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On the multiscale quantification of fracture network geometry from lineament maps of crystalline basement units

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Fractured crystalline basement units are attracting increasing attention as potential unconventional reservoirs for natural (oil, heat and water) resources and as potential waste (nuclear, CO_2) disposal sites. The focus of the current efforts is the characterisation of the structural permeability of fractured crystalline basement units, which is primarily related to the geology, geometry, and spatial characteristics of fracture networks. Fracture network properties may be scale–dependent or independent. Thus, a multi–scale characterisation of fracture networks is usually recommended to quantify the scale–variability of properties and, eventually, the related predictive scaling laws. Fracture lineament maps are schematic representations of fracture distributions obtained from either manual or automated interpretation of 2D digital models of the earth surface at different scales. From the quantitative analysis on fracture lineament maps, we can retrieve invaluable information on the scale–dependence of fracture network properties.

Here we present the results of the quantification of fracture network and fracture set properties (orientation, length, spacing, spatial organisation) from multi– (outcrop to regional) scale 2D lineament maps of two crystalline basement study areas of Western Norway (Bømlo island and Kråkenes). Lineament maps were obtained from the manual interpretation of orthophotos and 2D digital terrain models retrieved from UAV–drone and LiDAR surveys.

Analyses aimed at the quantification of: (i) scaling laws for fracture length cumulative distributions, defined through a statistically–robust fitting method (Maximum Likelihood Estimations coupled with Kolmogorov–Smirnov tests); (ii) variability of orientation sets as a function of scale; (iii) spatial organisation of fracture sets among scales; (iv) fractal characteristics of fracture networks (fractal exponent). Results suggest that: (i) a statistical analysis considering variable censoring and truncation effects allows to confidently define the best–fitting scaling laws; (ii) the analysis of orientation variability of fracture sets among different scales may provide important constraints about the geometrical complexity of fracture and fault zones; (iii) the statistical analysis of 2D spacing variability and fracture intensity can be adopted to quantify fracture spatial organisation at different scales.

A statistically robust analysis of the scaling laws, length distributions, spacing, and spatial organisation of lineaments on 2D maps provides reliable results also where only partial or incomplete dataset/lineament maps are available. Such properties are the fundamental input parameters for conceptual (geologic) and numerical (discrete fracture network, DFN) models of fractured crystalline basement reservoirs. Therefore, a statistically robust analysis of fracture lineament maps may help to improve the accuracy of conceptual and numerical models.