Can a deep geological repository in a clay formation maintain its integrity and still reactivate a nearby fault?

Luca Urpi[1], Antonio P. Rinaldi[1] , J. Rutqvist[2], Stefan Wiemer[1]

1 Swiss Seismological Service, Swiss Federal Institute of Technology, ETHZ, Zürich, Switzerland

2 Lawrence Berkeley National Laboratory, Energy Geoscience Division, Berkeley, CA, USA

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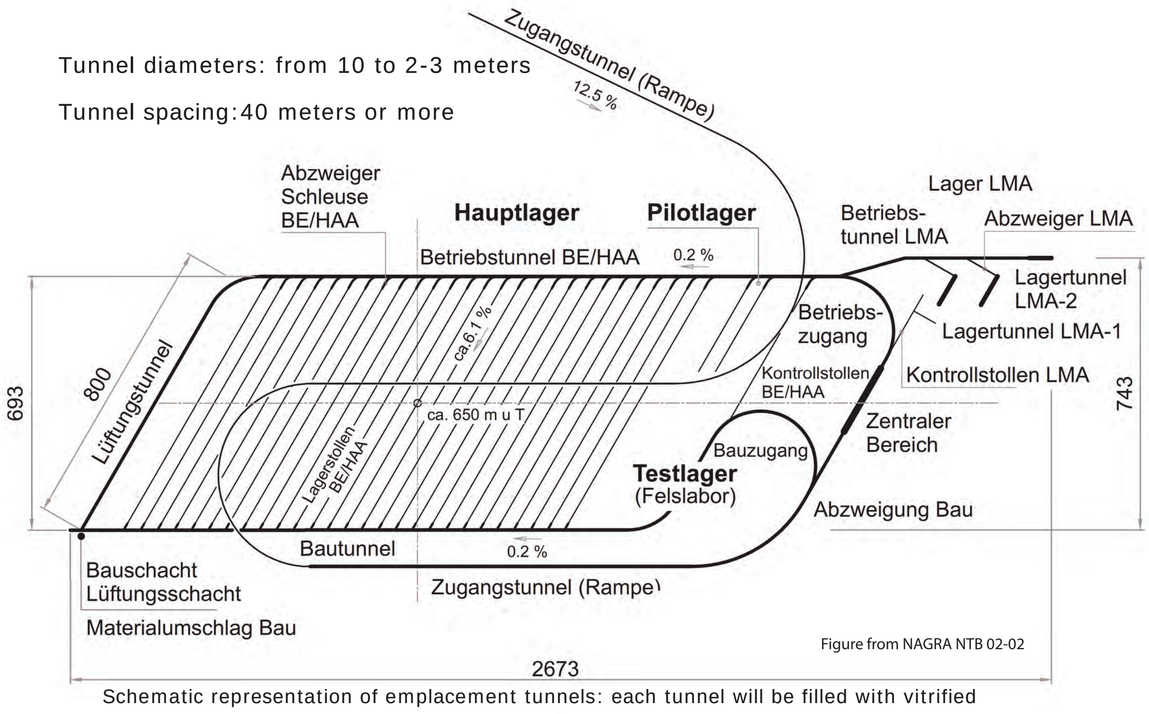
Introduction

The geological storage of high-level radioactive waste has been evaluated to be the safest option in the long term by a number of nations, among them Switzerland. With this work, we present results on the assessment of thermoelastic stress and pressure changes influence on the stability of a nearby fault, to evaluate if and when rupture take place. Laboratory and field scale experiment show that the heat produced by the nuclear waste is affecting the rock mass not only by means of an increase in temperature, but also by a strong pressurization that takes place in the first couple of thousands of years.



Schematic representation of emplacement tunnels: each tunnel will be filled with vitrified waste canisters, designed to mantain integrity and to sustain temperature increase by material decay

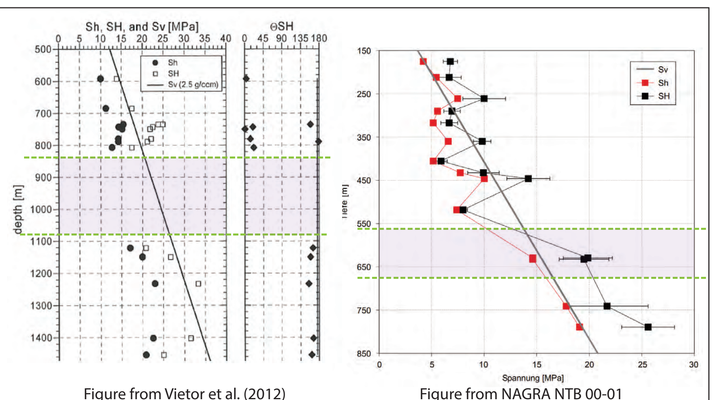
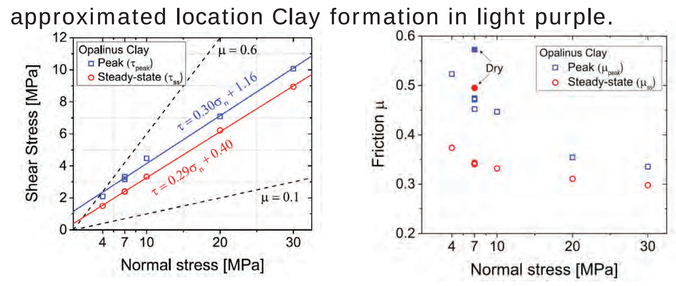


Figure from Vietor et al. (2012) — Figure from NAGRA NTB 00-01

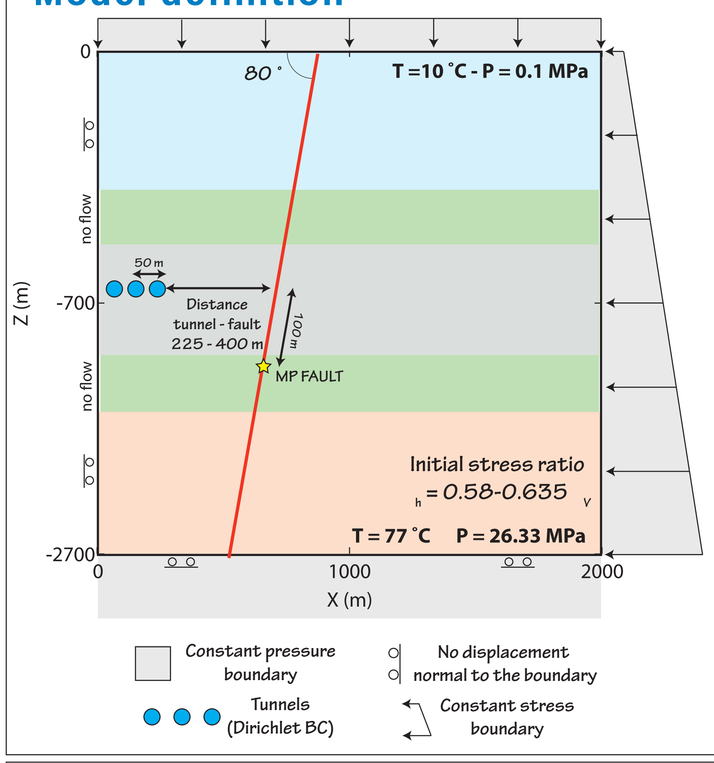
Stress state at two different locations in North Switzerland, approximated location Clay formation in light purple.



Figures from Orellana et al. (2018)

Frictional behavior of dry sheared pulverized fault gouge

Model definition

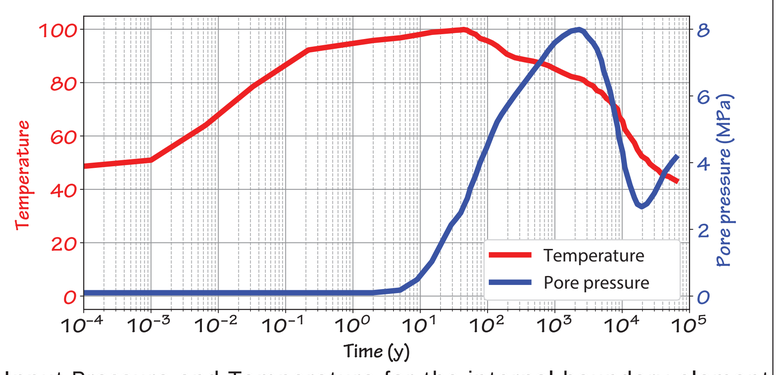


Elastic, hydraulic and thermal properties of the model units:

	Top	Overburden	Clay formation	Underburden	Bottom
Thickness (m)	550	75	150	75	1150
Density (kg/m^3)	2430	2430	2430	2430	2430
Young's mod. (GPa)	37	8	12.7	8	9
Poisson's ratio	0.27	0.27	0.2	0.27	0.27
Permeability (m^2)	10^{-18}	10^{-15}	//3 × 10^{-19} **T** 6 × 10^{-20}	10^{-15}	10^{-15}
Porosity (%)	10	10	7.4	10	1
Specific Heat (J/KgºC)	920	920	920	920	920
Thermal conductivity (W/M/ºC)	3.2	3.2	3.2	3.2	3.2
Thermal expansion coefficient (1/ºC)	2.00×10^{-5}	2.00×10^{-5}	2.00×10^{-5}	2.00×10^{-5}	2.00×10^{-5}
Pore compressibility (1/Pa)			10^{-9}		
Pore expansivity (1/ºC)			1.4×10^{-3}		

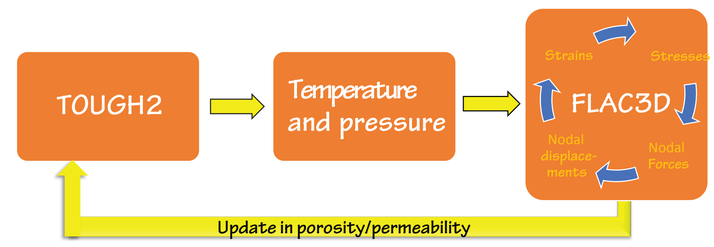
Fault and beddings included as ubiquitous joints (embedded oriented joints in FLAC3D).

Mohr Coulomb *before/after rupture*	Clay beddings	Fault
Dip	0	80
Friction angle (º)	20/20	20/20
Cohesion (MPa)	5.6/1.8	0.35/0
Dilation angle (º)	0	0



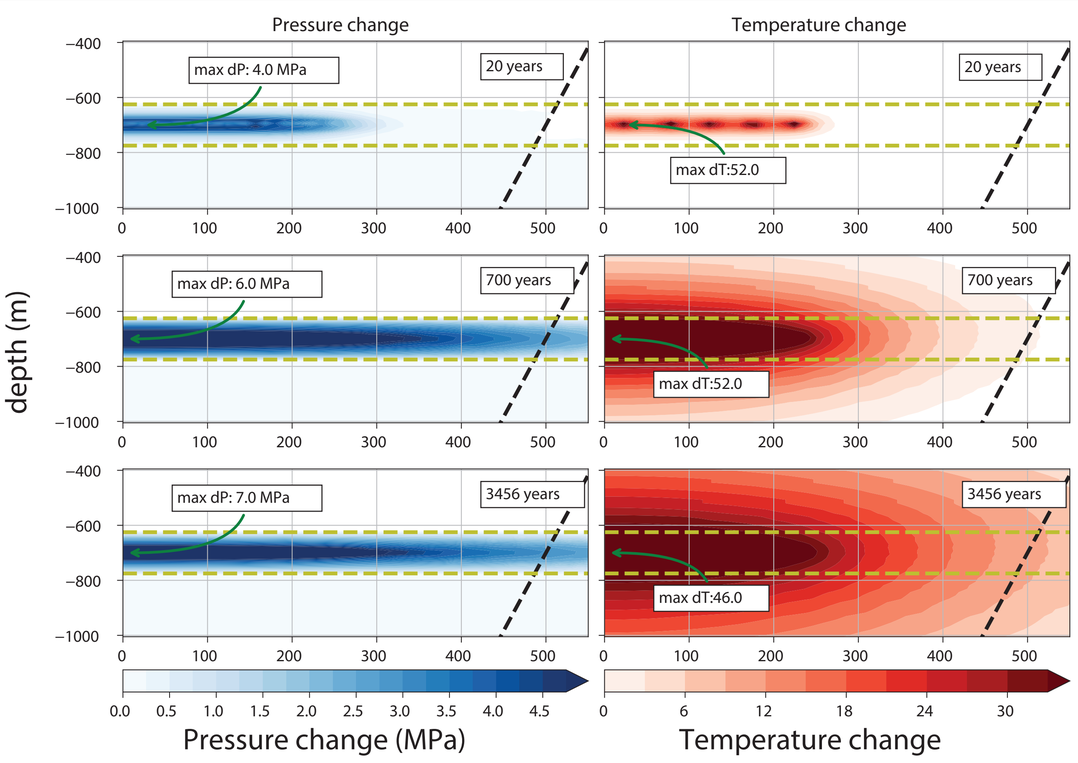
Input Pressure and Temperature for the internal boundary element

The problem is modelled via linking of FLAC3D to TOUGH2



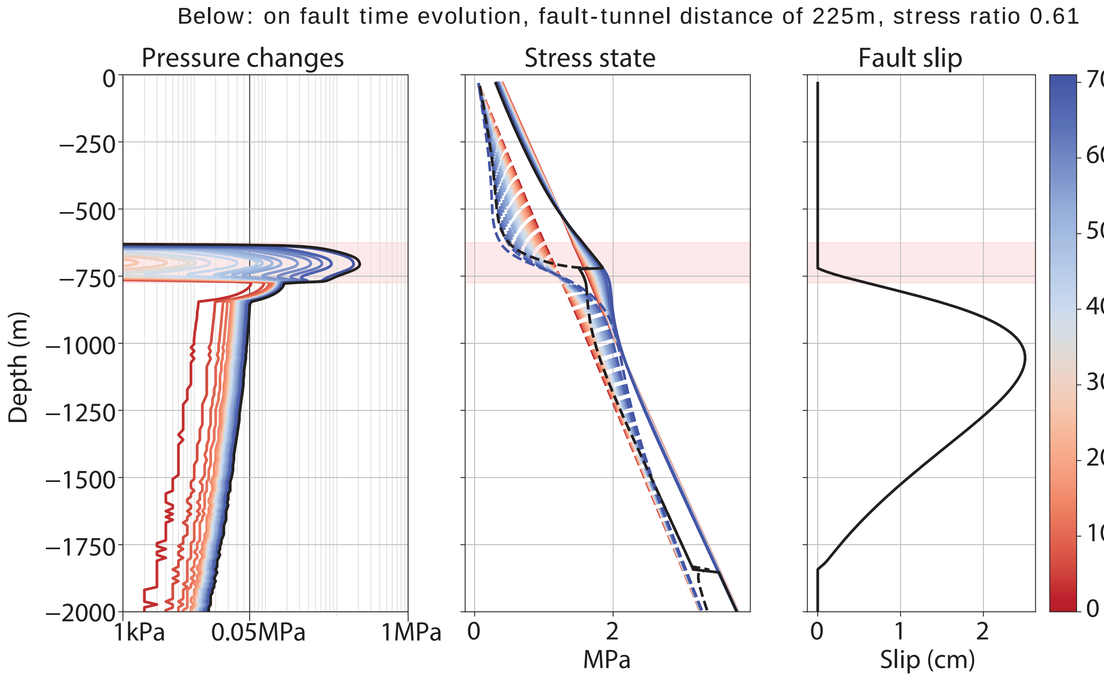
Results

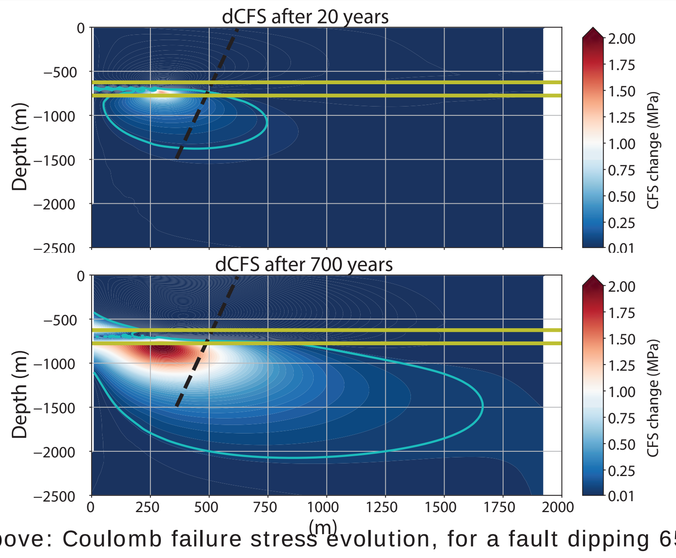
For the conditions considered in this study of nuclear waste disposal in a low permeability clay formation, the temperature increase imposed by the simulated heat releasing spent nuclear fuel contained in the canisters results in relevant changes in pore pressure(>1 MPa). The formation hosting the disposal site is heated, up to 10-40ºC, and pressurized, up to 1-5 MPa, during the first centuries of operation of the repository. The simulations showed how the combined stress transfer effect of thermoelastic and poroelastic stress change, with marginal contribution coming from the pore pressure diffusion, can create a nucleation patch of a seismic event on a fault located below the repository, outside the disposal formation. This lead to the possible reactivation of a fault located at a lateral distance from the outermost tunnel on the order of hundreds of meters (up to 500 meters), given a critical local stress ratio S_h/S_V (0.635 or less). Moreover, the simulations showed that reactivation is delayed with the increasing distance of the fault from the repository, but a delayed reactivation may rupture a slightly larger section of the weak structure, due to the thermal conduction resulting in a bigger volume of clay formation undergoing temperature changes. The thermoelastic and poroelastic response to temperature changes and thermal pressurization result then in an increased section of fault affected by a shear stress increase.



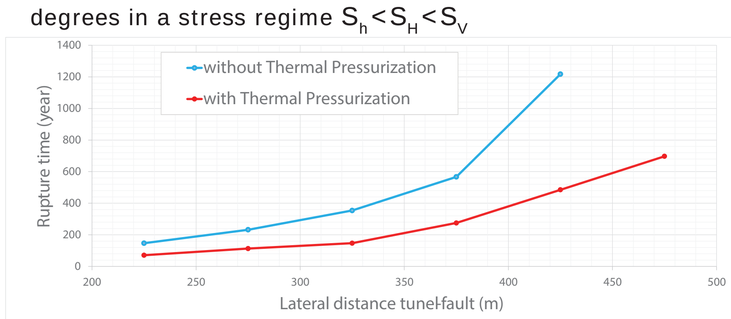
Above: time evolution of pressure and temperature

Below: on fault time evolution, fault-tunnel distance of 225m, stress ratio 0.61



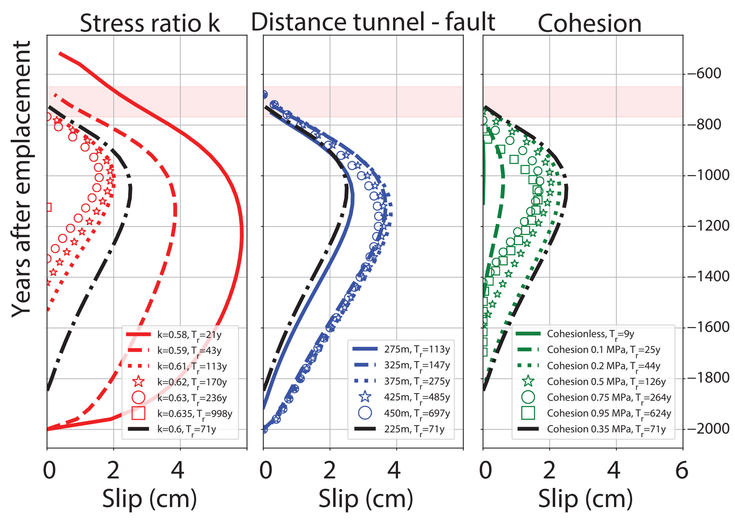


Above: Coulomb failure stress evolution, for a fault dipping 65 degrees in a stress regime $S_h < S_H < S_V$



Above: rupture time with and without thermal pressurization

Below: sensitivity of rupture on stress ratio, distance, cohesion



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corresponding author: luca.urpi@sed.ethz.ch

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All referenced reports are publicly available.