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DISCRETE FRACTURE NETWORK MODELS OF THE SECARB CARBON SEQUESTRATION TEST SITE, DEERLICK CREEK FIELD, BLACK WARRIOR BASIN, ALABAMA

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ABSTRACT

Discrete fracture network (DFN) models are stochastic representations of natural fracture systems and have been used increasingly in coalbed methane reservoir characterization. We have developed a computer software package, DFNModeler, for generating, visualizing, and analyzing discrete fracture networks. This modeling technique has been applied to a carbon sequestration test site in the Black Warrior basin. DFN modeling indicates that fracture networks in coal-bearing strata at the test site are highly compartmentalized and that large, first-order compartments envelop the reservoir coal zones, thus isolating them from shallow sources of fresh water.

INTRODUCTION

A pilot program that is designed to substantiate the carbon sequestration and CO_2-enhanced recovery potential of coal is scheduled to be conducted in the Black Warrior basin during 2008. This investigation consists of a series of production-buildup and injection-falloff tests in multiple coal seams of the Pottsville Formation and is designed to determine the viability of sequestration in coal seams with diverse reservoir properties. As part of this program, the Geological Survey of Alabama, with the support of the U.S. Department of Energy, is developing DFNModeler software, which can be used to assess leakage and seepage risks associated with carbon sequestration in coal through natural fracture systems.

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. DFN modeling is a computer modeling approach that can be used to assess the relationship of coalbed methane reservoirs to carbon sequestration by simulating fracture architecture and hydrologic compartmentalization [1]. Our previous studies indicate that natural fractures in the upper Pottsville formation in the Black Warrior basin include joints in shale and sandstone and fault-related shear fractures [1, 2]. Fractures in the coal beds predominantly are closely spaced cleats. DFN modeling can provide insight into potential risks associated with carbon sequestration and enhanced coalbed methane recovery. For this reason, we have been developing a DFN modeling software package called DFNModeler for the realization, visualization and analysis of natural fracture networks.

The complex processes of liquid and gaseous flow through natural fracture networks is an important subject of computer modeling. The flow of water and gas through fracture systems is dependent on the geometry of the fracture network and is influenced strongly by the magnitude of fracture apertures. In the Black Warrior basin, field investigations suggest that hydrologically insignificant hairline fractures predominate in the strata separating coal beds and that fluid flow is concentrated along large-aperture fractures. Thus it is important to analyze fracture systems and construct DFN models to understand the potential linkages among large-aperture fractures, which may pose risks during carbon sequestration and enhanced coalbed methane recovery operations.

DFNModeler: AN OVERVIEW

DFNModeler is an interactive, menu-guided computer program to generate, visualize, and analyze DFN model. This software has been developed under the Windows operation system and employs the OpenGL visualization engine. DFNModeler is designed to have 5 major functions: 1) input and editing of model data; 2) generation of discrete fracture networks; 3) analysis of compartmentalization and fluid migration pathways; 4) visualization DFN modeling results; 5) export of model data and results. Figure 1 shows the major modules of DFNModeler.

1) Model Data

Data for DFN modeling are composed of fracture properties, fracture region properties, and rock matrix properties. Fracture properties commonly include statistical data on fracture orientation, cross-cutting relationships, fracture size and spacing, and hydrologic properties, such as aperture, transmissivity, and storativity. Fracture region properties include the geometry and orientation of the region containing a fracture system. A fracture region is defined as a geometric unit where fracture sets have the same statistical properties. Two types of fracture regions are commonly defined: box and slab (Figure 2). A box region simulates a horizontal bed while a slab typically represents a dipping bed or fault zone, which can include fault-related shear fractures.

2) Generation of Discrete Fracture Networks

Once the data required to build a discrete fracture network have been entered, the next step is to generate a computer model of the fracture network. DFNModeler uses efficient algorithms to optimize the simulation of cross-cutting relationships between fracture sets and automatically clips fractures where they intersect the region boundary. This allows us to conveniently generate multiple realizations of fracture networks from the same input data for better understanding of the characteristics of the fracture network.

3) Compartmentalization and Fluid Migration

Compartmentalization is an important measure of the interconnectivity among fractures. Compartmentalization analysis determines how far fractures at different stratigraphic levels can be interconnected and therefore provides us with information how fluid can migrate and where effective no-flow boundaries may lie. A compartment is defined as a convex polyhedron, or hull, that connects the vertices of intersecting fractures. As the definition implies, fractures from different compartments are isolated from each other and thus fluid migration is hydrologically confined within the compartment boundaries.

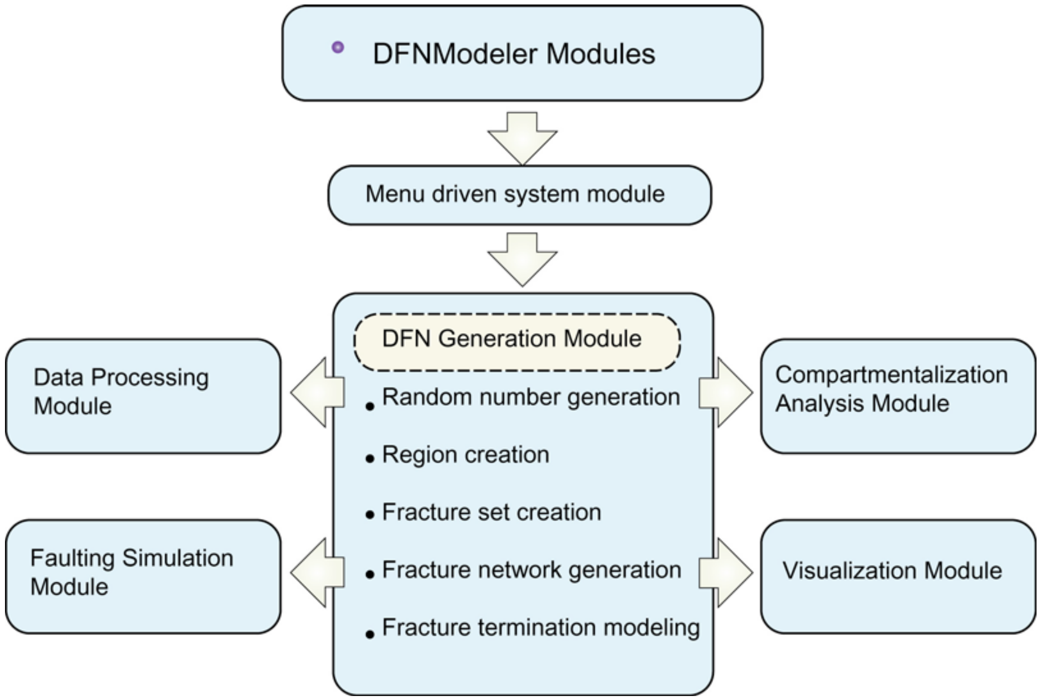


Figure 1—Modular architecture of DFNModeler software.

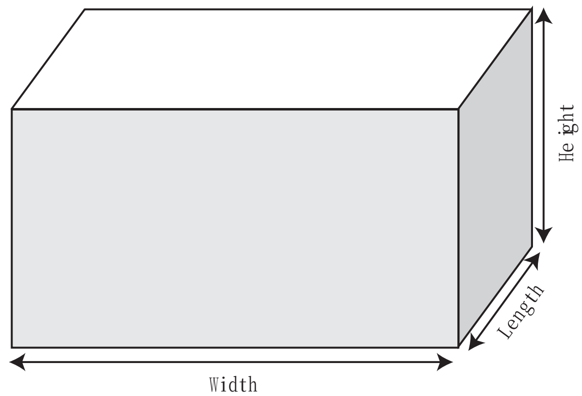
Fluid pathway analysis is associated with wells penetrating different compartments. Fluid in one compartment can be transported into other compartments through a well which is open to multiple stratigraphic horizons or geologic structures, such as faults. Therefore, DFNModeler will determine whether a how well placement may affect hydrologic communication among compartments that are separated geologically. All compartments that are connected to a well define the pathway of fluid migration from one compartment to another. For visual display, DFN modeler highlights compartments that are interconnected along a well path.

4) Visualization

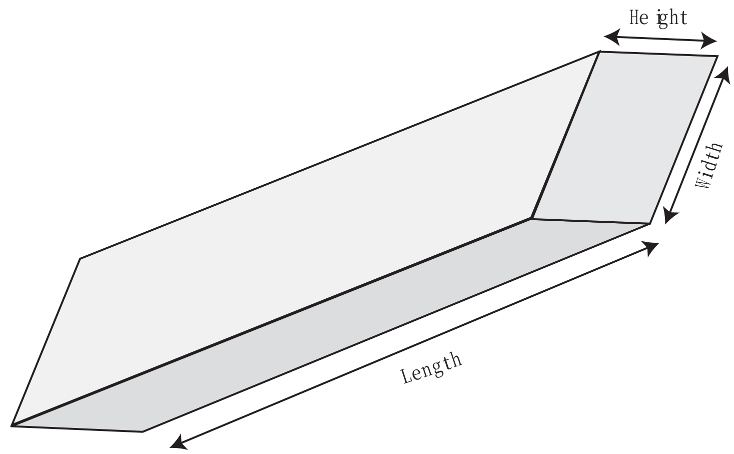
DFNModeler enables visualization of modeling results with the help of OpenGL graphic rendering techiques. OpenGL allows us to zoom in and out, translate, rotate, and vertically exaggerate a DFN model in real time. Apart from these standard visualization operations, DFNModeler can also color-contour fracture properties such as aperture, transmissivity, and storativity. In addition, variables such as color map and transparency can be customized.

5) Export

Import/export functionality is also implemented to enable DFNModeler to communicate with other modeling packages. For our implementation, we have chosen to export the fracture data in a text format that can be used by TOUGH2 for the modeling of fluid flow and solute transport.



A. Rectangular region



B. Slab region

Figure 2.—Types of fracture regions.

DFN MODELING IN THE BLACK WARRIOR BASIN

Our modeling efforts have focused on a site in Deerlick Creek Coal Degasification Field that was selected by the Southeastern Regional Carbon Sequestration Partnership (SECARB) to test the carbon sequestration and enhanced coalbed methane potential of coal in the Lower Pennsylvanian-age Pottsville Formation (Figure 3). The Pottsville Formation constitutes a thick succession of shale, sandstone, and coal. Pottsville coal beds are clustered in a series of coal zones, and most coalbed methane wells are completed in three Black Creek, Mary Lee, and Pratt coal zones. Coadbed methane and water are produced from the completed coal seams. Pottsville strata in the study area contain predominantly strata-bound joints, which were modeled based on statistical scaling rules for orientation, spacing, length, height, and kinematic aperture that were derived from outcrops and cores [2].

Stratigraphic control for the model is based on the geophysical well log of the Jobson 21-14 #11 well (State Oil and Gas Board of Alabama permit 4001-C), which is completed in the Black Creek, Mary Lee, and Pratt coal zones between depths of 2,488 and 1,340 feet. The well penetrates 96 layers of shale, sandstone, and coal in the Pottsville Formation, and coal beds constitute 16 of these layers.

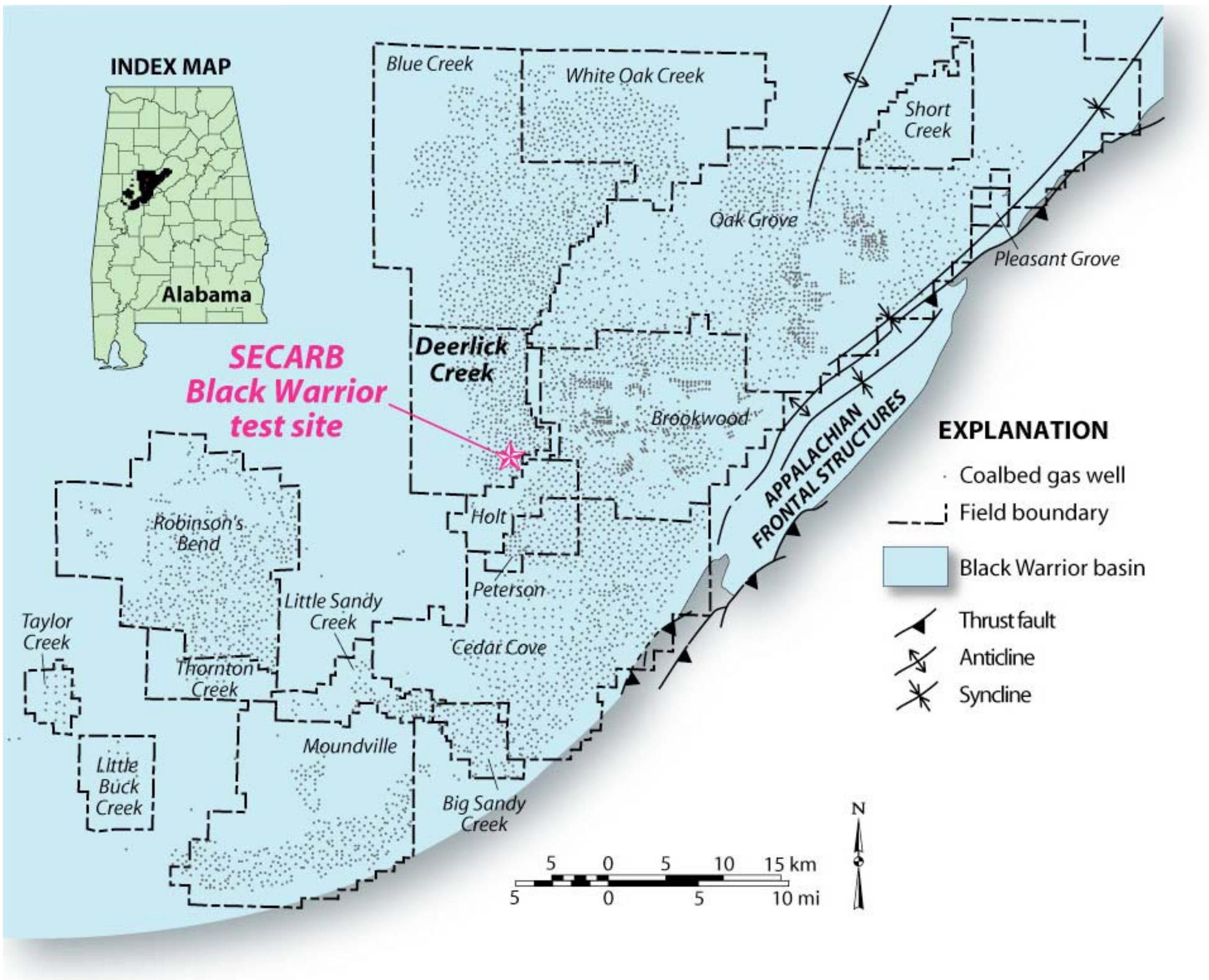


Figure 3.—Location of the SECARB Black Warrior test site in Deerlick Creek Field, Black Warrior basin, Alabama.

The area represented by the DFN model is 2 km^2. Each sandstone and shale unit is modeled as a fracture region. Within each shale and sandstone unit, systematic joints trending with a vector-mean azimuth of 55° NE, and cross joints are strike perpendicular to the systematic joints. All joints are modeled as strata-bound, and a strong tendency for younger joints to terminate at preexisting joints constrains fracture length. Fracture spacing was modeled as has a logarithmic relationship to bed thickness based on outcrop data. Core data indicate that fracture aperture follows an exponential function.

Figure 4 illustrates the resulting DFN model. For scale, four vertical wells were included in the model at a 40-acre spacing, which is typical of well spacing in Deerlick Creek Field. The thickest and most widely spaced strata-bound joint systems are in the thick marine shale that separate most Pottsville coal zones. Figure 5 shows a model that isolates the coal seams, and the seams are color contoured by storativity; the decrease of storativity downward in section reflects a loss of porosity with depth.

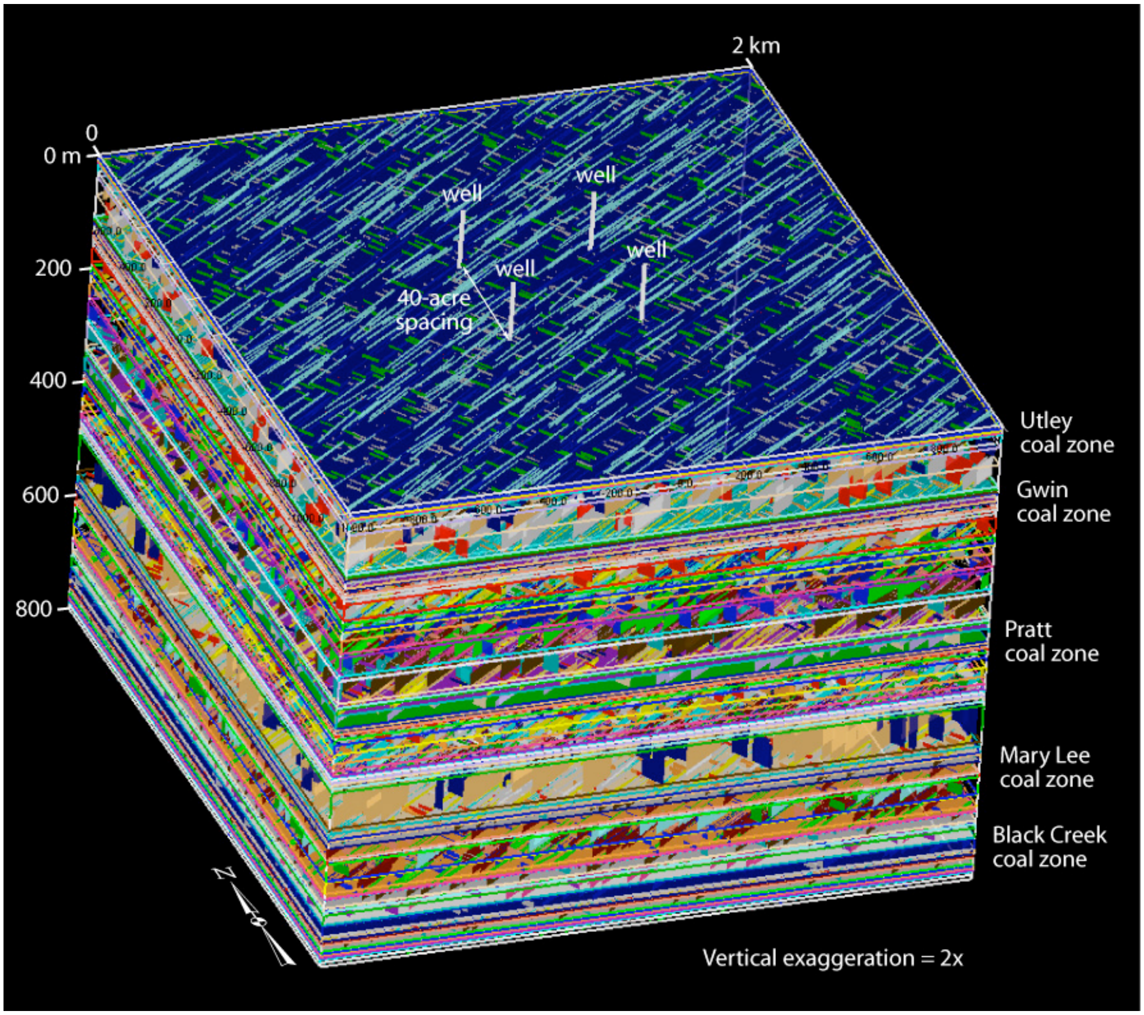


Figure 4.—Jointed DFN model based on stratigraphic relationships in the Jobson 24-14 #11 well and observations of fractures in core and outcrop.

Compartmentalization analysis of the DFN model highlights some basic relationships between the economic coal zones and the intervening siliciclastic strata (Figure 6). Coal beds and the networks of joints that are connected to the coals form large, first-order reservoir compartments. Closely spaced coal beds that are interconnected by joints fall within the same hydrologic compartments. Accordingly, the Mary Lee and Black Creek coal zones constitute a deep reservoir compartment, the Pratt coal zone constitutes an intermediate reservoir compartment, and the Gwin and Utley coal zones constitute a shallow compartment. The thick intervals of interbedded shale and sandstone separating the major compartments contain clusters of interconnected joints that are isolated hydrologically from coal.

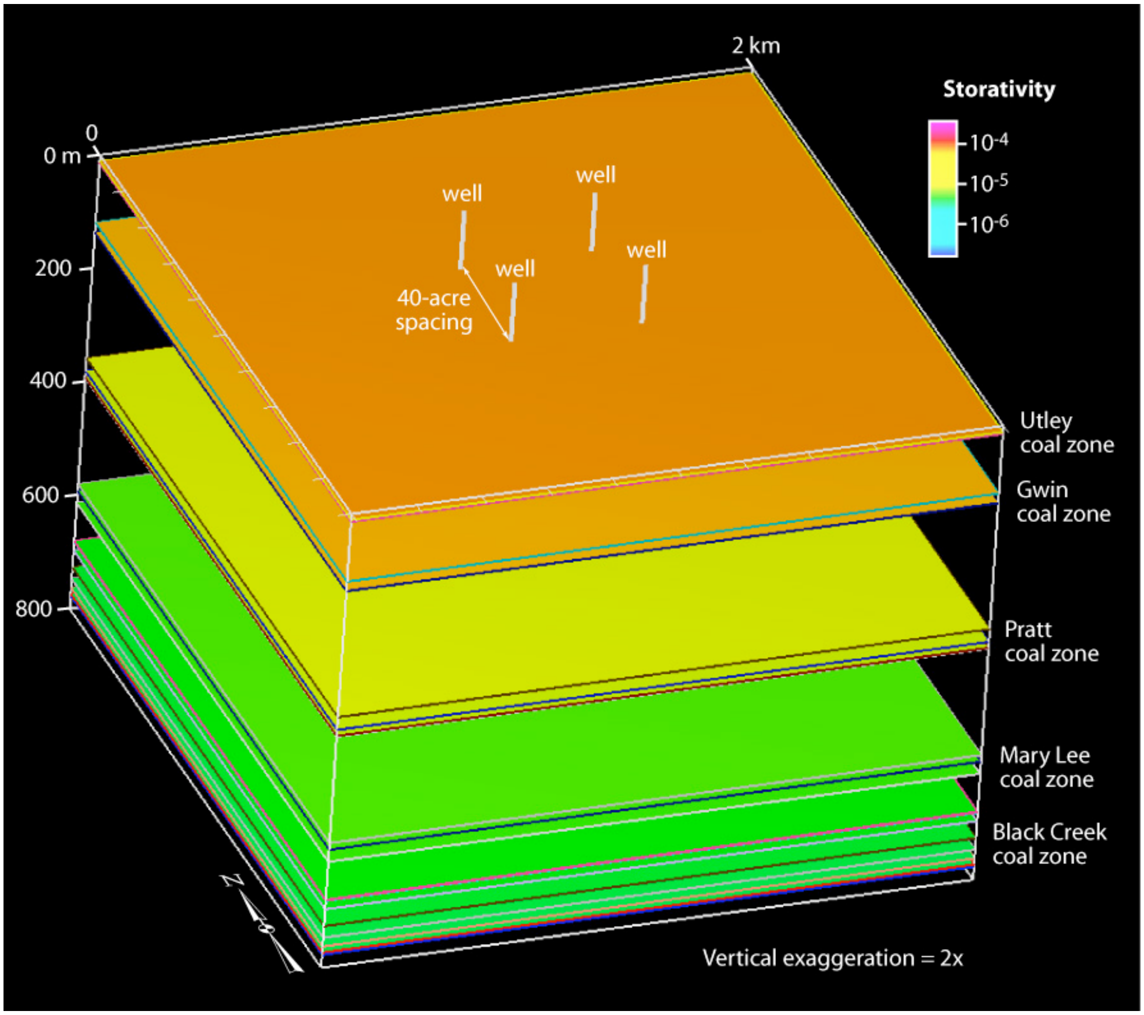


Figure 5.—Storativity model of coal beds in the Jobson 24-14 #11 well.

CONCLUSIONS

DFNModeler software provides a user-friendly interface that enables users to enter and edit fracture data, generate discrete fracture networks, analyze compartmentalization of fractures, and visualize the result with ease. Accuracy, efficiency, and reliability are three important factors that guided software development. DFNModeler can generate extremely large discrete fracture network models. For example, the Black Warrior models generated for this investigation contain more than 120,000 fractures and can be generated in less than a minute on a 3.0 gigahertz Pentium 4 computer with 1 gigabyte RAM.

The DFN model for the Black Warrior basin indicates that the Pottsville hydrologic system is highly compartmentalized. First-order compartments envelop the reservoir coal zones and are separated by thick marine shale units, which appear to function as sealing strata. Based on this model, hydrologic communication can be expected among closely spaced coal seams, but thick marine shale units help limit the risk of major cross-formational flow during carbon sequestration and enhanced coalbed methane recovery operations.

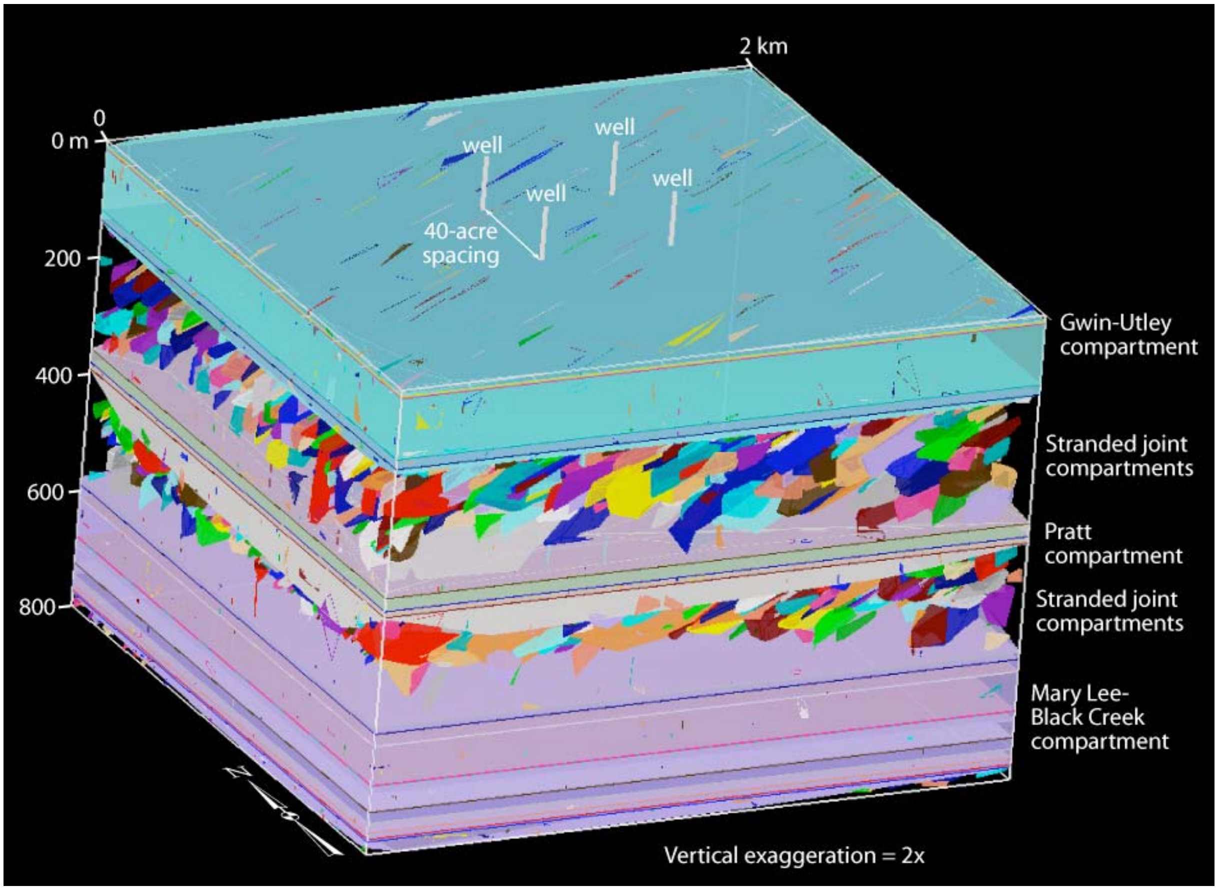


Figure 6.—Results of compartmentalization analysis. Note that shallow coal zones are in a compartment that is separate from the reservoir coal zones and that small, stranded joint compartments are stranded between the major reservoir compartments.

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[1] Guohai Jin, Pashin, J. C., and Payton, J. W., 2003, Application of discrete fracture network models to coalbed methane reservoirs of the Back Warrior Basin: Tuscaloosa, Alabama, University of Alabama College of Continuing Studies, 2003 International Coalbed Methane Symposium Proceedings, Paper 0321, 13 p.

[2] Pashin, J. C., Guohai Jin, and Payton, J. W., 2004, Three-dimensional computer models of natural and induced fractures in coalbed methane reservoirs of the Black Warrior Basin: Alabama Geological Survey Bulletin 174, 62 p.