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The effect of water content on the frictional behaviour of smectite: Implications for H_2 storage

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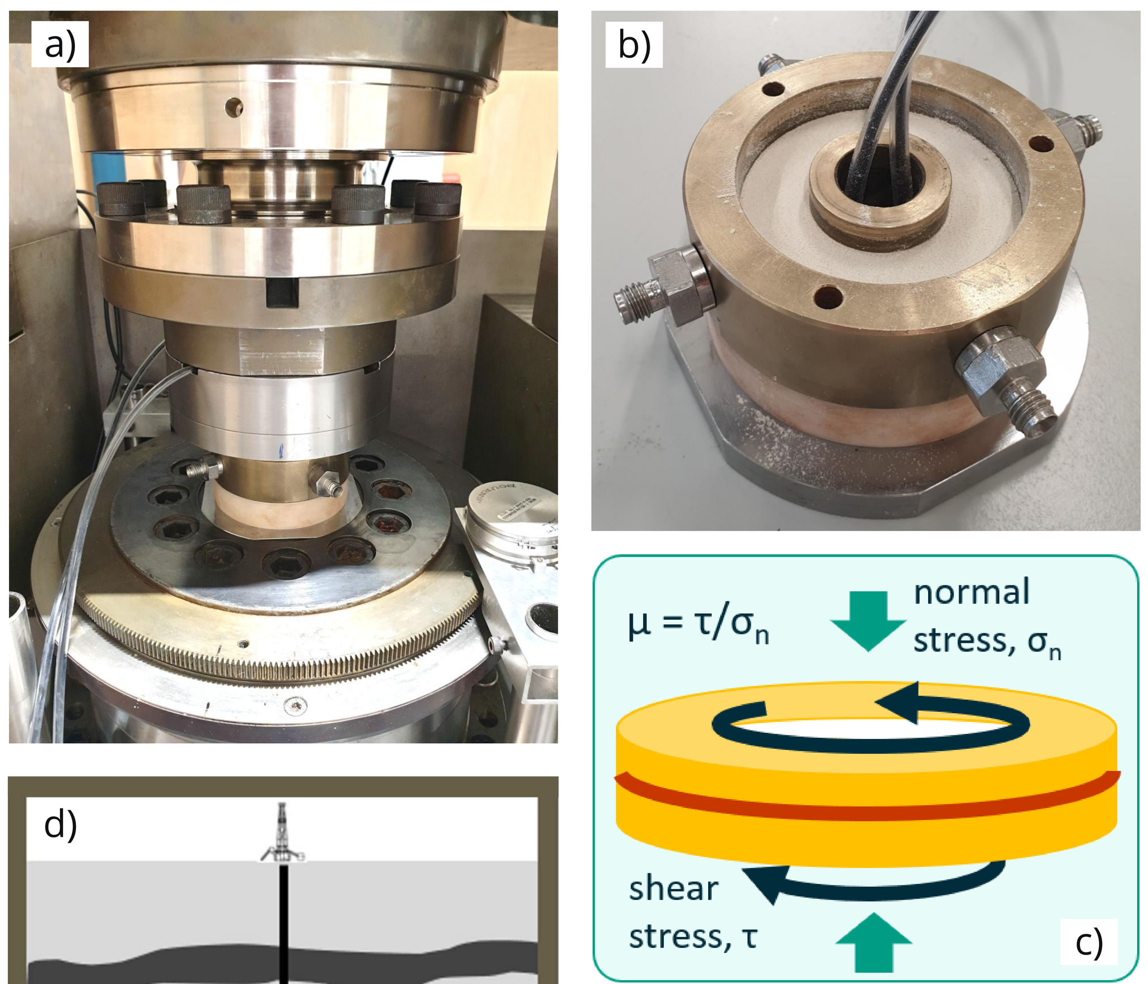
Introduction

As society transitions to a low-carbon energy system, green hydrogen produced from renewable electricity is expected to play an important role, and large-scale geological storage is needed to balance the seasonal supply and demand of wind and solar power. Many potential storage sites are overlain by clay-rich caprocks, where hydrogen sorption and swelling may affect the caprock integrity and fault stability. As hydrogen is a drying gas, repeated injection and extraction cycles could lead to swelling and shrinkage of the caprock, eventually causing fatigue and damaging the caprock integrity.

The swelling potential of clays is strongly influenced and directly correlated with the water content of the clay minerals, with no swelling observed for fully dry clays[1].

As such, we performed slide-hold-slide (SHS) experiments on water-wet, drying and dry Na-montmorillonite (swelling clay relevant for H_2 storage) to better understand the effect of water content on its frictional behaviour.



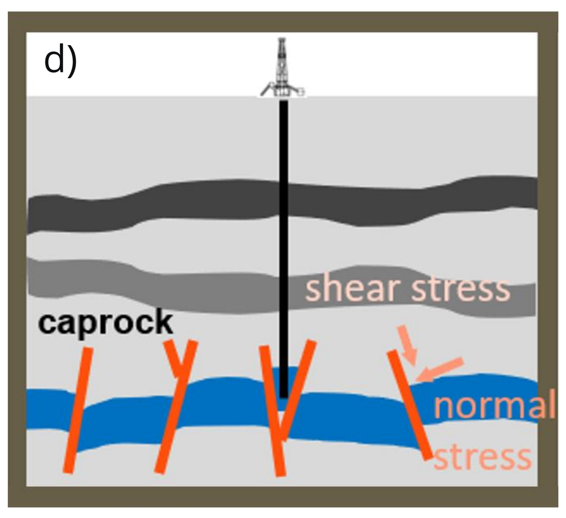


Figure 1: a) Ring-shear configuration in the HPT lab; b) Sample assembly (smectite layer visible); c) Imposed stresses (the red band represents the smectite layer); d) Schematic figure showing stresses in the subsurface.

Experimental Set-up

- Room temperature ring-shear experiments
- Material: Na-montmorillonite (smectite, swelling clay, Figures 1 & 2)
- Sliding at 2.5 μm/second (= 0.15 mm /min)
- Continued drying of the sample with air flow, and a heating wire set up from 40°C to 90°C
- SHS experiments at 15MPa applied normal stress (σ_n)
- Hold times: 3-10-30-100-300-1000-3000-10000-30000 s

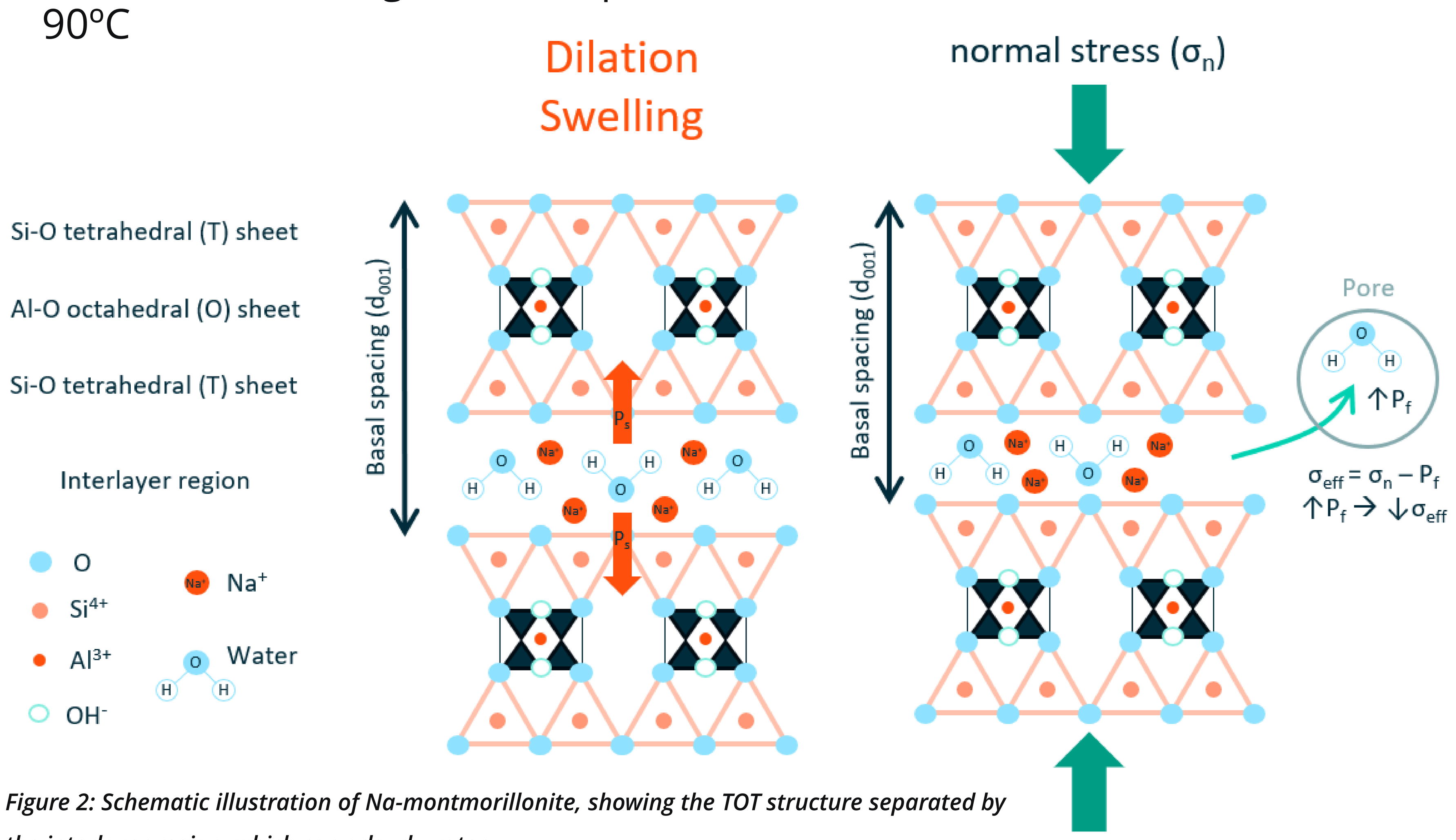


Figure 2: Schematic illustration of Na-montmorillonite, showing the TOT structure separated by the interlayer region, which can adsorb water.

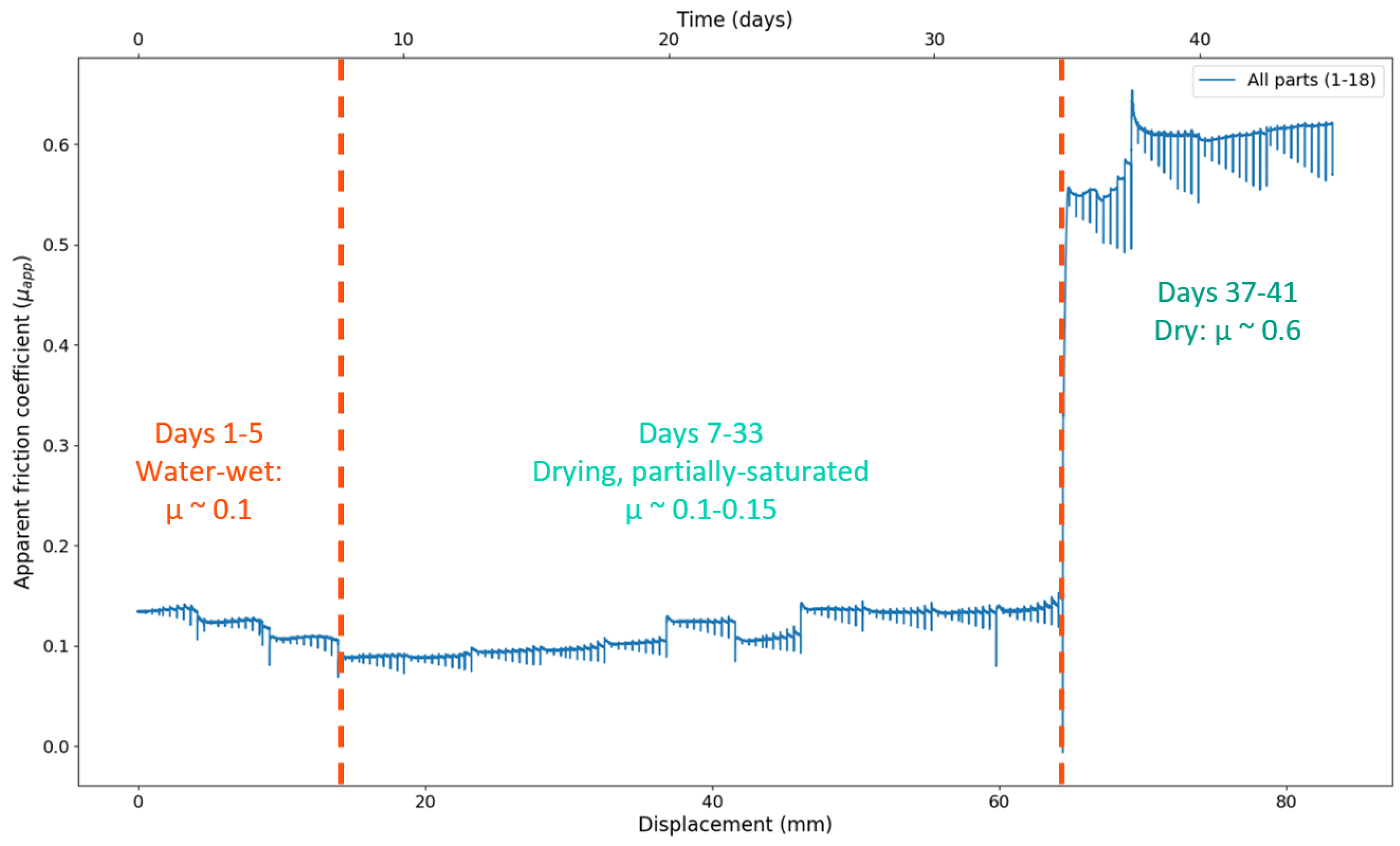


Figure 3: Results from the 42-days SHS experiments, showing the evolution of friction at an applied normal stress of 15 MPa.

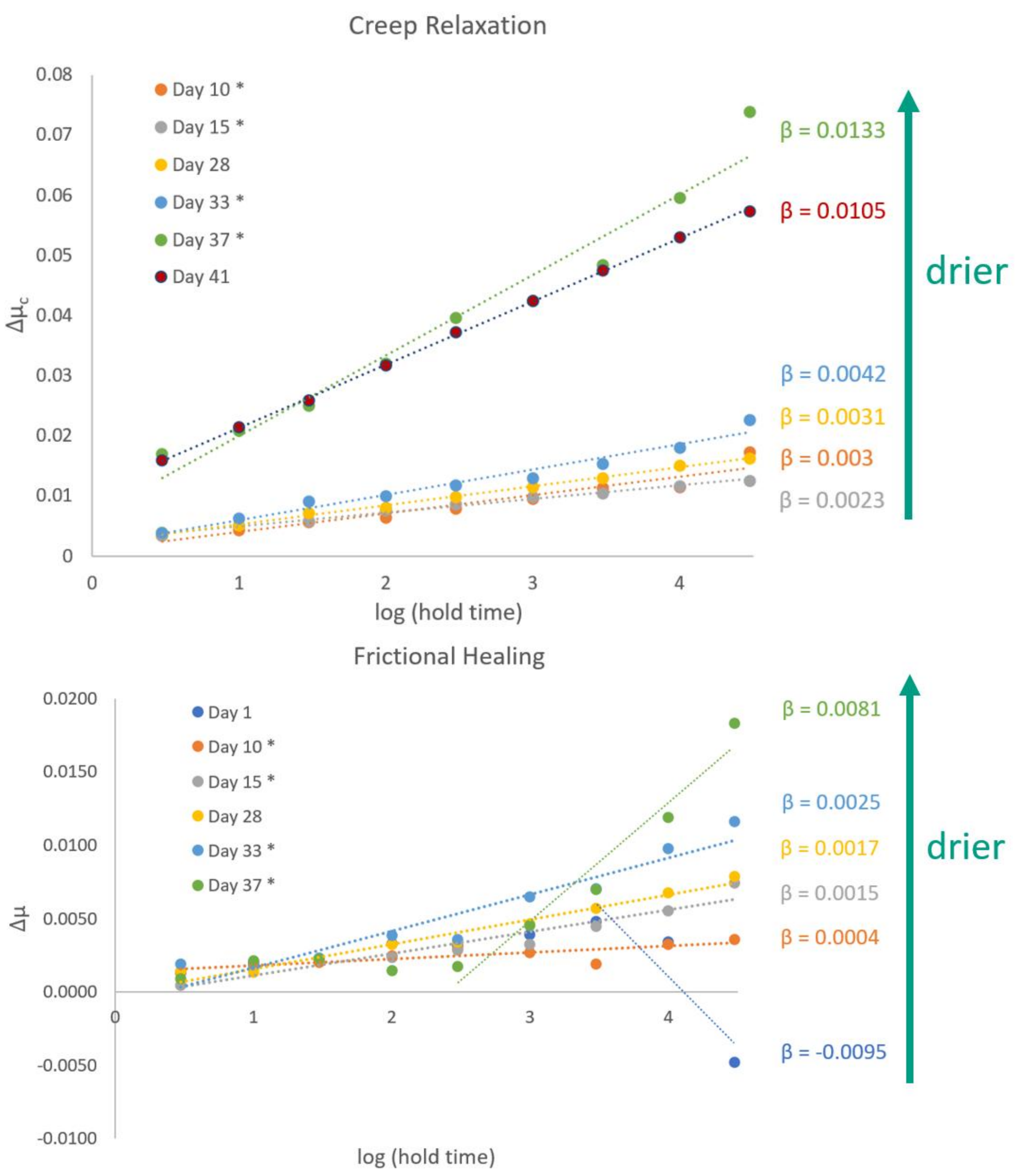


*Figure 4: Results from the SHS experiments, showing creep relaxation and frictional healing, as the sample was continuously drying. * indicates experiments that had the heating wire on.*

Results

- Apparent friction (μ) gradually increases as the sample is drying and jumps suddenly when the sample becomes fully dried (Figure 3).
- Creep relaxation and frictional healing increase as the sample is continuously drying → The sample regains strength after periods of no sliding (Figure 4).
- The sample becomes much stronger when fully dried.
- Sample dilates during holds when wet and compacts when dried (Figure 5).

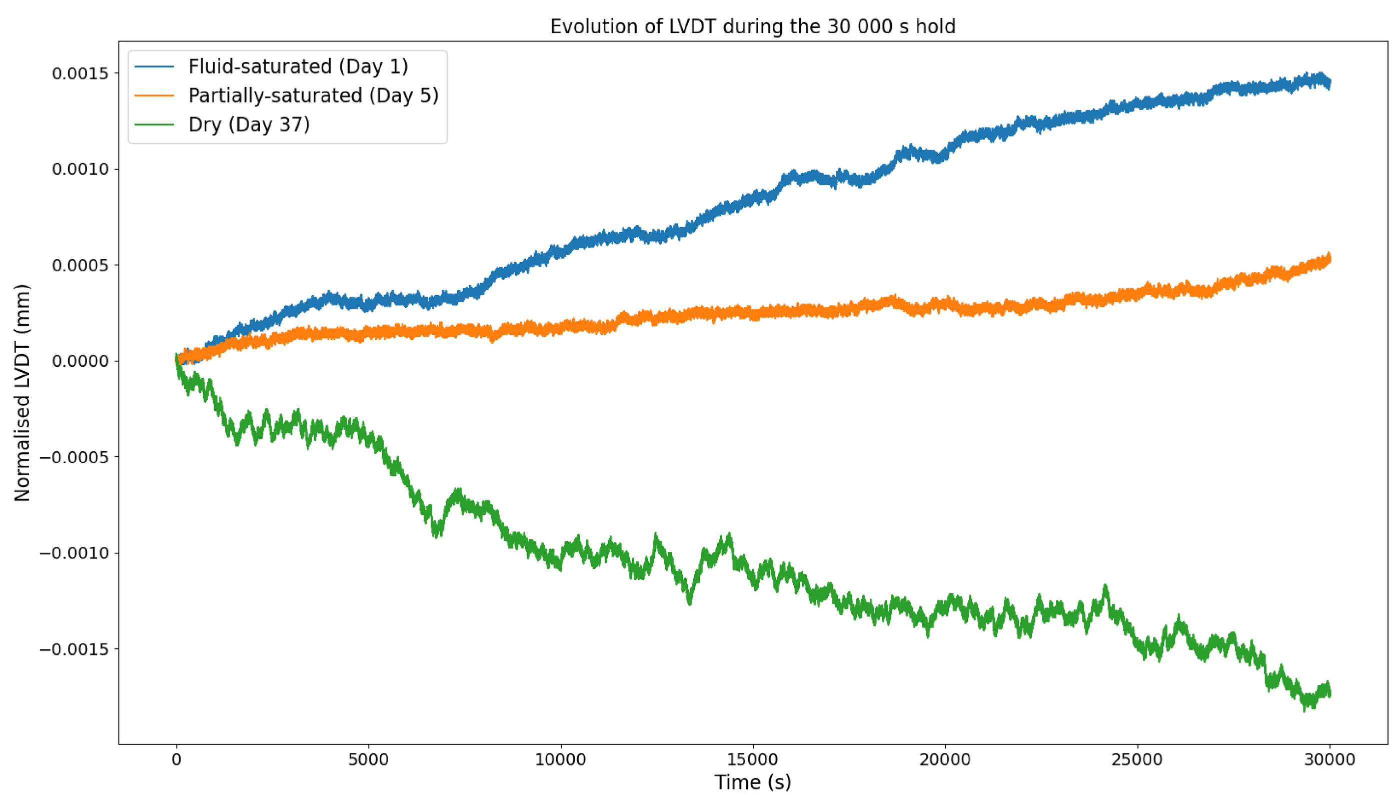


Figure 5: Showing the normalised axial displacement recorded by the local LVDT (Linear Variable Differential Transformer) vs time (sec), during the 30 000 s hold. This clearly shows dilation during holds for the fluid-saturated experiments, and compaction for the dry experiments.

Conclusions and Future Work

- Creep during fault inactivity leads to minor strengthening.
- Continuous drying of smectite faults increases both creep and restrengthening.
- Fully dried smectite faults are significantly stronger than partially saturated ones.
- Will we get similar behaviour with flow of H_2 through the sample? → new experiments including H_2.
- New friction experiments on ONE-Dyas cuttings (site-specific materials).

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References

1. Heinemann, N., Alcalde, J., Miocic, J. M., Hangx, S. J., Kallmeyer, J., Ostertag-Henning, C., ... & Rudloff, A. (2021). Enabling large-scale hydrogen storage in porous media–the scientific challenges. Energy & Environmental Science, 14(2), 853-864.