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How can accurate stress profiles help characterizing rock mass rheology at geological scales?

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While elastic behaviour can be sufficient to reproduce mechanical processes occurring in rock masses over short periods of time, it is usually quite unrealistic when tackling the modelling of geological phenomena involving very long time scales because, even at low temperatures, rocks exhibit a time-dependent behaviour. This long term response of the rock is reflected by a continuous deformation under constant load and by a progressive relief of the stresses even if any deformation of the material is prevented. Such properties are known to be of particular importance when dealing with tectonic processes. Characterizing these properties is difficult because they are out of reach of almost all laboratory or field testing methods, in view of the time scale involved.

To remedy this problem, we suggest using information contained in the stress profiles, since the current stress state within a rock mass is the response of the material to a series of past geological events. Thus, when the geological history is sufficiently simple, one may derive from stress profiles relevant pieces of information regarding the rheology of the considered rock mass at geological time and space scales.

This methodology was applied to the case of an almost non-fractured region, located in the Eastern Paris basin, in which detailed stress estimation was carried out and lead to a rather continuous stress profile through the considered rock mass, consisting of a hard-clay formation lying almost horizontally between two limestone units. From laboratory tests, hard-clays were known to have a visco-elastic behaviour that could be reproduced by a generalized Kelvin-Voigt model. The limestone rocks proved to have a nearly elastic behaviour at laboratory scale.

Assuming that the considered region was principally submitted to a combination of horizontal shortenings in two different directions and to erosion, we were able to reproduce the present state of stress by fitting the parameters of the constitutive law describing the hard-clay unit at geological scale. It also turned out that the limestone units should not behave in a purely elastic manner but should also have a significant viscosity over long time periods. We suggest that this property may be attributed to a pressure-solution creep (PSC) mechanism.

PSC is a widespread and essential mechanism of very slow rock deformation, whereby stresses acting on grains cause local dissolution of the material at grain contacts and transport of the solute toward the less-stressed porous space, where it precipitates. Until now, PSC was mainly studied by mean of indentation or powder-compaction tests, both of which are faced with the technical difficulty of being able to measure the resulting very low deformation rate. We believe that stress profile inversion may be a way to better characterize the macroscopic rheology corresponding to PSC, thus giving the opportunity to incorporate that process in further geological modelling.