1-year post-doctoral project on
“Multi-technique characterization of thin clay films during their creep”

Summary: This post-doctoral project aims at identifying the physical origin of clay creep, through a combination of original experiments on self-standing thin clay films. The films will be subjected to a constant tensile stress which will make them creep, i.e., deform over time. During this creep, the films will be observed with a variety of techniques of complementary scales: 1) environmental scanning electron microscopy (ESEM), 2) X-ray radiography and transmission X-ray microscopy (TXM), 3) small angle X-ray scattering (SAXS), 4) nuclear magnetic resonance (NMR). The combination of these observations will yield an original multiscale information on rearrangements of the micro/meso-structure and/or porosity of the films concomitant to their creep.

Skills of the ideal candidate: strong motivation, experimental skills, background in physical chemistry, knowledge of clays, knowledge of microstructural/nanoscale characterization techniques, proficiency at writing scientific articles.

Duration: 1 year, starting in January 2019

Principal location: Laboratoire Navier, Ecole des Ponts ParisTech, in Champs-sur-Marne, just outside Paris

Salary: Net salary of about 2 k€ per month. Funding is provided by DIM Respore (http://www.respore.fr/), the Ile-de-France network in porous solids science.

To apply: By **1 September 2018**, please send CV, publications, and motivation letter to matthieu.vandamme@enpc.fr

Advisors: Matthieu Vandamme (Laboratoire Navier, Ecole des Ponts ParisTech), Laurent Michot (Phenix, Sorbonne Université), Timm Weitkamp (Synchrotron Soleil), and their colleagues.

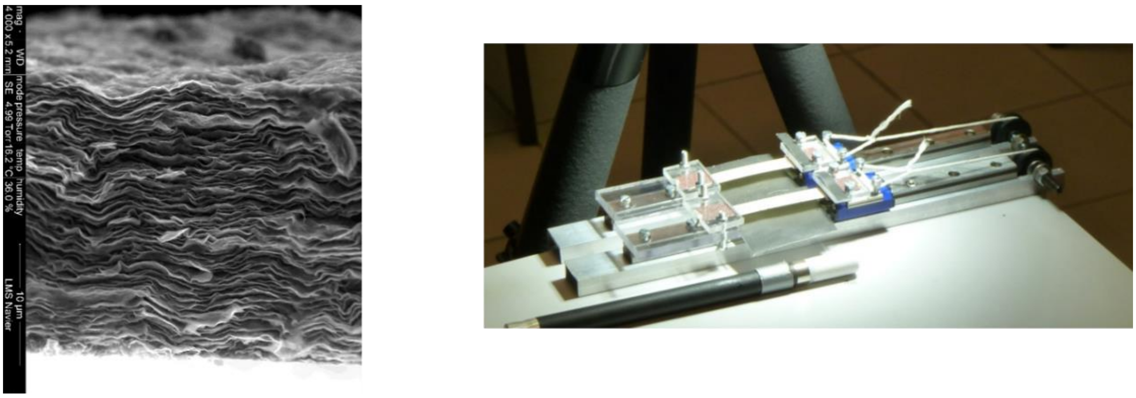

Figure 1: (left) Edge of a clay film of thickness of about 50 µm observed by ESEM and (right) 2 clays films in a device enabling mechanical solicitation for creep experiments. Figures from Carrier’s Ph.D. thesis (2013).

The mechanical properties of clay-based materials are critical in a variety of applications, such as nuclear waste storage, hydraulic fracturing, or the assessment of slope stability. In particular, the creep behavior of those materials (i.e., their propensity to deform over time when mechanically loaded) is of interest. Indeed, since the time scale of nuclear waste storage in underground clay rocks is extremely long (~ 100,000 years), creep will impact the long-term stress distribution in the rocks. Also, for what concerns hydraulic fracturing, creep can lead to a delayed closure of the created fractures and hence mitigate the expected permeability enhancement. In geotechnical engineering, creep can lead to delayed failures of soils and hence plays a role in landslides. In this post-doctoral project, we aim at identifying the physical origin of clay creep, through a combination of original experiments on clay systems.

We have demonstrated in the framework of the Ph.D. thesis of B. Carrier[1] the relevance of experimentally studying thin (i.e., thickness around 50µm) clay films (see Fig. 1-left) as models of realistic clay systems[2]. The objective of the post-doctoral project is to observe experimentally the clay films while they creep.

The films will be put in tension through a loading device (see Fig. 1-right). This tension will make them creep, i.e., the elongation of the films will increase over time. While creeping, the films will be observed with a variety of techniques of complementary scales: 1) environmental scanning electron microscopy (ESEM), 2) X-ray radiography and transmission X-ray microscopy (TXM), 3) small angle X-ray scattering (SAXS), 4) nuclear magnetic resonance (NMR). ESEM, in conjunction with digital image correlation, will make it possible to find out whether, during the creep process, the films deform homogeneously, or instead whether the deformations become localized. Observation of the films by X-ray radiography and TXM will make it possible to observe potential local variations of density of the films induced by the creep deformation, at a variety of scales. SAXS will provide information on the evolutions of basal spacing, of clay layers orientation, and of clay flocs[3], during the creep process. Proton NMR, from the evolution of the distribution of T1 relaxation times, will yield evolutions of pore size distributions upon creep. The combination of these observations will yield a multiscale information[3] on rearrangements of the micro/meso-structure and/or porosity of the films concomitant to their creep.

The thin clay films will be prepared by evaporation of clay suspensions at Phenix. The X-ray radiographies will be performed at Laboratoire Navier. For better resolution, increased flux, and for TXM measurements, we will employ the ANATOMIX beamline of Synchrotron Soleil. NMR will be performed at Phenix, and SAXS on the SWING beamline of Synchrotron Soleil. We will need to adapt and/or manufacture devices that allow mechanical solicitation during observations.

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[1] Carrier B. (2013). Effet de l'eau sur les propriétés mécaniques à court et long termes des argiles gonflantes : expériences sur films autoporteurset simulations moléculaires. Université Paris-Est.

[2] Carrier, B., Vandamme, M., Pellenq, R. J.-M., Bornert, M., Ferrage, E., Hubert, F., & Van Damme, H. (2016). Effect of water on elastic and creep properties of self-standing clay films. *Langmuir*, *32*(5), 1370–1379. https://doi.org/10.1021/acs.langmuir.5b03431

[3] Michot, L. J., Bihannic, I., Thomas, F., Lartiges, B. S., Waldvogel, Y., Caillet, C., … Levitz, P. (2013). Coagulation of Na-montmorillonite by inorganic cations at neutral pH. A combined transmission X-ray microscopy, small angle and wide angle X-ray scattering study. *Langmuir*, *29*(10), 3500–3510. https://doi.org/10.1021/la400245n