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An Integrated Tensorial Approach for Quantifying Porous, Fractured Rocks

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The patterns of fractures in deformed rocks are rarely uniform or random. Fracture orientations, sizes, shapes and spatial distributions often exhibit some kind of order. In detail, there may be relationships among the different fracture attributes e.g. small fractures dominated by one orientation, and larger fractures by another. These relationships are important because the mechanical (e.g. strength, anisotropy) and transport (e.g. fluids, heat) properties of rock depend on these fracture patterns and fracture attributes. Based on previously published work (Oda, Cowin, Sayers & Kachanov) this presentation describes an integrated tensorial approach to quantifying fracture networks and predicting the key properties of fractured rock: permeability and elasticity (and in turn, seismic velocities). Each of these properties can be represented as tensors, and these entities capture the essential 'directionality', or anisotropy of the property. In structural geology, we are familiar with using tensors for stress and strain, where these concepts incorporate volume averaging of many forces (in the case of the stress tensor), or many displacements (for the strain tensor), to produce more tractable and more computationally efficient quantities. It is conceptually attractive to formulate both the structure (the fracture network) and the structure-dependent properties (permeability, elasticity) in a consistent way with tensors of 2nd and 4th rank, as appropriate.

Examples are provided to highlight the interdependence of the property tensors with the geometry of the fracture network. The fabric tensor (or orientation tensor of Scheidegger, Woodcock) describes the orientation distribution of fractures in the network. The crack tensor combines the fabric tensor (orientation distribution) with information about the fracture density and fracture size distribution. Changes to the fracture network, manifested in the values of the fabric and crack tensors, translate into changes in predicted permeability and elasticity (seismic velocity). Conversely, this implies that measured changes in any of the in situ properties or responses in the subsurface (e.g. permeability, seismic velocity) could be used to predict, or at least constrain, the fracture network. Explicitly linking the fracture network geometry to the permeability and elasticity (seismic velocity) through a tensorial formulation provides an exciting and efficient alternative to existing approaches.