Effect of water saturation on the mechanical properties of various chalks characteristic of the Northwest European geoheritage

Ophélie Faÿ[1], Hannes Claes[2], Nicolas Gonze[1], Léa Pigot[3], Temenuga Georgieva[1,4], Van Malderen Eline[2], Rodrigo de Oliveira-Silva[5], Dimitrios Sakellariou[5], Serge Galaup[3], George Ajdanlijsky[6], Kalin Kouzmanov[7], Sara Vandycke[1], Fanny Descamps[1], Rudy Swennen[2]

1. UMONS, University of Mons, Faculty of Engineering, Mining Engineering Department, Rue du Joncquois 53, 7000, Mons, Belgium

2. KU Leuven, Geology, Department of Earth and Environmental Sciences, Celestijnenlaan 200E, 3001, Heverlee, Belgium

3. ENSEGID / EPOC UMR 5805 CNRS, 1 allée F. Daguin, 33607 Pessac cedex.

4. EURIDICE, Boeretang 200, 2400, Mol, Belgium

5. KU Leuven, cMACS, Department of Microbial and Molecular Systems (M2S), Celestijnenlaan 200F, Heverlee 3001, Belgium.

6. Bulgarian Academy of Sciences, Geological Institute, Dept. Palaeontology, Stratigraphy and Sedimentology, Sofia, Bulgaria

7. University of Geneva, Department of Earth Sciences, Geneva, Switzerland

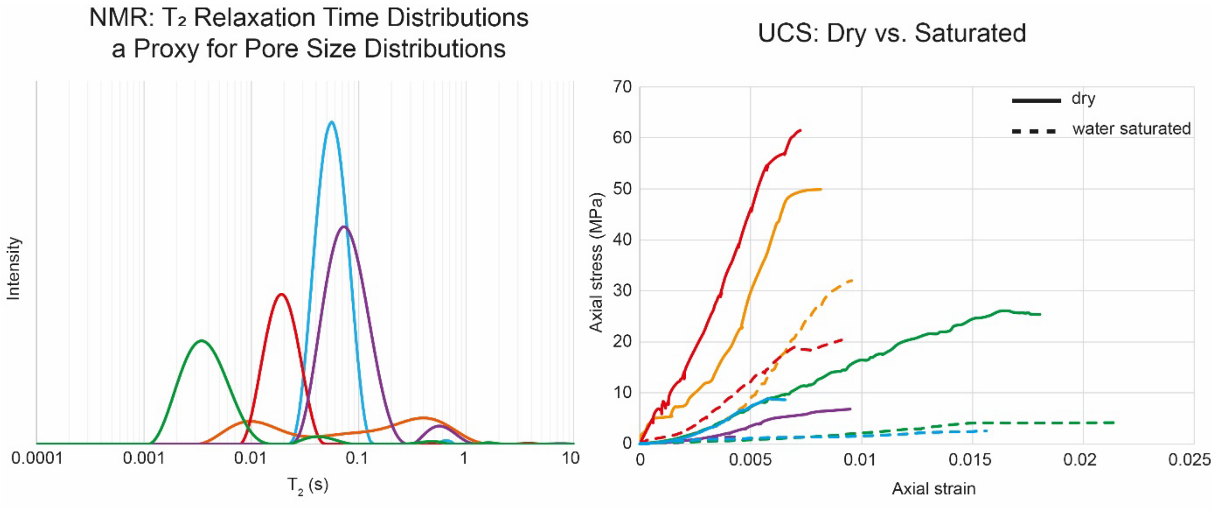
Chalk rock holds significant socio-economic value in Northwestern Europe, primarily because it serves as an important groundwater aquifer. It supplies about half of England's groundwater and up to a quarter in southern Belgium. Beyond its geological significance, chalk also has a deep cultural impact. It plays a substantial role in shaping landscapes, especially in coastal regions, such as the iconic Etretat cliffs. Chalk has also been used in construction, as is the case in the Beauvais Cathedral (France) built in the 13th century. Underground chalk quarries have historically provided lime for agriculture and building material. Some, like the “Crayères”, have been converted into Champagne cellars of which some are included in the UNESCO World Heritage list. Underground chalk quarries frequently face collapses, leading to engineering issues. The formation of sinkholes in northern France is becoming a recurring problem, and the spectacular landslides of chalk cliffs in Normandy and Boulonnais are also dependent on weather variations and chalk's water saturation.

Our study investigates the impact of water on the mechanical behaviour of different chalk lithotypes. We sampled five chalk lithotypes, namely white micritic, calcarenite, argillaceous, cemented and cemented phosphatic chalk (Faÿ-Gomord *et al.*, 2016). A thorough petrographic characterization was performed, including NMR analysis, MICP, optical microscopy, and SEM observations. The cemented phosphatic chalk displays a unique bimodal T_2 distribution, reflecting two major pore size populations. Microscopy allowed to determine that the first peak corresponds to the microporosity of the matrix, while the second corresponds to large pores. The latter may be associated with intense burrowing during eogenesis, within the early stages of hardground formation.

The mechanical properties of the chalk were characterized by performing uniaxial compressive tests on dry and 100% water-saturated samples. As reported in literature (Georgieva *et al.*, 2021; Geremia *et al.*, 2021, Pajiep *et al.*, 2024), saturated samples display a lower strength than dry samples. The sensitivity to water is often expressed by the wet-to-dry (WDR) ratio.

Strength in most samples drops by 60%, meaning a WDR of 0.4. However, the WDR of argillaceous chalk equals 0.2. On the other hand, the WDR of the phosphatic sample is only 0.77. This is likely due to the early cement consolidating the framework of the microtexture and the grain-to-grain contact not being easily affected by fluid-rock interactions. Additionally, the water-saturation of large pores - unlike micropores - may not significantly impact the strength of the rock. Similarly, the Young's modulus WDR equals 0.16 for the argillaceous chalk and ranges from 0.2 to 0.36 for most other chalks. However, for the cemented phosphatic chalk, the WDR equals 1, indicating that the elasticity of the sample is not altered by water saturation.

These preliminary results already highlight the influence of the chalk microtexture, its depositional setting, and diagenetic history on the mechanical properties of the samples when facing water-saturation. Given the expected increase in water infiltration due to climate change, water saturation could pose a significant threat. Therefore, additional analyses are being conducted to better understand and forecast its impact on chalk.



	Sampling location	He-Porosity (%)	Gas Permeability (mD)	Average Pore throat diameter (nm)	Tortuosity	Average dry UCS (MPa)	Average saturated UCS (MPa)	Average dry Young Modulus (MPa)	Average saturated Young Modulus (MPa)
White - micritic	Obourg quarry, BE	43,4	5,3	278	6,2	7,0	2,4	1904	384
Cemented	Flamborough cliffs, UK	21,5	0,4	168	4,2	58,1	24,1	9892	3606
Calcarenitic	Normandy cliffs, FR	44,1	15,4	670	6,6	5,0	1,9	1072	396
Argillaceous	Cap-Blanc Nez cliffs, FR	20,0	0,2	103	8,3	20,5	3,2	1536	255
Cemented phosphatic	La Malogne quarry, BE	17,2	4,3	463	7,2	41,4	31,9	6539	6567

Caption: (1) Representative NMR T_2 analysis reflecting pore size distribution (2) Characteristic Strain versus Stress curves from the uniaxial compressive tests (3) Main results and characterization of five chalk lithotypes. Colours in the table correspond to the colours of the curves.

References:

Faÿ-Gomord, O., Soete, J., Katika, K., Galaup, S., Caline, B., Descamps, F., Lasseur E., Fabricius I., Saïag J., Swennen R., Vandycke, S. (2016). New insight into the microtexture of chalks from NMR analysis. *Marine and Petroleum Geology*, *75*, 252-271.

Georgieva, T., Descamps, F., Gonze, N., Vandycke, S., Ajdanlijsky, G., & Tshibangu, J. P. (2023). Stability assessment of a shallow abandoned chalk mine of Malogne (Belgium). *European Journal of Environmental and Civil Engineering*, *27*(6), 2358-2372.

Geremia, D., David, C., Ismail, R., & El Haitami, A. (2021). An integrated study of water weakening and fluid rock interaction processes in porous rocks: linking mechanical behavior to surface properties. *Applied Sciences*, *11*(23), 11437.

Pajiep, D., Conil, N., Souley, M., Shao, J. F., Gombert, P., & Xie, S. Y. (2024). Experimental Investigation of Saturation Effect on the Mechanical Behaviour of Château-Landon Chalk. *Rock Mechanics and Rock Engineering*, 1-12.