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Carbon Sequestration and Enhanced Coalbed Methane Recovery Potential of the Cahaba and Coosa Coalfields in the Southern Appalachian Thrust Belt

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ABSTRACT

Pennsylvanian coal-bearing strata in the Pottsville Formation of the Black Warrior basin in Alabama have been recognized as having significant potential for carbon sequestration and enhanced coalbed methane recovery, and additional potential may exist in Pottsville strata in smaller coalfields within the Appalachian thrust belt in Alabama. The Coosa and Cahaba coalfields contain as much as 8,500 feet of Pennsylvanian-age coal-bearing strata, and economic coal and coalbed methane resources are distributed among multiple coal seams ranging in thickness from 1 to 12 feet. In the Coosa coalfield, 15 named coal beds are concentrated in the upper 1,500 feet of the Pottsville Formation. In the Cahaba coalfield, by comparison, coal is distributed through 20 coal zones that span nearly the complete Pottsville section. Limited coalbed methane development has taken place in the Coosa coalfield, but proximity of a major Portland cement plant to the part of the coalfield with the greatest coalbed methane potential may present an attractive opportunity for carbon sequestration and enhanced coalbed methane recovery. In the Coosa coalfield, coalbed methane and carbon sequestration potential are restricted to the Coal City basin, where data from 10 coalbed methane wells and 24 exploratory core holes are available for assessment. Because of its relatively small area, the Coal City basin offers limited potential for carbon sequestration, although the potential for coalbed methane development remains significant. The southwestern Cahaba coalfield is the site of intense coalbed methane development, and data from 599 wells were used to assess the carbon sequestration and enhanced recovery potential. The Cahaba coalfield not only has significant coalbed methane resources but it also offers significant carbon sequestration potential.

INTRODUCTION

Significant potential for carbon sequestration and enhanced coalbed methane (ECBM) recovery has been identified in the Black Warrior Basin of Alabama, and additional opportunities may exist in the Cahaba and Coosa coalfields of the nearby Appalachian thrust belt (fig. 1). Both coalfields are within 50 miles of major sources of atmospheric CO_2 emissions, including coal-fired power plants and a major Portland cement plant. Accordingly, the Cahaba and Coosa coalfields can potentially play an important role in reducing the region's greenhouse gas emissions through carbon sequestration while expanding the reserve base for coalbed methane through CO_2-enhanced coalbed methane recovery. With the sponsorship of the Southeastern Regional Carbon Sequestration Partnership, we have conducted a detailed assessment of the sequestration capacity and enhanced coalbed methane recovery potential of the Cahaba and Coosa coalfields.

The Cahaba and Coosa coalfields are located in the Appalachian thrust belt in central Alabama (fig 1). One coal degasification field is active in Cahaba coalfield (Gurnee Field) and 11 coalbed methane (CBM) wells have been drilled in the Coosa coalfield. The closely spaced wells in the southwestern part of the

Cahaba coalfield facilitate detailed study. Moreover, the 11 coalbed methane wells, along with 24 cores drilled in the 1940s [1] provide data for the study of the Coosa coalfield. The coalfields are in elongate synclines defined on the northern, western, and southern sides by the up-dip limits of the coal bearing rocks of the Lower Pennsylvanian Pottsville Formation and on the southeast by major thrust faults of the Appalachian orogenic belt. The Pottsville Formation in Alabama is composed principally of shale, sandstone, and coal and is locally thicker than 8,500 feet [2, 3, 4]. Numerous coal beds are distributed throughout the Pottsville section in the Coosa and Cahaba coalfields (fig. 2).

METHODS

Stratigraphic and structural data were collected from geophysical well logs and compiled in spreadsheets for both the Cahaba and Coosa coalfields. Well locations were calculated from surveyed line calls on file at the State Oil and Gas Board of Alabama. Stratigraphic data include regionally extensive stratigraphic markers that were used to define coal zones and net coal thickness within each coal zone. Coal beds less than 1 foot thick are generally not completed in CBM wells and were not included in the determination of net coal thickness. In the Coosa coalfield, data were compiled from 10 geophysical well logs in the files of the State Oil and Gas Board of Alabama and from written logs of 24 core holes and a geologic map that were published by Rothrock [1]. In the Cahaba coalfield, data from 599 well logs on file at the State Oil and Gas Board of Alabama were compiled.

Structural data include the elevation of stratigraphic markers and information on fault cuts. Marker elevation was determined by subtracting depth from the datum from which the well log was measured, which is typically ground level. Information on fault cuts includes depth, elevation, estimated vertical displacement, and juxtaposed coal zones. Structure contour and coal thickness maps were generated using a minimum curvature algorithm in PETRA software.

Proximate analyses published by Rothrock [1] were analyzed to determine the relationship between coal rank and depth in the Coosa coalfield. Rank data from the Cahaba coalfield were used to determine the rank-depth relationships. A map of volatile matter content for each coal zone was made using PETRA.

Geothermic information from 14 wells in the Cahaba coalfield was obtained from the headers of geophysical well logs and was compiled in a spreadsheet with the stratigraphic and structural data. The geothermal gradient for each well was calculated. Care was taken to eliminate anomalously low bottom-hole temperature readings on the basis of unrealistically low geothermal gradient (less than 6.0°F per 1,000 feet). No bottom-hole temperature data were available for the Coosa coalfield; therefore, the Cahaba temperature-depth relationship was used in the Coosa field.

The potential for CO_2 sequestration and enhanced coalbed methane recovery in the Cahaba and Coosa coalfields was estimated using grid-math techniques in PETRA. Using relationships of gas sorption to rank derived by Pashin and others [5] for the Black Warrior basin, the sorption capacity of each coal zone was computed for CO_2 and CH_4 in scf/ton at a temperature of 80° F (26.7C) and pressures of 50, 100, and 350 psi. Temperature-correction maps were created using the temperature maps and the temperature-correction equations from Pashin and others [5]. Total gas sorption capacity was calculated for each coal zone at each pressure. Finally, the grids of adsorption capacity were added to derive total sequestration and enhanced recovery values for each coalfield.

COOSA COALFIELD

Stratigraphy

The Pottsville Formation of the Coosa coalfield has been divided into three magnafacies by Pashin [4]. In the Coosa coalfield there are approximately 20 informal coal beds or zones (fig. 2). Coal resources are concentrated in the mudstone measures, which are the primary focus for coalbed methane development and assessment of sequestration potential. A total of 15 named coal beds are in the mudstone measures, which have been grouped for convenience into three coal zones: Coal City, Bibby, and Fairview (fig. 2).

Over 20 individual completeable coal beds exist in the Coosa coalfield and have a net thickness up to 27 feet (fig. 3). Net coal thickness increases in the structurally deeper portions of the basin due in part to the thicker section of coal–bearing rocks. The coal intervals are continuous throughout the basin; however the continuity of an individual coal seam is unknown for most of the basin. The named coal beds/intervals often comprise more than one coal seam. Seam thickness can vary from several inches to a couple of feet. The average thickness of the Coal City group is 8 feet; the Bibby group averages 6 feet; and the Fairview group's average is 7 feet.

Coal rank data are available from 24 cores, as well as several surface and mine exposures in the Coosa coalfield. Coals sampled at or near the surface range from 23 to 31 percent volatile matter [6], making them medium-volatile bituminous coals. Rank generally increases (decrease in volatile matter percent) with depth but remains in the medium-volatile range. Ash content in the Coosa field is between 3 percent and 48 percent and averages 13.6 percent [6]. Ash content increases slightly with depth. Ash content is highly variable within and between the individual coal beds. Sulfur content varies between 0.6 and 7.2 percent with an average of 3.4 percent [6]. In the Coosa coalfield sulfur content shows a slight increase with depth and average sulfur content per coal seam appears to decrease slightly with stratigraphic age. Sulfur content varies as much as 6 percent between samples of a single bed; therefore, it is difficult to draw conclusions about the relationship between sulfur content and age.

Structure

The area of potential coalbed methane production is the Coal City basin, a doubly plunging syncline bordered to the southeast by the Eden thrust fault, to the east by the Fairview thrust fault, and to the north, west and southwest by the outcrop of the Gann coal seam (fig. 4). Beyond the up-dip limit of the Gann coal seam there is insufficient coal for CBM exploration. The area of potential CBM exploration encompasses most of the Coal City and Fairview basins. A structure contour map of the top of the Gann coal zone shows a doubly plunging footwall syncline cut by four normal faults roughly perpendicular to the Eden and Fairview thrust faults (fig. 4). Cross-section A-A', parallel to the synclinal axis, shows the offset of these normal faults and doubly plunging form of the syncline (fig. 5). Cross-sections B, C, and D are perpendicular to the thrust faults and show the asymmetry of the footwall syncline. The normal faults have displacements ranging from 100 to 600 feet. Bedding dips average 11° in the northwestern limb of the syncline and range from 10° to 89° in the southeastern limb.

CAHABA COALFIELD

Stratigraphy

The Pottsville Formation of the Cahaba coalfield has been divided into three magnafacies by Pashin and Carroll [7] and Pashin and others [3]. Coal beds, and producible coalbed methane, are found throughout the Pottsville Formation. In the Cahaba coalfield there are approximately 20 informal coal zones. For the purposes of coalbed methane resource assessment and sequestration potential the coal was grouped into six coal zones: the Maylene, Yeshic, Thompson, Coke, Big Bone, and Nunnally groups (fig. 2).

Net coal thickness ranges from less than 2 feet to 62 feet (fig. 8). Net coal thickness is generally greater to the southeast but is highly variable. Individual coal beds have highly variable thicknesses. While many are not continuous over the study area, seams in similar stratigraphic positions can be traced over the study area. The net thickness of the coal groups follows a pattern similar to that of the total net thickness and ranges from less than a foot to 22 feet.

In the Cahaba field, coal rank at the surface ranges from high-volatile A to high-volatile C bituminous with volatile matter ranging from 44 to 32 percent (fig. 9). In general, isovols parallel structure but in some areas they cross structures. These differences in the relationship of coal rank to structure indicate complex burial and thermal histories in the Cahaba coalfield. Rank increases with depth from high-volatile A and B bituminous to medium-volatile and low-volatile bituminous at depth. In the Cahaba coalfield, coal mineral matter consists of clay, pyrite, calcite, and quartz. Ash content, excluding sulfur minerals which are reported separately, in the Cahaba coalfield ranges from less than 2 percent to 50 percent by weight. Fifty percent by weight is, by definition, the upper limit for coal. Mean ash, as calculated for log-normally distributed data, is 6.76 weight percent. Ash content varies significantly with depth and may indicate factors influencing swamp development during deposition [3]. The sulfur content of coal, usually pyritic and organic, is the most important factor affecting the marketability of a coal. Data for the Cahaba coal basin generally does not discriminate between organic and inorganic sulfur. Sulfur content ranges from 0.1 percent to 7.5 percent by weight with a log-normal mean of 0.85 percent. Ash content and sulfur content do not appear related in the Cahaba basin. Sulfur content generally increases with depth [3].

Structure

The Cahaba coalfield is in the southeastern portion of the Cahaba synclinorium in the Appalachian thrust belt. The synclinorium is bounded to the northwest by the Birmingham anticlinorium and to the southeast by the Helena thrust fault (fig. 1). Gurnee field is in the southern part of the Cahaba synclinorium. This area contains open folds and minor thrust faults as seen on the structure contour map (fig. 10) and cross sections (fig. 11). The reservoir strata dip an average of 10° with a range of dips from 0° to overturned.

SEQUESTRATION AND ENHANCED RECOVERY POTENTIAL

Based on sorption-rank relationships, the CH_4 capacity of coal in the Coosa coalfield ranges from 40 to 70 scf/t at 50 psi, which reflects the narrow range of rank in this area. At a pressure of 350 psi, the CO_2 capacity is estimated to range from 560 to 620 scf/t. The temperature-corrected gas capacity for coal in the mudstone measures averages 0.77 MMcf/acre of CH_4 at 50 psi and exceeds 2.00 MMcf/acre in the structurally deepest part of the coalfield (fig. 6, Table 1). The prospective part of the Coosa coalfield can store an average of 8.7 MMcf/acre of CO_2 at 350 psi, and capacity is as high as 25.0 MMcf/acre (fig 7, Table 1). Should the coalbed methane resources of the Coal City Basin be produced, an estimated 6.6 Bcf will be left in the reservoir at a mature reservoir pressure of 50 psi. The volume of CO_2 which can be sequestered at 350 psi is an estimated 70.7 Bcf (Table 1).

The overall rank-estimated CH_4 capacity of southwestern Cahaba coalfield ranges from 200 to 300 scf/t at 50 psi (fig. 12). The estimated volume of CH_4 left in the Cahaba coalfield at 50 psi is 239 BCF (Table 2). The rank estimated CO_2 capacity averages 598 scf/t at 350 psi in the Big Bone group (fig. 13). The volume of CO_2 which can be sequestered at 350 psi ranges in the coal groups from 164 BCF to 605 BCF, for a total of 2170 BCF of CO_2 at 350 psi (Table 2). Based on Telle and Thompson's [8, 9] original gas in place estimates (1.75 Tcf), 0.5% of the gas in place has been extracted. Gurnee Coal degasification field is currently being redeveloped with approximately 293 wells having been permitted in the last 5 years.

CONCLUSIONS

With proximity to existing CBM development and major CO_2 sources, the Coosa and Cahaba coalfields are attractive opportunities for CBM and ECBM development, and CO_2 sequestration. The Coal City Basin of the Coosa coalfield offers significant potential for CBM production (40 Bcf [10]). At a mature reservoir pressure of 50 psi approximately 6.6 Bcf of methane will remain in the formation making ECBM attractive in the Coosa coalfield. However, the Coosa coalfield is not an attractive target for CO_2 sequestration without CBM production due to its small size. The Cahaba coalfield has both significant reserves of methane and CO_2 sequestration potential. Based on original gas in place estimates and production figures, 1.74 Tcf of CH_4 remains in the Cahaba coalfield. Additionally, the Cahaba coal basin has no areas that must be avoided in CO_2 sequestration due to normal faulting; therefore, despite being much smaller than the Black Warrior basin, the volumes of gas calculated for the Cahaba basin are considerable when compared to those calculated for the same size area of the Black Warrior Basin [5]. The technically feasible CO_2 sequestration potential of the Black Warrior basin is 6.1 Tcf [5]. The volume of CO_2 that can be sequestered in the Cahaba coal basin at an equilibrated reservoir pressure of 350 psi is 2.17 Tcf. The addition of the Cahaba coal basin increases the CO_2 sequestration potential of the region by approximately 36% to 7.8 Tcf.

ACKNOWLEDGEMENTS

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Coal Group		Coal City Group Total Area 6,695 acres		Bibby Group Total Area 8,120 acres		Fairview Group Total Area 8,215 acres		TOTAL
Gas	Pressure (psi)	Volume (Bcf)	Avg MMcf/acre	Volume (Bcf)	Avg MMcf/acre	Volume (Bcf)	Avg MMcf/acre	Volume (Bcf)
CH_4	50	1.8	0.27	2.1	0.26	2.7	0.33	6.6
CH_4	100	3.4	0.50	4.0	0.49	5.0	0.61	12.4
CO_2	350	18.8	2.81	23.6	2.90	28.3	3.45	70.7

Table 1. Average sorption capacities and total volume of gas for the Coosa coalfield.

Coal Group		Yeshic Group Total Area 48,042 acres		Thompson Group Total Area 57,228 acres		Coke Group Total Area 68,759 acres		Big Bone Group Total Area 80,003 acres		Nunnally Group Total Area 67,974 acres		**Total**
Gas	Pressure (psi)	Volume (Bcf)	Avg MMcf/ acre	Volume (Bcf)	Avg MMcf/ acre	Volume (Bcf)	Avg MMcf/ acre	Volume (Bcf)	Avg MMcf/ acre	Volume (Bcf)	Avg MMcf/ acre	Volume (Bcf)
CH_4	50	14	0.30	27	0.47	51	0.74	61	0.76	57	0.83	239
CH_4	100	27	0.56	50	0.87	95	1.39	114	1.43	107	1.57	393
CO_2	350	164	3.41	296	5.18	533	7.75	605	7.56	573	8.42	2170

Table 2. Average sorption capacities and total volume of gas for the Cahaba coalfield.

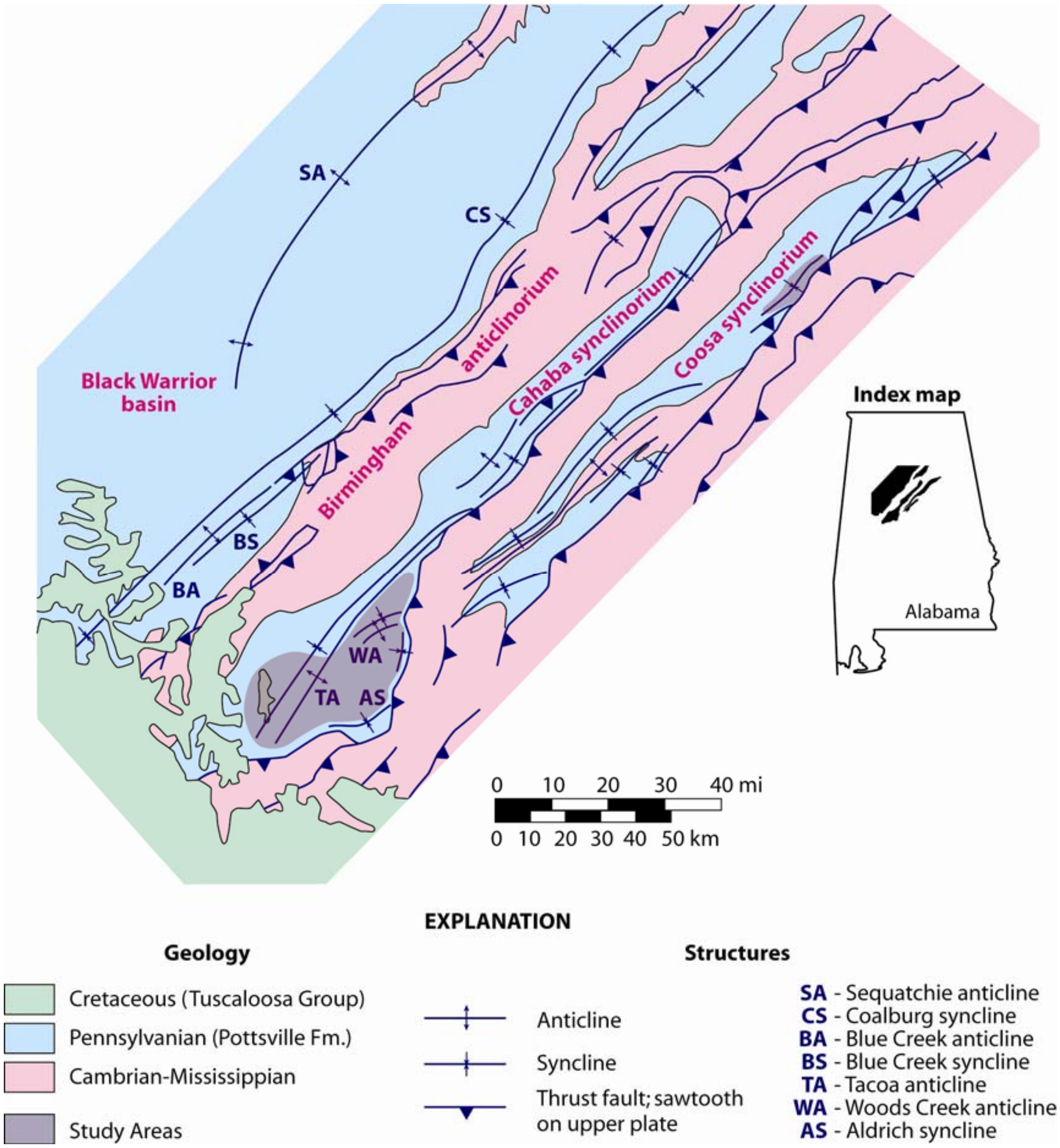

Figure 1. Location of the Cahaba and Coosa coalfields in the southern Appalachian thrust belt of Alabama.

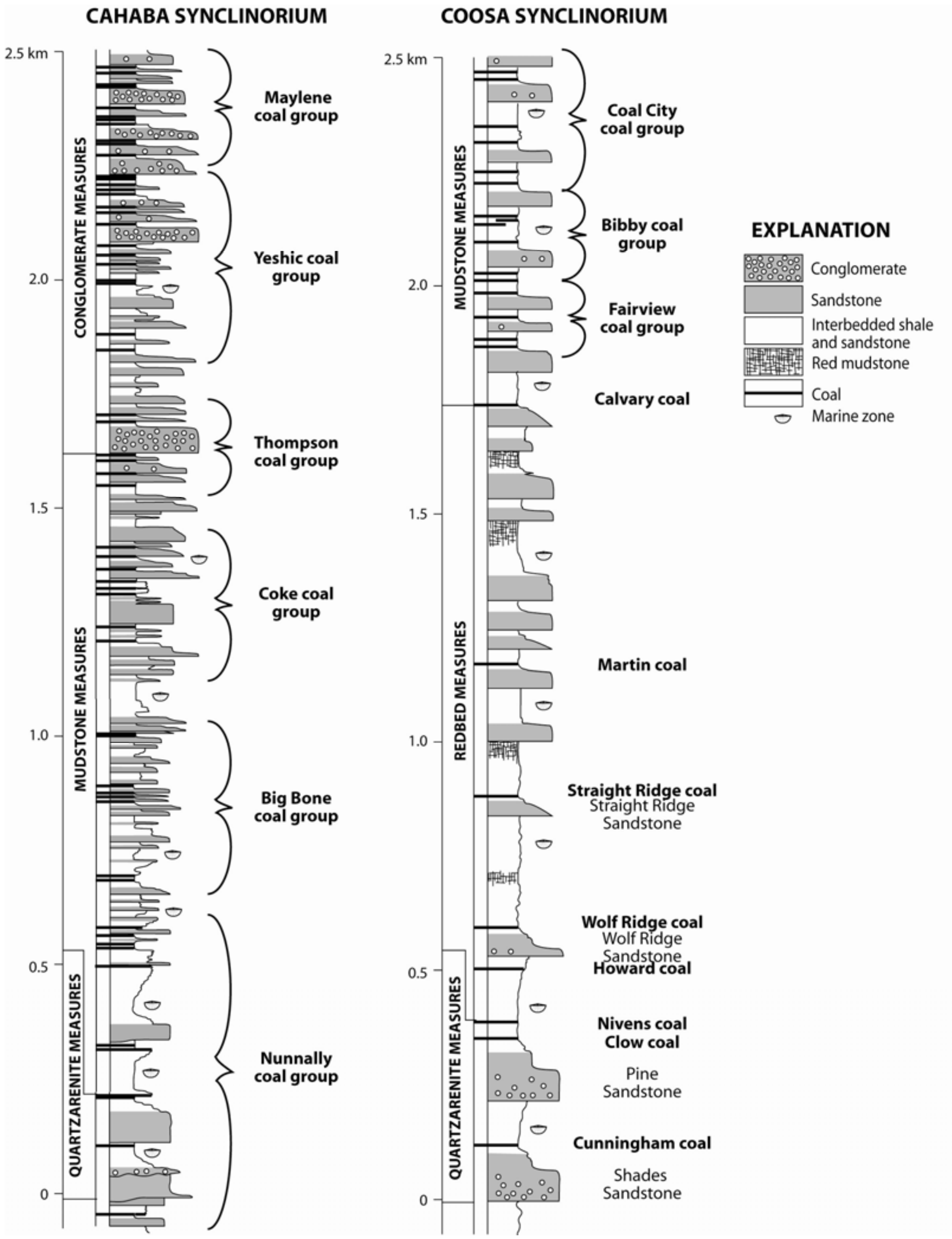

Figure 2. Stratigraphic column for the Coosa coalfield (modified from Pashin, 1997).

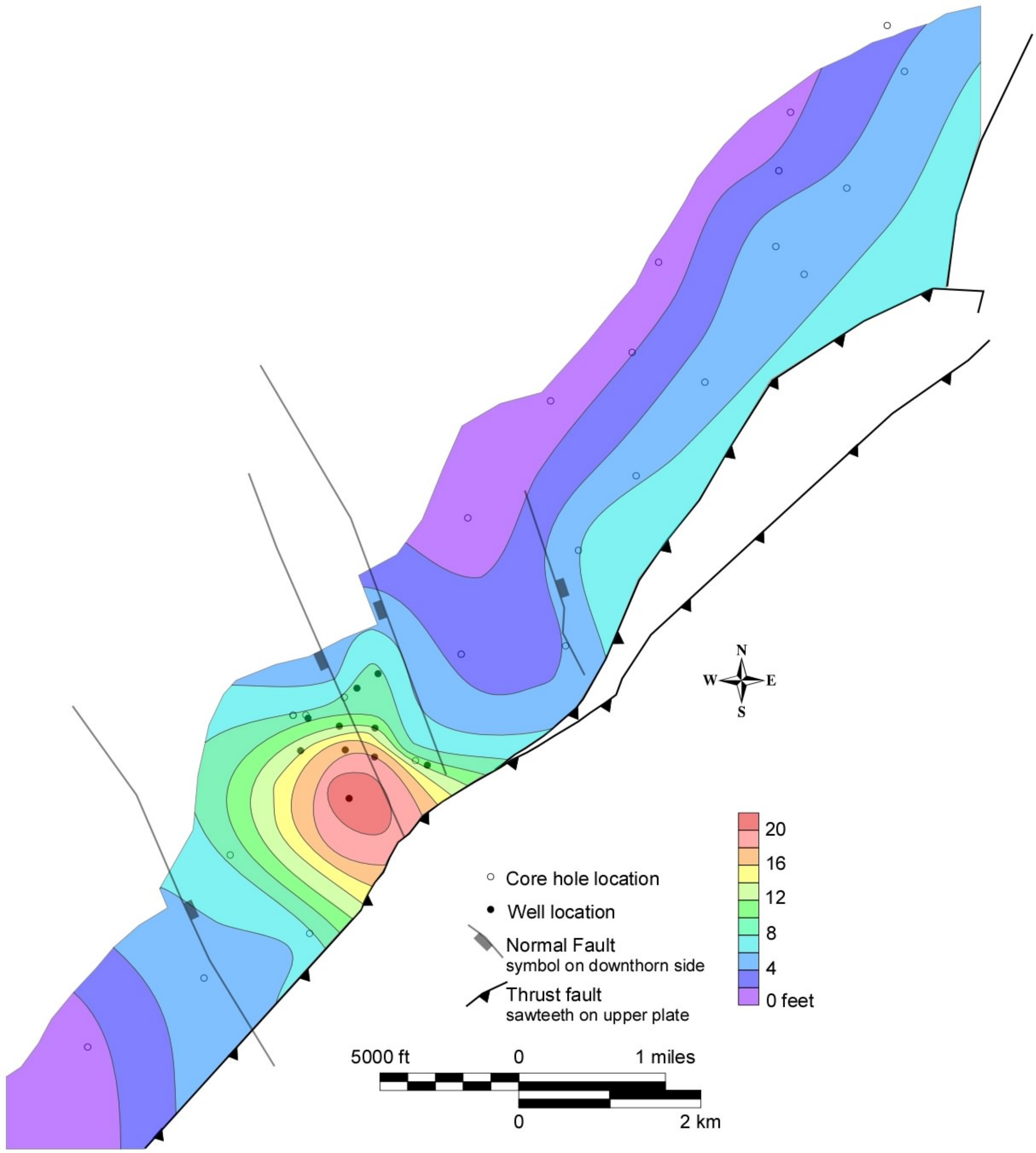

Figure 3. Net coal isolith map of the mudstone measures in the Coal City Basin of the Coosa coal-field.

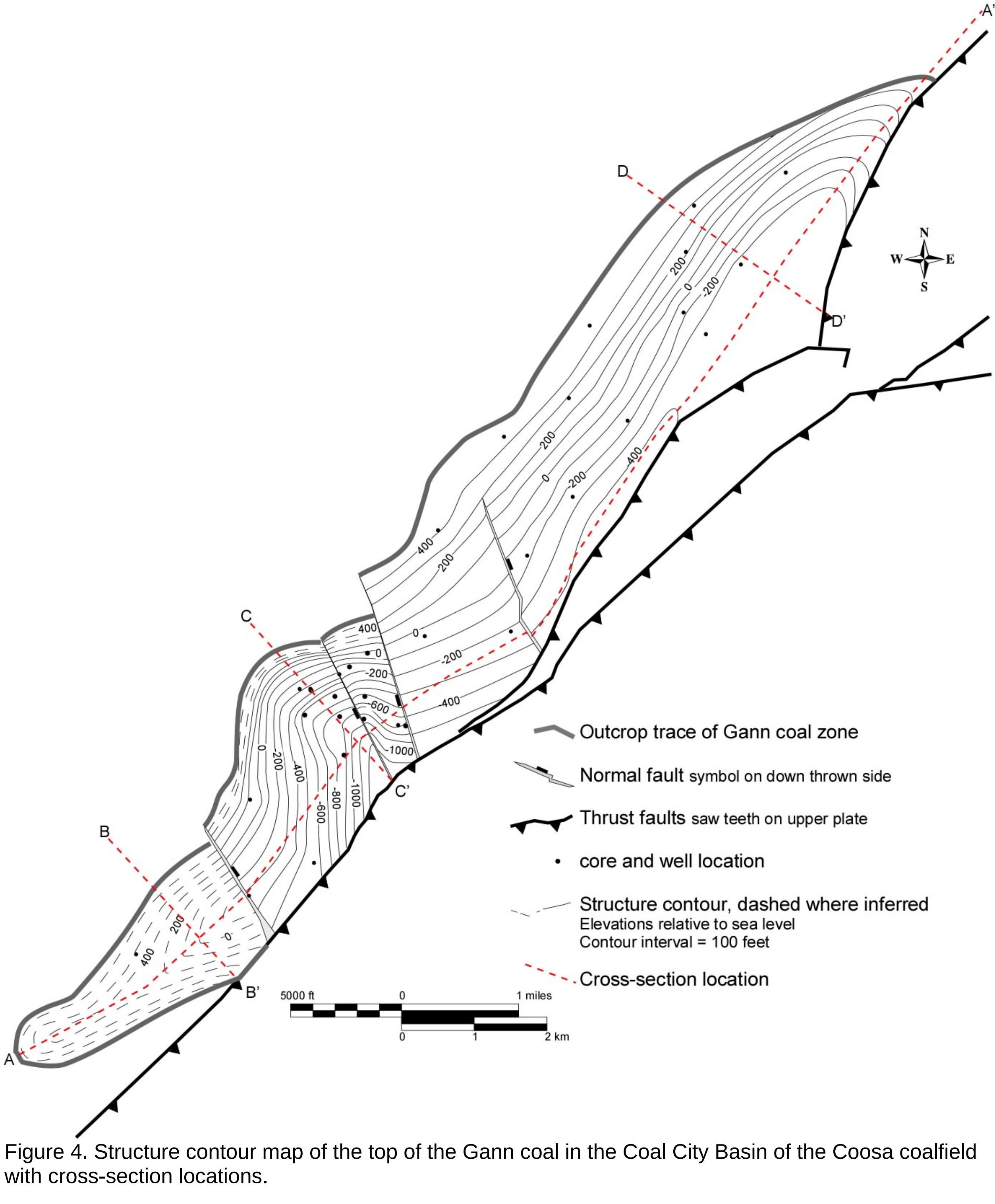

Figure 4. Structure contour map of the top of the Gann coal in the Coal City Basin of the Coosa coalfield with cross-section locations.

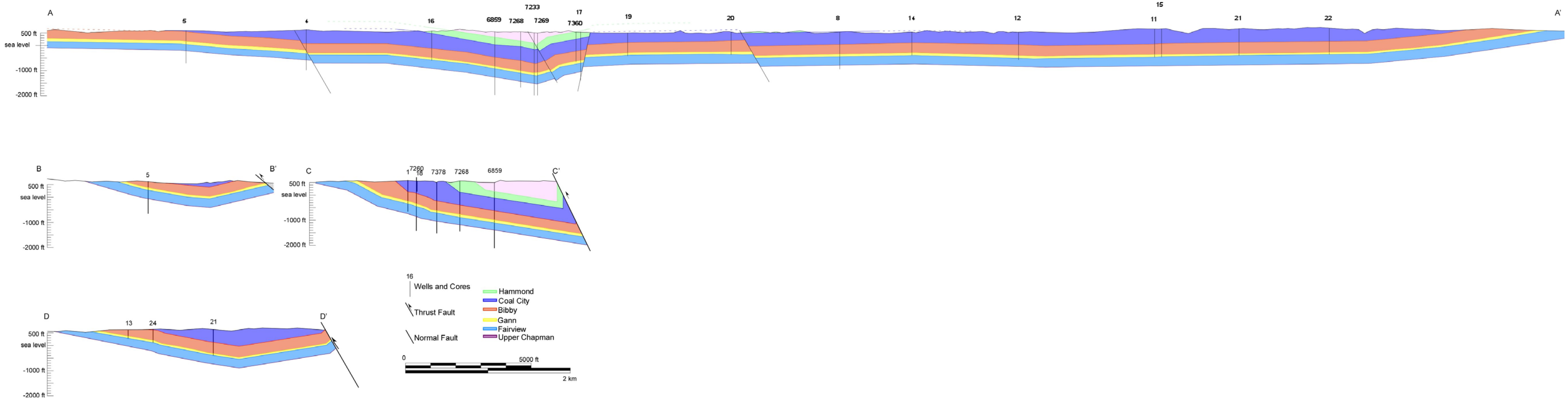

Figure 5. Structural cross-sections of the mudstone measures in the Coal City Basin of the Coosa coalfield. See Figure 4 for location. No vertical exaggeration.

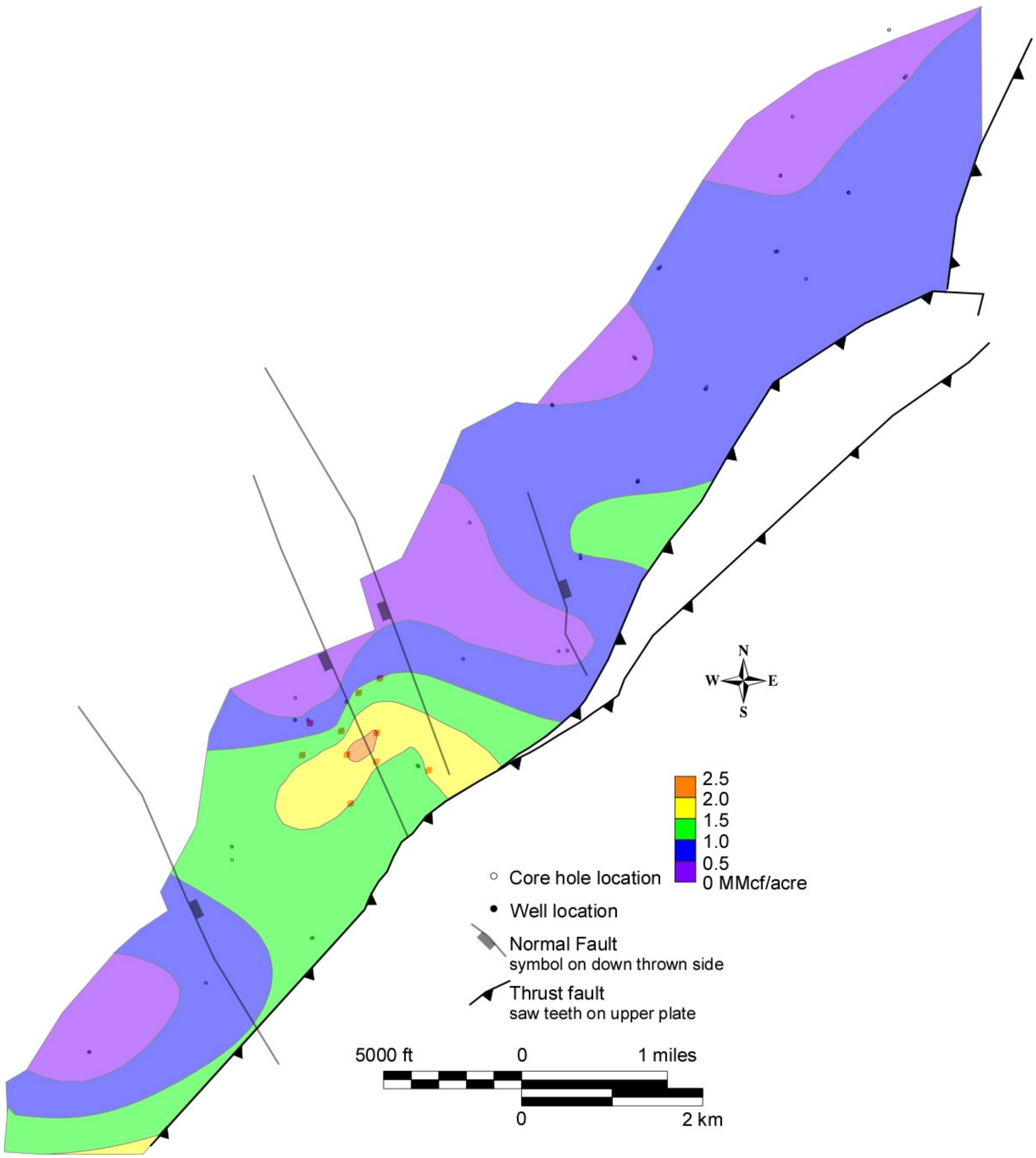

Figure 6. Estimated amount of CH_4 at 50 psi in the Coal City Basin.

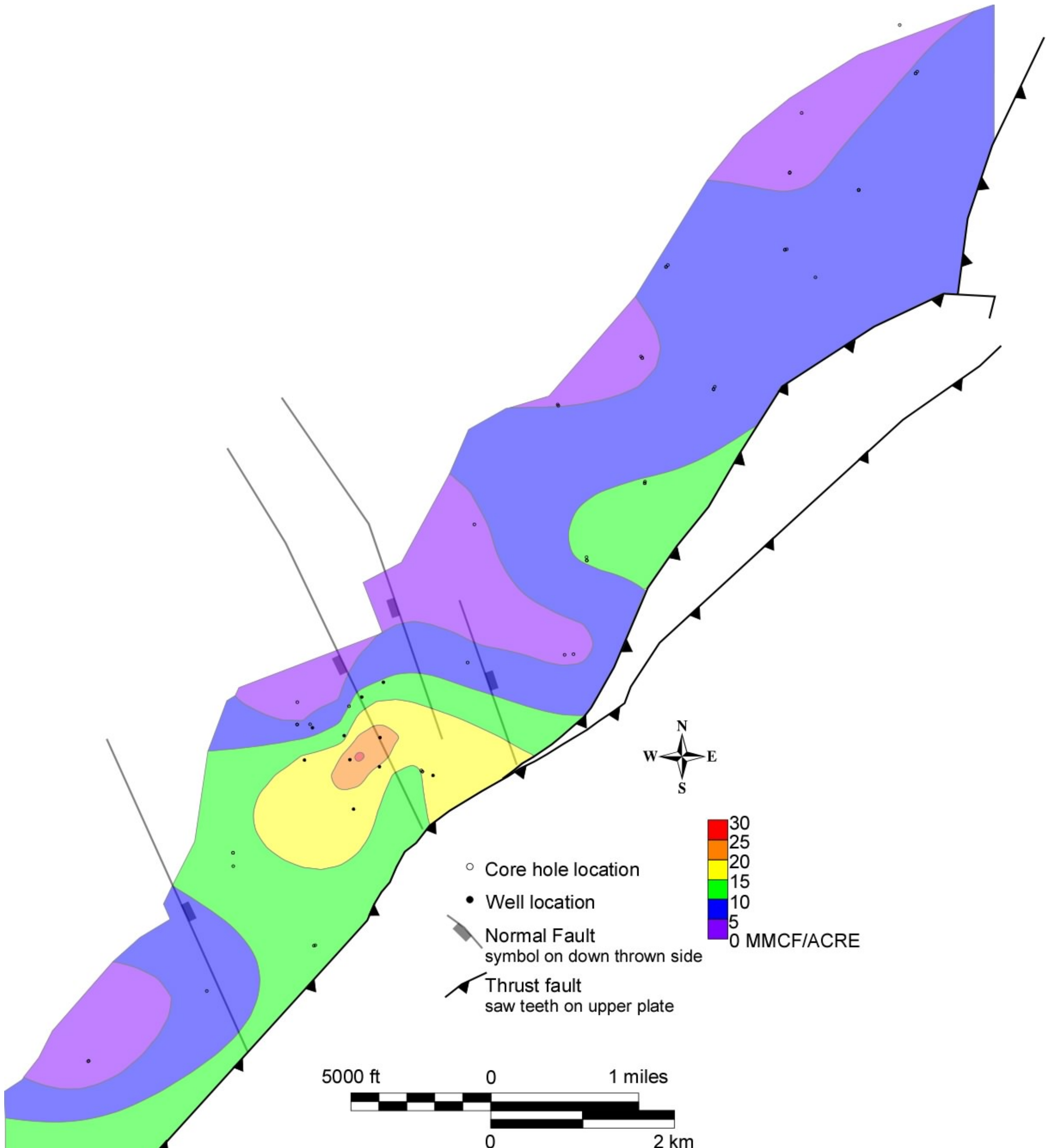

Figure 7. Estimated capacity of coal to sequester CO_2 at 350 psi in the Coal City Basin of the Coosa coalfield.

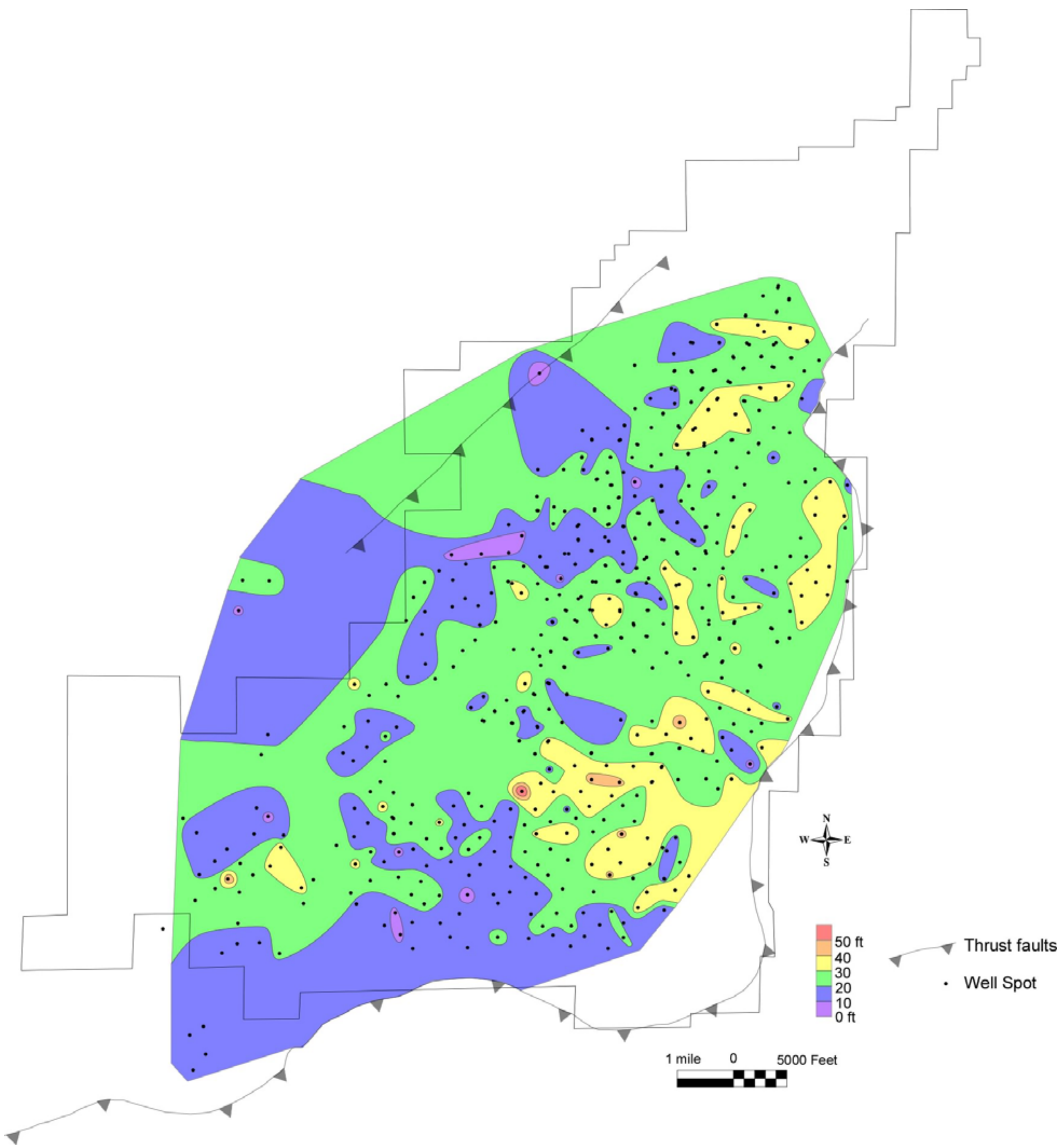

Figure 8. Net coal isolith map of the Nunnally through Yeshic groups in the southwestern Cahaba coal field.

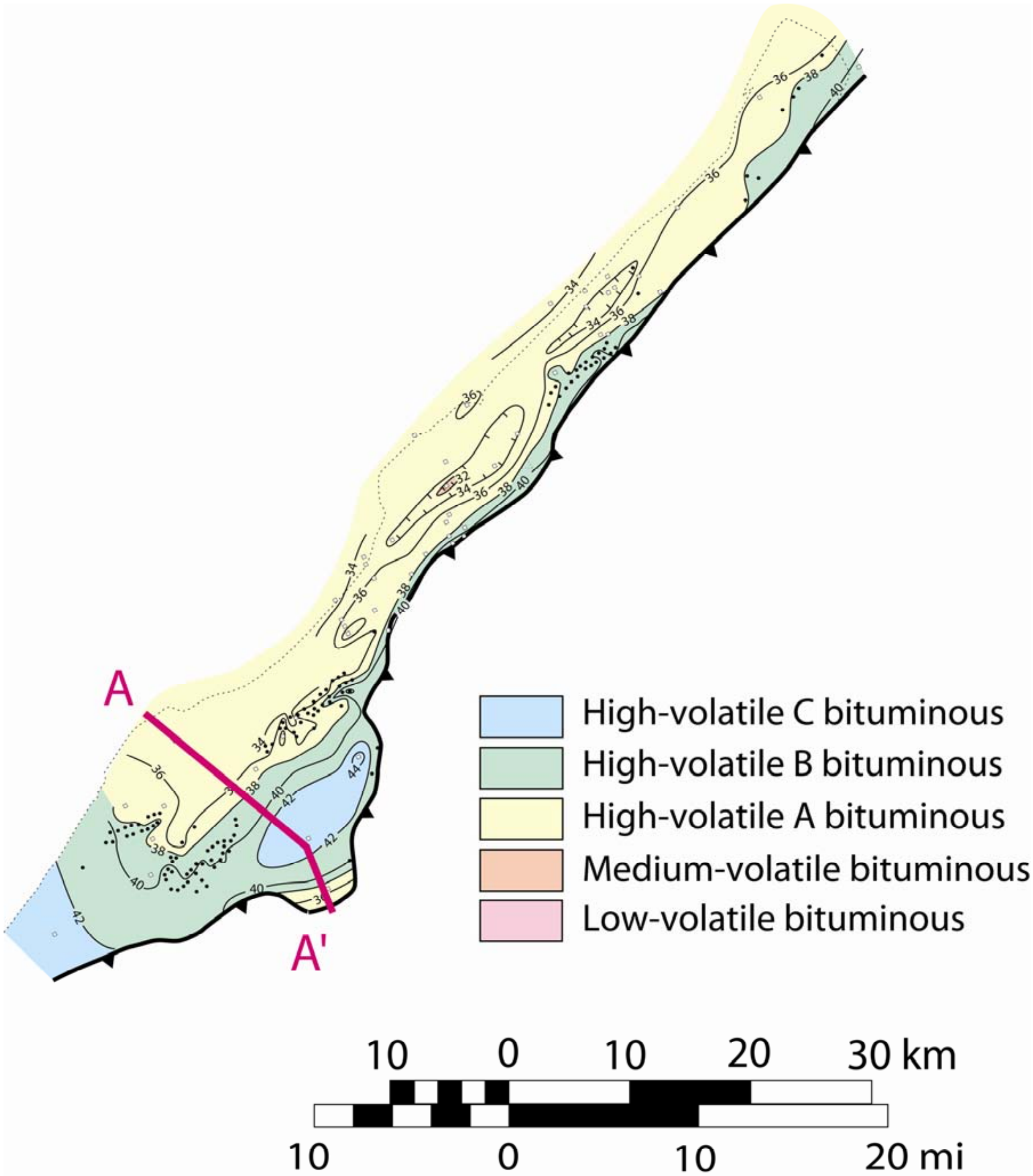

Figure 9. Isovol map showing coal rank in the Cahaba coalfield (modified from Pashin and others, 1999).

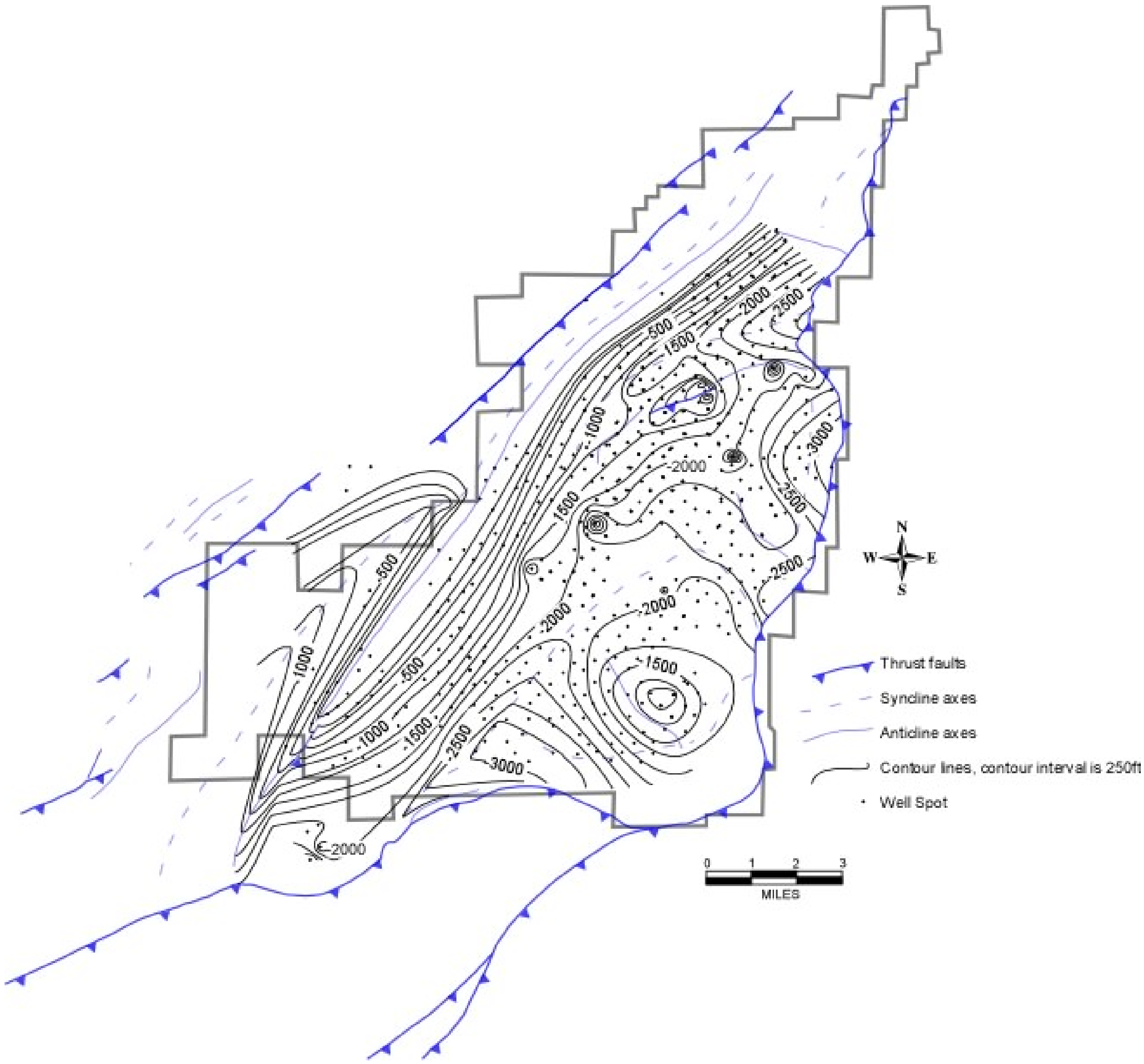

Figure 10. Structure contour map of the top of the Big Bone coal zone.

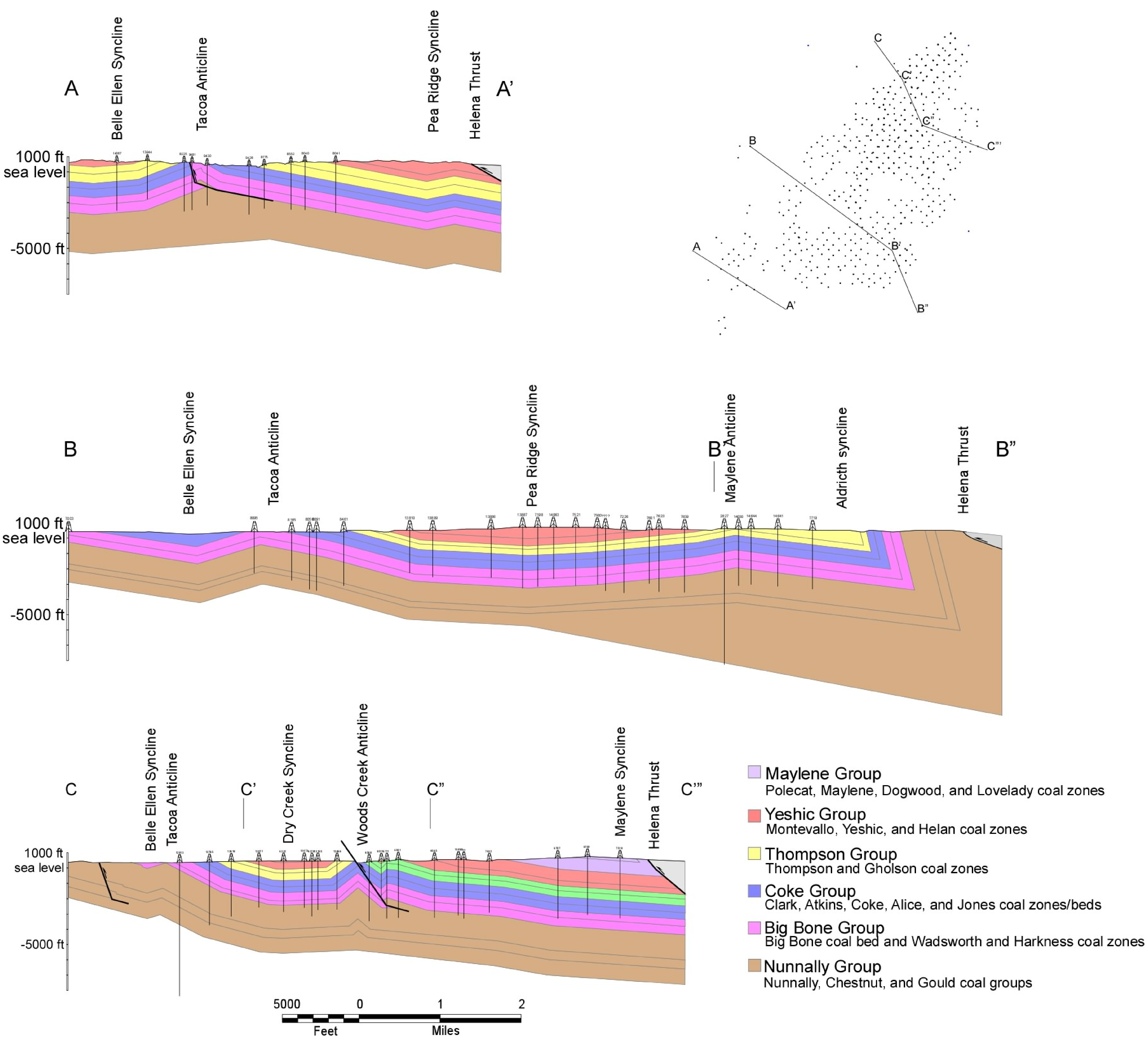

Figure 11. Cross-section location map and structural cross-sections of Cahaba coalfield. No vertical exaggeration.

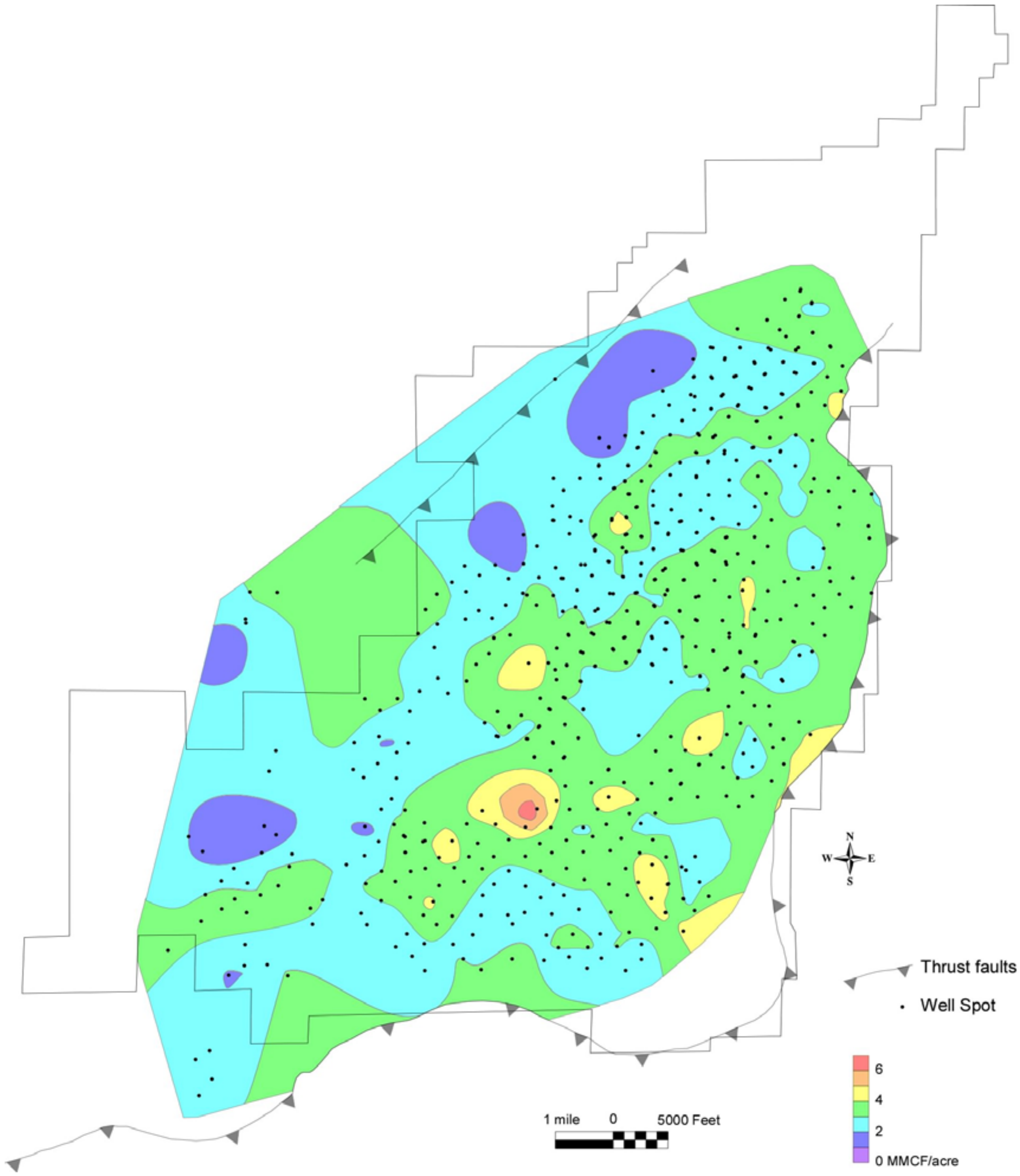

Figure 12. Estimated adsorption capacity for CH_4 at 50 psi for coal in the southwestern part of the Cahaba coal-field suggesting how much gas may remain following primary CBM recovery.

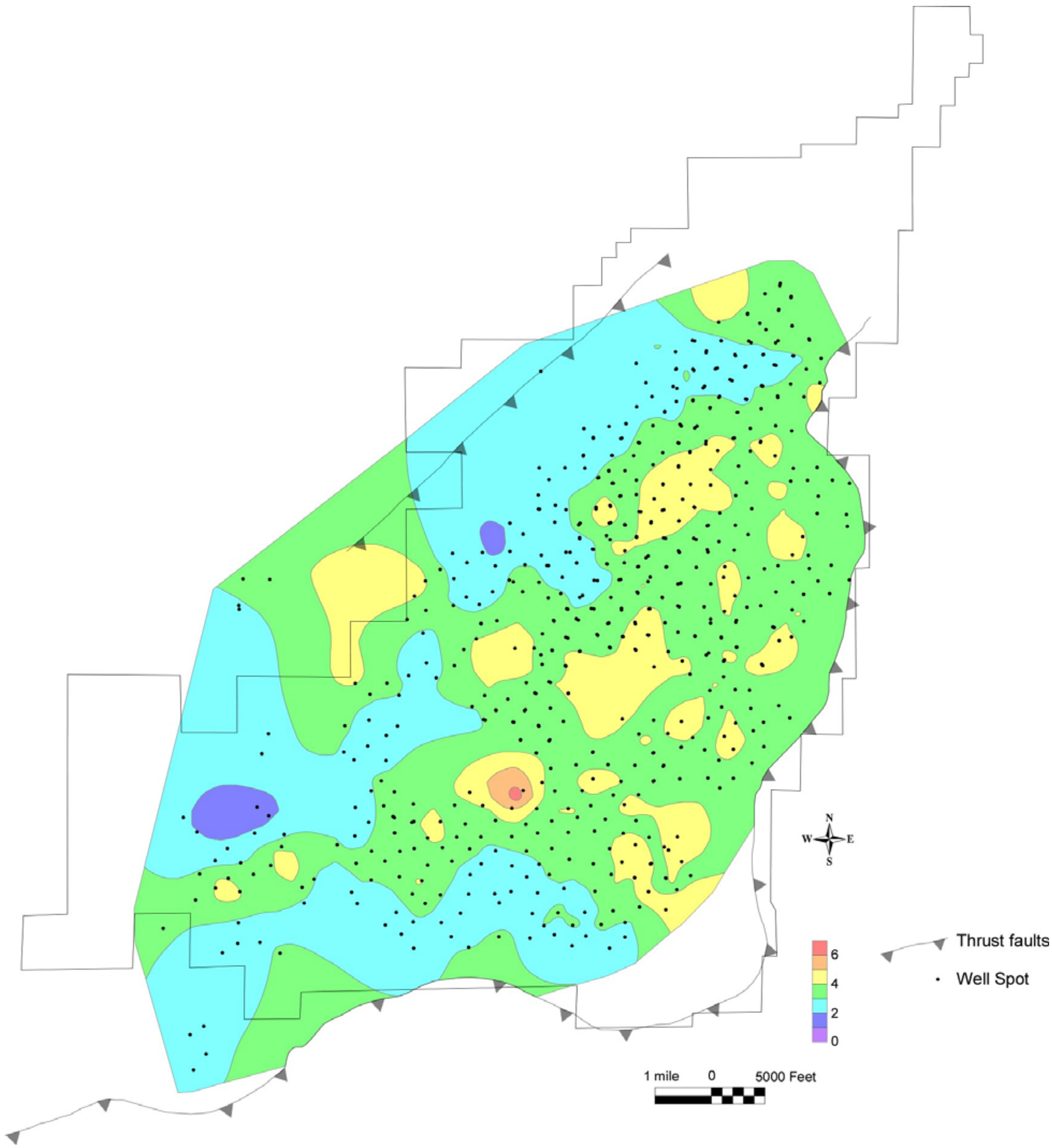

Figure 13. Temperature-corrected sorption capacity of CO_2 at 350 psi for the Cahaba coalfield.