3D evaluation of static and dynamic mechanical moduli in the Callovo-Oxfordian argillites

M. Adelinet[1], J. Fortin[2], M. H. Garcia[3], J. Espitalier[3], B. Yven[4]

1. IFPEN, France (mathilde.adelinet@ifpen.fr)
2. ENS, France (fortin@geologie.ens.fr)
3. KIDOVA, 155 avenue Roger Salengro, 92370 Chaville, France (michel.garcia@kidova.com)
4. ANDRA, France (Beatrice.Yven@andra.fr)

In the context of Cigeo facility project (industrial center for geological disposal), the 130 m thick Callovo-Oxfordian (COX) clay-rock formation has been thoroughly studied. A 250 km^2 area was investigated first, where well logging and coring were performed on many boreholes, then a restricted 30 km^2 area (called ZIRA: Zone of interest for further surveying), where a 3D high resolution seismic survey was carried out. The COX formation is a clay-rich layer located approximatively at a depth of 500 m and having key properties such as very low hydraulic conductivity, low diffusion coefficient, high self-sealing capacity and strong sorption capacity for radionuclides. From the bottom to the top of the COX, the layer is divided into five major petrophysical units: three argillaceous units (UA1, UA2, UA3), one transition unit (UT), and one silto-carbonated unit (USC). The UA2-UA3 units represent the mostly clayey levels of the formation where the deep disposal facilities will be built. From a mechanical behavior, previous studies show that these units have good properties to ensure construction and operation of a geological waste disposal. Here we propose to go further on this topic by evaluating the 3D distribution of static and dynamic mechanical moduli of Callovo-Oxfordian argillites in the ZIRA.

On the one hand, static moduli are obtained in the laboratory by stress-strain measurements. On the other hand, dynamic moduli are calculated from acoustic measurements that are made either on the field, or in the laboratory. In the framework of isotropic elasticity, we have two different methods to obtain two independent moduli (Young and Poisson for mechanic community or bulk and shear for geophysicists). If both methods are applied on a calibration sample of aluminum or glass, static and elastic moduli are the same. It is however quite never the case in rocks. This is due to the existence of flat heterogeneities in rocks, such as cracks or flattened pores. This effect is emphasized by the fluid content of rocks. The thermo-hydro-mechanical (THM) modeling of nuclear waste disposal requires to know the spatial variability of static moduli within the host rock. Inverted 3D seismic impedances are the only information available everywhere in the ZIRA. They can be used to calculate dynamic moduli that are representative of the scale of 3D seismic data. Equivalent static moduli must then be derived from them to be used as input to THM modeling.

A lot of empirical laws exist in the literature to relate static and dynamic moduli according to the rock type. Theoretical tools have also been developed to calculate static moduli from their dynamic equivalent. The proposed workflow combines two methods: effective medium modeling, to simulate dynamic moduli from micro and macro geological characteristics of the argillites, and Biot-Gassmann theory to derive static saturated moduli. Different models are required for units with different geological characteristics. The steps of the workflow can be summarized as follows:

1. Building of an effective medium model based on all geological data available for the COX argillites.
2. Inversion of the clay elastic moduli of the water-saturated effective medium model using the available well-logging data.
3. Direct modeling of drained (dry) moduli using the inversion parameters calculated at step 2.
4. Biot-Gassmann modeling to calculate undrained (saturated) moduli.
5. Comparison of drained and undrained moduli to static moduli measured in the laboratory to identify those that are more similar to static moduli (Figure 1).
6. Inference of bivariate distribution (histogram) models to relate undrained saturated moduli, estimated at the fine (log) scale, to dynamic moduli calculated in equivalent 3D seismic conditions along the boreholes (Figure 2.a).
7. Use of the bivariate distribution models to estimate local statistics on undrained saturated moduli everywhere within the ZIRA from dynamic moduli derived from 3D seismic impedance data that result from an elastic inversion made on 3D seismic prestack data (Figure 2.b).
8. Use of the statistical results of step 6 to estimate statistics on undrained saturated moduli for each unit.

Fine tuning of the effective medium model can be obtained by repeating steps 1 to 5 until the drained moduli, calculated at step 3 and that are closer to static moduli (Figure 1), best match the static moduli data measured in the laboratory. Especially, sensitive and QC tests is required to validate the inversion process results of step 2.

References:

Adelinet, M., Fortin, J., & Guéguen, Y. (2011) Dispersion of elastic moduli in a porous-cracked rock: Theoretical predictions for squirt-flow. Tectonophysics, 503(1), 173-181.

Adelinet, M., & Le Ravalec, M. (2015). Effective medium modeling: How to efficiently infer porosity from seismic data?. Interpretation, 3(4), SAC1-SAC7.

Garcia, M., A. Rabaute, B. Yven, D. Guillemot (2011), Multivariate and spatial statistical analysis of Callovo-Oxfordian physical properties from lab and borehole logs data: towards a characterization of lateral and vertical spatial trends in the Meuse/Haute-Marne Transposition Zone, *Phys. Chem. Earth*, Vol. 36, doi:10.1016/j.pce.2011.07.086.

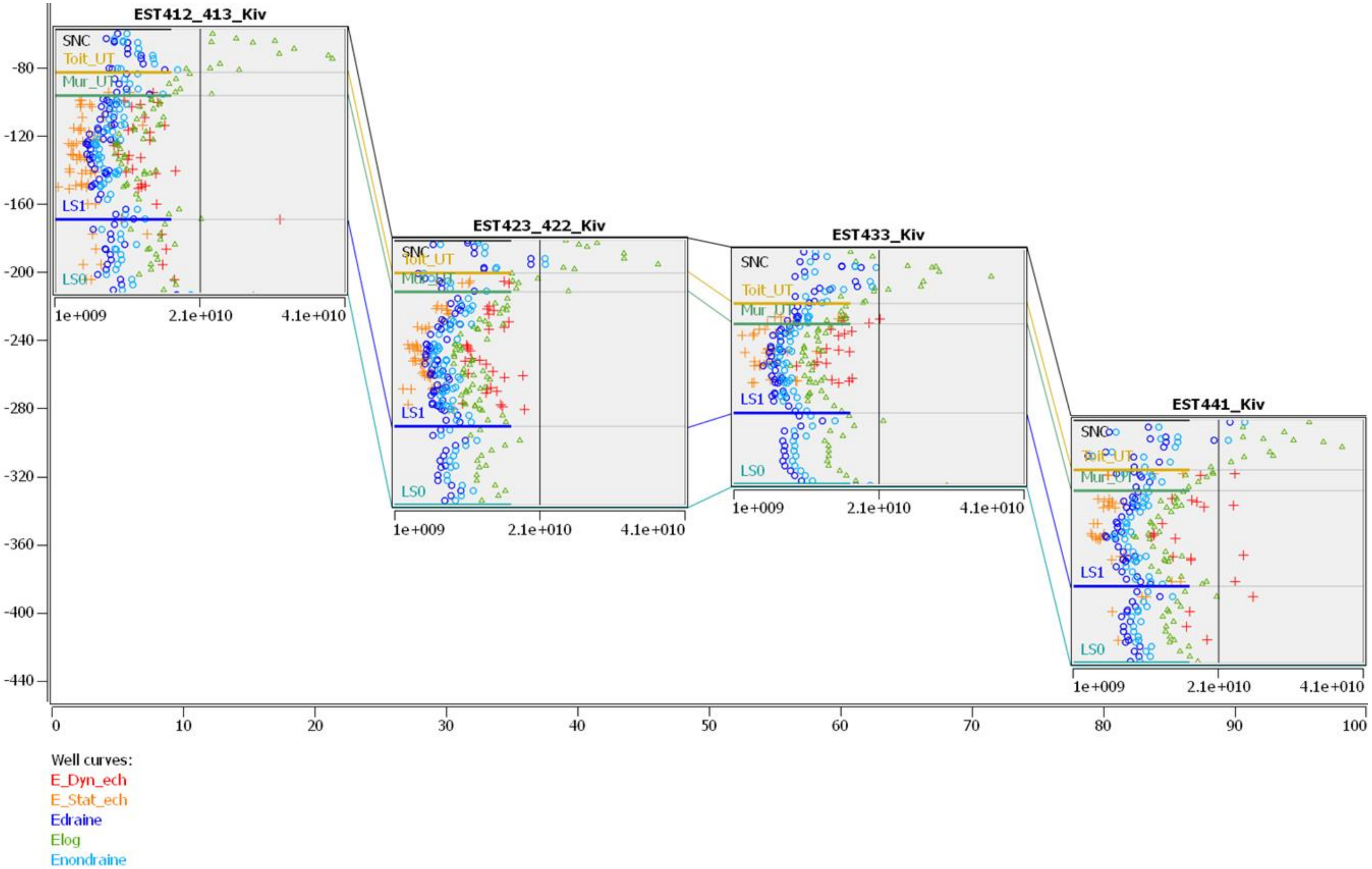
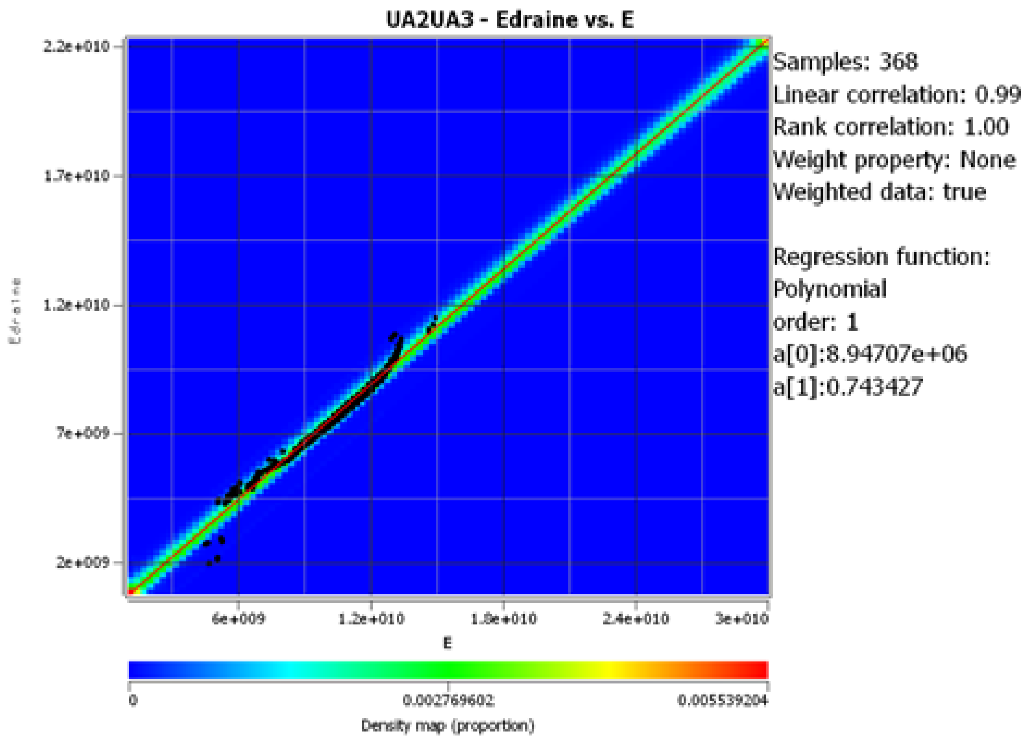
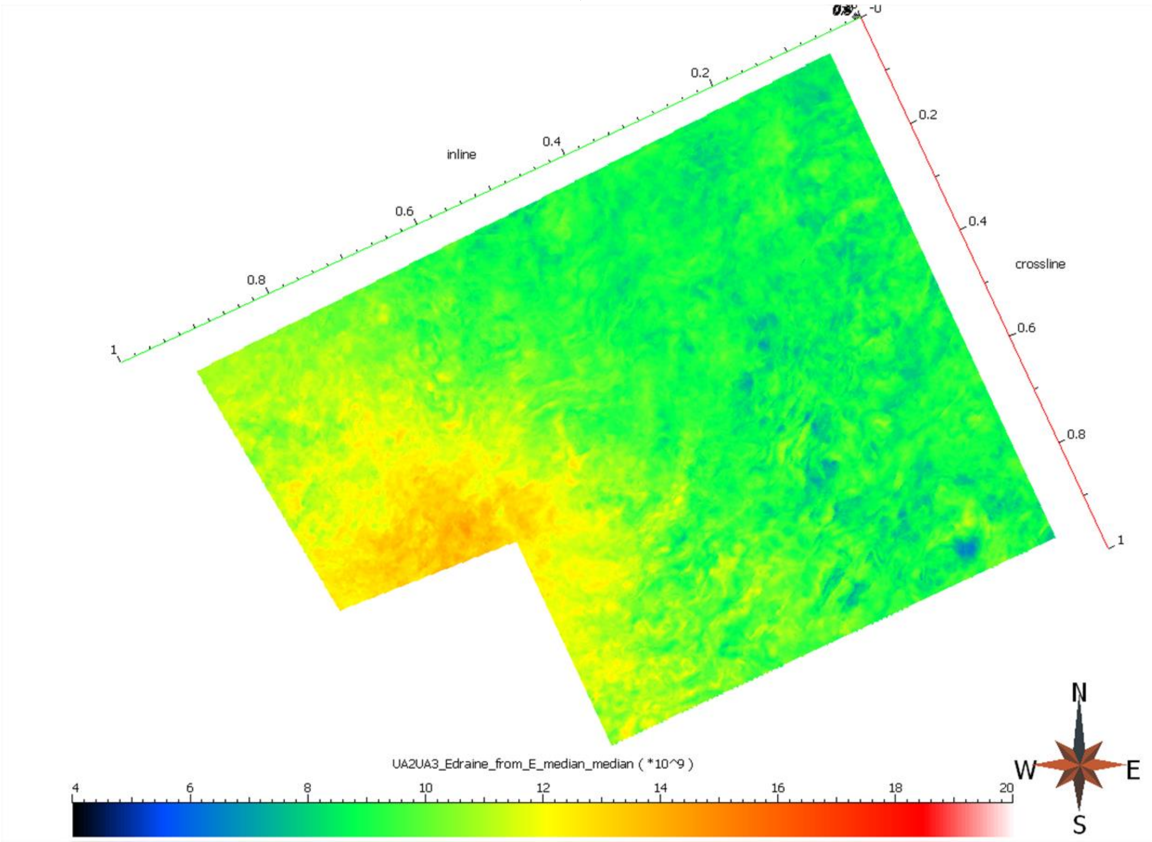


Figure 1 – Comparison of measured and calculated Young moduli along 4 boreholes located north from the ZIRA. Red and orange crosses: dynamic and static moduli measured in the laboratory. Green circles: dynamic moduli calculated from well-logging properties. Dark blue circles: drained moduli calculated with effective medium model. Light blue circles: drained moduli calculated with Biot-Gassmann model. The drained moduli appear closer to the static moduli, which make reference for THM modeling, but tend to be slightly higher.



a)



b)

Figure 2 – Use of dynamic Young modulus E, derived from 3D seismic data, to estimate local statistics on fine (log) scale drained Young modulus "Edraine" everywhere in the ZIRA. a) Bivariate distribution (histogram) model, estimated from well-logging data, showing a linear relationship between (fine-scale) drained Young modulus and dynamic Young modulus in 3D seismic conditions in units UA2/UA3. b) Map of the median of fine-scale drained Young modulus, vertically throughout units UA2/UA3, estimated from the bivariate distribution model and dynamic Young modulus data derived from 3D seismic impedances.