34th FORUM OF THE COAL GEOLOGISTS OF THE WESTERN INTERIOR COAL REGION PITTSBURG, KANSAS

Field Trips

Wednesday -- May 26, 2010
----Gas from Coal---
A Visit to the PostRock Energy Corporation Field Operations
Coffeyville to Chanute, Kansas and Vicinity

and

Tuesday (P.M.) -- May 25, 2010
Kansas Coal and the Big Brutus Coal Shovel
Near West Mineral, Kansas

Leaders
Lawrence L. Brady and K. David Newell, Geologists
Kansas Geological Survey
Lawrence, Kansas
and
Ken Recoy, Senior Geologist
PostRock Energy Corporation
Chanute, Kansas

KU THE UNIVERSITY OF KANSAS
The Kansas Geological Survey

GUIDEBOOK INFORMATION

Map of Southeast Kansas showing general location of the two field trips.

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Wednesday, May 26, 2010—Gas from Coal....A field trip led by Ken Recoy, Senior Geologist, PostRock Energy Corporation....from Coffeyville to Chanute, Kansas with four stops at different PostRock Corporation field operations.

Summary of the four stops on the field trip....locations and operations at each stop.

Photos of PostRock operations at each of the four stops.

Kansas Coalbed Methane Play by K. David Newell (Kansas Geological Survey), and Rolland J. Yoakum (Consulting Geologist)—a preprint of a paper prepared for "New Plays and Ways" by the Kansas Geological Society, Kansas Oil and Gas Fields, v. VI, Daniel F. Merriam (ed.)

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Tuesday, May 25, 2010--- (P.M. ~ 3-5:30)—A short field trip to discuss Kansas coal and visit Big Brutus near West Mineral (Cherokee Co.), Kansas.

Map showing Southeast Kansas strip mines, and coal crop lines.

Map showing Southeast Kansas deep mines in the Weir-Pittsburg coal bed.

Picture of Phoenix Coal Mining, Inc. Garland Mine highwall. This is the one coal mine presently operating in Kansas.

A measured geologic stratigraphic section at the Garland Mine. The measured section is located approximately ½ mile southeast of the highwall picture.

General stratigraphic section of the Cherokee Group in Southeast Kansas.

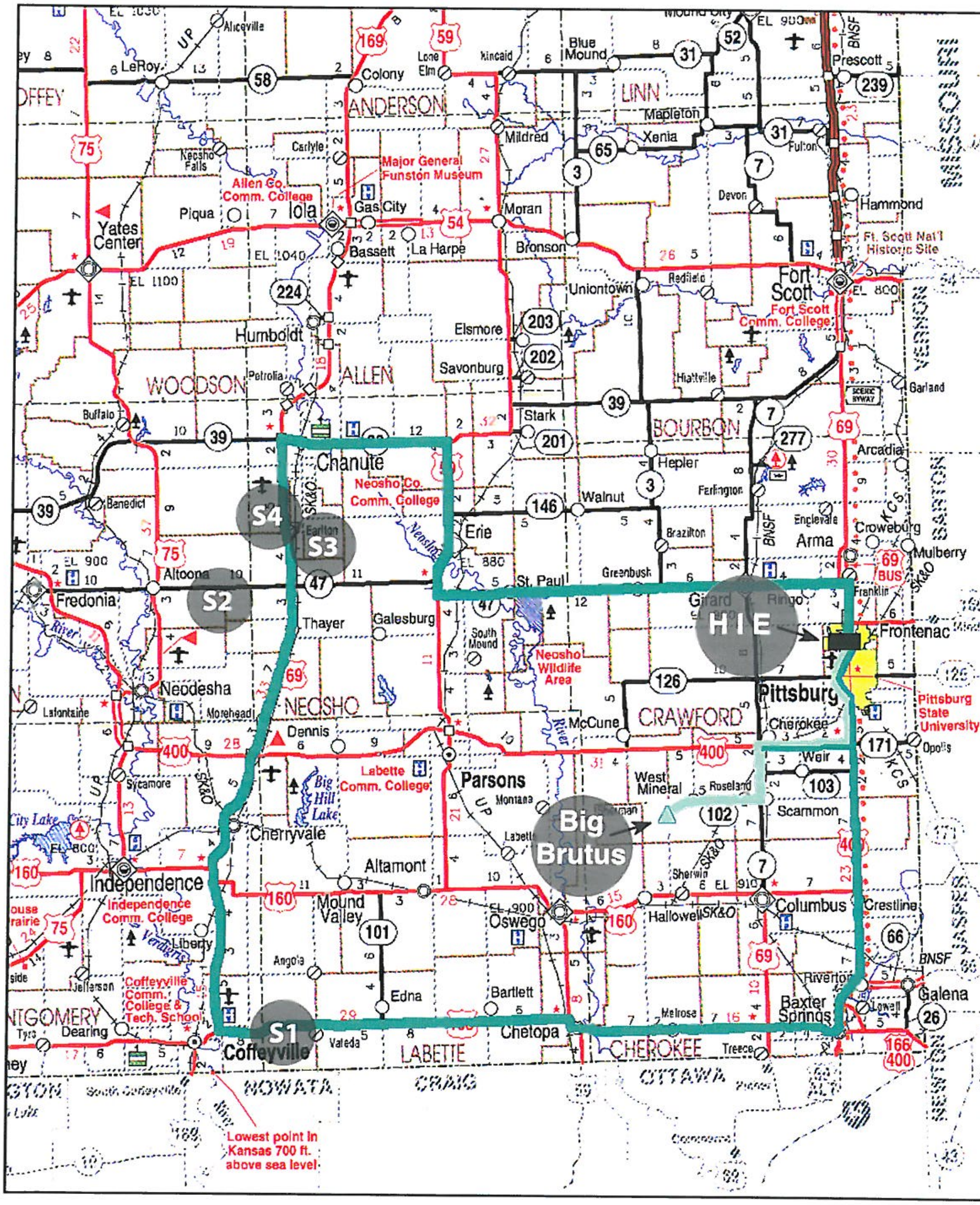
Kansas Coal Distribution, Resources, and Potential for Coalbed Methane, by Lawrence L. Brady is a paper published in "The Compass", Journal of Earth Sciences of Sigma Gamma Epsilon, v. 75, no. 2-3, (2000), p. 122-133.

Information sheet on "Big Brutus" from Big Brutus, Inc. <http://www.bigbrutus.org/about.htm>

Mine 19 Geologic Section, Pittsburg and Midway Coal Mining Company, Cherokee County, Kansas, by Lawrence L. Brady, in Geological Society of America Centennial Field Guide, v.4, South-Central Section (1988) O. T. Hayward (ed.), p. 75-78. This paper discusses the coal geology of the area mined by Brutus.

Acknowledgments

Field Trips



Coal and Big Brutus trip (Tue. PM)

Coalbed Methane trip to PostRock Energy operations (Wed.)

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SCALE IN MILES

34th FORUM OF THE COAL GEOLOGISTS OF THE WESTERN INTERIOR COAL REGION PITTSBURG, KANSAS

Field Trip

Wednesday -- May 26, 2010

----Gas from Coal---

A Visit to the PostRock Energy Corporation Field Operations

Coffeyville to Chanute, Kansas and Vicinity

Tour Plan:

I (Ken Recoy, Senior Geologist, PostRock Energy Corporation) would like for us to meet at Stop #1 at about 9:00 am May 26, 2010. I hope to spend about 30 minutes (at the most) at each Stop. From Stop #1 we will work our way North up US Hwy 169 for the other 3 Stops, ending at Stop #4 about 1 pm. At that point we will be about 3 miles Southwest of Chanute, KS. If you have a hard hat, safety glasses, ear protection, boots and gloves please bring them – they are all required at PostRock Energy Corporation well sites. We will have some hard hats, safety glasses, ear protection and gloves on site.

Stop #1 - Drilling Rig: McPherson Drilling. PostRock will be drilling the Taylor, James P. 7-1, T35S-R18E, NE NW, Labette County, near 2000 Road and Douglas, South & West into. Directions from the intersection of US Hwy 169 and US Hwy 166 (just Northeast of Coffeyville), go East about 6.3 miles on US Hwy 166 to Douglas, then go South on Douglas to 2000 Road, then continue South on Douglas about a half mile and West into the field. WE WILL MEET ON THE COUNTY ROAD (JUST SOUTH OF 2000 ROAD ON DOUGLAS) JUST OUTSIDE THE GREEN GATE SO WE CAN HAVE A BRIEF SAFETY MEETING BEFORE WE START OUR TOUR. Safety is #1 at PostRock, please follow all Safety measures during the Tour. Mr. Tony McWilliams is our Safety Director.

Stop #2 – PostRock Compressor Site: Fireside Compressor. Directions from Stop #1 to Stop #2, go North on Douglas to US Hwy 166, then West on US Hwy 166 to US Hwy 169, then North on US Hwy 169 about 35 miles to K47, go West on K47 about 6 miles to Viola, then South on Viola about a half mile and East into the field. We will plan to have additional PostRock Staff at each Site to help with questions and safety.

Stop #3 – PostRock Pump Jack Site: Schultz, John G. #27-3 (T28S-R18E) Neosho, County. Directions from Stop #2 to Stop #3, go back to the intersection of US Hwy 169 and K47, then go North on US Hwy 169 about 4 miles to 150th Road, then go East on 150th Road to Ford Road, then continue on East about 200 ft. & South into the field.

Stop #4 - PostRock Salt Water Disposal Site: Kepley, Robert A. SWD 18-1 (T28S-R18E) Neosho Co. Directions from Stop #3 to Stop #4, go West on 150th Road to US Hwy 169, then go North on US Hwy 169 about 1 mile to 160th Road, then go West on 160th Road about 50 ft. and North into the field. This is our last Stop.

Thank You!

Ken Recoy, Senior Geologist - Cell: 620-305-9900
AAPG Certified Petroleum Geologist CPG #5927
Think Safety! Attitude, Equipment, Teamwork & Training.

POSTROCK ENERGY CORPORATION http://www.pstr.com/
Geology Field Office & Coalbed Methane Desorption Laboratory
125 West Main Street
Chanute, Kansas 66720
Direct Line: 620-432-5188

STOP #1—Drilling Rig: McPherson Drilling. PostRock Energy will be drilling the Taylor, James P. 7-1. Located in NE/4, NW/4, Sec. 7, T.35S.R., 18E., Labette County.

STOP #2—PostRock Compressor Site: Fireside Compressor, Sec. 15, T.29S., R. 17E., Wilson County.

STOP #3—PostRock Pump Jack Site: Schultz, John G. #23-3, Sec. 23, T.28S., R.18E., Neosho County.

STOP #4—PostRock Salt Water Disposal Site: Kepley, Robert A. SWD 18-1, Sec. 18, T.28S., R.18E., Neosho County.

Kansas Coalbed Methane Play

by
K. David Newell
(Kansas Geological Survey, University of Kansas, Lawrence, KS 66047)
and
Rolland J. Yoakum
(consulting geologist, Liberty, MO 64068)

PREPRINT
to
New Plays and Ways
Kansas Geological Society, Kansas Oil and Gas Fields, v. VI
Editor: Daniel F. Merriam

Location

CBM (coalbed methane, also known as coalbed natural gas) development in eastern Kansas is largely confined to the southeastern part of the state in a four-county area composed of Labette, Montgomery, Neosho, and Wilson Counties. Development farther afield from this area of intense development has extended the production limits into other counties, including Allen, Bourbon, Chautauqua, Coffey, Crawford, Elk, Johnson, Linn, Miami, and Woodson Counties (Figure 1). The proximity of CBM developments to gas pipelines is important, since the cost of gathering systems and trunk lines taking the gas to market should be minimized.

The distribution of production in the play (Figure 1) is constrained by a combination of geologic and legal controls. Geologically, the northward and westward extent of the play is governed by the thickness, gas content, and extent of coalbeds. The play extends into Oklahoma in their part of the Cherokee Basin. The eastern extent – roughly a north-south line running through central Neosho and Labette Counties – is noticeably a sharper boundary than the limits in the other directions. This boundary marks the eastern limit of salt water disposal into the Cambrian-Ordovician Arbuckle Formation, as mandated by the Kansas Corporation Commission.

Geological Location

Geologically, the region is on the gently dipping eastern flank of the Cherokee Basin, in beds that dip, on average, 20 ft per mile west-northwestward (Merriam, 1963) off the Ozark Uplift in southern Missouri. The coal beds that produce gas are in the Middle Pennsylvanian (Desmoinesian) Cherokee and Marmaton Groups. Farther north, these strata are also targeted for CBM exploration and development on the Bourbon Arch, which is the ill-defined arch between the Forest City Basin and the Cherokee Basin, and the Forest City Basin itself.

Method of Discovery and History of Development

Early subsurface studies that eventually proved to be very useful in the evaluation of southeastern Kansas for CBM were a series of theses that elucidated the somewhat confusing stratigraphy and terminology of Pennsylvanian strata in the region. These studies at the University of Kansas (Harris, 1984; Killen, 1986; Staton, 1987; Huffman, 1991) were completed under the supervision of Dr. Lawrence L. Brady at the Kansas Geological Survey and Professor Anthony Walton at the Department of Geology. Earlier studies on which these theses were based were by Brady and a student employee of his at the Kansas Geological Survey, Neil Livingston (cf., Livingston and Brady, 1981; Brady and Livingston, 1989). Funding for the preliminary studies and the thesis research was from the NCRDS (National Coal Research Data System) at the United States Geological Survey. Brady had been focusing on the distribution of coals in outcrop and near subsurface for many years for mining purposes (cf., Brady and Dutcher, 1974; Brady, 1997; Brady and others, 1976, 1997), and this subsurface information on coal distribution and thickness fortuitously proved invaluable for early assessments of CBM potential. As a consequence, with each rush for CBM development, the Kansas Geological Survey was called upon by interested operators and landmen to supply information on the thickness and extent of major coal beds in the state.

The thickness of coal beds, both individually and in composite, is an important tool for CBM exploration. Four University of Kansas theses written by students of Dr. Timothy R. Carr at the Kansas Geological Survey (i.e., Lange, 2003; Johnson, 2004; Brown, 2005; Schurger, 2006) summarize the thicknesses and depositional environments of individual coals in eastern Kansas. A series of Open-File Reports by K.D. Newell at the Kansas Geological Survey summarize desorption testing of various coals and gas shales in eastern Kansas for their gas content. Much of this data are synopsized in Newell and Carr (2009).

The southeastern Kansas CBM play, unlike a conventional oil or gas field, has a somewhat obscure origin, with no clear-cut discovery well. Nevertheless, the play has been active on and off for several decades. Charles and Page (1929) originally reported in the AAPG Bulletin on unconventional gas production in eastern Kansas as being "shale gas", but some of this gas, if not most, originated from coal. They reported this type of gas was known since drilling began for oil and gas in the region in the latter half of the 19th Century, but low gas prices, small production volumes, no local gathering systems, and the presence of co-produced salt water inhibited development of the play. Stoeckinger (1989a) reports that after lenticular channel sandstones in the Pennsylvanian System in southeastern Kansas were largely depleted of their gas by 1920, operators increasingly sought "shale gas" production, which had formerly been considered a noncommercial nuisance. Modest development of the resource occurred in the eight years prior to the publication of the Charles and Page (1929) article, but further pursuit of this resource probably soon ceased with the discovery of easier-to-produce and more abundant gas from large conventional gas fields in western Kansas, most notably the giant Hugoton-Panhandle Gas Field (discovered, 1927). New interstate pipelines crossed the region and transported gas that was cheaper and more abundant than the local variety (Figure 1). These same pipelines, however, eventually worked for the ascendency of the play when it was reborn in the 1990s, because as the feed volume from the large gas fields to the west declined, these pipelines had excess capacity that could be filled by the increased CBM production in eastern Kansas.

At this point in the first half of the 20th Century, the continuity of CBM development in Kansas was interrupted for several decades and the possible economic viability of the resource was essentially forgotten. In the early 1970s, however, there was something of an epiphany among geologists and engineers who realized that coalbeds could indeed produce commercial quantities of natural gas. This realization primarily came from commercial gas development in the San Juan Basin in southwestern Colorado, after production geologists and engineers could not rectify the volume of historic production in certain wells with the apparently inadequate reservoir volume available in their pay zones (Schraufnagel and Schafer, 1996). Stratigraphically adjacent coals were determined to be responsible for the excess gas. Simultaneous efforts by mining companies and government agencies involved with mine safety in the eastern USA also proved that significant rates of gas flow sometimes occurred from wells that were experimentally drilled ahead of subsurface mining operations. Although, these wells were designed to remediate coal of its methane, which is hazardous in underground coal mines, the possible commerciality of the effluent gas could not be denied (Schraufnagel and Schafer, 1996).

One of the conceptual pioneers of CBM development in the Midcontinent was William T. Stoeckinger, a consulting geologist who lived in Denver, CO in the 1980s. He later moved to Independence, KS, and then to Bartlesville, OK where he passed away in 2008. Stoeckinger, while living in Denver, probably learned about CBM exploration by associating with geologists then active in the development of CBM plays in western USA coal basins, which were booming about this time. He also paid attention to developments in the Black Warrior Basin in Alabama, a CBM play that tapped several coals that are the same age and roughly the same rank as those in eastern Kansas (Ina Stoeckinger, George Jones, 2010, personal communication). Stoeckinger first put his beliefs in the potential of eastern Kansas CBM into action in the mid-1980s when he consulted for Zoandra Petroleum (Englewood, CO), who at that time was developing conventional oil and gas production in the Sycamore Valley Field in Montgomery County, north of Independence, KS. He was a frequent visitor with Larry Brady at the Kansas Geological Survey, comparing ideas on coal thickness, distribution, and gas potential.

However, Great Eastern Energy and Development, also out of Englewood, CO, bought out Zoandra Petroleum in the late 1980s. Great Eastern had their own geological staff and the consulting arrangement with Bill Stoeckinger that they had inherited from Zoandra was soon terminated. Although Zoandra and Great Eastern were likely aware of the possibilities of CBM on the acreage they had under lease in southeastern Kansas, the first operator to make a concerted effort at its production was a Kansas company. Soon after the buyout of Zoandra by Great Eastern, Bill Stoeckinger started consulting for George Jones (Wichita, KS). Jones, in partnership with Bruce Braden (San Francisco, CA), ran Stroud Oil Properties, which at that time was principally involved in developing waterfloods in northeastern Oklahoma. Stoeckinger urged Jones and Braden to take a gamble with CBM, but not before Jones steeled his resolve after additional conversations he sought out with representatives from a company named Taurus Exploration in northern Alabama. Taurus got its start in CBM in the Black Warrior Basin by means of dewatering coals in front of underground mining operations (personal communication, 2010, George Jones). Taurus, which was later acquired by Energen Corporation (Birmingham, AL) in 1996, was very open about their experience and graciously allowed Jones tours of their facilities.

As a result, Stroud Oil Properties developed the first modern pilot project for CBM production in Kansas -- a four-well site on their Miller lease (sec. 27-T.31S.-R.15E., Montgomery County), 2½ miles west of the town of Sycamore in August, 1989 (Stoeckinger, 1990) (Figure 1). The Weir-Pittsburg coal bed was first tested, and other coals soon followed.

Subsequent wells in Jefferson-Sycamore Field and adjacent Sycamore Valley Field that were drilled by Stroud, Great Eastern and other companies also list the Bevier, Riverton, Mulky, and Rowe coal beds as producing horizons. The Sycamore Valley Field is immediately north of the more extensive Jefferson-Sycamore Field. For the purpose of CBM, they are contiguous to each other. Both Zoandra and Great Eastern continued CBM development of this area, but it appears that their efforts were in the early 1990s, a few months after the development by Stroud Oil Properties.

The Stroud Oil venture proved to be the bellwether that got Kansas CBM started. Other companies followed. The CBM industry in Kansas was thus already established before the CBM industry in Oklahoma expanded to their part of the Cherokee Basin in 1994, although Oklahoma can claim that active modern CBM exploration in their state started farther south in the Arkoma Basin in 1988 (personal communication, Brian Cardott, 2010, Oklahoma Geological Survey). To date, no CBM production has been established in Missouri (personal communication, Scott Kaden, 2009, Missouri Department of Natural Resources), although Kansas production abuts the state line in Johnson and Miami Counties, south of Kansas City (Figure 1).

The drilling records for some of the local CBM developments prior to the operations by Stroud are somewhat murky. The distinction of the first CBM well recorded in modern records in Kansas (i.e., in the customary Kansas Corporation Commission ACO-1 well history forms) goes to the #14 O'Brien well, drilled by GeoMap, Inc. (Independence, KS) in sec. 12-T.31S.-R.18E. in Labette County (Figure 1). This well is listed as being completed in the Mulky coal in July, 1984. Another nearly contemporaneous development, in sec. 23-T.30S.-R.19E. (Neosho County), concentrated on gas produced by the Riverton coal (Figure 1). Information is sketchy for this operation, but some of these wells list Roy W. Cook (Colony, KS) as the operator. Cook apparently recognized coalbeds as potential pay zones, for he is also listed as either wellsite geologist or operator in several wells in the aforementioned Mulky coal project.

By virtue of his early involvement in southeastern Kansas CBM and his enthusiasm for its potential, Bill Stoeckinger became the chief chronicler of its development. In the late 1980s and early 1990s, Stoeckinger published several articles and talked to professional societies touting the potential commerciality of thin Middle Pennsylvanian coal beds in the Cherokee Basin of southeastern Kansas and northeastern Oklahoma (see Stoeckinger, 1989a, b; 1990a, b; 1992). Stoeckinger (1990) reported the resurrection of coalbed gas production in southeastern Kansas and stated that the Sycamore Valley Field in northern Montgomery County immediately south of the Wilson County line was enjoying the greatest success for CBM production in Kansas. Stoeckinger (1990a, 1992) cited several widespread developmental operations targeting the Weir-Pittsburg, Mulky, and Riverton coal seams in adjacent Labette, Neosho, and Chautauqua Counties, but specifically cited that Stroud Oil Properties was the prime-mover of the CBM development in the Sycamore Valley area, and as well he mentioned nearby operations captained by Conquest Oil (Greeley, CO), and Great Eastern Energy and Development (Englewood, CO).

One of the motivational forces of CBM development in the early 1990s was the availability of federal tax credits for unconventional gas production. These credits, known as Title 29, allowed 90 cents extra to be claimed on each mcf of unconventional gas produced from CBM wells drilled from January 1, 1980 to December 31, 1992. A second phase allowed tax credit on gas produced from old conventional wells recompleted as CBM wells from January 1, 1993 to December 31, 2002 (Cardott, 2005). When gas prices were running about $1.50/mcf, this supplement was in many cases crucial to the commerciality of production. A slight peak in the number of CBM wells drilled in the early 1990s is due to a brief drilling rush to qualify for this tax credit (Figure 2). An unforeseen effect of this tax credit was that many individuals and companies gained expertise in CBM and shale gas that later proved handy when prices rose around 2000, thus precipitating a second drilling boom that persisted into 2008 (Figure 2).

One of the difficult aspects of CBM development through which early operators had to persevere is the extraordinary start-up costs of an operation. George Jones (Stroud Oil Properties) reported substantial doubt in the early 1990s by his field engineers, who felt apprehensive about the proposition that coalbeds were best depressurized by clusters of wells, all drawing water and gas off the coals, rather than a single well. Furthermore, the promise that gas production would indeed increase as dewatering progressed over several months ran counter to their experience with conventional gas. In addition, the expense of a water disposal well and associated holding tanks are necessary for any group of CBM wells. Conversely, once CBM production is established, development wells are inherently low-risk due to the widespread and common occurrence of multiple coal beds and their relatively uniform maturation and depth.

CBM wells are relatively inexpensive, and their production rates are commensurately modest, but long-lived. The average CBM well in eastern Kansas in 2008 produced 20.2 mcf/d (thousand cubic ft per day) (Newell and Carr, 2009) compared to the average well in the venerable Hugoton-Panhandle Field in southwestern Kansas that produced 57.5 mcf/d. This relatively low rate of pay-out and large upfront costs impose a peculiar set of economic conditions on CBM development that encourages large-scale operations. Quantity, in a sense, becomes its own quality, so vast acreage tracts are typically assembled and numerous wells are drilled almost on a production-line basis. Although small operators can survive in this economic environment, the development of the resource is particularly amenable to larger energy companies with the financial wherewithal to conduct large projects.

One such key event facilitating the rapid development of Kansas CBM was a visionary project of acreage acquisition initiated by Jack Overstreet of Legacy International Group in Denver. In July, 2000, Overstreet was presented a large CBM prospect in southeastern Kansas by Larry Weis, a Denver consultant. Weis had been doing oilfield consulting in southeastern Kansas. He had read many of the Stoeckinger publications on CBM, and upon observing some of the early local CBM operations; he felt that they were rather undercapitalized and small in light of the potential of the entire play. A larger prospect, Weis surmised, could achieve an economy of scale, as well as connect to an interstate pipeline for a year-around market (personal communication, 2010, Larry Weis, Jack Overstreet). Overstreet was also convinced, and in turn, researched with other colleagues occurrences of similar production farther afield from the immediate prospect area presented by Weis. A minority investor and field office consultant of Overstreet's, Richard Wilson (Tulsa, OK), was charged with this latter task. Overstreet, who had prior experience with CBM land deals in the Powder River Basin in Wyoming, soon realized the potentially vast areal extent of the play and quickly endeavored with Scott Bowman and others of Meagher Oil & Gas (Denver, CO) to put together a large block of acreage that could attract the attention of a large independent operator. The research conducted by Overstreet and his associates ranged widely, and even included the old figures from the Charles and Page (1929) publication showing shale-gas "hot spots" in eastern Kansas (Figure 1). Even more important than conventional wireline logs showing the coals were the old driller's logs and notes – statements like "big gas in Mulky – well burned down in fire" – and other comments indicated direct evidence of gas that were key to their confidence (personal communication, 2010, Jack Overstreet). In addition, knowledge of the long-lived Riverton production in sec. 23-T.30S.-R.19E. was particularly encouraging to their efforts.

Overstreet unleashed a group of motivated landmen to assemble the acreage, primarily in northern Labette, western Neosho, and eastern Wilson Counties. Key personnel in buying leases included Rob Ganger of Colorado and Mark Patton (Chanute, KS). Negotiations were accelerated by mineral owners being paid with checks instead of drafts, and utilization of "landowner-friendly" oil-and-gas-lease forms and surface-damage agreements. Legacy capitalized on a technique that, despite being poor petroleum land practice, saved them countless hours in lease preparation. In many cases, landowners had irregular land parcels which were bounded by rivers and streams, so the "metes and bounds" full legal descriptions could go on for paragraphs and pages. Instead of dealing with this minutia, tracts were more simply described, for example, as "all that certain 86.98 acre parcel of land in the NW1/4 which is owned by Lessor". This largely worked, although with any large land play some ownership disputes and overleasing problems were dealt with later (personal communication, 2010, Jack Overstreet).

153,000 net acres were assembled. The Legacy Group drilled two wells to prove their concept, and in June, 2001, Devon Energy (Oklahoma City, OK) bought the entire block and started developmental operations. Key players in the negotiations and due diligence for Devon were Jack Richards of their land department, and Ralph Gill, a contractor who supervised the transition (personal communication, 2010, Jack Overstreet). The operation was whimsically dubbed the "Fireside Project" at Devon after a steak house in Thayer, KS frequented by its employees. In all fairness, they also were frequent clientele at Big Ed's, which is the other steak house in town, but application of the latter moniker to the project may have raised a few questions at their corporate headquarters.

Quest Cherokee, LLC (a component of other Quest companies that were recombined and renamed PostRock Energy Corp. in March, 2010), also out of Oklahoma City, purchased the Devon leases in 2004 after Devon decided to reorient their capital resources to development of Barnett Shale gas production in Texas. Quest aggressively developed the CBM resource and added acreage to their original holdings (Figure 3). In 2008, Quest accounted for 47% of the 49.1 BCF (billion cubic ft) of gas produced that year in the CBM fairways of eastern Kansas. As such, Quest that year was the 4th top gas producer in the state, behind three major companies (BP America, ExxonMobil, and Oxy USA) that principally produce their gas from the giant Hugoton-Panhandle Gas Field.

The acreage acquisition by Devon also had an electric effect on leasing in southeastern Kansas and in drawing attention to the potential of the play. Gas prices were also rising dramatically at this time, and companies were realizing the potential for increased profitability in CBM production. As a result of this second wave of development borne of high gas prices and big thinking, gas production in eastern Kansas dramatically rose in the first years of the 21st Century (see Figures 2, 4).

Other major producers of CBM gas in Kansas are Dart Cherokee Basin Operating Company, LLC (Mason, MI) and Layne Energy Operating, LLC (Mission Woods, KS), respectively accounting for 21% and 12% of the 49.1 BCF record production in 2008 (Figure 3). Like Legacy International and Devon, Dart's movement into Kansas was essentially motivated by the prior experience of their key personnel with CBM plays elsewhere in the USA, and the opportunity to quickly obtain a large block of acreage. Their Chief Geologist, Tom O'Neill, was initiated into CBM exploration and development in the Appalachian region of western Virginia and in northeastern Oklahoma (Nowata, Rogers, and Washington Counties). The advocacy of the play in publications by Bill Stoeckinger, and the nearly similar age and maturation of the coals in the Cherokee Basin encouraged O'Neill to employ a Marshall Miller & Associates, Inc. consultant in Kingsport, TN, Matt Conrad, to reconnaissance map thicknesses of major coalbeds and to develop regional stratigraphic cross-sections in eastern Kansas. As a result, Dart made an initial acquisition of acreage in July, 2002, when they quickly bought the old Great Eastern properties and holdings in the Sycamore Valley Field and Jefferson-Sycamore Field being sold by CB Pipeline (Lansing, MI) (personal communication, 2010, Tom O'Neill, Dart Oil & Gas). Dart bought 16,000 acres with pipe and 300 old well bores (40 wells were producing approximately 700 mcf/d), and eventually expanded this to 160,000 acres, principally in western Montgomery and southern Wilson Counties.

Layne Energy Operating, LLC, the third largest producer of eastern Kansas CBM, got its start in Kansas CBM production in a manner similar to Devon, when its parent company bought a block of acreage that was primarily assembled by Larry Weis, who was obviously following up on his ideas of economy-of-scale for CBM development. Weis and two colleagues, Gary Nydegger and Tom Wheatley (both of Golden, CO), sold this acreage (approximately 25,000 acres) in the spring of 2002 to Layne, the Kansas City-based drilling and consulting company (personal communication, 2010, Larry Weis). Layne, in turn, aggressively added new acreage to these initial holdings. Some of this additional acreage was transacted with the help of Bill Stoeckinger when he lived in Independence, KS. Layne Energy Operating, LLC was formed in 2004 and is a wholly-owned subsidiary of Layne. It now primarily produces acreage in two separate blocks -- northwestern Montgomery and southwestern Wilson Counties, and northeastern Montgomery and southeastern Wilson Counties (Figure 3).

During the large-scale development of the CBM resource post-2000, several companies established rank wildcat operations in the deeper parts of the Cherokee and Forest City Basins far from even conventional production. The normal mode of operation then (and now) is to drill an exploratory well to establish the presence of coal beds, and sometimes determine their respective gas contents by means of samples obtained by coring. If coal thickness and gas content are favorable, a decision is made to go ahead with a test plot of a few wells to determine how easily and economically the coal beds can dewater and give up their adsorbed gas. If volumes and rates of production are encouraging, more extensive development proceeds. Eastern Kansas has seen several pilot projects that have failed. Unfortunately, but understandably, the reasons for the failures are not usually advertized, but suffice to say, economic justification for any further development was lacking. The distribution of some of these attempts, shown in Figure 1, are just as enlightening as the successes, for they mark the limits of the play under certain economic conditions and mind sets at the time of their development. In general, the economics of CBM production appear to become more difficult northward in eastern Kansas. This may have much to do with the northward decreasing rank of the coal, which in turn, correlates to lower adsorbed gas content.

To date (March, 2010), 7,672 wells have been reported spudded for CBM in eastern Kansas. The Kansas production database at the Kansas Geological Survey reports that the state has had 6,221 producing coalbed gas wells; therefore 81% of the CBM wells drilled have produced some gas. The remaining 19% have either been failures or have yet to be put on production. The peak for drilling was in 2006, and successive declines in the number of wells have been recorded in 2007, 2008, and 2009 (Figure 2). 2008 apparently marks the peak of eastern Kansas CBM-dominated gas production (i.e., 49.1 BCF) (see Newell, 2010). Under present economic circumstances in early 2010, where gas prices are running low compared to previous years, future development may be relatively slow. Too few new gas wells will likely be drilled to compensate for natural depletion of existing wells.

CBM output for the entire Cherokee Basin, which comprises production from northeastern Oklahoma and southeastern Kansas, is summarized in Figure 4. CBM production for the Oklahoma portion of the Cherokee Basin peaked in 2006 at 18.9 BCF (personal communication, 2010, Brian Cardott). Peak CBM production for the entire basin was in 2008, at 63.3 BCF. This peak year is coincident with the Kansas peak year (i.e., 49.1 BCF in 2008). If an annual production decline of 12% (the approximate long-term decline rate of a Kansas CBM well; see Newell, 2010) is applied to this maximum output, future production would take on the form presented on the right side of Figure 4. This decline is essentially a worst-case scenario assuming no new wells are drilled after 2008. Lesser collective rates of declines are thus more realistic because CBM drilling will no doubt continue in the Cherokee Basin and this added production will partly offset the declines. For purposes of comparison, 10% and 8% decline rates are also presented on the figure. By 2020, if no new wells are drilled and assuming a collective 12% *per annum* decline, cumulative CBM production for the Cherokee Basin will be approximately 700 BCF. Cumulative production at the end of 2009 is approximately 370 BCF.

The predicted drop in production does not mean the CBM resource in this region is being depleted, for many drilling locations are still available. For example, PostRock Energy reported on their website (http://qrcp.publishpath.com/company-info) that they had in 2008 an inventory of more than 2,100 drilling locations on their leased acreage. The drop in Kansas CBM production in the near term is more of an artifact of marginal economics, where some of the production simply cannot be offered to the market given present low gas prices (Newell, 2010).

Geological Conditions -- age and nature of trap

Coals seams within the Cherokee and Marmaton Groups vary in thickness. Thirty-two coal beds, with thickness in excess of 14 inches, are identified in the Middle Pennsylvanian stratigraphic column in eastern Kansas. Most of these coals are in the Cherokee group -- a cyclothemic unit composed of marine and terrestrial sandstones and shales, marine carbonates, and minor coal. Up to 14 coal beds can be encountered in a typical well. Most coals are less than 28 inches thick (Brady, 1997). Isopachous thickness trends occur and are relatable to the depositional environments of the coal bed, and post depositional erosion (cf., Lange, 2003; Johnson, 2004; Brown, 2005). Major coal beds that have proven to be significant for their gas production include the Weir-Pittsburg, Mulky, Bevier, and Summit and Riverton coals, all of which were mined in outcrop farther east in eastern Kansas and Western Missouri. Stoeckinger (1989a) states that the thickest coal is the Weir-Pittsburg seam, which reaches 6 ft in thickness.

Associated with some coals (usually superjacent) are radioactive shales, usually 2 to 5 ft thick. Most of these shales contain adsorbed gas (Newell, 2007; Newell and Carr, 2009) and where they directly overly coals (such as the Excello Shale over the Mulky coal, and Little Osage Shale over the Summit coal) produced for CBM, these shales also probably contribute gas into the coal. These radioactive shales in the Cherokee, Marmaton, and overlying Lansing-Kansas City Groups may all be candidates for future shale gas production. The Excello Shale, in particular, has gas contents of approximately 50 scf/ton (see Newell, 2007; Newell and Carr, 2009) in localities in southeastern Kansas.

Reservoir Rocks

Gas in coal is not in its free state as it is when it resides in the porosity of a conventional reservoir such as a sandstone or porous carbonate, but rather it is mostly adsorbed on to the organic macerals of the coal. Other subsidiary ways by which the gas is contained in coal are as 1) gas trapped within the pores or fractures of the coal, and 2) or in solution within the formation water present in the coal (Zuber, 1996). These are also the main mechanisms by which unconventional gas is trapped in gas shales.

The gas will evolve off the coal when the confining pressure is released, which is usually facilitated by pumping down the hydrostatic head affecting the coal. The desorption of the gas occurs when the pressure is reduced to below what is called the desorption pressure (McLennan and others, 1995). Below this pressure, the gas will evolve off the coal and gather into bubbles, then ideally it will migrate with co-produced formation water to the wellbore from whence it can be produced. Some coals have more adsorbed gas than others. In general, the gas content is related to the depth of the coal and the maturation of the coal. If the coal is naturally fractured or has good cleat system development, the gas will be released faster and the area drained by the well will be more extensive.

Even though coal locally sources and reservoirs its gas, both Charles and Page (1929) and Stoeckinger (1990) emphasized that wells drilled along the crestal trace of an anticline have better production than those drilled on the flanks. Part of this may be due to a better developed cleat system in the area of maximum curvature, plus the effects of buoyancy when the gas enters its free state after desorption.

The origin of the gas may be either biogenic or thermogenic, although in southeastern Kansas, the thermogenic mechanism may be more influential. Stoeckinger (1989) reports southeastern Kansas coals have vitrinite reflectances ranging from 0.65 to 0.71 Ro, which correlates to the early part of the oil window. Local areas of high maturation where Ro approximates 1.0 or greater are inferred by regional studies by Barker and others (1992).

Desorption tests in northeastern, east-central, and eastern Kansas, reported in Newell and Carr (2009) (Figure 5), show a general northward decrease in their gas contents of coals and dark shales. Southeastern Kansas coalbeds have a median gas content of 139 scf/ton (as-received) with a maximum recorded value of 370 scf/ton. Newell and Carr (2009) show that northeastern Kansas is dominated by high-volatile C and B bituminous-rank coals, whereas southeastern Kansas is dominated by more-mature high-volatile A bituminous coals, and that the start of increased gas occurs in the middle of high-volatile B bituminous rank coals.

Coals in southeastern Kansas generally produce between depths of 600 to 1200 ft, although elsewhere in the USA production from coals appears to be viable down to a depth of about 3000 ft. Cleats start to compress shut at depths deeper than this (see discussions in Zuber, 1996; Mavor, 1996). The confining mechanism for gas adsorption becomes weaker with shallower burial, thus gas content becomes commensurately less farther east in Kansas. Newell (2006), however, reports gas content of 80 scf/ton for coal buried as shallow as 180 ft in western Cherokee County.

Character and Nature of Gas

Coalbed methane is somewhat of a misnomer in that the gas derived from coal is a mixture of several gases. More appropriately, CBM should actually be called CBNG (coalbed natural gas), but precedence and common usage dictates otherwise. The natural gas derived from coal is typically dry, with the hydrocarbon component dominated by methane (CH_4), and only very small amounts of higher-molecular-weight hydrocarbons (i.e., ethane, propane, butane, etc.). Other non-hydrocarbon gases commonly found in CBM include nitrogen (N_2) and carbon dioxide (CO_2) (Rice, 1993; Mavor, 1996).

Since CBM gas compositions are typically dominated by methane, with traces of heavier-molecular-weight hydrocarbon gases, the BTU content is approximately or slightly below that of methane (i.e., ~1000 BTU/scf), depending on the amount of nonhydrocarbon gases mixed in with the methane.

Analyses of CBM gases in eastern Kansas indicate that gas quality decreases northward, with more non-hydrocarbon gases present in the CBM gas when the coals are at a rank less than high-volatile bituminous A, or approximately with a heat content of 14,000 BTU/lb (moist, mineral-matter free) (Newell and Carr, 2009). The region where gas quality degrades below 950 BTU/scf (a heating-value cutoff imposed by many pipeline companies) is approximately north of the Bourbon arch (Figure 6). This BTU content corresponds to about 5% noncombustible gas content, or slightly more if higher-molecular-weight hydrocarbons are present.

Duration of production may also see degradation in quality of a CBM gas, in that carbon dioxide adheres more closely to the coal maceral and will not as readily evolve off the coal maceral until lower pressures are reached with continuing production. Comparison of isotherms for methane and CO_2 on Kansas coals show that the desorption pressure is considerably higher (approximately 3X) for CO_2 than methane (Figure 7). By these effects and with continued dewatering, which decrease confining pressure on the coal, CO_2 content sometimes rises in the production stream, thus requiring scrubbing of the gas before sale to pipelines. To stave off the expense of gas processing, some operators open newer, more methane-rich coalbeds to dilute their increasing CO_2 production from prior produced zones.

Average Well Costs

The cost of a CBM well in southeastern Kansas is somewhat ameliorated by the presence of close-by oil-field service companies. Spare parts and qualified personnel are always nearby in several of the small towns in this region. Used equipment gleaned from abandoned fields in this well-established producing region can help keep down costs.

CBM wells are usually air-drilled a few feet into the top of the Mississippian limestones within a day, or perhaps two days, if the well needs to be drilled over 1000 ft. Typical costs for drilling an average CBM well in the Cherokee Basin are approximately $25,000. This assumes a total depth of 1,000 ft below ground surface, and includes the drilling-site preparation and restoration costs. Performing a standard suite of downhole logs, including gamma ray, neutron, induction, density porosity, bulk density, and caliper, costs approximately $2,500. In many cases a high-resolution density log is also run on a CBM well so that coal thicknesses can be accurately determined. Thus, dry hole costs are generally less than $30,000 per well.

Average completion costs include approximately $21,000 for casing and cement, $9,000 for perforating, and $25,000 for the cost of the frac and acid job, bringing completion costs for the average well to $55,000. Pump jacks or submersible pumps for water removal, pipelines to transport gas and co-produced water to separators and tanks are also necessary. The installation of downhole and surface equipment, and the laying of pipelines to move gas and water off lease and to the gathering system costs approximately $65,000.

Water is disposed in injection wells open near the top of the Cambrian-Ordovician Arbuckle Group, which is as little as 200 ft deeper than the deepest coal in southeastern Kansas. The depth to the Arbuckle increases northward, however, other porous zones present in several Paleozoic units (e.g., Silurian-Devonian Hunton Dolomite, Ordovician Viola Limestone, and Ordovician Simpson Sandstone) can also serve as disposal zones in the Forest City basin. A typical salt-water disposal well can take the water of a dozen or more producing wells. Water co-produced with CBM is not required to be measured at the wellhead in Kansas, however, Cardott (2001) reported that most wells in the Cherokee Basin in northeastern Oklahoma produce less than 150 barrels of water per day, and the modal number of wells produced about 40 barrels of water per day.

Considered in total, the cost to drill, complete, and install the necessary production equipment for a typical CBM well in the Cherokee Basin ranges from $125,000 to $150,000 (personal communication, Patrick Morgan and Jim Stegeman, 2009, Colt Energy).

Completion and Production Techniques

Coal beds as thin as 1 ft are subject to perforating, usually 4 shots to a foot. There has been some experimentation with completion techniques in the Cherokee Basin, and most operators have settled on a simple sand and water frac technique. Some operators have experimented with using a polymer gel during completion, but most find that a polymer additive negatively impacts production rather than enhancing it.

In addition to experimenting with frac composition, operators have also experimented with the staging of the frac. Since in a typical Cherokee Basin CBM well, a dozen coals or shales are encountered, determining the placement of packers, and which coals will be completed in the same stage of a frac job can have an impact on the success of the completion job. Some operators claim that more successful completions result when packers are placed closer together, and a smaller number of coalbeds are fraced in each stage of the completion job (personal communication, Jim Stegeman, 2010, Colt Energy).

One persistent problem facing CBM operations in some areas of the Cherokee Basin has been how to produce gas from the Riverton coal, which lies unconformably directly over, or very near, the limestones and dolomites of the Mississippian System. The Riverton coal has a relatively high average gas content, and its proximity to the porous zone near the top of the Mississippian carbonates creates the potential for Mississippian water to communicate with the Riverton coal during fracing. Some operators have reduced the amount of rathole that they drill below the Riverton in an attempt to stay out of the Mississippian water. They also find that reducing the concentration of acid in the Riverton completion also helps avoid communication with the Mississippian (personal communication, Jim Stegeman, 2010).

Back pressure is sometimes kept on a well by some operators by means of a pressure regulator installed on the wellhead, but there is no consensus to its efficacy in improving or prolonging production. CBM wells, however, cannot be produced at a high rate without endangering the near-well permeability. Movement and lodging of fine material near the well bore can clog narrow throats in the cleat system. Customary procedure for keeping back pressure on a wellhead is to start the well pumping fluid with the casing closed. Once the fluid level is stabilized below all perforated zones and a maximum casing pressure is documented, pressure is then dropped increments (usually 5 psi) and compared with the volume of gas produced. At first, volumes usually increase, but at some pressure, which is different for each well (but averages approximately 50 psi), the volumes will start declining. At that point the casing pressure is stabilized and the well is allowed to produce for a while. Over time the volumes will again decrease, and then the casing pressure will be dropped slightly in an effort to increase the volume (personal communication, Bill Barks, 2010, Dart Cherokee Basin Operating Company, LLC).

The number of wells required to properly drain an area is hard to estimate, but it depends on the directional permeability of the coal, which, in turn, is related to the orientation of the cleat system. The through-going face cleats in southeastern Kansas are probably oriented NNW-SSE, similar to those in northeastern Oklahoma (see Friedman, 2001). Wells intersecting these face cleats will have similarly-oriented drainage areas. The spacing of CBM wells over the years has increased, probably because operators have noted production drops due to interference with nearby wells. Stoeckinger (1989a) reports that 80-acre spacings were commonplace at that time, but in post-2000, 160-acre spacings seem to be preferred by companies like PostRock, which develop many of their leases at 4 wells per section.

Since most of the gas-producing coals are thin, almost all CBM wells are vertical and completed in several coal beds (usually 5 to 9 coal beds per well). CEP Mid-Continent LLC, however, is on record as drilling three horizontal CBM wells in 2009 and four horizontal wells in 2008 in Montgomery County (see Figure 1). Most of the CEP wells report that the Weir-Pittsburg coal is the targeted pay horizon, but one well was completed in the Riverton coal. These seven wells have had sufficient production history to record their peak monthly production, and 5 of them are in the upper 10% of the maximum recorded production rates for Kansas CBM wells (i.e., >4330 mcf/month, or >144 mcf/day; see Figure 8), but their production histories are still too short to determine their decline behaviors. Due to the small number of wells that have been horizontally drilled in eastern Kansas, a generalized cost is not available.

Only seven horizontal wells were drilled prior to the seven CEP wells drilled in 2008 and 2009. The three earliest were drilled in 1999 in northern Miami County by Osborn Energy, LLC (see Figure 1).

Production History

CBM production is long-lived, where production can be sustained for well over a decade. Typically, CBM wells increase production gradually as the well is dewatered (Schraufnagel and Schafer, 1996). For CBM wells in southeastern Kansas, production peaks about one year after initial production (Newell, 2010), and then a long production decline ensues. Within one year after the month of peak production, the monthly production will be down about 1/3. As production continues, yearly decline rates will decrease until they stabilize at approximately 12% per year in about 6 years (Newell, 2010).

Newell (2010) surveyed the range of maximum production rates for CBM well in southeastern Kansas and determined that the median well will produce 1466 mcf/month (48.9 mcf/d), and the average well can be expected to produce 2000 mcf/month (66.7 mcf/d) (Figure 8). The production history of typical CBM wells can thus be depicted (Figure 9) by knowing their maximum monthly production rate, and expected rates of decline after that maximum production rate is achieved. The economics of the wells can also be inferred from the production history where, depending on gas prices, some wells unfortunately may never pay for themselves. For example, if gas prices stay low at $3/mcf, at least the lowest 25% of CBM wells may not pay for their drilling and completion costs (see Figure 9). $6/mcf sustained price over the life of a well will relegate approximately only the lowest 15% of the wells into the red over their production lifetime. The advantage of economics-of-scale thus becomes apparent in CBM operations. An operator needs to drill several wells to expect to have a majority of economical wells to more than offset the losses incurred by drilling and completing underachieving wells.

Any operator that can predict areas where better production will occur will have a distinct advantage over their competitors. To date, a map of maximum monthly production rates in single-well leases (Figure 10) shows considerable variability even over short distances, but, in general, areas where coal beds are individually and compositely thick constitute the sweet spots (see Newell and Carr, 2009). Production rates also generally increase westward, deeper into the basin.

Rulings

Coalbed gas wells are exempt from the frequent pressure testing mandated for conventional gas wells by the Kansas Corporation Commission (KCC). A KCC ruling in

July, 2008 (Docket No. 07-CONS-155-CSHO) held that Quest Cherokee, LLC was not financially responsible for plugging 22 unplugged or improperly abandoned "orphan" wells on a lease of theirs, because these wells were drilled and abandoned before this lease was acquired by them. The precedent set with this ruling should clarify who is responsible (i.e., not the new operator) for plugging old wellbores fortuitously discovered on existing leases. Currently, KCC is also reviewing the salinity boundaries where oilfield brines can be injected into Mississippian and Arbuckle carbonate rocks, so the present eastern limits of CBM development, dictated in part by the lack of saltwater disposal zones, may change in the future if new areas for water disposal are opened.

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Verbal and email conversations with several individuals greatly helped with summarizing the historical narrative of CBM development in eastern Kansas. These individuals include Larry Brady (Kansas Geological Survey) , Brian Cardott (Oklahoma Geological Survey), Tim Carr (West Virginia University), Matt Conrad (Marshall Miller & Associates), George Jones (Stroud Oil Properties), Tom O'Neill (Dart Oil & Gas), Jack Overstreet (Legacy International Group), Ina Stoeckinger (widow of Bill Stoeckinger), and Larry Weiss (Denver consultant). Patrick Morgan and Jim Stegeman of Colt Energy and Bill Barks (Dart Cherokee Basin Operating Company) are thanked for their discussions on costs for a CBM well. Much of the gas chemistry and coal-rank analyses (summarized in figures and discussed in the text) were supported by a grant (Agreement Number 05ERAG0033) to the Kansas Geological Survey from the United States Geological Survey National Coal Resources Data System (NCRDS) and by support through grants from the United States Department of Energy. Larry Brady and Dan Merriam, both at the Kansas Geological Survey, critiqued and corrected earlier versions of the manuscript, but the authors are solely responsible for any of its oversights or errors.

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Figures

Figure 1 – Map showing sections (nominally 1 X 1 mile) where CBM wells have been drilled. Section colored gray = no production recorded; red = production recorded. Orange lines are major pipelines crossing the region. Selected abandoned or inactive CBM pilot projects are noted, as are localities mentioned in the history of the play (in *italics*). Locations of the few horizontal wells that have been drilled for CBM are also noted. Trace of the Humboldt Fault System is from Cole (1976).

Figure 2 – CBM wells drilled each year in Kansas and yearly fluctuations in the price of natural gas. Note a slight peak in drilling in 1993 caused by a drilling rush to qualify for Title 29 tax credits on unconventional gas. Price rises caused the explosion of activity starting in 2000.

Figure 3 – Producing leases in 2009 by the three major CBM producers in Kansas – PostRock Energy (i.e., Quest Energy), Dart Cherokee Basin, LLC, and Layne Energy Operating, LLC (from Kansas Geological Survey website (http://www.kgs.ku.edu/PRS/petroDB.html)).

Figure 4 – Combined CBM production from the Oklahoma and Kansas parts of the Cherokee Basin up through 2009. Future production scenarios, expressed by 8%, 10%, and 12% constant decline percentages, are shown on the right side of the diagram, but increased drilling and production caused by increased natural gas prices in the future may drastically alter these decline projections. Oklahoma production data are from Brian Cardott (personal communication, 2010).

Figure 5 – Distribution of measured gas contents of Kansas coals, by region (from Newell and Carr, 2009). Southeastern Kansas coals, which are dominantly high-volatile bituminous A rank, have greater gas content than central and northeastern Kansas coals. Coal rank decreases northward. Northeastern Kansas is dominated by high-volatile bituminous C rank, even though the coals in northeastern Kansas are presently buried deeper than they are in southeastern Kansas.

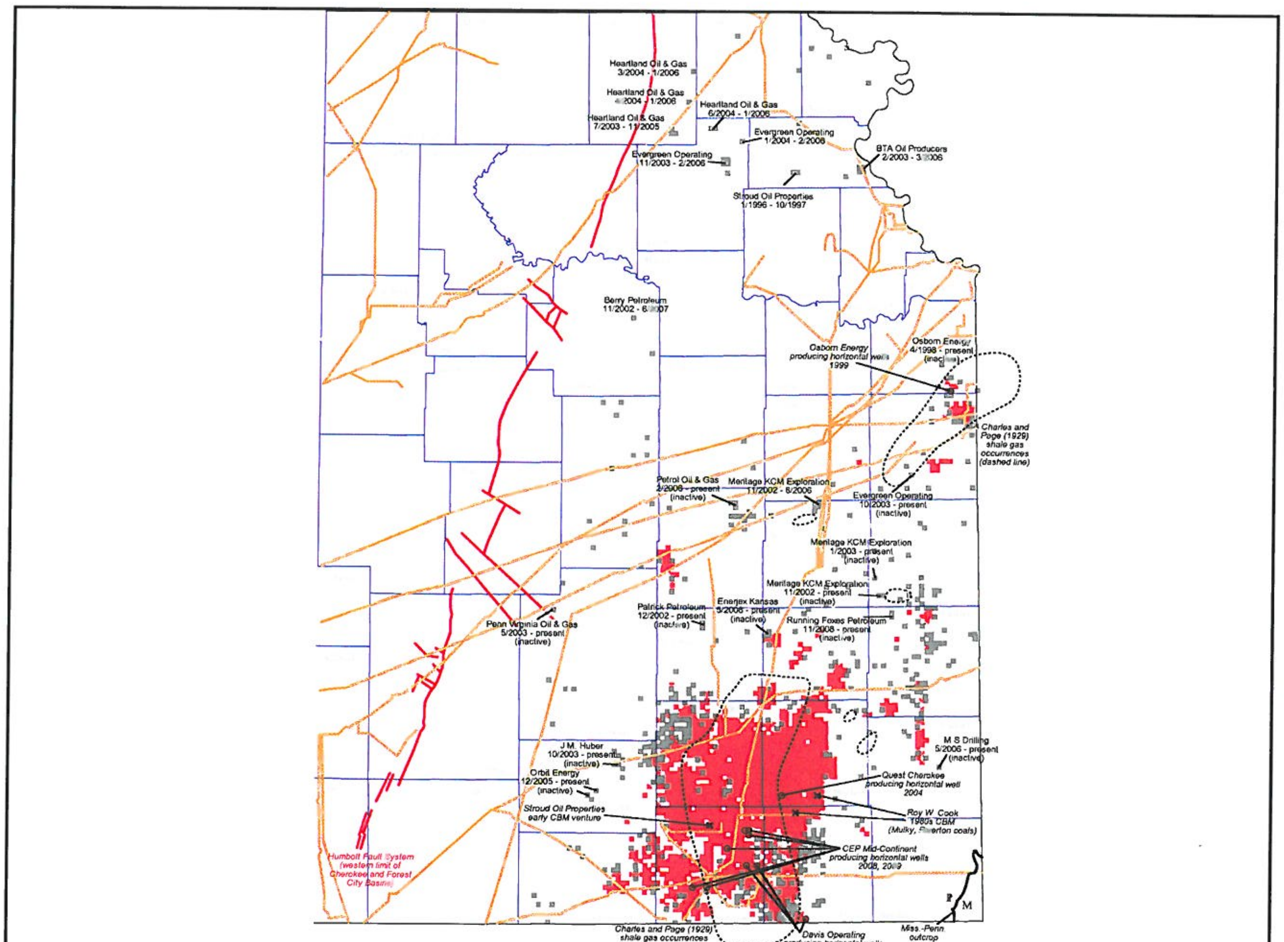
Figure 6 – Map of percentage of noncombustible gases present in CBM, from production and desorption tests (from Newell and Carr, 2009). Quality of gas appears to degrade northward.

Figure 7 – Isotherms of Kansas coals for methane and carbon dioxide from the Kansas Geological Survey #1B and #2 Deffenbaugh Quarry wells in Johnson County, KS. As pressure wanes in a coalbed being produced, more CO_2 will be produced from that coalbed, particularly if the pressure falls below the desorption pressure of CO_2. As a rule of thumb, Carr and others (2005) assumed 0.476 psi/ft (for 145,000 ppm total dissolved solids for average brine) for calculation of subsurface hydrostatic pressures in the Arbuckle Group. This gradient also can be used for approximating hydrostatic pressures in a coal in Kansas.

Figure 8 – A distribution of maximum monthly production rates determined from 2,973 CBM wells in southeastern Kansas (i.e., Labette, Montgomery, Neosho, and Wilson Counties) (after Newell, 2010).

Figure 9 – Calculated cumulative production for individual CBM wells, based on their maximum monthly rate of production and application of average yearly production declines after that monthly production is reached (from Newell, 2010). The volumes of production and duration of production necessary to recoup $125,000 in drilling and completion costs are noted for $3, $6, and $9/mcf gas prices. Operational costs are not considered.

Figure 10 – Map of the maximum monthly production rates recorded for CBM wells in southeastern Kansas Geological Survey (from Newell and Carr, 2009).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Evergreen Operating
11/2003 - 2/2006
BTA Oil Producers
2/2003 - 3/2006
Stroud Oil Properties
1/1996 - 10/1997
Berry Petroleum
11/2002 - 6/2007
Osborn Energy
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Petrol Oil & Gas
2/2006 - present
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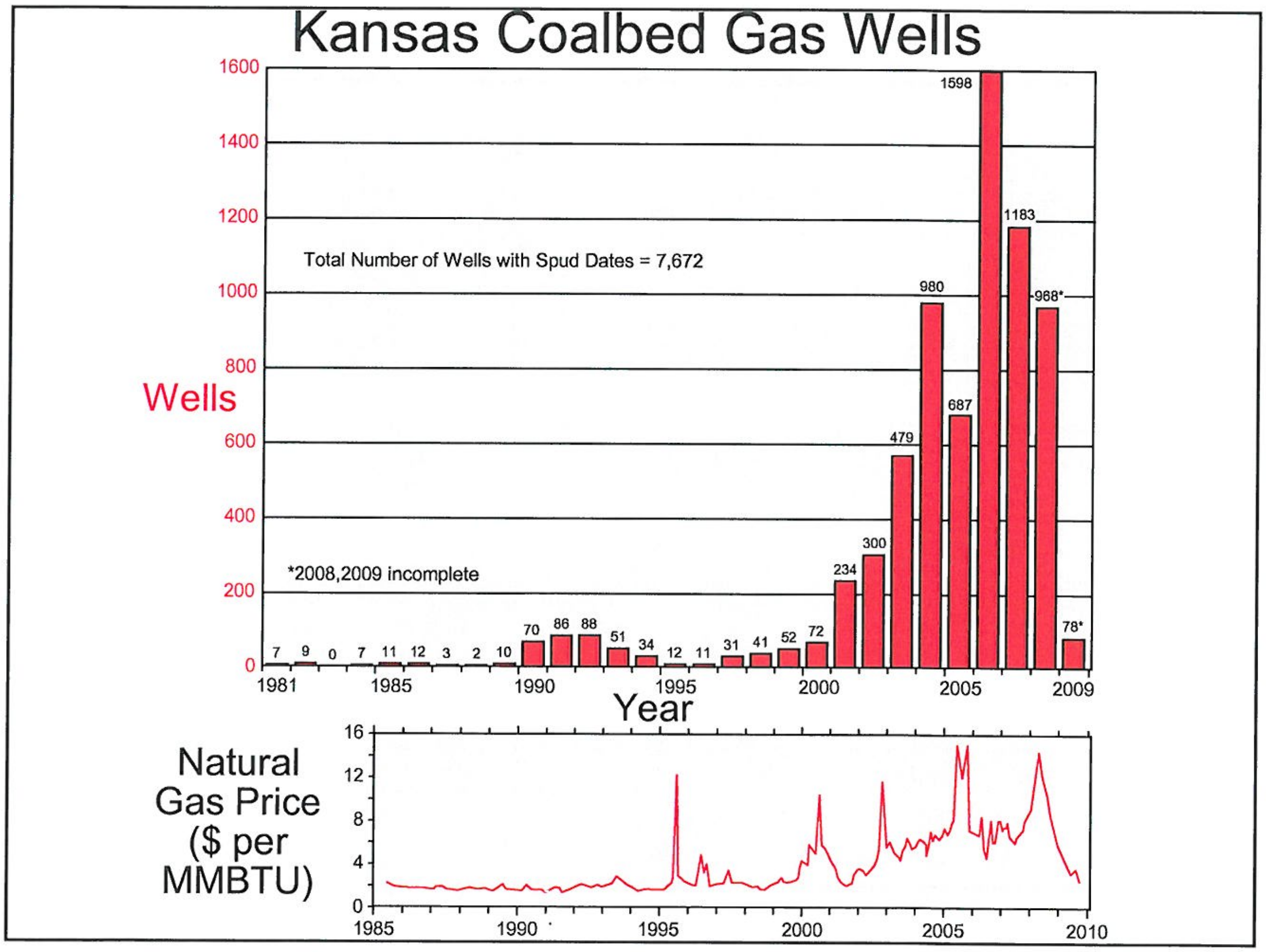
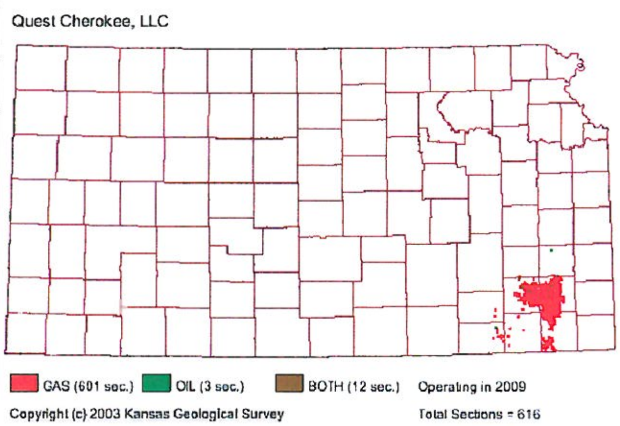
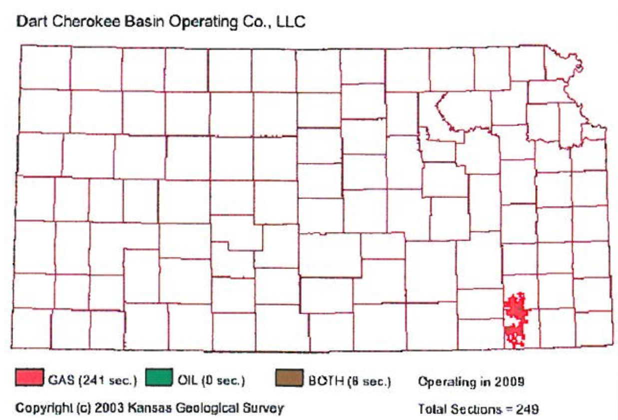
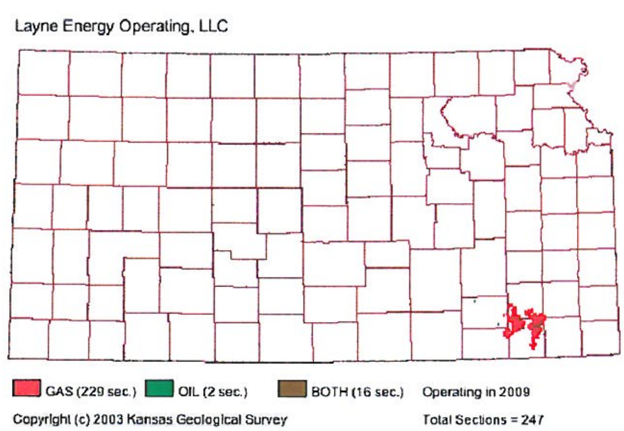
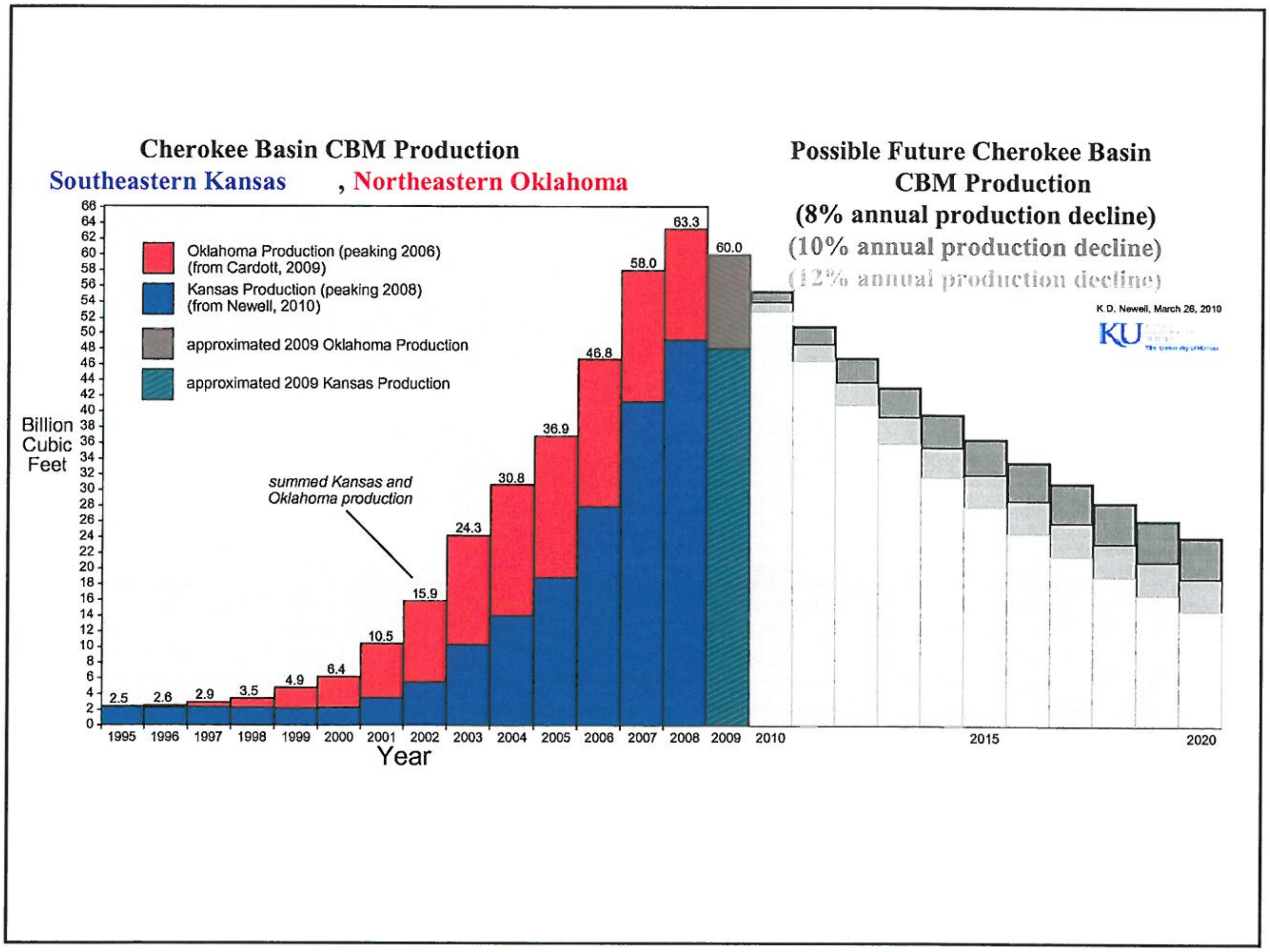
Meritage KCM Exploration
11/2002 - 6/2006
Evergreen Operating
10/2003 - present
(inactive)
Meritage KCM Exploration
1/2003 - present
(inactive)
Meritage KCM Exploration
11/2002 - present
(inactive)
Patrick Petroleum
12/2002 - present
(inactive)
Enerjex Kansas
5/2006 - present
(inactive)
Running Foxes Petroleum
11/2006 - present
(inactive)
Penn Virginia Oil & Gas
5/2003 - present
(inactive)
J.M. Huber
10/2003 - present
(inactive)
Orbit Energy
12/2005 - present
(inactive)
Stroud Oil Properties
early CBM venture
M S Drilling
5/2006 - present
(inactive)
Quest Cherokee
producing horizontal well
2004
Roy W. Cook
1980s CBM
(Mulky, Riverton coals)
CEP Mid-Continent
producing horizontal wells
2008, 2009
Humboldt Fault System
(western limit of
Cherokee and Forest
City Basins)
Charles and Page (1929)
shale gas occurrences
(dashed line)
Davis Operating
producing horizontal wells
2006
Miss.-Penn
outcrop
M


Kansas Coalbed Gas Wells
Total Number of Wells with Spud Dates = 7,672
*2008,2009 incomplete
Wells
Year
1600
1400
1200
1000
800
600
400
200
0
1981
1985
1990
1995
2000
2005
2009
7
9
0
7
11
12
3
2
10
70
86
88
51
34
12
11
31
41
52
72
234
300
479
980
687
1598
1183
988*
78*
Natural Gas Price ($ per MMBTU)
16
12
8
4
0
1985
1990
1995
2000
2005
2010

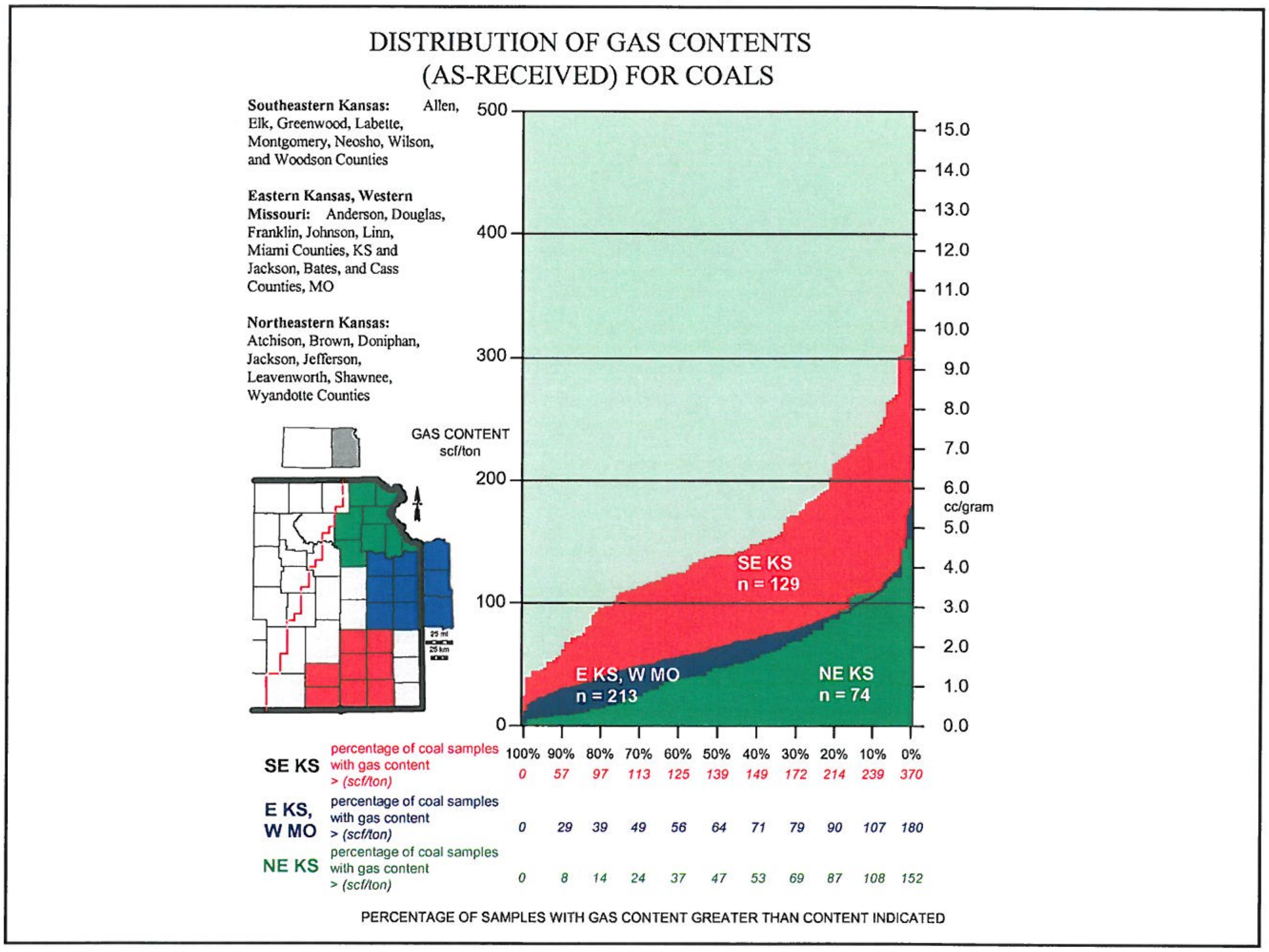

Quest Cherokee, LLC
GAS (601 sec.)
OIL (3 sec.)
BOTH (12 sec.)
Operating in 2009
Copyright (c) 2003 Kansas Geological Survey
Total Sections = 616

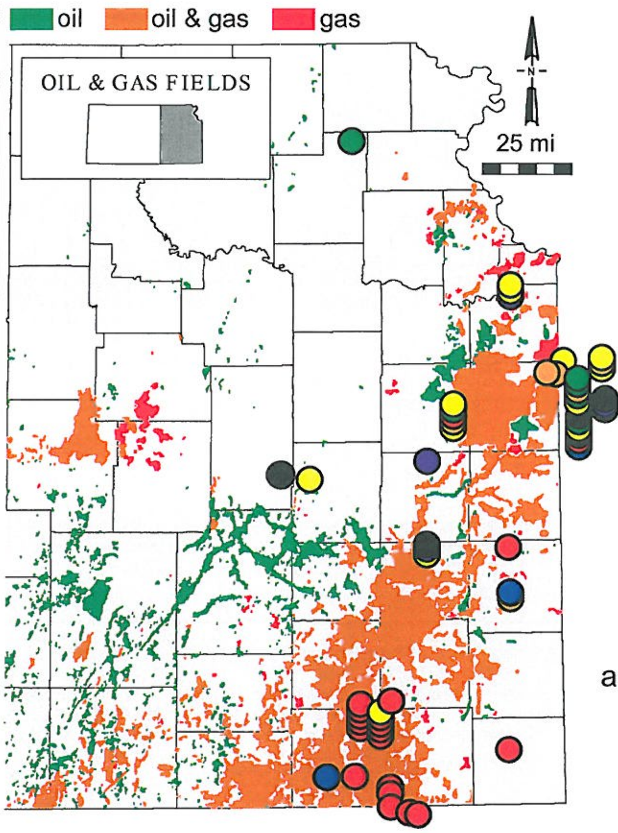

Dart Cherokee Basin Operating Co., LLC
GAS (241 sec.)
OIL (0 sec.)
BOTH (8 sec.)
Operating in 2009
Copyright (c) 2003 Kansas Geological Survey
Total Sections = 249


Layne Energy Operating, LLC
GAS (229 sec.)
OIL (2 sec.)
BOTH (16 sec.)
Operating in 2009
Copyright (c) 2003 Kansas Geological Survey
Total Sections = 247

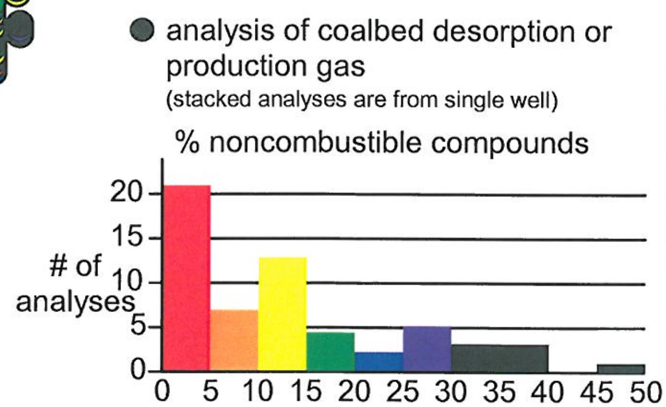


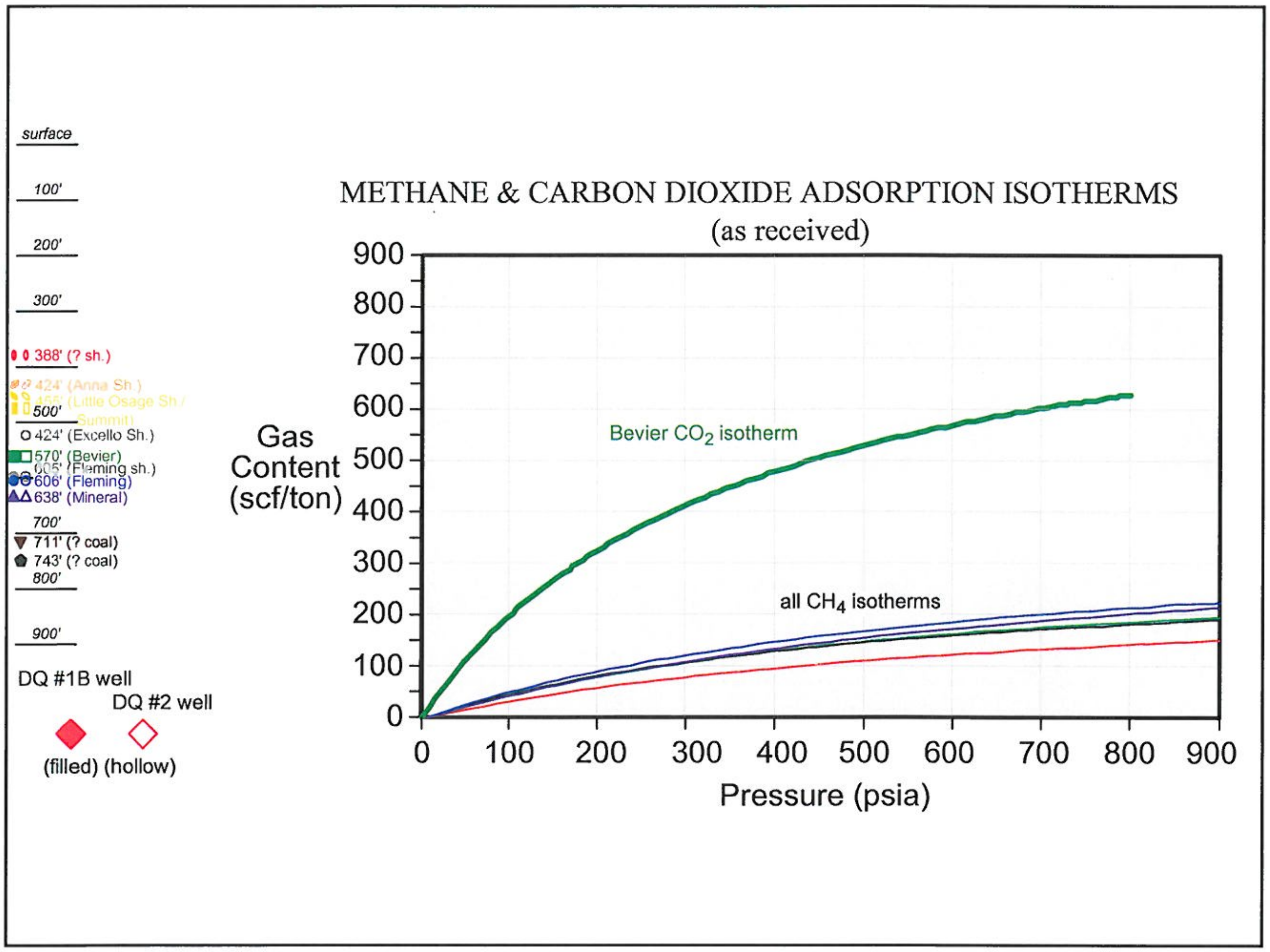
Cherokee Basin CBM Production
Southeastern Kansas , Northeastern Oklahoma
Possible Future Cherokee Basin CBM Production
(8% annual production decline)
(10% annual production decline)
(12% annual production decline)
K.D. Newell, March 26, 2010
Oklahoma Production (peaking 2006) (from Cardott, 2009)
Kansas Production (peaking 2008) (from Newell, 2010)
approximated 2009 Oklahoma Production
approximated 2009 Kansas Production
summed Kansas and Oklahoma production
Billion Cubic Feet
Year
2.5
2.6
2.9
3.5
4.9
6.4
10.5
15.9
24.3
30.8
36.9
46.8
58.0
63.3
60.0
1995 1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2015 2020

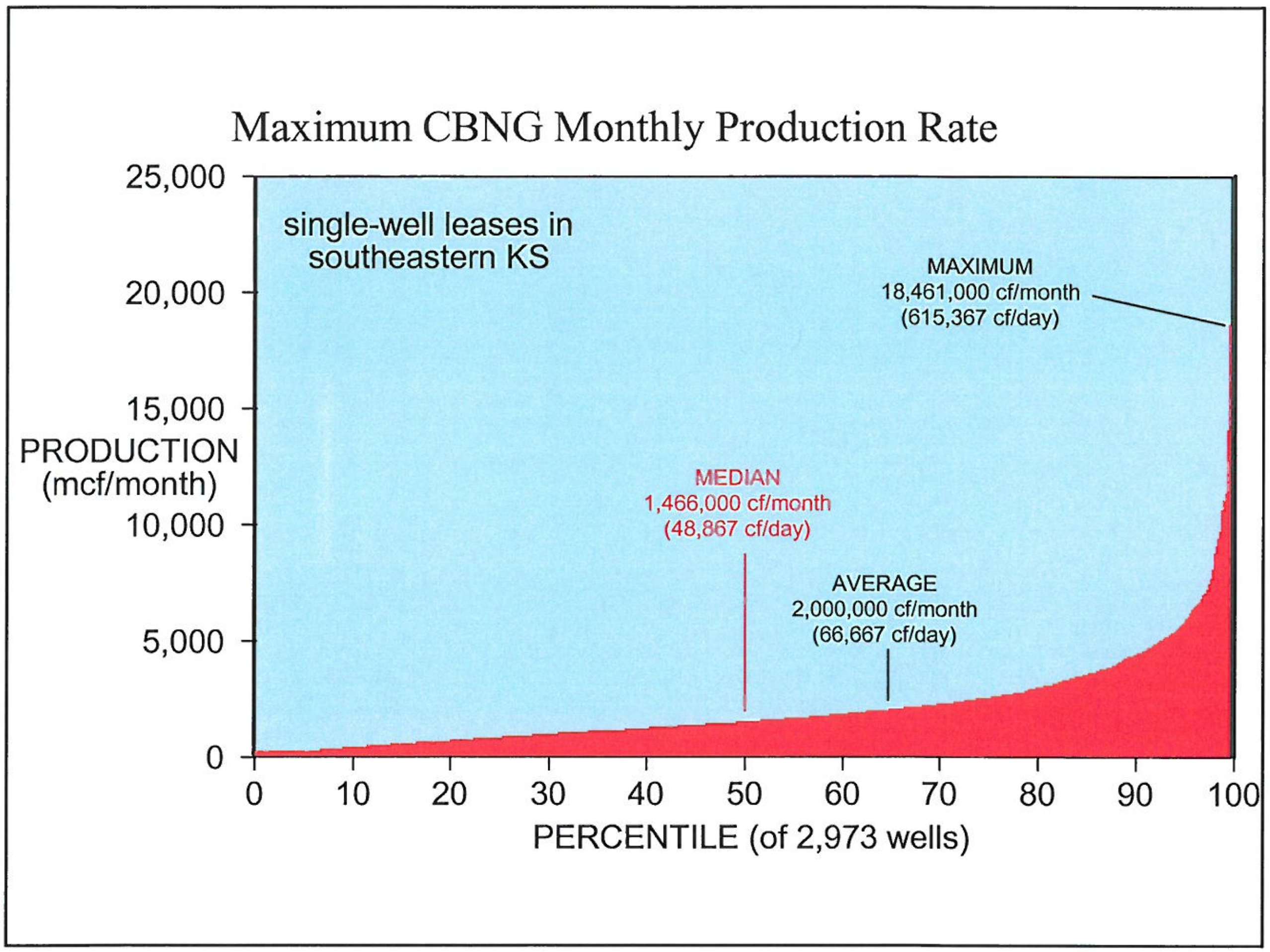

DISTRIBUTION OF GAS CONTENTS
(AS-RECEIVED) FOR COALS
Southeastern Kansas: Allen, Elk, Greenwood, Labette, Montgomery, Neosho, Wilson, and Woodson Counties
Eastern Kansas, Western Missouri: Anderson, Douglas, Franklin, Johnson, Linn, Miami Counties, KS and Jackson, Bates, and Cass Counties, MO
Northeastern Kansas: Atchison, Brown, Doniphan, Jackson, Jefferson, Leavenworth, Shawnee, Wyandotte Counties
GAS CONTENT
scf/ton
500
400
300
200
100
0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
cc/gram
5.0
4.0
3.0
2.0
1.0
0.0
SE KS
n = 129
E KS, W MO
n = 213
NE KS
n = 74
100% 90% 80% 70% 60% 50% 40% 30% 20% 10% 0%
SE KS percentage of coal samples with gas content > (scf/ton)
0 57 97 113 125 139 149 172 214 239 370
E KS, W MO percentage of coal samples with gas content > (scf/ton)
0 29 39 49 56 64 71 79 90 107 180
NE KS percentage of coal samples with gas content > (scf/ton)
0 8 14 24 37 47 53 69 87 108 152
PERCENTAGE OF SAMPLES WITH GAS CONTENT GREATER THAN CONTENT INDICATED



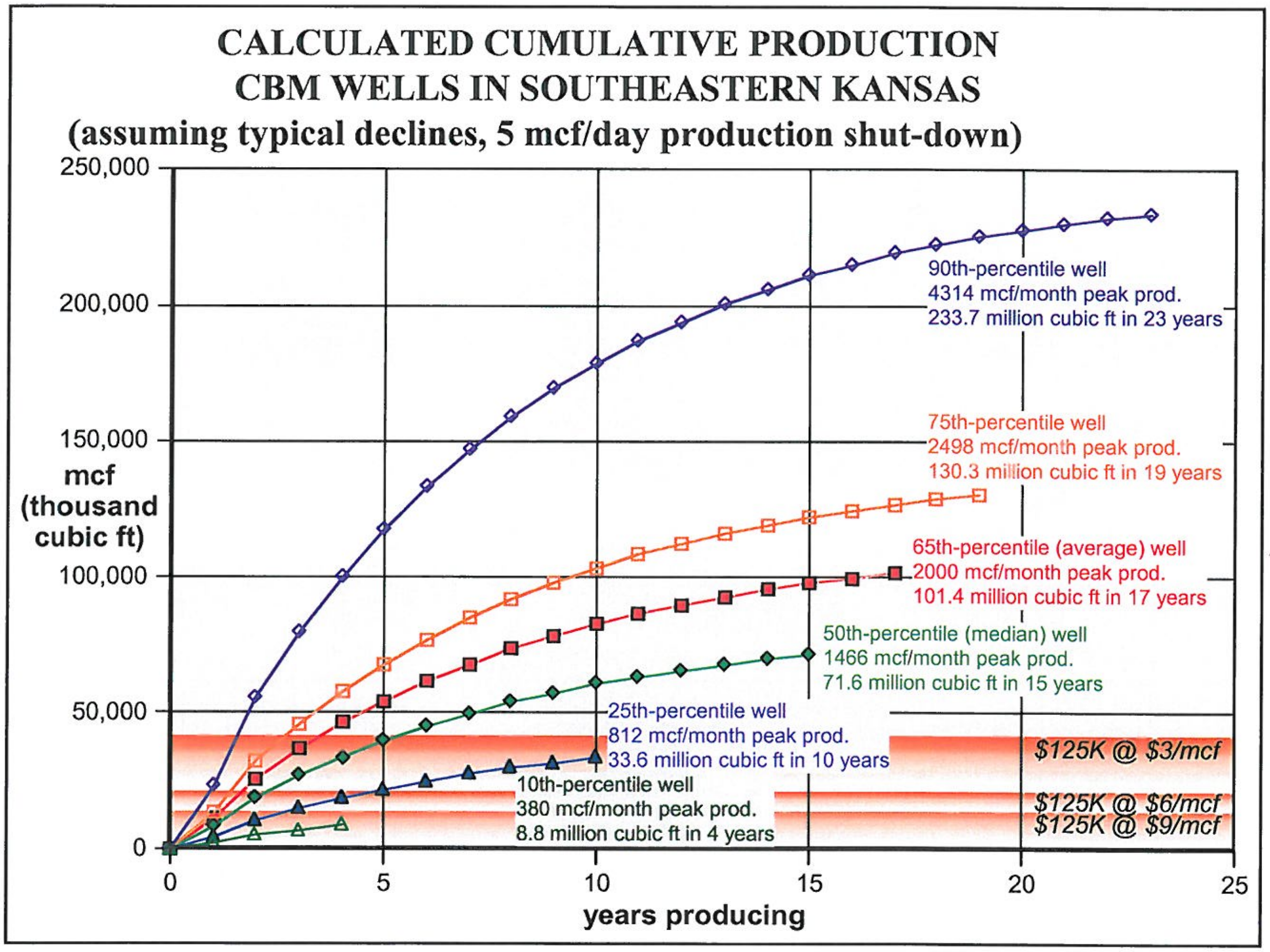
PERCENT NONCOMBUSTIBLE GAS IN GAS SAMPLES




surface
100'
200'
300'
388' (? sh.)
424' (Anna Sh.)
455' (Little Osage Sh / Summit)
500'
424' (Excello Sh.)
570' (Bevier)
605' (Fleming sh.)
606' (Fleming)
638' (Mineral)
700'
711' (? coal)
743' (? coal)
800'
900'
DQ #1B well
DQ #2 well
(filled) (hollow)
METHANE & CARBON DIOXIDE ADSORPTION ISOTHERMS
(as received)
Gas Content (scf/ton)
Bevier CO_2 isotherm
all CH_4 isotherms
0
100
200
300
400
500
600
700
800
900
Pressure (psia)

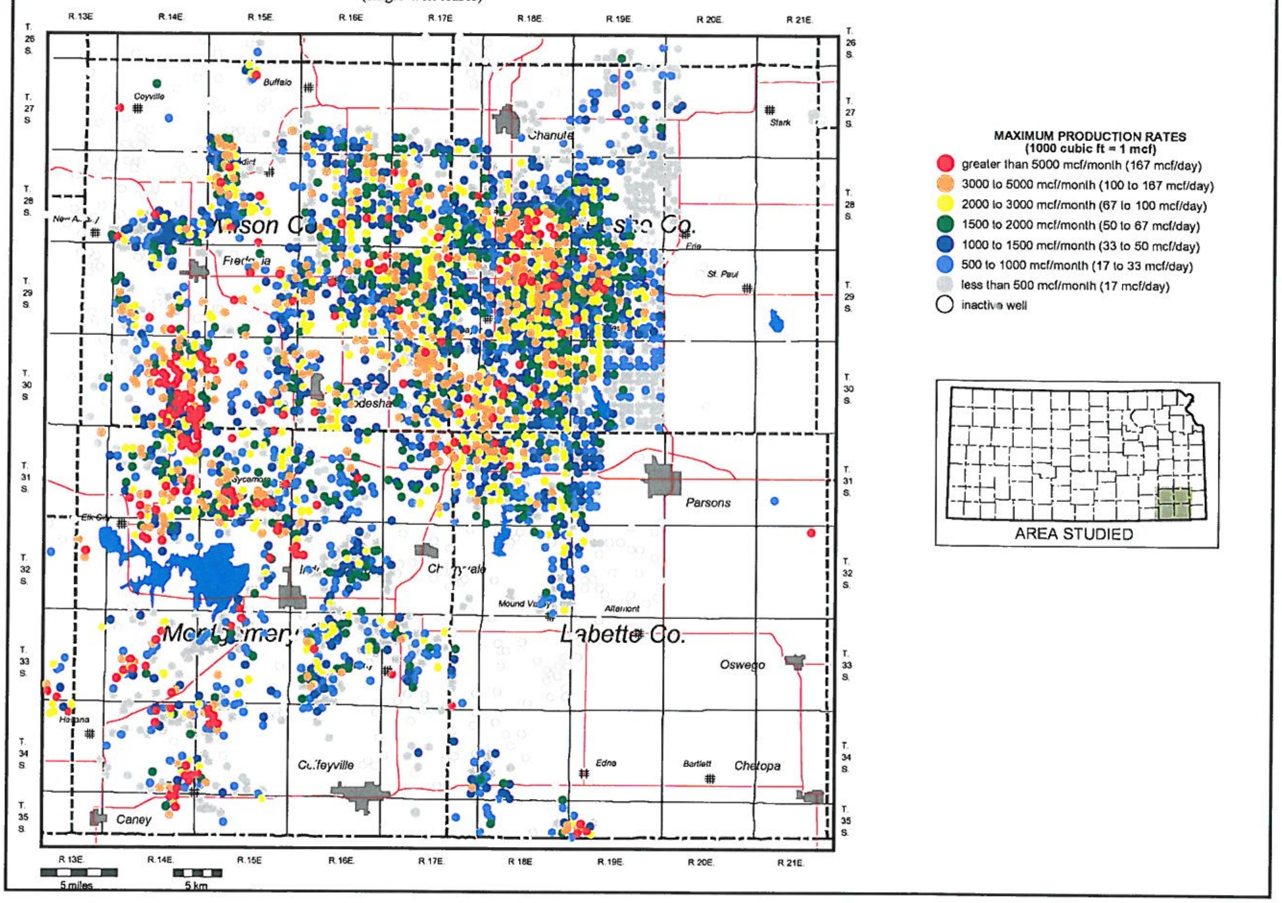


Maximum CBNG Monthly Production Rate
single-well leases in southeastern KS
MAXIMUM
18,461,000 cf/month
(615,367 cf/day)
MEDIAN
1,466,000 cf/month
(48,867 cf/day)
AVERAGE
2,000,000 cf/month
(66,667 cf/day)
PRODUCTION (mcf/month)
25,000
20,000
15,000
10,000
5,000
0
0 10 20 30 40 50 60 70 80 90 100
PERCENTILE (of 2,973 wells)


CALCULATED CUMULATIVE PRODUCTION
CBM WELLS IN SOUTHEASTERN KANSAS
(assuming typical declines, 5 mcf/day production shut-down)
250,000
200,000
150,000
100,000
50,000
0
mcf (thousand cubic ft)
0
5
10
15
20
25
years producing
90th-percentile well
4314 mcf/month peak prod.
233.7 million cubic ft in 23 years
75th-percentile well
2498 mcf/month peak prod.
130.3 million cubic ft in 19 years
65th-percentile (average) well
2000 mcf/month peak prod.
101.4 million cubic ft in 17 years
50th-percentile (median) well
1466 mcf/month peak prod.
71.6 million cubic ft in 15 years
25th-percentile well
812 mcf/month peak prod.
33.6 million cubic ft in 10 years
10th-percentile well
380 mcf/month peak prod.
8.8 million cubic ft in 4 years
$125K @ $3/mcf
$125K @ $6/mcf
$125K @ $9/mcf

MAXIMUM MONTHLY PRODUCTION for CBNG WELLS in SOUTHEASTERN KANSAS

(single-well leases)

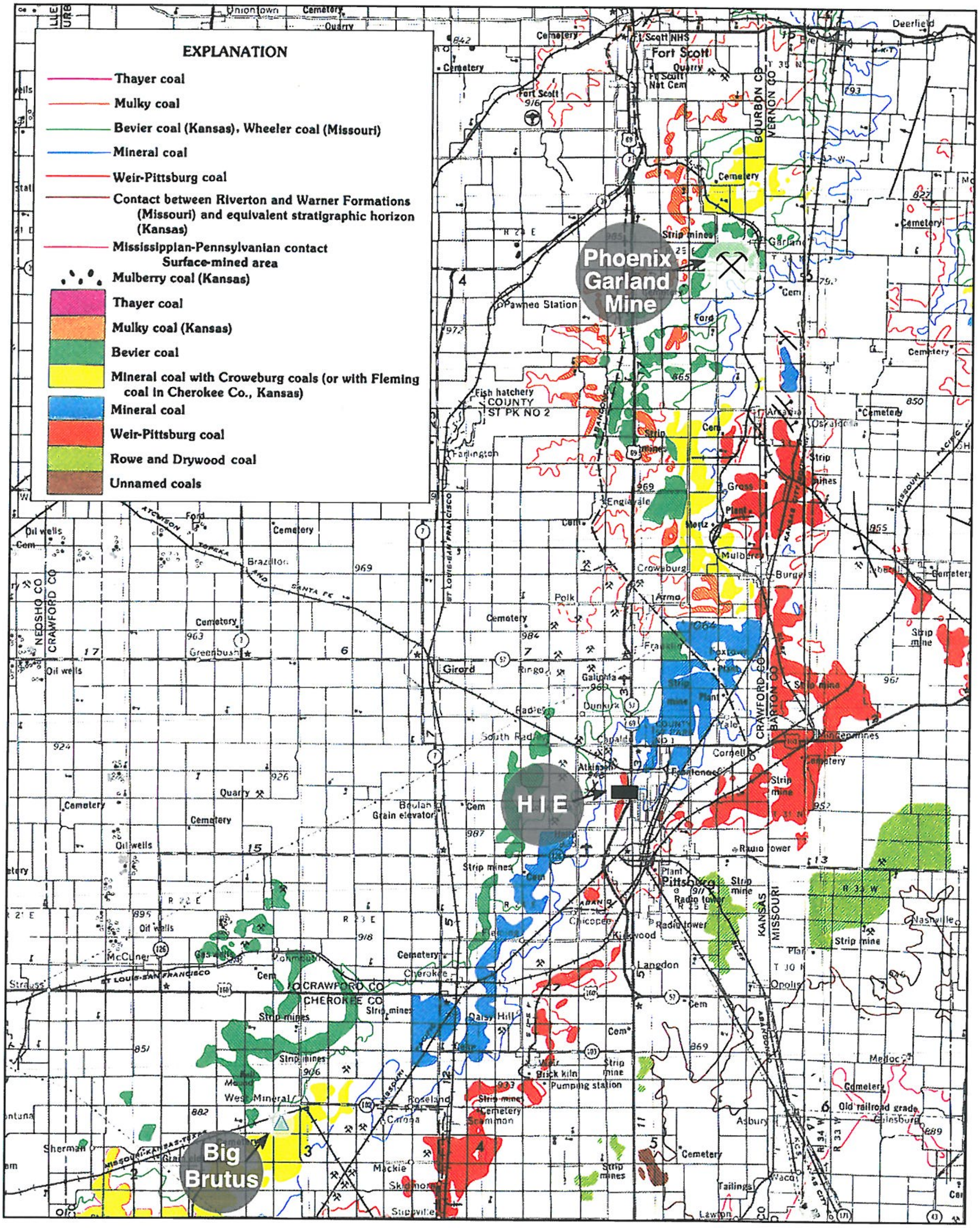


34^{th} FORUM OF THE COAL GEOLOGISTS OF THE WESTERN INTERIOR COAL REGION
PITTSBURG, KANSAS

Field Trip

Tuesday (P.M.) -- May 25, 2010
Kansas Coal and the Big Brutus Coal Shovel
Near West Mineral, Kansas

COAL STRIPPED MINED LANDS AND COAL CROP LINES



(Modified from Brady and others, 1994, Coal Resources of the Joplin 1°x2° Quadrangle, Kansas and Missouri: US Geological Survey Misc. Investigations Series I-2426-A, sheet 1).

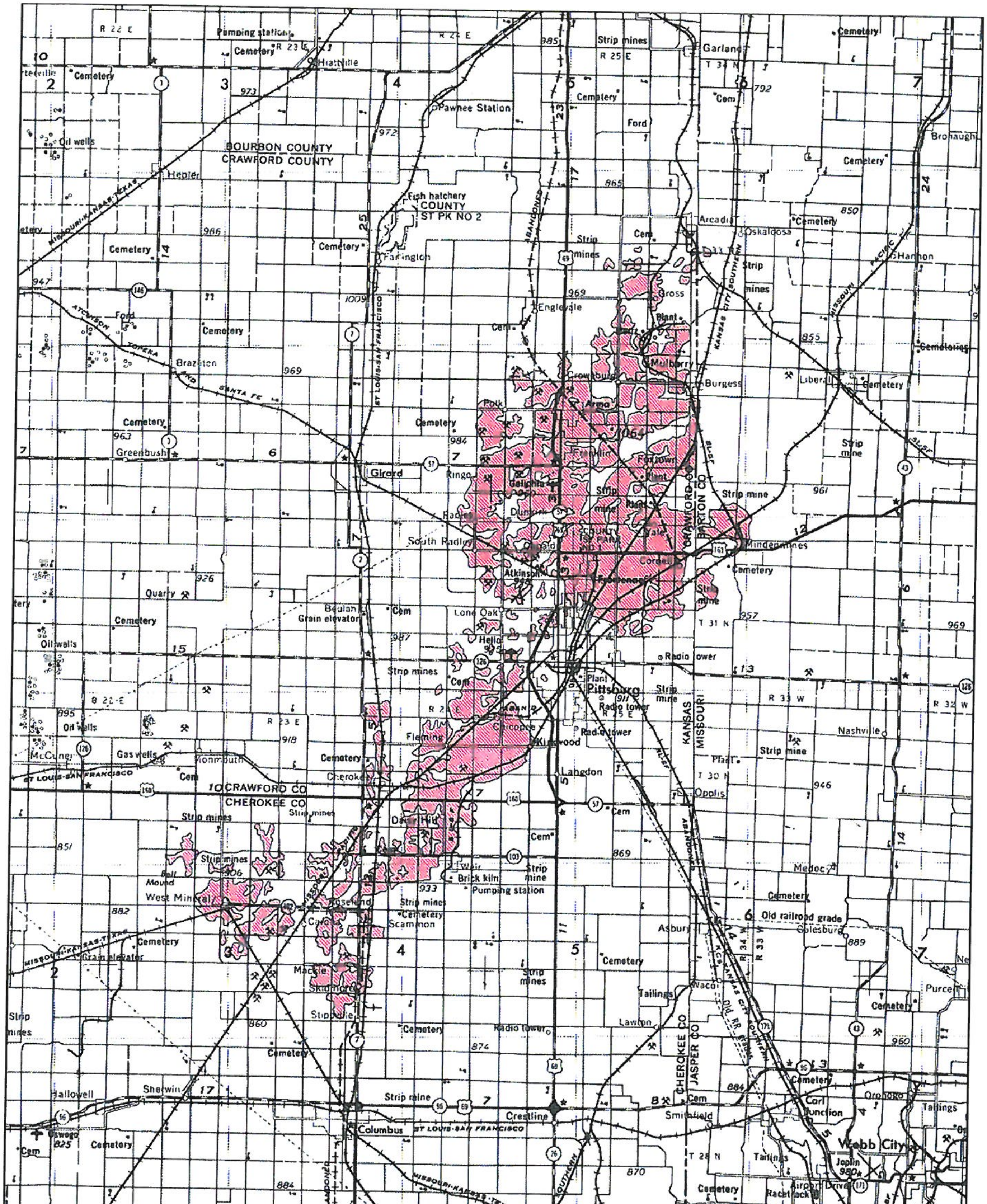
SCALE 1:250 000

5 0 5 10 MILES

5 0 5 10 KILOMETRES

NATIONAL GEODETIC VERTICAL DATUM OF 1929

LOCATION OF UNDERGROUND MINED AREAS IN THE WEIR-PITTSBURG COAL



(Modified from Brady and others, 1994, Coal Resources of the Joplin 1°x2° Quadrangle, Kansas and Missouri: US Geological Survey Misc. Investigations Series I-2426-A, sheet 1—original map from Abernathy, 1944).

SCALE 1:250 000

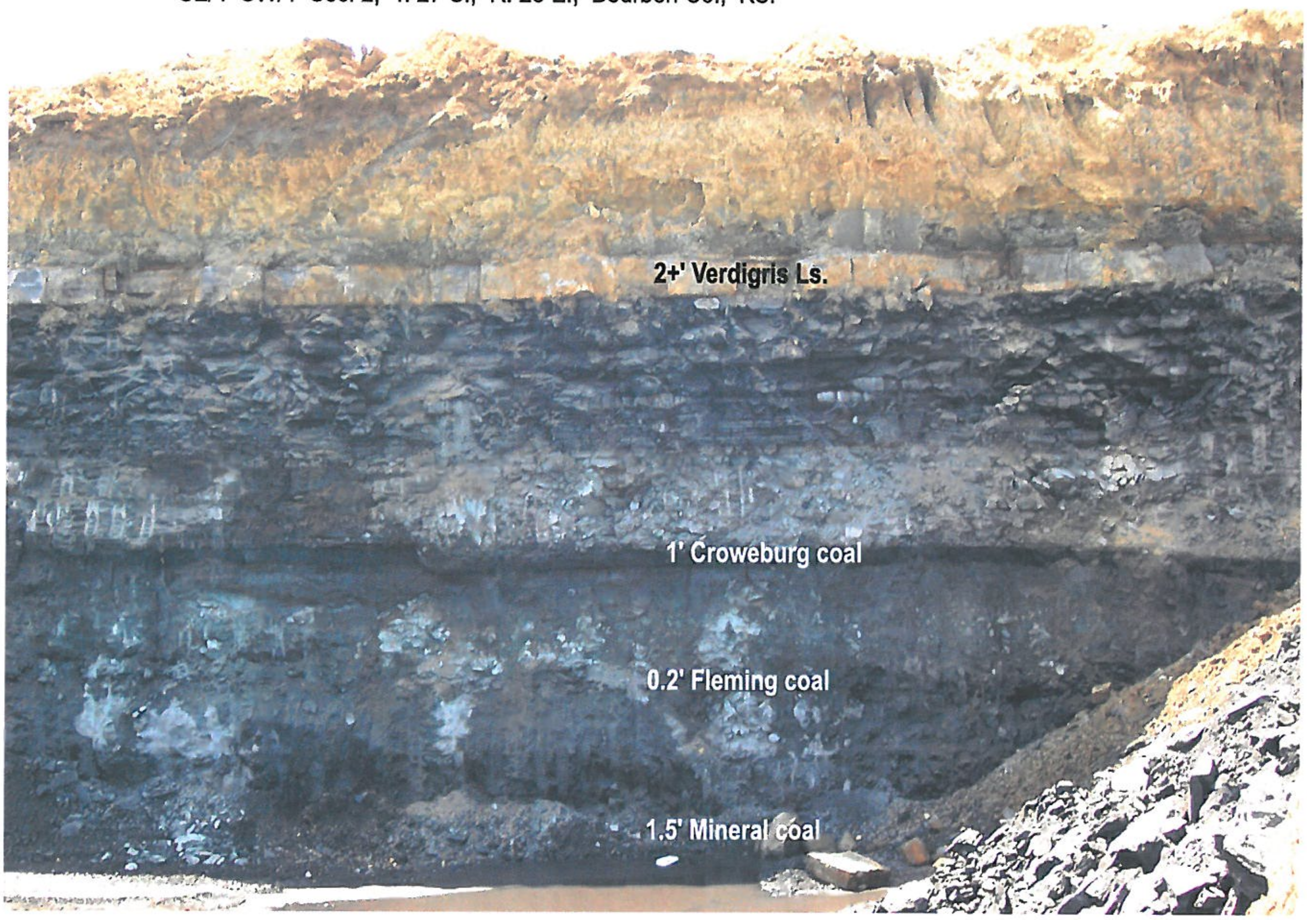
5 0 5 10 MILES

5 0 5 10 KILOMETRES

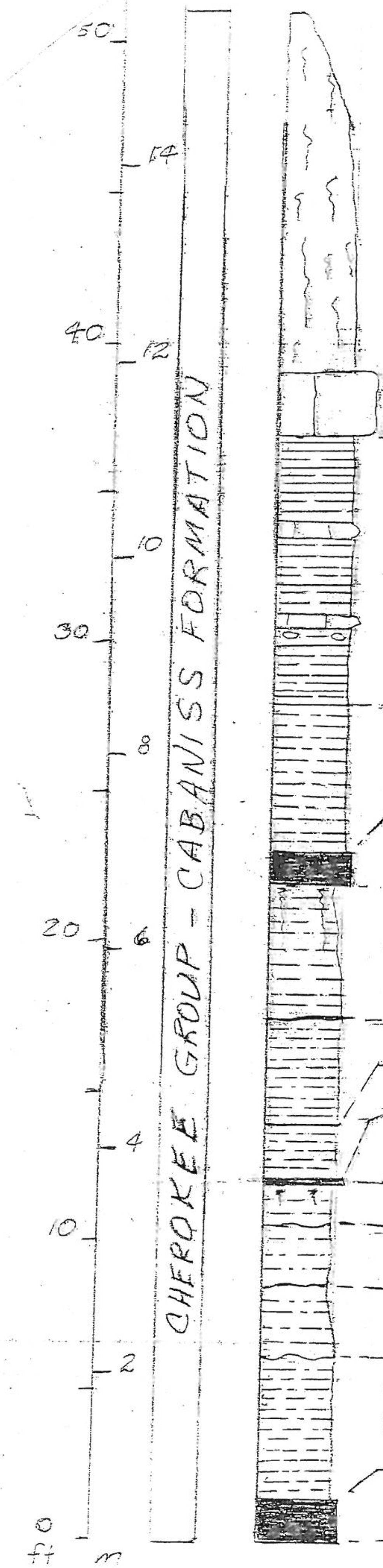
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Mine face – Phoenix Mining Company, Garland Mine (4/15/10)

SE/4 SW/4 Sec. 2, T. 27 S., R. 25 E., Bourbon Co., KS.



PHOENIX MINING CO. GARLAND MINE
NW,NE Sec 11, T27S, R25E
BOURBON COUNTY, KANSAS



Soil, clay to top of Verdigris Limestone, weathered brown, (10 ft).

Limestone (Verdigris) mudstone to wackestone; numerous fossils, medium gray, (2.0 ft).

Clay shale, hard, w/two hard limestone beds, nodular limestone below the lower limestone bed, (11ft).

Clay shale, hard, medium light gray, (4.8 ft).

Coal (Croweburg), banded, bright, with pyrite mineralization. (0.9 -1.3 ft., ave. 1.2 ft).

Claystone (seatrock), light to medium gray, blocky, (4.5).

Clay shale, silty, irregular bedding, burrowed, medium gray, (3.5 ft).

Clay shale, gray to medium dark gray, (1.8 ft).

Coal (Fleming) argillaceous, thin, with pyrite, black, (0.0 to 0.5 ft, ave. 0.2 ft).

Mudstone (seatrock), w/plant fossils, medium gray, (1.3 ft).

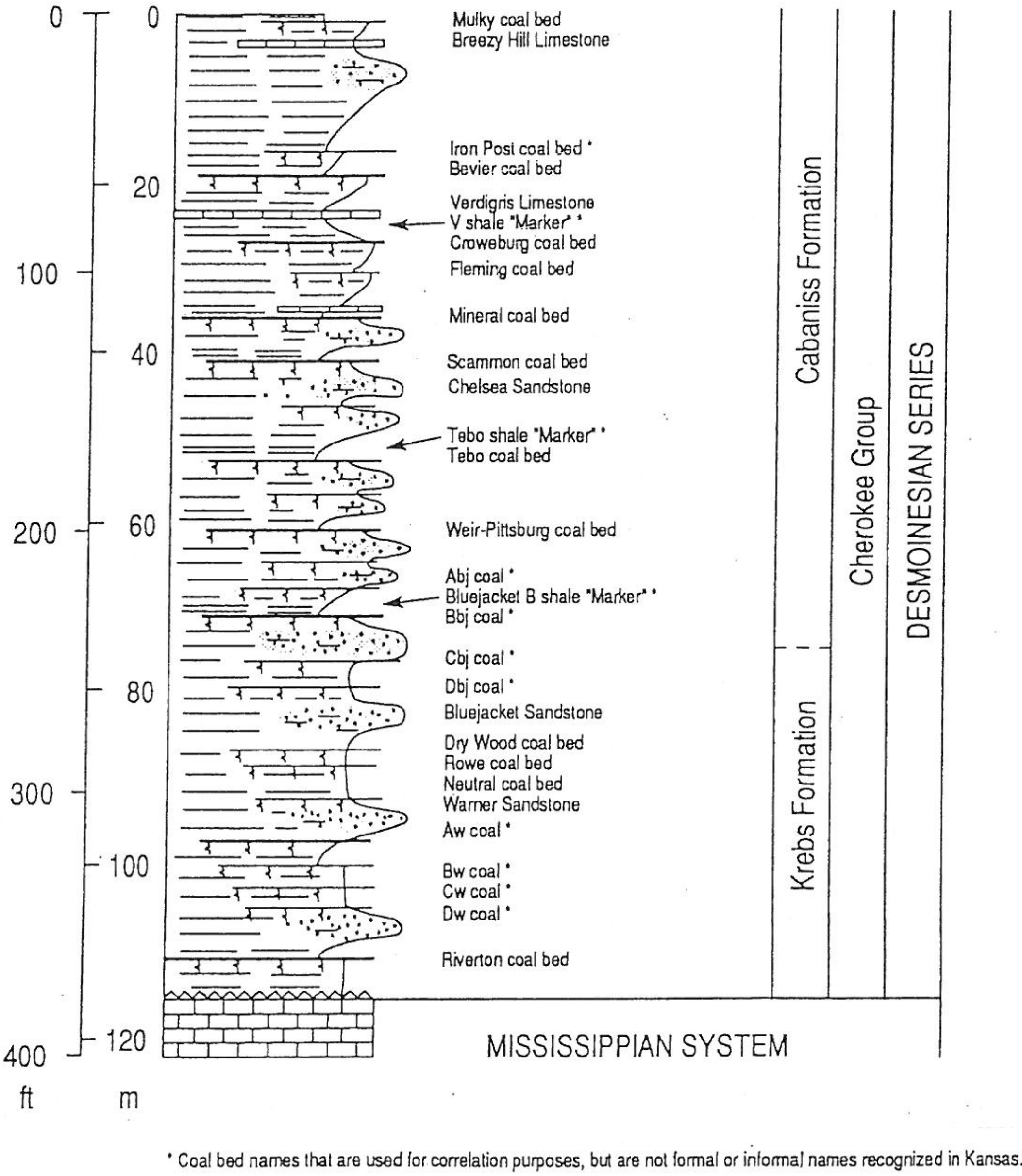
Mudstone, w/thin laminated siltstone and shale, grad. Lower contact, medium light gray, w/plant roots, (2.0 ft).

Mudstone, v. silty, blocky, light gray, w/plant roots, (2.4 ft).

Clay shale, hard, occasional hard siltstone beds and nodules, dark gray, (4.8 ft).

Coal (Mineral), banded, bright w/pyrite mineralization, black (1.3-1.5 ft., ave. 1.4 ft).

L BRADY 4/18/05



General stratigraphic column in Kansas showing formal and working names of coal beds and marker beds in the Cherokee Group.

The following article titled “Kansas Coal Distribution, Resources, and Potential for Coalbed Methane” by Lawrence L. Brady was originally prepared in 1999 for the 2000 volume of “The Compass” that was issued as volume 75, no. 2 -3, Winter and Spring of 2000, p. 122-133.

This article is a general summary of coal in Kansas at a time when coalbed methane was about to become an important energy source in southeast Kansas. In the article by K. David Newell, also in this guidebook, development of the coalbed methane production in Kansas is discussed from the origins up to the present (2010).

KANSAS COAL DISTRIBUTION, RESOURCES, AND POTENTIAL FOR COALBED METHANE

Lawrence L. Brady*

Kansas Geological Survey
The University of Kansas
Lawrence, KS 66047

ABSTRACT

Kansas has large amounts of bituminous coal both at the surface and in the subsurface of eastern Kansas. Preliminary studies indicate at least 53 billion tons (48 billion MT) of deep coal [>100 ft (>30 m)] determined from 32 different coal beds. Strippable coal resources at a depth < 100 ft (< 30 m) total 2.8 billion tons (2.6 billion MT), and this total is determined from 17 coals. Coal beds present in the Cherokee Group (Middle Pennsylvanian) represent most of these coal resource totals. Deep coal beds with the largest resource totals include the Bevier, Mineral, "Aw" (unnamed coal bed), Riverton, and Weir-Pittsburg coals, all within the Cherokee Group. Based on chemical analyses, coals in the southeastern part of the state are generally high volatile A bituminous, whereas coals in the east-central and northeastern part of the state are high-volatile B bituminous coals. The primary concern of coal beds in Kansas for deep mining or development of coalbed methane is the thin nature [<2 ft (0.6 m)] of most coal beds. Present production of coalbed methane is centered mainly in the southern Wilson/northern Montgomery County area of southeastern Kansas where methane is produced from the Mulky, Weir-Pittsburg, and Riverton coals.

INTRODUCTION

Coal deposits in Kansas have been exploited for nearly 150 years with a total production of about 300 million tons. There were two major peaks of production during this period corresponding to World War I and World War II. The peak production year was 1918 with 7.3 million short tons (6.6 million MT) of coal produced. Coal production in 1998 was 0.34 million tons (0.31 MT and as recent as 1987 production was as high as 2.0 million tons (1.8 million MT). During the past 30 years, 27 different coal mines operated in Kansas. These mines operated in Crawford (8 mines), Linn (7), Cherokee (4), Bourbon (4), Labette (3), and Wilson (1) counties in southeastern Kansas. During 1999 there are three coal mines operating in Kansas, all mining the Mulberry coal (within the Marmaton Group) in southeastern Linn County. Distribution of most of the southeastern Kansas strip mine areas, and the area of deep coal mines where the Weir Pittsburg coal was extensively mined in Cherokee and Crawford counties is shown in Brady and others (1994).

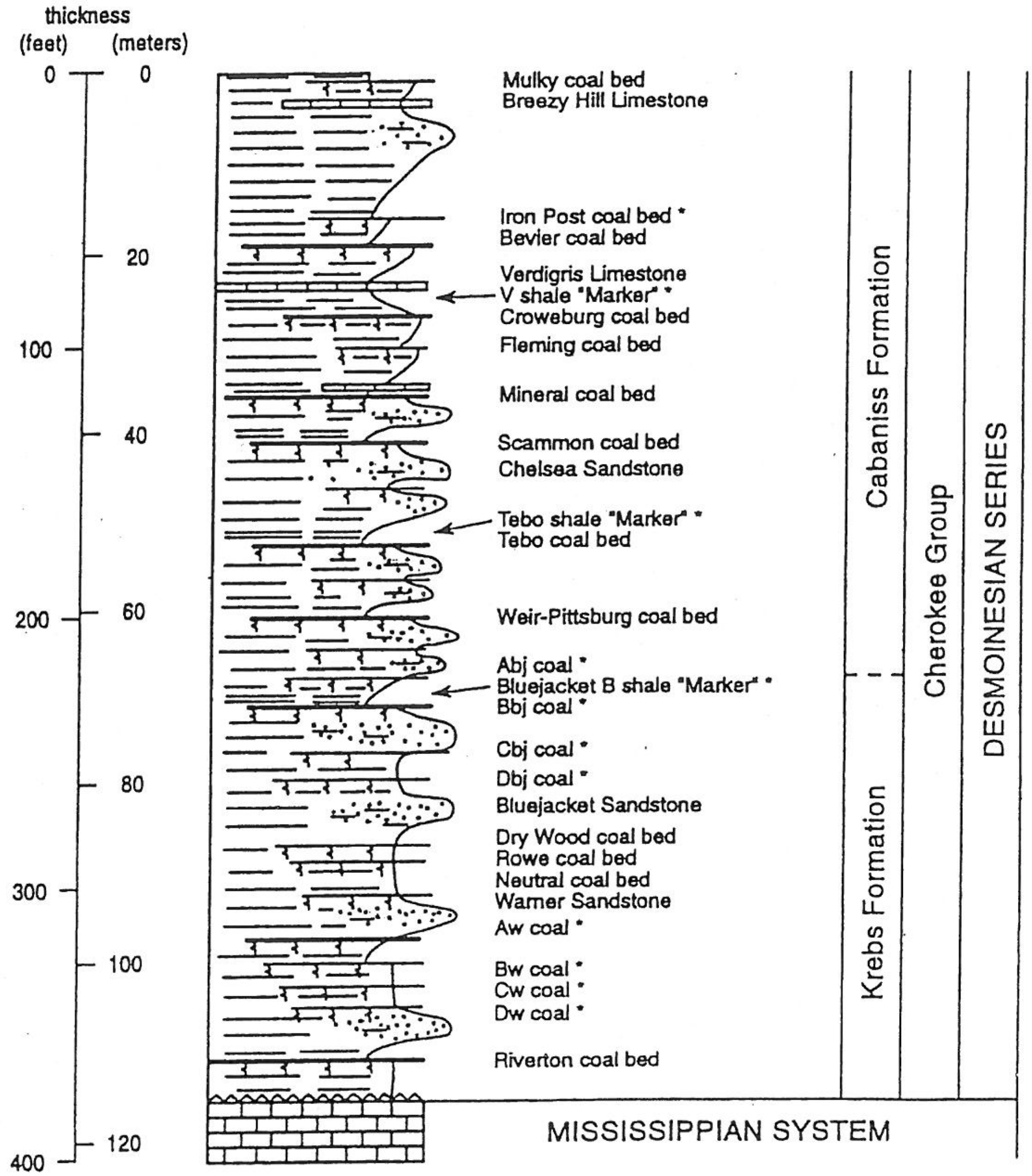
Bituminous coal resources of Pennsylvanian age are widespread in eastern Kansas and represent nearly all the coal resources in the state. There is a small amount of lignite in Lower Cretaceous rocks in central Kansas. Deep coal resources are known for 32 coal beds, and strippable coal resources for 17 coal beds. Most of the deep coal resources are determined for coals of the Cherokee Group. At the present time, six coals stratigraphically higher than the Cherokee Group also are included in the deep coal resource total. It is these deep bituminous coal resources that provide the potential for present and future development of coalbed methane in Kansas, and areas of adjacent states.

*Member and past President (1966–67) of Alpha Chapter at The University of Kansas

STRATIGRAPHIC POSITION OF COAL

Nearly 90% of all Kansas coal mined in the past was from the Cherokee Group and these coals also dominate the resources in the state. Two important exceptions are the Mulberry coal, present in the Marmaton Group and mined in Linn County, and the Nodaway coal of the Wabaunsee Group, that was mined in several counties — but mainly in Osage County. Mining of one coal (Weir-Pittsburg) represents nearly half of the total historic coal production in Kansas. Most of the original shallow-depth coal resources of this important coal bed were either stripped or mined underground mainly by room and pillar methods, especially in Crawford and Cherokee counties. Cherokee coal beds recently mined (past ten years) include the Mineral, Croweburg, and Bevier coals, but the Mulberry coal of the Marmaton Group is the one coal bed presently (late 1999) being mined in Kansas.

When evaluating the deeper coal resources, informal notation was used to identify unnamed coals and certain key marker beds, especially in the Cherokee Group, and these names are not recognized in Zeller (1968), or Baars and Maples (1998). Most of these Cherokee Group informal stratigraphic terms evolved during usage in coal and stratigraphic studies at the Kansas Geological Survey (Fig. 1).



* Coal bed names that are used for correlation purposes, but are not formal or informal names recognized in Kansas.

Figure 1. Stratigraphic column of Cherokee Group showing formal and working names of coal beds and marker beds in Kansas part of Cherokee Group—as used in this report (modified from Brady, 1990; Harris, 1984).

STRIPPABLE RESOURCES

Strippable coal resources in Kansas that are present under less than 100 ft (30 m) of overburden total nearly 2.8 billion tons (2.5 billion MT) as determined by Brady, Adams, and Livingston (1976). The demonstrated coal reserve base for Kansas as listed and used by the US Department of Energy is 976 million tons (885 million MT) for 1995 (Energy Information Administration 1998, p 47). This figure represents strippable coal in Kansas, in place, that is in the measured and indicated categories (Wood and others, 1983) with 0-100 ft (0-30 m) overburden as determined in the Brady, Adams, and Livingston (1976) study. A general analysis of the strippable coals, having a stripping ratio (overburden/coal) of 30:1 or less, indicates a total resource of nearly 1.3 billion tons (1.2 billion MT) of coal. Minimum thickness of the coals evaluated by Brady, Adams, and Livingston (1976) was 12 inches (30 cm). General areal distribution of the coal resources in Kansas by stratigraphic group is shown in Figure 2, with a stratigraphic section with coals having important stripping coal resources shown in Figure 3.

DEEP COAL RESOURCES

Deep coal resources in eastern Kansas were determined to be about 53 billion tons (48 billion MT) of coal (Table 1) measured from 32 different coal beds (Brady and Livingston, 1989; Brady, 1990). Emphasis of the deep coal resources was on Cherokee Group coals because of the stratigraphic importance of these coals in Kansas. However, six coal beds stratigraphically higher than the Cherokee coals are included in the deep resource total. For deep coals, a coal bed thickness of 14 inches or greater (>35 cm) is considered in the resource amounts. Coal resource amounts are determined to be present within three miles of a known data point (Fig. 4) if the coal is considered to be present as defined and described by Wood and others (1983, p.11).

Stratigraphy of the deep coal beds, especially of the Cherokee Group, was determined and developed from mine and outcrop studies, especially those of Abernathy (1937), Pierce and Courtier, (1938), Howe (1956), and Harris (1984) who established the stratigraphy of the Cherokee Group in outcrop and shallow subsurface studies. This

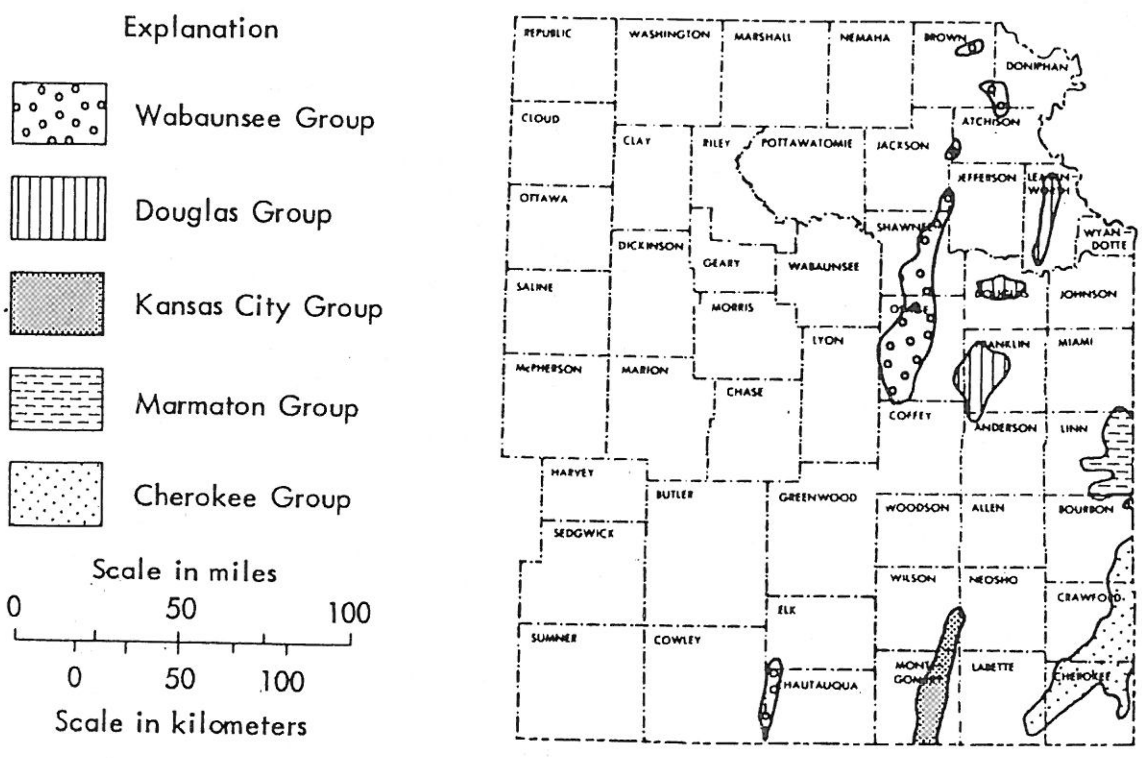


Figure 2. General distribution of strippable coal resources by geologic group (modified from Brady, Adams, and Livingston, 1976).

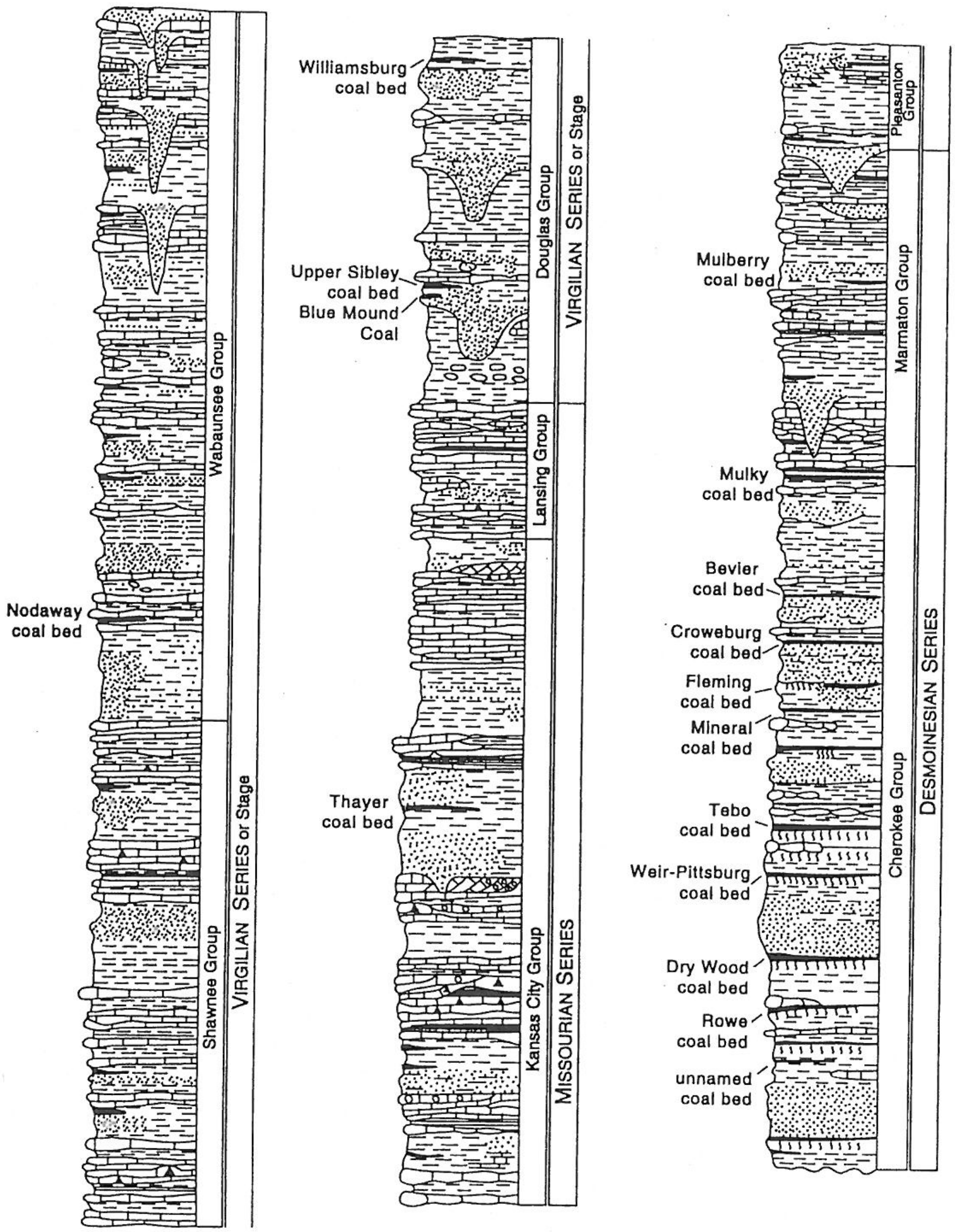


Figure 3. Stratigraphic position of coal beds in Kansas, with important coal resources having strip mining potential.

stratigraphic relation was extended into the subsurface using studies by Ebanks, James, and Livingston (1977), Livingston and Brady (1981), Harris (1984), Harris, Brady, and Walton (1985), Killen (1986), Staton (1987), Staton, Brady, and Walton (1987), Brady and Livingston (1989), Brenner (1989), Huffman (1991), Walton (1996), and Brady (1997).

Deep coal resources were determined from cores at the Kansas Geological Survey, deep coal tests by mining companies, but mainly from wireline geophysical logs run for oil and gas tests by numerous petroleum

Table 1. Summary of deep coal resources and reliability categories in Kansas.

Table 1. Summary of deep coal resources and reliability categories in Kansas

Geologic Group		Coal Bed	Tonnages (million short tons) by Reliability Category				
			Measured	Indicated	Inferred	Total	Total (MT)
Douglas	M	Williamsburg	1	6	109	116	(105)
Kansas City	M	Thayer	3	20	282	305	277
Pleasanton	*	"Dawson"	4	33	473	510	463
Marmaton	M	Mulberry	11	83	1,158	1,252	1,136
"	*	"Labette B"	19	120	1,381	1,520	1,379
"	*	"Labette C"	2	17	249	268	243
Cherokee	M	Mulky	5	31	413	449	407
"	*	"Iron Post"	13	82	771	866	786
"	M *	Unnamed	6	42	433	481	436
"	M	Bevier	90	561	5,477	6,128	5,559
"	M	Croweburg	20	141	1,613	1,774	1,609
"	M	Fleming	13	74	615	702	637
"	M	Mineral	87	540	4,975	5,602	5,082
"		Scammon	20	148	1,752	1,920	1,742
"	*	"Scammon B"	2	18	158	178	161
"		Tebo	16	117	1,576	1,709	1,550
"	*	"Tebo B"	1	6	99	106	96
"	M	Weir-Pittsburg	73	364	2,616	3,053	2,770
"	*	"Weir-Pittsburg B"	5	44	719	768	697
"	*	"Abj"	13	91	1,170	1,274	1,156
"	*	"Bbj"	3	23	298	324	294
"	M	Dry Wood	4	31	413	448	406
"	M	Rowe	35	258	3,135	3,428	3,110
"		Neutral	3	26	420	449	407
"	*	"Neutral B"	0	2	23	25	23
"	M *	"Aw"	49	381	4,579	5,009	4,544
"	*	"Bw"	15	109	1,330	1,454	1,319
"	*	"Cw"	29	228	2,862	3,119	2,830
"	*	"Dw"	15	114	1,446	1,575	1,429
"	*	Unnamed	2	17	175	194	176
"	M	Riverton	88	654	7,225	7,967	7,228
"	*	Unnamed	5	40	516	561	509
Totals		(short tons)	652	4,421	48,461	53,534	
		(metric tons)	(591)	(4,011)	(43,964)		(48,566)

* Coal bed names that are used for correlation purposes, but are not formal or informal names recognized in Zeller (1968).

M Coal with commercial mine production within last 50 years.

exploration companies. Gamma-ray density and gamma-ray neutron logs were used for most of the resource estimates, utilizing nearly 600 of these logs.

Methods used for determining coal thickness from geophysical logs are discussed in Wood and others (1983), and Hoffman, Jordan, and Wallis (1982, p. 125-140). However, it was determined that thin coals tend to show a greater thickness than the actual coal bed if the inflection point is used for coal thickness determination. For a coal thickness less than 30 inches (0.7 m or less), a coal thickness was determined for coal beds at a point half way between the inflection point and the maximum deflection of the neutron or density line. For coal-bed thickness of 30 inches or greater (0.7 m or greater) there is little difference in picking these two points. The inflection point is the usual place for picking the coal thickness as suggested in Wood and others (1983, p. 55–65).

Coal beds can be determined from the geophysical logs by their low density, low

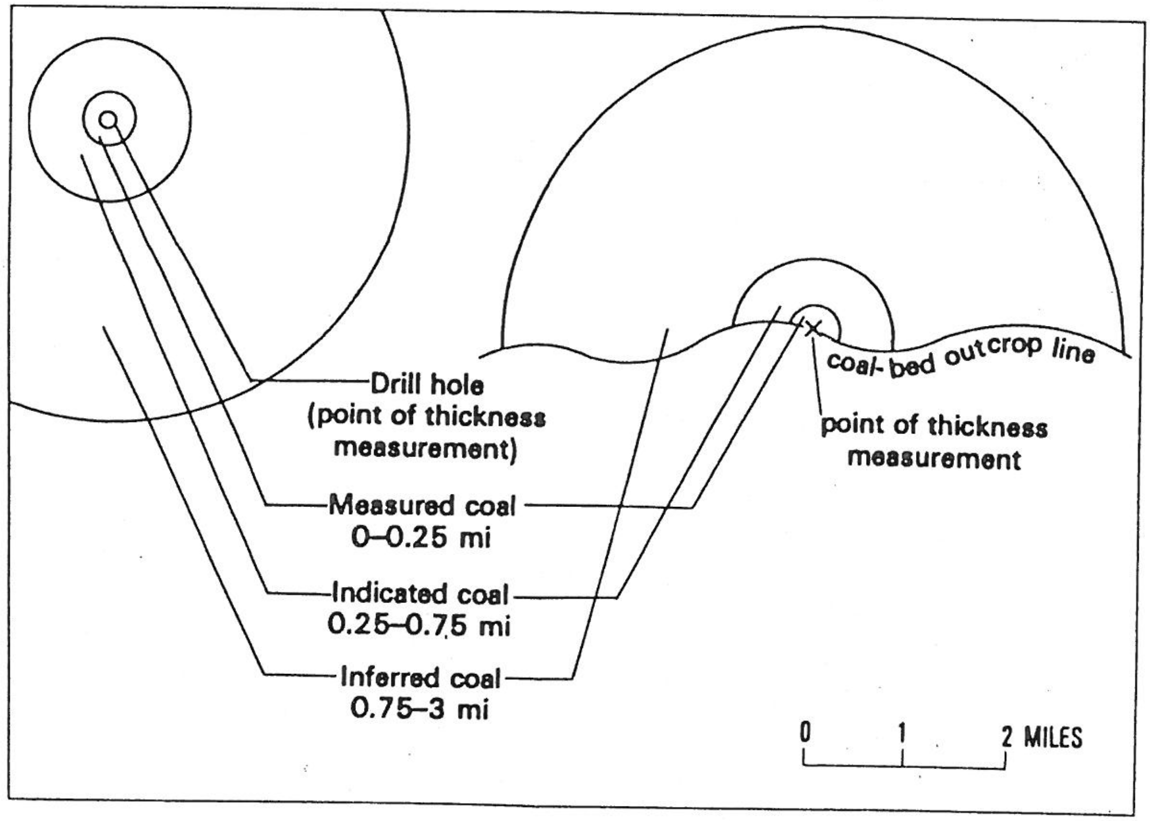


Figure 4. Radius of influence or reliability categories used in coal-resource studies (modified from Wood and others, 1983, p. 11).

neutron count, and for most coals (at least those in Kansas and surrounding areas) low natural gamma-ray reading. Indication of coal bed presence, as shown by gamma-ray density logs is illustrated in Figure 5, where the geophysical log on the left shows the low natural gamma radiation of the coals and the log on the right shows the low density reading of coal. Care must be taken with density logs because coals with high ash content and high amounts of sulfide minerals (mainly pyrite) can give higher density readings than a value of approximately 1.4 gm/cc that represents a low-ash bituminous coal.

The highly radioactive shales that give a high reading on the gamma-ray logs are important in the correlation of the different coal beds. These radioactive shales were used as stratigraphic markers and were determined to have widespread occurrences (e.g. Ebanks, James, and Livingston, 1977; Livingston and Brady, 1981; Harris, 1984; Harris, Brady, and Walton, 1985; Killen, 1986; Staton, 1987; Staton, Brady, and Walton, 1987; Brenner, 1989; Huffman, 1991; Walton, 1996; and Brady and Guy, 1999). Key marker beds in the Cherokee Group used for stratigraphic correlation are shown on Figure 1, and a profile showing the lateral extent of the major marker beds is shown in Figure 6.

Coal beds having the largest deep resources in Kansas include the Bevier, Riverton, Mineral, "Aw" (unnamed coal bed), and the Weir-Pittsburg coals. General distribution of these five coal beds in Kansas are shown in Figure 7A-D, and Figure 8. The Weir-Pittsburg coal was the most important coal produced in the state, with nearly 200 million tons (180 million MT) total production.

COAL QUALITY

Kansas coal of Pennsylvanian age is all of high-volatile bituminous rank. Nearly 90% of the coal produced in the past was of high-volatile A bituminous rank, with most of this coal produced in southeastern Kansas. Large amounts of high-volatile B bituminous coal were produced from Leavenworth County (Bevier coal of the Cherokee Group produced from deep mines), whereas

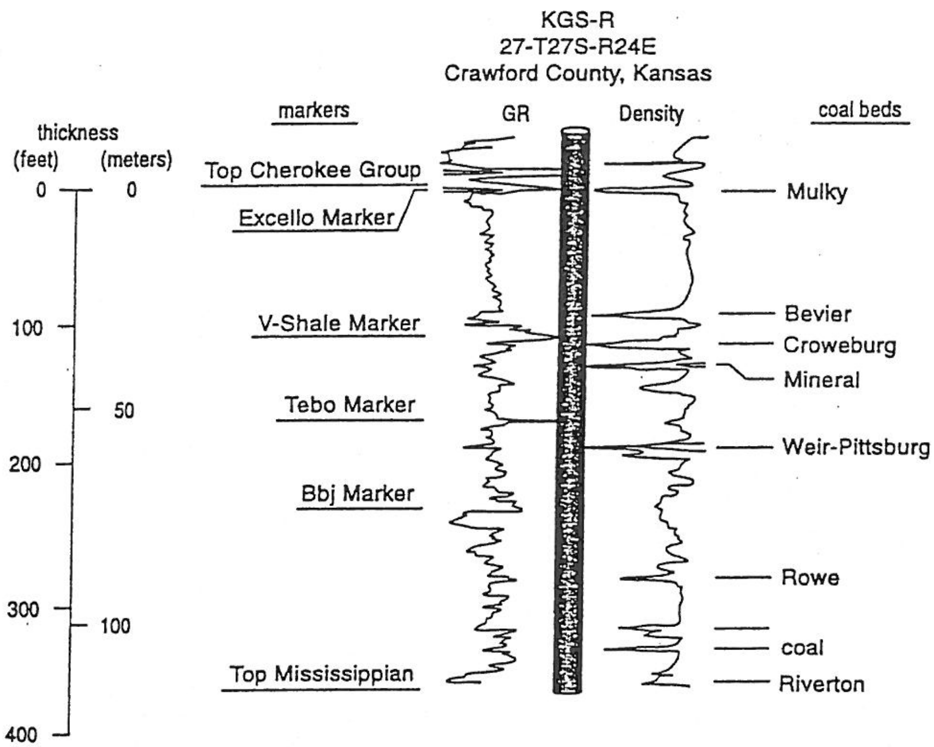


Figure 5. Gamma-ray density log showing response of main marker beds and coal beds.

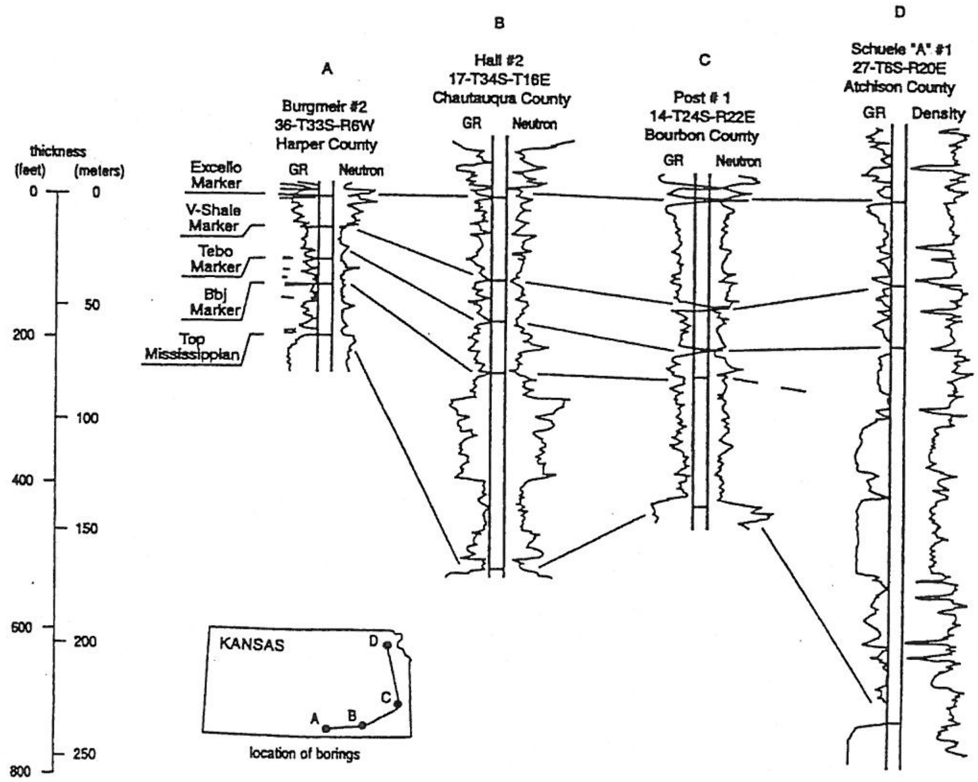


Figure 6. Profile showing distribution of important marker beds in eastern Kansas (modified from Brady, 1990).

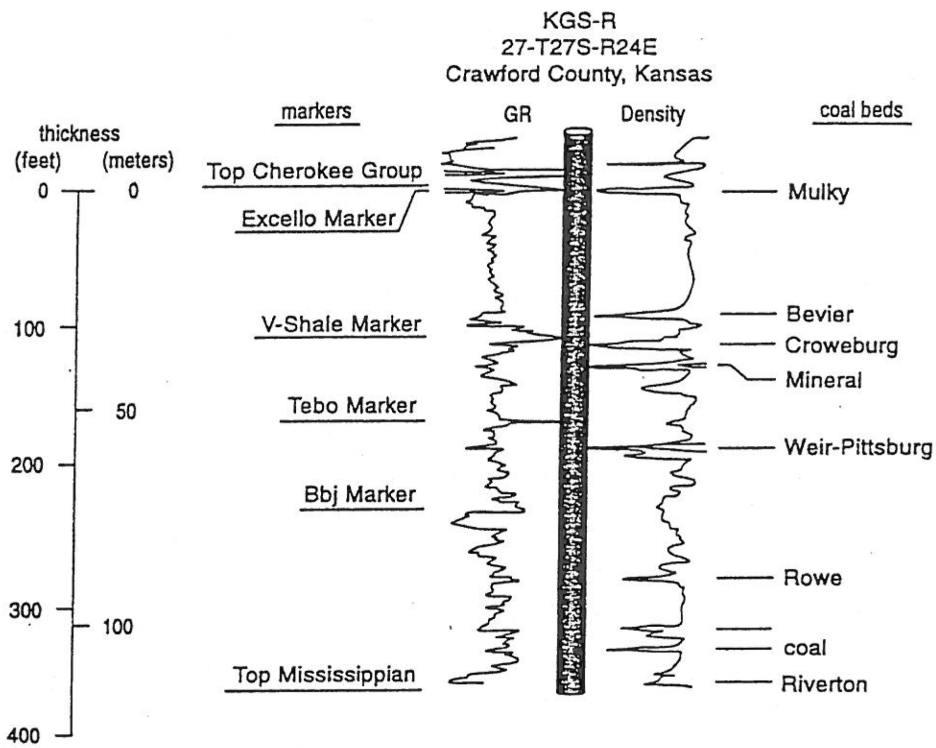


Figure 5. Gamma-ray density log showing response of main marker beds and coal beds.

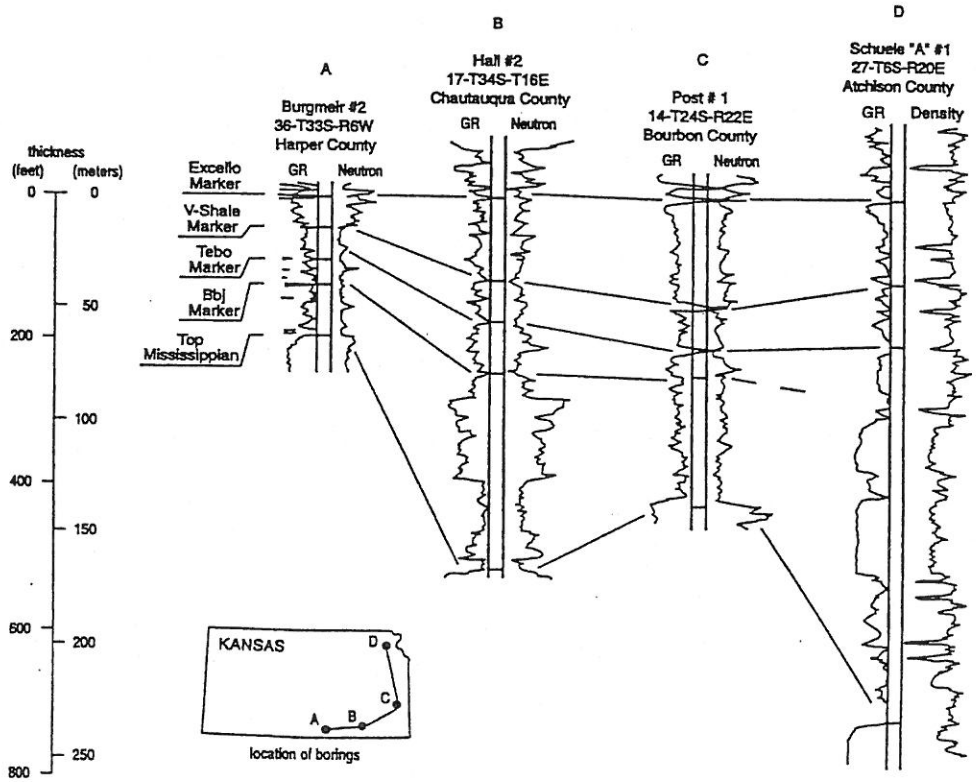


Figure 6. Profile showing distribution of important marker beds in eastern Kansas (modified from Brady, 1990).

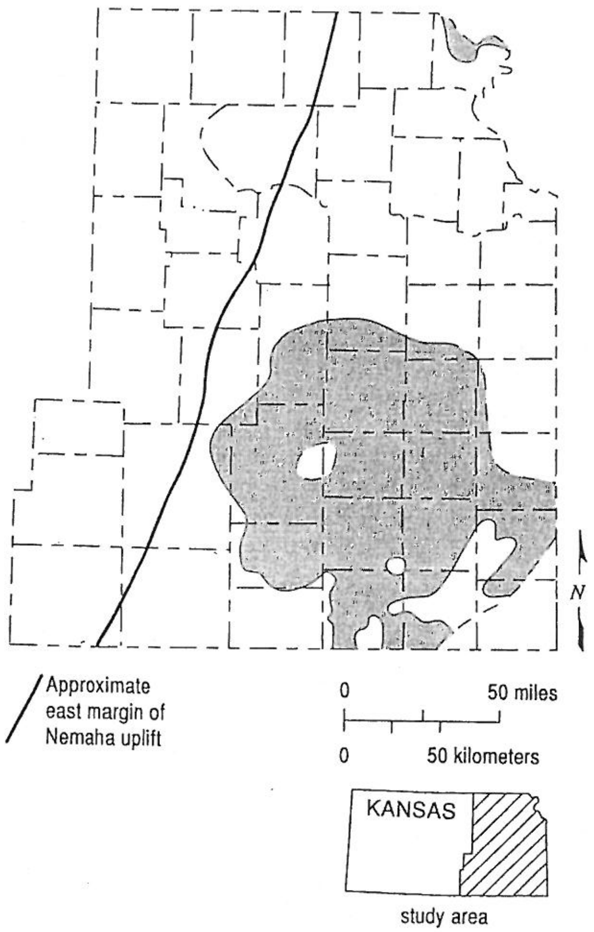


Figure 8. General distribution of Weir-Pittsburg coal in eastern Kansas where coal is considered to have thickness of 14 inches or greater (>35 cm), and is present under 100 ft or more ≥ 30 m) of overburden (Brady, 1997).

the Mulberry coal of the Marmaton Group was produced primarily by strip mining in Linn County. In Osage County, the Nodaway coal (within the Wabaunsee Group having a hvBb rank was produced by both strip and deep mining.

Proximate and ultimate analyses of Kansas coals are listed in numerous sources—including Young and Allen (1925), Fieldner, Cooper, and Osgood (1929, p. 30-37), and Pierce and Courtier (1938). Recent work that includes proximate and ultimate analyses and elemental analyses include: Swanson and others (1976), Tewalt and Finkelman (1990), Finkelman, Bragg, and Dulong (1990), Bostic and others (1993), and Brady and Hatch (1997),

METHANE FROM COAL

Methane can be present in large amounts in higher ranks of bituminous coal. For years this fact has been considered a major problem in deep coal mines because of the potential for explosions. In recent years, utilization of the methane from coal has become important as a commercial gas source. In areas of the San Juan Basin in New Mexico and Colorado and parts of the Warrior Basin in Alabama, large amounts of methane are being developed from deep coal beds. Coal gas now is being exploited in areas of thick subbituminous coal beds in the Powder River Basin in Wyoming (Montgomery, 1999). Kansas also has potential for additional production of this gas.

High-volatile A bituminous coal that is present in southeastern Kansas and adjacent areas if known to have potential to release large quantities of methane. If sufficient overburden is present over the coal and a seal such as thick shale overlies the coal bed to prevent loss of the methane, then methane of possible economic quantities could be present.

In Kansas areas where the coal is deeper than 500 ft (>150 m), the bituminous coals probably retain a large amount of methane. Drilling and artificial fracturing of the thicker coal beds or multiple coal beds could produce significant amounts of the gas. Stoeckinger (1989) measured and reported a gas content of 220 cu ft/ton (6.8 m3/MT) from a core sample of the Weir-Pittsburg coal bed in Montgomery county. Other coal beds from southeastern Kansas, reported by Stoeckinger (1989) and listed in Table 2, give good indication of large methane content. Recent developments in Kansas at recovering coalbed methane, as reported by the Oil and Gas Journal (1990, p. 70), shows good promise for this new gas source. A summary report on the coalbed methane potential of the Forest City Basin in parts of Kansas, Nebraska, Missouri, and Iowa (Bostic and others, 1993) shows that the potential exists for methane from coal beds in northeastern Kansas as well as the known production in southeastern Kansas.

By January 1993, there were at least 232 wells completed for coalbed methane in Kansas (Stevens and Sheehy, 1993, p.44). Total completions to 1997 has more than doubled that figure. Most of the activity has been in southeastern Kansas, primarily Montgomery, Wilson, western Labette, and eastern Chautauqua counties. Good potential for economic development exists in these areas. Important coals in these counties for methane include the Weir-Pittsburg and Riverton, and also the Mulky coal and its overlying Excello Shale. Development of methane from coal in these wells can take up to several months of development pumping work. The development pumping is needed to remove large quantities of water from the coal bed in order to lower the hydrostatic head of the formation water to allow the methane to be desorbed from the coal.

SUMMARY

Kansas has a total (deep and strippable) coal resource base of 56 billion tons (51 billion MT) that is widespread in the eastern one-fourth of the state. Most of that resource lies at a depth of less than 2500 feet (<750 m). based on coal chemistry, the rank of the coals is high-volatile bituminous, with the coal ranging from high-volatile A biuminous in southeastern Kansas to high-volatile B bituminous in the central and northern areas of eastern Kansas. Because of the cyclic nature of coals and associated rock units in the Pennsylvanian rock column, especially in the Cherokee Group, multiple coal beds (up to 14 coals) could be encountered in a given well drilled through the Pennsylvanian section. For coalbed methane, the main problem to solve is locating coals with sufficient thickness to provide the quantities of gas needed for economical development. Most of the Kansas coal beds making up the resource are less than 28 inches (70 cm) thick and this is a deterrent for large-scale coalbed methane development. This thickness figure represents only a limited sampling of the total resource. Many gas pipeline networks are in place, and Kansas has recognized disposal zones for the formation waters. Kansas represents an important area for present and future coalbed methane exploration and development.

ACKNOWLEDGMENTS

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Table 2. Volume of desorbed gas (mainly methane) determined in test canisters from selected wells in southeastern Kansas.

Location	Depth		Coal	Thickness		Volume Desorbed Gas		Remarks
	ft	(m)		ft	(m)	cf/ton	(m^3/MT)	
3-T27S-R15E Wilson Co.	865	(264)	Mulky	1.5	(0.5)	174-197	(5.4-6.1)	Drilled chips
3-T27S-R15E Wilson Co.	1200	(366)	Riverton	3.0	(0.9)	186	(5.7)	Clean core
7-T31S-R16E Montgomery Co.	970	(296)	Weir-Pittsburg	5.0	(1.5)	220	(6.8)	Good gas flow when drilled

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Mine 19 geologic section, Pittsburg and Midway Coal Mining Company, Cherokee County, Kansas

Lawrence L. Brady, Kansas Geological Survey, Lawrence, Kansas 66046

LOCATION

This site is an abandoned strip mine just south of West Mineral in northwest Cherokee County, in extreme southeastern Kansas. It can be reached most easily by traveling 5 mi (8 km) west from Kansas 7 on Kansas 102 to West Mineral and following local roads to the exposures shown in Figure 1.

SIGNIFICANCE

This locality consists of two high-wall exposures of limestone, shales, and coal that were uncovered while strip mining for coal (Fig. 2, A and B). These high-wall sections expose an important part of the Cherokee Group that has both widespread correlation potential and local economic importance.

GEOLOGY

The composite section (Fig. 3) consists of six geologic units (and a soil profile) that are located in the middle part of the Cabaniss Formation in the upper part of the Cherokee Group. Coals mined at these locations by the Pittsburg and Midway Coal Mining Company (Mine #19) include the Mineral, Fleming, and occasionally the Croweburg (where coal thickness was sufficient for economic recovery). A nearly complete core of the Cherokee Group (Fig. 4) was described by Harris (1984, p. 29, A-43, A-44). This core, drilled 4 mi (6.4 km) west of the west high-wall section, allows comparison of the Croweburg coal, the Verdigris Limestone, and adjacent shales and claystone at the measured section to the total section of the Cherokee Group.

The cyclicity of the Cherokee rocks in Kansas was recognized by Abernathy (1937, p. 19) as having 15 cyclothems that represent changes from nonmarine to marine conditions. Abernathy (1937) defined his *phases* of the normal Cherokee cyclothem in a depositional order as: (0.1) sandstone, (0.2) sandy shale, (0.3) underclay, (0.4) coal, (0.5) black shale, (0.6) gray shale, (0.7) limestone, and (0.8) calcareous shale. This sequence of nonmarine to marine rocks was close to the "ideal cyclothem" of Moore (1936, p. 24–25), except for the obvious lack of limestone, which is a feature more typical of cyclic deposits in the Upper Pennsylvanian rocks. In Figure 5, this normal Cherokee cyclothem of Abernathy is shown, along with the described composite geologic section. Different opinions exist on how this sequence of rock units fit this normal Cherokee cyclothem. Abernathy (1937) considered the underclay, coal, and black shale as part of the Croweburg cyclothem, and the shale below the limestone and the limestone as two phases of the Ardmore (Verdigris) cyclothem (Fig. 5).

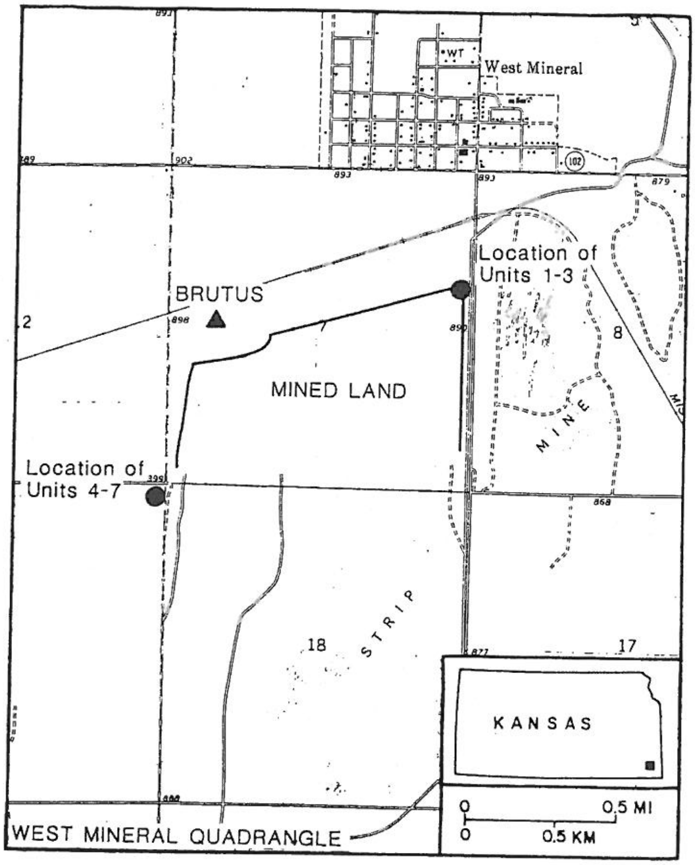

Figure 1. Location of the two mine high walls used for composite section description. The location of Brutus, the large mining shovel used to mine most of the land in this area, is also shown. This shovel forms the most prominent landmark in the area and can be used as a guide to this location.

In reviewing the Cherokee cyclothems, Moore (1949, p. 43, 45) considered Abernathy's Croweburg and Ardmore (Verdigris) cyclothems as a single cyclothem (Fig. 5). A gray shale overlying the Croweburg coal was not described by either Moore or Abernathy. Later, Moore and others (1951, p. 99, 101) referred to this sequence of rocks as the Ardmore cyclothem. The gray shale overlying the Croweburg was recognized at that time and it was considered by Moore and others (1951) that this shale, the Croweburg coal, underclay, and two underlying lithologic units might possibly constitute a distinct cycle.

Howe (1956) recognized 18 cyclothems in the Cherokee rocks. Five lithologic units were considered by Howe (1956, p. 21–26) to be common to most Cherokee cycles. These units

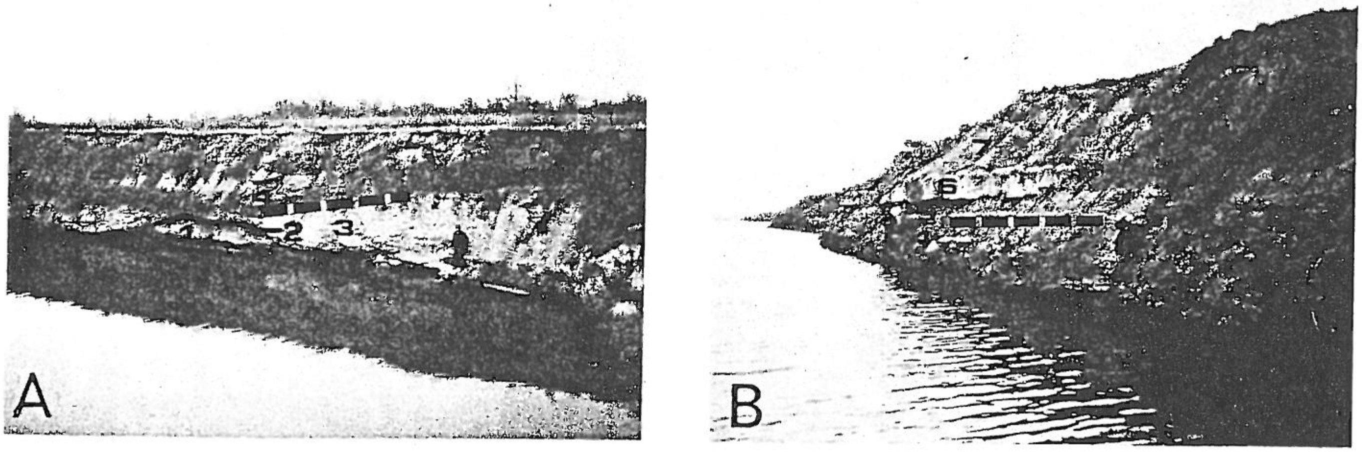

Figure 2. A: Location where units 1–3 were described—NE¼SE¼NE¼Sec.7,T.32S.,R.23E. Positive structure of the Croweburg coal (unit 2) shown on the north side of the high wall. This positive structure is also present on the east end of the pit just to the right of the photograph. B: Mine high wall showing prominent Verdigris Limestone (unit 6). Units 4–7 were described along the north side of this high wall, NE¼NE¼NE¼Sec.13,T.32S.,R.22E., Cherokee County, Kansas.

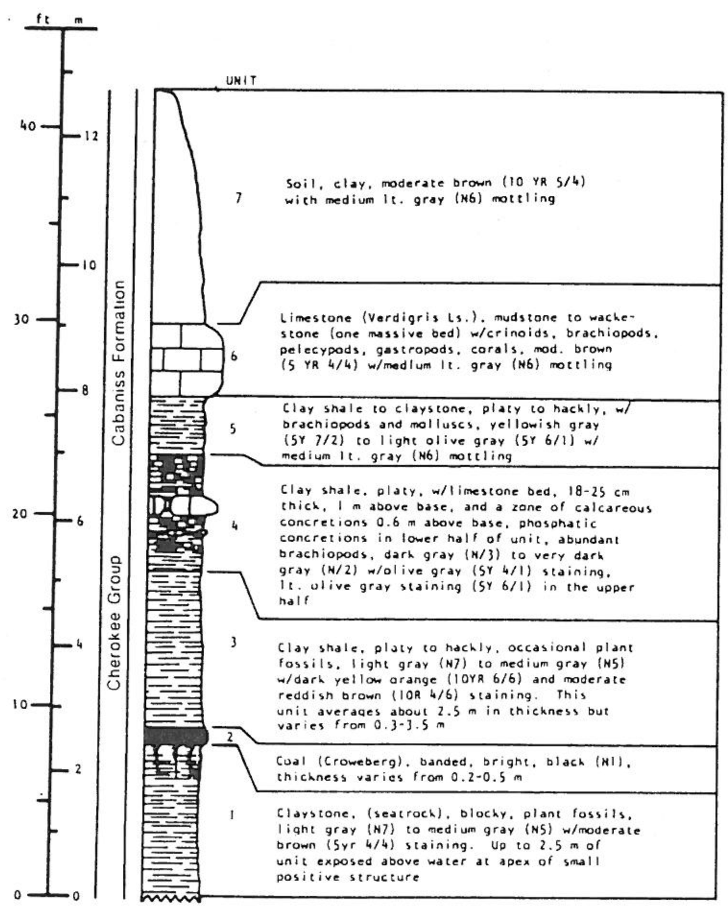

Figure 3. Composite geological section from P&M Mine #19 high walls. Actual mined section includes coal and shale down to the Mineral coal, approximately 26 ft (8 m) below the described section.

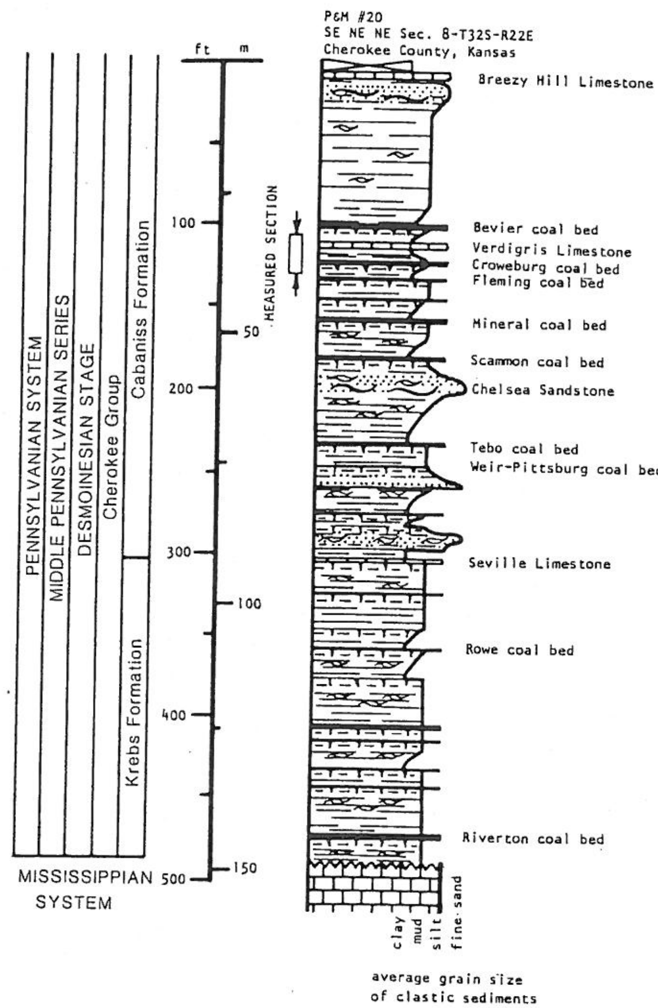

Figure 4. Cored section showing nearly complete Cherokee Group (less than 16 ft [5 m] missing). (Modified from Harris, 1984, p. 29.)

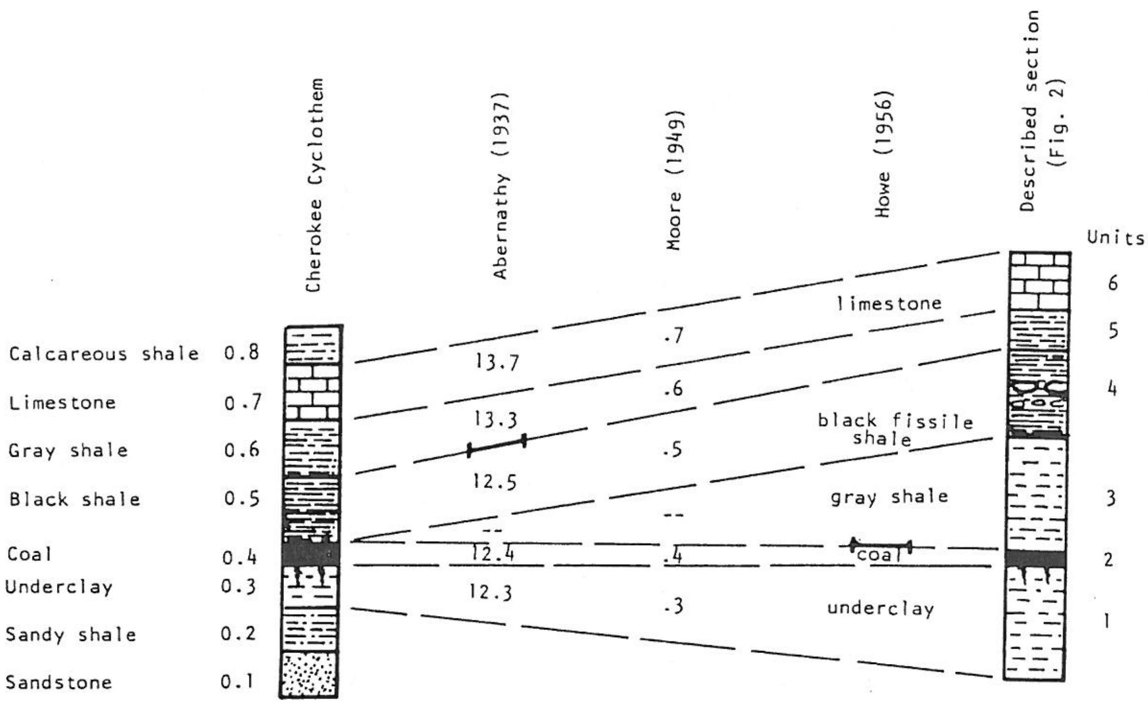

Figure 5. Generalized section comparing the described geologic section with the "normal" Cherokee cyclothem of Abernathy (1937) and interpretation of the rock sequence by various workers. Dashed lines between the geologic section and the "normal" Cherokee cyclothem are based on the interpretation of Moore (1949) and Moore and others (1951).

include (without the significance placed on the numbers as was the case by Abernathy [1937] and Moore [1949]), in depositional order of marine to nonmarine: (1) dark shale and dark irregular limestone, (2) gray shale, (3) underlimestone and sandstone, (4) underclay, and (5) coal. This sequence of lithologies was considered by Howe (1956, p. 23) to best fit the Cabaniss subgroup (Formation).

Use of Howe's Cherokee cycle to fit the described geological section indicates that parts of two of Howe's cycles are present—his Croweburg and Verdigris cycles (which he proposed as formations in his paper). The top of Howe's Croweburg cycle is the Croweburg coal.

Paleontological evidence was presented by Howe (1956, p. 72–74) and Williams (1937, p. 104–105) to indicate that at least part of the gray shale over the Croweburg coal might be of marine origin.

The Verdigris Limestone (unit 6) is the best-developed limestone in the Cherokee Group. The dark-gray shale (unit 4) has a high gamma-ray reading on geophysical logs, and both units are distinctive marker beds and have widespread distribution in the Midcontinent area.

Distribution of a large coal swamp—perhaps the most widespread in North America—resulted in the formation of the Croweburg coal in Kansas, Missouri, and Oklahoma, and its equivalents, the Colchester (No. 2) in Illinois, the Whitebrest coal in Iowa, the IIIa coal in Indiana, Shultztown coal in Kentucky, and the Lower Kittanning coal in the northern Appalachians (Wanless and others, 1969, p. 131–134; Wright, 1975, p. 78, Pl. 17). This widespread coal deposit was considered by Wright (1975) to have developed because sediments underlying the coal formed a broad platform on which the swamp could develop.

In Kansas, the marine dark-gray shale (unit 4) is unnamed. Its equivalent in Illinois is also unnamed, but in Indiana, the well-known Mecca Quarry Shale Member of the Linton Formation was considered its counterpart by Wright (1975, p. 79–180), who also noted that the physical characteristics of the shale are generally the same from Oklahoma to Indiana.

Distribution of the Verdigris Limestone (unit 6) and its equivalents extends from central Oklahoma to central Iowa (Wright, 1975, Pl. 17).

Additional information on the local stratigraphy of units observed at the high-wall section can be obtained from Pierce and Courtier (1937), and Howe (1956); paleontology is summarized by Williams (1937).

ECONOMIC GEOLOGY

Extensive mining for coal by surface and underground methods has been an important part of the economy of southeast

Kansas, especially in Cherokee and Crawford counties, where nearly 230 million metric tons of coal have been mined. The important coal beds mined other than the three mined at the P&M #19 Mine—the Mineral, Fleming, and Croweburg coals—are the Bevier and Weir-Pittsburg coal beds (see Fig. 4). Most of the underground mining (more than 50,000 acres [20,000 hectares]) of the Weir-Pittsburg coal was by the room-and-pillar system.

Coals from the Cherokee Group in southeast Kansas are high-volatile A bituminous in rank, and are currently used mainly for power generation and cement manufacturing.

A large amount of the observed strip-mined land in this area of Cherokee County was mined as part of P&M Mine #19. A significant amount of this mining was done by "Brutus," the large mining shovel located 0.5 mi (0.8 km) north of the west high-wall section. This Bucyrus-Erie 1850-B shovel has a bucket capacity of nearly 90 yd^3 (70 m^3) and was used by the Pittsburg & Midway Coal Mining Company to mine coal in this area from 1963 until 1974. At the time of its construction in 1962–63, this machine was the second-largest mining shovel in existence.

Coals mined at Mine #19 were processed at the company tipple near Hallowell, Kansas, a truck haul of 10 mi (16 km). The processed coal, consisting of blends of the Mineral, Fleming, and Croweburg coals, produced a product with 6.5% moisture, 12.5% ash, 3.3% sulfur, and a heat content of 12,300 Btu/lb (6,830 Kcal/kg).

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