Effects of heating and hydraulic cycling on the stiffness response of a rigid anisotropic clay: preliminary results

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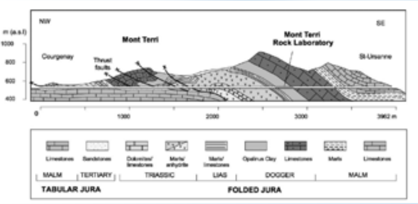
The poster presents the results of an experimental investigation aimed at evaluating the effects of heating and hydraulic cycling on the small-strain stiffness of a rigid Jurassic clay (Opalinus clay, Jura Mountains, Mont Terri Underground Laboratory, Switzerland). This clay was subjected to thermal loads during an in situ heating experiment (HE-D). After the test, intact samples were retrieved and analysed at laboratory scale. The influence of thermal loads was studied using basic characterisation, microstructural techniques (MIP) and non-destructive techniques (ultrasonic pulses). The retrieved samples were then subjected to wetting and drying paths. The hydraulic effects were tracked using basic characterisation (water content and porosity) and non-destructive techniques (ultrasonic pulses and bender elements). Test results showed a higher sensitivity of stiffness on suction increase for the material less affected by the thermal load (far from heater). Tests are currently being carried out on a new and fully instrumented high-pressure triaxial cell to monitor degradation effects induced by hydraulic cycling under a controlled stress field. Degradation is monitored by horizontal and vertical bender elements to track different directions.

In-situ heating test layout



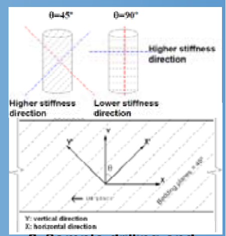
1. Mont Terri Underground Laboratory


2. Niche location


3. Borehole drilling


4. Heating:
H1: 90 days at 650 W
H2: 248 days at 1950 W

5. End of test: sample retrieving



6. Sample drilling and orientation

Laboratory characterisation of Opalinus clay

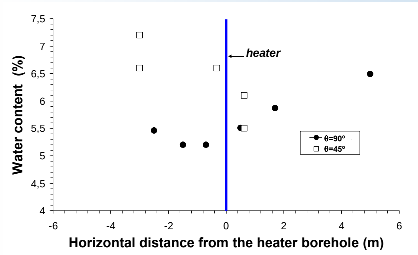
Opalinus clay is a very low permeable soft rock of marine origin, composed of 40–80% clay minerals, with clay mineralogy consisting mostly of kaolinite and illite.

	〉d (Mg/m3)	ρs (Mg/m3)	w (%)	Total suction, Ψ (MPa)	n	Sr	wL (%)	PI (%)
Average value	2.22-2.33¶	2.73± 0.01*	4.2 -8¶	10–16*	0.13–0.18¶	0.83–0.93*	-	-
Samples tested	2.28±0.01	2.73± 0.01	5.8 - 6.5	22-28	0.163	0.83	41	24

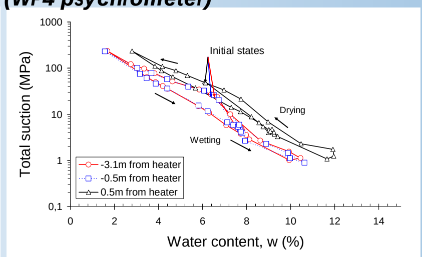
¶ data from Gens et al (2007)
* data from Muñoz (2007)

I. Influence of in-situ heating

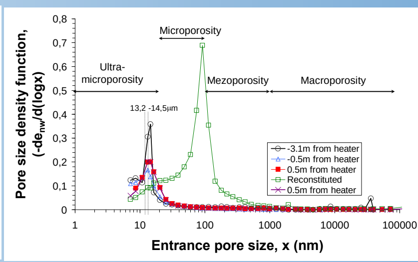
1. Water content variations



2. Water retention properties (WP4 psychrometer)

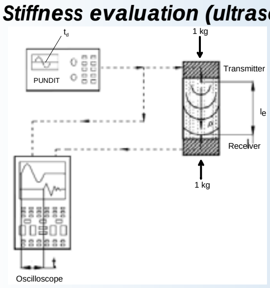


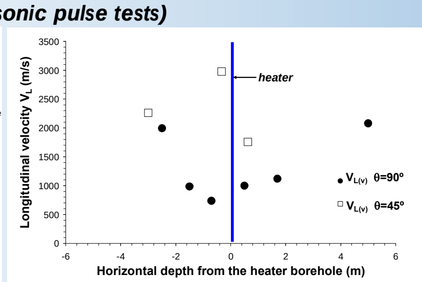
3. Pore size distribution PSD (MIP tests)

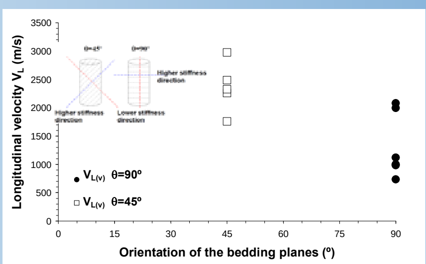


- Previous heating process induced moisture loss near the heater.
- Water retention curves showed a similar response although a higher water retention capacity was obtained at 0.5m from heater (macrostructural effect?).
- No appreciable effects on PSD

4. Stiffness evaluation (ultrasonic pulse tests)



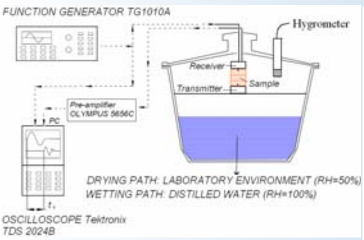




- Clear stiffness degradation is observed for samples located near the heater irrespective the orientation of the bedding planes.
- Samples with θ =90° showed a lower stiffness compared with θ =45° ($V_{L(v)}$).
- Possible rock damage induced by heating seems more evident for samples with θ =90° ($V_{L(v)}$).

II. Influence of hydraulic cycling: one wetting-drying cycle with bender element (BE) measurements

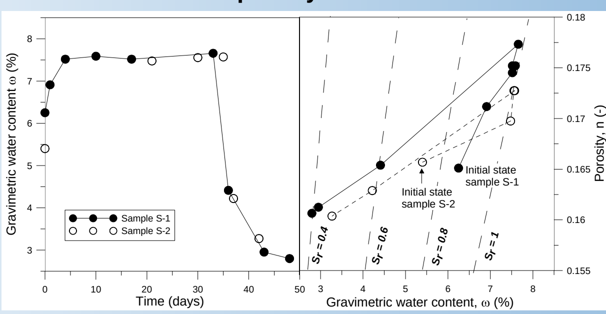
1. Set up for hydraulic paths



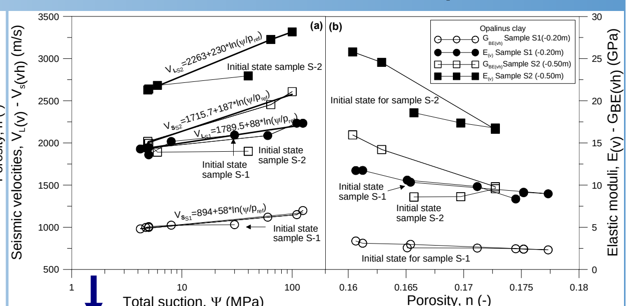
Psycrometric law:

$$\psi = -\frac{RT\rho_w}{M_w}\ln(RH)$$

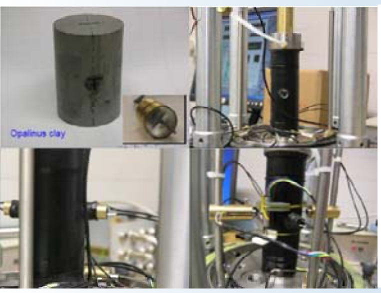
2. Water content and porosity evolution

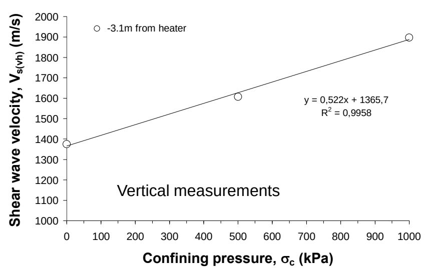


3. Influence of total suction on elastic parameters



III. Triaxial tests: vertical and horizontal BE (ongoing tests)





- Variation of seismic velocities during drying with total suction (ψ)

$$V_{L,s(ij)}(\psi) = V_{L,s(ij)}(\psi_{(0)}) + \beta * \ln\left(\frac{\psi}{p_{ref}}\right)$$

β: material parameter (in m/s).
It seems dependent on rock damage

For V_L measurements:

β=230 m/s	sample S2 (-0.5m from heater)
β=88 m/s	sample S1 (-0.2m from heater)

For V_S measurements:

β=187 m/s	sample S2 (-0.5m from heater)
β=58 m/s	sample S1 (-0.2m from heater)