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Quantifying rock's structural fabric: a multi-scale hierarchical approach to natural fracture systems and stochastic modelling

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We propose the description of fracture-fault systems in terms of a multi-scale hierarchical network. In most generic form, such arrangement is referred to as a structural fabric and applicable across the length scale spectrum. The statistical characterisation combines the fracture length and orientation distributions and intersection-termination relationships. The aim is a parameterised description of the network that serves as input in stochastic network simulations that should reproduce the essence of natural fracture networks and encompass its variability. The quality of the stochastically generated fabric is determined by comparison with deterministic descriptions on which the model parameterisation is based. Both the deterministic and stochastic derived fracture network description can serve as input in fluid flow or mechanical simulations that accounts explicitly for the discrete features and the response of the system can be compared. The deterministic description of our current study in the framework of tight gas reservoirs is obtained from coastal pavements that expose a horizontal slice through a fracture-fault network system in fine grained sediments in Yorkshire, UK. Fracture hierarchies have often been described at one observation scale as a two-tier hierarchy in terms of 1st order systematic joints and 2nd order cross-joints. New in our description is the bridging between km-sized faults with notable displacement down to sub-meter scale shear and opening mode fractures. This study utilized a drone to obtain cm-resolution imagery of pavements from ~30m altitude and the large coverage up to 1-km by flying at a ~80m. This unique set of images forms the basis for the digitizing of the fracture-fault pattern and helped determining the nested nature of the network as well as intersection and abutment relationships. Fracture sets were defined from the highest to lowest hierarchical order and probability density functions were defined for the length, orientation, chance of abutment and distance of separation in case of disconnectivity. The hierarchical subset defines the order in which the placement algorithm builds the network according to different topological rules and the assigned pdfs. The simulation starts by adding fractures of the highest order in a 2D domain according to certain placement rules and length and orientation pdfs until it reaches the prescribed fracture intensity. The stochastic placement of new fractures alternates between sets of the same hierarchical order until the fracture intensity reaches the defined limit. The fractures of the successively lower orders are placed according to the nested topological rules such that fractures terminate at, intersect with or have a dis-joint distance relative the higher order fractures. In addition to the simulations based on high-resolution imagery, we also attempted to reproduce the fault network for a Southern North Sea case area in the Broad Fourteens Basin, in the Dutch offshore sector. Our study shows that the resulting network more closely resembles the deterministic one because it acknowledges the topological arrangement of natural network better than commonplace stochastic network models.