Fracture distribution diversities: numerical simulation using 1-D competitive growth model

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1. Introduction: Numerous studies, including various modeling and numerical simulations, have been conducted for formation mechanisms and distribution regularities of earthquakes and faults, especially for their fractal characteristics and SOC since 1980's, though integrated understanding of the results are very difficult (e.g. Utsu, 1999). In this article, results of systematic numerical simulations based on a simple 1-D probability model will be shown for the formation and distribution of systems of fractures which have little interactions with their surroundings.

2. Model: Each element of an array (Mat_F; element no., N0), which represents lined points with equal distance in 1-D continuous homogeneous space, is given a random number (R0, 0.0 to 1.0), and the element given the highest value obtains a score (1, corresponding to fracturing). Through repeating the process (repeated no., M), the element (i) that has a score is given higher probability (Ri) for obtaining an additional score by the exponential equation of Ri = R0 * FF ^ Fi according to the obtained score (Fi) and 'competition factor value' (FF, nearly 1.0). Situations of a specific time M are listed by two arrays of Mat_A for the cumulative score, and Mat_B for the distance of a scored element to the next scored one (0 for not scored one).

By the above simple model experiment using two parameters M (corresponding to time flow and cumulative energy amount) and FF (related to brittle strength of rock), we may see phenomena caused by competitions of fracture development (formation of new ones and extension of old ones) in hypothetical homogeneous rock at a constant rupture-speed field (neglecting the spatial interactions of stress, strain, deformation and rupture). Mat_A and Mat_B correspond to data obtained by measuring fracture size (length, area, width and others), and spacing for rocks (outcrops, cores, experiment pieces and others).

3. Simulation results: Fig. 1 (N0 = 10,000) summarizes a series of numerical simulation results. The left and right figures show cumulative frequencies of fracture size (from Mat_A) and fracture spacing (from Mat_B) using log-log scales, respectively. The top and bottom figures show the changes with M, from 1000 to 10,000, for eight cases calculated by changing FF from 1.00 to 1.01. The results are summarized as follows:

(1) The fracture size distribution is fractal in a wide range of the figure field. The fractal dimension (D) is ca. 1.0 and 2.0 corresponding to the spatial features of the fractures, one- and two-dimensions, respectively.

(2) The fracture size distribution changes with time (M) from 'Poisson', through fractal to large-one dominated. The values of the 'fractal dimension (D)' decrease along the above changes.

(3) The number of fractures (NF) stabilized by the fractal distribution is ca. NF = 1 / (FF - 1), and the time to the stabilization (MF) is ca. MF = NF * 10 (normal distribution by FF = 1).

(4) Distributions of fracture spacing are rather logarithmic normal distribution, and are characterized by the larger average value and variance of the spacing, and the shorter stabilization time with the larger FF value.

4. Summary: The simple model and method of this article may help better understanding and controlling of fracture distributions. And, they may be variously expandable to many kinds of phenomena, including earthquakes and fault distributions. For example, the mineral vain system measured for the core samples from the Hishikari gold mine area by Sasaki (2004) has shown very concordant characteristics to the simulation results of this study. Shigeno (1995) has reported slightly complex simulation results for morphological diversities of hot-spring mineral deposits on the basis of the essentially same competitive growth model. However, the model and method of this paper have to be carefully applied to actual complex problems due to limitations from the high simplicity.

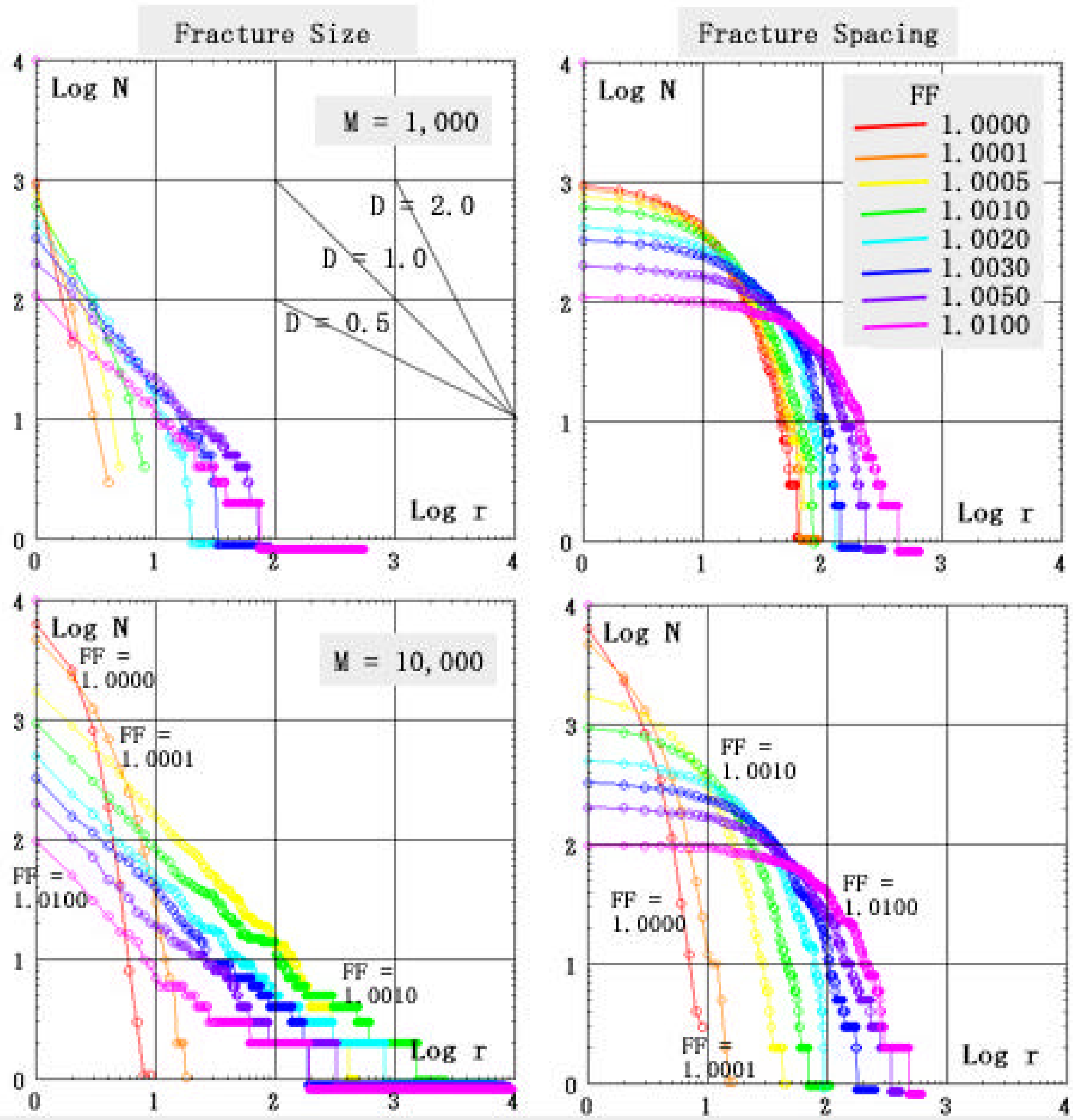

Fig.1 Fracture characteristics simulated using 1-D competitive growth model