Fault density scaling in the East Pennines Coalfield

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Coal mineplan data from the Carboniferous East Pennine Coalfield (EPC) have been used to construct a high quality 1000 km^2 fault map which permits examination of a broader range of fault scaling properties than is generally possible. The map contains over 8000 faults, with throws in the range of < 1m to 200m, and a lateral resolution of ca 10m. Fault density within domains down to 0.025 km^2 have been examined, to establish the spatial and scaling properties of the faults, and of fault-controlled permeability reductions, at scales down to the flow-simulator grid-block.

The spatial characteristics of the system have been analysed using a range of fractal and multi-fractal methods, none of which are capable of discriminating adequately between the EPC fault system and similar synthetic fault systems that possess random spatial properties. Instead, we examine the scaling of two, dimensionless, fault density terms; line density ($f(\text{Length})^2$) which is a measure of fault-trace density and connectivity, and throw density ($f(\text{Length} * \text{Throw})$) which is a measure of tectonic strain. These show that the EPC fault system is better connected, more clustered and shows more heterogeneous strain distributions than an equivalent synthetic fault system. Strain is localised onto more discrete, laterally continuous faults within the EPC fault system and there is an increase in the degree of strain localisation at increasingly larger scales. Fault connectivity and strain do not, therefore, correlate well, with NW-striking faults localising more displacement and strain, but without higher fault-trace densities, than NE-striking faults (Figure 1).

Line density and throw density calculated within each sub-domain can be used, in combination with fault and matrix permeability values and coefficients relating fault displacement to fault thickness, to establish flow tortuosity and transmissibility terms respectively (Figure 2). These terms can then be combined to estimate the scale-specific permeability of the sub-domains (Figure 3). The ultimate aim of this approach is to characterise the spatial and scaling properties of the fault-related permeability fields themselves. The geological detail required to construct high resolution fault maps encompassing both fault length and displacement, over a wide scale-range is seldom available. However, a characterisation of the scale-specific permeability fields derived from high resolution datasets such as the EPC fault map will allow permeability fields to be estimated at relevant scales, thereby short-circuiting the problematic step of stochastic fault modelling.

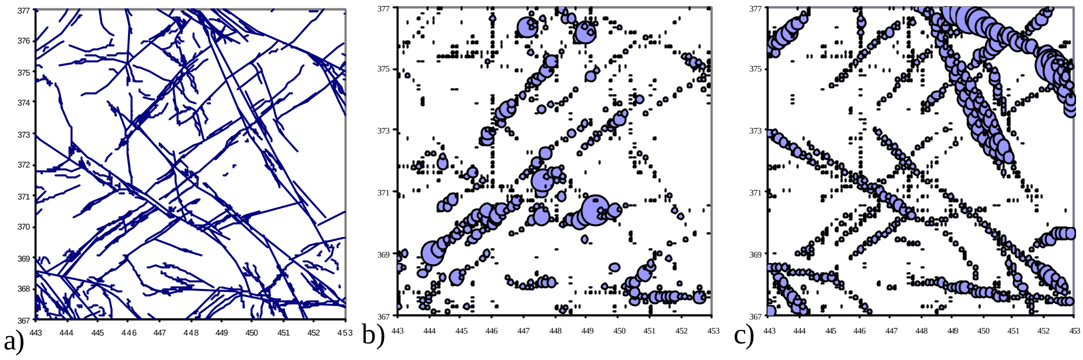

Figure 1. a) Fault trace map for a 100 km^2 region of the 1000 km^2 East Pennines Coalfield fault map. b) Line density and c) throw density calculated within 4096 sub-domains.

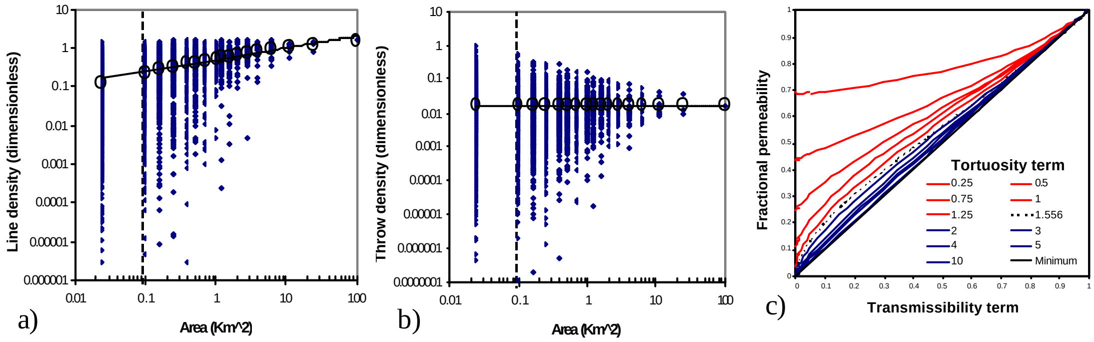

Figure 2. a) Line density, and b) throw density, at different scales for the area shown in Figure 1. Lines and larger circles are the means at each scale. c) Fractional permeability (equivalent permeability / matrix permeability) as a function of tortuosity and transmissibility terms, which are calculated from line density and throw density respectively.

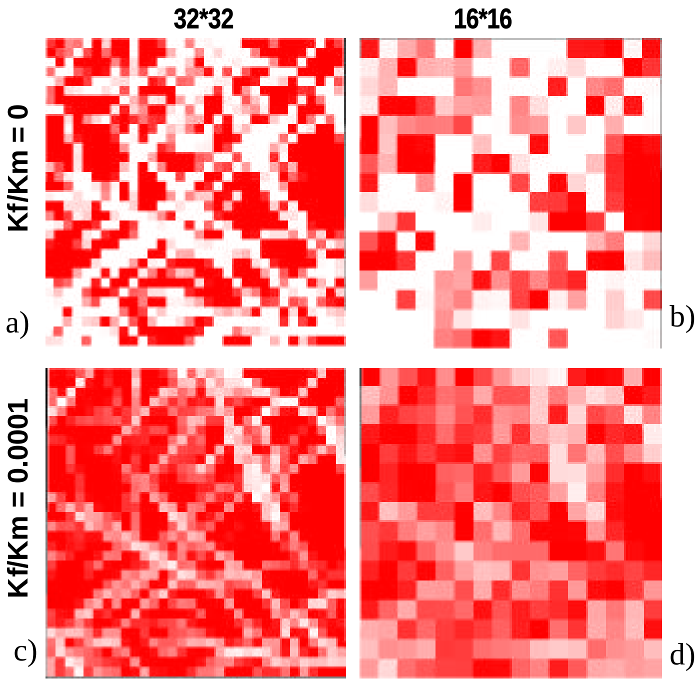

Figure 3. Fractional permeability at two resolutions, assuming impermeable faults (a,b) and faults four orders of magnitude less permeable than the matrix (c,d). Fractional permeability in each block ranges from 0 (white) to 1 (grey).