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DFNModeler: AN EFFICIENT DISCRETE FRACTURE NETWORK MODELER

Guohai Jin and Jack C. Pashin

Geological Survey of Alabama, P. O. Box 869999, Tuscaloosa, AL 35486

ABSTRACT

DFNModeler is a Windows application is designed for modeling discrete fracture network. The software has integrated fracture data input, generation of discrete fracture network, compartment and fluid migration pathway analysis, and visualization. The OpenGL advanced graphic library is integrated into the software to allow visualization of the generated discrete fracture network and analyzed results.

INTRODUCTION

Discrete fracture networks (DFN) are stochastic models of fracture architecture that incorporate statistical scaling rules derived from analysis of fracture length, height, spacing, orientation, and aperture. The DFN technique has been applied in a number of areas such as hydraulic fluid transport [1], carbon sequestration modeling [2, 3], and fractured reservoir characterization [4]. The goal of DFN modeling is to represent the important aspects of natural fractures within the mathematical framework of numerical simulation and engineering calculations. DFN models can be important vehicles for the simulation of flow and solute transport in a fractured rock mass, thus DFN modeling techniques have become important and powerful tools for fractured reservoir characterization and CO_2 sequestration studies.

We are developing a computer software package called DFNModeler, which is designed for the realization, visualization, and analysis of discrete fracture network models. Computerized analysis of fracture networks is important because fractures are abundant in reservoirs and aquifers and can have a strong effect on fluid flow patterns and compartmentalization. In this paper, we discuss the basic functionality and the logic behind the design of DFNModeler and provide some examples of how this software can be applied to coalbed methane reservoirs.

DFNModeler FUNCTIONALITY AND DESIGN: WHAT IT CAN DO

DFNModeler is designed to have four major functionalities: edit and input information on the statistical properties of fracture networks; realize the DFN model; analyze fracture compartmentalization and fluid migration pathways; and visualize the DFN model (Figure 1). These functionalities are provided through user-friendly, menu-driven interfaces (Figure 2). For example, the input of original data is conducted through spreadsheet-type tables (Figure 3) and through dialog boxes (Figure 4) that can be accessed through the menu structure.

1. Fracture data analysis

DFNModeler enables the definition of fracture populations using dialog interfaces. The statistical properties of the fracture data collected from outcrops and cores can be used to generate realizations of fracture networks with the same statistical properties. DFN models are characterized by stochastic descriptions of the orientation, location, area extent, cross-cutting relationships, and hydrologic properties of fracture sets. Once the statistical properties of the fracture systems in the study area are known, it is possible to generate a virtual realization of the fracture network and to solve for fluid flow through the realization.

A physical DFN model is composed of a number of fracture regions (Figures 5, 6). Each fracture region is specified according to its dimensions and the fracture sets contained therein. Fracture regions are defined as having two types: rectangular box and slab (Figures 2, 3). A rectangular region commonly represents a flat formation or rock unit, while a slab region is used to represent a dipping rock layer or fault zone. Fracture regions are the basic geologic units

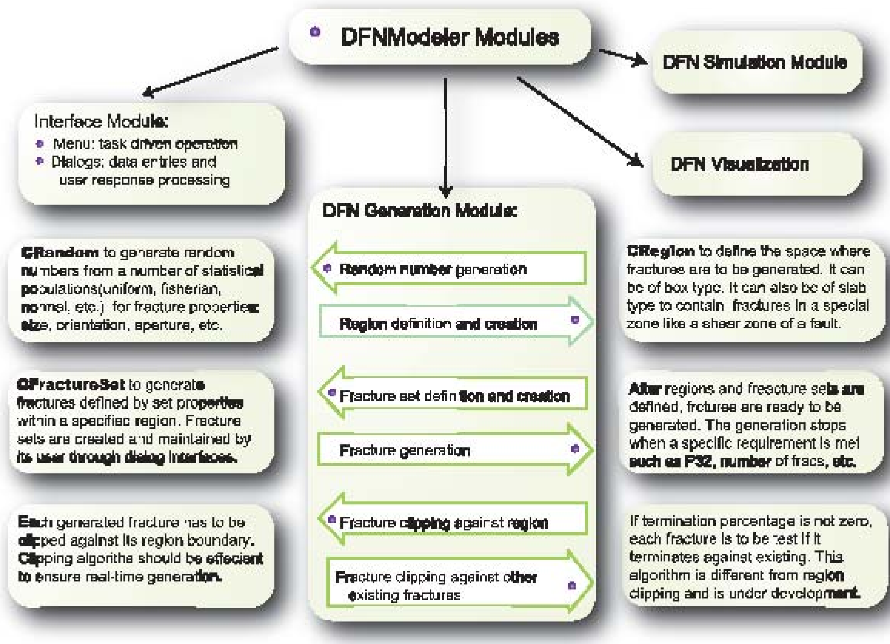


Figure 1. Flow chart showing organization of DFNModeler.

employed by DFNModeler. Fracture sets in a region are characterized by stochastic descriptions of fracture orientation, location, area extent, transmissivity, and storativity. Typically, fracture sets consist of genetically related groups of fractures. To simulate a joint system, for example, systematic joints are assigned to one fracture set, whereas cross joints are assigned to another fracture set. The geometrical shape of a fracture region can be one of the following: box, slab, and cylinder. A boxlike region is the default shape and is used for most fracture network generation such as a fracture set in a formation.

DFNModeler maintains a list of fracture regions. Each region can contain multiple fracture sets, which is explained in the next section. The region is defined by its center location, size and orientation. Fracture regions typically are assigned to unique stratigraphic intervals. For

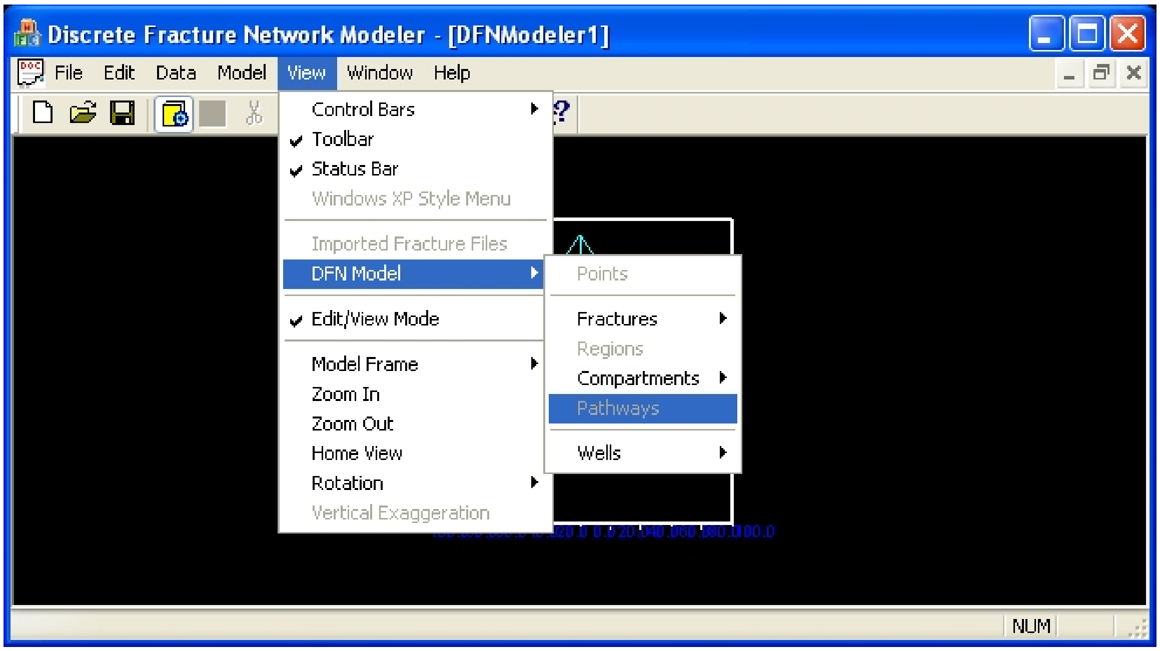
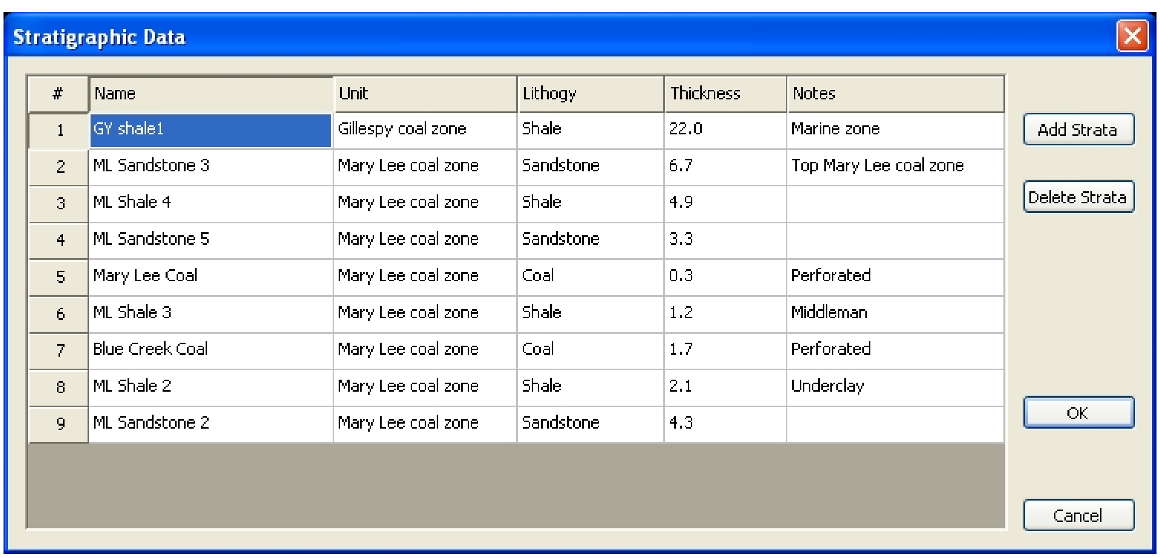


Figure 2. View menu architecture of DFNModeler.



#	Name	Unit	Lithogy	Thickness	Notes
1	GY shale1	Gillespy coal zone	Shale	22.0	Marine zone
2	ML Sandstone 3	Mary Lee coal zone	Sandstone	6.7	Top Mary Lee coal zone
3	ML Shale 4	Mary Lee coal zone	Shale	4.9	
4	ML Sandstone 5	Mary Lee coal zone	Sandstone	3.3	
5	Mary Lee Coal	Mary Lee coal zone	Coal	0.3	Perforated
6	ML Shale 3	Mary Lee coal zone	Shale	1.2	Middleman
7	Blue Creek Coal	Mary Lee coal zone	Coal	1.7	Perforated
8	ML Shale 2	Mary Lee coal zone	Shale	2.1	Underclay
9	ML Sandstone 2	Mary Lee coal zone	Sandstone	4.3	

Figure 3. Spreadsheet table for defining stratigraphic data.

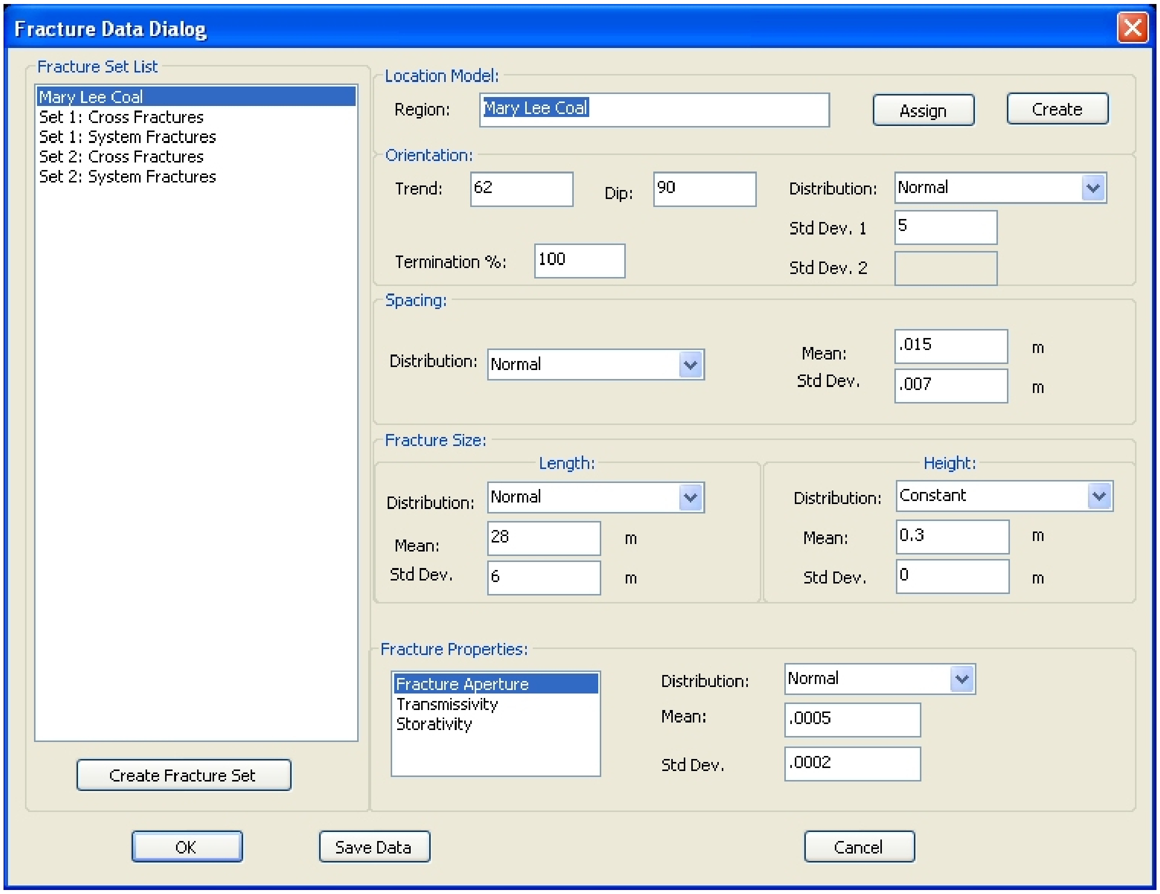


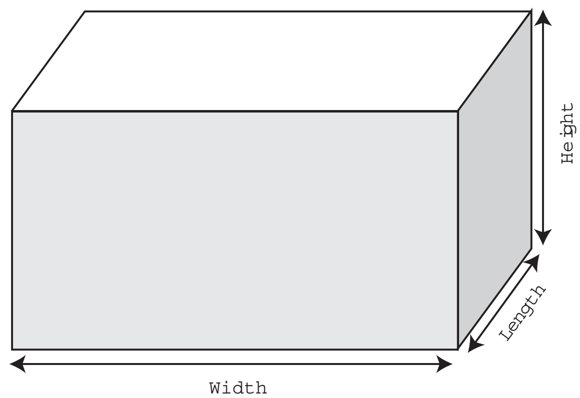
Figure 4. Dialog box defining the properties of fracture sets.

convenience, the properties of fracture regions can be saved for later input and can be loaded into the program from a file.

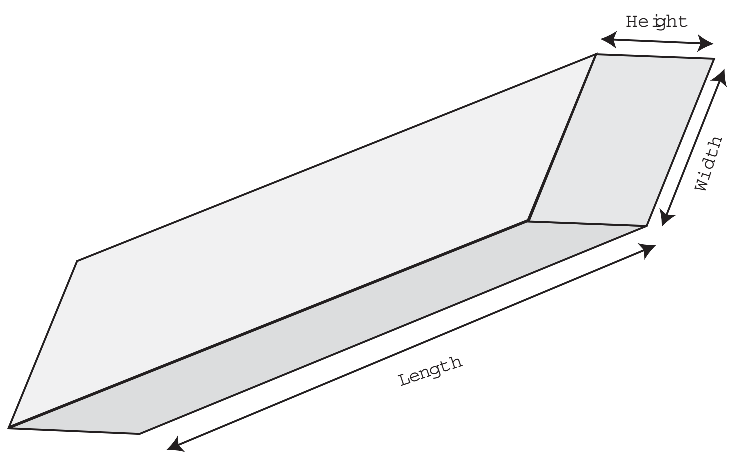
Once fracture regions and the statistical parameters of the contained fracture sets are defined, a DFN model can be generated.

2. Realization of a DFN model

Realization of DFN models involves generating fractures on the basis of the statistical parameters entered into DFNModeler. Because each fracture is generated stochastically, DFNModeler makes extensive use of a random number generator. Algorithms for random number generation that are consistent with the statistical properties of fracture populations are critical for the simulation of fracture networks. We have developed simulations for a number of different



(a) Rectangular region



(b) Slab region

Figure 5. Types of fracture regions.

types of statistical distributions that are common in natural fracture systems. Those distributions are uniform, normal, lognormal, exponential, Poisson, power law, gamma, and Fisher-von Mises distributions [5, 6, 7, 8]. Considerable effort has been directed toward optimization of the algorithms to facilitate the simulation of large fracture networks, which commonly contain tens of thousands of fractures.

Termination of fractures at intersections with preexisting fractures is typical of natural systems, and simulation of cross-cutting relationships is a necessity for the construction of realistic DFN models. In order to achieve this functionality, we use a fracture termination percentage to mimic cross-cutting relationships. The termination percentage defines the

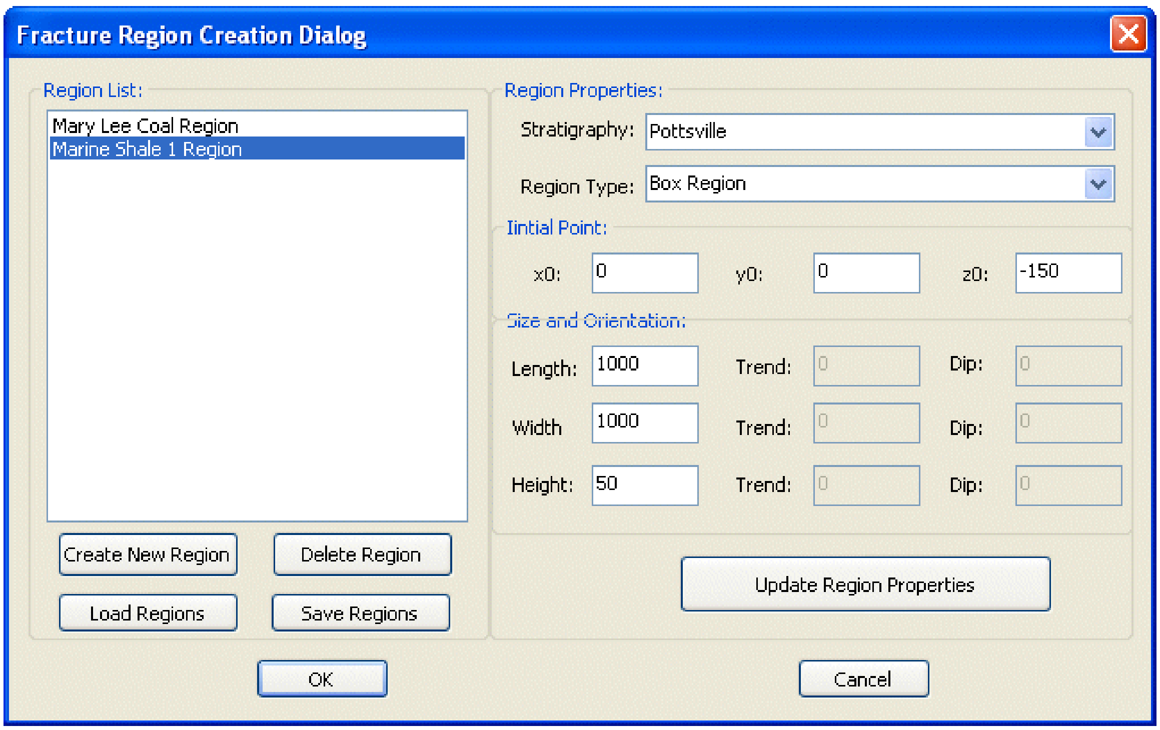


Figure 6. Dialog box for specifying the properties of fracture regions.

probability of a fracture terminating at an intersection with an older fracture. Where fractures are terminated, a clipping algorithm is applied during realization.

3. Compartment and fluid migration analysis

Once a DFN model is generated, DFNModeler is able to perform compartmentalization and fluid migration analyses. Compartmentalization is an important measure of the interconnectivity of a fracture network. A fracture compartment is defined as a convex polyhedron, or hull, that connects all vertices of intersecting fractures. The geometric process used for compartmentalization analysis determines whether and how many fractures are interconnected to form a compartment. Compartments ideally do not intersect, and the compartment hulls define effective no-flow boundaries. However, a reservoir compartment can contain smaller-scale other compartments.

Fluid migration analysis is associated with a well penetrating different compartments. Fluid in one compartment can transport into other compartments through a well that is open to multiple structural compartments. Therefore, DFNModeler will determine whether a placed well penetrate any compartment in a DFN model. All compartments that are connected to a well define the pathway of fluid migration from one compartment to another. DFN modeler will highlight those compartments for visual display

4. Modeling flow with third-party software

DFNModeler is designed to import and export data from and to a variety of third-party software packages. For example, ASCII files generated by other DFN modeling packages, such as FracMan [4] can be readily used by DFNModeler for the construction of extremely large DFN models, for advanced visualization, and to perform compartmentalization and fluid-migration analysis. Also, the files can be exported from DFNModeler to other software packages like TOUGH2 for the modeling of fluid flow and solute transport.

5. Visualization of DFN models

DFNModeler is designed not only to generate and analyze DFN models, but for visualization of the results in three dimensions. Visualization in DFNModeler is implemented with an OpenGL graphic library that enables real-time zooming, translation and rotation of the DFN models. The user can control features, such as vertical exaggeration and transparency, to aid in visualization. Figure 7 illustrates the visualization of an entire DFN model composed of 81 different stratigraphic units of the upper Pottsville Formation in the Black Warrior basin, southwest Alabama.

Another important feature of DFNModeler is that it enables color contouring of geological features. For example, the aperture, transmissivity, and storativity of fractures can be color contoured so that one can visualize how fracture properties are distributed. Figure 8 is a color contoured storativity of a fault related DFN model.

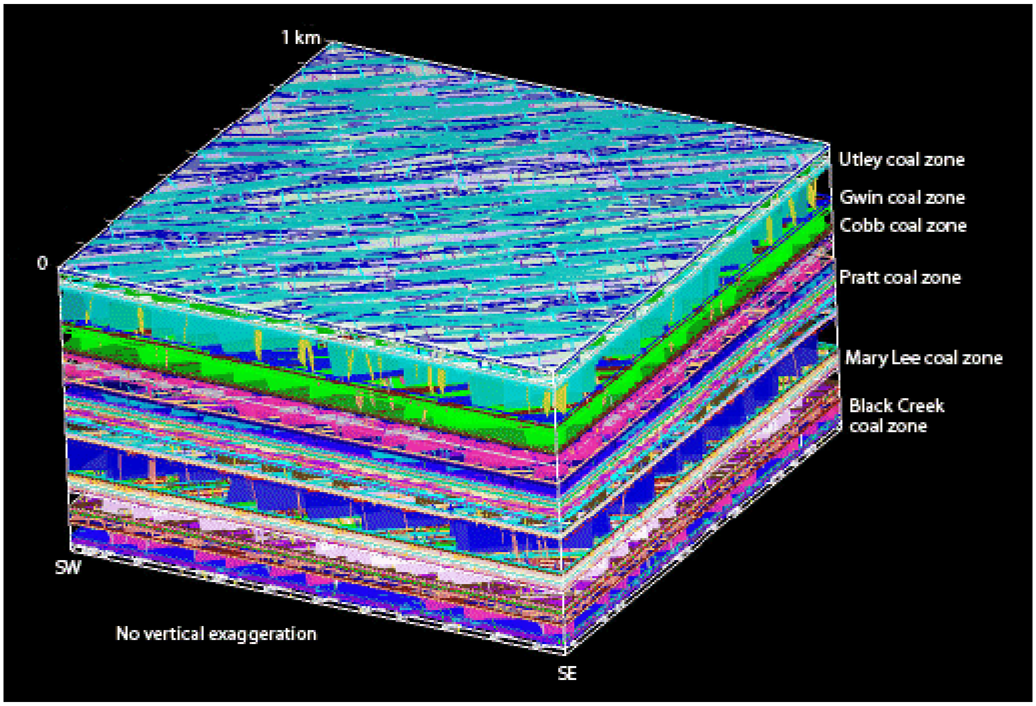


Figure 7. DFN model of the upper Pottsville Formation in the Black Warrior basin.

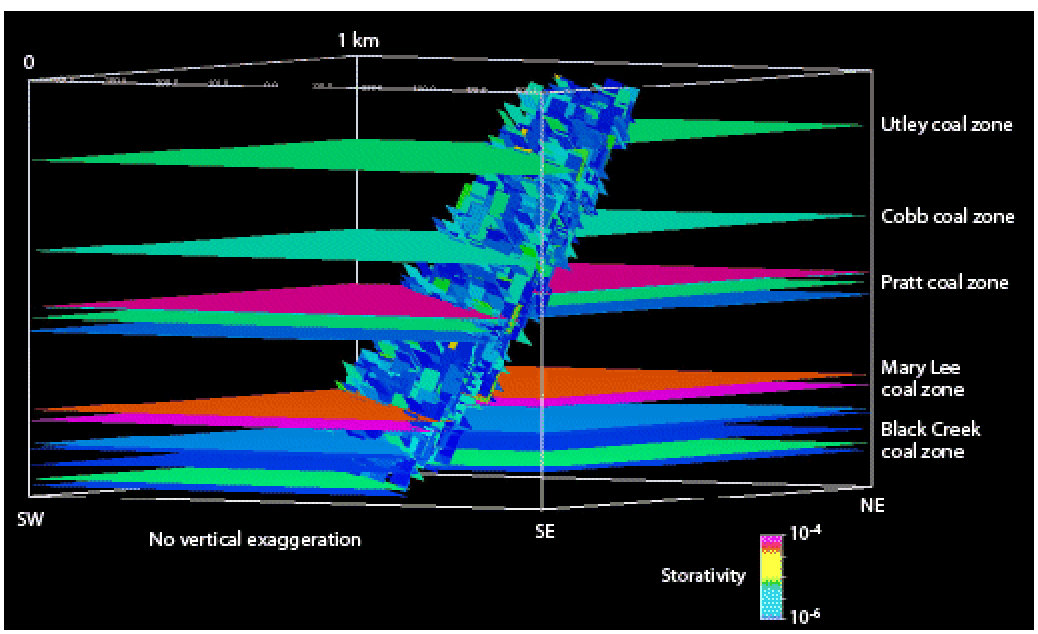


Figure 8. Color contoured storativity of a faulted DFN model.

Compartmentalization analysis is very important and useful to determine how anisotropy of a

DFN model. It can also indicate the volumetric information of any compartments. Visualization of compartmentalization of a DFN model can help us to determine the communication of fluid among different compartments and how fluid might be transported within a compartment. Figure 9a shows a DFN model composed of a single coal bed and the neighboring strata-bound joint system. Figure 9b indicates the compartmentalization model showing development of first-order compartments around interconnected coal and joints and second-order compartments developed around interconnected joints isolated from coal.

Figure 10 shows a compartmentalization model of the complete jointed DFN model, which suggests that distinctive patterns of compartmentalization are developed in the upper Pottsville Formation. Large first-order compartments are developed around the major coal zones. Numerous second-order compartments are stranded in the thick, shale-dominated intervals between the major coal zones [3].

Discussion and conclusions

Discrete fracture network (DFN) models have been used successfully to assess leakage risks associated with hydraulic fracturing and coalbed methane production, and these models show promise for assessing risks associated with carbon sequestration in coal. The objectives of our work are to develop a software package called DFNModeler using DFN theory for risk assessment and to use this software to assess risks in the Black Warrior basin of Alabama, where coal-bearing strata have high potential for carbon sequestration and enhanced coalbed methane recovery.

Accuracy, efficiency, and reliability are three major principles governing DFNModeler software development. In a DFN model of coal-bearing strata, tens to hundreds of thousands of fractures may need to be generated to accurately portray the geology in a given area. Moreover, the final position and shape of each modeled fracture has to be calculated, clipped, rendered according to the appropriate scaling rules and cross-cutting relationships, which can be a very

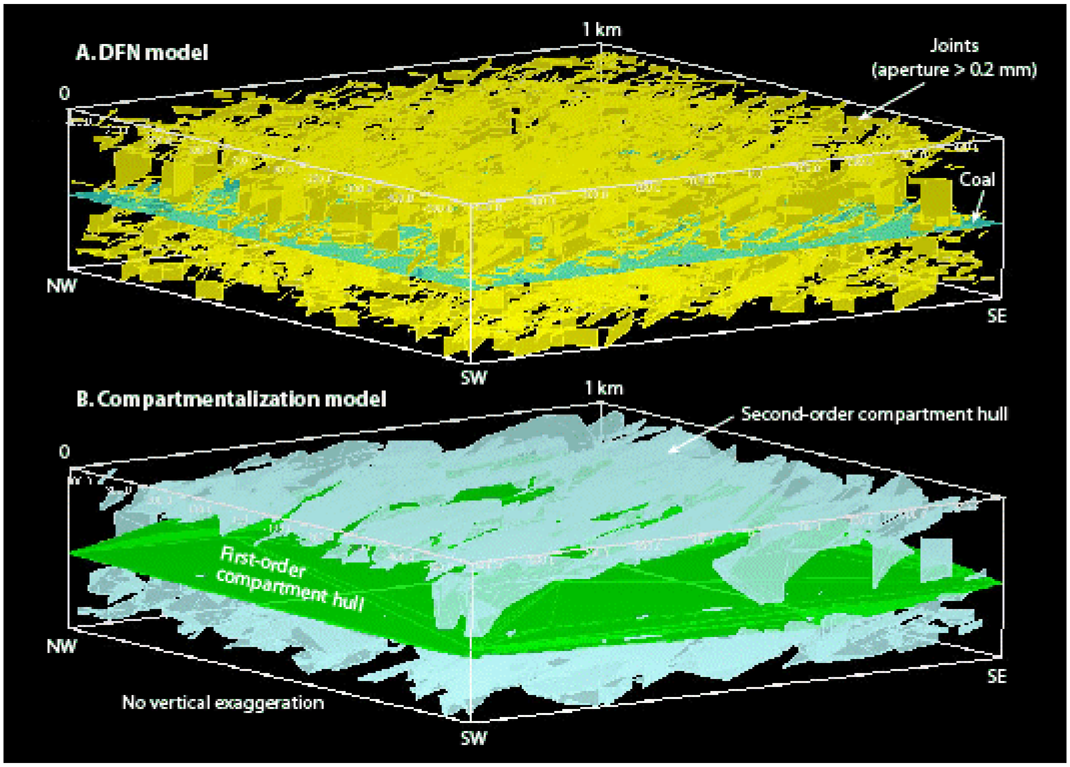


Figure 9. Compartmentalization analysis of single coal joints. (A) DFN model. (B) Compartmentalization model.

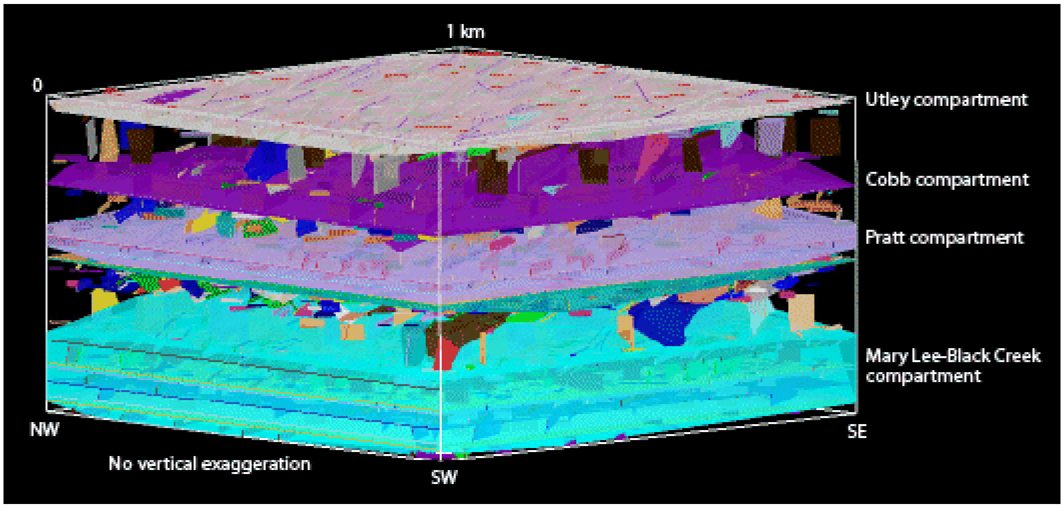


Figure 10. Compartmentalization model of the upper Pottsville Formation.

computationally intensive and time-consuming task. In order to achieve acceptable performance, each algorithm required for fracture generation and compartment and migration pathway analysis is carefully designed.

Acknowledgments

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