CHAPTER 4:

COALBED GAS IN THE BOURBON ARCH

4.1 Introduction

The Bourbon arch of eastern Kansas is a mature petroleum province with conventional hydrocarbon production in the declining stages over the past fifty years. Most conventional production is currently stripper production (Newell et al., 2002). Coalbed gas production can be dated back to the 1910's, when it was then known as "shale-gas" (Charles and Page, 1929). Documented areas of shale-gas production at the time include Miami and southeastern Johnson counties of Kansas, and northwest Cass and southwest Jackson counties in Missouri; small areas near Garnett and Mound City in Anderson and Linn counties, respectively; and southern Allen, eastern Wilson and Montgomery, and western Neosho and Labette counties of southeastern Kansas (Charles and Page, 1929). These counties correspond to present-day "hotspot" coalbed gas plays and pilot projects in eastern Kansas (Newell et al., 2002; 2004). Completion targets of shale-gas wells were the Little Osage Shale (and Summit coal) and Excello Shale (and Mulky coal) of the Marmaton and Cherokee groups, and to a lesser extent the deeper shales and accompanying coals of the Cherokee Group (Fig. 3.02). Gas production was reported to range from 10 to 300 thousand cubic feet per day (Mcfd), with a "typical" well producing 40 Mcfd of shale-gas. A few extraordinary wells were reported to produce 900 Mcfd in the Paola-Kansas City area of Miami and Johnson counties, Kansas. However, such high production rates were short-lived, lasting only a few days (Charles and Page, 1929).

Eastern Kansas coal was originally exploited by more conventional means. Approximately 300 million tons (270 million metric tons) of coal was mined over the past 150 years, with most production occurring south of the current study area in southeastern Kansas. Peak production occurred in the earlier half of the 20th century during both world wars. One open-pit coal mine currently operates in eastern Kansas—exploiting the Mulberry coal in Linn County (Brady, 1997).

Over the past two decades, coal-sourced natural gas has revitalized the petroleum industry in eastern Kansas (Fig. 4.01). Interest first originated in the early 1980's. Increased activity was triggered by coal-gas industry tax incentives in the early 1990's. Tax incentives have since been phased out and the current activity is the result of increasing gas prices and newer exploration and completion technologies (Stoeckinger, 1990; Newell et al., 2002). The first coalbed gas content analysis was reported from Wilson and Montgomery counties in southeast Kansas (Stoeckinger, 1990). Initial desorption analyses reported more than 200 standard cubic feet per ton (scf/ton) for the Mulky coal, more than 220 scf/ton for the Weir-Pittsburg coal, and more than 190 scf/ton for the Riverton coal in the Cherokee basin (Stoeckinger, 1990). Similar analyses for the Forest City basin showed gas contents ranging from 50 to 435 scf/ton (Tedesco, 1992). In 1990, coal gas desorption from a cored-well by the Kansas Geological Survey in Leavenworth County yielded coalbed gas contents ranging from 20 to 94 scf/ton (Bostic et al., 1993).

The bulk of Kansas coalbed gas production is currently concentrated in the Cherokee basin. However, new production and coalbed gas pilot projects are slowly migrating northward across the Bourbon arch and into Forest City basin (Fig. 1.05). Northward expansion is controlled by the pre-existing pipeline infrastructure, which

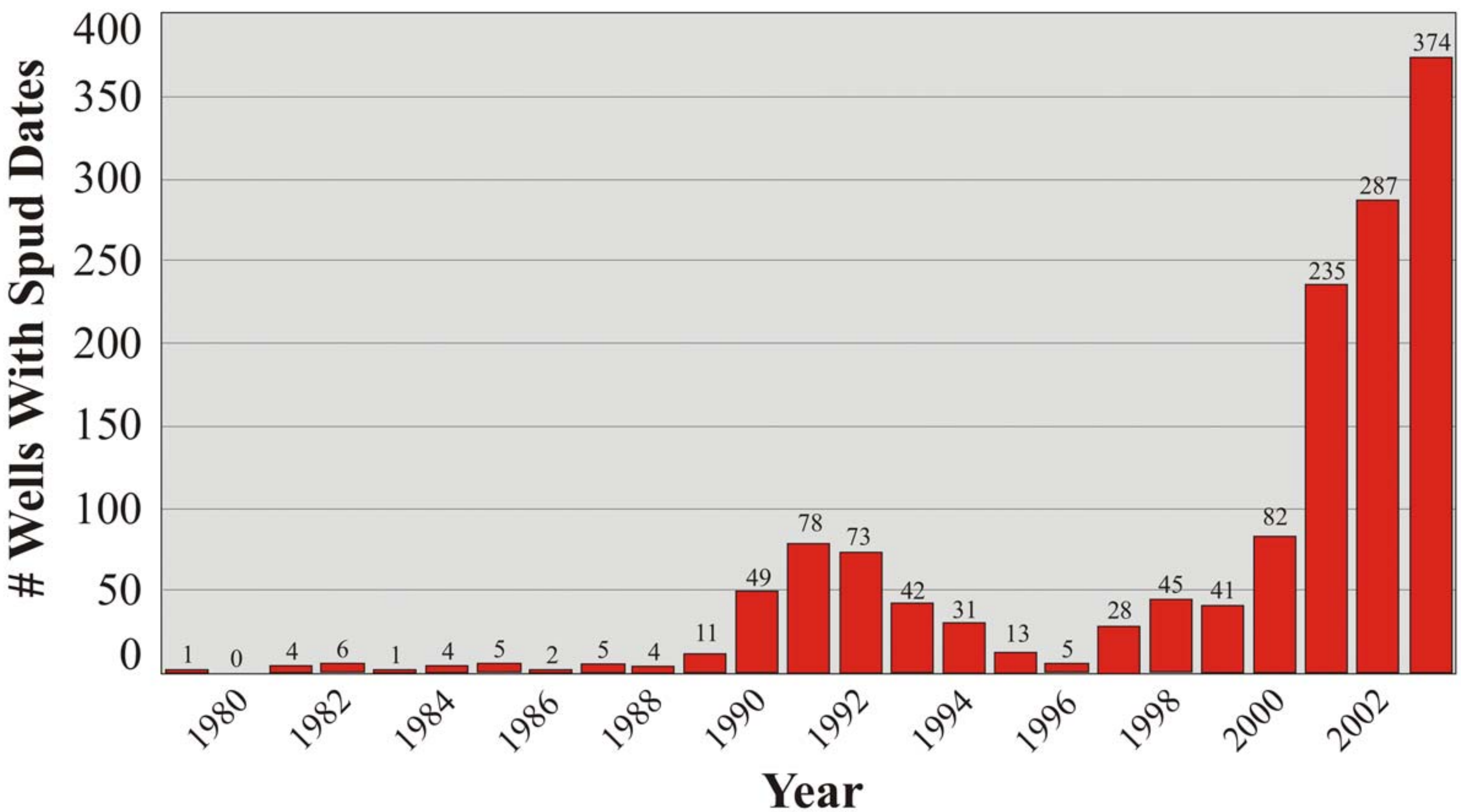

Figure 4.01 Completion activity by year through 2003 for wells with coalbed methane status in eastern Kansas. Activity in the early 1990's can be attributed to tax credits, whereas the most recent activity is due to higher natural gas prices. Modified from Newell et al. (2004).

connects the eastern Kansas coalbed gas region to several large markets (Fig. 1.05; Johnson et al., 2003). In addition to the pipeline infrastructure, several other positive factors influence coalbed gas production in eastern Kansas. These factors include:

1) High natural gas prices;
2) Low drilling costs due to the shallowness coal seams in eastern Kansas (< 2500 ft. [< 760 m]). The top of the Mississippian Limestone represents the maximum depth of Desmoinesian coals in eastern Kansas (Fig. 4.02);
3) Sufficient overburden for coalbed gas production and retention (Fig. 4.02);
4) Overlying seals of thick shale, which may also serve as possible gas sources adding to the total well productivity;
5) Possible fallback and upside opportunities on conventional hydrocarbon sources;
6) The high probability of encountering multiple coal beds (up to 14) within a single well (Brady, 1997; Newell et al., 2002);
7) Inexpensive salt-water disposal in the Cambrian-Ordovician Arbuckle Group located 200 to 400 feet (60- to 120 m) below the Mississippian-Pennsylvanian boundary. Disposal pumps are unnecessary since the Arbuckle Group is significantly below hydrostatic pressure (Newell et al. 2002, 2004).
8) The industry-friendly nature of eastern Kansas. Relative to other coalbed gas-producing regions in the United States, land in eastern Kansas is

MISSISSIPPIAN DEPTH STRUCTURE CONTOUR MAP

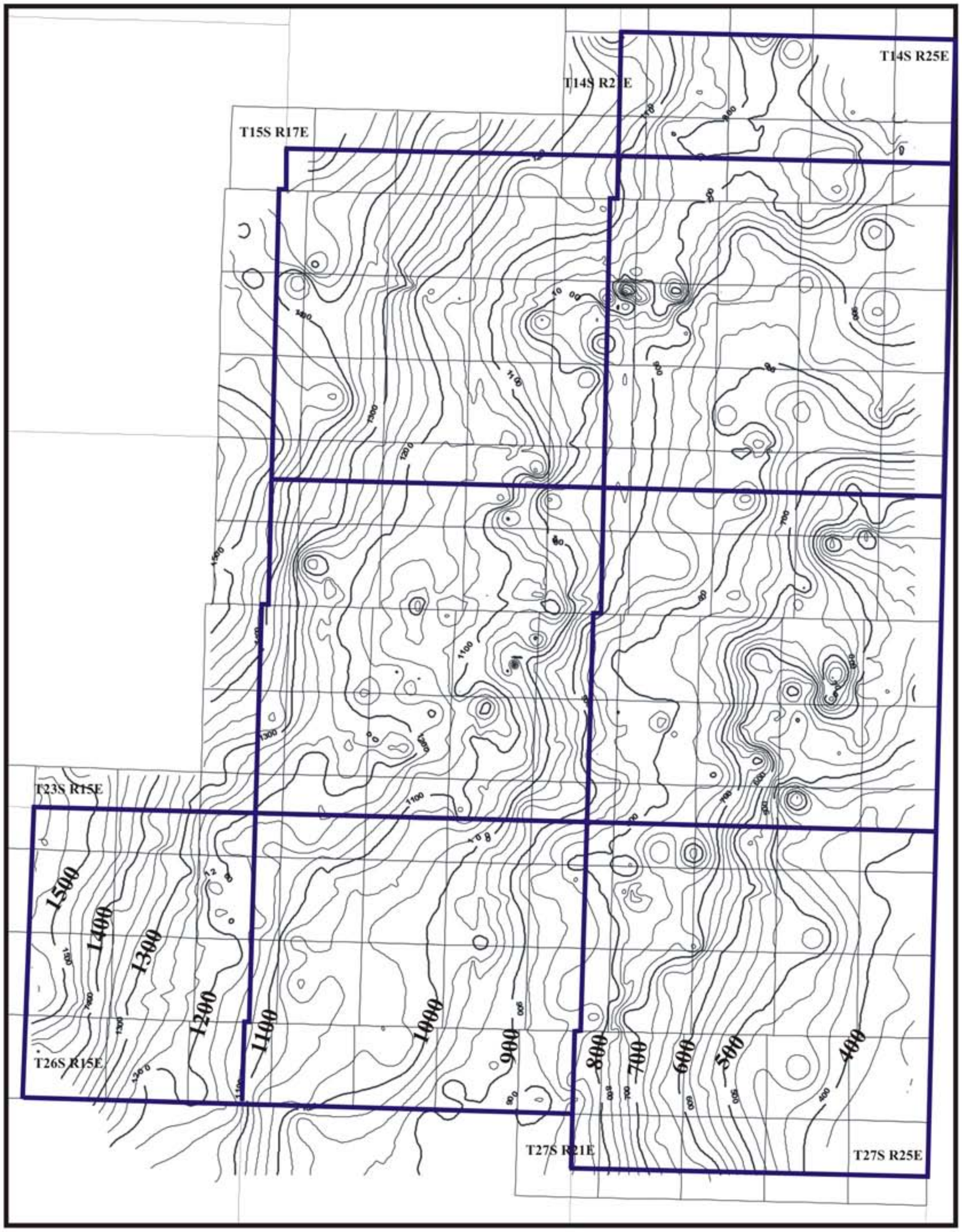

Figure 4.02 Structure contour map of the surface depth to the top of the Mississippian Limestone in the Bourbon arch study area. Regional structural dip trends to the west-northwest. C.I. = 25 ft.

predominately privately owned and landowners are open to industry development (Tedesco, 2003).

9) A local petroleum industry provides a pre-existing energy infrastructure.

Several factors negatively affect coalbed gas exploitation potential in eastern Kansas.

1) The coal rank (high volatile A- to C-bituminous) is less than ideal (medium-volatile bituminous) for coalbed gas generation (Rightmire, 1984; Brady, 1997).
2) The thinness of individual coal beds increases the difficulty of completion, and may negatively affect gas rates. Preliminary resource evaluation indicated that 85% of coal occurs in beds 14 to 28 inches (0.5 to 1.0 m) and the remaining 15% occurs in beds greater than 28 inches (>1.0 m; Brady, 1997).
3) Coalbed permeability in eastern Kansas is highly variable from well to well and within the same coal seam. Permeability values are reported to range from 0.01 to 500 md, averaging 10-20 md in productive areas (Tedesco, 2003). Calcite and other mineralization have been observed in cleats in various areas of eastern Kansas.

Gas contents derived from desorption of coal samples (excluding residual gas content) in the area are presented and compared to samples from the Cherokee basin. When combined with coal isopach maps and volumetric analysis, an estimate of original gas in place (OGIP) is calculated for the Bourbon arch. An analysis of coalbed gas geochemistry is also presented.

4.2 Gas Content

4.2.1 Desorption Results

Over the past five years the Kansas Geological Survey, in cooperation with several local coalbed methane operators, has carried out coal sampling for gas desorption in eastern Kansas. Coal desorption samples were collected from both cores and cuttings (Fig. 4.03). The methodology of coal sampling and desorption is described in Chapter 1. Gas contents (standard cubic feet per ton; scf/ton) for both the Bourbon arch and Cherokee basin study areas are reported as received (a.r.) and moisture- and ash-free (m.a.f.) bases (Figs. 4.04 and 4.05). The number of samples from individual coals and their nature (core or cuttings) is also reported. In the Bourbon arch, 23 core samples and 21 cuttings samples were analyzed as received, while 27 of each type were analyzed as received in the Cherokee basin. Based on 44 samples, coalbed gas contents of major coals in the Bourbon arch range from 5.2 to 142.8 scf/ton (a.r.; Fig. 4.04) and 16.7 to 181.3 scf/ton (m.a.f.; Fig. 4.05). Coals with the highest gas contents on the Bourbon arch are the Riverton, Neutral, Rowe, Scammon, Mineral, Bevier, Lexington, and Mulberry (Figs. 4.04 and 4.05). Gas contents on the Bourbon arch are generally lower than those in the Cherokee basin. Based on 54 samples, Cherokee basin coalbed gas contents range from 3.2 to 333.4 scf/ton (a.r.; Fig. 3.04) and from 28.3 to 446.4 scf/ton (m.a.f.; Fig. 3.05; Lange, 2003). Desorption analysis of coalbed gas contents include lost gas and desorbed gas components. Coalbed gas contents presented in this study *do not* include residual gas.

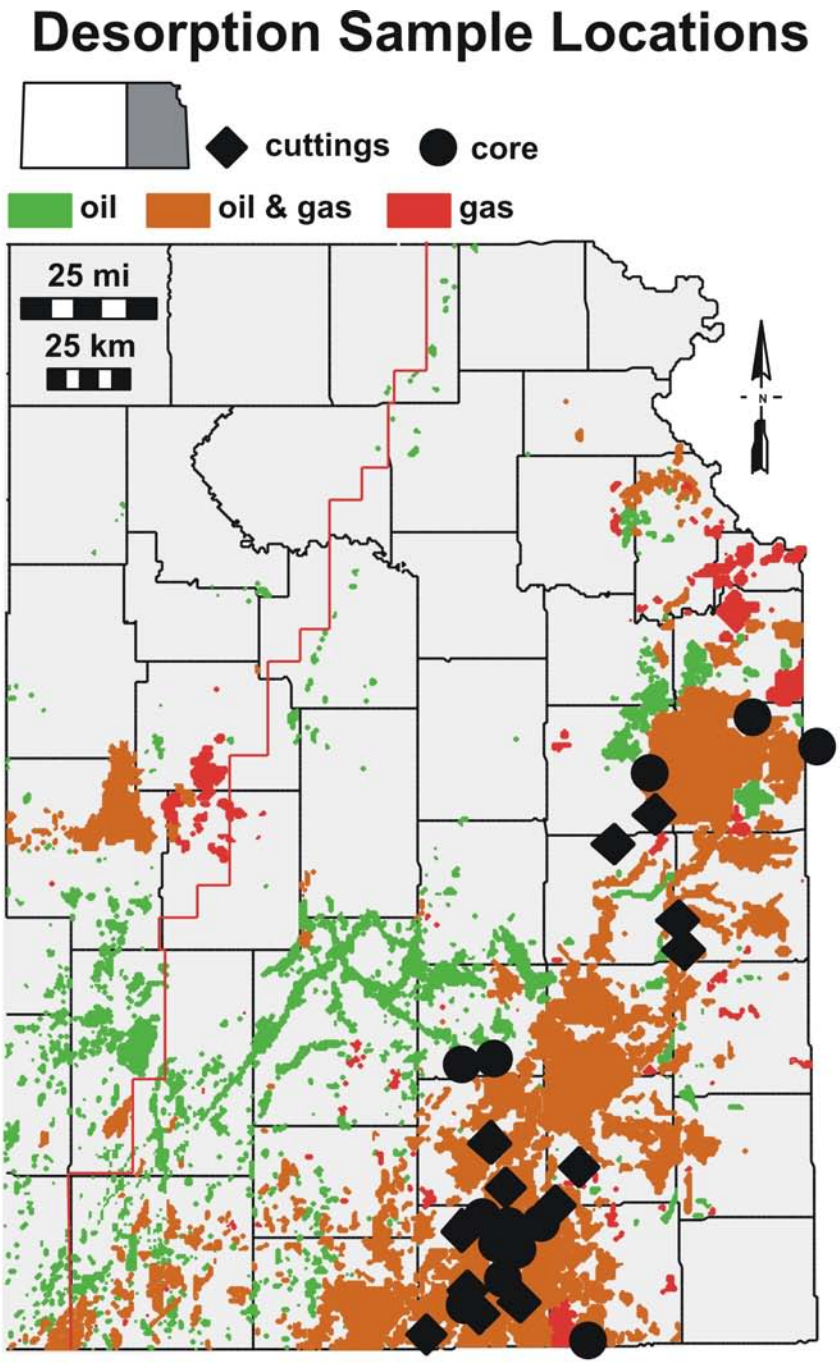

Figure 4.03 Approximate locations of coal desorption samples collected in Bourbon arch and Cherokee basin study areas of eastern Kansas. Coal desorption samples include both core (circles) and cuttings (diamonds). Modified and updated from Lange, 2003; and Newell et al., 2004.

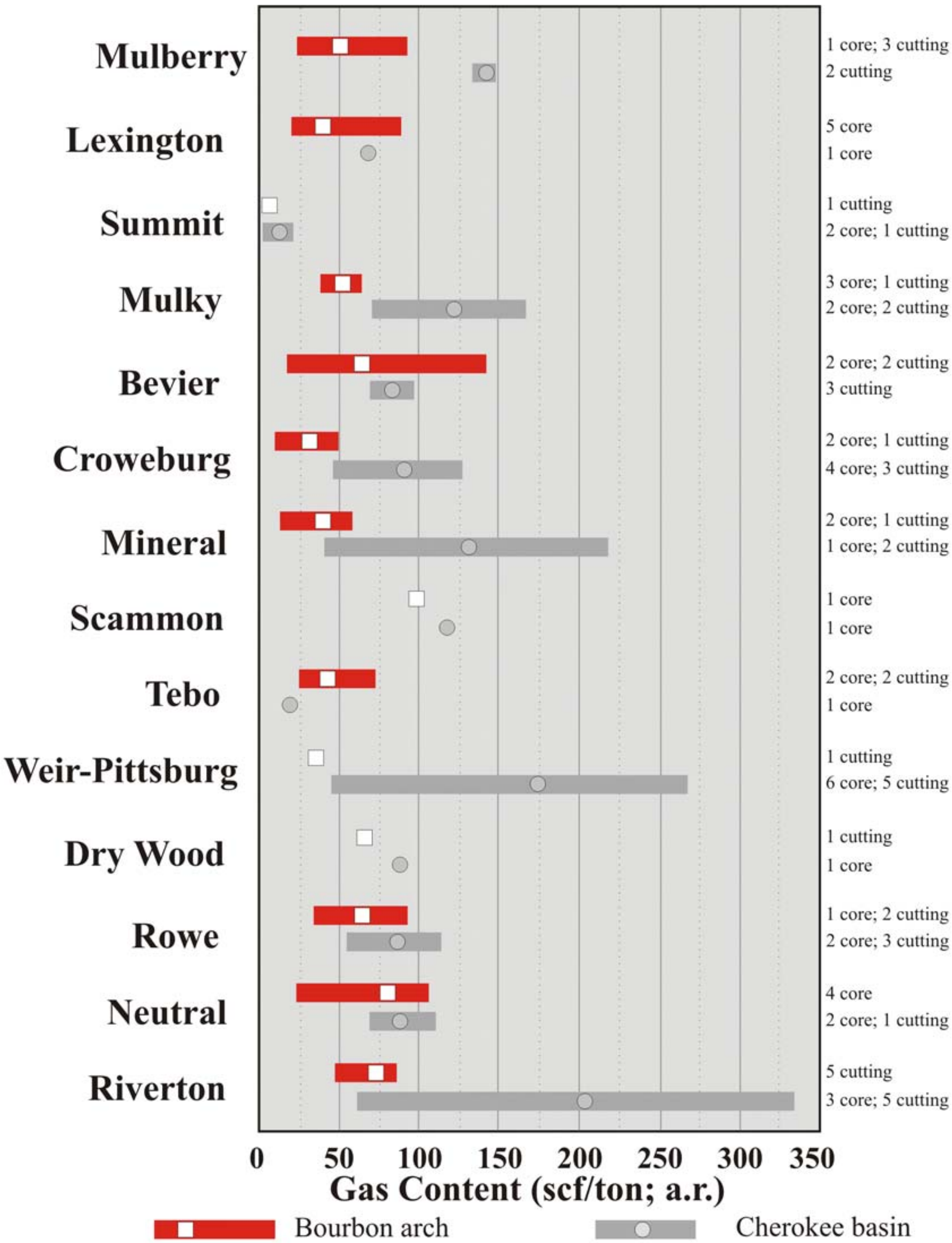

Figure 4.04 Range (lines) and average (squares and circles) gas content (scf/ton as received basis) of coals in the Bourbon arch and Cherokee basin (updated and modified from Lange, 2003). The number and type of coal desorption samples are given on the right. Gas content values do not include residual gas.

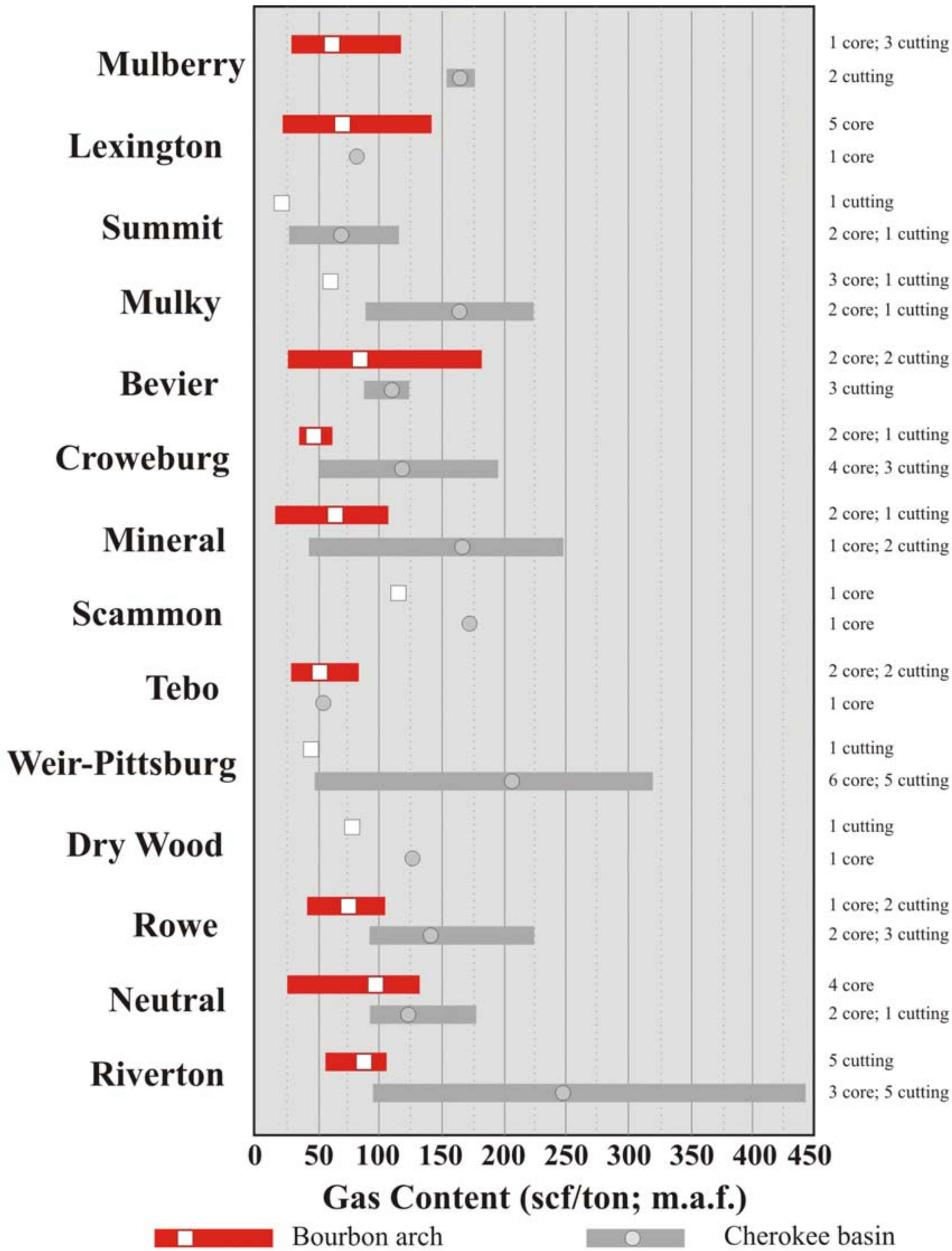

Figure 4.05 Range (lines) and average (squares and circles) gas content (scf/ton moisture- and ash-free basis) of coals in the Bourbon arch and Cherokee basin (updated and modified from Lange, 2003). The number and type of coal desorption samples are given on the right. Gas contents do not include residual gas.

Coal data points and curves are color-coded based on relative stratigraphic position (Fig. 4.06). Warmer colors represent stratigraphically higher coals such as the Mulberry and Lexington, while cooler colors represent stratigraphically lower coals such as the Neutral and Riverton. The desorption characteristics of coals are presented on an as received basis for individual counties (Franklin, Miami, Woodson, and Cass County, Missouri; Figs. 4.07, 4.08, 4.09, and 4.10).

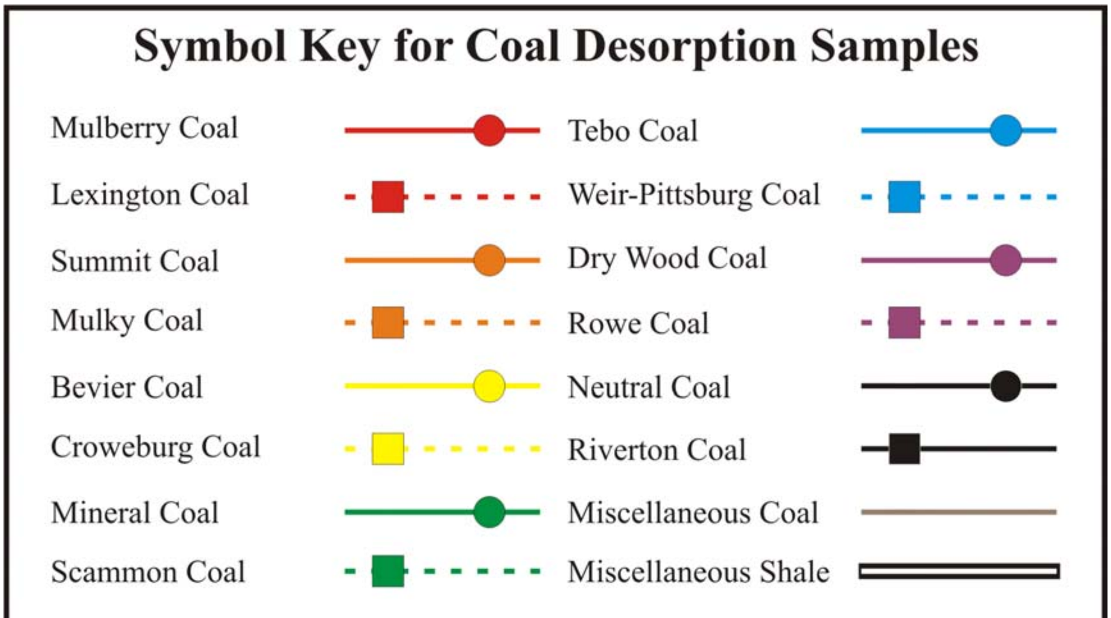

Figure 4.06 Symbol key for data curves and points of coal desorption samples. Major coals are color-coded on the basis of relative stratigraphic position to more easily distinguish coals and coal trends.

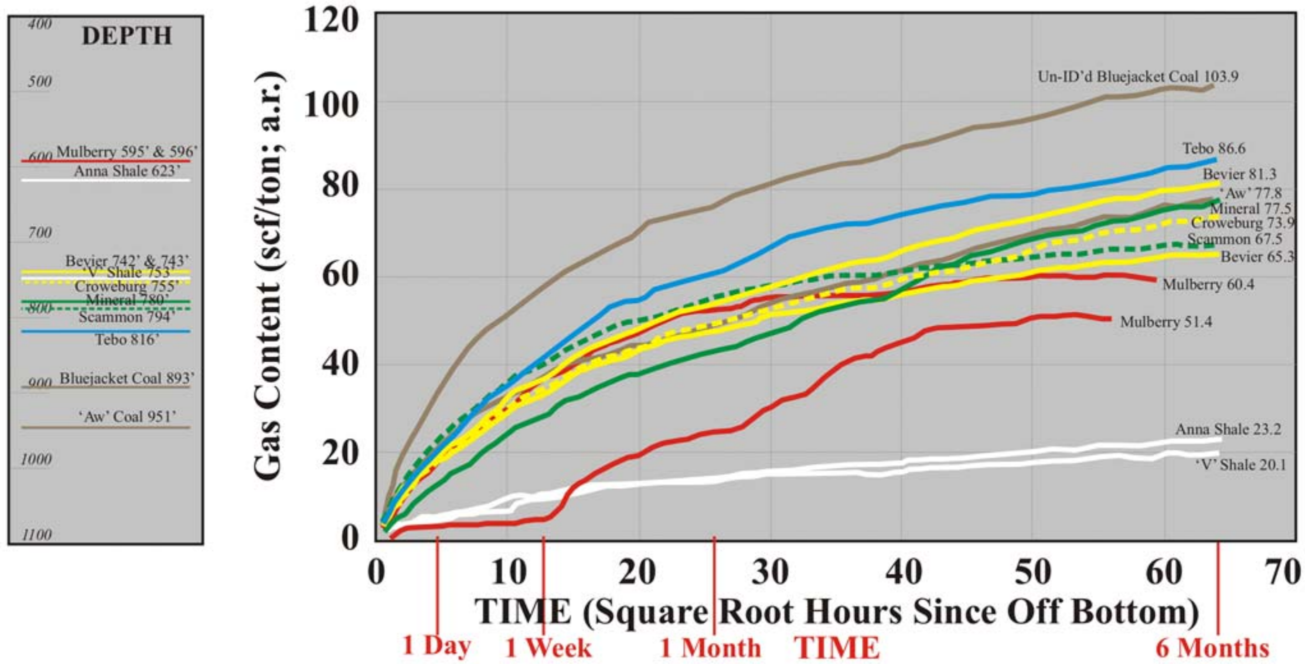

Figure 4.07 In progress (as of April, 2004) desorption characteristics for coal and shale samples collected from a single proprietary well in Franklin County, Kansas. Curves are labeled by coal and maximum gas content (as received to date). See Figure 4.06 for explanation of curve data colors.

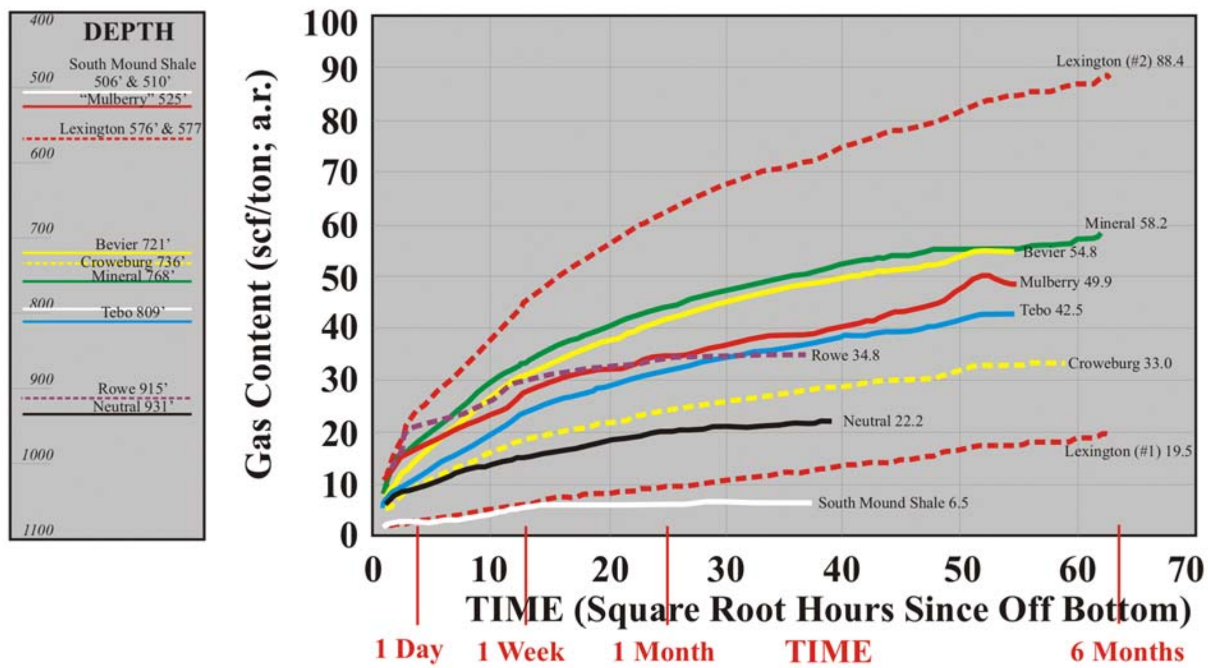

Figure 4.08 Desorption characteristics for coal samples collected from the Osborn-Layne Energy Rose Hill #1-6 well in Miami County, Kansas. Curves are labeled by sample name and maximum gas content (as received). See Figure 4.06 for explanation of curve data colors.

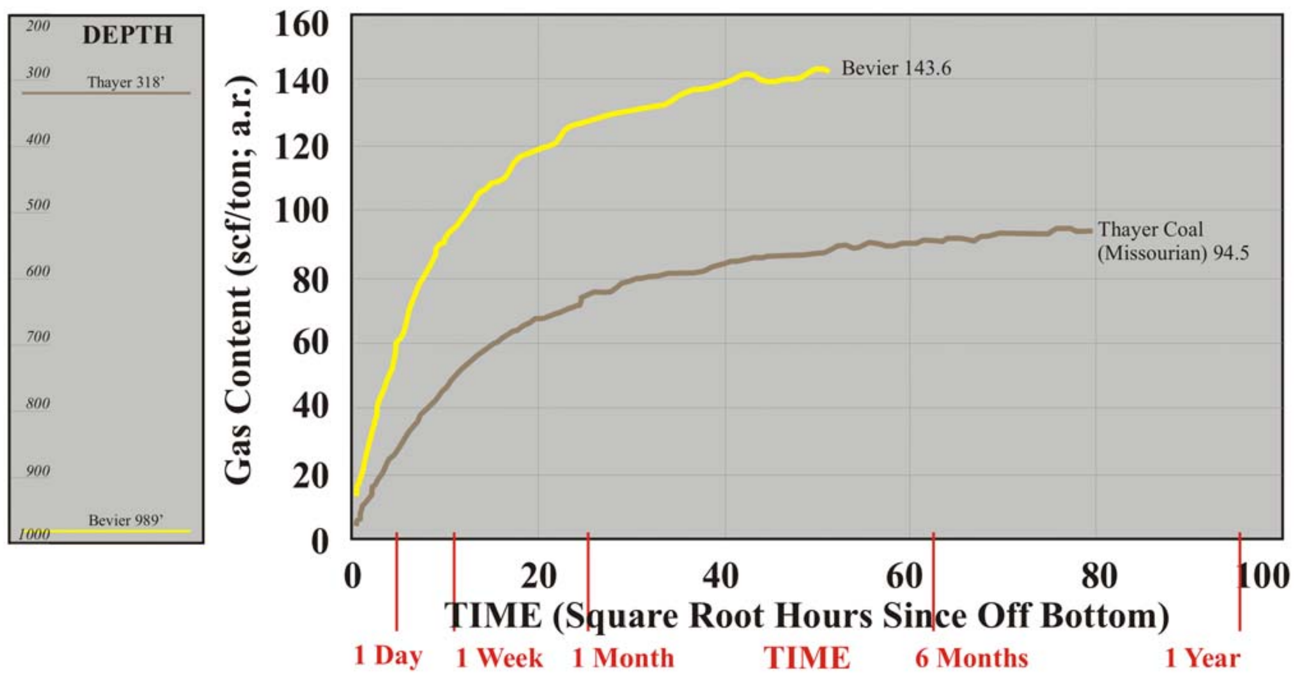

Figure 4.09 Desorption characteristics for coal samples collected from the KGS Eagle #5 well in Woodson County, Kansas (sec18, T26S, R16E). Curves are labeled by coal and maximum gas content (as received). See Figure 4.06 for explanation of curve data colors.

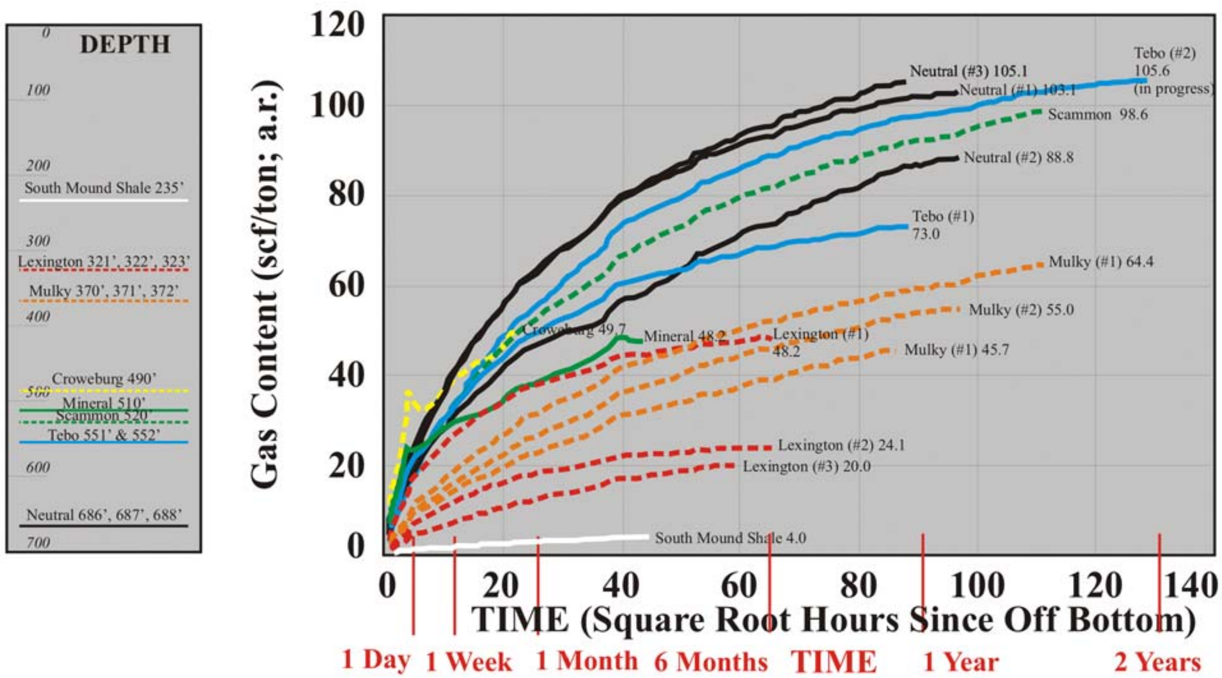

Figure 4.10 Desorption characteristics for coal samples collected from the Osborn-Layne Energy Smith #1-22 well in Cass County, Missouri. Curves are labeled by sample name and maximum gas content (as received). See Figure 4.06 for explanation of curve data colors.

Gas contents for cuttings are typically lower than those of core samples. This is due to the increased surface area of cuttings from pulverization during drilling. The increased surface area results in greater lost gas prior to canistering. The greater surface area also increases the rate and decreases the duration of desorption. On the other hand, the greater speed of cuttings reaching the surface may also affect lost gas estimates. Cuttings "lag time"—the travel time between the bottom of the hole and the surface—may be several tens of seconds, whereas the time for cores to reach the surface may be several minutes. Gas contents of cuttings have been reported as 24-28% less than core equivalents (Mavor et al., 1992). Nelson (1999) suggested cuttings desorbed 25-30% less gas than cores. A consistent correlation between gas contents of cores and cuttings has not been demonstrated. Continuing research at the Kansas Geological Survey is attempting to determine the relationship between gas contents from cores and cuttings. Cuttings were analyzed and segregated into shale and coal following sample decanistering. An average gas content of 3 scf/ton (as received) for shale in eastern Kansas was assumed in calculation of gas content of the coal portion of the sample (K.D. Newell, personal communication, 2004).

4.2.2 Coal and Coalbed Gas Resource Estimate

Using average coalbed gas contents and digital subsurface coal isopach maps, coalbed gas resources in the Bourbon arch were estimated. Coal mass (C_m), is estimated by the equation:

$$C_m = C_{A\text{-}F} * T/(A\text{-}F) \tag{1}$$

where C_{A-F} is the volume of coal (acre-feet) and T/(A-F) is tons of coal per acre-foot. Based on an average specific gravity of 1.32 for bituminous coal, a value of 1800 tons per acre-foot was used for T/A-F (Averitt, 1974). C_{A-F} was calculated from coal isopach maps for the coal volume greater than 1.0 foot (0.3 m). A thickness cutoff of 1 foot (0.3 m) reflects the present minimum completion thickness in the Bourbon arch. Original gas in place of each coal seam (OGIP in scf) was computed with the equation:

$$OGIP = G_c * C_m \tag{2}$$

by multiplying the average gas content for each seam (G_c) by the mass of each coal (C_m) as calculated from Equation 1. The numbers of coal samples (cuttings and core) desorbed are presented in Figure 4.04. Total original gas in place (TOGIP) for the Bourbon arch, summed from the 14 coals mapped in the current study, is estimated to be 2.0711 trillion cubic feet (tcf; Table 4.1). This compares to a TOGIP for the Cherokee basin of 6.612 tcf (Lange, 2003).

Table 4.1 Volumetric calculation values for the Bourbon arch.

Coal	Avg. Gas Content (scf/ton; Gc)	Coal Volume >1.0 ft. (Acre-feet; T/A-F)	Coal Mass (short tons; Cm)	OGIP (bcf)
Mulberry	52.5	1,824,560	3,284,208,000	172.4
Lexington	40.0	168,511	303,319,800	12.1
Summit	5.2	1,278,413	2,301,143,400	12.0
Mulky	50.9	2,009,245	3,616,641,000	184.1
Bevier	63.5	4,283,729	7,710,712,200	489.6
Croweburg	31.0	1,890,609	3,403,096,200	105.5
Mineral	39.5	1,817,834	3,272,101,200	129.2
Scammon	98.6	1,138,216	2,048,788,800	202.0
Tebo	43.4	1,352,736	2,434,924,800	105.7
Weir-Pittsburg	35.3	1,129,632	2,033,337,600	71.8
Dry Wood	65.7	237,226	427,006,800	28.1
Rowe	64.0	574,740	1,034,532,000	66.2
Neutral	79.8	1,031,500	1,856,700,000	148.2
Riverton	72.9	2,623,110	4,721,598,000	344.2
			Total OGIP (bcf)	**2071.1**

A net coal isopach of all significant, mapped coals in the study area ranges from 0 to 22 feet (0 to 6.7 m), averaging 9.0 feet (2.7 m) across the Bourbon arch study area (Fig. 4.11). Thicker net coal isopach values occur in southern Johnson, southern and western Franklin, central Miami, central Linn, eastern Allen, and western Bourbon counties. Additional local coals may be present in a well log at any given location and increase the net coal value of an individual well. In areas with historical hydrocarbon production from relatively shallow, upper-Cherokee or Marmaton reservoirs, many wells do not penetrate the entire coal-bearing sequence and deeper coals. As a result, deeper coals may not be adequately represented.

BOURBON ARCH NET COAL ISOPACH MAP

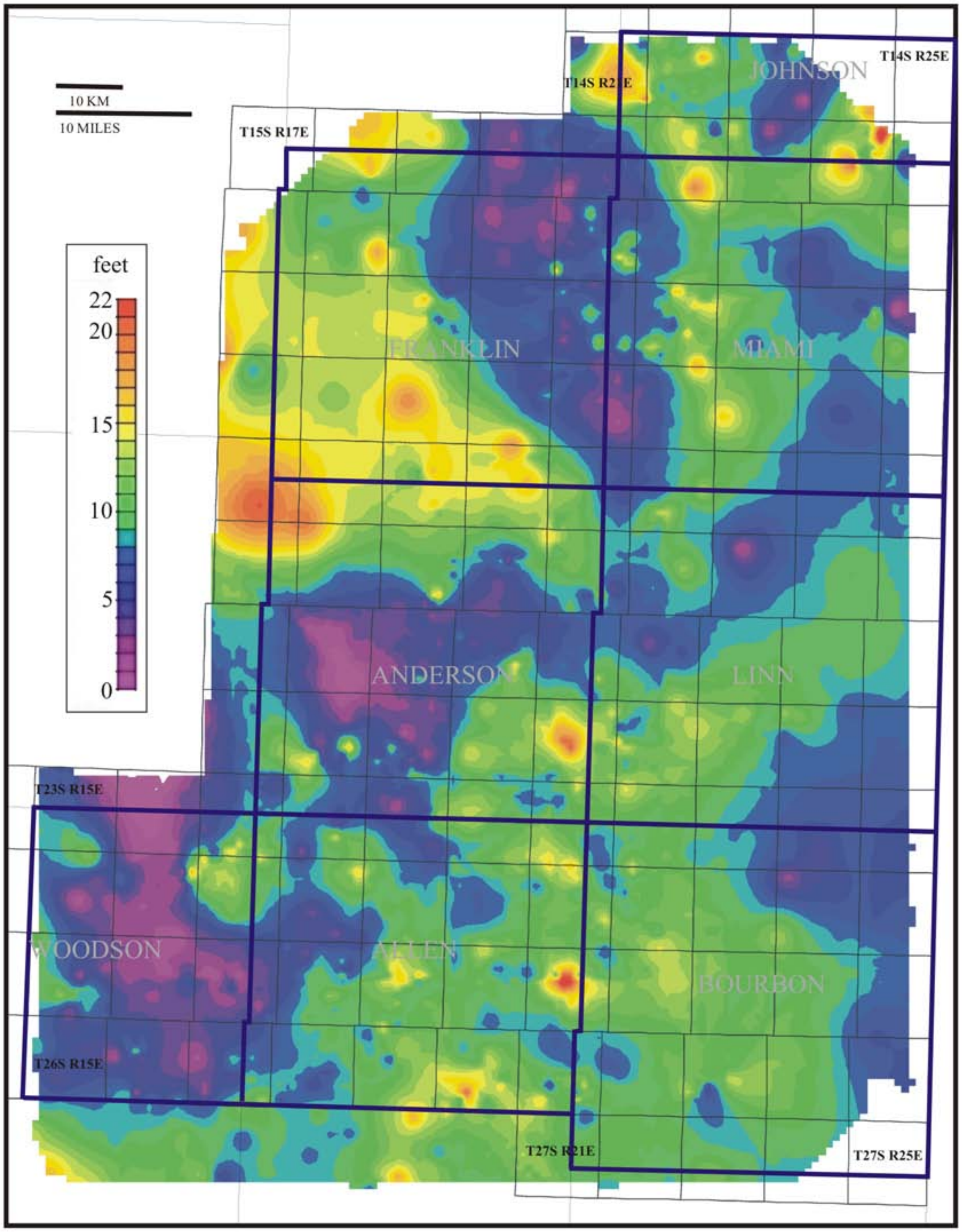

Figure 4.11 Net coal isopach map (range: 0 to 22 ft.; C.I.: 1.0 ft.). Isopach values represent a minimum net coal thickness at any given location.

4.3 Coalbed Gas Geochemistry

Coalbed gas is commonly termed "coalbed methane" given that methane is typically the highest concentration. Other components include heavier hydrocarbon gases such as ethane and propane. Nonhydrocarbon components include nitrogen, carbon dioxide, hydrogen sulfide, and helium (Rightmire, 1984; Rice, 1993). Geochemical analysis of coal gas samples provides insight into the origin of coalbed gas, and possible coalbed gas production fairways in eastern Kansas.

Conventional gas from fields in eastern Kansas originated from both thermogenic and microbial processes (Jenden et al., 1988). Thermogenic gas results from the thermal cracking of kerogen during catagenesis between temperatures of 80˚ to 150˚ C (wet, associated gas) and 150˚ to 200˚ C (dry, non-associated gas). The process of microbial CO_2 reduction forms gas at temperatures up to 80˚ C, as methanogenic bacteria reduce CO_2 and H_2 to form CH_4 and water. Microbial processes produce dry, non-associated gas (Hunt, 1996). Gases from Mississippian and Pennsylvanian strata in Kansas are both associated and non-associated, whereas Permian and younger gases tend to be drier (non-associated), and pre-Mississippian gases tend to be wetter (associated; Jenden et al., 1988).

Crossplots of $\delta^{13}C$ and δD, and $\delta^{13}C$ and methane wetness are used to determine the origins of both conventional and unconventional gases (Fig. 4.12). More negative $\delta^{13}C$ indicates methane with a high proportion of light carbon isotopes. More negative δD indicates methane with a high proportion of light hydrogen isotopes. Lighter $\delta^{13}C$ and δD isotopes are indicative of dry microbial gas generation, while heavier $\delta^{13}C$ and δD isotopes are indicative of wet thermogenic gas generation. Methanogenic bacteria preferentially consume lighter carbon and hydrogen isotopes during microbial CO_2 reduction, resulting in more negative $\delta^{13}C$ and δD values relative to thermogenic gas (Hunt, 1996).

When $\delta^{13}C$ and δD values, and $\delta^{13}C$ and methane wetness values are crossplotted for conventional associated (oilfield) and non-associated (gasfield) gases from eastern Kansas, thermogenic and microbial CO_2 reduction origins are indicated (Fig. 4.12; Jenden et al., 1988). Coalbed gas samples were collected by the Kansas Geological Survey and sent to a commercial laboratory for gas isotopic analysis. Isotopic analysis of coalbed gas samples of $\delta^{13}C$ versus δD, and $\delta^{13}C$ versus percent methane wetness compositions suggest mixed thermogenic and microbial origins, as well as dominantly microbial origins (Fig. 4.12; Jenden et al., 1988). Pennsylvanian rocks are marginally mature to mature based on vitrinite reflectance values ranging from 0.5 to 0.8% (Jenden et al., 1988; Walton et al., 1995). Given low maturity, conventional and coalbed gases likely originated from a combination of indigenous microbial CO_2 reduction, and indigenous and early-migrated thermogenic origins. Long-distance migration was from thermally mature source rocks in the Arkoma basin to the south (Jenden et al., 1988).

Gas composition and isotopic data show that coalbed gas samples have a greater thermogenic signature with increasing depth into the basin. Shallower updip coals tend to be less gassy and have more microbial signatures. As a result, coals have a generally greater gas content in the Cherokee basin than in the Bourbon arch

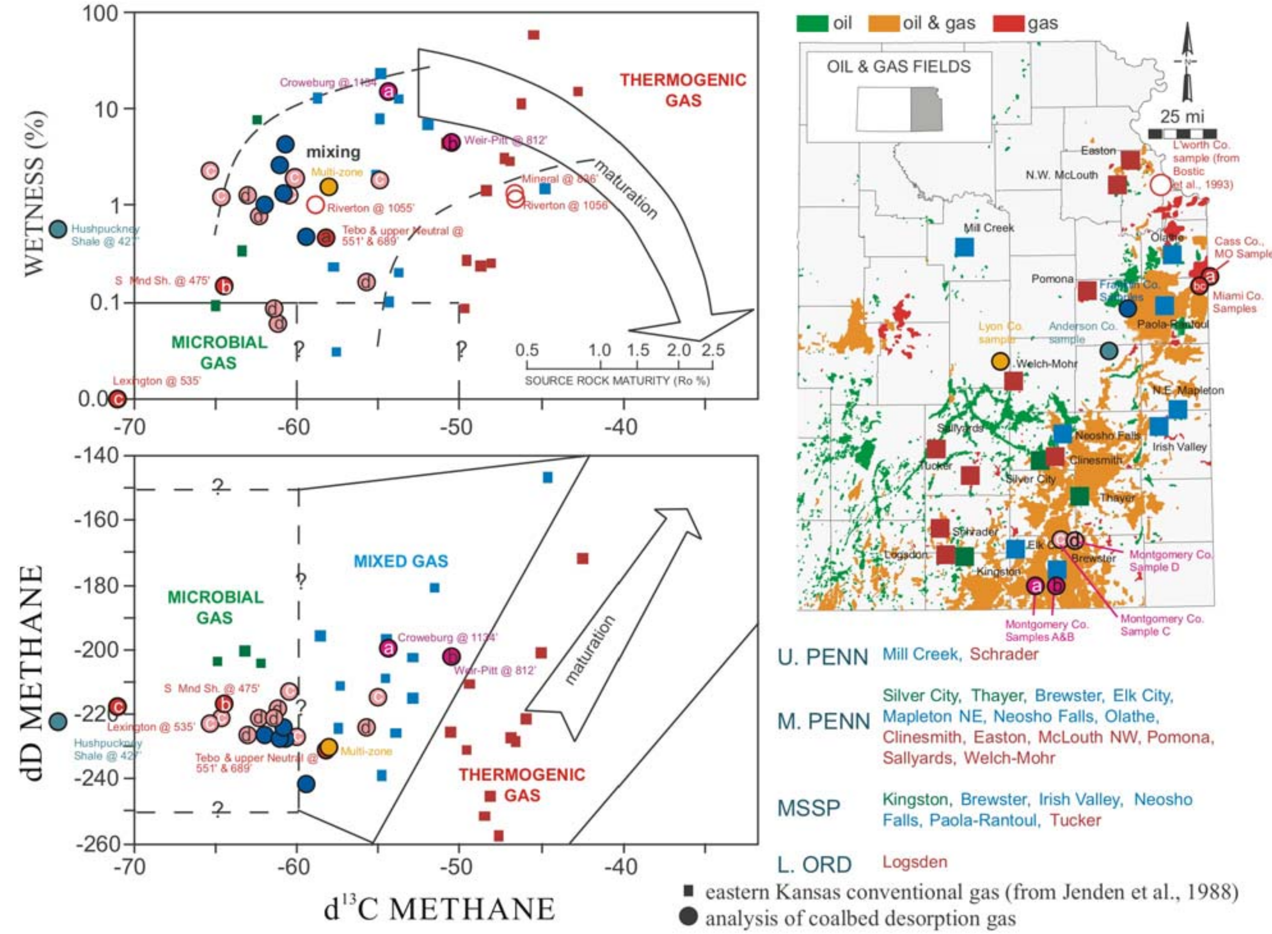

Figure 4.12 Crossplots of d^{13}C Methane vs. dD methane and % wetness for conventional and coalbed gas samples from eastern Kansas (modified from Jenden et al., 1988; Lange, 2003; and Newell et al., 2004).

(Figs. 4.04 and 4.05). In addition, coal seam gas contents generally increase with depth within a given well. Coalbed gas content data for the Smith #1-22 well in Cass County, Missouri (Fig. 4.10); the Franklin County, Kansas well (Fig. 4.07); and the Woodson County well (Fig. 4.09) follow this trend. However, in the Rose Hill #1-6 well of Miami County, Kansas, one of the shallowest coals (e.g. Lexington at 576') has much higher gas content relative to deeper coals in the same well (Fig. 4.08). According to the Lexington's gas isotope values in Figure 4.12, a microbial origin may account for the relatively high gas content. Other proprietary data points support this trend (e.g. Hushpuckney Shale sample from Anderson County and certain Montgomery County 'D' samples; K.D. Newell, personal communication, 2004). The possibility exists of a shallow, updip production fairway composed of microbial gas exists on the Bourbon arch. Additional data is required to better define the contribution of biogenic coal gas in eastern Kansas.

4.4 Gas Content Relationships

Gas contents of coals from the Cherokee basin and Bourbon arch were cross-plotted with associated values for depth (feet), ash content (wt. %), and calorific value (Btu/lb). A general trend of increasing gas content (both as received and moisture- and ash-free) with increasing depth exists for coals in eastern Kansas (Figs. 4.13 and 4.14, respectively). A similar trend was suggested in the Cherokee basin; gas contents were greater for deeper coals in Montgomery County, Kansas, than shallower, regionally updip coals in adjacent Labette County to the east (Lange, 2003). Individual coals (e.g. Rowe and Riverton) may also show trends of increasing gas content with depth (Figs. 4.13 and 4.14).

The relationship between depth and gas content may be related to increased hydrostatic pressure at greater depths, which results in higher quantities of adsorbed gas. Additionally, thermogenic processes typically increase with greater depths. Although the relationship between gas content and thermogenic versus microbial origin is inconclusive, the gas content of thermogenic or mixed nature is generally higher than pure microbial gas (Figs. 6.07; 6.08; 6.10; and 6.17). Microbial gas can have intermediate to high gas contents locally, as in the Lexington coal of Rose Hill #1-6 in Miami County (Figs. 6.08; 6.17). As depth and thermogenic signature increase, coalbed gas content in the western portions of the study area and Cherokee basin is generally greater than on the Bourbon arch.

No apparent trend exists between gas content (scf/ton; m.a.f.) and ash content (wt. %; moisture-free) for eastern Kansas coals as a whole, but several individual coals exhibit weak trends of increasing gas content with increasing ash content (Fig. 4.15). While highly variable, a cleaner coal can have relatively high gas content, whereas coals with higher ash content are expected to have low to moderate gas content (Fig. 4.15). A trend of increasing gas content (scf/ton; m.a.f.) with increasing coal rank, or calorific value (Btu/lb) also exists for coals in eastern Kansas (Fig. 4.16). Coals with calorific values greater or equal to 14,000 Btu/lb are classified as high volatile A-bituminous (Rightmire, 1984). Coals with calorific values between 13,000 and 14,000 are classified as high-volatile B bituminous. One coal sample plotted within the high-volatile C bituminous range (11,500 to 13,000 Btu/lb; Fig. 4.15).

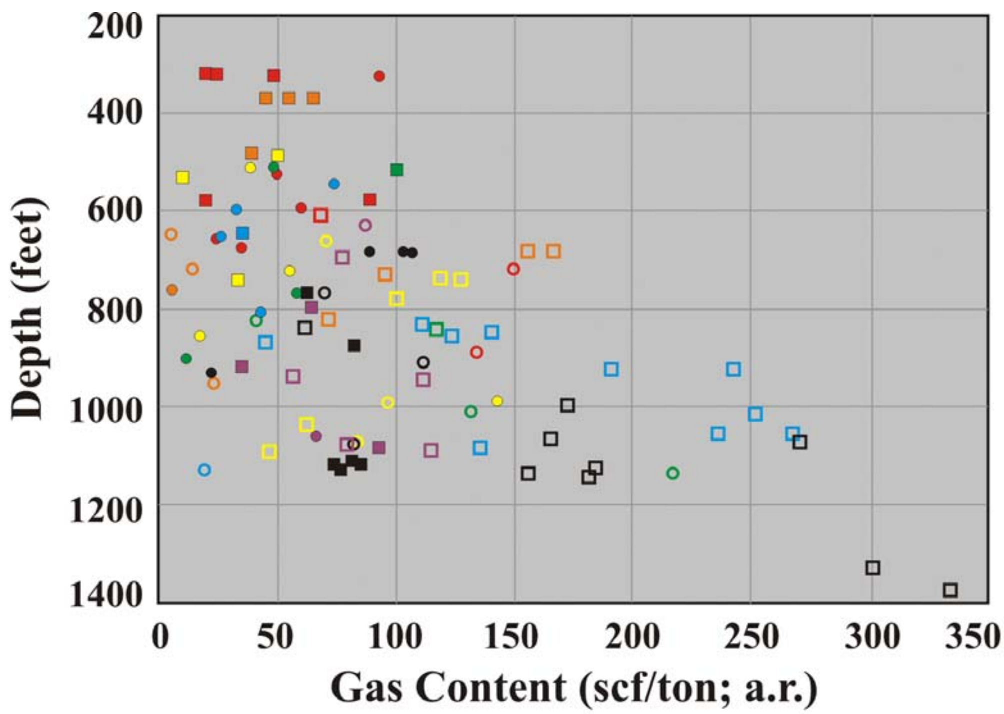

Figure 4.13 Cross-plot of gas content (scf/ton; as received) versus depth in feet for individual coals on the Bourbon arch (color-filled) and in the Cherokee basin (outlined) showing a trend of increasing gas content with increasing depth. See Figure 4.06 for explanation of data point symbols and colors.

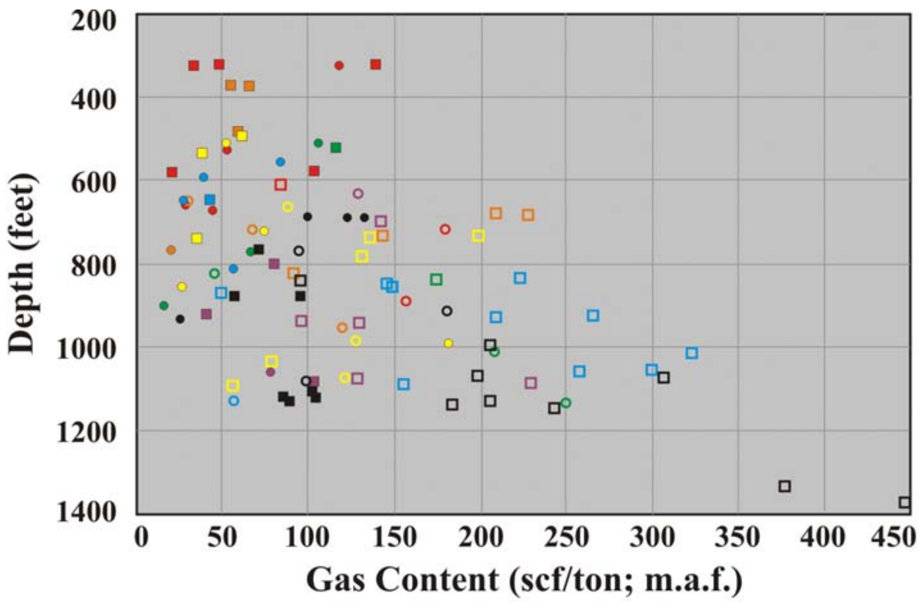

Figure 4.14 Cross-plot of gas content (scf/ton; moisture- and ash-free) versus depth in feet for individual coals on the Bourbon arch (color-filled) and in the Cherokee basin (outlined) showing a trend of increasing gas content with increasing depth. See Figure 4.06 for explanation of data point symbols and colors.

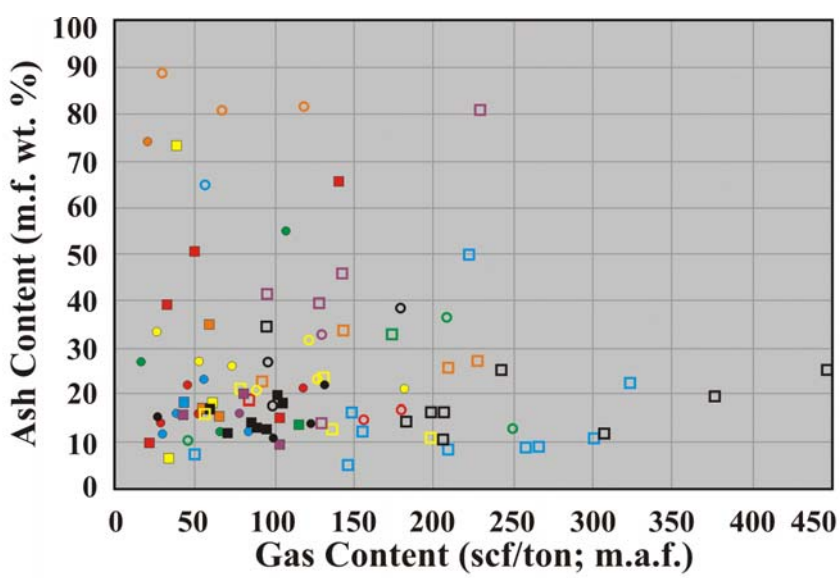

Figure 4.15 Cross-plot of gas content (scf/ton; moisture- and ash-free basis) versus ash content (wt. %; moisture-free basis) for individual coals on the Bourbon arch (color-filled) and in the Cherokee basin (outlined). No trend is apparent between gas content and ash content, although several individual coals show increasing trends of gas content with ash content. See Figure 4.06 for explanation of data point symbols and colors.

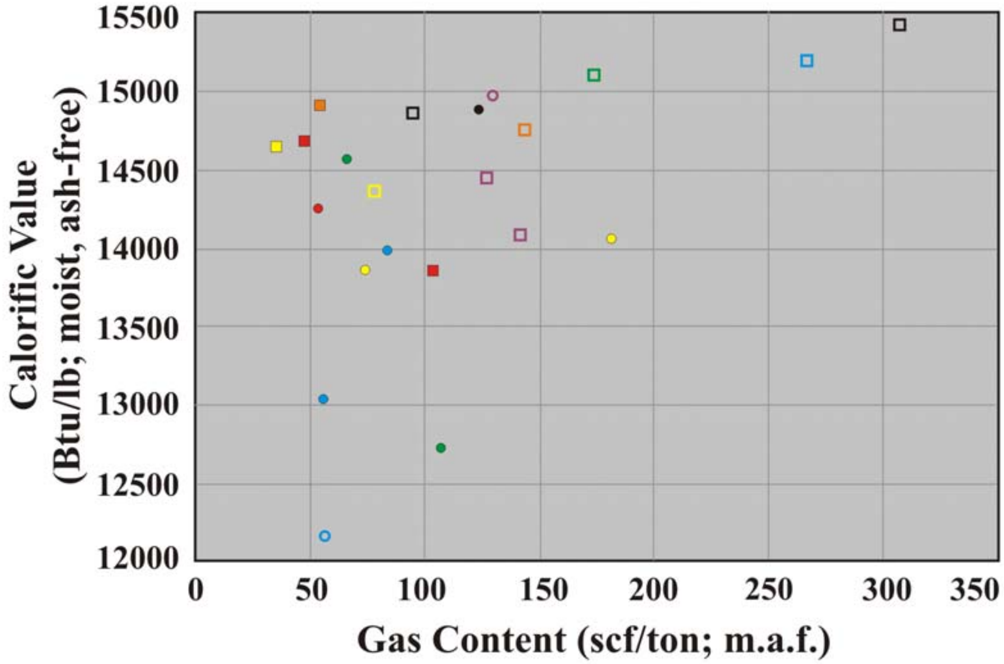

Figure 4.16 Cross-plot of gas content (scf/ton; moisture- and ash-free basis) versus calorific value (Btu/lb; moist, ash-free basis) for individual coals on the Bourbon arch (color-filled) and in the Cherokee basin (outlined). Gas content increases with coal rank. Bourbon arch coal samples range from high-volatile C to A bituminous (see text). See Figure 4.06 for explanation of data point symbols and colors.