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Quantitative Characterization of Fracture Frequency Variations Using a Linear Piecewise Regression Analysis and the Akaike Information Criterion

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ABSTRACT

We present a new quantitative approach for characterizing fracture frequency variations using a linear piecewise regression (LPR) analysis and the Akaike Information Criterion (AIC). Break points calculated for the LPRs produce linear segments with varying slopes for a cumulative fracture frequency (CFF) curve. An AIC value is calculated for each LPR model in order to determine the optimal number of linear segments that fit the CFF data. The optimal number of segments is obtained by minimizing the AIC value for a single dataset. Results from the statistical analysis produced three CFF slope intervals that define the distribution of possible fracture frequencies unique to the geologic setting from which they were derived. A total of 3678 fracture and vein measurements were collected using scanline, scangrid, and abbreviated methods at 38 sites in the Utica black shale and overlying coarser clastics of the Mohawk Valley in eastern New York State. To produce a CFF curve, fracture frequency is summed along a transect perpendicular to the strike of the fracture set. The piecewise function in the R package, "Segmented", calculates break points where the slope of the CFF changes. The AIC model selection method produces LPRs with the optimal number of breakpoints and segments by penalizing additional parameters introduced with each new segment. A comparison with the Bayesian Information Criterion (BIC) found that AIC models outperformed the BIC method because the BIC equation over-penalized additional parameters. Segmenting the CFFs produced three unique slope intervals, each with a set of defining characteristics. Background frequencies are defined by an average CFF slope of 8 with no significant changes in slope (including prominent frequency peaks). The average background fracture frequency is 2.4 fractures/m. Transition frequencies exhibit higher CFF slopes, averaging 111, and higher average fracture frequency of 12.3 fractures/m. Fracture intensification domains (including fractures in fault damage zones) are defined by the highest average CFF slope of 1649, produce prominent frequency peaks (>50 fractures/m) and have the highest average fracture frequency of 44.6 fractures/m. Results of the piecewise analysis provide quantified boundaries that can be used to create a fracture frequency framework for a defined geologic setting, aiding in predictions of fracture frequency variations due to local structural features.