Geomechanical Forward Modeling for Prediction of Sub-Seismic Deformation in Traps and Seals: a Numerical Case Study of Normal Fault Relay Zones in Layered Rocks

Rajesh Goteti[1], Gautam Mitra[2], Susan M. Agar[1], and Rainer Zuhlke[3]

[1]Geology Technology, Aramco Research Center - Houston , Houston, TX, United States.
[2]Dept, EES, University of Rochester, Rochester, NY, United States.
[3]Saudi Arabian Oil Company, Dhahran, Saudi Arabia.

ABSTRACT

Structural geologists commonly rely on geometric, kinematic and stochastic techniques for predicting likely locations of sub-seismic fractures and faults and their likely impact on hydrocarbon recovery. However, the impacts of mechanical stratigraphy and geological loading history, on the likely orientations of sub-seismic structures, cannot be assessed using such techniques alone. We propose that geomechanical forward models that take into account realistic material properties can complement kinematic techniques in predicting such sub-seismic structures. We present three dimensional elastic-plastic finite element models of antithetic convergent relay zones between echelon rift-scale normal faults with particular focus on the impact of mechanical stratigraphy on the orientations of secondary structures within the relay zones. The models comprise two layers - a weak sedimentary layer (‘basin fill’) overlying a relatively competent granitic layer (‘basement’). The models use frictional listric fault surfaces, isotropic elastic-plastic material properties and displacement-based boundary conditions. The model results suggest that mechanical stratigraphy exerts significant control on both the magnitude and orientations of strains in the relay zone. Outside the relay zone, the strains in both the layers are parallel to the imposed regional extension. However inside the relay zone, the strain field is oblique with respect to the regional extension direction. The strain orientations vary in a continuous manner with depth, when the layer interfaces are bonded. When the interfaces have finite friction and flexural slip is permitted, the maximum extensional strain orientation changes abruptly across the layer interface. For a given value of interface friction, this refraction in strain is directly proportional to the competence contrast between the two layers. From the standpoint of energy consumed during deformation, occurrence of multiple, slipping layer interfaces within a heterolithic column, is more favorable than having bonded interfaces. Insights such as those noted above, when combined with traditional kinematic analyses of structures, can support improved characterization of sub-seismic deformation. Rigorous uncertainty analysis on the primary model inputs (material properties and boundary conditions) can be used to further complement quantitative risking of structural traps and seals using mechanistic models.