Outcrop-based Geomechanical Fracture Aperture and Flow Modelling: The Importance of Shear on Flow

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ABSTRACT

Outcrop analog studies of fractured reservoirs provide the 3-D geometry of fracture systems that cannot be fully obtained in the subsurface, as outcrops provide the full fracture size, spacing and orientation distributions. Modeling of fluid flow through large, high-resolution outcropping fracture networks may provide a better understanding of the fluid flow patterns encountered in subsurface analog reservoirs, as the relation between fracture geometry (e.g. length, density) and subse-quent flow can be studied in detail.

Finding an accurate aperture distribution model for these out-cropping fractures is, however, a challenge. Generally, only burial-related veins are considered to give an accurate de-scription of pre-exhumation fracture aperture, whereas the majority of outcropping fractures generally consists of barren fractures, whose apertures are not representative of pre-exhumation conditions. In terms of subsurface stresses, which have a significant impact on fracture aperture and flow, veins only record information for one stress situation. The relation between geomechanical reservoir conditions and subsequent aperture is poorly understood.

Alternatively, fracture aperture can be modelled as a function of principle stresses using geomechanical numerical models, for which we apply an empirical fracture aperture model (e.g. Olsson and Barton, 2001). This model predicts both mechani-cal and hydraulic fracture aperture under compression taking into account normal and shear displacement along the frac-tures. The aperture normal to the fracture is a function of ini-tial fracture roughness, strength and normal stress acting on the fracture, while a shear opening component is defined us-ing the shear displacement.

We incorporate this fracture aperture model into geomechani-cal Finite-Element models of large 2-D outcropping fracture pavements. We calculate fracture aperture in these complex fracture systems as a function of different reservoir condi-tions, including a wide range of rock properties and principle stress magnitudes. The resulting models consist of complex deterministic fracture patterns with heterogeneous hydraulic fracture aperture distributions. These are then used as input for fluid flow modeling, using a hybrid Finite-Element Finite-Volume approach (e.g. Matthäi et al., 2009).

By quantifying the results in terms of effective permeability, which captures the combined impact of fracture and matrix flow, we obtain a direct relation between geomechanical reser-voir conditions and the resulting permeabilities (e.g. Nick et al., 2011) . Both variations in reservoir conditions as well as small variations in the fracture network geometry have a strong impact on the resulting effective permeability. Most notably, the orientation of the fractures with respect to the main direction of compression has a strong impact on aper-ture and subsequent

fracture permeability. Fractures oblique to compression have the largest aperture, which results from shear displacement along irregular fracture planes.