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3-D Channeling Flow through Rock Fracture Networks in Field-scale

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Rock fractures are recognized as the predominant pathways of fluid in the Earth's crust, because fractures usually have much greater permeability than the matrix permeability. Fluid flow through rock fractures is characterized by formation of preferential flow path (i.e. channeling flow) due to the heterogeneous aperture distribution created by the rough surfaces contacting, in part, each other.

In understanding the fluid migration within Earth's crust, discrete fracture network (DFN) model is one of the most powerful techniques to incorporate geometrical properties in fractures (fracture size, location, orientation, and density), and can account explicitly for the contribution of individual fractures on fluid flow. However, in the conventional DFN models, individual fractures were characterized by a single aperture value despite the fact that the real fractures had heterogeneous aperture distributions, and as a result the formation of 3-D preferential flow paths thorough fracture network were neglected. Therefore, the authors have developed GeoFlow, a novel DFN model simulator, where fractures are characterized by aperture distribution [Ishibashi et al., 2012]. In order to utilize GeoFlow for a field scale problems, the authors also developed a prediction method of fluid flow within multi-scaled fractures under confining stress [Ishibashi et al., 2012].

In the present study, we challenged to construct the precise fracture network with heterogeneous aperture distribution in field-scale. The Yufutsu oil/gas field in Hokkaido, Japan is well known as fractured type of reservoir, and selected as the subject for study. This is because reliable DFN models can be developed based on 3-D seismic data, acoustic emission data, in-situ stress measurement, and well logging for this field [Tamagawa et al., 2010]. The modeling domain is 1,050 (East-West) x 1,050 (North-South) x 1,050 (Depth) m3, and fractures are represented by squares of 50-390 m on a side. Aperture distributions are numerically determined by contacting a pair of fractal fracture surfaces to have the lab-scale non-scale-dependent contact area, and considered for the critically stressed fractures, which have high permeability due to shear dilation. Constructed DFN models are, then, converted into equivalent permeability continua that reflected contributions of both the matrix and fracture permeabilities. For the equivalent permeability continua, steady-state laminar flow of a viscous, incompressible fluid is simulated by GeoFlow under the unidirectional flow geometry.

The simulation results by GeoFlow show that the localization of flow paths in the fracture networks is much more remarkable than that simulated by conventional DFN models due to the 3-D channeling flow. Subsequently, percentage of total area of flow paths to total area of the fracture plane (flow area) is calculated for quantitative evaluation of flow path localization. As a result, the actual flow area is estimated to be around 20-50% of the flow area predicted by conventional DFN models. This finding implicates the followings: the reactive fields where water-rock interaction takes place are limited to narrower area than predicted by conventional DFN models, or 3-D channeling flow have a significant impact on well productivity of fractured type of reservoirs. In understanding the reality of the fluid migration within Earth's crust, 3-D channeling flow is one of the key phenomenon, and the suggested method in this presentation enables us to address this phenomenon.

Keywords: rock fracture, network model, channeling flow, heterogeneous aperture distribution, field-scale