Geophysical Research Abstracts
Vol. 21, EGU2019-14361-2, 2019
EGU General Assembly 2019

A robust non-parametric statistical approach to characterize fracture spatial distribution

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In the last years, tech-savvy structural geologists have learnt how to collect huge datasets in little time (e.g. with 3D Digital Outcrop Models), but paradoxically they might miss the statistical tools to carry out a proper analysis and exploit all the potential of the modern datasets. Here we propose a method to characterize the spatial distribution of fractures in 1D (scanlines) and 2D (scanareas), with bearing on fracturing processes. Compared with other approaches, we introduce the following three principles: (1) Random variables that can be used to characterize spatial distribution are position and spacing. Most approaches proposed in the literature use either the first or the latter variable, but just a few Authors consider both. This leads to misleading results. For instance, we can observe an exponential distribution of spacing both in randomly distributed fracture networks, and in fracture networks that show an increasing spacing along a trend in a fault damage zone. For this reason, we consider both spacing and position of fractures in our analysis, and the correlation between the two variables. (2) Particularly in the first steps of the analysis, we do not know which kind of distribution could describe our data. In this situation, assuming a certain parametric distribution (e.g. a lognormal) will introduce a bias in the analysis. For this reason, we use non-parametric statistics as far as possible. (3) In order to measure meaningful statistics, we must subdivide our datasets in homogeneous volumes, where the statistics is stationary. Any further analysis must be carried out within these volumes. Our workflow for the analysis of scanlines (e.g. large datasets obtained automatically from Digital Outcrop models) unfolds in five phases: (1) Definition of spatial variables: position of every fracture is X_i and spacing is calculated as $S_i = X_{i+1} – X_i$. (2) Non-parametric analysis of correlation between position and spacing using different forms of the Sperman's rank correlation coefficient. This allows detecting volumes (segments of scanline) where fractures show a stationary/homogeneous spatial distribution, and other segments where a trend (e.g. damage zone) or a pattern/clustering (e.g. fracture corridors) are present. Our non-parametric approach is more robust than parametric or spectral methods proposed by other Authors, since first of all we test the null hypothesis of homogeneity, rather than assuming specific parametric distributions or (as in some spectral approaches) imposing an arbitrary length scale. (3) Homogeneous volumes (segments of scanline), where statistics are stationary, are selected for the following analysis. (4) In homogeneous volumes, different parametric distributions of the random variables can be tested. For instance, knowing that in a certain volume the spatial distribution is homogeneous and no trend or pattern is present, we can test whether the distribution is random (characterized by an exponential spacing distribution and Poisson position distribution), or tends to some form of regularity (normal or log-normal distribution of spacing). (5) 2D scanarea analysis can be finally carried out on homogeneous volumes identified from scanline analysis, characterizing other important fracture network properties, such as fracture intensity, length distribution and termination statistics.