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Depth-dependent Clustering Analysis of Fractures in Crystalline Basement Rocks

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Understanding the complex seismic, thermal, hydraulic and mechanical processes active during the hydraulic stimulation or continuous operation of Enhanced Geothermal Systems (EGS) requires an accurate description of the pre-existing fractures and faults. However, the three-dimensional characterization of the fracture network is challenging, as direct observation of the discontinuity network at great depth is limited. Fracture image logs and continuous core, which provide line samples through the fracture network, are most valuable in this regard as they provide the most precise option to place constraints on network attributes in stochastic realizations of the fractured rock mass. Among various geometrical attributes, the spatial clustering of fractures plays a critical role on the rock mass properties.

Here, we analyzed the spatial distribution of fractures derived from image log runs in six deep boreholes in crystalline basement rock. In one well, the fracture distribution from continuous core was also available. The wells were drilled to depths between 2-5 km, and were all located in the same tectonic setting of the Upper Rhine Graben, which is recognized for its high geothermal potential. The normalized correlation integral method was employed to define the scaling relationships of fracture patterns. This methodology is demonstrated to be less affected by the finite size effects, delivering reliable estimates of scaling laws.

Detailed analyses of image log datasets revealed fractal scaling with similar fractal dimensions (between 0.85 and 0.96), prevailed over almost two orders of magnitude of scale. The same was true for the fracture distribution derived from the continuous core, although this distribution was found to be more clustered than that derived from image logs in the same well (i.e. the fractal dimension was lower, which may be due to the partial fracture sampling of image logs which have a coarser resolution than continuous core analyses). Analysis of fractures in sub-sections of the core dataset from progressively increasing depths revealed no systematic depth-dependency for the fractal dimension, although a local variation at a scale of hundreds of meters was identified.