Departament d'Enginyeria del Terreny, Cartogràfica i Geofísica

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ASSESSMENT OF THE VOLUME CHANGE BEHAVIOUR OF CLAY AGGREGATES BY ESEM OBSERVATIONS

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HE5. Moisture Transport through Clay
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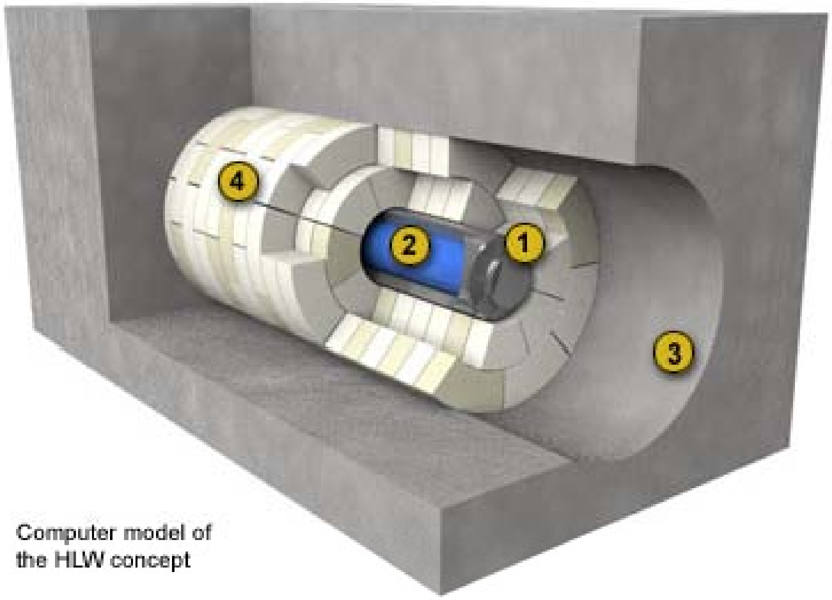
aipea

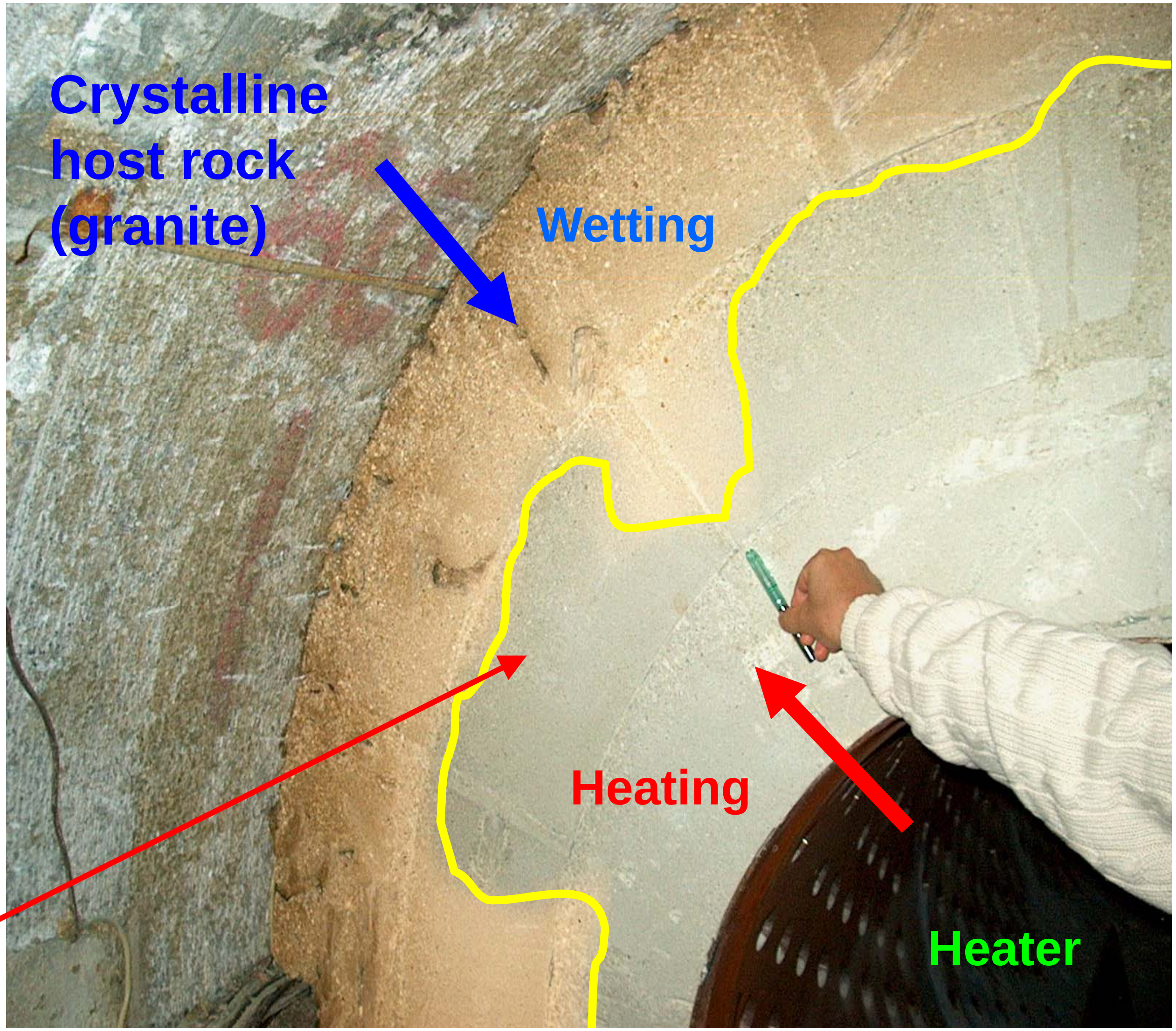
Compacted clays (aggregated structure and multi-scale porosity)

Engineered barriers (nuclear waste disposal, clay liners for waste isolation, …) and fills (core material in earth dams, river and canal dikes, …).



Computer model of the HLW concept

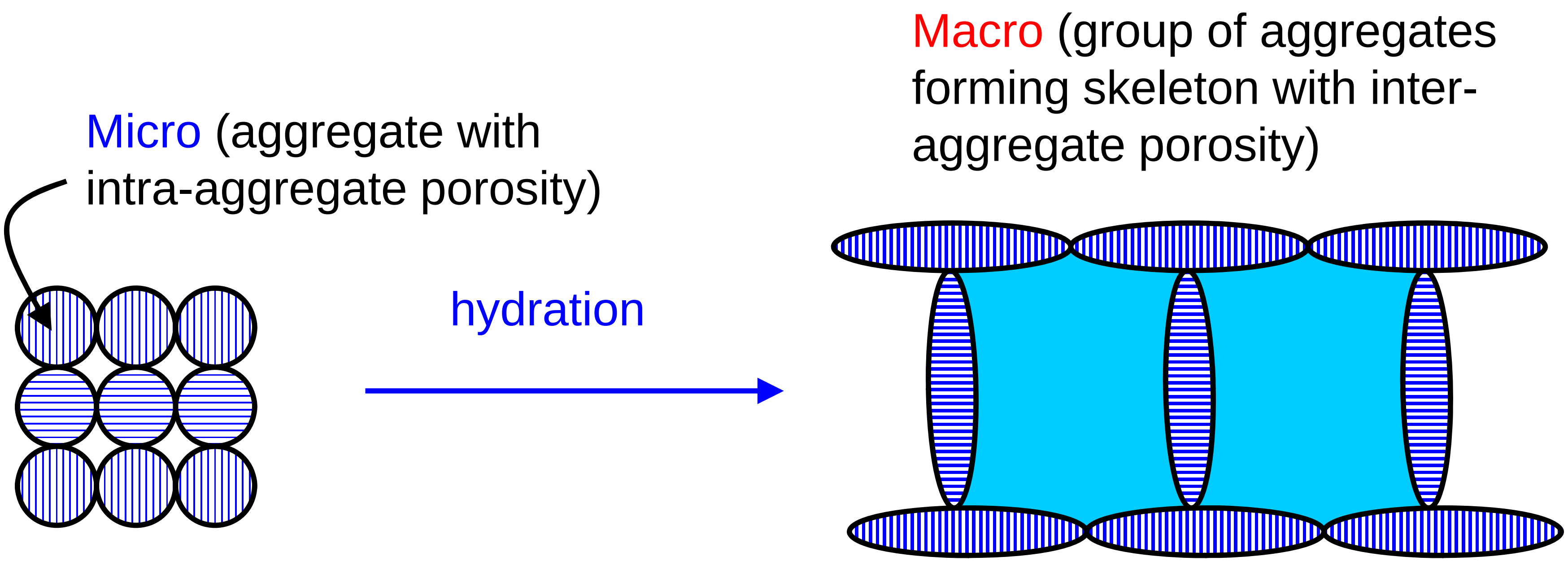
Engineered Barrier System for HLW disposal (FEBEX, Grimsel, Swiss Alps)



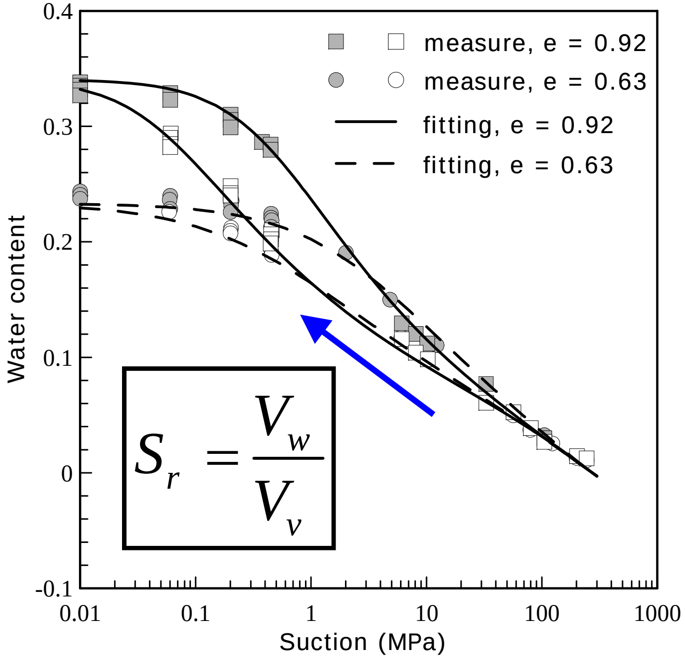
Clay barrier: Highly compacted bentonite blocks (ρ_d = 1.65 Mg/m^3)

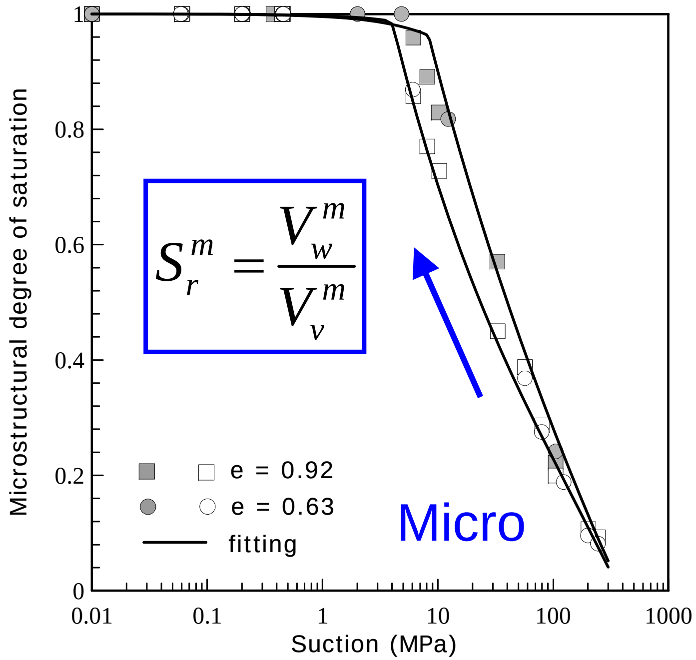
Multi-scale porosity (HM features at micro and macro-scale)

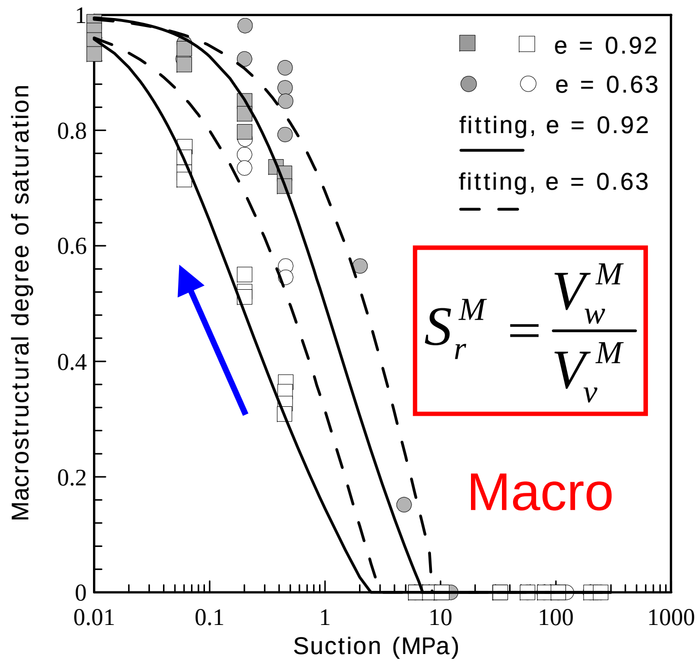
	Mechanical behaviour	Hydraulic behaviour
Microstructural scale (AGGREGATE with intra-aggregate porosity)	Quasi-reversible	Not dependent on porosity (water adsorption mechanism with small hysteresis)
Macrostructural scale (GROUP OF AGGREGATES FORMING SKELETON with inter-aggregate porosity)	Largely irreversible (depending on the stress paths)	Dependent on porosity (water storage mechanism with large hysteresis)



Boom clay (kaolinitic-illitic clay). Wetting / drying at constant volume

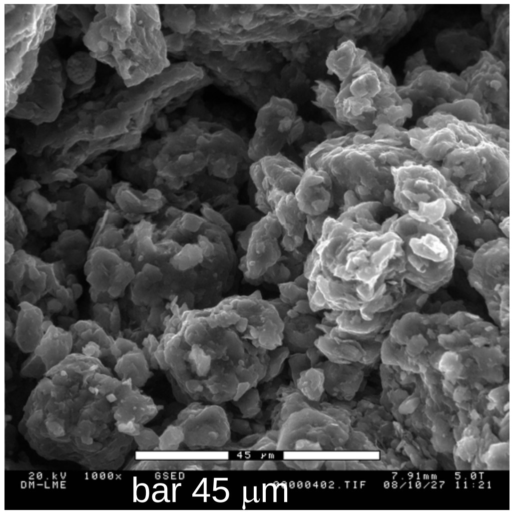


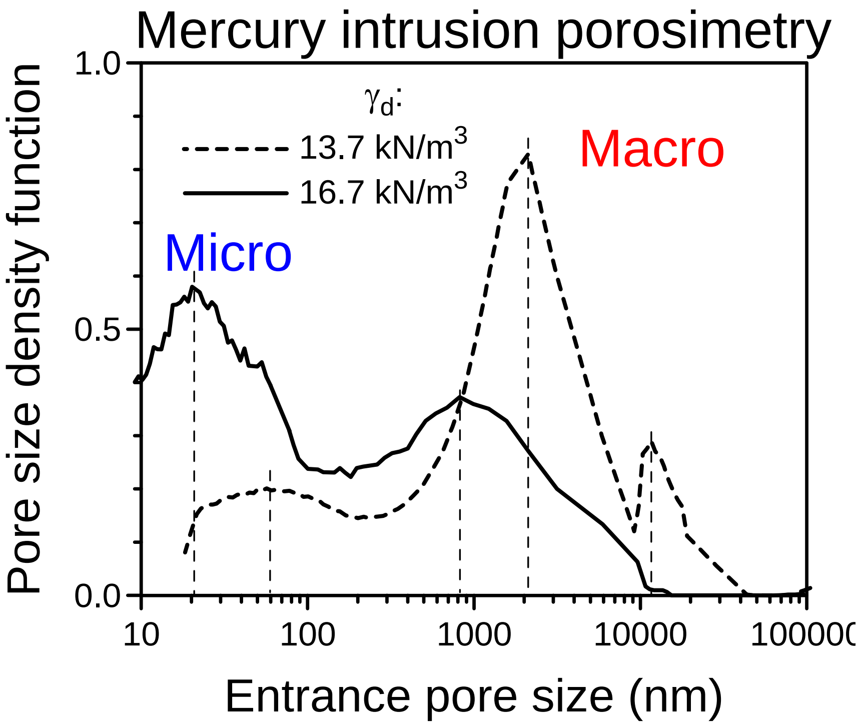




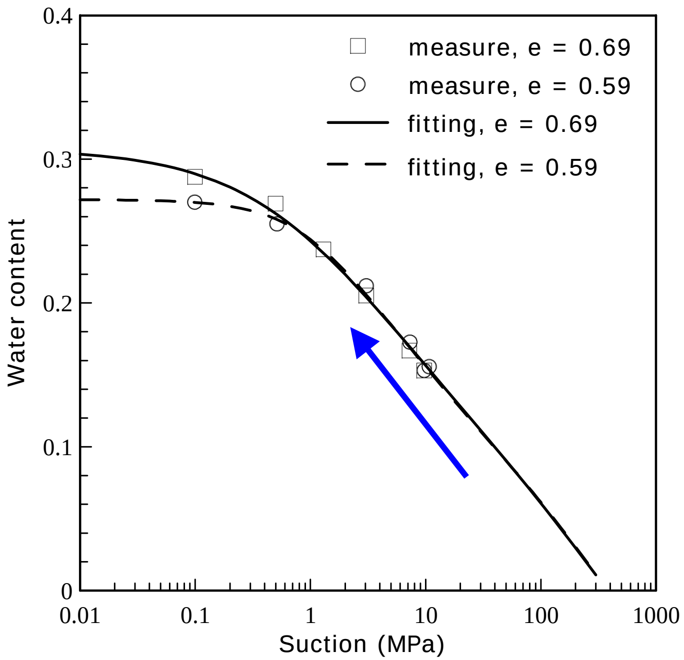
$$S_r = S_r^m \frac{e_m}{e} + S_r^M \frac{e_M}{e}$$

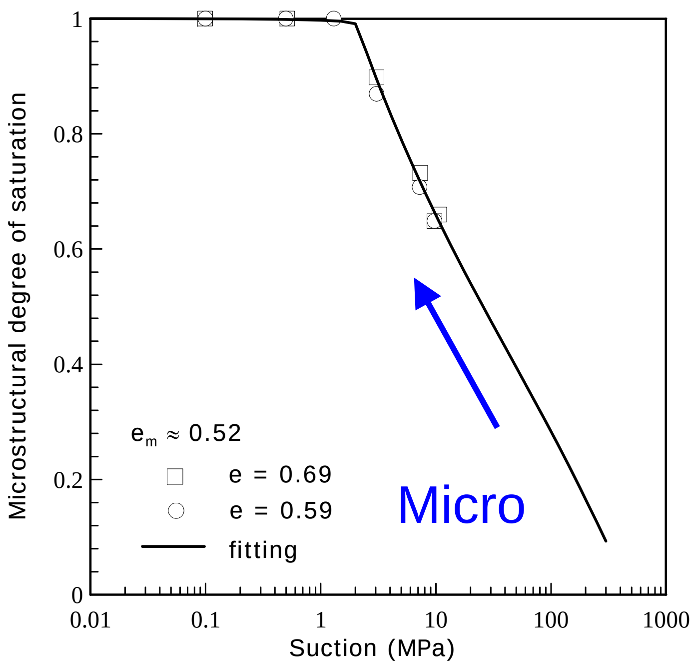
Consistency limits	w_L=56% w_p=29%
Specific surface	40-50 m^2/g
Compaction	ρ_d=1.4–1.7 Mg/m^3

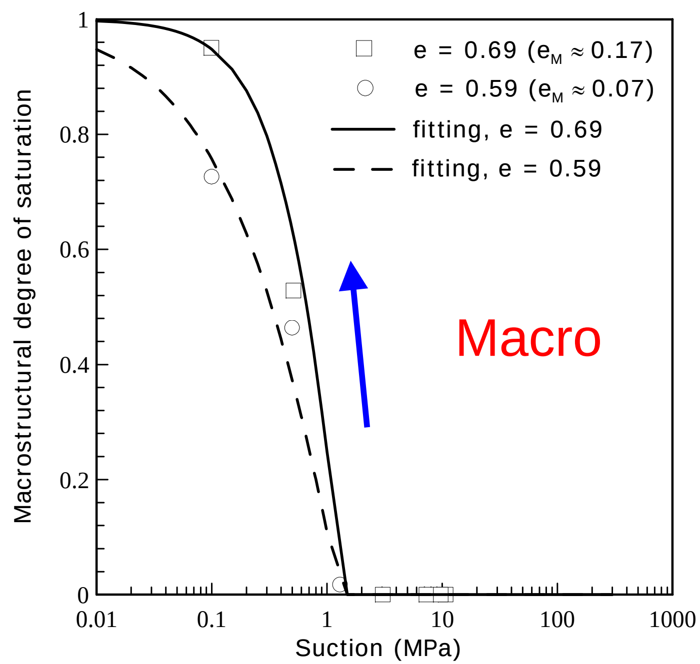




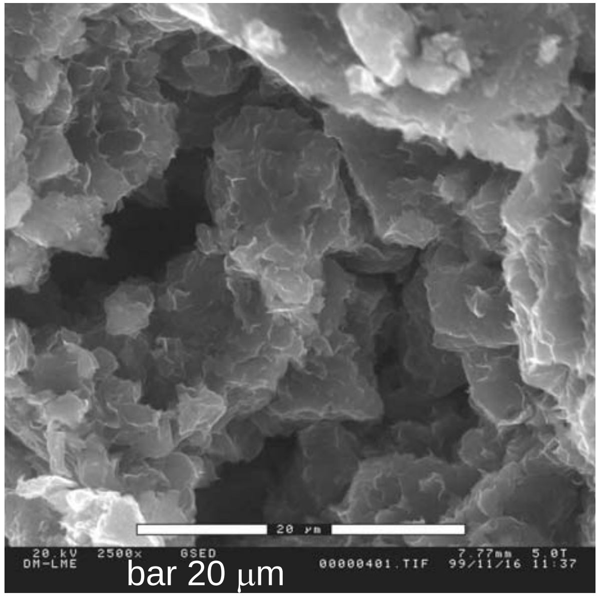
Febex bentonite. Wetting at constant volume

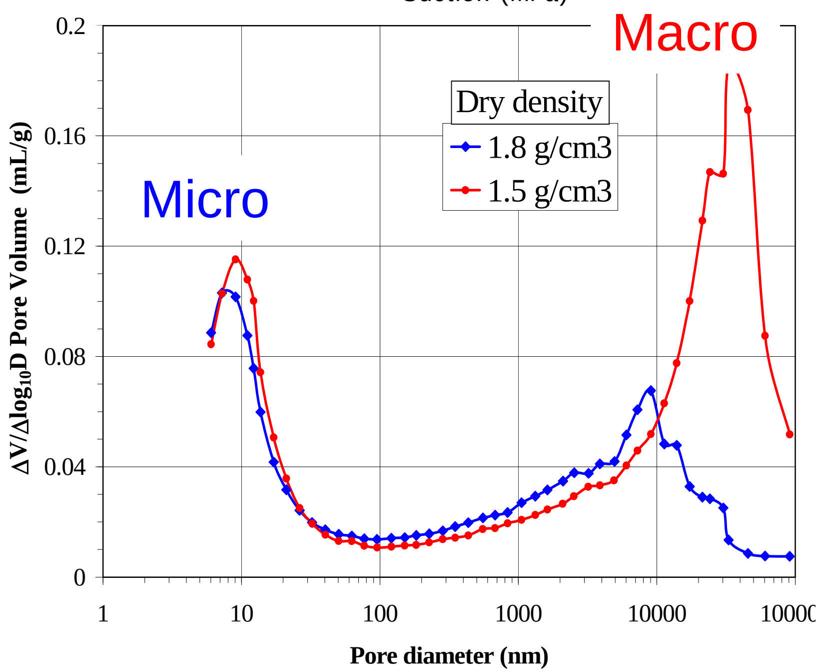






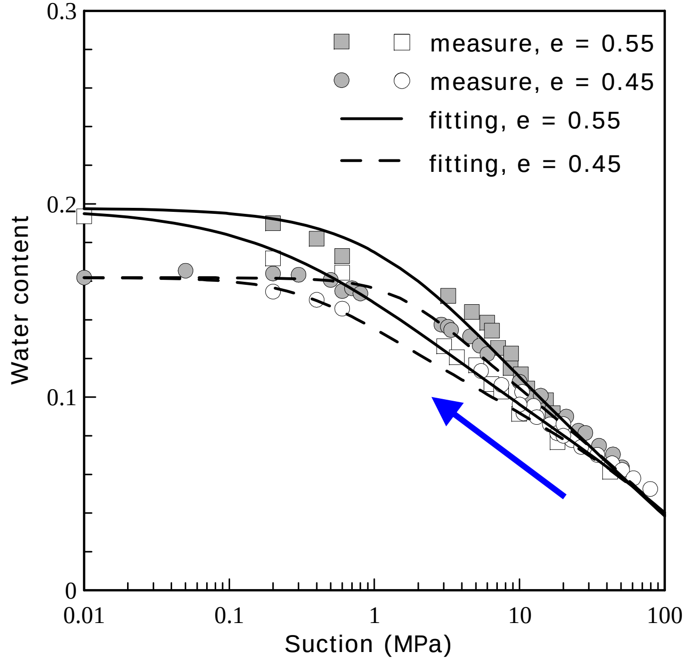
Consistency limits	w_L=102% w_p=53%
Specific surface	725 m^2/g external: 32 m^2/g
Compaction	ρ_d= 1.7 Mg/m^3

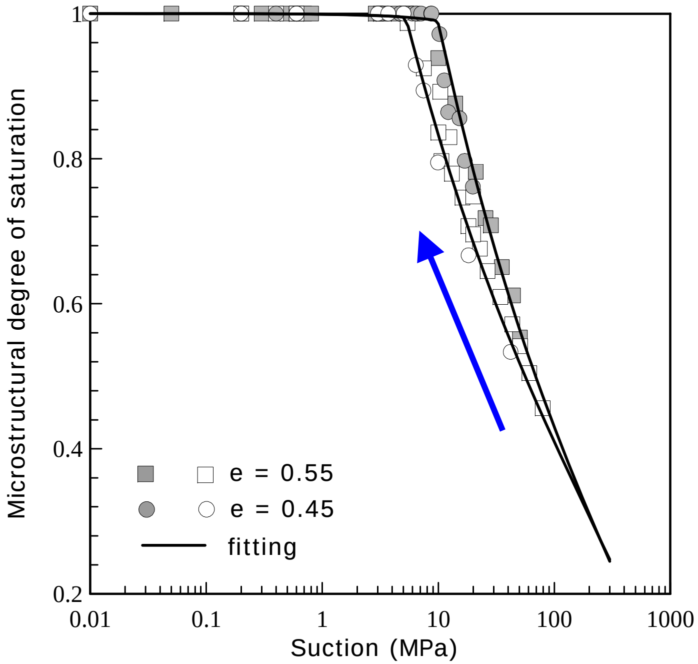


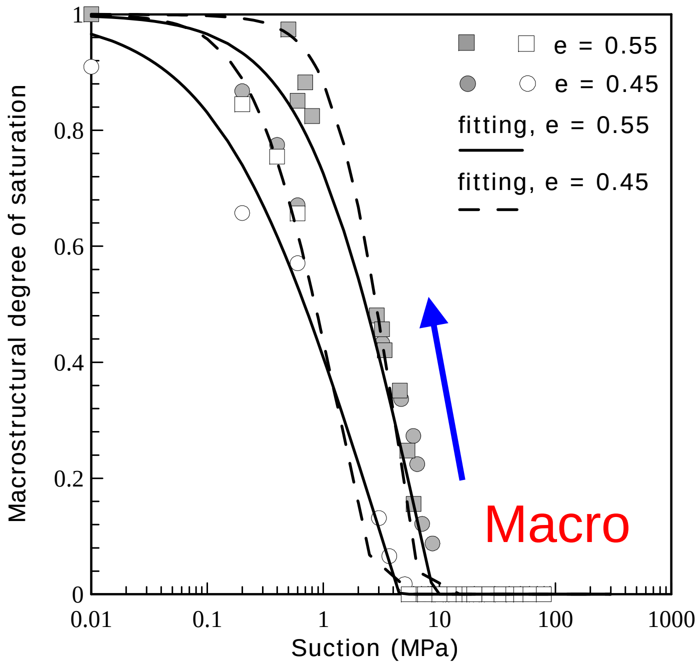


Lloret et al. (2003)

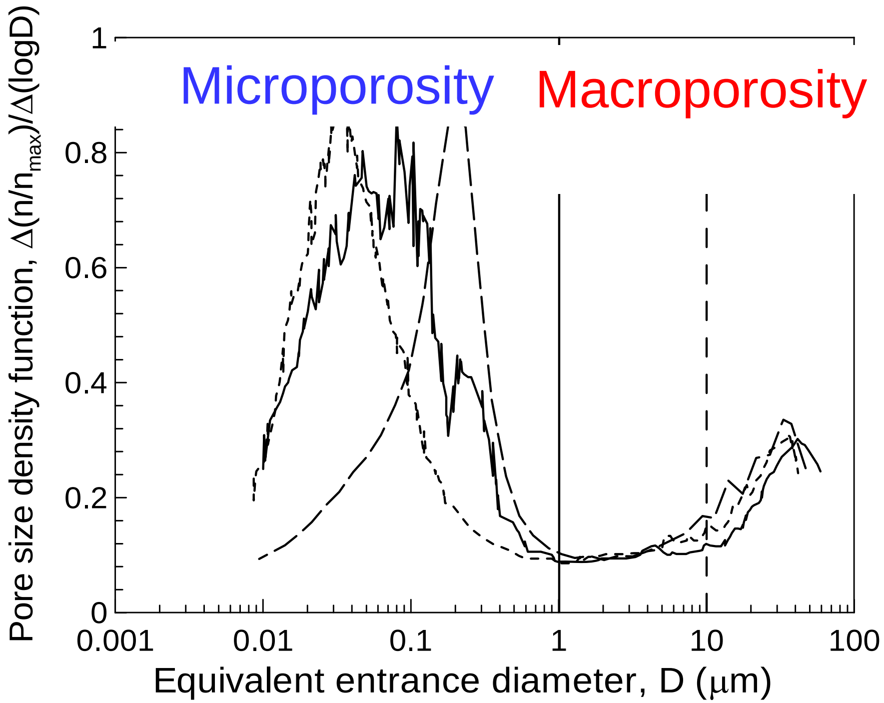
Sicilian scaly clay (kaolinitic-illitic clay). Wet / dry at constant volume



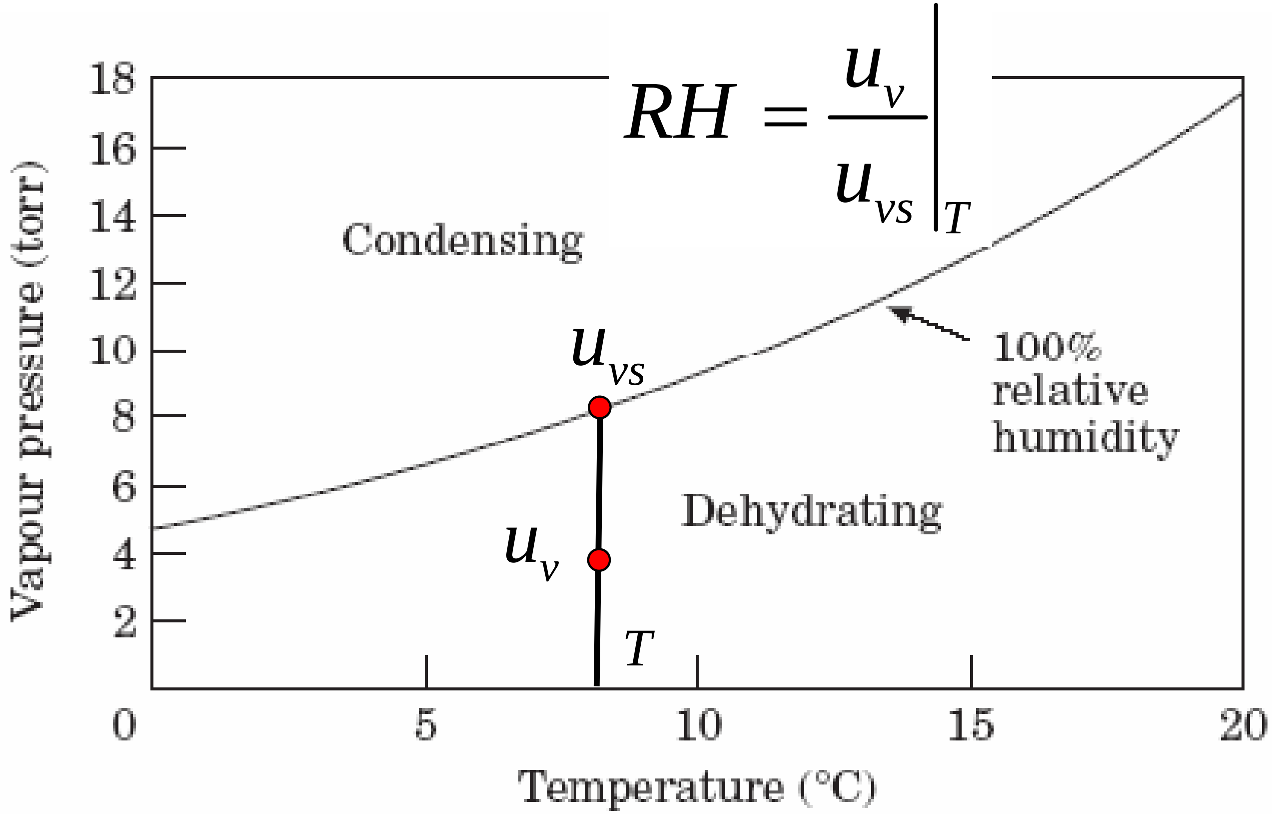




Consistency limits	w_L=58% w_p=28%
Compaction	ρ_d= 1.8 Mg/m^3



Environmental Scanning Electron Microscope (ESEM) observations



$$\psi = -\frac{RT\rho_w}{M_w}\ln(RH)$$

Ψ, total suction

R, universal gas constant

T, absolute temperature

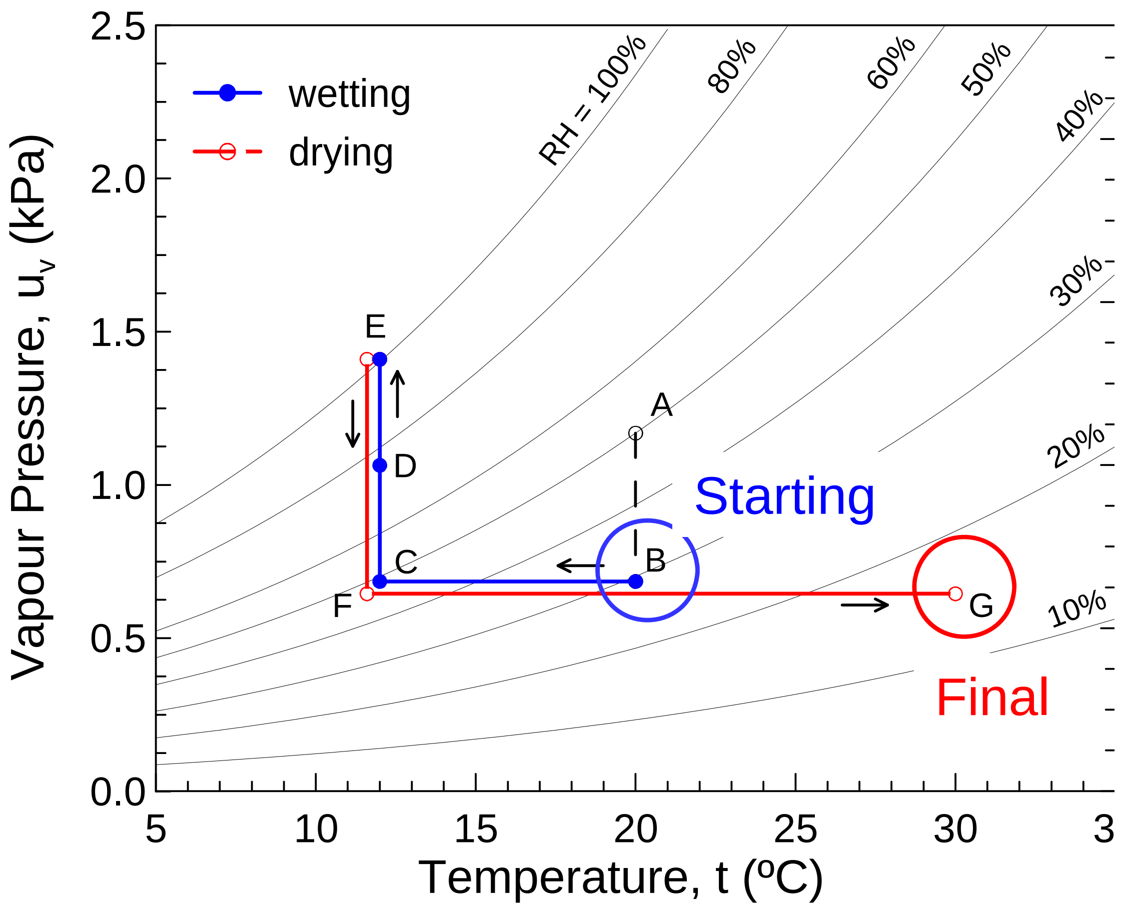
ρ_w, water density

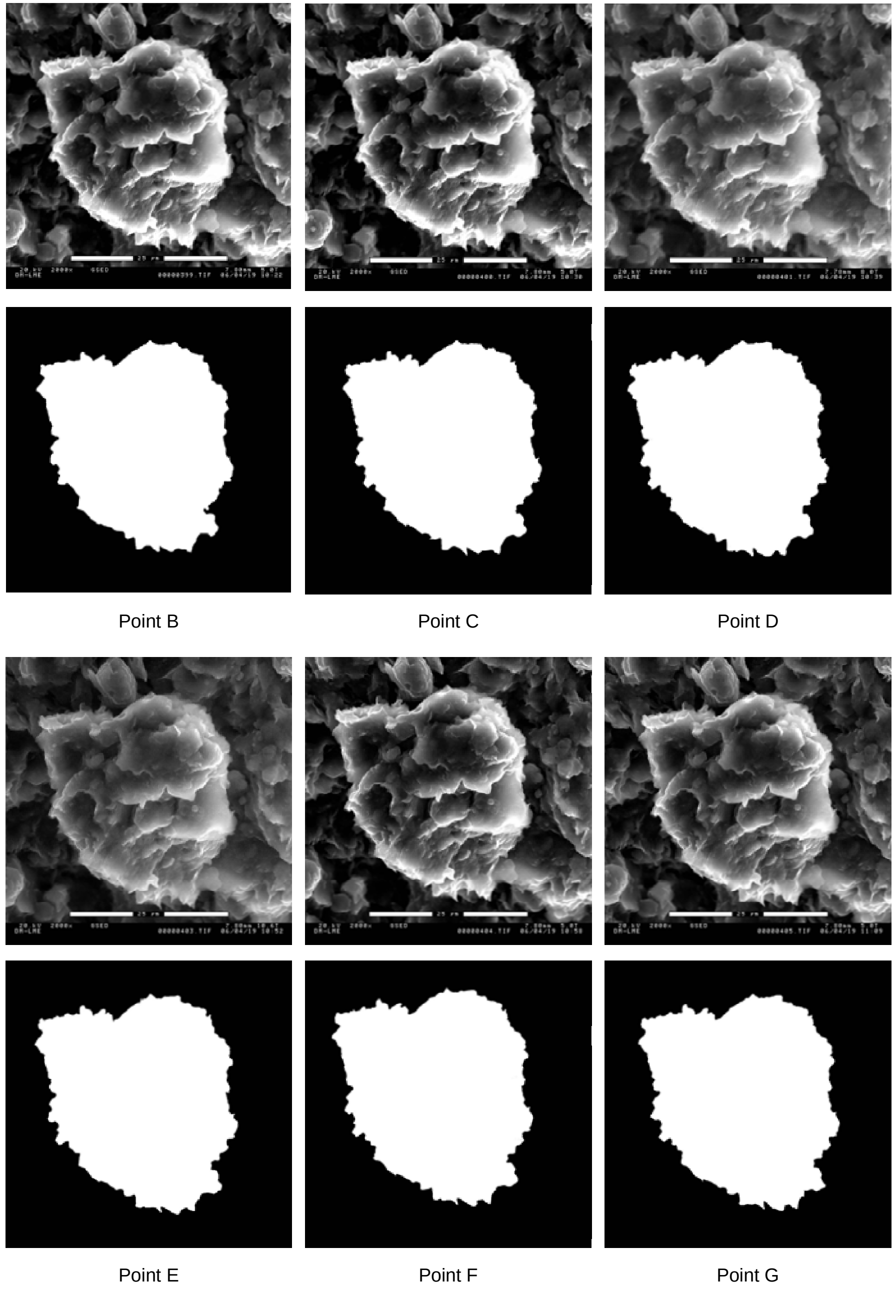
M_w, water molecular mass

RH, relative humidity

- Capability of fixing temperature and vapour pressure
- Technique suitable to study the gradual effects of wetting and drying stages. Photomicrographs can be taken at different hydraulic stages (usually after 10 min equalisation)
- Relative humidity associated with total suction (energy / volume) by the psychrometric law

Wetting and drying stages in ESEM



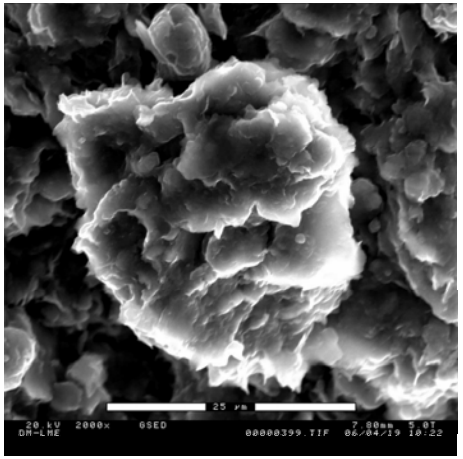


Volume change response of clay aggregates by digital image analysis

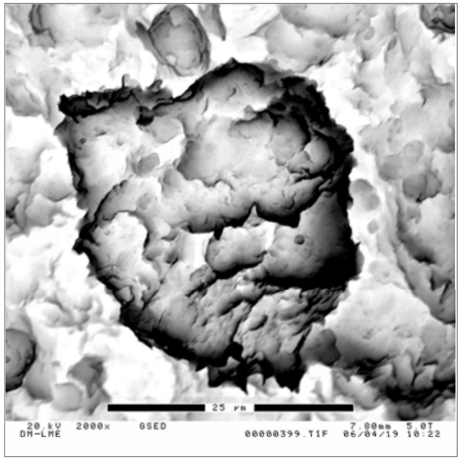
Image segmentation is applied to obtain quantitative information on the volume change response of the aggregate

$$\varepsilon_v = -\alpha \frac{A - A_0}{A_0}$$

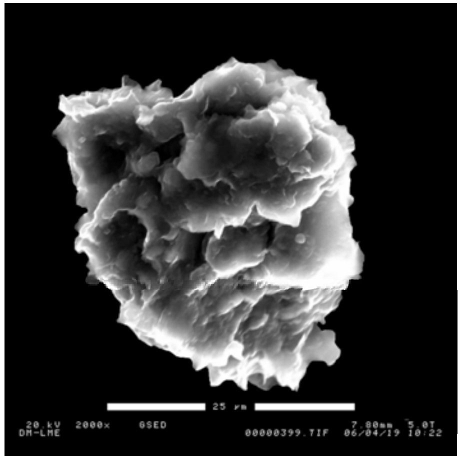
Image processing program ImageJ



(a) original image



(b) inverse image



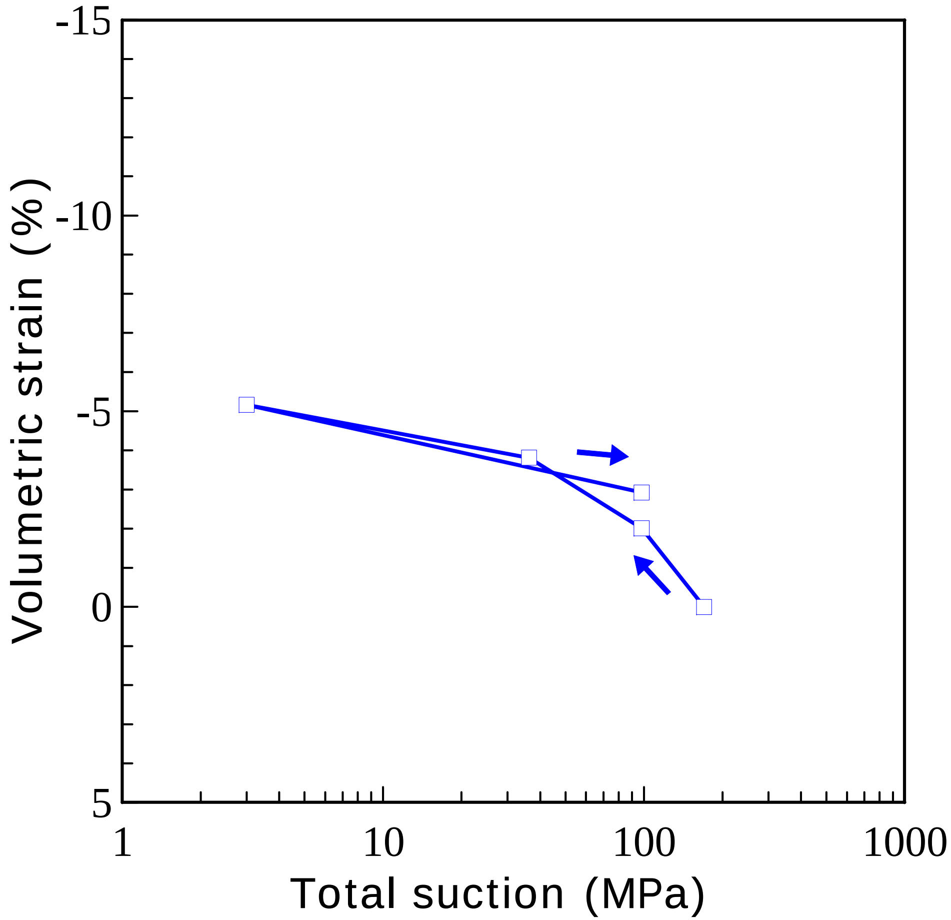
(c) aggregate edge identification

(d) aggregate area measurement

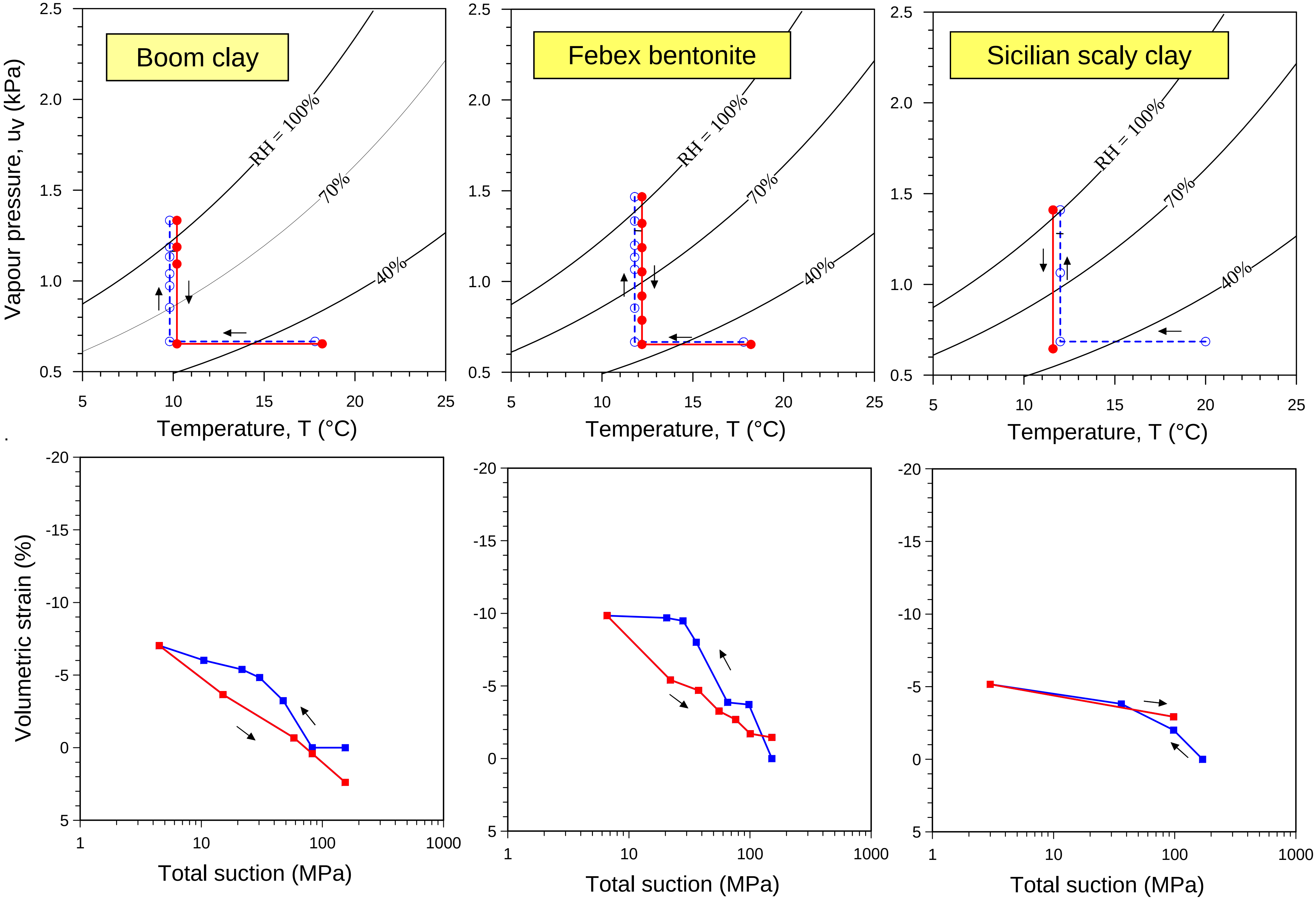
Isolation of aggregate

Binarisation of image

ε_v volumetric strain (negative for swelling); *A*, aggregate area; A_0 reference aggregate area; α = 1.5 for isotropic straining



Experimental results. Volume change behaviour during wet / dry cycle



Validate hydro-mechanical framework of double-scale models

Validation:

1) Hydro-mechanical response on wetting/drying at micro-scale

a) Is the mechanical response quasi-reversible or not?

b) Is the mechanical response influenced by other variables (water content, degree of saturation) in addition to suction?

c) …

2) Hydro-mechanical interaction between micro and macro-scales on wetting/drying

a) Comparison between micro and macro-scale of the mechanical response

b) Comparison between micro and macro-scale of the hydraulic response

c) …

An example of 1.b:

The microstructural volume change behaviour is assumed to be ruled by variations of the microstructural effective stress (this intensive stress variable includes information of degree of saturation)

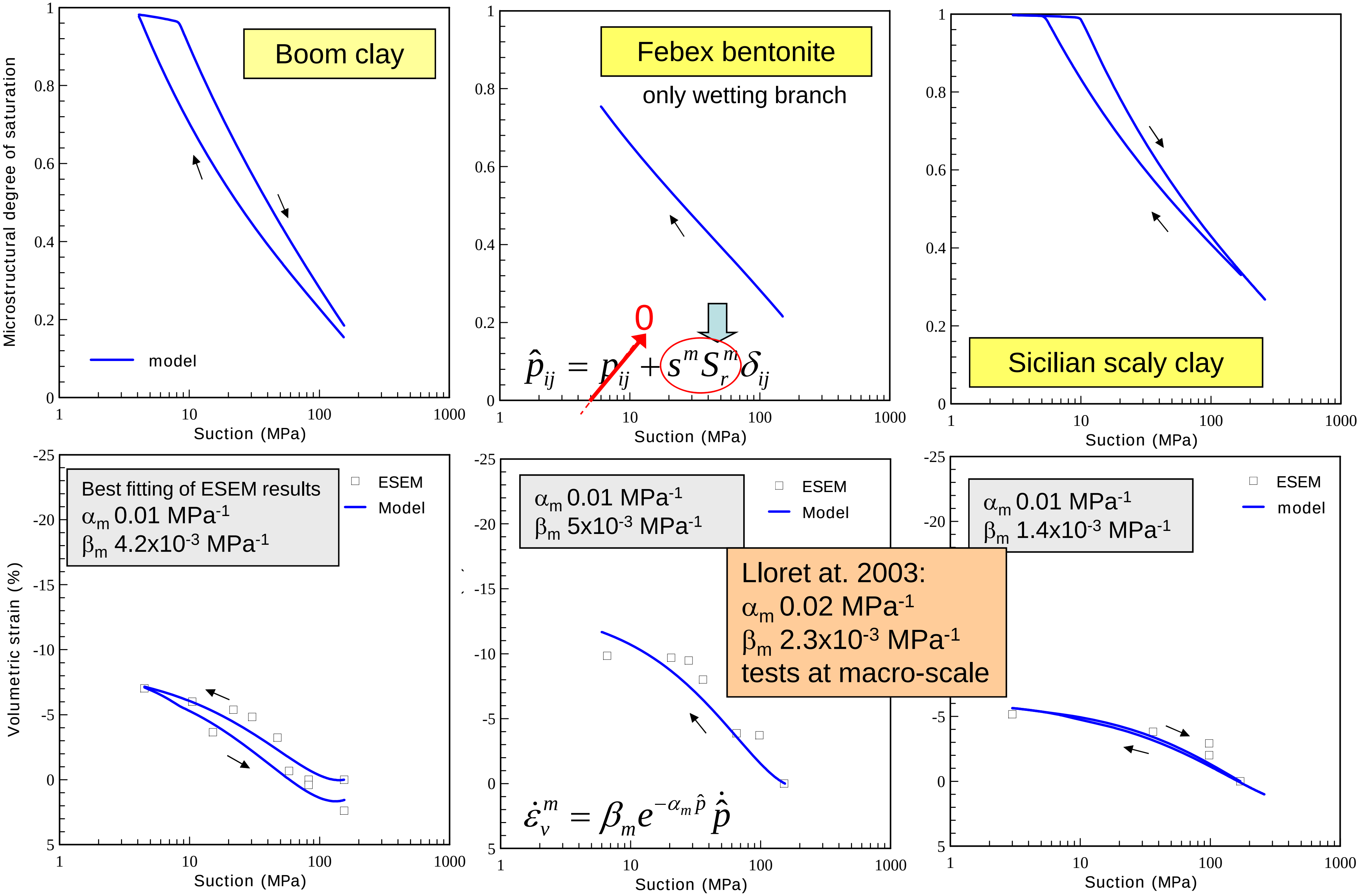
$$\hat{p}_{ij} = p_{ij} + s^m S_r^m \delta_{ij}$$

- $\hat{p}_{ij}$: effective stress tensor
- p_{ij}: net stress tensor
- s^m: microstructural suction
- S_r^m: microstructural degree of saturation

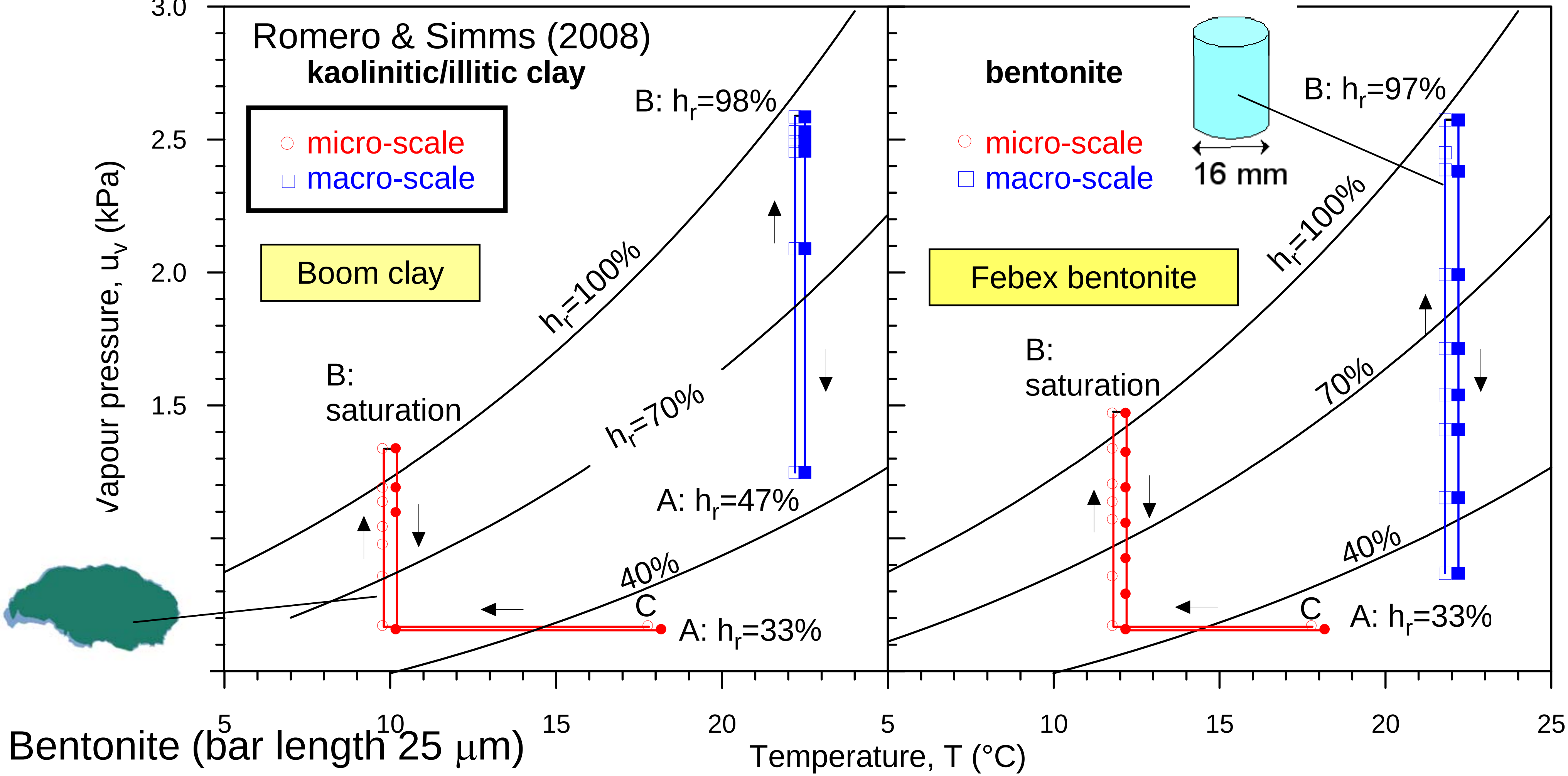
$$\dot{\varepsilon}_v^m = \beta_m e^{-\alpha_m \hat{p}} \dot{\hat{p}}$$

- $\dot{\varepsilon}_v^m$: microstructural volumetric strain variation
- β_m, α_m: material parameters
- $\dot{\hat{p}}$: mean effective stress variation

Model response of the microstructural behaviour

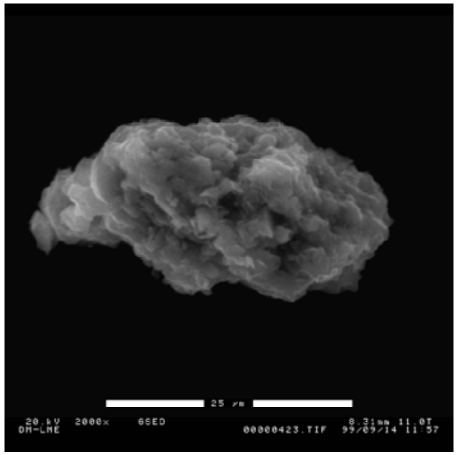


Comparison between micro and macro-scales (mechanical response)

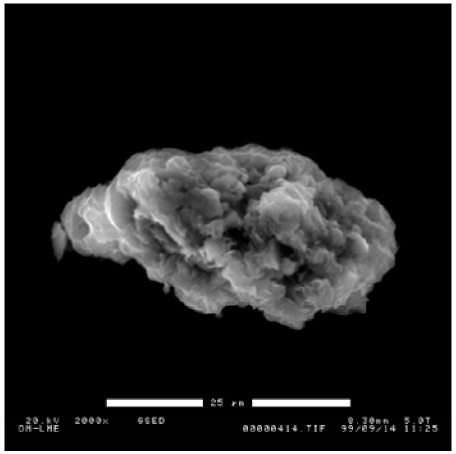


Bentonite (bar length 25 μm)

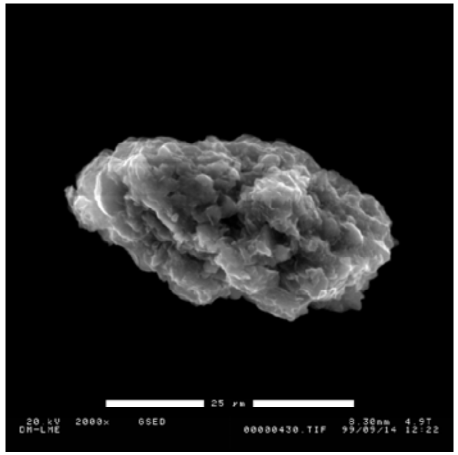
A)



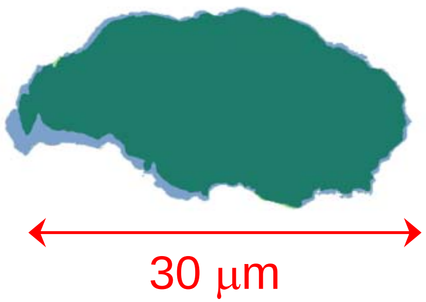
B)



C)

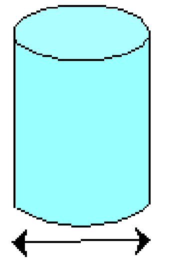


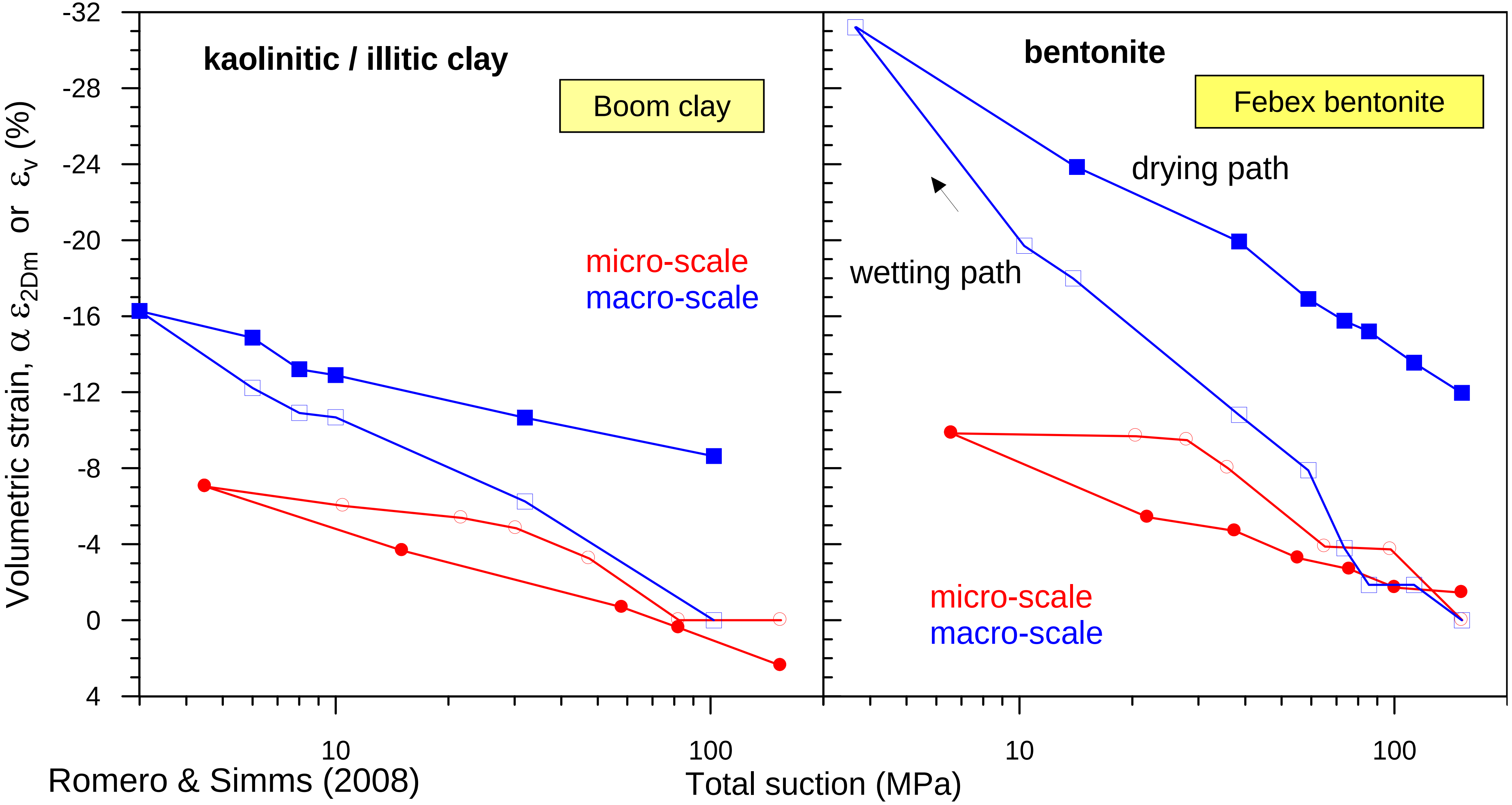
Comparison between micro and macro-scales (mechanical response)



Micro-scale
(quasi-reversible)

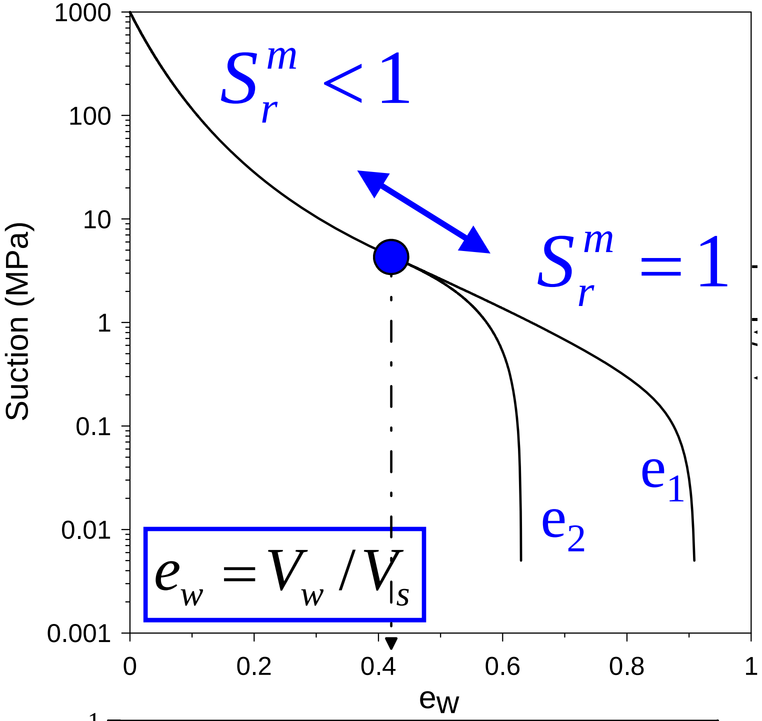
Macro-scale
(largely irreversible)





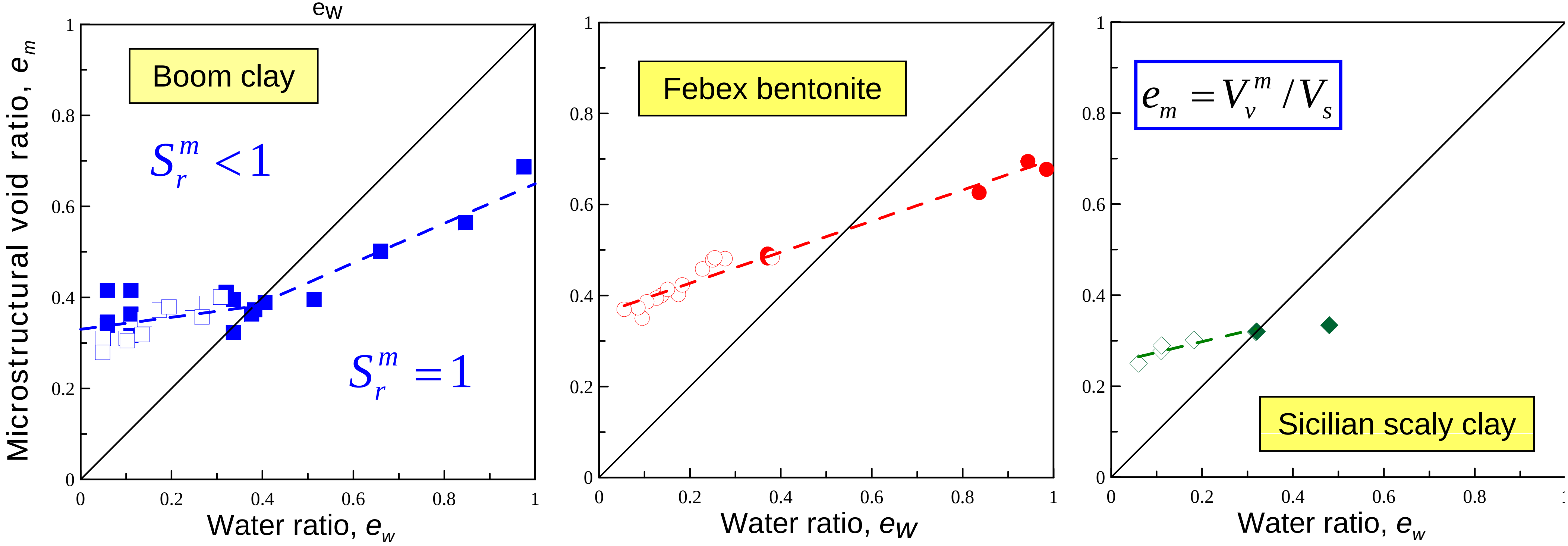
Romero & Simms (2008)

Micro and macro-scale interactions (hydraulic response)



Solid symbols
Test results from Mercury Intrusion Porosimetry: Romero et al. (2003), LLoret et al. (2003), Ferrari (2007), Della Vecchia et al. (2008)

Open symbols
ESEM results on clay aggregates



Conclusions

1. ESEM is a good equipment to investigate progressive wetting/drying consequences on the mechanical response of clay aggregations at the micro-scale

2. Microstructural studies should be made in conjunction with measurements at macroscopic scale. Assessment of the technique

3. Micro-scale measurements were quantitatively related to some macroscopic behavioural features (volume change behaviour and water retention properties)

4. This technique can help validating hypotheses used in multi-scale models (HM response at micro-scale level, interactions between micro and macro-scales)