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Experimental investigation of the delayed behaviour of the unsaturated argillaceous rocks by means of Digital Image Correlation techniques

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- Creep behavior under controlled HM

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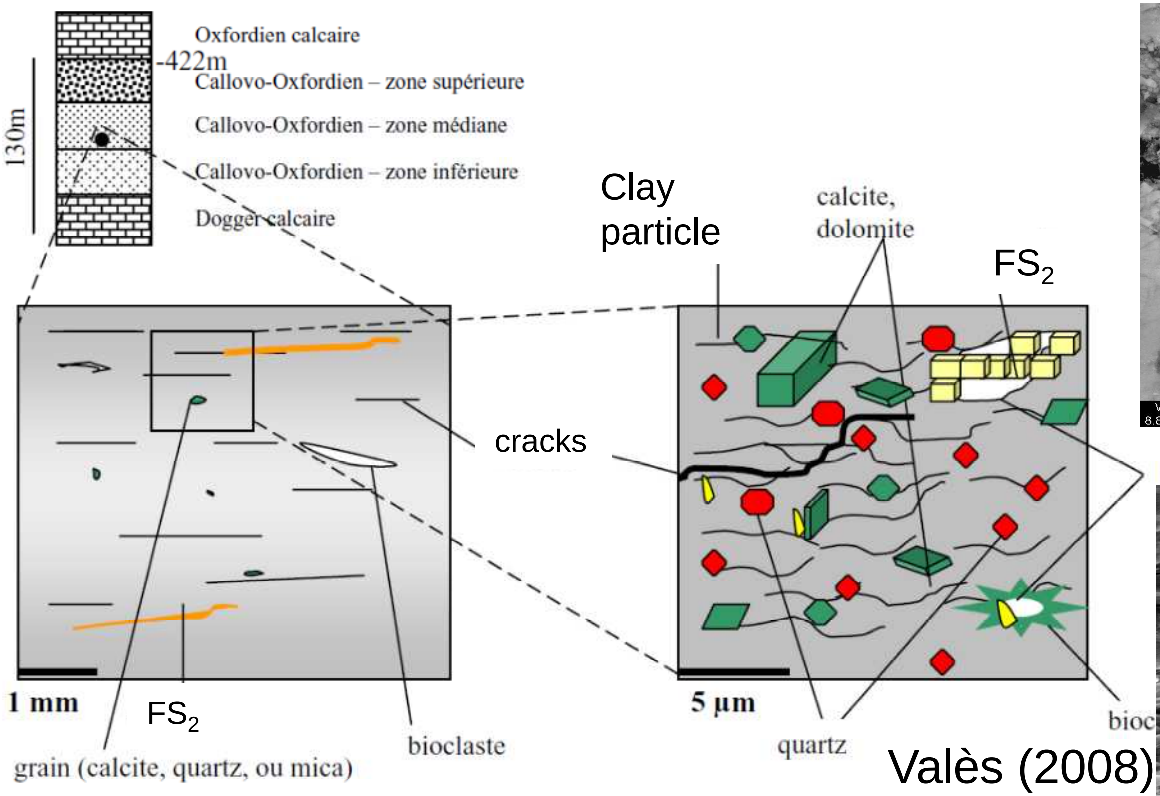
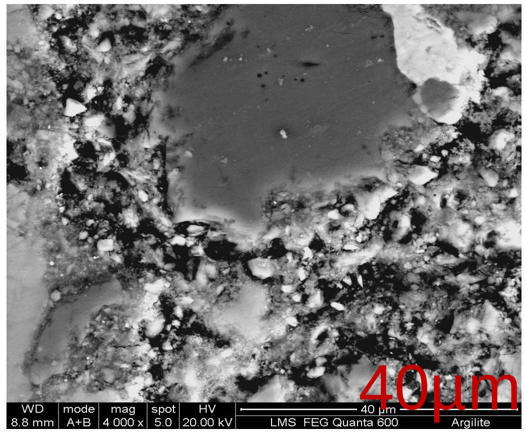
Introduction

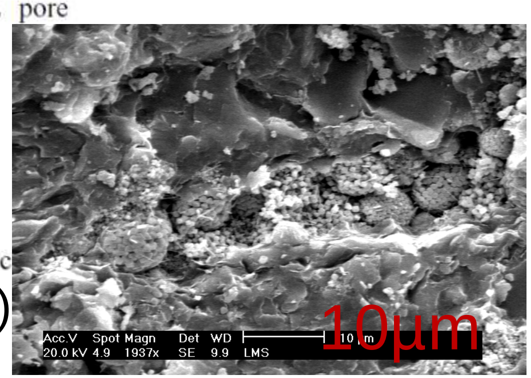
Argillaceous rocks of Meuse/Haute Marne

Depth: -420 et -550 m (130 m thick)
Mineralogy: clay minerals (~45%); carbonates (~20%); quartz (~30%)



Valès (2008)





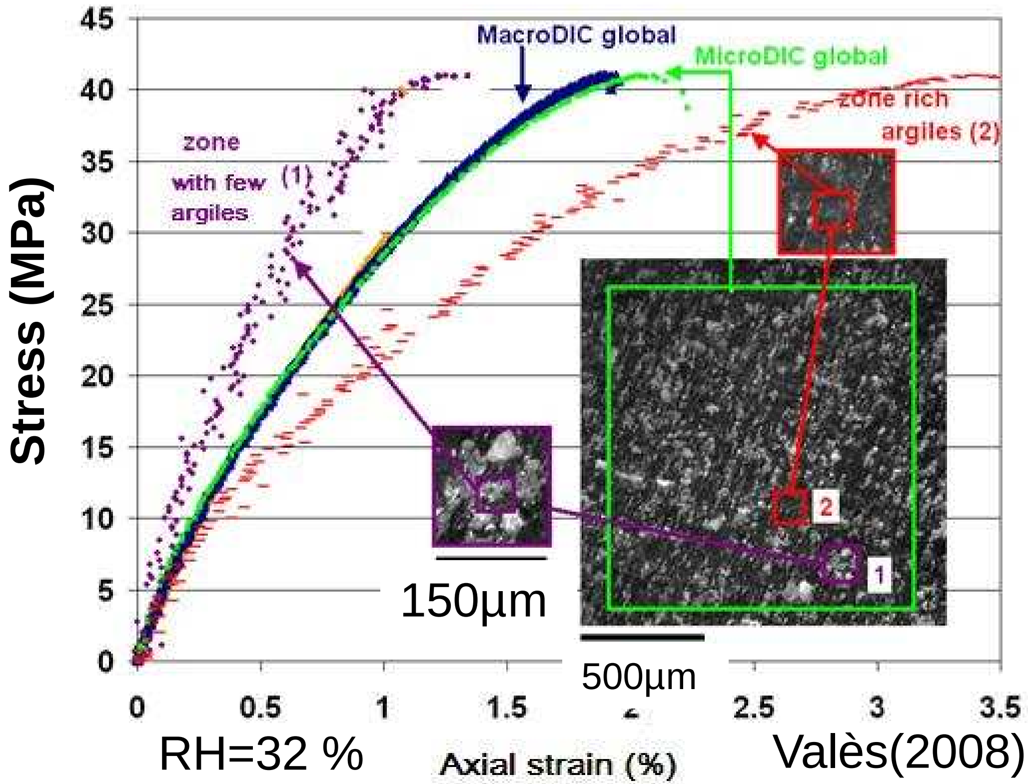
Total porosity : 15%
Permeability : <10^{-20} m²

Hydromechanical behavior of argillaceous rocks

Shrinking and Swelling: strain related to RH	10^{-4} / ° RH
E and Rc ↘, when RH ↗	10^{-2} $\varepsilon_{rupture}$
Creep : more significant, when RH ↗	10^{-4} / week

Microstructure induces heterogeneous mechanical response at various scales

Reversible,irreversible, elastic,plastic,creep, hydration … :
at which scale? RVE?

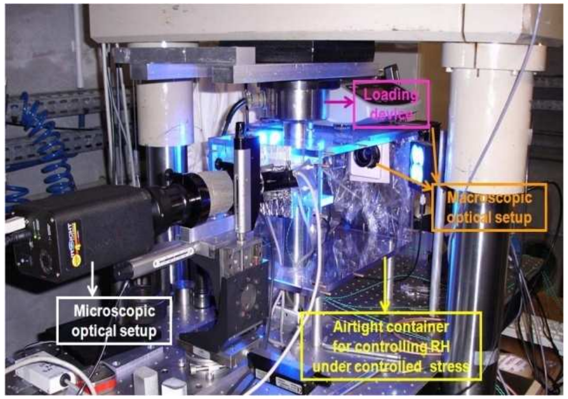


Object

Study of the mechanisms of delayed behavior of the argillaceous rocks under coupled HM conditions

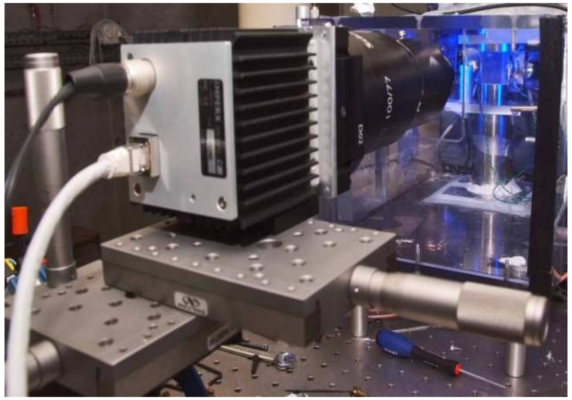
By means of DIC technique

Experimental setup



Uniaxial compression under controlled moisture with multiscale full-field strain measurements

- Loading device
- Macroscopic measurements : strain gauges, LVDT
- Suction control
- Optical multiscale full-field strain measurements during hydric-mechanical loading

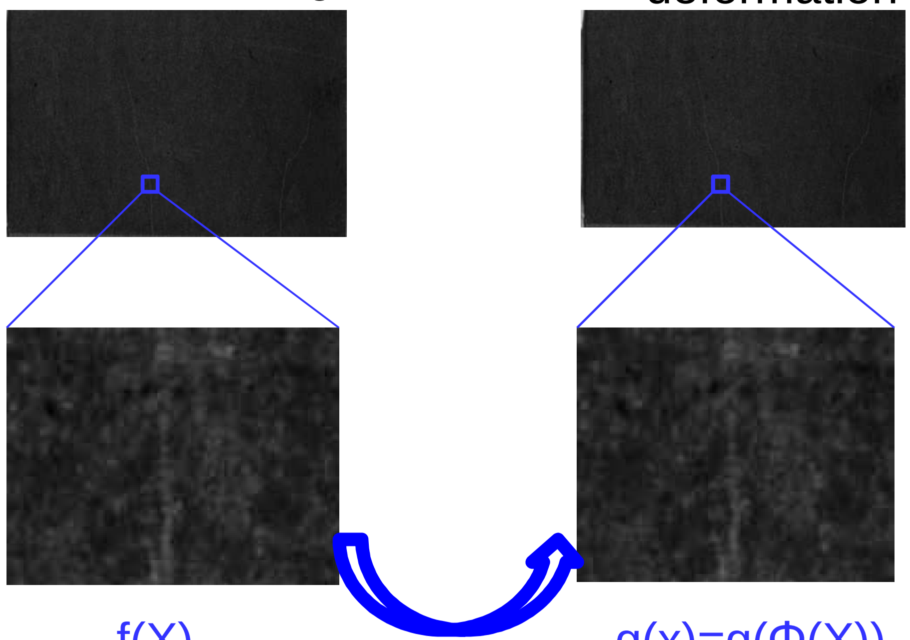


Macroscopic optical setup (24x36 mm)
& Microscopic optical setup (1.5x1.5 mm)

Digital image correlation (DIC) and associated errors

Reference image

Image after deformation



$f(X)$ $g(x)=g(\Phi(X))$

Φ transformation in subpixel accuracy

Digital image correlation

Identify the position of each object point in two images by correlation algorithm

$$\Phi_D \approx \underset{\Phi_0 \in V}{\mathrm{Argmin}}\ C(f,g,D,\Phi_0)$$

Example::

$$C(\Phi_0)=\int_D \left[f(u)-g(\Phi_0(u))\right]^2 du \approx \sum_{ij\in D}\left[f(u_{ij})-g(\Phi_0(u_{ij}))\right]^2$$

Determination of the local (full-field) or average strains

Average the transformation gradient over domains of interest

Various sources of random or systematic errors

Noise, image quality, **contrast, interpolation method**, **out-of-plane motion,** etc.

ÉCOLE POLYTECHNIQUE

Multiscale full-field strain measurements

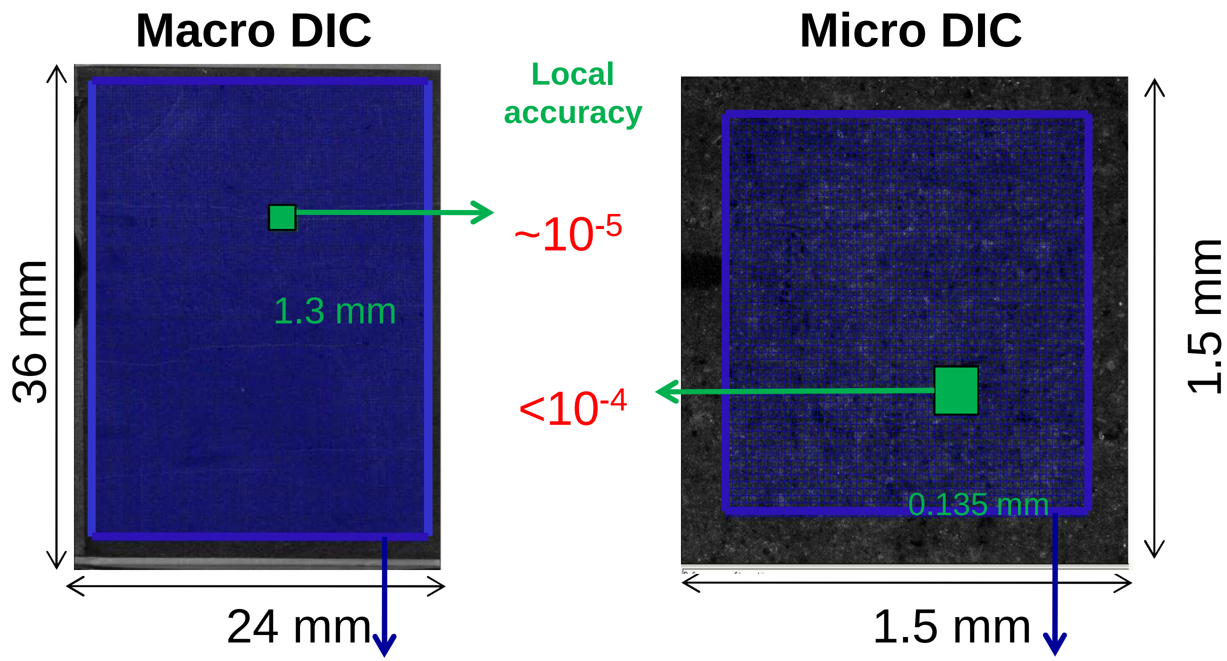
ANDRA

Improvement of the system (Yang and Michel *et al.* 2010)

Optimal aperture minimizes the systematic errors
Minimizing the effect of global out-of-plane motion

$$\varepsilon = \varepsilon_a - \Delta g/g\,\mathbf{1} \quad (\Delta g/g = -dZ/OC \quad \triangle Z^{macro} = \triangle Z^{micro} + D\,\varepsilon^{zz})$$

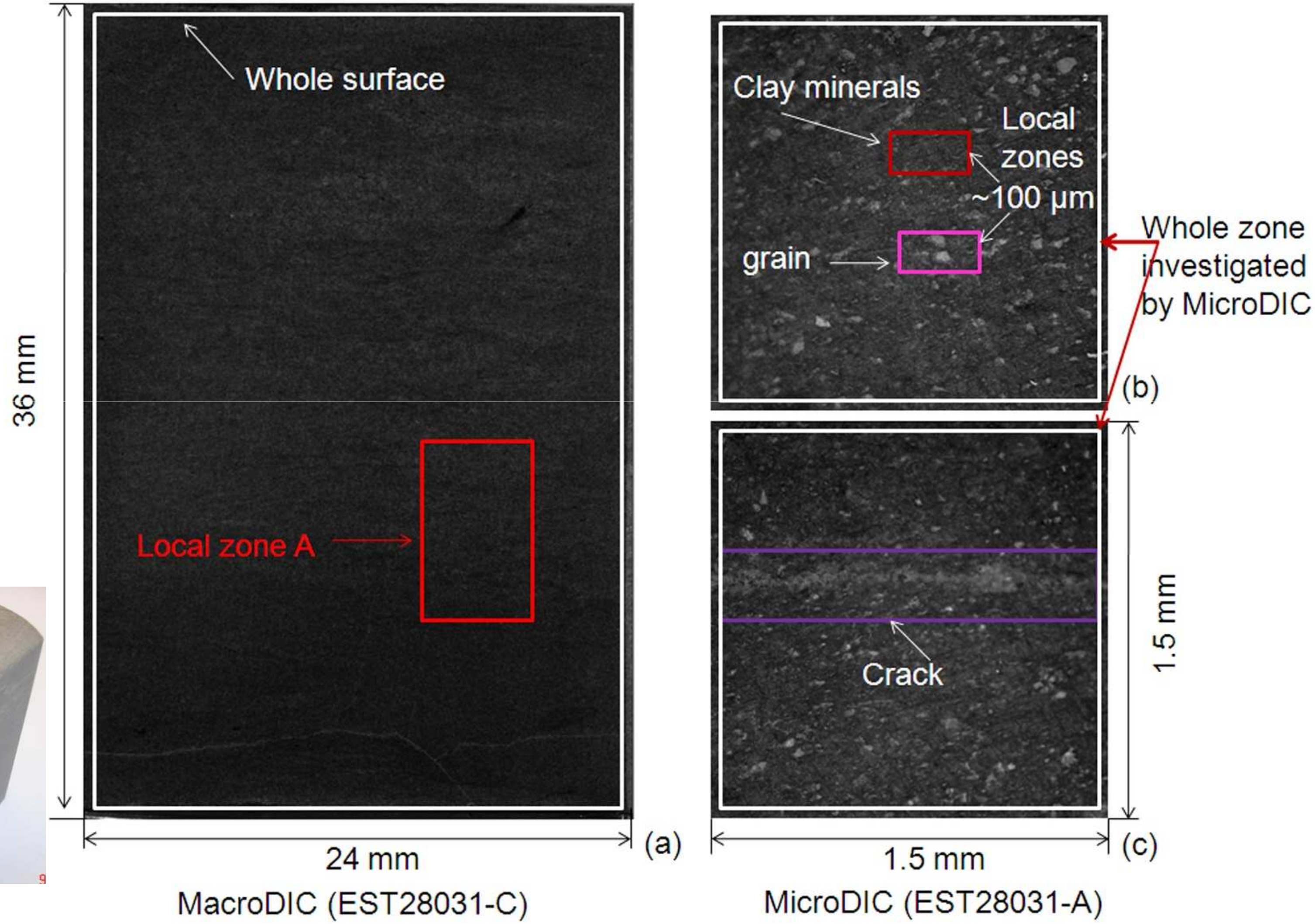
Strain measurement ε accuracy



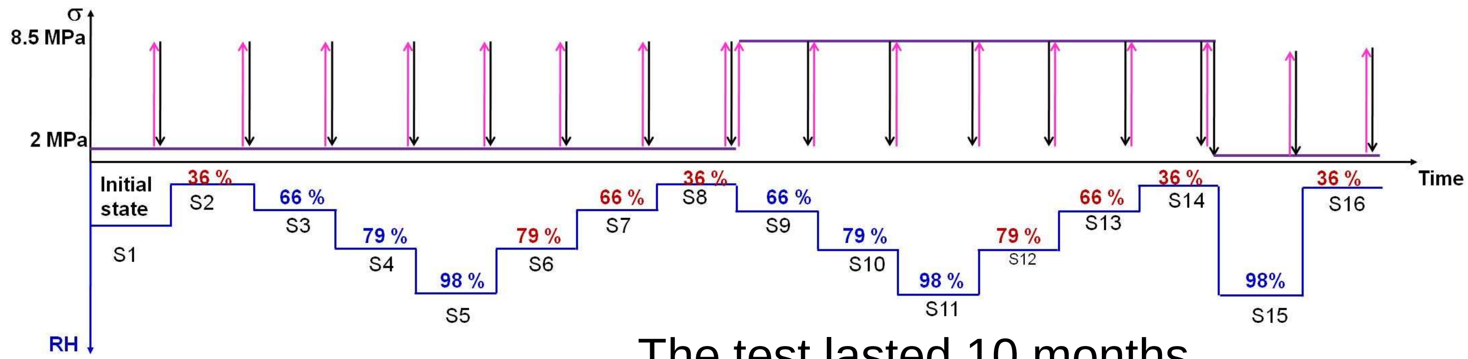
Global accuracy **$<10^{-5}$** **350 ×** **$<5.10^{-5}$**

(suitable for creep test)

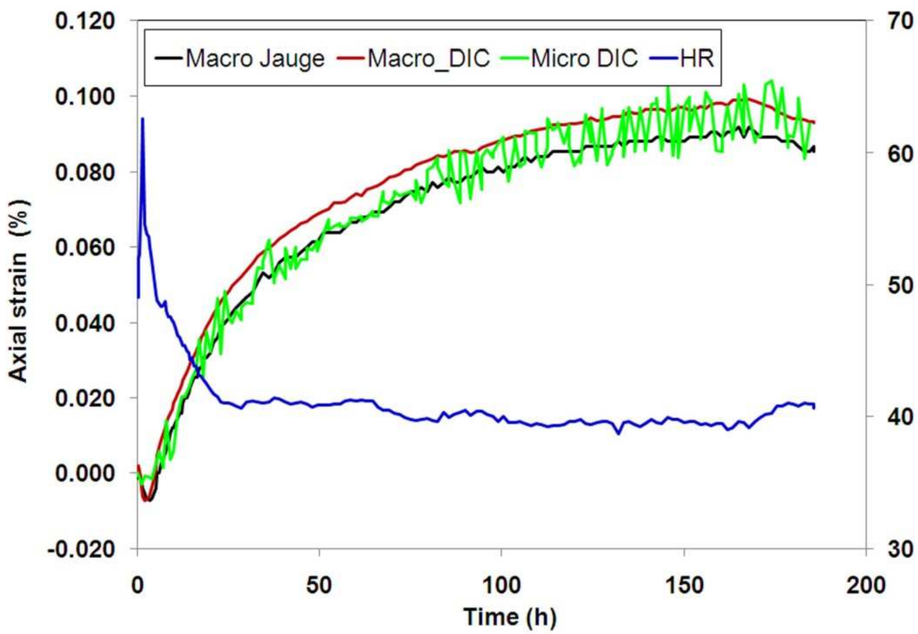
Characterization of the heterogeneity

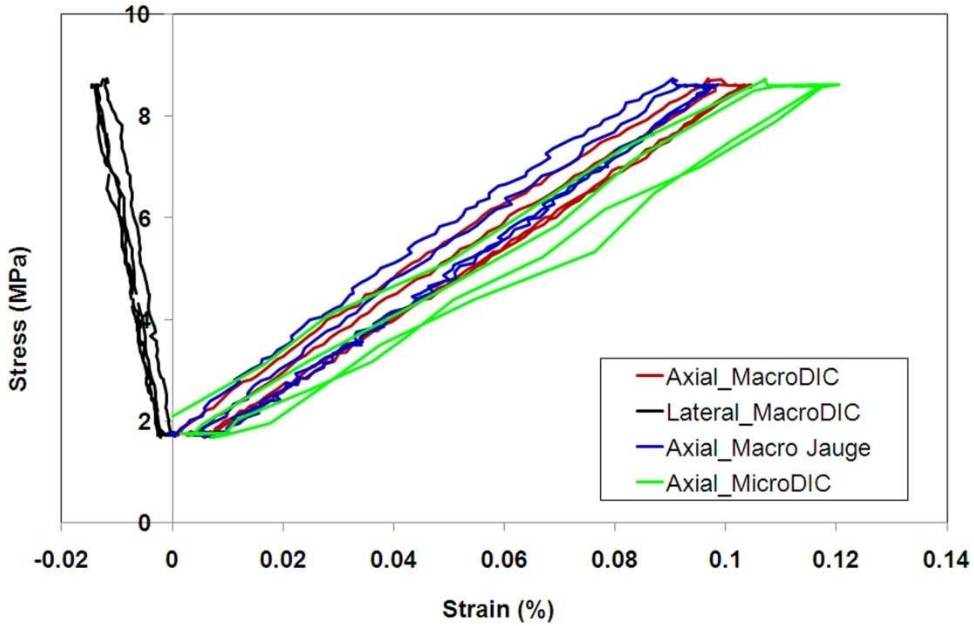


Hydration and dehydration under uniaxial stress (Yang and Michel et al. 2011,in preparing)

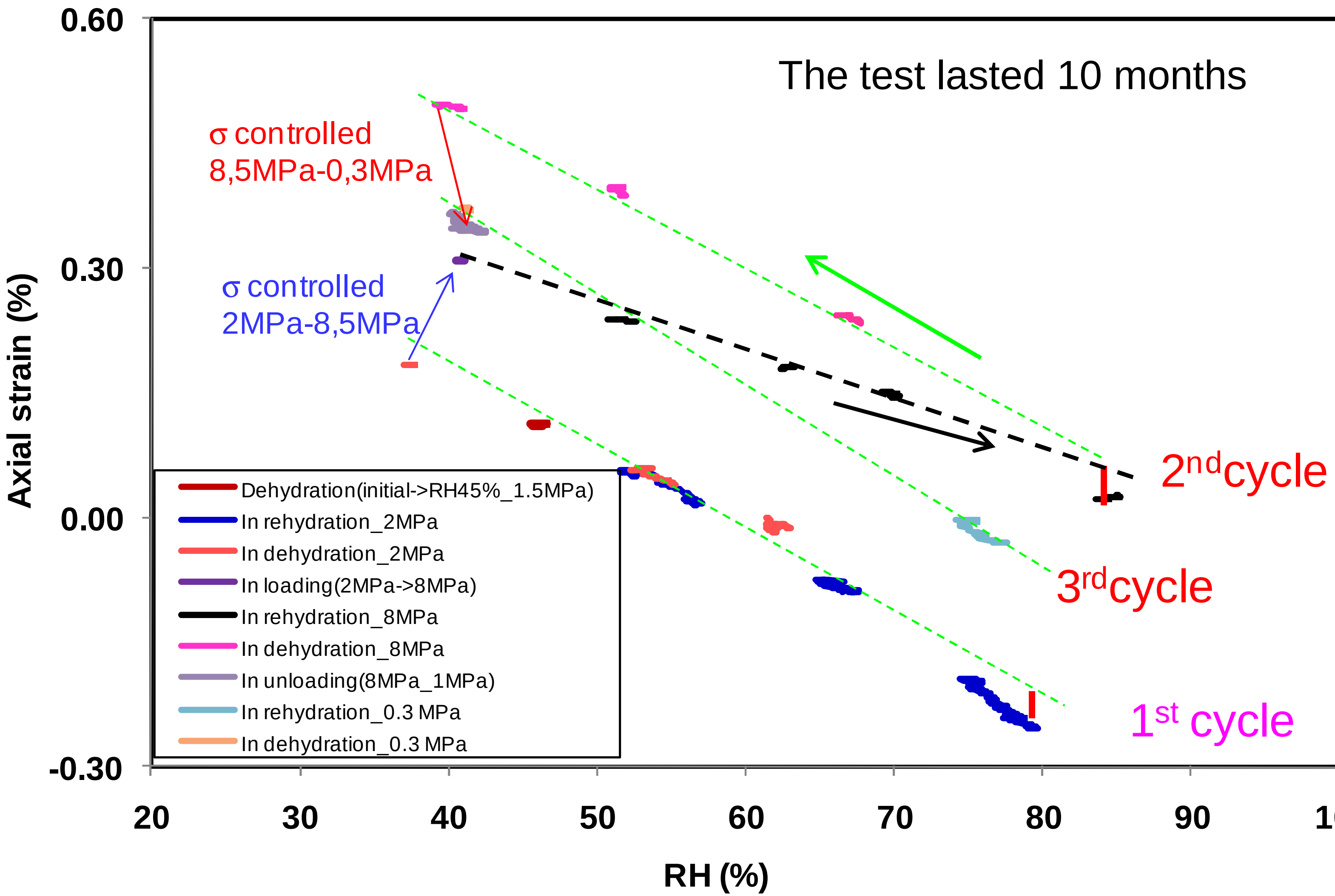


The test lasted 10 months

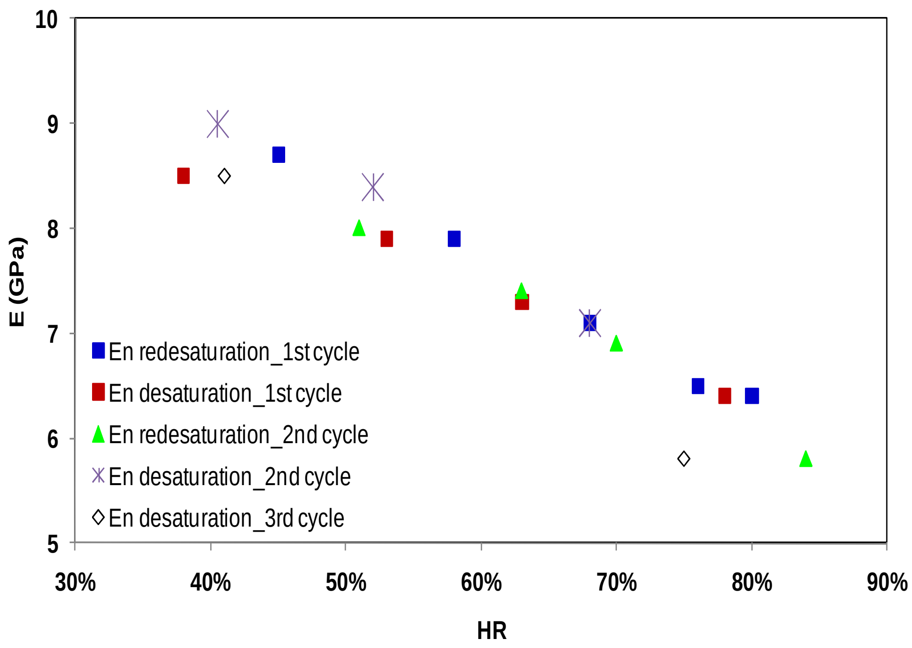


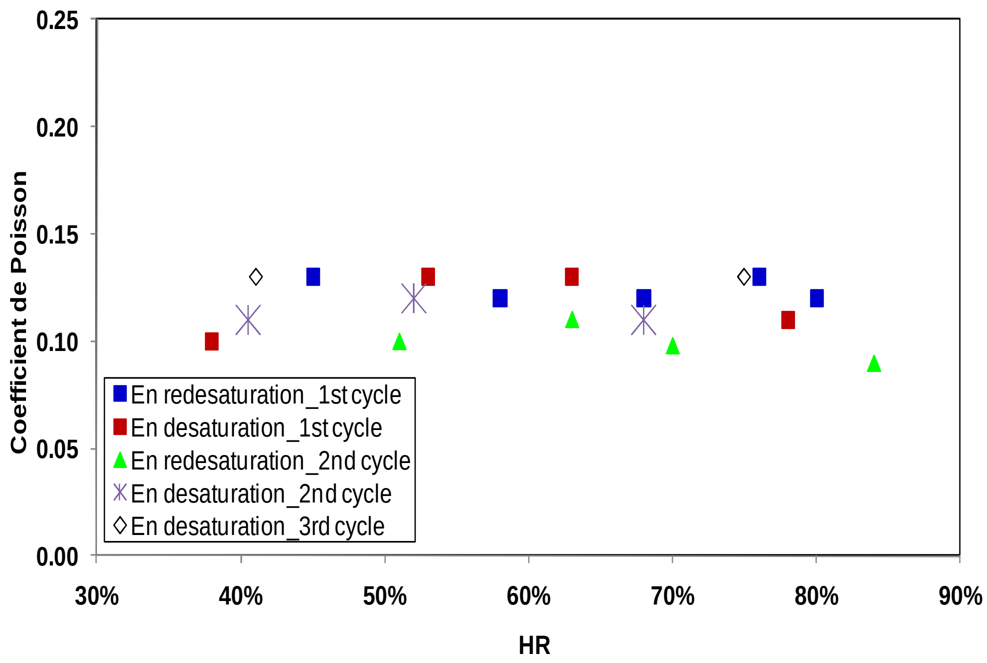


Hydration and dehydration under uniaxial stress



Hydration and dehydration under uniaxial stress

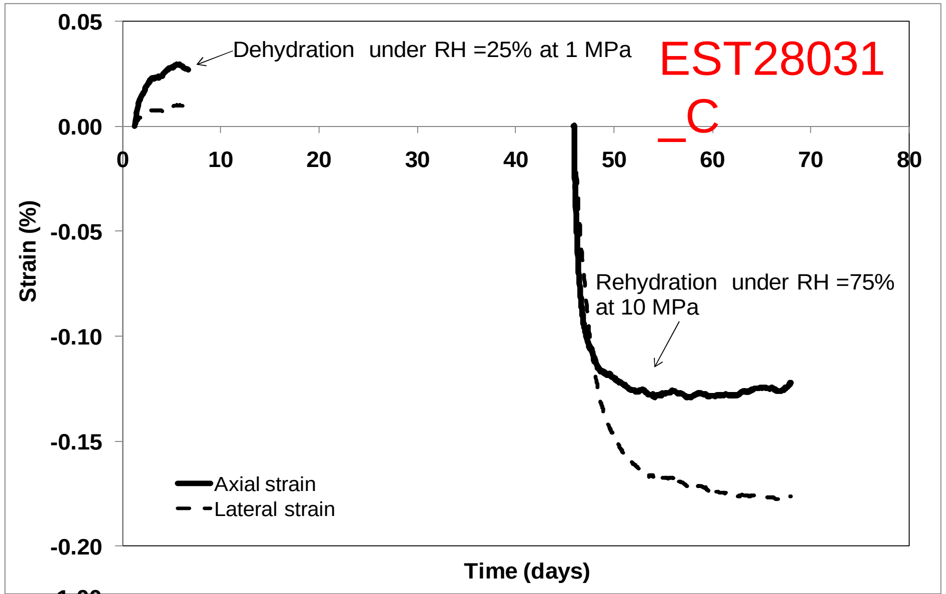




ε vs RH quasi-linear ,
reversible under low σ
and irreversible under high σ

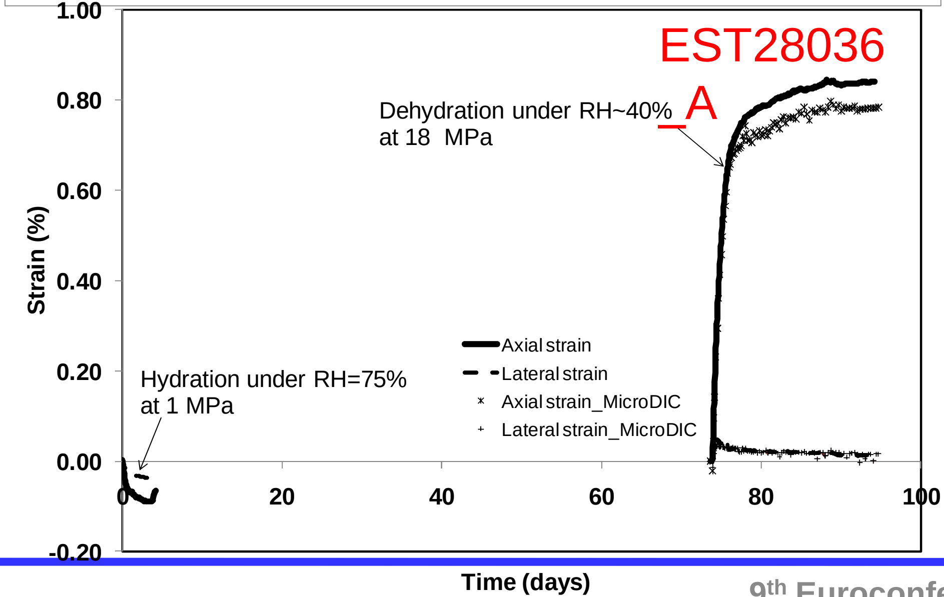
E vs RH quasi-linear
ν vs RH quasi-constant
for RH < 85%

Hydromechanical behavior of argillaceous rocks



$\varepsilon_{lateral}/\varepsilon_{axial} \sim 0.3$ at 1 MPa

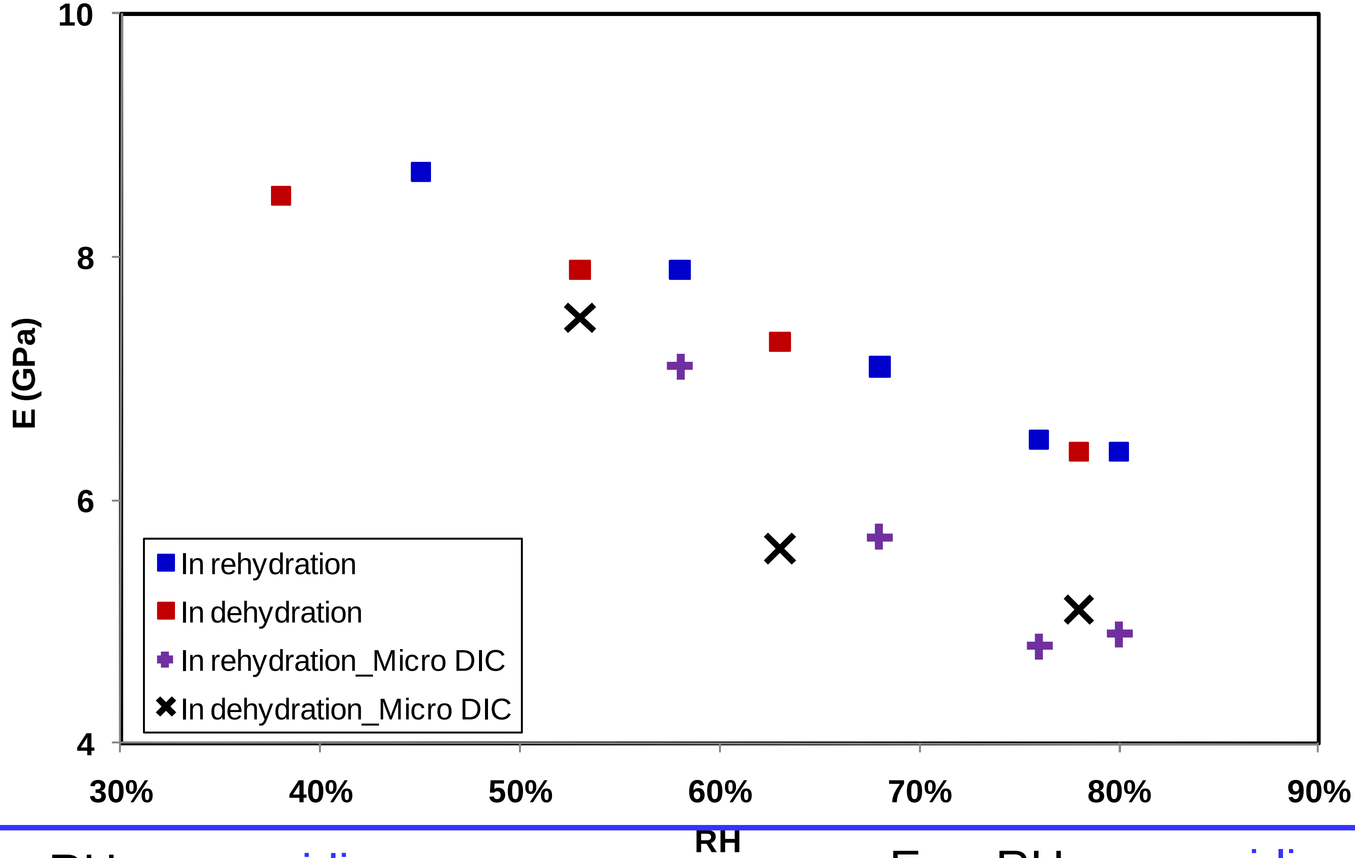
$\varepsilon_{lateral} = -0.18\% > \varepsilon_{axial} = -0.13\%$ at 10 MPa during rehydration



$\varepsilon_{lateral} = 0.08\% < \varepsilon_{axial} = 0.83\%$ at 18 MPa during dehydration

Shrinkage and swelling strongly depend on the applied stress
The classical Biot theory is not relevant

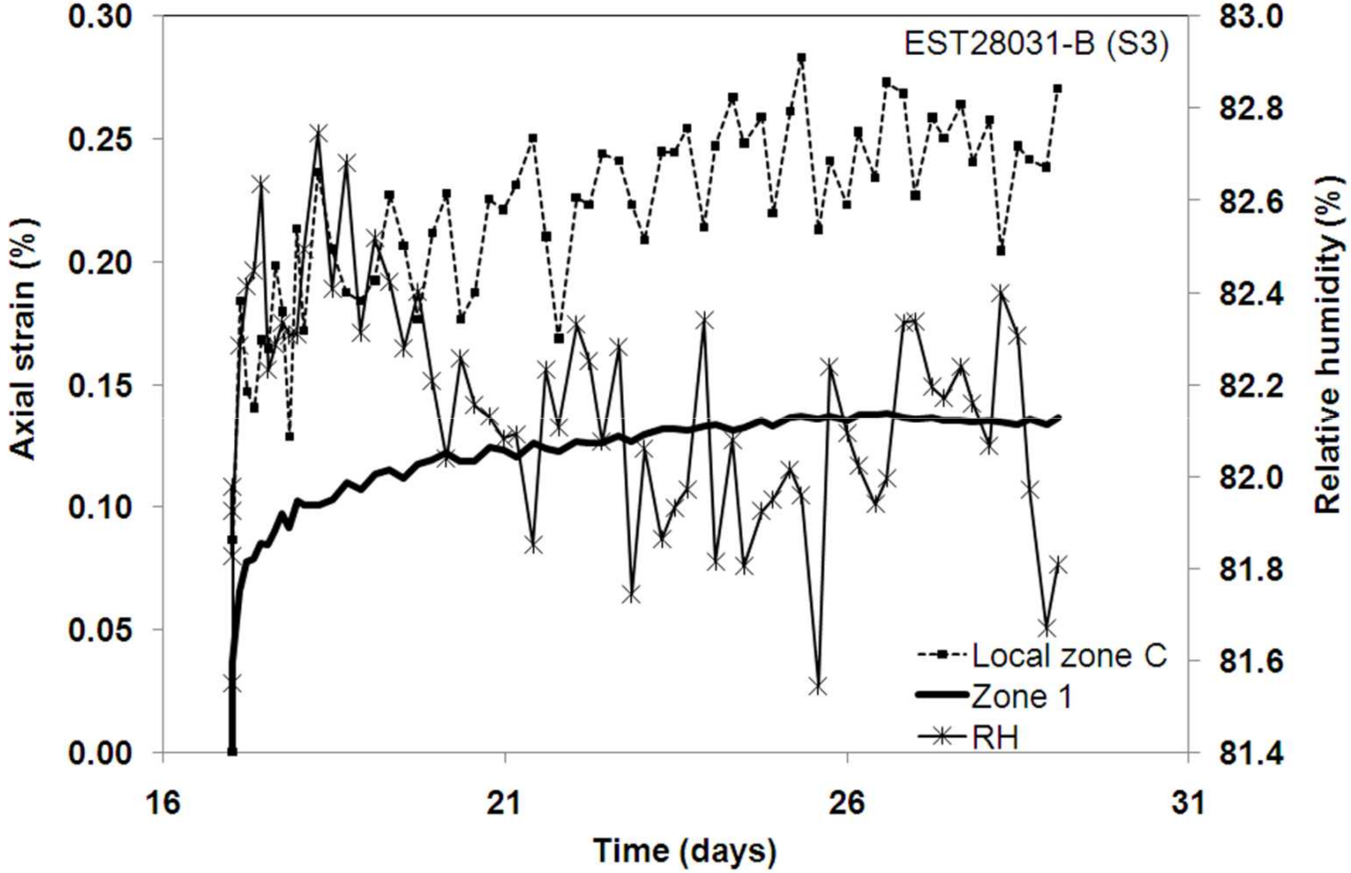
Hydration and dehydration under uniaxial stress



ε vs RH quasi-linear ,
reversible under low σ
and irreversible under high σ

E vs RH quasi-linear
ν vs RH quasi-constant
for RH < 85%

Strain at various scales



Local zone with high clay content (200 µm)

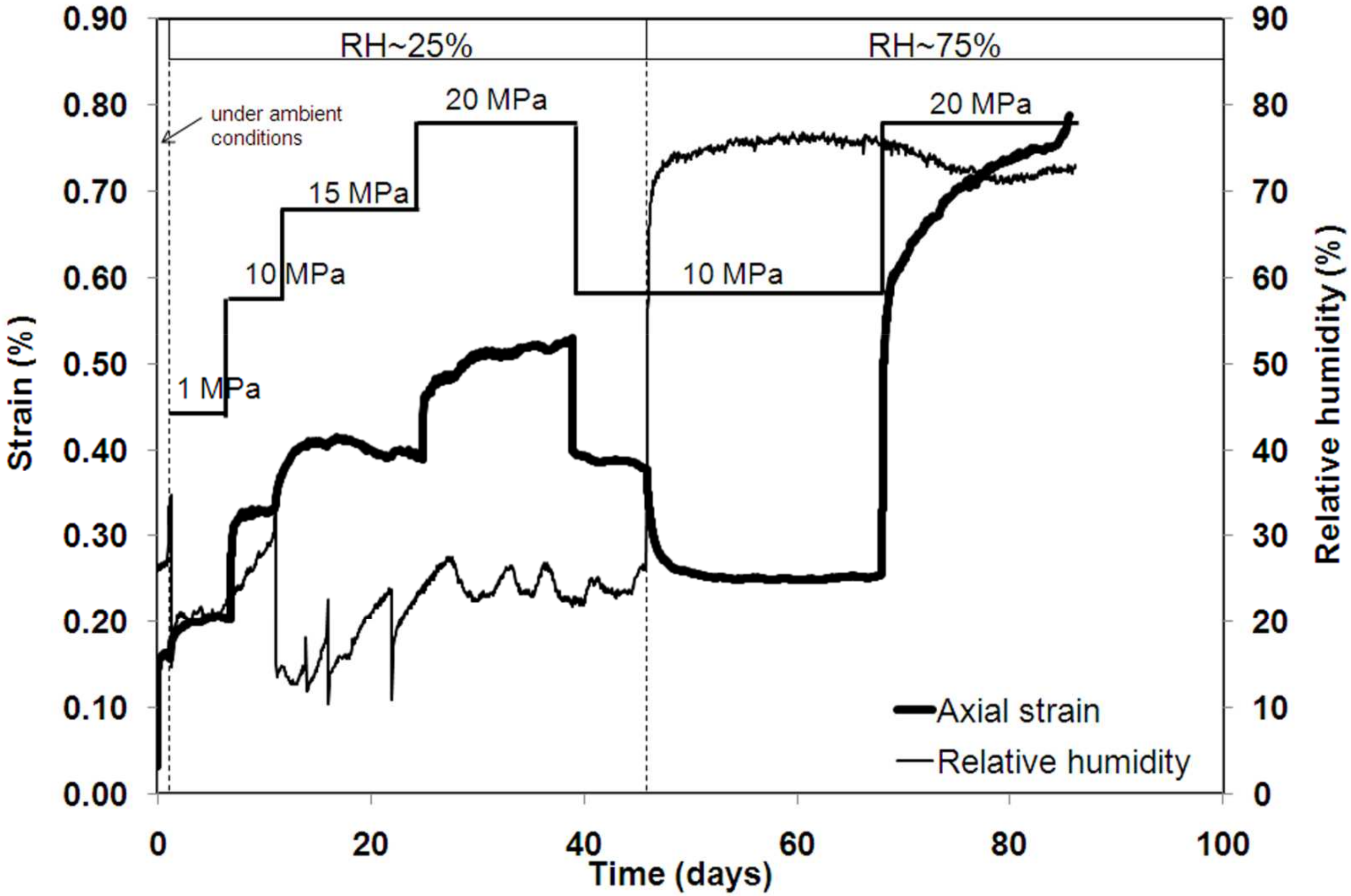
Zone 1 (millimetric scale)

$\Delta\varepsilon$ (local zone) ≈ 10 x $\Delta\varepsilon$ (Zone 1)
Subjected to ΔRH

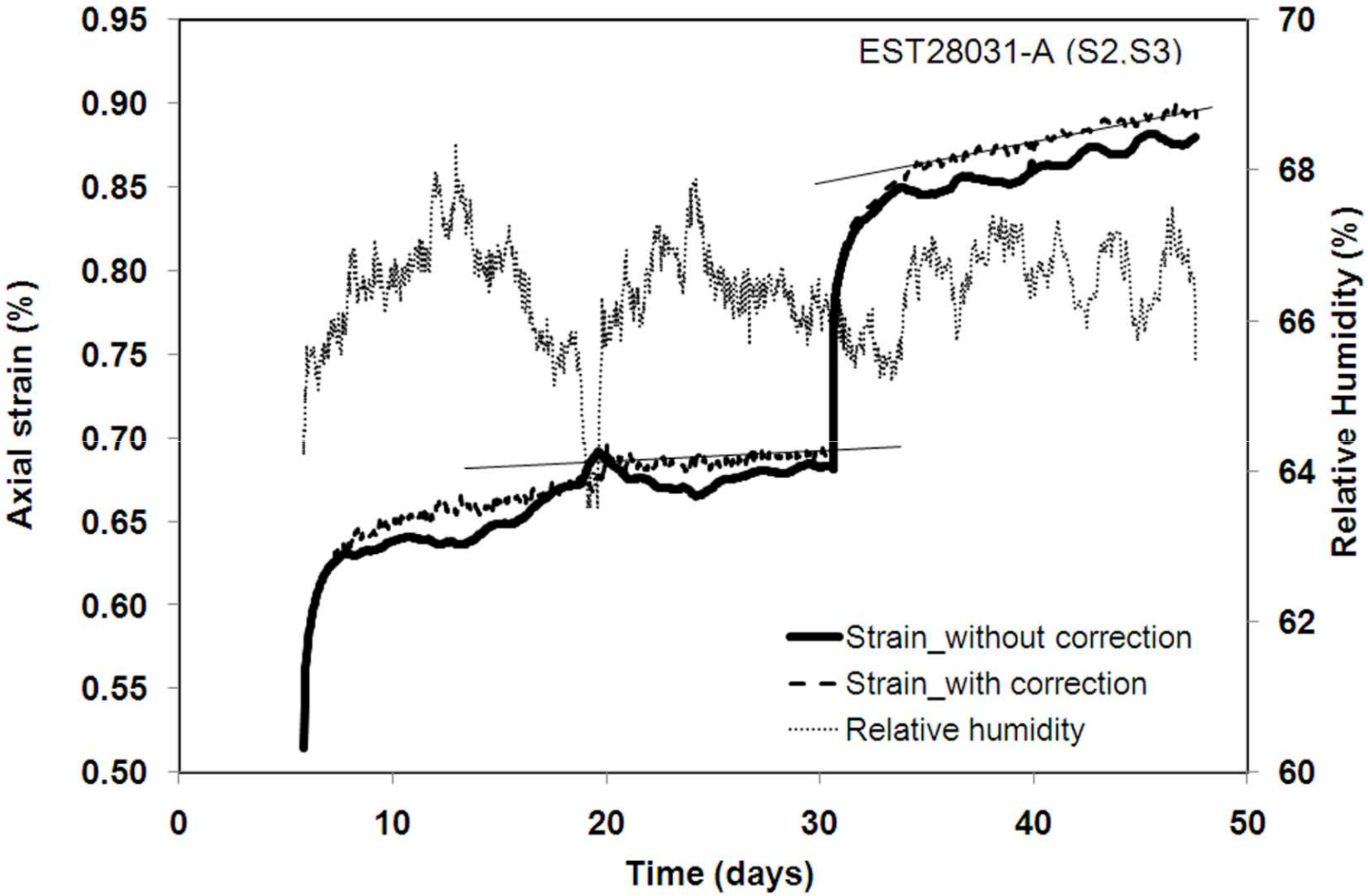
Creep behavior under controlled HM (Yang and Michel *et al.* 2011)

Loading paths: axial stress 10 MPa; 15 MPa; 20 MPa

RH 25%; 65%; 75%; 80%

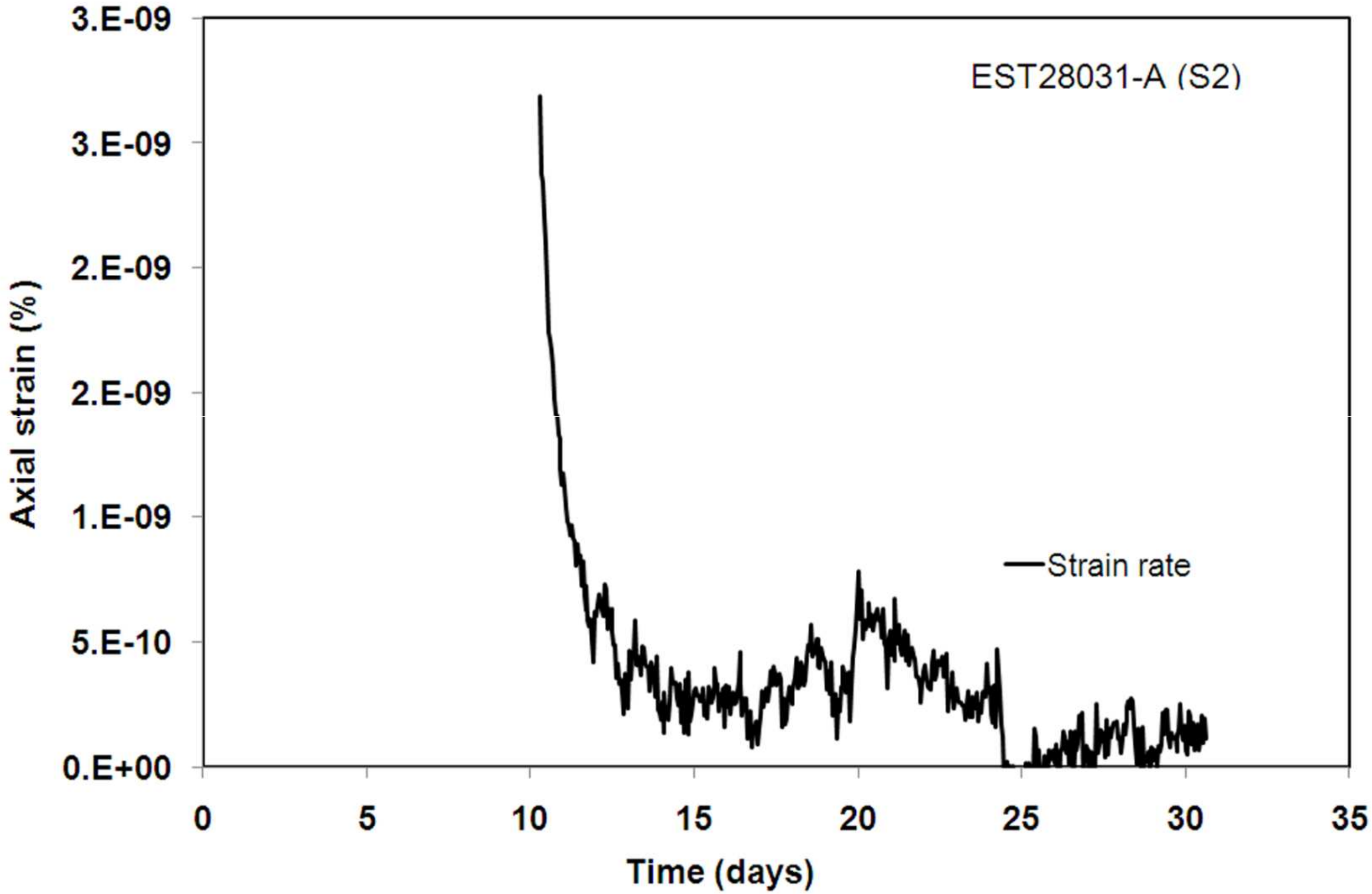


Characterization of strain rate



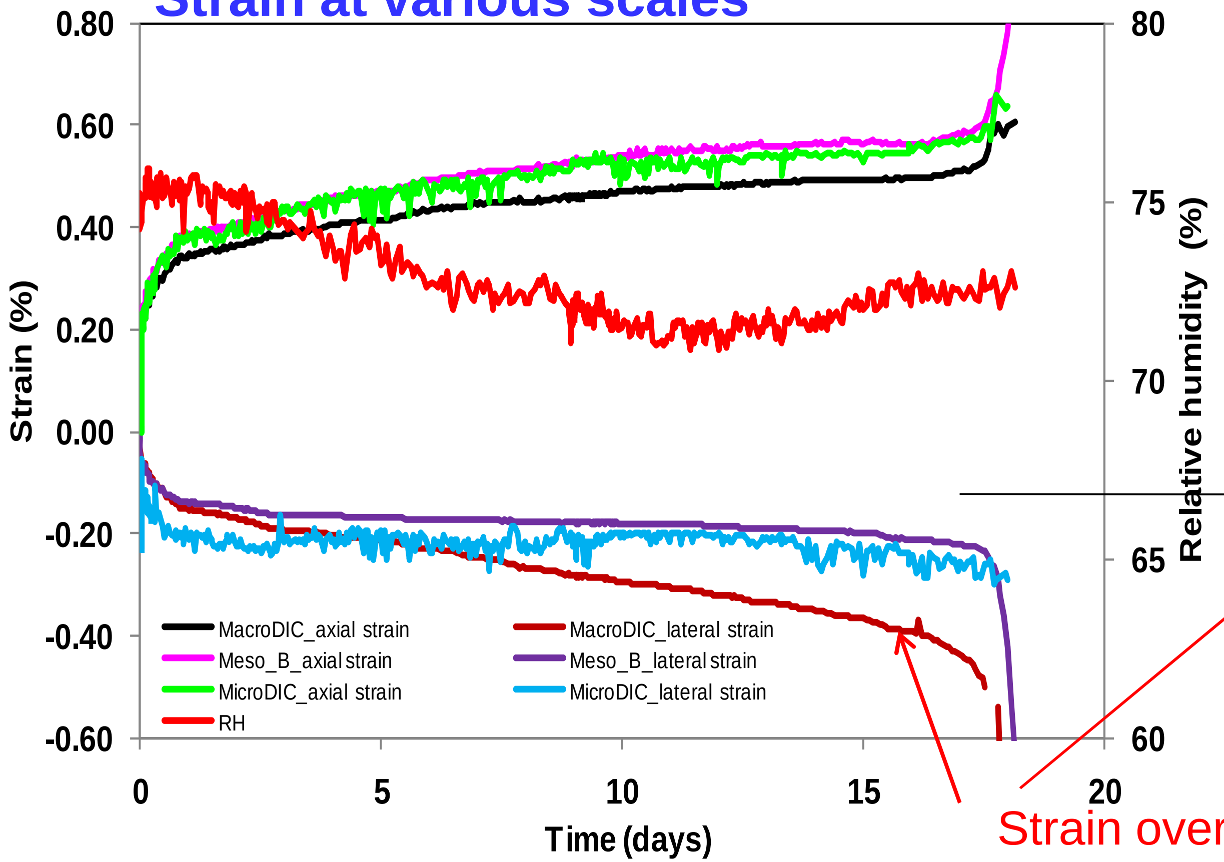
Correction of the strain using the linear relation between ε and RH

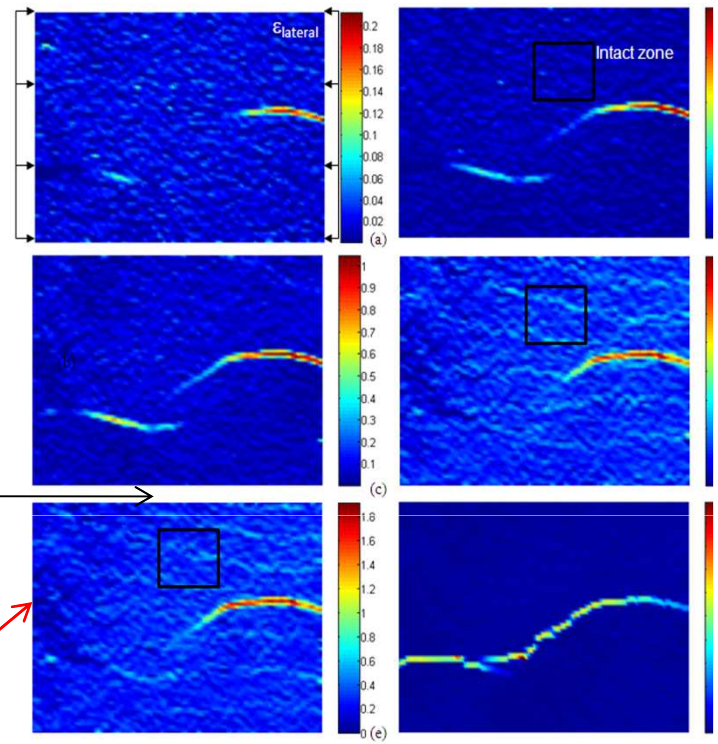
Strain rate over time



2 weeks
last 4 days

Strain at various scales



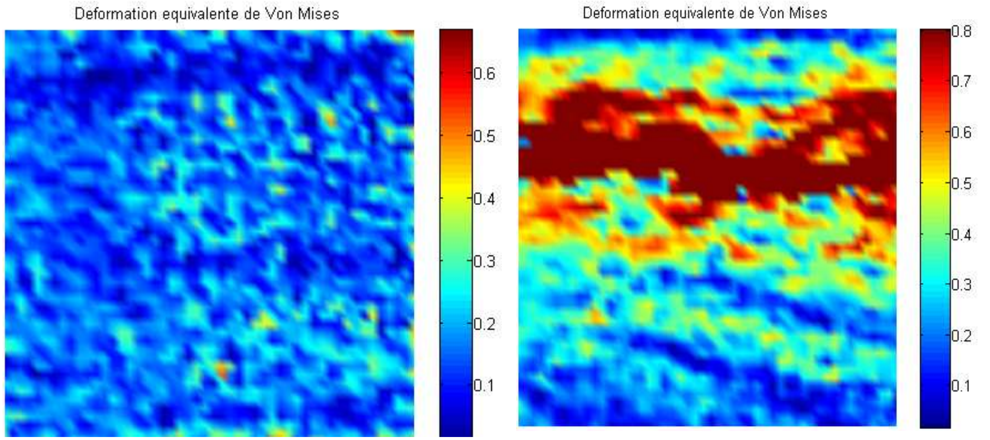


Strain over the whole area,
Effect of the macroscopic cracks

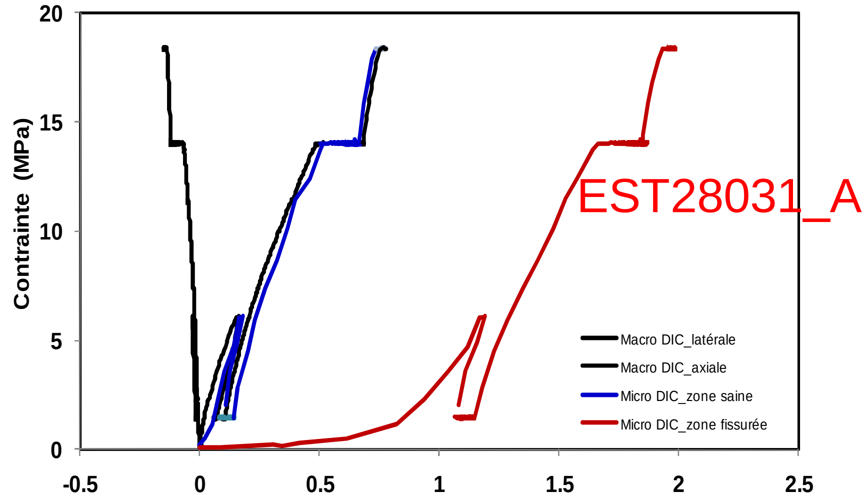
RH and/or σ ↗ strain rate ↗

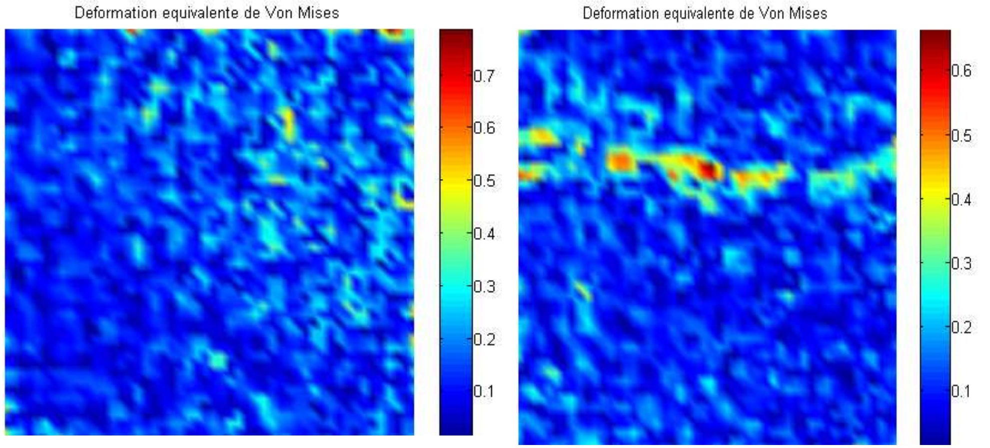
Strain rate 10^{-9} s^{-1} (18 MPa) - 10^{-11} s^{-1} (9 MPa)

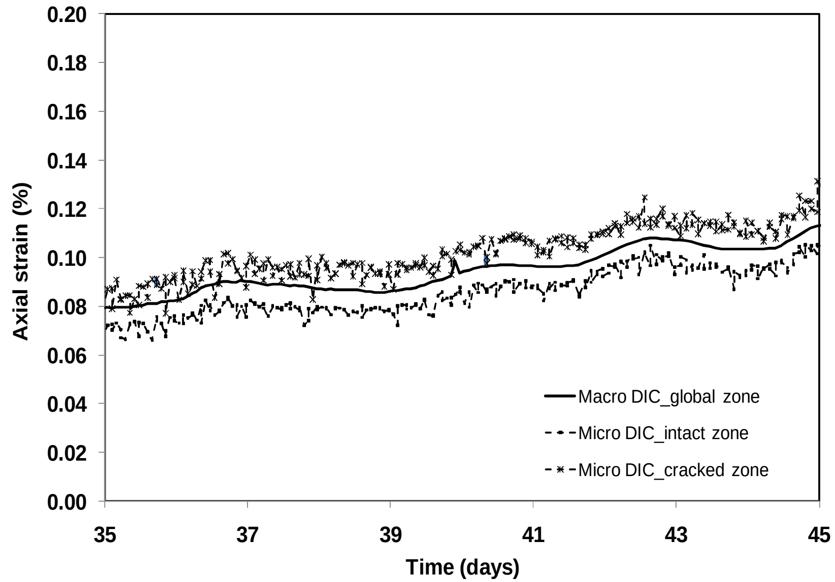
Crack perpendicular to the stress direction



Map of ε_{eq} σ from 1 MPa to 7 MPa







Map of ε_{eq} σ =18 MPa (30th – 35th day)

Conclusions

Hydromechanical behavior of the unsaturated clayey rocks

Mechanical behavior

σ - ε linear σ< 10MPa

E – HR linear, reversible under RH < 85%

Poisson's ratio constant = 0,13

Shrinkage and swelling

ε - HR linear and reversible < 85%, irreversible at high σ

Small damage > 85%

Shrinkage and swelling strongly depend on the applied stress
Classical Biot model is not relevant

Creep behavior under controlled RH

HR and /or σ ↗ Strain rate↗

Strain rate 10^{-9} s^{-1} (18 MPa)- 10^{-11} s^{-1} (9 MPa)

Areas with cracks perpendicular to the applied loads had a strain rate similar to that of intact zones

Cracks parallel to the applied stress developed and opened over time and could lead to fracture.

Thank you for your attention