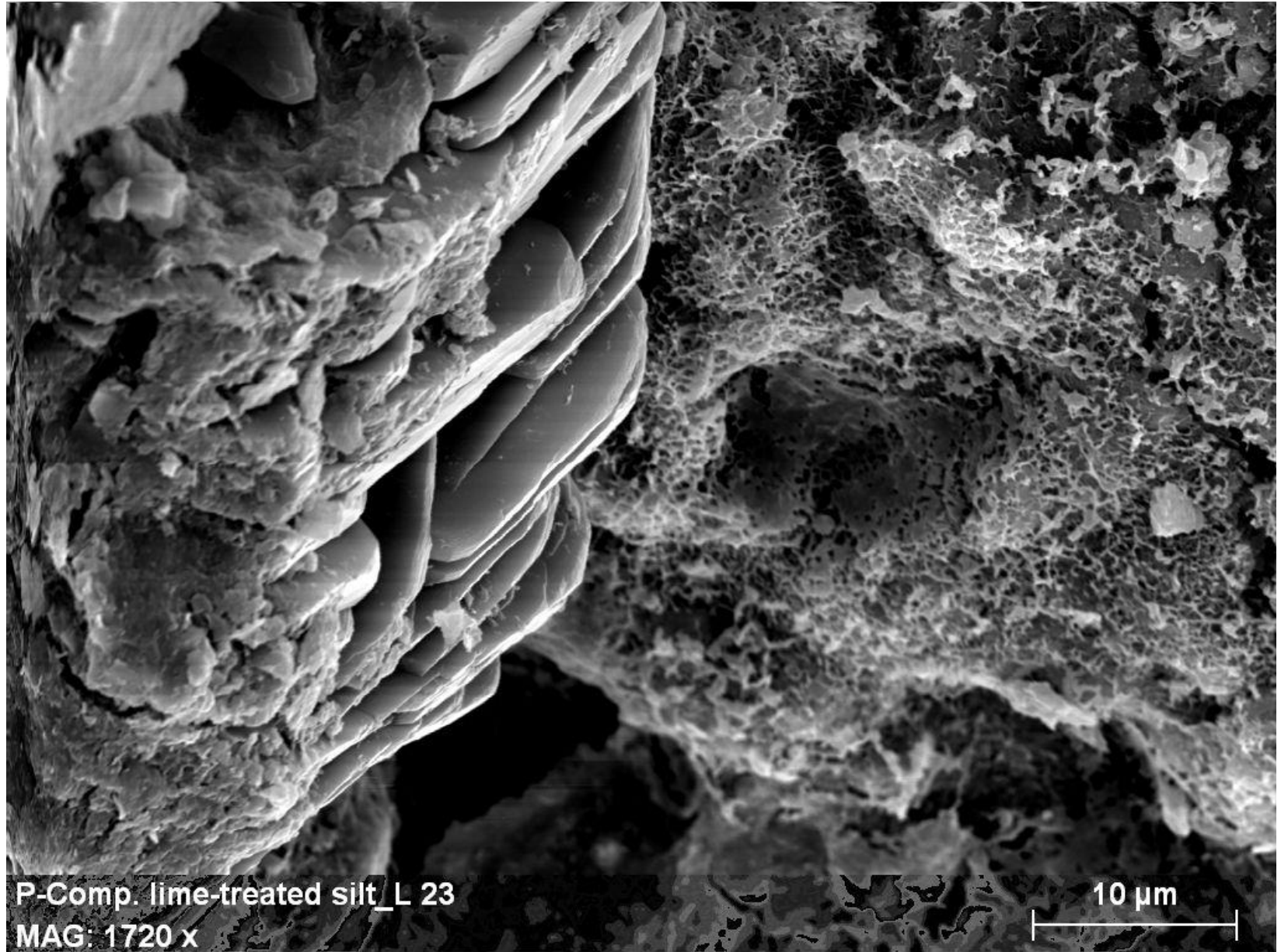
Effect of water amount– 3%CaO WMC



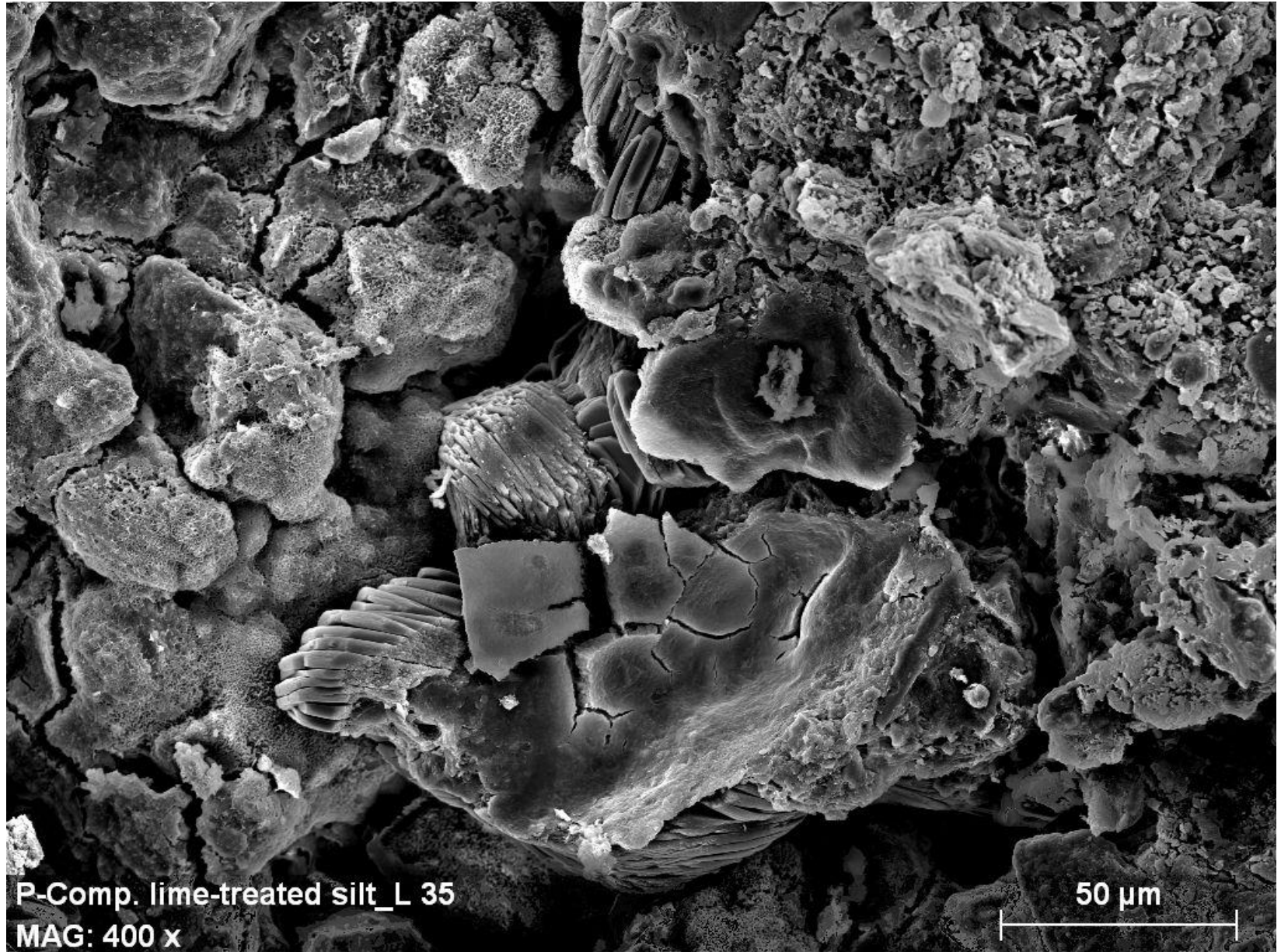
P-Comp. lime-treated silt_L 14
MAG: 500 x

40 µm

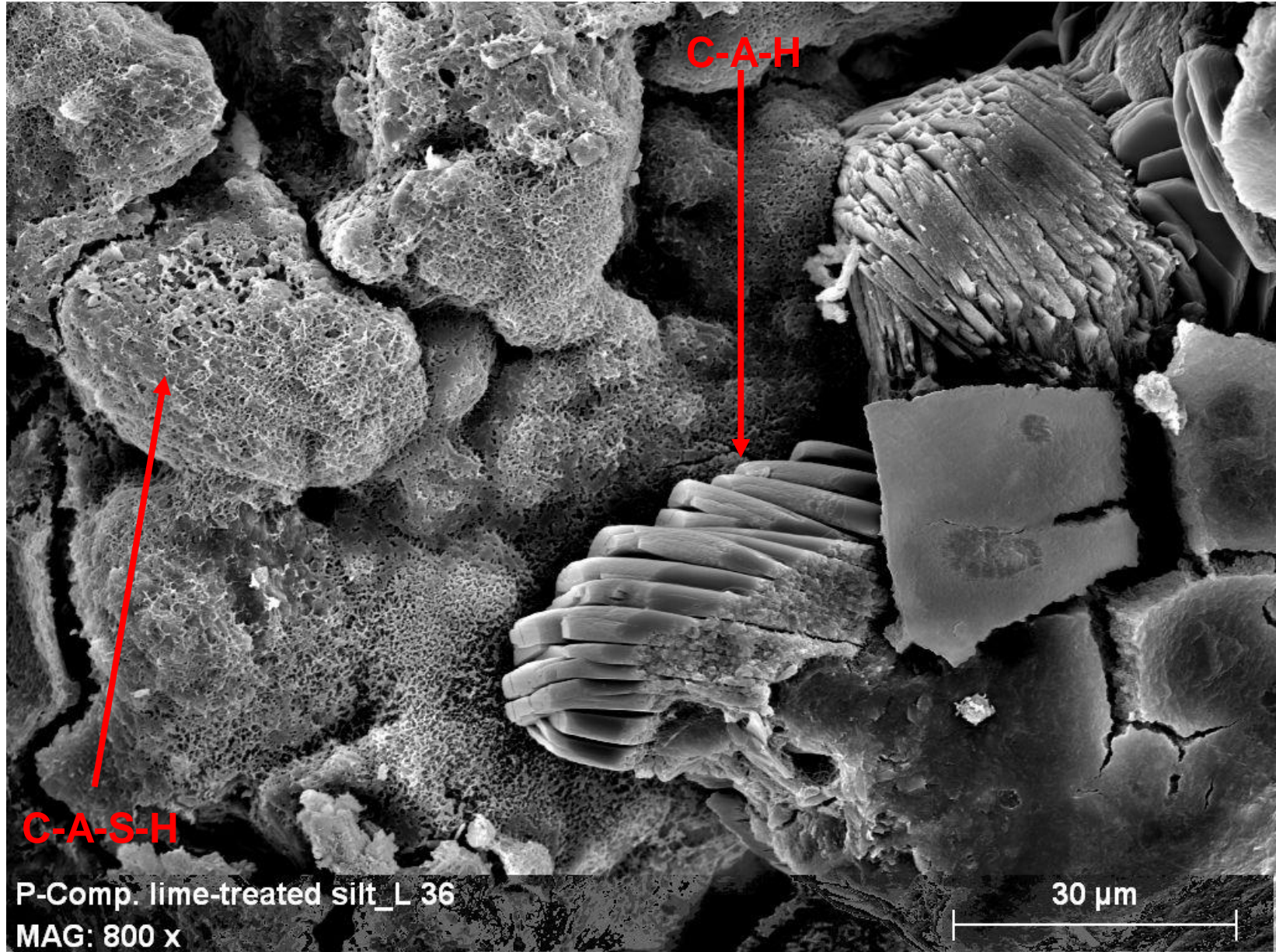
Effect of water amount– 3%CaO WMC



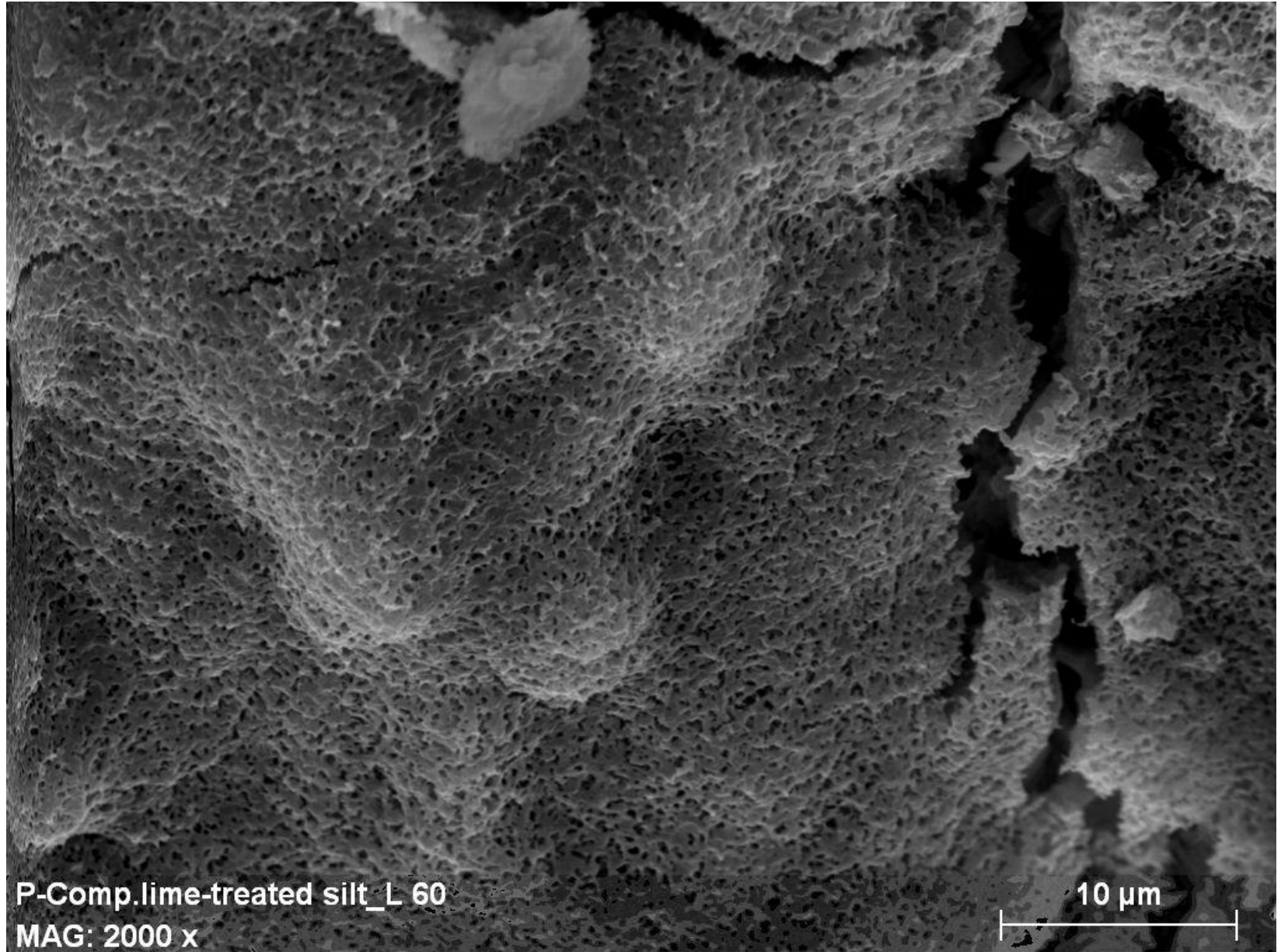
Effect of water amount– 3%CaO WMC



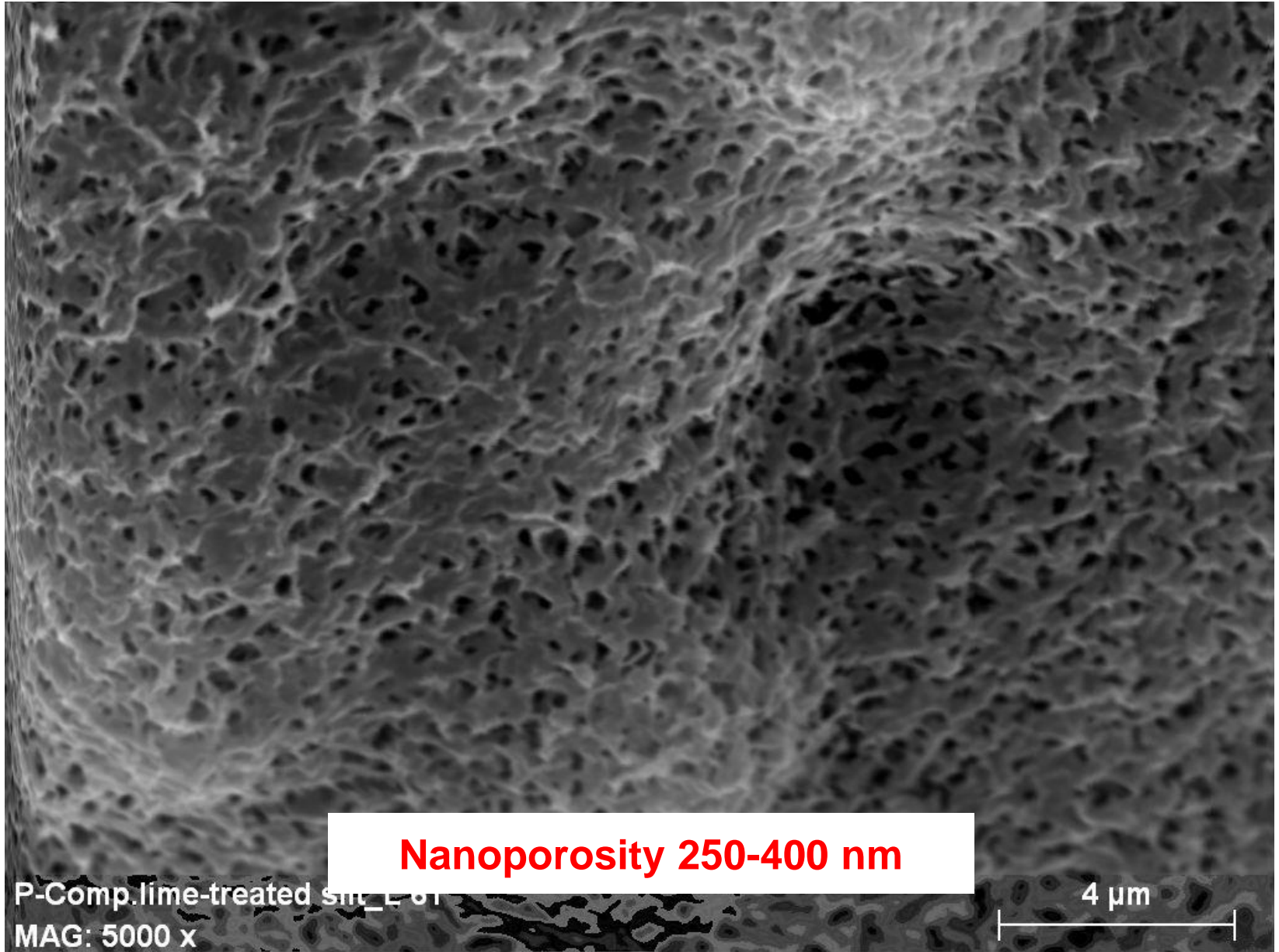
Effect of water amount– 3%CaO WMC



Effect of water amount– 3%CaO WMC



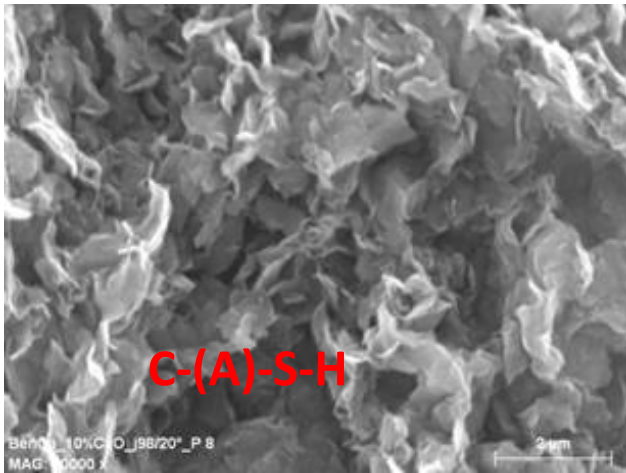
Effect of water amount– 3%CaO WMC



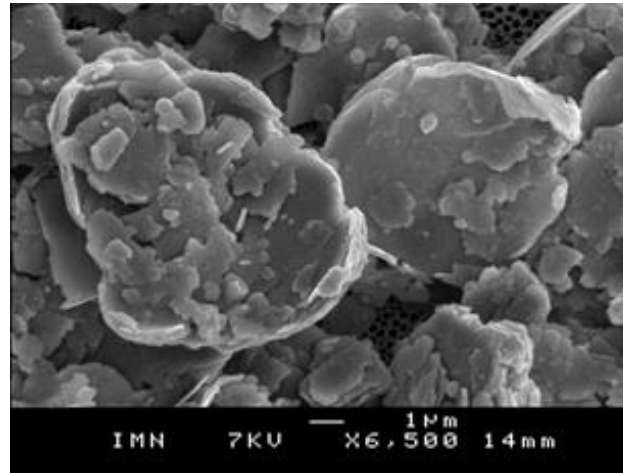
**What about the soil mineralogy in the
resistance increase ?**

Comparison of different soils

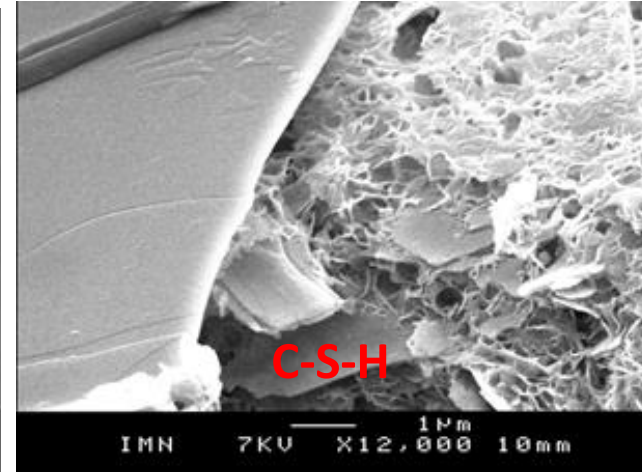
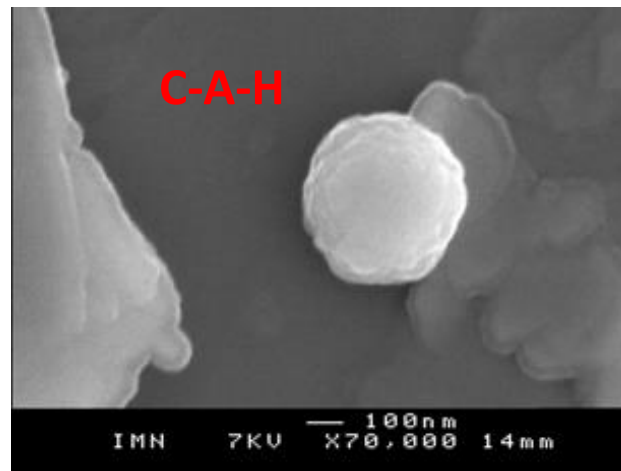
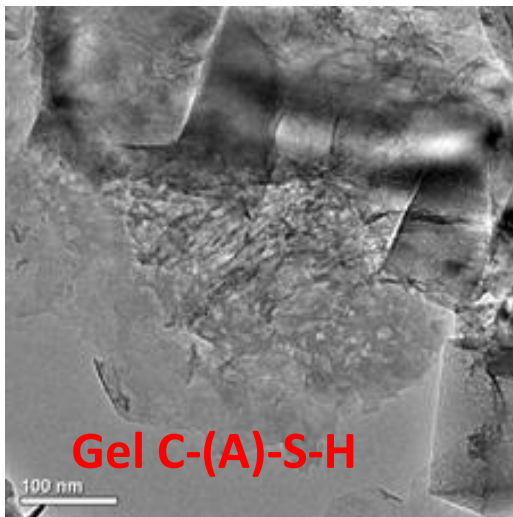
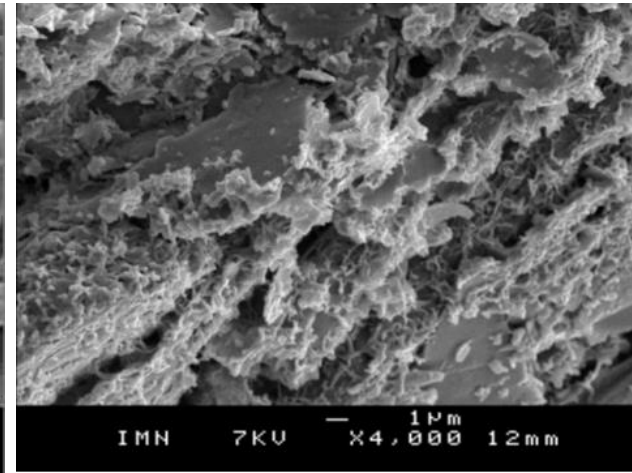
Bentonite



Kaolin



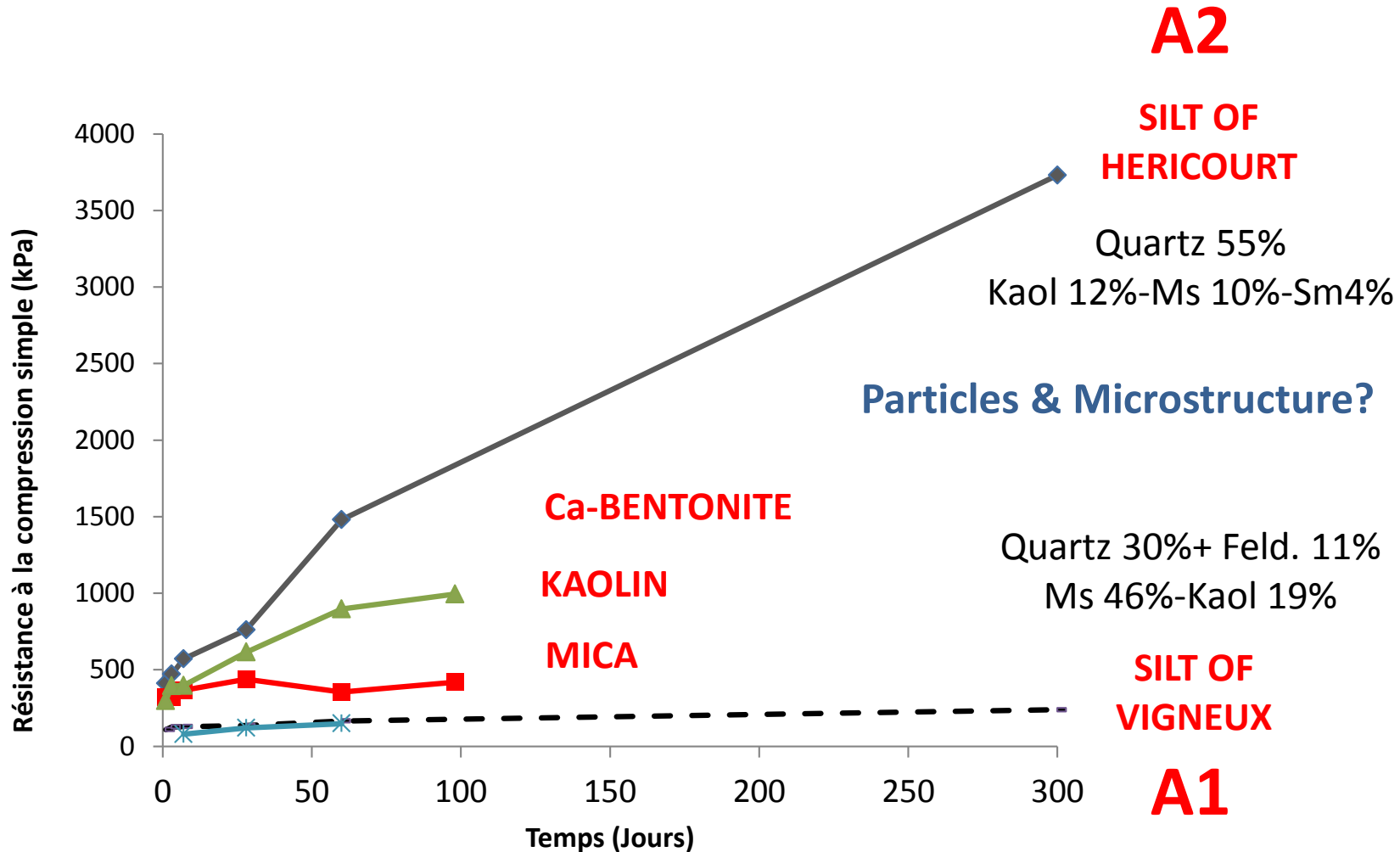
Mica



Cementitious phases and mechanical resistance ?

And natural soils ??

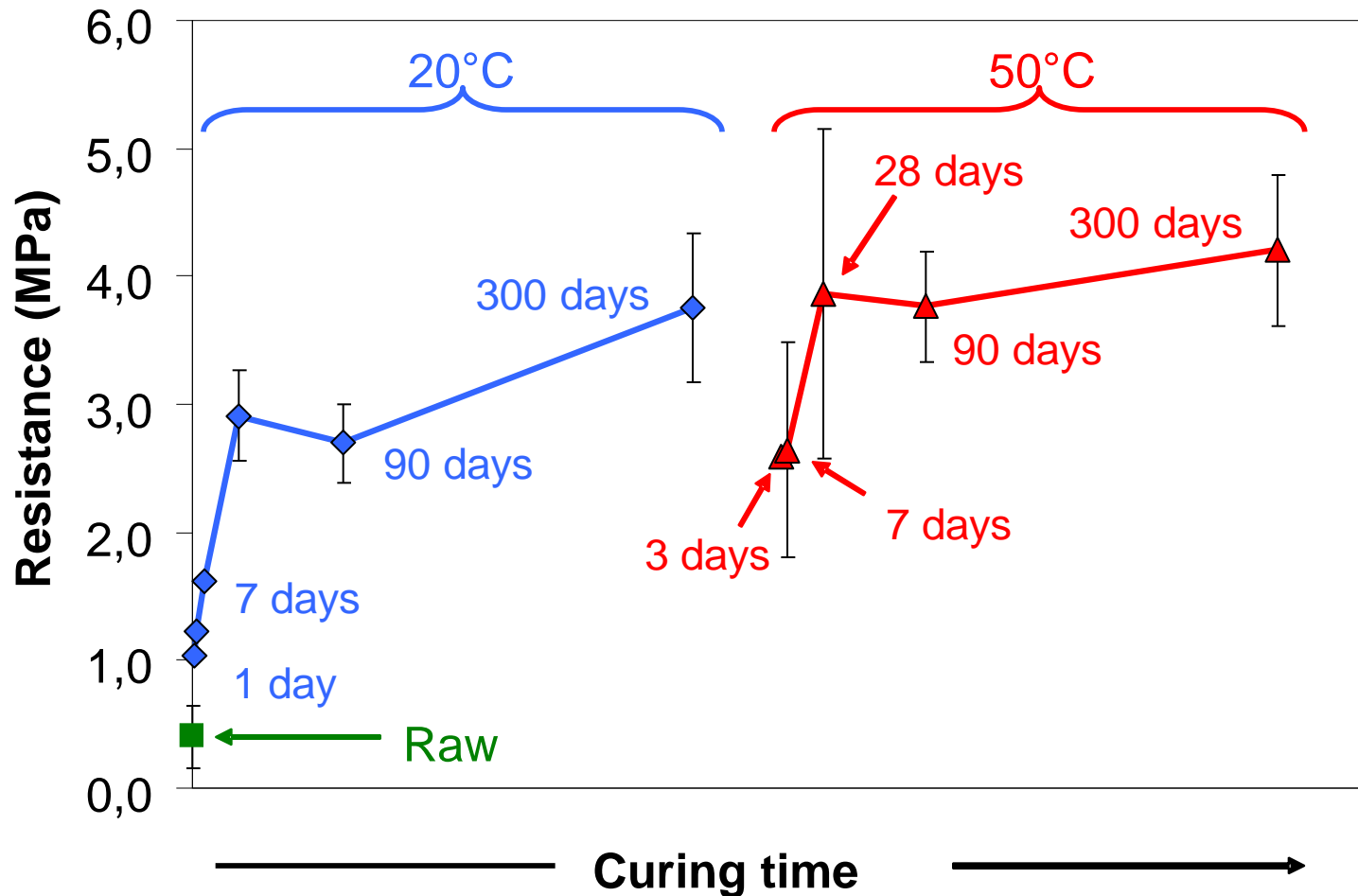
Mineralogical phases and associations ?





Reactivity vs. Microstructure

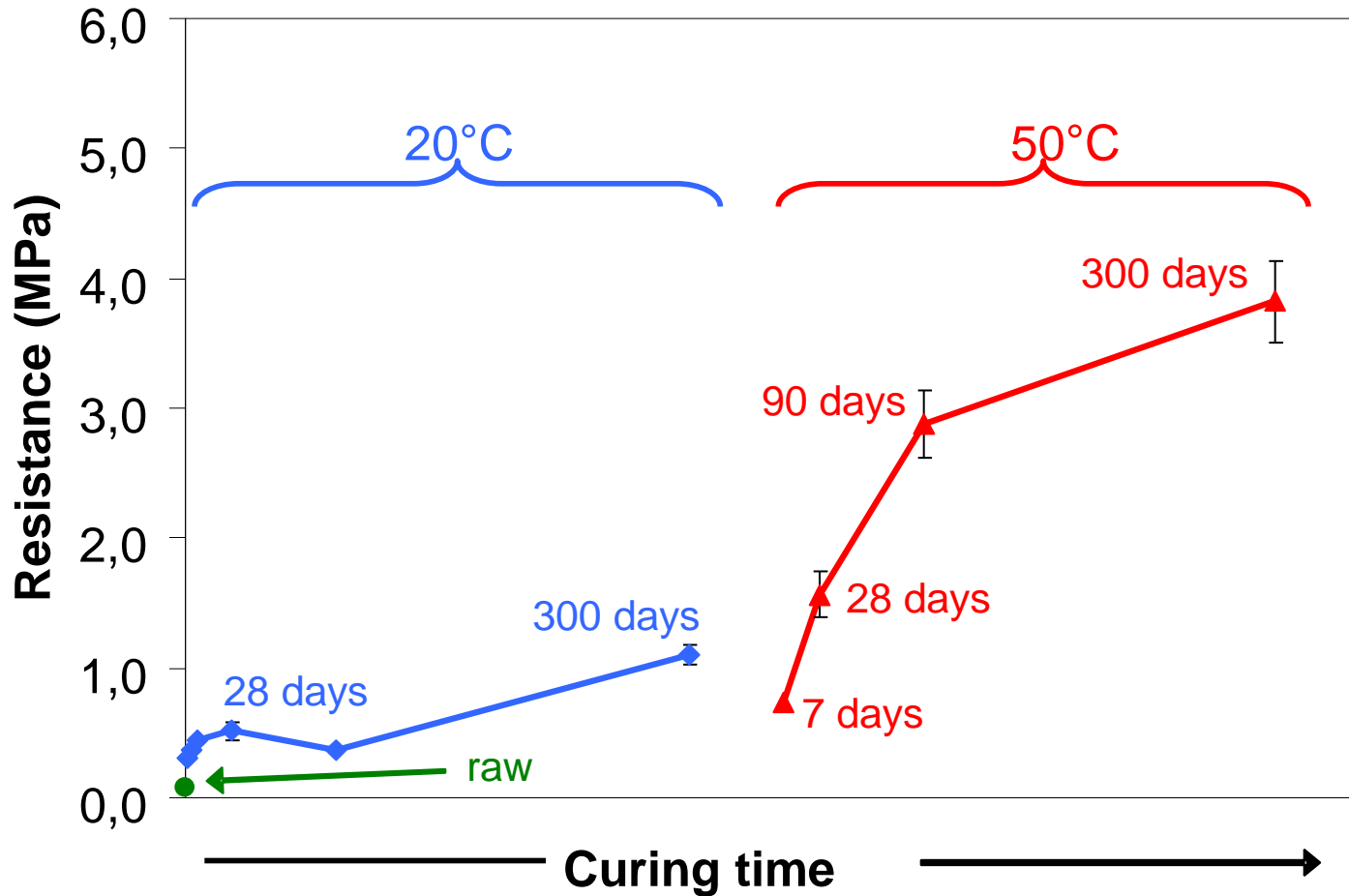
Treatment 1% CaO + 5% Cement
Pozz. Reaction + cement hydration



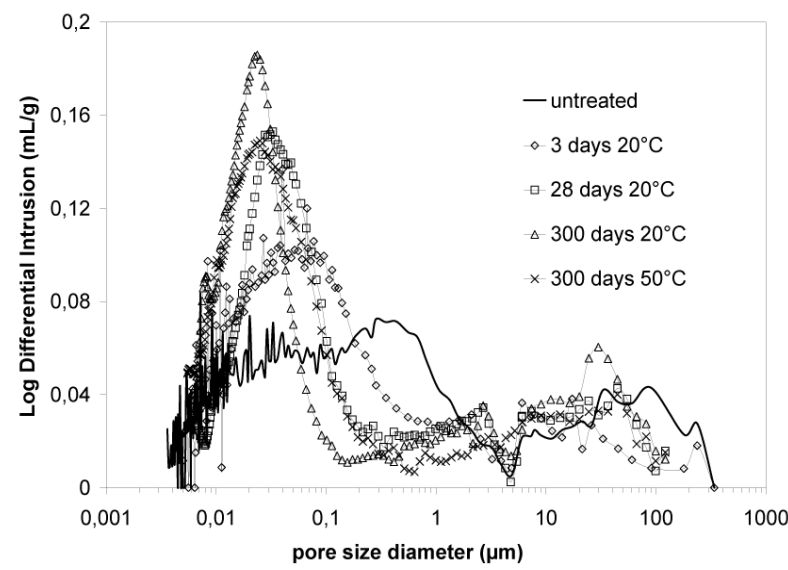
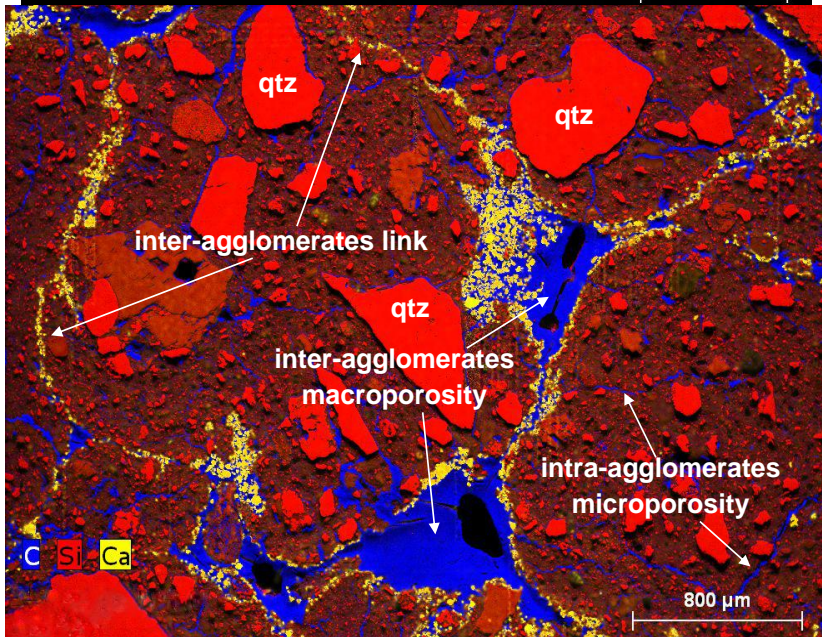
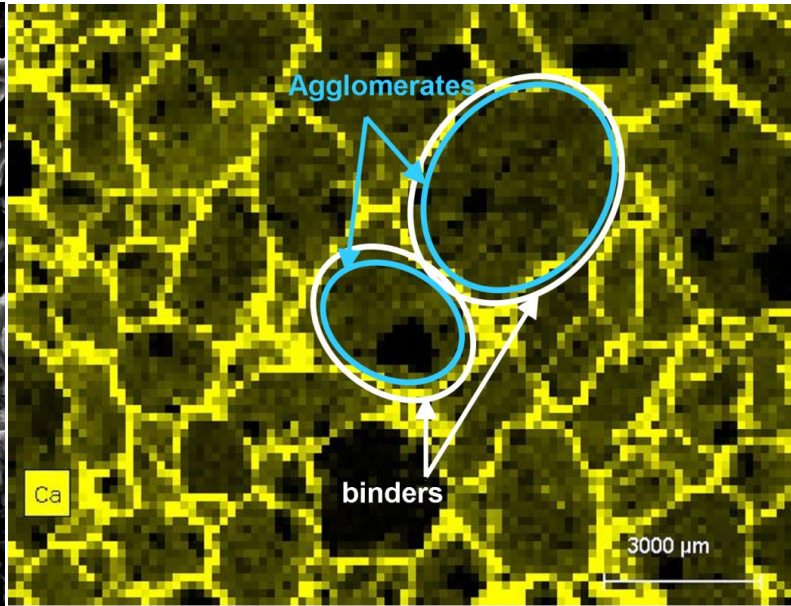
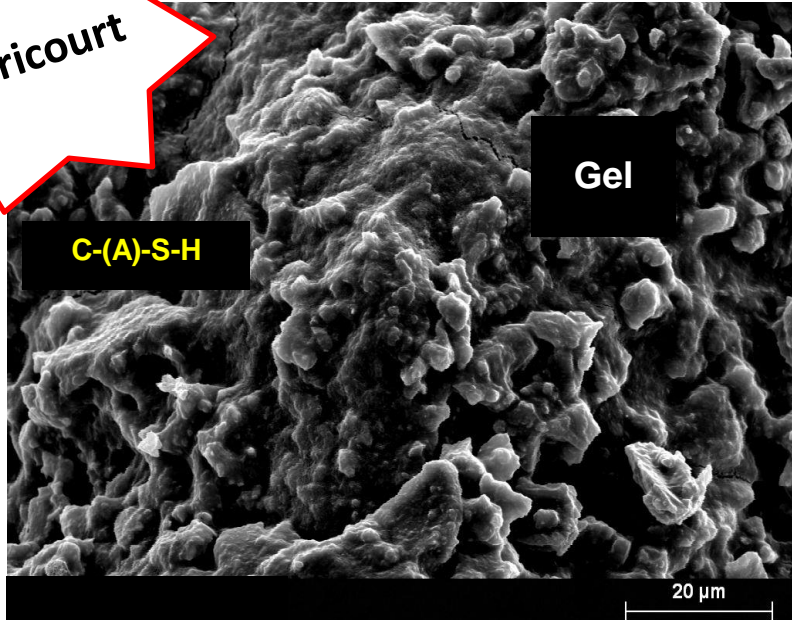


Reactivity vs. Microstructure

Treatment 1% CaO + 5% Cement
Pozz. Reaction + cement hydration

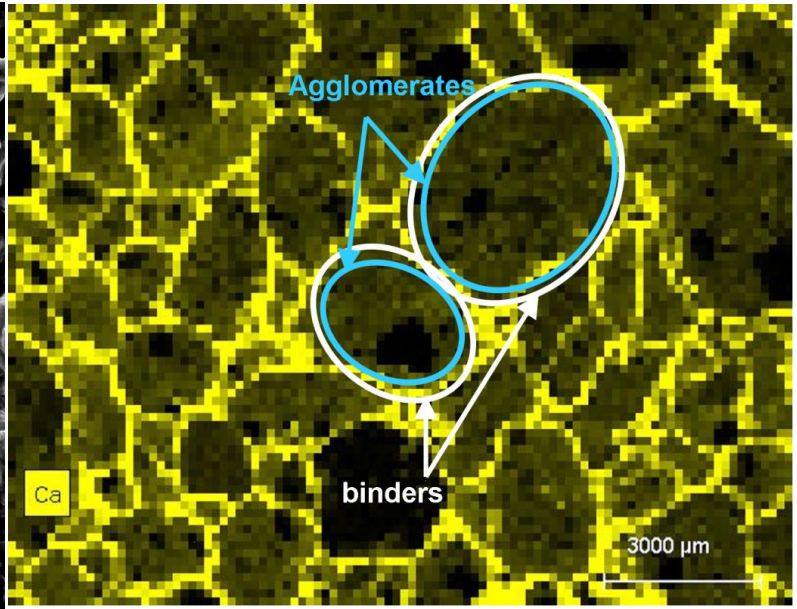
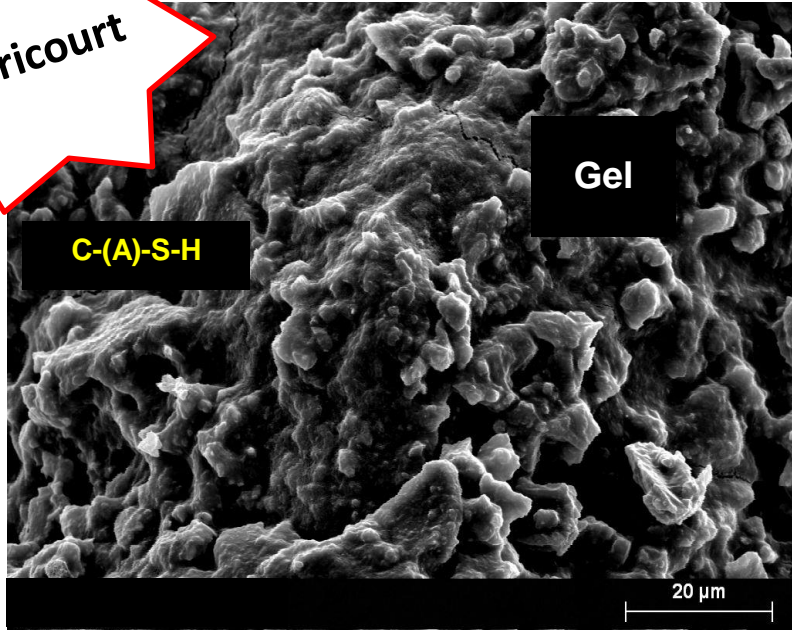


Héricourt

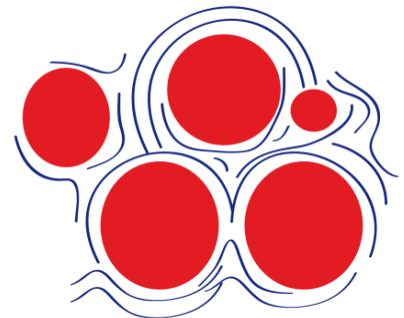


Poro
Hg

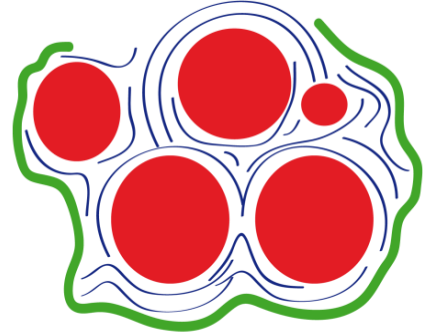
Héricourt



+ Lime



+ Cement



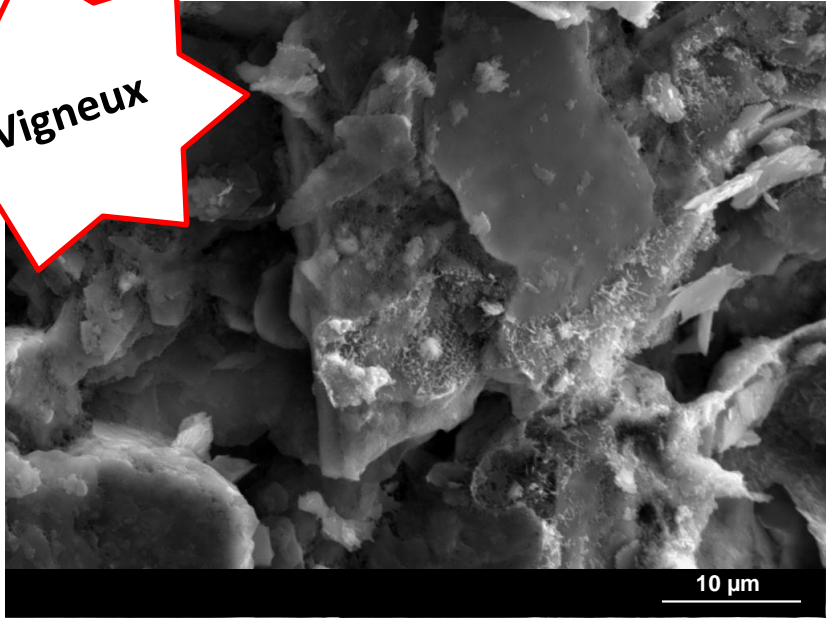
1 mm

Clays

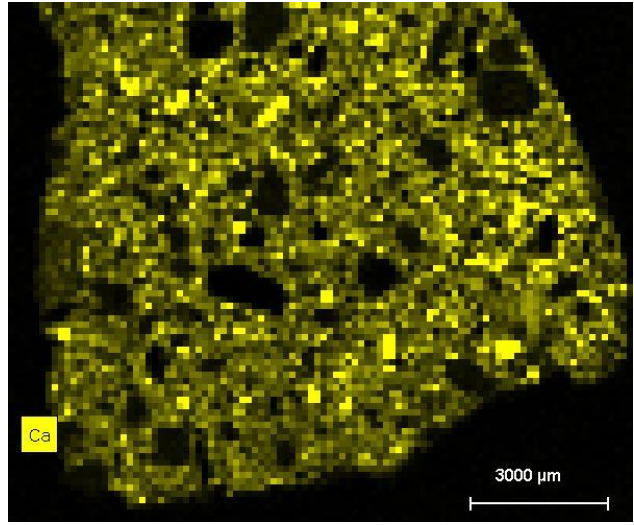
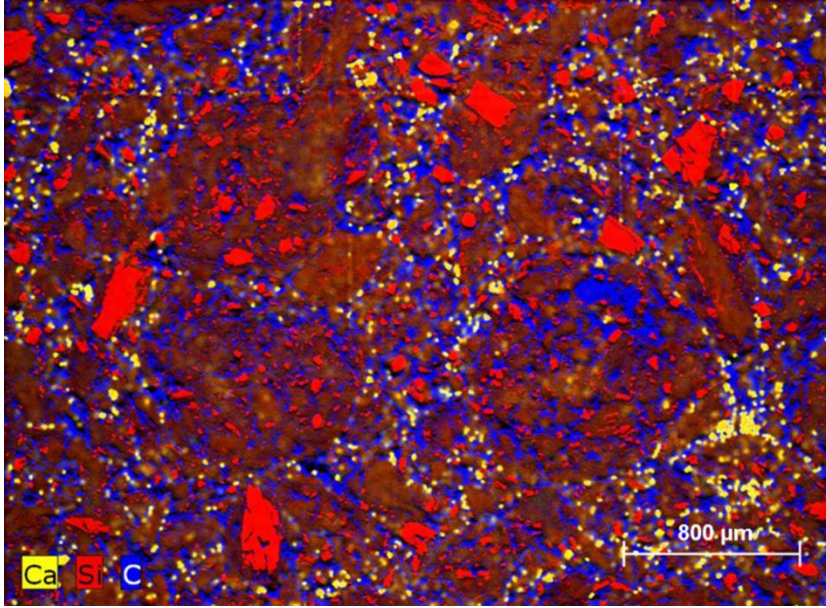
Quartz or Feldspar

C-A-S-H gel

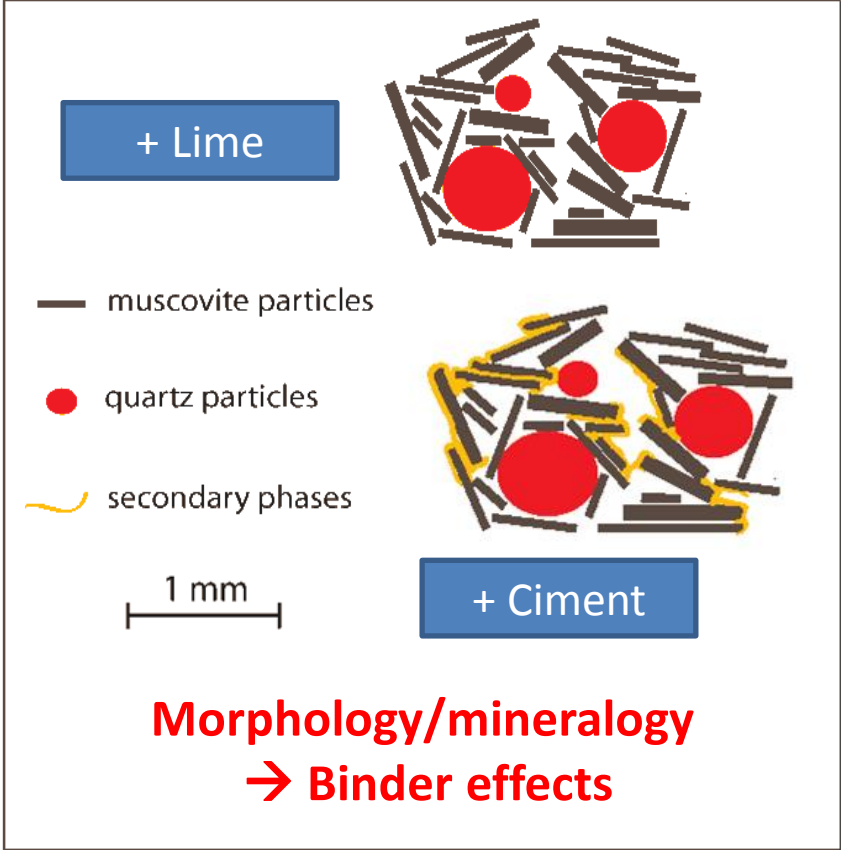
Vigneux



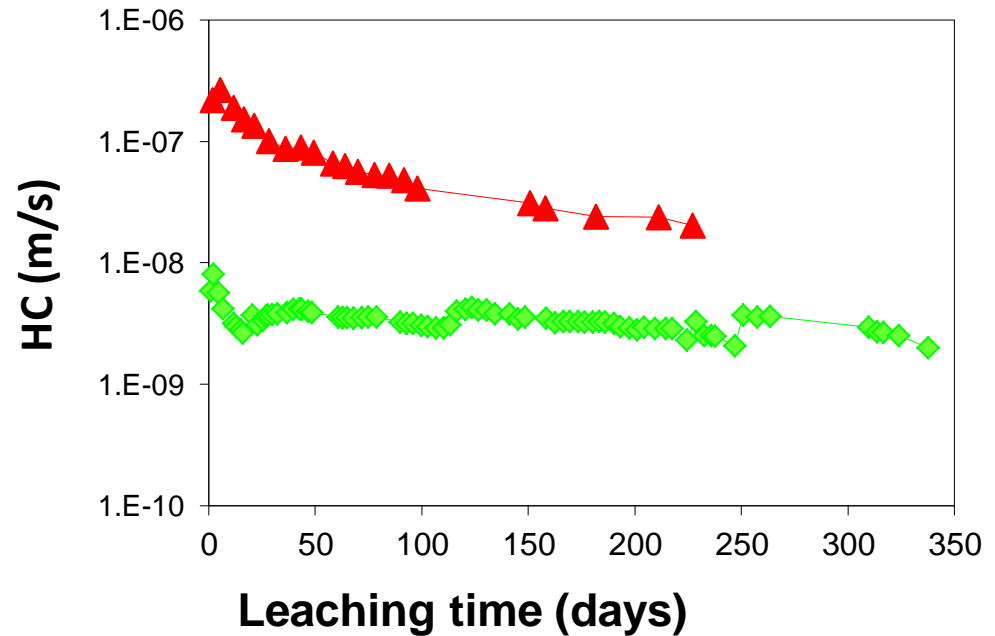
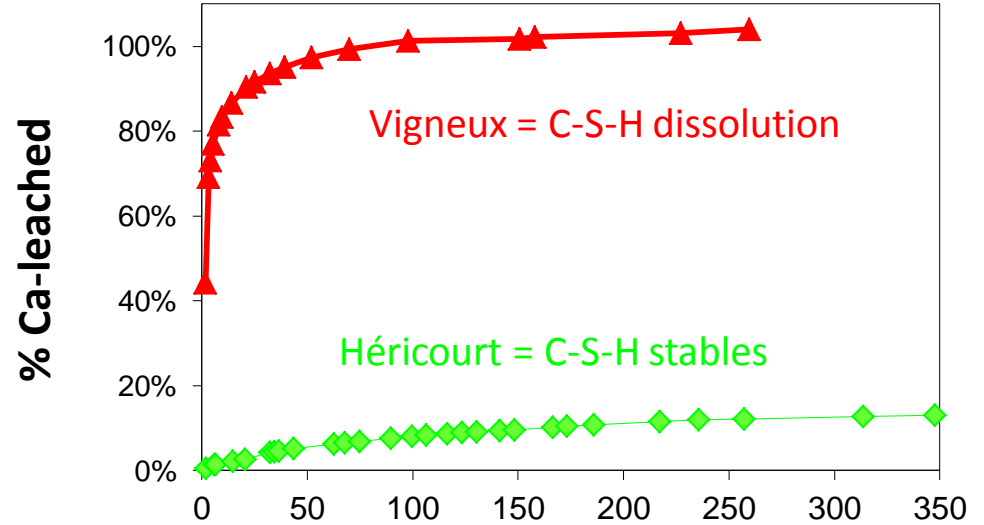
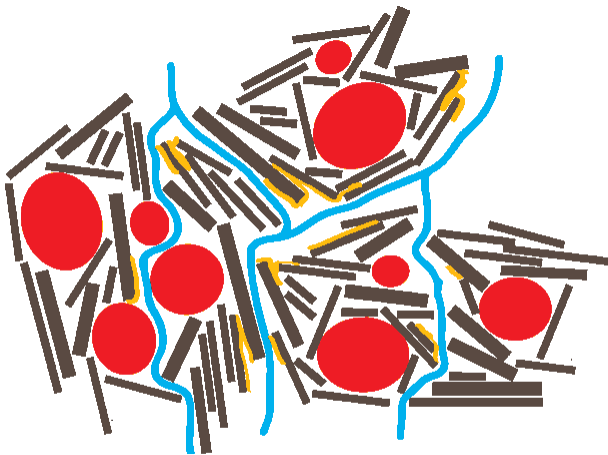
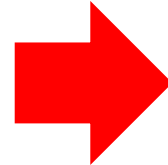
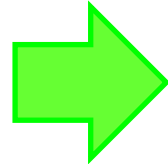
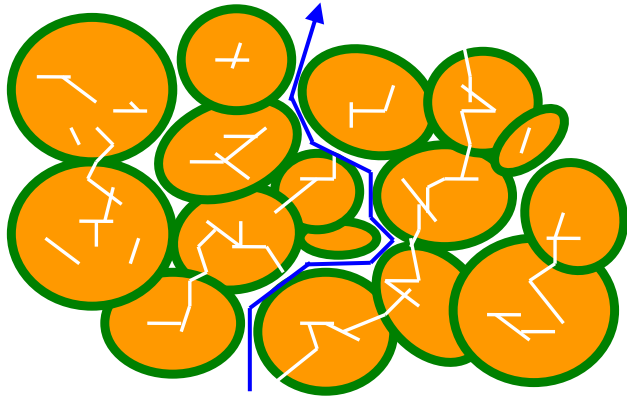
SEM



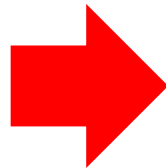
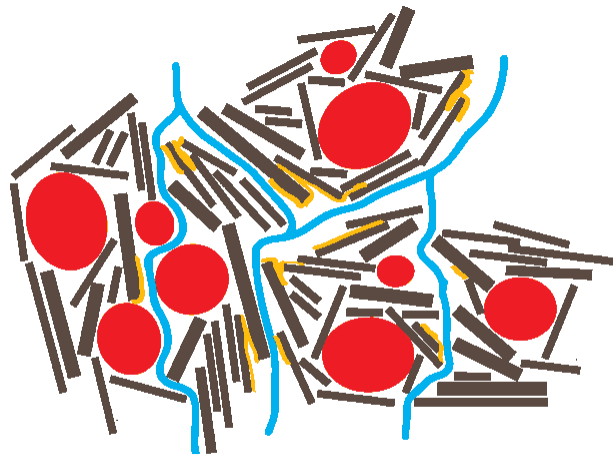
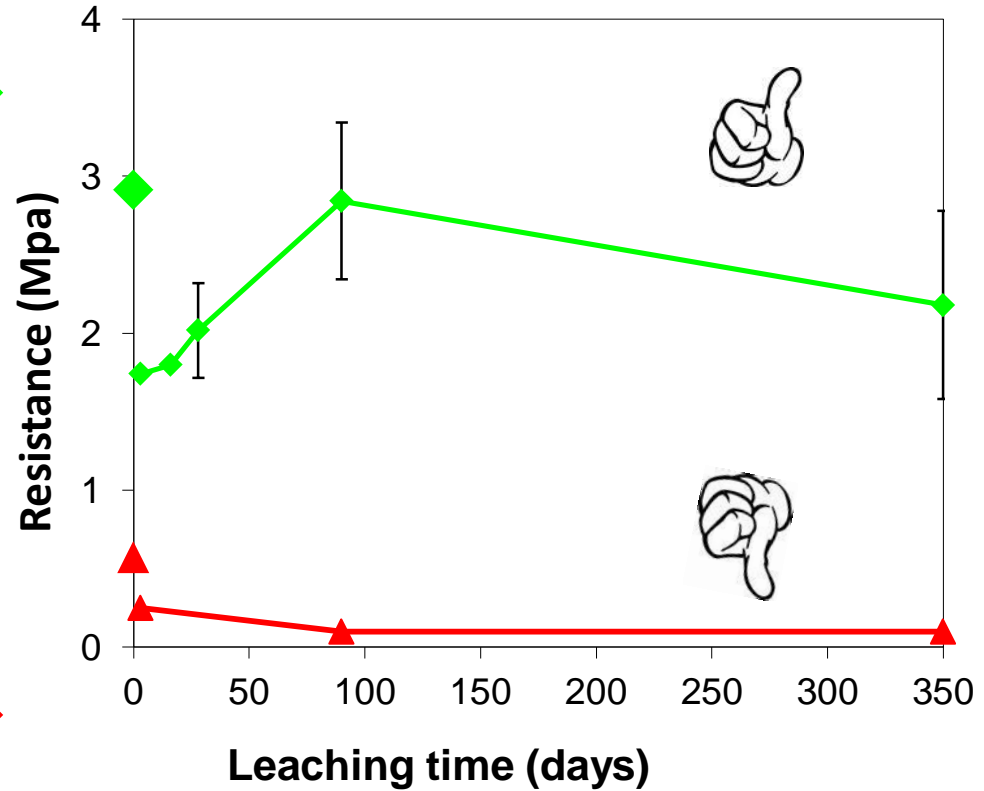
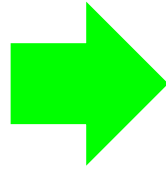
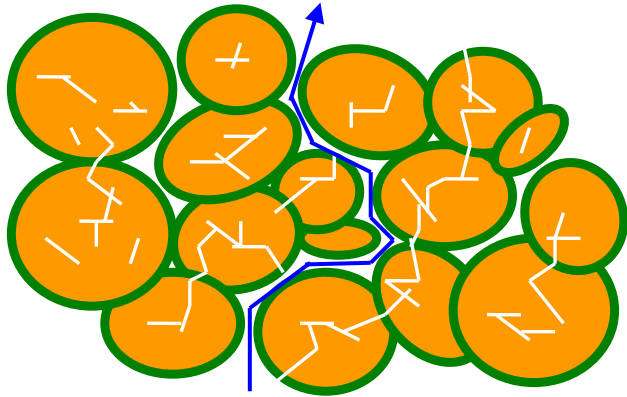
µ-XRF



Long-term behaviour?

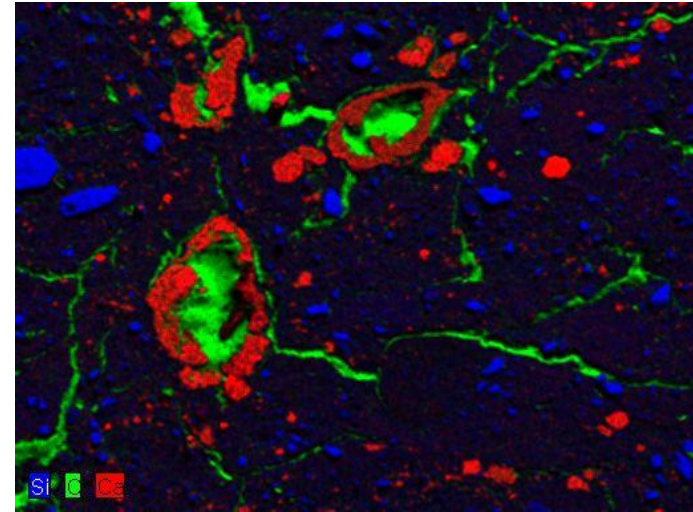
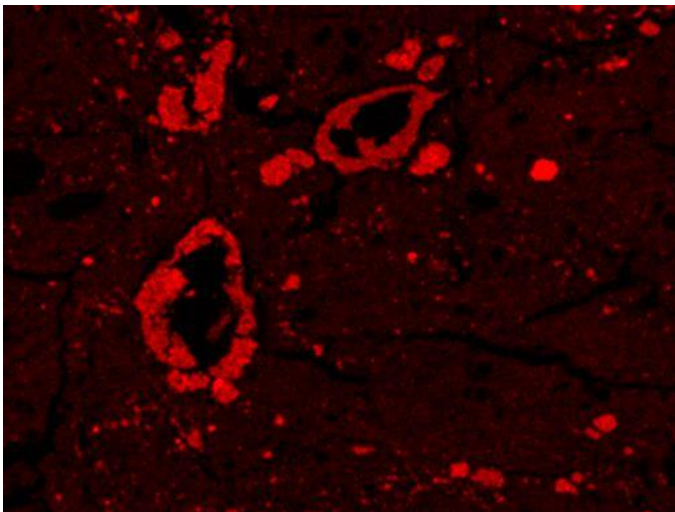
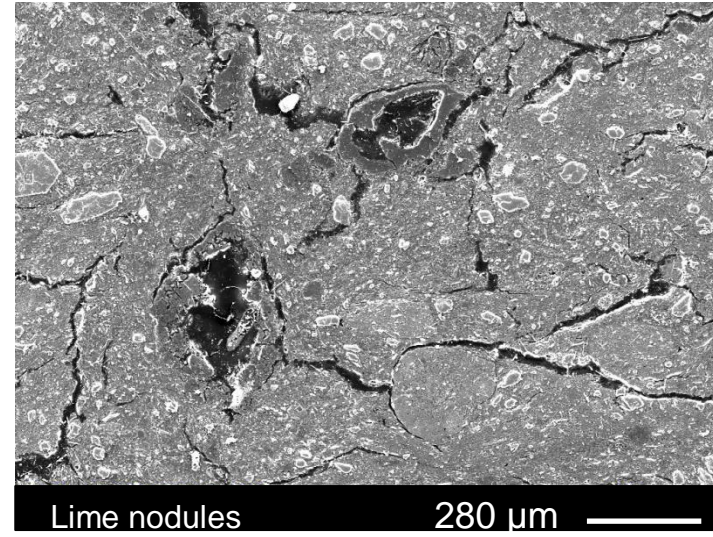
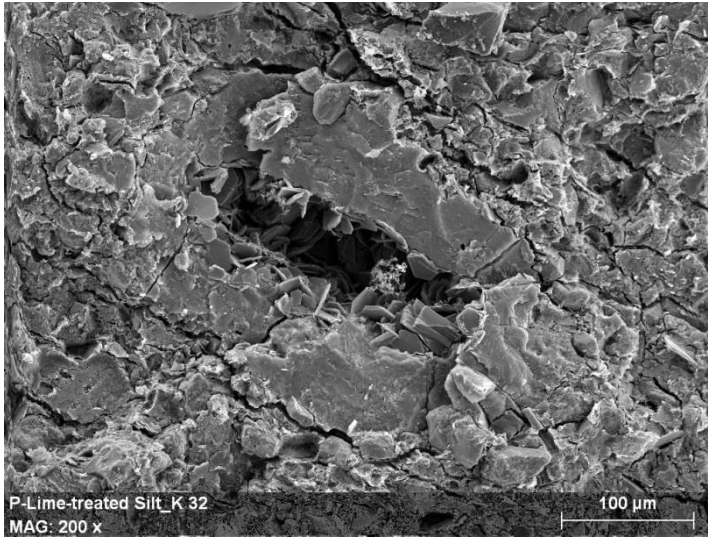


Long-term behaviour?



Mapping

Polished section of lime treated montmorillonite



Synthesis

- SEM is a very **useful and powerful technique** for microstructure investigations
- Maximum of precaution in the sample preparation (drying, sticking, coating)
- Information about the particle arrangements, in a large scale of observation
- Information and analyses about the pozzolanic products and their dispersion (lime and lime/cement)
- Complementary technique to MIP allowing a better description of the microstructure, hydraulic conductivity and durability

Thank you for your attention



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