Three-scale multiphysics framework modelling fault reactivation

Martin Lesueur[1,2,3] *, Manolis Veveakis[3,1], Thomas Poulet[2,1]

[1] University of New South Wales, Sydney, Australia
[2] CSIRO Mineral Resources, Perth, Australia
[3] Duke University, Durham, United States of America
* m.lesueur@unsw.edu.au

In petroleum engineering, fluid production in reservoirs can induce stress changes large enough in the vicinity of nearby dormant faults to reactivate them. Interestingly in some cases, this event can be followed by pressure equilibration between the two compartments delimited by an a priori impermeable fault, see Fig. 1.

In the particular example of a carbonate reservoir rock under specific conditions (relatively high temperature and pressure), the shear-heating of a creeping fault can activate the dissolution of the rock, producing excess pore pressure, lubricating the fault and causing its reactivation, along with a large increase of permeability (by orders of magnitude) allowing the fault to become a potential flow channel.

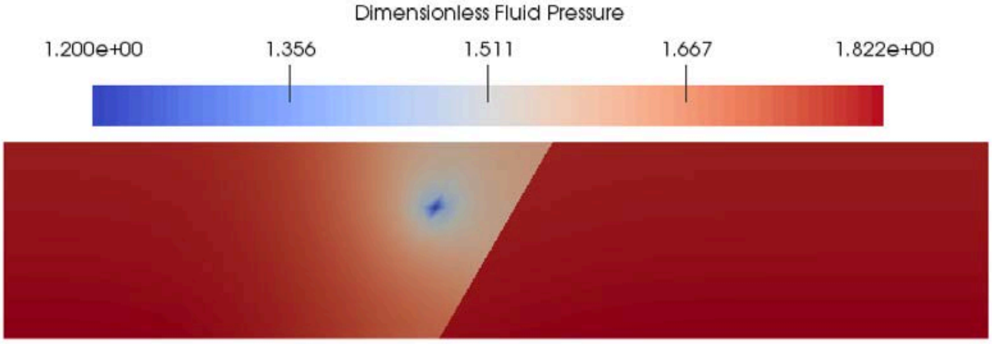
In this contribution, we present a numerical simulator implementing a THMC reactivation model (Alevizos et al. 2014), illustrated on Fig. 2, that encompasses all the necessary physics driving the fault reactivation phenomenon. The numerical framework links the three different scales of the problem: the reservoir (km) scale, the fault at the meso-scale (m) and its pore structure at the micro-scale (μm), where the meso-scale is selected as the master in this framework. This type of modelling allows to reduce the common use of empirical laws to the profit of upscaled physical laws.

The mechanical forces applied to the fault are given by the macro-scale simulation. The thickness of the fault at this scale is neglected and represented by a hydro-mechanical interface law. At the reservoir scale we solve for poromechanics coupled with Darcy's law and the stress state of the fault is evolving from fluid pressure changes due to a well production or injection.

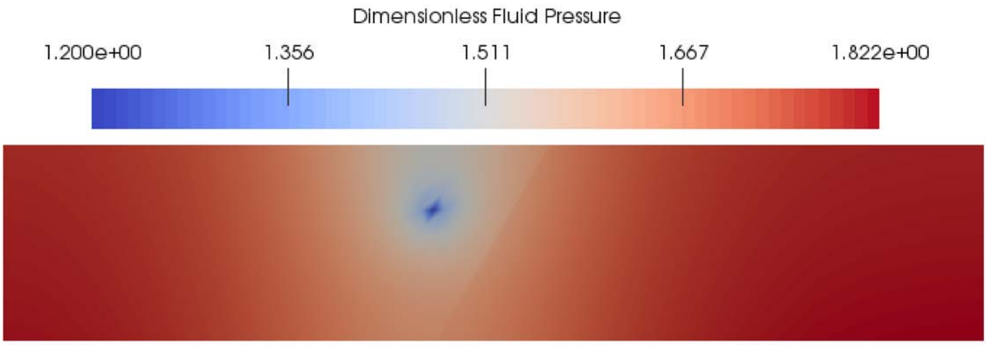
Permeability is one of the key material property driving the reactivation process. It dictates the amount of fluid transferred from one side of the fault to the other and is therefore crucial to account for in petroleum engineering. The fault's permeability is directly upscaled from the deformation of its porous micro-structure. This process being dominated by chemical dissolution, we implement at the micro-scale a chemical erosion algorithm applied on meshes reconstructed from CT-scan images (Lesueur et al. 2017), see Fig. 3. The permeability can then be upscaled from solving Stokes flow in the dissolved pores.

This finite element framework uses the REDBACK (Rock mEchanics with Dissipative feedBACKs) module built on MOOSE (Multiphysics Object Oriented Simulation Environment), linking the scales through the numerical *multiapp* feature of MOOSE.

We illustrate the capabilities of the framework by solving for the case of fluid invasion in the reservoir, leading to the problematic early water breakthrough at the production well. We demonstrate the possibility of quantifying the leakage with such a framework.

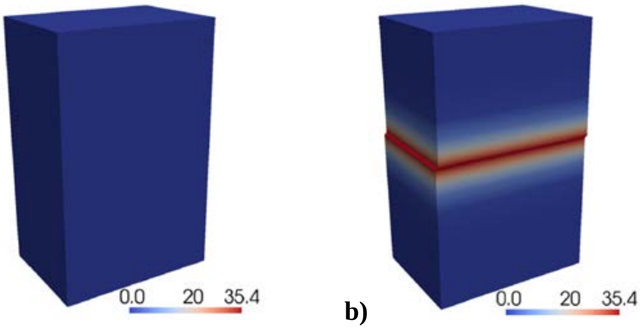


a)



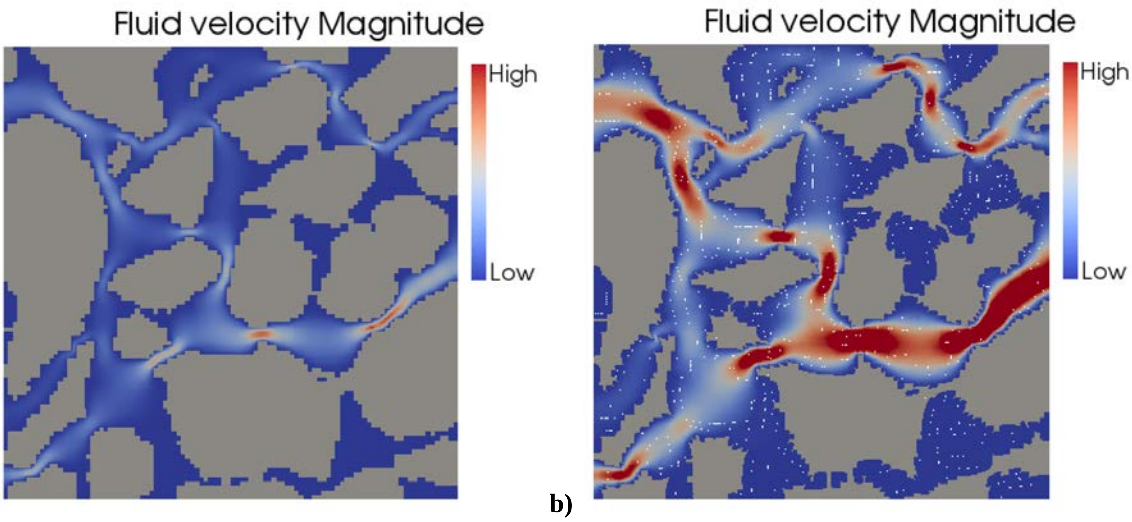
b)

Fig. 1: Reservoir separated by a fault in the middle. Evolution of pressure at the macro-scale before (a) and after (b) permeability increase from fault reactivation, due to pressure depletion from production on the left side of the fault



a) b)

Fig. 2: Evolution of temperature and displacement before (a) and after (b) reactivating the fault at the meso-scale, modified from (Poulet et al. 2017)



a) b)

Fig. 3: Hydro-chemical simulation on meshed CT-scan (Imperial College Consortium on Pore-scale Modelling, 2014) images. Visualisation of flow increase at the micro-scale after dissolution of the pores (b), due to fault reactivation. Case (a) for reference

References

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