Three-dimensional digital rock image of fractured rock

Guoliang Yan, Jianhu Gao and Zhonghua Xu.

PetroChina Research Institute of Petroleum Exploration & Development -- NorthWest (NWGI), Lanzhou, China. Contact email: yanguoliang@petrochina.com.cn

Summary

X-ray computed tomography technology can reveal the microscopic structure of the reservoir rock, but to fractured reservoir, it is very difficult to drill a characteristic rock sample with fracture because of the discontinuity of the rock. So it is hard to construct the digital rock image of fractured reservoir using X-ray computed tomography technology only. In this paper we propose a method to construct the three-dimensional digital rock image of rocks containing fracture.

Introduction

Three-dimensional information of rock microstructures is important for better understanding the pore scale physical properties and for rock characterization (e.g., Madonna et al., 2013; Pistone et al., 2012). Three-dimensional digital core is a kind of digital image of rocks which could be used to directly reflect the rock microstructures. At present, it have been developed a variety of methods to construct digital image of rocks, which can be mainly divided into two type from reconstruction tools: physical methods and mathematical methods.

Physical methods, which include destructive and non-destructive methods, construct the digital cores through physical instrument and physical principles. The destructive methods can destroy the rock sample after construction of digital core, for example, Focused Ion Beam Scanning Electron Microscopes (FIB-SEM) methods. The latter method is preferable because the same rock sample can be used to other investigation after imaging, for example in laboratory testing. This allow to compare the laboratory result with the calculations based on digital core image. The most common non-destructive 3D imaging methods for earth sciences is X-ray computed tomography (CT). Mathematical methods is based on the core slices, which contain gauss filed method, simulated annealing method, multipoint geological statistics method, Markov chain method and process-based method. They can't reproduce the real microstructure of the rock, but which can be effectively applied to the study of change of rock physical properties.

Throughout the various modelling methods of digital rock image, they can be suitable to construct the digital rock image of porous reservoir rock, but they can’t be used in fractured reservoir rock. In a word, we lack of construction methods of digital rock image for fractured reservoir rock.
For this paper, we present a construction method of digital rock image for fractured reservoir rock. Firstly, the three-dimensional digital core of rock matrix with different minerals is built with CT scan method, and then using the fractal parameters obtained from the statistic of fracture reservoir rocks as the input parameters, the three-dimensional fractal discrete fracture network is constructed. The last, we get the three-dimensional digital rock image with fracture by superimposing the fractal discrete fracture network upon the matrix digital image.

**Methods**

The construction of three-dimensional digital rock image with fracture mainly includes three steps.

Step 1: construction of three-dimensional digital core for multicomponent rock matrix by X-ray CT scanning technology. Filter (convolution) anti-projection technique is applied to implement the reconstruction of the X-ray CT images. After this, image enhancement, filtering method are used to get a clear grey image. Finally, the multicomponent digital core is obtained through the general Otsu’s (1979) segment algorithm.

Step 2: fractal discrete fracture network modelling (e.g., Kim et al., 2009). If fracture shape in 3D is assumed a disc, it include five parameters: fracture position, dip, dip direction, aperture and length. Fractures position is determined by the fracture centre distribution which generated by multiplicative cascade process. Fracture orientations including dip and dip direction are generated by the method suggested by Villaescusa (1993). In addition, fracture aperture and length are generated by corrected SRA and first-order model, respectively.

Step 3: construction of three-dimensional digital core for fractured reservoir rocks. The fractal discrete fracture network is grided through geometry transformation technology and the gridding step is the same as the resolution of matrix rock. At last, the three-dimensional digital rock image with fracture is finished by superimposing the fractal discrete fracture network upon the matrix digital image.

**Results**

Using the methods above, the three-dimensional digital core of a tight sandstone matrix is constructed firstly. Figure 1a is one of the raw images of X-ray CT. There are 984*1011 pixels and the pixel size is (3.83μm)². Figure 1b is the image after enhancement process. Figure 1c is the image after filtering process. Due to the computer memory, the segment area is only within the marked yellow square, and the segment result is show in figure 1d.

Fractal discrete fracture network is generated using the fractal theory. Seventeen fracture centre points (Figure 2a) are generated and so the same number of fracture with different orientation, length and aperture is got ((Figure 2b).

Figure 3a is the three-dimensional digital rock image of tight sandstone matrix with five components. Figure 3b is the three-dimensional fractured digital rock image of tight sandstone. In both of them, dark grey, light grey, white grey, white and black represent clay, quartz, feldspar, mica and pore, respectively.

**Conclusions**
X-ray CT scanning method can obtain the three-dimensional digital rock image of matrix rocks and the fractal discrete fracture network can be generated by fractal theory. Superimposing the fractal discrete fracture network upon the matrix digital image, the three-dimensional fractured digital core is got. All of those provides the foundation for physical property calculation and mechanism analysis of fractured reservoir rock.

Figure 1. Image processing procedure of X-ray CT. (a) The raw image of X-ray CT. (b) The image after enhancement. (c) The image after filtering. (d) The image after segment.
Figure 2. (a) The fracture centre distribution, which is generated using the multiplicative cascade process algorithm. The box provides 4003 voxels. (b) is fractal discrete fracture network and the blue colour means fractures.

Figure 3. (a) Three-dimensional digital rock image of tight sandstone matrix. (b) Three-dimensional digital rock image of tight sandstone with fractures.

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References


