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Extrapolation of fractal dimensions of natural fracture networks in dolomites from 1-D to 2-D environment

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Fractal dimensions of fracture networks (D) are usually determined from 2-D objects, like the digitized fracture traces in outcrops. Sometimes, extrapolations to higher dimensions are required if the measurements (for example fracture traces in the boreholes or in the scanlines) are performed in 1-D environment (D_{1-D}) and are later upscaled to higher dimensions (D_{2-D}). For isotropic fractals this relation should be straight-forward according to the theory: $D_{2-D} = D_{1-D} +1$, as the intersection of a 2-D fractal with a plane results in a fractal with D_{1-D} equal to D_{2-D} minus one. Some authors have questioned this relation and proposed different empirical relationships. Still, there exist very few field studies of natural fracture networks to support or test such a relationship. The study was therefore focused on the analysis of 23 natural fracture networks in Triassic dolomites in Slovenia. The traces of these fractures were analyzed separately in both 1-D and 2-D environments, and relationships between the obtained fractal dimensions were determined. For 2-D data, the digitized images of fracture traces in 2048x2048 pixel resolution were analyzed by the box-counting method, considering truncation and censoring effects (the 'cut-off' method, using only the valid data right of the cut-off points) and also by considering the complete data range interval (the 'full' method). These values were consequently compared to 1-D values. Those were obtained by dissecting images in both x- and y-directions into 2048 smaller linear images of 1-pixel width, simulating the intersection with a plane. Such line images were then examined by the fracture line-counting method, a 1-D equivalent of the box-counting technique. Results show that the values of all fractal dimensions, regardless of the different fracture networks or the method used, lie in a very narrow data range, and the standard deviations are very small (up to 0.03). The small range can be attributed to a similar fracturing style of the dolomites or to the isotropy of fractures. Results obtained by the 'cut-off' method give higher values of the fractal dimensions than the 'full' method, as only appropriate data values were considered in calculations. Values of one-dimensional values of the fractal dimensions can be reliably extrapolated to a two-dimensional environment by equation $D_{2-D}= D_{1-D}+ 1.03$ for the 'cut-off' method and $D_{2-D}= D_{1-D}+ 1.06$ for the 'full' method. Both differences between D_{1-D} and D_{2-D} values (1.03 and 1.06) lie very close to the theoretical value of 1.00, so the fracture networks in dolomites can be described as nearly ideal non-mathematical and isotropic fractal objects, and the field data adequately supports the theoretical extrapolation.