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Correlation lengths of fracture networks, and consequences for flow modeling

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Fractures are still an issue for groundwater flow modeling and the main reason is spatial correlation, which can be huge and makes most homogenized models irrelevant. The paper deals with impervious rocks where the flow takes place solely in fractures. Its objective is to review what is actually known about correlation lengths in fracture networks, and what could be the consequences for both flow modeling and observations.

Apart from connectivity effects, fracture size is the basic correlation length for these systems, which put emphasis on the fracture-length distribution as the main control of flow organization. This distribution was found to be adequately modeled by a power law, which render the trivial observation that fractures exist everywhere and at all sizes. The power-law exponent, the universality of the power-law model, the bounds of this distribution model remain however issues that require an exhaustive mapping of fractures over a large range of scales. We get new insight into these critical measures by analyzing the fracture data obtained by the Swedish company SKB, which is in charge of developing deep hard rock sites for nuclear waste disposal. To our knowledge, this is the most complete fracture database that ever exists in the literature, and certainly the most appropriate for testing the scaling model. Power-law scaling was demonstrated from 10 cm (borehole scale) up to 10 M (largest mapped outcrop) with exponents that was found to take only a few distinct values (two actually). One of them corresponds to self-similar patterns, where fracture networks look similarly whatever the scale. The other one is larger, meaning that, in a given system, the number of fractures equal or larger than the system size L increases with L. Scales in the range

10m – 1 km, which are typical of hydrogeological sites, cannot be resolved with this database, and no simple extrapolation can be proposed to fill the gap between outcrops and large-scale tectonic fractures. We also explore other aspects of fracture correlation patterns, such as surface effects (fracturing is likely to increase near the topographic surface), variability of the fracture distribution models, spatial correlation, and more.

Consequences in terms of connectivity are derived from statistical simulations. There are two distinguishable connectivity models: the first corresponds to the classical percolation theory, for which the connected backbone is much larger than individual fractures; in the second, connectivity is mainly ensured by the largest fracture in the system, and the percolation threshold is given by the probability to have such a large fracture. Interestingly the self-similar model just lies in between both end-members. We describe the connectivity properties that apply to observed fracture length distributions, and finally discuss the consequences of these observations and models in terms of flow organization and expected scaling dependency of flow parameters (permeability, dispersivity . . .).