Chaos, Solitons and Fractals 113 (2018) 16–24

Contents lists available at ScienceDirect

Chaos, Solitons and Fractals

Nonlinear Science, and Nonequilibrium and Complex Phenomena

journal homepage: www.elsevier.com/locate/chaos

Frontiers

Unreliable determination of fractal characteristics using the capacity dimension and a new method for computing the information dimension

Jingshou Liu[a,b,c,d,*], Wenlong Ding[a,b,c,d,*], Junsheng Dai[e], Gang Zhao[a], Yaxiong Sun[a], Haimeng Yang[f]

[a] School of Energy Resources, China University of Geosciences, Beijing 100083, China
[b] Key Laboratory for Marine Reservoir Evolution and Hydrocarbon Abundance Mechanism, Ministry of Education, China University of Geosciences, Beijing 100083, China
[c] Beijing Key Laboratory of Unconventional Natural Gas Geology Evaluation and Development Engineering, China University of Geosciences, Beijing 100083, China
[d] Key Laboratory for Shale Gas Exploitation and Assessment, Ministry of Land and Resources, China University of Geosciences, Beijing 100083, China
[e] School of Geosciences, China University of Petroleum, Qingdao 266580, China
[f] Zhongyuan Oilfield Co. Ltd., SINOPEC, Oil Recovery Plant No.3, Puyang 066004, China

ARTICLE INFO

Article history:
Received 28 December 2017
Revised 28 March 2018
Accepted 7 May 2018

Keywords:
Information dimension
Capacity dimension
Fractal
Unreliability
Jinhu sag
Fault

ABSTRACT

Fractal theory has been widely applied in a variety of disciplines to understand the theory behind chaotic phenomena based on internal self-similarity. In this study, three ideal geological models are used to analyze the unreliability of the capacity dimension in the fractal calculation of geological bodies with different scales. Additionally, by varying the side length r of the statistical units, the geological meanings of the fractal dimension D and the correlation coefficient R^2 are discussed. The points of information (POIs) are densely filled by binarizing the geological bodies to black/white. Based on the optimized r of a geological body, an algorithm is derived that divides the grids of the statistical units to determine the probability of the POIs falling into different grids. The information dimension (D_I) and R^2 of a geological body are obtained by fitting the variable data. An example calculation of the information dimension field in the Jinhu sag is presented to demonstrate the methodology and to test its reliability. The results show that determining the appropriate side length of the statistical unit is key to evaluating the fractal calculation. Compared to the capacity dimension, D_I is more reliable in the fractal calculation of multi-scale geological bodies; D_I is thereby the preferred fractal dimension to use in the analyses of these types of geological bodies.

1. Introduction

Fractal theory mainly describes the irregularity, complexity and similarity in nature and society and is used to identify the laws describing many irregular occurrences. It is believed that all the components of an object are self-similar in some way. In recent years, fractal theory has been introduced in disciplines such as earth science, physics, chemistry, medicine, biology, material science, and mineral processing and has become a popular research topic in the scientific community. Fractal theory has been applied in diverse geological fields, including metallogenic prognosis and dynamics analysis [1–3], fault and fracture characterization and forecasting [4–6], transportation and aggregation of oil and gas [7–9], assessment and prediction of geological hazards [10–13], porous media [14–16], geochemistry [17–19], geomorphological and remote data processing [20–23] and geological statistics [24,25].

The capacity dimension is calculated using the box-counting method. This statistical method is easy to use and apply [2,4,6,19]. In geological studies, the capacity dimension and the information dimension are especially practical [2,4,6,19,26]. Ouillon and Sornette [27] described a method for systematically correcting the finite size and irregular geometric boundary effects in multifractal analysis. Their method can be used to test the universality of multifractal spectra by comparing results at different scales with the respective adjusted corrections. Bonnet et al. [28] have already

---

[*] Corresponding authors.
E-mail addresses: liujingshou@126.com (J. Liu), Dingwenlong2006@126.com (W. Ding).

https://doi.org/10.1016/j.chaos.2018.05.008
0960-0779/

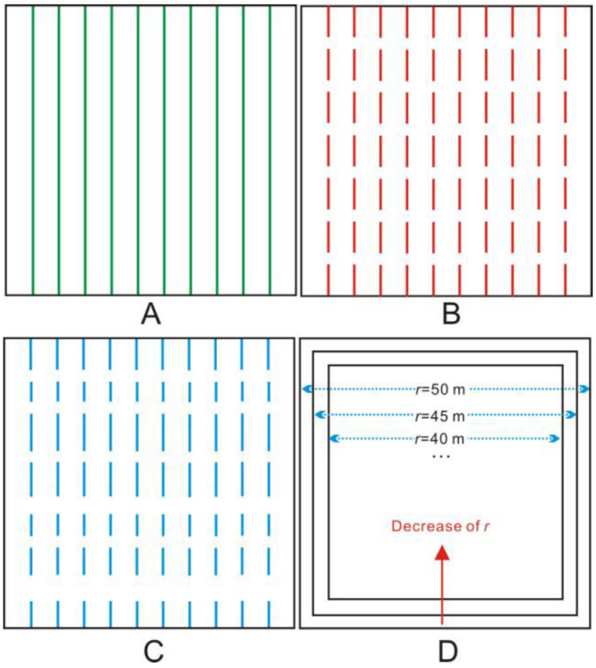

Fig. 1. Models for the comparison between the information and capacity dimensions: (A) Model 1; (B) Model 2; and (C) Model 3. (D) The variation method of the side length r in statistical units.

performed an extensive review of the limitations of scaling dimension analysis in faulted geological settings. Roy et al.'s [29] research addressed these issues by developing an improved version of the box-counting method. This improved method was validated for a synthetic fracture network with a known fractal dimension D and was then applied to a natural fracture pattern mapped at 7 resolutions. Souza and Rostirolla [30] proposed a program executed in MATLAB for quickly and accurately calculating fracture fractal dimensions and $f(\alpha)$ spectra. Chamorro-Posada [31] proposed a compressed fractal dimension, which provides a simple method for directly estimating the fractal dimension stored as a digital image file. However, the capacity dimension considers only whether geological bodies are observed in the grid, without taking into account the quantity and size of the geological bodies in the grid; in particular, when different geological units contain similar geological information (for example, fracture density or matrix porosity), the capacity dimension may be inaccurate. Generally, the fractal of geological bodies is scaled [28], resulting in possible discrepancies in the fractal dimension among statistical units with different side lengths. It can also be difficult reasonably determine the length of the statistical units [9]. In this study, based on three typical geological models, the side lengths of the statistical units are varied, the fractal dimension D and correlation coefficient R^2 are analyzed, and the selection principle of the optimal fractal length of the geological body is determined. The unreliability of the capacity dimension is verified in the calculation of geological bodies with different scales. The points of information (POIs) are densely filled using black/white binarization. The corresponding algorithm is derived using grid division to obtain the probability of interpolated points falling into different grids. The information dimension and the correlation coefficients are determined by fitting the variable data. Ultimately, an accurate and efficient calculation of the information dimension of geological bodies is completed.

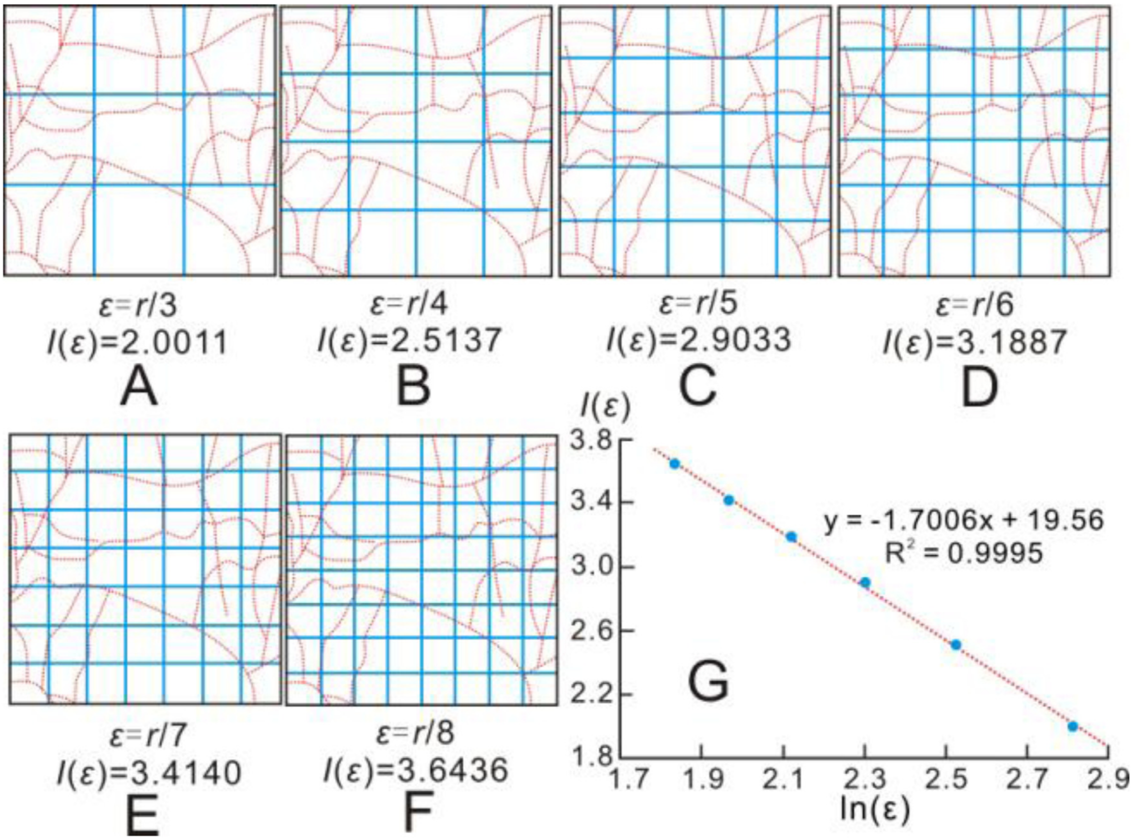

Fig. 2. Illustration of the fractal calculation.