# Investigation of creep slip of a fracture in Callovo-Oxfordian claystone with Digital Image Correlation

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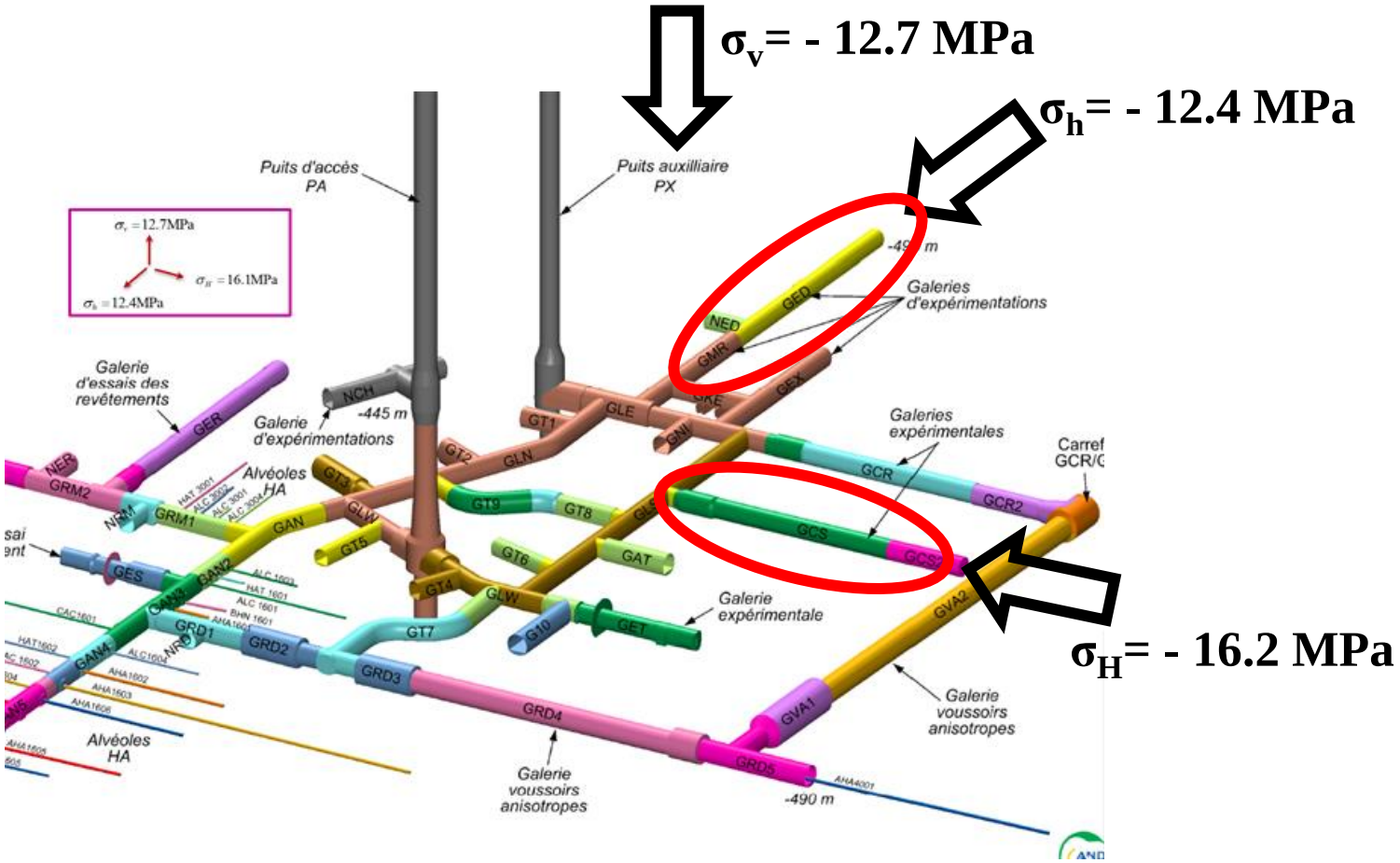
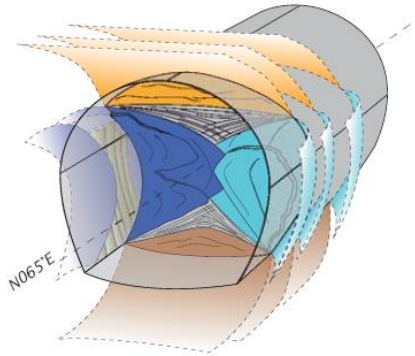
# CIGEO (Centre Industriel de Stockage Géologique / Industrial center for geological disposal) project

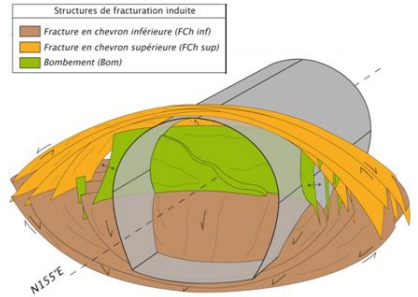



Underground Research Laboratory at 500m depth

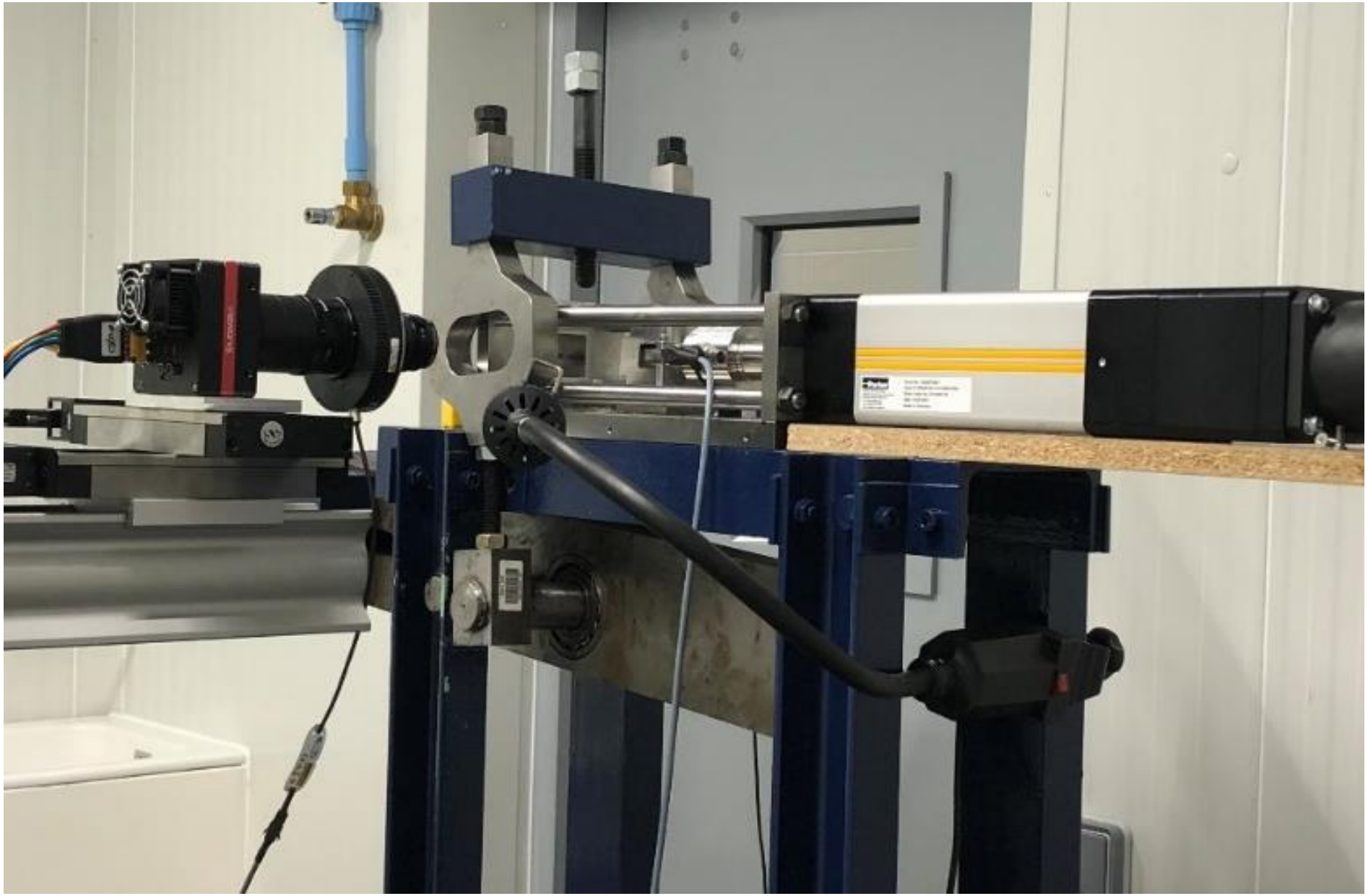
- GED ∥ $\sigma_h$

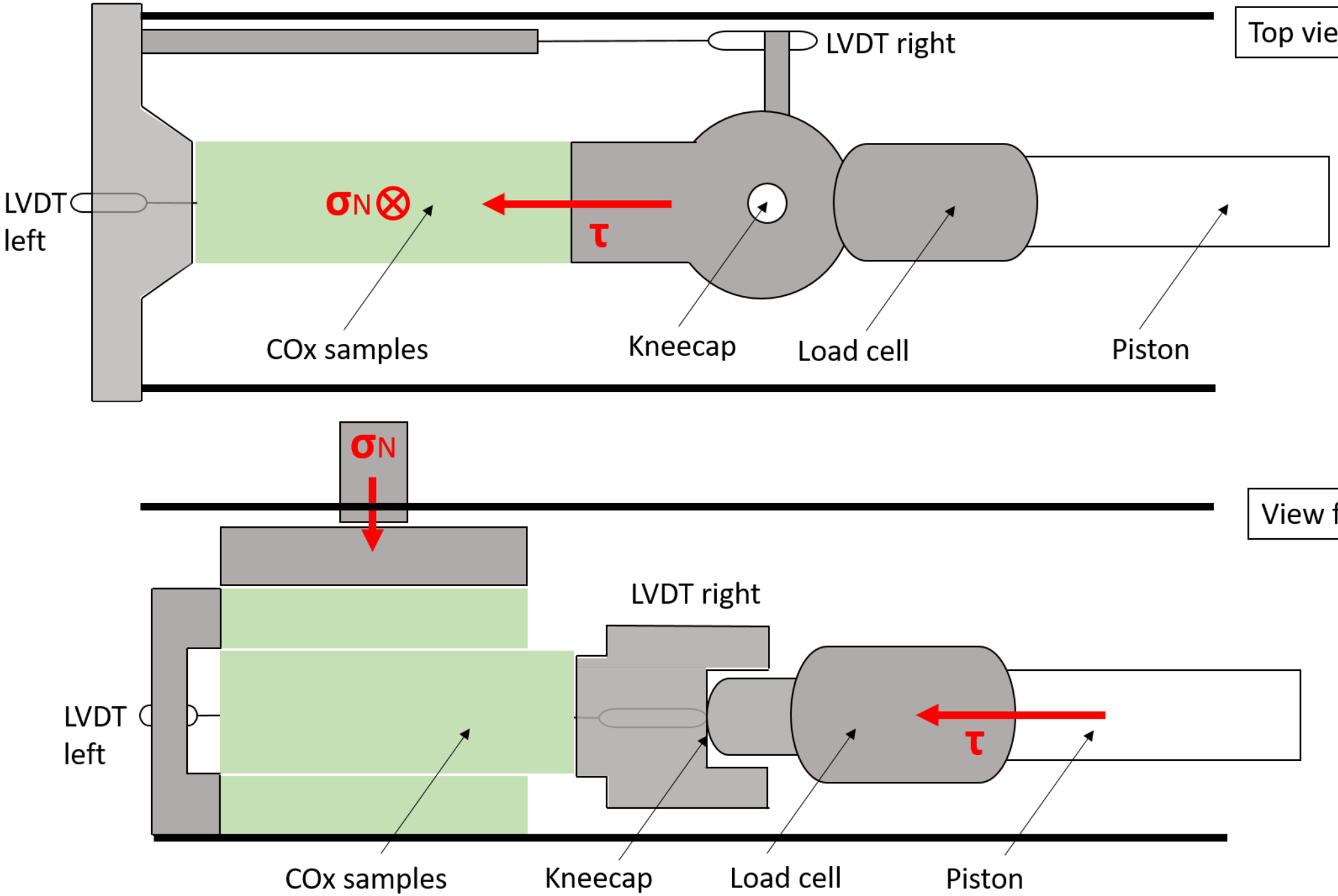



- GCS ∥ $\sigma_H$

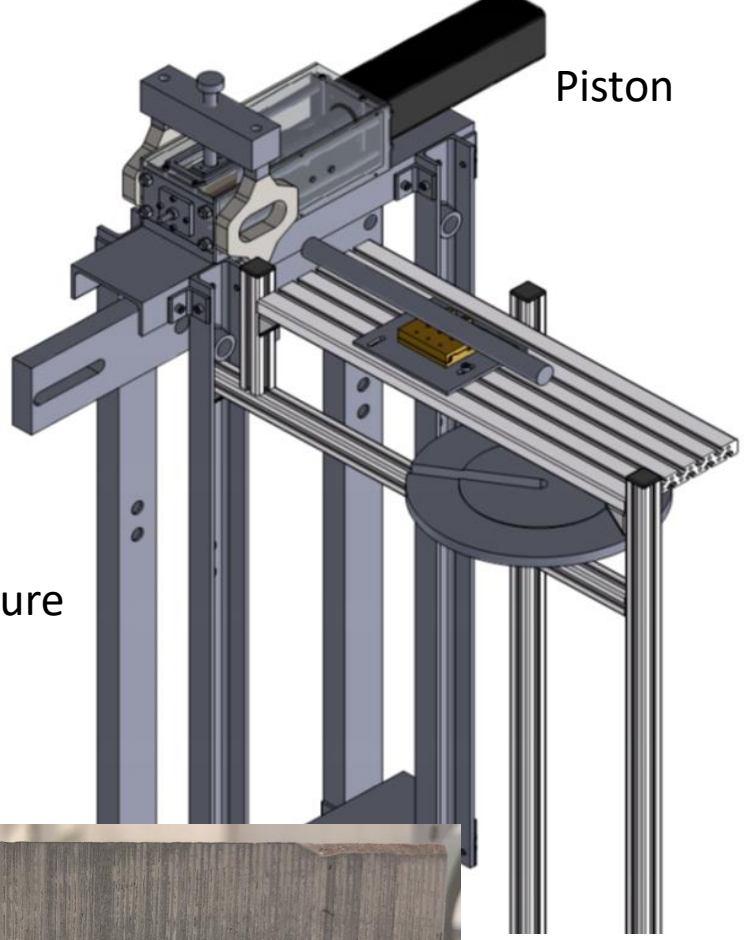


# Experimental setup – Creeping behavior of a fracture in the Callovo-Oxfordian claystone

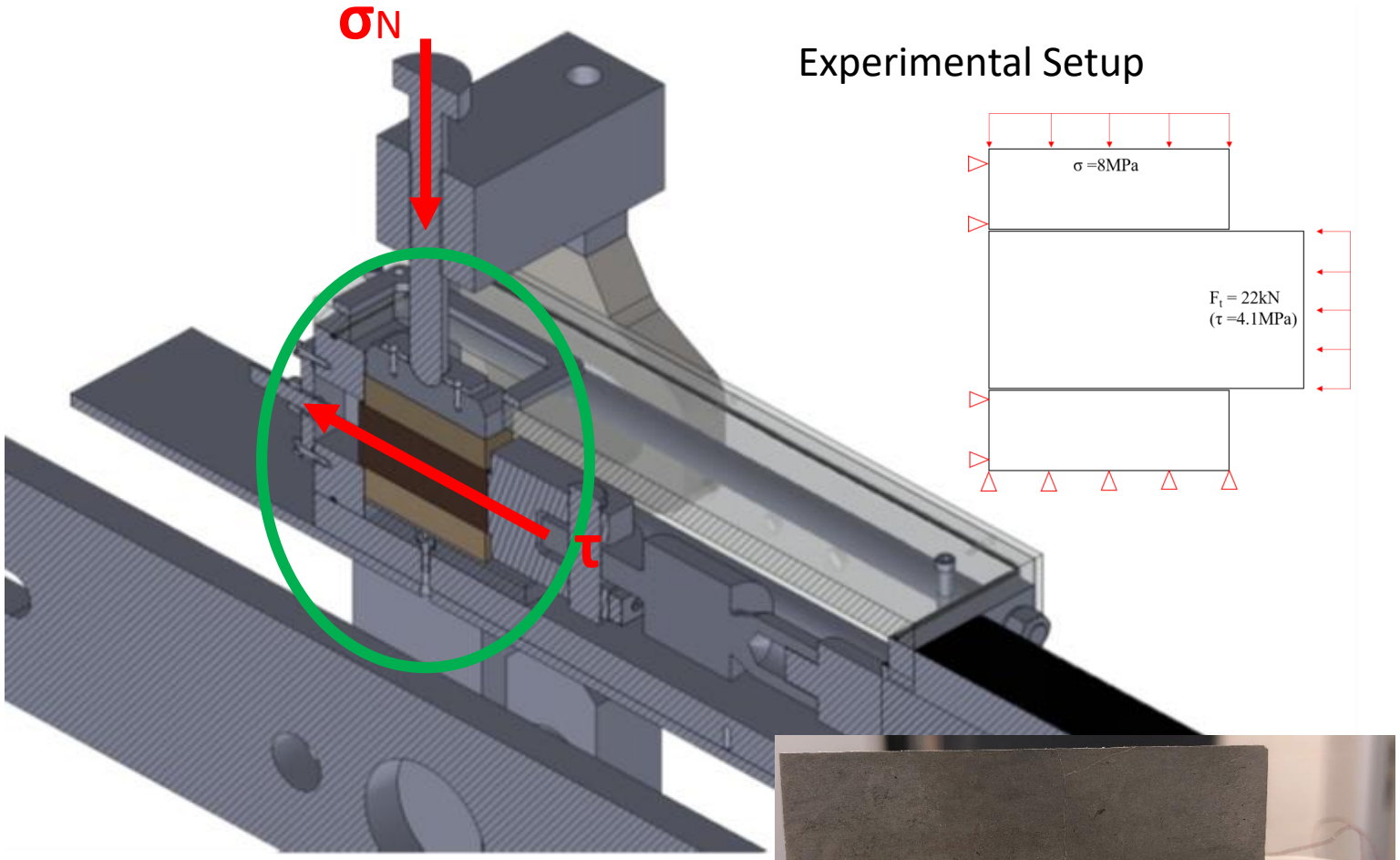



Top view
LVDT right
LVDT
left
σN ⊗
τ
COx samples
Kneecap
Load cell
Piston
σN
View from the side
LVDT right
LVDT
left
τ
COx samples
Kneecap
Load cell
Piston

Piston

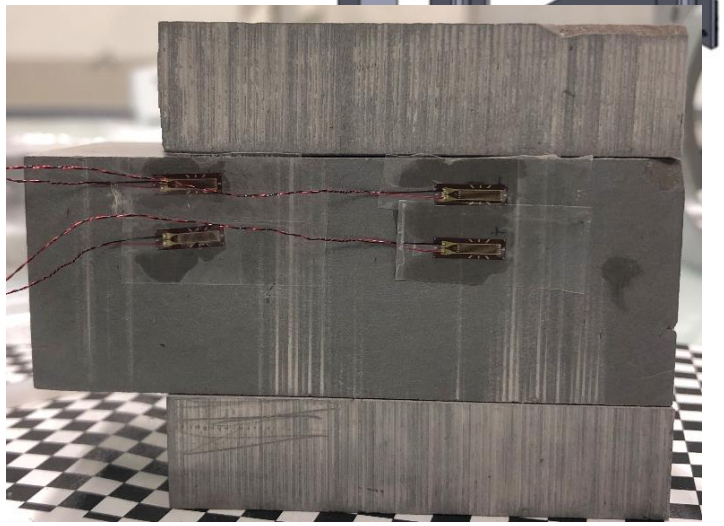


High pressure odometer frame




Experimental Setup



Methods :
Cut the block in the Core
Polish 3 faces for the DIC
Polish 4 faces for achieving a proper roughness of the sheared faces

# What to expect: Numerical Simulation

COx : viscoelastic isotropic material

$$\dot{\boldsymbol{\varepsilon}} = \dot{\boldsymbol{\varepsilon}}^{v} + \dot{\boldsymbol{\varepsilon}}^{e}$$

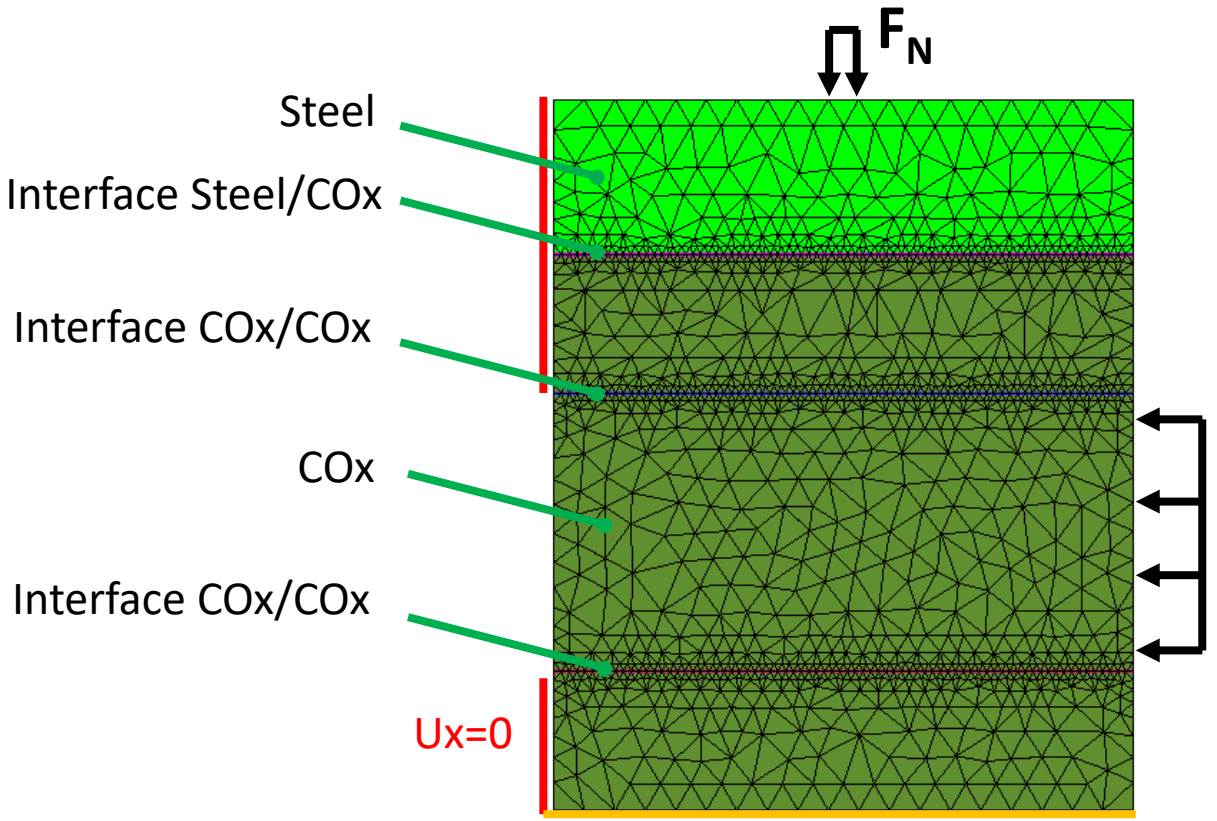
$$\dot{\boldsymbol{\varepsilon}}^{v} = \frac{3}{2}\alpha\xi^{\alpha-1}\dot{\xi}\frac{\boldsymbol{S}}{\sigma_e} \qquad \dot{\xi} = (a < \sigma_e - \sigma_c >^{n})^{1/\alpha}$$

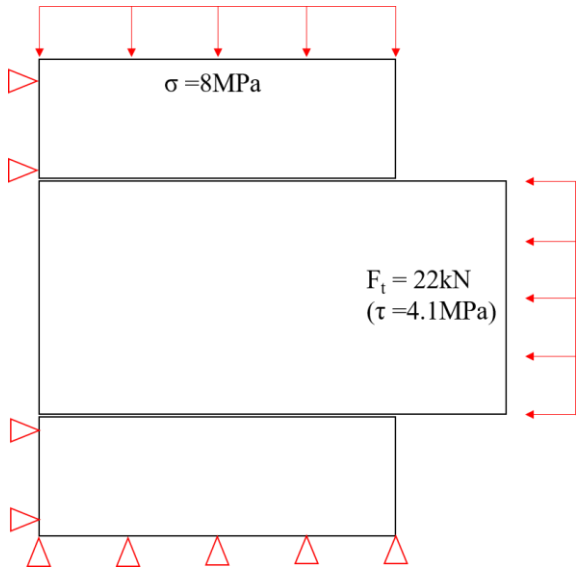
(For uniaxial stress : $\varepsilon(t) = a < \sigma - \sigma_c >^{n} t^{\alpha}$)

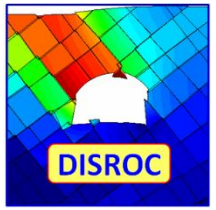
Fracture : Non linear elasticity with Lemaitre creep law

$$\dot{\underline{u}} = \dot{\underline{u}}^{v} + \dot{\underline{u}}^{e}$$

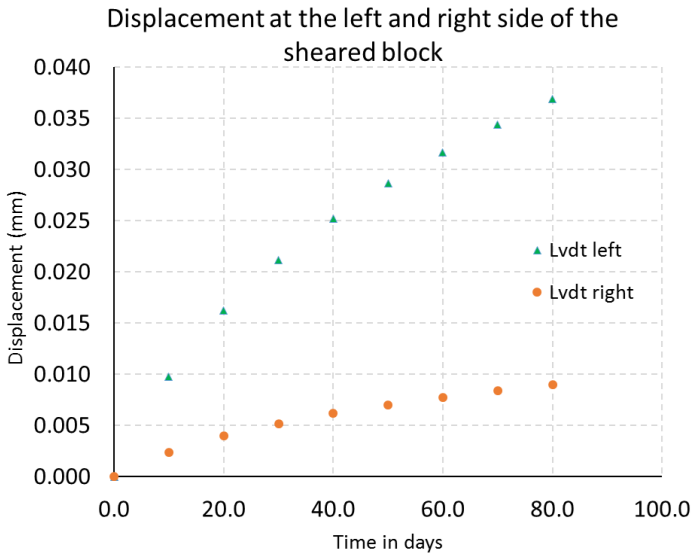
$$\underline{\sigma} = \boldsymbol{K}(\underline{u} - \underline{u^{v}}) \qquad \dot{\underline{u}}_t^{v} = \alpha\xi_t^{\alpha-1}\dot{\xi}_t \qquad \dot{\xi}_t = s(b_t < |\tau| - \tau_c >^{q})^{1/\alpha}$$

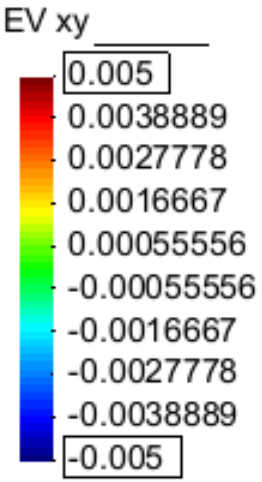


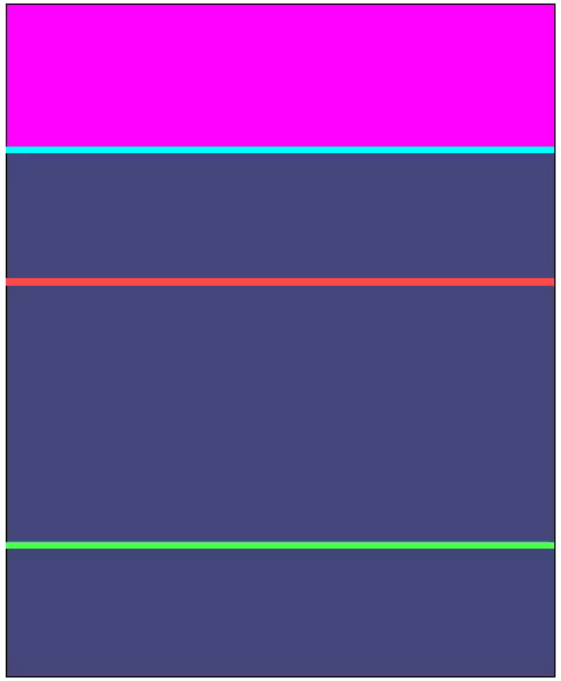



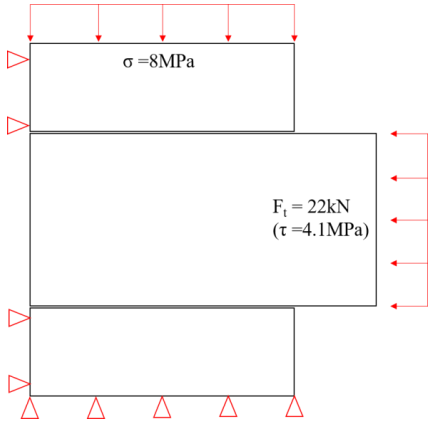



# What to expect: Viscous deformation of the rock matrix compared to the viscous slip of the fracture

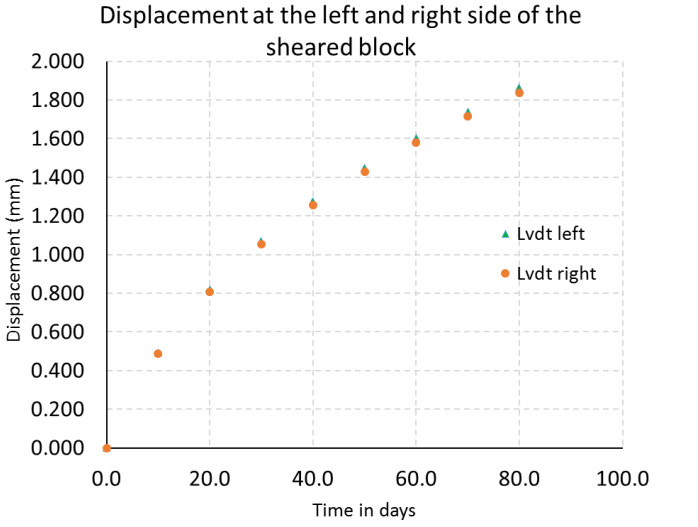


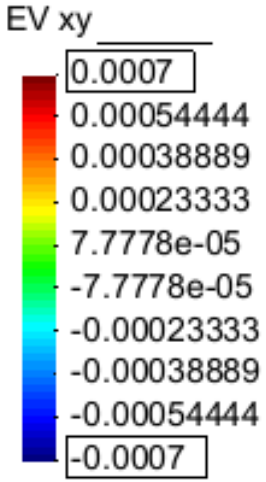



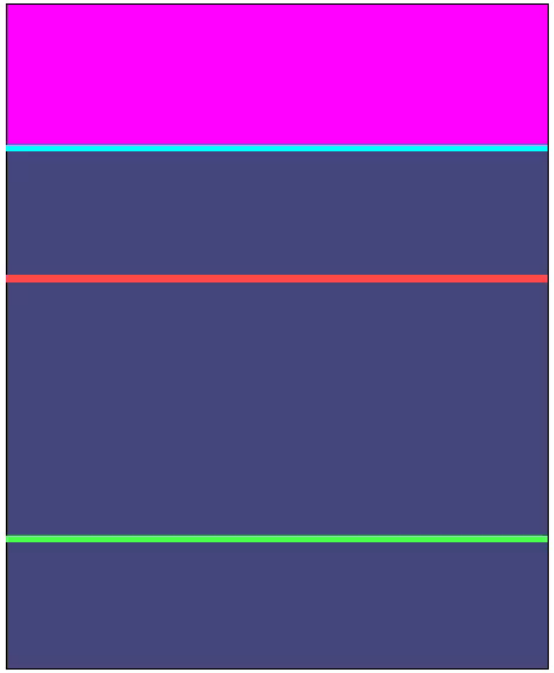






**Matrix Flow >> Fracture Flow**

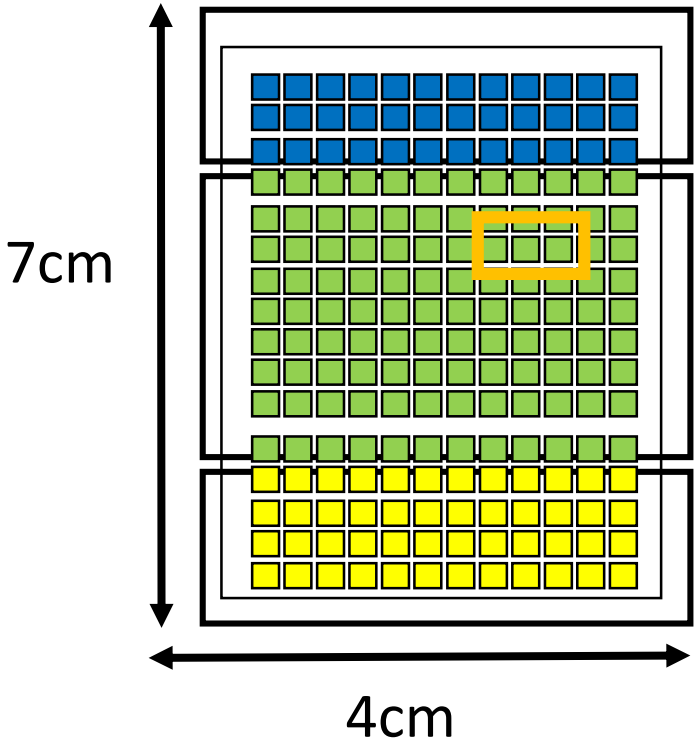


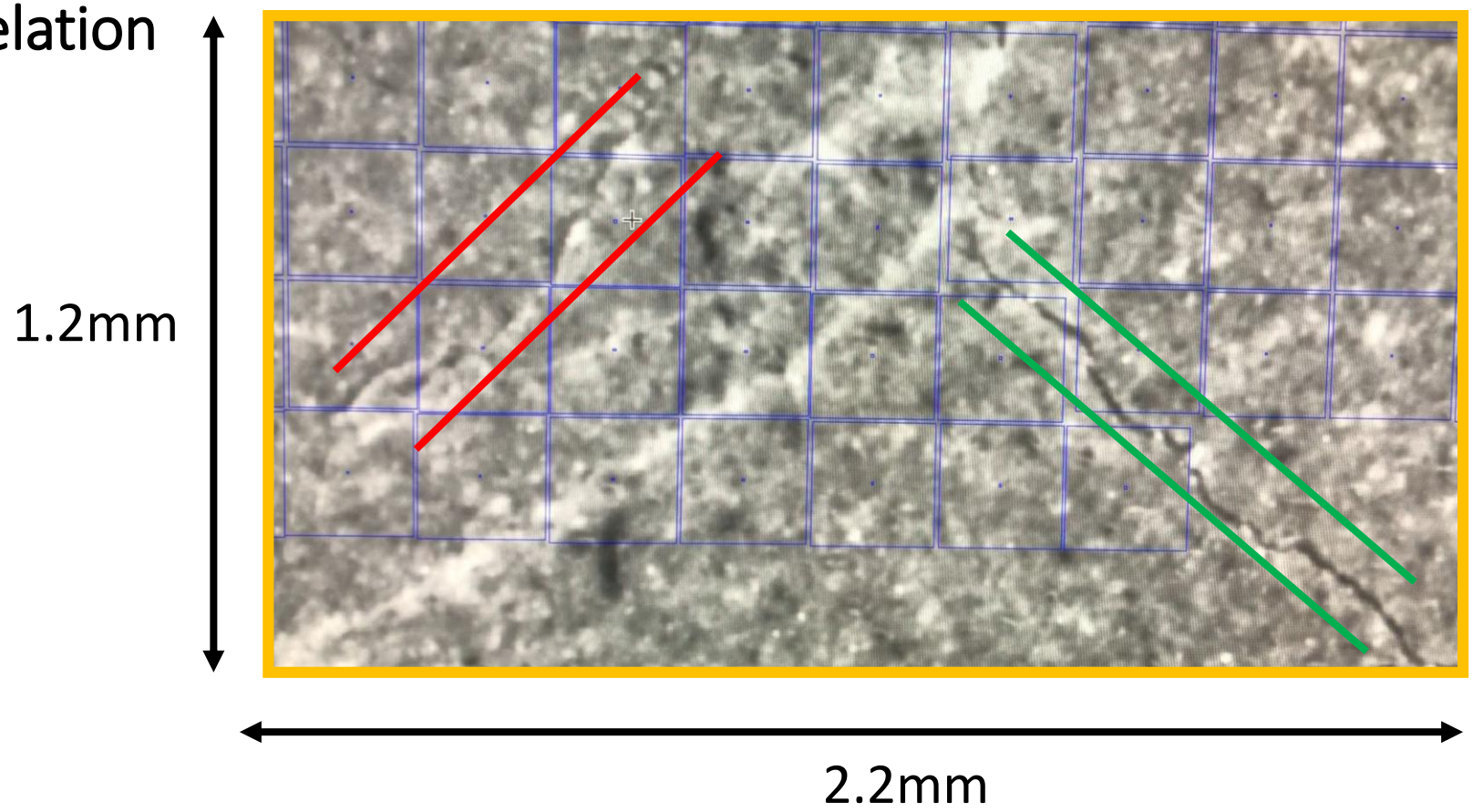



**Fracture Flow >> Matrix Flow**

# Principle of Digital Image Correlation



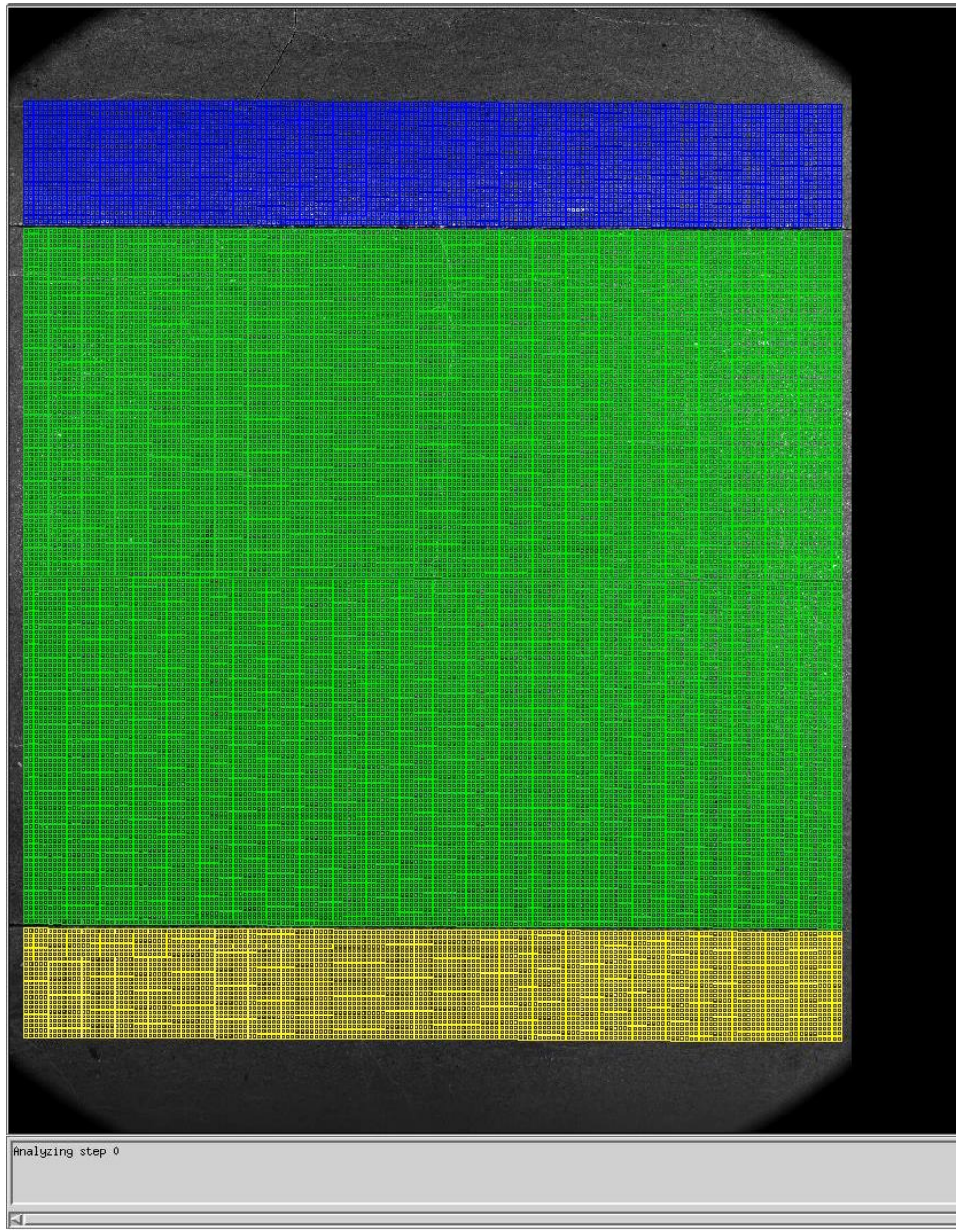



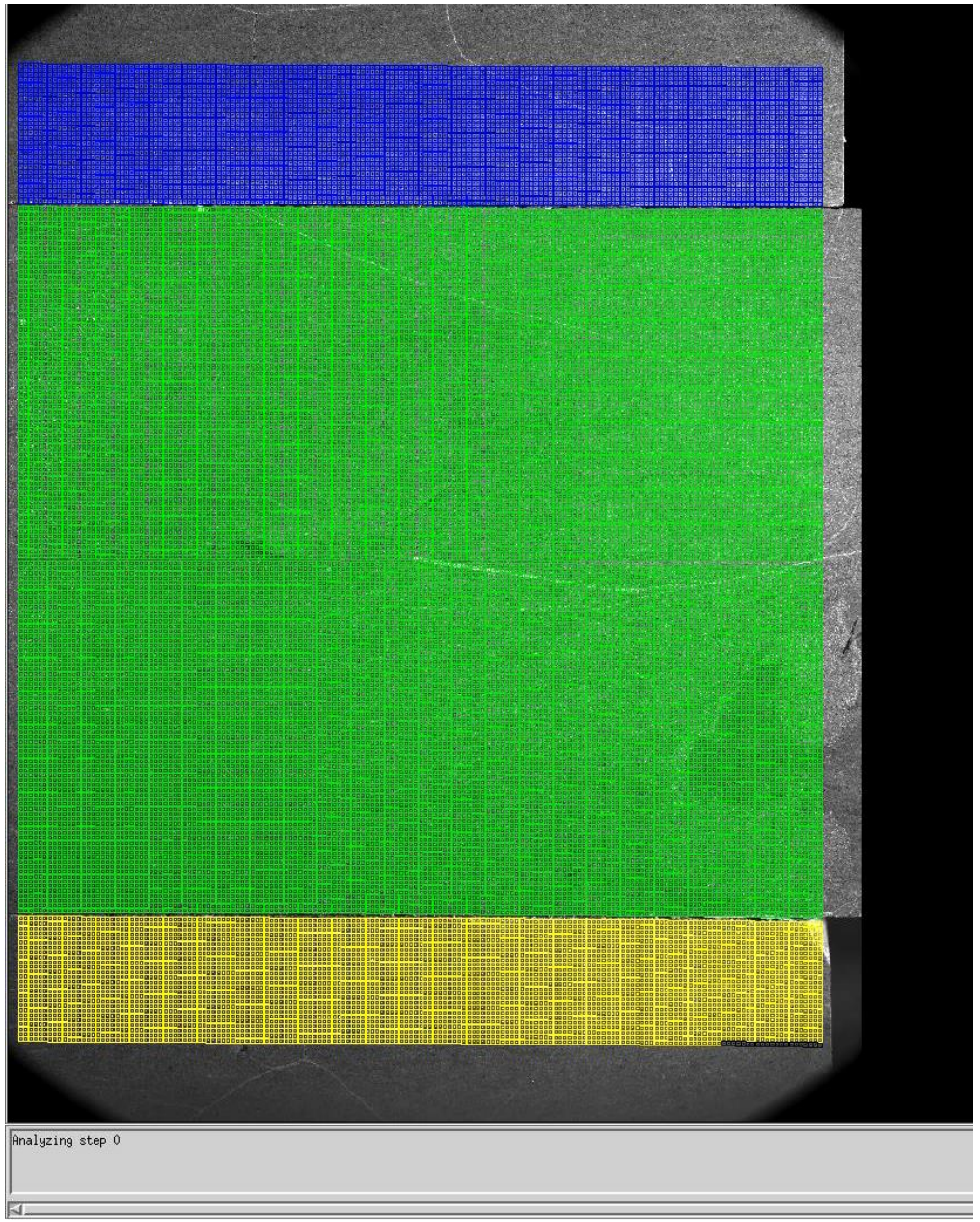

Search for homologous points between the reference image and the deformed image based on the similarity of their vicinity

150 millions pixels

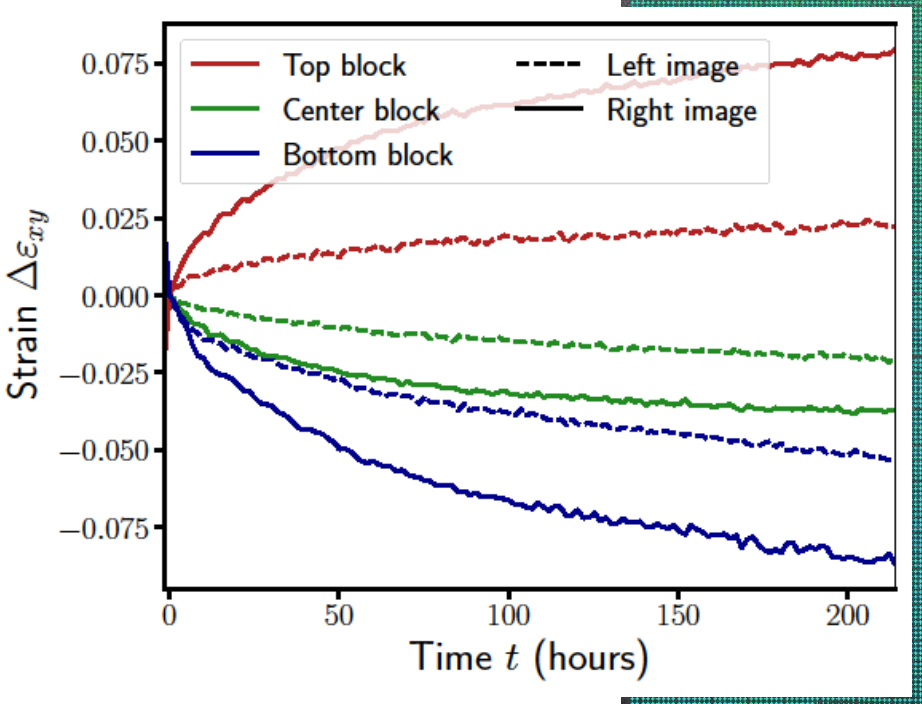
# Results provided by DIC

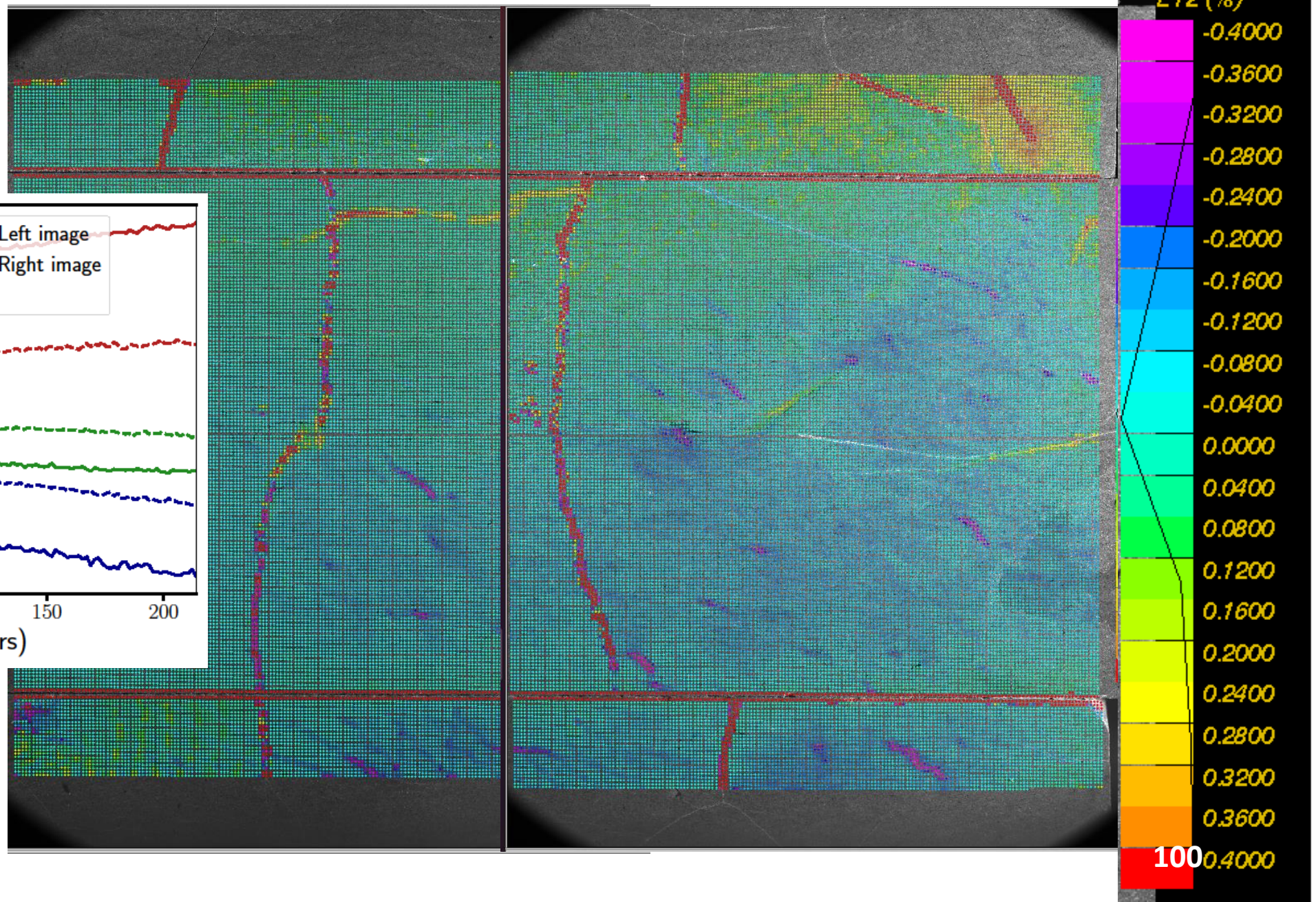
Displacement field Ux in time



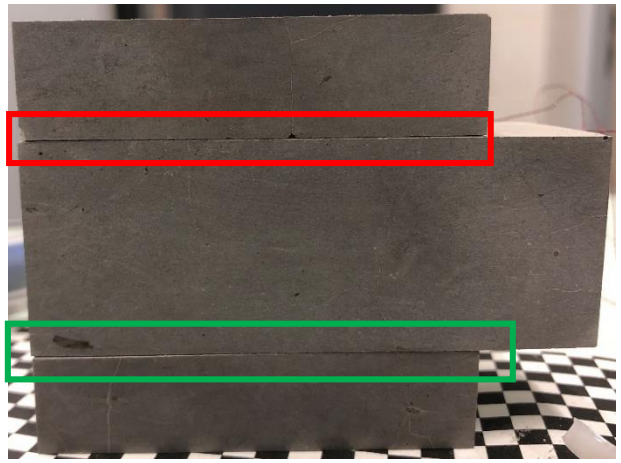



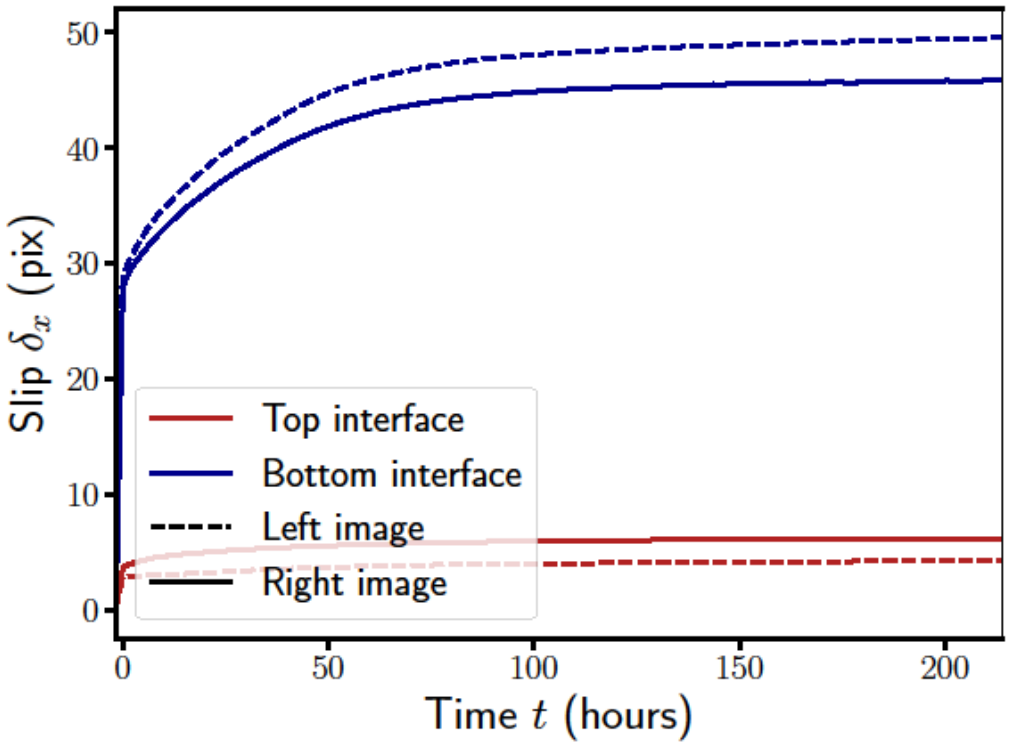
# Results provided by DIC

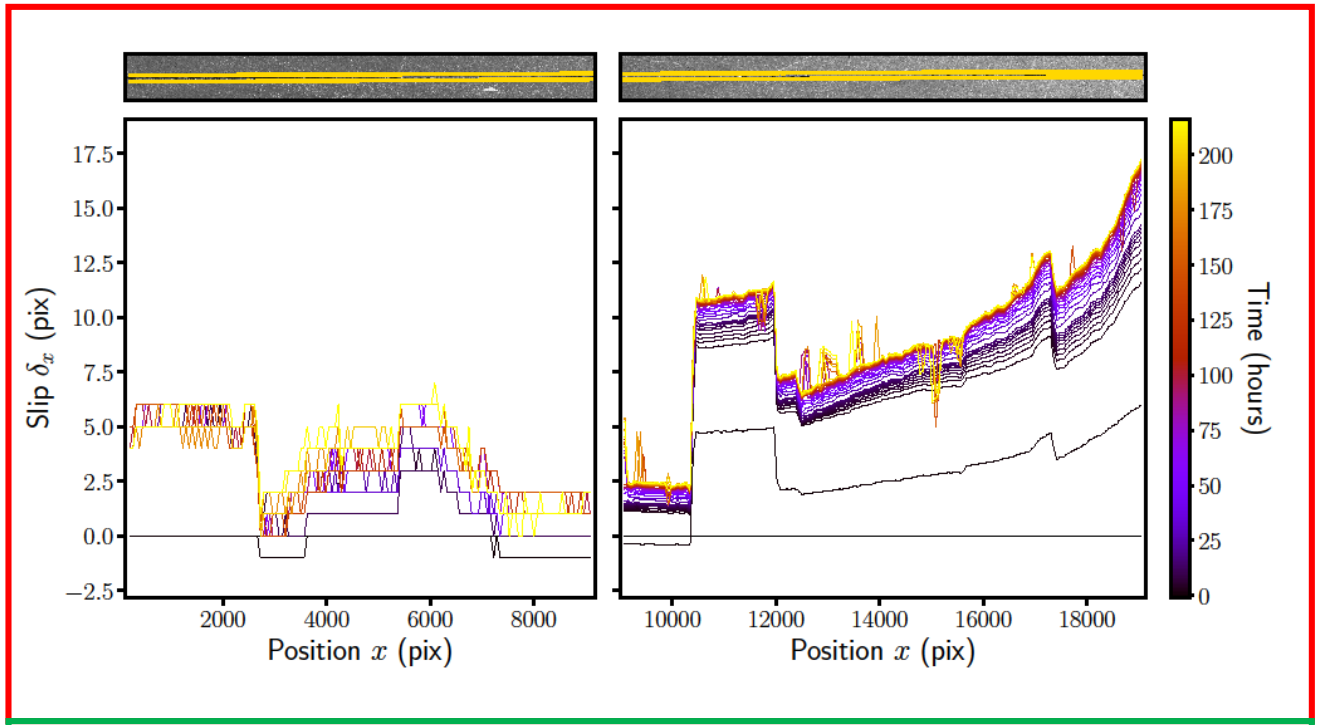


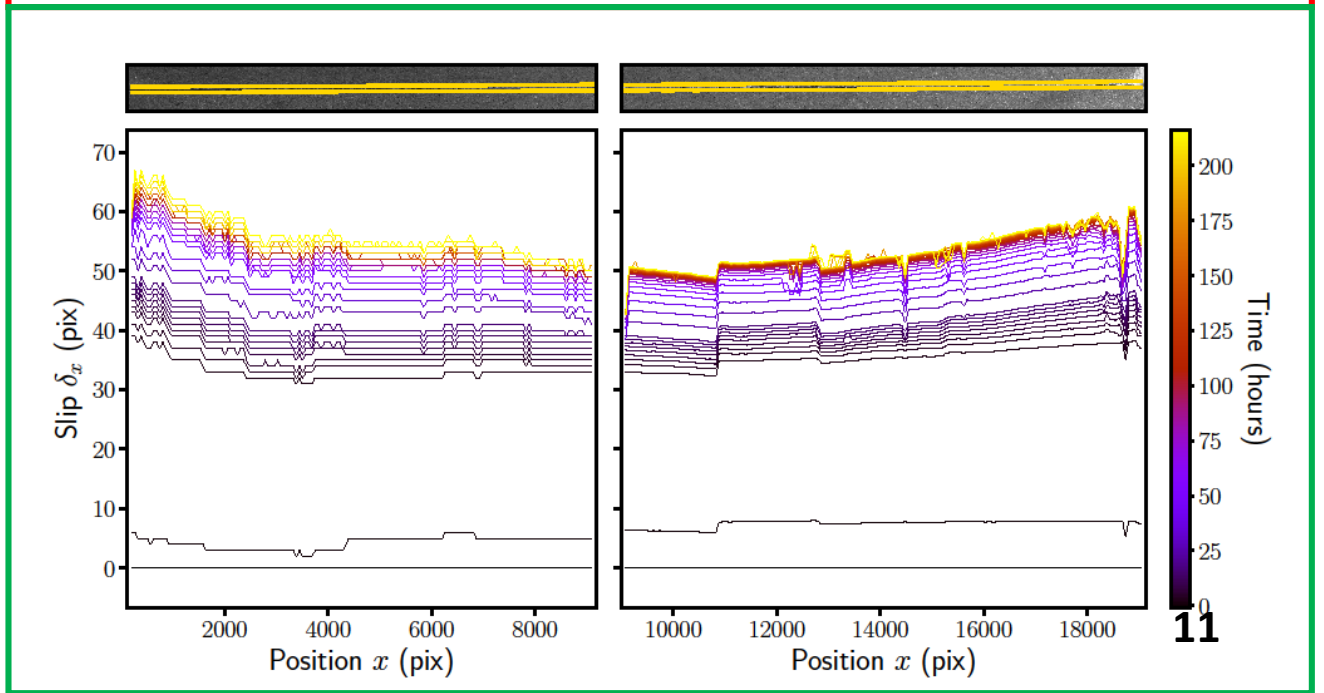



# If we take a closer look at the fracture





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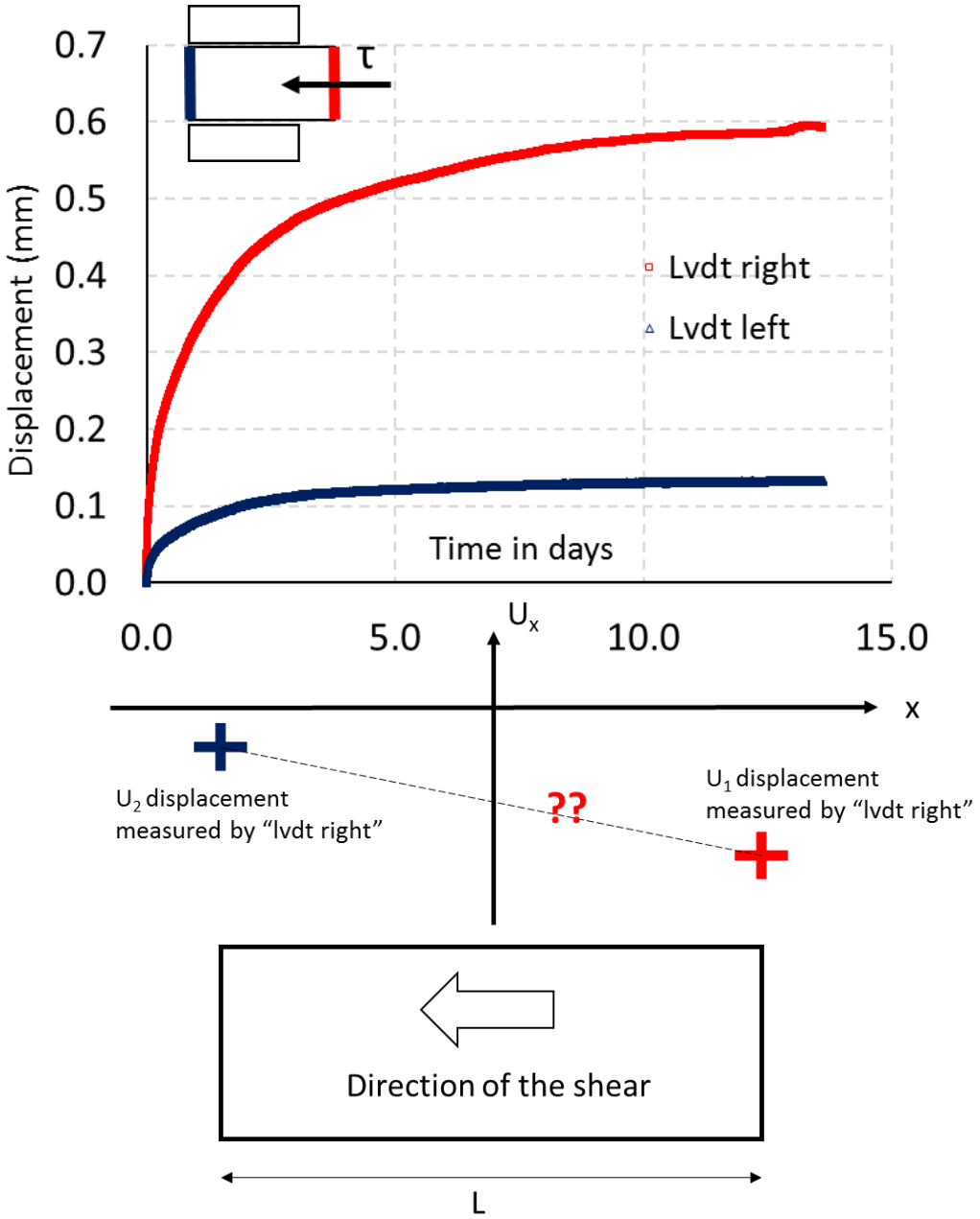


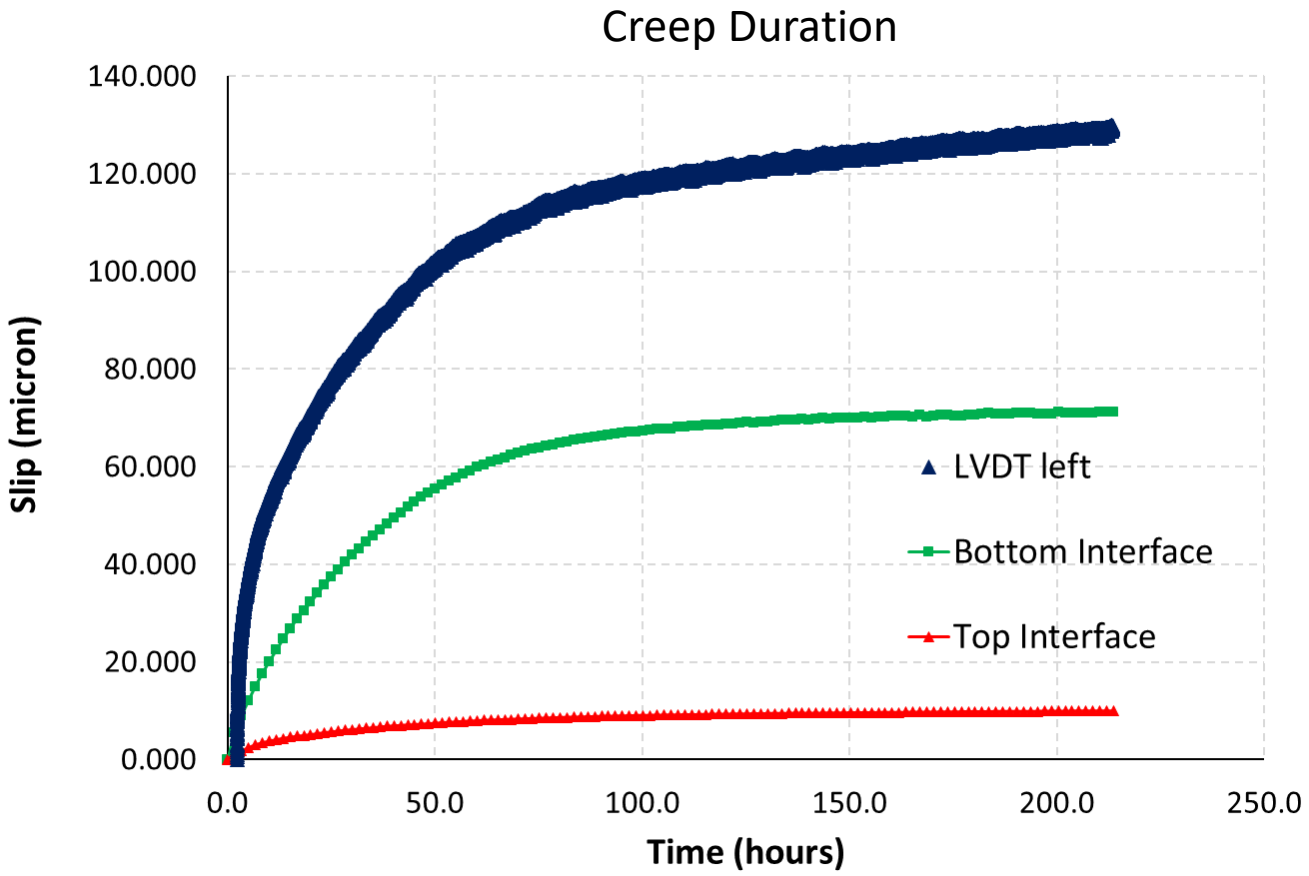

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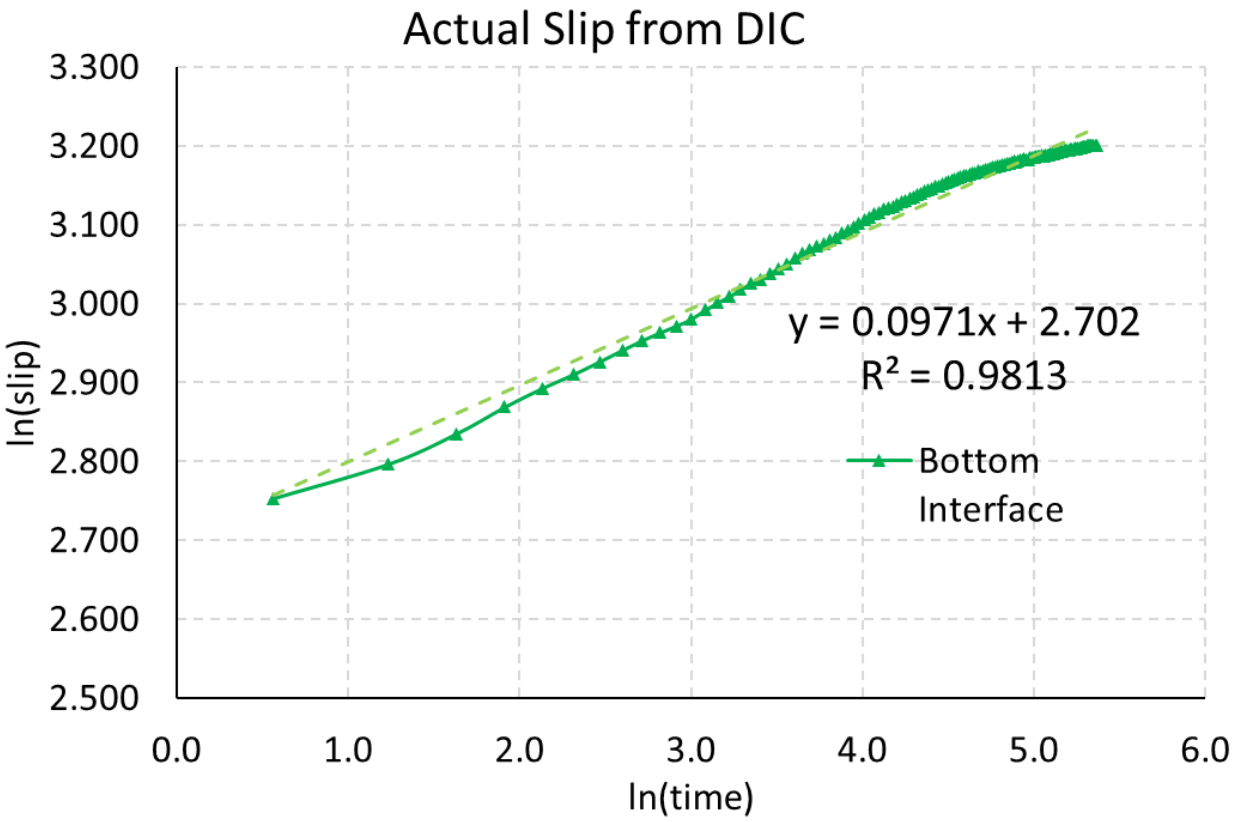
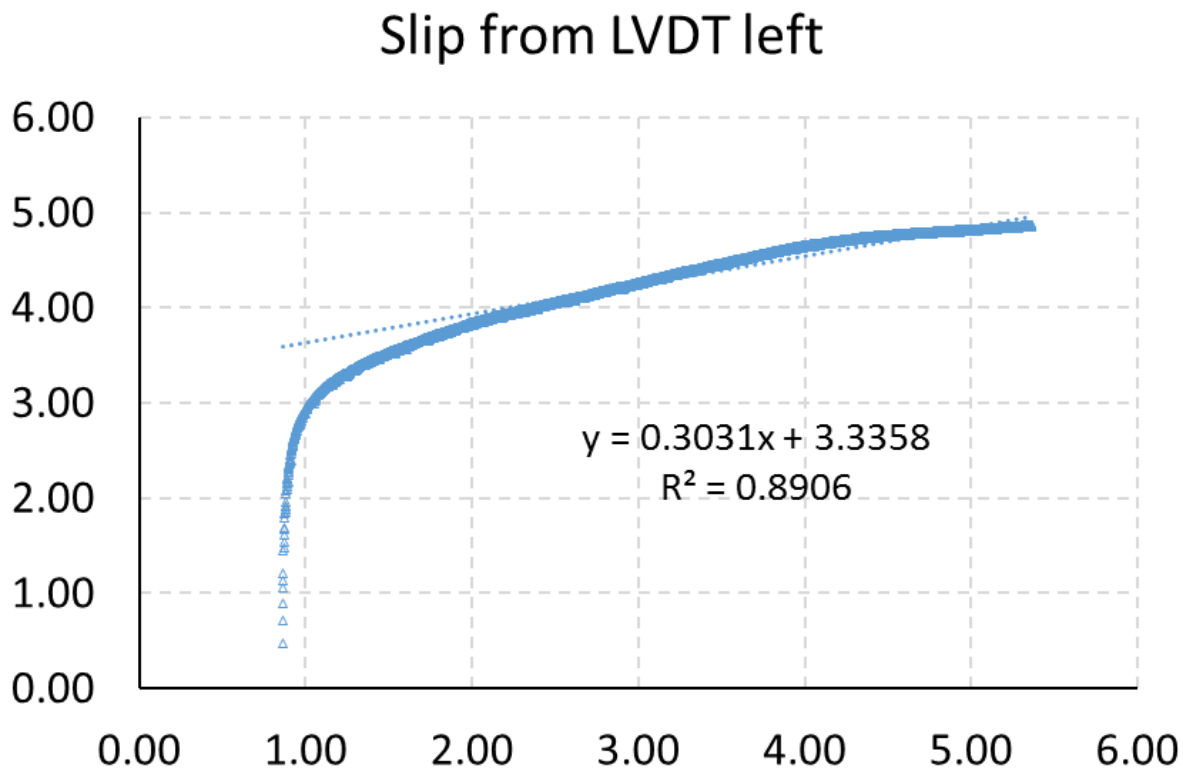
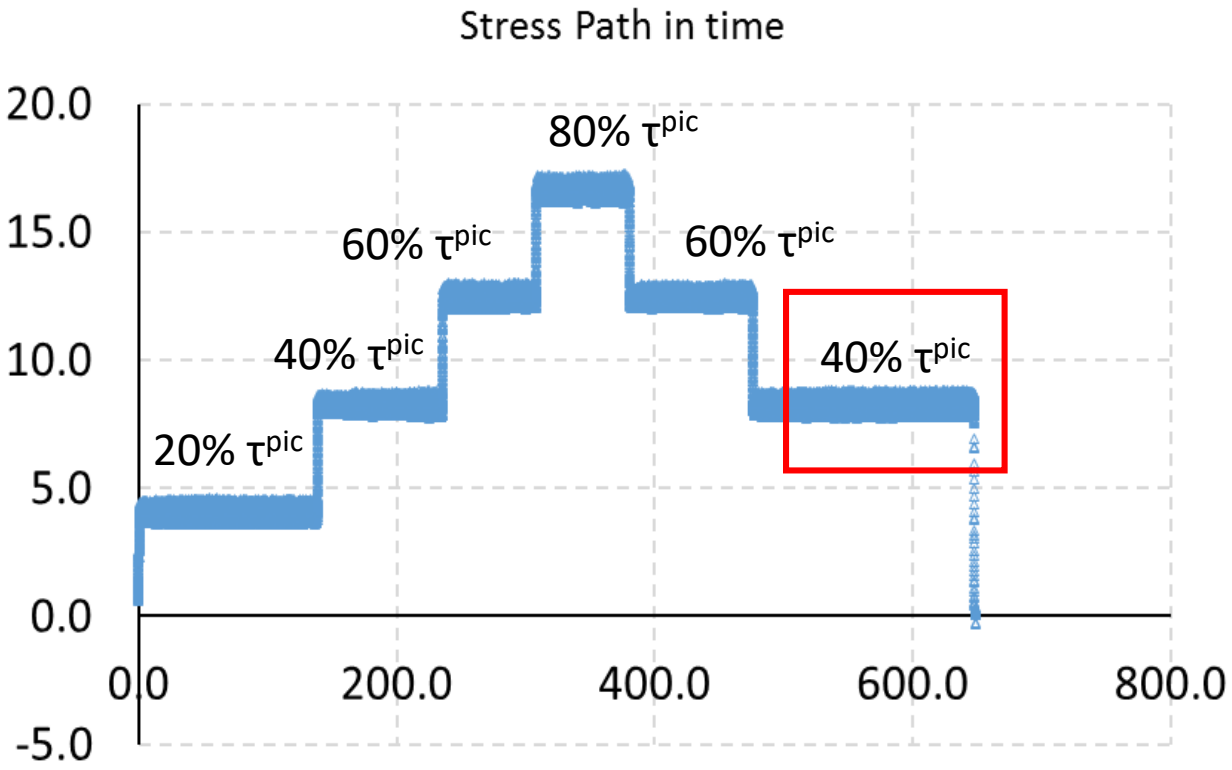
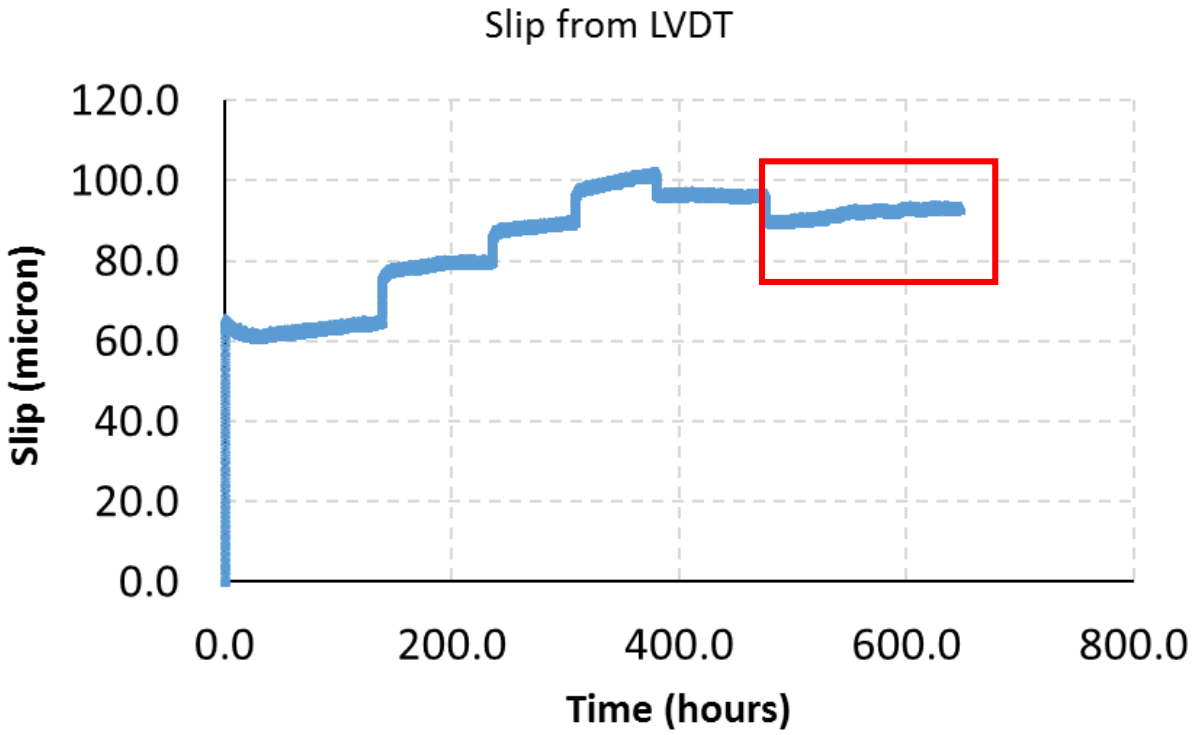


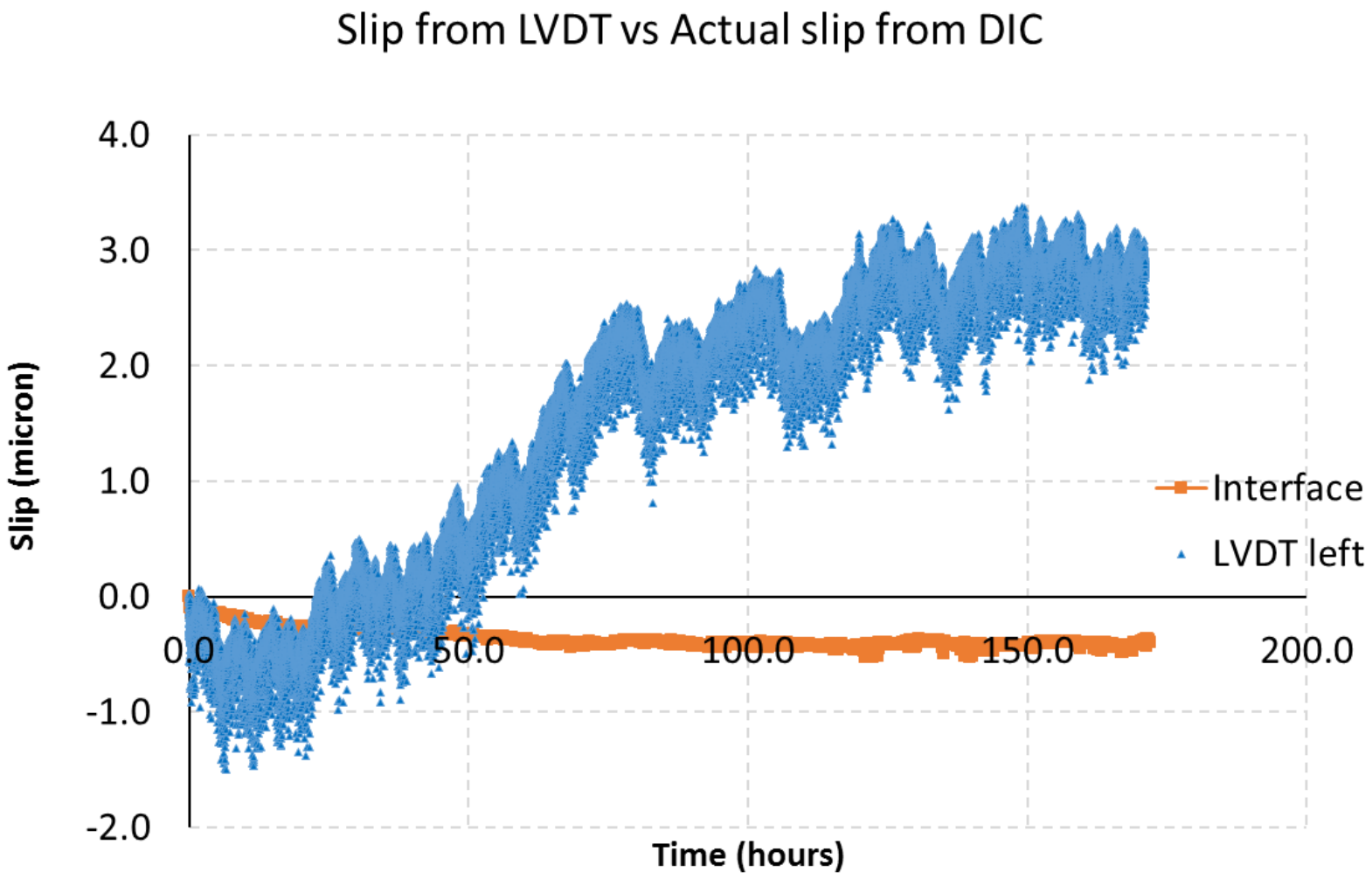



# Under lower stress conditions



# Under lower stress conditions – Data DIC



# Conclusion & perspectives

- The viscosity of the rock matrix does not appear to be negligible compared to the viscous slip of the fracture
- The viscosity of the matrix + fractures is complex but the DIC allows to separate the two phenomena and thus to clarify the problem
- At very low stress the macroscopic measure with lvdt seems to show that the block is slipping while DIC show no relevant viscous slip

- Callovo-Oxfordian claystone is a very difficult rock to manipulate (very sensitive too humidity) which make the experimental capmaign very difficult (technically)
- Test with other rock
- Influence of normal stress, shear stress, joint roughness

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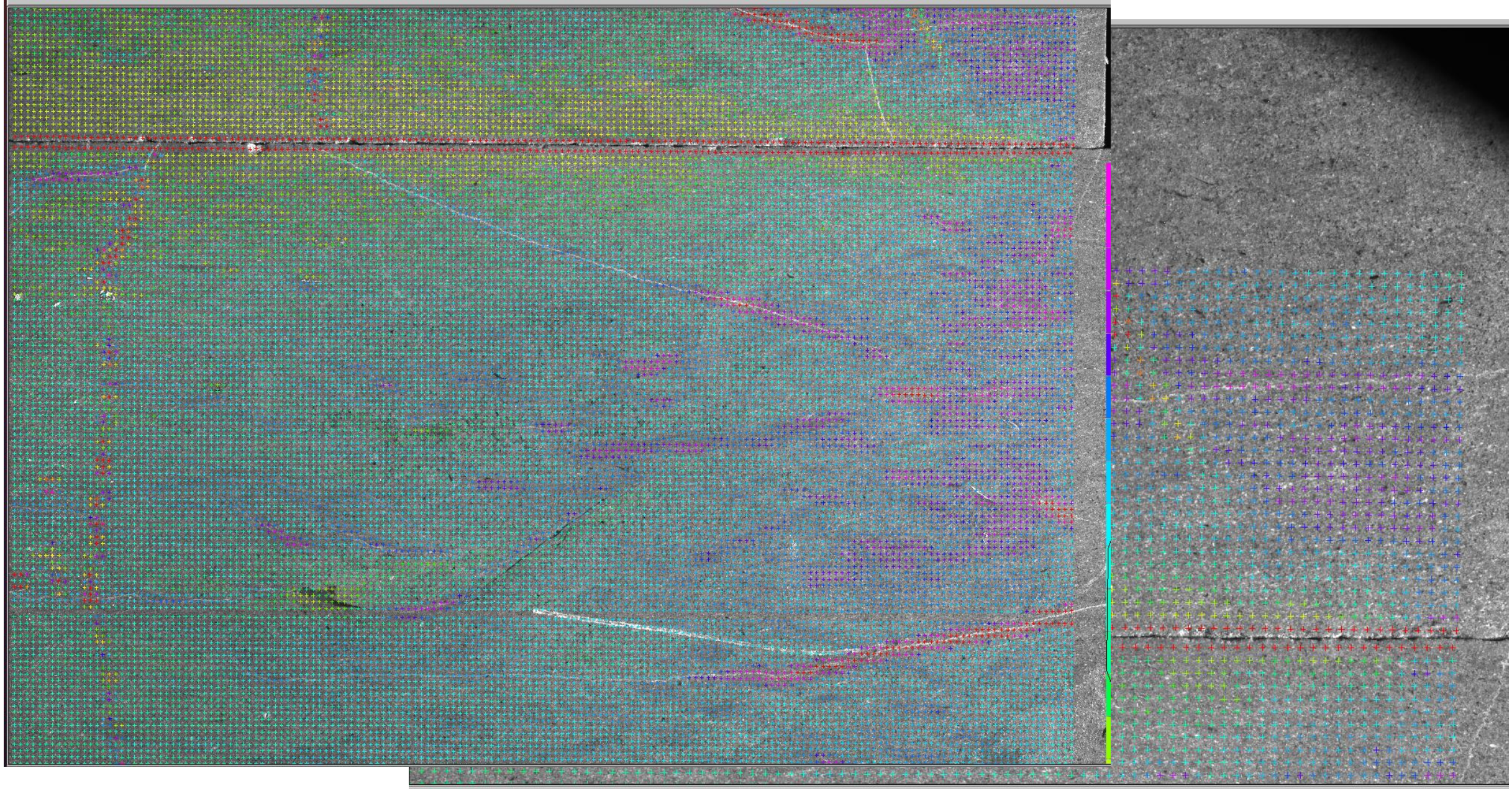
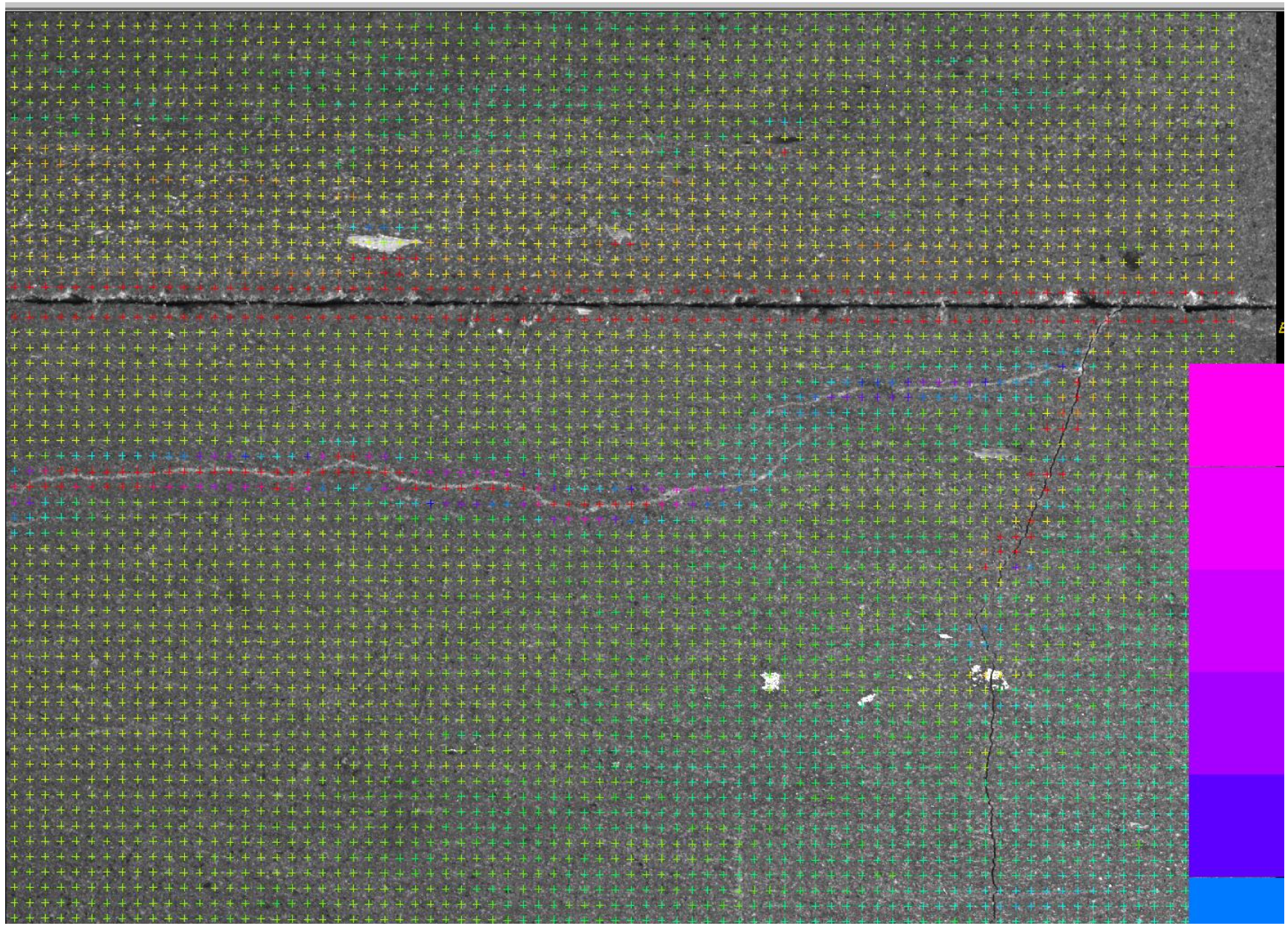
Merci de votre attention !

Questions ?





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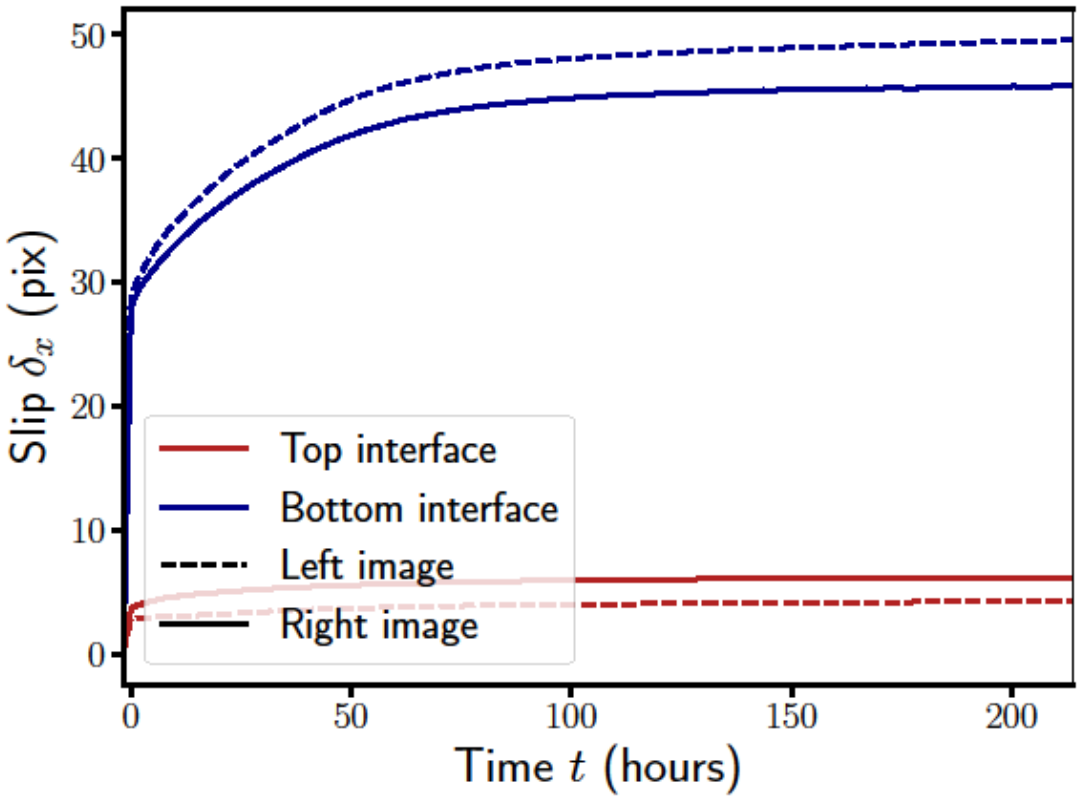
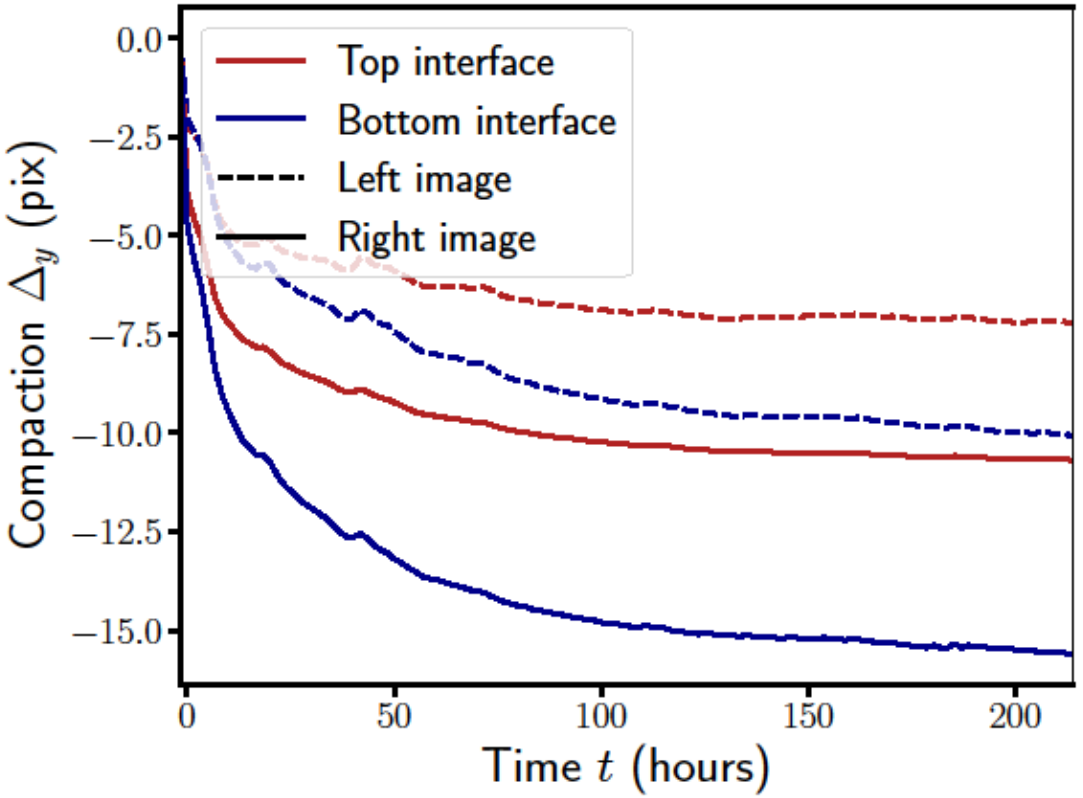
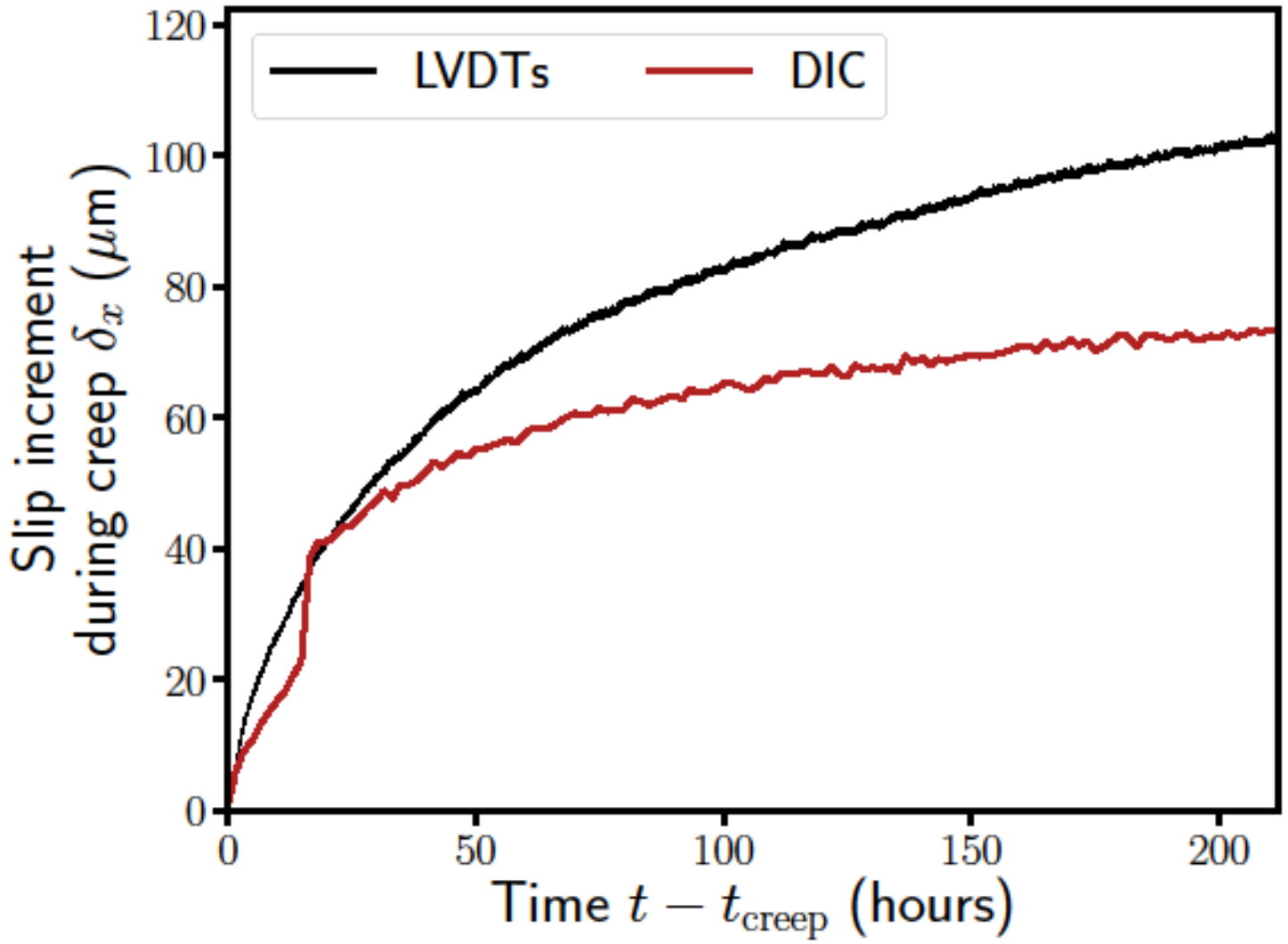


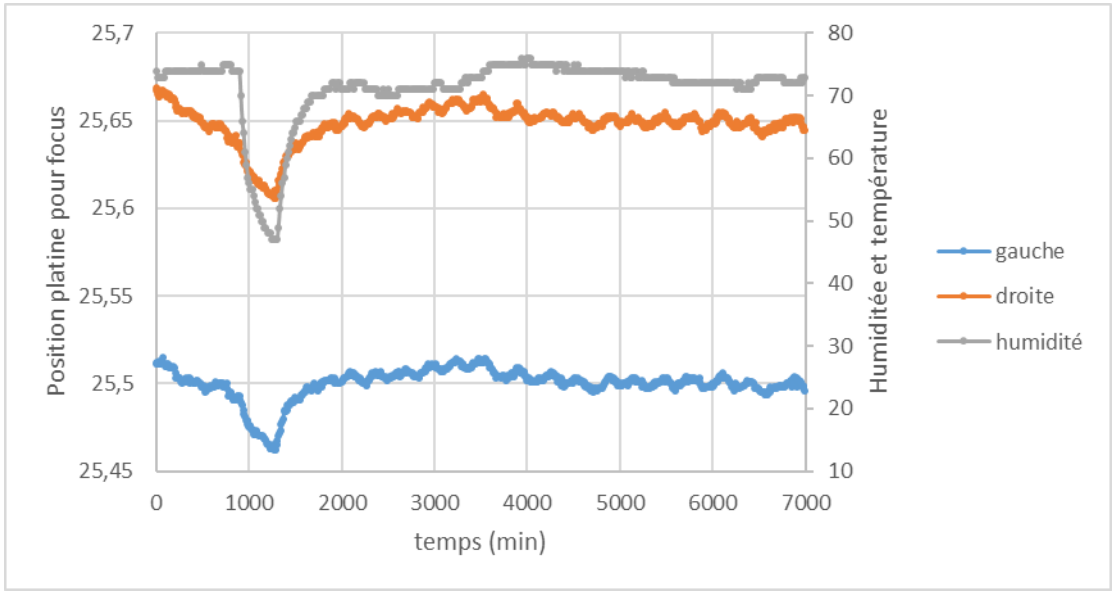




Comparaison des courbes log log du slip le long de la fracture en fonction du temps et des données des lvdt

Utiliser les données du 05/01 : montrer le glissement, tassement le long des fractures

Comparaison entre la mesure des LVDT et la meme mesure fait avec la DIC : ok (bout en plus dans la mesure physique avec les LVDT)





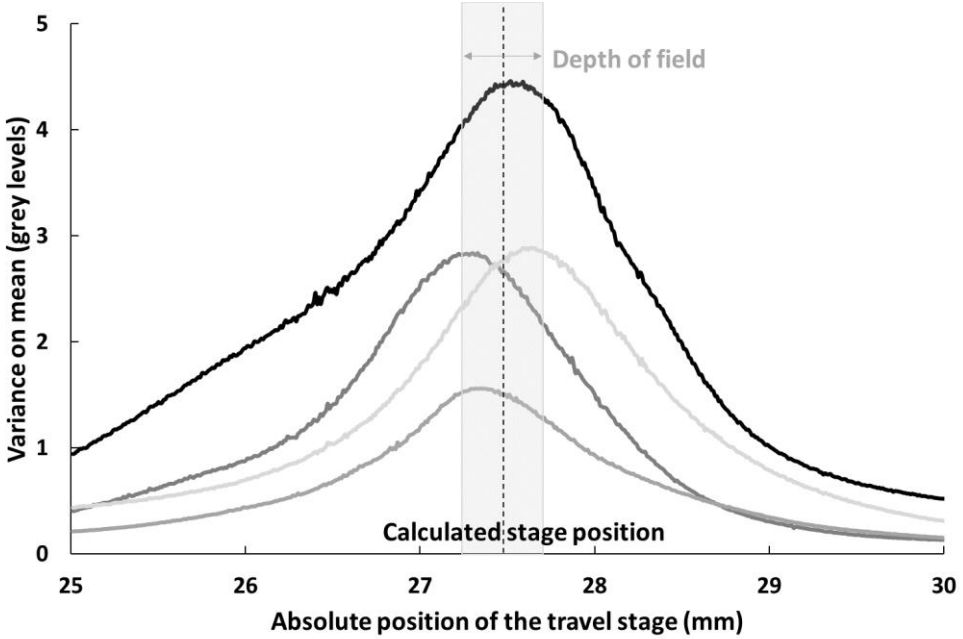
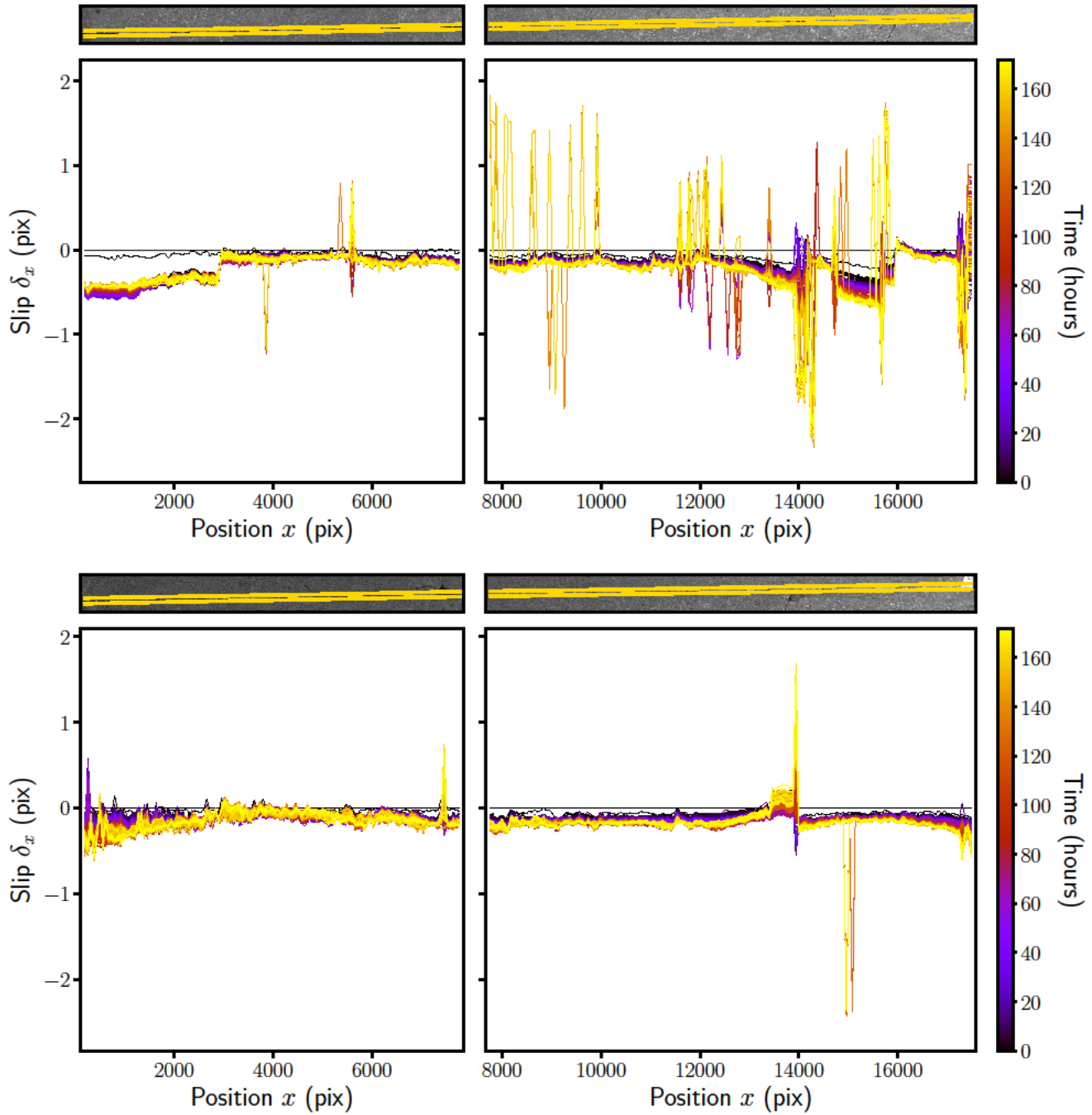
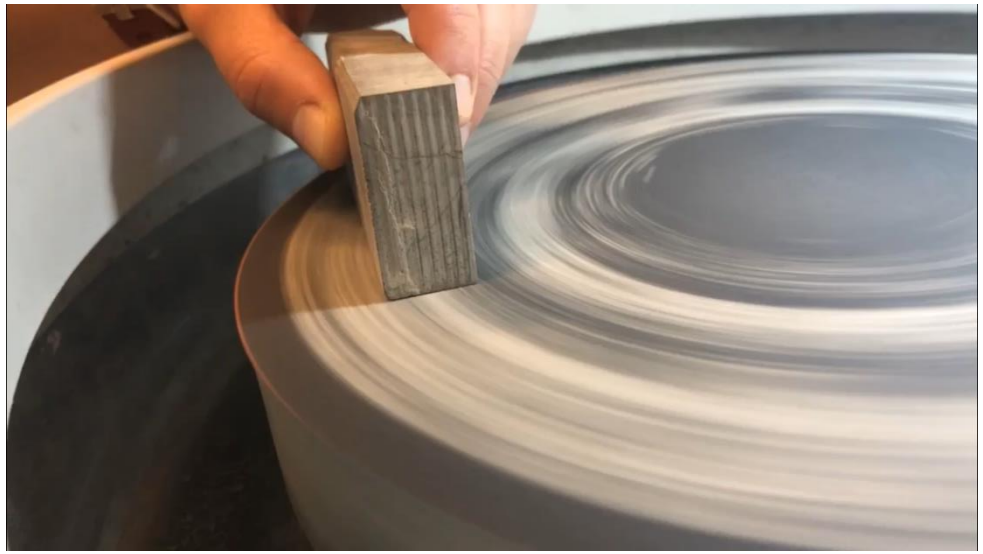




**Figure 2:** values of variance on mean as a function of the position of travel stage for the ● top left, ●bottom left, ●bottom right, ●top right regions of interest


Slip $\delta_x$ (pix)
Position $x$ (pix)
Time (hours)
2
1
0
−1
−2
2000
4000
6000
8000
10000
12000
14000
16000
0
20
40
60
80
100
120
140
160

# Préparation des échantillons

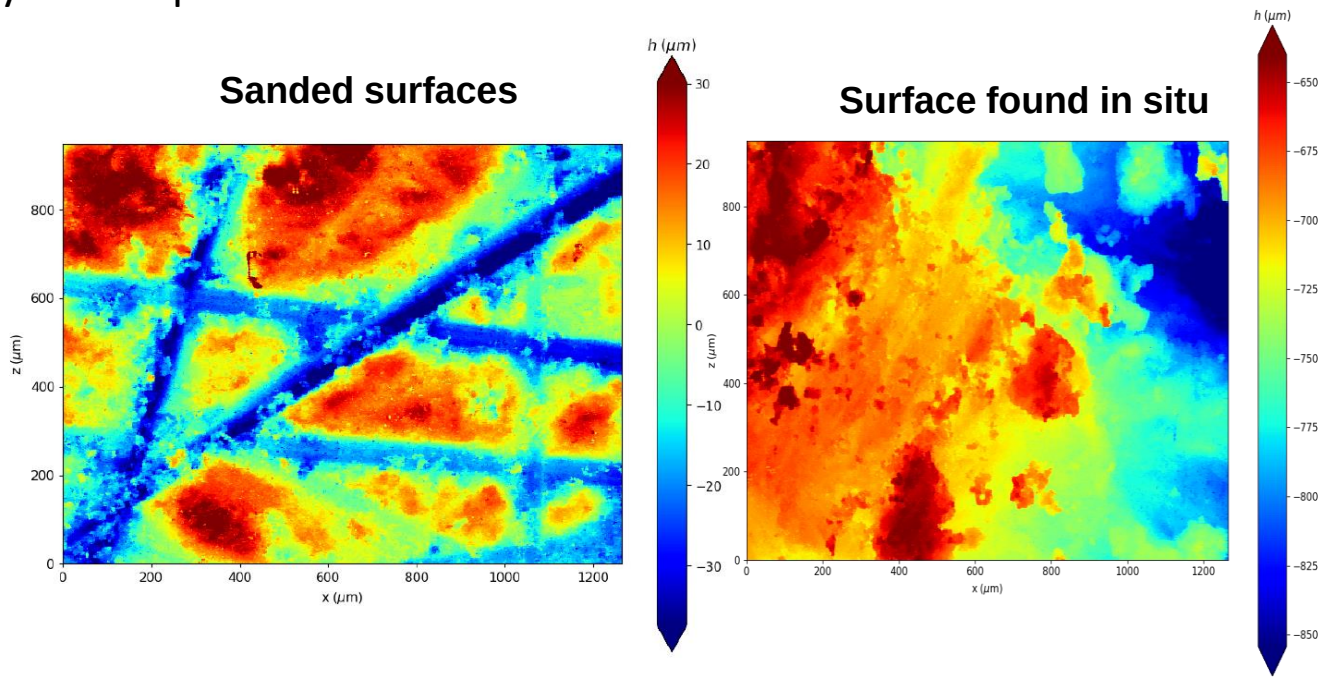
- Ouvrir et découper les blocs dans les carotte cylindrique fournit par l'ANDRA
- Polir les surfaces qui seront analysé par correlation d'images
- Polir les surfaces cisaillées



# Préparation des surfaces à cisailler

Analyse faite par Tortoise

Pattern only present in the sanded surfaces



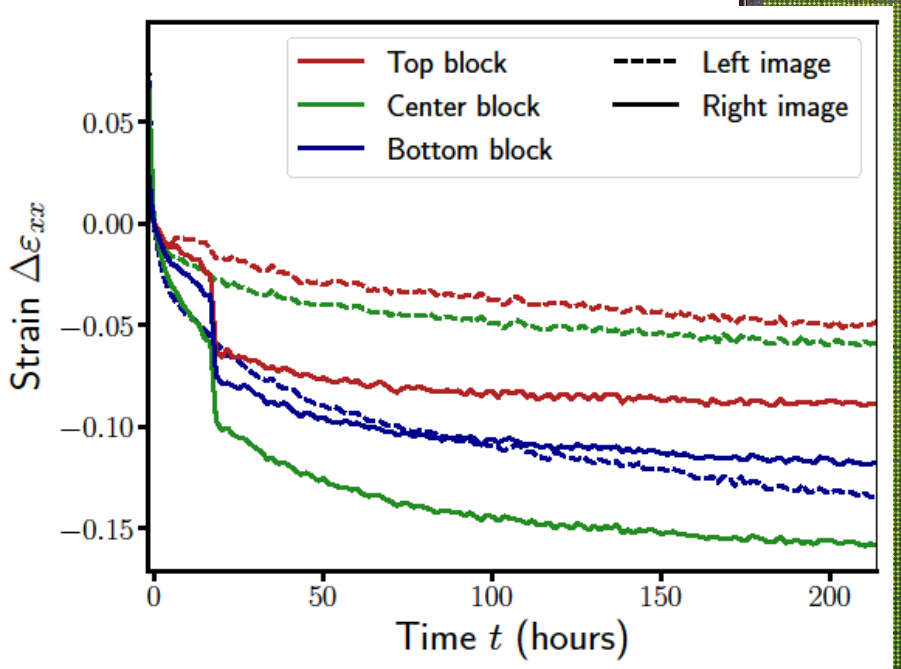

| No. Echantillon | No. Surface | ξ (µm) | | $\xi_{moy}$ (µm) |
|---|---|---|---|---|
| P40 | 1 | 13.68 | 16.4 ± 2.8 | 17.7 ± 4.4 |
| | | 20.43 | | |
| | | 15.67 | | |
| | | 17.32 | | |
| | | 18.21 | | |
| | | 12.92 | | |
| | 2 | 20.02 | 19.1 ± 5.4 | |
| | | 16.73 | | |
| | | 16.47 | | |
| | | 14.81 | | |
| | | 17.12 | | |
| | | 29.78 | | |
| P40 + P60 | 1 | 12.98 | 13 ± 1 | 13.7 ± 2 |
| | | 11.78 | | |
| | | 14.69 | | |
| | | 12.24 | | |
| | | 13.14 | | |
| | | 13.75 | | |
| | 2 | 19.01 | 14.2 ± 2.5 | |
| | | 14.97 | | |
| | | 14.13 | | |
| | | 12.79 | | |
| | | 11.62 | | |
| | | 13.19 | | |

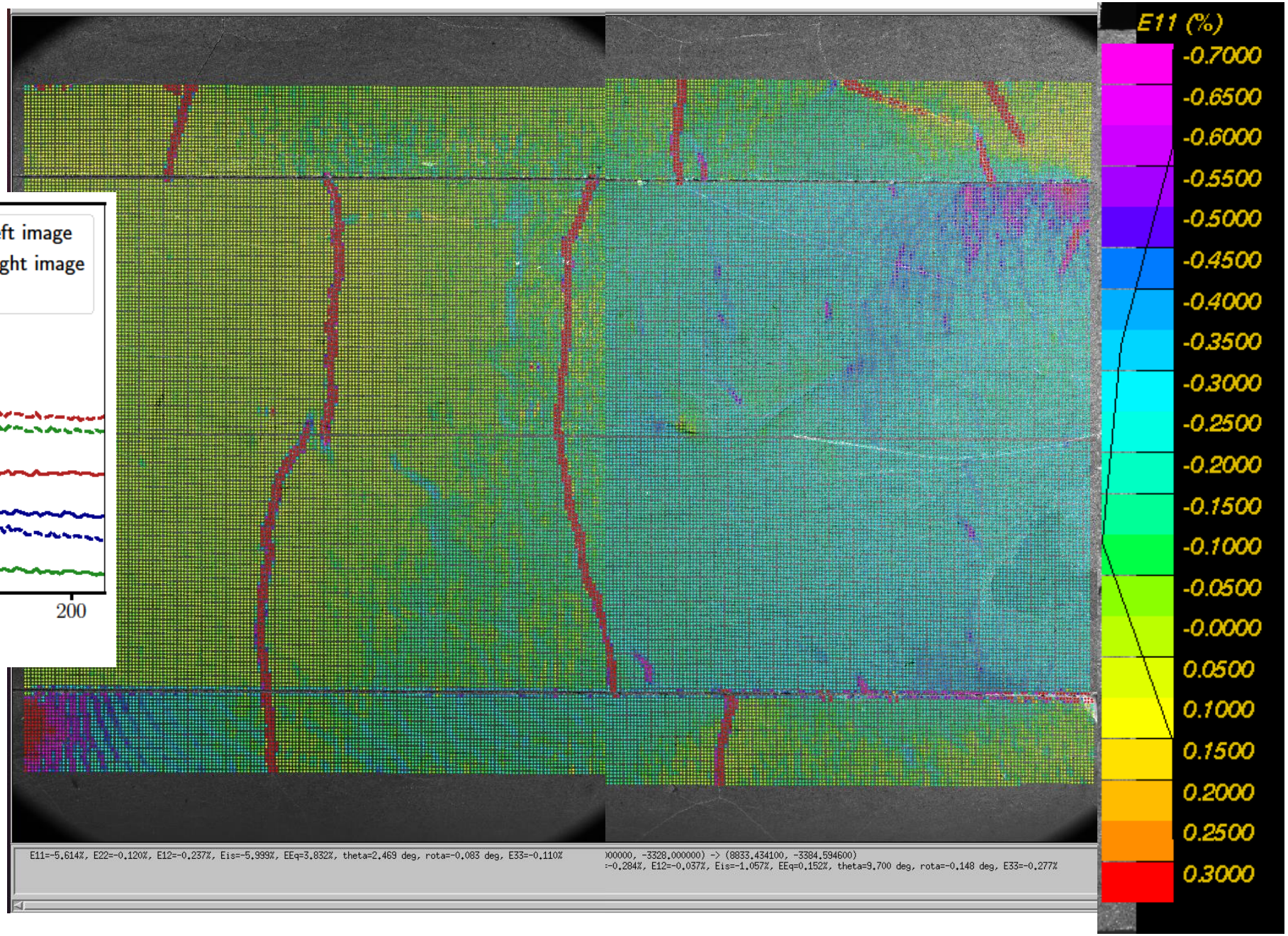
- Des différences qualitatives entre ces 2 surfaces existe. Une rugosité de l'ordre d'une centaines de microns est mise en évidence sur la surface poncé, ces motifs ne sont pas présents sur les surfaces in-situ
- La longueur caractéristique ξ mesuré par Tortoise, est estimé au delà de ces motifs. Les résultats sont résumés dans le slide suivant.
- On vise ξ = 15 ou 16 µm

# Campagne de cisaillement direct

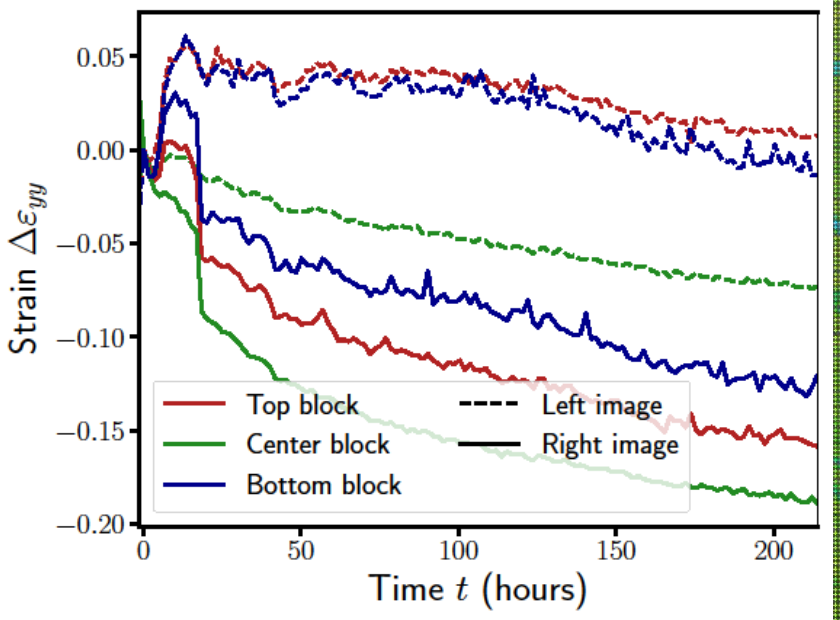
| | L'état de l'interface | Contrainte normale maximale | Paramètres de rigidité | Paramètres de résistance |
|---|---|---|---|---|
| Essais 1 | Polissage au papier de verre P500. | 8.3MPa | $K_n$=24.4MPa/mm<br>$K_t$=5.8MPa/mm | C=0.11 MPa,<br>$\phi$=19.4° |
| Essais 2 &3<br>Surface polie au P40<br>Après un fluage de 7 jours sous $\sigma_N$=4.3MPa<br>$\tau$=1.2MPa. | Les **débris** de roche à l'interface ne **sont pas éliminés.** | 7.1MPa | $K_t$=18.5MPa/mm | C=0.06MPa,<br>$\phi$=27.4° |
| | Les **débris** de roche à l'interface dus au fluage sont **éliminés**. | 7.1MPa | $K_t$=23.2MPa/mm | C=0.15MPa,<br>$\phi$=27.0° |
| Essais 4 | Polissage au papier de verre P40. | 7.1MPa | $K_n$=23.1MPa/mm<br>$K_t$=21.2MPa/mm | C=0.38MPa,<br>$\phi$=27.2° |

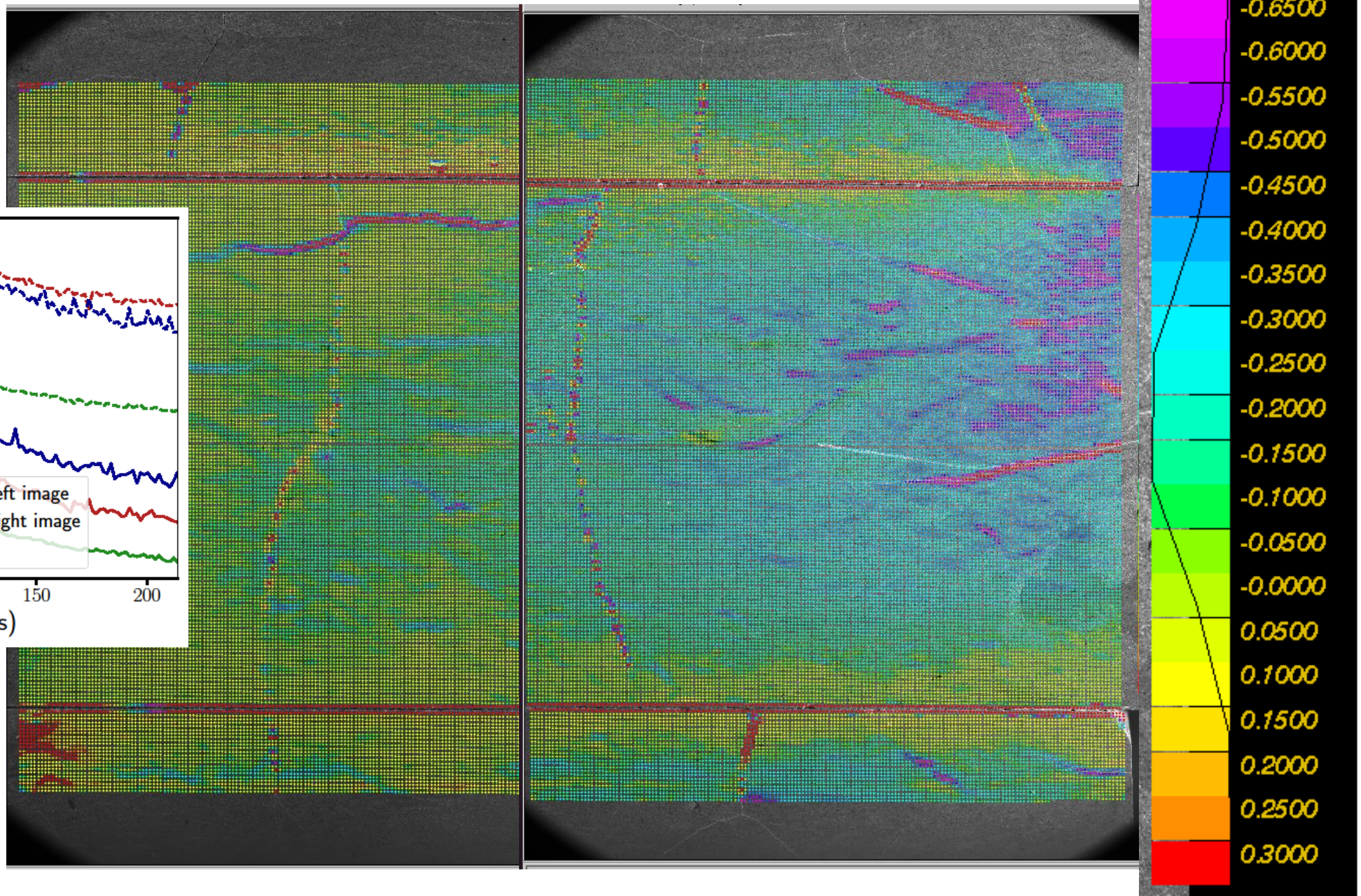
# Results provided by DIC



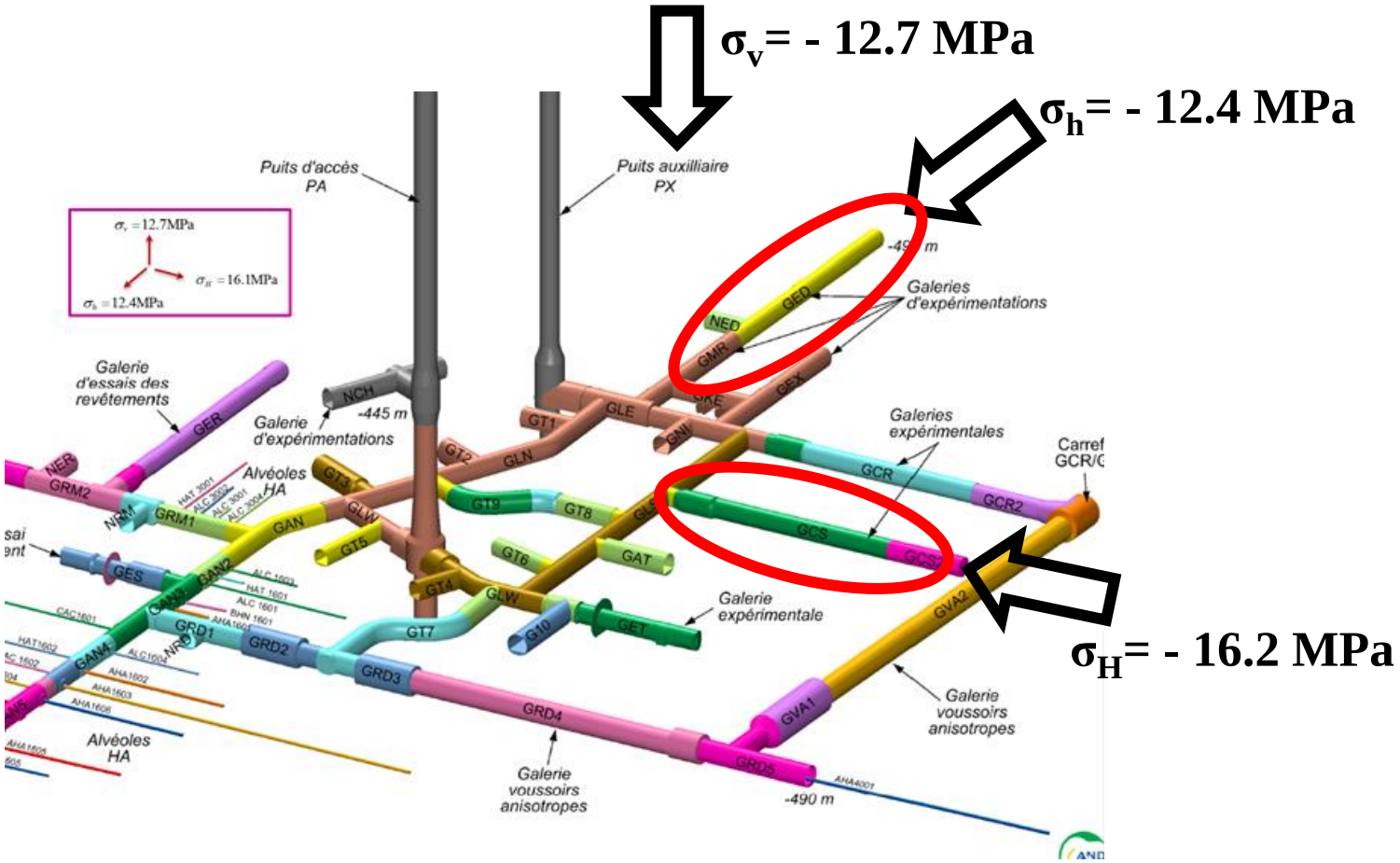



# Results provided by DIC



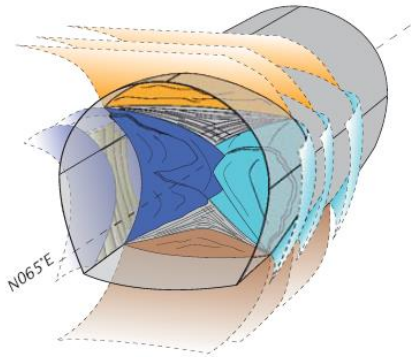



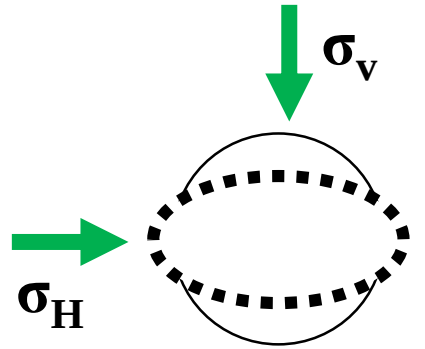
# CIGEO (Centre Industriel de Stockage Géologique / Industrial center for geological disposal) project




Underground Research Laboratory at 500m depth

- GED ‖ $\sigma_h$




- GCS ‖ $\sigma_H$