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Topological Mapping of SMTI Derived Fractures to Identify Percolation

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Summary

Hydraulic fracture stimulations generally result in microseismicity that is associated with the activation of pre-existing fractures or in the generation of new fractures. Typically, the event distribution provides a sense of where fracturing is occurring and the extent of fracturing away from the treatment zone. However, two fracture systems could contain the same geometrical elements in terms of fracture numbers, orientations and fracture lengths, but have very different topologies. In other words, without considering the interconnectivity and the types of connections, it is difficult to characterize the permeability of the network. The importance of this cannot be understated as this leads to an assessment of percolation and the potential for outlining the associated drainage both volumetrically and in time.

To consider fracture network topology, a multi-array, multi-well distribution of sensors surrounding the volume of interest is required. By so doing, a more complete descriptive image of the individual fractures can be obtained through seismic moment tensor inversion (SMTI), including the type of failure (eg., tensile, shear, or shear-tensile), fracture azimuth and dip, as well as the relative dimensions (assuming a penny-shaped crack). These fractures, in essence, define the discrete fracture network (DFN) that has been activated as a result of the stimulation program and offer a unique approach to characterizing the rock mass fracture state.

To characterize this DFN, we also consider the adaptation of traditional scanline approaches utilized in rock mechanics applications. Scanlines are an effective systematic approach that accounts for the location and number of discontinuities that intersect the scanline. In order to effectively apply this approach to microseismic data, consideration had to be made of the event location errors for placement along scanlines perpendicular to the treatment zone at points of perforation. Much like setting a scanline at a rock face, additional quantifiable estimates of fracture roughness were defined, thereby providing estimates of discontinuity aperture which are obtained based on the calculated tensile component of failure and corrections for angular differences between fractures obliquely oriented to scanlines.

By further considering a topological approach to fracture characterization, fracture nodes can be considered as either isolated, branching off from other fractures or crossing other fractures (see figure 1). By plotting the population of fractures in this manner, as in figure 2, as well as the nature of the branches between fracture nodes (figure 3) the percolation properties of the reservoir post stimulation can be assessed. Utilizing these approaches, we can further define the relative uniformity of rock mass structure with similar fracturing properties, and characterize the degree of uniformity with position from perforation intervals.

Our investigation focused on considering two stages related to the stimulation of an unconventional reservoir at approximately 2 km depth. Utilizing both scanline and topological approaches, the spatial and temporal characteristics of each injection were assessed, providing insight into the role of bedding

plane slip and sub-vertical fractures in the development of fracture complexity and thereby fracture intensity. Additional estimates of fracture aperture, for both individual fractures and fracture groupings were obtained. By applying percolation theory to the observed fractures, and the branching network that describes them, we were able to define the fracture behaviour that was sufficiently connected to allow for percolation to occur (figure 4). Further, we were able to show how percolation varies with position relative to the treatment well and how that could be closely related to the concept of trilinear reservoir models of production. These analyses provide further constraint or input on the development of geomechanical and reservoir models.

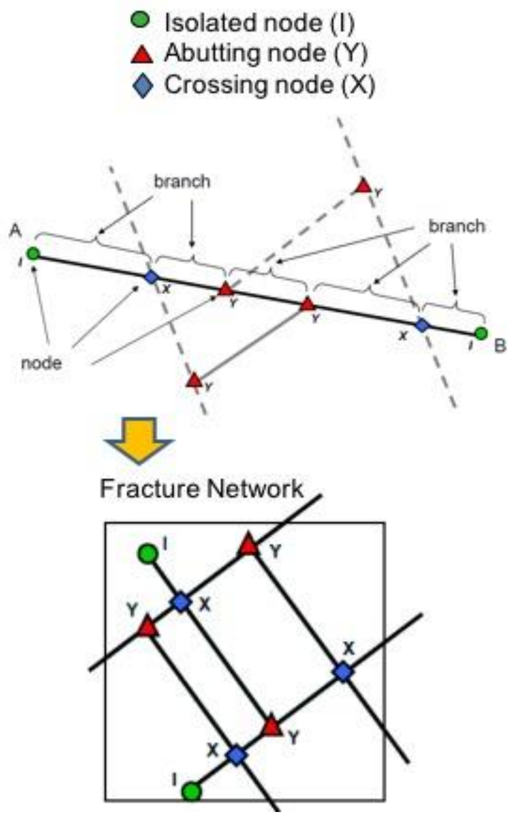

Figure 1. Fracture node counting based on connection type: isolated (I), crossing (X), or abutting (Y). In the 2D schematic provided, nodes and branches are defined based on the type of observed interconnectivity.

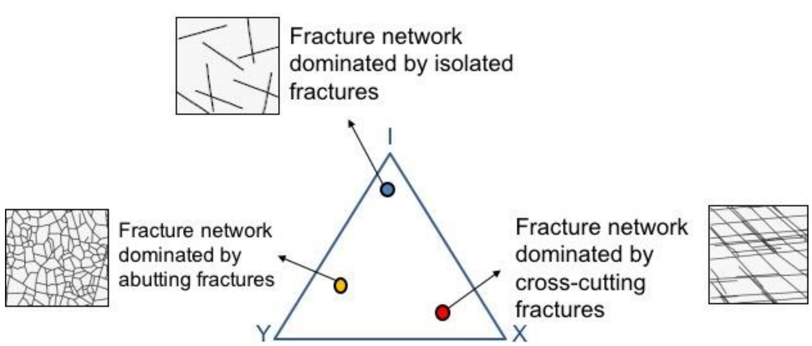

Figure 2. Ternary IXY plot of the interconnectivity for the observed fracture network based on volumetric scanlines.

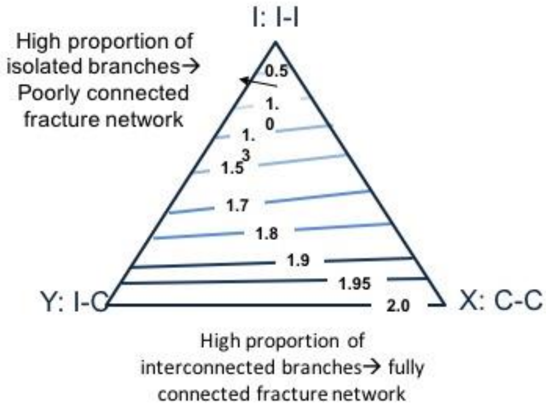

Figure 3. Branch behaviour leading to assessment of the potential for percolation.

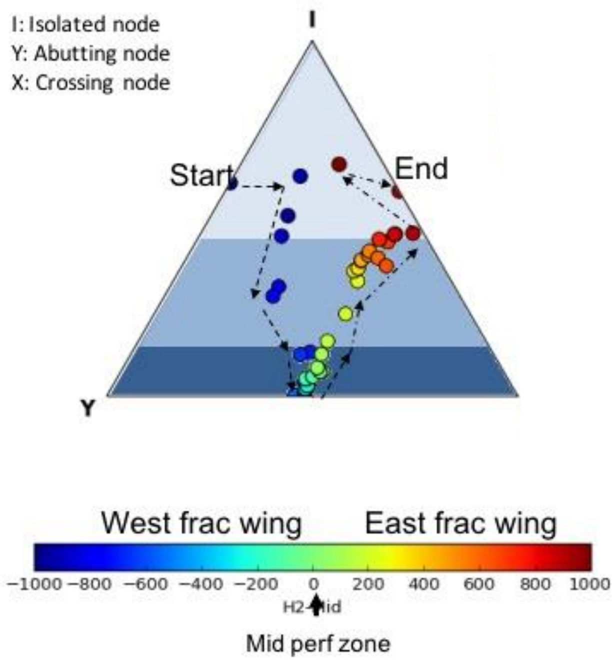

Figure 4. Topologic mapping of the fracture network with position relative to the treatment zone for one stage. Three zones are defined based on the observed interconnectivity of the network, suggesting a gradational variation in fracturing behaviour with position from the treatment zone, in-line with the concept of trilinear models.