Influence of the water table oscillation on the mechanical and petrophysical properties of chalk

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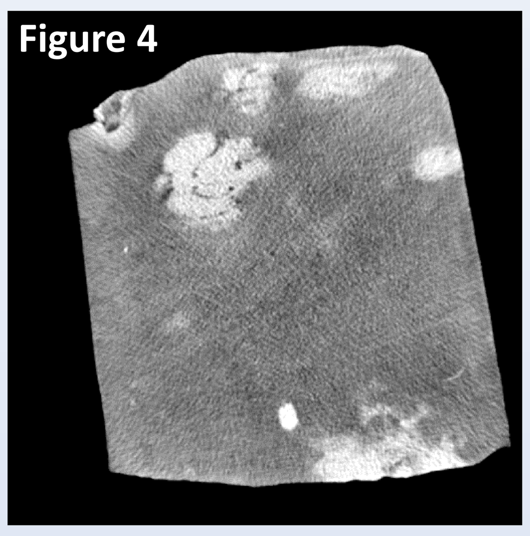
Materials

We cored and machined 10 cylindrical rock samples 50x25 mm from a chalk block collected in the La Malogne quarry. The Ciply chalk has a heterogeneous structure. It is composed by several high-density nodules (light in x-ray tomography in Figure 4), immersed in a homogeneous matrix made up of small coccolith fragments. The nodules, other than oxygen, calcium and carbon, contain phosphorus and fluor, typical of fluoroapatite.

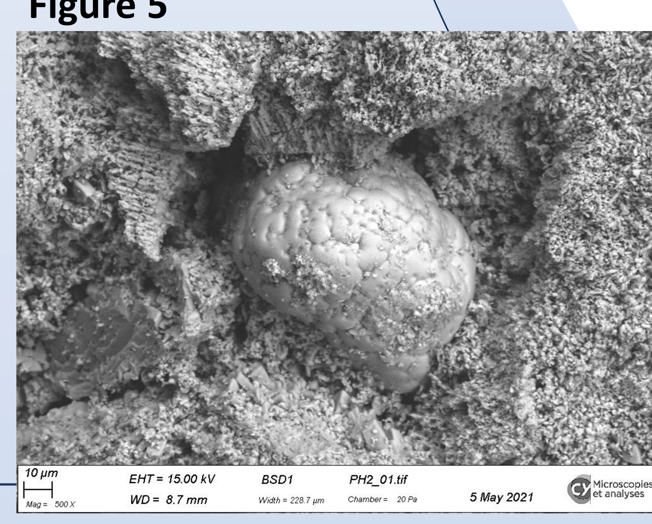
Figure 4



Scan the QR code for the full tomography video

This has been confirmed by Robaszynski & Martin (1988) where described these peculiar features as a brain-like cortex precipitated on the grains with the action of cyanobacteria (SEM micrograph in Figure 5).

Figure 5



Objectives

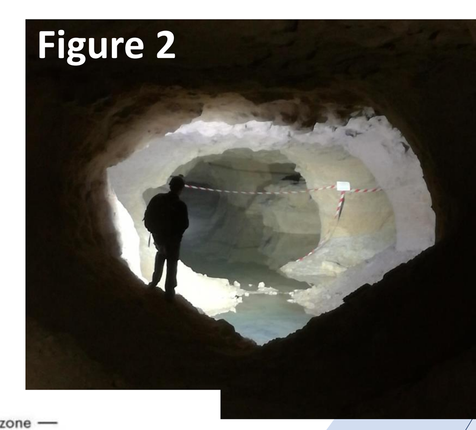
The southern Belgium has often experienced ground collapse in chalk formations due to the presence of several abandoned underground quarries (e.g. La Malogne quarry, Figure 1).

Figure 1

Georgieva et al., 2020

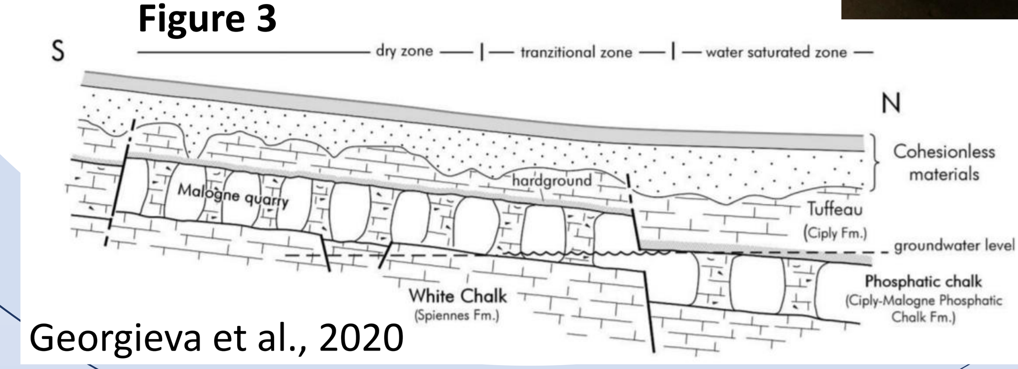
La Malogne site, mined in the 19th century underwent a collapse in 2015 resulting in a subsidence of up to 3 meters. The fluid-rock interaction and mostly, the well known mechanical weakening induced by water may be the cause of the observed collapse due to the partly flooded mine (Figure 2).

Figure 2



Therefore, we test the hypothesis that the largest weakening, hence, the highest risk, is in the area where the water table oscillates (Koffi & Pacyna, 2016), leading to repeated imbibition cycles (transitional zone in Figure 3)

Figure 3



Georgieva et al., 2020

Methodology

We adopted two experimental procedures: cyclic imbibition at ambient conditions and at constant load.

In the first scenario, we proceeded with the following steps:

- 15 cycles of imbibition-evaporation with distilled water (Figure 6);
  - Imbibition takes between 30 and 60 mins;
  - Evaporation takes three days;
    - We evaluated the UCS and Young's modulus at the beginning and after 2, 6, 10 and 15 cycles;
    - 5 samples for Young's modulus;
    - 5 samples for UCS.

Figure 6

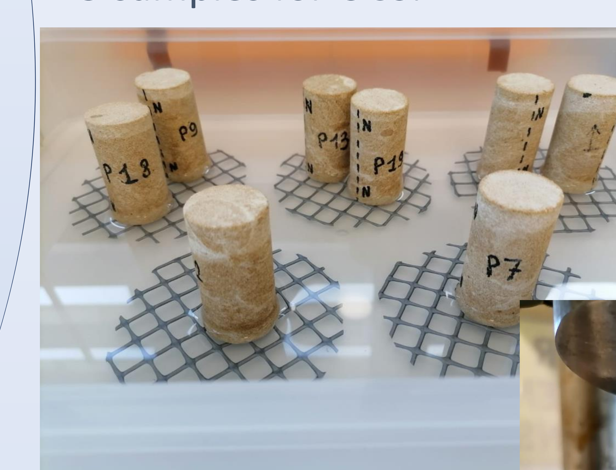
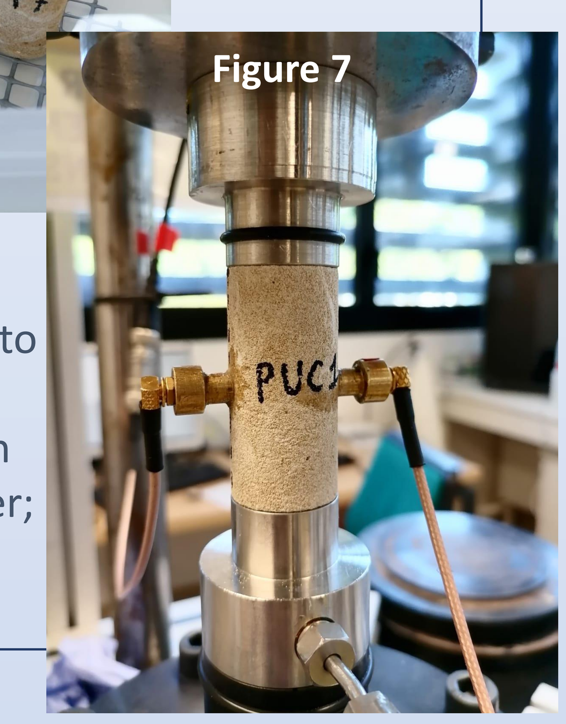


Figure 7



For the second method:

- Constant axial stress: 0.6 MPa to mimic the load on the pillars;
- 6 cycles of imbibition-evaporation with chemically equilibrated water;
- Imbibition takes around 60 mins
- Evaporation takes two days

Results at ambient conditions

No clear trend between the cycles number and the Uniaxial Compressive Strength is shown in Figure 8A and 9A. Indeed, it seems generally correlated with porosity (Figure 9B). Furthermore, the Young's modulus is also enhanced with increasing the loading/unloading cycles after a series of imbibition/evaporation (Figure 8B and 10).

Figure 8A

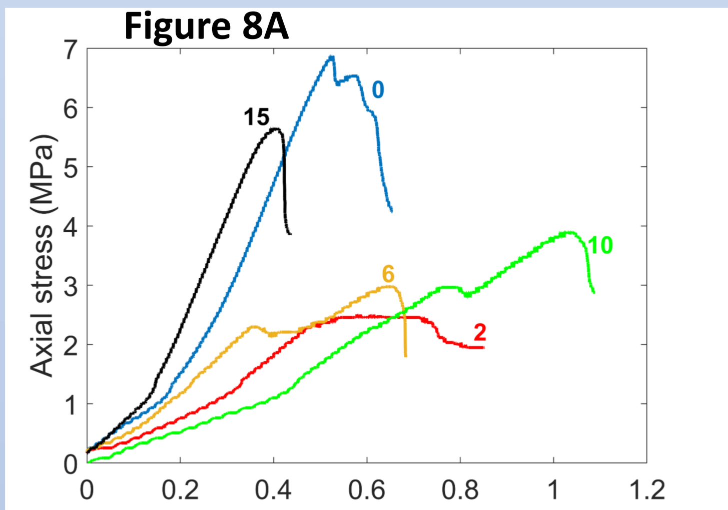


Figure 8B

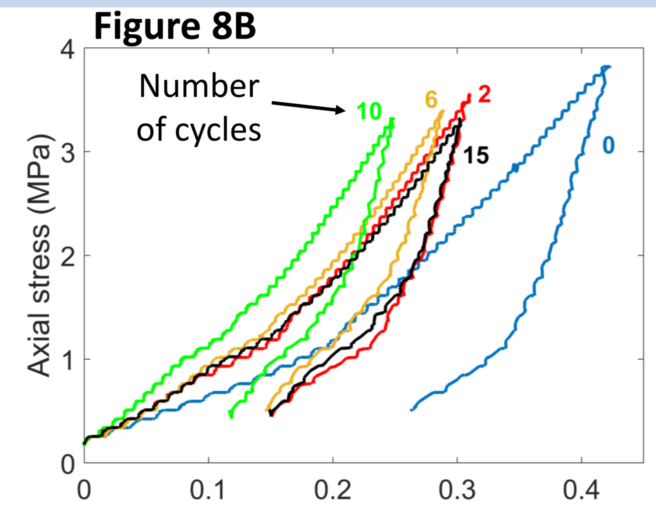


Figure 9A

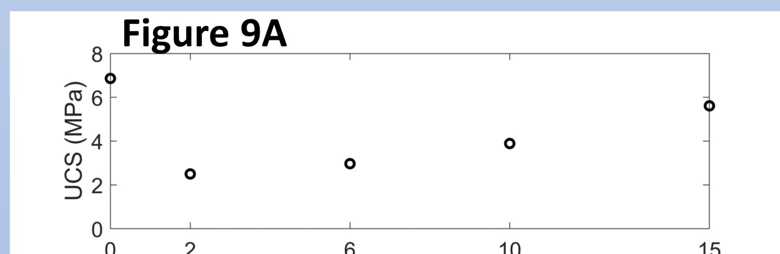


Figure 9B

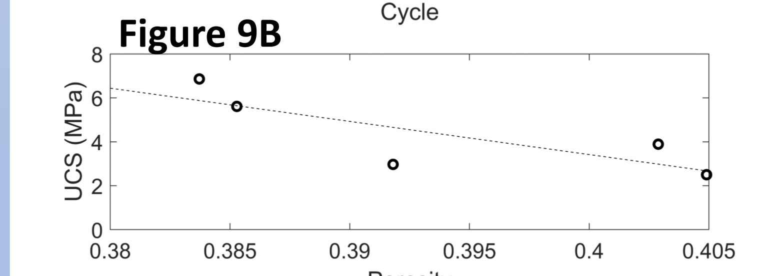
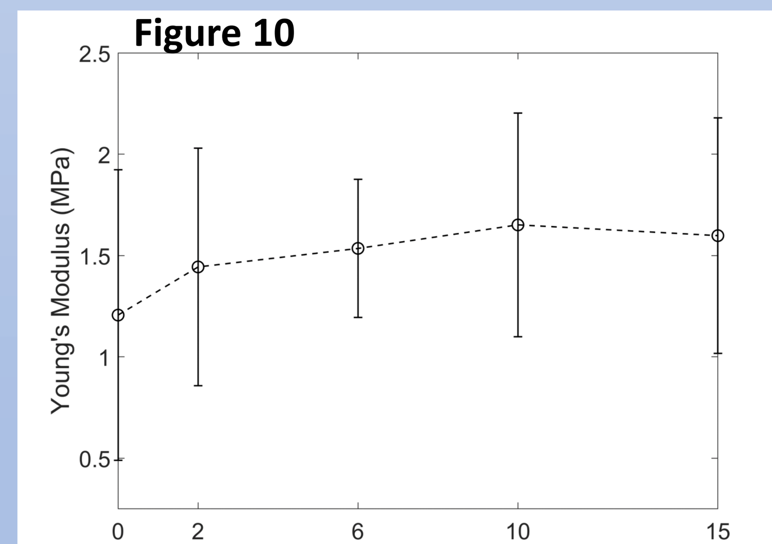


Figure 10



Results at constant load

The rock sample is also instrumented with 2 piezoelectric transducers (PZT) for shear stress, glued halfway (Figure 7). An ultrasonic survey is conducted every 30 seconds with the aim of monitoring the progression of the waterfront.

After the defined load is attained and a period of stabilization, the sample is left to imbibe in water. The first imbibition (Figure 11A) is marked by a sharp increase in axial strain which follows a progressive stabilization. The P and S-wave velocity, as well as, the wave amplitude undergo a variation when the waterfront approaches the PZT plane. Furthermore, when the water reaches the top of the sample, the velocities keeps in steady state.

The following imbibitions, after evaporation (e.g. the 2nd and 3rd here shown, Figure 11B and C) did not induce any change in the strain.

Figure 11A

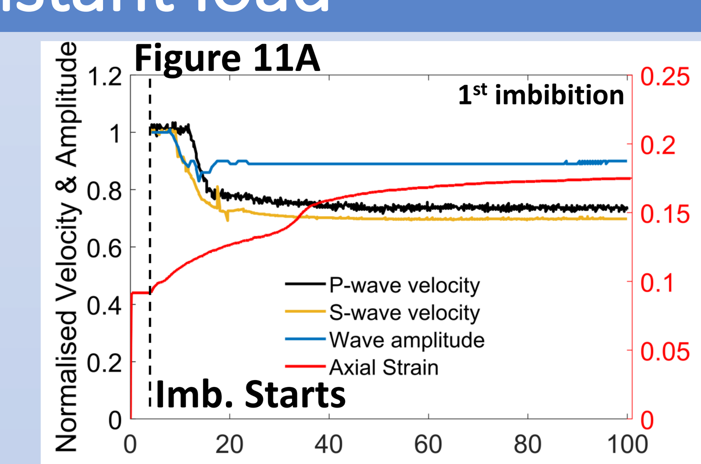


Figure 11B

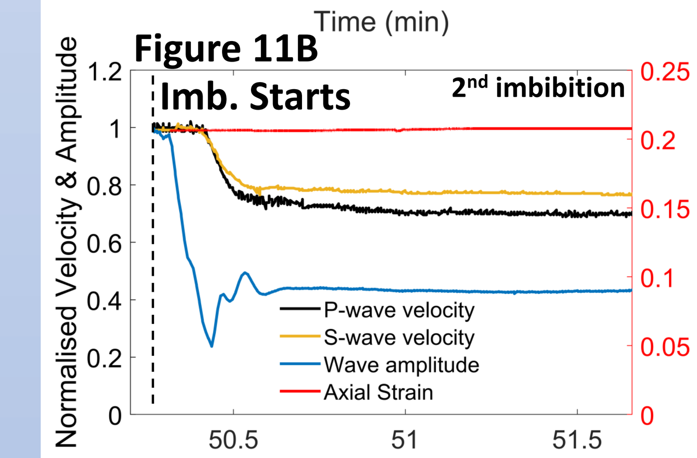
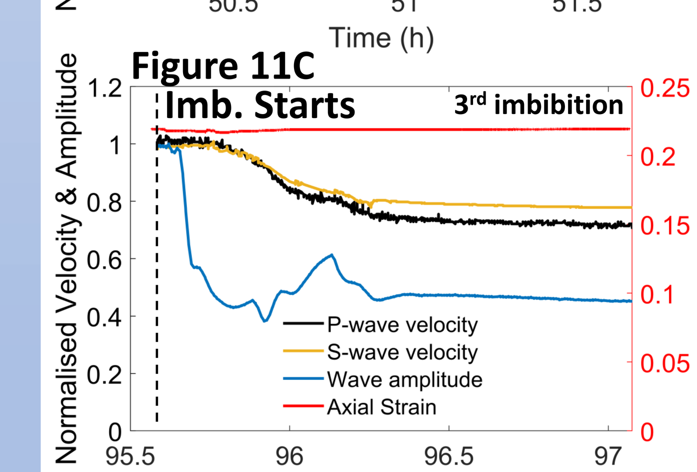
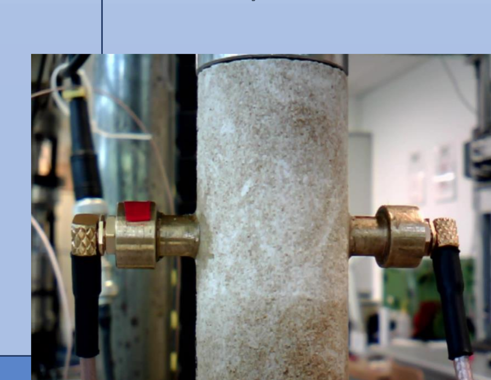


Figure 11C

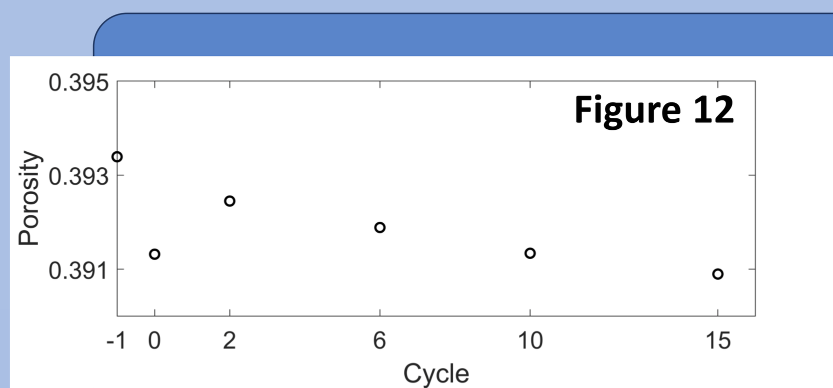




Scan the QR code for the full imbibition video

Conclusions

Figure 12



The cyclic imbibition at ambient stress showed no influence of the Young's modulus and the UCS with respect the cycles number:

- UCS seems to be more affected by the porosity rather than imbibition;
- Young's modulus is not weakened by the cyclic imbibition, it undergoes hardening, likely due to a reduction in porosity (Figure 12).

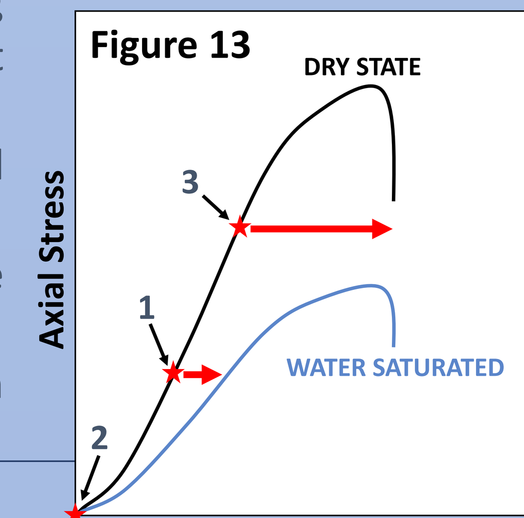
At constant load, the water saturation leads the rock sample from a dry state to a wet state producing irreversible strain (point 1 in Figure 13). When drying, the strain state remains at the wet state and is not recovered. Hence, a new imbibition does not induce further strain.

At ambient stress, water saturation does not induce strain. When dried, the rock strength is fully recovered (point 2 in Figure 13).

At applied load above the water-saturated strength, imbibition would lead to failure (Point 3 in Figure 13), see Geremia et al. (2021).

In conclusion, the mechanical behaviour in the transitional zone (water table oscillation) should not differ from the one in the water-saturated zone.

Figure 13



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