Selected Presentations on Coal-bed Gas in the Eastern United States

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Coal Gas Resource Potential of Cretaceous and Paleogene Coals of the Gulf of Mexico Coastal Plain (including a review of the activity in the Appalachian and Warrior basins)[1]

By Peter D. Warwick[2], F. Clayton Breland, Jr.[3], M. Edward Ratchford[4], and Paul C. Hackley[2]

Abstract

The primary focus of this presentation is on the coal gas resource potential of Lower Cretaceous and Wilcox Group (Paleocene-Eocene) coals of the Gulf Coastal Plain. In addition, a brief review of the coalbed methane exploration activity and resources of the Appalachian and Black Warrior basin is provided.

Recent investigations conducted by Federal, State, and industry organizations suggest that significant coalbed gas resources may exist in the lower Trinity Group and Hosston Formation (both Lower Cretaceous), Midway Group (Paleocene), and Wilcox Group (Paleocene-Eocene) of the Gulf of Mexico Coastal Plain. Drill records from Arkansas and Louisiana indicate that there are Cretaceous coal beds greater than 10 ft thick at depths of 1,500- 6,000 ft suitable for coalbed gas development. Vitrinite reflectance obtained from Cretaceous coal cuttings at these depths indicates that Ro_{max} equals up to 0.53%. Available data from conventional oil and gas wells in Louisiana indicate that upper, middle, and lower Wilcox Group coal zones have potential for coalbed gas accumulations and similar data from Texas, Arkansas, Mississippi, and Alabama indicate that gas may be present in coal beds of the lower and middle sections of the Wilcox. In addition, gas accumulations may occur in the coal beds of the upper part of the Midway Group in Mississippi and Alabama. Public data from several wells completed in Wilcox Group coal zones in north-central Louisiana indicate that initial production ranges from 7 to 122 thousand cubic feet (MCF) of gas per day and that production of saline water ranges from 0 to 550 barrels (bbls) per day.

In Louisiana, the depth to the targeted Wilcox coal beds ranges from 1,500 to 5,000 ft, and individual coal beds have a maximum thickness of about 20 ft. The thickest coal beds tend to be in the lower Wilcox coal zone and cumulative coal thickness can exceed 100 ft. Although geochemical and petrographic data from Wilcox Group coals from across the region indicate that the coal beds are lignite in rank at depths less than 350 ft, they reach a rank

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[1] Modified from Warwick and others (2004); and unpublished short course notes from Short Course 8: Advances in coalbed methane exploration and development: A review of coalbed methane potential and opportunities in North America, American Association of Petroleum Geologists Annual Meeting, Dallas, TX, April 18, 2004; and Coalbed methane resources in the Southeast, Petroleum Technology Transfer Council, Central Gulf Region, Short Course, Lafayette, LA, June 8, 2004

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[4] Arkansas Geological Commission, Little Rock, AR

of subbituminous B, or greater, at depths of approximately 5,000 ft. Preliminary gas isotope data indicate that Wilcox coal gas originated from the microbial reduction of CO_2 and that in some places, these gases may be mixed with migrated thermal gases. Proximity to salt dome structures or buried Late Cretaceous igneous intrusions and associated geothermal heat flow may be important exploration tools for finding coal beds with elevated rank and potentially increased gas content. More data are needed to better characterize and assess the coalbed gas potential for the Cretaceous coal beds in this region.

Current coal gas production in the Black Warrior basin is primarily located in Tuscaloosa, Jefferson, and Walker counties, Alabama. More than 1.5 trillion cubic feet (Tcf) of coal gas has been produced from the Black Warrior basin. In the Appalachian basin, current coal gas production is primarily located in southwestern Virginia and the adjacent part of southern West Virginia, and in northern West Virginia and adjacent parts of southwestern Pennsylvania. Cumulative coal gas production from the Appalachian basin is approximately 0.5 Tcf.

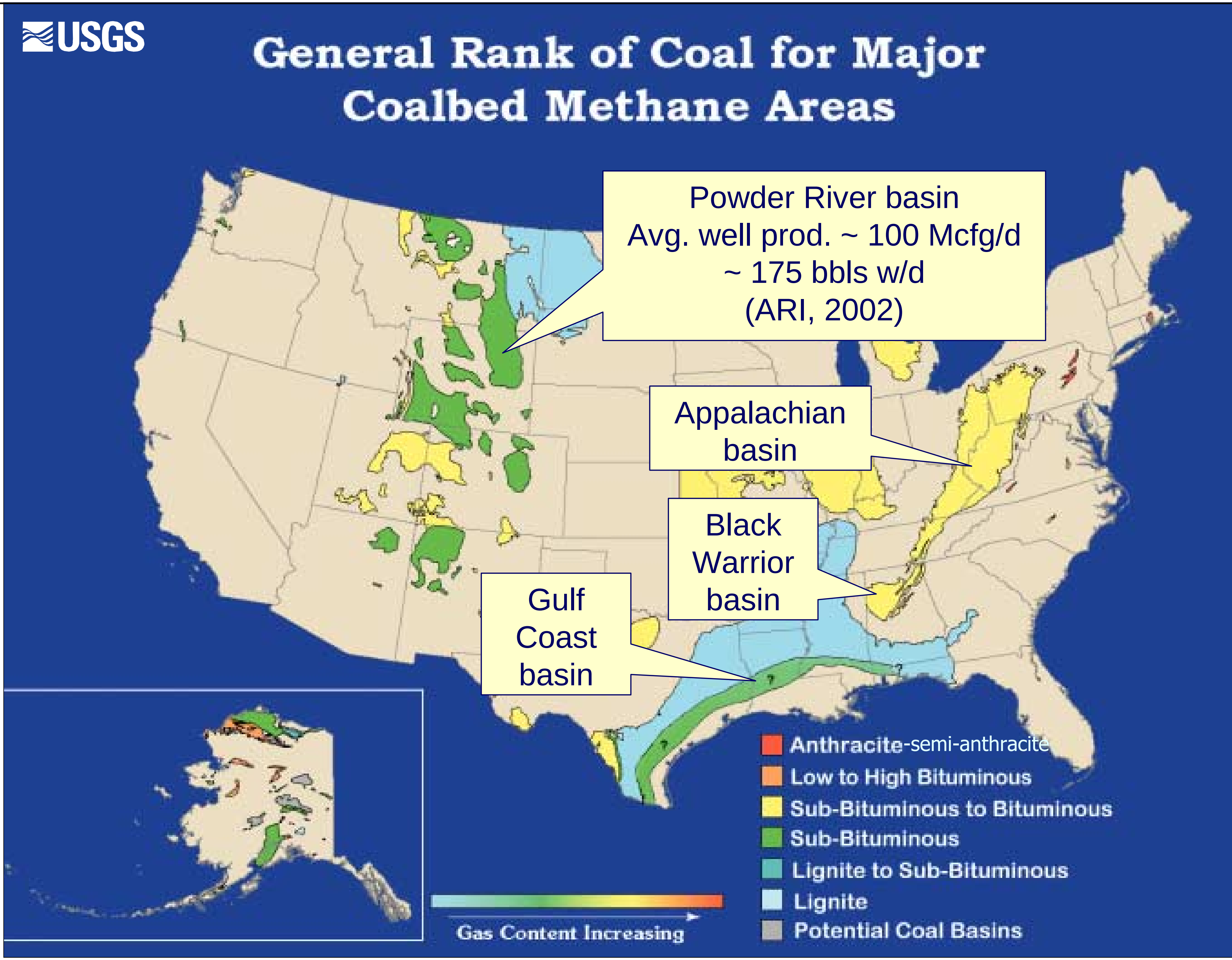
Acknowledgements

The U.S. Geological Survey and the Louisiana Geological Survey have Cooperative Research and Development Agreements with Devon SFS Operating, Inc., EnerVest Management Partners, Ltd., and Harvest Gas Management, L.L.C. Results of this research, which are currently proprietary, will be published in the near future. Cooperative research with these companies has led to a better understanding of the coal gas potential of the Gulf Coastal region. The Dolet Hills Mining Company provided access for mine coal sample collection and International Paper provided assistance in locating information on Cretaceous coal samples, and well logs from Arkansas.

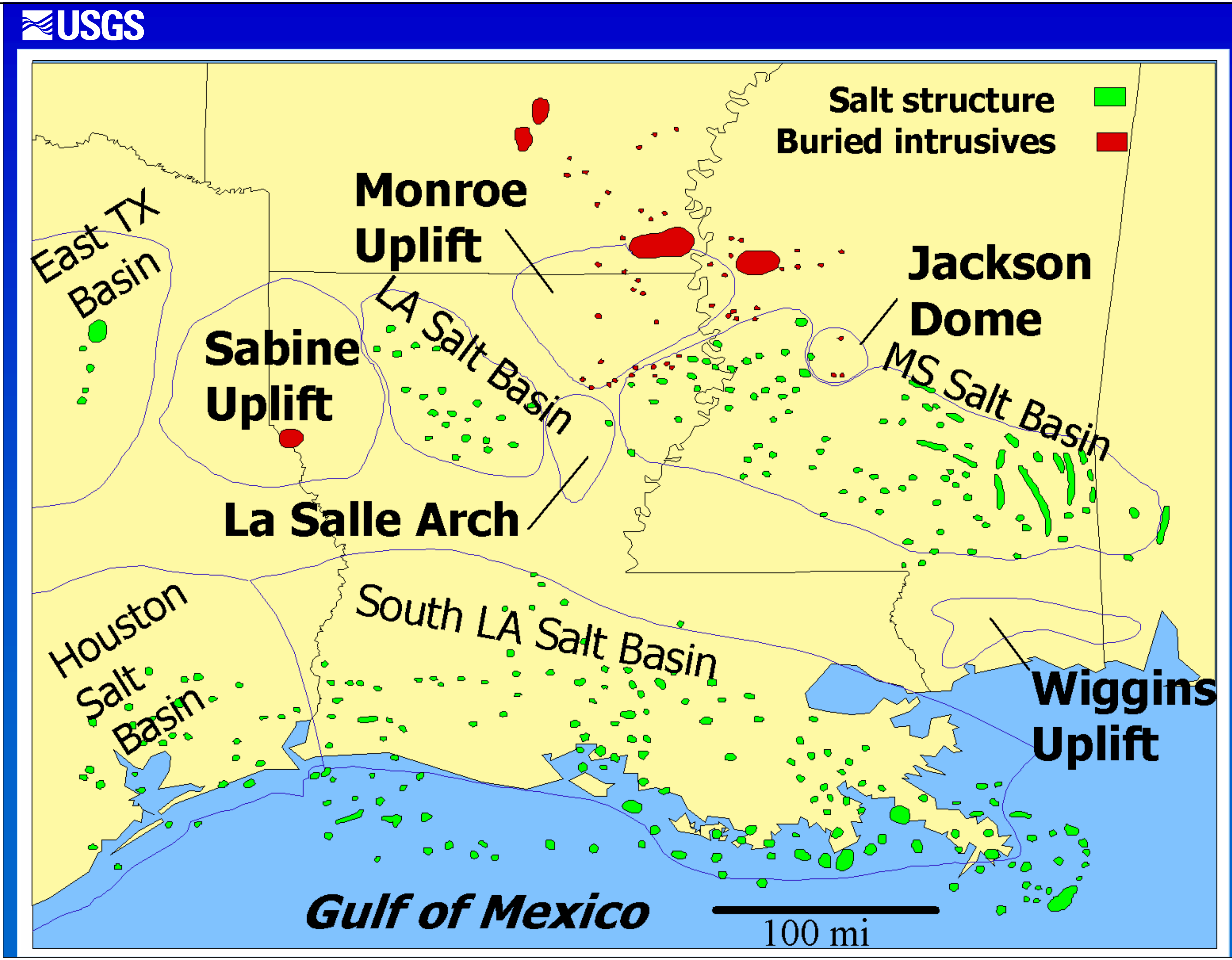
Outline

- Subsurface Cretaceous coals of AR-LA
  - unrecognized coal and CBM potential
- An update on the CBM activity in Tertiary Wilcox coals of north LA and coal gas potential for other areas
  - Stratigraphy
  - Hydrogeology
  - Exploration/Production
  - Gas Chemistry
- A review of coal gas activity and resources in the Appalachian and Warrior basins

Outline of presentation. CBM = coalbed methane.



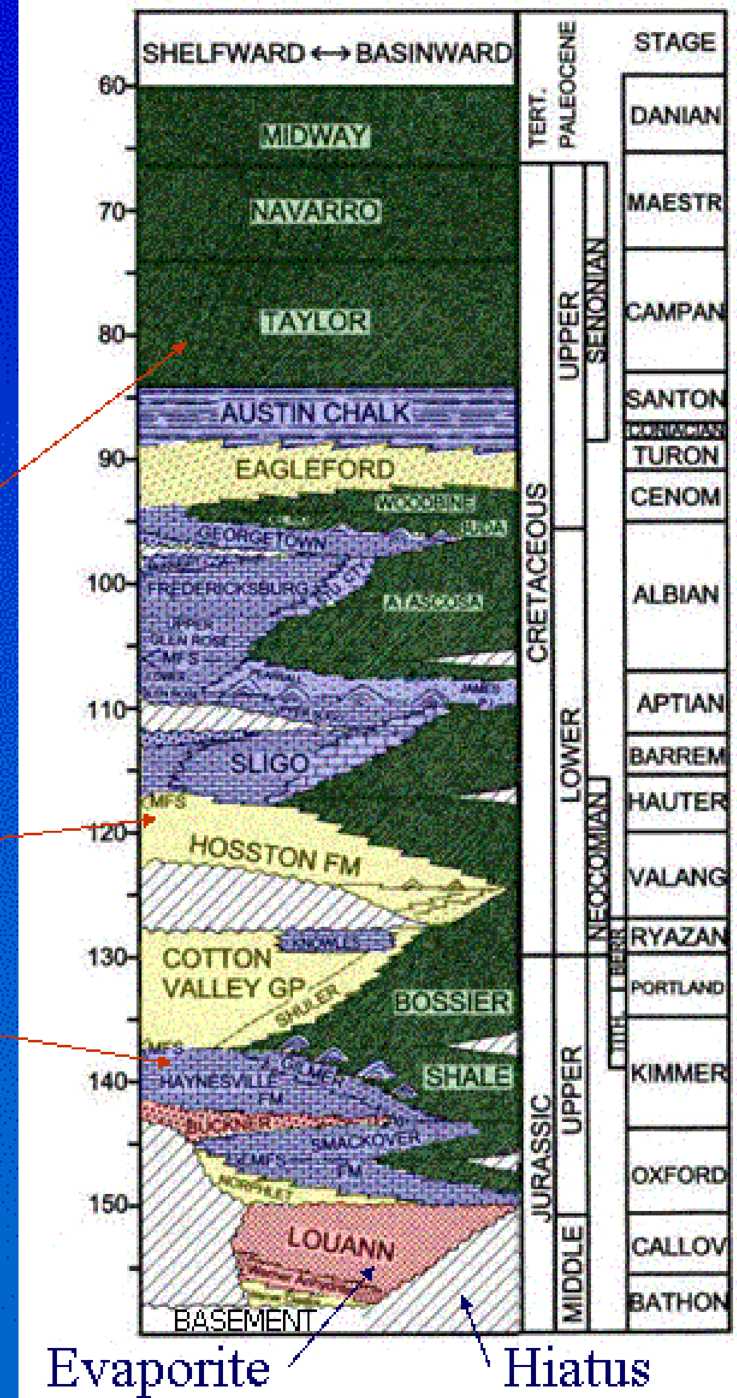
General rank of coal for major coalbed methane areas in the United States. Note that the rank of Gulf Coast coals increase with depth to sub-bituminous or greater. For later comparison to the Gulf Coast area, average coal gas and water production data are provided for the Powder River basin (Advanced Resources International [ARI], 2002). Note the location of the Appalachian and Black Warrior basins.



Major structural features (outlined in blue) of the Louisiana region of the Gulf Coast basin. Modified from Ewing and Lopez (1991).

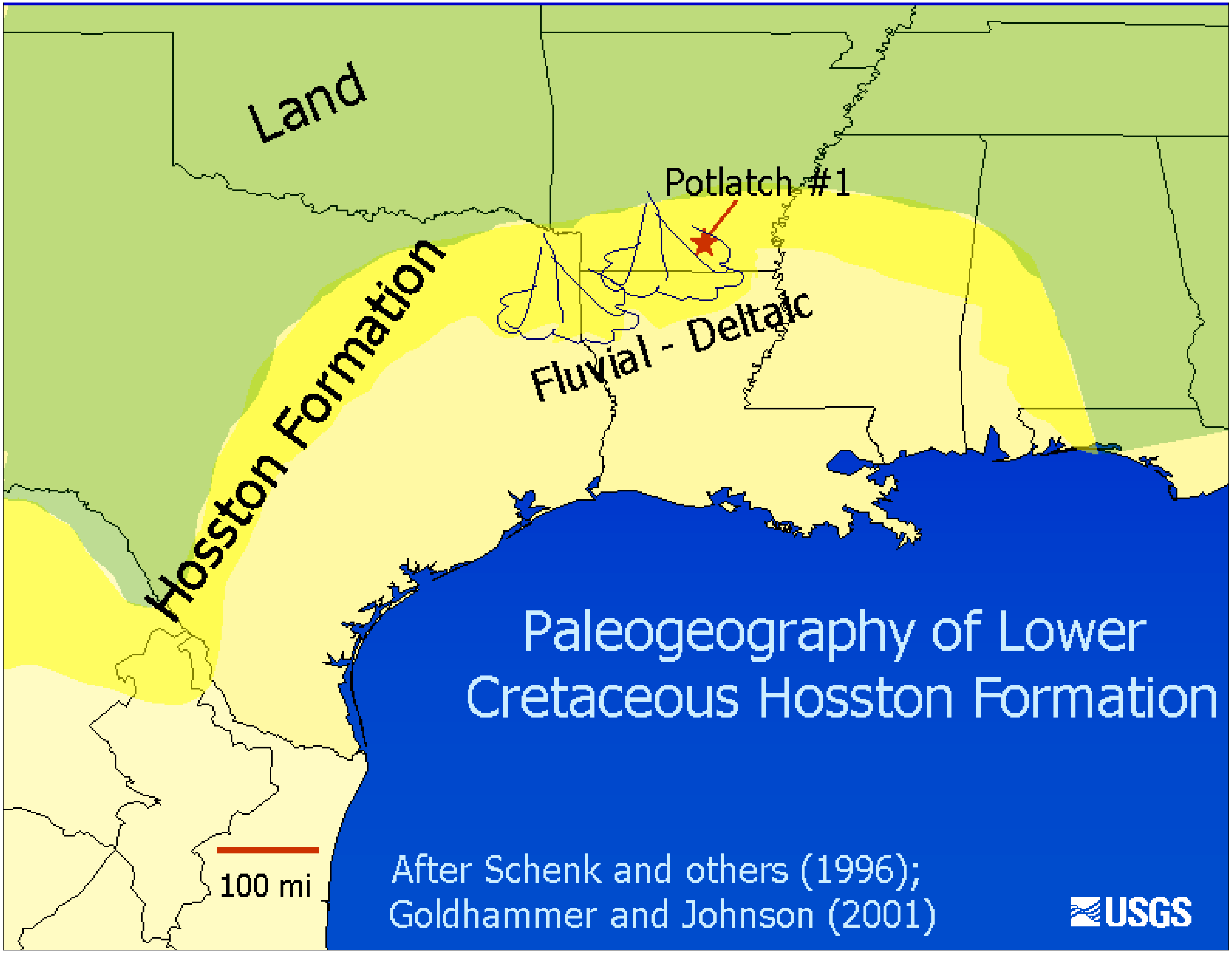
USGS

Generalized Jurassic and Cretaceous stratigraphy of the northwestern part of Gulf Coastal Plain

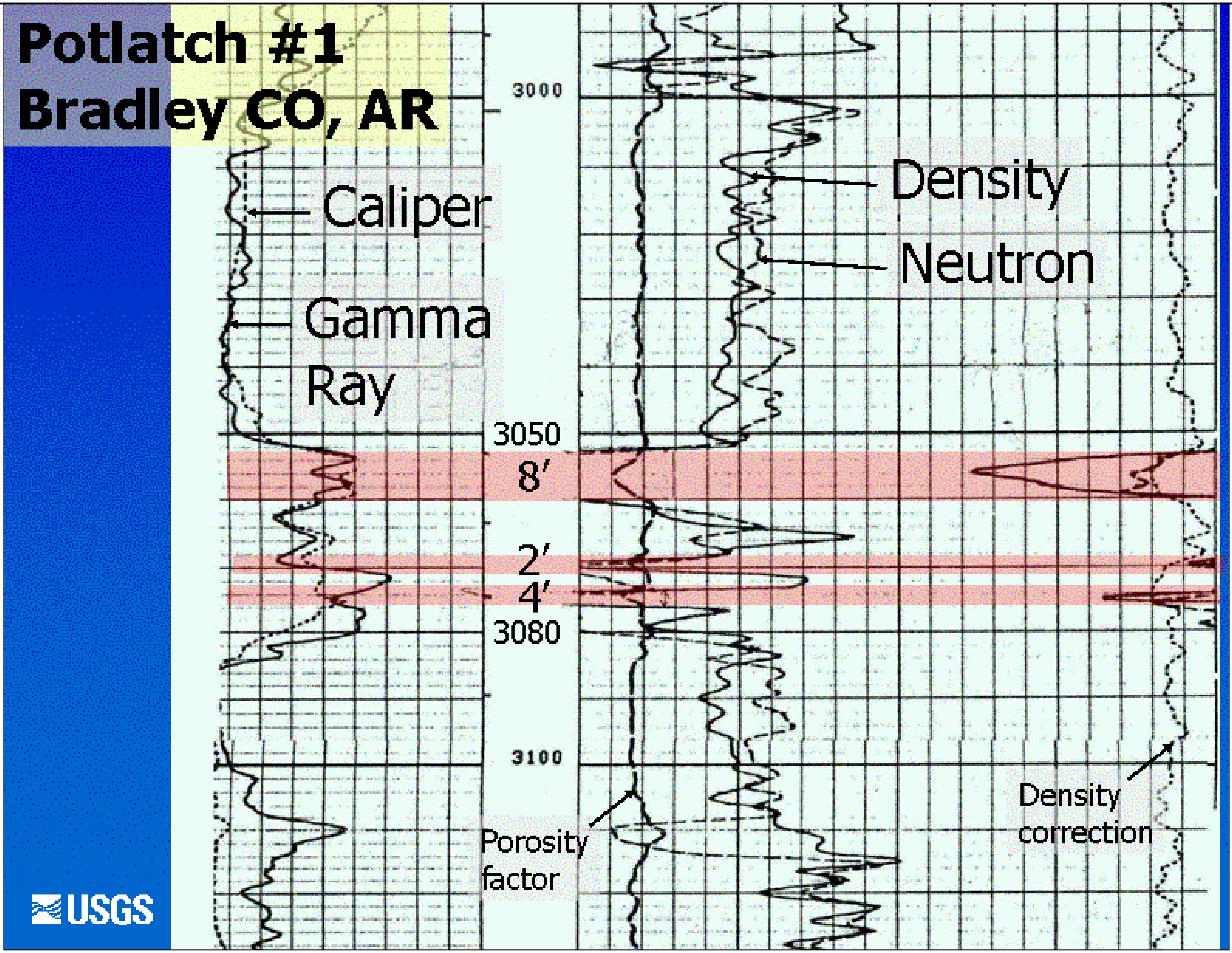


From Goldhammer and Johnson (2001)

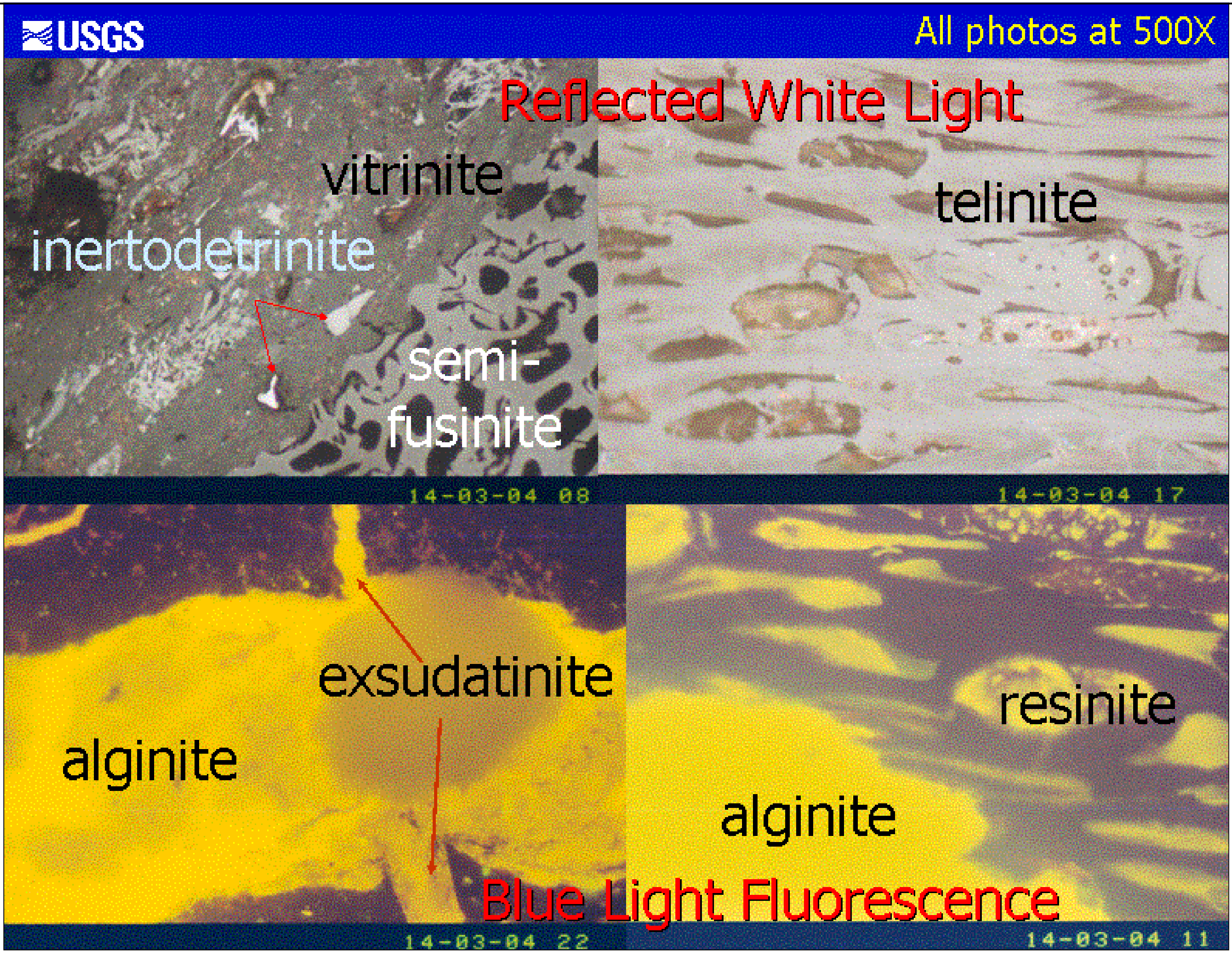
Generalized Jurassic and Cretaceous stratigraphy of the northwestern part of Gulf Coastal Plain. Note the location of the Lower Cretaceous Hosston Formation clastic wedge. Modified from Goldhammer and Johnson (2001).



Paleogeographic map of the Lower Cretaceous Hosston Formation clastic wedge. Adapted from Schenk and others (1996) and Goldhammer and Johnson (2001). Note the location of the fluvial-deltaic depositional environments proposed by Goldhammer and Johnson (2001) for northern Louisiana and southern Arkansas. These were potentially good environments for peat (coal) accumulation. The star indicates the location of the Potlatch #1 well in southern Arkansas. The mud log from the Potlatch #1 well reported coal cuttings from intervals within and near the Hosston Formation. There are other wells in northern Louisiana that report the occurrence of coal cuttings in the Lower Cretaceous section (Jim York, personal communication, 2003).



Portion of the caliper, gamma ray, density, and neutron well logs from the Potlatch #1 well (API # 03011100770000) in Bradley County, Arkansas. The red shaded area indicates the probable coal intervals with interpreted thicknesses. Depths are in feet. Coal cuttings were recovered from the following intervals 3050-3060 ft, 3060-3070 ft, and 3070-3080 ft. The mud log from this well reported other coal intervals from 3440-3460 ft and 3470-3480 ft. Regional correlations with other well logs indicate that the Potlatch #1 coal intervals are within, or are associated with, the Hosston Formation (or lower Trinity Group and Travis Peak Formation of Haley, 1993).

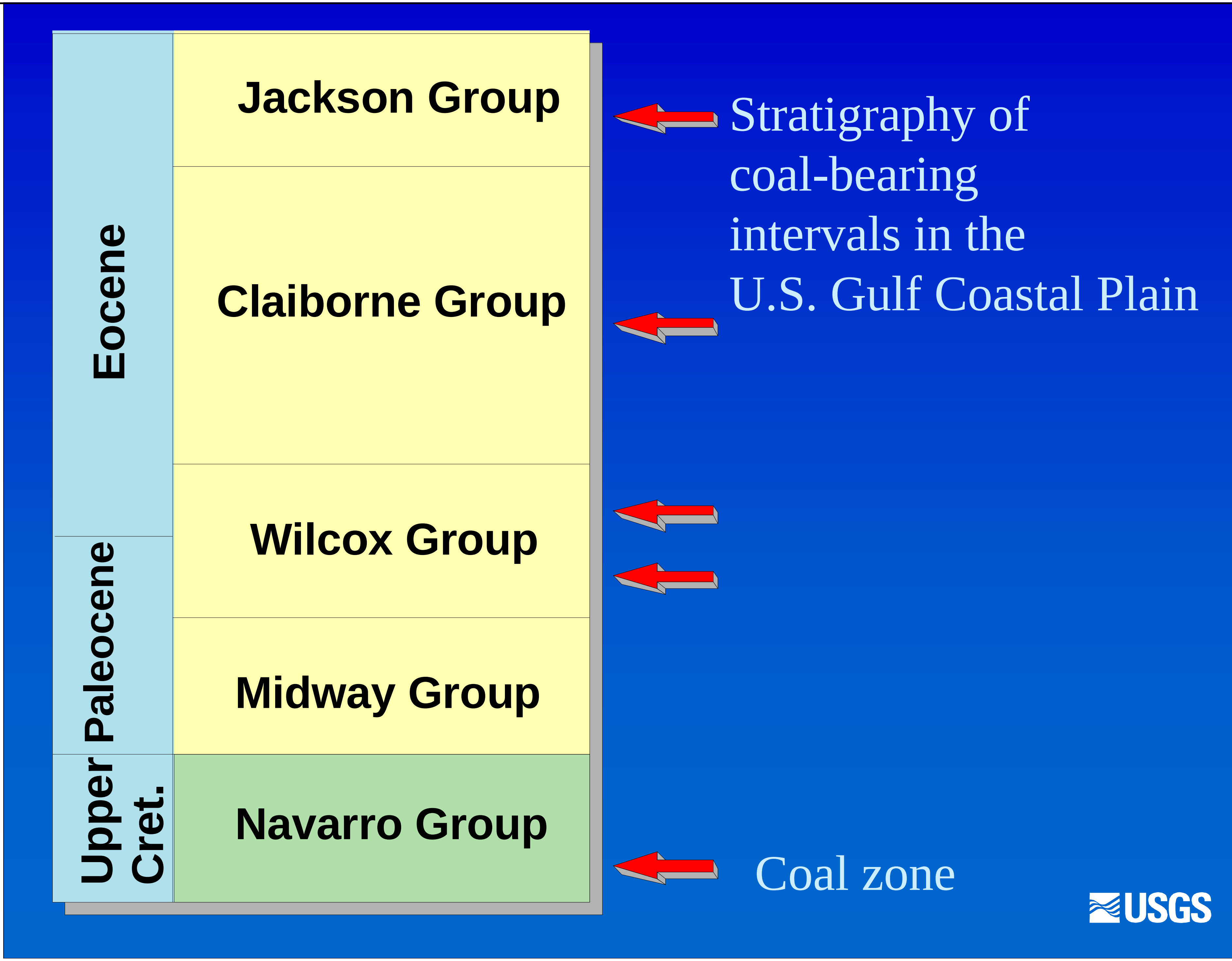


Photomicrographs of coal cuttings from the Potlatch #1 well. Photo 14-03-04 08: Vitrinite groundmass with inertodetrinite in the upper left and semifusinite showing remnant cell structures in the lower right of the photomicrograph; sample from the 3050-3060 ft interval, 500X magnification in reflected white light. Photo 14-03-04 17: Telinite showing well preserved cell structures; sample from the 3060-3070 ft interval, 500X magnification in reflected white light. Photo 14-03-04 22: Alginite with exsudatinite filling cracks; sample from the 3070-3080 ft interval, 500X magnification in blue light fluorescence. Photo 14-03-04 11: Alginite and resinite filling cell structures; sample from the 3060-3070 ft interval, 500X magnification in blue light fluorescence.

Potlatch #1, Bradley Co., AR

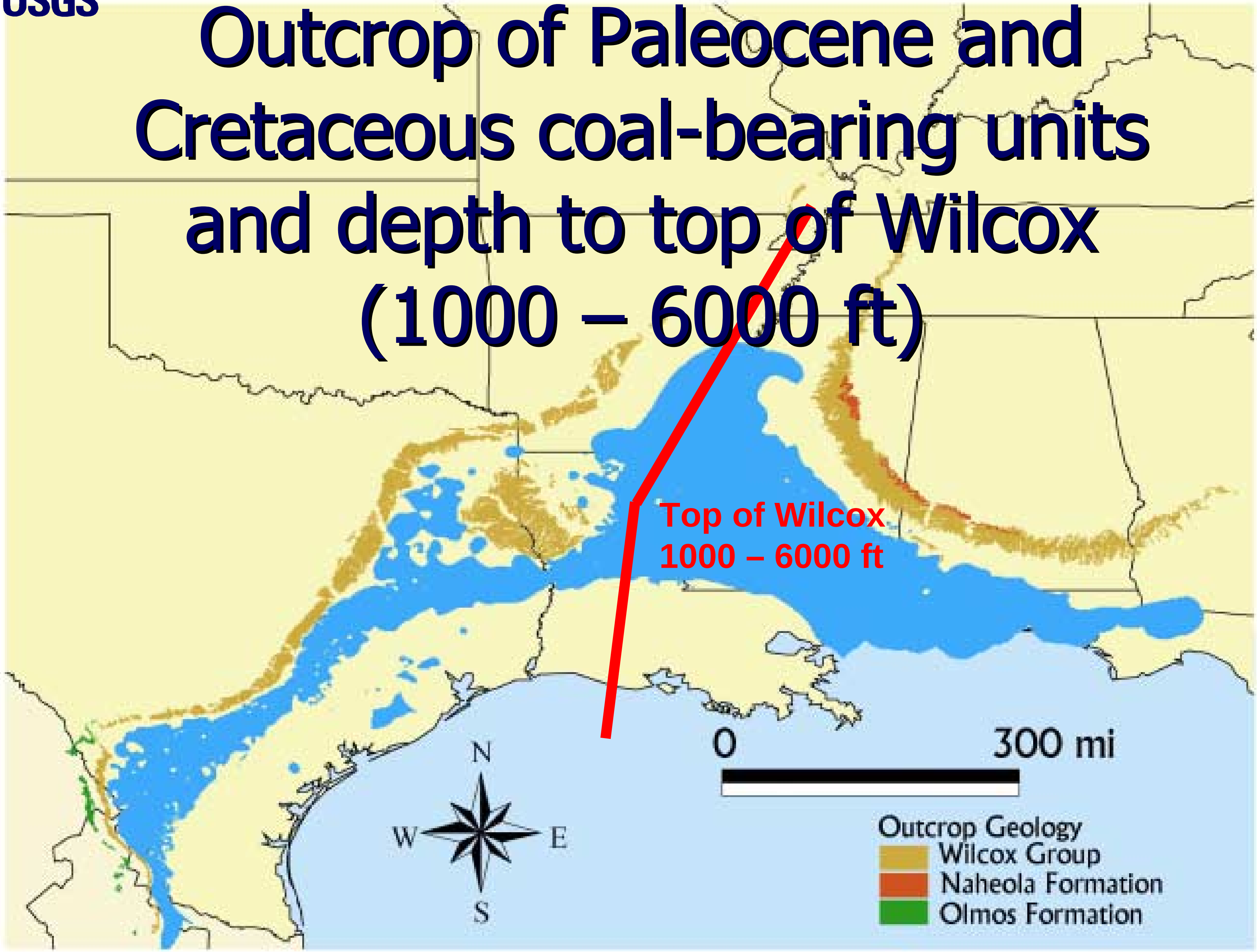
- Three coal zones recognized in the Trinity - Hosston Fm. (Travis Peak)
- Depths range from 3050 – 3500 ft
- About 20 ft cumulative coal with individual beds up to 8 ft thick
- Ro_{max} at 3050-3080 ft at 0.53 % (hvCb)
- Coal zone extends into northeastern LA
- Reports of Upper Cretaceous coals in MS & AL (Brown, 1907; Monroe and others, 1946)

Summary of findings for Cretaceous age coal from Arkansas and neighboring states. hvCb = high volatile C bituminous.

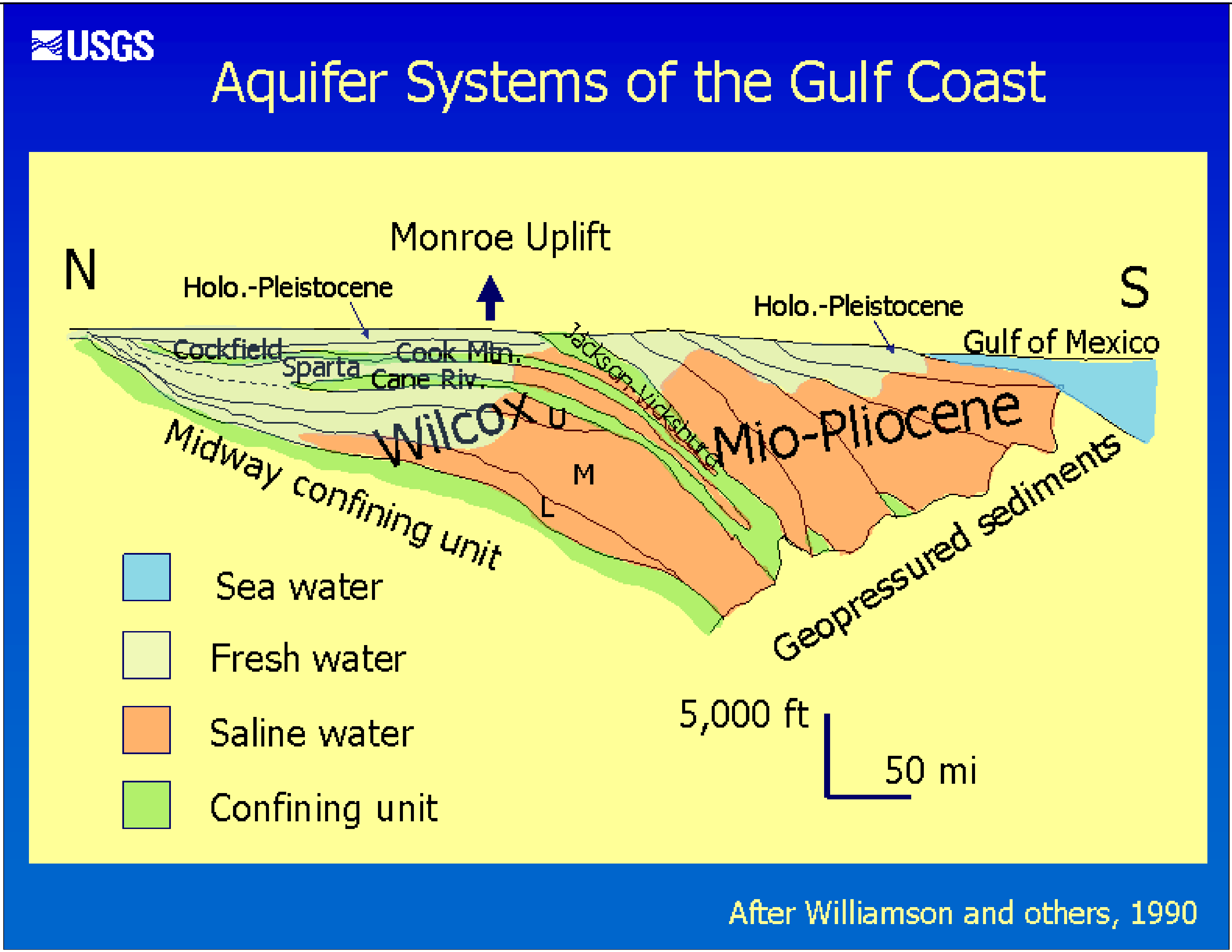


Generalized coal-bearing stratigraphy of the upper Cretaceous, Paleocene and Eocene of the Gulf Coastal Plain. From Warwick and others (2000b).

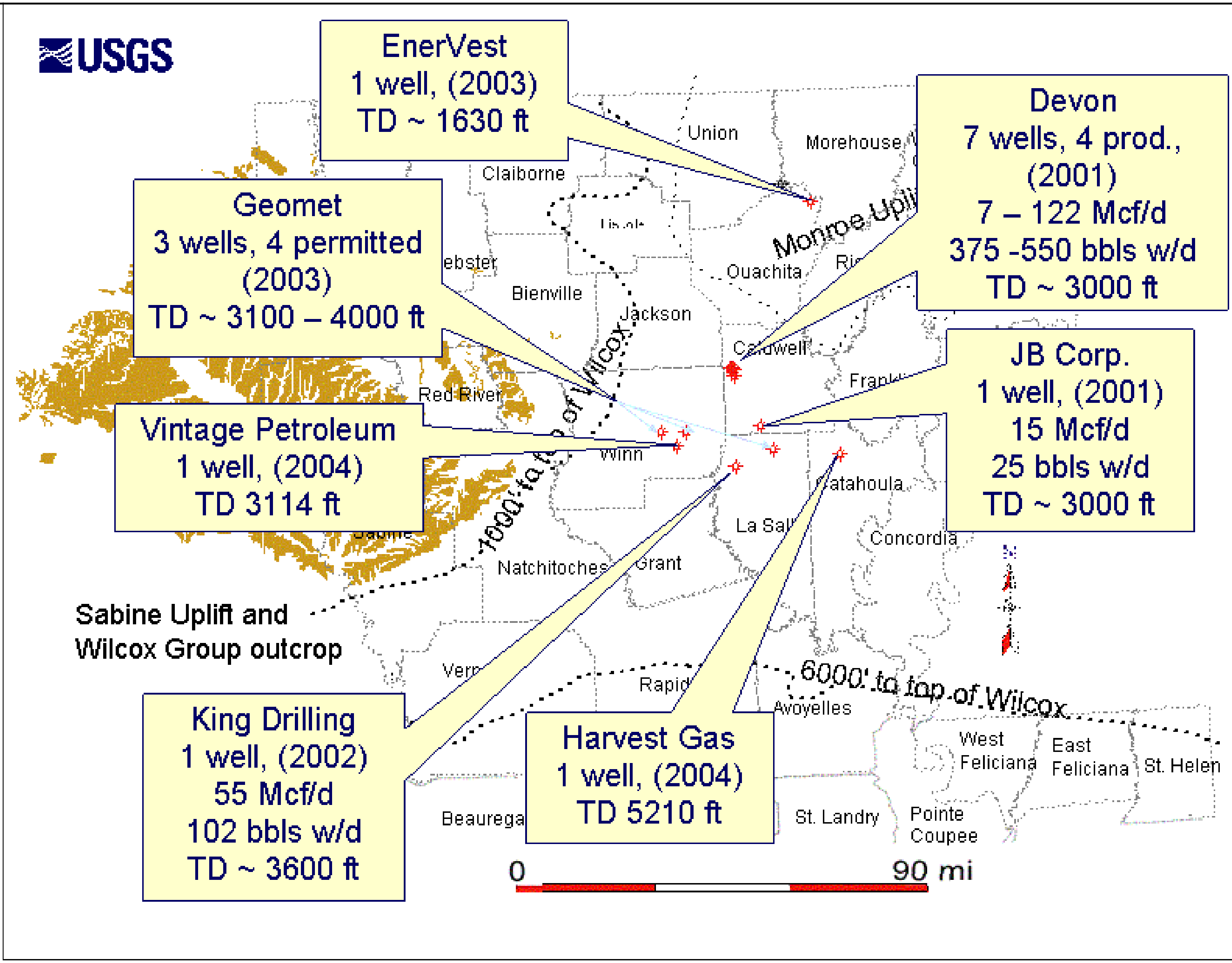
Outcrop of Paleocene and Cretaceous coal-bearing units and depth to top of Wilcox (1000 – 6000 ft)



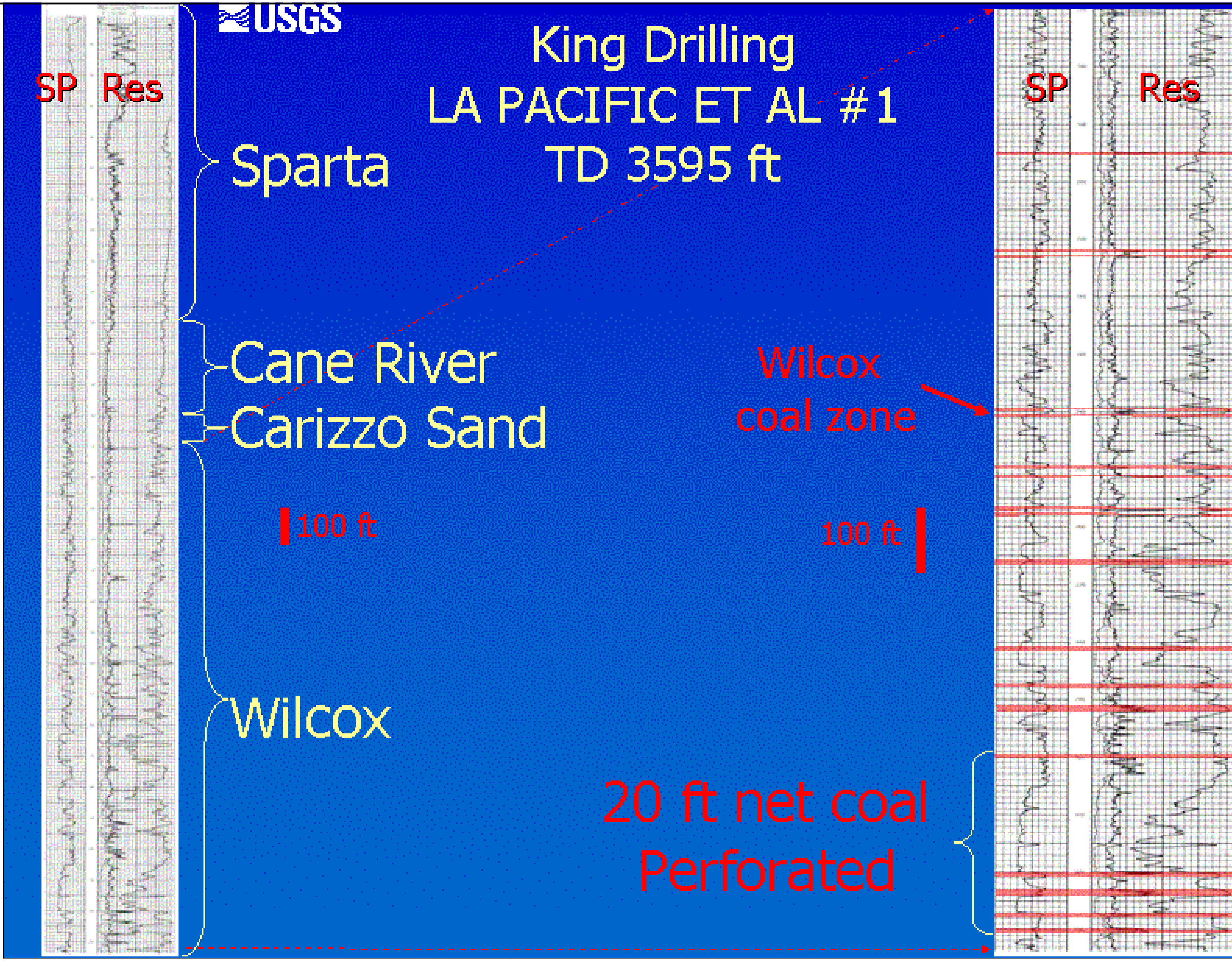
Outcrop of Paleocene and Cretaceous coal-bearing units in the Gulf Coastal Plain. The area shaded dark blue shows the area where the depth to the top of the Wilcox Group ranges from 1000 to 6000 ft. The heavy solid red line is the line of section on the next illustration. Modified from Barker and others (2000).



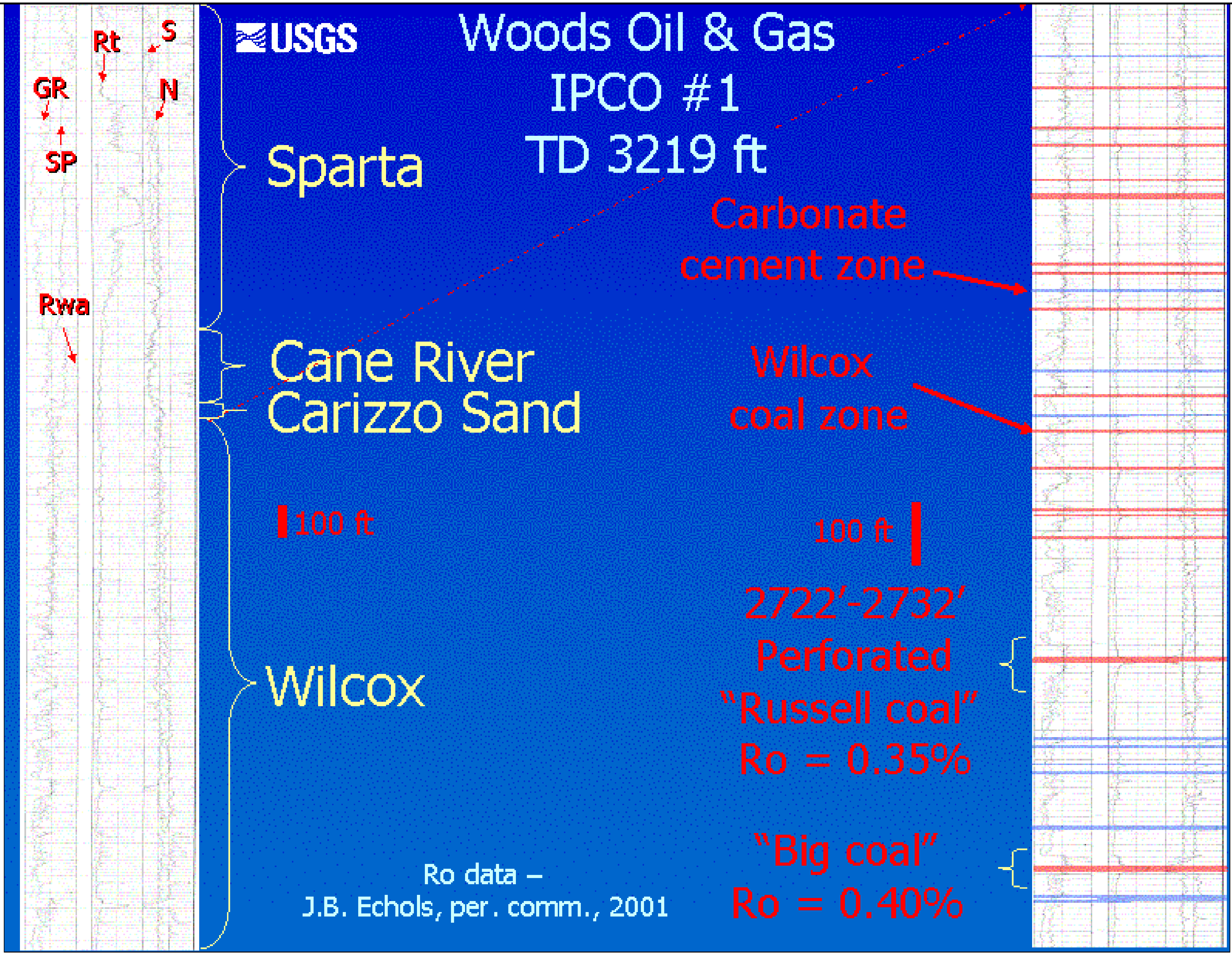
Generalized cross section showing the major Tertiary aquifers and confining units in the Mississippi Embayment and southern Louisiana. Note that much of the aquifer systems are filled with saline water derived from groundwater interaction with salt diapers (Huff and Hanor, 1997). Geopressured sediments are found at depth. Diagram modified from Williamson and others (1990). Holo. = Holocene; Mio = Miocene; L = Lower; M = Middle; U = Upper.



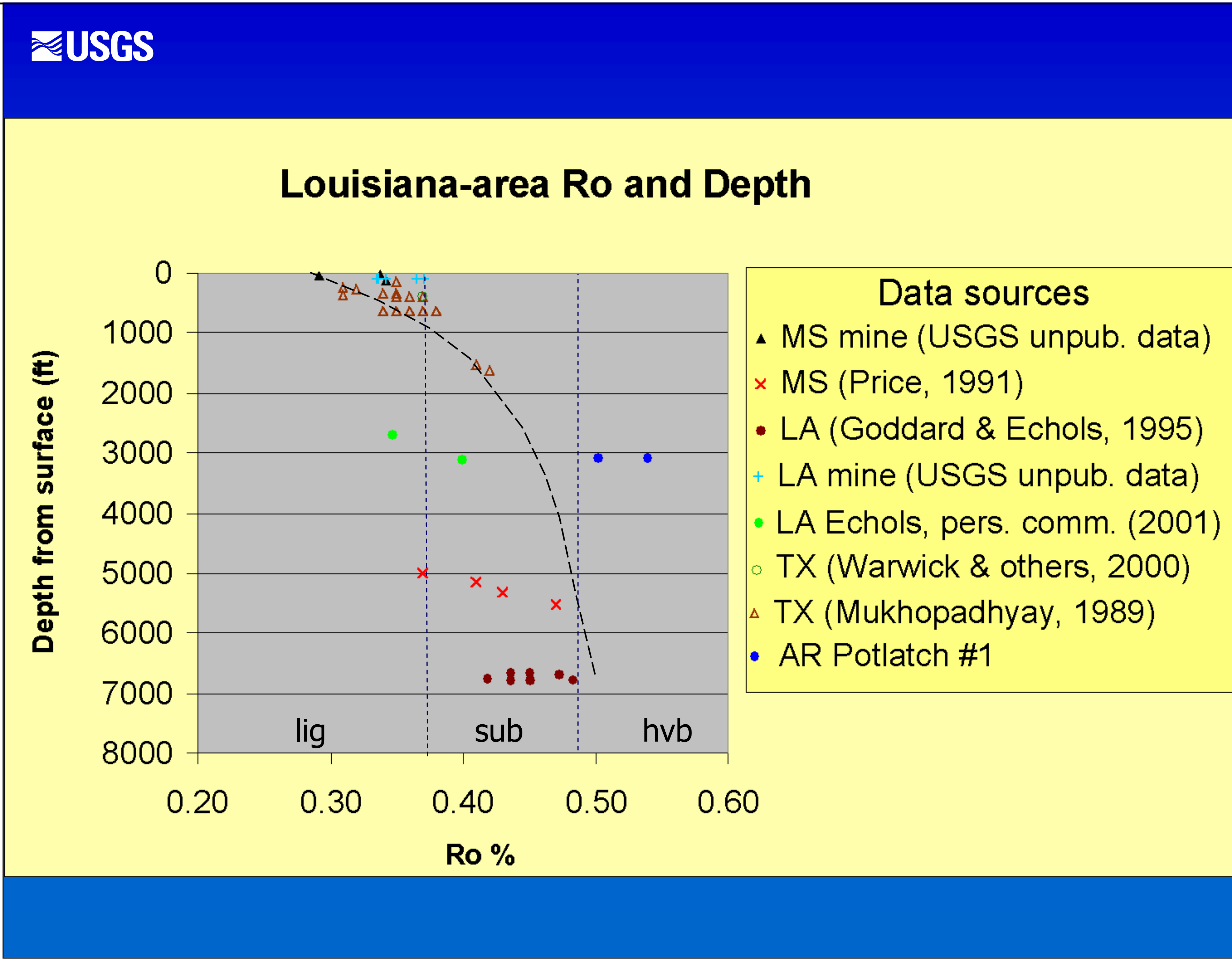
Review of coal bed methane (CBM) drilling activity in northern Louisiana since 2001. Approximately 15 wells have been drilled specifically for coal bed gas exploration or production. Boxes indicate company name, number of wells drilled or producing (prod.), year of first well (in parentheses), initial production of gas and water (if available), and total depth (TD) of the wells. Dotted lines indicate 1,000 to 6,000 ft depth range to the top of the Wilcox Group. Well data from Louisiana Department of Natural Resources Strategic Online Natural Resources Information System [http://sonris-www.dnr.state.la.us/www_root/sonris_portal_1.htm].



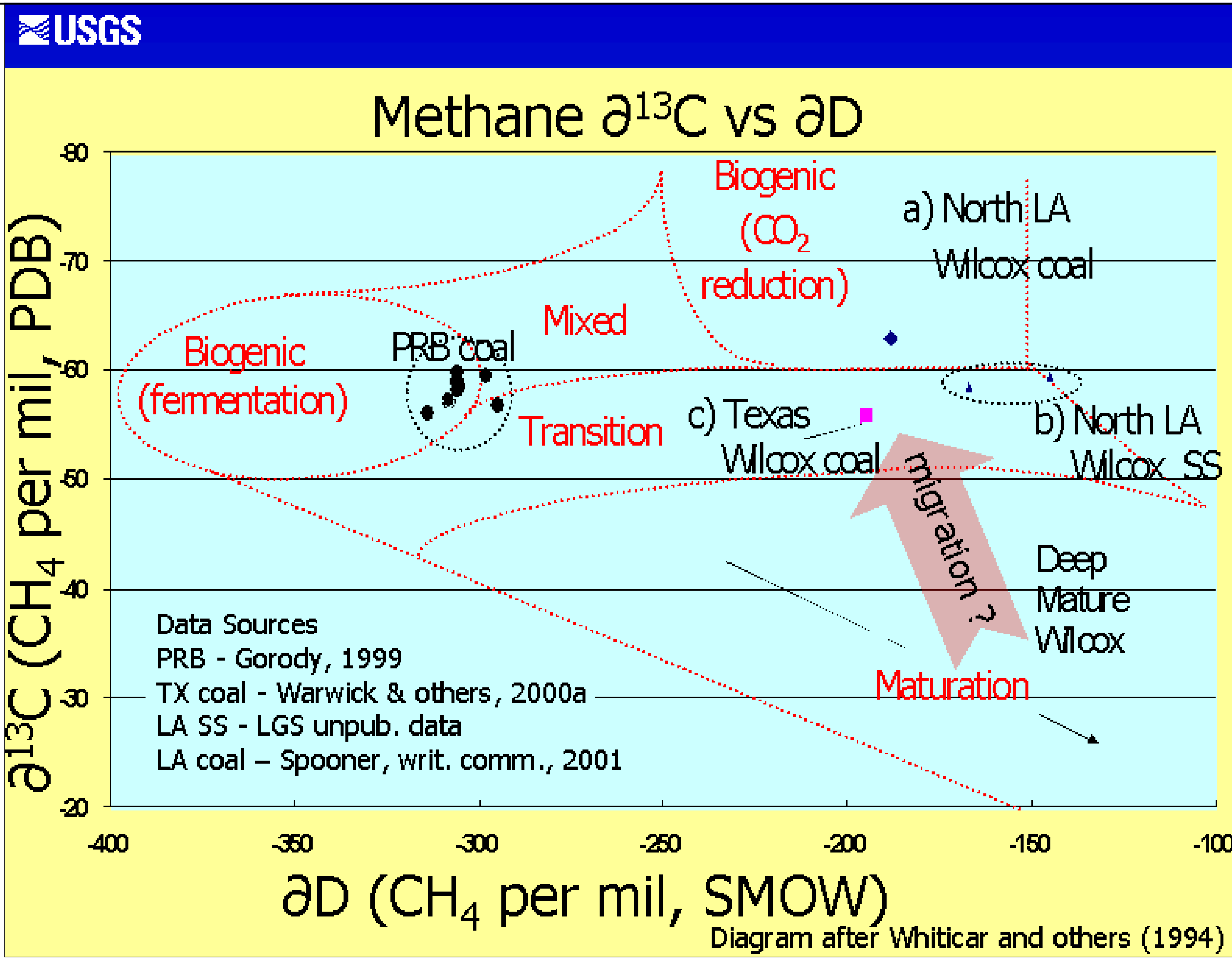
Example of well log stratigraphy and coal intervals (shaded in red) in the King Drilling LA Pacific Et Al #1 well in La Salle Parish, Louisiana. Note that there are multiple coal zones in the Wilcox and that the thickest coal beds tend to be in the lower part of the Wilcox. The log on the right is the expanded Wilcox part of the log on the left. On well logs consisting only of spontaneous potential (SP) and resistivity (Res), coal beds are hard to distinguish from limestone beds. Well data from Louisiana Department of Natural Resources Strategic Online Natural Resources Information System [http://sonris-www.dnr.state.la.us/www_root/sonris_portal_1.htm].



Example of well log stratigraphy with coal (shaded in red) and limestone (shaded in blue) intervals in the Woods Oil and Gas (John B. Company), IPCO #1 well in Caldwell Parish, Louisiana. Note that the thickest coal beds are in the lower part of the Wilcox. The log on the right is the expanded Wilcox part of the log on the left. On well logs that include gamma ray (GR), sconic (S), and neutron (N), coal and limestone beds are easily distinguished. Formation density curves are also very useful for coal identification. Well data from Louisiana Department of Natural Resources Strategic Online Natural Resources Information System [http://sonris-www.dnr.state.la.us/www_root/sonris_portal_1.htm]. SP = spontaneous potential; Rwa = apparent formation water resistivity, Rt = resistivity. Ro data from J.B. Echols, personal communication, 2001.



Plot of public coal reflectance data (Ro %) against depth for the Louisiana area. Vertical dashed lines indicate approximate boundaries between lignite (lig), subbituminous (sub), and high-volatile bituminous (hvb) coal ranks. A dashed best-fit line (exponential) is plotted that illustrates the approximate change of rank with depth. The trend line is based on public and confidential data. The wide scatter in the data may reflect variable heat flow rates and associated maturity in different parts of the basin. Sample states are indicated for each data set. Potlatch #1 data are from this report. Unpub. = unpublished.



Plot of the isotopic values of carbon (C) and hydrogen (D) with fields showing the origin of gases after Whiticar and others (1994). For reference, Powder River (PRB) coals primarily plot in the biogenic fermentation field. Wilcox coal gas from north Louisiana (a) plots within the biogenic CO_2 reduction field, whereas gas collected from conventional Wilcox sandstone reservoirs (b) falls within (near) the transition zone between biogenic and mature thermogenic gases. Coal gas collected from a shallow (380 ft) well in northeast Texas also (c) plots within the transition zone indicating that these gases may have originated from mixing of mature gases and gases with a biogenic, CO_2 reduction origin. The red arrow indicates the proposed migration direction and mixing pathway of thermal gas. Sources of data for the PRB = Gorody (1999); North Louisiana Wilcox coal = Harry Spooner, written communication, 2001; north Louisiana Wilcox conventional sandstone (SS) reservoir gas = unpublished (unpub.) Louisiana Geological Survey (LGS) data; Texas Wilcox coal = Warwick and others (2000b). PDB = Pee Dee Belemnite; SMOW = standard mean ocean water.

Photograph of coal fractures and cleats in the Oxbow Lignite mine in northwestern Louisiana.

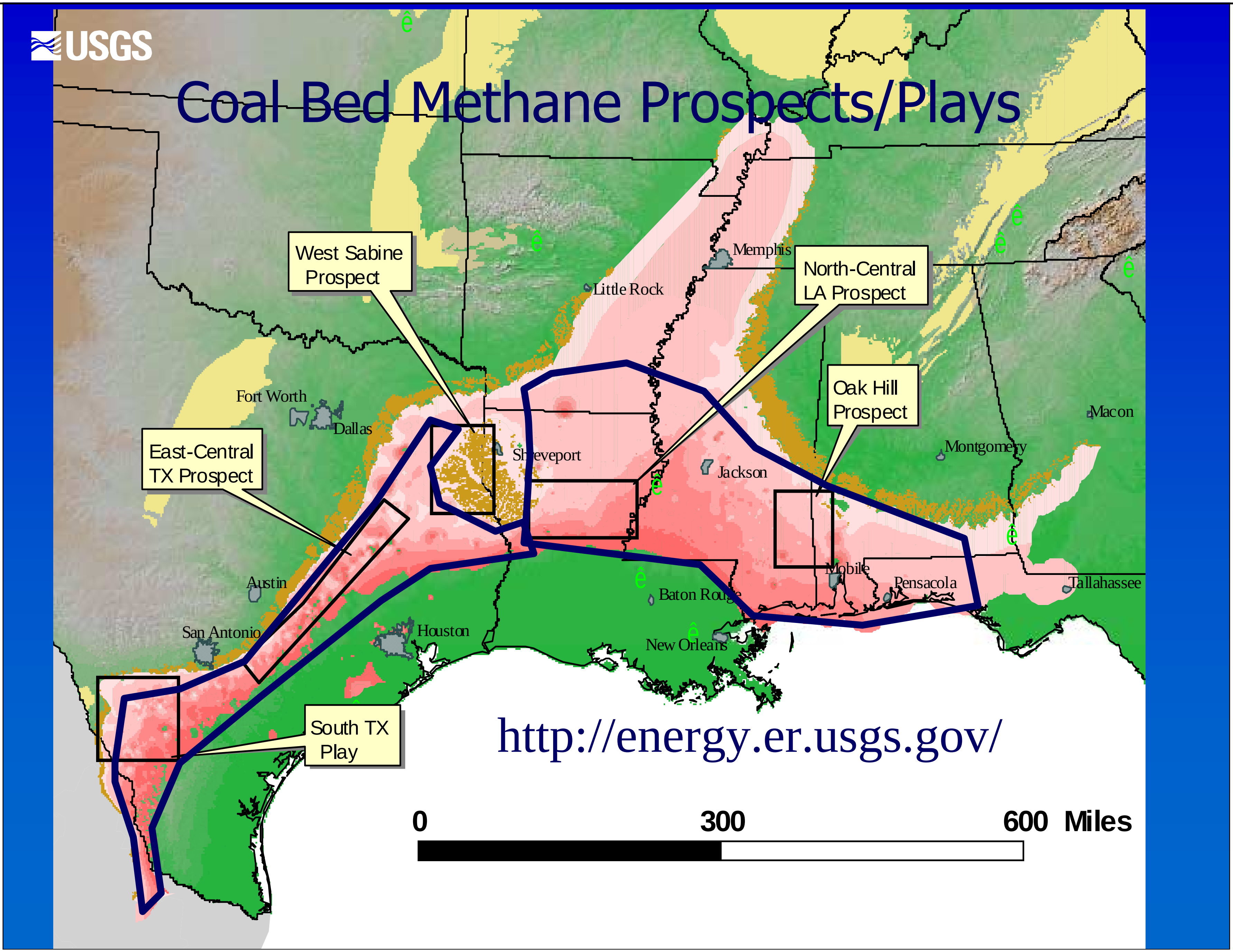
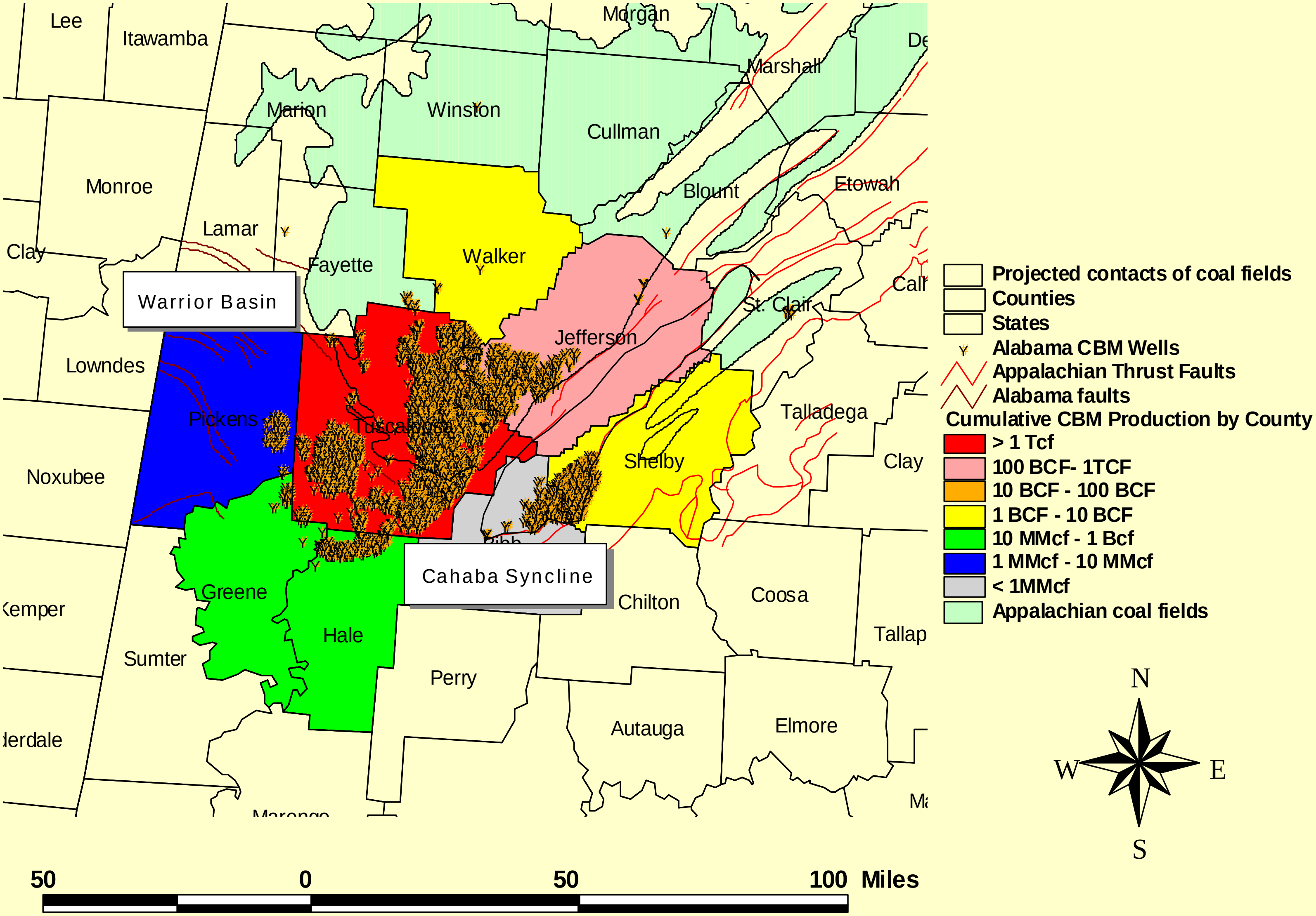


Diagram from Warwick and others (2002) which indicates potential coalbed methane prospects and plays (boxes). Based on the current coal gas exploration efforts in north Louisiana and the occurrence of bituminous Cretaceous coal in southern Arkansas, the potential exploration areas have been expanded as indicated by the heavy blue lines. Red shaded areas illustrate the depth to the top of the Wilcox Group, and ranges from 500 ft (light red) to 6000 ft (dark red). Outcrop of the Wilcox is indicated by the orange color and yellow indicates the location of other coal-bearing basins. Base map after Barker and others (2002).

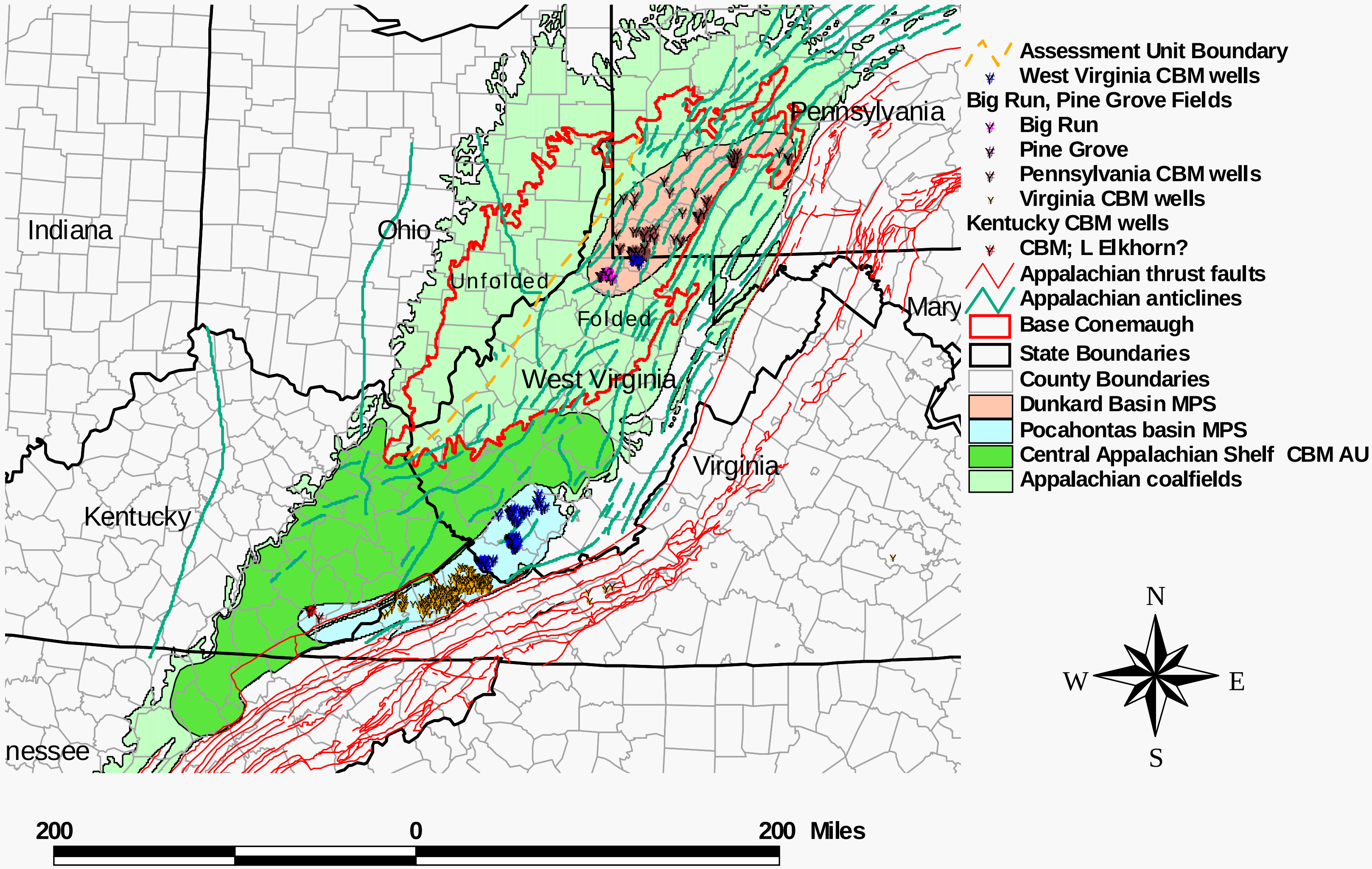
Alabama Coal Fields, Showing Cumulative Production by County, 2000



Milici, written communication, 2004

Map of Alabama coal fields and coalbed gas production areas. Cumulative gas production (CBM) by county is indicated by color fill. For an estimate of the remaining coal gas resources of the Black Warrior basin see Hatch and others (2003). Illustration from Milici, written communication, 2004.

CBM Fairways, Northern and Central Appalachian Basin



Milici, written communication, 2004

USGS coal gas (CBM) assessment map of northern and central Appalachian basin coal fields and coalbed gas production fields. For an estimate of the remaining coal gas resources of the Appalachian basin see Milici and others (2003). MPS = Minimum Petroleum System; AU = Assessment Unit. Illustration from Milici, written communication, 2004.

Conclusions

- Cretaceous coals of the northern Gulf Coastal plain should be evaluated for their CBM potential

- Wilcox coals contain saline water; initial gas isotope data indicates that Wilcox coal gas originated from biogenic reduction of CO_2; coal rank increases to near hvCb with depth

- Early production data from Wilcox coals indicate that there is a potential resource of coal-bed gas underlying a large area in the Gulf Coastal Plain

- There is potential for enhanced coal-bed methane production and CO_2 storage in the Gulf Region. This may includes the possibility of methane generation from reduction of introduced CO_2

Conclusions. CBM = coalbed methane; hvCb = high volatile C bituminous.

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Coalbed Methane Potential in Louisiana[1]

By F. Clayton Breland, Jr.[2]

Introduction and discussion

Recent reports indicate that while gas resource numbers may be increasing, domestic production has not kept pace with domestic demand (Duval and Chabrelle, 2001). Alternative sources of gas including unconventional accumulations such as coalbed methane (CBM) must be explored and developed domestically to offset increasing demand for natural gas. Most recent estimates of CBM resources of 1,777 trillion cubic feet (Tcf) Gas-In-Place (GIP) compared to 1,431 Tcf of U.S. conventional natural gas are indeed impressive (Scott, 2001). Presently, CBM supplies more than 7% of total domestic natural gas production and is projected to increase as a percentage of domestic production as more producing wells come on line in CBM basins nationally (Scott, 2001).

CBM production has been established in a number of basins in the U.S., notably from Paleozoic coals in the east and from younger, thicker coals in the west. However, very limited drilling activity has been conducted in the Gulf Coast Tertiary basin to define the CBM resource specifically. The age, thickness, and quality of the Gulf Coast coals have generally been considered a negative contributing factor in the potential development of the resource. With the success of CBM in the Tertiary-aged coals of the Powder River basin, a closer look at the CBM potential of the Gulf Coast coals is warranted. By way of comparison, according to the Gas Technology Institute (2001), the Powder River basin contains 1,300 billion short tons (bst) estimated in-place coal with 39 Tcf estimated coalbed GIP and 24 Tcf recoverable gas, and the Gulf Coast Coal Region has 400 bst estimated in-place coal with 8 Tcf estimated coalbed gas-in-place.

Initial evaluation of the coal resource in Louisiana was conducted by the Louisiana Geological Survey (LGS) (Meager and Aycock, 1942; Roland and others,1976) and focused on the distribution of surface and near-surface coals. Coals are mined at the surface in central northwestern Louisiana, in and around the Dolet Hills vicinity in De Soto Parish where the Wilcox Group (Paleocene-Eocene) crops out. The coals are generally confined to the lower Tertiary Wilcox Group and to a lesser extent to the overlying Eocene Claiborne and Jackson Groups. The coals appear to be widely distributed and some deposits are as thick as 10 ft. The coals are classified as lignites based on an average calorific value of 7,480 Btu per pound. Sulfur content is low, averaging 0.91 weight percent as received (ar) (Williamson, 1986).

Coates (1979) and Coates and others (1980) conducted research on the distribution and depositional environment of Wilcox lignites in the west-central Louisiana subsurface using well logs. These studies indicated that in the study area, the Lower Wilcox is a progradational delta complex to the east and a marginal delta plain to the west. They also noted that the Lower Wilcox is the major lignite-bearing interval containing as many as 35 coal seams (fig. 2). In an adjacent area with abundant subsurface data to the east, LGS has recognized the presence of numerous coal beds in the Lower Wilcox, with total coal thickness of a little more than 100 ft (fig. 3).

Warwick and others (2000) drilled two CBM test wells in Panola County, Texas, near Dolet Hills and reported calorific values above 8,300 Btu/lb, the boundary between lignite and subbituminous coal from shallow samples collected from 350 ft to 370 ft. Sulfur content averaged 0.52 percent (ar). Desorption analysis of the

[1] Modified from unpublished short course notes from Short Course #4, Coalbed methane potential in the U.S. and Mexican Gulf Coast, Gulf Coast Association of Geological Societies/Gulf Coast Section SEPM – 52nd Annual Convention, Austin, TX, October 30, 2002.

[2] Louisiana Geological Survey, Baton Rouge, LA

samples yielded an average gas content of 11 scf/ton dry-ash free (daf). Published adsorption values (Pratt and others, 1999) from the Powder River basin have similar adsorption values as those obtained from samples from the Texas wells. Isotope work on the Texas gas samples indicated a transitional biogenic/thermogenic mixed origin for the coal gases. Echols (1995) reported that analysis of gas samples from Paleocene-Eocene Wilcox conventional gas reservoirs in Winn Parish, Louisiana, believed to be sourced by CBM, were 99.94 percent methane and biogenic in origin.

Drilling in central North Louisiana in the prolific conventional Paleocene-Eocene Wilcox trend established the presence of numerous coal beds (fig. 4). Investigations by LGS initially defined a Central Louisiana Coalbed Methane basin (CELCOM), from detailed study of Caldwell and LaSalle, Parishes, Louisiana (Echols, 2000). There is every indication, based on previous work, (such as Coates and others, 1980; Rogers, 1983), that CELCOM extends to the southwest and northeast portions of North Louisiana (fig. 2). In fact, the name CELCOM was used for reference purposes only and is actually only a small portion of the entirety of the Gulf Coast Tertiary Coalbed Methane Basin which covers parts of seven southeastern states.

The first CBM production in Louisiana (and the Gulf Coast Tertiary CBM basin) was established in the Russell coal bed in April 1989 in Section 21, T14N, R4E, Caldwell Parish with the Torch Operating Co. #3 Greer well (figs. 2 and 5). The Torch #3 Greer came in flowing at 50 thousand cubic feet of gas per day (Mcfg/d) and 65 barrels of water per day (bblw/d) but was plugged and abandoned in 1989. More recently and in the same coal, the Woods Oil and Gas Co. IPCO #1 (completed 3/9/01) in Section 5, T11N, R3E, produced 15 Mcfg/d and almost no water (figs. 2 and 6). In an effort to stimulate gas flow, the IPCO #1 was water fraced approximately five months after completion. The procedure had the opposite effect of reducing gas flow and the well was later plugged and abandoned. In the area of detailed study in Caldwell and LaSalle Parishes, LGS has determined that the Russell coal is generally between 12 and 15 ft thick and calculated (using 13.5 ft as average thickness, coal specific gravity of 1.30, and 115 standard cubic ft of gas per ton of coal) an estimate of 63.3 billion cubic ft of coalbed methane gas GIP for the Russell coal in T11N-R3E. Based on other coalbed studies in east Texas (Griffiths and Pilcher, 2000), this GIP may be relatively low. More knowledge gained from tests and production from coalbed methane wells in the North-Central Louisiana should, however, provide more reliable estimates.

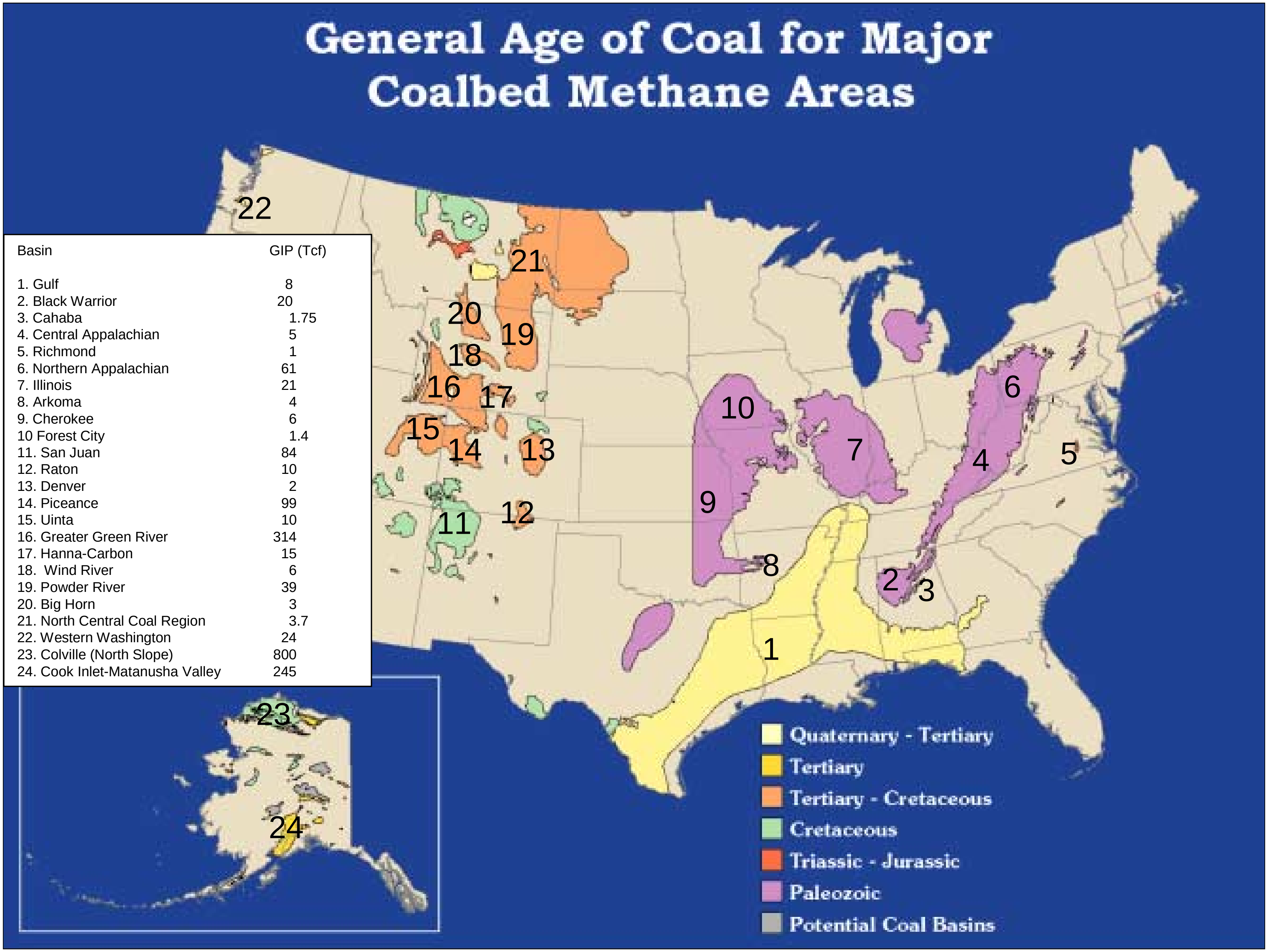

Figure 1. Coal map of the United States with Gas-In-Place (GIP) estimates in trillions of cubic feet (Tcf). Base map from USGS unpublished data; GIP estimates from Gas Technology Institute (2001).

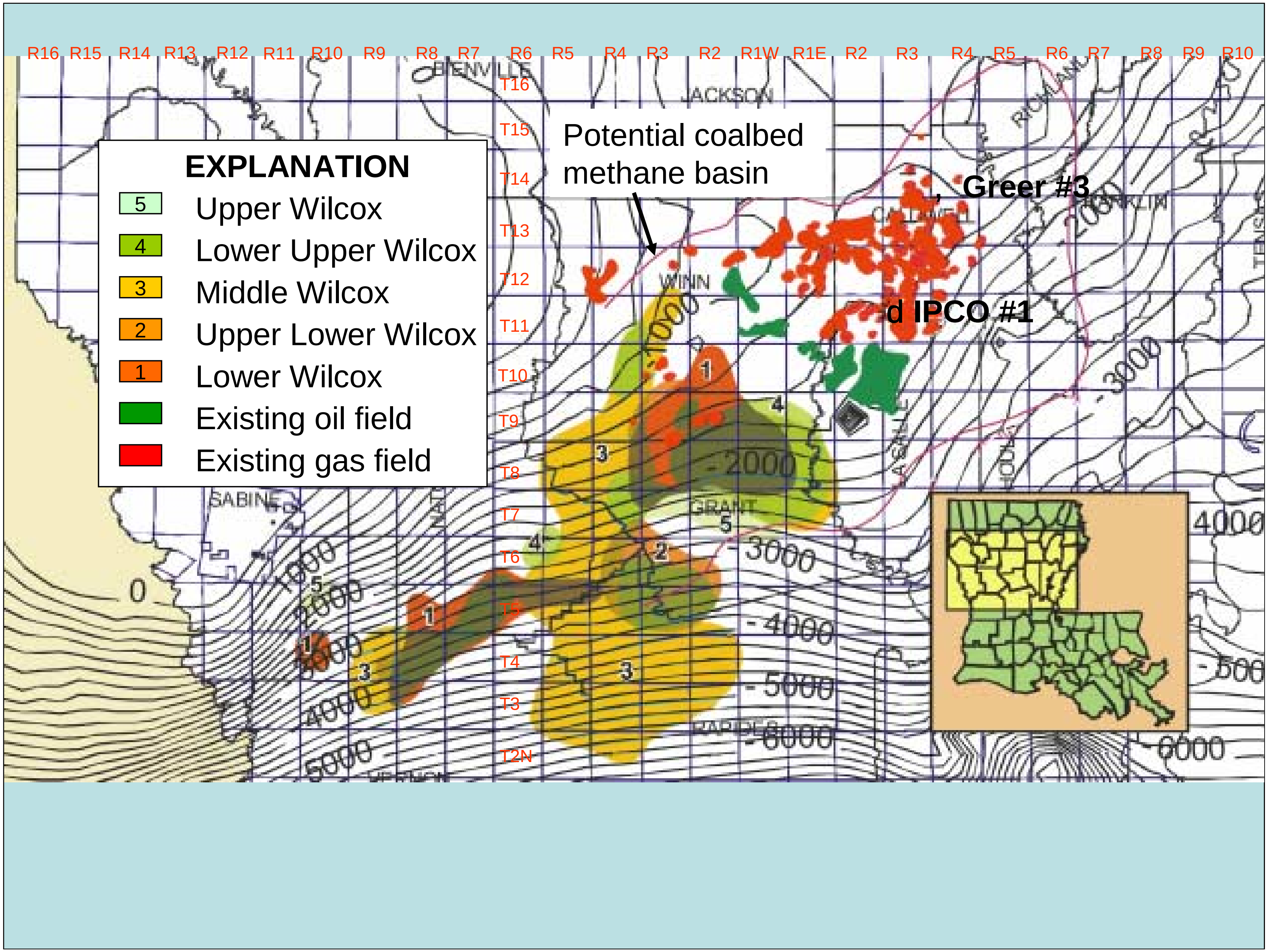

Figure 2. Structure map showing top (elevation below sea level; contour interval = 200 ft) of the Wilcox Group and location of existing oil and gas fields. The potential outline (red line) of a coalbed methane basin is indicated (from Echols, 2000). The distributions of Wilcox coal-bearing facies (1-5, modified from Coates and others, 1980) in North-Central Louisiana are also shown. The locations of two wells that have produced coal gas are indicated. Blue grid lines indicate Township and Range (red labels).

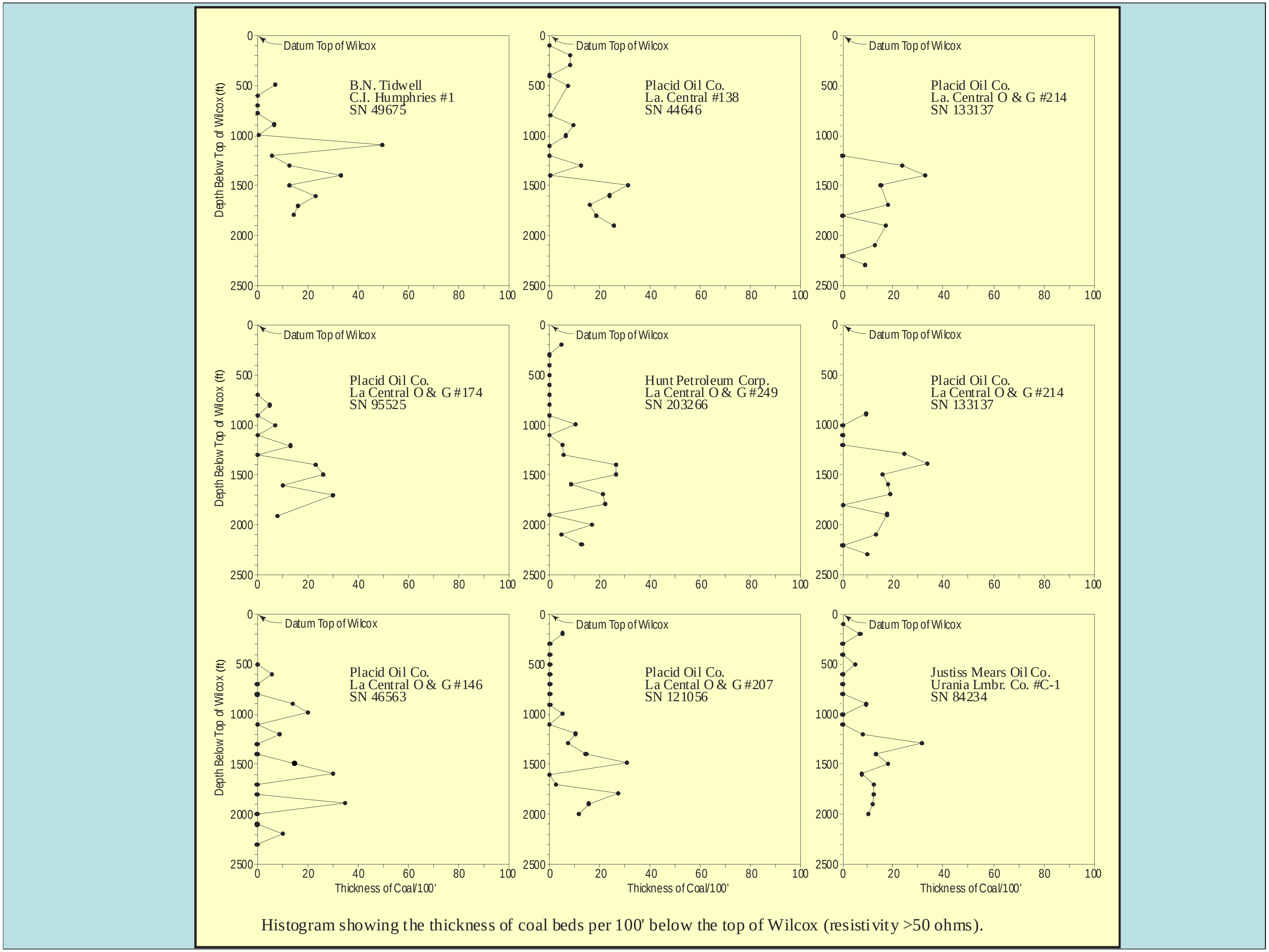

Figure 3. Histograms showing cumulative thickness of coal beds in each 100 ft interval below the top of the Wilcox Group (resistivity > 50 ohms). All wells are in LaSalle Parish, Township 10 N, Range 3 E (see fig. 2). SN = Louisiana well serial number.

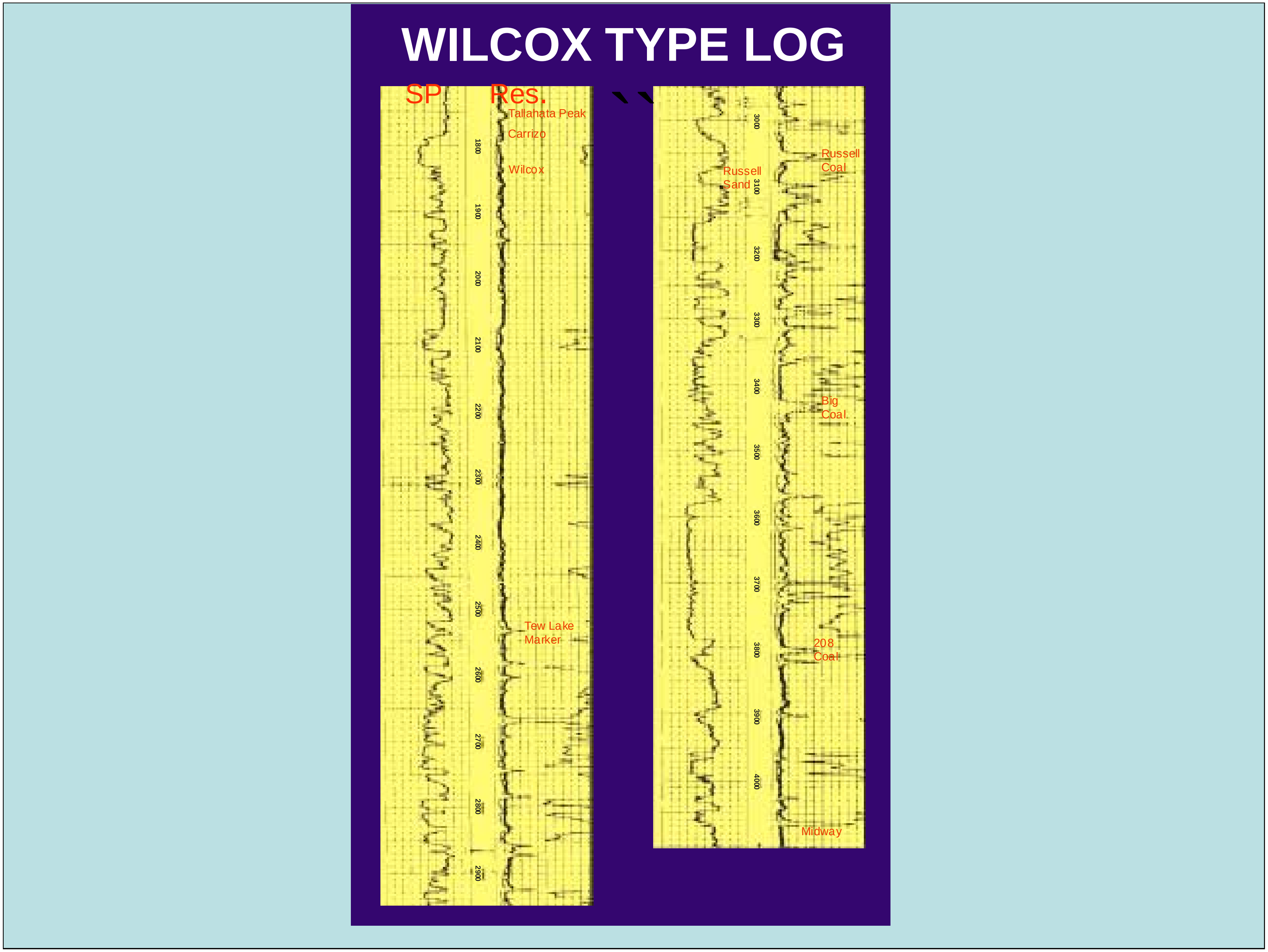

Figure 4. Type well logs (spontaneous potential, SP, and resistivity, Res.) for the coal-bearing Wilcox Group in Caldwell and LaSalle parishes in north Louisiana. Type log selected for the area is the Placid Oil Co., #214 Louisiana O&G Co., sec 15, T10N, R3E, LaSalle Parish (Olla Field), modified from Echols (2001).

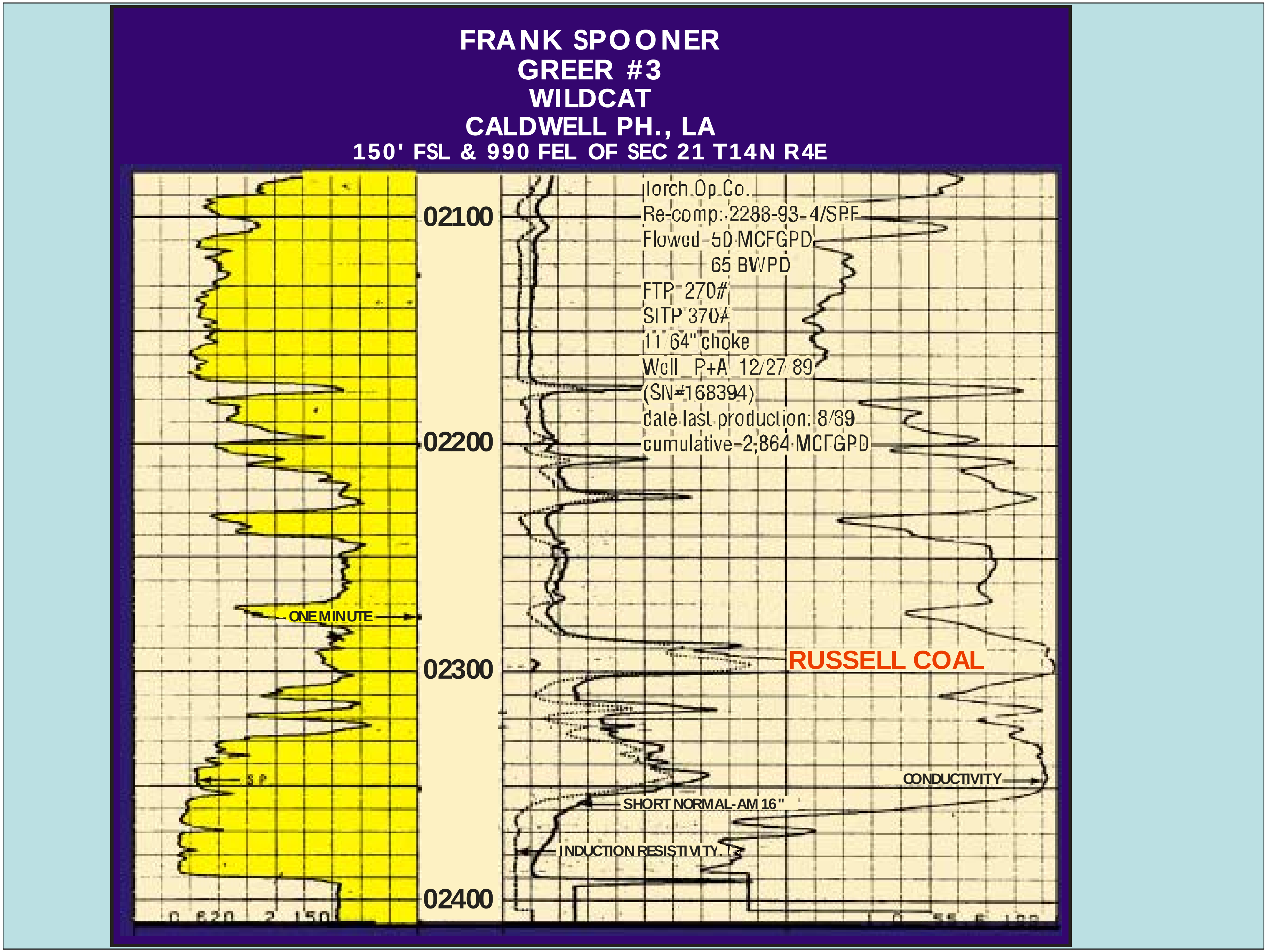

Figure 5. Portion of the electric log showing the Russell coal zone in the Greer # 3 well.

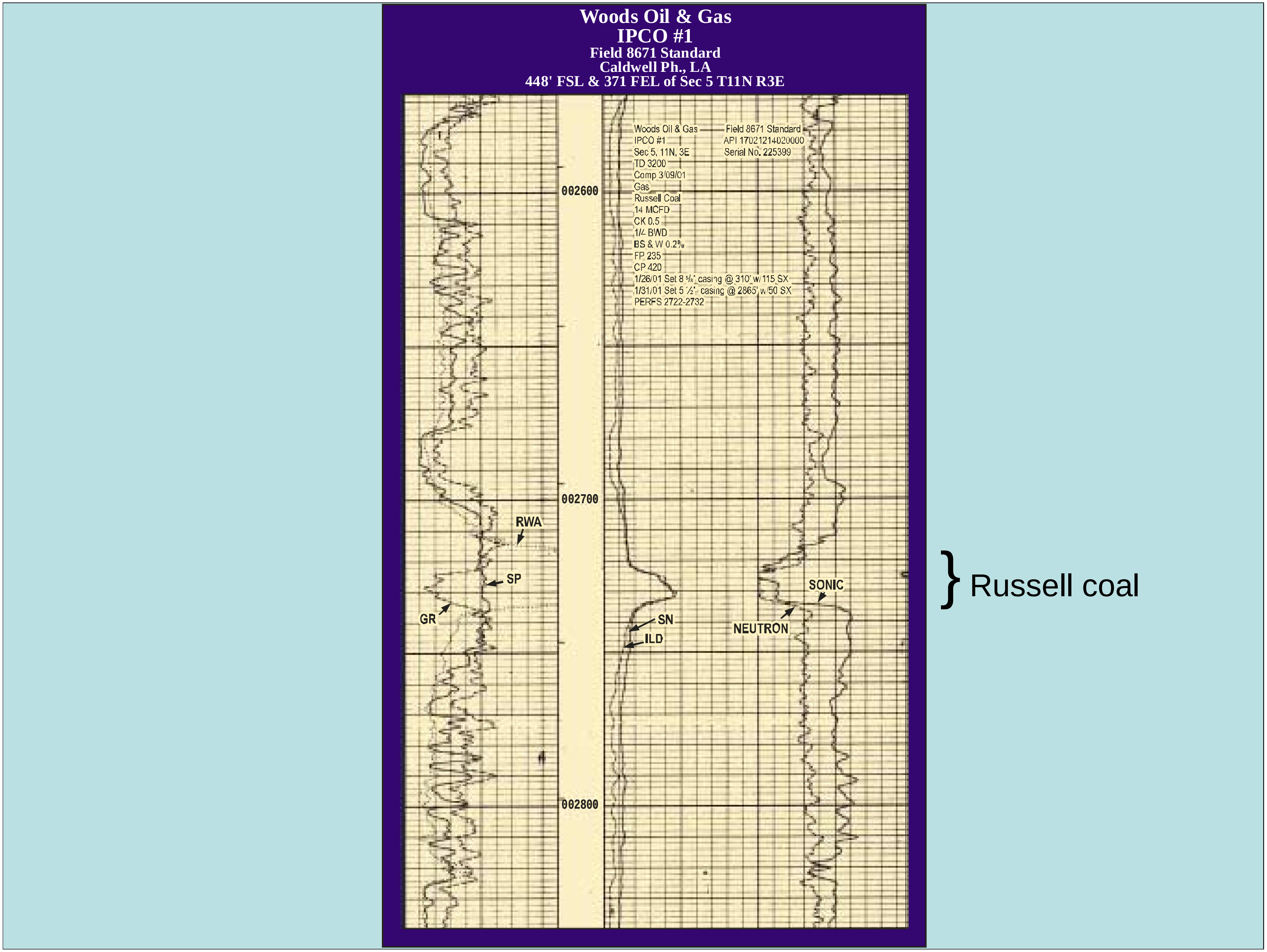

Figure 6. Portion of the electric log showing the Russell coal zone in the IPCO #1 well. GR = gamma ray; SP = spontaneous potential; RWA = apparent formation water resistivity; SN = short normal log; ILD = deep induction log

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The Pennsylvania Anthracite District – a Frontier Area for the Development of Coalbed Methane?[1]

By Robert C. Milici[2]

Abstract[3]

The anthracite region of eastern Pennsylvania consists of four major coal fields that are within the folded and faulted Appalachians, in the Valley and Ridge and Appalachian Plateaus physiographic provinces. These are, from south to north, the Southern Anthracite field, the Western Middle Anthracite field, the Eastern Middle Anthracite field, and the Northern Anthracite field. Rank of the coal ranges from semi-anthracite to anthracite. In general, the anthracite fields consist of Pennsylvanian strata that are complexly folded, faulted, and preserved in structural synclines within older Paleozoic strata.

Published gas-in-place (GIP) data for Pennsylvania anthracite range from 6.4 SCF/ton (0.2 cc/g) for the Orchard coal bed to a high of 691.2 SCF/ton (21.6 cc/g) from a sample of the Peach Mountain coal bed that was collected in the Southern Anthracite field at a depth of 685 feet. This is the largest GIP value that the U.S. Bureau of Mines (USBM) (Diamond et al, 1986) reported for coalbed methane (CBM) nationwide. Of the 11 CBM analyses reported for the Southern Field by USBM, seven exceed 396 SCF/ton (12.4 cc/g) (average of 11 samples: 325.8 SCF/ton [10.2 cc/g]). In addition, adsorption isotherms for the Mammoth, Seven-Foot, and Buck Mountain coal beds in the Southern Field indicate that these beds have a very high capacity to hold methane under pressure (Lyons et al, 2003), with values that range from about 320 to 850 SCF/ton (10 to 27 cc/g).

In spite of the complex geologic structures, there are several areas in the Southern Anthracite field where subhorizontal to moderately inclined coal beds may be accessed by the drill. For example, a detailed map and sections by Wood (1972) in Schuylkill County, Pennsylvania, has defined several areas of subhorizontal to gently inclined strata that contain 10 or more coal beds at depths of 500 to 2000 feet (150 to 600m), and with a cumulative coal thickness of 50 feet (15m), or more.

These data suggest that the Pennsylvania anthracite district is, at least, worthy of testing for CBM, using current desorption methodology and with coal samples collected from several coal beds in a single core hole.

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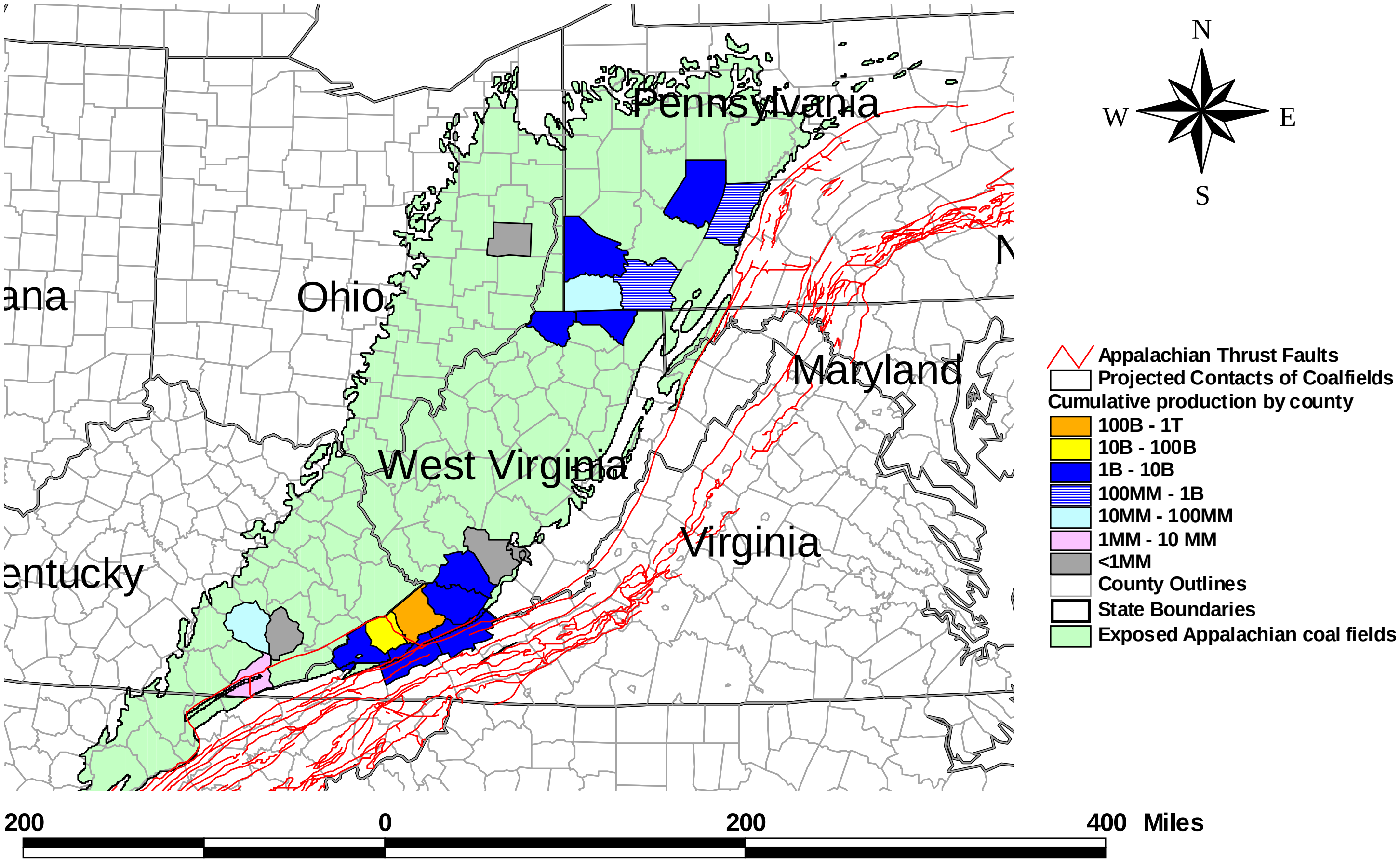
[1] Presented at 2004 combined annual meeting of the NE/SE Section of the Geological Society of America
[2] U.S. Geological Survey, Reston, VA
[3] Reprinted from Milici (2004)

Appalachian Basin CBM Overview

Appalachian Basin CBM Production



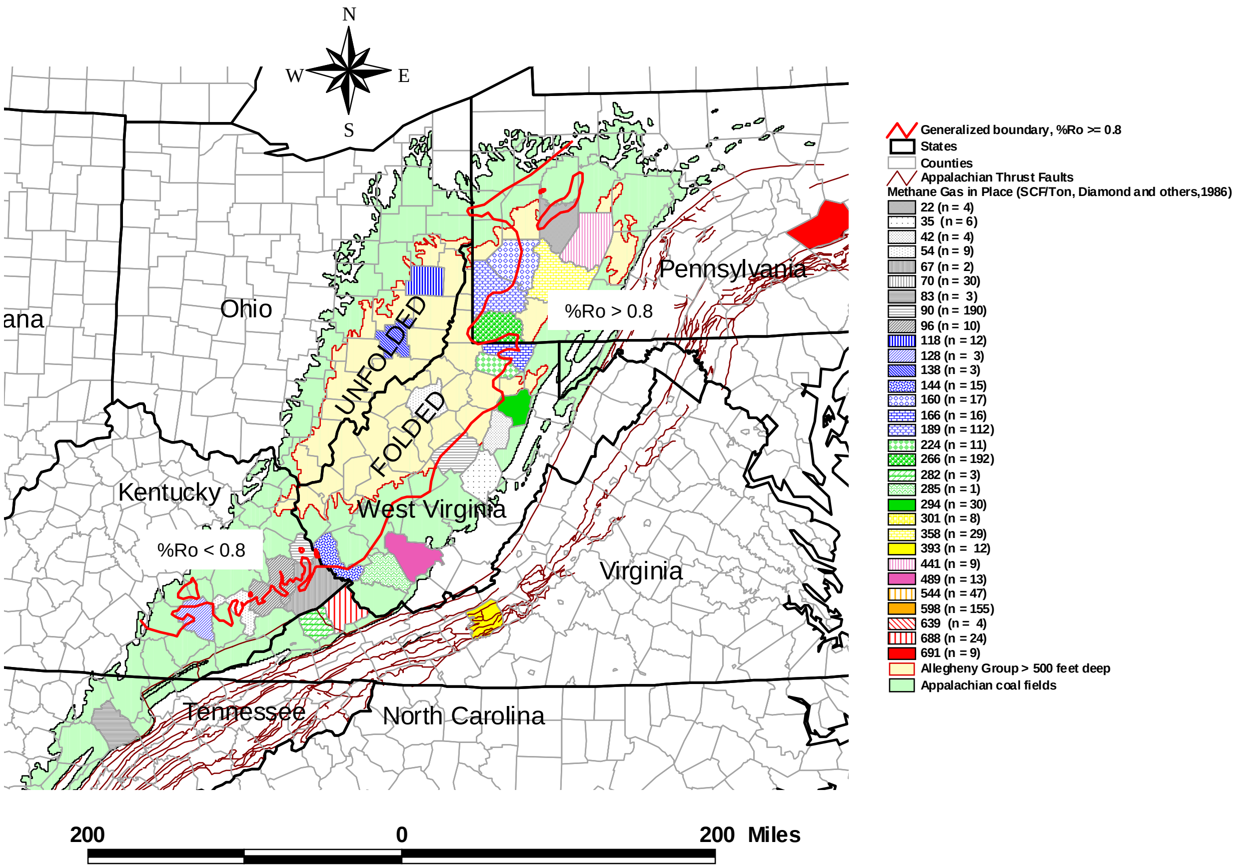
Cumulative coalbed methane (CBM) production by county in the northern and central Appalachian coal fields as of 2003. MM = million; B = billion; T = trillion. See next slide for data sources.

State	County	Date of first Production	Cumulative Production Date	No. Currently Producing Wells	CBM Cumulative Production (Mcf)
Alabama	Greene	1992	10/31/2003	0	99,565
	Hale	1990	10/31/2003	0	111,543
	Jefferson	1980	10/31/2003	655	184,658,319
	Pickens	1990	10/31/2003	0	1,873
	Shelby	1990	10/31/2003	0	3,969,067
	Tuscaloosa	1981	10/31/2003	3,096	1,310,241,313
	Walker	1989	10/31/2003	102	18,937,713
Alabama	Subtotal			3,853	1,518,019,393
Virginia	Buchanan	1992	2002	1,492	321,535,042
	Dickenson	1988	2002	474	71,810,618
	Russell	1990	2002	110	10,694,923
	Tazewell	1990	2002	93	5,620,269
	Wise	1990	2002	80	6,577,583
Virginia	Subtotal			2,249	416,238,435
West Virginia	Logan	2002	2002	1	157
	Marshall	ND	ND	ND	ND
	McDowell	1995	2002	40	3,571,128
	Monongalia	1992	2002	22	1,443,617
	Raleigh	1992	2002	2	62,811
	Wyoming	1994	2002	67	19,335,467
	*Wetzel	1931	2002	2	1,328,862
West Virginia	Subtotal			133	25,742,042
Pennsylvania	Cambria	1997	2002	Confidential	166,950
	Fayette	1999	2002	Confidential	199,718
	Greene	1988	2002	Confidential	774,910
	Indiana	1993	2002	Confidential	3,433,679
	Washington	1993	2002	Confidential	1,184,125
Pennsylvania	Subtotal			225	5,759,382
Kentucky	Bell	1998	2002	3	7,674
	Clay	1998	2002	5	56,478
	Leslie	2000	2002	1	
	Letcher	1997	2002	1	
Kentucky	Subtotal			10	64,152
Appalachian Basin Total				6,470	1,965,823,404
* Big Run and new unnamed fields, only					

Cumulative Production of CBM in the Appalachian Basin

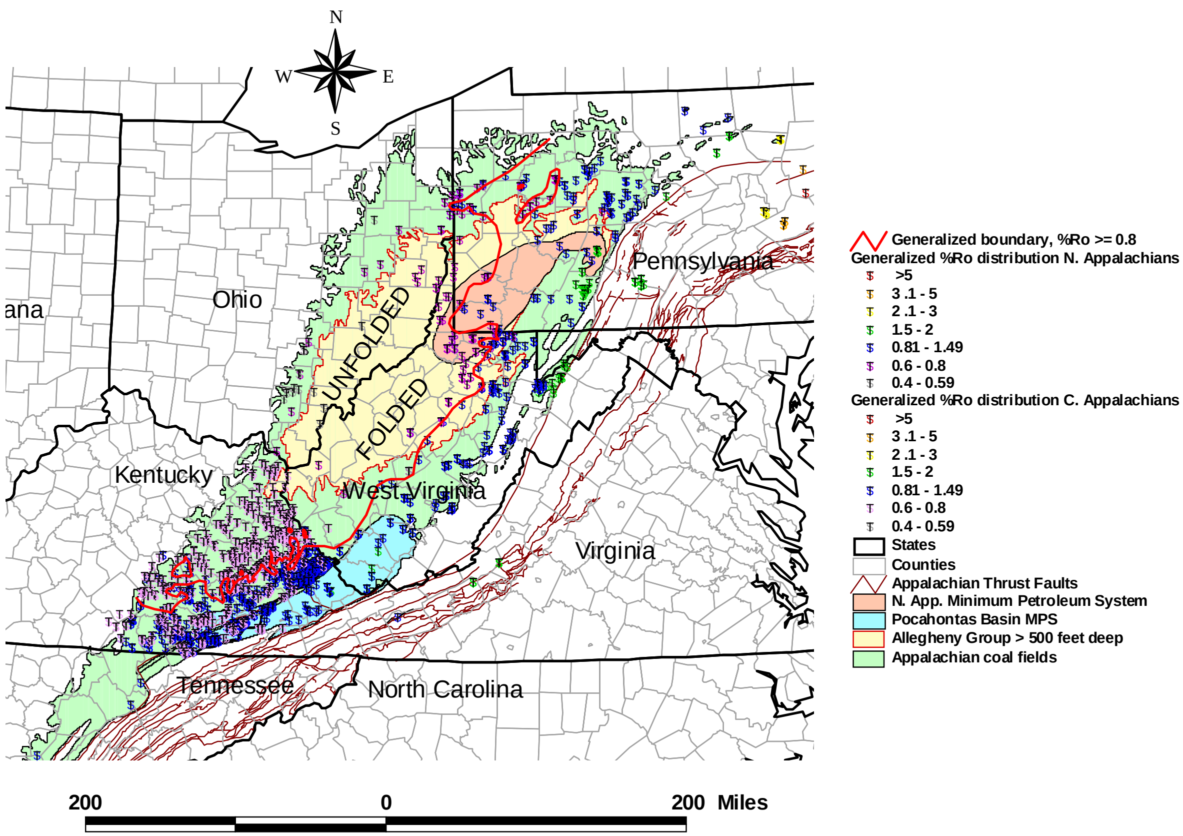
Cumulative production of CBM from the Appalachian Basin (1999-2003 data). Source of data: Alabama State Oil and Gas Board (2004); Kentucky Division of Gas and Oil (2004); Markowski (2004); Virginia Center for Coal and Energy Research (2004), and Avary (2004).

USBM Gas-in-place Values



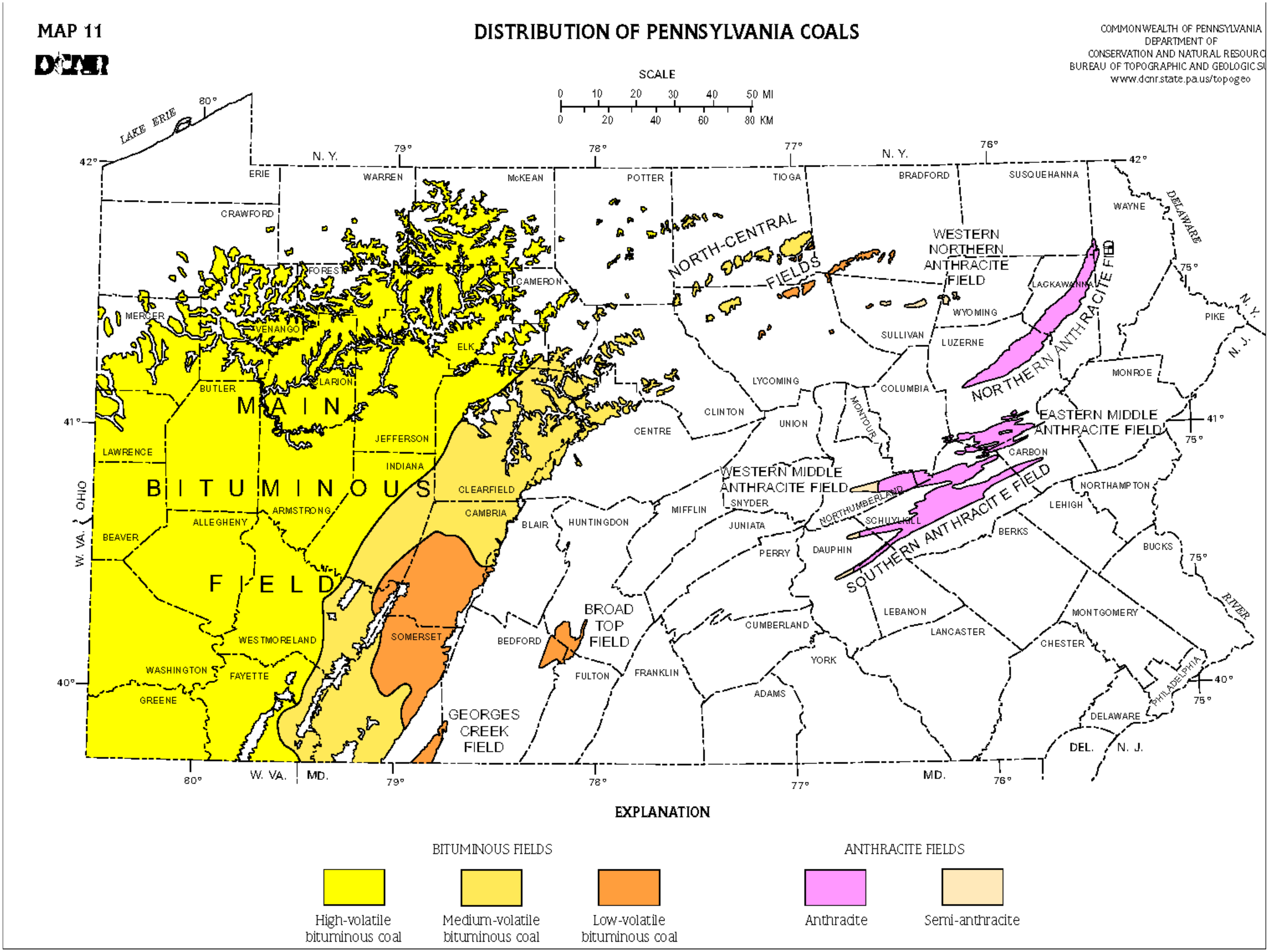
In-place gas values by county in cubic feet per ton (Diamond and others, 1986; in CF/TON). N = number of samples in the county; the values presented are the largest for each county represented. USBM = U.S. Bureau of Mines. Vitrinite reflectance line of 0.8 %Ro separates relatively immature region on the west from mature region on the east, similar to thermal maturation patterns in Alabama (Pashin and Hinkle, 1997).

Thermal Maturation Values (%Ro) in the Dunkard and Pocahontas Basins



Location and vitrinite reflectance values (%Ro) for coal samples studied courtesy of Leslie Ruppert, USGS. Illustration shows the minimum petroleum system boundaries for the Dunkard (Northern Appalachian) and Pocahontas basins, the folded and unfolded parts of the Dunkard basin, and a generalized boundary between thermally mature and immature coal beds. C. = Central, N. = Northern, App. = Appalachian, MPS = Minimum Petroleum System.

The Anthracite Region



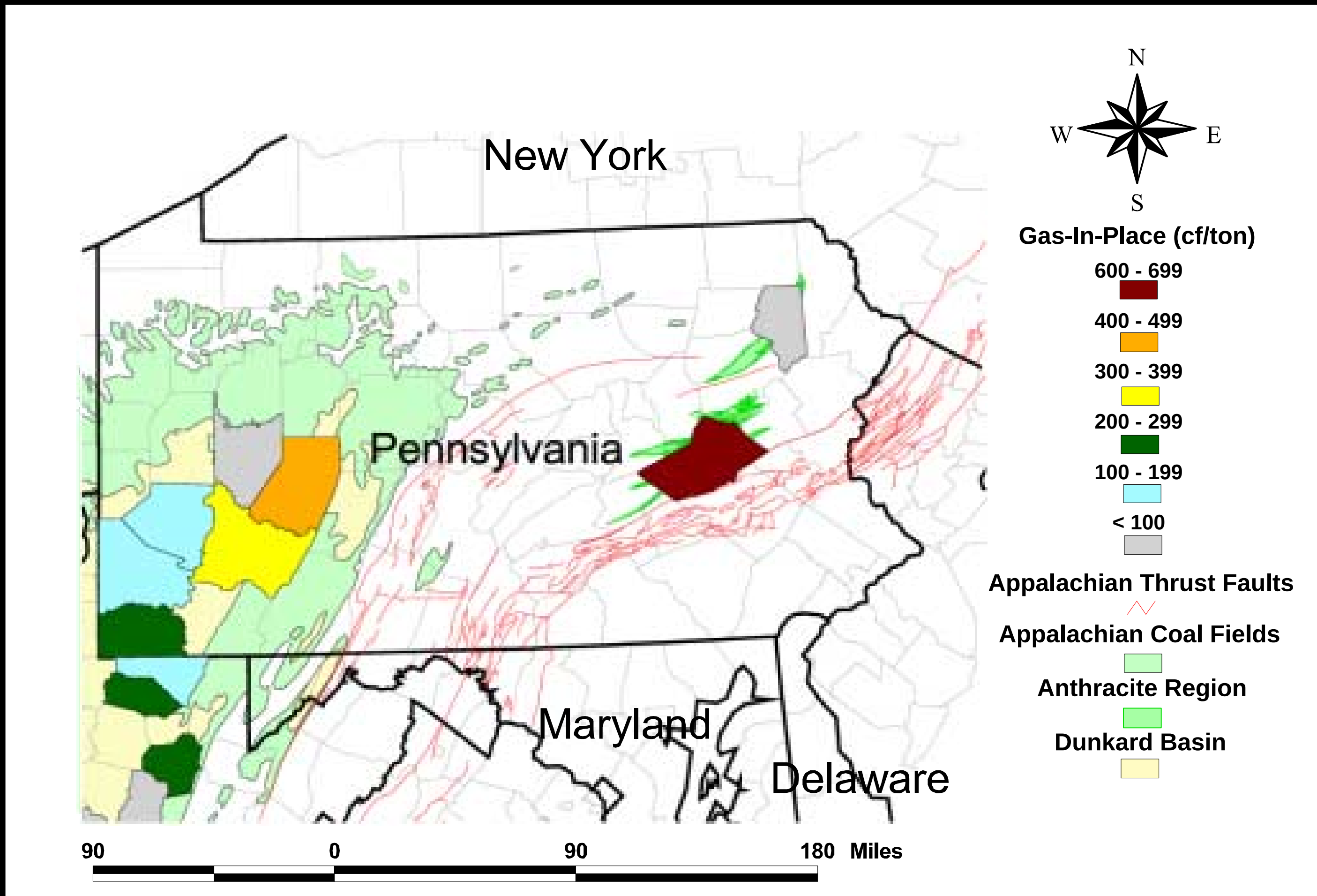
Map 11, Pennsylvania Bureau of Topographic and Geologic Survey, http://www.dcnr.state.pa.us/topogeo/maps/map11.pd.

Comparison of Pocahontas Basin and Anthracite Region

	Pocahontas Basin	Anthracite Region
Geologic Structure/ porosity/ permeability	Deep basin; bedding-parallel faulting in coal	Complex folding and faulting; conchoidal fracture in coal
Amount of Water	Generally low	Probably moderate to high
Gas-in-Place	688 cf/ton	691 cf/ton
Coal rank	Low-volatile bituminous to semianthracite	Bituminous to anthracite
Depth of overburden	About 2000 feet (max)	Maximum unknown, but > 1000 feet
Coal Quality	Low ash, low sulfur, high rank coal	Low ash, low sulfur, high rank coal

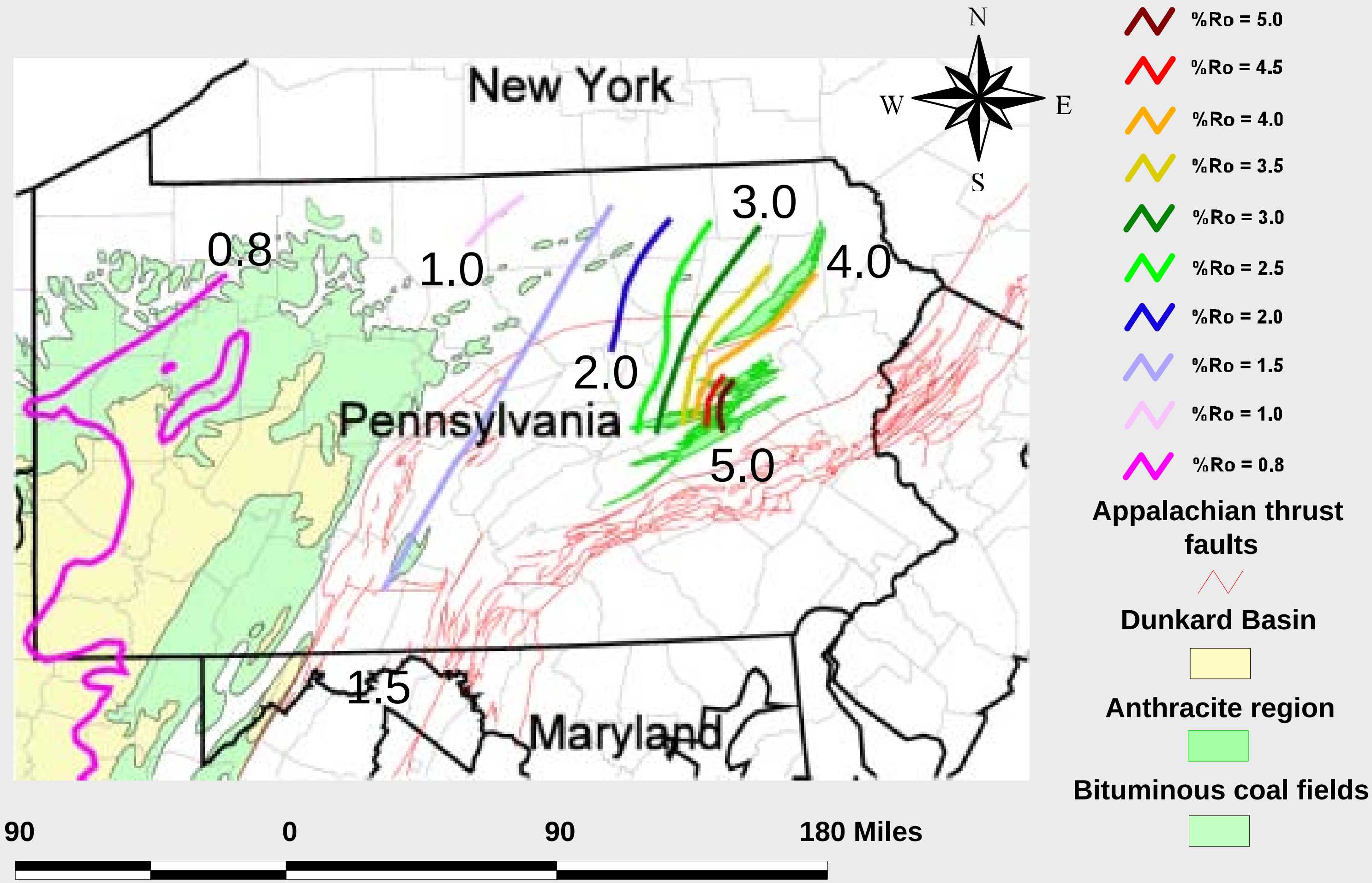
Although there is a great deal of difference, geologically, between the Pocahontas basin and the Pennsylvania anthracite district, the regions do exhibit some common characteristics. Gas-in-place data, the maximum for each basin (Diamond and others, 1986), in cubic feet per ton (cf/ton) were obtained from desorbing coal core samples under ambient conditions. Max = maximum.

Northern Appalachian Coal bed Gas-In-Place Data



Data from Diamond and others (1986). Gas-in-place data were measured under ambient conditions. See earlier slide for number of samples per county.

Thermal Maturation of Northern Appalachian Coal Fields in %Ro



The slide shows increase of thermal maturity from west to east across the northern part of the Appalachian coalfields. %Ro values range from about 2 on the western side of the anthracite region to 5, or more, in the Southern Anthracite Coalfield (data from Ruppert, written communication, 2002, and Hower and others, 1993).

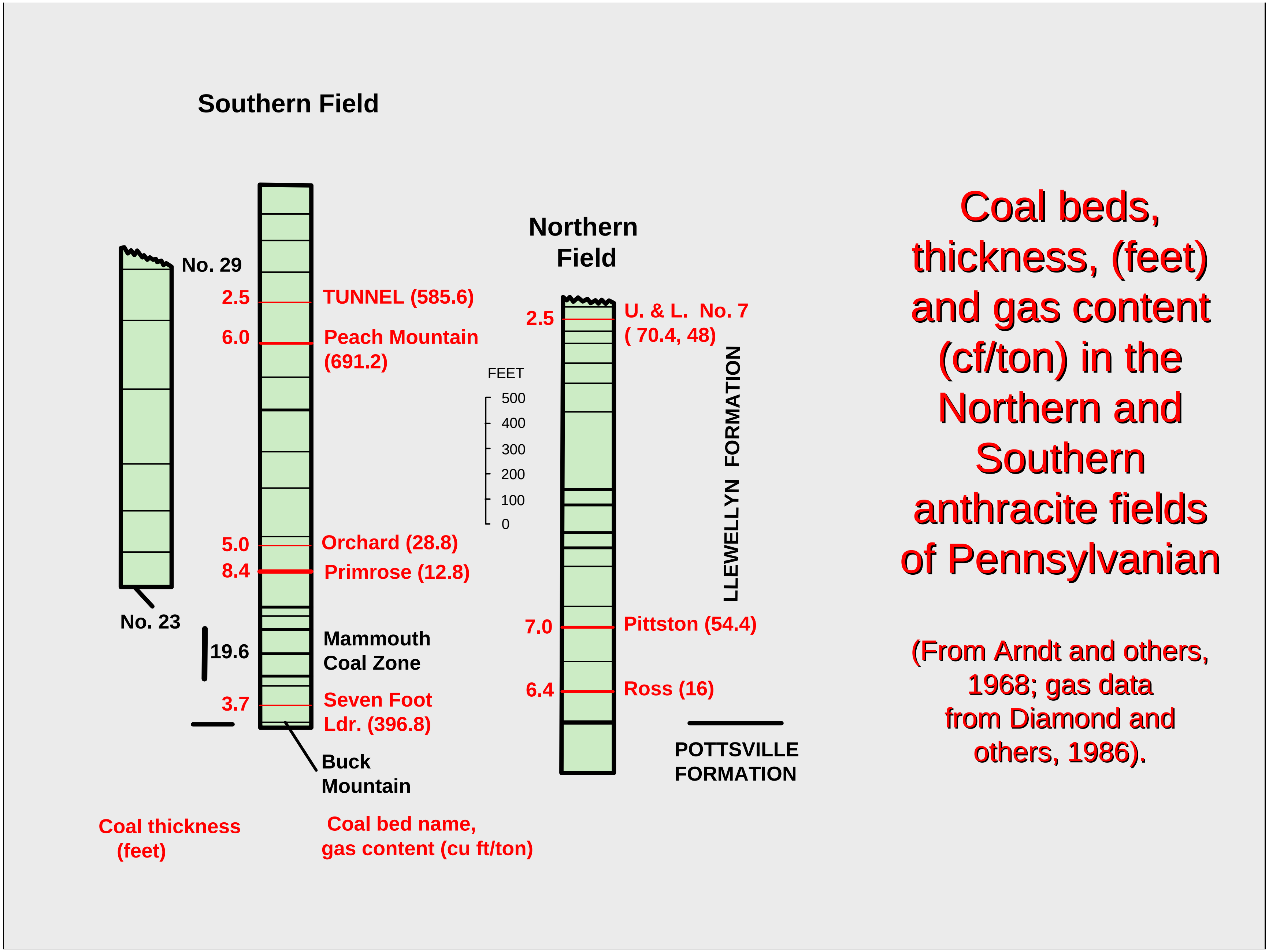
Northern Anthracite Field	Southern Anthracite Field
Total gas (cf/ton)	Total gas (cf/ton)
U. New County	Tunnel
70.4	585.6
54.4	482
L. New County	448
48	403.2
41.6	Peach Mountain
32	691.2
28.8	640
25.6	601.6
16	Orchard
Big Bed (Pittston)	28.8
64	6.4
54.4	
44.8	Primrose
32	12.8
28.8 (2)	
Clark (Ross)	Seven Foot Leader
16 (2)	396.8 (2)
12.8	
9.6 (2)	

Gas-in-place data for the Northern and Southern Anthracite fields

(Diamond and others, 1986; Trevits and others, 1988)

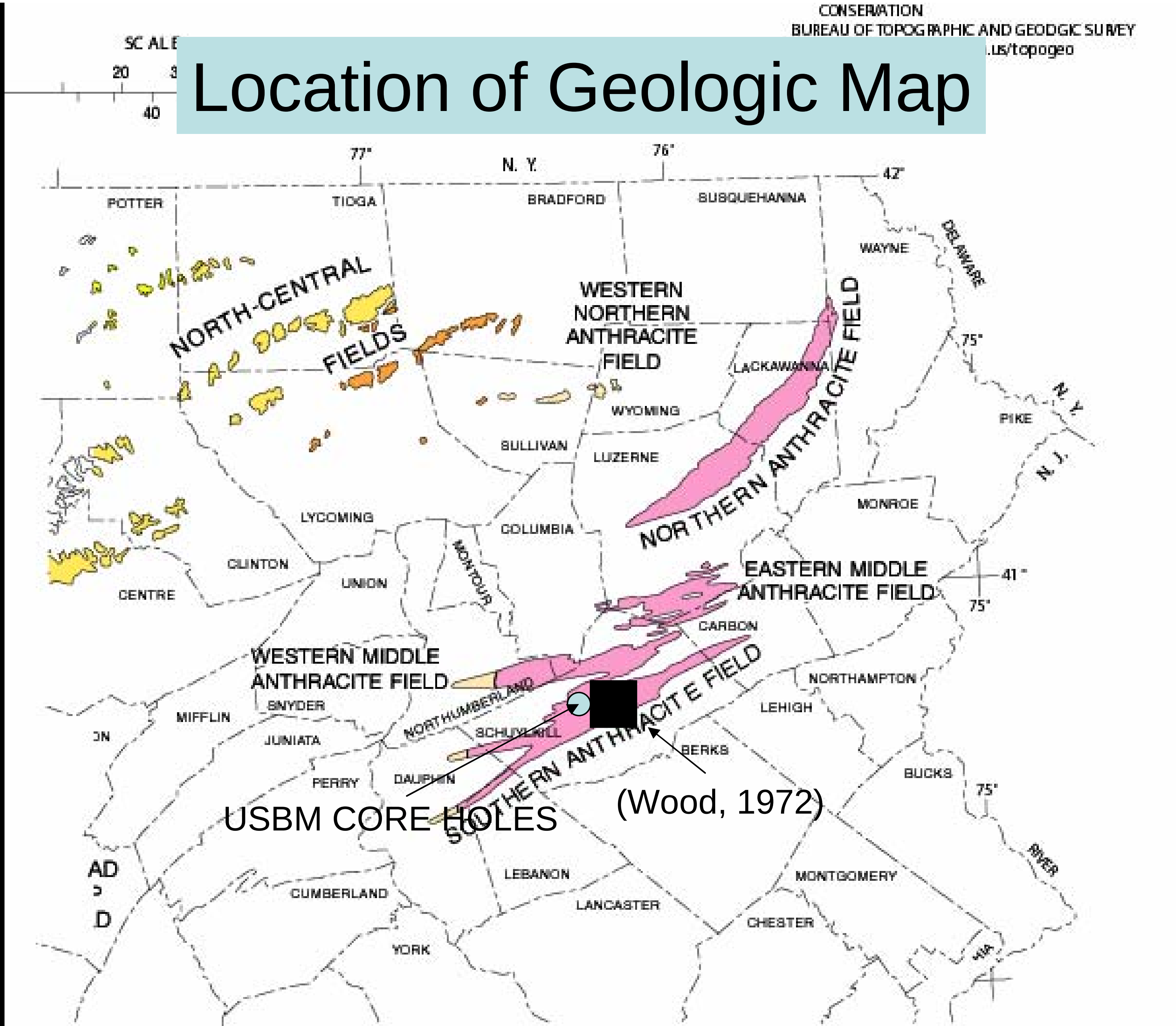
cf = cubic feet; L. = Lower; U. = Upper.

CBM desorption values, in ambient cubic feet per ton, obtained by the U.S. Bureau of Mines for the Northern and Southern Anthracite fields in Pennsylvania (Diamond and others, 1986).

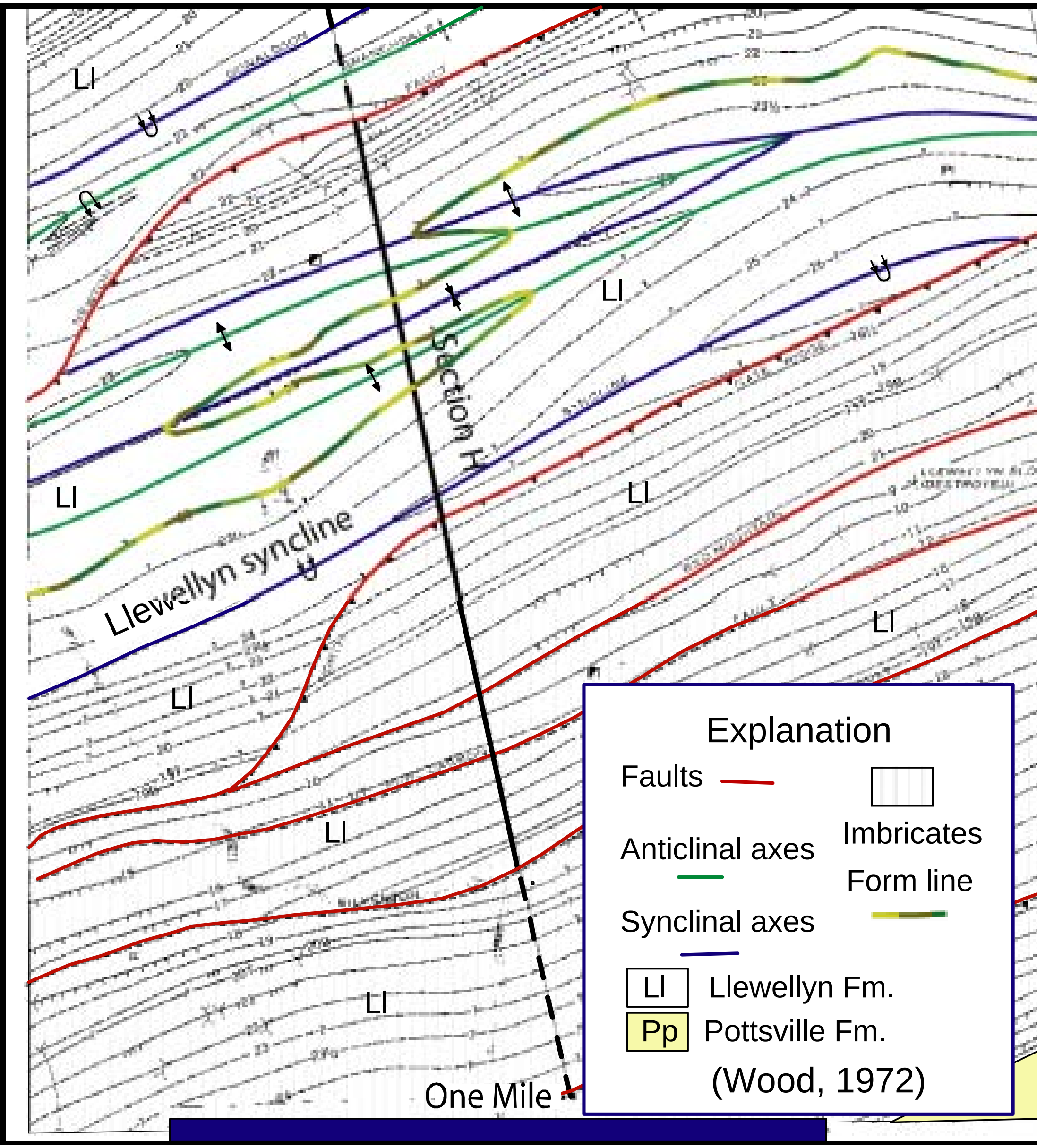


Generalized stratigraphic column for the Northern and Southern Anthracite fields (adapted from Arndt and others, 1968; gas data from Diamond and others, 1986). Coal bed names are shown generally on right of column, together with maximum tested values for gas content; names or numbers in red are for coal beds for which there is gas-in-place data. Numbers on the left side of columns show the average thicknesses of the coal beds.

Location of Geologic Map



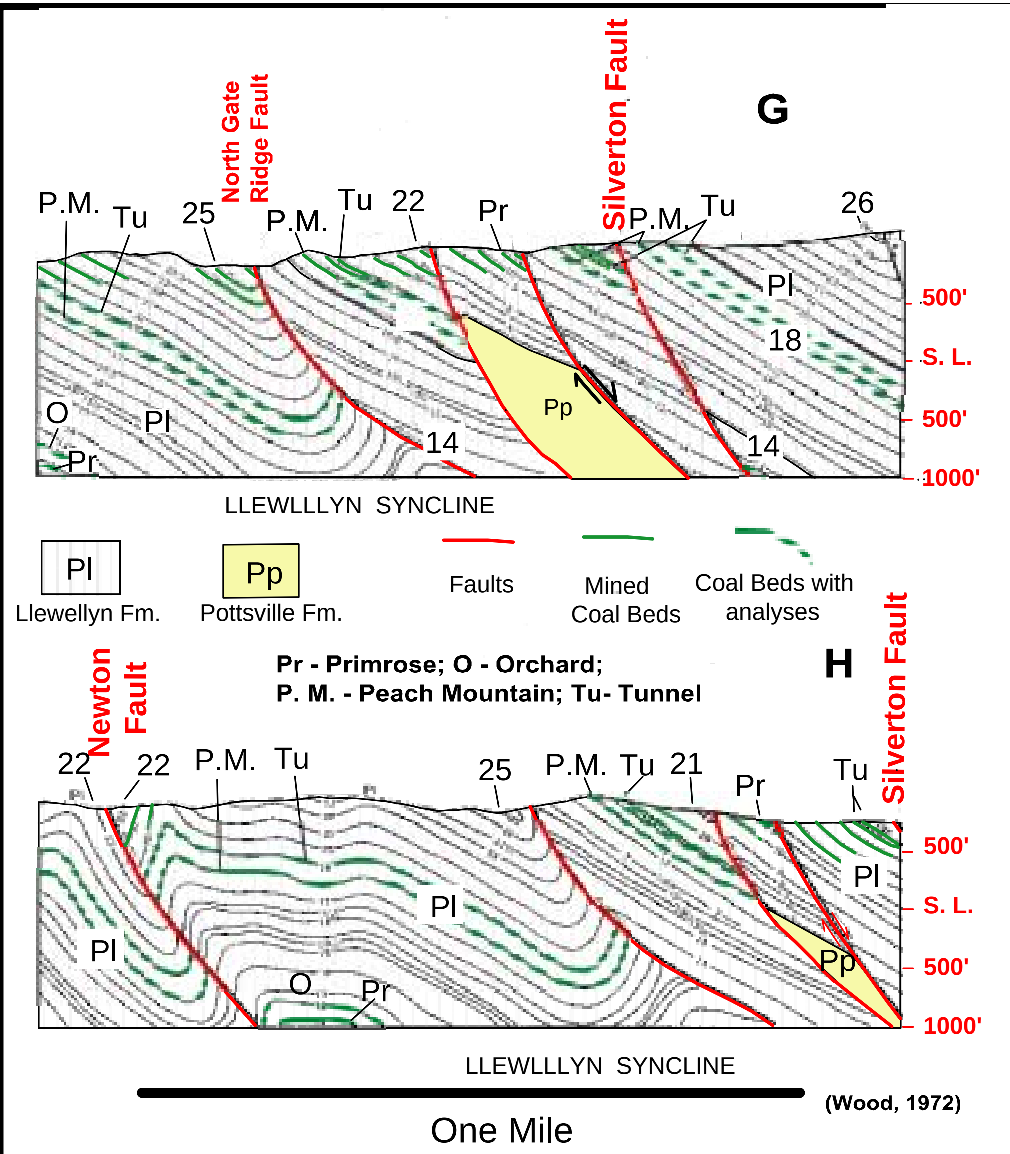
Part of Pennsylvania Topographic and Geologic Survey Map 11, showing the general location of the Schuylkill quadrangle (Wood, 1972) and two closely spaced USBM core holes (Trevits, and others, 1988). See earlier slide for explanation of colors.



South-west Corner of the Pottsville Quad-rangle, PA

(Wood, 1972)

In this illustration, the faults are shown in red and the coal beds in black, except for Coal bed 23, which is colored blue and yellow. Synclinal axes are shown in blue and anticlinal axes in green. The location of the cross section partly illustrated in the following slide (Wood's Section H) is shown by the straight blue line. The part of the section shown is indicated by the solid line. Note that the mapped area may be divided into an imbricate thrust-faulted zone, with strata that are moderately inclined to the southwest, and the Llewellyn syncline, which contains beds that are tightly folded. The scale of Wood's (1972) published map is 1:12,000.



Parts of G and H Cross Sections, Schuylkill Co., PA (Wood, 1972)

Note that the Pottsville Formation (Pp) is shown in yellow, and the Llewellyn Formation (Pl) with vertical ruled lines. The Primrose (Pr), Orchard (O), Peach Mountain (PM), and Tunnel (TU) coal beds are high-lighted in dashed green. Solid green-colored coal beds along the surface of the section have been mined. Section G is one mile northeast of section H.

USBM Boreholes

- Two holes drilled in Minersville Quadrangle in 1975 (Trevits and others, 1988)
  - 1. Drilled to 1,948 feet, stuck, flooded; 6 coal beds perforated, stimulated; Peach Mountain had 640 cu ft/ton, low porosity and permeability; little gas.
  - 2. Drilled to 2,355 feet; 8 coal beds perforated and stimulated; Tunnel coal 482 cu ft/ton, low porosity and permeability; little gas.

USBM Section, Southern field

(Trevits and others, 1988)

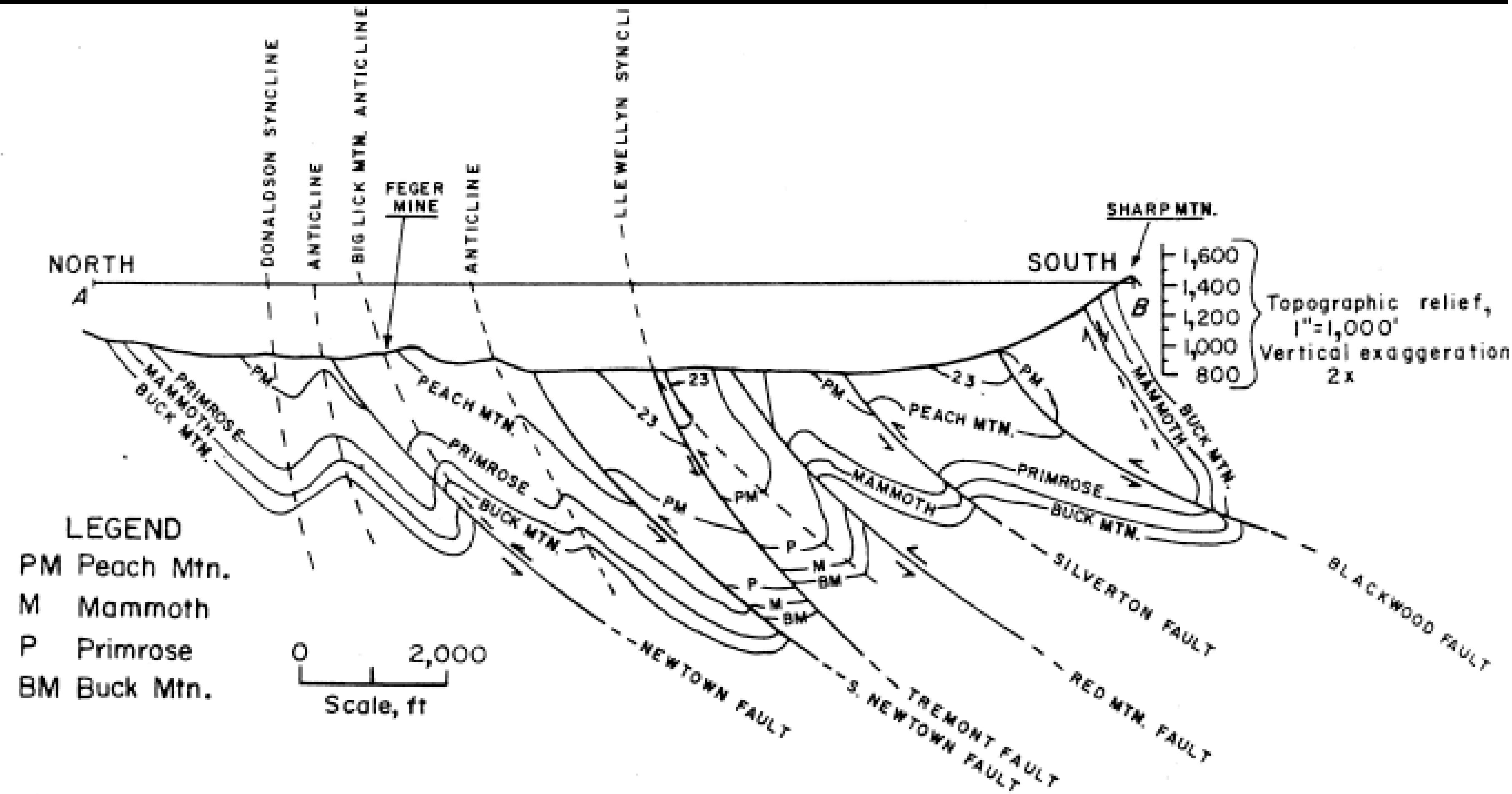


Figure 9-17.—Generalized cross section of coalbeds in anthracite region.

Cross section from Trevits and others, 1988, Figure 9-17.

Is there gas?

Explosions of fire-damp (CH_4)
in Anthracite coal mines 1870 to 1880

YEAR	NUMBER
1879	100
1878	29
1877	71
1876	65
1875	59
1874	77
1873	74
1872	81
1871	83
1870	40
Total	**679**

Casualties 1127; deaths 225

Data from Chance (1883).

Potential Problems for CBM Development

- Complex geologic structure; subsurface geology may not be as shown in cross –sections.
- Many surface and deep mines.
- Adequate seals, gas leakage?
- USBM Well, Minersville quadrangle, low porosity and permeability?
- Development of drilling units in areas of complex structure.
- Water disposal amounts and quality unknown.

Potential problems for CBM development.

Favorable factors for CBM Development

- Detailed Geologic studies.
- Many thick coal beds – great cumulative coal thickness, perhaps up to 100 feet locally.
- High GIP values.
- Good fractures, porosity, permeability?
- Thermally mature or post mature.
- Close to local markets.

Favorable factors for CBM development. GIP = Gas-in-Place.

Questions

- Does the coal have sufficient microporosity and permeability to store and release gas at economically sufficient rates to warrant development?
- Can we dewater the coal beds sufficiently to improve permeability and release methane to the well bore?

A major question for CBM development.

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Geologic Heterogeneity and Coalbed Methane Production – Experience from the Black Warrior Basin[1]

By Jack C. Pashin[2]

Opening Points

- Numerous geologic factors, including stratigraphy, structure, coal quality, and hydrology influence coalbed methane production in the Black Warrior basin of Alabama.
- Producing coalbed methane requires a different paradigm that is used for conventional reservoirs.
- The Black Warrior basin is an operationally mature basin in which extreme geologic heterogeneity influences gas and water production from coal.

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[1] Modified from unpublished short course notes from Short Course #4, Coalbed methane potential in the U.S. and Mexican Gulf Coast, Gulf Coast Association of Geological Societies/Gulf Coast Section SEPM – 52nd Annual Convention, Austin, TX, October 30, 2002.

[2] Geological Survey of Alabama, Tuscaloosa, AL

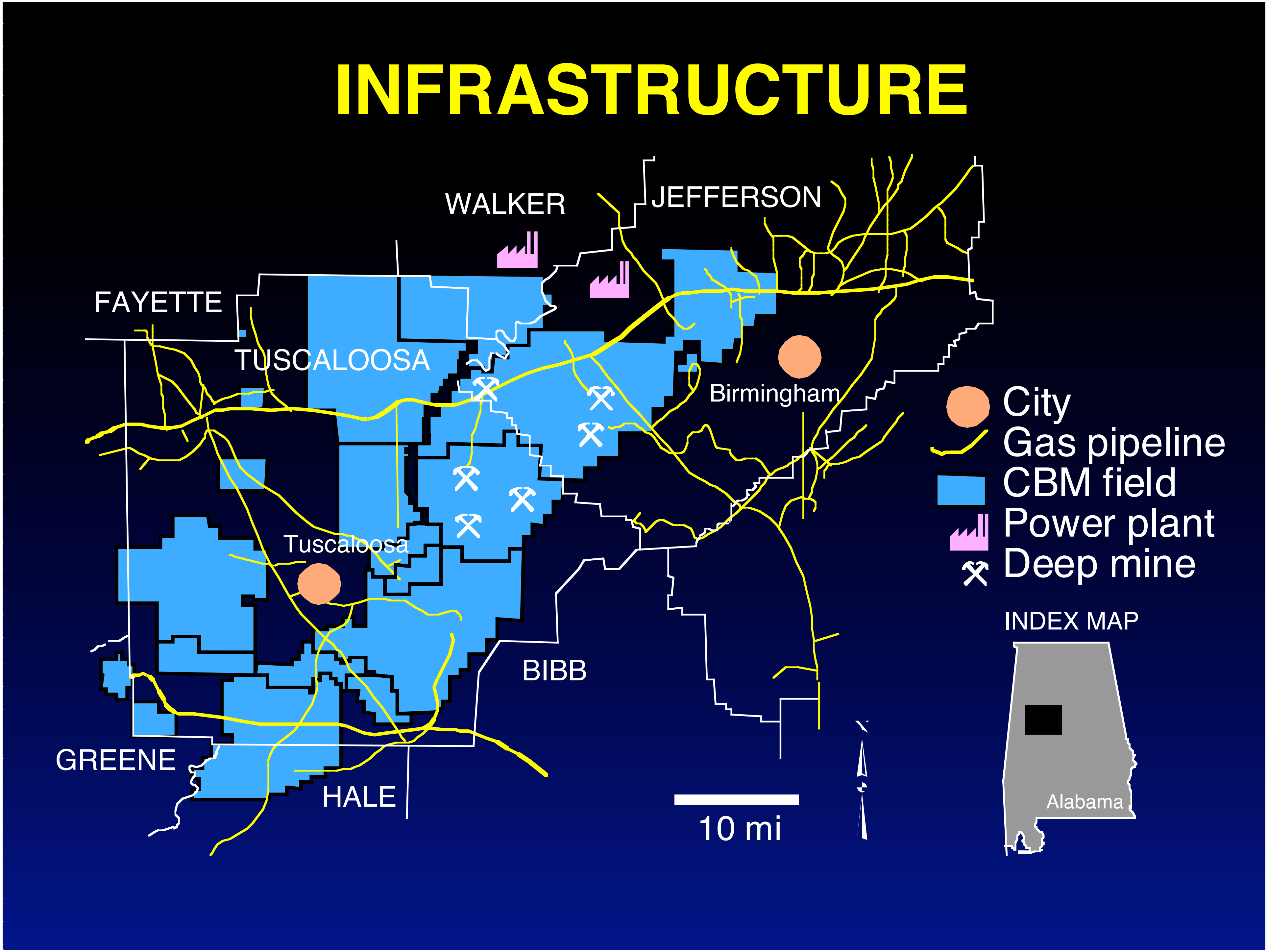


Figure 1. Infrastructure associated with coalbed methane fields in the Black Warrior basin of west-central Alabama.

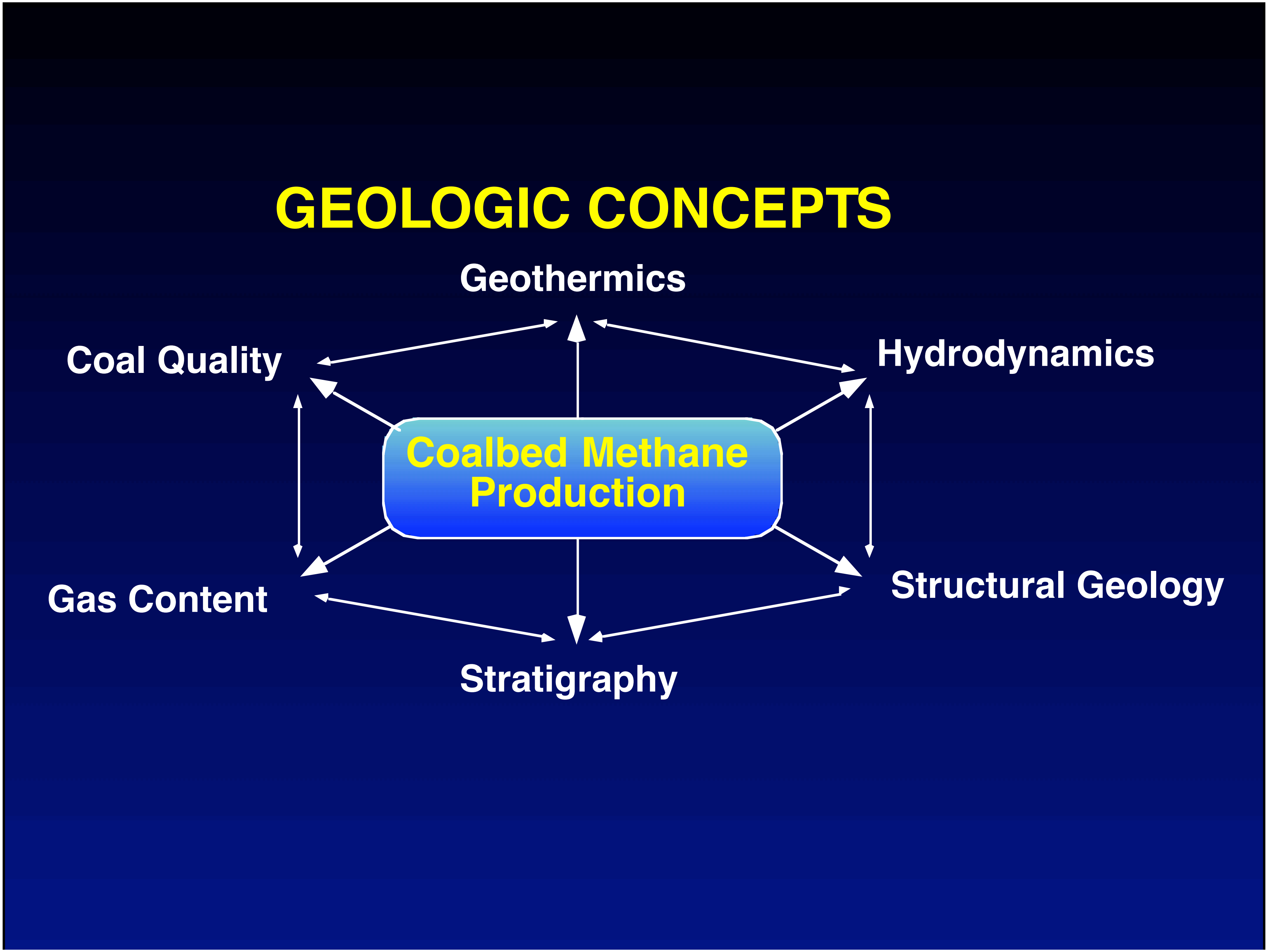


Figure 2. Major geologic concepts associated with coalbed methane production.

BLUE CREEK COAL BED

Medium volatile bituminous

Figure 3. The Blue Creek coal bed is the principal mining target in the Black Warrior basin and was the original focus of coalbed methane operations.

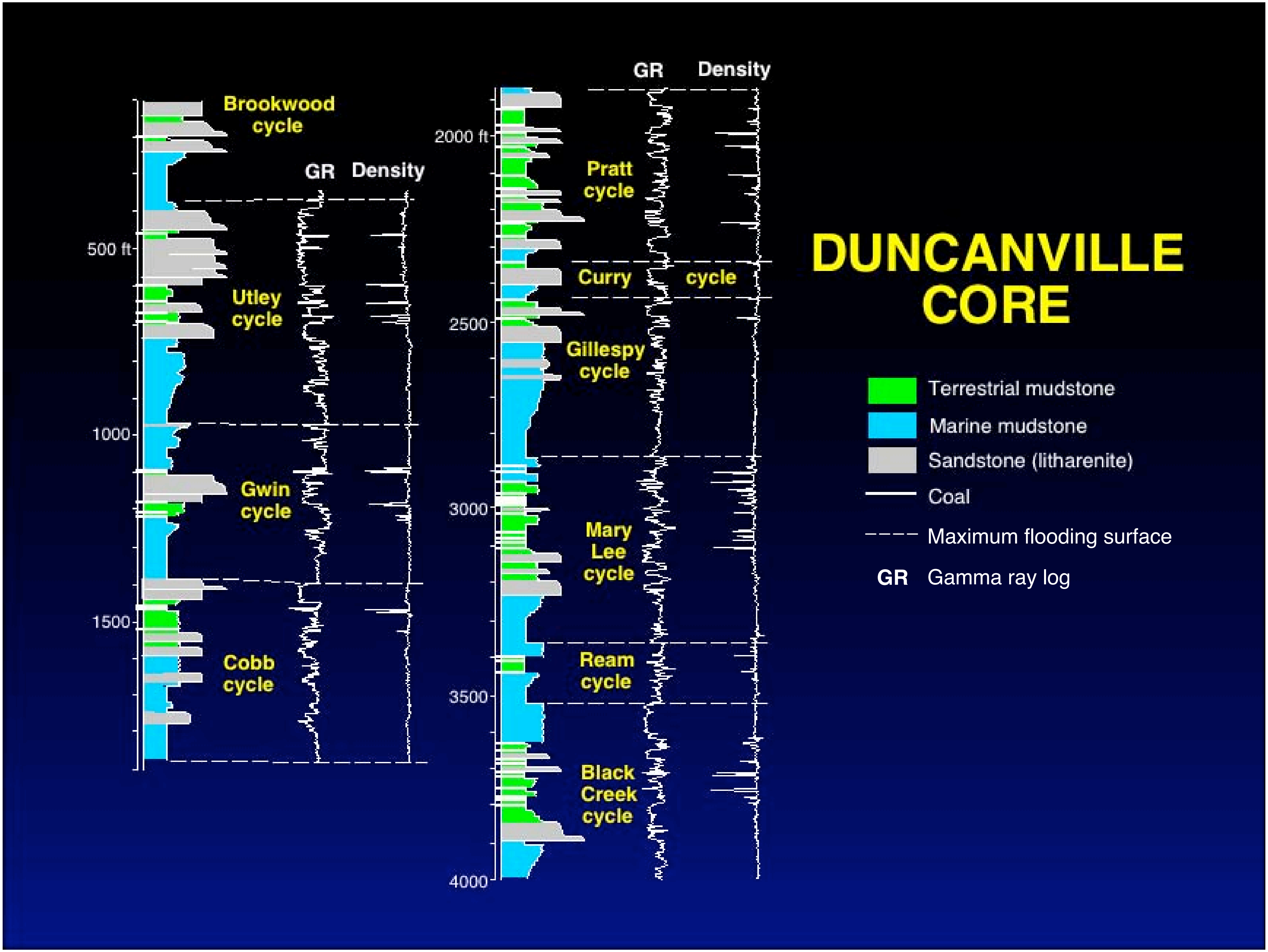


Figure 4. Graphic log of the Duncanville core showing upper Pottsville coal zones from which coalbed gas is produced.

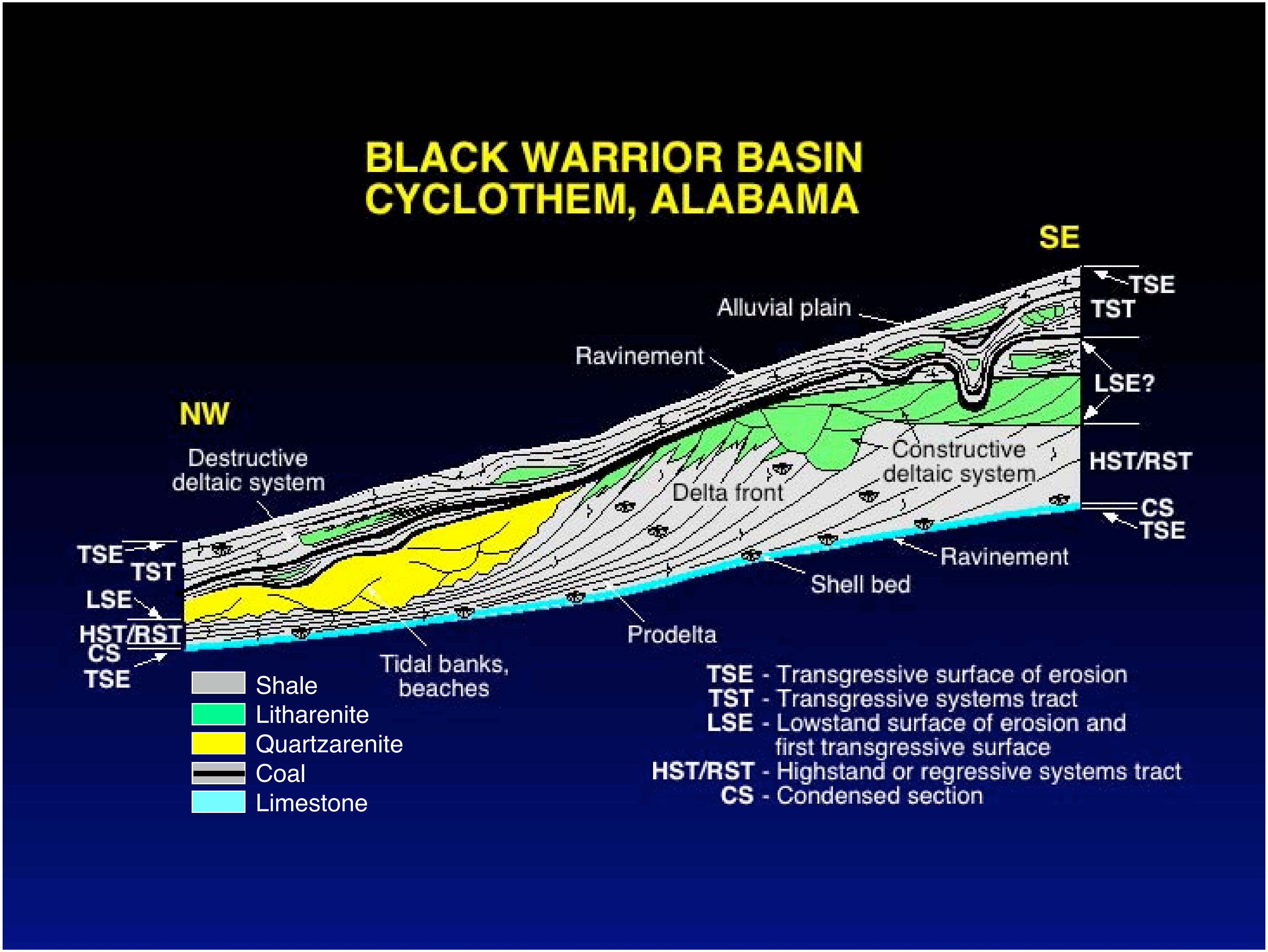


Figure 5. Stratigraphic model of an idealized Pottsville depositional cycle in the Black Warrior basin.

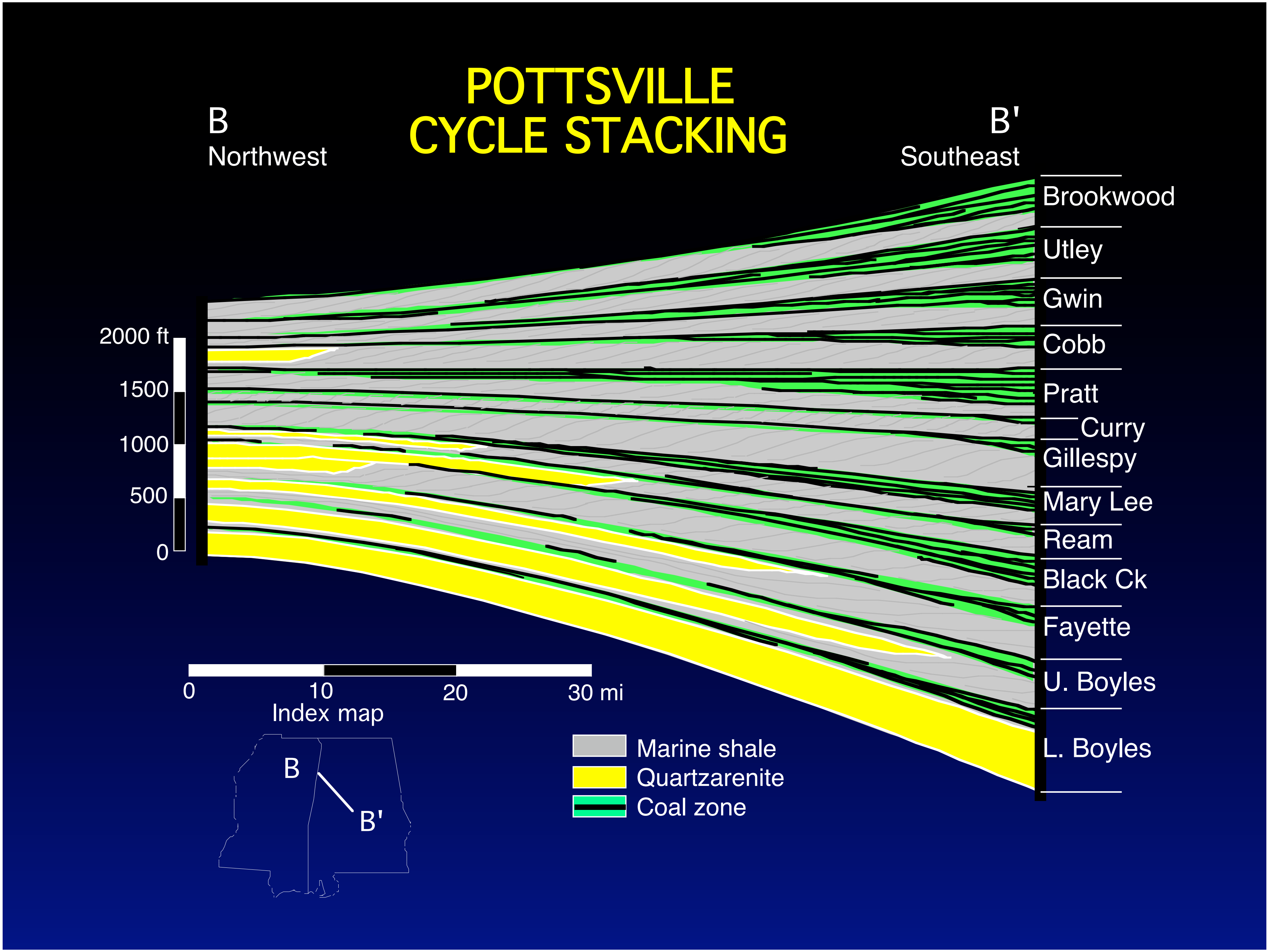


Figure 6. Cycle stacking patterns in the Pottsville Formation of the Black Warrior basin in Alabama.

FAULTING AND FRACTURING

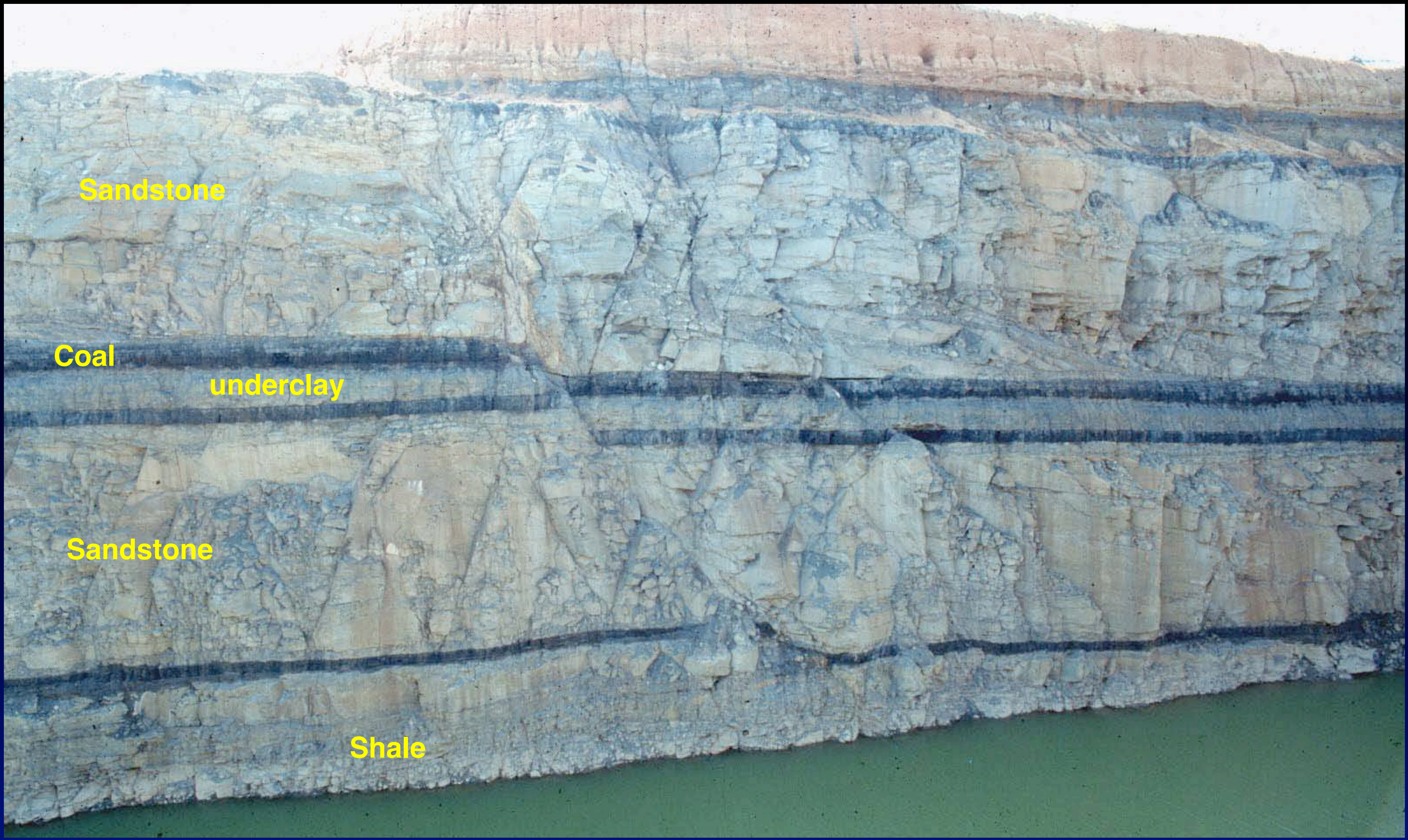


Figure 7. Flow of water in Pottsville coalbed methane reservoirs is exclusively through natural fractures, including cleats, joints, and shear fractures.

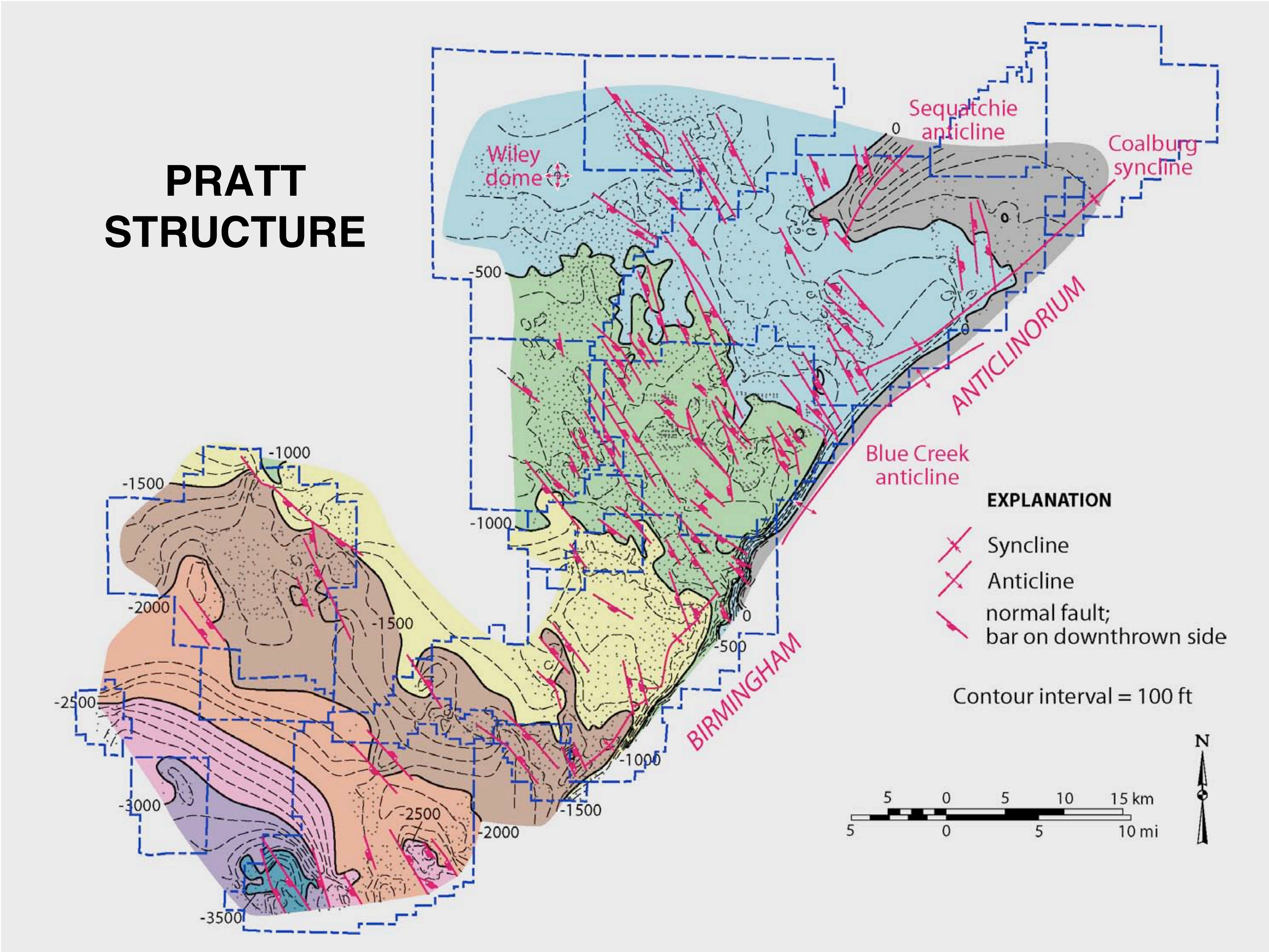


Figure 8. Structural contour map of the top of the Pratt coal zone in the Black Warrior coalbed methane fields. See Figure 3 for index map. Contours relative to mean sea level.

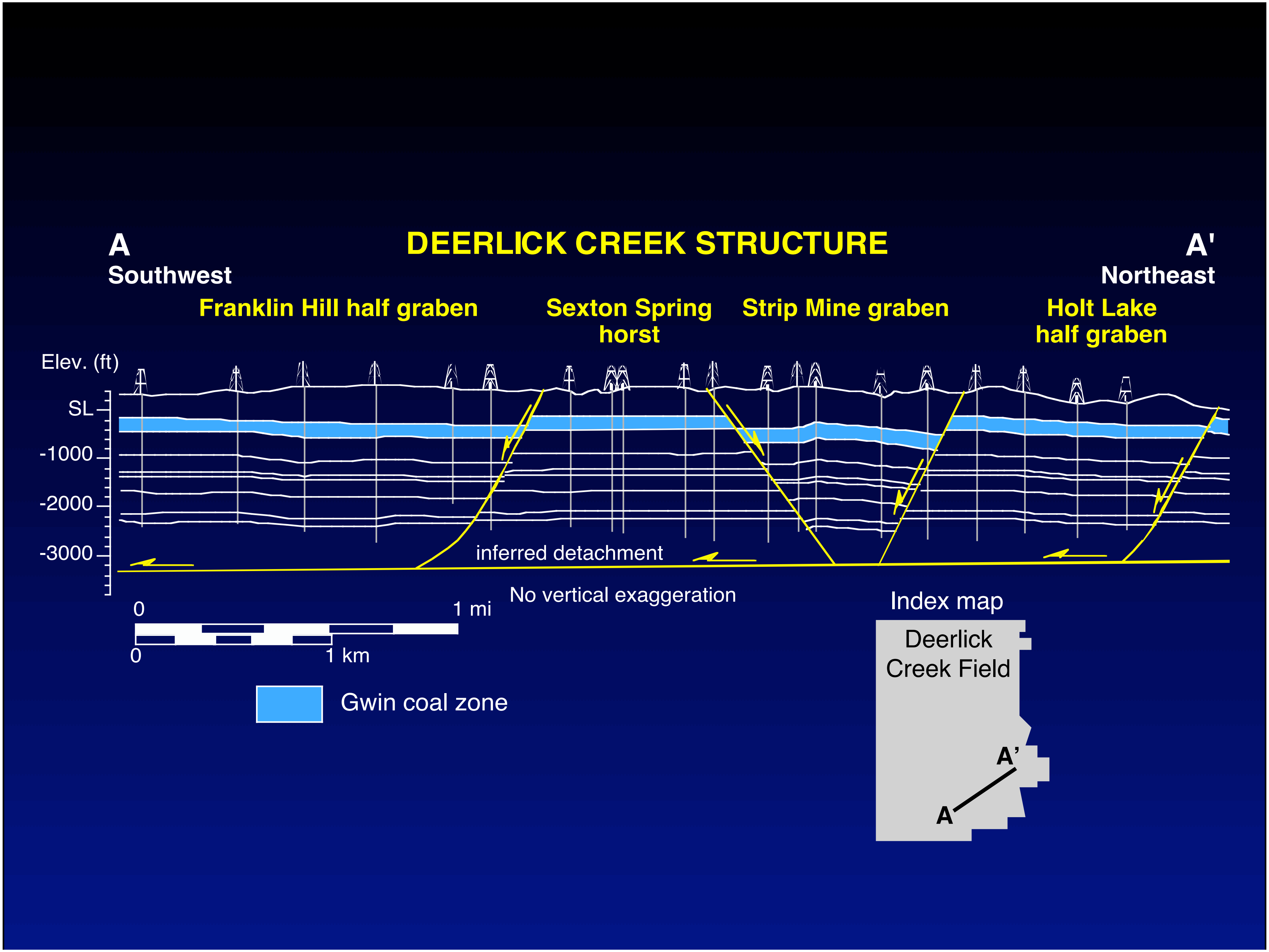


Figure 9. Structural cross section of thin-skinned horst-and-graben system in Deerlick Creek Field.

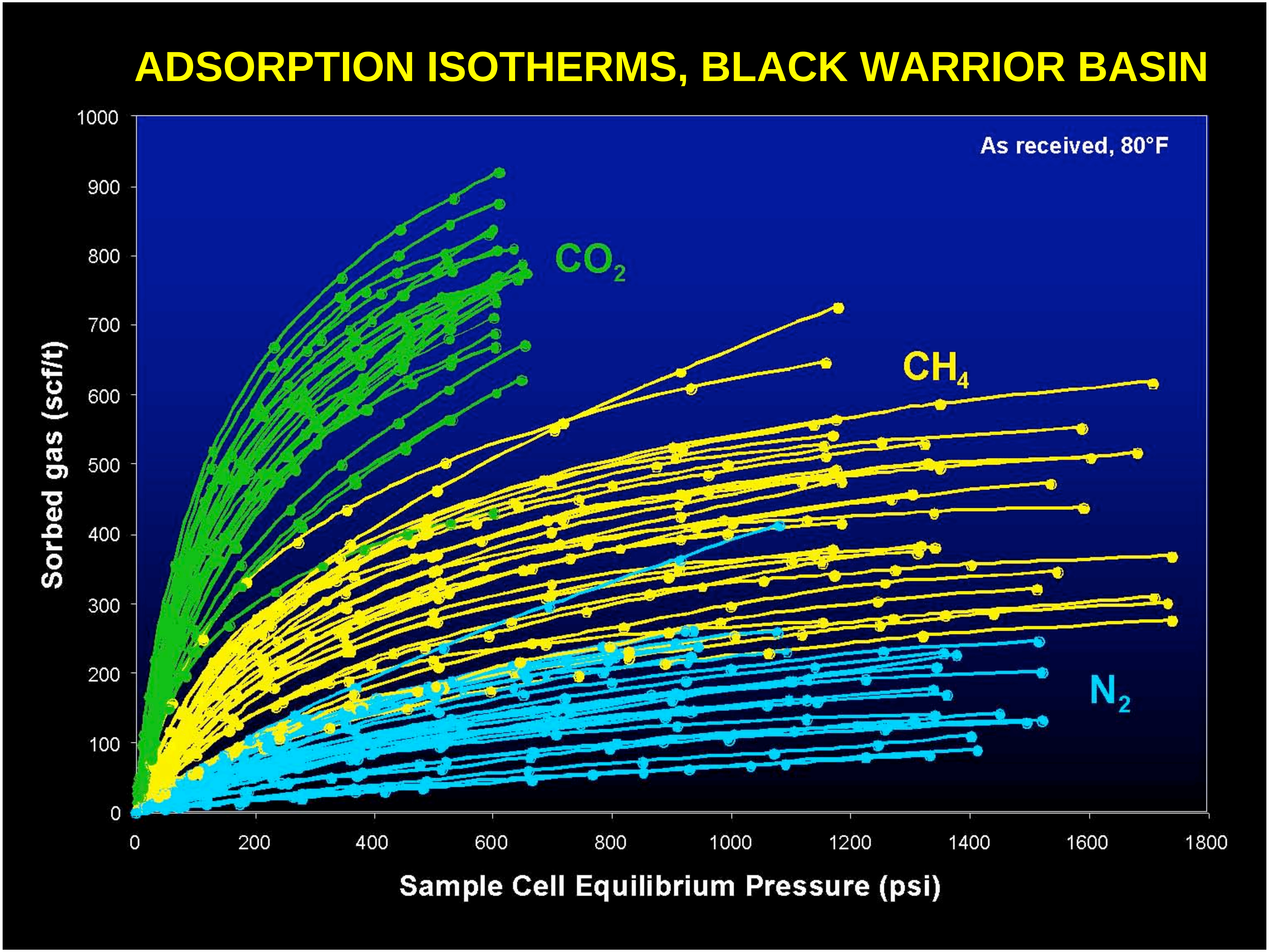


Figure 10. Isotherms showing variable sorption performance of Pottsville coal for three gases. Isotherms run by University of British Columbia.

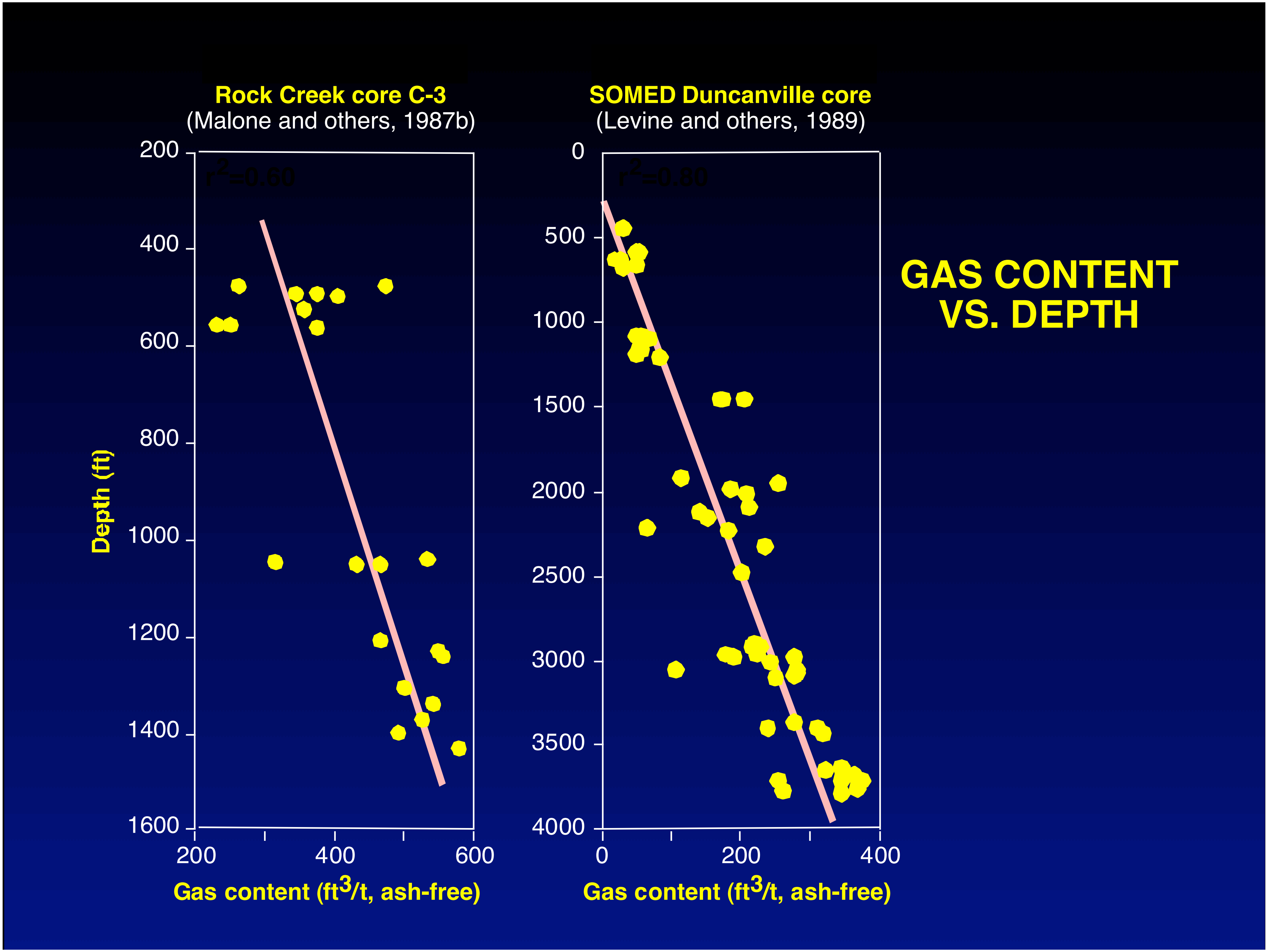
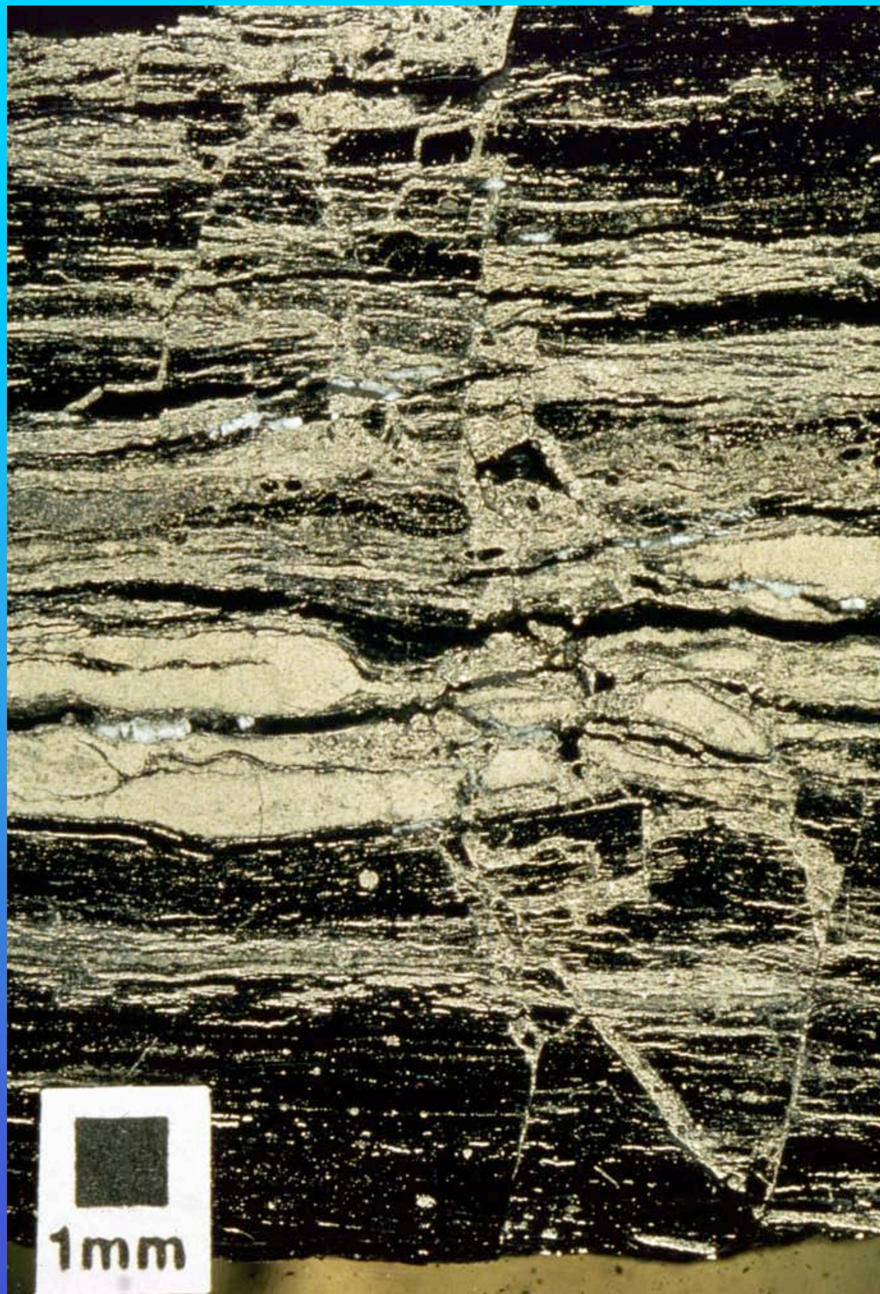


Figure 11. Plots of gas content versus depth showing heterogeneous distribution of coalbed gas in the Black Warrior basin.



COAL QUALITY

This may not be the world's best coalbed gas reservoir

Figure 12. Intensely pyritized coal with mineralized fractures suggests that coal quality affects reservoir properties.

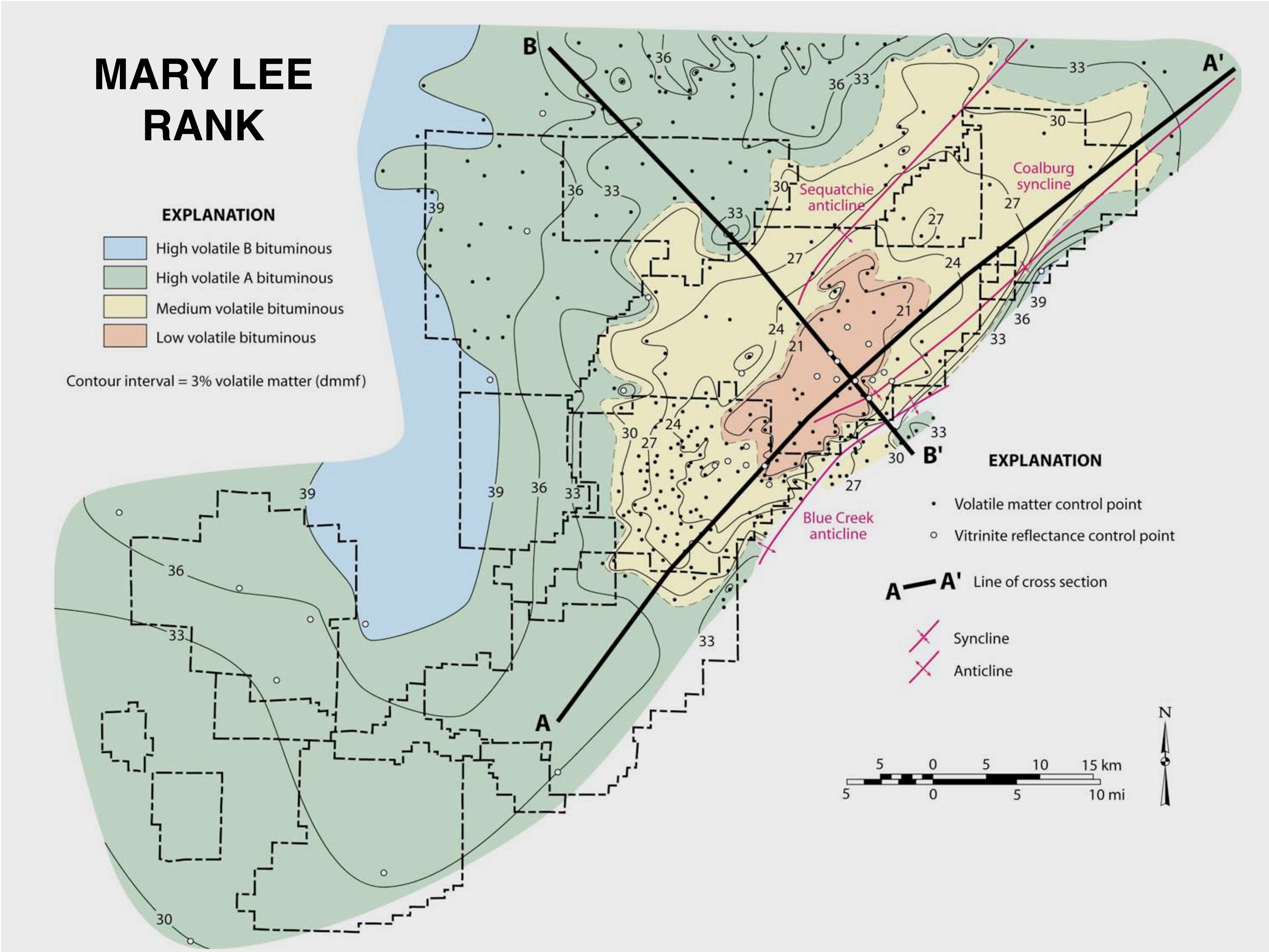


Figure 13. Map of coal rank in the Black Warrior coalbed methane fields.

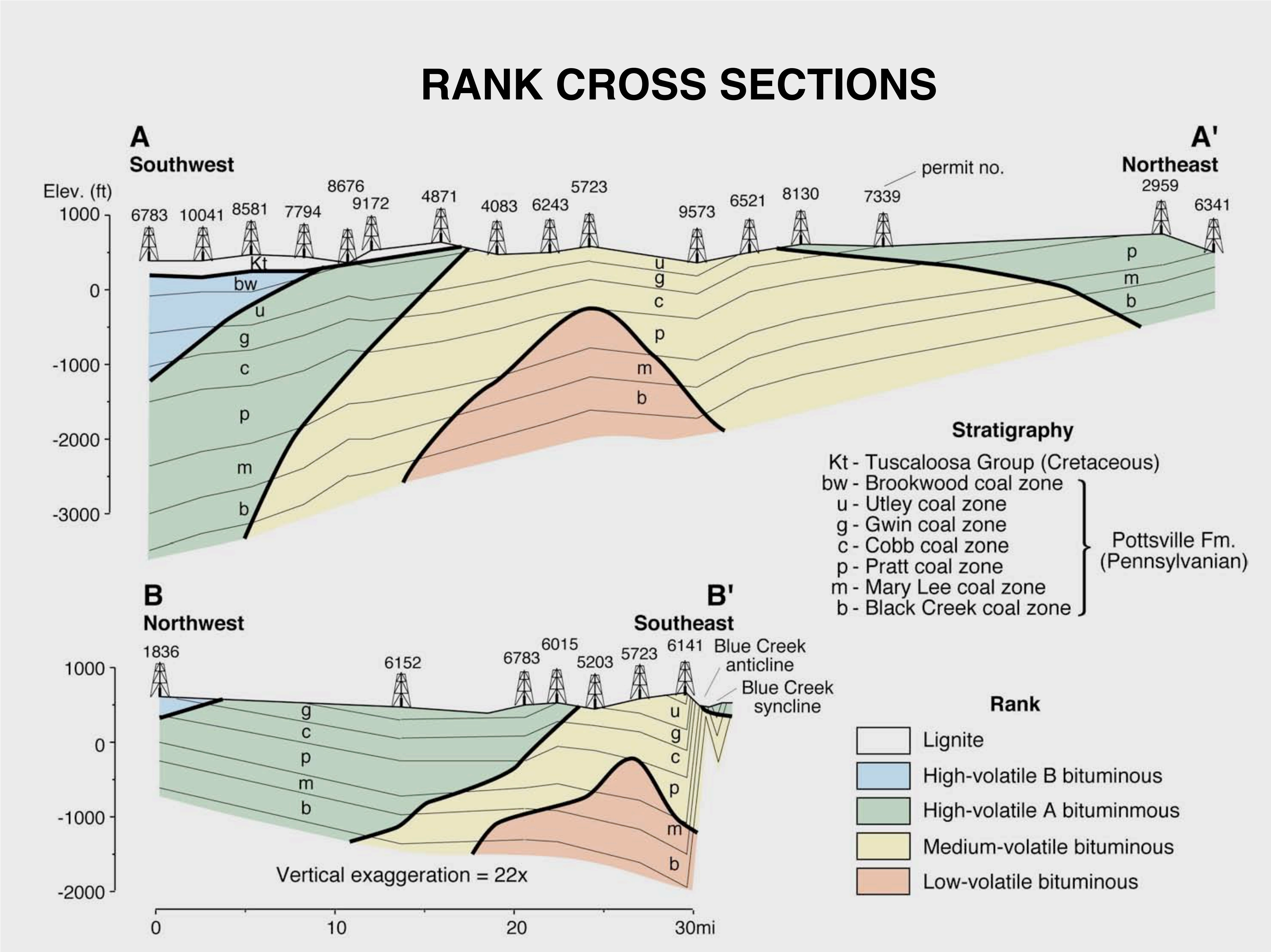


Figure 14. Cross sections showing coal rank in the Black Warrior basin. See Figure 15 for location.

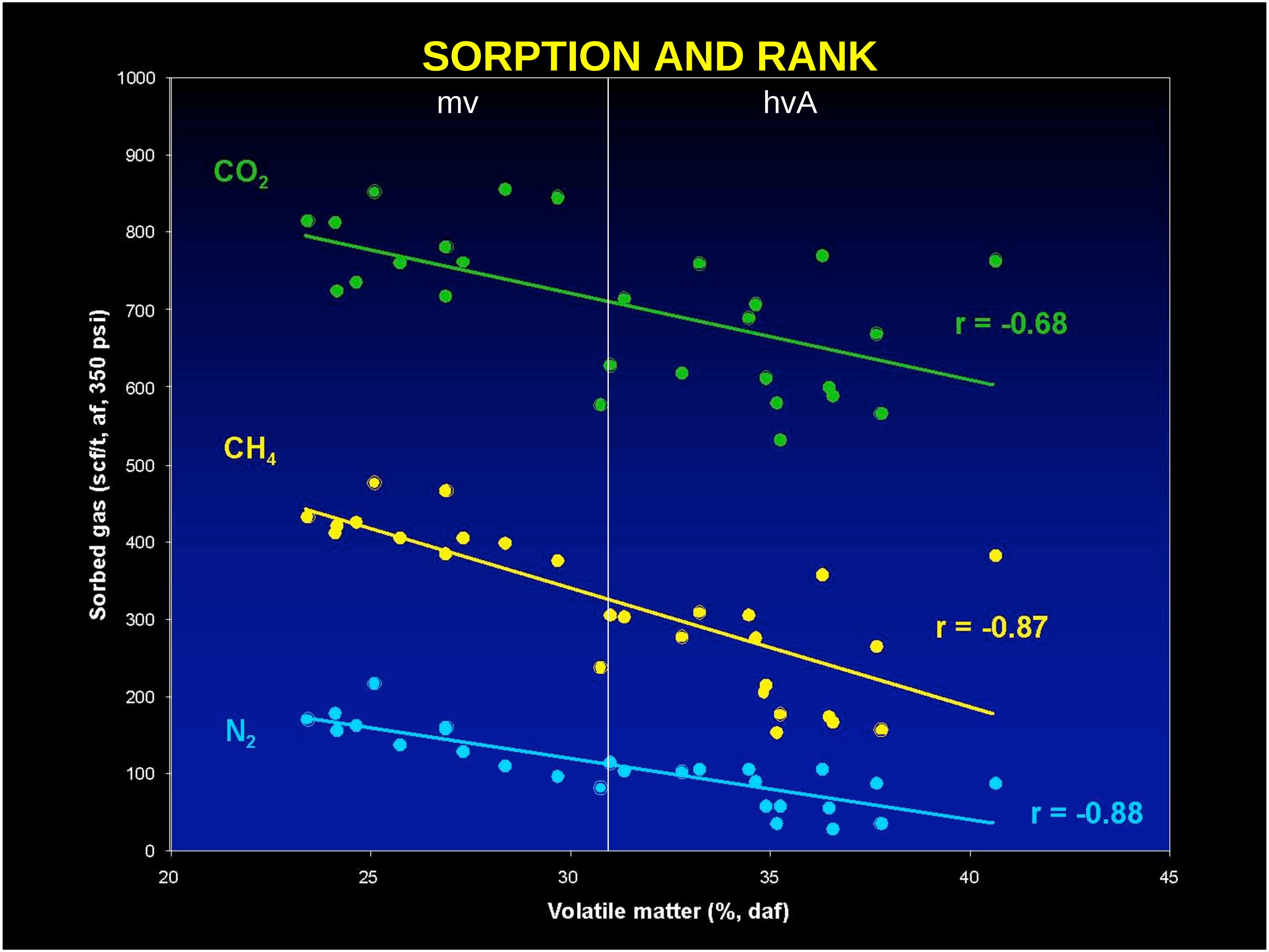


Figure 15. Relationship between coal rank and sorption capacity in the Black Warrior basin.

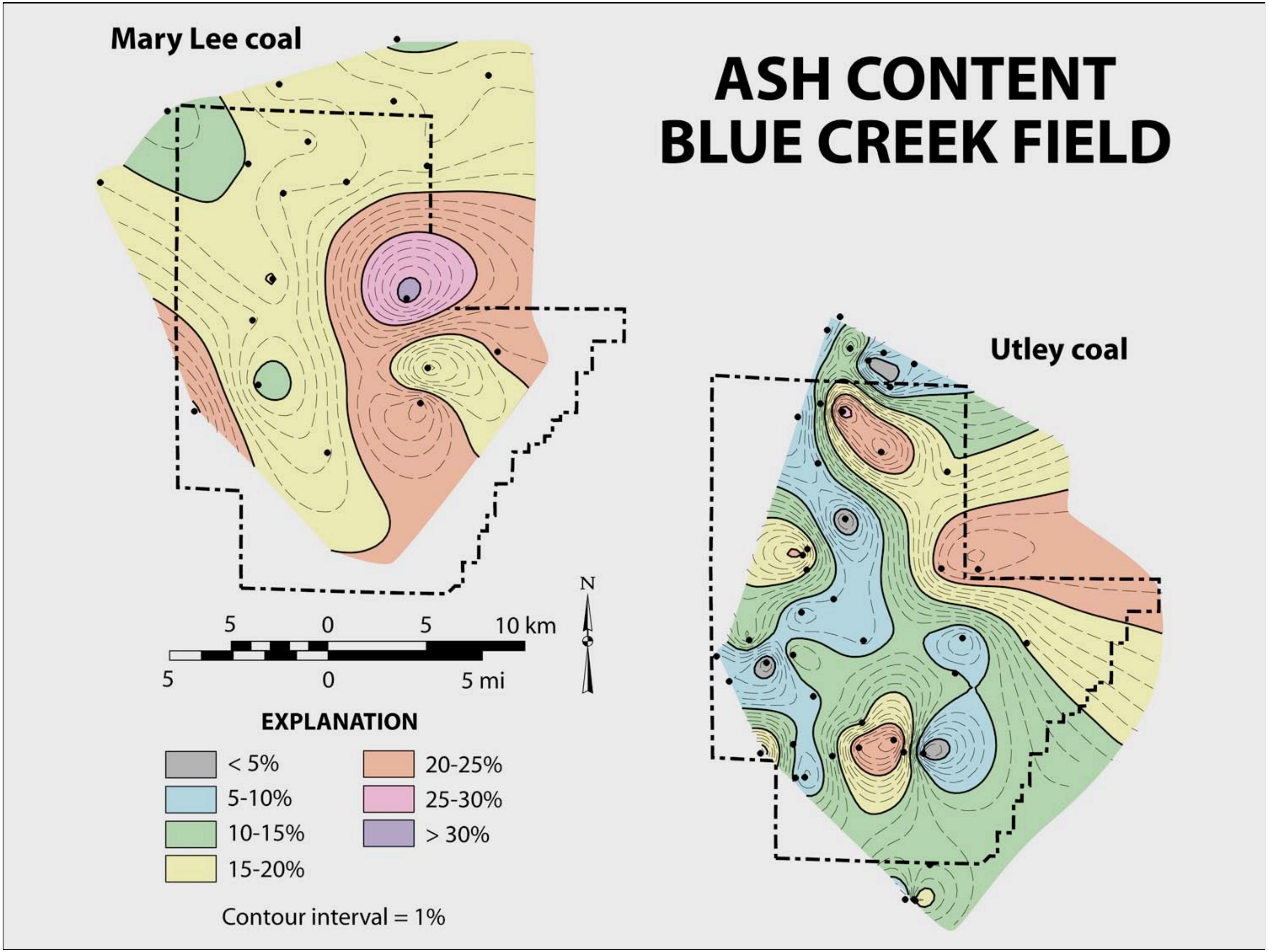


Figure 16. Maps of ash content contrasting the Mary Lee and Utley coal beds in Blue Creek Field.

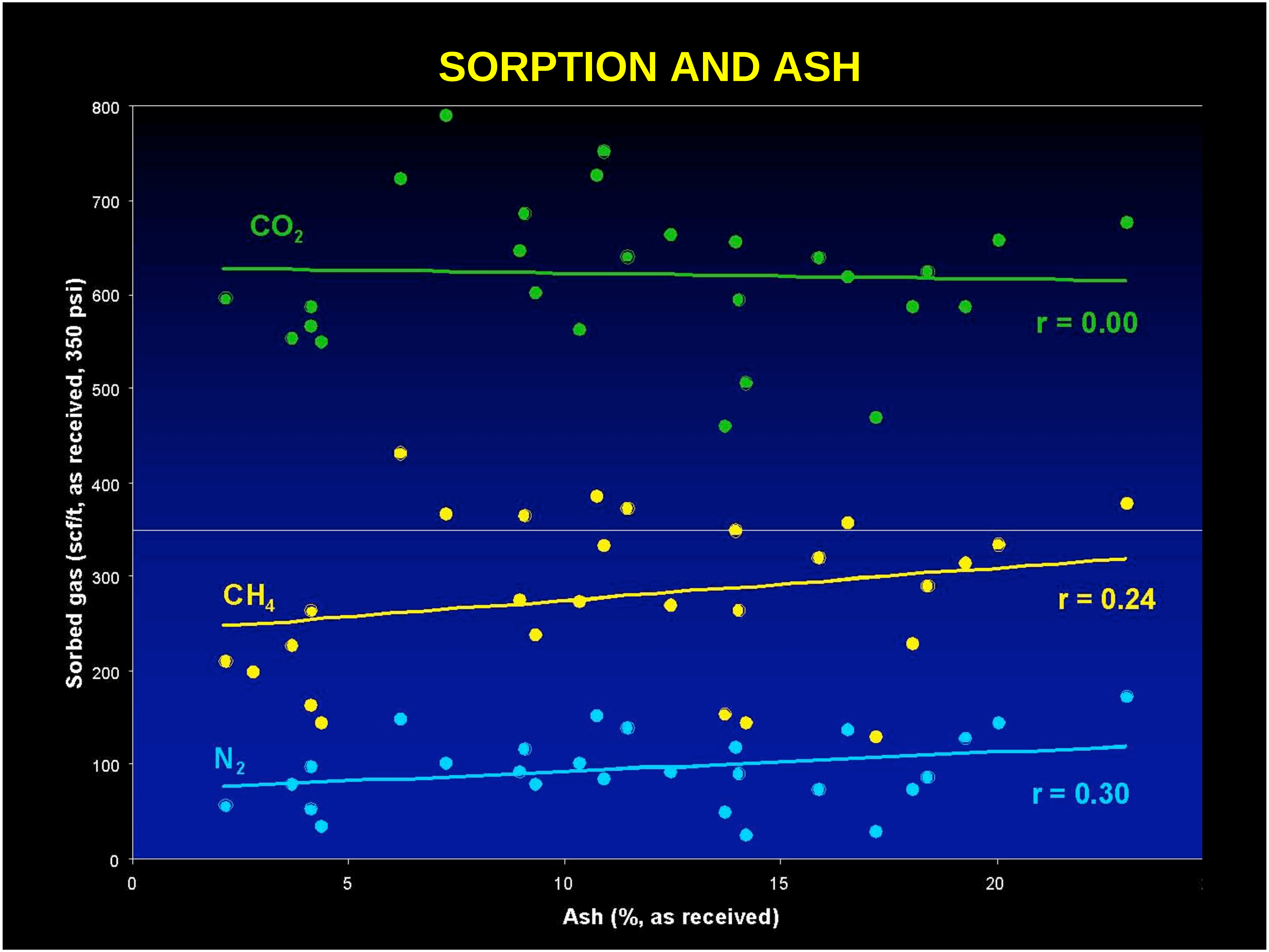


Figure 17. Relationship between sorption capacity and ash content and sorption capacity of coal in the Black Warrior basin.

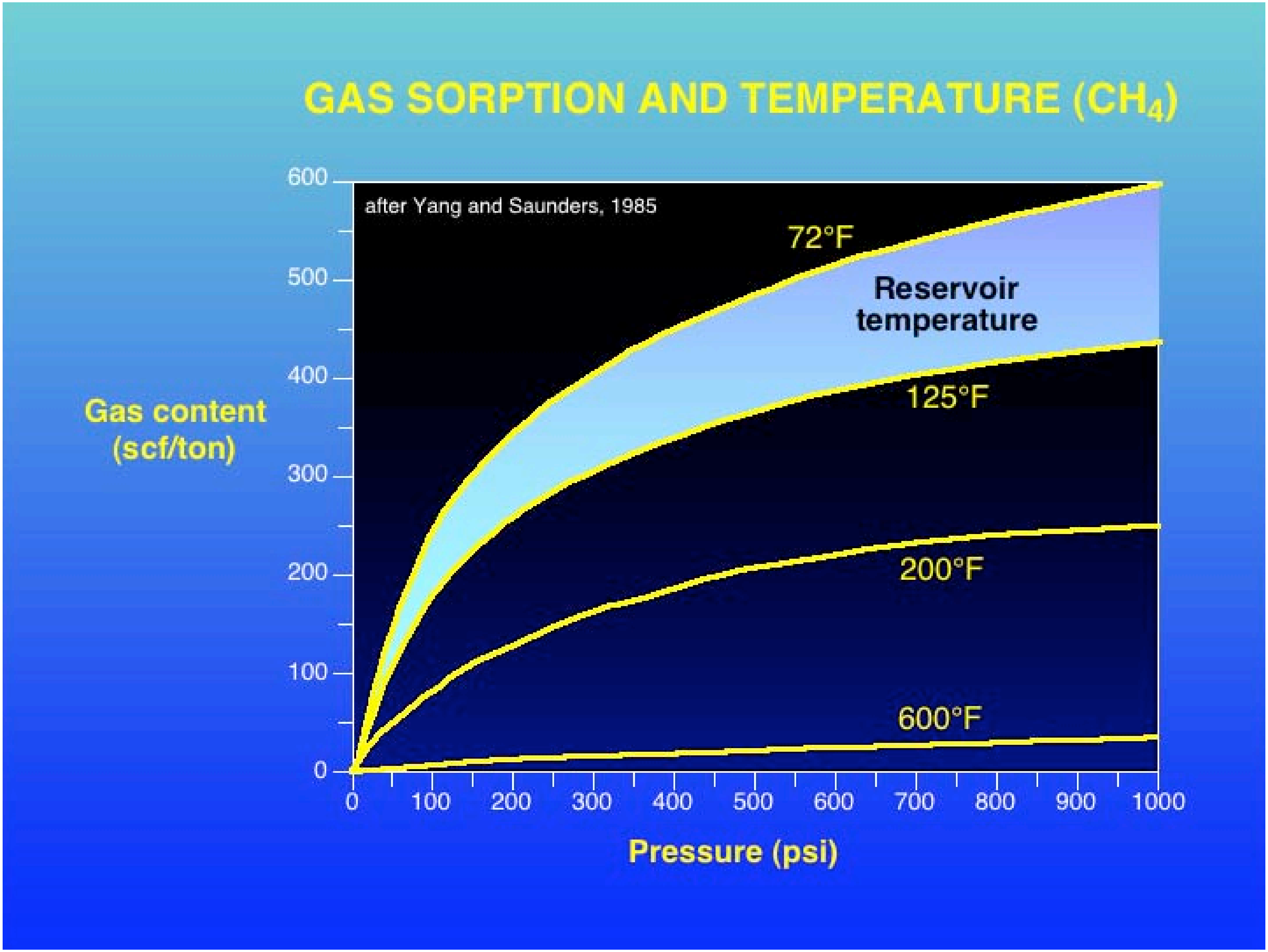


Figure 18. Relationship of methane sorption to temperature in a San Juan basin coal.

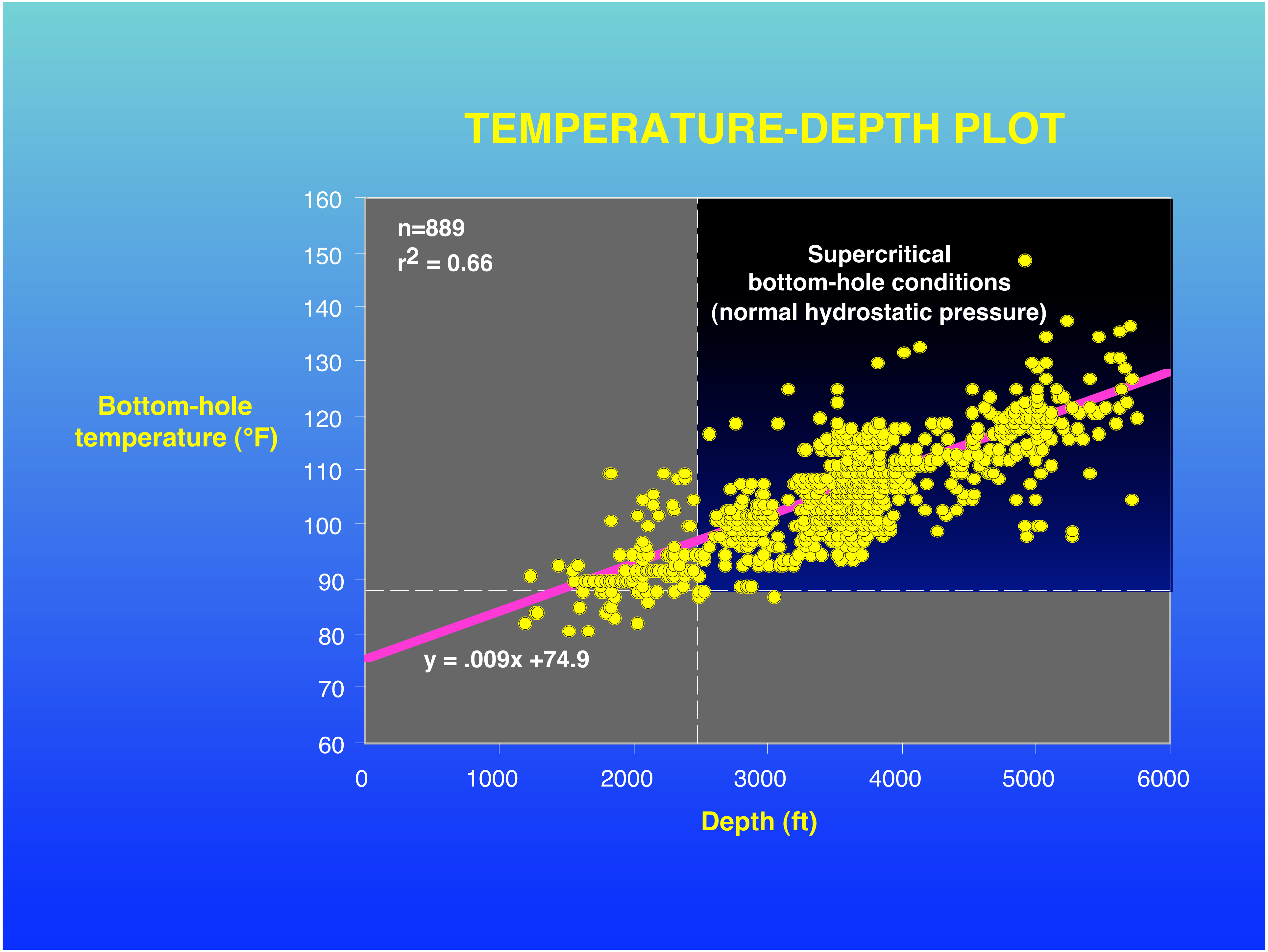


Figure 19. Temperature-depth plot for coalbed methane wells in the Black Warrior basin showing variation of geothermal gradient.

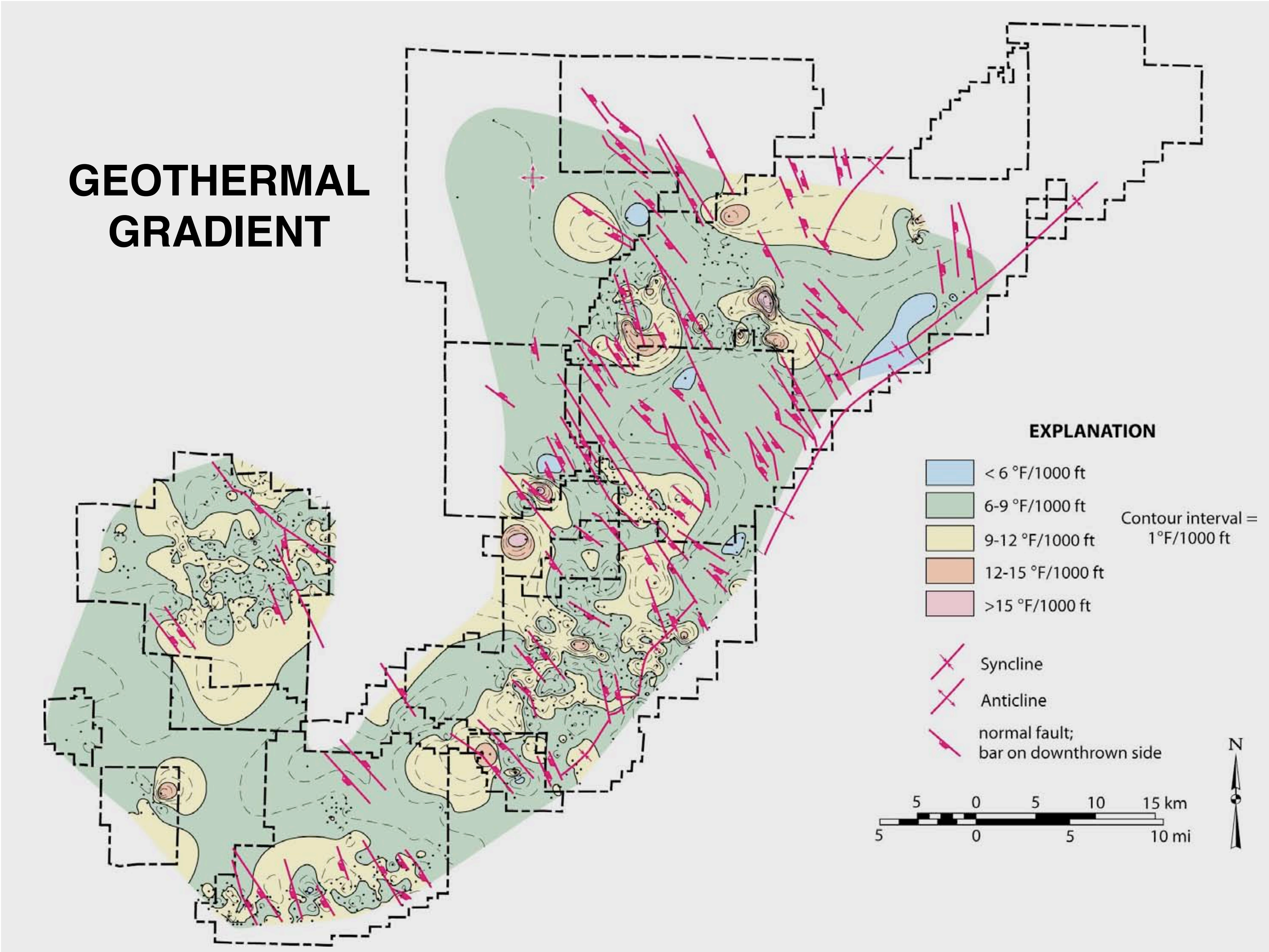


Figure 20. Map of geothermal gradient in the Black Warrior coalbed methane fields.

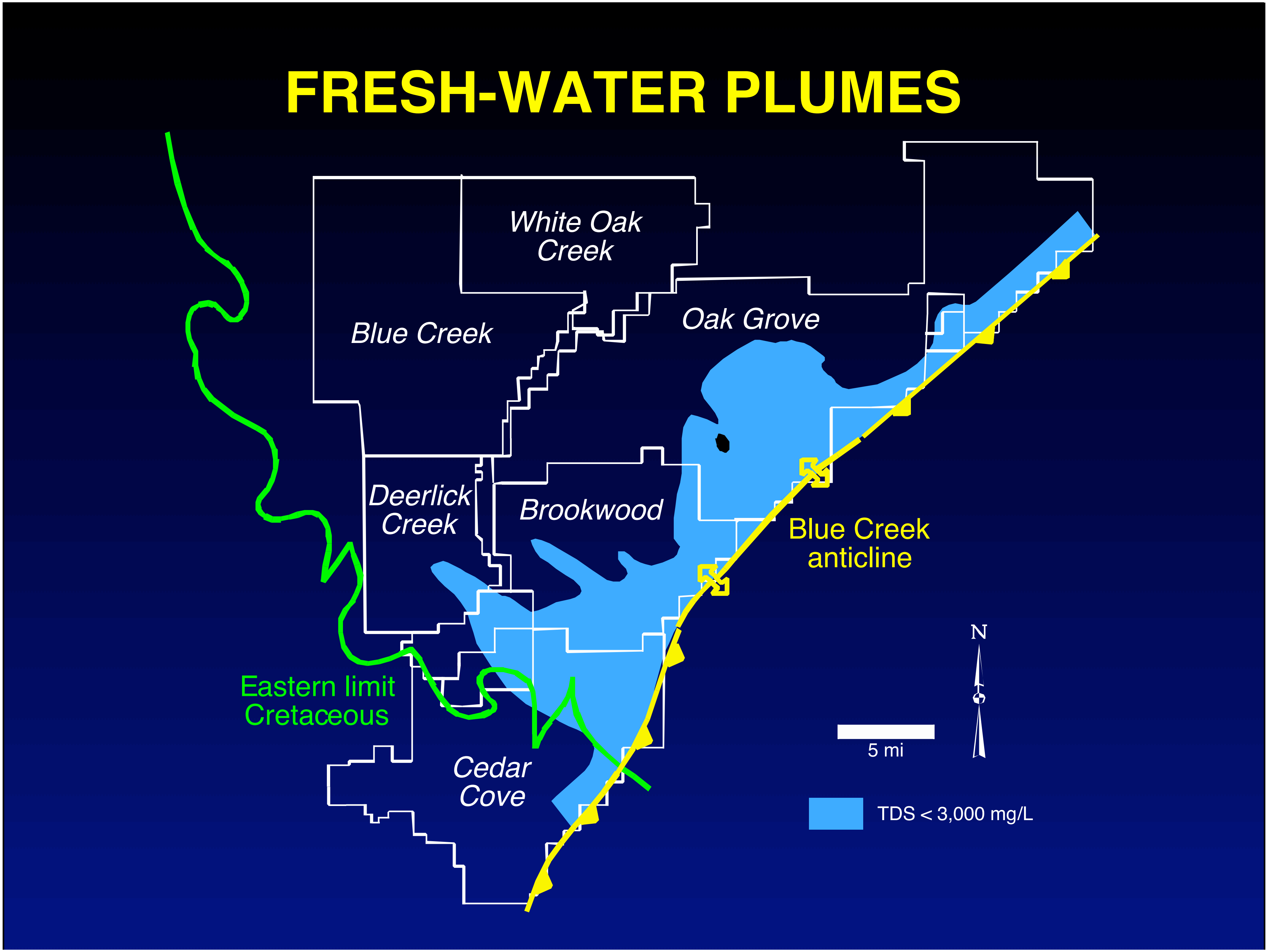


Figure 21. Location of fresh-water plumes in the Mary Lee coal zone, which are fed by recharge along the upturned southeast basin margin.

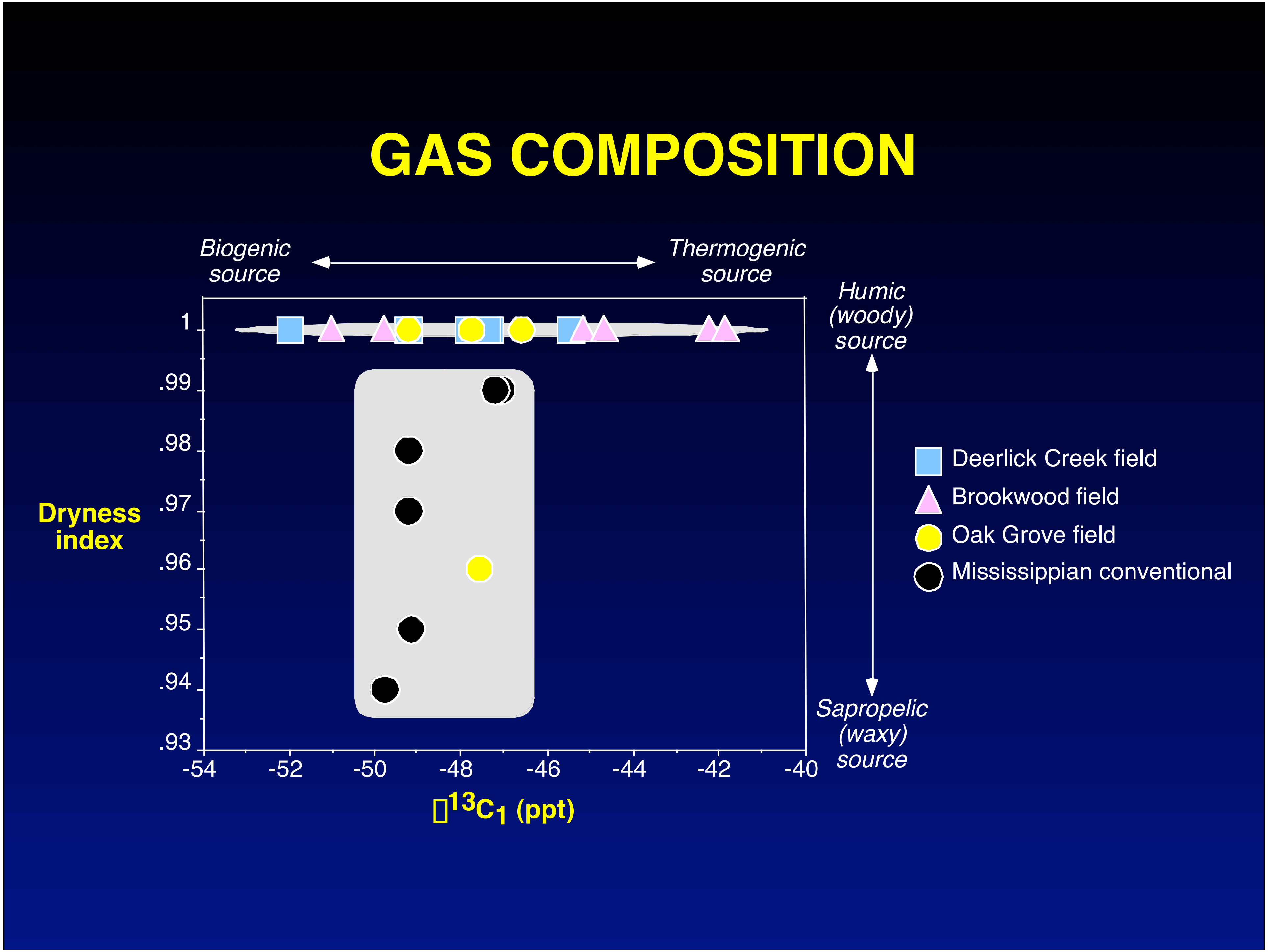


Figure 22. Comparison of composition of conventional and coalbed gas in the Black Warrior basin.

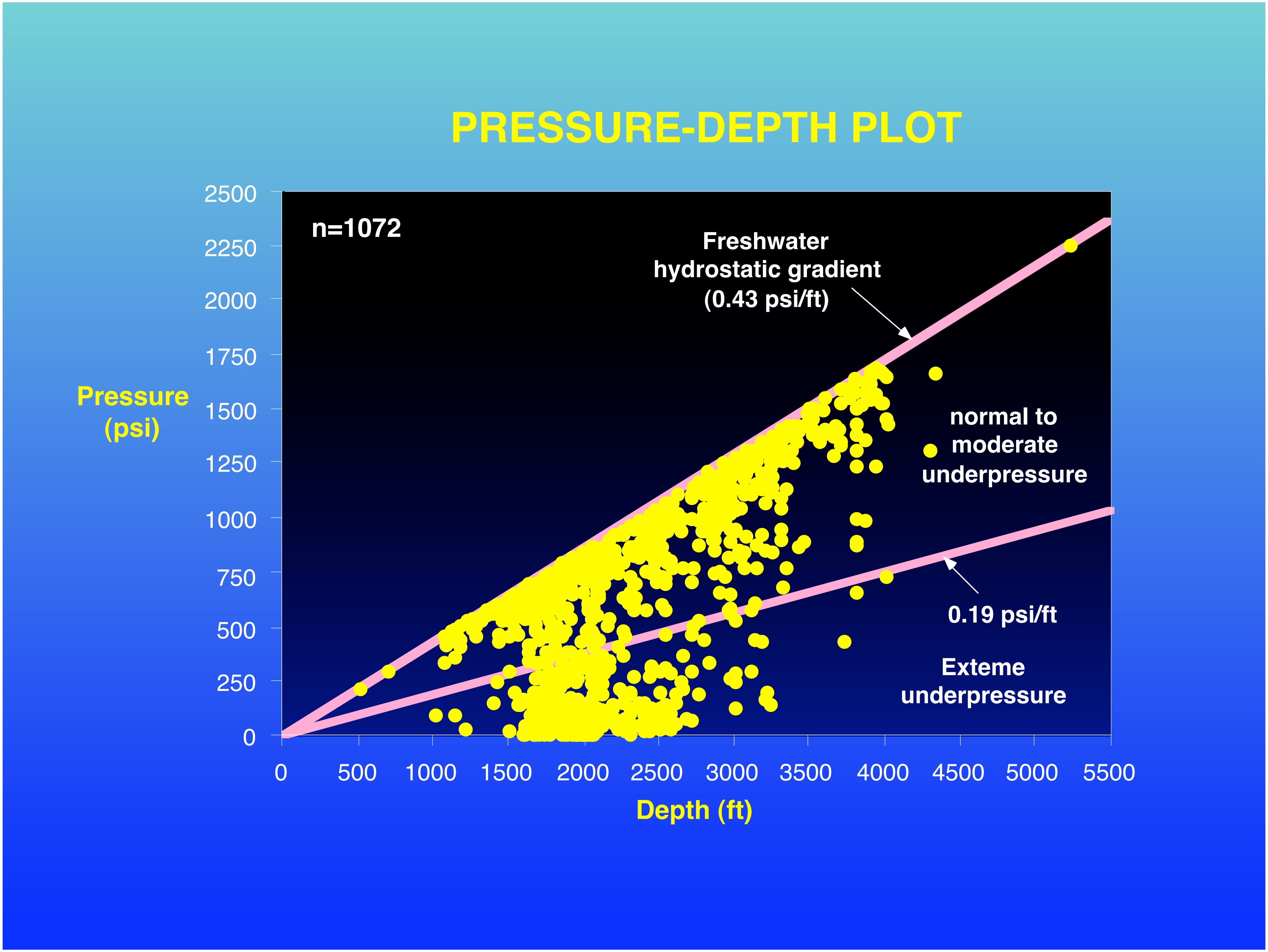


Figure 23. Pressure-depth plot showing bimodal pressure regime in the Black Warrior coalbed methane fields.

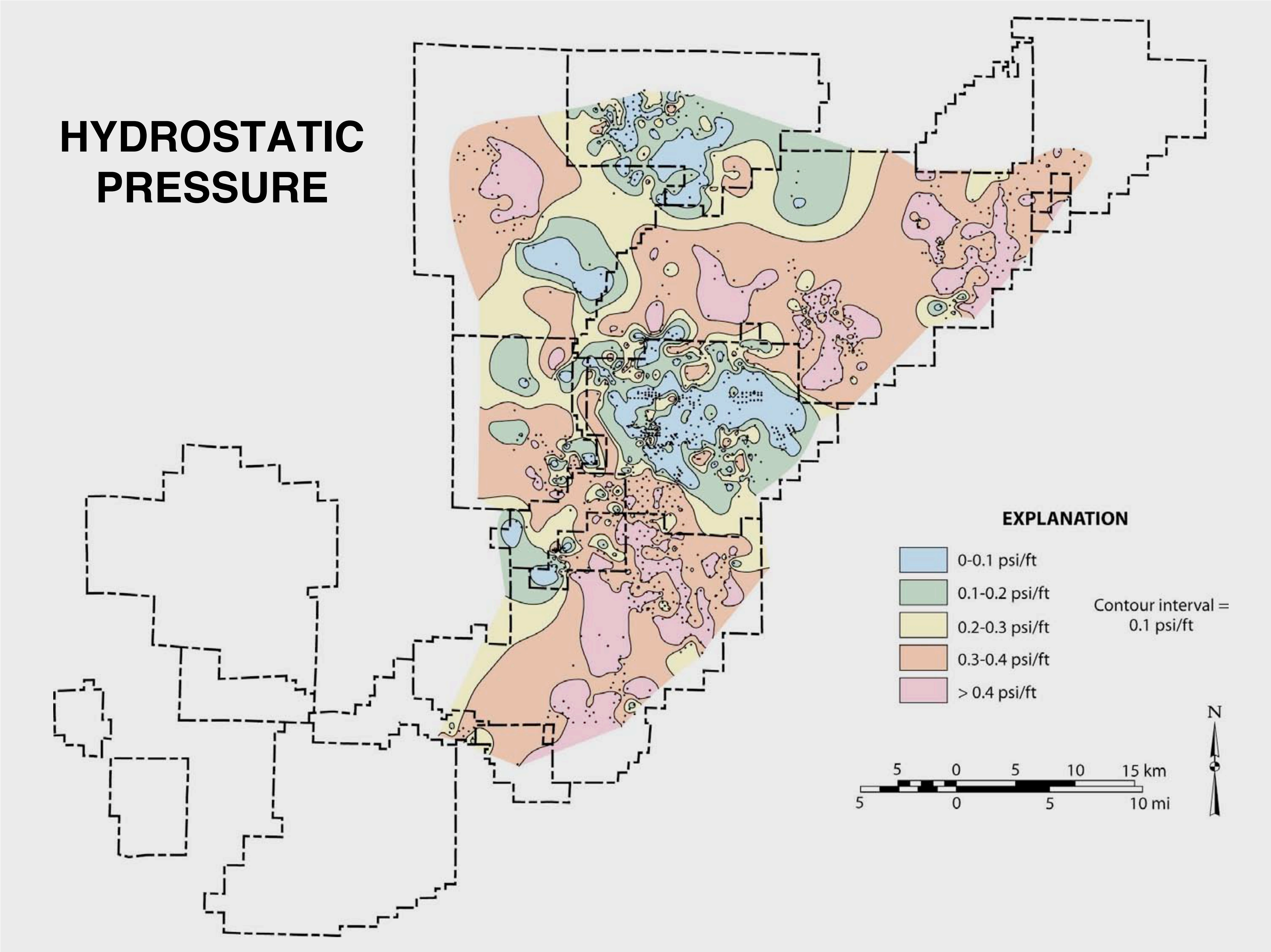


Figure 24. Map of hydrostatic pressure gradient determined from water levels in gas wells of the Black Warrior coalbed methane fields.

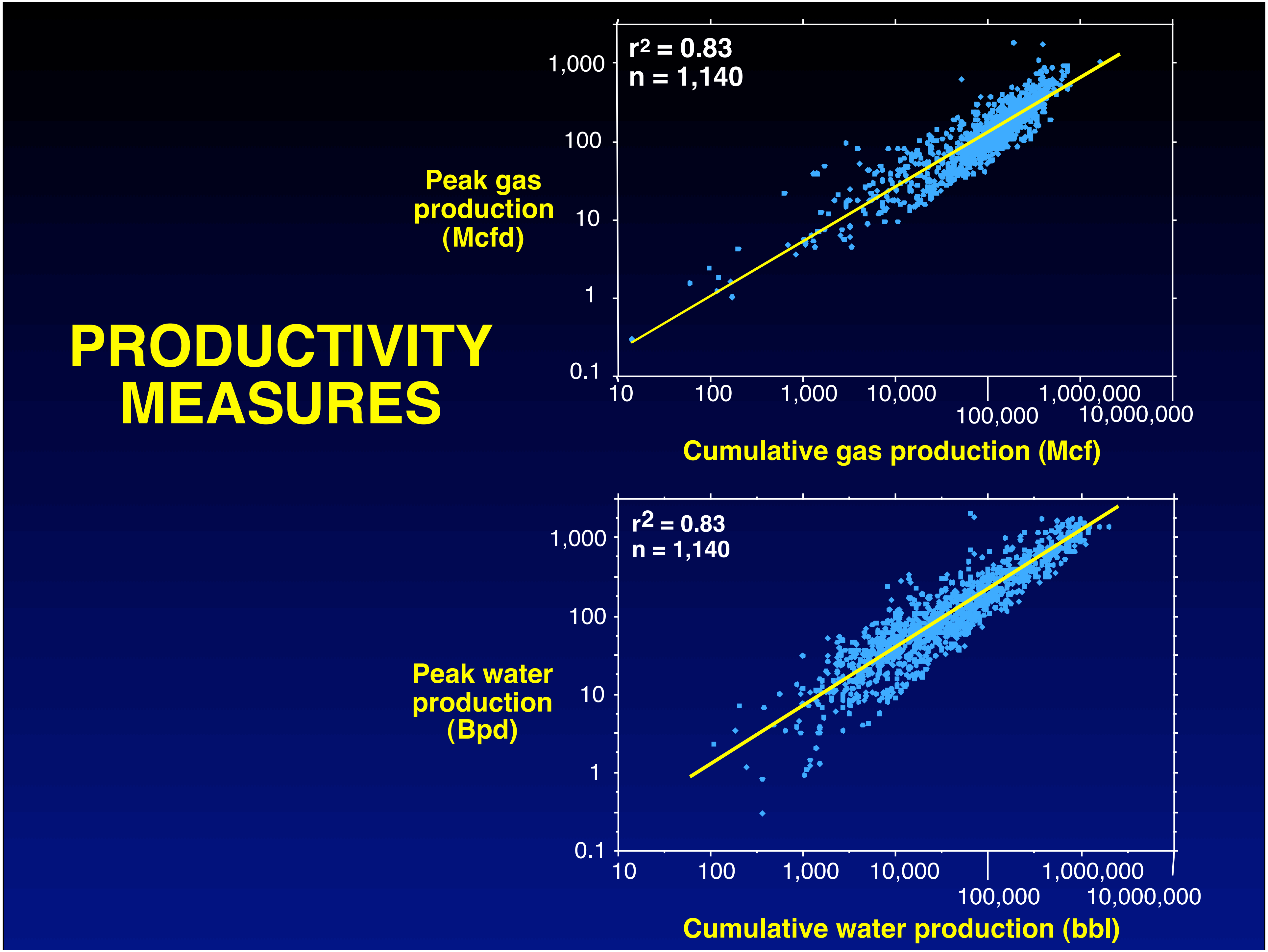


Figure 25. Relationship of peak and cumulative fluid production values in the Black Warrior coalbed methane fields.

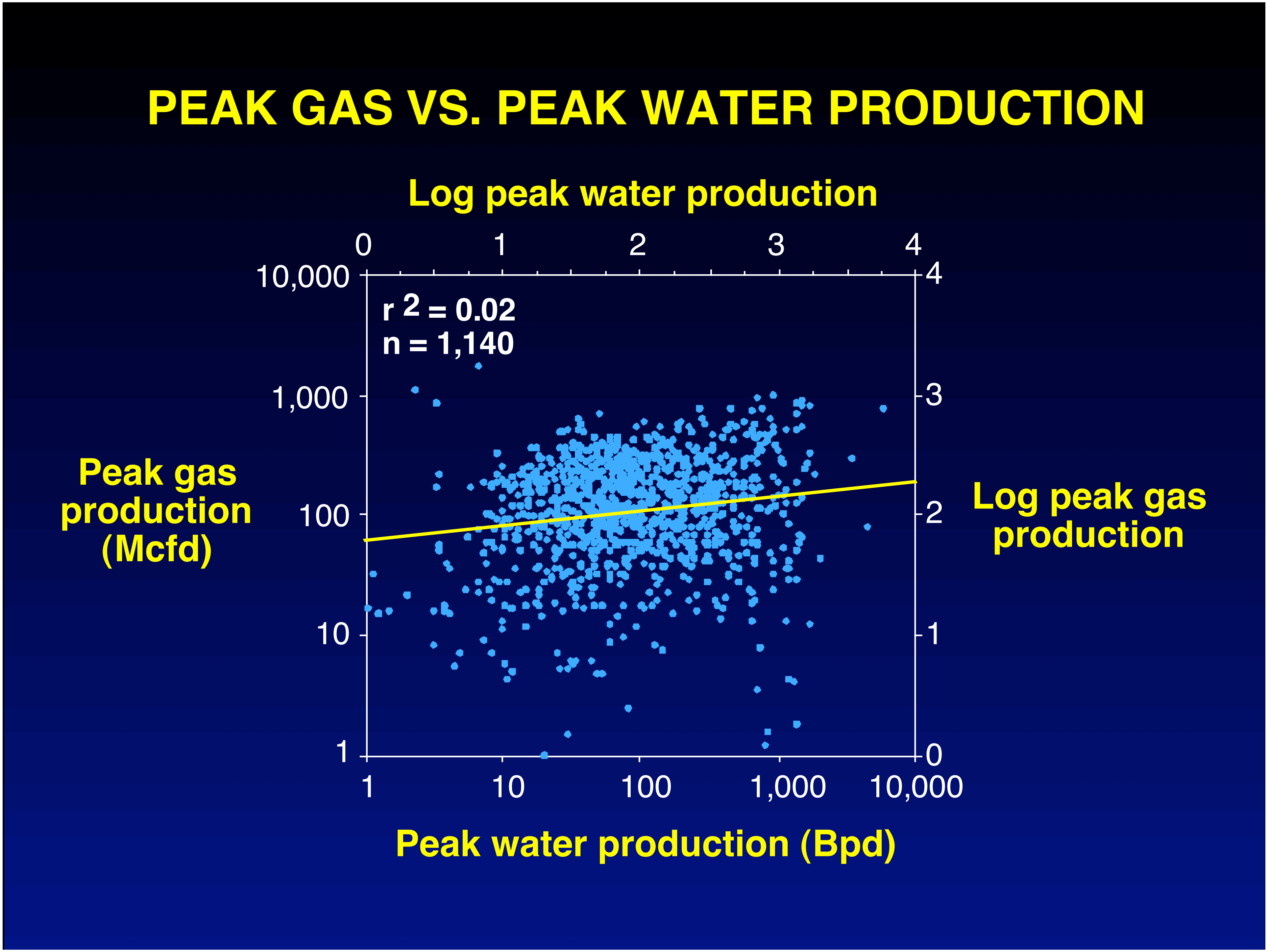


Figure 26. Scatterplot showing lack of correlation between peak and gas water production in the Black Warrior coalbed methane fields.

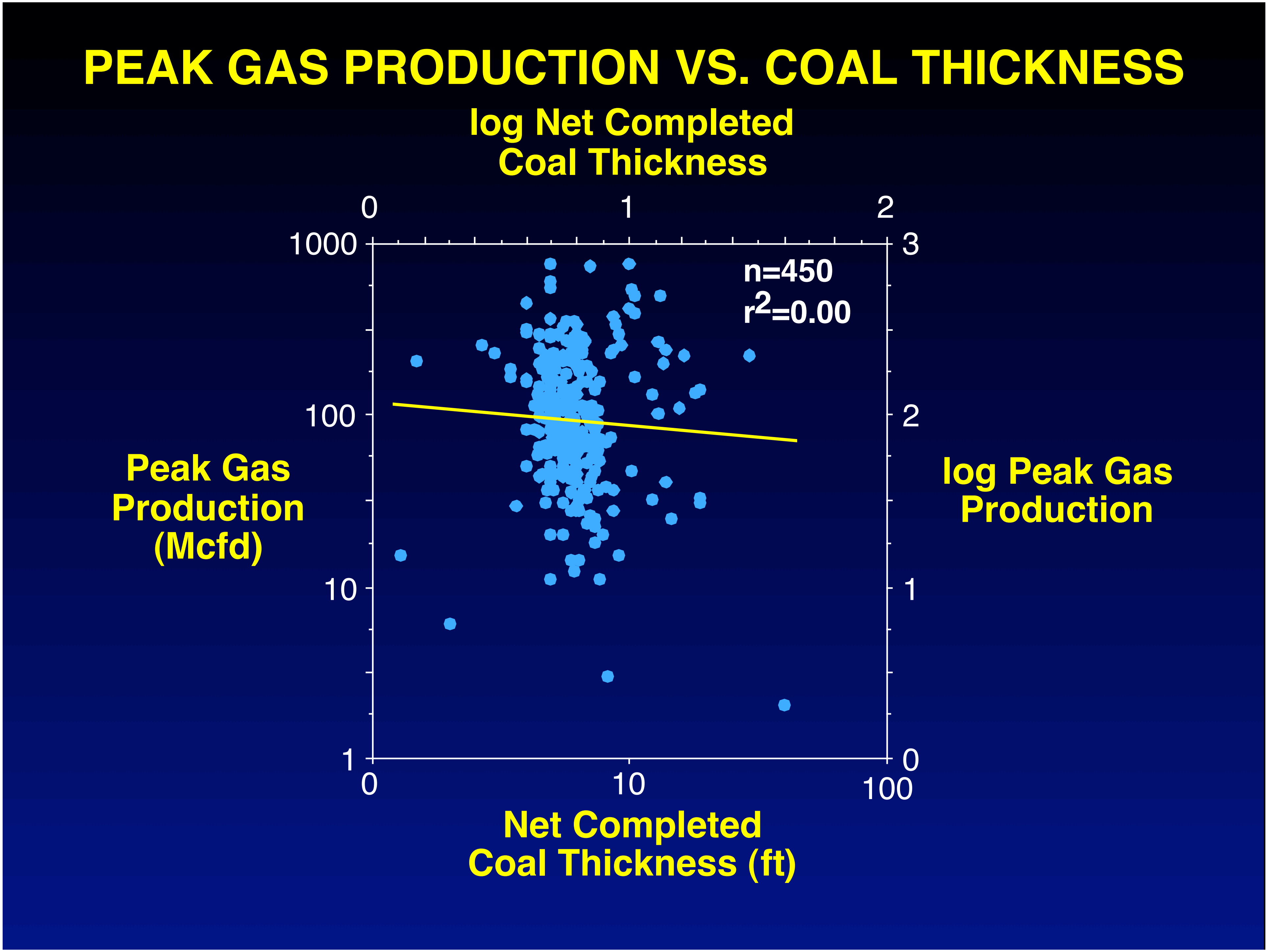


Figure 27. Scatterplot showing lack of correlation between peak gas production and net completed coal thickness in the Black Warrior basin.

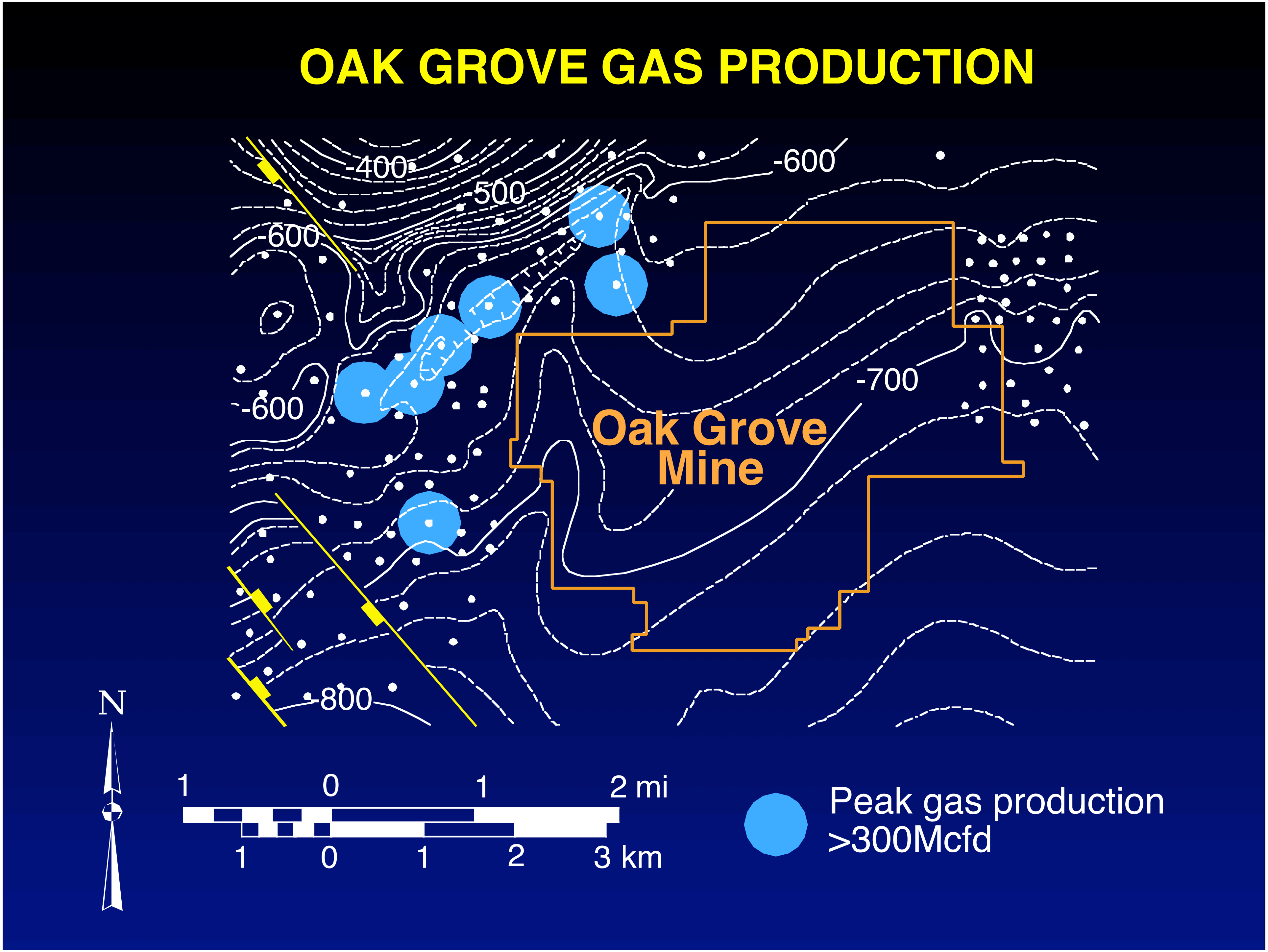


Figure 28. Map showing concentration of productive gas wells along a synclinal axis in Oak Grove Field. Structure contours (ft below sea level) on top of Mary Lee coal bed.

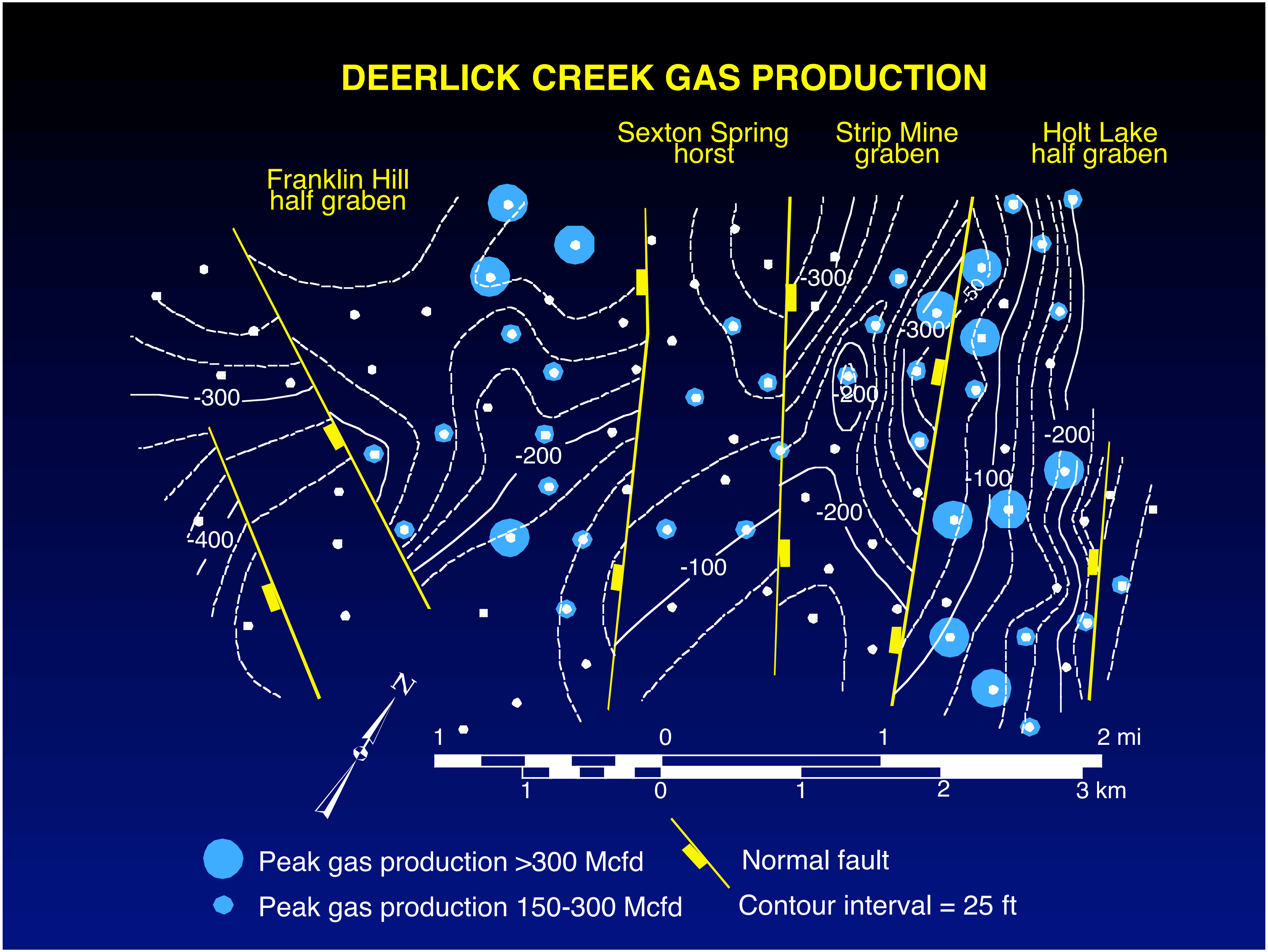


Figure 29. Map showing concentration of exceptional gas-producing wells in two half grabens in Deerlick Creek Field. Structure contours on top of Gwin coal zone.

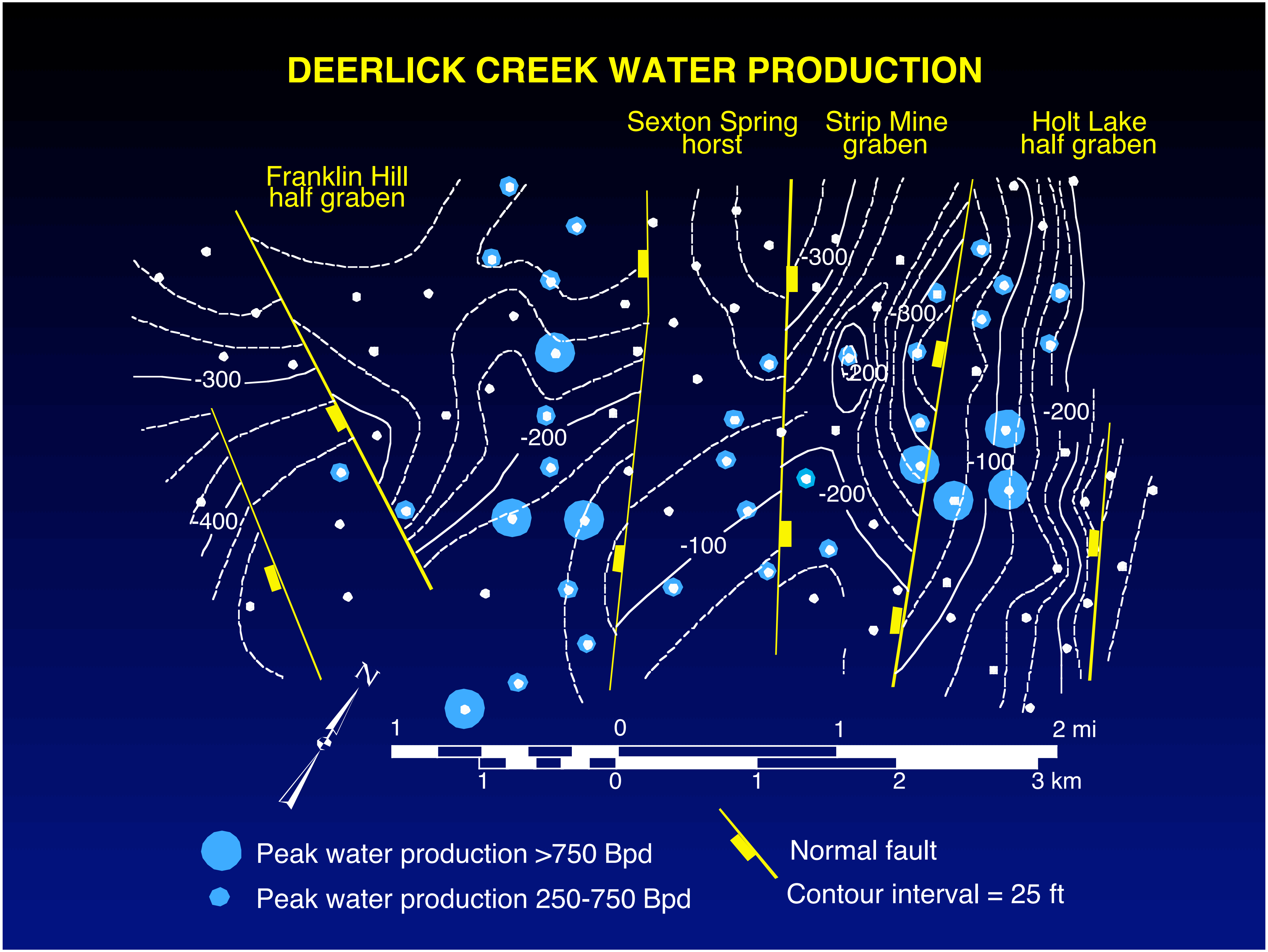


Figure 30. Map showing concentration of exceptional water-producing wells in two half grabens in Deerlick Creek Field. Structure contours on top of Gwin coal zone. Compare with Figure 29.

CONCLUDING THOUGHTS

CBM reservoirs in the Black Warrior basin are characterized by heterogeneous stratigraphy, structure, and coal quality.

This heterogeneity has a strong effect on sorption capacity, gas content, basin hydrology, and reservoir performance.

Similar factors affect CBM potential in other sedimentary basins, but differing geologic factors pose basin-specific challenges.

Figure 31. Concluding thoughts.