Modelling of the stress field: from regional to reservoir scale

Julie Maury[1] *, Théophile Guillon[1], Mariane Peter-Borie[1], Arnold Blaisonneau[1]

[1] BRGM, Orléans, France
* J.Maury@brgm.fr

Model presentation

Motivation

Because of its rifting setting, the Upper Rhine Graben (URG) shows great potential for implementing Enhanced/Engineered Geothermal Systems (EGS). Based on structural observations (GeORG team, 2013), a fault zone north of Vendenheim, among other structures, could be an interesting target. However, this first estimate must be validated prior to any drilling, and numerical simulations can provide arguments within this context. In this study, we focus on this first step by assessing the stresses around the fault, before any anthropic perturbation are added.

The URG is an intraplate area with low deformation (e.g. Nocquet, 2012). We have few information on the stress field at the local scale. To overcome this barrier, we model the stress field at the regional scale to get information at the reservoir scale. This regional model is validated by the few stress data available in this region.

Modelling of regional stresses deals with large dimensions (length of hundreds of kilometres). When such large scales are considered, the modelled rock masses are cut by major fault zones that affect the overall mechanical behaviour. Because these fault zones must be accounted for in the modelling (Yale, 2003), we choose to use a discrete fracture network approach in our model.

Model

The model geometry results from a structural analysis. With our discrete element approach, we must pay attention to the fault zone network. All fault zones cannot be included, and must be selected in terms of importance and assumed behaviour. Based on literature review, geophysical data and region-specific geological knowledge, a fault network is identified for the model (Guillon et al, 2016).

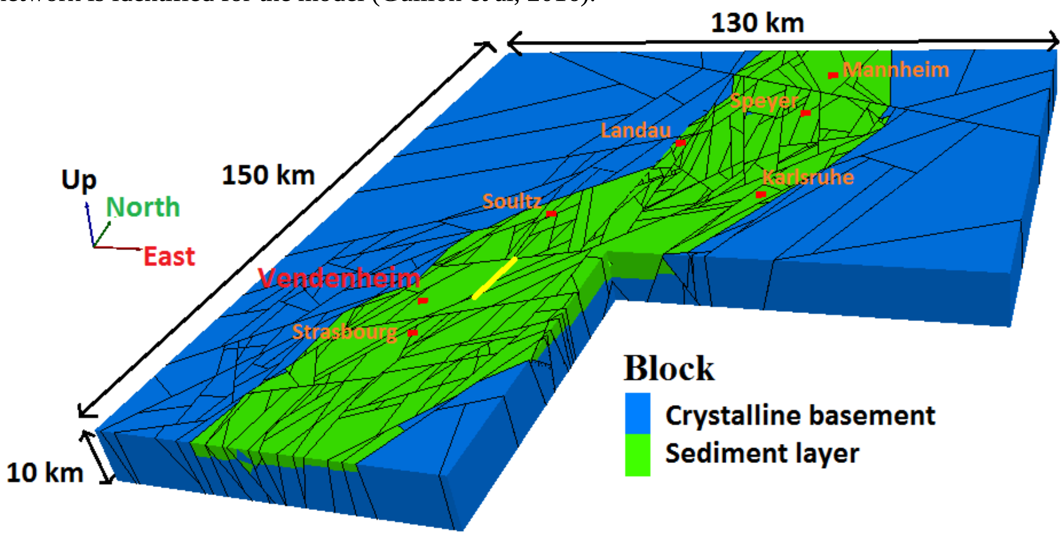

Fig. 1: 3D DFN geometry for the Upper Rhine Graben. The yellow line indicates the fault zone of interest. The red dots locate main cities. A portion of the model is not depicted to highlight its 3D extent.

We finally design a regional model of dimensions: 150*130*10 km^3. It takes into account faults, topography as well as basement-sediment interface. The faults are assumed to behave with a perfectly elastoplastic rheology associated with Coulomb criterion whereas the blocks are supposed to be elastic. Fig. 1 shows the geometry obtained in 3DEC™. Velocity boundary condition are applied, following Buchmann & Connolly (2007), that are in agreement with the low GPS velocity detected (Nocquet, 2012). Additionally, an initial state that considers the high horizontal to vertical stress ratio close to the surface (Sheorey, 1994) is implemented.

For the reservoir scale, we are focusing on one fault zone (Fig. 1) that, according to purely structural arguments, could be an interesting target for an EGS application. We consider the stress state at the local scale around this fault. We use results of the regional model to apply boundary conditions. Since both models are similar at the local scale (only the targeted fault varies in material), we extract the stress state from the regional model and apply it to the reservoir model as a boundary condition.

Results

Using a faulted model generates stress rotations that are visible even at the regional scale. This underscores the importance of getting boundary conditions from a regional model instead of directly applying “tectonic” boundary conditions. To assess the impact of these varying boundary conditions we compare our results with results obtained using a uniform boundary condition. The stress tensor determined at Soultz-sous-Forêt (Cornet et al, 2007) is chosen as a boundary condition because it is a well define stress measurement located only 10 km north of the upper boundary of the local model. We observe variations in the stress ratio as well as rotations of maximum horizontal stress directions (Fig. 2) between the two models. This rotation is especially notable in the northern part of the fault zone under investigation.

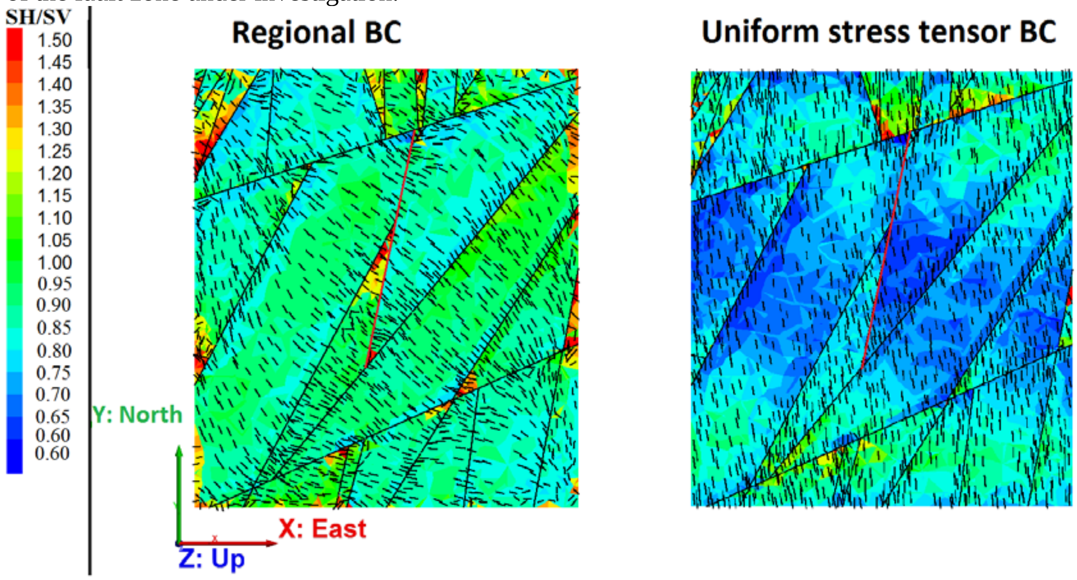

Fig. 2: Principal stresses results at 5000 m depth from the model with boundary conditions imported from the regional model (left) and from the model with uniform stress tensor boundary conditions (right). The vectors indicate maximum horizontal stress direction. The colours indicate the maximum horizontal stress over vertical stress ratio. The black lines indicate faults and the red line is the fault of interest.

The next step of this study is to quantify the impact of the estimated stress state on the fault potential of reactivation (e.g., opening, slip tendency…) and on the fault reactivation in itself (coupled response). At such a local scale, an additional factor must be considered: the fault internal geometry (e.g., Riedel system). The behavior of the fault zone in terms of slip and dilation tendencies presents some variations depending on the internal structure considered. However, we can confirm it should be closely investigated for EGS use.

References

Buchman, T. and Connolly, P. 2007. Contemporary kinematics of the Upper Rhine Graben: A 3D finite element approach, Global & Planetary Change 58, 287-309

Cornet, F.H. and Bérard TH. and Bourouis S. 2007. How close to failure is a granite rock mass at a 5 km depth?, Int. J. Rock Mec. & Min. Sci. 44, 47-66

GeORG team (2013): Geopotentials of the deep Upper Rhine Graben. Interreg Project GeORG scientific and technical report, online PDF (http://www.geopotenziale.eu), 1-4

Guillon, T. and Peter-Borie, M. and Gentier, S. and Blaisonneau, A. 2016. Regional stress distribution to help with locating exploration areas. In European Geothermal Congress: EGC 2016

Nocquet, J.M. 2012. Present-day kinematics of the Mediterranean: A comprehensive overview of gps results. Tectonophysics 579, 220-242

Sheorey P.R. 1994. A theory for In Situ stresses in isotropic and transversely isotropic rock. Int. J. Rock Mech. Min. Sci. & Geomech. Abstr. 31, 23-34

Yale, D. 2003. Fault and stress magnitude controls on variations in the orientation of in situ stress, Geological Society Special Publications 209, 55-64